ACHIEVING PROTECTION OF INTERNAL TENDONS THROUGH CONTINUOUS DUCT ENCLOSURES IN SEGMENTAL BRIDGE CONSTRUCTION

Larry B. Krauser

Abstract

Internal post-tensioning tendons are the primary structural element in segmental bridge construction. It is crucial that the tendon enclosure (duct) provide protection of the highly stressed post-tensioning steel. As construction proceeds there are discontinuities of the duct due to construction sequences. The duct must be adequately connected at the discontinuities to prevent ingress of unwanted corrosive elements.

This paper will examine post-tensioning duct materials and their ability to protect post-tensioning tendons from corrosive agents. It will provide examples of techniques to connect duct at precast segmental joints thus protecting tendons from water infiltration. It will show methods for achieving air and water tightness when connecting post-tensioning duct in cast-in-place segmental construction. Finally, the paper will present recommendations on best practices for achieving protection of internal post-tensioning tendon enclosures in segmental bridge construction.

Keywords: Tendons, post-tensioning, segmental duct couplers, tendon enclosures, corrugated plastic duct

1 What is an Internal Tendon Enclosure?

An internal tendon is a post-tensioning tendon that is encased in the concrete section of the structure; an internal tendon enclosure can be considered as an envelope (duct) enclosing the tensile element (prestressing steel) over its length. The duct covers the prestressing steel from anchorage to anchorage and is an essential element of tendon durability. In segmental bridge construction, discontinuities of the duct are created by segment joints.

2 Post-Tensioning Tendon Protection Levels

Internal post-tensioning tendons are the principal reinforcement in segmental concrete bridge construction and need to be designed and detailed to protect prestressing steels from corrosion and other deleterious factors. Identifying the degree to which a post-tensioning tendon is protected from corrosion and deterioration over time is defined as the tendon protection level (PL). Several documents define and categorize tendon PLs such as *fib* Bulletin 33, *Durability of post-tensioning tendons*[1] and draft of PTI/ASBI, *Guide Specification for Grouted Post-Tensioning*[2] along with

previous papers by the author *Post-Tensioning Tendon Protection Strategies for Precast Elements*[3], *Segmental Construction- Protecting Internal Post-Tensioning Tendons for 100-Year Service Life*[4], and *Selecting Post-Tensioning Tendon Protection Levels*[5]. These documents note the importance of the internal tendon enclosure (duct) along with good quality grout.

Selecting the required tendon PL for segmental projects is based upon the aggressivity of environment, exposure of structure or element, and protection provided by structure. Combination of the post-tensioning tendons' PL and protection provided by the structure together provides the resistance against the aggressivity of the environment and particular exposure conditions of the structural element.[1] It is clear that several elements are crucial in protecting prestressing steels from deterioration – the tendon enclosure (duct) and a means of maintaining duct continuity across segment joints along with quality grouting. These elements are vital in keeping contaminated water from accessing tendons and causing corrosion of the highly stressed steel.

3 Post-Tensioning Duct

Corrugated duct is the primary component of the tendon enclosure and is made out of two materials – corrugated metal and corrugated plastic. PL2 and PL3 require the use of corrugated plastic duct. For PL1 either corrugated metal or plastic duct may be used; however, there are valid reasons that only corrugated plastic duct should be utilized with precast segmental concrete construction.

Freyermuth in his 2007 introduction at ASBI Grouting Certification Training[6] makes note that for global durability protection robust plastic ducts should be used in segmental construction. The FHWA report on *Performance of Concrete Segmental and Cable-Stayed Bridges in Europe*[7] notes advantages of plastic "robust duct" are enhanced corrosion protection and increased durability, along with reduced friction losses. In Breen's paper on *Improving Corrosion Resistance of Post-Tensioning*[8], he makes the following points regarding duct type: superiority of plastic ducts was evident and all galvanized steel duct specimens showed some degree of corrosion.

Corrugated metal ducts, whether black steel or galvanized, quickly corrode once they are exposed to water and de-icing salts. Particularly vulnerable are zones which are not in direct contact with concrete or grout, e.g. zones underneath duct tape. Therefore, these ducts cannot be considered to represent an independent barrier for corrosion protection of prestressing steel.[1]

Post-tensioning tendons used in segmental concrete bridge construction are the principal reinforcement and should not be subjected to corrosion whether identified as PL1, PL2, or PL3. Due to the susceptibility of corrugated metal duct to corrosion in segmental construction and for redundancy of protection, the author recommends that robust corrugated plastic ducts be used for all tendon PLs. Today, there is little disparity in costs between corrugated metal and plastic duct while plastic duct provides significant improvement in the durability and quality of a structutre. [9]

Many types of corrugated plastic ducts have been used in post-tensioning applications including drainage pipes. Until *fib* Bulletin 7[9] was published in 2000, there were no standards for testing and inadequate materials were sometimes used giving plastic duct a flawed performance and quality reputation. Even today, ten years after publication, inferior materials are sometimes allowed on projects. Designers and owners are encouraged to require that all corrugated plastic duct for internal bonded post-tensioning applications be tested and affirmed to meet the requirements of *fib* Bulletin 7[9].

4 Precast Segmental Duct Couplers

Continuity of tendon enclosures should be maintained thru all joints per *fib* Bulletin 33[1]. Joints in precast segmental concrete bridges allow entry points for water (possibly contaminated with corrosive agents) to attack prestressing steel. Durable corrosion protection must be provided with any tendon PL.[3][4] In precast segmental construction, dry joints and internal tendons with discontinuous ducts are not acceptable for any tendon PL.[1] In evaluating the use of membranes or segmental duct couplers, membrane costs (including application, maintenance, expected life and re-

application) which can be significant[1] are evaluated against the one-time initial costs of the segmental duct coupler representing less than 3% of the total installed post-tensioning price. When total life-cycle costs are considered, using segmental duct couplers is usually more economical than membranes.[4]

In the research report *Final Evaluation of Corrosion Protection for Bonded Internal Tendons in Precast Segmental Construction*,[10] the authors conclude that segment joints leak regardless of joint type, noting that duct corrosion with dry joints was extremely severe, duct corrosion in sound epoxy joints was moderate to severe, epoxy joints with gaskets performed similar to those without gaskets, and in some cases the gaskets prevented the epoxy from adequately filling the joint area thus allowing moisture and chlorides to penetrate the joint.

Today, there are several manufacturers producing segmental duct couplers. When evaluating segmental duct couplers, designers and contractors should confirm their ability to create an airtight and watertight connection in addition to allowing correct alignment and positioning of ducts (15 degrees or more horizontal or vertical angle at some joints is necessary). From a constructability standpoint, segmental duct couplers need to be robust and user friendly for ease of installation at jobsites allowing field tolerance up to 6 mm in any axis. Segmental duct couplers must include the ability to maintain individual tendon integrity thereby preventing grout crossovers or epoxy leaking into the tendon.[11][12] Performance testing of segmental duct couplers is detailed in FDOT Post-Tensioning Specifications[13] and include at a minimum: sealing gasket compressive required force test, air pressure test, and assembly toughness test.

5 Cast-in-Situ Segmental Construction

Continuity of tendon enclosures should be maintained thru all joints per *fib* Bulletin 33[1]. Joints in cast-in-situ segmental concrete bridges allow entry points for water (possibly contaminated with corrosive agents) to attack prestressing steel. Durable corrosion protection must be provided with any tendon PL.[3][4] Maintaining durable corrosion protection for the tendons requires a watertight duct-to-duct connection for any PL. *fib* Bulletin 7[9] establishes testing requirements for the corrugated plastic duct system including duct-to-duct couplers. The essence of the performance testing is that the duct coupler will not allow intrusion of unwanted water into the post-tensioning system thus creating a watertight envelope. Mechanical connections and shrink sleeves with a slip-on coupler underneath are primarily used for duct-to-duct couplers; both have shown to perform adequately to the requirements of *fib* Bulletin 7[9]. Note that metal duct and typical metal duct couplers will not meet the leak tightness performance requirements of *fib* Bulletin 7[9].

6 Conclusions

Providing durable corrosion protection to post-tensioning tendons is a requirement of *fib* Bulletin 33 [1]. Protecting the continuity of the tendon enclosure is critical to achieving design service life for post-tensioning tendons in segmental bridge construction.

Corrugated plastic duct is recommended for tendon enclosures in segmental concrete bridges for any PL. PL1 allows the use of metal duct however research has found that even galvanized metal duct performs poorly in precast segmental concrete construction. PL2 and PL3 require the use of corrugated plastic duct. All corrugated plastic duct shall meet performance requirements of *fib* Bulletin 7[9].

Precast segmental duct couplers are recommended for continuity of tendon enclosures in precast segmental concrete bridges for any PL. Life-cycle costs should be considered when other options are proposed. Protecting tendons from water infiltration at vulnerable joints is essential. Performance testing of precast segmental duct couplers per FDOT Requirements[13] is recommended. Performance and constructability of precast segmental duct couplers should be considered prior to choosing a system.

Mechanical connections or shrink sleeves with a slip-on coupler underneath are recommended for continuity of tendon enclosures at duct-to-duct connections in cast-in-situ segmental concrete bridges for any PL. Even though the duct-to-duct coupler is not physically at the joint, contaminated water can infiltrate the joint and travel along the tendon duct to the connection. It is imperative to the long-term performance of the structure that duct-to-duct connections meets the testing requirements of *fib* Bulletin 7[9].

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Larry B. Krauser
✉ General Technologies, Inc.
13022 Trinity Drive
PO Box 1503
Stafford, TX 77477
USA
☎ +1 281 240 0550
🗐 +1 281 240 0990
☺ lkrauser@gti-usa.net
URL http://www.gti-usa.net/