Innovative Roofbolting Technologies
in Australian Coal Mines

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Abstract

Methods of rock reinforcement in Australian coal mines are being improved progressively along with better understanding of rock failure mechanisms around roadways and development of new types of roofbolts and new installation techniques.

It has been recognised that to improve performance of the rock reinforcement systems, their stiffness has to be improved. Therefore new style bolts having stiffer characteristics and providing more efficient load transfer properties together with stiffer plates are being developed.

The paper describes the technologies being developed in order to increase the stiffness of the reinforcement system. Some of the new techniques used to stabilise the roof beam, especially in high horizontal stress areas have been already proved in some mines and some of them are being tested now.

In particular, discussed in the paper are methods of pretensioning of bolts. That includes development of a special nut allowing for about 120 kN of tension of a roof bolt using standard roofbolting equipment and methods of tensioning of strand type bolts (HI-TEN Bolts) up to 250 kN.

Finally, the positive effect of pre-tensioned roof bolts and pre-tensioned Flexbolts on the strata reinforcement is shown in a case study from Central Colliery.

Key Words: ground control, support stiffness, pre-tensioning of roof bolts and cable bolts

Introduction

Longwall gate roads in Australian coal mines are often supported with considerably high densities of roofbolts and cable bolts. The time required for the installation of the bolts is seen as one of the major reasons for a relatively low roadway development rate. Therefore more effective strata reinforcement is required to reduce the bolting densities. It is also needed in areas where roof stability is being lost during the longwall retreat despite considerable bolts and cables densities.
Since the effectiveness of the strata reinforcement can be improved by increased stiffness of the support a number of ANU Amall's internal research projects have focused on the development of products with stiffer behavioural characteristics. In addition, special hardware is being developed to facilitate the roof bolt and cable bolt installation techniques, which also improve the support stiffness.

**STIFFNESS OF STRATA REINFORCEMENT**

Stiffness of a rock reinforcement system comprising of a roof bolt, can be defined by the amount of load generated in a bolt per unit of rock displacement.

Historically, the strata reinforcement system has changed from a soft one to much stiffer one as the fully grouted bolts superseded the point anchored resin and mechanical bolts. Stiffness of the support was further improved by the introduction of stronger i.e. stiffer bolts and by the minimisation of the resin annulus using smaller diameter holes. The result has been that the stability of rock around roadways has been significantly improved.

It is clear that the higher the stiffness of a support the more efficient the rock reinforcement.

There are a number of factors, which determine the stiffness of the support system. Most of them like the configuration of bolt deformations, properties of grout, bolt mechanical and physical properties, hole diameter and its shape as well as rock properties are clearly defined and understood. There are however at least two more factors which are not always fully appreciated. These are the levels of softening of the immediate roof and stiffness of the roof plate.

This paper will discuss both these factors as well as the other most significant improvements of the support stiffness achieved in recent years.

**ROOF BOLT STIFFNESS**

In view of the high deformation environments commonly encountered in Australian coal mines, the mechanical characteristic of a roof bolt is considered very important. A bolt loaded above its yield strength reduces its diameter and debonds itself from the resin and as a result, a progressively longer section of the bar is thus exposed to the high load. The longer the loaded section of the bar, the softer the bolt and therefore the larger its elongation.

Since even the strongest X type bolts are inevitably loaded above their yield point in certain situations it is clear that in such areas bolts of a higher yield strength will provide more efficient confinement.
Flexibolts

The Flexibolt is a high strength (580 kN) resin grouted strand bolt. Since its diameter is 23.5mm it is typically installed in a 28mm bore hole.

These bolts have been successfully used for strata reinforcement for the last four years. Their success can be attributed to number of features but the two most important factors are the high yield strength and the shear behaviour.

Tensile properties of the Flexibolt are shown in Fig.1. It shows the behavioural characteristic of Flexibolt being much stiffer than the X type bolt of which the ultimate strength is 340 kN.

![Graph showing load vs strain for Flexibolt and AX Bolt](image)

**Figure 1. Loading Characteristics of Flexibolt and X Type Bolt**

Although the majority of Flexibolts are point-anchored, the stiffness of such bolts can be further increased by full encapsulation.

There are reasons to believe that the stiffness of the point anchored Flexibolt may be increased due to the lateral movement of the strata. Since the large (55mm diameter) extensometer holes are often sheared it is easy to imagine that the much smaller 28mm hole will shear and "lock up" the relatively large diameter (23.5mm) strand. In effect the locking points provide additional anchors which reduce the free length of the cable and render the system stiffer.
The shear behaviour of Flexibolt strand is fundamentally different to the one of a solid bar. This is due to the small diameter wires of the strand, which can be bent to a much larger degree than the 22mm diameter bar during the shear action of the strata.

Since the rock strength is much lower than the strength of the steel, the Flexibolt strand is able to form an "S" shape, which is subjected to bending and tensile loading rather than bending and shear combination. Therefore, in weaker rocks, the Flexibolt strand provides shear confinement, which may be close to the maximum tensile strength of this bolt.

**AVH Bolt**

The AVH bolt has the stiffest characteristic among the standard 22mm solid bolts. This bolt has successfully replaced the 'softer' H type bolt.

The material yield stress of the AVH bolt is as high as 770 MPa and is achieved by cold working high grade steel. The bolt is produced out of a round bar, which passes through a set of dies, which form transverse deformations on the bar. A blank section of the bar is always left for thread rolling. The yield strength of the AVH bolt is 280 kN. The mechanical characteristics of the AVH and the H type bolts are compared in Fig 2.

![Figure 2. Loading Characteristics of AVH and H type Bolt](image)
Face Plate Stiffness

The stiffness of the roof plate is also considered important as in high deformation areas plates are often heavily loaded, especially in view of the fact that the bolts are seldom encapsulated right to the collar level. The stiffness of the reinforcement system was therefore also increased by the introduction of a new type of roof plate called a Turtle Plate. These plates have been formed in such a way that their stiffness is significantly higher when compared to conventional domed plates.

Figures 3 and 4 compare the behavioural characteristics of the conventional domed plates and the much stiffer Turtle Plates.

![Graph showing load vs displacement for round and square domed plates](image)

**Figure 3.** Loading Characteristics of 100 x 100 x 8mm Domed and 4mm Thick Turtle Plates

![Graph showing load vs displacement for round and square domed plates](image)

**Figure 4.** Loading Characteristics of 100 x 100 x 10mm Domed and 5mm Thick Turtle Plates
AX2 Bolt Type

A new type bolt has been designed to increase support stiffness by improved load transfer capability of the bolt. The AX2 bolt has the same tensile properties as the conventional X type bolt and the same core diameter. The important features of this bolt are higher than normal transverse ribs and low longitudinal cords.

The bolt transverse rib profile of the AX2 bolt has been designed to successfully develop rapid forces compressing the resin between the bolt and the rock, therefore reducing the risk of premature failure of the system on the resin rock interface.

The longitudinal cord lower profile creates less resistance and less resin pressure during mixing operation thereby alleviating the problem of resin being lost in cracks along with diminishing the risk of creating voids in the resin.

It must be noted that rolling a bar with higher ribs leads on to the higher cord. Therefore, rolling the AX2 bar with high ribs and standard cord height is regarded as a significant technical achievement.

The load transfer properties of the AX2 bolt has been improved significantly when compared to the conventional bolts.

Initial short embedment test results (300m long encapsulation) are shown in Table 1.

<table>
<thead>
<tr>
<th>Bolt Type</th>
<th>Hole Size (mm)</th>
<th>Average Peak Load (kN)</th>
<th>Average Displacement at Peak Load (mm)</th>
<th>Stiffness (kN/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X Type</td>
<td>27</td>
<td>150</td>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>AX2</td>
<td>28</td>
<td>225</td>
<td>6</td>
<td>37.5</td>
</tr>
</tbody>
</table>

As can be seen from Table 1, the AX2 bolt peak pull-out load and stiffness are considerably higher when compared to the X type bolt with conventional deformations.
PRE-TENSIONING OF ROOF BOLTS AND CABLE BOLTS

The pre-tensionings of both roof bolts and cable bolts is now fully proven as a highly effective method of increasing the stiffness of the support system. The cost effectiveness of making such changes to the bolting hardware is high as the improved effectiveness of the installed support system allows for lower installed densities, improved roof stability and a more controllable roof environment.

Without presenting a full technical discussion on the mechanics as to why support pre-tensioning is so effective, it can be summarised by the following points:

- Pre-tensioning generates a certain amount of bolt loading for no associated roof displacement.
- Roof bolt pre-tensioning demonstrably improves the retention of beam action within the bolted horizon, from which the ‘self supporting’ ability of the roof is increased.
- Cable pre-tensioning utilises the mechanical advantage inherent within a beam to generate significant resistance to horizontal stress across the roof. This will either immediately stop on going roof movement in many situations or delay, if not prevent further roof deflection during secondary extraction (ie. longwall retreat).

Pre-Tensioning Of Roof Bolts

It has long been understood that in order to increase the level of pre-load induced along a bolt from a given torque, the friction between the nut and the washer has to be reduced hence the development of the ACIRL thrust bearing. Only recently however it was recognised that the friction between the threads of a nut and the bolt is far more critical in the torque/tension relationship. Further more it was discovered that when the immediate roof is relatively compressible, such that the nut has to travel a greater distance under a high load, the friction between the nut and the bolt increases dramatically during nut tightening. The reason for the increased friction in such conditions was galling. Based on these findings the special high performance Oz nut (HP Oz nut) was developed.
The HP Oz Nut is a modified ANI small standard Oz nut. The standard Oz nut consists of a steel dish, which is crimped into the nut (outside its thread). The modifications made to the HP Oz nut have resulted in an improvement in two critical areas: mechanical advantage and friction. Firstly, to improve the mechanical advantage of the nut/bolt system, the nut thread form was modified.

Secondly, to reduce the friction, the nut has been coated with a high pressure resistant lubricant. The coating eliminated the galling completely. In effect, a roof bolt which is installed off a hydraulic bolter having a typical torque output of 300 Nm can be pre-tensioned to a load of 100 kN to 140 kN. In contrast, the standard Oz nut, allows for only 30 kN to 50 kN of load to be induced in the bolt from the same torque.

The initial underground trials with pre-tensioned roof bolts were carried out using the thrust bearing. Even though the pre-loads they achieved in the bolts were only between 65 and 85 kN, the trials carried out at Teralba Colliery conclusively showed that by increasing the pre-load applied to the roof bolt the added confinement induced in the roof and the increased stiffness of the bolting system significantly improved roof stability and formed a roof environment that could be managed more efficiently and effectively. (Frith and Thomas 1994)

Pre-Tensioning Of Flexibolts

Even though Flexibolts have a threaded end, high torque tensioning through the nut is not possible, as the bolt is furnished with a cone and collar on the head assembly and that secondly, due to the high coefficient of friction on the threads the free length of the cable twists under high torque. To alleviate some of these problems, the cone has been furnished with a rim (shown in Figure 5) which delays the wedging action of the barrel and cone until 50 kN of load in the cable has been achieved. At 50 kN the rim is then sheared by the collar.

![Flexibolt Cone and Collar](image)

Figure 5. Flexibolt Cone and Collar
To pre-tension the Flexibolts to higher loads of 200 to 250 kN, BFP (Barrett, Fuller and Partners) have developed a special system, tensioning the cable by pulling it away from the roof. The tension was then locked in the bolt by extending a spacer (locker) between the plate and collar on the bolt. The locker consisted of a threaded hollow bar and a supporting nut.

The BFP system was developed by an industry funded project to determine the effect of high pre-tensioned cable bolts on roof behaviour. However, in spite of a number of down-sides, the BFP tension-locker has been accepted at a number of mines as a production unit. Some of the down-sides include the high cost of the locker, the length of the bolt tail protruding from the roof (approximately 300mm) and the relatively cumbersome application of the tensioning jack.

First underground trialing at West Wallsend and Newstan Collieries demonstrated that following the pre-tensioning of the Flexibolts roof displacement was either immediately arrested or, as in the case of longwall retreat any related surcharge in displacement was reduced and delayed until only a few metres outbye the face. These were both highly significant results.

**HI-TEN Strand Bolt Development**

HI-TEN Strand Bolt is a variation of the Flexibolt developed in order to improve the pre-tensioning of the bolt. It consists of the same strand as Flexibolt but the strand is not threaded.

To tension the HI-TEN Strand Bolt to typically 200 to 250 kN, a custom designed tensioner was developed by ANI Arnall. It consists of two hydraulic cylinders, which through a set of grippers pull the end of the cable away from the roof. At the same time a collar and set of wedges are being pushed against the roof plate to lock the tension up. Figure 6 shows the sequence of the installation.

![HI-TEN Strand Bolt Installation](image)

*Figure 6. HI-TEN Strand Bolt Installation*
To allow for resin mixing, a square drive is welded to the end of the HI-TEN Strand Bolt as shown in Fig. 6 to engage with a dolly.

The tensioning unit is simple to operate. Once fitted over the end of the cable (70mm long tail required) it will engage automatically. To remove the unit after pre-tension of the cable a rope has to be pulled down to disengage the cable grippers. The tensioner can be operated by hand as its weight is about 24kg or it can be attached to a bolting rig.

The HI-TEN Strand Bolt tensioning system, ie the tensioner and the bolt fittings, have been designed to minimise the length of the tail of the bolt, to allow for angled installations of bolts (up to 30°) and to minimise the loss of tension in the cable.

Some loss of tension is inevitable, it will always occur since on the release of the tensioner pressure, the wedges will be drawn deeper into the collar which will allow for some relaxation of the load. It is important that this loss is minimised and also accounted for in the application of pre-stressed HI-TEN Strand Bolts.

One of the frequent reasons for a considerable loss of the pre-tension is tilting of the bearing plate due to an uneven roof surface.

As shown in Figure 7, the collar tilts together with the tilted roof plate being joined together through contact friction. It causes bending of the cable as the cable is being pulled always in a direction perpendicular to the face of the collar. Subsequently, there is more room for the wedge segment on one side of the cable than on the other, causing the misalignment of wedges as shown in Fig 7.

Figure 7. Misalignment of Wedge Segments Caused by Tilting Bearing Plate
To solve that problem, a special collar was developed as shown in Fig 8. It has a centralising rim which keeps the cable always in the centre of the collar allowing for proper alignment and proper function of the wedge segments.

Figure 8. Special Collar Ensuring Proper Alignment of Wedge Segments
APPLICATION OF PRE-TENSIONED ROOF BOLTS AND HI-TEN STRAND BOLTS AT CENTRAL COLLIERY – CASE STUDY

Central Colliery is situated in Central Queensland approximately 250km North West of Rockhampton and is one of three mines comprising the German Creek Coal Mining Operations. The mine was the first mechanised longwall coal mine in Queensland with underground mining commencing in January 1984 and the first longwall coal produced in 1986.

Longwall panels are extracted in two blocks, the 200's in the north and 300's in the south, blocks being divided by the eastern main headings (Fig 9). Gateroad pillars are currently developed on 100m by 45m centre. Five headings are driven with 50m by 50m centre to centre pillars. Primary gateroad development is carried out with a Jeffrey 1036 continuous miner with side mounted hydraulic rigs. Main dips development utilises the Joy 12CM11 Continuous miner.

Figure 9. Central Colliery Mine Layout

Coal is extracted from the German Creek seam which varies in thickness from 1.8m to 2.4m and dips gently to the east across the mining lease. A Rider seam, the German Creek Upper (approximately 0.3m thickness), splits away from the main seam in the southern side of the main lease to a height of greater than 8m to the North. The immediate roof to the south of the seam split comprises a thin mudstone unit which gives way to interlaminated fine grained micaceous sandstone and siltstone averaging 50 MPa UCS. To the north of the split line the roof comprises a carbonaceous siltstone interburden, averaging 60 Mpa UCS which is overlain to the north by interlaminated sandstones and siltstones. Immediate floor comprises a dark grey carbonaceous siltstone averaging 50 Mpa...
UCS, although recent underground drilling exposed floor of 20 MPa UCS in the vicinity of 307 longwall installation road.

Structures in the form of folds, faults, shears and jointing are present throughout the mining lease. Similarly, intrusions in the form of dykes and sills span the lease. All of these features tend to follow a northeast-southwest trend and are common to distinct structural domains often giving rise to more adverse roof conditions when mining. Current depth of mining is 300m with the major principal horizontal stress direction believed to be NNE at approximately 24 MPa.

Roof support at the colliery has historically seen an increase in support density as mining progressed to the east, reflecting the increase in stress levels acting on the roof as depth of cover increases. Support types and densities have also been adjusted to reflect local structural and geotechnical environments. Primary support has consisted of standard “T” and “X” steel grade roof bolts with lengths varying from 1.8m to 2.4m. Two speed resin cartridges with a 50:50 proportion of fast and slow set components have been used to fully encapsulate the bolts. More recently, trials have been conducted to assess the relative pre-tensioning abilities of different manufacturer’s hardware technologies, whilst monitoring and comparing roof behaviour.

Secondary support has traditionally been in the form of point anchored cables of various lengths and densities installed in areas where roadway widening has been necessary or where continued roof convergence has required the installation of additional support. Point anchored Flexibolts are now installed in all intersections as standard practice.

The 307 longwall installation road is located at the southern end of the mine, south of the German Creek / German Creek Upper seam split (Fig 9). Immediate roof lithology comprises interbedded and interlaminated sandstone and siltstone with occasional strong sandstone beds (eg 100 MPa at 4.5m). Earlier pretensioning trials had indicated improvements in the behaviour of the immediate laminated roof with higher applied preloads. The possibilities of optimising roof control and reducing total roof support for the 307 installation road, as compared with previous installation roads, were then investigated. Strata Engineering (Australia) Pty. Ltd. designed an initial support and monitoring plan in October 1997.

The initial roadway was driven uphill, from maingate to tailgate, 230m length at a width of 5.2m. The roadway was later to be widened out to 7m with the exception of the final 30m at 8m width to accommodate the shearer stable. A series of extensometers and tell tales were installed at the development face in 8m holes drilled from the left side (offside) rig as mining proceeded, with monitoring stations spaced at 20m centres. Monitoring took place on a daily basis while the roadway was being driven and at regular intervals thereafter. Primary roof support comprised 6 x 2.1m ANI Amall X grade roof bolts installed with HP Oz nuts per 1.1m of roadway with full meshing across the roof in the form of 1.2m mesh modules. Preloads exerted on the roof averaging 12 tonnes were measured with a load cell.
Following completion of the initial driveage, secondary support was installed with 1 x 8m ANI Arnall HI-TEN Strand Bolt located close to the centre of the initial 5.2m driveage per 2m of roadway length (with the exception of the final 30m where spacing between cables was reduced to approximately 5 cables per 4m of roadway in a zig zag fashion). All HI-TEN Strand Bolts were pre-stressed to a minimum of 20 tonnes prior to roadway widening. In the vicinity of the 80m inbye mark, four extra HI-TEN Strand Bolts were installed over 10m length where significant rib spall had occurred effectively artificially widening the roadway close to 7m, with an associated increase in measured roof convergence. Widening of the installation road took place with the same effective density of primary support as was installed in the initial driveage. No further secondary support was installed. Figure 10 illustrates a basic section of roadway with positions of bolts and cables, spans and extensometer locations.

![Diagram](image)

**Figure 10. LW307 Installation Roadway-Support and Monitoring**

On analysis of the extensometry data, roof deflections varying between 20mm and up to 100mm were observed, indicating that the roof experienced buckling without exception. There was no evidence of the roof exhibiting very low magnitude movements (<5mm) after driveage that would be more typical of a static roof environment. However all of the extensometer plots exhibited good beam retention, with displacement in most cases confined between 2m and 4.5m into the roof. It is interesting to note that the height of softening in all cases was no greater than 4.5m, coinciding with a strong (100 MPa) sandstone, which caused some drilling difficulties. Figure 11 shows a typical extensometry plot exhibiting beam retention in the 2.1m (roof bolt) horizon.
Time dependant extensometer plots demonstrated clearly the variation in roof buckling magnitude and time dependant creep that occurred in various locations along the roadway. The time dependant plot for the extensometer 160m from the maingate end (Figure 12), shows the effect of creep following driveage of 5mm per week up to the point at which +20 tonnes of preload was applied to the HI-TEN Bolts in the area. Beam retention in this area was significantly lower than in any other area (to approximately 0.8m height above the immediate roof), and resulted in higher roof deflection. The installation and subsequent tensioning to a minimum of 20 tonnes of the secondary 8m point-anchored HI-TEN Bolts in all cases brought on-going creep in the roof to a rapid cessation. This is clearly illustrated in Figure 12 where creep at 5mm/week is practically stopped following pre-stressing of the HI-TEN Bolts. A comparison between Figs 12 and 13 illustrates the local variation in roof deflection that was exhibited.
Figure 12. LW307 Installation Roadway – Exto Plot – 160m from MG End

Figure 13. LW307 Installation Roadway – Exto Plot – MG Intersection
Total support hardware costs were significantly reduced by the use of pretensioned bolting and cabling methods and development rates increased when compared with previously driven installation roads. The 306 longwall installation road, in similar geological conditions, utilised a total of 11 x 2.4m standard T grade roof bolts every 1m of roadway supporting both straps and mesh modules as primary support. This resulted in a total of at least 2530 x 2.4m roof bolts installed along 230m length of roadway, compared with approximately 1673 x 2.1m pretensioned roof bolts installed along 230m length of roadway in the 307 installation road (ie. a saving of almost 900 roof bolts).

In terms of secondary support, 306 installation road was driven with 2 x 8m Flexibolts and 1 x 8m cable bolts every 2m of roadway, resulting in a total of 345 x 8m tendons installed in total. For the 307 installation road, a total of 129 x 8m pre-stressed HI-TEN Strand Bolts were installed, representing a saving of 64% on total secondary support. Purely in cost terms, had a pattern of 3 rows of cable bolts at 2m intervals been used in the 307 installation road, (considered a reasonable initial estimate of support requirements had the design based on pretensioning not been implemented), total costs for secondary support were estimated at $200,000 - $300,000. The final cost using 8m pre-tensioned HI-TEN Strand Bolts including contract labour costs to install and pretension the HI-TEN Strand Bolts prior to widening was $50,000; a cost saving of at least $150,000.

The total number of shifts spent driving the 307 installation road, including widening was reduced by 28% when compared with 306 installation road drivage. The number of shifts spent mining would have been reduced further had it not been for maintenance issues associated with drill rigs and intersecting and bogging into areas of weak floor.

The 307 installation roadway was left to stand following completion for a period of approximately one month prior to the installation of longwall powered supports. Extensometer reading frequencies were reduced as it became clear that a condition of relatively slow long term creep had developed and a high level of confidence in roof control existed as longwall installation proceeded.

The design involving pretensioning of both primary and secondary support and in particular the process of monitoring roof behaviour enabled a greater understanding and confidence in strata control practice for all involved at the Colliery. Aside from monitoring results, a visible assessment of improved roof stability when compared with previous installation roadways was often commented on by crew members.

As a point of note, roof stability management in LW307’s installation roadway was managed via monitoring time dependent roof displacement trends rather than arbitrary values of roof displacement as ‘trigger’ levels. This resulted in a more focussed use of the monitoring data and led to no extra support being installed after widening of the roadway whereas trigger values may have necessitated extra support to be used.
installed after widening of the roadway whereas trigger values may have necessitated extra support to be used.

CONCLUSIONS

There has been significant development and proving of new support technologies in strata control in recent years in the Australian coal industry, both in terms of support hardware and also knowledge as to maximising its effectiveness when installed. The current state is one of a comprehensive understanding of how and why the changes have been so effective.

The paper has presented findings in a number of areas related to improving support system stiffness through both material properties, tendon and plate design as well as application methods (ie. pre-tensioning). These have led to a number of commercial products of improved cost effectiveness being available for use.

The case study from Central Colliery shows clearly the level of cost and stability benefits that can be made via the use of these new support technologies when applied according to the engineering principles that have been developed regarding their use. It also illustrates a different method of using roof monitoring data as part of strata management (compared to use of displacement based trigger levels) that also led to efficiency improvements.

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