Specification for Unbonded Single-Strand Tendons and Commentary

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This specification provides specific performance criteria for materials for unbonded single strand tendons and detailed recommendations for fabrication and installation of unbonded single strand tendons. Specifications are presented for tendons in non-aggressive environments and for tendons in aggressive environments. The more restrictive material, fabrication, and construction requirements for tendons used in aggressive environments are essential to the long-term durability of tendons used in such circumstances.

Notes to Specifier: This specification is incorporated by reference in the project specifications using the wording in P4 of the preface and including the information from the mandatory, optional, and submittal checklists following the specification.

ACI Specification 423.6-01 and Commentary 423.6R-01 are presented in a side-by-side column format, with specification text placed in the left-hand column and the corresponding commentary text aligned in the right column. Commentary section numbers are preceded by the letter "R." The Commentary is not a part of this specification.

ACI Committee Reports, Guides, Standard Practices, and Commentaries are intended for guidance in planning, designing, executing, and inspecting construction. The Commentary is intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. The American Concrete Institute disclaims any and all responsibility for the stated principles. The Institute shall not be liable for any loss or damage arising therefrom.

Reference to the Commentary shall not be made in contract documents. If items found in this document are desired by the Architect/Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer.

Keywords: anchorage; construction joint; contractor; coupler; deicer; post-tensioning; prestress; prestressing steel; sheathing; specification; strand; unbonded tendon.

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ACI 423.6-01/423.6R-01 became effective October 31, 2001.

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PREFACE TO ACI SPECIFICATION 423

P1. ACI Specification 423 is intended to be used by reference or incorporation in its entirety in the project specifications. Do not copy individual sections, articles, or paragraphs into the project specifications, because taking them out of context may change their meaning.

P2. If sections or parts of ACI Specification 423 are copied into project specifications or any other document, do not refer to them as an ACI Specification, because the specification has been altered.

P3. Each technical section of ACI Specification 423 is written in the three-part section format of the Construction Specifications Institute, as adapted for ACI requirements. The language is imperative and terse.

P4. A statement such as the following will serve to make ACI Specification 423 a part of the project specifications:

Work on (Project Title) shall conform to all requirements of ACI (Specification number with date suffix and title) published by the American Concrete Institute, Farmington Hills, Michigan, except as modified by these contract documents.

P5. *Units* — The values stated in inch-pound units are to be regarded as the standard. The values in SI units given in parentheses are for information only.

PART 1 — GENERAL

SPECIFICATION

1.1 — Scope

This specification provides specific performance criteria for materials for unbonded single strand tendons and detailed recommendations for fabrication and installation of unbonded single strand tendons. Specifications are presented for tendons in non-aggressive environments and for tendons in aggressive environments.

The more restrictive material, fabrication, and construction requirements for tendons used in aggressive environments are essential to the long-term durability of tendons used in such circumstances.

COMMENTARY

R1.1 — Scope

The intent of this document is to provide detailed specifications for all common structural uses of unbonded post-tensioning tendons. It is not intended to apply to tendons used in ground-supported post-tensioned slabs for light residential construction. There are certain special structures or applications that either because of their service requirements or structural behavior might impose additional requirements on the post-tensioning system that exceed the minimum requirements of this specification. In such cases, a special specification should be developed.

Structures exposed to aggressive environments include all structures subjected to direct or indirect applications of deicing chemicals, seawater, brackish water, or spray from these sources; structures in the immediate vicinity of seacoasts exposed to salt-laden air; and structures where anchorage areas are in direct contact with soil. Stressing pockets that are not maintained in a normally dry condition after construction should also be considered exposed to an aggressive environment. Nearly all enclosed buildings (office buildings, apartment buildings, warehouses, manufacturing facilities) are considered to be non-aggressive environments. The engineer should decide if the structure, or a part of the structure, is exposed to an aggressive environment. Attention should be paid to such areas as the location of stressing-end and intermediate anchors, construction joints, locations of planters, balconies and swimming pools.

The durability of prestressed structures in aggressive environments requires the use of consistently higher quality concrete, and superior construction practices than required in non-aggressive environments.

This specification is not intended to apply to nonstructural applications, which might include topping slabs, waterproofing slabs on fill, and post-tensioning used only for control of cracking or deflection. For nonflexural or membrane type structures primarily under tensile forces, the provisions, where appropriate, are intended to apply.

This specification should be considered a minimum standard and, due to experience or project considerations, may be made more restrictive by the engineer.

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1.2 — Definitions

Aggressive environment — An environment in which structures are exposed to direct or indirect applications of deicing chemicals, seawater, brackish water, or spray from these water sources; and salt-laden air as occurs in the vicinity of seacoasts. Aggressive environments also include structures where stressing pockets are wetted or are directly in contact with soils.

Anchorage — A mechanical device comprising all components required to anchor the prestressing steel and permanently transmit prestressing force to concrete.

Concrete contractor — Contracting entity responsible for placing, finishing, and curing the post-tensioned concrete.

Coupler — A device designed to connect ends of two strands together, thereby transferring the prestressing force from end to end of the tendon.

Encapsulated tendon — A tendon that is completely enclosed in a watertight covering from end to end, including a protective cap over the tendon tail at each end.

Engineer — Design professional responsible for the structural design of the post-tensioned concrete members on the project.

Non-aggressive environment — All environments not specifically defined herein as aggressive, including enclosed buildings.

Prestressing steel — High-strength steel used to prestress concrete, most commonly 7-wire strand. It is the element of a post-tensioning tendon that is elongated and anchored to provide the necessary design prestressing force.

Post-tensioning coating — Material used to protect against corrosion and reduce friction between prestressing steel and sheathing.

Post-tensioning installer — Contracting entity responsible for unloading the post-tensioning materials, storing and protecting them on the job site at all stages of handling, storage, placement, tendon installation, stressing, and tendon finishing in accordance with the contract documents and this specification.

Post-tensioning supplier — Contracting entity responsible for providing all components of the post-tensioning system including the tendons, anchorages, couplers, field placement drawings, and stressing equipment, and delivering them to the job site.

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Sheathing — A material forming an enclosure in which prestressing steel is encased to prevent bonding with surrounding concrete, to provide corrosion protection, and to contain post-tensioning coating.

Tendon — A complete assembly consisting of anchorages, prestressing steel, post-tensioning coating and sheathing. The tendon imparts prestressing forces to concrete.

Unbonded tendon — Tendon in which prestressing steel is prevented from bonding to concrete, and is free to move relative to concrete. Prestressing force is transferred to concrete by anchorages only.

1.3 — Referenced standards

ASTM

A370-97a Standard Test Methods and Definitions for Mechanical Testing of Steel Products

A 416/ 416M-99 Standard Specification for Steel Strand, Uncoated Seven-Wire for Prestressed Concrete

B 117-97 Standard Practice for Operating Salt Spray (Fog) Apparatus

C 1077-00 Standard Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation

D 92-98a Standard Test Method for Flash and Fire Points by Cleveland Open Cup

D 95-99 Standard Test Method for Water in Petroleum Products and Bituminous Materials by Distillation

D 512-89 (1999) Standard Test Methods for Chloride Ion in Water

D 566-97 Standard Test Method for Dropping Point of Lubricating Grease

D 610-95 Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces

D 638-00 Standard Test Method for Tensile Properties of Plastics

D 792-00 Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement

COMMENTARY

R1.3 — Cited references

1. Mattock, A. H.; Yamazaki, J.; and Kattula, B. T., "Comparative Study of Prestressed Concrete Beams, with and without Bond," ACI JOURNAL, *Proceedings*, V. 68, No. 2, Feb., 1971, pp. 116-125.

2. Society of Automotive Engineers, "SAE-J449 Surface Texture Control (1963)," 400 Commonwealth Drive, Warrendale, PA.

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D 2265-00 Standard Test Method for Dropping Point of Lubricating Grease Over Wide Temperature Range

D 3867-99 Standard Test Methods for Nitrite-Nitrate in Water

D 4289-97 Standard Test Method for Elastomer Compatibility of Lubricating Greases and Fluids

E 328-86 Standard Test Methods for Stress Relaxation Tests for Materials and Structures

American Public Health Association
APHA 4500-S^2E

Federal Test Method Standard
FTMS 791 B Method 321.2

Post-Tensioning Institute
Field Procedures Manual for Unbonded Single Strand Tendons, October 2000.

These publications may be obtained from these organizations:

American Society for Testing and Materials (ASTM)
100 Bar Harbour Drive
West Conshohocken, PA 19428-2957
610/832-9585 FAX 610/832-9555

American Public Health Association (APHA)
1015 15th Street N.W., 3rd Floor
Washington, D.C., 20005
202/789-5600

Federal Test Method Standard (FTMS)
U.S. Army General Materiel and Parts Center
Petroleum Field Office (East)
New Cumberland Army Depot
New Cumberland, PA 17070 (NCAD)

Post Tensioning Institute
1717 W. Northern Avenue, Suite 114
Phoenix, AZ 85021-5470
602/870-7540

1.4 — System description

Unbonded single-strand post-tensioning tendons are used as prestressed reinforcement in a wide variety of concrete building projects, and for the strengthening and retrofit of buildings built with all types of structural materials. The tendon consists of the prestressing steel and a post-tensioning coating encased in a sheath that prevents bond with the adjacent concrete and provides additional corrosion protection. Anchor-

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ages transfer the prestressing force to the concrete at the extreme ends of the tendon and at intermediate points as required. When stressing is required at either or both extreme ends of the tendon, the anchorage located at those points is called a stressing-end anchorage. When stressing is required at some point along the length of the tendon, between the ends, the anchorage at that point is called an intermediate anchorage. When stressing is not required at one extreme end of the tendon, the anchorage located at that point is called a fixed-end anchorage.

Tendons are typically fabricated in a manufacturing facility or plant. Fabrication consists of applying post-tensioning coating and sheathing to the prestressing steel, cutting the tendon to a specified length and marking it for a specific location in the structure, attaching the fixed-end anchorages, positioning intermediate anchors, if required, coiling and securing the tendons into bundles which are loaded onto trucks for delivery to the job site along with the stressing-end anchorages, wedges, stressing equipment, and all required accessories.

At the construction site, the tendons are installed into the forms (in new construction) or externally attached to an existing structure (in retrofits). The tendon profile and number of tendons (or effective prestress force) is specified by the engineer. Stressing of the tendons is done with hydraulic equipment (jacks and pumps). In new construction, stressing is done after the concrete is placed and reaches a minimum compressive strength, determined by the engineer. In retrofits tendon stressing is done as soon as practical after installation of tendons and required hardware. After stressing, the protruding ends of the tendons are cut off, and any pockets required to recess the stressing end anchorages inside the concrete surfaces are filled with grout and finished.

1.5 — Submittals

1.5.1 — Prestressing steel

Certified mill test reports shall be furnished for each coil or pack of strand, containing the following test information:

- Heat number and identification;
- Tensile strength;
- Yield stress at 1% extension under load;
- Elongation at failure;

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R1.5 — Submittals

R1.5.1 — Prestressing steel

It is recommended that designers verify the material properties of the strand on their project to avoid the possibility of inadvertent substitution of strand with material having lower physical properties, which might reduce the structural capacity of some members.

Although ASTM A 416/A 416M does not specify a standard chemical analysis for the heat of steel, such analysis is available.

Tensile strength is defined as the tensile stress at ultimate.

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- Modulus of elasticity;
- Diameter and net area of strand; and
- Type of material (normal = relaxation or low = relaxation).

1.5.2 — Anchorages and couplers

Static and fatigue test reports of representative assemblies shall be furnished for each different assembly to be used on the project.

1.5.3 — Sheathing

A sheathing material report shall be furnished containing type, thickness, and density of material; and supporting test data demonstrating compliance with all requirements of Section 2.3.

1.5.4 — Post-tensioning coating

Test results on post-tensioning coating, tested in accordance with Table 1, shall be furnished.

1.5.5 — Fabrication plant

A copy of the tendon fabrication plant certification shall be furnished.

1.5.6 — Stressing jack calibration

Calibration certificates for every jack and gage shall be furnished (Section 3.4.2).

1.5.7 — Stressing records

Stressing records shall be filled out during the stressing operation, with the following data recorded:

- Name of the project;
- Floor number and concrete placement area number;
- Tendon identification mark;
- Required elongation;
- Stressing jack calibration certificate (Section 1.5.6 and 3.4.2);
- Gage pressure to achieve required stressing force per supplied calibration chart;
- Actual elongation achieved;
- Actual gage pressure;
- Date of stressing operation;
- Name and signature of stressing operator or inspector;
- Serial or identification number of jacking equipment;
- Date of approved installation drawings used for installation and stressing; and

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- Weather conditions including temperature and rainfall.

Completed stressing records shall be submitted to the engineer for acceptance.

1.6 — Fabrication

1.6.1 — General

Unbonded single-strand tendons shall be fabricated in a plant certified by an externally audited quality assurance program, which shall ensure that the unbonded tendons and components comply with the requirements of this specification. The post-tensioning supplier shall be responsible for the fabrication and packaging of unbonded tendons. Individual tendons shall be secured in bundles using a tying product that does not damage the sheath. The tendon sheath shall be protected from damage by banding materials. Padding material shall be used between any metal banding and the tendon.

1.6.2 — Handling, storage, and shipping

The post-tensioning supplier shall be responsible for the handling, storage, and shipping of unbonded tendons, including:

1.6.2.1 — Handling

1) Tendons shall not be damaged during handling, loading, or moving at supplier's yard;

2) Smooth forklift booms or padded forks shall be used to handle tendons;

3) Slings used to lift tendons shall be non-metallic (metal chokers or chains shall not be used); and

4) All tendons shall be protected during bundling, handling, loading, and securing to transportation. Tendons shall be protected from rain, snow, deicing salts, and other corrosive elements during transportation.

1.6.2.2 — Storage before shipping

1) All tendons shall be protected from exposure to rain and snow;

2) Fabricated tendons shall be stored on a paved surface with proper drainage away from tendons; and

3) All tendons stored for 1 month or longer shall be protected from the damaging effects of direct sunlight.

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1.6 — Fabrication

R1.6.1 — General

The requirements of this section apply to tendons intended for use in both aggressive and non-aggressive environments. Plants certified by the Post-Tensioning Institute (PTI) have been shown to meet the fabrication requirements of this specification.

R1.6.2.2 — Storage before shipping

Protection is required to prevent water from penetrating tendons.

Means of protection from direct sunlight may be an additive to the sheathing material and/or by external protection.

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1.6.2.3 — Shipping

1) Non-metallic tie-downs shall be used to secure tendon bundles to trailer bed. Metal strapping or chains shall not be used;

2) Protection shall be provided between trailer bed and bundles to protect sheathing during transportation; and

3) Encapsulated materials shipped into areas defined as aggressive environments shall be protected during transportation.

1.7 — Delivery, handling, and storage

1.7.1 — Delivery

Tendons, accessories, and equipment shall be protected to maintain their integrity and satisfy this specification.

1.7.2 — Handling and storage

1.7.2.1 — During the unloading process, care shall be taken not to damage sheathing or anchorages. Chains or hooks shall not be used.

1.7.2.2 — Tendons shall be unloaded as close as possible to the designated storage area to avoid excessive handling.

1.7.2.3 — Materials and equipment shall be stored in a dry area on dunnage. Materials shall not be exposed to water, snow, deicing salts or other corrosive elements. When long-term storage is required (more than one month), materials shall be protected from exposure to direct sunlight.

1.7.2.4 — Wedges and anchorages shall be identified by individual concrete placement area, floor sequence, or both. Materials shall only be used in their identified concrete placement areas. In the event that materials intended for one concrete placement area are exchanged into another concrete placement area, the transaction shall be noted for traceability purposes.

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R1.6.2.3 — Shipping

It is not required that all shipments of encapsulated materials be shrink-wrapped. This may be determined by the engineer on each individual project. Protection of encapsulated tendons during shipping may be done by using enclosed trailers, covering by tarps, or by other methods specified by the engineer.

R1.7 — Delivery, handling, and storage

R1.7.1 — Delivery

If the engineer intends to assign responsibility for protection of tendons, accessories, and equipment to parties other than the post-tensioning supplier during shipping and the post-tensioning installer after shipping, this should be stated in the contract documents.

R1.7.2 — Handling and storage

R1.7.2.1 — It is recommended that nylon or other non-metallic slings be used during unloading and handling of tendons. Slings should never be choked in the handling of tendon coils. Coils should be cradled in the slings by passing them through the center of the coil.

R1.7.2.2 — Multiple storage moves increase the possibility of damage to sheathing and other components of the system.

R1.7.2.3 — Proper job site storage of materials is critical to the integrity of tendons. When tarps are used for protection of the tendons, they should be maintained by the installer and constructed in a tent-like fashion to allow the free circulation of air around the tendon bundles to avoid condensation being trapped under the tarps.

R1.7.2.4 — Any movement of anchorages and wedges about the job site should be done with care to retain the traceability of such materials.

PART 2 — PRODUCTS

SPECIFICATION

2.1 — Prestressing steel

2.1.1 — General

2.1.1.1 — Prestressing steel used in unbonded single strand post-tensioning tendons shall conform to one of the following requirements:

- ASTM A 416/A 416M
- Strand not specifically identified in ASTM A 416/A 416M shall conform to minimum requirements of this specification and have properties meeting requirements of ASTM A 416/A 416M.

2.1.1.2 — Relaxation losses for low-relaxation material shall be based on relaxation tests of representative samples for a period of not less than 1000 h, tested at 68 F ± 3.5 F (20 C ± 2 C) and stressed initially to not less than 70% of specified minimum breaking strength of strand. Tests shall be in accordance with ASTM A 416 /A 416M and ASTM E 328.

2.1.1.3 — Each strand pack or coil shall be clearly identified as to grade, coil and heat number, and either normal-relaxation or low-relaxation. Identification shall be included in the fabrication process documentation.

2.1.1.4 — Material shall be packaged in a manner that prevents physical damage to the strand during transportation and protects the material from deleterious corrosion during transit and storage.

2.1.2 — Acceptance criteria for surface condition

Strand used for tendon manufacture shall be dry. Surface rust, if any is present, shall be removable with a fine steel wool pad or with vigorous rubbing with a cloth. Pits on steel surface shall not exceed 0.002 in. (0.05 mm) in diameter or length.

COMMENTARY

R2.1 — Prestressing steel

R2.1.1 — General

R2.1.1.1 — Provision can be made for new steels, which would include new sizes, improved characteristics of relaxation, or improved mechanical properties. However, use of prestressing steels not covered by ASTM Specifications should be permitted only when the supplier provides test data certified by an independent testing laboratory substantiating that all characteristics of the material are comparable or superior to the properties of steels conforming to the ASTM Specifications. In particular, the stress corrosion characteristics of steels produced by quench and temper heat treatments and steels with specified minimum tensile strengths over 270 ksi (1860 MPa) should be evaluated carefully. Relaxation properties of new steels should be based on a minimum test period of 1000 h.

R2.1.1.2 — It is not practical to run 1000-h relaxation tests on each pack of strand. For qualitative identification of low-relaxation strand, a short-term relaxation test of 30 min to 10 h will suffice. However, a 30-min test will not provide an accurate indication of the ultimate relaxation value. Precise testing procedures are required with mechanical (not hydraulic) equipment in a room with stringent temperature control to evaluate steel relaxation losses.

R2.1.1.3 — Strand is identified by the producer with tags, pack markings, and other means, as well as mill certificates. The documentation flow minimizes the possibility of inadvertent substitution of strand with material having lower physical properties.

R2.1.1.4 — For additional corrosion protection of strand packs, they can be wrapped in special paper impregnated with vapor-phase inhibitor powder.

R2.1.2 — Acceptance criteria for surface condition

For further information, refer to Sason, A. S., “Evaluation of Degree of Rusting on Prestressed Concrete Strand,” *PCI Journal*, May-June 1992, V. 37, No. 3, pp. 25-30. These criteria are not intended for use in evaluating tendons that are in service in existing buildings. The specification for acceptable surface condition is the equivalent of Grade C or better. Grades D, E, or F are not acceptable for new strand used in tendon manufacture. The various grades of surface corrosion are listed below for informational purposes only:

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Grade A: No visible rust.

Grade B: Light surface rust that can be removed by vigorous rubbing with a cloth. No pitting noticeable to the unaided eye. Discoloration in steel surface in affected areas is permitted.

Grade C: Surface rust, removed with a fine steel wood pad, which leaves small pits on the steel of not more than 0.002 in. (0.05 mm) diameter or length.

Grade D: Same as Grade C, except pits exceed 0.002 in. (0.05 mm) diameter or length (can be felt with the fingernail.)

Grade E: Large oxidized areas, with flakes developing in the corrosion affected zones; loss of steel section noticeable to the unaided eye.

Grade F: Heavy oxidation on most or all of the exposed surface areas, with strong flaking and pit formation.

2.1.3 — Compliance requirements

Certified mill test results and typical stress-strain curves shall be submitted. For materials not covered by Section 2.1.1.1, minimum tensile strength, yield stress, and elongation shall be submitted. Samples from each heat (or 'manufacturer's length', in the case of strands), properly marked, shall be provided for verification of prestressing steel quality.

2.2 — Anchorages and couplers

R2.2 — Anchorages and couplers

2.2.1 — Anchorages

Anchorages and couplers of unbonded tendons shall be designed to develop at least 95% of the actual breaking strength of the prestressing steel. Actual strength of the prestressing steel shall not be less than specified by Section 2.1.1, and shall be determined by tests of representative samples of the tendon material in conformance with ASTM A 370. Total elongation under ultimate load shall not be less than 2% measured in a minimum gage length of 3 ft. (915 mm) between two points at least 3 in. (75 mm) from each anchorage.

R2.2.1 — Anchorages

These requirements are intended to provide an adequate strand/wedge connection. In developing these requirements, consideration was given to both previously published specifications and currently available test data on the performance of unbonded tendons. Of particular importance are the specifications for static strength and ductility set for anchorages and couplers in Sections 2.2.1 and 2.2.4, respectively. The following considerations led to these minimum requirements.

Static strength — For flexural members, the maximum permissible design strength f_{ps}, at nominal flexural capacity is approximately 222 ksi (1530 MPa) for normal-relaxation strand and 236 ksi (1627 MPa) for low-relaxation strand (ACI 318-99, Eq. (18-4)). These values are slightly less than the specified yield stress for these materials ($0.85 \times 270 = 229.5$ ksi [1582 MPa], and $0.9 \times 270 = 243$ ksi [1675 MPa] respectively) and are 82% and 88%, respectively, of the specified breaking strength of 270 ksi (1860 MPa). In nearly all cases, the design tendon stress will be substantially less than the yield stress. Accordingly, the requirement that anchorages for unbonded tendons develop 95% of the actual breaking strength of the tendon material provides a substantial safety margin between the ultimate tendon capacity and

SPECIFICATION

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Static ductility — Along with a strength requirement, it is important that specifications for unbonded tendons include a ductility requirement. This is usually expressed as a minimum percent elongation in the gage length under total load. This requirement ensures that the anchorage used does not damage the prestressing steel and lead to a failure at an elongation below that specified. The tendon should elongate appreciably to avoid the possibility of a brittle failure. Test data[1] indicate that the maximum strain that can be expected in an unbonded tendon in a concrete flexural member is approximately 1%.

Because of the sensitivity of the strain in high stress regions, and to provide a comfortable margin of safety, 2% is specified as the required total elongation under ultimate load. A tendon satisfying this requirement will possess ductility capacity greater than the member that contains it.

The gage length is defined as the length of prestressing strand measured between two points each at least 3 in. (75 mm) from each anchorage (3 ft [915 mm] minimum gage length is recommended). This eliminates the need to account for seating loss.

2.2.1.1 — Static tests

The test assembly shall consist of standard production quality components and tendons shall be at least 3.5 ft (1.1 m) long between anchorages. The test shall provide determination of the yield stress, tensile strength, and percent elongation of the complete tendon. It is not required to use the same specimen for static and fatigue tests.

R2.2.1.1 — Static tests

The engineer may not wish to require that static and fatigue testing be performed because these tests are expensive and usually are not necessary on every project. In lieu of testing, data from prior tests on representative tendon samples could be submitted (the provisions of Section 2.2.5 may be satisfactory).

The static test is a tensile test of an assembled tendon. The test specimen should be assembled using standard production quality components that are sampled at random.

The static test should represent as closely as possible actual conditions under which a tendon has to perform in a structure. Thus, the test should include a bearing plate embedded in concrete, or in systems using other means to transmit the prestressing force to the concrete, duplicate the actual working conditions of the anchorage in its concrete environment.

2.2.1.2 — Fatigue tests

Fatigue tests shall be performed on tendon specimens with standard production quality components and with a minimum length of 3 ft (1 m) between anchorages. In the first test, the tendon shall withstand 500,000 cycles between 60% and 66% of the minimum specified tensile strength. In the second test, the tendon shall withstand 50 cycles between 40% and 80% of the minimum specified tensile strength. The period of each cycle involves change from the lower stress level to the upper stress level and back to the lower. It is not required to use the same specimen for both fatigue tests.

R2.2.1.2 — Fatigue tests

Fatigue tests are conducted to prove that the tendon assembly has the capability to resist cyclic loading resulting from the expected service loads, building vibrations, and the dynamic effects of earthquakes. Since unbonded tendons experience changes of stress levels over their entire length, fatigue tests are required.

The 500,000-cycle test over a relatively low stress range is intended to conservatively simulate the variation in tendon stress due to service loads and vibrations that may be expected to occur over the useful life of a commercial building. The 50-cycle test over a high stress range is intended to conservatively simulate the effect of a severe earthquake on the tendon.

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2.2.1.3 — Bearing stresses

Average bearing stresses on concrete created by anchorage shall not exceed values computed by the following equations unless testing by a certified independent laboratory indicates anchorage performance equivalent or superior to anchorages satisfying the requirements of this section.

a) At transfer load—

$$f_{cp} = 0.83 f'_{ci} \sqrt{\frac{A'_b}{A_b} - 0.2}$$

but not greater than 1.25 f'_{ci}

b) At service load—

$$f_{cp} = 0.6 f'_c \sqrt{\frac{A'_b}{A_b}}$$

but not greater than f'_c

where:

f_{cp} = permissible concrete compressive stress;
f'_c = specified concrete compressive strength;
f'_{ci} = specified concrete compressive strength at time of initial prestress;
A'_b = maximum area of the portion of the concrete anchorage surface that is geometrically similar to and concentric with the area of the anchorage; and
A_b = net bearing area of anchorage.

f_{cp} is the average bearing stress P/A_b in the concrete, computed by dividing the force P of the prestressing steel by the net bearing area A_b between concrete and bearing plate or other structural element of the anchorage that has the function of transferring force to the concrete.

Special reinforcement required for the anchorage shall be indicated on installation drawings.

2.2.2 — Castings

Castings shall be nonporous and free of sand, blow holes, voids, and other defects.

2.2.3 — Wedge-type anchorages

Wedges shall be designed to preclude premature failure

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R2.2.1.3 — Bearing stresses

Permissible concrete bearing stresses are included in this tendon material specification because they directly affect the size of tendon anchorages. In the complete design of the anchorage zone, distribution of the concentrated anchorage force to the member should be considered. As the anchorage force spreads into the member, tensile and compressive stresses develop that should be accounted for in the design.

Design criteria for these stresses are not a part of this specification. The bearing stress limitations specified address only the high local stresses in the concrete immediately under the anchorage device. ACI 318 provides requirements for anchorage zones.

Oversized anchorages may be used to allow for early stressing. However, the increase in time-dependent prestress losses due to concrete creep and shrinkage should be considered.

For a rectangular anchorage, A'_b can be determined by extending the diagonals of the anchorage rectangle to form progressively larger rectangles concentric with the anchorage until one diagonal reaches an edge of the concrete bearing surface (either vertical or horizontal). The gross area of the resultant larger rectangle is A'_b. For other anchorage shapes, A'_b is determined in a similar manner.

R2.2.2 — Castings

Important considerations in the design of castings are: raw material grade, surface roughness, surface hardness, flatness of conical angle, compatible angle geometry, and tolerance in combination with wedge and specified strand (Section 2.2.3). The reference for standard surface conditions of castings is Society of Automotive Engineers SAE-J449.[2]

R2.2.3 — Wedge-type anchorages

Due to the dynamic interrelationship of the component parts

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of prestressing steel due to notch or pinching effects under test load conditions stipulated in Sections 2.2.1.1 and 2.2.1.2 for both normal and low-relaxation prestressing steel. Component parts from different manufacturers shall not be used without substantiating test data.

2.2.4 — Couplers

Couplers shall be used only at locations specifically indicated on contract documents. The location of the couplers shall be specified to maintain proper concrete cover.

Couplers shall not be used at points where tendon radius of curvature is less than 480 strand diameters. Couplers shall develop at least 95% of the actual breaking strength of prestressing steel without exceeding anticipated set. Tendon couplers shall not reduce elongation at rupture below that required for anchorages in Section 2.2.1.

Coupler components shall be protected with the same post-tensioning coating used on the strand, and shall be enclosed in sleeving with adequate length to permit necessary movements during stressing.

2.2.5 — Compliance requirements

2.2.5.1 *Conformance testing* — The adequacy of a tendon system shall be confirmed by satisfactory static and fatigue conformance tests in accordance with the minimum requirements outlined in Sections 2.2.1.1 and 2.2.1.2.

2.2.5.2 *Compliance* — Data shall be submitted upon request to show compliance with provisions of Sections 2.2.1.1 and 2.2.1.2.

2.2.6 — Anchorages and couplers in aggressive environments

2.2.6.1 — Anchorages intended for use in aggressive environments shall be protected against corrosion. The design shall require a watertight connection of sheathing to the anchorage and a watertight closing of the wedge cavity and prestressing steel in such a way as to achieve corrosion protection of the anchorage, wedges, and prestressing steel at the fixed-end, intermediate anchorage, and stressing-end. Anchorages shall be designed to attain watertight encapsulation of prestressing steel and all connections shall have demonstrated the ability to remain watertight when arranged in a horizontal position and subject to a uniform hydrostatic pressure of 1.25 psi (8.6 kPa) for a period of 24 h.

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during the transferring of force to wedge-type anchorages, the casting and the wedge should always be considered as one design unit.

R2.2.4 — Couplers

For a 1/2–in. diameter strand the minimum radius of curvature is $480 \times 0.5 = 240$ in. or 20 ft.

R2.2.6 — Anchorages and couplers in aggressive environments

R2.2.6.1 — Corrosion protection of the anchorage may be obtained by various means, including epoxy coating or plastic encapsulation. The use of epoxy coatings is acceptable, however, special inspection is required to identify damage that can occur to the epoxy system during transportation, handling, and installation. Damaging the epoxy coating would breach the encapsulation and make the system unacceptable. Encapsulation systems that employ the use of “bare” metallic anchorages produced from a material that is subject to corrosion are unacceptable.

When testing an encapsulated assembly for watertightness, the specimen should be arranged in a horizontal position to ensure equal hydrostatic pressure of 1.25 psi (8.6 kPa) (minimum) over the entire specimen length. The hydrostatic

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Hydrostatic testing shall include the following additional requirements:

a) Testing shall be certified by an independent testing laboratory and selected by the system manufacturer. The independent testing laboratory shall be certified under ASTM C 1077;
b) Representative samples from production runs selected and assembled by the manufacturer shall be used in testing;
c) Stressing, intermediate, and fixed-end assemblies shall each be tested;
d) Three tests are required for each assembly with all three passing for the system to pass;
e) Retesting is required whenever a component of an assembly changes or the testing criteria changes;
f) The manufacturer of the encapsulation system shall provide identification of all component parts of their individual system and provide assembly instructions that will be sent to the field for the system tested; and
g) During the testing procedure, the following method is required for detecting the presence of moisture:
    1) Add white pigment to the post-tensioning coating; and
    2) Use a colored dye in the water that will contrast with the white color of the post-tensioning coating.

No colored dye staining inside the encapsulation system anywhere on the white post-tensioning coating is permissible.

Encapsulation systems using tape as a component are acceptable provided they pass all requirements of the hydrostatic water test and the requirements of Section 3.2.5.2.

2.2.6.2 — Sleeves used to connect the sheathing to the anchorage of encapsulated systems shall:

a) Meet or exceed the same requirements as the sheathing for durability during fabrication, transportation, handling, storage, and installation;
b) Have 0.050 in. (1.27 mm) minimum thickness;
c) Have a positive mechanical connection to the anchorage at all stressing, intermediate, and fixed ends;
d) Have a minimum overlap between the end of the extruded sheathing covering the prestressing steel and the end of the sleeve and seal shall be 4 in. (100 mm);

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pressure of 1.25 psi (8.6 kPa) approximates 3 ft (1 m) of hydrostatic head. This pressure is considered to be a worst-case situation for normal beam and slab applications. For structures where the hydrostatic head may exceed 3 ft (1 m) (for example, swimming pools, tanks, beams, or slabs below grade) the project specification should require a more stringent test performance.

R2.2.6.2 — The requirements that prohibit voids may be satisfied by filling the sleeves with post-tensioning coating. Transition components at anchorages and couplers should be designed to be void-free.

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e) Be translucent or have another method of verifying that the post-tensioning coating material is free of voids; and
f) Be translucent or have other method of verifying overlap with sheathing.

Sleeves on stressing side of intermediate anchorages must be long enough to cover sheathing removed during stressing and have required 4 in. (100 mm) overlap.

2.2.6.3 — Couplers used in aggressive environments shall have a watertight connection between sleeving and tendon sheathing. Coupler sleeving shall not contain air voids.

2.3 — Sheathing

2.3.1 — General properties

Tendon sheathing for unbonded single-strand tendons shall be made of material with the following properties:

- Sufficient strength and durability to withstand damage during normal fabrication, transport, installation, concrete placement, and stressing;
- Watertight and impermeable to water vapor over entire sheathing length;
- Chemically stable, without embrittlement or softening over the anticipated exposure temperature range and service life of the structure. Free chloride ions shall not be extractable from the sheathing material; and
- Nonreactive with concrete, prestressing steel, reinforcing steel, and tendon post-tensioning coating.

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Some small bubbles and airspaces are normal and unavoidable in the fabrication and assembly process and should not normally be considered as “voids” in the context of this section.

R2.3 — Sheathing

R2.3.1 — General properties

If an encapsulated system is required, see Section 2.2.6 and 2.3.5.

In order to develop standards for determining the acceptability for other sheathing materials to meet the durability requirements reflected by the use of sheathing requirements listed under Section 2.3.2.1, a representative sample of an alternate product shall be used to determining comparable values considering the following baseline characteristics:

a) Abrasion resistance;
b) UV resistance with 6 months exposure;
c) Impact resistance;
d) Chemical resistance to concrete, admixtures, and post-tensioning coating;
e) Chloride ion permeability;
f) Tear resistance;
g) Cold weather exposure;
h) Thermal cracking;
i) Tensile strength;
j) Compressive strength;
k) Brittleness; and
l) Functionality within a temperature range of –20 × F (–30 × C) to + 120 × F (49 × C).

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2.3.2 — Minimum thickness and diameter

2.3.2.1 — Minimum thickness of sheathing used for all environments shall be 0.050 in. (1.27 mm) for polyethylene or polypropylene with a minimum density of 0.034 lb/in^3 (0.941 g/cm^3).

Other materials may be used if data is submitted demonstrating equivalent sheathing performance.

2.3.2.2 — Sheathing shall have an inside diameter at least 0.030 in. (0.76 mm) greater than the maximum diameter of the strand.

2.3.2.3 — Sheathing shall provide a smooth circular outside surface and shall not visibly reveal lay of the strand.

2.3.3 — Manufacturing processes

Sheathing shall be manufactured by a process that provides watertight encasement of the post-tensioning coating.

2.3.4 — Sheathing coverage

Tendon sheathing shall be continuous over the entire length, and shall prevent intrusion of cement paste or loss of coating materials.

2.3.5 — Aggressive environments

The sheathing connection to sleeving at couplers and to all stressing-end, intermediate, and fixed-end anchorages shall be watertight and free of air spaces. Connections shall remain watertight when subjected to a hydrostatic pressure of 1.25 psi (8.6 kPa) for a period of 24 h.

2.4 — Post-tensioning coating

2.4.1 — General properties

The post-tensioning coating shall have the following properties:

- Provide corrosion protection to prestressing steel;

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R2.3.2 — Maximum thickness and diameter

R2.3.2.1 — Due to the manufacturing process, slight variations in the wall thickness may occur locally around the sheath perimeter.

Equivalency can be determined by testing, subject to the approval of the engineer, which demonstrates that all requirements of Section 2.3 are satisfied by the alternate material.

R2.3.3 — Manufacturing processes

The sheathing system is intended to prevent internal migration of any water intruding from the ends or a break in the sheathing.

The sheathing extrusion process, in which the post-tensioning coating is applied to the strand under pressure and the plastic sheathing is extruded onto the strand, meets the intent and requirement of this section.

R2.3.4 — Sheathing coverage

Because of regional differences and varying industry practices, the engineer should specify the length of unsheathed strand permitted in non-aggressive environments at the stressing and the fixed end. Normally, a maximum of 1 in. (25 mm) of unsheathed strand is permitted at stressing ends and up to 12 in. (400 mm) is permitted at fixed ends.

R2.3.5 — Aggressive environments

The sheathing connections should encapsulate the tendon from end to end. A watertight connection may be achieved by either using special connector pieces that provide a watertight connection to the anchor at one end and to the sheathing at the other end, or by other means meeting the watertightness test performance criteria. For watertightness testing arrangement, refer to Section 2.2.6.

R2.4 — Post-tensioning coating

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- Provide lubrication between the strand and sheathing;
- Resist flow caused by gravity within anticipated temperature range of exposure;
- Provide continuous non-brittle coating at lowest anticipated temperature of exposure; and
- Be chemically stable and nonreactive with pre-stressing steel, reinforcing steel, sheathing material, and concrete.

2.4.2 — Type of coating

The coating shall be a compound with appropriate moisture displacing and corrosion-inhibiting properties as specified in Section 2.4.4.

2.4.3 — Minimum quantity

The minimum amount of post-tensioning coating on the prestressing strand shall be not less than 2.5 lb (1.14 kg) of coating material per 100 ft (30.5 m) for 0.5 in. (12.7 mm) diameter strand, and 3.0 lb (1.36 kg) of coating material per 100 ft (30.5 m) for 0.6 in. (15.25 mm) diameter strand. Minimum quantity of coating for other strand sizes may be determined by linear extrapolation. The coating material shall completely fill the annular space between the strand and sheathing. The coating shall extend over the entire tendon length.

2.4.4 — Performance criteria

Post-tensioning coating shall satisfy the requirements listed in Table 1.

COMMENTARY

R2.4.3 — Minimum quantity

The minimum amount of post-tensioning coating is based upon the assumption that the sheath has an inside diameter 0.030 in. larger than the strand resulting in an 0.015 in. coating thickness.

R2.4.4 — Performance criteria

The corrosion tests in Table 1 are based on a coating thickness of 0.005 in. (0.127 mm). The quantities of coating material specified in Section 2.4.3 provide a minimum coating over the crests of the strand of approximately 0.015 in. (0.38 mm).

It is recommended that all post-tensioning coating types be tested every 5 years, even if no chemical changes have been made to their composition during that period.

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Table 1 — Performance specification for post-tensioning coating

Test number	Test description	Test method	Acceptance criteria
1	Dropping point	ASTM D 566 or ASTM D 2265	Minimum 300 F (149 C)
2	Oil separation at 160 F (71 C)	FTMS 791B Method 321.2	0.5% max by mass
3	Water content	ASTM D 95	0.1% maximum
4	Flash point (refers to oil component)	ASTM D 92	Minimum 300 F (149 C)
5	Corrosion test (5% salt fog at 100 F (38 C) 0.005 in. [0.127 mm], minimum hours, Q Panel Type S)	ASTM B 117	Rust Grade 7 or better after 1000 hours of exposure according to ASTM D 610
6	Water-soluble ions:* a. Chlorides b. Nitrates c. Sulfides	 ASTM D 512 ASTM D 3867 ASTM D 4500-S^2E	 10 ppm maximum 10 ppm maximum 10 ppm maximum
7	Soak test [5% salt fog at 100 F (38 C) 0.005 in. (0.127 mm) coating, Q Panel Type S. Immerse panels 50% in a 5% salt solution and expose to salt fog]	ASTM B 117 (modified)	No emulsification of the coating after 720 hours of exposure.
8	Compatibility with sheathing: a. Hardness and volume change of polymer after exposure to grease, 40 days at 150 F (66 C) b. Tensile strength change of polymer after exposure to grease, 40 days at 150 F (66 C)	ASTM D 4289 (ASTM D 792 for density) ASTM D 638	Permissible change in hardness: 15%; volume: 10%. Permissible change in tensile strength: 30%

*Procedure: The inside (bottom and sides) of a 1 L Pyrex beaker (approximate outside diameter 105 mm, height 145 mm) is thoroughly coated with 100 +/– 10 g of corrosion-inhib iting coating material. The coated beaker is filled with approximately 900 cc of distilled water and heated in an oven at a controlled temperature of 37.8 C +/– 1.1 C for 4 h. The water extraction is tested by the noted test procedures for the appropriate water-soluble ions. Results are reported as ppm in the extracted water.

Table 1 — The tests for post-tensioning coatings presented in Table 1 are considered to be baseline tests to ensure that minimum corrosion protection properties are provided. New developments of coating materials may not meet some of these test requirements, and in such cases, other and more comprehensive tests may be necessary to ascertain their adequacy.

Tests 1 and 2 — Limiting the dropping point to 300 F (149 C) minimum is intended to ensure product stability under elevated temperatures, which is possible during tendon fabrication and installation. Together with Test 2, the bleeding of the lighter components from the coating is minimized.

Test 3 — Water content is limited to exclude the presence of free water in the coating material.

Test 4 — This test refers to the oil component in the coating material. Too low a flash point indicates higher content of volatile derivatives, which affect the long term stability and change of consistency of the coating material.

Test 5 — This test provides a method to determine the effectiveness of the corrosion-inhibiting properties of the coating. The method is a standard test used for corrosion-inhibiting coatings such as paints. The acceptance criteria of Grade 7 or better (according to ASTM D 610) after 1000 h of exposure requires that only 0.3% of the area exposed can have indications of corrosion. The test is conducted on a 3 × 6 in. (76 × 152 mm) steel panel with a coating thickness of 0.005 in. (0.127 mm). When determining the percent of area corroded,

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only the area inside 1/4 in. (6 mm) from the edges of the panel is evaluated.

Test 6 — Water-soluble ions known to cause corrosion are limited by this requirement.

Test 7 — The soak test is designed to determine the ability of the coating to provide corrosion protection after having been exposed to standing water for a period of time. Certain coatings will absorb water to the extent that they will emulsify and break down the barrier against moisture reaching the steel. This test will guard against use of such coatings.

Test 8 — Certain petroleum derivatives react with polyethylene or polypropylene, changing its physical properties to the point where they are no longer usable as sheathing materials. This test is required to preclude the use of coatings with such derivatives.

PART 3 — EXECUTION

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3.1 — General

R3.1 — General

3.1.1 — The post-tensioning installer shall inspect tendons and all accessory items at the time of delivery to the job site and prior to off-loading. The post-tensioning supplier shall be notified of any observed damages prior to off-loading. After acceptance, the post-tensioning installer shall have responsibility for all material at the job site.

3.1.2 — Installation shall be performed by individuals certified by an independent training and certification program.

R3.1.2 — Individuals certified by PTI have been shown to meet this requirement.

3.1.3 — The post-tensioning installer shall conform to the recommendations and installation drawings provided by the post-tensioning material supplier and the procedures stated in the "Field Procedures Manual for Unbonded Single-Strand Tendons" by the Post-Tensioning Institute.

3.1.4 — See Section 1.6.2 for requirements for protection of tendons and accessory items during handling, storage, and shipping.

3.2 — Tendon installation

R3.2 — Tendon installation

3.2.1 — General

R3.2.1 — General

3.2.1.1 — Prestressing tendons shall be firmly supported at intervals not exceeding 4 ft (1.25 m). Placing tolerances shall be in accordance with this section or ACI 117-90, whichever is the most restrictive, unless stated otherwise in the Project Specifications.

R3.2.1.1 — Limitations on tendon support intervals are required to prevent displacement during concrete placement.

3.2.1.2 — Tendons shall be attached to supporting chairs or reinforcement without damaging sheathing.

R3.2.1.2 — Sheathing damage would typically include penetrations in the sheathing, which expose the prestressing steel (Section 3.2.5).

3.2.1.3 — Deviations in tendon design profile shall be a maximum of 1/4 in. (6 mm) for member depth less than or equal to 8 in. (200 mm); 3/8 in. (9.5 mm) for member depth over 8 in. (200 mm) and less than or equal to 2 ft (610 mm); and 1/2 in. (12.7 mm) for member depth over 2 ft (610 mm).

R3.2.1.3 — These tolerances are primarily for beams and slabs. For other types of members, tolerances should be specified in the contract documents. These tolerances should be considered in establishing tendon cover dimensions, particularly in applications exposed to deicing chemicals or salt water environments where use of additional cover is recommended.

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3.2.1.4 — Lateral deviations in tendon location shall be permitted if necessary to avoid openings, ducts, chases, and inserts. Such deviations shall have a radius of curvature of not less than 480 strand diameters.

3.2.1.5 — Tendons shall not be exposed to temperatures that would degrade any component, to welding sparks, or to electric ground currents.

3.2.1.6 — In aggressive environments, all exposed components shall be protected within one working day after their exposure during installation.

3.2.1.7 — Water shall be prevented from entering the tendons during installation.

3.2.2 — Stressing-end anchorage

3.2.2.1 — Stressing-end anchorages shall be installed perpendicular to the tendon axis. The transition curvature in tendon profile shall not start closer than 1 ft (0.3 m) from the stressing-end anchorage.

3.2.2.2 — Stressing-end anchorages shall be securely attached to bulkhead forms. Connections shall be sufficiently rigid to avoid accidental loosening. In aggressive environments, the anchor shall be attached to the edge form using fasteners that will not corrode or are protected from corrosion by other means.

3.2.2.3 — Minimum top, bottom, and edge concrete cover for anchorages shall not be less than minimum cover to reinforcement at other locations in the structure. Minimum concrete cover from exterior edge of concrete to wedge cavity area of anchor shall be 1½ in. (40 mm) for non-aggressive environments and 2 in. (50 mm) for aggressive environments.

3.2.2.4 — Pocket formers used to provide a void form at stressing-end and intermediate anchorages shall prevent intrusion of concrete or cement slurry into the wedge cavity.

3.2.2.5 — Stressing-end anchorages in aggressive environments shall have the tendon tail and the gripping part of the anchorage capped at the wedge cavity to completely seal the area against moisture. See Section 2.2.6, 2.3.5, and 3.4.2.

3.2.2.6 — Minimum concrete cover for the tendon tail from the exterior edge of the concrete shall be 3/4 in. (20 mm) for non-aggressive environments and 1 in. (25 mm) to the encapsulating device for aggressive environments.

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R3.2.1.4 — Slab or wall behavior is relatively insensitive to lateral deviations in the location of tendons (perpendicular to the plane of the tendon design profile).

For a 1/2 in. diameter strand the minimum radius of curvature is $480 \times 0.5 = 240$ in. or 20 ft.

R3.2.1.5 — Excessive temperatures are defined as temperatures that deleteriously affect the prestressing steel, anchorages, post-tensioning coating, or sheathing material.

R3.2.1.7 — Possible collectors of water are the coupler and surrounding sheath, transition components between the sheath and anchorage, damaged sheath, and sheath replacement areas.

R3.2.2 — Stressing-end anchorage

R3.2.2.1 — With sharp curvatures at the anchorages, local friction may adversely affect the tendon efficiency and elongation.

R3.2.2.3 — See applicable building code for additional cover requirements, which may exceed these minimums.

R3.2.2.4 — At angled slab edges, minimum concrete covers shall be maintained to the edges of the anchors. Angled pocket formers should take this into account; especially when anchors are oriented horizontally.

R3.2.2.6 — See applicable building code for additional cover requirements, which may exceed these minimums.

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3.2.3 — Intermediate anchorages

3.2.3.1 — Intermediate anchorages shall be embedded in the first concrete placed at a construction joint or the joint shall be made watertight.

3.2.3.2 — Minimum top, bottom, and edge cover requirements of Section 3.2.2.3 shall apply to intermediate anchorages.

3.2.3.3 — In aggressive environments, caps and sleeves shall be installed within 1 working day after the acceptance of the elongation records by the engineer and the cutting of tendon tails.

3.2.4 — Fixed-end anchorages

3.2.4.1 — Wedge-type anchorages

Fixed-end wedges shall be seated with a load of not less than 80% nor more than 85% of the specified minimum breaking strength of the strand.

3.2.4.2 — Fixed-end anchorages shall be placed in formwork at locations shown on the installation drawings, and securely positioned. Minimum concrete cover requirements of Section 3.2.2.3 apply to fixed-end anchorages.

3.2.4.3 — Fixed-end anchorages intended for use in aggressive environments shall be capped at wedge cavity side with a watertight cover. Cover shall be shop installed, after coating the tendon tail and wedge area with the same post-tensioning coating material (Table 1) used over the length of tendon.

3.2.5 — Sheathing inspection and repair

3.2.5.1 — After installing tendons in forms and prior to concrete placement, sheathing shall be inspected by the post-tensioning installer for possible damage. Damaged areas shall be repaired by restoring post-tensioning coating in the damaged area and repairing the sheathing. Sheathing repairs shall be watertight, without air spaces, and acceptable to the engineer.

3.2.5.2 — Tape repair procedures shall conform to “Field Procedures Manual for Unbonded Single Strand Tendons,” Post-Tensioning Institute.

Tape used shall:

- Be self-adhesive and moisture-proof.

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R3.2.3 — Intermediate anchorages

R3.2.3.1 — Plate and barrel type anchors designed to bear against hardened concrete at construction joints are highly susceptible to water leakage through the joint and are not recommended for original construction. In remedial or retrofit work, the use of plate and barrel type anchorages bearing against hardened concrete is often unavoidable. In such cases, the joint, if it is exposed to an aggressive environment, should be waterproofed.

R3.2.5 — Sheathing inspection and repair

R3.2.5.1 — For tendons used in non-aggressive environments, small damaged areas in the tendon sheathing may be permitted without repair with the acceptance of the engineer.

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- Be non-reactive with sheathing, coating, or prestressing steel.
- Have elastic properties.
- Have a minimum width of 2 in. (50 mm)
- Have a contrasting color to the tendon sheathing.

3.3 — Concrete placement

3.3.1 — General

Water shall be prevented from entering the tendons during concrete placing and curing.

3.3.2 — Placement

The position of post-tensioning tendons and non-prestressed reinforcement shall remain unchanged during concrete placement. If tendons are moved out of their designated positions during concreting, they shall be adjusted to their correct position.

3.3.3 — Protection of tendons

3.3.3.1 — Pump lines, chutes, and other concrete placing equipment shall be supported above tendons.

3.3.4 — Sheathing repairs

Damage to sheathing that occurs during concrete placing shall be repaired in accordance with the requirements of Section 3.2.5.

3.4 — Tendon stressing

3.4.1 — General

3.4.1.1 — Water shall be prevented from entering the tendons during stressing and prior to completion of the tendon-finishing operation.

3.4.1.2 — The tendon stressing procedure shall conform to the requirements of the post-tensioning supplier.

3.4.1.3 — Hydraulic-stressing jacks used to stress unbonded single-strand tendons shall be equipped with strand grippers conforming to the requirements of Section 2.2.3.

3.4.2 — Jack calibration

Stressing jacks and gages shall be individually identified and calibrated to known standards at intervals not exceeding 6 months. Calibration certificates for each jack and gage used shall be provided (Section 1.5.6).

R3.4.2 — Jack calibration

It is preferable to calibrate jacks and gages together as a unit. However, gages may be calibrated to a master gage of known accuracy, provided the jacks are calibrated to the same master gage.

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3.4.3 — Elongation measurement

Elongation measurements shall be made at each stressing location. Measured elongations shall agree with calculated elongations within +/–7% as per ACI 318-99. Discrepancies exceeding +/–7% shall be resolved by the post-tensioning installer to the satisfaction of the engineer.

3.5 — Tendon finishing

3.5.1 — General

3.5.1.1 — As soon as possible after tendon stressing and acceptance of measured elongation, excess strand length shall be cut. Strand length protruding beyond wedges after cutting shall be between 0.5 and 0.75 in. (13 and 19 mm). If cutting is delayed more than 10 days after stressing, weather protection shall be provided to prevent water and snow from reaching the anchorages.

3.5.1.2 — The tendon tail shall be cut by means of oxyacetylene cutting, abrasive wheel, or hydraulic shears. Oxyacetylene flame cutting of the tendon shall not be directed toward the wedges.

3.5.2 — Aggressive environments

Before grouting stressing pockets, stressing-end anchorages intended for use in aggressive environments shall be sealed with a watertight cap filled with post-tensioning coating (Table 1, Section 2.2.6, 2.3.5, 3.2.2.5).

3.5.3 — Stressing pockets

3.5.3.1 — Prior to installing grout, inside concrete surfaces of pocket shall be cleaned to remove laitance or post-tensioning coating.

COMMENTARY

R3.4.3 — Elongation measurement

Elongation measurements assist in the verification that the tendon force has been properly achieved. Correlation of calculated and measured elongations within a +/–7% tolerance requires that the elongation calculations be based on the correct modulus of elasticity and area of steel of the tendon or tendons under consideration. Further, the friction and wobble coefficients used may be average values and could vary slightly from project to project. Variations in calculated and measured elongation values in excess of 7% should be evaluated from the standpoint of the number of tendons involved and the structural significance of the variation. Excess elongation resulting from a friction coefficient smaller than that assumed in calculations is usually not a structural problem. Caution should be exercised to avoid repeated restressing of tendons that, due to multiple wedge bites at the stressing end, could affect the long-term performance of the strand.

R3.5 — Tendon finishing

R3.5.1 — General

R3.5.1.1 — In aggressive environments, tendons should be cut within one working day after approval of elongations by the engineer. The elongation report should be submitted on the same day as the stressing operation is completed. The elongation report should be reviewed within 96 h after stressing. Encapsulation caps should be installed within one working day after cutting off tails.

Weather protection, recommended for both aggressive and non-aggressive environments, should be installed as soon as is practical, preferably within 48 h after the post-tensioning installer becomes aware that cutting will be delayed more than 10 days following stressing.

R3.5.2 — Aggressive environments

The design of the stressing end cap should provide a method for visual inspection to verify that the cap is filled with post-tensioning coating and that the cap has been properly installed.

R3.5.3 — Stressing pockets

R3.5.3.1 — To enhance the bond between the grout and the pocket, a bonding agent may be applied to the surface of the pocket. Bonding agents used in potentially wet or submerged applications should not emulsify in water.

SPECIFICATION

3.5.3.2 — Stressing pockets shall be filled with non-metallic non-shrink grout within 1 day after tendon cutting. Grout used for pocket filling shall not contain chlorides or other chemicals known to be deleterious to prestressing steel, and shall be nonreactive with prestressing steel, anchorage material, and concrete.

COMMENTARY

R3.5.3.2 — Early filling of stressing pockets is desirable when practical. See Section 3.5.1.1 for weather protection requirements for anchorages if cutting is delayed more than 10 days after stressing.

FOREWORD TO ACI SPECIFICATION 423.6-01 CHECKLIST

F1. This foreword is included for explanatory purposes only; it does not form a part of Specification ACI 423.6-01.

F2. ACI Specification 423.6-01 may be referenced by the specifier in the project specifications for any building project, together with supplementary requirements for the specific project. Responsibilities for project participants must be defined in the project specifications. The ACI Specification cannot and does not address responsibilities for any project participant other than the contractor.

F3. Checklists do not form a part of ACI Specification 423.6-01. Checklists assist the specifier in selecting and specifying project requirements in the project specifications.

F4. Building codes set minimum requirements necessary to protect the public. ACI Specification 423.6-01 may stipulate requirements more or less restrictive than the minimum. The specifier shall make adjustments to the needs of a particular project by reviewing each of the items in the checklists and including those the specifier selects as mandatory requirements in the project specifications.

F5. The mandatory checklist requirements indicate work requirements regarding specific qualities, procedures, materials, and performance criteria that are not defined in ACI Specification 423.6-01.

F6. The optional checklists identify specifier choices and alternatives. The checklists identify the sections, parts, and articles of the reference specification and the action required or available to the specifier.

Mandatory Checklist

Section/Part/Article of ACI 423.6-01	Notes to engineer
1.1 — Scope	Specify in the Contract Documents whether the tendons are to be fabricated for a non-aggressive or an aggressive environment. If a portion of the project is in each environment, state which portions of the project are in an aggressive environment and which are in a non-aggressive environment.

Optional Checklist

Section/Part/Article of ACI 423.6-01	Notes to engineer
1.5.1 — Certified mill test reports	Specify in Contract Documents if certified mill test reports for prestressing steel are not required to be furnished.
1.5.2 — Anchorages and couplers	Specify in Contract Documents if static and fatigue tests on anchorages and couplers are not required to be furnished.
1.5.3 — Sheathing	Specify in Contract Documents if a sheathing material report is not required to be furnished.
1.5.4 — Post-tensioning coating	Specify in Contract Documents if test results on post-tensioning coating are not required to be furnished.
1.5.5 — Fabrication plant	Specify in Contract Documents if a copy of the tendon fabrication plant certification is not required to be furnished.
1.5.6 — Stressing jack calibration	Specify in Contract Documents if calibration certificates for jacks and gages are not required to be furnished.
1.6.2.3 — Shipping	Specify in Contract Documents if encapsulated materials must be shrink-wrapped.
1.7.1 — Onsite tendon protection	Specify in Contract Documents if installer responsibilities for tendon protection are reassigned and to whom.
1.7.1 — Delivery	Specify responsibility for protection of tendons if other than installer, with consideration for responsibility at various steps in the construction process.
2.1.3 — Compliance requirements	Specify in Contract Documents if certified mill test results and typical stress-strain curves for prestressing steel are not required to be submitted.
2.2.1.1 — Static tests	Specify in Contract Documents if tendon static tests are not required to be submitted.
2.2.1.2 — Fatigue tests	Specify in Contract Documents if tendon fatigue tests are not required to be submitted.
2.2.5.2 — Compliance	Specify in Contract Documents if static and fatigue test data is required to be submitted.
2.2.6.1 — Anchorages and couplers in aggressive environments	Specify in Contract Documents if watertightness test reports for encapsulated tendons are not required to be submitted. Specify in Contract Documents if a hydrostatic pressure higher than 1.25 psi is required for hydrostatic testing.
2.3.4 — Sheathing coverage	Specify in Contract Documents if unsheathed strand is permitted and length of unsheathed strand allowed at fixed-ends and at stressing-ends.
2.4.4 — Performance criteria for post-tensioning coating	Specify in Contract Documents if tests on coating material are not required to be submitted.

Optional Checklist (cont.)

Section/Part/Article of ACI 423.6-01	Notes to engineer
3.1.3 — Installation	Specify in Contract Documents installation requirements other than those contained in the PTI "Field Procedures Manual for Unbonded Single Strand Tendons."
3.2.1.1 — Tendon installation (tolerances)	Specify in Contract Documents any tolerances that are different from ACI 117-90 or those stated in 3.2.1.1.
3.2.1.3 — Installation	Specify in Contract Documents tendon placement tolerances for members other than beams and slabs.
3.2.2.3 — Minimum anchorage cover	Specify in Contract Documents anchorage cover requirements required by the governing code that are in excess of those specified.
3.2.5.1 — Sheathing inspection	Specify in Contract Documents permissible length of unrepaired ruptured tendon sheathing in non-aggressive environments.