Efficiency through technology and collaboration

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Web Search:
FHWA UHPC

U.S. Department of Transportation
Federal Highway Administration
1st Intl. Interactive Symposium on UHPC

- July 18-20, 2016
- Des Moines, Iowa
- ABC
- Structural Design
- Material Design
- Repair & Retrofit
- Bridge Site Visits
What is “Every Day Counts”?

Stakeholder-based model to identify and rapidly deploy proven innovations
Design and Construction of Field-Cast UHPC Connections

- FHWA-HRT-14-084
- Reinforcement Detailing
- Mechanical Properties
- Construction
- Inspection
- Example Projects

Web Search: FHWA UHPC
UHPC Connections for ABC

WHAT:
- Ultra-High Performance Concrete
- Prefabricated Bridge Elements
- Bridge Construction

WHY:
- Accelerate Construction
- Enhanced Quality
- Increase Longevity
- Increase Robustness
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Sneak Peek

- Research-based, Deployment-infused
- Ultra-High Performance Concrete
- UHPC Connections
  - Design
  - Construction
  - Examples
- Q&A
Ultra-High Performance Concrete

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Foot Bridge of Peace - Seoul, South Korea
Jean Bouin Stadium Façade - Paris, France
MuCEM – Marseille, France
Mars Hill Bridge
Wapello County, Iowa

Jakway Bridge
Buchanan County, Iowa
What is Ultra-High Performance Concrete?

- Portland cement-based composite material
- Castable
- **Highly durable, strain-hardening concrete**
- Wide variety of potential applications
  - Infrastructure
  - Architecture
  - Urban Furniture
  - Security Applications
What is Ultra-High Performance Concrete?

- FHWA
  - UHPC is a cementitious composite material composed of an optimized gradation of granular constituents, a water-to-cementitious materials ratio less than 0.25, and a high percentage of discontinuous internal fiber reinforcement. The mechanical properties of UHPC include compressive strength greater than 21.7 ksi (150 MPa) and sustained post-cracking tensile strength greater than 0.72 ksi (5 MPa).
What is Ultra-High Performance Concrete?

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What is Ultra-High Performance Concrete?

Castable confinement
## Typical Composition of 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>
Steel Fibers
UHPC Properties: Some Ballpark Values

- Compressive Strength – 18 to 35 ksi
- Modulus of Elasticity – 6000 to 8000 ksi
- Sustained Tensile Capacity – 0.9 to 1.5 ksi
- Rapid Chloride Test – 20 to 360 Coulombs
- Freeze/Thaw Resistance – RDM > 95%
- Chloride Ion Diffusion Coefficient
  - $2 \times 10^{-11}$ m$^2$/s for conventional concrete
  - $2 \times 10^{-12}$ m$^2$/s for HPC
  - $2 \times 10^{-13}$ m$^2$/s for UHPC

Source: FHWA Report FHWA-HRT-06-103, Material Property Characterization of Ultra-High Performance Concrete
Compression Behavior

![Graph showing the compression behavior over days after mix initiation for different curing regimes. The graph plots compressive strength (ksi and MPa) against days after mix initiation.]
Tensile Behavior
Tensile Behavior
Example UHPC Mix Components

A: Diameter: 0.55 mm
   Length: 30 mm
   Strength: 160 ksi

B: Diameter: 0.2 or 0.3 mm
   Length: 13 mm
   Strength: ≥ 305 ksi

C: Diameter: 0.3 mm
   Length: 20 mm
   Strength: ≥ 305 ksi

D: Diameter: 0.2 or 0.3 mm
   Length: 13 mm
   Strength: ≥ 305 ksi
Tensile Behavior

- 2% Steel Fiber Reinforcement
- $13 \text{ ksi} \leq f_{c'} \leq 16 \text{ ksi}$
Tensile Behavior

- 13 ksi ≤ $f'_{c}$ ≤ 19 ksi

Graph showing the relationship between average axial strain and average axial stress for different materials labeled A, B, C, D, E, with specified strain limits.
Availability

• Proprietary Versions
  – Similar to conventional grouts
  – Availability depends on market

• Non-Proprietary Versions
  – Many academic lab mixtures under development
  – Dr. Kay Wille at UConn developed/published mixes
    • FHWA-HRT-13-100
Cost of PBE Grouts including UHPC…

• Products on the Market

<table>
<thead>
<tr>
<th>Grout Type</th>
<th>Approximate Cost per yd³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland Cement Grouts</td>
<td>$1000 to $2000</td>
</tr>
<tr>
<td>Repair Mortars</td>
<td>$1500 to $3000</td>
</tr>
<tr>
<td>Epoxy Grouts</td>
<td>$5000</td>
</tr>
<tr>
<td>UHPCs</td>
<td>$2500 to $3500</td>
</tr>
</tbody>
</table>

• Non-Proprietary Versions
  – $800+ for UHPC raw constituents
Benefits of using UHPC connections...

- For connections that are properly laid out, designed, and constructed:
  - Simplified fabrication
  - Expedited construction
  - Overlay not required (deck-level connections)
  - Connections that are:
    - Stronger than the elements connected
    - More durable than the elements connected
UHPC Connections: Structural Testing

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Deck-Level Connections

Non-Contact Rebar Lap Splice – cyclic loading
Adjacent Box Beam Connections
UHPC Composite Connection Testing

![Image of UHPC composite connection testing setup](image-url)
UHPC Connections: Structural Design

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Conventional Grout Deck Panel Connections

**U-Bar Connection**
(Zhu, Ma, and French, 2012)

**One-Layer Headed Bar Connection**
(Li, Ma, Griffey, and Oesterle, 2010)

**Two-Layer Headed Bar Connection**
(Graybeal, 2010)

**90° Hooked Bar Connection**
(Azizinamini, Power, Myers, and Ozyildirim, 2014)
UHPC Deck Panel Connection

Straight Bar Connection w/ UHPC
Design Guidance

- FHWA-HRT-14-084: pg. 11-16
- Reinforcement Detailing
- Closure Pours
- Shear Connections
- Ducted Substructure Cxns
- Mechanical Properties
- Physical Properties
Rebar Lap Splice Connection

SECTION D-D

TRANSVERSE UHPC BETWEEN DECK PANELS

ULTRA HIGH PERFORMANCE CONCRETE, SUPPLIED & INSTALLED BY CONTRACTOR
UHPC Connections b/t Deck-Bulb-Tee Girders

SR 31 over Canandaigua Outlet Lyons, New York

Closure Pour (UHPC)
Deck Bulb Tee Prestressed Girder
UHPC Connections b/t Modular Decked Units

U.S. 6 over Keg Creek
Pottawattamie County, Iowa
UHPC Connections b/t Adjacent Box Beams

Sollars Road over Lees Creek
Fayette County, Ohio
UHPC Connection for Substructures

Hooper Road over US 17C in Union, New York
Design Guidance - Rebar Lap Splice

Rebar Lap Splice Connections Require:

- UHPC
- Embedment Length, $l_d \geq 8d_b$
- Cover $\geq 3d_b$
- Bar clear spacing: between $2d_b$ and $l_s$
- $l_s \geq 0.75 \cdot l_d$
- $f'_c \geq 14$ ksi

Note: 1. Uncoated or epoxy coated bars with up to 75 ksi yield;
2. No. 4 to No. 9 bar.
Deck-Level Connections
w/ #5 Bars (60 ksi) Top & Bottom:

- Embedment Length, \( l_d \geq 5" \)
- Cover \( \geq 1.875" \)
- Bar clear spacing: between 1.25” and 3.75”
- \( l_s \geq 3.75" \)
- UHPC with \( f'_c \geq 14 \) ksi
Design Guidance - Rebar Lap Splice

Rebar Lap Splice Connections Require:

- UHPC
- Embedment Length, \( l_d \geq 10d_b \)
- Cover \( \geq 2d_b \)
- Bar clear spacing: between \( 2d_b \) and \( l_s \)
- \( l_s \geq 0.75 \ l_d \)
- \( f'_c \geq 14 \) ksi

Note: 1. Uncoated or epoxy coated bars with up to 75 ksi yield;
2. No. 4 to No. 9 bar.
Deck-Level Connections

w/ #5 Bars (60 ksi) Top & Bottom:

- Embedment Length, $l_d \geq 6.25”$
- Cover $\geq 1.25”$
- Bar clear spacing: between 1.25” and 4.7”
- $l_s \geq 4.7”$
- UHPC with $f’_c \geq 14$ ksi
UHPC Connections for Shear Interfaces

Traditional Studs

Shortened Studs
UHPC Connections for Shear Interfaces

Steel Girder Connection

Concrete Girder Connection
**Design Guidance - Interface Shear**

UHPC Interface Shear Connections Require:

- UHPC
- Follow LRFD Provisions of 5.8.4 and 6.10.10
- Clear shear plane height ≤ 3 in.
- Cyclic stress on minimum shear plane ≤ 150 psi
- Static stress on minimum shear plane ≤ 750 psi

**Note:**
1. Intentionally roughen precast surfaces
2. UHPC flow length ≤ 10 ft
UHPC Connections: Construction

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PBE Installation
PBE Installation
PBE Installation
Connection Formwork
Pre-Wetting Connection Interfaces
UHPC Mixing
UHPC Casting
UHPC Casting
Connection Overfilling and Top Forming
Connection Overfilling and Top Forming
Forms Removed
Riding Surface Preparation - Grinding
UHPC Connections: Example Projects

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• More than 60 bridges in the US across 13 States
• More than 70 bridges in Canada across 4 Provinces

• Major projects underway
  – Pulaski Skyway in NJ
  – Nipigon River cable stayed bridge in ON
  – Major Deegan Expressway (I-87 in the Bronx)
North American Bridges Using UHPC

In-Service
- Prior to 2011
- 2011
- 2012
- 2013
- 2014
- 2015
Precast Deck Panel Connections

US 6 over D&RGW Railroad
Spanish Fork, UT
Precast Deck Panel Connections

US 30 over Burnt River & UP Railroad
Huntington, OR
Precast Deck Panel Connections

I-81 Bridges (3)
Syracuse, NY
Precast Deck Panel Connections

Pulaski Skyway
Jersey City, NJ just west of Holland Tunnel
Modular Decked Units

US 6 over Keg Creek
Council Bluffs, IA
Modular Decked Units & Integral Abutments

I-81 over Preble Road
Preble, NY
Modular Decked Units

I-81 over Preble Road
Preble, NY
Semi-Integral Abutments

I-81 over Preble Road
Preble, NY
Pier Column to Cap Connection

Hooper Road over Route 17C
Union, New York
Pier Column to Cap Connection

Hooper Road over Route 17C
Union, New York
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