Virginia Experience with Post-tensioned Tendon Grouts

ACI Washington DC
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Prior to 1995

- PT tendon grouts were a mixture of water & cement (w/c ≤ 0.42) and sometimes an expansive admixture.
- Most significant bridge was the Varina Enon (VE) Bridge completed in 1990 which has 480 grouted tendons in the superstructure.
• As a result of FHWA sponsored research to improve grouts, 7 per cent silica fume was specified for grout used in tendons in the pier caps of Coleman bridge. Mockup showed voids in top of tendon. Addition of silica fume to mixer was not successful and prepackaged grout was needed.
2001

• Worked with industry to develop a prepackaged high performance grout (HPG).
• Smart Road bridge first to be grouted with a HPG.
2001

- 895 bridges grouted with a 2nd HPG.

- A 3rd HPG approved.
• Voids found in many tendons in Varina Enon Bridge. Tendons not sealed. Strands not corroded.

2007

- Tendon fails in Varina Enon Bridge after 17 years. Two tendons replaced. 20 tendon sites in VE bridge inspected by removing 2-ft of duct.
2007

- Eleven of 20 sites with different levels of corrosion selected for monitoring.

Broken Wires, NP13T10

Incomplete vacuum grout, NP3T16
2011

- Vendor announces grout contains chlorides.
- Chloride contaminated grout used in bridges:
  1. 895 Interchange
  2. US 33
  3. US 123
  4. Woodrow Wilson
<table>
<thead>
<tr>
<th>Test (independent lab1/lab2)</th>
<th>Requirement</th>
<th>Grout 1</th>
<th>Pass/Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water to cementitious materials ratio</td>
<td>Max 0.45</td>
<td>0.43/0.41</td>
<td>Pass</td>
</tr>
<tr>
<td>Fluidity, initial (ASTM C939) seconds</td>
<td>11 to 30</td>
<td>12/22</td>
<td>Pass</td>
</tr>
<tr>
<td>Fluidity, after 30 minutes (ASTM C939) seconds</td>
<td>Max. 30</td>
<td>14/26</td>
<td>Pass</td>
</tr>
<tr>
<td>Cube strength at 28 days, wet (ASTM C109) psi</td>
<td>Min. 5000</td>
<td>9035/7800</td>
<td>Pass</td>
</tr>
<tr>
<td>Permeability at 28 days, wet (AASHTO T277 at 30 V) coulombs</td>
<td>Max. 2500</td>
<td>1975/2070</td>
<td>Pass</td>
</tr>
<tr>
<td>Total chloride ion content, % by weight of cementitious material</td>
<td>Max. 0.08</td>
<td>0.03/.003</td>
<td>Pass</td>
</tr>
<tr>
<td>Volume change at 28 days (ASTM C1090) %</td>
<td>0.0 to + 0.2</td>
<td>+ 0.0/+0.1</td>
<td>Pass</td>
</tr>
<tr>
<td>Expansion 0 to 3 hours (ASTM C940) %</td>
<td>≤ 2.0%</td>
<td>+ 0.0/+1.1</td>
<td>Pass</td>
</tr>
<tr>
<td>Bleeding @ 3 hours (ASTMC940)* %</td>
<td>Max. 0.0</td>
<td>0.0/0.0</td>
<td>Pass</td>
</tr>
</tbody>
</table>
# Grout 2 Specification and Test Results, 2001

<table>
<thead>
<tr>
<th>Test (VDOT/independent lab)</th>
<th>Requirement</th>
<th>Grout 2</th>
<th>Pass/Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water to cementitious materials ratio</td>
<td>Max 0.45</td>
<td>0.33/0.33</td>
<td>Pass</td>
</tr>
<tr>
<td>Fluidity, initial (ASTM C939) seconds</td>
<td>11 to 30</td>
<td>18/15</td>
<td>Pass</td>
</tr>
<tr>
<td>Fluidity, after 30 minutes (ASTM C939) seconds</td>
<td>Max. 30</td>
<td>19/21</td>
<td>Pass</td>
</tr>
<tr>
<td>Cube strength at 28 days, wet (ASTM C109) psi</td>
<td>Min. 5000</td>
<td>7100/8039</td>
<td>Pass</td>
</tr>
<tr>
<td>Permeability at 28 days, wet (AASHTO T277 at 30 V) coulombs</td>
<td>Max. 2500</td>
<td>2011/1119</td>
<td>Pass</td>
</tr>
<tr>
<td>Total chloride ion content, % by weight of cementitious material</td>
<td>Max. 0.08</td>
<td>-/&lt;0.01</td>
<td>Pass</td>
</tr>
<tr>
<td>Volume change at 28 days (ASTM C1090) %</td>
<td>0.0 to + 0.2</td>
<td>-/+0.023</td>
<td>Pass</td>
</tr>
<tr>
<td>Expansion 0 to 3 hours (ASTM C940) %</td>
<td>≤ 2.0%</td>
<td>-/1.25</td>
<td>Pass</td>
</tr>
<tr>
<td>Bleeding @ 3 hours (ASTM C940) %</td>
<td>Max. 0.0</td>
<td>-/0.0</td>
<td>Pass</td>
</tr>
</tbody>
</table>
## Grout 3 Specification and Test Results, 2001

<table>
<thead>
<tr>
<th>Test (VDOT/independent lab)</th>
<th>Requirement</th>
<th>Grout 3</th>
<th>Pass/Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water to cementitious materials ratio</td>
<td>Max 0.45</td>
<td>0.38/-</td>
<td>Pass</td>
</tr>
<tr>
<td>Fluidity, initial (ASTM C939) seconds</td>
<td>11 to 30</td>
<td>15/-</td>
<td>Pass</td>
</tr>
<tr>
<td>Fluidity, after 30 minutes (ASTM C939) seconds</td>
<td>Max. 30</td>
<td>17/-</td>
<td>Pass</td>
</tr>
<tr>
<td>Cube strength at 28 days, wet (ASTM C109) psi</td>
<td>Min. 5000</td>
<td>8240/-</td>
<td>Pass</td>
</tr>
<tr>
<td>Permeability at 28 days, wet (AASHTO T277 at 30 V) coulombs</td>
<td>Max. 2500</td>
<td>-/1076</td>
<td>Pass</td>
</tr>
<tr>
<td>Total chloride ion content, % by weight of cementitious material</td>
<td>Max. 0.08</td>
<td>-/0.02</td>
<td>Pass</td>
</tr>
<tr>
<td>Volume change at 28 days (ASTM C1090) %</td>
<td>0.0 to + 0.2</td>
<td>-/+0.045</td>
<td>Pass</td>
</tr>
<tr>
<td>Expansion 0 to 3 hours (ASTM C940) %</td>
<td>≤ 2.0%</td>
<td>-/0</td>
<td>Pass</td>
</tr>
<tr>
<td>Bleeding @ 3 hours (ASTM C940)* %</td>
<td>Max. 0.0</td>
<td>-/0</td>
<td>Pass</td>
</tr>
</tbody>
</table>
Performance vs specification

- First grout was developed to provide high performance as defined by a series of test measurements for: zero segregation, zero bleed, zero shrinkage, low permeability, adequate strength.
- Future grouts were developed to meet a specification.
- Performance requires robustness (some idiot proof-ness)
- Grout should have acceptable properties with the addition of 10 per cent or more extra water
2012

- Mockup for US 460 segmental bridge identifies voids, segregation and soft grout in tendon grouted with an approved Grout 2.
US 460 Tendon Mock up end sections

1. TOWER SECTION
   - DBL 2x6 WALER SUPPORT BEAM AT 7'-0" LONG
   - TENDON**
   - 6' CROSS BRACING
   - H-PILE

2. ANGLE SECTION
   - 3x3x1/4 ANGLE POST
   - H-PILE
   - 3x3x1/4 ANGLE SUPPORT BEAM AT 6'-0" LONG

** TENDONS ARE TO BE TIED DOWN TO SUPPORTING BEAMS WITH STANDARD REBAR TIE WIRE
Tendon Mock up longitudinal sections
US 460 Tendon Mock up inlet end caps
grout 3 no void or soft grout, grout 2 void and soft grout
US 460 Tendon Mock up outlet end caps

Grout 3 no void or soft grout  
Grout 2 void and soft grout
US 460 Tendon Mock up

grout 3 provides filled tendon
grout 2 leaves void on top
Tests were conducted to determine the effect of grout water content on the segregation, length change and compressive strength.

The water to dry bag material ratio (w/b) recommended by the manufactures for grout 3 was 0.25 -0.28 and for grout 2 was 0.24 -0.27.

Given that we estimated the w/c ratio for grout in two tendons of the Varina Enon bridge exceeded 0.6 and the PTI specification allows a maximum w/c of 0.45 we batched mixes with w/b ratios that ranged between those recommended by the manufacturers and 0.65.
## Sieve Analysis, ASTM C 136

<table>
<thead>
<tr>
<th>Sieve Number</th>
<th>Percent Retained, grout 3</th>
<th>Percent Retained, grout 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>30</td>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>40</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>50</td>
<td>51.1</td>
<td>0.3</td>
</tr>
<tr>
<td>100</td>
<td>38.0</td>
<td>3.0</td>
</tr>
<tr>
<td>200</td>
<td>8.0</td>
<td>11.2</td>
</tr>
<tr>
<td>Pan</td>
<td>1.7</td>
<td>85.2</td>
</tr>
</tbody>
</table>
Schupack Pressure Bleed Test*  
Results, ml @ water to bag wt. ratios  
PTI M-55 Specification Sect. 4.4.6.2

<table>
<thead>
<tr>
<th>Vertical Rise, ft</th>
<th>Press., psi</th>
<th>Max. % (ml) bleed</th>
<th>Grout 3 @ 0.25, 0.28, 0.45, 0.65</th>
<th>Grout 2 @ 0.24, 0.27, 0.45, 0.65</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 ≤ 2</td>
<td>20</td>
<td>4 (8)</td>
<td>0,0, 1.2,3.3</td>
<td>0,0,0, 2.3</td>
</tr>
<tr>
<td>2 ≤ 6</td>
<td>30</td>
<td>2 (4)</td>
<td>-,-,-,-</td>
<td>-,-,-,-</td>
</tr>
<tr>
<td>6 ≤ 20**</td>
<td>50</td>
<td>0 (0)</td>
<td>-,1.2,-,-</td>
<td>-,-,-,-</td>
</tr>
<tr>
<td>&gt; 20</td>
<td>100 ***</td>
<td>0 (0)</td>
<td>0,1.2,2.6,6.0</td>
<td>0,0,1.5,4.3</td>
</tr>
</tbody>
</table>

*ASTM C 1741, **US460, *** 90, fails
Wick Induced Bleed Test
cement and water, aluminum powder, high
performance prepackaged grout (R. Gulyas)
Length Change Tests @ VCTIR

Length Changes from 4x8-in cylinders

Length Change (%)

Foam
Soft Grout
Grout 2 (w/b = 0.65)
Grout 3 (w/b = 0.65)
Soft Grout
Grout 2
Prepackaged grouts with different W/B

Grout 1: diminished properties
Grout 2: bleed, segregation, soft grout
Grout 3: foam
Grout Compressive Tests can be used to detect too much water (sample at outlet)

Cube Compressive Strengths

Compressive Strength (PSI)

0.2 0.25 0.3 0.35 0.4 0.45 0.5 0.55 0.6 0.65 0.7

Grout 2 @ 24 hrs, 7 day, 28 days solid
Grout 3 @ 24 hrs, 7 day, 28 days dashed

w/b
Excess Water Should not be a Problem

- PTI M55.1-12 requires that equipment consist of measuring devices (5.5.1) and that all materials shall be batched by weight except liquids may be batched by volume (5.6.1).
- Tendons should be capped and sealed to prevent water from entering prior to grouting.
- Sampling and testing the grout at the outlet end of the tendons can identify excess water in the grout regardless of the source.
Need for Mockups

- HPG has the potential to solve the material problem of bleeding, segregation and voids.
- Lab tests developed to approve HPG include:
  1. Schupack pressure bleed test ASTM C1741, 0-4%
  2. Volume change test ASTM C1090, 0%- + 0.2%
  3. Wick-induced bleed test ASTM C940, 0%
  4. Inclined tube test EN 445, ≤ 0.3% bleed
- Tendons with segregated grout, soft grout and voids have been identified that were grouted with HPG that pass lab tests.
Need for Mockups

• Incorrect batching and mixing, tendon geometry and length, and high pump pressures have been suggested as reasons for the problems.

• Until we have lab tests that can identify acceptable grouts, mockup tests should be done to identify problems prior to grouting the bridge.

• The mockup should include the most critical tendon situation (greatest height change and length) using grouts proposed for the project.

• The mockup done in 2012 for the US 460 bridge was successful.
## US 460 Test Results

<table>
<thead>
<tr>
<th>Batch</th>
<th>14 day comp., psi</th>
<th>28 day comp., psi</th>
<th>Perm. Top 2-in, coulombs</th>
<th>Perm. Bottom 2-in, coulombs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6135&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8705&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>5420&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7885</td>
<td>1964</td>
<td>1998</td>
</tr>
<tr>
<td>3</td>
<td>4665&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7895</td>
<td>1839</td>
<td>1916</td>
</tr>
<tr>
<td>average</td>
<td>5407</td>
<td>8162</td>
<td>1902</td>
<td>1957</td>
</tr>
</tbody>
</table>

Test results for grout 3 samples taken on 11-22-13 outlet end (average of 2 samples)<sup>a</sup> one sample
Compressive strength based on ASTM C109 cubes
Permeability based on AASHTO T277 @ 30 volts
Performance of Tendons in VE Bridge
Voids in Tendons Exposed Strands to Moisture and Oxygen

• Bleeding was approximately 4 percent in a properly batched grout ($w/c \leq 0.42$) prior to 1995.
• In a typical 150 ft long tendon 6 ft of void at the high points adjacent to the anchor plates in draped tendons is expected.
Design and Construction Practices Exposed Strands to Oxygen and Moisture

- Tendons not sealed because metal straps used to connect duct at diaphragms and bulk heads.
- Vent tubes were not sealed.
- Holes were often drilled in the plastic ducts to check for voids and grout.

Inside vent tube

Hole in duct
Typical VE span with draped tendon and bleed, leak and excess water voids
## Monitoring VE Tendons with Broken Wires

<table>
<thead>
<tr>
<th>Tendon</th>
<th>Broken wires 2007</th>
<th>Broken wires 2013</th>
<th>*Avg. broken wires /yr</th>
<th>Section loss 2007</th>
<th>Section loss 2013</th>
<th>*Avg. section loss/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>NP13 T10</td>
<td>2</td>
<td>4</td>
<td>0.33</td>
<td>7 wires 5.3 %</td>
<td>10 wires 2.9 %</td>
<td>0.5 wires 0%</td>
</tr>
<tr>
<td>SP12 T9</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>4.8 wires 3.6 %</td>
<td>15 wires 4.4 %</td>
<td>1.7 wires 0.13%</td>
</tr>
<tr>
<td>Avg.</td>
<td>1.5</td>
<td>2.5</td>
<td>0.17</td>
<td>5.9 wires 4.4%</td>
<td>12.5 wires 3.7%</td>
<td>1.1 wires 0.065%</td>
</tr>
</tbody>
</table>

* Change per year for 6 year period
Inadequate Corrosion Protection is a Local Rather Than a Widespread Issue

• Grout provides corrosion protection.

• Strands are often not protected because of voids or poor quality grout.

• Despite the perceived inadequate corrosion protection in the VE bridge, few tendons or wires have failed and corrosion is slow. Two of 480 tendons replaced after 24 years. Two wires of 133 wires in 1 tendon have failed over past 6 years (0.33 wires per years x 33 wires = 99 years until a tendon failure)(Section loss of 1.1 wire per year for 33 wires = 30 years until failure) (Section loss of 0.065% per year = 300 years).
Conclusions

• 99 per cent of the tendons in the V E Bridge appear to be performing well. Strand corrosion is slow.
• HPG 3 passed the mock up and is being successfully used to grout the US 460 bridge.
• Poor performing HPG 2 failed the mock up.
• Tests for identifying acceptable grouts need to be improved (bleeding and segregation are issues).
• Grouts need to be robust so that extra water that gets into the tendon or grout is not an issue.
• Mock ups must be used to identify acceptable grouts.
• Bag and water weights need to be correct during batching.
Recommendations

• Until we have lab tests that can identify acceptable grouts, perform a mockup test of the most critical tendon situation (greatest height change and length) using grouts proposed for the project.

• The mockup can be waived if the tendon design is similar and the proposed grout and grouting contractor are the same as approved for another project.

• While grouting, the water in each batch must be carefully measured and the bags of grout weighed to provide the required w/b.
QUESTIONS

Virginia Experience with Post-tensioned Tendon Grouts

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