

Post-Tensioning Best Practice Update and New Directions for Post-Tensioned Structures

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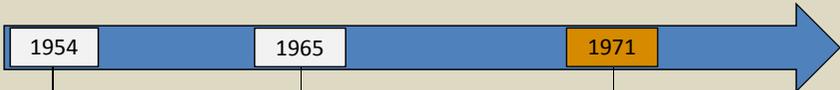


Outline

- Florida's History with Post-Tensioning
- Investigation Status and Corrosion Findings
- Grout as Corrosion Protection System
- Specification Changes
- Alternative Corrosion Protection Systems

Florida's History with Post-Tensioning

Florida's History with Post-Tensioning



1954

- First post-tensioned bridge in Florida
- Sunshine Skyway Approaches (Tampa)
- I-beams post-tensioned with bars



1965

- First drop-in span structure
- Dupont Bridge over St. Andrew Bay (Panama City) - Post-tensioned segments over piers
- Cantilever suspended spans (not continuous)



1971

- Corrosion found in a few of the girders on Sunshine Skyway
- Water penetrated anchor blocks and initiated local pitting in PT bars
- Corrosion due to insufficient concrete cover at anchor blocks, exposing the PT to salt spray and deck runoff through deteriorated deck joints

Florida's History with Post-Tensioning

- **First draped PT tendons in webs of precast girder sections**
- Chipola Nursery Road (New Hope Road) over I-10 (near Marianna)
- Two-span continuous girders



- **First segmental (span-by-span)**
- Long Key Bridge (Keys)
- Three more span-by-span bridges in the Keys:
 - Seven Mile Bridge
 - Channel Five Bridge
 - Niles Channel Bridge



- **First precast segmental balanced cantilever**
- Ramp I over I-75 (Fort Lauderdale)



Florida's History with Post-Tensioning

- New Sunshine Skyway
- Eau Gallie Bridge
- Dodge Island Bridge
- Acosta Bridge
- Mid-Bay Bridge
- Garcon Point Bridge



- **1 of 6 tendons failed on Niles Channel Bridge (Keys)**
- Tendon immediately replaced
- **Emergency investigations of other PT bridges**




- **2 tendons failed on Mid-Bay Bridge (Destin) – built in 1993**
- **11 excessively corroded tendons found and replaced**




Florida's History with Post-Tensioning

2000

- FDOT temporary design memoranda:
- Pre-bagged grouts
- Inspection of anchorages after grouting



2000

- **Failed tendon in precast segmental column of Sunshine Skyway high level approaches**



2002

- The FDOT makes changes to policies and procedures to ensure long-term durability of PT tendons
- 5-part strategy for PT durability



Florida's History with Post-Tensioning

2003

- Ringling Causeway Bridge (Sarasota)
- Wonderwood Connector (Jacksonville)




2011

Ringling Causeway

- **2 tendons failed on Ringling Causeway Bridge**
- Warranty repair made by contractor
- **New series of PT investigations**

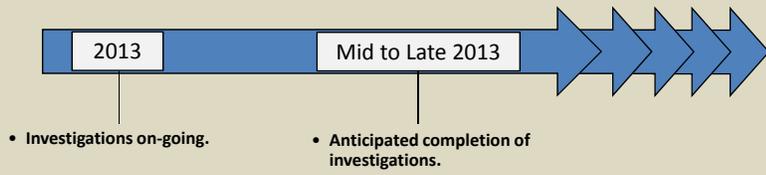
2012

Wonderwood Connector

- **Extensive soft grout and corrosion found.**




Florida's History with Post-Tensioning



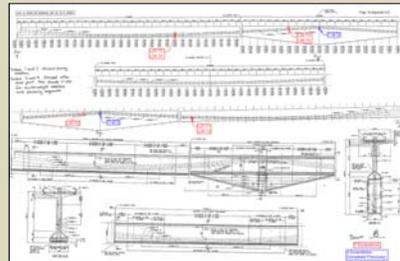
Investigation Status

Investigation Status

Post-Tensioned Structure Type	Completed	Remaining	Total
Segmental – External PT	9	0	9
Segmental – Internal PT	16	7	23
Concrete Girders with Continuity PT	5	7	12
Simple Span PT	4	0	4
Bridges with Substructure PT	15	1	16
Total	49	15	64

Inspection of Internal Grouted Tendons

- Internal tendons not easily inspectable
 - Full inspection not achievable
 - Spot inspection only
 - Limited view
 - Slow and expensive



Inspection of External Grouted Tendons

- External tendons on segmental bridges
 - Spot inspection only
 - Boroscope inspection of trumpets
 - Manual soundings
 - Observable failure



Investigation Status

- Segmental Bridges with External PT
- 9 of 9 investigations completed
 - One 8-year old bridge
 - 2 failed tendons
 - 17 tendons replaced
 - Over 500 voids re-grouted or repaired with epoxy
 - One 3-year old bridge
 - 6 of 32 tendons with soft grout
 - One bridge owned by expressway authority
 - Sand in duct caused minor corrosion to strand



Investigation Status

- Segmental Bridges with Internal PT
- 16 of 23 investigations completed
 - One bridge with small amount of soft grout in trumpet found



Investigation Status

- Concrete Girders with Continuity PT
- 5 of 12 investigations completed
 - 4 bridges with minor issues
 - One 9-year old bridge with significant problems found
 - Extensive soft grout
 - Corrosion in haunched areas of sloped tendons



Investigation Status

- Simple Span Post-Tensioned Bridges
- 4 of 4 investigations completed
 - No problems found



Investigation Status

- Bridges with Substructure PT
- 15 of 16 investigations completed
 - 14 bridges with no problems found
 - One bridge
 - High chloride content in PT straddle bent
 - 19 bridges with substructure PT
 - 3 with PT below ground line will not be investigated



Investigation Status

- Summary of Investigations
 - 49 investigations complete
 - 3 Bridges with soft grout/corrosion issues found
 - 15 investigations remaining
- **\$1.7 million contract cost to date**
 - Not included in this cost:
 - FDOT employees
 - Extensive warranty repair on one bridge
 - **Repairs to be performed**
- Problems on vertically deviated tendons
- Top slab tendons in segmental bridges
 - Simpler duct geometry
 - Shorter length for grouting



Past, Present, Future

- Post-Tensioning History and Current Investigation
 - Questioned durability unwarranted?
 - Apprehensive owners
 - Potential loss of credibility with tax payers
- Future goals based on past experience and current investigation
 - Greater confidence with nearly zero chance of leaving defects behind
 - Tendon repair or replacement
 - Less difficult, economical
 - Routine inspection and maintenance only
 - No emergency investigations of PT inventory

*"The past does not repeat itself,
but it rhymes."*

- Mark Twain

Grout as Corrosion Protection System

Grout as Corrosion Protection System

Why fill the duct with grout?

- Fills a void
- Bond to surrounding concrete
 - Internal tendons with corrugated duct
- Chemically passivating alkaline environment
- Economical



Grout as Corrosion Protection System

Prebagged grout product issues

- Bag weights?
- Contaminants?
- Inert fillers?
 - Segregation?
 - Sulfates?
- Shelf life?
- Partial hydration?
 - Climate controlled storage for cement and grout at grout manufacturer?
 - Climate controlled transport of prebagged grout to project site?



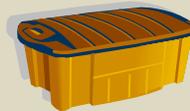
VS.



Grout as Corrosion Protection System

Prebagged grout storage on project site

- Proper storage?
 - Climate controlled storage?
 - Raised platform with waterproof covering?
 - Seal in “air tight” containers?

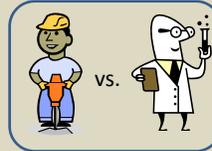


Grout as Corrosion Protection System

Mixing of prebagged grout on project site

Grout sensitivity to water and temperature

- Water in pump and hose from previous cleaning and/or priming of pump?
- Water content?
- Temperature?
 - Water temperature?
 - Prebagged grout temperature?
 - Temperature of mixed grout prior to injection?
 - Temperature of grout inside of duct?
 - Temperature of grout at outlet?



Grout as Corrosion Protection System

Pumping grout into deviated ducts

- Contamination in duct?
 - Debris, sand?
- Water in duct?
- Pumping pressures?
 - Pressure monitored at inlet?
 - Too much pressure in hose and at the pump?
 - Grout speed?
- Filtering effect?



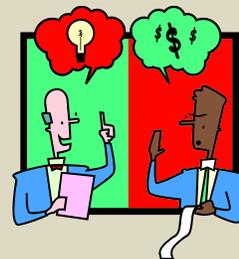
Grout as Corrosion Protection System

- Summary
 - Results mostly good
 - Finicky process
 - Many variables
 - Human factors
 - Lessons learned
 - Continued learning
 - Questions to answer
 - Issues to resolve

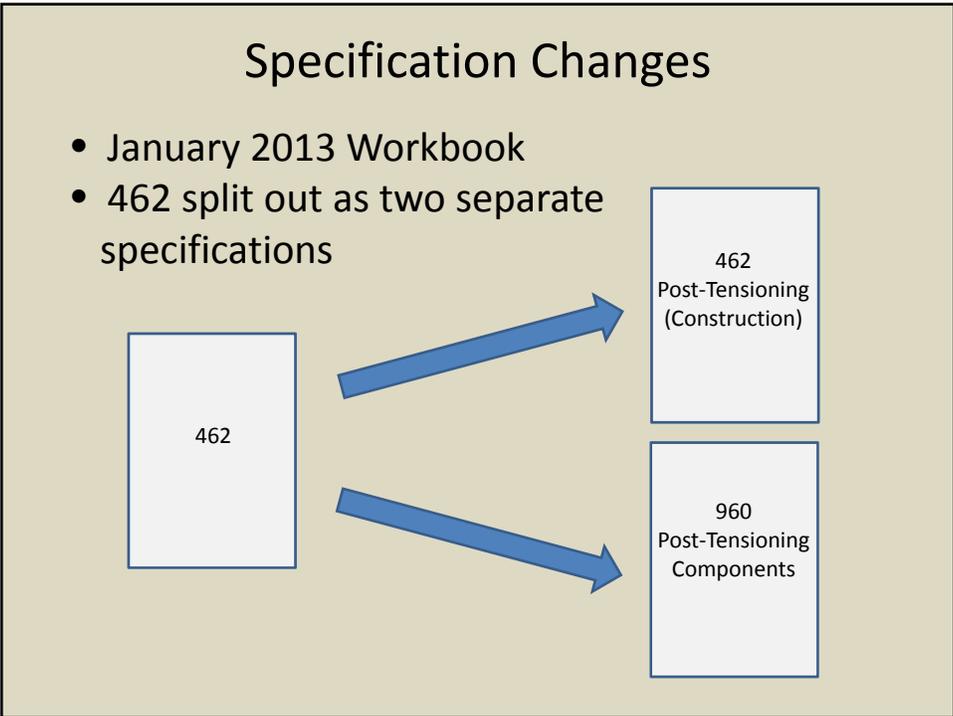


Maintenance's "Wish List"

- Improved Design, Construction and Materials
- Replaceable tendons
 - Internal and External
- Easier tendon inspection
 - NDE (Non-Destructive Examination)
 - Economical, Practical, Effective



Specification Changes



Specification Changes

- Separation of 462 and 960 was primarily a reformatting of the existing specifications.
 - Consistent with AASHTO spec format

- Changes to highlight:
 - 462
 - Full scale mock up test
 - 960
 - Vent hole in wedge plates
 - Combined wear/creep test for corrugated plastic duct



Specification Changes

- Full scale mock up test
- 462-7.4(e)

(e) Demonstrate, to the Engineer's satisfaction, grouting of a longitudinal tendon by constructing a full-scale mockup with all associated PT system components of a typical longitudinal tendon profile on the project. Utilize 'clear' duct for the mockup to facilitate visual inspection and verification that no voids or bleed are present in the tendon mockup after grouting. Place a non-stressed PT strand equivalent to the typical longitudinal tendon size inside the duct to simulate in-place PT strand.



contract on application of elastomeric coating onto test block. Apply coating using approved and experienced personnel with a minimum of three years experience applying similar performance systems. Submit condition of these persons to the Engineer for review and consideration for approval.

462-7.4 Grouting Operations:
 Complies all grouting operations in the presence of the Engineer.

462-7.4.1 Plan:
 (1) Submit a Grouting Operation Plan to the Engineer for approval at least 14 calendar days prior to grouting operations.

(2) Procedures for possible post grouting repair:
 (a) Conduct a post grouting of the Contractor grouting crew, and the Engineer before grouting operations begin. Discuss Grouting Operation Plan required testing, methods for conducting a full-scale mockup, and all associated PT system components of a typical longitudinal tendon profile on the project. Utilize 'clear' duct for the mockup to facilitate visual inspection and verification that no voids or bleed are present in the tendon mockup after grouting. Place a non-stressed PT strand equivalent to the typical longitudinal tendon size inside the duct to simulate in-place PT strand.

462-7.4.2 Tends and Ducts:
 (a) Ensure connections from grout pump lines to tubes are free of dirt and are air-tight.
 (b) Support tubes to ensure they are open and clear properly.

462-7.4.3 Supplies:
 Provide an adequate supply of water and compressed air for cleaning and testing ducts, as well as mixing and pumping grout before grouting operations start.

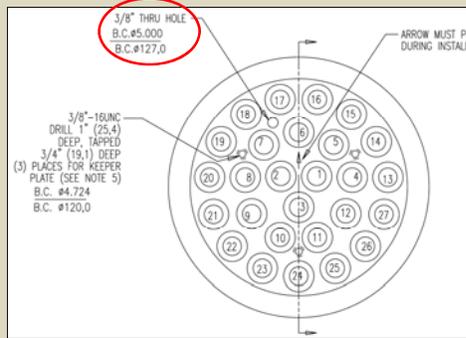
462-7.4.4 Equipment:
 (a) Provide grouting equipment consisting of measuring devices for water, a high-speed shear calculated mixer, a storage hopper (e.g., holding materials and pump with all necessary connecting lines, valves, and pressure gauge).

← Mock up test on VDOT cast-in-place segmental project

Specification Changes

- Vent hole in wedge plate
- 960-2(f) Component Standards

(f) Geometry of grout outlets must facilitate access for endoscope inspection directly behind wedge plate using a straight 3/8 inch diameter drill bit. *For all PT systems other than 4 strand flat configurations, place vent hole(s) of 3/8 inch minimum diameter through wedge plate to allow for passage of grout and inspection.*



10.1 For anchorage with typical steel reinforcement bars in concrete:

(a) Anchorages with grout outlets shall be suitable for inspection from either top or front of anchorage. Anchorages may be fabricated to facilitate both inspection locations or may be two separate anchorages of the same type, each providing singular inspection entry locations.

(b) Geometry of grout outlets must facilitate access for endoscope inspection directly behind wedge plate using a straight 3/8 inch diameter drill bit. For all PT systems other than 4 strand flat configurations, place vent hole(s) of 3/8 inch minimum diameter through wedge plate to allow for passage of grout and inspection.

(c) If grout outlet construction of an anchorage that can be embedded pre-concrete shall be performed in accordance with Section 962. Other anchorage assembly components, including wedges, wedge plates, and local zone reinforcement used are performed.

(d) All anchorages shall have a permanent vented anchorage cap bolted to anchorage.

Sub-2.1.1 Trampers:

(a) Trampers associated with anchorages shall be constructed from ferrous metal galvanized per ASTM A123, polypropylene plastics, or polyethylene.

(b) Trampers thickness at transition location shall be the thickness of the duct or grout.

Sub-2.1.2 Wedges and Wedge Plates:

(a) Wedge plate shall be ferrous metal.

(b) Wedge plates must have centering legs or shoulders to facilitate alignment with bearing plate.

(c) For longitudinal sections greater than four strands, design system with separate wedge plate and anchorage plate.

Sub-2.1.3 Grout Containment Assembly:

Sub-2.1.3.1 Duct and Pipe:

(a) Use plastic duct, steel pipe, or a combination of plastic duct and steel pipe in accordance with this Section.

(b) Ducts shall be manufactured by a suitable fabrication method. Fabricate all duct splices to prevent leaks during all phases of construction.

(c) Do not alter the internal duct unless that results from 1" protruded polymer.

(d) Corrugated ferrous metal ducts are prohibited.

Sub-2.1.3.1 Internal Duct (Corrugated Plastics):

(a) If PT systems need for random internal or concrete shall use corrugated polypropylene plastic material except where steel pipe is required.

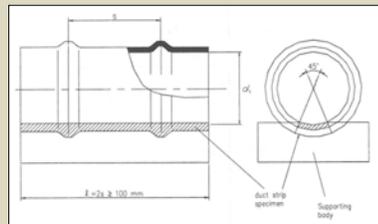
(b) Furnish ducts with minimum wall thickness as follows:

Table 2.1.3.1-1: Corrugated Plastic Duct Minimum Wall Thickness

Specification Changes

- Combined wear/creep test
 - Wear resistance test (*fib*) followed with short-term creep test on same specimen
- 960-3.2.2

(a) Modify procedure as follows: After the specimen has reached its final position, remove the specimen and confirm that the residual thickness is adequate. With confirmation that the residual thickness is acceptable, immediately (within 30 minutes) reapply the original clamping force for 14 days.



10.1 For post-tensioning with block tying method construction, when blocks are in place for a minimum of 12 hours:

(1) After concrete has hardened, pull blocks out and clean surface of any local residual material.

(2) Using an external apparatus, clamp blocks together and maintain 40 psi pressure on block connection during pressure test. Do not apply pressure compressed between blocks.

(3) Pressure duct within test block to 7 psi and hold off outside air source.

(4) Assembly must maintain a 7 psi internal pressure for three minutes with an over Bank at 4 psi or 40% reduction in pressure.

(5) Remove clamping device, separate duct coupling blocks from duct cap, and place a 1/8 inch layer of clean compressed 70 psi Bank 500 on top of both blocks, clamp blocks together, and maintain a pressure of 40 psi on block connection for 14 days. Upon removal of clamping force, attach blocks. Duct coupling and attached block should be intact and free of spew compound and properly attached without cracking, tearing, or other signs of failure.

Sub-2.1.2 Minimum Residue, Radius:

Fabricate bearing surface for duct through bearing. Test concrete of a specimen that may use as described in Chapter 6, Article 6.1.1 for the Technical Report, Institute 7 titled, "Corrugated Plastic Duct for Internal Bonded Post-Tensioning." Use identical conditions as that used for testing the 40 psi internal pressure test in concrete specimens of similar dimensions.

(a) Modify procedure as follows: After the specimen has reached its final position, remove the specimen and confirm that the residual thickness is adequate. With confirmation that the residual thickness is acceptable, immediately reapply the original clamping force for 14 days.

Specification Changes

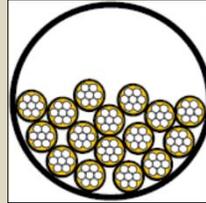
- Changes to 462 in the works...
 - Revise limits on grouting temperatures
 - Revise maximum pumping pressure to reduce grout flow rate
 - Revise location for grout pressure monitoring
 - Revise grout discharge quantity from vents and anchorages



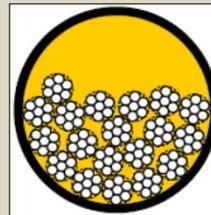
Alternative Corrosion Protection Systems

Unbonded Greased PT Systems

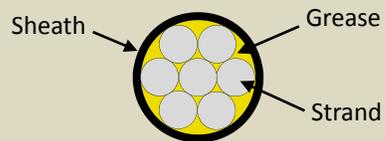
Greased and Sheathed Monostrand



Grease Filled Duct



Greased and Sheathed Monostrand



Greased and Sheathed Monostrand

Used in buildings and parking structures since the 1950s



Greased and Sheathed Monostrand

- Bridge tendon
 - Larger duct
 - Larger anchorage
 - Larger members

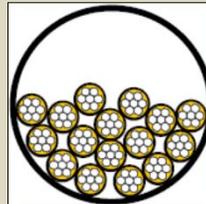
Anchorage for Greased and Sheathed



Grouted Duct



Ungouted Duct



Greased and Sheathed Monostrand

- Strands can be replaced one-by-one
- Installing new strand into existing sheath could be challenging



Greased and Sheathed Monostrand

- Challenges at deviators for external tendons
- Problem on recent European bridge



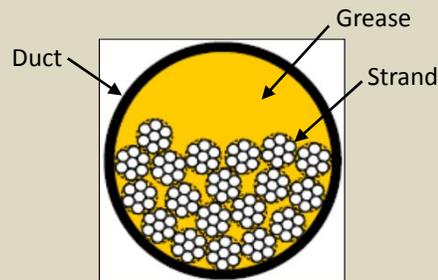
Greased and Sheathed Monostrand

- Summary
 - Larger members (larger duct)
 - Sheathing
 - Deviations
 - Splitting
 - Inner strands of tendon bundle
 - Not easily inspectable
 - Access for repair?
 - Replacing failed deviated strands?



Grease Filled Duct

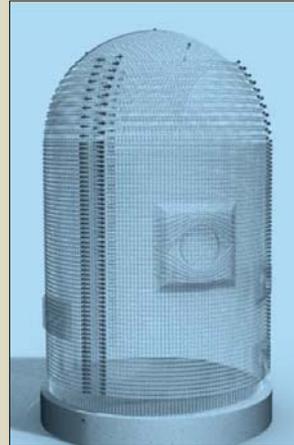
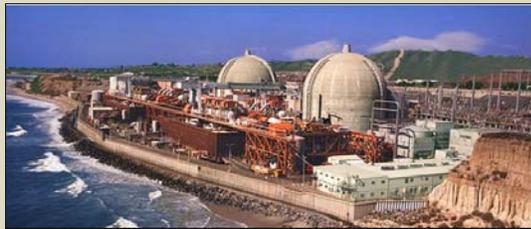
- Advantages
 - High level of corrosion protection
 - Replaceable
 - Inspectable
 - External tendons can be mechanically detensioned and removed for inspection
 - Grease injection can be restarted later



Grease Filled Duct

Nuclear containment structures

- Grease as PT corrosion protection has a 40+ year history of successful use around the world
- USA, Canada, England, Sweden, Spain, Japan, South Korea, China, Taiwan



Grease Filled Duct



- **European Bridge Post-Tensioning**

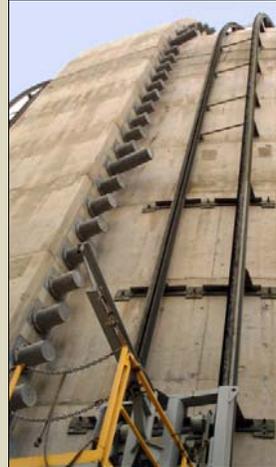
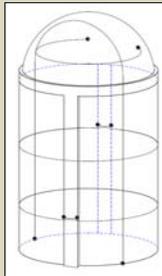
- France and Germany both require grease as corrosion protection for unbonded tendons.
- Germany requires all unbonded tendons to be replaceable.

Grease Filled Duct



Tendon Replacement Project (2009)

- California nuclear generating station
- Four steam generators replaced
- Removal of horizontal and vertical tendons
- Grease filled ducts



Grease Filled Duct

Tendon Replacement Project

- Total of 164 tendons de-tensioned and removed
- 82 tendons in each structure
 - 46 horizontal
 - 36 vertical
- Remove and replace steam generators
- Temporary 28-ft opening cut in 4-ft thick concrete containment structure



Grease Filled Duct

Tendon Replacement Project

- Containment structures built in 1979/80
- 65-70°F ambient temperature at the time of cap removal
- Existing tendon condition after 30 years



Grease Filled Duct

Tendon Replacement Project

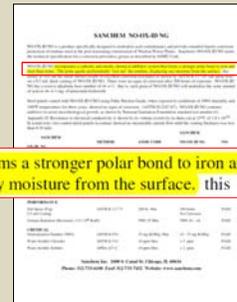
- Complex tendon geometries
- Limited access conditions
- QA program in compliance with Nuclear Regulatory Commission (NRC) regulations
- On-site tendon demonstration program



Grease Filled Duct

Grease Material

- Corrosion protection
 - Cathodic and anodic chemical inhibitor system
 - Forms stronger polar bond to steel than water
- Pumping
 - 135°F melting point
 - Once melted, flows readily below melting point
- Multiple suppliers
 - No sole-source product issues



NO-OX-ID NG incorporates a cathodic and anodic chemical inhibitor system that forms a stronger polar bond to iron and steel than water. The polar agents preferentially "wet out" the tendons, displacing any moisture from the surface. This

Grease Filled Duct

- Challenges
 - Unbonded design
 - Anchorage access
 - De-tensioning



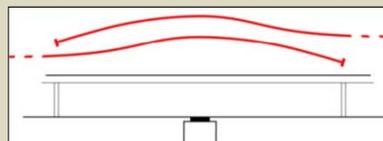
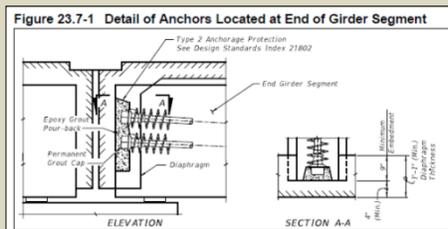
Grease Filled Duct

- Unbonded design
 - External tendons
 - No change
 - Internal tendons
 - Change from bonded to unbonded design may require additional tendons



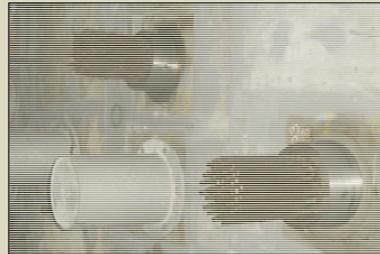
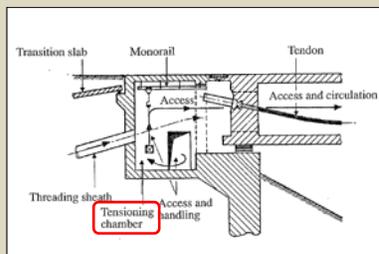
Grease Filled Duct

- Future anchorage access
 - Offset beam ends?
 - Consider new potential blister locations?



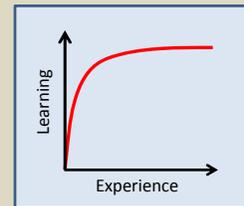
Grease Filled Duct

- De-tensioning
 - Strand tails
 - Mechanical de-tensioning
 - Tensioning chamber at end of bridge?



Grease Filled Duct

- **New application of existing technology**
 - New to bridge contractors
- **Initial Cost**
 - Estimated 15%-20% increase on PT system only
 - Recent segmental mega-project example:
 - 20% cost increase applied to external PT only
 - About 25% of tendons are external
 - Total PT bids increased by about 5%
 - Total bridge bids increased by less than 1%
- **Potential to reduce life cycle costs**
 - Corrosion protection
 - Replaceable



Grease Filled Duct

- **Implementation**

- Research
- Structures Manual
 - Design/detailing requirements
- Specifications
 - Construction
 - Materials
- Work with PT vendors
- Pilot construction project
- Hybrid system
 - Grease for certain tendons
 - Grout for simple geometries

*Existing technology...
Not reinventing the wheel*



Thank you

Questions?

