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Specification for Multistrand and Grouted Post-Tensioning

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Specification for Multistrand and Grouted Post-Tensioning

POST-TENSIONING INSTITUTE
Strength in Concrete

American Segmental Bridge Institute

Specification for Multistrand and Grouted Post-Tensioning

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FOREWORD

Multistrand and grouted post-tensioning is critical reinforcement for concrete bridges and many other structures. Bonded and unbonded multistrand tendons and bar are central to the performance and durability of these structures. This specification provides minimum requirements for the selection, design, testing, and installation of multistrand and grouted post-tensioning systems and is intended for use in a wide variety of structure types, including buildings and bridges.

It has been developed by the PTI/ASBI M-50 Multistrand and Bar Post-Tensioning Committee through a consensus-standards process. The committee is a diverse international group comprised of representatives from specifying government agencies, researchers, designers, contractors, industry suppliers, and other experts.

The committee began work on the specification in 2010, with the first edition published in 2012. The second edition was augmented by the addition of a Commentary and many updates in other sections, including provisions on grout inlets and outlets. The specification is a comprehensive document addressing selection of the tendon protection levels, system components, materials, installation, and stressing of tendons. This third edition includes important updates to the requirements specified in Section 4.3, Component standards, and Section 4.4, System approval testing.

The specifiers are encouraged to use this specification in its entirety and the contractors to apply all applicable provisions. The companion document, PTI M55.1 Specification for Grouting of Post-Tensioned Structures should be used in conjunction with this document.

PTI appreciates any comments or suggestions from the readership, as the committee's work continues.

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1.0 — INTRODUCTION

1.1 — Scope

This specification is intended to apply to buildings, bridges, storage structures, and other structures using grouted posttensioning tendons, except as follows: stay cables and rock anchors that are already covered by other PTI documents. This specification provides requirements and guidance for furnishing complete post-tensioning systems and all required accessories, including but not limited to anchorages, local zone reinforcement, ducts, pipes, strands, and bars from a single supplier, as required.

Provisions further address submittal samples, drawings, calculations, procedures, reports, manuals, and certifications. Both temporary and permanent post-tensioning shall comply with this specification. Guidance is provided for the minimum requirements for the Tendon Protection Levels identified in the Contract Documents.

The PTI M55.1 specification includes requirements for proper grout material selection, testing, and grouting procedures.

1.2 — Alternative post-tensioning scheme

The materials, components, and systems described herein reflect current multistrand and grouted post-tensioning technology. Nothing herein shall be construed to prevent other materials and components from being introduced or used, provided they are properly developed and tested according to sound engineering principles. The incorporation of any such developments not covered by this specification is subject to the Engineer's approval, on a project-by-project basis.

Alternative post-tensioning schemes may be submitted for the Design Engineer's approval, provided they meet the following:

- The net compressive stress in the concrete after all losses is equal to or greater than that provided by the post-tensioning shown on the Contract Documents;
- The distribution of individual tendons at each cross section generally conforms to the distribution shown on the Contract Documents;
- No reduction in the protection level;
- Minimum concrete cover and concrete quality is not reduced;

C1.2 – Alternative post-tensioning scheme

Once a history of satisfactory performance has emerged, such innovations become eligible for inclusion in formal codes and specifications through the normal committee development process.

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- The ultimate strength of the structure with the proposed post-tensioning layout shall be equivalent to or greater than that provided by the original design.
- Stresses at all sections and at all stages of construction meet the design requirements of the Contract Documents;
- All post-tensioning provisions of the Contract Documents are satisfied;
- The Contractor redesigns and details the elements where the alternative post-tensioning scheme and/or layout are to be used;
- The Contractor submits complete installation drawings for post-tensioning layout and systems, reinforcing steel, concrete cover, and supporting design calculations, including short- and long-term prestress losses; and
- Alternative post-tensioning schemes shall be designed and sealed by a professional engineer licensed in the state where the work is to be performed.

1.3 — Referenced standards and specifications

ASTM International

ASTM A53/A53M, Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless

ASTM A153/A153M, Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware

ASTM A240/A240M, Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications

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 A500/A500M, Standard Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes

ASTM A653/A653M, Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process

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C1.3 – Referenced standards and specifications

ASTM A421/A421M, Standard Specification for Stress-Relieved Steel Wire for Prestressed Concrete

ASTM A475, Standard Specification for Zinc-Coated Steel Wire Strand

ASTM A641/A641M, Standard Specification for Zinc-Coated (Galvanized) Carbon Steel Wire

ASTM A882/A882M, Standard Specification for Epoxy-Coated Seven-Wire Prestressing Steel Strand

ASTM A981/A981M, Standard Test Method for Evaluating Bond Strength for 0.600-in. [15.24-mm] Diameter Steel Prestressing Strand, Grade 270 [1860], Uncoated, Used in Prestressed Ground Anchors

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ASTM A722/A722M, Standard Specification for High-Strength Steel Bars for Prestressing Concrete

ASTM C1583/C1583M, Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method)

ASTM D570, Standard Test Method for Water Absorption of Plastics

ASTM D638, Standard Test Method for Tensile Properties of Plastics

ASTM D1000, Standard Test Methods for Pressure-Sensitive Adhesive-Coated Tapes Used for Electrical and Electronic Applications

ASTM D2240, Standard Test Method for Rubber Property—Durometer Hardness

ASTM D3035, Standard Specification for Polyethylene (PE) Plastic Pipe (DR-PR) Based on Controlled Outside Diameter

ASTM D3350, Standard Specification for Polyethylene Plastics Pipe and Fittings Materials

ASTM D3895, Standard Test Method for Oxidative-Induction Time of Polyolefins by Differential Scanning Calorimetry

ASTM D4101, Standard Classification System and Basis for Specification for Polypropylene Injection and Extrusion Materials

ASTM D5309, Standard Specification for Cyclohexane 999

ASTM D5989, Standard Specification for Extruded and Monomer Cast Shapes Made from Nylon (PA)

ASTM E23, Standard Test Methods for Notched Bar Impact Testing of Metallic Materials

ASTM E28, Standard Test Methods for Softening Point of Resins Derived from Pine Chemicals and Hydrocarbons, by Ring-and-Ball Apparatus

ASTM F593, Standard Specification for Stainless Steel Bolts, Hex Cap Screws, and Studs

ASTM F714, Standard Specification for Polyethylene (PE) Plastic Pipe (DR-PR) Based on Outside Diameter

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ASTM F2136, Standard Test Method for Notched, Constant Ligament-Stress (NCLS) Test to Determine Slow-Crack-Growth Resistance of HDPE Resins or HDPE Corrugated Pipe

Fédération Internationale du Béton (fib)

fib Bulletin 7, Technical Report, "Corrugated Plastic Duct for Internal Bonded Post-Tensioning," January 2000

fib Bulletin 75, Recommendation, "Polymer-Duct Systems for Internal Bonded Post-Tensioning," December 2014

German Institute for Standardization

DIN 30 672M

Post-Tensioning Institute

PTI M50.1-98, Acceptance Standards for Post-Tensioning Systems

PTI M55.1-19, Specification for Grouting of Post-Tensioned Structures

U.S. Department of Defense

Federal Specification MIL-P-3420, Performance Specification: Wrapping Materials, Volatile Corrosion Inhibitor Treated

2.0 — DEFINITIONS AND ABBREVIATIONS

2.1 — Definitions

Admixture, water-reducing – An admixture that either increases the slump of freshly mixed grout without increasing the water content or that maintains the slump with a reduced amount of water due to factors other than air entrainment.

Anchorage assembly – Mechanical device comprising all components required to anchor the prestressing steel and permanently transfer the post-tensioning force from the prestressing steel to the concrete.

Anchor nut – The threaded device that screws onto a threaded bar and transfers the force from the bar to the bearing plate.

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C2.1 – Definitions

Anchorage assembly – A strand tendon anchorage assembly includes: wedges, wedge plate, bearing plate, duct transition, grouting attachment, and system dependent confinement reinforcement in the local zone.

A bar anchorage includes the anchor nut and the bearing plate plus duct and grouting attachments and system-dependent confinement reinforcement.

Anchorage nut – The anchor nut is part of a bar tendon anchorage assembly and transfers the forces by mechanical interlock.

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Anchor set – The expected movement of the wedge into the wedge plate or nut into the bearing plate during the transfer of the prestressing force to the anchorage assembly.

AUTS – Acronym for Actual Ultimate Tensile Strength – measured as force.

Bar – Bars used in post-tensioning tendons conform to ASTM A722, Standard Specification for Uncoated High-Strength Steel Bars for Prestressing Concrete. Bars have a minimum ultimate tensile strength of 150,000 psi (1035 MPa). A Type 1 bar has a plain surface and a Type 2 bar has surface deformations.

Bearing plate – Any hardware that transfers the tendon force into the structure.

Bearing plate, basic – Flat plate bearing directly against concrete meeting the analytical design requirements of PTI (refer to "Acceptance Standards for Post-Tensioning Systems," Section 3.1).

Bearing plate, special – Any hardware that transfers tendon anchor forces into the concrete and does not meet the analytical design requirements of PTI (refer to "Acceptance Standards for Post-Tensioning Systems," Section 3.1).

Bleed – The autogenous flow of mixing water within, or its emergence from, newly placed grout; caused by the settlement of the solid materials within the mass and filtering action of strands and bars.

Confinement reinforcement – Nonprestressed reinforcement in the local zone, usually in the form of spirals, which provide concrete confinement and are considered part of the bearing plate.

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Bearing plate – Following References 1, 2, and 3). This specification distinguishes between "basic" and "special" bearing plates. (Refer to PTI's "Acceptance Standards for Post-Tensioning Systems," Section 3.)

Bearing plate, basic – Covered by this definition are square, rectangular, or round plates, sheared or torch cut from readily available steel plate, normally ASTM A36/A36M. They do not require testing because they can reliably be designed using the formulae given in PTI's "Acceptance Standards for Post-Tensioning Systems," Section 3.1; design information is not in this document. Bearing plates bearing against steel members or other structures must be designed by appropriate rational analysis.

Bearing plate, special – Covered by this definition are devices having single- or multiple-plane bearing surfaces and devices combining bearing and wedge plate in one piece. They normally require confinement reinforcement.

Confinement reinforcement – The confinement reinforcement in the concrete ahead of tendon anchorages is limited to the local zone. The confinement reinforcement consists of spirals, orthogonal reinforcing bars, or a combination of both. (Refer to the definitions for local and general zone.)

For basic bearing plates, confinement reinforcement is required in that volume of concrete in which compressive stresses exceed acceptable limits for unreinforced concrete as determined by rational analysis. (Refer to PTI's "Acceptance Standards for Post-Tensioning Systems," Section 3.1.)

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Contractor – The person, firm, or organization who has entered into a contractual agreement with the Owner to construct the project and who has the prime responsibility for the overall construction of the project in accordance with contract documents.

Coupler – A device transferring the prestressing force from one partial-length tendon to another.

Duct – Enclosure forming a conduit to accommodate prestressing steel installation and provide an annular space for grout that protects the prestressing steel.

Duct coupler – A device that connects individual lengths of duct forming a continuous enclosure around the prestressing steel.

Electrically isolated tendon (EIT) – Tendon demonstrating sufficient electrical resistance between the tensile elements and the structure.

Engineer (Licensed Design Professional, Engineer of Record, Design Engineer) – The person, firm, or organization engaged by the Owner to prepare the Contract Documents for the construction of the project.

f_{pu} – The nominal ultimate tensile unit stress sometimes referred to as GUTS. When stated as force, F_{pu}, the nominal ultimate tensile unit stress is multiplied by the nominal cross-sectional area of strand or bar.

Friction – The force resisting the relative lateral (tangential) movement of material elements that are in contact.

Grout – A mixture of cementitious materials and water—with or without mineral additives, admixtures, or fine aggregate—proportioned to produce a pumpable consistency without segregation of the constituents; injected into the duct to fill the space around the tendon strand or bar. Refer to PTI's "Specification for Grouting of Post-Tensioned Structures," Table 3.1, for classes of grout.

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For special bearing plates, the confinement reinforcement is system dependent as determined by tests on individual anchorages. The test block reinforcement, in the portion surrounding the special bearing plate and immediately ahead of it, essentially represents the confinement reinforcement required in the local zone for that particular system. (See also PTI's "Acceptance Standards for Post-Tensioning Systems," Section 3.2.)

Duct – Post-tensioning ducts consist of spiral-wound corrugated sheet metal, corrugated plastic tubing, metal pipe, or plastic pipe. Post-tensioning ducts are used for external and internal tendons.

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Grout, basic – Cementitious material consisting of cement and water that is proportioned and mixed on site. Class A (refer to PTI's "Specification for Grouting of Post-Tensioned Structures").

Grout, engineered – Grout designed and tested for specific performance characteristics (refer to PTI's "Specification for Grouting of Post-Tensioned Structures"). Class B (designed by the manufacturer and mixed on-site), Class C (designed by the manufacturer, prepackaged, and mixed on-site solely with water), or Class D (special) determined by design engineer.

Grout cap, temporary – A device that contains the grout by covering the post-tensioning steel at the wedge plate.

Grout cap, permanent – A device covering the post-tensioning steel and wedge plate at the anchorage that contains the grout and forms a protective cover, sealing the post-tensioning steel and wedge plate at the anchorage.

Hydrogen embrittlement – Brittle cracking process caused by the conjoint action of tensile stress and hydrogen ions (atomic hydrogen).

MUTS – Acronym for Minimum Ultimate Tensile Strength—measured as force, Fpu—for a single strand or bar breaking outside of the anchorage; or the multiple of those single-strand or bar forces for multi-strand or bar tendons.

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Hydrogen embrittlement – Refer also to definition of "stress corrosion cracking," a similar phenomenon.

MUTS used to allow precise description of strand, bar, and tendon forces. As further discussed as follows, it is necessary to specify strand, bar, and tendon properties either as "nominal" unit-stresses, or as MUTS, which is measured as force.

Because of dimensional tolerances, tendons are not sized on the basis of specified tensile unit stresses but are sized, tested, and evaluated as multiples of MUTS, which for a single strand or bar is equal to their specified minimum breaking force.

For instance, the dimensional tolerances allowed by ASTM A416/A416M for 0.5 in. (12.70 mm) strand, Grade 270 ksi (1860 MPa), permit tensile unit stresses between 244 and 277 ksi (1682 and 1910 MPa) for a strand with MUTS of 41.3 kip (183.7 kN). The literature uses a variety of terms and notations to specify the ultimate strength of tendons and their elements (bar, strands), and they leave room for different interpretations:

ASTM A416/A416M specifies strands in terms of "minimum breaking strength," measured as force. ASTM A722/A722M specifies bars in terms of "minimum ultimate tensile strength," measured in unit stresses.

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AASHTO and ACI 318 have notations and definitions for ultimate prestressing steel unit-stresses f_{pu} and f'_s, respectively, which must be understood as "nominal" unit stresses, based on "nominal" steel areas, as necessary for design purposes.

AASHTO also uses for design purposes "factored" tendon forces (P_u), which are not identical to tendon forces expressed as MUTS. ACI 318 does not have an expression for tendon forces.

AASHTO also expresses ultimate tendon forces as F_{pu}. However, it is not clear if this expression defines ultimate tendon forces as the multiple of the tendon element's (strand, bar) minimum ultimate tensile forces, or if it takes the reduction of tendon capacity due to anchorage efficiency into account.

Owner – The person, firm, or organization that initiated the design and construction of the project, provides or arranges for funding, is responsible for partial and final payments, and who will take possession and ownership of the project upon completion.

Post-tensioning – A method of prestressing in which prestressing steel is tensioned after the concrete has reached a specified strength.

Post-tensioning scheme or layout – The pattern, size, and locations of post-tensioning tendons in a structure.

Post-tensioning system (PTS) – A particular size of tendon, including prestressing steel, anchorages, local zone reinforcement, duct, trumpets, couplers, grout caps, inlets, outlets, all supplied by a single supplier.

Post-tensioning system – Different size tendons may have similar features, but for the purpose of this specification they are defined as separate systems, each requiring testing as specified herein. Only fully loaded anchorage assemblies need to be tested as a separate system; a tendon with 10 strands in a 12-strand system does not need separate testing provided the duct size is the same as for a fully loaded tendon and the strand distribution in the wedge plate is uniform.

Pourback – Blockouts created for tendon anchorage and/or vent access that are to be filled with concrete, nonshrink grout, or epoxy at a later date.

Pressure rating – The estimated maximum pressure that water in a duct or in a duct component can exert continuously with a high degree of certainty that failure of the duct or duct component will not occur. Commonly referred to as maximum allowable working pressure (MAWP).

Prestressing element – The tension element of a post-tensioning tendon, which is elongated and anchored to provide the necessary permanent prestressing force.

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Prestressing steel – High-strength steel strand or bar.

Profile – Vertical deviation (path) a tendon follows from end to end.

Quality assurance (QA) – Actions taken by the Owner or their representative to provide assurance to the Owner that the work meets the project requirements and all applicable standards of good practice.

Quality control (QC) – Actions taken by the Contractor to ensure that the work meets the project requirements and all applicable standards of good practice.

Setting – The process—due to the chemical reactions—occurring after the addition of mixing water, which results in a gradual development of rigidity of a cementitious mixture.

Sheathing – General term for the duct material surrounding the prestressing element to provide corrosion protection or conduit for installation.

Strand, seven-wire – Strand conforming to ASTM A416 and consisting of seven wires having a center wire enclosed tightly by six helically placed outer wires with a uniform pitch of not less than 12 and not more than 16 times the nominal diameter of the strand.

Stress corrosion cracking – Brittle cracking process caused by the conjoint action of tensile stress and a corrodent.

Stressing jack – Hydraulic jack designed for the explicit purpose of stressing one or more strands or bar to the desired load; sometimes also referred to as a ram.

Subcontractor – A person, firm, or organization engaged by the Contractor to provide select construction activities, materials, or other specialized construction or engineering services.

Tendon – A single element or group of prestressing elements and their anchorage assemblies, which impart the prestress force to a structural member. Also included are ducts, grouting attachments, grout, and corrosion protective materials or coatings.

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Sheathing – Sheathing used as conduit is herein referenced to as duct. This definition of sheathing also covers transitions.

Stress corrosion cracking (SCC) – SCC is a complex phenomenon, influenced by the metallurgy of the material, the chemistry of the environment, and the stress field. Generally, susceptibility of high-strength steels to SCC increases with increasing yield strength, exposure to marine environment, to solutions containing chloride, and in some cases to SO_4, PO_4, NO_4 ions, and possibly others.[10]

Tendon – Consists of a single tendon element (strand or bar) or a bundle of such elements. The tendon is stressed by a hydraulic jack and the reactions impart compression forces on the structure to which they are anchored. Tendons are most widely used in prestressed concrete structures.

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They are also used to increase the strength capacity of masonry, steel, and timber structures, and for rehabilitations and retrofitting of structures.

Tendon size – The number of individual strands of a certain strand diameter or the diameter of a bar.

Tendon type – Description of tendon relative to location in the concrete element and/or functional use (that is, internal, external, cantilever, transverse, longitudinal, continuity, stem wall, top slab, and so on).

Trumpet – Transition piece between bearing plate and duct, which collects the strands into a tight bundle that fits inside the duct.

Volume change – The change in volume produced by continued hydration of cement, excluding effects of the applied load and change in thermal or moisture content.

Wedge – A conically shaped device typically containing two or three pieces, which anchors the strand in the wedge plate.

Wedge – Strands are anchored by wedges, which have serrated surfaces (teeth) in contact with the strands and smooth cone-shaped outside surfaces, which bear against the smooth cone-shaped wedge holes in the wedge plate. Two- or three-part wedges grip each strand and anchor the strands by friction. The friction is enhanced by the indentations the wedge teeth bite into the strands.

Wedge plate (anchor head) – The hardware that holds the wedges of a multi-strand tendon and transfers the force from the strands to the bearing plate.

Wedge plate – For a multi-strand tendon this is a machined, forged, or cast metal disk with multiple conical wedge holes.

Wobble friction – Friction caused by unintended duct deviations from theoretical duct profile.

Zone, anchorage – The portion of the structure in which the prestressing force is transferred from the anchorage device onto the local zone of the concrete, and then distributed more widely into the general zone of the structure.

For anchorage devices located away from the end of the member, the anchorage zone includes the disturbed regions behind and ahead of the anchorage.

Zone, anchorage – By the Saint-Venant's Principle, the extent of this region is limited, but for practical purposes it can be taken as equal to the largest cross-sectional dimension of the member. Its extent is equal to the largest dimension of the cross section. It includes the local and general anchorage zones.

Refer to AASHTO LRFD 5.2, Definitions, and to 5.10.9, Post-Tensioned Anchorage Zone.

Zone, general – Region adjacent to the anchorage device within which the prestressing force spreads out to an essentially linear stress distribution over the cross section of the structure (Saint-Venant Region).

Zone, general – The general anchorage zone extends from the anchorage along the axis of the member for a distance equal to the overall depth of the member. The height of the general anchorage zone is equal to the overall depth of the member. It includes the local anchorage zone.

The main consideration in general zone design is to determine and provide for the flow of stress and forces as the

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concentrated tendon forces spreads out into the structure. The behavior of this Zone depends primarily on tendon forces and arrangements, stressing sequence, geometry of the structure, and other loads in the tendon anchorage zone—for example, bearing/reaction forces. It is independent of the shape of the anchorage assembly. These design elements are controlled solely by the Design Engineer.

General Zone reinforcement, which includes bursting and spalling reinforcement, should be included with the bid item for all other reinforcing steel, as it is not part of the post-tensioning system.

For more detailed and in-depth discussion of the General Zone and its geometry, readers are directed to PTI Anchor Zone Design (x).

The Design Engineer is responsible for the general zone design.

Refer to AASHTO LRFD 5.2, Definitions, and to 5.10.9.2.2, General Zone.

Zone, local – The volume of concrete that surrounds and is immediately ahead of the anchorage device.

Zone, local – Test block dimensions specified in PTI's "Acceptance Standards for Post-Tensioning Systems," Section 3.2.1, essentially represent the local zone for special bearing plates. (Refer also to confinement reinforcement.)

For more detailed and in-depth discussion of the Local Zone and its geometry, refer to PTI Anchor Zone Design (x).

The post-tensioning supplier (PTS) is responsible for local zone design and testing in conjunction with tendon anchorage components.

Refer to AASHTO LRFD 5.2, Definitions, and to 5.10.9.2.3, Local Zone.

2.2 – Abbreviations

ASQ – American Society of Quality

AMRL – AASHTO Materials Reference Laboratory

ASBI – American Segmental Bridge Institute

A2LA – American Association for Laboratory Accreditation

GAI – Geosynthetic Accreditation Institute

SPECIFICATION

3.0 — POST-TENSIONING SYSTEM (PTS) TENDON PROTECTION LEVELS (PL)

Furnish and install PTS meeting the following minimum requirements for the tendon PL as identified in the Contract Documents:

3.1 — Protection Level 1A (PL-1A)

Duct with filling material providing durable corrosion protection.

Performance requirements:

- Bare strand or bar per Sections 4.2.1 and 4.2.2, respectively;
- Duct sufficiently strong and durable for fabrication, transportation, installation, concrete placement, and tendon stressing, sufficiently leak-tight for concrete placing and grout injection. Duct shall meet the requirements of Section 4.3.5 and may be one of the following:
  - Galvanized duct per Section 4.3.5.1;
  - Plastic duct per Section 4.3.5.2;
  - Plastic pipe per Section 4.3.5.3; and
  - Duct connections per Section 4.3.6;
- Filling material to be chemically stable, nonreactive with prestressing steel and tendon duct, and may be one of the following:
  - Basic grout Class A per PTI's "Specification for Grouting of Post-Tensioned Structures";
  - Engineered grout Class B, C, or D per PTI's "Specification for Grouting of Post-Tensioned Structures"; and
  - Grout filling procedure to leave no voids in duct.

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C3.0 – POST-TENSIONING SYSTEM (PTS) TENDON PROTECTION LEVELS (PL)

The Engineer determines the tendon PL required for the project based upon the aggressivity of the environment, the exposure of the structure or element, the protection provided by the structure, the design life, and identifies the tendon PL in the Contract Documents. Assistance in determining tendon PL can be found in Fédération International du Béton (*fib*), Bulletin 33, Recommendation, "Durability of post-tensioning tendons,"11 and Krauser, "Selecting Post-Tensioning Tendon Protection Levels," *fib* Symposium Prague 2011.12

The Subcontractor should supply a PTS which, at a minimum, will provide the protection that is identified in the Contract Documents. The contractor may supply a PTS meeting the requirements of a higher tendon PL or may include features in the PTS of a higher tendon PL.

Refer to Appendix A for typical anchorage protection details of the different PLs.

C3.1 – Protection Level 1A (PL-1A)

PL-1A provides basic protection against corrosion.

PTI M55.1-19, "Specification for Grouting of Post-Tensioned Structures," provides additional information of grouts and grouting.

Grout procedures leaving no voids are critical to the long-term performance of the tendon.

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3.2 — Protection Level 1B (PL-1B)

PL-1A plus engineered grout and permanent grout cap.

Performance requirements:

- Bare strand or bar per Sections 4.2.1 and 4.2.2, respectively;
- Permanent grout caps meeting the requirements of Section 4.3.3;
- Duct sufficiently strong and durable for fabrication, transportation, installation, concrete placement, and tendon stressing, sufficiently leak-tight for concrete placing and grout injection. Duct shall meet the requirements of Section 4.3.5 and may be one of the following:
  - Galvanized duct per Section 4.3.5.1;
  - Plastic duct per Section 4.3.5.2;
  - Plastic pipe per Section 4.3.5.3; and
  - Duct connections per Section 4.3.6;
- Filling material to be chemically stable, nonreactive with prestressing steel and tendon duct, and be engineered grout Class B, C, or D per PTI's "Specification for Grouting of Post-Tensioned Structures"; and
- Grout filling procedure to leave no voids in duct.

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C3.2 – Protection Level 1B (PL-1B)

PL-1B provides somewhat better protection against corrosion than the basic protection provided by PL-1A.

Galvanized duct, plastic duct, or plastic pipe can be used in PL-1B.

PTI M55.1-19, "Specification for Grouting of Post-Tensioned Structures," provides additional information on grouts and grouting.

Grout procedures leaving no voids are critical to the long-term performance of the tendon.

3.3 — Protection Level 2 (PL-2)

PL-1B plus an envelope, enclosing the tensile element bundle over its full length, and providing a permanent leak-tight barrier.

Performance requirements:

- PTS shall meet the system pressure tests contained in Section 4.4.5;
- Bare strand or bar per Sections 4.2.1 and 4.2.2, respectively;
- Galvanize or epoxy coat the embedded part of the anchorage;
- Permanent grout caps meeting the requirements of Section 4.3.3;
- Envelope to be watertight and impermeable to water vapor over entire length. Envelope material to be chemically stable, without embrittlement or softening during anticipated exposure temperature range and service life, no free chloride ions extractable from material. Duct shall meet the requirements of Section 4.3.5 and may be one of the following:
  - Plastic duct per Section 4.3.5.2;
  - Plastic pipe per Section 4.3.5.3;
  - Duct connections per Section 4.3.6;

C3.3 – Protection Level 2 (PL-2)

PL-2 provides better protection against corrosion than the basic protection provided by PL-1B.

To achieve a watertight and impermeable-to-moisture envelope over the prestressing element, only plastic duct or plastic pipe can be used in PL-2. Galvanized duct is not watertight and impermeable to moisture penetration.

Precast segmental duct couplers maintain a leak-tight barrier against intrusion of water at segment joints.

PTI M55.1-19, "Specification for Grouting of Post-Tensioned Structures," provides additional information of grouts and grouting.

Grout procedures leaving no voids are critical to the long-term performance of the tendon.

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- Precast segmental duct couplers for precast segmental construction per Section 4.3.8.
- Filling material to be chemically stable, non-reactive with prestressing steel and tendon duct, and shall conform to:
    - Engineered grout Class C or D per PTI's "Specification for Grouting of Post-Tensioned Structures"; and
    - Thixotropic in nature.
- Grout filling procedure to leave no voids in duct.

3.4 — Protection Level 3 (PL-3)

PL-2 plus electrical isolation of tendon or encapsulation to be monitorable or inspectable at any time.

Performance requirements:

- PTS shall provide complete electric isolation of entire tendon and meet the system pressure tests contained in Section 4.4.5;
- PTS shall have the ability to be monitorable or inspectable at any time;
- Bare strand or bar per Sections 4.2.1 and 4.2.2, respectively;
- Electrically isolate the tensile elements;
- Permanent grout caps meeting the requirements of Section 4.3.3;
- Envelope to be watertight and impermeable to water vapor over entire length. Envelope material to be chemically stable, without embrittlement or softening during anticipated exposure temperature range and service life, no free chloride ions extractable from material. Duct shall meet the requirements of Section 4.3.5 and may be one of the following:
    - Plastic duct per Section 4.3.5.2;
    - Plastic pipe per Section 4.3.5.3;
    - Duct connections per Section 4.3.6;
- Precast segmental duct couplers for precast segmental construction per Section 4.3.8.
- Filling material to be chemically stable, nonreactive with prestressing steel and tendon duct, and shall conform to:
    - Engineered grout Class C or D per PTI's "Specification for Grouting of Post-Tensioned Structures"; and
    - Thixotropic in nature.
- Grout filling procedure to leave no voids in duct.

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C3.4 – Protection Level 3 (PL-3)

PL-3 provides the same protection against corrosion as the protection provided by PL-2 along with the ability to monitor or inspect the tendon for corrosion or deterioration and to verify the duct envelope has not been damaged during construction.

To achieve a watertight and impermeable-to-moisture envelope over the prestressing element, only plastic duct or plastic pipe can be used in PL-3. Galvanized duct is not watertight and impermeable to moisture penetration.

Precast segmental duct couplers maintain a leak-tight barrier against intrusion of water at segment joints.

PTI M55.1-19, "Specification for Grouting of Post-Tensioned Structures," provides additional information of grouts and grouting.

Grout procedures leaving no voids are critical to the long-term performance of the tendon.

Monitoring of electrically isolated tendons (EIT) provides reliable assurance to owners that tendons are properly installed and provide the full encapsulation specified. It also can provide an early warning system that can detect when a tendon is compromised by ingress of water possibly contaminated with chlorides into the duct envelope. EIT criterion requires well-detailed post-tensioning systems with suitable connectors, correctly detailed reinforcement/cross sections to avoid damaging the system, and quality installation and concrete placement.

When monitoring tendons, the designer should place the anchorages and monitoring connections where there is easy and convenient access for the monitoring equipment and maintenance of the monitoring equipment. Electrical cables for monitoring should be collected in cabinets allowing access for measurements or direct online monitoring. By providing electrical connections at both tendon ends, measurement techniques can be used to identify the location of the breech/corrosion.

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Additional information on EIT and monitoring can be found in References 13 through 16.

Stray electrical currents are a risk to the durability of post-tensioning tendons. PL-3 can be used to encapsulate and protect tendons from stray currents both at the entry (causing hydrogen embrittlement) and at the exit point (causing intensified metal dissolution) of the prestressing steel. Monitoring can verify the protection of the tendon. If tendon encapsulation is compromised, tendons may be electrically connected to the earth at both tendon ends to avoid damage from the stray currents.

4.0 — MATERIAL AND PERFORMANCE REQUIREMENTS

4.1 — General

Traceability shall be provided for all load-bearing or load-transfer components of the post-tensioning system. Specifically included are the following components/materials: strand, bar, bearing plates, wedge plates, wedges, nuts, couplers, duct, duct couplers, pipe, trumpets, grout tubes, and permanent grout caps.

Traceability for miscellaneous installation aids not permanently incorporated in the structure is not required.

C4.1 – General

Traceability of materials and components is a responsibility of the Supplier and the Contractor. As materials are delivered to the site the Contractor must accurately document where each heat or batch is used within the structure. These records are provided to the owner upon completion.

4.2 — Material standards

Supply materials meeting the following standards:

4.2.1 — Strand

Unless otherwise noted on the contract documents, use uncoated strand meeting the requirements of ASTM A416, Grade 270, low-relaxation, seven-wire strand.

C4.2.1 – Strand

ASTM A416 Strand

For most applications, strand conforming to ASTM A416 is adequate. The specification provides minimum requirements for mechanical properties (yield, breaking strength, elongation) and maximum allowable dimensional tolerances.

Packaging of strand

Strand must be well protected in shipping according to Section C8.6.

4.2.2 — Bar

Unless otherwise noted on the contract documents, use uncoated, high-strength thread bar meeting the requirements of ASTM A722, Grade 150.

C4.2.2 – Bar

ASTM A722 covers plain (Type I) and deformed (Type II) hot-rolled, cold-stressed, and stress-relieved bar. The ASTM specification is interpreted as a performance specification for physical bar properties and covers various

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For grouted tendons, do not use galvanized bars.

4.2.3 – Special prestressing materials

Prestressing materials not conforming to Sections 4.2.1 and 4.2.2 are acceptable, provided such materials are extensively tested to establish that their properties are equal to or better than those specified in this document. Such materials and their anchorage must be thoroughly tested and evaluated for ductility, bending properties, fatigue, relaxation, bond, susceptibility to mechanical damage, effect of hot and cold temperatures, and chemical attack.

4.3 — Component standards

4.3.1 — General

Ensure all connectors, connections, and components of post-tensioning system hardware are completely sealed against leakage of concrete paste. All hardware, components, and connections for PL-2 and PL-3—as defined in Section 3—shall be airtight and watertight and pass the pressure test requirements herein. Use smooth plastic duct for external tendons except where steel pipe is required. Use corrugated duct for all internal tendons except where steel pipe is required.

4.3.2 — Post-tensioning anchorages

Local zones and related anchorage devices shall be designed and tested in accordance with the AASTHO LRFD Bridge Design Specification, Design of Local Zones (AASHTO LRFD).

Maximum allowable angular misalignment of bars with respect to the bearing plate—For spherical bearing plate/nut applications, ±2 degrees for all live-end

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manufacturing processes, as hot-rolled, cold-drawn, and cold-deformed bars.

Steels with tensile strengths exceeding 150 ksi (1030 MPa) may exhibit sensitivity or embrittlement due to hydrogen. Galvanized bars are not permitted for use as a grouted tendon. During curing, the alkaline nature of the cement paste can corrode the zinc coating, resulting in hydrogen evolution. This hydrogen MAY diffuse into the steel and cause embrittlement issues, which in turn could lead to premature failure of the tendon.

Effective long-term corrosion protection is provided by grouting bars inside plastic duct. The alkaline cement grout passivates the bar surface and the plastic duct acts as a moisture barrier. Such corrosion protection requires special anchorage details to maintain thread-ability and corrosion protection.

C4.2.3 – Special prestressing materials

This section applies to post-tensioning steel in sizes and grades which ASTM A416 and A722 do not cover; it also covers wire conforming to ASTM A421. This section also applies to nonmetallic materials, which are under development and may find wide range of applications in the future.

Glass fiber and carbon fiber tendons (Aramid, Kevlar) have been installed in a few prototype structures.

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anchor nuts and ±3 degrees for all fixed-end anchor nuts; for non-spherical bearing plate applications, ±1 degree at live- and fixed-end anchor nuts.

Wedge plates and wedges shall meet the requirements of PTI's "Acceptance Standards for Post-Tensioning Systems," Section 4.1, except 4.1.1(1) is not applicable. Provide self-centering wedge plates to facilitate alignment with the bearing plate.

Equip all anchorages for PL-1B, PL-2, and PL-3 with a permanent, vented grout cap that is secured to the anchorage. Grout inlets/outlets shall also serve as post-grouting inspection access points (hence, manufactured anchorages with grout inlets/outlets on top or in front and suitable for inspections). The geometry of the grout inlets/outlets shall permit drilling using a 3/8 in. (9.5 mm) diameter straight bit to facilitate borescope inspection directly behind the wedge plate.

Permanent grout caps shall be nonmetallic, stainless steel, or galvanized ferrous metal with a minimum thickness of zinc of 4.7 mils (120 µm).

Trumpets associated with anchorages shall be made of either ferrous metal or plastic. For plastic trumpets, the trumpet shall be made of high-density polyethylene or polypropylene. The thickness of the trumpet at the duct end shall not be less than the thickness of the duct.

For PL-2 and PL-3, connections from the trumpet to the duct and the trumpet to the bearing plate shall have the same leak tightness requirements as duct-to-duct couplers.

4.3.3 — Permanent grout caps

Use permanent grout caps made from approved polymer: ASTM A240 Type 316 stainless steel or ASTM A123 galvanized ferrous metal. The approved resins for use in the polymer shall have ultraviolent [UV] stabilizer added. Seal the cap to the bearing plate with "O"-ring seals, gaskets, or precision-fitted flat gaskets. Place a grout vent on the top of the cap. Grout caps shall be pressure-tested prior to grout injection and certified to a minimum pressure of 150 psi by the PTS supplier. Use ASTM F593 Type 316 stainless steel bolts to attach the cap to the anchorage.

C4.3.3 – Permanent grout caps

This section applies to the types of materials that are used to make permanent grout caps. ASTM D5989 stipulates the properties of various classes of nylon that can be used for extrusion or monomer cast grout caps. ASTM D4066 stipulates the properties of various classes of nylon that can be used for injection molding of the grout cap. Acceptable callout designations are noted. Some types of nylon have sufficient durability and other types of nylon require addition of additives to provide the required durability. For added strength, glass fiber may be added to nylon that is injection molded.

4.3.4 — Bar couplers

High-strength bar couplers shall meet the requirements of ASTM A722 and shall develop 100% of the

C4.3.4 – Bar couplers

Consider using couplers equipped with set screws or use lock nuts on each side of a coupler to fix the coupler in position.

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specified tensile strength (f_{pu}) of the bar when tested in an unbonded state. Test and provide written certification that the couplers meet these requirements. Couplers and components shall be enclosed in enclosure long enough to permit the necessary movements. Tendon enclosure shall be designed so that complete grouting of all the coupler components is achievable.

Couplers require full and equal engagement of the bars they are joining.

4.3.5 — Duct

For multi-strand tendons, provide ducts with a minimum cross-sectional area two-and-a-half times the cross-sectional area of the prestressing steel based on the inside diameter of the duct. For prestressing bars, provide the duct with a minimum inside diameter of at least 1/2 in. (13 mm) larger than the outside diameter of the bar, measured across the deformations. For prestressing bars with couplers, size the duct to be 1/2 in. (13 mm) larger than the outside diameter of the bar and/or coupler.

4.3.5.1 — Corrugated metal duct

Ducts and connectors shall be fabricated from galvanized sheet steel meeting the requirements of ASTM A653/A653M, coating designation G90. Ducts shall be fabricated with either welded or interlocked seams. Galvanizing of welded seams is required. Semi-rigid ducts shall be corrugated and their minimum wall thickness shall be as follows: 26 gauge for ducts less than or equal to 2.625 in. (67 mm) diameter, 24 gauge for ducts greater than 2.625 in. (67 mm) diameter.

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Marking the bar with tape or paint to verify full engagement may assist in visually checking that couplers are fully engaged.

C4.3.5 – Duct

It is necessary to size the duct larger than the area of prestressing steel to allow for proper installation, placing tolerance and adequate space for grout to bond the prestressing steel to the duct and thus to the concrete. The length of the tendon, the total curvature of the tendon, and the method of installation of prestressing steel, pushing or pulling, could affect the ratio of duct ID to prestressing steel. Longer tendons may necessitate a ratio greater than two-and-a-half. Tendons that have great curvature or many spans may necessitate a ratio greater than two-and-a-half.

Past experience has shown that bar tendons with 1/4 in. clear on all sides is enough to allow placing of the prestressing bar and is adequate for grout bonding. Note that prestressing bars are typically installed in the duct prior to concreting.

A variety of different duct material types are suitable for post-tensioning systems, depending on the Tendon PL and application. Duct types are identified in Sections 4.3.5.1 through 4.3.5.3.

C4.3.5.1 – Corrugated metal duct

Corrugated metal duct is normally used for internal post-tensioning tendons. Corrugated metal duct is typically manufactured in a duct corrugator that takes flat metal sheets and through rollers it applies corrugations, creates a round shape, and seams the flat sheets together. When welding seams, re-galvanizing of the seams is required to maintain protection of the metal. Wall thicknesses can be greater than that shown at the subcontractor's option but cannot be thinner.

Corrugated metal duct is considered semi-rigid. It should have sufficient longitudinal stiffness to achieve a smooth duct profile, but be flexible enough to form common duct profiles without pre-bending. The depth and spacing of spiral ribs is determined by the requirement to resist fluid concrete pressure, denting during handling and installation, and damage from concentrated forces at support points.

Corrugated metal duct is normally grout-tight but not necessarily water- or vapor-tight.

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4.3.5.2 — Corrugated plastic duct

Use seamless fabrication methods to manufacture corrugated plastic duct. Manufacture from virgin, unfilled, non-colored polypropylene meeting the requirements of ASTM D4101 with a cell classification range of PP0340B44541 to PP0340B67884 or polyethylene fabricated from resins meeting or exceeding the requirements of ASTM D3350 with a cell classification of range of PE344434D to PE445574D.

Corrugated plastic duct for use in cold weather construction (–22 to 32°F) [-30 to 0°C] shall be manufactured from virgin, unfilled, non-colored polypropylene meeting the requirements of ASTM D4101 with a cell classification range of PP0340B44531 to PP0340B67884 or polyethylene fabricated from resins meeting or exceeding the requirements of ASTM D3350 with a cell classification of range of PE344434D to PE445574D.

Cell classification testing shall be performed by an independent lab for the initial vendor batch and once annually. Material certifications shall be submitted to the Owner for each batch of material used on a project. Duct lot numbers shall be maintained to track batch tests to ducts produced.

The corrugated plastic duct shall contain antioxidant(s) with a minimum oxidation induction time (OIT) according to ASTM D3895 of 20 minutes and containing a non-yellowing light stabilizer. Environmental stress cracking of the corrugated plastic duct shall be in accordance with ASTM F2136 at 348 psi (2.4 MPa) for 3 hours.

The minimum wall thickness of corrugated plastic duct shall be in accordance with Table 4.1.

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C4.3.5.2 – Corrugated plastic duct

Corrugated plastic duct is normally used for internal post-tensioning tendons. The cell classification ranges shown apply to the base material. Performance testing to confirm adequacy of the material and duct system is shown in Section 4.4.4. Certain characteristics of polypropylene and polyethylene may enhance different aspects of the duct system and should be taken into account when choosing a polymer.

In cold weather, some characteristics of polymers change. Cold weather additives are sometimes added to the duct during manufacture to enhance cold weather performance. These additives should be considered when the polymer duct system is exposed to cold weather construction.

It is important that the duct system supplied to a project will behave the same as the material that was performance tested.

Oxidation induction time (OIT) and environmental stress cracking (ESC) testing is performed on end product and confirm the duct system's materials ability to remain stable when exposed to certain test conditions. The test conditions chosen should satisfy most site conditions when the materials will not be exposed to the elements for extended periods of time.

The minimum wall thicknesses shown in Table 4.1 are prior to wear testing per Section 4.4.4.

Table 4.1—Minimum wall thickness of corrugated plastic duct

Duct shape	Size/Ø, in.	Wall thickness, in.
Flat	≤1.0 × 4.0	≥0.08
Round	≤2.375	≥0.08
Round	2.375 < Ø ≤ 3.35	≥0.10
Round	3.35 < Ø ≤ 4.0	≥0.12
Round	4.0 < Ø ≤ 4.5	≥0.14
Round	4.5 < Ø ≤ 5.75	≥0.16

Note: 1 in. = 25.4 mm.

4.3.5.3 — Smooth HDPE duct

Use a smooth duct manufactured from 100% virgin polyethylene resin meeting the requirements of ASTM D3350 with a minimum cell class of 445574C. Use resin containing antioxidant(s). Perform OIT test on samples taken from the finished product resulting in a minimum OIT according to ASTM D3895 of

C4.3.5.3 – Smooth HDPE duct

Smooth HDPE duct is normally used for external post-tensioning tendons. Many times, the duct is a water, sewer, or gas pipe that is manufactured with high-density polyethylene containing antioxidants.

In the past, smooth polyethylene pipe PE3408 was supplied as water pressure pipe, which was shorthand

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40 minutes. Manufacture duct with a dimension ratio (DR) of 17.0 or less as specified by either ASTM D5309 or ASTM F714, using appropriate dimensions and tolerances. Use a smooth duct meeting the minimum pressure rating (working pressure) of 100 psi (0.69 MPa) and manufactured to either of the following specifications: ASTM D3035 or ASTM F714.

Minimum wall thickness shall be *d*/17, where *d* is the outside diameter of the duct.

4.3.6 — Duct connections and fittings

Make all splices, joints, couplings, and connections to duct and anchorages with devices or methods (mechanical couplers, plastic sleeves, heat-shrink sleeve) producing a smooth interior alignment with no lips or kinks. Design all connections and fittings to be concrete-paste tight; when installed and cast into concrete prior to prestressing steel installation, fittings and connections shall be capable of withstanding 10 ft of concrete fluid pressure. When used

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for an ASTM D3350 commonly specified pipe. At some point in time, industry divided PE3408 into more accurate pipe values PE3408, PE3608, and PE4710 to identify higher quality of polyethylene resin. PE3608 and PE4710 have the same dimensions, except the pressure rating for PE3608 is 100 psi (0.69 MPa) and PE4710 is 125 psi (0.86 MPa). Therefore, industry continues to transition to the higher PE4710 material properties, which could be used for PE3608- and PE4710-specified projects. The PE4710 commonly has an ASTM D3350 cell class of 445574C, which is currently used for grouted PT ducts.

The "C" describes black material with 2% minimum carbon as UV stabilizer. The relatively low density and strength of such ducts and related susceptibility to damage during installation requires caution, especially for large, long, or curved ducts.

The large thermal expansion of HDPE duct, relative to the approximately 6×10^{-6} in./in./ºF (11 × 10-6 mm/mm/°C) of steel or concrete, may require long couplers to compensate for temperature differences between night and day. Softening of the plastic when hot may cause undesirable sagging between support points and denting at support points.

Oxidation induction time (OIT) testing is performed on end product and confirm the duct materials ability to remain stable when exposed to certain test conditions. The test conditions chosen should satisfy most site conditions when the materials will be used within a concrete box-girder bridge. When external tendons are not within a box or are continuously exposed to the elements, consideration should be given to the appropriate OIT test conditions.
The dimension ratio (DR) typically gives the required wall thickness of the duct for a specific diameter.

The minimum pressure rating is to assure that the duct does not split during the grouting process. If higher pressures are used during grouting or expansive agents are used within the grout, consideration of these factors shall be applied to the choice of smooth HDPE duct.

Single slightly lower test results out of several passing tests may not signify that the duct is of lower quality than specified.

C4.3.6 – Duct connections and fittings

Duct connections and fittings are an integral part of the duct system and, as such, must meet certain performance criterion.

A smooth interior alignment is necessary when installing prestressing steel so that the prestressing steel does not "hang-up" on a lip or kink.

Concrete applies a fluid pressure on the duct that may collapse or ovalize the duct, thus making installing the

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with preinstalled prestressing steel, prior to concreting, fittings and gaskets shall be capable of withstanding 5 ft (1.5 m) of concrete fluid pressure. All connections and fittings for PL-2 and PL-3 shall be airtight and watertight. Tape-sealed connections are permitted in PL-1 only but shall meet sealing requirements for the fluid pressure.

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prestressing steel or grouting the tendons difficult or impossible. Ten ft concrete fluid pressure is considered the maximum height of concrete placement before the concrete begins to harden, thus no longer applying a fluid pressure. If the duct system will experience greater concrete fluid pressures (such as when using self-consolidating concrete or thin vertical concrete members), consideration of these higher pressures should be applied to the choice of the duct system.

4.3.7 — Heat-shrink sleeves

Heat-shrink sleeves shall have unidirectional circumferential recovery manufactured specifically for the size of the duct being coupled consisting of an irradiated and cross-linked high-density polyethylene backing for external applications and linear-density polyethylene for internal applications. Furnish adhesive having the same bond value to steel and polyolefin plastic materials. Ensure the heat-shrink sleeves have an adhesive layer that will withstand 150°F (66°C) operating temperature and meet the requirements of Table 4.2.

Install heat-shrink sleeves using procedures and methods in accordance with the manufacturer's recommendations.

C4.3.7 – Heat-shrink sleeves

Heat-shrink sleeves are many times used at duct-to-duct and duct-to-anchorage connections to achieve performance requirements related to sealing connections and fittings for specific pressures. Section 9.8 includes some additional information on lengths and overlaps.

Proper installation of heat-shrink sleeves is important to maintain the quality of connection and manufacturer's recommendations should be used. The heat-shrink sleeve must be sealed on all sides evenly to perform correctly – sometimes this is not easy in the field.

Table 4.2—Requirements for heat-shrink sleeves

Property	Test method	Minimum requirements	
		Internal application	External application
Minimum fully recovered thickness	—	92 mils	111 mils
Peel strength	ASTM D1000	29 pli	46 pli
Softening point	ASTM E28	162°F	216°F
Lap shear	DIN 30 672M	87 psi	58 psi
Tensile strength	ASTM D638	2900 psi	3480 psi
Hardness	ASTM D2240	46 Shore D	52 Shore D
Water absorption	ASTM D570	Less than 0.05%	Less than 0.05%
Color	—	Yellow	Black
Minimum recovery	Heat recovery test	33%	23%

Notes: 1 mil = 0.0254 mm; 1 psi = 0.00689 MPa.

4.3.8 — Precast segmental duct couplers

PTS intended for use with precast segmental construction shall include duct couplers at the segment joints for Tendons PL-2 and PL-3 (unless otherwise specified in the Contract Documents). Ensure that the PTS precast segmental duct coupler system (components and connections):

C4.3.8 – Precast segmental duct couplers

Precast segmental duct couplers are used for continuity of the tendon envelope across segment joints in precast segmental construction. Joints can allow entry points for water (possibly contaminated with corrosive agents) to attack prestressing steel. Segmental duct couplers and polymer post-tensioning duct provide protection against

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- Are airtight and meet the performance requirements of this specification
- A segment coupler shall:
  - Be securely mounted to the joint (bulkhead);
  - Be designed to receive a duct at a minimum deviation angle from perpendicular equal to the maximum present in the structure and at an angle of at least 6 degrees deviation from perpendicular;
  - Be designed to allow for segment misalignment up to 1/8 in. (3.2 mm) in any axis; and
  - Not induce any additional angle change in the tendon as it passes through the coupler.
- Assemblies holding the precast segmental duct coupler sealing gaskets shall mount to the form bulkhead and provide for duct alignment;
- Shall be compatible with prestressing steel, concrete, grout, and duct material; and
- Sealing gaskets shall not interfere with erection or prevent the joint from being fully closed at temporary erection forces.

4.3.9 — External smooth HDPE duct connections

Connections made to or between HDPE smooth duct shall meet the minimum working pressure rating of 100 psi and the method used shall result in a smooth interior alignment with no lips or kinks. The connections shall be accomplished with one of the following methods:

- Heat-welding techniques or electrofusion couplers in accordance with the duct manufacturer's instructions.
- An EPDM coupler sleeve with a 316 stainless steel clamp.
- Other mechanical couplers meeting the material requirements of this specification.

4.3.10 — Rigid ducts and steel pipes

Rigid ducts shall be capable of being curved to the proper configuration without crimping or flattening. For deviation pipes in blocks and diaphragms, use galvanized ASTM A53, Grade B, Schedule 40 steel pipes; galvanized ASTM A500 structural steel tubing; smooth HDPE duct; or corrugated plastic duct meeting the requirements of this specification for the required bend radii. Pre-bent pipes shall be labeled for orientation.

4.3.11 — Connection tolerance between pipe and duct

Connect steel pipe and plastic duct directly to each other when the inside diameters do not vary more than ±1/16 in. (1.6 mm) Use a reducer when the diameters

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waterborne contaminants by enclosing the prestressing steel in a continuous watertight enclosure. Section 4.4.5.2 provides performance test requirements.

Precast segmental duct couplers can also be used with PL-1 tendons if specified in the Contract Documents.

Precast segmental duct couplers have the specified minimum characteristics. Greater construction flexibilities may be desired by the Contractor and individual precast segmental duct coupler systems should be evaluated prior to purchase. More stringent requirements or greater flexibility may be required by a specific project site and any additional requirements should be specified in the contract documents.

Sealing gaskets should compress so they do not act as shims during the erection process while still providing sealing capabilities required by performance testing.

C4.3.9 – External smooth HDPE duct connections

Couplers should be positioned to have equal engagement or overlap.

C4.3.10 – Rigid ducts and steel pipes

Proper orientation and placement of pre-bent pipes is critical. Survey should be done prior to concrete placement. Ensure the length of the rigid duct or pipe is such that it allows adequate protrusion length from concrete for proper coupling.

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of the steel pipe and the plastic duct are outside of this tolerance. Reducer shall be made of materials meeting the same requirements as steel pipe or plastic ducts used and have a connection method suitable to safely meet the same pressure requirements as the duct.

4.3.12 — Inlets, outlets, valves, and plugs

All inlets and outlets shall be equipped with pressure-rated mechanical shutoff valves or plugs. Inlets, outlets, valves, and plugs shall be designed and tested to resist a minimum pressure of 150 psi (1.0 MPa). Use inlets and outlets with a minimum inside diameter of 3/4 in. (19 mm) for strand and 3/8 in. (9.5 mm) for single-bar tendons and four-strand tendons. Provide dual mechanical shutoff valves when performing vertical grouting. Specifically designate temporary items—not part of the permanent structure—on the PT installation drawings.

4.4 — System approval testing

For acceptance and approval of a PTS, the components and system testing shall be witnessed and certified by an independent testing laboratory or institute. The testing laboratories or institutes shall be:

- AMRL or A2LA certified, or
- Other organizations accredited to ISO 17025 or AASHTO R 18, or
- Alternatively, for tests performed prior to the publishing of M50.3-19, an ABET Engineering accredited Academic Institute with a materials/structural testing laboratory with capabilities (subject to approval by the PTI CRT-140 Certification Advisory Board) to perform the tests.

System approval testing shall be completed prior to submission of PT Installation Drawings and other related documents to the Engineer for approval.

C4.4 – System approval testing

The system qualification test determines if the components as a tendon unit will perform as required.

4.4.1 — Post-tensioning anchorages

1. Test and provide test reports that anchorages develop at least 95% AUTS of the prestressing steel, when tested in an unbonded state, without exceeding anticipated set.

2. Test and provide written certification that anchorages meet the testing requirements in the AASHTO LRFD Bridge Construction Specifications, Section 10, “Prestressing”: Special Anchorage Device Acceptance Test (Section 10.3.2.3). Test the anchorage in a test block according to one of three procedures

C4.4.1 – Post-tensioning anchorages

Special anchorage device

Most suppliers have developed special anchorage devices. They have special shapes, frequently have multiple bearing surfaces, and often are ductile iron castings. Such special anchorage devices normally produce very high local bearing stresses on the concrete and, therefore, require spirals or equivalent confinement reinforcement in the local zone. They are not readily amenable to rational stress analysis and their adequacy must be established by tests.

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described (that is, cyclic loading, sustained loading, or monotonic loading, in full conformance with AASHTO Section 10.3.2.3).

3. Wedge plates shall pass the following wedge plate test. Adequacy of wedge plates shall be established by static tests. The number of tests is specified below. The following requirements shall be met.

(1) After loading to 95% of tendon MUTS and subsequent force release, the permanent deflection of the wedge plate's top surface shall be measured and recorded. Residual deformations of anchorage components after testing shall be less than the allowable deflection declared by the PT Supplier. The load test shall be performed with the wedge plate support simulating conditions in the anchorage assembly. The force shall be applied by pulling on a sample tendon using the standard system wedges.

(2) Wedge plates shall be tested to failure in static load tests, or to the loading capacity of the testing equipment. The tests shall simulate actual tendon forces applied to the wedges. The failure force shall be at least 120% MUTS.

Three successful qualification tests on wedge plates for each tendon size, shall establish that they will meet the requirements of Section 4.4.1.3. Each sample shall be taken from a different heat.

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Basic bearing plates design criteria
The design of single and grouped basic bearing plates depends on the size of the distribution area.

Wedge plate test requirements
Wedge plates have very complex loading conditions and internal stresses. Their safety margins against failure can only be established by destructive tests, which simulate the actual loading conditions. PTI's "Acceptance Standards for Post-Tensioning Systems," Section 6.1.5, specifies three static tests to failure.

The destructive tests must simulate the lateral forces the wedges exert on the wedge plate. Replacing the strand with high strength bolts of equivalent diameter and loading the assembly in a testing frame, over a relatively soft steel distribution plate, provides adequate realism to such tests. Figure C 4-1 shows how this test can be performed.

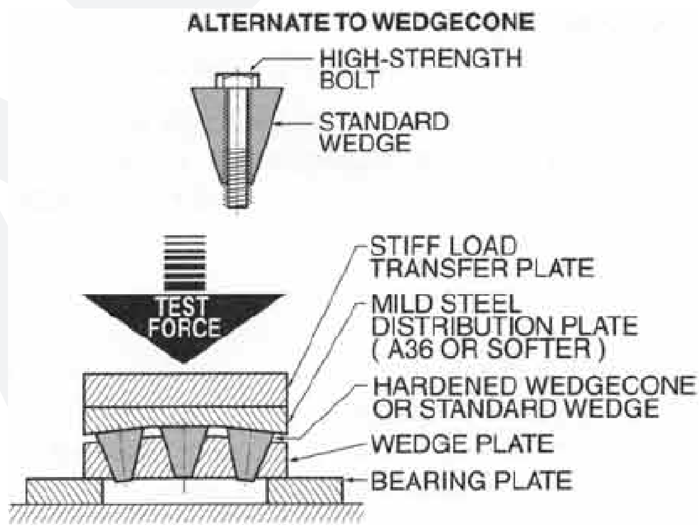

Fig. C4-1—Wedge plate test.

Typical wedge
Suppliers and manufacturers have developed a variety of different types of wedges for particular systems and specific applications. A standard wedge, which fits all systems and applications, has not evolved; but most wedges have certain features in common.

A typical wedge has a five- to seven-degree angle and has a length of at least 2.5 times the nominal strand diameter. It is manufactured from low carbon steel (AISI 12-L14 or 11-L17) or alloy steel (AISI 86L20), which are suitable for case-hardening while maintaining a ductile core. After machining, the wedge is case-hardened to at least 58 HRC measured at 1/3 case depth (or equivalent hardness scale), and an effective case depth of at least 0.008 in. (0.20 mm), while maintaining a ductile core hardness less than 46 HRC.

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Cracks in wedges
Wedges are designed to have hard surfaces, as required for the wedge teeth to bite into the high-strength strand. Wedges are also designed to have ductile cores, which allow the wedges to adjust to irregular strand shape and the form of the wedge holes. As wedges deform, their outer hard surfaces may crack, while the ductile cores prevent wedges from breaking into pieces.

Surface cracks have caused concern and acceptance problems on some projects. Experience has shown, however, that surface cracks are not a safety hazard and do not affect the performance of strand-wedge connections adversely. Surface cracks signify hard and brittle surfaces.

Not acceptable are wedges that have broken into several pieces, signifying not only hard surfaces but also brittle cores. Nevertheless, wedges broken longitudinally into several slices perform adequately. Horizontal or inclined breaks, however, are considered unacceptable.

Bar-anchor nut and bar-coupler connection performance requirements
Bars normally have threaded connections to anchor nuts and couplers. Such connections rely on mechanical interlock and have only a few important variables, such as type of thread, engagement length, dimensional tolerances, and material strength. Their performance can be established reliably by rational analysis and verified by small test series.

4.4.2 — Grouting component assembly pressure test (PL-1B, PL-2, and PL-3 only) and system safety proof test (PL-1A only)
Assemble anchorage and grout cap with all required grouting attachments (grout tube, valves, plugs, and so on). Seal the opening in the bearing plate where the duct/trumpet connect. For PL-2 and PL-3, condition the assembly at 150 psi (1.0 MPa) for 3 hours before conducting the pressure test.

The assembly shall sustain a 150 psi (1.0 MPa) internal pressure for 5 minutes with no more than 15 psi (0.1 MPa) reduction in pressure. The PL-1A system safety proof test is to withstand 75 psi (0.5 MPa).

4.4.3 — Duct testing
Duct and duct connections installed and cast into concrete prior to prestressing steel installation shall be capable of withstanding 10 ft (3.0 m) of concrete fluid pressure. Duct and duct connections for use with straight preinstalled prestressing steel, installed prior to concreting, shall be capable of withstanding 5 ft (1.5 m) of concrete fluid pressure. Duct and duct

C4.4.3 – Duct testing
Concrete applies a fluid pressure on the duct that may collapse or ovalize the duct, thus making installing the prestressing steel or grouting the tendons difficult or impossible. Ten ft concrete fluid pressure is considered the maximum height of concrete placement before the concrete begins to harden, thus no longer applying a fluid pressure. If the duct system will experience greater

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connections shall not permanently dent more than 1/8 in. (3.2 mm) under 150 lb (68 kg) of concentrated force applied between corrugations, using No. 4 reinforcing bar. Apply force for 2 minutes and measure the dent 2 minutes after force removal. The duct shall have adequate longitudinal bending stiffness for smooth placement.

In addition, corrugated metal duct shall be tested as outlined in Sections 5.1(6) and 6.1.8 of PTI's "Acceptance Standards for Post-Tensioning Systems."

4.4.4 — Corrugated plastic duct

The corrugated plastic duct system, components, and accessories shall meet the requirements of Fédération International du Béton (*fib*), Bulletin 7, Technical Report, "Corrugated Plastic Duct for Internal Bonded Post-Tensioning," Chapter 4, Sections 4.1.1 through 4.1.8.

The requirements of *fib* Bulletin 7 are modified as follows:

"Lateral Load Resistance of Duct" (*fib* 4.1.4)—Conduct this test without the use of a duct-stiffener plate, using a load of 150 lb (68 kg) for all sizes.

"Wear Resistance of Duct" (*fib* 4.1.7)—Acceptance criteria for remaining duct thickness after testing shall not be less than 0.06 in. (1.5 mm) for duct up to and including 3.35 in. (85 mm) in diameter and not less than 0.08 in. (2 mm) for duct greater than 3.35 in. (85 mm) in diameter.

"Bond Behavior of Tendons" (*fib* 4.1.8)—Acceptance criteria shall achieve 40% fpu in a maximum length of 16 duct diameters for round duct and 30 in. (760 mm) for flat duct.

"Modified Wear Resistance of Duct" (*fib* 4.1.7)—Test is in addition to "Wear Resistance of Duct" noted previously. Test apparatus shall be identical with the same clamping force as a function of the number of strands in the duct. Procedure modified: Do not move the sample along the strand to simulate wear. Clamp

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concrete fluid pressures (such as when using self-consolidating concrete or thin vertical concrete members), consideration of these higher pressures shall be applied to the choice of the duct system.

When prestressing steel is installed prior to concrete, there is no concern with prestressing steel installation; however, grouting could be an issue if the duct collapses or ovalizes, thus the requirement for 5 ft (1.5 m) of concrete fluid pressure.

If the duct or duct connectors dent more than 1/8 in. (3.2 mm), the concern is that installing prestressing steel or grouting the tendons may become difficult or impossible. Duct and duct connectors should be protected from damage during storage, transportation, and handling; however, after placing and prior to concrete placement, load may be inadvertently applied to the duct and the duct may dent at support bars, which may restrict installation of prestressing steel or grouting.

C4.4.4 – Corrugated plastic duct

Corrugated plastic duct shall be performance tested. *fib* Bulletin 7 identifies eight performance aspects of plastic duct and describes test procedures and acceptance criterion for each.

This specification follows Florida Department of Transportation recommendations to modify certain performance test procedures and acceptance criterion.

No stiffeners are allowed to pass the test because there is a chance their use will not be observed in the field. The applied load is the same for all duct sizes.

The acceptance criterion in this specification allows for a greater safety factor then that in *fib* Bulletin 7.

It is felt that loading the specimen to failure may be dangerous, thus the 40% f_{pu} requirement. This can be interpolated to establish 100% bond because bond behavior is linear in nature.

The "Modified Wear Resistance of Duct" test is added to *fib* Bulletin 7 performance tests. The duct should be sufficiently resistant to wear-through caused by the prestressing steel during the time before grouting but after stressing of the tendon when bent to the minimum-specified radius of curvature.

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duct to the strand for 7 days' duration. Upon completion of test duration, remove duct and measure minimum wall thickness along the strand path. Acceptance criteria is that the minimum wall thickness along the strand path shall not be less than 0.06 in. (1.5 mm) for duct up to and including 3.35 in. (85 mm) in diameter and not less than 0.08 in. (2 mm) for duct greater than 3.35 in. (85 mm) in diameter.

"Wear Resistance of Duct" and "Modified Wear Resistance of Duct" testing to be performed for each blend of polypropylene or polyethylene used in the manufacture of corrugated plastic duct.

Corrugated plastic duct performance testing per Fédération International du Béton (*fib*), Bulletin 7, Technical Report, "Corrugated Plastic Duct for Internal Bonded Post-Tensioning," Chapter 4, Sections 4.1.1 through 4.1.7, as modified herein, shall be repeated whenever material properties change or geometry of the duct changes. The "Bond Behavior of Tendons" (*fib* 4.1.8) test need only be repeated when tensile strength of the material has been reduced by more than 10% from the previous test or the geometry of the duct changes.

Testing shall be confirmed through a report prepared by an independent testing agency. Duct performance testing shall be repeated whenever material properties change or geometry of the duct changes. Bond behavior is dictated more by geometry of the duct than material properties; however, with a reduction of tensile strength of duct material by more than 10%, an additional bond test is required.

As an alternate, testing per Bulletin 75, Sections 6.1 through 6.10, is permitted to be used for testing of plastic ducts in lieu of Bulletin 7, Sections 4.1.1 through 4.1.8.

fib Bulletin 75 has been recently published, which is under consideration by the M-50 Committee for incorporation into the next edition of the M50.3 Specification. The bulletin 75 provides additional information on testing of plastic ducts.

4.4.5 — System pressure tests

For each assembly of PTS, including all sizes and configurations, assemble systems and perform the pressure test defined herein. The post-tensioning assembly includes at least one of each component required to make a tendon from grout cap to grout cap. If applicable, include plastic duct to steel pipe connections, segmental duct couplers, duct couplers and grout vents/tubes connections.

4.4.5 – System pressure tests

System pressure tests are qualification tests and are not intended to be performed in the field during construction.

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4.4.5.1 — Corrugated plastic duct connections

Corrugated duct connectors (couplers) shall meet the "Leak Tightness" requirements of Fédération International du Béton (*fib*), Bulletin 7, Technical Report, "Corrugated Plastic Duct for Internal Bonded Post-Tensioning," Chapter 4, Section 4.1.6, when tested on the same specimen without reassembly or reinstallation that has been subjected to *fib* Bulletin 7 Tests, "Flexibility" (*fib* 4.1.3), "Lateral Load Resistance" (*fib* 4.1.4), and "Longitudinal Load Resistance" (*fib* 4.1.5).

Procedure:

- Specimen shall be bent with a template to the minimum radius of tendon curvature;
- Specimen shall be pressure-tested underwater with an applied pressure of 7.25 psi (0.05 MPa) over a period of 5 minutes;
- Specimen shall be tested with both positive and negative pressures; and
- Acceptance criteria are no visibly detectable leaks with positive or negative pressure.

Testing shall be confirmed through a report prepared by an independent testing agency. Duct connector (coupler) performance testing shall be repeated whenever material properties change or geometry of the duct connector (coupler) changes.

4.4.5.2 — Precast segmental duct couplers

Perform the following performance test on each size of precast segmental duct coupler:

- Cast the segmental duct coupler with duct and connectors (assembly) into a two-part concrete test block (at least 12 x 12 x 12 in.) (305 x 305 x 305 mm) using match-cast techniques;
- After the concrete has hardened, separate the blocks and clean the joining surface of any bond breaker material;
- Sealing gasket compressive required force:
  - Using an external apparatus, apply a compressive force to the concrete test blocks to compress the sealing gasket to its final position; and
  - Acceptance criteria: The maximum force required to compress the sealing gasket to its final compressed position shall not be greater than 25 psi (0.17 MPa) times the area encircled by the sealing gasket.
- Segmental duct coupler air pressure test:
  - Using an external apparatus, clamp the test blocks together and maintain 40 psi (0.28 MPa) pressure on the test block cross section during this test;

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C4.4.5.1 – Corrugated plastic duct connections

The duct system including corrugated plastic duct connectors when in its final condition for PL-1 applications must be mortar-tight (similar to steel duct) and for PL-2 and PL-3 applications must be leak-tight. This means that after exposure to shipping, jobsite handling, installation, and concreting, the duct and connectors should be mortar-/leak-tight. Thus, assessment for mortar/leak tightness is performed on the same test specimen that has successfully passed "flexibility," "lateral load," and "longitudinal load" testing.

C4.4.5.2 – Precast segmental duct couplers

Testing of precast segmental duct couplers confirm their ability to provide continuity of the tendon envelope across segment joints in precast segmental construction.

The performance test for sealing gasket compressive force confirms that the sealing gasket will not act as a shim (preventing joint closure) when erection compressive forces are applied to a segment during the erection process.

The performance test for air pressure confirms that the precast segmental duct coupler is airtight after segment erection prior to application of permanent prestress forces.

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  - Do not apply epoxy between the test blocks during this test;
  - Pressurize the assembly within the test blocks to 50 psi (0.35 MPa) and lock off the outside air source;
  - Acceptance criteria: The assembly shall sustain a 50 psi (0.35 MPa) internal pressure for a minimum of 5 minutes with no more than a 5 psi (0.04 MPa) reduction in pressure; and
  - Separate the test blocks.
- Assembly toughness test:
  - Place a 1/16 in. (1.6 mm) layer of epoxy on the face of both test blocks and, using an external apparatus, clamp the test blocks together and maintain 40 psi (0.28 MPa) pressure on the test block cross section for 24 hours;
  - Remove the clamping force and inspect the inside of the duct and the segmental duct coupler; and
  - Acceptance criteria: The segmental duct coupler with duct and connectors (assembly) shall be intact and free of epoxy, and remain properly attached without crushing, tearing, or other signs of failure.

Testing shall be confirmed through a report prepared by an independent testing laboratory. The testing laboratories shall be AMRL or A2LA certified, or other organizations accredited to ISO 17025 or AASHTO R18. Precast segmental duct coupler performance testing shall be repeated whenever material properties change or geometry of the segmental duct coupler changes.

4.4.5.3 — Internal duct systems

Perform a system test of the assembly for compliance with the requirements of Chapter 4, Article 4.2, Stage 1 and Stage 2 Testing, contained in *fib* Technical Report, Bulletin 7, "Corrugated Plastic Duct for Internal Bonded Post-tensioning." Alternatively, perform a system test of the assembly for compliance with the requirements of Articles 7.4 and 7.5 (with their relevant Annex B.4 and B.5), contained in *fib* Technical Report, Bulletin 75, "Polymer-Duct Systems for Internal Bonded Post-Tensioning." For bar systems, modify the system test length to 15 ft (4.6 m).

4.4.5.4 — External duct systems

The anchorage connection to the duct/pipe assembly shall be tested in accordance with and meet the requirements for internal duct systems.

COMMENTARY

The performance test for toughness confirms that the precast segmental duct coupler system remains intact and that the components are not damaged during construction.

C4.4.5.3 – Internal duct systems

The Stage 1 performance test confirms that the components of an internal duct system from grout cap to grout cap can be successfully assembled and profiled within tolerances without profile discontinuities and without excessive duct deformations.

The Stage 2 performance tests that the fully assembled system from Stage 1 is sufficiently leak-tight.

C4.4.5.4 – External duct systems

The external duct systems performance test confirms that the duct and connections can handle grouting pressures without damage to the system.

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The duct and pipe assembly consisting of all external duct connections (welded duct splices, duct-to-pipe, and so on) and a grout vent shall comply with the following test. Condition the assembly at 150 psi (1.0 MPa) for 30 minutes before conducting the pressure test. The assembly shall sustain a 150 psi (1.0 MPa) internal pressure for 1 minute with no more than a 10% reduction in pressure.

It shall be permitted to perform the test in conjunction with the assembly pressure test detailed in Section 4.4.2. The length of the test pipe assembly for the second test shall be 15 ft (4.6 m).

5.0 — INSTALLATION DRAWINGS AND STRESSING CALCULATIONS

5.1 — General

Submit installation drawings for all post-tensioning to be installed in accordance with the Contract Documents. Installation drawings shall be approved by the Design Engineer prior to commencing post-tensioning materials installation. If specified, all post-tensioning installation drawings are to be produced, signed, and sealed by a professional engineer licensed in the state where the work is to be performed who has a minimum of 5 years of experience in this type of work.

5.2 — System drawings

Submit post-tensioning system drawings showing all components required for the tendon installation, both temporary and permanent (to include part numbers as appropriate). Define the nominal geometry and material composition of all components to be used.

As a minimum, show all applicable:

- Details for tendon protection level (that is, PL-1, PL-2, or PL-3);
- Wedge plates, wedges, bearing plates, trumpets, couplers, and local zone reinforcement;
- Permanent grout caps with installation accessories (if required);
- Ducts, couplers, and typical connection details;
- Typical details for all vents and inspection points in the anchorages and along the ducts;
- Duct inner diameter (ID) and outer diameter (OD) (major and minor) or other defining internal and external dimensions;
- Tendon types and sizes and duct types and sizes associated with different tendon lengths;

COMMENTARY

C5.2 – System drawings

When permanent caps are not installed, temporary corrosion protection details and means to seal the tendon ends during grouting should be provided. Filling anchorage recesses prior to grouting or the use of temporary caps are options.

Anchorage drawings should include the details during construction as well as the final condition with proposed corrosion protection.

When ducts are referred to by diameter, the referenced diameter should be the ID.

Duct OD should be noted on the placing drawings to check clearances to other elements.

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- Tendon “Z” factors (center of gravity of strand [cgs] offsets) for all duct and tendon size combinations;
- Friction coefficient and wobble details;
- Steel pipes, boots, and clamps;
- Duct minimum radius of bending and maximum support spacing;
- Methods for supporting all hardware before concreting;
- Minimum stressing tails for all tendon types;
- Minimum concrete blockout dimensions for equipment access and concrete cover;
- System seating losses (anchor set);
- Minimum concrete strength for stressing;
- Newly developed features not mentioned previously;
- Details for segmental duct couplers;
- System-specific details for full encapsulation of tendons (if required); and
- System-specific details for electrically isolated tendons (if required).

5.3 — Tendon drawings

Submit installation drawings defining the tendon duct and anchorage geometries with respect to the concrete outlines. As a minimum, the following is required:

5.3.1 — Plans and elevations

Show positions and angles of anchorages. The anchorage work points are normally the centers of the bearing plate faces;

- Show and dimension all duct high, low, and inflection points;
- Dimension the start and end points of all curve segments;
- Intermediate curve profiling points shall be given in every plane in which the tendon curves and at intervals in proportion to the curve length;
- For accurate friction calculations, indicate the type of curves used (parabolic, circular, and so on);
- For compound curves, the vertical and horizontal curves shall start and end at the same locations whenever practical;
- Show all inlets, outlets, and inspection ports; and
- All tendons shall be identified with their unique numbers or tags.

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C5.3.1 – Plans and elevations

For the ease of placement, it is generally preferred to express angles in terms of slope (1 in 12) versus degrees or radians

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5.3.2 — Sections

- Show member cross sections with fully dimensioned duct positions at critical locations, such as tendon high points and low points;
- Show anchorage layouts at the ends of members and at intermediate locations;
- All tendons shall be identified with their unique numbers or tags; and
- Tendons shall be shown in as many views as necessary to completely and unambiguously define the tendon geometry.

5.3.3 — Measurements

- Show radii for curved duct or pipe sections;
- Set-out dimensions shall be referenced off the formwork whenever possible. Indicate string lines for reference, if necessary;
- For vertical layout, define duct profiles to the underside of the duct, using the duct major OD as reference;
- Block out dimensions and locations; and
- Duct layout dimensions in general shall be given in local coordinate systems that align with the principal directions of the concrete members or elements. Layouts requiring plumb-bobs shall not be permitted.

5.3.4 — Tolerances

Show placement tolerances on the post-tensioning installation drawings. Tolerances shall be in accordance with Section 9.3.

5.3.5 — Stressing data

- Give each tendon a unique identifying number or tag;
- Show tendon stressing data and sequence in table form;
- Indicate single-end or double-end stressing; and
- If not specified in the contract plans, devise stressing sequences to minimize eccentric loads on members to minimize jack handling and to minimize the chance of crushing adjacent ducts.

5.3.6 — Material take-off

- Show a neat-line material take-off for every suitable section or element of the project; and
- Include quantities for bearing plates, wedge plates, wedges, trumpets, local zone reinforcement, grout caps, bolts, duct, couplers, vents, valves, prestressing steel, grout volume, and any other components.

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C5.3.3 – Measurements

Special attention should be placed on areas where ducts are closely spaced, stacked, and/or intersected.

Generally, duct profiles should be shown as the distance from the bottom soffit to the top of the duct support bar (or to the bottom of the duct) when ducts are supported from below.

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5.3.7 — Temporary openings for PT work

- Show any temporary holes required in decks or slabs to support the stressing equipment or to pass hoses and power;
- Show sizes and locations of any temporary access openings required for passing workers, materials, and machines to and from the work point; and
- Show methods of filling in (closing) and sealing temporary openings.

5.3.8 — Installation requirements

Show installation requirements for the post-tensioning system.

5.4 — Stressing calculations

- Submit stressing calculations for all tendons, stating all assumptions and giving target stressing forces and expected elongations based on nominal prestressing steel properties (area and modulus of elasticity);
- Use a modulus of 28,500 ksi (196,500 MPa) for strand and 29,700 ksi (204,800 MPa) for Type II deformed bars. Elongations may be field-adjusted for actual A and E values;
- For both strand and bar tendons, the temporary stressing force, anchorage force, and maximum force along the tendon may not exceed the allowable defined by the relevant design code(s);
- Calculate short-term losses due to friction, wobble, and wedge seating. Friction and wobble coefficients shall be in accordance with the applicable design code (Table 5.1); and

COMMENTARY

C.5.3.7 – Temporary openings for PT work

For typical details, refer to Appendix A.

C5.3.8 – Installation requirements

Post-tensioning operations should be performed only under the direct supervision of experienced personnel. Refer to Section 7.

Table 5.1—Typical friction (μ) and wobble (k) coefficients for different types of prestressing steel and duct*†

Type of prestressing steel	Corrugated metal duct, μ/k (ft^{-1})	Corrugated plastic duct, μ/k (ft^{-1})	Smooth steel pipe, μ/k (ft^{-1})	Smooth plastic pipe, μ/k (ft^{-1})
Strand	0.15 to 0.25/ 0.00005 to 0.0003	0.10 to 0.14/ 0.00005 to 0.0003	0.25 to 0.30/0	0.10 to 0.14/0
Strand in precast elements and constant curvature tendons	0.15 to 0.25/ 0.00005 to 0.0003	0.10 to 0.14/ 0.00005 to 0.0003	—	—
External tendons, bare dry strand	—	—	0.25 to 0.30/0	0.12 to 0.15/0
Lubricated strand	0.12 to 0.18/ 0.00005 to 0.0003	—	0.20 to 0.25/0	—
Strand greased and extruded	0.01 to 0.05/ 0.00005 to 0.0003	0.01 to 0.05/ 0.00005 to 0.0003	0.01 to 0.05/0	0.01 to 0.05/0
Bars, deformed, smooth and round	0.30/0 to 0.0002	0.30/0 to 0.0002	—	—

*For design purposes, designers shall use values found in current codes if such values are more conservative.

†Values established by friction testing Section 12.7 shall be permitted with Engineer's approval.

Note: 1 ft = 0.3048 in.

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- Elongations shall be given to the nearest 1/16 in. (1.6 mm) Provide elongation before and after seating.

6.0 — QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC)

6.1 — QA program

The PTS suppliers shall have a QA program and a qualified person of authority who is responsible for implementing and enforcing this QA program. Based on this program, project-specific procedures and controls shall be developed to ensure all system specifications and contract requirements are met. For each project, carefully plan, implement, and document this process.

6.2 — Procurement

The QA program shall address procurement of all materials, components, and equipment that will become part of the PTS.

Procurement documents shall clearly and completely describe the materials and components being ordered, specify all QA/QC activities to be implemented, and all records to be delivered (certified test reports, inspection reports, lab test reports, and so on).

Procurement documents shall be checked and approved by the PTS supplier's purchasing authority for consistency with the governing design and project requirements, including QA/QC activities.

Secondary suppliers shall:

- Be qualified per PTS supplier's QA program according to the following criteria: ability to meet specific contract requirements, safety record, consistency, workmanship, and production capacity;

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C6.1 – QA program

Quality control (QC) and quality assurance (QA) under this section for manufacturing and production of post-tensioning elements by the PTS supplier are slightly different from the broader definition in Section 2.1.

QC for manufacturing and production of post-tensioning elements includes all acts of examining, witnessing, inspection, testing to determine conformity with the PTS supplier's own QA/QC program as well as any project specific requirements including sampling and testing that may apply.

QA for manufacture and production of post-tensioning elements includes the total effort of developing, documenting and implementing procedures, defining roles and responsibilities, and assigning specific QA/QC tasks to individuals to achieve and verify quality in accordance with specified requirements.

C6.2 – Procurement

There are many components of a typical post-tensioning system and the source supply will be varied. It is important that rigorous standards by the PTS supplier are set and maintained to ensure the performance and compatibility of subcomponents and the system.

Compliance of the materials will typically be documented by a Certificate of Compliance with supporting test data as identified in the project requirements.

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- Demonstrate competence in statistical control techniques, inspection records management, vendor/supplier selection, and delivering on all requirements of procurement documents;
- Have an inventory control system, tool calibration program, designated inspection stations, and planned inspections; and
- Provide a signed certificate of conformance with shipments stating that the goods provided meet the requirements of the procurement documents.

The PTS supplier shall perform source, plant, and factory inspections and audits of secondary suppliers as required by the contract specifications and its own QA program.

The PTS supplier shall require testing of secondary suppliers' materials and components as required by the contract specifications and its own QA program.

6.3 — Project quality plan

A project quality plan shall be developed by the PTS supplier which, upon implementation, will ensure the installed PTS meets all contract requirements, including the following specifications.

Project quality plan shall include:

- Performance requirements (PTS and equipment);
- Specific standards, practices, processes, procedures, and instructions to be applied;
- Testing, inspection, examination, and audit programs for PTS components and processes;
- Allocation of responsibilities and authority to personnel;
- Documented procedure for changes and modifications of PTS components and processes;
- Methods for measuring achievement of performance objectives (verifications and checklists); and
- Other actions necessary to meet the performance requirements.

6.4 — Receiving

Materials arriving at the PTS supplier's facility shall be identified, cross-checked with the procurement documents for compliance, counted, inspected, rejected or accepted, and stored. Inspections and examinations of critical characteristics shall be performed

COMMENTARY

C6.3 – Project quality plan

The PTS supplier purchasing authority or designated QA/QC personnel are responsible to check that all elements of the PTS are compliant with the specific requirements of the Project Quality Plan and that all test data and Certificates of Compliance have been provided.

The Contractor's QA/QC manager(s) or Materials Approval Engineer will perform a verification role to also check for compliance.

The value of the post-tensioning supply and installation is often a significant component of the work and consideration should be given to inclusion in the Project Quality Plan—perhaps as an Appendix to that plan.

For projects with Buy America provisions, it is also required to provide Certificates of Material Origin for all steel or iron materials, track quantities, and retain these documents as part of the Project records.

SPECIFICATION

by qualified personnel in conformance with procedures established by the PTS supplier. For materials delivered from the secondary suppliers directly to the jobsite, the PTS supplier shall provide specific receiving inspection instructions for each item. The PTS supplier shall conduct periodic inspections at the project site or conduct a source inspection at the secondary supplier's facility prior to shipment. Only acceptable materials shall be released to inventory or to customers. The PTS supplier shall be permitted to self-perform such testing and inspections or require the secondary suppliers to perform them and submit appropriate reports to demonstrate compliance. Qualified third-party inspection and testing agencies shall also be permitted to perform these functions for the PTS supplier.

The PTS supplier's QA program shall contain procedures for receiving materials that shall include:

- Reviewing certified material test reports and certificates of conformance for compliance with the procurement documents;
- Checking for identification with heat and batch numbers, lot codes, and so on to ensure full traceability;
- Checking for specified material grades;
- Checking for unauthorized substitutions of materials (size or grade);
- Dimensional and angle checks;
- Acceptable ranges; and
- Nonconformance: documentation, control, and disposition.

The PTS supplier's materials receiving inspection for components shall include PTS component verification.

6.4.1 — Wedges
Confirm that the following are met:

- Requirements of applicable ASTM specifications;
- Surface finish is as specified; and
- For each heat treatment lot, certified material test reports per the specified standard showing:
    - Heat number;
    - Heat treatment lot number;
    - Chemical composition;
    - Mechanical properties;
    - Yield strength; and
    - Heat treatment requirements: case hardness, case depth, and core hardness:

COMMENTARY

C6.4.1 – Wedges
Wedges are a critical structural element of the PT anchorages system using wedge action to anchor post-tensioning forces.

In the United States, generally there are two sizes of strands used in the industry, either 0.5 in. (13 mm) or 0.6 in. (15 mm) diameter, although more strand types and sizes are used in other parts of the world. Typically, wedges are designed for a particular strand diameter. The PTS QC program shall include verification that the correct wedges are delivered to the project site.

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(a) Each heat treatment lot consists of material from only one heat of steel;

(b) Hardness tests are provided for no less than 5% of each heat treatment lot;

(c) Certified core hardness and case depth tests are provided for a minimum of three samples from each heat treatment lot;

(d) Heat treatment certificate and certificate of conformance are provided for each lot or batch delivered; and

(e) Wedges have unique identification for each lot.

6.4.2 — Prestressing steel
Confirm that the following are met:

- Strand and bars are of the correct size, length, and type;
- Material meets requirements of applicable ASTM specifications;
- For each lot, certified material test reports per the specified standard showing:
  - Coil/reel number (strand only);
  - Heat number;
  - Chemical composition;
  - Yield strength;
  - Breaking strength; and
  - Elongation properties
- Certificate of conformance is provided for each heat, lot, or batch of prestressing steel delivered;
- Strand reels/packs are identified with tags as specified in ASTM A416/A416M;
- Bars are identified with tags as specified in ASTM A722/A722M;
- Strand packaging is not torn, steel banding is not broken, and there is no evidence of moisture; and
- Strand and bar condition is checked when first received and periodically while in storage.

6.4.3 — Anchorages
Confirm that the following are met:

- Requirements of applicable ASTM specifications;
- Requirements of the PTS specifications;
- Specified tensile strength;
- Specified material hardness, if applicable;
- Charpy V-notch testing conforms to ASTM E23;

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- All material testing of steel products conforms to ASTM A370; and
- Anchorages have unique identification for each lot.

6.5 — Identification and traceability of materials

Stored and installed PTS shall be fully traceable to production lots and installation records. The PTS supplier shall maintain a complete list of all traceability numbers and documentation for materials supplied to the project. Records kept by the Contractor shall maintain traceability of stored and installed PTS materials to specific tendon numbers. Traceability documentation and records shall be formally transferred to the Owner.

Traceability shall be maintained for at least the following PTS components:

- Prestressing steel;
- Bearing plates;
- Wedge plates;
- Trumpets;
- Wedges;
- Duct; and
- Grout materials.

Positive identification and traceability marking on material shall be as follows:

- Prestressing steel—Each coil shall have an identifiable, weatherproof manufacturer's tag or equivalent identifying heat number, lot, size, grade, type, and manufacturer;
- Bearing plates—Each bearing plate shall have an identifying number or code punched into, cast in, or recorded on an attached, weatherproof tag;
- Wedge plates—Each wedge plate shall have an identifying number or code punched into, cast in, or recorded on an attached, weatherproof tag;
- Trumpets—Each trumpet shall have an identifying number or code punched into, cast in, or recorded on an attached, weatherproof tag;
- Wedges—Shall be identified through physical segregation and permanent, weatherproof tags listing part, manufacturer, heat numbers, lot numbers, and batch numbers as applicable;
- Duct—Each bundle shall be positively identified for traceability; and

COMMENTARY

C6.5 – Identification and traceability of materials

It is extremely important that all materials can be tracked from manufacture and production through installation, tensioning, grouting, and any additional tendon/anchorage corrosion protection.

In this way issues at the jobsite can be identified by location and addressed as necessary by the Contractor.

All such records should be available to the Owner as specified in contract requirements and are typically turned over to the Owner as a contract deliverable at the end of the project.

Traceability of all post-tensioning hardware and grout is also beneficial for:

- Timely identification and investigation in case of defective product discovery during construction.
- Timely decision to discontinue using the defective product from a particular heat number, lot, size, grade, type, and manufacturers on site.
- Timely removal of the defective products from the project site.
- Address remedial action and scope as necessary.
- Determining where the issue potentially impacts and isolating the issue from the remainder of the structure or other projects. Extensive investigation or remediation in areas not potentially affected can unnecessarily cause damage or durability issues to the structure.

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- Grout materials—Shall be identified through physical segregation and permanent, weatherproof tags listing grout type, manufacturer, heat numbers, lot numbers, and batch numbers as applicable.

Loss of positive identification and traceability before installation shall be cause for rejection of materials.

6.6 — Sampling of prestressing material

At the request of the Engineer, furnish prestressing material samples for testing to the Owner, if required by contract documents. Approval of any prestressing material shall not preclude subsequent rejection if material is damaged in transit or later found to be defective for any reason.

For strand, select three random samples—5 ft (1.5 m) long—per manufacturer, per size of strand, per heat, with a minimum of one sample for every 10 reels delivered.

For bars, select three random samples—5 ft (1.5 m) long—per manufacturer, per size of bar, per heat, with a minimum of one sample per shipment.

Testing shall conform to the applicable ASTM specifications.

With each sample of prestressing strand or bar furnished for testing, submit the manufacturer's mil certification for that sample.

One of each of the samples furnished per heat will be tested by the Owner at the Owner's discretion. The remaining samples, properly identified and tagged, will be stored by the Owner for future testing. If a test sample is lost or the prestressing steel fails, the stored samples will be used for evaluating minimum yield and strength requirements. For acceptance of the heat represented, tests shall achieve at least 100% of f_{pu}.

6.7 — Defects during installation

Materials discovered during installation to be defective shall be identified as such, segregated and controlled to prevent their unintended use. Deficiencies so identified shall be documented and brought to the attention of the Contractor and PTS supplier. Representative samples shall be tested and investigated through the process identified in the project

COMMENTARY

C6.7 – Defects during installation

It is important that the Contractor's Quality Plan include provisions for inspection of PTS elements prior to installation. Suspect or defective material identified should be quarantined until a determination is made if the material can be incorporated into the permanent work or rejected.

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quality plan. All materials confirmed to be defective shall be removed from the project site. Corrective action shall be taken at all levels of the supply chain to prevent similar breakdowns of the QA program.

7.0 — PERSONNEL QUALIFICATIONS

7.1 — Supervision

Post-tensioning operations:

- The Direct Supervisor of Post-Tensioning Operations shall be certified as PTI Level 2 Multistrand & Grouted PT Field Specialist;
- The Foreman of each installation and stressing crew shall be certified as PTI Level 2 Multistrand & Grouted PT Field Specialist; and
- The Foreman of each grouting crew shall be certified as PTI Level 2 Multistrand & Grouted PT Field Specialist and ASBI Certified Grouting Technician.

At least 25% of each crew shall be certified in PTI Level 1 Multistrand & Grouted PT Installation.

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C7.1 – Supervision

Training to the current standards is integral to the quality of the installation. The trainings also provide a context of why it is important to perform the operations properly. The referenced programs both have requirements for related experience in addition to the training provided for the secondary level certification. Training is available through the following organizations, contact information listed as follows:

PTI
38800 Country Club Drive
Farmington Hills, MI 48331
Phone: 248-848-3180
Website: www.post-tensioning.org

ASBI
142 Cimarron Park Loop, Suite F
Buda, TX 78610
Phone: 512-523-8214
Website: www.asbi-assoc.org

8.0 — SHIPPING AND STORAGE OF MATERIALS

8.1 — General

All post-tensioning components and prestressing steel shall be protected against damage, exposure, and contamination from manufacture to installation. All packs, bundles, barrels, boxes, and containers shall be clearly marked with their content and quantities contained. All packaging shall be forklift- or crane-friendly for easy loading and unloading. Dry, indoor storage is preferred. When items are to be covered with tarpaulins, they shall be securely wrapped, and the covering shall reach the ground on all sides. Air circulation is necessary if covered with tarpaulins. For outdoor storage, make provisions to avoid ponding water in the protective coverings.

All materials shall be tracked from the manufacture through installation ensuring mill heat numbers are maintained with project records.

C8.1 – General

When the material is shipped to site, it is important that the proper method of packaging and shipment be chosen to ensure that the material is neither damaged nor destroyed due to securing the load or managing tarpaulins.

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8.2 — Anchorages

Ship and store bearing plates, castings, trumpets, wedge plates, and local zone reinforcement in containers on raised platforms. Wedge plates shall be covered by properly secured, waterproof tarpaulins or warehoused until use.

8.3 — Wedges

Ship and store post-tensioning wedges in waterproof containers with resealable tops.

8.4 — Metal duct

Ship and store metal duct in bundles held together with lightweight framing. Store duct off the ground. Remove any contamination from duct before use. Caps are required at each end of duct during shipping and storage. Cover duct and couplers during shipment to prevent contamination (road salts and so on). Ship and store duct couplers in containers on raised platforms.

8.5 — Plastic duct

Ship and store plastic duct in bundles held together with lightweight framing. Store duct off the ground and shaded from the sun. Remove any contamination from duct before use. Caps are required at each end of duct during shipping and storage. Cover duct and couplers during shipment to prevent contamination (road salts and so on). Ship and store duct couplers in containers on raised platforms protected from the elements.

8.6 — Strand

Ship and store prestressing steel packaged in containers or shipping forms to protect against physical damage and corrosion. A rust-preventing corrosion inhibitor shall be placed in the package or be incorporated in a carrier-type packaging material. The corrosion inhibitor shall have no deleterious effect on the steel or the bond strength between steel and grout. Inhibitor carrier-type packaging material shall conform to the provisions of Federal Specification MIL-P-3420. Immediately replace or restore damaged packaging to the original condition. The shipping package shall be clearly marked with a statement that the package contains high-strength prestressing steel, the care to be used in handling. Specifically designate low-relaxation (stabilized) strands per the requirements of ASTM A416/A416M. Each strand pack or reel shall have two strong tags

COMMENTARY

C8.6 – Strand

ASTM A416 requires that strand must be well protected in shipping against mechanical injury, which includes damage from corrosion, stress corrosion, or hydrogen embrittlement through contact with deleterious chemicals. ASTM A416 leaves the prescription of the necessary level of protection to the project specifications, which should take the special structural and environmental project conditions into account.

Strand manufacturers, in cooperation with the California Transportation Department, developed an effective corrosion protective packing, known in the trade as CALWRAP, which meets the corrosion protective requirements of Caltrans Standard Specification, Section 50(9). CALWRAP provides long-term corrosion protection for strand if stored off the ground and in a dry place. For most bridge projects, equivalent packaging is specified. For building projects,

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securely fastened to it, showing the length, size, type, grade, ASTM designation A416/A416M, and the name or mark of the manufacturer. One tag shall be positioned where it will not be inadvertently lost during transit, such as the core of a reel-less pack. The other tag shall be placed on the outside for easy identification. Strand packs not so designated will be rejected.

8.7 — Bars

Ship and store prestressing bars on raised platforms and covered by properly secured, waterproof tarpaulins. Bars shall be grouped by size. Each bundle or lift shall be tagged showing the heat number, bar size, ASTM A722/A722M designation, and the identity of the finished bar manufacturer. The tags shall display the following statement: "High Strength Prestressing Bars." Bars or lifts not so designated will be rejected.

8.8 — Cement and grout

Ship and store cement and pre-bagged, engineered grout materials on raised platforms covered by properly secured, waterproof tarpaulins. Store materials in a permanently dry location. Project-specific indoor storage in a dry, controlled environment is limited to 6 months. With materials properly raised and covered, storage in the open is limited to 1 month. Total storage time—indoors and outdoors—shall not exceed 6 months from the date of manufacture.

8.9 — Accessories

Grout caps, vents, inlets, outlets, valves, and other accessories shall be stored off the ground in suitable containers. Keep plastic parts out of direct sunlight.

9.0 — BEARING PLATE AND DUCT INSTALLATION

9.1 — General

Accurately position and securely fasten all post-tensioning bearing plates, trumpets, local zone reinforcing steel, ducts, inlets and outlets, miscellaneous hardware, and other embedments at the locations shown on the approved installation drawings.

9.2 — Measurements

Layout dimensions are given on the approved installation drawings and generally reference the formwork.

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standard packaging provided by the strand manufacturers is normally adequate.

C8.8 – Cement and grout

Refer to product information sheets for handling and storage instructions, as suppliers have slightly differing requirements.

When possible, the supplier should order the product with shrink wrap installed at the mill and then tarped on-site at all times.

C8.9 – Accessories

As these products are generally smaller and come in cardboard boxes, it would be best kept secured on skids and under tarps.

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Use accessory equipment if necessary to position the PTS components within placing tolerances of this specification.

9.3 — Tolerances

Ensure that post-tensioning anchorages and ducts in their final positions are within the tolerances shown on the approved installation drawings. Tolerances shall be in accordance with Table 9.1.

Angle changes at duct couplers shall be avoided.

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C9.3 – Tolerances

Angle changes at couplers can be avoided by ensuring couplers are placed outside of transition areas. In general, duct couplers should not be installed at high-, low-, or inflection-points; flares; or any other location with significant curvature or a curve reversal.

Table 9.1—Duct position tolerances

Tolerances	Vertical position, in.	Lateral position, in.
Longitudinal draped tendons over supports or in middle third of span	±1/4	±1/2
Tendon in middle half of web depth	±1/2	±1/2
Longitudinal, generally horizontal, tendons usually in top or bottom of member	±1/4	±1/2
Horizontal tendons in foundations	±1/2	±1/2
Vertical tendons in walls	Longitudinal position ±1	Transverse position ±1/4
Vertical tendons in shafts	±1/2	±1/2
Horizontal tendons in slabs	±1/4	±1/2
All other cases	±1/4 in any direction	±1/4 in any direction

Note: 1 in. = 25.4 mm.

9.4 — Anchorage components

Install bearing plates against the formwork and anchorage blockouts as shown on the approved installation drawings. The bearing plate longitudinal axes shall be within 2 degrees of their design directions. Trumpets shall be perpendicular to the faces of the bearing plates and securely fastened in place. Local zone reinforcement shall be centered on the anchorage and positioned per the PTS supplier's installation drawings.

C9.4 – Anchorage components

Prior to installing the anchorage hardware, the formwork/blockout should be inspected to verify that they are constructed to the correct dimensions and locations shown on the installation drawings, and that the formwork will adequately support the weight of the installed anchorages.

An opening in the formwork, centered on the anchorage, should be present. This opening should be at least as large as the duct ID to permit passage of a torpedo for inspection of the duct following placement.

The installation drawings will provide angles or shim dimensions to establish the correct bearing plate angle. These angles typically reference a vertical formwork face.

9.5 — Deviation pipes

Curves in pre-bent pipes shall be inspected for proper radii, smoothness, and kink-free fabrication. Install and securely fasten pre-bent pipes as shown on the approved installation drawings. Verify the pipe is oriented correctly before releasing the installation for concreting. Ends of pipes shall be sealed until the duct is attached.

C9.5 – Deviation pipes

Secure installation of pre-bent pipes is crucial to maintaining the correct geometry during placement. If the pipes shift or rotate during concrete placement, significant rework could be required to restore alignment.

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9.6 — Ducts

Connect the ducts to the anchorage trumpets and secure ducts at these locations against displacement. Accurately place, align, and support all internal ducts as shown on the approved installation drawings. Inspect the duct installation and make adjustments if necessary, until a smooth, continuous, and kink-free profile is achieved for both curved and straight portions. Duct shall not be kinked at the anchorage trumpet and shall extend along the bearing plate longitudinal axis a minimum length equal to six times the duct ID before initiation of any angular deviation. Minimize any wobble. Adjustments that exceed the approved duct placement tolerances require the Engineer's approval.

If conflicts exist between the reinforcement and post-tensioning duct, the position of the duct shall prevail and the reinforcement shall be adjusted locally with the Engineer's approval.

Securely support ducts in place at regular intervals not exceeding 48 in. (1.2 m) for steel pipes, 48 in. (1.2 m) for round galvanized metal duct, 24 in. (0.60 m) for round plastic duct, 24 in. (0.60 m) for flat ducts with strand preinstalled, and 12 in. (0.30 m) for flat ducts without strand preinstalled to prevent displacement and damage during concreting. Strands or mandrels shall be installed in flat plastic ducts before concrete placement.

Do not tighten duct ties to the point where the duct deforms or is crushed against the reinforcing bar. In tight duct curves, the duct shall be pre-bent to the final radius prior to installation. Local duct buckling is not permitted and is cause for rejection. Slitting of duct to facilitate bending shall not be permitted.

Inspect the installed ducts for damage and make repairs as necessary. Remove dents and seal any pulling holes using the appropriate sealing method for Tendon PL, as shown on approved PT installation drawings. Ensure nothing infringes on the inside dimension(s) of the ducts before releasing the installation for concreting.

Ensure that external tendon ducts are straight between connections to internal ducts and pipes at anchorages, diaphragms, and deviation saddles and are supported at intermediate locations per the approved installation drawings.

COMMENTARY

C9.6 – Ducts

Damaged ducts cause strand installation problems and responsibility conflicts between duct installer and those trades placing reinforcing bars, formwork, and concrete. Responsibility conflicts can be avoided if each trade checks duct clearances after its work is completed and performs the necessary repair work. Experience has shown that it is prudent to check duct clearances after completion of duct installation, but prior to completing formwork and again after concrete placement. Because ducts may deform under concrete pressure (round ducts may get slightly oval), different bullet diameters for the two checks are advisable.

Flat ducts are particularly susceptible to collapse under concrete fluid pressure and contact with reinforcement. Preinstallation of strand or mandrels can help ensure internal clearance is maintained.

Small dents in corrugated metal ducts may often be removed by pulling and sealing as stated. Larger dents or sections containing multiple dents should be cut out and replaced by splicing in a new section of duct while adhering to all requirements for coupling.

The installation of saddle-type grout ports typically requires drilling into the duct. This hole must be concentric with the port opening and at least as large as the tubing ID.

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Grout inlets and outlets shall be installed with plugs or valves in the closed position. Low-point outlets shall be temporarily opened to drain any liquids. After that, the duct and anchorage assemblies shall be sealed-off units and remain so until the prestressing steel is installed.

9.7 — Accessories

The use of UV-resistant, waterproof tape is permitted for PL-1 (PE tape or equal). The use of approved heat-shrink sleeves (Section 4.3.7) shall be permitted for protection levels PL-1 to PL-3.

9.8 — Splices and joints

Use overlapping sleeves or couplers at duct and duct/pipe connections sealed as shown on the approved installation drawings for the tendon PL.

For proper sealing with taped joints, tape applied to metal duct shall follow the pitch of the duct seam first before wrapping at 90 degrees. Minimum placement coverage is two-and-a-half full wraps placed over the center of the splice or joint but not less than 3 in. (76 mm) on each side of the joint being sealed.

Heat-shrink sleeves shall extend the distance shown on the approved installation drawings, but not less than 3 in. (76 mm) on each side of the joint being sealed.

9.9 — Location of grout inlets and outlets

Place grout inlets and outlets at locations shown on the approved installation drawings. Equip all grout inlets and outlets with positive shutoff devices. Extend grout tubes a sufficient distance out of the concrete member to allow for proper closing of the valves. As a minimum, grout inlets and outlets shall be placed in the following positions, with letter designations corresponding to Fig. 9.1:

COMMENTARY

C9.8 – Splices and joints

Coupler locations should be staggered to limit the reduction of clearance between adjacent ducts.

Where the ends of the duct must be cut, the edges must be clean and square prior to coupling. Crushed or bent edges may be "caught" during strand installation and potentially damage the duct internally or create a restriction.

Duct surfaces should be clean and dry prior to applying tape or heat-shrink sleeves. The presence of dust, oil, moisture, or other contaminants may preclude proper sealing of the joint.

C9.9 – Location of grout inlets and outlets

Routing of grout tubes outside of the structure may be complicated by the location or construction method. Bridges cast on falsework may have limited access to the soffit for installation and operation of low-point drains. Bridges cast on concrete slabs may leave no practical options to install free-draining vents. In these instances, coordination to determine an appropriate path for the vents that allows for proper function and access during grouting operations is necessary.

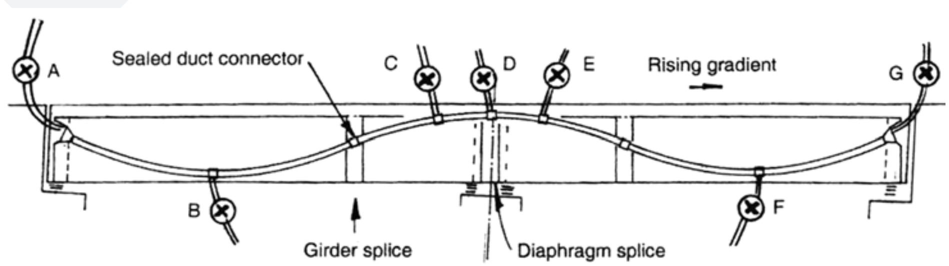

Fig. 9.1—Minimum reported locations for grout inlets and outlets.

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- Top of tendon anchorages: A and G;
- Top of the grout caps: A and G (grout caps not shown);
- At the high points of the duct when the vertical distance between the highest and lowest point is more than 20 in. (0.51 m): D;
- Where outlets are required at the high points, at a distance not to exceed 39 in. (1.0 m) in both directions from the high point outlets: C and E;
- At all low points: B and F; and shall be free draining;
- At major changes in the cross sections of duct; and
- Where necessary, to facilitate straight bores into the anchorages/ducts for post-grouting inspection, mandrels shall be used to keep grout hoses straight during concrete placement.

Vents must also be routed in a manner that will provide protection against damage during concrete placement and consolidation.

10.0 — PLACING CONCRETE

10.1 — Precautions

Use methods of placing and consolidating concrete, which shall not displace or damage the post-tensioning ducts, anchorage assemblies, splices, connections, reinforcement, or other embedments. Fabricate and support all duct to prevent duct kinks during concrete placement. Use removable mandrels as needed to maintain duct alignment and shape. Do not drop concrete directly onto duct from a height greater than 3 ft (0.91 m). Do not allow vibrator to rest against any part of the post-tensioning system. Thorough concrete consolidation in anchor zones is critical for anchorage performance. Special attention shall be paid during concrete placement in congested anchorage zones to prevent voids.

C10.1 – Precautions

PT anchor blockout dimensions should be checked to ensure concrete cover over cap and able to conduct post-grout inspections.

10.2 — Proving of post-tensioning ducts

Upon completion of concrete placement and initial set, prove that the post-tensioning ducts are undamaged and free of obstructions by passing a suitable torpedo of rigid material through them. Use a torpedo having the same cross-sectional shape as the duct and that is a 1/4 in. (6.3 mm) smaller than the clear, nominal inside dimensions of the duct as given on the installation drawings. The torpedo length shall reflect the expected duct curvature while maintaining the 1/4 in. (6.3 mm) clearance requirement. The torpedo shall pass through the duct easily when pulled by

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hand, without requiring excessive effort or mechanical assistance.

10.3 — Problems and remedies

If the torpedo will not travel completely through the duct, the duct shall be cleared and repaired by means specified in the project quality plan and approved by the Engineer.

11.0 — PRESTRESSING STEEL INSTALLATION

11.1 — General

Protect all prestressing steel against physical damage and corrosion at all times—from manufacture to final grouting. The Engineer shall reject prestressing steel that has been damaged. Causes for rejection include but are not limited to yielding, pitting, nicks, and exposure to excessive heat (that is, damage from adjacent welding or cutting operations). Normal wedge marks in the anchorage region do not constitute damage to the strand. Prestressing steel to be installed in the ducts shall be free of deleterious material such as dirt, grease, oil, wax, or paint. Wires shall be bright, uniformly colored, and have no foreign matter on their surfaces. Slight rusting, provided it is not sufficient to cause pitting visible to the unaided eye, shall not be cause for rejection (refer to Section 11.5, Acceptance Criteria).

11.2 — Strand

Inspect strand reels and packs for broken wires. Remove and discard lengths of strand containing broken wires. Push or pull strands through the ducts to make up tendons using methods that will not cause strands to snag on lips or joints in the ducts. Strands that are pushed shall have rounded-off ends or be fitted with smooth protective caps. Alternatively, strands may be assembled into complete tendons, which are pulled through the ducts using a special steel wire sock or other suitable pulling attachment such as a welded or brazed end lug. The tendon ends shall be rounded for smooth passage through the ducts. Strand shall not be intentionally rotated during installation. For each tendon, maintain traceability of materials by recording quantities of strands taken from packs. Cut strands using an abrasive saw, plasma torch, or mechanical shear. Flame cutting shall not be allowed.

C11.2 – Strand

Strands are normally installed after concrete placement: either by pulling preassembled tendons with a winch into the ducts or by pushing individual strands with a pusher into the ducts. It is preferred that strands be installed in flat ducts prior to concrete placement.

For safety reasons, installation equipment must have adequate safety margins to assure that they will not break and endanger the workers. Required pulling forces depend mainly on friction resistance along the strand bundle, the inclination of the structure, and angle changes.

Safety barricades should be put in place on both ends of tendons during strand installation and personnel kept to a minimum.

Damaged ducts cause strand installation problems and responsibility conflicts between duct installer and those trades placing reinforcing bars, formwork, and concrete.

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Welding of final tendon prestressing steel shall not be permitted. Welding of strands for installation purposes shall be permitted. Weld metal shall only be deposited on strand tails that shall be cut off after tendon stressing and no closer than 36 in. (914 mm) to the final prestressing steel (that is, to wedge plate surface after stressing). Preheating of prestressing steel shall not be allowed. No electrical current shall flow through the final prestressing steel and the welding operation shall be properly grounded. All welding on prestressing steel shall be done per written and approved welding procedures.

Strands shall be permitted to be brazed together for pulling. Brazing shall only be used on strand tails that shall be cut off after tensioning no closer than 36 in. (914 mm) to the final prestressing steel (that is, to wedge plate surface).

11.3 — Bar

At the time of installation, bars shall be free of defects injurious to its mechanical properties and have a workmanlike finish. They shall be free from loose rust, loose mill scale, dirt, paint, oil, grease, or other deleterious materials. Install prestressing bars into ducts before concrete placement whenever feasible. Ensure bars are fully threaded into couplers—where applicable—and protruding from anchor nuts on each end. For each tendon, maintain traceability of materials by recording the heat numbers for all bars installed.

11.4 — Corrosion protection

Prestressing steel shall be installed, stressed, and grouted as quickly as possible. If the tendon shall not be stressed and grouted within the time limits in Table 11.1, a corrosion inhibitor shall be applied. When the delay is known before strand installation, such corrosion inhibitor shall be permitted to be approved oils applied to prestressing steel before installation. When the delay is not known in advance, such corrosion inhibitor shall be blown into the duct after prestressing steel installation in the form of a vapor phase corrosion inhibitor (VPCI) powder conforming to the provisions of the U.S. Department of Defense Specification MIL-P-3420F-87 or as otherwise approved by the Engineer. When VPCI powder is applied, air circulation shall be kept to a minimum. Any rust appearing within the first 10 days after prestressing steel installation shall not be cause for rejection.

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Responsibility conflicts can be avoided if each trade checks duct clearances after its work is completed and performs the necessary repair work.

C11.3 – Bar

To ensure proper coupler engagement, it is advisable to mark each bar with paint or other means as a reference point. Set screws, lock nuts, or epoxy can also be used if bar tendons are to be prefabricated.

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Table 11.1—Permissible intervals between prestressing steel installation and grouting

Time limits for grouting exposure permissible intervals between prestressing steel installation and grouting without use of corrosion protection	
Very damp atmosphere or over salt water (humidity >70%)	7 days
Moderate atmosphere (humidity 40 to 70%)	20 days
Very dry atmosphere (humidity <40%)	40 days

11.5 — Acceptance criteria

Formation of light rust on the strand surface shall not be detrimental. The following test shall be used to determine the acceptability of strand for installation in the ducts.

Use a Scotch Brite Cleaning Pad No. 96—made by 3M—or its equivalent, made from synthetic, nonmetallic material. Hand-clean a strand sample longitudinally with a new pad using moderate pressure. Refer to Fig. 11.1 for evaluation. Based on Pictures 1A, 2A, and 3A, levels of rust shown in Pictures 1, 2, and 3 are acceptable. Picture 4A shows pitting visible to the unaided eye. Hence, rust levels corresponding to Picture 4 are cause for rejection.

C11.5 – Acceptance criteria

Evaluation criteria is based on paper by Augusto S. Sason, "Evaluation of Degree of Rusting on Prestressed Concrete Strand," *PCI Journal*, V. 37, No. 3, May-June 1992.

12.0 — STRESSING OPERATIONS

12.1 — General

Do not stress tendons until the concrete has attained the specified compressive strength, as determined by cylinder testing or other Owner-approved testing method. Stress all prestressing steel with hydraulic jacks of sufficient capacity to the forces shown on the approved installation drawings, or as otherwise approved by the Engineer. Do not use single-strand jacks to stress tendons except where wedge plates of flat-duct tendons are designed for individual strand stressing and shown on PT installation drawings or for special cases at the discretion of the Engineer.

C12.1 – General

Stressing equipment is system-related. A jack designed for one particular system is unlikely to fit another without major modifications. The design of the tendon anchorage assembly has to be coordinated with the design of the jack chair, wedge seating devices, tube bundles, and automatic or manual jack stressing heads.

Strand installation and grouting equipment, on the other hand, are not system-dependent.

12.2 — Maximum stress at jacking

The maximum stress in the prestressing steel at time of stressing shall not exceed 0.80 f_{pu}. Do not overstress tendons to achieve the expected elongations. Strands stressed past 0.80 f_{pu} shall either be replaced or specifically approved by the Engineer. This maximum value does not supersede lower limits that may be present in Contract Documents.

C12.2 – Maximum stress at jacking

This requirement assures that jacks can safely and routinely produce the operating pressures necessary to produce temporary jacking forces of 80% f_{pu} (tendon MUTS). A jack, which cannot safely withstand the 95% AUTS system test, has inadequate safety margins for normal tendon stressing operations.

Jack cylinder area should be permanently identified on the jack. This permits an easy and reliable field check. Serious stressing problems can be prevented if operating personnel

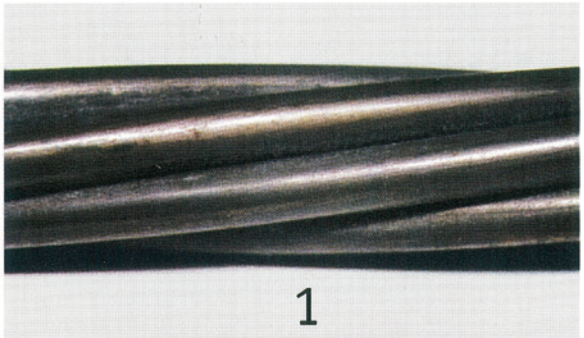

Photo 1. Strand surface before cleaning

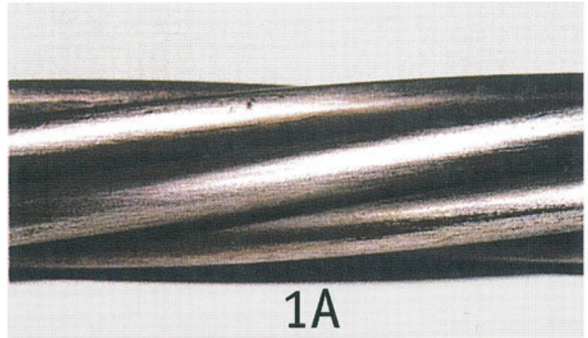

Photo 1A. Strand surface after cleaning

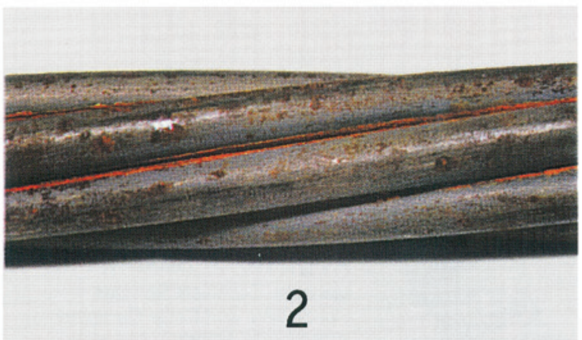

Photo 2. Strand surface before cleaning

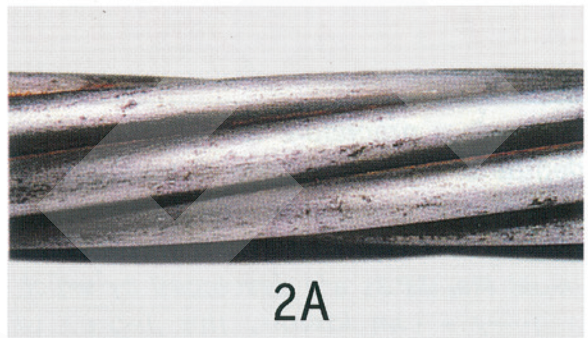

Photo 2A. Strand surface after cleaning

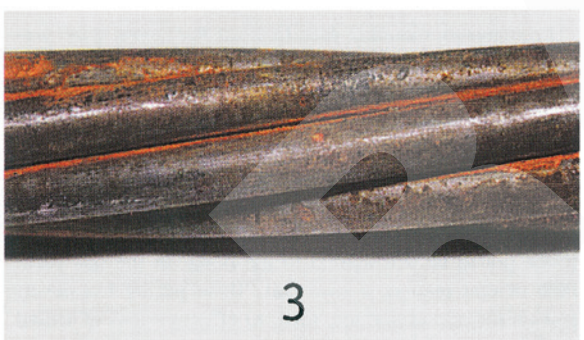

Photo 3. Strand surface before cleaning

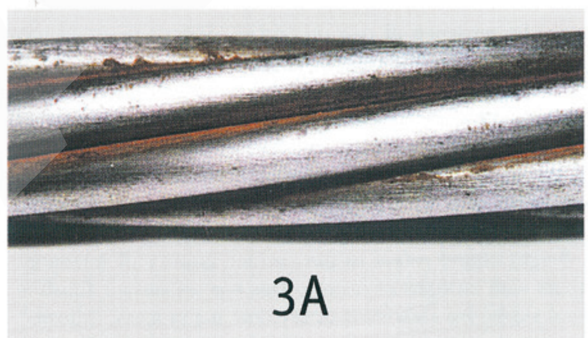

Photo 3A. Strand surface after cleaning

Photo 4. Strand surface before cleaning

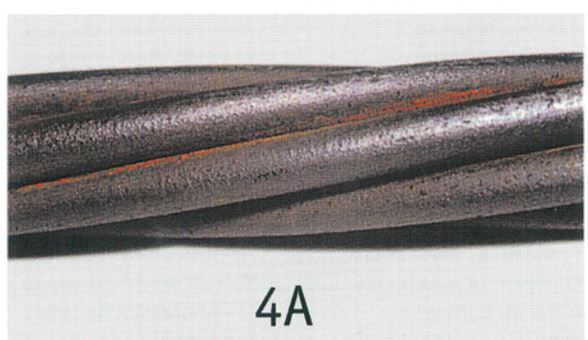

Photo 4A. Strand surface after cleaning

Fig. 11.1—Evaluation of prestressing steel for acceptance.

Photo 5. Strand surface before cleaning

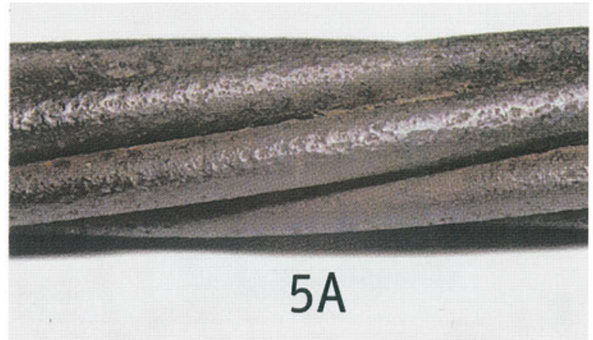

Photo 5A. Strand surface after cleaning

Photo 6. Strand surface before cleaning

Photo 6A. Strand surface after cleaning

Photo 7. Strand surface before cleaning

Photo 7A. Strand surface after cleaning

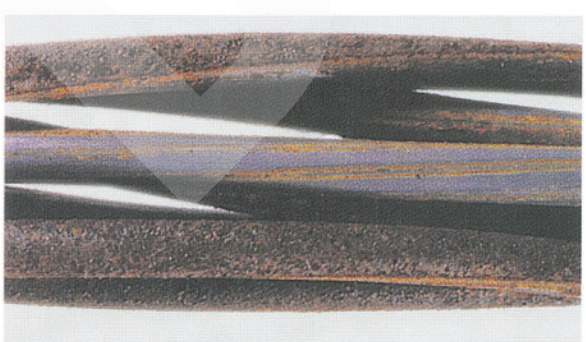

Photo 8. Strand surface before cleaning

Photo 8A. Strand surface after cleaning

Fig. 11.1 (cont.)—Evaluation of prestressing steel for acceptance.

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routinely compares the calibration charts with onsite calculation:

Pressure = Jacking Force / Jack Area.

Under normal conditions, jack friction losses at P_{jack} amount to only approximately 2 to 3%, which can be factored into the simple computations.

Proper strand anchoring requires that wedges segments seat equally.

Six in. (150 mm) diameter gauges usually are required by applicable specifications to assure adequate reading accuracy.

It is good practice to calibrate gauges to read true pressures at expected maximum jacking pressures prior to calibrating jacks and gauges as units. Such practice allows verification of calibration documents and allows gauge replacement.

12.3 — Stressing sequence

Post-tensioning tendons shall be stressed in the sequences indicated on the Contract Documents.

C12.3 – Stressing sequence

Unless a special requirement exists, which typically would be specified by the engineer in the contract documents, double end stressing does not need to occur simultaneously.

12.4 — Stressing jacks and gauges

Only use equipment furnished or approved for use by the PTS supplier. Equip each jack with a pressure gauge for determining the jacking pressure. The pressure gauge shall have an accurately reading dial face at least 6 in. (150 mm) in diameter. Pressure gauges or electronic pressure transducers with digital indicators shall indicate the load directly to 1% of the maximum gauge or sensor/indicator capacity or 2% of the maximum load applied, whichever is smaller.

C12.4 – Stressing jacks and gauges

Temperatures may affect the speed at which the needle moves on liquid-filled gauges. It is good practice to recognize this and make provisions to address this and be cognizant of it during stressing.

12.5 — Calibration of jacks and gauges

Calibrate each jack and two gauges as a unit. Separate calibrations shall be performed with the jack in the 1/4, 1/2, and 3/4 stroke positions. At each pressure increment, average the forces from the three stroke positions to obtain a standardized force. The PTS supplier, or an independent laboratory if necessitated by the Contract Documents, shall perform the initial calibration of jacks and gauge(s) and prepare the certified calibration report(s). The PTS qualified person per Section 7.1 is responsible for oversight of the calibration process, including preparation of the certified calibration report(s). Use load cells calibrated

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within the past 12 months to calibrate the stressing equipment every 6 months. For each jack and gauge unit to be used on the project, furnish certified calibration charts to the Project Resident Engineer prior to stressing.

For each load cell used, submit documentation showing the date and results for the most recent calibration, together with traceability to NIST (National Institute of Standards and Technology).

Provide the Project Resident Engineer with certified calibration reports prior to the start of stressing and every 6 months thereafter, or as requested. Calibrations after the initial calibration by load cell may be done with a master gauge. If applicable, supply the master gauge to the Project Resident Engineer in a protective waterproof container capable of preserving the calibration of the master gauge during shipping. Provide a hydraulic manifold that ensures quick and easy connection of the master gauge to any jack on site to verify the production gauge readings. The master gauge shall be calibrated in tandem with each jack/gauge calibration performed for the project and delivered to the Project Resident Engineer, together with all calibration data. Alternatively, if all gauges are calibrated to a current calibrated (NIST) deadweight tester, the master gauge does not need to be calibrated in tandem. The master gauge will remain in the possession of the Project Resident Engineer for the duration of the project. Any jack repair, such as replacing seals, shall be cause for recalibration using a load cell.

12.6 — Elongations and agreement with forces

Ensure that during tendon stressing the forces being applied to the tendon and the elongation of the tendon can be measured at all times.

All tendons shall be stressed to the corresponding forces shown on the approved installation drawings, as determined by gauge pressure readings. Do not stress tendons by matching the theoretical elongations. Tendon elongations shall be read and recorded to the nearest 1/16 in. (1.6 mm). The true elongations, free of all system effects, shall fall within 7% of the theoretical elongations shown on the approved installation drawings—modified if necessary—for the actual module of elasticity and prestressing steel areas shown on the prestressing steel mill certificates.

COMMENTARY

C12.6 – Elongations and agreement with forces

An occasional wire break is not uncommon. When experiencing repeated wire breaks, the root cause should be identified and resolved before proceeding.

Reference “Rational application of elongation tolerances” by C. Freyermuth.

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For tendons shorter than 40 ft (12 m), elongations shall fall within (7% + 1/4 in. [6.4 mm]) of the theoretical elongations shown on the approved installation drawings.

Where strands in a tendon are stressed individually, the average strand elongation shall be computed and compared to the theoretical elongation.

If actual elongations fall outside the allowable range, the entire operation shall be checked, and the source of error determined and remedied before proceeding further. Do not exceed the specified jacking force to achieve theoretical elongations.

Correct or compensate for deviations of calculated-versus-measured elongations in a manner proposed by the Contractor in consultation with the PTS supplier and reviewed and approved by the Engineer.

If elongations fall short by more than allowed herein and the Contractor cannot determine the cause, verify the fixed-end force with a stressing jack access permitting. If the fixed-end force is lower than theoretical, the tendon is still acceptable without further action if the average of all the tendon forces of the member cross sections have a final post-tensioning force of at least 98% of the design total post-tensioning force. If the fixed-end force is higher than theoretical, the tendon is acceptable without further action.

When strand tendons with one stressing end but with access to both ends show elongation outside of tolerance, additional stressing from the fixed end side shall be permitted if the additional calculated elongation is at least 0.5 in. (13 mm).

When all attempts at reconciling stressing forces and elongations have failed, representative in-place friction tests per Section 12.7 shall be permitted to resolve the discrepancy, if approved by the Engineer.

12.7 — Friction testing

The test procedure consists of stressing a tendon at one end and having a load cell or a second calibrated jack at the other end. Stress the test tendon to the jacking force in eight equal increments. For each increment, record the gauge pressure, elongation, and fixed-end force. Take into account any anchor set in both the stressing end (that is, back of jack) and the fixed end (that is, back of jack or load cell) and any friction within the anchorages, wedge

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plates, and jack as a result of slight deviations of the strands through these assemblies. The PTS supplier's personnel qualified to perform stressing operations shall conduct the test under observation of the Project Resident Engineer.

The PTS supplier shall reevaluate the theoretical elongations shown on the post-tensioning installation drawings using the results of the in-place friction test(s) and modify as necessary. Submit revisions to the theoretical elongations to the Engineer for approval. Friction-reducing agents may be used with the Engineer's approval.

12.8 — Wire failures in strand tendons

Multi-strand post-tensioning tendons with wire failures—by breaking or slippage—shall be permitted to be accepted provided the following conditions are met:

- All member cross sections shall have a final effective post-tensioning force of at least 98% of the design total post-tensioning force, based on the recorded jacking force or liftoff force, whichever is smaller; and
- Any single tendon shall have no more than a 5% reduction in cross-sectional area of post-tensioning steel due to wire failure.

One or more of the aforementioned conditions shall be permitted to be waived if the Contractor in consultation with the PTS supplier can offer acceptable alternative means of restoring the post-tensioning force lost due to wire failure and if approved by the Engineer.

12.9 — Cutting of post-tensioning steel

Once elongations of tendons have been verified and the tendon has been accepted, cut the strand tails within 1 day and install the grout cap. If acceptance of the tendon is delayed, seal all tendon openings and temporally weatherproof the exposed ends of the anchorage per tendon PL.

Cut post-tensioning steel with an abrasive disk, plasma torch, or mechanical shear within 1/2 to 3/4 in. (13 to 19 mm) away from the wedge, unless other details and dimensions are shown on the approved installation drawings. Ground connection for plasma cutting shall be placed directly on the strand bundle being cut.

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12.10 — Capping of tendons

For PL-2 and PL-3, install permanent grout caps and seal all other tendon openings within 1 day following cutting of strand tails, unless specified otherwise.

12.11 — Record of stressing operations

Keep a record of the following for each tendon installed:

- Project name and ID;
- Contractor and/or subcontractor;
- Approved PT Installation Drawing date and revision number;
- Tendon location, size, and type;
- Date tendon was installed in duct;
- Reel number(s) for strands and heat number for bars;
- Weighted, actual tendon cross-sectional area, based on mill certificates;
- Weighted, actual modulus of elasticity, based on mill certificates;
- Date stressed;
- Stressing operator(s) name;
- Jack and gauge numbers for each stressing end;
- Required jacking force;
- Target and actual gauge pressures;
- Elongations (theoretical and actual);
- Anchor sets (anticipated and actual);
- Stressing mode (one end/two ends/simultaneous);
- Witnesses to stressing operation (contractor and inspector);
- Stressing sequence (that is, tendon before and after);
- Daily temperature and relative humidity; and
- Use of temporary corrosion inhibitor, if applicable.

Record any other relevant information. Provide the Engineer with a copy of all stressing records at the conclusion of that day's stressing operations.

13.0 — GROUTING OPERATIONS

Grouting shall be performed in accordance with PTI M55.1, "Specification for Grouting of Post-Tensioned Structures."

COMMENTARY

C13.0 – GROUTING OPERATIONS

Grout provides long-term corrosion protection for prestressing steel and, therefore, must fill all voids and cover all prestressing steel surfaces.

The grout must achieve adequate strength to fulfill its structural purposes, bonding the prestressing steel to the

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surrounding concrete and to enhance the effective cross-sectional concrete area.

13.1 — Duct air test

For PL-1, PL-2, and PL-3, use the following tests when duct air tests are required by contract documents prior to grouting.

Pressurize tendons to 30 psi (0.21 MPa) and lock off the outside air source and inspect for leaks. Locate and repair leaks and retest. Refer to PTI M55.1-19, "Specification for Grouting of Post-Tensioned Structures."

C13.1 – Duct air test

The field test described is intended to identify leaks in the duct system so they can be addressed before grouting. There is no prescribed loss of pressure or pressure duration as the variation of tendon sizes is too great to establish one criterion. However, rough criteria of approximately 1 minute and less than 50% loss has been used for PL2 tendons. Judgment should be used in the evaluation of these criteria.

This field test is not to be confused with the system air tests described in Section 4.4.

14.0 — PROTECTION OF POST-TENSIONING ANCHORAGES

14.1 — General

Within 7 days of completion of grouting, unless otherwise specified, conduct all post-grouting inspections and address any voids found in tendons and/or caps by methods approved by Owner. Following that, protect the anchorages of post-tensioning tendons as indicated in the Contract Documents.

To construct pourbacks located at the anchorages, fill pockets and blockouts in accordance with tendon Protection Level (PL):

- PL-1: Use reinforced concrete, approved non-shrink grout, or epoxy grout
- PL-2 and PL-3: Use an approved epoxy grout or reinforced concrete

Protect anchorages inside box girder with permanent grout cap sealed with elastomeric coating.

Application of coating over the protected anchorages shall be permitted to be delayed up to 45 days after grouting, unless otherwise specified.

C14.1 – General

Because permanent grout caps are not required for PL-1A, pourbacks are the primary PT anchorage protection for PL-1A.

For PL-1B, PL-2, and PL-3, pourbacks are typically applied over the permanent grout caps as additional layer of anchorage protection.

Refer to Appendix A for typical details.

14.2 — Pourbacks

Remove all laitance, grease, curing compounds, surface treatments, coatings, and oils by grit-blasting or water-blasting using a minimum of 3000 psi (21 MPa) nozzle pressure. Prevent water from entering the post-tensioning system.

C14.2 – Pourbacks

Traditionally, non-reinforced concrete or non-shrink grout were used as pourback material. These materials could exhibit pourback and perimeter cracking, which compromised the corrosion protection of the anchorages. Therefore, epoxy grout is required for PL-2 and PL-3, except for

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Flush surface with water and blow-dry with clean, oil-free compressed air. Surfaces shall be clean, sound, and without standing water. If required, use ASTM C1583/C1583M for substrate testing and develop a minimum of 175 psi (1.2 MPa) tension (pulloff value). Mix and place portland cement concrete in accordance with the Contract Documents. Mix and apply non-shrink grout, or an approved epoxy grout per manufacturer's current standard technical guidelines in accordance with the Contract Documents. Construct all pourbacks in leak-proof forms creating neat lines. The epoxy grout may require pumping for proper installation. Construct forms to maintain a liquid head to ensure intimate contact with the concrete surface. Use vents as needed to provide for the escape of air to ensure complete filling of the forms.

14.3 — Anchorage coating system

Coat the exposed surfaces of all pourbacks not exposed to traffic and grout caps on the interior of box girder, as identified in the Contract Documents, with an approved elastomeric coating system to a thickness of 0.030 to 0.045 in. (0.76 to 1.1 mm), applied in accordance with the manufacturer's recommendations. Extend the coating 12 in. (305 mm) minimum past the perimeter of the pourback.

Coat the exposed surfaces of pourbacks exposed to traffic, as identified in the Contract Documents, with an approved high-molecular-weight methacrylate (HMWM), applied in accordance with the manufacturer's recommendations. Extend the coating 6 in. minimum past the perimeter of the pourback.

Perform tests to establish the number of coats required to obtain this required thickness per manufacturer's recommendations without runs and drips. Before applying the coating system to the structure, assure concrete, grout caps, or other substrates are structurally sound, clean, and dry. Over the application area, remove all laitance, grease, curing compound, surface treatments, coatings, and oils by grit-blasting or water-blasting using a minimum 3000 psi (21 MPa) nozzle pressure. Prevent water from entering the post-tensioning system. Blow-dry the surface with clean, oil-free compressed air. Mix and apply the elastomeric coating per the manufacturer's current standard technical specifications. Spray or roller application is permitted.

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large pourbacks where reinforced concrete should be used.

Proper surface preparation is required to provide bond of the pourback to the structure.

Refer to Appendix A for typical details.

C14.3 – Anchorage coating system

Anchorage coating systems are considered as an additional layer of protection. This waterproofing membrane is typically applied over permanent grout cap or pourback.

Refer to Appendix A for typical details.

For an example of anchorage coating system material requirements, refer to FDOT Specification Section 975. Refer to the FDOT Approved Products List for examples of FDOT Approved High Molecular Weight Methacrylate materials.

SPECIFICATION

15.0 — REPAIRS OF HOLES AND ACCESS OPENINGS

15.1 — Openings

Repair all holes and access openings with an approved repair material of the same or higher strength than the concrete in that structural member, in accordance with the Contract Documents. Provide a keyed joint for access openings and blockouts. Sequence of closing of access holes shall be as early as possible to potentially gain the benefits of compression provided by subsequent post-tensioning.

Before performing the repair, mechanically clean and roughen the existing concrete surfaces to remove any laitance and expose the small aggregate. Flush surface with water and blow-dry with clean, oil-free compressed air. Form, mix, place, and cure the repair material in strict compliance with the manufacturer's recommendations.

Coat the repaired holes, blockouts, and openings over an area extending 6 in. past the perimeter of the repair with an approved HMWM. Prepare the surface to be coated and apply the HMWM in accordance with the manufacturer's specifications.

COMMENTARY

C15.1 – Openings

Proper surface preparation is required to provide bond of the repair to the structure.

Refer to Appendix B for typical repair details for holes, blockouts, and openings.

16.0 — REFERENCES

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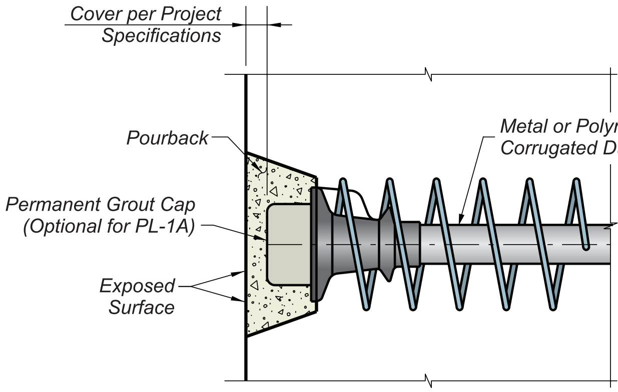
ASTRA, “Massnahmen zur Gewährleistung der Dauerhaftigkeit von Spanngliedern in Kunstbauten“ (Measures to ensure the durability of post-tensioning tendons in bridges), Richtlinie ASTRA 12010, Eidg. Departement für Umwelt, Verkehr, Energie und Kommunikation UVEK, Bundesamt für Strassen, 2007.

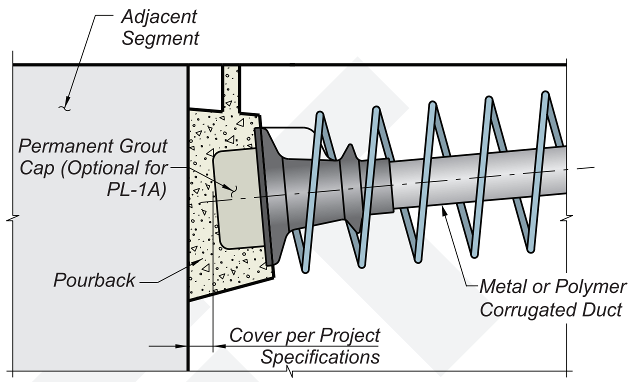
APPENDIX A – TYPICAL POURBACK DETAILS AND INLET AND OUTLET DETAILS

Protection Levels PL-1A and PL-1B

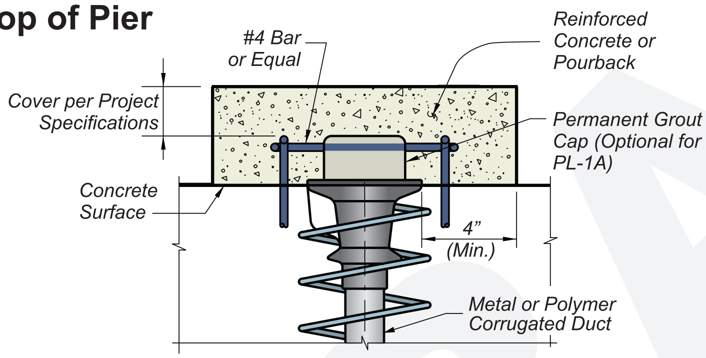
Exposed Surface



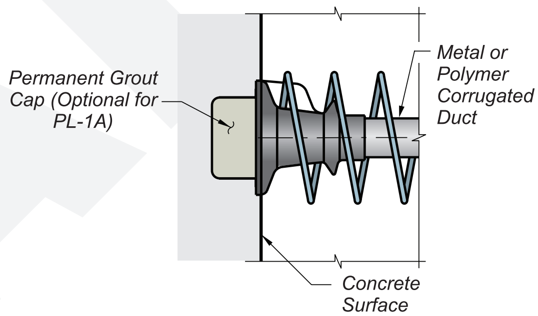
Blockout Between Segments



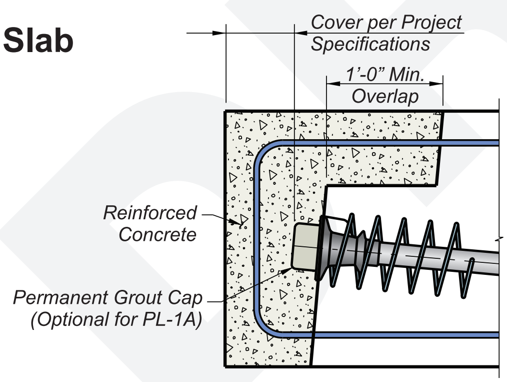
Top of Pier



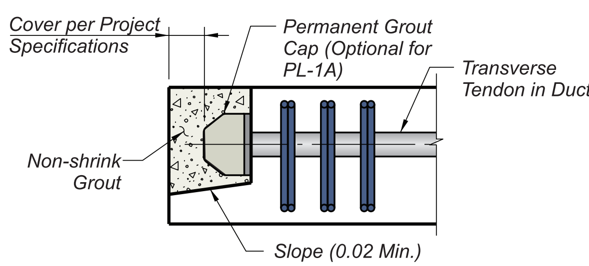
Interior of Box Girder



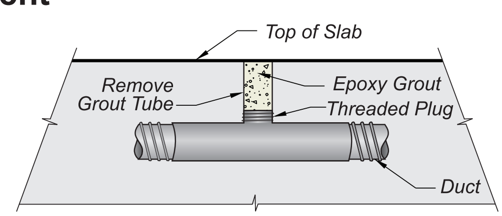
Flat Slab



Transverse Top Slab

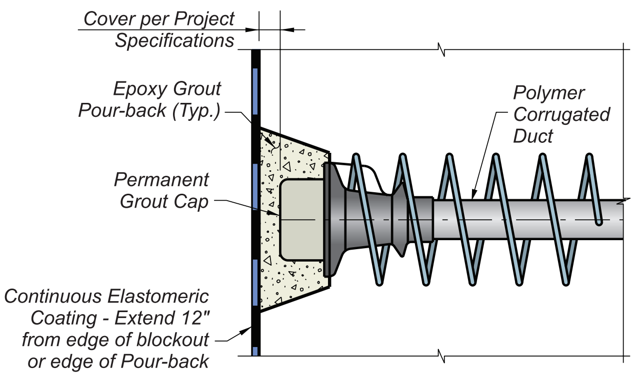


Grout Vent

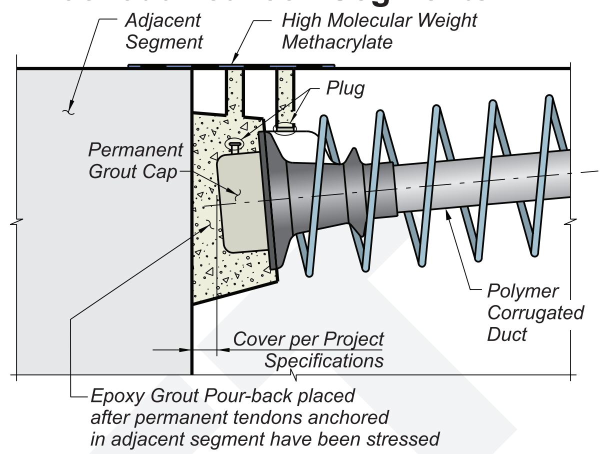


Protection Levels PL-2 and PL-3

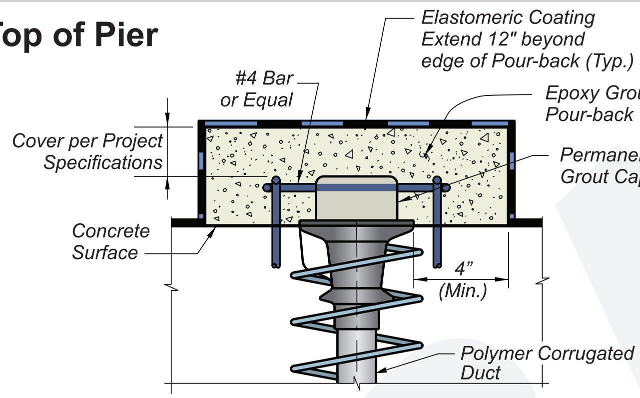
Exposed Surface



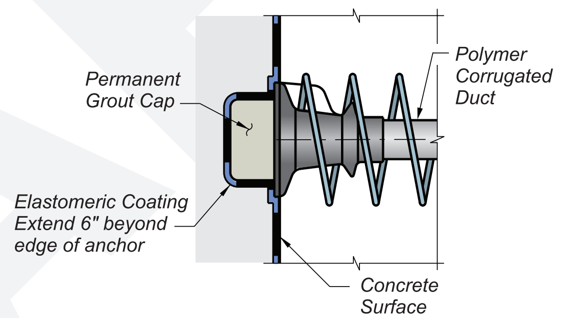
Blockout Between Segments



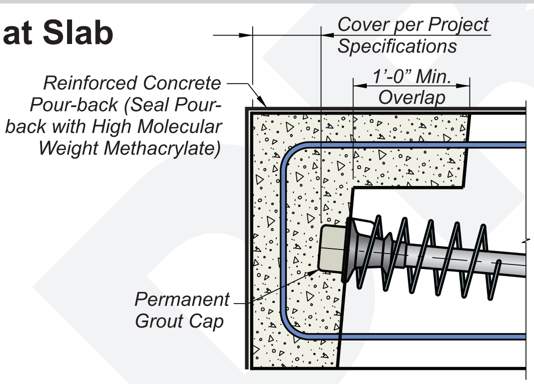
Top of Pier



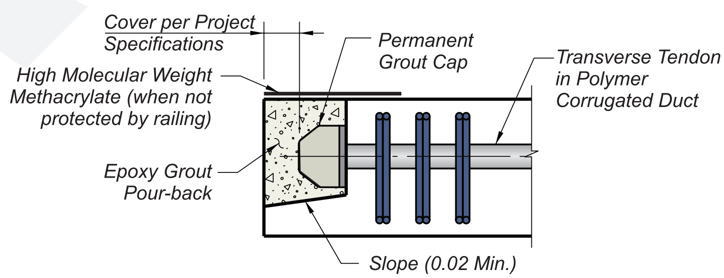
Interior of Box Girder



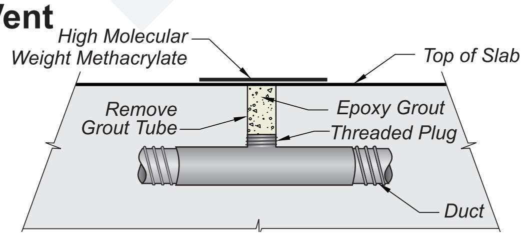
Flat Slab



Transverse Top Slab

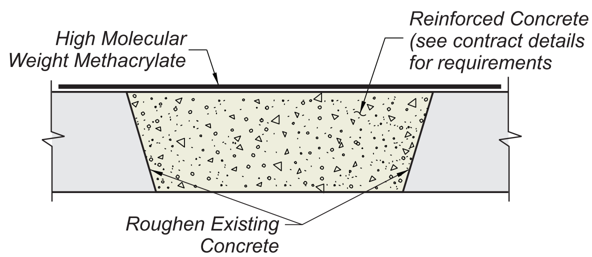


Grout Vent

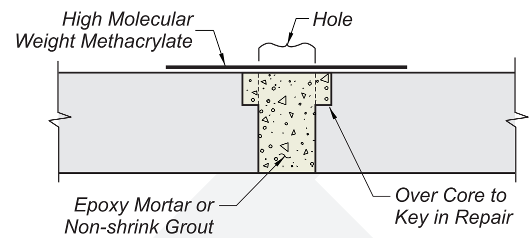


APPENDIX B – TYPICAL REPAIR DETAILS FOR ACCESS OPENINGS, BLOCKOUTS, AND HOLES

Access Opening and Blockouts



Hole in Slab



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*

American Segmental Bridge Institute (ASBI)

Mission

To work collaboratively to advance, promote, and innovate concrete segmental bridges and **complex concrete structures** technologies; share the knowledge; educate stakeholders; build professional relationships; and increase the value of our infrastructure by providing sustainable and resilient solutions.

Vision

Segmental bridges offer the best value bridging solution.

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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 website 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.

About ASBI

The American Segmental Bridge Institute (ASBI) was incorporated in 1989 as a nonprofit organization to provide a forum where owners, designers, constructors and suppliers can meet to further refine procedures and evolve new techniques that will advance the quality and use of concrete segmental bridges. Today, ASBI boasts a 70+ member Board of Directors with three committees and eight subcommittees that specialize in different aspects of communication, education, technology and innovation in the concrete segmental bridge industry.

ASBI is a focal point for the development of technical information for design and construction of segmental concrete bridges in the U.S. as well as internationally. Educational programs, training, and publications are provided in response to industry needs.

Information regarding ASBI activities and membership is available at **www.asbi-assoc.org**.

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