Western Bridge Engineers' Seminar

September 10, 2015
8:30 AM

SPECIALIZED POST-TENSIONING ASSESSMENT AND REPAIR

WJE

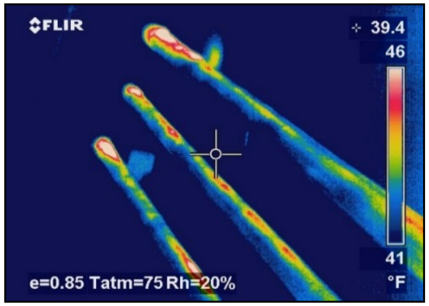
ENGINEERS
ARCHITECTS
MATERIALS SCIENTISTS

Outline

- WJE PT assessments
- PT basics
- Initial PT concerns
- Current durability strategy (FDOT)
- Assessment methods
- Monitoring options
- Repair methods
- Looking ahead…

WJE – PT Bridge Assessments

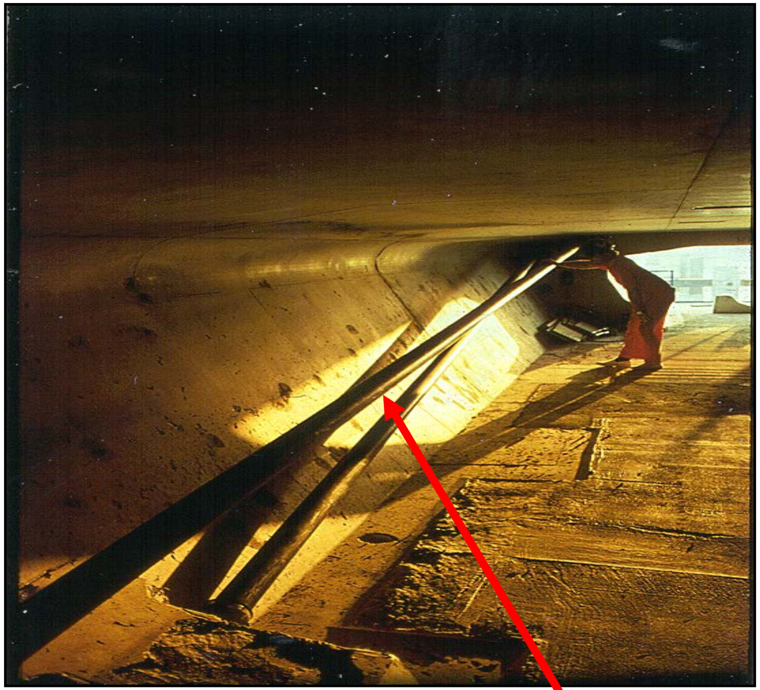
- Varina Enon Bridge – VA – External tendon failure investigation
- Steamboat Hills Bridge – NV – Stressing related web delamination
- Oklahoma Bridges – Statewide – Routine inspection and PT assessments
- Hawaii Bridges – HI – PT assessments and trial NDE
- San Antonio Y – TX – Routine inspection and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



PT – Introduction

- Precompression in concrete results in a durable structure; 60+ years of durable PT bridges
- PT system: prestressing strands or high strength bars; 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 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, 2002-2010, Marion, OH). Only one bridge in western states affected: Intersection 55 & 405 Freeway in California

Internal vs. External Tendons

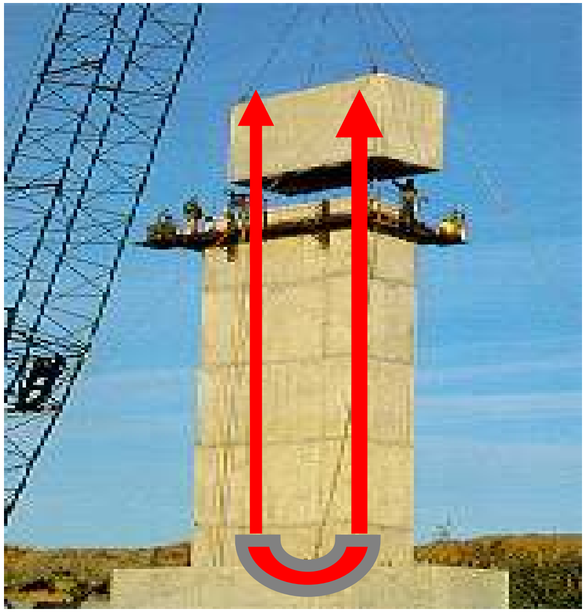


Internal PT Tendons

External PT Tendons

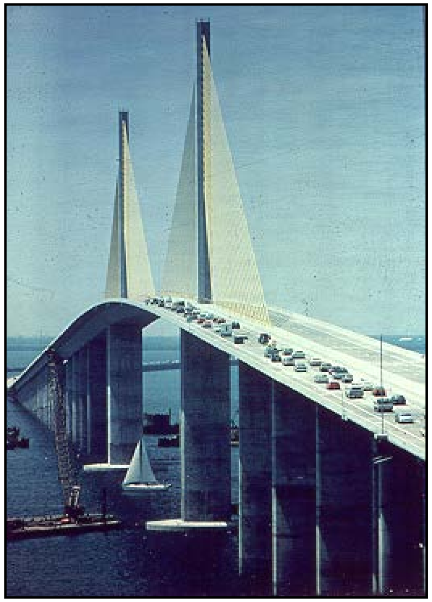
Early PT Distress

- Problem was first noticed in the mid to late 1990s in Europe
  - UK moratorium on PT
- 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
  - FDOT updated design guidelines and PT specs



Early PT Distress

- 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 - Drainage Details

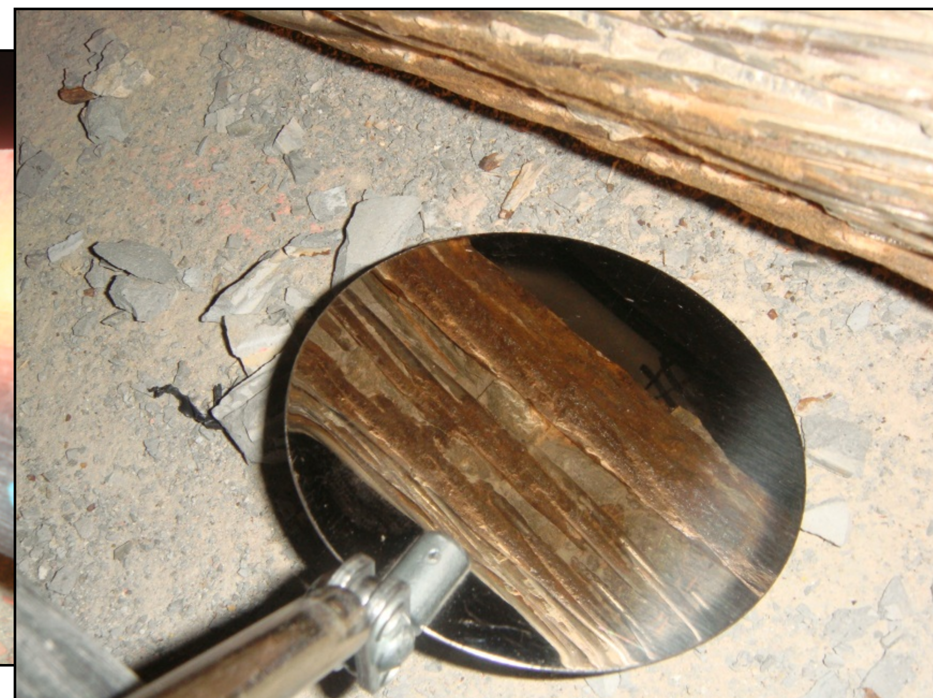
Example - Grout Voids and Corrosion

Example - Anchor Protection

- Incomplete pourbacks, spalled pourbacks
- Deck repairs over pourbacks

Example - External Tendon Cracking

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

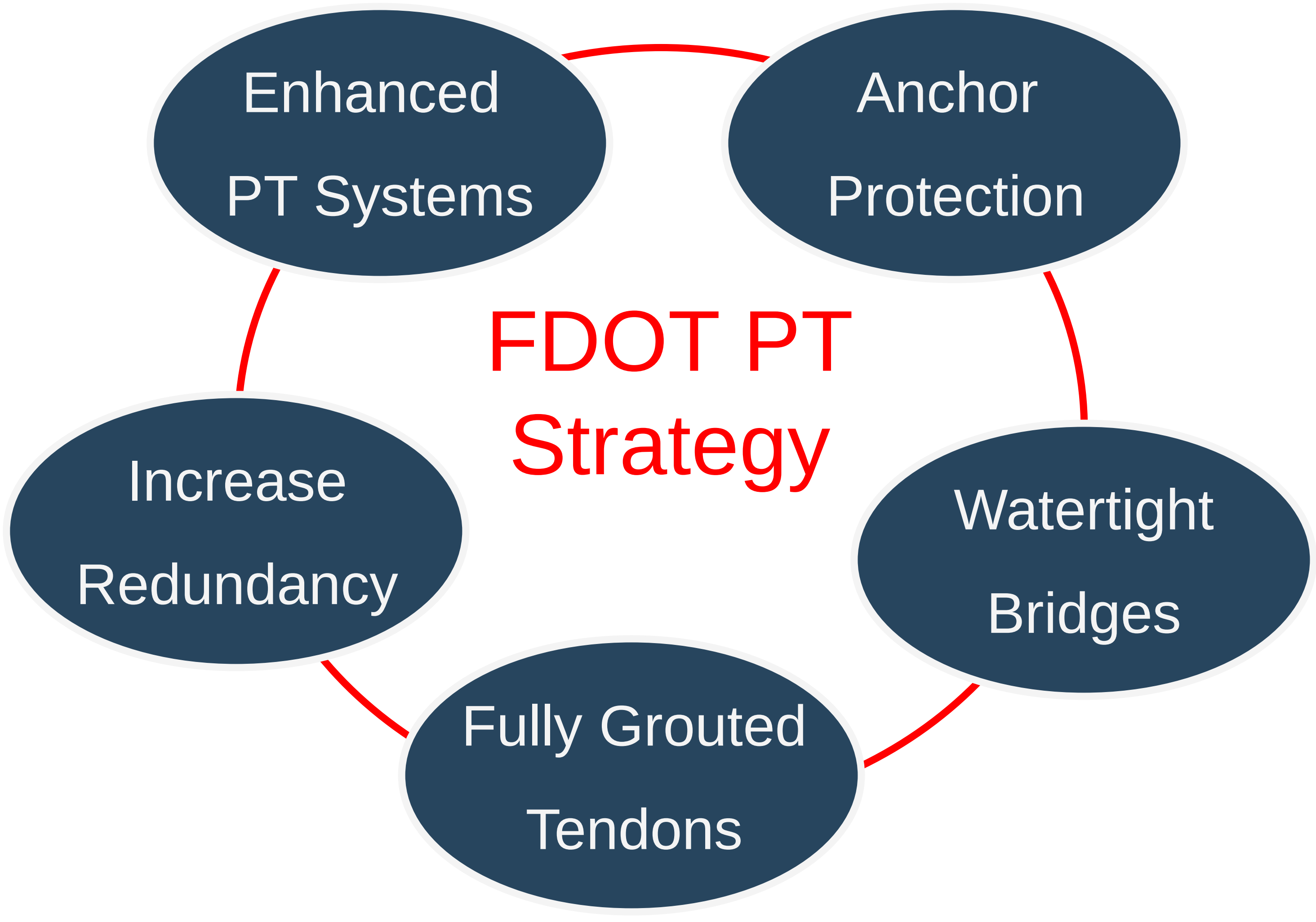
Example - Improper Use of Materials

- Duct tape is good but maybe not for permanent HDPE repairs

Example - Inadequate Duct Repair

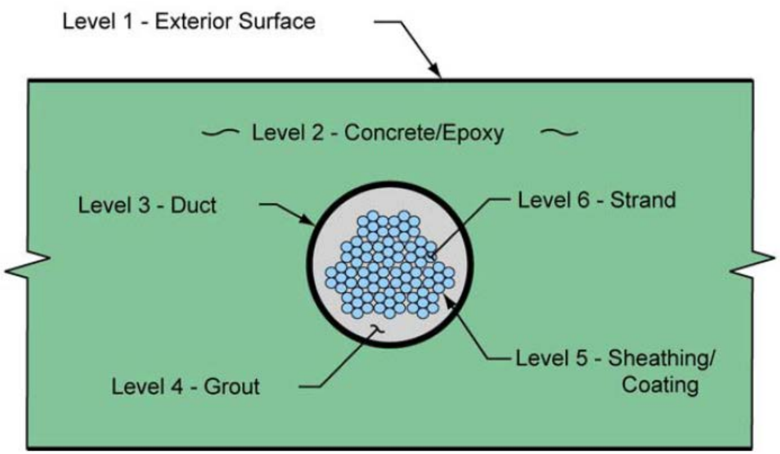
Example – Regrouting Materials

Durable PT Bridges

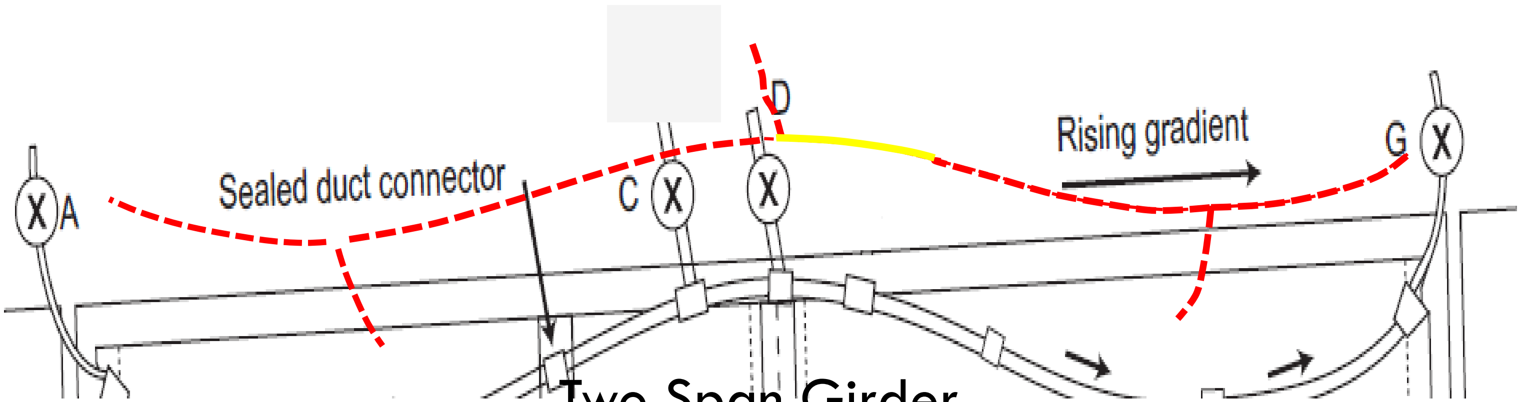


PT Tendon and Anchor Protection

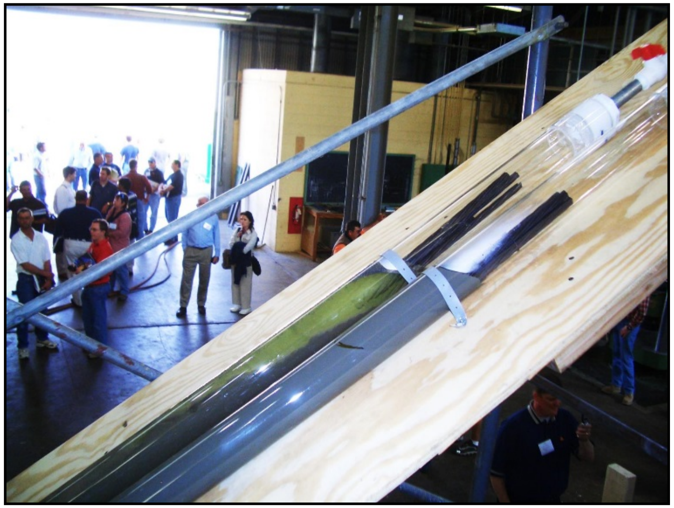
- Develop structural bond between concrete and the prestressing steel
- Provide protection to the prestressing steel against corrosion
  - Dense, low permeability concrete
  - Robust plastic ducts (or polyethylene pipe)
  - High performance, anti-bleed grout
  - Anchorage protection details
- Modified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



New Procedures and Grouts



Two Span Girder



ASBI Inclined Tube Example

SikaGrout 300PT Concerns

- Bridge Zero, Texas, 2010, chloride source was cement, 2001-2010
- FHWA chloride limit is 0.08% by weight of cement
- Affected >200 projects, 120 bridges, 39 states
- Resulted in the following:
  - Additional chloride testing during construction
  - Recommended ASTM C1152 be used to limit variable test results
  - Based on additional testing, FHWA said that risk of corrosion in well grouted tendons was low at levels based on suggested increased threshold of 0.75% weight/cement
  - Some have suggested that up to 1.5% weight of cement is OK.
  - Soft grout lead to research related to sulfate content, water content, and time/storage limitations, not tied to grout lot or other variables

FHWA Response: MgMT of PT bridges with elevated Chlorides

- Five tiered approach to management of identified bridges with elevated chlorides

  - Determine PT grout chloride level
    - Based on production period or testing (if available)
  - Determine PT system robustness (Protection Level)
    - Based on detailing and design
  - Determine corrosion risk level
    - Based on Protection Level and chloride content
  - Assess redundancy and PT ductility
    - Based on system factors
  - Follow-up actions.

FHWA Response: MgMT of PT bridges with elevated Chlorides

- Determine max. chloride concentration for construction period

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

Note: Only for Sika products

- 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

FHWA Response (cont)

- 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)

Number of Girders in Cross Section	Span Type	# of Hinges required for mechanism	System Factors (ϕ_s) No. of Tendons per Web			
			1	2	3	4
2	Interior span	3	0.85	0.90	0.95	1.00
	End span	2	0.85	0.85	0.90	0.95
	Simple span	1	0.85	0.85	0.85	0.90
3 or 4	Interior span	3	1.00	1.05	1.10	1.15
	End span	2	0.95	1.00	1.05	1.10
	Simple span	1	0.90	0.95	1.00	1.05
5 or more	Interior span	3	1.05	1.10	1.15	1.20
	End span	2	1.00	1.05	1.10	1.15
	Simple span	1	0.95	1.00	1.05	1.10

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

Table 3 - Structure Classification

FHWA Response (cont.)

- 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

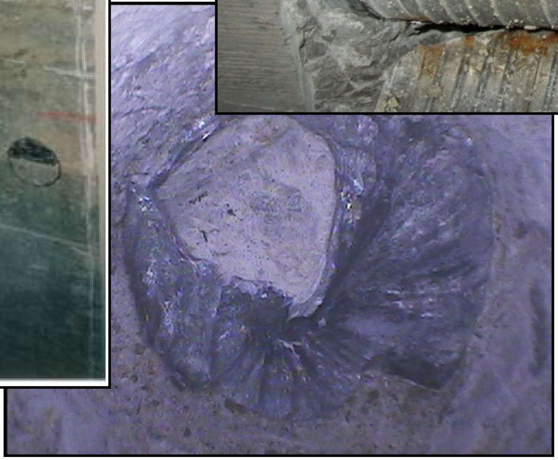
Table 4 –Recommended Management Follow-up Actions

WJE PT Assessment Methods

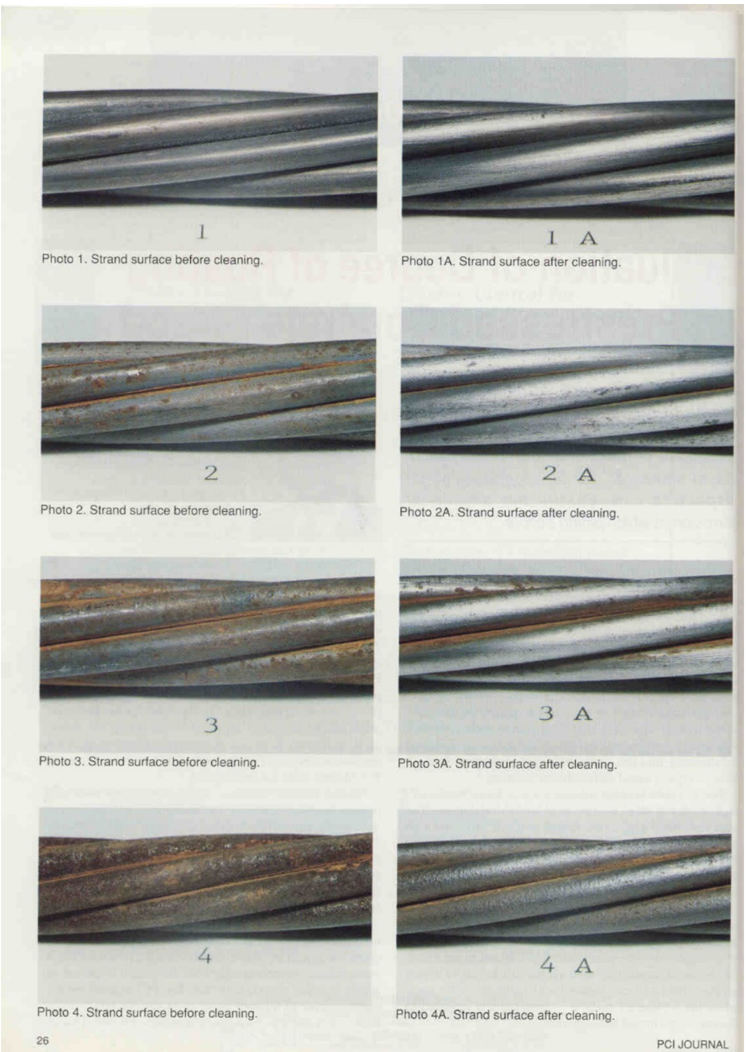
- Document review
- Visual inspection and acoustic sounding (cracks, deflection, water stains, efflorescence, water ponding, grout leakage)
- Nondestructive testing
  - GPR / Borescope
  - Infrared thermography
  - Ultrasonics (MIRA)
  - Magnetic Flux leakage
  - Corrosion monitoring (half cell, corrosion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

WJE PT Assessment Methods

- High Points and Anchor Inspection
  - 1” dia. drill hole openings
  - Slightly bigger duct openings



PCI Grading of Strands



1

Photo 1. Strand surface before cleaning.

1 A

Photo 1A. Strand surface after cleaning.

2

Photo 2. Strand surface before cleaning.

2 A

Photo 2A. Strand surface after cleaning.

3

Photo 3. Strand surface before cleaning.

3 A

Photo 3A. Strand surface after cleaning.

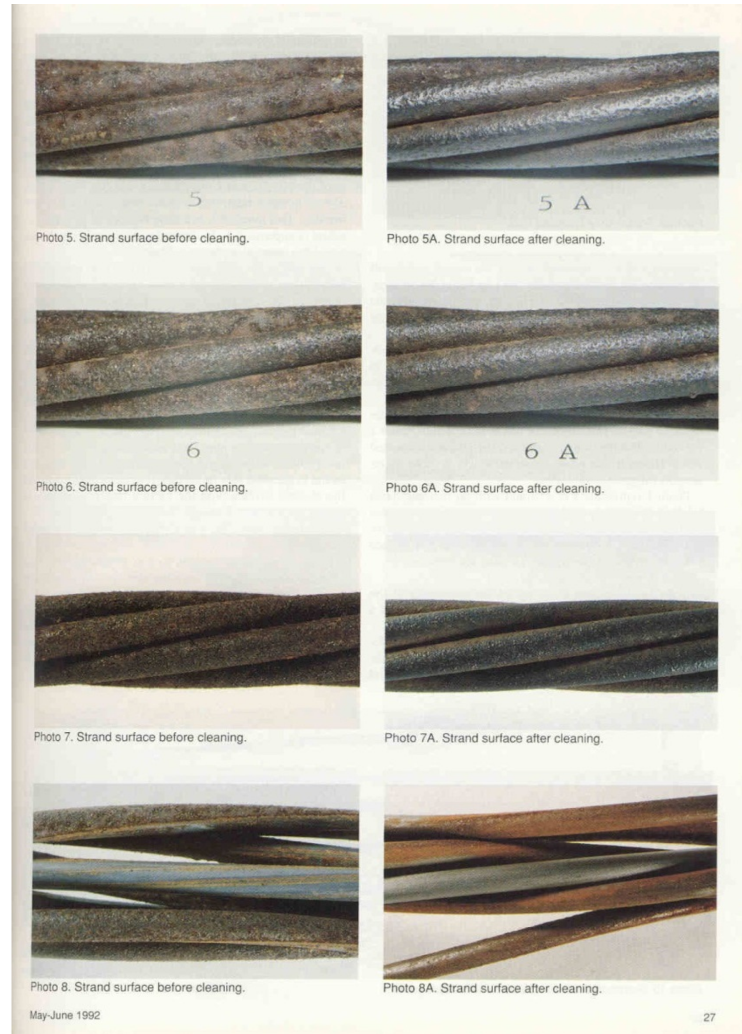
4

Photo 4. Strand surface before cleaning.

4 A

Photo 4A. Strand surface after cleaning.

26 PCI JOURNAL



5

Photo 5. Strand surface before cleaning.

5 A

Photo 5A. Strand surface after cleaning.

6

Photo 6. Strand surface before cleaning.

6 A

Photo 6A. Strand surface after cleaning.

Photo 7. Strand surface before cleaning.

Photo 7A. Strand surface after cleaning.

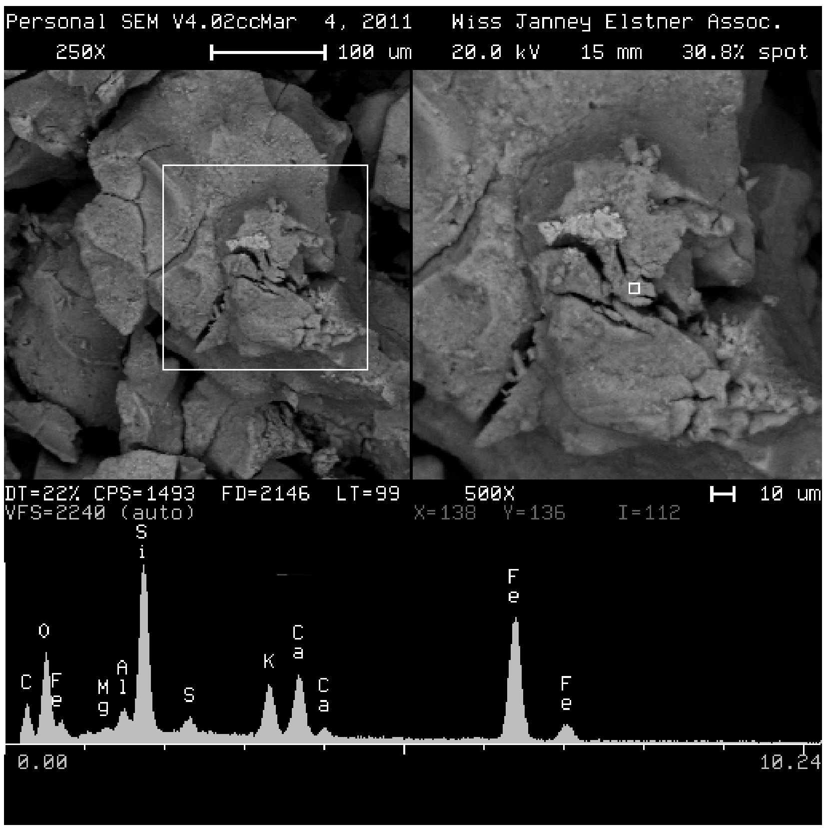
Photo 8. Strand surface before cleaning.

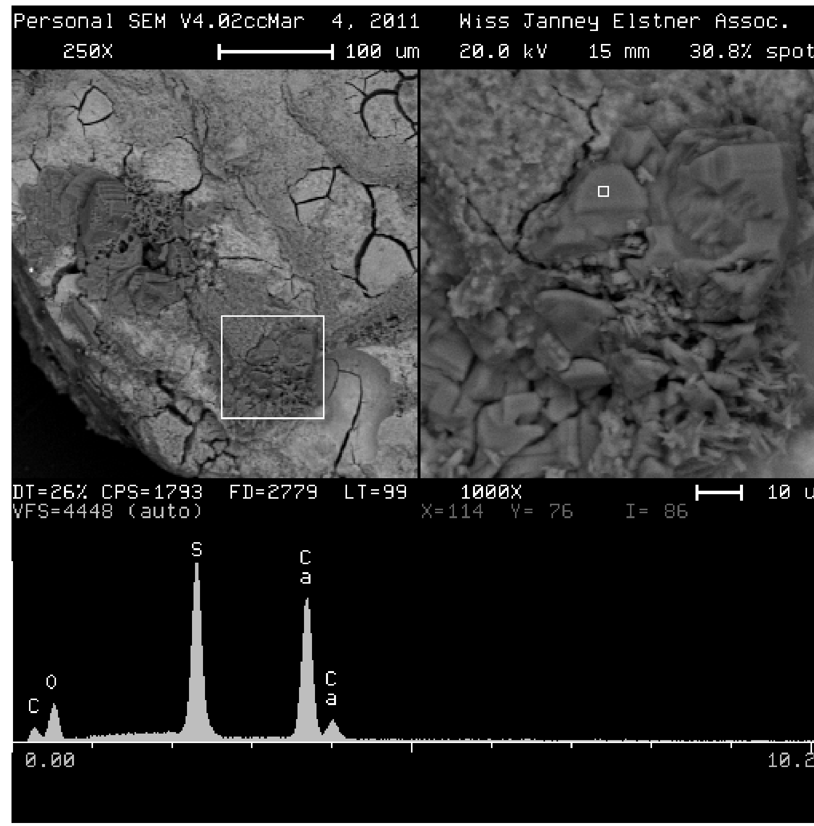
Photo 8A. Strand surface after cleaning.

May-June 1992 27

Materials Testing

- Scanning Electron Microscopy



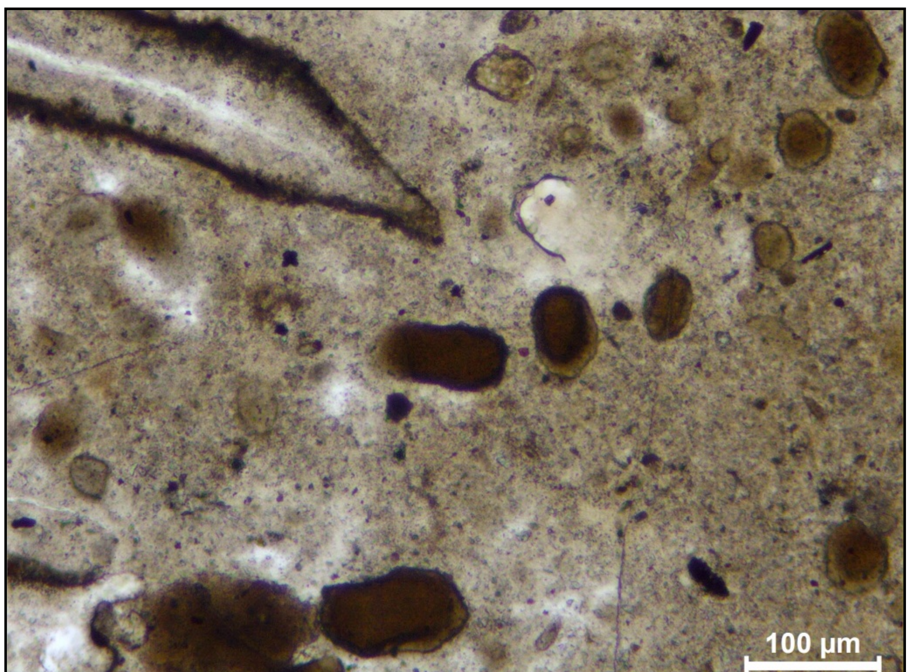


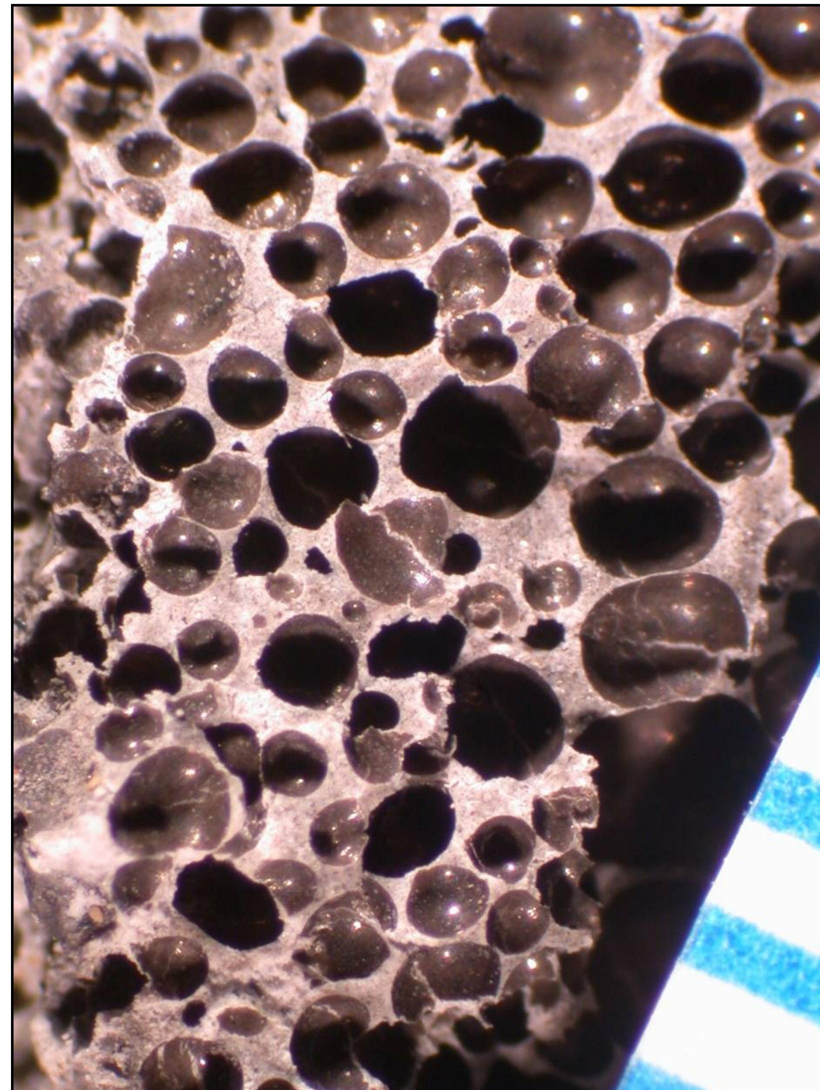
Materials Testing

- Petrography, Chlorides, Sulfates

Frothy grout – very high air

Grout with no unhydrated cement

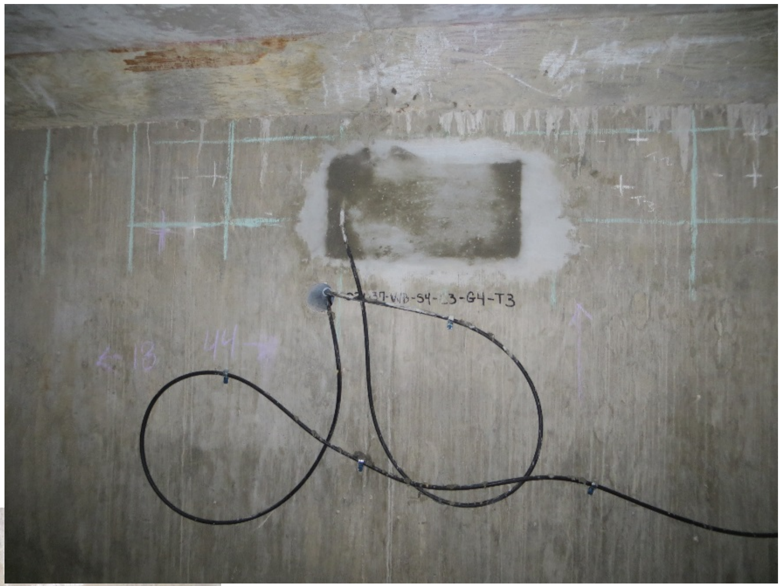




Corrosion Monitoring

- External corrosion rate and half cell potential measurements – what are you really measuring? Duct, strand, or rebar…
- Internal corrosion rate and potential measurements
  - Duct openings required to access grout and strands
  - Similarly, are we measuring duct or strand corrosion? WJE laboratory trials ongoing…
  - Commercially available probes
    - 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 (unbonded tendons only), other SHM techniques like vibration monitoring, etc.

C-Probe Data



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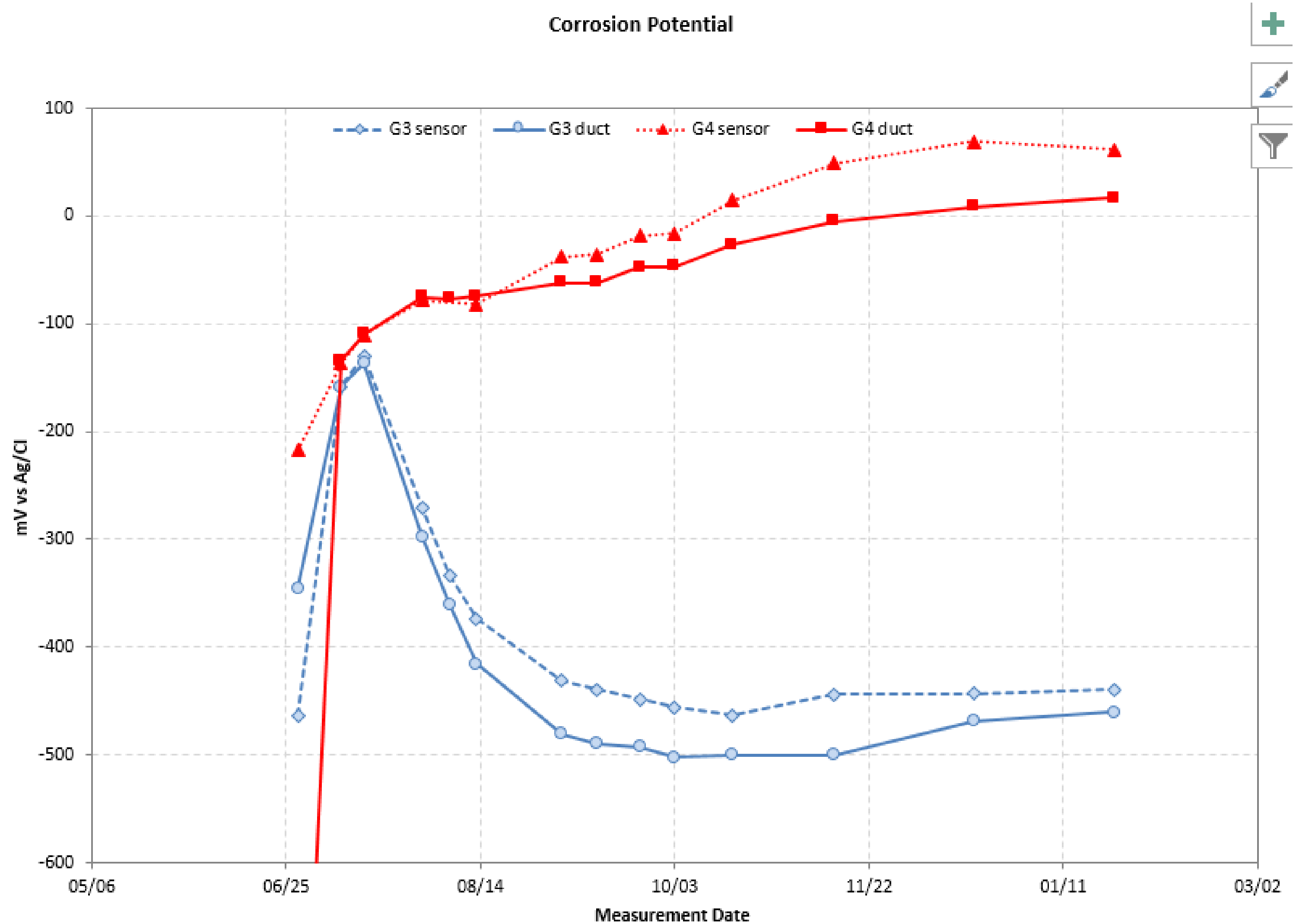


Corrosion Potential
G3 sensor
G3 duct
G4 sensor
G4 duct
100
0
-100
-200
-300
-400
-500
-600
mV vs Ag/Cl
05/06
06/25
08/14
10/03
11/22
01/11
03/02
Measurement Date

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:
  - Remedial grouting if strands are exposed, if strands are exposed to air/moisture infiltration (potentially regardless of structural analysis results)
    - Vacuum grouting, vacuum assisted grouting, pressure grouting
    - Make sure new grout is compatible with existing grout
  - Tendon replacement or strengthening (typically external)
  - Rehabilitation of PT anchor protection systems (install permanent grout caps)
  - HDPE pipe repair (heat shrink sleeves)
- As an alternate, consider periodic assessments/monitoring

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
- 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
- Development of standard vacuum assisted grouting and other post-tensioning inspection and repair details

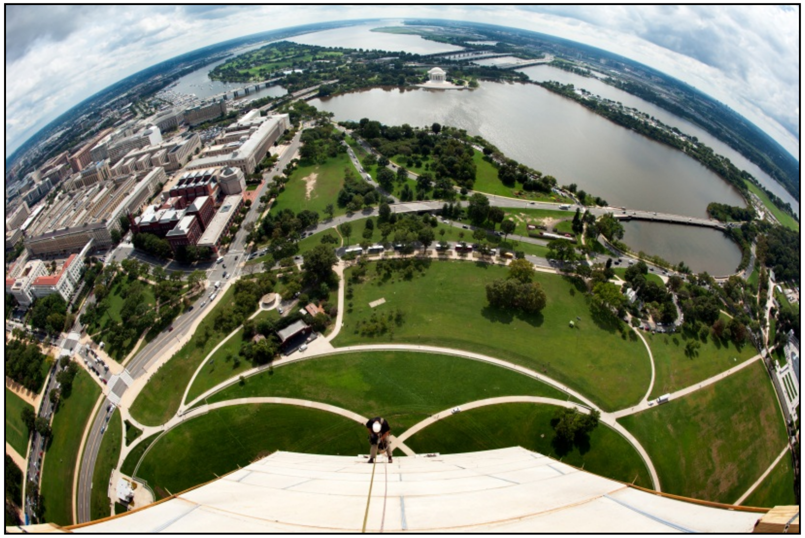
Looking Ahead…Larger Perspective

- Development of a tiered assessment and repair system
  - 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 - Capabilities

- Structural Evaluation
- Building Envelope Assessment
- Historic Preservation
- Failure Investigation and Disaster Response
- Earthquake Engineering
- Bridge Engineering / Load Rating
- Repair Design and Construction
- Construction Materials Evaluation and Research
- Litigation Support
- Structural Testing and Instrumentation

WJE – Projects



Discussion and Questions

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