AGENDA
PTI M-50 / ASBI Bonded Tendon Task Group
Sunday, November 4, 2018, 5:00 pm - 9:00 pm
Loews Chicago O’Hare Hotel, Chicago IL, Room Warhol

Voting Members Present (xx of 29; Quorum=12)

Dave Martin, Co-Chair
Guido Schwager, Co-Chair
Bob Sward, Incoming Chair
Edgar Zuniga, TAB Contact, NV
Miroslav Vejvoda, Secretary, NV
Randy Cox, Staff Liaison, NV
Tomaso Ciccone
Guy Cloutier
Tom DeHaven
H.R. Hamilton
Joe Harrison
Reggie Holt
Elie Homsi
Gregory Hunsicker
Larry Krauser
Bryan Lampe
Brian Merrill
Andrew Micklus
R. Kent Montgomery
Alan Moreton
Jerry Pfunther
Jose Luis Quintana
Greg Redmond
Robert Robertson, Jr.
Ralph Salamie
Mike Schwager
Leo Spaans
Michael Sprinkel
Teddy Theryo
Dustin Thomas
Scott Tumpaugh

Dywidag-Systems International USA, Inc.
Schwager Davis, Inc.
VSL
Dywidag-Systems International USA, Inc.
PTI
ASBI
TENSA
LCPT International Consulting, Inc.
Figg Bridge Engineers
University of Florida
LMS Reinforcing Steel Group
Federal Highway Administration
Parsons
Precision-Hayes International
General Technologies, Inc.
Dywidag-Systems International USA, Inc.
Wiss, Janney, Elstner Associates, Inc.
Freyssinet, Inc.
Figg Bridge Engineers
Corven Engineering, Inc.
Finley Engineering Group
Mexpresa
PT-Technologies
Florida DOT
Kiewit Infrastructure West
Schwager Davis, Inc.
Janssen & Spanns Engineering, Inc.
Virginia Transportation Research Council
Florida Department of Transportation

Associate Members Present

Yosbani Ballate
Mike Beauchamp
Robert Bennett
Hilliard Bond
John Crigler
Thomas Helm
Bijan Khaleghil
David Konz
Antonio Ledesma
Jim McTaggart
Shannon Meeks
John Pearson
Marcel Poser
Mario Salice
Joe Salvadori

VSL
Caltrans
RS&H
Parsons
VSL
NOVA
Washington State DOT
Atkins Global
WSP
CSI
Shimmick-Parsons
WJE
Schwager Davis, Inc.
Dywidag-Systems International USA, Inc.
ACTION ITEMS FROM LAST / THIS MEETING

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<th>Action</th>
<th>Responsible</th>
<th>Deadline / Completed</th>
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<tr>
<td>1.2</td>
<td>Specification &amp; Commentary</td>
<td>Document to TAB review</td>
<td>Staff</td>
<td>Asap</td>
</tr>
<tr>
<td>3.1.1</td>
<td>Replaceable Grouted Tendons w. Diabolos</td>
<td>Review proposed Specification and Commentary</td>
<td>TG: R Holt; M Schwager</td>
<td>June 30, 2018</td>
</tr>
<tr>
<td>3.1.2</td>
<td>Monitorable Tendons</td>
<td>Review proposed Specification and Commentary</td>
<td>TG: L Krauser; T Ciccone; R Holt; J Salvadori</td>
<td>June 30, 2018</td>
</tr>
<tr>
<td>4.1</td>
<td>Loops &amp; Tangent Length</td>
<td>Draft Specification and Commentary language</td>
<td>TG: M Schwager; R Sward</td>
<td>Before fall meeting</td>
</tr>
<tr>
<td>6.1</td>
<td>Bulletin 7 vs. 75</td>
<td>Review Bulletin 7 vs. 75 or other plastic duct requirements</td>
<td>TG: L Krauser; R Sward; J Myer</td>
<td>Before fall meeting</td>
</tr>
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</table>

Agenda Item | Expected Outcome / Actions Taken
--- | ---
**A. General**
A.1 Call to Order

A.2 Introductions / Attendance Sheet *(Exhibit A.2)*

A.3 Committee Roster

A.4 PTI Antitrust Policy *(Exhibit A.4)*

A.5 Committee Annual Report

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

A.1 Meeting called in order by Co-Chair at pm. Co-Chairs Guido Schwager and Dave Martin will lead the part of the meeting pertaining to the M50.3-XX Specification. New business part for the next edition of the Specification will be led by the incoming Chair Bob Sward.

A.2 All present are sked to introduce themselves and to sign the Attendance Sheet.

A.3 The official committee roster is on the PTI website. A copy of the roster is circulated for members to review their contact information.

A.4 All present are reminded of the PTI Antitrust Policy and asked to initial the right-hand side column on the Attendance Sheet to confirm their knowledge of and adherence to the policy.

A.5 The Annual Report to be prepared and submitted to TAB by November 30, 2018.

B.1 Any changes to the agenda?
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<th>Expected Outcome / Actions Taken</th>
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<tr>
<td>B.2 Approval of Minutes (Meeting ballot required)</td>
<td>B.2.1 Motion / Second to approve Meeting Minutes from 5/6/18: Name / Name, 0-0-0 (Y-N-A)</td>
</tr>
<tr>
<td>B.2.1 Meeting Minutes from May 6, 2018, distributed on May 11, 2018</td>
<td></td>
</tr>
<tr>
<td><strong>C. Actions Taken Between Meetings</strong></td>
<td></td>
</tr>
<tr>
<td>C.1 Letter Ballot: None</td>
<td>C.1</td>
</tr>
<tr>
<td>C.2 Web Meetings: None</td>
<td>C.2</td>
</tr>
<tr>
<td><strong>1. Action Item 1: M50.3-XX</strong></td>
<td>1.1 Document went to TAB review. It was approved with one relevant comment and some other comments, which will be distributed and reviewed during the meeting.</td>
</tr>
<tr>
<td>1.1 Status of Specification</td>
<td></td>
</tr>
<tr>
<td>1.2 Time table to completion</td>
<td>1.2 M-50 is to letter ballot responses to TAB comments. If responses are agreed at the meeting, a short ballot, possibly one week, can fulfil that requirement. The next step is the 45-day public review.</td>
</tr>
<tr>
<td><strong>2. Action Item 2: Monitorable, Replaceable and Assessable PT Research Project</strong></td>
<td>2.1 The documents for Replaceable and Monitorable tendons should be reviewed by the Task Groups and any comments discussed at the meeting.</td>
</tr>
<tr>
<td>2.1 Progress update of the FHWA Task 5009</td>
<td>2.1.1 Final draft with Specification and Commentary for replaceable grouted tendons was attached to the minutes from April 30 and October 22, 2017. The TG was to provide comments by June 30, 2018. Does the TG have any recommendations?</td>
</tr>
<tr>
<td>2.1.1 Replaceable Grouted Tendons including diabolos</td>
<td>2.1.2 Final draft with Specification and Commentary for monitorable tendons was attached to the minutes from April 30 and October 22, 2017. The TG was to provide comments by June 30, 2018.</td>
</tr>
<tr>
<td>TG: Reggie Holt, Mike Schwager</td>
<td>2.1.2.1 Monitorable PT Systems – EIT was reviewed by the TG (Exhibit 2.1.2.1).</td>
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<tr>
<td>2.1.2 Monitorable Tendons</td>
<td></td>
</tr>
<tr>
<td>TG: Larry Krauser, Tommaso Ciccone, Reggie Holt, Joe Salvadori</td>
<td></td>
</tr>
<tr>
<td>2.1.2.1 Reggie Holt will discuss the review of the EIT document and report on the FHWA Workshop at the Lehigh University on October 24, 2018.</td>
<td></td>
</tr>
<tr>
<td><strong>3. Action Item 3: Loops &amp; Tangent Length</strong></td>
<td>3.1 Loops and tangent lengths was to be addressed by this TG. A draft language was to be provided by the TG before the fall meeting. Does the TG have any recommendations?</td>
</tr>
<tr>
<td>3.1 TG: Mike Schwager, Bob Sward</td>
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<tr>
<td>Agenda Item</td>
<td>Expected Outcome / Actions Taken</td>
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<tr>
<td>4. Action Item 4: Bulletin 7 vs. Bulletin 75 or other plastic duct requirements</td>
<td>4.1 A draft language was to be provided by the TG before the fall meeting. Does the TG have any recommendations?</td>
</tr>
<tr>
<td>4.1 TG: Larry Krauser, Bob Sward, Jacob Myer</td>
<td></td>
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<tr>
<td>5. Action Item 5: Flexible Fillers</td>
<td>5.1 Any new development?</td>
</tr>
<tr>
<td>5.1 Status</td>
<td></td>
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<tr>
<td>5.2 TG: Natassia Brenkus/Trey Hamilton, Don Hill, Robert Bennett, Yosbani Ballate, Greg Hunsicker</td>
<td>5.2 Natassia Brenkus was putting together requirements from the FDOT specifications. Does the TG have any recommendations?</td>
</tr>
<tr>
<td>6. Action Item 6: PT Systems Qualification Testing</td>
<td>6.1</td>
</tr>
<tr>
<td>6.1 Progress report from CRT-70 Chair Hunsicker to report</td>
<td></td>
</tr>
<tr>
<td>7. Action Item 7: AASHTO Bridge Construction Specification</td>
<td>7.1 At their meeting on October 13, 2018, AASHTO T10 has approve 95% AUTS for the upcoming issue of their specifications. This was submitted as one of the TAB review comments; see Item 1.1.</td>
</tr>
<tr>
<td>7.1 Status of 95% MUTC (TG: Xia, Myer, Micklus, Ciccone, Holt)</td>
<td>7.2 AASHTO Updates (TG: Merrill, Cloutier, Krauser, Cox, Hunsicker)</td>
</tr>
<tr>
<td>7.2 This is an ongoing effort; does the TG have any items for discussion?</td>
<td></td>
</tr>
<tr>
<td>D. New Business</td>
<td>D.1</td>
</tr>
<tr>
<td>D.1 New items?</td>
<td></td>
</tr>
<tr>
<td>E. Next Meeting</td>
<td>E.1 PTI Convention</td>
</tr>
<tr>
<td>E.1 Sunday, May 5, 2019, at the Hyatt Regency Seattle, 808 Howell Street, Seattle, Washington. The time will be announced when the convention schedule is finalized.</td>
<td>E.2 Web Meetings</td>
</tr>
<tr>
<td>E.2 As needed</td>
<td></td>
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<tr>
<td>F. Adjourn</td>
<td>F. Meeting adjourned at pm.</td>
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**AGENDA / MINUTES EXHIBITS**

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<td>A.2 / A.4</td>
<td>Attendance Sheet / PTI Anti-Trust Policy will be in the meeting room</td>
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<td>2.1.2.1</td>
<td>Monitorable PT Systems – EIT, with review comments</td>
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PTI POLICY STATEMENT ON COMPLIANCE WITH ANTITRUST LAWS

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.
Monitorable post-tensioning systems

Sub task 2 – State-of-the-art report

Appendix B – EIT Specification Language

Draft
September 2016
# EIT Specification Language

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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.
SPECIFICATIONS

2.0—Definitions and Abbreviations

2.1—Definitions

**Half-shell** - plastic half-shells are placed between the duct and tendon support bars along the inside radius of curved PL-3 tendons 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 when there is a concern with electrical continuity. 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):

\[ R_l = R \times L \text{ (Ωm)} \]

**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
**SPECIFICATIONS**

**Specific capacitance (C)** - Capacitance per unit length of tendon, $C = C / L$ (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.

**COMMENTARY**

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.

Commented [TC5]: An electrically isolated tendon needs to be compulsorily encapsulated.

Commented [TC6]: In case of a pour back applied over grout caps, electrical isolation can be guaranteed only if cap is made of plastic (not allowed stainless steel). I would personally remove the option of using stainless steel caps. At par. 4.3.2 it is mentioned that permanent grout caps for PL3 shall be non metallic and non conductive.
• 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
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minimum pressure of 150 psi by the PTS supplier. Use ASTM F593 Type 316 stainless steel bolts to attach the cap to the anchorage.

4.3.12 – Inlets, outlets, Valves and plugs

Protrusion depth of plugs into duct cavity shall be minimized to the maximum extent possible.

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 of #11 bar (diameter 35.8 mm) is recommended. 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.

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].

COMMENTARY

Commented [RH10]: Maybe better suited for commentary.
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.

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 Recommendation, 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 outlined in CC12.9.4 is recommended for the following reading:

- 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

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, paragraph 4.1.4.).
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 inside 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.

Commented [RH13]: ½ shells are only needed at tendon curvature. Not along the entire length.
12.0—Stressing Operations

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

12.9 – Verification of Electrical Isolation (PL-3)

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)

C12.9.1 AC impedance measurement

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.

C12.9.3 Interpretation of impedance measurements

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.

C12.9.4 Acceptance criteria

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.).

Commented [TC14]: I believe that a guide specification should suggest acceptance values and cannot refer to project requirements which are usually written starting from standards! I suggest to use limit values set in document (4) of References, paragraph 5.3.2.
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 above 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.

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

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:

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

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).

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.

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.

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 \( R < \) ca. 10 Ω). 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...
where no metallic contact of the tendon and the reinforcing steel occur, can be detected.

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.

C13.2 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 without special details to provide electrical continuity over segment joint 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.