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SELECTING POST-TENSIONING TENDON PROTECTION LEVELS

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Abstract

Post-tensioning is the primary structural element used in many of today's structures. These structures vary from utilitarian to some of the most elegant imaginable. Design lives of the structure also vary, but the constant between them is the necessity to protect post-tensioning tendons from corrosion.

This paper will review and discuss pertinent requirements for post-tensioning tendons contained in Fédération International du Béton (fib) Bulletins. Information on accessing the aggressivity of the environment, exposure of the structure or element, and classifying the protection provided by the structure will be examined. Selecting the proper post-tensioning protection level will be reviewed with examples. Finally, identifying components required of post-tensioning systems for proper tendon protection levels will be presented.

Keywords: Tendons, post-tensioning, protection levels, corrugated plastic duct, monitoring

1 Introduction

Post-tensioning tendon protection level (PL) identifies the degree to which a post-tensioning tendon is protected from corrosion and deterioration over time. There are several documents that refer to 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] and *Segmental Construction-*

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Protection Internal Post-Tensioning Tendons for 100-Year Service Life[4]. This paper will lead the reader through the process of selecting the correct PL for their structure. *fib* Bulletin 33[1] lays the groundwork for selecting PLs; this paper organizes that information into an easy to understand process.

Designers are aware that structures must remain durable and fit for use during their design service life. One way to achieve this is using post-tensioning materials that, if well maintained, will not degenerate during this time.[5] Protecting post-tensioning tendons from external corrosive sources such as water, oxygen, airborne chlorides, and the infiltration of de-icing chemicals is of prime importance.[1]

Weak links in either external protection layers provided by various structural components or in corrosion protection of individual tendons can lead to deterioration of post-tensioned structures. The leading cause of deterioration in post-tensioned structures is chloride attack. Transport mechanisms for chlorides are influenced by combined effects of wind, water, and temperature.[1] Eliminating avenues for corrosive agents to enter tendons will prevent the attack on the highly stressed steel. How does contaminated water reach and attack tendons? Per Matt[6] the following are potential "weak points" where water (possibly contaminated with chlorides) can gain access to tendons and cause corrosion:

- Failure of external barriers:
  - Defective wearing course (e.g. cracks)
  - Missing or defective waterproofing membrane, including edge areas
  - Defective drainage intakes and pipes
  - Wrongly placed outlets for drainage of wearing course and waterproofing
  - Leaking expansion joints
  - Cracked and leaking construction or element joints
  - Inserts (e.g. for electricity)
  - Defective concrete cover
- Failure of tendon corrosion protection system:
  - Partly or fully open grouting inlets and outlets (vents)
  - Leaking, damaged metallic ducts mechanically or by corrosion
  - Cracked and porous pocket concrete
  - Grout voids at tendon high and low points

The objective of the process is to select the PL of 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 conditions of the structural element.[1]

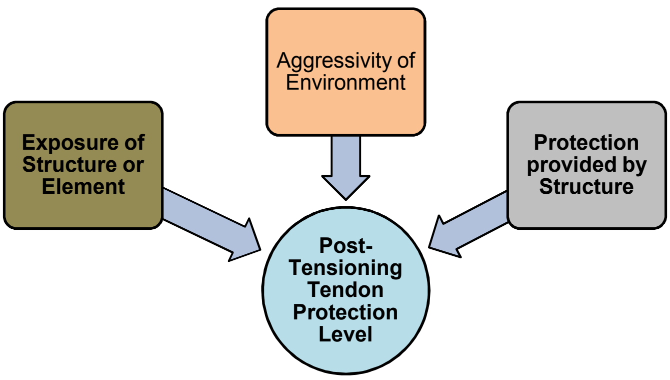

Fig. 1 Process of Selection Post-Tensioning Tendon Protection Level

2 Identifying Aggressivity of the Environment

In order to provide information on entry points for aggressivity and exposure, *fib* Bulletin 33[1] references EN 206-1[7]. It defines classifications 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

Aggressivity of the environment is used in determining the tendons' PL. Classification X0 provides a "low" aggressivity rating and requires a very dry environment. Classification XC varies from "low" for dry or permanently wet to "medium" for cyclic wet and dry. Classification XD yields a "medium" rating with moderate humidity up to a "high" rating with cyclic wet and dry. Classification XS designates "medium" when exposed to airborne salt gradually increasing to "high" in splash and spray zones. Classification XF is "medium" for freeze/thaw without deicing agents and "high" for freeze/thaw with deicing agents. Classification XA varies from "medium" for slightly aggressive chemical attack to "high" for highly aggressive chemical attack.

Designers should realize that the only areas with "low" aggressivity are when there is no risk of corrosion in a very dry environment (X0) or when corrosion is induced by carbonation and the environment is dry or permanently wet (XC1). There are many more possibilities for classifying an environment's aggressivity as "medium" or "high". Refer to **Tab. 1** in the next section for more detailed information.

3 Identifying Exposure of Structure or Element

The exposure of a structure or element is critical in determining the correct PL to use for the structure's tendons. **Tab. 1** identifies examples of where exposure classes may occur. In a specific structure there may be multiple exposure classes. The author recommends that the worst case be used in determining the tendon PL.

It is not practical to have various tendon PLs on one structure. Based upon the author's experience, post-tensioning material costs vary slightly from PL1 to PL3 in increments of 5-15% per PL. Labor costs are marginally higher per PL. However, mixing PLs on a structure can cause confusion and add to costs because several systems are used and labor learning curves are not as efficient. Quality control and inspection costs increase for the same reasons. Utilizing the same PL for the entire structure will simplify detailing, installation, and inspection of the post-tensioning system. It will provide the designer with confidence that the design life of the structure will not be compromised by using an incorrect PL for the most critical exposure class.

Tab. 1 is clear when identifying exposure classes for structures other than buildings; however, when considering exposure classes for buildings, identification of the humidity within the structure is necessary. EN-206-1[7] and *fib* Bulletin 33[1] classify as "no risk of corrosion or attack" buildings with low air humidity; this type of structure uses a "low" aggressivity rating for selecting tendon PL. What is not identified is "low humidity"; the author defines this as maintaining the building at less than 35% air humidity. Buildings with moderate or high air humidity use a "medium" aggressivity rating for selecting tendon PL per EN-206-1[7] and *fib* Bulletin 33[1]; again, the author defines this as above 35% air humidity. Special consideration should be given within building structures for areas that may be exposed to moisture, such as shower rooms, under air conditioners, certain types of laboratories, etc.

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Tab. 1 Aggressivity level and exposure examples as entry points.[1]

Aggressivity	Class Designation	Description of Environment	Examples where exposure classes may occur
	1 – 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
	2 – 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
	3 – 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
	4 – Corrosion induced by chlorides from sea water		
Medium	XS1	Exposed to airborne salt but not in direct contact with sea water	Structures near to or on the coast
	XS2	Permanently submerged	Parts of marine structures
High	XS3	Tidal, splash and spray zones	Parts of marine structures
	5 – 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
	6 – Chemical attack		
Medium	XA1	Slightly aggressive chemical environment	
Medium-High	XA2	Moderately aggressive chemical environment	
High	XA3	Highly aggressive chemical environment	

4 Identifying Protection Provided by the Structure

Designers must identify the protection provided by the structure to the internal post-tensioning tendons as "high", "medium", or "low". Many factors go into this decision including design concept, detailing, material selection, and construction quality. Designers should always keep in mind that corrosion of post-tensioning tendons is increased by means of ingress of chlorides and other deleterious agents through vulnerable areas of tendons such as anchorages, joints, cracks, porous concrete, and inadequate concrete cover.[1]

Individual construction details are an integral part of the structure's protection scheme and help to provide protection to tendons. The level of protection provided by construction details can vary from minimal up to the best possible available protection. The designer should consider the following construction details together when identifying protection provided to the structure as noted in *fib* Bulletin 33[1].

- Concrete Quality and Cover
- Concrete Cracking
- Construction Joint Details
- Expansion Joint Details
- Waterproofing Systems and other Surface Protection Systems
- Drainage System Details
- Segment Joint Details

Further discussion of the above construction details follows, including the author's recommendations for covering the range from "low" to "high" ratings. For an entire structure to qualify for a "high" rating in overall structural protection, all construction details necessary for the project need to have optimum protection schemes. This total structure rating should be used when determining tendon PLs.

4.1 Concrete Quality and Cover

Concrete quality involves using adequate mix designs and materials that do not add to structure deterioration. In some areas of the world, such as the Arabian Gulf, it is sometimes difficult to find aggregates, sands, and mix water that are not contaminated with salts.[8] Dense, low-permeability concrete mixtures of quality materials with adequate concrete cover should be specified for the structure thus providing optimal protection of reinforcing steel and tendons.[1] Mobility of fluids or gases through concrete allows a vehicle for corrosion. Obviously, more concrete cover provides a greater distance for chlorides or other deleterious materials to travel to tendons. See Rostam's PCI Article[9] for more information on concrete cover requirements. Providing greater concrete cover than required by code will improve the protection that a structure provides to the post-tensioning tendon's duct. Additionally, by specifying a denser and/or a lower permeability concrete will allow for better structure protection. In order to achieve a "high" rating, concrete covers and permeability of concrete material should be designed so that there is a 90% probability of not having any corrosion initiated before the structure's design life has passed, corresponding to acceptance of a 10% probability of premature corrosion initiation. A "low" rating is given when no special design analysis is undertaken, typical concrete covers for structural elements are used, and concrete permeability normally achieved with a concrete w/c ratio of 0.4 are used.

4.2 Concrete Cracking

Concrete cracking can occur for a number of reasons; its relevance to durability is largely related to corrosion and depends on the type and magnitude of cracks. Construction detailing is critical in minimizing cracking. Proper layout and sequencing of concrete pours to lessen the risks of cracking are necessary. Decreasing the risks of cracking by properly laying out and sequencing prestressing particularly in anchorage vicinities should be considered. Location and amounts of non-prestressed reinforcement should be checked for adequate distribution to avoid early-age

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cracking.[1] When all of the above considerations are properly addressed and solutions incorporated into the structure to eliminate cracking, a "high" protection rating is realized. With little or no consideration or inclusion of proper details in the structure, a "low" rating should be given.

4.3 Construction Joint Details

Construction joint details are critical when protecting post-tensioning tendons. Protecting well-made construction joints that are exposed to the elements with waterproofing membranes should assist in preventing leakage; however, waterproofing membranes often do not provide a complete seal and do not last indefinitely, causing joints to leak.[1] By keeping construction joints away from anchorages and preventing access for leakage to tendon anchorages will give a "high" structure protection rating. With little or no consideration of construction joint details and/or locations a "low" rating is set for this criterion.

4.4 Expansion Joint Details

Exposed expansion joints usually leak and their effectiveness and life span are dependent on the quality of material, installation and maintenance. Details should be based on the assumption that the expansion joint will leak and will not provide protection against ingress of water and corrosive elements.[1] A "high" protection rating is given when appropriate drainage paths for leakage are provided ensuring that there is no access to tendon anchorages or the structure's bearings. A"low" rating is given to structures with expansion joints where no details are provided for drainage paths.

4.5 Waterproofing Systems and other Surface Protection Systems

Waterproofing systems provide the first line of defense against intrusion of road salts; however, there are currently no systems available that are guaranteed to remain waterproof for the life of the structure.[1] When a surface protection system is installed and life-cycle costs are included for proper maintenance and re-application as necessary, a "high" protection rating is given to this criterion. Conversely, a "low" rating must be recognized with no waterproofing or surface protection system.

4.6 Drainage System Details

The drainage system should remove water from the structure's surface. Drains and slopes should be constructed so that water cannot migrate into tendons. Equipment failure or blockage of drains can allow paths for water to enter tendons.[1] Sloping surfaces without the possibility of blockages or dams will allow for a "high" protection rating; no sloping and/or drains that can become blocked would be considered a "low" protection rating.

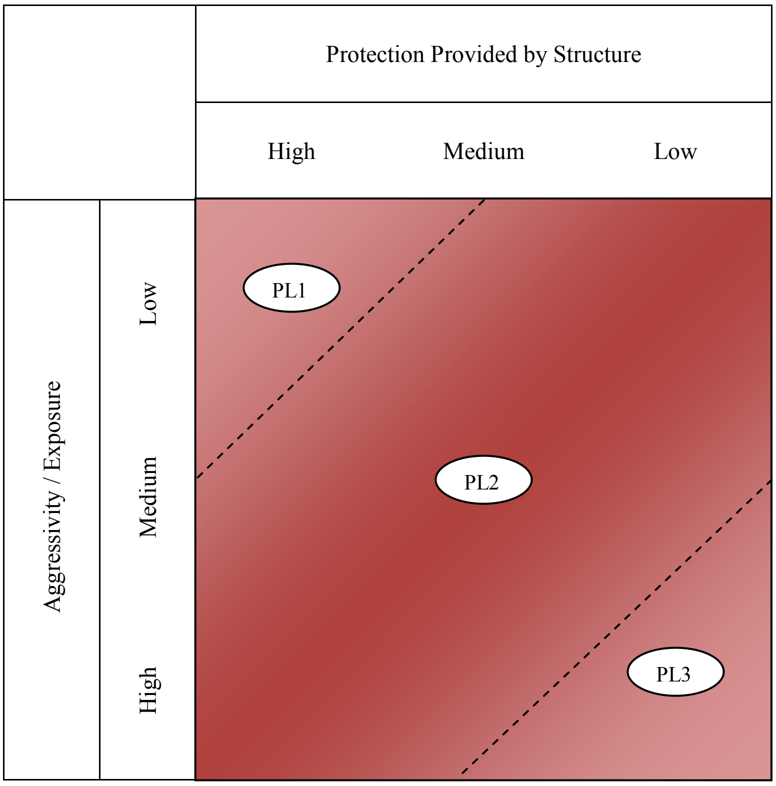
4.7 Segment Joint Details

Precast segmental concrete bridge construction typically uses match cast segment joints which if properly sealed with epoxy resin as erected are satisfactory in terms of durability. However particular care is required when considering the continuity of post-tensioning ducts across the joints. Providing a system that seals against ingress of aggressive agents, epoxy glue, or against leakage of cement grout should be considered.[1] Using a segmental duct coupler as part of the post-tensioning system will give a "high" protection rating, whereas erecting segments with just epoxy at the joints necessitates a "low" protection rating (dry joints are not acceptable).

5 Selecting the Post-Tensioning Tendon Protection Level

Selecting the tendon's PL for a specific project requires that the aggressivity of the environment attacking the prestressing element ("low" – "high") is identified; see **Tab. 1**. Then the protection provided by the structure for the element with the greatest exposure (“low” – “high”) is identified. Once these two tasks are completed, the PL for a specific project can be selected by using **Tab. 2**. The combination of the structural protection level and the tendon‘s PL provide the resistance against the aggressivity of the environment.

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



Following are examples for choosing tendon PL using **Tab. 2** for a bridge structure.

1. Project is located in a very dry environment with no risk of corrosion or attack (X0 = “low”) and the protection provided by the structure is “medium – high”. This would yield a tendon with a PL1.
2. Project is located in a very dry environment with no risk of corrosion or attack (X0 = “low”) and the protection provided by the structure is “low”. This would yield a tendon with a PL2.
3. Project is located in a northern climate that has freeze/thaw with moderate saturation with deicing agents (XF2 = “high”) and the protection provided by the structure is “high”. This would yield a tendon with a PL2.
4. Project is located in a temperate climate six miles (10 km) from the seacoast exposed to airborne salt but not in direct contact with sea water (XS1 = “medium”) and the protection provided by the structure is “medium-high”. This would yield a tendon with a PL2.
5. Project is located in an area with cyclic wet and dry exposure while being exposed to sprays containing chlorides (XD3 = “high”) and the protection provided by the structure is “medium-low”. This would yield a tendon with a PL3.

6 Post-Tensioning Protection Levels (PL) Defined

fib Bulletin 33[1] and PTI/ASBI Guide Specification[2] identify three PLs providing basic parameters for each. PTI/ASBI Guide Specification[2] further splits PL1 into an “A” and “B” section. There are subtle differences in definitions and performance requirements between *fib* and PTI/ASBI. **Tab. 3** differentiates the definitions and **Tab. 4** differentiates the performance requirements.

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Tab. 3 Protection Level (PL) Definitions. [1] [2] [10]

fib Bulletin 33[1]	PTI/ASBI Guide Specification[2]
Protection Level 1 (PL1)	
PL1 is defined as a duct with filling material (grout) providing durable corrosion protection.	PL1A – defined as a duct with grout providing durable corrosion protection.
	PL1B – defined as PL1A plus engineered grout and permanent grout cap.
Protection Level 2 (PL2)	
PL2 is defined as PL1 plus a watertight, impermeable envelope providing a leak tight barrier.	PL2 is defined as PL-1B plus an envelope, enclosing the tensile element bundle over its full length, and providing a permanent leak tight barrier.
Protection Level 3 (PL3)	
PL3 is defined as PL2 plus integrity of tendon or encapsulation to be inspectable or monitorable.	PL3 – defined as PL-2 plus electrical isolation of tendon or encapsulation to be monitorable or inspectable at any time.

Tab. 4 Generic Performance Requirements for each Protection Level (PL). [1] [2] [10]

Protection Level 1 (PL1)	
fib 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.
PTI/ASBI PL1A	• Bare strand or bar • Galvanized or Plastic Duct • Basic Grout or Engineered Grout • Grouting that leaves no Voids in Duct
PTI/ASBI PL1B	• PL1A Plus • Only Engineered Grout • Permanent Grout Cap
Protection Level 2 (PL2)	
fib 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).
PTI/ASBI PL2	• PL1B Plus • System Pressure Tests • Embedded Anchorage Components – Epoxy or Galvanized • Thixotropic Engineered Grout • Only Plastic Duct • Segmental Couplers
Protection Level 3 (PL3)	
fib PL2	• In addition to PL2. • Have a demonstrated means to inspect or monitor tendons for integrity and/or corrosion.
PTI/ASBI PL3	• PL2 Plus • Electrical Isolation of Tensile Element • Ability to be Monitorable or Inspectable at any time

Examples of materials used for tendons in each PL are identified below: [1] [3] [4]

- PL1, bare strand + corrugated metal duct + cement grout
- PL1, bare strand + corrugated plastic duct + cement grout or other filling materials (anchorage zone non-encapsulated)
- PL2, bare strand + corrugated plastic duct + cement grout or other filling materials + encapsulation of anchorage zone
- PL3, bare strand + corrugated plastic duct + cement grout or other filling materials + encapsulation of anchorage zone + inspection or monitoring

7 Conclusions

Protecting post-tensioning tendons from corrosion is paramount to structures remaining durable and fit for use during their design service life. Selecting the correct tendon protection level (PL) revolves around 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.

The designer indentifies the aggressivity of the environment based upon entry points for deleterious substances. Exposure of each structure or element should be classified from "low" to "high"; the worst case should be used in determining the tendon PL.

The structure itself will provide protection to the tendon; construction details affect how well that protection will perform. For a structure to qualify for a "high" rating in overall structural protection, all applicable construction details need to have optimum protection schemes; this total structure rating should be used when determining the tendon's PL.

Once the aggressivity/exposure and protection provided by the structure are determined, the designer uses **Tab. 2** to select the appropriate tendon PL. Post-tensioning tendons in the entire structure should have the same PL; this will provide the designer with confidence that the design life of the structure will not be compromised by an incorrectly placed tendon in a critical exposure location and will have minimal affect on the overall project costs.

Definitions and performance requirements of tendons for a specific PL are identified in both *fib* Bulletin 33[1] and PTI/ASBI Guide Specification[2] as shown in **Tab. 3 and 4**. Tendon PLs of these two codes are identified and evaluated; other similar codes may be available. While component requirements are comparable, specific project requirements should rely on which code governs the work.

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]

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