A QUALITY CONTROL BOND TEST FOR PRESTRESSING WIRES

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WORK IS PART OF A LARGER PROJECT TITLED

Quantifying the Effect of Prestressing Steel and Concrete Variables on the Transfer Length in Pretensioned Concrete Crossties
Project Goal:

“to develop a comprehensive understanding of the variables affecting the transfer length in prestressed concrete crossties, and to apply this knowledge to ensure the proper design and fabrication of these members for high speed railway applications.”
**Transfer Length**

- The transfer length (or transmission length) is the length required to transfer the effective prestress force to the concrete.

- It must be less than the distance to the rail seat location for the tie to have the maximum shear and moment capacity.
Background

In 2010–2011, Transfer Lengths were measured by KSU research team at 6 different concrete railroad tie plants in the United States
Goal of Quality Control Bond Test

Good bond here… … indicates good bond here.
Pullout Test Lab Work Conducted by...

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13 Wires (12 Original + 1 Added)
WA (smooth)
WC (spiral)
WD (chevron)
WE (spiral)
WF (diamond)
WG (chevron)
WH (chevron)
WI (chevron)
WJ (chevron)
WK (4 DOT)
WL (2 DOT)
Wire Specimen Dimensions

- 4" OD Steel Tubing w/ 1/8" Wall Thickness
- 5.32 mm Wire
- Sand-Cement Mortar
- 6" x 6" x \frac{3}{16}" Steel Plate

Dimensions:
- 2" Bond Break
- 6" Embedment Length
- 1" Bond Break
- 10" Height
- 20" Total Height
Standard Materials and Mix Proportions

- Type III cement (ASTM C150)
- ASTM C778 Sand (Ottawa Sand)
  - Pre-sieved, 50-pound bags

- $s/c = 2.0$
- $w/c = 0.427$
Mortar Flow Test Approx. 120-125 (ASTM C1437)

Tests workability of mortar (similar to slump test for concrete)
Batching

- 12 pullout specimens
- 12 mortar cubes (strength)
- Flow test (workability)
Specimens made and stored at room temperature (73.5 ± 3°F) and in a humidity controlled environment
Testing Protocol

- Tested when mortar compression strength between 4500-5000 psi
- Force-controlled loading rate of 2000 lbf/min.
- Data collected at intervals of 0.0005 in. of end slip
- Measure end slip and force in real time
# Wire Pullout Batch Summaries

<table>
<thead>
<tr>
<th>Mortar Batch Name</th>
<th>Avg. Specimen Cure Time (hrs)</th>
<th>Avg. Cube Strength at Time of Test (psi)</th>
<th>Flow Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire Batch #1</td>
<td>20.5</td>
<td>4544</td>
<td>124</td>
</tr>
<tr>
<td>Wire Batch #2</td>
<td>19.25</td>
<td>4638</td>
<td>124</td>
</tr>
<tr>
<td>Wire Batch #3</td>
<td>20.25</td>
<td>4541</td>
<td>122</td>
</tr>
<tr>
<td>Wire Batch #4</td>
<td>25.75</td>
<td>4544</td>
<td>125</td>
</tr>
<tr>
<td>Wire Batch #5</td>
<td>20.75</td>
<td>4542</td>
<td>121</td>
</tr>
<tr>
<td>Wire Batch #6</td>
<td>20.75</td>
<td>4640</td>
<td>119</td>
</tr>
<tr>
<td>Average</td>
<td>21.25</td>
<td>4575</td>
<td>122.5</td>
</tr>
</tbody>
</table>

1 batch = 12 specimens =
Force vs. End Slip Example (WF)

[WF] Force vs. End Slip
4 in. Diameter, 6 in. Bond Length

Force (lbf) vs. End Slip (in.)

- Averaged Results
- Specimen 1
- Specimen 2
- Specimen 3
- Specimen 4
- Specimen 5
- Specimen 6
Force vs. End Slip Averages

4 in. Diameter, 6 in. Bond Length


Force (lbf) vs. End Slip (in.)
Compare KSU Pullout Tests to KSU Transfer Lengths
3 pretensioned concrete prisms cast with each wire (6 Transfer Lengths)
### KSU Transfer Length Data

<table>
<thead>
<tr>
<th>Wire Identification</th>
<th>Avg. Transfer Length (in.)</th>
<th>Concrete Strength at De-tensioning (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[WA]</td>
<td>16.3</td>
<td>4664</td>
</tr>
<tr>
<td>[WB]</td>
<td>11.6</td>
<td>4453</td>
</tr>
<tr>
<td>[WC]</td>
<td>8.8</td>
<td>4701</td>
</tr>
<tr>
<td>[WD]</td>
<td>11.1</td>
<td>4400</td>
</tr>
<tr>
<td>[WE]</td>
<td>7.4</td>
<td>4650</td>
</tr>
<tr>
<td>[WF]</td>
<td>8.5</td>
<td>4466</td>
</tr>
<tr>
<td>[WG]</td>
<td>11.8</td>
<td>4697</td>
</tr>
<tr>
<td>[WH]</td>
<td>7.5</td>
<td>4695</td>
</tr>
<tr>
<td>[WI]</td>
<td>10.1</td>
<td>4547</td>
</tr>
<tr>
<td>[WJ]</td>
<td>9.0</td>
<td>4521</td>
</tr>
<tr>
<td>[WK]</td>
<td>14.0</td>
<td>4572</td>
</tr>
<tr>
<td>[WL]</td>
<td>18.7</td>
<td>4476</td>
</tr>
</tbody>
</table>

Note: Sample size = 6
Methods of Analysis

1. Force at a certain end slips (best correlation)
2. End slip at certain forces
3. Slope between two end slips (0.01” to 0.03”)
4. Slope between two forces (1000 to 4000 lbf)
1) Force at Certain End Slips

**Force vs. End Slip Averages**

4 in. Diameter, 6 in. Bond Length

The graph shows the relationship between force (in lb) and end slip (in inches) for various types of bonds.

- WA: Smooth
- WB: Chevron
- WC: Spiral
- WD: Chevron
- WE: Spiral
- WF: Diamond
- WG: Chevron

The graph includes multiple lines, each representing a different type of bond, with different markers and colors for easy identification.
Repeated this analysis for non-continuously indented wires.
1) Force at a Certain End Slip

Correlation (Between Force and Transfer Length), $R^2$ vs. Avg. End Slip
4 in. Diameter, 6 in. Bond Length, Ottawa Sand As-Received

NOTE:
- For 12 wires, $R^2 = 0.882$ for max force (ES $\leq 0.10$ in.) vs. transfer length.
- For 9 wires, $R^2 = 0.916$ for max force (ES $\leq 0.10$ in.) vs. transfer length.
Pump Capacity

Avg. Pullout Force vs. Avg. End Slip

- Max Pullout Force
- Pullout Occurs
- Infinite
- High
- Low
(only wires with non-continuous indentations)

Predictive Model

\[ TL = -0.00160(\text{Max Force}) + 20.9 \]

\[ R^2 = 0.916 \]
Wire WM
Verification of Wire Model

\[ TL = -0.00160 (Max\ Force) + 20.9 \]

where \( TL \) = expected as-received transfer length from prisms
\( Max\ Force \) = maximum force \( \leq 0.10 \) in. end slip

- \((\text{Avg. max force})_{WM} = 6879 \) lbf
- Expected \( TL_{WM} \) from prisms = 9.9 in.
- Actual Average Transfer Length for WM was 9.8 inches
Compare KSU Pullout Tests to CXT Transfer Lengths

(Transfer Length Measurements Obtained in January 2013)
Over 700 TL Measurements in 21 Days
KSU Pullout Tests vs. CXT Transfer Lengths

(only wires with non-continuous indentations)

\[ TL = -0.00080(\text{Max Force}) + 15.2 \]
\[ R^2 = 0.870 \]
Conclusion

- The un-tensioned pullout test method developed in this research project had outstanding correlation with the performance of the wires when placed in a pre-tensioned application (both prisms and actual ties).
Opportunities

- Tie manufacturing facility could develop a predictive relationship between pullout test results and transfer lengths (for their individual mix and release strength).
- A minimum bond value or a bond range could be established and specified as part of standard quality control measures.
Current Status

- ASTM Subcommittee A01.05 has requested a copy of the current test method and will be taking this up as an action item in the near future.
- We would also welcome other feedback and/or recommendations on how to move this test forward as a standard in the railroad industry.