UHPC FOR PBES CONNECTIONS

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Prefabrcinated Bridge Elements and Systems

• Benefits:
  – Reduced construction on critical path
  – Increased safety
  – Increased quality

• Challenges:
  – Transportation and Assembly
  – Connections

  Significant Hurdle
Connections are a Problem...

- Connections tend to be:
  - Difficult to Construct
  - Expensive
  - Less Durable

- Past Practice:
  - Discreet Connectors
  - Field-Cast Grout
Connections are a Problem...

- Connections tend to be:
  - Difficult to Construct
  - Expensive
  - Less Durable

- Emerging Solution...

  Discreet Connectors

  Field-Cast Grout
Solution: Rethink the Connection

What we need:
- Strong, Durable Material
- Good Bond to Concrete
- Good Bond to Rebar
- Self Consolidating
- Sustained Tensile Strength
- Short Development Length

Field-Cast Grout
Solution: Rethink the Connection

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Field-Cast UHPC
Introduction to UHPC

- NHI Innovations Webinars – November 18, 2010 and April 21, 2011
- FIU ABC Webinar – September 29, 2011
- TechNote: UHPC
  - FHWA HRT-11-038
  - Aimed at DOTs and practitioners
  - General information on casting, curing, testing, applications, inspection, etc.
What is Ultra-High Performance Concrete?

- Advanced cementitious composite material
- High strength, high stiffness
- Exceptional durability
- Internal steel fiber reinforcement for added ductility
- Self-consolidating

UHPC, UHPFRC, RPC
Ductal, CoreTUFF, BSI, Densit, TAKTL, …
Field-Cast UHPC Properties: Some Ballpark Values

- Compressive Strength – 18 to 25 ksi
- Modulus of Elasticity – 6200 to 7200 ksi
- Creep Coefficient – 0.5 to 0.8
- Sustained Tensile Capacity – 0.9 to 1.3 ksi
- Rapid Chloride Permeability – 200 to 360 Coulombs
- Freeze/Thaw Resistance – RDM > 95%

Source: FHWA Report FHWA-HRT-06-103
Material Property Characterization of Ultra-High Performance Concrete
# Typical Composition of UHPC

<table>
<thead>
<tr>
<th>Material</th>
<th>Amount</th>
<th>% by Weight</th>
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<tbody>
<tr>
<td>Portland Cement</td>
<td>1200 lb/yd³</td>
<td>28.5</td>
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<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>
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<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>

* 290 ksi, 0.5” long, 0.008” diameter
UHPC Mixing
UHPC Mixing
UHPC Placement
Compressive Strength Gain

The graph shows the compressive strength gain as a function of age at test for different curing temperatures:

- **Cure at 105°F**
- **Cure at 73°F**
- **Cure at 50°F**

The x-axis represents the age at test (days after mixing), and the y-axis represents the compressive strength (psi and MPa).
Practical Considerations

- Mixing/placing equipment must be clean
- Formwork must be sealed
- Flow test, not slump test
- Place as an SCC...with consideration of fibers
- Compression testing
  - Must grind cylinder ends...or use cubes
  - Smaller specimens are OK
- Take care w/ fibers. They can poke you.
Compression Behavior

Graph showing the relationship between Axial Stress (ksi) and Average Axial Strain.
Tensile Behavior
Tensile Behavior
Field-Cast UHPC Deck-Level Connections
Deck-Level UHPC Connections

Field-Cast, Non-Contact Lap Splice Connection
Field-Cast UHPC Connections for Modular Bridge Deck Elements

- Pooled Fund No. 5(217)
  - FHWA, NYSDOT, Iowa DOT
- Full-scale deck components
- Cyclic, static loadings
- Report: NTIS PB2011-101995
- TechBrief: FHWA HRT-11-022
UHPC Cxn Testing – Loading Program

- 16 kips
- 2 kip
- 21.3 kips
- 3 kip
- 32 kips
- 40 kips

- 57,369 Cycles
- 10,096,732 Cycles
- 1,118,000 Cycles
- 343,399 Cycles
Stress range in rebar was at least 28 ksi during final 340,000 cycles.

9 of 18 rebar failed in metal fatigue before test had to be halted.

Fatigue then Mating Surface Impact
Field-Cast UHPC Connections
b/t Precast Deck Panels

SR 23 over Otego Creek
Oneonta, New York
Field-Cast UHPC Connections b/t Deck-Bulb-Tee Girders

SR 31 over Canandaigua Outlet Lyons, New York
Field-Cast UHPC Connections
b/t Adjacent Box Beams

Highway 17 Bridge over Eagle River
In Western Ontario, Canada
Field-Cast UHPC Connections b/t Decked Steel Stringer Modules

U.S. 6 over Keg Creek
Pottawattamie County, Iowa

SHRP2 R04 Demonstration Project
Construction Scheduled for October 2011
Field-Cast UHPC Connections b/t Precast Deck Panels

Hwy 24 Bridge over Whiteman Creek
Brantford, Ontario, Canada
Other Projects Currently Underway...

- NYSDOT Emergency Contract re: Recent Flood Damage
  - Precast deck panels on steel girders, simple span
  - Near Poughkeepsie... Construction in October 2011

- Prospect Mountain Interchange Reconstruction – I-81 in Binghamton, NY
  - UHPC connections may be engaged as a bid alternate
  - Deck-level connections as well as deck-to-girder connections

- Hwy 449 over Union Pacific RR near Huntington, Oregon
  - UHPC connections between precast deck panels
  - Construction in 2012

- UHPC Waffle Slab Precast Panels w/ UHPC Connections – Wapello Cnty, Iowa
  - Construction in September 2011
Deck-to-Girder UHPC Connections

Traditional Studs

Shortened Studs

Reduced Stud/Stirrup Height & No Interference
Full-Scale Girder Test of UHPC Composite Cxn

- Shear Stud Connection
- Extended Stirrup Cxn
Extended Stirrup Connection
UHPC Composite Connection

Steel Girder Connection

Concrete Girder Connection
UHPC Composite Cxn – Loading Program

- Design Fatigue Load
- Applied Load per Jack (kN)
- Applied Load per Jack (kips)

- 50 kips
- 66 kips
- 82 kips
- 97 kips
- 3 kips

- 2,141,000 Cycles
- 2,044,000 Cycles
- 2,064,000 Cycles
- 5,211,000 Cycles
Cyclic Loading:  
11M total cycles w/  
5M at 2x fatigue load

Static Loading:  
Precast component failures at  
applied shear = 500 kips
Field-Cast UHPC Connections for PBES

- Precast Deck Panels
- Deck-Bulb-Tee Girders
- NEXT Beams
- Pretopped Steel Stringers
- Adjacent Box Beams
Field-Cast UHPC Connections

Simple, Robust Connection Solutions
UHPC FOR PBES: FREQUENTLY ASKED QUESTIONS

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What About Interface Bond???

As compared to conventional concretes and grouts, UHPC bonds very well to precast concrete components. The high cementitious materials content combined with the fine-grained mix result in a product that “sticks”.

Bonding can be enhanced by cleaning, roughening, and “exposing” the precast surfaces.

Prewetting of precast surface enhances bond.
What About Shrinkage???

UHPC does shrink...just like every other cementitious composite material. The shrinkage is similar to that you might observe with other prebagged cementitious grouts. The most important considerations are

1) that the UHPC is mixed and placed correctly, and
2) that the bonding surfaces are appropriately prepared.
How Much Does UHPC Cost???

The cost of UHPC per yd\(^3\) is similar to magnesium phosphate grouts and is slightly higher than conventional pre-bagged grouts. Remember that UHPC includes steel fibers, 1000+ lb cement, and 300+ lb silica fume per yd\(^3\).

Comparing the costs of conventional concrete and UHPC is like comparing the costs of steel and stainless steel. More refined products are used in specific applications where other solutions fall short.
How Much Does UHPC Cost???

Instead of focusing on the bulk cost of the material, I frequently suggest that owners consider the deployed cost of the overall project w/ and w/o UHPC. When compared to alternate solutions, the value of the UHPC solution becomes apparent.
Do “Buy America” Provisions Apply???

Yes. UHPC typically contains steel fiber reinforcement. Current interpretation is that federal-aid highway construction projects which include steel fiber reinforcement must abide by the provisions. No domestic suppliers of acceptable fibers currently exist. Project specific waivers have been granted for past projects. Nationwide 2-year waiver is being considered.
Are Multiple UHPC Suppliers Available???

At present, one large multi-national corporation has a supply chain in place to provide UHPC materials and engineering services.

Other multi-nationals and startups are beginning to develop U.S. supply capability.

Others are monitoring the market, waiting for greater demand.
At present, it is unlikely that you will be able to obtain a non-proprietary UHPC which both is available in appropriate volumes and has been demonstrated to perform appropriately.

In the U.S., various research labs and universities are developing UHPC-class materials...but none are ready for immediate deployment.
A general suggestion is to consider performance alternates instead of material alternates. The limited number of suppliers means that you cannot presently expect to have multiple UHPCs on a DOT “Qualified Materials” list. Instead, design the project using both conventional and UHPC solutions…then select the best value.
How Can I Specify UHPC in a Project???

Also, initial projects can be completed as experimental and/or demonstration projects.

Having a specific UHPC product “Certified” or approved through a “Public Interest Finding” is also possible.
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