Permanent Rockbolts — The Problems are in the Detail

P Pells[1] and R Bertuzzi[1]

ABSTRACT

Permanent rock bolts in civil engineering are taken as having to serve their design purpose for at least 50 years. In many projects the design life is specified as greater than 100 years. A review of recent Australian tunnelling projects shows that substantial differences exist in the level of corrosion protection provided for permanent steel shafted rock bolts. This paper reviews the current state of practice and sets out what the authors consider to be appropriate requirements for corrosion protection.

INTRODUCTION

A modern trend in tunnel design is to use rock bolts and shotcrete for permanent support. In Australia the trend is to specify a 50 or 100 year design life for these support elements. The difficulty is that there is very little information on which to base detailed design of these elements so as to ensure that the specified design life is achieved. For example a recent review of current rock bolting practice by Motherside and Weerasinghe (1998) makes no differentiation of bolt types in relation to design life and provides no guidance in regard to corrosion protection. At the other end of the scale there are suggestions that permanent rockbolts should be designed and constructed according to BS8081 (Code of Practice for Ground Anchorages) and EM1537.1966. These require double corrosion protection of all components.

In recent projects in Sydney the authors have encountered a wide divergence in support elements which are supposed to have equivalent design lives. From experiences in several major projects it has become apparent that in addition to general corrosion considerations a great deal of attention has to be given to details relating to head assemblies, grout tubes, temporary anchorage during grouting and final shotcrete cover so as to create a product with an appropriate design life. This paper sets out to define the requirements for permanent rock reinforcement in relation to current Australian practice.

The term rock bolt is used here in a generic sense and covers reinforcing elements comprising bars and strands.

It must be stated that the authors have benefited greatly from the ideas and suggestions of many professionals in the consulting, contracting and manufacturing industries.

BASES FOR COMPARISON OF ROCK BOLT TYPES

Rock bolt types should be compared from three viewpoints, namely:

- structural effectiveness,
- cost of supply and installation, and
- life expectancy.

This paper does not deal with the first two items explicitly but they have formed an essential part of assessing detailed design requirements for alternative permanent rock bolts. The paper deals primarily with long-term performance and in this regard the reader is referred to good reviews of the topic by Baxter (1996) and Barley (1997).

1. Pells Sullivan Meynink Pty Ltd, Suite 11, 10 East Parade, Eastwood NSW 2122.

It should be noted that the rock bolts dealt with in this paper as permanent support have ultimate capacities in the range of 240 kN to 760 kN and lengths from 1.2 m to 9 m. Fibre reinforced plastic bolts which typically have ultimate capacities less than 120 kN are not dealt with here although there are many situations where such bolts provide sufficient capacity and may be used for permanent support.

Life expectancy of rock bolts can be addressed from two viewpoints. The first is to attempt to assess the probable functional life of a given type of rock bolt in a given hydrochemical environment. For example one may attempt to assess how long a Split-Set bolt may last in a particular tunnel given knowledge of the groundwater chemistry. This approach is fraught with uncertainty and is not attempted by the authors. The second approach is to attempt to eliminate uncertainty by developing corrosion protection measures which precedents from areas such as reinforced concrete technology would indicate as being sufficient to provide a substantial level of safety. In following this path it becomes readily apparent that attention to detail is critical.

COMPONENTS OF ROCK BOLTS RELEVANT TO LONG-TERM PERFORMANCE

For ease of discussion, and clarification of key details, it is appropriate to decompose a typical rock bolt into the following components:

1. shaft, comprising bar or strand;
2. anchor or temporary hanger to facilitate installation;
3. face plate, washers, nut (or cable grips), rock seating; and
4. connection systems to mesh reinforced or steel fibre reinforced shotcrete.

Shaft

In recent projects in Sydney (M2 tunnel, Opera House Carpark, Bondi Treatment Plant, Eastern Distributor) permanent rock bolts have included the shaft materials given in Table 1.

TABLE 1

Permanent rock bolt shaft materials (recent Sydney projects).

Supplier	Material	Ultimate capacity kN
VSL	23 mm Stressbar	450
ANI-Arnall	24 mm High Strength	230
Ingersol Rand	M20 bar	260
Austress	18 mm Strand	380
Allthread Industries	24 mm 316 Stainless Steel	230

Table 2 sets out corrosion protection measures which are, in 1998, being adopted for shaft protection for 'permanent' rock bolts in Australia. Based on data given by Baxter (1996), Parry-Davies and Knottenbelt (1997), Weerasinghe and Anson (1997) and inspections by the authors of 20-year old cables anchors excavated in Sydney, an assessment has been made of the probable design lives of the various corrosion protection measures. These are also given in Table 2. In this context, design life is defined as the period during which the permanent rock bolts will serve their given function by preventing unacceptable crown or sidewall movements. However, during this period some corrosion will occur to some or all of the bolts.

TABLE 2

Shaft corrosion protection measures applied to permanent rock bolts in Sydney[a] tunnels and deep basements (1993 - 1999).

Shaft material	Corrosion protection	Expected design life of shaft
23 mm Stressbar	Zinc chromate primer followed by three 50 micron coats of epoxy, all full column cement grouted[b]	50 years
24 mm High Strength	Full column chemical resin[c]	<10 years
24 mm High Strength	Hot dip galvanised, full column cement grouted[b]	<30 years
24 mm High Strength	As per the 23 mm Stressbar	50 years
24 mm 316 Stainless	Full column cement grouted[b]	>100 years
M20 bar	3 mm dimpled polyethylene sheathing, full column cement grouted[b]	>75 years
18 mm strand	50 mm diameter by 1.5 mm thick corrugated sheathing in bond zone, 19 mm smooth polyethylene over free length, full column cement grouted[b]	>100 years

[a]Assessment for groundwater typical of Hawkesbury Sandstone (pH 4.9 to 7.5, low chloride)

[b]It is presumed that the shafts are properly encapsulated in Portland cement based grout and that the grout contains no additives that could affect the steel.

[c]At present it is considered by most specialists that cement grouting is necessary to create a high pH corrosion inhibiting environment, rather than relying on the integrity of a column of resin.

It is important to note that the expected design life given in Table 2 refers to the shaft only. The total bolt performance depends on detailed features discussed below.

In regard to the two encapsulation systems, the sheathed M20 bar (CT bolt) is assigned a lower design life because there is no encapsulation around the distal end of the bolt and therefore corrosion can progress axially from the distal end. The sheathed strand bolt is fully encapsulated.

Anchor or temporary hanger for installation

Pre-tensioning of rock bolts can be achieved using mechanical anchors. In strong rock (UCS > 50 MPa) a standard ANI-Arnall 24 mm shell anchor which requires a 41 mm diameter hole can readily provide a pre-stressing load of 100 to 150 kN. However, herein lies another problem of detail. If one wishes to get grout return through the breather tube it is necessary to use a minimum 12 mm OD tube. This is also consistent with the normal corrosion resistance requirements of having at least 10 mm of grout annulus around the bolt. Since the bolt is 24 mm diameter the hole must be at least 49 mm diameter. This precludes use of standard shell anchors.

In a recent project in Sydney special shell anchors were imported from the USA and South Africa for use in 51 mm and 55 mm holes and arrangements were made for a local company (ANI-Arnall) to manufacture shells suitable for 57 mm diameter holes. These latter shells have been used successfully for pre-tensioning up to 120 kN in relatively poor quality sandstone (Class III with UCS < 15 MPa). It is worth noting that standard off-the-shelf CT bolts are provided with shell anchors which are suitable for holes in the range 43 mm to 48 mm. It is understood that CT bolts could be supplied with the special 57 mm shells described above.

If pre-tensioned rock bolts are not required then it is a simple matter to create a hanger to hold the weight of the rockbolt, grout column and face assembly. However, matters are more difficult when the specifications for cement grouting include the requirement for return of the grout through the bleed tube. In this case a substantial hydraulic pressure (easily up to 2 kN) can be exerted against the face plate. Experience in recent projects in Sydney is that these loads can be provided by a simple spring type hanger in good quality rock (eg sandstone with UCS > 20 MPa). However, in poor quality rock a mechanical anchor is necessary. This can be easily attached to a rock bolt but is more difficult to attach to fully encapsulated strand. In a recent project in Sydney, 7 m and 9 m twin 18 mm encapsulated strand bolts had a short length of threaded bar attached to the end which carried a spring loaded shell anchor which held the cable bolt in place during grouting.

Face plates and rock seating

The face plate assembly is less critical in a fully bonded bolt than in a free length bolt. In the latter case if corrosion failure occurs in the face assembly or in the shaft where it connects to the face plate, the bolt is useless. However, it is wrong to presume that with a fully bonded bolt such corrosion is of little consequence. This is because most permanent rock bolt applications are associated with structural shotcrete. Design of the shotcrete normally assumes point support at the rock bolt locations. This can be achieved via a double face plate or a spider plate system (see Figure 1). If corrosion failure occurs in the seat area then even though a fully bonded bolt may still be operative the structural shotcrete may be largely useless.

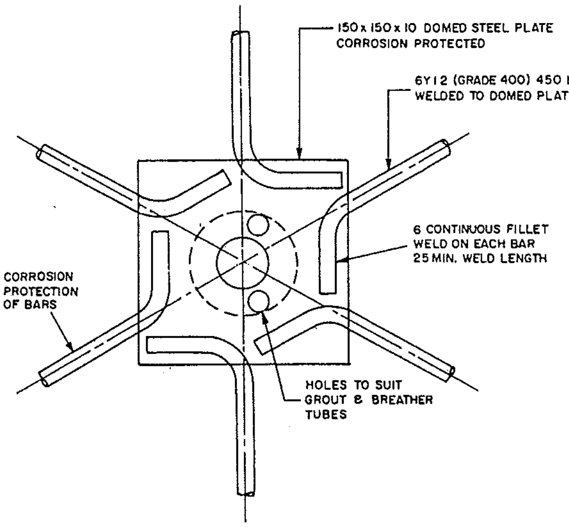

FIG 1 - Typical details of spider plate.

A satisfactory face plate assembly must provide the following.

1. a uniform seating surface on the rock, preferably normal to the axis of the rock bolt (a domed washer can allow for 15° out-of-square but high lateral shear forces are generated);
2. sufficient face plate stiffness so that only elastic deflections occur under ultimate loads;
3. protection of the rock-side of the face plate against corrosion caused by groundwater/oxygen flowing between the face plate and the rock;
4. corrosion protection of the rock bolt shaft into and through the face plate; and
5. corrosion protection of the whole head assembly against attack from the outside environment.

Each of these matters is dealt with in the following subsections.

Seating

In many projects bolts are not installed normal to the rock surface. For example in the Sydney Opera House Carpark 450 kN bolts were installed up to 40° from the normal to the rock surface. In this project use was made of a special cylindrical seating device but the system was not without its problems. In a more recent project in Sydney a successful solution to this problem was achieved by a special reaming percussion bit which would drill a 200 mm flat ended countersink after completion of the rock bolt hole. This creates a good flat surface for seating the face plate and allows all face plates to be installed normal to the bolt axes.

Face plate stiffness

Many face plates marketed for the mining industry are designed to flex and mould around protrusions and undulations on the rock surface. This level of flexibility is usually not appropriate in permanent rock bolting.

For 450 kN rock bolts recent practice has been to use 150 mm square or 150 mm diameter by 32 mm thick plates appropriately drilled for grout and breather tubes and for a bar or multiple strands.

For 240 kN rock bolts there are several off-the-shelf face plates which are of appropriate stiffness. These include the ANI-Arnall Dome Plate which is available up to 12 mm thickness and the 150 mm diameter ductile iron CD washer which has a yield load of 370 kN. Both types of plate can be drilled appropriately for grout and breather tubes.

Protection against corrosion from the rock side

Current practice is to provide three coats of epoxy to the face plates and also incorporate a nominal 10 mm high early strength mortar pad beneath the plate. This mortar pad is typically created by spreading a product such as Seacrete over the face plate which is then worked into position against the rock. Alternatively, a 20 mm wide strip of dense polyurethane foam is glued around the underside perimeter of the face plate to provide a seal for grouting. It is believed that the grouting operation fills most voids left between the mortar pad and the face plate.

The CT rock bolt has a patented dome plate which, if properly grouted forms a thin grout pad beneath most of the plate. However, the outer edge of the plate is directly against the rock and would corrode.

Corrosion protection at shaft/face plate join

It is considered that the highest risk of corrosion is in the zone where the bolt shaft enters the face plate.

For fully bonded epoxy coated bolts coupled with epoxy coated face plates, no special precautions are normally taken. As shown in Figure 2 these bolts are usually installed with domed washers and the grouting operation should give good grout cover where the bolt exits from the hole.

For post-tensioned bolts with a sheathed free-length current practice is to carry the sheathing through the face plate and to crimp it against the domed washer (see Figure 3).

In the Ingersol Rand CT bolt the HDPE sheathing connects into a steel tube which in turn is connected to a hollow spherical 'washer'. The steel tubing extends between 60 mm (Swedish Version) and 120 mm (Australian Version) into the rock bolt hole. This means that in the exit zone from the hole the M20 bar is protected by 7 mm inner annulus of grout, a 1.5 mm annulus of steel and a 5 mm outer annulus of grout. This would appear to be a weak point in the corrosion protection system. However, the 1.5 mm steel tube may be thought of as sacrificial steel, which in an alkaline environment may provide several decades of protection.

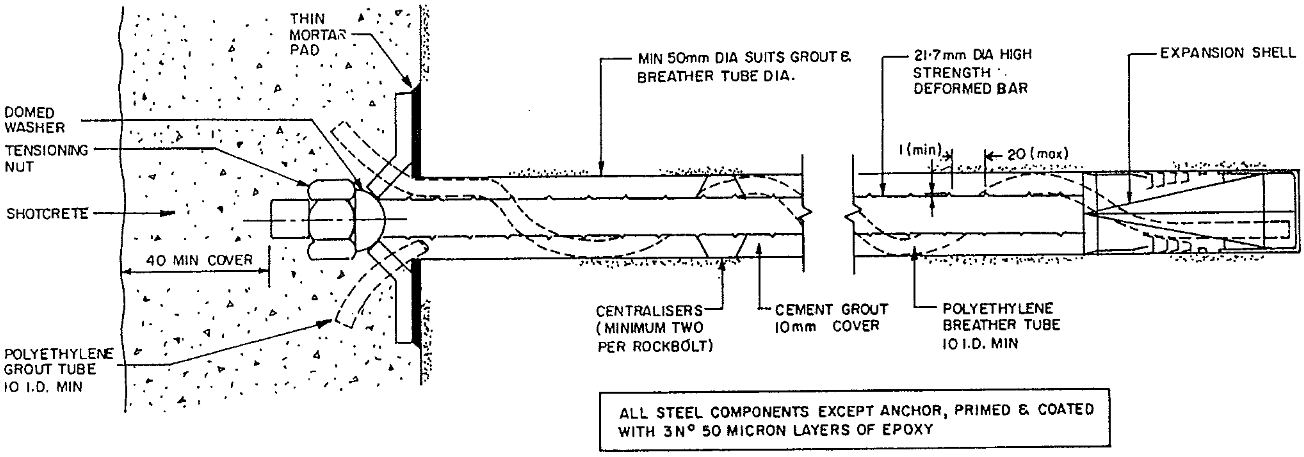

FIG 2 - 230 kN capacity permanent rock bolt.

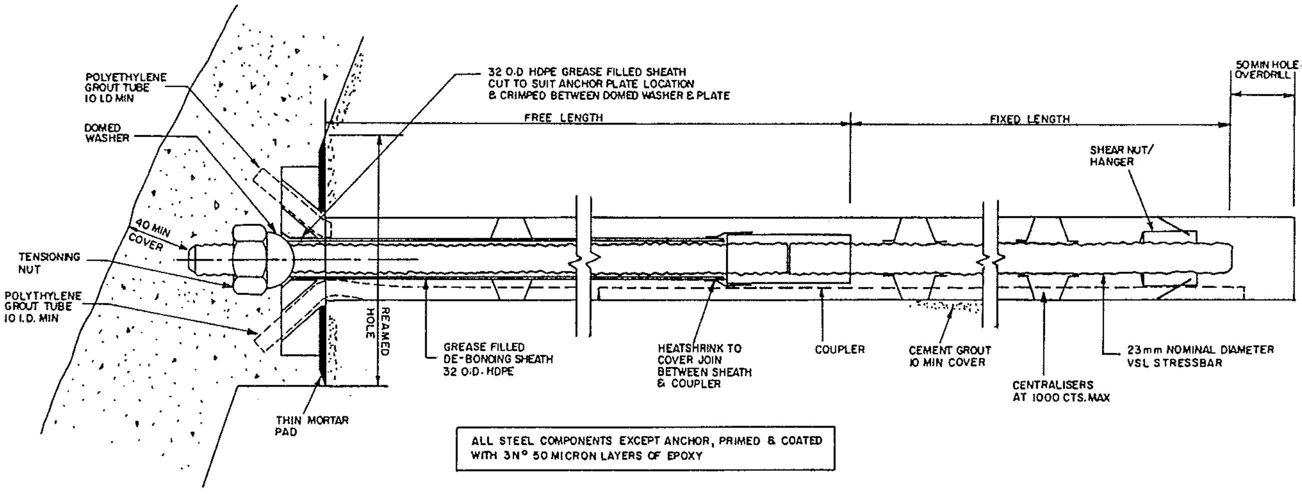

FIG 3 - 450 kN capacity permenent rock bolt.

Corrosion protection of head assembly

The prime protection system for the whole head assembly is considered to be provided by a minimum 40 mm cover of dense shotcrete. Current practice with bar bolts is to coat the nuts with epoxy in the same manner as the shafts. However, it is acknowledged that in the thread area the epoxy would be destroyed.

Consideration has been given to finishing bolts with grease filled caps in a manner similar to restressible ground anchors but the authors are unaware of this being done in Australia for rock bolts.

Load connection to fibre reinforced shotcrete

With the widespread use of fibre reinforced shotcrete there is no reinforcing mesh to provide load transfer between the structural shotcrete and the bolts.

In structures such as the Opera House Carpark and the Eastern Distributor tunnels the authors have designed the shotcrete to span between the bolts and to carry load from small masses of rock between the bolts. Connection between steel fibre reinforced shotcrete and bolts has been achieved by modifying the rock bolt face plates so as to carry a radiating system of reinforcing bars. These are termed spider plates and a typical example is shown in Figure 1. The bars and their welds are coated with epoxy.

EXAMPLES OF PERMANENT ROCK BOLTS

A review of recent projects in Australia has revealed a wide range of rock bolt types purporting to comprise permanent support. These include:

- End anchored black steel bolts cement grouted in 44 mm diameter holes to provide a 100 year design life for the M2 tunnel.
- 24 mm diameter deformed solid steel bars anchored into a 27 mm diameter holes by full chemical resin encapsulation to provide a 80 to 100 year design life for the drainage tunnels at West Ryde and Wombarra.
- Villaescusa and Wright (1997) have used cement grouted galvanised Spilt Set bolts as permanent rock reinforcement in the Mt Isa underground mine.
- The authors are aware of four projects which have been completed in Sydney since 1996 which have incorporated CT bolts as permanent support. These include two very deep CBD basement excavations and the soil nail structures for the Olympic Games rail station at Homebush and for the Devlin Street underpass at Ryde. The specified design lives are not known.
- Stainless steel bolts installed for permanent support in vertical cuts at the portals of the Eastern Distributor for 75 year design lives and in existing caverns in the Bondi underground treatment works.
- Specially designed bolts have been used in the Opera House Carpark and in the Eastern Distributor for 50 year design lives as shown in Figures 2 and 3.
- Sheathed cable bolts (Freyssibolts) have been used in part of the Eastern Distributor for 50 year design life (see Figure 4).

The authors cannot accept that these various bolt types have essentially equivalent design lives. Available data on ground anchor and bolt performance as cited above suggest that steel shafts, protected only with full column cement grouting cannot be deemed as permanent support, unless the definition of permanent is a design life less than 25 years.

CONCLUSIONS

A useful way to conclude this paper is to present the 50 to 100 year rock bolt design that the authors would currently recommend. This would comprise:

- Fully cement grout encapsulated epoxy coated bar, or fully cement grout encapsulated sheathed bar or strand. A minimum of 10 mm grout cover is required.
- The grout should have a toothpaste consistency, equivalent to 0.35 w:c.
- A show of consistent grout is required from the breather tube. A minimum inside diameter of the grout and breather tube is 10 mm.
- Bar bolts to be pre-tensioned against a mechanical anchor prior to grouting.
- The anchor zone of a strand bolt is to be birdcaged and fully cement grouted within a corrugated sheath in the factory. Strand bolts to be post-tensioned after a single stage of cement grouting.

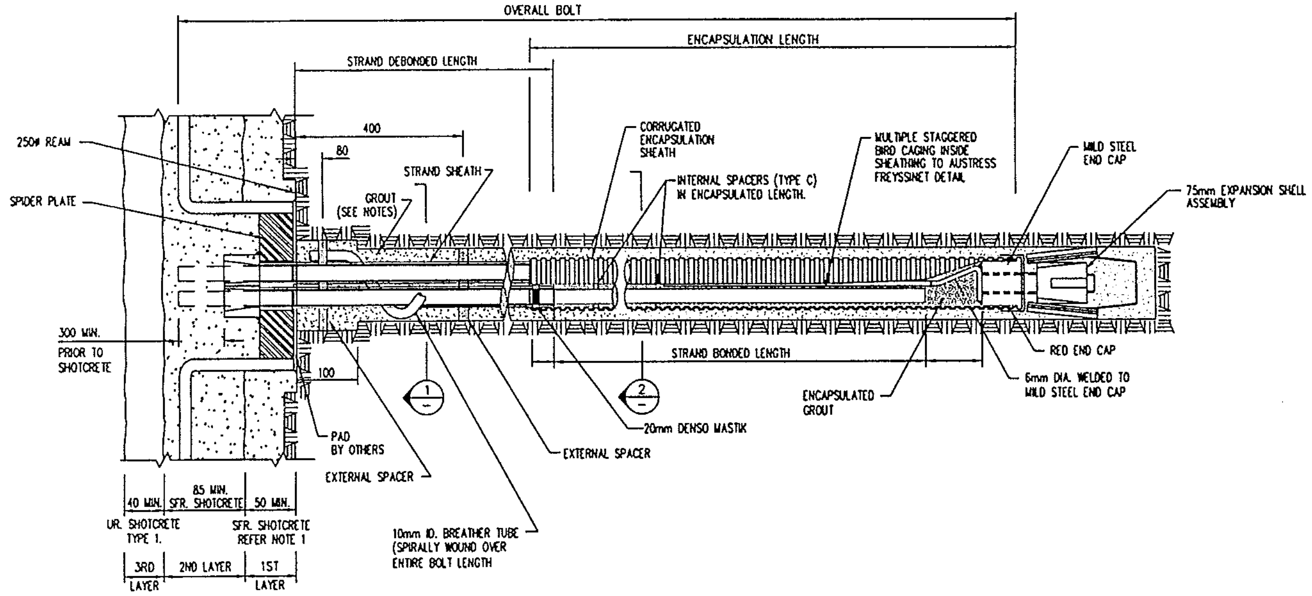

FIG 4 - Twin strand bolt (Austress-Freyssinet).

- For bolts less than 4 m long, a rigid breather tube tied with plastic cable ties can be used to centralise the bar. For longer bolts, dedicated centralisers at 2 m intervals should be used.
- Within sandstone, holes longer than 5 m are to be drilled with a retractable button bit with a guide tube and stiff rods to ensure uniform hole size and alignment.
- The face of the hole is to be reamed to provide a flat to provide a flat surface for the plate and ensure that the grout and breather tubes are not pinched.

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