Overview of Macrofiber Software and Guidelines for Concrete Overlay Design

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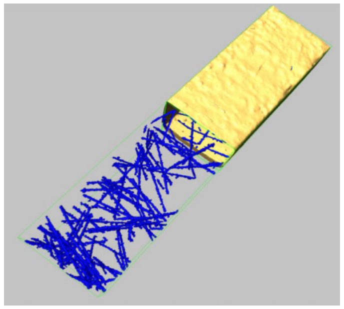
December 5, 2018
TTCC/Fiber Reinforced Concrete Project
National Concrete Consortium
Webinar 3 of 3



Acknowledgements

- 3rd of THREE 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”

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  - TTCC/Fiber-Reinforced Concrete Project
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  - “Fiber Reinforced Concrete for Pavement Overlays” Technical Advisory Committee
  - *Drs. Amanda Bordelon, Armen Amirkhanian, Alex Brand, and Jeffery Roesler*

FRC Overlay Project - Webinars

1. 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.

2. 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.

3. Overview of Macrofiber Software and Guidelines for Concrete Overlay Design

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

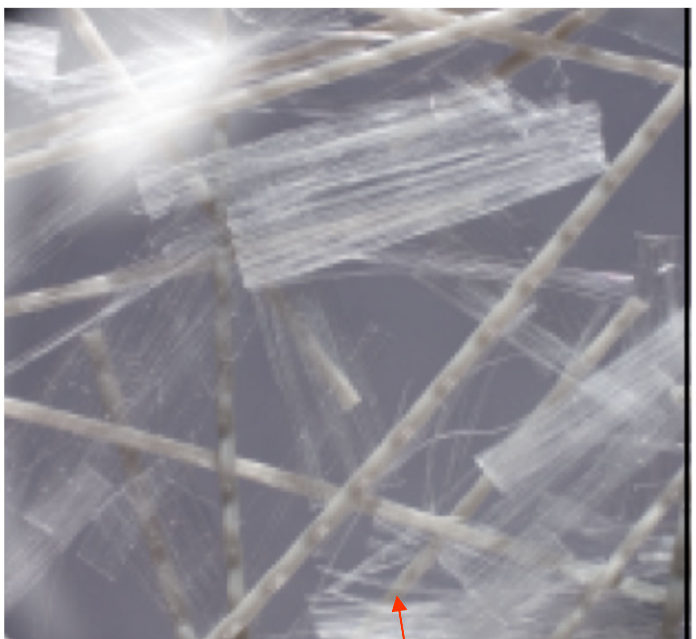
This webinar will provide an overview of the macrofiber software for determining the recommended fiber reinforced concrete residual strength values for application to concrete overlay design.

Webinar Objectives

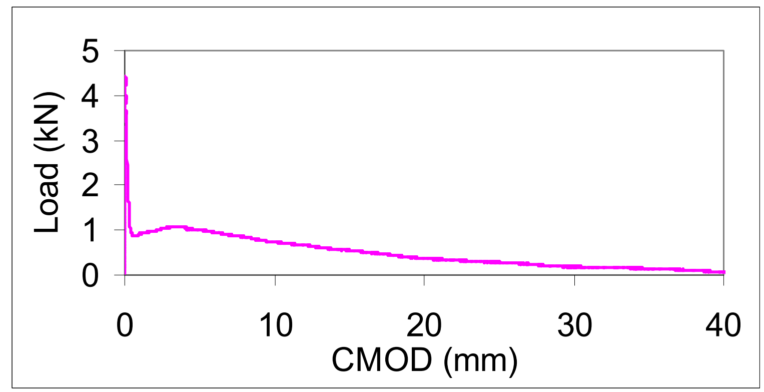
- Review of macrofibers and performance in concrete pavements (slabs)
- Review of ASTM C1609-12 residual strength test (FRC)
- Review FRC pav't design process
- FRC Overlay Performance Software
  - Demo: inputs and output (residual strength)
- Structural design example (FRC overlay)
- Specification tips

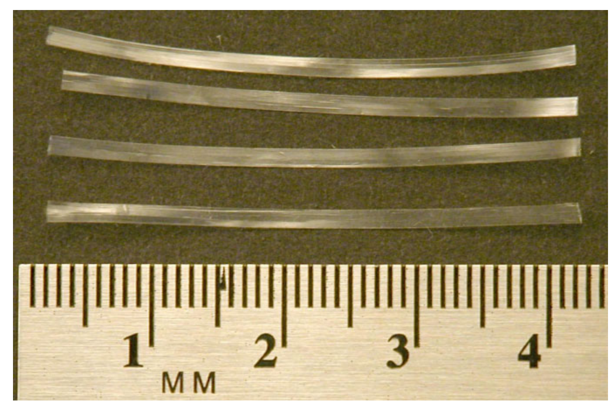
Fiber Type Comparison

- *Structural* (macrofibers) versus *non-structural* (microfibers)



Macro-
Fibers





Micro-Fibers – plastic shrinkage (non-structural)

PP – 6.7 lb/yd^3 or 0.44% V_f
Residual strength (e.g., f_{150} = 145 psi)

1867
ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Review of Fiber Reinforced Concrete Literature

for V_f<1.0% (Macrofibers)

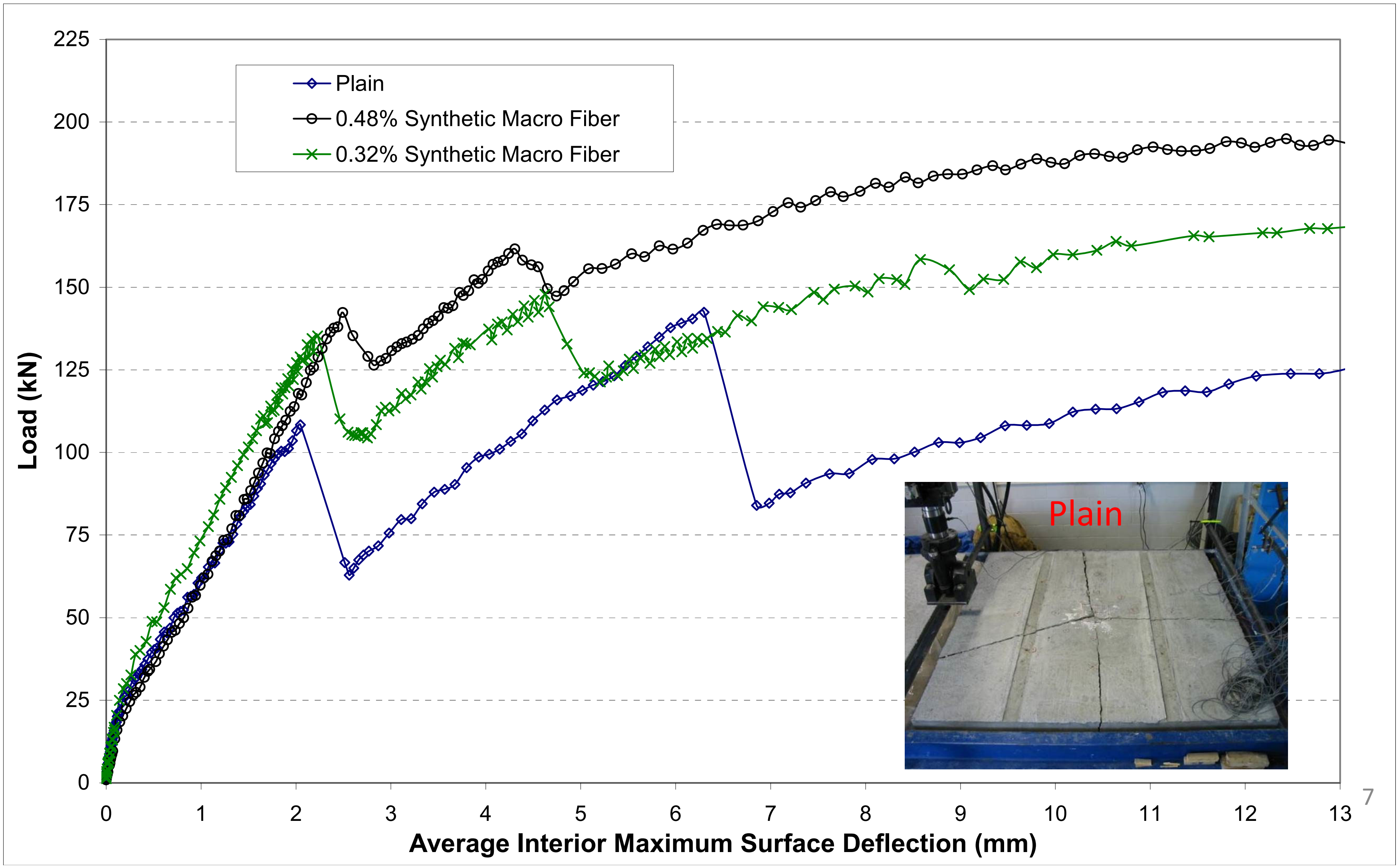
- FRC ***does not*** increase tensile or compressive strength of plain concrete

- FRC ***does not*** increase or *decrease* flexural strength or splitting strength of plain concrete beams

- FRC ***does*** increase concrete toughness/strain capacity

Monotonic Load-Deflection Plot

Plain/ Synthetic Macrofibers



Effect of Macrofibers on Concrete Slab Flexural Capacity

- Macrofiber addition improve flexural cracking load over plain concrete slab.

Increase in FRC slab capacity over plain concrete slab

- Synthetic Macrofiber#1 (0.48%) $\Rightarrow$ 32%
- Synthetic Macrofiber#1 (0.32%) $\Rightarrow$ 25%
- Hooked Steel Macrofiber (0.35%) $\Rightarrow$ 31%
- Crimped Steel Macrofiber (0.50%) $\Rightarrow$ 55%*

*higher concrete strength

How to specify macrofibers in concrete overlays?

- Comparison of Flexure Strength Tests
  - ASTM C1550 (RPT)
  - ASTM C1018 (old)
  - ASTM C1399 (beam)
  - **ASTM C1609-12 (beam)**
  - JCI-SF4 (1983) - beam

➢ **RESIDUAL STRENGTH**

Flexural Performance of FRC

ASTM C1609-12

Beams: 6 in x 6 in (15x15cm)

Span (L): 18 in (45cm)

L/150 = 0.12 in (3 mm)

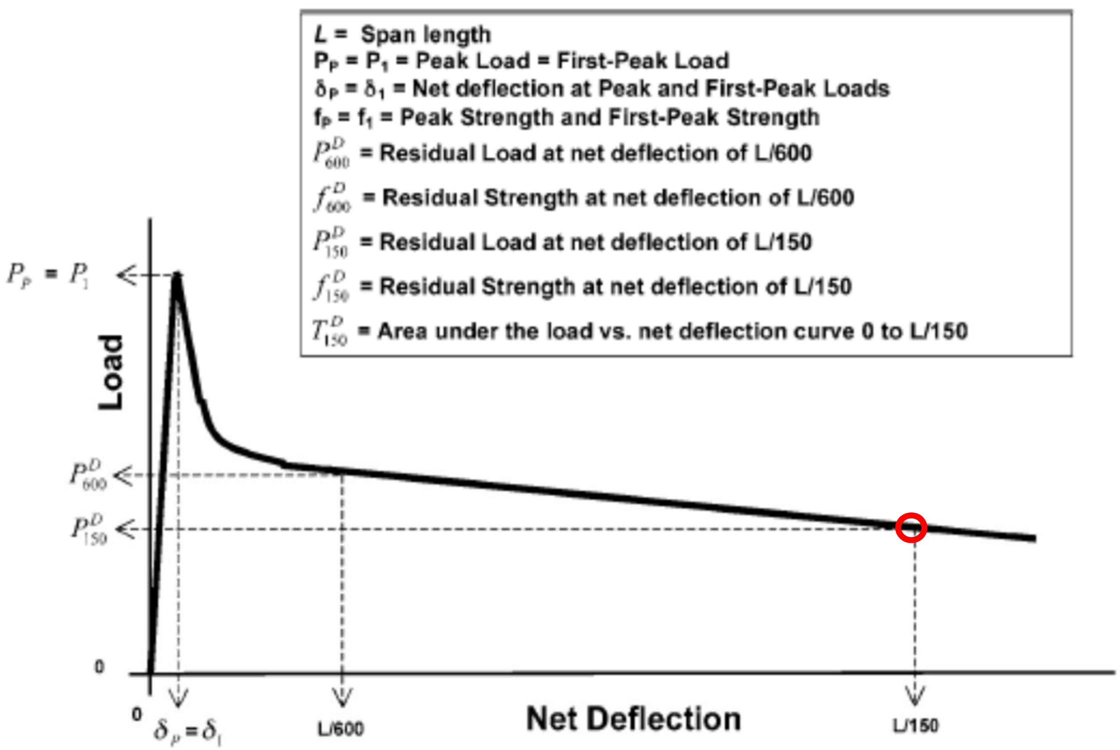


FIG. 3 Example of Parameter Calculations for First-Peak Load Equal to Peak Load (Not to Scale)

ASTM C1609-12

$$MOR = f_1 = \frac{P_1 L}{b \cdot d^2}$$

$$f_{150}^{150} = \frac{P_{150}^{150} L}{b \cdot d^2}$$

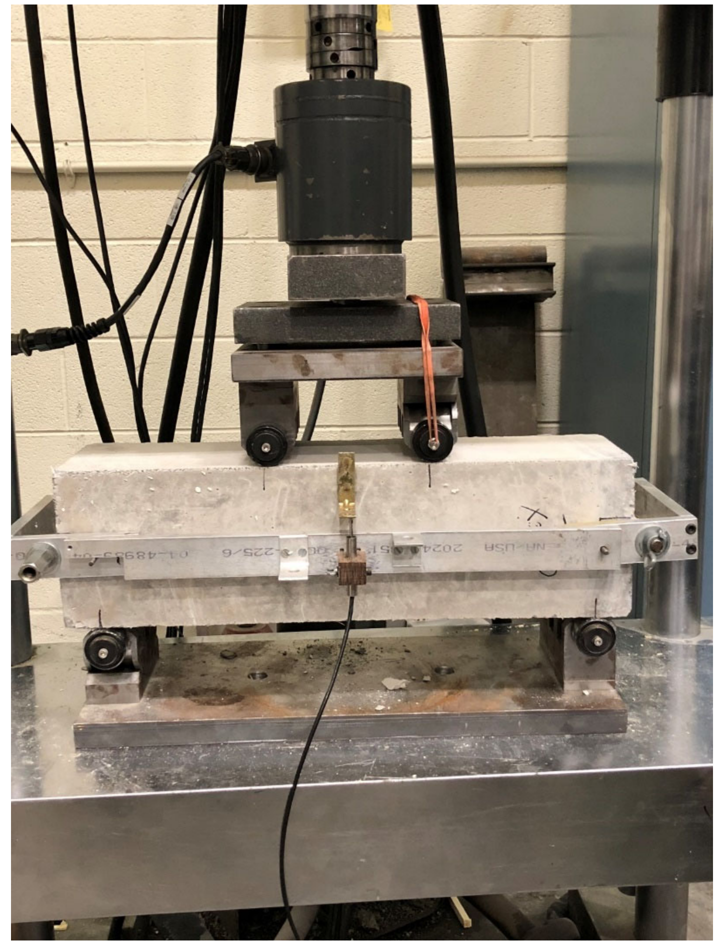
$$R_{T,150}^{150} = \frac{150 \cdot T_{150}^{150}}{f_1 \cdot b \cdot d^2}$$

f_{150}^{150} = residual strength

$R_{T,150}^{150}$ = Equivalent flexural strength ratio

How to specify fibers in concrete?

- Specific FRC mixture must:
  - Be tested according to ASTM C1609-12
  - Achieve a minimum f_{150} residual strength value (design target)
  - Be tested at a certain age (e.g., 7 or 28 days)
  - Be a certain specimen size (e.g., 6”x6” beam)

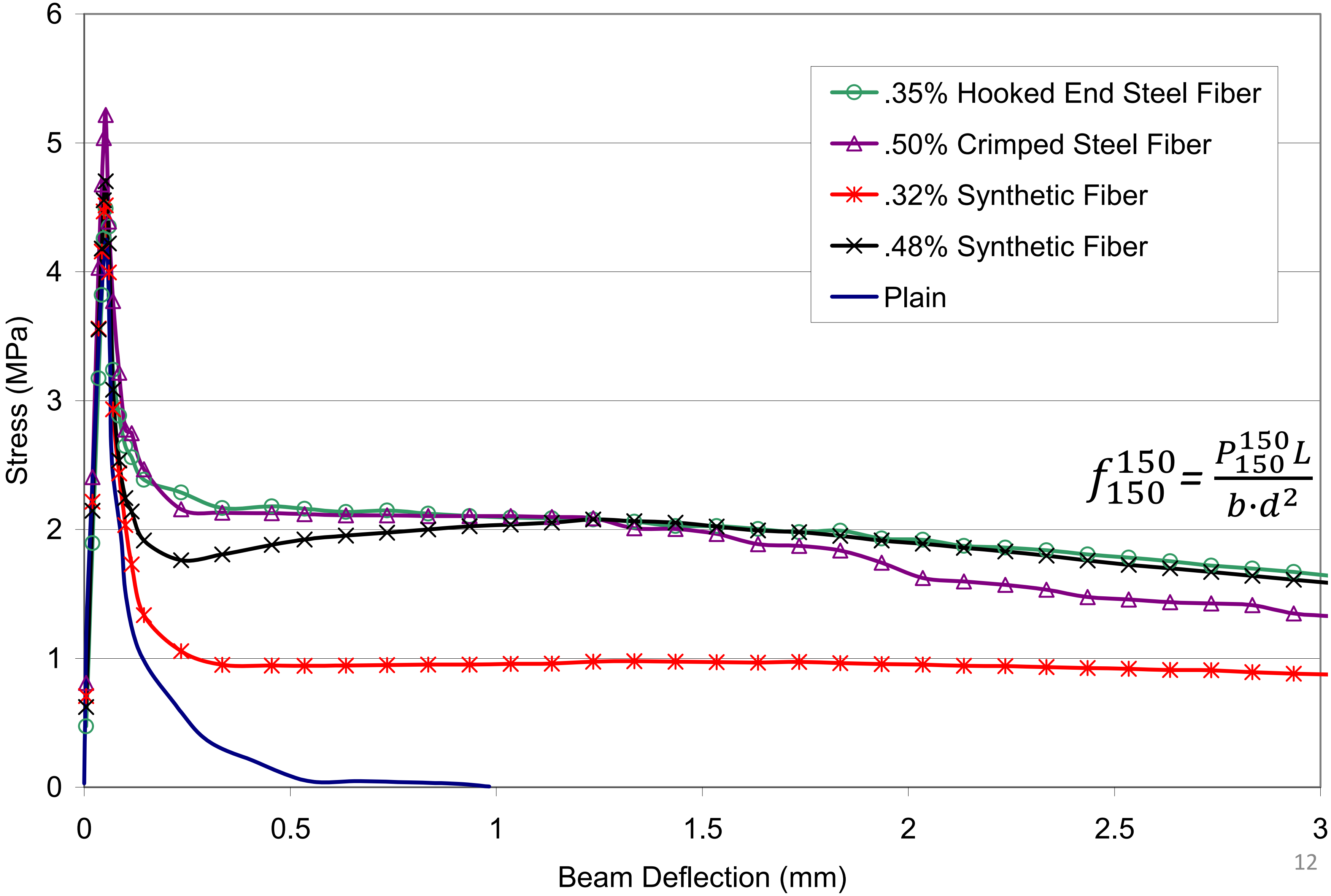


ASTM C1609-12 testing a 6x6x18 in^3 flexural beam

Flexural Beam Results

150x150x550mm

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



$$f_{150}^{150} = \frac{P_{150}^{150} L}{b \cdot d^2}$$

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)

Effects of Concrete Mixture Parameters on f_{150} values

f_{150} 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 #1	14	0.27%	4.09 [2.42]
155 [1.05]	Mix 1	Synthetic Fiber #1	28	0.38%	5.76 [3.42]
160 [1.10]	Mix 1	Synthetic Fiber #2	28	0.27%	4.14 [2.45]
160 [1.10]	Mix 2	Synthetic Fiber #3	28	0.50%	7.58 [4.50]
175 [1.21]	Mix 2	Steel Fiber	28	0.19%	25.13 [14.91]
225 [1.10]	Mix 1	Synthetic Fiber #2	28	0.38%	5.83[3.46]

Effective Flexural Strength Equation

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

Note:

$f_{150} = f_{150}^{150}$

- ➢ f_{150}= 125 psi (FRC mix for example)
- ➢ *MOR* = 625 psi (ASTM C78 at 28 days)
- ➢ $MOR' = 625\, psi + 125\, psi = 750\, psi$

- $Stress\ Ratio\ (SR) = \frac{Total\ Stress(\sigma)}{MOR'} = \frac{(\sigma)}{MOR + f_{150}}$
- Fatigue Life: $Log\ N_f = 17.61 - 17.61\frac{\sigma}{MOR'}$

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

Bonded Concrete Overlay of Asphalt:

15-year Illinois Experience with Macrofibers

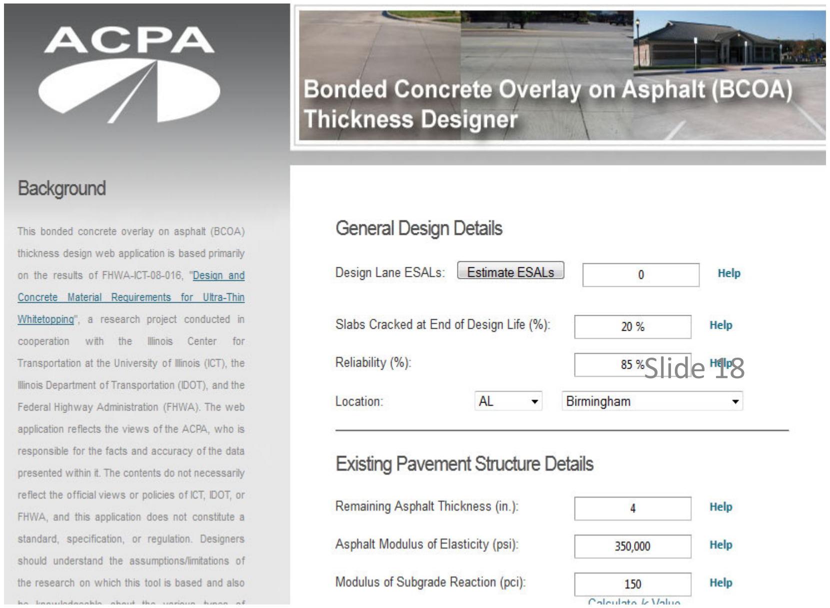
- **Macrofibers** important to good performance
  - Reduce required overlay thickness
  - Keep joints tight and reduce risk of faulting/misalignment
  - When distresses occur, fibers keep cracks tight, allowing pavement to remain relatively smooth and serviceable
  - Reduction to elimination in slab migration/movement
- Maintain panel sizes with fibers ≤ 6 ft
- No faulting or cracking on 4ft or 6ft slab sizes with macrofibers (>2006)
- If the HMA layer or underlying support have the potential to be variable condition (e.g. Schank Ave) and/or heavy truck traffic, ***try higher fiber dosages or fix support layer***

King et al. (2014)

Pavement Design Methods with FRC input

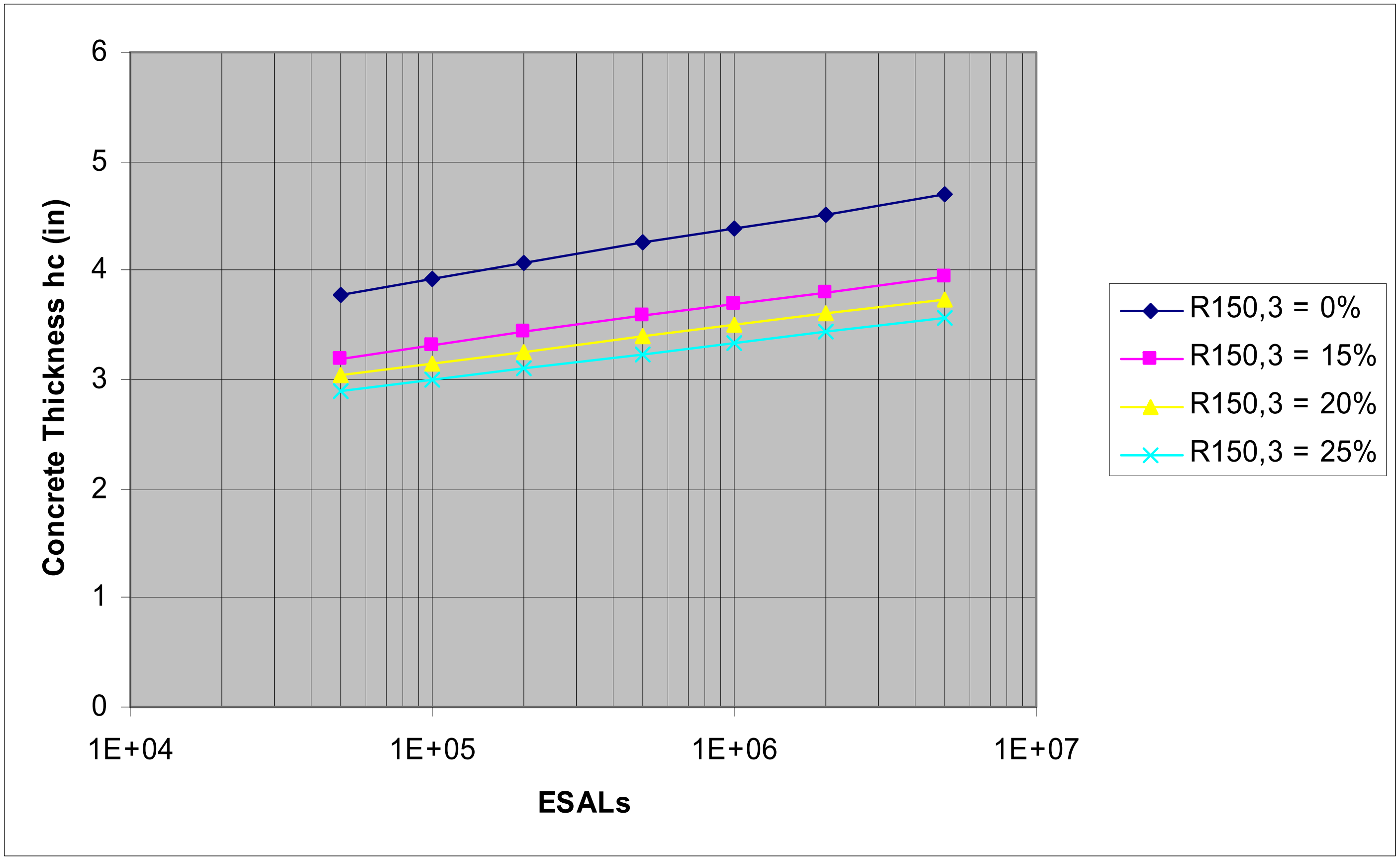
- **Existing design methods / codes**
  - British Concrete Society (TR34) – industrial floors
  - Bonded Concrete Overlay of Asphalt (BCOA)
    - IDOT Chapter 53 (2008) BCOA (*Bordelon and Roesler 2012)*
    - *ACPA BCOA calculator (http://apps.acpa.org/applibrary/BCOA/)*
  - OptiPave 2.0 (Covarrubias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

- **New software to select fiber performance*** (type/quantity)
  - Provides recommended $\boldsymbol{f_{150}}$ and MOR to be used in design methods
  - Provides estimate on LTE and Reduction of cracking severity after 10 yrs



Illinois Structural Design of BCOA (2007-09)

Effect of Macro-fibers on Slab Thickness



f_{150} = 0 psi

f_{150} = 112 psi

f_{150} = 150 psi

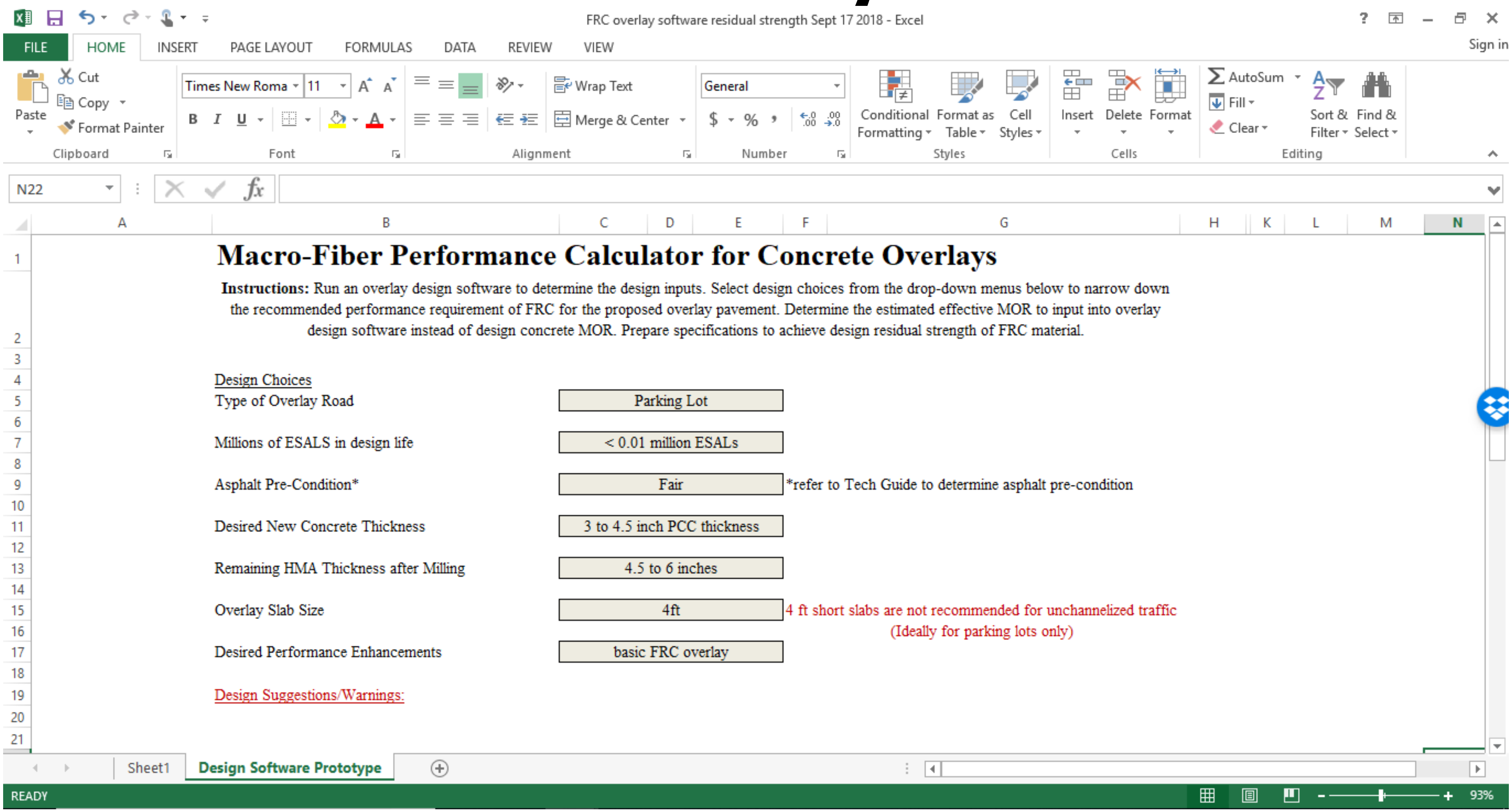
f_{150} = 187 psi

Bordelon et al. (2008)

Fiber-Reinforced Concrete Pavement Design

- Use existing concrete pavement design thickness methods *(AASHTO Pavement ME, ACPA Pavement Designer*, FAA, AASHTO 1993)*
  - MOR = plain concrete flexural strength
- Effective or modified flexural strength (MOR')
  - include macrofibers (f_{150}) = residual strength
- **Input MOR'** for concrete strength instead of MOR
- ***Warning:*** Slab size adjustment may be needed!!

New FRC Software for Concrete Overlays



WHEN to use new FRC Software

- Use existing design procedure for designing overlay or pavement
  - BCOA-ME *(select no fiber)
  - ACPA BCOA app **(put in R_{150})
  - AASHTO Pavement ME
  - Etc.
- Put select inputs from your design into the new FRC selection software
- Software will output recommended f_{150} values

*Warning: some of the existing software that includes “FRC” already changes the MOR internally. Use the MOR’ of this software and un-reinforced (no FRC).

** In software that uses f_{150} or R_{150} AND original MOR, please use these values from the FRC software.

Inputs for FRC Software

- Type of Overlay
- Traffic Amount (ESALs)
- Asphalt Pre-Condition* *(FRC software only asks about 1 layer below)*
- Desired Concrete Thickness
- Remaining HMA Thickness after Milling
- Slab Size
- Performance Enhancements*
- Plain (or FRC) Concrete MOR
- *Tested FRC f_{150} value (optional)*

*clarified further in this webinar and in full report

Asphalt Pre-Condition

- Software accepts Poor, Localized Poor, Fair, and Good
- Different ways to rate the existing condition
- Effects choice of bond vs. unbonded overlay primarily

	Poor and Localized Poor	Fair	Good +
HMA Structural Number	2		5
HMA Stiffness	100 ksi [0.7 GPa]	350 ksi [2.4 GPa]	600 ksi [4.1 GPa]
HMA Seasonal Resilient Modulus	430 ksi [3GPa]		580 ksi [4 GPa]
HMA Distresses	Stripping, delaminations, poor drainage, excessive rutting, moderate fatigue cracking, transvers cracking		Rutting, some surface cracks, aged

Software Demo

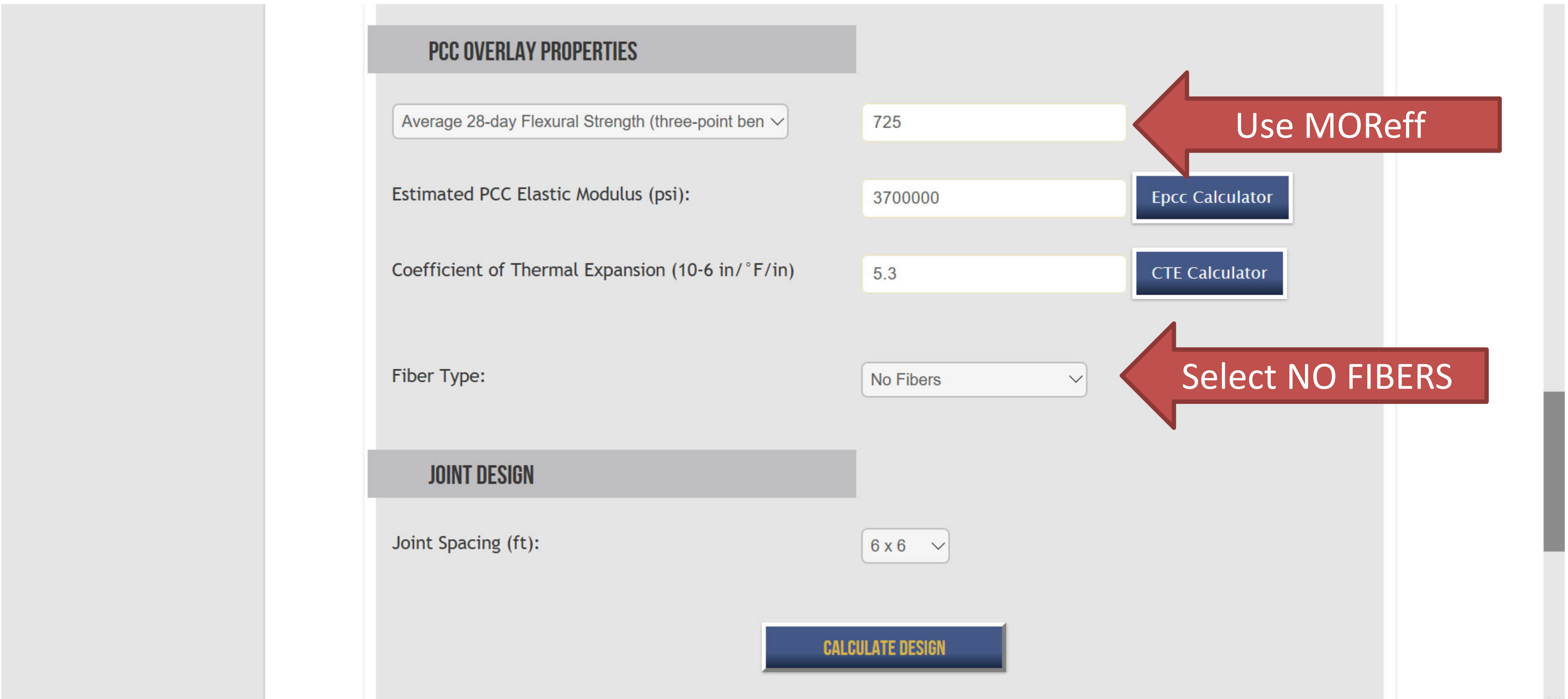
Example 1

- **Bus Pad:**
  - Low volume (<0.1 million ESALs) bus pad
  - Fair to poor condition existing HMA with 3 inches remaining after milling
  - Slabs at 6 ft spacing, 4 inch thick PCC
  - MOR = 600psi
  - Compare FRC design w/ plain un-reinforced overlay

  - Software suggests f_{150} between 125 and 200 psi
  - Software suggests an effective MOR' = 725psi for structural design (w/ macrofiber mix)

Example with BCOA-ME PITT

Plain Concrete compared to FRC



Example 1, continued

	Plain Concrete	**FRC**
BCOA-ME inputs	100,000 ESALs 3 in HMA remaining Marginal condition 600 psi MOR "No Fibers"	 725 psi MOR' **"No Fibers" still selected**
Calculated PCC Thickness	4.73 in	3.8 in
Design PCC Thickness	5 in	4 in

Keep Elastic Modulus and "No Fibers" inputs the same in the BCOA-ME software

FRC software states for f_{150} of 125psi the LTE is predicted to be 80-90% and a reduction in crack severity

Example 2

- **Arterial Roadway**
  - 10 million ESALs
  - Localized pot holes and otherwise moderate distresses in HMA with 3 inches remaining after milling
  - Slabs at 6 ft spacing, 6 inch thick, 600psi concrete
  - Want to compare the basic FRC design against plain un-reinforced overlay

  - Due to thin HMA and fair/poor condition, should check unbonded design

  - Software suggests f_{150} between 175 and 250 psi
  - Software suggests an effective MOR’ of 775psi be used in the design

Example 2 continued

	Plain Concrete	FRC basic
BCOA-ME inputs	10M ESALs 3 in. HMA remaining Marginal condition 600 psi MOR "No Fibers"	775 psi MOR' "No Fibers" selected
Calculated PCC Thickness	5.93 in	4.5 in
Design PCC Thickness	6 in	4.5 in

FRC software states LTE 80-90% and Yes reduced crack severity for f_{150} of 175 psi or more

Design Enhancement Input

(Optional)

- An option in the inputs is or a “design enhancement” based on specific benefits of fibers
  - Enhance Load Transfer Efficiency
  - Reduce Crack Deterioration Rate

- Will increase the recommended f_{150} value
  - Increases by *50 psi* total

Why use this FRC Performance software for Concrete Overlays?

- Other design methods (e.g., AASHTO Pavement ME) do not include benefit of fibers
  - Use this Excel spreadsheet to find how much to change the MOR to MOR’ in other design procedure.
- Can use design methods that have fibers (e.g., BCOA-ME) but include your fiber type through its performance value (f_{150}).
  - BCOA-ME and equivalent design procedures use same effective MOR’, but have internal correlation of fiber dosage rate to f_{150} value.
- Written with Excel with pull down menus so it is easy to use

What if I already have a FRC mixture?

- Can skip the inputs portion and go straight to the material properties portion
  - Input the MOR (28 day 4-point bending strength)
  - Input the f_{150} value
- Software will calculate the effective MOR' to use in structural design
- Software will also predict serviceability parameters
  - Load Transfer Efficiency and Reduced Severity of Cracking
  - Based on existing research and field estimates

	f_{150} = 50 psi	f_{150}=100psi	f_{150}=150psi
Anticipated Load Transfer Efficiency at 10 yrs	60-70%	80-90%	80-90%
Will the severity of cracking be reduced?	No reduction in severity	No reduction in severity	Yes reduction in severity

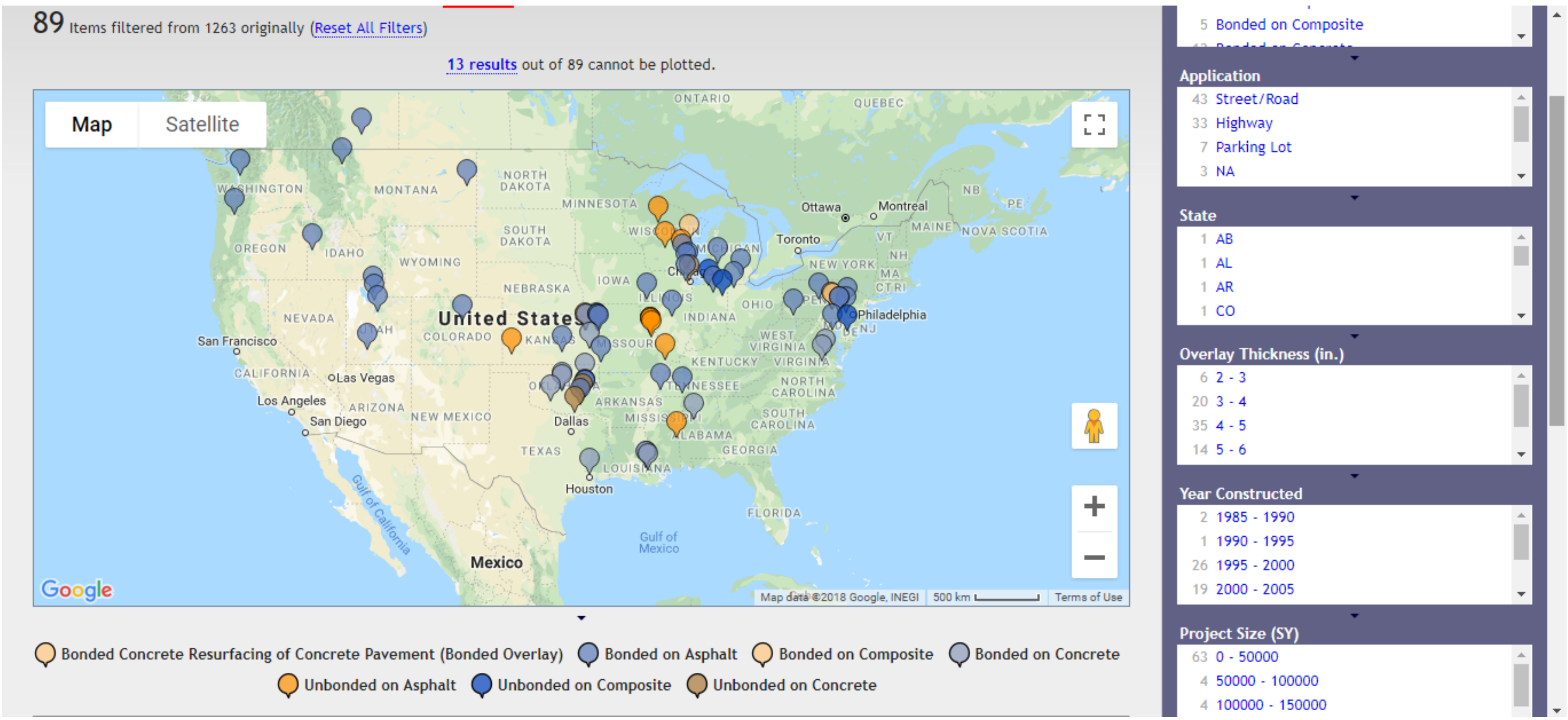
What we need from you?

- Try out the FRC Overlay Performance software
- Consider more FRC pavement projects (overlays for streets, highways, parking lots)
- Record actual parameters (thicknesses, stiffness, strengths, f_{150} values)
- Submit these parameters to an ACPA representative added in the National Overlay Database
- FRC Software can be updated in future as more FRC overlay projects designed, constructed, and monitored.

FYI:

ACPA National Concrete Overlay Explorer

overlays.acpa.org/webapps/overlayexplorer/index.html



Specifications for FRC Overlays

- ASTM 1116 – types of fibers allowed
  - Type I – steel (ASTM A820), Type II-glass (ASTM C1666), Type III-synthetic (ASTM D7508), etc.
- Fiber geometry (diameter & length)
- Batching and mixing macrofibers in concrete

- Residual strength (f_{150}) – ASTM C1609-12
  - e.g., quantity of fiber must achieve f_{150} =125 psi
- Max and min. fiber dosage (lb/cy)
  - Fiber balling (max) & variability in f_{150} (min)

Questions & Further Information

- Contact Speakers:
  - Jeffery Roesler, Ph.D., P.E., University of Illinois Urbana Champaign

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  - Amanda Bordelon, Ph.D., P.E., Utah Valley University

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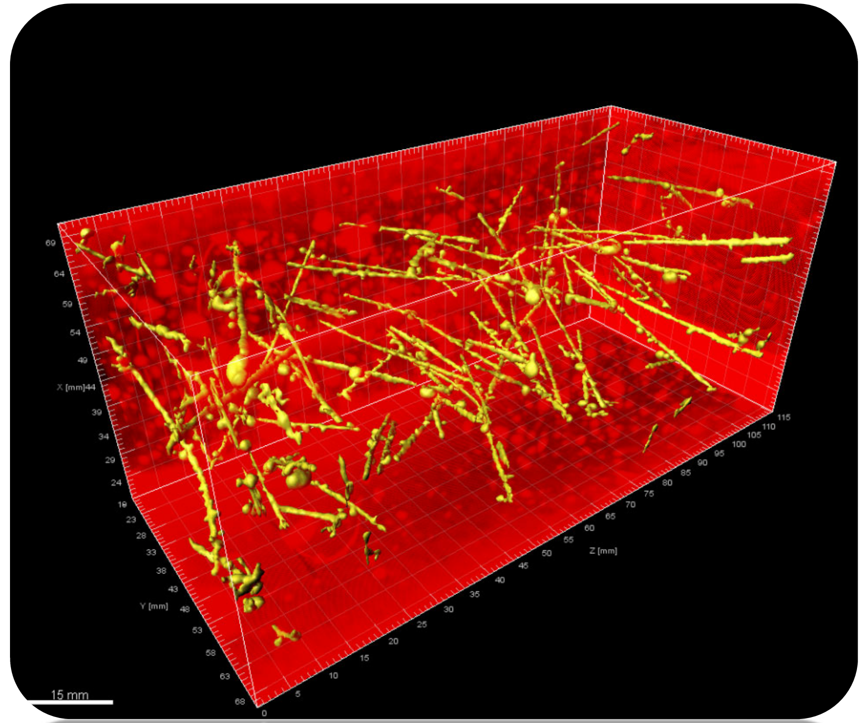
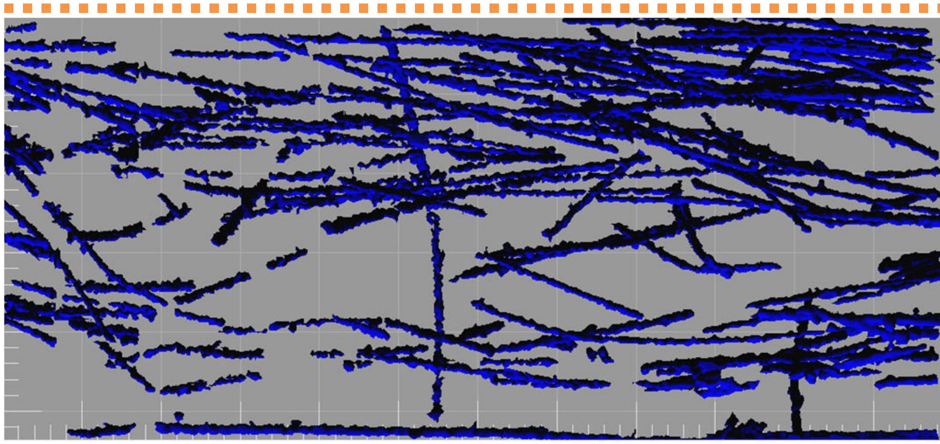
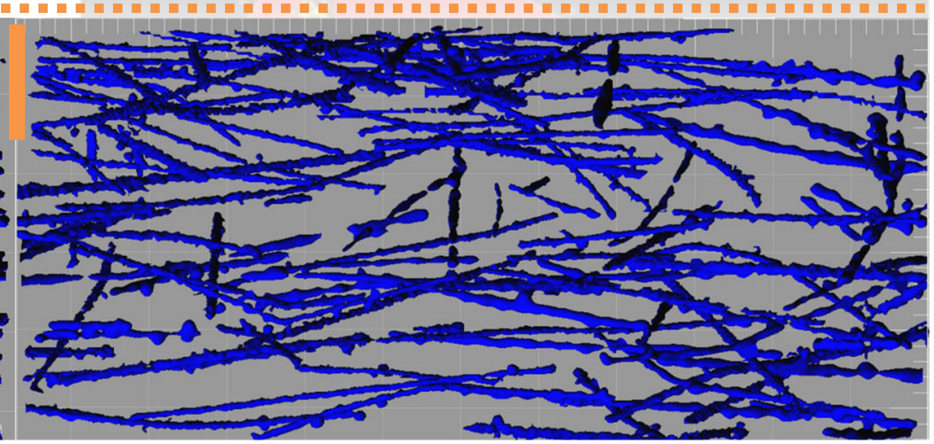
Questions?







141 fibers

Bordelon (2011)

131 fibers