MnDOT's Experience with Fibers in Pavements and Bridges

Minnesota Concrete Council MN Concrete Forum

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DEPARTMENT OF TRANSPORTATION

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Discussion Topics

- Use of Fibers in Concrete Paving
- Use of Fibers in Concrete Bridge Decks
- TH 4 Jointless Roundabout
- TH 63 and CSAH 25 Whitetopping Projects
- Ongoing Fiber Research at MnROAD

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History of FRC in Paving

- 1993
  - TH 30 - 5 test sections (5” to 6”)
  - LoRay Drive, Mankato (4” to 6”)
- 1997
  - US169 in Elk River at 3 intersections (3”)
  - MnROAD – 6 test sections (3”, 4” and 6”)
- 2004
  - MnROAD- 4 test sections (4” and 5”)
- 2008
  - MnROAD – 4 test sections (4” and 5”)
- 2017 & 2018

Polypropylene Fibers

Polyolefin Fibers

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Purpose of Fibers in Paving

- Mechanism to replace dowel bars for load transfer in thinner pavements (6” or less)

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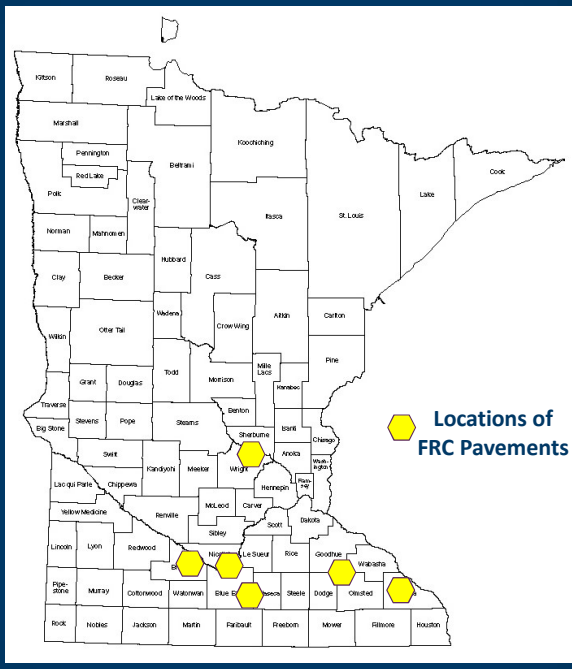

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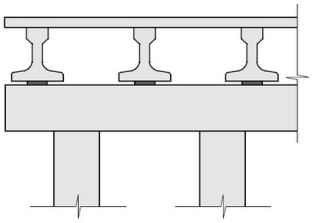
History of Fibers in Bridge Decks

- 2013 - 1st project constructed on TH 36 at Edgerton (Keller Lake Bridge 62037)
  - Inverted T-Beam Bridges
  - WB – No fibers
  - EB – 7.5 pounds/cubic yard



- 2013 – 2018 - 40 FRC Projects with Bridge Decks
  - 7 different types of fibers
  - Fiber dosage rate ranged from (3 – 7.5 lb/cy)

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Purpose of Fibers in Bridge Decks

- The stated manufacturer purpose of the non-metallic fibers is for controlling plastic shrinkage cracks in concrete (micro fibers) and to provide increased residual flexural strength in the concrete (macro fibers).

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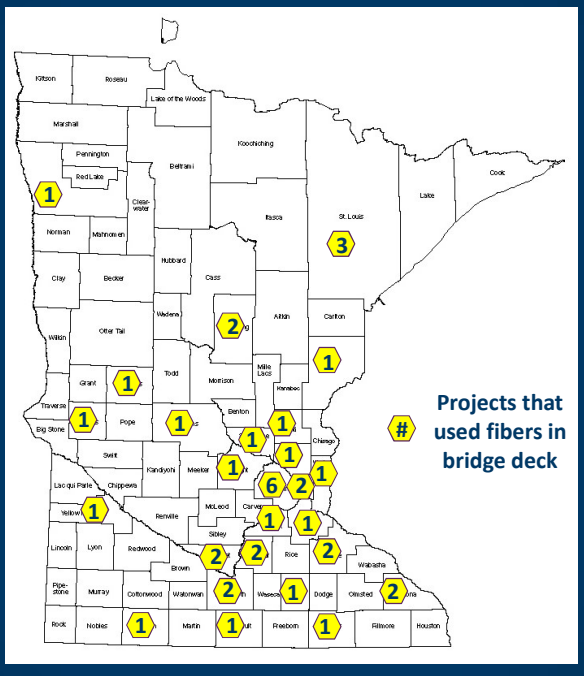

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Fiber Requirements for Bridge Decks

- Type III fibers in accordance with ASTM C1116.
- Minimum dosage rate of 4 lbs/cy
- Combination of micro and macro non-metallic fibers
- In all cases the trial placement with the contractor-designed mix will be required to demonstrate slump, air loss, and workability

Test	Requirement	Test Method
Equivalent Flexural Strength Ratio (RDT,150)	Minimum of 25%	ASTM C1609
Crack Reduction Ratio (CRR)	Minimum reduction >85%	ASTM C1579
Test beam specimens when the concrete strength is between 3500 and 4500 psi.		

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Fiber Addition Method Requirements

- Open bag and distribute fibers on aggregate belt at ready-mix concrete plant;
- Open bag, break apart any fiber clumps, and introduce fibers into ready-mix concrete truck in a well-distributed manner (i.e., "chicken feed")
- Any alternate methods to add fibers to the concrete mix must be submitted for acceptance by the Engineer and be demonstrated by a successful trial placement.

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Fiber Balling

- 2 inch diameter or greater conglomerate of fibers at the point of placement.
- Any balling more prevalent than 1 location in 20 CYDs will be considered a failed trial placement.
- Ensure the manufacturer's technical representative is available by phone or in person to troubleshoot fiber inclusion into the mix during the trial placement and bridge deck placement.

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MnDOT Approved Products List

Non-metallic Fibers (Bridge Applications)

Non-metallic Fibers - Bridge Applications (7/23/2018)				
Product	**Manufacturer**	**Dosage (lb/cu.yd)**	**Method of Incorporating Fibers ***	**Approval Date**
Advantage	GRT	4	1 & 2	7/16/18
FiberForce 650	ABC Polymer	4	1 & 2	9/13/18
MasterFiber MAC 360 FF	BASF	4	1 & 2	9/13/18
TUF-STRAND SF	Euclid	4	1 & 2	9/13/18

** 1) Open bag and distribute fibers on aggregate belt at ready-mix concrete plant.*

** 2) Open bag, break apart any fiber clumps, and introduce fibers into ready-mix concrete truck in a well-distributed manner (i.e., "chicken feed").*

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Fiber Reinforced Concrete Roundabout

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Snapshot from https://youtu.be/GmrP8G46_v4

Courtesy Greg Bauer, CPAM

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Why build a jointless roundabout?

- District 7 Mankato Materials Engineer contacted the Concrete Office to discuss the idea of constructing a Continuously Reinforced Concrete(CRC) Roundabout
- Goal was to not worry about jointing pattern
- Concern about cost and constructability
- Presentation at a National Concrete Consortium meeting discussing FRC roundabouts prompted the idea to build FRC roundabout without joints
- Lots and lots of discussion…

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Fiber Requirements

Provide Type III structural synthetic fibers meeting the requirements of ASTM C 1116 and the following:

a. Minimum mean residual strength of 175 psi (F175), when tested in accordance with ASTM C1609
b. A monofilament or bundled monofilament with a minimum length of 1.5 in and a maximum length of 2.25 in., and
c. A maximum aspect ratio (length divided by the equivalent diameter of the fiber) of 150, and with a target aspect ratio between 50 and 100.

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Quality Control Plan

Provide a Quality Control Plan for incorporation of synthetic fibers into the concrete mixture which includes the following:

- Identify dedicated personnel involved in introduction of synthetic fibers to mix
- Proposed method for adding the synthetic fibers into the mixer to ensure uniform distribution and random orientation of the fibers throughout the concrete mixture
- Mitigation strategies needed if unmixed fiber balls are identified after concrete mixing or during concrete placement.

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Trial Batching

- Minimum 5 cubic yard trial placement with the contractor-designed mix to demonstrate slump, air loss, and workability with the Contractor's mix design.
- Any trial batching of the FRC mix designs are at the Contractor's discretion with no additional cost to the Agency.
- Ensure the manufacturer's technical representative is available by phone or in person to troubleshoot fiber inclusion into the mix during the trial batching.

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Placement

- Plan to place the FRC inside the isolated circle of the roundabout in one continuous placement.
- Provide active crack control (notch) on the outside edge of the roundabout:
  - 15 inch long saw cut,
  - At a depth of 1.5 inch, and
  - Every 4 feet on the outside edge of the roundabout.
- Seal the active crack control (notch) saw cuts using hot pour

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TH 4 Roundabout with fibers

- Cemstone/Hoffmann
  - Required Test Data and Test Pour
  - Mean residual strength of 175 psi (equivalent strength ratio)
- BASF Macro 360FF
  - Dosage Rate 6 lb/cy
  - Used for temperature and drying shrinkage control
  - a synthetic micro- and macrofibers, is manufactured from a proprietary blend of polypropylene resins

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Fiber Reinforced Concrete Roundabout




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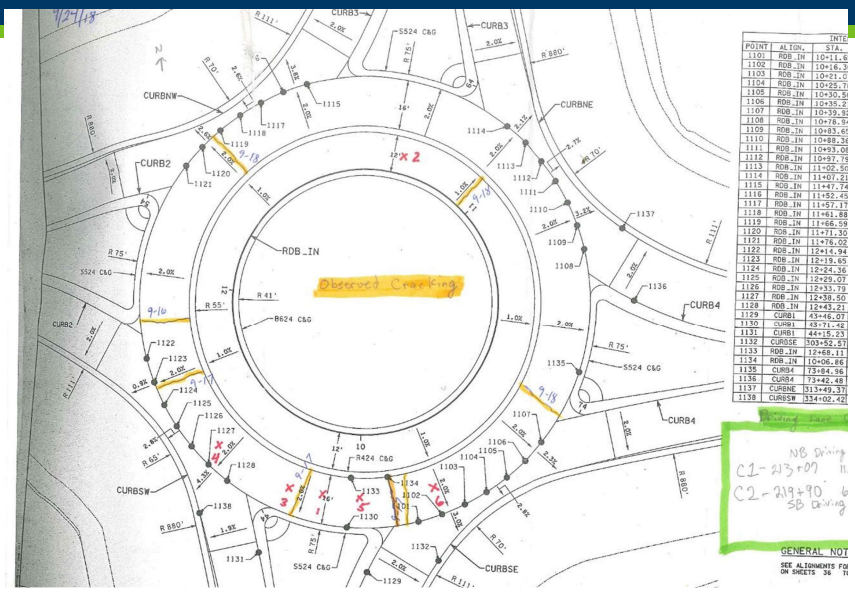
Fiber Reinforced Concrete Roundabout



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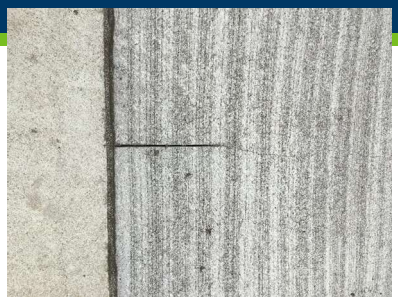
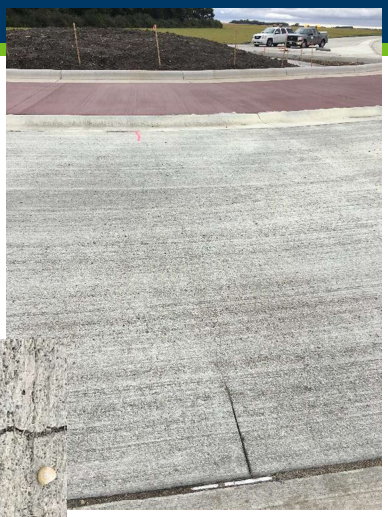
Fiber Reinforced Concrete Roundabout





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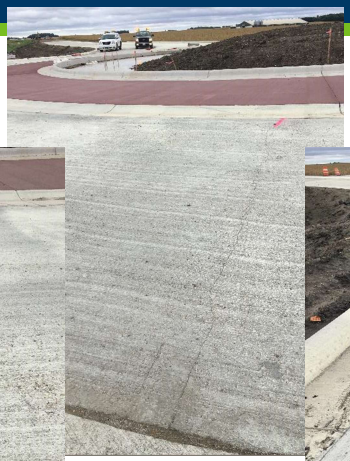
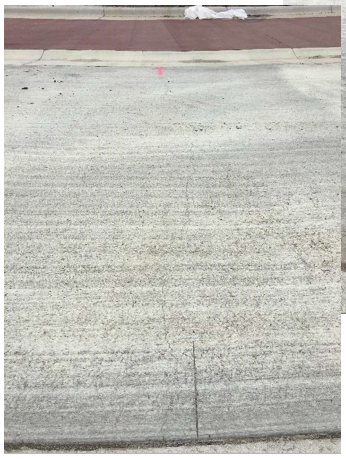
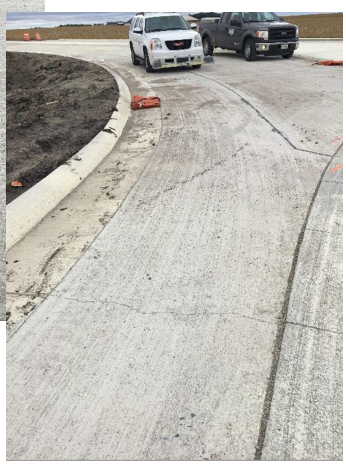
Fiber Reinforced Concrete Roundabout







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TH 63 5” Whitetopping with fibers

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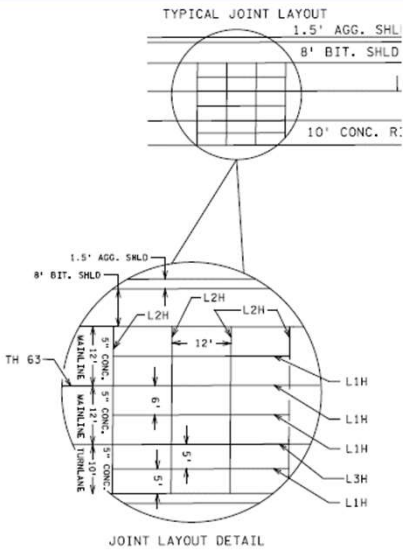
TH 63 5” Whitetopping with fibers

- Typical 6’ x 6’ panels
- ½ mile test section - 12’ long x 6’ wide panels
- 3D Profile Milling of Asphalt
- Stringless Paving



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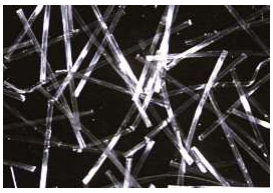
TH 63 5” Whitetopping with fibers

- Croell tried 3 different fibers
  - Forta Concrete Fiber - Forta Ferro One Macro
    - Virgin Copolymer/Polypropylene
    - Monofilament/Fibrillated Fiber System
  - Grace Construction Products - Strux 90/40 Synthetic Macrofiber
  - Mapei/GRT Advantage Macrosynthetic Fiber
    - Embossed tape fiber comprised of a blend of polypropylene and polyethylene resins



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Delivery of Fibers

- High production paving using Fibers was major concern
- Mixing Time may need to be increased
  - Croell has batched at increased batching times (15-30 sec) – once dialed in back to about 50 – 60 secs
  - Similar experience found in trial placement in Iowa in 2017

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Automated Fiber Dispensing/Conveying

- TH 63 Spec requires automated fiber dispensing or conveying system – Contractor fabricated their own
- Batched 10 cy loads – Used 8 – 5 # bags per load

Used a screw to keep bags separated – so laser eye could keep count of when to shut off belt for each load

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Placing the fiber reinforced concrete

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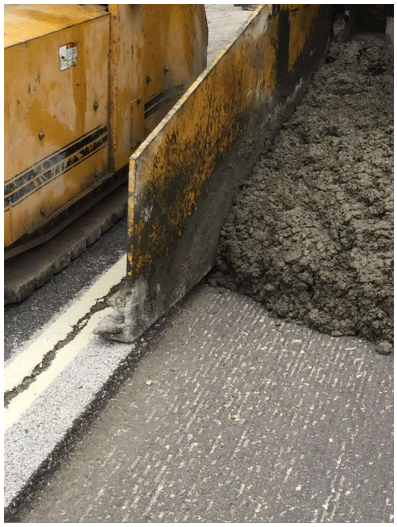
Placing the fiber reinforced concrete



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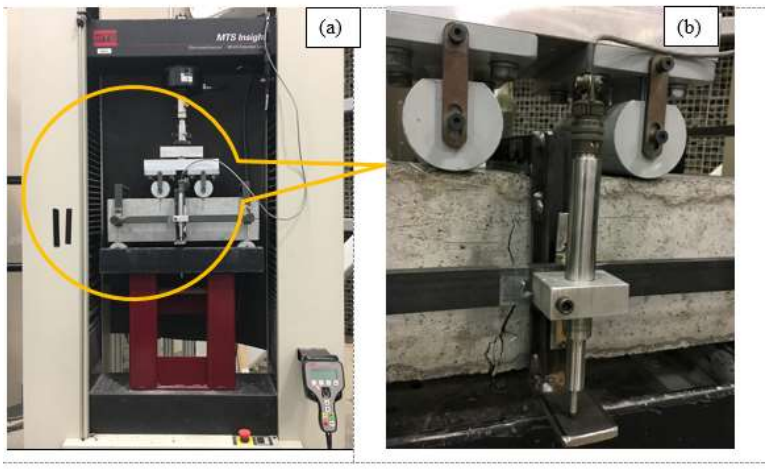
University of Minnesota Duluth Study – Best fibers for Load Transfer Efficiency



(a) and (b) Photographs of UMD's ASTM C 1609 test setup;

Photo courtesy of Dr. Manik Barnam, UMD

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Why Joint Activation Important

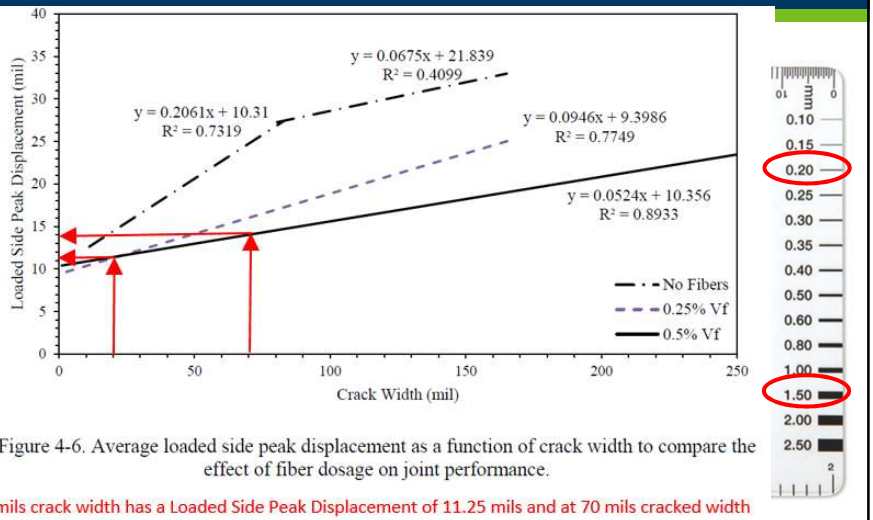

Figure 4-6. Average loaded side peak displacement as a function of crack width to compare the effect of fiber dosage on joint performance.

A 20 mils crack width has a Loaded Side Peak Displacement of 11.25 mils and at 70 mils cracked width has a Loaded Side Peak Displacement of 14 mils. A 20% difference in Loaded Side Peak Displacement just by reducing the crack width. Also, using 0.25% Vf would be cheaper that using 0.5% Vf for the same Loaded Side Peak Displacement results.

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TH 63 Joint Activation

- GOAL: Influence the number of working joints! Narrow joint widths – fibers more beneficial
- HOW: Drive on pavement to activate joints

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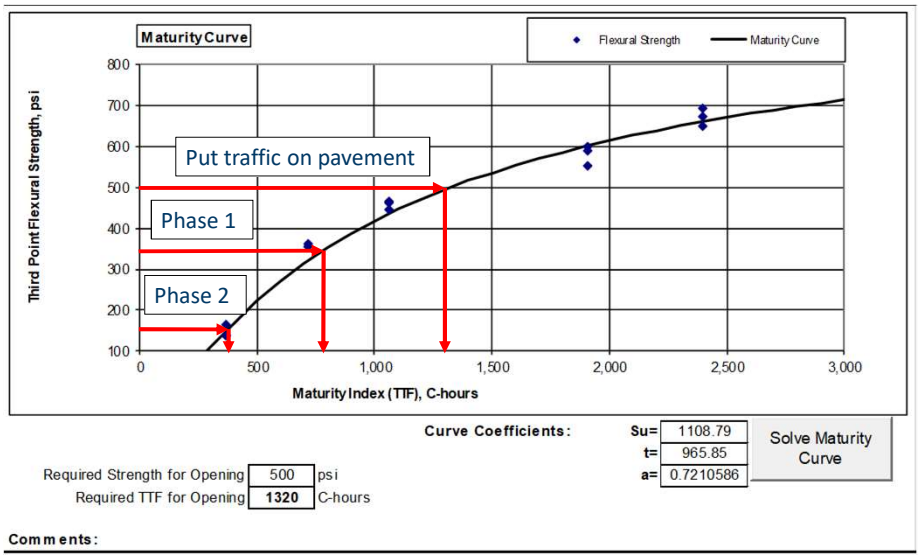
Concrete Maturity



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TH 63 Joint Activation - Results

- No loading 1 day – every 24 joints
- Phase 1 (24 hours old) – Didn't see much change
  - Felt concrete too strong
  - Did see increased activation when heavier construction traffic started driving on concrete
- Phase 2 (14 hours old) – 3800 ft section
  - First 1000 ft – 17 joints working
  - Next 2800 ft – 5 joints working
  - Per Tom Meath – Cracking every 4 to 6 joints more quickly

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Sawing Through Transverse Joints Fully

- Important to Note:
  - MN specs require sawing all the way through edge
  - IA specs do not
  - I requested Croell saw all the way through edge for TH 63 project
  - Not sure if it made a difference but I don't think it hurt

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A Little Excitement

- An 800-foot stretch of Highway 63 north of Rochester is ruined after a 95-year-old man drove through wet concrete.
- Repair estimates top $100,000.

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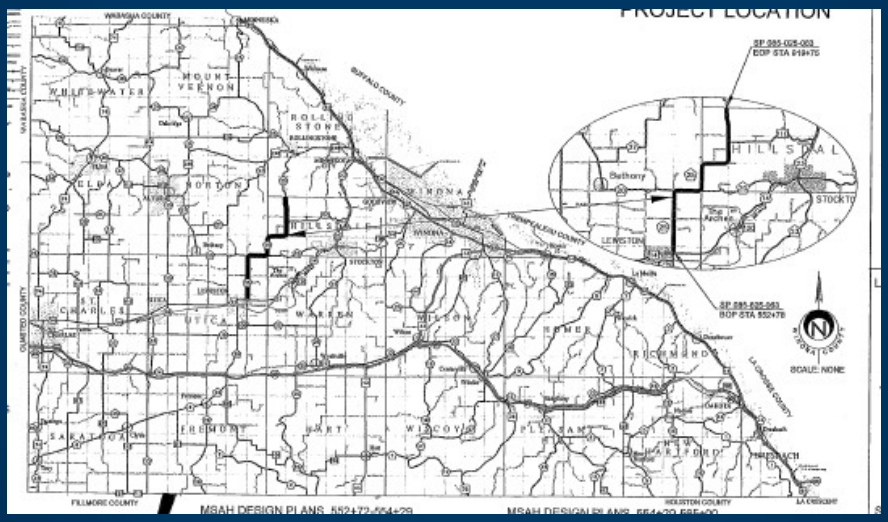
Winona County CSAH 25



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Winona County 5” Whitetopping

- Croell, Inc. – Iowa Contractor
- 7 miles
- Same Design as MnDOT TH 63
- Except Panel size 6’W x 7’L
- Project let without fibers
- Due to success of TH 63 project, fibers added by Supplemental Agreement

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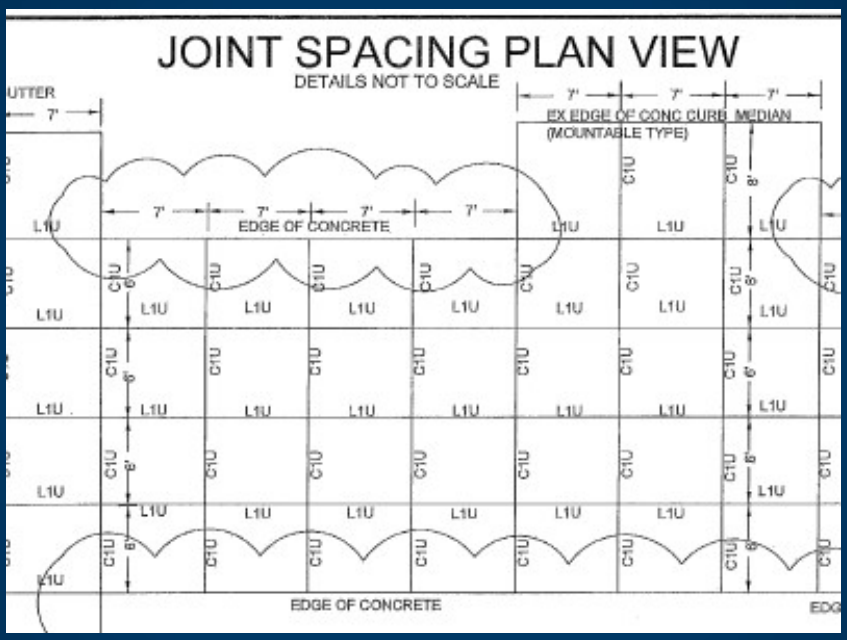

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Joint Activation on Winona CSAH 25

- Water truck on the pavement at 12 hours and then 24 hours after placement.
- Initial cracks were fairly easy to spot, but after that a lot of the cracks were hairline cracks and difficult to see.
- Spacing of activated joints (feet)
  - Day 1 – 112', 55', 52', 70'
  - Day 3 – 77', 17', 49'
  - Day 4 – 51', 33'
  - Day 7 – 56',14', 9'
- High Temp Range (69 – 89 degrees)
- Low Temp Range (55 - 69 degrees)
- Dewpoint (59 - 65 degrees)

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MnROAD Phase 3 Concrete Pavement Construction Update

Tom Burnham, P.E. | Senior Road Research Engineer, Minnesota Department of Transportation

TRB 97th Annual Meeting, AFN40 Committee Meeting

1/8/2018

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NRRA National Road Research Alliance

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MnROAD Facility

MnROAD

- Full-scale, cold climate pavement test facility near Albertville, MN
- 3.5 mile (5.6 km) "Mainline" section with diverted interstate I-94 traffic
- 2.5 mile (4 km) "Low Volume Road" closed loop test track
- Multiple pavement test sections
  - Asphalt
  - Concrete
  - Overlays
- Operation began in 1994
  - Beginning Phase 3 experiments

Provides opportunities for BOLD ideas!

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MnROAD History

- **MnROAD Phase 1 (1994-2007)**
  - ➢ Funded by MnDOT, Mn LRRB and FHWA
  - ➢ Experiments determined by MnDOT and Minne
- **MnROAD Phase 2 (2007-2015)**
  - ➢ Funded by MnDOT, Mn LRRB and FHWA, Pooled fund partners (state DOTs)
  - ➢ Experiments determined by MnDOT, Mn LRRB, Pooled fund partners (state DOTs)

- **MnROAD Phase 3 (2015-?)**
  - ➢ Research and operation funded by National Road Research Alliance (NRRA) [6 states, MnLRRB]. Construction $ = MnDOT
  - ➢ Experiments determined by NRRA members (includes input from 39 industry and academia members)

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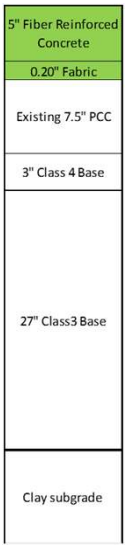
Fiber-Reinforced Concrete Study

Objectives

- Determine contribution of fibers in reducing panel fatigue cracking
- Determine contribution of fibers in mitigating joint faulting
- Determine optimal panel size for thin unbonded concrete overlays
- Determine minimum thickness of FRC for low-volume streets

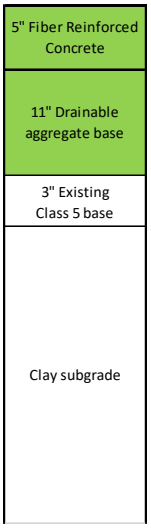
Fiber-Reinforced Unbonded Concrete Overlay

- **MnROAD Cells 705, 805 (Mainline interstate traffic)**
  - Fiber content: 20% RSR (ASTM C1609)
  - Non-woven geotextile fabric interlayer
  - Cell 705: 14'W x 12'L, 12'x12' panels
  - Cell 805: 6'Wx12'L & 8'Wx12'L panels
  - 4' wide passing lane PCC shoulder



Fiber-Reinforced Concrete On Grade

- **MnROAD Cells 506, 606, 706, 806**
  (Mainline interstate traffic)
  - **All cells: 6' x 6' panels**
  - **Fiber content:**
    - **Cell 506: No fibers (control)**
    - **Cell 606: 20% RSR (ASTM C1609)**
    - **Cell 706: 30% RSR (ASTM C1609)**
    - **Cell 806: 0.75% by volume**



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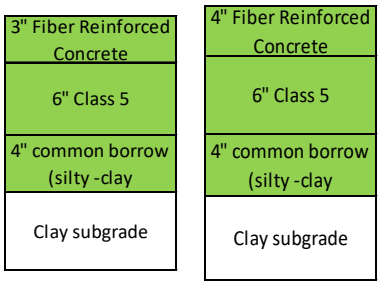
Ultra-thin Fiber-Reinforced Concrete On Grade

- **MnROAD Cells 139, 239**
  (Low Volume Road traffic)
  - **All cells: 6' x6' panels**
  - **Fiber content: 30% RSR (ASTM C1609)**



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Residual Strength Testing Results for FRC

Table 1 – Summary Test Results – ASTM C1609 – 28 days

Set ID		5 pcy	8 pcy	11.7 pcy
Specimen Dimension	Width (in.)	6.15	6.10	6.20
	Depth (in.)	6.05	6.05	6.00
Initial Deflections	δ_1 - Deflection at First Crack (in.)	0.0017	0.0019	0.0019
	δ_P - Deflection at Peak Load (in.)	0.0019	0.0020	0.0021
Loads	P_1 - First Crack Load (lbf.)	7,928	9,011	8,257
	P_P - Peak Load (lbf.)	8,109	9,433	8,866
	P_{600}^{150} - Load at L/600 (lbf.)	1,492	2,522	3,782
	P_{150}^{150} - Load at L/150 (lbf.)	1,322	2,437	3,528
Stress	f_1 - First Crack Stress (psi)	635	730	660
	f_P - Peak Stress (psi)	650	765	710
	f_{600}^{150} - Stress at L/600 (psi)	120	205	305
	f_{150}^{150} - Stress at L/150 (psi)	105	195	285
Toughness	T_{150}^{150} - Toughness (in-lbs)	187	327	460
	$f_{T,150}^{150}$ or Fe_{3mm} (psi)	126	221	307
	$R_{T,150}^{150}$ or Re_{3mm} (%)	20.1	30.3	46.6

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Table courtesy of American Engineering Testing/Testing, Engineering & Consulting Services, Inc.

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Performance Engineered Mixture (PEM) testing

Box Test after 30 minutes

Low cementitious mix

20% RSR Fiber mix

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Photos courtesy of American Engineering Testing

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Instrumentation

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Prepacking sensors

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Paving

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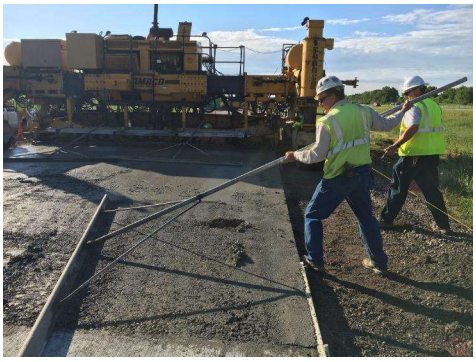
Paving



Cell 806, 5” FRC , 0.75% fibers by volume

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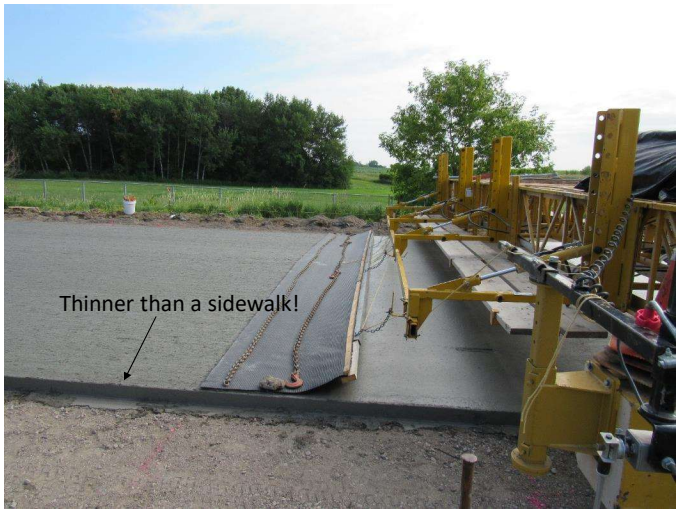
Paving



Cell 139, 3" FRC

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Lots of Sampling!

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Post Paving Activities

- Profile (Lightweight profiler)
- Mix uniformity mapping (MIRA)
- Slab thickness (MITScan T2)
- Transverse joint deployment
  - Edge observations before shoulder placement
- Warp and curl profiling (ALPS2 laser profiler)
- Install joint opening sensors and pins
- Initial FWD Tests (after shoulder placement)
- Initial load testing with MnROAD truck
- Compile PCC strength and durability specimen results

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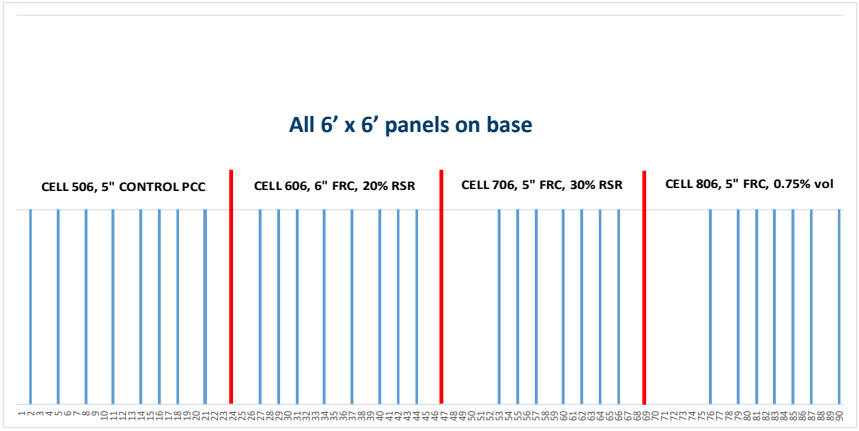
Early Transverse Joint Deployment



Observation (pavement edge) on 7-5-17, age range: 5 to 9 days, no traffic loads

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Thank you!

Any Questions?

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