Low Cracking - High Performance Concrete (LC-HPC) Bridge Decks

By
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56th Annual Concrete Conference
University of Minnesota
December 7, 2006
Research supported by:

- 15 State DOTs: Delaware, Kansas, Idaho, Indiana, Michigan, Minnesota, Mississippi, Missouri, Montana, New Hampshire, North Dakota, Oklahoma, South Dakota, Texas, Wyoming
- FHWA
- Lead state – Kansas
Outline

- Background
- Experiences
- Laboratory work
Project Scope

20 Low-Cracking High Performance Concrete (LC-HPC) Bridges

So far –

13 planned for Kansas
2 planned for South Dakota
1 planned for Minnesota
1 planned for Missouri
Selection of Bridges

Composite steel girder bridges
Full-depth slabs
Removable forms
Matching bridges to serve as a control where possible
Background

Why we use LC-HPC

Specifications for LC-HPC decks
Crack Surveys

Composite steel girder bridges
3 deck types
  Monolithic
  Conventional Overlay
  Silica Fume Overlay
3 studies – over 11 years
76 bridges
160 individual concrete placements
139 surveys
Factors

- Age
- Bridge Deck Type
- Material Effects
- Site Conditions - Temperature
- Date of Construction
Age
Bridge Deck Type

Monolithic
Conventional Overlay
Silica Fume Overlay

Overlay decks evaluated based on the properties of the subdeck
Crack Density, m/m²

<table>
<thead>
<tr>
<th>Bridge Deck Type</th>
<th>Number of Bridges</th>
<th>Number of Surveys</th>
</tr>
</thead>
<tbody>
<tr>
<td>7% SFO</td>
<td>(9)</td>
<td>(9)</td>
</tr>
<tr>
<td>5% SFO</td>
<td>(18)</td>
<td>(36)</td>
</tr>
<tr>
<td>CO</td>
<td>(30)</td>
<td>(52)</td>
</tr>
<tr>
<td>MONO</td>
<td>(16)</td>
<td>(32)</td>
</tr>
</tbody>
</table>

Age Corrected
Material Effects

Concrete Mixture Proportions
- Water content
- Cement content
- Volume of cement paste
- Slump
- Compressive Strength
- Air content
Water content
Crack Density, m/m²

Water Content, kg/m³ (lb/yd³)

Number of Placements

Number of Surveys

Monolithic
Cement content
Cement Content, kg/m³ (lb/yd³)

Crack Density, m/m²

Age Corrected

Number of Placement
(24) (8)

Number of Surveys
(47) (16)

Monolithic
Volume of cement paste
The chart illustrates the crack density in monolithic concrete, measured as Crack Density (m/m²) for different ages (26, 27, 28, 29). The values are age-corrected and represent the percent volume of water and cement (%). The number of placements and surveys for each age are also indicated:

- **Age 26**: Crack Density = 0.19, Number of Placements = 8, Number of Surveys = 16
- **Age 27**: Crack Density = 0.16, Number of Placements = 16, Number of Surveys = 31
- **Age 28**: Crack Density = 0.68, Number of Placements = 4, Number of Surveys = 8
- **Age 29**: Crack Density = 0.73, Number of Placements = 5, Number of Surveys = 11
Slump
Crack Density, m/m²

<table>
<thead>
<tr>
<th>Slump, mm (in.)</th>
<th>Number of Placements</th>
<th>Number of Surveys</th>
</tr>
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<tbody>
<tr>
<td>38 (1.5)</td>
<td>(5)</td>
<td>(10)</td>
</tr>
<tr>
<td>51 (2.0)</td>
<td>(20)</td>
<td>(40)</td>
</tr>
<tr>
<td>64 (2.5)</td>
<td>(5)</td>
<td>(11)</td>
</tr>
<tr>
<td>76 (3.0)</td>
<td>(1)</td>
<td>(3)</td>
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</table>

<table>
<thead>
<tr>
<th>Crack Density</th>
<th>Uncorrected</th>
<th>Adjusted for Water Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.18</td>
<td>0.11</td>
<td>0.15</td>
</tr>
<tr>
<td>0.31</td>
<td>0.15</td>
<td>0.19</td>
</tr>
<tr>
<td>0.51</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>0.87</td>
<td>0.22</td>
<td></td>
</tr>
</tbody>
</table>

Monolithic
Compressive Strength
Compressive Strength, MPa (psi)

Crack Density, m/m²

<table>
<thead>
<tr>
<th>Age Corrected</th>
<th>Number of Placements</th>
<th>Number of Surveys</th>
</tr>
</thead>
<tbody>
<tr>
<td>31 (4500)</td>
<td>(7)</td>
<td>(13)</td>
</tr>
<tr>
<td>38 (5500)</td>
<td>(12)</td>
<td>(24)</td>
</tr>
<tr>
<td>45 (6500)</td>
<td>(10)</td>
<td>(23)</td>
</tr>
<tr>
<td></td>
<td>0.16</td>
<td></td>
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<tr>
<td></td>
<td>0.26</td>
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<td></td>
<td>0.49</td>
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Air content
Monolithic

<table>
<thead>
<tr>
<th>High Air Temperature, C (F)</th>
<th>Crack Density, m/m²</th>
<th>Number of Placements</th>
<th>Number of Surveys</th>
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<tbody>
<tr>
<td>5 (41)</td>
<td>0.19</td>
<td>(4)</td>
<td>(8)</td>
</tr>
<tr>
<td>15 (59)</td>
<td>0.33</td>
<td>(15)</td>
<td>(31)</td>
</tr>
<tr>
<td>25 (77)</td>
<td>0.37</td>
<td>(9)</td>
<td>(17)</td>
</tr>
<tr>
<td>35 (95)</td>
<td>0.44</td>
<td>(4)</td>
<td>(9)</td>
</tr>
</tbody>
</table>
Monolithic

Crack Density, m/m²

Age Corrected

Number of Placements: (2) (20) (10)
Number of Surveys: (4) (42) (19)

Daily Temperature Range, C (F)

0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90

4 (7) 12 (22) 20 (36)

0.14 0.30 0.44
Crack Density, m/m²

<table>
<thead>
<tr>
<th>Date of Construction</th>
<th>Number of Bridges</th>
<th>Number of Surveys</th>
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</thead>
<tbody>
<tr>
<td>1984-1987</td>
<td>(6)</td>
<td>(12)</td>
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<tr>
<td>1990-1993</td>
<td>(7)</td>
<td>(16)</td>
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</tbody>
</table>

Monolithic
### Conventional Overlays

**Crack Density, m/m² (Age Corrected)**

- **1985-1987**: 0.24
- **1990-1992**: 0.53
- **1993-1995**: 0.81

**Date of Construction**

<table>
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<tr>
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<th>Number of Surveys</th>
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<td>1985-1987</td>
<td>(6)</td>
<td>(6)</td>
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<tr>
<td>1990-1992</td>
<td>(17)</td>
<td>(36)</td>
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<tr>
<td>1993-1995</td>
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<td>(6)</td>
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</table>
Silica Fume Overlays

Crack Density, m/m²

Date of Construction

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<tr>
<th>Date</th>
<th>Number of Bridges</th>
<th>Number of Surveys</th>
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<td>1990-1991</td>
<td>(2)</td>
<td>(6)</td>
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<td>1995-1996</td>
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<td>1997-1998</td>
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<td>2000-2002</td>
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Control of Early Evaporation
Silica Fume Overlays

Crack Density, m/m^2

<table>
<thead>
<tr>
<th>Special Provision, (R#)</th>
<th>Number of Bridges</th>
<th>Number of Surveys</th>
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<tr>
<td>NONE</td>
<td>(2)</td>
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<td>R1, R2</td>
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<td>R3</td>
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<td>R4, R5, R6</td>
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<td>R8, R9</td>
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The chart shows the crack density in m/m^2 for different special provisions (R1 to R9). The density values range from 0.39 to 0.87. The number of bridges and surveys associated with each special provision are also listed.
Overall Approach

Low cement & water contents
Low slump
High strength is not always good
Low evaporation rate
Construction methods and materials matter
More early cracking means more total cracking
LC-HPC

- 1 inch Max Size Aggregate
- Optimized Aggregate Gradation
- Cement Content < 535 lb/yd³
- Air Content of 8 ±1½%
- Max w/c ratio of 0.42
- Improved curing
- Controlled temperature
Thermal Cracking

Rule of Thumb: Cracking will result when the temperature of the concrete deck exceeds the temperature of the girders by more than 20° C (36° F).
Thermal Cracking

PennDOT\textsuperscript{1} 15° C (27° F)

KDOS 14° C (25° F)

\textsuperscript{1} Pennsylvania Department of Transportation, “Prevention of Cracks in Concrete Bridge Decks – Summary Report,” Report No. 89-01, March 1996.
Alternatives to Pumping

- Concrete Buckets
- Conveyor Belts
Consolidation Requirements

Vertically mounted internal gang vibrators
Machine Fogging
Early Wet Burlap Cure – within 10 minutes
Curing

- 14 days wet cure with burlap, soaker hoses, and plastic
- Followed by curing compound to slow the rate of evaporation
Qualification Slab

To demonstrate implementation of the specialized process and address problems before bridge deck casting.

- Process
- Contractor
- Ready Mix Plant
- Inspectors

NO SUPRISES
Selection of Contractors

Prequalified

Multiple bridge contracts (to gain from experience)
Experiences
Kansas Bridges

Unless specifically noted, all control bridges are in the same county as LC-HPC bridge.
# Kansas Bridges - Timeline

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<th>Bridge Groups</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
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- **LET Date**
- **Pre-Construction Meeting**
- **Qualification Slab**
- **Cast Deck**
- **1st Crack Survey**

*Prestressed-Girder Bridge*
Construction experiences
Qualification Slabs 1 and 2 – Fall 2005, Spring 2006 - Kansas City Area
Burlap placement within 10 min and 10 ft of strike off
Qualification slabs

- Contractor learned:
  - Could pump mix
  - Need two bridges to place burlap, pre-fold
  - Fogging could not be used as finishing aid (especially in front of roller)
KsDOT Project Manager: “This proves the value of the trial slab. You can see how much the contractor learned from the beginning to the end of the slab.”
Cores of deck show that finishing methods leave large coarse aggregate particles close to the upper surface of the deck.
Bridge 1: October & November 2005
Bridge superintendent observed that he preferred working with optimized concrete with cement content of 540 lb/yd$^3$ to traditional mix with cement content of 602 lb/yd$^3$. 
Bridge Placements

- Temperature controlled with ice, place at night in mid-summer
- Pumpable even with 1.5-in. slump
- Bullfloating worked well
- Each contractor needs to work on perfecting the art of placing burlap, keeping wet
- Cure barriers same as deck
Conclusions - Experiences

- Optimized concrete mixes with relatively low cement (paste) contents are very pumpable, placeable, and finishable.

- Temperature can be controlled using ice.
• Techniques can be learned easily and workers can become proficient in a short period of time

• Bid prices are dropping as contractors become more familiar with the methods involved
Laboratory Work - Briefly
Average Free Shrinkage (Drying Only). 535 lb/yd^3 Type I/II Cement
Average Free Shrinkage (Drying Only). 535 lb/yd³ Type I/II Cement \(w/cm = 0.42, 23.26\%\) paste
Average Free Shrinkage (Drying Only). \( w/cm = 0.42, 23.26\% \) paste
Average Free Shrinkage (Drying Only). \( \text{w/cm} = 0.42, \) 23.26% paste
Summary

Background

Experiences

Laboratory Work – in brief