INNOVATIVE GROUND SUPPORT SYSTEM

by

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ABSTRACT

Artificial ground support has developed into a refined science over the past 20 years. From reactive support systems such as timber props and steel supports, to active systems such as roof bolts and cable anchors, ground support technology has now developed efficient systems that work well in many instances.

However this paper demonstrates that there is still a long way to go to develop optimum ground support systems. Some conventional rock bolts and cable anchors emphasise their tensile capacity only, without considering other factors such as their shear strength or shear modulus, or if the support member can transfer all of its support capacity to the surrounding rock.

Examples are given of the use of ground anchors with high tensile and shear capacity in underground coal mining as well as examples of slope failures in open pits where the cable bolts have remained intact because they have been unable to transfer their full capacity to the surrounding weak rock mass. For underground coal mines, speed of installation is also of primary concern, but it must also have high tensile and shear capacity both in terms of strength and stiffness. Ground support systems of the future must therefore address these problems.

An innovative new rock bolt is discussed which goes some way towards solving these problems. This new rock bolt is screwed into the rock and thus has a direct mechanical interlock with the rock. Initial field results show that it has an extremely high anchor capacity and can be fully installed in approximately 30 seconds. It has considerable capacity to improve the productivity of the coal mining industry.

INTRODUCTION

The support of rock openings and excavations has been the subject of intense investigation by mining engineers and researchers throughout the world, and many different support systems have been developed. These support systems generally fall into two broad categories, namely, passive support systems, and active support systems.

Passive support systems are those which provide support in response to movement of the soil or rock mass and consist of timber props, steel arches, steel beams, mesh, straps, shotcrete etc. Passive support systems generally consist of heavy steel or timber members since they have to resist high compressive or bending forces (e.g. steel arches, beams etc). This results in considerable handling difficulties to transport and place the support member into position, and hence adds to the total installed cost of the support.

Active support systems provide an active support force essentially before and after movement of the soil or rock mass occurs, and consist of rock bolts, cable bolts, shear pins and soil nails etc. Active internal reinforcement systems can consist of both tensioned and un tensioned members.

The mode of action of an active internal reinforcement system is through modifying the physical characteristics of the rock mass by applying normal and shear resistance to deformation. These normal and shear forces provide a confinement to failing rock units and discontinuities and so can increase the in-situ material strength allowing the integrity of the rock mass to be maintained.

In general the active internal reinforcement system provides a stiffer stabilisation system which significantly reduces the levels of deformation occurring compared with any passive system. This level of stability is achieved with much lower

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quantities of consumables compared with passive systems giving significant advantages in materials handling and cost.

ROCK SUPPORT CONSIDERATIONS

The development of a total support system approach is also of paramount importance to mining operations, and it is the total installed support cost which is significant, not the cost of the individual support element. Consideration must be given to factors such as: the time to install supports; the cost of installation equipment; the handling and transport difficulties both in underground and in open pits, as well as the load transfer mechanisms provided by the support system.

OPEN PIT MINES

For open pit mines there has been a general trend towards fully grouted cable bolts for ground support, because of ease of handling of long lengths (including plain strand, birdcage and bulb cables). Stabilising large slope failures requires that the support member to be anchored in stable ground and hence cable bolts are often 30 m long or greater.

However, there are many examples in Australia of weak, clayey rock masses failing around fully grouted cable bolts and it is obvious that cables have been unable to transfer their full support capability to the rock mass. In these cases, the bond between the grout and the rock is very poor. Birdcage and bulb systems offer advantages over plain strands where moderate bonding can be achieved especially where high stress and stiff grout formulations are used because their design generates a higher normal force between the grout and the rock than plain strands.

In addition, problems of angle of installation of the bolt are often decided in terms of convenience rather than choosing the optimum support angle. Shear pins have not gained wide acceptance due to the difficulty of installation, even though their support characteristics are superior to cables. Face support is normally provided by split sets and mesh, again mainly due to convenience.

Problems of stiffness, cracking of the grout, corrosion and load transfer mechanisms, must be considered if the support system is to be effective. In particular, the effectiveness of load transfer is a major problem to be addressed in supporting weak rock masses.

UNDERGROUND MINES

Similar factors must be considered for support of underground mines as for open pit mines. Load transfer mechanisms from the support member to the rock mass are crucial, and these vary with different rock types. In addition, the roof support operations are the major controlling factor on the rate of production. Rock bolts are therefore more common than cable bolts, since they can be installed rapidly at the working face.

Nevertheless, for heading development in underground coal mines, significant costs are incurred by the delays caused by installing rock bolts. Studies within BHP have shown that up to 45% of available development time is lost due to rock bolting. New support systems must therefore be developed which not only have efficient load transfer characteristics, but which also improve productivity by having more efficient installation equipment and by having supports which are suited to fast, automatic installation.

THE DEVELOPMENT OF ROCK BOLTS

The development of rock bolts over the past 20 years has seen a large number of different types being produced. The early rock bolts were simple point anchor bolts using wedge type anchors (split and wedge bolts), which relied on generating friction between the wedge and the rock. These bolts were later refined to produce screw-activated wedge bolts (expansion shell bolts), which produced a higher normal force between the wedge and the rock at the time of installation, and hence generated more reliable anchor capacity.

Bolts were also introduced which were anchored with cement grout, but there were inherent difficulties with the grout, since it was slow to cure and was difficult to place into a hole.

Chemical resins were then introduced which cured very rapidly and could be placed easily by using a chemical cartridge. Further developments have seen both fast and slow setting resins used in the same hole to provide ease of installation and a pre-tensioning effect, while allowing virtually full encapsulation of the bolt with resins. All of the above developments used solid bars for the rock bolt.

The fully encapsulated bolts provided a significant improvement in conditions because of the improved stiffness of the reinforcement. The
loads are generated in the bolt at a much greater rate as only short sections of the bolt are stretched in response to rock deformation compared with the full length of a point anchor bolt.

Rapid developments have also taken place with "friction" anchors. These bolts generate friction directly between the bolt and the rock. Split sets are the most common type of friction anchor and they are a split tube which relies only on the skin friction generated between the bolt and the rock. Swellex bolts are an inflatable tube design and rely on friction and some slight mechanical interlock with the rock to generate anchor capacity. The Delkor bolt is a split tube and wedge system which relies on friction and a positive point anchoring system with the wedge.

All of the friction type bolts rely on the anchor capacity generated by the friction caused by creating a normal force pushing the bolt against the rock. In the case of split sets, this normal force is very low and consequently the anchor capacity is also low and heavily dependent upon the appropriate hole size. In the case of Swellex bolts, the normal force is initially very high caused by the water pressure inside the bolt which deforms the bolt to the exact shape of the bolt, but this normal force is subsequently reduced as the water pressure is relieved. The anchor capacity for a Swellex bolt is higher than for a split set bolt.

One of the major advantages of friction anchors is that they do not rely on chemicals or cement. Chemical resinanchors have a short shelf life, particularly in hot climates, whereas cement grouts are inconvenient to insert into a rock bolt hole and are slow to develop full anchor capacity. Chemical and cement grouts also require an additional logistical step for the roof bolting operation.

NEW ROCK BOLT DEVELOPMENTS

There have also been many other developments with cable bolts and rock bolts in the last few years. Most of these developments are simply variations on existing bolts and do not offer any significant additional advantages over current bolting systems. However, notable developments with bolting systems include continuously threaded bolts (eg. Gywidag), self-drilling bolts (eg. Ischebeck), and high strength bolts (eg. 40 tonnes capacity and above). But all these bolts rely on chemicals or cement grout to develop anchor capacity, and there is little point in having a high strength bolt if this strength cannot be transferred to the rock mass.

Continuously threaded bolts offer some retensioning advantages, but they offer little improvement in bond capacity and cannot be installed faster than conventional bolts. All of the current self-drilling rock bolts require grout or resin to be pumped into the rock bolt after it has been drilled into the rock. This is a time consuming, and hence expensive task. High strength bolts have no reduction in installation time, but have provided better levels of stability for a given bolt density.

In summary, virtually all rock bolts rely on one of the following two methods to develop anchor capacity: either:

(i) developing friction between the bolt and the rock; or,
(ii) bonding the bolt to the rock with grout or resin.

This places limitations on both the load transfer, and hence anchor capacity that can be generated, and the speed at which a bolt can be installed.

NEW ROCK BOLT DESIGN: TAKING ADVANTAGE OF ROCK STRENGTH

The "friction" or the "bonding" methods of anchoring bolts suffer a major disadvantage particularly in weak, clay-rich rocks. Since most rock bolt holes are drilled with water for flushing, the rotary action of the drill and the water combine to cause the clay in the rock to be released. This clay is left as a thin film of wet clay coating the inside the rock bolt hole. With dry drilling, the clay and fines created during the drilling process also prevents high levels of bonding being achieved. It is therefore difficult to develop a high anchor capacity by either by using friction or bonding against this wet clay or fines layer in the rock bolt hole. Virtually all existing rock bolts have this disadvantage.

Figure 1 shows the performance for a resin anchored bolt in three different rock types, and it can be seen that the bond capacity developed in clay-rich rock is very poor.

The ideal rock bolt would be one which has a rough profile which is intimately interlocked with the rock and does not rely on grout or resin or friction to transfer the load.

A new rock bolt design has been developed which achieves this by relying on mechanical interlock to generate anchor capacity. This new
rock bolt is screwed into the rock in the same way that a bolt is screwed into a nut, and this overcomes many of the anchoring problems of existing bolts.

**Figure 1 - Pull Out Performance of Resin Anchored Bolts with Different Bonding Characteristics.**

![Graph showing pull-out force vs bond quality](image)

Note: Poor Bond indicates clay-rich rock; Moderate Bond and Good Bond are dependent upon rock type and installation technique.

**AN INNOVATIVE SELF-TAPPING ROCK BOLT**

A self-tapping rock bolt has been developed which cuts a thread into the wall of the rock bolt hole as it is inserted. Thus a positive, mechanical interlock is developed between the bolt and the rock which does not rely solely on friction or on bonding.

Also the power of the drilling machine is used to generate anchor capacity as well as to drill the hole for the rock bolt. New hydraulic bolting machines have both high speed and high torque which can be effectively utilised to anchor the bolt.

Initial tests have shown that rock threads can be cut in rocks from 5MPa to 100MPa (unconfined compressive strength), at speeds of up to 600 rpm. Since most bolting machines operate at speeds of 400 to 600 rpm, this would give an approximate installation time for a 2 m long rock bolt of 20 to 30 seconds.

The anchor capacity generated by the self-tapping rock bolt is dependent upon the strength of the rock and this is shown in Figure 2. These initial test results indicate that the anchor capacity is up to 100 tonnes/m for good quality sandstone, which is the highest anchor capacity of any rock bolt. Even for lower strength rocks, the self-tapping bolt has a higher anchor capacity than all other bolts.

**Figure 2 - Pull Out Performance of the Self-Tapping Bolt**

![Graph showing pull-out force vs unconfined compressive strength](image)

A chart showing the field performance of the self-tapping bolt and other bolts in weak rock is shown in Figure 3. In this particular series of field tests, the self-tapping bolt achieved a load of 17 tonnes before the pull-out jack began to crush the roof and this could be considered to be a minimum pull-out figure.

It should be emphasised that the ideal support performance of all bolts is often not achieved when efficient load transfer cannot be developed. In the case of the self-tapping bolt, field tests confirm that the current bolt design will work in rocks from 5MPa to 100MPa (UCS), but for clays and for coal a slightly different design is required.
TABLE 1 - COMPARISON OF EXISTING BOLTS AND THE SELF-TAPPING BOLT

<table>
<thead>
<tr>
<th>Installation Time</th>
<th>Anchor Capacity</th>
<th>Comments/Problems</th>
<th>Suits to Automation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Split Set Bolts</td>
<td>3 - 5 minutes</td>
<td>6 tonnes/metre</td>
<td>Corrosion, very poor capacity</td>
</tr>
<tr>
<td>Swellex Bolts</td>
<td>6 minutes</td>
<td>12 tonnes/metre</td>
<td>Corrosion, requires extra equipment</td>
</tr>
<tr>
<td>Chemically Anchored Bolts</td>
<td>2 - 3 minutes</td>
<td>60 tonnes/metre</td>
<td>Requires resin, poor shelf life, manual installation</td>
</tr>
<tr>
<td>Cable Anchors</td>
<td>At least 15 minutes</td>
<td>30 tonnes/metre</td>
<td>Requires grout, slow installation</td>
</tr>
<tr>
<td>Self Tapping Bolt</td>
<td>1 minute 30 seconds</td>
<td>85 tonnes/metre plus</td>
<td>High speed, high capacity</td>
</tr>
<tr>
<td>Self Drilling/ Self Tapping Bolt</td>
<td>20 - 30 seconds</td>
<td>85 tonnes/metre plus</td>
<td>Very high speed, high capacity</td>
</tr>
</tbody>
</table>

Figure 3 - Comparison of Pull Out Performance in Weak Rock for Different Bolts

The pull out load (in tonnes) for different bolts:
- Resin Bolt: 3.4
- Cable Bolt: 11.2
- Swellex Bolt: 13.5
- Tapped Bolt: 14.2
- Self Tapping Bolt: 17

Note: Pull out tests conducted in rock with UCS=7MPa.

Table 1 also presents a comparison of the major rock bolt types including friction anchors, cable bolts, chemically anchored bolts, the self-tapping bolt, and the advanced self-drilling and self-tapping bolt. It can be seen that friction anchored bolts have a very poor anchor capacity and have installation problems. Resin anchored bolts have a much higher anchor capacity, but require resin which presents additional difficulties, and is cumbersome to automate. Cable bolts are slow to install and are usually slow to develop anchor capacity. The new self-tapping bolt mechanism overcomes most of the disadvantages of other anchoring and bolting systems.

SELF-TAPPING AND SELF-DRILLING ROCK BOLT

BHP have also been developing an advanced self-drilling and self-tapping rock bolt. This has all the advantages of the self-tapping bolt, plus it drills its own hole at the same time as cutting the rock thread. This results in a true one pass bolt installation procedure.

The advantages of this bolt are:
(i) one pass operation suited to automation;
(ii) 20 - 30 seconds total installation time;
(iii) highest anchor capacity of any bolt;
(iv) no grout or chemicals required.

The above advantages mean that this bolt is suited to a wide range of mining environments and rock types. In particular, it has all the advantages of fast installation and no chemicals of a friction anchor, and has the high anchor capacity of a chemical bolt.

CONCLUSIONS

The new self-tapping anchoring system develops a mechanical interlock between the bolt and the rock, and thus develops a very effective load transfer mechanism which out-performs all current rock bolts. It overcomes the problems of friction and bonding anchoring systems. It is can also be installed very quickly. However the major benefit to the mining industry will be that it will increase productivity by being a true one-pass installation operation and is thus suited to automation of the rock bolting process.

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