DEVELOPMENT OF A SPECIFICATION FOR LOW CRACKING BRIDGE DECK CONCRETE IN VIRGINIA

Virginia DOT Workshop – Charlottesville, VA

Harikrishnan Nair, Ph.D., P.E, VTRC
Senior Research Scientist

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Presentation Outline

• INTRODUCTION
• RESEARCH
• SPECIFICATION DEVELOPMENT
• IMPLEMENTATION
Deck Cracking Problem

• Cracks can result from excessive loading, environmental conditions, chemical reactions, construction or design errors.

• Cracks act as a pathway for water and aggressive chemical ions to penetrate concrete and enable its deterioration.
### Classification of Cracks (TRB Circular, E-C107)

<table>
<thead>
<tr>
<th>Type of Cracking</th>
<th>Time of Appearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic Shrinkage</td>
<td>30 min to 6 h</td>
</tr>
<tr>
<td>Plastic settlement</td>
<td>10 min to 3 h</td>
</tr>
<tr>
<td>Thermal expansion and contraction</td>
<td>1 day to 2–3 weeks</td>
</tr>
<tr>
<td>Drying shrinkage</td>
<td>Weeks to months</td>
</tr>
</tbody>
</table>
Deck Cracking Problem

Drying shrinkage cracks – may occur weeks to months after pour.
Deck Cracking Problem

Difficult to penetrate cracks < 0.1 mm wide. Cracks with a width over 0.20 mm can be and should be sealed.

Chloride diffusion in cracked concrete

Corrosion Resistant Rebars
To investigate the effectiveness of reducing drying shrinkage in VDOT concrete mixes using the following:

- Normal weight concrete with Shrinkage Reducing Admixture (SRA)
- Lightweight (LW) concrete with LW coarse aggregate
- Shrinkage compensating concrete
Typically shrinkage reduction achieved is between 35–45%

SRAs function by reducing capillary tension of pore water
VDOT Use of Lightweight Concrete Bridge Deck

Route 629 over Cowpasture River
After 33 Years
No Transverse Crack (Continuous two span bridge on Steel Beams)

Route 60 over Maury River
After 30 Years
Skew, no cracks
Shrinkage Compensating Concrete

Ref: P.K. Mehta and P.J.M. Monteiro, Concrete: Microstructure, Properties, and Materials
## METHODS

### Details of Bridges That Used SRA, LWC, and SC

<table>
<thead>
<tr>
<th>No.</th>
<th>Route or Bridge No./Name</th>
<th>Length (ft)</th>
<th>Width (ft)</th>
<th>No. of Spans</th>
<th>Type of Beam Support</th>
<th>Skew Angle (Degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>NWC with SRA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Northern Virginia District (I-95 Express Lanes)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>B607 (Telegraph Road)</td>
<td>313</td>
<td>40</td>
<td>2</td>
<td>Steel</td>
<td>19</td>
</tr>
<tr>
<td>2</td>
<td>B609 (GHS Ramp)</td>
<td>448.3</td>
<td>30</td>
<td>2</td>
<td>Steel</td>
<td>0 (curved)</td>
</tr>
<tr>
<td>3</td>
<td>B603 (JHS Ramp)</td>
<td>541</td>
<td>30</td>
<td>3</td>
<td>Steel</td>
<td>0 (curved)</td>
</tr>
<tr>
<td>4</td>
<td>B602 (Ramp)</td>
<td>558</td>
<td>30</td>
<td>3</td>
<td>Steel</td>
<td>0 (curved)</td>
</tr>
<tr>
<td>5</td>
<td>B601 (Ramp)</td>
<td>964</td>
<td>30</td>
<td>9</td>
<td>Concrete (1 span)/Steel</td>
<td>0 (curved)</td>
</tr>
<tr>
<td></td>
<td><strong>Staunton District</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Route 633 Covington</td>
<td>340</td>
<td>26</td>
<td>3</td>
<td>Steel</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>Route 1421 Linville Creek</td>
<td>260</td>
<td>29.67</td>
<td>4</td>
<td>Prestressed concrete box beams</td>
<td>15</td>
</tr>
<tr>
<td>8</td>
<td>Route 250 Ramseys Draft</td>
<td>65</td>
<td>40</td>
<td>1</td>
<td>Prestressed concrete box beams</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td><strong>Fredericksburg District</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Route 600 Herring Creek</td>
<td>99</td>
<td>40</td>
<td>1</td>
<td>Steel</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td><strong>LWC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Route 657, Senseny Road, Winchester/ Staunton</td>
<td>249</td>
<td>32</td>
<td>4</td>
<td>Steel</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>Route 128, Chandlers Mountain Road, Lynchburg/Lynchburg</td>
<td>264</td>
<td>36</td>
<td>4</td>
<td>Steel</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>Route 15, Opal/Culpeper</td>
<td>256</td>
<td>28</td>
<td>2</td>
<td>Lightweight concrete beams</td>
<td>27</td>
</tr>
<tr>
<td>13</td>
<td>Route 49, The Falls Road, Crewe/Richmond</td>
<td>175</td>
<td>42</td>
<td>3</td>
<td>Steel</td>
<td>0</td>
</tr>
<tr>
<td>14</td>
<td>Route 646, Aden Road, Nokesville/Northern Virginia</td>
<td>167</td>
<td>32</td>
<td>3</td>
<td>Prestressed concrete slab</td>
<td>0</td>
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<tr>
<td>15</td>
<td>Route 3, Piankatank River, Mathews County/Fredericksburg</td>
<td>4186</td>
<td>28</td>
<td>30</td>
<td>Steel</td>
<td>0</td>
</tr>
<tr>
<td>16</td>
<td>I-95 HOV Lane, Stafford/Northern Virginia</td>
<td>159</td>
<td>48</td>
<td>1</td>
<td>Steel</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td><strong>SC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Route 613/South Fork/ Staunton</td>
<td>320</td>
<td>28</td>
<td>4</td>
<td>Prestressed concrete box beams</td>
<td>0</td>
</tr>
</tbody>
</table>
METHODS

• Trial batches were conducted for the proposed mix designs.

• Bridge deck placement details (Concrete temperature, air temperature, relative humidity and wind speed) were documented.

• Concretes were tested for fresh and hardened properties.

• Decks were wet cured for 7 days followed by curing compound.

• Crack survey’s (length, width, location) were conducted at different intervals.
## Concrete Mix Designs for All Bridges (per cubic yard)

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Cement (lb)</th>
<th>Fly Ash (lb)</th>
<th>Slag (lb)</th>
<th>Total Cementitious Content (lb)</th>
<th>Water (lb)</th>
<th>w/c</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NWC with SRA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I-95 Express Lanes</td>
<td>300</td>
<td>-</td>
<td>300</td>
<td>600 (SRA 1)</td>
<td>271</td>
<td>0.45</td>
</tr>
<tr>
<td>Route 633</td>
<td>464</td>
<td>116</td>
<td>-</td>
<td>580 (SRA 2)</td>
<td>262</td>
<td>0.45</td>
</tr>
<tr>
<td>Route 1421</td>
<td>325</td>
<td>-</td>
<td>325</td>
<td>650 (SRA 2)</td>
<td>260</td>
<td>0.40</td>
</tr>
<tr>
<td>Route 250</td>
<td>480</td>
<td>120</td>
<td>-</td>
<td>600 (SRA 3)</td>
<td>262</td>
<td>0.44</td>
</tr>
<tr>
<td>Route 600</td>
<td>480</td>
<td>120</td>
<td>-</td>
<td>600 (SRA 2)</td>
<td>258</td>
<td>0.43</td>
</tr>
<tr>
<td><strong>LWC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Route 657</td>
<td>529</td>
<td>176</td>
<td>-</td>
<td>705</td>
<td>267</td>
<td>0.38</td>
</tr>
<tr>
<td>Route 128</td>
<td>318</td>
<td>-</td>
<td>317</td>
<td>635</td>
<td>286</td>
<td>0.45</td>
</tr>
<tr>
<td>Route 15</td>
<td>330</td>
<td>-</td>
<td>330</td>
<td>660</td>
<td>292</td>
<td>0.44</td>
</tr>
<tr>
<td>Route 49</td>
<td>525</td>
<td>171</td>
<td>-</td>
<td>696</td>
<td>313</td>
<td>0.45</td>
</tr>
<tr>
<td>Route 646</td>
<td>540</td>
<td>135</td>
<td>-</td>
<td>675</td>
<td>292</td>
<td>0.43</td>
</tr>
<tr>
<td>Route 3</td>
<td>508</td>
<td>127</td>
<td>-</td>
<td>635</td>
<td>286</td>
<td>0.45</td>
</tr>
<tr>
<td>I-95 HOV Lane</td>
<td>330</td>
<td>-</td>
<td>330</td>
<td>660</td>
<td>292</td>
<td>0.44</td>
</tr>
<tr>
<td><strong>SC Concrete</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Route 613</td>
<td>572</td>
<td>143</td>
<td>-</td>
<td>715</td>
<td>349</td>
<td>0.48</td>
</tr>
</tbody>
</table>
Trial Batch Results

- Acceptable Compressive strength (VDOT Spec: 28 day min 4000 psi)
- Very low permeability – Below 1000 coulombs (VDOT Spec: 28 day max 2500 Coulombs)
- Excellent Freeze Thaw Durability

SRA (producer 3) reduced the air content
  - Higher dosage of air entraining agent was required

Reduction in shrinkage with use of SRA ranged from 10 – 58%
Placement and Fresh Concrete properties

**VDOT spec**: Range of slump: 2-4 in, Air content: 5-8%
With high-range water–reducing admixture: slump: 2-7 in, Air content: 5-9%

**NWC with SRA**
- In most cases concrete mixture was placed by pumping.
- Slump ranged from 2.6 to 6 in and Air content 5.0 to 7.8%
- Paste content (total volume of cementitious material and water) close to 27%
- The concrete evaporation rates were very low (less than 0.1 lb/ft$^2$/hr) in all projects
Placement and Fresh Concrete properties

**Lightweight Concrete**
- unit weight of the LWC ranged from 114.2 to 120.9 lb/ft$^3$
- In most cases concrete mixture was placed by pumping.
- Average slumps ranged from 4 to 8 inches, and air content ranged from 5.5% to 8.0%.
- The concrete evaporation rates were very low.

**Shrinkage compensating concrete**
- Hydration stabilizer was used to control the slump loss.
- All fresh concrete properties and the evaporation rate met the VDOT specification.
Hardened Concrete Properties

Compressive Strength and Permeability

- NWC with SRA
- LWC
- SC Concrete

Compressive Strength (psi) vs. Specimen No.

Permeability (C) vs. Specimen No.
Hardened Concrete Properties

28-day Length Change and Elastic Modulus

- Length change (%)
  - NWC with SRA
  - LWC
  - SC Concrete

- Elastic Modulus (x10^6 psi)
  - NWC with SRA
  - LWC
  - SC Concrete

Specimen No.
Shrinkage Results – Lightweight Concrete (2012 Projects)

Cementitious content: 635 lb/yd^3
Cementitious content: 660 lb/yd^3
Cementitious content: 705 lb/yd^3
## Crack Survey: NWC with SRA

<table>
<thead>
<tr>
<th>Route or Bridge No.</th>
<th>Length of Bridge</th>
<th>No. of Cracks: Length (ft) and Width (mm)</th>
<th>Age at Time of Survey (months)</th>
<th>Crack Density (ft/ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B607 (Telegraph Road)</td>
<td>313 ft</td>
<td>1 crack: 36 ft (0.2 mm)</td>
<td>15</td>
<td>0.0028</td>
</tr>
<tr>
<td>B609 (GHS Ramp)</td>
<td>448 ft</td>
<td>4 cracks: 3 ft (0.25 mm), 15 ft (0.2 mm), 9 ft (0.3 mm), 1 ft (0.25 mm)</td>
<td>7</td>
<td>0.0020</td>
</tr>
<tr>
<td>B603 (JHS Ramp)</td>
<td>542 ft</td>
<td>No cracks</td>
<td>14</td>
<td>0.0</td>
</tr>
<tr>
<td>B602 (Ramp)</td>
<td>558 ft</td>
<td>1 crack: 7 ft (0.2 mm)</td>
<td>13</td>
<td>0.0004</td>
</tr>
<tr>
<td>B601 (Ramp)</td>
<td>964 ft</td>
<td>20 short cracks: Average length: 4-5 ft</td>
<td>5</td>
<td>0.0049</td>
</tr>
<tr>
<td>Route 1421</td>
<td>260 ft</td>
<td>3 transverse cracks over the piers</td>
<td>14</td>
<td>0.0115</td>
</tr>
<tr>
<td>Route 250</td>
<td>65 ft</td>
<td>No cracks</td>
<td>9</td>
<td>0.0</td>
</tr>
<tr>
<td>Route 600</td>
<td>99 ft</td>
<td>5 short longitudinal cracks at abutments</td>
<td>9</td>
<td>0.0062</td>
</tr>
<tr>
<td>Route 633</td>
<td>340 ft</td>
<td>Several cracks</td>
<td>19</td>
<td>0.1853</td>
</tr>
</tbody>
</table>
Did not follow placement sequence (C&D combined)
Crack Survey: NWC with SRA
Temperature data for Rte.633 bridge (Pour F)

Temperature (F)

Time

Air temp
- top @ center of bridge deck
- middle @ center of bridge deck
- bottom @ center of bridge deck
- top @ edge of bridge deck
- middle @ edge of bridge deck
- bottom @ edge of bridge deck
- steel beam

Top of bridge deck
Steel Beam
Air
Crack Survey – Lightweight concrete

Winchester (2 Years)

No Crack

Opal (1 ½ Years)

No crack on LWC deck. Cracks in NWC approach slab

Lynchburg (1 ½ Years)

No Crack

After 2 winters no cracks on deck

I-95 Expressway, Stafford (6 months)

No Crack
Crack Survey – Lightweight concrete

Mathews County, Fredericksburg (6 Months)

Tight Cracks in Closure Pour

Crewe, Richmond (7 Months)

No Crack

Nokesville, NOVA (10 Months)

Cracks

Nokesville, NOVA (10 Months)
Crack Survey – Lightweight concrete

Crack Survey Plots for Route 646 Nokesville (not to scale)
Shrinkage compensating concrete

Route 613 Bentonville – Staunton District

ASTM C878: 7-Day Expansion

- Batch 1
- Batch 2
- Batch 3
- Batch 4
Reflective cracking caused by the differential movement of the box beams at the keyway

Transverse cracks over the piers were observed
• Bridge decks with fewer cracks can be constructed.

• The use of SRA along with low cementitious contents (600 lb/yd$^3$ maximum) was found to be very effective in reducing cracks in bridge decks.

• For low cracking decks, the 28-day drying shrinkage (ASTM C157) should be kept below 350 microstrains.

• Decks with reduced cracks or no cracks can be successfully placed using LWC with a cementitious content below 650 lb/yd$^3$ while meeting strength and permeability requirements.
CONCLUSIONS

• The LWCs used in this study had shrinkage values as high as 0.060% and did not crack. This shows the benefits of the lower elastic modulus, internal curing, and lower coefficient of thermal expansion of LWC.

• Proper concrete placement, consolidation, and curing are important factors in achieving crack-free bridge decks.

• Following a proper construction sequence and maintaining a low temperature differential between concrete and air are important for reducing cracks in bridge decks.

• A low permeability value for concrete can be achieved by using fly ash or slag.
1. The cementitious materials content shall be less than or equal to 600 pounds per cubic yard for NWC. The 28-day drying shrinkage shall be less than or equal to 0.035% (based on the average of three specimens) when tested in accordance with ASTM C157.

Specimens shall be moist cured for 7 days prior to testing for drying shrinkage. A shrinkage reducing admixture shall be used unless the 28-day drying shrinkage is less than or equal to 0.035% without the admixture.

2. The cementitious materials content shall be less than or equal to 650 pounds per cubic yard for LWC and the maximum fresh density shall be 120 lb/ft\(^3\).
Included in 2016 Road and Bridge specification


SECTION 217—HYDRAULIC CEMENT CONCRETE

217.12—Low Shrinkage Class A4 Modified Concrete
ACKNOWLEDGEMENT

VTRC
VDOT Central Office and Districts
FHWA
Industry
Questions?

Contact Information:

Harikrishnan.Nair@VDOT.Virginia.gov