Rockbolts and cables

Introduction

Rockbolts and dowels have been used for many years for the support of underground excavations and a wide variety of bolt and dowel types have been developed to meet different needs which arise in mining and civil engineering.

Rockbolts generally consist of plain steel rods with a mechanical or chemical anchor at one end and a face plate and nut at the other. They are always tensioned after installation. For short term applications the bolts are generally left ungrouted. For more permanent applications or in rock in which corrosive groundwater is present, the space between the bolt and the rock can be filled with cement or resin grout.

Dowels or anchor bars generally consist of deformed steel bars which are grouted into the rock. Tensioning is not possible and the load in the dowels is generated by movements in the rock mass. In order to be effective, dowels have to be installed before significant movement in the rock mass has taken place. Figure 1 illustrates a number of typical rockbolt and dowel applications that can be used to control different types of failure that occur in rock masses around underground openings.

The move towards larger underground excavations in both mining and civil engineering has resulted in the gradual development of cable reinforcement technology to take on the support duties which exceed the capacity of traditional rockbolts and dowels. Some of the hardware issues that are critical in the successful application of cables in underground excavations are reviewed in this chapter.

Rockbolts

Mechanically anchored rockbolts

Expansion shell rockbolt anchors come in a wide variety of styles but the basic principle of operation is the same in all of these anchors. As shown in Figure 2, the components of a typical expansion shell anchor are a tapered cone with an internal thread and a pair of wedges held in place by a bail. The cone is screwed onto the threaded end of the bolt and the entire assembly is inserted into the hole that has been drilled to receive the rockbolt. The length of the hole should be at least 100 mm longer than the bolt otherwise the bail will be dislodged by being forced against the end of the hole. Once the assembly is in place, a sharp pull on the end of the bolt will seat the anchor. Tightening the bolt will force the cone further into the wedge thereby increasing the anchor force.

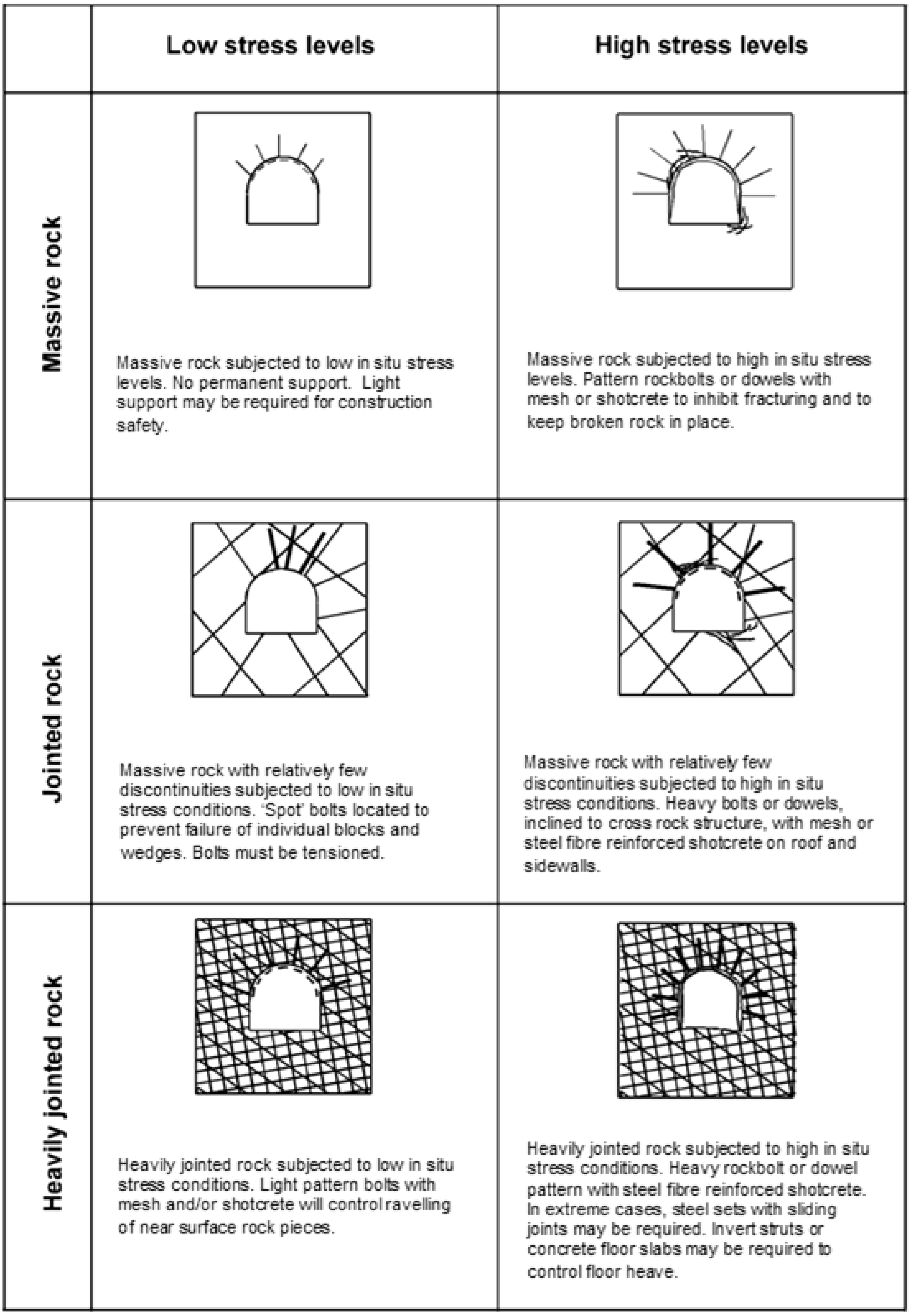


Figure 1: Typical rockbolt and dowel applications to control different types of rock mass failure during tunnel driving.

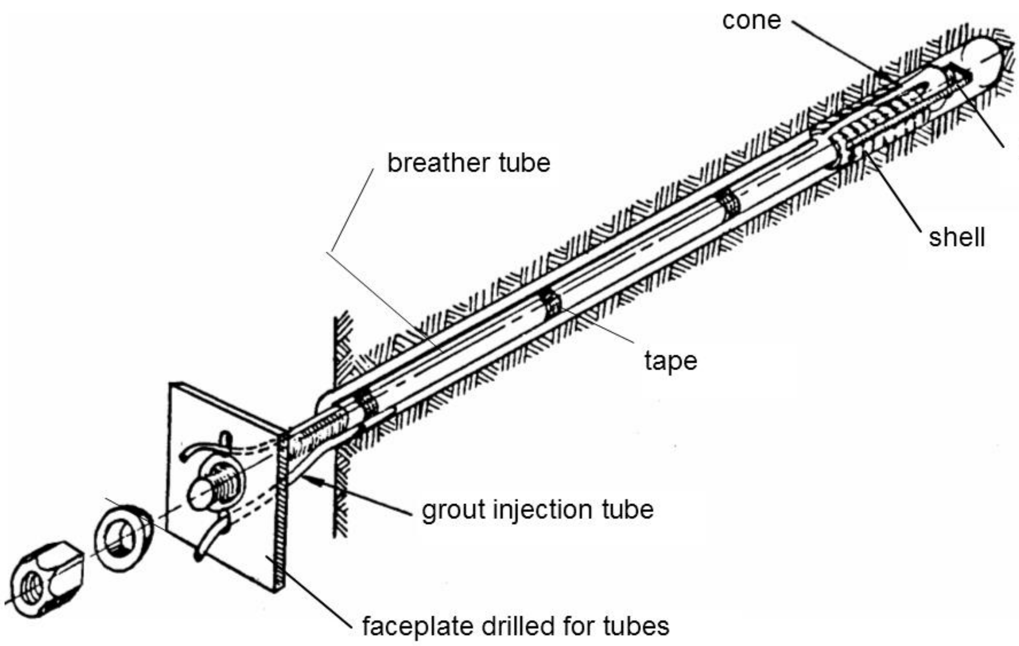


Figure 2: Components of a mechanically anchored rockbolt with provision for grouting.

These expansion shell anchors work well in hard rock but they are not very effective in closely jointed rocks and in soft rocks, because of deformation and failure of the rock in contact with the wedge grips. In such rocks, the use of resin cartridge anchors, described later in this chapter, is recommended.

At the other end of the rockbolt from the anchor, a fixed head or threaded end and nut system can be used. In either case, some form of faceplate is required to distribute the load from the bolt onto the rock face. In addition, a tapered washer or conical seat is needed to compensate for the fact that the rock face is very seldom at right angles to the bolt. A wide variety of faceplates and tapered or domed washers are available from rockbolt suppliers.

In general, threads on rockbolts should be as coarse as possible and should be rolled rather than cut. A fine thread is easily damaged and will cause installation problems in a typical underground environment. A cut thread weakens the bolt and it is not unusual to see bolts with cut threads that have failed at the first thread at the back of the nut. Unfortunately, rolled thread bolts are more expensive to manufacture and the added cost tends to limit their application to situations where high strength bolts are required.

Tensioning of rockbolts is important to ensure that all of the components are in contact and that a positive force is applied to the rock. In the case of light 'safety' bolts, the amount of tension applied is not critical and tightening the nut with a conventional wrench or with a pneumatic torque wrench is adequate. Where the bolts are required to carry a significant load, it is generally recommended that a tension of approximately

70% of the capacity of the bolt be installed initially. This provides a known load with a reserve in case of additional load being induced by displacements in the rock mass.

One of the primary causes of rockbolt failure is rusting or corrosion and this can be counteracted by filling the gap between the bolt and the drillhole wall with grout. While this is not required in temporary support applications, grouting should be considered where the ground-water is likely to induce corrosion or where the bolts are required to perform a 'permanent' support function.

The traditional method of grouting uphole rockbolts is to use a short grout tube to feed the grout into the hole and a smaller diameter breather tube, extending to the end of the hole, to bleed the air from the hole. The breather tube is generally taped to the bolt shank and this tends to cause problems because this tube and its attachments can be damaged during transportation or insertion into the hole. In addition, the faceplate has to be drilled to accommodate the two tubes, as illustrated in Figure 2. Sealing the system for grout injection can be a problem.

Many of these difficulties are overcome by using a hollow core bolt. While more expensive than conventional bolts, these hollow bolts make the grouting process much more reliable and should be considered wherever permanent rockbolt installations are required. The grout should be injected through a short grout tube inserted into the collar of the hole and the central hole in the bolt should be used as a breather tube. When installing these bolts in downholes, the grout should be fed through the bolt to the end of the hole and the short tube used as a breather tube.

Since the primary purpose of grouting mechanically anchored bolts is to prevent corrosion and to lock the mechanical anchor in place, the strength requirement for the grout is not as important as it is in the case of grouted dowels or cables (to be discussed later). The grout should be readily pumpable without being too fluid and a typical water/cement ratio of 0.4 to 0.5 is a good starting point for a grout mix for this application. It is most important to ensure that the annular space between the bolt and the drillhole wall is completely filled with grout. Pumping should be continued until there is a clear indication that the air has stopped bleeding through the breather tube or that grout is seen to return through this tube.

Resin anchored rockbolts

Mechanically anchored rockbolts have a tendency to work loose when subjected to vibrations due to nearby blasting or when anchored in weak rock. Consequently, for applications where it is essential that the support load be maintained, the use of resin anchors should be considered.

A typical resin product is made up of two component cartridges containing a resin and a catalyst in separate compartments, as shown in Figure 3. The cartridges are pushed to the end of the drillhole ahead of the bolt rod that is then spun into the resin cartridges by the drill. The plastic sheath of the cartridges is broken and the resin and catalyst mixed by this spinning action. Setting of the resin occurs within a few minutes (depending upon the specifications of the resin mix) and a very strong anchor is created.

This type of anchor will work in most rocks, including the weak shales and mudstones in which expansion shell anchors are not suitable. For 'permanent' applications, consideration should be given to the use of fully resin-grouted rockbolts, illustrated in Figure 4. In these applications, a number of slow-setting resin cartridges are inserted into the drillhole behind the fast-setting anchor cartridges.

Figure 3: Typical two-component resin cartridge used for anchoring and grouting rockbolts

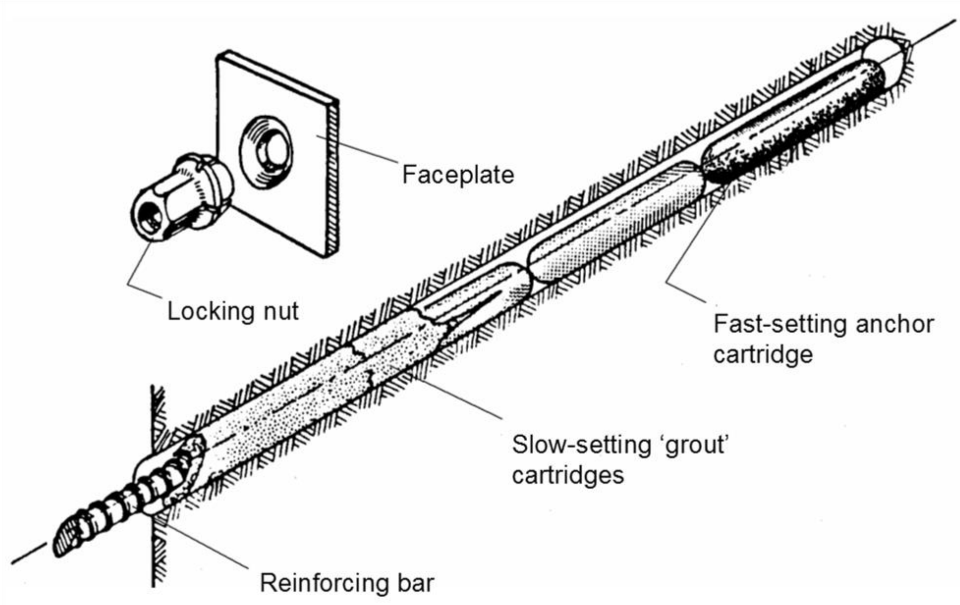


Figure 4: Typical set-up for creating a resin anchored and grouted rockbolt. Resin grouting involves placing slow-setting resin cartridges behind the fast-setting anchor cartridges and spinning the bolt rod through them all to mix the resin and catalyst. The bolt is tensioned after the fast-setting anchor resin has set and the slow-setting resin sets later to grout the rod in place.

Spinning the bolt rod through all of these cartridges initiates the chemical reaction in all of the resins but, because the slow-setting 'grout' cartridges are timed to set in up to

30 minutes, the bolt can be tensioned within two or three minutes of installation (after the fast anchor resin has set). This tension is then locked in by the later-setting grout cartridges and the resulting installation is a fully tensioned, fully grouted rockbolt.

The high unit cost of resin cartridges is offset by the speed of installation. The process described above results in a completely tensioned and grouted rockbolt installation in one operation, something that cannot be matched by any other system currently on the market. However, there are potential problems with resins.

Most resin/catalyst systems have a limited shelf life which, depending upon storage temperatures and conditions, may be as short as six months. Purchase of the resin cartridges should be limited to the quantities to be used within the shelf life. Care should be taken to store the boxes under conditions that conform to the manufacturer's recommendations. In critical applications, it is good practice to test the activity of the resin by sacrificing one cartridge from each box, before the contents are used underground. This can be done by breaking the compartment separating the resin and catalyst by hand and, after mixing the components, measuring the set time to check whether this is within the manufacturer's specifications.

Breaking the plastic sheath of the cartridges and mixing the resins effectively can also present practical problems. Cutting the end of the bolt rod at an angle to form a sharp tapered point will help in this process, but the user should also be prepared to do some experimentation to achieve the best results. Note that the length of time or the number of rotations for spinning the resins is limited. Once the setting process has been initiated, the structure of the resin can be damaged and the overall installation weakened by additional spinning. Most manufacturers supply instructions on the number of rotations or the length of time for spinning.

In some weak argillaceous rocks, the drillhole surfaces become clay-coated during drilling. This causes slipping of the resin cartridges during rotation, resulting in incomplete mixing and an unsatisfactory bond. In highly fractured rock masses, the resin may seep into the surrounding rock before setting, leaving voids in the resin column surrounding the rockbolt. In both of these cases, the use of cement grouting rather than resin grouting may provide a more effective solution.

There is some uncertainty about the long-term corrosion protection offered by resin grouts and also about the reaction of some of these resins with aggressive groundwater. For temporary applications, these concerns are probably not an issue because of the limited design life for most rockbolt installations. However, where very long service life is required, current wisdom suggests that cement grouted bolts may provide better long term protection.

Dowels

Grouted dowels

When conditions are such that installation of support can be carried out very close to an advancing face, or in anticipation of stress changes that will occur at a later excavation stage, dowels can be used in place of rockbolts. The essential difference between these systems is that tensioned rockbolts apply a positive force to the rock, while dowels depend upon movement in the rock to activate the reinforcing action. Mining drawpoints, which are mined before the overlying stopes are blasted, are good examples of excavations where untensioned grouted dowels will work well.

The simplest form of dowel in use today is the cement grouted dowel as illustrated in Figure 5. A thick grout (typically a 0.3 to 0.35 water/cement ratio grout) is pumped into the hole by inserting the grout tube to the end of the hole and slowly withdrawing the tube as the grout is pumped in. Provided that a sufficiently viscous grout is used, it will not run out of the hole. The dowel is pushed into the hole about half way and then given a slight bend before pushing it fully into the hole. This bend will serve to keep the dowel firmly lodged in the hole while the grout sets. Once the grout has set, a face plate and nut can be fitted onto the end of the dowel and pulled up tight. Placing this face place is important since, if the dowel is called on to react to displacements in the rock mass, the rock close to the borehole collar will tend to pull away from the dowel unless restrained by a faceplate.

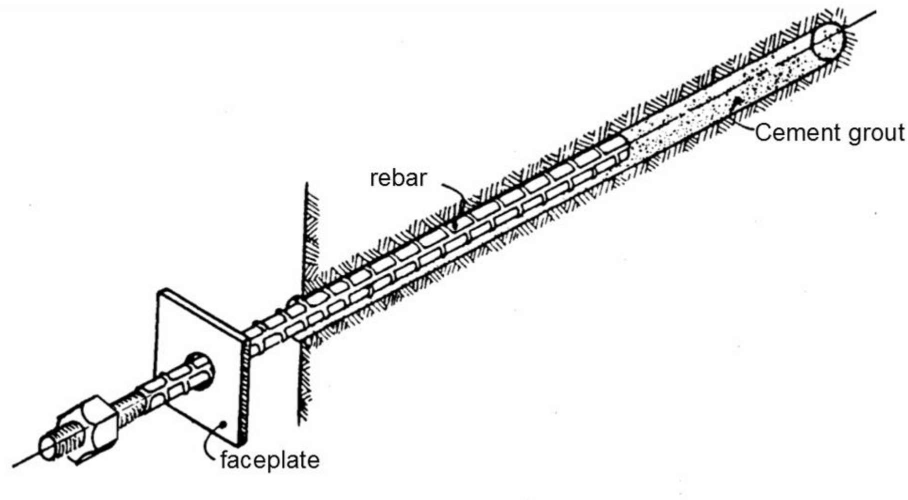


Figure 5: Grouted dowel using a deformed bar inserted into a grout-filled hole

In mining drawpoints and ore-passes, the flow of broken rock can cause serious abrasion and impact problems. The projecting ends of grouted rebars can obstruct the flow of the rock. Alternatively, the rebar can be bent, broken or ripped out of the rock mass. In such cases, grouted flexible cable, illustrated in Figure 6, can be used in place of the more rigid rebar. This will allow great flexibility with impact and abrasion resistance.

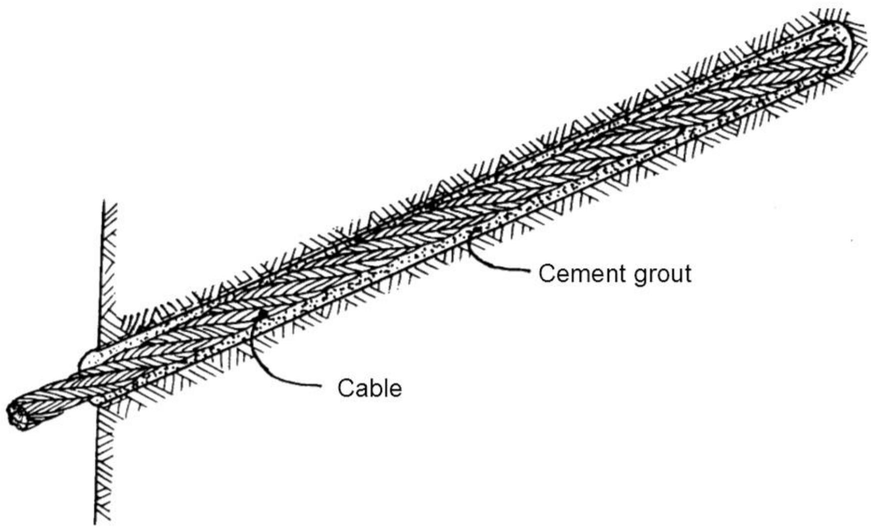


Figure 6: Grouted cables can be used in place of rebar when more flexible support is required or where impact and abrasion can cause problems with rigid support.

Older type grouted dowels such as the Scandinavian 'perfobolt' or dowels, where the grout is injected after the rod has been inserted, tend not to be used any more. The installation is more complex and time consuming and the end product does not perform any better than the simple grouted dowel described earlier.

Friction dowels or 'Split Set' stabilisers

Split Set stabilisers were originally developed by Scott (1976, 1983) and are manufactured and distributed by Ingersoll-Rand. The system, illustrated in Figure 7, consists of a slotted high strength steel tube and a face plate. It is installed by pushing it into a slightly undersized hole and the radial spring force generated, by the compression of the C shaped tube, provides the frictional anchorage along the entire length of the hole. A list of typical Split Set stabiliser dimensions and capacities is given in Table 1.

Because the system is quick and simple to install, it has gained acceptance by miners throughout the world. The device is particularly useful in mild rockburst environments, because it will slip rather than rupture and, when used with mesh, will retain the broken rock generated by a mild burst. Provided that the demand imposed on Split Sets stabilisers does not exceed their capacity, the system works well and can be considered for many mining applications. They are seldom used in civil engineering applications.

Corrosion remains one of the prime problems with Split Set stabilisers since protection of the outer surface of the dowel is not feasible. Galvanising the tube helps to reduce corrosion, but is probably not a preventative measure which can be relied upon for long term applications in aggressive environments.

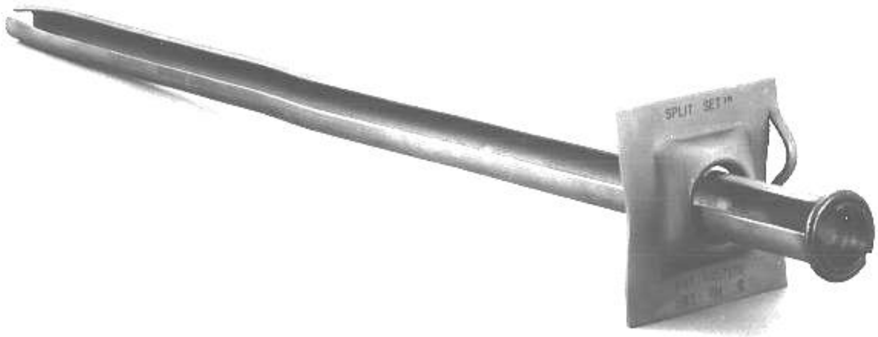


Figure 7: Split Set stabiliser. Ingersol-Rand photograph.

Table 1: Split Set specifications (After Split Set Division, Ingersol-Rand Company).

Split Set stabiliser model	*SS-33*	*SS-39*	*SS-46*
Recommended nominal bit size	31 to 33 mm	35 to 38 mm	41 to 45 mm
Breaking capacity, average	10.9 tonnes	12.7 tonnes	16.3 tonnes
minimum	7.3 tonnes	9.1 tonnes	13.6 tonnes
Recommended initial anchorage (tonnes)	2.7 to 5.4	2.7 to 5.4	4.5 to 8..2
Tube lengths	0.9 to 2.4 m	0.9 to 3.0 m	0.9 to 3.6 m
Nominal outer diameter of tube	33 mm	39 mm	46 mm
Domed plate sizes	150x150 mm	150x150 mm	150x150 mm
	125x125 mm	125x125 mm	
Galvanised system available	yes	yes	yes
Stainless steel model available	no	yes	no

'Swellex' dowels

Developed and marketed by Atlas Copco, the 'Swellex' system is illustrated in Figure 8. The dowel, which may be up to 12 m long, consists of a 42 mm diameter tube which is folded during manufacture to create a 25 to 28 mm diameter unit which can be inserted into a 32 to 39 mm diameter hole. No pushing force is required during insertion and the dowel is activated by injection of high pressure water (approximately 30 MPa or 4,300 psi) which inflates the folded tube into intimate contact with the walls of the borehole.

During 1993 the original Swellex dowel was replaced by the EXL Swellex which is manufactured from a high strength but ductile steel. This steel allows significant displacement without loss of capacity. Stillborg (1994), carried out a series of tests in which bolts and dowels were installed across a simulated 'joint' and subjected to tensile loading. In the EXL Swellex dowel tests, opening of the joint concentrates loading onto the portion of the dowel crossing the joint, causing a reduction in diameter and a progressive 'de-bonding' of the dowel away from the joint. The ductile characteristics of the steel allows the de-bonded section to deform under constant load until, eventually, failure occurs when the total displacement reaches about 140 mm at a constant load of approximately 11 tonnes. These tests are described in greater detail later in this Chapter.

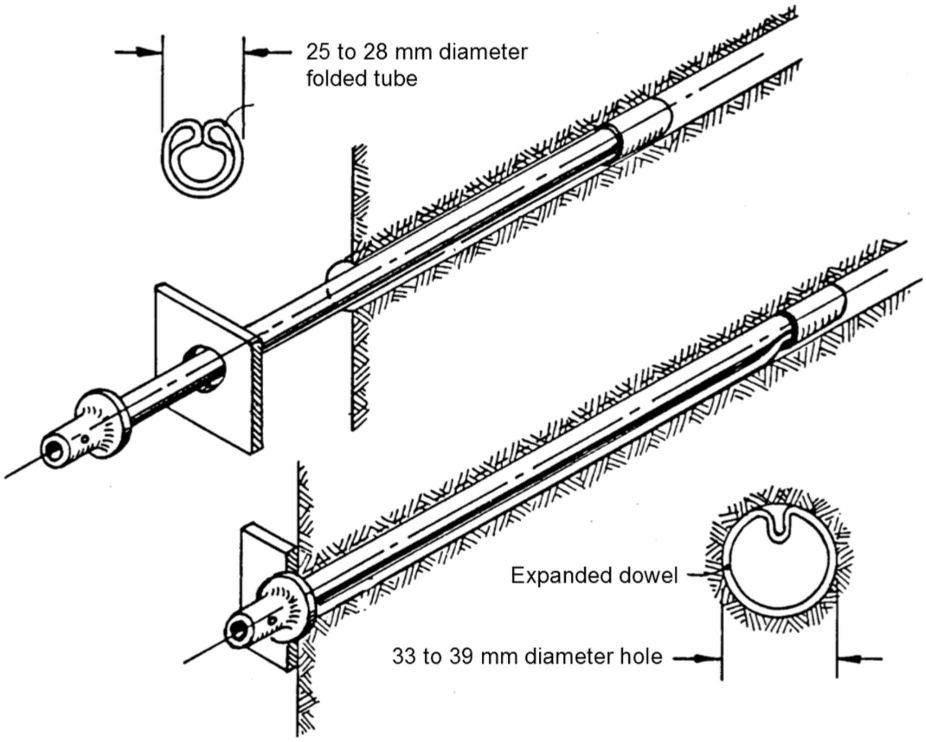


Figure 8: Atlas Copco 'Swellex' dowel.

Corrosion of Swellex dowels is a matter of concern since the outer surface of the tube is in direct contact with the rock. Atlas Copco has worked with coating manufacturers to overcome this problem and claim to have developed effective corrosion resistant coatings.

Speed of installation is the principal advantage of the Swellex system as compared with conventional rockbolts and cement grouted dowels. In fact, the total installation cost of Swellex dowels or Spilt Set stabilisers tends to be less than that of alternative reinforcement systems, when installation time is taken into account. Both systems are ideal for use with automated rockbolters.

Load-deformation characteristics

Stillborg (1994) carried out a number of tests on rockbolts and dowels installed across a simulated 'joint', using two blocks of high strength reinforced concrete. This type of test gives a more accurate representation of conditions encountered underground than does a standard 'pull-out' test.

The rockbolts and dowels tested were installed in percussion drilled holes using the installation techniques used in a normal underground mining operation. The installed support systems were then tested by pulling the two blocks of concrete apart at a fixed rate and measuring the displacement across the simulated 'joint'.

The results of Stillborg's tests are summarised in Figure 9 which gives load deformation curves for all the bolts and dowels tested. The configuration used in each test and the results obtained are summarised on the next page:

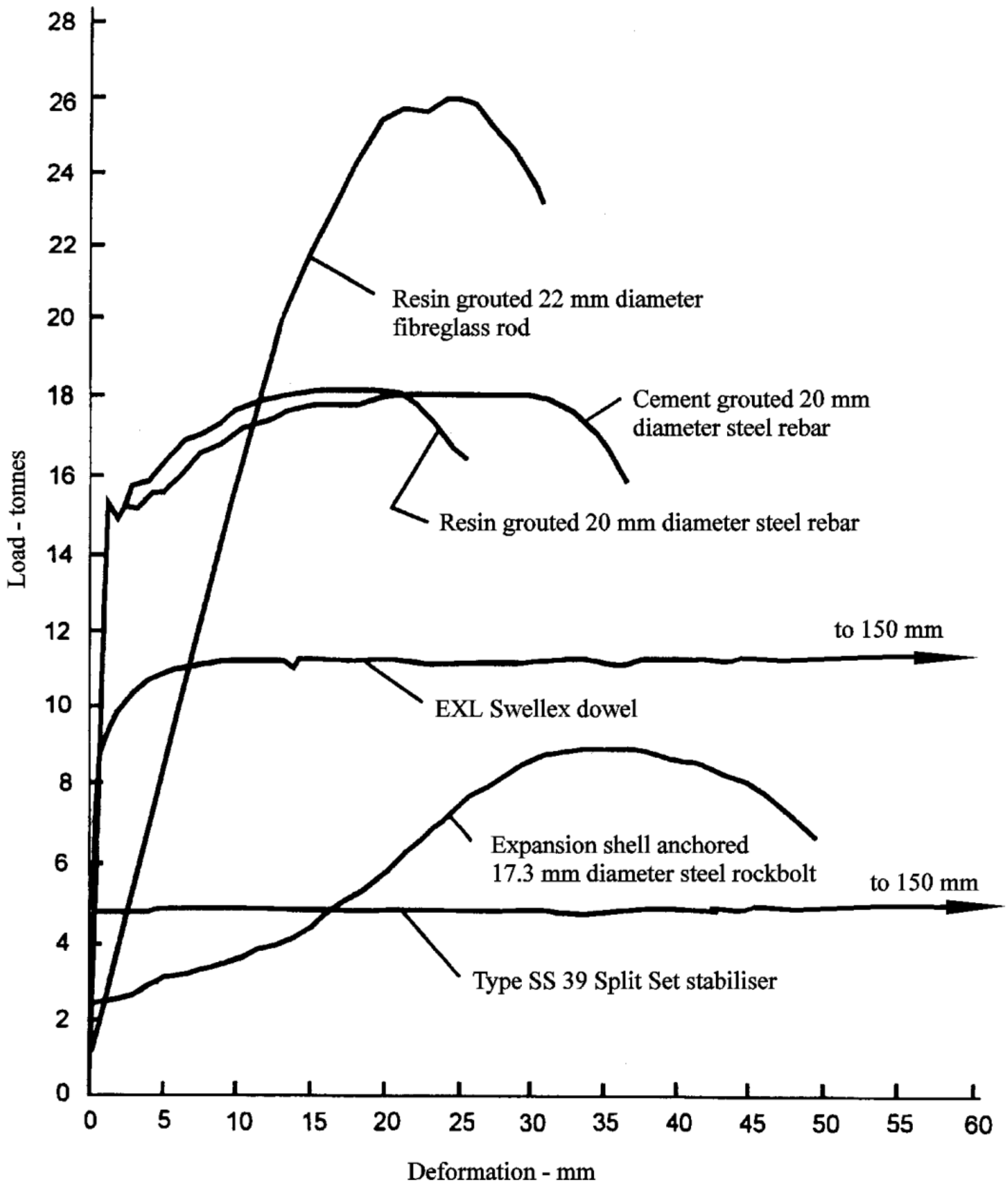


Figure 9: Load-deformation results obtained by Stillborg in tests carried out at Luleå University in Sweden. High strength reinforced concrete with a uniaxial compressive strength of 60 MPa was used for the test blocks and holes were drilled with a percussion rig to simulate in situ rock conditions.

1. Expansion shell anchored rockbolt

Steel rod diameter: 17.28 mm

Ultimate tensile strength of bolt shank: approximately 12.7 tonnes

Expansion shell anchor: Bail type three wedge anchor

At the pre-load of 2.25 tonnes, no deformation of the face plate.

At a load of 4 tonnes, the face plate has deformed 9.5 mm and is completely flat, the bolt shank has deformed an additional 3.5 mm giving a total deformation of 13 mm at 4 tonnes load.

Failure initiates at a load of 8 tonnes and a deformation of 25 mm with progressive failure of the expansion shell anchor in which the cone is pulled through the wedge.

Maximum load is 9 tonnes at a deformation of 35 mm.

2. Cement grouted steel rebar

Steel bar diameter: 20 mm

Ultimate tensile strength of steel rebar: 18 tonnes

Faceplate: flat plate

Borehole diameter: 32 mm

Cement grout: 0.35 water/cement ratio grout cured for 11 days

At a load of 15 tonnes and an elastic deformation of about 1.5 mm, a sudden load drop is characteristic of hot rolled rebar steel.

Maximum load is 18 tonnes at a deformation of 30 mm.

3. Resin grouted steel rebar

Steel rebar diameter: 20 mm

Ultimate tensile strength of steel rebar: 18 tonnes

Faceplate: flat plate

Borehole diameter: 32 mm

Resin grout: Five 580 mm long, 27 mm diameter polyester resin cartridges. Curing time 60 minutes. Mixed by rotating rebar through cartridges in the borehole

At a load of 15 tonnes and an elastic deformation of about 1.5 mm, a sudden load drop is characteristic of hot rolled rebar steel.

Maximum load is 18 tonnes at a deformation of 20 mm

The resin is stronger than the cement grout and local fracturing and bond failure in and near the joint is limited as compared with the cement grouted rebar, leading to a reduced ultimate displacement at rebar failure.

4. Resin grouted fibreglass rod

Fibreglass rod diameter: 22 mm

Ultimate tensile strength of fibreglass rod: 35 tonnes

Faceplate: special design by H. Weidmann AG. Switzerland (see margin drawing - after Stillborg)

Borehole diameter: 32 mm

Resin grout: Five 580 mm long, 27 mm diameter polyester resin cartridges. Curing time 60 minutes. Mixed by rotating fibreglass rod through cartridges in the borehole

At approximately 1.5 tonnes load, failure of the fibreglass/resin interface initiates and starts progressing along the rod. As bond failure progresses, the fiberglass rod deforms over a progressively longer 'free' length.

General bond failure occurs at a load of approximately 26 tonnes and a deformation of 25 mm.

The ultimate capacity of this assembly is determined by the bond strength between the resin and the fibreglass rod and by the relatively low frictional resistance of the fibreglass.

5. Split Set stabiliser, type SS 39

Tube diameter: 39 mm

Ultimate tensile strength of steel tube: 11 tonnes

Faceplate: special design by manufacturer (see Figure 8)

Borehole diameter: 37 mm

Dowel starts to slide at approximately 5 tonnes and maintains this load for the duration of the test which, in this case, was to a total displacement of 150 mm

6. EXL Swellex dowel

Tube diameter: 26 mm before expansion

Ultimate tensile strength of steel tube: 11.5 tonnes (before expansion)

Type of face plate: Domed plate

Borehole diameter: 37 mm

Pump pressure for expansion of dowel: 30 MPa

At 5 tonnes load the dowel starts to deform locally at the joint and, at the same time, 'bond' failure occurs at the joint and progresses outward from the joint as the load is increased. General 'bond' failure occurs at 11.5 tonnes at a deformation of approximately 10 mm. The dowel starts to slide at this load and maintains the load for the duration of the test which, in this case, was to 150 mm.

Cables

A comprehensive review of cable support in underground mining has been given in a book by Hutchinson and Diederichs (1996). This book is highly recommended for anyone who is concerned with the selection and installation of cable support for either mining or civil engineering applications.

Some of the main cable types used by mining were summarised by Windsor (1992) and are illustrated in Figure 10.

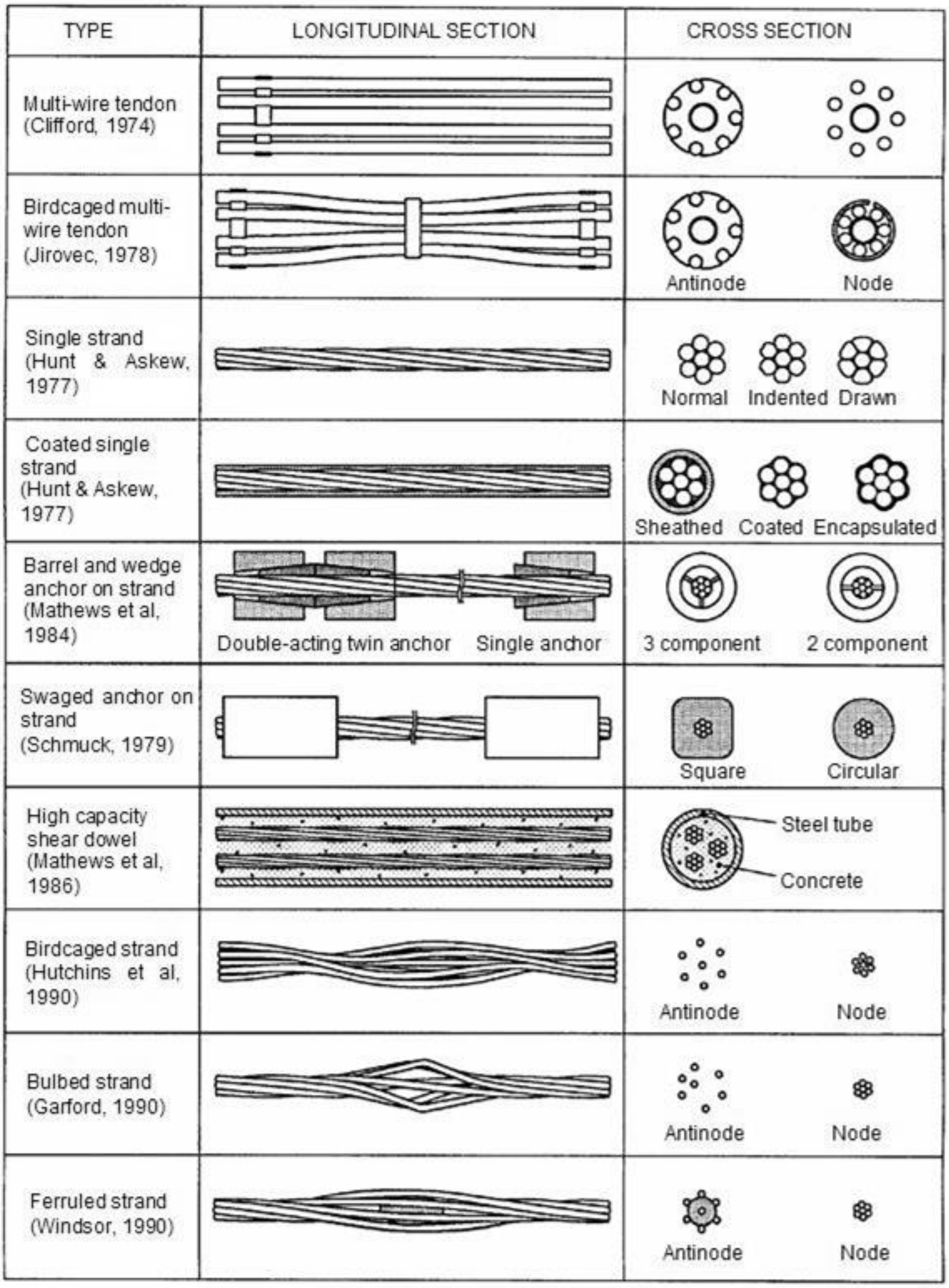


Figure 10: Summary of the development of cable reinforcing systems for underground mining (Windsor, 1992).

Bond strength

The forces and displacements associated with a stressed cable grouted into a borehole in rock are illustrated in Figure 11.

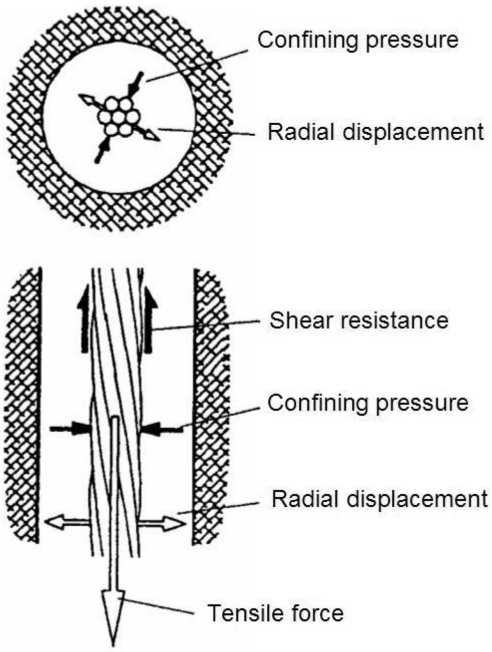


Figure 11: Forces and displacements associated with a stressed cable grouted into a borehole in rock.

As the cable pulls out of the grout, the resultant interference of the spiral steel wires with their associated grout imprints or flutes causes radial displacement or dilation of the interface between the grout and the cable. The radial dilation induces a confining pressure that is proportional to the combined stiffness of the grout and the rock surrounding the borehole. The shear stress, which resists sliding of the cable, is a product of the confining pressure and the coefficient of friction between the steel wires and the grout. Shear strength, therefore, increases with higher grout strength, increases in the grout and the rock stiffness and increases in the confining stresses in the rock after installation of the cable. Conversely, decrease in shear strength can be expected if any of these factors decrease or if the grout crushes.

Theoretical models of the behaviour of this rock/grout/cable system have been developed by Yazici and Kaiser (1992), Kaiser et al (1992), Hyett et al (1992). The second of these models has been incorporated into the program PHASE2.

Grouts and grouting

The question of grout quality has always been a matter of concern in reinforcement systems for underground construction. One of the critical factors in this matter has been the evolution of grout pumps capable of pumping grouts with a low enough water/cement ratio (by weight) to achieve adequate strengths. Fortunately, this problem has now been overcome and there is a range of grout pumps on the market which will pump very viscous grouts and will operate reliably under typical underground conditions.

The results of a comprehensive testing programme on Portland cement grouts have been summarised by Hyett et al (1992) and Figures 12, and 13 are based upon this summary. Figure 12 shows the decrease in both 28 day uniaxial compressive strength and deformation modulus with increasing water/cement ratio. Figure 13 gives Mohr failure envelopes for three water/cement ratios. These results show that the properties of grouts with water/cement ratios of 0.35 to 0.4 are significantly better than those with ratios in excess of 0.5. However, Hyett et al found that the scatter in test results increased markedly for water/cement ratios less than 0.35. The implication is that the ideal water/cement ratio for use with cable reinforcement lies in the range of 0.35 to 0.4.

The characteristics of grouts with different water/cement ratios are described as follows (after Hyett et al 1992):

w/c ratio	*Characteristics at end of grout hose*	*Characteristics when handled*
< 0.30	Dry, stiff sausage structure.	Sausage fractures when bent. Grout too dry to stick to hand. Can be rolled into balls.
0.30	Moist sausage structure. 'Melts' slightly with time.	Sausage is fully flexible. Grout will stick to hand. Easily rolled into wet, soft balls.
0.35	Wet sausage structure. Structure 'melts' away with time.	Grout sticks readily to hand. Hangs from hand when upturned.
0.4	Sausage structure lost immediately. Flows viscously under its own weight to form pancake.	Grout readily sticks to hand but can be shaken free.
0.5	Grout flows readily and splashes on impact with ground.	Grout will drip from hand - no shaking required.

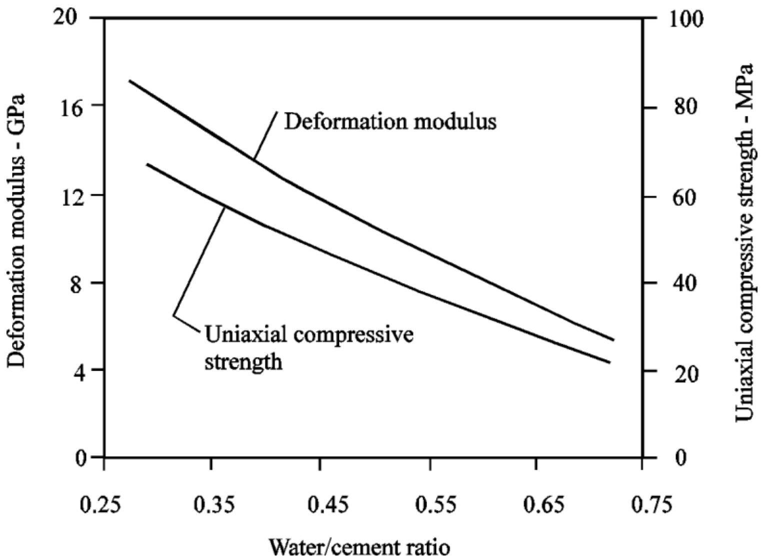
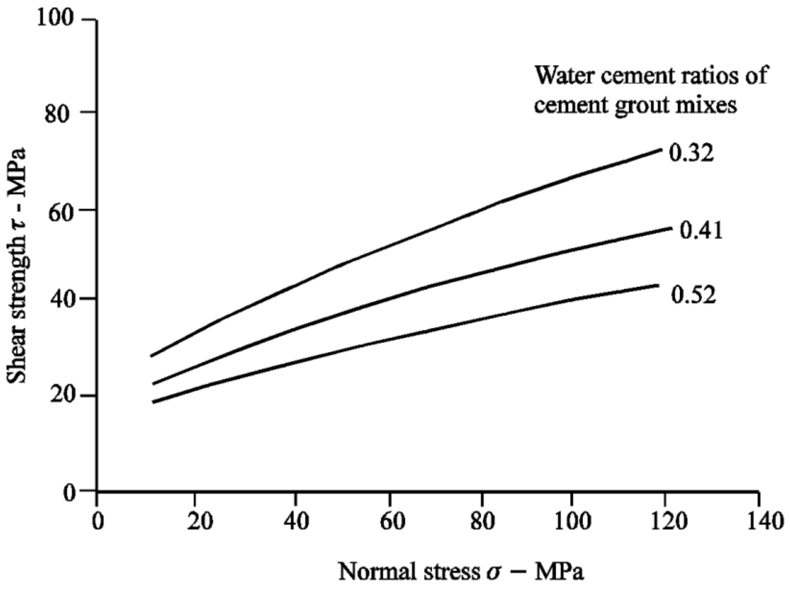


Figure 12: Relationship between the water/cement ratio and the average uniaxial compressive strength and deformation modulus for grouts testes at 28 days.



w/c ratio	σ_c *MPa*	*constant m*	*constant s*	*Friction angle* $\phi°$	*Cohesion c MPa*
0.32	78	3.05	1	24	25
0.41	54	2.14	1	20	19
0.52	38	1.67	1	17	14

Figure 13: Mohr failure envelopes for the peak strength of grouts with different water/cement ratios, tested at 28 days.

Cable installation

The left hand drawing in Figure 14 shows the traditional method of grouting a cable in an uphole. This method will be called the 'breather tube method'. The grout, usually having a water/cement ratio ≥ 0.4, is injected into the bottom of the hole through a large diameter tube, typically 19 mm diameter. The air is bled through a smaller diameter tube which extends to the end of the hole and which is taped onto the cable. Both tubes and the cable are sealed into the bottom of the hole by means of a plug of cotton waste or of quick setting mortar. As shown, the direction of grout travel is upwards in the hole and this tends to favour a grout column which is devoid of air gaps since any slump in the grout tends to fill these gaps.

Apart from the difficulty of sealing the collar of the hole, the main problem with this system is that it is difficult to detect when the hole is full of grout. Typically, the hole is judged to be full when air ceases to flow from the bleed tube. This may occur prematurely if air is vented into an open joint along the hole. In addition, a void the size of the bleed tube is likely to be left in the grout column. Therefore, it is preferable to stop grouting the borehole only when grout returns along the bleed tube. However, a viscous grout will not flow down a 9 mm bleed tube and so a larger tube is required.

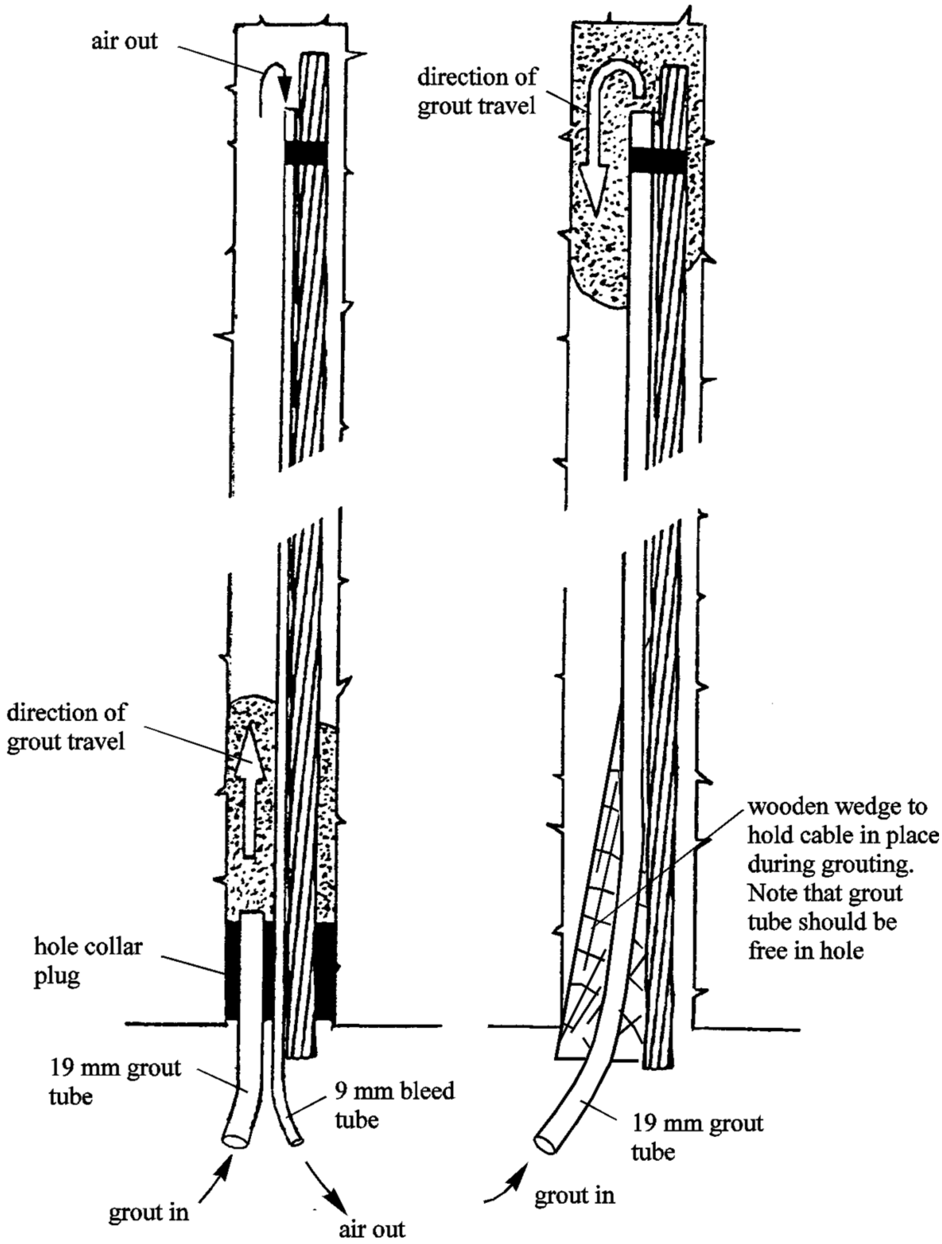


Figure 14: Alternative methods for grouting cables in upholes.

An alternative method, called the ‘grout tube method’ is illustrated in the right hand drawing in Figure 14. In this case a large diameter grout injection tube extends to the end of the hole and is taped onto the cable. The cable and tube are held in place in the hole by a wooden wedge inserted into the hole collar. Note that care has to be taken to avoid compressing the grout tube between the wedge and the cable. Grout is injected to the top of the hole and is pumped down the hole until it appears at the hole collar. If a watery grout appears first at the collar of the hole, grout pumping is continued until a consistently thick grout is observed.

Provided that a very viscous mix is used (0.3 to 0.35 water/cement ratio), the grout will have to be pumped into the hole and there is little danger of slump voids being formed. However, a higher water/cement ratio mix will almost certainly result in air voids in the grout column as a result of slumping of the grout. The principal advantage of this method is that it is fairly obvious when the hole is full of grout and this, together with the smaller number of components required, makes the method attractive when compared with the traditional method for grouting plain strand cables. In addition, the thicker grout used in this method is not likely to flow into fractures in the rock, preferring instead the path of least flow resistance towards the borehole collar.

The procedure used for grouting downholes is similar to the grout tube method, described above, without the wooden wedge in the borehole collar. The grout tube may be taped to the cable or retracted slowly from the bottom of the hole as grouting progresses. It is important to ensure that the withdrawal rate does not exceed the rate of filling the hole so the air voids are not introduced. This is achieved by applying, by hand, a slight downward force to resist the upward force applied to the tube by the rising grout column. Grout of any consistency is suitable for this method but the best range for plain strand cables is between 0.3 and 0.4 water/cement ratio.

Modified cables, such as birdcage, ferruled or bulbed strand, should be grouted using a 0.4 water/cement ratio mix to ensure that the grout is fluid enough to fill the cage structure of these cables. Therefore, the breather tube method must be used for these types of cables, since the grout flow characteristics required by the grout tube method is limited to grouts in the range of 0.3 to 0.35 water/cement ratio.

One of the most critical components in a cable installation is the grout column. Every possible care must be taken to ensure that the column contains as few air voids as possible. In the breather tube method, a large diameter breather tube will allow the return of grout as well as air. When using the grout tube method in upholes, a 0.3 to 0.35 water/cement ration grout will ensure that pumping is required to cause the grout column to flow, and this will avoid slumping of the grout in the borehole. A grout with a water/cement ratio of less than 0.3 should be avoided, since it will tend to form encapsulated air voids as it flows around the cable.

A hollow cable, illustrated in Figure 15, has been introduced by Atlas Copco and this could reduce some of the grouting problems discussed above.

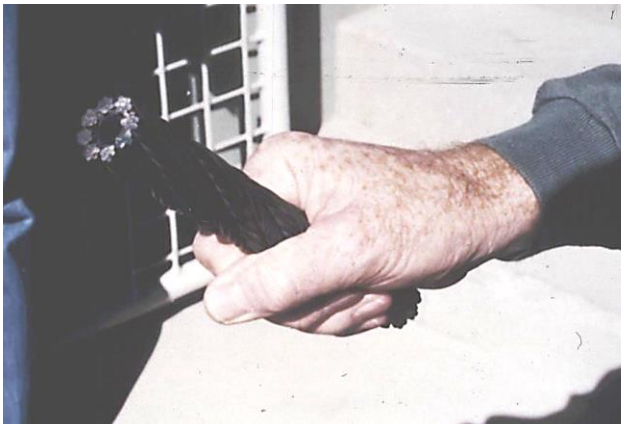


Figure 15: Hollow cable by Atlas Copco.

Cables for slope reinforcement

Most of the applications described in this chapter have been related to underground excavations. However, under certain circumstances, it may also be necessary to reinforce slopes and foundations and cables have proved to be very effective in such applications.

Figure 16 illustrates a unit set up for drilling 140 m long 50 mm diameter holes for the installation of cables, illustrated in Figure 17, in a slope.

Figure 16: Drilling machine for the installation of 40 m long reinforcing cables in 150 mm diameter holes in a dam excavation.

Figure 17: 40 m long multi-strand cables with a capacity of 200 tons each being prepared for installation in a dam excavation.

These cables were installed to stabilise the slopes of a dam foundation in gneiss. Sheet jointing parallel to the surface of the steep slopes would have resulted in large scale slope instability if the excavation, which undercut these sheet joints, had not been reinforced.

The cables illustrated have an ultimate capacity of 312 tons and a working load of 200 tons. The cables were fully grouted after tensioning. The cost of materials and installation for these cables was approximately US$ 500 per metre.

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