CAPTURING 30+ YEARS OF REAL LIFE PERFORMANCE OF CONCRETE OVERLAYS

Dan King, E.I.T.
Iowa Concrete Paving Association
Iowa’s History of Concrete Overlays
Performance Study—Background & Objectives
Results & Analysis
Lessons Learned & Future of Concrete Overlays
ACKNOWLEDGMENTS

- Full report: Concrete Overlay Performance on Iowa’s Roadways
  - Phase I of Iowa Highway Research Board TR-689
- Project team:
  - CP Tech Center: Jerod Gross, Dale Harrington, Dr. Peter Taylor
  - Iowa State University: Yu-An Chen, Dr. Halil Ceylan, Inya Nnelanya, Dr. Omar Smadi
IOWA’S HISTORY OF CONCRETE OVERLAYS

Concrete overlays: increasing use and acceptance nationwide over past few decades

CP Tech Center Guide:
IOWA’S HISTORY OF CONCRETE OVERLAYS

- Overlay types:
  - Bonded Concrete Overlay of Concrete (BCOC)
  - Bonded Concrete Overlay of Asphalt (BCOA)
  - Unbonded Concrete Overlay of Concrete (UBCOC)
  - Unbonded Concrete Overlay of Asphalt (UBCOA)
IOWA’S HISTORY OF CONCRETE OVERLAYS

- Iowa: over 2,000 centerline miles of concrete overlays have been constructed since the late ‘70s
  - Over half constructed since 2005
  - Mostly on county highway system
IOWA’S HISTORY OF CONCRETE OVERLAYS

- Early experimentation
  - Bonded concrete resurfacing of concrete
  - Many BCOC projects constructed over the years, but have fallen out of favor since the 80s & 90s

Plans for US 30, 1949

Experimental Concrete Overlay, 1970s
IOWA’S HISTORY OF CONCRETE OVERLAYS

- “Whitetopping” projects begin to emerge in 1970s
  - Concrete over asphalt
- By late 1970s, they begin to be constructed regularly on county highways

Storm Lake Airport, 1971
IOWA’S HISTORY OF CONCRETE OVERLAYS

- “Whitetopping” projects begin to emerge in 1970s
  - Concrete over asphalt
- By late 1970s, they begin to be constructed regularly on county highways
**IOWA’S HISTORY OF CONCRETE OVERLAYS**

- Prevailing early whitetopping designs: 6 inch PCC over HMA
- PCC/HMA bond
  - Tendency is for the two layers to bond together
  - Early designs did not consider bond in design or construction
- Modern convention:
  - **BCOA**: PCC ≤ 6 in.
  - **UBCOA**: PCC > 6 in.

Washington County, IA, Constructed 1977
IOWA’S HISTORY OF CONCRETE OVERLAYS

- 1980s: Unbonded concrete overlays of concrete (UBCOC) begin construction
  + Again, predominantly on county highways
  + HMA interlayer becomes the preferred method of de-bonding
  + 2000s: geotextile interlayer is introduced
1990s: Experiments begin with “Ultra-thin Whitetopping”

- Thin PCC overlay (3-6 inches)
- Designed to bond to underlying HMA for structural support
  - Bond is critical
- Shorter joint spacings help reduce stresses, reduce slab curling
IOWA’S HISTORY OF CONCRETE OVERLAYS

- Modern era of overlays of asphalt:
  + In some Iowa cities and counties (and with Iowa DOT), thin BCOA designs have become popular
    - Commonly 4 or 5 inch PCC over HMA
    - 5 to 6 ft joint spacing
    - Fiber-reinforced

- Thin UBCOC have also been constructed w/ short slab designs

Le Mars, IA, Constructed 2013
IOWA’S HISTORY OF CONCRETE OVERLAYS

- Modern era of overlays of asphalt:
  - Many Iowa counties continue to build 6+ inch PCC overlays of asphalt (BCOA/UBCOA) with conventional joint spacing

Buchanan County, IA, Constructed 2013
Concrete overlays have been used successfully in Iowa for decades

- Grown over time to comprise 20-30% of Iowa’s annual PCC paving market (1 to 2 million SY annually)
- 60-80% of Iowa’s annual county PCC paving market (800k to 1 million SY annually)
Despite this history, we still needed to define how these overlays were performing

- What kind of service life can we expect when we build a new concrete overlay? From our existing overlays?
- What makes particular projects successful? What hasn’t worked?
What did we already know?

- Approximately 470/506 overlay projects still in service as of 2015
- Includes 68/96 constructed before 1990
- Compare to older sources that indicate expected service life for a concrete overlay is only about 20 years
PERFORMANCE STUDY

- Project Objectives:
  + Plot performance data
  + Analyze specific design choices and characteristics and link to performance
    - Thickness
    - Joint spacing
    - Traffic
    - Overlay type (thin bonded, unbonded)
  + Field reviews to verify findings
- Incorporate lessons learned to improve overlay design and performance
- Iowa Pavement Management Program (IPMP)
  + Organizes automated pavement condition data collected for local agencies
  + Program began in early 2000s (opt-in)
  + Since 2013, all streets & roads are covered every other year
- This data then combined with ICPA overlay project records to produce the complete data set
Full data set contains all overlay types and designs:

- **BCOA**: 47% (Number of projects: 178)
- **UBCOA**: 18% (Number of projects: 69)
- **UBCOC**: 32% (Number of projects: 125)
- **BCOC**: 3% (Number of projects: 13)

Note: Total number of projects is 385
## PERFORMANCE STUDY

### Data distribution based on overlay thickness:

<table>
<thead>
<tr>
<th>PCC slab thickness (in.)</th>
<th>Total number of projects</th>
<th>Percent of data based on number of projects (%)</th>
<th>Project length (mile)</th>
<th>Percent of data based on length of projects (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;3</td>
<td>8</td>
<td>2</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
<td>13</td>
<td>283</td>
<td>19</td>
</tr>
<tr>
<td>5</td>
<td>36</td>
<td>9</td>
<td>178</td>
<td>12</td>
</tr>
<tr>
<td>6</td>
<td>186</td>
<td>48</td>
<td>621</td>
<td>41</td>
</tr>
<tr>
<td>7</td>
<td>42</td>
<td>11</td>
<td>177</td>
<td>12</td>
</tr>
<tr>
<td>8</td>
<td>52</td>
<td>13</td>
<td>165</td>
<td>11</td>
</tr>
<tr>
<td>9</td>
<td>8</td>
<td>2</td>
<td>45</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>2</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>387</td>
<td>100</td>
<td>1,499</td>
<td>100</td>
</tr>
</tbody>
</table>
PERFORMANCE STUDY

- Performance characterized by PCI (Pavement Condition Index) & IRI (Int’l. Roughness Index)
- IPMP PCI equation incorporates:
  - IRI (accounts for 40% of PCI)
  - Transverse Cracking
  - Joint Spalling
  - D-cracking

(Faulting considered separately)

Le Mars, IA, Constructed 2011
PERFORMANCE STUDY

- Performance charts:
- PCI scale:
  - Excellent: 81-100
  - Good: 61-80
  - Fair: 41-60
  - Poor: 21-40
  - Very Poor: 0-20
RESULTS & ANALYSIS

Data set as a whole:

Total number of data points: 1,212
Total number of projects: 385

Figures: Chen and Ceylan
RESULTS & ANALYSIS

• Data set as a whole:

![Graph showing IRI vs. Age for different pavement conditions with FHWA Threshold at 170 in/mile. R² = 0.27, ~40 years to IRI = 170. Total number of data points: 1,212, Total number of projects: 385. Figures: Chen and Ceylan.]
RESULTS & ANALYSIS

- BCOA only (organized by thickness):

**Figure:** Chen and Ceylan

![Graph showing PCC slab thickness (PCI vs. Age) with different lines for 4 in., 5 in., and 6 in. thicknesses.](image)
RESULTS & ANALYSIS

✓ BCOA only (organized by joint spacing):

**Short slab designs**

PCI = 60%

Total number of data points: 428
Total number of projects: 162

Figures: Chen and Ceylan
RESULTS & ANALYSIS

 UBCOA only (organized by thickness):

![Graph showing PCC slab thickness (PCI vs. Age)]

- Excellent
- Good
- Fair
- Poor
- Very Poor

PCI = 60%

R² = 0.17
R² = 0.56

Total number of data points: 172
Total number of projects: 61

Figures: Chen and Ceylan
RESULTS & ANALYSIS

× UBCOC only (organized by thickness):

![Graph showing PCC slab thickness (PCI vs. Age)]

- R² = 0.86
- R² = 0.47
- R² = 0.28
- R² = 0.03

- PCI (PCC slab thickness) 5 in.
- PCI (PCC slab thickness) 6 in.
- PCI (PCC slab thickness) 7 in.
- PCI (PCC slab thickness) 8 in.

Poly. (PCI (PCC slab thickness) 5 in.)
Poly. (PCI (PCC slab thickness) 6 in.)
Linear (PCI (PCC slab thickness) 7 in.)
Linear (PCI (PCC slab thickness) 8 in.)

Total number of data points: 451
Total number of projects: 117

Figures: Chen and Ceylan
RESULTS & ANALYSIS

Key findings and trends:

+ Overall performance of Iowa’s concrete overlays has been excellent
  √ As a whole: approximately 35 years to PCI = 60
  √ Approximately 40 years to IRI = 170 in/mi

+ Good performance from each of BCOA, UBCOA & UBCOC
  √ Overlays of asphalt performed slightly better than UBCOC
  √ BCOC: less successful overall, but performed well in context of design life expectations
RESULTS & ANALYSIS

Key findings and trends:

• Thickness
  • In general: thicker overlays have performed better for all overlay types (e.g. for BCOA, 6 in. > 5 in. > 4 in.)

• Transverse joint spacing
  • Good early performance from short slab designs (6 in.) on BCOA/thin overlays
  • Older designs with conventional joint spacing performed well over longer periods of time

• Traffic—inconclusive
  • Most of these projects are low-volume, <1,000 vpd
  • Not enough truck traffic data available from local agencies
RESULTS & ANALYSIS

 Field reviews

+ Performed to supplement data analysis, verify findings, and investigate trends & outliers

~5% of data points were “outliers”
RESULTS & ANALYSIS

- Observed distresses:
  - Joint deterioration

Pottawattamie County, IA, Constructed 1992
RESULTS & ANALYSIS

× Observed distresses:

+ Materials-related
RESULTS & ANALYSIS

✓ Observed distresses:
  + Rough ride—construction or curling/warping
  + Occasionally (but rarely) faulting

Buchanan County, IA, Constructed 1996
RESULTS & ANALYSIS

❌ Observed distresses:

+ Load-related, possibly mis-designed or under-designed
  ❌ Inadequate thickness
  ❌ Curling/too large of slabs

Dallas County, IA, Constructed 2006
LESSONS LEARNED

✗ Poor performing outliers & early failure causes:

  + Materials-related distresses (most common)
  + Load-related/under-design
  + Rough ride

✗ These are many of the same issues we run into with conventional PCC pavements
LESSONS LEARNED

- Iowa’s concrete overlays have performed very well overall
  - Based on performance data, they can be designed to last 30+ years
  - Observed performance generally matches data
  - Concrete overlays are very well-suited to county highways
  - Good success to date on interstate, state highways, and city streets as well

Pottawattamie County, IA, Constructed 1993
LESSONS LEARNED

- With proper materials, construction and design, there is still plenty of room to improve performance!
LESSONS LEARNED

- With proper materials, construction and design, there is still plenty of room to improve performance!

<table>
<thead>
<tr>
<th>Cause of Poorer Performance (Data Outlier)</th>
<th>Recommendations for Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material-related distress</td>
<td>Use high-quality materials</td>
</tr>
<tr>
<td></td>
<td>Use water/cement ratio 0.40 to 0.43</td>
</tr>
<tr>
<td></td>
<td>Use proper air entrainment system</td>
</tr>
<tr>
<td>Structural failure</td>
<td>Plan for future truck traffic</td>
</tr>
<tr>
<td></td>
<td>Use overlay design software:</td>
</tr>
<tr>
<td></td>
<td>(ACPA StreetPave, BCOA-ME, ACPA BCOA, AASHTO Pavement ME)</td>
</tr>
<tr>
<td>Inadequate drainage system</td>
<td>Properly drain existing pavement and new overlays (BCOA, UBCOA, and UBCOC)</td>
</tr>
<tr>
<td></td>
<td>Consider surface and joints</td>
</tr>
<tr>
<td>Excessive joint spacing</td>
<td>Refer to Guide to Concrete Overlays, Third Edition (Harrington and Fick 2014)</td>
</tr>
</tbody>
</table>
FUTURE OF CONCRETE OVERLAYS

Where do we go from here?

+ Move from performance history $\rightarrow$ survivability, performance models (MIT)

+ Results of this study & other ongoing research can be used to further improve and optimize PCC overlay design
FUTURE OF CONCRETE OVERLAYS

- Phase II research: optimized joint spacing
  - Thin overlays (4-6 in.) commonly have short joint spacing
  - Based on performance results, are smaller slabs necessary for county highways with low traffic volumes?
    - Potential savings in initial cost + maintenance
    - Cracks don’t always form beneath joints on concrete overlays

Mitchell County, IA, Constructed 2015
FUTURE OF CONCRETE OVERLAYS

- Phase II research: optimized joint spacing
  - How does using fiber-reinforced concrete (FRC) play into optimized joint spacing?
    - Helps keep cracks and joints tight
    - Reduces slab curling?
FUTURE OF CONCRETE OVERLAYS

- Phase II research: optimized joint spacing
  - Construction of FRC test sections in Mitchell County, IA
    - 4 and 6 in. BCOA
FUTURE OF CONCRETE OVERLAYS

- Phase II research: optimized joint spacing
- Construction of FRC test sections in Mitchell County, IA
FUTURE OF CONCRETE OVERLAYS

- Phase II research: optimized joint spacing
  + Construction of FRC test sections in Mitchell County, IA
FUTURE OF CONCRETE OVERLAYS

- Phase II research: optimized joint spacing
  + Construction of FRC test sections in Mitchell County, IA
FUTURE OF CONCRETE OVERLAYS

- Phase II research: optimized joint spacing
  - Construction of FRC test sections in Mitchell County, IA
FUTURE OF CONCRETE OVERLAYS

- Phase II research: optimized joint spacing
  - Construction of FRC test sections in Mitchell County, IA
FUTURE OF CONCRETE OVERLAYS

- Phase II research: optimized joint spacing
  - Test sections will be analyzed to measure whether all cracks develop beneath joints, along with slab curling
  - Will help determine optimized joint spacing & effect of FRC
FUTURE OF CONCRETE OVERLAYS

Thinking farther ahead...

- Fibers give concrete more ductility (ability to deform under tensile stress)
- With innovations in fiber technology, are joint-free, continuously fiber-reinforced overlays a possibility?
FUTURE OF CONCRETE OVERLAYS

- Thinking farther ahead...
  + Internal curing
    - Has been shown to reduce shrinkage, slab curling
    - Greatest potential impact for PCC pavements: overlays?
    - Particularly impactful on joint spacing?