Recent Durability Performance Results in Closure Joints of Modular Bridge Decks

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Cast-in-Place Concrete Connections for Precast Deck Systems (2006-2010)

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Consultants
• UTK Subtasks Objectives (NCHRP10-71):

  – Develop design guidelines for longitudinal and transverse connections between full-depth deck panels or deck flanges (no overlays or post-tensioning to be used)

  – Emphasize increasing construction speed while achieving durability and ride quality
Longitudinal and Transverse Joints in Deck Panels
Longitudinal Joint in Deck Bulb Tees
Outline

• Introduction
• Connection Concepts and Design
• Durability of Closure Pour (CP) Materials
• Conclusions
Current Joint Details
U-/Loop Joint used in Japan
# Rebar Bend Diameter Requirements

<table>
<thead>
<tr>
<th>Reinforcement Type</th>
<th>Publication</th>
<th>Bar Size</th>
<th>Bend Diameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Rebar</td>
<td>ACI Code</td>
<td>#5</td>
<td>6*d</td>
</tr>
<tr>
<td>Deformed Wire Reinforcement (DWR)</td>
<td>ASTM Standards</td>
<td>D31 (approx. #5)</td>
<td>4*d</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>ASTM Standards</td>
<td>#5</td>
<td>3.5*d</td>
</tr>
</tbody>
</table>

![Stress vs. Strain Graph](image-url)
U-Bar Detail

- 3d (1 7/8") bend used to minimize deck thickness
- *Using DWR and SS*
Headed Rebar Joint Detail
Test Set-Ups

Longitudinal Joint Test

Transverse Joint Test
Joint Design by Strut-and-Tie Model (STM)

The tension capacity may be controlled by the yielding of U-bars or lacer bars, or crushing of concrete within the overlapping U-bars.

\[ T_u = n_\Delta \cdot \min \left[ 0.85 f_c' \frac{D l_0^2 s}{l_0^2 + (s/2)^2}, \quad f_{y, ubar} A_{ubar}, \quad \frac{4 f_{y, lbar} A_{lbar} l_0}{s} \right] \]
Joint Design Example

Centerline of Joint

See "Joint Reinforcement Detail"

#5 U bar spacing
4.5" (Typ.)

#4 bar spacing
12" (Typ.)

#5 bar spacing
6" (Typ.)

#4 lacer bar (Typ.)

For detailed design examples, please see the following NCHRP Web-only Document 173:

http://www.trb.org/Publications/Blurbs/164971.aspx

“Joint Reinforcement Detail“
Outline

• Introduction
• Connection Concepts and Design
• Durability of Closure Pour (CP) Materials
• Conclusions
Two categories for accelerated construction:

• Overnight (8 hours) cure of CP materials
• 7-day cure of CP materials
Performance Characteristics Investigated

To have a more durable deck joint

- Shrinkage
- Chloride Penetration
- Freezing-and-thawing Durability
- Bond Strength

To develop headed bars and/or U-bars within a short overlap length

- Compressive Strength
“Nonshrink” grouts are still susceptible to drying shrinkage.
Cementitious grouts must be kept continuously wet to keep them from shrinking.
Grout materials that do not shrink include magnesium ammonium phosphate (MAP).
If MAP is used, surface preparation is very important.
Literature Review

• Overnight Cure:
  – Two magnesium ammonium phosphate (MAP) based grouts (with and without aggregate extension)
  – Non-shrink cement grout
  – Polymer-modified grout**

• 7-day Cure:
  – Five HPC mixes (Three from HPC Showcase Bridge Projects; and two from Lafarge North America)
  – Rapid set low permeability (RSLP) hydraulic cement mix
  – Two latex modified concrete mixes
  – UHPC**
## Candidate Overnight Cure Materials Selection

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Neat Grout</th>
<th>Extended Grout</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial Water, pints</td>
<td>Additional Water, pints</td>
</tr>
<tr>
<td>Neat Grout</td>
<td>3.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Five Star® Patch</td>
<td>5.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Set® 45</td>
<td>3.25</td>
<td>0.50</td>
</tr>
<tr>
<td>Set® 45 HW</td>
<td>3.25</td>
<td>0.50</td>
</tr>
<tr>
<td>Extended Grout</td>
<td>3.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Five Star® Patch</td>
<td>5.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Set® 45</td>
<td>3.25</td>
<td>0.50</td>
</tr>
<tr>
<td>Set® 45 HW</td>
<td>3.25</td>
<td>0.50</td>
</tr>
</tbody>
</table>
Compressive Strength at 8 hours

- Compressive Strength (psi)

- EUCO-SPEED MP
- Five Star Patch
- SET 45
- SET 45 HW
- EUCO-SPEED MP extended
- Five Star Patch extended
- SET 45 extended
- SET 45 HW extended

- Air Curing
- Moist Curing
## HPC Mixes Selection

- NCHRP project 18-08A (NCHRP Report 566: Guidelines for Concrete Mixtures Containing Supplementary Cementitious Materials to Enhance Durability of Bridge Decks)

### Predicted Desirability for the Five HPC Mixes

<table>
<thead>
<tr>
<th></th>
<th>MIX 1</th>
<th>MIX 2</th>
<th>MIX 3</th>
<th>MIX 4</th>
<th>MIX 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Predicted Overall Desirability</strong></td>
<td>0.71</td>
<td>0.71</td>
<td>0.81</td>
<td>0.89¹</td>
<td>0.83²</td>
</tr>
<tr>
<td><strong>7-day Compressive Strength Desirability</strong></td>
<td>0.96</td>
<td>0.46</td>
<td>0.60</td>
<td>1.0</td>
<td>0.67</td>
</tr>
</tbody>
</table>

1 - Type C Fly ash; 2 - Slag
# 7-day Cure Mixes Selection

<table>
<thead>
<tr>
<th>Compressive Strength (psi)</th>
<th>HPC MIX# 1</th>
<th>HPC MIX# 4</th>
<th>HPC MIX# 5</th>
<th>LMC-VE</th>
<th>RSLP</th>
<th>Emaco T430 mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>6394</td>
<td>4112</td>
<td>2784</td>
<td>4404</td>
<td>11640</td>
<td>1470</td>
<td></td>
</tr>
</tbody>
</table>
## Candidate 7-day Cure CP Materials

<table>
<thead>
<tr>
<th>Mix Number</th>
<th>HPC Mix 1</th>
<th>RSLP</th>
</tr>
</thead>
<tbody>
<tr>
<td>W/CM Ratio</td>
<td>0.31</td>
<td>0.40</td>
</tr>
<tr>
<td>Cement Type</td>
<td>I</td>
<td>CTS RSLP</td>
</tr>
<tr>
<td>Cement Quantity, lb/yd³</td>
<td>750</td>
<td>658</td>
</tr>
<tr>
<td>Type C Fly Ash Quantity, lb/yd³</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>Fine Aggregate, lb/yd³</td>
<td>1400</td>
<td>1695</td>
</tr>
<tr>
<td>#8 Coarse Aggregate, lb/yd³</td>
<td>1400</td>
<td>1454</td>
</tr>
<tr>
<td>Water, lb/yd³</td>
<td>255</td>
<td>263</td>
</tr>
<tr>
<td>Air Entrainment, fl oz/yd³</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Water Reducer, fl oz/yd³</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>HR Water Reducer, fl oz/yd³</td>
<td>135</td>
<td></td>
</tr>
</tbody>
</table>
Candidate Materials (Long-term Tests)

**Overnight:** Two magnesium ammonium phosphate (MAP) mortars [MAP1 = “EUCO-SPEED MP” and MAP2 = “SET 45 HW”]

**7-Day:** HPC (i.e., HPC Mix 1) and RSLP
Shrinkage Test Method

Cracks due to the restraint, the stiffness, and the drying shrinkage.

ASTM C157

AASHTO PP34
Chloride Penetration Test Method

RCP test has some interference problems with materials such as nitrate corrosion inhibitors and even the test materials (e.g. Set-45).

ASTM C1202 RCP test

ASTM C1543 Ponding test
Freezing-and-Thawing Durability

• ASTM C666

Freezing-and-Thawing Apparatus  Temperature Recorder
Bond Strength

• ASTM C882
Shear Key Detail

4 in.  4 in.

5.5 in.  5.5 in.

1 in.

2.5 in.

2.5 in.

1 in.
Joint Surface Preparation

Before

After

Black Beauty 2050 sand was chosen for sandblasting to prepare the surface.
Curing

Worst case scenario (no cure): Air cure

Something in between: Curing compound

Best case scenario (100% humidity cure): Moist Room OR Water Storage Tank

Both the membrane-forming compound method and the water method with burlap
Shrinkage Steel Ring Test Results

- Cracks were found for specimens of the HPC at the age of 20.5 days.

- No crack was observed to occur for MAP1, MAP2, and RSLP throughout the tests which were terminated at the ages of 62, 58, and 61 days, respectively.
Chloride Content Profile (90-day ponding)

Chloride Concentration (% cement mass)

Specimen Layer (Average Depth in)

HPC Specimen 1
HPC Specimen 2
HPC Specimen 3

TENNESSEE BRIDGE RESEARCH LABORATORY
# Freezing-and-thawing Durability Test Results

<table>
<thead>
<tr>
<th>Relative dynamic modulus of elasticity after 300 cycles</th>
<th>MAP 1</th>
<th>MAP 2</th>
<th>HPC</th>
<th>RSLP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>92%</td>
<td>96%</td>
<td>96%</td>
<td>Fail after 70 cycles</td>
</tr>
<tr>
<td>Material Type</td>
<td>Specimen Number</td>
<td>Test Age</td>
<td>Shear Stress (psi)</td>
<td>Average Shear Stress (psi)</td>
</tr>
<tr>
<td>---------------</td>
<td>-----------------</td>
<td>-----------</td>
<td>-------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>MAP 1</td>
<td>1</td>
<td>8 hours</td>
<td>456</td>
<td>397</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>159</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
<td>576</td>
<td></td>
</tr>
<tr>
<td>MAP 2</td>
<td>1</td>
<td>8 hours</td>
<td>1161</td>
<td>1176</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>1121</td>
<td></td>
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<tr>
<td></td>
<td>3</td>
<td></td>
<td>1240</td>
<td></td>
</tr>
<tr>
<td>HPC</td>
<td>1</td>
<td>7 days</td>
<td>1607</td>
<td>1817</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>1917</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
<td>1925</td>
<td></td>
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<tr>
<td>RSLP</td>
<td>1</td>
<td>7 days</td>
<td>659</td>
<td>705</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>634</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
<td>823</td>
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</tbody>
</table>
Outline

• Introduction
• Connection Concepts and Design
• Durability of Closure Pour (CP) Materials
• Conclusions
Conclusions

• Development of a comprehensive design guide (Research Results Digest 355, http://www.trb.org/Main/Blurbs/165677.aspx) for the design and construction of longitudinal and transverse joints for full depth deck panels and decked bulb T’s

• Development of both loop bar and headed bar details

• For loop bar detail, shallow deck thicknesses (e.g. 6 inches) required the use of tighter bends; and thus recommendations are restricted to wire reinforcement and stainless steel reinforcement which may accommodate tighter bends due to their higher levels of ductility
## Conclusions: Proposed Performance Criteria of CP Materials

<table>
<thead>
<tr>
<th>Performance Characteristic</th>
<th>Test Method</th>
<th>Performance Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive Strength (CS), ksi</td>
<td>ASTM C39 modified</td>
<td>6.0 ≤ CS @ 8 hours (overnight cure)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>@ 7 days (7-day cure)</td>
</tr>
<tr>
<td>Shrinkage (S), (Crack age, days)</td>
<td>AASHTO PP34 modified</td>
<td>20 &lt; S</td>
</tr>
<tr>
<td>Chloride Penetration (ChP), (Depth for Percent Chloride of 0.2% by mass of cement after 90-day ponding, in.)</td>
<td>ASTM C1543 modified</td>
<td>ChP &lt; 1.5</td>
</tr>
<tr>
<td>Freezing-and-thawing Durability (F/T), (relative modulus after 300 cycles)</td>
<td>ASTM C666 Procedure A modified</td>
<td>Grade 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>70% ≤ F/T</td>
</tr>
<tr>
<td>Bond Strength (BS), psi</td>
<td>ASTM C882 modified</td>
<td>300 &lt; BS</td>
</tr>
</tbody>
</table>
Acknowledgements

UTK Graduate Students (Peng Zhu, Sam Lewis, Beth Chapman, Lungui Li, and Qi Cao)
Panel Members of NCHRP10-71
NCHRP Senior Program Officers (David Beal and Waseem Dekelbab)

BASF Construction Chemicals, LLC
CTS Cement Manufacturing Corporation
Dow Reichhold, Specialty Latex LLC
Enco Materials, Inc.
Engineered Wire Products
Five Star Products, Inc.
Gerdau Ameristeel
Lafarge North America, Inc.
Ross Prestressed Concrete, Inc.
Salit Specialty Rebar Inc.
References