Fiber Reinforced Concrete Overview for Concrete Pavement and Overlays

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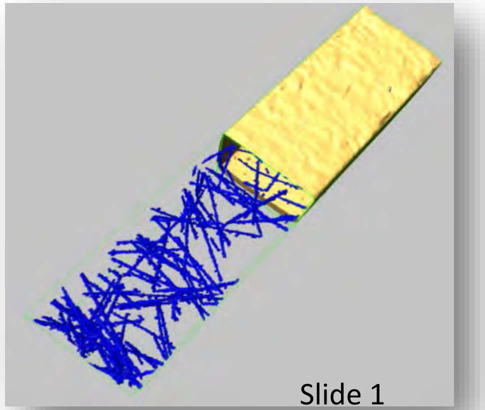
October 24, 2018
TTCC/Fiber Reinforced Concrete Project
National Concrete Consortium
Webinar 1 of 3



Disclaimer and Acknowledgements

- First of THREE free separate webinars on FRC overlays
- Presentation and audio will be recorded and posted afterwards
- Webinar information presented can also be found in the upcoming Technical Report and Technical Brief on “Fiber Reinforced Concrete for Pavement Overlays”

- Funding and oversight for this research was provided by:
  - TTCC/Fiber-Reinforced Concrete Project
  - National Concrete Consortium
  - National Concrete Pavement Technology Center
  - Snyder and Associates, Inc.
  - “Fiber Reinforced Concrete for Pavement Overlays” Technical Advisory Committee

NATIONAL CONCRETE CONSORTIUM

FRC Overlay Project - Webinars

Fiber Reinforced Concrete Overview for Concrete Pavement and Overlays

October 24, 2018 9:00-10:00 a.m CST

This webinar will give a general overview of fibers used for concrete pavements with an emphasis on macrofibers and their effect on concrete properties and pavement construction.

Effect of Macrofibers on Behavior and Performance of Concrete Slabs and Overlays

November 7, 2018 9:00-10:00 a.m CST

This webinar will review the significant findings of macrofiber addition to concrete slabs on grade, which include the increase in plain concrete slab capacity, reduction in crack widths, and increase in pavement performance.

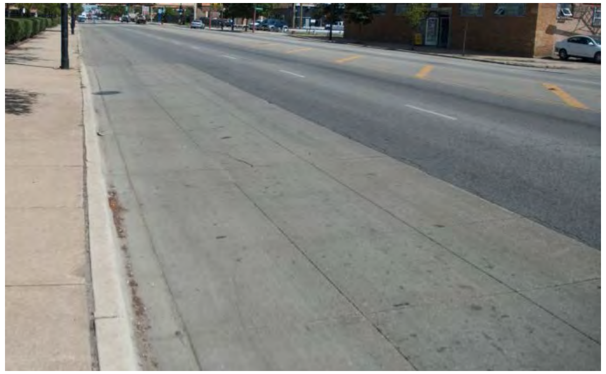
Overview of Macrofiber Software and Guidelines for Concrete Overlay Design

December 5, 2018 9:00-10:00 a.m CST

This webinar will provide an overview of the macrofiber software for determining the recommended fiber reinforced concrete residual strength values for application to concrete overlay design.

Presentation Overview

- General overview of macrofibers in concrete pavements (Jeff)
- Macrofibers types available (Amanda)
- Effect on fresh and hardened properties (Amanda)
- Test methods to specify macrofibers for overlays (Amanda)
- Construction best practices & guidelines (Jeff)



Past Benefits of FRC in Pavements

- FRC used in rigid pavements since 1970s
  - U.S. Army (airfield) tests (Parker 1974)
  - V_f =1 to 2% steel fibers with higher cement content

- FRC benefits from past studies:
  - Improve cracking resistance
  - Improve load carrying capacity of slabs
  - *Reduce slab thickness (30% to 50%) – empirical-based*
  - *Increase allowable joint spacing in design – experience-based*
  - Reduce or limit crack widths and crack deterioration rates
  - Less joint spalling in pavements

What have been past FRC challenges?

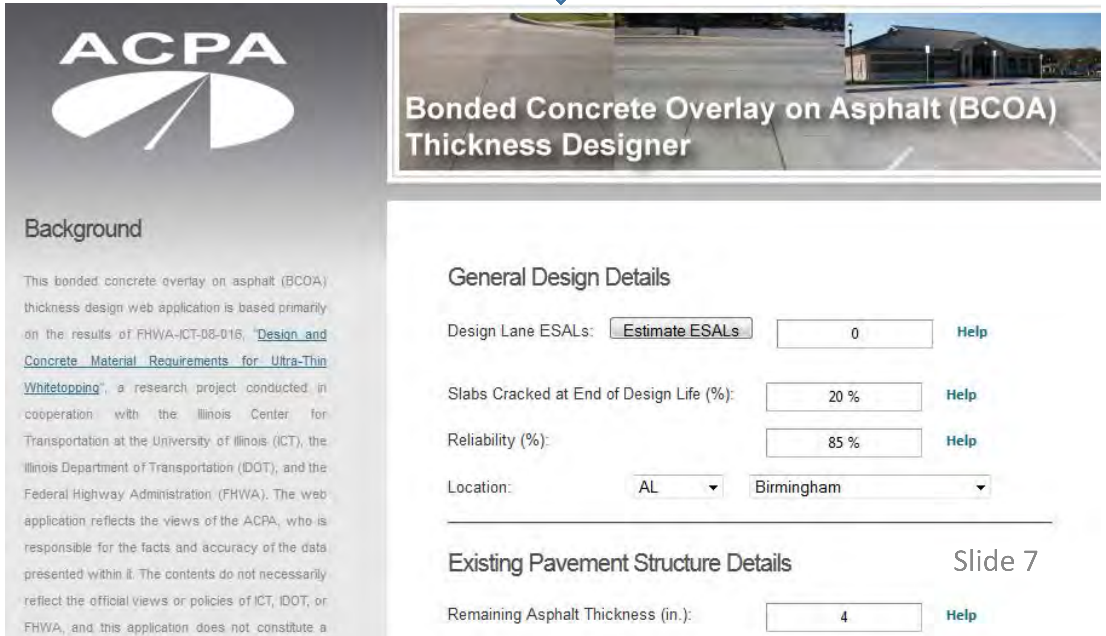
- Several premature slab failures in field *(Rollings 1993)*
  - Excessive slab sizes (1.5*L to 2.0*L) with higher paste contents (shrinkage) and too thin
  - Slab curling
  - Larger crack widths (dominant joints)

- Dosage amount and type of fiber chosen on "**experience**"
  - Various fiber types, shapes, and materials

- Structural Design benefit was *NOT effectively standardized in past*

Pavement Design methodology with FRC

- Design methods and codes
  - British Concrete Society (TR34) – industrial floors
  - Bonded Concrete Overlay of Asphalt (BCOA)
    - IDOT Chapter 53 (2008) BCOA (*Bordelon and Roesler 2012)*
    - *ACPA BCOA calculator (http://apps.acpa.org/applibrary/BCOA/)*
  - OptiPave 2.0 (Covarrubias et al. 2011)
    - Short slab technology



- Software to select fiber performance (type/quantity)
  - Discussed in Dec 5th 9 a.m. webinar
  - Provides recommended f_{150} and MOR to be used in above design methods

Fiber Reinforcement
(defined by ASTM C1116)

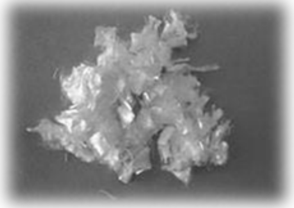



- Fiber Materials:
  - Type I: Steel FRC
  - Type II: Glass FRC (alkali-resistant only)
  - Type III: Synthetic FRC (moisture and alkali-resistant)
  - Type IV: Natural FRC (moisture and alkali-resistant)

- Traditionally, specified as a dosage rate (lb/cy or kg/m^3) or volume fraction (% of total volume), e.g.,
  - Steel 30 kg/m^3 ~ 0.38% by V_f
  - Polypropylene 4 kg/m^3 ~ 0.44% V_f
- *To consider different types of fibers, specify performance:*
  - *Residual strength f_{150}, e.g., = 1.0 MPa*

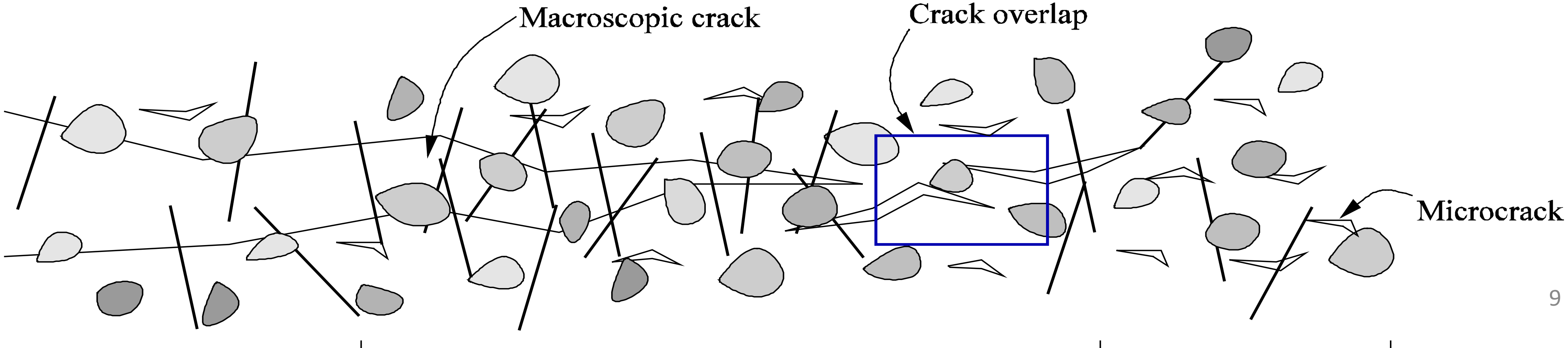
Macro-Fibers

- Materials:
  - steel, polypropylene, polyethylene, basalt
- Dosage:
  - 0.2 to 1.0% by volume
  - (e.g.) 3 to 15 lb/cy (synthetic) or 26 to 132 lb/cy (steel)
- Fiber dimensions:
  - Diameter > 0.012 inch
    0.2 to 0.8 mm
  - Length 0.5 to 2.5 inches
    20 to 65 mm
- Textures/Shapes:
  - fibrillated, straight, hooked-end, crimped, embossed



Micro-Fibers

- Materials:
  - polypropylene, carbon, cellulose, steel
- Dosage:
  - 0.05 to 0.2% by volume
  - 0.75 to 3 lb/cy
- Fiber dimensions:
  - Diameter < 0.012 inch
    < 0.1 mm (or in denier)
  - Length < 0.5 inch
    6 to 20 mm
- Textures/Shapes:
  - fibrillated, mesh, straight, chopped, pulp



How does FRC effect mixture properties?
(Fresh Properties)

- Slump/workability
  - Expect a decrease with addition of fibers (less slump, harder to work with)
  - Can counteract this with water-reducers or mixture adjustments (add more paste, reduce aggregate size)
- Air content
  - You may see some change due to fibers
  - Can counteract with adjustments to air-entraining admixture
- Unit weight or other properties
  - No significant difference

How does FRC effect mixture properties?
(Hardened Properties)

- Strength (tensile, compressive, flexural)
  - Should be no different if you left out fibers
  - If you see a reduction, you may have honeycombing or fiber clumping/balling/compaction issues
- Drying shrinkage
  - Free shrinkage tests do not show any change
  - Restrained shrinkage tests should be significantly longer lasting or lower strains at cracking
- Fatigue (flexural) – fixed stress ratio
  - FRC mixture will provide similar to longer number of fatigue cycles at failure (increased endurance limit)

Fiber Performance Reiterated
(for $V_f < 1.0\%$ typical in pavements)

- FRC ***does not*** increase tensile or compressive strength of plain concrete
- FRC ***does not*** increase or *decrease* flexural strength or splitting strength of plain concrete beams
- FRC ***does*** increase concrete toughness/strain capacity

Learn specifically how FRC effects pavement performance

listen to webinar on Wed Nov 7th 9am

How to specify fibers in concrete?

- Specify the FRC mixture must:
  - **Be tested according to ASTM C1609**
  - **Achieve a minimum f_{150} residual strength value**
  - **Be tested at a certain age (e.g., 7 or 28 days)**
  - **Be a certain specimen size (e.g., 6”x6” beam)**

Image of ASTM C1609, testing a 6” beam
https://www.admet.com/testing-applications/materials/concrete-testing/

Flexure Test Method

ASTM C1609-12 and JCI-SF4

Beams: 6 in x 6 in (15x15cm)

Span (L): 18 in (45cm)

L/150 = 0.12 in (3 mm)

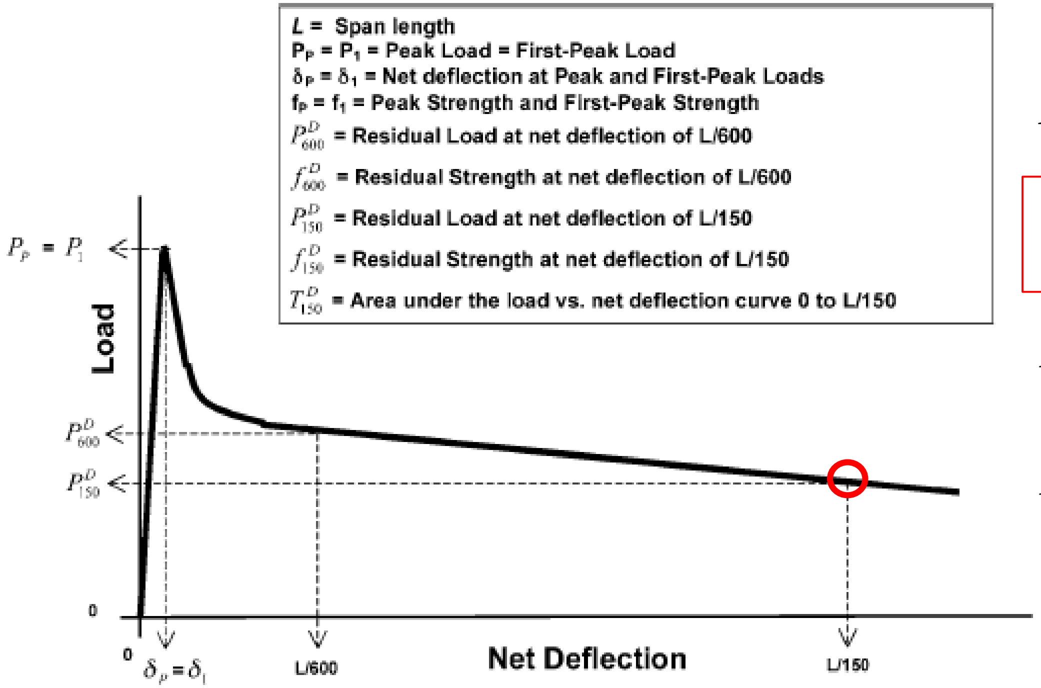


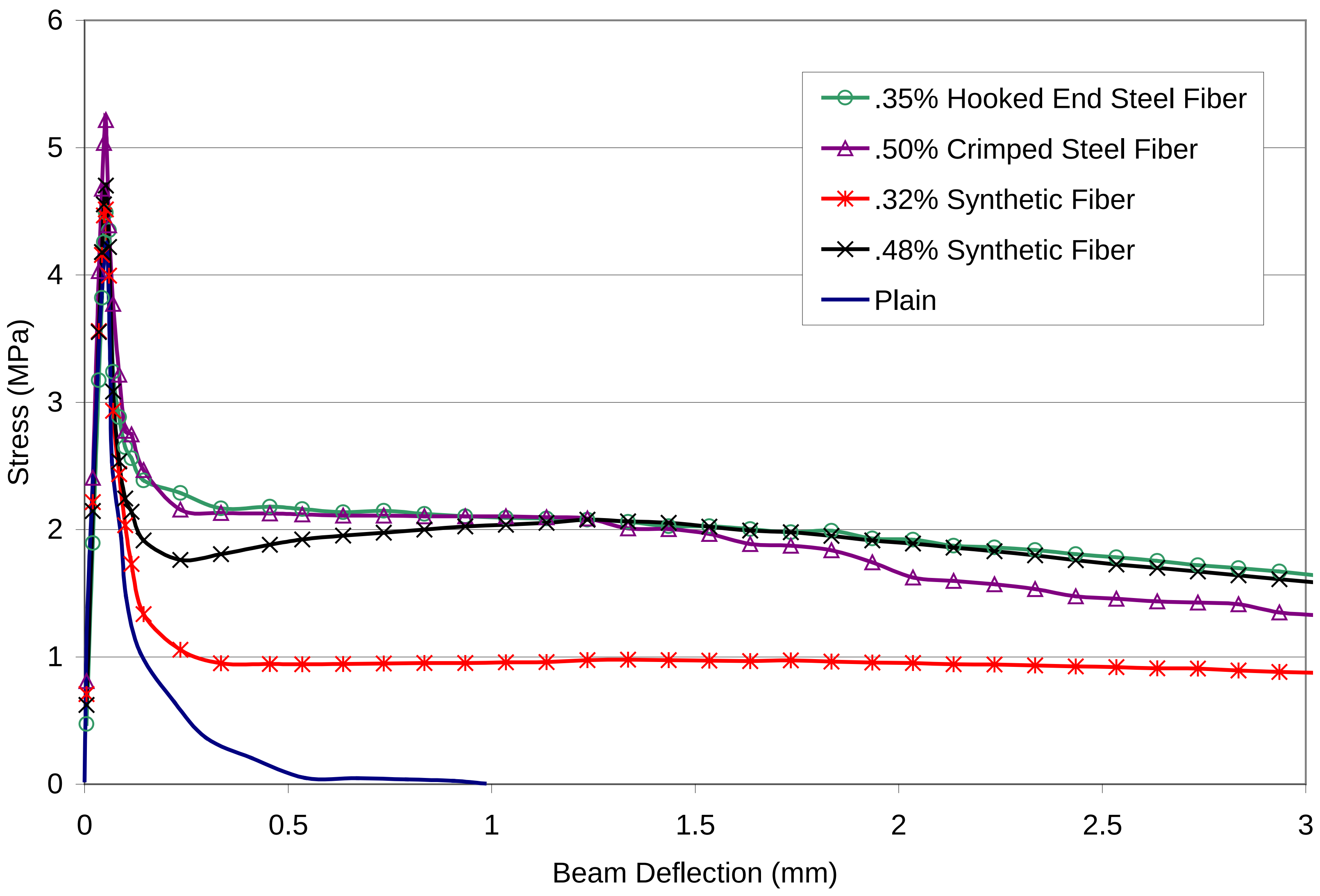
FIG. 3 Example of Parameter Calculations for First-Peak Load Equal to Peak Load (Not to Scale)

ASTM C1609-10	JCI-SF4
$MOR = \dfrac{P_1 L}{bd^2}$	$f_{e,3} = \dfrac{T_{150,3} S}{bd^2}$
$f_{150}^{150} = \dfrac{P_{150}^{150} L}{bd^2}$	$R_{e,3} = \dfrac{f_{e,3}}{MOR} * 100$
$R_{150}^{150} = \dfrac{f_{150}^{150}}{MOR} * 100\%$ *or*	
$R_{T,150}^{150} = \dfrac{150 \cdot T_{150}^{150}}{MOR \cdot bd^2} * 100\%$	

Flexural Beam Results

150x150x550mm

$$MOR = \frac{PL}{bd^2}$$



Flexural and Residual Strength Values*

	Flexural Strength MOR psi [MPa]	f_{150} psi [MPa]	R_{150} (%)
Plain Concrete	686 [4.73]	0	0.0
0.32% Synthetic	680 [4.69]	126 [0.87]	18.0
0.48% Synthetic	699 [4.82]	225 [1.55]	32.0
0.35% Hook Steel	679 [4.68]	234 [1.61]	34.5
0. 50% Crimp Steel	766 [5.28]	184 [1.27]	24.0

*Actual values measuring according to ASTM C1609-07 (different roller assembly)

Examples of parameters that effect f_{150} values

f_{150} value psi [MPa]	Mixture	Fiber type	Age tested days	Fiber volume % of total concrete volume	Fiber dosage amount lb/cy [kg/m³]
90 [0.65]	Mix 1	Synthetic Fiber Option 1	14	0.27%	4.1 [2.4]
155 [1.05]	Mix 1	Synthetic Fiber Option 1	28	0.38%	5.8 [3.4]
160 [1.10]	Mix 1	Synthetic Fiber Option 2	28	0.27%	4.1 [2.5]
160 [1.10]	Mix 2	Synthetic Fiber Option 3	28	0.50%	7.6 [4.5]
175 [1.21]	Mix 2	Steel Fiber	28	0.19%	25.1 [14.9]
225 [1.10]	Mix 1	Synthetic Fiber Option 2	28	0.38%	5.8[3.5]

Modified Strength Equations

- $MOR' = MOR + f_{150}$
  - *MOR* = plain concrete flexural strength
  - f_{150} = residual strength
  - *MOR'* = effective flexural strength of FRC

- If you use a mix with f_{150}= 1.0 MPa (for example)
- And your ASTM C78 test *MOR* = 5.0 MPa (at 28 days)

- $Stress\ Ratio\ (SR) = \frac{Total\ Stress}{MOR+f_{150}}$

Altoubat et al. (2007)
Bordelon and Roesler(2012)

What is new with fiber technology?

- New fiber technologies being developed
  - New synthetic fibers (shape, length, surface texture)
  - Materials
- New admixtures and new mixing techniques to aid dispersion of fibers
  - Plasticizer admixtures
  - Batching process improvements
- Economically viable
  - Volume fractions often $< 0.5\%$ to keep initial cost low

Concrete Mixture changes for FRC Overlay

- Batching/mixing
  - Trial concrete mixture should be made first
  - At < 0.5% volume fraction of fibers, typically no need to change batching/mixing
    - Slump loss may occur.
  - Fiber Balling may occur if:
    - Fibers added too quickly
    - Fiber volume too high
    - Fibers already clumped (in delivery bags)
    - Mixer inefficient or worn blades
    - Mixture too stiff
    - Concrete mixed too long after fibers added
    - Mix sequencing - fibers added to mixer before other ingredients

- If Mix adjustment required: Add water reducer or ↑ Paste content.

Construction changes with FRC Overlays

- Placement/Consolidation
  - Can use conventional tools to place (e.g., slip form pavers, screeds, vibrators, etc.)
  - For significant slump loss with FRC, adjust as needed similar to normal concrete
  - Fiber balls should be removed. Adjust the batching/mix design to avoid additional fiber balls

- Finishing
  - Use magnesium floats and straightedges
  - Do not use wood floats with FRC
  - Be careful when tining, broom-finish, or using a burlap drag so as not to pull out fibers (maintain a small angle to the horizontal surface)
  - Expect the surface to look “hairy” or textured, especially with low flexural stiffness synthetic macrofibers

Construction changes with FRC Overlays

Finishing

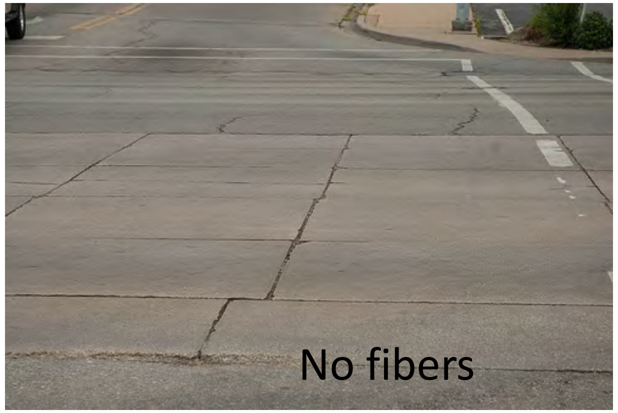
Curing

- For thinner overlays, concrete is sensitive to early temperature changes and moisture loss. Curing is critical to maintain a quality concrete.
- Use same curing practices as with conventional pavements

Construction changes with FRC Overlays

JOINTS

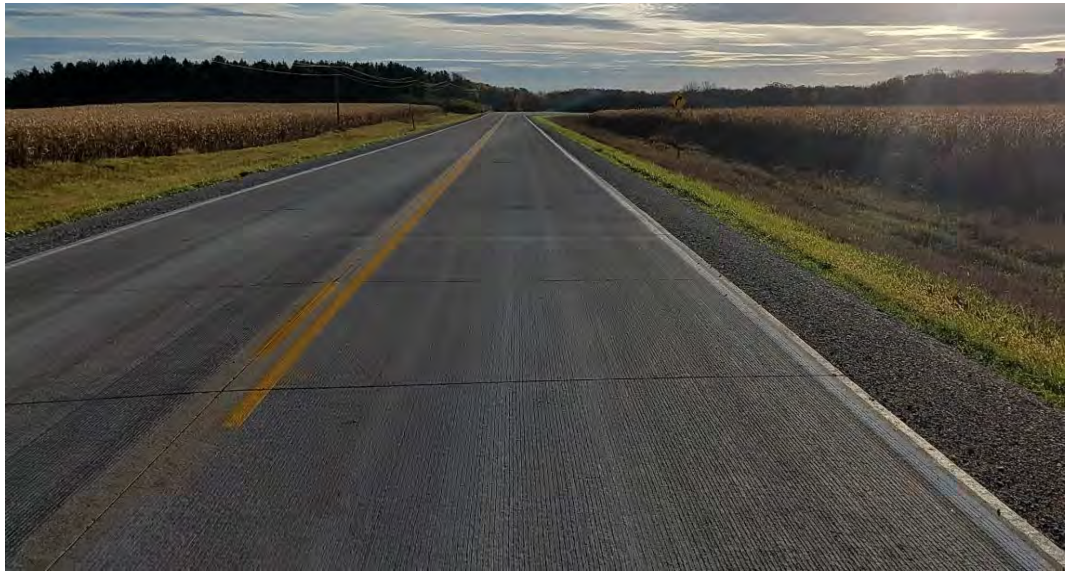
- For thinner overlays, slab sizes are reduced and more saw-cut joints required.
- Saw-cut timing and depth is critical for maintaining narrow joints and good load transfer efficiency.
- Cut contraction joints as early as possible (after final set); may need to cut every 4 to 20 slabs to relieve early stresses
- If fibers appear to be pulling out or raveling joint at early sawing, wait 30 min. and try again.
- Transverse joints are typically cut at 1/4 of depth or at least 1-inch
- Longitudinal joints are typically cut at 1/3 of depth
- Schedule *extra* saws for smaller panel sizes
- Fibers are not a substitute for dowel bars; more like tie bars in behavior



Construction changes with FRC Overlays

Maintenance

- For overlays, macro-fibers are designed to maintain a tight joint opening (< 1mm) so sealing is not needed
- May seal multiple longitudinal contraction joints
- If IRI or faulting occurs, diamond grinding may be performed



Questions & Further Information

- Contact Speakers:
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  - Amanda Bordelon, Ph.D., P.E., Utah Valley University
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- Future Webinars:
  - How FRC effects pavement design: Wed. Nov 7th, 9-10am
    https://register.gotowebinar.com/register/2042679693142465795
  - Overview of new software to select fiber amount: Wed. Dec 5th, 9-10am
    https://register.gotowebinar.com/register/2109690528809036035