Fiber-Reinforced Concrete for Bridge Structures

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Virginia Concrete Conference, 2019
Outline

• Goal: longevity
• Deterioration mechanisms
• Protective measures
• Fiber-reinforced concrete (FRC)
• Field Applications of FRC
• Conclusions
Goal is Longevity! Build to Last!

Innovations in concretes and reinforcement have enabled:

- Improved durability
- Low environmental impact
- Cost-effectiveness
- Minimal inconvenience to traveling public
- Improved safety
CONCRETE IS DURABLE!

Roman concrete, 2,000 years old!
Year 1,002,019

Awesome stuff! I wish we had that on Mars.

Cast: 2019

Design and Build it right! Keep it dry!
Infiltration into Concrete

• Deterioration because of water and solutions penetrating through poor quality concrete and cracks:
  ➢ Freezing and thawing
  ➢ Alkali-aggregate reactions
  ➢ Sulfate attack
  ➢ Corrosion: if reinforced
Freezing and Thawing Damage

Saturated, non-air entrained
Alkali-Silica Reactions

Water is necessary.
Sulfate Attack

Sulfate solution penetration
Corrosion

- Corrosion is a major distress in reinforced concrete structures exposed to the environment.
Improvements in Concrete

• Low Permeability
  – Supplementary cementitious material (SCM)
  – Low water-cementitious materials ratio

• Low shrinkage
  – Low paste content, shrinkage reducing admixture (SRA)

• Crack resistant: (reduce amount and width)
  – Fibers

• Abrasion resistant

• Good construction practices
  – Proper consolidation and curing
Improvements in Reinforcement

- Corrosion-resistant conventional reinforcement
  - Stainless steel (SS), MMFX2, etc.

- Corrosion-resistant and corrosion-free prestressed reinforcement
  - Carbon Fiber Reinforced Polymer (CFRP) and SS
CFRP Reinforcement

CFRP is corrosion-free.
Cracks

There are two kinds of concrete:
• One cracked
• One about to crack

Charlie Robson
Former VDOT State Materials Engineer
Cracks

• Occur when tensile stresses exceed the tensile strength of concrete

• Causes:
  ➢ Volumetric changes: moisture and temperature
  ➢ Chemical reactions
  ➢ Loading
Crack Control – FRC

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

- Larger amounts of fibers up to 2% needed for crack control in hardened concrete. The goal is to keep crack width less than 0.1 mm. Such tight cracks resist infiltration of water and solutions.
Crack Control – FRC

• FRC: fiber-reinforced concrete
  – Improve tensile strength
  – Increase ductility
  – Control cracking

• Special FRC
  ➢ ECC: engineered cementitious composite
  ➢ VHPC: very high-performance concrete
  ➢ UHPC: ultra high-performance concrete
Flexural Test - FRC

Load (lbf) vs. Deflection (in)

- No fiber
- Deflection Hardening
- Deflection Softening
Early Work with FRC - Lexington

Load (lbf)

Deflection (in)

Residual strength

9 lb/yd³ PP+PE
Lexington – FRC 2000
## Lexington Crack Survey - FRC

<table>
<thead>
<tr>
<th>Crack</th>
<th>Control</th>
<th>Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Length (ft)</td>
<td>151</td>
<td>59</td>
</tr>
<tr>
<td>Average Width (mm)</td>
<td>0.53</td>
<td>0.29</td>
</tr>
</tbody>
</table>

After 5 years
ECC – 2013 on

• Shear Keys
  – Winchester
  – Surry
• Closure Pours
  – I-64 Bridge over Dunlap Creek
• Culvert Repair

7-d comp str > 4,000 psi
ECC Mixtures

First crack flexural strength at 7 days: 667 psi
Max flexural strength at 7 days: 1,140 psi
ECC

- Bendable concrete, tight cracks <0.1 mm
ECC

Deflection

Tight cracks
(<0.1 mm)
Route 645 Bridge: Shear Keys ECC
Route 645 - Shear Keys - 2013

Non-shrink grout

After 3 months, only ECC did not leak
ECC – Culvert Repairs – 2017, 2018
Trailer Pump
Finished Repair with ECC
I-64 Dunlap Creek Bridges: 2014, 2015
Link Slab (Closure Pour)
Fiber Reinforcements – I-64
Tight Cracks
VHPC work at Bristol - 2018

• The mix had high flow rates but was sticky
VHPC in Block-outs

28-d compressive strength > 11,500 psi
VHPC work at Sperryville - 2019
VHPC work at Sperryville - 2019
28-d compressive strength ≥ 30,000 psi with steam curing
Brass coated steel fibers;
L = 14 mm, diameter = 0.185 mm
UHPC Mixture
UHPC Beams

Plant had twin shaft mixer
Flexural Strength

First crack strength: 1,510 psi
Max strength: 2,650 psi

4-in-thick beams at 2 months
UHPC - Tight Cracks

1-in-thick beam
Planetary mixer
28-d compressive strength $\geq 17,000$ psi
Flexural Strength – New UHPC

First crack strength: 1,790 psi
Max strength: 3,340 psi

First crack strength: 1,435 psi
Max strength: 2,570 psi
Conclusion

• Fibers provide residual strength after cracking, which limits the size and length of cracks and can be used in shear keys, closure pours, block-outs, and culvert repairs.

• The level of residual strength depends on the type and amount of fibers.

• High residual strengths that exhibit strain and deflection hardening limit cracks widths below 0.1 mm.
Acknowledgements

• FHWA
• VDOT CO
• VDOT Districts
• VTRC
• Industry
Thank You.