Corrosion Protection Options for Permanent Ground Anchorages

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Abstract
The subject of appropriate corrosion protection for permanent ground anchorages can appear daunting to an engineer faced with a new anchorage design for the first time. There are at least ten different methods of corrosion protection available, not all of them applicable to permanent anchorages.

Defining the appropriate materials or methods which constitute an acceptable physical barrier for corrosion protection, in accordance with the codes of practice, is one of the most important subjects within ground anchorage practice. This paper aims to clarify the subject by briefly describing the current methods available, redefining terms that have been confused or misused and highlighting some practical issues in implementation.

Introduction
The six most common methods considered for corrosion protection are: Double Corrosion Protection, Single Barrier Protection, Epoxy Coating, Galvanizing, Sacrificial Corrosion Allowance and Borehole Grout. A number of these are not suitable for permanent anchorages and one has practical limitations during site handling.

Further confusion as to which method to apply has arisen due to three reasons:

a) The belief that a lower level of corrosion protection applicable to different installations (i.e. mini piles or soil nails) may be suitable for ground anchorages.
b) Incorrect reclassification of the anchorage as a tension pile, in order that a lower level of protection may be applied.
c) The desire to utilize a self-drilling hollow bar where ground conditions are variable or where cased installation is problematical.

The importance of corrosion protection for permanent anchorages is illustrated below in figures 1 and 2, where the durability of the anchorage is relied upon as a dependable element of the permanent works.
Classification of Installation (Ground Anchorage, Mini Pile, Soil Nail)

In order that the appropriate level of corrosion protection may be selected, the installation should be classified according to load, mode of loading (active or passive, tension or compression), consequences of failure and required design life. Table 1 summarizes typical installations together with their requisite levels of protection.

<table>
<thead>
<tr>
<th>Installation / Component</th>
<th>Load Classification (indicative)</th>
<th>Mode of Loading</th>
<th>Consequence of Failure due to Corrosion</th>
<th>Corrosion Protection, Technical Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground Anchorages (soil anchorages, rock anchorages)</td>
<td>Often heavily loaded 500-20,000 kN</td>
<td>Active (debonded, prestressed free length)</td>
<td>Risk of overload to adjacent anchorages</td>
<td>Double corrosion protection to BS8081 or Single barrier protection, Tube-a- Manchette / sheathing combinations to EN1537</td>
</tr>
<tr>
<td>Rock Bolts for tunnels or caverns (internal)</td>
<td>Loads: 150-1,100 kN</td>
<td>Fully Bonded (with or without prestress)</td>
<td>Risk dependent on loading and application</td>
<td>Dependent on load and aggressivity. Double corrosion protection or epoxy coating. (BS8081)</td>
</tr>
<tr>
<td>Mini Piles / Micro Piles (Tension)</td>
<td>Up to 3,500 kN (single bar reinforcement)</td>
<td>Passive (Fully Bonded)</td>
<td>Risk dependent on loading and application</td>
<td>Double corrosion protection (BS8081) or lower level of protection depending on risk or aggressivity levels (EN14199)</td>
</tr>
<tr>
<td>Mini Piles / Micro Piles (Compression)</td>
<td>Up to 2,000 kN (single bar reinforcement)</td>
<td>Passive (Fully Bonded)</td>
<td>Settlement (Lower corrosion risk due to compression loading)</td>
<td>Sacrificial corrosion allowance, galvanizing, grout cover (EN14199)</td>
</tr>
<tr>
<td>Soil Nails</td>
<td>Lightly loaded 30-150 kN</td>
<td>Passive (Fully Bonded)</td>
<td>Low risk (built-in system redundancy)</td>
<td>Sacrificial corrosion allowance or galvanizing (CIRIA 637, EN14490)</td>
</tr>
<tr>
<td>Rock Bolts / Rock Dowels (external)</td>
<td>Lightly loaded 30-100 kN</td>
<td>Passive (Fully Bonded)</td>
<td>Low risk (built-in system redundancy)</td>
<td>Sacrificial corrosion allowance, galvanizing or stainless steel</td>
</tr>
</tbody>
</table>
Common Corrosion Protection Methods
The six most commonly considered methods for corrosion protection, together with their constraints for use on permanent anchorages, are outlined below.

Double Corrosion Protection
Double corrosion protection (i.e. double barrier protection) is the provision of two impermeable barriers between the tendon and the external environment, such that the outer barrier ensures the integrity of the inner barrier should the potential for damage arise during handling or installation.

Protection measures that constitute acceptable barriers in accordance with BS8081:1989 and EN1537:2000 are often misrepresented, leading to confusion. Borehole grout, galvanizing or sacrificial corrosion allowance are all not accepted by the above standards. Acceptable barriers must ensure:

a) durability over the lifespan of the anchorage (often up to 120 years),
b) integrity, i.e. an impermeable barrier over the full length of the tendon,
c) remain intact during handling, installation and stressing.

Double corrosion protection for bar anchorages and strand anchorages are summarised below.

Bar Anchorages
Permanent bar anchorages comprise a threadbar, of either high yield or prestressing steel, surrounded by an internal cement grout encapsulated within a corrugated plastic duct (see figure 3). The internal grout should be applied under factory conditions and is not to be confused with borehole grout, which does not constitute a fully protective barrier (see separate section, borehole grout).

The internal grout of bar anchorages may be considered as an acceptable barrier to corrosion on the basis that crack widths generated under load at each threadform, can be limited to less than 0.1mm. Each crack width is uniform in thickness, due to the regularity of the thread pitch in conjunction with the linear extension of the bar. Crack width control is reliant upon the confinement from the corrugated plastic duct in order that the cracks propagate at each threadform as opposed to intermittently (see figure 4).
Strand Anchorages
Corrosion protection for strand anchors is provided by two plastic sheaths as the internal grout is unable to act as a protective barrier. Crack width control of the grout on strand anchors is not possible due to:
  a) the lack of ribs or threads on the strand,
  b) the increased strain of the strand (strand is worked much harder than bar).

Triple Corrosion Protection
This is somewhat of a misnomer and usually arises from either, the aspiration to add a further protective layer on the assumption that it is a simple process, or the misinterpretation of borehole grout or galvanizing as a protective barrier. Neither is credible. Double corrosion protection remains one of the most practical methods of protecting permanent anchorages and provides the highest level of protection in comparison to other systems.

Single Barrier Protection
This method has become popular for high capacity strand anchorages employed in the stabilization of dams. It comprises one physical barrier, the integrity of which shall be proven in-situ by either a falling head water test, or an electrical integrity test (see electrically isolated anchorages).

Corrugated Plastic Ducting - Wall Thicknesses
The corrugated plastic duct is an integral part of corrosion protection systems for both bar and strand anchorages.

For double corrosion protection, current developments are incorporating increased wall thicknesses of 1.0-1.5mm for the corrugated ducts (previously 0.8mm taking account of manufacturing tolerances), on the basis that there are two barriers.
For single barrier protection, guidelines laid down by EN1537:2000 (Clause 6.10.1) have incorporated even greater wall thicknesses for the single corrugated duct (see table 2). Both systems now provide better abrasion resistance, should the potential for damage arise during handling or placement of the anchorage.

<table>
<thead>
<tr>
<th>External Corrugated Duct (i.d.)</th>
<th>Wall Thickness</th>
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<tbody>
<tr>
<td>≤ 80 mm</td>
<td>1.0 mm</td>
</tr>
<tr>
<td>&gt; 80 mm but ≤ 120 mm</td>
<td>1.5 mm</td>
</tr>
<tr>
<td>&gt; 120 mm</td>
<td>2.0 mm</td>
</tr>
</tbody>
</table>

For high capacity strand anchorages used in dam stabilization, even larger corrugated ducts of diameters up to 254mm with a 3mm wall, are now being used.

**Limitations of Borehole Grout as a Protective Barrier**

Borehole grout (i.e. grout injected during installation or subsequently) is often misquoted as a recognized barrier for protection. Whilst it will provide a degree of protection, its cover and integrity cannot be verified in-situ, hence its use for permanent anchorages is not recognized by either BS8081:1989 or EN1537:2000.

Where borehole grout is used with self-drilled hollow bar systems, installed using the simultaneous drill and grout technique, its effectiveness as a protective barrier is problematical due to:

a) Reduced grout cover at coupler locations or at points along the full length of the drilled bar, which often takes the form of a lazy spiral. Spacers are disruptive, restricting grout circulation / flush and causing disturbance to the borehole wall.

b) Crack width control of the grout body, irrespective of threadform, is inconsistent at coupler locations or in areas of poor confinement.

c) Grout placement is workmanship sensitive. Simultaneous drill and grout can produce grout bulbing through the assistance of reaming, but it is irregular over the full length of the tendon. Exhumed tendons have shown wide variations in grout cover.

d) Contamination of the grout from the drill spoil or ground water.

BS8081:1989 Clause 8.2.3 summarizes the limitations of borehole grout as “grout injected in situ to bond the tendon to the ground does not constitute a part of a protective system because the grout quality and integrity cannot be assured”.

In recent years, self-drilled systems have become popular for soil nailing, as the concept of a self-drilled system in loose overburden has attractive cost benefits over conventional drilled and cased systems. However, their use as permanent anchorages is universally not accepted.

**Epoxy Coatings**

**Epoxy Coated Bars**

Epoxy coatings are occasionally applied to rock bolts or anchors in hard rock tunnelling applications, where slenderess of the borehole is a key cost requirement. The coating
has the added benefit in that its application process or chemical composition is not detrimental to prestressing grade steel threadbars, which are sometimes used in areas of high loading in tunnels.

Damage during handling remains the limiting factor for epoxy coated threadbars. The baked coating is brittle, with the highpoint of each thread particularly susceptible to nicks or chipping during transportation and handling. Each bar requires wrapping individually in a disposable protective sleeve, which is removed prior to installation. On site repairs can be time consuming as multiple nicks or chips all require repairing (see figure 5).

Figure 6  Damage to Duplex coated hollow bar, caused by hydraulic jaws used for rod release.

Duplex coating is a term used to describe two protective coatings, typically comprising a galvanized coating overlaid with a layer of epoxy or polyester. Its application has led to confusion as it does not offer double corrosion protection. It is rarely used on solid bars and has real limitations when used on self-drilled systems as the coating becomes compromised through:

a) Abrasion damage from rotary installation.
b) Perforation of the coating by hydraulic jaws or stilsons, used to grip the bar for release from the drill head (see figure 6). Soft jaws have been trialed, but are ineffective.

Epoxy Coated Strand
The epoxy coating of strand for permanent anchorages is acknowledged as a popular process in the USA and Japan, but its application to strand anchorages in Europe is rare. The principle areas where attention is required are:

a) Creep under load of the bonded strand within the grout. Creep values need quantifying.
b) Adhesion of the epoxy to the strand. Adhesion is heavily dependent on the strand preparation process (i.e. shot blasting or pickling in acid).
c) Abrasion damage during handling. Sand added to the epoxy coating to enhance its bond in the grout is extremely abrasive, requiring special care on multi-strand anchorages.
d) Coating thickness and uniformity. Both require careful checking.
e) Grip of the wedges. Long teeth are required to bite through the epoxy coating, in order that the steel can be gripped.

**Sacrificial Corrosion Allowance**

This method has evolved from sheet piling and buried corrugated steel structures. It is now also regularly applied to soil nails and rock bolts (both passive installations), as these are generally classified as low risk installations, on the basis of an element of redundancy. This is not routinely the case for ground anchorages.

In addition, the application of sacrificial corrosion allowance to anchor tendons is not acceptable as corrosion rates are rarely uniform and not predictable, tending to extend more rapidly at localized pits or surface irregularities.

Both BS8081:1989 and EN1537:2000 preclude the use of sacrificial corrosion allowance for the permanent protection of anchorages, with EN1537:2000 (Clause 6.9.1) stating “There is no certain way of identifying corrosive circumstances with sufficient precision to predict corrosion rates of steel in the ground. All steel components which are stressed shall be protected against corrosion for their design life”.

**Galvanizing**

Galvanizing is universally recognized as a method of protecting exposed steel surfaces. Its use on low risk installations such as rock bolts (figure 7) or soil nails (figure 8) is popular as it provides a robust coating, but its use as a protective coating for anchor tendons is not accepted.

The use of galvanizing as a means of increasing lifespans for buried installations should be considered on the following basis:

a) Lifespans are variable and are dependent upon the aggressivity levels of the environment, typically 5-15 years for buried installations.

b) Coating thicknesses vary according to the application process. Hot Dipped Galvanizing (in accordance with EN1461:1999) provides a minimum zinc cover of 85 µm (microns), Electro Plated Galvanizing only offers 5-12 µm.

c) It is not suitable for prestressing grade threadbars as the preparation process (pickling in acid) can induce the potential for hydrogen embrittlement.

d) Both BS8081:1989 and EN1537:2000 preclude the use of galvanizing as permanent protection, on the basis that it is a sacrificial coating.
Alternative Protection for Permanent Anchorages

EN1537:2000, The European Standard for Ground Anchors, includes a range of protection options:

a) Double Corrosion Protection, as detailed above

b) Tube-a-Manchette and Compression Tube Anchorages. Each system features different mechanisms for load transfer in the bond length, but both anchorages include for two impermeable barriers as corrosion protection.

c) Electrically Isolated Anchorages, as detailed below.

Electrically Isolated Anchorages

These anchorages feature a single protective barrier (typically a corrugated plastic duct), which is subjected to an electrical resistance test. The principle of the system is based upon proving the integrity of the protective barrier by measuring the resistance between the anchorage and the surrounding soil. The concept is attractive to designers, as it enables the integrity of the protective barrier to be checked, following installation and stressing.

There are, however, two considerations where a detailed understanding of the system is required:

a) Contractual implications of the system are quite complicated, as the integrity of the plastic sheathing should be tested at the time of delivery to site, where ownership of the anchor is transferred to the installer. Conductivity tests prior to installation require a water bath.

b) Moisture is a problem, as resistivity readings can be unreliable and difficult to interpret.

Other Corrosion Protection Options

Stainless Steel and Cathodic Protection are occasionally considered for corrosion protection of permanent anchorages. The use of stainless steel is rare on permanent anchorage applications and there is little guidance on its use without protective barriers in either BS8081:1989 or EN1537:2000. Its application for external rock bolting or dowelling is more common. Durability of stainless steel is dependent on the grade; also, the cost of higher grades can be prohibitive.
Cathodic Protection, whilst popular in other applications, has practical limitations for ground anchorages in the following respects:

a) the determination of the correct electrical current sufficient to provide protection,
b) the need for continual monitoring and maintenance of an impressed current system.

Ground Anchorage or Tension Pile?
The key distinction between ground anchorages and tension piles is that ground anchorages are active installations (featuring a prestressed free length), as opposed to tension piles which are passive installations (fully bonded, initially unstressed). A debonded tension pile requiring stressing is a misnomer and should be classified as a ground anchorage.

The extension characteristics of tension piles (figure 9) under service loadings differ from those of ground anchorages (figure 10). Tension piles will extend under load as restraint is progressively mobilized in the ground, whereas ground anchorages do not, as they feature a free length which enables the extension to be stressed out at the time of installation.

For temporary works, the increased extension of a tension pile is often not critical, but for permanent works, the increased extension often requires careful consideration in the context of the overall structure, where additional movement could lead to cracking in the concrete faces. Typically, a design incorporating tension piles will have to allow for movement on a global basis.

Critical Areas of Anchorages Requiring Protection
The location at the underside of the bearing plate is typically the area of highest risk. At this point, both oxygen and moisture are present, which when combined will promote corrosion if the tendon is unprotected. Access to this area for inspection, even with the
use of an endoscope, is notoriously difficult (see figure 11). Repairs are usually only possible by de-stressing the anchorage and removing the full head assembly. Protective end caps, used on the face of the bearing plate to enclose the anchor head, do not contribute to protection below the plate. It is the section of anchorage directly below the bearing plate which requires comprehensive protection.

Figure 11. A typical application for anchorages. Access to the underside of the bearing plate is notoriously difficult.

**Practical Issues on Site**

Flushing Out of Grout at the Anchor Head
Flushing out of the grout (wash-back) over the top 1.0m of the anchor tendon is required in order to avoid any strut effect during stressing and also to facilitate the placement of the sealing tube (at the underside of the bearing plate) over the anchor tendon, see figure 12.

This is of particular importance for bar anchorages, where the grease filled sealing tube is an integral part of the bearing plate. Failure to flush out can lead to the sealing tube not being properly placed around the anchor tendon, resulting in the potential for corrosion.

Figure 12. The importance of flushing out, for placement of the sealing tube.

*Prevention of Ingress of Ground Water in Anchor Heads*
In areas of high ground water pressure, additional sealing measures may be required. This is a complicated detail that needs to be carefully thought through, as practical limitations during installation require a specific order of assembly.

The use of additional sealing components or gaskets as well as the injection of specialist resins should be considered where high water pressures are anticipated.

**Conclusion**

Ground anchorages remain a popular choice with engineers for a range of applications. Their durability in permanent works is of utmost importance, requiring careful attention in respect of corrosion protection. The re-classification of the installation in order that a lower level of protection may be applied, or the application of unsuitable barriers, is to ignore the fundamental issues of durability. It is the area of least protection that defines the effectiveness of all corrosion protection measures.

In practice, the corrosion protection principles outlined in both BS8081:1989 and EN1537:2000 tend to complement each other, in that either double corrosion protection or single barrier protection (coupled with an in-situ integrity test) will ensure permanent protection for the anchorage.

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**References:**