AGENDA
PTI M-50 / ASBI Bonded Tendon Task Group Meeting
April 30, 2017
1:00 PM – 5:00 PM
Hyatt Regency Hotel Atlanta, Atlanta GA, Room Embassy C

Voting Members Present (x of 29)

Dave Martin, Co-Chair
Guido Schwager, Co-Chair
Ken Bocchicchio
Guy Cloutier
Tom DeHaven
Tim Gattie
H.R. Hamilton
Reggie Holt
Elie Homsi
Ian Hubbard
Gregory Hunsicker
Larry Krauser
Bryan Lampe
Brian Merrill
Andrew Micklus
R. Kent Montgomery
Alan Moreton
Jerry Pfuntner
Jose Luis Quintana
Robert Robertson, Jr.
Ralph Salamie
Mike Schwager
Leo Spaans
Michael Sprinkel
Bob Sward
Teddy Theryo
Dustin Thomas
Scott Turnpaugh
Yash Paul Virmani
John Crigler, TAB Contact, NV
Randy Cox, NV
Ted Neff, NV
Miroslav Vejvoda, Secretary, NV

Dywidag-Systems International USA, Inc.
Schwager Davis, Inc.
Caltrans
General Technologies, Inc.
Figg Bridge Engineers
PCL
University of Florida
Federal Highway Administration
Parsons
Parson Brinkerhoff
VSL
Freyssinet, Inc.
Figg Bridge Engineers
Corven Engineering, Inc.
Finley Engineering Group
Mexpresa
Florida DOT
Kiewit
Schwager Davis, Inc.
Janssen & Spanns Engineering, Inc.
Virginia Transportation Research Council
VSL
Parsons Brinkerhoff, Inc.
Minnesota DOT
Traylor Bros., Inc.
Federal Highway Administration
VSL
ASBI
PTI Staff
PTI Staff

Associate Members Present

Yosbani Ballate
Mike Beauchamp
Robert Bennett
Tommaso Ciccone
Joe Harrison
Thomas Helm
Bljan Khaleghi
David Konz
Jim McTaggart
Marcel Poser
Mario Salice
Joe Salvadori
Don Singer
Eric Sommer
Jack Torok

VSL
Caltrans
RS&H
Tensacciai srl
General Technologies, Inc.
Geotechnical and Environmental Services
Washington State DOT
Atkins Global
J&L Steel
Tectus Group
Schwager Davis, Inc.
Dywidag-Systems International USA, Inc.
DYWIDAG-Systems International Canada, Ltd.
VSL
Target Products
**ACTION ITEMS FROM LAST / THIS MEETING**

<table>
<thead>
<tr>
<th>Item #</th>
<th>Subject</th>
<th>Action</th>
<th>Responsible</th>
<th>Deadline / Completed</th>
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<tbody>
<tr>
<td>1</td>
<td>TG-Editorial</td>
<td>Review definitions, references and general editorial issues</td>
<td>Cox, Helm, M. Schwager, Salvadori</td>
<td>After next ballot</td>
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<tr>
<td>2</td>
<td>Ballot M-50-1601</td>
<td>Initiate a ballot with final Commentary changes and other outstanding changes that have already been prepared</td>
<td>Staff</td>
<td>December 2016 See items 1.1 and 1.2</td>
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<tr>
<td>1.2</td>
<td>TG-AASHTO Updates, joined with DC-40</td>
<td>Review AASHTO Specifications for other items that should be changed; propose changes including proposal from TG-AASHTO 95%</td>
<td>Merrill, Cloutier or Krauser, Salvadori, Cox, Hunsicker</td>
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**Agenda Item**

**Expected Outcome / Actions Taken**

**A. General**
A.1 Call to Order
A.2 Introductions / Attendance

A.3 The current roster is above and on the PTI website. There are currently 29 voting members; meeting ballot quorum is 12 members.

A.4 Members are reminded of the PTI Antitrust Policy that is circulated with the attendance sheet; all are asked to initial it to acknowledge the policy and attest the adherence to it.

A.5 The Annual Report needs to be prepared and distributed before the fall meeting so that it can be finalized at the fall meeting.

**B. Agenda & Minutes**
B.1 Approval of Agenda

B.2 Approval of Minutes (Meeting ballot required)
B.2.1 Meeting Minutes from November 6, 2016, distributed on January 3, 2017.

B.2.2 Web Meeting Minutes from April 13, 2017

B.1 Any changes to the agenda?

B.2.1 Motion / Second to approve Meeting Minutes from 11/6/16: Name / Name, 0-0-0 (Y-N-A)

B.2.2 Motion / Second to approve Meeting Minutes from 4/13/17: Name / Name, 0-0-0 (Y-N-A)
<table>
<thead>
<tr>
<th>Agenda Item</th>
<th>Expected Outcome / Actions Taken</th>
</tr>
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<tbody>
<tr>
<td><strong>C. Actions Taken Between Meetings</strong></td>
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<tr>
<td>C.1 Letter Ballot-M-50-1701; ballot end March 10, 2017</td>
<td>C.1 Ballot Summary <em>(Exhibit C.1)</em></td>
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<tr>
<td>C.2 Web Meeting on April 13, 2017 to resolve negatives on Ballot-M-50-1701</td>
<td>Unresolved Ballot Item: No. 13 (Section 4.4.4 – Corrugated plastic duct) C.2 Negative resolution <em>(Exhibit C.2)</em></td>
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<td><strong>1. Action Item 1: Commentary</strong></td>
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<tr>
<td>1.1 Status of Commentary: Document with approved Commentary and outstanding items</td>
<td>1.1 All commentary and other modified sections approved except for Ballot Item 13; See Exhibit C.2. Resolution of Ballot Item 13:</td>
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<tr>
<td><strong>2. Action Item 2: PT Systems Qualification Testing</strong></td>
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<td>2.1 Progress report / Discussion 2.1.1 CRT-70 Membership 2.1.2 Draft document</td>
<td>2.1 Report from CRT-70 meeting on April 30, 2017. 2.2 Promotion will start when the program is published.</td>
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<td>2.2 DOT Visits: FDOT, VDOT, MnDOT, TxDOT, Caltrans 2.2.1 Feedback</td>
<td>2.3 Finalizing Manual; selecting independent Inspection Agency</td>
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<td>2.3 CRT-70 Action Items 2.3.1 Membership 2.3.2 Qualification testing criteria (PTI 95% MUTS vs. AASHTO 96% actual vs. EN 95% actual) 2.3.3 PT System Review Form (Check list) 2.3.4 Certification process</td>
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<td><strong>3. Action Item 3: Monitorable, Replaceable and Assessable PT Research Project</strong></td>
<td>3.1 Final draft with Specification and Commentary for replaceable grouted tendons is attached <em>(Appendix 3.1.1)</em></td>
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<tr>
<td>3.1 Progress update of the FHWA Task 5009 as of April 2017 3.1.1 Replaceable Grouted Tendons</td>
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<td>Agenda Item</td>
<td>Expected Outcome / Actions Taken</td>
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<tr>
<td>3.1.2 Monitorable Tendons</td>
<td>3.1.2 Final draft with Specification and Commentary for monitorable tendons is attached <em>(Appendix 3.1.2)</em></td>
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<td>3.2 Discussion and time table for integration into M-50</td>
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<td>4.1 Items for the next edition.</td>
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<td>4.1.1 Commentary</td>
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<td>4.1.2 Requirements</td>
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<td>4.1.3 Monitorable, Replaceable and Assessable PT</td>
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<td>4.2 Time table to completion of the next edition.</td>
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<td><strong>5. Action Item 5: AASHTO Bridge Construction Specification</strong></td>
<td>5.1</td>
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<td>5.1 Status of 95% MUTS (TG: Xia, Myer, Micklus, Ciccone, Holt)</td>
<td>5.1.1</td>
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<td>5.2 AASHTO Updates (TG: Merrill, Cloutier/Krauser, Salvadori, Cox, Hunsicker)</td>
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<td><strong>6. Action Item 6: Flexible Fillers</strong></td>
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<td>6.1 Current Status</td>
<td>6.1.1</td>
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<td>6.2 Action items?</td>
<td>6.1.2</td>
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<td><strong>D. New Business</strong></td>
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<tr>
<td>D.1 New items?</td>
<td>D.1.1</td>
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<td><strong>E. Next Meeting</strong></td>
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<td>E.1 ASBI Convention – Sunday, October 23, 2017, at the Marriott Marquis in New York</td>
<td>E.1.1</td>
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<td>E.2 Web Meetings:</td>
<td>E.2.1</td>
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### Agenda Item

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<tr>
<th>Exhibit #</th>
<th>Subject</th>
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<tr>
<td>A.4</td>
<td>PTI Anti-Trust Policy</td>
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<tr>
<td>C.1</td>
<td>Ballot-M-50-1701 Summary</td>
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<tr>
<td>C.2</td>
<td>Ballot-M-50-1701 Negative resolution in Web Meeting on April 13, 2017</td>
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<tr>
<td>3.1.1</td>
<td>Final Draft with Specification and Commentary for Replaceable Grouted Tendons</td>
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<tr>
<td>3.1.2</td>
<td>Final Draft with Specification and Commentary for Monitorable Tendons</td>
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### Expected Outcome / Actions Taken

- **F. Adjourn**
  
The meeting adjourned at
At a meeting on October 8, 1980, the Board of Directors first discussed the Institute's status and policies regarding compliance with antitrust laws. After review of both the internal and external compliance procedures, the following resolution was approved:

"The staff, officers, directors and members of the Post-Tensioning Institute are reminded that they are required to comply with the spirit and specific requirements of the antitrust laws on all activities within the scope of, and related to, the official functions of PTI. Further, this restated position, along with appropriate explanatory material, should be placed in all meeting folders/books periodically, beginning with the 8th of October meeting of PTI."

On July 24, 2012 and again on October 7, 2015, the Executive Committee authorized Legal Counsel to review and update this Policy Statement in the perspective of the Department of Justice Business Review Letter of July 30, 1997 and current case law. As a continuing guide for your participation in PTI's meetings, please review and continue to adhere to the following "Legal Limitation on Discussions at PTI Meetings."

LEGAL LIMITATION ON DISCUSSIONS AT PTI MEETINGS AND EVENTS

A free exchange of ideas on matters of mutual interest to the members is necessary for the success of all meetings. Indeed, such an exchange of views is essential to the successful operation of every trade association and the law specifically allows legitimate exchange of views pertaining to, e.g., quality control, safety, building design and construction integrity, etc.

It is not the purpose of this memorandum to discourage the exploration in depth of any matters of legitimate concern to meeting participants. Nevertheless, to ignore certain antitrust ground rules, either through ignorance or otherwise, is to create a civil and criminal hazard businessmen simply cannot afford.

It is for these reasons that PTI provides you with a reminder that certain areas of formal and informal communication between competitors or between manufacturers and their suppliers and customers must be avoided, as posing potential antitrust problems.

The Sherman Antitrust Act, the Clayton Act, the Federal Trade Commission Act, and the Robinson-Patman Act comprise the basic federal antitrust laws, which set forth the broad areas of conduct considered illegal as restraints of trade. In general, agreements or understandings between competitors that operate as an impediment to free and open competition are forbidden. Federal antitrust prohibitions forbid any "agreement or understanding...to substantially lessen competition or tend to create a monopoly in any line of commerce." An important point to keep in mind is that communications and discussions between competitors or between sellers and customers, about matters which may be considered anti-competitive, often comprise the evidence from which courts infer antitrust violations. It is the policy of the Post-Tensioning Institute that such agreements, understandings or communications shall not be tolerated at any formal or informal meetings or social events of the Institute.

The general prohibitions contained in the federal antitrust laws, have been particularized in the form of a series of consent decrees, originally entered against a number of member companies of various trade associations and the associations themselves. It is important to note that these laws not only apply to PTI members, but also to PTI itself. Often trade associations have been and are presently co-defendants in cases brought by the Justice Department and the Federal Trade Commission (“FTC”). Recently, the FTC has stated: “Because trade associations are by their nature collaborations among competitors, the Commission and courts have long been concerned with anti-competitive restraints imposed by such organizations under the guise of codes of conduct. Competing for customers, cutting prices, and recruiting employees are hallmarks of vigorous competition. Agreements among competitors not to engage in these activities injure consumers by increasing prices and reducing quality and choice.” Similar “codes” or policies and requirements that encourage directly or indirectly members’ unlawful activity are strictly forbidden by PTI in the course of its business with its members.
SPECIFIC EXAMPLES OF ACTIVITIES AND PRACTICES PROHIBITED
AT ALL PTI MEETINGS AND EVENTS:

Included in activities and practices which are forbidden, and are contrary to the policy of the Institute, both under the general antitrust laws and the consent decrees, subject to the said Business Review Letter, are the following:

- Agreeing to allocate markets, customers or suppliers among competitors, classify certain customers or suppliers being entitled to preferential treatment by manufacturers, and establish geographic trading areas.

- Participating in any plan designed to induce any manufacturer or distributor to sell or refrain from selling, or discriminate in favor of, or against any particular customer or class of customers.

- Agreeing in any manner to fix or otherwise establish bids, prices (including price increases, decreases, standardization or stabilization), profits, costs, contract terms affecting price (such as discounts and credit terms), etc. because, e.g. prices were too low, with the exception of certain resale pricing agreements between manufacturers and retailers or distributors.

- Agreeing in any manner to limit or restrict the quality of products to be produced (e.g., restrictions on selling coated strand to certain customers).

- Participating in any plan which has the effect of discriminating against, or excluding competitors, suppliers or customers.

These examples are provided to guide you in your discussions during formal and informal PTI meetings and social events. If the occasion arises, more specific advice will be provided by legal counsel, who is required by Article IV, Section 7 of the PTI By-Laws to be present at all meetings of the Board of Directors and the Executive Committee.
### Ballot Summary:

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<th>Ballot Item</th>
<th>Yes</th>
<th>No</th>
<th>Abs/Vote Not Returned</th>
<th>Meets ½ Rule</th>
<th>Meets 2/3 Rule</th>
<th>Item Passes</th>
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Voting: Y – Approve; Y-E – Approve with Editorial Comment –N – Negative; A – Abstain.
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*nonvoting members  
** ballot items with all affirmative votes not shown for clarity
Guide Specification for **Multistrand and** Grouted Post-Tensioning

PTI Committee M-50/ASBI Joint Task Group

[The roster will be adjusted per Technical Committee Manual requirements before publication.]

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*Dywidag-Systems International*  
*Co-Chair*

Guido Schwager  
*Schwager Davis, Inc.*  
*Co-Chair*

Miroslav Vejvoda  
*Post-Tensioning Institute*  
*Secretary*

Mike Beauchamp*  
*Caltrans*

Gregory Hunsicker  
*VSL*

Salamie Ralph  
*Kiewit*

Ken Bocchicchio  
*Caltrans*

Larry Krauser  
*General Technologies, Inc.*

Robert V. Robertson Jr.  
*Florida DOT*

Guy Cloutier  
*Harris P.T. General Technologies, Inc.*

Bryan Lampe  
*Dywidag-Systems International*

Mike Schwager  
*Schwager Davis, Inc.*

Randy Cox†  
*American Segmental Bridge Institute*

Alan Matejowsky  
*HDR Engineering, Inc.*

Eric Sommer*  
*VSL*

Tom DeHaven  
*FIGG*

Brian Merrill  
*Texas DOT*

Leo Spaans  
*Janssen & Spaans Engineering, Inc.*

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Michael Sprinkel  
*Virginia Transportation Research Council*

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The purpose of this document is to establish a unified, nationally recognized specification for grouted post-tensioning. It is intended to apply to buildings, bridges, storage structures, and other structures using grouted post-tensioning tendons, except as follows: stay cables and rock anchors that are already covered by other PTI documents.

The stated goals of this specification are:
• To set a minimum standard for all post-tensioning work;
• To define the testing requirements before a post-tensioning system can be used;
• To ensure the installed components meet the approved system description;
• To ensure the system is installed in a technically sound manner;
• To ensure the durability goals will be achieved; give designers a choice of performance levels for a post-tensioning system based on the aggressiveness of the environment and protection provided by the structural element;
• To give suppliers an avenue for innovation beyond current best practice; and
• To provide minimum requirements for individual components used as part of the post-tensioning system.

This specification recognizes three tendon protection levels (PL):
• PL1A Protection Level 1A—Duct with filling material providing durable corrosion protection;
• PL1B Protection Level 1B—PL-1A plus engineered grout and permanent grout cap;
• PL2 Protection Level 2—PL-1B plus an envelope, enclosing the tensile element bundle over its full length, and providing a permanent leak-tight barrier; and
• PL3 Protection Level 3—PL-2 plus electrical isolation of tendon or encapsulation to be monitorable or inspectable at any time.
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<td><strong>1.0 — INTRODUCTION</strong></td>
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<td><strong>1.1 — General description</strong></td>
<td>Furnish 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. Submit samples, drawings, calculations, procedures, reports, manuals, and certifications. Both temporary and permanent post-tensioning shall comply with this specification.</td>
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<td><strong>1.2 — Alternative post-tensioning scheme</strong></td>
<td>Alternative post-tensioning schemes may be submitted for the Design Engineer’s approval, provided they meet the following:</td>
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<td></td>
<td>• 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;</td>
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<td>• The distribution of individual tendons at each cross section generally conforms to the distribution shown on the Contract Documents;</td>
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<td>• No reduction in the protection level;</td>
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<td>• Minimum concrete cover and concrete quality is not reduced;</td>
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<td>• 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.</td>
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</table>
- 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.

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. 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. [This was part of the specification; better suitable for commentary.]

---

### 1.3 — Referenced standards and specifications

| ASTM International | C 1.3 Referenced standards and specifications | [Per meeting in Hartford, standards and references will be formatted by staff in accordance with] |

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<table>
<thead>
<tr>
<th>ASTM A53/A53M, Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless</th>
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<tr>
<td>ASTM A153/A153M, Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware</td>
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<td>ASTM A240/A240M, Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications</td>
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<tr>
<td>ASTM A370, Standard Test Methods and Definitions for Mechanical Testing of Steel Products</td>
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<tr>
<td>ASTM A416/A416M, Standard Specification for Steel Strand, Uncoated Seven-Wire for Prestressed Concrete</td>
</tr>
<tr>
<td>ASTM A500/A500M, Standard Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes</td>
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<tr>
<td>ASTM A653/A653M, Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process</td>
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<td>ASTM A722/A722M, Standard Specification for Uncoated High-Strength Steel Bars for Prestressing Concrete</td>
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<td>ASTM C1583/C1583M, Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete</td>
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<td>ASTM A421, Standard Specification for Uncoated Stress-Relieved Steel Wire for Prestressed Concrete</td>
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<td>ASTM A475, Standard Specification for Zinc-Coated Steel Wire Strand</td>
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<td>ASTM A641, Standard Specification for Zinc-Coated (Galvanized) Carbon Steel Wire</td>
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<td>ASTM A882, Standard Specification for Filled Epoxy-Coated Seven-Wire Prestressing Steel Strand</td>
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<td>ASTM A981, 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</td>
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<td>Repair and Overlay Materials by Direct Tension (Pull-off Method)</td>
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<td>ASTM D570, Standard Test Method for Water Absorption of Plastics</td>
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<td>ASTM D638, Standard Test Method for Tensile Properties of Plastics</td>
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<td>ASTM D1000, Standard Test Methods for Pressure-Sensitive Adhesive-Coated Tapes Used for Electrical and Electronic Applications</td>
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<td>ASTM D2240, Standard Test Method for Rubber Property Durometer Hardness</td>
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<td>ASTM D3035, Standard Specification for Polyethylene (PE) Plastic Pipe (DR-PR) Based on Controlled Outside Diameter</td>
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<td>ASTM D3350, Standard Specification for Polyethylene Plastics Pipe and Fittings Materials</td>
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<td>ASTM D4101, Standard Specification for Polypropylene Injection and Extrusion Materials</td>
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<td>ASTM D5309, Standard Specification for Cyclohexane 999</td>
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<tr>
<td>ASTM D5989, Standard Specification for Extruded and Monomer Cast Shapes Made from Nylon (PA)</td>
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<td>2.0 — DEFINITIONS AND ABBREVIATIONS</td>
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<tr>
<td>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.</td>
</tr>
<tr>
<td>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.</td>
</tr>
<tr>
<td><strong>Anchorage assembly</strong> - A strand tendon anchorage assembly includes: wedges, wedge plate, bearing plate, duct transition, grouting attachment, and system dependent confinement reinforcement in the local zone.</td>
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<tr>
<td>A bar anchorage includes the anchor nut and the bearing plate plus duct and grouting attachments and system dependent confinement reinforcement.</td>
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<td>Anchor nut</td>
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<td>Anchorage nut</td>
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<td>Anchor set</td>
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<tr>
<td>Bar</td>
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<tr>
<td>Bearing Plate</td>
</tr>
<tr>
<td>Bearing plate, basic</td>
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<tr>
<td><strong>Bearing plate, special</strong> – 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).</td>
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<tr>
<td><strong>Bleed</strong> – 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.</td>
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<tr>
<td><strong>Confinement reinforcement</strong> – Nonprestressed reinforcement in the local zone, usually in the form of spirals, which provide concrete confinement and are considered part of the bearing plate.</td>
</tr>
</tbody>
</table>

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.
In that volume of concrete in which compressive stresses exceed acceptable limits for unreinforced concrete as determined by rational analysis. (See PTI's "Acceptance Standards for Post-Tensioning Systems, Section 3.1)

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)

**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** - 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.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tr>
<td><strong>Duct coupler</strong> – A device that connects individual lengths of duct forming a continuous enclosure around the prestressing steel.</td>
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<td><strong>Electrically isolated tendon (EIT)</strong> – Tendon demonstrating sufficient electrical resistance between the tensile elements and the structure.</td>
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<tr>
<td><strong>Engineer (Licensed Design Professional, Engineer of Record, Design Engineer)</strong> – The person, firm, or organization engaged by the Owner to prepare the Contract Documents for the construction of the project.</td>
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</tr>
<tr>
<td><strong>Friction</strong> – The force resisting the relative lateral (tangential) movement of material elements that are in contact.</td>
<td></td>
</tr>
<tr>
<td><strong>Grout</strong> – 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.</td>
<td></td>
</tr>
<tr>
<td><strong>Grout, basic</strong> – 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”).</td>
<td></td>
</tr>
<tr>
<td><strong>Grout, engineered</strong> – 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.</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td></td>
</tr>
<tr>
<td><strong>Grout cap, temporary</strong> – A device that contains the grout by covering the post-tensioning steel at the wedge plate.</td>
<td></td>
</tr>
<tr>
<td><strong>Grout cap, permanent</strong> – 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.</td>
<td></td>
</tr>
<tr>
<td><strong>F_{pu}</strong> – 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.</td>
<td></td>
</tr>
</tbody>
</table>
| **Hydrogen embrittlement** – Brittle cracking process caused by the conjoint action of tensile stress and hydrogen ions (atomic hydrogen).  

*Hydrogen embrittlement - See also definition of “stress corrosion cracking,” a similar phenomenon.* |
| **MUTS** – Acronym for Minimum Ultimate Tensile Strength – measured as force – 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.  

*MUTS used to allow precise description of strand, bar and tendon forces. As further discussed below, 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 for 0.5 in. (12.70 mm) strand, Grade 270 ksi (1,860 MPa), permit tensile unit-stresses between 244 and 277 ksi (1,682 and 1,910 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 A 416 specifies strands in terms of "minimum breaking strength," measured as force. ASTM A722 specifies bars in terms of "minimum ultimate tensile strength," measured in unit-stresses.
AASHTO and ACI 318 have notations and definitions for ultimate prestressing steel unit-stresses $f_{pu}$ and $f'_{pu}$, 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.
<table>
<thead>
<tr>
<th><strong>Post-tensioning</strong> – A method of prestressing in which prestressing steel is tensioned after the concrete has reached a specified strength.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Post-tensioning scheme or layout</strong> – The pattern, size, and locations of post-tensioning tendons in a structure.</td>
</tr>
<tr>
<td><strong>Post-tensioning system (PTS)</strong> – A particular size tendon, including prestressing steel, anchorages, local zone reinforcement, duct, trumpets, couplers, grout caps, inlets, outlets, all supplied by a single supplier.</td>
</tr>
<tr>
<td><strong>Post-tensioning system</strong> - 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.</td>
</tr>
<tr>
<td><strong>Pourback</strong> – Blockouts created for tendon anchorage and/or vent access that are to be filled with concrete, nonshrink grout, or epoxy at a later date.</td>
</tr>
<tr>
<td><strong>Pressure rating</strong> – 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</td>
</tr>
</tbody>
</table>

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Page 23 of 124
will not occur. Commonly referred to as maximum allowable working pressure (MAWP).

**Prestressing steel** – High-strength steel strand or bar.

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

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

**Quality assurance (QA)** – Actions taken by the Owner or his/her 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. **Sheathing** - Sheathing used as conduit is herein referenced to as duct. This definition of sheathing also covers transitions.
<table>
<thead>
<tr>
<th><strong>Strand, seven-wire</strong> – 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.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stress corrosion cracking</strong> – Brittle cracking process caused by the conjoint action of tensile stress and a corrodent.</td>
</tr>
<tr>
<td><strong>Stress corrosion cracking (SCC)</strong> - 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.</td>
</tr>
<tr>
<td><strong>Stressing jack</strong> – 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.</td>
</tr>
<tr>
<td><strong>Subcontractor</strong> – A person, firm, or organization engaged by the Contractor to provide select construction activities, materials, or other specialized construction or engineering services.</td>
</tr>
<tr>
<td><strong>Tendon</strong> – A single or group of prestressing elements and their anchorage assemblies, which impart the prestress force to a structural member. Also included are ducts, grouting attachments,</td>
</tr>
<tr>
<td><strong>Tendon</strong> - Consists of a single tendon element (strand or bar) or a bundle of such elements. The tendon is stressed by a hydraulic</td>
</tr>
</tbody>
</table>
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 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 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. |

| **Wobble** – Friction caused by unintended duct deviations between profile control points. |
| **Wedge plate** - For a multi strand tendon this is a machined, forged, or cast metal disk with multiple conical wedge holes. |

| **Zone, anchorage** – The portion of the member through which the concentrated pre-stressing force is transferred from the anchorage device onto the local zone of the concrete, and then distributed across the section into the general zone of the structure. It includes the local and general anchorage forces. |
| Zone, anchorage - By the Saint-Venant 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. |

3

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

[Reason for change: Match AASHTO definitions. Deviations form AASHTO: The second paragraph is added.]

Refer to AASHTO LRFD 5.2 Definitions and to 5.10.9 Post-Tensioned Anchorage Zone.
Zone, general — The region adjacent to the anchorage device within which the concentrated prestressing force spreads out over to an essentially linear stress distribution over the cross section of the structural member structure (Saint Venant Region). It includes the local anchorage zone.

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.

[Reason for change: Match AASHTO definitions. Deviations from AASHTO: Post-tensioned anchorage changed to anchorage device; cross-section of the component changed to cross-section of the member. The second paragraph moved to commentary for consistency; the local zone does not include dimensional definition but it referred elsewhere in the commentary.]
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 prismatic region in which the concentrated prestressing force is introduced into the concrete, surrounding the bearing plate including confinement reinforcement and the minimum concrete cover. The length of the local anchorage zone extends over the confinement reinforcement. The volume of concrete that surrounds and is immediately ahead of the anchorage device.

[Reason for change: Match AASHTO definitions. Deviations from AASHTO: The last part of the definition, “and that is subjected to high compressive stresses” is deleted; it is not completely accurate as the local zone is also subjected to high splitting (tensile) forces.]

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.

**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. (See also confinement reinforcement.) For more detailed and in-depth discussion of the Local Zone and its geometry, readers are directed refer to PTI Anchor Zone Design (x)

2.2 – Abbreviations

ASQ – American Society of Quality
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:

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” and Krauser, “Selecting Post-Tensioning Tendon Protection Levels”, fib Symposium Prague 2011.

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 Exhibit Appendix 2 for typical anchorage protection details of the different PLs.

[This ballot item is to confirm reference to Appendix 2; Review and vote on pourback details in Appendix 2 – Separate Ballot Item]
### 3.1 — Protection Level 1A (PL1A)

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;
  - 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.

### C3.1 Protection Level 1A (PL-1A)

PL-1A provides basic protection against corrosion—PTI M55.1-12(13), “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.

### 3.2 — Protection Level 1B (PL-1B)

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

### C3.2 Protection Level 1B (PL-1B)

PL-1B provides somewhat better protection against corrosion than
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;
  - 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.

<table>
<thead>
<tr>
<th>3.3 — Protection Level 2 (PL-2)</th>
<th>C3.3 Protection Level 2 (PL-2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PL-1B plus an envelope, enclosing the tensile element bundle over its full length, and providing a permanent leak-tight barrier.</td>
<td>PL-2 provides better protection against corrosion than the basic protection provided by PL-1B.</td>
</tr>
<tr>
<td>Performance requirements:</td>
<td>In order to achieve a watertight and impermeable to moisture envelope over the prestressing element, only plastic duct or plastic</td>
</tr>
<tr>
<td>- PTS shall meet the system pressure tests contained in Section 4.4.5;</td>
<td></td>
</tr>
<tr>
<td>- Bare strand or bar per Sections 4.2.1 and 4.2.2, respectively;</td>
<td></td>
</tr>
</tbody>
</table>

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

PTI M55.1-12(13), “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.
- 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;
- 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.

<table>
<thead>
<tr>
<th>C3.4 Protection Level 3 (PL-3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PL-3 provides the same protection against corrosion as the protection provided by PL-2 along</td>
</tr>
</tbody>
</table>
• 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:
  o Plastic duct per Section 4.3.5.2;
  o Plastic pipe per Section 4.3.5.3;
  o 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:
  o Engineered grout Class C or D per PTI’s “Specification for Grouting of Post-Tensioned Structures”; and
  o Thixotropic in nature.
• Grout filling procedure to leave no voids in duct.

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.

In order 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.


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 on-line monitoring. By providing electrical connections at both tendon ends, measurement techniques can be used to identify the location of the breech/corrosion.

Additional information on EIT and monitoring can be found in references 13, 14, 15, and 16.

Stray electrical currents are a risk to the durability of post-tensioning tendons. PL3 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.

4.2 — Material standards

Supply materials meeting the following standards:

4.2.1 — Strand

ASTM A 416 Strand
Unless otherwise noted on the contract documents, use uncoated strand meeting the requirements of ASTM A416, Grade 270, low-relaxation, seven-wire 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

ASTM A 416 requires that strand must be well protected in shipping against material injury, which includes damage from corrosion, stress corrosion, or hydrogen embrittlement through contact with deleterious chemicals. ASTM A 416 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. CALWRAP provides long term corrosion protection for
stranded if stored off the ground and in a dry place. For most bridge projects, equivalent packaging is specified. For building projects, standard packaging provided by the strand manufacturers is normally adequate.

### 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.

For grouted tendons, do not use galvanized bars.

**C 4.2.2 Bars**

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

Galvanized bars are not permitted for use because during curing the zinc layer may react with the alkaline grout and may generate hydrogen. Hydrogen can reduce the ductility of steel bars.

**Bars Grouted Inside Plastic Duct**

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 steels with tensile strengths exceeding 150ksi 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.

4-13-2017, WM:
Motion: Martin (persuasive)
Second: Krauser
### 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 resistance, and corrosion protection.

**Votes:** 13-0-0 (Y-N-A)

* N – Salvadori (AM-comment)

Steels with tensile strengths exceeding 150ksi 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.

C 4.2.3 – 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 A 421. This section also applies to nonmetallic
tigue, relaxation, bond, susceptibility to mechanical damage, effect of hot and cold temperatures, and chemical attack. 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.

### 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 AASHTO 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 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. 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 bolts 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. diameter straight bit to facilitate borescope inspection directly behind the bearing-wedge plate.

Permanent grout caps shall be nonmetallic, stainless steel, or galvanized ferrous metal with a minimum thickness of zinc of 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 ultraviolet [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 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

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.

Marking the bar with tape or paint to verify full engagement.
permit the necessary movements. Tendon enclosure shall be designed so that complete grouting of all of the coupler components is achievable.

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

may assist in visually checking that couplers are fully engaged.

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. 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. larger than the outside diameter of the bar and/or coupler.

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 4.3.5.1 through 4.3.5.3.

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. diameter, 24 gauge for ducts greater than 2.625 in. diameter.

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
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 range of PE344434D to PE445574D.

Corrugated plastic duct for use in cold weather construction (–22 to 32°F) 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 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 for 3 hours.

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

<table>
<thead>
<tr>
<th>Duct Shape</th>
<th>Size / Ø</th>
<th>Wall Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat</td>
<td>1.0 in. x 4.0 in.</td>
<td>≥ 0.06 in.</td>
</tr>
<tr>
<td>Round</td>
<td>≥ 2.375 in.</td>
<td>≥ 0.08 in.</td>
</tr>
<tr>
<td>Round</td>
<td>2.375 in. ≤ Ø ≤ 3.35 in.</td>
<td>≥ 0.10 in.</td>
</tr>
<tr>
<td>Round</td>
<td>3.35 in. ≤ Ø ≤ 4.0 in.</td>
<td>≥ 0.12 in.</td>
</tr>
<tr>
<td>Round</td>
<td>4.0 in. ≤ Ø ≤ 4.5 in.</td>
<td>≥ 0.14 in.</td>
</tr>
<tr>
<td>Round</td>
<td>4.5 in. ≤ Ø ≤ 5.75 in.</td>
<td>≥ 0.16 in.</td>
</tr>
</tbody>
</table>

It is important that the duct system supplied to a project will have the same material 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.

[Removed section of commentary is clearly stated in the spec; no need to repeat.]

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

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
<table>
<thead>
<tr>
<th>Minimum wall thickness shall be ( \frac{d}{18} ), where ( d ) is the outside diameter of the duct.</th>
<th>Minimum wall thickness shall be ( \frac{d}{18} ), where ( d ) is the outside diameter of the duct.</th>
</tr>
</thead>
</table>

**OIT according to ASTM D3895 of 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 and manufactured to either of the following specifications: ASTM D3035 or ASTM F714.

**Polyethylene containing antioxidants.**

In the past, smooth polyethylene pipe “PE3408” was supplied as water pressure pipe, which was shorthand 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 and PE4710 is 125 psi. 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 U-V, 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 added verbiage "Minimum wall thickness shall be \( \frac{d}{18} \)" is in conflict with the DR 17.0 in the text above it.

4-13-2017, WM: Motion: Krauser (persuasive)  
Second: M. Schwager  
Votes: 14-0-0 (Y-N-A)
The large thermal expansion of HDPE duct, relative to the approximately $6 \times 10^{-6}$ in/in/$^\circ$F ($11 \times 10^{-6}$ mm/mm/$^\circ$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.
<table>
<thead>
<tr>
<th>4.3.6 — Duct connections and fittings</th>
</tr>
</thead>
<tbody>
<tr>
<td>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 with preinstalled prestressing steel, prior to concreting, fittings and gaskets shall be capable of withstanding 5 ft 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.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C4.3.6 Duct Connections and Fittings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duct connections and fitting are an integral part of the duct system and, as such, must meet certain performance criterion.</td>
</tr>
<tr>
<td>A smooth interior alignment is necessary when installing prestressing steel so that the prestressing steel does not “hang-up” on a lip or kink.</td>
</tr>
<tr>
<td>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. 10 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...</td>
</tr>
</tbody>
</table>
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 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.

Table 4.2

<table>
<thead>
<tr>
<th>C4.3.7 Heat-shrink sleeves</th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
</tr>
<tr>
<td>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.</td>
</tr>
</tbody>
</table>
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 PL2 and PL3 (unless otherwise specified in the Contract Documents). Ensure that the PTS precast segmental duct coupler system (components and connections):

- 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. in any axis; and

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Method</th>
<th>Minimum Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Internal</td>
<td>External</td>
</tr>
<tr>
<td>Minimum Fully Recovered Thickness</td>
<td>92 mils</td>
<td>111 mils</td>
</tr>
<tr>
<td>Peel Strength</td>
<td>ASTM D 1000</td>
<td>29 psi</td>
</tr>
<tr>
<td></td>
<td></td>
<td>46 psi</td>
</tr>
<tr>
<td>Softening Point</td>
<td>ASTM E 28</td>
<td>162°F</td>
</tr>
<tr>
<td></td>
<td></td>
<td>226°F</td>
</tr>
<tr>
<td>Lap Shear</td>
<td>DIN 30 672M</td>
<td>87 psi</td>
</tr>
<tr>
<td></td>
<td></td>
<td>58 psi</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>ASTM D 638</td>
<td>2,900 psi</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3,480 psi</td>
</tr>
<tr>
<td>Hardness</td>
<td>ASTM D 2240</td>
<td>46 Shore D</td>
</tr>
<tr>
<td></td>
<td></td>
<td>52 Shore D</td>
</tr>
<tr>
<td>Water Absorption</td>
<td>ASTM D 570</td>
<td>Less than 0.05%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Less than 0.05%</td>
</tr>
<tr>
<td>Color</td>
<td>Yellow</td>
<td>Black</td>
</tr>
<tr>
<td>Minimum Recovery</td>
<td>Heat Recovery Test</td>
<td>33%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23%</td>
</tr>
</tbody>
</table>

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 water borne contaminants by enclosing the prestressing steel in a continuous water tight enclosure. Section 4.4.5.2 provides performance test requirements.
- 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.

**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.

<table>
<thead>
<tr>
<th>4.3.9 — External smooth HDPE duct connections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use heat-welding techniques to make splices between sections of HDPE duct in accordance with the duct manufacturer’s instructions or make connections with electro-fusion couplers or other mechanical couplers meeting the material requirements of this specification. Ensure all connections</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C4.3.9 — External smooth HDPE duct connections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Couplers should be positioned to have equal engagement or overlap.</td>
</tr>
</tbody>
</table>
have a minimum pressure rating (working pressure) of 100 psi and produce a smooth interior alignment and a connection with no lips or kinks.

Ensure all connections between steel pipe and HDPE duct are made with an ethylene propylene diene monomer (EPDM) coupler with a minimum wall thickness of 3/8 in. or other mechanical coupler, having a minimum working pressure rating of 100 psi. Use a 3/8 in. wide power seated band clamp with EPDM couplers made of 316 stainless steel to seal each end of the coupler against grout leakage.

<table>
<thead>
<tr>
<th>4.3.10 — Rigid ducts and steel pipes</th>
</tr>
</thead>
<tbody>
<tr>
<td>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; or corrugated plastic duct meeting the requirements of this specification for the required bend radii. Pre-bent pipes shall be labeled for orientation. Duct in deviator and diaphragm shall not be allowed.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C4.3.10 Rigid ducts and steel pipes</th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4.3.11 — Connection tolerance between pipe and duct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connect steel pipe and plastic duct directly to each other when the inside diameters do not vary more than ± 1/16 in. Use a reducer when the diameters of the steel pipe and the plastic duct are outside of this tolerance. Reducer shall be made of materials meeting the same requirements as</td>
</tr>
</tbody>
</table>
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. Use inlets and outlets with a minimum inside diameter of 3/4 in. for strand and 3/8 in. 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, all components and system testing shall be witnessed and certified by an independent approval body or testing laboratory. The testing laboratories shall be AMRL or A2LA certified. This testing shall be completed prior to submission of PT Installation Drawings and other related documents to the Engineer for approval.

#### 4.4.1 — Post-tensioning anchorages

1. Test and provide test reports that anchorages develop at least 95% of the $f_{pu}$ of the prestressing steel, when tested in an unbonded state, without yielding or visual distortion. Use anchorage system components cast in a test block.

2. Test and provide written certification that anchorages meet the testing requirements in the [editorial changes]

### C 4.4 System approval testing

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

#### C4.4.1 Post-tensioning anchorages

**C4.4.1.1 Special Anchorage Device**

Most suppliers have developed special anchorage devices. They have special shapes, frequently have multiple bearing surfaces, with current discussion between M50 and AASHTO on 96% AUTS and 95% MUTS, we may want to re-visit this section 1 so that we have truly nationwide
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 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 wedge plate test per PTI’s “Acceptance Standards for Post-Tensioning Systems,” Section 4.1.1

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.

C 4.4.1.2 Basic Bearing Plates Design Criteria

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

C 4.4.1.3 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 3 static tests to failure.

C 4.4.1.4 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.

**C.4.4.1.4.1 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.

**C.4.4.1.5 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.

| 11 | 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 anchorage where the duct connects. For PL-2 and PL-3, condition the assembly in concrete at 150 psi for 3 hours before conducting the pressure test. The assembly shall sustain a 150 psi internal pressure for 5 minutes with no more than 15 psi reduction in pressure. The PL-1A system safety proof test is to withstand 75 psi. |

| 12 | 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 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 of concrete fluid pressure. Duct and duct connections shall not permanently dent. 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. 10 ft concrete fluid pressure is considered the maximum height of concrete placement. |
more than 1/8 in. under 150 lb 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.”

[Section 2.7.4 – Testing of ducts has been voted to be remove from M-55; plastic duct is extensively covered in M-50 but there is no section on testing of corrugated metal duct. Section 5.1(6) of the Acceptance Standards is not covered unless it is added here.]

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 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 of concrete fluid pressure.

If the duct or duct connectors dent more than 1/8 in., 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.
4.4.4 — Corrugated plastic duct


The requirements of fib Bulletin 75 are modified as follows:

“Lateral Load Resistance of Duct” (fib 4.16.4)—Conduct this test without the use of a duct-stiffener plate, using a load of 150 lb for all sizes.

“Wear Resistance of Duct” (fib 4.1.76.8)—Acceptance criteria for remaining duct thickness after testing shall not be less than 0.06 in. for duct up to and including 3.35 in. in diameter and not less than 0.08 in. for duct greater than 3.35 in. in diameter.

“Bond Behavior of Tendons” (fib 4.1.8)—Acceptance criteria shall achieve 40% $f_p$ in a maximum length of 16 duct diameters for round duct and 30 in. for flat duct. [Not necessary as fib now follows this concept.]

“Modified Wear Resistance of Duct Under Sustained Load” (fib 4.1.76.9)—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

C4.4.4 Corrugated Plastic Duct

Corrugated plastic duct shall be performance tested. fib Bulletin 75 identifies eight ten performance aspects of plastic duct and describes test procedures and acceptance criteria 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 75.

It is felt that loading the specimen to failure may be dangerous thus the 40% $f_p$ requirement—This can be interpolated to establish 100% bond because bond behavior is linear in nature. [Not necessary as fib now follows this concept.]

4-13-2017, WM: Motion: Sward (persuasive) Second: Martin Votes: 9-5-1 (Y-N-A) Motion fails 40% rule
sample along the strand to simulate wear. Clamp 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 0.0603 in. for duct up to and including 3.35 in. in diameter and not less than 0.0804 in. for duct greater than 3.35 in. in diameter.

“Wear Resistance of Duct” and “Modified Wear Resistance of Duct Under Sustained Load” 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 Bulletin 75. Recommendation, “Polymer-duct systems for Internal Bonded Post-Tensioning,” Chapter 6, Sections 6.1 through 6.9, as modified herein, shall be repeated whenever material properties change or geometry of the duct changes. The “Bond Behavior of TendonsDucts” (fib 4.1.86.10) 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 by...
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.

<table>
<thead>
<tr>
<th>4.4.5 — System pressure tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4.4.5.1 — Corrugated plastic duct connections</th>
</tr>
</thead>
<tbody>
<tr>
<td>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).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Procedure:</th>
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<tbody>
<tr>
<td>• Specimen shall be bent with a template to the minimum radius of tendon curvature;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>System pressure tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>System pressure tests are qualification tests and are not intended to be performed in the field during construction.</td>
</tr>
</tbody>
</table>

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
Specimen shall be pressure-tested underwater with an applied pressure of 7.25 psi 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.) 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

“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.
Acceptance criteria: The maximum force required to compress the sealing gasket to its final compressed position shall not be greater than 25 psi 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 pressure on the test block cross section during this test;
  - Do not apply epoxy between the test blocks during this test;
  - Pressurize the assembly within the test blocks to 50 psi and lock off the outside air source;
  - Acceptance criteria: The assembly shall sustain a 50 psi internal pressure for a minimum of 5 minutes with no more than a 5 psi reduction in pressure; and
  - Separate the test blocks.

- Assembly toughness test:
  - Place a 1/16 in. layer of epoxy on the face of both test blocks and, using an external apparatus, clamp the test blocks together and maintain 40 psi 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.

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.

The performance test for toughness confirms that the precast segmental duct coupler system remains intact and that the components are not damaged during construction.
without crushing, tearing, or other signs of failure.

Testing shall be confirmed through a report prepared by an independent testing agency. The testing laboratories shall be AMRL or A2LA certified. 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.” For bar systems, modify the system test length to 15 ft.

#### 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.

### 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. Test the assembly at 150 psi.
- The duct and pipe assembly consisting of all external duct connections (welded duct

#### C4.4.5.4 Duct for External Tendons

The external duct systems performance test confirms that the duct and connections can handle grouting pressures without damage to the system.
splices, duct-to-pipe, and so on) and a grout vent shall comply with the following test. Condition the assembly at 150 psi for 30 minutes before conducting the pressure test. The assembly shall sustain a 150 psi 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.

<table>
<thead>
<tr>
<th>See #2</th>
<th>4.5 — New systems and materials</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The materials, components, and systems described herein reflect current 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. 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.</td>
</tr>
</tbody>
</table>

C 4.5 New systems and 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.
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;

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
<p>| | | |</p>
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</table>
|  | • 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;  
• 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). | placing drawings to check clearances to other elements. |
|  |  |  |
|  | **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:

<table>
<thead>
<tr>
<th>5.3.1 — Plans and elevations</th>
<th>C 5.3.1 Plans and elevations</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Show positions and angles of anchorages. The anchorage work points are normally the centers of the bearing plate faces;</td>
<td>For the ease of placement it is generally preferred to express angles in terms of slope (1 in 12) vs. degrees or radians</td>
</tr>
<tr>
<td>• Show and dimension all duct high, low, and inflection points;</td>
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<tr>
<td>• Dimension the start and end points of all curve segments;</td>
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<tr>
<td>• Intermediate curve profiling points shall be given in every plane in which the tendon curves and at intervals in proportion to the curve length;</td>
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<tr>
<td>• For accurate friction calculations, indicate the type of curves used (parabolic, circular, and so on);</td>
<td></td>
</tr>
<tr>
<td>• For compound curves, the vertical and horizontal curves shall start and end at the same locations whenever practical;</td>
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<tr>
<td>• Show all inlets, outlets, and inspection ports; and</td>
<td></td>
</tr>
<tr>
<td>• All tendons shall be identified with their unique numbers or tags.</td>
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<thead>
<tr>
<th>5.3.2 — Sections</th>
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<tbody>
<tr>
<td>• Show member cross sections with fully dimensioned duct positions at critical locations, such as tendon high points and low points;</td>
<td></td>
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<tr>
<td>• Show anchorage layouts at the ends of members and at intermediate locations;</td>
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<tr>
<td>• All tendons shall be identified with their unique numbers or tags; and</td>
<td></td>
</tr>
</tbody>
</table>
- 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;
- 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.

C 5.3.3 *Measurements*

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

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.

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.
| 14 | 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. | | |
| | C.5.3.7 Temporary openings for PT work  
For typical details refer to Appendix 2.  
[This ballot item is to confirm reference to Appendix 2; Review and vote on pourback details in Appendix 2 — Separate Ballot Item] | | |
| | 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. | | |
| | C 5.3.8 Installation requirements  
Post-tensioning operations should be performed only under the direct supervision of experienced personnel. Refer to Section 7. | | |
| | 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 | | |
<table>
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<tr>
<th></th>
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<th>steel properties (area and modulus of elasticity);</th>
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<tr>
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<td>• Use a modulus of 28,500 ksi for strand and 29,700 ksi for Type II deformed bars. Elongations may be field-adjusted for actual A and E values;</td>
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<tr>
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<td></td>
<td>• 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);</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Calculate short-term losses due to friction, wobble, and wedge seating. Friction and wobble coefficients shall be in accordance with the applicable design code; and</td>
</tr>
<tr>
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<td>• Elongations shall be given to the nearest 1/16 in. Provide elongation before and after seating.</td>
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</tbody>
</table>

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.

### 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.

Quality Control 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.

Quality Assurance 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.

<table>
<thead>
<tr>
<th>6.2 — Procurement</th>
<th>C6.2 Procurement</th>
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<tbody>
<tr>
<td>The QA program shall address procurement of all materials, components, and equipment that will become part of the PTS.</td>
<td>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 sub-components and the system.</td>
</tr>
<tr>
<td>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).</td>
<td>Compliance of the materials will typically be documented by a Certificate of Compliance with supporting test data as identified in the project requirements.</td>
</tr>
<tr>
<td>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.</td>
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</tbody>
</table>
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;
- 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.

<table>
<thead>
<tr>
<th>6.3 — Project quality plan</th>
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<tbody>
<tr>
<td>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.</td>
</tr>
</tbody>
</table>

**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
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.

compliant with the specific requirements of the Project Quality Plan and that all test data and Certificates of Compliance have been provided.

The Contactor’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.

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 by qualified personnel in conformance with procedures established by the PTS
supplier. For materials delivered from the secondary suppliers directly to the job site, 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 (refer to Section 12.5); 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:
    - (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.

---

**C6.4.1 Wedges**

Wedges are critical structural element of PT anchorages system using wedge action to anchor post-tensioning forces.

In the US, generally there are two sizes of strands utilized in the industry, either 0.5” or 0.6” 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.
### 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;
- All material testing of steel products conforms to ASTM A370; and
- Anchorages have unique identification for each lot.

<table>
<thead>
<tr>
<th>6.5 — Identification and traceability of materials</th>
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<tbody>
<tr>
<td>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.</td>
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<tr>
<td>Traceability shall be maintained for at least the following PTS components:</td>
</tr>
<tr>
<td>- Prestressing steel;</td>
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<tr>
<td>- Bearing plates;</td>
</tr>
<tr>
<td>- Wedge plates;</td>
</tr>
<tr>
<td>- Trumpets;</td>
</tr>
<tr>
<td>- Wedges;</td>
</tr>
<tr>
<td>- Duct; and</td>
</tr>
<tr>
<td>- Grout materials.</td>
</tr>
<tr>
<td>Positive identification and traceability marking on material shall be as follows:</td>
</tr>
<tr>
<td>- Prestressing steel—Each coil shall have an identifiable, weatherproof manufacturer’s tag or equivalent identifying heat</td>
</tr>
</tbody>
</table>

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 Contactor.

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
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
- 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 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 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

It is important that the Contractor’s Quality Plan include provi-
brought to the attention of the Contractor and PTS supplier. Representative samples shall be tested and investigated through the process identified in the project 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.

<table>
<thead>
<tr>
<th>7.0 — PERSONNEL QUALIFICATIONS</th>
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<tbody>
<tr>
<td>7.1 — Supervision</td>
</tr>
<tr>
<td>Post-Tensioning Operations:</td>
</tr>
<tr>
<td>• The Direct Supervisor of Post-Tensioning Operations shall be certified as PTI Level 2 Bonded PT Field Specialist;</td>
</tr>
<tr>
<td>• The Foreman of each installation and stressing crew shall be certified as PTI Level 2 Bonded PT Field Specialist; and</td>
</tr>
<tr>
<td>• The Foreman of each grouting crew shall be certified as PTI Level 2 Bonded PT Field Specialist and ASBI Certified Grouting Technician.</td>
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</tbody>
</table>

At least 25% of each crew shall be certified in PTI Level 1 Bonded PT – Field Installation.

<table>
<thead>
<tr>
<th>C 7.1 Supervision</th>
</tr>
</thead>
<tbody>
<tr>
<td>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 below:</td>
</tr>
<tr>
<td>PTI</td>
</tr>
<tr>
<td>38800 Country Club Drive</td>
</tr>
<tr>
<td>Farmington Hills, MI 48331</td>
</tr>
<tr>
<td>Phone: 248-848-3180</td>
</tr>
<tr>
<td>Website: <a href="http://www.post-tensioning.org">www.post-tensioning.org</a></td>
</tr>
<tr>
<td>ASBI</td>
</tr>
<tr>
<td>142 Cimarron Park Loop, Suite F</td>
</tr>
<tr>
<td>Buda, TX 78610</td>
</tr>
</tbody>
</table>
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.

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

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.
<table>
<thead>
<tr>
<th>8.4 — Metal duct</th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>8.5 — Plastic duct</th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>8.6 — Strand</th>
</tr>
</thead>
<tbody>
<tr>
<td>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 ASTM A 416.</td>
</tr>
</tbody>
</table>

C 8.6 Strand

*ASTM A 416 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 pro-
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 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.

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 standard packaging provided by the strand manufacturers is normally adequate.

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

C8.8 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—in indoors and outdoors—shall not exceed 6 months from the date of manufacture.

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.

<table>
<thead>
<tr>
<th>8.9 — Accessories</th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C8.9 Accessories</th>
</tr>
</thead>
<tbody>
<tr>
<td>As these products are generally smaller and come in cardboard boxes, it would be best kept secured on skids and under tarpas.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>9.0 — BEARING PLATE AND DUCT INSTALLATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.1 — General</td>
</tr>
<tr>
<td>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.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>9.2 — Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layout dimensions are given on the approved installation drawings and generally reference the formwork. Use accessory equipment if necessary to position the PTS components within placing tolerances of this specification.</td>
</tr>
</tbody>
</table>
### 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.

### 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.

### 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
<table>
<thead>
<tr>
<th>9.5 — Deviation pipes</th>
<th>C9.5 Deviation pipes</th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
<td>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.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>9.6 — Ducts</th>
<th>C 9.6 Ducts</th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
<td>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.</td>
</tr>
</tbody>
</table>

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. for steel pipes, 48 in. for round galvanized metal duct, 24 in. for round plastic duct, 24 in. for flat ducts with strand pre-installed, and 12 in. for flat ducts without strand pre-installed 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.  
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 | Flat ducts are particularly susceptible to collapse under concrete fluid pressure and contact with reinforcing. Pre-installation 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. |
liquids. After that, the duct and anchorage assem-
blies 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 per-
mitted for PL-1 (PE tape or equal). The use of ap-
proved 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 ap-
proved installation drawings for the tendon PL.

For proper sealing with taped joints, tape ap-
plied to metal duct shall follow the pitch of the duct 
seam first before wrapping at 90 degrees. Mini-
mum placement coverage is two-and-a-half full 
wraps placed over the center of the splice or joint 
but not less than 3 in. on each side of the joint be-
ing sealed.

Heat-shrink sleeves shall extend the distance 
shown on the approved installation drawings, but 
not less than 3 in. 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 de-
vices. Extend grout tubes a sufficient distance out

| 15 | C9.8 Splices and joints | C9.9 Location of grout in-
|     | Coupler locations should be staggered to limit the reduction of clearance between adjacent ducts. | lets and outlets |
|     | 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 re-
|     | striction. | striction. |
|     | 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. | Routing of grout tubes outside of the structure may be complicated by the location or construction |
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:

- 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.: D;
- Where outlets are required at the high points, at a distance not to exceed 3 ft 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.

[The added requirement of being free draining is in M-55 and in process of being removed and referred to M-50. This requirement would get lost if it is not added here.]

<table>
<thead>
<tr>
<th>10.0 — PLACING CONCRETE</th>
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<tbody>
<tr>
<td>10.1 — Precautions</td>
</tr>
</tbody>
</table>

Use methods of placing and consolidating concrete, which shall not displace or damage the post-tensioning ducts, anchorage assemblies,
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 ¼ in. 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 ¼ in. clearance requirement. The torpedo shall pass through the duct easily when pulled by 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

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

### 11.2 Strand Installation Equipment

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...
ing 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.

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. 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. to the final prestressing steel (that is, to wedge plate surface).

<table>
<thead>
<tr>
<th>11.3 — Bar</th>
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| 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 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. Responsibility conflicts can be avoided if each trade checks duct clearances after its work is completed and performs the necessary repair work.

<table>
<thead>
<tr>
<th>11.3 Bar</th>
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<tbody>
<tr>
<td>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.</td>
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</tbody>
</table>
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.

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

11.5 Acceptance criteria

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.

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.

C 12.1.1 Installation Equipment

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.

C 12.2 Stressing Equipment

Requirement 7.1 (1) and (2)

Requirement 7.1 (1) assures that jacks can safely and routinely produce the operating pressures necessary to produce temporary jacking forces of 80% tendon MUTS. A jack, which cannot safely withstand the 95% MUTS system
test, has inadequate safety margins for normal tendon stressing operations.

Requirement 7.1 (3)

This requirement permits an easy and reliable field check. Serious stressing problems can be prevented if operating personnel routinely compares the calibration charts with onsite calculation:

\[
\text{Pressure} = \frac{\text{Jacking Force}}{\text{Jack Area}}.
\]

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

Requirements 7.1 (4),(5), and (6)

Proper strand anchoring requires that wedges segments seat equally.

Requirement 7.1 (10)

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

Requirements 7.1 (11) and (12)
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. (See also Requirement 7.1 (3).)

<table>
<thead>
<tr>
<th>12.3 — Stressing sequence</th>
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<tbody>
<tr>
<td><strong>C 12.3 Stressing sequence</strong></td>
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<tr>
<td>Post-tensioning tendons shall be stressed in the sequences indicated on the Contract Documents.</td>
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<tr>
<th>12.4 — Stressing jacks and gauges</th>
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<tbody>
<tr>
<td><strong>C 12.4 Stressing jacks and gauges</strong></td>
</tr>
<tr>
<td>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. 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.</td>
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<tr>
<th>12.5 — Calibration of jacks and gauges</th>
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<tbody>
<tr>
<td><strong>C 12.5 Calibration of jacks and gauges</strong></td>
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<tr>
<td>Calibrate each jack and two gauges as a unit. Separate calibrations shall be performed with the jack in the ¼, ½, and ¾, stroke positions. At each</td>
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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 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) dead-weight 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.

<table>
<thead>
<tr>
<th>12.6 — Elongations and agreement with forces</th>
<th>C 12.6 Elongation and agreement with forces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ensure that during tendon stressing the forces being applied to the tendon and the elongation of the tendon can be measured at all times.</td>
<td></td>
</tr>
<tr>
<td>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. 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.</td>
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</tr>
<tr>
<td>For tendons shorter than 40 ft, elongations shall fall within (7% + ¼ in.) of the theoretical elongations shown on the approved installation drawings.</td>
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<tr>
<td>Where strands in a tendon are stressed individually, the average strand elongation shall be computed and compared to the theoretical elongation.</td>
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</tr>
<tr>
<td>An occasional wire break is not uncommon. When experiencing repeated wire breaks, the root cause should be identified and resolved before proceeding.</td>
<td></td>
</tr>
<tr>
<td>Reference “Rational application of elongation tolerances” by C. Freyermuth</td>
<td></td>
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</tbody>
</table>
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.

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 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 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 temporarily 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. 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.

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.
13.0 — GROUTING OPERATIONS

Grouting shall be performed in accordance with PTI’s “Specification for Grouting of Post-Tensioned Structures.”

C 13.0 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 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 and lock off the outside air source and inspect for leaks. Locate and repair leaks and retest. Refer to PTI’s “Specification for Grouting of Post-Tensioned Structures.”

C 13.1 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 criteria. However rough criteria of approximately 1 minute and less than 50% loss has been used for PL2 tendons. Judgement
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):

- **PL1**: Use portland cement reinforced concrete, approved non-shrink grout, or epoxy grout
- **PL2 and PL3**: Use an approved epoxy grout or reinforced concrete

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

Application of elastomeric coating over the epoxy/concrete-protecting anchorages shall be permitted to be delayed up to 45 days after grouting, unless otherwise specified.

C14.1 General

Since 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.

See APPENDIX 2 for typical details.
C14.2 Pourbacks

Traditionally, nonreinforced concrete or non-shrink grout were used as pourbacks material. These materials could exhibit pourback and perimeter cracking and other cracks in the pourbacks, which compromised the corrosion protection of the anchorages. Therefore, epoxy grout is required for PL-2 and 3, except for large pourbacks where reinforced concrete should be used. Large pourbacks will require the use of reinforced concrete.

Proper surface preparation is required to provide bond of the pourback to the structure. See APPENDIX 2 for typical details.

[This ballot item is to confirm changes here and reference to Appendix 2; Review and vote on pourback details in Appendix 2 - Separate Ballot Item]

N-G. Hunsicker
Commentary indicates PL2 and PL3 require epoxy grout which conflicts with the previous section which allows epoxy grout or reinforced concrete. The following sentence of the commentary says large pourbacks require the use of reinforced concrete.

Revise wording of commentary.

N – Krauser
Commentary notes that epoxy grout is required for PL2 and PL3; however, 14.1 also allows reinforced concrete. If 14.1 is approved this commentary should be re-written.

Suggest: “Therefore, epoxy grout or reinforced concrete is required for PL2 and PL3. Most likely, large pourbacks will require the use of reinforced concrete because XXXXX.”

4-13-2017, WM: Motion: Hunsicker (revise commentary as shown)
14.3 — *Elastomeric Anchor*age 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., applied in accordance with the manufacturer’s recommendations. Extend the coating 12” 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, applied in accordance with the manufacturer’s recommendations. Extend the coating 6” minimum past the perimeter of the pourback.

First 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 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 C14.3 *Elastomeric Anchor*age coating system

_Elastomeric Anchor*age coating systems are considered as an additional layer of protection. This water proofing membrane is typically applied over permanent grout cap or pourback.

See APPENDIX 2 for typical details.

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

[This ballot item is to confirm changes here and reference to Appendix 2; Review and vote on pourback details in Appendix 2 – Separate Ballot Item]
15.0 — REPAIRS OF HOLES AND ACCESS OPENINGS

<table>
<thead>
<tr>
<th>19</th>
<th>15.1 — Openings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repair all holes and access openings with an approved concrete 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.</td>
<td></td>
</tr>
</tbody>
</table>

Before performing the repair casting the concrete, mechanically clean and roughen the mating 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 concrete-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 High-Molecular-Weight Methacrylate (HMWM). Prepare the surface to be coated and apply the HMWM in accordance with the manufacturer’s specifications.

C15.1 Openings

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

See APPENDIX 2 for typical coating-repair details for holes, blockouts, and openings.

[This ballot item is to confirm changes here and reference to Appendix 2; Review and vote on pourback details in Appendix 2 – Separate Ballot Item]
16.0 — REFERENCES


C 16.0 - REFERENCES


2. “Anchorage Zone Reinforcement for Post-Tensioned Concrete Girders,” NCHRP Report 356, National Academy Press, Washington, DC, 1994; NCHRP Project 10-29; J.E. Breen, O. Burdet, C. Roberts, D. Sanders, G. Wollmann, Ferguson Structural Engineering Laboratory; The University of Texas at Austin

3. “Laboratory Bond Strength Testing of 0.6” 7-Wire Strand from 7 different Manufacturers,” for Post-Tensioning Institute by A. J. Hyett, S. Dube & W. F. Bawden, Department of Mining Engineering, Queen’s University, Kingston, Ontario


[All references must be reviewed by staff / E TG; some will be referenced standards in the mandatory part and some others nonmandatory references referred to in the commentary.]

[Check all reference numbers in commentary – need to be renumbered once references settle.]

4/24/16-TG-Editorial was established to review references.


## APPENDIX 1 – TABLES

## APPENDIX 2 – TYPICAL **POURBACK DETAILS**

Protection Levels PL-1A and PL-1B

[Review and vote on pourback details in Appendix 2; PL-1A and PL-1B]

N - G. Hunsicker
Details do not appear to match text above (Interior of box girder – PL1A does not require permanent grout cap) (Pourback can be any of three materials, not just non-shrink grout)

4-13-2017, WM:
Motion: Hunsicker (add “optional” to interior of box girder detail for permanent grout cap)
Second: Martin
Votes: 14-0-0 (Y-N-A)

Y-E – Krauser
<table>
<thead>
<tr>
<th>21</th>
<th>APPENDIX 2 – TYPICAL <strong>POURBACK</strong> DETAILS</th>
<th>[Review and vote on pourback details in Appendix 2; PL-2 and PL-3]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Protection Levels PL-2 and PL-3</td>
<td></td>
</tr>
</tbody>
</table>

**Editorial** – In “Blockout between Segments”, change “duct” to “Metal or Polymer Corrugated Duct”. This is to be consistent with the other sketches.

Y-E – Lampe
Remove “pocket former” callout from segmental detail.

N - G. Hunsicker (withdrawn)
Pourback material consistent with text above (i.e. is reinforced concrete allowed?)

Y-E – Lampe
Remove “pocket former” callout from segmental detail.
## APPENDIX 1 – TABLES

### Table 4.1—Minimum wall thickness of corrugated plastic duct

<table>
<thead>
<tr>
<th>Duct shape</th>
<th>Size/Ø, in.</th>
<th>Wall thickness, in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat</td>
<td>£1.0 × 4.0</td>
<td>≥0.08</td>
</tr>
<tr>
<td>Round</td>
<td>£2.375</td>
<td>≥0.08</td>
</tr>
<tr>
<td>Round</td>
<td>2.375 &lt; Ø ≤ 3.35</td>
<td>≥0.10</td>
</tr>
<tr>
<td>Round</td>
<td>3.35 &lt; Ø ≤ 4.0</td>
<td>≥0.12</td>
</tr>
<tr>
<td>Round</td>
<td>4.0 &lt; Ø ≤ 4.5</td>
<td>≥0.14</td>
</tr>
<tr>
<td>Round</td>
<td>4.5 &lt; Ø ≤ 5.75</td>
<td>≥0.16</td>
</tr>
</tbody>
</table>

### Table 4.2—Requirements for heat-shrink sleeves

<table>
<thead>
<tr>
<th>Property</th>
<th>Test method</th>
<th>Minimum requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum fully recovered thickness</td>
<td>—</td>
<td>92 mils</td>
</tr>
<tr>
<td>Peel strength</td>
<td>ASTM D1000</td>
<td>29 pli</td>
</tr>
<tr>
<td>Softening point</td>
<td>ASTM E28</td>
<td>162°F</td>
</tr>
<tr>
<td>Lap shear</td>
<td>DIN 30 672M</td>
<td>87 psi</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>ASTM D638</td>
<td>2900 psi</td>
</tr>
<tr>
<td>Hardness</td>
<td>ASTM D2240</td>
<td>46 Shore D</td>
</tr>
<tr>
<td>Water absorption</td>
<td>ASTM D570</td>
<td>Less than 0.05%</td>
</tr>
<tr>
<td>Color</td>
<td>—</td>
<td>Yellow</td>
</tr>
<tr>
<td>Minimum recovery</td>
<td>Heat recovery test</td>
<td>33%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Black</td>
</tr>
</tbody>
</table>

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

<p>| Type of prestressing steel | Corrugated metal duct, (m/k(\text{ft}^{-1})) | Corrugated plastic duct, (m/k(\text{ft}^{-1})) | Smooth steel pipe, (m/k(\text{ft}^{-1})) | Smooth plastic pipe, (m/k(\text{ft}^{-1})) |</p>
<table>
<thead>
<tr>
<th>Strand</th>
<th>Vertical position, in.</th>
<th>Lateral position, in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal draped tendons over supports or in middle third of span</td>
<td>±1/4</td>
<td>±1/2</td>
</tr>
<tr>
<td>Tendon in middle half of web depth</td>
<td>±1/2</td>
<td>±1/2</td>
</tr>
<tr>
<td>Longitudinal, generally horizontal, tendons usually in top or bottom of member</td>
<td>±1/4</td>
<td>±1/2</td>
</tr>
<tr>
<td>Horizontal tendons in foundations</td>
<td>±1/2</td>
<td>±1/2</td>
</tr>
<tr>
<td>Vertical tendons in walls</td>
<td>±1/2</td>
<td>±1/2</td>
</tr>
<tr>
<td>Vertical tendons in shafts</td>
<td>±1/4</td>
<td>±1/4</td>
</tr>
<tr>
<td>Horizontal tendons in slabs</td>
<td>±1/4</td>
<td>±1/4</td>
</tr>
<tr>
<td>All other cases</td>
<td>±1/4 in any direction</td>
<td>±1/4 in any direction</td>
</tr>
</tbody>
</table>

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.

Table 9.1—Duct position tolerances

<table>
<thead>
<tr>
<th>Strand</th>
<th>Vertical position, in.</th>
<th>Lateral position, in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>External tendons, bare dry strand</td>
<td>—</td>
<td>0.25 to 0.30/0</td>
</tr>
<tr>
<td>Lubricated strand</td>
<td>0.20 to 0.25/0</td>
<td>—</td>
</tr>
<tr>
<td>Strand greased and extruded</td>
<td>0.01 to 0.05/0 to 0.0003</td>
<td>0.01 to 0.05/0 to 0.0003</td>
</tr>
<tr>
<td>Bars, deformed, smooth and round</td>
<td>0.30/0 to 0.0002</td>
<td>0.30/0 to 0.0002</td>
</tr>
</tbody>
</table>

| 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 | 0.25 to 0.30/0 | 0.10 to 0.14/0 |

| 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 | — | — |

Table 11.1—Permissible intervals between prestressing steel installation and grouting

<p>| Time limits for grouting exposure permissible intervals between prestressing steel installation and grouting without use of corrosion protection |</p>
<table>
<thead>
<tr>
<th>Very damp atmosphere or over salt water (humidity &gt;70%)</th>
<th>7 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate atmosphere (humidity 40 to 70%)</td>
<td>20 days</td>
</tr>
<tr>
<td>Very dry atmosphere (humidity &lt;40%)</td>
<td>40 days</td>
</tr>
</tbody>
</table>
Ballot Item 20: Pourback Details, PL-1A and PL-1B:
Grout Vent

Typical Repair Details for Access Openings, Blockouts, and Holes

Access Opening and Blockouts

Hole in Slab

High Molecular Weight Methacrylate

Reinforced Concrete (see contract details for requirements)

Roughen Existing Concrete

High Molecular Weight Methacrylate

Epoxy Mortar or Non-shrink Grout

Over Core to Key in Repair
Ballot Item 21: Pourback Details, PL-2 and PL-3:
Replaceable Grouted External Tendon Specification Language

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Introduction

This appendix provides suggested specification language that can be incorporated into a future version of PTI/ASBI M50.3 "Guide Specification for Grouted Post-Tensioning".

The following document presents changes and additions to M50.3-12 necessary to accommodate replaceable grouted external tendons into that specification. Suggested changes are based on the 2012 version of M50.3 and are made to the relevant passage and numbering. Underlined text means an addition to the current version of M50.3; strike-through means that text needs to be removed from the current version of M50.3.
1.0—INTRODUCTION

1.3—Referenced standards and specifications

   European Organization for Technical Approvals (EOTA)

   European Technical Assessment Guidelines (ETAG) 013, Guideline for European Technical Approval of Post-Tensioning Kits for Prestressing of Structures
2.0—DEFINITIONS AND ABBREVIATIONS

2.1—Definitions

*Diabolo* - A formed void in a deviator or diaphragm with trumpet shaped ends to align and direct an external tendon through the concrete section.

*Guide pipe* – A structural assembly that aligns and directs the tendon at the anchorage location, and provides separation between the anchor body/trumpet and duct to the surrounding concrete section.

*Replaceable tendon* - Post-tensioned tendon designed and detailed to allow speedy removal and replacement without causing structural damage.
4.0—MATERIAL AND PERFORMANCE REQUIREMENTS

4.3—Component standards

4.3.13 – Guide pipes

Guide pipes used for replaceable external post-tensioning anchorages shall align the tendon and allow anchorage replacement.

Plastic guide pipes shall be made of high-density polyethylene or polypropylene. For steel guide pipes, use galvanized ASTM A53, Grade B, Schedule 40 steel pipes or galvanized ASTM A500 structural steel tubing.

Ensure guide pipes:
- Are sufficiently stiff to withstand handling, installation, and concreting;
- Are dimensioned with inside diameter sufficient to allow free movement and replacement of anchorage;
- With a diabolo end are designed with an additional deviation angle of 3 degrees at exit end;
- Shall contact the tangent portion of the tendon duct within 1/8” tolerance where tendon deviation is required; and
- Shall be sealed against leakage of concrete paste at the bearing plate.

4.3.13 – Diabolos

Provide diabolos with a minimum inside diameter at least 1/2 in. larger than the outside diameter of the tendon duct. Diabolos may be constructed using permanent or removable forms.

Permanent forms may be constructed using solid nylon or polyethylene shells. Steel is allowed for temporary/removable forms.

Ensure diabolos:
- Are sufficiently rigid to maintain their shape during handling, installation, and concreting;
- Provide a smooth surface with no kinks; and
- Are designed with an additional deviation angle of 3 degrees.

C4.3.13 – Diabolos

The stressed tendon will deform the duct into an oval shape as it bends through the diabolo. The 1/2 in. gap is to ensure the deformed duct can be removed from the diabolo if replacement is required.

4.4—System approval testing
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 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 of concrete fluid pressure. Duct and duct connections shall not permanently dent more than 1/8 in. under 150 lb 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.

Ducts for replaceable external tendons shall meet the following requirements:


2. EOTA, ETAG 013, “Guideline for European Technical Approval of Post-Tensioning Kits for Prestressing of Structures,” Section 6.1.5-I.
5.0—INSTALLATION DRAWINGS AND STRESSING CALCULATIONS

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, couplets, 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;
- 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 couplets;
• Details for guide pipes and diabolo forms (if required);
• System-specific details for full encapsulation of tendons (if required); and
• System-specific details for electrically isolated tendons (if required).
9.0—BEARING PLATE AND DUCT INSTALLATION

9.4—Anchorage components

Install bearing plates against the formwork and anchorage blockouts as shown on the approved installation drawings. The bearing plate and guide pipe (if required) 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.

9.5—Deviation pipes and diabolo forms

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

Sub task 2 – State-of-the-art report

Appendix B – EIT Specification Language

Final Draft (working)

November 2016
EIT Specification Language

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SPECIFICATIONS

COMMENTARY

Introduction

The 1st edition of PTI/ASBI M50.3-12 "Guide Specification for Grouted Post-Tensioning", issued in 2012, recognizes three protection levels for post-tensioning tendons. Protection Level 3 requires electrical isolation or encapsulation of the tendons and “to be monitorable or inspectable at any time”. However, there are no guidelines on PT material / hardware system requirement, installation and performance measurement, and test procedures for the EIT system. This appendix provides suggested specification language that can be incorporated into a future version of PTI/ASBI M50.3-12 "Guide Specification for Grouted Post-Tensioning".

The following document presents changes and additions to M50.3-12 necessary to incorporate electrically isolated tendons into that specification. Suggested changes are based on the 2012 version of M50.3 and are made to the relevant passage and numbering. Underlined text means an addition to the current version of M50.3; strike-through means that text needs to be removed from the current version of M50.3.
2.0—Definitions and Abbreviations

2.1—Definitions

Half-shell - plastic half-shells are placed between the duct and tendon support bars to protect the duct from being damaged during tendon stressing.

Isolating plate - Plate (typically made from fiber-reinforced plastic) that transfers the load from the anchor head to the cast-iron anchorage body, while ensuring that the anchor head is electrically isolated from the anchorage body.

Longitudinal main conductor - Reinforcing steel bar (or another uncoated metallic component) installed in the reinforced concrete structure in longitudinal direction in order to guarantee continuous electrical conductance of the reinforcing steel cage. Usually, relatively thick reinforcing steel bars are used (e.g. #11 bar (diameter 35.8 mm)).

Transverse main conductor - Reinforcing steel bar (or another uncoated metallic component) installed in the reinforced concrete structure in transverse direction in order to guarantee continuous electrical conductance of the reinforcing steel cage. Usually, relatively thick reinforcing steel bars are used (e.g. #11 bar (diameter 35.8 mm)).

Resistance (R) - ohmic resistance between the prestressing steel and the reinforcing steel in the surrounding concrete. Used to assess the quality of the encapsulation of the tendon. (Ω)

Specific resistance (R_l) - Product of the measured resistance of a tendon (R) and the tendon length (L):

\[ R_l = R \cdot L \ (Ωm) \]

Capacitance (C) - Capacitance of the plastic duct (F).

C2.1—Definitions

Longitudinal main conductors are typically used when there is concern that electrical continuity is not continuous through the reinforcing steel cage such as when epoxy-coated reinforcement is used. Thus, to guarantee the presence of a continuous conductor acting as counter electrode in the AC impedance measurement, it is recommended to install “longitudinal main conductors” in the structure. It is recommended to have at least two of the “longitudinal main conductors” and to connect them to each other at least at both ends with help of “transverse main conductors”.

The ohmic resistance is affected by the presence of duct perforations, i.e. with increasing size and number of duct perforations R decreases.

The length of a tendon strongly affects R. Low values of R may not always indicate the presence of perforations, but may also arise from high tendon lengths.

The capacitance is significantly affected by dielectric properties, diameter, and wall thickness of the duct. C decreases with...
**Specific capacitance (C)** - Capacitance per unit length of tendon. \( C = \frac{C}{L} \text{ (F/m)} \) where \( L \) is the tendon length.

**Loss factor (D)** - Ratio of the real and imaginary component of the impedance \( Z \). The loss factor \( D \) has no unit and it is independent of the length of the tendon. \( D \) depends on the number of defects in the duct, i.e. the magnitude of \( D \) increases with increasing number of defects.

Increasing wall thickness, and for a given wall thickness, \( C \) increases with increasing duct diameter. However, \( C \) is relatively unaffected by the presence of duct perforations.

The capacitance of a given duct type increases proportionally with an increase in duct length.

Assuming a parallel equivalent circuit of \( R \) and \( C \), the loss factor can be written as:

\[
D = \frac{\text{Re}(Z)}{\text{Im}(Z)} = \frac{1}{\omega RC}
\]

where \( \omega \) is the angular frequency of the imposed A.C. measuring signal and \( \text{Re}(Z) \) and \( \text{Im}(Z) \) are the real and imaginary parts of the impedance, respectively.
3.0—Post-Tensioning System (PTS) Tendon Protection Levels (PL)

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 electrical isolation of the entire tendon and meet the system pressure tests contained in Section 4.4.5; the wedge plate and prestressing steel shall be electrically isolated from the bearing plate with a non-conductive insert.
- PTS shall have the ability to be monitorable or inspectable at any time. Junction boxes with electrical terminals and electrical cable connections made directly to the prestressing steel shall be installed meeting the requirements of section 4.3 to ensure continuous monitorability;
- 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:

C3.4—Protection Level 3 (PL-3)

PL-3 provides better protection against corrosion as the protection provided by PL-2. In addition to the protection offered by PL-2, the completely electrically isolated tendon in PL-3 has no macro-cell interaction with reinforcing steel. Thus, even in the case of perforations in the duct and chloride penetration to the prestressing steel, the corrosion rate is lower than in the cases PL-1 and PL-2. Additionally, PL-3 allows to monitor or inspect the tendon for corrosion or deterioration and to verify the duct envelope has not been damaged during construction.

Selection criteria for PL-3 may be the exposure environment (from lowly to highly corrosive), the durability of the design (cover depths, joints, etc.) and selected materials of the construction, the importance of the structure, the ability to monitor the structure over its service life, etc.

In order 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 ducts are not watertight and impermeable to moisture penetration and do not provide electrical isolation.

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

PTI M55.1-12, “Specification for Grouting of Post-Tensioned Structures” provides additional information of grouts and grouting.
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.

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

Complete electrical isolation is achieved by using electrically isolating materials not only for the duct, but also at the anchor head (protective cap and inserts as sketched in Figure 1. Schematic illustration of tendon system for protection level 3 (PL-3) (according to the Swiss guidelines [2-4])).

Figure 1. Schematic illustration of tendon system for protection level 3 (PL-3) (according to the Swiss guidelines [2-4]).

Typically, the load from the wedge plate (anchor head) is transferred to a cast-iron anchorage body or bearing plate. To achieve electrical isolation, the wedge plate and the cast-iron anchorage body (or the bearing plate, respectively) are separated by a fiber-reinforced polymer disc, which ensures that load is transferred to the anchorage body while maintaining electrical isolation of the tendon. This requires the isolation system to be integrated into the anchorage system, which is typically proprietary. Thus, different solutions are possible, depending on the type of anchorage.

The main advantage of EIT in PL-3 is that this solution is non-destructively monitorable over time. Figure 1 shows “electrical connections” at both ends of the tendon. These connections permit contacting the tendon with measurement equipment that allows assessing the condition/quality of the encapsulation or other parameters at any point in time during the service life of the structure.

The main goal of long-term monitoring during the life of a structure is to detect ingress of moisture or chlorides through defects in the encapsulation into the tendon early, i.e. before
they can cause any damage to the prestressing steel.

This is possible by performing electrical impedance measurements over time and evaluating the change in measurement rather than the absolute value.

In principle, the ohmic resistance of a tendon with perforations should increase over time due to continuing cement hydration of the grout and the concrete surrounding the duct. When the logarithm of the resistance is plotted vs. the logarithm of time, this corresponds approximately to a straight line. A deviation from this trend, usually a pronounced decrease of the electrical resistance, indicates the ingress of water or chlorides at the duct defect. For more information about long-term monitoring and data interpretation, refer to [10, 11].
4.0—Material and Performance Requirements

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.

Metal half-shells and steel tie wires are not allowed for protection levels PL-2 and PL-3.

For PL-2, use smooth plastic duct for external tendons except where steel pipe is required. Use corrugated plastic duct for all internal tendons except where steel pipe is required.

For PL-3, use smooth plastic duct for external tendons and corrugated plastic duct for internal tendons.

4.3.2—Post-tensioning anchorages

Permanent grout caps for PL-2 shall be nonmetallic, stainless steel, or galvanized ferrous metal with a minimum thickness of zinc of 120 µm. Permanent grout caps for PL-3 shall be nonmetallic and non-conductive.

Trumpets associated with PL-2 anchorages shall be made of either ferrous metal or plastic. Trumpets for PL-3 anchorages shall be made of 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.

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 for PL-2. Use permanent grout caps made from approved polymer for PL-3. The approved resins for use in the polymer shall have ultraviolet [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.

4.3.13 – Electrical Components for PL-3

Wiring used for electrical measurements on PL-3 tendons shall be at least #12 AWG solid copper. Wiring shall have water-proof insulation. When cast into concrete, the insulation shall be resistant to alkaline environment in the concrete. Alternatively, wiring shall be permitted to be placed in non-conductive electrical conduits.

Electrical contacts to the tendon shall be located at the anchorage at both ends of the tendon (Figure 2). Contact shall be made by means of a bolted cable strap. Galvanized conductors and contact bolts shall not be permitted. Prior to installing the bolted cable strap, any surface rust on the components shall be removed to ensure unimpeded electrical contact.

A junction box with electrical terminals shall be installed at each anchorage. Junction boxes shall be provided with an air ventilation opening protected with anti-insect mesh at the lowest position of the box. Junction boxes shall be installed in an easily accessible position on the structure and shall be suitable to protect all cables and measuring connections from weather and mechanical damage.

Wiring shall be soldered to the terminals and sealed permanently with heat shrink tubes. Terminals shall be adequately labeled in the junction box including the tendon identification and whether the connection is with the tendon or reinforcement.

Reinforcing steel bars (or other approved metallic component) shall be installed in concrete section both parallel and perpendicular to the tendon to ensure continuous electrical conductance of the reinforcing steel cage. Bar size shall be at least #11 bar (diameter 35.8 mm). Contacts to these bars shall be made by means of bolted cable straps. Galvanized conductors and contact bolts shall not be permitted. Prior to installing the bolted cable strap, any surface rust on the components shall be removed to ensure unimpeded electrical contact. The wiring shall be connected to the junction box.

After installation of connections and cables, the electrical connections shall be checked for continuity by appropriate electrical measurements.

C4.3.13 – Electrical Components for PL-3

Junction boxes are required at each anchorage as shown in Figure 2. Electrical measurements can then be made independently from either anchorage. This ensures redundancy, for instance if one of the connections fails over time. In addition, having the possibility to electrically connect the tendon from both ends facilitates localizing defects in the duct.

Figure 2. Schematic illustration of the installations needed for the electrical resistance measurements [2, 4].

A number of such measurements exist. Guidance may be found in standard ISO 12696.
4.4—System approval testing

4.4.5—System pressure tests

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 75, “Corrugated Plastic Duct for Internal Bonded Post-tensioning.” For bar systems, modify the system test length to 15 ft.

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.

For PL-3, EIT performance of the assembled duct system (including duct, connectors and vents) shall be tested with the method (“EIT performance of duct system”) described in appendix B.2 of fib Technical Report, Bulletin No. 75 and shall satisfy the corresponding requirements.

The objective of this test is to demonstrate that the polymer duct system components can achieve sufficient electrical resistance to meet the EIT requirements for PL-3 on site.

For PL-3, EIT performance of the anchorage-duct assembly (including anchorage, trumpet, duct and duct connector) shall be tested with the method (“EIT performance of anchorage-duct assembly”) described in Appendix B.3 of fib Bulletin No. 75 and shall satisfy the corresponding requirements.

The objective is to confirm that the electrical resistance of the anchorage-duct assembly is sufficiently high to be used for PL-3 tendons. Another important aspect is to verify that the materials used in the anchorage-duct assembly (such as eventual coatings of metallic surfaces of anchorage members) have long-term stability in alkaline environments.
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.

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.

Quality Control 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.

Quality Assurance 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.

The quality of the execution on-site is crucial for the technology of EIT to be successful. Hence, post-tensioning systems should be installed only by specialized companies that are capable of documenting corresponding experience and have suitably trained (eventually certified) personnel. These companies should have a quality plan, adapted to the size and importance of the project, which describes all key processes such as duct placing, tendon installation, stressing, and application of the permanent protection. During execution, these processes should be supervised by a qualified supervisor. Installation on-site must be done in accordance with the general procedures defined by the system supplier.

The owner may wish to develop a long-term monitoring plan that incorporates electrical resistance readings. To ensure the usefulness of the long-term monitoring data, it is important that the methodology used when taking readings after stressing and after grouting be thoroughly documented along with the results for comparison and use on future monitoring.
When PL-3 is specified, the owner shall specify the electrical readings required and the corresponding acceptance criteria:

- Immediately after post-tensioning, but before grouting.
- 28 days after grouting.

These specifications should describe the measurement methods, test equipment, measuring points, and acceptance criteria to meet the project requirements.

Before starting installation, a meeting shall be held between all parties involved in the construction of PL-3 tendons to ensure that all relevant information is shared with all parties and all interfaces are well covered.

For acceptance criteria and threshold values please compare sections 12.9 and 13.3. The Swiss guidelines [3, 4] may also be consulted for further information.
8.0—Shipping and Storage of Materials

8.5—Plastic duct

C8.5—Plastic Duct

Plastic ducts are an important part of EIT as they ensure the leak-tight encapsulation of the tendon over its length. They are particularly susceptible to damage during transport, storage and handling. Plastic ducts and other components of the encapsulation must thus be carefully handled and stored in clean environments in order to avoid damage (compare fib bulletin no. 75).
9.0—Bearing Plate and Duct Installation

9.6—Ducts

Before concrete placement, 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 in-side dimension(s) of the ducts before releasing the installation for concreting.

For PL-3 tendons, plastic duct shall be visually inspected before installation. In case of damage, they shall be rejected.

For curved PL-3 tendons, the duct shall be protected from damage caused by support bars placed along the inside radius of the duct. At locations where the duct is in contact with support bars along the inside radius, plastic half-shells shall be placed between the duct and the support bars. Half-shells shall be fixed in place using plastic ties (metal ties not allowed).

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.

During tendon assembly and concrete placement, ducts may be indented at locations of high curvature on duct support bars. Half-shells can protect the duct from mechanical damage at these locations. If damage does occur to the duct, then the strand may cut through the duct and make contact with the support bar, thus severely diminishing the electrical isolation of the tendon.
12.0—Stressing Operations

(Insert this new section at 12.9 and renumber all following sections.)

12.9 – Verification of Electrical Isolation (PL-3)

Prior to grouting (but after stressing the tendon) the AC impedance shall be measured between the tendon and the reinforcing steel using the terminals in one of the junction boxes.

12.9.1 AC impedance measurement

Prior to grouting (but after stressing the tendon) the AC impedance shall be measured between the tendon and the reinforcing steel using the terminals in one of the junction boxes.

C12.9–Verification of Electrical Isolation (PL-3)

To assess the quality of the encapsulation of EIT (leak-tightness, etc.) and for monitoring the condition over time, the AC impedance between the tendon and the ordinary reinforcing steel is measured. This is schematically shown in Figure 3.

To simplify matters, the AC impedance measurements will be referred to as “electrical resistance measurements”. This may be justified by the fact that the ohmic resistance is the main component of interest of the measured AC impedance.

Figure 3. Schematic illustration of electrical impedance measurement.

12.9.2 Measurement instrumentation

The instrument used to measure AC impedance shall satisfy the following requirements:

- AC measuring frequency of 1 kHz
- At least 0.5 V AC output voltage
- Digital display
- Measuring Ranges:
  - R: 0.1Ω – 10 MΩ (with a resolution of 0.1 Ω at the lower end of the range)
  - C: 0.1 nF – 100 μF
  - D: 0.001 – 10

C12.9.2 Measurement instrumentation

Typically, LCR-meters are used that can automatically resolve the ohmic and capacitive component of the AC impedance (assuming a parallel R-C circuit).
12.9.3 Interpretation of impedance measurements

Measured resistances <10 Ω indicate the presence of a metallic contact between the tendon and the reinforcing steel.

In theory, if the tendon is electrically isolated, the ohmic resistance will be controlled by the resistance of the polymer duct, which is relatively high. In the presence of duct perforations, the ohmic resistance will be lower.

During post-tensioning, the strands move relative to the plastic duct, which can gouge the inside of the ducts (wear damage). If not properly installed the duct may be damaged at locations of high curvature (at duct support bars) severely enough such that the prestressing steel is in direct contact with reinforcing steel. Metallic contacts may also arise at the anchorages, e.g. due to improper installation of the anchorage head. Such direct contacts tendon/anchorage–reinforcing steel can easily be detected by performing electrical resistance measurements after tensioning, but before grouting. The reason is that such metallic contacts strongly depresses the electrical resistance and that the absence of grout does not yet blur the results. Values of R (not related to the tendon length) lower than approx. 10 or 20 Ω have been found to indicate the presence of such a metallic contact [2-5].

Prior to grout injection only resistance is measured; capacitance (C) and loss factor (D) measurements are only meaningful after the grout has been injected.

Additional resistance measurements may be taken during the stressing process to provide feedback on the tensioning process, i.e. to indicate whether or not damage is caused to the plastic duct and thus to the encapsulation.

12.9.4 Acceptance criteria

Readings shall be compared to the threshold limits or other assessment criteria established for the project and action taken as dictated by the project requirements.

Acceptable limits for non-compliance for each structure or specific structural member should be specified. Criteria may depend strongly on a number of factors, such as the type of structure, the exposure conditions, the presence of additional measures of corrosion protection, considerations regarding structural load-bearing behavior, but also on the objectives of using EIT (e.g. to improve quality control, for monitoring purposes, etc.).
At this stage, AC impedance measurements permit detecting the presence of metallic contacts between tendon and reinforcing steel. The following rules may be applied:

- The acceptable non-compliance rate is 10% or less.
- If non-compliance is in the range of 10% to 20%, the payment is reduced to PL2 rate for the non-compliance tendons.
- For non-compliance rates above 20%, the non-compliance tendons must be repaired until the threshold value of the AC impedance measurement is satisfied.

Note, however that from a durability (corrosion) viewpoint, repairing such metallic contacts may be problematic, because whenever concrete is removed and the plastic duct is locally “repaired” there is a risk for creating additional pathways for ingress of chloride. As an alternative to repair, the owner may ask the contractor to localize the defects non-destructively and document their location for future considerations.
13.0—Grouting Operations

13.2–Inlet and vent seals

Inlets and vents must be properly sealed after grouting with leak-tight plastic caps.

13.3–Post-Grouting Electrical Measurements (PL-3)

13.3.1 AC impedance measurement

This second AC impedance measurement shall be made at approximately 28 days after grouting. See section 12.9 for details regarding the measurement, measurement instrumentation, and data interpretation.

If measurements are taken at a time different from 28 days after grouting, the time effect shall be taken into account using the following equation:

\[ R = R_t \cdot \sqrt{28/t} \]

where resistance \( R_t \) is measured at time \( t \) (age of the grout in days = time after grouting) and \( R \) is the value converted to 28 day age.

Measurements shall be taken at ambient temperatures in the range 10 to 30 °C (50 to 86 °F).

The resistance \( R \), the conductance \( C \), and the loss factor \( D \) shall be documented along with the ambient temperature and the time after grouting (grout age) for each tendon. Also the respective tendon length shall be indicated.

C13.2–Inlet and vent seals

Inlets and vents can potentially create an electrolytic connection to the concrete and thus decrease the electrical resistance of EIT.

C13.3–Post-Grouting Electrical Measurements

C13.3.1 AC impedance measurement

For more information about the correction of the time effect see [3, 4, 10].

Temperature strongly affects the electrical resistivity of mortar and concrete and thus the AC impedance measurements. To reduce the error, it is recommended to perform measurements only within a pragmatic range of ambient temperatures. In a range of 10 to 30 °C, for instance, the temperature can induce deviations for resistance measurements of up to 30%. The local temperature inside the concrete of a structural member is often unknown and is also likely spatially variable. Temperatures measured at the outer concrete surface or in the air are poor indicators for the temperature in the concrete.

At this stage, the measurement allows assessment of the leak-tightness of the tendon encapsulation, and thus the quality of the installation.

It will also be possible to detect metallic contacts as described in section 12.9 (i.e. if \( R < \text{ca. 10 } \Omega \)). If such metallic short circuits are present, however, then they will completely dominate the results and no other imperfections, such as perforations in the duct
13.3.2 Acceptance criteria

Readings shall be compared to the threshold limits or other assessment criteria established for the project and action taken as dictated by the project requirements.

C13.3.2 Acceptance criteria

Acceptable limits for non-compliance for each structure or structural member should be specified. Criteria may depend strongly on a number of factors, such as the type of structure, the exposure conditions, the presence of additional measures of corrosion protection, considerations regarding structural load-bearing behavior, but also on the objectives of using EIT (e.g. to improve quality control, for monitoring purposes, etc.). If monitoring is the objective, the Swiss guidelines [3, 4] suggest that tendons with a specific resistance that is less than 50 kΩm shall be considered to have failed. Up to 10% of the tendons are permitted to fail specific resistance thresholds without penalty [3, 4].

Note that for precast segmental bridge construction or for use of epoxy-coated reinforcing steel, there is currently no experience upon which threshold values and acceptance criteria can be based.
References


6. fib (Fédération internationale du béton), *fib Bulletin no. 75 "Polymer duct-systems for internal bonded post-tensioning"*. 2014.


