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# Quality Control of Soil Nailing and Ground Anchors

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**Jury**

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**Abstract**

The main purpose of this dissertation is to enlarge the knowledge of the actual Portuguese situation in the quality control during the design, construction and testing of ground anchors and soil nailing.

This work was divided in two major parts, soil nailing and ground anchors.

Another goal is also to establish the design and construction procedures compatible with the European Standard EN 1537 (1999), which specifically embrace ground anchors, with the purpose of achieve the desirable quality to ensure the design life time of engineering works.

In view of the fact that the physical integrity of anchors is a concern for guarantying their lifetime, an evaluation is made of problems referred to corrosion, the types of corrosion and the classes of protection of anchors against corrosion.

It's presented reference to the different types of load tests, to be performed on anchors, as well as the number and type of control required by the European Standards.

The present dissertation had as a support, in addition to the existing bibliography in this area, field attendance (installation and testing phases) and quality control procedures in the construction of Baixo Sabor Dam at the expense of "Bento Pedroso Construções e Lena, ACE".

**Keywords**: ground anchors; soil nails; EN1537; quality control.

## Introduction

The construction of soil nailing and ground anchors have increased remarkably due the development of the urban districts and the railroads and road system.

The technology of soil nailing and ground anchors were developed mainly by constructions companies that projected and executed temporary support systems.

Afterwards, the base of the development, mostly in France, Germany, Switzerland and Sweden was the optimization of the injection and drilling techniques associated with the innovations in the steel industries (high resistance steel for the manufacture of bars or strings).

The construction of this kind of works with a high complexity level of execution requires an objective and rigorous quality control, in order to ensure the life-time and performance expected.

The evolutions we've seen in the last years have given more influence to quality.

In order to ensure the physic integrity of ground anchors and soil nails, it's necessary to develop a quality control methodology of the execution.

To achieve this goal, quality control will have to embrace every step of the execution:

- Site investigation (geologic and geotechnical study);
- Design;
- Reception and handling;
- Execution;
- Final verifications (stressing)
- Monitoring and maintenance.

# Soil Nailing

### Basic elements of a soil nail wall

Soil nailing consists of the passive reinforcement of existing ground by installing closely spaced steel bars (nails), which are subsequently encased in grout.

The solid steel reinforcing bars are the main component of the soil nail wall system. These elements ate placed in pre-drilled holes and grouted in place. Tensile stress is applied to the nails in response to the deformation of the retained materials during subsequent excavation activities.

The grout in placed in the pre-drilled borehole after the nail is placed and it serves the primary function of transferring stress from the ground to the nail. The grout also provides a level of corrosion protection to the soil nail.

The nail head is the threaded end of the soil nail that protrudes from the wall facing.

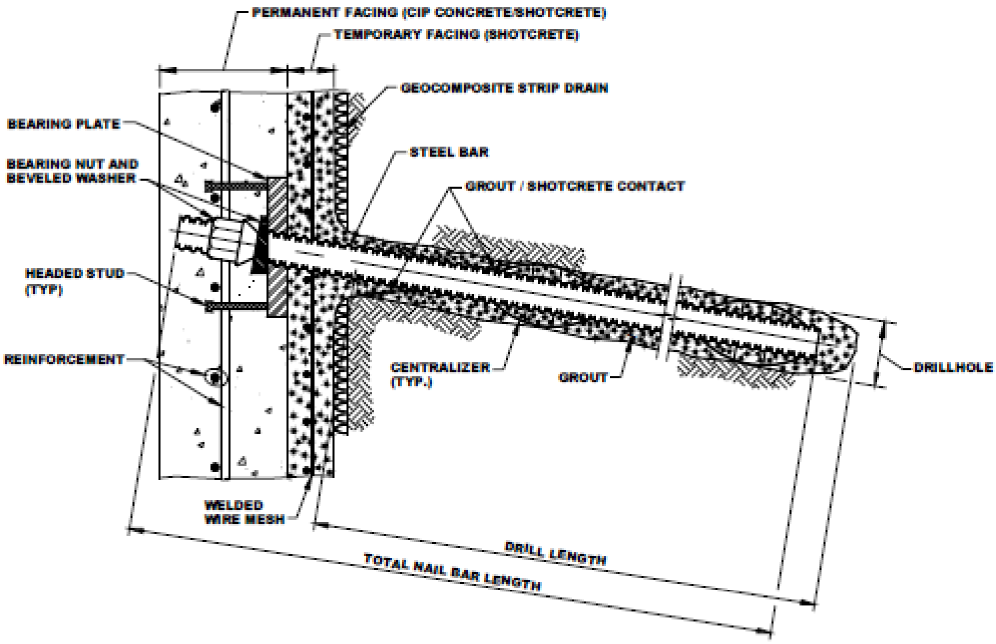


Figure 1 – Main components of a typical soil nail.

### Analysis of soil nails walls

External failure modes refer to the development of potential failure surfaces passing through or behind the soil nails (i.e., failure surfaces that may or may not intersect the nails). For external failure modes, the soil nail wall mass is generally treated as a block. Stability calculations take into account the resisting soil forces acting along the failure surfaces to establish the equilibrium of this block. If the failure surface intersects one or more soil nails, the intersected nails contribute to the stability of the block by providing an external stabilizing force that must be added to the soil resisting forces along the failure surface. Within this framework, the three failure modes identified by Byrne (1998) as “external” (i.e., failure surfaces not intersecting the nails), “internal” (i.e., failure surfaces intersecting all nails), and “mixed” (i.e., failure surfaces intersecting some nails) are classified as external failure modes in this document.

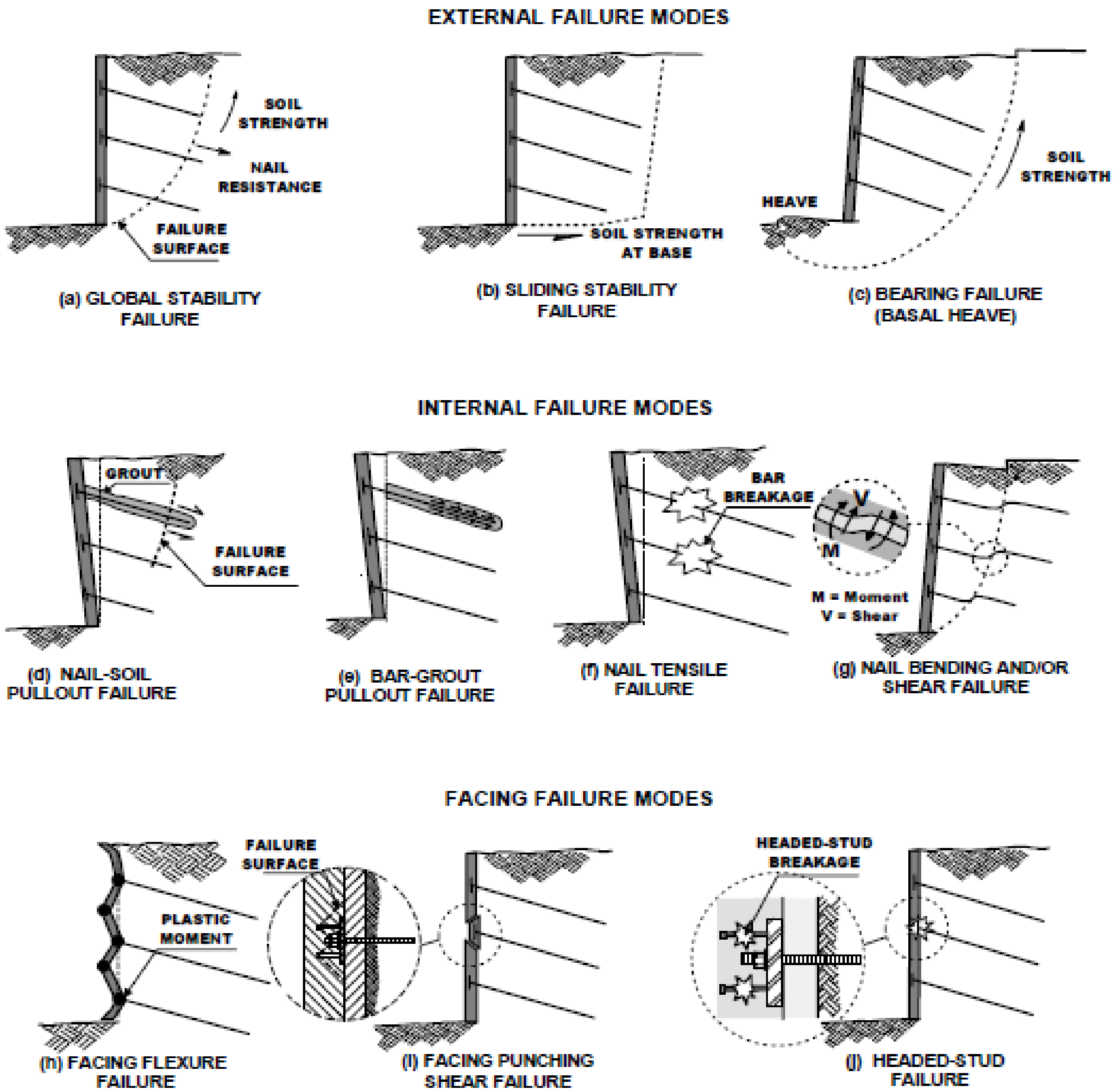


Figure 2 – Principal modes of failure of soils nail walls systems

External stability analyses are performed to verify that the proposed soil nail wall is able to resist the destabilizing forces induced by the excavation, service loads, and extreme loads (e.g., seismic) for each of the potential failure modes. Factors that control external stability include wall height; soil stratigraphy behind and under the wall; width of the nailed zone (i.e., soil nail lengths); and soil, nail, and interface strengths.

Internal failure modes refer to failure in the load transfer mechanisms between the soil, the nail, and the grout. Soil nails mobilize bond strength between the grout and the surrounding soil as the soil nail wall system deforms during excavation. The bond strength is mobilized progressively along the entire soil nail with a certain distribution that is affected by numerous factors. As the bond strength is mobilized, tensile forces in the nail are developed.

**Quality control and performance monitoring**

Inspection activities, if properly conducted, play a vital role in the production of a high-quality soil nail wall because conformance to project plans and specifications should result in a soil nail wall that will perform adequately for the intended service life. Inspection may involve evaluation of the following:

- Conformance of system components to material specifications;
- Conformance of construction methods to execution specifications;
- Conformance to short-term performance specifications (i.e., load testing);
- Long-term monitoring.

Monitoring activities may include short-term or long-term measurements of soil nail wall performance. Short-term monitoring is usually limited to monitoring measurements of soil nail wall performance during load testing (i.e., proof, verification, and creep tests). In some cases, short-term monitoring may include monitoring lateral wall movements and ground surface settlements.

**Inspection roles**

Quality assurance measures must be implemented during construction to ensure that:

- construction is being performed in accordance with plans and specifications;
- allowable excavation heights are not exceeded;
- nail drillholes have not caved during nail installation;
- nail bars are of the right size and type (i.e., steel grade, length, diameter);
- corrosion protection systems are in compliance;
- grouting, installation of facing rebar and mesh, and shotcrete are in compliance with respect to materials and methods;
- nail pullout testing verifies the design values required by the specifications;
- required drainage is properly installed.

**Quality control of construction materials**

The quality of all materials used is controlled on-site by one or a combination of the following procedures:

- visual examination for defects due to poor workmanship, contamination, or damage from handling;
- certification by the manufacturer or supplier that the materials comply with the specification requirements;
- laboratory testing of representative samples from materials delivered to the site or approved storage area.

Nails, cement, bars, and drainage materials must be kept dry and stored in a protected location. Note that bars should be placed on supports to prevent contact with the ground.

**Quality control of construction activities**

It is the responsibility of the inspection staff to ensure that all required construction activities and testing for each lift has been completed in accordance with the contract specifications and plans. Quality control activities are listed below:

- inspecting nail bars for damage, required length, and checking mill test certificates to certify grade and corrosion protection;

- verifying that the stability of the excavated face is maintained at all stages of construction; if stability cannot be maintained at the initial depth of cut, the depth of subsequent excavation lifts should be reduced and followed by immediate shotcreting;
- verifying that the nails are installed to the correct orientation, spacing, size/grade, and length; in drilling the drillhole, the contractor must maintain an open hole without any loss of ground, otherwise casing must be used; subsidence of ground above the drilling location or large quantities of soil removal with little or no advancement of the drill head should not be permitted; drilling mud should not be permitted because bentonite residue on the drill-hole perimeter will likely reduce the capacity of the nail;
- verifying that centralizers are used to provide proper location of the nails in the drilled hole; insertion of the bar may be done before or after tremie grouting the drillhole; centralizers must be placed along the length of the nail such that flow of grout in the borehole is not impeded;
- inability to achieve the required nail length in uncased holes is usually a sign of caving and may require re-drilling;
- verifying that proper grouting of the borehole around the nail bar is employed; the grouting operation involves injecting grout at the lowest point of the drill hole in order to fill the hole evenly without air voids (i.e., via a tremie pipe);
- verifying that shotcrete is placed to the required thickness, is placed in accordance with standard practice, and that the facing reinforcement is installed in accordance with the specifications and plans;
- verifying proper placement of the bearing plate; deviations of perpendicularity between the plate and nail should be adjusted by using tapered washers below the nut;
- verifying proper installation of drain pipes, weepholes, and prefabricated vertical drains; it is essential that hydraulic continuity of the vertical drains be assured if installed incrementally;
- verifying that grout cubes and shotcrete cores are taken for strength testing of permanent walls.

**Load testing**

Soil nails are load tested in the field to verify that the nail design loads can be carried without excessive movements and with an adequate factor of safety. Testing is also used to verify the adequacy of the contractor's drilling, installation, and grouting operations prior to and during construction of the soil nail wall. If ground and/or installation procedures change, additional testing may be required to evaluate the influence on soil nail performance. It is typical practice to complete testing in each row of nails prior to excavation and installation of the underlying row. If test results indicate faulty construction practice or soil nail capacities are less than that required, the contractor should be required to alter nail installation/construction methods. Testing procedures and nail acceptance criteria must be included in the specifications.

## Ground Anchors

**Basic elements of ground anchors**

A prestressed grouted ground anchor is a structural element installed in soil or rock that is used to transmit an applied tensile load into the ground. Ground anchors, are installed and then the drill holes are filled with grout. The basic components of a grouted ground anchor include the: (1) anchorage; (2) free stressing (unbounded) length; and (3) bond length. These and other components of a ground anchor are shown schematically in figure 3.1.

The anchorage is the combined system of anchor head, bearing plate, and trumpet that is capable of transmitting the prestressing force from the prestressing steel (bar or strand) to the ground surface or the supported structure. The unbounded length is that portion of the prestressing steel that is free to elongate elastically and transfer the resisting force from the bond length to the structure. The tendon bond length is that length of the prestressing steel that is bonded to the grout and is capable of transmitting the applied tensile load into the ground. The anchor bond length should be located behind the critical failure surface.

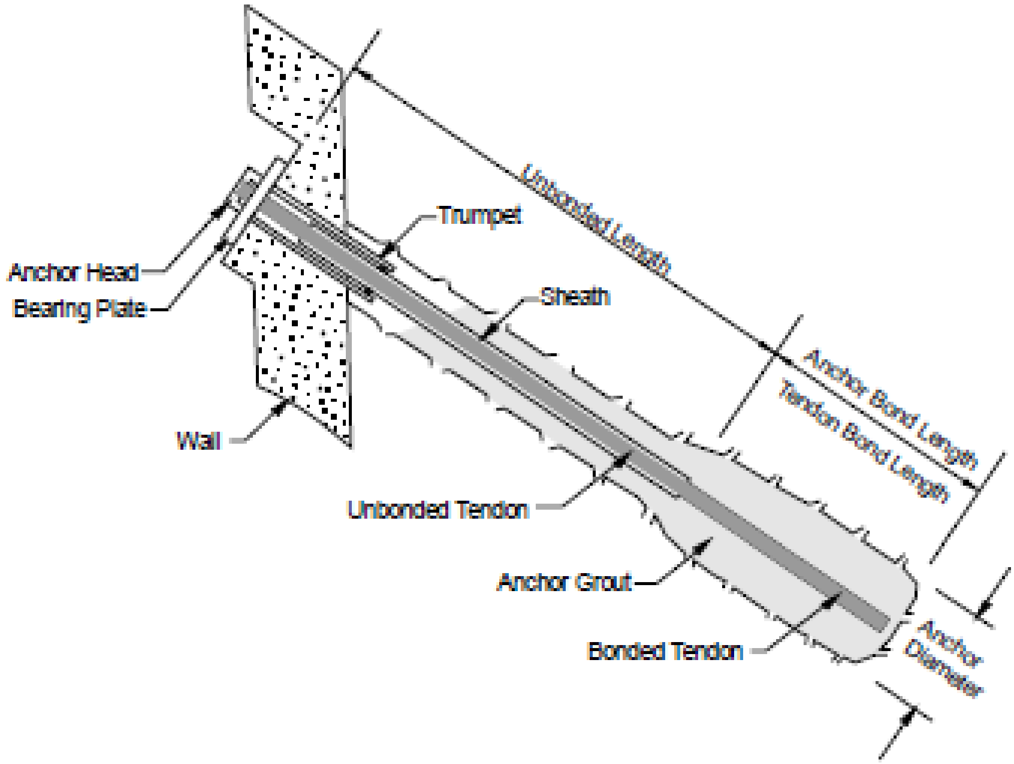


Figure 3 – Components of a ground anchor.

In terms of design life, there are two types of ground anchors:

- temporary ground anchors are defined as those which are required to be in service no longer than two years;
- permanent ground anchors are defined as those which are required to have a design life of more than two years.

**Analysis of ground anchors**

To provide new slope geometry by means of an excavation supported by an anchored wall, the following is necessary:

- The anchored wall should support the soil immediately adjacent to the excavation in equilibrium. This support typically governs the maximum required force in the anchors and the maximum required dimensions, strength, and bending moments in the wall section.
- The anchors should be extended sufficiently deep into the soil to beneficially affect a range of shallow and deep-seated potential failure surfaces with inadequate factors of safety. The anchor forces act on these potential slip surfaces to ensure they have an acceptable factor of safety.

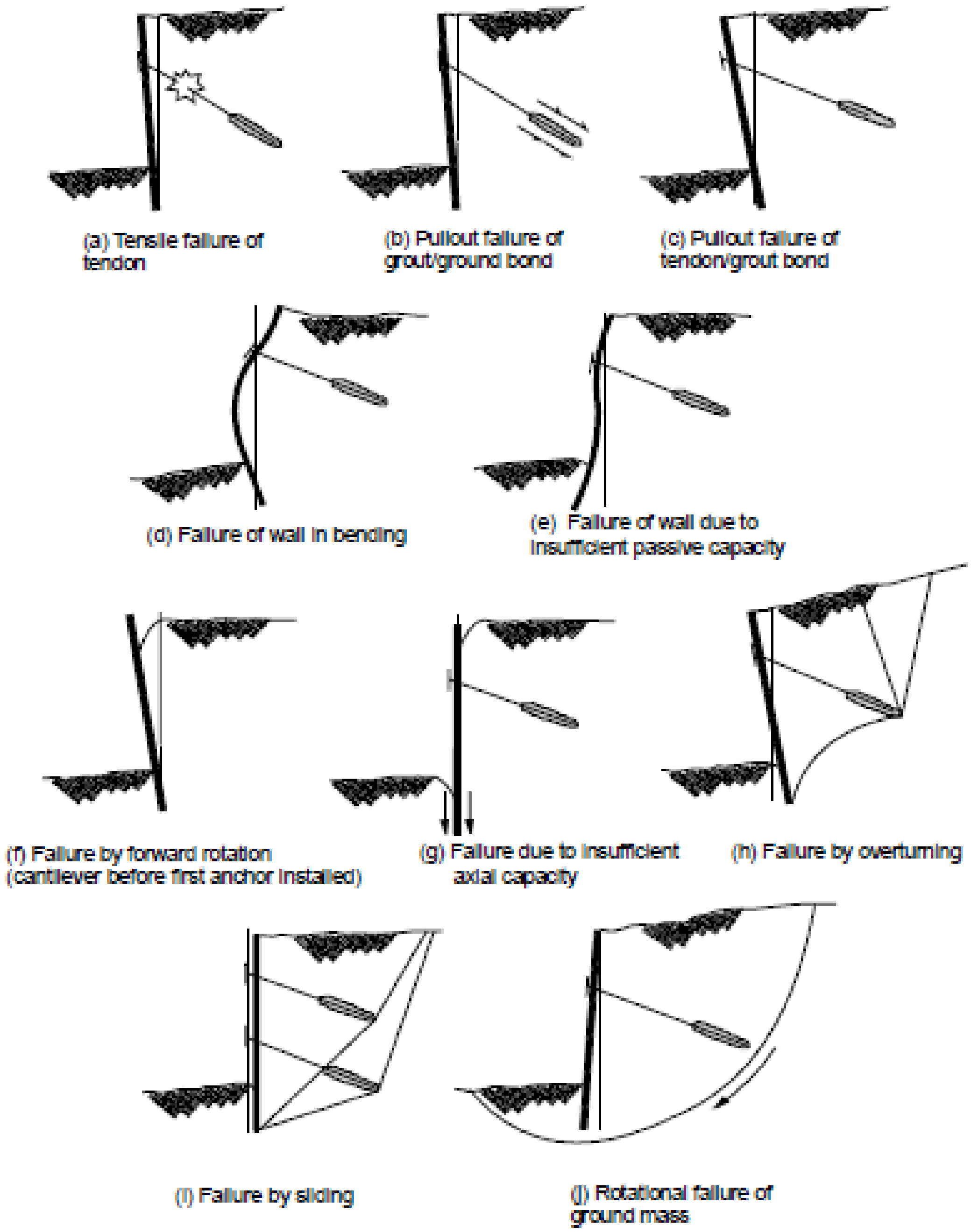


Figure 4 – Potential failure conditions to be considered in design of anchored walls

**Corrosion protection**

Protecting the metallic components of the tendon against the detrimental effects of corrosion is necessary to assure adequate long-term durability of the ground anchor. Corrosion protection for ground anchor tendons includes either one or more physical barrier layers which protect the tendon from the corrosive environment (EN1537, 1999). The barrier layers include anchorage covers, corrosion inhibiting compounds, sheaths, encapsulations, epoxy coatings, and grouts. The selection of the physical barrier depends on the design life of the structure (i.e., temporary or permanent), aggressively of the ground environment, the consequences of failure of the anchored system, and the additional cost of providing a higher level of protection.

**Types of corrosion for prestressing steel**

Corrosion of prestressing steel may be classified according to the following six major types: general corrosion; localized corrosion; stress corrosion/hydrogen embrittlement; fatigue corrosion; stray current corrosion; and bacterial attack.

**Requirements of corrosion protection systems**

Corrosion protection systems protect the ground anchor from corrosion by providing one or more impervious physical barrier layers around the tendon. Protection systems should satisfy the following criteria:

- ensure that the service life of the anchor with respect to corrosion failure is at least equal to the anticipated service life of the anchored system;
- produce no adverse impacts on the environment or reduce the capacity of the anchor;
- allow unrestricted movement of the tendon along the unbounded length such that all load is transferred to the bond length;
- comprise materials that are chemically stable and nonreactive with adjacent materials;
- require no maintenance or replacement (with few exceptions) during the service life of the anchor;
- be sufficiently strong and flexible to withstand deformations that occur during stressing of the tendon;
- be durable enough to withstand

| Class | Protection Requirements | | |
|---|---|---|---|
| | Anchorage | Unbonded Length | Tendon Bond Length |
| I (Encapsulated Tendon) | 1. Trumpet<br>2. Cover if exposed | 1. Encapsulate tendons composed of individual grease filled extruded strand sheaths with a common smooth sheath<br>2. Encapsulate tendons composed of individual grease filled strand sheaths with grout filled smooth sheath<br>3. Use smooth bondbreaker over grout filled bar sheath | 1. Grout-filled encapsulation or<br>2. Fusion-bonded epoxy |
| II (Grout protected tendon) | 1. Trumpet<br>2. Cover if exposed | 1. Grease-filled sheath, or<br>2. Heat shrink sleeve | Grout |

Table 1 - Corrosion protection requirements

**Quality control and performance monitoring**

**Site investigation (geologic and geotechnical study)**

Site investigation and testing programs are necessary to evaluate the technical and economical feasibility of an anchored system for a project application. The extent of the site investigation and testing components for a project should be consistent with the project scope (i.e., location, size, critical nature of the structure, and budget), the project objectives (i.e., temporary or permanent structures), and the project constraints (i.e., geometry, constructability, performance, and environmental impact).

**Design**

The responsibilities of the owner and the contractor with respect to design, construction, and performance of the ground anchor system must be specified in the project.

**Reception and handling**

All materials should be accompanied and controlled during loading, transportation, storage and installation.

Steel tendons should be stored above the ground surface and be protected against mechanical damage and exposure to weather. Tendons should be lifted using fiber ropes or webbing and should be supported at several locations along the tendon to prevent excessive bending.

Cement and resin based materials should be stored in a dry location and in such a way as to prevent deterioration. Cement that is caked or lumpy should not be used.

**Execution**

Prior to tendon installation, the borehole should be checked for obstructions and cleanliness in addition to length. Tendon installation should be carried out in a controller manner with care being taken to avoid relative displacement of the components.

Every step of the execution of ground anchors must be supervised, checked and kept in record. This control allows to prevent and detect at early phases problems that may occur during construction.

**Final verifications (stressing)**

For anchored system applications, each ground anchor is tested after installation and prior to being put into service to loads that exceed the design load. This load testing methodology, combined with specific acceptance criteria, is used to verify that the ground anchor can carry the design load without excessive deformations and that the assumed load transfer mechanisms have been properly developed behind the assumed critical failure surface. The load test is performed at the ground surface and consists of tensioning the prestressing steel element (i.e., strand or bar) and measuring load and movement.

The acceptance or rejection of ground anchors is determined based on the results of: performance tests; proof tests; and extended creep tests. In addition, shorter duration creep tests (as opposed to extended creep tests) are performed as part of performance and proof tests.

After acceptance, the ground anchor is stressed to a specified load and the load is “locked-off.”

During anchor load testing, the following general guidelines should be observed:

- at no time should the anchor be loaded such that tensile stresses within the tendon exceed 80 percent of the specified minimum tensile strength of the tendon;
- at no time should the applied load be reduced below the alignment load;
- test measurements should be plotted as the test proceeds in order to identify unusual behavior;
- for strand tendons, regripping of strands should be avoided such as would cause overlapping wedge bites or wedge bites below the anchor head;
- for fully bonded anchors, the free length must remain unbonded until after testing is complete and the anchor has been accepted;
- after lock-off of an anchor, a lift-off test should be performed to verify that the intended load is maintained in the anchor.

**Monitoring and maintenance**

Ground anchors can be installed with a monitoring facility. Where a structure is sensitive to changes in load or ground movement use can be made of this facility to monitor the behavior throughout its design life.

The number of ground anchors to be monitored and the intervals between measurements shall be specified in the project.

The corrosion protection of the accessible parts of the anchor head shall be inspected periodically and renewed, if necessary.

**Records**

A signed record shall be kept for each anchor installation, this record shall include any special features of construction. All installation and testing records shall be kept after the completion of works.

Records of anchor construction shall be complied in accordance with ENV 1997-1-1, for future reference. This shall cover:

- the sequence of deliveries of all cements, resins, hardeners and resin grouts;
- site investigation;
- drilling technique;
- installation and geometry of ground anchors elements;
- date and time of installation of each anchor;
- for grouted anchors: material, pressure, grouted volume, grouting length, grouting time;
- installation of the chosen corrosion protection;
- grouting;
- stressing and anchor testing.

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