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Fiber-Reinforced ECC, VHPC, and UHPC in Bridge Structures

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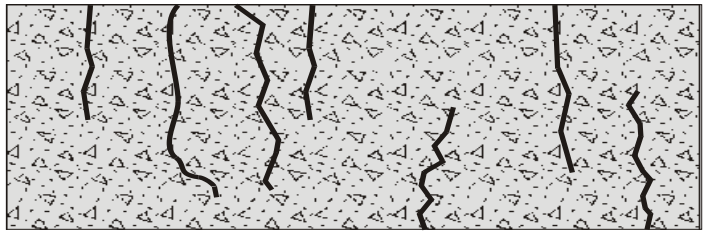
Outline

- Cracks, joints
- Fiber-reinforced concrete (FRC)
- High Performance FRC
  - ECC
  - VHPC
  - UHPC
- Field Applications
- Prepackaged Material
- Conclusions

Cracks

There are two kinds of concrete:

- One cracked
- One about to crack



Charlie Robson

Former VDOT State Materials Engineer

Plastic Shrinkage Cracks

Eliminated by proper curing!

Crack over the Pier

Leaking Joints

Leaking Joints

Leaking Shear Keys

Why Fiber-reinforced Concrete (FRC)

- Fibers can improve tensile and flexural strengths
- Fibers can be used to limit crack length and width. Fibers provide residual strength (load carrying ability after cracking).
- It is difficult to penetrate tight cracks (<0.1 mm wide). Crack widths > 0.2 mm can be and should be sealed.

Why Fiber-reinforced Concrete (FRC)

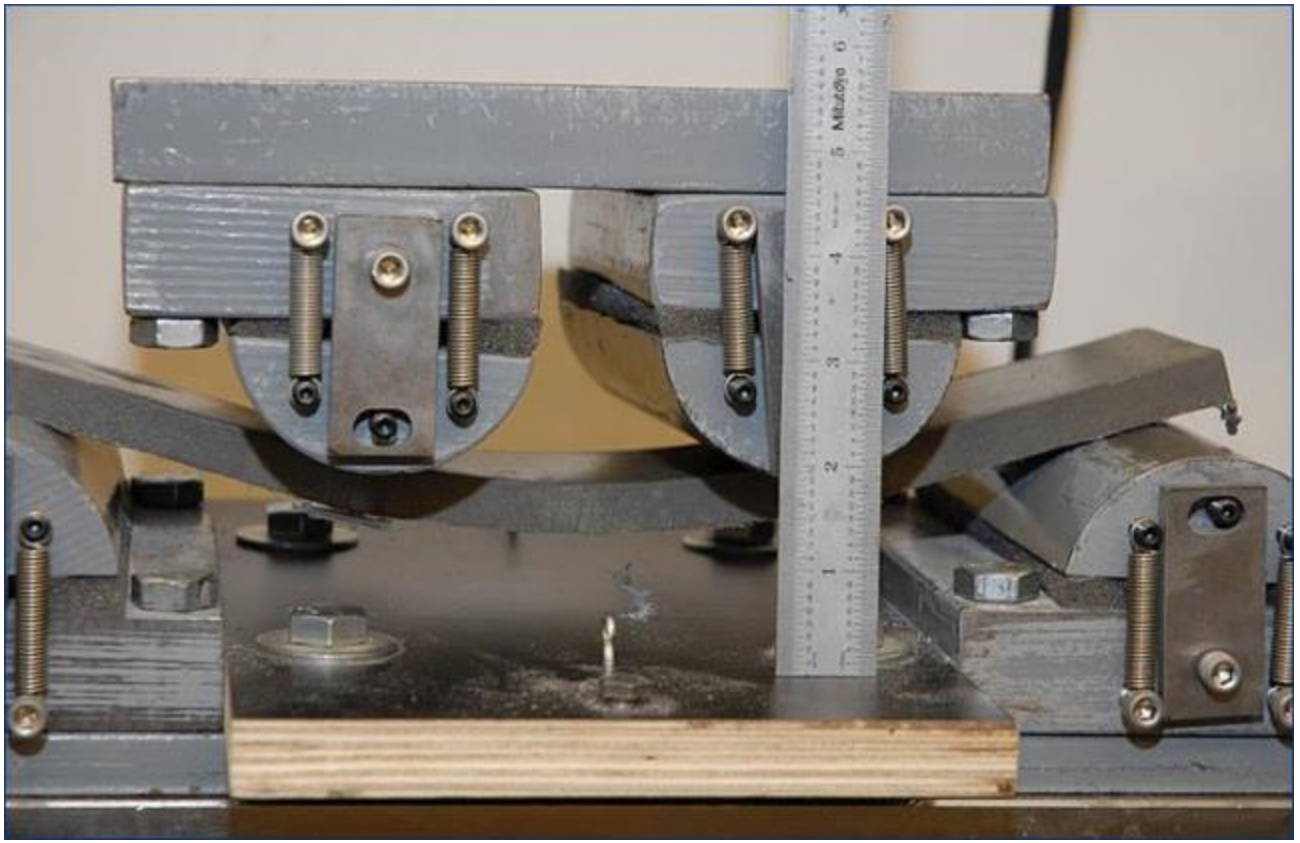
- Connections, short lap splices

Tests

Splitting Tensile Strength

Concrete is weak in tension!

Flexural Test



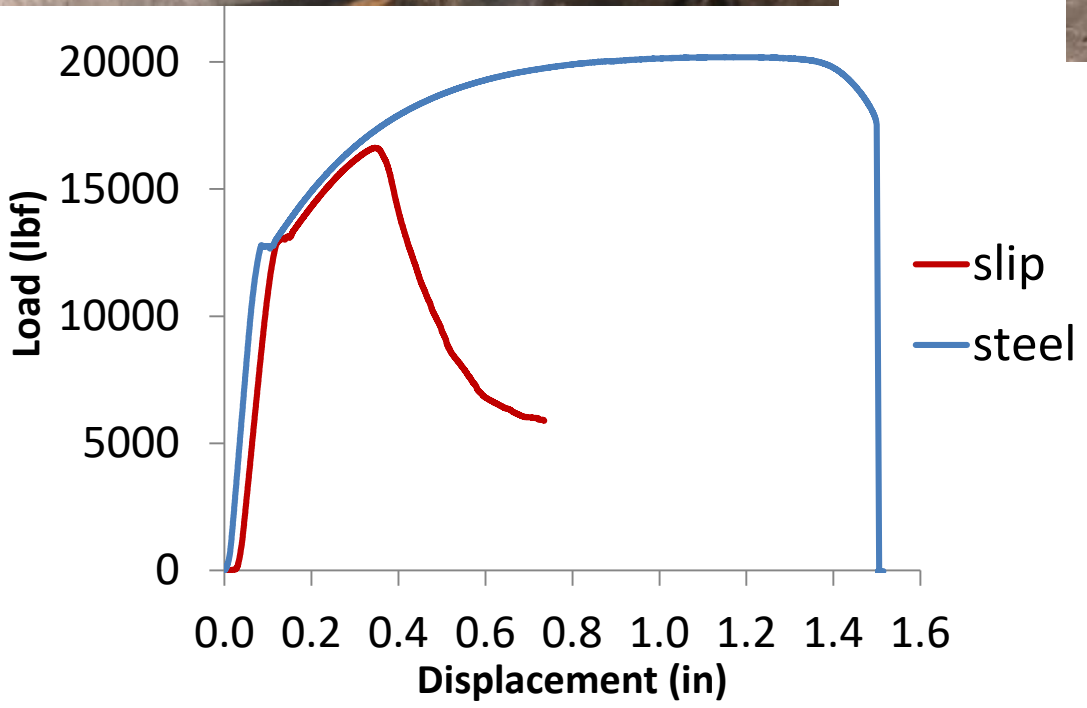
Tests

Cube Compressive Strength

Cylinder Compressive Strength

Pull-out Test

Typical pullout test graph

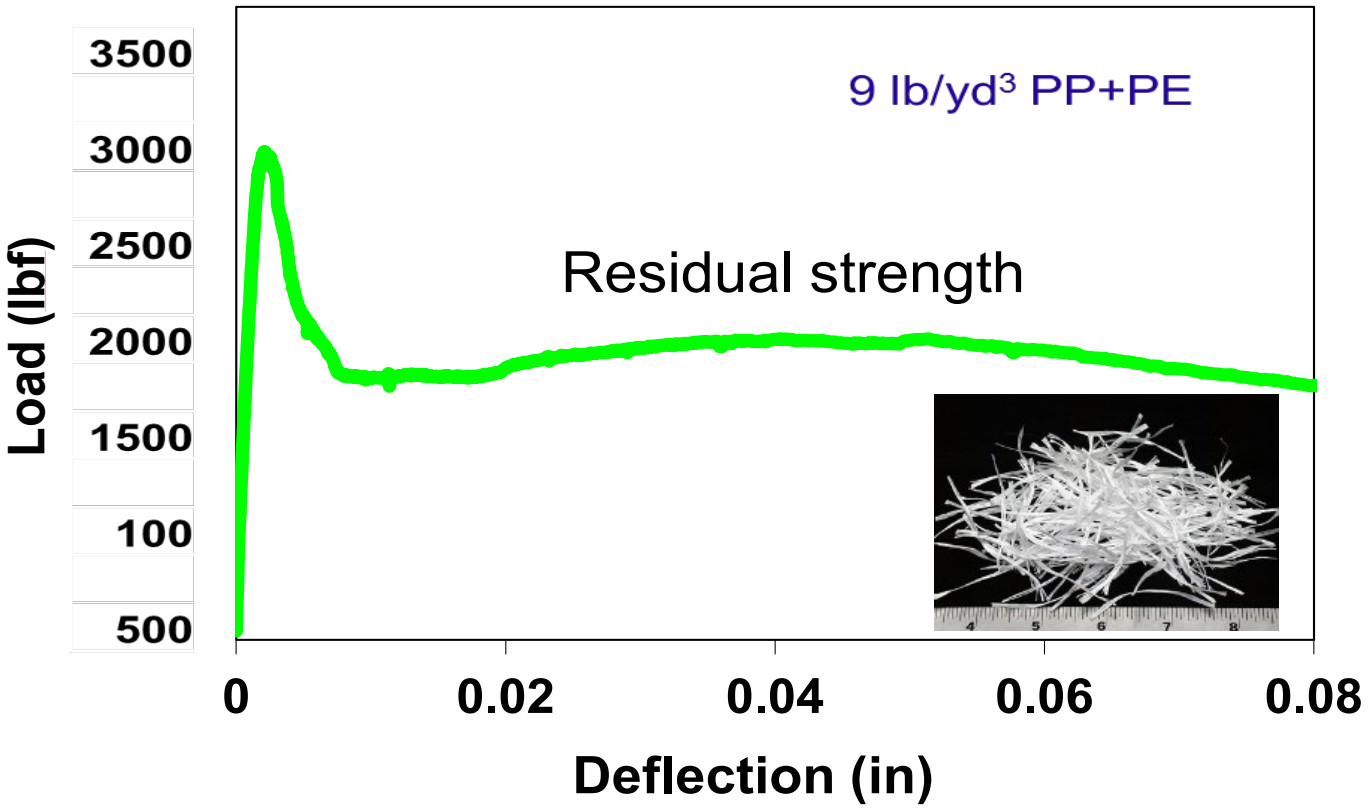


FRC

- Synthetic fibers in low amounts, 1.5 lb/yd^3 (0.1%) are used to minimize plastic shrinkage cracks.

- Larger amounts of structural fibers (steel or synthetic) up to 2% needed for crack control in hardened concrete.

Early Work with FRC - Lexington



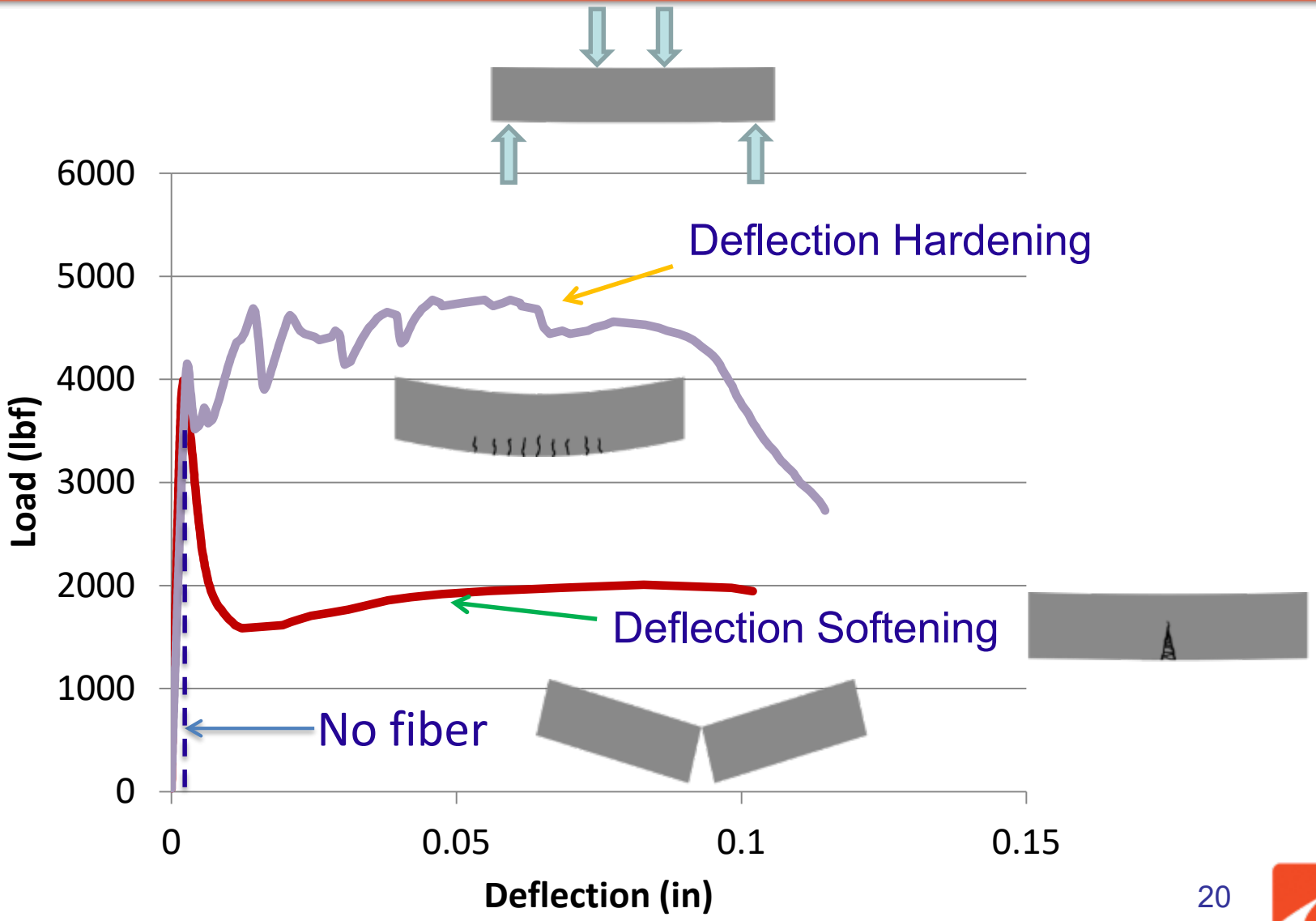
Lexington – FRC 2000

Lexington Crack Survey - FRC

Crack	Control	Fiber
Total Length (ft)	151	59
Average Width (mm)	0.53	0.29

After 5 years

Flexural Test - FRC



Tight Cracks

High Performance FRC

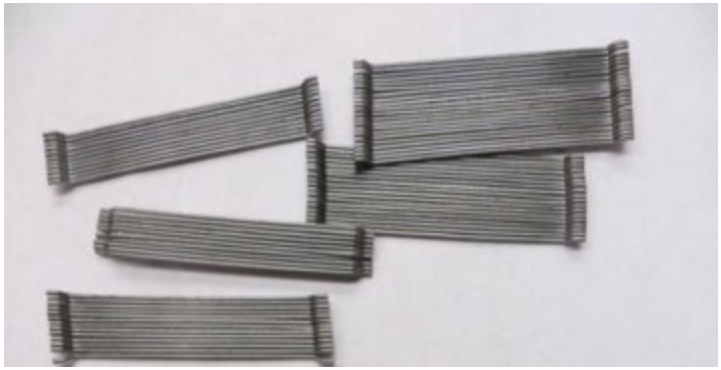
- Self-consolidating
- Contain structural fibers at high dosage
- Deflection harden enabling tight cracks (<0.1 mm)
  - ECC: engineered cementitious composite has high ductility
  - VHPC: very high performance concrete has high compressive strength and ductility
  - UHPC: ultra high performance concrete has very high compressive strength and ductility

Fibers

- ECC

PVA fiber

- VHPC / UHPC



Steel fiber hooked end

Steel OL fiber

ECC

- ECC is also known as bendable concrete
- 2% PVA fibers by volume.
- 7-d comp. str. ≥ 4,000 psi
- High splitting tensile str.

Polyvinyl alcohol fiber (PVA)

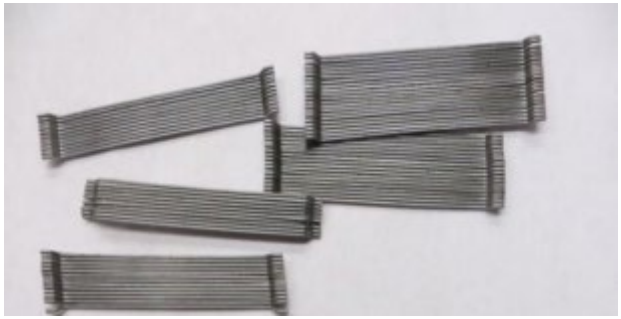
ECC

Deflection

Tight cracks (<0.1 mm)

VHPC

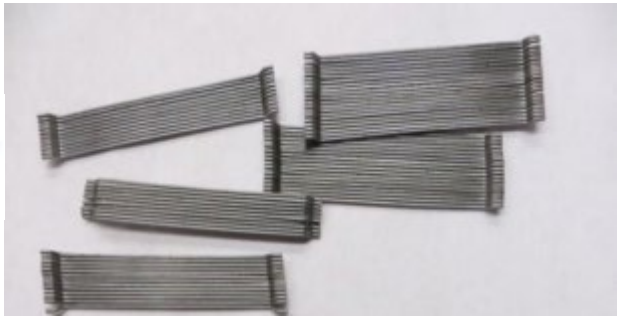
- High compressive strength ≥ 11,500 psi at 28 days
- High splitting tensile strength
- High pull-out strength (new test)



Steel fiber

UHPC

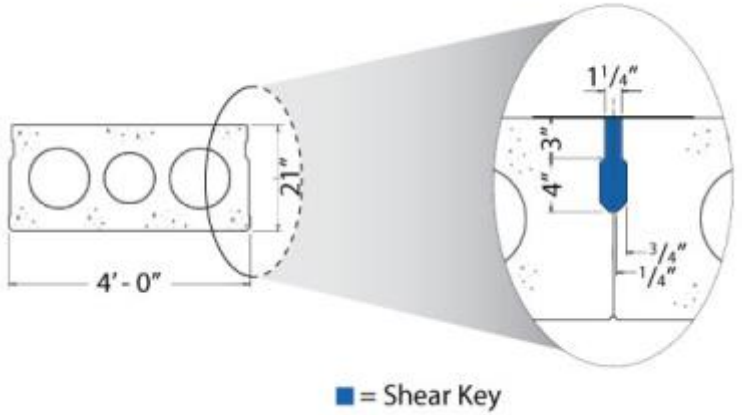
- Very high compressive strength ≥ 17,000 psi (per ASTM C1856)
- High splitting tensile strength
- High pull-out strength (new test)
- UHPC at early ages achieve VHPC strength



Steel fiber

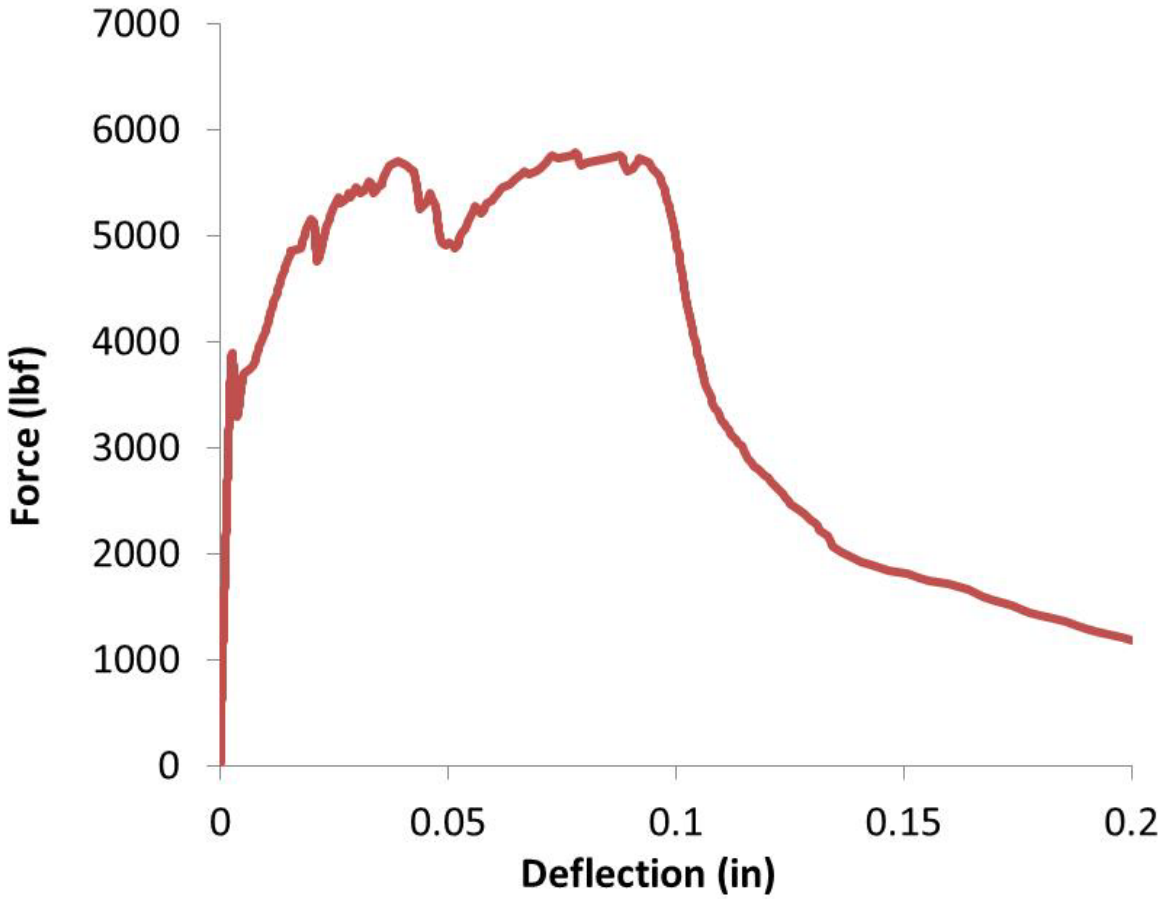
ECC Field Application– 2013 on

- Shear Keys
  - Winchester
  - Surry
- Closure Pours
  - I-64 Bridge over Dunlap Creek
- Culvert Repairs



ECC Mixtures

28-day Flexural Strength



ECC Mixing

- In small amounts use mortar mixer

- In larger amounts used RMC trucks; however, fiber dispersion is difficult in truck mixing

Shear Keys - ECC

Route 645 Bridge, 2013

Route 645 - Shear Keys - 2013

Non-shrink grout

UHPC

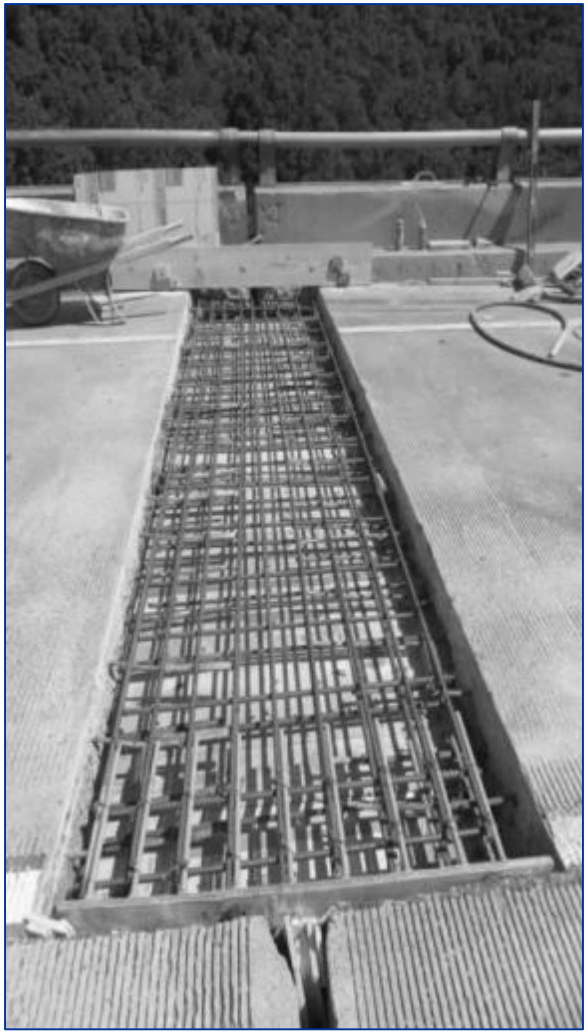
ECC with PVA fibers

After 3 months, only ECC did not leak

Link Slabs (Closure Pours) - FRC

I-64 Dunlap Creek Bridges: 2014, 2015, included ECC

Link Slab (Closure Pour)

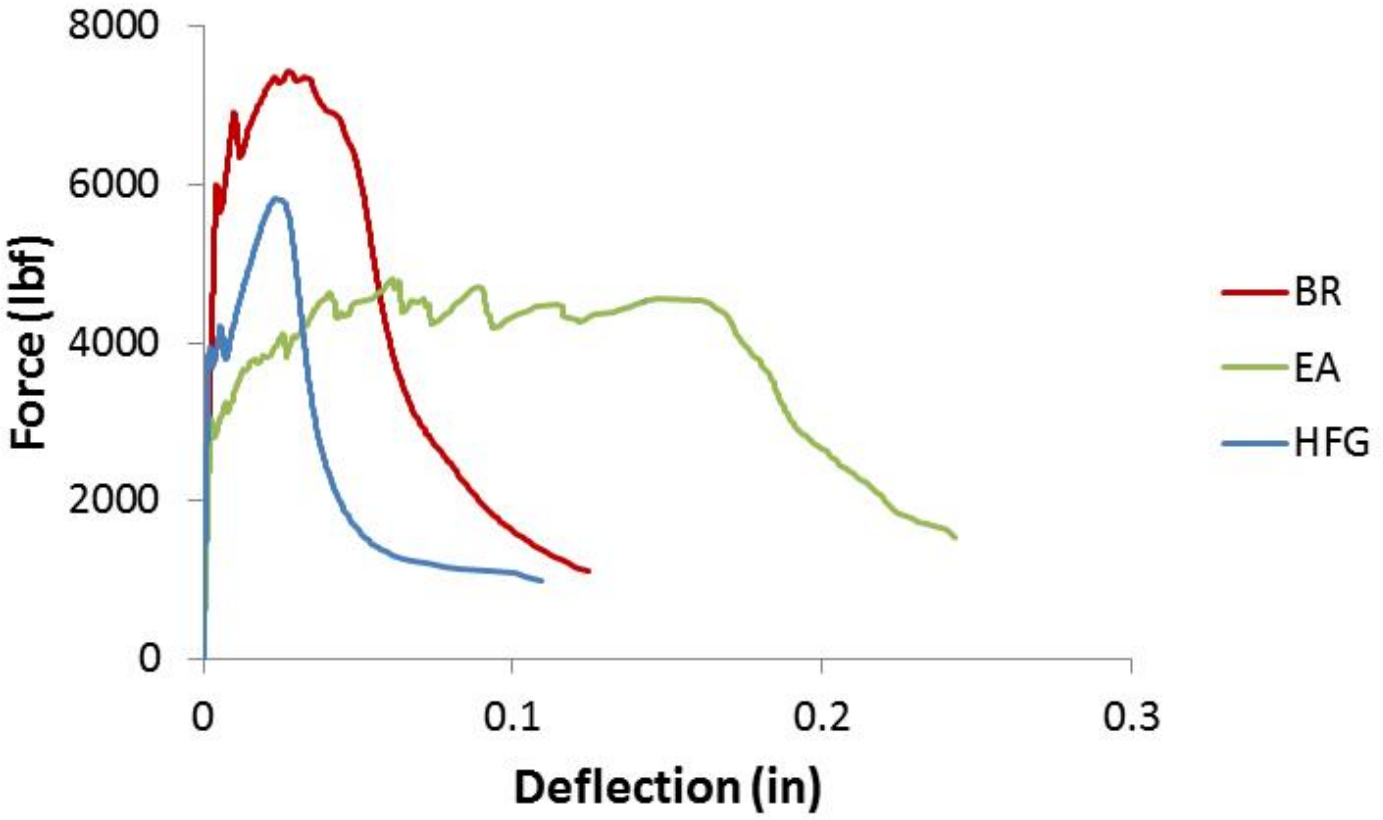


ECC – Culvert Repairs – 2017, 2018

Trailer Pump and RMC Truck

ECC Test Results for Prepackaged Material

28-day flexural strength



VHPC Field Application- 2018 on

- In adjacent member connections when there are block-outs.
- Planning to use in partial depth link slabs

Block-outs

VHPC in Block-outs

VHPC Work at Bristol - 2018

- The mix was self consolidating, but very sticky

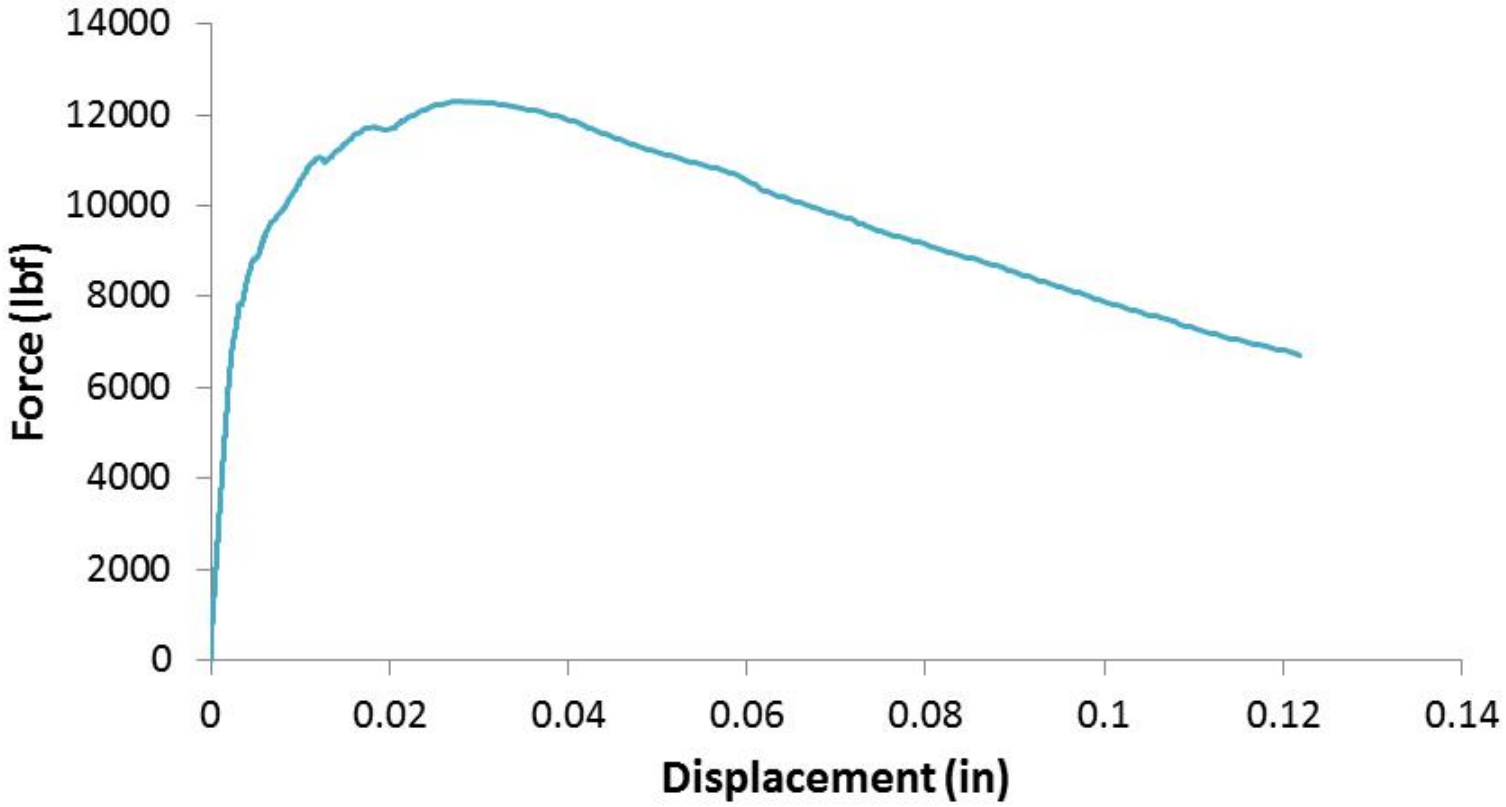
Difficult to make in RMC trucks!

VHPC work at Sperryville - 2019

Compressive strength > 11,500 psi

VHPC Test Results for Prepackaged Material

28-day flexural strength with hooked end steel fiber



UHPC Field Application

UHPC - Steel Fibers

Brass coated steel fibers

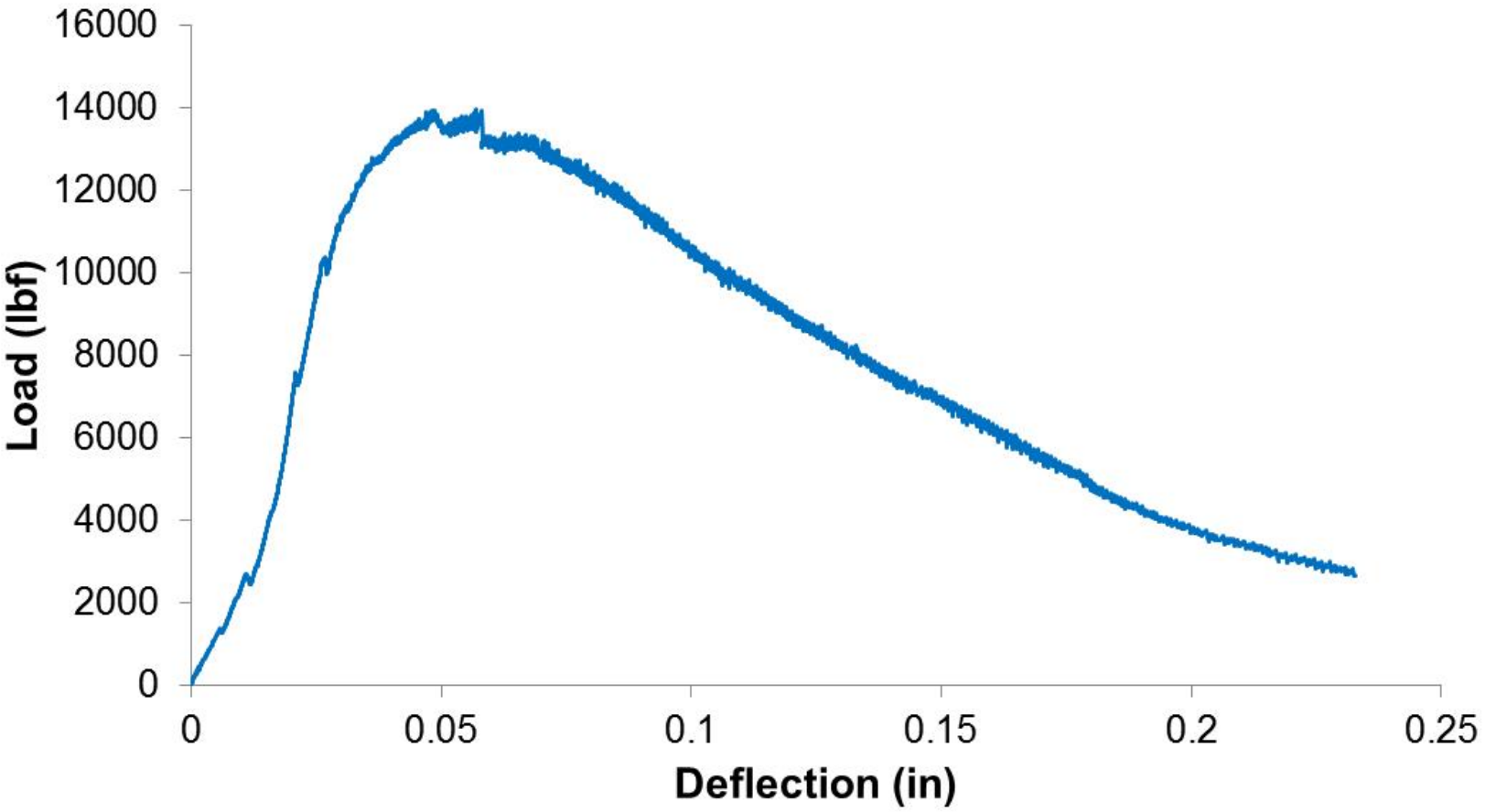
UHPC - Route 624 - 2007

28-d compressive strength ≥ 30,000 psi
with steam curing

UHPC Beams

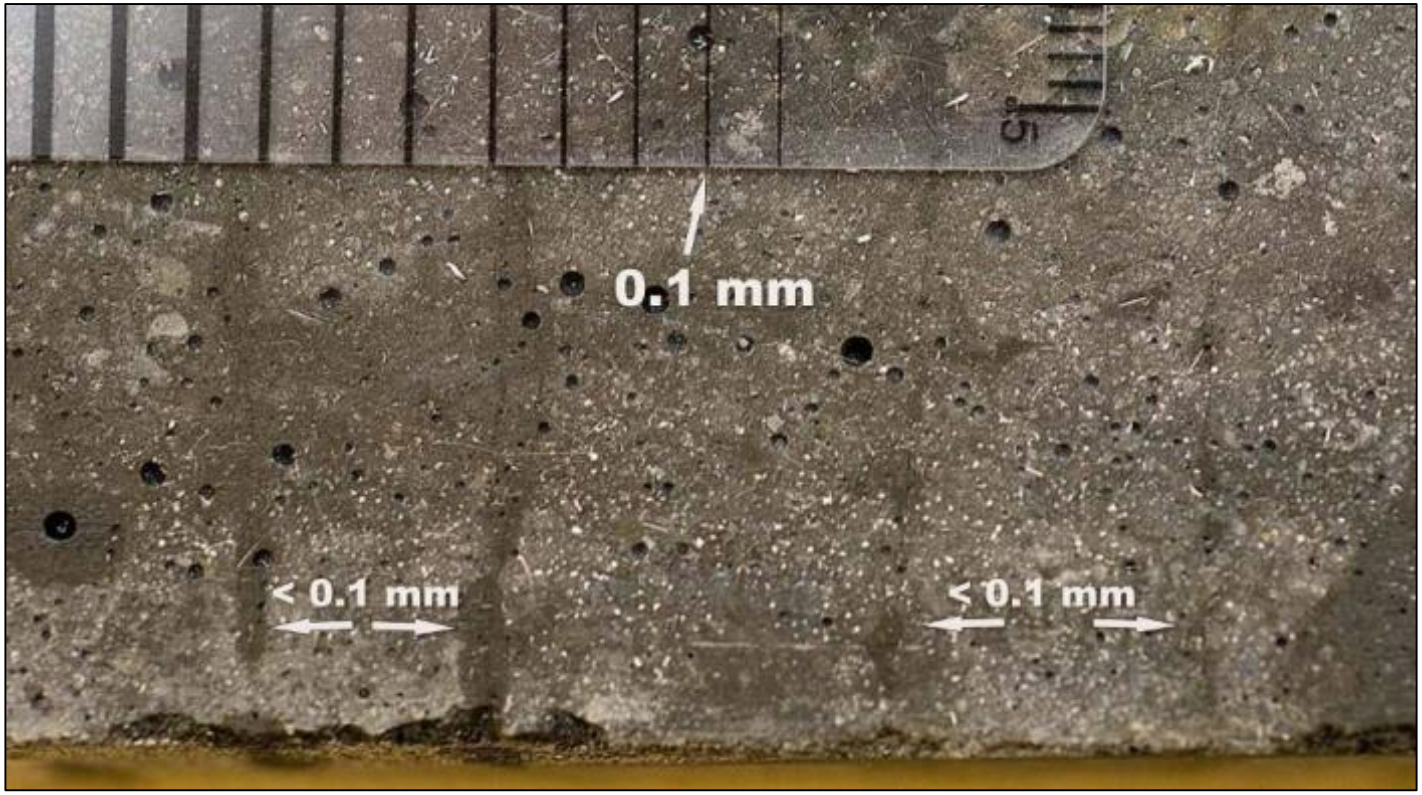
Plant had twin shaft mixer

Flexural Strength



4-in-thick beams at 2 months

UHPC - Tight Cracks



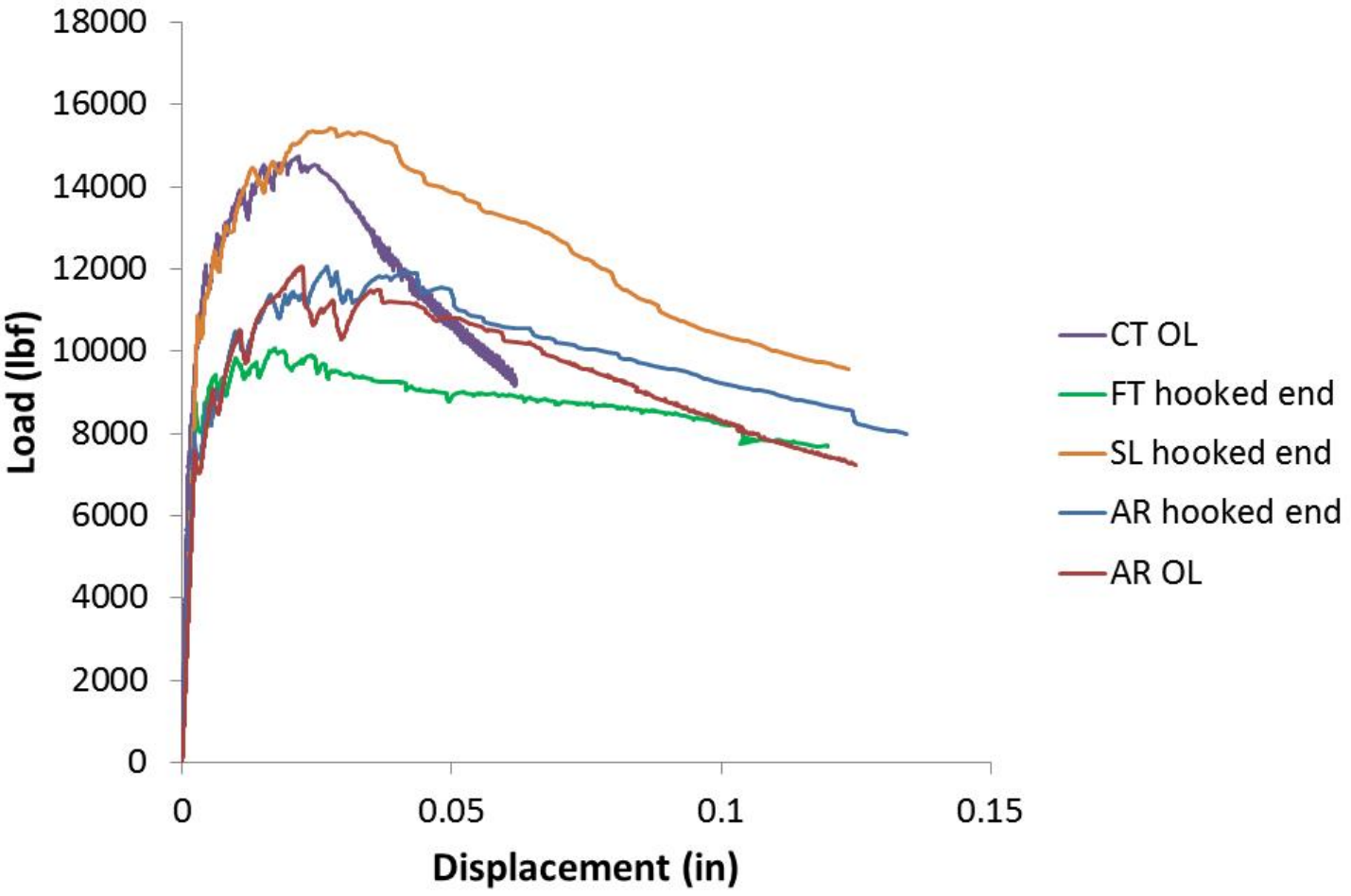
1-in-thick beam

UHPC - 2019

Planetary mixer

UHPC Test Results for Prepackaged Material

28d flexural strength



Conclusion

- Fibers provide residual strength after cracking, which limits the size and length of cracks and can be used in shear keys, connections, closure pours, block-outs, and culvert repairs.
- The level of residual strength depends on the type and amount of fibers.
- Concretes with fibers that exhibit strain and deflection hardening limit cracks widths below 0.1 mm.

Acknowledgements

- FHWA
- VDOT CO
- VDOT Districts
- VTRC
- Industry

Thank You.