SPECIALIZED POST-TENSIONING ASSESSMENT AND REPAIR OF BRIDGES

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Outline

- Past projects
- PT history and basics
- Initial and FDOT detailed concerns
- Examples of challenges
- Current durability strategy
- PT protection
- SikaGrout 300PT issues
- FHWA response
- Assessment methods
- Monitoring options
- Remedial Actions
- Looking ahead…

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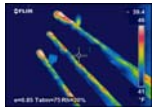
Past Projects

- Varina Enon Bridge, VA – External tendon failure investigation
- Steamboat Hills Bridge, NV – Stressing related web delamination
- Oklahoma Bridges, Statewide – PT assessments
- Hawaii Bridges, HI – PT assessments and trial NDE
- San Antonio , TX – Routine inspection and grout materials testing
- Branch Avenue Bridge, MD – Routine inspection and trial NDE
- Minnesota Bridges, Statewide – Inspection, grout testing, and monitoring
- Oregon Bridges, Statewide – PT assessments
- Florida Bridges, District 5 – PT assessments



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PT History

Table 2.1 Key Developments in Prestressed Concrete History[42]

Year	Author/Researcher	Description
1888	P.H.Jackson	Concept of imposing preservice stresses on hardened concrete
1907	M. Koenen	Identify losses due to classic shortening
1908	G.R. Steiner	Recognized losses due to shrinkage
1928	F.Dischinger	Loss of prestress compensated by retensioning
1933	E.Freyssinet	Demonstrated advantage of using higher strength concrete and high strength steel to minimize losses
1939	K.Wettstein E.Hoyer	Used high strength piano wire
1943	J.M.Crom	Used high tensile drawn wire for tanks and pipe
1944	G.Magnel	Identified the relaxation losses of work-hardened steels under constant strain
1950	Reported by W.O. Everling.	Use of stress relieved wire 240 ksi (1.65 GPa) and strand 250 ksi (1.72 GPa) to provide user friendly steel
1963	T.Cahill	Developed low-relaxation steel reducing loss from about 12 to 2.5%

FHWA/UT - Conclusions, Recommendations and Design Guidelines for Corrosion Protection of Post-Tensioned Bridges 2004

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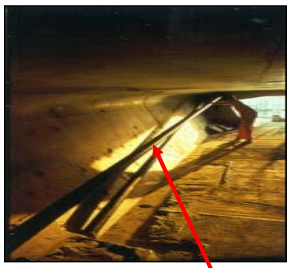
PT Basics

- Precompression in concrete results in a more durable structure
- History of 60+ years of durable PT bridges (introduced in US in 1960s)
- PT system: bonded or unbonded
- Components: prestressing strands or high strength bars; anchorages and couplers; metal or plastic ducts; and cementitious grout, grease, or wax
- Prior to early 2000's, grout comprised of cement and water which led to bleed water and grout voids
- Newer PT specifications require high performance grout and attention to vents and drains
- On November 23, 2011, FHWA notified the public of 34 bridges with elevated chloride levels; SikaGrout 300PT between 2002-2010 from Marion, Ohio plant

PT Basics

Internal vs. External Tendons

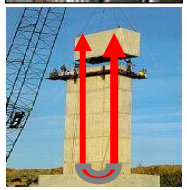
Internal PT Tendons



External PT Tendons

Initial Concerns

- Grout voids, water infiltration, and cracking noted in UK in 1970s; Ynys-Y-Gwas bridge collapsed in 1985; Malle bridge collapsed in 1992
- UK moratorium on PT in September 1992
  - Lifted in 1996 for CIP grouted PT but precast PT moratorium remained in place due to joint detailing
- US problem first noticed in 2002 at the Midbay Bridge and Sunshine Skyway Bridge in Florida
  - Investigation to determine root cause and how wide spread the problem was – grout voids, water infiltration, and chloride intrusion led to corrosion
  - FDOT updated design guidelines and PT specs



FDOT Detailed Concerns

- Voids associated with accumulation of bleed water at tendon anchorages
- Recharge at tendon anchorages with salt water or surface drainage during construction
- Leakage through end anchorage protection details
- Quality of the grout installation and grout material
- Splitting of polyethylene ducts
- Deficiencies in implementation and inspection of grouting procedures

Example of Challenges
Poor Drainage Details

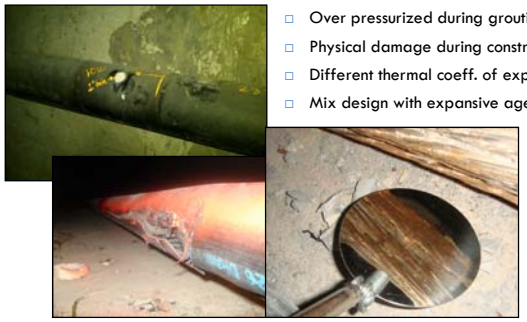
Example of Challenges
Grout Voids and Corrosion

Example of Challenges
Anchor Protection

- Incomplete and deteriorated pourbacks
- Deck repairs over pourbacks


Example of Challenges
External Tendon Duct Cracking

- Over pressurized during grouting
- Physical damage during construction
- Different thermal coeff. of expansion
- Mix design with expansive agents



Example of Challenges
Improper Use of Materials

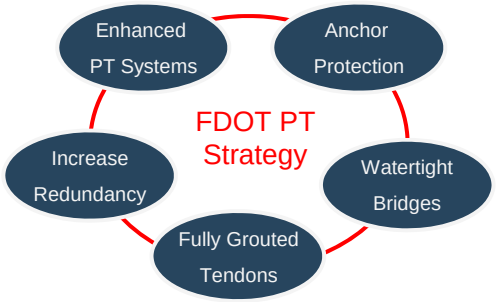
- Duct tape is good but not for permanent HDPE repairs

Example of Challenges
Inadequate Duct Repair

Example of Challenges
Regrouting Materials

- Repair material with gypsum was identified as contributing factor

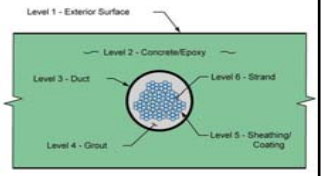
Durability Strategy



PT Protection

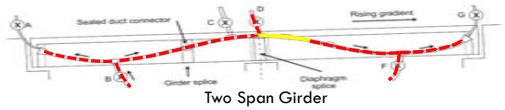
- Develop structural bond between concrete and the prestressing steel (bonded system)
- Provide protection to the prestressing steel against corrosion
  - Deck overlay (bridges)
  - Dense, low permeability concrete
  - Robust plastic ducts (or polyethylene pipe)
  - High performance, anti-bleed grout
  - Anchorage protection details
- Modified grouting procedures to limit voiding
- Developed new thixotropic grouts
  - 1st generation had silica sand
  - 2nd generation had calcium carbonate as filler

PT Protection



PT Protection

New Procedures and Grouts



Two Span Girder

ASBI Inclined Tube Example

PT Grout Concerns

- Bridge Zero, Texas, 2010, chloride source was cement
- FHWA chloride limit is 0.08% by weight of cement
- Affected >200 projects including 120 bridges, 39 states
- Resulted in the following:
  - Additional chloride testing during construction
  - Recommended ASTM C1152 be used to limit variable test results
  - Increased threshold to 0.75% weight/cement
  - Industry Organizations, FHWA and other engineers, corrosion investigations leading to new chloride thresholds (up to 1.5% weight of cement)
  - Soft grout led to research related to sulfate content, water content, and time/storage limitations, not tied to grout lot or other variables
  - We need to wait and see what the research and physical performance will be…

FHWA Response

- Determine max. chloride concentration for construction period
- Determine PT protection level (PL 1A to 3)
  - PL 1A – bare strand, filling material stable/nonreactive, galvanized/plastic duct, **no grout voids**
  - PL 1B – 1A plus engineered grout and permanent grout caps
  - PL 2 – 1B plus enclosure capable of permanent leak-tight barrier
  - PL 3 – 2 plus electrical isolation or encapsulation to be monitorable and inspectable at any time

Maximum Chloride Concentration by Production Period (% Cl^- per wt. of cement)				
2001 to 2006	2007	2008	2009	2010
0.25%	0.43%	0.48%	0.56%	0.18%

Table 1 – Maximum Chloride Concentration by Production Period

FHWA Response

- Determine risk level based above (RL1 to 4)
- Assess bridge system redundancy and element ductility
  - Ductility - easily detectable cracking before debilitating strength loss
  - Redundancy - based on the load rating system factors (phi factors)
- Structure classification - based on ductility and redundancy (S1 to 3)

Protection Level	Chloride Concentration (% Cl^- per wt. of cement)				
	$Cl^- \leq 0.08\%$	$0.08\% < Cl^- \leq 0.30\%$	$0.30\% < Cl^- \leq 0.50\%$	$0.50\% < Cl^- \leq 0.65\%$	$Cl^- > 0.65\%$
PL-1A	No Risk	RL 1	RL 2	RL 3	RL 4
PL-1B		RL 1	RL 2	RL 3	RL 4
PL-2 & PL-3		RL 1	RL 2	RL 2	RL 4

Table 2 - Corrosion Risk Levels (RL)

Structure Classification	Indicators	Expected Performance
S1	• System factor: $\phi s \geq 1.10$ • Pass ductility check	A highly redundant bridge that develops easily detectable cracking before debilitating strength loss.
S2	• System factor: $1.10 > \phi s \geq 1.00$ • Pass ductility check	A moderately redundant bridge that develops easily detectable cracking before debilitating strength loss.
S3	• System factor: $\phi s < 1.00$ • Fail ductility check	A bridge with limited ductility and / or redundancy.

Table 3 - Structure Classification

FHWA Response

- Determine follow-up actions (FA-I to 4)
  - FA-1 - no additional measures needed
  - FA-2 - biennial in-depth inspection needed
  - FA-3 - annual in-depth inspection needed
  - FA-4 - plan repairs/replacement

Corrosion Risk Level	Structure Classification (Table 3)		
	S1	S2	S3
RL 1	FA I	FA I	FA II
RL 2	FA I	FA II	FA III
RL 3	FA II	FA III	FA III
RL 4	FA IV	FA IV	FA IV

Table 4 –Recommended Management Follow-up Actions

PT Assessment Methods

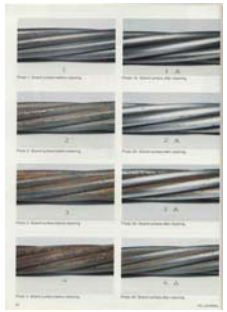
- Document review
- Visual inspection and acoustic sounding (cracks, deflection, water stains, efflorescence, ponding water, grout leakage)
- Nondestructive testing
  - GPR / Borescope (typical, other methods less common)
  - Infrared thermography
  - Ultrasonics (MIRA)
  - Magnetic flux leakage (MFL)
  - Relative capacitance
  - Corrosion monitoring (half cell, corrosion rate, other probes)
  - Vibration analysis
  - Gamma radiography

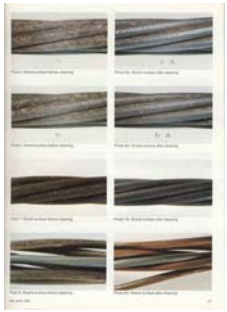
PT Assessment Methods

- High Point and Anchor Inspection
  - 1" dia. drill hole openings
  - Inspection openings

PT Assessment Methods

PCI Grading of Strands

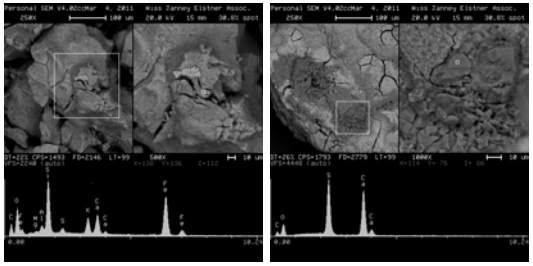




PT Assessment Methods

Materials Testing

- Scanning Electron Microscopy

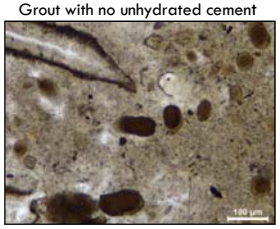


PT Assessment Methods

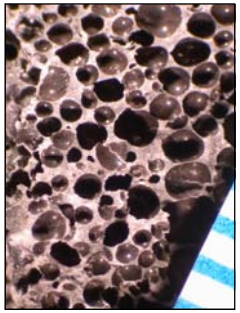
Materials Testing

- Petrography - Chlorides, Sulfates

Grout with no unhydrated cement



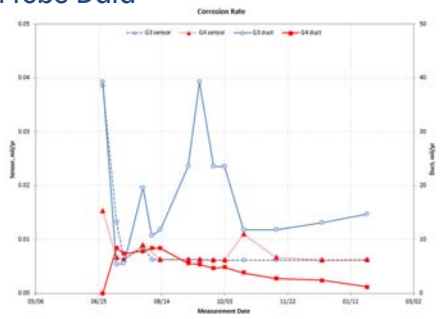
Frothy grout - very high air



Monitoring Options

- Corrosion rate and potential measurements
  - Duct openings required to access grout and strands
  - Are we measuring duct or strand corrosion
  - Commercially available probes (C-probes installed for MNDOT project)
    - Sensor installed inside duct
    - Data acquisition system, modem, and power needed
    - Some have sample strand that is used as a reference element
- Other options: Bulk water probes (washing machine parts), relative humidity probes, temperature probes, acoustic monitoring, vibration monitoring, etc.

Monitoring Options
C-Probe Data



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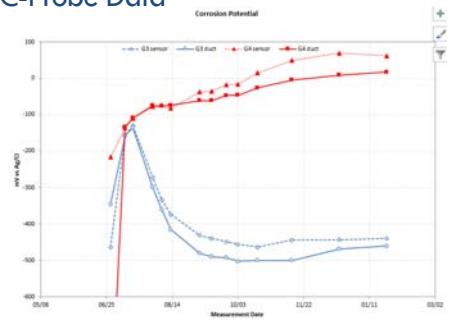

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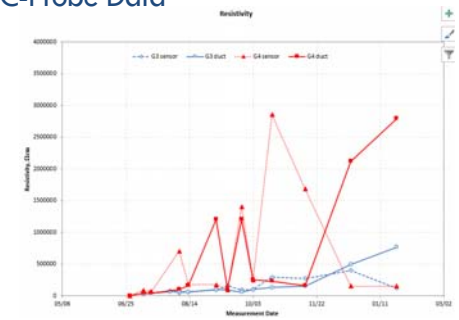
Monitoring Options
C-Probe Data



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Common Remedial Actions

- May do nothing if:
  - No grout voids, corrosion, or moisture infiltration noted
  - Grout voids observed but strands are protected by grout
- If corrosion, voids, etc. are noted, perform detailed analysis to determine how many strands or tendons are needed?
- If repairs are needed (client often decides this due to various considerations):
  - Remedial grouting if strands are exposed to air/moisture infiltration
    - Vacuum grouting, vacuum assisted grouting, pressure grouting
  - Tendon replacement or strengthening (typically external)
  - Rehabilitation of PT anchor protection systems (install permanent grout caps and treat pourbacks)
  - HDPE pipe repair (heat shrink sleeves)
- As an alternate, consider periodic assessments/monitoring

Common Remedial Actions
Vacuum Assisted Grouting

Looking Ahead…
Agency Perspective

- Numerous post-tensioned bridges in each agency
- Limited inspection/assessment funds
- No specific mechanism to report post-tensioning distress
- Limited existing contracts to perform specialized inspections and remedial work
  - Currently we are working with MNDOT and ODOT on this issue
- Specialized bridge inspector training related to post-tensioning distress needed
- Reporting mechanisms, within the confines of existing bridge inspection software, that will allow post-tensioning observations to be sorted and tracked needed
- Development of standard vacuum assisted grouting and other post-tensioning inspection and repair details needed

Looking Ahead…
Agency Perspective

- Development of a tiered assessment and repair system (Presentations to ODOT and FHWA)
  - Tier 1 – Visual inspection by maintenance personnel to locate and document conditions
  - Tier 2 – Perform limited borescope inspection of high points and/or anchors
  - Tier 3 – Perform more detailed inspection
    - Up to 20% high points/anchors
    - More advanced NDE techniques
  - Tier 4 – Perform 100% inspection of high points and anchors
    - Use more advanced NDE techniques
  - Tier 5 – Develop plans and specifications for remedial grouting and bridge rehabilitation
  - Overriding Option – Emergency bridge closure, shoring, in-depth inspection, etc.

WJE

Discussion and Questions




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