Characterization of Structural Fibers for Thin Concrete Overlays

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Thin Concrete Pavement/ Overlay

- Thin conc. Pavement
  - Over agg. base
- Thin conc. Overlays
  - Over asphalt
  - Over composite
  - Over concrete

Thickness: 3 to 6 inches (bonded/unbonded)
Thin Concrete Pavement Distresses

- Cracks
- Joint faulting
- Slab migration

Use of Structural Fibers

Verities of Fibers; Many States

Observed benefits:

1. Reduce cracking/hold cracks tight
2. Increase load transfer efficiency - reduce faulting
3. Reduce slab migration
4. Reduce slab thickness
5. Increase slab size (?)
Research Objectives

To quantify the contribution of fibers in reducing fatigue cracking

To quantify the contribution of fibers in reducing joint faulting

To determine the influence of fibers on the slab size

To investigate whether fibers can help in city street designs (too thin slab)

Test Sections
## NRRA-MnROAD FRC Test Cells

<table>
<thead>
<tr>
<th>Cell number</th>
<th>Length (ft)</th>
<th>Pavement/ overlay Type</th>
<th>Underlying layer (constr. year)</th>
<th>Type of concrete/ fiber dosage*</th>
<th>Panel size W ft x L ft</th>
<th>Panel thickness (inch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>506</td>
<td>144</td>
<td>Thin pavement on grade</td>
<td>11 in. class 5Q aggregate base (2017)</td>
<td>Plain concrete</td>
<td>6 x 6</td>
<td>5; 6*</td>
</tr>
<tr>
<td>606*</td>
<td>138</td>
<td>Thin pavement on grade</td>
<td>11 in. class 5Q aggregate base (2017)</td>
<td>FRC/ standard (20% RSR)</td>
<td>6 x 6</td>
<td>3</td>
</tr>
<tr>
<td>706</td>
<td>270</td>
<td>Ultra-thin Pavement on grade</td>
<td>6 in. class 5 aggregate base (2017)</td>
<td>FRC/ enhanced</td>
<td>6 x 6</td>
<td>4</td>
</tr>
<tr>
<td>806</td>
<td>273</td>
<td>Thin Pavement on grade</td>
<td>6 in. class 5 aggregate base (2017)</td>
<td>FRC/ enhanced</td>
<td>6 x 6</td>
<td>4</td>
</tr>
<tr>
<td>705</td>
<td>144</td>
<td>Thin unbonded overlay</td>
<td>Concrete (1993)</td>
<td>FRC/ standard</td>
<td>12 x 12</td>
<td>5</td>
</tr>
<tr>
<td>805</td>
<td>124</td>
<td>Thin unbonded overlay</td>
<td>Concrete (1993)</td>
<td>FRC/ standard</td>
<td>6 x 12 and 7 x 12</td>
<td>5</td>
</tr>
</tbody>
</table>

### Typical Sensor Layout

- Joint Opening Sensor
- Dynamic Strain Gauge*
- Vibrating Wire Strain Gauge*
- Temperature Tree

*Strain gauges placed at top and bottom of concrete at each location shown

MnDOT, 2018

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Sensors

Photographs of various sensors used in this study and one of MnROAD’s weather stations: (a) thermocouple tree, (b) vibrating wire sensors, (c) dynamic sensors, (d) joint opening sensor, and (e) weather station.

Fatigue Cracking
### Crack Survey Dates and the Corresponding ESALs

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>139</td>
<td>Jul 17</td>
<td>May 1/49K</td>
<td>Mar 18/82K</td>
</tr>
<tr>
<td>239</td>
<td>Jul 17</td>
<td>May 1/38K</td>
<td>Mar 18/62K</td>
</tr>
<tr>
<td>705</td>
<td>Sep 5</td>
<td>Mar 13/750K* Apr 25/825K*</td>
<td>Mar 18/1,800K*</td>
</tr>
<tr>
<td>805</td>
<td>Sep 5</td>
<td>Mar 13/750K* Apr 25/825K*</td>
<td>Mar 18/1,800K*</td>
</tr>
<tr>
<td>506</td>
<td>Jun 26</td>
<td>Mar 14/750K*</td>
<td>Mar 19/1,800K*</td>
</tr>
<tr>
<td>606</td>
<td>Jun 27</td>
<td>Mar 14/750K*</td>
<td>Mar 19/1,800K*</td>
</tr>
<tr>
<td>706</td>
<td>Jun 29</td>
<td>Mar 14/750K*</td>
<td>Mar 19/1,800K*</td>
</tr>
<tr>
<td>806</td>
<td>Jun 30</td>
<td>Mar 14/750K*</td>
<td>Mar 19/1,800K*</td>
</tr>
</tbody>
</table>

*Approximate

### Cell 139 (Pavement on gravel base)

- 3 in. FRC
- 6x6 ft joints
- 24 ft width
- 6 in. Class 6 agg base
- 4 in. Clay loam (A-6) borrow
- Clay loam (A-6) subgrade (existing)

Approximately 35,000 ESALs
Cell 139 (Pavement on gravel base)

- 3-inch maybe too thin on unstabilized based
- Approximately 63,000 ESALs

Replacement of Damaged Slabs of Cell 139

- 14 slabs were replaced
Replacement of Damaged Slabs of Cell 139

Slabs of Cell 139 in April 2019

Another replacement may be coming soon(?)
Cell 239 (Pavement on gravel base)

- Number of cracks:
  - 5/1/2018: 2 longitudinal, 10 corner
  - 3/18/2019: 14 longitudinal, 10 corner

Cells 705 and 805 (Thin unbonded Overlay on PCC)

- Number of cracks:
  - 3/13/2018: 1 longitudinal, 1 corner
  - 4/25/2018: 2 longitudinal, 3 corner
  - 3/18/2019: 6 longitudinal, 6 corner

- Large slab = More long. cracks
- Small slab = More trans. cracks

Photos of Cell 705, 2018

5" x 14', 13'W X 12'L
5" x 6', 7', 8'W and X 12'L
Cells 506 through 806 (Pavement on gravel base)

Cracking and Spalling Summary for all the Cells but 139
Fatigue Crack vs ESALs

- Cell 139 has more long cracks now.
- Cell 239 has more long cracks now.

Riding Quality: IRI

- Chart Title
- Data for Cell 506 needs to be included.

Date of Test: March 19, 2019
Joint Faulting

<table>
<thead>
<tr>
<th>Joint Number</th>
<th>Faulting (mm)</th>
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<tbody>
<tr>
<td>Joint 1</td>
<td>0.5</td>
</tr>
<tr>
<td>Joint 2</td>
<td>0.3</td>
</tr>
<tr>
<td>Joint 3</td>
<td>0.2</td>
</tr>
<tr>
<td>Joint 4</td>
<td>-0.1</td>
</tr>
<tr>
<td>Joint 5</td>
<td>-0.2</td>
</tr>
<tr>
<td>Joint 6</td>
<td>-0.3</td>
</tr>
<tr>
<td>Joint 7</td>
<td>-0.4</td>
</tr>
<tr>
<td>Joint 8</td>
<td>-0.2</td>
</tr>
<tr>
<td>Joint 9</td>
<td>0.1</td>
</tr>
<tr>
<td>Joint 10</td>
<td>0.3</td>
</tr>
</tbody>
</table>

**Cell 139 and 239**

- **Cell 139 and 239**: May 3, 2018
- **Other Cells**:
  - Apr. 28, 2018
  - Oct. 03, 2018
  - Nov. 16, 2018

**Cells 139 and 239**

- **Cell 239**: Negative faulting - leave slab up
Cells 705 and 805

Faulting in Nov. 16, 2018

<table>
<thead>
<tr>
<th></th>
<th>Max. (mm)</th>
<th>Min. (mm)</th>
<th>Ave. (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell 705</td>
<td>1.6</td>
<td>0.2</td>
<td>1.00</td>
</tr>
<tr>
<td>Cell 805</td>
<td>2.7</td>
<td>0.1</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Joint Faulting - Cells 506 through 806

Faulting in Nov. 16, 2018

<table>
<thead>
<tr>
<th></th>
<th>Max. (mm)</th>
<th>Min. (mm)</th>
<th>Ave. (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell 506</td>
<td>7.2</td>
<td>1.5</td>
<td>2.9</td>
</tr>
<tr>
<td>Cell 606</td>
<td>2.8</td>
<td>-0.2</td>
<td>1.1</td>
</tr>
<tr>
<td>Cell 706</td>
<td>2.4</td>
<td>0.1</td>
<td>1.2</td>
</tr>
<tr>
<td>Cell 806</td>
<td>1.9</td>
<td>-1.1</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Fibers are decreasing faulting
It seems fiber is helping reduce faulting.

Faulting in Cell 506

(Faulting is exaggerated due to a broken corner in slab on leave slab)

Faulting Summary

Reduced crack width
Dowel action by fibers

Pavement Responses
FWD Test Results: LTE

**Cell 506 DL**
- Slab ID: 20, 13, 7
- LTE %: No fiber

**Cell 606 DL**
- Slab ID: 18, 14, 4
- LTE %: 5 lb/cy

**Cell 706 DL**
- Slab ID: 18, 11, 5
- LTE %: 8 lb/cy

**Cell 806 DL**
- Slab ID: 16, 10, 5
- LTE %: 11.7 lb/cy

Lab Testing on Joint Performance
**Lab Testing on Joint Performance**

![Graph showing LTE (%) vs Crack Width (mil)](image)

- LTE - Extension 1
- LTE - Contraction 1
- LTE - Extension 2
- LTE - Contraction 2

**Joint Movement**

- Diagram of joint opening sensor

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Joint Movement

Cell 506, Sensor 1
Cell 705, Sensor 1
Cell 706, Sensor 1
Cell 706, Sensor 3

Good data

Ambient Temperature

Weather Station, MnROAD

Ambient Temperature

-22 F
Temperature Sensor

- Warmest temp @ May 28, 2018; 2.15 PM
- Coldest @ Dec 31, 2017; 8:45 AM

Concluding Remarks

Fatigue Cracking

- 3-inch thick FRC on unstabilized gravel may not work, 75% slabs cracked with ~50,000 ESALs
- 4-inch thick is little better but concerning, significant no. of long. cracks developed in the second spring
- Large-paneled thin unbonded overlays experienced more long. cracks compared to the small-paneled ones- which experienced more trans. cracks
- Compared to the pavement-at-grade cells, they experienced significantly higher fatigue cracks (Cells 705 and 805 vs Cells 606 through 806)
Concluding Remarks

Fatigue Cracking

• All the four cells are performing better than the other cells with two cracks in PCC Cell (506)
• Good or bad- we still do not have a good data size to determine the contribution of fibers in mitigating fatigue cracks at the second spring

Faulting

• Fibers’ contribution was observed in Cells 506 through 806.
• Cell 806 (11 lb/cy fiber) showed lower faulting than Cell 506 (no fiber)
• Some LTE data are questionable (e.g., Cells 705 and 805); second year faulting data may provide a better picture
• Fibers helped in reducing the slab displacement

Slab Size

• Large-panel cell (Cell 705) experienced more cracks than its counter part 805.
Thank You

Questions?
mbarman@d.umn.edu

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Extra Slides

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Pavement Structure Information

Cell 139 and 239
- FRC
  - 6 in. Class 6 agg base
  - 4 in. Clay loam (A-6) subbase
  - Clay loam (A-6) subgrade (existing)

Cell 705 and 805
- FRC
  - Geosynthetic
  - 7.5 in. PCC (existing)
  - 3.0 in. agg base (existing)
  - 27.0 in. gran subbase (existing)

Cell 506 through 806
- PCC
  - 11 in. Class SQ aggregate base
  - 3.0 in. agg base (existing)
  - Clay loam (A-6) subgrade (existing)

Cracking and Spalling: Cell 805
- Corner cracks = 2#
- Longitudinal cracks = 3#
- Transverse cracks = 4#
- Spalling = 0#
**Distress survey: Joint Faulting - Cells 139 and 239**

**Cell 139 and 239**
May 3, 2018

**Other Cells**
- Apr. 28, 2018
- Oct. 03, 2018
- Nov. 16, 2018

**Tempr. Sensor: Tempr. Gradient**

<table>
<thead>
<tr>
<th>Cell</th>
<th>Temperature °C</th>
<th>Date</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>139</td>
<td>Max 45.3</td>
<td>7/17/2017</td>
<td>2:45:00 PM</td>
</tr>
<tr>
<td></td>
<td>Min -21.7</td>
<td>12/31/2017</td>
<td>8:45:00 AM</td>
</tr>
<tr>
<td></td>
<td>Max Outer 49.1</td>
<td>5/28/2018</td>
<td>2:15:00 PM</td>
</tr>
<tr>
<td></td>
<td>Min Outer -20.3</td>
<td>12/31/2017</td>
<td>8:30:00 AM</td>
</tr>
<tr>
<td>239</td>
<td>Max Inner 48.3</td>
<td>7/17/2017</td>
<td>2:45:00 PM</td>
</tr>
<tr>
<td></td>
<td>Min Inner -22.4</td>
<td>12/31/2017</td>
<td>8:15:00 AM</td>
</tr>
<tr>
<td>705</td>
<td>Max 44.0</td>
<td>5/28/2018</td>
<td>4:15:00 PM</td>
</tr>
<tr>
<td></td>
<td>Min -21.8</td>
<td>12/31/2017</td>
<td>8:45:00 AM</td>
</tr>
<tr>
<td>805</td>
<td>Max 47.9</td>
<td>5/28/2018</td>
<td>2:45:00 PM</td>
</tr>
<tr>
<td></td>
<td>Min -22.4</td>
<td>12/31/2017</td>
<td>8:45:00 AM</td>
</tr>
<tr>
<td>606</td>
<td>Max Inner 49.8</td>
<td>5/28/2018</td>
<td>3:00:00 PM</td>
</tr>
<tr>
<td></td>
<td>Min Inner -23.3</td>
<td>12/31/2017</td>
<td>8:15:00 AM</td>
</tr>
<tr>
<td></td>
<td>Max Outer 46.7</td>
<td>5/28/2018</td>
<td>3:45:00 PM</td>
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<tr>
<td></td>
<td>Min Outer -22.2</td>
<td>12/31/2017</td>
<td>8:45:00 AM</td>
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</table>
**Tempr. Sensor: Tempr. Gradient**

<table>
<thead>
<tr>
<th>Month</th>
<th>Cell 606 Inner (5-inch)</th>
<th>Cell 606 Outer (5-inch)</th>
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<tbody>
<tr>
<td>Jul-17</td>
<td>-0.38</td>
<td>0.74</td>
</tr>
<tr>
<td>Aug-17</td>
<td>-0.50</td>
<td>0.74</td>
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<td>Sep-17</td>
<td>-0.37</td>
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<td>Oct-17</td>
<td>-0.34</td>
<td>0.55</td>
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<td>Nov-17</td>
<td>-0.43</td>
<td>0.52</td>
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<td>Dec-17</td>
<td>-0.47</td>
<td>0.33</td>
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<td>Jan-18</td>
<td>-0.49</td>
<td>0.61</td>
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<td>Feb-18</td>
<td>-0.46</td>
<td>0.72</td>
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<tr>
<td>Mar-18</td>
<td>-0.47</td>
<td>0.91</td>
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<td>Apr-18</td>
<td>-0.47</td>
<td>1.06</td>
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<td>May-18</td>
<td>-0.53</td>
<td>1.12</td>
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</table>

*Data collection started July 7th 2017*

**Environmental Strain Sensor**

- Cell 705 2nd slab
- Cell 805 2nd slab
### Materials and Mix Designs

#### Mix Designs

<table>
<thead>
<tr>
<th>MIX/CELL</th>
<th>AIR (%)</th>
<th>WATER (lbs)</th>
<th>CEMENT (lbs)</th>
<th>FLY ASH (lbs)</th>
<th>FLY ASH (%)</th>
<th>W/C RATIO</th>
<th>FA #1 (lbs)</th>
<th>CA #1 (lbs)</th>
<th>FIBERS (lbs/CY)</th>
<th>SLUMP RANGE (in.)</th>
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</thead>
<tbody>
<tr>
<td>MR-3A21FC506</td>
<td>7.0</td>
<td>239</td>
<td>400</td>
<td>170</td>
<td></td>
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<td>0.42</td>
<td>1222</td>
<td>1798</td>
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<td>413</td>
<td>177</td>
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<td>1204</td>
<td>1773</td>
<td>5</td>
<td>0.5 - 3</td>
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<td>MR-3A21F2139, 239, 706</td>
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<td>420</td>
<td>180</td>
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<td>1196</td>
<td>1761</td>
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<td>1184</td>
<td>1743</td>
<td>11.66</td>
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Cement increased and aggs. decreased with increase in fibers

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