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Recommendations for Prestressed Rock and Soil Anchors

POST-TENSIONING INSTITUTE ®

Recommendations for Prestressed Rock and Soil Anchors

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RECOMMENDATIONS

1.0 — SCOPE

These Recommendations provide practical guidance in the application of permanent and temporary prestressed rock and soil anchors using high-strength prestressing steel. They represent the current state of practice and provide recommendation for the design, installation, and testing of grouted prestressed rock and soil anchors, but are not necessarily applicable to other anchor systems.

Due to the broad nature of these Recommendations, particular sections shall be clearly referenced when included in the specifications for a specific project.

These Recommendations contain significant revisions and supersede PTI DC35.1-04. The revisions enhance the consistency of the recommendations and provide additional guidance in many subjects, including:

- Special prestressing materials
- Corrosion protection
- Drilling methods
- Water pressure testing
- Sheath repair
- Grouting
- Creep testing
- Resin anchors (Supplement B)

A list of the standard specifications and references cited throughout this document can be found in Section 9.2

The values stated in either SI units or in.-lb units are to be regarded as standard. Within the text, the in.-lb units are shown in brackets. The values stated in each system are not exact equivalents, and so each system must be used independently of the other.

These Recommendations were prepared by PTI Committee DC-35, Prestressed Rock and Soil Anchors, with input and review by the ADSC - International Association of Foundation Drilling Anchored Earth Retention Committee.

COMMENTARY

C1.0 — SCOPE

These Recommendations do not address the design of anchored structures in general, but are limited to considerations specific to the prestressed anchors themselves.

The applicability of certain sections of these Recommendations will depend on the type of specification used and whether the anchors are for a permanent or temporary application.

Anchor systems not considered by these Recommendations include mechanical anchors, helical anchors, and soil nails.

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2.0 — DEFINITIONS

Admixture – Substance added to the grout components during mixing to modify fluid grout properties in a controllable fashion (for example, bleed, pressure filtration, shrinkage, hydration, rheology) or set properties (for example, strength, permeability, durability).

Alignment load (AL) – A nominal minimum load applied to an anchor during testing to keep the testing equipment correctly positioned.

Anchor – A tendon installed in a drilled and grouted hole in the ground (soil or rock) that is stressed after installation (Fig. 2.1).

Anchor head – The device by which the prestressing force is permanently transmitted from the prestressing steel to the bearing plate (wedges and wedge plate for strand tendons or anchor nut for bar tendons).

Anchor nut – The threaded device that transfers the prestressing force in a bar to a bearing plate.

Anchorage – The combined system of anchor head, bearing plate, trumpet, and corrosion protection that is capable of transmitting the prestressing force from the prestressing steel to the surface of the ground or the supported structure.

Anchor head cover – A cover to protect the anchor head from corrosion and physical damage.

Apparent free tendon length – Theoretical length of tendon that would undergo an identical magnitude of elastic movement during unloading as that measured during load testing.

Bearing plate – A steel plate under the anchor head that distributes the prestressing force to the anchored structure.

Bleed – The autogenous flow of mixing water within, or its emergence from, newly placed grout; caused by the settlement of the solid materials within the grout mass and further facilitated in anchors by filtering action of strands ("wicking").

Bond breaker – A sleeve placed over the tendon in its free stressing length to allow elongation of the tendon free stressing length during stressing.

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Bond length – The length of the grout body that transmits the applied tensile load to the surrounding soil or rock. (See also the definition of **tendon bond length**)

Cast – The amount of curvature of a length of strand, which is not restrained when placed on a flat surface.

Centralizer – A device to support and position the tendon inside the drill hole or the sheath, so that a minimum grout cover is provided.

Coarse-grained soils – Soils with more than 50%, by weight, of material larger than the No. 200 sieve size.

Cohesive soils – Soils that exhibit plasticity. Atterberg limits are commonly used to determine plasticity and better define a soil as cohesive or non-cohesive.

Contractor – The person/firm performing the anchor construction.

Corrosion-inhibiting compound – Material used to protect against corrosion, lubricate the prestressing steel, or both.

Coupler – The means by which the prestressing force can be transmitted from one partial length of prestressing steel to another (mainly for bars).

Creep movement – The movement that occurs under a constant load and as measured during the creep test of an anchor.

Creep test – A test to determine the long-term load-carrying capacity of an anchor under a constant load.

Design load – Anticipated final maximum effective load in the anchor after allowance for time-dependent losses or gains (also referred to as **working load**).

Detensionable anchor head – An anchor head that is restressable and, in addition, permits the tendon to be completely detensioned in a controlled way at any time during the life of the structure.

Elastic movement – The recoverable movement measured during an anchor test.

Encapsulation – A corrugated or deformed sheath protecting the prestressing steel against corrosion.

COMMENTARY

RECOMMENDATIONS

Epoxy coating – A product containing pigments, thermosetting epoxy resins, cross-linking agents, and other additives, which is applied in the form of a powder onto a clean, heated metallic substrate and fuses to form a continuous barrier coating.

Extended temporary anchor – Any prestressed anchor for temporary use having a service life of 2 to 5 years.

F_{PU} – Specified minimum tensile strength of the prestressing steel, as defined in the pertinent ASTM specification.

Fine-grained soils – Soils with at least 50%, by weight, of material smaller than the No. 200 sieve size.

Free stressing (unbonded) length – The designed length of the tendon that is not bonded to the surrounding ground or grout during stressing.

Fully bonded anchor – Anchor in which the free stressing length without bond breaker is surrounded by grout, after stressing, and so is bonded to the surrounding structure or ground.

Gel time – Time between the start of mixing of a polyester resin with the catalyst, and the point at which the liquid phase changes to a viscous state.

Grit – Fine-grained material impregnated onto the outer surface of the epoxy coating, which improves the epoxy-coating bond to cement grout.

Grout – A mixture of portland cement and water that can provide corrosion protection, transfer loads between the tendon and the ground, or both. Polyester resin is used in place of cement grout in some applications.

Grout sock – A geotextile encasement around all or part of the ground anchor length, used to control grout loss in certain highly permeable ground conditions.

Holiday – A discontinuity in a coating that is not discernible to a person with normal or corrected vision.

Jack length – The length of stressing tail that is tensioned during testing.

Liftoff load – The load in the tendon determined at any time by doing a liftoff test.

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Liftoff test – Procedure to measure the actual load in a locked-off tendon by reapplying force until initial movement of the anchor head or wedges is observed.

Lock-off load – The prestressing force in the tendon immediately after transferring the load from the jack to the anchor head.

Memory – The tendency of seven-wire prestressed strand to retain the position in which it has previously been, such as on a reel or spool.

Non-cohesive soils – Material that is generally nonplastic.

Patching material – A liquid two-part epoxy used to repair damaged coating areas.

Permanent anchor – Any prestressed anchor for permanent use having at least a 5-year service life.

Performance test – An incremental cyclic test loading of an anchor, wherein the total movement of the anchor at each increment, including AL, is recorded.

Power seating – Use of hydraulic force to push wedges into the wedge cavity in the wedge plate.

Pregrouting – Injection of portland-cement-based grout into the drill hole or encapsulation prior to either injection of primary grout or placement of the tendon into the drill hole. Pregrouting of the drill hole may be used to reduce the permeability of the rock immediately surrounding the drill hole or to otherwise improve the ground conditions (for example, improve drill hole stability).

Post-grouting – The injection of grout along the anchor bond length after the primary grout has set. Post-grouting is performed to increase the pullout resistance of the anchor.

Pressure filtration – The expression of water from a cement-based grout under the application of pressure, through a permeable medium. In anchor work, this filtration is facilitated by the existence of interstices in the strand as well as the natural permeability of the surrounding ground.

Prestressing steel – High-strength steel consisting of seven-wire strands, solid bars, or groups of such elements.

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Primary grout – Grout that is injected into the drill hole prior to or after the installation of the tendon to allow the tendon to transfer load to the surrounding ground along the tendon bond length (also known as anchor grout).

Proof test – Incremental loading of an anchor, wherein the total movement of the anchor at each increment is recorded.

Pulling head – Temporary anchor head that transfers force from the jack to the prestressing steel during testing and stressing (also known as a **stressing head**).

Pull rod – Bar used during stressing and testing to eliminate the need for long stressing tails on bar anchors. It is attached above the anchor nut and extends through the hydraulic jack.

Relaxation – The decrease of stress or load with time while the prestressing steel is held under constant strain.

Residual movement – The nonelastic (non-recoverable) movement of an anchor measured during load testing at return to the **alignment load**.

Resin cartridge – Package containing polyester resin with filler material and a separated catalyst (hardener).

Restressable anchor head – An anchor head that permits the anchor load, throughout the life of the structure, to be measured by liftoff and adjusted.

Rheology – The study of the deformation and flow of materials. The American Concrete Institute (ACI) defines rheology as the science dealing with flow of materials, including studies of deformation of hardened concrete; the handling and placing of freshly mixed concrete; and the behavior of slurries, pastes, and the like.

Safety factor – The ratio of the ultimate capacity to the working load used for the design of any component or interface.

Secondary grout – Grout that is injected into the drill hole after lock-off of the tendon and within its free stressing length for corrosion protection or load transfer.

Sheath – A smooth or corrugated pipe or tube or heat-shrink sleeve protecting the prestressing steel against corrosion.

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Single-stage grouting – The injection of grout in a single operation along both the bond length and the free stressing length.

Spacer – A device to separate elements of a multiple-element tendon to ensure full bond development of each prestressing steel element.

Stressing head – Temporary anchor head that transfers force from the jack to the prestressing steel during testing and stressing (also known as a **pulling head**).

Stressing tail – The portion of the prestressing steel extending out beyond the anchorage to be gripped for stressing.

Supplemental cementitious materials – Materials having cementing properties that are added to portland cement grout.

Temporary anchor – Any prestressed anchor for temporary use having a service life less than 2 years.

Tendon – An assembly consisting of prestressing steel, spacers, anchorage, corrosion protection, bond breakers, and centralizers.

Tendon bond length – The length of the prestressing steel that is bonded to the grout.

Test load (TL) – The maximum load to which the anchor is subjected during testing.

Thixotropy – The property of a material that enables it to stiffen in a short time while at rest, but to acquire a lower viscosity when mechanically agitated, the process being reversible.

Transition tube – A common sheath that is inserted into the top of the fluid grout and extended into the trumpet.

Tremie grouting – Injection of grout by means of introducing the grout at the lowest elevation within the drill hole.

Trumpet – Device to provide corrosion protection in the transition length from the bearing plate to the free stressing length.

Unbonded anchor – Anchor in which the free stressing length remains permanently unbonded to the surrounding ground or structure.

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Wedge – The device that transfers the prestressing force in the strand to the wedge plate.

Wedge plate – The device that holds the wedges of multi-strand tendons and transfers the prestressing force to the bearing plate.

Wedge seating – The process in which elastic shortening of the strand pulls wedges into the tapered wedge cavities and causes the hardened teeth of the wedges to bite into the strand, enabling the prestressing force to be transferred from the strand to the wedge plate.

Wedge seating load – The load in the strand immediately after wedge seating (with shims in place under the wedge plate, if applicable).

Wedge seating loss – The loss of elongation as a wedge slides into the tapered wedge cavity during lock-off.

Working load – Anticipated final maximum effective load in the anchor after allowance for time-dependent losses or gains (also referred to as **design load**).

COMMENTARY

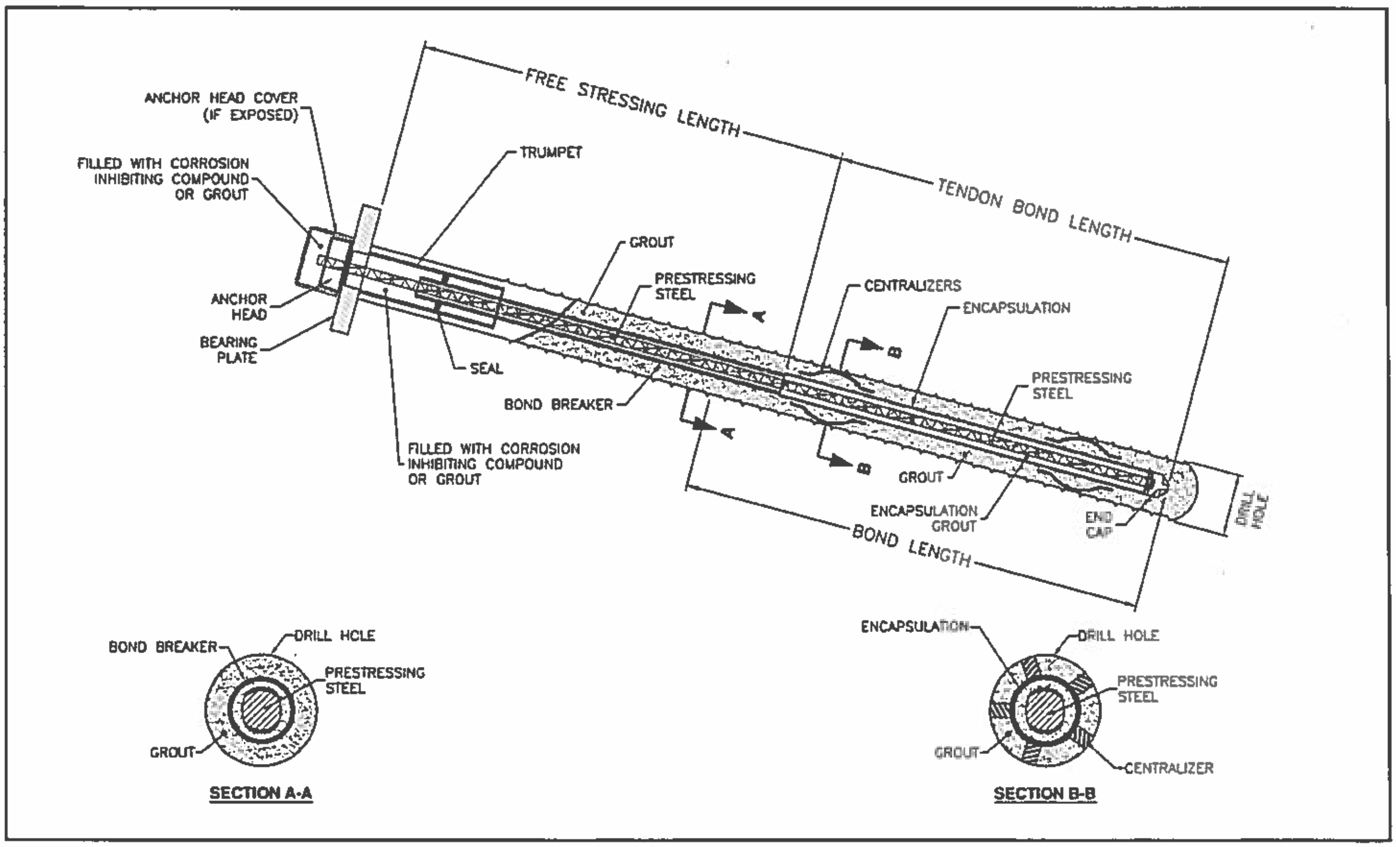

Fig. 2.1—Typical anchor components.

RECOMMENDATIONS

3.0 — SPECIFICATIONS, RESPONSIBILITIES, AND SUBMITTALS

3.1 — Specifications

The three types of specifications most commonly used for rock and soil anchor work are as follows.

3.1.1 — Prescriptive specifications

The Owner describes specific procedures that must be followed. These may not necessarily fully define the objective of the work.

3.1.2 — Performance specifications

The Contractor assumes greater control over certain design, construction procedures, or both, but must demonstrate to the Owner through testing, certification, or both, that the final product meets the specified project performance criteria.

3.1.3 — Open specifications

These leave the scope and design of the installation completely up to the anchor Contractor. This method is especially common for securing bids on temporary anchor work. The responsibility for design and performance is placed entirely on the Contractor. Open specifications are not recommended for permanent anchor applications. The corrosion protection requirements must always be specified by the Owner.

3.2 — Responsibilities

The contract documents must clearly describe the respective responsibilities of the Owner, Engineer, and Contractor. Prior to commencing the work, the Contractor shall demonstrate to the satisfaction of the Owner that he has sufficient resources and experience, both organizationally and individually, to perform the work in accordance with the specifications.

A list of the major tasks to be performed on an anchor project is shown in Table 3.1. The responsible party for each task must be clearly identified and mutually

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C3.0 — SPECIFICATIONS, RESPONSIBILITIES, AND SUBMITTALS

C3.1 — Specifications

C3.1.1 — Prescriptive specifications

When prescriptive specifications are used, the Owner is responsible for the satisfactory performance of the system. The Contractor is responsible for satisfying the detailed requirements of the specifications.

C3.1.2 — Performance specifications

This method allows and encourages the Contractor to provide a competitive/innovative anchor system design within the framework of the overall design requirements. The responsibilities for the work are shared between the Owner and the Contractor in well-defined categories.

It is important when using this method to provide the information that the contractor needs for design, or to allow sufficient time for the contractor to obtain it. An example of this is data on corrosion potential of the ground.

C3.1.3 — Open specifications

This method allows the Contractor to select the most economical anchor system and keeps change orders to a minimum.

C3.2 — Responsibilities

The allocation of responsibilities will depend on the type of specification and whether the work is temporary or permanent. The installation of anchors requires specialized equipment, knowledge, techniques, and expert workmanship. Not every detail of the work can be specified, and not every potential problem can be anticipated. Therefore, only Contractors who are thoroughly experienced in anchor work should be selected.

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agreed upon at the earliest point in the contracting process. The process of continuous communication between all the parties involved, regardless of the allocation of responsibilities and tasks, is essential to achieve a result of suitable quality. Clear communication and close cooperation are particularly important in the startup phase of a project. In addition, timely preparation and review of all submittals is always beneficial in any project.

Table 3.1 — Tasks and responsibilities to be allocated for anchor works

1.	Site investigation, geotechnical investigation and interpretation, site survey and potential work restrictions.
2.	Decision to use an anchor system, requirements for a precontract testing program, type of specification and procurement method, and Contractor prequalification.
3.	Obtaining easements, permits, permissions.
4.	Overall scope of the work, design of the anchored structure, and definition of safety factors.
5.	Definition of service life (temporary, extended temporary, or permanent) and required degree of corrosion protection.
6.	Anchor spacing and orientation, minimum total anchor length, free anchor length and anchor load.
7.	Anchor components and details.
8.	Determination of bond length.
9.	Details of water pressure testing, pregrouting, and redrilling of drill holes.
10.	Details of corrosion protection.
11.	Type and number of tests.
12.	Evaluation of test results.
13.	Construction methods.
14.	Requirements for QA/QC program.
15.	Supervision of the work.
16.	Maintenance and long-term monitoring.

RECOMMENDATIONS

3.3 — Submittals

3.3.1 — General

Project specifications shall establish the requirements for submittals. Proper submittals and records are essential for both temporary and permanent anchor installations.

If required by the project specifications, records covering site investigation, drilling, grouting, stressing, and acceptance testing shall be compiled for future reference. Certificates of Conformance for all materials and their relevant properties shall be retained.

3.3.2 — Preconstruction submittals

The following items shall be submitted for approval if required by the contract specifications:

- Contractor qualification and experience statement.
- Contractor construction method statement. These must include all details of drilling, grouting, and water pressure testing activities, including means, methods, and materials.
- Contractor-designed items.
- Shop drawings describing tendon fabrication and corrosion protection details.
- Installation requirements and repair procedures for corrosion protection (sheath or coating).
- Sequence of construction necessary to satisfy identified design requirements.
- Materials certifications for all grout components.
- Equipment to be used for testing and stressing and for measuring movement, including calibration records.
- Construction Quality Plan, describing the testing and recordkeeping to be conducted, by whom and at what frequency.

The Contractor shall ensure that all the aforementioned referenced submittals are internally consistent in detail and are in compliance with the requirements delineated in the project specifications.

COMMENTARY

C3.3 — Submittals

C3.3.1 — General

All parties should cooperate to share the responsibility for record keeping. For example, the Owner may compile the site investigation and background data, whereas the Contractor's construction records may be adequate to cover the drilling, grouting, and stressing aspects.

C3.3.2 — Preconstruction submittals

The complete list of items to be included in a preconstruction submittal pertains to a prescriptive specification. When an open specification is used for temporary work, the preconstruction submittals are often limited to the Contractor designed items and a shop drawing.

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3.3.3 — As-built records

The following documents shall be prepared and retained as prescribed in the contract provisions:

- As-built drawings showing the location and layout of anchors as installed;
- Certified material test reports for the prestressing steel and other steel components which may be required by the Owner;
- Manufacturers' certificates of compliance with contract specifications or test reports for materials other than steel;
- Drilling and grouting records, water pressure testing, pregrouting (if conducted), grout mixture design, and lab tests on grout cubes; and
- Anchor test and monitoring results with corresponding graphs. These records must be neat, legible, and suitable for reproduction.

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C3.3.3 — As-built records

As-built drawings will provide a permanent record of the location and layout of anchors as installed. Records of the final anchor locations should be filed with the local authorities having jurisdiction, because:

1. Future excavations may damage the tendons.
2. Removal of soil may adversely impact anchor performance.
3. Future fills may cause settlements and subsequent tendon bending.

RECOMMENDATIONS

4.0 — MATERIALS

4.1 — General

These Recommendations cover materials for prestressed rock and soil anchor systems using prestressing steel.

4.2 — Prestressing steel

Tendons shall be fabricated from single or multiple prestressing steel strands or bars.

Mill test reports for each heat or lot of prestressing material used to fabricate tendons shall be submitted if required by the Owner. Test reports for strand shall include bond capacity tests results in accordance with ASTM A981/A981M.

4.2.1 — Strand

Strand shall conform to ASTM A416/A416M, including the Supplementary Requirement S1, and shall be weldless, low-relaxation grade.

4.2.2 — Bar

Bars shall conform to ASTM A722/A722M for Type II (deformed) bars.

COMMENTARY

C4.0 — MATERIALS

C4.1 — General

For the ASTM designations, the latest edition applies.

C4.2 — Prestressing steel

Tendons fabricated from wire or indented or compacted strand, or nonmetallic materials, are not commonly used for anchors in North America and are not included in these Recommendations. This should not preclude their use when suitability is established.

C4.2.1 — Strand

The use of low-relaxation strand is recommended because of its low long-term load losses. 15.2 mm (0.6 in.) diameter strand is the most common size of strand used for anchors.

Supplementary Requirement S1 in ASTM A416/A416M references ASTM A981/A981M, a test method for evaluating the bond between strand and grout. ASTM A416/A416M requires that strand tested according to ASTM A981/A981M develop at least 35.6 kN (8000 lb) at 0.25 mm (0.01 in.) slip. Strand meeting this requirement has performed adequately in the field.

ASTM A1081/A1081M presents another test method using sanded grout. This test method has shown less variability than ASTM A981. At the time of this publication, the North American Strand Producers and the Precast/Prestressed Concrete Institute have established a preliminary criterion that strands develop at least 56 kN (12,600 lb) at 0.25 mm (0.1 in.) slip when tested according to A1081/A1081M. Test data indicate that strands meeting this criterion should meet A416/A416M and ASTM A981/A981M.

C4.2.2 — Bar

ASTM A722/A722M does not address relaxation requirements for bars.

RECOMMENDATIONS

The Engineer shall include relaxation requirements in the project specifications.

COMMENTARY

Bars meeting the relaxation values specified for low-relaxation strand are available.

ASTM A722/A722M requires that bars be subject to cold-stressing to not less than 80% of the minimum ultimate strength and then stress relieved. These steps produce an essentially linear stress-strain relationship in the elastic range and also eliminate bars having rolling or metallurgical defects.

The availability of cold-stressed and stress-relieved bars larger than 36 mm (1.375 in.) varies between manufacturers and country of origin.

4.2.3 — Epoxy-coated strand

Epoxy-coated strand shall conform to ASTM A882/A882M and shall be epoxy-filled and grit-impregnated.

For more information, refer to the "Supplementary Requirements for Epoxy-Coated Strand Tendons" section of this document.

C4.2.3 — Epoxy-coated strand

Unfilled epoxy-coated strand is not allowed for anchors because water may enter the interstices around the center wire and subsequently lead to corrosion of the steel.

4.2.4 — Epoxy-coated bar

Epoxy coating for ASTM A722/A722M bars shall conform to the coating requirements stated in ASTM A775/A775M or in A934/A934M, except that coating thickness shall not exceed 0.30 mm (12 mils).

C4.2.4 — Epoxy-coated bar

Requirements for thicker coatings than specified in ASTM A775/A775M and A934/A934M may result in reduced bond to grout, and reduction in the epoxy's impact resistance. Coating thickness greater than 0.30 mm (12 mil) may result in difficulties in threading hardware over the coated bar.

Of the two standards, A934 will result in an epoxy coating on the bar that is more abrasion-resistant.

4.2.5 — Special prestressing materials

Prestressing materials not conforming to Sections 4.2.1 through 4.2.4 are acceptable, provided such materials have been tested to ensure that their properties are equal to or better than those specified in this document.

Cold-stressing and stress-relieving of bars, if required, shall be specified by the Engineer. For bars that have not been cold-stressed to 80% of their minimum ultimate strength and stress relieved, the following shall be submitted to evaluate the anticipated elongation behavior of the bars during testing:

C4.2.5 — Special prestressing materials

This section applies to post-tensioning steel in sizes and grades which ASTM A416/A416M and A722/A722M do not cover. These properties may include, but are not limited to, ductility, fatigue, relaxation, and bond.

Bars that have not been cold-stressed and stress-relieved will exhibit plastic behavior prior to reaching the yield point defined by ASTM A722/A722M. ASTM A722/A722M allows determining the yield strength for bars either at a total strain of 0.7% or by the offset at 0.2%.

Figure C4.1 compares typical stress-strain curves for bars before and after cold-stressing.

RECOMMENDATIONS

1. Representative stress-strain curve for full bar cross section.
2. Creep test data at 80% F_{PU}.

COMMENTARY

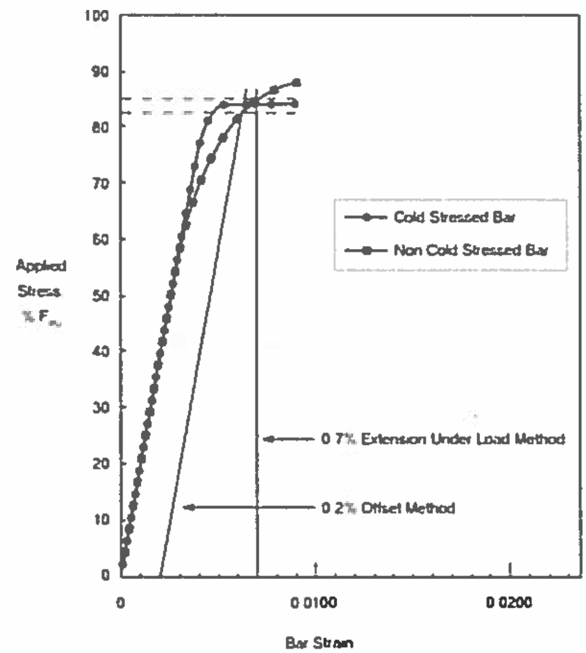

Fig. C4.1—Typical stress-strain curves for bars.

4.2.6 — Patching materials

The patching material shall be a product approved by the powder coating manufacturer and be curable and inert in cement grout.

C4.2.6 — Patching materials

Two-component compounds are used for patching holidays and damaged areas of the epoxy coating of bars or strand.

4.3 — Anchorages

Anchorages shall be a combination of either a steel bearing plate with wedge plate and wedges, or a steel bearing plate with a threaded anchor nut. The steel bearing and wedge plate may also be combined into a single element.

Wedges and wedge plates shall conform to the static and, when applicable, dynamic strength requirements of Section 4.1 in PTI M50.1.

For wedge-type anchorages, due to the critical interrelationship of the component parts, different suppliers' component parts shall not be mixed. Wedges for anchor heads shall not be reused.

Anchor nuts for bars shall comply with the performance requirements of Section 4.2 in PTI M50.1.

C4.3 — Anchorages

Project specifications should state whether the anchorages need to be of a restressable or destressable type.

PTI M10.2, Section 4.1, requires that these components be capable of developing 95% of the ultimate tensile strength of the prestressing steel when tested in an unbonded state.

Two- and three-part wedges are used. Two-part wedges require larger ductile deformations than three-part wedges for proper uniform embedment of the wedge teeth into the strand under a fully seated position. Longitudinal cracking is not uncommon, more so for two-part wedges than for three-part wedges.

RECOMMENDATIONS

Anchor nuts and other threadable hardware for epoxy-coated bars shall be designed to thread over the epoxy-coated bar and still comply with the requirements for carrying capacity. Uncoated bar ends for permitting easier threadability shall not be allowed.

The bearing plate shall be fabricated from steel conforming to ASTM A36/A36M, A588/A588M, A709/A709M or A572/A572M specifications, or equivalent, or may be a ductile iron casting conforming to ASTM A536.

The trumpet shall be fabricated from a steel pipe or tube conforming to the requirements of ASTM A53/A53M for pipe or ASTM A500/A500M for tubing. The trumpet shall have a minimum wall thickness of 3 mm (0.125 in.) for diameters up to 100 mm (4 in.) and 5 mm (0.20 in.) for larger diameters.

Transition tubes shall be minimum Schedule 40 polyvinyl chloride (PVC), encapsulation, or metal pipe.

Anchorage covers shall be fabricated from steel or plastic with a minimum thickness of 2.3 mm (0.09 in.). The joint between the cover and the bearing plate shall be watertight. Anchorage covers for exposed applications shall be fabricated from steel.

4.4 — Couplers

Couplers for bar tendons shall comply with the performance requirements of Section 4.2 in PTI M50.1. Couplers for epoxy-coated bars shall thread over the epoxy coating and shall comply with the same Section 4.2.

The use of set screws or other suitable means to prevent unthreading during installation is recommended.

Strands shall not be coupled, except in the case of repairs of already-installed tendons and for extending already-stressed strand anchors.

4.5 — Centralizers and spacers

Centralizers and spacers shall be made from steel, plastic, or material which is nondetrimental to the prestressing steel. Wood spacers shall not be used.

COMMENTARY

The trumpet provides a suitable transition from the bearing plate to the free stressing length corrosion protection. The length and diameter of the trumpet need to be coordinated with bearing plate geometry and corrosion protection requirements.

The cover needs to completely encapsulate the anchor head and any remaining length of stressing tail, and has to be sealed against the bearing plate.

C4.5 — Centralizers and spacers

Centralizers are not required on pressure-grouted anchors installed in coarse-grained soils when the grouting pressure exceeds 1 MPa (150 psi), or on hollow-stem augered anchors, when they are grouted through the auger with grout having a slump of 250 mm (10 in.) or less.

RECOMMENDATIONS

The centralizer shall support the tendon in the drill hole and position the tendon so a minimum grout cover of 13 mm (0.5 in.) is achieved. Centralizers used inside a sheath shall provide a nominal grout cover of 5 mm (0.2 in.) between prestressing steel and the inside of the sheath. All centralizers shall be designed to permit grout to flow freely around the tendon and along the drill hole.

Spacers shall be used in multiple element tendons to separate the strands or bars individually or into small groups.

4.6 — Corrosion-inhibiting compounds

The corrosion-inhibiting compound placed in either the free stressing length or the anchorage area shall be an organic compound with corrosion-inhibiting additives and appropriate moisture-displacing and self-healing properties. The compound shall stay permanently viscous and be chemically stable and not reactive with the prestressing steel, the sheathing material, or the anchor grout. Three types of corrosion-inhibiting compounds are presently used with the properties shown in Table 4.1.

4.6.1 — Grease

Grease shall conform to the requirements in Table 4.1 per Section 2.4 in PTI M10.2.

4.6.2 — Gel

The requirements for a gel are listed in Table 4.1.

4.6.3 — Wax

Because of the different nature, the requirements for a wax-based corrosion-inhibiting compound, as shown in Table 4.1, differ somewhat from the ones stated for grease. For further information, refer to Reference 5.

COMMENTARY

Minimum grout covers are required to provide adequate load transfer and corrosion protection.

Spacers allow the effective penetration of the anchor grout so each element is adequately bonded and protected.

C4.6 — Corrosion-inhibiting compounds

These compounds have varying properties and characteristics in areas of moisture resistance, stability, lubrication, viscosity, density, weight, and ease of placement.

C4.6.1 — Grease

Grease is a metallic organic soap that is mixed with oil containing various rust-inhibiting additives. When the grease is fully encapsulated within nonporous materials, such as metal or plastic, it has performed well over time. Grease can be pumped at ambient temperatures.

C4.6.2 — Gel

For corrosion-protection purposes, a gel is a colloidal dispersion of a metallic complex containing microscopic crystalline solids and microcrystalline wax in oil that forms an extremely stable gel/wax product. Gel can be pumped at ambient temperatures.

C4.6.3 — Wax

Wax is a by-product of refining crude oil and is a very stable material. It is insoluble in water and, when further refined into microcrystalline wax and blended with polar compounds (oil), it provides excellent corrosion protection. Wax must be liquefied and applied at approximately 93°C (200°F).

RECOMMENDATIONS **COMMENTARY**

Table 4.1—Requirements for corrosion-inhibiting compounds

Properties (Typical)	Test method	Criteria		
		Grease	Wax	Gel
Dropping point, °C (°F) minimum. Grease	ASTM D566	149 (300)	N/A	N/A
Melting point, °C (°F) minimum. Wax*	ASTM D127	N/A	63 (145)	260 (500)
Oil separation at 71°C (160°F) maximum	FTMS 791B Method 321.2	0.5	N/A (product is liquid)	0.5
Water, % maximum	ASTM D95	0.1	0.4	0.4
Flash point, °C (°F) minimum	ASTM D92	149 (300)	149 (300)	
Accelerated corrosion test: Salt fog at 38°C (100°F) at 0.13 mm (5 mils), hours	ASTM B117	1000	1000	1000
Water-soluble ions, ppm maximum (a) Chlorides (b) Sulfides (c) Nitrates	 ASTM D512 APHA 4500-S2 ASTM D3867	 10 10 10	 10 10 10	 10 10 10
Soak test: salt fog 50/50 immersion, hours	ASTM B117 Modified	720+	720+	720+
Sheathing compatibility at 66°C (150°F) (a) Hardness, % maximum change (b) Volume, % maximum change (c) Tensile strength, % maximum change	 ASTM D4289 ASTM D4289 ASTM D638	 15% change 10% change 30% change	 15% change 10% change 30% change	 15% change 10% change 30% change

*ASTM D566 may be used when wax product consistency warrants it.

4.7 — Plastic tubing

Plastic tubing or pipe used to fabricate bond breaker, sheathing, or encapsulation shall have the following properties:

1. Resistant to chemical attack from aggressive environment, grout, or corrosion-inhibiting compound;
2. Resistant to aging by ultra-violet (UV) light;
3. Nondetrimental to prestressing steel;
4. Resistant to damage caused by abrasion, impact, crushing, and bending during handling and installation;
5. Enable the prestressing steel to elongate during testing and stressing; and

C4.7 — Plastic tubing

Plastic tubing made from one of the following has performed satisfactorily:

1. A tube made from hot-melt extruded polyethylene conforming to ASTM D1248
2. A tube made from hot-melt polyethylene conforming to ASTM D3350
3. A tube made from hot-melt extruded polypropylene conforming to PP 210 B55542-11, as defined by ASTM D4101.
4. Pipe or tube of PVC conforming to ASTM D1784, Class 12454 or 13464.

RECOMMENDATIONS

6. Resistant to distortion caused by heat generated by curing of the grout.

The wall thickness shall meet or exceed:

	Nominal	Minimum
HDPE/PP	1.5 mm (0.060 in.)	1.25 mm (0.050 in.)
PVC	1.0 mm (0.040 in.)	0.9 mm (0.035 in.)

4.7.1 — Bond breaker

The bond breaker shall allow the prestressing steel to elongate elastically with minimal friction during testing and stressing. If the bond breaker is factory-applied and does not serve as a sheath, then the minimum thickness shall be 1.0 mm (0.040 in.).

4.7.2 — Sheath

In addition to the materials listed previously, heat-shrink sleeves (refer to Section 4.8.1) with a minimum recovered wall thickness of 1 mm (0.04 in.) can be used as a sheath.

4.7.3 — Tendon bond length encapsulations

The tendon bond length encapsulation shall be capable of transferring stresses from the grout surrounding the prestressing steel to the bond length grout.

End caps shall be made from materials described for the plastic tubing.

4.8 — Heat-shrink sleeves and tapes

4.8.1 — Heat-shrink sleeves

Heat-shrink sleeves shall be fabricated from a radiation cross-linked polyolefin tube internally coated with an adhesive sealant and with the following properties:

1. Resistant to chemical attack from aggressive environment, grout, or corrosion-inhibiting compound;
2. Nondetrimental to prestressing steel; and
3. Capable of withstanding abrasion and impact.

COMMENTARY

HDPE tubing is sensitive to prolonged exposure of UV light and, when pregrouted, can be subject to stress cracking. Prolonged exposure to UV light should also be avoided for PVC materials.

A heavier wall thickness may be required for large-diameter plastic tubing to resist differential grouting pressures.

C4.7.1 — Bond breaker

The bond breaker leaves the prestressing steel unbonded after lock-off.

C4.7.2 — Sheath

The sheath is part of the corrosion protection system. A smooth sheath may also function as a bond breaker.

Sheaths fabricated from a corrugated tube need a separate bond breaker.

C4.7.3 — Tendon bond length encapsulations

The encapsulation is part of the corrosion protection for the tendon bond length.

C4.8 — Heat-shrink sleeves and tapes

C4.8.1 — Heat-shrink sleeves

Heat-shrink sleeves are mainly used for watertight connections or for minor repairs of corrugated sheaths. Heat-shrink sleeves with a nominal wall thickness of 0.6 mm (0.02 in.) prior to shrinkage and internally coated with an adhesive sealant with a nominal thickness of 0.5 mm (0.02 in.) have been commonly used.

RECOMMENDATIONS

If the installed sleeves are to be exposed to sunlight for a prolonged time, they shall have UV-resistant characteristics.

COMMENTARY

UV resistance is generally not required because tendons are installed into the drill holes shortly after heat-shrink sleeve installation.

4.8.2 — Heat-shrink tapes

Heat shrink tapes shall have the properties described under Section 4.8.1 and must provide sufficient adhesion to withstand storage and handling as well as grouting pressures.

4.8.3 — Petrolatum (wax) tapes

Petrolatum tapes consist of a stable composition of petrolatum compound (wax) with inert fillers carried by a synthetic fabric.

C4.8.3 — Petrolatum (wax) tapes

Petrolatum tapes mold to irregular shapes, are nonhardening, and are highly resistant to mineral acids, alkalis, salts, and organic soils. They also form a solid water barrier.

4.8.4 — Adhesive tapes

Tapes shall have elastic properties, be self-adhesive and moisture-proof, and shall have a minimum width of 50 mm (2 in.). Additionally, the tape, including adhesive, shall be nonreactive with the sheath or encapsulation, coating, prestressing steel, or grout.

Duct tape shall not be considered corrosion protection.

C4.8.4 — Adhesive tapes

Tapes are generally used for small sheathing repairs and as a seal for plastic component connections, which are a part of the corrosion protection system. A PTI Research Update (http://www.post-tensioning.org/Uploads/Research Update - Tape Qualifications.pdf) includes results of tape qualifcation testing. Tapes conforming to these requirements perform well provided they are applied properly.

4.9 — Grout tubes

Grout tubes shall have an inside diameter adequate to enable the grout to be pumped readily and without blockage to the bottom of the drill hole. They shall be able to withstand the expected grout pressure. Post-grout tubes shall be strong enough to withstand the post-grouting pressure.

C4.9 — Grout tubes

Grout tubes are normally made from polyethylene and usually have a minimum inside diameter of 13 mm (0.5 in.), although smaller diameters are possible to fill the insides of encapsulations or trumpets and anchorage covers. For most anchors, a 1 MPa (150 psi) pressure is suitable. In some instances, higher pressure ratings may be required.

Post-grouting pressures can reach up to 8 MPa (1200 psi).

4.10 — Grout socks

Grout socks shall be made from a woven synthetic fabric resistant to tears and handling damage.

The geotextile apparent opening size (ASTM D4751) shall be such that they will allow water to filter out of the grout but prevent significant amounts of cement particles to pass.

C4.10 — Grout socks

Geotextiles made of long-chain synthetic polymers composed at least 95% by mass of polyolefin or polyesters are commonly used.

Grout socks may be used for the bond length only, or over the entire length of the anchor, provided that a bond breaker is used in the free stressing length.

RECOMMENDATIONS

4.11 — Cement grout

Cement grout is the most commonly used grout for anchors.

The ingredients for cement grout may include:

- Portland cement
- Water
- Aggregates
- Admixtures
- Supplemental cementitious materials

Prepackaged cement grouts shall conform to the requirements of PTI M55.1.

4.11.1 — Cement

Cement shall be Type I, II, III, or V portland cement conforming to ASTM C150.

4.11.2 — Water

Water used in grout shall be potable (suitable for public consumption), clean, and free of injurious quantities of substances known to be harmful to portland cement or prestressing steel. In areas where potable water is not readily available, local water may be used provided the water is tested to ensure that it is not detrimental to the prestressing steel or grout.

4.11.3 — Aggregates

Aggregates, if used, shall meet all the requirements of ASTM C33 except for gradation. Aggregates shall not be used inside of the encapsulation.

4.11.4 — Admixtures

Admixtures shall be in accordance with ASTM C494/C494M and PTI M55.1 and can be used to modify rheology, improve stability, and vary hydration rates in fluid grouts, and increase strength and durability in set grouts. Their use shall be subject to the approval of the Engineer, based on successful prior use, specific tests, or both.

COMMENTARY

C4.11 — Cement grout

Polyester resin has been used in certain applications for prestressed rock anchors (refer to Supplement B).

Cement grout is typically batched in the field.

Cement grout may incorporate fine or coarse aggregate depending on the geological and construction conditions. The grout may also include admixtures or supplemental cementitious materials designed to modify fluid and set properties to satisfy project-specific goals.

Prepackaged grouts are sometimes used for special applications.

C4.11.1 — Cement

Blended cements (to ASTM C595) are typically neither necessary nor used for anchors, nor are oil well cements.

C4.11.2 — Water

Refer to Section 6.11.

C4.11.3 — Aggregates

Historically, aggregates have been used only for drill hole pregrouting and for grouts in large-diameter anchors formed by augering.

The shape of the sand particles and their gradation strongly influence the rheology of the grout and therefore its pumpability and homogeneity.

C4.11.4 — Admixtures

Admixtures are not routinely needed, but may prove beneficial or even essential in certain circumstances, such as pregrouting.

RECOMMENDATIONS

All admixtures shall be compatible with the cement, and other admixtures, if used, and shall not cause any short- or long-term damage to the grout or any tendon component. Admixtures shall be used in strict conformance with the manufacturer's recommendations.

Expansive admixtures may be used in grouts that fill sealed encapsulations, trumpets, anchor covers, or in some applications for secondary grouting and inside a sheath. Expansive admixtures in the bond length shall not be used. For inert gas-forming materials, the level of vertical height change shall be no greater than 2% up to 3 hours (ASTM C940).

Calcium chloride or admixtures containing chloride from sources other than impurities in admixture ingredients shall not be permitted.

4.11.5 — Supplemental cementitious materials

The following materials shall be permitted to be used in grout:

- Fly ash (Class C and Class F) conforming to ASTM C618;
- Slag cement (Grade 120) conforming to ASTM C989/C989M; and
- Silica fume conforming to ASTM C1240.

COMMENTARY

In any multi-component grout mixture formulation, all admixtures should be supplied by the same manufacturer to avoid potential problems with chemical incompatibility between the components. Alternatively, their compatibility should be demonstrated during a test program.

Expansive admixtures are only effective when used in a confined space—that is, a sealed encapsulation or trumpets, but are not necessary to achieve bond capacity. Expansive admixtures achieve expansion by the generation of gas. In an open anchor drill hole, the expansion occurs upwards and the resulting grout and corrosion protection may actually be weakened.

Chlorides cause corrosion of prestressing steel.

C4.11.5 — Supplemental cementitious materials

Potential benefits of these materials when used in grout include increased long-term strength, decreased permeability, and reduced bleeding. However, compatibility with the other grout components should be evaluated or tested prior to use.

RECOMMENDATIONS

5.0 — CORROSION PROTECTION

5.1 — Design aspects

The corrosion protection systems shall be designed and constructed to provide reliable and acceptable anchors for temporary and permanent structures. Corrosion protection systems are divided into two classes of protection as described in Section 5.3. Selection of the corrosion protection class shall be based on the service life of the structure and the aggressivity of the environment. The class of corrosion protection system for a project shall be selected using the principles outlined in Fig. 5.1.

The level of corrosion protection required for prestressed rock and soil anchors shall be specified in contract documents or shall be determined by the Engineer.

COMMENTARY

C5.0 — CORROSION PROTECTION

C5.1 — Design aspects

Permanent anchors have been installed routinely in North America since the mid-1960s. They continue to perform well in a variety of environments, applications, and ground conditions.

In addition to service life and aggressivity, the Engineer may also consider such factors as consequences of failure (loss of life or serious economic impact) and costs (due to change in hole size or installation method). Based on these considerations, the Engineer may specify a higher level of corrosion protection than indicated by the decision tree.

Temporary anchors normally do not require corrosion protection.

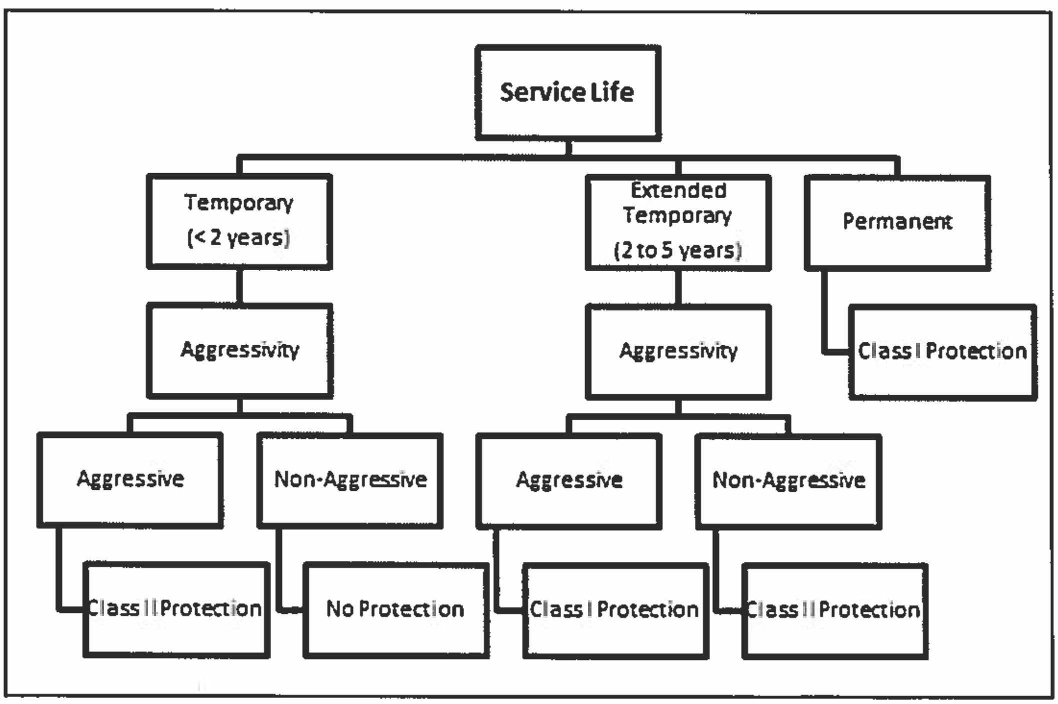

Fig. 5.1—Corrosion protection decision tree.

RECOMMENDATIONS

5.2 — Corrosion protection selection criteria

5.2.1 — Service life

Service life is used to distinguish between temporary, extended temporary, and permanent anchors (refer to Fig. 5.1).

5.2.2 — Aggressivity of anchor environment

Test/field observations shall be used to classify the aggressivity of the anchor environment.

Ground shall be considered aggressive if it has one or more of the following:

- A pH value less than 4.5;
- A resistivity less than 2000 ohm-cm;
- Any sulfides present;
- Stray currents present; or
- Has caused chemical attack to other buried concrete structures.

In addition, aggressive atmospheric conditions need to be considered.

For temporary and extended temporary ground anchors, aggressive conditions shall be assumed if the aggressivity of the ground has not been quantified by testing. The environment shall be considered aggressive if one or more of the following conditions exist:

1. Salt water or tidal marshes
2. Cinder, ash, or slag fills
3. Organic fills containing humic acid
4. Peat bogs
5. Acid mine or industrial waste.

The ground is considered aggressive to Type I portland cement if the water-soluble sulfate (SO_4) content of the soil exceeds 0.10% by weight.

Type II portland cement shall be used if the sulfate content is between 0.1 and 0.2% and Type V cement shall be used if the sulfate content exceeds 0.2% or if nearby concrete structures have experienced sulfate attack.

COMMENTARY

C5.2 — Corrosion protection selection criteria

C5.2.2 — Aggressivity of anchor environment

Aggressivity of the ground is influenced by:

1. Resistivity of the soil;
2. pH value of the soil;
3. Chemical composition of the groundwater and the soil or rock;
4. Water and air permeability of the ground;
5. Groundwater elevation (stable or fluctuating); and
6. External electrochemical and physical factors (long-line and stray-current corrosion systems).

If sulfates are present, they could attack portland cement grout. Sulfate attack on cement grout is assumed to be the same as for concrete.

There have been no recorded anchor failures resulting from chemical attack on portland cement grout.

Regional practices for the cement type used in buried concrete structures should provide guidance on cement type for anchors.

RECOMMENDATIONS

The site investigation shall identify nearby buried concrete structures that have suffered corrosive or chemical attack.

5.2.2.1 — Soil resistivity

Electrical resistivity of the soil shall be determined on representative soil samples using the soil box method described in ASTM G57 or by AASHTO Test Procedure T 288. The resistivity shall be determined for the soil at the natural moisture content, and when it is saturated with distilled water. The lowest resistivity shall be used when determining the anchor corrosion protection requirements.

5.2.2.2 — pH

Hydrogen ion concentration (pH) of the soil shall be measured using the method described in Reference 7 or according to AASHTO T 289.

For rock anchors, the pH value of the groundwater in the tendon bond length shall be measured.

5.2.2.3 — Chemical properties of soil and groundwater

The presence of sulfides shall be determined by a field test using the method described by AWWA C105.

A laboratory test, according to AASHTO T 290, shall be required to determine the soluble sulfate content.

COMMENTARY

C5.2.2.1 — Soil resistivity

Resistivity testing is the simplest method of evaluating soil aggressivity. Tests are made on samples immediately after removal from the field-sampling device, or in the laboratory on samples, which were sealed in airtight containers for shipment and storage. The samples should be taken from the different strata along the tendon bond length. Boring and recovery techniques should prevent sample contamination from wash boring water.

C5.2.2.2 — pH

Reference 7 describes a method of determining the approximate pH of soils in the field. This method measures the potential difference between an antimony electrode and a copper sulfate reference electrode both in contact with the soil sample. This test is performed on fresh soil samples as soon as they are recovered.

AASHTO T 289 describes a lab test for determining the pH of a soil sample. This test can be used for soils whose pH will not change if the sample is exposed to the atmosphere or allowed to dry. Coarse-grained soils may damage the pH meter.

This pH measurement is of the groundwater, not the water used to drill the hole or the water in the hole after drilling.

C5.2.2.3 — Chemical properties of soil and groundwater

AWWA C105 describes a sodium azide-iodine qualitative test used to detect sulfides. Hydrogen sulfide gas is evolved when a 3% sodium azide in a 0.1 N (normal) iodine solution is added to a soil containing sulfides. A rotten egg smell or effervescence indicates the presence of sulfides.

AASHTO T 290 describes a lab test to determine the soluble sulfate ion content. Soil samples uncontaminated by wash water should be recovered and placed in sealed containers for storage and shipment to the laboratory.

RECOMMENDATIONS

COMMENTARY

5.2.2.4 — Physical properties of soil and groundwater

The soil shall be completely described in accordance with the "Unified Soil Classification System" in ASTM D2487. The groundwater level shall be measured and fluctuations in the level shall be recorded.

C5.2.2.4 — Physical properties of soil and groundwater

The geotechnical report should indicate whether the soil is a natural deposit or a fill, the location of nearby mining operations, and the proximity of the site to chemical plants or chemical storage areas.

5.2.2.5 — Potential stray current sources

Existing impressed current and sacrificial anode cathodic protection systems in the vicinity of the anchors shall be identified. Potential sources of stray direct currents shall also be noted. (Refer to Section 5.4.5)

C5.2.2.5 — Potential stray current sources

Direct current electrical transmission lines, electric power generating stations, railways, welding operations, mine transportation equipment, and grounded industrial equipment are potential sources of stray direct current.

5.3 — Corrosion protection requirements

C5.3 — Corrosion protection requirements

The principles of protection are the same for bar or strand tendons, but the details may vary. The corrosion protection must be compatible with the tendon, drilling method, tendon insertion method, and grouting methods selected.

There are two classes of corrosion protection:

Class I protection — A Class I protection system encases the prestressing steel inside a plastic sheath filled with either grout or corrosion-inhibiting compound.

This is the most common type of Class I protection. A Class I protected tendon is often referred to as an encapsulated tendon or a double corrosion-protected tendon. Refer to Fig. 5.2a through c.

Class I protection is also provided by epoxy-coated strand tendons grouted into drill holes that successfully pass the water pressure test in Section 7.5.

Class II protection — A Class II protection system encases the prestressing steel along the free stressing length inside a plastic sheath filled with either grout or corrosion-inhibiting compound and relies on the cement grout to protect the prestressing steel along the tendon bond length.

This is the most common type of Class II protection. A Class II protected tendon is often referred to as a grout-protected tendon or a single corrosion-protected tendon. Refer to Fig. 5.3a and b.

Class II protection is also provided by the following:

- Fully or partially bonded tendons with grout encasement in sound rock or concrete along the bonded portion of the free stressing length; and
- Fully or partially bonded bar tendons with polyester resin encasement in sound rock or concrete along the bonded portion of the free stressing length.

RECOMMENDATIONS

Both Class I and Class II protection shall include an anchor head cover (if exposed) and a trumpet.

Epoxy coating on bar tendons provides enhanced corrosion protection but does not qualify alone as Class I or II protection. If epoxy coating is used, all damaged areas must be patched.

Table 5.1 outlines the requirements for each class of protection. Figures 5.2a, 5.2b, 5.2c, 5.3a, and 5.3b show the essential components of each class of protection. Figure 5.4 shows an anchor with no corrosion protection.

COMMENTARY

Aggressive conditions are assumed to exist near the anchorage; therefore, all corrosion-protected tendons include these items.

Epoxy coating may provide additional protection along the bond length of a Class II protected bar tendon without a significant cost increase. Epoxy applied to bars may have holidays and is not considered to be a Class I protection.

Epoxy coatings for bar and strand are not equivalent. ASTM A775/A775M and A934/A934M are written for epoxy-coated reinforcement bars and do not apply to prestressing steel bars.

On average, the coating thickness required for bars is only one-third of the coating thickness required for strand. Both A775/A775M and A934/A934M allow an average of 3 holidays per m (1 holiday per ft) of bar without requiring patching, while A882/A882M for strand allows only 2 holidays per 30 m (100 ft), and the holidays must be patched. Additionally, the epoxy coating on bars is not as resistant to damage as the epoxy coating on strand.

Table 5.1 — Corrosion protection requirements

Class	Corrosion protection requirements		
	Anchorage	Free stressing length	Tendon bond length
I Encapsulated tendon	• Trumpet • Grout or corrosion-inhibiting compound-filled cover if exposed	• Corrosion-inhibiting compound-filled sheath encased in grout, or • Grout-filled sheath, or • Grout-encased epoxy-coated strand in a successfully water-pressure-tested drill hole	• Grout-filled encapsulation, or • Epoxy-coated strand tendon in a successfully water-pressure-tested drill hole.
II Grout-protected tendon	• Trumpet • Grout or corrosion-inhibiting compound-filled cover if exposed	• Corrosion-inhibiting compound-filled sheath encased in grout, or • Grout-filled sheath, or • Grout-encased fully or partially bonded tendon in sound rock or concrete, or • Polyester resin-encased fully or partially bonded bar tendon in sound rock or concrete (refer to Supplement B, Section SB1.5 For polyester resin).	• Grout encasement, or • Polyester resin-encased bar tendon in sound rock (refer to Supplement B, Section SB1.5)

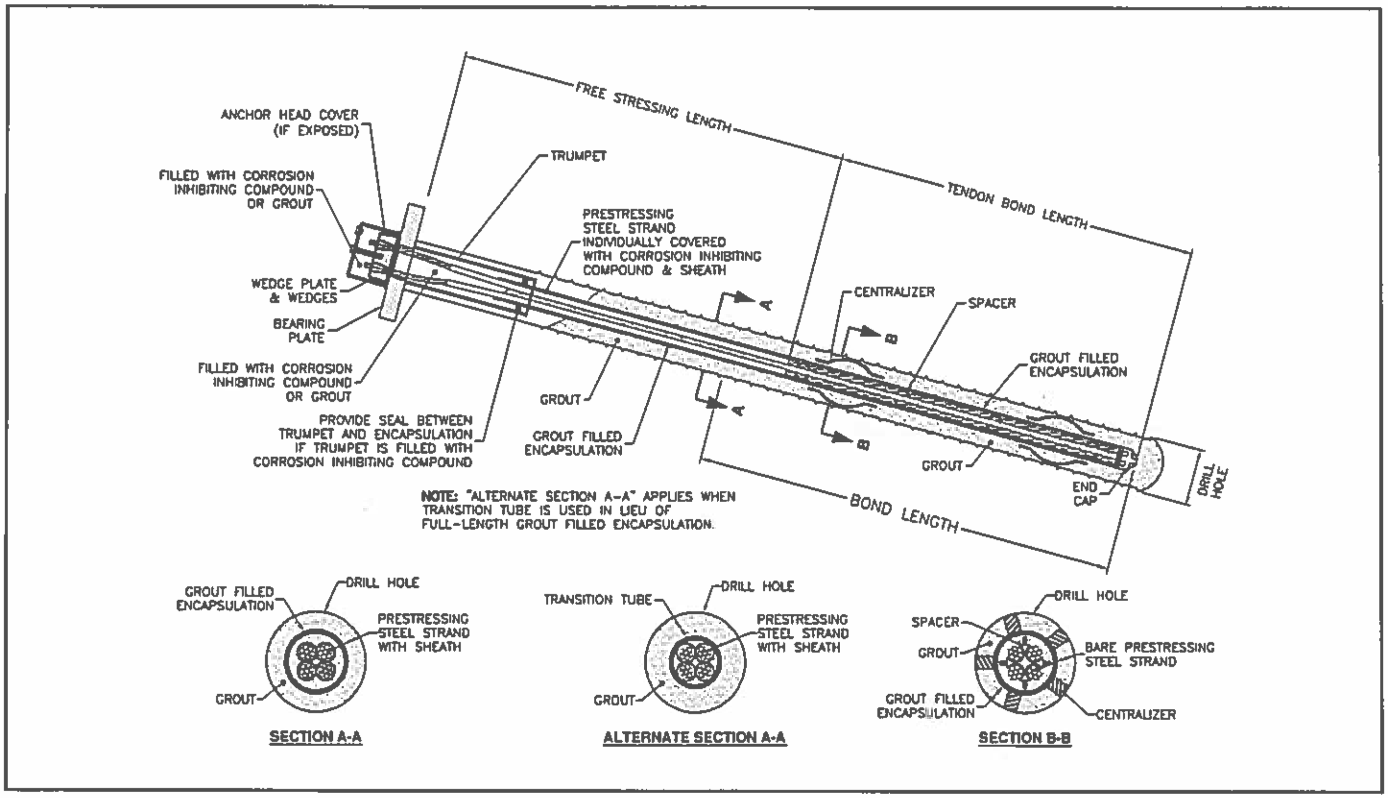

Fig. 5.2a—Class I protection: encapsulated strand anchor.

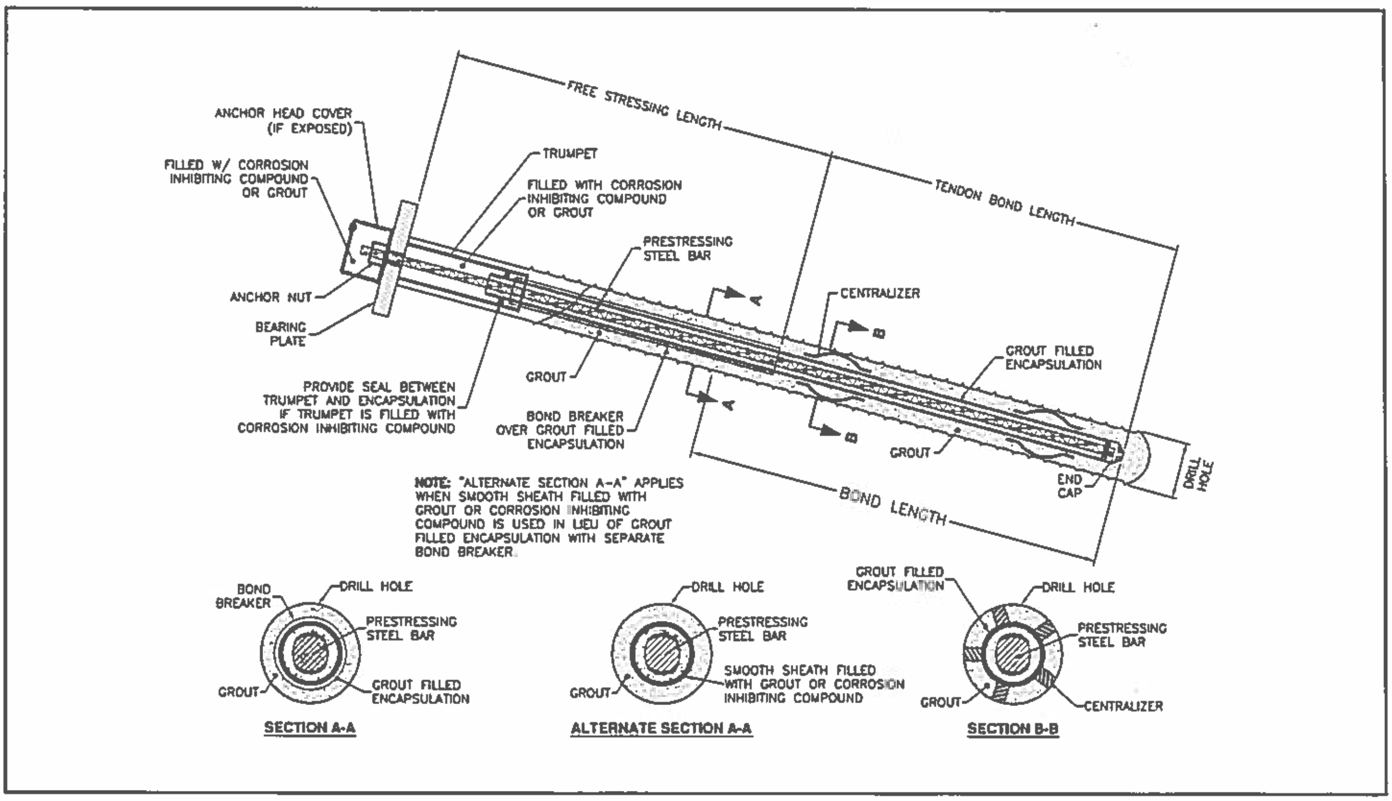

Fig. 5.2b—Class I protection: encapsulated bar anchor.

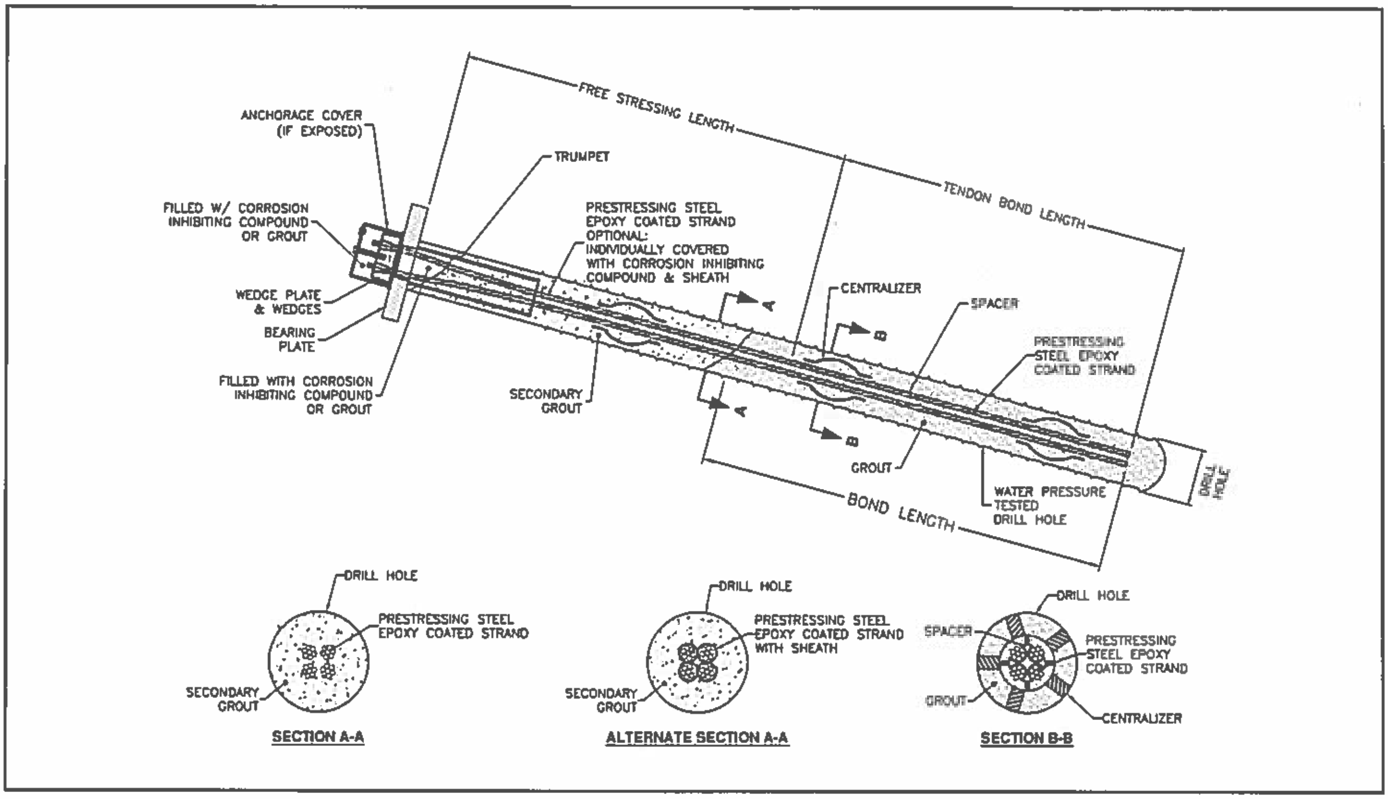

Fig. 5.2c—Class I protection: epoxy-coated strand anchor.

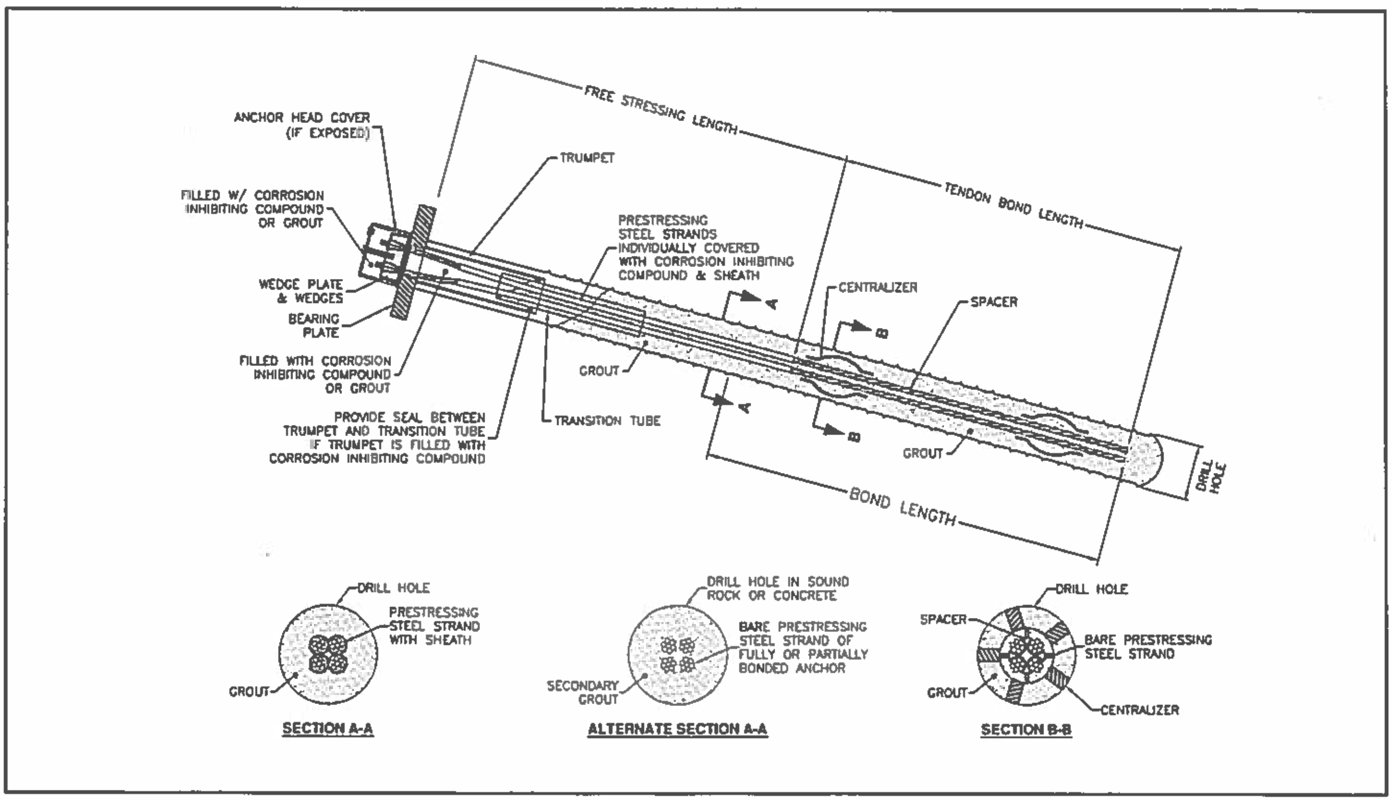

Fig. 5.3a—Class II protection: strand anchor.

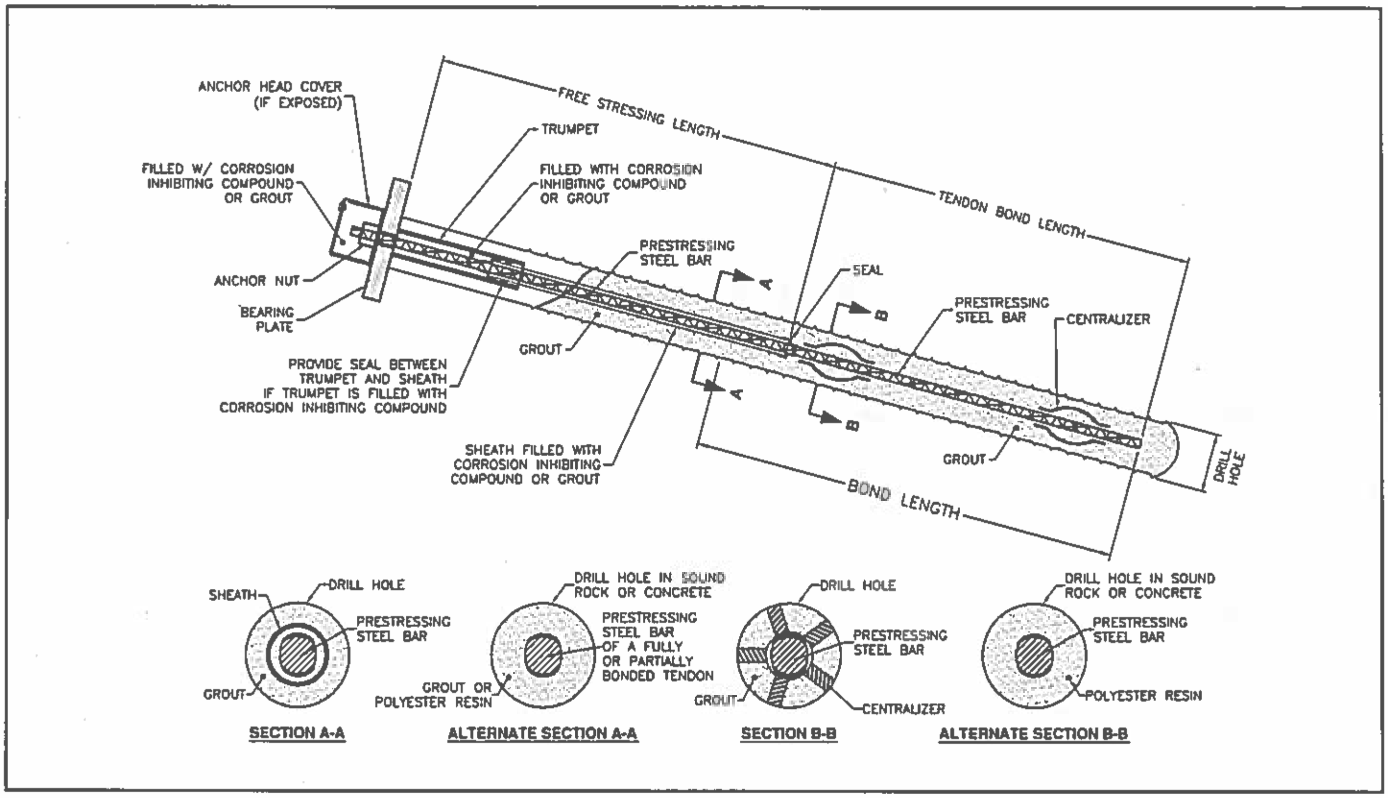

Fig. 5.3b—Class II protection: bar anchor. Optional: epoxy coating for enhanced protection.

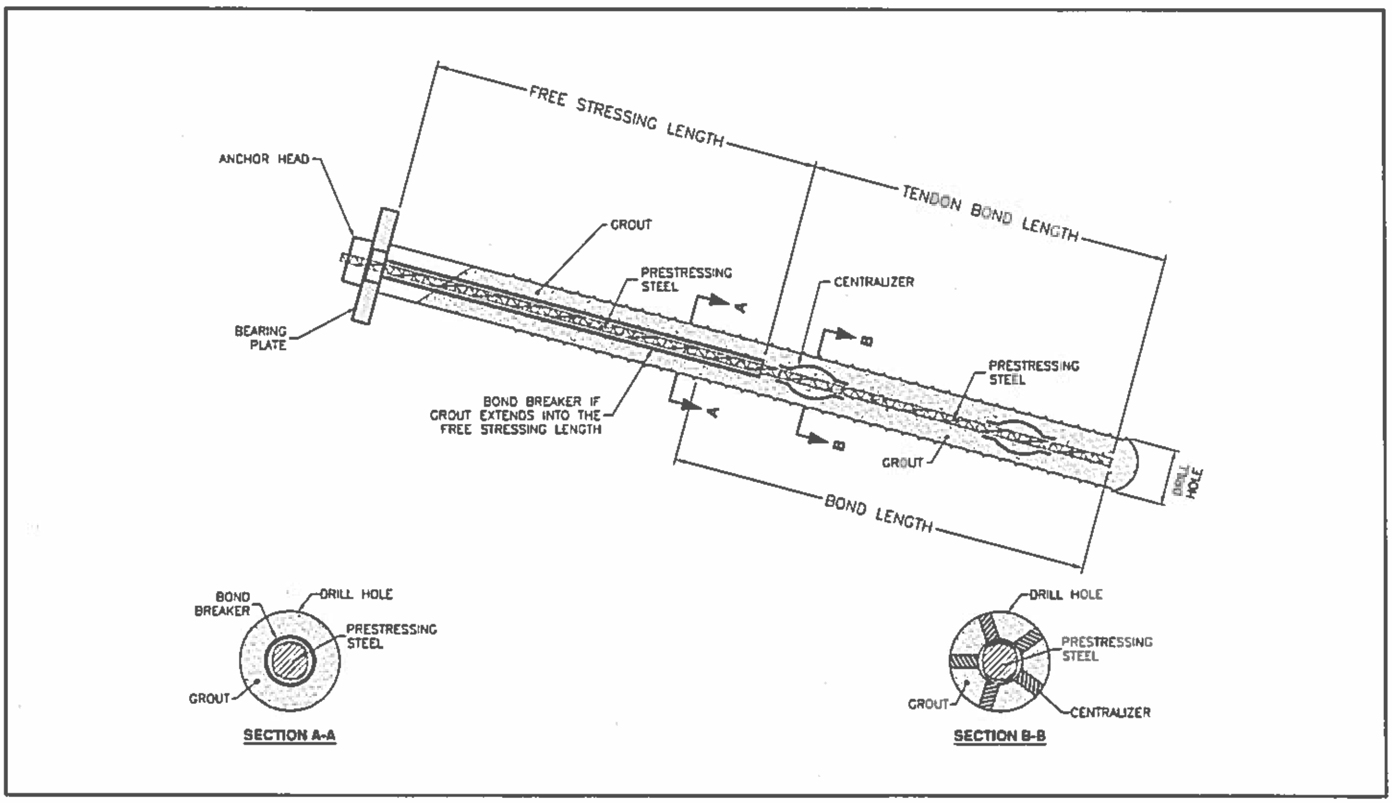

Fig. 5.4—"No" protection anchor.

RECOMMENDATIONS

5.4 — Corrosion protection details

Sacrificial metal coatings shall not be applied to the prestressing steel, but may be used for protecting bearing plates, trumpets, or anchorage covers.

5.4.1 — Anchorage protection

The corrosion protection of the prestressing steel within the anchorage shall be carefully designed and constructed.

5.4.1.1 — Anchor heads

Anchor heads shall be encased by at least 50 mm (2 in.) of concrete cover or shall be protected with a corrosion-inhibiting compound-filled or grout-filled cover. For non-restressable anchorages, grout shall be used. For restressable anchorages, a corrosion-inhibiting compound must be used. A watertight compression seal between the bearing plate and cover is required for corrosion-inhibiting compound-filled covers.

5.4.1.2 — Bearing plates and anchor head covers

Bearing plates and steel covers for exposed anchorages shall be galvanized or coated with a durable UV-resistant coating. Anchor head covers shall have at least the same design life as the rest of the tendon.

COMMENTARY

C5.4 — Corrosion protection details

Galvanizing reduces the strength of the prestressing steel and may cause hydrogen embrittlement, especially during the liquid phase of the grout. Zinc also dissolves easily in highly acidic or highly alkaline environments.

Impressed current or sacrificial anode cathodic protection methods are also not recommended for protecting prestressing steel because of concerns for hydrogen embrittlement and lack of long-term reliability.

C5.4.1 — Anchorage protection

Of the few anchor corrosion failures known most have occurred on unprotected tendons near the anchorage.[4] It is important to properly detail this region under the anchorage. Poor-quality grout will allow aggressive elements to attack the prestressing steel. Poorly designed or installed trumpets, covers, and seals will allow corrosion-inhibiting compounds to leak out, leaving the prestressing steel unprotected.

C5.4.1.1 — Anchor heads

Cement grout is required for non-restressable anchorages because it provides reliable corrosion protection that does not rely on containment seals to hold it in place for the life of the anchor.

Corrosion-inhibiting waxes have been developed for filling anchorage covers and trumpets of restressable anchorages. These waxes are stable and semi-solid at normal temperatures. All waxes require heating to be placed. As of 2014, PTI has not developed specifications for corrosion-inhibiting waxes and gels. Field trials need to be conducted to demonstrate the suitability of a specific product.

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5.4.1.3 — Trumpets

The trumpet shall:

1. Be continuously welded all around to the bearing plate to provide a watertight joint;
2. Overlap the free stressing length corrosion protection by at least 100 mm (4 in.) when a permanent seal is provided and 300 mm (12 in.) when a seal is not provided; and
3. Be long enough to accommodate installation tolerances and movements of the structure and the tendon during testing and stressing.

Trumpets used with strand tendons shall be long enough to enable the tendon to make a transition from the diameter of the tendon along the free stressing length to the diameter of the tendon at the wedge plate without damaging the encapsulation or the trumpet.

The outside of steel trumpets shall be protected from corrosion. A minimum 50 mm (2 in.) grout or concrete encasement, galvanizing, coal tar epoxy, or fusion bonded epoxy coating is a suitable means of protection.

The trumpet shall be completely filled with a corrosion-inhibiting compound or grout. For non-restressable anchorages, grout shall be used. For restressable anchorages, a corrosion-inhibiting compound shall be used. Compounds may be placed any time during construction. Grout must be placed after the anchor has been tested and stressed to the lock-off load.

Trumpets filled with a corrosion-inhibiting compound shall have a permanent seal between the trumpet and the free stressing length corrosion protection.

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C5.4.1.3 — Trumpets

The trumpet provides the continuity between the anchorage corrosion protection and the free stressing length corrosion protection.

Cold joints within the 300 mm (12 in.) overlap should be avoided. This is especially important in flat inclined or horizontal anchors where the grout surface level intersects a substantial length of the trumpet.

Coal tar epoxy and fusion-bonded epoxy coatings can be used when the trumpet is not exposed to sunlight.

This prevents load from being transferred from the trumpet to the grout body; it also prevents bleed water or laitance from the initial grouting from accumulating within the trumpet.

Experience indicates that it is very difficult to install an effective seal in the field. When a corrosion-inhibiting compound-filled trumpet is used, care must be taken to ensure that an effective seal has been installed at each trumpet.

In some locations, such as within the transition tube or encapsulation, there may be contact between the corrosion-inhibiting compound and grout. If grease is used, then degradation and loss of volume of the grease can occur as oil within the grease is absorbed by the grout. Periodic

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inspection to assess the volume and condition of the grease may be warranted.

5.4.2 — Free stressing length protection

5.4.2.1 — Permanently unbonded free stressing length

The permanently unbonded free stressing length of an unbonded anchor shall be protected by a corrosion-inhibiting compound or grout-filled sheath. The corrosion-inhibiting compound shall completely coat the prestressing steel, fill the void between it and the sheath, and fill the interstices between the wires of seven-wire strands (refer to Section 7.2). Provisions shall be made to retain the compound within the sheath.

The corrosion protective sheath surrounding the free stressing length of the tendon shall extend into the trumpet per Section 5.4.1.3, but shall not come into contact with the wedges in the wedge plate during testing or stressing.

For full-length, pregrouted encapsulations on bar tendons, a separate bond breaker shall be provided to prevent the tendon from bonding to the grout surrounding the free stressing length.

The free stressing length is not pregrouted on strand tendons. The strand is protected by the corrosion-inhibiting compound-filled sheath and grout, or a grout-filled sheath surrounding the inhibitor-filled sheath. A 1.5 to 3 m (5 to 10 ft) long, grout-filled transition tube shall be used when a separate grout-filled sheath is not used. The grout is placed inside the sheath or transition tube after the tendon is installed in the drill hole.

5.4.2.2 — Fully or partially bonded free stressing length

For Class I protection, the bonded portion of the free stressing length shall be protected by a grout-filled encapsulation or by using epoxy-coated strand.

For Class II protection, the bonded portion of the free stressing length shall be protected by cement grout or polyester resin. The cement grout or polyester

C5.4.2 — Free stressing length protection

C5.4.2.1 — Permanently unbonded free stressing length

The permanently unbonded free stressing length of an unbonded permanent anchor is assumed to be in aggressive ground. Reference 4 indicates that aggressive conditions often exist immediately under the anchorage.

Special precautions should be taken when wax is used instead of grease or gel to fill the void between prestressing steel and sheath when single-stage grouting is used without a separate bond breaker. The shear strength of wax is much greater than that of grease or gel and prevents the free stressing length from elongating freely. Refer to Section 8.3.

Pregrouted encapsulations are common for bar tendons.

Most Class I protected anchors have encapsulation extending into the trumpet. Therefore, transition tubes are not required.

The transition tube ensures the tendon is encased in grout above the top of the grout and below the trumpet, and enables an effective seal to be made between the tendon and the trumpet.

C5.4.2.2 — Fully or partially bonded free stressing length

A redundant anchorage is provided by fully or partially bonding the tendon to the supported rock or concrete after testing and stressing.

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resin shall only be used in sound rock or concrete and must completely encapsulate the prestressing steel. Polyester resin shall only be used with bar tendons (Refer to Supplement B for polyester resin).

5.4.3 — Free stressing length/bond length transition protection

The transition between the corrosion protection for the bond length and the free stressing length shall be designed and fabricated to ensure continuous corrosion protection of the prestressing steel.

5.4.4 — Tendon bond length protection

5.4.4.1 — Class I protection

The tendon bond length shall be protected by either a grout-filled encapsulation or by an epoxy coating on strand tendons installed in a successfully water-pressure-tested drill hole.

Grout-filled encapsulations provide a layer of corrosion protection in addition to the grout over the tendon bond length in aggressive ground or where the aggressivity of the ground is unknown. The prestressing steel can be grouted inside the encapsulation before or after the tendon is inserted into the drill hole. The encapsulation can be grouted inside the drill hole before or after the prestressing steel is inserted into the encapsulation. Encapsulation shall be designed to be watertight over its full length, including any joints and end caps. Centralizers or grouting techniques shall ensure a minimum of 13 mm (0.5 in.) of grout cover over the encapsulation (refer to Section 4.5).

Epoxy-coated strand provides a layer of corrosion protection in addition to the grout when installed in drill holes that have successfully passed the water pressure test. The drill holes shall pass the test either initially or as a result of pregrouting operations.

COMMENTARY

C5.4.3 — Free stressing length/bond length transition protection

Protection along the tendon bond length may differ from the protection applied to the free stressing length.

The cold joint between the two grouting stages of fully bonded tendons may increase the risk of corrosion in this area. Bleed or dilution may cause poor-quality grout to exist at the top of the first grout stage. Partially bonded tendons use a sheath with a corrosion-inhibiting compound at the cold joint to provide additional corrosion protection.

C5.4.4 — Tendon bond length protection

C5.4.4.1 — Class I protection

Care must be taken during fabrication and installation not to compromise the integrity of the encapsulation.

Prepackaged grouts satisfying the requirements of PTI M55.1 or neat cement grout with expansive admixtures may be used to fill pregrouted encapsulations. The encapsulation shall be sealed to retain expanding grout if an expansive admixture is used.

Pregrouted encapsulations over the bond lengths are common for relatively short, low-capacity multi-strand tendons.

Installing encapsulations for long, high-capacity anchors is difficult and requires great care and special measures to prevent damage during insertion and to prevent rupture or collapse during grouting.

Epoxy-coated strand tendons are most often used in lieu of encapsulated tendons for long, high-capacity anchors because the encapsulation requires a larger drill hole size and may be damaged during installation or grouting.

The integrity of the epoxy coating on the installed strand cannot be verified, while it is possible to check an installed encapsulation for leakage prior to final grouting.

RECOMMENDATIONS

When a corrosion-inhibiting compound-filled sheath is used in the free stressing length, only the bond length needs to be successfully water pressure tested.

Care must be taken in fabricating, handling, and installing epoxy-coated strand. Coating damage observed in the field must be promptly repaired using manufacturer's recommended materials and procedures (refer to Supplement A for additional requirements to these Recommendations).

5.4.4.2 — Class II protection

The tendon bond length shall be protected by either cement grout or polyester resin.

Cement grout can be used to protect the tendon bond length when the installation methods ensure that the grout will completely encapsulate the prestressing steel. The grout shall overlap the free stressing length sheath by at least 0.3 m (1 ft). Centralizers or grouting techniques shall ensure a minimum of 13 mm (0.5 in.) of grout cover over the tendon bond length (refer to Section 4.5).

Polyester resin can be used to protect the tendon bond length when bar tendons are installed in sound rock or concrete (refer to Section 9.5).

5.4.5 — Protection against stray currents

When direct stray currents have been determined to be present, the prestressing steel shall be electrically isolated from the ground. A plastic sheath over the free stressing length and the bond length, with all joints sealed by heat-shrink sleeves, may electrically isolate the prestressing steel from the ground and interrupt stray current corrosion cells that potentially could attack the prestressing steel. The electric isolation shall be tested after installation of the tendon, but before grouting. Tendons that are not acceptable need to be removed, resealed, reinstalled, and retested.

COMMENTARY

C5.4.4.2 — Class II protection

Pressure-grouting soil anchors, water pressure testing, and pregrouting rock anchor drill holes (refer to Section 7.5) greatly enhance the corrosion protection by ensuring that the prestressing steel will be completely surrounded with grout when it sets.

C5.4.5 — Protection against stray currents

Electrical isolation of the anchorage and trumpet is extremely difficult to achieve. There are currently no known anchor suppliers that regularly and successfully provide electrically isolated systems in North America. Electric isolation results in a significant increase in cost of both anchor material and installation. The sheaths typically used for ground anchors are unlikely to pass electric isolation tests, and the special materials required to pass the test criteria may not be readily available.

Metal elements used during construction of DC-powered rapid-transit systems are often electrically connected to the negative terminal of the substation. Connecting each element and grounding to the negative terminal prevents the stray current system that might attack the prestressing steel.

EN 1537[3] describes a test to check the integrity of the plastic sleeve over the prestressing steel. During testing, the positive pole of the measurement circuit is connected to the anchor and the negative pole is connected to ground.

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In EN 1537,[3] the electric resistance is required to be larger than 0.1 mega-ohm. An undamaged plastic sheath has a resistance of >100 mega-ohm.

Inappropriate test methods may lead to erroneous results. Environmental factors, such as humidity, may also skew results. Present experience with electric isolation testing in the United States is currently limited.

5.4.6 — Coupler protection

Couplers on bar tendons shall be protected with the same level of protection as the joined tendon lengths, including the requirements for grout cover. The protection details will depend on the location of the coupler and the class of protection.

C5.4.6 — Coupler protection

The tendon manufacturer may provide specific details of coupler protection meeting the minimum requirements of this section.

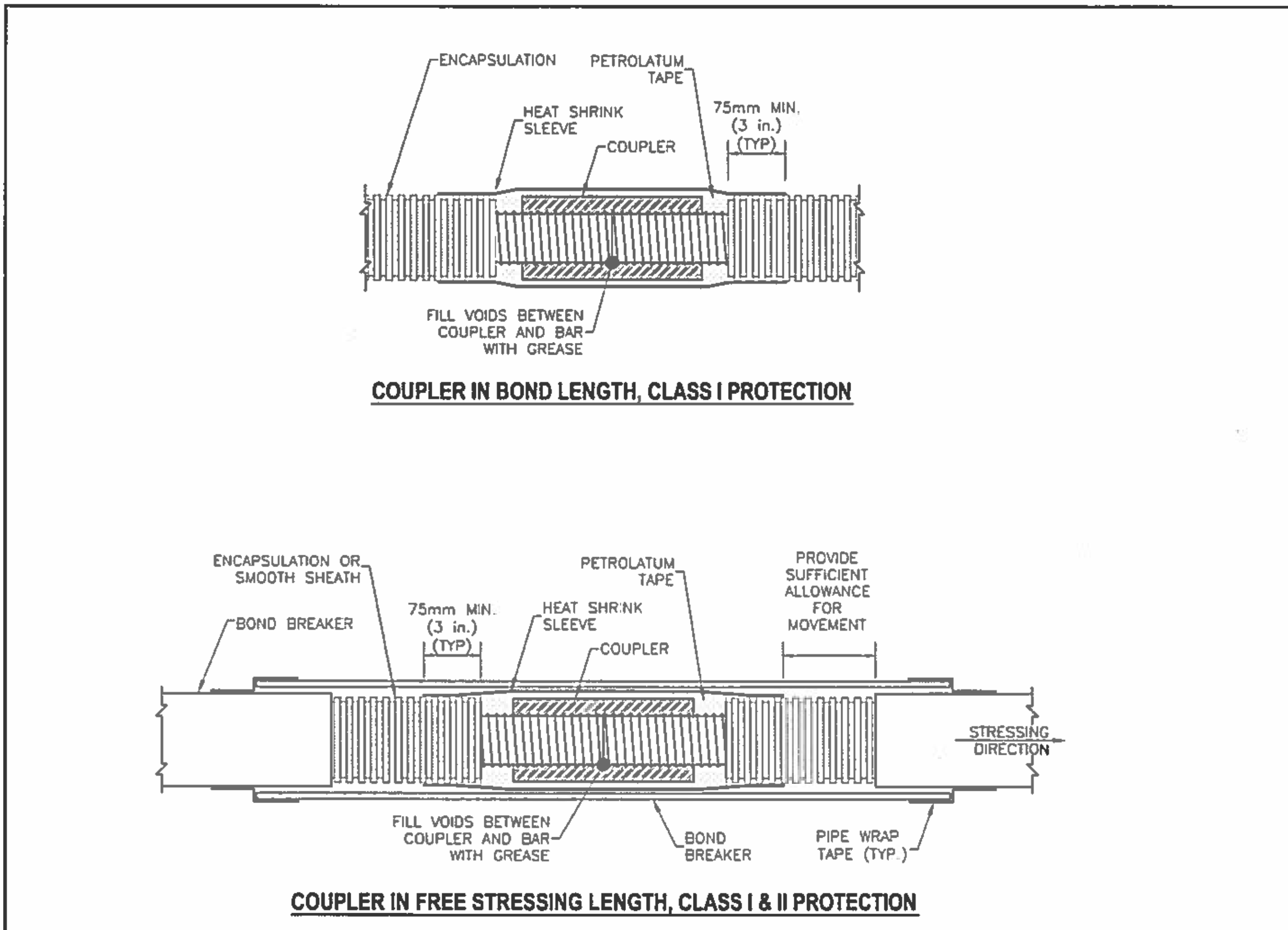

Fig. 5.5—Coupler protection.

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Couplers located in the free stressing length of Class I and Class II protected bar tendons shall be protected by a heat-shrink sleeve over corrosion-inhibiting compound and petrolatum tape (Fig. 5.5). Voids inside the coupler shall be filled with corrosion-inhibiting compound. The coupler and bars shall be wrapped with at least two layers of petrolatum tape and covered with the heat-shrink sleeve. The heat-shrink sleeve shall overlap the free stressing length sheath by at least 75 mm (3 in.). The coupler and corrosion protection shall fit inside a bond breaker that allows the coupler to move during stressing.

Couplers located in the bond length of a Class I protected bar tendon shall be protected by a heat-shrink sleeve over corrosion-inhibiting compound and petrolatum tape (Fig. 5.5). Voids inside the coupler shall be filled with corrosion-inhibiting compound. The coupler and bars shall be wrapped with at least two layers of petrolatum tape and covered with the heat-shrink sleeve. The heat-shrink sleeve shall overlap the encapsulation by at least 75 mm (3 in.).

Couplers located in the bond length of a Class II protected bar tendon or the free stressing length of a fully or partially bonded bar tendon in sound rock or concrete do not need special protection other than the minimum grout cover of 13 mm (0.5 in.), except that they shall be epoxy-coated if the bar is epoxy-coated.

Notes

RECOMMENDATIONS

6.0 — DESIGN

6.1 — Introduction

This section focuses solely on the design of anchors and not on the design of anchored structures. The overall stability of an anchored structure shall be determined by an experienced Engineer. This analysis must consider the system's factor of safety, anchor spacing, minimum free stressing length, and the ability of the anchored structure to withstand the applied anchor loads, group action, soil and rock profile, soil and rock strength, groundwater conditions, the geometry of the structure or site, and the consequences of the failure of a single anchor.

6.2 — Feasibility of anchors

Prior to designing anchors, a determination must be made to determine if anchors are feasible. Consideration shall be given to: underground obstructions, utilities, the aggressivity of the ground and the groundwater, the condition and properties of the rock or soil in the bond length, access to the site, potential damage to the structure being anchored, stray electrical currents, right of way and easement limitations, and effects on adjacent structures during installation.

6.3 — Design objectives

The design objective for anchors shall be to arrive at safe, economical systems that meet the acceptance criteria (Chapter 8) during load testing and that perform satisfactorily throughout the life of the project.

COMMENTARY

C6.0 — DESIGN

C6.1 — Introduction

In most instances, project design may consider either a large number of low-capacity anchors or a smaller number of high-capacity anchors. The final choice should take into consideration the design economics of the overall structure, as well as feasibility.

References 12, 13, 14, and 16 provide additional guidance for the selection and design of anchors.

C6.2 — Feasibility of anchors

The load-carrying capacity of anchors may be relatively low in soils with Standard Penetration Test (SPT) values less than 10 (for non-cohesive soils), or with a liquidity index greater than 0.2 (for cohesive soils).

Anchors located in highly fractured rock or rock containing large voids may require the Contractor to employ special drilling and grouting techniques (Chapter 7).

In situations where settlement may cause bending in the tendon, such as fill that is placed around or above after installation of the anchor, the following details are suggested:

- Use of strand tendon; and
- Installation of the tendon in an empty conduit of sufficient size for expected settlement and sufficient strength for the overburden load (refer to Section 6.4.5).

Location of the bond length of anchors within sanitary landfills or weak organic soils is not recommended.

Consultation with an experienced anchor Contractor can yield useful information on the feasibility of anchors in a case of uncertainty.

C6.3 — Design objectives

A unique aspect of prestressed anchors, compared to other structural elements, is that the load-carrying capacity of each anchor is verified by load testing after installation and prior to being placed in service.

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In the design of anchors, consideration must be given to the specific site conditions, corrosion protection, construction means, methods and materials, and the performance requirements.

Construction means, methods, and materials can have a significant impact on the load-carrying capacity of anchors (refer to Chapter 7).

6.4 — General considerations

6.4.1 — Corrosion protection requirements

Corrosion protection requirements are governed by the service life of the anchors and the aggressivity of the environment. Corrosion protection shall be provided in accordance with Chapter 5.

6.4.2 — Fully bonded, partially bonded, or unbonded anchors

The Engineer shall determine whether the free stressing length of an anchor shall be fully bonded, partially bonded, or unbonded to the surrounding ground or structure.

C6.4 — General considerations

C6.4.1 — Corrosion protection requirements

Temporary anchors generally require less extensive corrosion protection than permanent anchor systems. Permanent anchors often require a larger drill hole diameter as compared to temporary anchors to accommodate added corrosion protection requirements.

C6.4.2 — Fully bonded, partially bonded, or unbonded anchors

Generally, the free stressing length should remain unbonded after stressing, except to satisfy specific structural requirements.

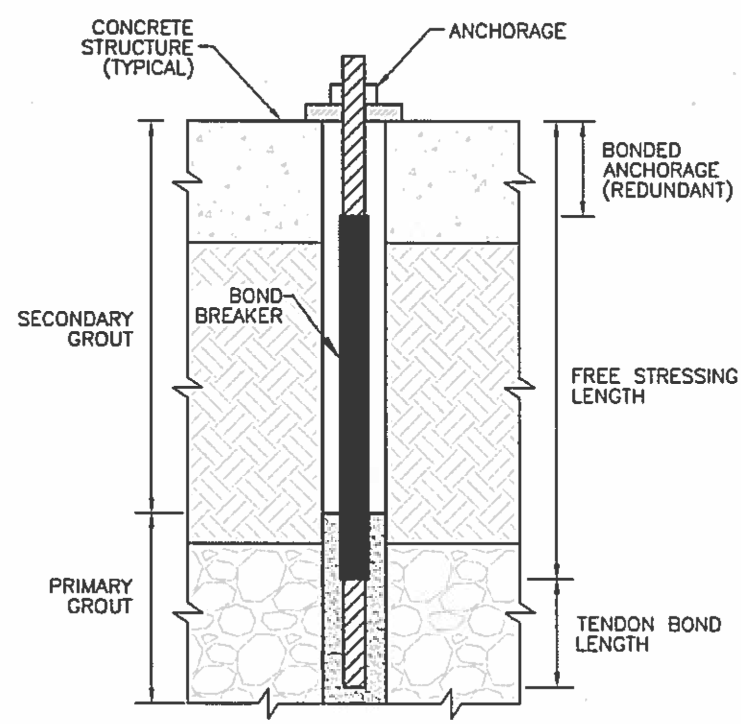

Fig. C6.1—Partially bonded tendon.

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Fully bonded free stressing lengths force the anchor to strain with the structure. Unbonded free stressing lengths allow a more flexible anchor performance, and the averaging of structure strains results in less load change in individual anchors.

Partially bonded free stressing lengths provide redundant load transfer at the anchorage while at the same time leaving a certain amount of unbonded free stressing length (Fig. C6.1).

Typically, fully bonded and partially bonded free stressing lengths are only applicable in massive concrete structures (such as dams and diaphragm wall T-panels).

Fully and partially bonded anchors require that grouting be accomplished in two stages—the first to grout the bond length and the second to grout the free stressing length after the anchor has been stressed and tested.

Partially bonded free stressing lengths can be designed by terminating the bond breaker at some depth below the anchor head and limiting the primary grout to a level below the top of bond breaker. This upper bond length is then bonded to the structure by secondary grout.

When fully or partially bonded tendons are intended for redundancy of the anchor head, the upper bond length must be designed for adequate grout to structure bond and tendon to grout bond.

For tendon-grout bond in the upper bond length, the depth to the top of bond breaker is similar to transfer length in pre-stressed precast concrete, which is presented in ACI 318.

6.4.3 — Restressable anchor systems

For anchors to be restressable, the free stressing length of the anchor must remain unbonded from the surrounding grout. If a restressable system is desired, provisions must be made at the anchor head to allow for restressing.

Wedges shall not be allowed to release and regrip the strand during load adjustments.

C6.4.3 — Restressable anchor systems

Generally, anchor loads should not need to be adjusted during their service life.

Restressable systems may be required when a significant portion of the lock-off load may be lost or gained due to movement of the ground, structure, or both.

Load adjustment of strand anchors is typically accomplished by lifting the anchor head in its entirety and installing or removing shims. An option is to provide a ring nut around the anchor head, which allows the position of the anchor head to be adjusted.

The load in bar tendons is adjusted by applying a load to unseat the anchor nut, turning the nut as required, and then releasing the load back onto the nut.

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6.4.4 — Destressable and removable anchor systems

After an anchor has fulfilled its design intent, special conditions may require its destressing or even removal. Destressing may be accomplished by use of a wedge plate that allows destressing, by unthreading of the nut on a bar tendon, or by the controlled application of heat to the prestressing steel.

6.5 — Site evaluation

Prior to design, a geotechnical site investigation shall be performed. Such studies shall include an evaluation of the site geology and an interpretation of the rock, soil borings, or both.

The geotechnical site investigation shall determine the nature of the block of ground that is influenced by or that influences the installation and behavior of anchors.

Borings shall be located to identify the geologic profile and those strata which control the assessment of

COMMENTARY

C6.4.4 — Destressable and removable anchor systems

Removable anchors may be required where permanent easements cannot be obtained or local regulations apply.

When removal of the anchor is necessary, consideration should be given to remove only the prestressing steel in the free stressing length.

The removal of anchors has traditionally proved difficult and expensive and can be justified only in rare cases. Before selecting removable anchors, the overall impact on the planned construction sequence and details such as floor slab installation and waterproofing of the structure must be considered. Even if designed for, some anchors may resist removal in practice.

Removal of the prestressing steel in the free stressing length may be accomplished by:

- The use of a coupler in bar tendons; or
- Controlled weakening of the strand at the top of the tendon bond length.

Removal of all prestressing steel may be accomplished by:

- Using a sleeved bar tendon with a load-transfer mechanism at the bottom end;
- Drilling to remove prestressing steel;
- Proprietary loops of strands with saddles and short reinforcement. These small steel elements remain in the ground; or
- Proprietary metallic compression elements that connect to unbonded strand and transfer load to the grout body. The metallic elements remain in the ground after removal of the strand.

C6.5 — Site evaluation

Where possible, borings should be located so that the strata profile can be interpolated rather than extrapolated from the borehole information.

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overall stability and the design of the anchors. Borings shall also be located to determine the subsurface conditions within the anchor bond length. The depth of boreholes shall be chosen to allow exploration of the bond length and at least 1.5 m (5 ft) beyond to ensure that a known geologic formation is proved and that no underlying stratum exists which may adversely affect the design.

The soil samples and rock cores shall be preserved and made available for inspection and interpretation by all parties.

Static and artesian water levels shall be measured and recorded.

Easements required for the installation of anchors shall be obtained prior to commencement of the work. Critical structures and utilities shall be located and identified.

6.5.1 — Rock anchors

For rock anchors, core drilling to explore the rock quality is a minimum requirement. Water pressure testing of core holes shall be performed at depths which lie within the planned anchor bond length. The results are used to assess the probable need to pre-grout the anchor drill holes (refer to Section 7.5).

COMMENTARY

C6.5.1 — Rock anchors

Core drilling to recover rock core for anchor design should be performed as part of the geotechnical site investigation. Core drilling of the anchor bond length during anchor installation is typically not performed, as it is time-consuming, reduces grout-rock bond, and can add significant cost to the anchor installation.

The following data are most useful for the design of a rock anchor:

- Classification of mass and material (geometry and characteristics of discontinuities, degree of weathering, index test results, lithology);
- Rock quality designation and recovery percentage;
- Unconfined compressive strength of intact rock and shear strength of weaker rock;
- Unit weight;
- Groundwater level and presence of confined aquifers;
- Permeability; and
- Aggressivity of rock and groundwater.

The following information may also be useful on a site-specific basis:

- Modulus of elasticity of rock mass; and
- Determination of stray currents present.

RECOMMENDATIONS

COMMENTARY

Typical spacing for investigating rock borings is in the range of 30 to 60 m (100 to 200 ft) depending on the uniformity of the ground.

6.5.2 — Soil anchors

As a minimum for soil anchors, standard penetration tests and sampling shall be performed at 1.5 m (5 ft) intervals within each boring and at significant changes in the soil profiles.

C6.5.2 — Soil anchors

The following data are most useful for the design of a soil anchor:

- Boring logs, including standard penetration resistance, cone penetration resistance, or both;
- Depth to groundwater and presence of confined aquifers;
- Classification (gradation, moisture content, Atterberg limits, liquidity index);
- Shear strength and compressibility;
- Unit weight and relative density;
- Permeability;
- Aggressivity of soil and groundwater; and
- Determination of stray currents present.

Typical spacing for the soil borings is in the range of 15 to 30 m (50 to 100 ft).

The geotechnical report should also include an interpretation of the mode of deposition of the soil because this may give an indication of vertical and lateral variability and drilling/grouting conditions.

6.6 — Anchor design load and safety factors

The design load for an anchor is the maximum anticipated load to be resisted by an anchor during its service life. During design of the anchor itself, potential failure mechanisms shall be identified and evaluated.

A separate safety factor shall be chosen for each potential failure mechanism. The factor is defined as the ratio of the ultimate load-holding capacity (or estimated failure load) to the design load. The safety factors shall be chosen considering the accuracy with which the relevant characteristics are known.

C6.6 — Anchor design load and safety factors

The design load is determined by the design Engineer using standard design procedures, which incorporate uncertainty and risk associated with the work. Any factor of safety included in the design loads should be defined so that it is clearly understood and not duplicated. The Engineer should not compound various factors of safety when designing an anchored structure. These recommendations are based on Allowable Stress Design. Load and resistance factors should not be used in combination with the safety factors presented herein.

The smallest safety factor is applied to the prestressing steel, the properties of which are best known and documented Failure is possible:

- Within the ground mass;
- At the ground-grout interface;
- At the grout-prestressing steel interface;
- At the grout-encapsulation interface; or
- Within the prestressing steel.

RECOMMENDATIONS

The safety factor on the prestressing steel at the design load shall not be less than 1.67. Therefore, tendons must be designed so that the design load is not more than 60% F_{pu}. The lock-off load for tendons shall be chosen based on anticipated time- or activity-dependent load changes, but shall not exceed 70% F_{pu}. The maximum test load shall not exceed 80% F_{pu}. For strand tendons, lock-off loads less than 50% F_{pu} require shimming per Section 8.4.

The accuracy with which other failure mechanisms can be quantified varies for each project. The Engineer is required to use judgment in assessing the available information and choosing appropriate safety factors.

For permanent anchors, a minimum safety factor of 2.0 shall be applied to the ground-grout interface.

Strand-grout bond shall be evaluated by strand bond tests for each strand manufacturer.

6.7 — Bond length

Bond length dimensions shall be adequate to transfer the design load from the prestressing steel to the ground for the service life of the anchor. The design of the bond length shall consider the properties of the ground and the anchor installation techniques. The performance of all anchors shall be verified by field testing.

The required bond length shall be estimated from the following equation

$$L_b = \frac{P \cdot FS}{\pi \cdot d \cdot \tau_u}$$

where:

L_b = bond length
P = design load for the anchor
π = 3.14
d = diameter of the drill hole
τ_u = average ultimate bond strength along interface between grout and ground
FS = factor of safety on average ultimate bond strength (refer to Section 6.6)

COMMENTARY

The lock-off load may be higher or lower than the design load. A higher lock-off load can compensate for relaxation of the prestressing steel and creep in the ground. A lower lock-off load may be required in special cases.

For anchors installed in ground susceptible to creep, the safety factor for the grout-ground interface may need to be increased to reduce average working stresses and so keep long-term losses within tolerable limits. Reference 15 provides additional guidance for evaluating creep.

Verification of this safety factor is typically not done. Refer to Section 8.3.1.

Strand from different manufacturers has shown very different bond properties to grout. Strand meeting the Supplementary Requirements of ASTM A416/A416M is expected to have adequate bond capacity.

C6.7 — Bond length

This section does not address overall stability requirements, which may dictate the overall tendon length.

The drill hole diameter depends on the tendon diameter, as well as drilling methods and equipment. Actual bond length dimensions for specific design loads are dependent on installation techniques and are frequently determined by the Contractor.

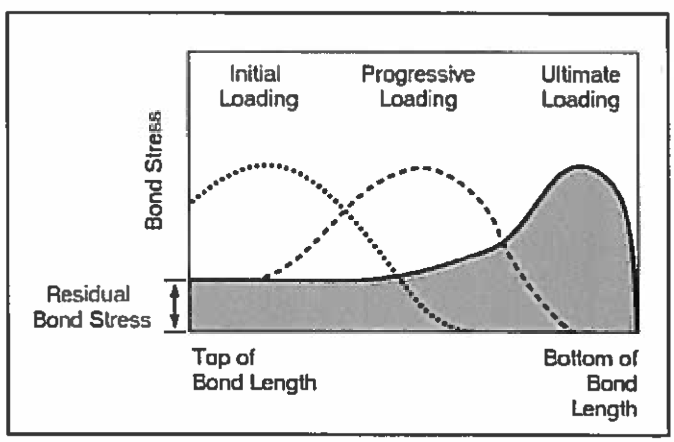

Fig. C6.2—Anchor load transfer concepts.

RECOMMENDATIONS

COMMENTARY

The required bond length is calculated based on average ultimate bond strength. Theoretical and experimental data show that bond stress is not uniformly distributed along the bond length during loading (Fig. C6.2). For anchor bond lengths under tension, the bond stress distribution is concentrated at the top of the bond length. Little or no load reaches the bottom. As additional load is applied to the anchor, the relative displacement at the grout-ground interface may exceed the peak strain of the ground or the ultimate bond strength at the interface. Where this occurs, post-peak bond strength may be mobilized, which is lower than the peak strength of the interface. In some cases, the post-peak bond strength may be significantly lower than the peak bond strength. Increasing the bond length under these conditions is generally inefficient and can result in small increases in anchor capacity for the corresponding increase in bond length.

Efficiency factors for estimating bond length, which consider the nonuniform distribution of bond stress, have been proposed in Reference 1. The bond values given in Tables 6.1, 6.2, and 6.3 already allow for inefficiencies of bond lengths of 6 to 12 m (20 to 40 ft). Reference 15 provides additional guidance for estimating bond strength.

Modifying the way the tendon is bonded to the grout can increase the efficiency of a ground anchor. Improved efficiency will result from:

- Extending the free stressing length of the prestressing steel a sufficient depth into the bond length so that the bond length is partially loaded in compression;
- Installing an end plate on the prestressing steel so that the bond length is loaded in compression; and
- Installing strands with different free stressing lengths within the anchor drill hole to more uniformly distribute load from the tendon to different sections of the bond length.

For anchors where the grout body is in compression, the design should consider whether there is adequate confinement by the ground for compression loading.

Pre-production anchor test programs may be specified to confirm the load-transfer capacity used during design or for Contractor design of the bond length (refer to Section 8.3.1).

For acceptable prestressing steel-grout bond, the minimum tendon bond length shall not be less than:

These minimum lengths have worked successfully provided that lubricants, grease, or soil do not contaminate the steel surface, especially for strand. These minimums may need to be increased for soil anchors.

RECOMMENDATIONS COMMENTARY

Table C6.1 — Typical average ultimate bond strengths—rock/grout

Rock	Average ultimate bond strength—rock/grout, MPa (psi)
Granite and basalt	1.7 to 3.1 (250 to 450)
Dolomite limestone	1.4 to 2.1 (200 to 300)
Soft limestone	1.0 to 1.4 (150 to 200)
Slates and hard shales	0.8 to 1.4 (120 to 200)
Soft shales	0.2 to 0.8 (30 to 120)
Sandstones	0.8 to 1.7 (120 to 250)
Weathered sandstones	0.7 to 0.8 (100 to 120)
Chalk	0.2 to 1.1 (30 to 155)
Weathered marl	0.15 to 0.25 (25 to 35)
Concrete	1.4 to 2.8 (200 to 400)

- 4.5 m (15 ft) for ASTM A416/A416M strand;
- 3.0 m (10 ft) for ASTM A722/A722M Type II bars 44 mm (1.75 in.) diameter or smaller; or
- 4.5 m (15 ft) for ASTM A722/A722M Type II bars larger than 44 mm (1.75 in.) diameter.

These minimum lengths may be reduced if special provisions are provided.

These minimum bond lengths for bars are based on ACI 318 development length requirements of deformed reinforcement in tension, assuming full confinement of the grout, as would be provided by a rock socket.

6.7.1 — Rock anchors

The average ultimate bond strength in rock depends on the following:

1. Strength and modulus of elasticity of the rock;
2. Discontinuities in the rock mass, including spacing, orientation, and width of bedding planes, joints, and fractures;
3. Minerals in the rock, which may lubricate the bond length or reduce the grout strength;
4. Method of drilling and cleaning the drill hole;
5. Drill hole wall roughness;
6. Timing between drilling and grouting in soft rocks;
7. In-place strength of grout;
8. Grouting methods, pressures, and mixture designs; and
9. Bond length.

C6.7.1 — Rock anchors

Table C6.1 provides typical values of ultimate bond strength for anchors in rock. Ultimate bond strength values can also be approximated using a value of 10% of the unconfined compressive strength of the rock, up to a maximum bond strength value of 4.2 MPa (600 psi).

For conventional rock anchors installed in competent rock, the bond stresses are typically concentrated at the top of the bond length. The maximum strain in the tendon bond length occurs at the top of the tendon bond length and may cause local load redistribution within the rock or the displacement of a small cone of rock. When this occurs, the peak stress position moves down the tendon bond length.

Most bond lengths are less than 10 m (35 ft). Bond lengths greater than 10 m (35 ft) become less efficient, unless special provisions are taken to transfer load throughout the bond length.

It is recommended that grouting be done as soon as possible after drilling, especially in rock prone to time-dependent degradation.

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COMMENTARY

For anchors in weak or weathered rock masses, pressure-grouting techniques may be used to enhance grout-rock bond strength values (refer to Sections 7.8.3.2 and 7.8.4). Reference 10 provides additional guidance for evaluating the effects of pressure grouting on bond srength.

6.7.2 — Soil anchors

The average ultimate bond strength in soil depends on the following:

1. Method of drilling, flushing, and cleaning of the drill hole;
2. Soil properties:
   (a) Permeability;
   (b) Density;
   (c) Angle of internal friction;
   (d) Undrained shear strength;
   (e) Degree of consolidation;
   (f) Changes of soil properties within the bond length;
   (g) Grain size distribution;
3. Overburden pressure;
4. Hole diameter;
5. Grouting methods, pressures, and mixture designs;
6. Number of post-grouting cycles; and
7. Tendon configuration.

C6.7.2 — Soil anchors

Tables C6.2 and C6.3 provide typical values of ultimate bond strength for anchors in cohesive and non-cohesive soils, respectively. The tables include values for gravity-grouted and pressure-grouted anchors. The values in Table C6.3 for pressure-grouted anchors are based on 75 to 150 mm (3 to 6 in.) diameter anchors installed with grout pressures of 0.35 to 2.8 MPa (50 to 400 psi) with overburden depths of 4.5 m (15 ft) or more.

For cohesive soils, the ultimate bond strength is sometimes expressed as a function (typically 50 to 100%) of the undrained shear strength of the soil. The ultimate bond strength may be increased by pressure grouting through the casing or hollow-stem auger or by post-grouting (refer to Sections 7.8.3.2 and 7.8.4). Post-grouting can increase the load-carrying capacity of straight-shafted anchors by 20 to 50% or more per phase of post-grouting. Three post-grouting phases are generally considered a practical limit.

For non-cohesive soils, the ultimate bond strength depends on overburden pressure, angle of internal friction, density and grain size of the soil particles, hole diameter, grout pressure, grout take, grout composition, and method of drilling. Pressure-grouted or post-grouted anchors in non-cohesive soils will develop capacities in excess of the load expected

Table C6.2 —Typical average ultimate bond strengths-cohesive soils

Anchor type	Average ultimate bond strength—soil/grout, MPa (psi)
Gravity-grouted anchors (straight shaft)	0.03 to 0.07 (5 to 10)
Pressure-grouted anchors (straight shaft):	
- Soft silty clay	0.03 to 0.07 (5 to 10)
- Silty clay	0.03 to 0.07 (5 to 10)
- Stiff clay, medium to high plasticity	0.03 to 0.10 (5 to 15)
- Very stiff clay, medium to high plasticity	0.07 to 0.17 (10 to 25)
- Stiff clay, medium plasticity	0.10 to 0.25 (15 to 25)
- Very stiff clay, medium plasticity	0.14 to 0.35 (20 to 50)
- Very stiff sandy silt, medium plasticity	0.28 to 0.38 (40 to 55)

Note: Actual values for pressure-grouted anchors depend on the ability to develop pressures in each soil type.

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from applying conventional soil mechanics theory (refer to Sections 7.8.3.2 and 7.8.3.5). Post-grouting in non-cohesive soils is not as common as in cohesive soils. Reference 10 provides additional guidance for evaluating the effects of pressure grouting on bond srength.

Most bond lengths for soil anchors are in the range of 6 to 12 m (20 to 40 ft). Bond lengths greater than 12 m (40 ft) become less efficient, unless special provisions are taken to transfer load throughout the bond length.

In general, cohesive soils will require longer bond lengths than non-cohesive soils.

Minimum bond lengths of 4.5 m (15 ft) are recommended for all types of soil.

6.8 — Free stressing length

The free stressing length for rock and soil anchors shall not be less than 4.5 m (15 ft) for strand tendons and 3.0 m (10 ft) for bar tendons.

Longer free stressing lengths may be required:

1. To locate the bond length a suitable distance beyond the critical failure plane;
2. To locate the bond length in the appropriate ground and at a sufficient depth to provide the necessary soil overburden pressure or rock wedge stability;

C6.8 — Free stressing length

The minimum free stressing length recommended for strand accounts for the wedge seating losses that occur during lock-off. Shims placed below the wedge plate after initial lift-off or wedges seated by power seating can compensate for these losses. For more information, the Engineer should contact the tendon supplier.

For retaining walls, the top of the bond length is typically located a minimum of 1.5 m (5 ft) or 20% of the wall height, whichever is greater, beyond the critical failure plane.

Table C6.3 — Typical average ultimate bond strengths: non-cohesive soils

Anchor type	Average ultimate bond strength—soil/grout, MPa (psi)
Gravity-grouted anchors (straight shaft)	0.07 to 0.14 (10 to 20)
Pressure-grouted anchors (straight shaft):	
- Fine-medium sand, medium dense to dense	0.08 to 0.38 (12 to 55)
- Medium-coarse sand (w/gravel), medium dense	0.11 to 0.66 (16 to 95)
- Medium-coarse sand (w/gravel), dense to very dense	0.25 to 0.97 (35 to 140)
- Silty sands	0.17 to 0.41 (25 to 60)
- Dense glacial till	0.30 to 0.52 (43 to 75)
- Sandy gravel, medium dense to dense	0.21 to 1.38 (31 to 200)
- Sandy gravel, dense to very dense	0.28 to 1.38 (40 to 200)

Note: Actual values for pressure-grouted anchors depend on the ability to develop pressures in each soil type.

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3. To ensure overall stability of the anchor/structure system; and
4. To accommodate long-term movements.

The free stressing length may:

1. Be grouted together with the bond length (single-stage);
2. Be grouted in a separate operation (two stages); or
3. Remain ungrouted (temporary anchors with no corrosion protection only).

COMMENTARY

The design of rock anchors must consider the resistance to pullout of the rock wedge, which also governs anchor length.

Single-stage grouting is the most common and economical method for constructing soil and rock anchors. Single-stage grouting will result in optimum continuity of the grout cover for corrosion protection purposes and will prevent possible collapse of the drill hole and subsequent surface settlements. Single-stage grouting will result in load transfer above the tendon bond length, particularly in the case of large annular areas between the drill hole and the outer component of the tendon; the free stressing length may need to be increased to prevent load transfer above the critical failure plane.

6.9 — Anchor geometry

6.9.1 — Anchor spacing in bond length

Center-to-center spacing between bond lengths shall be at least four times their nominal diameter and normally shall be greater than 1.2 m (4 ft). If closer spacing is necessary, then staggering the bond lengths or varying the inclinations of adjacent anchors shall be adopted.

6.9.2 — Drill hole diameter

The drill hole diameter shall be sized to provide a minimum of 13 mm (0.5 in.) grout cover over the prestressing steel and its corrosion protection. The drill hole diameter shall also be sized to allow for grout placement around the tendon.

The drill hole diameter for multiple-element tendons shall be large enough so that the area of prestressing strand within the drill hole does not exceed 15% of the total area of the hole.

6.9.3 — Overburden depth

The Engineer shall ensure that there is sufficient overburden pressure to develop the soil-grout bond strength used.

C6.9 — Anchor geometry

C6.9.1 — Anchor spacing in bond length

The intent of the minimum separation of bond lengths is to prevent anchor load-transfer interaction and physical intersection due to drilling deviations.

C6.9.2 — Drill hole diameter

The purpose of the ratios given is to ensure proper grout cover for adequate load transfer and corrosion protection.

The size of the wedge plate, especially for epoxy-coated strand, may require a larger drill hole below the wedge plate to allow for the splay of the strands into the wedge plate.

C6.9.3 — Overburden depth

Sufficient overburden pressure is required to confine the grout during pressure grouting and to provide the necessary soil pressure to develop the anchor capacity. The load-carrying capacity of anchors installed in cohesionless soils may be adversely affected if the overburden over the bond length is less than 4.5 m (15 ft).

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6.9.4 — Anchor inclination

Anchors can be installed at any inclination, except that the range of +0.1 to −0.1 rad (+5 to −5 degrees) from the horizontal shall be avoided. Horizontal and upwards sloping anchors require specialized grouting techniques.

C6.9.4 — Anchor inclination

Nominal horizontal anchors may be difficult to properly install and grout, except for resin anchors, pressure-grouted anchors in coarse-grained soils, and where pressurized grout socks are used. Concerns with the grouting include: grout coming out of the hole and bleed development at the crown of the hole.

6.10 — Tendon components

Design requirements for the following tendon components are provided in this section:

- Anchorage;
- Encapsulation; and
- Spacers and centralizers.

C6.10 — Tendon components

6.10.1 — Anchorage

The anchorage shall comply with the requirements set forth in Section 4.3.

Bearing plates shall be designed to transfer loads from the tendon to the structure.

Bearing plates bearing on concrete shall be designed in accordance with PTI M50.2.

Bearing plates bearing on steel plates or wales shall be designed for extreme fiber bending stress less than the yield strength of the steel bearing plate at 95% F_{pu} of the prestressing steel.

Bearing plate testing in accordance with PTI M50.1 and M50.2 by an independent testing laboratory is acceptable to demonstrate performance in lieu of design.

Test results shall be subject to the approval of the Engineer.

C6.10.1 — Anchorage

Bearing plate testing, when performed, is generally required to demonstrate that at the maximum test load:

- The bearing plate is not permanently deformed; and
- The material (steel or concrete) beneath the bearing plate is not damaged.

6.10.2 — Encapsulation

For an encapsulated multi-element tendon, the encapsulation shall be sized to limit the prestressing steel area to 30% of the area defined by the inner diameter of the encapsulation. Special grouting techniques and grout materials may be required to provide satisfactory penetration of grout around the strands.

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For bar tendons, the inside diameter of the encapsulation shall be at least 10 mm (0.4 in.) larger than the nominal diameter of the bar.

6.10.3 — Spacers and centralizers

Spacers and centralizers are required for both permanent and temporary anchors, except as noted under Section C4.5. Spacers and centralizers, both external and internal to the encapsulation, shall be sized to permit the free flow of grout and not to cause bleed pockets, segregation of the grout, or both. Spacers shall be designed to provide adequate grout cover and bond of the prestressing steel elements to the surrounding grout.

The lowermost spacer and centralizer shall be located not more than 1.0 m (3 ft) from the tip of the tendon, and then 3.0 m (10 ft) or less on center.

C6.10.3 — Spacers and centralizers

Spacers help ensure that multi-element tendons will fully bond to the grout along the tendon bond length.

Centralizers and spacers are most commonly used in the bond length only. In the case of corrosion-protected anchors, centralizers in the free stressing length may provide some additional corrosion protection benefits.

Closer centralizer spacing may be practical for larger, multi-strand inclined tendons.

6.11 — Grout mixture

The grout mixture used for rock and soil anchors shall be pumpable and provide strength of at least 21 MPa (3000 psi) at time of stressing.

For permanent anchors, the grout mixture shall have bleed less than 2% (ASTM C940).

The type of cement that is selected for grout that will be in contact with the ground shall take into account the known or possible presence of aggressive substances. Soil samples may be necessary to evaluate the aggressivity of the soil (refer to Section 5.2.2).

When aggregates or nonpotable water are used in direct contact with prestressing steel, the constituent

C6.11 — Grout mixture

A properly mixed neat cement grout made with a water-cement ratio (*w/c*) of 0.4 to 0.45 by weight and Type I cement will easily satisfy these requirements.

For permanent anchors, the grout is an integral part of the corrosion protection system.

Bleed tests in excess of 2% may be indicative of excess water, insufficient mixing resulting in incomplete hydration, or both. Either or both of these phenomena may lead to lower strength and lower durability.

If significant grout pressures are used in noncohesive soils, water added to the cement during mixing will be squeezed out of the grout as it attempts to travel through the soil (pressure filtration). This results in an in-place grout with a lower *w/c* than for the grout that was initially injected. For this reason, *w/c* water as high as 0.55 can be used in cohesionless soils, if the effective grout pressures exceed 0.4 MPa (50 psi).

In-place grout may be weakened if diluted with groundwater prior to setting. The rate of strength gain of grouts cured at very low in-place temperatures will be reduced. Special grouts for low-temperature applications, even for installations in permafrost, are available.

Neat cement grout mixed with ASTM C150/C150M cement and potable water does not need to be tested for chemistry.

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materials shall be such that the acid-soluble chloride ion content of the grout shall not exceed 0.08% by weight of portland cement as measured by ASTM C1152/C1152M.

Performance characteristics of grout, especially when supplemental cementitious materials and admixtures (one or more) are used, shall be fully investigated to determine if there are any adverse interactions or deleterious effects.

6.12 — Grout socks

If grout socks are used, the diameter of the grout sock shall be sufficient to expand at least 50 mm (2 in.) beyond the drill hole in the uninstalled condition. Grout socks shall not be used in lieu of water pressure testing.

COMMENTARY

Because material and material combinations will vary from location to location, the chloride ion content should be determined by independent analysis of the combined materials used at the site before grouting operations begin.

C6.12 — Grout socks

Different fabrics have different filtration characteristics. The amount of filtration will also depend on the grout pressure and the cement type. Out-of-ground tests can be useful to understand the performance of a grout sock. Grout socks permit a tendon to develop pullout resistance with the ground only by mechanical interlock with the roughness of the drill hole wall. Bond developed through ground-grout adhesion cannot be relied on in design or performance.

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7.0 — CONSTRUCTION

7.1 — General

The construction of anchors shall be carried out in a manner consistent with the design assumptions (refer to Chapter 6).

7.2 — Fabrication

Mill test reports for the prestressing steel materials (refer to Section 3.3.3) shall be maintained by the Contractor. Identification on the tendon shall allow tracing of the prestressing steel to its heat or reel number.

For greased and sheathed tendons, per Section 5.4.2, the anchor fabricator shall maintain records of grease consumption to verify and certify compliance with Section 5.4.2. These records shall be submitted to the Engineer upon request.

Anchors shall be either shop- or field-fabricated in accordance with the approved drawings and schedules using personnel trained and qualified for this work.

Prestressing steel shall be cut with an abrasive saw or, with the prior approval of the prestressing steel supplier, an oxyacetylene torch.

The tendon bond length, especially if strand is used, must be free of dirt, manufacturers' lubricants, corrosion-inhibiting coatings, or other deleterious substances that may significantly affect the grout-prestressing steel bond or the service life of the tendon.

When encapsulated tendons are pregrouted, it shall be done on an inclined, rigid frame or bed by injecting the grout from the low end of the tendon. Grouts used to fill any encapsulation, whether pregrouted or grouted in place, shall be sufficiently fluid to ensure full penetration around every prestressing element, sufficiently stable to eliminate segregation and bleed pockets, and sufficiently strong to properly transfer the applied tensile loads.

COMMENTARY

C7.0 — CONSTRUCTION

C7.1 — General

The contract documents may require that the Contractor submit detailed methods and procedures intended for construction to the Engineer for review prior to start of field operations (refer to Chapter 3).

C7.2 — Fabrication

These records are useful in analyzing unusual behavior of individual or groups of anchors.

Sharp edges should be removed from cut ends.

Bond capacity of strand can vary widely depending on the manufacturer.

Other methods can be used, provided it can be demonstrated that the encapsulation is reliably and completely filled with grout.

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When bar tendons are coupled, each bar shall be engaged in the coupler for half the coupler length.

Grout socks, if used, shall be attached to the tendon, together with the corresponding grout tubes, as shown on the approved project shop drawing. The bottom end shall be sealed against the tendon to ensure that the grout is retained within the sock during grouting. The grout sock shall be inspected for tears or improper stitching prior to the installation of the sock on the tendon.

7.3 — Storage and handling

Upon delivery, all tendon components shall be stored and handled in a manner that avoids mechanical damage, corrosion, contamination with dirt or deleterious substances, and exposure to moisture and UV light.

Cement and admixtures for grout shall be stored under cover and protected against moisture, and in temperatures consistent with the manufacturers' recommendations.

Wedges and wedge plates shall be protected against dirt and corrosion, such as by the use of corrosion inhibitors and shrink-wrap, particularly if this hardware is attached to the prestressing steel.

Prestressing steel shall not be welded or used for grounding of welding electrodes, or exposed to excessive heat (more than 230°C [450°F]).

Heavy or pitting corrosion on the prestressing steel shall be cause for rejecting the tendon. A light coating of rust on the steel is acceptable.

Handling of the tendons shall not cause mechanical damage or contamination to the prestressing steel, the corrosion protection, or the epoxy coating.

Lifting of any pregrouted tendons shall not cause excessive bending, which can debond the prestressing steel from the surrounding grout.

7.4 — Drilling

Each drill hole shall be drilled at the location and to the length, inclination, and diameter shown on the

COMMENTARY

Center stops in the coupler or marking of the bar ends reflecting the proper engagement length are commonly used methods to ensure equal coupling.

C7.3 — Storage and handling

In the event of prolonged storage, the tendons should be stored in a manner that limits condensation and permits air to circulate around the tendons. This may be accomplished by supporting the tendons on blocking and providing plastic sheeting both on the ground and above the tendons. Depending on duration of storage and site conditions, storage in a container or warehouse may be necessary.

ASTM D3963 gives information on fabrication and handling of epoxy-coated bars.

Wedges and wedge plates with significant rust have been shown to exhibit wedge slippage and excessive wedge seating losses (Reference 6).

A light coating of rust will enhance the grout-steel bond strength. Reference 8 provides guidance regarding the acceptable amount of corrosion on seven-wire prestressing strands.

Rope or nylon slings are recommended.

Tests have shown that bar tendons, pregrouted in a PVC sheath, have been bent to a radius of 6 m (20 ft) during lifting without causing such damage.

C7.4 — Drilling

RECOMMENDATIONS

approved drawings and schedules. The drill bit or casing crown shall not be more than 3 mm (0.125 in.) smaller than the specified or approved hole diameter. The drill hole diameter shall accommodate the method and sequence of grout placement.

Drilling methods shall be left to the discretion of the Contractor, whenever possible. The Contractor shall be responsible for using a drilling method to establish a stable hole of adequate dimensions within the tolerances specified. However, the Engineer/Owner must specify what is not permissible.

Repeated failure to install the tendon into the drilled hole easily shall be cause for modification of the drilling procedure.

Special care shall be exercised in the selection of drilling methods when excessive loss of ground could endanger the stability of adjacent structures or utilities. A casing will normally be required in such cases.

COMMENTARY

Special concerns such as noise, vibrations, hole alignment, and damage to existing structures should be identified by the Owner in the project specifications. Any other drilling-related issue not acceptable or permitted should also be clearly specified. Guidance on drilling methodologies is provided in Reference 2.

Drilling methods may involve, amongst others, rotary, percussion, rotary/percussive or auger drilling, or percussive- or vibratory- driven casing.

Artesian or hydrostatic water pressure, excessive flushing, or unchecked conveying of soil during auger drilling may cause loss of ground.

Caution should be exercised to obtain the proper return flow and pressure drop when using compressed air flushing to clean the drill hole. Excessive pressure or volume buildup may cause structural damage, excessive ground loss, or ground heave, particularly when the drill holes are at a shallow angle or near the ground surface. Use of compressed air flushing methods to clean the drill hole in cohesionless soils below the groundwater table requires specific consideration of subsurface conditions, installation methods and equipment, and impacts to surrounding structures and utilities.

7.4.1 — Open hole drilling

Open hole drilling techniques may be used for soil or rock anchors if the drill hole does not cave and the tendon can be inserted into the hole without difficulty.

C7.4.1 — Open hole drilling

Hole sizes may range up to 0.6 m (24 in.) or more, in diameter, but are typically less than 0.3 m (12 in.).

Percussion drilling methods are used in rock and very competent soils. Drills equipped with top drive air or hydraulically powered rotary-percussive hammers, or

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down-the-hole hammers are employed when percussion drilling methods are used.

Rotary drills equipped with continuous-flight augers, tricone roller bits, or drag bits are commonly used to advance uncased holes in soft rocks or soils.

Core drilling is an expensive method of drilling and used only for special applications. The smooth surface of a core-drilled hole may result in reduced bond. Rotary or rotary-percussive methods are preferred.

Drill cuttings are removed from the hole by the augers or by the use of water or air as a flushing medium. Additives in the flushing fluid (mud or foam) may be used to improve the stability of the drilled hole. A stable hole may also be maintained by filling the drilled hole with grout prior to insertion of the tendon (refer to Section 7.8.3.1).

The use of bentonite or other clay-based drilling muds shall be prohibited.

The use of drilling muds and foams has greatly expanded the application of this type of drilling to different types of soils. The use of mud or foam must be carefully evaluated prior to use to prevent any remaining fluid from significantly affecting grout-ground bond.

7.4.2 — Cased holes

A casing may be used in unstable soil or rock formations to maintain an open hole. Drill casings may be advanced alone using rotary or rotary-percussive techniques, or may be advanced with an inner drill string (duplex method), depending on project conditions and restraints.

C7.4.2 — Cased holes

Drilled casings typically have diameters varying from 75 to 225 mm (3 to 9 in.). The diameters of driven casings normally range from 75 to 150 mm (3 to 6 in.). Individual lengths of casings range from 1.5 to 6 m (5 to 20 ft), although full-length casings may be installed using long drill guides mounted on large drill rigs or suspended from cranes.

Drilled casing systems may employ rotary or rotary-percussive or rotary/sonic-resonant methods using concentric or eccentric bits to drill through difficult ground. Duplex, single-tube, and reverse-circulation drilling methods may be used.

Duplex (internal flush) drilling is performed with an outer casing and an internal drill string. Air or water pumped down the inner drill string removes the drill cuttings as they return to the ground surface in the annular space between the drill string and the casing. Upon completion of the hole, the inner drill string is removed, leaving a clean-cased hole for installation of the tendon. The outer casing may be installed in this way through the unstable ground and the remainder of the hole completed using an open hole drilling method.

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Single-tube (external flush) drilling with casing is performed without an inner drill string. The leading edge of the casing is normally fitted with a casing crown or a drill bit. Drilling fluid is pumped down the casing as the casing is advanced. The drilling fluid returns the cuttings to the ground surface around the outside of the casing.

Reverse circulation drilling is a variation of duplex drilling that reverses the flow path of the drilling fluid. It is performed with an outer casing and an internal drill string. Air or water is pumped down the annulus between the drill string and the casing. The drilling fluid returns the cuttings to the ground surface through the inside of the internal drill string.

Driven casing systems may employ percussive hammers or vibratory, sonic, or resonant oscillators to advance casing. These methods are primarily used in cohesionless soils. The leading edge of the casing is normally equipped with a knockoff (lost) point to prevent soil intruding into the casing as it is driven. After the casing has reached the required depth, the lost point is knocked off the end of the casing, leaving a clean casing for installation of the tendon.

7.4.3 — Hollow-stem augers

Continuous-flight hollow-stem augers can be used for anchors constructed in soils and soft rocks.

Care must be taken that the grout body surrounding the free stressing length of hollow-stem auger anchors does not transfer load to the structure. This may be achieved by ending the grout shaft at least 0.3 m (1 ft) from the structure.

C7.4.3 — Hollow-stem augers

Full-length augers with an outside diameter of 200 to 450 mm (8 to 18 in.) and an inside diameter of 65 to 105 mm (2.5 to 4 in.) are typically used.

The tendon is inserted into the hollow stem and a detachable bit is secured over the bottom hole in the auger before drilling. The auger is advanced into the ground to the required depth. Then the bit is removed and grouting commences. A sand-cement grout with fluidifiers or water-reducing agents may be used.

Grout is pumped through the drill head, down the hollow stem, and out the bottom of the auger surrounding the tendon. As grouting is continued, the auger is withdrawn. Some slight rotation of the auger may be necessary during withdrawal. The auger is kept immersed in the grout during withdrawal to produce a continuous shaft.

Hollow-stem augers are not recommended for the installation of anchors in clean cohesionless soils under the water table. In these soils, augers are likely to convey collapsing sand to the top of the hole, resulting in loss of ground.

Tendons installed through the stem of the auger do not require centralizers if, during extraction of the auger, the

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hole is maintained full of grout with a slump of 250 mm (10 in.) or less.

Pressure can be applied to the hollow-stem auger grout. The pressure is dictated by the nature of the ground, the amount of soil remaining on the auger flights, and the Contractor's equipment and procedures. Pressure grouting will improve grout-soil bond and the quality of the grout.

7.4.4 — Combination methods

Two or more of the aforementioned methods may be combined to complete the drilling of an individual hole. Examples include:

(a) An open-ended casing driven to rock by a rotary-percussive drill head. The same drill head is used with appropriate drill rods and drill bits to drill out the soil inside the casing and the bond length in the rock below.

(b) Open holes, predrilled with a down-the-hole hammer and then subsequently stabilized prior to tendon and grout insertion by advancing a casing using water flushing.

7.4.5 — Hole alignment and tolerances

Unless other tolerances are specified, the drill hole entry shall be located within 300 mm (12 in.) in either direction of its plan location, and the entry angle deviation of the drill hole from its specified inclination shall be no more than ±0.05 rad (±3 degrees).

Deviations of the "as-drilled holes" from their theoretical alignment are generally inconsequential. However, when holes are drilled close together, or at long distances through existing structures, the deviations shall be specified to reliably keep the anchor within the structure and prevent intersecting of drill holes. A tolerance of 0.035 rad (2 degrees) is routinely achievable using normal drilling methods. Tighter tolerances down to 0.01 rad (0.5 degrees) will require special drilling methods.

C7.4.5 — Hole alignment and tolerances

The entry angle is typically measured by placing an angle indicator on the drill mast. Angle indicators with digital readouts are accurate to 0.01 rad (0.5 degrees.)

If accurate measurements of "as-drilled" deviations from the theoretical centerline of the hole are required, down-the-hole instruments such as optical survey tools or an electronic inclinometer can be used. Extremely tight drilling tolerances will be difficult to provide and equally difficult to measure accurately.

7.4.6 — Hole cleaning and overdrilling

Open holes and drilled casings shall be cleaned upon completion of drilling. If the hole is to be grouted prior to insertion of the tendon, the hole depth may be sounded to verify that the tendon can be installed to

C7.4.6 — Hole cleaning and overdrilling

Augered holes do not require cleaning. Open holes may be overdrilled to provide a sump into which drill spoils, not removed by flushing, may settle. Sounding is accomplished by inserting a grout tube or with the drill steel itself.

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full length. Holes open for longer than 8 to 12 hours shall be recleaned prior to insertion of the tendon and grouting.

7.5 — Water pressure testing, pregrouting, and redrilling rock anchor drill holes

Water pressure testing shall be specified by the Engineer when holes for permanent anchors for hydraulic structures are drilled in rock formations where water flow or fractures may permit grout to be lost around the tendon bond length.

A water pressure test is most simply performed by filling the entire hole in the rock with water and subjecting this water to a pressure, conventionally selected as 0.035 MPa (5 psi) in excess of the hydrostatic head and as measured at the top of the hole. If the free stressing length portion of the hole is in fractured rock or soil, a packer or casing shall be used to allow the bond length portion of the hole alone to be pressure tested. If the leakage from the hole over a 10-minute period exceeds 10.3 L (2.75 gal.) of water, then the hole shall be pregrouted, redrilled, and retested. If the subsequent water pressure test fails, the entire process shall be repeated until acceptable results are attained.

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C7.5 — Water pressure testing, pregrouting, and redrilling rock anchor drill holes

Separate unit price pay items should be established for the setup, water pressure test, grout, and redrilling, because these items are difficult to accurately estimate.

Rock anchor drill holes for temporary and extended temporary anchors are not typically water-pressure-tested because the anchor capacity is verified by testing and corrosion generally is not significant over the short service life of the anchor.

The decision to water-pressure-test all rock anchor drill holes can add significant costs to a project, and therefore should be based on careful review of the rock core and permeability test results from the Site Evaluation (Section 6.5), consideration of the corrosion system desired, and the rock anchor application. It is common practice to water-pressure-test each rock anchor drill hole on projects where high differential water head and rock discontinuities create paths for seepage through the tendon bond length, such as tiedowns for a dam and anchors under artesian conditions. Water-pressure-testing of the drill hole is not necessary for rock anchor applications where there is no seepage or differential head, and the method of grout placement will fill the drill hole and open fractures without loss of grout from around the tendon bond length. The Engineer should make this assessment during design after review of the rock core and permeability tests from the site evaluation.

Careful observation of the pregrouting and redrilling operations can indicate that grout loss is not occurring, despite repeated failures of water pressure tests. In such cases, the Engineer may instruct that further such operations in that hole be terminated and the tendon placed and grouted.

The rock mass requiring pretreatment may vary from one comprising families of small aperture fissures to one containing large, open cavities. Therefore, the grout mixture must be designed with appropriate rheology and hydration properties to limit take and optimize sealing. While most pretreatment is conducted with neat cement grouts with *w/c* of 0.5 to 1.0 (by weight), extreme conditions may merit the use of other materials (such as sand) or admixtures (for example, accelerators and anti-washout agents).

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Appropriate batching and injection equipment and processes must be used for each type of grout.

It may be estimated that in a rock drill hole, a fissure of 160-micron width will permit Type I/II cement particles to escape. A single 160-micron fissure will also accept a water flow of 3 L (0.8 gal.) per minute at 1 bar (14.5 psi) excess pressure.

Therefore, the acceptance criterion would be 30 liters over 10 minutes at 1 bar, or:

$30 \times (5/14.5) = 10.3$ L (2.74 gal.) over 10 minutes at 5 psi.

Redrilling shall be done when the grout strength is less than the strength of the surrounding rock.

This will increase the likelihood that the redrilled hole will follow the path of the initial hole. Redrilling is normally performed a minimum of between 18 and 36 hours after grouting.

If artesian or flowing water is encountered in the drilled hole, the hole shall be grouted and redrilled prior to water pressure testing.

Even on successfully tested anchors, artesian or flowing water may have diluted or washed away some of the grout, leaving a Class II corrosion-protected anchor tendon partially unprotected.

Pressure may need to be maintained on the grout to prevent artesian water from washing the grout out of the drilled hole.

7.6 — Tendon repairs

Damage to the corrosion protection system shall be repaired or replaced.

Project-specific repair procedures shall be submitted.

Encapsulation repairs shall be as follows:

(a) Cuts or tears less than 25 mm (1 in.) long and 3 mm (1/8 in.) wide may be repaired with multiple layers of self-adhesive moisture-proof tape.
(b) Cuts or tears larger than 25 mm (1 in.) long and 3 mm (1/8 in.) wide may be repaired using heat-shrink sleeves or heat-shrink tape.
(c) Cuts or tears larger than 25 mm (1 in.) long and 3 mm (1/8 in.) wide may also be repaired by removing the damaged section, sliding the encapsulation down, adding encapsulation at top, and splicing both joints with heat-shrink sleeve with overlap of three-quarters of the encapsulation diameter but never less than 75 mm (3 in.).

C7.6 — Tendon repairs

The reduction of bond capacity within the repaired area needs to be considered.

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Bond breaker (for example, sheath on strand) shall be repaired using self-adhesive, moisture-proof tape spirally wrapped to ensure at least a double thickness of cover over the damaged area.

Repair sleeves or tapes shall overlap the undamaged area by a minimum of 75 mm (3 in.) and be wrapped to provide a minimum thickness of 1 mm (0.04 in.).

Loose spacers or centralizers shall be reconnected to prevent shifting during insertion.

7.7 — Tendon insertion

Tendons shall be placed in accordance with the approved drawings and details and with the recommendations of the tendon manufacturer or specialist anchor Contractor.

Each tendon shall be inspected by field personnel during its installation into the drill hole or casing. Damage to the corrosion protection system shall be repaired, or the tendon replaced if not repairable.

Installation methods that might damage the encapsulation must be avoided. Special care shall be taken to avoid cracking the corrugated sheath when uncoiling it in cold temperatures.

On projects where routine water pressure testing of the drill hole is specified, pressure testing of the encapsulation after installation and prior to any grouting shall be considered. The testing program must be designed based on the material type and depth of the encapsulation, making sure not to use pressures that might rupture the encapsulation. The testing parameters and acceptance criteria shall be as detailed for rock anchor drill holes per Section 7.5.

The rate of placement of the tendon into the hole shall be controlled such that the sheath, coating, grout tubes, and any grout socks are not damaged during installation of the tendon. Tendons shall not be subjected to sharp bends.

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C7.7 — Tendon insertion

A funnel-shaped temporary guide has been successfully used at the top of the hole to prevent damage to the corrosion protection system.

On long, multi-strand tendons, the encapsulation could be damaged during installation by the weight of the strands and may need to be grouted in place in the hole prior to placing the tendon. Such an operation requires special care to ensure that no damage or distortion is caused to the encapsulation.

A mechanical means (that is, an uncoiler) may be needed to accomplish controlled placement of long-strand tendons. The bottom end of the tendon may be fitted with a cap or bull nose to aid its insertion into the hole, casing, or sheathing.

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If the prestressing steel is anticipated to be in prolonged contact with acidic water in the drill hole, chemical additives shall be introduced for neutralizing purposes to raise the pH value to 9.

Concentrated sodium hydroxide and calcium hydroxide have been proven effective for this purpose.

If the corrosion protection over the free stressing length does not extend beyond the trumpet seal or sufficiently far into the trumpet, either the corrosion protection or the trumpet shall be extended.

Corrosion protection that extends too close to the anchorage may interfere with the ability of stressing and testing the anchor.

The corrosion protection surrounding the free stressing length of the tendon shall not contact the bearing plate or the anchor head. Any excessive protection length shall be trimmed.

Anchors shall not be used for grounding electrical equipment.

7.8 — Grouting

The details of grouting operations for rock and soil anchors shall be addressed with care because the result of the process is not directly observable in place. The requirements for grout mixture design are set forth in Section 6.11.

Grout may be neat cement grout or contain sand.

C7.8 — Grouting

Further guidance on the details of materials, mixture design, testing, QA/QC, and construction may be found in PTI M55.1, insofar as they are valid to the particular requirements, customs, and practices of the rock and soil anchor industry.

7.8.1 — Grouting equipment and mixing

Mixers, storage tanks, and pumps shall have adequate capacity and shall be sized to allow continuous grouting of an individual anchor within a period of less than 1 hour.

C7.8.1 — Grouting equipment and mixing

Normally, as a minimum, grouting equipment consists of a mixer, storage tank, pump, and the associated pressure gauges and hoses.

7.8.1.1 — Neat cement grouts

Neat cement grouts with or without admixtures are mixed on site with colloidal or paddle mixers. Water and admixture measuring devices (batchers) are recommended to ensure accurate proportioning of grout ingredients. The accuracy of batching shall be sufficiently controlled to assure that the *w/c* of the grout is within ±5% of the target value. The accuracy of the dosage rate for admixtures shall be within ±10% of the target value.

The grout shall be continuously agitated until pumped, and shall be used within 30 minutes after commencing of mixing unless hydration-control

C7.8.1.1 — Neat cement grouts

Colloidal (or high-speed, high-shear) mixers provide superior cement hydration efficiency and uniformity relative to other types. They permit grouts of lower *w/c* to be quickly hydrated, and so they provide grouts of superior stability, rheology, and set properties.

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admixtures are used. The storage tank shall be kept at least partially full at all times during injection.

Noncolloidal mixers shall contain a screen having clear openings of 6 mm (0.25 in.) maximum size to screen the grout prior to its introduction into the storage tank. The screen shall be inspected periodically during grouting operations.

7.8.1.2 — Site-mixed sanded grouts

Sanded grouts require mixers and pumps built for grouts containing fine aggregates.

7.8.1.3 — Ready mixed sanded grouts

Sanded grouts may be mixed at a ready mix plant and delivered to the site by truck.

7.8.2 — QA/QC for mixed grout

The level of grout testing depends on the service life of the anchor, prior experience with the grout mixture, and the type of specification for the project. Figure 7.1 depicts the minimum QC programs requirements for grouts.

The Engineer may offer to waive the need for project-specific tests if the Contractor can satisfy the Engineer as to the acceptability of the proposed mixture designs via relevant and comparable studies conducted for prior projects. Such preliminary acceptance shall be conditional upon successful results from the preproduction or production field tests.

7.8.2.1 — Preproduction lab tests

If required, preproduction lab tests shall be conducted in a testing laboratory. Compressive strength, specific gravity, and bleed tests shall be performed using the methods listed in Section 7.8.2.4. As far as possible, the principle of mixing shall be as foreseen for the production mixing, and the materials and curing environments foreseen for production mixing shall be employed. The program shall be conducted and analyzed within a time frame that does not adversely impact the contract schedule.

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The presence of lumps of cement on the screen may be indicative of incomplete mixing and may result in blockages during injection.

C7.8.1.2 — Site-mixed sanded grouts

When heavily sanded grouts are to be used, such as for pregrouting or for filling large-diameter holes, then paddle- or drum-mixed grout may be acceptable, provided adequate fluid and set performance has been previously demonstrated.

C7.8.1.3 — Ready mixed sanded grouts

Ready mixed grouts are used for hollow-stem-augered anchors and for pregrouting open formations.

C7.8.2 — QA/QC for mixed grout

The Owner determines the level of QA on any given project.

The behavior of neat cement grouts without admixtures is well understood. Specific gravity testing will ensure that grouts with the desired *w/c* are mixed.

Prepackaged grouts conforming to the Class C requirements of PTI M55.1 may be used without requiring such laboratory or preproduction testing.

Reference 11 provides additional quidance for quality control procedures for grout.

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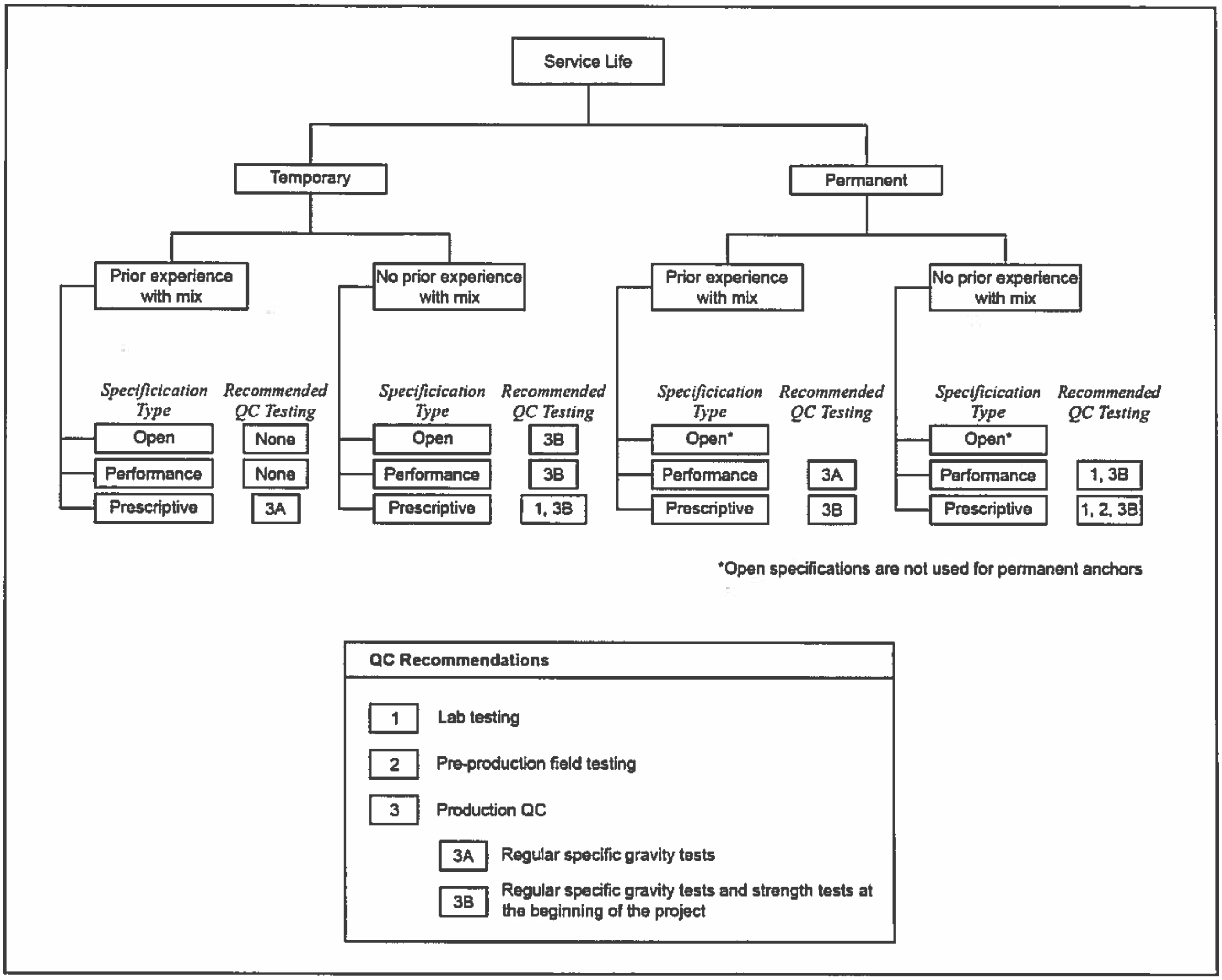

Fig. 7.1—Minimum recommended levels of grout QC programs.

7.8.2.2 — Preproduction field tests

If required, preproduction field tests shall be conducted using the equipment and materials proposed for production work under typical ambient conditions. The purpose of these tests will be to provide a quality and parameter "baseline" against which to judge the results from production testing. Compressive strength, specific gravity, and bleed tests shall be performed using the methods listed in Section 7.8.2.4. In particular, rate of gain of strength over a period of at least 7 days shall be demonstrated.

C7.8.2.2 — Preproduction field tests

The location of these field tests may not actually be the job site.

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The Contractor may proceed with the construction only after the Engineer approves the results of the tests.

7.8.2.3 — Routine QA/QC during production

Figure 7.1 establishes the minimum requirements for routine QC testing during production. Compressive strength testing, when required, need not be repeated after the initial phase of testing, provided:

1. There is no significant change thereafter in materials, equipment, or conditions; and
2. A regular program of fluid grout testing is conducted to verify the correct specific gravity (and hence water-cement ratio [*w/c*]).

Maintaining records of all grouting activities (including volumes, pressures, components, and mixture designs for every hole) and test results shall be the responsibility of the Contractor.

Insufficient cube strength shall be investigated, but not be cause for rejecting a successfully tested anchor.

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C7.8.2.3 — Routine QA/QC during production

Measurement of the specific gravity of the mixed grout permits the *w/c* to be determined and is a practical indicator that the grout has been correctly batched (Fig. C7.2). The strength can then be predicted with accuracy based on previous strength testing.

For further guidance on grout properties and testing, refer to PTI M55.1

A regular program of specific gravity testing typically includes one test per batch of grout during the beginning of the project. The frequency of testing is often later relaxed to no less than one test per day of grouting.

The Owner may reserve the right to request grout cubes at any time throughout the project if doubts arise as to the in-place grout strength.

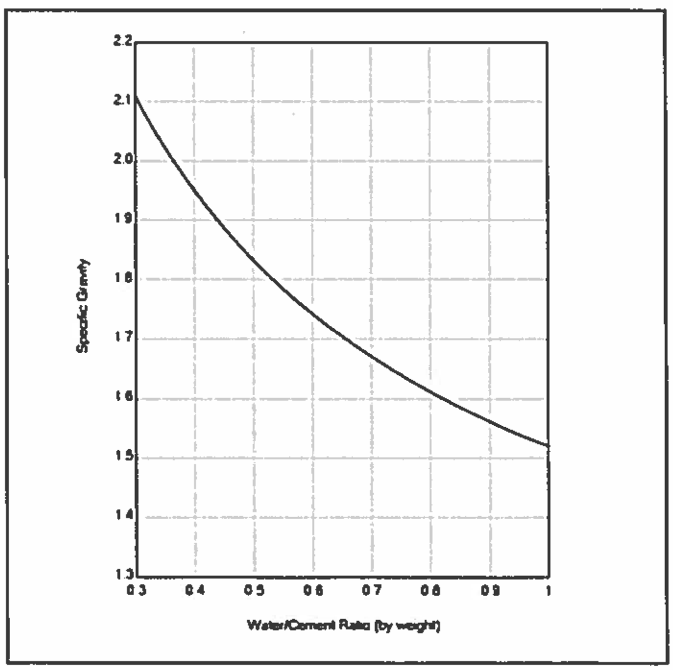

Fig.C7.2—Specific gravity versus w/c for neat cement grout (cement specific gravity = 3.15).

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7.8.2.4 — Test methods for cement-based grouts

Compressive strength tests shall be performed in accordance with ASTM C942 for grout cubes, or ASTM C39 for grout cylinders.

Specific gravity of the grout shall be determined using the API Mud Balance Test (Section 9.1.6) or ASTM C138/C138M.

Bleed tests shall be performed in accordance with ASTM C940.

7.8.3 — Grouting operations

When the wedge plate for strand anchors is not in place, grouting of tendons shall be stopped far enough behind it to allow flaring of the individual strands into the wedge plate without sharp deviations. Care shall be taken to prevent contamination of the wedges and wedge cavities with grout. The tendon shall be supported at the top of the hole to maintain alignment for testing.

C7.8.3 — Grouting operations

It is good practice to rinse the stressing tail of the strands after grouting to prevent wedge contamination.

7.8.3.1 — Grouting uncased holes

Once the hole has been drilled, the tendon can be inserted and the drill hole filled with grout. The grout is pumped through a tube extending to the bottom of the drill hole. The grout tube may remain in place or be pulled as the grout level rises. The end of the grout tube shall be kept below the top of the grout surface when pulling the grout tube.

C7.8.3.1 — Grouting uncased holes

Alternatively, the hole may be filled with grout prior to insertion of the tendon.

7.8.3.2 — Grouting cased or hollow-stem auger holes

Once the casing or hollow-stem auger has been fully installed and the tendon has been inserted, any full-face drill bit, if used, is disengaged from the leading edge of the casing, and the casing or auger is filled with grout.

For pressure grouting, the casing or auger is then withdrawn as additional grout is pumped through the casing cap or grout swivel. Pressure may vary from 0.35 to 2.8 MPa (50 to 400 psi) depending on the

C7.8.3.2 — Grouting cased or hollow-stem auger holes

Alternatively, the casing may be filled with grout prior to insertion of the tendon.

Attention should be paid to the grout pressure, volume, and time characteristics during the injection of each anchor to avoid possible ground heave.

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nature of the ground in the bond length and any additional grouting that will be performed (refer to Section 7.8.4).

For gravity grouting, the casing or auger is then withdrawn as additional grout is placed to maintain grout above the bottom of the casing or auger.

7.8.3.3 — Grouting encapsulated tendons

Grout to be placed inside the encapsulation shall have the minimum performance requirements identified in Section 6.11. The Contractor shall demonstrate, prior to commencing work on-site, that the grout design, batching, and placing techniques will ensure a stable, flowable grout that will not segregate when placed in the watertight duct.

Care shall be taken to ensure that excess differential grout pressures acting on the encapsulation do not damage, distort, or displace it. Cutting "windows" in the encapsulation or omission of the end cap to allow equalization of interior and exterior grout levels shall not be permitted. A dedicated tremie grout tube for grouting the annulus around the encapsulation may penetrate the end cap or the side of the encapsulation within the bottom 300 mm (12 in.) provided:

- The penetration is permanently sealed by the fabricator;
- The penetration is watertight;
- The end cap and grout tube connection are firmly fixed to each other; and
- The grout tube extends the full length of the tendon.

Multiple lifts of grouting may be required in cases where the encapsulation is grouted in the hole prior to tendon placement. This will typically involve the use of numerous grout tubes placed around the encapsulation and terminating at different elevations.

7.8.3.4 — Grouting very permeable ground

Special measures are required when grouting anchors in nested cobbles, boulders, talus, ballast, riprap, cavernous limestone, open fractures and faults, or other ground containing large voids and having high permeability.

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C7.8.3.3 — Grouting encapsulated tendons

Research indicates that bleed and segregation may occur in long tendons in grout placed in a hydraulically closed system. It may prove necessary to use multi-component grouts inside such encapsulations to ensure that appropriate grout performance parameters can be met (refer to PTI M55.1).

This applies regardless of whether the encapsulation is preplaced or placed simultaneously with the prestressing steel.

The sealing of this penetration will require special care to maintain the integrity of the corrosion protection.

This procedure applies typically only in long, multi-strand tendons where the encapsulation could be damaged during installation by the weight of the strands.

C7.8.3.4 — Grouting very permeable ground

These conditions can make it extremely difficult to prevent the loss of grout surrounding the tendon. This will result in decreased load capacity and corrosion protection and may cause environmental problems. It may prove necessary to modify the rheology, the hydration, or both of the cement-based grout via the use of other materials (such as sand) or admixtures (including anti-washout agents or, in the case of pregrouting, accelerator). In particularly open

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conditions, concrete-like materials (low-mobility grouts) may be beneficial.

Grout socks have also been used to retain the grout in open formations (refer to Section 6.12).

7.8.3.5 — Temperature considerations

During grouting operations in high ambient temperature, above 38°C (100°F), the temperature of the grout shall not exceed 32°C (90°F). If it is unavoidable that the temperature of the grout exceeds 32°C (90°F), then special precautions such as the use of suitable admixtures shall be taken to control flash set.

Grout shall be prevented from freezing for a period of 48 hours or until the grout has reached an unconfined compressive strength of 5.5 Mpa (800 psi).

C7.8.3.5 — Temperature considerations

For grouting in hot weather, several techniques can be employed to reduce the temperature of the components quite effectively at the job site. Maintaining a suitably cool water temperature, with the addition of ice for instance, can reduce the temperature of the freshly mixed grout to a level low enough to avoid flash set. Careful shading of the dry materials out of the hot sun has also been found to be effective.

Freezing of grout in drill holes is rarely an issue. Grout used to fill trumpets, covers, and stressing pockets is particularly susceptible to exposure to freezing temperatures. In extreme cold, this grout should only be placed after some measures have been undertaken to preheat the annulus or pocket to be grouted and to maintain temperature above freezing for the required period of time. Heating of the mix water or dry cement may also be beneficial.

7.8.4 — Post-grouting

Post-grouting, if required, shall be performed via a post-grouting tube installed simultaneously with the tendon assembly. The tube shall be equipped with special check valves in the bond length of the anchor that allow additional grout to be injected under high pressures after the initial, primary grout has set.

C7.8.4 — Post-grouting

The check valves in the bond length open when grout is pumped at high pressure (up to 8 MPa [1200 psi]) into the post-grouting tube. The high-pressure grout cracks the primary grout column at the location of the valves, allowing additional grout to penetrate or consolidate the soil surrounding the anchor. The high-pressure grout may increase the "in-place" stresses between the grout and the surrounding soil, thereby increasing the frictional resistance to pullout along the soil-grout interface. The high-pressure grout may also create protrusions along the bond length that contribute to pullout resistance. When the pressure is removed, the valves close to prevent backflow of grout into the tube. The valves also remain closed as the tube is washed out with low-pressure water for the next post-grouting stage.

The post-grouting tube and methods may be designed so that the individual valves open in an uncontrolled, indiscriminate fashion or, alternatively, with the use of specially designed packers, so that the opening and grouting of each valve or a group of valves can be controlled. The use of a packer to isolate individual valves may significantly improve reliability and carrying capacity in weak soils.

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Post-grouting shall be repeated as necessary to increase the anchor capacity.

7.9 — Installation of anchorage

The bearing plate shall be installed perpendicular to the prestressing steel, within ±0.05 rad (±3 degrees) and centered on the drill hole, without bending or kinking of the prestressing steel elements.

Wedge cavities and wedges shall be free of rust, grout, and dirt. Special care shall be exercised to obtain the continuity of corrosion protection in the vicinity of the anchorage as described in Section 5.4.1. The stressing tail shall be cleaned and protected from damage until final testing and lock-off.

COMMENTARY

Three post-grouting events is a practical limit.

C7.9 — Installation of anchorage

A set of wedge washers underneath the nut for a bar tendon can compensate for angle deviations of additional 0.35 rad (20 degrees).

Slippage of the strand through the wedges will result if the cleanliness requirements are not observed.

RECOMMENDATIONS

8.0 — STRESSING, LOAD TESTING, AND ACCEPTANCE

8.1 — General

Stressing and testing are required for every anchor to fulfill the following two functions:

1. To demonstrate that the anchor meets the acceptance criteria; and
2. To stress and lock-off the tendon at its specified load.

The equipment and procedures shall be designed accordingly. Testing procedures are independent of ground type.

8.1.1 — Preparation prior to stressing

All practical and reasonable steps shall be taken prior to stressing to ensure a level of cleanliness and adequate lubrication of wedge cavities and wedges, such that all components can perform as designed.

8.2 — Equipment

8.2.1 — Requirements for equipment

Stressing equipment shall be capable of stressing the whole tendon, preferably in one stroke to the specified test load.

Stressing and testing of multiple element tendons with single-element jacks is not permitted, unless the single-element jacks are synchronized and apply the total test load to the entire anchor simultaneously.

The equipment shall be capable of stressing the tendon to the maximum specified test load within the rated capacity.

The equipment shall permit the tendon to be stressed in increments so that the load in the tendon can be raised or lowered in accordance with the test specifications, and allow the anchor to be liftoff tested to confirm the lock-off load.

COMMENTARY

C8.0 — STRESSING, LOAD TESTING, AND ACCEPTANCE

C8.1 — General

Stressing and recording should be carried out by experienced personnel under the control of a suitably qualified supervisor, preferably provided by a specialist anchor Contractor/Supplier or an engineering agency fully experienced with the procedures.

C8.1.1 — Preparation prior to stressing

Adequate lubrication is important to ensure that the wedges, during seating, do not become restricted under the lateral load resulting from strand deviations. Wedges restricted in this way can cause strand slippage through the wedge during lock-off operations.

C8.2 — Equipment

C8.2.1 — Requirements for equipment

Long-stroke equipment avoids regripping of strand tendons.

A single-strand jack may be used to place an equal alignment load (AL) on the individual strands of long multi-strand tendons prior to stressing with a multi-strand jack.

The rated pressure is lower than the actual jack capacity. Pressure-limiting valves on the hydraulic jacks or pumps should be set by the supplier such that the rated pressure cannot be exceeded.

A production gauge is the gauge that is routinely used during stressing and testing. A reference gauge is a backup gauge to be used in the field to check the accuracy of the production gauges. A master gauge is the off-site master gauge calibrated every 6 months against a dead weight

RECOMMENDATIONS

Hydraulic jacks shall be calibrated with a master gauge or together with the production and reference gauges against a load cell whose calibration is traceable to NIST. Production and reference gauges shall be concurrently calibrated against the master gauge. These calibrations shall be done to an accuracy of ±2% within 9 months prior to shipment to the project. All gauges shall have graduations no larger than 0.7 MPa (100 psi). All calibration certificates and graphs shall be available on-site at all times. Once on the project, the jack is required to be recalibrated (provided the gauges have been confirmed to be accurate) only if:

1. The results of anchor stressing are suspect or inconsistent;
2. The jack has been internally machined or the seals replaced; or
3. The jack has been damaged.

The reference gauge shall be kept on-site to check the production gauge at a frequency of one test per day or when the accuracy of the production gauge becomes suspect. The production/reference gauge shall be recalibrated if:

1. The results of anchor stressing are suspect or inconsistent;
2. There is a difference between the two gauges that exceeds their original difference by more than 2% of the gauge pressure; or
3. The gauge has been damaged.

If the gauges require recalibration, the performance of the anchors stressed since the previous gauge check shall be reevaluated to determine that they, in fact, satisfy project requirements.

Load cells or elastomagnetic sensors, if required, shall be used to monitor small changes in load during extended creep testing, rather than total load.

Dial gauges shall be used which permit the measurement of total tendon movement at every load increment to be read to the nearest 0.03 mm (0.001 in.). The gauge shall have sufficient travel to record the total anchor movement at test load without the need to reset at an interim point.

COMMENTARY

tester, whose calibration is traceable to the National Institute of Standards and Technology (NIST).

Usually, recalibration of the entire system, jack, and gauges, is not required, unless maintenance work on the jack has changed its piston area or internal friction.

Hydraulic pumps do not require calibration.

Load cells are very sensitive to loading eccentricities and end conditions. As a result, they are best used to measure small changes in load rather than total load. Elastomagnetic sensors may also be used for these purposes but are not similarly affected by loading eccentricities.

RECOMMENDATIONS

Mechanical dial gauges do not require calibration; however, they shall be kept in good working order and periodically checked to ensure that the stem is free to move smoothly over its entire measurement range.

Digital gauges shall require calibration at the same interval as the jack.

8.2.2 — Equipment setup

The stressing equipment, the sequence of stressing, and the procedure to be used for each stressing operation shall be determined at the planning stage of the project. The equipment shall be used strictly in accordance with the manufacturer's operating instructions.

Stressing shall not begin before the grout has reached adequate strength.

Prior to setting the dial gauges, the alignment load (AL) shall be accurately placed on the tendon. The magnitude of AL depends on the type and length of the tendon.

Dial gauges shall bear against a plate fixed to the end of the tendon or on the pulling head. Their stems shall be parallel with the tendon orientation.

The gauges shall be supported on an independent reference frame, such as a tripod, which will not move as a result of stressing or other construction activities during the operation.

Pull rods and couplers for bar tendons shall be properly sized for the prestressing steel and any coating on it, shall be designed to carry the ultimate load of the bar, and must be completely engaged on the bar end.

During stressing, proper safety precautions are essential. Operators and observers must stand to the side of

COMMENTARY

Dial gauges with travels greater than 100 mm (4 in.) are especially susceptible to field damage. An alternative is to use two or more gauges of shorter travel in tandem. These are then reset at interim points in the stressing sequence. Considerable care is needed in the subsequent calculation of tendon movement based on such data.

C8.2.2 — Equipment setup

Anchor stressing and testing can normally start 5 days after grouting with Type I or II cements, and after 3 days using Type III cements (refer to Section 4.11.1).

The alignment load (AL) typically varies from 5 to 15% of the design load (DL), and 10% is common. A higher AL may be necessary as approved by the Engineer. The AL is applied to secure all the components during stressing and to ensure that the residual movements are accurately and consistently determined when unloading during a performance test. The AL may be applied to large multi-strand tendons with a monostrand jack to more equally load the individual strands.

The movement of the pulling head wedges into the wedge plate may be considered in addition to the reading taken from the dial gauges when analyzing the extension data.

Where such a setup cannot be used, the dial gauges may be supported on the body of the jack, but they will then record only jack ram extension. Particular judgment must be exercised in the interpretation of such data because ram extension may include reaction movement of the structure being anchored, and possibly other movements, too. In such cases, ram extension will be an overestimation of the true total tendon movement. Without an independent reference frame, it is not possible to accurately measure creep.

Couplers used in conjunction with pull rods may be case hardened to extend their service life.

Serious injury may occur if a tendon fails during stressing.

the stressing equipment and never pass behind when it is applying load.

8.3 — Testing

No preloading other than the alignment load (AL) of the tendon is allowed prior to testing.

No tendon shall be stressed at any time beyond 80% F_{pu} of the prestressing steel. Per Section 6.6, the recommended design load is limited to 60% F_{pu}.

The three types of tests are:

1. Preproduction tests;
2. Performance tests; and
3. Proof tests.

Every anchor shall be tested in accordance with the proof or performance test procedures. If the anchor is installed in ground that may be susceptible to appreciable creep, then the performance test procedures shall be modified in accordance with Section 8.3.4.

C8.3 — Testing

Real-time assessment of test data is recommended to verify realistic data are being obtained.

The maximum test load for testing procedures outlined in the following is 133%. It may be increased, however, beyond 133% of the design load (DL) under special conditions, but shall not exceed 80% F_{pu}. Such a special condition may arise if fixed reference points cannot be practically established, against which to directly measure pulling head movement, for example. However, such an increase in maximum test load may require additional steel area, and therefore a larger hole diameter.

8.3.1 — Preproduction tests

Preproduction tests, if required, shall satisfy the minimum requirements of the performance test but may be more rigorous in detail. Preproduction tests that are intended to determine ultimate grout-ground bond strengths shall feature bond length dimensions likely to cause grout-ground failure within the safe operating limits of the other interfaces (for example, grout-steel bond) or components (such as steel stress to 80% F_{pu}).

C8.3.1 — Preproduction tests

Due to cost and time considerations, such tests are specified only in special circumstances. They may be necessary when there is uncertainty in the ultimate bond strength. They are particularly useful on projects where a large number of high-capacity anchors will be installed because the test data can be used to determine an efficient bond length. The number of preproduction tests will vary based on the size of the project and the number of anchors to be installed. Typically, one to three tests may be performed for each significantly different ground condition or bond length. The Contractor responsible for anchor installation typically conducts the preproduction test program. The test program should evaluate the tendon design, materials, and installation method.

8.3.2 — Performance tests

Performance tests are conducted on selected production anchors constructed under methods and conditions identical to those foreseen for the overall project.

The first two or three anchors, as determined by the Engineer, shall be performance-tested. Thereafter, a minimum of 2% of the remaining anchors shall be performance-tested.

C8.3.2 — Performance tests

The number of performance tests may be increased, especially when the anchors are being used for permanent applications, when creep susceptibility is suspected, or when varying ground conditions are encountered, but normally will not exceed 5% of the total number of anchors.

Performance tests are used to determine:

(a) Whether the anchor has sufficient load-carrying capacity;
(b) That the apparent free tendon length has been satisfactorily established;
(c) The magnitude of the residual movement; and
(d) That the rate of creep stabilizes within the specified limits.

Table 8.1 — Performance test steps

Load	Total movement at load cycle maximum δ_t	Residual movement at AL after cycle maximum δ_r	Elastic movement at load cycle maximum δ_e
AL 0.25 DL	δ_{t1}		$\delta_{t1} - \delta_{r1} = \delta_{e1}$
AL 0.25 DL 0.50 DL	δ_{t2}	δ_{r1}	$\delta_{t2} - \delta_{r2} = \delta_{e2}$
AL 0.25 DL 0.50 DL 0.75 DL	δ_{t3}	δ_{r2}	$\delta_{t3} - \delta_{r3} = \delta_{e3}$
AL 0.25 DL 0.50 DL 0.75 DL 1.00 DL	δ_{t4}	δ_{r3}	$\delta_{t4} - \delta_{r4} = \delta_{e4}$
AL 0.25 DL 0.50 DL 0.75 DL 1.00 DL 1.20 DL	δ_{t5}	δ_{r4}	$\delta_{t5} - \delta_{r5} = \delta_{e5}$
AL 0.25 DL 0.50 DL 0.75 DL 1.00 DL 1.20 DL 1.33 DL	δ_{t6} Test Load (zero reading for Creep Test) δ_{tn} Final Load hold reading	δ_{r5}	$\delta_{t6} - \delta_{r6} = \delta_{e6}$
AL Adjust to lock-off load		δ_{r6}	

Data from such tests may be used to supplement or enhance the evaluation of the results from subsequent proof tests.

The test load should be reached as quickly as possible.

Test procedures that record pressure loss over an interval of time should not be used because they cannot account for pressure losses in the hydraulic circuit, wall movement, and temperature effects, and therefore cannot accurately evaluate anchor performance.

Exceeding the original test load will result in additional movement, which will distort the creep measurement results. This is of particular importance for bars which have not been cold-stressed (refer to Sections 4.2.2 and 8.6.1).

RECOMMENDATIONS

The performance test shall be conducted by cyclically and incrementally loading and unloading the anchor in accordance with the schedule in Table 8.1.

The load shall be decreased to the alignment load (AL) after each cycle maximum. It is particularly important to accurately record the extension at each successive AL step.

At each load increment, the total movement of the pulling head shall be recorded to the nearest 0.03 mm (0.001 in.) with respect to the independent fixed reference point. The load shall be held at each increment just long enough to obtain the movement reading but no longer than 1 minute. Movement readings at test load shall be taken at 1, 2, 3, 4, 5, 6, and 10 minutes after reaching the test load. If the total creep movement between 1 and 10 minutes exceeds 1 mm (0.040 in.), the test load shall be maintained for an additional 50 minutes. Total movements shall then be recorded at 20, 30, 40, 50, and 60 minutes.

During the load hold periods, the anchor load shall not be allowed to deviate from the test pressure by more than 0.35 MPa (50 psi). Repumping back to test load will compensate for small movements, hydraulic oil seepage, and changes in temperature of the hydraulic oil. The load shall always be returned to the specified test load prior to taking the movement reading at the specified interval. The test load shall not be exceeded during the period of observation.

Test data shall be plotted and analyzed as shown in Fig. 8.1a and 8.1b.

Figure 8.1a shows the total movement as a function of load.

Figure 8.1b is developed from Fig. 8.1a, and shows the partition of total movement δ into its elastic δ_e and residual δ_r components for each load maximum. The elastic movement δ_e is calculated by deducting the subsequent residual movement reading δ_r from the total movement δ_t measured at the previous cycle maximum.

Analysis of the elastic movement permits calculation of the apparent free tendon length, at each load maximum from the relationship:

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Only the successive load cycle maxima are shown for clarity and are numbered 1 through 6, respectively.

The residual movement consists of the displacement of the grout body in the ground and a portion of the elastic movement, which friction does not allow to completely dissipate.

Apparent free tendon length is the theoretical length of tendon that would undergo an identical magnitude of elastic movement during unloading as that measured during load testing. In Fig. C8.2, the area under the load-versus-depth diagram divided by $A_t \times E_s$ is equal to the elastic movement of the anchor. The apparent free tendon length assumes a uniform rectangular load-versus-depth diagram. However,

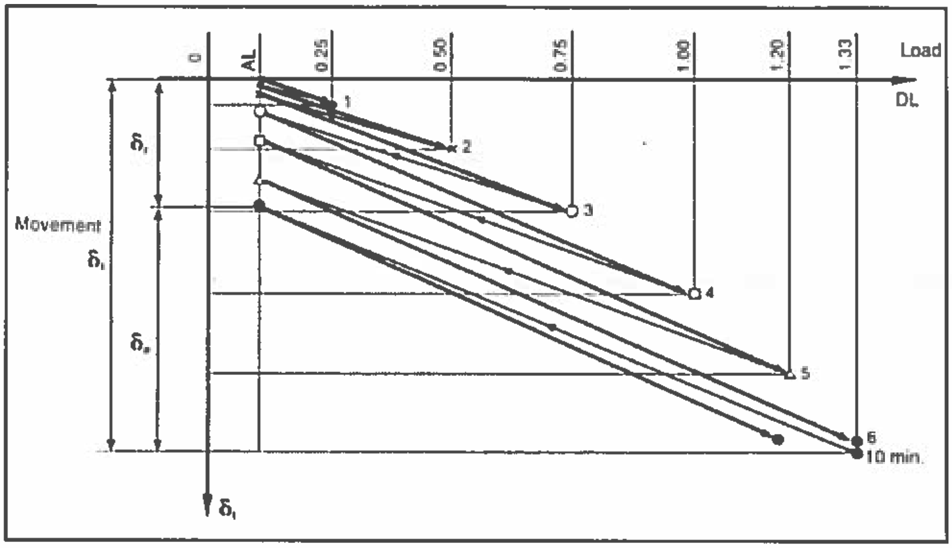

Fig. 8.1a—Plotting of performance test data.

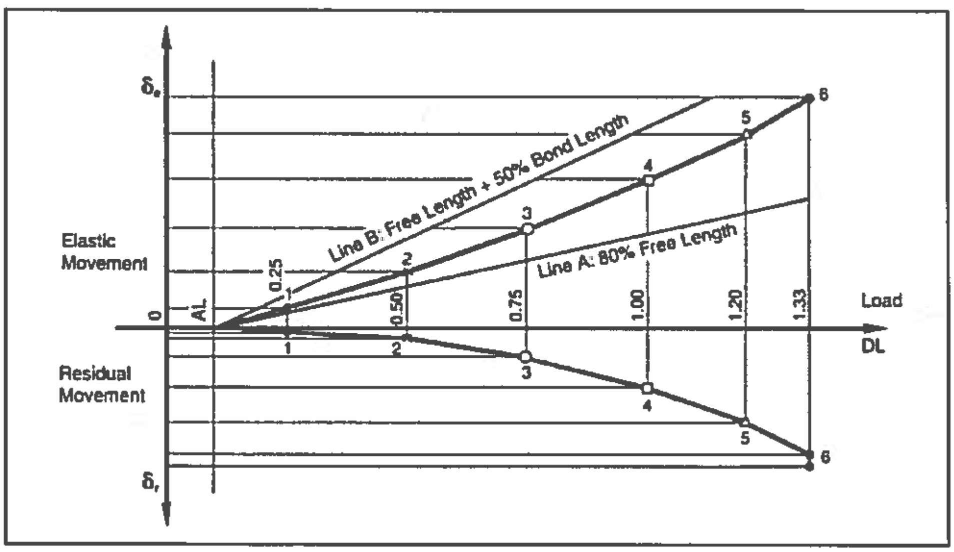

Fig. 8.1b—Graphical analysis of performance test data.

RECOMMENDATIONS

Apparent free tendon length = $\dfrac{A_t E_s \delta_e}{P}$

where:

A_t = Cross-section area of the prestressing steel
E_s = Modulus of elasticity of the prestressing steel
δ_e = Elastic movement (that is, total tendon movement minus subsequent residual movement of alignment load [AL])
P = $TL - AL$

COMMENTARY

in reality, load is transferred above and below the bottom of the apparent free tendon length. Assuming uniform load transfer (triangular distribution), one half of the load is transferred below this apparent free tendon length and one half above. Even given its simplicity, the apparent free tendon length is a very useful indicator of load transfer distance along a bond length.

Due to differences in torsional restraint, the actual modulus of elasticity of a long multi-strand tendon may be less than the manufacturer's reported modulus of elasticity value for a single strand measured over a relatively short gauge length. A reduction of 3 to 5% in the manufacturer's modulus of elasticity may be allowed in any field diagnosis.

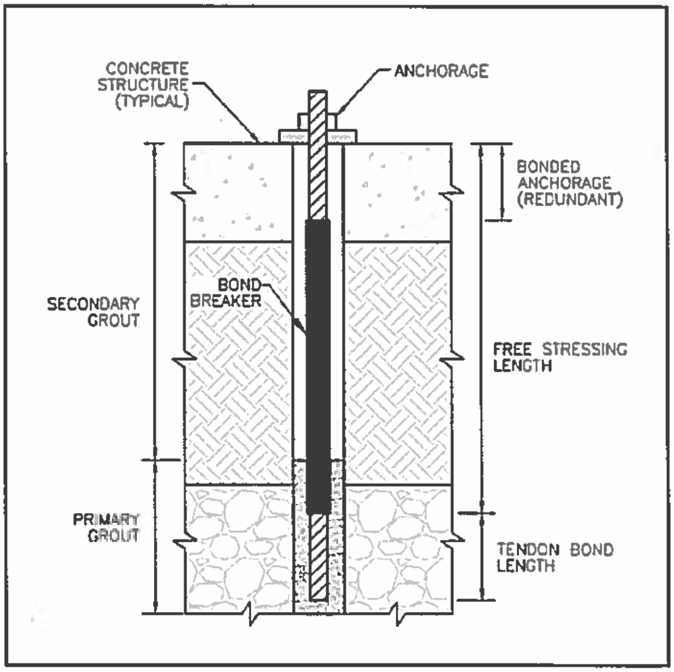

Fig. C8.2—Apparent free tendon length.

8.3.3 — Proof tests

Proof tests shall be carried out on all production anchors not subjected to a performance test. This test is intended to quickly and economically determine:

(a) Whether the anchor has sufficient load-carrying capacity;
(b) That the apparent free tendon length has been satisfactorily established; and
(c) That the rate of creep stabilizes within the specified limits.

C8.3.3 — Proof tests

A comparison of the total movement graphs of the proof test with those of the performance tests (conducted in similar conditions) may allow additional insight into the load transfer characteristics of the proof-tested anchors.

RECOMMENDATIONS

The proof test shall be conducted by incrementally loading the anchor in accordance with the schedule in Table 8.2. At the test load, the load shall be maintained constant for 10 minutes and total movement readings shall then be recorded at 1, 2, 3, 4, 5, 6, and 10 minutes after reaching the test load. If the total creep movement between 1 and 10 minutes exceeds 1 mm (0.040 in.), the test load then shall be maintained for an additional 50 minutes and the movement readings shall be recorded at 20, 30, 40, 50, and 60 minutes.

During the load hold periods, the anchor load shall not be allowed to deviate from the test pressure by more than 0.35 MPa (50 psi). Repumping back to test load will compensate for small movements, hydraulic oil seepage, and changes in temperature of the hydraulic oil. The load shall always be returned to the specified test load prior to taking the movement reading at the specified interval. The test load shall not be exceeded during the period of observation.

The test data shall be plotted and analyzed as shown in Fig. 8.3a and 8.3b. For approximating the elastic elongation of proof-tested anchors, the value for the residual movement of adjacent representative performance-tested anchors shall be deducted from the total movement measured.

When the results of performance tests cannot be compared directly to those of proof tests, the anchor shall be returned to alignment load (AL) after the 10-minute hold at test load and raised again to lock-off. This will permit the determination of residual movement and calculation of the elastic movement at the test load.

8.3.4 — Supplementary extended creep tests

At least two extended tests shall be made on permanent anchors in soils having a Plasticity Index greater than 20. The creep test shall be conducted by incrementally loading and unloading the anchor in accordance with the schedule of the performance test, except that at each new load maximum, the load shall be held constant in accordance with the schedule in Table 8.3.

The times for reading the creep movements shall be 1, 2, 3, 4, 5, 6, 10, 15, 20, 25, 30, 45, 60, 75, 90, 100, 120, 150, 180, 210, 240, 270, and 300 minutes (where appropriate).

COMMENTARY

The test load should be reached as quickly as possible.

For temporary anchors where ground conditions, loading conditions, and installation procedures are sufficiently understood, and installation procedures are well controlled; proof test maximum loads as low as 1.20 design load (DL) may be appropriate. However, regardless of how low the proof test maximum is, the DL may not exceed 0.6 F_{pu}.

Table 8.2 — Proof test steps

AL
0.25 DL
0.50 DL
0.75 DL
1.0 DL
1.20 DL
1.33 DL (test load) (minimum 10-minute hold)
AL (optional)
Adjust to lock-off load

C8.3.4 — Supplementary extended creep tests

Extended creep tests are normally not performed on rock anchors because they do not exhibit time-dependent movements. However, anchors installed in very decomposed or argillaceous rocks may exhibit significant creep behavior.

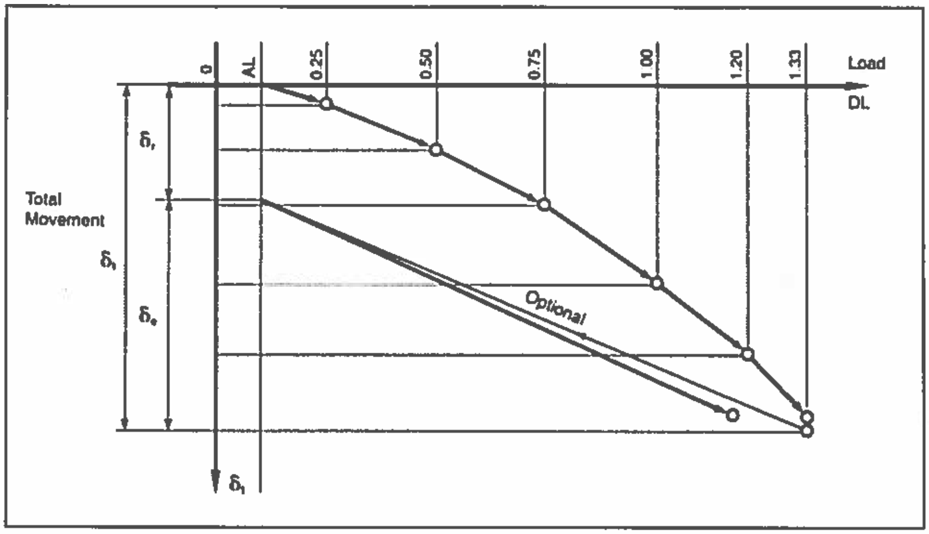

Fig. 8.3a—Plotting of proof test data.

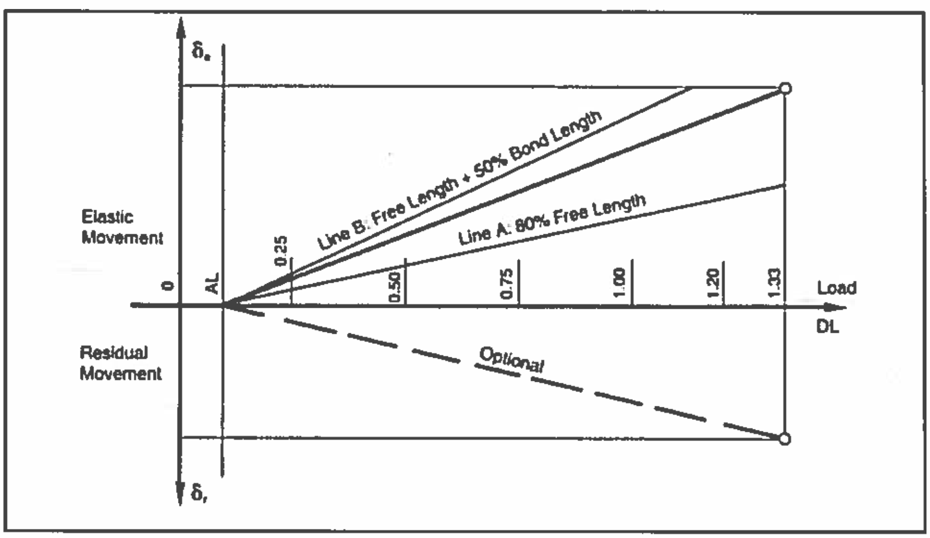

Fig. 8.3b—Graphical analysis of proof test data.

RECOMMENDATIONS

During the load hold periods, the anchor load shall not be allowed to deviate by more than 0.25%. If the corresponding pressure change is less than the precision of the pressure gauge, then a load cell shall be required. Repumping back to test load will compensate for small movements, hydraulic oil seepage, and changes in temperature of the hydraulic oil. The load shall always be returned to the specified test load prior to taking the movement reading at the specified interval. The test load shall not be exceeded during the period of observation.

If the creep rate exceeds 2 mm (0.080 in.) per logarithmic cycle, the observation period may be extended in an attempt to determine if the creep rate will diminish to the 2 mm (0.080 in.) per logarithmic cycle of time.

The family of creep curves shall be plotted as in Fig. 8.4 on a semi-logarithmic chart.

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Table 8.3 — Supplementary extended creep test

Load	Observation period, minutes
AL	10
0.25 DL	10
0.50 DL	30
0.75 DL	30
1.0 DL	45
1.20 DL	60
1.33 DL	300

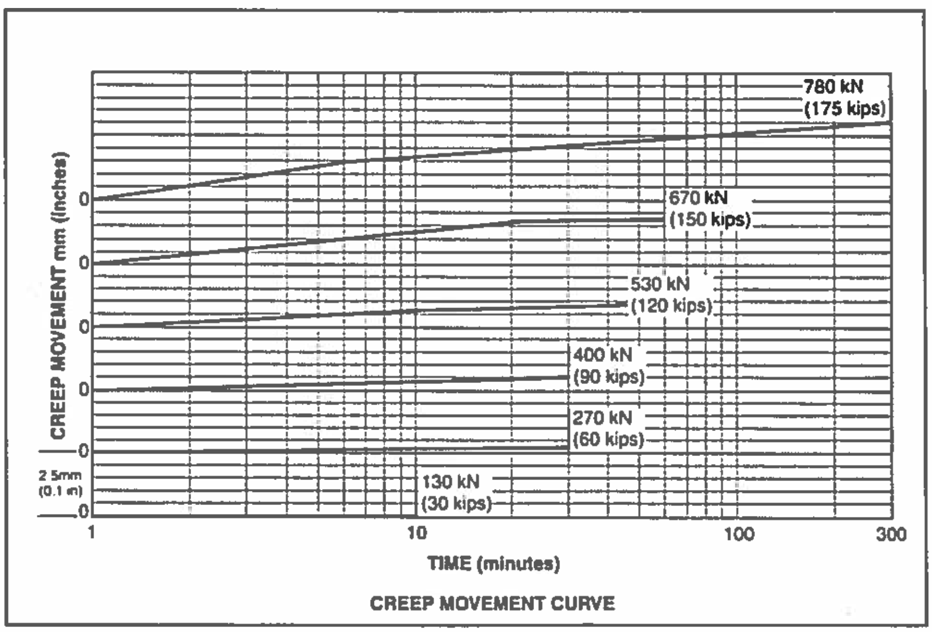

Fig. 8.4—Typical creep movement plot.

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8.4 — Lock-off procedure

After testing has been completed, the load in the tendon shall be adjusted to the lock-off load and transferred from the pulling head to the anchor head.

C8.4 — Lock-off procedure

During lock-off, the load in the tendon is typically reduced from a higher load to the lock-off load. As the load decreases, the prestressing steel decreases in length and the wedges or anchor nut move closer to the wedge plate or bearing plate. Ideally, the wedges will seat in the wedge plate or the anchor nut will contact the bearing plate when the load in the tendon is equal to the desired lock-off load. The exact positioning of the wedges or anchor nut on the tendon to achieve the desired lock-off load is the product of many factors and needs careful field verification.

There is no minimum lock-off load for either bar or strand tendons. However, these Recommendations specify a minimum wedge seating load for strand tendons.

The magnitude of the lock-off load shall be specified by the Engineer, and shall not exceed 70% F_{pu}.

Wedges for strand tendons shall be seated at a minimum load of 50% F_{pu} during the lock-off procedure. The wedge seating load shall be verified by a liftoff test.

The minimum wedge seating load helps ensure that the strand does not slip through the wedges during service life, especially if the load in the tendon increases above lock-off load. It also accounts for the intrusion of neat cement grout in and around the wedges that occurs when anchor head caps and trumpets are filled with grout. Power seating does not eliminate the minimum wedge seating load requirement.[6]

If the specified lock-off load for a strand tendon is less than 50% F_{pu}, shims shall be placed under the wedge plate and the wedges seated at a minimum load of 50% F_{pu}. The shims shall then be removed to reduce the load in the tendon to the specified lock-off load.

The removal of shims allows the strand to decrease in length, thereby decreasing the load in the tendon. The shimming process allows the wedges to be seated at a minimum load of 50% F_{pu} before locking off at a lower load.

Regripping of strands, which would cause overlapping wedge bites or wedge bites on the strand below the anchor head, shall be avoided.

Regripping of strands during stressing may have to be considered on practical grounds in certain instances.

Refer to Section 8.6.3 for the acceptable tolerance for lock-off and wedge seating loads.

8.5 — Initial liftoff reading

After transferring the load to the anchor head and prior to removing the jack, a liftoff test shall be conducted to confirm the magnitude of the load in the tendon. This load is determined by reapplying load to the tendon to lift off the wedge plate, wedges, or anchor nut.

C8.5 — Initial liftoff reading

The liftoff load is measured by:

(a) Observing on the pressure gauge the point at which there is a marked reduction in the rate of gain of pressure;

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(b) The load at which two shim-wires installed diametrically opposite under the wedge plate can be first withdrawn; or
(c) Visible lifting of nut wedges or wedge plate.

A load accuracy of ±2% may be expected.

On a multi-strand anchor individual wedges can unseat during a liftoff test due to uneven loading in the strands.

The pressure reading (load) is determined after the pump is turned off.

This is to avoid the hydraulic line pressure loss being included in the liftoff reading.

8.6 — Acceptance criteria

The Engineer shall evaluate the test data and determine whether the anchor is acceptable. Three groups of acceptance criteria shall all be satisfied:

- Creep;
- Movement; and
- Lock-off load.

C8.6 — Acceptance criteria

If anchors fail during testing, it may be necessary to modify the design or construction procedures. These modifications may include reducing the anchor design load by increasing the number of anchors, increasing the bond length, changing the anchor type, or modifying the installation techniques. The Engineer and the anchor Contractor should work closely together to determine the most suitable modifications within the framework of the specifications.

For anchors that have failed a test load criterion, single-strand stressing may help to ascertain mode of failure; for example, pullout of individual strands may indicate debonding at the grout-strand interface, whereas if all strands hold their individual test loads, attention is directed toward failure at the ground-grout interface.

8.6.1 — Creep

The creep amount shall not exceed 1 mm (0.040 in.) at test load during the period of 1 to 10 minutes. If this value is exceeded, then the total creep movement within the period of 6 to 60 minutes shall not exceed 2 mm (0.080 in.).

C8.6.1 — Creep

When an independent fixed reference frame cannot reasonably be used for the dial gauge, the maximum test load on anchors may be increased to 2.0 design load (DL) without holding the load for creep measurements because an anchor that carries 2.0 DL will not likely exhibit creep behavior during testing at the design load (refer to Reference 15).

There are several sources of creep:

1. Movement at the grout-ground interface;
2. Movement within the steel (stress relaxation);
3. Reduction of friction loss in the free stressing length during load hold (most significant for strand with wax in the free stressing length); and
4. Movement at the grout-steel interface.

The creep criterion is intended to determine the creep movement of the grout body through the ground (the first source listed previously). The creep rate of 2 mm (0.080 in.) per log cycle was established for anchors using bare steel at

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stress levels with negligible steel creep. For further discussion, refer to Reference 9.

Bars that have not been cold-stressed will show significant creep within the bar itself when stressed near 80% F_{pu} (refer to Section 4.2.5).

Strand that is stressed near 80% F_{pu} may also show significant creep. Laboratory testing may overestimate the amount of creep that will occur during full-scale field testing. The following approaches may be considered to account for strand creep:

- A correction factor may be determined from a minimum of four single-strand tests of anchors with similar free stressing lengths and strand heat number on the project. The single strand should be tested to the same tensile stress as the multi-strand anchor.
- Single-strand stressing of each strand to 80% F_{pu} and unloading may be performed to reduce the strand creep prior to anchor testing.

Single-strand testing applies only a fraction of the test load to the bond length. In most cases, the effect on the geotechnical performance of the anchor will be insignificant.

For both bar and strand, a telltale (rod not bonded to the grout within the free stressing length) may be used to measure creep of the grout body at the top of the bond length.

8.6.2 — Movement

8.6.2.1 — Residual movement

There is no absolute criterion for the amount of residual movement which is acceptable. Measurement of this residual movement is, however, essential to determine the elastic movement. From that, the apparent free tendon length of the anchor can be calculated for which the acceptance criteria are described in Sections 8.6.2.2 and 8.6.2.3.

The residual movement shall not be interpreted as displacement of the entire bond length.

C8.6.2 — Movement

C8.6.2.1 — Residual movement

The amount of residual movement depends on many geotechnical, installation method, load, and testing factors. Residual movement increases with load, and is typically larger in soil than in competent rock.

Residual movements can also be the result of friction in the free stressing length, which does not allow the prestressing steel to fully return to its unstressed condition. Similarly, movements in the upper portion of the bond length will not be fully recoverable because of friction.

Plastic elongation of bars that have not been cold-stressed will also contribute to the residual movement.

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8.6.2.2 — Minimum apparent free tendon length

The minimum apparent free tendon length at the test load, as calculated on the basis of elastic movement, shall be equivalent to but not less than 80% of the designed free stressing length plus the jack length. If this criterion is not met, the anchor shall be reloaded up to two times more from alignment load (AL) to TL and the calculation repeated on these cycles. If the criterion is still not met, then the cause of this inefficiency in load transfer shall be investigated and the anchor may be rejected or derated.

A limit higher than 80% of the designed free stressing length shall be set in cases where later movements occurring as a result of dissipation of the free stressing length friction would cause unacceptable structural movement.

8.6.2.3 — Maximum apparent free tendon length

The maximum apparent free tendon length at the test load, as calculated on the basis of elastic movement, shall be less than 100% free stressing length plus 50% tendon bond length plus the jack length. However, anchors with longer apparent free tendon lengths shall not be rejected if the cause of the behavior has been investigated and can be satisfactorily explained.

8.6.3 — Initial liftoff reading

This reading shall be within 5% of the specified lock-off load or wedge seating load, whichever is applicable. If this criterion is not met, the load in the tendon shall be adjusted accordingly and the initial liftoff reading repeated.

8.7 — Procedures in the event of failure during testing

If an anchor does not reach the test load as a consequence of grout-ground bond failure, subsequent actions depend on whether the anchor can be post-grouted or not. The decision making process shall follow the decision tree in Fig. 8.5.

COMMENTARY

C8.6.2.2 — Minimum apparent free tendon length

This is calculated to verify that the anchor load is being transferred beyond any potential failure or slip plane in accordance with the overall stability requirements of the anchor-structure system.

C8.6.2.3 — Maximum apparent free tendon length

The apparent free tendon length as determined at the test load also provides additional information on load transfer characteristics within and around the bond length. Apparent free tendon lengths longer than the free stressing length plus half the tendon bond length may be caused by installing the bond length in variable ground where the more competent ground surrounds the lower part of the bond length or the anchor approaching or having reached its ultimate load-carrying capacity.

C8.6.3 — Initial liftoff reading

When the load in a strand tendon is more than 5% above the specified load, it may be preferable to accept the load and so avoid the danger of having wedge marks on the strand below the wedge plate as a result of strand/wedge regripping.

C8.7 — Procedures in the event of failure during testing

RECOMMENDATIONS | **COMMENTARY**

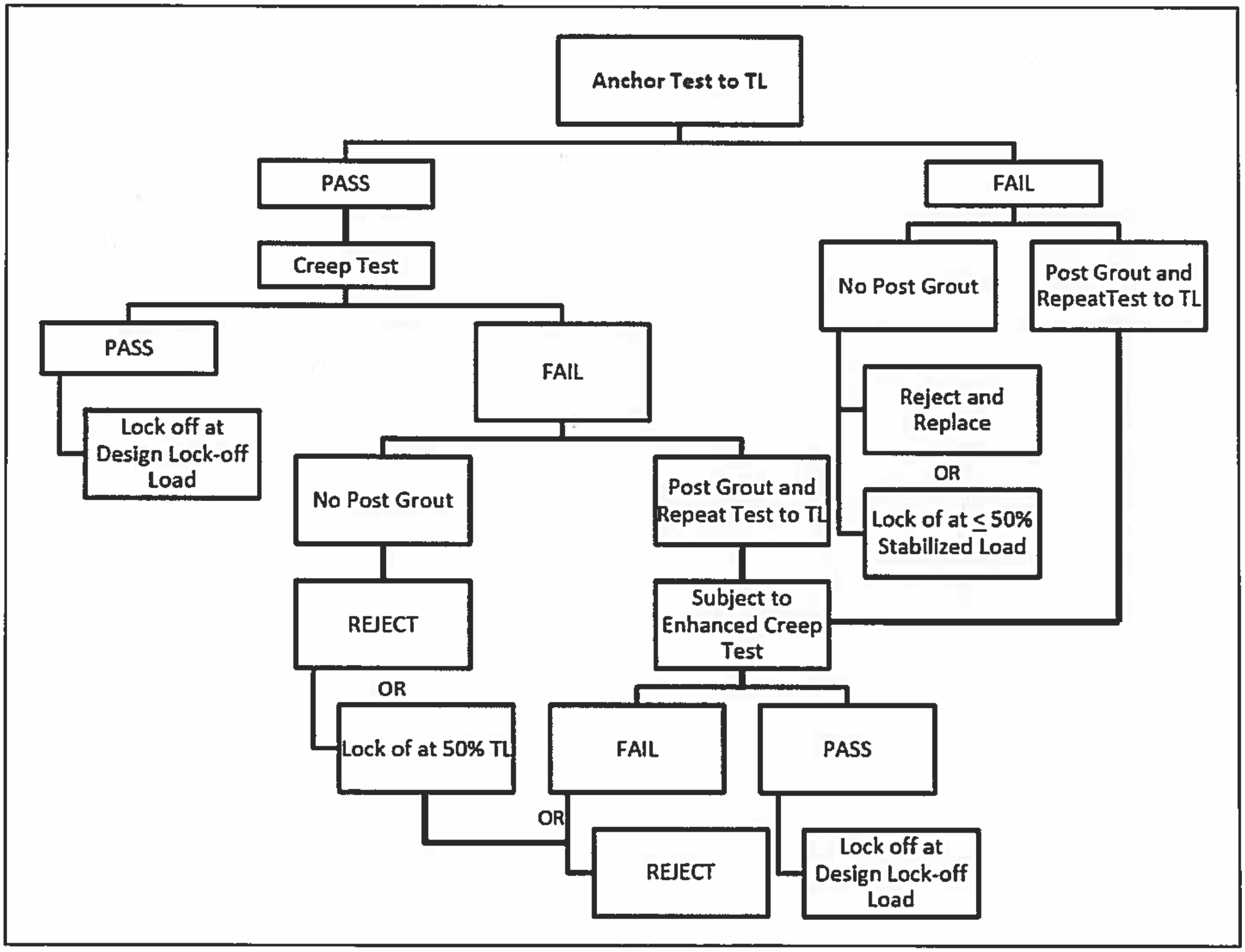

Fig. 8.5—Decision tree for anchor acceptance.

With respect to Fig. 8.5, stabilized load shall be the load on the anchor after 10 minutes of either no pumping of the jack or holding constant deflection.

The enhanced criterion requires a creep movement of not more than 1 mm (0.040 in.) between 6 and 60 minutes at test load.

The enhanced creep criterion allows half the creep movement allowed during a routine load hold.

8.8 — Finishing work for permanent anchors

C8.8 — Finishing work for permanent anchors

RECOMMENDATIONS

8.8.1 — Cutting stressing tails

After stressing and testing has been completed, the stressing tail shall be left uncut until no more liftoff readings are required. After the Engineer has accepted the anchor, the stressing tail shall be cut to its final length by abrasive disks or band saws leaving at least a 13 mm (0.5 in.) protrusion above the wedges or anchor nut.

8.8.2 — Corrosion protection (Class I or II)

For two-stage grouted anchors, the free stressing length shall be filled by tremie grouting.

The transition tube, if required, shall be filled completely with grout.

The trumpet shall be filled completely with grout or corrosion-inhibiting compound per Section 5.4.1.1.

Grout for anchorage covers and trumpets shall be placed when the temperature of the anchorage is expected to remain above freezing for 48 hours. Grouts compatible with the prestressing steel and formulated for below-freezing applications can be used with the Engineer's approval.

The grouting methods and materials shall be selected such that the trumpet and cover are completely filled.

Bearing plate corrosion protection shall be repaired (if damaged) in accordance with the coating supplier's recommendations.

The anchorage cover shall be placed over the anchor head and sealed against the bearing plate. Complete filling of the cover with grout or corrosion-inhibiting compound is required per Section 5.4.1.1.

If covering of the projecting portion of the anchor is a component of the corrosion protection system, appropriate cover per Section 5.4.1.1 shall be provided.

8.9 — Monitoring service behavior

Monitoring of the anchor and the anchored structure during and after construction may be appropriate and the frequency of monitoring shall be decided at the design stage. Monitoring can include visual inspection, measurement of loads, or both.

COMMENTARY

C8.8.1 — Cutting stressing tails

Longer protrusions may be required to remain if the anchor is specified to be restressable.

C8.8.2 — Corrosion protection (Class I or II)

Prepackaged grouts satisfying the requirements of PTI M55.1, neat cement grout with expansive admixtures or multi-stage grouting operations may be required to ensure that the anchor head cover and trumpet are completely filled with grout.

Excessive bleeding in poor-quality grout potentially exposes the prestressing steel to aggressive element attack.

C8.9 — Monitoring service behavior

The purpose of long-term monitoring is to determine if the anchor has maintained its load, has suffered damage, or both, from corrosion.

Load cells have become more reliable and are being used more frequently for long-term monitoring of anchor loads.

RECOMMENDATIONS

Measurement of loads on individual anchors may be performed using load cells, elastomagnetic sensors, liftoff tests, measurement of the performance of the structure, excavation, or a combination of methods. Anchors to be monitored for load changes must remain unbonded in the free stressing length. Specifications may require the load in the anchor to be adjusted at a later time. Specially designed anchor heads will be required to allow later lift-off readings and load adjustments.

The Engineer shall prescribe the monitoring program in terms of anchor number, location, frequency of monitoring, and reporting procedures.

The Engineer shall further determine the maximum loss or gain of load that can be tolerated in any anchor during its service life, taking into account the design of the overall system.

The Engineer shall specify a measurement system for monitoring the anchored structure for movement. The movement of the anchored structure must be known to determine the cause for the change in anchor load and whether remedial measures are required.

In general, observations shall initially be at short intervals of 1 to 3 months, with later monitoring at longer intervals typically not more than 2 years, depending on the results. Any significant load changes shall be evaluated.

Periodic liftoff tests can comprise a portion of a typical monitoring program. Liftoff readings are obtained similarly to the initial liftoff readings. When comparing subsequent liftoff readings with the initial liftoff reading, allowance shall be made for time-dependent load losses (tendon relaxation) and possible movement of the anchored structure.

COMMENTARY

Hydraulic and vibrating wire load cells and elastomagnetic sensors are better suited for job-site conditions than electric resistance load cells. Electric resistance strain gauges and load cells have not shown long-term reliability, although they are better for measuring rapidly changing loads. The design of such systems must address appropriate bearing plate conditions and the length-diameter ratio of the load cell to minimize inaccuracies due to uneven loading and end effects. Hydraulic load cell readings can be influenced by temperature changes.

Monitoring gauges should be secured from damage or vandalism and should be easily accessible. Remote read-out facilities, where practical, permit easy and frequent monitoring.

Liftoff readings within a few hours or days after the initial liftoff are not routinely specified, but when required, are usually performed on permanent anchors only, selected at random. They are not used normally to determine acceptability of anchors.

When unusual behavior is observed, random liftoff readings may be helpful to verify the long-term, load-carrying capacity of a rock or soil anchor; investigate anchor-structure interaction; and explain unusual performance phenomena. They are also used to evaluate anchor performance when no independent reference point for measuring anchor movement is available during testing.

The primary time-dependent load loss for anchors in competent rocks or soils is the result of steel relaxation. Relaxation losses may be up to 3% of the lock-off load in 7 days, depending on the type of steel and its stress level. Estimated values of relaxation losses can be obtained from the tendon supplier.

RECOMMENDATIONS

When an anchor load gain is measured, monitoring shall continue until the load stabilizes. If the load in the anchor approaches the test load, then the tendon shall be destressed to the design load if possible, additional support shall be installed, and the overall anchored structure shall be monitored until the system stabilizes.

COMMENTARY

In cohesive soils and argillaceous rocks, creep can be a significant source of loss of load with time.

9.0 — REFERENCES

9.1 — Referenced standards

9.1.1 — ASTM International

A36/A36M	Standard Specification for Carbon Structural Steel
A53/A53M	Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated Welded and Seamless
A416/A416M	Standard Specification for Steel Strand, Uncoated Seven-Wire for Prestressed Concrete
A500/A500M	Standard Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes
A536	Standard Specification for Ductile Iron Castings
A572/A572M	Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel
A588/A588M	Standard Specification for High-Strength Low-Alloy Structural Steel, up to 50 ksi [345 MPa] Minimum Yield Point, with Atmospheric Corrosion Resistance
A709/A709M	Standard Specification for Structural Steel for Bridges
A722/A722M	Standard Specification for Uncoated High-Strength Steel Bars for Prestressing Concrete
A775/A775M	Standard Specification for Epoxy-Coated Steel Reinforcing Bars
A882/A882M	Standard Specification for Filled Epoxy-Coated Seven-Wire Prestressing Steel Strand
A934/A934M	Standard Specification for Epoxy-Coated Prefabricated Steel Reinforcing Bars
A981/A981M	Standard Test Method for Evaluating Bond Strength for 0.600-in. [15.24-mm] Diameter Steel Prestressing Strand, Grade 270 [1860], Uncoated, Used in Prestressed Ground Anchors
A1081/A1081M	Standard Test Method for Evaluating Bond of Seven-Wire Steel Prestressing Strand
B117	Standard Practice for Operating Salt Spray (Fog) Apparatus
C33/C33M	Standard Specification for Concrete Aggregates
C39/C39M	Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
C138/C138M	Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
C150/C150M	Standard Specification for Portland Cement
C494/C494M	Standard Specification for Chemical Admixtures for Concrete
C595/C595M	Standard Specification for Blended Hydraulic Cements
C618	Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
C940	Standard Test Method for Expansion and Bleeding of Freshly Mixed Grouts for Preplaced-Aggregate Concrete in the Laboratory
C942	Standard Test Method for Compressive Strength of Grouts for Preplaced-Aggregate Concrete in the Laboratory
C989/C989M	Standard Specification for Slag Cement for Use in Concrete and Mortars
C1152/C1152M	Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete
C1240	Standard Specification for Silica Fume Used in Cementitious Mixtures
D92	Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester
D95	Standard Test Method for Water in Petroleum Products and Bituminous Materials by Distillation
D127	Standard Test Method for Drop Melting Point of Petroleum Wax, Including Petrolatum
D512	Standard Test Methods for Chloride Ion in Water
D566	Standard Test Method for Dropping Point of Lubricating Grease
D638	Standard Test Method for Tensile Properties of Plastics
D1248	Standard Specification for Polyethylene Plastics Extrusion Materials for Wire and Cable
D1784	Standard Specification for Rigid Poly(Vinyl Chloride) (PVC) Compounds and Chlorinated Poly(Vinyl Chloride) (CPVC) Compounds
D2487	Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
D3350	Standard Specification for Polyethylene Plastics Pipe and Fittings Materials
D3867	Standard Test Methods for Nitrite-Nitrate in Water
D3963/D3963M	Standard Specification for Fabrication and Jobsite Handling of Epoxy-Coated Steel Reinforcing Bars

D4101	Standard Specification for Polypropylene Injection and Extrusion Materials
D4289	Standard Test Method for Elastomer Compatibility of Lubricating Greases and Fluids
D4751	Standard Test Method for Determining Apparent Opening Size of a Geotextile
G57	Standard Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method

9.1.2 — American Association of State Highway and Transportation Officials (AASHTO)

T 288	Determining Minimum Laboratory Soil Resistivity
T 289	Determining pH of Soil for Use in Corrosion Testing
T 290	Determining Water Soluble Sulfate Ion Content in Soil

9.1.3 — American Public Health Association (APHA)

APHA 4500-S2	Standard Methods for the Examination of Water and Wastewater

9.1.4 — American Water Works Association (AWWA)

AWWA C105	Polyethulene Encasement for Ductile-Iron Pipe Systems

9.1.5 — American Concrete Institute (ACI)

ACI 318	Building Code Requirements for Structural Concrete

9.1.6 — American Petroleum Institute (API)

API RP 13B-1	Standard Procedure for Field Testing Water-Based Drilling Fluids

9.1.7 — Federal Test Method Standard (FTMS)

FTMS 791B	Lubricants, Liquid Fuels and Related Products; Methods of Testing

9.1.8 — Post-Tensioning Institute (PTI)

PTI M10.2-00	Specification for Unbonded Single Strand Tendons
PTI M50.1.98	Acceptance Standards for Post-Tensioning Systems
PTI M50.2-00	Anchorage Zone Design
PTI M55.1-12	Specification for Grouting of Post-Tensioned Structures

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RECOMMENDATIONS

COMMENTARY

SUPPLEMENT A — SUPPLEMENTARY REQUIREMENTS FOR EPOXY-COATED STRAND TENDONS

SA1.0 — SCOPE

Ground anchors using epoxy-coated strand require experience and techniques beyond those for bare-strand anchors. This Supplement provides insight in the use of epoxy-coated strand and offers specific guidance in its use for anchor applications.

This Supplement applies to Chapters 3, 4, 6, 7, and 8 only and contains additional recommendations and commentary pertinent to epoxy-coated strand tendons and shall be read in conjunction with these sections of the PTI Recommendations.

CSA1.0 — SCOPE

This supplement was prepared primarily based on experiences with high-capacity anchors in dams. Refer to References 1 through 6.

Primary concerns related to epoxy-coated strand include:

- Increased creep of the steel (stress relaxation) as compared to bare strand;
- Wedge performance; and
- Maintaining integrity of the epoxy coating.

SA3.0 — SPECIFICATIONS, RESPONSIBILITIES, AND SUBMITTALS

SA3.3.2 — Preconstruction submittals

The Contractor's preconstruction submittals shall address installation, testing, stressing, and quality control procedures that are specific to epoxy-coated strand. These include:

- Handling and storage of tendons;
- Insertion of the tendons into the drill hole, including methods for preventing epoxy coating damage;
- Repair of damaged epoxy coating; and
- Stressing and testing of tendons, including procedures to be used in case of inefficient tendon lock-off.

These submittals and procedures shall be developed in conjunction with the tendon manufacturer.

CSA3.0 — SPECIFICATIONS, RESPONSIBILITIES, AND SUBMITTALS

CSA3.3.2 — Preconstruction submittals

Experience has shown that good results have been achieved on epoxy-coated strand anchor projects where thoughtful procedures and quality control measures have been prepared in advance.

Epoxy-coated strand tendon manufacturers provide valuable experience.

SA4.0 — MATERIALS

SA4.2.3 — Epoxy-coated strand

Epoxy-coated strand shall conform to ASTM A882/A882M.

CSA4.0 — MATERIALS

CSA4.2.3 — Epoxy-coated strand

ASTM A882/A882M specifies a minimum coating thickness of 0.38 mm (0.015 in.). Corrosion salt-spray tests of samples have shown that a 0.38 mm (0.015 in.) coating thickness provides adequate corrosion protection.

RECOMMENDATIONS

The epoxy-coating surface shall be grit-impregnated.

In addition to ASTM A882/A882M, the following shall apply to epoxy-coated strand for anchor tendons:

The epoxy coating shall generally be uniform in thickness circumferentially and shall be free of lumps, which would increase the coating thickness beyond the maximum allowed in ASTM A882/A882M.

The epoxy coating shall be free of craters or collapsed bubbles visible to the unaided eye.

Holiday checks to determine acceptability of the strand shall be made at the manufacturer's plant using a minimum 67 V holiday detector.

Epoxy-coated strand shall be supplied on reels with a minimum outside diameter of 900 mm (3 ft).

When specified by the Engineer, creep testing shall be performed by the strand manufacturer by loading the strand to 70% F_{pu} and maintaining this load constant over a period of 1 hour. The creep movement shall be recorded as a percent of the sample length at 1, 2, 3, 4, 5, 6, 10, 20, 30, 40, 50, and 60 minutes.

If Option 3 in Table SA8.1 is used, relaxation testing shall be performed by the strand manufacturer at a stress level corresponding to the anticipated lock-off load.

A minimum of three creep tests per heat of steel shall be performed on representative samples for every 50,000 m (164,000 ft) of strand for a particular anchor project.

The creep test results for the material supplied and the results of the preceding three sets of tests shall be submitted to the purchaser and shall become part of the construction submittals.

COMMENTARY

Adhesion of the epoxy to the strand is a critical factor in both wedge lock-off effectiveness and corrosion protection. The grit-impregnated surface is very abrasive.

Only a minimum amount of grit is required for bond development with epoxy-coated strand to exceed that of bare strand regardless of how much grit is lost during tendon handling and installation.

A local excess of coating thickness may prevent the wedges from seating and biting evenly into the strand. This could result in strand slippage through the wedge.

Bubbles or blisters in the coating result from the escape of vapors during the coating process and may indicate poor epoxy adhesion. Minute internal bubbles of some degree can be found in all epoxy coating examined with enough magnification and usually are not classifiable as holidays.

Epoxy-coated strand has a memory that maintains part of any previously introduced bend (cast). Large reels will reduce the cast of epoxy-coated strand

Creep in epoxy-coated strand is generally higher than for bare strand. The relaxation of epoxy-coated strand can be as high as 6.5% in 1000 hours at $0.7F_{pu}$, compared to 2.5% for bare strand.

The increased creep is due to metallurgical changes in the steel that result from the heat applied during the epoxy-coating process.

Epoxy-coated strand with creep behavior similar to that of standard ASTM A416/A416M low-relaxation strand is available by special order by some manufacturers (Refer to Reference 7).

Tests have shown that the amount of creep between strands from one manufacturer can vary by up to 50% from the average creep and up to a factor of 3 between manufacturers.

Both creep and relaxation are the result of plastic deformation in the strand under load.

RECOMMENDATIONS

SA4.3 — Anchorages

Wedges for epoxy-coated strand shall be three-part wedges and shall be capable of biting through the epoxy coating and into the strand. Removal of the epoxy coating to allow the use of standard bare strand wedges shall not be permitted.

COMMENTARY

CSA4.3 — Anchorages

Removal of the epoxy coating is difficult and may damage the strand. It also eliminates the corrosion protection where removed.

Wedges for epoxy-coated strand are longer, are larger in diameter, and have deeper and differently shaped teeth than wedges for bare strand. As a result, wedge plates for epoxy-coated strand tendons are larger in diameter and thicker than those for equal capacity bare strand tendons.

SA6.0 — DESIGN

SA6.6 — Anchor design load and safety factors

The quantity of strands required for a given design load shall depend on the testing option chosen from SA8.6.1.

The Engineer shall make provisions for defining the anchor design load in the event of unsatisfactory anchor creep test results.

CSA6.0 — DESIGN

CSA6.6 — Anchor design load and safety factors

The testing options in Table SA8.6.1 account for the stress relaxation properties of epoxy-coated strand. Experience has shown that significantly less creep occurs at $0.7F_{pu}$ than $0.8F_{pu}$. Therefore, anchors tested to $0.7F_{pu}$ at 1.33 DL will have design loads corresponding to $0.53F_{pu}$.

Creep within the steel that occurs during the load hold period does not negatively affect the capacity of the anchor during its service life. Creep that occurs during the load hold will reduce the long-term relaxation losses in the anchor.

SA6.8 — Free stressing length

The minimum free stressing length for epoxy-coated strand shall be 11.5 m (35 ft), unless special details are employed.

The upper 11.5 m (35 ft) shall not be grouted prior to stressing, even if greased and sheathed epoxy-coated strand is used, unless special details are employed.

Spacer/centralizers shall be used in the free stressing length of inclined tendons unless the free stressing length is greased and sheathed.

CSA6.8 — Free stressing length

A longer free stressing length is required for epoxy-coated strand to compensate for the higher wedge seating loss, typically 15 to 25 mm (5/8 to 1 in.), versus 3 to 12 mm (1/8 to 3/8 in.) for bare strand.

The installed tendon tends to have a slightly twisted and wavy shape (from coiling and self-weight). Also, splay of the strands at the anchor head will be present. If these deviations are locked in by grouting around the free stressing length prior to stressing, increased friction can result between the grit-impregnated strand and the bond breaker.

This helps prevent damage to the epoxy coating during installation.

RECOMMENDATIONS

SA7.0 — CONSTRUCTION

SA7.2 — Fabrication

The wedges and wedge cavities shall be thoroughly lubricated with dry graphite spray. Care shall be taken to avoid filling the wedge teeth with grit or epoxy shavings during the tendon assembly. Epoxy-coated strand shall be handled with care to avoid damaging the coating. Stress tails shall be cleaned from excess grit.

Damaged coating shall be patched in accordance with the manufacturer's recommendations. The patching thickness shall not exceed 1.14 mm (0.045 in.) where wedges may grip and bite the strand.

Padding shall be provided underneath the banding of fabricated tendons and on tendon coilers to avoid damage to the epoxy coating.

If the tendons are to be delivered with wedge plates and wedges in place, secure and effective temporary corrosion protection for these parts shall be provided.

SA7.3 — Storage and handling

Upon delivery, the fabricated tendons, even though epoxy-coated, shall be stored in a manner that avoids exposure to moisture, or contamination with dirt or deleterious substances.

Prolonged storage shall be avoided to prevent excessive memory developing in the epoxy-coated strand.

SA7.7 — Tendon insertion

Coiled, epoxy-coated strand tendons will likely have a larger cast than uncoated strand tendons at the insertion end of the anchor. The cast shall be straightened by hand as needed prior to or during the tendon installation.

During insertion of the tendon into the drill hole, the epoxy coating on the strand shall be examined for damage. Damaged epoxy coating shall be repaired in accordance with the manufacturer's recommendations. If the patch is not allowed to cure prior to inserting the tendon in the drill hole, the patched area shall be protected by tape or other suitable means.

COMMENTARY

CSA7.0 — CONSTRUCTION

CSA7.2 — Fabrication

Wet lubricants will attract loose grit, dust, and dirt.

Development of rust on the wedges or in the wedge cavities will interfere with the seating mechanics of the wedge and can result in slippage of the strand upon lock-off.

CSA7.3 — Storage and handling

Exposure of the epoxy coating to sunlight may change the appearance of the product, but does not damage the coating.

Excessive memory will result in a large cast in the tendon, making the insertion into the drill hole more difficult and increasing the risk of damage to the epoxy coating on the outer strands.

CSA7.7 — Tendon insertion

The use of a mechanical straightener is not recommended.

Because the epoxy coating is the primary protection against corrosion, inspection and coating repair are critical.

Patching of the epoxy coating and drying of the patching material slows the installation process. The speed of the tendon insertion will be dependent on the method of repair. Epoxy does not need oxygen for curing, and will fully cure if covered by tape.

RECOMMENDATIONS

Only approved patching materials supplied by the tendon manufacturer shall be used for repairs to the epoxy coating. The Contractor shall allow sufficient time for repairing any damaged epoxy coating during tendon insertion.

SA7.9 — Installation of anchorage

Accurate alignment of the epoxy-coated strand and anchorage hardware is critical, and shall be carefully checked. The bearing and wedge plates shall be installed perpendicular to the tendon axis to enable the wedges to bite evenly through the epoxy. Wedge cavities and wedges shall be free of rust, grout, grit, epoxy shavings, and dirt.

Once the wedge plates and wedges are placed, steps shall be taken to protect them from corrosion.

SA8.0 — STRESSING, LOAD TESTING, AND ACCEPTANCE

SA8.1 — General

Stressing of epoxy-coated strand requires a higher degree of quality control and a better understanding of the wedge seating mechanism than the stressing of bare strand. Therefore, it is important that only personnel with appropriate experience in stressing epoxy-coated strand tendons carry out this work.

SA8.1.1 — Preparation prior to stressing

All practical and reasonable steps shall be taken prior to testing and stressing to ensure a level of cleanliness and lubrication of wedge cavities and wedges that will permit all components to perform as designed.

The wedge teeth shall not be permitted to fill with excessive grit or epoxy when the wedge moves over the epoxy-coated strand prior to and during stressing.

COMMENTARY

CSA7.9 — Installation of anchorage

Epoxy-coated strand is less tolerant to angle variations within the wedge plate than bare strand, because the grit on the strand significantly increases friction resulting from excessive deviations.

Exposed tails can collect condensation that will flow down into the wedges and wedge cavities, potentially causing degradation to the sharp wedge teeth and affecting the amount of friction between wedge and wedge cavity.

CSA8.0 — STRESSING, LOAD TESTING, AND ACCEPTANCE

SA8.1 — General

CSA8.1.1 — Preparation prior to stressing

Contamination resulting from loose grit, rust, grout, and construction debris can cause excessive friction and therefore uneven wedge segment movement during wedge seating. The dry graphite lubrication on the wedges significantly reduces risk of wedge restriction during wedge seating.

Cleaning of the stressing tails from excessive grit during tendon assembly will help considerably in avoiding such problems later in the field.

RECOMMENDATIONS

SA8.2 — Equipment

SA8.2.1 — Requirements for equipment

Jack chairs that allow access to the wedges and provide space for shimming underneath the wedge plate shall be used.

If slack exists in the installed tendon free stressing length, a monostrand jack shall be used to achieve a uniform alignment load (AL) in all strands within the tendon. This jack shall be applied only behind the pulling head of the multi-strand jack.

SA8.3 — Testing

During stressing, the epoxy-coated strand shall not be allowed to pass through a wedge held stationary inside the wedge cavity. Plates used to limit the travel of the wedges (keeper plates) shall be set high enough so that all wedge segments can move out of the wedge cavity at least 75% of the wedge length.

Regripping strands shall be avoided, unless the wedge teeth do not retain epoxy.

SA8.4 — Lock-off procedure

The lock-off procedure for epoxy-coated strand wedges shall allow for the greater wedge seating loss of epoxy-coated strand wedges.

Steel shims shall be placed under the wedge plate after the initial lock-off of the anchor if the liftoff load is less than 95% of the desired lock-off load.

Wedges for epoxy-coated strand shall not be power seated or otherwise forced into the wedge cavity of the wedge plate.

Epoxy-coated strands shall be visually monitored after stressing, especially in the first 1 to 2 days after lock-off, to confirm that strand slippage through the wedges has not occurred.

COMMENTARY

CSA8.2 — Equipment

CSA8.2.1 — Requirements for equipment

Access to the wedges is needed for manipulating them prior to and during stressing operations. "Open-faced" jack chairs supported on the bearing plate also are required for allowing the wedge plate to lift off during liftoff readings and for shimming under the wedge plate.

Using the monostrand jack at the wedge plate may cause the wedge teeth to bite deeply into the epoxy coating, which can make it more difficult to move the wedges later and could allow epoxy to fill the wedge teeth.

CSA8.3 — Testing

Epoxy-coated strand passing through wedges held too tightly around the strand can cause grit or epoxy shavings to build up in the valleys of the wedge teeth, thus preventing full bite of the wedges through the epoxy coating during seating.

Intermediate seating and disengaging of permanent wedges may cause wedge teeth contamination and result in strand slippage.

CSA8.4 — Lock-off procedure

The wedge seating loss for epoxy-coated strand depends on the coating thickness. Also refer to Section S6.8.

This condition occurs when the elongation corresponding to the difference between the test load and the lock-off load is less than the wedge seating loss.

Power seating of wedges will shear the epoxy off the strand. This will prevent proper wedge seating and result in strand slippage.

Slippage may be gauged by observing the relative positions of the stressing wedge bite marks.

SA8.6 — Acceptance criteria

SA8.6.1 — Creep

SA8.6.1.1 — Creep correction values

Because the creep behavior of epoxy-coated strand cannot be predicted with a sufficient degree of accuracy and consistency, creep acceptance criteria based on the use of correction values shall not be used.

SA8.6.1.2 — Creep test options

Table SA8.1 presents the acceptable options for creep testing in order of preference. The Engineer shall specify the option most applicable for the project.

CSA8.6 — Acceptance criteria

CSA8.6.1 — Creep

CSA8.6.1.1 — Creep correction values

Epoxy-coated strands can display significant creep behavior at a test load of 80% F_{pu}.

Under the provisions of the 1996 edition of these Recommendations, the creep test on epoxy-coated strand anchors was to be performed at a test load of 80% F_{pu} and the total measured creep movement was to be reduced by a correction value (based on laboratory creep tests) reflecting the anticipated creep within the epoxy-coated strand itself. The correction value was to be calculated as a percentage of the apparent free tendon length. The correction value was intended to enable the anchor creep movements to be compared with the recommended creep rate of 2 mm (0.080 in.) per log cycle that was established for anchors using bare prestressing strand.

However, the large correction values derived from laboratory creep tests would often either exceed the measured creep movement or be a large percentage of the measured creep.

Furthermore, laboratory tests from 2003 have shown that creep in epoxy-coated strand varies between manufacturers and also within production lots. For example, at a test load of 80% F_{pu}, creep movements of epoxy-coated strand from one manufacturer can be estimated to be 0.017% of the length during the 6 to 60 minute log cycle, with a variation possible between 0.006 to 0.024%. Results from another manufacturer show higher creep movements, varying from 0.033 to 0.067%.

These large variations in laboratory test results have produced a wide range of potential correction factors, even for samples from the same manufacturer. As a result, the determination of reliable correction factors was problematic, and led to creep acceptance concerns on some projects.

CSA8.6.1.2 — Creep test options

The decision on which option to choose will depend on the interpreted creep susceptibility of the ground and the type of epoxy coated strand that is used.

Table SA8.1 — Creep test options

Options		Creep criteria	Test load as % of F_{pu}	Comments
1	Test to 1.5 DL	None	80	No creep test is conducted
2	Test to 1.33 DL	Same as bare strand	70	Limited test data suggest creep for epoxy-coated strand at this stress level is similar to bare strand
3	Test to 1.33 DL and conduct subsequent liftoff tests	None	80	Lift-off must be at least the original load minus the predicted tendon relaxation at the lock-off load stress.

Options 1 and 2 will result in a lower stress level in the strands at design load and will therefore require a greater number of strands at a given design load compared to Option 3.

SA8.6.1.4 — Acceptance criteria

Option 1:

Creep testing of epoxy-coated strand anchors installed in rock or coarse-grained soil shall be omitted and the test load (TL) increased to 1.5 times the design load (DL) but not exceeding $0.8F_{pu}$ at 1.5 DL. In this case, the design load of the anchors shall be lowered to not more than $0.53F_{pu}$.

Option 2:

Creep testing of epoxy-coated strand anchors shall be conducted at a test load of 1.33 DL and a maximum strand stress of $0.7F_{pu}$. In this case, the same acceptance criteria as for bare strand apply. The design load for the anchor shall be lowered to not more than $0.53F_{pu}$.

Option 3:

Creep testing of epoxy-coated strand anchors installed in rock or coarse-grained soil shall be replaced by subsequent liftoff tests. A liftoff reading shall be made immediately after locking the anchor off, at 24 hours and at longer periods that may be specified by the Engineer. The new liftoff load, within reading errors, shall correspond to the original liftoff load minus the predicted relaxation losses for the 24-hour period. This procedure may also be applied to anchors where unexpectedly high creep movements have been observed under Option 2.

CSA8.6.1.4 — Acceptance criteria

These anchors, when tested to an overload of 1.5 design load (DL), would be expected to have creep movements at the groutground interface of less than 2 mm (0.080 in.) per log cycle, which is the creep requirement applied to anchors tested to 1.33 DL.

A limited number of laboratory and field tests have shown that the creep rate of epoxy-coated strand at $0.7F_{pu}$ is similar to the creep rate of bare strand at $0.8F_{pu}$.

This option relies on the anchor performance at the initial lock-off load, as measured over a limited time, rather than on creep failure criteria under an elevated test load.

Liftoff readings can usually be taken with an accuracy of 1 to 2%. The load loss in the prestressing steel within 24 hours can be predicted from the relaxation curves supplied by the strand manufacturer at the stress level corresponding to the lock-off load. The use of relaxation data at higher stress level is unconservative.

In case of unsatisfactory behavior, further liftoff readings may be taken up to 30 days later to verify an acceptable predicted long-term behavior of the anchor, based on criteria similar to the 24-hour liftoff parameters.

The 24-hour lift-off reading usually gives sufficient insight into the predicted long-term behavior of the anchor.

SA8.6.2 — Movement

SA8.6.2.2 — Minimum apparent free tendon length

CSA8.6.2 — Movement

CSA8.6.2.2 — Minimum apparent free tendon Length

Friction in the free stressing length of greased and sheathed epoxy-coated anchors may be higher than for bare strand anchors because of the grit-impregnated in the epoxy surface.

SA8.7 — Procedures in the event of strand slippage through wedges

In the case of individual strand slippages after lockoff, restressing the slipped strand with a monostrand jack and seating new wedges either in the existing wedge cavity or in a barrel chuck placed on top of the wedge plate shall be an acceptable repair procedure.

CSA8.7 — Procedures in the event of strand slippage through wedges

Difficulties in removing wedges from the wedge cavity may be encountered.

SA9.0 — REFERENCES

SA9.2 — Cited references

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RECOMMENDATIONS | COMMENTARY

SUPPLEMENT B — REQUIREMENTS FOR POLYESTER RESIN ROCK ANCHORS

SB1.0 — Scope

This section provides guidance for the use of prestressed polyester resin rock anchors. Polyester resin bonded rock anchors require different design, installation, and testing procedures than cement grout bonded anchors. This section describes polyester resin materials and addresses the procedures required when polyester resin cartridges are used in the bond length of bar tendons installed in rock.

In addition to the requirements of this Chapter, the design and installation of polyester resin anchors shall conform to the requirements of the polyester resin manufacturer.

CSB1.0 — Scope

Polyester resin bonded anchors are installed in rock using rotary percussion drilling equipment. Cement grout bonded anchors are installed in all types of rock and soil using many different drilling methods.

Polyester resin manufacturers typically have design and installation requirements that are specific for their product.

SB1.1 — Definitions

Refer to Chapter 2.0.

SB1.2 — Specification, responsibilities, and submittals

Refer to Chapter 3.0.

Polyester resin manufacturer's product data sheets and installation instructions shall be included in submittals.

SB1.3 — Materials

Materials used for polyester resin anchors shall conform to the applicable requirements of Chapter 4.0 in addition to the requirements that follow.

Polyester resin shall be formulated from an unsaturated polyester resin and a separate catalyst. The resin shall be a high-strength polyester resin, evenly filled with nonreactive, inorganic aggregate of suitable size. The catalyst shall be filled with a nonreactive inorganic filler.

The following properties of polyester resin shall be specified for each project:

CSB1.3 — Materials

The polyester resin, together with a filler material, is usually contained in a sausage-shaped tube of polyester film or glass. The catalyst is enclosed in a separate container inside the cartridge, or separated from the resin by a physical/chemical barrier. Liquid resins, where the two components are mixed just before being pumped into the drill hole, may also be used provided their gel time characteristics are appropriate.

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(a) Gel time is controlled by the amount and kind of catalyst contained in the cartridge and can range between less than 1 minute to 30 minutes or more. Based on a temperature of 22°C (72°F), resin is classified as:

- Fast setting: 2 minutes or less;
- Medium setting: 5 to 10 minutes; or
- Slow setting: 15 to 30 minutes or more.

(b) Cure time normally ranges between 5 and 20 minutes or more: Typically 80% of the compressive strength can be reached over a period of five times the gel time.

(c) Physical properties of cured resin: Typical properties of the cured resin are:

- Compressive strength: 48 to 124 MPa (7000 to 18,000 psi);
- Tensile strength: 21 to 41 MPa (3000 to 6000 psi); and
- Shear strength: 17 to 34 MPa (2500 to 5000 psi).

(d) Viscosity: Resin cartridges are available in different viscosities. Viscosity of the resin also depends highly on temperature. Increased temperatures reduce viscosity.

(e) Shelf life: For each shipment, the manufacturer shall state the shelf life of the resin. Expired resin cartridges shall not be used unless proper performance has been established by tests. The cartridges shall be stored in a dry, cool ventilated place away from direct sunlight. Extreme temperatures shall be avoided.

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Gel time is dependent on temperature, rotational mixing speed, and time. A 35°C (95°F) temperature can reduce gel times by half and a 7°C (45°F) temperature may quadruple standard gel times as defined at 22°C (72°F). For extreme conditions, such as temperatures below 7°C (45°F), the resin manufacturer should be consulted.

Cure time depends on the amount and type of catalyst, as well as on temperature.

Resin properties vary with the manufacturer. For detailed information, the resin manufacturer should be consulted. Normally, the physical properties of the resin do not influence the resin anchor design, as the compressive and shear strength of the rock will be the governing factor in rock/resin bond design.

Special project conditions may require a resin with a modified viscosity. For easier installation of long fully bonded anchors or for low temperature conditions, the use of a low-viscosity resin may be of advantage. To prevent loss of resin from overhead anchors, a high-viscosity resin may be used.

Depending on the manufacturer and type of cartridge, the shelf life normally ranges from 6 months to 1 year.

SB1.4 — Corrosion protection

Polyester resin shall be used to provide corrosion protection for rock anchors in accordance with Chapter 5.

The Engineer shall specify the level of corrosion protection required and the details of the corrosion protection system, including the anchorage protection.

Polyester resin provides Class II protection when it surrounds the bonded portions of fully or partially bonded bar tendons that are installed in sound rock or concrete. The polyester resin must completely cover

CSB1.4 — Corrosion protection

Refer to Fig. 5.1, Corrosion protection decision tree.

The anchorage is redundant for fully or partially bonded tendons because all or a portion of the free stressing length is bonded to the supported rock or concrete after testing and stressing. The Engineer may determine that a corrosion-protected anchorage is not necessary.

Polyester resin protects the prestressing bar by forming a barrier but does not provide a passivating environment around the steel like portland cement grout. Complete

RECOMMENDATIONS

the prestressing bar in order to provide Class II protection.

Class II protection shall conform to Section 5.4.1 and shall include both an anchor head cover (if exposed) and a trumpet, if specified by the Engineer. Polyester resin shall be allowed to be substituted for cement grout for filling anchor head covers and trumpets.

SB1.5 — Design

The design of polyester resin rock anchors shall conform to the applicable requirements of Chapter 6. The following items shall also be specifically considered by the Engineer and evaluated for compatibility:

- Selection of fully bonded, partially bonded, or unbonded anchor;
- Drill hole inclination;
- Resin cartridge diameter and volume;
- Corrosion protection requirements;
- Testing requirements; and
- Installation method.

The design shall incorporate the resin manufacturer's recommendations for resin cartridge selection and installation. All design assumptions shall be verified by field tests.

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coverage of the prestressing bar with resin may be difficult in the vicinity of the anchorage or in fractured rock. No corrosion protection is provided where the resin is not present.

CSB1.5 — Design

Prestressed resin anchors may be fully bonded, partially bonded, or unbonded anchors. All resin anchors have resin along the bond length; however, the drill hole along the free stressing length may be filled with resin or cement grout or left empty.

Polyester resin anchors can be installed in upward, downward, or horizontal positions. The viscosity of the resin should be such that resin will not flow out of upward sloping drill holes. Retainer clips may be required to retain resin cartridges in upward sloped holes.

Standing fresh or salt water in the drill hole will dilute the resin and may degrade the drill hole wall, possibly reducing the bond strength of the anchor compared to dry conditions. Selection of the resin cartridge diameter is based on the manufacturer's suggested relation between the drill hole and the bar diameter. For best results, the difference between the drill hole diameter and bar diameter should be kept to a minimum. The volume of resin in the cartridges shall be such that the resin will flow toward the drill hole opening during the installation of the bar tendon.

If fractured rock exists along the drill hole, resin loss is possible. In this case, the resin cannot be relied upon for corrosion protection or load transfer. If this occurs, pregrouting with a cement-based grout may be required to prevent subsequent loss of resin.

The amount of bond length depends primarily on the compressive strength of the rock. Additional factors affecting the bond length are: the conditions of the drill hole wall, diameter relationship between bar and drill hole, resin type, bar deformations, and proper anchor installation, including resin mixing procedure.

Installation may be difficult for resin anchors with a bonded length exceeding 6 m (20 ft). In such cases, the resin manufacturer should be contacted.

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SB1.6 — Installation

The placing of the resin cartridges and the insertion and rotation of the prestressing bar for mixing the resin components shall follow the manufacturer's recommendations. The bar shall be inserted until it contacts the first cartridge. At this point, the bar shall be rotated and advanced down the hole at a penetration rate of approximately 3 to 8 m (10 to 25 ft) per minute. When the bar reaches its final position, rotation shall be continued for 15 to 30 seconds or a minimum of 60 revolutions to ensure complete mixing of the resin. Care shall be taken to stop mixing before the gel time of the fast-setting resin has expired.

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CSB1.6 — Installation

The equipment used for drilling is also normally used for pushing and rotating the prestressing bar through the resin cartridges.

Resin manufacturers typically recommend rotation speeds during mixing of 60 rpm or higher. Rotating at less than 60 rpm may cause incomplete mixing of the resin. It may be difficult to maintain minimum rpm when the bonded length exceeds 6 m (20 ft).

To facilitate puncturing of the resign cartridges, the prestressing bar may be cut at a 45-degree angle on the down-hole end. If epoxy-coated bars are used, the bevel cut must be patched with an approved epoxy-coating patch kit.

When resin cartridges are used along the full length of the tendon, fast-setting cartridges are placed in the tendon bond length and slow-setting resin cartridges are placed in the free stressing length. The tendon must be prestressed after the fast-setting resin has cured but before the slow-setting resin has cured. The timing is critical to ensure load transfer to the bond length only.

When resin cartridges are not used along the free stressing length, special measures may be required if the free stressing length is to be bonded to the surrounding rock or concrete. In one method, the free stressing length is overdrilled to a diameter that will later accommodate a grout tube to fill the free stressing length of the anchor with cement grout consistent with Section 4.11 or liquid resin in accordance with SB1.4. The bearing plate for the anchor must accommodate the grout tube by means of a keyhole or drilled hole in the plate. The anchor bond length is drilled with a hole diameter in accordance with the polyester resin manufacturer's recommendations for bar and resin diameter. To facilitate resin cartridge placement in the bond length, a PVC tube is inserted through the larger-diameter drill hole in the free stressing length. Resin cartridges are placed through the tube and pushed to the back of the bond length until the bond length is completely full. The PVC tube is removed and the prestressing bar is inserted and rotated until initial set is attained in the bond length. The bearing plate, washers, and hex nut are installed; the proof or performance test is conducted; and the anchor is locked off at the specified load. The grout tube is then inserted through the keyhole or drilled hole in the plate to the top of the bond length and the free stressing length is filled with grout.

SB1.7 — Testing

Stressing and testing shall be in accordance with Chapter 8.0 of these recommendations.

SB1.7.1 — Performance testing

Performance tests shall be in accordance with Section 8.3.2 and Table 8.1 of these recommendations.

CSB1.7.1 — Performance testing

It is not possible to conduct a performance test on a resin anchor that uses slow-set resin cartridges in the free stressing length because the resin will harden prior to completion of the test. Therefore, the free stressing lengths of selected tendons are typically left without resin to conduct performance tests. If special provisions are not made to compensate for the missing resin in the free stressing length, the anchors may not be able to be incorporated as production anchors in permanent applications.

SB1.7.2 — Proof testing

Proof tests shall be in accordance with Section 8.3.3 and Table 8.2 of these recommendations.

CSB1.7.2 — Proof testing

Proof tests can be conducted on resin anchors installed with fast-set resin in the bond length and slow-set resin in the free stressing length. After inserting and rotating the prestressing bar, the anchorage hardware must be installed and testing equipment placed on the anchor in a timely manner. This enables the proof test to be conducted and the anchor locked off at the specified load prior to the slow-set resin hardening in the free stressing length.

For anchors with free stressing lengths exceeding 3 m (10 ft), lengthy installation times may result in the free stressing length resin hardening prior to the proof test being completed. In these cases, the diameter of the drill hole along the free stressing length may need to be increased to accommodate a grout or resin injection tube as described in SB1.7.

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