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

Teddy S. Theryo, P.E.
FDOT Structures Design Office
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
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

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**.
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

Project Implementation

Project: Wildwood I-75 Turnpike Interchange
Subject: Post-tensioned straddle pier cap with flexible filler
Status: Completed construction
Project completion: Open to traffic 2018

Introduction

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
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
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
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?
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>
<thead>
<tr>
<th>Anchorage Type and Location</th>
<th>Minimum Clearance Requirement</th>
<th>Example Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stressing End Anchorage Near Devisor</td>
<td>Dimension B&lt;sup&gt;1&lt;/sup&gt;</td>
<td>SDM Figure 20.8-1</td>
</tr>
<tr>
<td>Stressing End Anchorage at Intermediate Diaphragm Near Minor Obstruction&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Dimension A&lt;sup&gt;1&lt;/sup&gt; + 1'-0&quot; (min.)</td>
<td>SDM Figure 20.8-2</td>
</tr>
<tr>
<td>Non-Stressing End Anchorage Near Abutment</td>
<td>2'-6&quot; + Δ&lt;sub&gt;T&lt;/sub&gt;</td>
<td>SDM Figure 20.8-3</td>
</tr>
<tr>
<td></td>
<td>Δ&lt;sub&gt;T&lt;/sub&gt; = Maximum Design Thermal Expansion</td>
<td>SDM Figure 20.8-3</td>
</tr>
<tr>
<td></td>
<td>2'-6&quot; + ΣΔ&lt;sub&gt;T&lt;/sub&gt;</td>
<td>SDM Figure 20.8-4</td>
</tr>
<tr>
<td></td>
<td>ΣΔ&lt;sub&gt;T&lt;/sub&gt; = Summation of Maximum Design Thermal Expansion of both adjacent structures</td>
<td>SDM Figure 23.7-4</td>
</tr>
<tr>
<td>Stressing End Anchorage at Other Locations</td>
<td>Dimension A&lt;sup&gt;1&lt;/sup&gt; + Δ&lt;sub&gt;T&lt;/sub&gt; (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)</td>
<td>SDM Figure 23.7-1</td>
</tr>
<tr>
<td>Non-Stressing End Anchorage at Other Locations</td>
<td>2'-6&quot; + Δ&lt;sub&gt;T&lt;/sub&gt; (if applicable)</td>
<td>-</td>
</tr>
</tbody>
</table>

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 Requirement

Abutment

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

End Diaphragm
General Requirements

Tendon Replaceability
### Table 1.11.1-2 Jack Envelope Dimensions for Design and Detailing

<table>
<thead>
<tr>
<th>Tendon Size &amp; Type</th>
<th>Jack Envelope Dimensions (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>4 - 0.6 Strands</td>
<td>50</td>
</tr>
<tr>
<td>7 - 0.6 Strands</td>
<td>51</td>
</tr>
<tr>
<td>12 - 0.6 Strands</td>
<td>51</td>
</tr>
<tr>
<td>15 - 0.6 Strands</td>
<td>60</td>
</tr>
<tr>
<td>19 - 0.6 Strands</td>
<td>60</td>
</tr>
<tr>
<td>27 - 0.6 Strands</td>
<td>60</td>
</tr>
<tr>
<td>31 - 0.6 Strands</td>
<td>60</td>
</tr>
<tr>
<td>1&quot; Diameter Bar</td>
<td>42</td>
</tr>
<tr>
<td>1-1/4&quot; Diameter Bar</td>
<td>43</td>
</tr>
<tr>
<td>1-3/8&quot; Diameter Bar</td>
<td>43</td>
</tr>
<tr>
<td>1-3/4&quot; Diameter Bar</td>
<td>51</td>
</tr>
<tr>
<td>2-1/2&quot; Diameter Bar</td>
<td>56</td>
</tr>
<tr>
<td>3&quot; Diameter Bar</td>
<td>60</td>
</tr>
</tbody>
</table>

1. See [SDG Table 1.11.1-1](#) for required dimension for Tendons with Flexible Filler.

### General Requirements

**Tendon Replaceability**

---

**Figure 1.11.1-1 Jack Envelope Dimensions for Design and Detailing**

- **ELEVATION**
  - Fully extended Piston
  - Strand tails
  - Wedge Plate Max. Stroke
- **SECTION A-A**
  - (STRAND JACK SHOWN; BAR JACK SIMILAR)
General Requirements

Tendon Replaceability

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

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

Table 1.11.4-2 Minimum Duct Radius and Tangent Length

<table>
<thead>
<tr>
<th>Tendon Size</th>
<th>Minimum Duct Radius Between Two Tangents (ft)</th>
<th>Minimum Duct Radius and Tangent Length Adjacent to Anchorages (see Figure 1.11.4-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Minimum Radius R (ft)</td>
</tr>
<tr>
<td>4 - 0.6&quot; diameter strands</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>7 - 0.6&quot; diameter strands</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>12 - 0.6&quot; diameter strands</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>15 - 0.6&quot; diameter strands</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>19 - 0.6&quot; diameter strands</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>27 - 0.6&quot; diameter strands</td>
<td>13</td>
<td>16</td>
</tr>
<tr>
<td>31 - 0.6&quot; diameter strands</td>
<td>13</td>
<td>16</td>
</tr>
</tbody>
</table>

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

NOTE: Internal tendon shown, external tendon similar.
Superstructure

Conventional detail with bonded rigid steel pipe

Rigid steel pipe pulled out due to failed tendon

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

Diabolo Static and Wear Testing
Superstructure

Typical diabolos form for segmental bridges in Europe
Superstructure

Another form of diabolos (Germany)
Superstructure

Background for switching to Diabolo Form

Rendering and diabolo basic geometry per FHWA Research Project, Draft Report “Replaceable Grouted External Pos-tensioned Tendon” by Parsons Brinckerhoff (WSP), April 2017.
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 1\(\frac{1}{2}\)\text{-inch} clearance between the outer duct surface and the adjacent face of the concrete as shown in SDM Figure 20.8-9.
Superstructure

FDOT Diabolo
Form Standard
Superstructure

FDOT Diabolo Form Standard

Figure 20.8-7  Detail at Blister without Anchorage

*See SDG Table 1.11.4-2 for R (Min.)
Superstructure

FDOT Diabolo Form Standard

Figure 20.8-5  Detail at Pier Segment with Tendon Anchorage

*See SDG Table 1.11.4-2 for L (Min.) and R (Min.)
Superstructure

FDOT Diabolo Form Standard
Superstructure

FDOT Diabolo
Form Standard

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

Top Flange
End Diaphragm

Diabolo
Continuous PT Duct attached to Anchorage

PT Duct Embedded in Concrete
Type I Anchorage Protection

See Figure 20.8-10 Detail A
Superstructure

FDOT Diabolo Form Standard

Figure 20.8-8  Detail at Pier Segment with Tendon Saddle

* See SDG Table 1.11.4-2 for R (Min.)
## Minimum Center-to-Center Duct Spacing

<table>
<thead>
<tr>
<th>Post-Tensioned Superstructure Type</th>
<th>Minimum Center To Center Vertical Spacing “d” between Longitudinal Ducts&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Minimum Center To Center Horizontal Spacing “s” between Longitudinal Ducts&lt;sup&gt;1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precast Balanced Cantilever Segmental Bridges (see SDG Figure 4.5.3-1)</td>
<td>2 times outer duct diameter plus 1-inch, or outer segmental coupler diameter plus 2-inches, whichever is greater.</td>
<td>2 times outer duct diameter plus 1-inch, or outer segmental coupler diameter plus 2-inches, whichever is greater.</td>
</tr>
<tr>
<td>C.I.P. Balanced Cantilever Segmental Bridges (see SDG Figure 4.5.3-1)</td>
<td>Outer duct diameter plus 1.5 times maximum aggregate size, or outer duct diameter plus 2-inches, whichever is greater.</td>
<td>Outer duct diameter plus 2½-inches.</td>
</tr>
<tr>
<td>Post-Tensioned I-Girder and U-Girder Bridges&lt;sup&gt;2&lt;/sup&gt; (see SDG Figure 4.5.3-2)</td>
<td>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).</td>
<td>Outer duct diameter plus 2½-inches.</td>
</tr>
<tr>
<td>C.I.P. Solid or Voided Slab Bridges and C.I.P. Multi-Cell Bridges (see SDG Figure 4.5.3-3)</td>
<td>Outer duct diameter plus 1.5 times maximum aggregate size, or outer duct diameter plus 2-inches, whichever is greater.</td>
<td>Outer duct diameter plus 3-inches.</td>
</tr>
<tr>
<td>Integral Pier Caps (see SDG Figure 3.11.1-1)</td>
<td>See SDG Table 3.11.1-2</td>
<td>See SDG Table 3.11.1-2</td>
</tr>
</tbody>
</table>

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

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

Duct Spacing
Superstructure

- Shear Capacity Limit
- Support hinge locations

1.11.6 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:

\[ V_n \leq 0.15f_{c}b_{v}d_{v} + V_p \quad \text{or} \quad 0.379 \cdot f_{c}b_{v}d_{v} - V_p, \text{ whichever is greater} \]

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

- External PT unsupported length
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 $0.5d_v\cot\theta$ 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:

<table>
<thead>
<tr>
<th>Nominal Shear Stress Range</th>
<th>Maximum Transverse Spacing of Stirrup Legs $S_w$ as shown in Figure 4.1.4-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v_n \leq 0.08\sqrt{f'_c}$</td>
<td>$S_w \leq 42''$</td>
</tr>
<tr>
<td>$0.08\sqrt{f'_c} &lt; v_n \leq 0.16\sqrt{f'_c}$</td>
<td>$S_w \leq d_v$ or 24'', whichever is less</td>
</tr>
<tr>
<td>$v_n &gt; 0.16\sqrt{f'_c}$</td>
<td>$S_w \leq 0.5d_v$ or 12'', whichever is less</td>
</tr>
</tbody>
</table>

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

$V_u = \text{Factored shear force per LRFD Chapter 5}$

$b_v = \text{Effective web width per LRFD Chapter 5}$

$d_v = \text{Effective shear depth per LRFD Chapter 5}$

$f'_c = \text{Compressive strength of concrete per LRFD Chapter 5}$

$\phi = \text{Resistance factor per LRFD Chapter 5}$
Superstructure
Wide Beam Member
Superstructure

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


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

Tendon Replaceability

Staggered Tendon Overlap
PT Spliced Girder Bridge

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

NOTE: See SDG Table 1.114.2 for:
R (Min.) and L (Min.) Dimensions.

SECTION A-A
(ANCHORAGE IN THICKENED WEB ALTERNATIVE)
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
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

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

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

Project: Wekiva Section 6
Closing

Thank you for your attention

Any questions?