Florida Department of Transportation

New Directions for Florida Post-Tensioned Bridges

Volume 3 of 10: Design and Construction Inspection Of Precast Segmental Span-By-Span Bridges

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Preface

As a result of recent findings of corrosion of prestressing steel in post-tensioned bridges, the Florida Department of Transportation (FDOT) will be changing policies and procedures to ensure the long-term durability of post-tensioning tendons. The recommendations of the Consultant for revising FDOT policies and procedures is presented in this study entitled, *New Directions for Florida Post-Tensioned Bridges*. The study will be presented in several volumes, with each volume focusing on a different aspect of post-tensioning or bridge type.

Volume 1: Post-Tensioning in Florida Bridges presents a history of post-tensioning in Florida along with the different types of post-tensioned bridges typically built in Florida. This volume also reviews the critical nature of different types of post-tensioning tendons and details a new five-part strategy for improving the durability of post-tensioned bridges.

Volumes 2 through 8: Design and Construction Inspection of various types of post-tensioned bridges - applies the five-part strategy of Volume 1 to bridges in Florida. Items such as materials for enhanced post-tensioning systems, plan sheet requirements, grouting, and detailing practices for watertight bridges and multi-layered anchor protection are presented in detail. The various types of inspection necessary to accomplish the purposes of the five-part strategy are presented from the perspective of CEI along with detailed checklists of critical items or activities.

Volume 9: Condition Inspection and Maintenance of Florida Post-Tensioned Bridges addresses the specifics of ensuring the long-term durability of tendons in existing and newly constructed bridges. The types of inspections and testing procedures available for condition assessments are reviewed, and a protocol of remedies are presented for various symptoms found.

Volume 10: Load Rating Segmental Post-Tensioned Bridges in Florida provides guidance for meeting AASHTO LRFD load rating requirements as they pertain to precast and cast-in-place segmental bridges.

Disclaimer

The information presented in this Volume represents research and development with regard to improving the durability of post-tensioned tendons; thereby, post-tensioned bridges in Florida. This information will assist the Florida Department of Transportation in modifying current policies and procedures with respect to post-tensioned bridges. The accuracy, completeness, and correctness of the information contained herein, for purposes other than for this express intent, are not ensured.

Volume 3 – Design and Construction Inspection of Precast Segmental Span-by-Span Bridges

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Introduction

The Florida Department of Transportation is committed to continued development of post-tensioned bridges as a viable solution for many of Florida's infrastructure needs. The challenge, in light of recent instances of corrosion of some post-tensioning tendons, is to consistently produce prestressed bridges with highly durable post-tensioning. The Department defines a durable structure as one that serves its design purpose over the intended life of the bridge, while requiring only routine inspection and maintenance.

Consistent production of durable structures and durable post-tensioning is affected by many factors that become critical at different stages in the life of the structure. The selection of materials and post-tensioning details by the Designer has the first and foremost impact on the resulting durability. During construction, the Contractor's ability to effectively build in accordance with the plans and specifications is critical to creating durable structures. Finally, over the service life of the bridge, inspectors and maintainers must be familiar with symptoms and remedies available to ensure the long-term durability of structures with post-tensioning tendons.

Past performance of post-tensioned bridges in Florida has shown that improper consideration for important design, construction and maintenance features leads to reduced durability. Furthermore, even where post-tensioning tendons have been installed and maintained with existing appropriate standards of care on the part of designers, contractors, and maintainers, there have still been instances where high durability has not been achieved. Consequently, new procedures are needed to create a design, construction and maintenance environment that consistently produces durable post-tensioned bridges.

In response, the Department is taking a new direction to produce more durable post-tensioned bridges, based on a five-part strategy. The components of this strategy, and the requirements that further define them, are devised to raise the level of performance in design, construction, and maintenance to ensure consistency and confidence in post-tensioned structures. The new direction, expressed by the five strategy components, is shown in Figure 1.1.

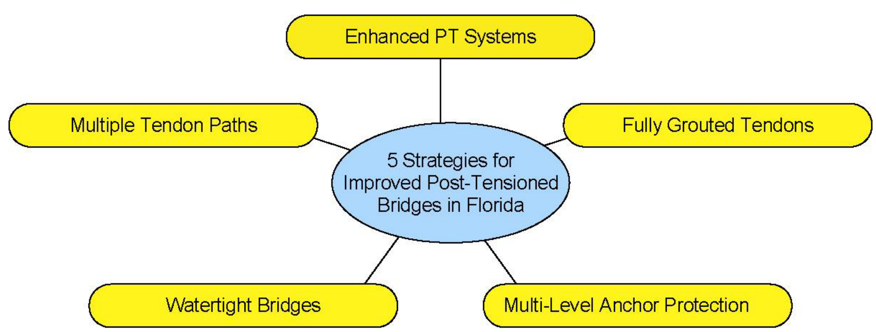


Figure 1.1 – Five-part strategy for more durable post-tensioned bridges in Florida.

Volume 1: Post-Tensioning in Florida Bridges introduced the development of the five-part strategy for more durable post-tensioned bridge in Florida. This volume applies these strategies to a particular type of post-tensioned construction.

Volume 3 – Precast Segmental Span-By-Span Bridges

Post-tensioning tendons for precast segmental span-by-span bridges are typically placed external to the concrete, inside the box girder. These tendons anchor in pier segment diaphragms, are draped between the diaphragms and deviators, and are straight at mid-span in order to provide eccentricities required by design. Occasionally, fully internal bottom slab tendons are used in addition to draped external tendons in order to improve the ultimate flexural capacity of the bridge. Tendons which are both internal and external (combined tendons) have been used in the Evans Crary Bridge in Stewart, Florida. These tendons are external between the pier segment diaphragms and deviators, enter the bottom slab at the deviators, and are internal to the bottom slab over the central portion of the span.

This volume provides direction for accomplishing the Departments philosophy for more durable post-tensioned bridges by applying the five strategies to the specifics of span-by-span construction.

Strategy 1 – Enhanced Post-Tensioning Systems

Strategy 1 requires that all post-tensioning systems be fabricated using enhanced post-tensioning systems. The Designer implements the strategy by incorporating appropriate details in the plans. The CEI checks that these systems are correctly installed during construction, with allowance for Contractor's chosen post-tensioning system and means and methods of construction.

Summarizing, the responsibilities for meeting Strategy 1 are:

- Designer - incorporate the policies and standards into the Contract Drawings that utilize enhanced post-tensioning system components, materials and appropriate structural details.

- Contractor - install all components and materials in accordance with the Contract Drawings, approved Shop Drawings, Specifications and QPL.

- CEI – inspect the work to verify compliance with the Contract Documents and approved Shop Drawings as required. Advise the Contractor of any areas of non-compliance.

Specific requirements for enhanced post-tensioning systems are provided in the following sections.

1.1 Qualified Products List (Requirement 1.A)

In the future, post-tensioning systems must be selected from the Department's Qualified Products List (QPL). New components and new post-tensioning systems must be pre-approved by the Department prior to use in any application. This requirement is to be enforced throughout construction.

1.2 Three Level Protection (Requirements 1.B)

Enhanced post-tensioning systems require three levels of corrosion protection using the barriers defined in Volume 1 “Post-Tensioning in Florida Bridges”. Post-tensioning tendons in precast segmental span-by-span construction are usually external. However, internal tendons may also be used. Consequently, requirements for three levels of protection are addressed for both internal and external tendons.

Internal Tendons:

Components of the protection system depend upon whether the duct is within the concrete of the segment or at a precast joint. The three-levels of protection for these two cases are:

- Within the segments:
  (1) Fully grouted tendon.
  (2) Impervious plastic duct.
  (3) Concrete cover.

- At precast joints:
  (1) Fully grouted tendon.
  (2) Effective continuity of the impervious plastic duct.
  (3) Epoxy sealed joints between match-cast segments.

External Tendons:

Components of the protection system depend upon whether the duct is embedded within or is outside the concrete. The three-levels of protection for these two cases are:

- Duct embedded within the concrete:
  (1) Fully grouted tendon.
  (2) Steel pipe.
  (3) Concrete cover.

- Duct outside the concrete:
  (1) Fully grouted tendon.
  (2) Impervious plastic pipe.
  (3) Enclosure within the surrounding, watertight and drained, hollow box.

Combined Tendons: Tendons that are both external (unbonded) and internal (bonded) over a significant length are no longer permitted in Florida. Unlike typical external tendons, these combined tendons are virtually impossible to replace.

Levels of Protection:

The first level of protection, Level (1), is provided by filling the annular space between the duct and strands with pre-approved grout. Refer Strategy 2 “Fully Grouted Tendons” below for these requirements.

The second level of protection, Level (2), is provided by using impervious ducts meeting the following requirements:

- For internal tendons – use corrugated plastic duct (per Specifications and QPL) with positively sealed connections.
- For external tendons - use smooth plastic pipe and steel pipe (per Specifications and QPL) with positively sealed connections.

To achieve the third level of protection, Level (3), provide concrete cover in accordance with FDOT requirements, epoxy seal joints between segments, or enclose the tendon within the hollow box girder. Refer to Strategy 4 "Watertight Bridges" below for these requirements. Also, in order to accommodate internal tendons, adopt recommended clearances, dimensions and details herein (Sections 1.13 and 1.14 below).

1.3 Materials (Requirements 1.A through F)

Responsibilities regarding materials for enhanced post-tensioning systems are:

- Designer - incorporate the policies and standards into the Contract Drawings and Specifications that utilize enhanced post-tensioning system components and materials.

- Contractor – make sure that all materials and components comply with the Standard Specifications and the QPL. These include, but are not limited to, post-tensioning steel, ducts (plastic ducts, plastic pipes, steel pipes), anchors, duct and anchor connections (couplings), grout pipes and connections, and grout. Also assure compliance of:
  - epoxy for sealing match-cast joints (if any) between precast girder components,
  - non-shrink, high-bond, high-strength, air-cured concrete for filling holes for equipment or temporary access holes,
  - epoxy grout for filling grout recesses and encasing anchors (pour-backs), including coatings for sealing areas of concrete or pour-backs.

  Keep records of submittals, test reports, approved component deliveries, and track materials and components from delivery through installation at Precast Yard and Bridge Site. Provide CEI with copy of all records.

CEI - verify that materials and components comply with Specifications and/or FDOT "Qualified Products List" and keep proper records of submittals, test reports, component deliveries and installation at precast yard and at project site.

1.4 Internal Tendons – Ducts and Connections

Refer to Volume 2, "Design and Construction Inspection of Precast Segmental Balanced Cantilever Bridges" for details related to internal tendons.

1.5 External Tendons – Ducts and Connections

(a) Plastic Pipe for External Tendons (Requirement 1.C)

Two different types of ducts are typically used to fabricate external tendons:

- Smooth plastic pipe for the external portions of the tendon.
- Steel pipe for the portions embedded in the concrete at diaphragms and deviators.

In the past, plastic pipes were smooth, HDPE with a wall thickness of 1/21 of the outside diameter and a hydrostatic design basis of 1250 psi conforming to one of the following designations:

ASTM D 1248, Type III, Category 5, grade P33 or P34
ASTM D 2239 or ASTM D 3035, cell classification PE345433C
ASTM F 714, cell classification PE 345433C
ASTM D 2447, grade P33 or P34

Experience has shown that over a period of time pipe used meeting these criteria can split. Duct splitting is attributed to a combination of effects including significant temperature changes and wall stress due to locked pressure from grout or head. In several cases, intentional puncturing of the pipe by drills or nails (to check for grout) aggravated or initiated damage. As a result, stricter requirements are now placed on the material, wall thickness and grouting operations.

Ducts for external tendons shall meet the following requirements:

- Smooth plastic pipe of high density polyethylene (HDPE) conforming to the requirements of ASTM D3350 with a minimum cell classification of 344464C.
- A minimum DR of 17.
- A hydrostatic design basis of 1600 psi and a minimum pressure rating of 100 psi.
- Containing material to protect against degradation from ultra-violet light.
- Thermally stable for the range of temperatures anticipated while exposed during construction.
- Plastic ducts to be pre-approved as a part of the post-tensioning system and conforming to all requirements of the Specifications.

(b) Steel Pipes for External Tendons (Requirement 1.B)

For steel pipes used as duct for portions of external tendons embedded in concrete:

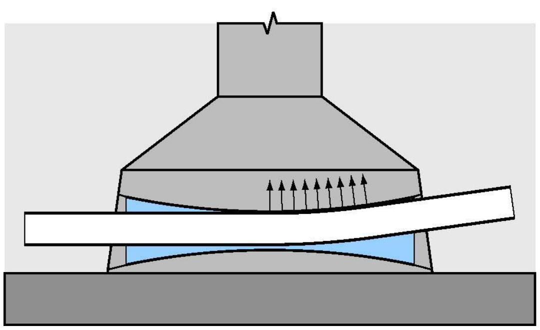
- Use galvanized, schedule 40, rigid steel pipe.
- Extend steel pipe at least 6 inches, but not more than 12 inches beyond face in which it is embedded, following the tangent direction of the tendon path.
- Use a uniform radius between tangent points approximately three inches inside the concrete face.
- Where steel pipe exits concrete face, provide an O-ring of neoprene or other suitable soft material 2 inches long (i.e. greater than cover), with wall thickness of ¼ inch to ½ inch, set into the concrete. (The purpose is to prevent local spall of cover concrete due to any minor misalignment of the pipe and tendon.)
- Provide details of true (3-dimensional) radii of steel pipes and the theoretical location of the points of intersection and tangent lengths.

(c) Diabolo Deviators for External Tendons (Requirements 1.B and 1.C)

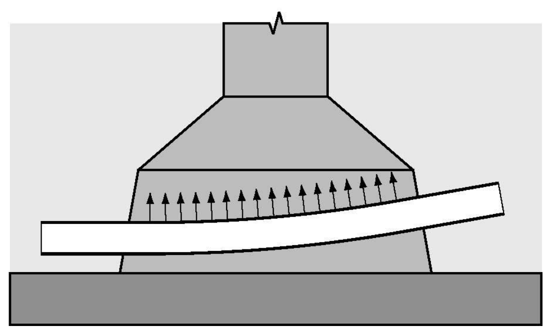
Diabolos are curved pipes in deviators that flare open at each end. Tendons may enter and exit in a range of geometric angles in plan and elevation. Diabolos offer an alternative solution to calculating and detailing individual tendon pipe bends. However, structurally they are different from individual pre-bent pipes that bear evenly over a uniform radius. The actual contact length in diabolos varies, and may be quite short, depending upon the minimum radius of the deviator flare. Figure 3.1 illustrates the difference in bearing and contact between pre-bent pipes and diabolo deviators.

Difficulties arise in developing effective corrosion protection for tendons with diabolos. One option is to pass a continuous plastic duct through the diabolo. This offers the elimination of duct connections at deviators but the concentrated radial contact pressures of the deviating tendon on the duct can damage the duct and breach a vital component of corrosion protection. An alternative option is to insert the end of the plastic pipe into the diabolo a predetermined length but make no connection between the diabolo pipe and plastic duct. Instead, a bead of sealant material placed within the flare of the diabolo and around the inserted pipe is intended to provide the continuity of the duct for grouting and corrosion protection. It is difficult to verify the adequacy of this type of seal.

Based on the possible effects of localized bearing stresses and potentially lesser quality of the corrosion protection system, diabolos are not to be used for bridges in Florida.



Diabolo Deviator



Deviator with Curved Pipe
Pre-bent to Radius

Figure 3.1 – Comparison of Diabolo Deviator and Deviator with curved pipe pre-bent to radius.

(d) Pipe Connections for External Tendons (Requirement 1.D)

Provide positively sealed couplings between embedded steel pipes and plastic pipes, between lengths of plastic pipe and between steel pipes and anchorages. Duct tape does not serve as a positive seal in joining any pieces of pipe or duct or to connect duct or pipe to anchorages. The contract documents should properly note that duct tape does not qualify and is not allowed for making a positive seal. Duct tape may be used to temporarily support of ducts during fabrication.

Two options for positively sealed couplings between embedded steel pipes and plastic pipes are shown in Figures 3.2 and 3.3:

Option 1: Enhanced Neoprene Sleeves (Figure 3.2)

1. Steel pipe and plastic pipe to have the same outside diameter.
2. Inside diameter of neoprene sleeve to be compatible with outside diameter of steel and plastic pipes.
3. Minimum wall thickness of neoprene sleeve to be ½ inch.
4. Properties of neoprene to be in accordance with AASHTO Specifications:
   - Shear Modulus between 0.080 to 0.175 ksi
   - Low temperature zone “A” AASHTO 1996, Table 14.6.5.2.2
   - Hardness (Shore “A” Durometer) between 50 and 60
5. Neoprene to be reinforced with minimum of 1 layer of fabric reinforcement of 100 percent glass fibers of “E” type yarn – (per 18.4.5.2 AASHTO Division II*)*.
6. Neoprene sleeve to be secured to both steel pipe and plastic pipe with power-seated stainless steel banding clamps using a circumferential seating force of 80 to 120 lbs.
7. Band clamps to be a minimum 1-inch wide and permanently secured with swaged fitting.
8. Both band clamps and swaged fitting to be of stainless steel.
9. Wrap splice with an approved tape to prevent direct long-term contact to atmosphere.

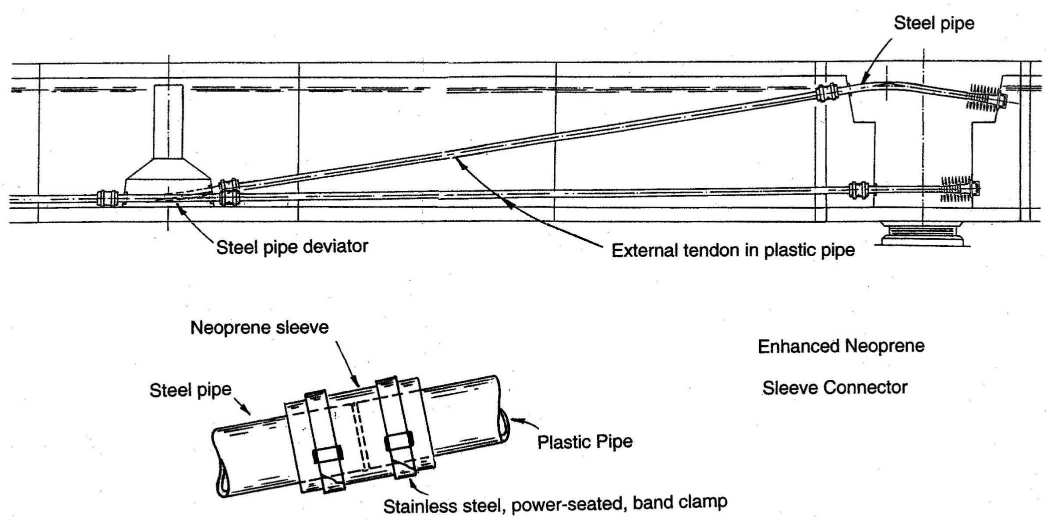


Figure 3.2 – External tendon duct coupling – Option 1

Option 2: Compression Coupling (Figure 3.3)

1. Steel pipe and plastic pipe to have the same outside diameter.
2. Compression coupling to fit both steel and plastic pipes.
3. Compression coupling to be of an approved plastic (PP / PE / PVC).
4. Provide tolerance in coupling to accommodate fit and assembly. Three couplings, one at each end and one in the middle, may be required to provide required tolerances.

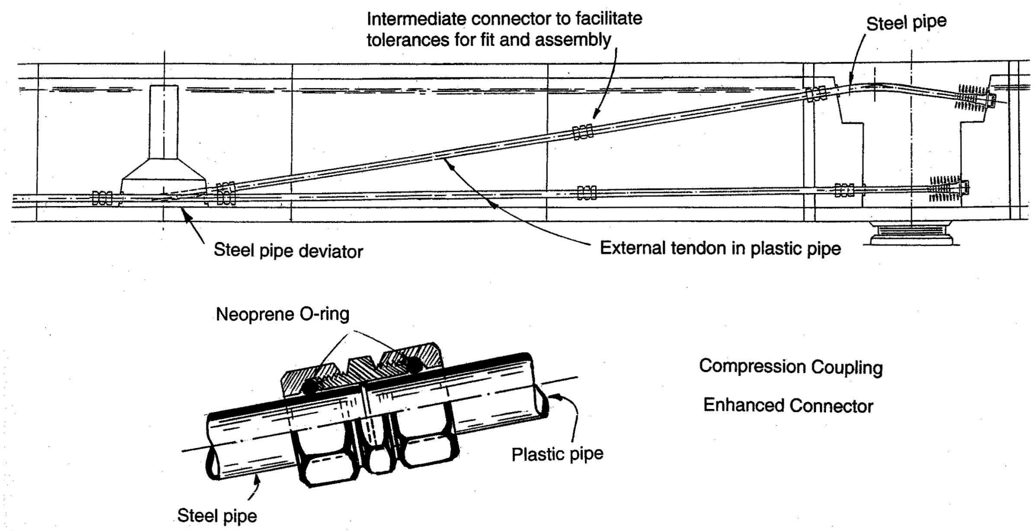


Figure 3.3 – External tendon duct coupling – Option 2

1.6 Permanent Grout Cap (Requirement 1.F)

Provide all post-tensioning tendon anchors with a permanent, heavy duty, plastic grout caps mechanically secured and sealed against the anchor plate with a compressible, neoprene o-ring. Show details of a typical permanent grout cap on the Contract Drawings in accordance with FDOT Standard Drawings. Fully fill permanent cap with grout. Provide grout outlet vent of ¾" minimum diameter in the cap. Permanent grout cap is to completely cover the anchor plate and head. For strand tendons, the anchor head is the wedge plate, wedges and strand tails. For bar tendons, the anchor head is the nut and bar tail. Before installing the tendon, temporary caps may be used and then be replaced by permanent caps after stressing but before grouting.

Show details of a typical permanent grout cap on the Contract Drawings in accordance with FDOT Standard Drawings.

1.7 Pipes for Grout Ports, Vents and Drains (Requirement 1.D)

Pipes for grout ports, vents and drains are necessary to allow the escape of air, water, bleed-water and the free flow of grout. Use pipe with an inner diameter of at least 3/4 inch for strand tendons and 3/8 inch for single bar tendons. Pipe is to be flexible, HDPE or HDPP plastic material compatible with that of the main plastic duct for the tendon. Plastic components are not to react with concrete or encourage corrosion of the post-tensioning steel, and must be free of all water-soluble chlorides.

Connect grout pipes to ducts and anchor components in a manner that creates a seal and does not allow leaks or ingress of water, chlorides or other corrosive agents.

To facilitate inspection of complete filling of a tendon with grout, direct grout vents at high points (crests) to exit the top (riding surface) or other appropriate surface. Also, provide caps and seals to all vents to prevent ingress of water or corrosive agents into the tendon. For locations of grout ports, vents and drains see Strategy 2, "Fully Grouted Tendons" below.

1.8 Shop Drawings (Requirements 1.A through D, F and G)

Shop Drawings are required for the integration of approved post-tensioning systems (i.e. post-tensioning supplier's information and details), reinforcement, post-tensioning, and other embedded items (including those for the Contractor's chosen "means and methods" of construction) for precast segments. Shop Drawings responsibilities include:

- Contractor - submit the necessary "Shop Drawings" to the Engineer (Designer) for review and approval.

- Designer - review the Shop Drawings and other relevant information and notify the Contractor and the CEI of its acceptability.

- CEI - coordinate and keep a record of submittals and responses.

1.9 Installation (Requirements 1.A, 1.B, 1.C, 1.D, 1.E and 1.F)

During fabrication at the Precast Yard and during erection when making closure joint pours at the Bridge Site, installation shall include but not be limited to:

Ducts For Internal Tendons:

During fabrication make sure that ducts are:

- Installed to correct profile (line and level) within specified tolerances.
- Installed to connect correct duct location in bulkhead with correct duct location in match-cast segment.
- Correctly aligned with respect to the orientation of the segment in the casting cell and the direction of erection.
- Tied and supported at intervals or 2ft (or per recommendations of duct supplier).
- Connected with positively sealed couplings between pieces of duct and between ducts and anchors*.
- Aligned with sealed couplers at temporary bulkheads.

During erection make sure that:

- Internal ducts have positively sealed connections* at match-cast joints.
- All internal ducts are thoroughly swabbed at new epoxy joint so that no epoxy that exudes into ducts causes blockages.
- Match-cast joints are properly prepared and sealed with epoxy (refer to Strategy 4 "Watertight Bridges" below).

  (* Note - duct tape does not qualify as a seal although it may be used for temporary support purposes.)

Ducts For External Tendons –

During fabrication make sure that embedded parts (i.e. steel pipes in deviators and diaphragms) are:

- Installed to correct profile (line and level) within specified tolerances.
- Tied and correctly supported at frequent intervals.
- Connected with positively sealed couplings between pieces of duct and between ducts and anchors*.
- Properly aligned and sealed* at faces of diaphragms and deviators.

During erection make sure that:

- Ducts have positively sealed connections between external plastic and steel pipes and between individual lengths of plastic pipe*.
- Match-cast joints are properly prepared and sealed with epoxy (refer to Strategy 4 “Watertight Bridges” below).

  (* Note - duct tape does not qualify as a seal although it may be used for temporary support purposes.)

Cover – make sure that cover is correct to rebar and ducts (longitudinal and transverse).

Anchors **–** for internal and external tendons, make sure that anchors are:

- The correct type and size for the type and size of tendon used.
- Supplied with permanent, heavy duty, plastic caps with o-ring seal.
- Properly aligned and well supported by formwork.
- When required, set in a recess (anchor pocket or block-out) of correct size, shape and orientation.
- Provided with correct bursting reinforcement at correct location and spacing.

Grout injection ports, outlet vents and drains **–** make sure that all injection ports, grout vents and duct drains are installed correctly, in particular that:

- They are of correct type and size.
- They are correctly located, connected and sealed to ducts.
- Ports or vents at anchors are oriented correctly.
- Grout pipes are taken to proper exit surface.
- Grout pipes, ducts and connections are sealed before concrete is placed.
- (Refer also to Strategy 2 “Fully Grouted Ducts” below).

Epoxy Joints – for match-cast segments, sealed epoxy joints are necessary in order to ensure the integrity of one of the required three levels of protection. For requirements for epoxy joints refer to Strategy 4 “Watertight Bridges” below.

Post-Tensioning Tendons For Precast Span-by-Span Bridges **–** make sure that:

- Ducts are clear for installation (for internal tendons in particular, ducts may be tested by passing through a suitably sized torpedo prior to installing the tendons).
- Number and size of strands (or bar) is correct.
- Strands (or bars) are satisfactory (i.e. no rust etc.) per specification.
- Longitudinal PT tendons are installed in their correct duct locations.
- Anchor plates and wedges (or nuts) are properly installed on each strand (or bar).
- For tendons anchoring in precast segments or cast-in-place concrete, check that the strength is satisfactory for stressing.
- At cast-in-place closures, concrete attains the required minimum strength before stressing continuity tendons.
- Tendons are stressed in the correct sequence to the required force and elongation as specified on the plans, the approved shop drawings or erection manual.
- All stressing records are made and kept per specifications.

Temporary Protection of Post-Tensioning Tendons – Make sure that tendons are properly protected by approved temporary protection in accordance with Specification B460 from the time they are installed in the ducts to the time of grouting (whether stressed or not).

Grout Caps – Permanent plastic grout caps shall be installed prior to tendon installation to keep ducts clean and dry. Caps shall be removed for tendon installation and replaced prior to grouting. Temporary caps may be used if they are replaced by permanent caps before grouting.

1.10 Pressure Test before Grouting (Requirement 1.G)

Pressure test all duct assemblies prior to grouting - preferably before installing tendons. Run tests in accordance with FDOT Specifications, with caps installed and vents plugged and check for possible leaks. Properly seal all leaks as necessary before grouting. If the test is run after installing and stressing the tendon it may be very difficult to repair leaks and make a proper seal.

1.11 Grout Material (Requirement 1.E)

All grout is to be pre-bagged and pre-approved in accordance with FDOT Standard Specification 938. Grout must be fresh, handled, stored and mixed properly for use in accordance with FDOT Specifications for Post-Tensioning and Grouting.

1.12 Sealing of Grout Ports, Vents and Drains – (Requirements 1.B, 1C, 1D)

In order to maintain the integrity of the duct system and its effectiveness as a barrier, all grout ports, vents and drains must be properly terminated and sealed. Responsibilities regarding sealing of grout ports, vents and drains include:

- Designer - show details and/or include post-tensioning Standard Drawings into the Contract Drawings.

- Contractor - follow and implement details provided on the Contract Plans or approved Shop Drawings.

- CEI - check that this work is performed properly.

One detail for sealing grout ports, vents and drains is shown in Figure 3.4. Requirements for this detail include:

(1) At all grout vents or ports that exit or enter the top slab, provide a recess not less than 2 inches or more than 3-1/2 inches in diameter around the pipe. Make depth of recess not less than 2-1/2 inches or more than 3 inches from the initial roadway surface before grinding and grooving. i.e. final depth of recess after ½ inch of surface has been removed by grinding and grooving to be not less than 2 inches or more than 2-1/2 inches.

(2) Provide a separate recess around each port or vent pipe of each tendon. Do not merge recesses into one large one. Keep each recess separate from an adjacent one by at least 6 inches of concrete (edge to edge of recesses) so that if a recess or pipe is breached only on tendon will be at risk. Multiple grout pipes attached to an individual tendon at one location (such as a grout pipe from an anchor trumpet and grout pipe from cap attached to that anchor) may be housed in one recess.

(3) Provide sides of each recess with an irregular or corrugated finish to ensure a good mechanical bond (in addition to chemical bond with filler).

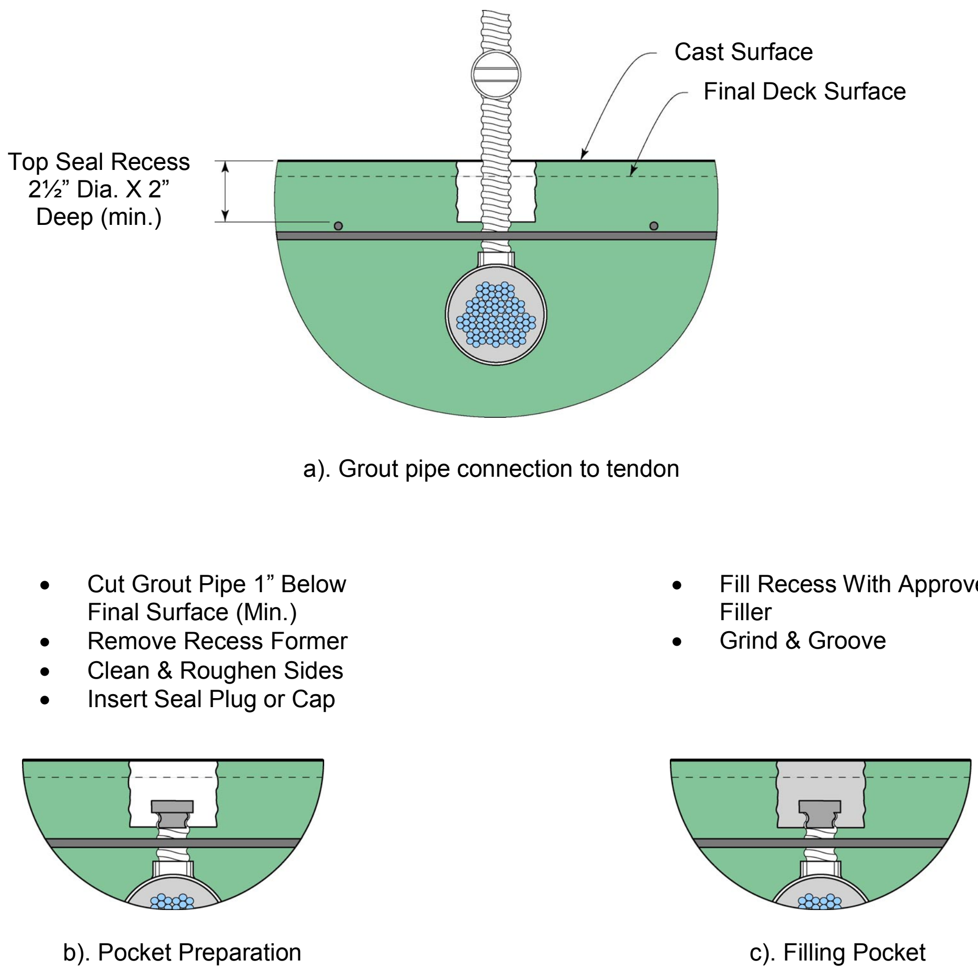


Figure 3.4 – Sealing grout ports and vents in top slabs.

(4) Form recess with a material that can be easily removed such as corrugated polyethylene or other suitable material.
(5) After grout from both primary and secondary grouting has hardened, trim grout pipes that exit through top slab to 1 inch above bottom of recess.
(6) Seal trimmed grout pipes with permanent plastic cap (or plug) screwed or glued to pipe.
(7) Remove all traces of recess forming material and thoroughly clean sides and bottom of each recess to sound, dry concrete surface.
(8) Fill each recess with an approved low modulus, high-strength, high-bond, sand-filled epoxy grout selected from the Department's Qualified Product List.
(9) In deck and other top, horizontal surfaces use a flow-able epoxy mix with the above characteristics (8) and allow it to set and cure properly before grinding and grooving.
(10) For grout pipes exiting vertical surfaces and soffit, use a stiffer epoxy mix that may be applied with a trowel and secured with a suitable form. Use a form surface that does not adhere to the epoxy (wax paper coating or similar).

1.13 Internal Tendons – Clearances, Dimensions, Details

Refer to Volume 2 "Design and Construction Inspection of Precast Segmental Balanced Cantilever Bridges", for requirements concerning the use of internal tendons.

- Spacing between Longitudinal Ducts.
- Thickness of Top Slab for Cantilever Tendons.
- Thickness of Bottom Slab for Internal Continuity Tendons.
- Thickness of Slab for Temporary Post-Tensioning Bars.
- Multiple Internal Tendons in Thin Slab.
- Duct Supports.
- Web Reinforcing and Cantilever and Continuity Tendons.
- Space for Concrete Vibrators.

1.14 External Tendons – Clearances, Dimensions, Details

(a) Expansion Joint Segment Diaphragm Length (Requirement 1.B)

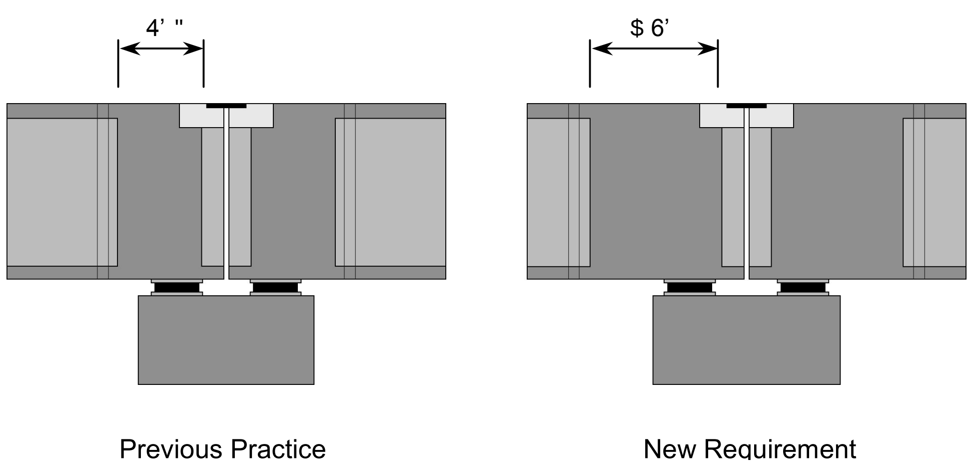


Figure 3.5 – Expansion joint segment diaphragm length.

The longitudinal length of that portion of the expansion joint diaphragm where external tendons are anchored shall be greater to or equal to 6 feet in box girders with depths up to 10 feet. Diaphragm details for deeper box girders should be proportionally increased. Figure 3.5 shows comparison of previously used diaphragm dimensions and the new requirements.

The previous practice of using a short length diaphragm arose from attempts to make the length of the expansion joint segment half the length of interior pier segments (less one half of the expansion joint opening) while essentially using the same diaphragm shape as for interior pier segments. This was done in order to standardize forms, maintain weight of the “half” segment, and to standardize the lengths of typical segments in all spans. In spite of the use of vertical post-tensioning, cracking resulting from the distribution of longitudinal post-tensioning in short diaphragms has been experienced in most expansion joint segments in Florida.

Longer diaphragms are required to minimize concrete cracking and to preserve the integrity of the anchor zone and thereby the post-tensioning system. This does not necessarily mean the overall weight of the segment is increased, but rather redistributing concrete to best resist the applied forces. As no significant post-tensioning eccentricity is required at expansion joints, the tendon anchors are typically distributed along the height of the web, as close to the web as possible. Effective anchorage concrete should be place coincident with these anchor locations. Web shear passes through this concrete to the bearings. A transverse torsion-resisting shape, usually placed in an “A” or “V”, is required to transfer eccentric loads. However, the thickness of this shape, however, does not need to be equal to the full length of the segment diaphragm.

When appropriately proportioned, expansion joint pier segments for span-by-span bridges with external tendons should not typically weigh more than other pier segments. Longer expansion joint segments require different forms and an adjustment to segment lengths in expansion joint spans. However, these impacts are warranted in order to reduce or eliminate cracking in anchorage diaphragms.

(b) Full Height Deviation Diaphragms (Requirement 1.B)

All external post-tensioning tendons shall be deviated in full height diaphragms directing the deviation forces directly into the webs and slabs. Previously used systems of partial height diaphragms or deviation saddles used with or without transverse bottom slab ribs shall not be used. Figure 3.6 illustrates the previously used and new deviation diaphragm details.

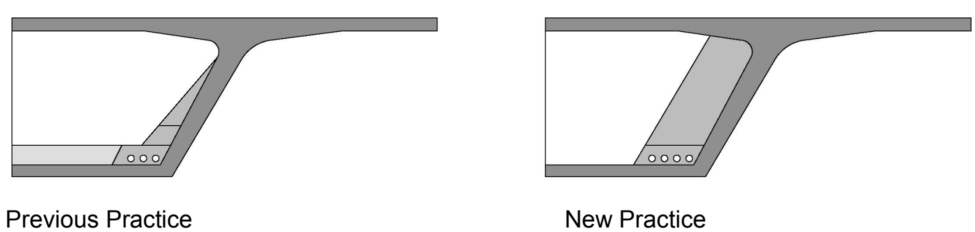


Figure 3.6 – Deviator Segment.

Strategy 2 – Fully Grouted Tendons

This strategy requires that all post-tensioning tendons in precast segmental span-by-span bridges must be completely filled with grout. Ideally, in span-by-span construction, all tendons of each span are grouted at the end of installation and stressing as each span is completed. However, span-by-span construction can attain the rapid pace of two spans per week to one span per day. Under such circumstances, it may be prudent to grout the tendons of several spans at the same time in one grouting operation. This is provided that the time between installation and grouting of any tendon never exceeds that allowed by the Standard Specifications.

For internal tendons, complete filling of the ducts may be accomplished on an individual basis or in groups. Group grouting can lead to construction efficiencies and help overcome any problem from possible cross-flow between ducts. Tendons must be stressed and grouted in within the time period allowed in the Standard Specifications.

To ensure compliance with Strategy 2:

- Designer - incorporate details and requirements in the Contract Drawings to facilitate fully grouted tendons.

- Contractor - install all components and grout in accordance with the Contract Drawings, approved Shop Drawings, Specifications and QPL.

- CEI – inspect the work to verify compliance with the Contract Documents and approved Shop Drawings as required. Advise the Contractor of any areas of non-compliance.

2.1 Accessible Anchors – (Requirement 2.A)

All anchors for both internal and external post-tensioning tendons are to be accessible throughout all construction operations, up to and including the installation and grouting of permanent plastic grout caps. In particular:

- Provide a 2’ lateral clear dimension from the sides of the anchor plate for a length along the tendon of 1’-3” for dead end (non-stressing) anchorages. For live (stressing) anchors provide clearance for tendon installation and stressing jacks.

Anchors for new construction are to have an inspection port to accommodate probes and/or bore-scope equipment. Although it is desirable to have access for inspection, poorly sealed inspection ports may be potential points of entry for contaminants or chlorides. Consequently, keep the number of deliberately introduced inspection ports (and grout vents) at or near anchors to a minimum.

Bridges that combine span-by-span and cantilever construction shall also comply with Volume 2, “Design and Construction Inspection of Precast Segmental Balanced Cantilever Bridges”.

2.2 Grouting of Tendons (Requirements 2.B and 2.C)

To help ensure that tendons are fully grouted, certain details and procedures for grouting must be shown on the Contract Drawings, addressed in the Specifications and enforced during construction. In accordance with the FDOT Standard Drawings on the Contract Drawings:

- Require all anchors to have temporary seals or caps to keep debris out of ducts during construction prior to grouting.
- Show locations of all low point grout injection ports, outlet vents and drains.
- Show direction of grouting, taking into account the longitudinal profile of the tendon allowing for the profile of the bridge.
- Locate the grout injection port at the lowest point of the tendon profile, accounting for bridge profile.
- If two or more low points are at equal elevations then select one for the injection port and provide drains at the others.
- Provide outlet vents at all high point crests and between 3 to 6 feet beyond the crest in the direction of grouting.
- Locate injection ports, vents and drains on ducts so as to allow free drainage and free flow of grout unimpeded by the presence of the tendon - whether of strands or bars.
- Locate drains at all low points.
- Locate drains on bottom one third of duct (Figure 3.7).
- Orient anchors so that the grout vent or injection port is at the top.
- Require all internal ducts for temporary longitudinal post-tensioning be fully grouted during construction whether the PT remains in place or not and whether stressed or not.

Ducts may be moist at the time of grouting, but all freestanding water must be removed before grouting begins. This minimizes the risk of excess water compromising the grout mix, causing bleed or voids. Drains at all low points are required to facilitate removal of freestanding water.

Examples of application to different types of external tendons used in precast span-by-span bridges are provided in Sections 2.7 and 2.8 below.

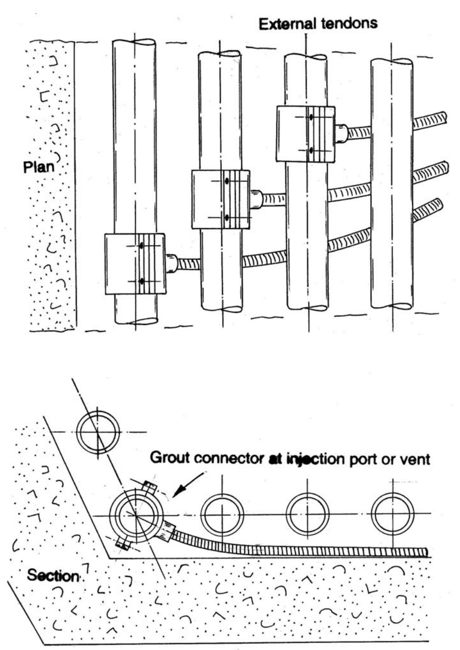


Figure 3.7 – Grout Port and Drain Connections for External Tendons

2.3 Shop Drawings (Requirements 2.A, 2.B, 2.C)

Shop Drawing responsibilities include:

- Contractor – submit necessary "Shop Drawings" to the Engineer (Designer) for review and approval.

- Designer - review the Shop Drawings and other relevant information and notify the Contractor and CEI of its acceptability.

- CEI – coordinate, keep a record of submittals and responses and check that the correct details are followed – e.g. that grout ports, vents and drains are correctly installed. This requires checking at the precast plant before casting and, in some cases, on the job site where such items are installed in cast-in-place closures.

On Shop Drawings, show injection ports, grout vents and drains at locations in accordance with details shown on the Contract Drawings and required by the Specifications. In particular show:

- Port or vent type and size (e.g. plastic / diameter).
- Location, connection and seal to ducts.
- Grout pipes taken to proper exit surface.
- Grout pipes, ducts and connections to be sealed before concrete is placed.
- Anchors oriented so that ports and vents are to the top and remain accessible not only for grout installation but also for inspection and checking for complete filling by grout.

2.4 Materials – Grout (Requirements 2E, 2.F, 2.G and 1.E)

In existing structures, corrosion damage to tendons has been found at locations of incomplete grouting. Major contributors to voids in tendons include significant bleed water and entrapped air. Much research and effort has been invested in improving the performance of grout to reduce bleed-water and air voids. Consequently, Strategy 1 requires that all grout must be pre-bagged and pre-approved in accordance with FDOT Standard Specification 938.

Careful attention to proper mixing, injection and venting procedures is required in order not to negate the benefits of improved pre-bagged grout materials.

2.5 Installation (Requirements 2.A through 2.G)

Responsibilities regarding installation include:

- Designer – make sure that the Contract Documents address installation of post-tensioning duct system components and grout.

- Contractor - install anchors, grout injection ports, outlet vents and drains in accordance with the Contract Drawings or approved Shop Drawings or approved Grouting Plan.

- CEI - inspect the installation of grout injection ports, outlet vents and drains for compliance. Make sure grouting is carried out in accordance with the approved Grouting

Plan, Shop Drawings, Specifications and QPL. Witness the acceptability of the grouting on Contractor's records and keep a separate copy.

Specific installation requirements include:

- Grouting to be done only by qualified personnel.
- Prior to grouting (may be before installing tendon), ducts to be pressure tested for leaks.
- Cross-flow or leaks are sealed.
- Consistency of grout mix (flow cone) to be satisfactory before injection (use moist cone).
- Grout to be injected at lowest point of tendon profile.
- Steady rate of injection in accordance with the Specifications.
- Grout to be evacuated at each vent in turn until consistency is same as that being injected (test evacuated grout using flow-cone, as necessary).
- Pressure to be held at 75 psi for two minutes – checked for leaks and fixed.
- If no leaks are present, reduce pressure to 5 psi and wait 10 minutes to allow entrapped air to flow to high points.
- Open vents to release any air or bleed water.
- Pressure to be pumped to 30 psi and locked off to allow initial set.
- After set, grout caps to be checked and any voids completely filled. (Do not remove cap except for unusual circumstances.)
- After set, vents and anchors to be probed, inspected and any voids filled by secondary vacuum grouting.

Application of these requirements to two different types of external tendons in precast span-by-span bridges is provided in Sections 2.7 and 2.8 below.

2.6 Grouting Plan (Requirements 2.A through 2.G)

Grouting Plans shall be developed for all bridges and implemented during construction. Responsibilities regarding the Grouting Plan include:

- Contractor – prepare and submit a "Grouting Plan" according to the requirements of the Specification for Post-Tensioning (B460).

- CEI - record submittals, review and notify the Contractor of acceptability of Grouting Plan. The CEI may seek an opinion from the Designer regarding the Grouting Plan. However, the CEI has responsibility for review and approval of the Contractor's plan.

The Grouting Plan must address (but is not necessarily limited to):

- Grouting procedures to be followed at precast yard and on site (may be separate grouting plans).
- Qualifications and Certification of Grouting Personnel (at precast yard and site).
- Proposed grout material and reports of qualification tests (must be to QPL).
- Equipment for mixing and testing daily grout production.
- Stand-by equipment.

- Accessibility of anchors for injection and evacuation of grout and inspection of anchor for completeness of filling (follow details per FDOT Standard Drawings, the Contract Plans or approved Shop drawings).
- Embedded Face Anchors - extra precautions for grouting and sealing embedded face anchors (see 3.8 below).
- Means of pressure testing duct system for leaks and sealing as necessary.
- Sequence of injecting and evacuating grout for each external tendon type.
- Injection of grout at the low point of each profile.
- Direction of grout injection and sequence of closing vents.
- Provisions for grouting of a group of tendons*.
- Means of checking or ensuring all tendons are completely filled.
- Means and details for sealing grout inlets, vents and drains – particularly in top deck (riding) surface.
- Procedure for secondary (vacuum) grouting.
- Forms or other means of keeping records of grouting operations (supply copy to CEI for corroboration and witness).
- Temporary PT - procedures to ensure that all internal ducts used for temporary post-tensioning bars for erection are fully grouted at the end of erection, whether bars remain in place or not and whether stressed or not.

* Note: In span-by–span construction, tendons are usually external and grouted one at a time. Provision for group grouting is mainly necessary in the event of potential cross-flow between internal tendons and usually applies to cantilever construction.

2.7 Grouting Procedure – End Spans (Requirements 2.B, 2.C, 2.E, 2.F, 2.G)

Figure 3.8 illustrates and end span of a typical span-by-span superstructure with external post-tensioning tendons.

For a system comprising sealed plastic pipes connected to steel pipes at diaphragms and deviators fitted with injection port, vents and drains:

- Take into account longitudinal gradient, if any, and establish intended direction of grouting.
- Orient both end anchors (A and E) so that grout port or vent is at top.
- Provide outlet vent at end anchor (A).
- Provide grout injection port at low point of tendon profile (B).
- Provide another outlet vent at (C) if the tendon is longer than 150 feet.
- Provide a grout outlet vent (D) at the highest point of the tendon profile.
- Provide another outlet vent at the end anchor (E).
- Show direction of grouting.
- Show sequence of closing vents.

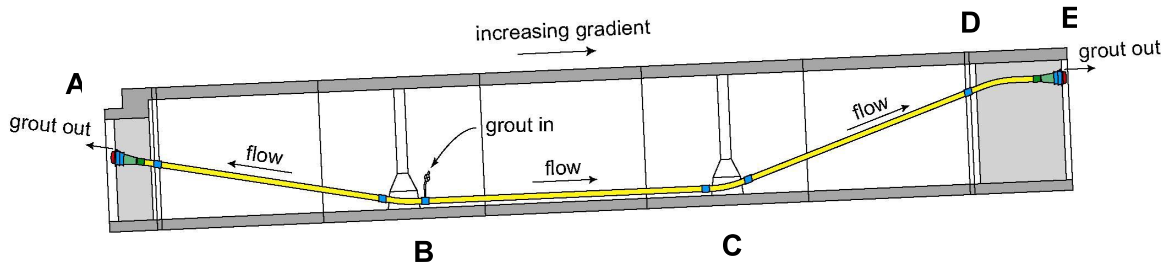


Figure 3.8 – Grouting procedure for end spans of Span-By-Span Bridges

Figure 3.9 shows the possible grout vent locations for the two most common layouts of external tendons in interior pier segments.

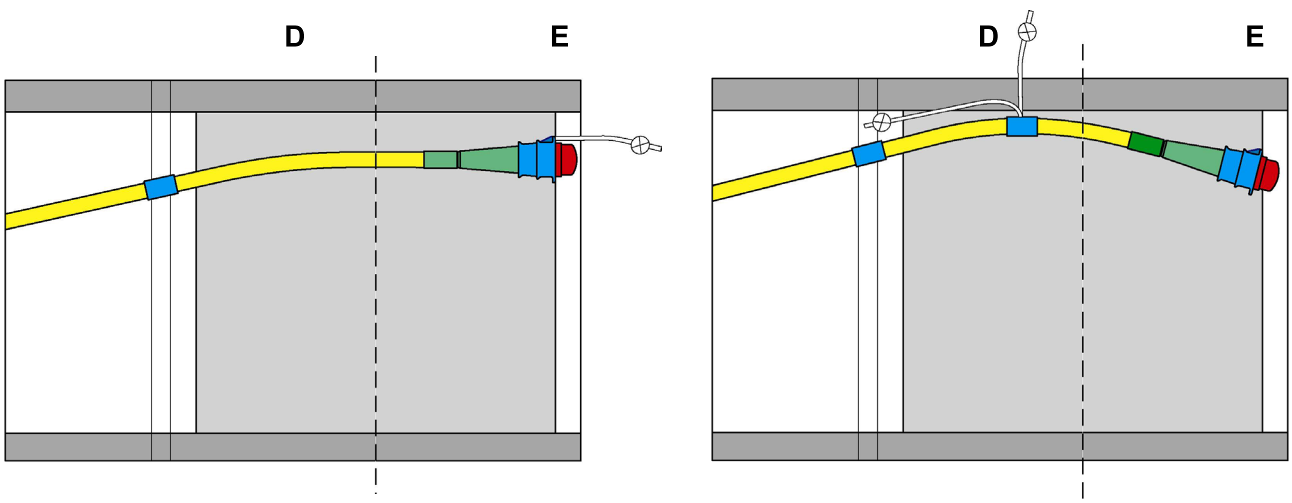


Figure 3.9 – Grouting vent locations for span-by-span bridges

After erection and blocking of cast-in-place construction joints at each end of the span - but prior to installation of post-tensioning tendons, the system should be blown out using clean, oil-free air and, if necessary, the ducts tested with a torpedo. If satisfactory, post-tensioning tendons may then be installed and tensioned to force in the required sequence.

***Grouting operation** (end span)*

(1) Open all vents and drains (A through E) and check that there is no free water in the ducts – if there is, then blow out with oil free air.

(2) Mix grout and perform QA/QC material field tests per specifications.
(3) Inject grout at lowest point of duct system (i.e. point B).
(4) Inject grout at a steady rate in accordance with the Specifications.
(5) Allow air, excess water and grout to flow freely from vent (C - if fitted – and if lower than vent A) at a satisfactory consistency per specifications. Then close vent (C) and continue pumping at steady rate.
(6) Allow air, excess water and grout to flow freely from end anchor vent (A) until consistency is satisfactory per specifications. Close vent (A) and continue pumping at a steady rate.
(7) Allow air, water and grout to flow from vent (D) until consistency is satisfactory per specifications. Then close vent (D) and continue pumping at steady rate.
(8) Allow air, water and grout to flow from anchor vent (E) until consistency is satisfactory per specifications. Then close vent (E).
(9) Pump to a pressure of 75 psi – hold for two minutes and check for grout leaks. If leaks are indicated by reduced pressure, then fix the leaks.
(10) If no leaks are present, reduce pressure to 5 psi for 10 minutes to allow entrapped air to flow to the high points.
(11) Open vent (A) to release any accumulated air or bleed water. If necessary, pump grout in again until grout flows consistently from vent (A). Then close vent (A). (Normally grouting pressures should be approximately 80 to 100 psi. Do not exceed a grouting pressure of 150 psi.)
(12) Open vent at (C – if fitted) to release any accumulated air or bleed water. If necessary, pump grout in again until it flows consistently from vent (C). Then close vent (C).
(13) Repeat at vents (D and E).
(14) Pump up pressure and lock off at 30 psi.
(15) Allow grout to take an initial set.
(16) Probe each vent - for any vents not completely filled, or where nearby voids are suspected, implement vacuum-assisted, secondary grouting of unfilled zones. (Refer to “Secondary, Vacuum Assisted Grouting” - below)
(17) After completion of both primary and secondary grouting (if implemented) of tendons, seal all grout injection ports, grout outlet vents and drain vents. (See “Sealing of Grout Ports, Vents and Drains” - above)

2.8 Grouting Procedure – Interior Spans (Requirements 2.B, 2.C, 2.E, 2.F, 2.G)

Figure 3.10 illustrates and interior span of a typical span-by-span superstructure with external post-tensioning tendons. The example applies to a bridge with no longitudinal gradient or a gradient rising to the right. (If the gradient rises to the left, then locate injection port (C) at the other end of the bottom mid-portion of the tendon, adjacent to the next deviator saddle.)

For a system comprising sealed plastic pipes connected to steel pipes at diaphragms and deviators fitted with injection port, vents and drains:

- Orient both end anchors (A and F) so that grout port or vent is at top.
- Provide outlet vent at end anchor (A).
- Provide outlet vent at high point over first pier (B)** if anchor is not high point.
- Provide grout injection port at low point of tendon profile (C).
- Provide another outlet vent at (D) if the tendon is longer than 150 feet.
- Provide a grout outlet vent (E) at the highest point of the tendon profile.

- Provide another outlet vent at the end anchor (F).
- Show direction of grouting.
- Show sequence of closing vents.

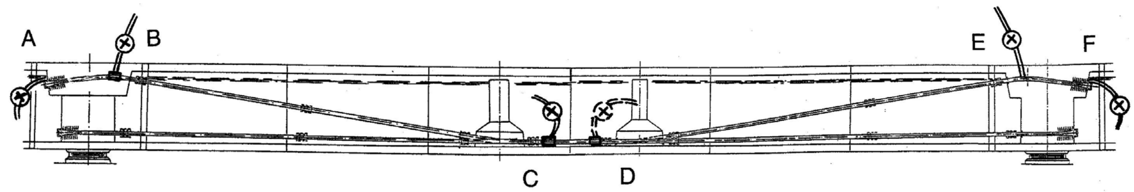


Figure 3.10 - Grouting procedure for interior spans of Span-By-Span Bridges

After erection and blocking of cast-in-place construction joints at each end of the span - but prior to installation of post-tensioning tendons - the system should be blown out using clean, oil-free air and, if necessary, the ducts tested with a torpedo. If satisfactory, post-tensioning tendons may then be installed and tensioned to force in the required sequence.

Grouting operation *(interior span)*

(1) Open all vents and drains (A through F) and check that there is no free water in the ducts – if there is, then blow out with oil free air.
(2) Mix grout and perform QA/QC material field tests per specifications.
(3) Inject grout at lowest point of duct system (i.e. point C).
(4) Inject grout at a steady rate in accordance with the Specifications.
(5) Allow air, excess water and grout to flow freely from vent (D - if fitted) at a satisfactory consistency per specifications. Then close vent (D) and continue pumping at steady rate.
(6) Allow air, excess water and grout to flow freely from high point vent (B – if fitted) until consistency is satisfactory per specifications. (Note – it may be necessary to vent grout at end anchor A and close A before grout vents at B. i.e. step 7.)
(7) Allow air, excess water and grout to flow freely from end anchor vent (A) until consistency is satisfactory per specifications. Then close vent (A) and continue pumping at steady rate.
(8) Close vent (B) after consistent grout flows as required.
(9) Allow air, water and grout to flow from high point vent (E) until consistency is satisfactory per specifications. Close vent (E).
(10) Allow air, water and grout to flow from anchor vent (F) until consistency is satisfactory per specifications. Then close vent (F). (Note – it may be necessary to vent grout at anchor (F) and close (F) before grout flows from vent (E) in step (9).)
(11) Pump to a pressure of 75 psi – hold for two minutes and check for grout leaks. If leaks are indicated by reduced pressure, then fix the leaks.
(12) If no leaks are present, reduce pressure to 5 psi for 10 minutes to allow entrapped air to flow to the high points.
(13) Open vent (A) to release any accumulated air or bleed water. If necessary, pump grout in again until grout flows consistently from vent (A). Then close vent (A). (Normally grouting pressures should be approximately 80 to 100 psi. Do not exceed a grouting pressure of 150 psi.)

(14) Open vent at (B), if fitted, release air and bleed water. If necessary, pump grout in again until it flows consistently from vent (B). Then close vent (B).
(15) Repeat at vents D, E and end anchor F.
(16) Pump up pressure and lock off at 30 psi.
(17) Allow grout to take an initial set.
(18) Probe each vent. For vents not completely filled, or where nearby voids are suspected, implement vacuum-assisted, secondary grouting. (Refer to “Secondary, Vacuum Assisted Grouting” - below)
(19) After completion of both primary and secondary grouting (if implemented) of tendons, seal all grout injection ports, grout outlet vents and drain vents. (See “Sealing of Grout Ports, Vents and Drains” - above)

2.9 Secondary Vacuum-Assisted Grouting (Requirement 2.G)

After primary grouting has been done, all anchors, ports and vents must be inspected and probed. If a void is found, then it must be completely filled with grout using vacuum-assisted grouting. Figure 3.11 illustrates principal details of vacuum injection connections. The procedure is as follows:

(1) After the grout has set, open each vent in turn and probe to see if duct and vent is full.
(2) Where any void is found, introduce additional grout by vacuum assisted means.

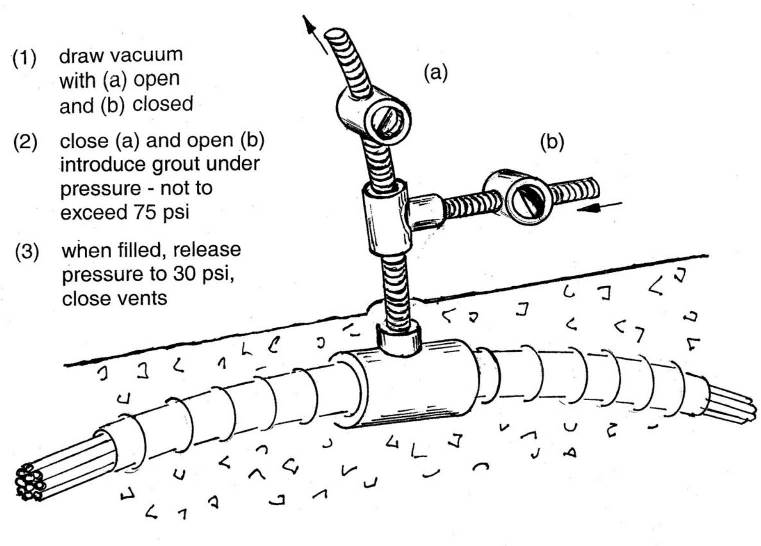


Figure 3.11 – Details of Vacuum Grouting Connections

(3) Attach a T-connector to the exit vent and attach to it two lines, each with a shut-off valve. Attach grout injection pipe to one of them. Attach vacuum pump to other.
(4) With the grout valve closed and vacuum valve open, draw a vacuum to evacuate any air or bleed water.
(5) When no more air or water can be withdrawn, switch valves and inject grout under pressure up to 75 psi – but no more.

(6) When secondary grout fills voids, reduce pressure to between 30 psi and 40 psi, and close vents.
(7) Repeat, in turn, at each voided vent as necessary.
(8) After completion of both primary and (when implemented) secondary vacuum-assisted grouting, seal all grout injection ports, grout outlet vents and drain vents. (See “Sealing of Grout Ports, Vents and Drains”)

Strategy 3 – Multi-Level Anchor Protection

Significant corrosion of post-tensioning tendons resulted from lack of adequate protection at anchorages. In some bridges, corrosion was exacerbated by leaks at expansion joints with water seeping behind pour-backs and into tendon anchors. Along with incomplete grouting, this led to the failure of a few tendons and the need to replace others.

As a result, Strategy 3 requires that all anchors have a minimum of four levels of corrosion protection. In this context a “level” is not necessarily a layer of material as such – rather it is a step taken to ensure protection. A level may be a layer created by a material (such as a pour-back) or it may be a layer made up of one or more coats of a sealing compound or it may be action taken to seal a cold joint.

A distinction is made between anchors inside a hollow box girder away from direct exposure to corrosive elements and anchors directly exposed to water and windborne salts.

Responsibilities in meeting the requirements of Strategy 3 are:

- Designer - incorporate details and requirements in the Contract Drawings to provide the necessary levels of anchor protection.

- Contractor - install all components and materials in accordance with the Contract Drawings, approved Shop Drawings, Specifications and QPL.

- CEI - inspect and check this work, advise the Contractor of any defects or omissions and prepare proper records.

3.1 FDOT Standard Drawings (Requirement 3.A)

Show anchor protection on the Contract Drawings in accordance with the FDOT Standard Drawings.

3.2 Shop Drawings (Requirements 3.A, 3.B, 3.C)

Shop Drawings and other relevant information (e.g. manufacturer’s catalogue data) are required for the post-tensioning system. Anchor protection details on Shop Drawings must comply with that shown on the Contract Plans, in accordance with the FDOT Standard Drawings. For precast segmental span-by-span construction, relevant information (such as dimensions, angles, sizes, cover etc. for anchor pockets, blisters or block-outs) must also be integrated into Shop Drawings for precast segments as appropriate. Shop Drawing responsibilities include:

- Contractor - submit the necessary “Shop Drawings” to the Engineer (Designer) for review and approval.

- Designer - review the Shop Drawings and other relevant information and notify the Contractor and CEI of its acceptability.

- CEI - coordinate and keep a record of submittals and responses.

3.3 Materials (Requirements 3.A, 3.B, 3.C)

Responsibilities regarding materials for anchor protection include:

- Designer – make sure that the Contract Documents address and require the proper materials for anchor components and protection.
- Contractor - ensure that all materials and components comply with the Contract Plans, Specifications, FDOT Qualified Products List and the approved Shop Drawings. This includes but is not necessarily limited to – grout, permanent plastic grout caps, epoxy grout for pour-backs to anchors and seal coatings as necessary. Also, keep records of submittals, test reports, approved component deliveries, and track materials and components from delivery through installation at both precast yard and bridge site.

- CEI - verify that materials and components comply with contract requirements. Also - check and record submittals, test reports, component deliveries and installation at both precast yard and bridge site.

3.4 Installation (Requirements 3.A, 3.B, 3.C)

Responsibilities regarding installation of anchor protection include:

- Designer – make sure that the Contract Documents address proper installation for anchor components and protection.

- Contractor - install components and materials in accordance with the Contract Drawings, approved Shop Drawings and Specifications.

- CEI – inspect the work to verify compliance with the Contract Documents and approved Shop Drawings as required. Advise the Contractor of any areas of non-compliance.

Particular requirements for installation are addressed in Sections 3.5 through 3.8 below.

3.5 Anchors inside a hollow box - (Requirements 3.A, 3.B, 3.C)

Typical anchor locations that fall into this category include:

- Anchors in blisters typically at the intersection of the web with the top or bottom slab.
- Anchors in interior diaphragms or deviator ribs.
- Face-anchors in recesses permanently open to the interior hollow core.

Provided that the structure is sealed from leaks through the bridge deck and is drained at all low spots so that water cannot accumulate against anchorages, the four-levels of anchor protection are provided by:

- Grout.
- Permanent grout cap.
- Elastomeric Seal coat.
- Surrounding box structure.

Details of corrosion protection for anchors inside a hollow box are show in Figure 3.12

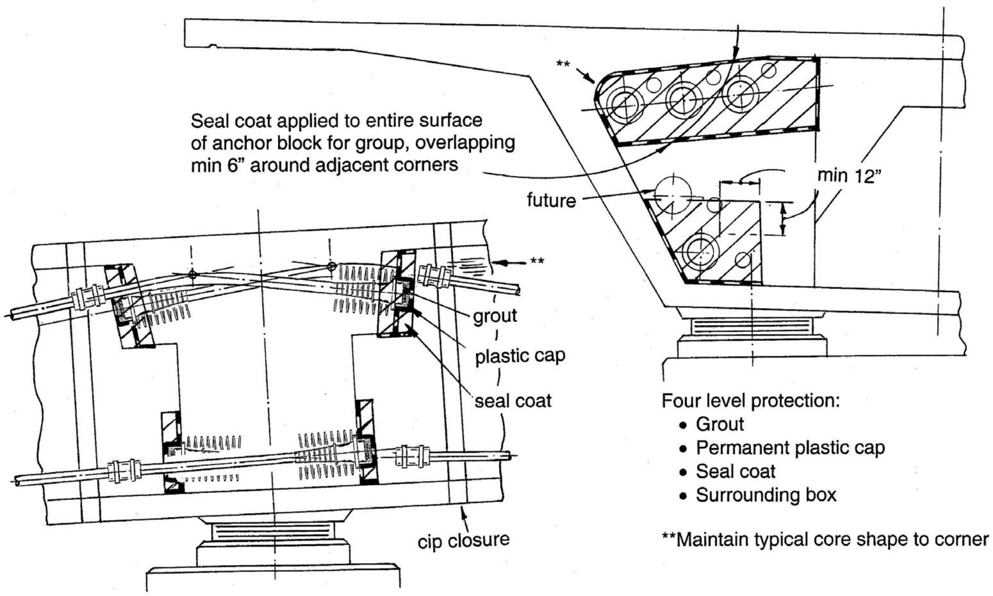


Figure 3.12 – Anchor protection at interior piers

Specific requirements for anchors inside a hollow box:

- Correct grout (per FDOT QPL) properly installed to completely fill tendon and anchor.
- Permanent grout cap of high density plastic, of the correct size and mechanically secured and sealed against the anchor plate with a compressible neoprene O-ring.
- Permanent grout cap fully filled with grout.
- Elastomeric seal coat selected from FDOT QPL.
- Seal coat applied over the cap, over the edge of anchor plate and overlapping onto adjacent structural concrete by a minimum of 12 inch all around the anchor plate.
- The surrounding box-structure designed, detailed and built properly to be ventilated, watertight and drained.

3.6 Tendons Anchored in Blisters (Requirements 3.A, 3.B, 3.C)

Refer to Volume 2, "Design and Construction Inspection of Precast Segmental Balanced Cantilever Bridges" for details and requirements of protection at anchor blisters and in recesses on the interior of a hollow box.

3.7 Anchors at Expansion Joints - (Requirements 3.A, 3.B, 3.C)

At expansion joints where an anchor or concrete containing anchors is directly exposed to windborne spray and water – the four levels of anchor protection are:

- Grout.
- Permanent grout cap.
- Encapsulating pour-back.
- Elastomeric seal coat.

Typical details for anchor protection at expansion joints in Figures 3.13 and 3.14.

Specific requirements for anchors at expansion joints:

- Correct grout (per FDOT QPL) properly installed to completely fill tendon and anchor.
- Permanent grout cap of high density plastic, of the correct size and mechanically secured and sealed against the anchor plate with a compressible neoprene O-ring.
- Permanent grout cap fully filled with grout.
- The pour-back encapsulating the anchor and grout-cap of an approved, high-strength, high-bond, low-shrink, sand-filled epoxy grout selected from FDOT QPL.
- Pour-back to provide minimum cover over cap of 1-1/2 inch.
- For an individual anchor in a recess, surface of pour-back be even with adjacent face of diaphragm or anchor block.
- For a group of anchors, similar individual recesses or, a single enclosing pour-back to encase all anchors in the group.
- A single enclosing pour-back must be secured to concrete substrate with embedded reinforcement (screw coupled rebar may be used) in order to ensure bond.
- Shape and dimensions of single enclosing pour-back be even with adjacent features of structural concrete with chamfers at all outside corners.
- All concrete surfaces of recesses and pour-back substrates be cleaned and roughened prior to casting pour-backs.
- All finished surfaces of pour-backs and adjacent structural concrete must be properly prepared to receive seal-coats.
- An approved elastomeric seal coating (per FDOT PQL) is applied over the pour-back overlapping onto adjacent structural concrete by a minimum of 12 inches all around.

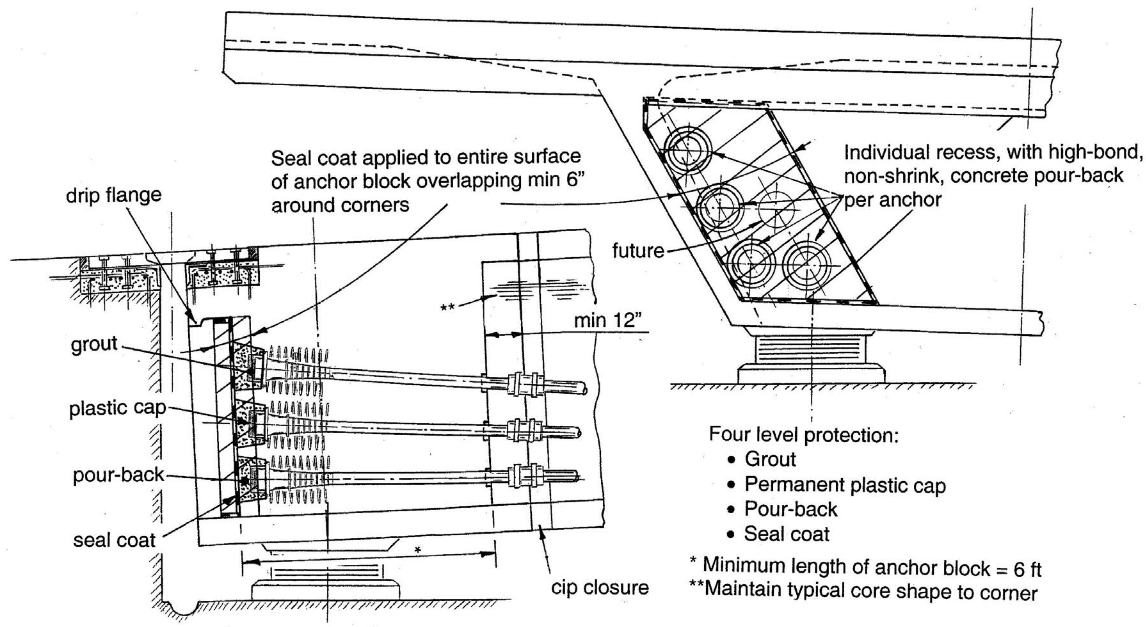


Figure 3.13 – Protection of individual anchorages at expansion joints.

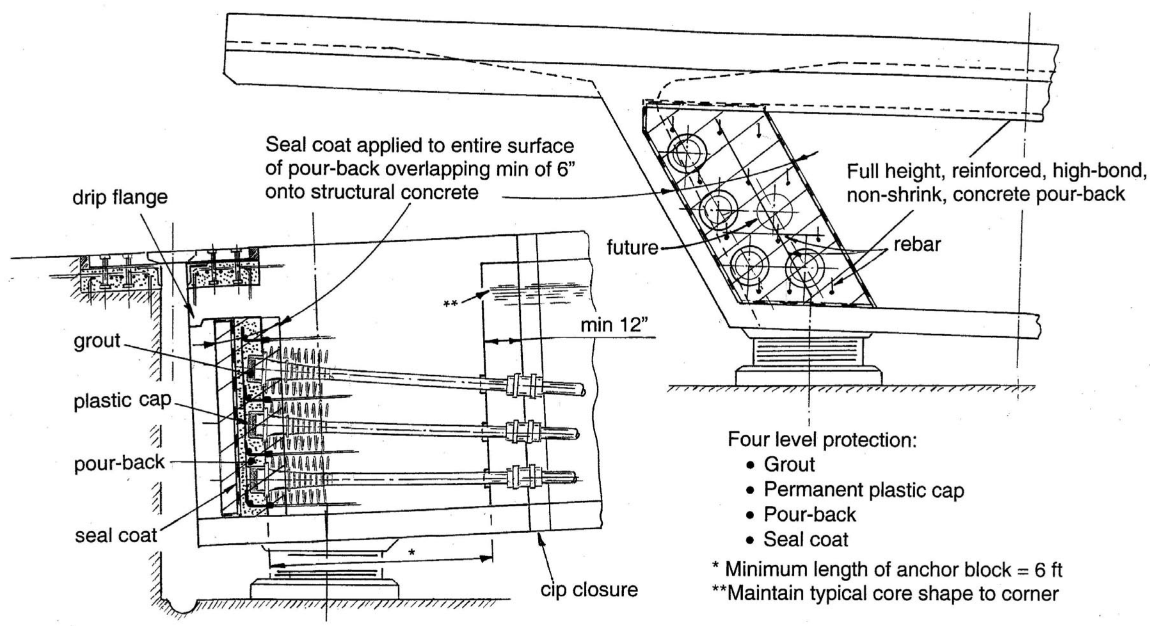


Figure 3.14 – Protection of a group of anchors at an expansion joint segment.

Also, protect anchors from dripping water at expansion joints (3.4 below). Note - a drip flange provides a positive, protective edge for the top of the seal coat.

In coastal areas, consider providing additional protection by means of skirts or baffles at expansion joints to minimize the direct effect of wind borne spray.

3.8 Embedded Face Anchors (Requirements 3.A, 3.B, 3.C)

Should there be a need in a *span-by-span* bridge for a tendon to be anchored at a segment joint using an embedded face anchor, refer to Volume 2, "Precast Segmental Balanced Cantilever Bridges".

3.9 Temporary Protection during Construction (Requirement 3.C)

During construction, all post-tensioning ducts and tendons must be temporarily sealed or capped to prevent ingress of water, corrosive agents or site debris and any low point drains should remain open.

In particular, ensure that:

- Post-tensioning anchors are sealed at all times to prevent the entrance of water or waterborne contaminants and are not blocked with construction debris.
- Temporary caps are used as necessary.
- Permanent grout caps are installed immediately after stressing.
- Vents and ports in anchors, grout caps and intermediate grout pipes are closed with threaded plugs or threaded caps until grouting.
- Plugs and caps are replaced after grouting but prior to completing permanent anchor protection.

Strategy 4 – Watertight Bridges

All bridge decks of post-tensioned structures shall be watertight. A watertight structure is the first line of defense against attack by corrosive agents. Several sources of leaks have been observed in existing precast span-by-span bridges. Some of these sources include:

- Dry joints (non-epoxied) between the precast segments.
- Holes for attachment of temporary lifting equipment and stressing jacks.
- Blockouts in the bridge deck to provide access for supplying tools.
- Pour-backs in blockouts of cast-in-place closure joints.
- Pour-backs in expansion joint seats.

Holes and block-outs are potential sources of leaks when the fill concrete shrinks away from the precast concrete. Consequently, although such provisions are important to facilitate construction, it is vital that they are properly filled and sealed.

4.1 Epoxy Sealed Joints (Requirement 4.A)

All match-cast joints in precast segmental span-by-span construction shall be sealed with epoxy applied to both faces of the mating segments. Responsibilities regarding epoxy sealed joints include:

- Designer – make sure Contract Documents require appropriate epoxy joining for bridge construction, application, site location and weather conditions.

- Contractor – prepare segments and apply epoxy in accordance with Contract Specifications and requirements.

- CEI - check that epoxy is properly applied to seal joints.

Requirements for epoxy sealed joints:

- Epoxy is the correct formulation (i.e. usually normal-set for cantilever erection or slow-set for span-by-span erection).
- Formulation is correct for application temperature and relative humidity.
- Materials do not exceed shelf life.
- Components are mixed according to manufacturers recommendations.
- Mating surfaces are properly prepared, clean and dry.
- Correct amount of epoxy is applied (i.e. number of cans for face area of application).
- Epoxy is properly applied to both faces - but carefully around internal ducts to avoid unnecessary spillage of epoxy into any internal duct connectors.
- Segments are drawn together within the open time before epoxy can take initial set.
- Requisite temporary PT force is applied to compress tight the epoxy, create the seal and secure the new segment to the previous one.
- After mating, all internal ducts are swabbed to remove any exuded epoxy and prevent blockages.
- All exuded epoxy is cleaned from visible joints (may be done after epoxy has set).

4.2 Cast-in-Place Closure Joints (Requirements 4.B and 4.C)

In span-by-span construction, short cast-in-place closures are typically provided at each end of each span between the last typical segment and the pier segment. These closure joints provide clearance for placing the typical segments between pier segments and accommodate small adjustments to the as-cast length and erected geometry of the segments. The lengths of closure joints are typically between 6 inches and 9 inches and are not reinforced unless over 10 inches long.

These closures are poured after all the segments have been placed, positioned, aligned and a nominal amount (usually about 10%) of the permanent longitudinal post-tensioning has been applied. Temporary concrete spacer blocks (precast or rapid setting concrete) are first placed in the closures at suitable locations to carry the nominal post-tensioning force. This locks in the span geometry and enables forms to be fixed across closures while the weight of the structure remains on the erection truss or gantry. Concrete of the same mix design as the precast segments is placed in the closures and allowed to cure sufficient to carry the full post-tensioning (typically when the closure concrete attains 2,500 psi).

Requirements for narrow cast-in-place closure joints in *span-by-span* construction:

- Show locations and sectional dimensions of the concrete spacer blocks on Contract Drawings and Shop (erection) Drawings.
- Edge of blocks to be no closer than 12 inches (300mm) from the nearest tendon.
- Concrete for space blocks to be same as segments or an approved, rapid setting, high strength material.
- Concrete for cast-in-place joint to be of same mix as segments, thoroughly consolidated and cured in accordance with the Specifications.
- Seal top of closure with methyl methacrylate across the full deck width at each interface of the closure joint (particularly any secondary pour-backs in closure – 3.4.6 below).

4.3 Upper Reveal for Stressing Jacks at Pier Segments at Closure Joints

Some existing span-by-span segmental bridges have top slab dimensions different than the top slabs of the adjacent typical segments. This detail was used in order to achieve maximum eccentricity at the piers while providing a horizontal exiting trajectory for the tendons. The altered slab dimensions required odd shaped closure joints between the pier segments and typical segments. Difficulties in forming these closures have led to a local source of leaking.

New construction shall maintain the same cross section shape on both sides of the closure joint as shown in Figure 3.15. Horizontal exiting trajectories were the result of concern for the localized action of overlapping tendons in the top of the pier segment in earlier bridges. This type of tendon geometry is, however, not necessary if the proper allowance is made for local forces and the diaphragm detailed to provide clearance for stressing jacks. Alternatively, if the exit angle remains horizontal, then the tendon anchors must be lowered to retain the full section shape.

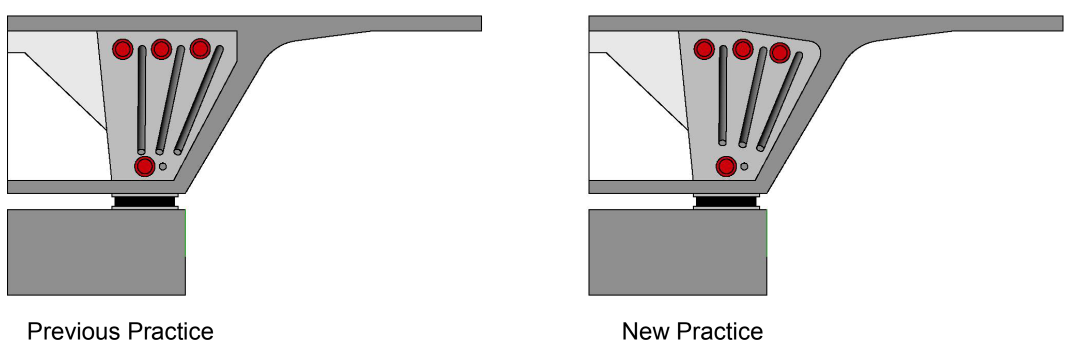


Figure 3.15 – Maintaining complete cross section at pier segments.

4.4 Holes in Top Slabs (Requirements 4.B and 4.C)

Holes for Lifting Segments

Holes through the top slab within the interior core of the section may not be required if segments are lifted by slings. However, this method of lifting the segments is not always feasible holes may be needed for attaching lifting frames. Holes are essential when individual segments of a span-by-span bridge are suspended from an overhead gantry. Typically, such holes are up to approximately 3" diameter.

Holes for Supports for Access Platforms and Longitudinal Tendon Stressing Jacks

Holes are essential for securing support legs for overhead gantries or special segment lifting equipment. Also, in span-by-span construction, tendons are stressed at the pier segment or expansion joint segment at the leading end of construction. Stressing jacks and access platforms are often supported by temporary frames that resting on top of segments and secured by post-tensioning bars in holes passing through the segment.

Forming and Filling Temporary Holes in Top Slabs (Requirements 4.C and 4.D)

Avoid placing holes where leaks would drip directly onto anchor heads and, as far as possible, onto post-tensioning inside the box girder. Where possible, locate holes for lifting frames, closure devices or equipment attachments outside of webs in the cantilever wings. Responsibilities regarding forming and filling of temporary holes include:

- Designer - show permissible sizes and locations of temporary holes on the Contract Drawings and make sure Contract Documents address required filling and sealing.

- Contractor - use only tapered (top wider than bottom) temporary holes in accordance with the details on the Contract Drawings or approved Shop Drawings.

- CEI - check that all such holes are correctly installed, filled and sealed after use.

Requirements for Temporary holes through Top Slabs:

(1) Taper sides - top larger diameter than bottom by at least ¾ inch.
(2) Form with removable mandrel to provide a clean, interior concrete surface.
(3) Locate at least 12 inch from the nearest anchor.
(4) Use no pipe of any kind (plastic, steel, ribbed or plain) as permanent liner through slab unless over 18 inch deep – in which case a ribbed plastic liner may be used.
(5) Sides to be clean of all dirt, debris, grease and oil immediately prior to filling.
(6) Fill with an approved high strength, high bond, non-shrink, quick set, air cured concrete material or epoxy grout.
(7) Seal of top surface (deck) with an approved sealer (methyl methacrylate) applied over and around the filled holes. A seal is not required when epoxy grout is used.
(8) Where temporary holes pass through the full depth of structure (e.g. diaphragms) –make appropriate allowance and adjust details for local geometry, super-elevation, grade and possible interference with other components or tendons.

4.5 Temporary Post-Tensioning (Requirements 4.C and 4.D)

During span-by-span construction, segments are supported by temporary erection trusses or overhead gantries. Temporary post-tensioning is not needed to support the segment weight as in cantilever erection. However, temporary post-tensioning is necessary to apply required pressure to close epoxy joints.

In most cases it is unlikely that the temporary post-tensioning would be placed in and anchored in the top and bottom slabs. However, temporary block-outs may be needed to attach brackets that in turn anchor external temporary bars for pulling segments together. If internal temporary post-tensioning is used, block-outs must not be used where the tendons pass through match-cast joints.

Wide segmental box girder sections may require temporary or permanent post tensioning in the wings of the top slab in order to properly close epoxy joints or overcome shear lag effects. These bars may have to be placed inside longitudinal ducts cast into the slab. In this case, details to accommodate end anchors, intermediate anchors, couplers and blockouts need to be provided. The necessary size of block-outs depends upon the bar size, plates, couplers and alignment geometry. As far as possible, locate such PT under the edge traffic barriers where blockouts can be properly backfilled and additionally protected by the barrier.

Upon completion of erection, all un-used internal ducts for temporary bar tendons must be completely filled with grout whether PT bars are left in place and whether stressed or not.

An alternative to avoid blockouts through slabs is to place temporary post-tensioning within the box core using holes through diaphragms and deviator ribs. Holes may be formed of any suitable duct material. Temporary post-tensioning may extend from a pier segment to a deviator segment or between deviator segments, and be anchored and coupled as convenient to the structural configuration. External temporary post-tensioning bar blisters may also be placed on the interior of the hollow section in a similar manner to balanced cantilever construction.

Consequently, for temporary post-tensioning:

- Designer - show acceptable range of locations, dimensions and details for temporary post-tensioning and associated block-outs on the Contract Drawings.

- Contractor - use temporary post-tensioning in accordance with details on the Contract Drawings, approved Shop Drawings and / or Erection Manual.

- CEI – make sure that temporary post-tensioning is properly installed and removed accordingly and that any block-outs are properly formed, filled and sealed.

Typical locations for temporary post-tensioning bars for span-by-span construction are shown in Figure 3.16

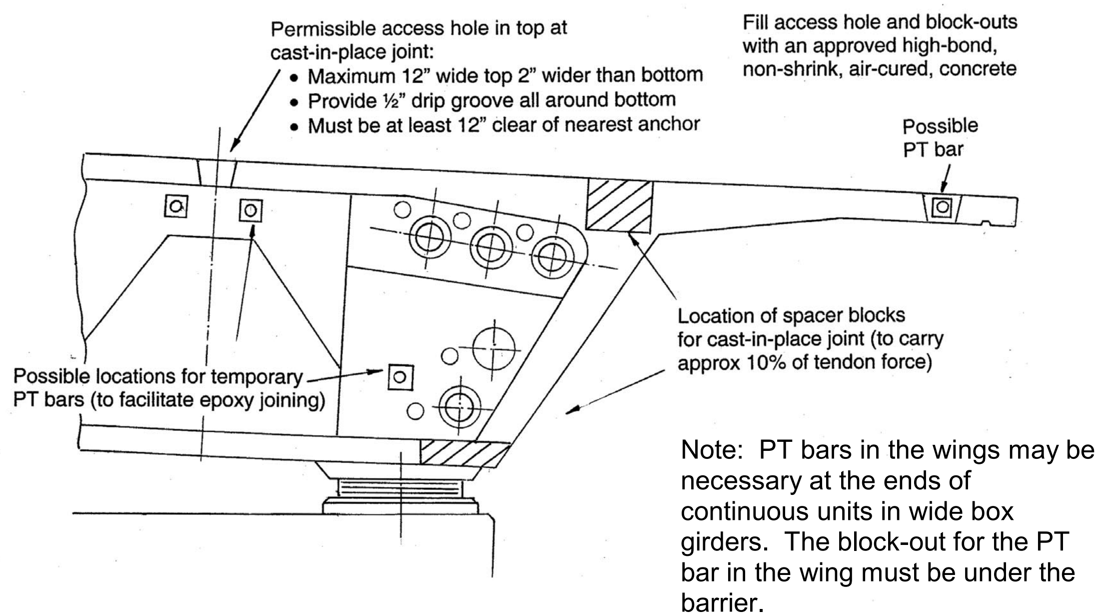


Figure 3.16 – Temporary post-tensioning bar locations

Requirements for locating, forming, filling and sealing Block-outs in Top Slabs:

(1) Do not place block-outs where leaks would drip onto another anchor or external tendon.
(2) Do not locate any block-out where it encroaches upon or interferes with a longitudinal tendon duct – keep edge of block-out clear by at least 3 inch.
(3) Locate block-outs greater than 12 inch from the nearest anchor.
(4) Provide tapered sides to block-outs, at least 2 inch wider at the top than bottom, in order to develop wedge action support and help seal pour-back concrete.
(5) Limit plan-view size to less than 12" by 12".
(6) Form block-outs to provide a neat internal concrete surface.
(7) Avoid use of excessive sealant or layers of duct tape to ends of any internal tendon ducts at bulkheads or match cast segments near block-outs that might cause a local defect.
(8) All block-out surfaces must be cleaned of grease, debris, dirt, oil, and lightly roughened.
(9) Backfill block-outs with an approved, high strength, high bond, non-shrink, quick setting, air-cured concrete or an epoxy grout.
(10) Seal top slab pour-back with an approved sealer (methyl methacrylate). A seal is not required when epoxy grout is used.

Treat block-outs through the bottom slab the same as the top except seal with an approved elastomeric coating applied for a minimum of 12 inches all around and over the pour-back.

4.6 Secondary (Construction Equipment Access) Block-outs in Closure Joints (Requirements 4.C and 4.D)

It is appropriate to use concrete of the same mix design as the precast segments for closure joints in each span since the entire section is compressed when post-tensioned. However, if a secondary access block-out is made in this closure, it may become a source of leaks if later filled only with segment concrete. The secondary concrete shrinks, allowing water to leak through the deck and onto nearby tendons and anchors.

Nevertheless, there is usually a need for small access holes for tools, hoses, air-lines, electrical cables and communications. The number and size of these equipment access blockouts provided for this purpose must be kept to a minimum. In precast segmental span-by-span bridges, the number of such block-outs in the slabs between the webs must be limited to one per cast-in-place closure joint per cell in the top slab (i.e., a maximum of two block-outs of this type per span in a single cell box). Block-outs must be located away from tendons and be completely filled and sealed after use in accordance with the procedures in Section 3.4.5 above. Responsibilities regarding secondary block-outs in closure joints include:

- Designer - show acceptable locations, dimensions, forming, filling and sealing for block-outs on the Contract Drawings.

- Contractor – provide and use block-outs in accordance with details on the Contract Drawings or approved Shop Drawings.

- CEI - check that all block-outs are correctly installed, filled and sealed after use.

4.7 Temporary Access Holes (Requirements 4.C and 4.D)

Unlike precast and cast-in-place balanced cantilever, access manholes for construction purposes are seldom required in span-by-span construction. If temporary access holes are needed, however, locate them at suitable locations and use a size to accommodate the necessary pieces of equipment, such as stressing jacks. Typically an access should be at least 2'-6" diameter, square or rectangular up to approximately 2'-6" by 3'-6". Responsibilities regarding temporary access hole include:

- Designer - show acceptable range of locations, dimensions and details for temporary access holes on the Contract Drawings.

- Contractor - use only tapered (top wider than bottom) access holes in accordance with details on the Contract Drawings or approved Shop Drawings.

- CEI – check that access holes are correctly installed, filled and sealed.

Requirements for temporary access holes (manholes):

- Allow one access hole per span per cell in top or bottom slab.
- Locate to avoid tendons and anchors.
- Locate to avoid possibility for water to drip onto anchors or components.
- Locally design transverse PT and mild reinforcement to accommodate access hole.
- Reinforce pour-back to hole with spliced and / or screw-coupled rebar.
- Provide tapered sides all around with top of manhole larger than bottom.
- Sides to be thoroughly cleaned and roughened.
- Sides to be free of dirt, debris, grease and oil prior to filling.

- Fill with an approved no-shrink, high-bond, high-strength, air-cured concrete or epoxy grout.
- On the top slab, seal with an approved sealer (e.g. methyl methacrylate). A seal is not required when epoxy grout is used.
- On the bottom slab, seal with approved elastomeric coatings (to FDOT QPL).

4.8 Expansion Joint Recess and Seats (Requirements 4.C and 4.D)

At expansion joints it is necessary to provide a recess and seat across the segment to receive the assembly, anchor bolts and frames of the expansion joint hardware. In the past, block-outs have been made in these seats to provide access for stressing jacks of anchors located high in the diaphragm. These block-outs are a source of leaks during and after construction.

Expansion joint recesses and seats for new construction shall contain no block-outs. Lower the upper tendon anchors and re-arrange the anchor layout as necessary to provide access for the stressing jacks. It is unlikely that this will result in any significant loss of tendon eccentricity or structural efficiency. Figure 3.17 compares previous details with new requirements.

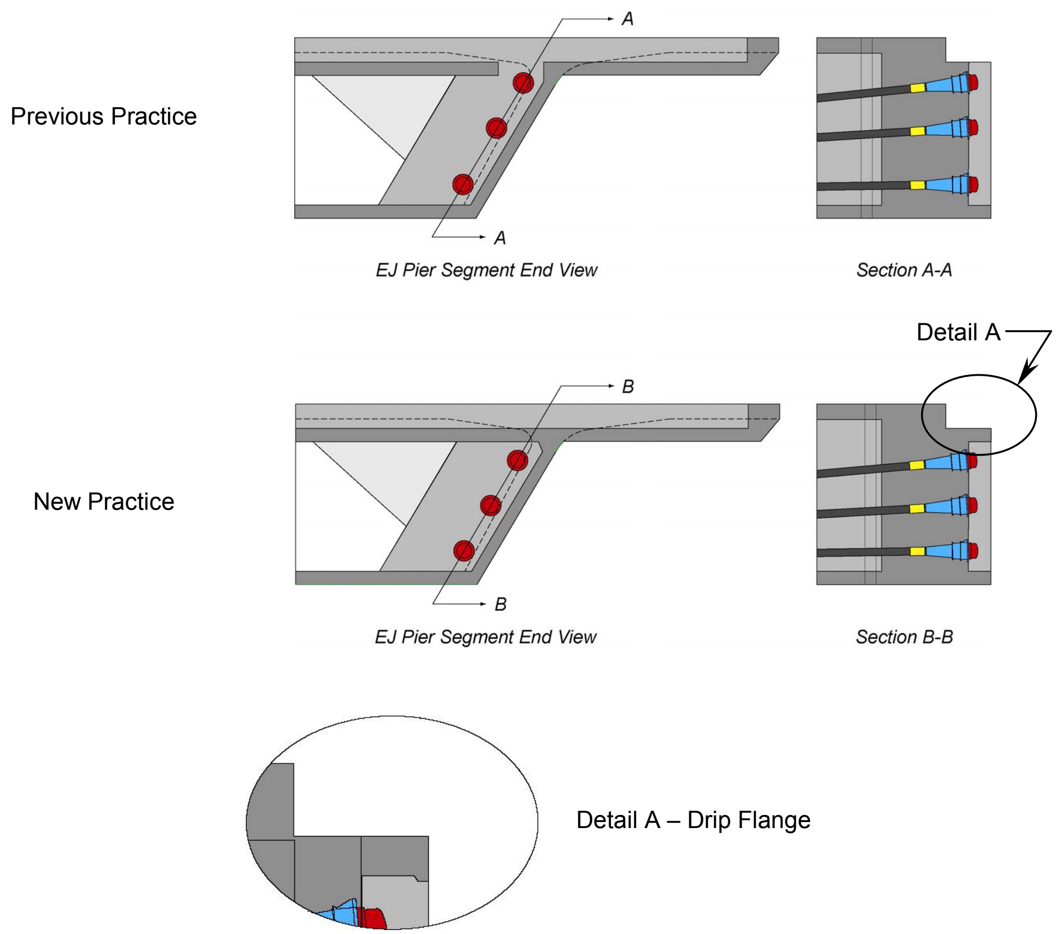


Figure 3.17 – Continuous recess and seat for expansion joints.

Responsibilities regarding expansion joint recess and seats include:

- Designer – select and show required expansion joint details on Contract Drawings.
- Contractor - construct expansion joint device recesses and seats in accordance with the details on the Contract Drawings or the approved Shop Drawings.
- CEI - check there are no block-outs or penetrations of the expansion joint recess and seat, that it is constructed correctly and cast monolithically with the precast segment.

4.9 Drip Notches and Flanges (Requirement 4.F)

Even though protected by expansion joint components, glands or drainage troughs, water nevertheless can leaks into expansion joint recesses and seats. It can then seep behind pour-backs into anchorages. Provide drip flanges on the underside of the transverse seat for expansion joint device so that any leaking water cannot flow back under the slab and behind seal coats or pour-backs (Figure 3.17). Responsibilities regarding drip notches and flanges include:

- Designer - show on the Contract Drawings details for all drip notches or flanges in locations where water may directly flow to any component of the post-tensioning system.
- Contractor - construct drip notches or flanges in accordance with the details on the Contract Drawings or the approved Shop Drawings.
- CEI - check that drips notches and flanges are correctly installed.

4.10 Bottom Slab Drains (Requirement 4.G)

Provide drains through bottom slab in box girder bridges to prevent water that enters from any source, including condensation, from ponding in the vicinity of post-tensioning components. Responsibilities regarding bottom slab drains include:

- Designer – Contract Drawings, show locations and details for bottom slab drains.
- Contractor - install segment drains in accordance with the details on the Contract Drawings or the approved Shop Drawings – including drains at all low points made by barriers introduced to accommodate means and methods of construction, such as additional blocks or blisters.
- CEI - check that all segment drains are correctly installed

Requirements for drains:

- Use 2 inch diameter permanent plastic pipes set flush with the top of the bottom slab.
- Provide a small drip recess, ½ inch by ½ inch around bottom of pipe insert.
- Provide at all low-points against internal barriers.
- Provide on both sides of box, regardless of cross-slope – to avoid confusion.
- Show locations and details for drains taking into account bridge grade and cross-slope.

- Provide same drain details at internal barriers created by barriers introduced as a consequence of the Contractor's chosen means and methods of construction.

Strategy 5 – Multiple Tendon Paths

5.1 Multiple Tendon Paths (Requirements 5.A and 5.B)

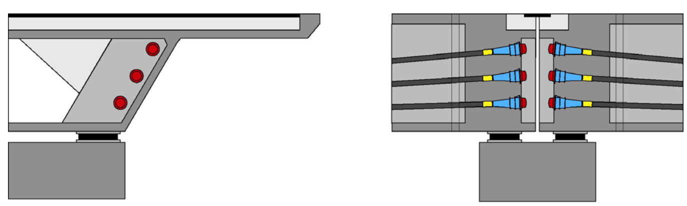
Precast segmental span-by-span superstructures typically consist of a single cell, (two web) trapezoidal box with a minimum depth of approximately 7 feet. The post-tensioning tendons are typically full span length, external to the concrete and drape throughout the span to provide required eccentricities. For these bridges, redundancy of the post-tensioning load paths depends directly upon the number of properly functioning tendons within the span. It is important, therefore, to ensure that the loss of any one tendon due to corrosion does not critically diminish overall bridge performance.

Consequently, for a typical single cell precast segmental span-by-span bridge:

- Provide no less than 8 individual tendons per box, per span.
- Do not use a tendon size greater than 19-0.6 inch diameter strands or 27-0.5 inch diameter strands.
- Select and size each tendon to approximately represent 1/8th (12.5%) of the total post-tensioning.
- Select size of tendons so that the loss of one tendon does not result in the loss of more than 15% of the total post-tensioning force in the superstructure at any section.

Previously used details are compared to new requirements at expansion joints and interior piers in Figure 3.18 and 3.19

Previous Practice



New Practice

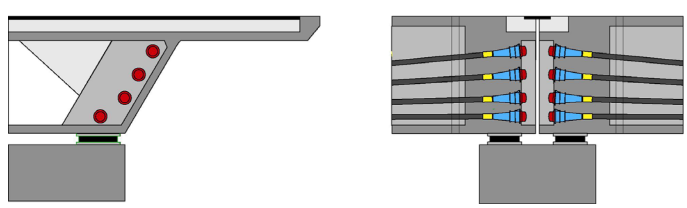


Figure 3.18 – Minimum tendon requirements at expansion joint piers

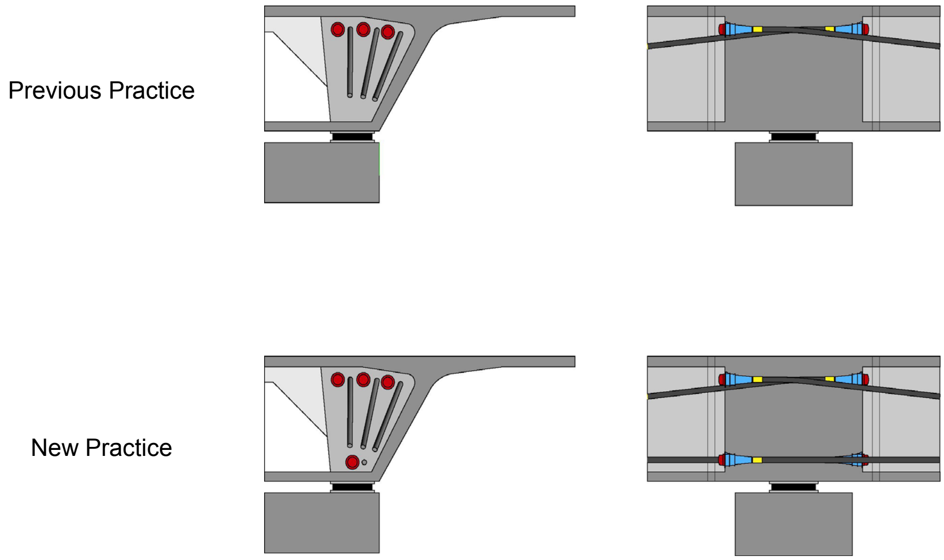


Figure 3.19 – Minimum tendon requirements at interior piers

5.2 Extra (Corrosion Loss) Post-Tensioning (Requirement 5.C)

External tendons in a span-by-span bridge, unlike bonded tendons in cantilever construction, can be inspected, and if necessary, they can be removed and replaced. As a result, for precast segmental span-by-span bridges with external tendons, no extra (corrosion loss) post-tensioning is required to compensate for potential and unknown loss due to corrosion.

5.3 Provisional Post-Tensioning (Requirement 5.C)

Provide superstructure with details to accommodate straight or draped, external tendons for future strengthening or rehabilitation in accordance with the AASHTO – LRFD Specification, Paragraph 5.14.2.3.8c. However, make the details such that the 10 percent provisional prestressing force (of all permanent tendons) closely follows the center of gravity of the final post-tensioning force in the completed structure after all long-term effects.

5.4 Construction – Multiple Tendon Paths (Requirements 5.A, B and C)

Once established by the design, the number of longitudinal tendons must be implemented in Construction. The Contractor must follow the Contract Drawings or otherwise comply with all the requirements of this Volume related to Multiple Tendon Paths. This means that it may not be acceptable to substitute via Shop Drawings or a VECP fewer large sized post-tensioning tendons for smaller sized ones of the original design. Responsibilities regarding multiple tendon paths during construction include:

- Contractor - comply with the above requirements when preparing Shop Drawings or changes by VECP, when allowed by the Contract and submit the necessary “Shop Drawings” to the Engineer (Designer) for review and approval.

- Designer - review Shop Drawings and other relevant information and notify the Contractor and CEI of its acceptability.

- CEI - coordinate and keep a record of submittals and responses.