EXECUTIVE SUMMARY

POST-TENSIONING TENDON PROTECTION STRATEGIES FOR PRECAST ELEMENTS

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Post-tensioning tendon protection strategies for precast elements is a complicated subject. The presentation simplifies the task by providing descriptions of available strategies including definitions of individual tendon protection levels (PLs).

Fédération Internationale du Béton (*fib*) recently published tendon protection strategies in *fib* Bulletin 33, "Durability of post-tensioning tendons". *fib* is the recognized international authority on concrete construction and develops codes, reports, recommendations, etc. Review of how to select PLs for post-tensioning tendons per *fib* Bulletin 33 is presented.

Precast elements have some additional requirements for protection of the post-tensioning tendons. Whether a precast segmental or spliced girder bridge project is being constructed, protection of the tendons at the interface of the elements is crucial. A discussion of solutions at this critical location is presented.

The first step of the strategy is to select the tendons' protection level (PL) based upon aggressivity of environment, exposure of structure or element, and protection provided by structure. It is the combination of the tendons' PL and protection provided by the structure that determines how durable the post-tensioning system (and the structure) will be.

Three post-tensioning tendon PLs are identified. They are:

1. PL1 is defined as a duct with grout providing durable corrosion protection.
2. PL2 is PL1 plus a watertight, impermeable envelope providing a leak tight barrier.
3. PL3 is PL2 plus integrity of tendon or encapsulation to be inspectable or monitorable.

Corrugated plastic duct and a segmental duct coupler are recommended for precast segmental concrete construction. These components provide for durable corrosion protection that is required with any tendon PL. Background provided on performance of galvanized corrugated metal duct for segmental construction does not justify its use even for PL1.

A duct-to-duct coupler meeting specific water-tightness requirements along with corrugated plastic duct is recommended for precast spliced girder construction. This combination provides the desirable durable corrosion protection required for all tendon PLs. Metal duct and metal duct couplers will not provide the leak tightness that is necessary for durable corrosion protection.

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INTRODUCTION

Post-tensioning tendon protection strategies for precast elements is a complicated subject. This paper simplifies the task by providing the reader with descriptions of available strategies including definitions of individual tendon protection levels (PLs).

Fédération Internationale du Béton (*fib*) recently published tendon protection strategies in *fib* Bulletin 33, "Durability of post-tensioning tendons"(1). *fib* is the recognized international authority on concrete construction and develops codes, reports, recommendations, etc. Review of how to select PLs for post-tensioning tendons per *fib* Bulletin 33(1) is presented. Specific PLs for all types of structures including precast elements are similar.

Precast elements have some additional requirements for protection of the post-tensioning tendons. Whether a precast segmental or spliced girder bridge project is being constructed, protection of the tendons at the interface of the elements is crucial. A discussion of solutions at this critical location is presented.

TENDON PROTECTION STRATEGIES

The majority of information presented in this section comes from *fib* Bulletin 33(1). In the past, causes of deterioration in post-tensioned structures have been identified as weak links found either in external protection layers provided by various structural components or in the corrosion protection of the tendons themselves. The objective of the following strategy is to select the PL of the post-tensioning tendons based on: aggressivity of environment, exposure of structure or element, and protection provided by structure.

Combination of the post-tensioning tendons' PL and the protection provided by the structure together provides the resistance against the aggressivity of the environment and particular exposure condition of the structural element.

IDENTIFYING AGGRESSIVITY OF THE ENVIRONMENT(1)

In order to provide information on entry points for aggressivity and exposure, *fib* Bulletin 33(1) references EN 206-1(2). It defines the classification of principal environments to which concrete structures are exposed and the corrosivity of these environments.

For post-tensioned structures, six classes of aggressivity are considered:

1. No risk of corrosion or attack: X0
2. Corrosion induced by carbonation: XC
3. Corrosion induced by chlorides other than from sea water: XD
4. Corrosion induced by chlorides from sea water: XS
5. Freeze/thaw attack with or without de-icing agents: XF
6. Chemical attack: XA

Table 1 – Aggressivity level and exposure examples as entry points.(1)

Aggressivity	Class Designation	Description of Environment	Examples where exposure classes may occur
	No risk of corrosion or attack		
Low	X0	For concrete without reinforcement or embedded metal: all exposures except where there is freeze/thaw, abrasion or chemical attack. For concrete with reinforcement or embedded metal: very dry.	Concrete inside buildings with very low air humidity
	Corrosion induced by carbonation		
Low ↕ Medium	XC1	Dry or permanently wet	Concrete inside buildings with very low air humidity Concrete permanently submerged in water
	XC2	Wet, rarely dry	Concrete surfaces subjected to long-term water contact Many foundations
	XC3	Moderate humidity	Concrete inside buildings with moderate or high air humidity External concrete sheltered from rain
	XC4	Cyclic wet and dry	Concrete surfaces subject to water contact, not within exposure class XC2
	Corrosion induced by chlorides other than from sea water		
Medium ↕ High	XD1	Moderate humidity	Concrete surfaces exposed to airborne chlorides
	XD2	Wet, rarely dry	Swimming pools Concrete exposed to industrial waters containing chlorides
	XD3	Cyclic wet and dry	Parts of bridges exposed to spray containing chlorides Pavements Parking structure decks
	Corrosion induced by chlorides from sea water		
High	XS1	Exposed to airborne salt but not in direct contact with sea water	Structures near to or on the coast
Medium	XS2	Permanently submerged	Parts of marine structures
High	XS3	Tidal, splash and spray zones	Parts of marine structures

Aggressivity	Class Designation	Description of Environment	Examples where exposure classes may occur
	Freeze/thaw attack with or without de-icing agents		
Medium	XF1	Moderate water saturation without de-icing agent	Vertical concrete surfaces exposed to rain and freezing
High	XF2	Moderate water saturation with de-icing agent	Vertical concrete surfaces of road structures exposed to freezing and airborne de-icing agents
Medium	XF3	High water saturation without de-icing agent	Horizontal concrete surfaces exposed to rain and freezing
High	XF4	High water saturation with de-icing agent	Road and bridge decks exposed to de-icing agents Concrete surfaces exposed to direct spray containing de-icing agents and freezing Splash zones of marine structures exposed to freezing
	Chemical attack		
Medium	XA1	Slightly aggressive chemical environment	
Medium-High	XA2	Moderately aggressive chemical environment	
High	XA3	Highly aggressive chemical environment	

IDENTIFYING PROTECTION PROVIDED BY THE STRUCTURE[1]

Protection provided to tendons by individual construction details are an integral part of an overall project's protection scheme. The level of protection provided by construction details can be minimal up to the best possible available protection. The designer should consider the following construction details together when identifying protection provided to the structure.

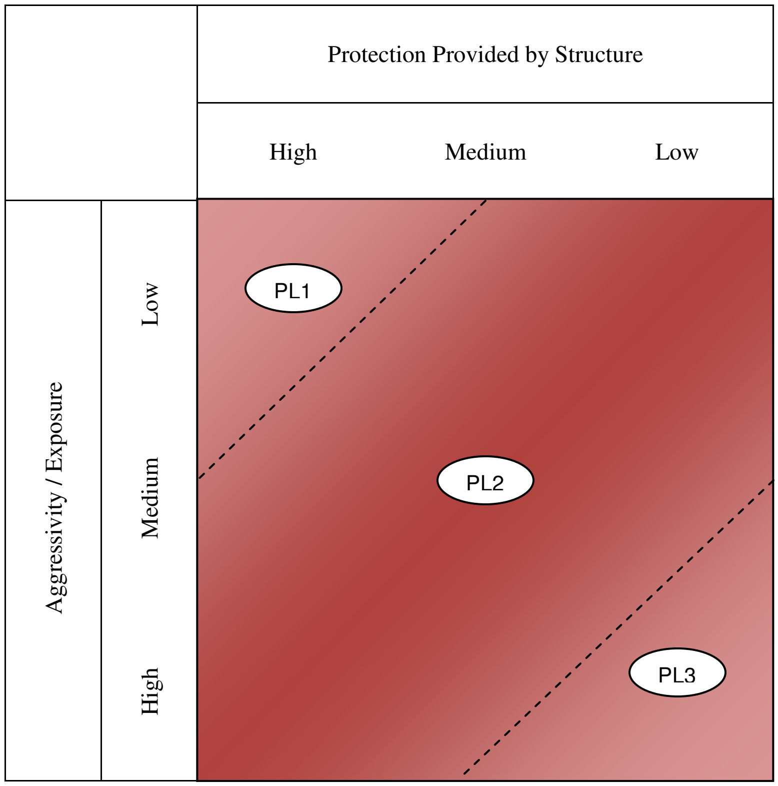
- Concrete quality and cover
- Waterproofing systems and other surface protection systems
- Drainage system details
- Expansion joint details
- Concrete cracking
- Construction joint details
- Segment joint details
- Tendon layout details
- Access for inspection and maintenance

For the structure to qualify for a "high" rating in overall structural protection, all above mentioned details would need to have optimum protection schemes. This total structure rating should be used when determining tendon PLs.

SELECTING PROTECTION LEVELS[1]

Selecting PLs for a specific project requires that the aggressivity of the environment attacking the prestressing element ("low" – "high") is identified; see Table 1. Then the protection provided by the structure ("low" – "high") is identified. Once these two tasks are completed, the PL for a specific situation can be selected by using Table 2. The combination of the structural protection level and the tendons' PL provide the resistance against the aggressivity of the environment.

Table 2 – Protection levels for post-tensioning tendons based on aggressivity/exposure versus protection provided by structure.[1]



PROTECTION LEVELS (PL) [1]

fib Bulletin 33[1] identifies three PLs providing basic parameters for each. PL1 is defined as a duct with filling material (grout) providing durable corrosion protection. PL2 is PL1 plus a watertight, impermeable envelope providing a leak tight barrier. PL3 is PL2 plus integrity of tendon or encapsulation to be inspectable or monitorable.

Initial costs for post-tensioning systems increase from PL1 to PL3. However, this increase in initial overall structure costs is relatively minimal and consistently beneficial when evaluating the life-cycle costs of the structure.[1]

Protection Level 1 (PL1)

- Duct sufficiently strong and durable for fabrication, transportation, installation, concrete placement and tendon stressing
- Duct sufficiently leak tight for concrete placing and grout injection

- Duct material non-reactive with concrete, prestressing steel, reinforcing steel, and tendon grout materials
- Grout to be chemically stable, non-reactive with prestressing steel and duct
- Grouting procedures to leave no voids in duct
- Example 1: bare strand + corrugated metal duct + cement grout
- Example 2: bare strand + corrugated plastic duct + cement grout or other filling materials (anchorage zone non-encapsulated)

Protection Level 2 (PL2)

- In addition to PL1
- Corrugated plastic duct to be watertight and impermeable to water vapor over entire length including connections (segmental duct couplers required in segmental construction)
- Corrugated plastic duct material to be chemically stable without embrittlement or softening during anticipated exposure temperature range and service life (no free chloride ions extractable from material)
- Anchorage components to have an enclosure that is watertight and impermeable to water vapor (encapsulated)
- Example: bare strand + corrugated plastic duct + cement grout or other filling materials + encapsulation of anchorage zone

Protection Level 3 (PL3)

- In addition to PL2
- Have a demonstrated means to inspect or monitor tendons for integrity and/or corrosion
- Example: bare strand + corrugated plastic duct + cement grout or other filling materials + encapsulation of anchorage zone + inspection or monitoring

PRECAST ELEMENTS

Post-tensioned, precast elements are used on many highway projects. This includes precast segmental concrete bridges and spliced girder bridges along with other types of applications. In general, post-tensioning tendon protection strategies are identical to that of cast-in-place concrete construction. However, when using precast elements, there are additional requirements that involve maintaining integrity of tendons across the joint between precast elements.

Precast element joints, whether match cast (segmental construction) or a wet joint (spliced girder), invite attack to the prestressing steel by corrosive elements. Thus, additional measures need to be undertaken at these locations. This is essential with all PLs; even PL1 requires "durable corrosion protection"(1).

PRECAST SEGMENTAL CONCRETE CONSTRUCTION

Joints of precast segmental concrete bridges allow for entry points for water (possibly contaminated with corrosive agents) to attack prestressing steel. Durable corrosion protection must be provided with any tendon PL. Additionally, it is recommended that the continuity of tendon enclosure to be maintained thru all joints.

In segmental construction, precast concrete elements are typically prefabricated using match cast techniques. When erected, joints between these segments are buttered with epoxy and segments clamped together using temporary post-tensioning tendons. The ability of water borne contaminants to attack permanent post-tensioning tendons through joints causes concern in this type of construction. As noted in *fib* Bulletin 33[1], preventing water intrusion into the duct enclosure at the joint can only be met if a proper system provides this function. Today, there are components available that create an air and watertight connection allowing correct alignment and positioning of the duct. Segmental duct couplers must include the ability to maintain individual tendon integrity therefore preventing grout crossovers or epoxy leaking into the tendon.[3, 4]

Figure 1 shows one such segmental duct coupler that is currently being used worldwide and on several precast segmental bridge projects in the United States. It offers the ability to maintain tendon alignment up to 15 degrees and allows field tolerances up to 1/4” in any axis.[3, 4]

Figure 1 – GTI Precast Segmental Duct Coupler.[4]

Per the PLs identified previously, PL2 and PL3 require the use of corrugated plastic duct. For PL1 either corrugated metal or plastic duct may be used; however, there are several valid reasons that only corrugated plastic duct should be utilized with precast segmental construction. The first is that even though a waterproofing membrane may be used, it often does not provide a complete seal and does not last indefinitely, and joints still leak.[1] Freyermuth in his 2007 introduction at ASBI Grouting Certification Training[5] 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*[6] 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*[6], he makes the following points regarding duct type in his segmental testing:

- Superiority of plastic ducts was evident. Specimens with plastic duct had the best overall performance (quantified in terms of strand, mild steel and duct corrosion).
- All galvanized steel duct specimens showed some degree of duct corrosion: twelve had duct destruction and pitting, two had severe uniform corrosion and one had moderate uniform corrosion.

Breen[6] makes another statement about ducts in his post-tensioned beam corrosion test series: "The galvanized steel ducts performed poorly. Typically they corroded severely with gaping holes. In many cases, the ducts completely corroded away across several inches. Therefore, galvanized steel ducts should not be used in aggressive environments."

PRECAST SPLICED GIRDER CONSTRUCTION

Precast spliced girder construction also allows entry points for water (possibly contaminated with corrosive agents) to attack prestressing steel at joints. Durable corrosion protection must be provided with any tendon PL. Additionally, it is recommended that the continuity of tendon enclosure to be maintained thru all joints.

In spliced girder construction, multiple precast girders are placed end-to-end with post-tensioning tendons provided for structural continuity. Typically, on these projects, the individual girders are set on falsework and a wet joint is placed between girders. The width of wet joint varies and allows for attaching post-tensioning duct from each element, maintaining the integrity of the tendon.

Maintaining durable corrosion protection for the tendons requires a watertight duct connection for any PL. This can be sustained by using a coupler tested per the requirements of *fib* Bulletin 7[8]. This report identifies performance requirements for flexibility of duct (4.1.3), lateral load resistance of duct (4.1.4), longitudinal load resistance of duct system (4.1.5), and leak tightness of duct system (4.1.6). 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.

Figure 2 shows a duct-to-duct coupler meeting the requirements of *fib* Bulletin 7[8]. This coupler is used to attach two pieces of corrugated plastic duct in the wet joint or anywhere along the tendon path. Depending on the size of the wet joint and how far the cast-in corrugated plastic duct is exposed, this coupler could be used at both ends with a connecting piece of corrugated plastic duct.

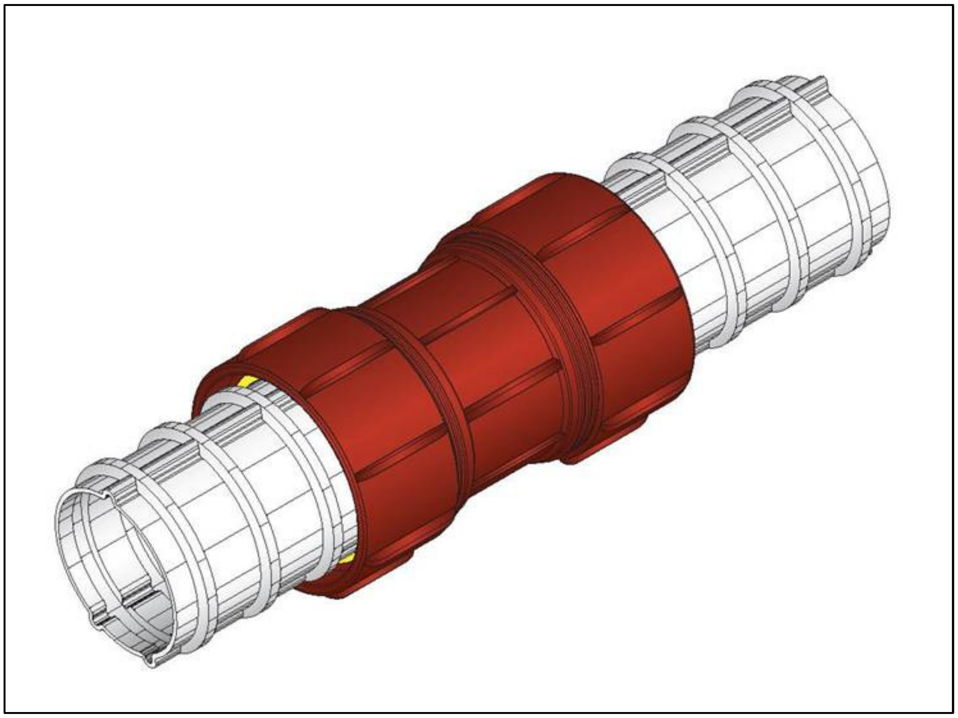


Figure 2 – GTI Twist-Lock Duct Coupler.

Corrugated plastic duct should be utilized for spliced girders with any tendon PL for the same reasons as identified with precast segmental construction. Note that metal duct and metal duct couplers will not meet the leak tightness performance requirements of *fib* Bulletin 7[8]. Even though *fib* Bulletin 7[8] requirements are for corrugated plastic duct, the leak tightness test is a measure of the ability of any duct coupler to prevent water intrusion.

CONCLUSIONS

Post-tensioning tendon protection strategies for precast elements are similar to those used for cast-in-place construction with a few additional details required. The first step of the strategy is to select the tendons' protection level (PL) based upon aggressivity of environment, exposure of structure or element, and protection provided by structure. It is the combination of the tendons' PL and protection provided by the structure that determines how durable the post-tensioning system (and the structure) will be.

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A duct-to-duct coupler meeting specific water-tightness requirements along with corrugated plastic duct is recommended for precast spliced girder construction. This combination provides the desirable durable corrosion protection required for all tendon PLs. Metal duct and metal duct couplers will not provide the leak tightness that is necessary for durable corrosion protection.

REFERENCES

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