EVALUATING DEVELOPMENT IN ROOFBOLTING TECHNOLOGY IN AUSTRALIAN COAL MINING

Key Words

Roofbolts – cable bolts – support stiffness – rock confinement

Abstract

Roof bolting technology in Australian coal mines has advanced considerably during the 40 years since introduction. However, there is constant need for more efficient strata control in mining in order to improve safety, maximise productivity and decrease costs. Therefore, the changes introduced to roofbolting technology are being assessed and the directions for further future development are discussed.

The main area where the majority of improvements have taken place is in the stiffness of the support. The gradual increase of the support stiffness has been achieved mainly by the introduction of chemical anchors and full encapsulation of bolts, higher grades of steel with more efficient deformations and the introduction of cable bolts and resin grouted strand bolts.

Another important development occurred in the area of direct application of confinement to the rock mass by applying high support pre-tension.

All the changes introduced to roof bolting technology which have resulted in better rock reinforcement are analysed and the directions for further future development are discussed.

1. INTRODUCTION

Roof bolting continues to be improved despite the fact roof bolts have been used for well over 40 years in Australian coal mining. In recent years the rate of improvement is probably greater than ever, which can be attributed to such factors as better understanding of the strata/bolt interaction, availability of better materials, development of more efficient installation methods, and availability of more sophisticated monitoring techniques.

As a result, rock bolts today are the most cost effective method of strata reinforcement but their development is not yet complete.

The biggest improvement in the roofbolting development has been achieved in the area of stiffness of the support. Recent years have also seen significant development in installation techniques in Australian mines which are looking for more efficient confinement of the strata. One of the more substantial techniques is the high pre-tensioning of bolts.

Individual roof bolting features which have evolved over the years will be discussed in order to form a view on the directions for future hardware and technique development.

2. DEVELOPMENT EFFECTING SUPPORT STIFFNESS

Stiffness of rock reinforcement is measured by the response and effectiveness of the bolt reaction to strata deformation. The faster the bolt generates loads opposing displacement, the stiffer the support.

There are four major areas where the stiffness of the support may be effected. These are: anchorage efficiency, tendon mechanical properties, stiffness of the system between the rock face and the tendon end fitting, and orientation of the tendon in relation to strata shear planes.

Basically, all the important changes that have been introduced to the roof bolting system fall into a category effecting the stiffness of the roof support.

2.1 From mechanical to resin anchor

The first bolts used in Australia were slot and wedge bolts. They were installed at Elrington colliery in late 1940's. The expansion shell bolts were introduced In the mid 1950's .

Although it was obvious that these mechanical bolts were effective in supporting the roof there were a number of problems which had to be overcome. The major problems were associated with weak sedimentary rock types where the mechanical point anchored bolts rapidly lost efficiency (Howe, 1968). Another problem was anchor creep, particularly if explosives were used to win the coal.

In order to overcome these problems, chemical anchors were developed and trialed in the early 1960's. The early underground and laboratory testing of chemical anchors found that chemical anchorage was considerably stiffer than mechanical anchors (Barnes & Howe, 1964). The difference in performance of the two type anchors is illustrated in Fig 1.

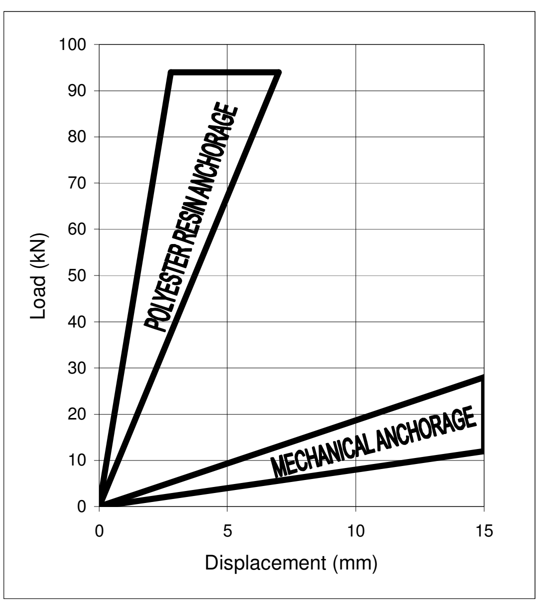

Fig. 1. Range of performance of mechanical and polyester resin anchors (Barnes and Howe, 1964)

Figure 1 illustrates the difference in stiffness of these two types of anchors when tested in a weak rock. It is easy to imagine that the stiffness of the slot and wedge bolt would be even lower than that of the expansion shell because the contact area of the slot and wedge anchor with the rock is much smaller when compared to the expansion shell leaves.

As the performance of chemical anchors proved to be significantly better (provided higher stiffness) than the mechanical anchors, by mid 1970's chemical anchors were used on a relatively large scale.

2.2 Chemical anchor bolt profile

The first commercially economic chemical bolts were manufactured from mild steel round bar (21.7mm diameter) and had a 150mm rolled M24 thread on each end.

One end was threaded to fit a nut whereas the other end was threaded to provide deformations on the bar to improve the resin bond strength.

The type of deformations achieved by threading was not very efficient. The relatively small pitch of the thread form (3mm) generated only marginal radial forces required to wedge the resin between the bolt and the rock. The resistance, which prevented the bolt from being pulled out of the hole, relied mainly on the shear strength of the resin between the threads or on the rock interface. Since the shear strength of the resin is about 3 times less than its compressive strength the anchors could fail at a relatively low load.

Subsequent extension of the anchor length by threading longer sections of the bar (up to 700mm) significantly improved its performance, but the real breakthrough was the introduction of the ribbed LHA (Left Hand Anchor) bar or "T-bar" (Norris & Yearby, 1980). The spacing of the ribs was 10 to 12 mm and their average height was 0.7 – 0.8 mm.

The ribs move against the resin column as the bolt is loaded by strata movement and develop radial (wedging) forces which compresses the resin between the rock and the bolt ribs. This then resists the bolt/rock relative movement in a more efficient (stiffer) way when compared to the threaded bar.

Further improvements in the anchorage stiffness have been achieved by the recent introduction of bolts (AXR and HPC) with significantly higher ribs when compared to the LHA bar. Their rib heights, which vary between 1.3 to 1.6 mm provide a 40 to 60% increase in the anchorage peak shear stress.

2.3 Reduction of hole diameter

The earlier used pneumatic rotary percussive rigs had difficulty in both drilling the preferred 27 mm diameter hole and rotating fast enough to effectively mix the chemical anchors. This was overcome by the introduction and development of lightweight, portable pneumatic rotary drill legs and efficient wet drilling bits. Rotation speed under load was typically 500 RPM and chemical mixing efficiency dramatically improved.

Reduction of hole diameter or rather reduction of the annulus between the hole and the bolt is important for two reasons. Firstly, the smaller the annulus the more efficient is the mixing of the resin as well as more effective shredding of the cartridge plastic casing. Secondly, the smaller the thickness of the resin the stiffer the bond between the bolt and the rock.

2.4 From partially to fully encapsulated bolts

Partially encapsulated roof bolts in areas of strata with several active dilation zones may be loaded quickly and unacceptably. The entire free length of the bolt is loaded by the sum of all loads coming from individual displacement zones. Therefore, it is relatively easy to exceed the yield strength of the bar and once this happens, the bar becomes soft (plastic mode). For example, the 1.5 m free length of a point anchored bolt of 21.7 mm diameter bar in Gr.250 steel (which has yield strength of about 10 tonnes) will elongate about 150 mm when loaded with 13 tonnes. This significant elongation of the bar may then allow for an increase in roof deformation.

Implementation of full encapsulation of bolts dramatically improves the support stiffness. Individual dilation horizons affect only the corresponding local section of the fully grouted bolt. This will minimise or delay the building up of loads exceeding the yield strength of the bar.

Support stiffness also increases relative to the lateral movement of the rock because the fully grouted bolt provides an immediate resistance to such movements as there is no void surrounding the bolt.

2.5 Introduction of higher strength steel

Fully encapsulated roof bolts, in high stress and high strata deformation areas, may also be subjected to loads exceeding their yield strength. The higher the yield strength of the bar the stiffer the system becomes under load conditions. Therefore, the gradual introduction of bolts having higher and higher yield strength again improved stiffness of the support.

Fig. 2. shows the mechanical characteristics of the standard strength steel bolt (AS), the subsequently introduced high strength bolt (AH) and the introduced in mid 1980’s extra high strength bolt (AX).

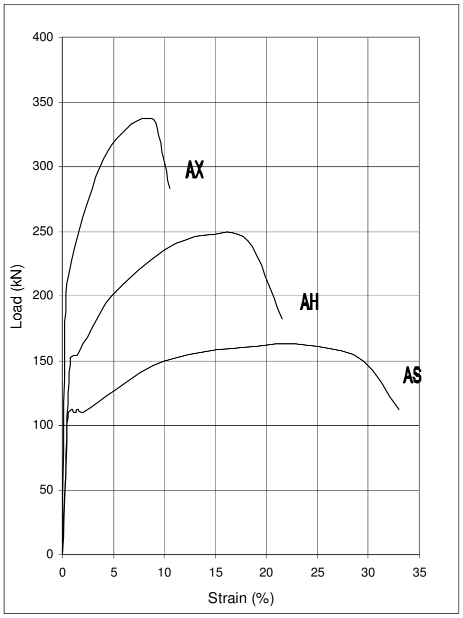

Fig. 2. Mechanical characteristics of roofbolts (21.7 mm bar diameter)

The introduction of the AX type bolt, having a significantly higher yield strength compared to the other bolts (as shown in Fig. 2.), allowed more efficient control of the strata in difficult conditions.

In recent times another bolt type (AVH) having high mechanical stiffness was also introduced to further improve the stiffness of the support. The AVH type bolt was introduced to improve performance of the AH type bolt as an alternate to the more expensive AX type bolt. The AVH bolt is manufactured by a cold working process which significantly increases the yield strength of the bar. Characteristics of the AVH and AH bolts are compared in Fig. 3.

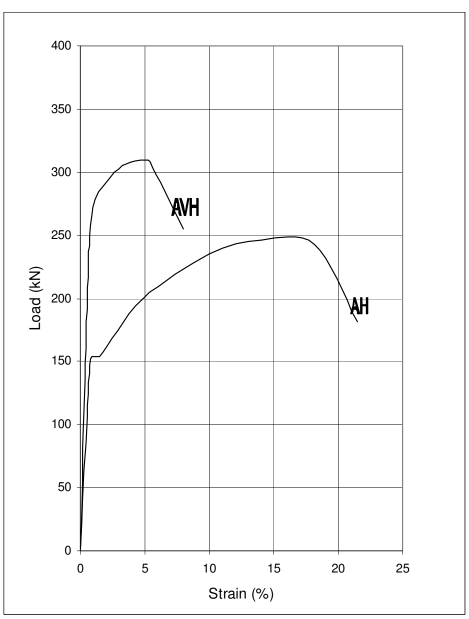

Fig. 3. Mechanical Characteristics of AVH and AH bolts.

It must be remembered that higher strength steel bolts provide higher stiffness not only in regards to axial elongation but also where shear resistance is concerned. The higher the tensile strength of the bar, the higher its bending and shear resistance.

The reinforcing tendons currently in use having the highest yield strength are the cable bolts and strand type bolts. Their performance will be discussed in paragraph 2.7.

2.6 Introduction of longer bolts

Improvements in strata reinforcement using longer bolts has been clearly observed. It is appreciated that these longer bolts create a thicker beam which gives increased strata stability.

One of the major changes achieved by installing longer bolts is increased anchorage efficiency within the upper section of the bolt. In areas where strata movement causes a tensile load in the top section of the bolt, the end of the bolt may be pulled out from the hole. For example, given the current regular bolting system in rock of say 40 MPa UCS conditions, a loading (dilation) zone which is 300mm below the end of the bolt will move that section of the bolt at a rate shown in Fig. 4.

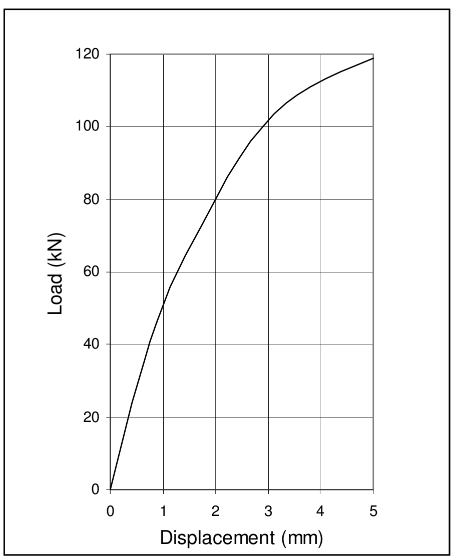

Fig. 4. Typical bolt displacement versus load ratio for 300mm long anchor (40 MPa rock)

Fig. 4. shows that in such conditions load as little as say 8 tonnes causes as much as 2 mm bolt displacement. Therefore, increasing bolt length will increase the stiffness at the upper end of the bolt's anchorage and increase the overall stiffness of the support.

2.7 Introduction of cable and strand type bolts

The term "Cable Bolt" generally is considered as being cement grouted, whereas the term "Strand Bolt" refers to the bolt being resin/chemical grouted.

In the mid 1960's cable bolts were starting to be used in coal mines. These cables were basically 7 wire plain cables of 15.2 mm diameter, commonly up to 10 metres long, and were fully cement grouted and un-tensioned.

Subsequent cable development resulted in "bird caging" of the strand which dramatically improved bond strength. This improvement, together with development of non shrink high performance cementitious grout, led to considerable usage of the bird cage cable bolts in coal mines.

These cables are most often doubled up giving a tensile load capacity of 52 tonnes.

In the early 1990's a new long tendon (Strand bolt) Flexibolt was introduced. This bolt was manufactured from 21 wire strand (23.5mm diameter) and had an ultimate capacity of 58 tonnes.

Important features of Flexibolts are:

- stiff enough for installation similar to solid bolts using chemical anchors;
- flexible enough to allow installation of long lengths;
- could be installed at the face with existing drilling equipment in a 28mm diameter hole; and
- could be pre-tensioned up to 5 tonnes using a nut on the threaded section of the strand.

The success of the Flexibolt led to the development and introduction in 1997 of the Hi-Ten Strand Bolt. This bolt is manufactured from the same strand, as above, but does not have a thread for tensioning. Tensioning at the face to 25 tonnes can now be readily accomplished with special end fittings and a pneumatic powered hydraulic jack.

Also, in recent years another type of strand bolt was introduced ie Megabolt. This bolt consists of number of straight wires bundled together in a cage like form.

The use of cable bolts and strand bolts is nowadays the most efficient form of strata reinforcement. These type of support can supply a very high system stiffness. The high effectiveness of these bolts in strata control may be explained firstly by the efficient clamping of thicker roof strata beam which may be prone to dilation, and secondly by the competent fixing of the beam to overlaying sound strata.
The critical features which make this support so successful is the high bond stiffness of the anchor and the very stiff mechanical characteristics of the cable. High bond stiffness is attributed to the length of the anchor in sound strata.

In contrast to cable bolts which are always fully grouted, a large portion of strand bolts are anchored with partial encapsulation only. The partial encapsulation of the strand bolts is due to the present technical constraints regarding the installation of these tendons. Currently using hand held air leg type bolting equipment, 4 to 8m long strand bolts are installed with 1.2m to 1.5m long single resin cartridge which provides 2 to 3m of encapsulation in a 28mm diameter hole.

In order to fully encapsulate strand bolts, special equipment allowing for simultaneous spinning and pushing of the strand through a longer column of resin cartridges is being used.

It must be noted however, that even partially encapsulated strand bolts may provide effective strata control by “fastening” the immediate roof strata into the sound rock above.

Strand bolts are characterised by the same feature as conventional cable bolts ie very stiff anchor (due to its length) and very stiff mechanical characteristics. Their effectiveness is further improved by full encapsulation and application of pre-tensioning during installation.

Comparison between the mechanical characteristics of the strand bolt (23.5mm diameter) and the solid bar AX bolt (21.7mm diameter) is shown in Fig. 5.

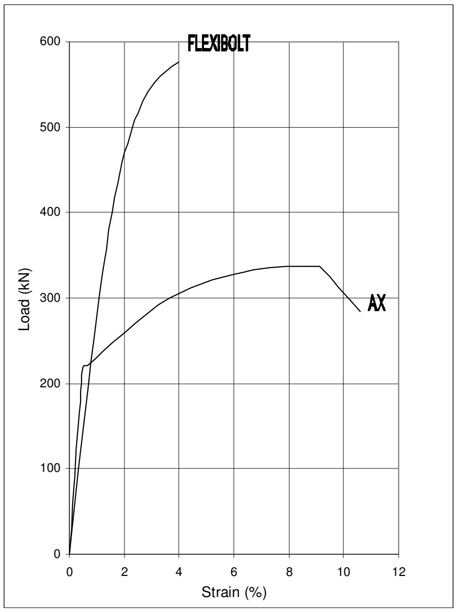

Fig. 5. Mechanical characteristics of strand type bolt and the AX type bolt

2.8 Angled bolt installation

Angled installation of roofbolts has been recognised as an important factor in resisting lateral (shear) movement of the strata.

Their effectiveness depends on the angle between the bolt and shear plane. By angling the bolt in a way that its ends are inclined in the direction of the moving planes as shown in Fig. 6, bolt A will prove to be more efficient to providing stiffer shear resistance when compared to the bolt B which is angled less.

Such mechanisms often exist in the roof close to the rib side. It has been observed that roof bolts which are angled over the rib are more effective than those installed vertically. This indicates that stiffer shear restriction provides better roof conditions.

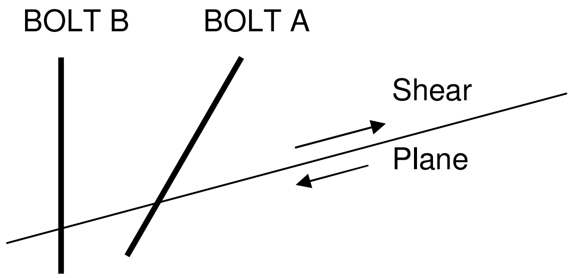

Fig. 6. Bolt inclination relative to shear plane movement.

2.9 Introduction of stiffer roof plates

Roof plate stiffness is also considered important, where in high deformation areas plates are often heavily loaded, especially due to roof bolts being seldom fully encapsulated right up to the collar. The stiffness of the reinforcement system has been increased greatly by introduction of domed plates having stiffer characteristics compared to initially used flat plates.

In recent years new types of roof plates have been developed to further increase their stiffness, but at the same time to reduce their weight. Typically, specially formed 5mm thick plates can be used in lieu of the 10mm thick domed plates.

2.10 Pre-tensioning of bolts

Beneficial effects on strata reinforcement by pre-tensioning roofbolts has long been recognised. Initial use of forge headed bolts have been replaced with threaded bars and nuts enabling pre-tension to be applied. To further increase the pre-tension torque multipliers were used, but for a short time only, as they were too cumbersome and too expensive to maintain. After that special anti friction washers were used to reduce friction between the nut and ball washer to increase pre-tensioning from a given torque.

Recently, significant improvement in pre-tensioning of the rigid bolts has been achieved with special, low friction nuts (HP Oz Nut). The HP Oz Nut allows for increasing the level of pre-tensioning from typical 5 tonnes to 10-12 tonnes for the typical 300 Nm of torque.

Data obtained from a number of collieries show that following the introduction of roof bolts with increased pre-tension, roof stability was improved allowing for a reduction in the amount of either the primary or secondary reinforcement (Rataj & Thomas, 1997).

Very encouraging results are being achieved by the introduction of strand type bolts tensioned to a level of 25 tonnes. A recent study at Central Colliery clearly identified the significant cost benefits achieved by introduction of pre-tensioned rigid and strand bolts (Rataj, Hanson & Frith, 1998).

There are several areas where pre-tensioning effects the stiffness of the support. The first one is the additional compression of the plate, W-strap or mesh and the immediate surface of the strata. Fig. 7 shows performance of a roof plate in weak immediate strata, where additional pre-tensioning from 10 to 20 tonnes eliminates 5mm of softness of the system.

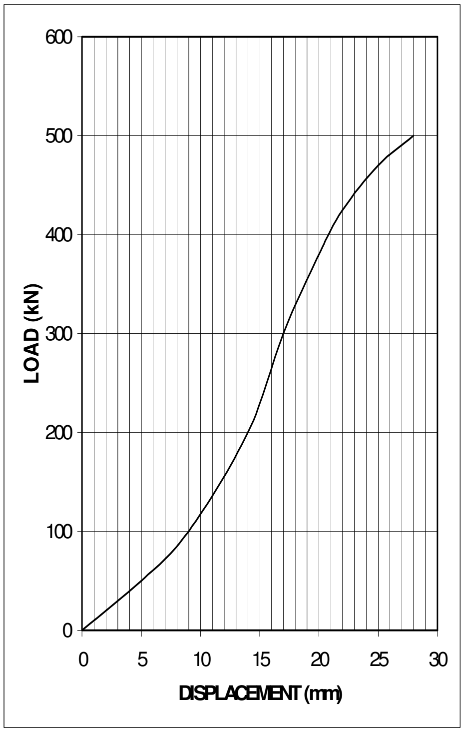

Fig. 7. Performance of 200x200x12mm domed plate on mesh on 10 MPa bed.

Another way pre-tensioning increases support stiffness is by providing extra load to the roof surface which prevents separations along planes of weakness. This in turn reduces lateral displacement which may occur in the immediate roof.

Additional load applied to the roof plate also prevents vertical dilation of the strata, as any strata displacement will have to overcome the plate load first. It means that the pre-tensioned bolts react faster to the strata movement ie provide stiffer support.

3 CONCLUSIONS AND DIRECTIONS FOR FUTURE DEVELOPMENT

Over the years there have been a large number of modifications introduced to rock reinforcement hardware and installation techniques. As a result, significant improvement in strata control has been achieved even though mining and geological conditions have become more difficult due to greater depths.

Analysis of the introduced modifications show that all of them provided more efficient confinement of the strata.

The more efficient confinement has been achieved through making bolts react in a faster and more efficiently to any strata displacement (improved stiffness) and through introduction of techniques which confine the strata in a direct way ie by high pre-tensioning of roof support.

Therefore, it can be concluded that to improve the efficiency of the current roofbolt support the new development should be directed towards hardware allowing for even more increased stiffness of the support and installation techniques which all together should provide even more efficient strata confinement.

The support stiffness is determined by many factors. The most important are anchorage efficiency, tendon mechanical properties, stiffness of roof plate and level of pre-loading of the plate. While it may be difficult to improve on some of the factors, there are others which can be greatly improved.

Listed below are individual factors which effect the various areas of the support stiffness and thereby the strata confinement. Directions for further development are outlined too.

3.1 Factors Affecting Strata Confinement And Directions For Future Development

- Bolt Deformation Profile

  The required bolt profile should be able to develop maximum radial forces which would compress the grout between the bolt and the rock at a minimum displacement of the bolt.

- Hole diameter

  Hole diameter should be as small as practically possible to increase the mixability of the resin, facilitate more efficient shredding of the resin plastic casing and reduce the level of compressibility of the resin.

- Encapsulation Length

  To provide maximum stiffness of the system bolt should be fully encapsulated. However, if the ground is fractured some resin is being lost in the cracks and full encapsulation by using the current resin cartridges is very difficult to achieve.

  Development of a better system for such conditions is therefore required. In the meantime to reduce the resin loses drilling of a slightly larger diameter hole may be considered. Studies have shown that by increasing hole diameter from 27 to 28mm, encapsulation length has been improved. This is due to lowering the pressure of the resin in the hole which causes lesser losses in the cracks.

  Pressure of the resin in the hole can also be affected by the bolt deformation profile. In particular, bolts with excessive height of the two longitudinal ribs (chords) which is typical for standard concrete reinforcing bar for example, will develop higher resin pressure in the hole.

- Resin Mechanical Properties

  Resin Uniaxial Compressive Stress (UCS) and it s modules of stiffness (G) considerably affect the overall stiffness of the support system. Therefore, further development is still required particularly in ares of the stiffness of the resin. The higher stiffness resin will relax the current demand for very tight diameter holes which is not always desirable particularly in fractured ground and in ground having claystone bands which swell when exposed to moisture.

- Quality of Resin Anchor

  The quality of the resin anchor to a large extent depends on the operator's skills. Proper installation of a bolt requires that the bolt is pushed and spun into the hole at the same time. Too rapid pushing of the bolt into the hole with no or minimum spinning will result in a very poor shredding of the resin plastic casing.

  On the other hand, too early spinning of the bolt before the cartridge is pushed to the back of the hole may develop air pockets causing lack of bolt encapsulation particularly around the top end of the bolt.

  Also, premature tightening of the nut, before the resin sets properly may cause significant damage. Work is then required in the area of bolt installation to eliminate the current shortcomings.

- Roof Plate and Rock Interface Stiffness

  Stiffness of the roof plate is very important. Even though significant improvement has been achieved in this area in recent years, there is room for further improvement. The plate/roof interface may also be a very soft spot of the system, especially where wire mesh is used and the immediate roof is rugged and fragile. In such conditions the loaded through the bolt and the plate wires of the mesh, cutting into the rock may allow for relatively large displacement of the roof in relation to the plate. One way to alleviate this problem is to pre-load the plate during bolt installation which will pre crush the protrusion of the rock.

- Anchor Length

  The length of the anchor is one of the most significant factors affecting the support stiffness. Therefore, the cable bolts and the strand bolts provide so efficient rock reinforcement. Development of a more cost effective full encapsulation method for the strand bolts is still required.

- Tendon Mechanical Properties

  To further increase the yield strength of the bolt, higher tensile steel would have to be used. This would however, reduce the elongation of the currently strongest AX type bolt and possibly increase the bolt vulnerability to Stress Corrosion Cracking. Some work is required to determine if the currently required minimum elongation of the bolt could not be reduced particularly in view of the commonly used cable and strand bolts having significantly lower elongation when compared to the rigid bolts.

  The area of the SCC is not clear either. It is not known exactly what causes the brittle failures of some bolts in some of the mining conditions. At this stage it is not known to what degree (if any) the stronger steel would be susceptible to the SCC.

The mechanical characteristic of the bolt can also be stiffened by using larger diameter bar. This option requires however, development of mechanical method of handling of the bar, as the weight of the bolt may be too much for the operator.

- Angled Bolts

  Angling of the bolt in a right direction in relation to the shear plan improves bolt resistance. However, effectiveness of the bolt in vertical support may be reduced if the angle is excessive. Studies would be required to determine the optimum inclination of bolts in given conditions.

- Pre-Loading of Roof Plate

  The pre-loading of a roof plate by tensioning of the bolt, as already discussed reduces the plate/roof softness. However if the pre-load is large enough it will also prevent rock separations and even close some of the existing separations. Further work is though required to determine the optimum load for given conditions.

Today the stiffest roofbolt support system can be provided by the highly tensioned fully grouted, high load capacity strand bolts, which can be installed in pre-failed conditions if required. It gives the mining engineer a powerful tool in the strata reinforcement.

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