CHALLENGES FOR THE POST-TENSIONING INDUSTRY

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INTRODUCTION

Unbonded post-tensioning is one of the most important construction methods available today. It is an efficient structural system that has successfully been used worldwide in construction, offering a wide range of advantages and benefits for large as well as small projects. Unbonded tendons are used in all areas of construction, including new construction, repair, rehabilitation, and retrofit. Project applications range from residential slab-on-ground to parking structures to high-rise condominiums. Structural members are primarily slabs, beams, joists, and girders; however, unbonded tendons have also been used in walls and columns.[1]

The use of unbonded post-tensioning became common during the late 1950s and early 1960s as progress was made in establishing design and materials standards.[2] Bondy[3] notes that parameters for prestressed concrete were first included in the 1963 edition of the ACI Building Code. The post-tensioning industry has progressed significantly over the years and in 2012, Bondy[4] noted that "in the United States alone, it is estimated that there are 2.5 billion square feet of two-way post-tensioned slabs with unbonded tendons in service" and this is only in buildings. Indeed, unbonded post-tensioning is the method of choice for a variety of construction applications.

The construction industry as a whole has found it necessary to address corrosion problems with all types of construction. Despite the great benefits and widespread use of unbonded post-tensioning, there are still occasional issues with corrosion that must be tackled. As Bondy[3] noted, "without a doubt the biggest problem ever faced by the (post-tensioning) industry was tendon corrosion." ACI 423.4R-14[2] notes that even with corrosion problems "there are no recorded incidents of sudden collapse of structures using unbonded tendons while the structure is in service" and "demolition of these structures has shown that they possess greater reserve of strength than is shown by structures that are not post-tensioned"—this is a strong declaration for post-tensioned structures that most other construction methods cannot claim. This does not mean that structures constructed with unbonded tendons should get a free pass; to the contrary, the industry must continue to be proactive in addressing issues as they have consistently done in the past.

As all industries progress, challenges arise—the unbonded post-tensioning industry is no different. Specifications and codes continue to evolve based upon lessons learned. Owner's and designer's stipulations adjust as their requirements change. Advancements in materials require modifications to processes. These changes create challenges that any industry must address.

This article identifies three current challenges that the unbonded post-tensioning industry must address. For each challenge, it examines the issue, progression of specifications and codes, and lessons learned. Past practices can become outdated due to quality requirements and perceptions that continue to change; these processes must be examined for improvements.

The unbonded post-tensioning industry as a whole needs to consider these perceived issues that may or may not create problems for the future. Continual improvement may be a buzzword but in this case it is apropos. The industry needs to put on its collective thinking cap to provide simple solutions to these sometimes complex challenges.

CHALLENGE: SHEATHING SHRINKAGE

The sheathing shrinkage challenge is to prevent sheathing from slipping out of or moving within the encapsulation sleeves, resulting in an overlap that is less than that required by the specifications.

It is important to maintain the sheathing from anchorage to anchorage, as described by industry specifications. PTI M10.2-93,[5] published in 1993, and PTI

M10.2-00,[6] published in 2000, state that the "tendon covering shall be continuous over entire length to be unbonded." ACI 423.6-01[7] states that the "tendon sheathing shall be continuous over the entire length"; this was somewhat modified by ACI 423.7-07[8] to "sheathing shall be continuous"; and further modified by ACI 423.7-14[9] to "watertight and impermeable to water vapor over entire sheathing length."

As far back as 1985, PTI M10.2-85[10] introduced for corrosive environments what is now called encapsulated tendons by requiring "design features permitting a watertight connection of the sheathing to the anchorage." In 2011, PTI amended PTI M10.2-00[6] to require encapsulated anchorages in all applications governed by ACI 318; in 2014, ACI followed PTI's lead in ACI 423.7-14.[9]

PTI M10.2-93[5] included a criterion that the watertight connection sustains a hydrostatic water pressure of 1.25 psi (8.62 kPa) for 24 hours. This requirement is still in place today in current PTI and ACI Specifications. Basically, there must be some kind of a seal at the end of the sleeve that maintains the watertight connection. Tape was allowed as a component in PTI M10.2-00,[6] ACI 423.6-01,[7] and ACI 423.7-07[8] for encapsulation systems as long as they passed the hydrostatic water pressure test. In ACI 423.7-14,[9] tape is no longer referenced as an acceptable component of encapsulation systems. This author notes that tape may be adequate in a laboratory situation but in the field, a seal is virtually impossible to achieve with tape.

PTI M10.2-00[6] added specific requirements that sleeves "should be designed to be as void-free as possible" while ACI 423.6-01[7] and ACI 423.7-07[8] say "designed to be void-free." This created some industry troubles, as many of the encapsulation sleeves at the time had large voids which now required filling with PT coating. But at the same time, it forced innovation to reduce the voids to make a more convenient system for ironworkers that would not have to be filled with PT coating, such as the GTI Zero Void System®, introduced in 1997, that relies on seals to maintain watertightness, and was designed to be as void-free as possible. ACI 423.4R-14[2] states that a push-through post-tensioning system requires the sheathing to be sufficiently oversized to insert the strand; and this resulted in a tendon with many air voids. Schupak,[11] in his article on corrosion of unbonded tendons, notes that with push-through sheaths

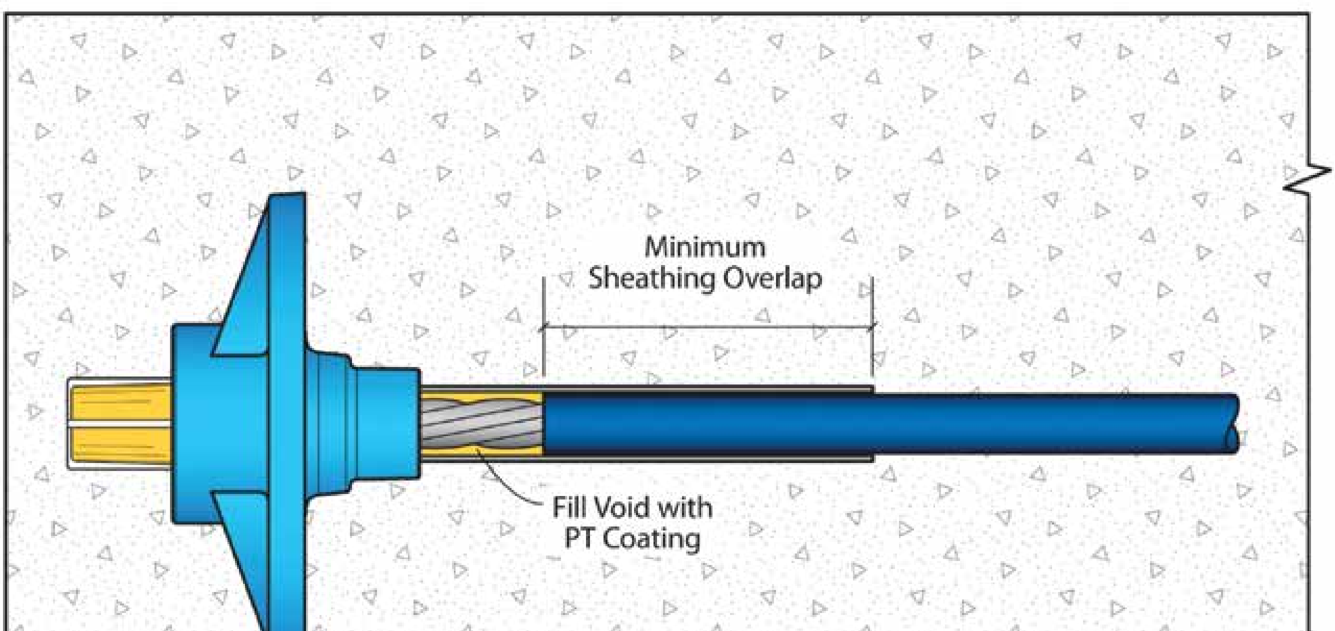

Fig. 1—Minimum sheathing overlap.

there were more incidents of corrosion and that the annular space (void) further exacerbated corrosion problems. Voids in sleeves of a post-tensioning system can allow moisture (or water) to collect during storage, shipping, and installation. Over time, this can lead to corrosion problems and possibly failure of the post-tensioning tendon.

ACI 423.7-14[9] further defined the sleeves connecting the sheathing to the anchorage by stating "within the connecting component or enclosure, either the prestressing steel shall be covered by sheathing for its full length, or the annular space between the sleeve and the strand shall be filled with PT coating." The intent is to eliminate any void within the sleeve. This author believes the industry needs to move forward and eliminate areas that may lead to future corrosion problems.

A minimum overlap of 4 in. (102 mm) between the end of the sheathing and the end of the sleeve was also required by PTI M10.2-00,[6] ACI 423.6-01,[7] ACI 423.7-07,[8] and ACI 423.7-14[9] to allow for movement of the sheathing. Why does the sheathing move? There are two primary reasons: thermal movement and release of internal plastic stresses after unbonded tendons have been placed. The thermal movement of plastic and prestressing steel is different—the plastic sheathing will move more. The sheathing contains residual internal plastic stresses from manufacture which, when the tendon is laid flat, causes sheathing to shrinkage. Figure 1 shows the minimum sheathing overlap at an encapsulated anchorage.

Why is this sheathing shrinkage an issue now? As PTI and ACI specifications have evolved, requirements for sheathing thickness have increased from 0.25 to 0.50 in. (6 to 13 mm). During the post-tensioning extrusion process, the sheathing is coiled before it is cooled. Many post-tensioning extrusion lines contain the same cooling troughs that were used with the thinner sheathing. Thus, packs of extruded cable are coiled at higher temperatures today and after cooling to room temperature contain greater residual internal plastic stresses then before. When the sheathing is stripped at fixed ends or laid out on a deck, the sheathing is at a different temperature than when manufactured. From research and testing done by the author in 2008, the movement of plastic sheathing can be approximated by calculation to be around 5/8 in. per 100 ft (16 mm per 30 m) for each 10°F (5.6°C) difference in temperature from extrusion coiling to laying out at a jobsite. Sheathing shrinkage is not as noticeable with pull seating fixed-end anchorages (for standard systems and older encapsulation systems) because the sheathing is already stripped away 8 to 10 in. (200 to 250 mm). Modern encapsulation systems use push seating and the sheathing is cut close to the anchorage so any movement is more noticeable. At stressing ends, inaccurate precutting of sheathing without taking into consideration the actual thermal shrinkage can create issues with the required overlap. After uncoiling of tendons, excessive "whipping" to straighten out tendon alignment can boost the release of internal stresses, which will cause further retraction of the sheathing along the tendon.

Challenge: sheathing shrinkage

The industry must develop a product, technique, or method to hold/retain the sheathing at fixed ends of unbonded tendons and to allow sheathing at stressing ends of unbonded tendons to pass through anchorages and be removed only prior to stressing.

CHALLENGE: STRESSING POCKET

The stressing pocket challenge is to install a grout plug that will stay in place and retain its position, thus protecting the stressing-end anchorage from water possibly contaminated with chlorides and from fire exposure.

How is a stressing pocket formed and what is its function? A stressing pocket is a void created by a pocket former between the stressing anchor and the edge of the concrete to allow access for the stressing equipment. After stressing, this void is filled in with an approved cementitious patch material to provide protection for the tendon end.[12] The stressing pocket patch is the first line of defense for protecting stressing anchorages; quality stressing pocket patches are essential for the long-term durability of the post-tensioning system.[13]

Recently, stressing pocket patches have come to the forefront of challenges in unbonded post-tensioning. This was identified as one of the reasons for the recent demolition of the McGuire Apartments in Seattle. Post[14] states that "McGuire's problems center around corrosion of steel tendons at stressing-end anchors due to a lack of corrosion-resistant paint and non-shrink grout." Discussions with several engineers familiar with the project imply that inadequate bond between the patch and concrete was a major culprit. In 1991, Schupak[11] cautioned that stressing pocket patches that are not adequately bonded to the concrete can form a working cold joint that can transmit water and said that "in his experience poor end-anchorage protection has been a common cause of tendon failure."

PTI M10.2-85[10] specified that "prior to installing the pocket mortar, the inside concrete surfaces of the pocket shall be coated or sprayed with a resin bonding agent." PTI

M10.2-93[5] added a stipulation to clean the inside surfaces of the pocket to remove laitance or grease, thus enhancing bond. Prior to applying any bonding agent to the concrete surface of the stressing pocket, PTI FAQ No. 11[13] states that the surface "should be free of PT coating, grease, form release agents, dirt, loose concrete, debris, or any deleterious material," otherwise the performance of the bonding agent may be negated.

Stressing pockets are filled with a cementitious patch material, usually mixed on site out of cement, sand, and water. Sometimes prepackaged products are used and sometimes anything available on the project is used. PTI Specifications have evolved over the years; PTI M10.2-85[10] specified "nonshrink mortar," and PTI M10.2-93[5] and PTI M10.2-00[6] specified "non-metallic non-shrink grout." Since 2001, ACI specifications have maintained "non-metallic non-shrink grout"; the identical term is in ACI 423.6-01[7] and ACI 301-10.[15] The terms evolve but the meaning remains—a good patch material is needed to protect the anchorage.

What is the primary issue? It seems bonding of the patch material to the concrete structure is critical because many times the patch material shrinks away from the pocket. How can this occur with a "non-shrink" material? PTI FAQ No. 11[13] says it best:

In reality, there are no nonshrink cementitious grouts but, rather, shrinkage compensating grouts that expand in either the plastic and/or the hardened states to counteract the effects of shrinkage. These are high-quality grout materials that work well in confined spaces such as beneath base plates; however, in the application of a stressing pocket patch where the grout is unconfined, no benefit is derived from its shrinkage compensating properties.

Schupak[11] says that "corrosion found in unbonded tendons can be related to inadequate protection of end-anchors." Schupak[11] also noted and ACI 423.4R-14[12] reiterated that defects in the anchorage region can be caused when "anchorage pocket plug shrinks and becomes loose" due to poor bond, which permits "aggressive materials access to anchorage and prestressing steel" (refer to Fig. 2). The patch shrinking away allows water possibly contaminated with chlorides to penetrate into the anchorage or the patch can completely fall out, leaving the anchorage exposed to the elements. This can become an issue for all

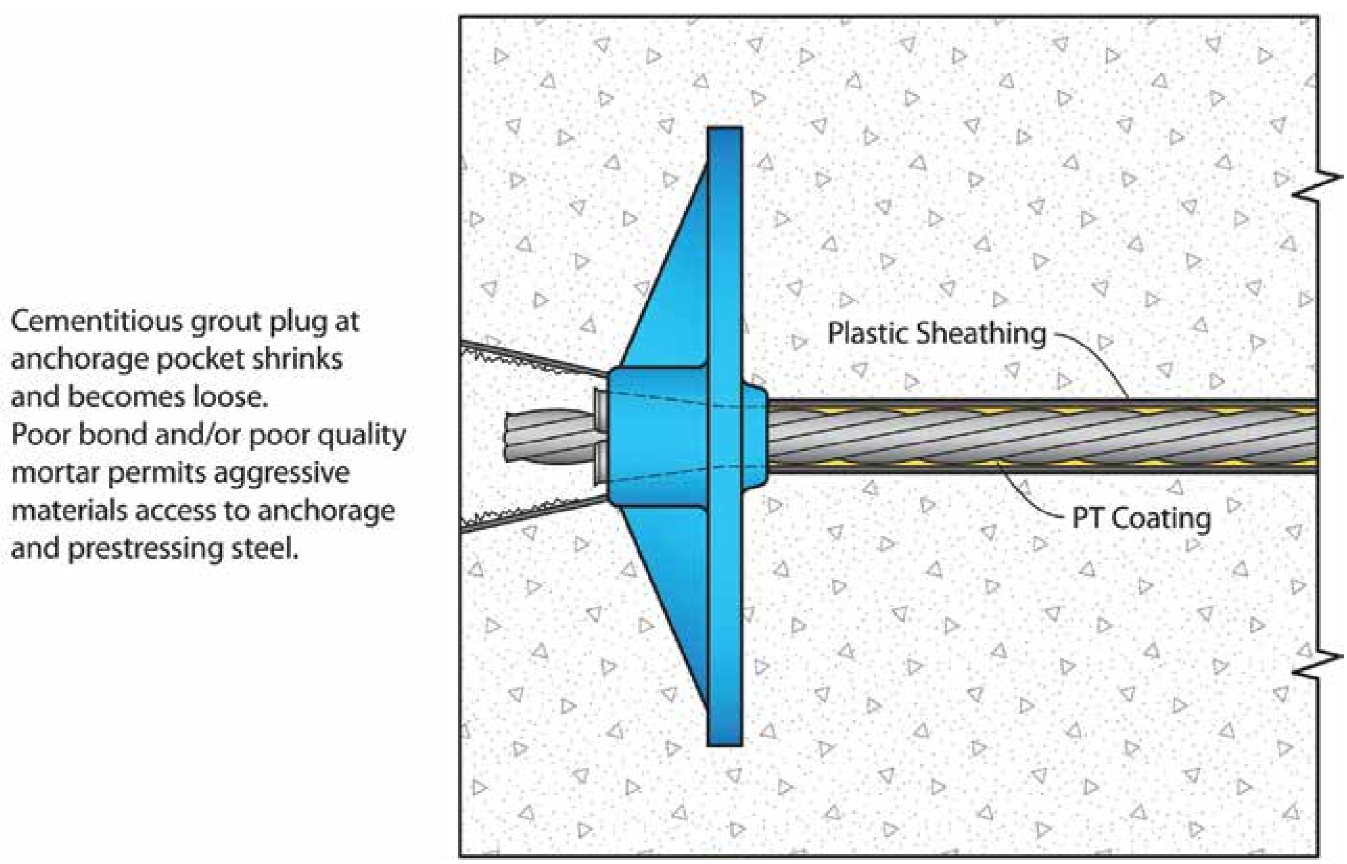

Fig. 2—Defects at pocket former patch.[2,12]

types of applications. Residential slab-on-ground foundations are particularly susceptible because their unbonded post-tensioning tendons typically do not have the added protection of tendon encapsulation.

Challenge: stressing pocket

The industry must develop a product, technique, or method to bond the patch material whereby the patch stays in place, eliminating avenues for water possibly contaminated with chlorides to attack the stressing ends of unbonded tendons.

CHALLENGE: WATER INTRUSION INTO ANCHORAGE DURING INSTALLATION

The water intrusion during the installation challenge is to protect the unbonded tendon anchorages from water getting into them during installation at the jobsite.

Unbonded post-tensioning anchorages consist of an anchor casting, prestressing steel, and steel wedge during construction and the encapsulation cap is only installed after the tendon is stressed, elongations are approved, and the tendon tail is cut off. All these components are, before the encapsulation cap is installed, susceptible to corrosion brought on by moisture/water or water possibly contaminated with chlorides, nitrates, or sulfides. During manufacture, shipping, and storage, protection of the tendon anchorages is readily achievable and commonly practiced; however, once the ironworkers start to install the tendons, protection of the anchorages is a challenge.

PTI M10.2-00,[6] ACI 423.6-01,[7] and ACI 301-10[15] all say encapsulated "components shall be protected within one working day after their exposure during installation" and "water shall be prevented from entering tendons during installation." From these specifications, it is apparent the industry believes that protection of the anchorage components is of paramount importance to the overall durability and corrosion protection of unbonded post-tensioning tendons.

Project jobsites are not protected from the elements: wind, rain, snow, and airborne contaminants. Many jobsites continue to work regardless of weather conditions. Projects near seacoasts are exposed to airborne salts. At project jobsites, unbonded post-tensioning tendons are brought from storage areas to the location (deck, beam, or slab) where they will be installed. Individual coiled tendons are typically banded into bundles. The bands on these bundles are cut and then the individual coiled tendons are taken to their proper location. Tie wire or plastic ties holding the individual coiled tendons are cut and the tendons are laid out along their specific tendon paths. The individual tendons typically have fixed-end anchorages installed in the plant when they will be stressed only from one end. Stressing-end anchors are individually attached to edge forms and then the tendons are "stabbed" into them. Sheathing may be stripped at stressing ends or not, depending on the processes used by the installer. After this, the tendons are "chaired up" into their specific tendon profile and then they are ready for inspection and concrete placement. This process of taking tendons from storage to concrete placement typically takes 2 to 3 days, but it could be completed in 1 day or take weeks.

How can moisture/water enter the anchorages? Once anchors are attached to edge forms and prior to tendons being "stabbed" into them, they are open to elements on the wedge cavity side and sleeves are open to the elements on the back side. Moisture and airborne contaminants have free access to metal components. After the individual tendons are inserted through the anchors, water can carry contaminants along the stressing tails into the anchorage components—sleeves can act as a reservoir retaining this fluid. This water intrusion route continues until tendons are stressed and anchorages are capped (encapsulated tendons) or stressing pockets are properly patched with the correct patch material according to specification requirements (standard tendons). Figure 3 shows how water can travel down the strand and wind can drive water possibly contaminated with chlorides, nitrates, or sulfides into anchorage components during construction; keep in mind that water and oxygen can begin the corrosion process.

Challenge: water intrusion into anchorage during installation

The industry must develop a product, technique, or method to protect tendons and anchorages from water intrusion once installation of unbonded tendons has begun on the jobsite.

CONCLUSIONS

As with all industries, the unbonded post-tensioning industry is not free of its share of challenges/issues/problems. Three distinct current challenges are presented for industry consideration. The author believes these challenges are all attainable. What will distinguish the best option to the challenge is the simplicity of the solution to achieve the desired results.

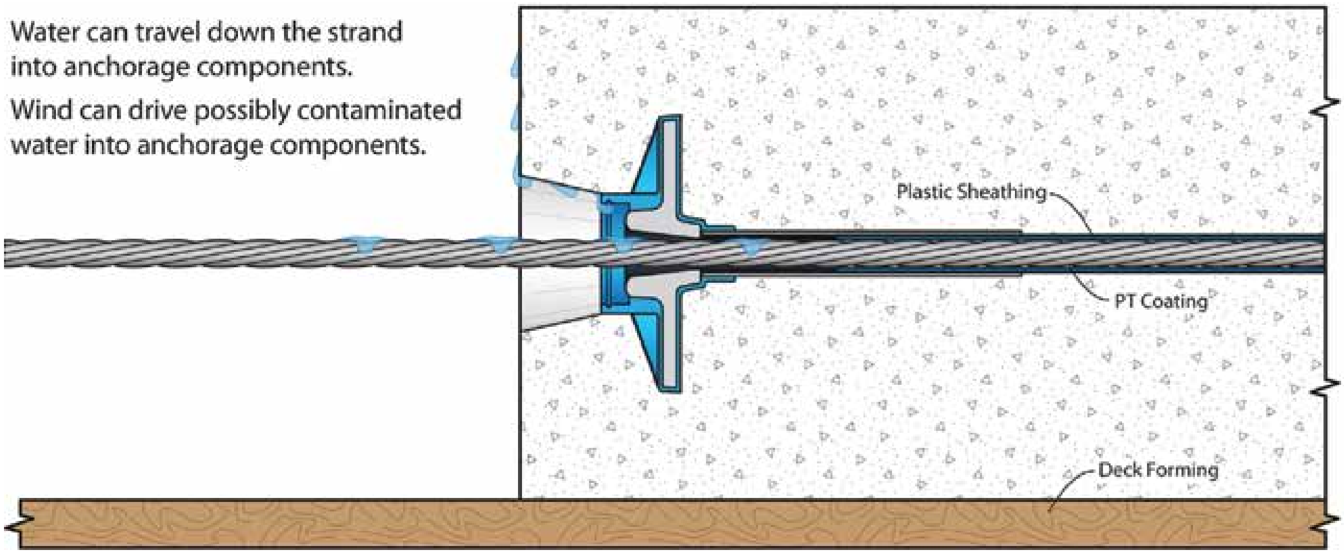

Fig. 3—Access to anchorage components.

For each challenge, background on the issue was presented, relevant PTI and ACI specification language was discussed, and possible root causes of the issues were reviewed. This foregoing information will be invaluable in assisting the industry in developing a solution to each challenge. The unbonded post-tensioning industry must develop a product, technique, or method to:

1. Hold/retain the sheathing at fixed ends of unbonded tendons and to allow sheathing at stressing ends of unbonded tendons to pass through anchorages and be removed only prior to stressing.
2. Bond the patch material whereby the patch stays in-place, eliminating avenues for water possibly contaminated with chlorides to attack the stressing-ends of unbonded tendons.
3. Protect tendons and anchorages from water intrusion once installation of unbonded tendons has begun on the jobsite.

This article presents three distinct challenges currently faced by the unbonded post-tensioning industry; there might be more to come. The industry cannot have perceived issues that foster doubts about unbonded post-tensioning that will affect its future use. Finding simple solutions to the challenges will enhance the overall quality of the entire post-tensioning experience. The industry needs to continue to be proactive as it has in the past and address all challenges as they arise. The unbonded post-tensioning industry must continually evolve and innovate to improve the quality of the post-tensioning projects.

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