Expected Performance of MnRoad Composite Pavements

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August 23, 2010
MnRoad Open House
Presentation

• Performance measures
• Initial performance results
• Prediction of future performance
  – HMA / RCA
  – EAC / RCA
  – EAC / LCC
• Summary
Performance Measures

• HMA surface on Recycled Aggregate Concrete (RCA): Initial & over Time
  – Smoothness, IRI
  – Texture depth
  – Noise
  – Friction
  – Rutting
  – Fatigue Cracking (transverse, longitudinal)
  – Joint Reflection Cracking (HMA)
    • No treatment
    • Saw & Sealed joints cut in HMA
Performance Measures

• Instrumentation results (not exactly performance measures, but affect they may performance)
  – Temperature gradations
  – Moisture gradations
  – Dynamic strains (from moving wheel loads)
  – Vibrating wire strains (temperature & moisture)
Performance Measures

• EAC surface of Recycled Concrete Aggregate (RCA) & Low Cost Concrete (LCC): Initial & over Time
  – Smoothness, IRI
  – Texture depth
  – Noise
  – Friction
  – Fatigue Cracking (transverse, longitudinal)
## Initial Results: Noise

<table>
<thead>
<tr>
<th>Surface</th>
<th>Sound Intensity Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMA</td>
<td>???</td>
</tr>
<tr>
<td>Exposed Aggregate Concrete</td>
<td>101.7 dBA</td>
</tr>
<tr>
<td>Conventional Diamond Grind of EAC</td>
<td>100.4 dBA</td>
</tr>
<tr>
<td>Next Generation Concrete Surface (Special grinding) of EAC</td>
<td>98.8 dBA</td>
</tr>
</tbody>
</table>
**Initial Smoothness: IRI**

<table>
<thead>
<tr>
<th>Surface</th>
<th>IRI, in/mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMA</td>
<td>???</td>
</tr>
<tr>
<td>Exposed Aggregate Concrete</td>
<td>???</td>
</tr>
<tr>
<td>Conv. Diamond Grind of EAC</td>
<td>???</td>
</tr>
<tr>
<td>Improved Diamond Grind of EAC</td>
<td>???</td>
</tr>
</tbody>
</table>

Results to be obtained from MnRoad soon.
## Initial Texture, inches
ASTM E 965

<table>
<thead>
<tr>
<th>Surface</th>
<th>Texture Depth, in</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMA</td>
<td>0.334</td>
</tr>
<tr>
<td>Exposed Aggregate Concrete</td>
<td>0.784</td>
</tr>
<tr>
<td>Conv. Diamond Grind of EAC</td>
<td>1.127</td>
</tr>
<tr>
<td>Next Generation Diamond Grind of EAC</td>
<td>To be measured</td>
</tr>
</tbody>
</table>
## Initial Friction

<table>
<thead>
<tr>
<th>Surface</th>
<th>Friction</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMA</td>
<td>0.656</td>
</tr>
<tr>
<td>Exposed Aggregate Concrete</td>
<td>0.615</td>
</tr>
<tr>
<td>Conv. Diamond Grind of EAC</td>
<td>0.720</td>
</tr>
<tr>
<td>Improved Diamond Grind of EAC</td>
<td>0.547</td>
</tr>
</tbody>
</table>
Prediction Future Performance

• AASHTO Mechanistic-Empirical Pavement Design Guide
  – Overlay design procedure for HMA OL of JPCP & Bonded Concrete OL of JPCP
  – Use for new composite pavements?
    • Some limitations, but with proper inputs can be used.
    – Inputs for new composite pavements for 3 MnRoad sections

• Thickness designs were intended for practicality of two layer constructability. They are not intended for long life.
# Experimental Plan for Construction at MnROAD

<table>
<thead>
<tr>
<th>Cell 70</th>
<th>Cell 71 (433 m (1420 ft))</th>
<th>Cell 72</th>
</tr>
</thead>
<tbody>
<tr>
<td>144 m (474 ft)</td>
<td>76-mm (3-in) HMA (S &amp; S joints except for a few joints)</td>
<td>289 m (947 ft)</td>
</tr>
<tr>
<td>152-mm (6-in) PCC, 4.6-m (15-ft) joints 32-mm (1.25-in) dia. dowels driving lane, nondoweled passing lane. Recycled PCC</td>
<td>152-mm (6-in) PCC, 4.6-m (15-ft) joints, 32-mm (1.25-in) dia. dowels. Recycled PCC (84 m, 275 ft)</td>
<td>152-mm (6-in) PCC, 4.6-m (15-ft) joints, 32-mm (1.25-in) dia. dowels. Low-cost (high fly ash content) PCC (205 m, 672 ft)</td>
</tr>
</tbody>
</table>

- **Cell 70**
  - 144 m (474 ft)
  - 76-mm (3-in) HMA (S & S joints except for a few joints)
  - 152-mm (6-in) PCC, 4.6-m (15-ft) joints 32-mm (1.25-in) dia. dowels driving lane, nondoweled passing lane. Recycled PCC

- **Cell 71**
  - 433 m (1420 ft)
  - 76-mm (3-in) Granite (~145 m (475 ft) diamond grind; ~145 m (475 ft) exposed aggregate)
  - 152-mm (6-in) PCC, 4.6-m (15-ft) joints, 32-mm (1.25-in) dia. dowels. Recycled PCC (84 m, 275 ft)

- **Cell 72**
  - 289 m (947 ft)
  - 76-mm (3-in) Granite (~145 m (475 ft) diamond grind; ~145 m (475 ft) exposed aggregate)
  - 152-mm (6-in) PCC, 4.6-m (15-ft) joints, 32-mm (1.25-in) dia. dowels. Low-cost (high fly ash content) PCC (205 m, 672 ft)

- **203-mm (8-in) Class 5 Special (Granular Base)**
- **Clay Subgrade**
MEPDG Inputs

- Traffic: I-94 WIM data
- Climate: Nearest weather stations
- HMA: Test data from MnDOT.
- Concrete: EAC, RCA, LCC test data from FHWA mobile trailer.
- Subgrade: test data from MnDOT & backcalculation of modulus
- Design: joints, dowels, joint spacing, thickness of layers, shoulders
MEPDG Inputs

• Traffic: I-94 WIM data MP 200 WBL
  – AADT: 29,000
  – Percent Class 4 to 13 trucks: 12
  – Percent trucks outer lane: 78%
  – Axle load distribution: Used MEPDG defaults, need to obtain MnDOT WIM measured on I-94 at MP 200.
### MEPDG Inputs
#### Vehicle Classification Data

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>Percent Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>2.5</td>
</tr>
<tr>
<td>5</td>
<td>12.7</td>
</tr>
<tr>
<td>6</td>
<td>4.2</td>
</tr>
<tr>
<td>7</td>
<td>0.8</td>
</tr>
<tr>
<td>8</td>
<td>3.4</td>
</tr>
<tr>
<td>9</td>
<td>66.9</td>
</tr>
<tr>
<td>10</td>
<td>4.2</td>
</tr>
<tr>
<td>11</td>
<td>1.7</td>
</tr>
<tr>
<td>12</td>
<td>0.8</td>
</tr>
<tr>
<td>13</td>
<td>2.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>
# Climate (5 Weather Stations)

<table>
<thead>
<tr>
<th>Distance</th>
<th>Location</th>
<th>Airport</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation</th>
<th>Months</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.9 miles</td>
<td>MINNEAPOLIS, MN</td>
<td>CRYSTAL AIRPORT</td>
<td>45.04</td>
<td>-93.21</td>
<td>872</td>
<td>101 (C)</td>
<td></td>
</tr>
<tr>
<td>25.0 miles</td>
<td>ST CLOUD, MN</td>
<td>ST CLOUD REGIONAL AIRPORT</td>
<td>45.32</td>
<td>-94.03</td>
<td>1024</td>
<td>116 (M1)</td>
<td></td>
</tr>
<tr>
<td>32.0 miles</td>
<td>MINNEAPOLIS, MN</td>
<td>FLYING CLOUD AIRPORT</td>
<td>44.5</td>
<td>-93.28</td>
<td>922</td>
<td>100 (C)</td>
<td></td>
</tr>
<tr>
<td>34.9 miles</td>
<td>MINNEAPOLIS, MN</td>
<td>MINPLIS-ST PAUL INTL ARPT</td>
<td>44.53</td>
<td>-93.14</td>
<td>874</td>
<td>116 (C)</td>
<td></td>
</tr>
<tr>
<td>39.2 miles</td>
<td>ST PAUL, MN</td>
<td>ST PAUL DWTWN HOLMAN FD AP</td>
<td>44.56</td>
<td>-93.03</td>
<td>711</td>
<td>116 (M6)</td>
<td></td>
</tr>
</tbody>
</table>
MEPDG Inputs

• HMA materials data
  – PG Grade: 64-34
  – Percent asphalt: 5.4 % by weight (assume 10.8% by volume)
  – Percent inplace air voids: 5.5 % measured
  – Density: 148 pcf
  – Gradation of HMA
    • Retained on ¾ in = 0%
    • Retained on 3/8 in = 20%
    • Retained on #4 = 40%
    • Passing #200 = 4.3%
MEPDG Inputs

- Concrete: EAC, RCA, LCA test data

<table>
<thead>
<tr>
<th>Test</th>
<th>EAC</th>
<th>RCA</th>
<th>LCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexural Strength, psi</td>
<td>854 psi</td>
<td>677</td>
<td>548</td>
</tr>
<tr>
<td>Modulus of Elasticity, psi</td>
<td>4.9 M psi</td>
<td>4.9 M psi</td>
<td>5.1 M psi</td>
</tr>
<tr>
<td>Coef. Expansion</td>
<td>5.6/F</td>
<td>5.8/F</td>
<td>5.4/F</td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td>0.23</td>
<td>0.25</td>
<td>0.23</td>
</tr>
</tbody>
</table>
Layer Thickness
(from cores)

<table>
<thead>
<tr>
<th>Section</th>
<th>HMA / RCA</th>
<th>EAC / RCA</th>
<th>EAC / LCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Layer</td>
<td>3.0 in</td>
<td>3.5 in</td>
<td>2.9 in</td>
</tr>
<tr>
<td>Bottom Layer</td>
<td>6.3 in</td>
<td>5.6 in</td>
<td>6.7 in</td>
</tr>
</tbody>
</table>
MEPDG Inputs

• Unbound base course:
  – 8-in thick
  – Class 5 granular base per MnDOT specifications.
  – Used default of 18,000 psi.
MEPDG Inputs

• **Subgrade:** FWD tested on top of slab & backcalculation of subgrade modulus (dynamic k-value, kd)
• Mean backcalculated k-value = 140 psi/in.
• Corresponding Input $Mr = 14,000 \text{ psi}$ at optimum density and water content gives k-value output of about 140 psi/in. This Mr is about the default for A-6 soil.
MEPDG Inputs

• **Design:**
  – Joint spacing: 15-ft
  – Joint sealing: None, single saw blade cut
  – Dowels:
    • Driving lane: 1.25-in diameter, 12-in spacing
    • Passing lane: No dowels
HMA/RCA Predictions

• MEPDG outputs:
  – Slab fatigue transverse cracking
  – Rutting of HMA
  – IRI

• Other potential distress
  – Transverse saw and seal joints
3-in HMA / 6-in RCA Section
Saw & Seal Transverse Joints
Slab Cracking, 3-in HMA / 6-in RCA

Predicted Cracking

Percent slabs cracked, %

Pavement age, years

0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32
Rutting, 3-in HMA / 6-in RCA

Permanent Deformation: Rutting

AC Rutting Design Value = 0.5
Total Rutting Design Limit =
**MEPDG Prediction HMA / RCA**

<table>
<thead>
<tr>
<th>Age / Trucks</th>
<th>% Slab Cracking</th>
<th>Rutting, in</th>
<th>Smoothness IRI, in /mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>63</td>
</tr>
<tr>
<td>5 years 3 million</td>
<td>0.3</td>
<td>0.09</td>
<td>94</td>
</tr>
<tr>
<td>10 years 6 million</td>
<td>1.2</td>
<td>0.13</td>
<td>100</td>
</tr>
<tr>
<td>15 years 10 million</td>
<td>2.7</td>
<td>0.17</td>
<td>107</td>
</tr>
</tbody>
</table>

Reflection cracking of transverse joints: controlled by saw and seal.
HMA / RCA Composite after 10 years and 6 million trucks

- Transverse Cracking < 5 % slabs.
- Rutting < 0.10 in. mean.
- IRI < 125 in/mile.
- Two layer HMA over RCA composite pavement should be in good condition after 10 years and 6 million trucks in driving lane.
  - Major question: will saw and seal of transverse joints hold up?
EAC / RCA Predictions

- MEPDG outputs:
  - Slab fatigue transverse cracking
  - Transverse joint faulting
  - IRI
3-in EAC / 6-in RCA
3-in EAC / 6-in RCA
3-in EAC / 6-in LCC
Slab Cracking, 3-in EAC / 6-in RCA

Predicted Cracking

Percent slabs cracked, %

Pavement age, years
Joint Faulting, 3-in EAC / 6-in RCA

Predicted Faulting

Faulting, in

Pavement age, years
IRI, 3-in EAC / 6-in RCA

Predicted IRI

IRI, in/mile

Pavement age, years
**MEPDG Prediction EAC / RCA**

<table>
<thead>
<tr>
<th>Age / Trucks</th>
<th>% Slab Cracking</th>
<th>Joint Faulting, in</th>
<th>Smoothness IRI, in /mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>63</td>
</tr>
<tr>
<td>5 years 3 million</td>
<td>0.8</td>
<td>0.02</td>
<td>82</td>
</tr>
<tr>
<td>10 years 6 million</td>
<td>2.7</td>
<td>0.05</td>
<td>103</td>
</tr>
<tr>
<td>15 years 10 million</td>
<td>5.9</td>
<td>0.07</td>
<td>125</td>
</tr>
</tbody>
</table>
EAC / RCA Composite after 10 years and 6 million trucks

- Transverse Cracking < 5 % slabs.
- Joint faulting < 0.10 in. mean.
- IRI < 125 in/mile.
- Two layer composite concrete pavement should be in good condition after 10 years and 6 million trucks in driving lane.
EAC / LCC Predictions

• MEPDG outputs:
  – Slab fatigue transverse cracking
  – Transverse joint faulting
  – IRI
Cracking, EAC / LCC Predictions

Graph showing the percentage of slabs cracked against pavement age.
Faulting, EAC / LCC Predictions
IRI, EAC / LCC Prediction

![Graph showing the relationship between pavement age and IRI values.](image)
## Comparison RCA & LCC

<table>
<thead>
<tr>
<th>Property</th>
<th>Recycled Aggregate Concrete, RCA</th>
<th>Low Cost Concrete, LCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement, pounds</td>
<td>360</td>
<td>240</td>
</tr>
<tr>
<td>Flyash, pounds</td>
<td>240</td>
<td>360</td>
</tr>
<tr>
<td>Compressive Strength, psi</td>
<td>4300</td>
<td>5062</td>
</tr>
<tr>
<td>Flexural Strength, psi</td>
<td>665</td>
<td>650</td>
</tr>
<tr>
<td>Modulus Elasticity, psi</td>
<td>4.8 million</td>
<td>5.1 million</td>
</tr>
<tr>
<td>Coefficient of Thermal Expansion, per degree F</td>
<td>5.8</td>
<td>5.4</td>
</tr>
<tr>
<td>Age / Trucks</td>
<td>% Slab Cracking</td>
<td>Joint Faulting, in</td>
</tr>
<tr>
<td>----------------</td>
<td>-----------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5 years 3 million</td>
<td>0.2</td>
<td>0.02</td>
</tr>
<tr>
<td>10 years 6 million</td>
<td>0.7</td>
<td>0.03</td>
</tr>
<tr>
<td>15 years 10 million</td>
<td>1.6</td>
<td>0.05</td>
</tr>
</tbody>
</table>
EAC / LCC Composite after 10 years and 6 million trucks

- Transverse Cracking < 5 % slabs.
- Joint faulting < 0.10 in. mean.
- IRI < 125 in/mile.
- Two layer composite concrete pavement with “cheap” concrete lower layer should be in good condition after 10 years and 6 million trucks in driving lane.
What If?
30-year Design: 23 million Trucks

• 3-in HMA / 8-in RCA
  – No structural fatigue cracking
  – HMA would need replacement at 8 to 15 years depending on:
    • Saw and seal transverse joints: will these hold up?
    • Rutting of HMA
What If?
30-year Design: 23 million Trucks

• 3-in EAC / 8-in RCA
  – No structural fatigue cracking
  – Some joint faulting and roughness.
  – EAC should perform with no problems: good friction, no significant wear.
  – Diamond grinding should perform with no problems: good friction, low noise.
30-year Design: 23 million Trucks

• 3-in EAC / 8-in LCC
  – No structural fatigue cracking
  – Some joint faulting and roughness.
  – EAC should perform with no problems: good friction, no significant wear.
  – Diamond grinding should perform with no problems: good friction, low noise.
Summary

• Construction quality of each section appears to be good.
• Material properties as expected.
• Initial performance measures reasonable.
• Future performance predictions show longer than expected life for HMA/RCA and EAC/RCA and less for EAC/LCC.
• Actual monitoring over time will provide proof of concept.