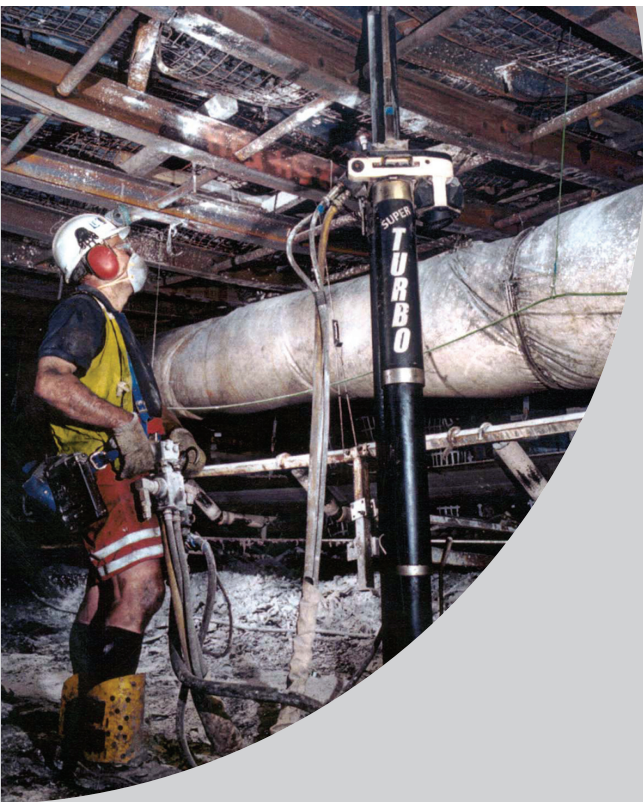


THE MINOVA GUIDE TO Resin-Grouted Rockbolts



THE MINOVA GUIDE
to
**Resin-Grouted
Rockbolts**



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Contents

Prefaces iv–xiii

Introduction xv

CHAPTER 1

The motivation for rockbolting with full column anchors 1

CHAPTER 2

How rockbolts work 5

CHAPTER 3

Rockbolt support design 20

CHAPTER 4

Types of rockbolts and grouting materials 42

CHAPTER 5

Guide to the use of resin-grouted rockbolts 50

CHAPTER 6

Installation methods and equipment 62

Appendix: Examples of international rockbolting practices 74

References 82

Illustrations and Figures 84

Index 86

Contact list 88

Preface

The provision of adequate strata control for underground access roads or tunnels has always been and remains a key success factor for ensuring the life of a mine or tunnel. The success of roof support is not just measured in how it prevents the excavation from closing – albeit this is the key factor – but also in how it impacts on the cost of a mine.

It is now internationally accepted that full column resin bolting in underground roadway drivages provides rapid and effective strata control at a much lower cost than traditional external set supports. The development, application requirements and usage of the resin capsule has evolved in every mature mining country and as a result the operational requirements of the resin capsule and reinforcement element differ widely. It was with this in mind that Minova International set out to provide this handbook on rockbolting in an attempt to present the various accepted methods of use of resin-grouted anchors.

This handbook is a culmination of thirty years' experience in the manufacturing and application of resin capsules (or cartridges) throughout the world by Minova. Minova is perhaps uniquely positioned in having manufactured resin capsules in the USA, Australia, Poland, South Africa, Russia, Germany and India, and having its own brand, Lokset®, reinforced by experience gained from the acquisition of brands such as Celtite, Titafix and CarboTech SiS.

The object of this handbook is to provide an insight into the use of grouted anchors as rock reinforcement in mining and tunnelling. It deals principally with resin-grouted rockbolts. Alternative bolting systems are also covered at a general level.

The handbook will give the reader a broad idea of how full column resin bolting can be used. It provides a general approach to the theory, as well as the criteria that need to be observed to create an effective design for roof rockbolting. It then covers how grouted rockbolts perform against other types of rockbolts, the correct use of resin capsules, and troubleshooting problems. The appendix gives examples of the diverse approach to rockbolting through brief descriptions of resin rockbolting in the USA, Australia, South Africa and the UK.

A handwritten signature in black ink, appearing to read 'Bell', written in a cursive style.

Peter Bell
International Business Development Director
Minova International Limited



A typical rockbolted roadway.

Introduction

When an opening is created in rock, the surrounding strata invariably become unstable but can be strengthened by various methods of support. The support's main purpose is to activate, conserve and improve the inherent strength (tensile and shear) of the strata, and maintain their load-bearing capacity.

In this case support is defined as all methods which essentially provide surface restraint to the rock mass via installation of structural elements at the surface: timber props, steel arches, timber packs, mesh and sprayed material such as gunite/concrete. These methods are termed 'passive' methods of support as they rely on the rock mass moving to develop their resistance load.

In contrast, reinforcement is considered to include methods which modify the internal behaviour of the rock mass by the installation of structural elements within it. Reinforcement methods are described as 'active methods' of support. These

include tensioned point anchored bolts, friction bolts (split sets) and resin-anchored bolts. These active reinforcing elements are intended to react to rock mass movement, develop a restraining force and transfer that force back to the rock mass. This counteracts the driving force and eventually a balanced condition is reached when the total mobilised resistance within the rock mass is at least equal to the available driving force.

Rockbolts modify rock and strata performance using reinforcement principles. The bolts act in much the same way as the steel in reinforced concrete.

Resin-grouted rockbolts offer advantages over expansion shell bolts in providing higher strength anchorage in weak or intensely jointed rock conditions. They also perform more reliably than expansion shell bolts when subjected to blast vibrations.

Resin-grouted bolts provide far greater anchor strength per metre than friction bolts (split sets): friction bolts tend to fail in tension if they are initially subject to shearing.

Rockbolts that are most suited to resin-anchored applications have a deformed or rough external surface to increase bonding efficiency, frictional resistance, enhanced load transfer and resin mixing capability. There are several different types of rockbolt available and selection will depend on a number of factors, such as:

- extraction height;
- rock type;
- presence of laminations, breaks and fractures;
- strength and stiffness of rock;
- location of competent strata;
- installation equipment;
- point anchor or full encapsulation;
- primary support, rehab work;
- life expectancy of tunnels or excavations;
- presence of water – corrosive action.

All these factors have to be accounted for when bolting design is undertaken.

The motivation for rockbolting with full column anchors

The purpose of underground rock support can be summarised as follows:

'To control the movement of strata surrounding an opening in such a way that the availability of the opening to perform its designed functions is not impaired.'

The practice of reinforcing the strata surrounding an underground excavation by the insertion of rigid rods is a very old one. The earliest examples date back to the primitive Baiga tribes of the Indies, who strengthened weak ground by driving wooden 'nails' into it. In so doing, they exhibited a fundamental belief that, with a little help, the ground itself is the best means of support.

Openings supported with elements external to the rock (commonly known as 'passive' systems), such as steel arches or timber sets, require an enlarged excavation to accommodate the support elements and still give good access. The support elements themselves are usually difficult to handle, and costly both to purchase and to install. The oldest known mining examples were exposed in the Angers slate quarries of France. Here chestnut-wood dowels were used several centuries ago in room and pillar mining to reinforce the shafts and rooms. However, bolting as a method of strata reinforcement was slow to gain acceptance.

The early twentieth century saw many isolated references to the use of rockbolting systems, but it was not until 1947 that the method was developed on an industrial scale. In the USA concern about the rising rate of accidents due to falls of ground

prompted the reassessment of underground supports. The US Bureau of Mines introduced roof bolting at this time to help combat the adverse statistics. By 1952 the annual consumption of bolts had risen to 25 million. At this time the bolts or reinforcement units were solely mechanical point anchored bolts. Following the introduction into the mines of USA and its success in not only combating roof falls but also in making the mining operations more efficient, the practice of roofbolting as a primary support in mines spread throughout the world.

By 1952 the use of mechanical point anchored bolts had spread to the mines of the UK. Unfortunately for several reasons – mainly the ineffectiveness of mechanically anchored bolts in weak strata and the difference in mining methods between the USA and the UK – the adoption of roof bolting as a primary support did not wholly succeed at this time. It also became apparent in other countries, including the USA, that mechanical point anchored bolts in weak strata prone to deformation had an inherent limitation in their application. In weak strata it was observed that the head of the anchor would creep. The result was slackening of the bolt, leading to it ultimately becoming ineffective. This prompted research into embedding the bolt into a material introduced into the borehole after bolt installation to prevent creep of the point anchor in the borehole. Synthetic epoxy resins were introduced in the USA in 1956. These were placed into the hole by injection. Cement injection was also tried in France but the setting time was too long for it to be accepted on a widespread scale. By that time it was considered possible that the bolt could be anchored in the hole solely by a material that would allow the bolt to contribute to the reinforcement of an underground opening within a few minutes after installation.

Work began on a system that would allow the bolt and an anchor material – resin – to be installed in one operation, the resin being mixed within the borehole by the agitation of the bolt. In 1959 SEBV of the Federal Republic of Germany introduced the first resin capsule system. The resin was

contained in a glass cartridge, which broke as the bolt was installed. This first resin capsule was called the Klebanker. Although the Klebanker proved that resin could be an easy and effective means of anchoring a bolt, it was limited by its high manufacturing cost. Further improvements of the resin-anchored bolt were made in the French iron ore mines, developing the idea of using a plastic film to contain the polyester resin. Charbonnages de France's chemists assisted with the development of a special resin for this purpose. In the light of the French experience with grouted roof bolting, Germany introduced the system in 1980.

The introduction of steel rockbolts in the late 1960s has influenced mining methods and equipment, with the increased mechanisation of underground development being traceable to this.

Initially, mechanical expanding-shell anchor bolts were introduced in underground mining. However they perform poorly in weak rock and in the early 1970s fully grouted non-tensioned bolts, termed dowels, came into use in Europe. Mechanisms to explain the action of rockbolts in controlling the roof of an excavation were developed. The principal theories amongst these were the key block theory, suspension theory, beam formation theory and arch formation theory. From these concepts, and experience in the field, a variety of design methods have been developed to derive bolt density and bolt length to reinforce an excavation.

In early designs using point anchor bolts, tension in the bolt was required to produce a normal force between layers of strata, thus increasing the frictional resistance. However, the development of full column grouted bolts offered a new approach. Beam formation could be achieved with or without tension, the horizontal shear forces being resisted by the lateral stiffness of grout/bolt combination.

The development of rock bolting technologies throughout the world has seen a steady trend towards using bolts as a primary support, enabling the openings to be reduced in size

and be freed of restrictions imposed by supports. The method has proved to be safe, efficient and far more cost effective than traditional support methods.

The success of full column grouted bolts as a support medium in weak ground, in particular in stratified deposits, has seen an increased usage throughout the world. In many cases using roof bolts with full column resin has become the only viable option for the extraction of coal. Their development has also found a use in secondary support in providing planned preventative reinforcement. In areas where disturbed ground exists, reinforcement of the ground in advance of a working has enabled production to continue with little or no loss to production. The full column resin-grouted dowels have also found a use in fall recovery, by adding reinforcement to the broken ground around a fall.

Throughout the world resin-grouted rockbolting has become accepted as a primary support. The USA now uses approximately 100 million bolt units per year. South Africa uses about five million units with ninety per cent being full column grouted, and Australia's four million units are almost totally full column grouted bolts. Today resin-grouted rockbolting has also been developed as a secondary support for reinforcing weak strata and gained wide acceptance for use in fall recovery.

How rockbolts work

Rockbolts work by reinforcing the rock – this means they improve the strength of the rock mass into which they are installed so that the rock itself becomes part of the support system.

In order to understand how this reinforcing action is achieved we need to look first at how rock fails. Rock around mine openings and tunnels almost always fails in shear, either along joints and other planes of weakness or through the rock material itself. Typically failure is driven by the rock stress field which is concentrated around the opening (see Chapter 3). For rectangular openings, the horizontal stress component is

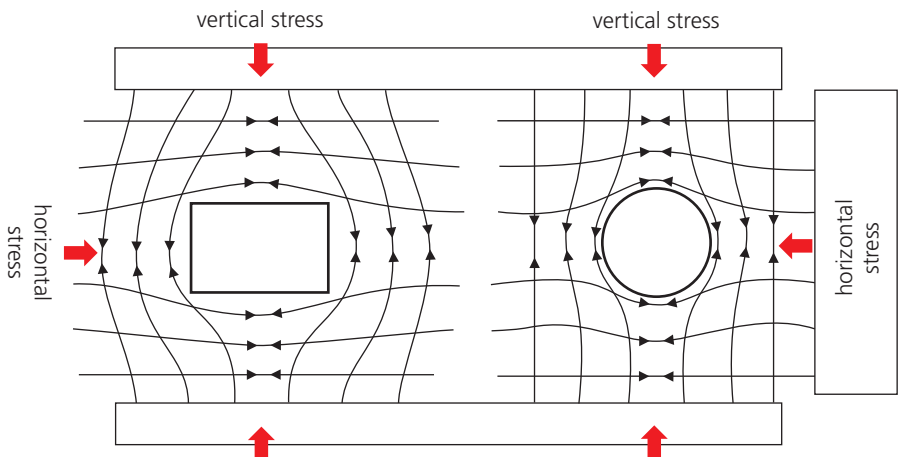


Figure 1a Stress concentration around rectangular and circular openings

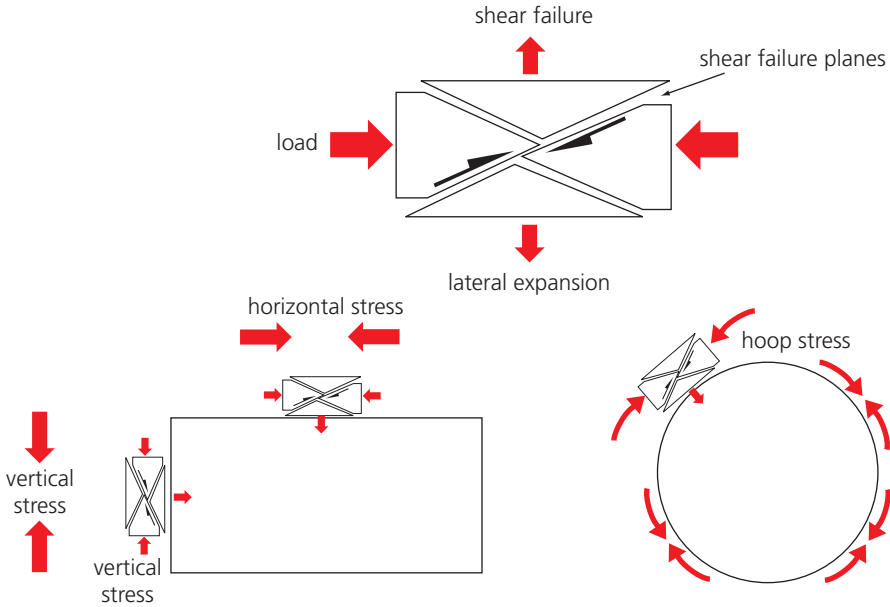


Figure 1b Concept of stress driven shear failure for rectangular and circular section openings

concentrated in the roof and floor and the vertical component in the sides. For circular openings, the resulting stress concentration can be visualised as a hoop stress surrounding the opening (Figure 1a).

If this load exceeds the rock material strength, shear failure occurs with shear displacement and lateral dilation of the failing rock (Figure 1b). When a bolted tunnel or mine roadway fails in this way the result can be seen in terms of roof 'shortening', where the distance between installed bolt ends across the roadway actually reduces, and roof lowering, caused by the dilation of the failing rock.

Alternatively shear may involve sliding displacements along preferentially orientated joint planes and other discontinuities. This may be stress driven or, under very low stress near surface

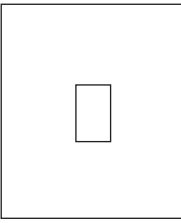
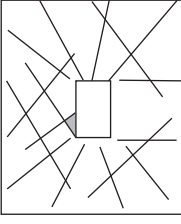
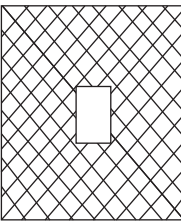
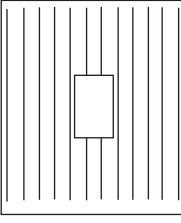
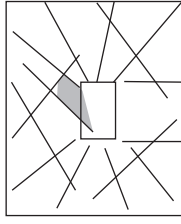
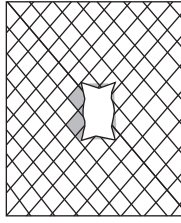
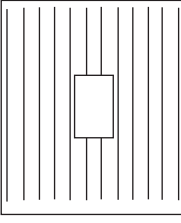
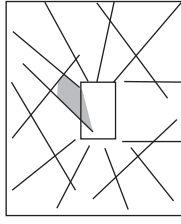
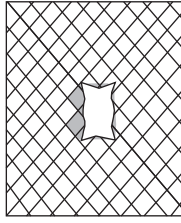
	Low stress levels			High stress levels	
Massive rock	 <p>Linear elastic response with little or no rock failure.</p>	Jointed rock	 <p>Blocks or wedges, released by intersecting discontinuities, slide under gravity.</p>	Heavily jointed rock	 <p>Failure as a result of unravelling of small interlocking blocks and wedges. Failure can propagate into the rock mass if it is not controlled.</p>
Stratified rocks	 <p>Immediate roof beds or sides may fail on discontinuities under gravity.</p>	Jointed rock	 <p>Failure occurs as a result of sliding on discontinuity surfaces and also by crushing and splitting of rock blocks.</p>	Heavily jointed rock	 <p>Shear failure occurs through rock pieces and sliding on discontinuities.</p>
Stratified rocks	 <p>Roof and floor beds fail in shear due to horizontal loading. Sides fail in shear due to vertical loading.</p>	Jointed rock	 <p>Failure occurs as a result of sliding on discontinuity surfaces and also by crushing and splitting of rock blocks.</p>	Heavily jointed rock	 <p>Shear failure occurs through rock pieces and sliding on discontinuities.</p>

Figure 2 Rock failure patterns for high and low stress conditions (adapted from Hoek et al. 1995)

conditions with stronger rocks, gravity alone may result in the sliding of blocks on joints or sagging of beds into an excavation, or pieces may simply fall out (which, strictly speaking, is tensile failure). Figure 2 illustrates a range of rock failure patterns for rectangular openings in high and low stress fields for massive, jointed and stratified rock.

When rockbolts are installed they modify the ground behaviour and can prevent or restrict rock failure. They do this by transferring load from the unstable part of the rock mass to the rockbolt itself and then into stable ground. The strength of bond between the anchor and the rock is a measure of the effectiveness of this load transfer mechanism.

For all bolt types – mechanically anchored, friction anchored and grouted – the bond results from a combination of friction and interlocking at the bolt/rock or bolt/grout and grout/rock interfaces. Adhesion plays no significant part in bond strength and it is wrong to think of resin-bonded bolts as being ‘glued’ to the rock. Shear in the resin layer caused by rock or bolt displacement generates high radial stresses which act across the interfaces and maximise the frictional resistance. Both the bolt profile design and rifling of the borehole wall, as well as the properties of the resin, are important factors in generating this frictional resistance.

In the case of point anchored systems, the bond strength can be measured by pull testing the anchorage. For fully bonded systems, the short encapsulation pull test is used (Chapter 3).

Load transfer

Load transfer between the bolt and rock can be considered to occur in three ways:

- 1 suspension;
- 2 direct shear restraint;
- 3 axial restraint.

1 Suspension or block anchorage

The suspension of a weak layer by bolting it to an overlying stronger layer represents the initial concept for which mechanically anchored rockbolts were developed. In this case the suspended load imposed on the end plate is transferred to the stable rock above via the anchor. This simple support situation is, however, uncommon in present day bolting applications. A similar principle applies where loose blocks or wedges in a strong jointed rock mass are supported by bolting through them and into adjoining stable blocks.

2 Direct shear restraint

Rockbolts installed through a potential shear plane will directly resist shear deformation. Partially encapsulated types allow some displacement before resistance starts to build up. Fully grouted types are the most effective in this application because they provide immediate resistance. Crushing of rock and grout occurs due to localised stresses and load transfer occurs by bending of the bolt which also generates axial load. The stronger and stiffer the bond, the greater the resistance to shear displacement (Figure 3). Direct shear restraint is effective in preventing sliding movement on joints and so on, but is less useful in restricting shear failure through the rock material. In this latter case the influence of the bolt is limited to its immediate locality.

3 Axial restraint

Rockbolts installed through a potential shear plane also provide axial restraint to resist the lateral dilation associated with shearing movements (Figure 4). Again fully grouted types are the most effective. Load transfer results in an axial tensile load developed in the bolt centred at the shear plane position. This acts as a clamping load, increasing the normal force (and therefore shear strength) across the shear plane, restricting the

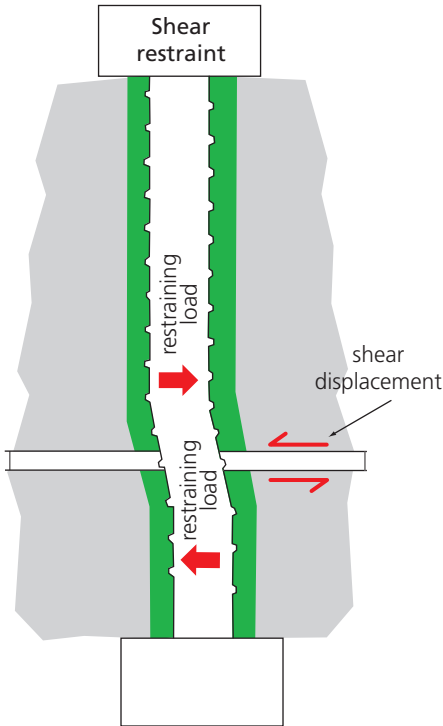


Figure 3

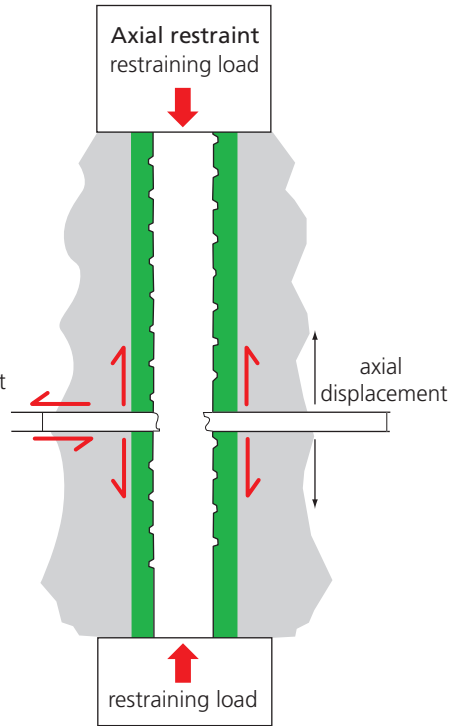


Figure 4

shear failure. The stronger and stiffer the bond, the more effective this action will be. For partially encapsulated types the complete bolt free length can stretch in response to lateral dilation, so the resulting clamping load is much smaller. However many partially encapsulated types are pretensioned on installation, resulting in a more complex situation as explained later.

Retention of stress in the roof

When rockbolts are used successfully to reinforce an underground opening or tunnel, the end result is the retention

of a significant level of horizontal stress in the roof of rectangular openings (or of hoop stress in the case of a circular tunnel).

Even at shallow depths the initial horizontal stress level acting across the immediate roof of a rectangular opening is likely to exceed 2 MPa, which means that a horizontal force of some 200 tonnes is being transmitted through every square metre. In contrast, the weight of rock contained in a typical bolted height of 2 m for a 5 m wide opening is around 25 tonnes per metre run (Figure 5a). It is easy to see that even if the roof contains vertical breaks which would potentially allow roof blocks to fall, they could not do so whilst the horizontal stress is present and preventing the blocks from sliding under gravity. However if the immediate roof fails under this horizontal stress loading, the transmitted load reduces and horizontal stress is redistributed higher into the roof.

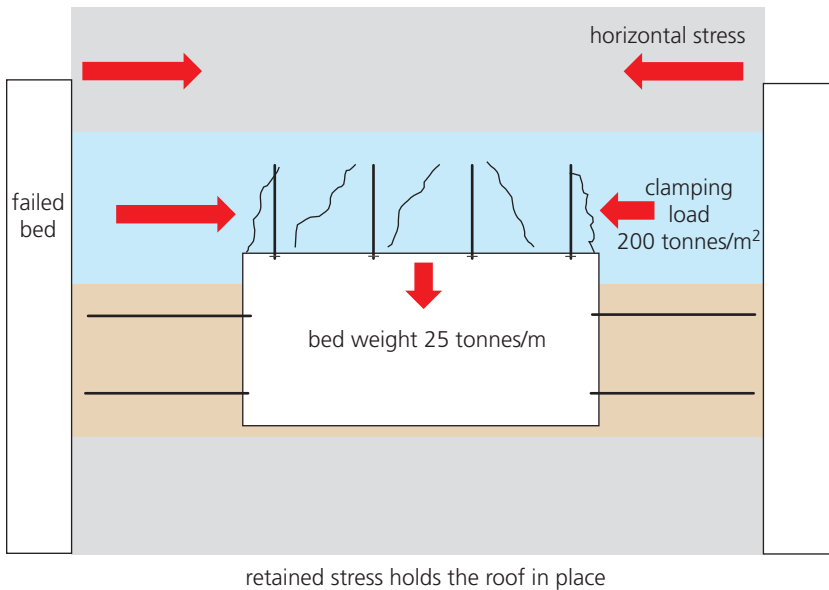
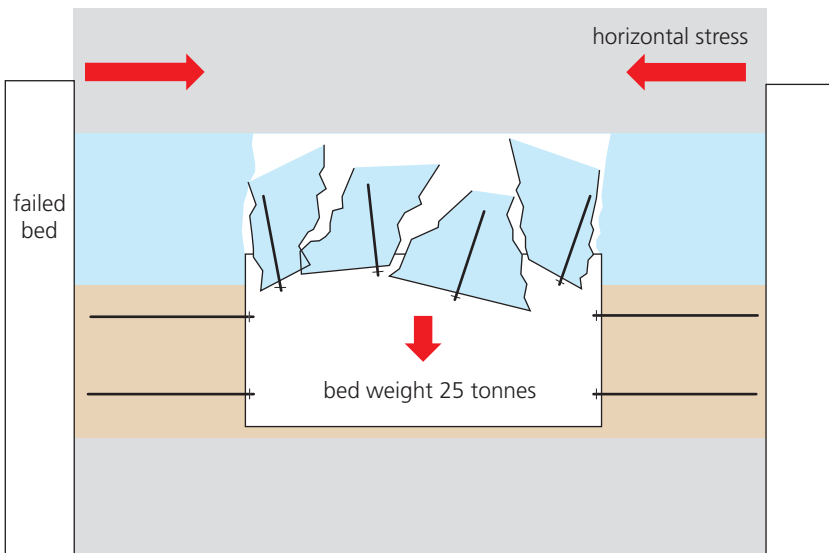


Figure 5a The concept of roof stability through retention of stress

Ultimately the transmitted load can become low enough to allow a roof fall to occur (Figure 5b).

Support of highly stressed weaker rock as typically found in deep coal mines perhaps represents the most challenging application for bolt systems. In this case, the initial stress levels are high and a high bond strength and stiffness fully bonded system is essential to maximise the reinforcing effect. Some shear failure under horizontal stress loading inevitably occurs, and the stability of the roof depends on retention of a safe residual level of horizontal stress loading (Figure 6).

Axial restraint provided by the bolts is the key to roof stability in this situation. The effect is less localised than direct shear restraint and results in a general reinforcing effect where failure is occurring through the rock material. In this situation a relatively small additional restraining force (e.g. through



if no stress is retained a roof fall can occur

Figure 5b The concept of roof stability through retention of stress

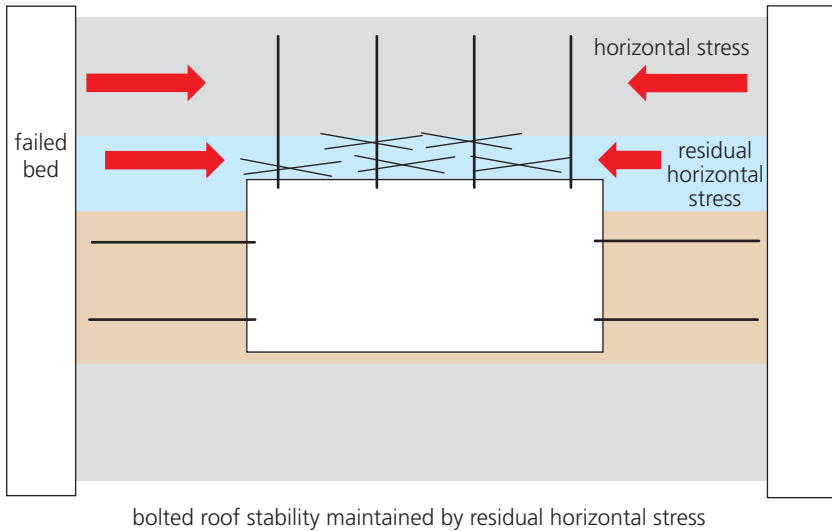


Figure 6 Support of weak roof under high stress conditions

installation of extra bolts or use of a higher performance bolt system) can give a significant increase in residual bolted roof strength which determines the stress transmitted through it. Figure 7 illustrates the stress transmitted by a bolted roof as shear displacement increases. The residual stress level after shear failure for the high restraint bolt system (B) is considerably larger than for the low restraint system (A).

The reinforcing action of rockbolts therefore works by preventing or restricting shear failure in the rock surrounding the opening, through axial and direct shear restraint, so that the level of stress transmitted through the bolted zone remains high enough to maintain the opening in a stable condition. Depending on the opening shape and the rock conditions, this action has been described in terms of 'beam building' or 'arch building' but the essential feature in either case is the retention of stress transmitted through the bolted zone.

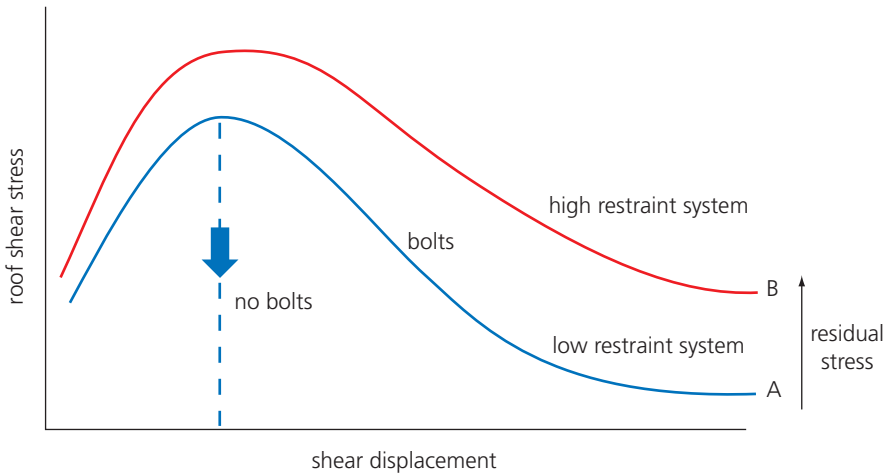


Figure 7 Effect of bolt system axial restraint on roof stress level

Bolt tensioning

Bolt tensioning is essential with point or partially encapsulated rockbolt systems. It was originally applied to mechanical point anchor bolts in order to lock the bolt head in position but with resin-anchored types it is also necessary to tension the end plate to the roof to make the bolt effective as a support. Tensioning loads as high as 15–20 tonnes are now used with higher capacity systems such as strand type bolts (Rataj 2002). This practice, generally known as pretensioning, has been claimed to increase bolt effectiveness.

Since the advent of fully encapsulated systems some publications have made a distinction between ‘rockbolts’ which are partially encapsulated and tensioned and provide ‘active’ support, and ‘dowels’ which are fully encapsulated untensioned bolts and provide ‘passive’ support. The implication is that the latter are less effective as support, when often the reverse is the case.

In practice many fully encapsulated systems are tensioned. The use of two resins of different gel times ('fast' and 'slow' resins) with full column bolts has been common practice for some years, with the primary object of facilitating bolt installation. Tightening the nut after the fast resin sets but before the slow resin gels, results in tension being imparted into a full column bolt. The loads generated during normal installation (up to about 3 tonnes) are relatively small.

Forged head bolts cannot be tensioned in the conventional way and normal practice has been to use the installation drilling mast to hold these in position until the resin cures. However the technique of 'thrust bolting' has emerged in recent years in which the drill thrust is used to push the bolt end and compressible plate tight to the roof as the resin sets. This is claimed to result in tension being developed in the bolt following the expansion of the compressed rock and plate, once the thrust force is removed.

Tensioning of point or partially encapsulated bolts produces a compression zone in the rock above the bolt plate. This results in tightening of discontinuities, increasing the shear strength on the discontinuity planes and so increasing bolt effectiveness (Lang 1961). However, because the bolt is typically fifteen times stiffer than the rock, with only a small deformation of the rock above the plate (through local crushing, shrinkage or creep) or anchorage slip the initial tension is lost. Loosening or tension loss with partially encapsulated bolts is consequently a common experience in mines (Mark 2000; Van de Merwe and Madden 2002). The tension-induced compressive zone is also limited in extent – most computer modelling suggests to within about 0.5 m of the end plate (Unrug et al. 2004; Yassien et al. 2002). The effect of tensioning is to provide additional axial constraint in this zone at the expense of a reduced bolt capacity (because of the tension load) available to resist dilation further into the roof.

Possibly the greatest benefit from high pretension loads comes from the closing of any open joints or fractures, which increases the discontinuity shear strength.

With fully encapsulated rockbolts, the slow resin sets after any tensioning and this may result in the tension being 'locked in' and not so easily dissipated as it is with partially encapsulated systems (Unrug and Thompson 2002). Full column resin rockbolt systems also have a much higher effective stiffness than the point anchored rockbolt systems for which tensioning was originally employed. Dilation in the surrounding rock is transmitted to the bolt via the grouted annulus, and bolt tension resisting this movement rapidly develops, centred at the position where movement is occurring. It is therefore often claimed that there is no advantage in using high tension loads with full column grouted bolts. In practice the main benefit of tensioning in this case may again be that it ensures the bolt plate is set tight to the roof and any open discontinuities are closed.

Effectiveness of different bolting systems

Fully grouted rockbolt systems, now account for eighty per cent of US mining usage (Unrug et al. 2004), and their increasing application worldwide suggests that practising engineers generally prefer this type of system, particularly for support in deeper mines and weaker rocks. In addition, several studies have suggested that the performance of untensioned or lightly tensioned fully encapsulated bolts compares favourably with partially encapsulated tensioned bolts. Yassien et al. (2002) concluded from computer modelling that whilst tensioned bolts were only effective at supporting the first metre of roof, fully grouted bolts were effective over their full length. Snyder (1983) summarised a decade of research into use of roof bolts in room and pillar mines in the USA, using analytical, experimental and full scale studies. He concluded that full column resin-grouted bolts were generally superior to point anchored bolts.

Limits to rockbolt effectiveness

Rockbolts are only effective over a relatively small deformation range – for fully grouted resin bolts this can be less than 50 mm of rock movement and will usually be less than 100 mm. Beyond this, the bolt is likely to be broken or ineffective because of reduced bond strength. Broken bolt ends, deformed or broken plates or significant ground movement, unrestrained by the bolts, are all signs of an ineffective bolt system. The use of long tendons such as cablebolts, in addition to rockbolts, to reinforce the upper roof and to suspend the bolted zone from a stable upper roof is a common practice where rockbolts alone are insufficient.

Yielding bolt systems, which can accommodate large movement, are used in some applications, for example in deep hard rock mines where large rock deformations or rockbursts are expected. Yielding bolts are normally point anchored types with a controlled deformation mechanism such as a slip nut at the plate end.

Typical rockbolting applications

The suitability of different bolting systems for the range of possible support applications can now be considered, based on the information presented above.

The main factors dictating the pattern of rock failure are the in situ stress level, the rock material strength and the frequency and orientation of discontinuities such as joints and bedding planes. Figure 2, presented earlier, illustrated a range of possible failure patterns for low and high stress conditions. Appropriate rockbolting practice for these conditions can be summarised as follows.

1 Low stress level massive rock

Practice: no support or 'skin' support to prevent isolated loose pieces from falling

Appropriate bolt system: any short low capacity bolts – perhaps with lightweight mesh

Examples: shallow depth salt/limestone/metal mines with massive conditions

2 High stress level massive rock

Practice: systematic rockbolting with mesh to limit shear failure and retain broken pieces

Appropriate bolt system: high capacity full column resin bolting

Examples: deep salt potash mines; deep tunnels in massive rock

3 Low stress level with some discontinuities

Practice: spotbolts located to secure blocks and wedges

Appropriate bolt system: point anchored tensioned bolts or fully bonded tensioned bolts

Examples: metal/gypsum mines at shallow depth; shallow tunnels in hard jointed rock (e.g. sandstone, granite, gneiss)

4 High stress level with some discontinuities

Practice: systematic pattern of high capacity rockbolts angled if necessary to intersect discontinuities with mesh or shotcrete to retain broken pieces

Appropriate bolt system: point anchored tensioned bolts or full column resin bolts

Examples: deep tunnels in igneous/metamorphic rocks

5 Low stress level with many discontinuities

Practice: systematic light pattern of bolts with mesh or shotcrete to keep rock pieces in position and prevent unravelling

Appropriate bolt system: point anchored tensioned bolts or fully bonded tensioned bolts

Examples: shallow tunnels in foliated and jointed or broken rock

6 High stress level with many discontinuities

Practice: systematic pattern of high capacity rockbolts with mesh or shotcrete; may need side and invert support

Appropriate bolt system: high capacity full column resin bolts perhaps with long tendons

Examples: deep tunnels in foliated and jointed or broken/shattered rock/rock shear zones associated with faulting

7 Low stress level stratified rock

Practice: light systematic rockbolt pattern to strengthen the roof and prevent shear failure

Appropriate bolt system: tensioned point anchored or fully bonded rockbolts

Examples: shallow coal mine entries

8 High stress level stratified rock

Practice: heavy systematic bolting pattern to restrict shear failure

Appropriate bolt system: high capacity fully bonded rockbolts to roof and sides with mesh and possibly long tendons, cables

Examples: deep coal mine entries

Rockbolt support design

The design problem

Rockbolts utilise the strength of the surrounding rock to support an opening made within it. Therefore the engineering behaviour of rock is fundamental to the rockbolt support design process.

The problem of support design for rock structures is in principle no different from that in other branches of engineering – the rock is the material under consideration and the loads which must be carried are represented by the rock stress field. Unfortunately rock is an extremely variable material: it can be strong or weak, massive or bedded, lithology varies both within and between rock units, and both major and minor structural features (faults, shear zones, bedding, joints etc.) are common. In addition the magnitudes of rock stresses are unlikely to be known in detail. These depend on crustal tectonics as well as depth of cover, and may be concentrated around rock structural features.

Because of these complications, many support design methods have been developed and these are often specific to particular rock and stress conditions.

Rockbolt support is used over a very wide range of rock conditions. At one extreme where the rock is strong and stresses are low (e.g. hard rock conditions in shallow mines, tunnels and surface excavations), rock failure may be purely gravitational and exhibits as loosening of blocks and movement on joints. Design methods for these conditions

concentrate on joint geometry and properties and the ability of the installed reinforcement to prevent block movement.

In deep mines with relatively weak rocks (e.g. deep coal or evaporite mines), failure is predominantly stress driven, with shear failure propagating both through the rock mass and along preferentially orientated planes of weakness such as bedding and joint planes. Design methods for these conditions concentrate on rock mass behaviour under the imposed stresses and the ability of installed reinforcement to resist active rock shear and dilation.

Conditions in most underground excavations will lie between these extremes and design methods should consider all feasible modes of failure.

Regulations and standards

By no means are all rockbolt support patterns designed in any formal way – in fact the majority are probably not. Rockbolting patterns in many mines have evolved by trial and error, perhaps from an initial design or experiment. The pattern may subsequently be varied in response to conditions encountered, based on the judgement of mine engineers. Coal mining regulations sometimes include minimum bolt lengths and maximum spacings which effectively determine the pattern used. In the USA, for example, the maximum spacing is five feet (1.5 m) and most mines install four bolts per row to give around 1.2 m bolt spacing. In addition to regulation, standards or codes of practice may impose limits both on the design and on the design method to be used. The first requirement of any design is therefore to comply with relevant standards and regulations.

Design parameters

All design methods are likely to involve consideration of a range of parameters relating to both the rock material and the

stress field in which excavation is made. These are likely to include the following.

1 Rock material parameters

Rock type

This is determined from geological investigation including examination of borehole cores. Excavations in homogenous massive rock represent the simplest design problem. More commonly the rock will vary through the excavation and contain numerous joints and other structures which need to be taken into account in the design. Sedimentary rocks are made up of beds – layers of rock which are usually continuous over large plan areas – hence the coal mining term ‘strata’. Support design for stratified deposits has to take into account the properties and thickness of each bed and the nature and position of the major bedding planes.

Rock mechanical strength

The strength of a rock may be defined as the ability of the material to resist stress without large-scale failure and is measured by rock testing. Rock strength tests should be undertaken using a standard procedure to allow comparison with other data. The uniaxial compressive strength (UCS) from a compression test on a core sample is the most commonly measured strength parameter.

The response of confined rock material to loading is generally considered important in reinforcement design. This is measured by triaxial testing in which the relation between sample peak stress (σ_1) and confining pressure or minor principal stress (σ_3) can be determined, allowing estimation of the angle of friction and shear strength. In rocks which demonstrate significant creep under static stress loading, the strength is difficult to define and may be of minor significance in practice.

Figure 8 illustrates typical results from repeated triaxial testing showing the response of the rock to increasing

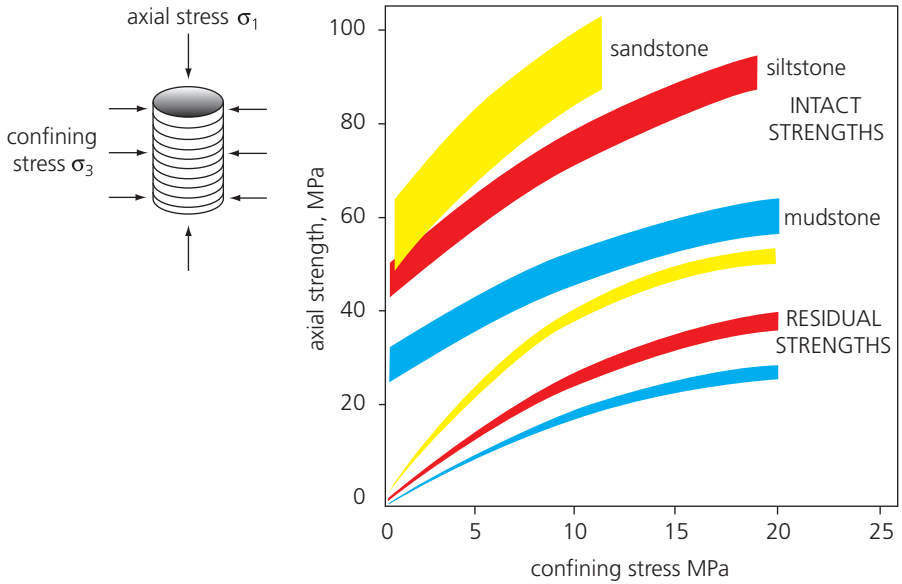


Figure 8 Triaxial test results for carboniferous rocks

confinement. The reinforcing action of rockbolts increases σ_3 which in turn increases the rock mass peak and residual strength.

It should be noted that all rock strength tests suffer from the problem of scale. Small intact test samples are not fully representative of the in situ rock mass. Consequently the larger the test sample, the lower the test result obtained. This has to be taken into account when using rock test data for design.

Structural features

Structural features such as faults, joints, bedding planes and foliation are important, especially in hard rock/low stress environments. Mapping of geological structure to determine the orientation, persistence, spacing and discontinuity surface properties is therefore an essential component of design in this

situation. The shear strength of joint or bedding plane surfaces may be measured using specialised laboratory testing.

2 Rock stress field parameters

Stress magnitudes

The rock stress field before excavation can be visualised in terms of three orthogonal components – the principal stresses. Usually (but not always) one will be vertical and the other two horizontal. The vertical stress is normally equal to the weight of overlying rock per unit area and is therefore directly related to the depth. Horizontal stresses will also increase with depth but in a less predictable way. At very shallow depths these may be influenced by surrounding topography but, as a consequence of tectonic forces, as depth increases one of the horizontal principal stresses is likely to be significantly larger than the other, and also larger than the vertical stress in many parts of the world, including Western Europe, Australia, the USA and South Africa. This has important consequences for design so ideally measurements of the in situ stress field should be undertaken.

As excavation takes place the initial stress field is concentrated around the opening. The relative magnitude of this concentrated stress, compared with the rock mass strength, will determine if the rock surrounding the excavation will fail without additional support. At shallow depths, openings in relatively strong rock may be self-supporting or just require rockbolts to secure loose blocks. As depth increases, a progressively higher level of reinforcement may be needed to resist active rock shear and dilation and maintain the excavation profile.

Geometry of the excavation

Both the size and shape of the excavation are major contributors to the pattern of the stress field surrounding the finished excavation. The larger the excavation, the greater the

support required, and there may be a critical dimension beyond which support becomes very difficult. If the excavation is large and created in stages, different rockbolting patterns may be needed at each stage to maintain opening stability.

Interaction from adjacent openings

Nearby openings, either existing or formed later, will influence the stress field surrounding an excavation, and resulting stress concentration effects can have a major effect in some circumstances. Vertical stress concentrations beneath mine pillars, for example, can affect workings a considerable distance above or below. The possible influence of other workings during the planned life of the excavation should therefore be considered.

Influence of excavation method

Rockbolting is used successfully as support in conjunction with both tunnelling machines and where excavation is undertaken using explosives. Measurements in two hard rock tunnels and a coal mine confirmed that blasting had no significant effect on the bond strength of resin-grouted bolts installed one metre away, for values of peak particle velocity less than 92 mm/s in the coal mine and 650 mm/s in the hard rock tunnels (Clifford 1995). Drivage by blasting may, however, disturb the immediate surface of the opening to a degree that meshing is required to contain the loosened fragmented rock. Poor blasting practices such as drilling off-line, overcharging and over-burdening, significantly increase local rock damage and increase rockbolting requirements.

Groundwater and rockbolt corrosion

Knowledge of groundwater conditions may influence the choice of rockbolting as a primary support or require consideration in the selection of the bolting method and

materials. Water reduces effective rock strength for porous or water-sensitive rocks, lubricates joints and other potential failure planes, and may directly affect bolt installation by flowing from drill holes. In addition, where water is in contact with unprotected bolt steel, corrosion will occur.

In cases where high flow rates are present within the rock, prior treatment by pressure grouting may be necessary to prevent the rockbolt grout from being flushed out before it sets. The presence of water is a significant factor when deciding whether or not the steel bolt requires corrosion protection. The corrosion potential of the water can be estimated from its pH value. Fortunately, the polyester resin used in full column resin bolts is unaffected by groundwater and can form an impermeable barrier, protecting the steel bolt.

Feasibility of rock reinforcement

Rockbolting can be used as support in a wide range of conditions. The limits beyond which it is likely to prove ineffective can not be defined precisely, as the rock material properties, stress conditions and the size of the opening are all influencing factors.

The most basic requirement is that the rock should be competent (i.e. it should have a measurable unconfined compressive strength). Rockbolting has been successfully undertaken in rocks of less than 20 MPa strength providing stresses are low. The minimum strength is likely to increase at higher stresses and for larger excavations, but rockbolting has been used successfully in coal and halite mines (UCS around 50 MPa) at depths exceeding 1000 m, and in stronger rocks in gold mines at far greater depths.

Other conditions which might prevent bolting from being effective include an adverse combination of: heavily jointed or crushed rock, especially with open, smooth or slickensided joints; high water inflows; high in situ stresses; swelling or squeezing rock.

Design methods for roof bolt support

Design principles

The complex nature of rock and rock stresses mean that the design of rockbolted support is not straightforward. Consequently a range of support design methods have been developed and these are often specific to particular rock and stress conditions. The main design methods in current use are:

- 1 analytical design techniques;
- 2 empirical techniques;
- 3 computer modelling;
- 4 observational design.

In selecting a design method the following general guidelines are recommended.

- 1 The site conditions should be defined by consideration of the main design parameters as described above. Possible modes of failure should be identified. The chosen method should be one which has been developed for and used in similar conditions and addresses the same failure mechanisms.
- 2 It may be appropriate to choose more than one technique in order to fully consider the range of failure mechanisms, for example, sliding of sidewall blocks on joints and shear failure in the roof. Where relatively simplistic methods are used, the output of several methods should be compared as an additional check.
- 3 The results of these methods should be used as guidelines only and should be checked on site by monitoring the rock deformation and performance of the support.
- 4 The final choice will also be influenced by operational issues such as type of installation equipment available. From this it follows that bolting system design should be integrated with overall mine or tunnel planning.

1 Analytical design techniques

These are essentially mathematical equations based on rock mechanics principles which allow calculation of required bolt length and spacing directly from design parameters. Such methods usually involve considerable simplification of the design problem so that a mathematical solution can be derived. Consequently they should be used with great caution. Examples are the use of a 'dead weight' calculation to determine the number of bolts required to suspend a rock beam from stable rock above, or the assumption that the bolted roof acts as an elastic beam or arch, allowing calculation of the support required to maintain stability.

One analytical technique which is widely used is consideration of the sliding under gravity of blocks or wedges bounded by joints. This relates particularly to jointed harder rocks. Computer programs (e.g. UNWEDGE) are available to undertake the design calculations and indicate suitable bolt lengths and spacings (Figure 9).

2 Empirical techniques

Empirical techniques are 'rules of thumb' derived from previous experience. Some of the simplest are no more than a list of recommended support for different values of one or more design parameters. The best known set of empirical design rules are those developed by Lang (1961) during construction of the Snowy Mountains hydroelectric scheme in Australia.

Farmer and Shelton (1980) developed Lang's rules and the experience of others and formulated a set of design guidelines for excavations in rock masses having clean, tight discontinuity interfaces.

Design guidelines of this type are simplistic and should be used with caution. However empirical design based on rock classification schemes has been considerably developed in

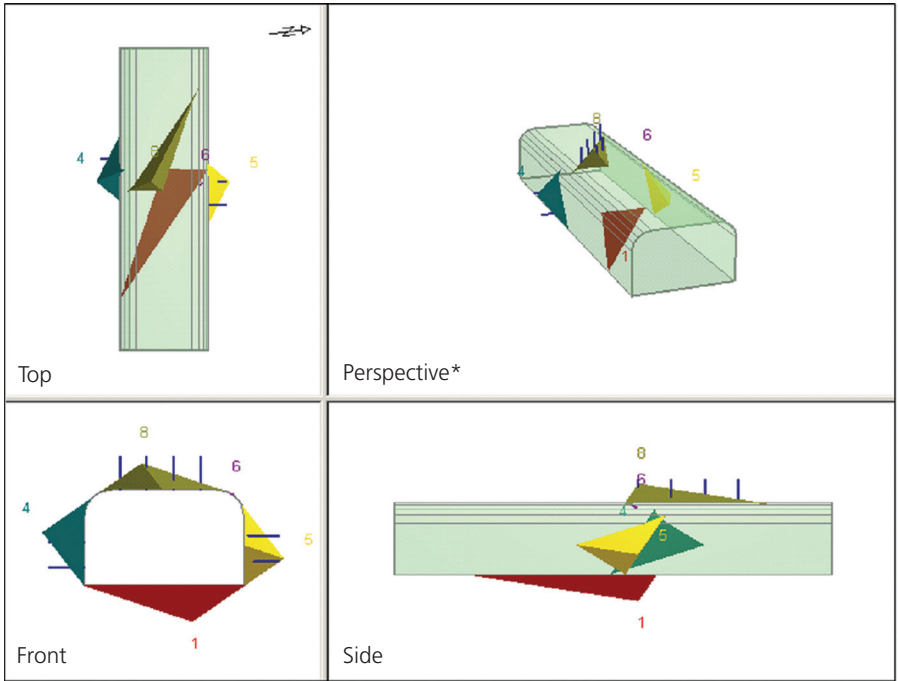


Figure 9 Analysis of wedge failure using UNWEDGE

recent years, and two of the best known, the Rock Mass Rating (RMR) (Bienawski 1989) and the NGI 'Q' system (Barton et al. 1974), are widely used for support design in mines and tunnels in harder rocks.

The RMR is based on intact rock strength, drill core quality (RQD), the spacing and condition of discontinuities, and ground water conditions. The Q system was developed from the analysis of Scandinavian tunnelling projects. The value of Q is based on numerical assessment of rock mass quality using six parameters: RQD; four parameters relating to the number of joints and their condition; and a stress reduction factor taking into account stress conditions.

Grimstad and Barton (1993) give support guidelines for different values of Q , taking into account the dimensions and use of the excavation (Figure 10).

Both methods are described in detail in most rock mechanics text books.

These rock classification methods have been derived in harder rocks and place emphasis on joint properties. Consequently they are not widely used in coal mining, where there can be large numbers of weakness planes of several types, and in addition intact rock strength may be much lower. NIOSH in the USA has, however, recently developed a design method for coal mines based on rock classification and taking into account stress levels (Mark 2000).

3 Computer modelling

Modelling as a support design technique means simulating the rock material, its behaviour under load, and the action of the supports. In the past plaster scale models were constructed for this purpose, but these have been replaced by computer numerical modelling which is now widely used. The continuing increase in the power and speed of microcomputers, together with developments in computer numerical modelling packages, means that realistic 2-D or even 3-D simulations of rock support problems can be run on desktop computers, although this work very much remains the province of the specialist.

Numerical modelling packages have been specifically developed for rock mechanics applications. For harder well-jointed rocks, the discrete element method allows simulation of an assemblage of blocks. Alternatively the finite element method is well established providing elastic behaviour can be assumed. For softer rocks such as coal bearing strata, the explicit finite difference method is usually preferred as it allows large displacements and non elastic behaviour to be simulated more easily (Figure 11).

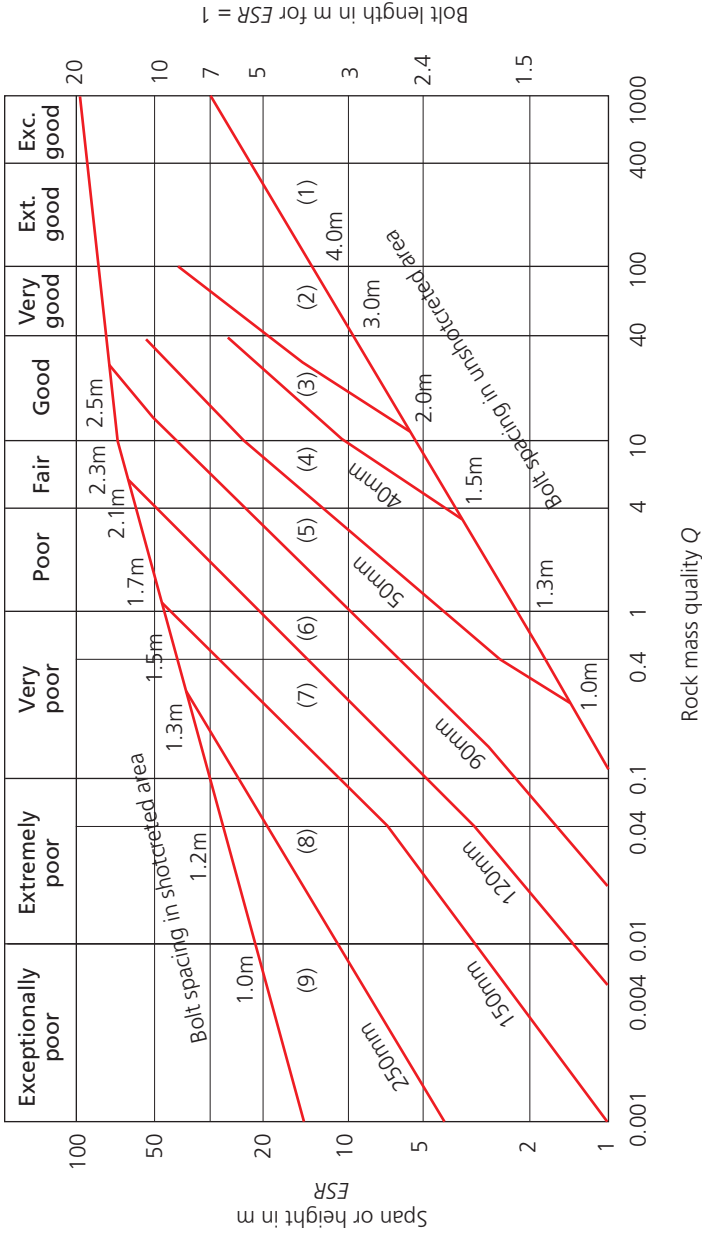


Figure 10 Support guidelines for the 'Q' system (after Grimstad and Barton 1993)

ESR = Excavation support ratio is between 1 and 5 depending on excavation type
 Shotcrete thickness shown in millimetres (red lines)

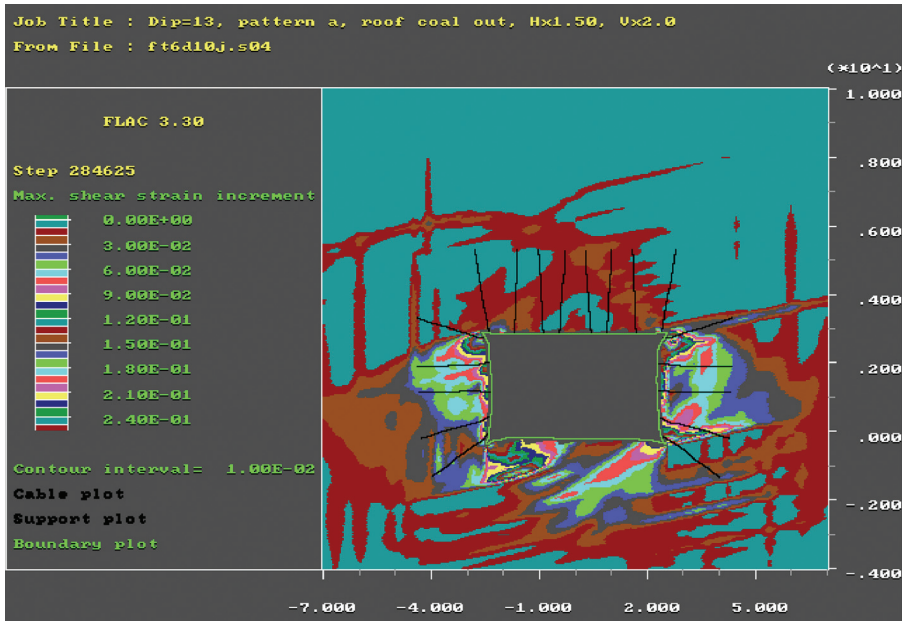


Figure 11 Computer model of a rockbolted mine roadway

Computer modelling can be a very powerful design tool allowing extensive parametric or ‘what if?’ studies to be undertaken. However three basic requirements have been identified as necessary for effective design using this method.

- 1 The model must be capable of properly simulating the rock behaviour and failure mechanisms.
- 2 Material properties and initial stress levels should be known in detail, preferably from site measurements.
- 3 Model output should be validated by comparing measured parameters such as rock displacements and rockbolt loads with model predictions.

By no means all modelling work meets these requirements, as they add considerably to the difficulty and cost. However if they are met, numerical modelling is one of the most reliable design methods available.

4 Observational design

Observational design means design by measurement, a technique which is increasingly being used in both mining and civil engineering. With this system an initial design is completed using available information and the design is then modified during construction, based on the information obtained from monitoring key parameters. A good example of this technique in tunnelling is the New Austrian Tunnelling Method (NATM) which usually makes use of rockbolts and shotcrete as support. The timing of support application and thickness of shotcrete applied is varied, depending on tunnel closure rates and support loads. To use this system it is important that closure is progressive and that additional support can be installed in good time.

Observational design applied to rockbolt support in coal mining was developed in Australia and adopted by British Coal and is now incorporated in UK coal industry guidance (HSE 1996). The system makes use of data from borehole extensometers and strain gauged rockbolts to confirm support effectiveness. Additional support is installed if roof movement exceeds predefined action levels.

Coal mining conditions are generally suitable for the application of observational design techniques because deformation of rockbolted coal mine strata occurs relatively slowly, giving time for extra support to be installed, and the flexibility of mining systems usually allows later installation of additional support without seriously affecting mining production. This method is likely to spread to other mines with generally similar conditions, because it optimises the level of support installed whilst maintaining a high level of safety.

Instrumentation and monitoring

Monitoring of rockbolt performance after installation is important to ensure safety and can also be used to optimise

the design, as described above. The range of instruments available for this include closure meters, several kinds of borehole extensometers from simple visual 'telltales' to multi-anchor types, with remote reading versions available, and strain-gauged rockbolts (Figures 12 & 13). Where monitoring is used to determine the required level of support, as in the observational design method, the responsibilities of personnel involved, the required monitoring procedures, additional supporting actions and the trigger levels at which the extra support should be installed, should all be specified.

Optimising support patterns

In designing roof bolt support systems several factors can be varied to aid the designer in achieving the optimum solution. These are:

- 1 bolting material properties;
- 2 length of bolt;
- 3 bolt annulus, bolt profile and borehole wall condition;
- 4 diameter of bolt;
- 5 bolting density;
- 6 bolt orientation;
- 7 bolt tension.

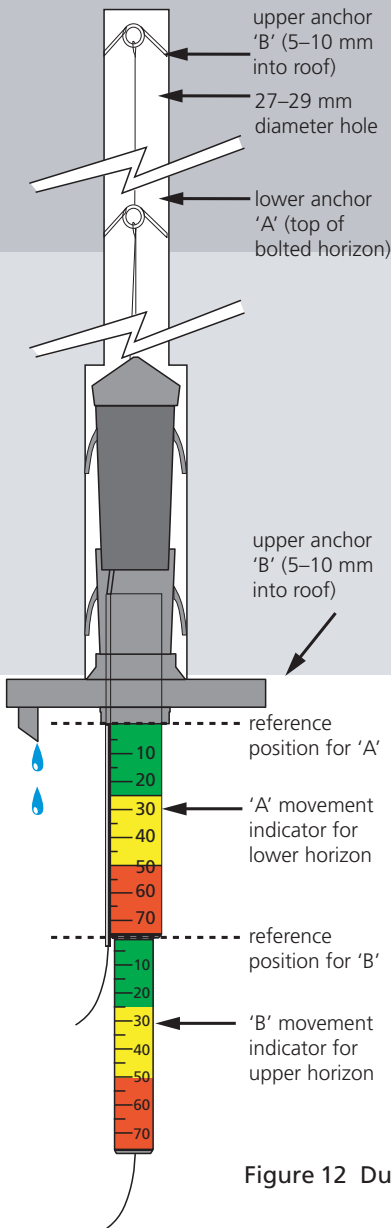


Figure 12 Dual height telltale

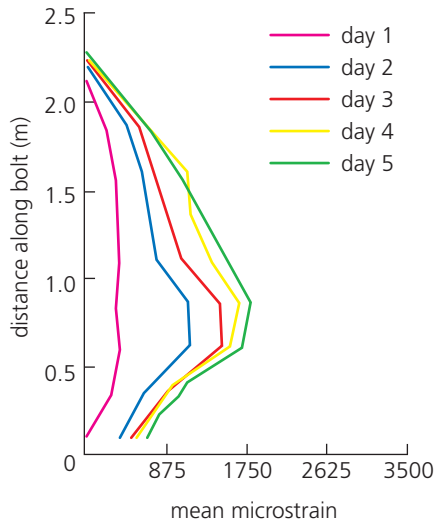
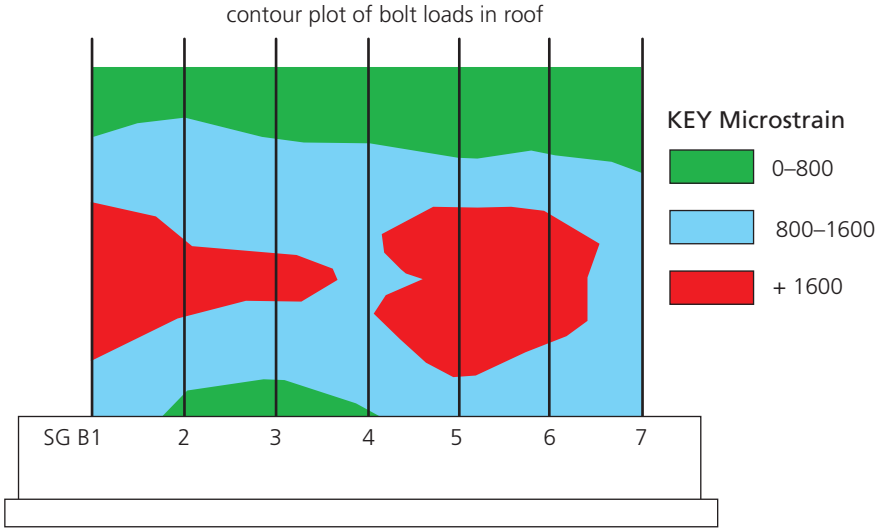


Figure 13 Typical example of strain gauged bolt data

1 Bolting material properties

The vast majority of bolts are made of steel. Originally bolts were formed from standard rebar but are now usually of higher specification in order to maximise yield strength and elongation. Threads are generally rolled rather than cut to give the threaded portion a similar strength to the rest of the bolt. Galvanised or stainless steel may be used where corrosion protection is desired. In addition to rigid bolts, flexible types made from steel wires are available, usually in the form of a twisted strand. These are used where the required bolt length is not achievable with a rigid bolt. The most common alternative to steel as a bolt material is glass-reinforced plastic. These bolts are lightweight, corrosion resistant and can have a high strength in tension. They are not usually used as sole support because of their less favourable post yield behaviour compared with steel.

The main choice of grouting medium is between polyester resins and cementitious grouts. Cement grouts are strong and stiff, but the big advantage of polyester resin is that it sets rapidly and achieves useful strength in less than one hour, compared with up to three days for cementitious materials. In capsule form it makes bolt installation straightforward and is

Rotary telltale.





more 'foolproof' than cement grouts which can be seriously weakened if mixed with excess water.

Reading dual height telltale.

2 Length of bolt

The length of the bolt used can vary from less than one metre up to several metres, either single rigid units, coupled rigid units or flexible units being used. Maximum length may be constrained by operational considerations such as accessibility, hole alignment and installation method.

The choice of bolt length is influenced primarily by conditions. If the rock mass is largely self-supporting, the role of the bolts may be to provide 'skin support', preventing spalling of the immediate roof. Short bolts may then be adequate, sometimes with mesh to increase area support. As a general rule, bolts of less than 500 mm should not be used. Longer bolts may be required to prevent movement of rock

blocks or to provide active reinforcement of over-stressed and failing roof, and in these cases the required bolt length will be indicated by the design method.

Maximising the rockbolt bond strength allows the length of bolt used to be minimised. The stronger the bond, the shorter the anchorage zone of the bolt and the longer the full resistance zone over which the full bolt strength is available to resist roof movement (Figure 14). This applies where the bolting system is designed to act principally to suspend a weak layer from stronger rock above, and where the bolt is actively resisting movement throughout the reinforced zone.

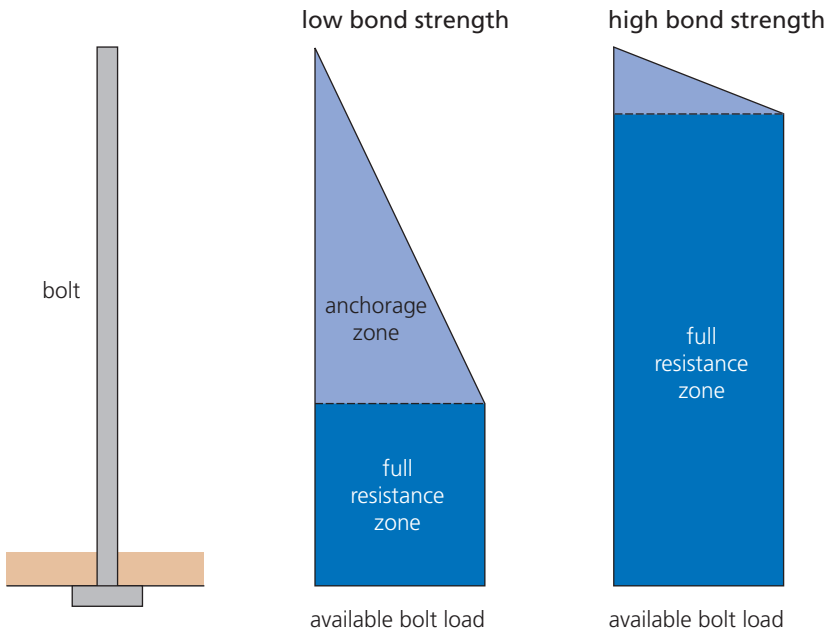


Figure 14 Effect of bond strength on maximum available bolt load for fully bonded rockbolts (after Mark et al. 2002)

3 Bolt annulus, bolt profile and borehole wall condition

Resin grout acts as a mechanical interlock between the bolt and rock and this interlock strength depends on these three basic parameters – bolt annulus, bolt profile and borehole wall condition – which determine the bond strength achieved for a given rock type.

The annulus width (the difference between the bolt and hole radii) has a critical influence on the bond strength achieved. There are two reasons for this: the interlock strength is maximised if the annulus is small and, if the hole is large in relation to the bolt, resin capsule mixing is poor. ‘Finger gloving’ can occur where the capsule is penetrated by the bolt end and spins round with it instead of being properly shredded. Too small an annulus, however, results in difficulty in installing the bolt. The optimum annulus is generally considered to be around 3 mm. This means the drill bit diameter should be around 5 mm bigger than the bolt diameter, because hole diameters are usually about 1–2 mm greater than drill bit diameters. Local standards may specify the maximum bolt annulus to be employed and site tests can be used to confirm hole sizes drilled and bond strengths achieved.

The pattern of ribbing on the bolt also influences the bond strength and profiles which maximise it have been developed by many suppliers. The use of a round bolt cross section is also important to give a consistent annulus width.

The borehole wall condition is important. Borehole rifling significantly increases the bond strength. Some bit designs produce more rifling than others. Spade and button bits generally give a smooth hole compared with twin wing bits which are often designed to maximise rifling. However most bits can be modified to improve rifling if necessary, and operational factors such as drill rotational speed and feed rate are also important in improving hole rifling.

Borehole flushing is also important because if the hole is not properly cleaned the walls remain coated with dust which reduces the bond strength. Water flushing is generally the most effective in cleaning the hole, but halites and some clay-rich rocks are water sensitive and wet flushing cannot be used. Vacuum flushing is the main alternative.

4 Diameter of bolt

This is determined by the strength of the bolt required and by the need to keep the annulus width small. Bolt diameter therefore has to be selected taking into account the diameters available, in relation to achievable drill hole sizes. Within these constraints, the larger the diameter, the higher the bolt yield load resulting, in most circumstances, in less bolts to be installed.

5 Bolting density

The bolting density is the number of bolts installed per unit area. Where the bolting system is designed to act to suspend a weak layer from stronger rock above, the bolt density can be calculated from the weight of rock required to be sustained and the strength of bolts to be used, as below:

bolt density =

$$\frac{\text{weight of roof rock to be supported} \times \text{factor of safety}}{\text{yield strength of rock bolts} \times \text{roof area}}$$

This assumes that the bolt anchorage in the stronger layer allows the full bolt strength to be mobilised, otherwise the bolts would pull out before the yield load was reached. Generally bolts play a more active role in reinforcing the rock and the bolt density is greater than would be required simply to support gravitational loads. Where failure involves

movement of blocks on discontinuities, the bolt density is determined by the need to intersect discontinuities and anchor blocks in position, and therefore depends on discontinuity orientations and spacings.

6 Bolt orientation

Most roof bolts are installed vertically where the opening is essentially rectangular in section. This is logical when the maximum reinforcing effect is required in high stress/low strength environments (e.g. bolting stratified deposits in deeper coal mines). Where the intersection of discontinuities is the primary aim, it may be advantageous to set the bolts off vertical to intercept discontinuity planes. Drill rig operational limitations, for example with combined cutter bolters, sometimes mean that bolts have to be angled slightly off vertical in order to achieve the desired pattern. Where bolts are installed in arched profile openings they are usually deployed in a radial or fan pattern. Sidewall bolts may be horizontal or angled to intercept discontinuities.

7 Bolt tension

Bolt tensioning was originally applied to mechanical point anchor bolts in order to lock the bolt head in position, but is now often used with resin-anchored bolts as this pretensioning effect is believed to improve bolt effectiveness by producing a compression zone within the bolted volume. Chapter 2 includes a section on the technical aspects of bolt tensioning, which concludes that, although tensioning increases the effective stiffness of point anchored systems, at the present time there is disagreement over the desirability of using high tension loads with full column systems. The main benefit of tensioning full column resin-grouted bolts may be that it ensures the bolt plate is set tight to the roof and any open discontinuities are closed.

Types of rockbolts and grouting materials

Types of rockbolts

Mechanically anchored bolts

Mechanically anchored bolts or expansion shell anchors (Figure 15) are a simple, relatively inexpensive and widely available means of providing rock support. This type of bolt gives immediate support after installation. The bolt is engaged by applying torque to the head of the bolt which in turn develops

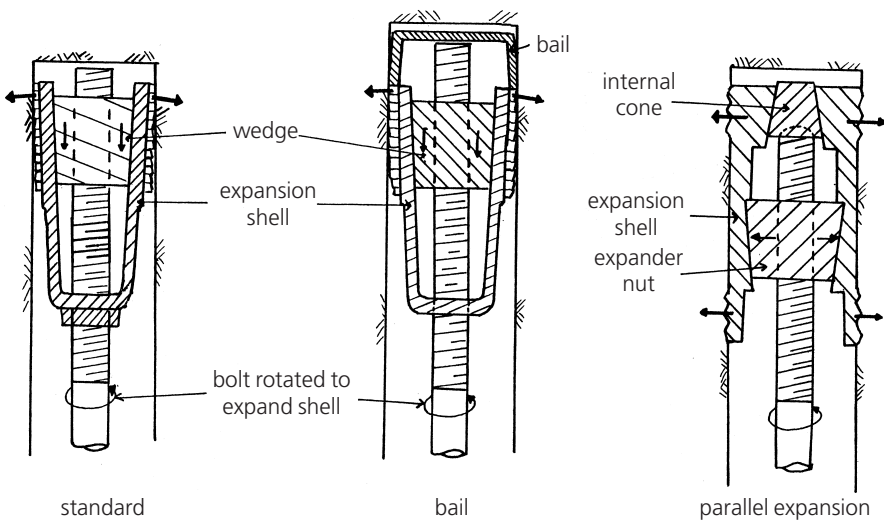


Figure 15 Mechanically anchored bolts or expansion shells

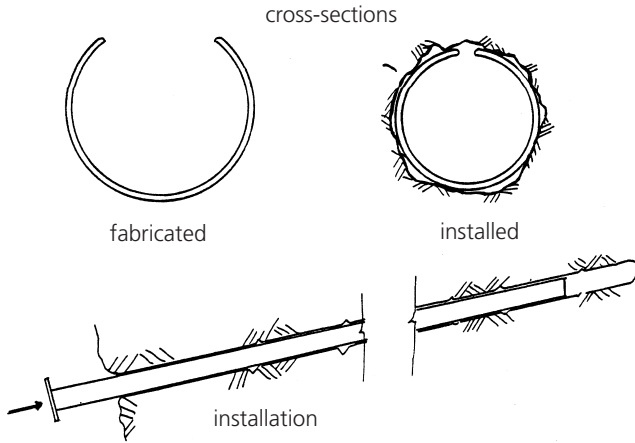


Figure 16 Friction bolts

tension in the bolt shank. These are often post grouted to turn the bolt into a permanent anchor.

These kinds of bolts, however, do have limitations. The nature of the action by which they work limits their use to mines with fairly hard rock conditions. They are also difficult to install reliably as the correct degree of torque must be applied to ensure an adequate load is achieved. Bearing capacity losses also occur through vibration after blasting or when rock spalls from around the bore hole collar through high stresses.

2 Friction bolts

Friction bolts ('split sets') (Figure 16) are widely used in the hard rock mining industry where there is a high degree of bolting mechanisation and strata that are suitable for this medium. As the name implies, these bolts work by utilising the friction generated between the strata and the bolt. Friction bolt anchors are relatively expensive and should not be used for medium/long-term support unless they are protected from corrosion, and even then their life is limited.

3 Expandable friction anchors

Expandable friction anchors (Figure 17) are often used as temporary support in metal mines and tunnels and are generally associated with highly mechanised mining. These anchors are operated by using a high pressure water system to expand the folded bolt against the predrilled hole. The water is then released from the system. These bolts can be susceptible to corrosion and it is becoming common practice to post grout them to prevent this.

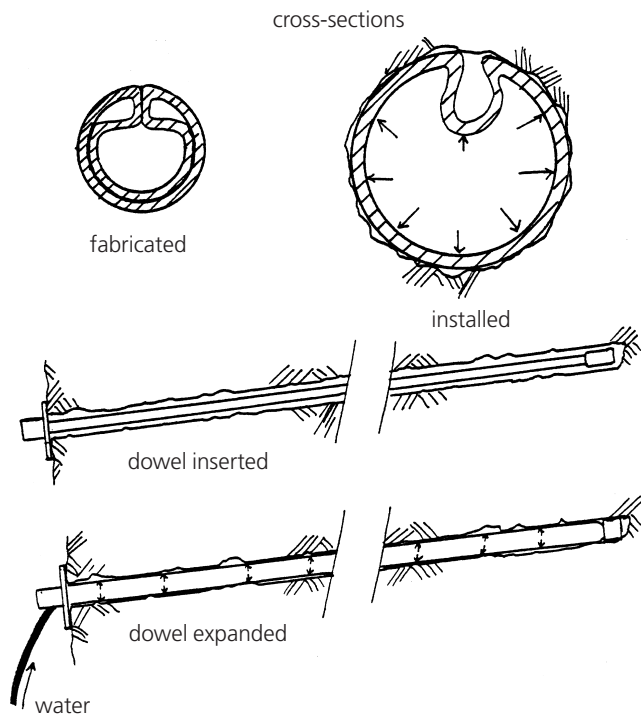


Figure 17 Expandable friction anchors



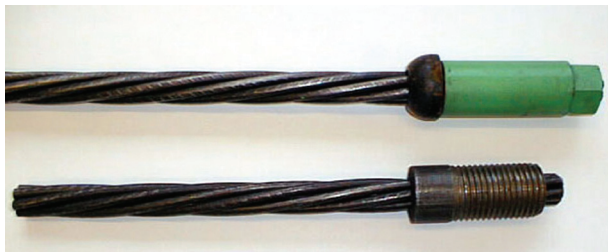
4 Grouted bolts

Steel rockbolts.

Grouted bolts have been widely used for many years. The most commonly used bolt is the grouted steel rebar or thread bar. These bolts are usually used in conjunction with resin or cement grouts and can be used either tensioned or untensioned, for temporary and permanent support in a variety of rock conditions.

Another type of grouted bolt in common use is the grouted cable bolt. There are many different types of cable bolt in use, including flexible cable bolts and birdcage cables. These are usually applied in areas which require secondary support. They can be fully grouted using resin or cement, or point anchored using resin and then post grouted using a pumped cement system.

Flexibolts.

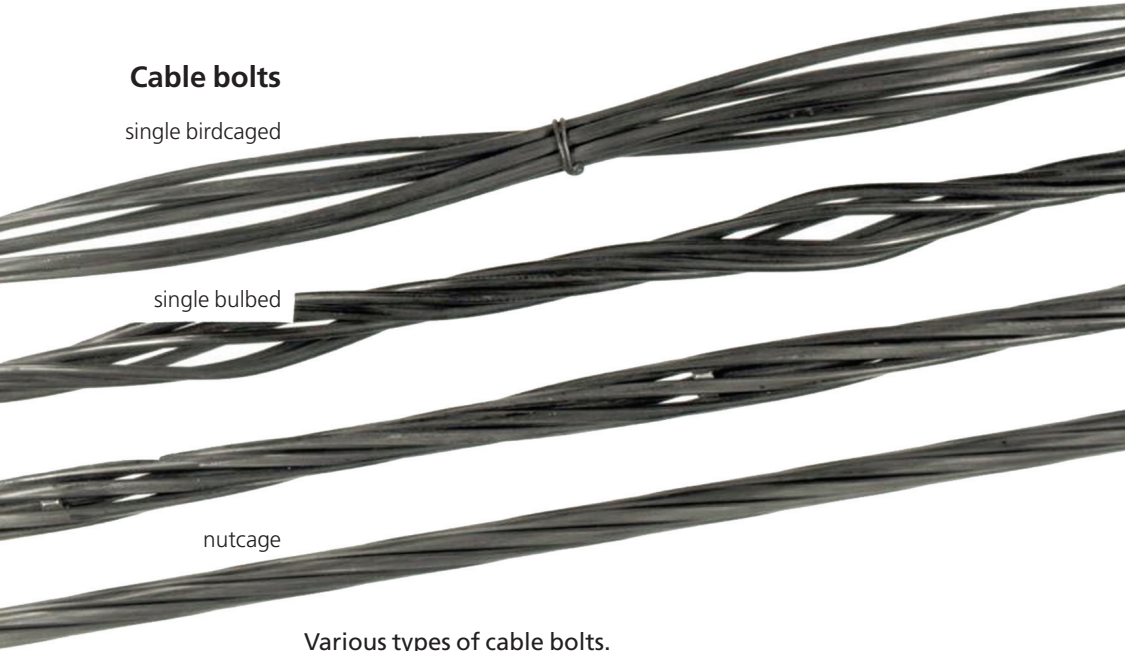


Cable bolts

single birdcaged

single bulbed

nutcage



Various types of cable bolts.

Types of grouting materials

1 Pumped cement grouts

There is a wide range of proprietary pumped cement grouts available for use. These range from simple Portland cement mixes to pre-bagged, formulated grouts such as Minova's Lokset CB® with highly engineered characteristics such as pre- and post-set expansion. These systems are usually batch mixed using simple mixer and pump units, many of which are available.

The nature of the grout allows for good penetration of the strata: full column grouting usually ensuring a good bond between bolt/cable and the strata.

These grouts tend to be relatively low cost but are subject to performance variations, caused mainly by poor discipline in the mixing operation. The uncontrolled addition of excess water to

make pumping easier is a frequent issue. This adversely affects the performance of the grout and therefore the performance of the anchor.

The main application for these type of grouts is for installing secondary support in conjunction with long tendon bolts and birdcage style bolts.

2 Cement capsules

Cement capsules, such as Minova's Capcem[®] cartridge, provide a good alternative to pumped cement grouts. They are relatively low in cost and simple to use. The nature of the cement encapsulation removes some, but not all, of the

Capcem[®] cement capsules.



problems associated with poor mix discipline that sometimes occur with pumped systems. The speed of set may be a limiting factor, as may be the relatively slow strength gain.

The main application for cement capsules is in areas where the stand up time of the strata is long, as is often the case in excavations in massive rock deposits.

3 Resin capsules

Polyester resin capsules such as Minova's Lokset® are probably the most widely used type of grout material. Usually supplied in a two-component capsule, they are easy to use and install. Installation requires some degree of mechanisation and the relationship between hole and bolt size has a large effect on the efficiency of the finished reinforcement. Installation involves spinning the bar or cable through the capsule, the action of which breaks the capsule and mixes the mastic and catalyst together. The resultant mix then hardens, fixing the bolt into the hole.

Most capsule manufacturers offer a range of sizes and set times that can be tailored to suit the needs of the bolting system in place and local strata conditions. This means that resin capsules offer a flexible solution to almost all bolting problems. As the size and speed of the capsule can be altered, it allows for a very flexible bolting regime which can be tailored to meet nearly all bolting situations.

The ability to change the speed of set and use different set times in the same hole makes the resin cartridge ideal for use where post-tensioned systems are required. Some manufacturers also produce capsules such as the Lokset

Lokset® resin capsules.

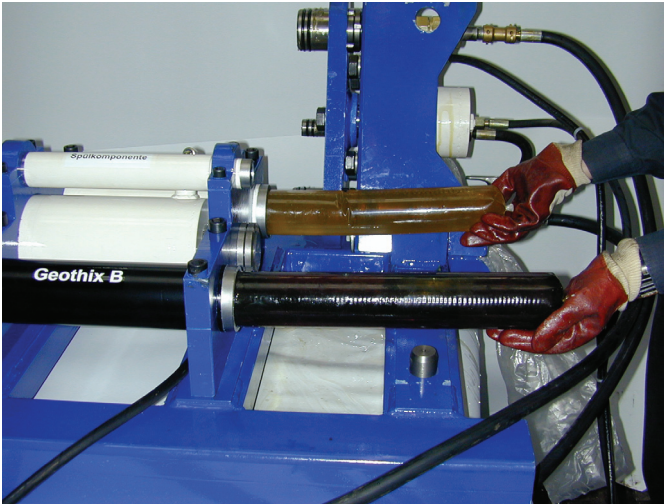


'Toospeedie'[®] with two speeds of resin in a single capsule. This enables reduced handling of materials underground.

4 Pumped resins (PUR, epoxy, polyester)

In some places the use of pumped resins for anchoring has become commonplace. These are often used in conjunction with self-drilling anchors such as Wiborex[®], and are currently used mainly for consolidating broken and friable ground in conjunction with PUR grouts such as Bevedan/Bevedol[®].

Thixotropic pumped resins and grouts such as Geothix[®] and Wilthix[®] are also available for use with long tendon bolts. The hole is filled with grout and the thixotropic nature of the grout allows the tendon to be inserted into the hole.



Geothix[®] pump.

Guide to the use of resin-grouted rockbolts

Description

Resin capsules usually consist of a two-component polyester resin system packaged in a film and separated by a physical barrier (Figure 18). The polyester-based mastic comprises polyester resin and fillers in one compartment, and a paste comprising an organic peroxide and fillers in the other. This physical barrier is broken and the components mixed together by the action of spinning the anchoring element through the resin cartridge. The rotation of the bolt during installation ruptures the capsule, shreds the skin and mixes the two components, causing a chemical reaction and transforming the resin mastic into a solid. Once the two components are mixed, the resin begins to cross-link and as a result hardens to hold the element in the hole giving an effective anchor. The chemistry of the resin can be altered to give different gel and set times which allows for pretensioning by using two different speeds of resin in the same hole.

The resin within the capsule can be tailored to meet the needs of the local situation by altering the speed, viscosity and mastic to catalyst ratio. This allows ambient operating temperatures and different bolt and combinations to be taken into account. The last factor is important as it ensures intimate mixing of the resin base and catalyst components when the anchoring element is spun through it. If the two components are not mixed well, the cross-linking process to harden the resin will not be sufficient to provide an effective anchor.

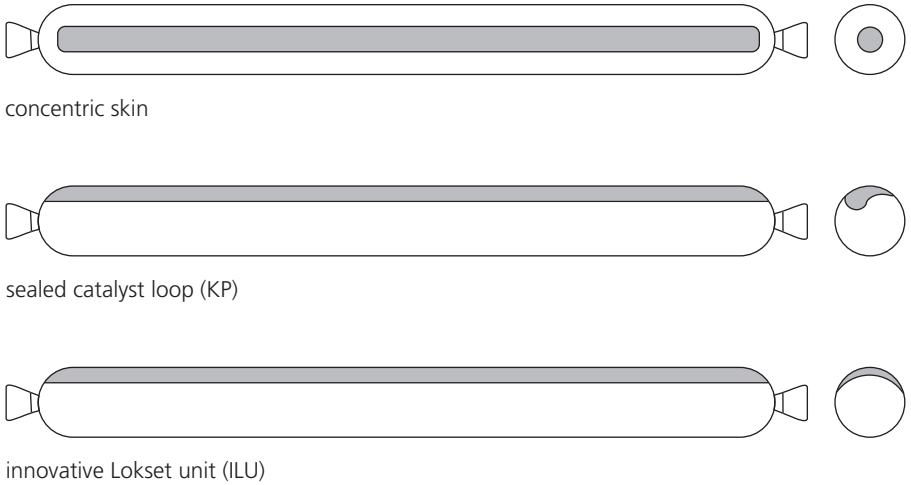


Figure 18 Various resin capsule configurations

Definitions and manufacturers' recommendations

Gel time

When the polyester resin mastic and organic peroxide catalyst are mixed at the correct ratio, the resin begins to cross-link, causing the resin to harden. The **gel time** is deemed to be the time after which any further mixing would lead to damage being done to the set resin causing a loss of strength. The Lokset® 'Spin to Stall' system, developed by Minova, has been designed in such a way that over spinning is eliminated by means of a specially formulated resin and a torque-limiting device on the bolt.

Set time

The **set time** is the time at which the mixed system has reached eighty per cent of its ultimate strength.

Cure time

The **cure time** is the time taken to reach its ultimate strength.

Compressive strength

Most rockbolting standards indicate a minimum **compressive strength** required for the resin components. BS 7861:pt 1, for example, requires a minimum compressive strength of 80 MPa at no longer than 24 hours.

Spin time

The **spin time** is the length of time for which the bolt must be spun to ensure an effective mix of the two components within the capsule. It also helps to ensure that the film around the capsule is adequately destroyed. It is important that this time is not exceeded as spinning through the gel of the resin will cause damage to the system, leading to an inefficient or even useless anchor. Whilst this is the case for most systems, there have been developments made recently that eliminate the risk of over spinning. The Lokset® 'Spin to Stall', as mentioned above, has been designed so that the bolt cannot be over spun and this reduces the risk of damage to the resin anchoring medium.

Hold time

The **hold time** is the approximate length of time that the operator must wait after spinning before the bolt can be tensioned or the bolter removed from the bolt. Tightening must never be attempted before this as damage to the resin may occur.

Many manufacturers indicate spin times and hold times for their resin capsules and it is these times which are of most use to the miner underground.

As the reaction taking place when the two components in the resin capsule are mixed is temperature dependent, it is highly recommended that trials be performed in conjunction with the manufacturer to ascertain the most appropriate operating procedures for the location. This will allow the manufacturer to recommend a capsule that best suits the local conditions. Figure 19 shows the effect of reduced temperatures on reaction and set time.

Considerations that the manufacturer will take into account will include ambient operating temperatures, bolt/hole configuration, length of hole, strata type/conditions, and local regulations. These factors dictate what diameter and length of capsule is needed, what gel time suits the ambient operating temperatures, and what strength, creep and rigidity are required to meet the designed support parameters.

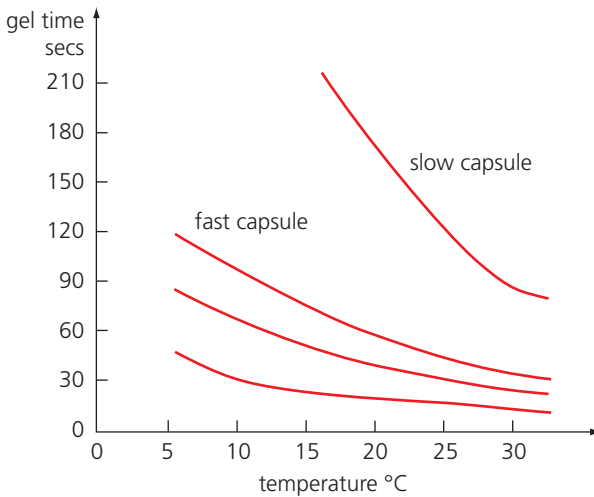


Figure 19 Effect of temperature on setting time

Testing of components and installations

In the past few years the mining industry's expectations and demands with respect to the consistent high quality of products and services has increased. It is essential that all components involved in the roof bolting process are carefully tested and controlled to ensure that all are suitable for use. There are many different standards for rockbolting consumables (e.g. BS 7861, ASTM F432-95), each one applying to a specific region. These standards are usually drawn up to suit the conditions found in that region and it may be that consumables that pass in one region are not suitable in another.

Laboratory testing

All manufacturers of rockbolting consumables should have conducted exhaustive research programs to ensure that the product reaches the desired minimum standard. They should also carry out quality control tests to ensure that the standard is maintained in manufacture, and preferably possess an internationally recognised quality system certification or at least aspire towards it. These tests often include gel time and compressive strength tests to ensure that the local requirements are met.

Storage

Correct storage of resin capsules is essential to ensure effective performance. They must be stored undercover in a cool, dry place and out of direct sunlight at all times. Ideally they should be stored underground or in a cool room as soon as possible after receipt. Insulated cool rooms with double entry (in and out doors) and air conditioning/refrigeration units are strongly recommended. The next best storage method is to store underground (where temperatures in warmer climates can be cooler than on the surface) immediately after receipt.

- Suggested shelf life is four months when stored between 20 to 25°C.
- Storage at higher temperatures such as 35°C will reduce the shelf life to approx 2–3 months.
- Storage at lower temperatures will increase the shelf life: storage at 10°C, for instance, will increase shelf life to approx 5–6 months and at 0–3°C to approx 6–8 months.
- Stock rotation must be practised – i.e. the oldest material should be used first.

Only quantities should be ordered sufficient for four weeks' usage to avoid the expiry date being exceeded before use.

Storage at high temperatures (above 25°C) will result in the capsule mastic thickening up prematurely and consequently the capsules will be harder to penetrate. (The capsules may become limp and floppy and hence difficult to handle when placing in the bolthole.) The first signs of this phenomenon are when nuts break out early and the back of the hole is not reached. To combat this, often operators may push through the resin without spinning (in an attempt to reach the back of the hole) and then spin when the back of the hole is reached, or commence spinning half-way through the capsule.

The capsule mastic thickening should not, in itself, cause a weaker bond if the correct installation procedures are followed and the back of hole is reached: with maximum spin the bond strength may actually be improved. Even with storage at ambient temperature (20–25°C) the capsule mastic will gradually thicken and after approximately four months, some machines, such as hand-held rigs where air pressures are poor, may experience problems. In general, the higher thrust hydraulic bolting rigs in common use today should not experience these problems with old capsules.

The shelf life is a guideline only, and will depend on the storage conditions and the type of equipment the mine possesses.

If there is any doubt as to the performance of the capsules that have exceeded their expiry date, then short encapsulation

pull tests (see below) should be conducted to verify load transfer properties. If these meet the mine requirements, and the back of the hole can be reached whilst spinning through the entire length of the capsule, then the capsules should perform satisfactorily. Manufacturers are usually willing to perform their own in-house laboratory tests on the capsules.

Short encapsulation pull test

Most of the recognised standards recommend a short encapsulation pull test to ensure that the chosen consumables are suitable for use. Whilst methods used in different locations may vary, the general principle is to test the consumables to ascertain the performance that can be achieved rather than testing to destruction, which is usually only an indication of the bolt strength. For example, the short encapsulation test allows an in situ measurement of the bolt/resin/rock at various roof horizons to be made and thus allows the relationship between the three parameters to be established. A full column test to destruction, unless the installation is very poor, will only show the failure load for the bolt.

As the short encapsulation pull test is performed underground in the conditions prevalent in the mine, it is a very good example as to how the bolt/resin/rock system will perform.

A series of holes should be drilled to various depths to ensure that the bolting system will be adequate in all the different strata layers found in the bolting area. Bolts are then installed into the hole using a shortened resin capsule the length of which has been previously calculated to give a bonded length of not more than 300 mm.

Using calibrated pull test equipment, trained operators and the appropriate safety procedures, the resulting bolt should then be pulled no sooner than one hour and no later than 24 hours after installation. This is to ensure that the resin anchoring the bolt has sufficient time to gain strength and that



no roof movement has mechanically locked the bolt into place giving a false reading.

Short encapsulation pull test.

Location and methods

The tests should be done as close to the face of the heading as possible and a section of roof should be chosen which is clean and not subject to spalling. Test bolts should not be installed through mesh or straps and should be placed at least 300 mm apart with bolts of the same length being separated by at least one metre.

Method using reamed hole

The test hole should be drilled to the top of the test horizon using the required bit and then reamed out to a larger diameter to within 300 mm of the hole depth. This ensures an accurate encapsulation test.

The capsule should be shortened by using a cable tie to shorten the capsule to give sufficient resin to allow for a 300 mm bond length, with the excess capsule being removed by cutting the waste away.

The required length of capsule can be calculated using the following equation (where d = diameter):

$$\text{capsule length} = \frac{(\text{hole } d^2 - \text{bolt } d^2)}{\text{capsule } d^2} \times \text{encapsulated length}$$

Once the capsule has been clipped, carefully insert the shortened capsule into the hole ensuring that it does not get damaged on the lip between the test hole and the over-reamed section.

Method using a non-reamed hole

Local strata conditions may dictate that the above method is not possible. This is usually when drilling weak strata such as mudstone and flushing with water. The flushing water may push a mixture of mudstone and water into the test hole. This would cause a reduction in the efficiency of the mechanical lock between resin and rock, leading to spurious test results.

In this case the hole should be drilled to the desired length using a standard bit. The diameter of the hole, the bolt and the capsule should be measured. This can be used to determine the exact length of resin capsule needed to provide a 300 mm bond length.

$$\text{capsule length} = \frac{(\text{hole } d^2 - \text{bolt } d^2)}{\text{capsule } d^2} \times \text{encapsulated length}$$

Bolt installation

Once the holes have been prepared and the capsule clipped to the correct length the bolt can be installed.

- Insert the capsule and bolt and push by hand until the capsule reaches the back of the hole and the bolt is resting beneath the capsule.
- Raise the bolting machine to the bolt and engage.
- Thrust and spin the bolt to the back of the hole taking 3–5 seconds to penetrate the capsule.
- On reaching the back of the hole spin the bolt for a further 5 seconds.
- Wait for the hold time recommended by the manufacturer and then lower the machine.

Pull testing

Bolts should be pulled no sooner than one hour after installation and no later than 24 hours after installation. This ensures that the resin has had time to cure and that no roof movement has locked the bolt into the hole.

The equipment should be assembled as shown in Figure 20. The ram should be aligned along the axis of the hole to ensure that the bolt does not contact the side of the hole or the ram. This is best done by first clearing the area around the hole and then using steel shims wedged between the roof and the bearing plate. Once the assembly is fully aligned, the stem of the dial gauge is located into the indent on the end of the pull bar so that it is also in line with the axis of the bolt, and the gauge is securely anchored.

The load should be applied slowly and evenly and without pause. The displacement of the bolt should be noted at 10 kN intervals.

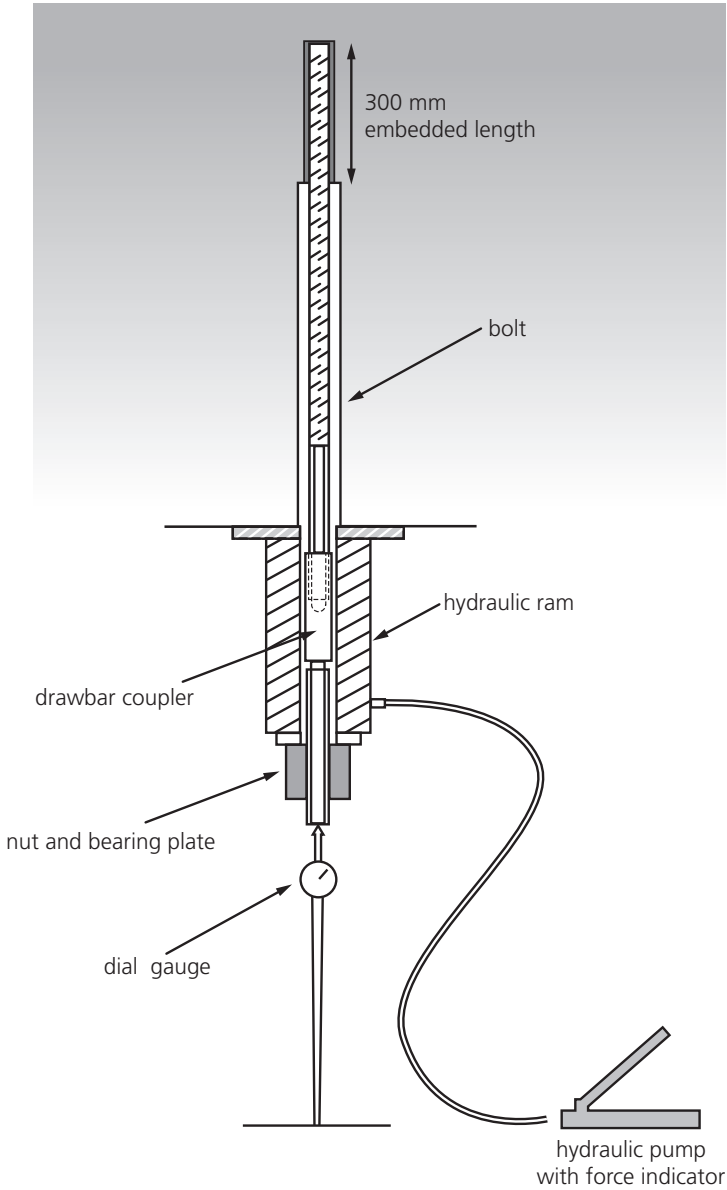


Figure 20 Equipment set up for short encapsulation pull testing

Analysis

In most cases computer software is available to calculate the yield bond stress of the bolt/resin/rock system.

The software is based on the following calculations:

$$\text{Extension in bolt} = \frac{F \times L^F}{E^S \times \Pi \times D^2/4}$$

bond displacement = measured bolt displacement – (bolt extension + drawbar extension)

Where:

F = applied force
(Newtons)

L^F = bolt free length (mm)
= bolt length –
(encapsulated
length + length in pull
bar)

E^S = Young's modulus for
steel (MPa)

D = nominal bolt core
diameter (mm)

A plot of applied force (kN) v
bond displacement (mm)
should be plotted (see Figure
21). The bond strength is the
applied force at which the
slope of the graph falls below
20 kN/mm.

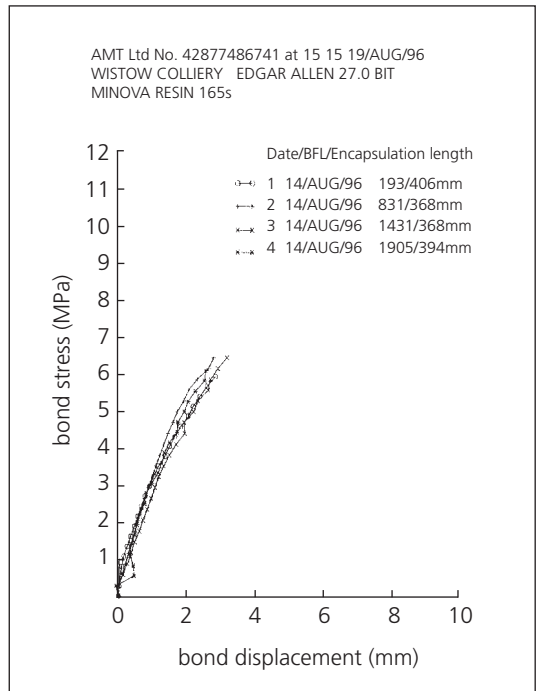


Figure 21 Results of a short encapsulation pull test performed underground

Installation methods and equipment

Installation

A full column resin bolt unit consists simply of a two-part polyester resin-catalyst capsule and a steel bar with a plate and nut. The installation of the unit is carried out as follows.

Step 1

Drill hole to correct diameter and length for bolt being used. Over-drilling will waste resin and reduce the performance of the bolt.

The drill should be marked at the correct depth using tape or some other method (Figure 22). The ideal hole length should be 50–60 mm shorter than the bolt.

With rotary drilling, energy is transmitted to a cutter via a drill steel, which rotates and presses the drill bit to the cutting face. The cutting edge exerts a pressure against the rock and chippings are broken loose.

Drill bit performance is dependent on correct roof bolting machine settings and the correct operation of the bolter. Improper settings contribute more to poor bit performance and excessive wear than any other factor.

The rotation speed and thrust settings must be set for the strata conditions on site, then continually checked to obtain maximum performance from the bit.

For wet drilling in a hard roof, the general rule is to increase thrust and reduce rotation speed. In a soft roof the reverse is true: reduce thrust and increase rotation speed.

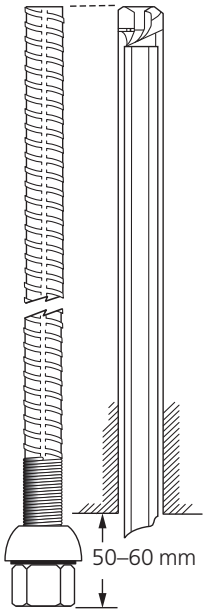


Figure 22
Marking the drill

Alignment

Drilling alignment is the single most crucial aspect of drilling. After collaring the hole it is vital that alignment with the drill pod is checked and adjusted as required.

Correct alignment:

- maintains the drilling forces/energy travelling in a straight line;
- improves drilling speeds/times;
- enables strata support to work as designed.

Incorrect alignment:

- (and the resulting misalignment of holes) compromises the design strength of strata support;
- can lead to difficulty in installing bolts;
- accelerates wear on drilling components;
- directly leads to breakages of drill steels.

Diameter

It is essential that the correct hole diameter is drilled. An optimal diametric difference between bolt and hole is between 4 and 10 mm. Larger diameters can be used but this can result in:

- longer resin cure times which must be allowed for before the bolt can be pretensioned; in this case often the resin is described as being too slow;
- longer resin cure times due to intermixing of the Slow into the Fast components (e.g. in the TooSpeedie® capsule);
- less efficient mixing of the two components in the capsule, poor shredding of capsule film, and possible 'finger gloving';
- a reduction in load transfer (pull out strength);
- a reduction in encapsulation length (e.g. a 29 mm diameter hole results in a forty per cent reduction in encapsulation compared to a 27 mm bit).

If diameters outside the recommended range are considered, then pull tests must be performed to verify that required load strengths are achieved.

Also many bits, in particular strata, will in fact drill a larger hole diameter than the actual bit diameter. It is recommended that the internal hole diameter is measured to within 0.1 mm from top to bottom with a borehole micrometer.

Possible reasons for larger diameter holes are:

- incorrect or out-of-specification drill bit;
- change in strata;
- starter bit;
- incorrect feed/spin settings;
- too much thrust;
- too much play in the drill string.

Length

The hole should then be drilled to the correct length.

The bolt should bottom in the hole leaving sufficient thread protruding to accommodate the nut, plate, domed ball washer etc. The ideal hole length should be 50–60 mm shorter than the bolt. Often a mark or tape can be attached to the drill steel to act as a guide for the hole depth. It is a good idea to measure the length of the hole from time to time with a tape measure. Correct flushing procedures must be used.

If the hole is too deep (overdrilled) then:

- part of the resin capsule will not be penetrated or mixed by the bolt causing a reduction in strength;
- there may be insufficient thread left on the bolt to tighten the nut, so tension is reduced and load carrying ability;
- there may be a reduction in encapsulation length.

Possible reasons for overdrilled holes are:

- incorrect length drill steel;
- change in bolt length but drill steel not changed or left in panel;
- rig pushed in too far;
- marker moving or being worn away.

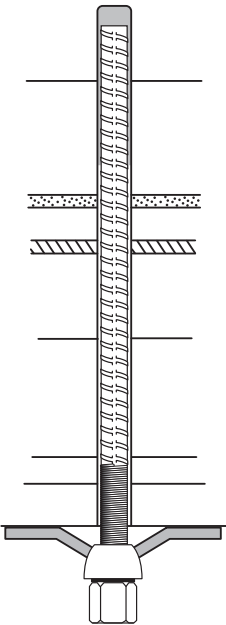


Figure 23
Overdrilled
holes

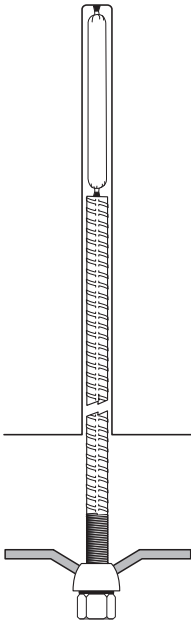
If the hole is too short (underdrilled) then:

- the designed bolt horizon may not be reached with potential partings left unsupported;
- little or no thread remains to tighten the bolt;
- there is the possibility of resin splashing operators;
- the bolt may protrude too far into the excavation causing injury to personnel.

Possible causes of underdrilled holes are:

- incorrect length drill steel;
- a change in bolt length but not the drill steel, or the old bolts/steels may not have been removed from the panel;
- a change in roof height so the machine is unable to drill as deep;
- insufficient depth drilled.

Step 2



Install the prescribed number of capsules of the correct diameter and length to fully grout the bolt in the borehole (Figure 25). Table 1 gives an indication of how many capsules are required for a given bond length. Check that the use by date on the box label has not expired. If a tensioned system is being used, the order of insertion is important: the faster resin capsule/portion must be inserted first. (Never insert upside down.) At this point any accessory required can be selected (e.g. Plastic hat, installer etc). Insert the capsule and push it gently all the way to

Figure 25
Capsule installation

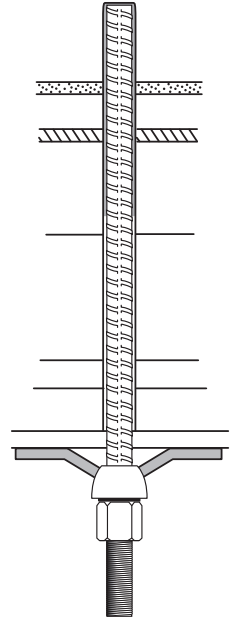


Figure 24
Underdrilled holes

Table 1 Average length of bond obtained per capsule

Bolt Diameter/mm	Capsule Diameter/mm	Average hole diameter/mm				
		25	28	30	32	35
20	20	88.9	52			
	24	128	75	57.6	46	
	28			78.4	63	
22	20	142	67	48	37	
	24		96	69	53	39
	28			94	73	53
25	20		126	73	50	33
	24		181	105	72	48
	28			143	98	65

Figures based on an assumed capsule length of 500 mm. In fractured or porous strata the bond length will be reduced.

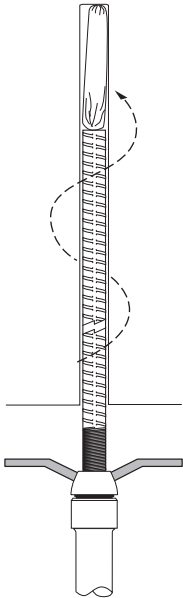


Figure 26
Rotation of capsule

the top of the hole using the bolt or insertion device if available.

Step 3

Connect the bolt to the spinning device such as a dolly/spanner. Forcibly spin the bolt into the hole at the same time rotating for the manufacturer's recommended time at high rpm throughout the entire length of the capsule (Figure 26). When the back of the hole is reached a further 2–4 seconds' spinning will suffice to ensure complete mixing. This results in shredding of the capsules and mixing the resin and catalyst. Note the spin time will vary with temperature and must always be less than the resin gel time for the operational temperature. It is essential the bolt is pushed and spun to the back of the hole before mixing is completed.

The manufacturer's recommended spin time must not be exceeded as this will result in damage to the setting resin, leading to an ineffective and dangerous bolt.

Step 4

Hold bolt in place without movement until resin has gelled sufficiently to hold the bolt in the hole. Retract the spinning device.

Step 5

Attach washer and nut, if not attached during installation. (It is possible to install a complete unit in one operation.) In most modern bolting systems the plate and washer are added prior to installation.

Pretensioned systems require the bolt to be tightened to a predetermined level. This is usually done by means of a torque-limiting device which allows the nut to tighten up the bolt at a predetermined load. These devices include shear pins, chemdrive nuts, nuts with crimped inserts and modified thread sections.

Once the resin has reached a sufficient strength, usually determined by the manufacturer's spin and hold times, the nut is spun causing it to break the torque-limiting device and move up the thread, imparting tension into the bolt via the threaded section.

The hold time is the approximate time allowed after completion of the spin time before bolt tensioning is attempted. The times listed on the box are an indication only and may vary with temperature, mining conditions, equipment, hole:bolt annulus, age and storage conditions of resin capsules. Each mine site and area should be evaluated to determine optimum installation parameters.

Fault finding and solving

Sometimes the bolt cannot be inserted to the correct depth. This can be due to:

- low air pressure where hand-held rigs are used;
- bit wear resulting in a narrower hole;

- oversize bolt (diameter);
- premature nut break out: this could be a result of nuts being at the lower end of the break out specification, misaligned drill rigs, angled holes or high rig feed rate;
- hole closure;
- high temperatures (ambient and/or resin);
- old/out-of-date resin.

Sometimes the resin appears to be too slow. This can be due to:

- cracks, partings, cleats or fissures in the strata resulting in resin loss and an apparent slow setting anchor. Checking the encapsulation length with a tape measure and comparing with the theoretical length is usually a good indicator of resin loss.

One answer to roof partings is to bolt closer to the face and as soon as possible after extraction. Additional or multiple capsules may appear to solve the problem, but no assurances can be given for the uniformity of the installation, so periodic load testing should be undertaken;

- larger drill bits resulting in larger holes and an apparent slower set;
- pushing the bolt without spinning;
- intermixing of Slow into Fast set components;
- low temperatures (ambient and/or resin);
- large annular gaps (> 7mm);
- a machine where the torque load level is set too high;
- the nut break out torque is too high.

Should the resin appear to be going off too fast or too slow, then the reason for this will invariably be due to one or a combination of the reasons listed above. Stop bolting, report to your supervisor and investigate.

Occasionally the capsule may 'finger glove' around the bolt. Finger gloving can occur in overdrilled holes or in holes where the diametric difference between the bar and hole is large. The reinforcement element pushes up the middle of the capsule

without breaking the outer skin. This results in a reduced contact between the cured resin and the strata, leading to a reduction in effectiveness of the system. As previously highlighted, resin bolts are spun and pushed simultaneously to the back of the hole during installation to mix the resin and catalyst components and to assist in shredding the capsule skin to avoid gloving. So to reduce the gloving phenomenon:

- The annular gap between the bolt and the bolt hole must not be too large (4–7 mm). This could be caused by a large diameter hole or a ‘thinner’ bolt.
- Check the bolt is spun through the entire length of the resin capsule. If the bolt is pushed (without spinning) well through the resin capsule before rotation commences, some of the capsule skin may be pushed to the top of the hole without effective shredding, and/or finger gloving could occur.
- Ensure drill rpm is high during bolt installation.
- Ensure bolt rotation continues when the bolt reaches the back of the hole for 2–4 seconds.

If the above phenomenon is suspected, then bolt pull out tests should be performed to verify required pull loads are achieved.

Bolting machines

Mechanised mobile roof bolters

The mechanisation of rockbolting was a milestone in the development of this support method. In fully mechanised rockbolting the operator never has to go under an unsupported roof during the operation. All functions – drilling, resin feed, bolt installation – can be performed safely under the protection of a canopy. The mechanised functions give a bolting capacity of eight to twelve bolts per hour and can be carried out by one operator.

Semi-mechanised roof bolters, where drilling and bolt installation is carried out remotely, are still in the majority. The



resin is placed in the hole by hand, followed by positioning of the bolt.

Leg-mounted bolters

Since the 1980s a large amount of development has taken place in bolting using hand-held, leg-mounted units. These units are relatively light in weight and can be easily moved and handled. Improvements in manufacturing techniques mean that the units are an effective way of drilling and installing roof bolts.

These units are available both pneumatically and hydraulically powered, making them a very versatile tool in the roof bolting cycle.

Mast-mounted bolting machines

These are the first step to mechanising the installation of roof bolts. Usually mounted on wheels, they can be manhandled into position and then hydraulically stacked between roof and floor for each bolt installation. The boring machine is power driven up and down the mast. Although extremely versatile and relatively inexpensive, they are slow and cumbersome to move.

A recent development has been low-profile, mast-mounted jackhammer drills for the installation of rockbolts in low stopes



Pneumatic leg-mounted bolting machine – Minova Super Turbo.

OPPOSITE: Fully automated bolting rig.

(less than 1.8 m) such as in the South African gold and platinum mines. Jackhammers must be used as rotary-percussion drilling must be used in the hard rock. At the location of each hole the rig is fixed between the hanging wall and footwall by pneumatic stingers; further pneumatic cylinders are used to elevate the drill itself. Installation of resin-grouted rockbolts with these rigs takes care as the low rotation

Radial rib drill.





speed and torque of the jackhammer makes it less efficient than high-speed purpose-built roof bolters in mixing the resin.

Hand-held bolter.

Hand-held bolting machines

The hand-held boring machine is somewhat limited in installing roof bolts. The thrust to insert the bolt is supplied by the operator or – more usually – operators. The operator is exposed to the roof and tires quickly. These are simple machines and are very flexible. However, the rate of installation is slow, the length of support can be limited, and the operator is still exposed.

The main use for this type of bolter is for installing rib bolts and wooden reinforcement dowels.

Appendix: Examples of international rockbolting practices

USA

1 Regulations

The regulation of mine roof support in the USA is based on the Federal Code of Regulations, Title 30, Part 75.200. Sub Part 75.204 references the attached American Society for Testing Materials publication F432-95, titled 'Standard Specification for Roof and Rock Bolts and Accessories'. The majority of the roof bolting materials used in the USA are manufactured and tested in accordance with the specifications of ASTM F432-95. Any materials not certified may be used with the approval of the Mine Safety and Health Administration's District Manager.

2 Bolting practices

Approximately 100 million fully grouted rebar roof bolts are installed each year in the USA. Eighty per cent of fully grouted rebar are $\frac{5}{8}$ inch (15.8 mm) fully grouted rebar in a 1-inch (25.4 mm) borehole. The lesser used $\frac{3}{4}$ inch (19 mm) fully grouted rebar in a 1 inch (25.4 mm) borehole, maximises resin performance. The former gives only sixty per cent of the resin pull out resistance of the latter. This reduction in resin strength is due to the less than optimal resin mixing associated with the $\frac{3}{8}$ inch (9.5 mm) annulus, defined as the hole diameter minus the bolt diameter. The $\frac{1}{4}$ inch (6.4 mm) annulus maximises the mixing action of the shear stress upon bolt rotation and provides optimum resin mixing.

The dominance of the cost effective $\frac{5}{8}$ inch (15.8 mm) rebar in US coal mines is due to widespread favourable geological conditions, multi-entry mining methods, and the regulatory environment. Those coal mines with immediate roof problems too severe to be controlled with the $\frac{5}{8}$ inch (15.8 mm) bolt, 1 inch (25.4 mm) hole combination are bolted with a fully grouted $\frac{3}{4}$ inch (19 mm) bolt, 1 inch (25.4 mm) hole, which may be post tensioned, or with a combination of mechanically assisted point anchor and cable bolts.

The Eclipse® System was developed by Minova Inc USA to improve the performance of $\frac{5}{8}$ inch (15.8 mm) deformed rebar fully grouted into a 1 inch borehole. A $\frac{1}{8}$ inch (3.2 mm) offset bolt head combined with specially formulated Eclipse Lokset® resin cartridge results in:

- reduced gloving;
- increased mixing efficiency;
- increased pull out strength;
- uniform resin anchorage;
- no cavitation;
- consistent quality mixing to the end of the bolt.

The Eclipse® System was found to reduce finger gloving approximately seventy per cent in laboratory testing. This novel and patented system was test marketed in 2002, through Excel Mining Systems. As of April 2004, one million linear feet of Eclipse® System per month were installed in US coal mines, with the majority in the Illinois Basin.

3 Differences for hard rock, coal and civil

US and Canadian hard rock mines employ a wider variety of bolting methodologies. Grouted rebar has a minor segment of a market dominated by friction and mechanical shells/anchor bolts. The purpose of roof bolting in igneous hard rock mines is to hold the loose key pieces of back in place, permitting movement of the immediate roof under load. Friction anchor

bolts are not employed in layered sedimentary coal measure strata because the rock does not tolerate movement. Igneous strata are generally massive with failure dominated by blast induced fracture systems. The igneous rock can tolerate movement with advance or the face, enabling the cheaper friction methodology to dominate the market. Grouted rebar is the standard methodology in sedimentary strata and a premium methodology used in special conditions in hard rock mines.

4 Installation methods

The vast majority of the grouted and friction roof bolts installed in the USA and Canada are installed with modern hydraulic drilling machines from Fletcher, Joy, Cannon and other specialty equipment manufacturers. Powered by electricity or diesel engines, these machines are generally rubber tyre mounted mobile machines. A few precious metal mines employ pneumatic stoper drills.

Fully grouted rebar is anchored with Minova USA's 20 to 35 speed formulations. Mechanically assisted point anchor systems are grouted with a 50 speed formulation.

5 Design methods and theory for pattern and bolt length plus testing used to trial anchor performance

NIOSH and university researchers have put forward roof bolt selection methodologies. However, roof bolt design is based on historical bolt performance in a given geological setting. Design changes are evolutionary, not revolutionary. Bolt type, strength, and length changes are motivated by recent failures or cost cutting initiatives.

Australia

1 Regulations

Specific mine site strata management plans are compiled by mining/geotechnical engineers. These are then signed off by the mine manager and then approved by local mines department.

2 Bolting practices

Full column bolting is the preferred method in almost all situations in both coal and hard rock. There is occasional point anchor in conglomerate strata.

All coal roof bolts are pretensioned, as are approximately half rib bolts.

Coal primarily uses X grade 21.7 mm core deformed bar in Titan pattern or J profile.

Hard rock primarily uses:

- DSI Posimix – mixing wire wrapped around solid bolt;
- paddle bolts – SCS Secura/Reo bolt, JMA Paddle bolt, DSI Paddle bolt;
- tubular bolts – SCS Jumbolt and DSI Tigerbolt.

3 Differences for hard rock, coal and civil

Typically in coal 27–28 mm drill bits are used in conjunction with 24 mm capsules.

In hard rock 33–35 mm drill bits are used alongside solid bolts, also 24, 26, 30 mm capsules depending on local conditions. Tubular bolts using 44–45 mm bits and 38 mm capsules are common.

4 Installation methods

Installation equipment is typically hydraulic with some pneumatic machines used in the coal mines. Pneumatic

launching of capsules is used in some areas, as is the Quickchem® installation system.

5 Design methods and theory for pattern and bolt length plus testing used to trial anchor performance

Rules of thumb

Minimum roof bolt length is the greatest of:

- twice the bolt spacing;
- three times the block width;
- 0.3 times span for spans < 6 m;
- 0.25 times span for spans 18–30 m;

Cable bolts use the same rule of thumb as for roof bolts and add 2 m to length. Spacing of 1.4 m is the normal economic limit.

Empirical

The use of rock mass classification techniques with empirically based charts are used to identify the appropriate level of support.

Design for specific conditions

Empirical designs are adjusted where possible mechanisms of failure and ground stress conditions are better known and understood.

Testing

Pull testing, both full and short encapsulation is required.

South Africa

1 Regulations

By law, each mine needs to draw up a Code of Practice (COP). This is done by the rock engineer and this is then forwarded to the DME for approval. This COP is mine specific.

2 Bolting practices

In practice at least eight-five per cent of the industry uses a full column system of support. This full column system is then also almost always a pretensioned one.

The other fifteen per cent would be point anchor and this would constitute the small independents that use one capsule of resin to reduce costs. Contractors would use this system as well with their cable anchors. The rest of the hole would then be filled with a cementitious grout.

There are numerous bar types in use in collieries. The popular types in use at present are:

- Step bar (JAE) and DD Bar (DSI): step bars are made in diameters of 18 mm (becoming more popular lately due to price). These are installed in holes drilled with a 23.5 mm bit. The 20 mm bars are installed in holes drilled with 25–28 mm drill bits (Amcoal drills with a 25.6 mm bit).
- Chemical Bar (Videx): typical diameter of 17.4 mm used in conjunction with a 22 or 23.5 mm drill bit.
- rebar (Duraset): supplied in 16 mm and 18 mm diameter.

Minova South Africa has developed the Lokset® ‘Spin to Stall’ system. This system helps to eliminate the effects of operational variables such as ambient temperature and spin speed so that the installation becomes self-timing and self-checking. Minova South Africa formulated a unique resin capsule that combines extremely fast setting with high strength. The special resin is used in combination with a threaded rockbolt and a nut that turns the rockbolt until a predetermined torque is reached, when it breaks free and runs up the thread.

The whole cycle is complete in 9–11 seconds and the amount of thread showing below the nut is a good indication of the success of the installation.

3 Differences for hard rock, coal and civil

The hard rock industry uses GEWI bar, Shepherds crooks, split sets, Hydro bolt, backfill, packs, and mechanicals.

Cable bolts and Gewi bar are predominantly in the civil engineering industry.

All the above would be installed using cement capsules or pumpable grouts. A certain amount of resin is used in the gold mines and more in the platinum mines.

Where the difference comes is that there are multiple blasts in coal mines or continuous cutting by continuous miners etc. Support must be put in on a continuous basis here and therefore speed is required.

4 Installation methods

Ninety-three per cent mechanised and seven per cent hand-held installations.

Mechanised machines are Fletcher, Biz Africa, RHAM, ARO, Klockner Bekorit and the onboard bolters on the Voest and Joy machines.

Hand-held operations with jackhammer at Secunda (previously mentioned). Tshikondeni uses Wombats® primarily for supporting the roof. It also has an onboard system on its coal cutters. All the contractors on the mines use Wombat-type machines, as well as jackhammers for their installations.

The mechanised systems would use 15 or 30 second resin plus the slower resins in the mixed boxes.

Hand-held would use setting times from 60 seconds and higher.

5 Design methods and theory for pattern and bolt length plus testing used to trial anchor performance

Pattern and bolt length is mine specific. This is done in the COP. Tests are also done to get the critical bond length of the resin.

UK

1 Regulations

The Code of Practice is set out by the Health and Safety Commission. Site investigation and geological survey is carried out to ascertain suitability for rockbolting. If deemed suitable, then a bolting plan is drawn up and field trials with extensive monitoring are carried out.

2 Bolting practices

All bolting is done to the 'AT' system. All rockbolts are pretensioned using a fast and slow resin. Rib bolts are generally untensioned.

All consumables must conform to BS 7861:part 1:2002

Supplementary support is usually provided by fully grouted cable bolts where required, although in recent times the use of Megabolts® has become more frequent.

3 Installation methods

Bolts are installed using airleg bolters, on-board multi-bolters or dedicated bolting machines. Issues with vibration white finger have led to the development of 'hands free' bolters which have stinger legs to react between roof and a bolting head to drill the hole and spin the bolt.

Capsules are usually inserted into the hole with the use of plastic launching tubes, but pneumatic launching is coming into use.

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List of illustrations and figures

A typical rockbolted roadway	xv
Rotary telltale	36
Reading dual height telltale	37
Steel rockbolts	45
Flexibolts	45
Various types of cable bolts	46
Capcem® cement capsules	47
Lockset® resin capsules	48
Geothix® pump	49
Short encapsulation	57
Fully automated bolting rig	70
Pneumatic leg-mounted bolting machine – Minova Super Turbo	71
Radial rib drill	72
Hand-held bolter	73
Figure 1a Stress concentration around rectangular And circular openings	5
Figure 1b Concept of stress driven shear failure for Rectangular and circular section openings	6
Figure 2 Rock failure patterns for high and low stress conditions	7
Figure 3 Shear restraint	10
Figure 4 Axial restraint	10
Figure 5a The concept of roof stability through retention of stress (retained stress)	11

Figure 5b	The concept of roof stability through retention of stress (no retained stress)	12
Figure 6	Support of weak roof under high stress conditions	13
Figure 7	Effect of bolt system axial restraint on roof stress level	14
Figure 8	Triaxial test results for carboniferous rocks	23
Figure 9	Analysis of wedge failure using 'unwedge'	29
Figure 10	Support guidelines for the 'Q' system after Grimstad and Barton	31
Figure 11	Computer model of a rockbolted mine roadway	32
Figure 12	Typical example of strain-gauged bolt data	34
Figure 13	Dual height telltale	35
Figure 14	Effect of bond strength on maximum available bolt load for fully bonded rockbolts	38
Figure 15	Mechanically anchored bolts or expansion shells	42
Figure 16	Friction bolts	43
Figure 17	Expandable friction anchors	44
Figure 18	Various resin capsule configurations	51
Figure 19	Effect of temperature on setting time	53
Figure 20	Equipment set up for short encapsulation pull testing	60
Figure 21	Results of a short encapsulation pull test performed underground	61
Figure 22	Marking the drill	62
Figure 23	Overdrilled holes	64
Figure 24	Underdrilled holes	65
Figure 25	Capsule installation	65
Figure 26	Rotation of capsule	66

Index

References in **bold** are to illustrations and diagrams.

American Society for Testing
Materials 74

analysis, of system 61

anchors, expandable friction 44

Angers slate quarries 1

annulus and profile, bolt
39–40

applications, typical 17–19

ARO 80

ASTM F432-95 54, 74

'AT' system 81

Australia iv, v, 4, 24, 28, 33

bolting practices 77

design methods 78

installation methods 77–8

regulations 77

axial restraint 9–10, **14**

backfill 80

Bevedan/Bevedol® 49

Biz Africa 80

block anchorage 9

bolters

leg-mounted 71, 71

mechanised mobile roof
69, **71**

bolting machines 69–73, **73**

bolting rig, fully automated **70**

borehole wall condition

39–40

British Coal 33

BS 7861 52, 54, 81

Bureau of Mines, United
States 2

cable bolts **46**

Canada 75–6

Cannon 76

Capcem® cement capsules
47, **47**

capsules

cement 46, 47–8, **47**

resin 48–9, 50–61, **51**

carboniferous rocks, triaxial
test results **23**

CarboTech SiS iv

Celtite iv

cement

capsules see capsules

grouts, pumped 44–5

injection 2

Portland 46

Charbonnages de France 3

Chemical Bar 79

compressive strength 52

computer modelling 30, 32

corrosion 25–6

cure time 52

DD Bar 79

density, bolting 40–1

design methods 20–1

Australia 78

roof belt support

27–33

South Africa 80

USA and Canada 76

design parameters 21–2

diameter, bolt 40

DSI DD Bar 79

DSI Paddle bolt 77

DSI Posimix 77

DSI Tigerbolt 77

dual height telltale **34, 37**

Duraset Rebar 79

Eclipse Lokset® resin

cartridge 75

Eclipse® System 75

effectiveness, bolting systems
16–17

encapsulation, short, pull test
56–7, **60, 61**

epoxy resins 2, 49

Europe 3, 24

excavation 24–5

Excel Mining Systems 75

Federal Code of Regulations 74

'finger gloving' 39, 68–9, 75

Fletcher 76, 80

flexibolts **45**

France 1, 2, 3

friction bolts 43, **43, 44**

gel time 51

geometry of excavation 24–5

Geothix® 49, **49**

Germany iv, 2, 3

GEWI bar 80

gold mining 72

groundwater 25–6

grouted bolts 45

grouting materials 46–7

grouts, pumped cement 44–5

Health and Safety

Commission 81

hold time 52–3, **53**

Hydro bolt 80

installation 62–7

Australia 77–8

bolt 59

South Africa 80

UK 81

USA and Canada 76

instrumentation 33–4

international rockbolting

practices 74–81

jackhammers 71–3, 80

JAE step bar 79

JMA Paddle bolt, 77

Joy 78, 80

Klebanker 3

Klockner Bekorit 80

laboratory testing 54

leg-mounted bolters 71, **71**

length, bolt 37–8

load transfer 8

- Lokset® iv; *see also* Eclipse, 'Spin to Stall', 'TooSpeedie'
- Lokset CB® 46
- Lokset® resin capsules 48, **48**
- Lokset® 'Spin to Stall' 51, 52
- machines, bolting 69–73
- material properties, bolts 36
- mechanical bolts 80
- mechanically anchored bolts 42–4, **42**
- mechanised mobile roof bolters 69, 71
- Megabolts® 81
- Mine Safety and Health Administration (MSHA) 74
- mines, types
- Australia 77
 - South Africa 80
 - USA and Canada 75–6
- Minova *see* Eclipse® System, Super Turbo
- Minova Inc USA 75, 76
- Minova South Africa 79
- monitoring 33–4
- New Austrian Tunnelling Method (NATM) 33
- NGI 'Q' system 29, **31**
- NIOSH 76
- orientation, bolt 41
- packs 80
- paddle bolts 77
- platinum mining 72
- Poland iv
- polyester resins 49
- Portland cement 46
- pull test, short encapsulation 56–7, **60, 61**
- PUR resins 49
- 'Q' system 29, **31**
- Quickchem® installation system 78
- radial rig drill **72**
- rebar roof bolts 74–6, 79
- regulations 21
- reinforcement xv–xvi, 5–6, 8
- resin capsules 2–3, 48, 50–61, **51**
- Lokset® 48–9, 48
 - resins, pumped 49
 - RHAM 80
- rig drill, radial **72**
- roadway, rockbolted **xv**
- computer model **32**
- Rock Mass Rating (RMR) 29
- rock(s)
- carboniferous 23
 - failure patterns **7**
 - material parameters 22–4
 - mechanical strength 22–3
 - reinforcement 26
 - stress field 5–8, 24–5
 - structural features 23–4
 - type 22
- rotary telltale 36
- Russia iv
- Scandinavia 29
- SCS Jumbolt 77
- SCS Secura/Reo bolt 77
- SEBV 2
- Secunda 80
- set time 51–2
- shear failure 6
- shear restraint 9, **10**
- Shepherds crooks 80
- Snowy Mountains hydroelectric scheme 28
- South Africa iv, 4, 24, 72
- bolting practices 79
 - design 80
 - installation 80
 - regulations 78
- spin time 52
- 'Spin to Stall' 79
- split sets 80
- standards 21
- steel rockbolts **45**
- step bars 79
- storage 54–6
- strain gauged bolt data **35**
- stress
- concentration **5**
 - magnitudes 24–5
 - retention in roof 10–13, **11–13**
- stress driven shear failure **6**
- Super Turbo 71
- support, passive xv, 1
- support patterns, optimising 34, 36–41
- suspension 9
- telltale
- dual height **34, 37**
 - rotary **36**
- temperature 53, **53**, 54–6
- tension, bolt 14–16, 41
- testing 54–9, **60, 61**
- Titafix iv
- 'TooSpeedie®' 48–9, 63
- Tshikondeni 80
- tubular bolts 77
- United Kingdom 2, 33
- bolting practices 81
 - installation methods 81
 - regulations 81
- United States iv, v, 1–2, 4, 24, 30
- bolting practices 74–5
 - design methods 76
 - installation methods 76
 - regulations 21, 74
 - research 16
 - types of mine 75–6
- UNWEDGE (computer program) 28, **29**
- Videx Chemical Bar 79
- Voest machine 80
- wedge failure **29**
- Wiborex® 49
- Wilthix® 49
- Wombats® 80

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