

# Factors Affecting Ground Support Performance in Mining

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## ABSTRACT

Mine operators are currently in a situation where market forces are acting to reduce profit margins and at the same time, regulatory bodies are insisting on improved mine safety and stability. This means that ground support must be made more cost efficient while maximising operator and equipment safety.

A key aspect of ground support efficiency is the 'in the ground' performance. This paper discusses the factors that influence the way rock bolts and cable bolts perform. It highlights the need to know how support efficiency varies in different ground conditions.

Quality control issues relating to bolt and cable installation are also discussed. The need for properly designed *in-situ* testing of bolts as a quality control measure is emphasised. Various examples of *in-situ* tests are presented to demonstrate how to use the results from *in-situ* testing in the support selection process.

## INTRODUCTION

Many mine sites commence or carry out routine rock support programs based on some form of support specification. This may only comprise a nominal hole length and bolt spacing. Consequently, the support is often installed with little if any consideration of the many factors which influence the performance of rock bolts or cable bolts. The end result is that mine operators may not be achieving anywhere near optimum support performance and therefore could be paying too much for their ground support.

This paper will illustrate the factors which affect support performance. Operators need to be aware of these so that they can at least aim for both *peak* performance and *consistent* performance from their support. The practical objective must be to try to achieve the optimum performance from each installed rock bolt or cable bolt so that the entire support system is cost efficient. Secondly, installation quality needs to be specified for all bolts so that *consistent* performance is developed and the entire support system performs reliably.

The net result of this increased awareness of support performance is that support effectiveness can be increased with little, if any increase in cost. The only cost penalty may be related to more care and quality assurance, including some *in-situ* testing.

## SUPPORT MECHANICS

Figure 1a and 1b illustrate a simplified, fully bonded ground support system intersecting a discontinuity. The mechanism of all ground support systems is essentially the same in that ground movements are restrained by the support which may be any type of rock bolt or cable bolt.

Ground movement generally consists of either opening across a structure, shearing or sliding along a structure or some combination of opening and shearing. Hence, the support may be called upon to provide axial restraint and shear resistance (Figure 1a and Figure 1b) to control ground movement which if remained unchecked, could lead to failure.

Obviously, in practice, the situation is more complex with more than one structure intersecting the bolt at different angles. However, the basic mechanisms of resistance provided by the

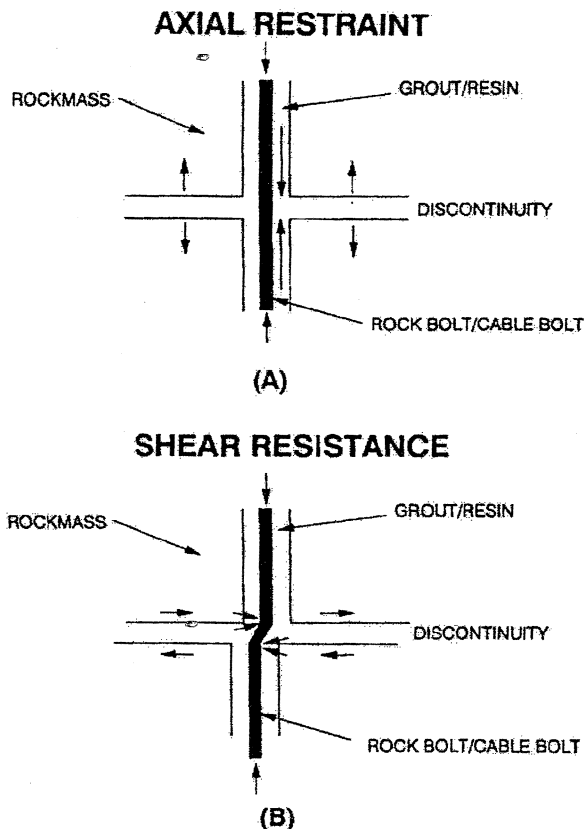


FIG 1 - Axial restraint and shear resistance.

support at each structure is always the same. In all cases the transition of ground movement to a restraining force by the bolt is via the bond or anchor developed between the bolt and the rock. As will be illustrated later, it is this bond that controls the capacity or performance of any rock bolt system. Getting the most out of a support system simply involves achieving and then maintaining an appropriate bond/anchor strength for the particular ground conditions.

Operators often mistakenly believe that it is the tensile strength of the bolt or cable which is the capacity of their support. However, because of premature bond failure the amount of support resistance that can develop is often substantially less than this.

## METHODS TO INCREASE SUPPORT EFFECTIVENESS

A support system can be made more effective without any substantial cost increase by methods (a), (b) and (c) shown below;

- (a) Decreasing the number of bolts by selecting bolts with increased performance, thereby decreasing the installation time and cost.

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- (b) Selecting and using the appropriate bolts for the particular ground conditions ie do not use high capacity more expensive bolts if they are not required.
- (c) Achieving an optimum and consistent performance from the selected support.

(a) and (b) above are related to some degree and may involve an alteration to a basic support design. For example, ground support for an underground development may consist of a regular pattern of resin bonded rock bolts, each capable of providing at least ten tonnes of resistance. However the ground conditions may not require this degree of support such as in slabby ground on a side wall. In this case, a less expensive rock bolt may be entirely adequate with the result that the installation time and total cost of the support system will be substantially less.

Where there is an increasing demand for support, it is possible to select a support type to provide low to moderate restraint initially and then to increase the support performance by making a modification. For example, a standard Split Set\* or Cotter Pin<sup>x</sup> can be modified to increase its capacity by grouting the inner section and, if necessary, adding a cable bolt. The additional pull-out resistance achieved by these modifications is shown in Figure 2. Figure 2 is the result of a series of *in-situ* pull-out tests on short bond lengths carried out at the Pasminco Zinc Mine at Broken Hill (Reference 1). In these tests, a grouted Split Set or Cotter Pin achieved peak loads of two to three times the value for the standard bolt. In the case of the grouted Split Set with a cable inserted inside, the peak loads were greater than with a resin grouted paddle bolt.

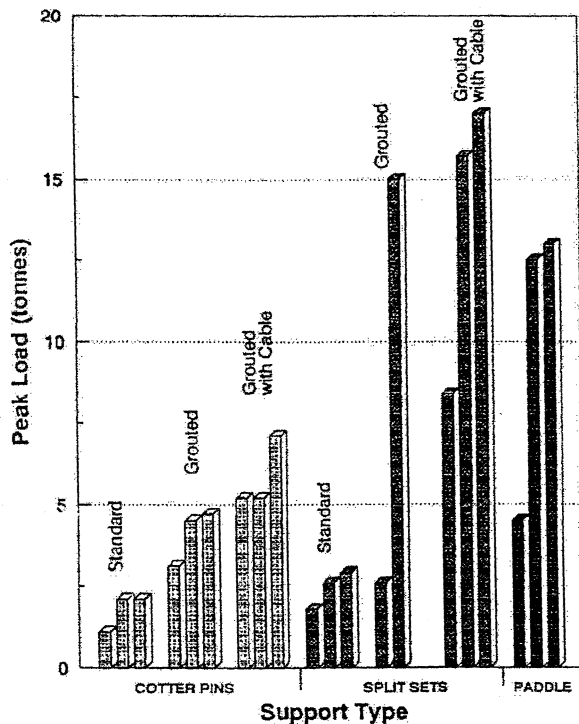


FIG 2 - Summary of pull-out test results (Pasminco, Broken Hill).

\* Split Set is a registered trademark of Ingersoll-Rand.  
 x Cotter Pins are manufactured by Hardi Drilling Supplies.

Following such *in-situ* tests in the particular ground conditions, a mine operator then needs to decide on the bolt type by considering the following questions:

1. Which option is the cheapest and allows the quickest installation ie which system can be installed for the lowest total cost?
2. Is the larger capacity of the modified bolts or the resin bolts required in all or part of my ground and, if so what is the cost penalty in terms of material costs and additional installation time?
3. Which type of bolt will give me the most consistent performance with normal quality control measures?

### FACTORS TO OBTAIN OPTIMUM PERFORMANCE

Figure 3 is similar to the simple support system illustrated in Figure 1 but with the three main components of the support system labelled as A, B and C. These represent:

- A. Drill Hole and Surrounding Rock Mass
- B. Bolt Anchor Material
- C. Rock Bolt and Accessories

The individual factors which should be considered by mine operators before and during rock bolt operations are outlined below.

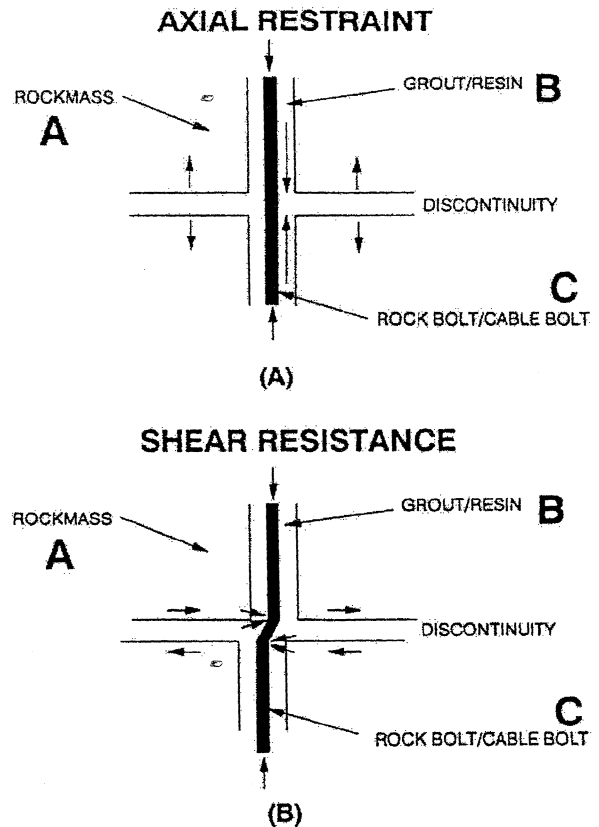


FIG 3 - Individual factors affecting performance.

**Drill hole and surrounding rock mass**

*Rock mass*

The ground conditions may vary significantly throughout a mine site. For example, even along a decline development the ground may change from soft to hard or from massive to very closely jointed. The effect of changing ground conditions can be to modify the bond strength of the supports. The result may be that a so-called ten tonne bolt may only develop two to three tonnes bond strength in poor ground but ten tonnes in very good ground. The poor ground may fail around the bolt because the anchor/rock bond strength is not adequate.

Swellex<sup>+</sup> bolts, which rely on pressure to expand a thin wall tube against the side of the hole may actually fracture and 'open up' weak ground during installation. If there is a risk of this, Swellex bolts should be expanded at pressures less than 30 MPa.

Figure 4 illustrates the results of *in-situ* testing at two different locations at Broken Hill. Both areas were in ground conditions classified as 'good' and the test results were essentially identical at each area.

*Drill hole cleanliness and hole profile*

To maximise the anchor to rock bond the drill hole should be clean and free from cuttings and sludge. Drill holes should be cleaned out by flushing with water or air prior to bolt installation.

This is necessary to maximise the roughness of the borehole. Figure 5, taken from Reference 2 illustrates the significance of the drill hole profile to bolt performance. This shows that although the tests were done with different borehole diameters, even the smallest diameter hole with a rough profile, gave the best performance.

*Drill hole depth*

For fully bonded resin bolts the hole depth is critical to ensure bolts bottom in the hole so that the maximum bonded length is achieved and to leave sufficient thread protruding for the nut and

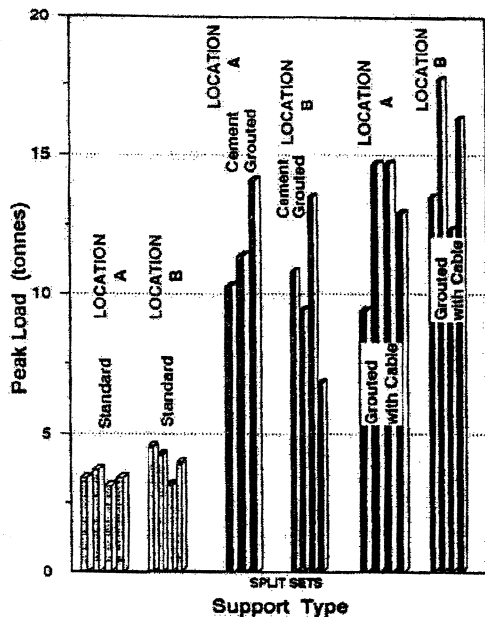


FIG 4 - Comparison of pullout test results (Pasinco, Broken Hill) locations A and B.

+ Swellex is a registered trademark of Atlas Copco.

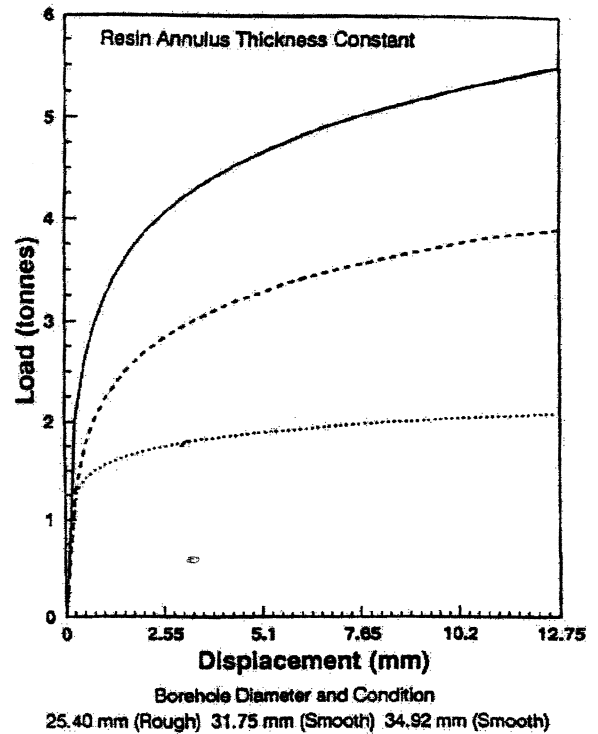


FIG 5 - Pullout tests on a 300 mm length of Rebar 6.4 mm less than the borehole diameter (Karabin and Debevec, 1978).

washer to be properly installed (Reference 3). If the hole is drilled too long the resin at the end of the hole is poorly mixed and is therefore wasted. This results in reduced chemical encapsulation along the bolt and the bolt cannot be adequately tensioned. If the hole is drilled too short, then the result may be that the potential failure surface was not reached and there is no thread left to adequately tighten the nut and washer against the rock face.

Hole depth is important for friction bolts such as Split Sets, Cotter Pins and Swellex because unless it is greater than the bolt length, plates cannot be installed firmly against the rock surface. Bolts left protruding from the surface are a safety hazard for personnel and equipment. The solution (which is normally the case) is additional care and quality control such as the correct ordering and use of drill steels.

*Drill hole diameter*

Hole diameter is critical for the proper functioning of bolts such as Split Sets and Cotter Pins where the bolt relies on a smaller hole diameter than the original maximum bolt diameter to develop friction. Manufacturers recommend that trials be conducted at the mine site in different ground conditions within the hole range recommended by the manufacturer. This will establish the optimum hole diameter for bolts to be driven home with the available equipment without the bolt bending or buckling. From the trials, an appropriate drill bit should be selected and should then be monitored regularly with a template. Undersize drill bits should be repaired or discarded.

Hole diameter is also critical for resin bolts since an oversize hole causes a reduction in mixing efficiency, longer curing times and reduced shear strength. Reference 3 indicates that the bonded length is reduced by 20 per cent per mm increase in bit diameter. Reference 3 also states that the hole annulus should be between 2 mm to 5 mm. Figure 6 illustrates the pullout results in terms of maximum and minimum peak load for a particular bolt/resin combination in an area of the Pasinco operations at Broken Hill.

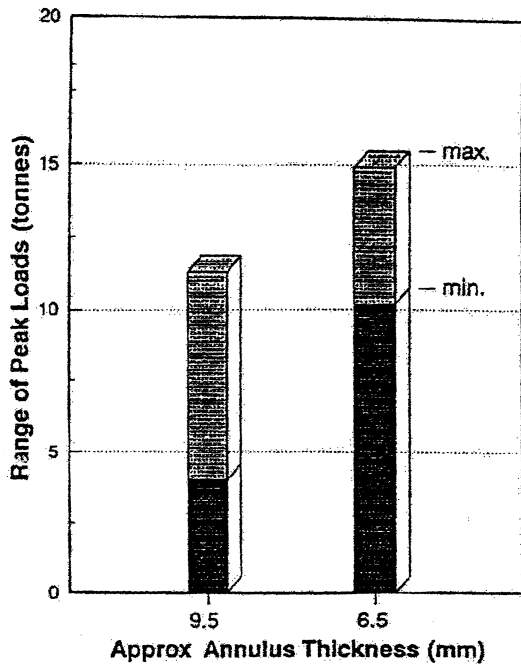


FIG 6 - Resin annulus vs peak load (Pasmenco, Broken Hill), 16 mm square bolt, 2 x roloc cartridges.

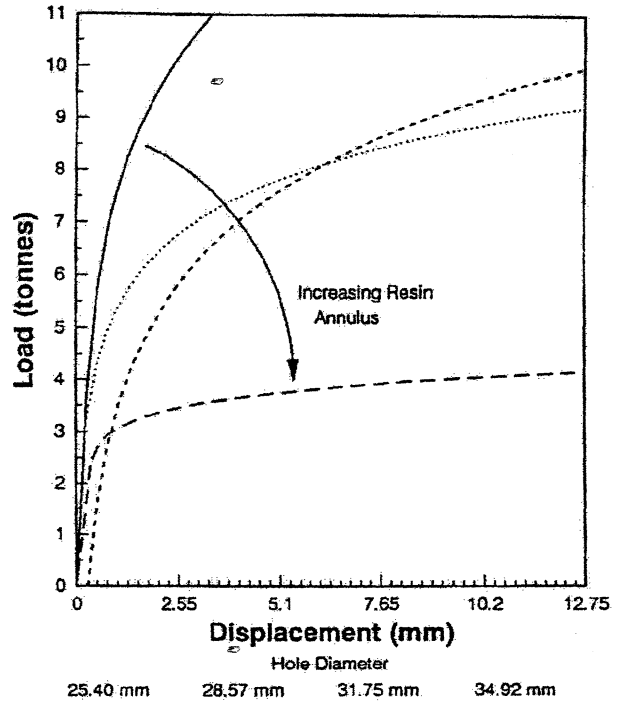


FIG 7 - Pullout test result, 19 mm rebar, 300 mm long.

Figure 7 shows a significant decrease in bond performance as the resin annulus is increased from an optimum (in this case) of 3.2 mm to about 8.0 mm. Figure 8 shows the increased performance with a larger hole diameter when the failure occurs at the borehole wall. In this case the penalty would be the increased cost of drilling the larger hole and the cost of a larger bolt. In practice, the minimum hole diameter should be chosen within the limits of the available drilling machine, drill steels and drill bits. From this a bolt diameter should be selected to preferably achieve a resin annulus of about 3 mm to 5 mm.

For cable bolts bonded with cement grout, increased hole diameter is not so critical to performance. Therefore a minimum hole diameter should be selected to allow sufficient space for a grout tube and breather tube. Hole diameters any larger will take a longer time and hence greater cost to drill and require more grout.

#### Bolt anchor material

The bolt anchor may be a point or mechanical type but it is now more common to form a continuous anchor along the entire bolt with resin or cement. Bolt performance is improved by increasing the bonded length and maximising the bond strength.

Cement grout is the common anchor material used with cable bolt systems. Figure 9 indicates that the correct water to cement ratio grout must be used to increase the strength of the grout which has been shown to increase the bond with the bolt.

Water: cement ratios should preferably not exceed 0.40 by weight. Trials on-site are useful to determine the lowest water: cement ratio grout which is pumpable with the available equipment. During installation water volumes should be measured with a calibrated system and not the 'human eye'. Cement grout mixes can be readily sampled and tested in compression after a fixed cure time (eg 7,14 or 28 days). Correct

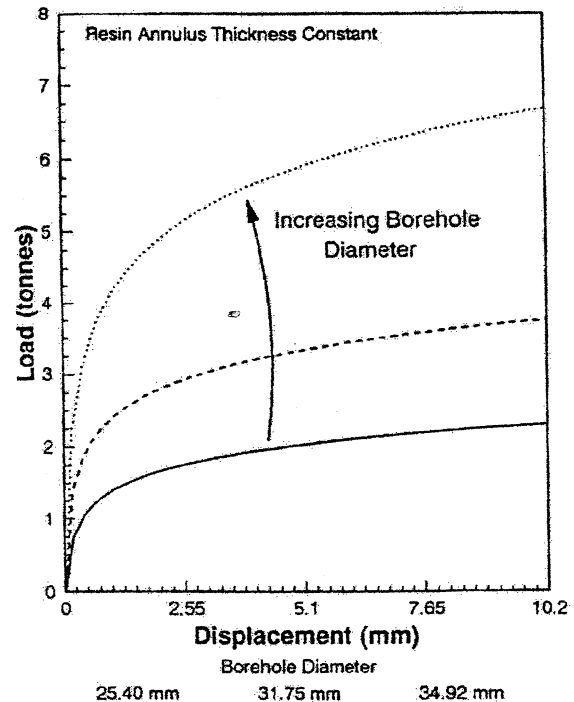


FIG 8 - Pullout tests on a 300 mm length of rebar 6.4 mm less than the borehole diameter (Karabin and Debevec, 1978).

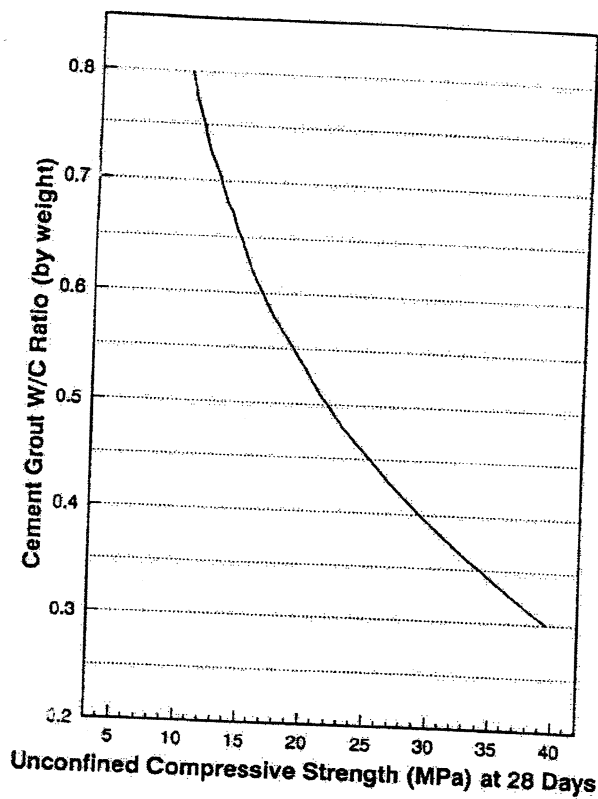


Fig 9 - Effect of w/c ratio on grout properties, type one cement.

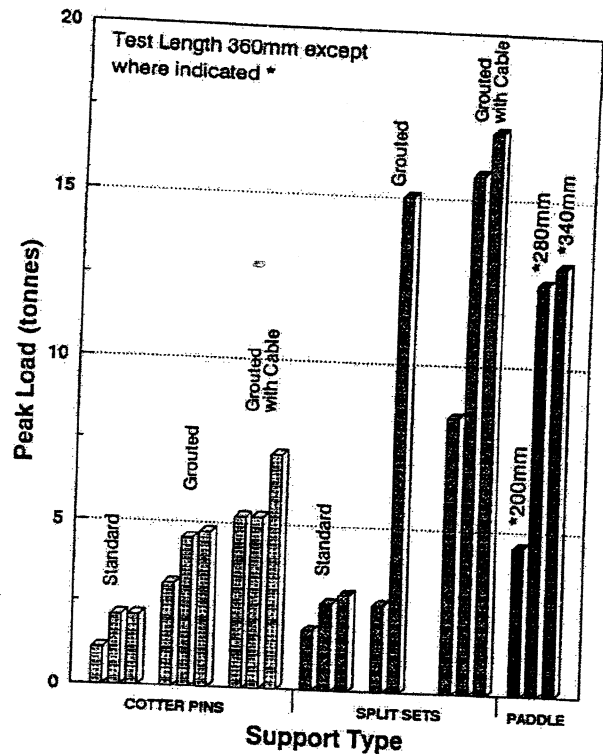


Fig 10 - Summary of pullout test results (Pasminco, Broken Hill).

pumping techniques should also be employed in 'up' and 'down' holes to avoid voids and ensure a continuous bond.

The quality and length of resin in fully bonded resin bolts is critical. Inconsistent or low performance of resin bolts can normally be attributed to one of the following:

- over-extended shelf life of cartridges or storage at high temperatures,
- incorrect spinning time,
- incorrect set or hold time before tensioning, or
- incorrect installation of slow and fast cartridges.

Again, quality control is vital and manufacturers will recommend spinning times and hold times. However field tests may be required to determine the most appropriate resin type, spinning time and hold time at a particular site. For example, field tests from Reference 2 indicate a 50 per cent increase in peak load for water based resin compared with oil based resin.

### Rock bolt and accessories

Currently there is a vast range of different bolt types available, some of which have already been mentioned. At a particular site, it is likely that more than one type of bolt will do the job so the final choice often comes down to total installed support cost. The difference in performance of three different bolt types tested at Pasminco, Broken Hill is shown in Figure 10. The mean peak loads ranged from about two to almost 14 tonnes. Such a large range of peak loads from one example highlights the importance of correct *in-situ* testing of different bolt types for different ground conditions at the mine site to establish bolt effectiveness.

The effect of bolt diameter and bolt length have been discussed earlier. As with hole cleanliness, bolt cleanliness has a significant influence on bolt performance. Figure 11 shows the results of a pull-test program on cable bolts performed to compare clean cables with those which had been deliberately coated with a thin

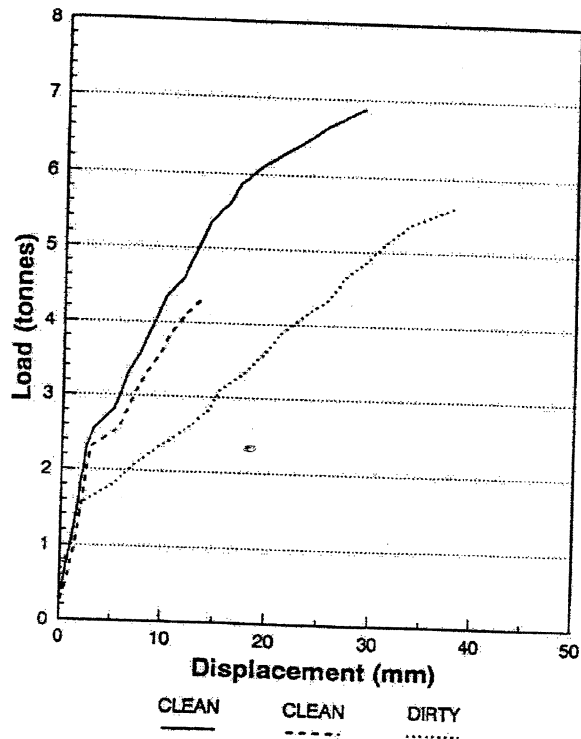


Fig 11 - Pullout test results for clean and dirty cables.

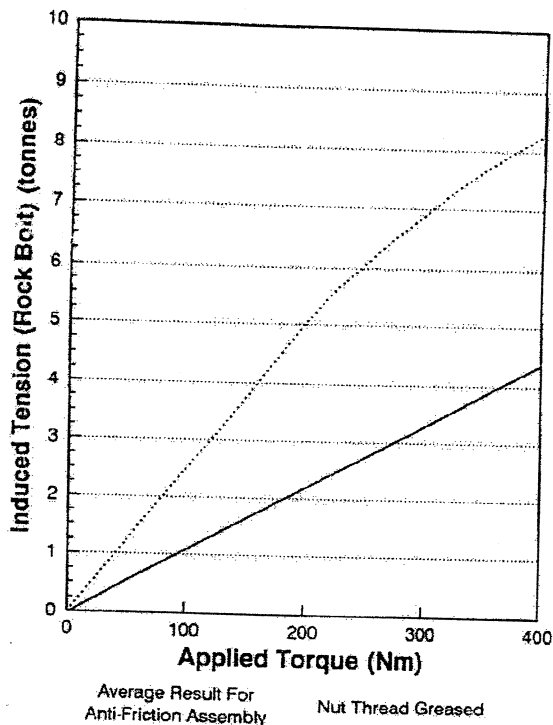


FIG 12 - Effect of booster washers.

layer of mud. In this case the dirty cable developed only about 50 per cent of the bond strength of the clean cables.

A range of bolt accessories are available from manufacturers to increase bolt performance.

Examples are domed ball and plates for use in ground with highly irregular surfaces. Another example is the use of washers to reduce the friction at the nut/plate washer interface. Simply greasing the nut thread gave minimal improvement (Reference 3) but a friction reducing assembly almost doubles the bolt tension achieved during installation (Figure 12). Such items need to be considered and, if necessary, tested on site.

### IN-SITU TESTING

*In-situ* testing is usually the only means of assessing the performance of different rock bolts in different ground conditions. Tests at different areas of a mine site may show:

- High performance
- Low performance
- Performance that is extremely variable

High performance may initially be reassuring but could mean that high capacity support is an overkill and costing too much. Low performance may mean the support is adequate for the ground conditions providing there have been no failures. If failures have occurred then the low performance is a safety issue and may be improved by better quality control. Inconsistent performance can be due to variable rock conditions but it can also point to inadequate quality control. If inconsistent test results were obtained but no ground failures have occurred, then it may mean that only low performance bolts are necessary anyway.

### CONCLUSIONS

This paper has outlined some of the factors which must be considered by mine operators to optimise their rock support. The factors outlined should be considered before and during a rock bolting program. If they are ignored, it is likely that money is being wasted on support or that safety is being compromised, perhaps unknowingly.

Having aimed to maximise the support effectiveness, an on-going quality assurance program should be carried out to maintain optimum performance. These programs can take the form of either a check on installation practices and grout quality and/or destructive testing such as pullout tests to check the bond strength or laboratory tests to check grout strength.

Because of the many factors which influence bolt performance, there is no universal rule to obtain the peak performance of a rock bolt at a particular location. Currently, *in-situ* pull testing on short bolt lengths is the only way to check and quantify bolt performance, either for comparison purposes between different bolt types (always with the same bond length and in the same ground conditions) or as a check on quality control.

### REFERENCES

1. Barrett, Fuller and Partners, 1991. Rock Bolt 'Pull Testing'. Pasmenco Zinc Mine, Broken Hill. Reports on Stages 1, 2 and 3.
2. Schutte, A J. A cost effective and safe grouted tendon support technology for underground excavations. Thesis for Masters Diploma in Technology, The School of Mines, Johannesburg, South Africa.
3. ANI - ARNALL, Practical Guide to Rock Bolting.
4. Falconbridge Limited. Pull-out test results, Lockerby Mine, Internal Report, AMIRA Project P124A.
5. Fuller P G and Dight, P M, 1991. Ground support in mining, AMF Course Notes.