PRESENTATION OUTLINE

• Maintenance: Findings of field investigations
• Materials: Explanation of material performance
• Structures Design: Revisions to Design and Construction Direction
BACKGROUND

• In 1990s several tendon failures revealed problems with plain cement grouted tendons
• Department changed protection of tendons and anchorages and also began to use pre-bagged thixotropic grout
• February 2011 a failed external tendon was found on the Ringling Bridge in Sarasota built 2003
• Subsequently a second external tendon failed on the Ringling Bridge
ACTION

• Complete investigation and repairs of Ringling under contractor warranty
• Interdisciplinary team formed (Maintenance, Materials, Design, Construction and Specifications)
• Investigation began on all pre-bagged thixotropic grouted post tensioned bridges built with new protection strategies
• Bridges built prior to 2001 not inspected
INVESTIGATION

• 69 bridges consisting of Segmental bridges, post tensioned girder bridges and bridges with post tensioned substructures

• Ringling Bridge received most extensive inspection – 17 total tendons required replacement and over 500 voids repaired
RINGLING BRIDGE
TENDON REQUIRING REPLACEMENT
INVESTIGATION FINDINGS CONTINUED

• SR 116 Bridge over Intracoastal Waterway (Wonderwood) built 2003
  • 16 corroded ducts
  • 14 tendons with soft grout
  • 15 tendons with minor corrosion of strands
MULTI SPAN CONTINUOUS PT GIRDER WONDERWOOD BRIDGE WITH INTERNAL TENDONS
CORRODED TENDON ON GIRDER BRIDGE
WITH CONTINUITY PT
SOUNDING EXTERNAL TENDON WITH HAMMER
INTERNAL TENDON EXPOSED FOR INSPECTION
MEASURING ELECTROCHEMICAL CORROSION POTENTIAL
INSPECTING TRUMPET WITH BOROSCOPE
DUCT COUPLER REMOVAL FOR INSPECTION
NATIONAL GROUTING ISSUES ARISE

- FHWA letter concerning excessive chlorides in Sika 300PT grout
- Other DOT’s reported grout quality control issues
- Other DOT’s reported similar corrosion findings
- Some Sika 300PT bag weights were 10% lighter than specified on the packaging
- Wood chips were found in prepackaged bags of thixotropic grout from various Manufactures
INSPECTION SUMMARY

• Most bridges had little to no corrosion present in sampled areas
• Corrosion was only indentified in deviated tendons
• Tendons with flat geometry showed no corrosion
MAINTENANCE CONCERNS

• Non Destructive Evaluation Techniques at this time are not adequate to inspect grouted post tensioning tendons
• Current destructive methods limited FDOT’s investigation to less than 1% of internal tendon lengths
• Current investigation methods are very slow and expensive
• If tendons are compromised repairs are very costly
NDE METHODS

• NCHRP 14-28 “Condition Assessment of Bridge Post-Tensioning and Stay Cable Systems Using NDE Methods”
• NDE Methods being Investigated:
  - Ground Penetrating Radar
  - Electrical Capacitance Tomography
  - Radiography
  - Magnetic Flux Leakage
  - Infrared Thermography
  - Ultrasonic Tomography
  - Impact Echo
  - Sounding
GROUT MATERIALS INVESTIGATION

- During the field investigation, FDOT State Materials Office (SMO) received grout samples from around the state for testing
- At some locations results showed grouts had segregation (a soft putty like product with high water content)
- FDOT and FHWA performed Research into causes
SEGREGATED GROUT

- Grout segregation characterized as:
  - A. Wet plastic
  - B. Sedimented Silica
  - C. White chalky

✓ Corrosion attributed to wet plastic grout but not necessarily to void presence.
✓ Grout segregation created environment with dissimilar pore water chemistry and physical properties.
Figure 12. Color and consistency differences between samples of hard grout (bottom sample in each photograph) and samples of putty like grout or soft cohesive grout (top two samples in the left photograph and top sample in the right photograph).
COLLOIDAL GROUT PLANT (MIXER AND PUMP)
INCLINED BLEED TESTS USING CLEAR PVC DUCTS
MOISTURE CONTENT RESULTS FOR SIKA 300PT GROUT AT MAXIMUM WATER CONTENT

![Graph showing moisture content results for Sika 300PT grout at maximum water content. The graph displays moisture content percentages along the duct's position (in inches), with separate lines for the top and bottom sections of the X-section.](image-url)
POTENTIAL CAUSES OF "BAD" GROUT

• Theory of why problems occurred
  • Too much water
  • Too small duct
  • Poor workmanship, etc.
  • Grout Temperatures in excess of 90°F?

• Poor quality control by grout Producers
  • High Chloride Content (Sika 300 PT)
  • Low Bag Weight (Sika 300PT)
  • Wood Chips and other foreign matter
FACTORS THAT RESULT IN PT CORROSION IN NEAT GROUT BRIDGES

• Low ph
• High Chloride Content
• Water
• Oxygen

FACTORS THAT RESULT IN PT CORROSION IN THIXOTROPIC GROUT BRIDGES

• Segregation of Grout
• High Sulfate Content
• Water
• Oxygen
SUMMARY OF MATERIALS FINDINGS

• Corrosion
  • Excessive Water
  • Soft grout ~ 50 to 80% water content
  • Chalky grout ~ 20% to 50% water content
  • Sulfate ions prevent passivation
  • Very high corrosion rates
    • Regardless of amount of chloride
SUMMARY OF MATERIALS FINDINGS, CONTINUED

• Segregation
  • Very high corrosion rate
  • Limited to SIKA product. Minor segregation for Master Builder.
  • Partially hydrated grout leaving water behind in sealed duct

• Lack of QC by producer
  • Bags underweight by 10% from nominal (Sika 300PT). Extra water initiates segregation
  • Chlorides (Sika 300PT)
  • Wood chips

• Construction workmanship may have contributed

• All grout materials are currently susceptible to problems due to minimal extra water, QC, storage time, environment conditions, etc.

• Predictability concerns
Based on the latest inspections and material evaluations, alternates to grout were investigated:

- Alternates to bare steel strand (epoxy coated strand, greased and sheathed, stainless, carbon fiber)
- Alternates to grout were considered in deviated tendons (grease, wax)
BARE STEEL STRAND ALTERNATIVES

• Epoxy coated strands – coatings can be damaged during installation, require specialized anchor details and grouts

• Stainless and Carbon fiber strands – very expensive, limited suppliers, no anchor devices which will fit into bridges for carbon fiber strands

• Greased and sheathed strands – sheathing damaged during installation, grouted anchorage area, grease breaks down
GROUT ALTERNATIVES

- Grease filled ducts – grease breaks down losing protective properties, can leak from ducts, initially expensive relative to grout
- Wax filled ducts – does not break down over time, repels water, will not leak from ducts, initially expensive relative to grout
  - Wax is made up of chemically inert components derived from petroleum refining with anti-corrosion additives
- Used successfully for 40 years in nuclear industry
FDOT STRUCTURES DESIGN
VISITED FRANCE

- To observe the injection of wax in PT tendons in a segmental bridge during construction.
- To obtain information on flexible material filler used as corrosion protection with regard to material properties, specifications, policy and potential maintenance issues.
- To obtain information on site implementation such as cost and construction issues.
TRIP TO FRANCE

• Visited two bridge sites utilizing wax filled tendons
• Met with SETRA, IFSTTAR, Freyssinet
• Very similar corrosion history to Florida
• Numerous bridges still with corrosion concerns built prior to 2001
• France changed to wax after multiple tendon failures around 2001
• Been using wax since with no defects found
• Still use grout for internal tendons
• Wax is becoming the standard for Europe for deviated tendons
LGV SEA TOURS BORDEAUX PROJECT SITE
WAX INJECTION VEHICLE
WAX PUMP
WAX SAMPLE
WAX INJECTION
WAX TERMINATION
PORTABLE WAX PUMP
ADVANTAGES OF WAX FILLED TENDONS

• Caps, ducts can be opened for inspection
• Allows for easy tendon replacement if necessary
• Wax is stable over time
• Repels water and provides corrosion protection
• Uses similar tendon system components to grouted systems
DISADVANTAGES TO WAX FILLED TENDONS

• Material costs 7 times grout material costs
  • Total bridge cost increase likely less than 1%
• Injected into tendon at about 220 degrees F
• Unbonded tendons not as effective as bonded(grouted) tendons when internal to concrete. Not an issue in segmental construction as built by FDOT
• New technology – limited suppliers but not proprietary
• Anchorage protection details may need development
WAX 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
STRUCTURES DESIGN BULLETIN 14-06

DATE: April 30, 2014

TO: District Directors of Transportation Operations, District Directors of Transportation Development, District Design Engineers, District Construction Engineers, District Structures Design Engineers, District Maintenance Engineers

FROM: Robert V. Robertson, P. E., State Structures Design Engineer

COPIES: Brian Blanchard, Tom Byron, Duane Brautigam, David Sadler, Tim Latimer, Jeffrey Ger (FHWA)

SUBJECT: Revisions to Policy for Post-Tensioning Tendons

REQUIREMENTS

The Florida Department of Transportation (FDOT) will be implementing the use of wax filler material in lieu of grout for corrosion protection on certain post-tensioning tendons in the near future.

The tendons for which wax filler material will be used include external tendons and the following internal tendons:

- Tendons with vertical deviation greater than 20° as currently defined by Instructions for Design Standards 21800
- Continuity tendons in segmental box girders
- Tendons in I-beams and U-Girders
- Strand tendons with vertical or predominantly vertical geometry
- Horizontal strand tendons in hammerhead, straddle and C-piers

All tendons with wax filler material will be assumed to be unbonded and must be designed and detailed to be fully replaceable. The wax filler material that will be used will be the same as, or very similar to, that which is already being used in Europe and elsewhere for the same purpose. Smooth wall polyethylene (PE) duct will continue to be used for external tendons and will also be used for internal tendons with wax filler material.
DESIGN BULLETIN INSTRUCTIONS

• Use wax filled tendons for:
  ▪ Continuity tendons in segmental box girders
  ▪ Tendons in I-Beams and U-Girders
  ▪ Stranded tendons with vertical or predominately vertical geometry
  ▪ Horizontal strand tendons in hammerhead, straddle and C-Piers

• Continue to use to use grouted tendons for:
  ▪ Tendons with vertical deviation less than or equal to 20”
  ▪ Transverse and longitudinal tendons in slabs
PROPOSED CHANGES TO FDOT GROUT SPECIFICATION

- New Chloride threshold 0.4 lbs./cy.
- Dynamic shear rheometer (DSR) to verify the thixotropic nature of grout at high temperature
- Measure moisture content using a commercial grout plant to pump grout into the modified inclined tube test (MITT) to verify segregation and soft grout at the top of the tube
- Establish (+/-) threshold for bag weights
- The mud balance test will be used to verify the unit weight of grout in the field
- Other more minor changes are under consideration
- Develop Specifications for Waxed Filled Ducts
ON-GOING RESEARCH TO IMPROVE THE FDOT GROUT SPECIFICATION

- FDOT is performing laboratory and field tests to Vector Corrosion Technologies’ “Post-Tech CI” corrosion inhibitor, which has some unique properties
- Post-Tech CI has very low viscosity, and has been observed to displace water
- FDOT laboratory and field testing is being done to confirm the passivity, durability and flowability of Post-Tech CI
- FDOT believes Post-Tech CI has the potential to fill voids and interstitial spaces between strands, displace water and passivate PT steel inside internal and external ducts for both new and existing bridges
Post-Tech PTI Impregnation
VERIFICATION OF CORROSION PROTECTION

Steel Plate

Post-Tension Strand in Grout

Post-Tension Strand

Potentiostatic Testing

Tension in Chloride Contaminated Grout (2% Cl)

93.1% Reduction

PfT Treated vs. Untreated Tendon

Total Current (Curie)