ACI AND PTI REQUIREMENTS FOR ENCAPSULATION SYSTEMS

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1.0 INTRODUCTION

This paper will assist the reader in understanding the critical aspects of current American Concrete Institute (ACI) and Post-Tensioning Institute (PTI) documents as they relate to unbonded post-tensioning encapsulation systems. The ACI document is titled: *Specification for Unbonded Single-Strand Tendons and Commentary*. The PTI document is similar but does not have "and Commentary" in its title even though both documents contain similar commentary. There is a significant amount of correlation between the ACI Committee 423 and PTI Committee for Unbonded Tendons documents; primarily due to the PTI specification being the starting point of the ACI specification. The first edition of the PTI document was published in 1993 and the second edition in 2000 whilst the ACI document was officially published in October 2001.

As both documents are "living" documents, the author will interject his recommendations for future changes and improvements throughout this paper. A "living" document is a document that is refined and improved over time through various updating procedures. Both documents offer areas for enhancement in relation to encapsulation systems that the author will identify. As new techniques for component manufacture are developed and codes require higher quality systems, continual improvement of encapsulation systems will be market driven.

This paper will quote the requirements of ACI and note any major differences with PTI. It will follow the documents from beginning to end. When quoting the documents the source will be noted.

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2.0 DOCUMENT DEFINITIONS

Firstly, encapsulation systems are required for aggressive environments as noted in ACI 1.1 Scope (and PTI 1.1):

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

The definition of an aggressive environment is given in ACI R1.1 Scope (and PTI 1.1):

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

A similar definition is given in ACI 1.2 Definitions (and PTI 1.2):

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

At present the ACI document does not "apply to tendons used in ground supported post-tensioned slabs for light residential construction." The PTI document in the November 2003 Addenda removed this wording from the Scope but added similar wording to PTI 2.2.6.2

Anchorages. The author believes that both ACI and PTI should revisit the above wording of aggressive environments as they relate to "ground supported post-tensioned slabs for light residential construction". It does not make sense that the post-tensioning in buildings whose "anchorage areas are in direct contact with soil" would be in more danger than that of light residential construction. It is the author's opinion that the post-tensioning tendon does not know whether it is in a residential foundation or multi-level parking structure and will perform the same, so why should there be a difference? The author recommends this distinction be removed.

There is a sentence in the commentary of ACI R1.1 Scope (and PTI C1.1) that the author feels should be revisited: "Nearly all enclosed buildings (office buildings, apartment buildings, warehouses, manufacturing facilities) are considered to be non-aggressive environments." This seems like a reasonable statement as many engineers feel that the construction phase of a project is short enough that final durability criteria are not necessary until project completion provides protection; however, the author notes that in some cases encapsulation of the post-tensioning tendons in these structures should be considered, such as in locations where the tendons may be affected during construction by "salt-laden air" and any other source of corrosion (rain?) prior to enclosure. Once elements of corrosion have been introduced into the post-tensioning system they remain. Similarly, the author believes that intermediate anchorages at construction joints should be encapsulated when encapsulation systems are specified for stressing-end and fixed-end anchorages even in enclosed buildings.

The definition of an encapsulated tendon is given in ACI 1.2 Definitions (and PTI 1.2):

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

The PTI document furthers this with "The encapsulation shall be free of voids as possible and shall inhibit corrosion of all tendon elements." The PTI document adds under the commentary side that "Some small bubbles and air spaces are normal and unavoidable in the fabrication and assembly process and should not be considered as 'voids' in the context of this definition." Similar wording is contained in ACI R2.2.6.2. What PTI (and ACI) says is the encapsulation system "shall be as free of voids as possible" but it notes that there may be "small" air bubbles. However, neither PTI nor ACI has quantified what a "small" air bubble is in their respective documents. The author suggests quantifying "small air bubbles" as "the total volume of all air bubbles within the design of the system transition components shall not be greater than ¼ cubic inch." This would allow for a certain amount of tolerance within the system for assembly. The author notes that if the design of the transition components (sleeves and seals) creates more airspace than ¼ cubic inch, then per ACI R2.2.6.2 and PTI C2.2.6.2, post-tensioning coating (grease) may be used to fill the void within the transition components. Small air bubbles created by the extrusion process will vary by manufacturer, type and speed of equipment, and are virtually impossible to measure; therefore they cannot be reasonably quantified.

3.0 COMPONENT REQUIREMENTS

Requirements for components of anchorages in aggressive environments can be found in ACI 2.2.6.1 (and almost identical wording in PTI 2.2.6.1):

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

Injection molded plastic is typically used to protect the anchor castings; however, the commentary allows epoxy-coated anchors as long as additional inspections are performed and damage to the epoxy coating is repaired. Bare anchor castings are not allowed. The author suggests the elimination of epoxy-coated anchors because the epoxy coating is rather brittle and in a job site situation the damage goes unnoticed most of the time. Another option may be to require a "thickness" for the epoxy coating of 50 mils which would give the epoxy coating similar durability characteristics to that of injection molded plastic.

The requirement for testing "in a horizontal position" does not seem essential to the author as long as the minimum hydrostatic pressure is maintained. The author suggests removing this requirement and substituting: "… ability to remain watertight when subjected to a minimum uniform hydrostatic pressure of …"

The same hydrostatic testing requirements are contained in both the ACI and PTI documents. The test method was developed in the late 1980's and was a great start; however, the author believes these test requirements are obsolete and should be enhanced. The reason for this is:

- The manufacturer is allowed to select and assemble samples. The manufacturer will select the best samples not necessarily those that will be consistently going to the job sites. The manufacturer is intimately familiar with his system and can assemble it precisely – this is not necessarily a "field condition" which is what should be tested. Having the independent testing agency select and assemble components would be more representative of how the system will perform.

- There are no intervals identified for re-testing. Plastic injection molds wear out and change over time. Some type of interval should be identified.
- The test method for detecting the presence of moisture can actually hide moisture infiltration. By adding white pigment to the grease any moisture infiltration is hidden because emulsification of the grease cannot be seen (emulsification gives the grease a milky color – white). The colored dye used in the water is not strong enough to be seen contrasting with the emulsified grease.
- The test method encourages adding grease into the system. The test method should test the components for watertightness without grease to cover up poor connections.
- There are no test requirements for field conditions after cutting of the tendon tails to make sure that the cap will actually perform correctly. Burning of tendon tails may adversely effect how the cap locks into the wedge cavity.

With advancements in testing and manufacturing of plastic encapsulation components and to improve system quality, enhanced testing should be required. The author recommends that the following be incorporated into new testing requirements:

- Hydrostatic testing shall be performed annually by an independent testing agency.
- Representative samples should be selected and assembled by the independent testing agency following assembly instructions provided by the manufacturer.
- Retesting is required whenever a component of an assembly changes or the testing criteria changes
- No grease should be allowed in the testing of components for watertightness – grease covers up poor connections.
- The criteria for successful performance of an encapsulation system is no evidence of moisture or air infiltration entering the system through the encapsulation of the anchorage, seals, sleeves, caps, connections, and any other component meant to keep moisture away from the metal components of the tendon when a hydrostatic pressure of 1.25 psi (8.6 kPa) is maintained for 24 hours. There is no need for a "horizontal" test as long as the minimum hydrostatic pressure is maintained.
- The criterion for successful performance of the mechanical connections of an encapsulation system, both caps and seals/sleeves, is a minimum separation force of 50 lbs (23 kg).
- Testing of encapsulated stressing-end anchorages shall be performed with wedges and strand in place, and strand tails cut by the various cut-off methods employed in the field prior to installing caps. The test report shall state the methods successfully employed with the system and the manufacturer shall state in their instructions the proper tendon cut-off methods to use with their system.

A specification allowing tape to be used in encapsulated systems is given in ACI 2.2.6.1 (in PTI 2.2.6.2 under Encapsulation Systems):

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

The author recommends that this section regarding tape as part of the encapsulation system will be deleted in the future because of the advancements in manufacturing plastic components of the encapsulation systems. The author believes tape should not be allowed as a component of encapsulation systems because of the difficulties in the field emulating the "perfect taping" that was done during testing, and additionally because the availability within the marketplace of encapsulation systems that do not use tape as a component.

Tape should continue to be allowed for repairs of damaged sheathing in the unbonded length of a tendon because it provides an adequate (though not perfect) solution for repairs in the field. The key for repairs using tape is to achieve a smooth tape repair without any ripples.

The specification for sleeves of encapsulated systems is similar in both ACI and PTI and contained in ACI 2.2.6.2 and PTI 2.2.6.2:

> *Sleeves used to connect the sheathing to the anchorage of encapsulated systems shall:*
>
> *a. Meet or exceed the same requirements as the sheathing for durability during fabrication, transportation, handling, storage, and installation;*
>
> *b. Have 0.050 in. (1.27 mm) minimum thickness;*
>
> *c. Have a positive mechanical connection to the anchorage at all stressing, intermediate, and fixed ends;*
>
> *d. Have a minimum overlap between the end of the extruded sheathing covering the prestressing steel and the end of the sleeve and seal shall be 4 in. (100 mm);*
>
> *e. Be translucent or have another method of verifying that the post-tensioning coating material is free of voids; and*
>
> *f. Be translucent or have other method of verifying overlap with sheathing.*
>
> *Sleeves on stressing side of intermediate anchorages must be long enough to cover sheathing removed during stressing and have the required 4 in. (100 mm) overlap.*

The first part of commentary to the sleeve specification given in ACI R2.2.6.2 (PTI C2.2.6.2 is similar) is:

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

This commentary allows systems with sleeves that create air voids to be used for encapsulated systems as long as they are filled with post-tensioning coating and meet the testing requirements. However, it also states that these sleeves and seals should be designed to be "void-free". The authors of the ACI and PTI documents recognized that it would be a good idea for the "transition components" to be "void-free" but acknowledged that this may not be possible in all situations and, thus allowed the use of post-tensioning coating (grease) to fill any voids.

The second part of commentary to the sleeve specification given in ACI R2.2.6.2 is:

> *Some small bubbles and air spaces are normal and unavoidable in the fabrication and assembly process and should not normally be considered as "voids" in the context of this section.*

This commentary is similar to that given by PTI under the definition of an Encapsulated Tendon. As with PTI, ACI has not quantified what a "small" air bubble is in their document. The author suggests quantifying "small air bubbles" as "the total volume of all air bubbles within the design of the system transition components shall not be greater than ¼ cubic inch." This would allow for a certain amount of tolerance within the system for assembly. The author notes that if the design of the transition components (sleeves and seals) creates more airspace than ¼ cubic inch, then per ACI R2.2.6.2 and PTI C2.2.6.2, post-tensioning coating (grease) may be used to fill the void within the transition components. Small air bubbles created by the extrusion process will vary by manufacturer, type and speed of equipment, and are virtually impossible to measure; therefore they cannot be reasonably quantified.

In ACI 2.3.5 Aggressive environments, a specification for sheathing connections is given (PTI 2.3.5 only contains the first sentence):

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

Commentary ACI R2.3.5 Aggressive environments (PTI 2.3.5 is similar) states:

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

These statements in the Sheathing section of the documents reinforce what has been stated earlier and this author's previous recommendations apply to these as well.

4.0 INSTALLATION REQUIREMENTS

The author suggests both ACI and PTI review the installation sections of these documents so they are consistent and carry through all installation activities related to each section of the document such as "Stressing-End Anchorages", "Intermediate Anchorages", and "Fixed-End Anchorages". All activities in each section should be identified and specified. This review should encompass both standard and encapsulated systems; however, the review of all installation activities is beyond the scope of this paper.

Continuing with the encapsulation information contained in the documents, ACI 3.2.1.6 (and PTI 3.2.1.6) states:

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

The author interprets this to mean that once the tendons are placed on the deck and before the concrete is placed all components need to be protected from water infiltration within one day after taking them from "protective" storage. This protection should continue until after completion of post-tensioning operation defined as capping of tendon ends.

The key to preventing corrosion damage is not allowing water to enter the system as stated in ACI 3.2.1.7 (and PTI 3.2.1.7) and ACI R3.2.1.7 (and PTI C3.2.1.7), respectively:

> *Water shall be prevented from entering the tendons during installation.*

> *Possible collectors of water are the coupler and surrounding sheath, transition components between the sheath and anchorage, damaged sheath, and sheath replacement areas.*

If water (and airborne salts) is prevented from entering the system, then one element of the corrosion cycle is eliminated. If the seals/sleeves are in place on the bearing side of the anchor and if the system is performing as designed and tested, water (and airborne salts) will not enter the system with the possible exception of where the tendon tails go into the wedge cavity at the stressing-ends and intermediates. This is the area that would need to be protected as noted in ACI 3.2.1.6 (and PTI 3.2.1.6). However, if the seals/sleeves are not installed after one day's exposure, then the entire anchorage and any exposed strand would need to be protected.

Section ACI 3.2.2.5 (PTI 3.2.2.5 is similar) addresses Stressing-Ends in aggressive environments:

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

The author notes that the last section number in ACI 3.2.2.5 is a typo and should be "3.5.2".

There is no mention of "sleeves" or "seals" which the author considers as critical components for the proper installation of the tendon. In the future, these items should be addressed to improve the specification. PTI 3.2.2.5 makes mention of installing caps within one day of cutting tails; ACI moved that requirement to the commentary of ACI 3.5.1.

When addressing Intermediate locations, ACI 3.2.3.3 (PTI 3.2.3.3 is similar), states:

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

The author notes that the end of this sentence has a flaw within it as the tendon tails are not cut at intermediates unless an intermediate coupler is used. In that case caps and sleeves would not be introduced. The author's suggestion is to add "when encapsulated couplers are used" to the end of this sentence.

For Fixed-End installation, ACI 3.2.4.3 (PTI 3.2.4.4 is similar), states:

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

As long as this section is talking about covers (caps), why not add sleeves as they are not mentioned anywhere for fixed-ends? The author's experience indicates that caps and sleeves should be shop installed on the fixed-ends prior to shipment to the site.

Under Tendon Finishing the commentary, ACI R3.5.1.1 (PTI C3.5.1.1 is similar), notes:

In aggressive environments, tendons should be cut within one working day after approval of elongations by the engineer.

Encapsulation caps should be installed within one working day after cutting off tails.

Time is of the essence when dealing with aggressive environments and encapsulated systems. The sooner protection is in place, the better the long-term performance of the encapsulated system will be.

ACI 3.5.1.1 and commentary section ACI R3.5.1.1 also note that additional measures need to be taken if there will be delays in cutting tendon tails. They are respectively:

If cutting is delayed more than 10 days after stressing, weather protection shall be provided to prevent water and snow from reaching the anchorages.

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

This information is excellent and weather protection should be required in such cases. However, the author notes two areas where the specifications could be improved. The first is when considering aggressive environments. He recommends that the weather protection should be required after one day not ten in aggressive environments. And the second is allowing "48 hours after becoming aware that cutting will be delayed to protect"; why add two more days without protection? The author recommends rewording this to: "Weather protection, recommended for both aggressive and non-aggressive environments, should be installed as soon as the post-tensioning installer becomes aware that cutting will be delayed more than 10 days following stressing."

The PTI document is silent on this matter and the author believes that this should be added in the next edition.

The last item that ACI addresses under Tendon Finishing is ACI 3.5.2 Aggressive Environments (and PTI 3.5.2) and commentary ACI R3.5.2 Aggressive Environments (PTI 3.5.2 is similar), respectively:

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

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

The caps used for encapsulated systems should be translucent and come from the factory with a measured amount of post-tensioning coating. Properly installing the caps is critical to the long-term performance of the encapsulated system. Care should be exercised when oxyacetylene torch cutting is used for cutting tendon tails to ensure that the metal ring is not warped out of shape (or the plastic encapsulation melted) and thus not allowing the cap to fit properly.

5.0 SUMMARY

Both ACI and PTI documents addressing post-tensioning encapsulation systems need improvement. They are both "living" documents and as such should be continually updated. The author believes that the information presented in this paper will assist in improving the quality of post-tensioned encapsulation systems and installations as well as improving both the ACI and PTI documents.

The author notes that ACI Committee 423 is in the process of reissuing their "Unbonded Spec" in two separate documents, one as a materials specification and one as an installation specification.

The following is a summary of some recommendations to improve both the ACI and PTI documents:

- Update testing requirements and define criteria
- Add a requirement for a "positive locking connection" for the cap just as there is for the sleeve
- Quantify total volume of "small air bubbles" within the design of the system transition components
- Improve the Installation Section by making it more consistent
- Limit the exposure of tendons, especially to water infiltration and salt-laden air
- Include post-tensioning in "light residential construction" because corrosion is the same process regardless of the type of construction

REFERENCES

1. PTI, "SPECIFICATION for UNBONDED SINGLE STRAND TENDONS, 2nd Edition," Post-Tensioning Institute, Phoenix, AZ, December 2000.
2. ACI Committee 423, "ACI 423.6-01, Specification for Unbonded Single-Strand Tendons and Commentary," American Concrete Institute, Farmington Hills, MI, October 2001.
3. PTI, "Addenda to the Specification for Unbonded Single Strand Tendons, 2nd Edition," Post-Tensioning Institute, Phoenix, AZ, November 2003.
4. PTI, "Addendum #2, Addenda to the Specification for Unbonded Single Strand Tendons, 2nd Edition," Post-Tensioning Institute, Phoenix, AZ, March 2007.

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