

## SUPPORT IN UNDERGROUND HARD ROCK MINES

Evert Hoek, NSERC Industrial Research Professor, Department of Civil Engineering,  
University of Toronto, Toronto, Canada.

David. F. Wood, Senior Engineer, Golder Associates, Vancouver, British Columbia,  
Canada

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## **Introduction**

Rock support is the term widely used to describe the procedures and materials used to improve the stability and maintain the load bearing capacity of rock near to the boundaries of an underground excavation. In this paper, a distinction is drawn between rock reinforcement or active support, where the supporting elements are an integral part of the reinforced rock mass, and rock support or passive support, where the supporting members are external to the rock and respond to inward movement of the rock surrounding the excavation. A good example of active reinforcement is a pattern of untensioned grouted dowels which are tensioned as the rock deforms and which interact with the rock in much the same way as reinforcing steel does with concrete. Steel sets are an example of passive support since they external to the rock mass and can only respond to progressive inward movement of the loosened rock mass.

The primary objective of a support system is to mobilize and conserve the inherent strength of the rock mass so that it becomes self-supporting. Rock support generally combines the effects of reinforcement, by such elements as dowels, tensioned rock bolts and cables, and support, with shotcrete, mesh and steel sets which carry loads from individual rock blocks isolated by structural discontinuities or zones of loosened rock. These notes are intended to assist the underground support engineer in choosing the most appropriate, and the easiest to install, combination of reinforcement and support. If possible, the installation of rock support should be carried out as an integral part of the excavation cycle to enhance the self-supporting aspects of rock mass improvement.

## **Rock support**

The choice of the type of support installed in a particular underground excavation depends upon the extent of the zone of loosened or fractured rock surrounding that excavation. A very crude guide to support selection is given in Table 1.

## **Active rock reinforcement**

Underground mines use two principal types of rock reinforcement - tensioned mechanically anchored rockbolts and untensioned grouted or friction anchored dowels. It is important that the different ways in which these reinforcing systems work is fully understood and a brief discussion on this subject is given on the pages which follow.

### *Mechanically anchored rockbolts*

Mechanically anchored rockbolts are probably the oldest form of rock reinforcement used in underground mining and are still the most common form of rock reinforcement used in Canadian mines. Provided that the rock is hard enough to provide a good grip for the anchor, an expansion shell anchor which is well seated will usually allow a rockbolt to be tensioned to its maximum load-carrying capacity. In fact, if a bolt is overloaded, it usually fails in the threads at either the faceplate or anchor end rather than by anchor slip.

Tensioned rockbolts are most effective in retaining loose blocks or wedges of rock near the surface of the excavation. These blocks may have been loosened by intersecting joints and bedding planes in the rock or they may have been created by poor quality blasting. In either case, falls of loose rock create unsafe working conditions and some form of support is required.

Since the amount of loosening does not usually penetrate very far into the rock mass, the support is only required to hold up the dead weight of the loose material. Mechanically anchored rockbolts, with the addition of mesh where small pieces of rock are likely to fall out between bolt heads, provide very effective support for these conditions. Tensioning of the bolts, usually to about 70% of their ultimate breaking load, is required in order to tighten the loose blocks and wedges and to provide as much interlocking between these blocks as possible. It is by helping the rock to support itself and by the prevention of further unravelling and deterioration of the rock mass that the tensioned rockbolts provide effective support.

Unfortunately, mechanically anchored rockbolts suffer from several problems. There is a tendency for anchors to slip progressively with time, probably as a result of vibrations induced by nearby blasting. Hence, old rockbolts which have clearly lost all their tension are frequently seen in underground mines. Another problem relates to rusting of the bolts in rock masses with aggressive groundwater, for example, in massive sulphides. Sometimes, the life of an unprotected bolt may be less than one year under such circumstances and, where long term life is required, the bolts should be grouted in place.

The need for mechanically anchored rockbolts is reduced significantly by careful blasting and by correct scaling. These techniques reduce the amount of loose rock which has to be supported and hence the need for bolts and mesh.

#### *Grouted or friction anchored dowels*

One of the main disadvantages of mechanically anchored rockbolts is that, if the anchor slips or the bolt breaks, the capacity of the bolt drops to zero and the rock being supported can fall. This problem is less severe in the case of a fully grouted or friction anchored dowel because, even if slip does occur or if the face plate breaks off, the remaining length of the dowel is still anchored and will continue to provide support.

The problem with grouted or friction anchored dowels is that they cannot be tensioned and hence they have to be installed before significant movement has taken place in the rock. In fact, experience has shown that this apparent problem can be turned to advantage and that a combination of careful blasting and the installation of dowels as close as possible to the advancing face can provide very effective support for a much wider range of rock conditions than can be handled by mechanically anchored bolts. The installation of the dowels close to the advancing face ensures that relatively little movement has taken place in the rock mass and that the maximum amount of interlocking between individual pieces is retained. Retention of this interlocking is critical to the self-supporting characteristics of the rock mass and any loss of interlock causes a very severe drop in strength.

**Table 1: Suggested support for various rock conditions.**

<b>Rock Conditions</b>	<b>Suggested support type</b>
Sound rock with smooth walls created by good blasting. Low in situ stresses.	No support or alternatively, where required for safety, mesh held in place by grouted dowels or mechanically anchored rockbolts, installed to prevent small pieces from falling.
Sound rock with few intersecting joints or bedding planes resulting in loose wedges or blocks. Low in situ stresses.	Scale well then install tensioned, mechanically anchored bolts to tie blocks into surrounding rock. Use straps across bedding planes or joints to prevent small pieces falling out between bolts. In permanent openings, such as shaft stations or crusher chambers, rockbolt should be grouted with cement to prevent corrosion.
Sound rock damaged by blasting with a few intersecting planes. Low in situ stresses	Chain link or weld mesh held by tensioned mechanically anchored rockbolts, to prevent falls of loose rock. Attention must be paid to scaling and to improving blasting to reduce amount of loose rock.
Closely jointed blocky rock with small blocks ravelling from surface causing deterioration if unsupported. Low stress conditions.	Shotcrete layer, approximately 50 mm thick. Addition of micro-silica and steel fibre reduces rebound and increases strength of shotcrete in bending. Larger wedges are bolted so that shotcrete is not overloaded. Limit scaling to control ravelling. If shotcrete not available, use chain-link or weldmesh and pattern reinforcement such as split sets or Swellex.
Stress-induced failure in jointed rock. First indication of failure due to high stresses are seen in borehole walls and in pillar corners.	Pattern support with grouted dowels or Swellex. Split sets are suitable for supporting small amounts of failure. Grouted tensioned or untensioned cables can be used but mechanically anchored rockbolts are less suitable for this application. Typical length of reinforcement should be about ½ the span of openings less than 6 m and between ½ and 1/3 for spans of 6 to 12 m. Spacing should be approximately ½ the dowel length. Support should be installed before significant movement occurs. Shotcrete can add significant strength to rock and should be used in long-term openings (ramps etc.). Mesh and straps may be required in short-term openings (drill-drives etc.)
Drawpoints developed in good rock but subjected to high stress and wear during blasting and drawing of stopes.	Use grouted rebar for wear resistance and for support of drawpoint brows. Install this reinforcement during development of the trough drive and drawpoint, before rock movement takes place as a result of drawing of stopes. Do not use shotcrete or mesh in drawpoints – place dowels at close spacing in blocky rock.
Fractured rock around openings in stressed rock with a potential for rockbursts	Pattern support required but in this case some ‘flexibility’ required to absorb shock from rockbursts. Split sets are good since they will slip under shock loading but will retain some load and keep mesh in place. Grouted dowels and Swellex will also slip under high load but some face plates may fail. Mechanically anchored bolts are poor in these conditions. Lacing between heads of reinforcement helps to retain rock near surface under heavy rockbursting.
Very poor rock associated with faults or shear zones. Rock-bolts or dowels cannot be anchored in this material.	Fibre-reinforced shotcrete can be used for permanent support under low stress conditions or for temporary support to allow steel sets to be placed. Note that shotcrete layer must be drained to prevent build up of pressure behind the shotcrete. Steel sets are required for long-term support where it is evident that stresses are high or that roc is continuing to move. Capacity of steel sets estimated from amount of loose rock to be supported.

With the development of grouted or friction anchored dowels which are both economical and simple to install, the use of untensioned dowels has become very wide-spread in mining and will probably become the dominant rock reinforcement technique in years to come.

#### *Grouted cables*

Rockbolts and dowels can be replaced in most mining applications by means of grouted cables. The main advantage of these cables is that they can be installed in openings with very low headroom. The cables can be grouted in place without tensioning or they can be tensioned before grouting. In recent years, simple tensioning techniques have been developed which eliminate the complex and time-consuming procedures previously used.

Grouted cables are very effective in applications such as the reinforcement of ore or waste passes. The progressive wear of the exposed cable does not reduce the support provided by the remaining length of grouted cable. The flexibility of the cables allows the rock mass to 'work' without a significant loss of strength.

In cut and fill mining, long grouted cables can be pre-placed in the ore-body to be mined in order to provide support for the stope backs. As the cables are shortened by progressive cuts, the remaining grouted lengths are tensioned by downward movement of the rock above the stopes and support forces are generated. When the remaining length of cable has been reduced to about 2m, a new set of cables is installed to overlap the first set and to assume the support duties when the first set is mined out.

When a large zone of potentially unstable rock is to be supported, say adjacent to a fault or shear zone, long tensioned and grouted cables can be installed from development headings before mining of the stopes takes place. Long grouted cables have also been used successfully in many civil engineering applications such as the anchoring of crane beams in large underground powerhouse excavations or the support of very large span openings where normal rockbolts would have proved inadequate.

### **Passive rock support**

In order to complement the reinforcement achieved using dowels, bolts or cables, rock support often includes the use of mesh, straps, shotcrete or steel sets. Each of these rock support elements is reviewed briefly in the notes which follow.

#### *Mesh*

A general rule which can be used deciding upon the spacing of rockbolts is that the distance between faceplates should be approximately equal to three times the average spacing of the weakness planes in the rock mass. Hence, if a set of intersecting joints and bedding planes create wedges or blocks with an average side length of 0.5m, the ideal bolt spacing should be about 1.5m and the bolt length should be twice the bolt spacing, i.e 3m. This example gives reasonable bolt lengths and spacing but, what is

the solution if the average joint spacing is about 100mm? Obviously, it would be impractical to place bolts at 300mm centres and, under these circumstances, mesh is used to keep the small blocks between the faceplates in place.

Mesh may be either chainlink or weldmesh. Chainlink mesh is flexible and has a very high load bearing capacity. It is, however, rather difficult to handle during installation and it is also completely unsuitable for use with shotcrete because of the difficulty of eliminating the air pockets trapped behind the links in the mesh. Weldmesh, fabricated by welding a grid of crossing wires at their intersection points, is more rigid and is easier to install than chainlink mesh. It is also suitable for use with shotcrete because the wire intersections are small in area and it is easy for the shotcrete to penetrate behind these intersections.

### *Straps*

When the rock mass surrounding an underground opening is very slabby, in other words, most of the weakness planes run in one direction, the strength of the rock mass is much higher in the direction of the weakness planes than it is across these planes. Under these circumstances, straps may be a more effective means of face support than mesh. These straps are placed between rockbolts and run across the planes of weakness. Straps placed parallel to the planes of weakness are generally a waste of money.

### *Shotcrete*

Shotcrete is used very widely in civil engineering construction but is not used by the mining industry to the extent that it deserves. This is partly due to the fact that a typical mine has many working faces and it is difficult to schedule the shotcreting equipment efficiently. It is also due to traditional attitudes which are gradually changing in recognition of the fact that each element in underground support plays a different role and that shotcrete can be a very effective support medium. The shotcrete acts in much the same way as mesh in that it prevents small pieces of rock from unravelling from the surface of an excavation. This helps to retain the interlocking and self-supporting characteristics of the rock mass. Since shotcrete is generally stronger than mesh, particularly if it is fibre-reinforced, and since it is corrosion resistant, it is generally considered to be a more effective support system. It is particularly useful in excavations such as ramps and haulages where long-term stability is important.

Shotcrete has developed into a versatile support system with the addition of microsilica and steel fibre reinforcement to the mortar/aggregate mix. The complex installation of thin layers of shotcrete, reinforced with weldmesh fabric can now be replaced quickly and economically by a single pass of steel fibre reinforced microsilica shotcrete. Sufficient research has now gone into shotcrete mix design and the constituent materials used, that shotcrete quality now rests almost entirely with the equipment operators. Shotcrete application requires constant attention to the supply pressure and volume of water, mix and air to ensure that the material leaves the nozzle in a continuous uninterrupted stream which can be applied by the nozzleman in such a fashion as to maximize compaction and quality while minimizing rebound and overspray.

## *Support in Hard rock Underground Mines*

As shotcrete develops strength with time after application, it may be used effectively soon after excavation. Local readjustment of the in situ stress field due to mining is unlikely to induce excessive loading on the green shotcrete, and shotcrete has shown good resilience and durability to nearby blasting. As loading is transferred on to the support system, it is gaining strength and producing a stiffening support member. Most products are shot with up to 5% accelerator if a high early strength is required. This obviously leads to the development of a faster supporting member, but care must be exercised in design to ensure that the support will not become overstressed by load transferred from relaxing ground in high stress environments.

The use of a micro-silica additive means that rebound is reduced considerably, thickness of application can be increased, weak zones of rock with running water can be covered and voids can be filled effectively. Silica does not appear to affect the long term strength of the product.

The addition of high aspect ratio, deformed steel fibres, usually 30-38 mm long and 0.5 mm in equivalent diameter, enhances the post crack load bearing capacity of the support system, although it does not give a marked improvement to the initial bending strength of the shotcrete layer. Early problems with balling of steel fibres and excessive equipment wear have been largely overcome and the addition of steel fibres do not usually give rise to significant operational problem.

### Typical shotcrete mix design

Components	kg/cu.m	Percent
Cement	420	18.6
Micro-silica additive	42	1.9
Blended aggregate	1735	76.9
Steel fibres	59	2.9

### *Steel sets*

Steel sets have generally replaced timber as the traditional 'passive' support system in underground construction. The term 'passive' derives from the fact that the steel sets (or timber) do not interact with the rock in the same way as rockbolts or dowels. These elements become part of the rock mass in much the same way as reinforcing becomes part of the concrete in reinforced concrete. On the other hand, passive support such as steel sets can only respond to loads imposed on them by the inward movement of the rock. Since they are generally placed some distance behind the advancing face, most of the short-term movement in the rock has already taken place before the sets are in place and the only load which they are called upon to carry is the dead-weight of rock failing around the opening.

In hard rock mining, steel sets have very limited application since most support duties can be performed more effectively by rockbolts, dowels or shotcrete or by some combination of these systems. The exception is in mining through faults or in very badly broken ground associated with faults or shear zones. In such cases, it may be impossible to anchor the rockbolts or dowels in the rock mass and steel sets may be required in order to carry the dead weight of the failed material surrounding the

opening.

Blocking is a critical part of steel set installation since it is essential that the rock loads be transferred uniformly onto the steel sets. Badly blocked sets are a very poor investment. Traditionally, wood is used as a blocking medium and this can be very effective if carefully placed and tightly wedged in place. In some mining applications, where large rock movements are anticipated, timber poles placed parallel to the opening axis are used to distribute the load onto the sets. These poles act rather like roller bearings and move with the rock to give a uniform load distribution on the sets. Where wood is difficult to obtain or where a skilled labour force is not available to install timber blocking correctly, timber blocking can be replaced by means of sacks of lean concrete. These sacks are pushed into place behind the sets and then sprayed with water to initiate setting of the concrete. The weak concrete provides adequate blocking to transfer the rock loads uniformly onto the steel sets.

### **Illustrations of support systems**

Illustrations of different support systems are presented on the pages which follow. These illustrations are intended to provide a condensed summary of the most important features of each system and to act as simple design aids to rock support designers and users.

*Warning:* Some of the systems or components illustrated in this series of drawings are protected by patents. Potential users intending to manufacture similar systems or components should check patent regulations.

#### ***1. Mechanically anchored, tensioned rockbolt***

##### *Background:*

Figure 1 illustrates a number of components which can be used in different combinations. The expansion shell anchor is one of a large number of different types, all of which operate in basically the same way. A wedge, attached to the bolt shank is pulled into a conical anchor shell forcing it to expand against the drillhole walls. When grouting a bolt, the rubber grout seal is used to centre the bolt in the hole and to seal the collar of the hole against grout leakage. An alternative system is to use a quick setting plaster to seal the hole collar. The grout is injected into the collar end of the hole (except in down-holes) and the return pipe is extended for the length of the hole. Grout injection is stopped when the air has been displaced and grout flows from the return tube.

##### *Advantages:*

Bolt can be tensioned immediately after installation using an impact wrench, torque wrench or hydraulic jack, and grouted at a later stage when short term movements have ceased. This system provides very reliable anchorage in good rock and high bolt loads can be achieved.

##### *Disadvantages:*

Correct installation requires skilled workmen and close supervision. Grout tubes are often damaged during installation.



*Applications:*

These bolts are very widely used for permanent support applications in civil engineering. Mechanically anchored bolts without grout are widely used in mining.

*Typical data:*

Steel designation	ASTM A 615 (Grade 60) or ASTM A 722 (Grade 150)
Yield stress	414 MPa (60000 psi) or 1034 MPa (150000 psi)
Steel diameter	19 mm ( $\frac{3}{4}$ "") to 35 mm ( $1\frac{3}{8}$ "")
Hole diameter	41 mm ( $1\frac{5}{8}$ "") to 63 mm ( $2\frac{1}{2}$ "")
Length	variable

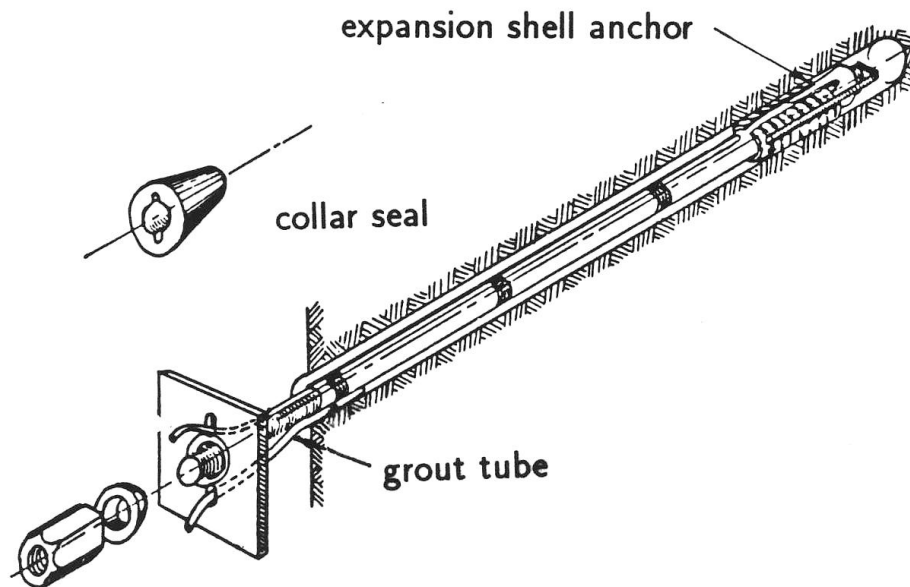


Figure 1. Mechanically anchored, tensioned rockbolt

## **2. Untensioned grouted dowel**

*Background:*

Developed as an inexpensive solution where use of untensioned dowels is appropriate. A thick grout is pumped into the drillhole by means of a simple hand pump or a monopump. The dowel is pushed into the grout as shown in Figure 2. For up-holes, the dowel is sometimes held in place by bending the dowel slightly during insertion. A faceplate and nut can be added if required although, for light support, a plain dowel is sometimes used. Resin cartridges can also be used to encapsulate the bar and provide bonding to the rock.

*Advantages:*

Simple and inexpensive. High corrosion resistance in permanent installations.

*Disadvantages:*

Cannot be tensioned and hence must be installed before significant deformation of the rock mass has taken place. Care must be taken to ensure resin 'grout' is properly

mixed. Resin has limited shelf life.

*Applications:*

Widely used in the mining industry for general support duties.

*Typical data:*

Steel designation	ASTM A 615 (Grade 60)
Yield stress	414 MPa (60000 psi)
Steel diameter	19 mm ( $\frac{3}{4}$ " ) to 25 mm (1")
Hole diameter	35 ( $1\frac{3}{8}$ " ) to 38 mm ( $1\frac{1}{2}$ " )
Length	variable

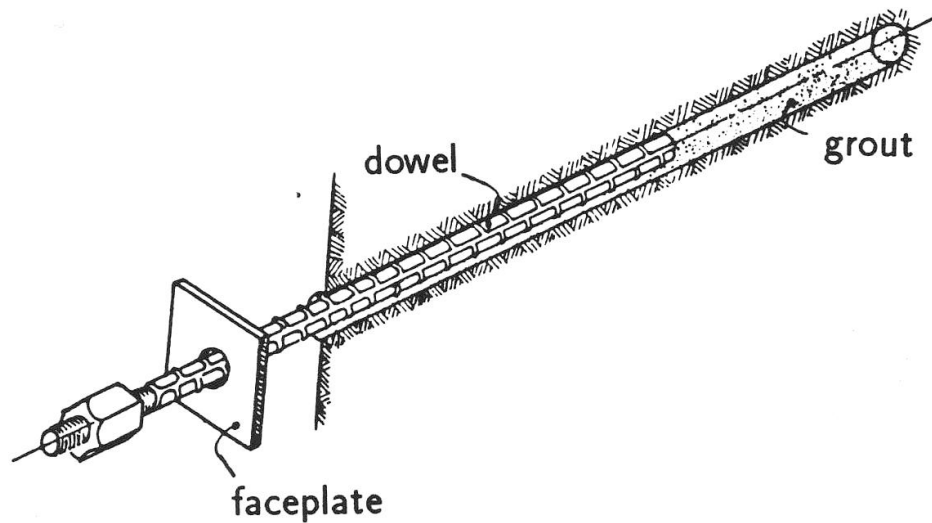


Figure 2. Untensioned, grouted dowel

### **3. Friction anchored rockbolt - Swellex**

*Background:*

Developed by Atlas Copco AB, the Swellex deformed tube is expanded by water pressure to the shape of the drill hole. Mechanical interlock of the bolt and the rock then prevents the bolt from sliding. Expansion of the deformed tube leads to some reduction in length, which puts the Swellex into tension.

*Advantages:*

Rapid and simple installation. Gives immediate support action after installation. Can be used in a variety of ground conditions. The installation causes contraction in the bolt length. This effectively tensions the face plate against the rock surface.

*Disadvantages:*

Corrosion can be a problem in long term installations. Requires a pump for installation. May require a sleeve at the collar to prevent spalling under certain rock conditions.

*Applications:*

Swellex bolts are commonly used in the mining industry for medium-term support requirements. Becoming increasingly used in civil engineering tunneling work.

*Typical data:*

Yield load	130 kN (13 ton f)
Tube diameter	26 mm (1")
Hole diameter	33 mm (1 3/8") to 39 mm (1 1/2")
Lengths	Up to 8 m (24ft)
Inflation pressure	20 MPa (3000psi)

*Warning:* Swellex bolts are patented by Atlas Copco AB, Sweden.

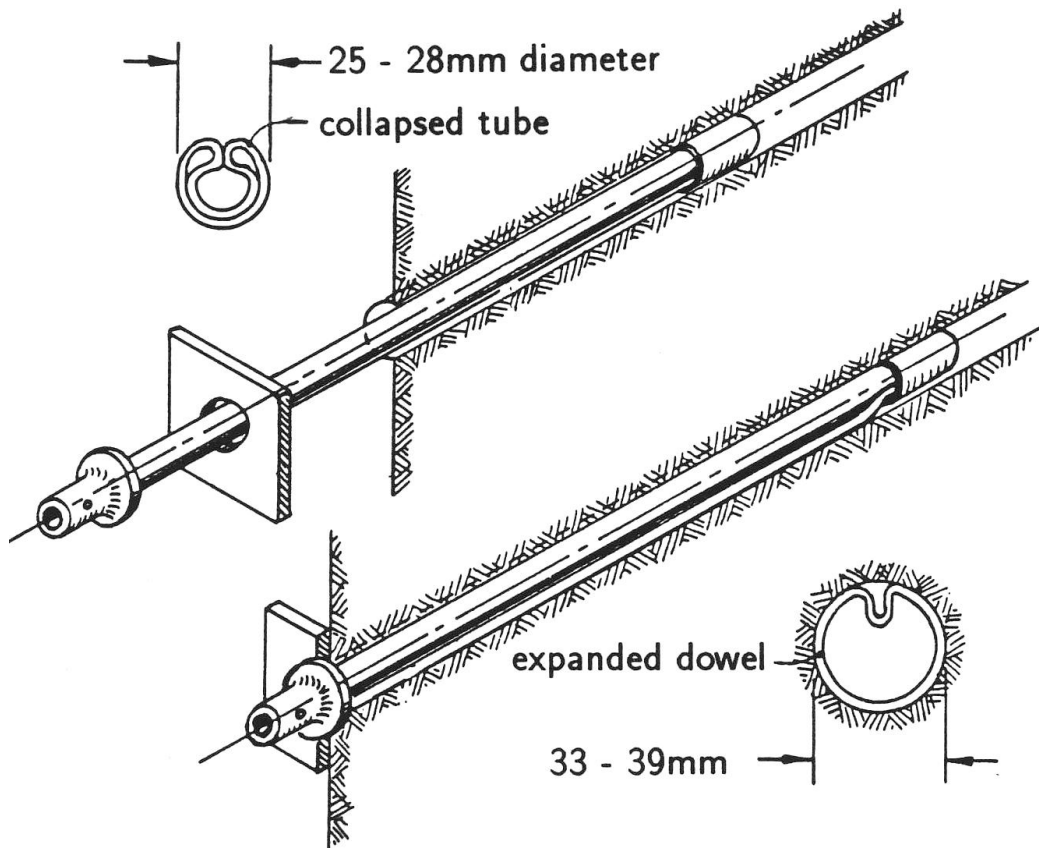


Figure 3. Friction anchored rockbolt – Swellex

#### 4. Friction anchor or Split Set

*Background:*

Developed by Scott in conjunction with the Ingersoll -Rand Company in the U.S.A., this device has gained considerable popularity in the mining industry. As the split tube is forced into a drillhole, the spring action of the compressed tube applies a radial force against the rock and generates a frictional resistance to sliding of the rock on the steel. This frictional resistance increases as the outer surface of the tube rusts.

*Advantages:*

Simple and quick to install and claimed to be cheaper than a grouted dowel of similar capacity. Useful in moving and bursting ground.

*Disadvantages:*

Cannot be tensioned and hence is activated by movement in the rock in the same way as a grouted dowel. Its support action is similar to that of an untensioned dowel and hence it must be installed very close to the face. The drillhole diameter is critical and most failures during installation occur because the hole is either too small or too large. In some applications, rusting has occurred very rapidly and has proved to be a problem where long term support is required. The device cannot be grouted.

*Applications:*

Used for relatively light support duties in the mining industry, particularly where short term support is required. Little application in civil engineering at present.

*Typical data:*

Yield load        90 kN  
Tube diameter   33 mm (1.32"), 39 mm (1.55") and 46 mm (1.81")  
Hole diameter   32 mm (1 1/8"), 35 mm (1 3/8") and 41 mm (1 5/8")  
Lengths:         variable

*Warning:* Split Set friction rock stabilizers are patented by the Ingersoll-Rand Company, U.S.A.

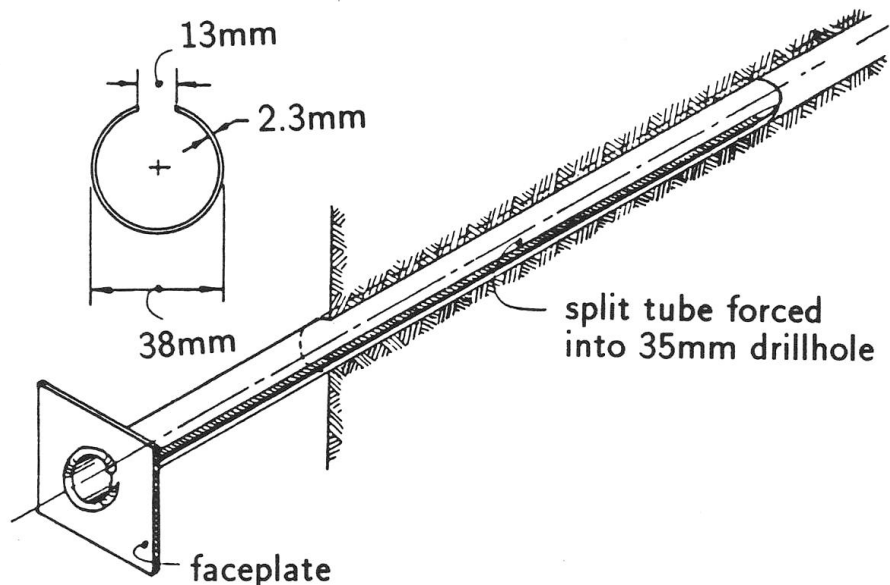


Figure 4. Friction anchor or Split Set

### 5. Resin grouted, tensioned threaded bar

*Background:*

The most sophisticated rockbolt system currently in use, combines most of the advantages of other bolt systems. Resin and a catalyst are contained in plastic 'sausages', the catalyst being separated in a glass or plastic container in the resin. These capsules are pushed into the hole with a loading stick and the bar is then inserted. Rotation of the bar during insertion breaks the plastic containers and mixes the resin and catalyst. The bar illustrated in Figure 5 has a very coarse rolled thread which gives good bonding and allows the length of the installation to be adjusted very easily.

*Advantages:*

This system is very convenient and simple to use. Very high strength anchors can be formed in rock of poor quality and, by choosing appropriate setting times, a 'one shot' installation produces a fully grouted tensioned rockbolt system.

*Disadvantages:*

Effective resin mixing requires careful adherence to recommendations provided by manufacturers. Resins are expensive and many have a limited shelf-life, particularly in hot climates.

*Applications:*

Increasingly used in critical applications in which cost is less important than speed and reliability.

*Typical data:*

As for mechanically anchored rockbolts.

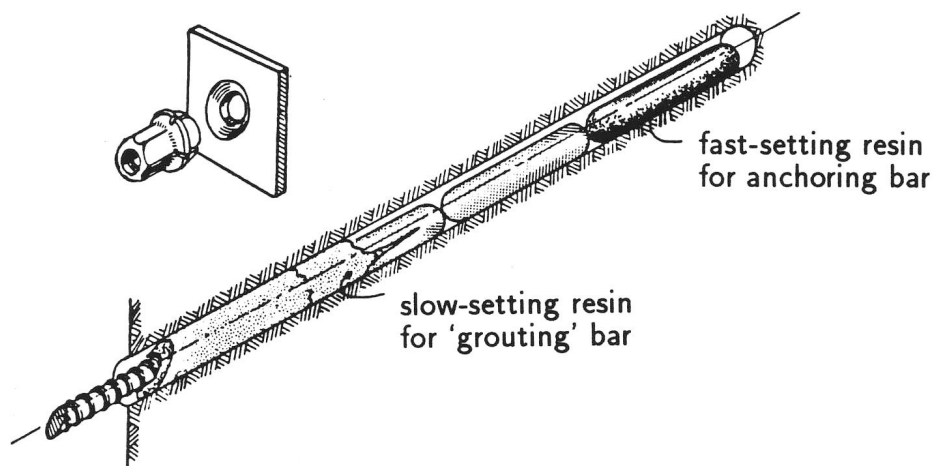


Figure 5. Resin grouted, tension threaded bar

## 6. Grouted Cable Bolt

### *Background:*

Grouted cables were introduced to mining for reinforcement of the backs of cut and fill stopes. Cable reinforcement, using tensioned or untensioned, fully grouted cables, is very widely used in mining applications. Cables can be installed effectively in very narrow tunnels, they are inexpensive and have a very high load bearing capacity.

### *Advantages:*

This system is inexpensive. If properly installed, it provides competent and durable reinforcement. It can be installed to any length in narrow areas. The system gives very high bolt loads in various rock conditions, as well as high corrosion resistance in permanent installations.

### *Disadvantages:*

Tensioning of the cable bolt is possible only if a special installation procedure is adopted. The use of standard cement in the grout requires several days curing before the cable can be loaded.

### *Applications:*

The system is gaining increasing use in mining applications.

### *Typical data:*

Yield stress	1770 Mpa (257000 psi)
Yield load	500 kN (50 ton f)
Cable diameter	20 mm ( $\frac{25}{32}$ " )
Hole diameter	35 mm ( $1\frac{3}{8}$ " )
Lengths:	Any length required

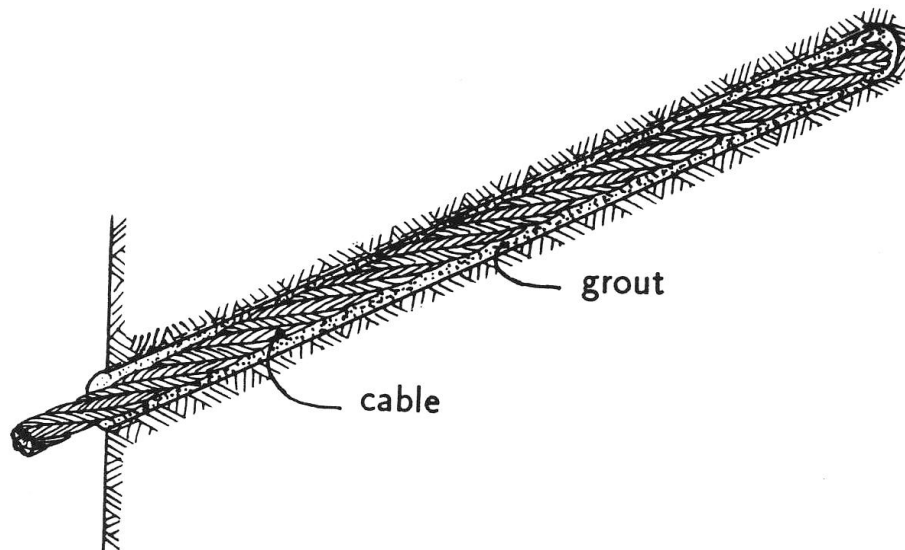


Figure 6. Grouted cable bolt

## **7. Strap**

*Background:*

This system is used extensively in mining and civil engineering applications to hold slabby ground between rock bolts or to prevent slabs from loosening.

*Advantages:*

Straps are easy to install with rock bolts. They are very effective in stratified, slabby ground.

*Disadvantages:*

Straps cannot be used to control raveling in loose, blocky ground if the block size is small.

*Applications:*

Steel straps are used to give roof control in ground where rockbolts or dowels alone cannot hold intermediate and relatively thin slabs of rock. The strap is formed to follow the rock surface and held with regular rock reinforcement or specially installed pins. Straps should always be installed across weakness planes.

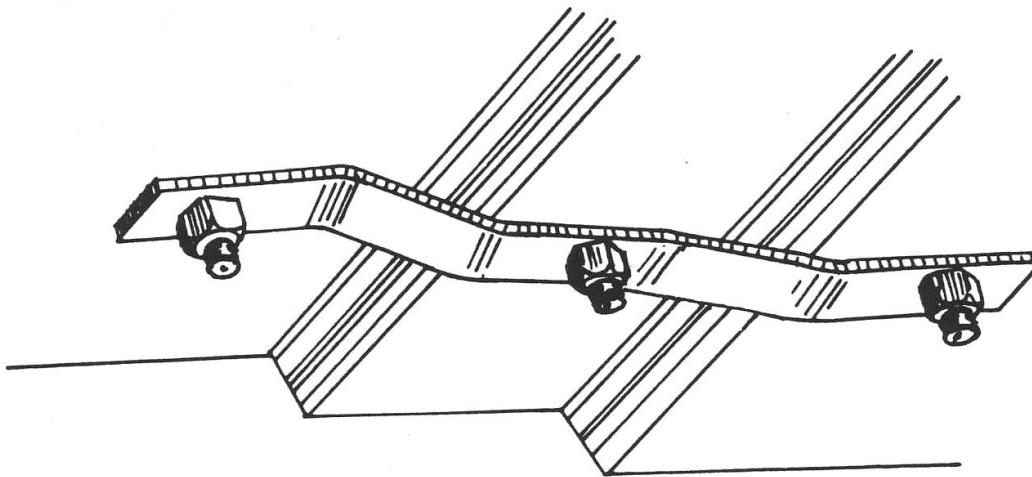


Figure 7. Strap

## **8. Mesh**

*Background:*

Wire mesh is used to support small pieces of loose rock and broken rock from falling. Two types of wire mesh currently used in underground operations are chainlink mesh and weld mesh.

*Advantages:*

Mesh is very economical and quickly installed. It is easy to attach to roof

reinforcement with extra faceplates and nuts. It is easily repaired.

*Disadvantages:*

Mesh cannot carry excessive load of broken rock without failure. It is easily damaged by flyrock from nearby blasts.

*Applications:*

Mesh is useful for supporting small pieces of broken rock. Weldmesh is used traditionally as reinforcement for shotcrete, but is rapidly being replaced by steel fibre reinforced shotcrete. Mesh, like straps, is held in place with additional faceplates or washers and nuts on rockbolts or using separate pins.

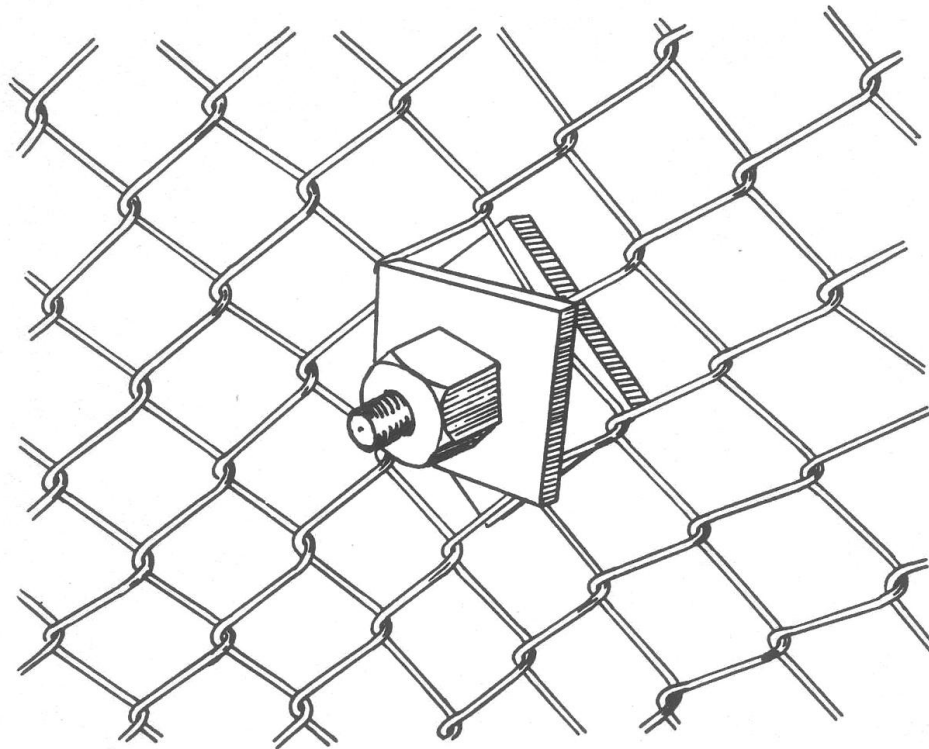


Figure 8. Mesh

**9. Typical dry-mix shotcrete operation**

*Background:*

Pneumatically applied mortar and concrete have been used increasingly in the support of underground excavations both in civil and mining applications. Two basic types of shotcrete (dry-mix and wet-mix) can be used. Flexibility of equipment, batching and availability often result in the use of the dry-mix process in mining.

*Advantages:*

This system is very adaptable to the tunneling environment. New technology has made mix design easier.



*Disadvantages:*

Final product is highly dependent on the operators and especially on the nozzleman.

*Applications:*

The system has rapid support potential for loosened rock and changing stress conditions. It is as durable as concrete in most applications for roadways or as roof support. It is not recommended for drawpoints.

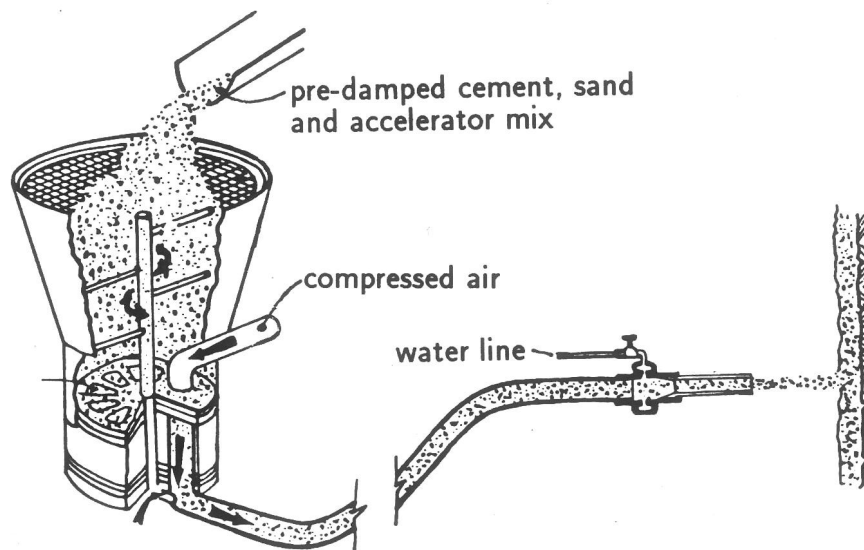


Figure 9. Typical dry-mix shotcrete operation

## **10. Steel arches**

*Background:*

This system developed from the earliest use of timber supports underground, steel arches are now manufactured as rigid or yielding supports. They are employed for long term, permanent rock mass support especially in critical areas of roadways and intersections.

*Advantages:*

Highly effective under heavy strata loading conditions. Continues to provide support after substantial deformation has occurred.

*Disadvantages:*

Steel arches are time consuming to install properly. Unless well blocked, sets are ineffective. Prone to twisting under eccentric loading. Rock mass must undergo deformation before arch starts to take load, i.e. a 'passive' support.

*Applications:*

This system used in support of long term haulages and critical intersections especially

in highly stressed ground. Yielding and rigid supports are required in different applications.

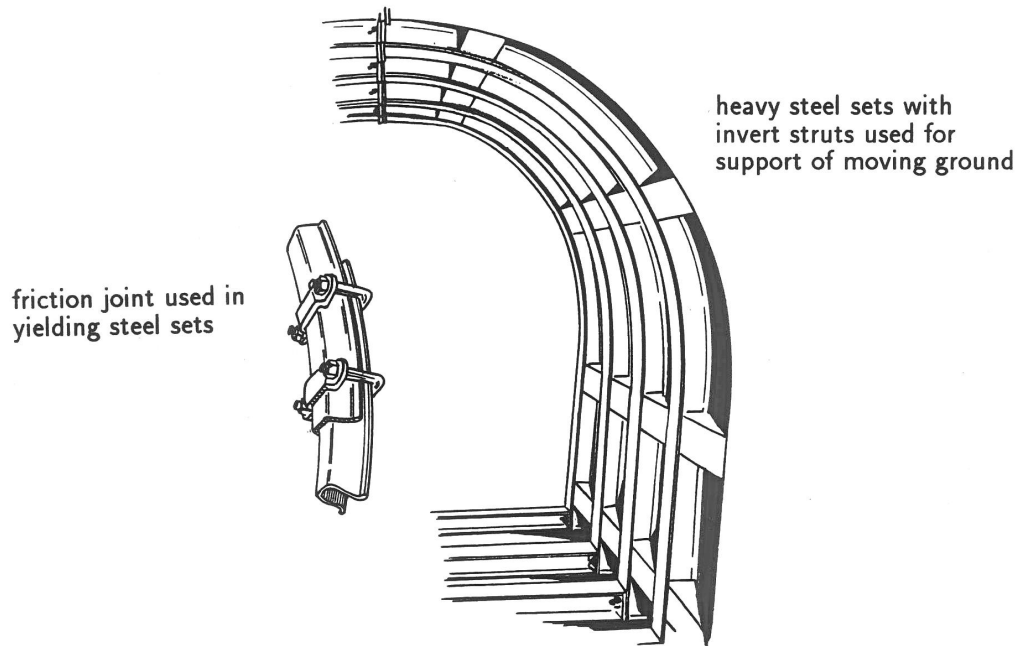


Figure 10. Steel arches

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