TWENTY-FOUR CONFERENCES; MORE THAN ONE-HUNDRED AND SEVENTY PAPERS; UNDERSTANDING ROOF BOLT SELECTION AND DESIGN STILL REMAINS *PRICELESS*

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ABSTRACT

The International Ground Control Conference in Mining has always provided an open forum for the publication, presentation, discussion, and often heated debate on roof bolting systems mostly with attention to how, when, and why they work. During the last 24 Conferences at least 170 papers have been presented by International Experts on these "simple" devices that range in length from 30-inches to 20 ft and from 5/8 to 2 inches in diameter. Roof bolts are primarily mechanically anchored, glued, cemented, or driven. Bolts are placed vertically, angled, or tied together with special fixtures (trusses and slings). They have been termed active, passive, stick-slip, and several other descriptive acronyms or mining slang expressions. This retrospective paper will present the changes in bolt types and usage, point out some of the biggest myths and hail the most significant advances (according to the authors' opinions of course).

INTRODUCTION

Ground control, like golf, is an eternal conflict between elation and despair. Our favorite response to "How did you shoot?" upon returning to the clubhouse after a beautiful day at the Lakeview resort is a rousing "I think I found the secret and know what I've been doing wrong!!" Inevitably, the next day the response is a hopeless "I think I lost it again." Secrets and successes in both golf and ground control come and go rapidly. You find one secret and lose it between the 8th and 9th hole or in as short of a distance as the next break or cross-cut. And even if you rediscover the magic, it doesn't help to have a bunch of secrets stored in your head just as you are about to start your backswing or develop a new miner section. The brain just can't handle "straight left arm, keep your head down, follow through to the target" all at the same time. "Just hit it or just mine it" seems to work the best from both a golfing and operational perspective. Unfortunately, as if getting to the green isn't difficult enough, you are often faced with a 5 ft putt where things can really go wrong. You push'em, pull'em, and often leave them short. Of course every bad shot on a golf course usually makes someone in the foursome happy. Unfortunately, mistakes made in an effective ground control program can have a devastating instant effect and negative repercussions for the safety of the miners or the life of an entire operation.

If we have learned anything at the International Ground Control Conference in Mining (IGCCM) over the past 24 years as we head into our Silver Anniversary, it is that some things have changed tremendously while many others have simply stayed the same. Case study after case study has revealed that the practical or commonly used theories show that little can be done with roof bolts to prevent rock movements, especially for the elastic part, around an underground coal mine opening. Of course, some people have argued that massive, preloaded supports, which are difficult (slow) to install and can be quite expensive can prevent or at least minimize movements. The competent ground control engineer tries to install the supports as quickly as the entry is developed to take advantage of the movement that will indirectly load the supports and prevent or minimize additional downward roof movements. Some quick snapshots of bolt usage may provide some insight into what developments have been made in the last 25 years.

ROOF BOLT USAGE TRENDS

An analysis of roof bolt usage may provide valuable insight into the development of the systems and what has proven to be most effective over time. The IGCCM has been the stage for the introduction, description, and subsequent analysis of several of these bolting or roof support systems. While occurring after the beginning of the IGCCM in 1980, an estimated roof bolt count was presented that summarized usages in 1988 (Scott, 1989). Scott discussed the trend of using higher quality roof bolt systems that featured higher strength steels, matched bearing plate strengths, and complex anchorage devices that included the use of mechanical shells and resin. The picture painted by Dr. Scott is much different than the statistical sampling of roof bolt usage presented in 1976 from reportable Mine Safety and Health Administration (MSHA) data (Karabin and Debevec, 1976). That report was quite simple - of the estimated 100 million roof bolts used that year 80% of the bolts used were mechanical anchored bolts and the remaining 20% were fully grouted (resin or cement). Figure 1 shows the distribution of roof bolt usage in the U.S. in 1988. In 1988, approximately 85 million bolts were used in underground mining applications. Resin rebar accounted for 34 million or 40% of all roof bolts used. Mechanical anchored bolts (commonly called Conventional bolts) accounted for 35% of bolt usage or about 30 million units. Resin-Assisted Mechanical Anchor bolts are mechanically anchored bolts whose ultimate anchorage has been enhanced or transformed with the addition of a resin plug used at

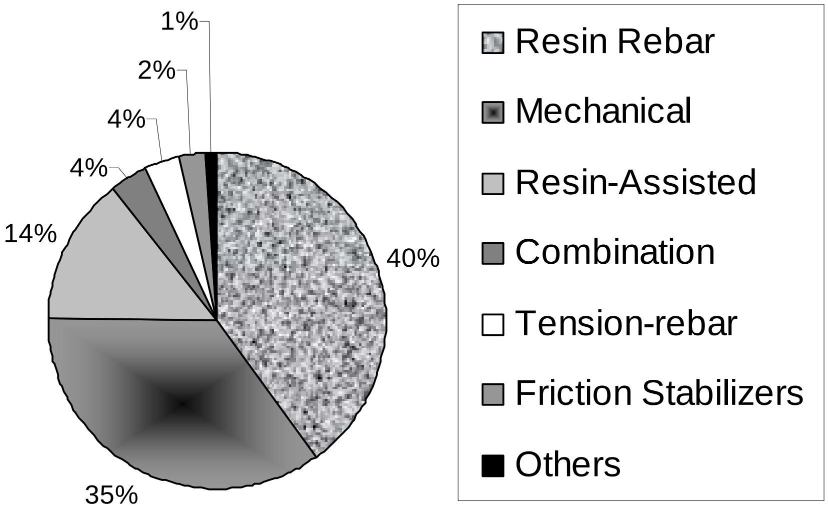

Figure 1. Distribution of roof bolt usage in the U.S. in 1988 (Scott).

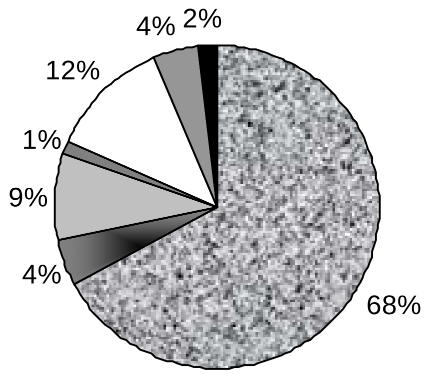

Figure 2. Estimated roof bolt usage in the U.S. in 2005.

the top of the bolt. These systems are installed using the same techniques as a mechanical bolt with a resin cartridge placed in the hole before the bolt is inserted. Resin Assisted Mechanical Anchor bolts accounted for about 14% or 12 million bolts. Combination bolts, essentially a two-piece bolt, commonly used when the mining height is less than the required support height, accounted for 3 million bolts (3.5 percent), and 3 million tension-rebar bolts were used and tallied 3.5 percent of the annual usage that year. The remaining 15 million bolts included friction stabilizers (Swellex and Split-sets), trusses/slings (both rigid and cable), Dyna-Roc's, Fiberglass and wooden dowels.

A similar survey was conducted for this paper to report the estimated roof bolt usage in the U.S. for 2005 and results are shown in Figure 2. Resin rebar accounted for about 68% of bolt usage, which was an increase of 28% from the 1988 survey. Mechanical anchored bolts dropped to about 4% of support types used and Resin-Assisted bolts also decreased from about 14 to 9%. Tension-rebar bolts experienced an increase from 3.5 to 12%. Friction stabilizers, used primarily in hard rock applications, accounted for 4% of the bolts used in 2005. Cable bolts (about 1 million units) and Cable Slings and Trusses account for the remaining 1.5% of roof support usages.

The most significant difference between the 1988 and 2005 survey results, besides roof bolt usage trends that will be discussed in more detail, is the decrease in the number of bolts used in the U.S. underground mining applications. The 1988 survey estimated the number of units at 85 million and in 2005 that number was reduced to about 68 million bolts. This reduction in roof bolt usage can be partially explained if a quick analysis of underground (UG) coal mine tonnage is completed. In 1988 the total number of UG coal mines was 1,768 and produced 376 million tons. Of the 1,768 mines, 1,696 were room and pillar operations, which accounted for 246 million tons, and 72 were Longwall mines that produced 131 million tons or 34.7% of the total UG production. In 2005, a total of 606 mines were active; 562 room and pillar mines accounted for 176 million tons, while 44 Longwall mines produced 190 million tons or 52% of the total 376 million tons. While the total of tons produced in UG coal mines has remained relatively flat, longwall production increased 45 percent. Of course roof bolt usage is greatly reduced in longwall operations when considering the number of bolts per ton of coal. In general, the number of roof bolts used is about 4 times higher for room and pillar than longwall mining for the same extracted tonnage. The reduction of 70 million tons in Room and Pillar operations from 1988 to 2005 off-set by Longwall mining would account for about a 10 percent usage difference of 8.5 million roof supports. This only accounts for about half of the reduced 17 million bolts, and additional theories and hypotheses could be presented but are highly speculative and beyond the scope of this effort.

WHAT HAS WORKED, WHAT HAS NOT, WHAT IS CURRENTLY CHANGING, WHERE ARE WE NOW?

Mechanical Anchored Bolts

An examination of roof bolt usages does provide some valuable insight into what has worked and what has not in mining applications, particularly coal. Obviously the reduction of mechanical anchored bolts has been dramatic. The mechanical anchored bolt, as shown in Figure 3, can be quickly installed and anchorage capacities up to 25,000 lbs have been achieved. The rock strength, more specifically shear strength, always controls the anchorage and the amount of bolt tension that can be applied by the mechanical anchor. The real critical issue of the system is the "bleed-off" or loss of tension after embedment and mechanical relationships of the strata and bolting components occurs was examined at the First IGCCM (Mahyera et al., 1981). The report examined several techniques to control the thrust and minimize the variability in installation torque and subsequent bolt tension, as well as all the "frictional" factors that can impact effective installations. At the Fourth Conference Maleki described the use of hardened washers, lubricated threads, facing the hole surface (a complicated process to account for bending), and installing the bolt with additional torque so the "predicted" subsequent bleed-off was at an acceptable limit. The conclusions stated that installed tensions were normally 50% less than those required to ensure proper bolt installation and subsequent performance (Maleki et al., 1985).

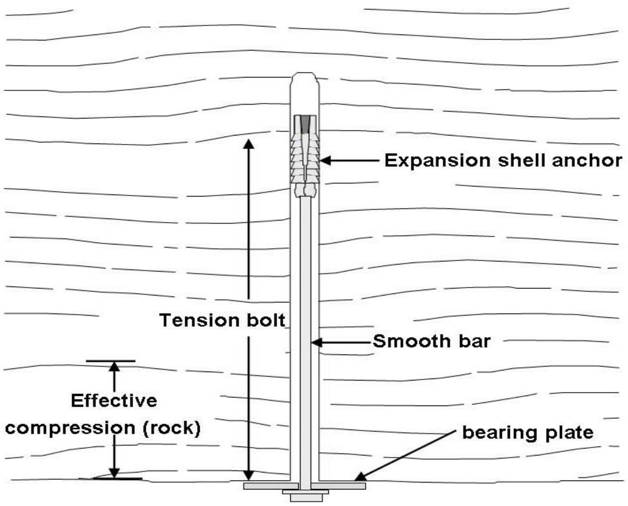

Figure 3. Mechanical anchored roof bolt (high-tension, low anchorage capacity, low system stiffness, low-shear resistance).

While several technical concerns have been evaluated and solutions developed and published, the decline in the use of Mechanical anchored bolts can also be largely attributed to the required installation issues and subsequent torque measurement requirements cited in the CFR75.204(f)(4) and (5). This regulation requires that in each roof bolting cycle, the actual torque or tension in the first tensioned roof bolt with each bolter head be measured immediately after it is installed. Thereafter, at least one out of four bolts is checked after installation and if the place is open for 24 hours, at least one out of ten bolts is checked from the outby corner of the last open crosscut to the face in every advancing section. The labor required, coupled with the lower bit costs for a 1-inch diameter hole, to ensure quality bolt installations simply out weighs the costs of alternative supports. This fact, coupled with the introduction, performance, and subsequent approval of no. 5 resin rebar, led to large decreases in mechanical bolts and the increase in resin-rebar usage.

Resin Rebar Bolts

At the Fourth IGCCM, Serbousek reaffirmed the concept that resin grouted bolts, illustrated in Figure 4, did not anchor because of chemical bonds or adhesion. Rather, it is the mechanical interlock between the rock-resin-and bolt interface that is the most important parameter and develops the reinforcing mechanism used for anchorage and bolt strength development today (Sebousek and Signer, 1985). This work served as the foundation for research that has culminated in the lively and often debated topics of glove-fingering, annulus thicknesses, pull-test anchorage capacities, bolt stiffness, etc. The system basically works because of superior anchorage and stiffness that develops as a result of the full bolt length resin anchor. The high stiffness is accomplished because of the full contact of the resin anchor and the ability of the resin to *quickly* transfer the developed loads, via the bolt, back into the rock mass. Because of the bolt's superior stiffness, a significant resistance to rock movement is developed both axially and laterally. Loads that are developed along the bolt, if roof separations occur, are *quickly* transferred back into the rock and the movement is resisted at the parting or separation. As mentioned, the annulus or the distance between the rock and the bolt has been adequately debated. Research results show that effective load transfers can be developed with annulus thickness or distances as small as 0.0625 inch (Tadolini and Hendon, 1998) or *optimized* at 0.125 inch which accounts for fluctuations in rebar size, potential resin losses due to installation pressures, and some mixing issues (Campoli et al., 1999). Researchers fundamentally agree that there are two critical aspects to performance of the resin rebar bolts based on the resin annulus distance; the correct bolt installation (annulus, mixing, hold-times, etc.) and the load transfer along the bolt. Both can be negatively impacted by a large annulus size which is the distance from the borehole wall to the rebar. As mentioned, the no. 5 resin-rebar system (5/8-inch diameter) has served as the primary replacement support for mechanical anchored bolts. No. 5 rebar bolts are routinely installed in a 1-inch diameter hole, the annulus for this specific system is 0.1875 inch. Installation solutions and bolt modifications have been introduced to ensure adequate mixing of the resin. However, the transfer mechanics of the bolt can be slightly diminished and should be considered if large roof movements and high loads are expected (Rico et al., 1997). Also, this is important, there is a significant difference in the shear capacity and system stiffness between a no. 5 and the more "ideal" no. 6 rebar systems.

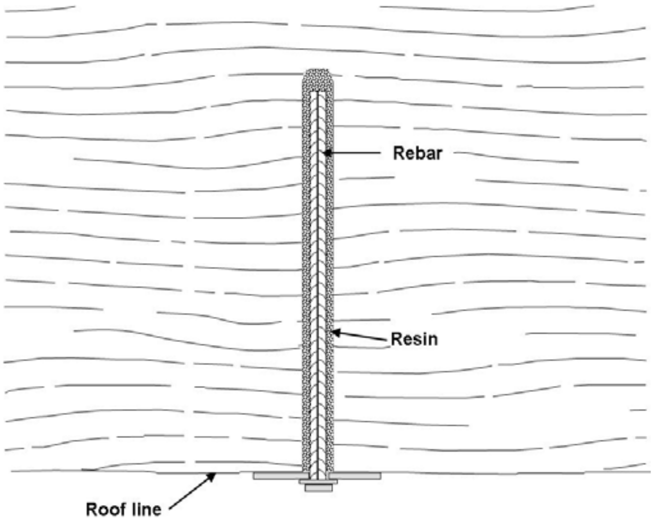

Figure 4. Resin rebar bolt (low-tension, high anchorage capacity, high system stiffness, high-shear resistance).

No instrument or system has been developed that can be routinely used to determine the effectiveness of resin rebar bolt installation; not resin mixing, simply the assurance that the bolt is fully grouted (if that is the specific application). At the Second IGCCM, a device called "The Roof Bolt Bond Tester" developed under contract by the U.S. Bureau of Mines, was introduced that utilized ultrasonic energy weightings that were turned into green, yellow, and red lights that indicated 100%, 50 to 75%, and less than 50% resin contact to the bolt (Stateham, 1982). Unfortunately, the Roof Bolt Bond Tester system later proved to be no more than a random color generator and never was modified or successfully marketed. Because no systems are available to perform non-destructive testing of resin-grouted bolts, this may still be a potential research area.

In summary, resin rebar bolts have proven to be extremely effective in several applications. Rebar bolts are particularly effective for supporting highly stressed, weak roof strata with the length being increased for high overburden depths. They are easy to install; even in restricted seam heights by bending the bolts, and they are cost-effective and provide superior anchorage and support stiffness.

Tension-Rebar Bolts

A Tension-rebar bolt is the best of both worlds - it is essentially a resin-grouted rebar bolt that is tensioned upon installation. The support system consists of rebar that is threaded on the end to allow a nut to be installed and tightened against the bearing plate. While it is still very common that only the top portion of the bolt be anchored in resin, the maximum stiffness or complete benefit of the system is attained when two speeds of resin are used to achieve a full-column or complete anchorage of the bolt. To achieve a full-column of resin and still be able to tighten or tension the bolt, the top portion is anchored with a fast setting resin and the bottom with a slower resin. Current resin manufacturing processes limit this application to a two cartridge system. As the bolt is inserted into both cartridges of resin, a delay mechanism on the nut or reverse rotation is used to mix the resin thoroughly. The fast setting resin sets and the bolt is tightened before the lower or slower setting resin has had a chance to cure. This permits the lower portion of the mine roof to be placed in compression, distributing the forces over the lower portion or length of the bolt, as shown in Figure 5. These systems combine the positive characteristics of a mechanical bolt and the superior anchorage developed in a resin rebar bolt. Maleki reported that tension-rebar bolts were extremely effective in supporting a difficult tailgate and even maintained loads, recorded with strain gages along the bolt axis, after the heads had been sheared off! The mechanical interlock created along the entire length of the bolt was high enough to redistribute the applied bearing plate loads (Maleki et al., 1986). Without a bearing plate, fully grouted bolts can still function and resist rock movements. However, the control provided by the plate and the subsequent loads measured between the mine roof and bearing plate indicate that plates can add significantly to the roof support. Adequate plates help resist roof movements in the lower 2 ft of the roof and are an important support element in roof reinforcement (Tadolini and Ulrich, 1986).

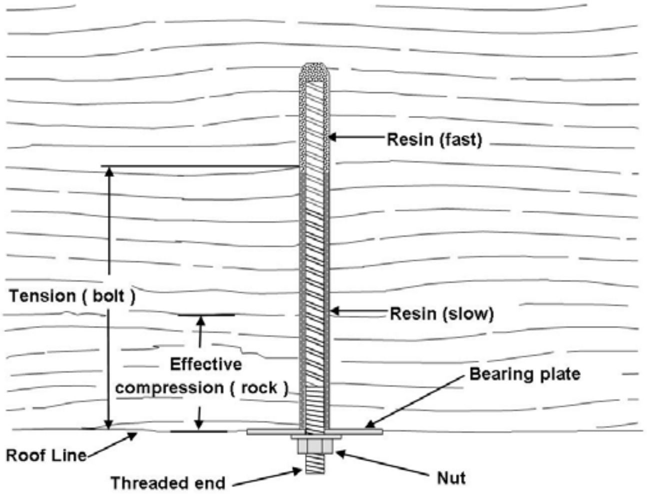

Figure 5. Tension rebar bolt (high-tension, high anchorage capacity, high system stiffness, high-shear resistance).

Resin-Assisted Bolt

Resin-assisted bolts (sometimes called point anchors) are essentially mechanical anchor bolts that have been transformed with the addition of a resin anchor at the top of the system. They can be installed like a mechanical bolt with the addition of a cartridge of resin placed in the hole before the bolt. As the bolt is inserted, the resin flows around the shell and then the bolt is tightened against the mine roof. Because the bolt is installed with resin, it experiences less tension bleed-off and a superior final anchorage than achievable with a mechanical shell system. A typical installation is shown in Figure 6. The bolts are used widely and successfully in difficult ground conditions.

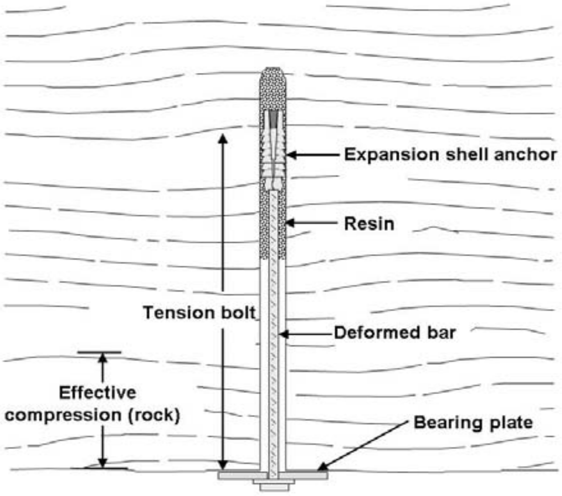

Figure 6. Resin-Assisted bolt (high-tension, high anchorage capacity, low system stiffness, low shear resistance).

At the Second IGCCM in 1982, White published and presented comprehensive details on several types of resin-assisted systems being manufactured and evaluated by the Birmingham Bolt Company working closely with Jim Walter Resources. A very insightful portion of the conclusion stated, “We must base decisions on roof control and roof bolting in particular, largely on experience and far too often on few “knowns” and many “unknowns”. Point anchors are not, of course, the answer, but are a very reliable tool” (White, 1982).

These bolting systems are broadly used today and incremental improvements have been made and presented throughout the history of the Conference. In 1990, Stankus reported on the design and development of the Jennmar Corporation “Insta’l Compression” system that incorporated anti-friction washers between the bearing plate and the bolt head, resin compression rings, and a new design of expansion shell. Incremental improvements in the systems by several manufacturers and positive case studies have been reported (Stankus, 1990). In 1997, Stankus presented a new concept and design criteria, utilizing these high installed tensions. At that time Stankus introduced the term OBE or Optimum Beaming Effect using Resin-Assisted bolting systems defining OBE as a roof beam that had no separations within and above the beam with the shortest roof bolt possible. The analysis was largely generated by using finite-element modeling techniques that utilized a one-dimensional truss element with a simulation of loads between concentrated points (Stankus and Guo, 1997). While the modeling results were reported to be different than the magnitudes obtained from field measurements, the trends were determined to be the same. Furthermore, although the theory was based on the condition that no separations could occur within or above the beam, the authors reported that from real practice we know that there can be some bed separations while maintaining stable roof. Reducing the bolt length in difficult ground conditions is contrary to current roof bolt support design criteria. The utilization of the OBE design criteria has not been reported on and has not gained acceptance.

Cable Bolts

While not included in the 1989 roof support usage estimates, cable bolts have become an extremely useful ground control technique for controlling mine roofs. High-strength cables are being used in two basic applications, slings and vertically, to support coal mine roofs. The estimated number of vertical cables used in 2005 was one million, a testimonial to the success of the support system. At the First IGCCM, Scott presented a paper that described the application of the Scott Cable Sling, a one-piece strand of cable drive and held into place by Split Set Stabilizers (Scott and Castle, 1981). Cement cartridges were placed into the borehole prior to insertion and allowed to cure to provide long-term anchorage and enhance the performance. The conclusions stated, “In many cases it should be considered as a quick-fix “band-aid” support to eliminate the ground control hazard so that other, stiffer and/or stronger supports may be placed. In other cases, it may prove to be cost effective and advantageous to use Scott Cable Slings as a complete substitute for traditional timber, steel or truss support methods.”

Cable slings (often incorrectly called trusses) can be installed over the ribs into competent strata to develop the capacity of a 0.5 or 0.6 inch diameter cable. Unfortunately, field measurements have indicated that while it is possible to install a cable sling with 4-6 tons of load using the bolting machine or hydraulic jacking systems, subsequent monitoring indicates that the load is quickly dissipated. Cable sling applications should be regarded as purely passive supports that perform adequately when the reaction is downward into the entry. Cable slings, or traditional trusses for that matter, are not as effective when the entry movements are horizontal which dissipates the tension, directly reducing the support forces. The stiffness of a cable sling is directly related to the free-lengths of cable(s) used in the application. Other extremely important factors include the installation angle over the pillar, the location of the “angle” bolt with respect to the rib-line, and pull-in or slippage in the barrel/wedge anchors. Both two and three-piece wedge assemblies are only effective when they are evenly “buried” deeply into the barrel which permits full-teeth penetration into the strand. This position can only be achieved when the strand tension is high and delivered at the back of the barrel, and the wedges can slide freely into the barrel. Installation issues and incremental improvements in sling design and application were summarized at the 23rd IGCCM (Pile et al., 2004). This specific system, which is closely related to a truss system, used bar/bolt systems for the angle bolts but the mechanics and cable tightening techniques remained largely unchanged. The biggest advantage of cable truss systems is that the angle bolt, usually a resin assisted or tension rebar bolt, places the immediate roof into compression prior to the tensioning of the cross member. This helps establish a “roof beam” which resists downward movements during subsequent loading. Cable slings are still used in several applications and Operations personnel are familiar with the drawbacks (shear failures of individual strands and tension losses) and benefits (roof suspension and high deformation capabilities) of the systems. Figure 7 shows a typical cable sling failure resulting from combinations of vertical and horizontal roof movements.

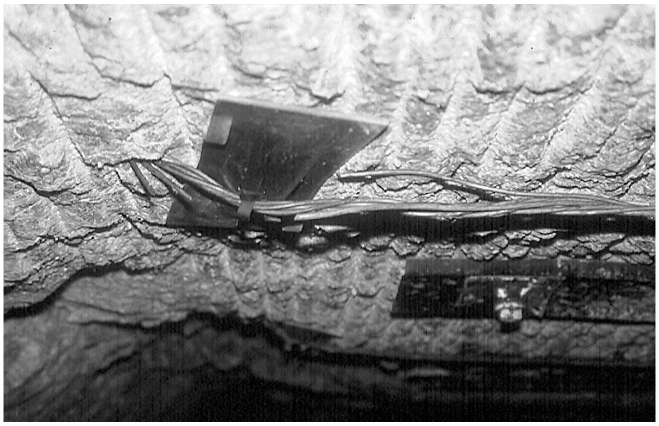

Figure 7. Cable sling failure in mine entry subjected to vertical and horizontal loading.

Vertical cable bolts have been extremely successful in underground mining applications with the paradigm shift coming to fruition when traditional bolting equipment and resin grouted systems could be used to rapidly install vertical cables that have ranged in length from 8 to 24 ft. The first applications of resin-grouted cable bolts were reported on at the 13th IGCCM when three different systems, passive, stiff, and tensionable, were installed to support an active underground longwall tailgate. Of course the development work was completed before and concurrently with the test area installation by the recognized inventor of resin-grouted cable bolts, Doug Gillespie, owner of Rocky Mountain Bolt Company and George Seely, Sales Manager of Fosroc (now Minova), who are both now happily retired. The development team diligently overcame installation problems, resin mixing issues, the challenge of developing adequate bolt anchorage, and cable insertion problems (Tadolini and Koch, 1994). Since that time, a plethora of research has been completed on vertical cable supports and applications. The capacities of cables currently used range from 20 to 65 tons and are installed with no additional tension, high post-tensioning with jacking system, low-tension using expansion shell technology and even post grouting of the cables after tension is applied. Forty-one technical papers presenting research results on cable bolts from around the world have been published at the IGCCM since 1991. These reports detail the mechanics of cable bolts, present underground case studies and describe laboratory and numerical modeling results. The IGCCM has served, and will continue to serve, as a technical discussion platform for this multifaceted, but highly effective, support system.

OTHER EAGLES AND BOGEYS

While it is difficult to summarize all of the ground control support system types and selections in this short retrospective paper, a few items remain that are worth mentioning. These include rigid truss systems, pull-tests, roof bolt design systems and MSHA’s role in the roof support approval process.

Rigid Truss Systems

Rigid roof truss systems have been discussed in 24 papers at the IGCCM, often in great detail. The introduction of roof truss systems can be traced back to the patent of C. C. White in 1969 (Birmingham Bolt Company). Correctly stated, the roof truss systems were used primarily in weak roof areas to artificially "narrow" the width of the entry span. The recommended installation was about 3 to 5 ft from the rib-line (depending on the entry width) on both sides that were linked together by using hardware attached to a cross-member. At the Second IGCCM, Bollier reported that Peabody had purchased and installed over 180,000 trusses and Birmingham Bolt Co had supplied over 1 million systems to 50 underground mines in 1975 (Bollier, 1982). At the same conference, Mangelsdorf presented the results of an extensive laboratory investigation, funded by the U.S. Bureau of Mines, presenting component tensions and the complex interactions that occur at the bearing plate and angle bolt (Mangelsdorf, 1982). As shown in Figure 8, the descriptions of the active or compressive forces can be quite misleading (Cox, 2002). In fact, current research indicates that tensioned bolts, installed with high installation torques that generate high bolt tension, used in some systems for the angle bolts, can provide an active compression component to a maximum depth of about 36 inches (Zhang and Peng, 2004). The compressive forces developed in the roof through the tightening of the cross-member remain unproven. Roof Truss Systems move in and out of favor depending on incremental improvements in component and installation designs. The systems are effective in supporting previously supported roof that is subjected to downward deflections. No longwall tailgates in the U.S., usually the highest loading levels in coal mine applications, are currently using roof truss systems solely for secondary roof support.

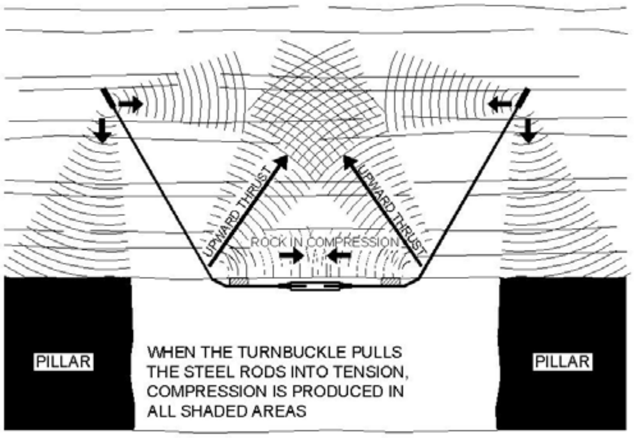

Figure 8. "Theoretical" compression forces produced by a roof truss (Cox, 2002).

Pull-Tests

Pull-tests, commonly called anchorage capacity tests, are performed using pull test equipment. Basically, the system consists of a hydraulic jack that pulls the bolt from the developed anchorage while the loads and deformations are recorded. Load vs. deformation plots are created and the "yield" of the anchorage or the bolt is recorded. At the Fifth IGCCM, held in 1986, two papers were presented that utilized pull-tests data in very different ways. Cincilla calculated the effective column lengths, called ECLs, an index property, by performing pull-tests on over 1,000 bolts varying the anchorage length between 12 and 48 inches on a 48-inch long bolt. The obvious conclusion stated that longer lengths of resin were required in weaker rock types to meet the established criteria of 8 tons of applied load while maintaining less than 0.2 inch of displacement. The unique conclusion was that there appeared to be a relationship between the Rock Mass Rating (RMR) and the determined effective column length, a premise that has evolved into the routine evaluation of shorter columns of resin (or even shells) on tested bolts to determine the tons/inch of anchorage for design considerations and final support selection (Cincilla, 1986).

At the same conference, Kempen presented a method to design an efficient bolting plan based on simple in-mine measurements that included pull-tests (Kempen et al., 1986). The author estimated that the pull strength of a typical mechanical anchor was about twice the compressive strength of the host material, which appears reasonable. He also presented a concept that stated that average installation loads and subsequent bolt tensions, combined with pull-tests, could be used to determine safe life stand times for underground openings. This conclusion was based on the safe life peak, which was a function of strength (estimated from the pull-test results) of the anchorage horizon. The design technique is complex and worth reviewing in detail. However, the use of pull-test or anchorage capacity testing results in this manner requires an unproven extrapolation of data. The author states, "Standard Unit Roof (SUR) control technology is intended to complement, not substitute for seasoned judgment and underground experience." In reality, a properly performed pull-test can provide an index value that has been mathematically related to the shear strength or capacity of a specific bolt, in a specific hole, at a specific horizon. Any use beyond that should be considered a statistical crapshoot.

Roof Bolt Design Systems

With regard to roof support selection government regulations usually dictate minimum requirements, but offer little guidance for determining an optimum support design. In most instances roof support is chosen based on past experiences of mines in the area or the familiarity of the mine operator with a specific support. Numerous papers have been presented at the IGCCM regarding support design, but for the most part most of these papers focus primarily on the analysis of current roof support efforts at a specific mine with the intent of improving support selection for the future development of that particular mine. These papers use a variety of procedures to achieve their goal including geologic analysis, stress evaluation, pull-tests and even monitoring of actual support loading utilizing strain gaged roof bolts. Very few of the papers presented at the conference have attempted to develop a support design methodology that a mine engineer could use to design a support system for a new mine or section. One of the first to attempt this was presented at the Fifth IGCCM and utilized the Standard Unit Roof (SUR) which was previously mentioned (Kempen, 1986). However, the reliance on monitoring conventional bolts would make this method somewhat dated.

At the 8th and 12th IGCCM, Unal and Ozkan outlined the design and subsequent verification of a computer program that could be used to select support systems (Unal, 1989 and Unal and Ozkan, 1993). After calculating a modified RMR the authors utilized the computer program (Rockbolt 5.0) to evaluate a set of input parameters that included the unit weight of the overburden and immediate roof, roof span, and horizontal to vertical stress ratio in addition to roof geology parameters. The output generated would provide the user with support length, diameter, spacing, and grade, as well as the anchorage capacity necessary to successfully support the roof. Although reporting that their studies demonstrated that the design criteria provided a realistic means of determining rock-reinforcement for the case study, they correctly concluded that "further studies and feed back cycles are required to explore the effectiveness of the design approach in different mining conditions."

The National Institute for Occupational Health and Safety (NIOSH) presented the most recent support design procedure at the 20th IGCCM (Mark et al., 2001). In this approach support selection is determined by utilizing a set of empirical formulas that were statistically derived from analyzing roof falls in nearly 100 case histories under a variety of different mining conditions. Two noteworthy findings were a statistical relationship between depth of cover (related to stress) and CMRR (a measure of roof quality). The roof fall data indicated that when the CMRR was less than 40 at shallow cover, and less than 45-50 at deeper cover, both essentially moderately weak roof conditions, high roof fall rates could be encountered even with relatively high roof bolt densities. As intersections (sum of the diagonals) in weak roofs increased, the likelihood of roof falls also increased. As with the previous two papers mentioned related to support design, the authors concluded that "much more remains to be learned to further improve the efficiency of roof bolt design."

MSHA Technical Support

The Mine Safety and Health Administration (MSHA), primarily the Roof Control Division of Technical Support, has been instrumental in performing laboratory and field testing for various roof bolt types, resins, and critical support components; such as bearing plates, expansion shells, threaded nuts, etc. The role that they perform to ensure that roof bolt components meet or exceed ASTM Standards, to review installation and use applications, and analyze failed materials is critical to the safety of all underground miners. There are no ASTM Standards for bolting systems comprised of "parts" that met or exceeded ASTM testing requirements. However, and it appears in technical papers throughout the IGCCM Proceedings, you see statements saying, ""ASTM approved" or "MSHA has approved this support" or "this bolt has been approved by MSHA," it is simply not true. All roof bolts and subsequent installation applications (spacing, length, diameter, etc.) are presented in the mines Roof Control Plan that is approved by the MSHA District Manager (where the mine is located). MSHA-Technical Support may have indeed tested the components of the bolt, witnessed the installations or even monitored the performance of the final systems; however, no "blanket" approval is provided to the manufacturer or mine operator. If you read that, be very skeptical.

SUMMARY OR THE 19th HOLE

In golf, after you have bought all of the latest equipment, taken the lessons and joined that golf league your game reaches a certain level. Sure you can put together a good game or hit a great shot on occasion, but then on the next round the bogeys and double bogeys mount up and you just can't figure out what happened. Golf and roof control require a commitment to make it to the next level. In order to become a more consistent golfer you have to focus on the weak parts of your game and work on them until they have been mastered. If you just buy the latest "gadget" club rather than spend the time to learn the game you will always be an amateur (aka "duffer"). It's the same with roof support design, it requires focus and commitment. Most of the papers presented at the IGCCM over the years have one thing in common. They all conclude that further research is needed in the particular area that they report on. The focus and commitment however, seem to be lacking. Promising research is typically rarely continued and the direction of the research seems to lack focus. Rather than spend the extra effort needed to take promising research to the next level, the authors take a totally different direction or report on the latest "gadget" roof support. There have been great strides taken in ground support, but we're all still just duffers. We occasionally have that good "game" but we definitely haven't approached "pro" status yet. One reviewer reminded us that while the bolting "hardware" has progressed nicely, the bolting "software" still lags behind. Papers published throughout the conference on bolt monitoring and modeling have made valuable contributions toward understanding complex support mechanisms, bolt selection and design. Due to the complexity of roof geology and the variations of rock properties under various stress and physical environments, no universal design tools for roof support design has or may ever be developed.

The timely vision of Professor Syd S. Peng to establish this conference was to promote closer communication among researchers, consultants, regulators, manufacturers, and mine operators. The cumulative experience that we continue to share, discuss and debate with each other is extremely important to attain our goals. We believe that the continuation of his vision, combined with the hard work and dedication of these groups, will eventually result in a comprehensive understanding of roof bolt selection and design solutions that improve the safety, productivity, and economics of mining throughout the world…..now we have to get to the No. 1 tee.

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