Design Guidelines and Detailing Update Related to Post-Tensioning and Segmental Bridges

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Background Behind the Flexible Filler PT Policy

- PT Grout - Crisis of Confidence
- An opportunity for Improvement

Background Behind the Flexible Filler PT Policy

THE FDOT STUDY TOUR MEMBERS AT PROJECT SITE IN FRANCE (October 16, 2013)

Learning Objectives

- ❖Status of FDOT Flexible Filler PT tendons
- ❖Flexible Filler project implementation in the state of Florida
- ❖Update on the design aspect and detail requirements for post-tensioned and segmental concrete bridges
- ❖Update on Structures Design Guidelines related to post-tensioned and segmental bridge design
- ❖Update on Structures Detailing Manual related to post-tensioned and segmental bridge detailing
- ❖Update on tendon filler injection mock-up test requirements

Presentation Outline

1. Introduction
2. General Requirements
3. Superstructures
4. PT Spliced Girder Bridge
5. PT Tendon Mock-up Test
6. Closing

Introduction

Focus of this Presentation

Structures Design Guidelines and Structures Detailing Manual updates in implementing the Policy Changes in PT bridges since 2016

Reference: Structures Manual – January 2019

Major Changes in Policy

Implement **Flexible Filler** as PT Tendons corrosion protection for all tendons, except PT tendons in the deck, such as cantilever tendons, transverse tendons, slab tendons with maximum 2’-0” drape.

Tendon **Replaceability** is one of the major factors in changing the Policy toward **flexible filler**.

Introduction (cont.)

Flexible Filler/ Replaceable Tendons - Status of Post-tensioned and Segmental Bridges in Florida

- April 2014: Revision to FDOT Policy for Post-Tensioned bridges was posted (Structures Design Bulletin 14-06)
- January and May 2015: Updated on the Revised Policy were posted (Structures Design Bulletin 15-01 & 15-03)
- Since May 2015 Structure Design Office continue updating Structure Design Guidelines related Post-tensioned and segmental bridges
- The Policy for PT Bridges was effectively implemented since January 1, 2016.
- Projects implementation: two flexible projects have been completed, and several other major projects are under construction
- Flexible filler injection Training in Tallahassee, sponsored by FDOT, ASBI & PTI (1st training – May 2017, 2nd training – August 2018, 3rd training – August 2019).

Project Implementation

Introduction

Project: Wildwood I-75 Turnpike Interchange

Subject: Post-tensioned straddle pier cap with flexible filler

Status: Completed construction

Project completion: Open to traffic 2018

Photo Courtesy of VStructural

Introduction

Project Implementation

Project: I-295 Express in Jacksonville

Subject: Three straddle pier caps are post-tensioned with flexible filler tendons

Status: Completed construction

Project completion: Open to traffic May 2019

Introduction

Project Implementation

Project: Wekiva – Section 6
Subject: Three 3 span CIP balanced cantilever bridges, post-tensioned tendons with flexible filler and grout
Status: Under construction
Expected project Completion: Spring 2021

Introduction

Project Implementation

Project: Selmon Expressway – West Extension (THEA Project)

Subject: Post-tensioned Precast segmental superstructure, including some pier columns. PT tendons are flexible in combination with grout fillers

Status: Under construction

Expected completion: Fall 2020

Rendering courtesy of Kiewit

Introduction

Project Implementation

Project: I-395 Project in Miami

Subject: Post-tensioned Precast Segmental Structures (Arches and box girders)

Status: Under construction

Expected completion: 2022

I-395 Project Renderings - Courtesy of Connecting Miami (Archer Western De Moya Joint Venture)

General Requirements

Corrosion and Tendon Redundancy

1.11.2 Corrosion Protection

A. Include the following corrosion protection strategies in the design and detailing of post-tensioned structures:

1. Completely sealed ducts and permanent anchorage caps
2. Ducts and anchorage caps completely filled with approved filler
3. Multi-level anchorage protection
4. Watertight bridges
5. Multiple tendon paths

How is this Strategy # 5 applied to flexible filler?

General Requirements

Tendon Replaceability/Redundancy

4.5.2 Minimum Number of Tendons (Rev. 01/19)

Design and detail post-tensioned superstructure elements to meet or exceed the minimum number of tendons in accordance with Table 4.5.2-1. In addition, design post-tensioned superstructures such that any unbonded tendon can be removed and replaced one at a time utilizing the ***LRFD*** Table 3.4.1-1 Service I load combination with the live load placed only in the striped lanes. Under this load combination, limit tension stresses for precast superstructure elements with match cast joints to $0.0948\sqrt{f'_c}$ (ksi), and to $0.19\sqrt{f'_c}$ (ksi) for all other concrete superstructure elements.

Table 1.11.1-1 Minimum Clearance Requirements at Anchorages for Replaceable Strand and Wire Tendons

Anchorage Type and Location	Minimum Clearance Requirement	Example Detail
Stressing End Anchorage Near Deviator	Dimension B[1]	*SDM* Figure 20.8-1
Stressing End Anchorage at Intermediate Diaphragm Near Minor Obstruction[2]	Dimension A[1] + 1'-0" (min.)	*SDM* Figure 20.8-2
Non-Stressing End Anchorage Near Abutment	2'-6" + Δ_T Δ_T = Maximum Design Thermal Expansion	*SDM* Figure 20.8-3 *SDM* Figure 23.7-3
Non-Stressing End Near Other Structure	2'-6" + $\sum\Delta_T$ $\sum\Delta_T$ = Summation of Maximum Design Thermal Expansion of both adjacent structures	*SDM* Figure 20.8-4 *SDM* Figure 23.7-4
Stressing End Anchorage at Other Locations	Dimension A[1] + Δ_T (if applicable) + sufficient clearance for pulling existing tendon and installation of new tendon (Prior SDO approval is required to use this approach at locations other than webs of I-girders as shown in *SDM* Figures 23.7-1 and 23.7-2)	*SDM* Figure 23.7-1 *SDM* Figure 23.7-2
Non-Stressing End Anchorage at Other Locations	2'-6" + Δ_T (if applicable)	-

1. See ***SDG*** Figure 1.11.1-1 and ***SDG*** Table 1.11.1-2.
2. A minor obstruction is a bridge component or projection that does not impede future tendon replacement operations.

General Requirements

Tendon Replaceability

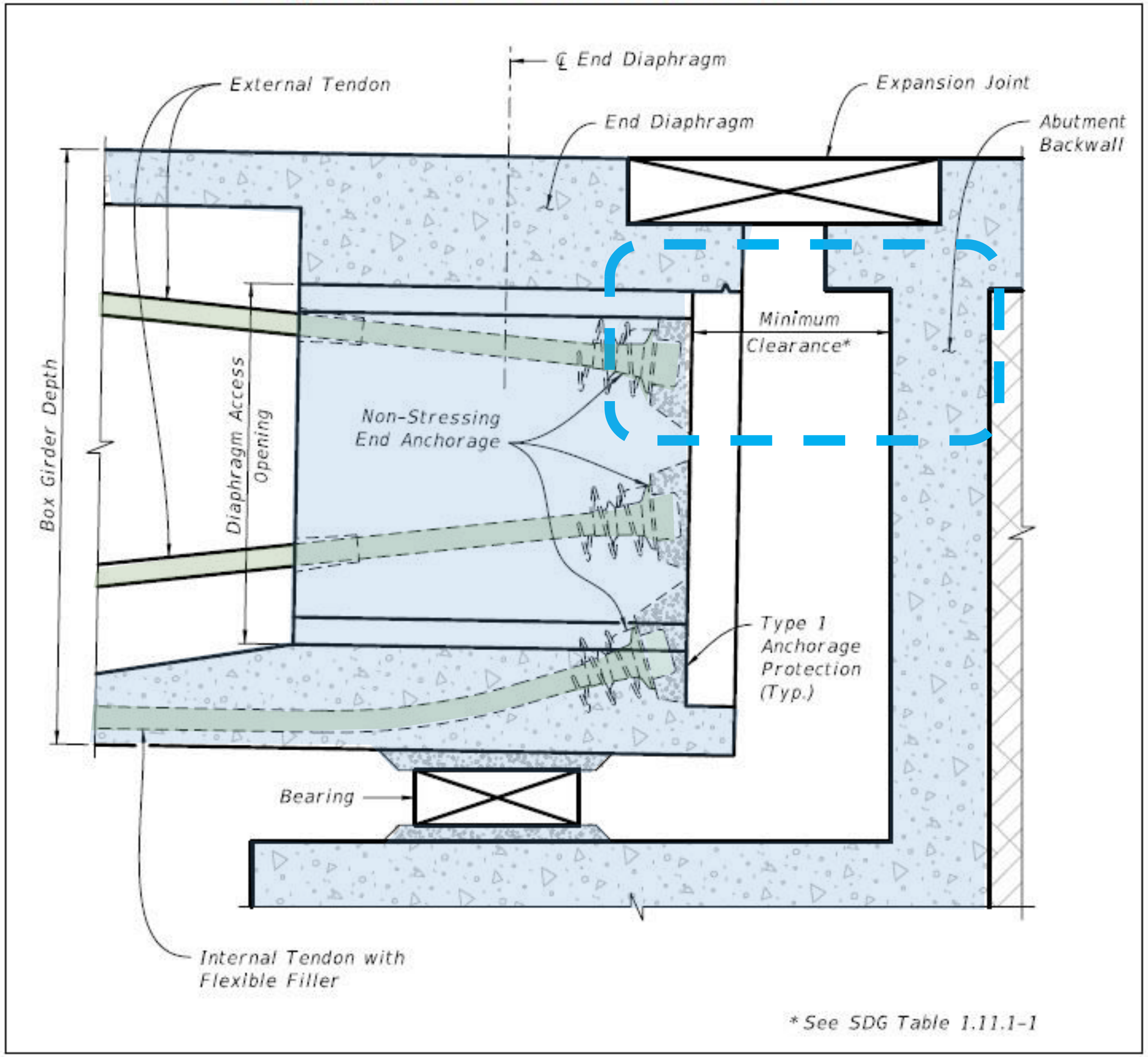
General Requirement

Abutment

Maintenance / stressing spaces at Abutment (typical for bridges in Europe)

End Diaphragm

Figure 20.8-3 Non-Stressing End Anchorage Clearance at End Diaphragm Near Abutment Backwall



General Requirements

Tendon Replaceability

Figure 1.11.1-1 Jack Envelope Dimensions for Design and Detailing

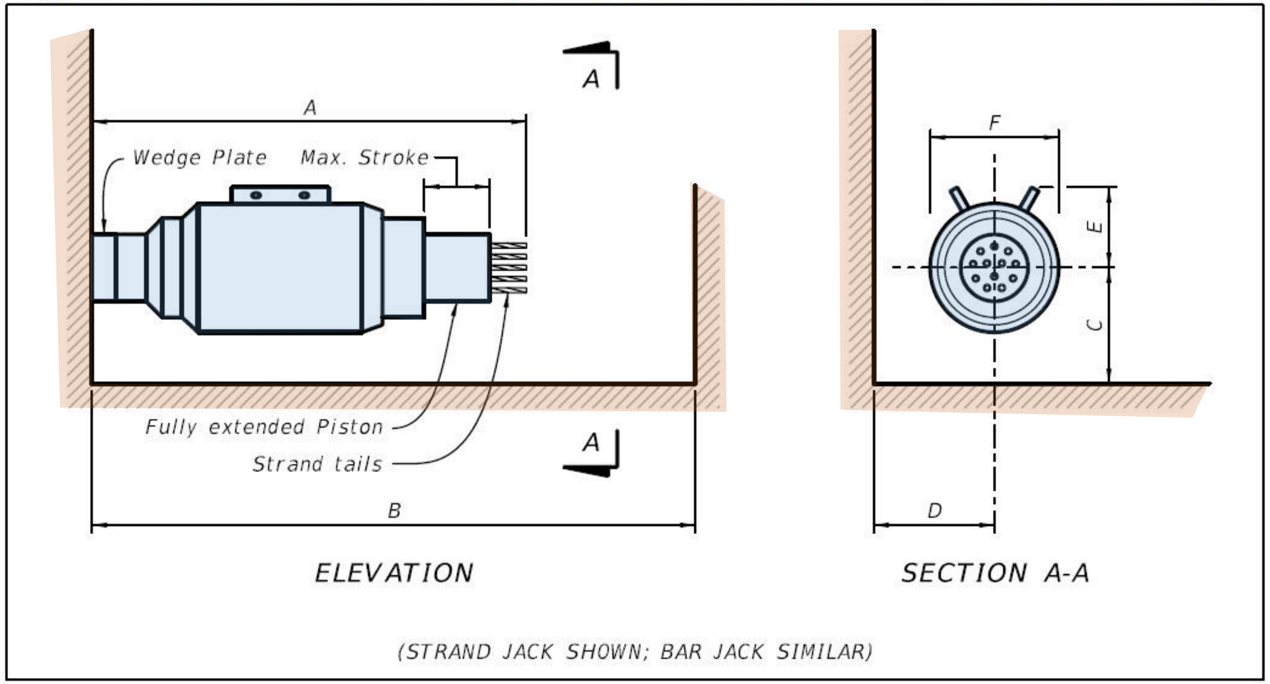


Table 1.11.1-2   Jack Envelope Dimensions for Design and Detailing

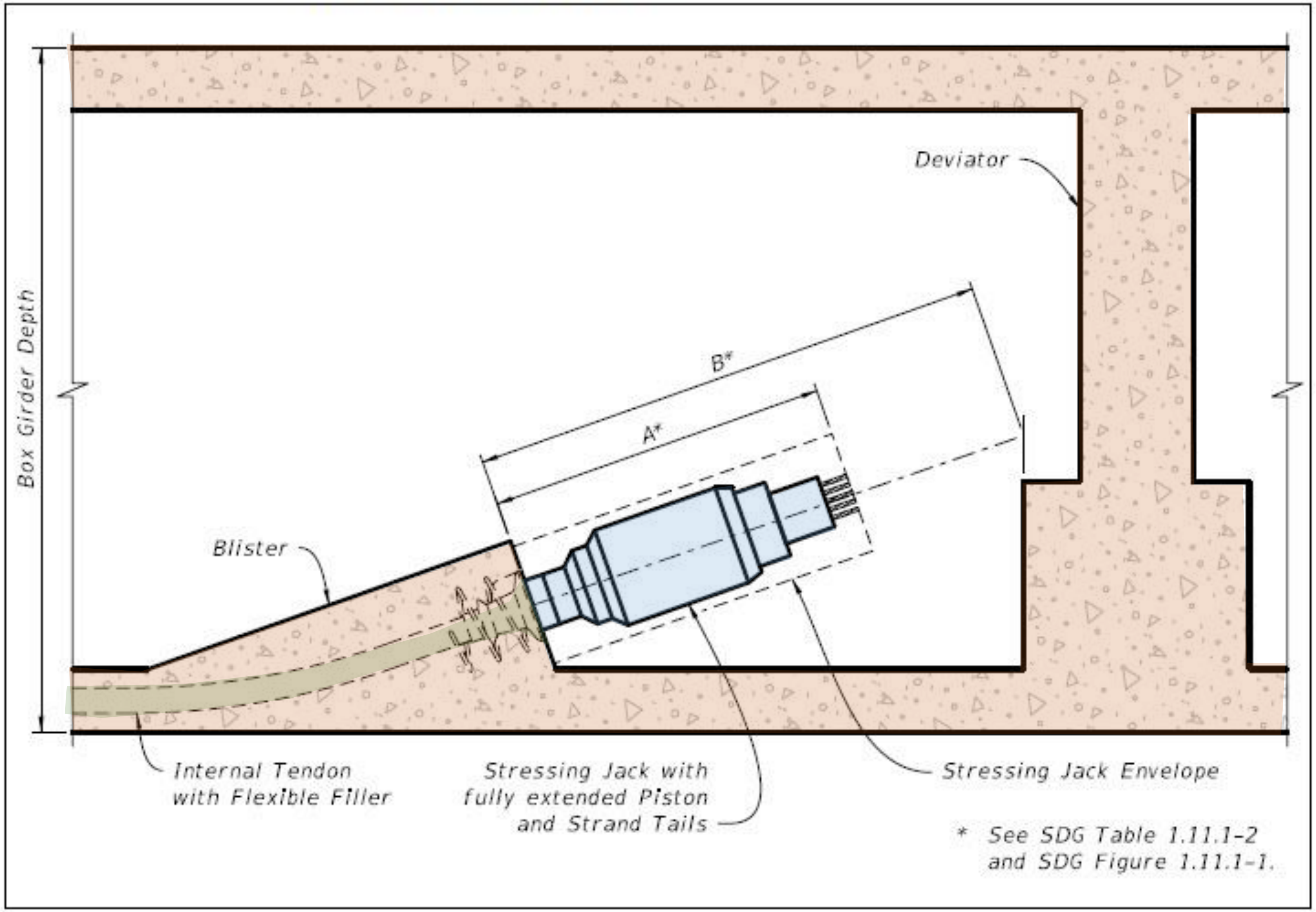
Tendon Size & Type	Jack Envelope Dimensions (in)					
	A	B[1]	C	D	E	F
4 - 0.6 Strands	50	86	15	15	17	11
7 - 0.6 Strands	51	92	15	15	17	15
12 - 0.6 Strands	51	92	15	15	14	15
15 - 0.6 Strands	60	120	15	15	21	19
19 - 0.6 Strands	60	120	15	15	17	19
27 - 0.6 Strands	60	120	15	15	19	24
31 - 0.6 Strands	60	120	18	18	19	25
1" Diameter Bar	42	72	15	15	10	11
1-1/4" Diameter Bar	43	72	15	15	10	11
1-3/8" Diameter Bar	43	72	15	15	10	11
1-3/4" Diameter Bar	51	92	15	15	12	15
2-1/2" Diameter Bar	56	92	15	15	13	16
3" Diameter Bar	60	120	15	15	17	19

1. See ***SDG*** Table 1.11.1-1 for required dimension for Tendons with Flexible Filler.

General Requirements

Tendon Replaceability

Figure 20.8-1 Stressing End Anchorage Clearance of Bottom Internal Tendon Near Deviator



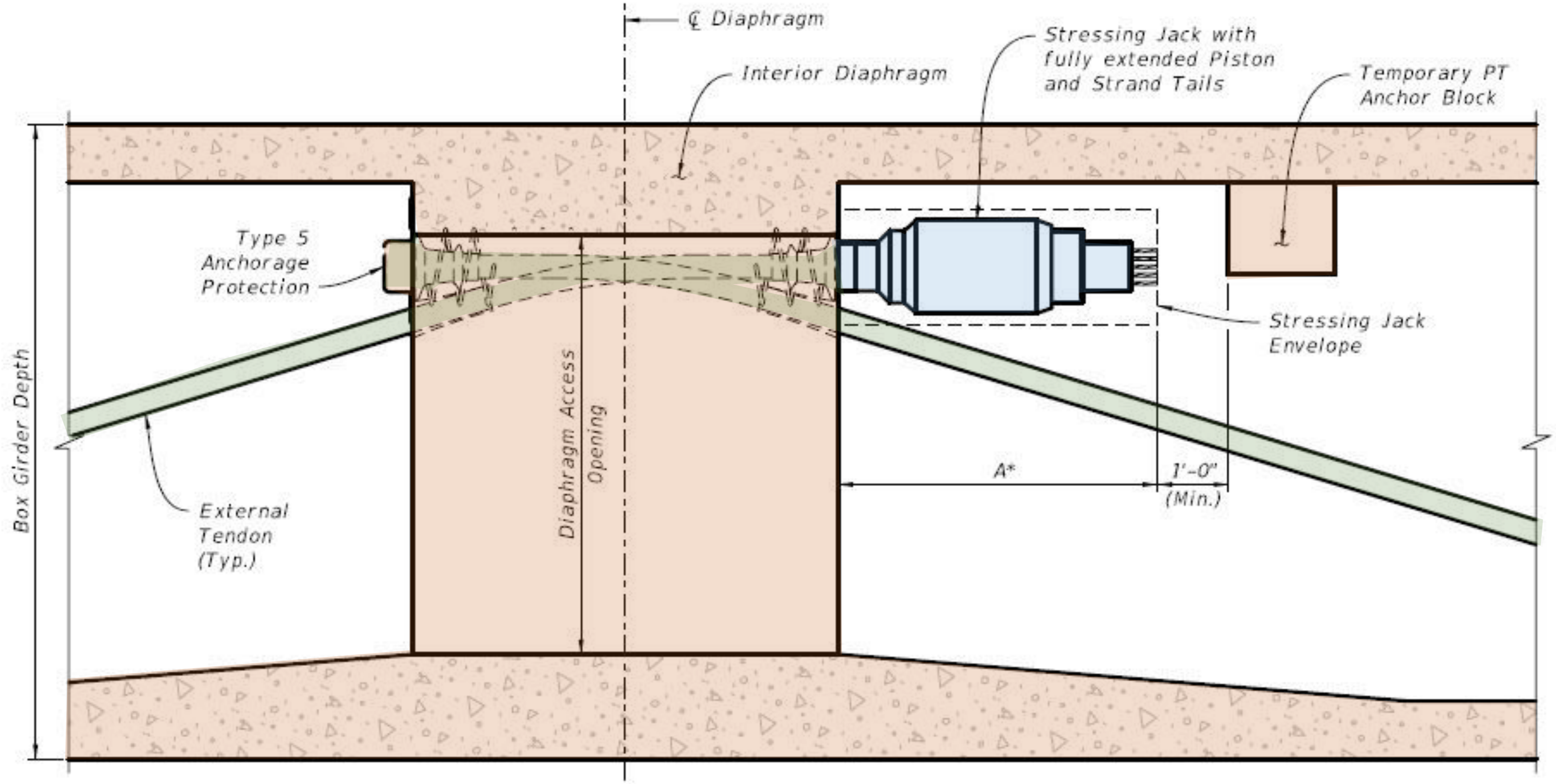
General Requirements

Tendon Replaceability

General Requirements

Tendon Replaceability

Figure 20.8-2 Stressing End Anchorage Clearance of External Tendon at Diaphragm Near Anchor Block

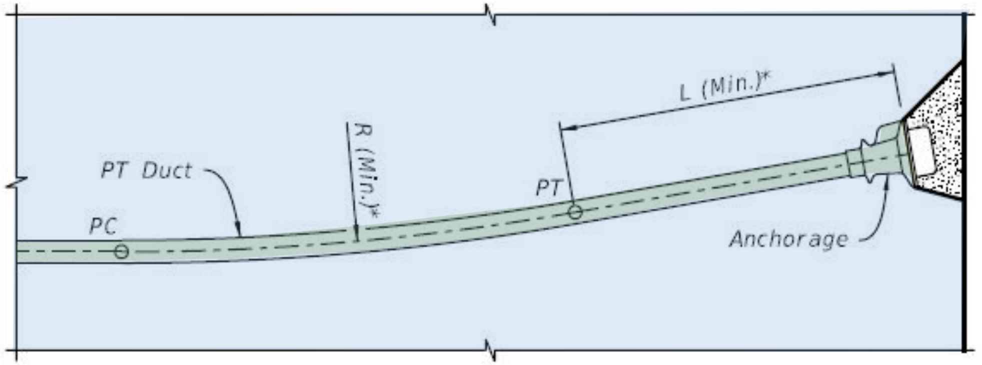


* See SDG Table 1.11.1-2 and SDG Figure 1.11.1-1.

General Requirements

Tendon Duct Geometry

Figure 1.11.4-1 Minimum Duct Radius and Tangent Length Adjacent to Anchorages



NOTE: Internal tendon shown, external tendon similar.

* See Table 1.11.4-2

Table 1.11.4-2 Minimum Duct Radius and Tangent Length

Tendon Size	Minimum Duct Radius Between Two Tangents (ft)	Minimum Duct Radius and Tangent Length Adjacent to Anchorages (see Figure 1.11.4-1)	
		Minimum Radius R (ft)	Minimum Tangent Length L (ft)
4 - 0.6" diameter strands	6	9	2
7 - 0.6" diameter strands	6	9	3
12 - 0.6" diameter strands	8	11	3
15 - 0.6" diameter strands	9	12	3
19 - 0.6" diameter strands	10	13	3
27 - 0.6" diameter strands	13	16	3.5
31 - 0.6" diameter strands	13	16	3.5

Superstructure

Conventional detail with bonded rigid steel pipe

Rigid steel pipe pulled out due to failed tendon

Courtesy of Teddy Theryo

Figure 3-2
Bonded Rigid Steel Pipes in Deviator

Courtesy of Teddy Theryo

Figure 3-3
Bonded Rigid Steel Pipe in Diaphragm

Courtesy of Teddy Theryo

Figure 3-5
Rigid Steel Pipe Pull-out Resulting in Spalled Concrete

Background for switching to Diabolo Form

Superstructure

Background for switching to Diabolo Form

Diabolo was prohibited by Spec. 462. The winner of D/B Team for SR 826/SR 836 Interchange in Miami proposed to use Diabolos as Technical Innovation. FDOT would only accept the Diabolos provided two tests to be conducted:

- Wear test per ETAG 13
- Flexibility test per ETAG 13

Both test results were satisfactory and the proposal was accepted.

Diabolo Static Load Testing

Superstructure

Background for switching to Diabolo Form

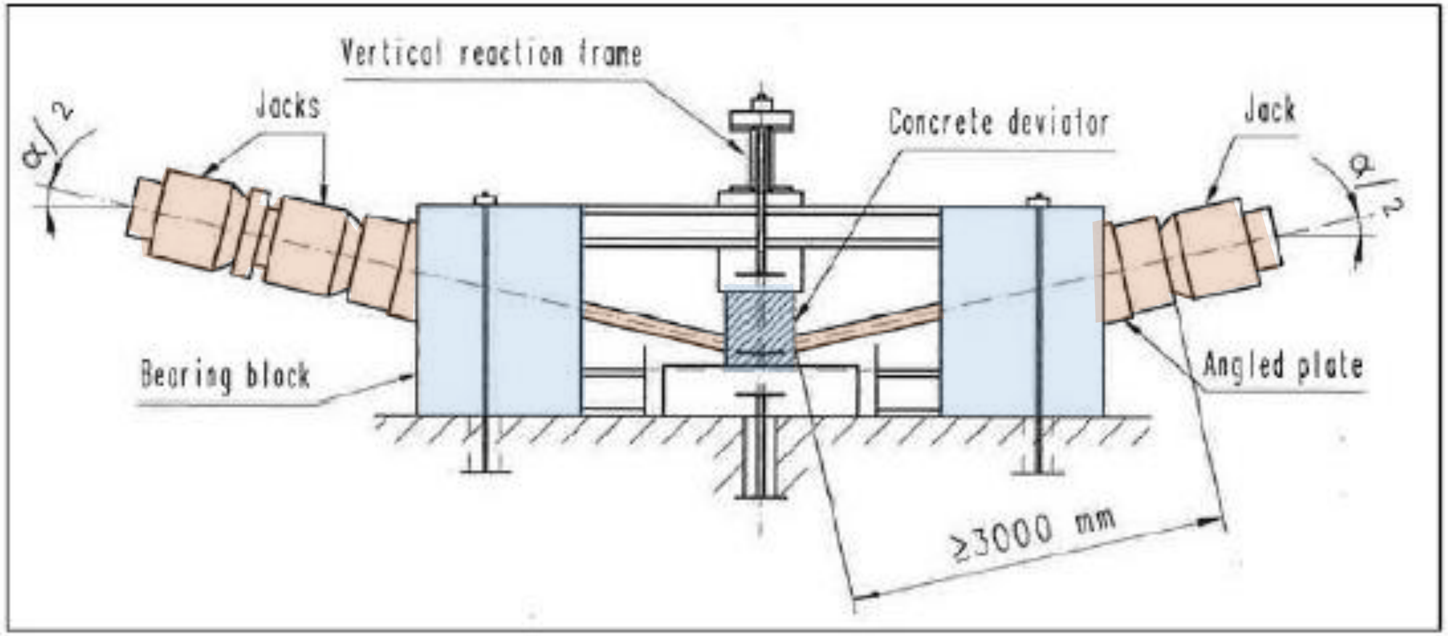


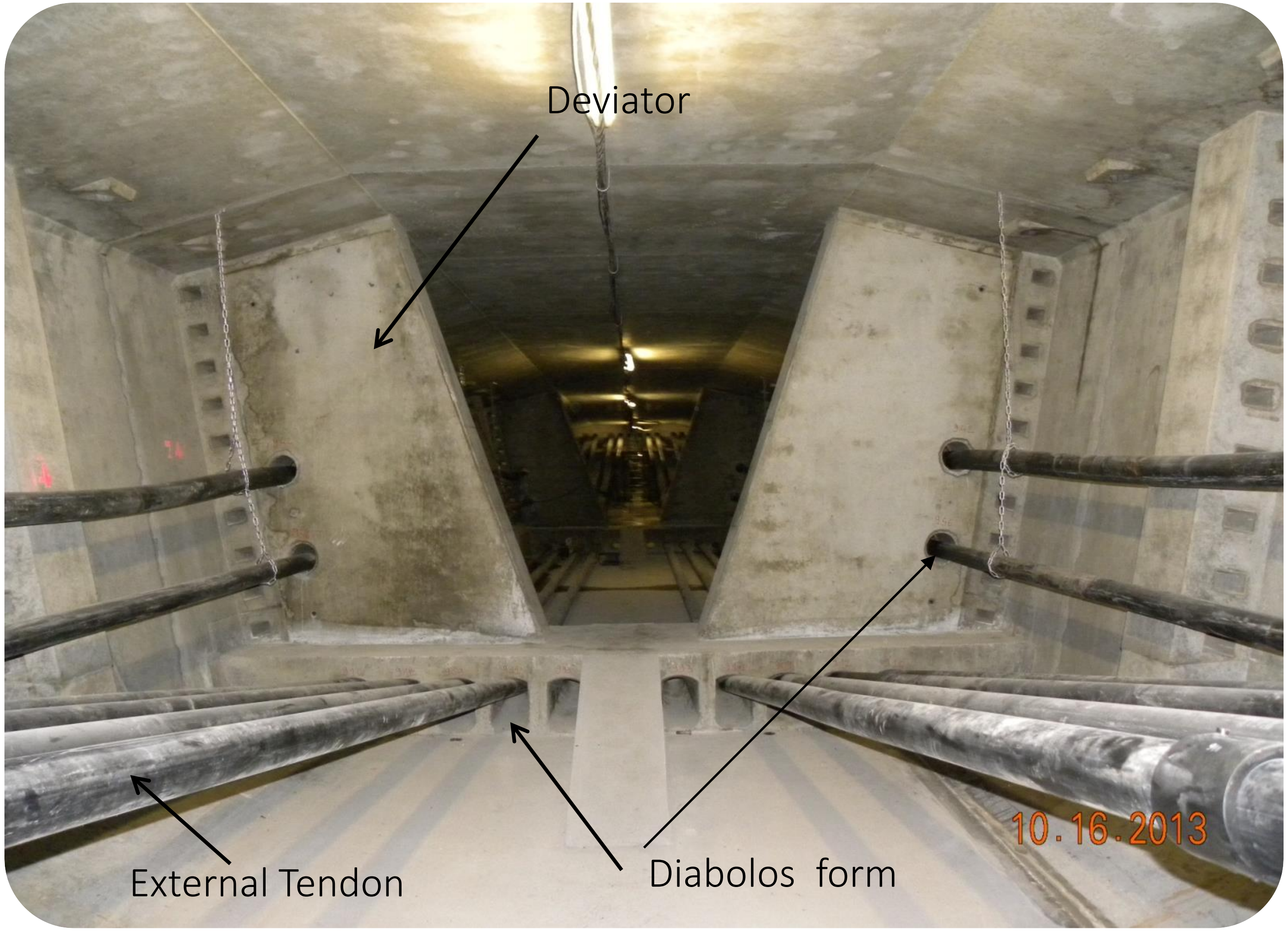
Figure 6-1
ETAG 013 Deviator Test Set-up for Static Load Test

Pending Permission from VSL

Figure 6-5
Duct Internal Area Wear after Testing

Diabolo Static and Wear Testing

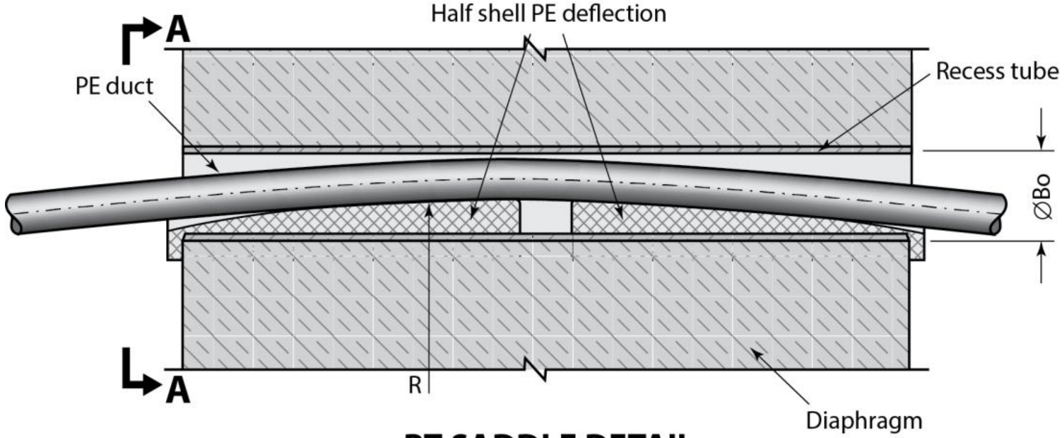
Superstructure



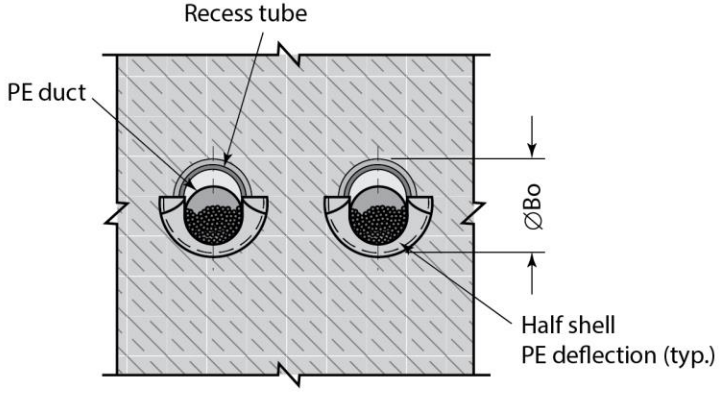
Typical diabolos form for segmental bridges in Europe

Superstructure

Another form of diabolos (Germany)



PT SADDLE DETAIL



SECTION A-A

Superstructure

Background for switching to Diabolo Form

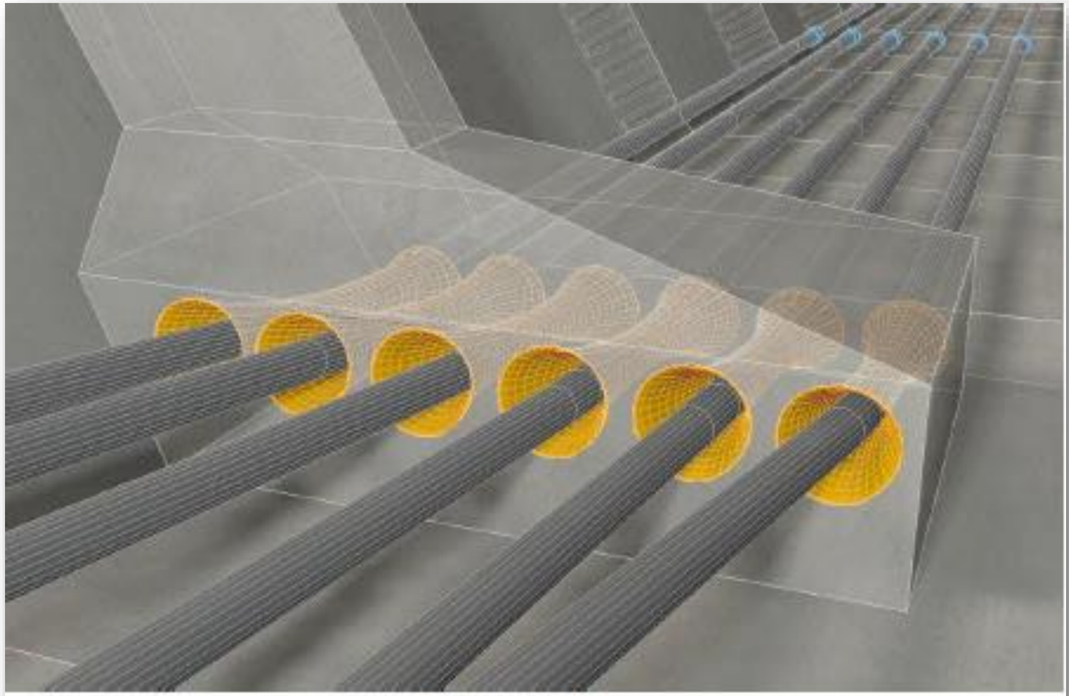
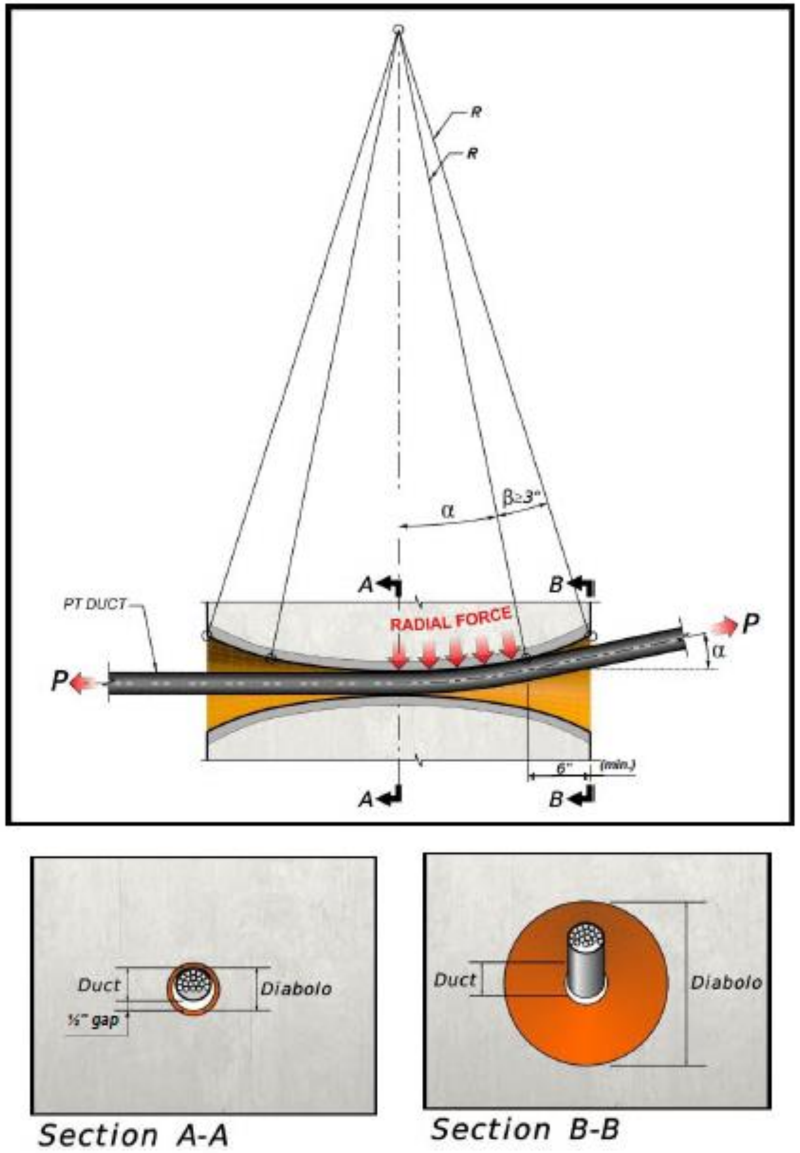


Figure 4-2
Rendering of Trumpet Shaped Diabolos at a Deviator

Rendering and diabolo basic geometry per FHWA Research Project, Draft Report “Replaceable Grouted External Pos-tensioned Tendon” by Parsons Brinckerhoff (WSP), April 2017.



Where:

α refers to the tendon deviation angle required

β refers to the additional deviation tolerance of the system (β ≥ 3 degrees)

Figure 4-5
Diabolo Form Basic Geometry

Superstructure

Background for switching to Diabolo Form

Advantages with Adopting Diabolos Form

1. Ease of tendon installation
2. Ease of external tendons replacement
3. Allow more tolerances in 3D tendon geometry control between two points, e.g. from deviator to diaphragm

Superstructure

Background for switching to Diabolo Form

SDG 1.11.4 (E)

E. Design and detail ducts for external tendons as follows:

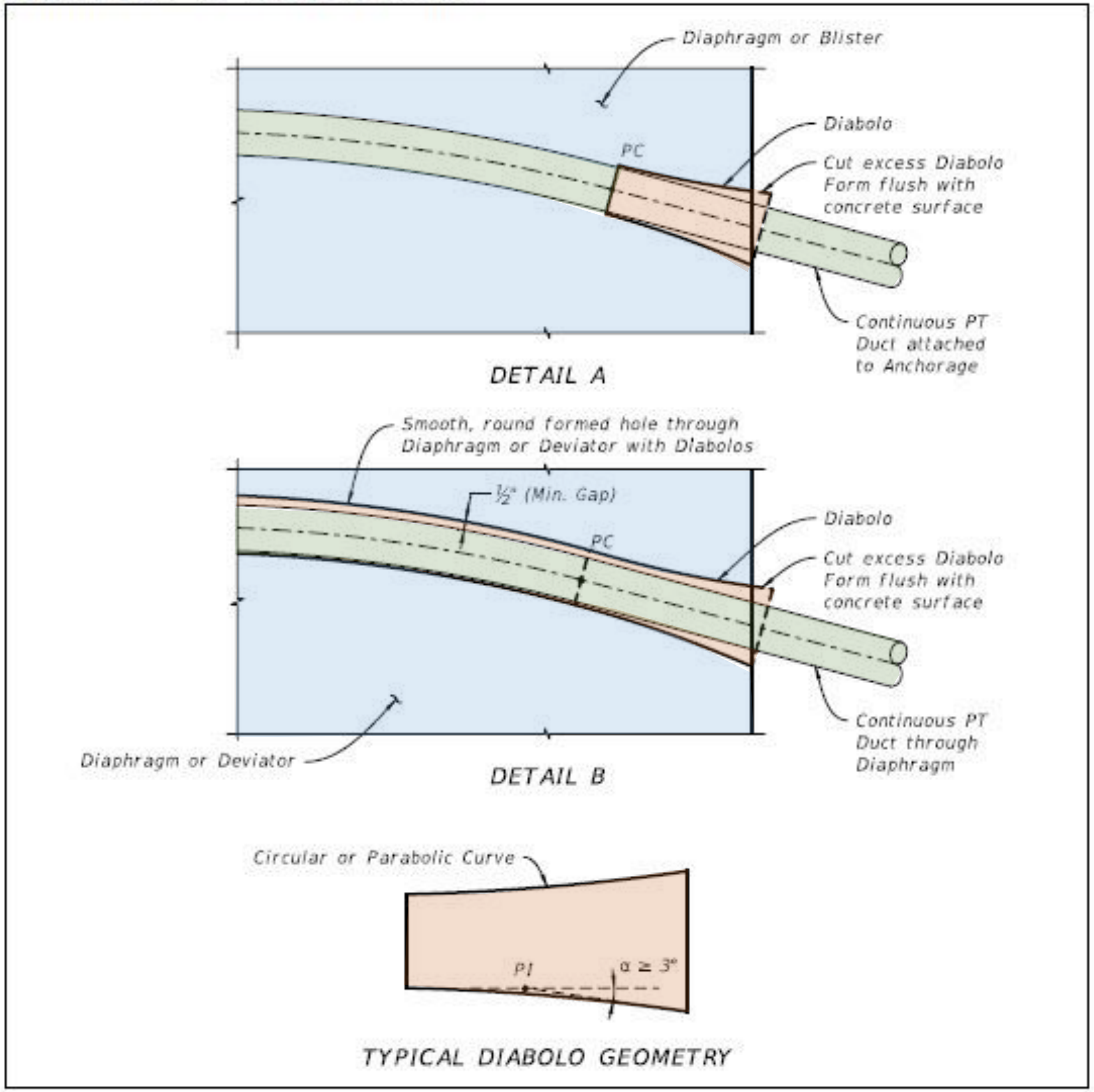
1. Design and detail duct geometry using circular Diabolos at the faces of all pier diaphragms, deviators, and blisters without anchorages. See ***SDM*** Figure 20.8-10 for Diabolo details.

2. At pier diaphragms with anchorages and at blisters without anchorages, design and detail using ducts that are embedded in the concrete and not removable as shown in ***SDM*** Figure 20.8-5, ***SDM*** Figure 20.8-6 and ***SDM*** Figure 20.8-7.

3. At pier diaphragms without anchorages and at deviators, design and detail using smooth round formed holes and completely removable ducts that are external to the concrete as shown in ***SDM*** Figure 20.8-8 and ***SDM*** Figure 20.8-9.

4. To allow room for the installation of duct couplers, design and detail all external tendons to provide a 1½-inch clearance between the outer duct surface and the adjacent face of the concrete as shown in ***SDM*** Figure 20.8-9.

Figure 20.8-10 Diabolo Details

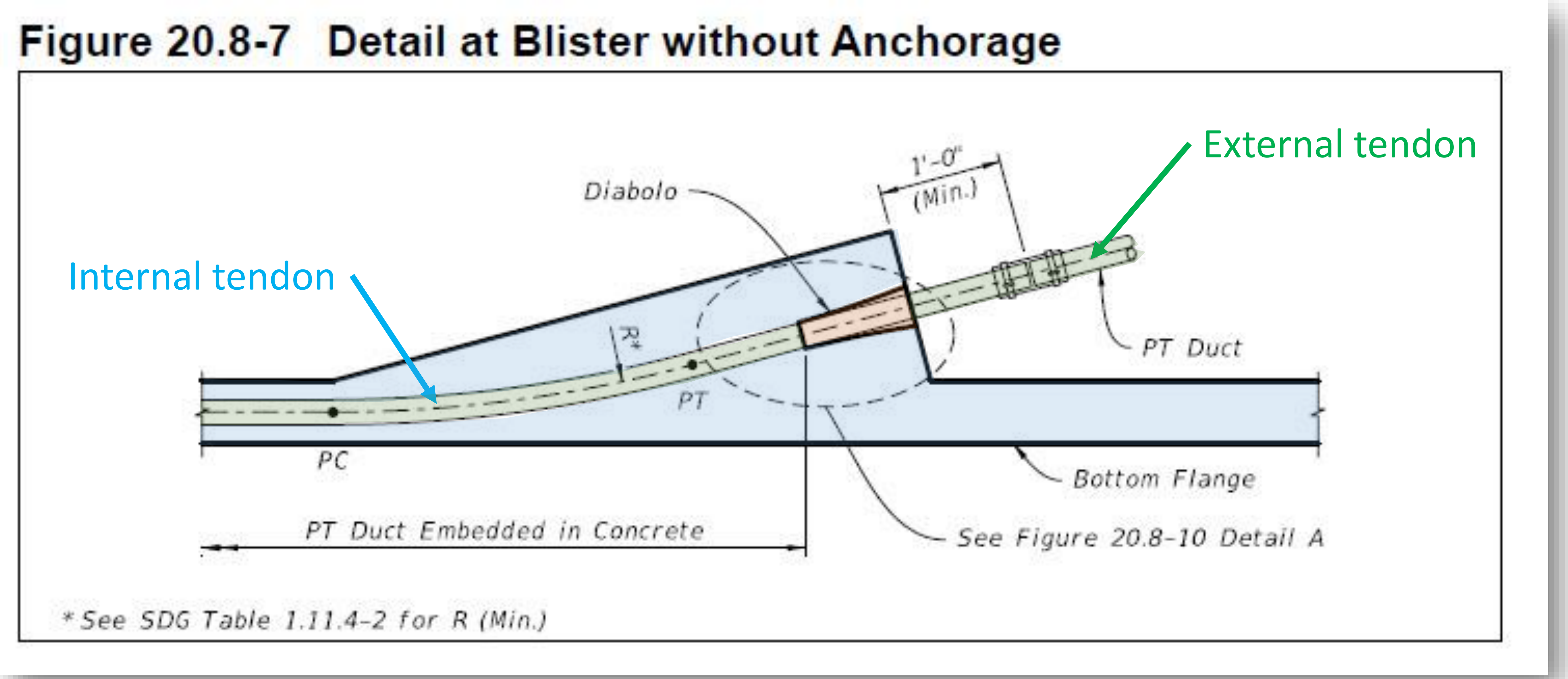


Superstructure

FDOT Diabolo
Form Standard

Superstructure

FDOT Diabolo Form Standard



Superstructure

FDOT Diabolo Form Standard

Figure 20.8-5 Detail at Pier Segment with Tendon Anchorage

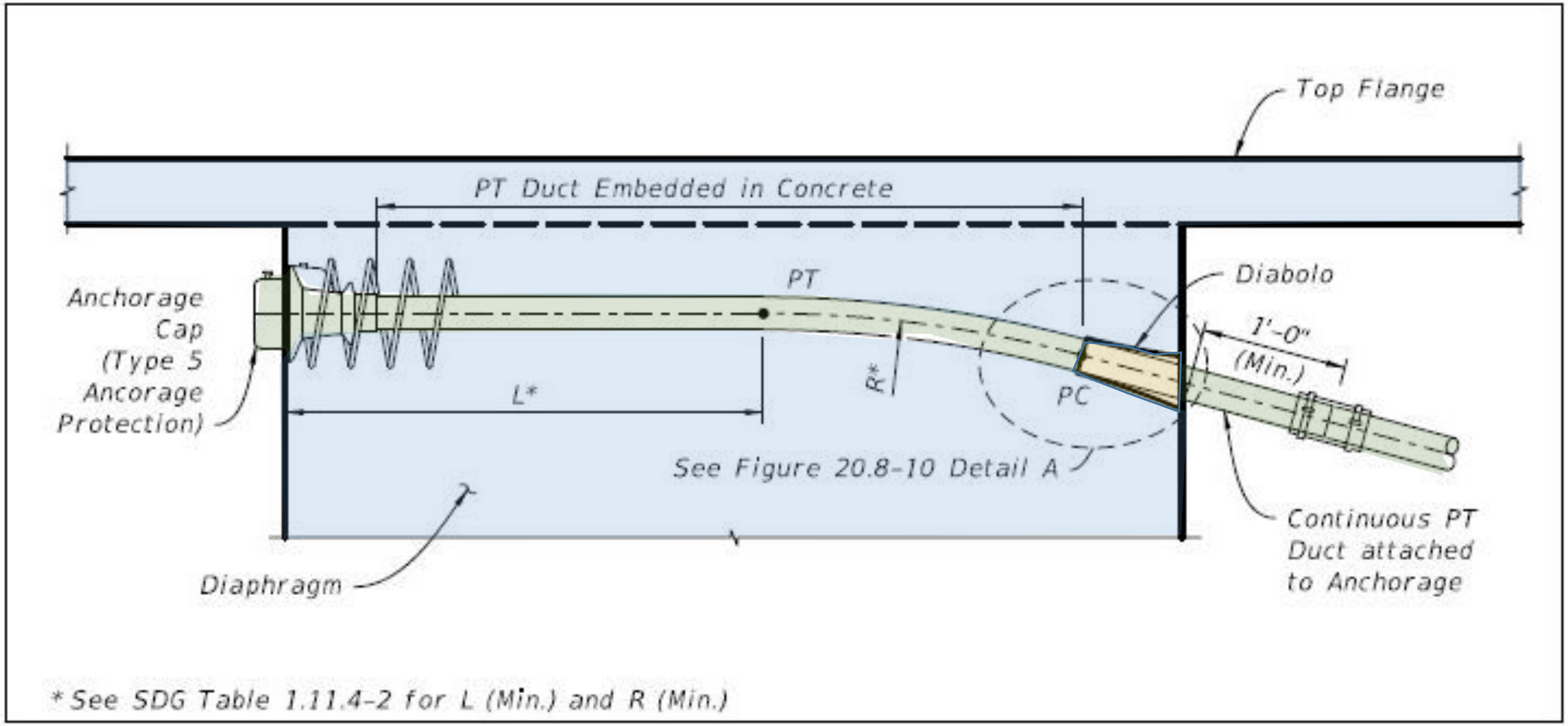
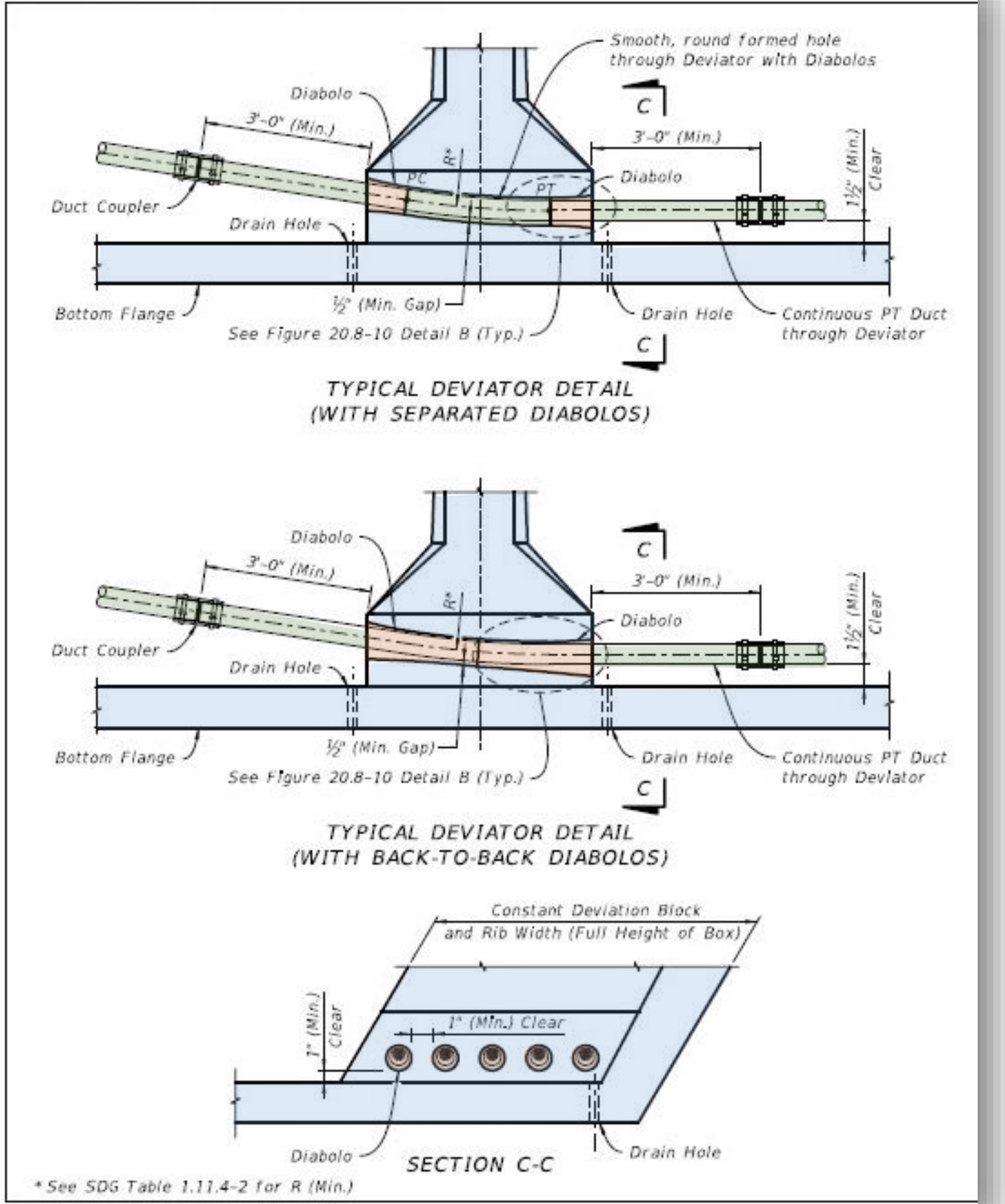


Figure 20.8-9 Detail at Deviator



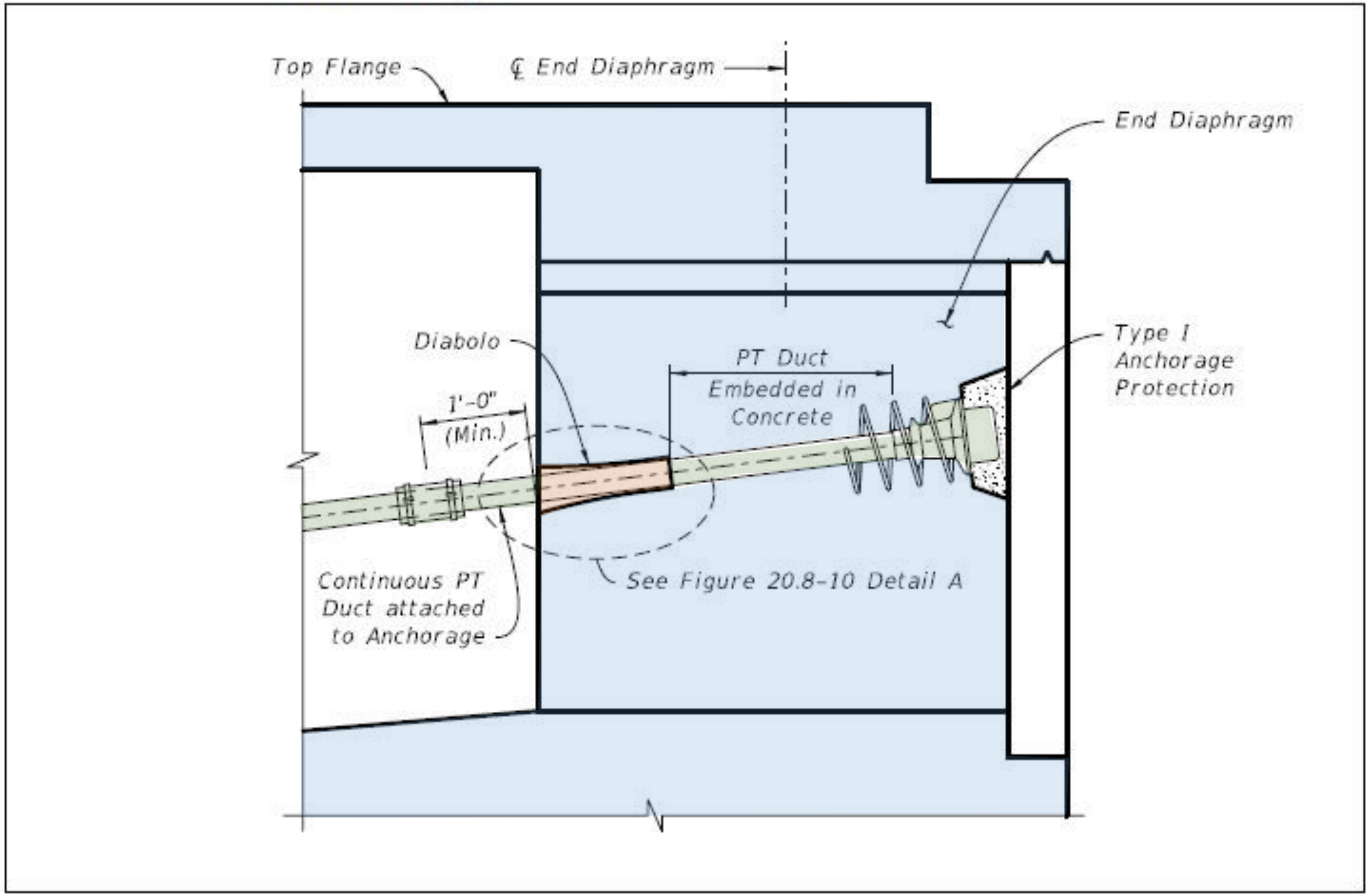
Superstructure

FDOT Diabolo Form Standard

Superstructure

FDOT Diabolo Form Standard

Figure 20.8-6 Detail at Expansion Joint Segment with Tendon Anchorage



Superstructure

FDOT Diabolo Form Standard

Figure 20.8-8 Detail at Pier Segment with Tendon Saddle

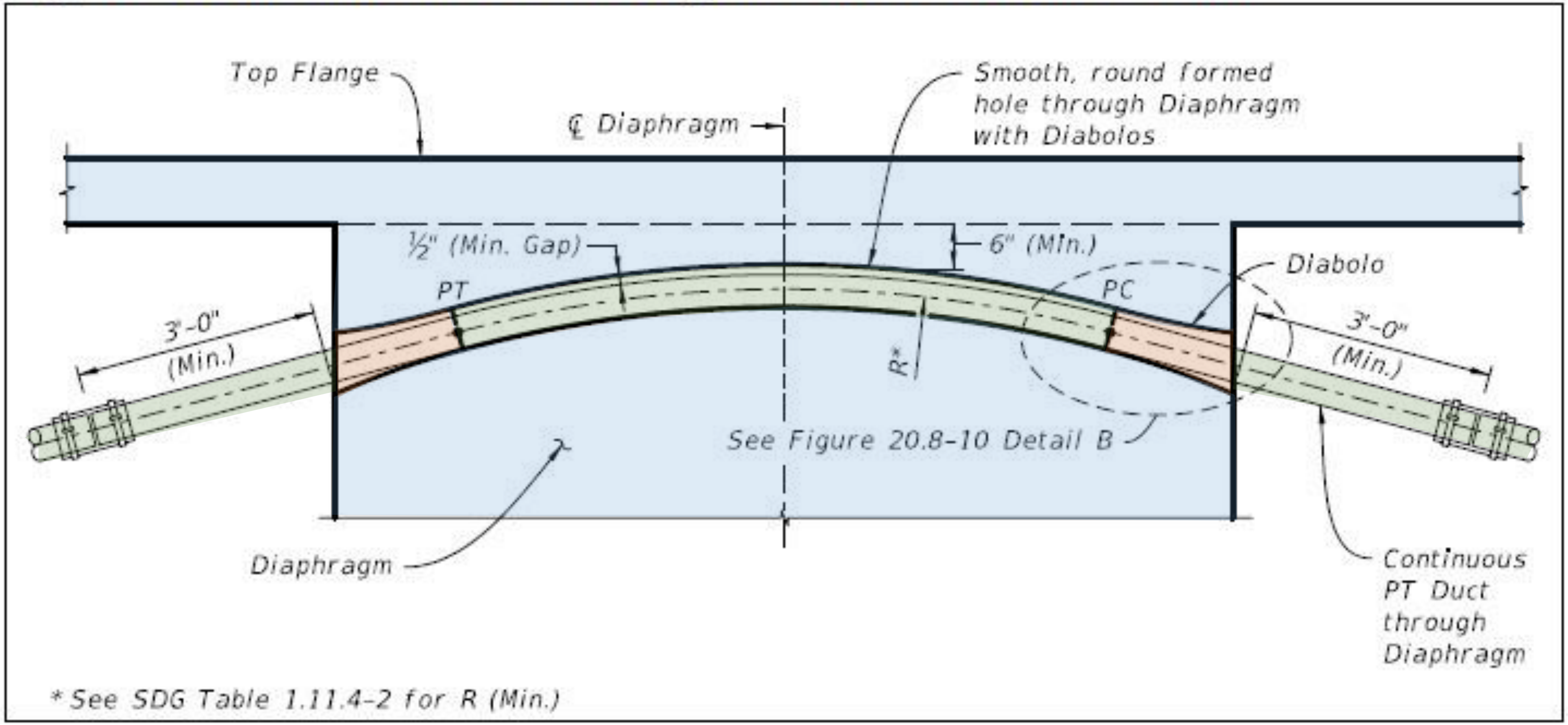


Table 4.5.3-1 Minimum Center-to-Center Duct Spacing

Post-Tensioned Superstructure Type	Minimum Center To Center Vertical Spacing "d" between Longitudinal Ducts[1]	Minimum Center To Center Horizontal Spacing "s" between Longitudinal Ducts[1]
Precast Balanced Cantilever Segmental Bridges (see *SDG* Figure 4.5.3-1)	2 times outer duct diameter plus 1-inch, or outer segmental coupler diameter plus 2-inches, whichever is greater.	2 times outer duct diameter plus 1-inch, or outer segmental coupler diameter plus 2-inches, whichever is greater.
C.I.P. Balanced Cantilever Segmental Bridges (see *SDG* Figure 4.5.3-1)	Outer duct diameter plus 1.5 times maximum aggregate size, or outer duct diameter plus 2-inches, whichever is greater.	Outer duct diameter plus 2½-inches.
Post-Tensioned I-Girder and U-Girder Bridges[2] (see *SDG* Figure 4.5.3-2)	Outer duct diameter plus 1.5 times maximum aggregate size, or outer duct diameter plus 2-inches, whichever is greater (measured along the slope of webs or flanges).	Outer duct diameter plus 2½-inches.
C.I.P. Solid or Voided Slab Bridges and C.I.P. Multi-Cell Bridges (see *SDG* Figure 4.5.3-3)	Outer duct diameter plus 1.5 times maximum aggregate size, or outer duct diameter plus 2-inches, whichever is greater.	Outer duct diameter plus 3-inches.
Integral Pier Caps (See *SDG* Figure 3.11.1-1)	See *SDG* Table 3.11.1-2	See *SDG* Table 3.11.1-2

1. Bundled ducts are not allowed.
2. Detail draped tendons in post-tensioned I-Girders and U-Girders utilizing round ducts only.

Superstructure

Duct Spacing

Superstructure

Duct Spacing

Figure 4.5.3-1 Section Through Segmental Box Girder Showing Duct Spacings

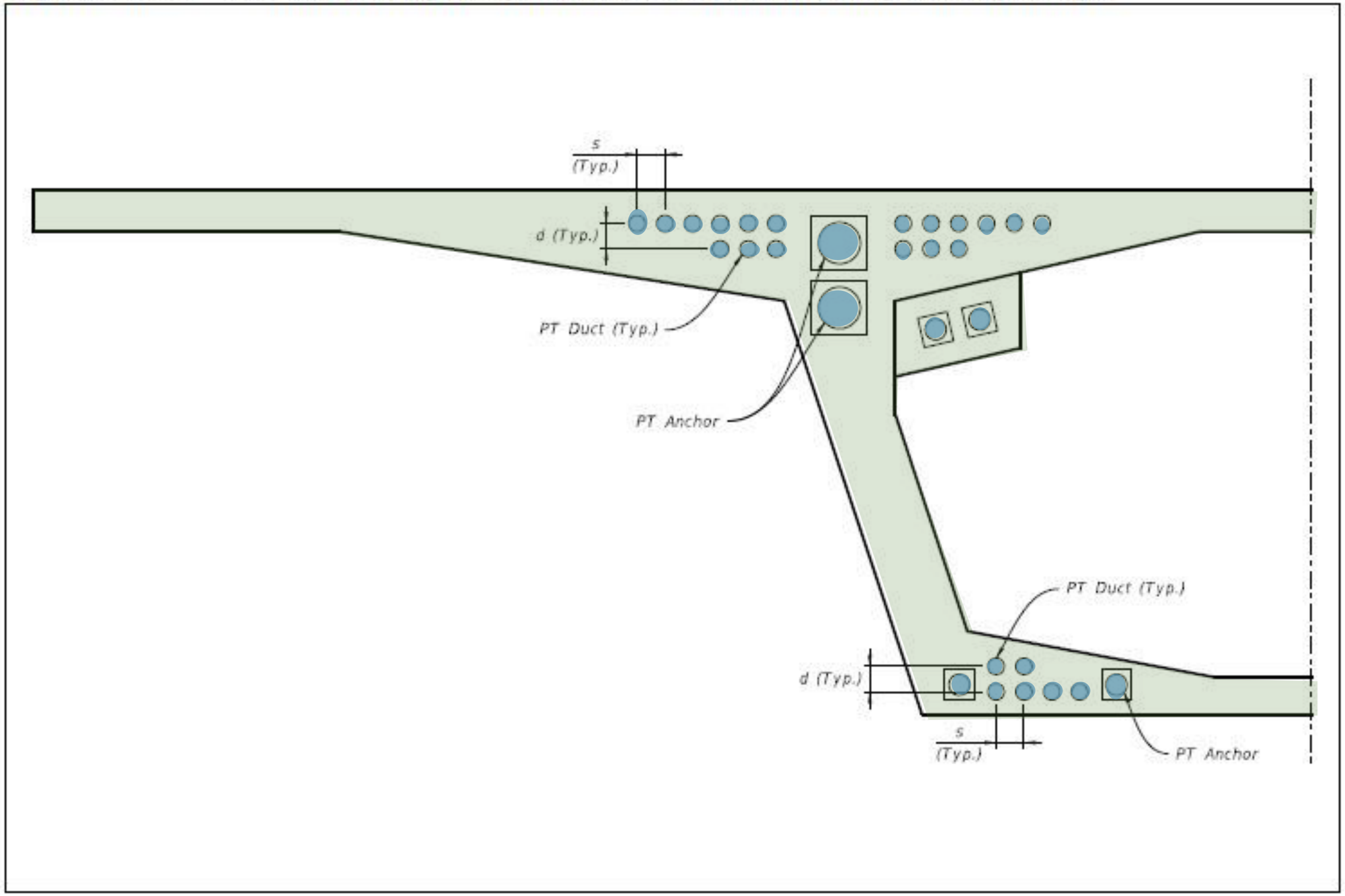


Figure 4.5.3-3 Section Through Slab or Multi-Cell Box Girder Bridge Showing Duct Spacings

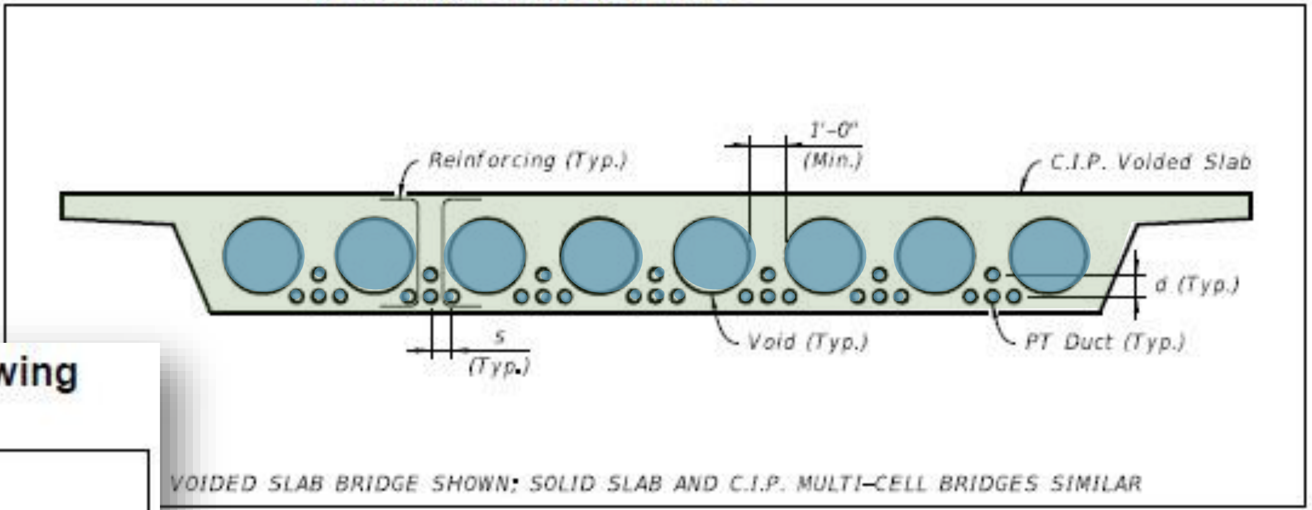
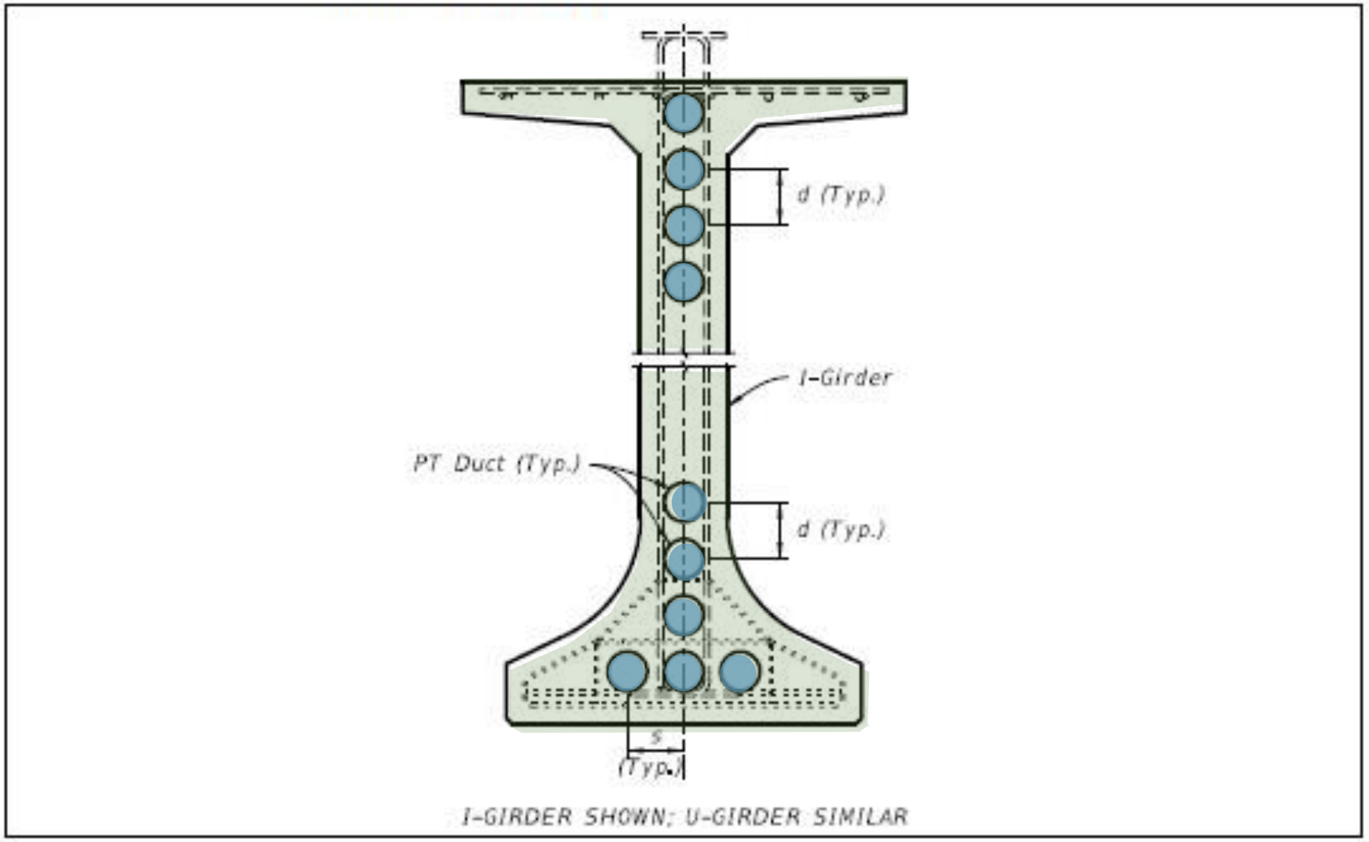


Figure 4.5.3-2 Section Through Post-Tensioned I-Girder Showing Duct Spacings



Superstructure

Duct Spacing

Figure 3.11.1-1 Section Through Post-Tensioned Pier/Beam Caps Showing Duct Spacings

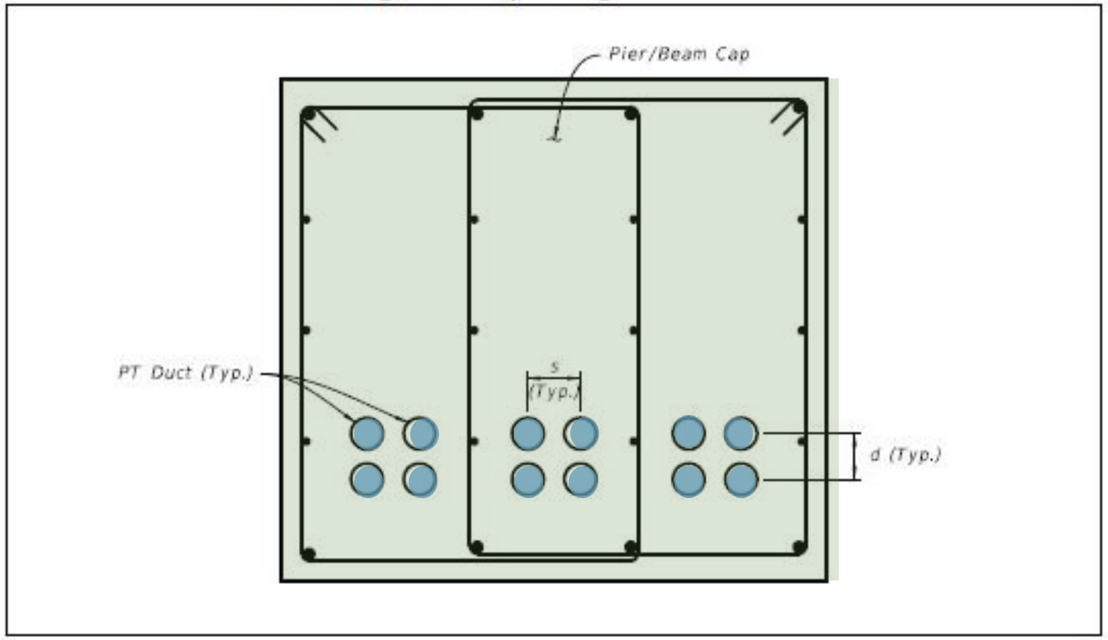
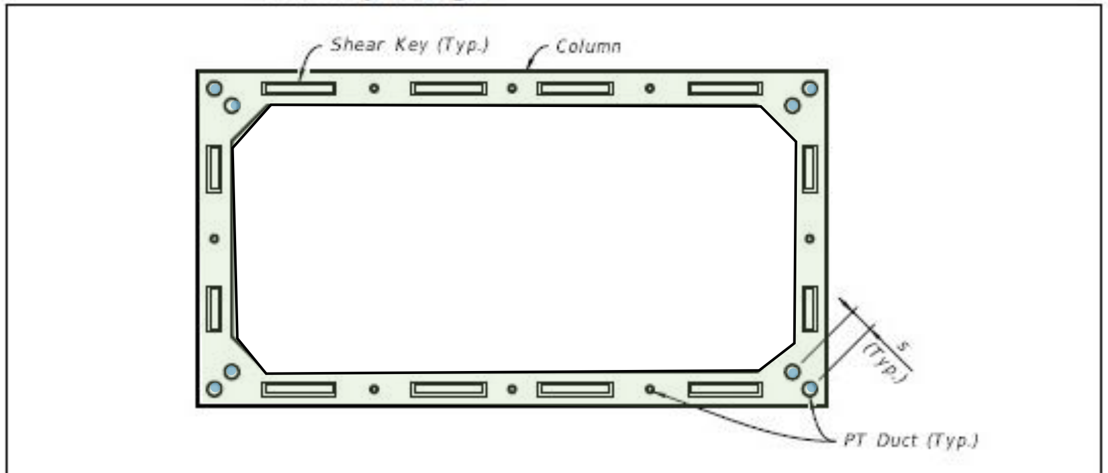


Figure 3.11.1-2 Section Through Post-Tensioned Columns Showing Duct Spacings



HOLLOW PRECAST COLUMN SHOWN; SOLID PRECAST AND HOLLOW OR SOLID C.I.P. COLUMNS SIMILAR

Substructure

Duct Spacing

1.11.5 Tendon Design

A. Design and detail all tendons to be unbonded except those listed in Paragraphs B and C below. For unbonded tendons, specify the use of flexible filler in the ***Standard Plans*** Index 462-000 Series data tables and include the data tables in the Plans.

B. Design and detail the following internal strand tendons with predominantly flat geometries to be bonded:

1. Top slab cantilever longitudinal tendons in segmental box girders
2. Top slab transverse tendons in segmental box girders
3. Tendons that are draped 2'-0" or less in post-tensioned slab type superstructures

For bonded tendons, specify the use of grout in the ***Standard Plans*** Index 462-000 Series data tables and include the data tables in the Plans.

C. Design and detail the following tendons to be bonded or unbonded:

1. Straight strand or parallel wire tendons other than continuity tendons in U-beams and girders.
2. Bar tendons (predominately vertical or horizontal)

For these tendons, specify the use of grout for bonded designs or flexible filler for unbonded designs in the ***Standard Plans*** Index 462-000 Series data tables and include the data tables in the Plans.

D. Design and detail all other tendon types for which grout is not specifically required or allowed as unbonded. For these tendons, specify the use of flexible filler in the ***Standard Plans*** Index 462-000 Series data tables and include the data tables in the Plans.

E. For all types of prestressed concrete bridges using bonded and/or unbonded tendons, use ***LRFD*** [5.7.3.3] General Procedure to design for shear and torsion, except replace Equation (5.7.3.3-2) with the following:

$$V_n \le 0.15 f'_c b_v d_v + V_p \quad \text{or} \quad 0.379\sqrt{f'_c}\, b_v d_v + V_p \text{, whichever is greater}$$

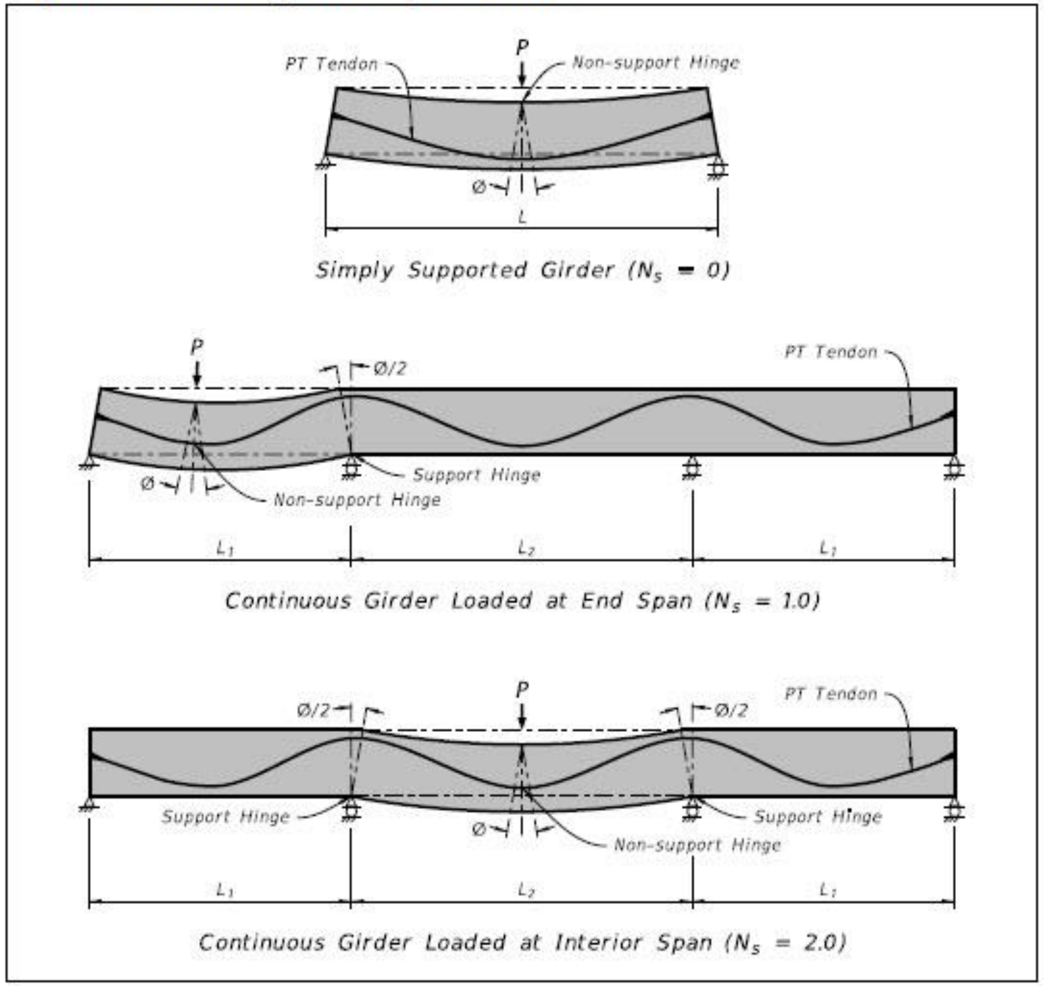
Check principal stresses in the webs using ***LRFD*** [5.9.2.3.3].

F. Use ***LRFD*** [5.6.3.1.2] for predicting unbonded PT ultimate average stress. Use Figure 1.11.5-1 for determination of the number of support hinges (N_s).

Superstructure

- **Shear Capacity Limit**
- **Support hinge locations**

Figure 1.11.5-1 Support Hinge Locations



G. Use the maximum outside duct diameter to determine the effective web width at a particular level per ***LRFD*** [5.7.2.8] and [5.12.5.3.8a].

H. Limit the external tendon unsupported length to 100 feet. For external tendons longer than 100 feet, provide hangers to restrain the tendon laterally and vertically. At the hanger contact point with the external tendon duct, provide a neoprene sheet to protect the duct from damage.

Superstructure

- **External PT unsupported length**

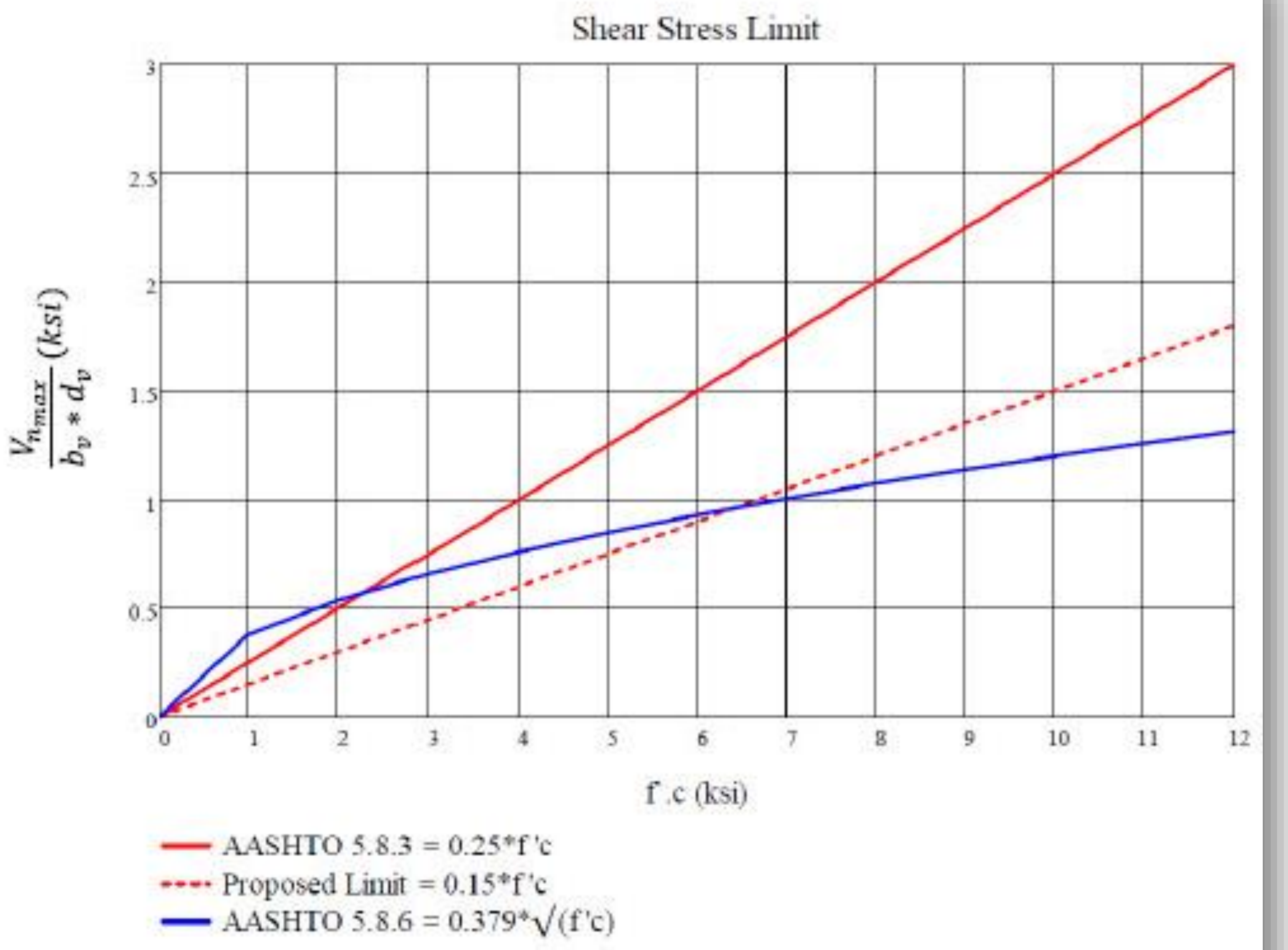


Figure 4.1 Current and Proposed Limits on Shear Stress

Superstructure

Based on Study: "Review of AASHTO LRFD Bridge Design Specifications and ACI-318 Unbonded PT Provisions for FDOT Implementation" by Parsons Brinckerhoff (WSP), Nov. 17, 2015

4.1.4 Shear Design [5.7.3]

A. When calculating the shear capacity, use the area of stirrup reinforcement intersected by the distance $\mathbf{0.5d_v cot\theta}$ on each side of the design section, as shown in ***LRFD*** [Figure C5.7.3.3-2].

B. Use twin leg closed stirrups or multiple sets of twin leg closed stirrups as shear reinforcement in beam members except where open stirrups are required to avoid conflicts with other components, e.g. in pile bent caps directly over the tops of the piles and in post-tensioned beams where access is required for PT tendon installation. Do not use single leg stirrups.

C. Use the following methodology to determine the transverse spacings of shear reinforcement in beam members:

Nominal Shear Stress Range	Maximum Transverse Spacing of Stirrup Legs S_w as shown in Figure 4.1.4-1
$v_n \le 0.08 \sqrt{f'_c}$	$S_w \le 42"$
$0.08 \sqrt{f'_c} < v_n \le 0.16 \sqrt{f'_c}$	$S_w \le d_v$ or 24", whichever is less
$v_n > 0.16 \sqrt{f'_c}$	$S_w \le 0.5d_v$ or 12", whichever is less

Where: v_n = Nominal shear stress = $\dfrac{V_u}{\phi b_v d_v}$

V_u = Factored shear force per ***LRFD*** Chapter 5

b_v = Effective web width per ***LRFD*** Chapter 5

d_v = Effective shear depth per ***LRFD*** Chapter 5

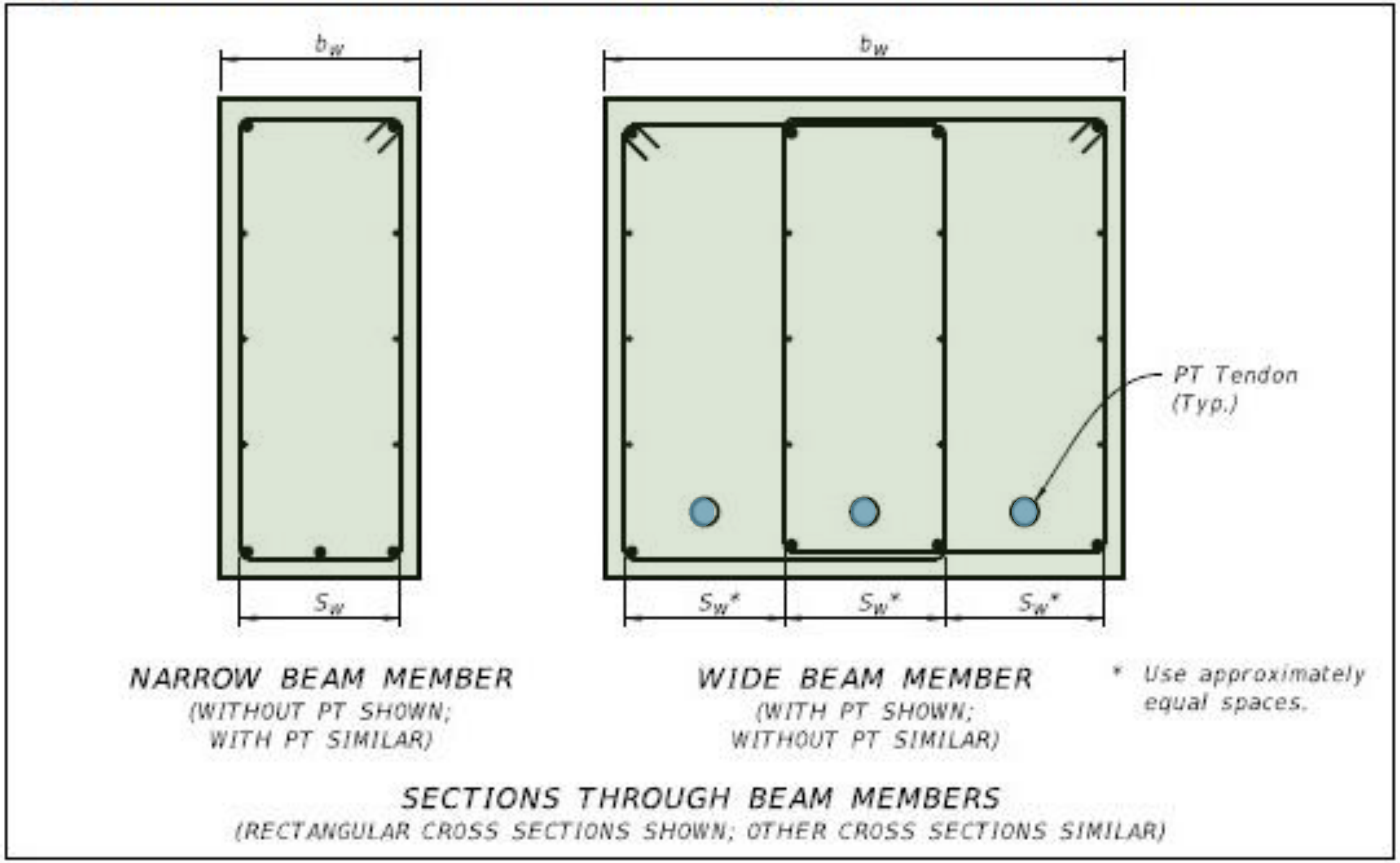
f'_c = Compressive strength of concrete per ***LRFD*** Chapter 5

ϕ = Resistance factor per ***LRFD*** Chapter 5

Superstructure

Wide Beam Member

Figure 4.1.4-1 Shear Reinforcement Layout in Beam Members



Superstructure

Wide Beam Member

Superstructure

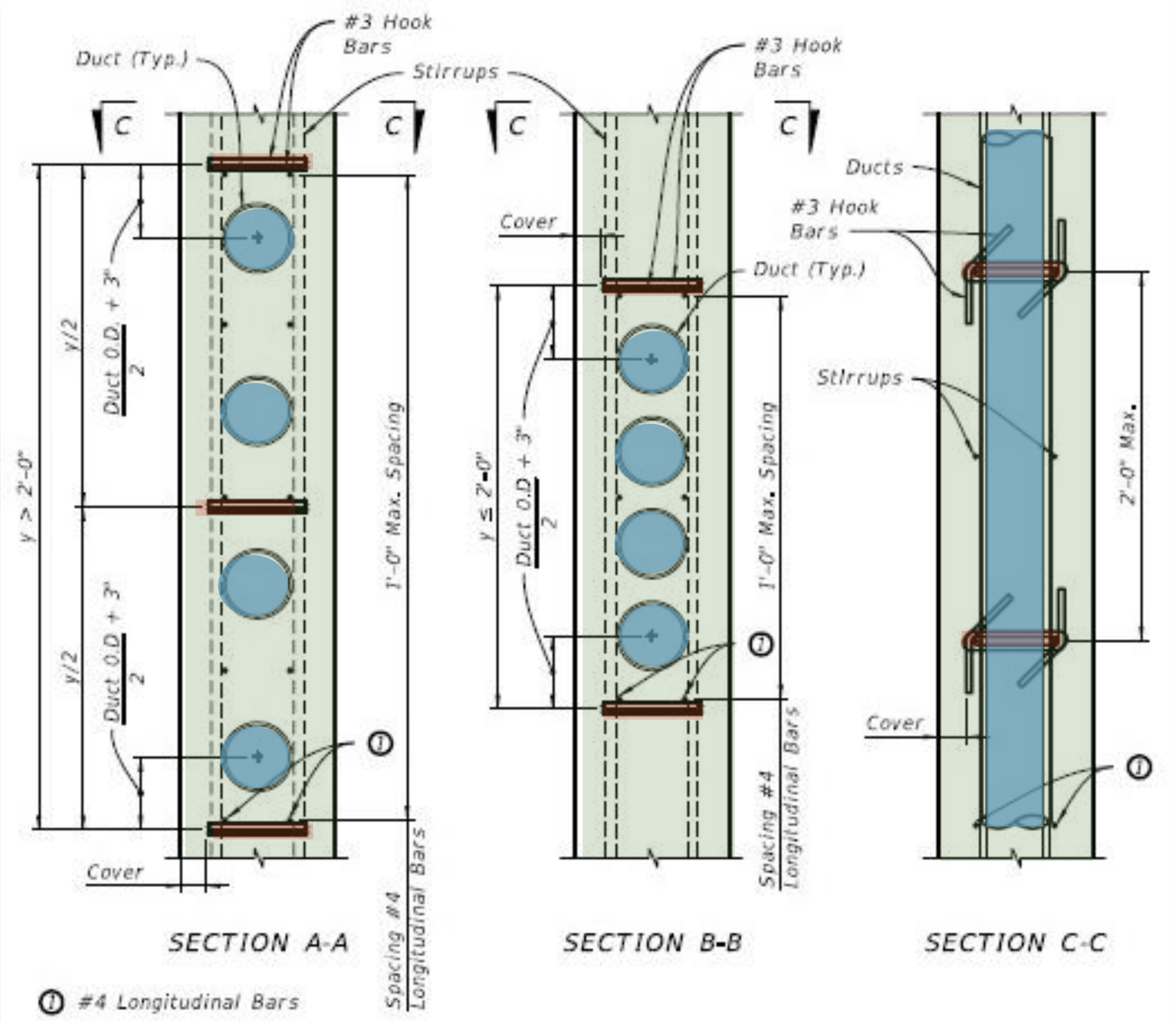
On going research on Shear and Flexural strength of combined unbonded and bonded tendons

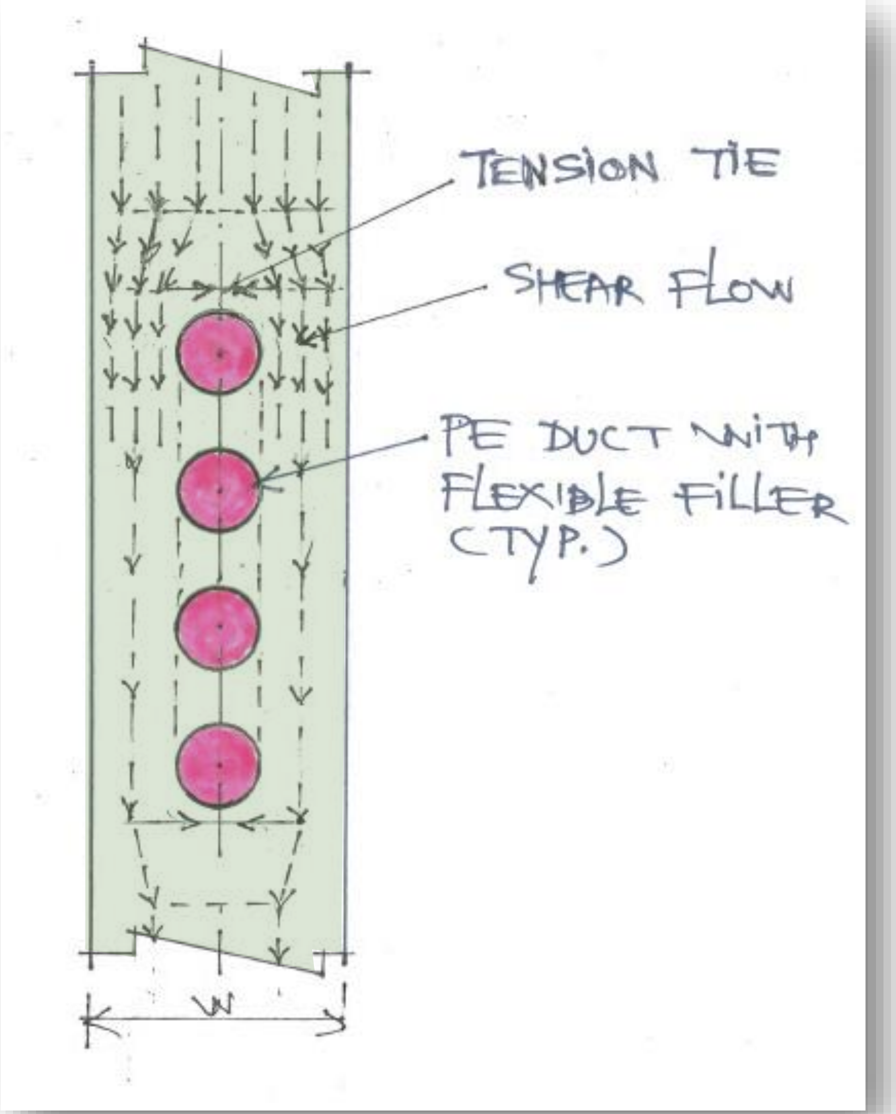
1. NCHRP 12-118: "Design Construction Specifications for Bonded and Unbonded Post-Tensioned Concrete Bridge Element".
   Expected completion: 2021

2. FDOT Research projects
   (a.) "Flexural Capacity of Concrete Elements with Unbonded and Bonded Presstressing"
   FDOT Contract No. BD31-977-93

   (b.) "Shear Behavior of Webs Post-Tensioned with Tendons Containing Flexible Filler"
   FDOT Contract No. BDV31-977-71

PT Spliced Girder Bridge

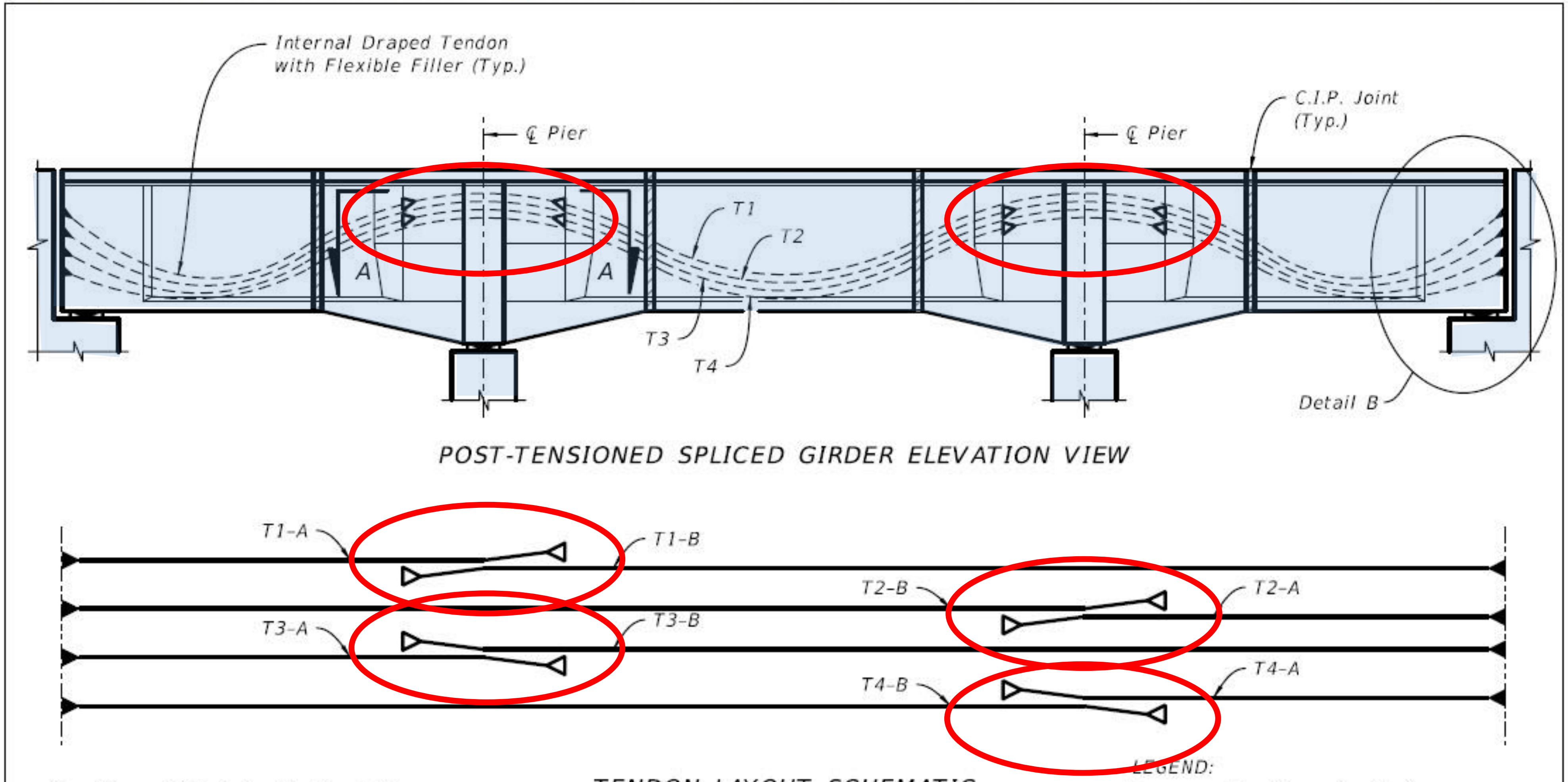




Shear Detailing in Thin Web - SDG Figure 4.5.1-1

PT Spliced Girder Bridge

Figure 23.7-1 Post-Tensioned Spliced Girder Details - Tendons Internal to the Web (1 of 4)



See Figure 23.7-2 for Section A-A.
See Figure 23.7-3 for Detail B adjacent to abutments.
See Figure 23.7-4 for Detail B adjacent to other structures.

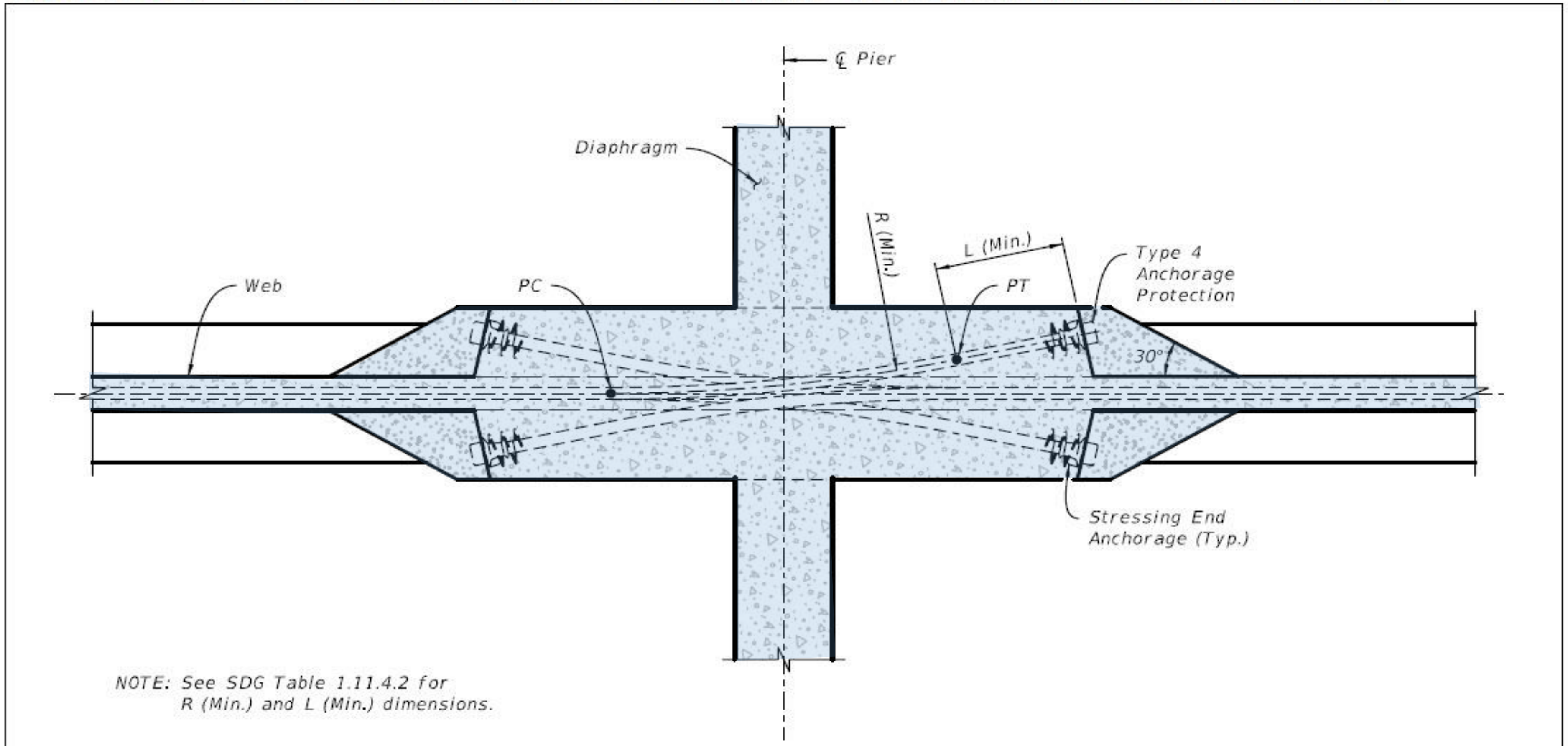
Staggered Tendon Overlap

Tendon Replaceability

FDOT TRANSPORTATION SYMPOSIUM

PT Spliced Girder Bridge

Figure 23.7-2 Post-Tensioned Spliced Girder Details - Tendons Internal to the Web (2 of 4)



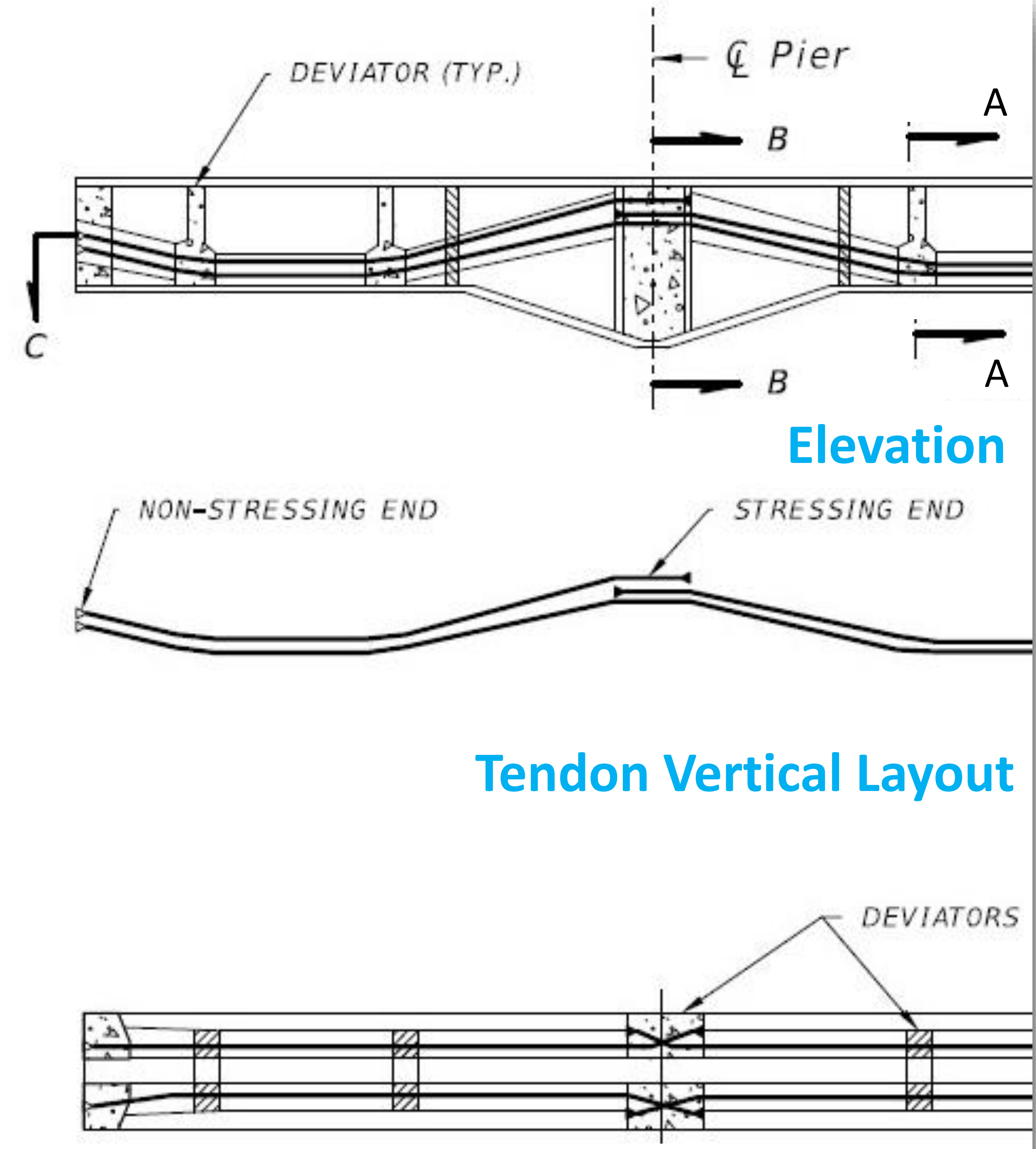
SECTION A-A
(ANCHORAGE IN THICKENED WEB ALTERNATIVE)

Tendon Replaceability

PT Spliced Girder Bridge

External Tendon Option

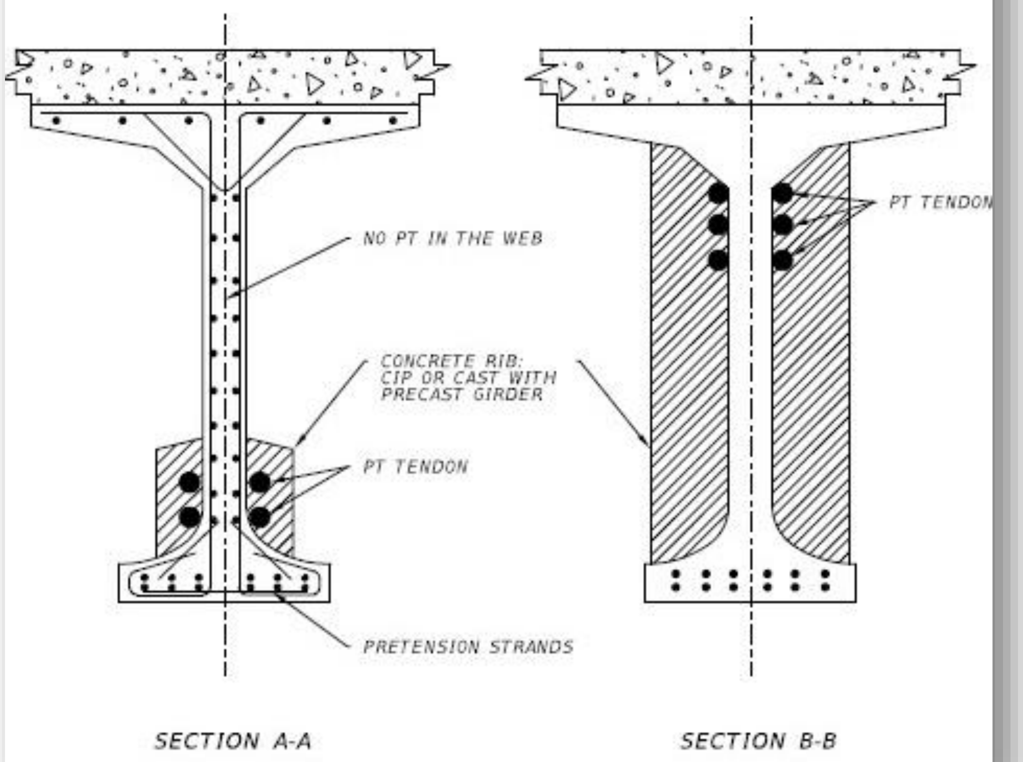
SDM 23.7-4 & 23.7-6



Elevation

Tendon Vertical Layout

Section – Plan View



PT Tendon Mock-up Test

PT mock-up test required under Standard Specification 462-7.4 Filler Injection

- Required full scale mock-ups both for flexible and grout filler tendons associated with PT system components, including filler materials proposed for the project (see Index 21800 Series and its IDS for guidance in preparing mock-up test plans)
- Submit a Report of the test and findings
- Repeat mock-up test if required by the Engineer

PT Tendon Mock-up Test

The objectives of mock-up test

- To demonstrate that the proposed PT system, filler material, equipment used and injection method will be able to fully fill the ducts from end to end
- Opportunity for the contractor to train the workers
- Opportunity to improve the quality of their products
- For FDOT to provide opportunity to observe the results, lessons learned and improve our specifications

PT Tendon Mock-up Test

Project: Wildwood – I-75 Interchange

Flexible filer: Fill Flex 100 (Trenton)

Date: July 12, 2018

Inlet port

Heated holding tank

Photos courtesy of VStructural

PT Tendon Mock-up Test

Project: Wildwood I-75

Outlet port

Vacuum device

Photos Courtesy of VStructural

PT Tendon Mock-up Test

Project: Wildwood I-75

Void

Project: Wekiva Section 6 Bridge

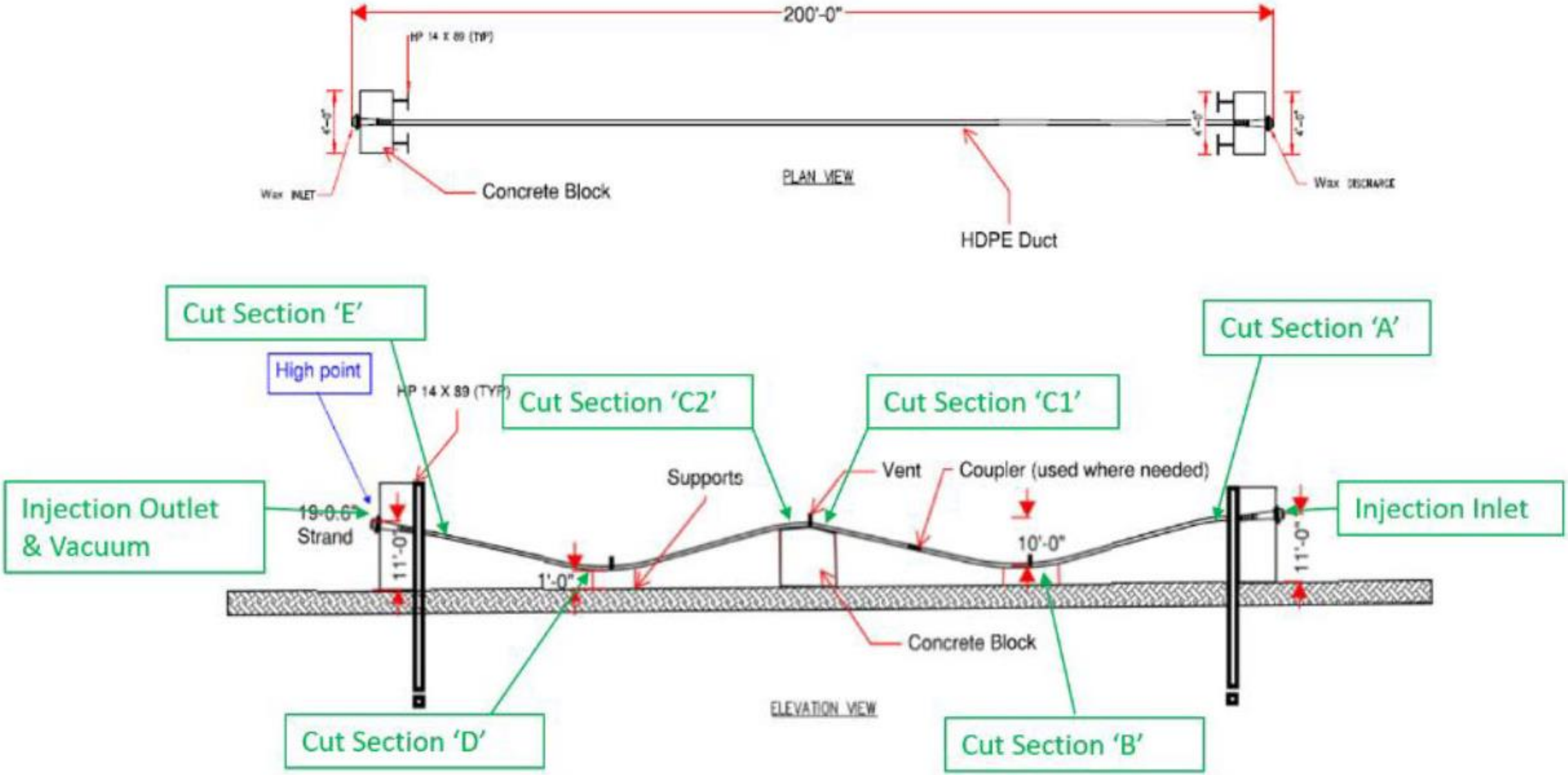
Flexible filler: RENOLIN CL 4 RO (Fuchs Lubricants, Co)

Date injected: April 22, 2019

PT Tendon Mock-up Test

Mock-up: two span continuous with draped tendon 2 @ 100’ = 200’ total length.

Wax leaking at inlet (top) and outlet (cap) ports connections



PT Tendon Mock-up Test

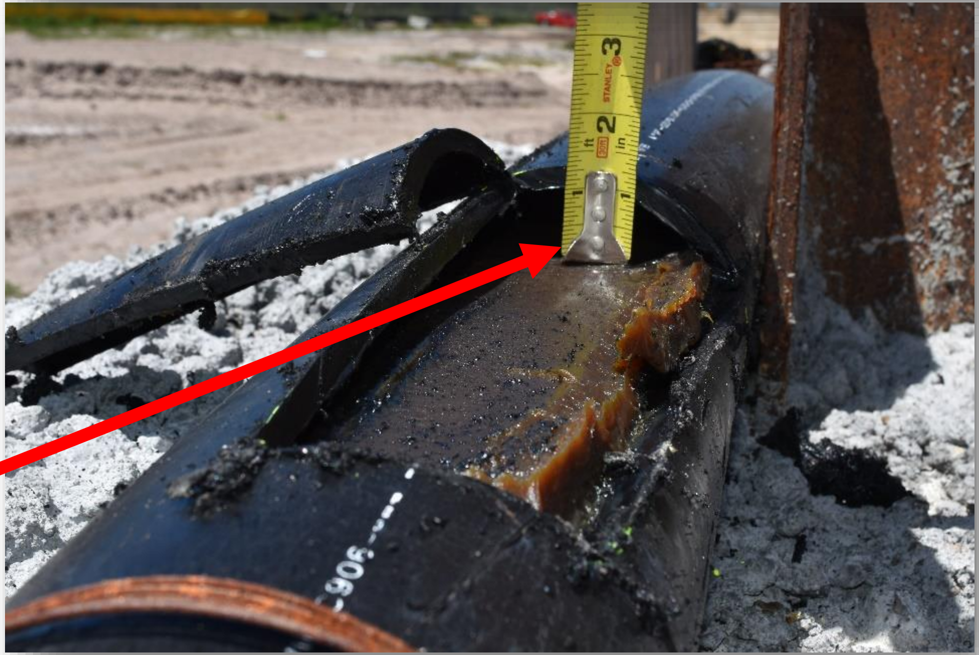
Curtesy of Superior Construction

FDOT TRANSPORTATION SYMPOSIUM

PT Tendon Mock-up Test

PT Tendon Mock-up Test

Project: Wekiva Section 6



Void

Closing

Thank you for your attention

Any questions?