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Specification for Unbonded Single-Strand Tendons Used for Slab-on-Ground Construction

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Specification for Unbonded Single Strand Tendons Used for Slab-on-Ground Construction

POST-TENSIONING INSTITUTE
Strength in Concrete

Front matter

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SPECIFICATION	COMMENTARY
1.0—General	
1.1—Scope	**C1.1 — Scope**
These specifications provide performance criteria for materials and detailed recommendations for the fabrication and installation of unbonded single-strand tendons specifically used in any application of slab-on-ground construction using unbonded post-tensioned (PT) reinforcement. Specifications are presented for both “standard” and “encapsulated” unbonded single-strand tendon systems.	The intent of this document is to provide detailed specifications for all common uses of unbonded PT tendons for slab-on-ground applications.
The more restrictive materials, fabrication, and construction requirements for tendons used in aggressive environments referred to as encapsulated tendons in this specification are essential to the long-term durability of the PT system when used in	There are certain special slab-on-ground foundations or applications that, either because of their service requirements or structural

foundations that are exposed to or constructed in these environments. Where appropriate, a commentary follows most major sections of the document.	behavior, might impose additional requirements on the PT system that exceed the minimum requirements of this standard specification. In such cases, a special specification should be developed. Slab-on-ground foundations exposed to potentially aggressive environments may require additional protection of the PT system, as determined to be appropriate by the licensed design professional (LDP). The LDP should evaluate the conditions for each project to determine if the environment in which the foundation is built is to be considered aggressive. This specification may also be used to apply to nonstructural applications, such as topping slabs or waterproofing slabs on fill. This specification should be considered a minimum standard and, due to experience or project considerations, may be made more restrictive by the LDP. The LDP should evaluate the conditions for each project to determine if the environment in which the foundation is built requires additional protection of the PT system. Residential slab-on-ground foundation

	construction requires that there is a minimum of 8 in. from the top of the finished floor to the top of finished grade and that positive drainage away from the foundation be provided. This will, in most cases, ensure that the stressing pockets of the PT system are not permanently in contact with the soil and will prevent ponding of water against the foundation and immersion of the stressing pockets.
1.2 — Definitions	
The following definitions govern in this specification. Refer to "Post-Tensioning Terminology (PTT)" for additional definitions (https://www.post-tensioning.org/education/publications/terminology.aspx). *Aggressive environment* – An environment in which slab-on-ground foundations 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 and coastal waterways. Aggressive environments also include applications where stressing pockets are subject to hydrostatic head. These environments typically require encapsulated tendons. *Anchor* – For unbonded single-strand tendons, a device that houses the wedges and transfers the prestressing force to the concrete. *Anchorage* – A mechanical device consisting of all components required to transfer the PT force from the prestressing steel to the foundation. *Concrete contractor* – Contracting entity responsible for placing, finishing, and curing the PT concrete.	

Coupler – A device used to connect the ends of tendons, making them structurally continuous.

Elongation – Increase in the length of prestressing steel due to the stressing force.

Encapsulated tendon – A tendon that is completely enclosed in a watertight covering from end to end, including anchorages, sheathing with PT coating, and an encapsulation cap over the strand tail at each end.

Encapsulation cap – Plastic cap filled with PT coating with a positive watertight connection to the anchor protecting the wedges and the strand tail.

Jack – A mechanical device (normally hydraulic) used to apply force to a single strand.

Licensed design professional (LDP) – An engineer or architect who is licensed to practice as defined by the statutory requirements of the professional licensing laws of a state or jurisdiction and who is responsible for the structural design and the preparation of Contract Documents for the work.

Nonaggressive environment – All environments not specifically defined herein as aggressive.

Post-tensioning (PT) – Method of prestressing in which prestressing steel is tensioned after concrete has hardened.

PT installer – Contracting entity or entities responsible for unloading and handling the PT materials, storing and protecting them on the jobsite, tendon installation, stressing, and tendon finishing in accordance with the Contract Documents, including this specification.

PT supplier – Contracting entity responsible for furnishing and delivering to the jobsite all components of the PT system, including PT installation drawings and stressing equipment.

Prestressing steel – High-strength steel used to prestress concrete, consisting of seven-wire strands.

PT coating – Material used to protect the prestressing steel against corrosion and reduce friction between prestressing steel and sheathing.

Sheathing – For unbonded single-strand tendons, an enclosure in which prestressing steel is encased to prevent bond with surrounding concrete that provides corrosion protection and contains PT coating.

Slab-on-ground – A concrete foundation supported by the ground and designed to transfer both horizontal and lateral loads to the soil. The foundation may be ribbed or uniformly thick and may be reinforced to resist the effects of soil movement, shrinkage and temperature, and structural loading.

Strand – High-strength steel wires wound around a center wire, typically seven-wire strand, conforming to ASTM A416/A416M.

Strand tail – The protruding length of the strand from the face of the anchor casting that remains in place after the tendon tail has been cut off.

Stressing pocket – The recess created by the pocket former between the stressing or intermediate anchorage and the edge of the concrete to allow the nosepiece access for stressing.

Tendon – A complete assembly of a prestressing element consisting of anchorages and couplers, prestressing steel, PT coating, and sheathing.

Tendon profile – The specified path of a tendon from end to end in a member.

Tendon tail – The protruding length of the tendon outside the stressing anchorage needed temporarily for stressing of the tendon.

Unbonded tendon – Tendon in which the prestressing steel is prevented from bonding to the concrete, and is permanently free to move relative to the concrete. The prestressing force is transferred to the concrete only through the anchorages.

Wedges – Pieces of tapered, high-strength, heat-treated steel with serrations (teeth) that penetrate the prestressing steel during transfer of prestressing force.

Wedge cavity – The tapered opening in the anchor designed to allow the strand passing through and to accommodate the seating of the wedges.

1.3 — References

1.3.1 — Referenced standards and organizations

The standards and reports listed as follows were the latest editions at the time this document was prepared. Because these documents are revised frequently, the reader is advised to contact the proper sponsoring group if it is desired to refer to the latest version.

ASTM International

ASTM A370, Standard Test Methods and Definitions for Mechanical Testing of Steel Products

ASTM A416/A416M, Standard Specification for Low-Relaxation Seven-Wire Steel Strand for Prestressed Concrete

ASTM A1061/A1061M, Standard Test Methods for Testing Multi-Wire Steel Prestressing Strand

ASTM B117, Standard Practice for Operating Salt Spray (Fog) Apparatus

ASTM D92, Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester

ASTM D95, Standard Test Method for Water in Petroleum Products and Bituminous Materials by Distillation

ASTM D217, Standard Test Methods for Cone Penetration of Lubricating Grease

ASTM D445, Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)

ASTM D512, Standard Test Methods for Chloride Ion In Water	
ASTM D610, Standard Practice for Evaluating Degree of Rusting on Painted Steel Surfaces	
ASTM D638, Standard Test Method for Tensile Properties of Plastics	
ASTM D792, Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement	
ASTM D2265, Standard Test Method for Dropping Point of Lubricating Grease Over Wide Temperature Range	
ASTM D3867, Standard Test Methods for Nitrite-Nitrate in Water	
ASTM D4289, Standard Test Method for Elastomer Compatibility of Lubricating Greases and Fluids	
ASTM D4658, Standard Test Method for Sulfide Ion in Water	
ASTM D6184, Standard Test Method for Oil Separation from Lubricating Grease (Conical Sieve Method)	
International Code Council Evaluation Service (ICC-ES) ICC AC303, Post-tensioning Anchorages and Couplers of Prestressed Concrete	
International Organization for Standardization (ISO) ISO/IEC 17065:2012, Conformity assessment — Requirements for Bodies Certifying Products, Processes and Services	
Post-Tensioning Institute (PTI) PTI-CRT20 G1, Manual for Certification of Plants Producing Unbonded Single Strand Tendons	

PTI DC10.2, Construction and Maintenance Manual for Post-Tensioned Slab-on-Ground Foundations

M10.2, Specification for Unbonded Single Strand Tendons

PTI M50.2, Anchorage Zone Design

Society of Automotive Engineers (SAE)
SAE-J449, Surface Texture Control

These publications may be obtained from the following organizations:

ASTM International
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959
www.astm.org

International Code Council Evaluation Service (ICC-ES)
4051 West Flossmoor Road
Country Club Hills, IL 60478
www.icc-es.org

International Organization for Standardization (ISO)
Chemin de Blandonnet 8
CP 401
1214 Vernier (Geneva)
Switzerland
www.iso.org

Post-Tensioning Institute (PTI)
38800 Country Club Drive
Farmington Hills, MI 48331
www.post-tensioning.org

Society of Automotive Engineers (SAE)
400 Commonwealth Drive
Warrendale, PA 15096-0001
www.sae.org

1.3.2 — Cited publications

Chacos, G. P., 2007, “Back-Up Bars for Residential Slab-on-Ground Foundations,” PTI Journal, July, V. 5, No. 1, pp. 17-22.

Sason, A. S., 1992, "Evaluation of Degree of Rusting on Prestressed Concrete Strand," PCI Journal, May/June, V. 37, No. 3, pp. 25-30.

1.4 — System description	**C1.4 — System description**
Unbonded single-strand tendons consist of prestressing steel covered with a PT coating and encased in a continuous sheathing with anchorages at each end and at intermediate locations as required.	Tendons are typically fabricated in a fabrication plant. Fabrication consists of applying PT coating and sheathing to the prestressing steel, cutting the tendon to a specified length, marking it for a specific location in the slab-on-ground foundation, attaching the fixed anchorages, positioning intermediate anchorages (if required by design), and coiling and securing the tendons into bundles. Bundles are then loaded onto trucks for delivery to the jobsite along with the stressing anchors, wedges, and other accessories. At the jobsite, the tendons are installed in accordance with approved installation drawings. The tendon location (profile control points) and the final effective force (or the number of tendons) are specified by the LDP. Stressing of the tendons is done with hydraulic equipment (jacks, pumps, and gauges) after the concrete is placed and reaches a minimum compressive strength specified by the PT supplier and acceptable to the LDP.

	After stressing, the tendon tails are cut off, and any stressing pockets are filled with a patch material and finished.
1.5 — Submittals	**C1.5 — Submittals**
1.5.1 — Prestressing steel Certified mill test reports shall be furnished for each coil of strand, containing as a minimum the following test information: Heat number and identification; Specified tensile strength; Yield strength at 1% extension under load; Elongation at failure; Modulus of elasticity; Diameter of strand; Net area of strand; and Type of material (normal relaxation or low relaxation).	It is recommended that the LDP verify the material properties of the strand on their project to confirm that they are consistent with the material properties specified. Although ASTM A416/416M does not specify a standard chemical analysis for the heat of steel, such analysis is available. Modulus of elasticity should be based on an average value determined from each heat.
1.5.2 — Anchorages and couplers Static and fatigue test reports of representative production assemblies shall be furnished for each different assembly to be used on the project.	
1.5.3 — Sheathing A sheathing material report covering the requirements of Sections 2.3.1 shall be furnished.	
1.5.4 — PT coating Test results on PT coating, tested in accordance with Table 1, shall be furnished.	
1.5.5 — Fabrication plant A copy of the PT Supplier's PTI Unbonded Tendon Plant Certification covering both extrusion and fabrication, or equivalent shall be furnished.	
1.5.6 — Stressing records	

Stressing records shall be completed during the stressing operation, with the following data recorded as a minimum: Name of the project; Date of stressing operation; Name and signature of stressing operator or third-party inspector; Serial or identification number of stressing equipment (jack and gauge) used at each stressing location; Date of approved Contract Document or installation drawing used for installation and stressing; Weather conditions, including temperature and rainfall; Building foundation number or other concrete placement area identification; Tendon identification mark; Calculated elongation; Gauge reading to achieve required jacking force using actual jack calibration certificate; Actual measured elongation at each stressing location; and Actual gauge reading at each stressing location. Completed stressing records shall be submitted to the LDP, if required by the Contract Documents.	
1.6 — Fabrication	**C1.6 — Fabrication**
1.6.1 — General Unbonded single-strand tendons used in PT slab-on-ground foundation construction shall be fabricated in a plant meeting the requirements of Sections 1.6.1.1 or 1.6.1.2. The PT 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 sheathing. The tendon sheathing shall be protected from damage by banding material. Unbonded single-strand tendons shall be fabricated in a plant audited and certified by an external program accredited by a national accreditation body such as the American National Standards Institute (ANSI), International Accreditation Service (IAS), or	*C1.6.1 — General* The requirements of this section apply to tendons intended for use in both nonaggressive and aggressive environments. Padding material may be used between any banding and the tendon to prevent damage. Damage as defined in the context of this specification refers to a rupture or breach in the sheathing, which could allow the possible

equivalent. Nonaccredited certification programs shall meet the essential requirements of the ISO/IEC 17065:2012, Conformity Assessment, including at a minimum the following: (a) Have a documented structure which safeguards impartiality, including provisions to ensure the impartiality of the operations of the certification body; this structure shall enable the participation of all parties concerned in the development of policies and principles regarding the content and functioning of the certification program. (b) Be free of commercial/financial pressures which might influence results and be independent from the entity they are certifying. (c) Have personnel who are competent and who meet defined minimum relevant criteria as defined by the certifying agency. (d) Have criteria outlined in specified standards. (e) Have a procedure for making rules and procedures available to the public.	intrusion of moisture into the tendon**.**
1.6.1.1 — PTI-certified plants Plants shall be certified by the Post-Tensioning Institute (PTI) according to the procedures set forth in PTI-CRT20 G1.	
1.6.1.2 — Non-PTI-certified plants In non-PTI-certified plants, conclusive test data certified by an independent testing laboratory shall substantiate that all characteristics of the unbonded tendons—including traceability of all components; corrosion resistive characteristics; sheathing; and anchorage system, including encapsulation, if required—are equivalent to or superior to the characteristics of tendons fabricated in accordance with this specification (refer to Section 1.6.1.1). The independent testing laboratory shall be accredited to ISO/IEC 17025, General Requirements for the Competence of Testing and Calibration Laboratories, The American Association for Laboratory Accreditation (A2LA), or other equivalent accrediting organizations.	

1.6.2 — Handling, storage, and shipping	*C1.6.2 — Handling, storage, and shipping*
The PT supplier shall be responsible for the handling and storage of unbonded tendons prior to shipping, including:	
1.6.2.1 — Handling prior to shipping (a) Tendons shall not be damaged during handling, loading, or moving at the supplier's plant. (b) Smooth forklift booms, padded forks, or nylon slings shall be used to handle and lift tendons (metal chokers or chains shall not be used). (c) Tendons shall be protected during bundling, handling, loading, and securing to the transport vehicle.	
1.6.2.2 — Storage prior to shipping (a) Stored PT materials that are exposed to any precipitation (snow, rain, and so on) for a period of time longer than 7 days (staging) shall be protected from this exposure (tenting or tarping with adequate ventilation, or shrink-wrapping with moisture control is appropriate). PT materials shall not be exposed to any elements known to be deleterious or corrosive. (b) Tendons shall be stored on dunnage or paved surface with proper drainage away from tendons. Protect tendons that are exposed to sunlight (ultraviolet [UV] degradation). Acceptable protection includes: UV stabilizers added to the sheathing per the manufacturer's recommendation to achieve at least 90 days minimum of UV protection. Protect fabricated tendons that are exposed to sunlight (UV degradation) longer than 1 month maximum from this exposure by tenting or tarping with adequate ventilation unless UV light stabilizers are added to the sheathing per manufacturer recommendations.	*C1.6.2.2 — Storage prior to shipping* Protection is required to prevent water from penetrating tendons.
1.6.2.3 — Shipping (a) Nonmetallic tie-downs shall be used to secure tendon bundles to the bed of the transport vehicle. Metal strapping or chains shall not be used.	*C1.6.2.3 —Shipping* It is not required that all shipments of encapsulated tendons be shrink-wrapped.

(b) When PT materials are transported further than 500 miles (805 km) from the point of fabrication, or during inclement weather, protection shall be provided between the bed of the transport vehicle and bundles to protect sheathing during transportation. (c) PT materials shipped into areas or used on projects defined as aggressive environments shall be protected during transportation by shipping inside of enclosed trailers, covering by tarps, or by shrink-wrapping the tendon bundles. PT materials shall be protected from deicing salts and other corrosive elements during transportation.	This may be determined by the LDP for each project.
1.7 — Delivery, handling, and storage	**C1.7 — Delivery, handling, and storage**
1.7.1 — Delivery	*C1.7.1 — Delivery*
Tendons, accessories, and equipment shall be protected to maintain their integrity.	If the LDP intends to assign responsibility for protection of tendons, accessories, and equipment to parties other than the PT supplier during shipping or the PT installer after shipping, this should be stated in the Contract Documents.
1.7.2 — Handling and storage	*C1.7.2 — Handling and storage*
1.7.2.1 — Handling	*C1.7.2.1 — Handling*
During the unloading process, care shall be taken not to damage sheathing or anchorages. Chains or hooks shall not be used.	It is recommended that nylon or other nonmetallic 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 the slings through the center of the coil.

1.7.2.2 — Storage	*C1.7.2.2 — Storage*
The unloading process shall be done as close as possible to the designated storage area to avoid excessive handling of tendons.	Multiple storage moves increase the possibility of damage to sheathing and other components of the system.
1.7.2.3 — Exposure	*C1.7.2.3 — Exposure*
Upon delivery, all PT tendons and accessories shall be protected from deicing salts and other corrosive elements. Tenting or tarping is acceptable. Tendons shall not be exposed to water, snow, deicing salts, or other corrosive elements. When long-term storage (more than 1 month) is required, tendons shall be protected from exposure to direct sunlight per Section 1.6.2.2.	When tarps are used for protection of the tendons, they should be 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.
1.7.2.4 — Wedges and anchors	*C1.7.2.4 — Wedges and anchors*
Wedges and anchors shall be identified by individual concrete placement areas. These components shall only be used in their identified concrete placement areas. In the event components intended for one concrete placement area are exchanged into another concrete placement area, the transaction shall be noted for traceability purposes.	After assignment to a project, any moving of anchors and wedges should be done with care to retain the traceability of such materials.
2.0 — PRODUCTS	**C2.0 — PRODUCTS**
2.1 — Prestressing steel	**C2.1 — Prestressing steel**
2.1.1 — Mechanical properties	C2.1.1 — Mechanical properties
Prestressing steel shall conform to one of the following requirements: ASTM A416/A416M Strand not specifically identified in the latest edition of ASTM A416/A416M shall conform to or exceed the minimum requirements of this standard.	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 standards should be permitted only

	when the supplier provides conclusive 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 standards. The independent testing laboratory should be accredited to ISO 17025 by A2LA, or other equivalent accrediting organizations. In particular, the stress corrosion characteristics of steels produced by quench and temper heat treatments and steels with specified 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 hours.
2.1.2 — Thermomechanical treatment	
The process shall be conducted at a constant and controlled range of temperature, speed, and stress to ensure proper stress relieving.	
2.1.3 — Traceability	
The strand manufacturing process shall be controlled and documented in a manner providing identification and traceability with regard to coil(s) of strand and wire rod heat number and wire coil(s) used to produce the strand.	
2.1.4 — Testing	
Mechanical Properties:	

Perform breaking strength, yield strength, elongation, and dimensional testing on each 30 ton (27 MT) production lot of finished strand(s) to confirm the requirements of 2.1.1.

Relaxation properties:

Test the finished strand for relaxation at least annually, and also if there is a change in the type of raw material or manufacturing process. Perform the relaxation test according to the requirements of ASTM A416/A416M and ASTM A1061/A1061M.

Perform the relaxation test as a full 1000-hour test at initial production and every third year thereafter. Interim annual 200-hour relaxation tests are acceptable provided that the results when extrapolated to 1000 hours compare consistently to previous satisfactory full 1000-hour test results.

Reporting:

Mechanical, dimensional, and relaxation testing shall be reported showing appropriate heat/coil identification, steel area, and test results. Units shall be in in.-lb units and language shall be English.

Identify testing facility used, whether in-house or otherwise, including physical address and contact information.

2.1.5 — Strand producer records

The manufacturer shall produce and maintain for a period of at least 5 years the following records related to material production:

- Purchasing records showing the purchase of appropriate base materials used in production;
- Product traceability through production and shipping;
- Testing results for tests required under Section 2.1.4, conformities (or nonconformities), and resultant actions;

Calibration records for testing devices indicating calibration to known standards at intervals not exceeding 1 year; Records of quality performance evidencing the occasion, frequency, and percentage of accepted and rejected final product. Records shall include internal and external occurrences, such as on-site lab results and customer responses; Suitability and testing of raw materials including quality reports from wire or rod suppliers; and Procedure for the quarantine and disposal of noncompliant product and records of same.	
2.1.6 — Identification	*C2.1.6 — Identification*
Each coil of strand shall be clearly identified as to grade, coil and heat number, and type of steel (either normal-relaxation or low-relaxation). Identification shall be included in the manufacturing process documentation.	Strand is identified by the producer with tags, coil 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.
2.1.7 — Packaging, marking, storage, and protection	*C2.1.7 — Packaging, marking, storage, and protection*
Each coil of strand shall be packaged in a manner that prevents physical damage to the strand during transportation and protects the strand from deleterious corrosion during transit and storage. Packaging shall meet the purchaser's requirements, or in the absence of specific requirements, shall be appropriate for the environment and conditions that are likely to be encountered during shipping. Strand must be stored in a protected manner to prevent damage. The strand must be protected from corrosion and damage until the customer takes responsibility of it. This responsibility transfer occurs at the point of delivery and acceptance. Controlled access and strand movement shall be used to minimize the possibility of mixing the strand types. Procedures shall be documented. Each coil of strand produced shall have	For additional corrosion protection, the coils of strand can be wrapped in special paper impregnated with vapor phase-inhibitor powder.

two (2) weatherproof and durable tags affixed that indicate the following: Coil number; Strand type (that is, ASTM A416—low relaxation); Grade; Size; and Manufacturer’s name or mark.	
2.1.8 — Acceptance criteria for surface condition	*C2.1.8 — Acceptance criteria for surface condition*
Strand used for tendons shall be dry and shall be graded as follows: 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 area is permitted. Grade C: Surface rust, removed with a fine steel wool pad, which leaves small pits on the steel surface of not more than 0.002 in. (0.05 mm) diameter or length.	For further information, refer to Sason (1992). These criteria are not intended for use in evaluating tendons that are in service in existing foundations. Grades D, E, and F, while not acceptable for new strand used in tendon fabrication, are listed as follows for informational purposes only: 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.

2.1.9 — Compliance requirements	
Certified mill test results and stress-strain curves shall be submitted when requested. A representative stress-strain curve shall be obtained to certify compliance with Section 2.1.1. Properly marked samples from each heat or "producer's length" shall be provided for verification of prestressing steel quality.	
2.2 — Anchorages and couplers	**C2.2 — Anchorages and couplers**
2.2.1 — Anchorages	*C2.2.1 — Anchorages*
Anchorages and couplers shall be designed to develop at least 95% of the specified tensile strength of the prestressing steel specified by Section 2.1.1. Tensile strength shall be confirmed by tests of representative samples of the tendon material in conformance with ASTM A370. Total elongation of the strand under ultimate load shall not be less than 2.0% measured in a minimum gauge length of 3 ft (915 mm) between two points a fixed distance inside each anchorage.	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 requirements for static strength and ductility set forth for anchorages and couplers in Sections 2.2.1 and 2.2.4, respectively. Determination of anchorages meeting these criteria should be based on a series of three consecutive tests with strand from the same heat. 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. These values are slightly less than the specified yield strength for these materials (0.85 × 270 = 229.5 ksi [1582 MPa] and 0.9 × 270 = 243 ksi [1675 MPa], respectively) and are 82% and 88%, respectively, of the specified tensile strength of 270 ksi (1860 MPa). In nearly all cases, the design tendon strength will be substantially less than the yield strength. 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 the tendon design strength.

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 gauge 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. Because of the sensitivity of the strain in these high-stress regions, and to provide a comfortable margin of safety, 2.0% is specified as the required minimum total elongation under ultimate load. A tendon satisfying this requirement will possess ductility capacity greater than the member that contains it. The gauge length is defined as the length of prestressing steel measured between two points a fixed distance inside each anchorage. This eliminates the need to account for seating loss. A 3 ft (915 mm) minimum total gauge length is recommended.
2.2.1.1 — Static tests	*C2.2.1.1 — Static tests*
The test assembly shall consist of standard production quality components and tendons that shall be at least 3.5 ft (1.1 m) long between anchorages. The test shall provide determination of the yield strength, specified tensile strength, and percent elongation of the complete tendon. It is not required to use the same specimen for static and fatigue tests.	The LDP 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.
2.2.1.2 — Fatigue tests	*C2.2.1.2 — Fatigue tests*
Fatigue tests shall be performed on tendon specimens with standard production quality components and with a minimum gauge length of 3.5 ft (1.1 m) between anchorages. In the first test, the tendon shall withstand 500,000 cycles between 60 and 66% of the specified tensile strength. In the second test, the tendon shall withstand 50 cycles between 40 and 85% of the specified tensile strength. One complete cycle involves change from the lower stress level to the upper stress level and back to the lower stress. It is not required to use the same specimen for both fatigue tests.	Fatigue tests are conducted to prove that the tendon assembly has the capability to resist cyclic loading resulting from the flexural and thermal movements of the foundation concrete and the dynamic effects of earthquakes. Because unbonded tendons experience changes of stress levels over their entire length, fatigue tests are required. It is common in the PT industry to refer to these tests as dynamic tests but they are in fact low-cycle fatigue tests. The 500,000-cycle test over a relatively low stress range is intended to conservatively simulate the variation in tendon stress due to flexural and thermal movements of the foundation concrete that may be expected to occur over the useful life of the slab-on-ground foundation. The 50-cycle test over a high stress range is intended to conservatively simulate the effect of a

	severe earthquake on the tendon.
2.2.1.3 — Bearing stresses	*C2.2.1.3 — Bearing stresses*
Average bearing stresses on concrete created by anchorages shall not exceed values computed by the following equations unless testing by an independent testing laboratory indicates anchorage performance equivalent or superior to anchorages satisfying the requirements of this section. The independent testing laboratory shall be accredited to ISO 17025 by A2LA, or other equivalent accrediting organizations. (a) At transfer load $f_{cp} = 0.8 f'_{ci}\sqrt{\frac{A'_b}{A_b} - 0.2}$ but not greater than $1.40 f_{ci}'$ (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} is permissible concrete compressive stress; f_c' is specified concrete compressive strength; f_{ci}' is specified concrete compressive strength at time of initial prestress; A_b' is the 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 is the net bearing area of the 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. Any special reinforcement required for the anchorage shall be determined by the PT supplier and indicated on the installation drawings.	Permissible concrete bearing stresses are included in this tendon material specification because they directly affect the size of tendon anchorages. The constant has been increased for slab-on-ground construction from 1.25 to 1.40 at transfer to allow for stressing of the tendons at a minimum concrete compressive strength of 2000 psi (13.8 MPa). Experience has shown that this is an acceptable practice provided that the anchorages are cast into a perimeter rib or thickened section that is at least 11.5 in. (290 mm) deep, that the anchorage is located and oriented such that $\sqrt{A_b' / A_b}$ is greater than 3.2, and that the nominal slab tendon spacing is greater than 24 in. (0.6 m). For further information, refer to Chacos (2007). 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 bearing area of the resultant larger rectangle is A_b'. For other anchorage shapes, A_b' is determined in a similar manner. The specified bearing stress limitations address only the high local stresses in the concrete immediately around the anchorage device. PTI provides design guidance for anchorage zones in PTI M50.2.
2.2.2 — Castings	*C2.2.2 — Castings*
Castings shall be nonporous and free of sand, blowholes, voids, and other defects. Casting dimensions shall be compatible with anchorage system design specifications.	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 conditions of casting surface conditions is SAE-J449.
2.2.3 — Wedges used in anchorages	*C2.2.3 — Wedges used in anchorages*
Wedges shall be designed to preclude failure of prestressing steel due to notching 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 complete tendon test data.	Due to the dynamic interrelationship of the component parts during the transferring of force to the anchorages, the casting and the wedges should always be considered as one design unit (ICC AC303).

2.2.4 — Couplers	*C2.2.4 — Couplers*
Couplers shall be used only at locations specifically indicated on Contract Documents or as authorized by the LDP. The location of the couplers shall be specified to maintain proper concrete cover. Couplers shall not be used at points where tendon horizontal radius of curvature is less than 20 ft (6.5 m) for 0.5 in. (12.7 mm) diameter strand (adjusted proportionally for other diameters). Couplers shall develop at least 95% of the specified tensile strength of prestressing steel. Tendon couplers shall not reduce elongation at rupture below the 2% required for the tendon in Section 2.2.1. Coupler components shall be protected with the same PT coating used on the strand, and shall be enclosed in sleeving with adequate length to accommodate the elongation of the tendon during stressing.	An example of adjusting the radius proportionally to the strand diameter is: for a 0.375 in. (9.5 mm) diameter strand, the radius of curvature should not be less than 0.375/0.5(20 ft) = 15.0 ft (4.5 m). Refer to Section C2.2.1 for additional background on the strength criteria.
2.2.5 — Compliance requirements	
2.2.5.1 — Conformance testing	
The adequacy of a tendon system shall be confirmed by satisfactory static, fatigue and hydrostatic conformance (if required) tests in accordance with the minimum requirements outlined in Sections 2.2.1.1, 2.2.1.2, and 2.2.6.1.	
2.2.5.2 — Compliance	
Upon request, data shall be submitted to show compliance with provisions of Sections 2.2.1.1, 2.2.1.2, and 2.2.6.1.	
2.2.6 — Anchorages and couplers in aggressive environments	*C2.2.6 — Anchorages and couplers in aggressive environments*
2.2.6.1 — Anchorages	*C2.2.6.1 — Anchorages*

Anchorages used for PT slab-on-ground foundation construction shall be protected against corrosion when the LDP determines the soils or environment in which the foundation is built is to be considered aggressive, as defined in Section 1.2. When anchorages are to be protected against corrosion by encapsulation, a watertight connection of the sheathing to the anchorage and a watertight enclosure of the wedge cavity and prestressing steel are required to provide corrosion protection of the anchor, wedges, and prestressing steel at all anchorages. Anchorages shall be designed to attain watertight encapsulation of the prestressing steel and all connections shall have demonstrated the ability to remain watertight when subject to pressure of 1.25 psi (0.0086 MPa) for a period of 24 hours.	The LDP should evaluate the condition for each project to determine if the environment in which the foundation is built is to be considered aggressive. Protection of the anchorages of the PT system may be obtained by various means, including epoxy coating, plastic encapsulation, or other acceptable means. The use of epoxy coating 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. Encapsulated tendons 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 position to ensure at least a pressure of 1.25 psi (0.0086 MPa) over the entire specimen length. The pressure of 1.25 psi (0.0086 MPa) approximates 3 ft (1 m) of water pressure. This pressure is considered to be a worst-case situation

for normal applications. For applications where water pressure may exceed 3 ft (1 m) (for example, slabs below grade), the project specification should require a more stringent test performance.

It is recommended that pressure testing include the following additional requirements:

(a) Testing should be certified by an independent testing laboratory selected by the system manufacturer. The independent testing laboratory should be accredited to ISO 17025 by A2LA, or other equivalent accrediting organizations.

(b) Representative samples from production runs selected and assembled by the manufacturer should be used in testing.

(c) Stressing, intermediate, and fixed anchorage assemblies should 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 encapsulated tendons should 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. Encapsulated tendons using components from different manufacturers are acceptable provided they are tested in accordance with (a) through (f) mentioned previously. The following suggested method may be used for detecting the presence of moisture: (i) Add white pigment to the PT coating. (ii) Use a colored dye in the water that will contrast with the white color of the PT coating. (iii) The “Pass” criterion is no colored dye staining, anywhere on the white PT coating, inside the encapsulated tendon.
2.2.6.2 — Encapsulated tendons	
Any component used to connect the sheathing to any anchorage or coupler enclosure in encapsulated tendons shall conform to the following: 1. The connecting components shall:	

(a) Be watertight in conformance with Section 2.2.6.1. (b) Conform to the same requirements as the sheathing for durability during fabrication, transportation, handling, storage, and installation. (c) Have a minimum thickness of 0.050 in. (1.25 mm). (d) Have a watertight, positive mechanical connection to the anchorage protection or coupler enclosure and a watertight connection at the tendon sheathing. (e) Have a minimum 2 in. (50 mm) overlap and maintain seal between the end of the extruded sheathing covering the prestressing steel and the watertight connection at the tendon sheathing. (f) Be translucent or have other method of verifying compliance with Sections 2.2.6.2, Item 1(a), and Section 2.2.6.2, Item 2. Within the connecting component or enclosure, prestressing steel shall be either covered by sheathing for its full length, or be in full contact with PT coating in conformance with Section 2.4.3 where sheathing is not present.	
2.3 — Sheathing	**C2.3 — Sheathing**
2.3.1 — General properties	*C2.3.1 — 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 fabrication, transport, installation, concrete placement, and stressing; Watertight and resistant to water vapors;	To develop standards for determining the acceptability for other sheathing materials to meet the durability requirements reflected by the use of sheathing meeting the requirements listed under Section 2.3.2.1, a

Chemically stable, without embrittlement or softening over the anticipated exposure temperature range and service life of the slab-on-ground foundation. Free chloride ions shall not be extractable from the sheathing material; and Nonreactive with concrete, prestressing steel, reinforcing steel, and PT coating.	representative sample of the alternate product should be used to determine comparable values considering the following characteristics: A. Abrasion resistance; B. UV resistance up to 6 months' exposure; C. Impact resistance; D. Chemical resistance to concrete, admixtures, and PT coating; E. Chloride permeability; F. Tear resistance; G. Cold weather exposure; H. Thermal cracking; I. Tensile strength; J. Compressive strength; K. Brittleness; L. Temperature range of –20 to 120°F (–30 to 49°C). Equivalency can be determined by testing, subject to the approval of the LDP, which demonstrates that all requirements of Section 2.3 are satisfied by the alternate material.
2.3.2 — Minimum thickness and diameter	*C2.3.2 — Minimum thickness and diameter*
2.3.2.1 — Minimum thickness	*C2.3.2.1 — Minimum thickness*
Minimum thickness of sheathing shall be 0.040 in. (1.02 mm) for polyethylene or polypropylene with a minimum density of 0.034 lb/in.^{3} (0.941 g/cm^3), or equivalent if other materials are used.	Due to the fabrication process, slight variations in sheathing thickness may occur around the perimeter. Local reductions in sheathing thickness of up to

For encapsulated tendons, the minimum thickness of sheathing using the aforementioned material properties shall be 0.050 in. (1.25 mm).	10% are acceptable provided an average of four equidistant readings along the circumference equals or exceeds the required thickness.
2.3.2.2 — Inside diameter	
Sheathing shall be concentric with the strand and shall have an inside diameter at least 0.030 in. (0.75 mm) greater than the maximum diameter of the strand.	
2.3.2.3 — Appearance	
Sheathing shall provide a smooth circular outside surface and shall not visibly reveal lay of the strand.	
2.3.3 — Fabrication process	*C2.3.3 — Fabrication process*
Tendons shall be fabricated by a process that provides watertight encasement of the PT coating.	The watertight encasement is intended to prevent migration of any water intruding from the ends or a break in the sheathing. The sheathing extrusion process, in which the PT 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. Some small bubbles and air spaces are normal and unavoidable in the fabrication process.
2.3.4 — Sheathing coverage	*C2.3.4 — Sheathing coverage*

Tendon sheathing shall be continuous and prevent intrusion of cement paste or loss of the PT coating.	Because of regional differences and varying industry practices, the LDP should specify the length of the unsheathed, coated strand permitted to remain unsheathed in nonaggressive environments at the stressing, intermediate, and fixed anchorages. Generally, no more than 1 in. (25 mm) of unsheathed strand is permitted at the stressing and intermediate anchorages and no more than 12 in. (305 mm) is permitted at the fixed anchorages.
2.3.5 — Encapsulated tendons	*C2.3.5 — Encapsulated tendons*
The sheathing connection to sleeving at couplers and to all stressing, intermediate, and fixed anchorages shall be in conformance with Section 2.2.6.2. Connections shall remain watertight when subjected to a pressure of 1.25 psi (0.0086 MPa) for a period of 24 hours.	This requirement ensures complete encapsulation of 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 pressure test performance criteria. For watertightness testing requirements, refer to Section C2.2.6.1.
2.4 — PT coating	**C2.4 — PT coating**
2.4.1 — General properties	
The PT coating shall have the following properties:	

• Provide corrosion protection to the prestressing steel; • Provide lubrication between the strand and sheathing; • Resist flow within anticipated temperature range of exposure; • Provide continuous non-brittle coating at lowest anticipated temperature of exposure; and • Be chemically stable and nonreactive with prestressing steel, reinforcing steel, sheathing material, and concrete.	
2.4.2 — Type of PT coating	
The PT 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	*C2.4.3 — Minimum quantity*
The minimum weight of the PT coating on the strand shall be not less than 2.5 lb (1.14 kg) per 100 ft (30.5 m) for 0.5 in. (12.7 mm) diameter strand. Minimum quantity of PT coating for other strand sizes can 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.	The quantity of PT coating specified provides a minimum coating over the crests of the strand of 0.015 in. (0.40 mm).
2.4.4 — Performance criteria	*C2.4.4 — Performance criteria*
Provide PT coating compound that complies with the tests and associated acceptance criteria specified in Table 2.4.4.1. Conduct qualification tests 1 through 10 from Table 2.4.4.1 every 30 months or whenever any change is made to their chemical composition. In addition, conduct and report the results of tests 1, 9, and 10 specified in Table 2.4.4.1 for every batch of PT coating supplied.	Table 2.4.4.1: The tests for PT coatings presented in Table 2.4.4.1 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 that are possible during tendon fabrication and installation. Test 1, together with Test 2, ensures that 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 D610) after 1000 hours of exposure requires that only 0.3% of

	the exposed area can have indications of corrosion. (Refer to Fig. 1, Examples of Area Percentages, from ASTM D610.) The test is conducted on a 3 x 6 in. (75 x 150 mm) steel panel with a coating thickness of 0.005 in. (125 mm). When determining the percent of area corroded, only the area inside 0.25 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 an extent that they will emulsify and no longer provide a 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 their 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.

2.4.5 — Shipping and handling

Transport bulk shipments of PT coating in a manner that ensures it is not mixed with any PT coating not certified according to Section 2.4.4. All shipping containers/tanks hoses and pumps being used for the transport/transfer of PT coating shall be dedicated for the transport/transfer of PT coating or be cleaned and free from any other contaminates that could have a deleterious impact on the PT coating. In the event that non-dedicated equipment is used for the transport/transfer of PT coating, verification of cleaning shall be required.

Table 2.4.4.1—Performance specification for PT coating

No.	Test description	Test method	Acceptance criteria
1	Dropping point	ASTM D2265	Minimum 300°F (149°C)
2	Oil separation at 160°F (71°C) All weight/mass measurements shall be recorded to four (4) significant digits in grams. Run three (3) separate samples from the same batch. The bleed shall be calculated for each sample and the result reported as the average/mean of the three recorded samples. Final result shall be reported to the nearest two (2) significant digits (0.xx%).	ASTM D6184 (modified)	0.5% maximum by mass
3	Water content	ASTM D95	0.1% maximum
4	Flash point (refers to oil component)	ASTM D92	Minimum 300°F (149°C)
5	Corrosion test (5% salt fog at 100°F [38°C], 0.005 in. [0.127 mm], Q Panel Type S)	ASTM B117	Rust Grade 7 or better after 1000 hours of exposure according to ASTM D610

6	Water-soluble ions Chlorides Nitrates Sulfides Procedure: The inside (bottom and sides) of a 1.06 qt (1 L) glass beaker (approximate outside diameter 4.13 in. [105 mm], height 5.71 in. [145 mm]) is thoroughly coated with 3.53 ± 0.35 oz (100 ± 10 g) of corrosion-inhibiting coating material. The coated beaker is filled with approximately 30 oz (900 cc) of distilled water and heated in an oven at a controlled temperature of 100°F (37.8 ± 1.1°C) for 4 hours. 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.	ASTM D512 ASTM D3867 ASTM D4658	10 ppm maximum for all
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 B117 (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 D4289 (ASTM D792 for density) ASTM D638	Permissible change in hardness 15%, volume 10% Permissible change in tensile strength 30%
9	Cone penetration	ASTM D217	265 to 295 (NLGI 2) worked penetration
10	Kinematic viscosity of base oil	ASTM D445	The base oil for each batch shall be within the same

	Report measurement at 104°F (40°C) in ISO Viscosity Grade numbers (Appendix A)		ISO Viscosity Grade as the PT coating that was submitted for tests at the 30-month intervals

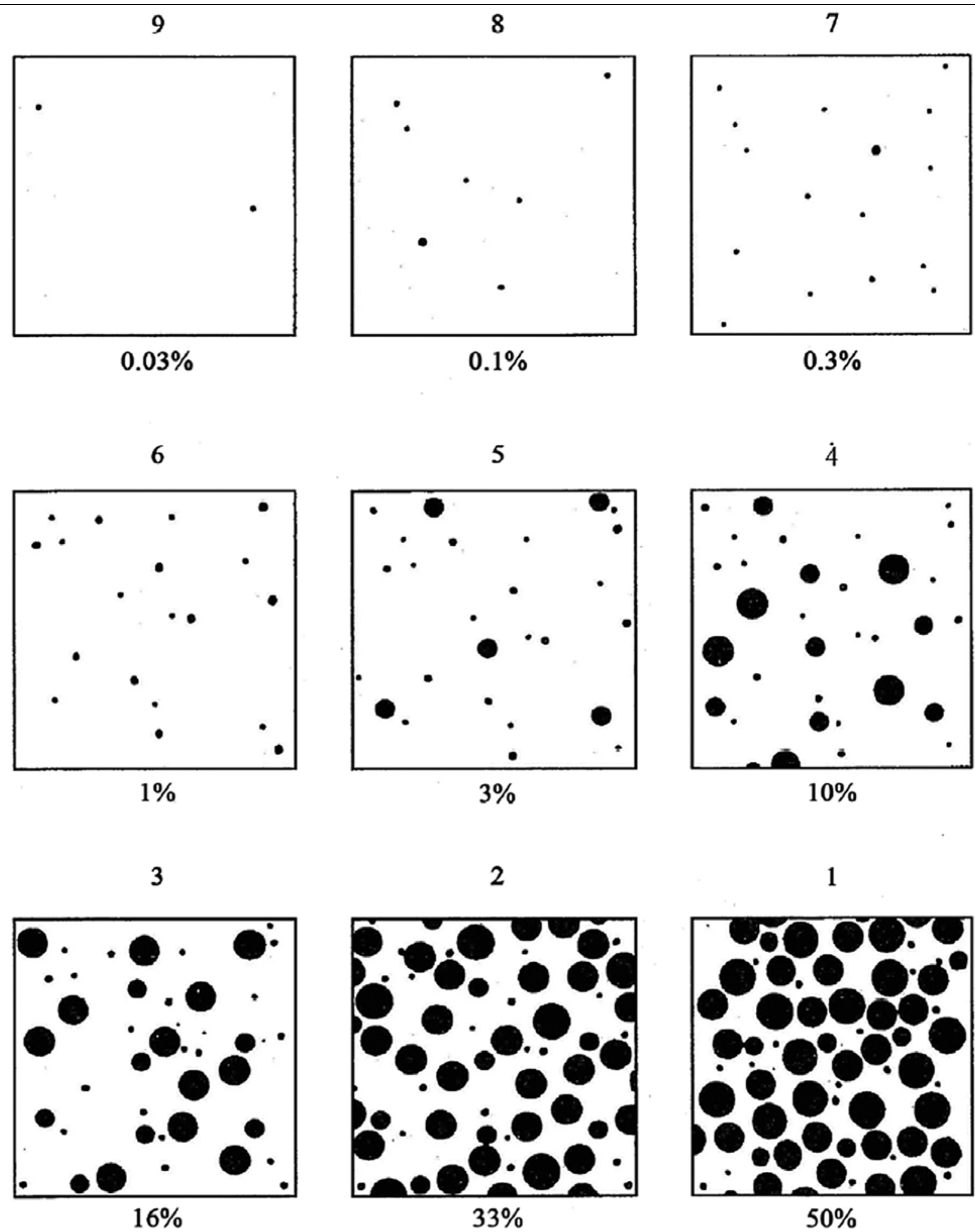

Fig. 1—Example of area percentages. Rating of painted surfaces of area percent rusted (SSPC Vis 2/ASTM D610). Courtesy ASTM International.

2.5 — Alternative materials

A PT system is comprised of a tensile element that has an anchorage mechanism permanently connected at each end that transfers the force connecting the anchorage mechanisms from the tensile element into a structural element. During the application of the force, the tensile element is free to move relative to the structural element.

In an unbonded PT system, the tensile element is permanently isolated from the structural element and both the tensile element and anchorage mechanism are permanently protected from any source that could cause corrosion or deterioration of the materials used in these elements.

In current unbonded systems, the tensile element is a steel strand, and the anchorage mechanism is a steel element with a conical void that uses steel wedges with gripping teeth that form a mechanical connection to the strand to transfer the force into the anchorage mechanism when the wedges are pulled into the conical hole.

The materials, systems, and components described herein reflect current technology. Nothing herein shall be construed to prevent other materials or components from being introduced or used, provided alternate components manufactured from different material and associated dimensional differences shall be tested to confirm performance equivalency, including the requirements of PTI M10.6, Specification for Unbonded Single-Strand Tendons Used for Slab-on-Ground Construction. The use of any components after successful testing is subject to the approval of the LDP.

Proposed components comprised of alternate materials shall be presented and balloted in by PTI Committee M-10, Unbonded Tendon, for possible equivalency to PTI M10.2, Specification for Unbonded

Single Strand Tendons Used for Slab-on-Ground Construction. Conformance shall be established through testing by an independent testing laboratory accredited to ISO 17025 by A2LA, or other equivalent accrediting organizations, and approval by an independent task group appointed by PTI Committee M10 and approved by the Technical Advisory Board (TAB). It shall be comprised of a minimum five-person task group that has relevant experience in the product for which the alternate material is used, while not having any direct financial or monetary interest in the proposed alternative material. The independent task group shall review the new component/product, taking into account the results of the independent testing laboratories, manufacturing tolerances, and other acceptance qualifications necessary to ensure that the proposed alternate component/product of this specification meet or exceed the qualifications and performance of the current specification.	
3.0 — EXECUTION	**C3.0 — EXECUTION**
3.1 — General	**C3.1 — General**
3.1.1 — Qualifications and inspection	*C3.1.1 — Qualifications and inspection*
3.1.1.1 — Installation and stressing shall be performed under the supervision of individuals holding a current certification from the PTI Slab-on-Ground Installer/Stressor Field Certification Program or equivalent, unless otherwise specified in the Contract Documents. **3.1.1.2 —** If required by Contract Documents, an inspection shall be conducted to ensure the requirements of this Specification and Contract Documents are	When required, it is recommended that the inspection be conducted by an individual holding a certification from the PTI Level 2 Unbonded PT Inspector Program.

met. Inspection shall include, but are not limited to:

- Material cleanliness;
- Location and quantity of materials;
- Corresponding material and stressing equipment certifications; and
- Stressing of prestressing tendons.

The PT supplier shall be notified of any observed damages.

3.1.2 — Recommended procedures

The PT installer shall conform to the requirements shown on the LDP's design drawings and/or the installation drawings provided by the PT supplier and shall conform to the procedures stated in PTI DC10.2 unless otherwise specified in the Contract Documents. Should conflicts exist between the documents cited previously, the requirements of the Contract Documents shall govern first, followed by the requirements of the PT supplier's installation drawings.

3.1.3 — Handling

Nonmetallic slings shall be used to lift tendons. Metal chokers or chains shall not be used. Tendons shall not be dragged on any surface where tendon sheathing damage can occur.

3.1.4 — Protection

Tendon bundles and accessory items shall not be stored where they will be subjected to rain, snow, or standing that they are not damaged during or after unloading.

3.2 — Tendon installation	C3.2 — Tendon installation
3.2.1 — General	*C3.2.1 — General*
Installation of tendons used in PT slab-on-ground foundations shall conform to the requirements of PTI DC10.2.	
3.2.1.1 — Support intervals	*C3.2.1.1 — Support intervals*
PT tendons shall be firmly supported at intervals not exceeding 54 in. (1.37 m). Placing tolerances shall be in accordance with Section 3.2.1.3, or the Contract Documents, whichever is the most restrictive.	Limitations on tendon support intervals are required to prevent displacement during concrete placement.
3.2.1.2 — Support system	*C3.2.1.2 — Support system*
Tendons shall be attached to support chairs or reinforcement in a manner that does not cause damage to the sheathing and that will prevent displacement during concrete placing operations.	Due to the large spacing of tendons and minimal conventional reinforcement present in PT slab-on-ground foundations, it is recommended that the tendons be securely tied at all tendon intersections and to the support system unless an acceptable alternate means is approved by the LDP.
3.2.1.3 — Tendon tolerances	
Maximum permissible deviations from tendon design locations shall be as follows: 1. Ribbed foundations Slab tendons/Vertical: Center of gravity of strands (CGS) in the middle one-third of the actual slab thickness for $t > 4.75$ in. (120 mm) and in the middle one-half of the actual slab thickness for $t \leq 4.75$ in. (120 mm). Slab tendons/Horizontal: Variance from plan location ±12 in. (±305 mm) with smooth transition around obstructions with a minimum deviation of 1:6.	

Rib tendons/Vertical: Anchor location: ±1 in. (±25 mm) Low point: –1 in. (25 mm)/+3 in. (75 mm) Rib tendons/Horizontal: ±2 in. (±50 mm) from rib center line. 2. Uniform thickness foundations Tendons/Vertical: CGS in the middle one-third of the actual foundation thickness, but not to exceed ±1 in. (±25 mm). Tendons/Horizontal: Variance from plan location ±12 in. (±305 mm) with smooth transition around obstructions with a minimum deviation of 1:6. Tolerances shall not reduce clear cover to tendons.	
3.2.1.4 — Lateral deviations	*C3.2.1.4 — Lateral deviations*
Lateral deviations in tendon location shall be permitted if necessary to avoid plumbing blockouts and risers, hold-down devices, and other inserts (refer to Section 3.2.1.3). Such deviations shall have a radius of curvature of not less than 20 ft (6.5 m) for 0.5 in. (12.7 mm) diameter strands. Minimum radius of curvature shall be adjusted proportionally for other diameters.	Slab behavior is relatively insensitive to lateral deviations in the location of tendons (perpendicular to the vertical plane of the tendon design location). An example of adjusting the radius proportionally to the strand diameter is: for a 0.375 in. (9.5 mm) diameter strand, the radius of curvature should not be less than 0.375/0.5(20 ft) = 15.0 ft (4.5 m).
3.2.1.5 — Protection	
Tendons shall not be exposed to welding sparks, electric ground currents, or excessive temperatures that deleteriously affect the prestressing steel, anchorages, PT coating, or sheathing material. Keep tendons and components clean and undamaged.	

3.2.1.6 — Protection from water	*C3.2.1.6 — Protection from water*
Water shall be prevented from entering the tendons during installation.	Possible collectors of water are the coupler and surrounding sheathing, transition components between the sheathing and anchorage, damaged sheathing, and sheathing replacement areas.
3.2.1.7 — Encapsulated tendons	*C3.2.1.7 — Encapsulated tendons*
All exposed metal tendon components shall be protected within 24 hours after their exposure during installation.	The protection method should be suitable to the environment in which the tendons are located.
3.2.2 — Stressing anchorages	*C3.2.2 — Stressing anchorages*
3.2.2.1 — Installation	*C3.2.2.1 — Installation*
Stressing anchorages shall be installed perpendicular to the tendon axis. Any transition curvature in tendon alignment shall not start closer than 12 in. (305 mm) from the stressing anchorage.	Tendon curvatures at the anchorage may cause excessive local friction and adversely affect the tendon efficiency and elongation.
3.2.2.2 — Attachment requirements	
Stressing anchorages shall be securely attached to bulkhead forms. Connections shall be sufficiently rigid to avoid accidental loosening.	
3.2.2.3 — Cover requirements	*C3.2.2.3 — Cover requirements*
Minimum concrete cover from the top surface to the anchorage shall not be less than 1 in. (25 mm) and the minimum corner concrete cover not less than 3 in. (75 mm). Minimum concrete cover from exterior face of concrete to the face of the stressing-end and fixed-end anchor casting shall be 1.5 in.	At angled slab edges, minimum concrete covers should be maintained at all edges of the anchorages.

(40 mm) for nonaggressive environments and 2 in. (50 mm) for encapsulated tendons.	
3.2.2.4 — Pocket formers	
Pocket formers used to provide a void at the stressing anchorages shall prevent intrusion of cement paste into the wedge cavity.	
3.2.2.5 — Encapsulated tendons	
Stressing anchorages for encapsulated tendons shall have the strand tail and the gripping part of the anchorage capped at the wedge cavity to completely seal the area against moisture. Refer to Sections 2.2.6, 2.3.5, and 3.5.2. Encapsulation caps shall be installed as soon as possible but within 8 hours after the cutting of the tendon tails.	
3.2.2.6 — Strand tail cover	*C3.2.2.6 — Strand tail cover*
Minimum concrete cover for the strand tail from the exterior edge of the concrete shall be 0.75 in. (20 mm) for nonaggressive environments unless a protective tendon cover cap is used and 1 in. (25 mm) to the encapsulating device for encapsulated tendons.	In nonaggressive environments in certain regions, the prevailing construction practice is to use an abrasive wheel cutoff saw to cut the tendon tail, resulting in less than the 0.75 in. (20 mm) of cover. This is an acceptable practice provided that a protective tendon cover cap or other acceptable method is used that covers at least 1 in. (25 mm) of the strand tail that is nearest the exterior edge of the concrete.
3.2.3 — Intermediate anchorages	
3.2.3.1 — Installation	

Intermediate anchorages shall be installed perpendicular to the tendon axis. Any transition curvature in the tendon profile or alignment shall not start closer than 12 in. (305 mm) from the intermediate anchorage.	
3.2.3.2 — Placement	
Intermediate anchorages shall be embedded in the first concrete placed at a construction joint.	
3.2.3.3 — Cover requirements	
Minimum cover requirements of Section 3.2.2.3 shall apply to intermediate anchorages.	
3.2.3.4 — Pocket formers	
Pocket formers used to provide a void at the intermediate anchorage shall prevent intrusion of cement paste into the wedge cavity.	
3.2.3.5 — Encapsulated tendons	
Encapsulation caps and sleeves for encapsulated tendons shall be installed as soon as possible but within 8 hours after the approval of the stressing operation by the LDP.	
3.2.4 — Fixed anchorages	*C3.2.4 — Fixed anchorages*
3.2.4.1 — Installation	
Fixed anchorages shall be installed on the tendon: (a) At the fabrication plant prior to shipment to the jobsite. (b) At the jobsite, provided the PT supplier furnishes appropriate equipment and instructions satisfactory to the LDP.	

3.2.4.2 — Wedge seating methods for fixed anchorages	*C3.2.4.2 — Wedge seating methods for fixed anchorages*
Fixed anchorages that use wedges for gripping the strand shall be attached to the prestressing steel by any method that permanently fastens the anchor onto the strand. These methods may include pulling the wedges into the wedge cavity, pushing the prestressing steel, which in turn pulls the wedges into the wedge cavity, pushing the wedges into the wedge cavity without applying force on the strand, or any other method that will prevent release of the prestressing steel and satisfies the requirements of Section 2.2.1. Temporary force applied to seat wedges shall be limited to a percentage of the specified tensile strength of the prestressing steel as follows: • Pull method = 80 to 85% • Strand push method = 85 to 90% • Wedges push method = 85 to 120% Any method used to connect a fixed anchorage to a tendon shall limit the amount of wedge travel to no more than 0.050 in. (1.25 mm), between the fully seated position resulting from any of the three aforementioned methods, and the position when a force of 95% of the specified tensile strength is applied to the tendon. The fixed end wedge seating method that is chosen shall result in the wedge halves being seated with a maximum offset between wedge halve of 1/4 in.	Three methods of connecting fixed anchorages are currently in use. One grips the prestressing steel extending opposite the wedge cavity side of the anchor and pulls the wedges into the wedge cavity. This is referred to as the “pull method.” One pushes the prestressing steel, which in turn pulls the wedges into the wedge cavity. This is referred to as the “strand push method.” One pushes directly on the wedges, which pushes the wedges into the wedge cavity. This is referred to as the “wedges push method.” With any method, a temporary force is applied to seat the wedges. Experience has shown that the key element to properly connecting a fixed anchorage to a strand is limiting the distance that the wedges will travel from the fully seated position to the ultimate anchorage load of 95% of the specified tensile strength of the prestressing steel.

(6.44 mm). The strand tail extending past the wedge after completion of the seating method shall be no greater than the maximum length specified by the encapsulation system manufacturer to insure proper seating of the encapsulation cap.	
3.2.4.3 — Placement	
Fixed anchorages shall be placed in formwork at locations shown on the installation drawings provided by the LDP or the PT supplier, and securely positioned. Concrete cover requirements of Section 3.2.2.3 apply to fixed anchorages.	
3.2.4.4 — Encapsulated tendons	
Fixed anchorages intended for use in an encapsulated tendon shall be covered at the wedge cavity side with an encapsulation cap. The encapsulation cap shall be installed at the fabrication plant after coating the strand tail and wedge area with the same PT coating meeting the requirements of Sections 2.4.1 and 2.4.4.	
3.2.5 — Sheathing inspection	*C3.2.5 — Sheathing inspection*
3.2.5.1 — Sheathing damage	*C3.2.5.1 — Sheathing damage*
After installing the tendons in the forms and prior to the concrete placement, the sheathing shall be inspected for damage. Damaged areas shall be repaired by restoring the PT coating in the damaged area and repairing the sheathing. Sheathing repairs shall be watertight and acceptable to the LDP.	For tendons used in nonaggressive environments, small damaged areas in the tendon sheathing of up to 3 in. (75 mm) in length may be permitted without repair if the damaged areas are spaced a minimum of 8 ft (2.6 m) apart and the total damaged length is less than 2% of the total tendon length, with the acceptance of the LDP. All gaps in the sheathing should be repaired.

3.2.5.2 — Repair procedure	*C3.2.5.2 — Repair procedure*
Tape repair procedures shall conform to PTI DC10.2 and acceptable to the LDP.	Tape used should: • Be self-adhesive and moisture-proof; • Be nonreactive with sheathing, coating, or prestressing steel; • Have elastic properties; • Have a minimum width of 2 in. (50 mm); and Have a contrasting color to the tendon sheathing.
3.3 — Concrete placement	
3.3.1 — General	
Water and cement paste shall be prevented from entering tendons during concrete placing and curing.	
3.3.2 — Placement	
The position of PT tendons, the tendon support system, and nonprestressed reinforcement shall remain within tolerance 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	
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	**C3.4 — Tendon stressing**
3.4.1 — General	
Stressing of tendons shall conform to PTI DC10.2.	
3.4.1.1 — Protection from water	
Water shall be prevented from entering the tendons prior to completion of the tendon finishing operation.	
3.4.1.2 — Stressing procedures	
The tendon stressing procedures shall conform to the requirements of the PT supplier.	
3.4.1.3 — Stressing jacks	
Hydraulic jacks used to stress unbonded single strand tendons shall be equipped with jack grippers that will not notch the strand more severely than normal anchoring wedges.	
3.4.2 — Jack calibration	*C3.4.2 — Jack calibration*
Stressing jacks and gauges shall be individually identified and calibrated to known standards at intervals not exceeding 6 months or at the beginning of each new project. For equipment that is moved between jobsites, the interval shall not exceed 3 months. Calibration certificates for each jack and gauge used shall be provided. The calibrated jack-gauge system shall be capable of measuring the jacking force within an accuracy of 2%.	It is preferable to calibrate jacks and gauges together as a unit. However, gauges may be calibrated to a master gauge of known accuracy, provided the jacks are calibrated to the same master gauge. Because of the small size of many slab-on-ground foundation projects, it is common practice for stressing equipment to be transported between jobsites on a daily basis. Because of

The jack calibration shall be performed by an independent testing agency or by the PT supplier furnishing the stressing equipment. If the PT supplier performs the jack calibration, the jack calibration shall reference the certificate from an independent testing agency specifying the latest calibration date of the test instrument. Provide the test instrument certificate if requested.	this, it is required that the calibration interval be reduced to 3 months.
3.4.3 — Elongation measurements	*C3.4.3 — Elongation measurements*
Elongation measurements shall be taken at each stressing location immediately after stressing. Measured elongations shall agree with calculated elongations by the larger of ±10% or ±0.25 in. (±6 mm). Discrepancies exceeding these values shall be resolved by all parties involved in the PT process to the satisfaction of the LDP.	Elongation measurements assist in the verification that the tendon force has been properly achieved. Correlation of calculated and measured elongations within a ±10% 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 are average values and may vary slightly from project to project. Variations in calculated and measured elongation values in excess of 10% 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. Repeated restressing of tendons should be avoided because multiple wedge bites at the stressing could affect the long-term performance of the strand. In many slab-on-ground applications, especially single-family residential foundations,

	tendons are less than 30 ft (9 m) in length, resulting in small calculated elongations. In these cases, the ±10% tolerance may be too stringent due to inaccuracies in the marking and measuring process. In these cases, the ±0.25 in. (±6 mm) tolerance may be used.
3.5 — Tendon finishing	**C3.5 — Tendon finishing**
Finishing of tendons shall conform to PTI DC10.2.	
3.5.1 — General	*C3.5.1 — General*
3.5.1.1 — Cutting of tendon tails	*C3.5.1.1 — Cutting of tendon tails*
Tendon tails shall not be cut until approval has been given by the LDP or if approval is not required by the Contract Documents, within 7 days after stressing. The strand tail after cutting of the tendon tail shall not be less than 0.5 in. (12.7 mm). Minimum concrete cover to the strand tail from the exterior face of the concrete shall be 0.75 in. (20 mm) for nonaggressive environments unless a protective tendon cover cap is used and 1 in. (25 mm) from the exterior face of concrete to the encapsulating device for encapsulated tendons.	For encapsulated tendons, it is recommended that the cutting of the tendon tails be performed within 1 day after approval by the LDP. The elongation report should be submitted on the same day as the stressing operation is completed and the approval or rejection is given by the LDP within 96 hours after stressing. Encapsulation caps should be installed within 8 hours after cutting off tendon tails. The length of strand tails should be compatible with the requirements of the encapsulation manufacturer to ensure a watertight connection of the encapsulation cap.
3.5.1.2 — Cutting methods	
The tendon tail shall be removed by oxyacetylene cutting, abrasive wheel, hydraulic- or electric-powered cold shear, gas plasma cutting, or other method acceptable to the LDP that will not damage the strand, anchorages, or encapsulation. If oxyacetylene cutter is	

used, flames shall not be directed toward the wedges.	
3.5.2 — Encapsulated tendons	*C3.5.2 — Encapsulated tendons*
At anchorages intended for use in encapsulated tendons, encapsulation caps filled with PT coating shall be installed within 8 hours after cutting the tendon tails and before filling the stressing pockets. (Refer to Sections 2.2.6, 2.3.5, and 3.2.2.5.)	The design of the encapsulation caps should provide for a method of visual inspection to verify that the encapsulation cap is filled with PT coating and has been properly installed.
3.5.3 — Stressing pockets	*C3.5.3 — Stressing pockets*
3.5.3.1 — Preparation	*C3.5.3.1 — Preparation*
Prior to installing stressing pocket patch material, the inside concrete surfaces of the pocket shall be cleaned to remove any laitance or PT coating. The patch material shall be placed to assure complete bonding and filling of the stressing pocket.	The stressing pocket should be prepared according to the procedures outlined in PTI FAQ #11, “Proper Filling of Single-Strand Tendon Stressing Pockets” (https://www.post-tensioning.org/Portals/13/Files/PDFs/Education/FAQ11.pdf). Sounding of the filled pocket can detect poor bond or filling of a stressing pocket. If poor bond or voids are found, the patch material should be removed and replaced.
3.5.3.2 — Timing	*C3.5.3.2 — Timing*
Stressing pockets shall be filled with nonmetallic, non-shrink cementitious patch material within 4 days after tendon tail cutting. The patch material 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 materials, and concrete.	The filling of the stressing pocket provides the primary protection of the stressing anchorage in nonaggressive applications. Therefore, earlier filling of stressing pockets is desirable. If stressing pockets are unable to be filled within 4 calendar days of tendon tail cutting,

Brick mortar shall not be used for filling stressing pockets.	then additional protection should be provided. The quality of the patch material as well as the mixing and installation are essential in providing protection of the stressing anchorages. It is recommended that packaged patch material containing premixed portions of cement, sand, and additives be used in lieu of on-site mixtures to ensure that the quality of the patch material achieves the required result.

APPENDIX A — ISO VISCOSITY GRADES FOR INDUSTRIAL OILS

ISO Viscosity Grade	Kinematic Viscosity at 104°F (40°C), Min cSt	Kinematic Viscosity at 104°F (40°C), Mid cSt	Kinematic Viscosity at 104°F (40°C), Max cSt
2	1.98	2.2	2.42
3	2.88	3.2	3.52
5	4.14	4.6	5.06
7	6.12	6.8	7.48
10	9	10	11
15	13.5	15	16.5
22	19.8	22	24.2
32	28.8	32	35.2
46	41.4	46	50.6
68	61.2	68	74.8
100	90	100	110
150	135	150	165
220	198	220	242
320	288	320	352
460	414	460	506
680	612	680	748
1000	900	1000	1100
1500	1350	1500	1650
2200	1980	2200	2420
3200	2880	3200	3520

The Post-Tensioning Institute provides the following activities in support of its members and the industry:

- Technical and certification committees that provide consensus guides, reports, manuals, specifications, standards, and certification manuals
- Spring PTI Convention and Fall PTI Committee Days to facilitate the work of its committees
- Technical sessions at the Spring PTI Convention to provide a forum for technical information exchange
- Educational seminars and webinars to disseminate information on post-tensioned concrete
- Programs for certification of personnel working with post-tensioned concrete, for certification of plants producing unbonded single-strand tendons, and for certification of multistrand and bar post-tensioning systems
- Research projects and student scholarships
- Coordination and cooperation with other related societies
- The PTI *JOURNAL*

The Post-Tensioning Institute

Established in 1976, the Post-Tensioning Institute is recognized as the worldwide authority on post-tensioning. PTI is dedicated to expanding post-tensioning applications through marketing, education, research, teamwork, and code development while advancing the quality, safety, efficiency, profitability, and use of post-tensioning systems.

One of PTI's principal functions is to provide technical guidance on the design, construction, maintenance, and repair & rehabilitation of post-tensioned structures. PTI has published many informative manuals and technical guides covering most aspects of post-tensioning. In addition, PTI publishes the PTI JOURNAL, Newsletters, Technical Notes, Frequently Asked Questions, and Technical Updates that give in-depth discussion and/or analysis of issues pertinent to designers in the post-tensioning field. Members are also kept up-to-date on industry-related events and information on the PTI Web site at www.post-tensioning.org.

PTI technical committees, as well as PTI as a whole, operate under a consensus process that ensures that all participants have their views considered. Members of the Institute include major post-tensioning materials fabricators; manufacturers of prestressing materials; companies supplying materials, services, and equipment used in post-tensioned construction; and professional engineers, architects, and contractors. Individuals interested in the activities of PTI are encouraged to become a member.

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