Internally Cured Concrete (ICC) For Paving Applications

ACPA Webinar
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ARA, Inc.

SH 121 Dallas, TX
First Internal Cured Concrete Major Highway Pavement 2006
ICC Residential St. (Ft. Worth, TX)
ICC Pavement Projects

• Texas SR 121 freeway north of Dallas, 2006
• Dallas UP Multi-Modal facility, 2005
• Ft. Worth residential streets, 2005+
• Project in Kansas, 2014
  – US-54 in Iola, Kansas (Dave Meggers and Andrew Jenkins)
• Others in planning
Introduction

• ICC has been used successfully on many bridge decks in several States. The primary reason is **reduction of shrinkage cracking & permeability**.

• Use of ICC in pavements would also provide less shrinkage cracking and lower permeability.

• But there are other benefits for pavements:
  – **Improved structural capacity**: small changes in a few key variables may lead to longer structural life.
  – **Potential reduction in slab upward curling/warping**.
  – **Additional durability advantages** such as possible reduction of joint disintegration.
EVALUATION OF
INTERNALLY CURED CONCRETE
FOR PAVING APPLICATIONS

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1 Structural Advantages of Internally Cured Concrete

Small Changes In Key ICC Inputs:
- + Strength
- - Modulus Elasticity
- - Thermal Expansion
- - Unit Weight
- - Shrinkage
- - Curling/Warping
Curl/Warp of Slabs

• Upward curling of JPCP & CRCP is critical!
• Note the shadow under string line, about 4 mm.
• If Internal Curing reduces moisture gradient curling, major benefit to reduce top down cracking!
• Research underway at U of Illinois (Prof Roesler)
Upward Curl & Top Down
Transverse & Longitudinal Cracking
Upward Curling From Moisture Gradient

Just after placement – flat slab, no gradient

Over time, greater surface shrinkage occurs. Top down cracking may develop rapidly over time (plus temp. gradient)
Upward Curling, CA 1949
(CRCP & JPCP Profile)
Top-Down Punchout Cracking Mechanism

Traffic

Critical Stress Location Top of Slab

Transverse Crack

Pavement Edge
2 EXISTING ICC FIELD PROJECTS

SH 121 Dallas

Fort Worth Residential

UP Intermodal Dallas
SR 121 Dallas, ICC Shoulder & Right Lane

Experimental section begins and continues SB/WB. Note where the color of the pavement surface turns darker.
SH 121 Project Details

• 13-in CRCP (very thick design, AASHTO 93)
  – 0.7 percent longitudinal steel
• 4-in asphalt base layer
• 10-in Lime treated base layer
• AASHTO A-7-6 subgrade (from USGS Soil Maps)
## SH 121 IC Concrete Mix Design

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement type I / II</td>
<td>413 lb/yd³</td>
</tr>
<tr>
<td>Fly ash class C</td>
<td>91 lb/yd³</td>
</tr>
<tr>
<td>1” - #4 Limestone</td>
<td>1084 lb/yd³</td>
</tr>
<tr>
<td>1 1/2” – ¾” Limestone</td>
<td>706 lb/yd³</td>
</tr>
<tr>
<td>Concrete sand</td>
<td>857 lb/yd³</td>
</tr>
<tr>
<td><strong>Intermediate lightweight aggregate</strong></td>
<td>300 lb/yd³</td>
</tr>
<tr>
<td>Water</td>
<td>241 lb/yd³</td>
</tr>
<tr>
<td>Air entraining agent</td>
<td>2.5 oz</td>
</tr>
<tr>
<td>Water reducer</td>
<td>15 oz</td>
</tr>
</tbody>
</table>
SH 121 Dallas, TX
CRCP 2006
# PCC Properties, SH 121

<table>
<thead>
<tr>
<th>Property</th>
<th>Control</th>
<th>ICC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness, inch</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Unit weight, pcf</td>
<td>143</td>
<td>137</td>
</tr>
<tr>
<td>CTE, $x 10^{-6}$ in/in/°F</td>
<td>4.8</td>
<td>4.3</td>
</tr>
<tr>
<td>Zero-stress temperature</td>
<td>78.2</td>
<td>74</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>5200</td>
<td>6000</td>
</tr>
<tr>
<td>Aggregate type</td>
<td>Limestone</td>
<td>Limestone</td>
</tr>
<tr>
<td>w/c ratio</td>
<td>0.48</td>
<td>0.48</td>
</tr>
<tr>
<td>Perm Curl/Warp</td>
<td>-10 F</td>
<td>-10 F</td>
</tr>
</tbody>
</table>
Shrinkage of Conventional and ICC
Kim & Won 2008

The graph shows the measured strain in millionths of an inch (10^-6 in/in) over time after placement in days. The x-axis represents time after placement in days, ranging from 0 to 30. The y-axis represents measured strain, with values ranging from -250 to 0. The graph includes two main lines, one for shrinkage with light weight aggregate and another for normal aggregate, along with temperature measurements for both light weight and normal aggregate. The assumed CTE (Coefficient of Thermal Expansion) is 4.0 x 10^-6/°F.
Crack Patterns 2013
## CRCP Crack Spacing

<table>
<thead>
<tr>
<th>Year</th>
<th>Inside Lane (Control)</th>
<th>Adjacent Lane (Control)</th>
<th>ICC Lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>Construction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>9.4 ft</td>
<td>9.4 ft</td>
<td>22.7 ft</td>
</tr>
<tr>
<td>2009</td>
<td>7.4</td>
<td>7.2</td>
<td>8.6</td>
</tr>
<tr>
<td>2010</td>
<td>6.5</td>
<td>7.0</td>
<td>8.9</td>
</tr>
<tr>
<td>2011</td>
<td>6.9</td>
<td>7.6</td>
<td>7.7</td>
</tr>
<tr>
<td>2012</td>
<td>5.7</td>
<td>6.1</td>
<td>6.4</td>
</tr>
<tr>
<td>AASHTO Prediction</td>
<td>5.6</td>
<td>5.6</td>
<td>6.3</td>
</tr>
</tbody>
</table>
SH 121 CRCP Crack Spacing

Mean Crack Spacing, Ft.

Years (Construction 2006)

IC Concrete
Conventional
Predicted
Crack Opening ICC and Conventional
(10 Months, Friggle and Reeves, 2008)
Assumptions for LCCA

• Unit Cost In-place Concrete/Reinforcement.
  – PCC slab
    • Concrete materials cost was reported as $10/CY additional for ICC in Dallas area.
      – Conventional concrete CRCP: $160/CY
      – IC Concrete CRCP: $170/CY
    – Conventional concrete JPCP: $147/CY
    – IC Concrete JPCP: $157/CY (7% increase)
## AASHTO ME Design Results

<table>
<thead>
<tr>
<th>Design Feature</th>
<th>Conventional Concrete</th>
<th>Internally Cured Concrete</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRCP thickness</td>
<td>11.0 in</td>
<td>10.0 in</td>
<td>Difference due to the concrete mixture properties</td>
</tr>
<tr>
<td>Percent longitudinal reinforcement</td>
<td>0.7</td>
<td>0.7</td>
<td>Same</td>
</tr>
<tr>
<td>Base course</td>
<td>4-in HMA</td>
<td>4-in HMA</td>
<td>Same</td>
</tr>
<tr>
<td>Lime stabilized subgrade</td>
<td>10-in</td>
<td>10-in</td>
<td>Same</td>
</tr>
<tr>
<td>Subgrade</td>
<td>A-7-6</td>
<td>A-7-6</td>
<td>Same</td>
</tr>
</tbody>
</table>
# Predicted Performance CRCP: 50-Years

<table>
<thead>
<tr>
<th>AASHTO ME Performance</th>
<th>Conventional PCC</th>
<th>ICC</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRI in/mile</td>
<td>141</td>
<td>110</td>
<td>ICC lower</td>
</tr>
<tr>
<td>Punchouts No./mile</td>
<td>22</td>
<td>5</td>
<td>ICC lower</td>
</tr>
<tr>
<td>Crack Spacing, inch</td>
<td>66</td>
<td>68</td>
<td>Same crack spacing</td>
</tr>
<tr>
<td>Crack Width, inch</td>
<td>17*10^{-3} in</td>
<td>12*10^{-3} in</td>
<td>ICC tighter cracks</td>
</tr>
<tr>
<td>Crack LTE</td>
<td>60</td>
<td>99</td>
<td>Higher LTE</td>
</tr>
</tbody>
</table>
SH 121 Site CRCP Summary

• CRCP slab thickness
  – Conventional concrete was 11-in.
  – ICC was 10-in.

• ICC lower initial construction cost: **5 percent** (due to overall net effect of reduction in CRCP thickness & reinforcement & increase in IC concrete cost).

• Maintenance and rehabilitation net present cost: ICC lower cost: **21 percent** (due to reduced punchouts)
Union Pacific Intermodal Facility
JPCP, 2005
UP Intermodal Terminal, 2005
Curling Measurement at UP Intermodal Project

- No measureable up-ward curling of any slab measured after 8 years of service.
Durability for UP Terminal ICC

• No concrete durability problems were noted during the field survey at 8 years age.
  – No plastic or drying shrinkage
  – No random cracking
  – No scaling or spalling
# Concrete Inputs

<table>
<thead>
<tr>
<th>Inputs (Measured or Est.)</th>
<th>Control</th>
<th>ICC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit weight, pcf</td>
<td>145</td>
<td>137</td>
</tr>
<tr>
<td>CTE, $\times 10^{-6}$ in/in/$°$F</td>
<td>4.8</td>
<td>4.3</td>
</tr>
<tr>
<td>Compressive strength, psi</td>
<td>5130</td>
<td>6070</td>
</tr>
<tr>
<td>Coarse aggregate (Limestone)</td>
<td>NA</td>
<td>49%</td>
</tr>
<tr>
<td>Fine aggregate (Natural Sand)</td>
<td>NA</td>
<td>35%</td>
</tr>
<tr>
<td>Intermediate Light Wt. Agg.</td>
<td>0</td>
<td>16%</td>
</tr>
<tr>
<td>w/cm ratio</td>
<td>0.43</td>
<td>0.43</td>
</tr>
<tr>
<td>Permanent (Upward) Curling</td>
<td>-10 F</td>
<td>-10 F</td>
</tr>
</tbody>
</table>
AASHTO ME Project Analysis

• 240 trucks per day per lane
  – Class 9 single trailer trucks
• 8.5 inch JPCP, 12 X 15-ft joint spacing
• 12 inch aggregate base on subgrade
• Construction through several months (all seasons)
  – Measured zero curling in the slab with string line
• 60-yr analysis period
AASHTO ME Prediction Cracking

Conventional Concrete

Internally Cured Concrete
UP Terminal JPCP LCCA

• JPCP slab thickness
  – Conventional concrete was 9-in.
  – ICC was 8.5-in.

• Overall LCCA savings over 60-years was 0.9 percent.

• The LCCA is related to structural capability of the pavement.

• Other benefits from improved durability of the JPCP may be much greater.
Fort Worth, Texas Residential
ICC 2005, Excellent Condition
(Windsor Park, South Forth Worth 2005)

Note black specs in top of concrete slab are LWA
ICC 2005, Excellent Condition
Alexandria Meadows, North Ft. Worth, TX
Residential Concrete Pavements

- Two sub-divisions in Fort Worth, TX
- Traffic – Relatively low traffic
  - 10 trucks/day
- Jointed plain concrete with no dowel bars
- 12 x 15-ft slabs
- Slab thickness = 7 inches
- Intermediate size light weight aggregate
- Curling measured 2013: Zero diagonal corner to corner curl
Ground Off ICC Surface
Alexandria Meadows, North Ft. Worth, TX
3 Concrete Pavement Durability

• There has been a large amount of concrete pavement durability failures over the past 6 decades!
  – “D” Cracking and disintegration
  – ASR cracking and disintegration
  – Plastic shrinkage cracking and scaling
  – Cracking and disintegration from insufficient entrained air voids
  – Joint “rot” or disintegration of the lower portion of the concrete slab. This is a critical problem in the midwest that is begging for a solution.

• How many of these major problems can ICC help to reduce?
Joint Durability Problems
Many slabs were removed and replaced with this shrinkage cracking.
Random Cracks
Plastic Shrinkage Cracks
ICC Pavement & Durability

• Lots of opportunity in concrete pavements for ICC to show benefits.

• Bridge deck benefits should be directly applicable and useful to pavements, however, ICC may be even more beneficial for pavement (more PCC saturation in pavements).

• **Slab replacement & full depth repair**, early opening slabs often exhibit early cracking from high shrinkage.
  
  – ICC may prevent some of these cracks from developing.
High Early Strength ICC to Avoid Cracks
I-635 Off Ramp, Dallas, TX
4 Conclusions: ICC & Pavements

• Changes that occur in a concrete mixture when a small proportion of LWA is introduced are beneficial to JPCP & CRCP from structural & from durability points of view.

• **Structural benefits:** The AASHTO ME Design procedure was utilized to analyze several existing CRCP and JPCP projects. The long term performance predictions show ICC with less cracking than conventional for same thickness.
Conclusions: ICC & Pavements

• **Durability:** ICC has a distinct advantage in reducing shrinkage cracking, permeability, scaling, and less upward curling. Long life PCC pavements must be durable for 40-60+ years.

• **Construction Costs:** Initial construction cost of an ICC pavement is higher if same thickness as conventional is considered. Initial construction cost is slightly lower if ICC inputs are used to design pavement, due to a 0.5 to 1.0-inch thickness reduction.
Conclusions: ICC & Pavements

• **LCCA analysis** estimated the net present worth of a couple sections comparing conventional concrete and internally cured concrete CRCP and JPCP.

• Results showed that the ICC alternative had a lower net present cost over a 50-60 year period based only on structural considerations. **Durability benefits**, however, may decrease deterioration and thus reduce costs substantially.
Recommendations

• **Construct some ICC test sections** as recently happened in the State of Kansas and monitor their performance over time.