Benefit and Application of Fiber Reinforcement in Concrete Pavement

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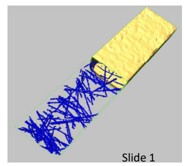
CPTech Center
2021 Webinar Series



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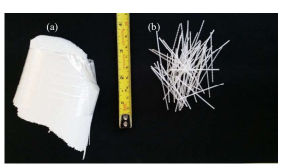
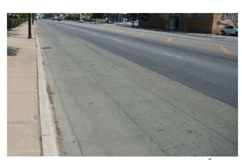
    - "Fiber Reinforced Concrete for Pavement Overlays" Technical Advisory Committee
    - National Concrete Consortium
    - National Concrete Pavement Technology Center (Iowa State)
      - Peter Taylor, Steve Tritsch, etc.
    - Snyder and Associates, Inc.
      - Jerod Gross, Dale Harrington

NATIONAL CONCRETE CONSORTIUM

Presentation Overview

- FRC pavement resources
- General overview of macrofibers in concrete pavements
- Macrofibers types available
- Effect on fresh and hardened properties
- Test methods to specify macrofibers
- Construction best practices & guidelines
- Applications of FRC to concrete pavements



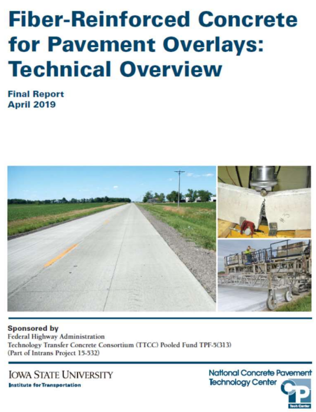


Driveway Rehabilitation (2003)

5lb/cy of Synthetic Macrofibers

FRC Pavement Overlay Report: T.O.C.

https://intrans.iastate.edu/app/uploads/2019/04/FRC_overlays_tech_ovw_w_cvr.pdf



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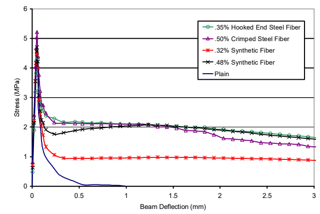
Fiber-Reinforce Concrete Overlay - Tech Brief

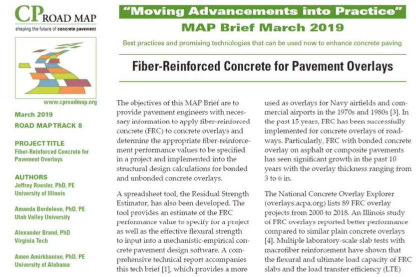
Tech Brief - FRC for Pavement Overlays (*8 pages*)

- https://intrans.iastate.edu/app/uploads/2019/10/MAPbriefMarch2019.pdf

-Fiber types, mixture proportions, properties, slab performance, structural design, construction, testing, residual strength

ASTM C1609-12

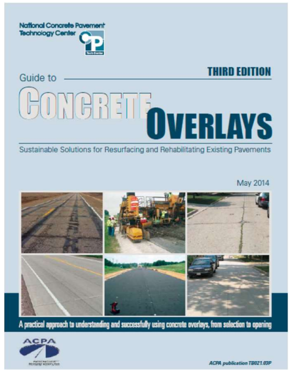




Concrete Overlay Guide, ~~Third Edition~~ *(4th edition soon)*

Contents

- Overview of Overlays
- Overlay types and uses
- Evaluations & Selections
- Six Overlay Summaries
- Design Section
- Misc. Design Details
- Overlay Materials Section
- Work Zones under Traffic
- Overlay Construction
- Accelerated Construction
- Specification Considerations
- Repairs of Overlays

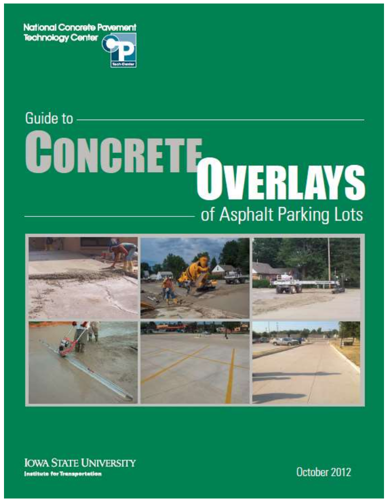


http://www.cptechcenter.org/technical-library/documents/Overlays_3rd_edition.pdf

Guide to Concrete Overlays of Asphalt Parking Lots (2012)

Contents:

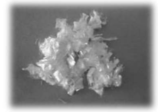
- Parking Lot Features
- Existing Pavement Condition
- Concrete Overlay Design
- Jointing
- Parking lot details
- Materials
- Construction
- Fibers



What is new with FIBERS?

1. New fiber technologies being developed
   - New synthetic fibers (shape, length, surface texture)
   - Materials
2. New admixtures and new mixing techniques to aid dispersion of fibers
   - Plasticizer admixtures
   - Batching process improvements
3. Pavement design tools
   - Thickness, slab size, crack width, crack deteriorate rates
4. Economically viable
   - Volume fractions often < 0.5% to keep initial cost low

Fiber Types (Sizes)

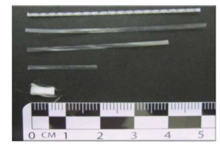


Micro-Fibers

- Material:
  - Synthetic, natural or glass fibers
- Dosage:
  - 0.05 to 0.2% by volume
  - 0.75 to 3 lb/cy
- Fiber dimensions:
  - Diameter < 0.012 inch
  - Length < 0.5 inch

MACRO-FIBERS

- Material:
  - Synthetic or steel
- Dosage:
  - 0.2 to 0.5% by volume
  - 3 to 8 lb/cy (synthetic) or 25 to 75 lb/cy (steel)
- Fiber dimensions:
  - Diameter > 0.012 inch
  - Length 0.5 to 2.5 inches



Benefits & Challenges of FRC Pavements

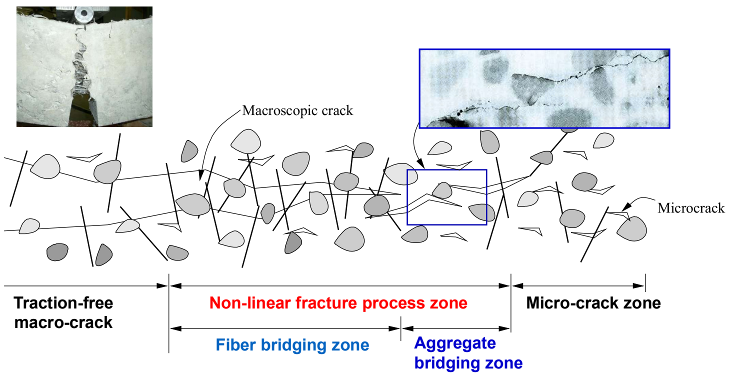
- FRC in rigid pavements since 1970s
  - U.S. Army (airfield) tests (Parker 1974)
  - V_f =1 to 2% steel fibers with higher cement content
- FRC benefits from past studies:
  - Improve cracking resistance & load carrying capacity of slabs
  - *Reduce slab thickness (30% to 50%) – empirical-based*
  - *Increase allowable joint spacing in design – experience-based*
  - Reduce or limit crack widths and crack deterioration rates
  - Less joint spalling in pavements
- Challenges:
  - Several premature slab failures in field *(Rollings 1993)*
  - Dosage amount and type of fiber chosen on "**experience**"
  - Structural Design benefit was *NOT effectively standardized*

Concrete Properties with Fiber Reinforcement

(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

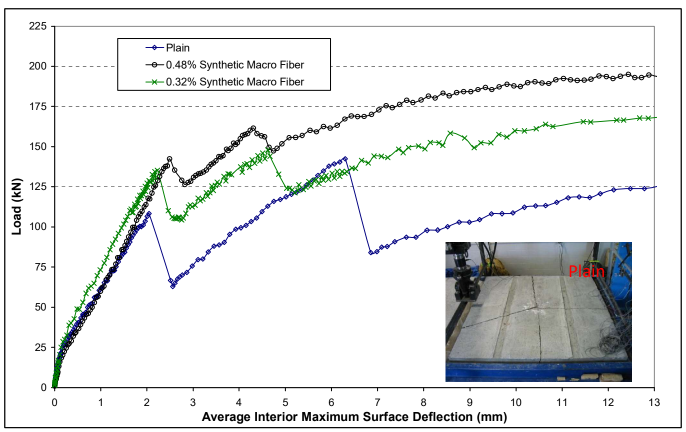
Fiber Bridging Mechanism

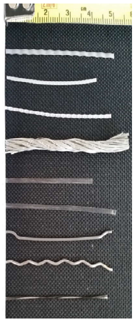


How does FRC effect mixture properties?
(Hardened Properties)

- Strength (tensile, compressive, flexural)
  - Should see no different between plain and FRC
  - If you see a reduction, 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)

Monotonic Load-Deflection of FRC Slab
Plain vs Synthetic Macrofibers





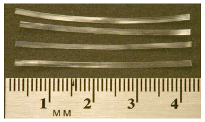
Effect of Macrofibers on Concrete Slab Flexural Capacity

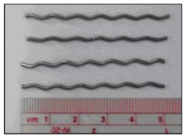
- Macrofiber addition improve flexural cracking load over plain concrete slab.

Increase in FRC slab capacity over plain concrete slab

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

  *higher concrete strength





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 to specify macrofibers in concrete pavement?

- 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 in³ flexural beam

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)

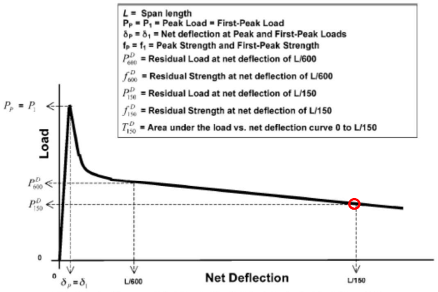


FIG. 3 Example of Parameter Calculations for First-Peak Load Equal to Peak Load (Not to Scale)

ASTM C1609-12

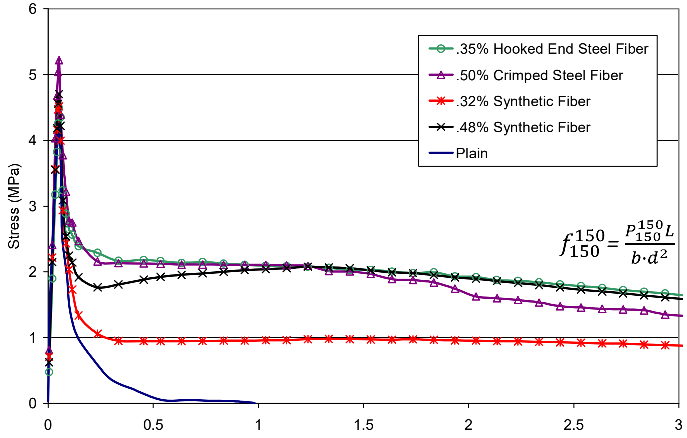
$$MOR = f_1 = \frac{P_1 L}{b \cdot d^2}$$

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

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

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)

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]

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)*
    - Pitt BCOA-ME *(Vandenbossche et al 2013)*
  - OptiPave 2.0 (Covarrubias et al. 2011)
    - Short slab technology
- Software to select fiber performance (type/quantity)
  - Provides recommended f_{150} and MOR to be used in above design methods

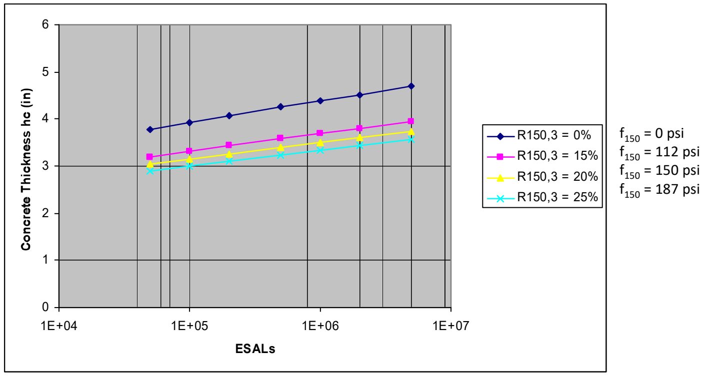
Modified Strength Equations

- $MOR' = MOR + f_{150}$
  - *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)

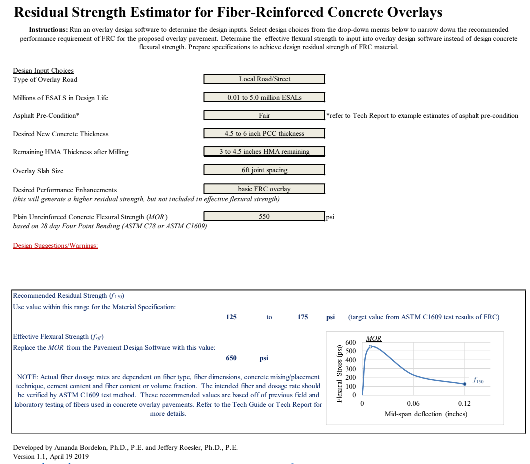
Illinois Structural Design of BCOA (2007-09)

Effect of Macro-fibers on Slab Thickness Design



Bordelon et al. (2008)

Residual Strength Estimator Software: FRC Overlays



Residual Strength Estimator for Fiber-Reinforced Concrete Overlays

Instructions: Run an overlay design software to determine the design inputs. Select design choices from the drop-down menus below to narrow down the recommended performance requirement of FRC for the proposed overlay pavement. Determine the effective flexural strength to input into overlay design software instead of design concrete flexural strength. Prepare specifications to achieve design residual strength of FRC material.

Design Input Choices

Type of Overlay Road	Local Road/Street	
Millions of ESALS in Design Life	0.01 to 5.0 million ESALs	
Asphalt Pre-Condition*	Fair	*refer to Tech Report to example estimates of asphalt pre-condition
Desired New Concrete Thickness	4.5 to 6 inch PCC thickness	
Remaining HMA Thickness after Milling	3 to 4.5 inches HMA remaining	
Overlay Slab Size	6ft joint spacing	
Desired Performance Enhancements *(this will generate a higher residual strength, but not included in effective flexural strength)*	basic FRC overlay	
Plain Unreinforced Concrete Flexural Strength (*MOR*) *based on 28 day Four Point Bending (ASTM C78 or ASTM C1609)*	550	psi

Design Suggestions/Warnings:

Recommended Residual Strength (f_{150})
Use value within this range for the Material Specification:
125 to **175** **psi** (target value from ASTM C1609 test results of FRC)

Effective Flexural Strength (f_{eff})
Replace the *MOR* from the Pavement Design Software with this value:
650 **psi**

NOTE: Actual fiber dosage rates are dependent on fiber type, fiber dimensions, concrete mixing/placement technique, cement content and fiber content or volume fraction. The intended fiber and dosage rate should be verified by ASTM C1609 test method. These recommended values are based off of previous field and laboratory testing of fibers used in concrete overlay pavements. Refer to the Tech Guide or Tech Report for more details.

Developed by Amanda Bordelon, Ph.D., P.E. and Jeffery Roesler, Ph.D., P.E.
Version 1.1, April 19 2019

https://intrans.iastate.edu/app/uploads/2019/03/Residual-Strength-Estimator-for-FRC-Overlays-April-19-2019_public.xlsx

#1 Construction Challenge – Fiber Balling

- 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.

Pavement Joints with FRC

- 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 LTE.
- 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
  - Similar to tie bars in behavior

Macrofiber Reinforcement Benefits: Concrete Pavements

- ***Increase*** *in structural capacity* of slab
  - Can reduce required slab thickness for pavement/overlays
- Maintain crack/joint widths
- Non-uniform (variable) support condition

- Tie **longitudinal**/transverse contraction joints
  - *Avoid slab migration*
- Extend overlay serviceability
  - Reduce deterioration rates after initial cracking
  - slab deflect ↑ and displace more easily
  - Thin concrete overlays deteriorate more rapidly under traffic

- Consider Macrofibers for every concrete overlay ≤ 6 in. and use 6ft panels when possible

Illinois (USA) Concrete Overlay Survey
19 Projects Visited (2012)

King & Roesler (2014) & NCHRP 01-61 (2021)

Chicago, IL: Western Avenue Bus Pads (2003)

- Project consisted of a number of stops along Western Avenue (5 were surveyed) 10ft x 100ft sections, 3.3ft x 4ft joint spacing
- ***4-in thick inlay, high fiber dosage of 7.5 to 8.5 lb/yd³***
- Considered a **bonded/unbonded hybrid** project, as the conditions of the underlying layer varied project to project

Western Ave. and Iowa

2012

Kane County, IL: North Lorang Road (2004)

- 4.25-4.5" thick concrete overlay of 3-3.5" of HMA over aggregate base
- 4 lb/yd³ synthetic macro-fibers
- Square 5 ft x 5 ft panels
- Project built to serve a quarry: average of 30 trucks/day (peak of 280/day)

2012

E-15 Parking Lot (2006)

- UIUC campus FRC UTW Project
  - 65mm AC
  - 8 cm Thick slab
  - 1.2 x 1.2m Joint spacing
  - 1.8kg/m³ or 0.2% Fibers
  - Fly ash

Material	Amount (lb/yd^3)
Coarse Agg	1903
Fine Agg	1214
Cement	428
Water	219
Fly Ash	133
Strux Fibers	3
Admixture	Daracem 19

Final X-sect

Asphalt Before

During Paving

Sawcutting

2007 McKinley Parking Lot at Univ. of Illinois

McKinley Parking Lot (6 years old)

2013

Richland County, IL: County Highway 9 (2010)

- 5.5-in. PCC overlay of a ?" HMA surface
- 5.5' x 5.5' square panels
- **4 lb/yd³ structural synthetic fibers**

2012

Hamilton County, IL (Sept. 16, 2014)

4 lb/cy of macro-fibers

- FRC Pavements with smaller panel sizes

Uruguay (2011) – Ruta 24 (Madera)

Bonded Concrete Overlay of Asphalt
Slab thickness = 14 cm
Slab size = 1.8x1.8m
Synthetic fibers = 2.5 kg/m^3

Ruta 24 (2016) – 1.8m x 1.8m

Ruta 60 Ch Camino La Pólvora (Valparaíso), Chile

Espesor

23 cm (9 in) con fibra

Tráfico

189.000.000 EE

Año de Construcción

2016

Fibras sintéticas
1 MPa Resistencia
Residual

https://www.youtube.com/watch?v=It-2vbBQokQ&t=19s

TCPavements
innovación en pavimentos

Ruta 60 Ch Camino La Pólvora (Valparaíso), Chile

TCPavements
innovación en pavimentos

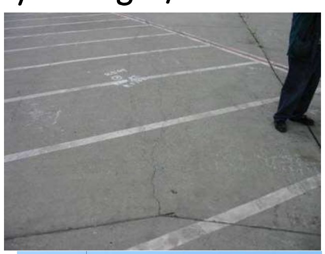
I-72 Unbonded Concrete Overlay (2015)

- 6-inch concrete slab thickness
- Asphalt or geotextile interlayer
- 8-inch existing CRCP
- Slab sizes 1.80x1.80m
- 4lb/cy Macrofibers

I-72 Unbonded Concrete Overlay (2020)

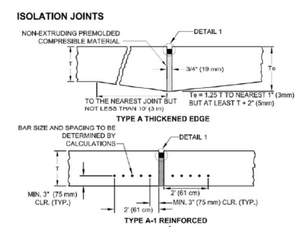
Commercial Airport Loadings

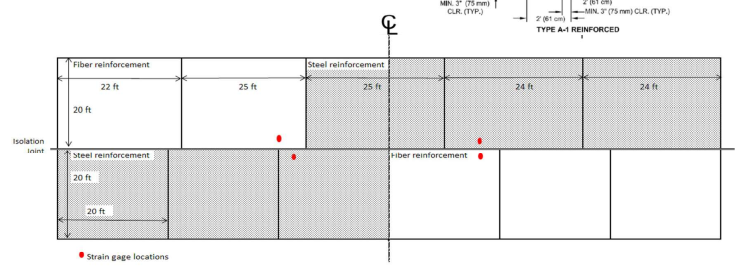
Airport Bonded Concrete Overlay Paving w/ Fibers



Chicago O'Hare Airport (2013)

- Construction Joint – Thickened edge isolation joint
- FRC vs. Steel Reinforced (bars)





Rockford, IL Airport - Prestressed FRC Taxiway

Prestressed Concrete Pavement

Commercial Concrete Floors

- Table 4.2 (ACI 360)
  - Rated capacity = 2.5t to 20t
  - 1t to 10t payload

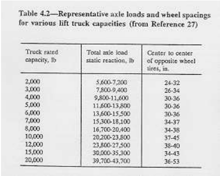


Table 4.2—Representative axle loads and wheel spacings for various lift truck capacities (from Reference 27)

Truck rated capacity, lb	Total axle load static reaction, lb	Center to center of opposite wheel tires, in.
2,000	5,600-7,200	24-32
3,000	7,800-9,400	26-34
4,000	9,800-11,600	30-36
5,000	11,600-13,800	30-36
6,000	13,600-15,500	30-36
7,000	15,300-18,100	34-37
8,000	16,700-20,400	34-38
10,000	20,200-23,800	37-45
12,000	23,800-27,500	38-40
15,000	30,000-35,300	34-43
20,000	39,700-43,700	36-53

- Can have payload = 30t
  - results in thick slabs

Specification Suggestions for FRC Pavements

- 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 process for macro-fibers 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)

Concrete Pavements w/ Macrofibers Summary

- Many successful projects (parking lots, overlays, bus stops, commercial floors, airports, full-depth repairs)
- Macrofibers increase slab capacity
- Many acceptable macrofibers (synthetic and steel)
- Residual strength test (ASTM C1609-12) is acceptable method
- Design tools exist now!
- Construction – fiber mixing and dispersion

Questions & Further Information

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

Useful Resources for Concrete Overlays

- NCHRP 01-61 – Performance of BCOA (2018-20)
- National Concrete Pavement Technology Center at Iowa State University
  - http://www.cptechcenter.org/research/research-initiatives/overlays/
  - Guide to Concrete Overlays (3rd edition), 2014
  - Guide to Concrete Overlays of Asphalt Parking Lots, 2012
  - Guide to Design of Concrete Overlays, 2012
- Illinois Center for Transportation at the University of Illinois Urbana-Champaign
  - http://ict.illinois.edu/research/publications/
  - Design and Concrete Material Requirements for Ultra-Thin Whitetopping, 2008
  - Structural Performance of Ultra-Thin Whitetopping on Illinois Roadways and Parking Lots, 2014
- BCOA-ME at the University of Pittsburgh
  - http://www.engineering.pitt.edu/Vandenbossche/BCOA-ME/