Composite Pavement Technology

Timothy R. Clyne, P.E.
Minnesota Department of Transportation

January 13, 2011

Presented to the Transportation Learning Network and the NDLTAP
Presentation Outline

- Background & Introduction
- MnROAD Test Section Construction
- Instrumentation, Material Properties, and Performance
- Performance Predictions Using MEPDG
- Cost Estimating Scenario (Contractor)
- TICP Pooled Fund Study
Acknowledgements

- Shreenath Rao, Applied Research Associates
- Mark Watson, Mn/DOT
- Tony Johnson, C.S. McCrossan
- Derek Tompkins, University of Minnesota
- Mike Darter, Applied Research Associates
- Luke Johanneck, University of Minnesota
What is a Composite Pavement?

- AC/PCC or PCC/PCC pavement constructed as an integrated system
- Provides strong, durable, safe, smooth, and quiet surface
- Requires minimal maintenance
Strategic Highway Research Program

- Established by Congress in 2006
- Short term program of focused research
  - Safety
  - Renewal
  - Reliability
  - Capacity
## R21 Composite Pavement Systems

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Key Staff</td>
<td>Darter, Rao, Khazanovich, Von Quintus, Harvey, Signore, Worel, Clyne, Watson, Palek, Vandenbossche, Tompkins</td>
</tr>
<tr>
<td>Duration</td>
<td>48 Months</td>
</tr>
<tr>
<td>Start Date</td>
<td>September 2007</td>
</tr>
</tbody>
</table>

This project focuses on two applications of intentionally designed composite pavement systems:

1. Asphalt over concrete (JPC, CRC, RCC)
2. Concrete surface over concrete (wet on wet)
R21 Objectives

– Determine the behavior and identify critical material and performance parameters
– Develop and validate mechanistic-empirical performance models and design procedures consistent with the Mechanistic-Empirical Pavement Design Guide (MEPDG)
– Recommend specifications, construction techniques and quality management procedures and guidelines
European Survey

- Visited Germany, Austria, Netherlands
- Europe has built composite pavements for many years
- Why?
  - Surface Characteristics
  - Economical
  - Sustainable

Construction of Composite Test Sections at UCPRC for HVS Testing

- Several Test Sections
- HMA/PCC Only
- Instrumentation
- Rutting & Cracking Behavior
Test Section Construction at MnROAD
# Experimental Plan for MnROAD

<table>
<thead>
<tr>
<th>Material</th>
<th>Length</th>
<th>Surface Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>474 ft</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-in HMA</td>
<td>1421 ft</td>
<td>3-in Granite</td>
</tr>
<tr>
<td>6-in PCC, 15-ft joints</td>
<td>947 ft</td>
<td>475 ft diamond grind; 475 ft exposed aggregate</td>
</tr>
<tr>
<td>1.25-in dia. dowels driving lane, nondoweled passing lane. Recycled PCC</td>
<td></td>
<td>6-in PCC, 15-ft joints, 1.25-in dia. dowels. Low-cost (high fly ash content) PCC (672 ft)</td>
</tr>
<tr>
<td>8-in Class 7 (Recycled) Granular Base</td>
<td>1421 ft</td>
<td></td>
</tr>
<tr>
<td><strong>947 ft</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6-in PCC, 15-ft joints</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.25-in dia. dowels. Recycled PCC (275 ft)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Clay Subgrade</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note: S & S joints (except for a few) 6-in PCC, 15-ft joints, 1.25-in dia. dowels.*
RCA Salvage Operations

RCA Percent Absorption 2.93%
Demonstration Slab

Consolidation around dowels

Joint Condition

Layer Interface
Temperature, Moisture, Static & Dynamic Strain Gauges
Vibrating Wires, Moisture/Humidity Sensors, CE Strain Gauges
Wet-on-Wet PCC/PCC Paving

Behind 2\textsuperscript{nd} Paver:
- Bow Floats
- Cure/Retarder Cart
- Broom
- Final Cure Cart
PCC Placement
HMA/PCC Construction

Longitudinal Tine

Cure

HMA Paving & Rolling

Tack Coat
Sawing and Sealing

- 100 ft: no seal
- 375 ft: saw & seal
  - 1 ft into shoulder
  - 1 ft away from edge of shoulder
MnROAD Test Sections
Challenges: Mix Consistency

- Short Test Cells
- Stiff Mix
- Sensitive to Adjustments
Challenges: Mix Delivery

- Deliver PCC to top layer
- Keep mixes straight
Lessons Learned: Brushing Time

Too Early

Just Right
Challenges: Locating PCC Joints
What Worked Well: Demonstration Slab

- Dress Rehearsal
- Value as Research and Preparation
- Sensor Installation Techniques
- Construction Techniques
- Materials Sampling and Testing
- Video, Photographer
What Worked Well: Sensors

• Live as Concrete was Placed
• More than 500 Sensors!
What Worked Well: Diamond Grinding

Cell 71 = 96.8dBA ( Quieter than HMA! )
Material Properties, Instrumentation, and Performance
## EAC-RCC Material Properties

<table>
<thead>
<tr>
<th>PCC mix</th>
<th>Compressive strength (psi)</th>
<th>Modulus of rupture (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7 day</td>
<td>14 day</td>
</tr>
<tr>
<td>EAC</td>
<td>5044</td>
<td>5315</td>
</tr>
<tr>
<td>RCA</td>
<td>3599</td>
<td>4117</td>
</tr>
<tr>
<td>Low-cost</td>
<td>3773</td>
<td>4364</td>
</tr>
</tbody>
</table>

- Above are average values for tests conducted on 80+ specimens
- Overall compressive and flexural strengths for all 3 concretes are more than adequate
- Thanks to the FHWA Mobile Concrete Lab
NDT Evaluation, Ultrasound Imaging

- Ultrasonic tomography used to evaluate PCC-PCC non-destructively
- Use technique to get quicker QA without sacrificing reliability
- Device used on R21 MnROAD demo slabs and mainline section
Tomogram of Sound PCC-PCC Interface

Design location for PCC/PCC interface

Design location for base
Tomogram of Poor PCC-PCC Interface
Instrumentation

- 6.5% failure rate overall
- Strains, joint opening, temperature, moisture data
- Will use this response data to validate MEPDG models
Performance Predictions Using the MEPDG
Performance Measures

• HMA Surface on RCA: Initial & Over Time
  – Smoothness, IRI
  – Texture Depth
  – Noise
  – Friction
  – Fatigue Cracking (transverse, longitudinal)
  – Rutting
  – Joint Reflection Cracking (HMA)
    • No treatment
    • Saw & Sealed joints cut in HMA
Performance Measures

• EAC Surface of RCA & Low Cost Concrete: Initial & Over Time
  – Smoothness, IRI
  – Texture Depth
  – Noise
  – Friction
  – Fatigue Cracking (transverse, longitudinal)
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 (due to temperature & moisture)
# Initial Results: Noise

<table>
<thead>
<tr>
<th>Surface</th>
<th>Sound Intensity Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMA</td>
<td>100.5 dBA</td>
</tr>
<tr>
<td>Exposed Aggregate Concrete</td>
<td>101.6 dBA</td>
</tr>
<tr>
<td>Conventional Diamond Grind of EAC</td>
<td>100.2 dBA</td>
</tr>
<tr>
<td>Next Generation Concrete Surface (Special Grinding) of EAC</td>
<td>96.9 dBA</td>
</tr>
</tbody>
</table>
### Initial Results: Texture

<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>Conventional Diamond Grind of EAC</td>
<td>To be measured</td>
</tr>
<tr>
<td>Next Generation Diamond Grind of EAC</td>
<td>1.127</td>
</tr>
</tbody>
</table>
## Initial Results: Friction

<table>
<thead>
<tr>
<th>Surface</th>
<th>Dynamic Friction Tester</th>
<th>Skid Trailer</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMA</td>
<td>0.66</td>
<td>53.2</td>
</tr>
<tr>
<td>Exposed Aggregate Concrete</td>
<td>0.62</td>
<td>46.5</td>
</tr>
<tr>
<td>Conventional Diamond Grind of EAC</td>
<td>0.72</td>
<td>49.2</td>
</tr>
<tr>
<td>Next Generation Diamond Grind of EAC</td>
<td>0.55</td>
<td>44.9</td>
</tr>
</tbody>
</table>
Prediction of 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.
MEPDG Inputs

- Traffic: I-94 WIM data
- Climate: Nearest weather stations
- HMA: Test data from Mn/DOT
- Concrete: EAC, RCA, LCC test data from FHWA mobile trailer
- Subgrade: Test data from Mn/DOT & backcalculation of modulus
- Design: joints, dowels, joint spacing, thickness of layers, shoulders
### 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>
Rutting, 3-in HMA / 6-in RCA

Permanent Deformation: Rutting

AC Rutting Design Value = 0.5
Total Rutting Design Limit = 0.5
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
  - Major question: will saw and seal of transverse joints hold up?
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

0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32
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
Cracking, EAC / LCC Predictions
Faulting, EAC / LCC Predictions
IRI, EAC / LCC Prediction

```
<table>
<thead>
<tr>
<th>Pavement age, years</th>
<th>IRI, in/mile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
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<tr>
<td>6</td>
<td>6</td>
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<tr>
<td>8</td>
<td>8</td>
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<td>10</td>
<td>10</td>
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<td>12</td>
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<td>28</td>
<td>28</td>
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<tr>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>32</td>
<td>32</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
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
Case Study
By C.S. McCrossan
Paving Division

Conventional vs. Composite Paving
Objective

• Find a project located in an area that has poor availability of Class A aggregates.
  – Take paving costs from project bid as Conventional Paving and compare to expected costs of Composite Paving.

• Under these circumstances is Composite Paving an economical alternative?
Case Study

• Project
  – U.S. Highway 14 Concrete Paving

• Location
  – Near Waseca, MN

• General Stats
  – 90,000 Cubic Yards of Concrete
    • 80,000 CY Mainline, 310,000 SY
    • 10,000 CY Crossroads and Ramps
  – 19.5 Miles paving
  – 22 total days paving scheduled
  – Closest Class A aggregate source was New Ulm Quartzite (2 hour round haul)
Comparison

• Conventional
  – 1 Boom Truck
  – 1 Paver
  – 1 Belt Placer
  – 1 Cure/Texture
  – 1 Skidsteer
  – 1 Pickup
  – 1 Service Truck
  – 1 Water Truck
  – 13 Crew Members

• Composite
  – 1 Boom Truck
  – 2 Pavers
  – 2 Belt Placers
  – 2 Cure/Texture
  – 1 Skidsteer
  – 1 Pickup
  – 1 Service Truck
  – 1 Water Truck
  – 1 Steel Bristle Broom
  – 18 Crew Members
Conventional Paving
Batch Plant

Two Batch Plants would be necessary to batch the different mix designs simultaneously.
COMPOSITE PAVING

- 2 Pavers
- 2 Belt Placers
- 2 Cure/Texture Machines
- 18 Crew Members
The lower lift comprised of recycled concrete as the source of coarse aggregate.

The upper lift used the high quality, Class A aggregates.
## Conventional vs. Composite

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>Composite</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pave, Tie, Green Saw</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sq. Yds.</td>
<td>310,000</td>
<td>310,000</td>
</tr>
<tr>
<td>$ per Sq. Yd.</td>
<td>$2.98</td>
<td>$3.70</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$923,800.00</td>
<td>$1,147,000.00</td>
</tr>
<tr>
<td><strong>Structural Concrete</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cubic Yards</td>
<td>80,000</td>
<td>80,000</td>
</tr>
<tr>
<td>$ per CY</td>
<td>$71.54</td>
<td>$69.31</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$5,723,200.00</td>
<td>$5,544,800.00</td>
</tr>
<tr>
<td><strong>Conventional Cost</strong></td>
<td>$6,647,000.00</td>
<td>$6,691,800.00</td>
</tr>
<tr>
<td><strong>Composite Cost</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**0.7% Difference in Construction Costs**
## Aggregates

### Conventional Aggregates

<table>
<thead>
<tr>
<th>Type</th>
<th>Tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4” Class A</td>
<td>34,270</td>
</tr>
<tr>
<td>1 1/2” Class A</td>
<td>37,213</td>
</tr>
<tr>
<td><strong>Total Tons</strong></td>
<td><strong>71,483</strong></td>
</tr>
</tbody>
</table>

### Composite Aggregates

<table>
<thead>
<tr>
<th>Type</th>
<th>Tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4” Class A</td>
<td>11,310</td>
</tr>
<tr>
<td>1 1/2” Class A</td>
<td>12,280</td>
</tr>
<tr>
<td>Recycled Agg.</td>
<td>47,893</td>
</tr>
<tr>
<td><strong>Total Tons</strong></td>
<td><strong>71,483</strong></td>
</tr>
</tbody>
</table>

### Class A

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Material $/Ton</td>
<td>$12.78</td>
</tr>
<tr>
<td>Trucking (2 Hour)</td>
<td>$7.46</td>
</tr>
<tr>
<td><strong>Total $ Per Ton</strong></td>
<td>$20.24</td>
</tr>
</tbody>
</table>

### Recycled

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Material $/Ton</td>
<td>$7.00</td>
</tr>
<tr>
<td>Trucking (2 Hour)</td>
<td>$1.45</td>
</tr>
<tr>
<td><strong>Total $ Per Ton</strong></td>
<td><strong>$8.45</strong></td>
</tr>
</tbody>
</table>


Conclusion

• Implementation of a Composite Paving process would be a viable and competitive alternative to Conventional Paving, if:
  – Class A aggregates aren’t readily available
    • Long haul times drive the price of the aggregate too high
  – Recycled Concrete could be produced on or near the site
    • Haul times would have to be cut to minimal levels
    • Would have to produce Recycle at about 50% the cost of Class A
  – You were capable of producing and paving at an equal rate to conventional paving
Thermally Insulated Concrete Pavements
Pooled Fund Study

- MN, CA, WA, FHWA Sponsored Study
- U’s of Minnesota, California, Washington
- 36 Months
- $439,000

- Task 1 – Literature Review
- Task 2 – Life Cycle Analysis
- Task 3 – EICM Validation
- Task 4 – Evaluate Pavement Response Models
- Task 5 – Develop Design Guidelines
- Task 6 – Develop Construction Guidelines
- Task 7 – State of the Practice Synthesis
- Tasks 8 & 9 – Final Report
Issues with Weather Station Data

Blue < 16%     Green 16-25%     Yellow 26-40%     Red > 40%
Thermocouple Flags

Cell 106, Sensor 28, Subset (UNK, 2, ML, 5)
Thermal Gradients

![Graph showing thermal gradients over time with different colors for different temperatures.]

- 113TC 109–113
- 106TC 112–114
Next Steps

- Continue Data Collection at MnROAD and other sites
  - Pavement performance monitoring
  - Surface characteristics
  - Instrumentation
- MEPDG and EICM Modeling and Calibration
- Write Design Procedures and Construction Guidelines
- Life Cycle Analysis (Costs, Performance)
- Training Materials to Aid in Implementation
Thank You!