Applications of Ultra-High-Performance Concrete and Prefabricated Concrete Elements in Accelerated Bridge Construction

2018 Virginia Concrete Conference

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Outline

Projects

• IADOT - Keg Creek ABC Bridge Replacement
• VDOT - Piney Run ABC Bridge Replacement

UHPC

• General Features
• Concerns about UHPC
• Other UHPC Applications
Keg Creek Bridge Rapid Replacement - IADOT

- SHRP2 R04 ABC Demonstration Project #1
- ABC 14 Day Road Closure
- Total Prefabricated Bridge Elements and Systems (PBES)
- 3-span bridge
- Jointless construction
- Predecked steel beam (with option for PS girders)
Cross-Sections / Plan

EXISTING CROSS SECTION AT CENTERLINE

UHPC Joints
Prefabrication Yard Adjacent to Bridge

- Bottom mat of deck reinforcing nearly complete
- Column sections cast and curing
- Rebar cage for next column section
- Abutment and wingwall components complete
Prefabrication Yard Adjacent to Bridge
Prefabrication of Abutments and Piers
Day 1 - Rapid Demolition

- One day demolition
- Two hydraulic breakers
- Crane with wrecking ball
Days 3 & 4 - Precast Abutment Assembly
Day 5 - Precast Pier Assembly

- Pier caps: 168 kips
- Required two 110 ton cranes to lift into place
Days 7 and 8 - Superstructure Elements

Span = 70 ft
Days 7 and 8 - Superstructure Elements
Days 7 and 8 - Semi-Integral Abutment
Day 10 – UHPC Deck Closure Pours

Transverse UHPC Joints

Longitudinal UHPC Joints

HNTB
Day 13 - Deck Riding Surface

- No open deck joints
- Integral wearing surface (no overlay)
- Extra ½ inch for grinding for smooth riding surface
Concrete Material Highlights

- UHPC joint reinforced to carry the full LL tension
- First use of UHPC for transverse joints over pier
Concrete Material Highlights

- UHPC
- Full moment transfer
- No post-tensioning
- 6 in. wide
Concrete Material Highlights

- 5,000 psi HPC in prefabricated elements
- HES SCC at abutment closure pours and full depth pockets
- No post-tensioning
Concrete Material Highlights

• Grouted Splice Couplers
• Low seismic zone
# ABC Seismic Connections

<table>
<thead>
<tr>
<th>Column-to-Cap Connection Type</th>
<th>Seismic Design Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grouted Splice Sleeve&lt;sup&gt;1&lt;/sup&gt;</td>
<td>A, B, C</td>
</tr>
<tr>
<td>Grouted Duct&lt;sup&gt;2&lt;/sup&gt;</td>
<td>A, B, C, D</td>
</tr>
<tr>
<td>Cap Pocket&lt;sup&gt;2&lt;/sup&gt;</td>
<td>A, B, C, D</td>
</tr>
</tbody>
</table>

1. NCHRP 12-74 has recommended use for limited-ductility applications only.

2. NCHRP 12-74 tested both a limited-ductility and a full-ductility cap pocket connection.
ABC Seismic Connections

- Grouted Couplers
  - Fast assembly
  - Limited ductility
  - Suitable for low to moderate seismic zones
ABC Seismic Connections

- Grouted Duct
  - Full ductility
  - Suitable for high seismic zones
ABC Seismic Connections

- Cap Pockets
  - Full ductility
  - Suitable for high seismic zones
ABC Toolkit and References
VDOT Route 681 over Piney Run – Fairfax, VA

- Existing structure:
  - Single-span bridge
  - ADT = 6,200
  - Single Lane
  - High number of accidents
  - Bridge Length = 19’
VDOT Route 681 over Piney Run – Fairfax, VA

- Major flood damage at approaches in 2006, 2008 and 2011
VDOT Route 681 over Piney Run – Fairfax, VA

- Proposed bridge preliminary design in 2015
- ABC 10-day road closure to minimize traffic impact
- Prefabricated Bridge Elements
- 50’ long bridge with improved hydraulic opening
- 2-lanes of traffic and a 6’ raised sidewalk
- Retaining walls and 100’ long reinforced concrete approach slabs as flood protection measure
- Improved approach sight distance
VDOT Route 681 over Piney Run – Fairfax, VA
VDOT Route 681 over Piney Run – Fairfax, VA

CONSTRUCTION STAGE I (PRIOR TO ROAD CLOSURE)

CONSTRUCTION STAGE II (DURING ROAD CLOSURE)

CONSTRUCTION STAGE III (DURING ROAD CLOSURE)

FINAL ELEVATION
VDOT Route 681 over Piney Run – Fairfax, VA

**Bridge Transverse Section**

**Approach Roadway Transverse Section**
What is UHPC?

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Amount</th>
<th>% by Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland Cement</td>
<td>1200 lb/yd³</td>
<td>28.5</td>
</tr>
<tr>
<td>Silica Fume</td>
<td>390 lb/yd³</td>
<td>9.3</td>
</tr>
<tr>
<td>Ground Quartz</td>
<td>355 lb/yd³</td>
<td>8.5</td>
</tr>
<tr>
<td>Fine Sand</td>
<td>1720 lb/yd³</td>
<td>41.0</td>
</tr>
<tr>
<td>Steel Fibers</td>
<td>263 lb/yd³</td>
<td>6.3</td>
</tr>
<tr>
<td>Superplasticizer</td>
<td>51 lb/yd³</td>
<td>1.2</td>
</tr>
<tr>
<td>Water</td>
<td>218 lb/yd³</td>
<td>5.2</td>
</tr>
</tbody>
</table>
UHPC – General Features

- Compressive Strength: 20 ksi to 32 ksi
- High tensile capacity: 0.75 ksi to 1.5 ksi
- Flexural strength: 3 ksi to 7 ksi
- Early strength: 10 ksi to 12 ksi in 12 hours
- Very low creep and shrinkage
- Higher ductility
- Highly durable: Lower 100-yr life cycle cost
- Impermeability: Almost no carbonation and penetration of Chloride
UHPC – General Features

• Self Consolidating: Vibrating will result steel fiber settlement
• Bondable to any type of existing concrete surface
• Abrasion resistance: Similar to natural rock
• Short lap length: FHWA publication - 5” lap for #5
• Workable up to an hour
• Highly flowable and castable (as low as 5/8” thick)
• Self leveling: Flows up to 10 ft
• No post-tensioning is required
UHPC – General Features

Temperature VS Strength Gain Curve
Ductal® JS1212

Source: Ductal®
Concerns about UHPC

• Proprietary products
  – FHWA Memorandum
  – Performance based specification
  – Non-proprietary mix design
  – Sole source issue

• Domestic source

• Forming and casting
Concerns about UHPC

- **Cost**

<table>
<thead>
<tr>
<th>Concrete Type</th>
<th>Approximate cost ($/yd^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular Concrete</td>
<td>100</td>
</tr>
<tr>
<td>Proprietary UHPC (low volume)</td>
<td>2,000</td>
</tr>
<tr>
<td>Non-proprietary UHPC</td>
<td>850</td>
</tr>
<tr>
<td>Non-proprietary UHPC (without fiber reinforcement)</td>
<td>500</td>
</tr>
<tr>
<td>HPFRC - Engineered Cementitious Composite (ECC)</td>
<td>300</td>
</tr>
<tr>
<td>Epoxy Grout</td>
<td>5,000</td>
</tr>
<tr>
<td>Portland Cement Grout</td>
<td>1,500</td>
</tr>
</tbody>
</table>
Concerns about UHPC

- Aesthetics concern
Other UHPC Applications
UHPC Connections in Precast Deck Panels

• 2017 Virginia Concrete Conference: Deck Panels and UHPC Joints – David Liu, PhD, PE, SE

PennDOT Route 30 over Bessemer Ave Superstructure Replacement in 57 hours
NYDOT Link Slab

Deck Joint

Source: 2017 NYDOT UHPC Workshop
NYDOT Link Slab

Traditional Link Slab

20'

10'
Pier

10'

6.5'

Debonded Link Slab

Existing Slab

Roofing Paper

6.5'

6.5'

Elastomeric Bearing (Exp)

Existing Girder

(b) Debonded Link Slab Details

Source: 2017 NYDOT UHPC Workshop
NYDOT Link Slab

UHPC Link Slab

Source: 2017 NYDOT UHPC Workshop
NYDOT Link Slab

**Traditional vs. UHPC**

<table>
<thead>
<tr>
<th>Traditional</th>
<th>UHPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>• HP Concrete</td>
<td>• UHP Concrete</td>
</tr>
<tr>
<td>• Full depth</td>
<td>• Partial depth - 4&quot;</td>
</tr>
<tr>
<td>• 5% of span + anchor</td>
<td>• Approx. 2’ - 3’ long</td>
</tr>
<tr>
<td>• Heavily reinforced</td>
<td>• Nominal long. reinf.</td>
</tr>
<tr>
<td>• Low material cost</td>
<td>• High material cost</td>
</tr>
<tr>
<td>• High rotational restraint</td>
<td>• Minimal rotational res.</td>
</tr>
<tr>
<td>• Average durability</td>
<td>• High durability</td>
</tr>
<tr>
<td>• CIP deck replacement</td>
<td>• Precast deck/joint replacement</td>
</tr>
</tbody>
</table>

Source: 2017 NYDOT UHPC Workshop
Precast Deck Connections to Girders
Hidden Pockets with UHPC
Precast Concrete Deck with Hidden Pockets
Kosciuszko Bridge - NYSDOT
Girder End Repair

[Diagram showing details of a girder end repair, including UHPC, concrete deck, steel girder, and studs.]

Source: 2016 FDOT FHWA Design Training
Girder End Repair

Source: 2017 UCONN UHPC workshop
Concrete Girder Using UHPC

- Long span shallow concrete girder
  - Minimize superstructure depth (50% reduction)
  - Shorter fabrication duration (no vibration, early strength and no mid steel reinforcement)
  - No stirrups and higher number of strands
  - Eliminate piers

Source: Ductal® Repair/Retrofit Solutions

<table>
<thead>
<tr>
<th>Pre-stressed</th>
<th>Reinforced Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (weight) of Beams</td>
<td>Lbs/lineal ft.</td>
</tr>
<tr>
<td></td>
<td>94</td>
</tr>
</tbody>
</table>

Source: Ductal® Repair/Retrofit Solutions
Bondable Interface – Alternative to grout and overlay

Source: 2016 FDOT FHWA Design Training
Seismic Retrofit

Mission Bridge – Pier Retrofit, Mission, BC

Source: Ductal® UHPC
Concrete Pile Retrofit

Source: 2016 FDOT FHWA Design Training
Deck Overlay

- 1-in to 2'-in bonded overlay
- Harsh environments, waterproofing & strengthening

- 1.6” thick overlay
- $20/ft^2

Chillon Bridge Repair Project, Switzerland

Source: FHWA Field testing of UHPC overlay
Deck Overlay

- 60% increase in the moment and shear capacity

Source: Ductal® Repair/Retrofit Solutions
Precast waffle deck bridge panels

Source: FHWA UHPC for PBE Connections
Questions?