The Development of Active Cable Anchors for Primary Supports in Coal Mines

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Abstract

High strength cable strand supports are predominately used as a supplemental means of ground control in longwall and development operations in the U.S. The advantages of cable strand supports have been documented and include flexibility, strength, and ease of installation. Since the majority of cable supports installed in the U.S. today are partially grouted, and this same segment of supports has no inherent installed tension, the supports are considered currently arbitrarily strictly supplemental and therefore, cannot currently be deemed primary support (in most mining districts).

This paper details and discusses two distinctly different configurations and the technical advantages of active partially grouted cable supports for certain primary support applications. The evolution of the designs for both systems is highlighted. Field data illustrates the amount of active load in relationship to installed torque and the affects that component variables have on this load measurement. Roof control patterns using active cable supports are examined as alternatives for combination patterns using primary and supplemental systems. The importance of maintaining consistent installation procedures plays an important role in the level of performance of the system. Economics comparing the installation of active cables with other primary/supplemental patterns is also included.

INTRODUCTION

Cable bolts have been used in hard rock mines for many years. They were introduced into Canada in about 1963 (Marshall, 1963) and into South Africa in about 1964 (Thorn and Muller, 1964). More recently in the early 1980s, coal mines in Australia started to use cable bolts (O'Grady et al., 1994) mainly as supplemental support for roadway intersections.

Supplemental support refers to the installation of additional support after the excavation has been initially supported (during excavation) where primary support is installed.

Cable bolts are most commonly made from high-strength seven strand material, where six outer strands are helically wound (in a clockwise direction) around a central strand (called the king wire).

Figure 1 shows a typical 7 strand cable:

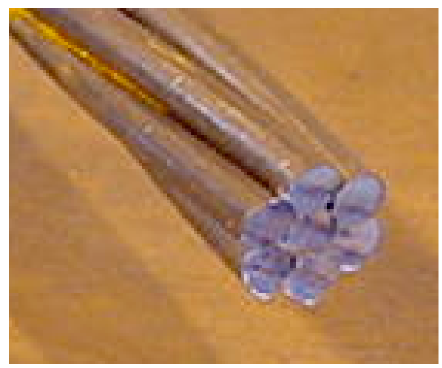

Figure 1 – 7 strand cable

Figure 2 shows the typical components of a standard cable bolt (after Dolinar and Martin, 2000).

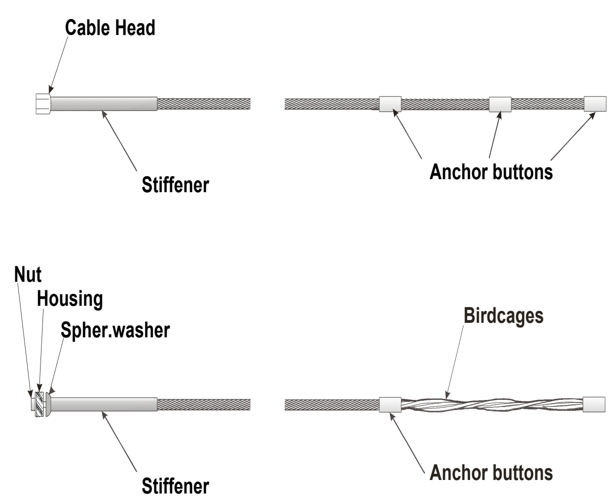

Figure 2: Typical cable bolt components

As can be seen from Figure 2 a typical cable bolt consists of:

- A 7 strand cable with a typical diameter of 0.6” (with a minimum tensile breaking load of 55,700 lbs) or a 0.7” diameter (with a minimum tensile breaking load of 71,500 lbs).
- Resin cartridges to anchor the cable (cementitious grouts are frequently used on hard-rock mines and on underground civil construction projects).
- A head/barrel and wedge mechanism to grip the cable, spin it through the resin during installation, permit pretension (if not pre-set at the factory) and hold a bearing (face) plate in contact with the rock around the drilled hole.
- A stiffener tube that is needed mainly to assist with the cable bolt insertion/installation through the resin cartridges.
- An anchor button (or ferrule) at least at the end of the cable to hold the strands together during the installation.
- Bulbs (or birdcage or equivalent) in the cable to assist with the anchoring of the cable.

Cables with yielding head assemblies have also been available for areas of larger expected deformation (Tadolini and McDonnell, 1998).

FACTORS AFFECTING CABLE BOLT PERFORMANCE

External conditions affect the performance of a cable bolt (and any other form of support) including:

- The local geology
- The presence of water (as it effects corrosion and the local rock structure and properties).
- The in situ rockmass properties.
- The stress tensor (and any changes due to future mining operations).
- The excavation dimensions (especially the span).

A variety of cable bolt design parameters significantly affect the performance of the installed support unit such as:

- The drill hole size.
- The cable steel type.
- The cable diameter.
- The cable construction (including the strand format and any anomalies such as “bulbs” or “bird-cages” that increase grout anchorage).
- The overall cable length and the overall hole length.
- The grouted and free (un-grouted) length.
- The type and properties of the grout.

Other factors also affect the effectiveness and performance of the cable bolt from a roof support standard point of view:

- The total installed cost.
- The ease and effectiveness of the installation technique used.
- The training and skills level of the operators installing the unit.

THE EVOLUTION OF CABLE BOLTS IN US COAL MINES

Cable bolts have been traditionally used in supplemental (secondary) support applications such as:

- Longwall tailgates (to replace cribs or similar free standing supports).
- Bleeder entries.
- Headgate support.
- Critical excavations (such as major belt drives).
- Roadway intersections.
- Room/bord and pillar mines.

The first full-scale supplemental test of a cable bolted cribless tailgate took place in the Eagle Coalbed in the eastern USA and was completed in December 1995 (Mucho, 1998). Earlier successful trials had all been in western coal mines (from about 1992). The results of the cribbed and cribless tailgates were similar (with less floor heave in the cable bolted area). The caving was also reported to be “tighter” in the area supported with cable bolts and hence higher face ventilation was achieved (reducing the dust) but this advantage may be negated if the gob is gassy.

It is surprising that timber cribs are still used on some longwall coal mines considering the issues associated with their use and the more effective alternatives that are available.

The issues include:

- The negative environmental impact of the timber use (up to 248 acres of timber needed for a single longwall in the west as reported by Tadolini and Koch (1993)).
- The underground fire hazard.
- The labor cost in material transportation and erection.
- The inherent hazard potential in erecting timber cribs especially in high entries.
- The performance deterioration caused by moisture loss over time from the timber.
- The restriction of the cribs to men, material and ventilation passage.

The alternatives that can be generally considered include:

- Cable bolts (possibly with yielding head assemblies).
- Cable trusses.
- Steel free standing supports.
- Pumped or concrete cribs.
- Timber based free standing support (a more efficient use of timber than cribs).

THE ADVANTAGES OF CABLE BOLTS

Rock anchors in general have some advantages over free-standing supports, such as: cheaper installed cost, no ventilation restriction, no fire hazard (only relevant when comparing with timber based supports) and no restrictions for men and material transportation. Where high deformation is expected however, a yielding free-standing support is still the obvious choice at present, as most of the other support types cannot sustain stable reaction loads at high deformations.

Cable bolts also have advantages over other rock anchors and these include:

- More "stretch" than the conventional solid (rebar) type of anchors.
- More load capacity generally than a solid anchor of equivalent diameter.
- Higher shear strength than an equivalent sized solid anchor.
- The cable's inherent flexibility is an advantage especially when long rock anchors are required (or in low seam heights).

The only potential disadvantage is that the higher surface area of a cable, compared with an equivalent rod or rebar, can make it more prone to corrosion but this can be offset by the use of a coated or galvanized strand.

Clearly cable bolts are generally a more costly type of rock bolt support and hence should only be used where appropriate from a roof control (safety) point of view. They are the obvious choice for longer length applications (say > 8 ft) or high capacity (say >25 t).

THE DEVELOPMENT OF TENSIONABLE CABLE BOLTS FOR PRIMARY SUPPORT

There are currently no ASTM or other nationally recognized specification for tensioned cable bolts for underground coal mines. Although this aspect is currently being addressed by an ASTM sub-committee, a specification is unlikely to be ready in the short term.

The only MSHA documentation related to this is A Procedure Instruction Letter No. I03-V-6 with an effective date of 04/21/2003 and an expiration date of 03/31/2005. This letter mandates that any tensioned cable bolt shall have specifications in the roof control plan as follows, if it is to be approved as required (primary) support:

- Each component must be specified and dimensioned.
- A drawing with each component in its location must be included.
- The cable specifications must be given.
- Each cable bolt should be marked to identify length, cable type and manufacturer.
- The hole diameter, resin cartridge diameter and length must be given.
- The installation procedure must be detailed.
- The tension range and method to determine it must be documented.

The letter also notes that at the "present time" (assumed to be the issue date) only 2 mines have permission to use tensioned cable bolts as required support.

The 2 main reservations to the use of cable bolts as primary support appear to be:

- The slowing down of the support installation cycle and hence any cable bolt used for this must be relatively quick and easy to install.
- The lower system stiffness of a cable as compared with a rod/rebar. This can at least be partially overcome by tensioning the cable bolt and in certain conditions, the increased stretch of a cable could in fact be an advantage.

An advantage of installing all the rock support as primary without the need for any supplementary (or secondary) support is that the rock mass generally becomes more "stable" the sooner it is supported.

Excel Mining Systems and F.M. Locotos (the inventor) have collaborated on the development of two cable bolt designs that could be pre-tensioned to the currently mandated 8,000 lb minimum in MSHA District 3 (Morgantown, WV) and hence be used as primary support there.

These 2 designs both have the advantage that the tension is distributed along the entire cable length.

Design 1 – A resin grouted mechanically anchored tensionable cable bolt

This unit relies in torquing the barrel/head and wedges which causes the mechanical shell to lock and create a pre-load. Designing the mechanical anchor system that could be forced through the resin cartridges was a technical challenge that had to be overcome. Part of the solution was to select a short shell (the pre-load target was only taken as 10,000 lbs) and create as much space as possible to allow the resin to pass through during the installation. The extra anchor buttons fitted also assisted, by not only creating a better bond with the resin but also reducing the tension loss effect by effectively "stiffening" the cable helix.

Figure 3 shows the tensionable cable bolt components.

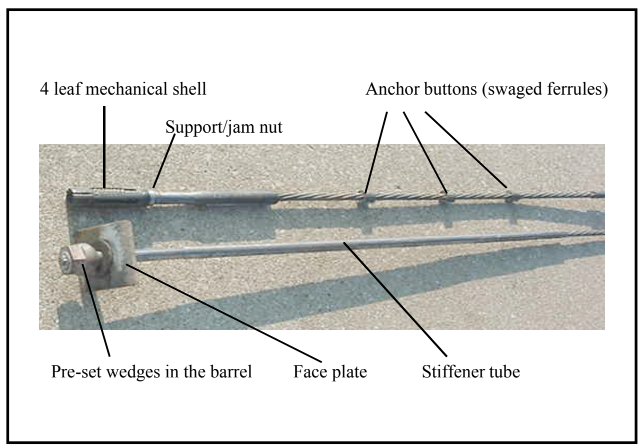

Figure 3 – A tensionable cable bolt (Design 1)

Whilst this design achieves the target performance, it was felt that a more efficient tensioning mechanism may be desirable. This lead to the second design detailed below.

Design 2 – A partially resin grouted mechanically anchored tensionable cable bolt

This initial design involved first spinning the cable anti-clockwise to mix the resin and then after the resin had set, spinning it clockwise to tension the cable. This approach worked but was considered unacceptable because the resin spinning tended to "unwind" the cable and this was thought to be potentially a problem. The solution adopted was to modify the nut and fit a shear pin so that at low torque the resin could be mixed and after setting (at high torque) the shear pin would fail and the cable could be tensioned (Figures 4 and 5). This method involved rotation with the cable's helix and was found to be acceptable in some mining districts.

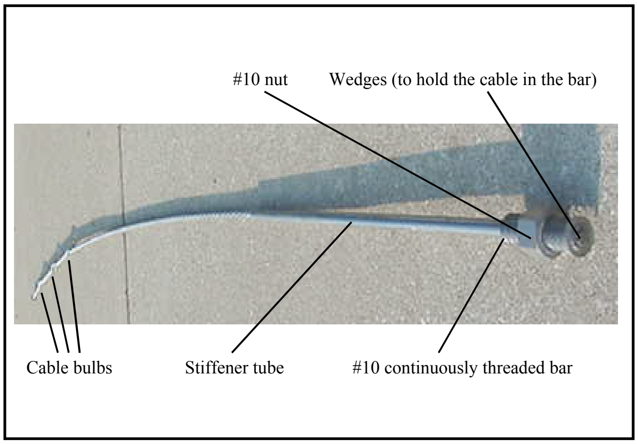

Figure 4 – A tensionable cable bolt (Design 2)

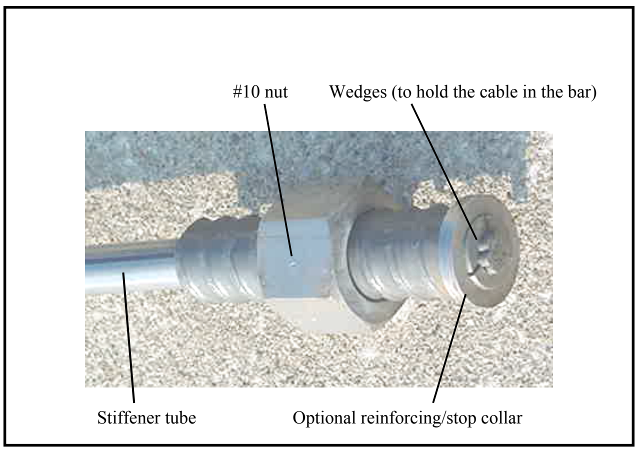

Figure 5 – Detail of the tensioning mechanism

TENSIONED CABLE BOLT PERFORMANCE

Tensioning a cable using a pure torque is not ideal because of the cable helix. This causes some tension reduction after the machine is removed. Tests however indicate that the 8,000 lb tension can be readily achieved in practice by initially torquing the unit to a higher value (Table 1).

Table 1: Bolt tensioning results for Design 1.

Test No.	Installed tension	Residual tension	Applied torque	Torque to tension ratio
1	11,100 lbs	10,360 lbs	230 ft-lbs	45:1
2	17,390 lbs	11,000 lbs	230 ft-lbs	48:1

Design 2 prototype units with a #11 threaded bar (1_" diameter) have been tested by MSHA's Roof Control Division, and in each case the cable failed at levels generally achieved with cable only tests (not the threaded rebar assembly). Tests using a #10 threaded bar are looking encouraging and will have the added advantage of being able to easily fit into a standard 1_" drill hole without the additional step of reaming the collar. This will be a significant advantage from a productivity point of view.

ROOF CONTROL SUPPORT PATTERNS

There are many layout comparisons that can be made but Figure 6 is illustrative of a typical layout (with 18ft spans) using supplemental support and using active cables (with no supplemental support).

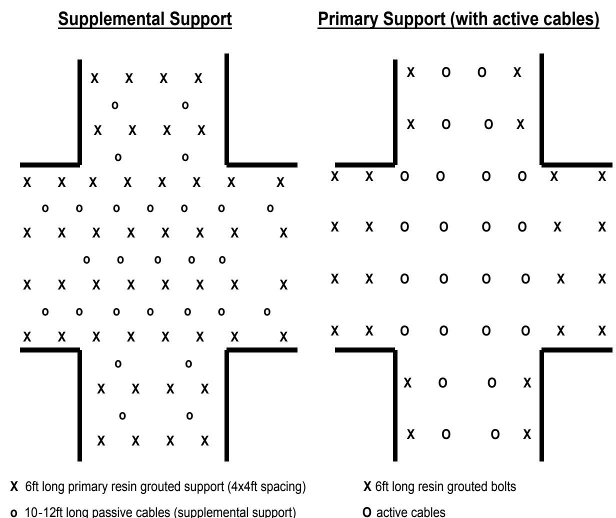

Figure 6

Clearly the anchor pattern could also be diamond or herring bone.

Using only primary support (with active cables) has therefore considerable advantages including:

- Less support units are needed.
- All the support is installed at the same time on cycle and although active cables would take slightly longer, overall time and cost savings can be realized.
- Possibly more effective support as the long cables are installed in the intersections on cycle (i.e. much sooner) and are tensioned.

COSTS

The true installed cost of a rock anchor needs to be considered, including the material costs and the installation costs. The true installed rock anchor cost consists of:

- Drilling costs
  - Labor
  - Materials
  - Consumables
  - Equipment maintenance
- Installation costs
  - Labor
  - Materials
  - Consumables
  - Equipment maintenance
- Any rehabilitation costs

For all practical purposes it is not possible to consider rehabilitation costs if the support system fails prematurely. These costs should be noted when rehabilitation is undertaken as it is always significant and underlines the need for "the correct support the first time". In the long term corrosion is frequently the cause of rock anchor failure, and this should always be considered carefully when designing ground support for long life critical excavations.

Typically the drilling costs are double those of the installation cost. It is therefore often foolhardy to try and save on the actual rock anchor cost by possibly selecting the less than ideal unit when its contribution to the "real" cost is actually quite marginal.

It is difficult to make cost comparisons that can withstand detailed scrutiny and the costing below is only introduced as a rough comparison based on Figure 6.

The support pattern that utilizes primary and supplemental support requires:

- 48 6ft resin grouted #6 rebars as primary support.
- 27 12 ft 0.6 inch diameter passive black cables as secondary support.

The support pattern that only utilizes primary support needs the following (based on an equivalent intersection):

- 24 6ft resin grouted #6 rebars.
- 24 10ft 0.6 inch diameter active black cables (the length reduction could be possible because the support is being installed earlier)

The following assumptions are made:

- Total material cost for a 6ft grouted rebar, plate and resin is assumed to be $6.25. The average installation time is 2 minutes.
- Total material cost for a 12ft headed passive cable, plate and resin is assumed to be $18.25. The average installation time is assumed to be 3.25 minutes.
- Total material cost for a 10ft active cable, plate and resin is assumed to be $22.25. The average installation time is assumed to be 4 minutes.
- A total labor cost of $35/hour for bolter operators is assumed.

The total support material costs are therefore (for the single intersection and 10ft either side):

- Primary and supplemental support at $792.75.
- Primary support only at $684.00.

The material support cost savings are therefore about 14%.

The drilling time is approximately as follows:

- Primary and supplemental support
  96 minutes for primary support
  88 minutes for supplemental support

- Primary support only
  144 minutes

The total support installation time when utilizing only a primary support system is about 22% less than a system requiring primary and supplemental support ($23.45 in installation labor cost saving per intersection).

The time for primary support is however increased in this example by 40 minutes. Assuming a twin boom drill rig this is about 20 minutes of extra on-cycle development time per intersection. This is however the worst case scenario and the actual effective cycle time increase should be much less and would depend mainly on the number of working faces, the number of faces worked and the number of bolting units.

Additional advantages that have not been considered are the possible improved rock conditions and the reduced transport costs associated with the primary support only option.

CONCLUSIONS

Based on results to date the following conclusions can be made:

- It would seem that tensioned cable bolts can be produced that meet the MSHA District pre-tension requirement.
- Such units could be technically acceptable in many support applications.
- Cost savings can result without adversely influencing safety (and probably improving it).

REFERENCES

Dolinar, R.D., Martin L.A., Cable support in longwall gate roads –Proceedings: New Technology for Coal Mine Roof Support NIOSH, 2000, IC 9453.

Locotos, F.M. Patents pending

Marshall, D. Hangingwall control at Willroy. – Can. Min. Metall. Bull. 56, 1963, pp 327-331.

Mucho, T.P. In The Field – Cribs versus cables. HAS Bulletin, March 1998.

O'Grady, P., Fuller, P. and Dight, P. Cable bolting in Australian coal mines – current practice and design considerations. Min. Engr. 154 (9),1994, pp 63-69.

Tadolini, S.C., Koch, R.L. Cable support for improved longwall gateroad stability. 12th International Conference on Ground Control in Mining, Morgantown WV, 1993, pp 9-15.

Tadolini, S.C., McDonnell, J. Recent developments in cable support technology – 1998 SME Annual Meeting, preprint 98-026.

Thorn, L.J., Muller, D.S. Prestressed roof support in underground engine room chambers in Free State Geduld Mine Ltd. Papers and Discns, Assn Mine Mngrs S. Afr. , 1964, pp 411-428.