2015 Design Training Expo

Flexible Filler

Florida's Policy for Post-Tensioning Tendons

Presented By: Rick W. Vallier, P.E. • FDOT Structures Design Office • June 2015

Innovative Solutions for Tomorrow's Transportation Needs

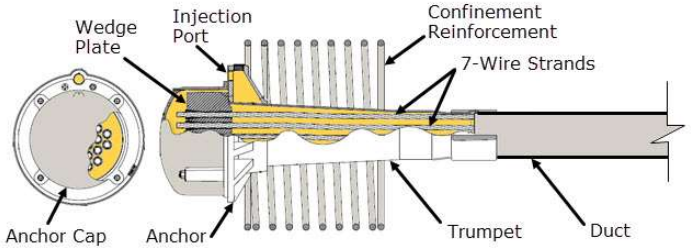
Presentation Outline

- Research Overview
- Policy & Design Criteria
- Implications Using Flexible Filler

Innovative Solutions for Tomorrow's Transportation Needs

Research Overview

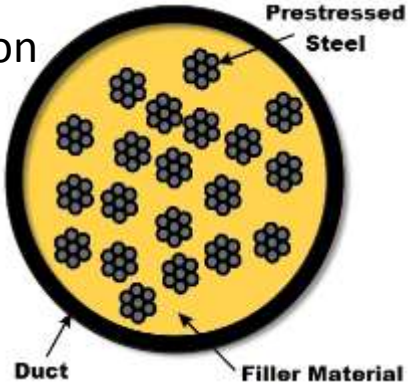
Conventional Post-Tensioning



Research Project BDV31-977-15

Replaceable Unbonded Tendons for Post-Tensioned Bridges

Task 1 – Mock-up Injection
Task 2 – Internal Tendon Testing
Task 3 – External Tendon Testing
Task 4 – Final Report



Research Project BDV31-977-15

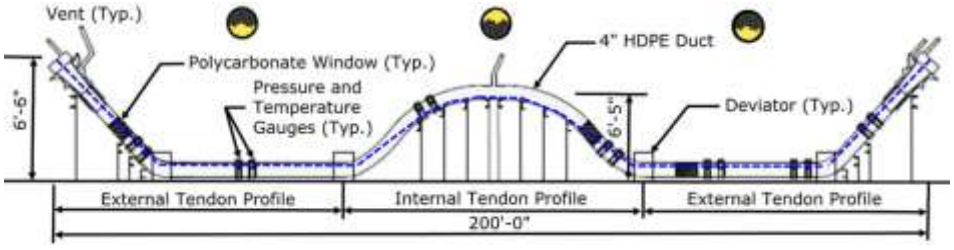
Replaceable Unbonded Tendons for Post-Tensioned Bridges

Task 1	– Mock-up Injection	Ongoing
Task 2	– Internal Tendon Testing	Summer 2015
Task 3	– External Tendon Testing	Summer 2015
Task 4	– Final Report	Early 2016

Full-Scale Mock-up Injection

Test Set-Up

- Clear Windows
- Temperature and Pressure Gauges
- Deviations



Full-Scale Mock-up Injection

Microcrystalline Wax

- Metal Adhesion Properties
- Homogenous
- Hydrophobic

Wax Installation

- **Wax Material**
- **Heating Elements**

Photo Courtesy of Trenton Corp.

Photo by C. Frank Starmer (http://ravenelbridge.net)
Used under CC BY / Cropped

Pumping Accessories

- Pump
- Plumbing

- Pipe Connections
- Valves
- Hoses

Inlets and Vents

Equipment & Safety Protection

- Protective Clothing
- Face Mask

- Temperature Gauge
- Uniform Wax Temperature

Example Wax Injection

1. Heat Wax Between 212°F and 240°F
2. Pump Wax into Duct at Low Point
3. Pump Wax between 40 and 70 Feet Per Minute
4. Vent Duct at High Points
5. Maximum Injection Pressure of 75 PSI
6. Lock-Off Pressure Between 30 psi and 45 psi

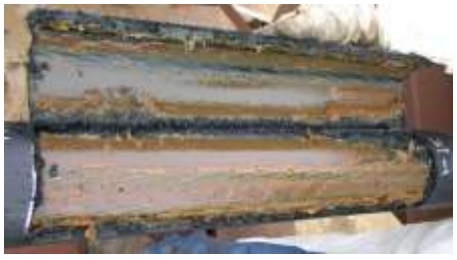
Wax Injection

Venting

Example Vacuum Assisted Injection

1. Heat Wax Between 212°F and 240°F
2. Vacuum Duct to 28 in. Mercury
3. Pump Wax End-to-End
4. Final Lock Off Pressure Between 30 PSI and 45 PSI

Vacuum Assisted Injection Results



Anchor

Anchor Cap

Anchor

Anchor Cap

Policy & Design Documents

Structures Design Bulletin 15-03

- Structures Manual
- Design Standards 21800 Series
- Specifications 105, 452, 462, 938 and 960

Implementation

- **Design-Bid-Build**
  Plans at 30% or less as of January 28, 2015
- **Design-Build**
  Advertised after May 20, 2015

Policy & Design Documents

Release Schedule

• Structures Manual Bulletin 15-03	**May 2015**
• Design Standards 21800 Series	**July 2015**
• Specifications 105, 452, 462, 938 and 960	**January 2016**

Project Schedules

I-95 at North I-295 Interchange (FIN 213323-1)

Duval County

- Advertisement August 2015
- Award of Project May 2016
- $180 Million

I-395 in Miami (FIN 251688-1)

Miami-Dade County

- Advertisement September 2015
- Award of Project September 2016
- $600 Million

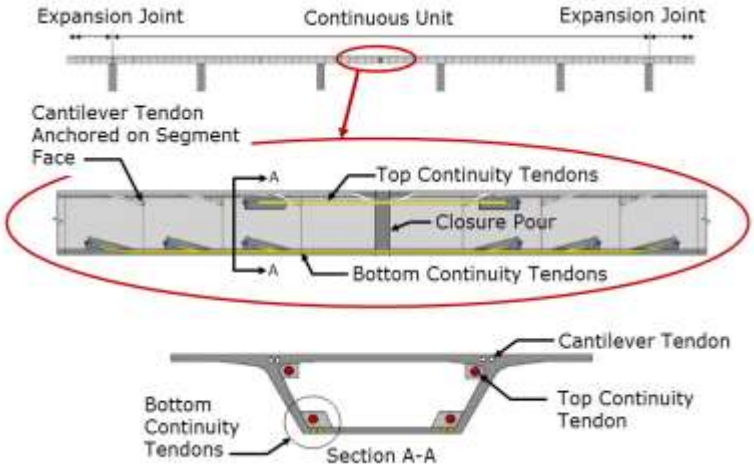
Information From ProjectSuite On 6/2/2015 • Subject to Change

Flexible Filler

External Tendons

Flexible Filler

Continuity Tendons



Flexible Filler

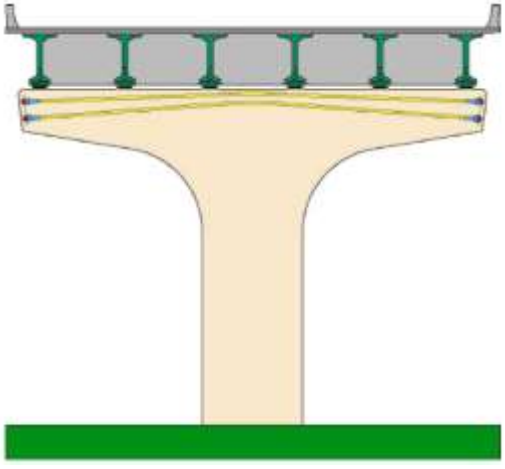
Post-Tensioned I-Beam Tendons

Flexible Filler

Post-Tensioned U-Girder Draped Tendons

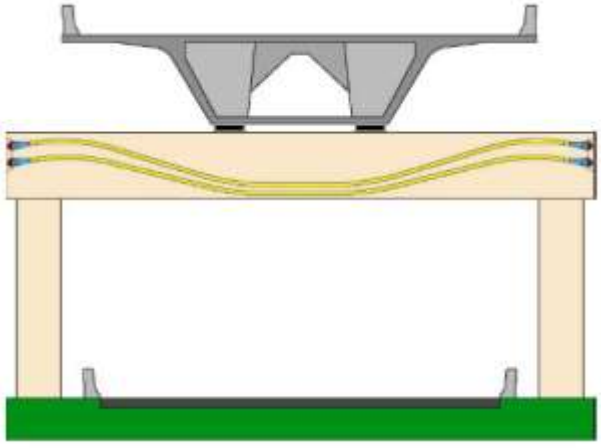
Flexible Filler

Hammerhead Pier Strand Tendons



Flexible Filler

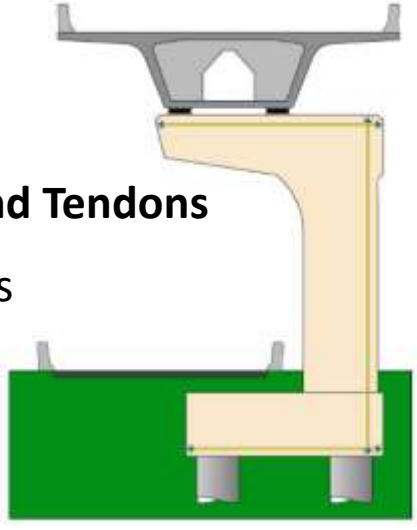
Straddle Pier Strand Tendons



Flexible Filler

Cantilever Pier Strand Tendons

- Horizontal Strands
- Vertical Strands



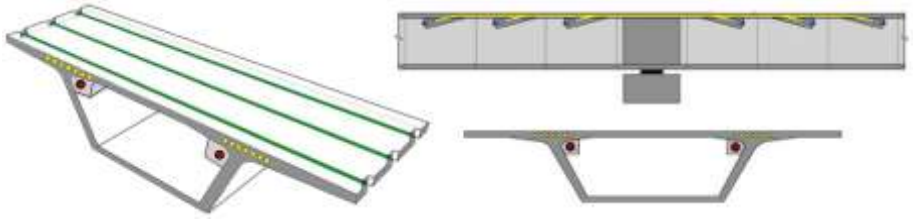
Cement Grout

<u>May</u> Use Cement Grout

- Post-Tensioning Bar Tendons
- Straight Tendons in U-Beams and Girders

<u>Must</u> Use Cement Grout

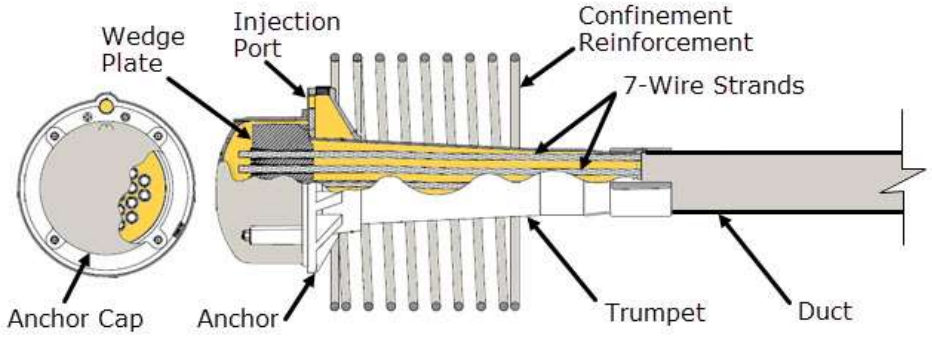
- Transverse Tendons in Top Slabs
- Cantilever Tendons in Top Slabs



Implications

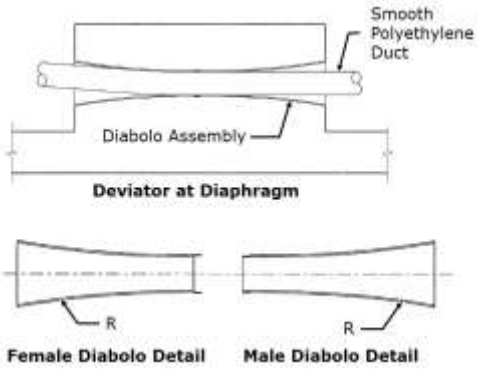
PT Systems for Flexible Filler

- Similar to Cementitious Grouted PT Systems
- Tendons are Replaceable



Diabolos

Permanently Embedded Diabolo Assembly



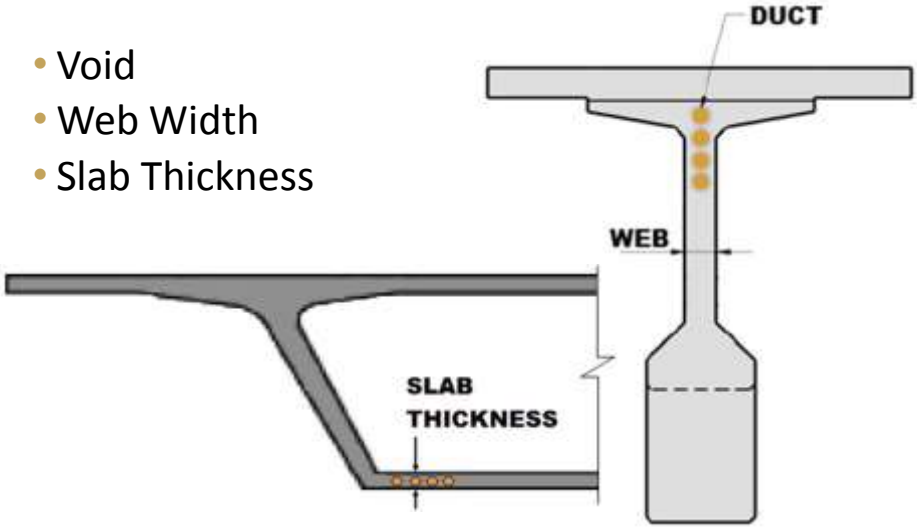
Reusable Diabolo Inserts

Design Methodology

- Unbonded Tendon Design
- Similar to Grouted External Tendon Design

Cross-Section

- Void
- Web Width
- Slab Thickness



Stress in Unbonded Strands (Ultimate)

~~LRFD 5.7.3.1.2~~

$$f_{ps} = f_{pe} + 900\left(\frac{d_p - c}{\ell_e}\right)$$

ACI 318-11 Section 18.7

Unbonded Tendons Span-to-Depth Ratio ≤ 35	Unbonded Tendons Span-to-Depth Ratio > 35
$f_{ps} = f_{se} + 10{,}000 + \frac{f'_c}{100\rho_p}$	$f_{ps} = f_{se} + 10{,}000 + \frac{f'_c}{300\rho_p}$

Strength I Moment

AASHTO LRFD Bridge Design Specifications

- Capacity Decreases for Unbonded Design

Table 5.5.4.2.2-1 - Resistance Factor for Joints in Segmental Construction

	ϕ_f Flexure	ϕ_v Shear
Normal Weight Concrete		
Fully Bonded Tendons	0.95	0.90
Unbonded or Partially Bonded Tendons	0.90	0.85

5.7.3.2 - Flexural Resistance $M_r = \phi M_n$

LRFD 5.7.3.1.2 & ACI 318 Stress in Unbonded Tendons Limited to Yield $f_{ps} \le f_{py}$

LRFD 5.7.3.2.2 Nominal Flexural Resistance

$$M_n = A_{ps} f_{ps} \left(d_p - \frac{a}{2} \right) + A_s f_s \left(d_s - \frac{a}{2} \right) - \ldots$$

Cracking Moment

AASHTO LRFD Bridge Design Specifications

5.7.3.3.2 Minimum Reinforcement

- Cracking Moment Decreases

$M_r \ge$ minimum $(1.33\, M_u\,,\, M_{cr})$

$$M_{cr} = \gamma_3 \left[\left(\gamma_1 f_r + \gamma_2 f_{cpe} \right) S_c - M_{dnc} \left(\frac{S_c}{S_{nc}} - 1 \right) \right]$$

γ_2 = prestress variability factor
= 1.1 for bonded tendons
= 1.0 for unbonded tendons

f_{cpe} = compressive stress in concrete

Service III Longitudinal Stress

Segmental Box-Girder Parametric Study				
Property			Tendon Encapsulation	
			Grout Filler	Flexible Filler
Pier	Cross Section	Area (ft^2)	98.3 →	**96.0**
		Moment of Inertia (ft^4)	2041.2	1996.9
		Height (ft)	12	12
		Ctop (ft)	4.85	4.95
	Service III Stresses and Rating Factors	Permanent (ksf)	-89.9	-98.0
		Live Load (ksf)	41.5	43.4
		Total Stress (ksf)	-48.4	-54.7
		Rating Factor	2.16	**2.26**
Midspan	Cross Section	Area (ft^2)	82.3 →	**81.4**
		Moment of Inertia (ft^4)	986.2	959.1
		Height (ft)	9.5	9.5
		Ctop (ft)	3.10	3.06
	Service III Stresses and Rating Factors	Permanent (ksf)	-109.4	-105.4
		Live Load (ksf)	88.2	91.4
		Total Stress (ksf)	-21.2	-14.1
		Rating Factor	1.24	**1.15**

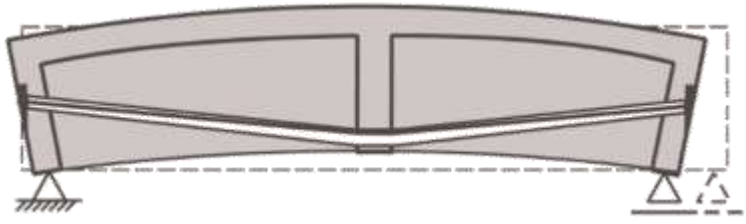
Fatigue & Deflection

Strand Fatigue & Fretting

- Low Stress Range

Creep & Shrinkage

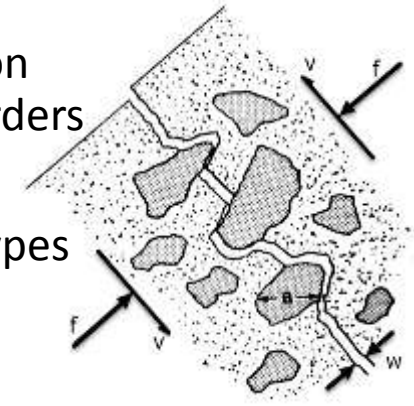
- Not Expected to Change Significantly Between Bonded and Unbonded Design



Shear & Torsion

AASHTO LRFD Bridge Design Specifications

- 5.8.6.1 Shear & Torsion for Segmental Box Girders
- 5.8.3.4.3 For Other Types of Structures

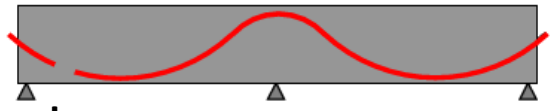


Prestress Behavior of Local Failure

Internal Grouted Tendons

Tendons
Redevelop Prestress

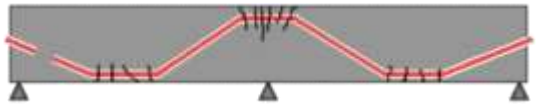
Little to No Warning of Failed Tendon



External Grouted Tendons

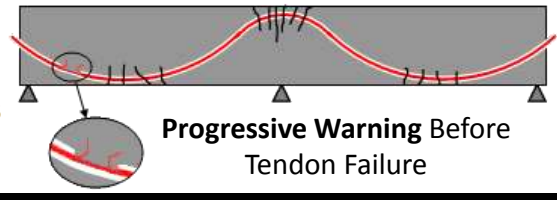
Strands
Redevelop Prestress
Within Duct

Little to No Warning Prior to Tendon Failure



Internal and External Waxed Tendons

Strand Failure
Leads to
Incremental Prestress Loss



Progressive Warning Before
Tendon Failure

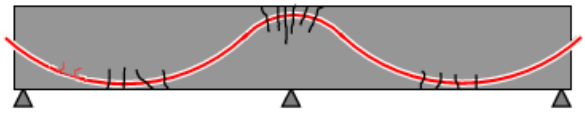
Construction Cost Estimate

- **Post Tensioning Pay Item Cost**
  15% to 26% above similar grouted systems
- **Superstructure Cost**
  0.5% to 2.4% higher than a similar grouted system
- **Total Project Cost**
  Less than 1% increase compared to a grouted system

Maintenance

Inspection Areas

- Cracking at Maximum Bending Locations
- Loose Strands in Duct



Replaceable Tendons

- Access to Tendon Anchorages

Innovative Solutions for Tomorrow's Transportation Needs

Terminology

- **Injection** – Process of Pumping Filler into Duct
- **Filler** – Grout or Flexible Filler
- **Flexible Filler** – Grease, Wax, Gel, or other Pliable Filler
- **Tendon** – Bar or Strand

Example: *"Inject filler into duct."*

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