Master Thesis

Mechanization and Automation of Rock Bolting in Mines

Eyüp Türkmen
2009

Department Mineral Resources and Petroleum Engineering
Chair of Mining Engineering

AFFIDEVIT

I declare in lieu of oath, that I wrote this thesis and performed the associated research myself, using only literature cited in this volume.

EIDESSTATTLICHE ERKLÄRUNG

Ich erkläre an Eides statt, dass ich diese Arbeit selbständig verfasst, andere als die angegebenen Quellen und Hilfsmittel nicht benutzt und mich auch sonst keiner unerlaubten Hilfsmittel bedient habe.

Datum

Unterschrift

Abstract

Rock bolts are a type of reinforcement element, which is used in underground excavations to increase the stability and to prevent rock falls. They are designed to provide the safety of crews and to generate stable working conditions. Nowadays, rock bolting applications are widely operated in underground mines, ground engineering and tunnelling fields.

In the first part of this study, the relationships between rock bolts and rock mechanics as well as the positive outcomes of the usage of rock bolts applied in underground mining and construction have been investigated.
All commercial rock bolts available on the market, automated or none automated types, as well as different types of patented systems not yet introduced in the market, have been examined. However, this studies main part focuses on available automated rock bolts, which are described in detail.

Other important parts discussed in this study are the available automated and mechanized systems for rock bolt installation, a brief overview of the historic development of rock bolting and the future trends of rock bolting systems.

Acknowledgements

I would like to thank my supervisor Dipl.-Ing. Wolfgang Hohl, for his guidance and helps through this thesis.

I also thank my other supervisor Mr. Uwe Seifter from Sandvik Mining and Construction G.m.b.H. (Zeltweg/Austria).

Also, I extend sincere thanks to the other members of advisor committee: Prof. Dr. Peter Moser, Dr. Nikolaus Sifferlinger.

A special thanks to Prof. Dr. Horst Wagner for his great contribution to the correction of errors and his guidance.

Table of Contents

List of Figures

List of Tables

1 Introduction and Aim of the Thesis

After blasting and ore removal has been performed in the stope of a mine, rock falls must be prevented if personnel are to be allowed into this area. This is most commonly done using rock bolts installed over head in the roof of the stope and in the upper parts of the walls, to create a stable arch of rock.

Rock reinforcement is necessary operation in most underground rock excavations. An improved understanding of the mechanism of rock reinforcement will lead to the further development of equipment and installation methods. Bolting involves heavy manual work, and exposes the miners performing the work to some danger. Automation of rock bolting operation increases safety and improves overall productivity, minimizing the necessary time and costs of rock bolt installation.

Today's efforts in the field of research of rock bolts will certainly result in the development of more flexible automated rock bolt systems. These systems will have different properties and behaviour in different reinforcement situations. The rock bolts could be installed to work as a full length supporting anchor in a typical beam forming situation, a sliding bolt in a rock mass where large deformations are expected or a tensioned bolt in a rock mass that has already been subjected to extensive deformations. Such a bolting operation, where every bolt is optimized for its job, will require fewer bolts to be installed to reach the required safety, or provide increased safety for the same bolting effort [1] [2].

This study examines commercially available rock bolts from the point of view of mechanization and automation. It provides an overview on rock bolting technology being used in mining and tunnelling, describes the different rock bolting systems, works out their advantages and disadvantages, and provides an understanding of installation principles.

2 Overview of Rock Bolting

For rock bolts the following properties, depending on their use, are expected:

- High stiffness for maximum reinforcing
- Provision of immediate bolting effect
- High load bearing
- High deformation at failure
- Resistance to corrosion
- Quick installation
- Ease of installation, user-friendliness

Although there are many various types of rock bolting available, there are some specific main differences between them. In this thesis the different types of rock bolts are divided into categories according to the anchoring mechanism. For each category the most representative rock bolt is described in detail [3].

2.1 Rock Mechanics of Rock Bolting

2.1.1 How Bolts enhance the Strength of Rock Surrounding Underground Excavations

If failure around an excavation, whether at surface or underground occurs for example blocks of rock moving into the excavation, two approach philosophies can be considered for stabilisation:

- block displacement is occurring because the rock mass is a discontinuum, and hence the rock is reinforced so that it behaves like a continuum or
- direct support elements are introduced into the excavation in order to maintain block displacement at tolerable levels

The first option is known as rock reinforcement and second is known as rock support. For rock reinforcement the engineering elements are installed within the rock mass, for rock support they are inserted on the surface of the rock mass.

In the case of reinforcement, steel cables or bars grouted within boreholes are used in an attempt to minimize displacement occurring along the pre-existing discontinuities, so that rock supports itself.

Rock reinforcement applied to mainly continuous rock masses differs from that used in discontinuous rock masses because of action of the reinforcing elements [4].

2.1.1.1 Rock Reinforcement in Continuous Rock

It seams that the use of rock reinforcement is only of use in discontinuous rock masses in order to prevent discrete block displacement. However, the use of rock reinforcement in a continuous medium can also be of benefit because of the reinforcement effect of on the overall rock properties and hence rock behaviour. If continuous rock is competent, it maybe well capable of withstanding the induced stresses without further support. Conversely, if continuous rock is weak, heavy direct support may be required, such as segmental pre-cast concrete rings.

Consider an element of reinforced rock adjacent to the excavation boundary. The effect of reinforcing elements is to produce effective confining stress of

$$\sigma_r = A \cdot E \cdot v \cdot \sigma_\theta \qquad (2.1)$$

Where A and E are the ratios of the cross-sectional areas and Young's moduli of the reinforcing element to that of the rock being reinforced. v is Poisson's ratio for the rock, and σ_θ is the tangential stress. The larger the ratios A and E, for an increased rock density and lower stiffness rock, respectively, the larger the effective confining pressure will be. The effect of a small confining stress on the strength and shape of the complete stress-strain curve of rock in compression can be seen in figure 1. Use of this type of analysis provides a rapid means of determining the value of reinforcing continuous rock, which will clearly be most effective in low-stiffness, low-strength, brittle rocks.

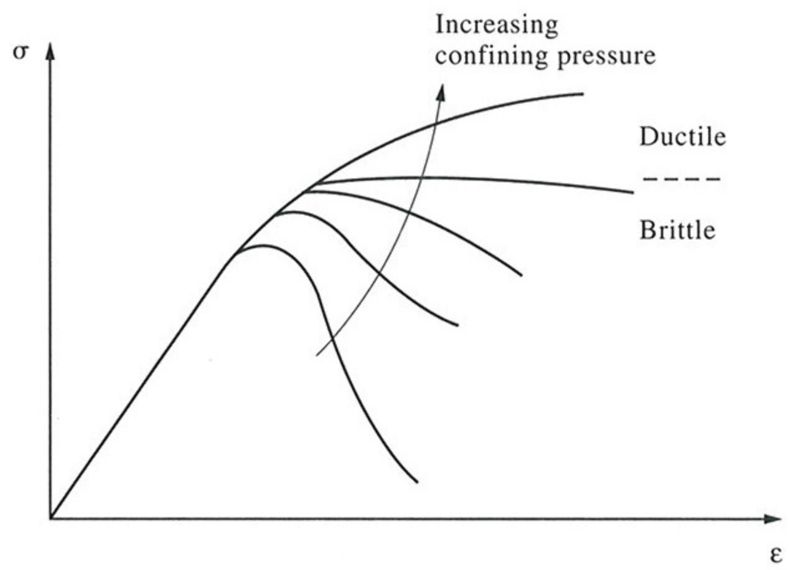


Figure 1: Effect of confining pressure in the triaxial test and the brittle-ductile transition [4]

The curve demonstrates less brittle behaviour as the confining pressure is gradually increased. The post-peak curve is essentially a horizontal line, presenting continuing strain at a constant stress level or strength is not affected by increasing strain. Below this line, the material strain softens: above this line strain hardening occurs. The horizontal line is termed the brittle-ductile transition [4].

2.1.1.2 Rock Reinforcement in Discontinuous Rock

The mode of action of the reinforcement in a discontinuous medium is different to that described in section 2.1.1.1 because, not only improvement of the rock structure properties, but also the avoidance of large displacements of complete blocks. Two of the most important factors are whether the blocks are free to move, given the geometry of the rock mass and excavation, and the character of the reinforcement. The simplest case of reinforcing a discontinuous material, a single block on a rock surface is reinforced by a tension anchor is shown in figure 2. The tension anchor should be installed such that the block and the rock beneath act as a continuum, and block movement is prevented [4].

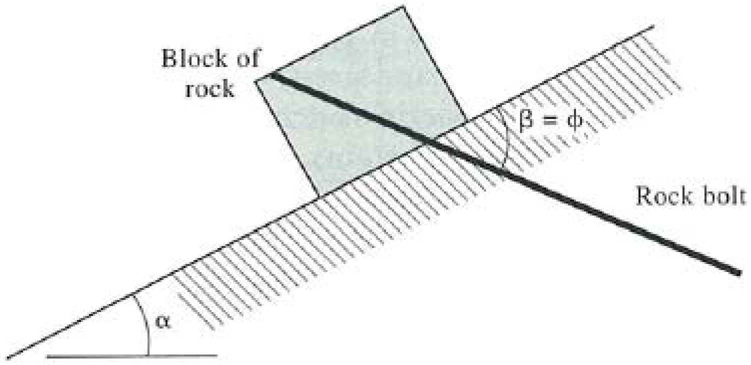


Figure 2: Optimized rock reinforcement for the case of a block on a rock surface [4]

For the simple geometry without rock bolt, basic mechanics indicates that the block will slide if the angle of the slope exceeds the angle of friction of the rock surfaces for a cohesionless interface. This is therefore the first criterion for indicating the potential for failure. Considering now the length and diameter of the bolt, these have to be sufficient to ensure that the strength of the bonds across the anchor-grout and grout-rock interfaces are capable of sustaining the necessary tension in the anchor, in turn will depend on the basis of the tensile strength of the anchor material.

With respect to the bolt orientation and tension, it is not obvious at what angle the anchor should be orientated for optimal effect, taking into account the basic mechanics and the rock structure. The optimal orientation for the anchor enables the anchor tension to be a minimum. The angle between the anchor and the slope surface is equal to the friction angle between the block and the slope. If the reinforcement inhibits block movement, and sufficient stress can be transmitted across the interface, then in principle the rock reinforcement has changed the rock discontinuum to a rock continuum.

In practice, when rock anchors are installed in a discontinuous rock mass, the rock surface is often covered with wire mesh and then covered in shotcrete. It is emphasized that the wire mesh and shotcrete are part of the rock reinforcement system [4].

2.1.1.3 Rockbolt anchors for high Convergence or Rock Burst Condition

In deeper hard rock mines, the rock mass and stress conditions can lead to extensive rock fracturing and dilatation resulting in high ground convergence around mine opening and drifts. In some cases, the convergence occurs violently and rapidly in the form of rock bursts. As these mines proceed to greater depths, the ground control problems will become worse and new rock support systems must be developed and used.

High horizontal in situ stress is one of the most important parameters affecting the planning and understanding of the behaviour of the rock mass around an underground excavation. By opening the tunnels in highly stressed rocks the primary stress state redistributes and high boundary stresses are likely to occur around and in the vicinity of excavated holes. The magnitudes of the boundary stresses might be close to the strength of the intact rock. Under these conditions, the occurrence of rock failure might be possible. The objective of this section is to understand the problems that maybe caused by excavating underground structures in high stress field. The exceeding of rock strength and intensive failure might exist around the tunnels based on high stress/strength relation.

In the design phase, the effect of excavation works of the surrounding rock mass should be taken into account. The purpose of rock support planning is to generate an additional forces against the tangential compressive stress and prevent rock mass loosening. In the vicinity of high contact stress, two main functions of support systems are used:

- Strengthen a jointed rock mass by forming a rock arch to carry the induced stresses, minimize the loosening and the weakening of the rock mass. Support elements acted in a stiff manner.
- Retain the broken rock and hold the material in place by tying it back, so called the yielding method.

Service life, design of span, magnitude and direction of the in situ stress and geology in the vicinity of an opening are important factors for the design of the support system. When magnitude of in situ stress and deformations will increase, the retaining or holding function of the reinforcement apparently becomes more critical and the reinforcing and strengthening function will diminishes.

When planning the support system in burst-prone areas, the following aspects should be considered:

- high initial stiffness of reinforcing elements for strengthening the rock mass
- maintaining the supporting function even under conditions of large deformations
- maintaining the integrity of full areal coverage
- strong connection between retaining and holding elements
- efficient integration of elements from low to higher level support system

In case of spalling and rock burst, the main support method is rock bolt installed with steel platens [5].

Conventional rock bolts such as resin-grouted rebars and mechanical end-anchored rock bolts are proved highly effective under most ground conditions, even for drifts in highly fractured and stressed ground where moderate ground convergence occurs. However, when these rock bolts are used in tunnels or mine drifts with large ground convergence or rock bursts, their limited ability to yield often results in their failure. Within economic and practical limits, ground support can not be used to prevent movement and rock fracturing. Under these conditions, the primary support design philosophy is not to enhance the stiffness and strength of the rock bolts to resists or prevent the ground movement. In this case, the rock bolts must be designed to yield or slide with the ground movements while simultaneously providing a substantial resistive force, thereby helping to control rock displacements and minimizing damage to the excavation [6].

The need for yielding rockbolts for use in highly stressed and rockburst-prone drifts has long been recognized in deep mines. This has lead to the development of recommended performance requirements for yielding rock bolts and the development and testing of yielding rock bolts. A yielding rock bolt based on a fully grouted deformed bar with sliding nut near the plate has been developed for use in burst-prone ground. This sliding support nut concept was also adapted for squeezing ground and openings subject to high convergence [7].

2.1.1.4 Soft Rock Mass Behaviour

Since the mechanical properties of the rock mass influences the behaviour of the rock bolting system significantly, the behaviour of rock mass is discussed separately. Accordingly, the soft rock mass around tunnel may divided into three zones such as the plastic flow zone, the strain-soften zone and the elastic zone, as shown in figure 3.

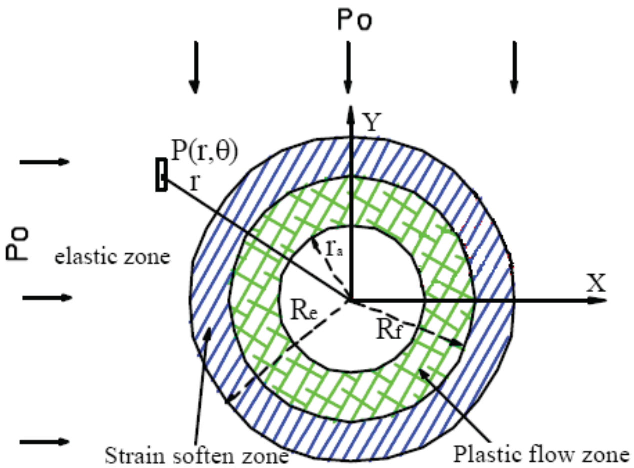


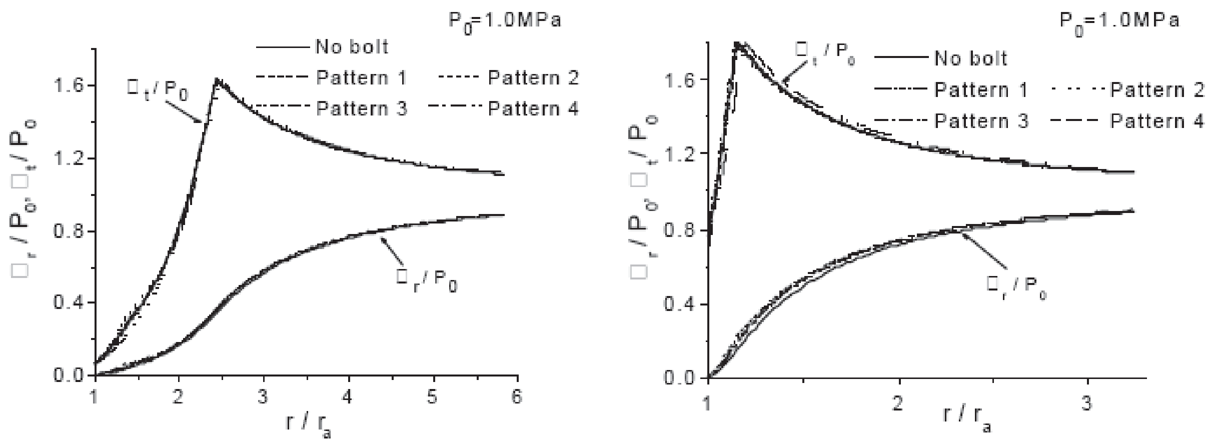
Figure 3: Tunnel excavation in soft rock mass [8]

The displacement formulas of each zone can be obtained according to different constitutive law. It should be pointed out that the strain softening constitutive law describes the behaviour of homogenous material, it also can be referenced to describe the rock bolting system together considering the anisotropic characteristic of rock mass [8].

2.1.1.4.1 Rock Bolting Effect on Soft Rock Mass Behaviour

The stress distribution of the rock mass is a useful index to evaluate the stability of the rock mass, and it is also an index of the rock bolting effect.

The ground condition is often described by the so-called competency factor $Srp = \sigma_c / p_0$, where σ_c is the strength of the rock mass and p_0 is the in-situ stress. For the standard supporting pattern, the stress distribution in the bolted rock mass under different ground condition is shown in figure 4.



$Srp = \sigma_c / p_0 = 0.1$ $Srp = \sigma_c / p_0 = 1.0$

Figure 4: Stress distribution of rock mass with different rock bolting pattern [8]

Under the low Srp ground condition, e.g. $Srp = 0.1$, the stress of the rock mass almost has no changes before and after bolting, which implies that the rock bolting effect is not significant. This is because a decoupling failure has taken place at the interface between the rock bolt and rock mass.

When $Srp = 0.5$, the rock bolting effect is the largest and the most significant. When the ground condition is relatively good, e.g. $Srp = 1.0$, the rock bolting effect also becomes insignificant. This is because the deformation of the rock mass becomes smaller in a good ground condition, and the initiated axial force in the rock bolt becomes smaller correspondingly [8].

2.1.2 Support Action of Bolts

2.1.2.1 Suspension

When an excavation is formed the equilibrium in the rock mass is disturbed. Rock can fracture around the excavation and block of rock can be detached. Blocks of rock formed by pre-existing discontinuities and/an arch induced fractures can form. These blocks, when not properly supported, can move into the excavation and constitute a danger for the mining personal and the stability of the excavation. The objective of support in this instance is to secure rock blocks to intact rock strata [3].

Suspending beam, in the case of roofs having layered structure like sedimentary rocks, horizontally layered roof layers may not be able to bear their own weight and detach from the main roof, in this case we suspend those unstable roof layers to the competent rock strata, as in the figure 5 as an example [1].

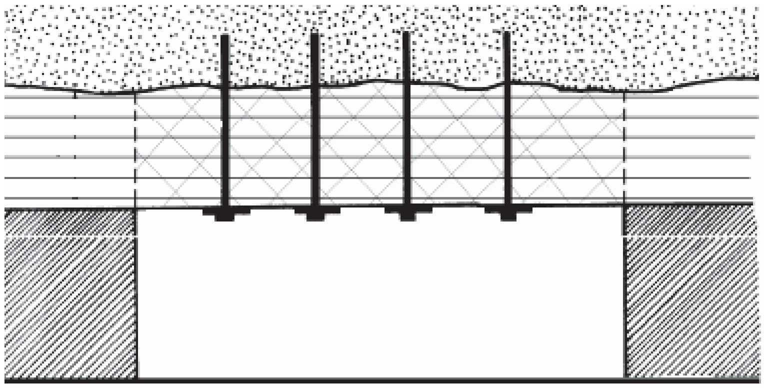


Figure 5: Suspension effect of rock bolting [9]

Design of a support system through the suspension mechanism must consider the following factors [10]:

- System anchorage load capacity must be greater than the weight of the roof layer to be supported
- Critical length of anchorage must be recognised
- Anchorage stratum must be competent, with consideration given to high contact stress around mechanically anchored rockbolts
- Rockbolt spacing must consider thin strata sagging between rockbolts
- Support factor of safety must be appropriate

2.1.2.2 Beam Building

The aim of beam concept is to increase the bearing capacity of thin laminated rock strata by building a thick beam, rather than hanging the detached layers to the competent roof. By clamping together through rock bolting these layers, multiple beams then become a single beam. This massive beam provides increased stiffness and strength. When the beam deflects, compression occurs in the upper layers, and tension in the immediate roof layers (figure 6). This results in differential movement between layers, thus generating frictional shearing. Resistance to this mechanism is through the following:

- Cohesion between the layers (C)
- Frictional resistance between layers (φ) due to clamping forces acting normal to the layers [11].

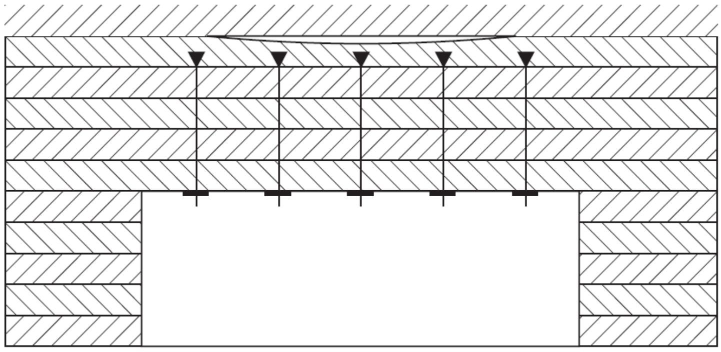


Figure 6: Rock bolting to generate beam effect [12]

The improvement of bending strength is always good for roof stability. Under certain conditions, increasing bending stiffness may cause extra load from the overlying strata acting on the beam. The beam may not fail in tension because of the increased bending strength, but may fail by shearing at the two ends once the accumulated shear forces exceed the shear strength of the composite beam (figure 7). This kind of failure has the following features:

- The bolted composite beam falls out
- Failure planes at the two ends of the beam are nearly vertical
- The upper failure plane is exactly at the bolted horizon where pre-tension of the bolts creates a tensile stress area around the anchor of each bolt
- Sometimes using longer bolts just increases the height of roof fall [9].

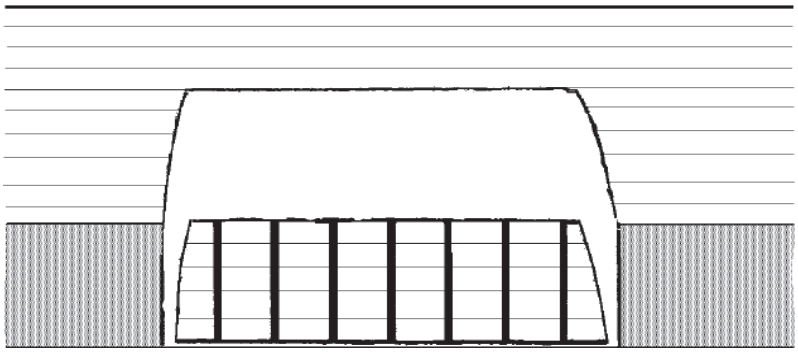


Figure 7: Shear failure of beam building [9]

Various ordered and numbered bolts are placed on a gallery roof having rectangular cross-section as seen in figure 8.

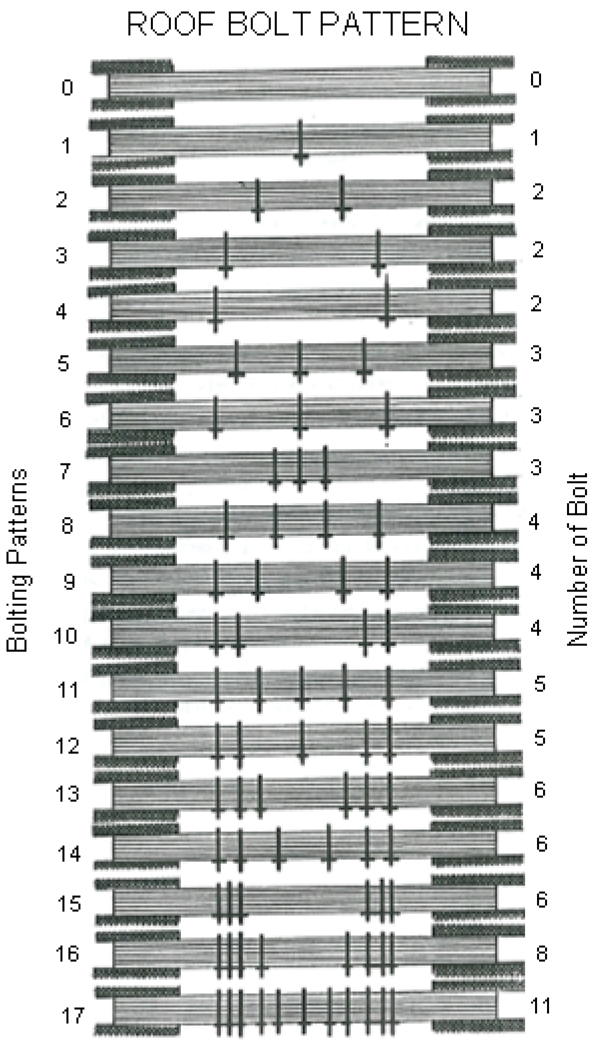


Figure 8: Different bolting patterns [13]

As a result of the studies based on this fact, a significant relationship among beam deflections occurring according to the various ordered bolting is illustrated in figure 9.

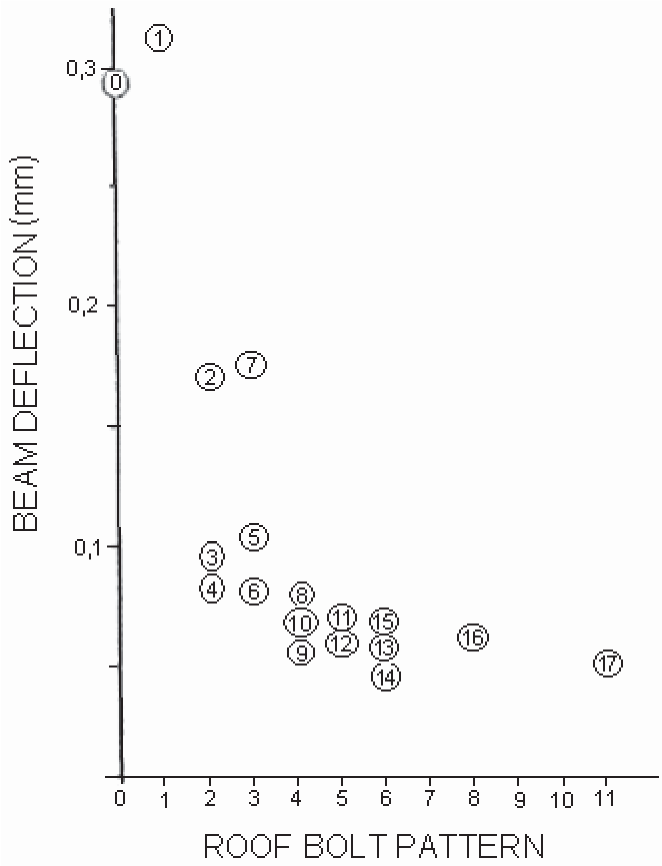


Figure 9: Comparing the beam deflection for various bolting patterns [13]

Shear stress in the middle of a beam which is fixed on both sides is zero and a bolt ordered in the middle of a beam is not able to take a load at beam building [13]. The effect of increasing bending strength is illustrated in figure 10.

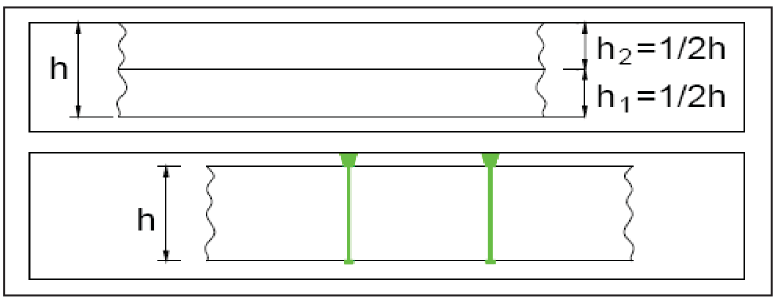


Figure 10: Layers without bolting and with bolting

When bending strengths of h_1 and h_2 layers with equations thickness are compared such a result comes up in (2.2) and (2.3):

$$(E \cdot I)_{Withoutbolting} = \frac{E \cdot \sum_i (h_i^3)}{12} = \frac{E}{12} \cdot \left[\left(\frac{h}{2} \right)^3 + \left(\frac{h}{2} \right)^3 \right] = \frac{1}{4} \cdot \frac{E \cdot h^3}{12} \tag{2.2}$$

$$(E \cdot I)_{Withoutbolting} = \frac{E \cdot h^3}{12} \tag{2.3}$$

As mentioned above equals (2.2) and (2.3), bending strength of bolted layers is likely to increase four times. Beam widths of rectangle cross sections are taken to be 1 meter by unit [14].

2.1.2.3 Rock Arches

If an opening with a curved roof is excavated in a jointed rock mass, a natural arch is formed at some depth in the rock, above the ceiling of the opening illustrated in figure 11 [1]. This mechanism relies on the identification of critical blocks to be supported, and the systematic placement of supporting rockbolts to establish a compressive rock arch.

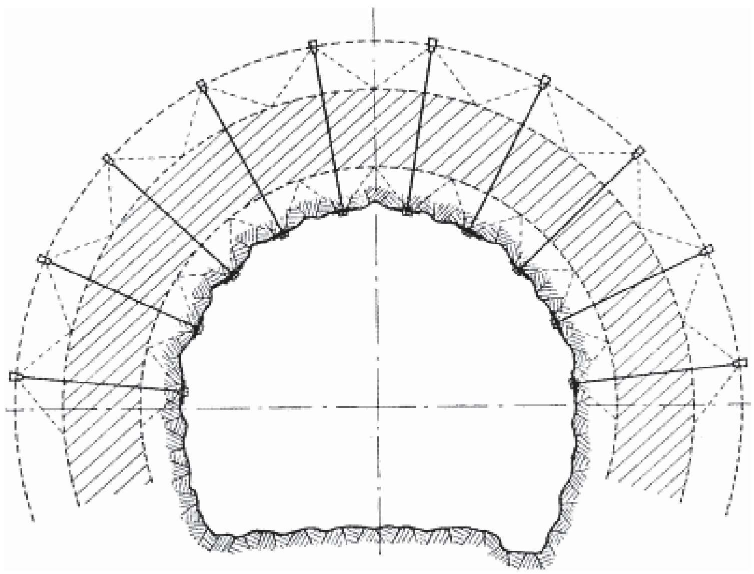


Figure 11: Ground arch produced by rock bolts [15]

When the roof strata is highly fractured and blocky, or the immediate roof contains one or several sets of joints with different orientations to the roofline, roof bolting provides significant frictional forces along fractures, cracks and weak planes. Sliding and/or separation along the interface is thus prevented or reduced.

Besides to rock bolts, cable bolts are also used to maximise support effectiveness, and to increase the scope of the compressive arch. It should be noted that this mechanism is seldom used in soft rock mining [11].

2.2 Types of Rock Bolts

2.2.1 According to Anchor Mechanism

There are many different rock bolts currently on the market all can be classified based on the coupling length. The main categories are:

- Point anchorage
- Full-length anchorage

2.2.1.1 Point anchored Rock Bolts

Point anchored rock bolts are common in competent ground conditions, such as those encountered in hard rock mining applications. With the development of resin technology, the use of resin rather than cementitous or mechanical anchorage has been favoured where appropriate.

The two families of point anchored support systems are mechanical and grouted anchorage.

2.2.1.1.1 Mechanically Point-anchored Rock Bolts

This anchorage system relies on the development of frictionally interlock between the rock bolt and the surrounding rock. Rock bolts using this system are slot and wedge rock bolts, or more commonly, the expansion shell rock bolts.

An expansion shell rock bolt is anchored through the application of torque to the tendon, tensioning the rock bolt between the anchorage and the bore hole collar.

High contact stresses are generated between the shell and the rock, limiting application to strata with uniaxial compressive strengths of greater than 50 MPa. The main failing of point-anchored rock bolts are that system capacity is often dependent on the performance of anchorage point. Thus, while full load capacity for the tendon may not be reached, the system may fail through anchor failure, or the rock surrounding the anchor may fail through excessive contact stresses.

2.2.1.1.2 Resin or Grout Point-anchored Rock Bolts

Grouted anchorage systems substitute a resin or cementitous grout for the mechanical anchor, bonding the rock bolt to the rock. This system provides higher load capacity and the grout encapsulation length can be adjusted according to in situ conditions.

2.2.1.3 Full-length Anchored Rock Bolts

Full-length anchored rock bolts have continuous contact, either directly or via grout, with the borehole along the full length of the rock bolt. The mechanism of anchorage is distinct to that of point-anchored rockbolts, and developments in resin technology have advanced their use throughout the mining industry. The two main full-length anchorage methods are friction and grouting.

A fully encapsulated rock bolt is considered more effective, as the mechanism of load capacity may allow maximum load capacity to be achieved at multiple locations along the tendon. This, the performance of full-length anchored rock bolt is dictated by load transfer characteristic of the support system. The effective length of the encapsulation is based on the length of the encapsulation along which load transfer occurs, rather than the full length of the encapsulated rock bolt. A comparison between forces generated on full-length anchored and point-anchored systems can be seen in figure 12 [11].

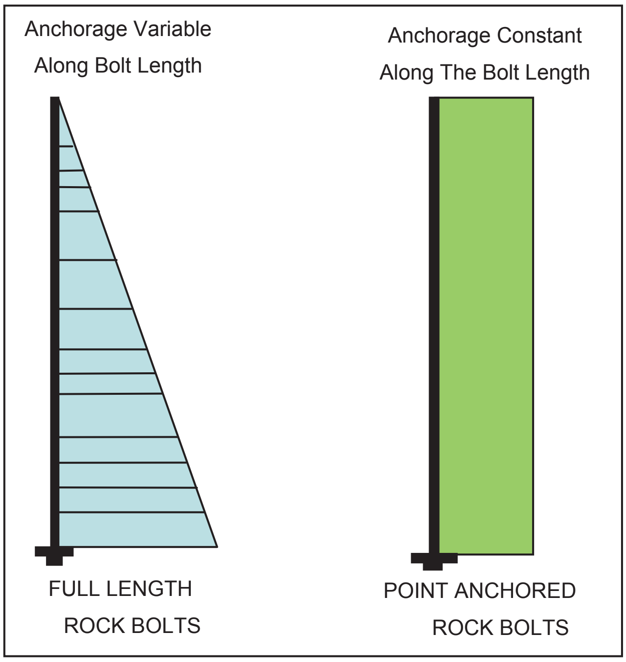


Figure 12: Comparison between support capacity of point-anchored and full-length anchored rockbolts

2.2.2 Areas of Application

Bolting is done for improving the stability and maintaining the load-bearing capacity of the rock mass near the boundaries of an underground excavation. Bolts are used as part of a support system for the excavation which can combine support effects. Their use is often the only way of giving stability to excavation of the final concrete lining [17].

In underground excavations, rock bolts are installed:

- to support discrete wedges or blocks of rock that would otherwise be free to fall or slide
- to reinforce the crown or sidewalls or a tunnel
- in older designs rock bolts were used as part of temporary support, but more recently as part of the permanently support system

Rock excavations, slopes and faces:

- for highway works, rock bolts are predominantly used to stabilise relatively small instabilities

- Rockbolts can give support to discrete unstable blocks bounded by discontinuities of various types, where there is widespread instability a gridage rock bolts has been used to improve the overall integrity and stability of the rock mass
- Future usage could be envisaged in areas of maintenance and improvement schemes (i.e. rock slope protection)

Other applications:

- Rock bolts has been used to restrain light structures, such as gantry signs, which are subject to overturning or tension forces.
- Rock bolts have also been used to strengthen or repair earth retaining walls [12].

In table 1 the main characteristics of some commonly used systems and their main application areas based on a simplified description of the rock properties listed.

			SN-Bolt	Self-drilling Bolt	Grouted Bolt	Split-Set	Swellex	Expansion-Shell	Cablebolt
Rock Conditions	Quality of Rock Mass (Strength)	Very Poor Quality Rock Mass		x					
		Poor Quality Rock Mass		x	x				
		Fair Quality Rock Mass		x	x	(x)	(x)		(x)
		Good Quality Rock Mass	x	x	x	x	x	x	x
		Very Good Quality Rock Mass	x	(x)	(x)	x	x	x	x
	Borehole Conditions (Quality of Hole)	Unstable Borehole		x		(x)			
		Brittle Borehole (Fractured)	(x)	x	(x)	(x)	(x)		(x)
		Stable Borehole	x	x	x	x	x	x	x
Main Features of Anchor Systems	Complaisance	Yielding			(x)	x	(x)	(x)	x
		Rigid	x	x	x	(x)	x	x	x
	Bonding Material	Injection (Presured)		(x)					
		Filling	x	x	x				x
		Decoupled from the Drilling	x	x	x				x
		During the Drilling		(x)	x				
		Fluid Form	x	x	(x)				x
		Cartridge Form	(x)		x				
	Installation of Bolt	Independent of Drilling	x	(x)	x	x	x	x	x
		With the Drilling		x	x	(x)			(x)
	Material of Bolt	Wooden						(x)	
		Fiberglass	(x)	x	x			(x)	(x)
		Steel	x	x	x	x	x	x	x
	Shape of Bolt	Cable							x
		Hollow Bar		x	(x)	x	x		
		Solid (Rod) Bar	x		x			x	
	Type of Anchoring	Chemical/Physical	x	x	x				x
		Mechanically				x	x	x	(x)
	Anchoring (Bonding)	Partly-bounded (Point-anchor)	(x)	(x)	(x)			x	(x)
		Fully-bounded	x	x	x	x	x	(x)	x
	Tension Conditions	Un-tensioned	x	x	x	x	x		x
		Deformed	x	x	x		(x)	(x)	x
		Pre-tensioned (Active)		(x)	x			x	(x)

x: Typical Application, (x): Special (conditional) Application

Table 1: Classification matrix for the common used rockbolting systems [16]

3 Detailed Discussion of Individual Rock Bolts according to Types

3.1 Description of Bolts

3.1.1 Point Anchored Rock Bolts

3.1.1.1 Automated Systems

3.1.1.1.1 Expansion Shell Bolt

There are a lot of Expansion-Shell bolt manufacturers and brand products on the market. Some of these are Dywidag-System International, Strata Control Systems, Aveng (Duraset) Ltd., Jennmar Corparation, Mansour Mining Inc., Arnall Poland sp.zo.o., Ankra spol. sr.o., VSL International Ltd. and ArcelorMittal S.A.

In Expansion-shell rock bolts, anchoring are achieved either mechanically or with resin. A common expansion shell bolt is cone shaped, with a hole in the centre and there are a few geared wedges around the cone. Figure 13 illustrates a typical expansion shell bolt [18].

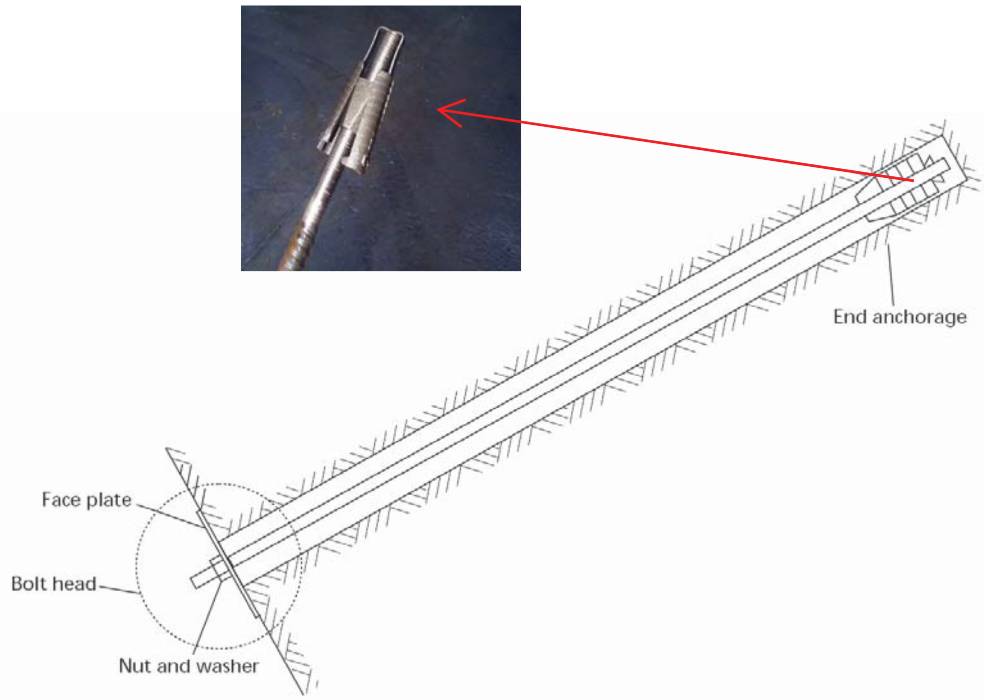


Figure 13: Commonly expansion shell rock bolt [12]

After the cone is placed into the hole, it will be pulled down forcefully when the screw at the end of the cone is wedged and thereby forces will be transmitted to the wedges. A pretension will be achieved after installation. This mechanism is placed at the end of the bolt. The length of the hole must be at least 10 cm longer than the bolt length [19].

Tensioning of expansion-shell rockbolts is necessary to ensure that all of the components are in contact and that positive forces are applied to the rock. It is generally recommended that a tension of approximately 70% of the capacity of the bolt is achieved during installation. Tightening the nut with a conventional wrench or with a pneumatic torque wrench is adequate. This provides a known load with a reserve in case of additional load being induced by displacements in the rock mass [19]. In corrosive environments an additional grouting of the bolt is possible.

Advantages:
In the first place it is inexpensive, it shows immediate support effect after installation. It can be used as long term bolting when the annulus is grouted, and it is convenient for high bearing capacity when used in hard rocks.

Disadvantages:
Its use is limited to rock masses with medium to high strength. The installation of the bolt is labour intensive. Its tension must be monitored. It is negatively affected by the vibration resulting from explosion and loses its bearing capacity. Its bearing capacity will also be badly affected due to the fragmentation occurring at the point of anchorage. Annulus diameter’s being too wide or too narrow effects negatively anchoring of the bolt. For example this is illustrated in figure 14 [1].

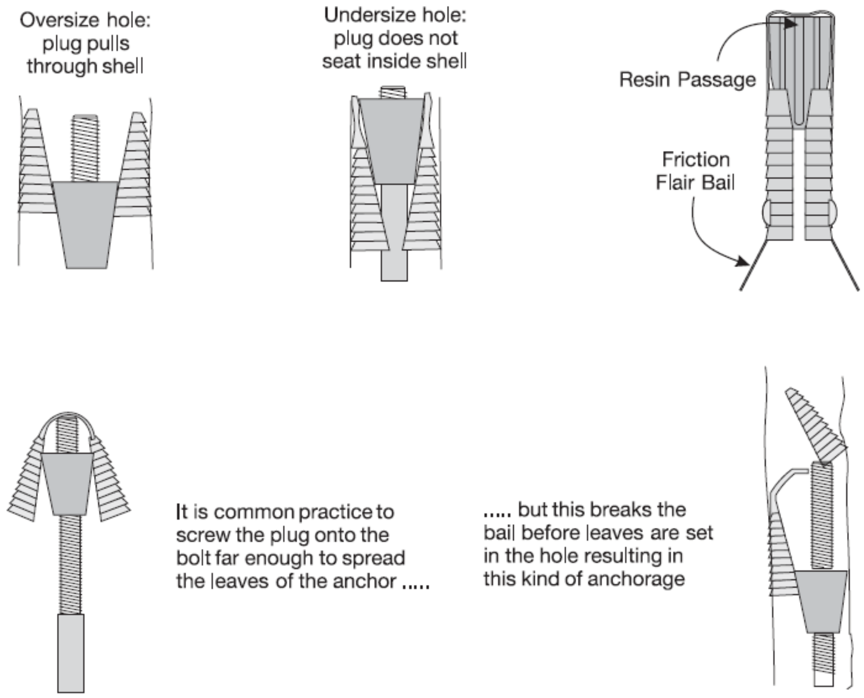


Figure 14: Some failure mechanism of expansion elements [20]

The working principle of a point anchored reinforcement system is generally hanging the loosened part of rock to the roof. This kind of rock bolts are not first choice in effective bolting a sliding rock mass, in other words they are weak at preventing lateral movement. They are not recommended for use in very hard rock, since a very hard rock will prevent the expansion shell from gripping the rock, and anchor will slip under load [1]. It is compatible with mechanization and its expansion shell is complete present during placement generally on all parts of bolt (wedge, faceplate, nut, etc.). In this way, machine automatically takes a ready bolt and does installation.

3.1.1.2 Non-automated Systems

3.1.1.2.1 Slotted Bolt and Wedge

Slotted bolt and wedge, one of the first used rock bolt types, was used for roof reinforcement in coal mines which are operating by room and pillar method as its installation is easy and the cost is low. Today its use is quite rare. Slotted bolt and wedge anchor are illustrated in figure 15. Slotted bolt and wedge anchors, which are smaller dimensioned compared to the types used in mining, are being used at construction industry in our day.

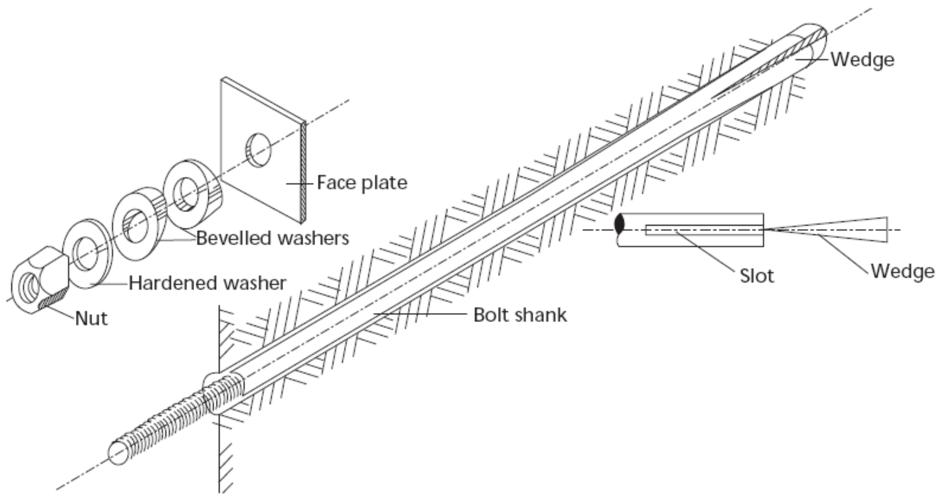


Figure 15: A Slotted bolt and wedge anchor [21, p.314]

The device comprises a smooth bar with a short cut at its distal end, a wedge is fitted into this slotted end. During installation, the wedge is driven into the end of the bar by driving the assembly against the bottom of the borehole. The wedge expands the end of the rod, thus anchors it to the rock.

Although the installation of slotted bolt and wedge is easy and its cost is low, there are a lot of disadvantages at application, which are:

Due to the fact that intact surface between bolt and rock is too small, the distance between hole diameter and bolt diameter must be 6-8 mm at hard rocks, and 4-5 mm at normal rocks. Local crushing of the rock can occur with consequent slip of the anchor, that’s why intact rock strength must be no less than 10 MPa. These bolts cannot be recovered after installation. They are negatively affected by vibrations which are of blasting activities origin [21].

3.1.1.2.2 Resin Assisted Mechanical Anchor Bolt

There are a lot of resin assisted mechanical anchor bolt manufacturers on the market. Some of these are Dywidag-System International, Strata Control Systems, Aveng (Duraset) Ltd., Jennmar Corparation, Mansour, Arnall Poland sp.zo.o., VSL International Ltd. and ArcelorMittal S.A.

Resin-assisted mechanical anchor bolts are formed as a result of using mechanical anchor bolt and resin together and they are named as point anchor bolts. Various resin-assisted mechanical bolts are available but the system is generally in a state that mechanical shell anchor is attached to the end of smooth bar or rebar. There is a figure illustrating the bolt (figure 16). This system is usually used with short resin cartridge which is a fast-setting and its anchor length is about between 30 cm and 60 cm.

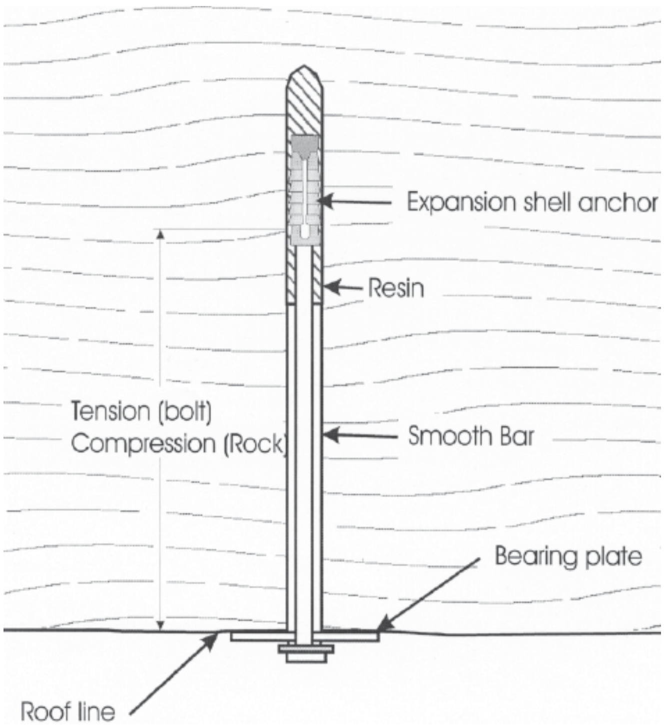


Figure 16: Resin-assisted expansion-shell rock bolt [22]

Resin mixing is done by inserting bolt, and immediate tension is done to the bolt thanks to the mechanical bolt. Generally bolt tension is set at 70 % of the bearing capacity of the bolts. These kinds of bolts are used at where there are less favourable ground conditions [22] [23].

3.1.1.2.3 Combination Bolt

There are a lot of Combination bolt manufacturers on the market. Some of these are Dywidag-System International, Strata Control Systems, Aveng (Duraset) Ltd., Jennmar Corparation, Mansour, Arnall Poland sp.zo.o., VSL International Ltd. and ArcelorMittal S.A.

In general a combination bolt consists of rebar bolt approximately 90 cm to 122 cm length and this rebar bolt is extended by being tied to a smooth bar thanks to a coupling. Total length is up to 2.44 m at large. A typical combination bolt is seen in figure 17 as installed with borehole resin.

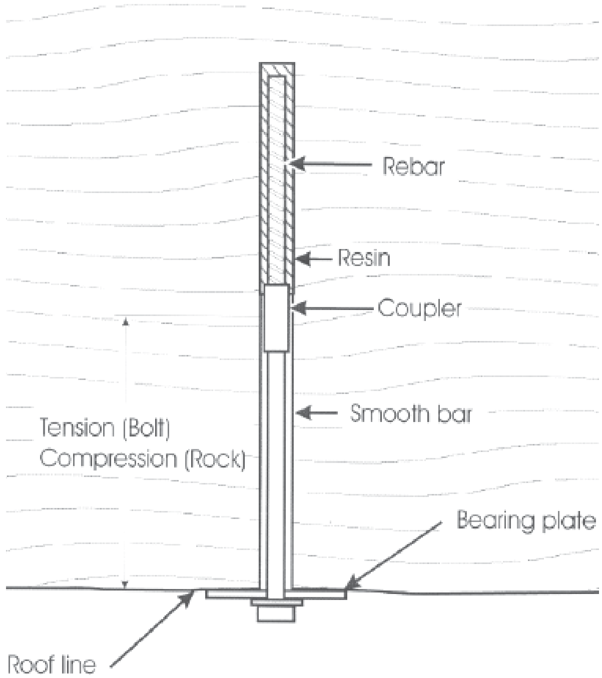


Figure 17: A combination rock bolt [22]

Rebar is fully grouted with resin and application providing an anchorage point for the smooth bar and reinforcement to the roof. Both ends of the smooth bar at the of system are threaded. Bearing plate and nut are added to the end of the smooth bar remaining out of the borehole and it is screwed thus clamping force is applied to the rock. As the system consists of two parts installation at low seams becomes easier. The weakest point of the combination bolt system is the place where the coupler is, but couplers are designed in such a way that tensile force to be applied to the coupler equals bolt failure. Perhaps, coupler may be shear due to the lateral rock movement [22] [23].

3.1.1.2.4 Kesp Ground Anchor

It is a point anchor manufactured by Kühler Ankertchnik AG (Switzerland) and is used in the field of ground stabilisation.

The components of this system are a galvanized rebar, a stable nut at the end of rebar, a pipe worn on the outer surface of the rebar and 6 slots on this pipe, face plate and nut attached to the other end of the galvanized rebar. Kesp ground anchor diameter is inserted into the borehole, possible diameters between 24 and 34 mm. the pipe of the bolt is compressed and expended by the aid of a hydraulic cylinder. The slotted anchor pipe expands like a flower in the borehole and couples the bolt to the borehole. Finally, the hydraulic cylinder and rigid pipe are detached. Faceplate and nut are attached and screwed for pre-tensioning. In figure 18 the Kesp ground anchor is illustrated.

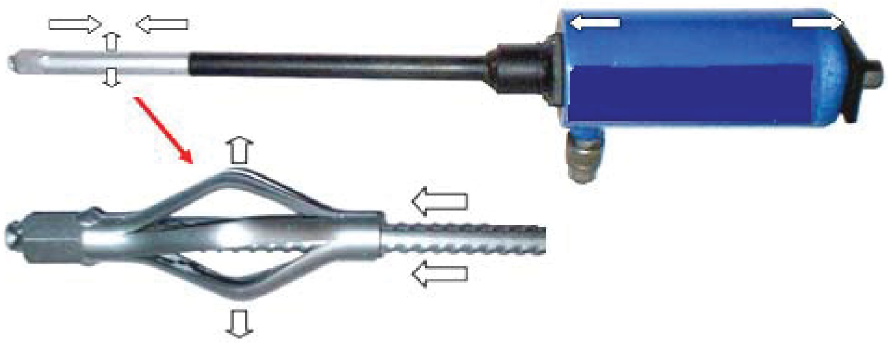


Figure 18: Kesp ground anchor [24]

The force that hydraulic cylinder applies to the anchor element (slotted pipe) is approximately 35 kN and the slotted pipe expands up to 110 mm diameter. The diameter of the slotted pipe becomes 5 times bigger than its previous state after compressing. The maximum tensile load of Kesp ground anchor is 50 kN. The Kesp ground anchor is used to solve ground stability and some other stability problems against erosion [24].

3.1.1.3 Patented Systems

3.1.1.3.1 Point Anchor

This rock bolt, which is a different type of mechanical anchoring bolt, is a rock reinforcement patented with PCT/CA04/01878 patent number on 26th October, 2004.

This invention generally consists of those components. There is a long threaded metal rod, and a cylindroid shaped expansion shell is attached to the end of this rod. The surface of expansion shell is generally covered with a few elongated metallic blades (typically 2 or 4). Figure 19a illustrates this bolt. Bearing plate and nut are installed at the other end of the bolt. The expansion shell of bolt, which is rotated in a specific direction after being placed into the hole, blooms like a flower in the hole and widens radially. Steady sheath at the low end of the cylindroid shaped expansion serves as a wedge during screwing.

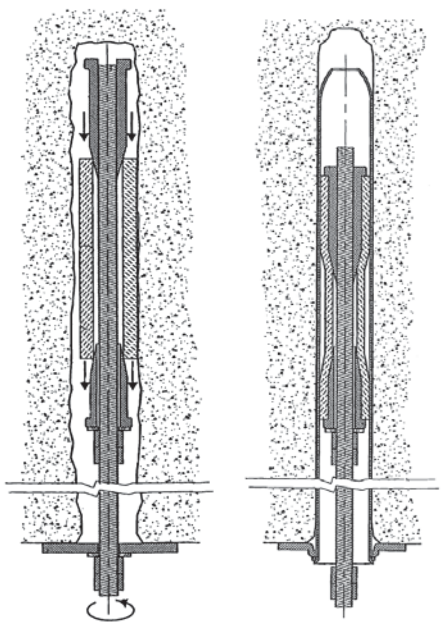


Figure 19: A point anchor bolt [25]

Diameter of borehole, where this bolt is to be installed, must be bigger than the diameter of cylindroid expansion shell of bolt and must be suitable for the bolt to reach borehole bottom. The bolt is fixed by being rotated with for example shaft pneumatic tool until toothed blades of expansion shell cling to the borehole wall thoroughly. Stress is applied by screwing the bolt against the excavation wall through adding face plate and nut to the low end of bolt.

It is possible to list some advantages of these rock bolts. For example, they are mounted quickly and easily, they are cheap, they provide active support, and they apply support effect soon after installation.

However, they are not suitable for every rock conditions. For instance, they have a low performance on broken and soft rocks. Besides, they are sensitive to vibrations therefore they may lose their load when blasting activities occur. These bolts have a very small resistance to shear force, and this is again a disadvantage. When the shear forces between bore hole internal surface and toothed blades of the expansion shell are too high, borehole surface may crumble and teeth of blades may not grip and thus may slide. Each bolt needs to be checked before installation. The application of this bolt with split-set is illustrated in figure 19b [25].

3.1.1.3.2 Resin-assisted Bolt

It is an anchoring system developed by Celtite Inc. (Cleverland, Ohio) company with US 4129007 patent number in the year of 1978. The system is structurally a smooth bar and consists of an anchor, a face plate and nut. The system is illustrated in figure 20.

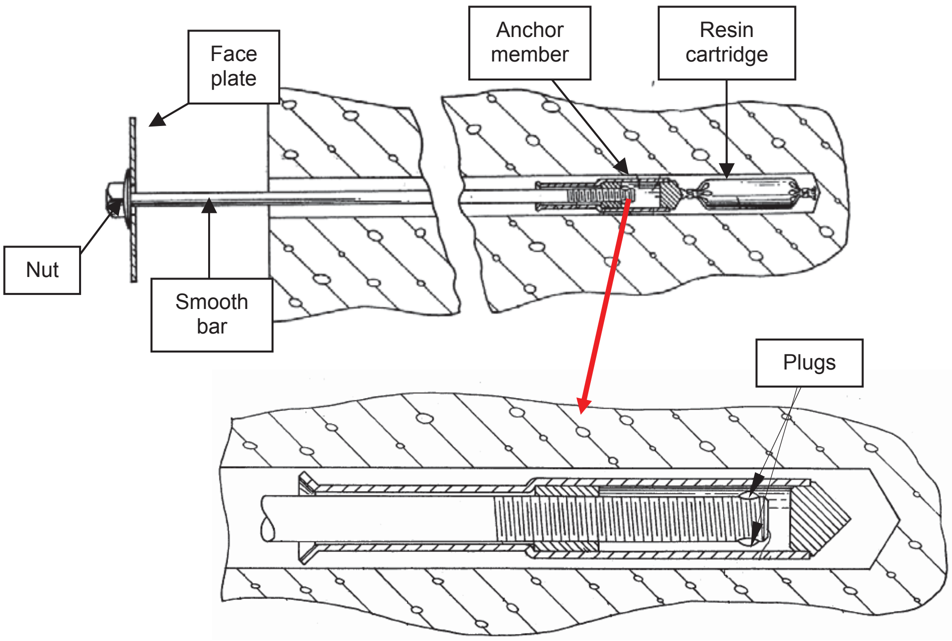


Figure 20: Detailed view of the system [26]

The part of the bolt which is left inside the anchor element is threaded and there are lugs at the end of it. Thanks to these lugs the bolt is prevented from coming out of the anchor element. The bolt may move forward or withdraw in the threaded area which is in the interior surface of the anchor element but its complete detachment is not possible.

The resin cartridge being sent to the borehole during installation is opened by the spinning movement of bolt and by being ruptured with the anchor element at its end. After a while the resin hardens and bolt is tensed by being rotated in reverse direction. This system lets the bolt be tensed as well as providing a resin mixing [26].

3.1.1.3.3 Point-anchored Cable Bolt

This bolt is a resin grouted point anchored cablebolt patented with PCT/AU92/00369 patent number and by J.J.P. Geotechnical Engineering Pty. Ltd Company from Australia on 5th November, 1996 and it consists of multi-strand steel wires. Strand cross-sections and diameter ranges preferred for cable bolt are presented in table 2. In addition, thread indentations must not exceed the 20 percent of outer wire diameter so that cable bolt will supply the adequate rigidity and experience tells that outer diameter range must be 5 to 5.5 mm.

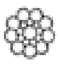
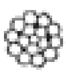
	Configuration	Strand diameter range (mm)	Approximate wire diameter (mm)	
	1×7 (6/1)	15.2 to 15.5	Centre Outer	5.2 5.1
	1×19 (9/9/1)	21.0 to 21.4	Centre Inner Outer	5.98 2.93 5.2
	1×21 (10/5+5/1)	22.8 to 23.3	Centre Inner Filler Outer	4.2 4.8 2.3 5.3

Table 2: Preferred cable bolt diameters [27]

It is possible to do In-situ cutting at the desired length and thus it does not have to be at fixed length for holes with different lengths. After the cut end of this multi strand wrapped around cable bolt is in-situ threaded, it becomes available for directly fitting nut on, when the load to be transferred to each wire is fixed. Besides, as a result of testing a 23.1 mm diameter cable bolt with nuts having different lengths, the relationship between nuts having different lengths and nut load capacity is given in table 3.

Nut load transfer capacity (tonne)	**Nut length (mm)**
20	30
26	36
30	42
35	48

Table 3: Some relationship between nut length and nut capacity [27]

The nut can transfer a minimum force equivalent to the strength of the outer wires. If there is some wire interaction, for example by friction or wire compression, the transfer force can be increased and therefore it is useful to use a nut with frusto-conical end piece.

Outer wires of cable bolt are wounded with a lay direction opposite to the screw direction of the thread direction of cable. Thanks to the lay direction, cable bolt which is nut threaded is made to rotate until the resin is set in drill hole. Through welding to the free end of the cable bolt, wires are provided not to fall apart. In figure 21 a left hand lay cable and the threaded end of the cable bolt is illustrated in the state that nut has been placed.

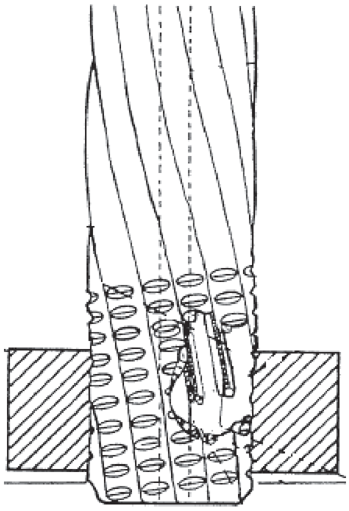


Figure 21: A left hand lay cable with end nut [27]

Resin point-anchored cable bolt installation steps are as following; pushing resin cartridge into a pierced drill hole by means of cable bolt, cutting cable bolts at the determined length and securing the cut ends by welding so that wires will not fall apart, shaping the end of the cable bolt which is to be left out of the hole in the form of rolling a thread, and adding face plate and nut. Then after resin has been setted, pre-stressing can be done by nut’s being tightened [27].

3.1.2 Full-Length Anchored Rock Bolts

3.1.2.1 Automated Systems

3.1.2.1.1 Resin Grouted Rebar

As the mechanically anchored rock bolts are not effective at soft rocks and in cases of vibration, resin or cement anchored bolts are developed [19]. During the installation, the rockbolt is grouted into the hole by means of resin. The rockbolt is in a continuous connection with hole-surface by the aid of cement or resin. Resin grouted rockbolts are used as the primary precaution at the struggle against hard roof conditions. A resin grouted rockbolt is illustrated in figure 22 [11].

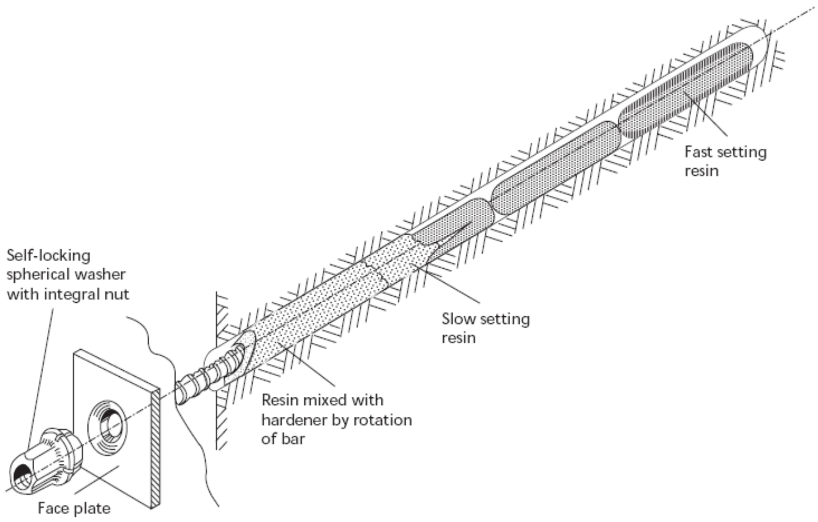


Figure 22: Resin grouted rock bolt [19]

The resin grouted rebars provide high resistance and quick hardening and thus they are suitable for soft rocks. The resin is generally in the form of a cartridge. The bolt is spun and it is made to pierce the resin cartridge and resin stiffens while being mixed [11]. A classic resin product is composed of two structures. One is the resin and the other one is the catalyst. These two components are not mixed with each other in the cartridge. Resin cartridges visually resemble explosive cartridges. During application, the plastic bag of the cartridge is torn by the bolt rod than the resin and catalyst are mixed with each other. This mixture provides a very strong anchor in a few minutes. It is useful that the bolt rod is sharpened so that it can tear the resin cartridge easily [19].

Firstly fast setting resin cartridges and then slow setting resin cartridges are rubbed on the hole. The bolt, which is piercing into the slow setting resin cartridges reaches the fast setting resin cartridge and enables pre tension by means of hardening in a short time [11].

As it has an immediate support effect soon after the application, this provides an important advantage. It is resistant against corrosion. The fact that shelf life of resin changes depending on the conditions can be stated as a disadvantage. Soon after a resin application, its mechanical features are expected to develop. Preferred features of resins are:

- Rapid development of mechanical properties after setting
- Intensity to variations in mastic/catalyst ratio
- Resistance to degradation
- Engineered curing time
- Resin viscosity altered as needed
- Long shelf life [11] [19].

Some undesired conditions stemming from the rock structure may present a disadvantage for resin grouting. At highly fractured rocks, resin cartridge may hold on a cavity (space) before reaching the bottom of hole and in this case anchoring cannot be achieved.
When the shear tension is applied to the fully grouted bolts, failure will appear either between bolt bar and grout or between grout and borehole wall. Resin grouted bolts are used as permanent or temporary support according to the state of rock [1] [28]. Mechanization of full-length resin grouted bolts is already developed. Driving the resin cartridges into the hole with the assistance of a machine has made the mechanization easier. Or this is provided by means of bolts on which resin cartridges are fixed.

3.1.2.1.2 Cement-grouted Cable Bolt

Cable bolts were used for mining for the first time in 1963, in Canada. Generally ground anchors are bolting components having high capacity and long-term service, and generally used in aboveground structures. Rock bolts are bolting components serving at low capacity and for short term. As to the cablebolts, they take place between ground anchor and rock bolt and generally are used in mining. Cable bolts are highly resistant and flexible anchoring components which are formed by weaving the steel wires spirally and thus forming a steel cable. In figure 23, various wrapping up steel wires methods are illustrated [29].

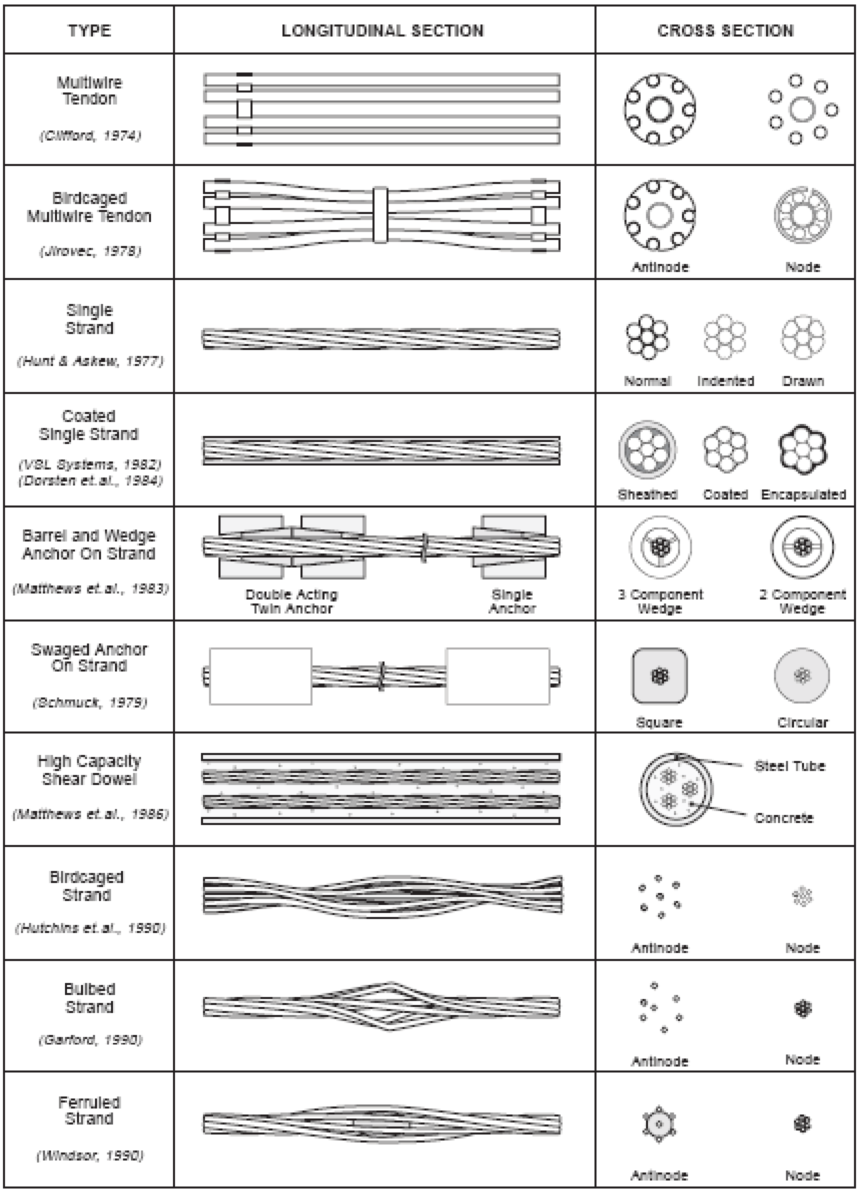


Figure 23: Development of cable bolt configurations (according to Windsor)

Quality of grout is a very important factor in reinforcement. For the use of Portland cement grout, typical w/c proportion changes between the values of 0.35 and 0.4. This is a cement grout with high viscosity, with the disadvantage of possible problems in filling the fissures of the borehole, fractures and air holes.

Different methods are used in grouting cablebolts, but installation principle is the same as smooth or rebar bolt. One of installation method is that, firstly grouting the borehole with cement or resin then driving the cablebolt into the hole. This is a common method. However, the problem with grouting the cable bolt with a resin cartridge is that it is not easy for a cablebolt to pierce the cartridge because the cable bolt is flexible. Fully grouted cables may fail in one or more of the following modes by failure with the rock mass, the grout/rock bond, grout/cable bond or failure of cable [19] [30].

The process of firstly grouting the hole with cement and then driving the cablebolt is also called the Malmberget method. A second method is that cablebolt is driven into the hole firstly and then cement is pumped into the hole and the annulus (space between cablebolt and borehole wall) is filled, this is called the Kiruna method. The cablebolt is placed into the borehole and the hole is filled with cement by means of the pump. Air in the hole must be taken out while the cement is being pumped otherwise the air in the hole will be compressed and cavities will remain. A venting pipe is necessary for letting the air out, this venting pipe, which is attached to the cablebolt, is either inserted into the hole with cablebolt or the air in the hole is taken out by making use of the cablebolts which are specially fabricated and having a hole in the middle. It is understood that the borehole is filled with cement when the cement comes out of the vent pipe. A classic grouted cablebolt is illustrated in figure 24 [19]. Cable reinforcing increases thanks to the bracelet shaped anchor points which are placed on the cable on specific intervals.

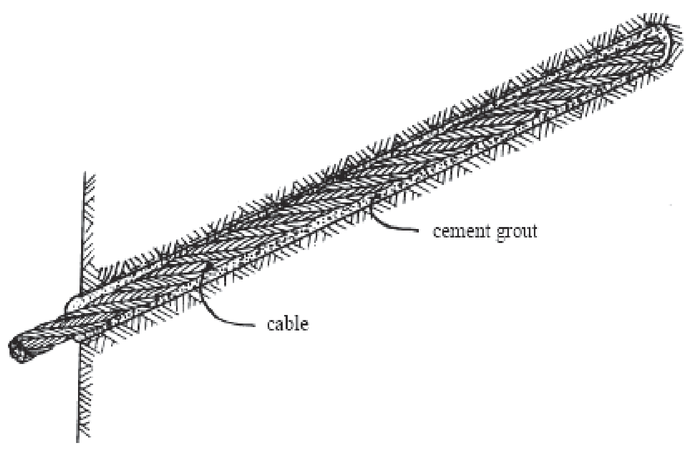


Figure 24: Schematic view of a typical cement grouted cable bolt [19]

Main advantages of cablebolts:
Its extension, that is flexible, high bearing capacity, shear strength are more than rebar bolts and its installation is easy in narrow spaces. High flexibility during transportation, high resistance and it is not affected by the vibrations resulting from explosions and all these are among other advantages. However, following facts can be recognised as a disadvantage: It has low contact stress and high stiffness, its surface space is more than rebar and this situation decreases its resistance against corrosion [31]. It is possible to say that application fields of grouted cable bolts are rocks with low rigidity and layered [3].

As those bolts are intalled into the small-scale holes: cost is reduced, installation process is easy, it is fast and of high quality. Installation equipment of these bolts are the same as of the traditional rockbolts. A pre-tension can be achieved as a fast setting resin is used [32].

3.1.2.1.3 CT-Bolt

This bolt known as CT-Bolt (Orsta Stal from Norway) is a post-groutable expansion-shell rock bolt and was first used in 1993. In figure 25 a typical CT-Bolt is illustrated.

Figure 25: CT-Bolt [33]

CT-Bolt comprises a rebar steel bolt, an expansion-shell on the top of the bolt, a polyethylene sleeve or sheath surrounding bolt (there is a space between this polyethylene sleeve-sheath and bolt), a faceplate which is generally circular, a hemispherical dome on which there is a hole for grout injection and a nut at the end.

On the market, two types of Steel bar diameters of CT-bolts are encountered as 20mm and 22mm. Their lengths vary from 1.5 meter to 6 meter and in Lötschberg tunnel in Switzerland 8 meter length CT-Bolt were used.

Technical specifications of CT-Bolt are:
Yielding load of a CT-Bolt with 20 mm diameter is 140 kN and its failure load is 170 kN. Yielding load of a CT-Bolt with 22 mm diameter is 230 kN and its failure load is 290 kN. Load-Displacement curves for different CT-Bolts are illustrated in figure 26. Borehole diameters suggested for CT-Bolt are 44 mm and 51 mm.

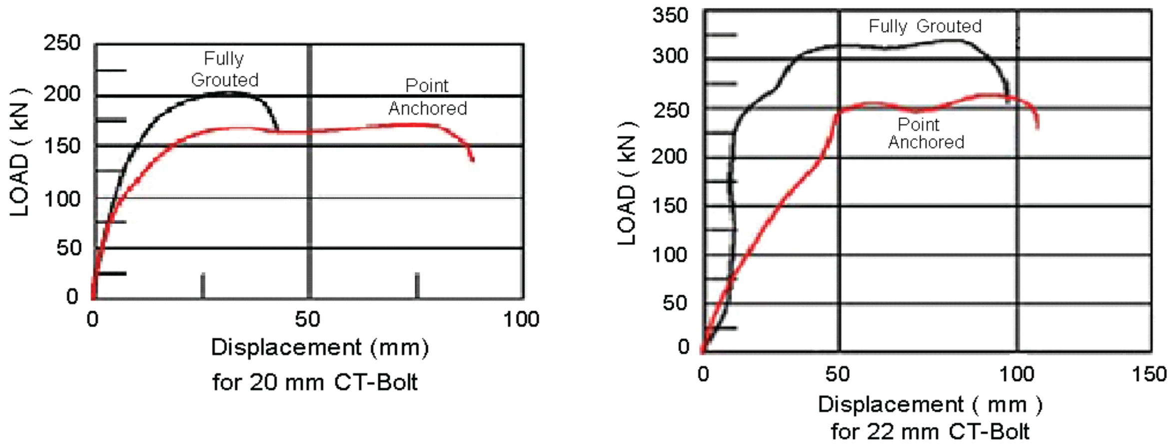


Figure 26: Load-Displacement curves of CT-Bolt with 20 mm and 22 mm diameter [33]

CT-Bolt installation is as following:
Borehole length where CT-Bolt is to be installed must be at least as much as CT-Bolt length. Afterwards, CT-Bolt is driven into the borehole and bolt is pre-stressed by screwing and immediate support is provided. In order to be able to inject grout into the bolt, an injection nozzle is connected to the grout hole on the hemispherical dome and then grout injection is achieved. Grout flows through the polyethylene sheath and fills inside the borehole and polyethylene circulates the outer surface of the sheath and goes out of the air nozzle on the faceplate. In this way, it can be understood that the borehole is completely grouted. In figure 27, installation stages of CT-Bolt are illustrated.

Stage 1 inserting CT-Bolt into the borehole and screwing

Stage 2 injecting grout into the bore

Stage 3 when the grouting process is completed, nozzle is sent away

Figure 27: Installation stages of CT-Bolt [33]

Fully mechanized installation process of CT-Bolt was applied by modified Tamrock rock bolter in Kemi Mine in Finland and a quite high efficiency was gained. At the end of the fully mechanized installation of CT-Bolt, a CT-Bolt having a 2.4 m length is installed within 3.5 minutes. A modified rock bolter installing a CT-Bolt is illustrated in figure 28.

Figure 28: Mechanized rock bolter for CT-Bolt installation [33]

Advantages of CT-Bolt:

In addition to showing immediate support effect, CT-Bolt also features as being post groutable. When grouted Polyethylene sheath protects bolt against corrosion, provides an easy and effective grouting. Besides, grout material grouts around the bearing plate as well. Polyethylene sheath must not be harmed.

Fully mechanized installation saves time [33].

3.1.2.1.4 Split-Set Friction Bolt

Split set friction rockbolts were first developed in 1976. Their structure is quite simple. The system consists of a slotted high strength steel tube which is narrow at the end part and face plate. It is installed into a slightly undersized hole by pushing and the radial spring force generated, by the compression of C shaped tube, provides frictional anchorage along the entire length of the bore hole. A split set sample is illustrated in figure 29 [19].

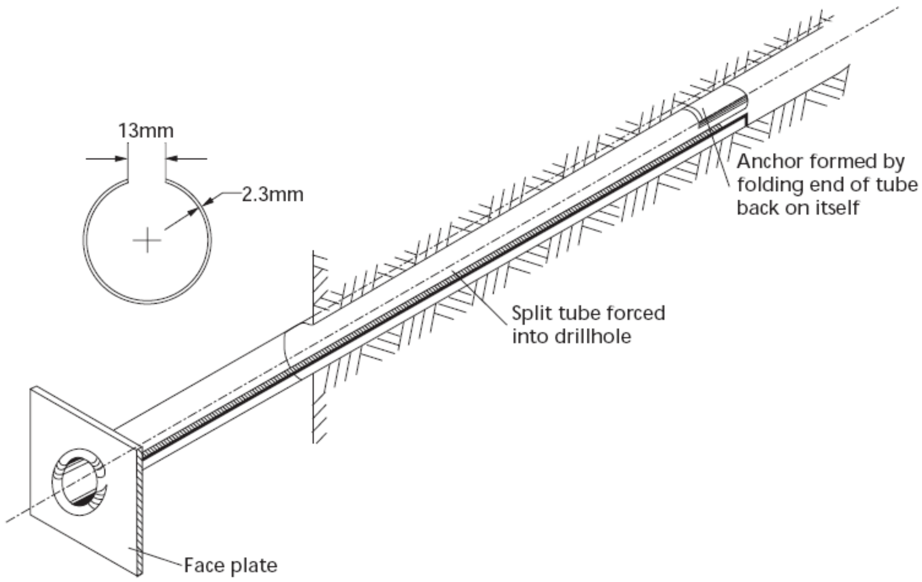


Figure 29: Split-set friction anchor [19]

Split set rockbolts form a radial pressure stress between rock and rockbolts. As a result, friction strength occurs between rock and iron bolt tube.

Following factors affect anchoring:

- Diameter difference between hole and tubebolt
- Physical and geometric features of the tube
- Effective friction angle between metal and rock

Pull-out strength increases with increasing thickness of the steel tube. However, this benefit is offset by a greater difficulty of installation, extra cost, and additional weight. Despite a lower pull-out strength than other bolts, nonetheless, popular because of the rapidity and ease of installation and its ability to provide rock support immediately upon installation. Although various aspect of the design of friction-tube rockbolts can, in principle, be modified to change performance, the ability to change frictional resistance along the metal-rock contact is more limited. Roughening of the metal surface would accelerate corrosion of the tube.
It has been set that an increase in strength with time after installation. This increase depends on those reasons:

- Closure of the hole due to rock creep

- Shear along weakness planes intersected by the split-set so that the tube is bent
- An increase in shear resistance along the steel-rock contact (e.g. corrosion or deposition of cohesive materials [34].

Its use is limited on hard rock conditions and its bearing capacity is depending on the borehole diameter. If the borehole diameter is too small installation is difficult, if the borehole diameter is big then there will not be enough normal stress between the bolt and the borehole. They are generally used as temporary support. Corrosion decreases the bearing capacity of split-set with time. Besides, the fact that it is expensive is a disadvantage. It is a kind of support which is suitable for automation and it is compatible with mechanization as its structure is very simple [1].

3.1.2.1.5 Swellex Friction Bolt

It was firstly developed and introduced to the market by Atlas Copco company. Swellex rock bolts principally work by developing friction strength against sliding in the hole. In other words, they apply a radial force to the surface of the hole. It has got a folded pipe shape, as illustrated in figure 30. After being placed into the hole, it is swelled with pressured water. Since the diameter of the bolt before swelling is smaller than the borehole diameter, the bolt is easy to install and there is no need for a force to push forward. Approximately 30 MPa pressure is applied in order to swell the bolt [19].

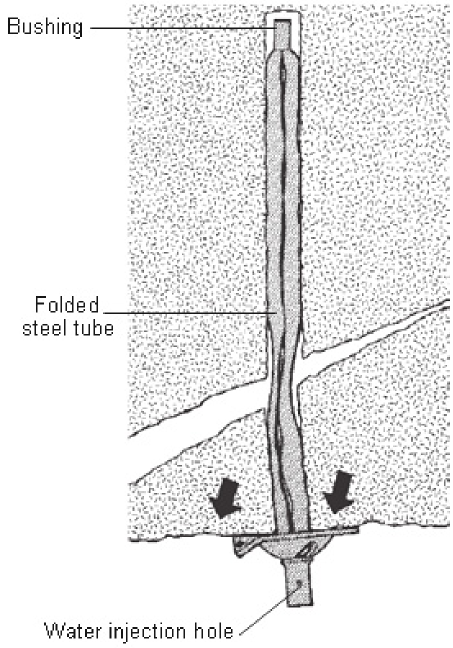
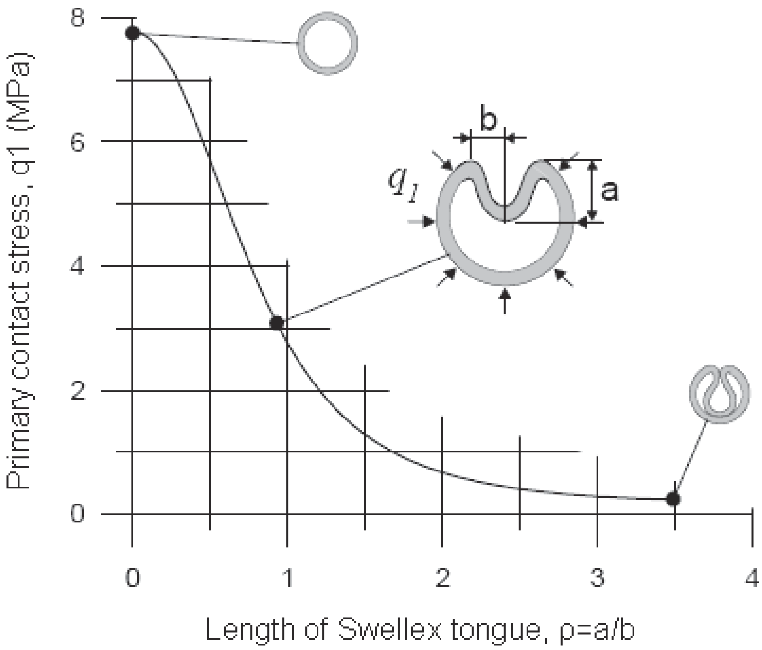


Figure 30: Swellex rock bolt

Anchorage capacity for swellex bolt is different at hard and soft rocks. In soft rocks, the primary contact stress depends on the strength of the rock and Young's modulus of the rock.

Primary contact stress on the borehole wall is a function of the stiffness of the rock and that of the Swellex bolt. The stiffness of the swellex depends on the length of the bolt tongue, a short tongue resulting in a high stiffness. Primary contact stress (q1) is also a function of the degree of expansion (figure 31). In soft rocks, mechanical interlock makes only a small contribution to the anchoring of the bolt, but it is friction plays the main role and the friction is proportional to the primary contact stress on the borehole wall.

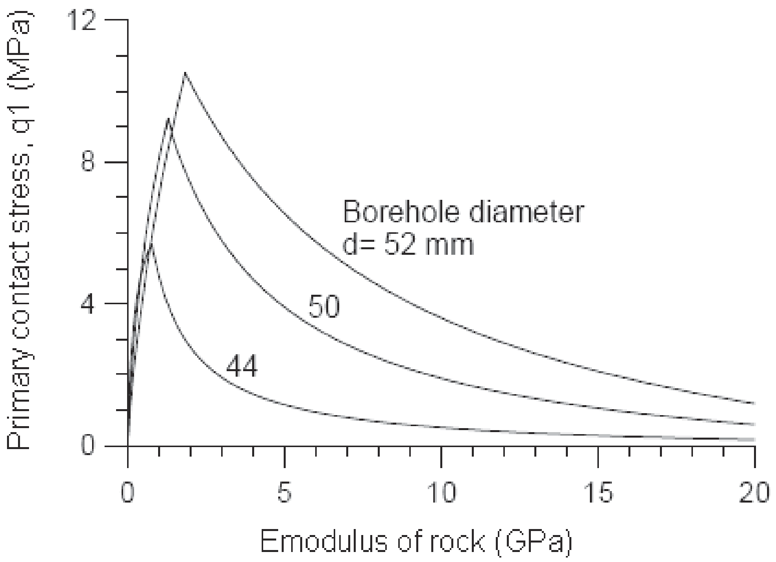


Parameter values used for the calculation:

E=210 GPa for steel, E=10 GPa for rock, Pomp pressure=30 MPa, Borehole pressure=15 MPa (pressure on the wall during the bolt installation)

Figure 31: Primary contact stress versus the expansion of the swellex bolt [35]

In hard rocks, primary stress is related to the Young's modulus of the rock, but thanks to the mechanical interlock the secondary contact stress occurring on borehole wall is important. Due to this fact, as the roughness of the borehole wall affects the anchorage capacity directly borehole wall must be adequately rough (figure 32) [35].



Parameter values used in the calculations:

Diameter of swellex=4 mm, Thickness of swellex=3 mm, b=10 mm, E modules=210 GPa for steel, Vs=0.3 possion's ratio for steel, Vr=0.2 possion's ratio for rock, Pomp pressure=30 MPa, Borehole pressure=15 MPa (pressure on the wall during the bolt installation), Ø=30˚ (friction angle between rock and bolt)

Figure 32: Primary contact stress vs. Young' modulus of rock in hard rocks [35]

As to the disadvantages of swellex, it is possible to say that its resistance against corrosion is low. When materials which are resistant against corrosion are used, the cost increases [19]. Besides, under condition that contact stresses around excavation is high, lateral deformation which is to occur around the hole will weaken the bearing capacity of swellex. The facts that it depends on the hole diameter, it is expensive and it has a limited bearing capacity can be regarded as disadvantages as well. When compared to the other rockbolts, we can say that its most important advantage is that it can be quickly installed.

Its anchoring effect soon after the installation is an advantage. Besides, they are effective for layered rock mass [3]. Another important advantage is that they make installation easy at narrow seams, that is, short swellexes are spliced and they provide flexibility at narrow seams. This situation is described in figure 33.

Figure 33: Connectable Swellex [36]

In addition, it is in question that it operates pre-tension via connecting to the self drill anchor, as illustrated in figure 34.

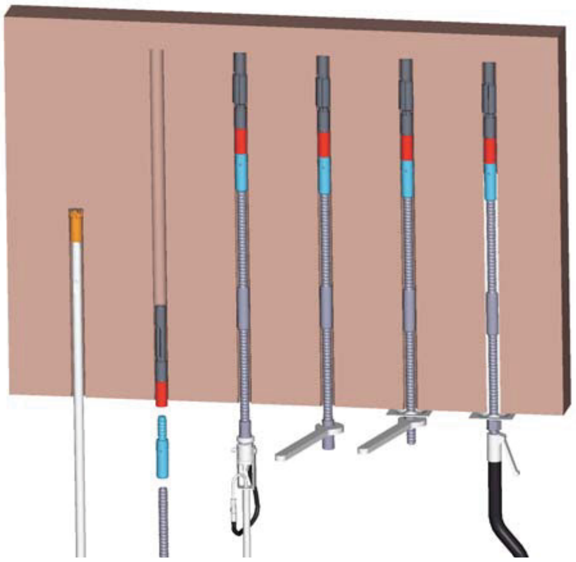


Figure 34: Installation sequence of Swellex Hybrid [36]

3.1.2.1.6 Self Drilling Bolt

In addition to being commonly used in tunnelling and ground engineering, self drilling anchors are also used in mining. There are a lot of self-drilling bolt manufacturers and brand products (figure 35). Some of these are Atlas Copco MAI Hollow Bar Anchor systems, Alwag IBI and IBO Self-drilling anchors, Stainless Steel Grip Bar injection anchor for self-drilling application from United Kingdom.

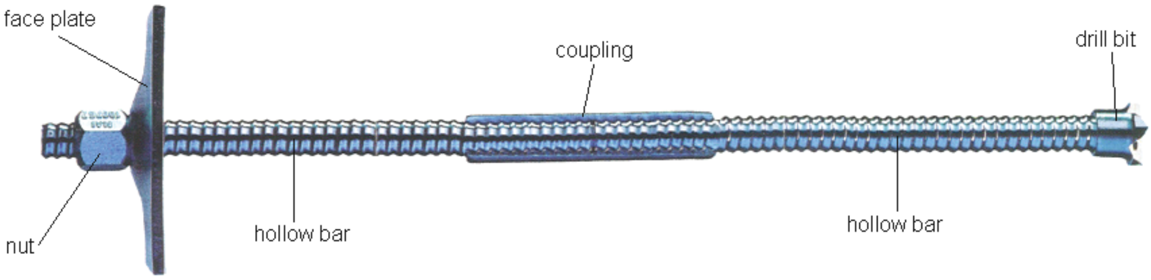


Figure 35: A Typical self-drilling anchor bolt [36]

Self-drilling anchors are hollow fully-threaded bars. They do both drilling and bolting and they are installed at a single operation. That outer surface of the self-drilling rods are fully-threaded provides attaching drill-bit at the end of the rod and splicing plural rods with an external coupling. Besides, it is being fully-threaded provides well bonding with the grouting material. Self-drilling rods vary in terms of material and dimension, in other words they may be made of various thickness, diameter, material quality and form. There are some technical specifications belonging to the Williams/MAI hollow bar in table 4.

Anchor Designation	**Outside Diameter**	**Internal Diameter (Average)**	**Ultimate Load Capacity (kN)**	**Yield Load Capacity (kN)**	**Weight per kilo**
R 25	25 mm	14 mm	200	150	0.68
R 32N	32 mm	19 mm	280	230	1.08
R 32S	32 mm	15 mm	360	280	1.29
R 38	38 mm	19 mm	498	400	1.81
R 51L	51 mm	36 mm	550	450	2.13
R 51N	51 mm	33 mm	801	630	2.54
T 76N	76 mm	51 mm	1601	1201	4.54
T 76S	76 mm	45 mm	1904	1503	5.99

Table 4: Technical data of Williams/MAI Hollow bar anchors [37]

It is possible to attach a different drill bit at the end of the self-drilling rod and it is necessary to choose bit according to the conditions of the rock to be drilled. Some drill bit options given for different self-drilling bolts are illustrated in figure 36.

Figure 36: different bit options for Self-drilling hollow rods [37]

Rotary-percussion hammer is used for drilling (figure 37).

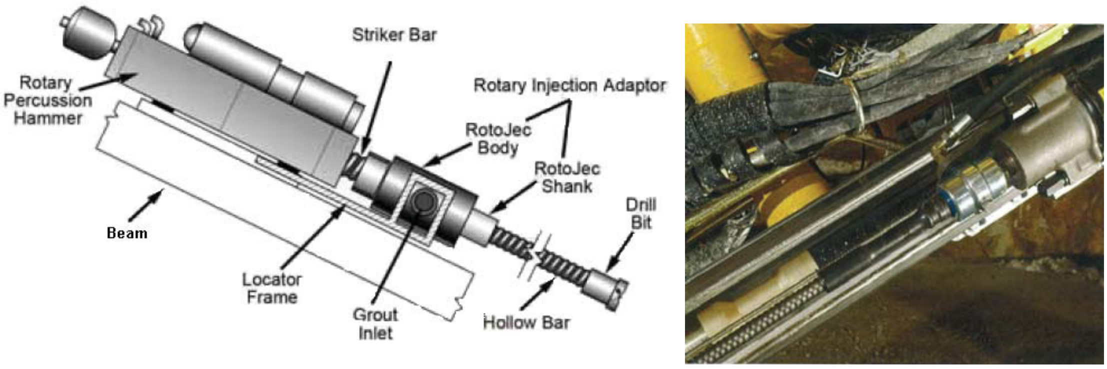


Figure 37: A rotary percussion hammer used for self-drilling bolt installation fixed on Beam [36] [37]

Self-drilling hollow bar anchor installation is done in a single stage and in a fully-automated way. The installation stages of self-drilling hollow bar anchor is presented in figure 38.

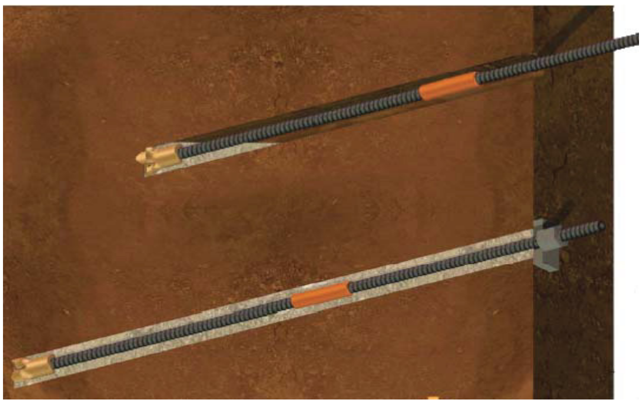


Figure 38: Self-drilling anchor during installation [37]

Firstly, the hollow bar at the end of which there is drill bit is given a suitable position for installation and rotary percussive drilling operation starts. Water flushing, grout flushing or air flushing is applied during drilling [37].

Flushing types determined for some ground conditions are like this:

- Air or water flushing at rocks
- Cement flushing for sand or gravel
- Bentonite for clay and brick clay
- Air for clay [38]

A typical hollow drill rod length is 3 m. When more than one hollow rod is required to reach the desired borehole depth, it is possible to extend by adding a second hollow rod thanks to a coupling. Drilling operation stops during the extension of hollow rods and another hollow bolt is taken from bolt magazine and attached to the end of the other bolt. Once the drilling reaches the final depth, grouting operation starts. The water/cement ratio of a typical grouting mixture is 0.4. After the cement in the borehole is hardened, faceplate and nut are attached.

The advantages of self-drilling systems:
It is a very appropriate method for the areas having the problem of stabilization of borehole. Grouting fills in the fissures, fractures, and voids around the borehole and consolidates the rock or ground as well as providing corrosion protection. As the self-drilling anchor systems are one-step, they are quickly installed, it saves time and money. Time comparison of conventional anchor systems and self-drilling anchor systems in rock and soil conditions are presented in figure 39. Thanks to the various drill bit options, it can be applied in every kind of ground and rock conditions. Continuously threaded bar pattern can be easily cut and shortened or it can be combined with coupling and its length can be increased, and due to these facts it can be arranged according to the working conditions and it provides flexibility.

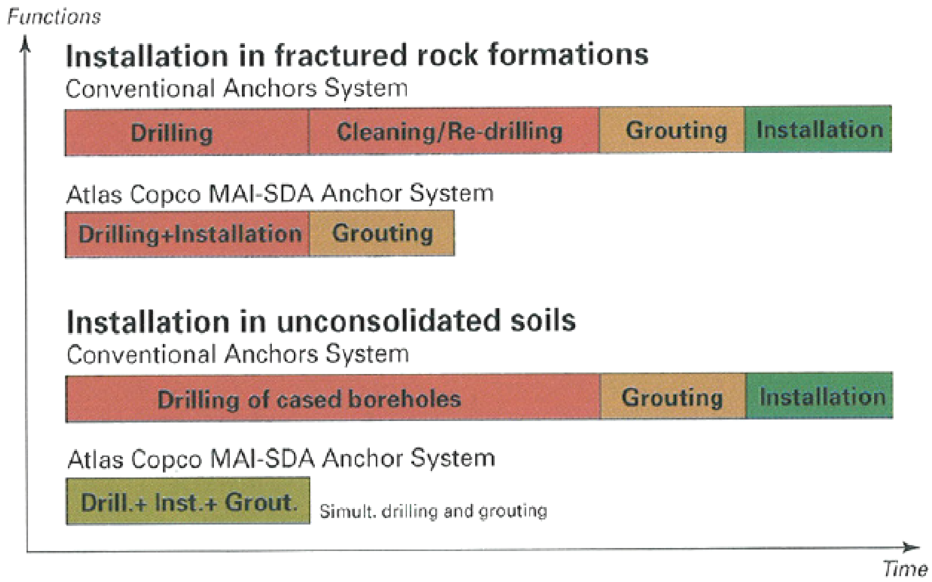


Figure 39: The advantage of self-drilling anchor in terms of time [36]

3.1.2.1.7 Hilti OneStep Rock Anchor

The Hilti OneStep self drilling bolt (figure 40) was first started to be used in Deutsche Steinkohle (DSK) coal mines in 2004-05 and their use in mines are still increasing with a growing demand.

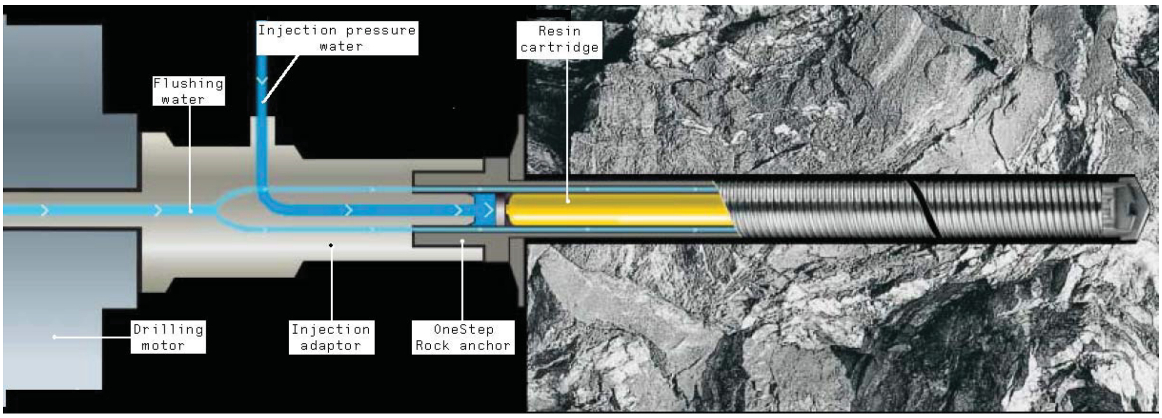


Figure 40: Hilti OneStep rock anchor [39]

Hilti Onestep anchor consists of these components: A drill bit head, drill steel, hollow steel bolt and adhesive resin in a single unit. The two components and adhesive resin take place in a cartridge and this resin cartridge is located in a steel inner tube enclosed in a second 4 mm gauge steel tube. Thanks to this design, the resin cartridge is protected against damage or leak. A typical Hilti Onestep rock anchor is of 2.5 meter length, the outer diameter of hollow steel bolt is 38.5 mm and the expandable drill head diameter at the end of the bolt is 40.5 mm. Drill head may have many various versions depending on the use and method of it. A technical specification example belonging to the Hilti Onestep rock anchor is presented in table 5.

Anchor shaft diameter	38.5 mm
Length	2500 mm
Ultimate load	320 kN
Yield point	270 kN
Elongation at break	10%
Drilling method	Rotary, wet
Adhesive	10-20 sec. curing time, depending on rock temperature

Table 5: Technical specifications of Hilti HOS-W 250/320 OneStep rock ancor [39]

The application of the Hilti Onestep anchor is as following:
A dispenser tool must be attached to the drill motor holding a place on the bolting rig. Wet drilling is done. The fragments are flushed out during drilling process through the annulus between the bolt and the drill hole. When the Onestep bolt has reached the required depth, the drilling process ends and then resin cartridge is pushed from the bottom by means of the pressured water and bolt is enabled to be encapsulated with the mixed resin. The installation stages of the Hilti Onestep rock bolt are presented in figure 41.

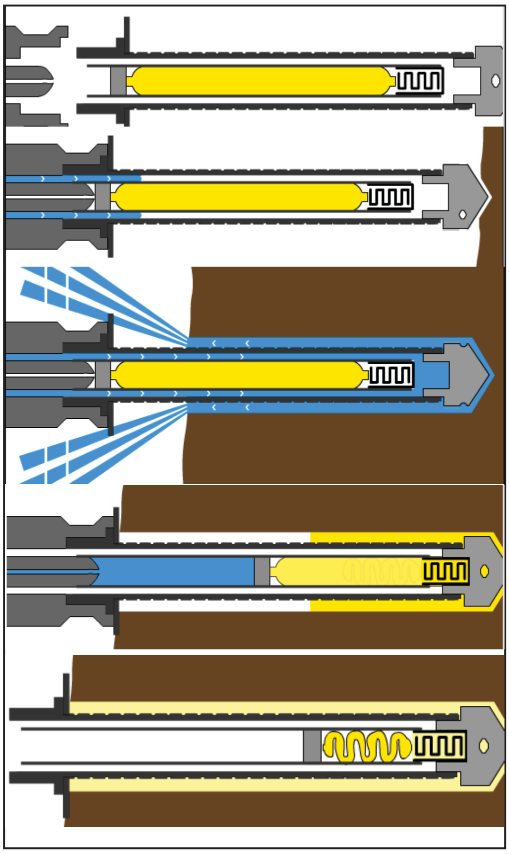


Figure 41: Hilti OneStep installation stages [39]

The installation stages of the Hilti Onestep rock bolt are different from the ones of the other conventional rock bolts. As the Onestep anchor is self-drilling, it saves time for bolt installation and increases the productivity. Besides, it decreases the error rate of workers and increases the safety.

The advantages of the Hilti Onestep rock anchor can be listed as following:

- Quick bolt installation. As many installation processes are eliminated, the bolt installation cycle time decreases. In other words, it achieves a multi-step process in only a single stage. Comparison of the Hilti Onestep anchor and the conventional resin-grouted anchor is given in figure 42
- When the bolt is bonded well, the load generation at the bolt will increase and thus more load will be transmitted to the roof strata
- Dust does not occur thanks to the wet drilling and the resin cartridge pushed by the water pressure will have no risk of being torn as a result of rubbing against the drill hole wall

- They are effective especially at collapsing holes, weak rocks and in rib drilling situations
- Hilti Onestep rock anchor includes fewer steps, the system can offer advantages for automation

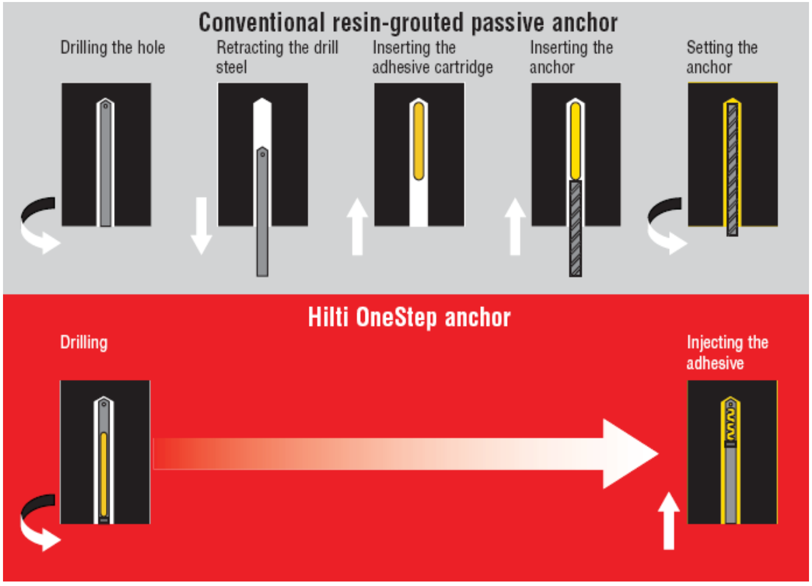


Figure 42: Comparison of bolt installation steps between conventional resin anchor and Hilti OneStep rock anchor [39]

As a result of the Hilti Onestop bolt and Rambor roof bolter manufacturer combination in June, 2006, quick installation of onestep rockbolt is provided as continuous support, and thanks to this, the impediment to the development cycle of Continuous Miner was minimised. Weak geological nature affects bolting in a negative way; as the bolting of the coal face on the longwall mine is hole closure, the installation of conventional bolts used to be unsuccessful, however it did not turn out to be a problem for the Hilti Onestep bolt.

Thanks to the design of Rambor manufacturer, Onestep bolt is installed in a quick and safe way with the bolt fixed on the ranging arm of the coal shearer [40] [41].

3.1.2.1.8 One-/Two Step Rock Bolt

Minova Carbotech GmbH (MCT) has been a member of Orica group since 2007 and it is a widely known name in injection and roof bolting technology.

It has got two types of commonly used immediate bearing bolt support which are used with resin. The first one is the bolt with resin cartridge and the second one is self-drilling bolt with integrated polyester resin cartridge. The systems where cartridges are used have very flexible curing times, they are compatible with boreholes with any length and diameter, they are also compatible with various bolt types, the use of machine is not needed. In other words it can be installed manually. On the other hand, it takes a long time to place it in unstable boreholes and it cannot be used when the borehole collapses.

As mentioned in section 3.1.2.1.7, Self-drilling bolts with integrated polyester resin cartridges (e.g. Hilti OneStep) are installed in a single stage. High setting rates are achieved at rocks whose compressive strength is 40-60 MPa and they can be used in unstable boreholes. The resin volume of the bolt is limited and fully embedding of the rockbolt changes according to the borehole volume (cracks, air holes). Rotary percussive drilling is not possible.

Basics of One-/Two-Step procedure:
In line with the conditions and needs at mining industry, there has been new developments in bolting technology. A different concept has been developed against Integrated polyester resin cartridge method. One-/two –step bolts, which are again immediate bearing grouted systems, have been developed. The main advantages are:

- decreasing the bolt installation time
- providing rotary percussive drilling
- gaining maximum efficiency at embedding
- automated insertion of one/two-step is increasing the safety in the working medium

As the quality of resin is also important, a test was applied in order to see the quality of immediate bearing bolt resin and the results are given in table 6. 600 mm and 200 mm bonding lengths which were put through bolt tensile test were used with Geothix M 1:2 silicate resin. The bolt type used was Wiborex T30/11 (outer/inner diameter) by Friedrich Ischebeck GmbH.

Tested bonded length [mm]	Setting Time	Maximum tensile force [kN]	Tension Distance [mm]	Cause of failure
600	60 min	385	25	Bolt fails due to fracture in the fissure
600	240 min	338	21	Bolt fails due to fracture in the fissure
600	240 min	335	19	Bolt fails due to fracture in the fissure
600	28 d	393	19	Bolt fails due to fracture in the fissure
2000	45 s	391	35	Bolt fails due to fracture in the fissure
2000	1 min	354	41	Bolt nut sheared off
2000	2 min	387	46	Bolt fails due to fracture on the bolt head

Table 6: Tensile tests results of Geothix M 1:2 composition [42]

The demanded features of resin are: it must be hardening quickly, it must not react with water, it must have a sound bonding property, it must not flow out of the borehole, and it must be homogeneous.

Reinforced glass-fibre and hollow steel bolts can be used as one-/two-step bolts. As it is in figure 43, there is a static resin mixer in the middle of the hollow steel bar. Figure 43 is an example of Wiborex 30/11 injection bolt. It is found at injection connection, face plate and expandable drill bit.

Figure 43: Wiborex T30/11 injection bolt with integrated static resin mixer [42]

3.1.2.1.8.1 One-Step Procedure

Drilling, inserting bolt and grouting occur in a single stage with one-step bolts. Connection adapter developed by Ischebeck company does the drilling and injection. This adapter connects the hammer drill and bolt and provides the function of grouting. In other words, rotary percussion can also be achieved.

During drilling bolt is connected to the drilling and injection head. During drilling water flows through the GEOTHIX A coupling and provides wet drilling. When the drilling process is done, GEOTHIX component A and GEOTHIX component B function as injection ducts individually and they pour in the borehole by flowing through the static mixer and getting mixed. Following a specific injection time is over the process comes to an end. After the grouting process finishes the connection of A and B components is cut and the tool which has been designed to be flushing is clean and ready for the next bolt. A sectional view of drilling and injection adapter is seen in figure 44.

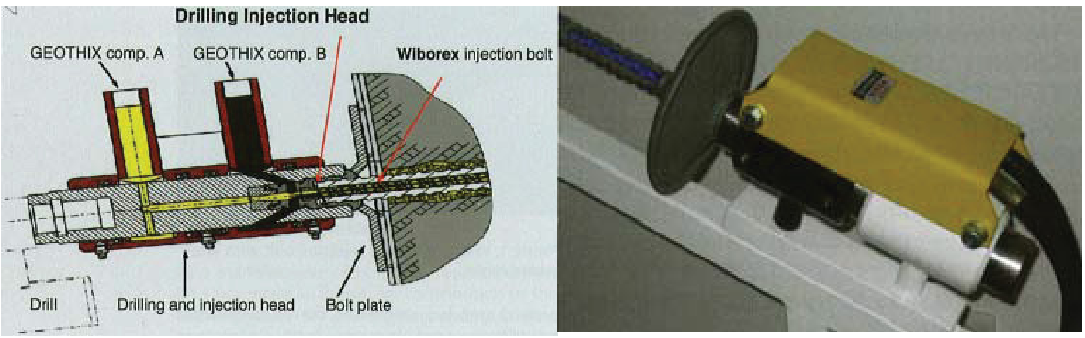


Figure 44: The sectional view and picture of the drilling and Injection adapter for One-Step procedure [42]

A comparison of installation times between cartridge method and one-step bolt is seen in table 7.

Cartridge method (stemming the holes via charging tube)	
Drilling	70 s
Stemming with cartridges	100 s
Setting he bolt	35 s
Holding time	10 s
Total	215 s
One-Step-procedure (the times are mean values of the results of the field tests so far available or development aims)	
Drilling	90 s
Grouting	15 s
Holding time	5 s
Release of adapter	5 s
Total	115 s

Table 7: A time comparison between the cartridge and One-step procedure [42]

It is a system suitable to be used at heavily stressed rocks and collapsed boreholes. It shows immediate bearing effect and its maximum tensile force is 400 kN after 45 s. Resin can be pumped even to long distances by the aid of a pump. It can be used universally.

3.1.2.1.8.2 Two-Step Procedure

It includes static mixer, bolt nut and face plate in two-step procedure as well. It can be applied manually or as an automated system and two-step systems are used manually especially for smaller bolting measurement.

There are those steps in manual application: Firstly the borehole is drilled, secondly bolt is placed and injection adapter is connected to the bolt and then injection process goes on until grout comes out of the borehole mouth, and thus bolt is fully embedded.

High performance is achieved with automated two-step procedure. Hydraulic injection adapter is used at automated two-step procedure. The formal and sectional view of hydraulic injection adapter is presented in figure 45.

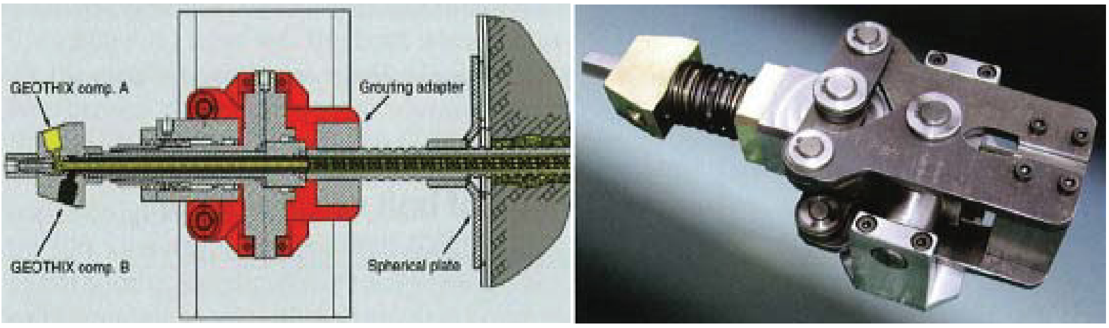


Figure 45: The sectional view and picture of hydraulic injection adapter [42]

Installation stages of automated two-step process are as following:

- The process of attaching bolt to the injection adapter and drilling borehole
- Spinning of injection adapter in the borehole axis
- Injecting grout process until grout comes out of the borehole collar
- The process finishes on detaching injection adapter after a specific setting time

Automated two-step procedure provides tensile strength up to 400 kN after 45 seconds and shows immediate bearing effect. It provides rotary percussive drilling opportunity and the bolt is fully embedded in the bolt resin. A comparison of installation times for cartridge method and automated two-step procedure is seen in table 8. It provides time advantage up to 100 seconds for a single bolt.

Cartridge method (stemming the holes via charging tube)	
Drilling	70 s
Stemming with cartridges	100 s
Setting he bolt	35 s
Holding time	10 s
Total	215 s
Two-Step-procedure (automated)	
Drilling	70 s
Grouting adapter with bolt	25 s
Bring bolt into borehole axis	5 s
Introduce bolt	5 s
Grouting	10 s
Holding time	5 s
Release of adapter	5 s
Total	120 s

Table 8: A time comparison between cartridge and Two-step procedure [42]

For both one and two-step procedures the need for drilling time takes the biggest share of installation time (70-90 s) [42].

3.1.2.1.9 Roofex Yieldable Bolt

Roofex is a fully-grouted yieldable rock bolt developed by Atlas Copco (figure 46). Roofex yieldable rock bolt is developed for deep underground mines having high rock stresses and as it retains its reinforcement strength whilst it is under stress, it adapts to rock deformations and faulting.

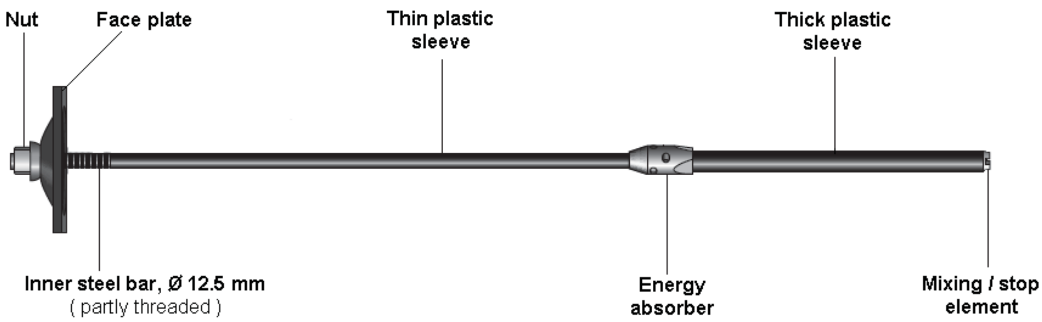


Figure 46: Components of roofex bolt [36]

Roofex rock bolt comprises a high quality inner steel bar going through an energy absorber, and the steel bar is surrounded by 6 pins which are present in the energy absorber and systematically arranged. Except the cage of energy absorber, steel bar and pins are illustrated in figure 47.

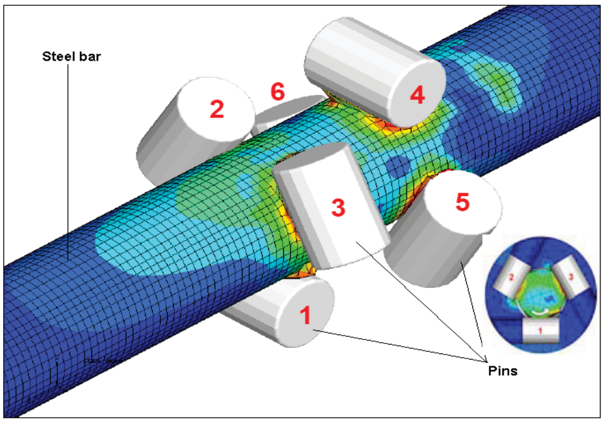


Figure 47: The pins placed around the steel bar [43]

Roofex has a strong faceplate so that the rock mass pressure can be transferred to the bolt during the dynamic activities. The nut is attached to the threaded end of the bolt after faceplate. The back of the half-ball shaped nut is rectangular (figure 48). Inner steel bar of the roofex is covered with plastic sheath. The plastic sheathing protects the roofex from damping and it is covered so that it provides extra friction.

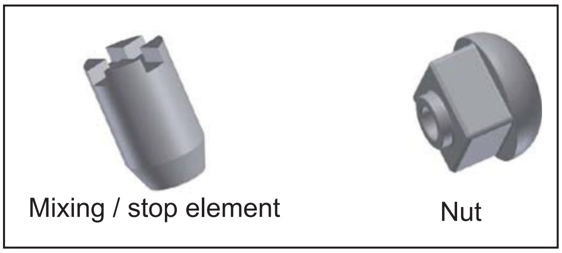


Figure 48: Mixing/stop element and nut belonging to roofex [43]

The most important part of the roofex is the energy absorber, which allows the inner steel bar to move towards the excavation at a stable load. The shape of the energy absorber is presented in figure 49. The energy absorber is a hollow steel bar with holes for 6 pins. The inner steel bar runs through the energy absorber and the pins on the energy absorber deforms the inner steel bar, preventing sliding of the inner bar.

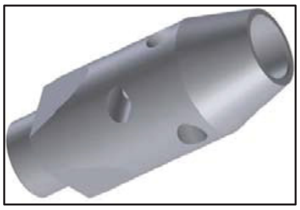


Figure 49: Energy absorber of the Roofex bolt [43]

Hard metal pins are placed into the holes on the energy absorber for dynamic application of Roofex bolt, during dynamic applications heat is generated because of rapid movement of the steel bar and pins are used as carbide. Ordinary pins are used at absorber for static applications. There is a mixing/stopping element at the very end of the roofex. It is designed in a suitable form to smash and mix the resin cartridges inserted into the borehole. If the inner-steel bar slides through the energy absorber, stopping element stops at the end of the sliding length and thus maximum deformation occurs (figure 50).

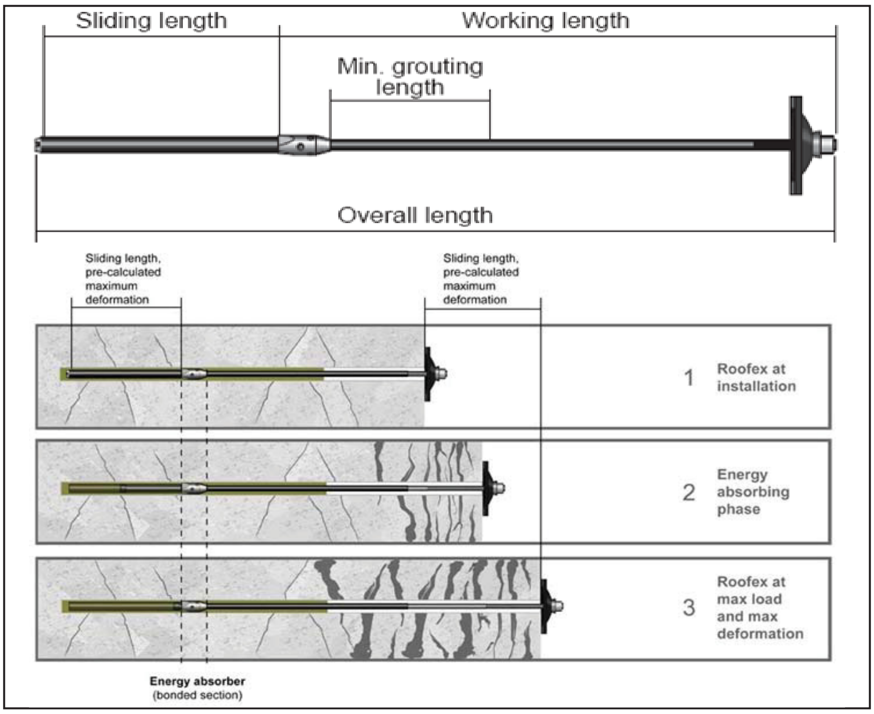


Figure 50: The movement of Roofex yieldable bolt during dynamic loading [44]

Roofex lets both high energy release in the rock mass and very large deformations in the rock mass. The overall length of roofex is 2.4 m and its diameter is 12.5 mm. Sliding length of the roofex is 0.3 m. Some technical information related to Roofex is given in table 9.

The installation stages of the roofex are as following:

The borehole is drilled as the first stage and the borehole length must not be shorter than the overall length of the Roofex. Then the borehole is grouted with cement or resin. The resin cartridges are automatically shot into the borehole and the roofex bolt is inserted into the borehole by being spinned. Mixing/stop element breaks and mixes the resin cartridges and the nut is screwed after the curing time. The installation stages of the roofex is the same as of the conventional resin bolt, but they have more displacement capacity than the conventional bolts (figure 51).

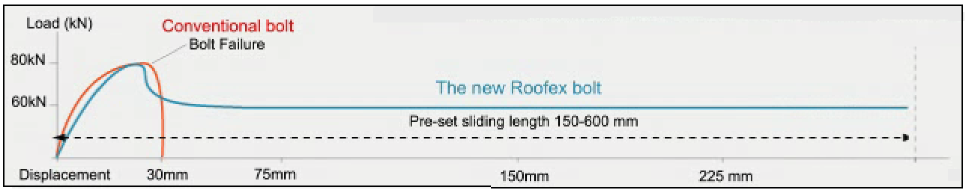


Figure 51: The displacement curves of conventional bolt and Roofex under dynamic application [44]

The stop element at the end of the inner steel bar comes closer to the energy absorber under loading and sliding length shortens. In the meantime, the surface of inner steel bar going through the energy absorber is distorted. If the deformation is continues, sliding length is finished and the steel bar will fail (figure 52).

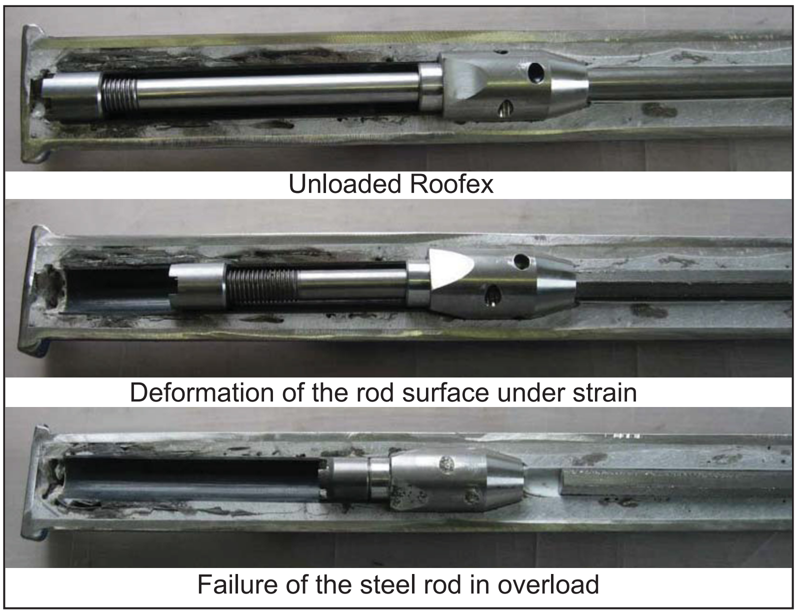


Figure 52: Roofex under working conditions [43]

Steel bar Ø	12,5 mm
Nut (hexagonal)	35 mm
Energy absorber outer Ø	30 mm
Mixing element outer Ø	30 mm
Plastic sleeve1 outer Ø / wall thickness	22,8 / 1,4 mm
Plastic sleeve2 outer Ø / wall thickness	17,0 / 0,7 mm
Drill bit Ø	33 mm
Resin cartridge Ø	28 mm (for 33 mm drill bit)
Min. grouting length	500 mm
Sliding length	300 mm
Overall length	1,5 – 3,6 m
Ultimate load	100 kN
Yield load	90 kN
Sliding load	80 kN
Static elongation of steel bar	< 15%
Dynamic elongation of steel bar	< 10%
Static energy absorption	~ 800 J / cm sliding length
Dynamic energy absorption	~ 290 J / cm sliding length

Table 9: Technical specifications of the Roofex [44]

Roofex yielding rock bolt system is effective in massive rock with high stress conditions where dynamic events occur. In the case of a sudden release, it transfers the energy to the sliding length before any damage occurs [44] [45].

3.1.2.1.10 Hardi Friction Bolt

The Hardi friction rock bolt is a V-structure metal tube in terms of appearance. The end part of the Hardi bolt is formed slightly in a conical way. The Hardi bolt is illustrated in figure 53.

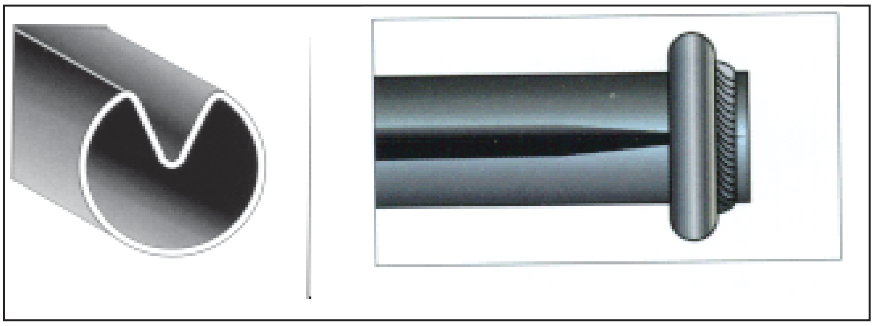


Figure 53: Hardi rock bolt [46]

The Hardi bolt is similar to the split-set bolt from mode of action aspect but it looks like a swellex bolt. The borehole diameter is smaller than hardi bolt diameter and tube is compressed during installation, applying radial forces against the borehole wall (figure 54). The concave inlet section of the tube narrows during installation process.

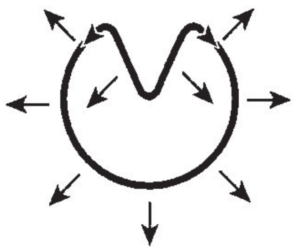


Figure 54: V-structure and radial forces [46]

The installation principles of Hardi bolt:

For the drill bit diameter to be used for the hardi bolt is chosen 1-2.5 mm smaller than the bolt diameter and the borehole is drilled. An adapter is needed for the hardi bolt to be placed into the borehole and the adapter is fixed on the drilling device. As a next step, the hardi bolt is hammered into the borehole. A hardi friction bolt fixed on a boom and ready for installation is presented in figure 55.

Figure 55: Hardi bolt on boom and ready for installation [46]

There are different types of hardi friction bolts: regular steel, galvanised and Cr-Ni steel. Some technical specifications related to the hardi bolt are presented in table 9. Maximum hardi bolt length is up to 6 m.

Stabilizer Model	HB-33	HB-39	HB-46
Normal tube Outer Diameter	33 mm	39 mm	46 mm
Optimum performance bit size range	30.5 - 32 mm	36.5 - 38 mm	43.5 - 45 mm
Estimated initial anchorage	6 - 10 tons	8 - 12 tons	10 - 14 tons
Stabilizer tube lengths	0.9 - 2.4 m	1.0 - 6 m	1.0 - 6 m
Tensile Strength (kN)	10.0	13.2	16.2

Table 10: Features belonging to Hardi friction bolt [46]

Advantages:

Its installation is simple and quick, it has immediate support effect with installation, installation by using of the drilling machine is possible, it elongates up to % 30.

Disadvantages are these:

It cannot be used as permanent support due to corrosion, automatic installation is done, it has low friction effect in highly fissured rocks [46] [47].

3.1.2.1.11 Hardi Cable Friction Bolt

The difference of Hardi Cable Friction bolt lies in the fact that a seven strand steel cable goes through it and the low part of it is made in a suitable form for grout clamp. Hardi cable friction bolt is presented in figure 56.

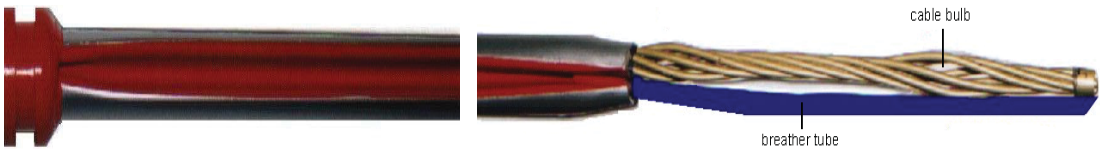


Figure 56: Hardi cable friction bolt [46]

Installation principles of hardi cable friction bolt:
Borehole diameters needed for hardi cable friction bolt are the same as of the hardi friction bolt. After the borehole is drilled, the bolt is hammered into the borehole. Then, hardi cable bolt needs to be grouted and a grouting clamp is used for this (figure 57). Grouting clamp is attached to the low end of the hardi cable friction bolt and grout is pumped through the bolt.

Figure 57: Connection of grouting clamp [46]

Air in the hole is sent out via the V-structure or sent out by the aid of a breather tube (figure 58). There being bulbs at specific intervals on the cable provides high bondage when grouted.

Figure 58: Cross-sectional view of cemented Hardi cable friction bolt [46]

Some technical features belonging to the hardi cable friction are presented in table 11.

Cable Model	HFCB 46
Normal tube outer diameter	46 mm
Optimum performance bit size range	43.5 - 45 mm
Estimated initial anchorage	10 - 14 tonnes
Grouted anchorage	16 - 20 tonnes
Stabilizer tube lengths	1.0 - 2.4 m
Total length tube + cable	various

Table 11: Technical features of Hardi cable friction bolt [46]

As the hardi cable bolt is grouted, it is protected against corrosion and can be used as permanent support as well. Its pull-out strength and bearing capacity increases, too. Due to the ground movement, elongation up to 30% occurs. It shows immediate support effect [46] [47].

3.1.2.1.12 Tubex

Tubex is a tube which is studded on its surface and deforms a like Split-set. Tubex is a kind of post-groutable friction bolt. Tubex diameter is bigger than the borehole diameter and the studs will slide all along the drill hole wall while being driven into the borehole. All radial forces are transmitted into the rock mass over the studs, which serve as well for centring the tube in the drill hole. In this way, grout thickness distribution in the drill hole is uniform everywhere. Tubex lets cement grout after it is installed. Cement can be pumped through its free end, which is the upper part. Free end of the tubex functions as automatic sealing at the same time. Because at that part there is no annulus between drill hole wall and tubex out surface, so seepage will not occur when the cement is pumped from the low end of tubex. On the contrary, cement will go into the rock fractures and to the ways among the cavities and more efficiency will be gained. Inner part of tubex as well as its outer part is grouted and the area in the state of metal/grout contact is rather high. Tubex bolt is illustrated in figure 59.

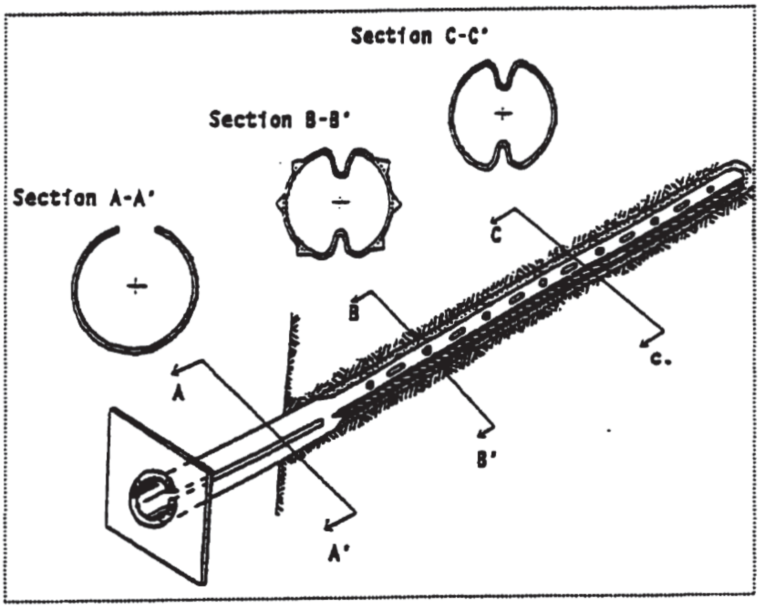


Figure 59: Tubex grouted friction tube [48]

Pull-out resistance of the Tubex bolt will occur between tube, grout and drill hole wall. In addition, that tubex is groutable increases the rock mass strength. As the tubex is grouted with cement the risk of corrosion disappears. Tubex can be used as permanent support. The fact that it is automatically installed provides a lot of advantages and it is a cheap method [48].

3.1.2.1.13 Ezi Bolt

Ezi bolt is a system developed by Celtite Pty Ltd. Company. The system comprises a hollow steel bolt, and a static mixer with a resin cartridge in the bolt. Ezi bolt and its components are illustrated in figure 60.

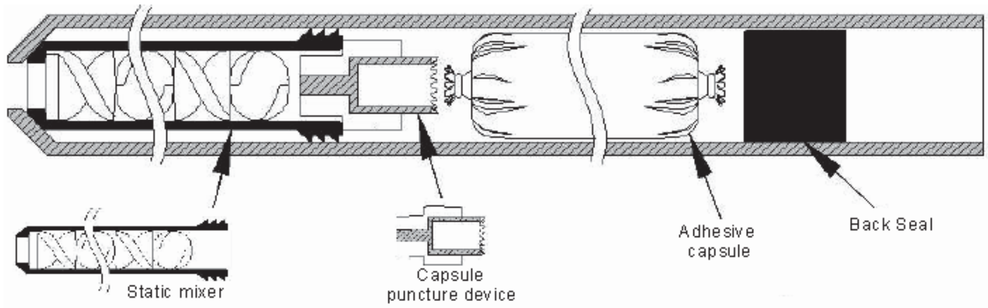


Figure 60: Ezi bolt and its components [49]

When the Ezi bolt is compared with the resin bolts which are conventional in terms of installation stages, it is seen that Ezi bolt eliminates most installation stages. While installing the Ezi bolt, first the borehole is drilled and then the bolt is inserted into borehole. Next step is a hydraulic pressurisation of the resin capsule that involves opening of the resin bag with a puncture device and squeezing out the resin through the static mixer. The state of Ezi bolt during installation is seen in figure 61.

Figure 61: Installation of Ezi Bolt [49]

The system is suitable for all strata types and ground conditions. Thanks to the static mixer, it becomes an effective resin mixing. As the system is installed only in two stages, it saves time and decreases the margin of error [49].

3.1.2.1.14 AT-Power Self-drilling Split-Set Bolt

This friction bolt known as power-set anchor is principally the same as Split-set anchor. It is a pipe cleaved lengthwise. Its radius is 50 mm and wall thickness changes between 3.75 mm and 5 mm. Its installation process is different and power-set is placed into the hole during drilling.

Split bolt is around the drill rod and slides on the rod. At the end of the rod, there is drill bit doing the drilling operation and drill bit diameter is smaller than bolt diameter. During drilling, AT-power set bolt is pushed into the borehole by hammer continuously and by the aid of power set adapter. Anchoring is achieved via the friction of bolt to the borehole wall. After the installation of bolt, the drill rod is retracted. Figure 62 presents a AT-power-set friction bolt.

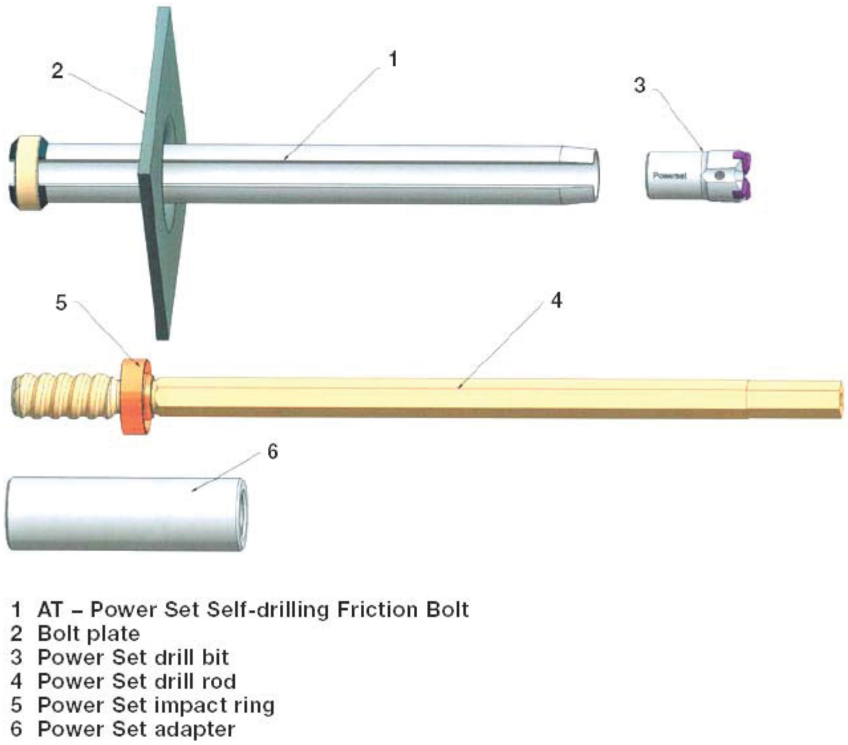


Figure 62: AT - Power Set Self-drilling friction bolt [50]

Its advantages can be listed as following:
The installation process of the bolt is simple and easy and shows immediate support effect. It is time-saving as the drilling and installation are all in-one, there is no risk of rock fall stemming from drilling for crew because bolt is installed during drilling. The bolt has a high shear resistance, even higher than its tensile strength. It is not affected by the blasting activities underground.

As to the disadvantages:
Material costs are high, drilling takes much time, and cannot be used as permanent anchor due to the fact that it has danger of corrosion [51].

3.1.2.2 Non-automated Systems

3.1.2.2.1 Worley Bolt

This bolt has been developed by the American company Worley of Philadelphia in 1967. A figure of Worley bolt is presented in figure 63. It consists of two jagged metals jointed to each other. Activation and use of Worley bolt is very easy. The nut is screwed and pressed towards the washer and the expanding bolt applies pressure to the hole walls. In addition, dismantling the Worley bolt is easy, that is after its nut is removed, it is hit with a hammer at the bottom and a counter effect is applied on the anchor thus it is dismantled easily and resumes its previous form and becomes ready to be reused.

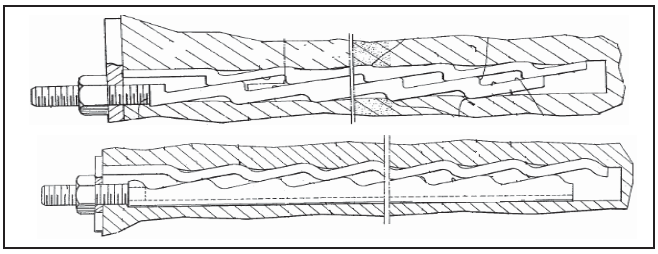


Figure 63: Worley bolt with anchoring effect over full borehole length [52]

The Worley bolt can be mechanically expended to a certain degree, nevertheless the drill hole diameter must be suitable. The Worley bolt has never been used with cement or resin in practice, and is used at short term applications in softer and weaker rocks [52] [53].

3.1.2.2.2 Cement Grouted Rebar

As the mechanically anchored rock bolts are not effective at soft rocks and in cases of vibration resin or cement anchored bolts are developed [19]. Via this method, rockbolt is grouted into the hole by means of cement. The rock bolt is in a continuous connection with the hole surface by the aid of cement. Cement grouted rockbolts are used as the primary precaution at the struggle against hard roof conditions. A cement grouted rockbolt is presented in figure 64.

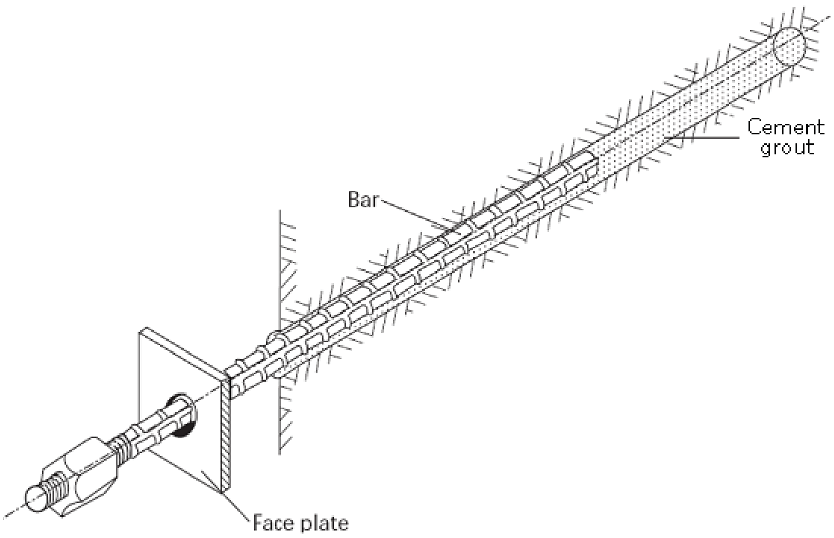


Figure 64: Cement grouted rebar rock bolt [19]

When axial deformation is applied to the fully grouted bolts, failure will appear either between bolt bar and grout or between grout and hole wall. Cement grouted bolts are used as permanent or temporary support according to the state of rock [1] [28].

3.1.2.2.3 Kiruna Bolt

Slotted bolt and cross wedge is a groutable rebar bolt known as anchor or Kirunabolt, which is the generic name. The very end part of the bolt is slotted in the shape of cross and a wedge is inserted into this slot in the shape of cross.

Installation operation of Kirunabolt is simple: A borehole pierced in advance is grouted and then bolt and wedge driven into hole mouth is hammered to the bottom of borehole by means of a pneumatic device. However, hole length and bolt length must totally balance each other. Face plate with a half-ball and nut are all fixed to the bolt, this provides screwing and thus bolt is pre-stressed [54] [55].

A spherical washer with a half-ball is fixed between the faceplate and nut, which makes it possible to install the bolt to uneven rock surfaces without causing adverse tensile tensions in the bolt. Primary function of the washers is to transfer the stresses caused by movement of the rock to the bolt. A picture showing to the Kirunabolt is presented in figure 65.

Figure 65: Kiruna Bolt

The bolt diameter used in Kiirunavaara (Sweden) is 20 mm, bolt length is 2,25 m and load capacity is 160-180 kN. The bolt mounted wedge gives an immediate load about 30-50 kN [54] [55].

3.1.2.2.4 Thorbolt

The bolt known as System Thorbolt is a dynamic injection bolt invented by Gurlita GMA AB (Sweden).

The system thorbolt can be used with a standard rebar. In general, the diameter of the rebar used is 25 mm but they can also be used with other rebars with different diameters. A figure belonging to the system thorbolt is illustrated in figure 66.

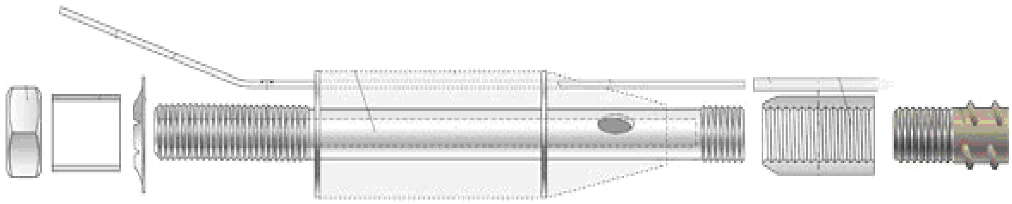


Figure 66: Thorbolt injection system [56]

Installation of Thorbolt :

The rebar is placed at the end of the thorbolt and inserted into the hole, that was drilled in the previous step. On tensioning the nut placed under the thorbolt, the rubber of the thorpack is compressed and expanded radially against the hole wall. Thus the expanded thorbolt tights the low end of the borehole and then grout is pumped into the borehole. The annulus between rebar and borehole is grouted and grout fills to the fissures of rock as well. Thorbolt installation is illustrated in figure 67.

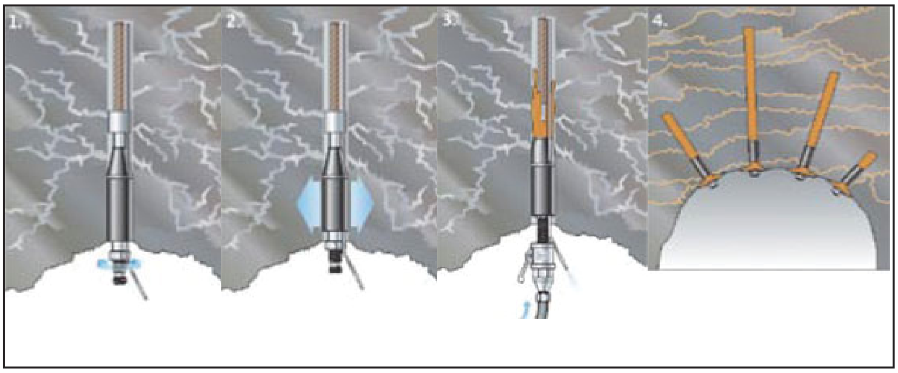


Figure 67: Installation stages of Thorbolt [56]

The uses of system thorbolt are as following:

Especially in water carrying holes the grout pressure can be balanced against actual groundwater pressure. Thorbolt provides the protection of rebar against corrosion and does not allow the grout to flow out of the borehole during installation. As the bolting and grouting occur concurrently it saves time. As the thorbolt pumps grout into the crack and fissure systems in the rock, it builds active arch structure around the excavation and provides up-classing and also prevents the water leaking from roof to the excavation. Thorbolt is applicable to many rebars thanks to different couplings. Technical specification belonging to the thorbolt holds a place in table 12.

Central pipe	Ø 25×8 mm, length 420 mm
Material	S355 J2G3 according to EN 10025
Surface treatment	Hot-galvanised
Yield load	177 kN
Central pipe, thread	M24, M20
Ultimate load	219 kN
Injection pressure	Up to 70 bar
VCT (cement mix)	Optional
Evacuation pipe	Ø 6×1 mm
Drainage hose	Ø 8×1 mm
Adapter, thread	M24, M20
Standard bolt, usually rebar (not included)	Ø 25 mm med gänga M24, M20
Rubber	Natural SBR, D=44-61 mm

Table 12: Technical specification of the Thorbolt [56]

The fact that drilling, bolting and grouting can be done with a single equipment allows the bolting automation of thorbolt [56].

3.1.2.2.5 Dynamic Cable Bolt

This system known as dynamic cable bolt is patented by Garford Pty Ltd. (Garford Ground Support Systems) company with AU2003/001667 patent number.
Dynamic cable bolt is a cablebolt consisting of an energy absorber fixed at a specific part of the bolt. The outer surface of the cablebolt is covered with plastic material. The lower end of cablebolt is threaded and the faceplate, half ball dome and nut are fixed on it.

The bolt consists of 15.2 mm diameter seven wire compact strands and its length is up to 5 m. The possible borehole diameters where it is installed are 45-51 mm. The Dynamic cable bolt is illustrated in figure 68, the mechanical and dynamic properties are given in table 13.

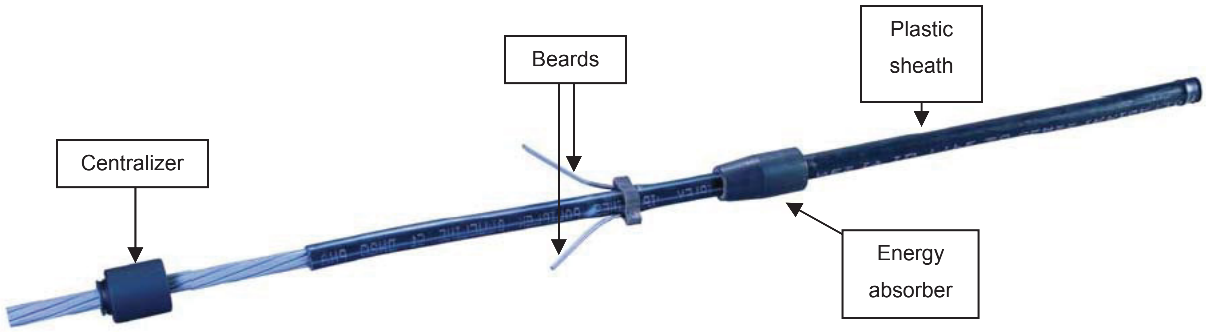


Figure 68: Dynamic cable bolt [57]

It can be installed with cement or resin. As the energy absorber is bonded with cement, it cannot perform axial displacement. Due to the reason that the outer part of the cable bolt is sheathed the cable can perform axial movement up to a certain limit.

If any movement of rock occurs the cable is pulled through the energy absorber and extrudes it. Dynamic cable bolts are used in places where seismic activity is expected [57].

MECHANICAL PROPERTIES	Minimum	Typical
Yield Force (kN)	212	285
Tensile Strength (MPa)	300	310
Mass per meter (kg)	-	1176
DYNAMIC PROPERTIES		
Static Yield Force Capacity	150 – 180 kN	
Dynamic Yield Force Capacity	80 - 120 kN	
Ultimate Displacement Capacity	300 mm	
Ultimate force Capacity at displacement capacity	250 kN (25 tonne)	

Table 13: Technical specification of dynamic cable bolt [57]

3.1.2.2.6 Fibreglass Bolts

Fibreglass rock bolts provide very popular rock reinforcement for coal mines. Especially, as fibreglass rock bolts can be cut, they are light, not corrosive and have high bearing capacity, they are mostly preferred in coal mines. Thanks to this, cutting tools of coal cutting machines can cut the fibreglass rock bolt without being harmed.

In general, diameter of the fibreglass rock bolts being used is 22 mm, and their theoretical tensile strength is approximately 350 kN and their Young's modulus is 46.2 Gpa. Typical bolt lengths being used in coal mines in United Kingdom are ordered as 1.2 m, 1.5 m, 1.8 m and 2.4 m. Some technical specifications belonging to the threaded fibreglass rock bolts having different sizes and belonging to Dywidag company are presented in table 14.

Glass fibres are composed of a fibrous composite material having complex mechanical features. Under usual conditions, it is not possible to measure the tensile strengths of fibreglasses directly because gripping the ends of test samples poses a problem. However, strength can be increased by using an epoxy resin of better quality or different glass fibre rovings. The resin bond between rock and bolt, and end-system-design are important for the strength of the fibreglass [58].

Diameter	Solid bolt (20 mm)	Solid bolt (25 mm)	Hollow bolt (25 mm)
Resin Type	Polyester / epoxy resin		
E – Modulus, minimum	35 GPa		
Breaking strain, maximum	3 % maximum		
Tensile Strength, minimum	167 kN	262 kN	202 kN
Shear strength, minimum	43 kN	66 kN	49 kN
Nut/Thread Strength, min.	95 kN	120 kN	120 kN
Nut Break out torque	80-90 Nm	n/a	n/a
Grout hole diameter	Not available	Not available	12 mm
Weight	0.55 kg / m	0.88 kg / m	0.66 kg / m

Table 14: Technical specifications related to the fibreglass rock bolts [20]

Installation stages of conventional fibreglass rock bolts are as following:
First, the borehole is created. Secondly the resin cartridges are inserted into the borehole and then the solid fibreglass is driven into the borehole with a spinning movement. The bolt is bonded with resin, after the curing time the faceplate and the nut are applied.

Different methods related to forming the fibreglass bolt are developed by fibreglass manufacturers. The most popular fibreglass form in our day is the one like rebar texture or threaded texture. Examples of Fibreglass rebar forms are presented in figure 69. In order to reach the most optimum bonding between bolt and resin at fibreglass rock bolts, fibre resin and bolting resin are advised to be of the same chemical composition [58].

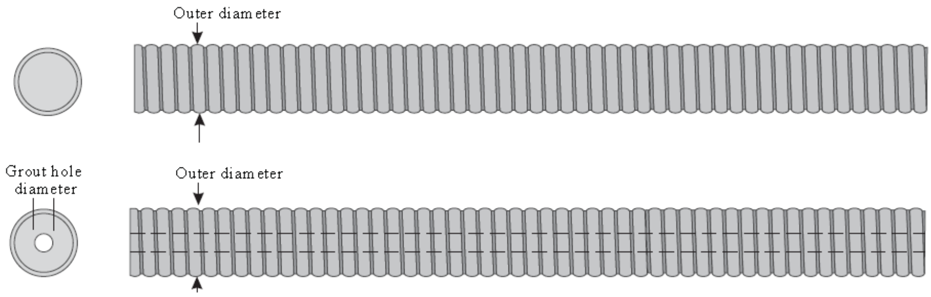


Figure 69: Solid and hollow bar fibreglass rock bolts with threaded form [20]

The torsion performance of fibreglass bolts are limited, torque being applied to the nut during the installation must be to a certain degree. However, some systems designed by manufacturers have prevented bolt from being harmed during installation. A highly resistant coarse threaded nut end is directly attached to the end of the bolt. These nuts have 80 kN and sometimes up to 100 kN bearing capacities. As it is seen before in figure 69, the development of hollow fibreglass rebars has given the chance of post-grouting for fibreglass rock bolts. Thanks to this, installation stages of fibreglass rock bolts have decreased.

Advantages of fibreglass rock bolts:

- as the shear strengths of the fibreglass rock bolts are low, they can be cut easily by cutting machines,
- they have high bearing capacities,
- as they are manufactured of light material, their transport is also easy,
- as they are not affected by corrosion, they can be used as permanent support,
- During the manufacturing of the fibreglass bolt, it is possible that an artificial failure point, for easy cutting of the bolt is implemented in the rebar

Fibreglass rock bolts are generally used to support coal production face or to support side walls at drifts, rib bolting and sometimes to bolt floor in coal mines [58].

3.1.2.2.7 Dynamic Solid Bolt

The Dynamic solid bolt is patented by Garford Pty Ltd. with AU2007/000396 patent number. The Dynamic solid bolt is composed of a helical threaded tube which is geared on a specific section of a solid rod. In figure 70 dynamic solid bolt is presented.

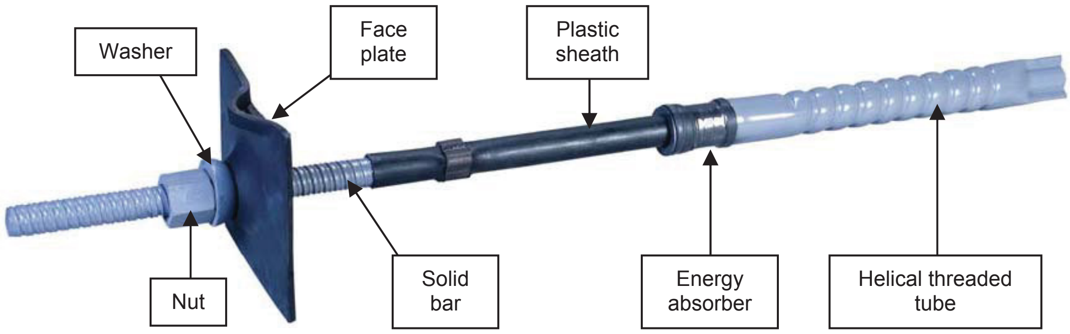


Figure 70: Dynamic solid rock bolt [57]

The Dynamic solid bolt can be installed with resin or cement. First, the resin cartridges are sent into a drilled borehole. Secondly, the dynamic bolt is driven into the borehole while being rotated. Resin cartridges are torn during rotation and the resin is mixed. The helical threaded tube geared on the outer surface of the bolt prevents resin from coming out of the borehole mouth. The mechanical and dynamic properties belonging to the dynamic solid bolt are presented in table 15.

MECHANICAL PROPERTIES	Minimum	Typical
Core Diameter – Bar (mm)	21.45	21.7
Cross Sectional Area – Bar (mm2)	361	370
Yield Strength (MPa)	550	580
Yield Force (kN)	199	215
Tensile Strength (MPa)	850	915
Tensile Force (kN)	307	339
Elongation (%)	12	16
Mass per meter – Bar (kg/m)	3.0	-
DYNAMIC PROPERTIES		
Static Force Capacity	140 kN	
Dynamic Force Capacity	100 kN	
Displacement Capacity	up to 500 mm	

Table 15: Technical specifications of dynamic solid bolt [57]

The most important feature of the dynamic bolt is that it absorbs seismic events and remains intact. It absorbs the vibrations caused by blasting and thus it precludes secondary fissures or fractions that are likely to occur on the rock [57].

3.1.2.2.8 Dynamic Tiger Bolt

The tiger rock bolt is a permanent resin bolt system manufactured from high strength steel tube. The tiger bolt is composed of a drive nut, a faceplate, threaded bar, a collar and a destructible cardboard resin cartridge holder. Tiger bolt is presented in figure 71.

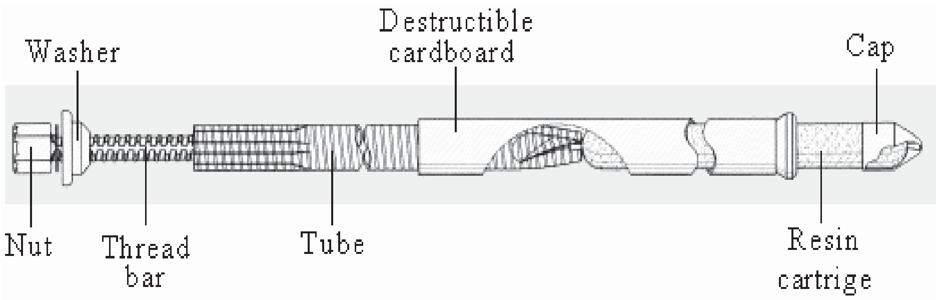


Figure 71: Tiger bolt [20]

After installation the tiger bolt is fully encapsulated by resin, it is pre-tensioned and can be used as permanent support. Technical specifications belonging to the tiger bolt are presented in table 16.

	Minimum		Typical	
Yield Strength	350MPa	123kN	460MPa	162kN
Ultimate Tensile Strength	430MPa	152kN	520kN	183kN
Standard Elongation			20 %	
Mass Per Meter			2.74 kg	
Tube Diameter			38.1 m	

Table 16: Technical specification about tiger bolt [20]

The standard length of the tiger bolt is 2.4 m but 2.2 m of this length is tube and 0.2 m of it is thread bar tail. The thread bar tail is swaged to the low end of the bolt and the thread bar-tube strength is equal to the strength of the tube. The other end of the tube/tiger bolt is crimped [20].

3.1.2.2.9 Post Injection Bolt

This bolt which is a post-groutable expansion shell bolt provides grout injection into the fault zones and pores of the rock mass. This injection bolt system is an Arnall Poland company production. The system comprises an expansion-shell, a steel bar, a steel tube, a rubber seal, a square washer and a hexagonal nut. A picture belonging to this bolt is illustrated in figure 72 [59].

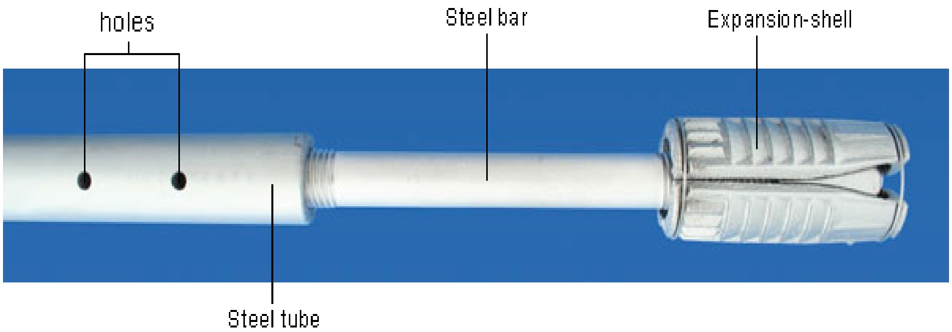


Figure 72: Arnall Poland Post-groutable expansion-shell rock bolt [59]

A smooth steel bar with 18.3 mm diameter is attached at the one end of a steel tube which has 30 mm diameter. There are 4 holes at the end of the steel tube positioned close to where the steel tube connects with the smooth bar. These holes provide the flow of grout into the borehole and the diameter of these holes is 6 mm. In the mid-section of the steel tube, there is stop collar which serves for sealing. The seal expands after applying the tube and nut. The technical specifications belonging to this injection bolt are given in table 17 [59].

Tube diameter	ø 30x6,3 mm
Bar diameter	ø18,3 mm
Tube thread size	M20 internal M30 x 2 external
Bar thread size	M20
Bolt length	from 1300 to 5000 mm
Expansion-shell diameter	ø 42 mm
Head length	93 mm
Bolt capacity	over 120 kN
Nominal injection pressure	10 MPa

Table 17: Some technical specifications belonging to Arnall Poland post-groutable expansion-shell rock bolt [59]

The installation of injection bolt system:
First the borehole is created which has approximately 44 mm diameter and its length is equal to the length of bolt. The injection bolt is inserted into the borehole and places by expanding of the expansion-shell. Torque applied for screwing must be at least 250 Nm. As a next step, the bolt protrudes from the hole surface about 85-95 mm and then the nut is removed from the bolt.
After the nut is removed, a seal, tube, washer and nut are attached to the bolt and rubber seal is expanded through an application of at least 30 kN tension. After the rubber seal is expanded in the borehole, the grout pump is attached and grout is injected. As the grout is injected in a pressurized way, fault zones and pores in the rock are grouted and rock becomes stronger, its water permeability decreases and the stability of the rock rises [59].

3.1.2.2.10 Gemini Post Groutable Rock Bolt

The Gemini system is a Post-groutable expansion-shell rock bolt. The system comprises a fully threaded hollow steel bar which has an expansion-shell element at its very end, a seal at the other end of the hollow bar, a domed faceplate, a nut, a face plate and a grouting tube which is passing through the seal. A picture belonging to Gemini system is illustrated in figure 73.

Figure 73: Gemini system rock bolt [60]

Outer diameters of Gemini system are 20 mm, 21.8 mm and its inner diameters are 14.5 mm, 16.5 mm. Their lengths vary from 0.6 m to 3 m. Some mechanical properties related to the Gemini system are presented in table 18.

Nominal diameter (mm)	Ultimate tensile strength MPa (min)	Ultimate tensile load (kN)	Elongation at fracture % (min)
145	600	100	6-8
200	600	180-200	6-8

Table 18: Mechanical properties of the Gemini system [60]

Installation stages of Gemini system:

At the first stage, the borehole with a diameter not bigger than the shell diameter plus 5 mm is drilled. The bolt is installed into the drilled hole, the seal at the low end of the bolt seals the borehole mouth and the bolt is pre-stressed by screwing the nut. Then, grout is pumped into the borehole by means of grouting tube. The hollow part of the bolt has the function of a breathing tube, the complete filling of the borehole is indicated by out-flowing grout. Finally, the grout pump is taken off and grouting tube is sealed off. The sealing section of Gemini system during installation is illustrated in figure 74 [60].

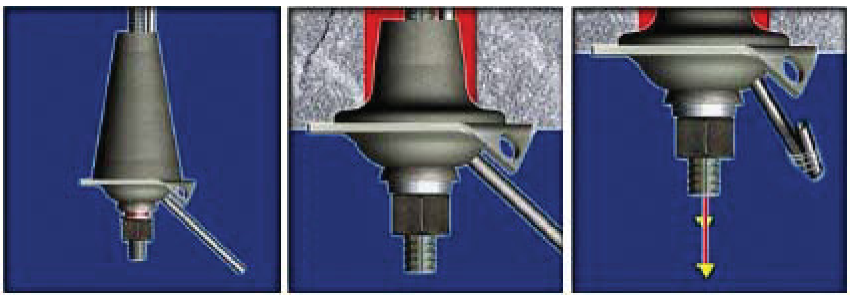


Figure 74: Sealing section of the Gemini system [60]

Advantages of Gemini system:

It provides immediate support effect soon after the installation, it is protected against corrosion as it is grouted and the Gemini system does not need an extra breathing tube during installation [60].

3.1.2.2.11 RS-Bolt

The RS-bolt is a pre-stressed rock bolt developed by New Concept Mining Company. Its working principle and installation are quite similar to the working principle and installation of swellex bolt. The RS-bolt (figure 75) has curved sections in specific intervals to allow installation in narrow seam environments. The RS-bolt provides anchoring by the frictional effect between rock and bolt. There is a valve instead of a hole on the RS-bolt. As the bolt is expanded with pressurised water, the valve allows two options: the first one is that the water in the bolt is blocked after the bolt is expanded, the other is that the water is allowed the flow out [61].

Figure 75: The view of RS bolt [61]

Technical specifications of RS-Bolts:

The RS-bolt is available with two un-flatted diameters, which are 26 mm or 29 mm. The corresponding inflated diameters are 37 mm and 41 mm. The suggested borehole diameter for 26 mm diameter bolt is 30-36 mm and 34-40 mm for 29 mm diameter bolt. Bolt lengths reach up to 3 m. Typical RS-bolt wall thickness is 2 mm and 2.3 mm. As already mentioned RS-bolts are bent at specific intervals with bending degrees of 45°, 60° or 90°. The bolt has gained flexibility thanks to these curves, so the use of the RS bolts is possible at places that have less stopping height than the bolt (figure 76). When the critical bond length of the RS-bolt reaches 300 mm, bolt bearing capacity reaches 10 tons. The minimum pressure needed to expand the RS bolt must not be less than 20 MPa and typical pressure must be 20-30 MPa [61].

Figure 76: RS bolt during installation [61]

Installation stages of RS bolt are also similar to the installation stages of swellex. First, borehole must be drilled in such a way that it will not be shorter than the total length of bolt and then bolt is inserted into the borehole by making its curved parts smooth (figure 76). After the bolt is inserted into the borehole, pressurised water pump is applied to expand the bolt.

The different colours on the valves of RS-bolts represent the specific bolt lengths, an useful tool for installation (figure 77) [61].

Figure 77: Different valve colours for the RS Bolts [61]

3.1.2.2.12 Pakran Injection Bolt

The Pakran injection bolt was developed by Ankra spol sr.o company (in Czech Republic) for use in soil and rock. The bolt provides both injection and friction. Ankra injection bolts enable the cracks in the rock mass to be improved and grow stronger by means of grouting material injection. Pressured grout injection fills in the pores and joints of a rock mass, sealing and reinforcing the rock mass.

The Pakran injection bolt consists of a metal tube which is folded on its sides and valves attached at both sides of it. Its cross-sectional view looks like a four-leaved clover (figure 78). During the installation of the Pakran bolt, the bolt is expanded with pressurised grouting material. After expanding, a valve at the top of the bolt opens at 7 MPa, allowing the grout to fill the borehole and surrounding fissures. A rubber seal near the mouth of the borehole prevents pressure loss [62].

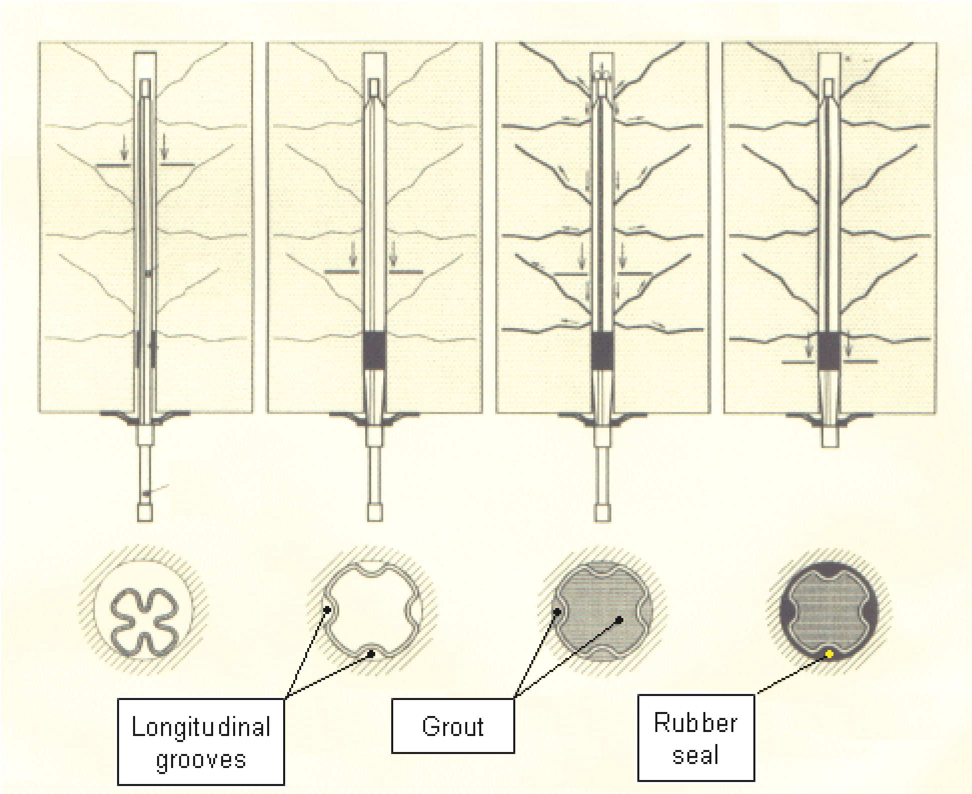


Figure 78: Cross-sectional and vertical-sectional views of pakran bolt [62]

The advantages of the bolt: it shows immediate support effect after installation, it is protected against corrosion as it is grouted, and it injects grout into the cracks in the rock [62].

3.1.2.2.13 D – Bolt

D-Bolt is a yielding rock reinforcement developed by Norwegian University of Science and Technology (NTNU) and use in mines and tunnels (figure 79).

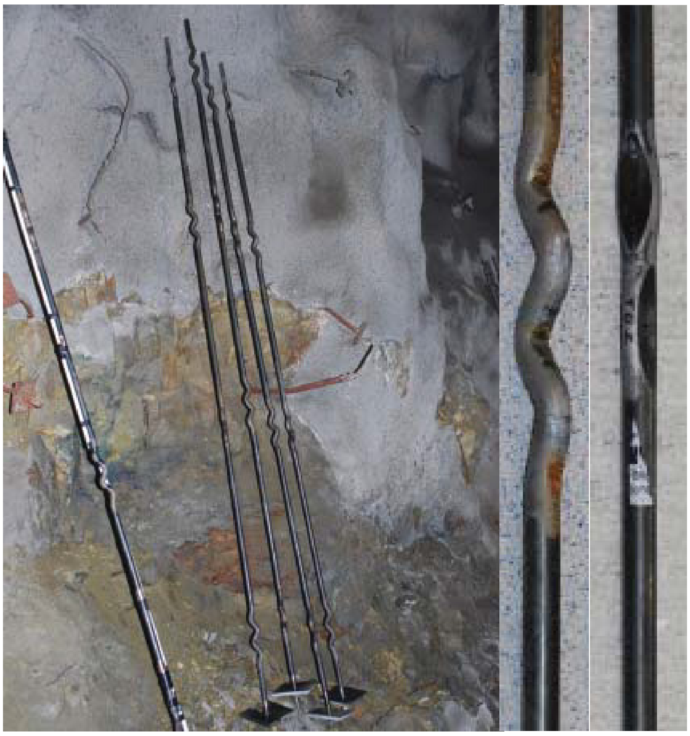


Figure 79: D-Bolt and anchor alternatives [63]

The D-bolt is a smooth rod with spiral shapes that are created by being bent or pressed on specific intervals. The D-bolt can be grouted with cement or resin. The D-bolt has a high tensile and shear strength, withstanding large rock deformations. The yielding characteristic of the D-bolt has worked out well against the vibrations in rock which result from the deformations in high stressed rock. The laboratory pullout test results of the D-bolt (figure 80) shows that D-bolt has a high load-bearing and large deformation capacity.

According to the laboratory test results, a D-bolt with 20 mm diameter and 640 mm smooth section has deformed for 6 mm during the ultimate yielding. Yielding load of a specimen with two spiral sections was 150 kN. Loading curves belonging to different bolts are also given in figure 80 in order to be able to compare D-bolt with other bolt types. The ultimate strength of the D-bolt is on the same level with the ultimate strength of rebar rock bolt, but the maximum elongation of D-bolt is approximately three times more than of rebar and D-bolt dissipates high amounts of energy [63].

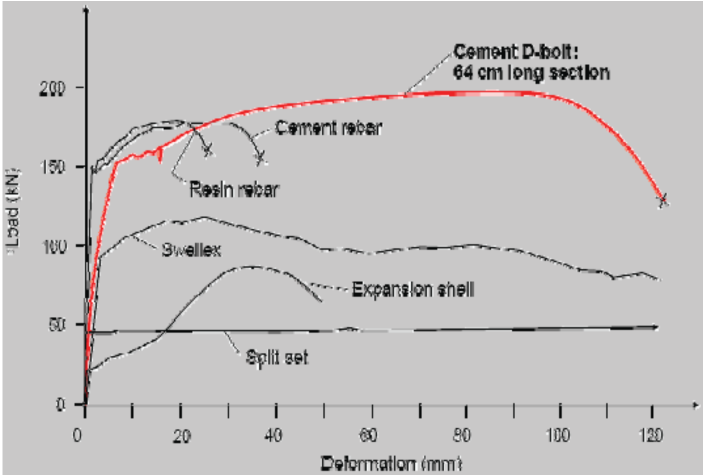


Figure 80: Laboratory pull out test results of D-bolt [63]

After a month of installation time, the load on a 3 sectioned D-bolt and a 22 diameter rebar bolt were measured in the field tests in Sweden at Kristineberg Mine, and consequently D-bolt appeared to provide better rock reinforcement than rebar (figure 81) [63].

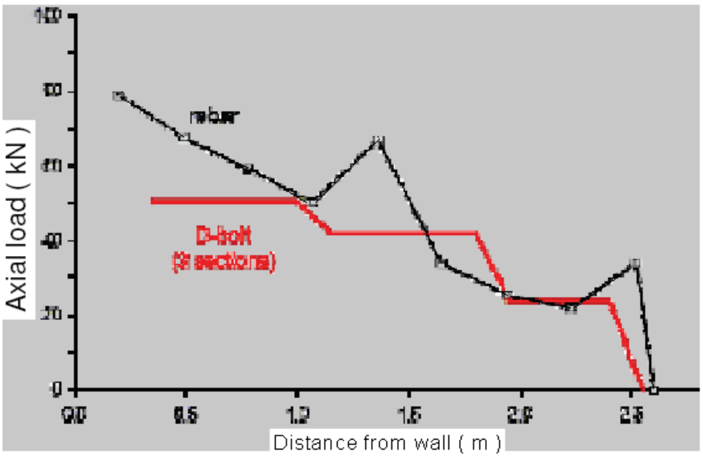


Figure 81: Field-test results of D-bolt [63]

The D-bolt shows a smoother loading response compared to a rebar bolt and unexpected failures do not occur at peak positions. The distributed spiral shapes on the D-bolt system increase the energy absorption capacity of the bolt and lead to a higher useable deformation of the bolt [63].

3.1.2.3 Patented Systems

3.1.2.3.1 Full-length Mechanical Friction Anchor

Another example for full length expansion bolt is a system patented with US3680430 patent number by Robert E. Cannon et al in 1972. The shape of this bolt is presented in figure 82 and its application is almost the same as the Worley bolt. It consists of two smooth iron metals which are in contact with each other. It provides anchoring by applying pressure against the hole wall.

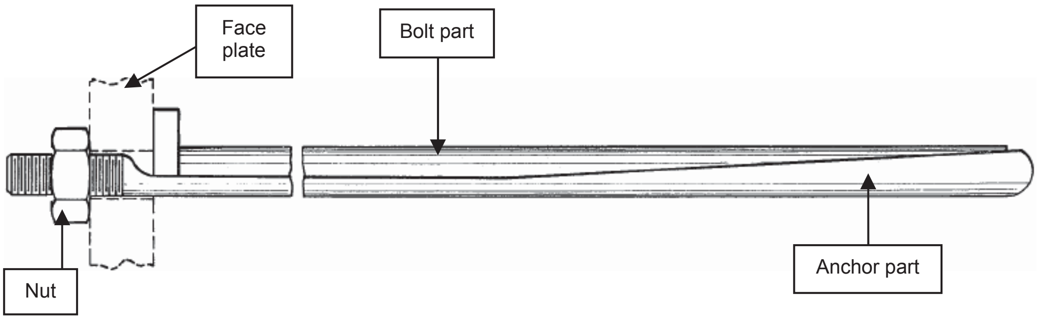


Figure 82: Full-length mechanical anchor [64]

The borehole diameter must be compatible with the bolt diameter. Its use is limited to hard rock conditions. It is a simple and cheap method and it shows immediate support effect but it has limited resistance against corrosion. It can be used as a temporary support [64].

3.1.2.3.2 Groutable Cable Bolt

This cable bolt patented by Quantx Pty Ltd (AU) company with WO98/11324 patent number is a system which can be used with cement or resin (figure 83).

The system is similar to the cablebolt as mentioned section 3.1.2.1.2. Only the shape of the bottom part of the bolt was designed different. The system includes all components before installation to the borehole [65].

.

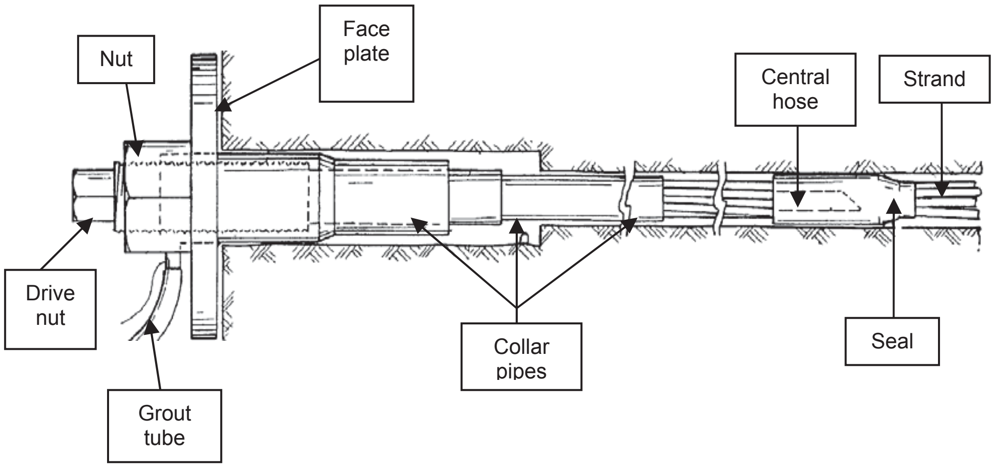


Figure 83: Groutable cable bolt [65]

3.1.2.3.3 Multi Bolt

This bolt patented by Gurlita Maskin AB (Sweden) company with SE00/00191 patent number is a kind of grout injecting system.

It is a combination of a point- and full-length anchored bolting system. As first step of installation an expandable element (length 0.5-2 m, diameter 35-50 mm, wall thickness 1.5-3 mm) on the top of the bolt is expanded by the use of pressurised water. The next step is grouting of the rebar with cement or resin. A breathing tube allows the air to get of the borehole and indicates the end of the filling process. After hardening of the grouting material the rubber seal is removed and the system is pre-tensioned [66].

.

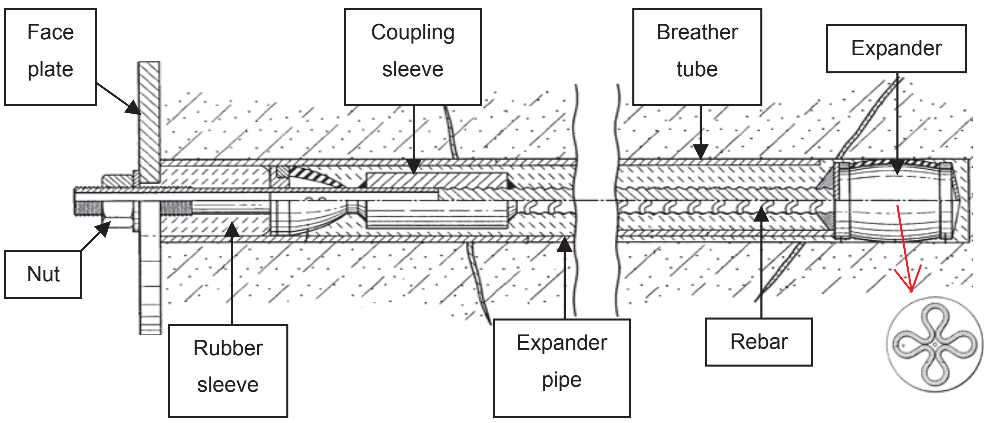


Figure 84: Multi bolt [66]

3.1.2.3.4 Bolt with Cutting Blades

This invention which can create spaces at the bottom of the borehole thanks to its blades opening in the borehole was patented in Korea with PCT/KR02/01272 patent number.

This invention consists of a body member which can be fixed at the end of a threaded steel rod. Body member comprises an operating element and cutting blades. The shape of the invention is presented in figure 85.

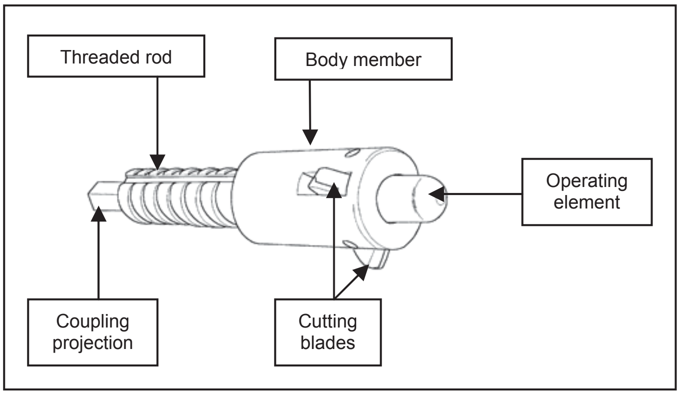


Figure 85: Components of invention [67]

The invention is thought to be designed as having the dimensions of a normal rock bolt, therefore its dimensions are 36-40 mm and its length is not less than 2 m.

For installation, the bolt with the cutting blade system is pushed against the bottom of the borehole, enabling the cutting blades to open. Cutting blades can open up to 90°. The next step is the rotating of the bolt to create voids for the cutting blades in the rock (figure 86). After pre-tensioning it is possible to grout the bolt [67].

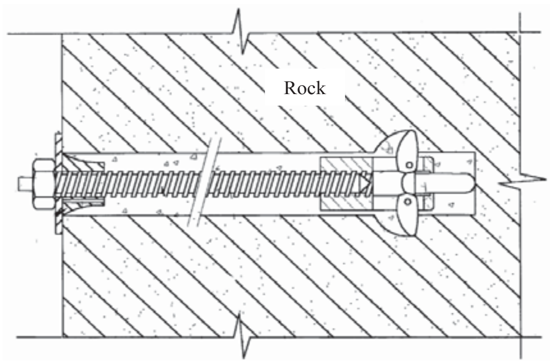


Figure 86: A rock bolt whose cutting blades have expanded in the borehole [67]

3.1.2.3.5 Resin Stored Rock Bolt

This is a rockbolt patented by Jarmo Leppaenen in 1991. The bolt has a resin reservoir with two separate agents stored inside the bolt.

After the rock bolt is placed into the drill hole, the grout components are pumped by means of pressurised fluid, the grout is enabled to flow out of the bolt end, being mixed at the same time. The end of the bolt is closed with a plug and prevents grouting components from going out. In figure 87, components are better understood from a schematic sectional view belonging to bolt.

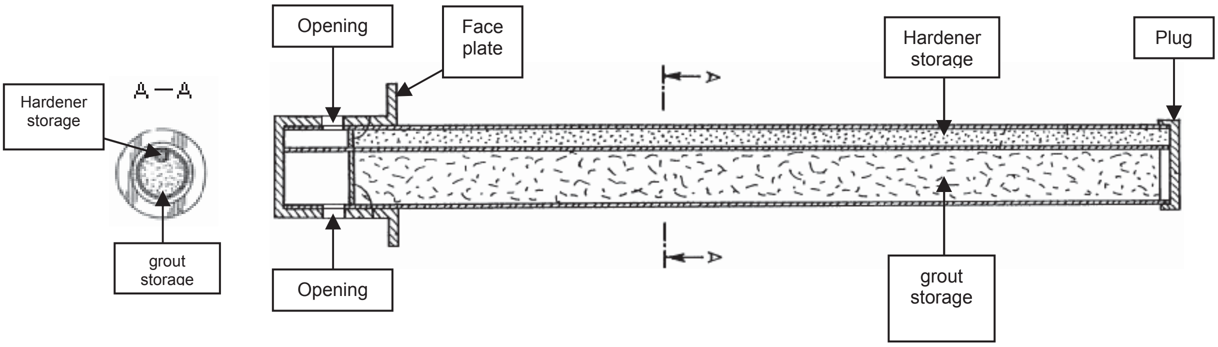


Figure 87: Resin storage bolt [68]

Spinning the bolt during installation helps the mixture of resin. What makes this method advantageous is that resin is in bolt and it is transported safely. It can be mechanically installed and this is a big advantage as well.

Corrosion of the inner surface is a disadvantage and it is not used at places that require permanent support. It is available for every kind of rock condition and it is a cheap method [68].

3.1.2.3.6 Friction Bolt

The friction bolt is an expandable bolt, its unique feature is, that it is expanded by a projectile that is pushed through the bolt (figure 88). The projectile remains in the bolt, the pushing dowel is retracted. Figure 89 gives an example of an alternative projectile that is completely removed. [69].

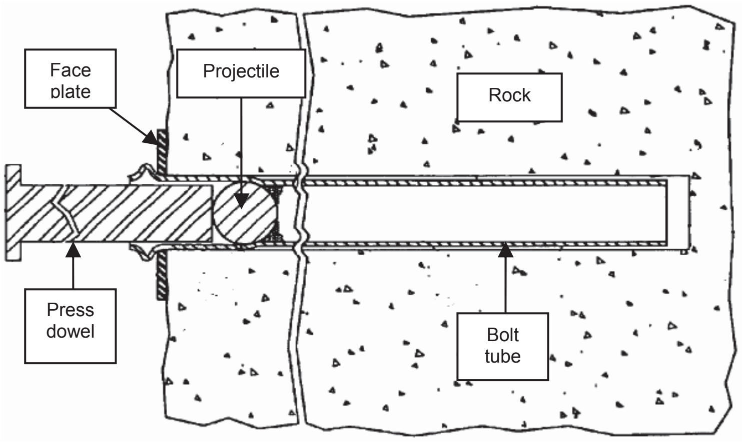


Figure 88: Installation of friction bolt [69]

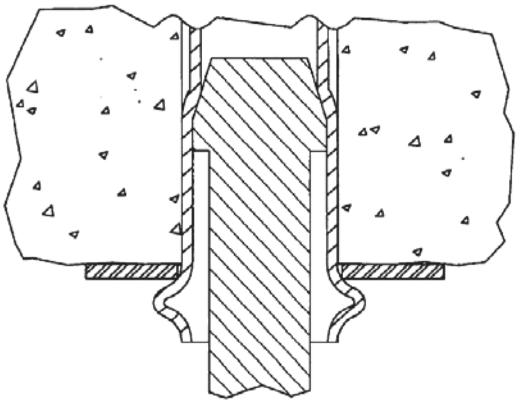


Figure 89: An alternative projectile [69]

Rock and bolt hold frictionally and interfacial anchorage strength between them is between 7 bar and 70 bar (0.7 – 7 MPa). Force applied on the projectile which is expanding the bolt tube in the borehole is less 89 kN (20.000 pounds).
As in the case of split-set, corrosion is a big negative factor in here as well and it can be used as a temporary support. It is available for mechanization and a cheap method. It is generally used at middle hard and hard rocks [69].

3.1.2.3.7 Full-length Mechanical Friction Anchor

The self-drilling rockbolt with an expansion-shell element is a system patented by Sandvik Intellectual Property AB. The system is available for use in hard rocks and also softer rocks like coal mines.

This self-drilling system comprises a hollow steel bar, an expansion shell element and drill bit at one end of the hollow bar and faceplate, washer and nut at the other end of the hollow bar compatible with the adapter of the drilling device (figure 90).

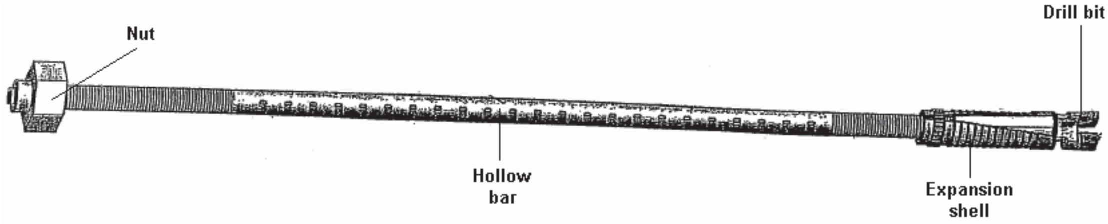


Figure 90: A self-drilling bolt and integrated expansion shell [70]

The installation is planned in a single stage. Flushing water passes through the hollow bolt and goes out of the hole between borehole and the outer surface of the hollow bolt. It is possible to extend the hollow bolt with a coupling. When the drilling process finishes, grouting process does not start immediately. When the drilling activity finishes, hollow bolt is rotated in the reverse direction that hollow bolt was rotated beforehand and the expansion shell is expanded. Pre-stressed bolt shows active support effect and does immediate support effect. Grouting material is pumped through the inner hole of the hollow bolt and it becomes fully-grouted bolt [70].

3.2 Installation Requirements

3.2.1 General Requirements and Limitations

3.2.1.1 Advantages

Point-anchored Bolts

- Relatively inexpensive
- Immediate support action after installation
- By rotating the bolt, a torque is applied to the bolt head and tension accumulates in the bolt
- By post-grouting, the bolt can serve as permanent reinforcement.
- In hard rock, high bolt loads can be achieved
- It is a versantile system for rock reinforcement, assuming hard rock conditions

Full-length anchored Bolts

- The bolt gives rapid support action after installation when fast-setting resin is used
- High corrosion resistance in permanent installations
- Grouted cable bolts can be installed to any length in narrow areas
- High bearing capacity

Friction Bolts

- Rapid and simple installation
- Gives immediate support action after installation
- Can be used various ground conditions

3.2.1.2 Disadvantages

Point-anchored Bolts

- Difficult to install reliably
- Must be monitored and checked for proper tensioning
- Loses bearing capacity as result of blast vibrations or when rock spalls of around borehole collar due to high rock stresses

Full-length anchored Bolts

- Difficulties with the resin cartridges in underground environment (resin has a limited shelf life)
- Use of standard cement in the grout requires several days curing before the bolt can take load
- Quality of grout is difficult to check and maintain constant
- Tensioning of the cable bolt is possible only if a special installation procedure is adopted

Friction Bolts

- Relatively expensive
- Corrosion protection required if used in long term applications
- Borehole diameter is crucial in the prevention of failure during installation and in the provision of the intended holding force

3.2.1.3 Limitations

Point- anchored Bolts

Mechanically anchored rock bolts are not recommended for use under the following conditions:

- in soft rock conditions where the rock type or the joint filling material may effect the gripping force of the anchor
- near blasting activities, where the tension in a bolt may be lost
- in permanent reinforcement systems, unless the bolt is grouted
- close to an advancing face where subsequent rock mass definition is significant
- in areas of large rock stresses where rock burst or spalling problems may be encountered
- in application where rockbolt tension cannot be checked
- to resist shear movement of the rock
- in very hard rock
- in very fractured rock

Full-length anchored Bolts

- In applications where the quality of the grouting agent cannot be checked, are not recommended
- Using is not recommended where in boreholes with a continuous flow of groundwater
- In rocks having open joints, unless the grouting can be checked
- In rock masses which have been subjected to extensive deformation, is not recommended to use of un-tensioned grouted rockbolts
- Close to an advancing face where subsequent rock mass deformation is significant
- Using of tensioned grouted rockbolts are limited in areas of large rock stresses, where rock burst or spalling problems may be ancountered

Friction Bolts

- In permanent reinforcement systems
- To resist ahear movements of the rock
- In narrow or confined areas
- Where borehole diameters are difficult to control
- In very fractured or soft rock conditions
- In areas where large deformations can be anticipated for the swellex bollts

3.2.2 Specific Requirements

3.2.2.1 Expansion-shell Bolt

Installation Requirements:

- It must be installed as close as possible in a right angle to the rock surface unless domed washers are used.
- The hole-diameter must not be under-sized or over-sized. Holes 3.175 mm (1/8") oversized can reduce holding strength by 70%. Oversized holes can be caused using the wrong bit size, leaving the drill running while flushing the hole, soft ground (faults, gouge, etc.) and bent drill steel. Undersized holes will not permit the plug in the expansion shell to seat properly. The leaves or bail

can break and distort upon forced entry. Undersized holes are usually caused by worn bits and/or wrong bit sizes being used [20]

- It is imperative that the hole diameter suits the expansion shell to be used.
- The drilled hole length must be longer than the bolt by approximately 50 mm.
- Appropriate components are fitted to the bolt. The expansion shell is screwed onto the bolt until the bolt thread just protrudes through the expansion shell plug.
- After placing the bolt in the hole to its full length, the bolt nut is rotated to set the shell and tension the bolt.

3.2.2.2 Split Set

Installation Requirements:
The clearance requirement of a hole-diameter is most strict among all bolts. An over-sized hole results in insufficient anchorage and an under-sized hole proven installation.

- The hole length should be longer than the bolt, nominally 150 mm, to allow for any rock fretting during installation.
- The friction bolt is inserted into the hole. The driving dolly is fitted into the rock drill's chuck and then the bolt (with accessories) is placed onto the dolly.
- Using full percussion and thrust, the bolt is fully driven into the hole until the domed plate is firmly against the rock surface. Care should be taken to ensure the rock drill's feed/thrust is in the same orientation as the hole or the bolt may be bent during installation.

3.2.2.3 Swellex bolt

Installation Requirements:

- Borehole diameter is critical
- Pump maintenance is critical

3.2.2.4 Fully Grouted Bolts

Installation Requirements:

- In the case of a resin grouted bolt, resin shelf life must be observed and underspinning or overspinning avoided. In the case of cement grouted bolts or cables, the specified water to cement ratio must be strictly to between 0.3 and 0.4. The surfaces of the bolts and cables must be clean to ensure maximum frictional resistance if desired. In wet holes care must be taken to easure setting of the grout.

3.2.2.5 Cable Bolts

Installation Requirements:

- Holes are drilled approximately 20 cm shorter than the bolt length. If bolts are to be tensioned, a tail of between 20 to 50 cm is required, dependent on the type of tensioning unit to be used.
- Plain cable bolts are prepared for installation by attaching a breather tube to the full length of the bolt. An excess of breather tube, approximately 2 metres, to protrude from the hole mouth. These cables can also be installed using an alternate "retreat" grouting method by withdrawing the grout tube from the hole.
- Approximately 1 metre of grout tube is attached to the bottom of the cable with sufficient tail provided to connect to the pump.
- The cable bolt is inserted into the hole and the hole mouth sealed to eliminate loss of grout when pumping.
- Connect the grout tube to the pump. The air bleed (breather) tube is placed into a container of water and pumping commenced. Air bubbles will exhaust from the hole whilst pumping and be visible in the water container. When the hole is full of grout, these air bubbles will cease to flow.
- After the grout has cured, the cable bolt can be tensioned, provided sufficient free length of cable is available.

3.2.2.6 Fibreglass Bolts

Installation Requirements:

- Borehole diameter is critical. 26-27mm hole diameters are preferred for 20 mm bolt diameter. Holes over 28mm diameter are not recommended.
- Hole depth is critical, it should be less than the length of the bolt to allow installation of the washer and nut.
- After insertion of the chemical anchors, the bolt is rotated through the anchor(s) while being pushed to the back of the hole.
- It is important to follow the chemical manufacturer's recommended mixing and hold times as printed on the chemical anchor cartons.

3.3 Resulting Requirements for System Automation

From an anchorage point of view rock bolts have been divided into three groups, namely:

- Point-anchored rock bolts
- Full-length anchored rock bolts
- Friction-anchored rock bolts

If we look at the automation stages of each group of anchoring system, we can see the following results:

1) Automation requirements for the point-anchored rock bolts

In this type of bolts the installation stages of the point-anchored systems include the following steps:

- Drilling a Borehole
- Retracting the drill steel from borehole
- Bolt Insertion
- Screwing

This four installation stages are done automatically by drilling jumbos at the automatic systems. The relationship between automated Expansion-shell rock bolt and its installation stages can be better understood in table 19.

Bolt Type	Installation Stages			
	Drilling a borehole	Retracting the drill steel from borehole	Bolt insertion	Screwing
Expansion-Shell	A	A	A	A

Automated: A

Table 19: Automated expansion-shell bolt and installation steps

2) Automation requirements for the fully-grouted rock bolts

In this category there are different types of fully-grouted rock bolts which are automated. Some of them are cement grouted and some are grouted with resin. The installation stages of these rock bolts are mentioned below:

- Drilling (Borehole) [1]
- Retracting the drill steel from borehole [2]
- Grouting (pre-/post-grouting) [3]
- Bolt insertion [4]
- Curing (for the resin cartridges) [5]
- Pre-stressing (Screwing if required) [6]
- Drilling + Insertion + Grouting (for one-step anchor) [7]

The relationship between automated full-length anchored systems and installation stages of them can be better understood in table 20.

Bolt Types	Installation Stages						
	1	2	3	4	5	6	7
Resin Grouted Rebar	A	A	A	A	A	A	-
Cement-Grouted Cable Bolt	A	A	A	A	-	-	-
CT-Bolt	A	A	A	A	-	A	-
Self-Drilling Anchor	-	-	-	-	-	-	A
Hilti OneStep Bolt	-	-	-	-	-	-	A
One-/Two-Step Procedure	-	-	-	-	-	-	A
Roofex Yieldable Bolt	A	A	A	A	A	A	
Hardi Cable Friction Bolt	A	A	A	A	-	-	-
Tubex	A	A	A	A	-	-	-
Ezi Bolt	A	A	A	A	-	-	-

Automated: A, Eliminated: -

Table 20: Automated full-length anchored systems and installation stages

3) Automation requirements for the frictionally-anchored rock bolts

As mentioned earlier for this bolting system installation stages also play an important role. Installation steps of the friction bolts are given as under:

- Drilling (Bolthole) [1]
- Retracting the drill steel from borehole [2]
- Bolt insertion [3]
- Swelling [4]
- Drilling + Insertion (for self-drilling friction anchor) [5]

The relationship between automated frictionally-anchored systems and installation stages of them can be better understood in table 21.

Bolt Types	Installation Stages				
	1	2	3	4	5
Split-Set	A	A	A	-	-
Swellex	A	A	A	A	-
Hardi Friction Bolt	A	A	A	-	-
AT-Power Set Self-drilling Friction Bolt	-	-	-	-	A

Automated: A, Eliminated: -

Table 21: Automated frictionally-anchored systems and installation stages

Installation stages of non-automated systems are mostly done semi-automatically. For example drilling action of these bolt types is done by mechanically, but bolt installation has to be done manually.
Installation stages of non-automated rock bolting systems are presented as follows:

1) Installation requirements for the point-anchored rockbolts (non-automated sys.)
In this type of bolts the installation stages of the point-anchored systems include the following steps:

- Drilling a Borehole [1]
- Retracting the drill steel from borehole [2]
- Bolt Insertion (including faceplate, nut, etc.) [3]
- Grouting (pre-/post grouting) /cartridge insertion [4]
- Curing (for the resin cartridges) [5]
- Pre-tension (screwing) [6]

Most of this six installation stages are done manually by the crew, most recent developments helped to automate the drilling operations. The relationship between non-automated point-anchored systems and installation stages of these systems can be better understood in table 22.

Bolt Types	Installation Stages					
	1	2	3	4	5	6
Slotted Bolt and Wedge	A	A	M	-	-	M
Resin Assisted Mechanical Anchor	A	A	M	M	M	M
Combination Bolt	A	A	M	M	M	M
Kesp Ground Anchor	A	A	M	-	-	M

Automated: A, Manual: M, Eliminated: -

Table 22: Non-automated point-anchored systems and installation stages

2) Installation requirements for the fully-grouted rock bolts (non-automated systems)

In this category there are different types of fully-grouted rock bolts which are non-automated (semi-automated). Some of them are cement grouted and some are grouted with resin. The installation stages of these rock bolts are mentioned below:

- Drilling (Bolthole) [1]
- Retracting the drill steel from borehole [2]
- Grouting (pre-/post-grouting) /cartridge insertion [3]
- Bolt insertion [4]
- Curing (for the resin cartridges) [5]
- Pre-stressing (Screwing if required) [6]

The relationship between non-automated full-length anchored rock bolt and installation stages of them can be better understood in table 23.

Bolt Types	Installation Stages					
	1	2	3	4	5	6
Cement Grouted Rebar	A	A	M	M	-	-
Kiruna Bolt	A	A	M	M	-	M
Thorbolt	A	A	M	M	-	-
Dynamic Cable Bolt	A	A	M	M	M	M
Dynamic Tiger Bolt	A	A	-	M	M	M
Dynamic Solid Bolt	A	A	M	M	M	M
Fiberglass Bolts	A	A	M	M	M	M
Post-injection Bolt	A	A	M	M	-	M
Gemini Post-groutable Rock Bolt	A	A	M	M	-	M
Pakran Injection Bolt	A	A	M	M	-	-
D – Bolt	A	A	M	M	M	M

Automated: A, Manual: M, Eliminated: -

Table 23: Non-automated full-length anchored rock bolt and installation stages

3) Installation requirements for the frictionally-anchored rock bolts (non-automated systems)

For this bolting system installation stages also play an important role. Installation steps of the non-automated friction bolts are presented in the following list:

- Drilling (Bolthole) [1]
- Retracting the drill steel from borehole [2]
- Bolt insertion [3]
- Screwing [4]
- Swelling [5]

Bolt Types	Installation Stages				
	1	2	3	4	5
Worley Bolt	A	A	M	M	-
RS – Bolt	A	A	M	-	M

Automated: A, Manual: M, Eliminated: -

Table 24: Non-automated frictionally anchored systems and installation stages

The relationship between non-automated frictionally anchored systems and installation stages of these systems can be better understood as shown above in table 24

4 Market Analysis of Automated Rock Bolting Systems

4.1 Requirements for Automated Rock Bolting Systems

There are two main reasons in rock bolting automation. The first one is the personal and equipment safety and second one is for economical reasons. In anyway it is difficult to justify the expense of a fully mechanized bolting.

Cost and time optimization for bolting compels the product developers to apply a total system approach to their work. The cost of the rock bolt or its tensile strength is not of so much interest. The total cost and the time needed to reinforce a given rock mass and the safety of the reinforcement system installed is more important. Most of the new types of rock bolts introduced in recent years have been presented, together with a method for rapid and easy installation [1].

The following reasons have been showed importance of the rock bolting automation:

- Operator safety is significantly improved. During the entire operation, the operator is located at a safe distance from the bolting, under a roof that has already been bolted
- Damage to equipment is minimized. Since each bolt is installed immediately after the hole has been drilled, and before the stinger of the bolting turret has been removed, the risk of rock fall is minimized
- Installation quality of grouted rockbolts is improved
  - With pneumatic charging of cement or resin cartridges, it is more likely that the bottom of the hole will be reached without cartridge damage in the drilled hole
  - Thanks to the high pressure injection of a thin string of cement will almost always reach the bottom of the borehole despite irregularities in the hole
- Better reach. Equipment for roof hights exceeding 12 m is available and several bolts can be installed from the same machine set-up

- Increased bolt lengths. Bolting heads for bolts whose lengths range various are available
- Increased precision. Thanks to the modern design of the hydraulic system, booms and joy-stick, the position time between holes is minimized. The boom and bolting turret can be readily positioned and the bolt set parallel to other bolts if desired
- Increased speed. High speed is often required during automated rock bolting
- One man operation. At present, fully mechanized bolt installations are designed for one man operation. The operator is protected by a roof or an ergonomically designed cabin
- Optimum long term capacity. The following factors, most of which are site specific, will affect the long term bolting capacity:
    - Systematic bolting or spot bolting, bolt type and length, roof high, rock type and rock mass conditions, transport distance between worksites, operator experience and service organisation, equipment reliability, equipment utilization, work planning, number of men in operation, maintenance routines, work continuity, wages system, ambient temperature and altitude.

Since the bolted roof can provide an unobstructed opening with minimum maintenance, production has increased, costs have decreased [1].

4.2 Existing Systems

4.2.1 Rock Bolting Equipments for Point-anchored Rockbolts

Rock bolt installation is done in 3 ways and these are manual, semi-mechanized or full mechanized installation types.

- Manual bolt installation is done by using only manual equipment for bolt installation operation during rock bolting.
- As to the semi-mechanized bolt installation, mechanized drilling and manually rock bolt installation operation is in question.
- In fully mechanized rock bolt installation, drilling and rock bolting operation is done by an operator which is situated in a safe environment, for example a platform or cabin. Fully mechanized rock bolting operation is very advantageous regarding the operator's safety and in terms of quick installation, however, fully-mechanized bolting rigs may not adapt to every working condition due to the limited flexibility [1].

4.2.1.1 An Automated Rock Bolter for Hardrock Mines

The automated rock bolting machine developed by Spar Aerospace Ltd. in 1985 enabled mechanical rock bolts to be installed automatically.

This machine provides a supply of rock bolts as well as drilling and bolting operations. The bolter assembly of the machine consists of a hydraulic motor, and a socket which is to screw the nut at the low end of the bolt during bolt installation. Besides, this bolting assembly is fixed on chain feed and thus its movement is achieved. There is a griper support to grip the bolt and place it into the borehole during installation.

The rock bolter has a bolt magazine with a capacity for 18 rock bolt. In figure 91 it is illustrated that one rock bolt is taken by gripper from one bolt magazine and it is placed on a rotation unit on the driver chuck. Later on, the driver chuck will take the rock bolt towards the inside of the borehole [2].

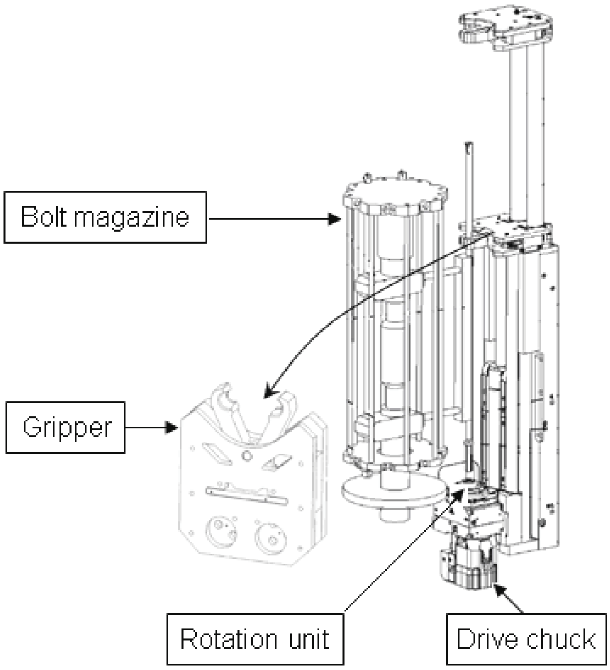


Figure 91: Mechanized bolt installation unit [71]

The borehole drilling operation is the first stage in bolting cycle. The drill bit is flushed with a cooling water-air mist during drilling. After the borehole was created, the expansion-shell bolt is automatically installed into the borehole and screwed. All of the stages from beginning to the end are fully-automatic. Semi-automatic control is also possible moreover the switch from the automatic to the semi-automatic mode can be done by the operator at anytime.

Thanks to this automatic bolt installation, bolting operation is achieved in a safe and easy way even in hard conditions. In addition, a safe working environment is created for the operator where he can control his work in a comfortable and easy way. This automated system has completely increased the operating productivity, safety and efficiency to a significant extent [2].

4.2.1.2 A Bolter for Expansion-Shell Bolts Installation

Mechanized rock bolting boom which is installing the point anchored rock bolt developed by Hydraulik and Maschinenbau GmbH from Germany presents a different innovation for underground mines. This vehicle is described in figure 92.

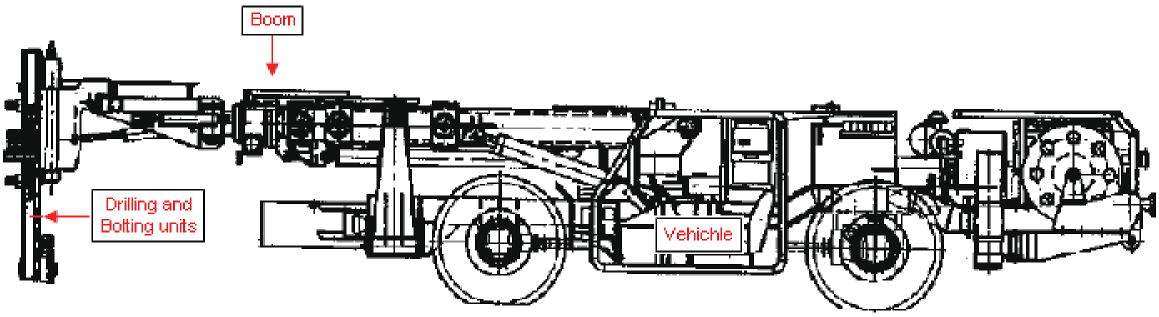


Figure 92: A rock bolter [72]

This system consists of a bolt magazine fixed on a boom with drilling and bolting devices. This boom is attached to an underground vehicle by means of a carrier arm. A layout belonging to the system is illustrated in figure 93.

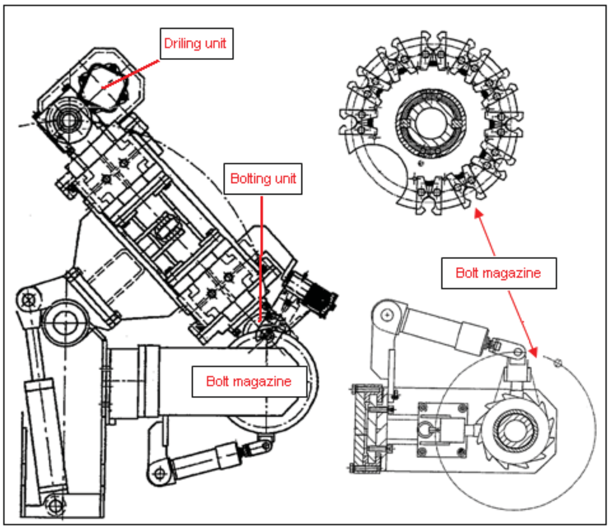


Figure 93: Cross-sectional views of the bolting magazine [72]

The working principle of the system is simple. The drilling device drills a borehole in the roof, after reaching the designed depth the drill rod reposition automatically. As a next step, the bolting unit swings by the aid of a hydraulic jack to the formal position of the drilling unit and installs the rockbolt into the borehole. After installation, the bolting unit swings back to the bolting magazine for reloading [72].

4.2.2 Rock Bolting Equipments for Full-length Anchored Rock Bolts

4.2.2.1 Automatic Insertion of Resin Capsules

The resin cartridges insertion activity takes place after the borehole is created. In most of the cases, automatic injecting operation of resin cartridges into the borehole is achieved by the means of compressed air.

The lengths of resin cartridges vary between 100 mm and 1500 mm and their curing times change between 4 seconds and 25 minutes at 25 celcius and also the diameters of the resin cartridges are found to be from 14 mm up to 40 mm.

The computerized automatic resin cartridge injection operation has a special integrated system for resin cartridge injection.

For example the Boltec system from Atlas Copco has two booms, one of them only does automatic controlled drilling and the second boom is responsible for automatic controlled resin cartridges injection and rockbolt inserting operation. On the bolting boom there is a bolt magazine with a capacity of 10 bolts, a cartridge magazine with a capacity of 80 resin cartridges and a compressed air system is positioned on the vehicle. A detailed view of the resin cartridges magazine is presented in figure 94.

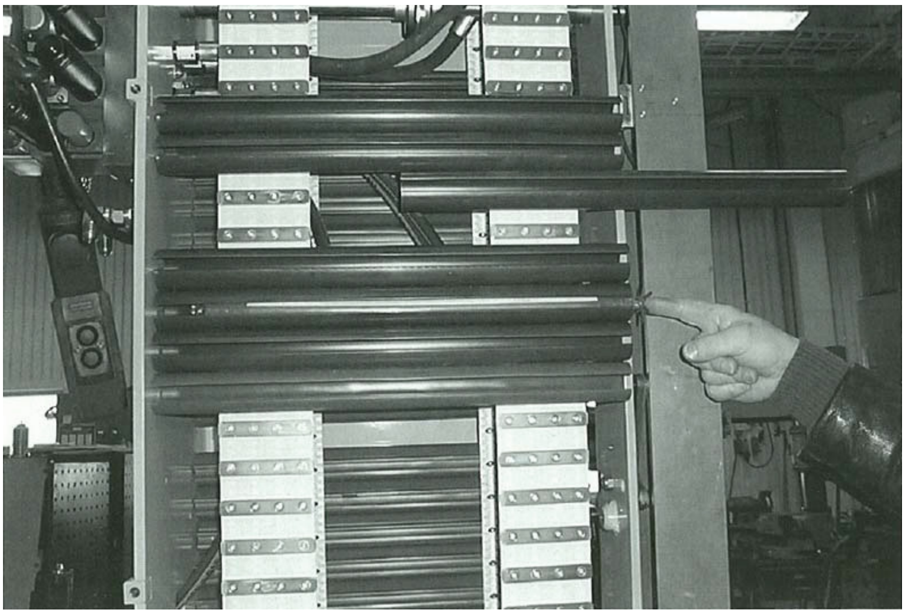


Figure 94: Details of the Magazine [73]

The cartridges have length of 450 mm, the simultaneous use of normal curing and fast curing cartridges is possible. The magazine loading process of resin cartridges by operator is presented in figure 95 and pneumatic injection of resin cartridges into the borehole is presented in figure 96 [73].

Figure 95: Filling Magazine with resin cartridges [73]

Figure 96: injection of the resin cartridge into the Borehole [73]

4.2.2.2 Mechanized Bolting Equipment for Self-Drilling Anchor

Automated installation of self drilling anchors has eliminated and minimized many stages in the rock bolting field.

A self-drilling rock bolting equipment comprises a rotary injection adapter fixed at the end of a drilling device moving back and forth on a borehole axis and the system is fixed on a boom. A rotary injection adapter integrated to a drilling motor is presented in figure 97 [36].

Figure 97: Integrated rotary injection adapter fixed on the boom [36]

Again, there is a rod gripper taking the anchor rods for extending from the anchor rod magazine which is fixed on the boom. This operation is described in figure 98.

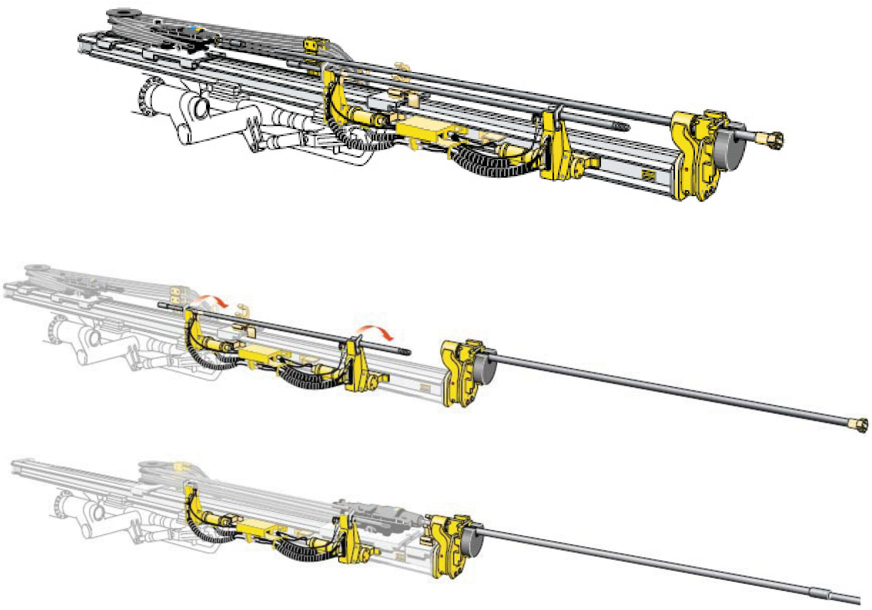


Figure 98: Mechanized anchor rod adding [36]

After the installation operation of the self-drilling anchor, the grout injection is done with the grout injection adapter through the hollow rod. Again during the grout injection operation, the anchor rod is slowly rotated for letting the grout pervade well. A borehole grout pump for a self-drilling anchor is presented in figure 99 [36].

Figure 99: a grout pump for a self-drilling anchor [36]

4.2.3 Mechanized Bolter for all sorts of Rock Bolts

In order to be able to install all rock bolt types with a single vehicle, more than one boom is integrated on the vehicle (figure 100). The rigs necessary for point anchored and full-length anchored rock bolt installation are present on a single boom and in addition to this there is drilling device and bolt magazine on the same boom. However, for cable bolt installation another boom is needed. This boom serves for cable insertion operations into the borehole with a hose which is going to inject cement into the borehole.

Figure 100: Rock bolting machine with two booms [44]

Rod handling system developed for the drilling phase of the system is seen in figure 101. There is a rod magazine with 35 rods capacity on the drilling rig. Rod magazine can be filled with rods with 1.5 and/or 1.8 m length. Taking the rods from the magazine with rod catching grippers and extending rods has become easier. A cement injection adapter is attached at the end of the drill hammer for self-drilling rock bolt installation (figure 97) [74].

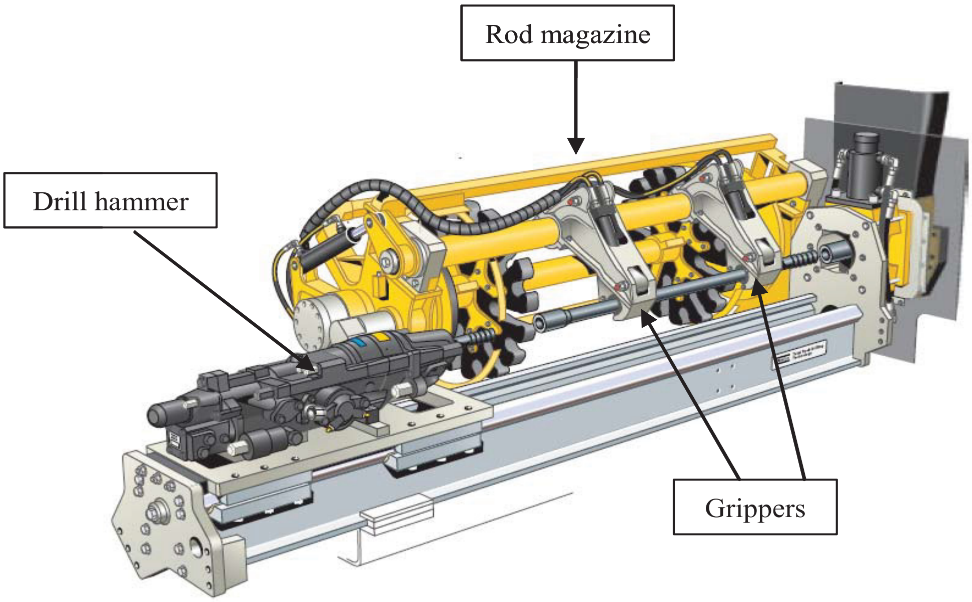


Figure 101: Rod handling magazine [36]

The grouting hose for cablebolt installation and the cablebolt installation device is presented in figure 102.

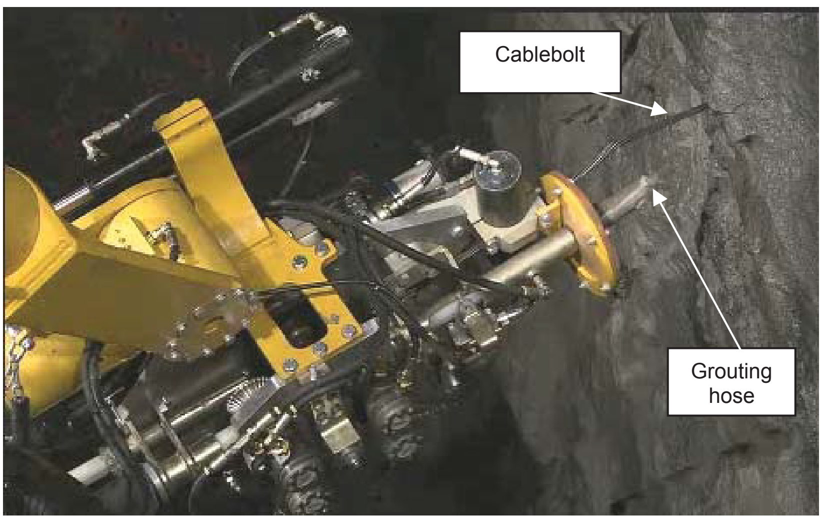


Figure 102: The system which is grouting and cable inserting [44]

The cement is mixed in an automatic and controlled way from the cement silo which is positioned on the vehicle. The water/cement ratio is automatically checked. Again there is a cable reel with 1700 kg cable capacity and also a hose reel (figure 103). When the cable diameter used is thought to be 15.2 mm and 1.125 kilo per meter, its cable length is approximately 1500 m [74].

Figure 103: Cable reel and grouting hose reel [44]

4.3 Market Potential

4.3.1 Technical

The versatile researches carried out, development projects and experiences on the rock bolting technology in German coal mines for the last 20 years and the developments in rock bolting technology have undergone significant changes. This changing process is roughly described in figure 104.

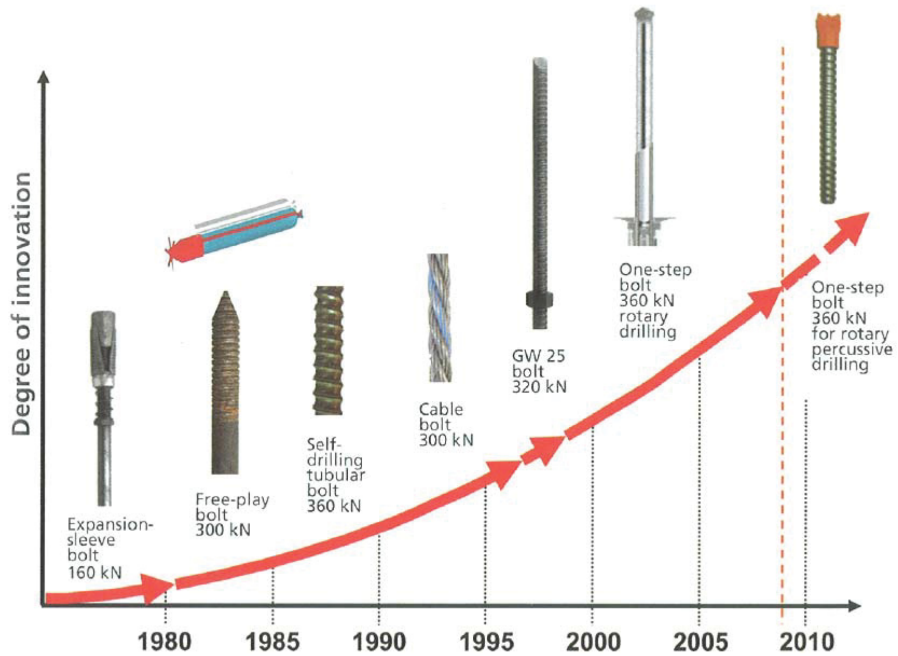


Figure 104: Development and tendency of rock bolting technology [75, p.425]

Towards 1980s, that can be seen the expansion-shell system based on friction based technology is placed by the synthetic resin cartridge having a higher bond force and bearing capacity. In addition, it is also possible meaningful increase of bolt supporting forces in the meantime. The further stage has been on the economical optimization of rock bolting. Besides, the smooth or rebar with 25 mm diameter has been defined as a standard. Following on these developments Onestep rock anchor which is a Hilti AG product stands out as the newest generation. Onestep is not alone ergonomic but also has provided simple and sensitive installation, and also eliminated the faults occurring during the resin cartridge insertion. However a deficiency has remained due to the fact that this bolting method enables only the use of rotary drilling methods. With the development of One/two step rock bolting methods which enable rotary percussive drilling, it is seen that the improvement in rock bolting technology has not come to an end yet and it will make more progress [76].

4.3.2 Commercial

According to the statistical findings of the research on bolt usage done by National Institute for Occupational Safety and Health (NIOSH) in the mines of USA, especially in coal mines, those results have emerged. When the bolt usage trends are examined, different bolt types are seen. These are as following; resin bar bolts, mechanical bolts which are expansion-shell anchors, resin-assisted bolts which are expansion shell anchors with resin, combination bolts which are two-piece bolts with fast-setting resin, tension-rebar bolts which are rebars with fast and slow setting resin, friction stabilizers (swellex and split-set), fibre glass and wooden dowels. 85 million bolts were used in the underground coal mines of USA in 1988 and the distribution of the bolts used is presented in figure 105.

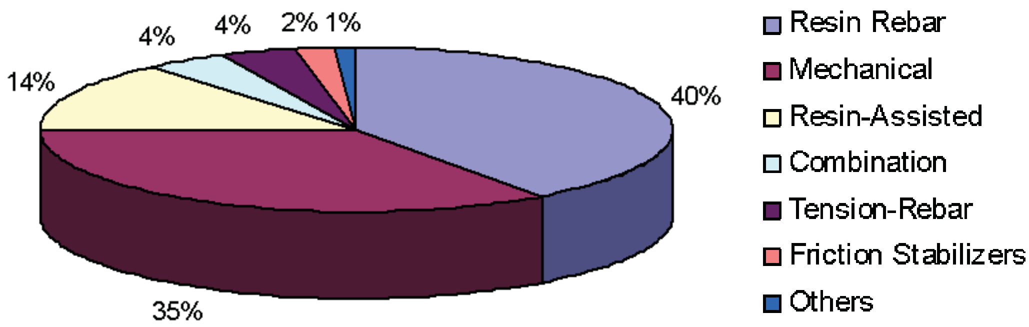


Figure 105: The bolt usage distribution in the underground mines of USA in 1988 [22]

The resin bar takes the front rank with a 40% ratio and mechanical anchored bolts follow resin bar with 35%.

The case is quite different in 2005 and 65 million bolts were used. An estimated roof bolt usage in 2005 is presented in figure 106. Resin bar outstands with its 68% bolt usage ratio.

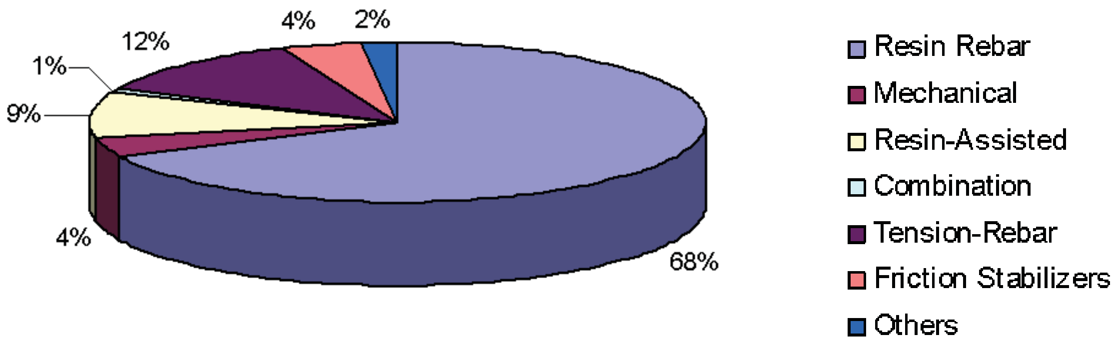


Figure 106: Estimated bolt usage distribution in underground coal mines of USA in 2005 [22]

Besides, the distribution of amount of production of Underground coal mines in America according to their production methods is presented in table 25. Total amount of underground coal production has almost remained the same but the number of underground coal mines has changed [22].

Year	Room & Pillar		Longwall	
	Mines	Production (million tons)	Mines	Production (million tons)
1988	1696	246	72	131
2005	562	176	44	190

Table 25: The distribution of amount of production of Underground coal mines in America in 1988 and in 2005

5 Conclusions

In this study, market analysis related to the mechanized and automated rock bolting type has been carried out. All bolt types present in the market have been searched and examined. The results of the study have shown that bolt types mostly used in mining and tunnelling have been automated. Thanks to the automation, the stages of bolt installation could be operated by remote control rather than being operated manually.

There are two main reasons in rock bolting automation. The first one is the personnel and equipment safety and the second one seems to be economical reasons. Besides, the market analysis shows that the recently developed bolting systems eliminate most of the complications during bolting operation and presents an easy and simple solution for the user.

Mainly, following conclusions can be drawn:

- Automation of rock bolting begun with common system (expansion-shell) which had already been used in many operations. In addition, new systems were developed which are suitable for automation.
- There are a lot of product in the field of full-length anchored rock bolts, leading to many automated systems and inventions.
- From the working cycle point of view, automated systems inherently have big time advantages compared to non-automated.
- Automatic installation of resin anchored rock bolts is approximately two times quicker than manually installation and is less labour intensive.
- Even with long cable lengths, installation of automated cablebolts were achieved successful. It is normally harder to install cablebolts manually than other types of rockbolts.
- Automated CT-Bolt provides rational solution for the grouting of cracks and fissures of the fractured rock.

- It was carried out that self-drilling bolts (one-step) achieve maximum time saving during automatic installation, for this reason and an orientation towards one-step bolting systems can be observed on the market
- Simple shapes and forms of friction bolts allow automatic bolt installation.
- Automated AT-power set anchor provides an installation of a split-set friction bolt during the drilling operation.
- Recently, some friction bolts were specially shaped or formed to increase the bearing capacity (e.g. Tubex with special studs or V-shaped Hardi bolt, etc.) and suited for using with post-grouting.
- In recent years, mining operations go down to deeper and deeper mines and rock masses are highly stressed. These hard conditions of mining operations have shown that there is a need for new rock bolting systems and some systems like dynamic bolts have been developed. Again when mining conditions are considered vibrations due to blasting activities have led to these kind of dynamic bolts.

References

[1] Stillborg, B., (1986). Professional Users Handbook, Trans Tech Publications, p.59-68

[2] Haines, T., (1987). An Automated Rock Bolter for Hardrock Mines, Canadian Mining Journal, December, 1987, p. 28-29

[3] Wagner, H., (2007). Rock Mechanics II, Lecture Records, Chair of Mining Engineering, University of Leoben, Austria

[4] Hudson, J.A. and Harrison, J.P., (1997). Engineering Rock Mechanics: An Introduction to the Principles, 1th edition, Pergamon, Oxford, ISBN 0-08-041912-7

[5] Jaeger, J.C., and Cook, N.G.W., (1969). Fundamentals of Rock Mechanics, London, Chapman and Hall

[6] Ortlepp, W.D., (1983). Consideration in the Design of Support for Deep Hard-Rock Tunnels, Proceedings of the 5th International Congress on Rock Mechanics, Melbourne, Volume 2, p. 179 – 187

[7] Tannant, D.D., and Kaiser, P.K., (1995). Friction Bolt Anchored Wire Rope for Support in Rockburst-Prone Ground, Canadian institute of Mining and Metallurgy Bulletin, 88(988): 98 – 108

[8] Cai, Y.; Jiang, Y.J., and Esaki, T., (2004). A Study of Rock Bolting Design in Soft Rock, Int. J. Rock Mech. Min. Sci., Volume 41, Issue 3, Elsevier Ltd., 2004

[9] Luo, J., (1999). A New Rock Bolting Design Criterion and Knowledge-Based Expert System for Stratified Roof, Doctoral Thesis, Virginia Polytechnic Institute and State University, Virginia, p. 1 – 177

[10] Wagner, H.; Galvin, J.M; Hebblewhite, B.K., (1997). Roof Bolt Mechanics, Pillar and Roadway Mechanics Workshop, University of New South Wales, School of Mining Engineering, Sydney, Australia

[11] Weckert, S., (2003). Anchorage and Encapsulation Failure Mechanisms of Rockbolts, Master Thesis, UNSW, Sydney

[12] UK(United Kingdom) Highways Agency (Publisher), (1999): Design Manual for Roads and Bridges, Volume 2, Section 1, Part 7, 1999, URL:http://www.highways.gov.uk, (Page view: 15.10.2008)

[13] Wagner, H., (1995). Praktische Erfahrungen mit Ankerausbau im südafrikanischen Kohlebergbau, Ankerausbau im Bergbau, Verlag Glückauf Essen, Band 3, ISBN 3-86073-352-4, p.52 – 55.

[14] Hausdorf, A., (2006). Numerische Untersuchungen zur Stabilität von Kammerfirsten im Salzbergbau unter besonderer Beachtung einer Systemankerung mit elasto–plastisch verfestigender Ankerkennlinie und unterschiedlichen Ankervorspannwerten, Veröffentlichungen, Institut für Geotechnik TU Bergakademie Freiberg, ISSN 1611-1605, p. 1 – 196.

[15] Kovari, K., (2003). History of the Sprayed Concrete Lining Method – Part II: Milestones up to the 1960s, Tunnelling and Underground Space Technology, Elsevier Publisher, Volume 18, p. 71 – 83

[16] Kainrath, S. and Dolsak, W., (2008). Gebirgsanker in Berg- und Tunnelbau, BHM Berg- und Hüttenmännische Monatshefte, Springer, Oktober, p. 397 – 404

[17] Reed, M.B.; Grasso, P.; Rizzi, D., and Rabajoli, G., (1993). Improvement of Rock Properties by Bolting in the plastic Zone around a Tunnel: A numerical Study, Int. J. Rock Mech. Min. Sci., Volume 30, Issue 5, p. 567 – 571

[18] Roberts, D.P.; Roberts, M.K.C., and Acheampong, E., (2002). Improved Understanding of the Use of Short Tendons for Stope Support Under Rockfall and Rockburst Conditions-Phase I, CSIR Mining Technology, South Africa, p.1-28

[19] Hoek, E.; Kaiser, P.K.; Bawden W.F., (1995). Support of Underground Excavations in Hard Rock, A.A. Balkema, Rotterdam, p. 1 – 215

[20] DSI Dywidag-System International (Ed.), (2008): Company Homepage. URL:http://www.dsigroundsupport.com/uploads/media/DSI_Ground_Support_Catalogue-v3_us.pdf (Page view: 15.10.2008)

[21] Brady, B.H.G., and Brown, E.T., (1999). Rock Mechanics for Underground Mining, Kluwer Academic Publishers, 2nd edition, Dordrecht, Netherlands

[22] Tadolini, S.C., and Mazzoni, R.A., (2006). Understanding Roof Bolt Selection and Design Still Remains Principless, 25th Int. Conference on Ground control in Mining, July 1-3, West Virginia, p. 382 – 386.

[23] Dolinar, D.R.; Bhatt, S.K., (2000). Trends in Roof Bolt Application, New Technology for Coal Mine Roof Support, U.S. Department of Health and Human Services (Ed.), National Institute for Occupational Safety and Health (NIOSH), Proceedings, Information Circular 9453. p. 43 – 52

[24] Kühler Technik AG (Ed.): Kesp Anchor Catalogue. URL:http://www.ankertechnik.ch/dokumente/ankertechnik_ankerzubehoer2.pdf (Page view: 15.10.2008)

[25] Bruneau, M., (2004). Anchor Device With An Elastic Expansion Sleeve, International Application Number PCT/CA04/01878, Canada, October 26, 2004

[26] Rausch, P.G., (1978). Anchor Device for Resin Anchor System, United State Patent, Application No.: 821890, Pub. No.: US 4129007, Ohio, USA, December 12, 1978

[27] Fuller, P.G. and O'Grady, P., (1992). Cable Bolt, International Application Number PCT/AU92/00369, Australia, July 22, 1992

[28] Li, C. and Stillborg, B., (1999). Analytical Models for Rock Bolts, Int J of Rock Mech and Min Sci, Volume 36, p. 1013 – 1029, Pergamon Publisher, Lulea, Sweden

[29] Windsor, C.R. and Barley, A.D., (2000). Recent Advantages in Ground Anchor and Ground Reinforcement of The Art, GEO 2000 International Conference on Geotechnical and Geotechnical Engineering, p.1-23

[30] Stillborg, B., (1984). Experimental Investigation of Steel Cables for Rock Reinforcement in Hard Rock, Doctoral Thesis, Lulea Uuniversity of Technology, Sweden, p. 1 – 125

[31] Shapkoff, S.A.; Sppearing, A.S.; McDonnell, J.; Grounds D., (2006). The Development of Active Cable Anchors for Primary Support in Coal Mines, 25th International Conference on Ground Control in Mining, West Virginia, p.1-5

[32] Altounyan, P., and Clifford B., (2001). Suitable Long Tendon Technologies and Practices, Rock Mechanics Technology Limited, COL704, South Africa, p.23

[33] Vik Orsta AS (Ed.), (2008): CT – Bolt Catalogue.
URL: http://www.ct-bolt.com/default.asp?page=28 (Page view: 15.10.2008)

[34] Stimson, B.,(1998). Split Set Friction Stabilizers: An Experimental Study of Strength Distribution and The Effect of Corrosion, Canadian Geotechnical Journal, Volume 35, p. 678 – 683

[35] Li, C., and Hakansson, U., (1999). Performance of The Swellex Bolt in Hard and Soft Rocks, Rock Support and Reinforcement Practice in Mining, Balkema, Rotterdam, ISBN 9058090450, p. 103-108

[36] Atlas Copco Rock Drills AB (Ed.) (2007). Rock and Soil Reinforcement, 3th edition, Örebro, Sweden, p. 1 – 208

[37] Williams Form Engineering Corp. (Ed.), (2008). Company Hompage
URL:http://www.williamsform.com/Ground_Anchors/Hollow_Bar_Ground_Anchors/ (Page view: 15.11.2008)

[38] Ischebeck, E.F., (2000). New Rock Bolt Technology for Stabilizing and Foundation Work, Glückauf: Die Fachzeitschrift für Rohstoff, Bergbau und Energie, Volume 136, Issue 1, 2000, p. 43-46

[39] Hilti Corporation (Ed.): Professional Solution for Underground Mining.
URL:http://www.hilti.com/holcom/modules/editorial/edit_singlepage.jsp?edtid=-14741_000003 (Page view: 25.09.2008)

[40] Opolony, K.; Polysos, N.; Bartel, R.; Lüttig. F., (2004). Neue Ausbauteile und verbesserte Dimensionierungsansätze für den Ankerausbau, Ankerausbau im Bergbau, Verlag Glückauf Essen, Band 3, ISBN 3-7739-5988-5, p.568 – 570

[41] Corbert, P., (2008). The Use of Hilti OneStep Self Drilling Bolts in High Risk Strata Conditions, Roof Bolting in Mining and Injection Technology and Roadway Support Systems, Verlag Glückauf Essen, Band 7, ISBN 978-3-86797-015-0, p. 35 – 52

[42] Wiegrad, J., (2008). Immediate Load Bearing Injection/Bolting Systems According to the One-/Two-Step Procedure, Glückauf , Volume 144, Issue 7/8, p. 437-443

[43] Domitner, J., (2007). Entwurf eines Automatisierten Montagesystems für Gleitanker, Diplomarbeit, University of Leoben, Sept 2007, Austria, p. 1-56

[44] Atlas Copco Group AB (Ed.) (2008): Company Homepage.
1.URL: http://www.roofexrockbolt.com/kampanj/pdf/Roofex_spec_sheet.pdf
2.URL: http://img01.atlascopco.com/Standard/ (Page view: 15.11.2008)

[45] Plouffe, M.; Anderson, T.; Judge, K., (2008). Dynamic Testing of Tendons (Roofex), Canmet Mining and Mineral Sciences Laboratories, Report Canmet-MMSL 07-053, Ontario, Mai 2008, Canada, p. 21

[46] Hardi Rock Control Europe BV (Ed.), (2008): Company Homepage.
URL:http://www.hardirockcontrol.com/ (Page view: 15.10.2008)

[47] Rezai, N., (2004). Wirtschaflicher und technischer Vergleich einzelner Ankertypen in dem Bergbau Breitenau der Veitsch Radex GmbH&Co., Bergmännische Meldearbeit, p. 11 – 13

[48] Borovichkova, Y., (1997). The Tubex Grouted Friction Tube System for Rock Support, Master Thesis, Geological Engineering Division, Department of Civil and Geological Engineering, University of Manitoba, Canada, July, 1997

[49 ATS Australiasian Tunnelling Society (Ed.), (2008). Company Homepage.
URL:http://www.ats.org.au/index.php?option=com_docman&task=doc_view&gid=14 (Page view: 25.10.2008)

[50] ALWAG Tunnelausbau G.m.b.H., (2008). Company Homepage.
URL:http://www.alwag.at/uploads/media/DSI_ALWAG_AT_Power_Set_Self_Friction_Bolt_02.pdf (Page view: 10.10.2008)

[51] Kölbl, N., (2004). Im BB Breitenau der VR GmbH & Co sollen Ankerzugversuche aller eingesetzten Ankertypen gemacht werden und mögliche Einsatzgebiete für die Ankertypen herausgearbeitet werden, Bergmännische Meldearbeit, University of Leoben, Austria, p. 13 – 14

[52] Worley, W.E., (1966). Mine Roof Bolt, United State Patent, US 3301123, USA, March 30, 1966

[53] Hobst, L., and Zajic, J., (1977). Anchoring In Rock, Elsevier Scientific Publishing Company, p. 88

[54] Kangas J., Stöckel B.M., (2005). Bergförstärkning i Kiirunavaara, Lulea TU, Lulea, p.7

[55] Habenicht H., (1976). Anker und Ankerungen zur Stabilisierung des Gebirges, Springer Verlag, Wien u.a., p.9

[56] Gurlita GMA AB (Ed.), (2008): Company Homepage
URL: www.gma.se/injection-fittings/thorbolt/ (Page view: 15.09.2008)

[57] Garford Pty Ltd. (Ed.), (2008): Company Homepage.
URL:http://www.garfordcablebolts.com.au/ (Page view: 15.10.2008)

[58] Reddish, D.J., Dunham., R.K., (1995). Glass Fibre Rock Reinforcement, Roofbolting in Mining, Proceedings, 2nd international Kolloquium, Aachen, March 27.-28., p. 133-153

[59] ARNALL POLAND Sp. z o.o. (Ed.), (2008): Company Homepage.
URL:http://www.arnall.com.pl/en/index.php?id=kotw_iniek (Page view: 15.10.2008)

[60] Grinaker-Duraset Mining Products, Aveng Ltd. (Ed.), (2008). Company Homepage
URL: http://www.duraset.com/product_no_top.html (Page view: 15.10.2008)

[61] New Concept Mining Ltd. (Ed.), (2008). Company Homepage.
URL:http://www.ncm.co.za/rs-bolt.html (Page view: 15.10.2008)

[62] Ankra spol. s r.o. (Ed.), (2008). Company Homepage.
URL:http://www.ankra.cz/show_english.php?kat=kotevni_tech (Page view: 15.10.2008)

[63] NTNU Technology Transfer AS (Ed.), (2008). Company Homepage.
URL:http://folk.ntnu.no/charliel/D-Bolt%20flyer.pdf (Page view: 15.10.2008)

[64] Cannon, R.E. and Frailing, L.H., (1972). Anchor Bolt, Unites States Patent, Patent No. US3680430

[65] Hutchins, W.B., (1998). A Cable Bolt, World Intellectual Property Organization, International Application No. PTC/AU1997/000587

[66] Eriksson, H., (2000). Device and Method in Connection with a Rock Wall, World Intellectual Property Organization, International Application No. PTC/SE2000/000191

[67] Na, J., (2002). Rock Bolt, World Intellectual Property Organization, International Application No. PTC/KR2002/001272

[68] Leppänen, J., (1991). Method of Installing A Rock Bolt and A Rock Bolt, World Intellectual Property Organization, International Application No. PTC/FI1991/000130

[69] Simmons, W.N. and Simmons, W.J., (2002). Frictional Mining Bolt, United State Patent, Patent No. US 6935811

[70] Weaver, S.; Webb, D.; Horsch, J. and Keny, M., (2006). Self Drilling Rock Bolt, World Intellectual Property Organization, International Application No. PTC/AU2006/001669

[71] Eddowes, W.; Broad, G.W. and Bailey, J.E., (2007). Drilling Rig, United State Patent, US 2007/0286707

[72] Reukauf, B.; Seeber, J. and Bayer, A., (2003). Vorrichtung zum Setzen eines Ankers, Deutsches Patent- und Markenamt, Patent No. DE 101 63 082 A1

[73] Richter, A., Beimdieck, J., (2004). Weiterentwicklung in der Ankertechnik und Ankersetztechnik, Roof Bolting in Mining, Proceedings International Mining Symposia, Juni 2.-3., p. 453 – 476

[74] Ericson, P., (2008). Experiences with the new Cable Bolting Rig " Cabletec LC " at the Kemi Mine in Finland, Rockbolting in Mining & Injection Technology and Roadway Support Systems, 6th International Mining Symposia, Aachen, 14. – 15. May , p. 551 – 559

[75] Eikhoff, J., (2008). Rockbolting Technology in the Roadway Support System, Glückauf, Volume 144, Issue 7/8, p. 425

[76] Eikhoff, J., (2008). Rockbolting Technology in the Roadway Support System, Rockbolting in Mining & Injection Technology and Roadway Support Systems, VGE Verlag GmbH, Essen, 2008, ISBN 978-386797-015-0, p. 1 – 16