Bridge Engineering/Construction
Ultra High Performance Concrete (UHPC)

Ductal® UHPC

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LafargeHolcim
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UHPC Premix/Constituents

- **Premix**
  - Blend of cement, silica sand, quartz flour and silica fume
  - Largest “aggregate” less than 1 mm

- **Superplasticizer**

- **Water**
  - w/c ratio less than 0.25

- **Fibers**
  - Steel (structural)
  - Organic (architectural)
Properties of UHPC

- **Compressive Strength**
  - 140 to 225 MPa
    (20,000 to 33,000 psi)

- **Flexural Strength**
  - 20 to 50 MPa
    (3,000 to 7,000 psi)

- **Ductility**
  - Greater capacity to deform and support flexural and tensile loads even after initial cracking

- **Abrasion Resistance**
  - Similar to natural rock

- **Impermeability**
  - Almost no carbonation and penetration of chlorides
UHPC Matrix

Conventional Concrete – 4000 psi

High Performance Concrete – 10,000 psi

Ultra High Performance Concrete – 21,000 psi
Impermeability & Longevity

US Army Corp, Exposure Site
Treat Island, Maine

EXPOSURE: 500 freeze/thaw cycles and 4500 wet/dry cycles in saturated sea water

August 14, 2002
Ductility

Greater capacity to deform and support flexural and tensile loads even after initial cracking!
Ductility

Steel Fibers Bridging the Crack - Ductility
UHPC Connections

Cyclic Loading (Fatigue):

• 2000 to 16,000 pounds for 8,900,000 cycles

• 2000 to 21,300 pounds for 5,200,000 cycles

“No leakage through the joint”
Design Details

#5 epoxy-coated bars @ 8 in. spacing

All units in inches

Design longitudinal reinforcement

1 1/2

8

1 1/2

1/4 in. grind joint excess

LIHPC

6 in. min
(Note 2)

Exposed aggregate finish

Continuous form (typical)

Presoak and clean connection interface

Note 1: Distance could be increased based on construction tolerance

Note 2: Required lap length based on bar type and size

All units in inches
Design Aids

French Association Civil Engineering

First Came Out 2002
Revised Part 2 in June 2013 to be Consistent with the Euro Code
Design Aids
Design Aids

Table 1. Typical field-cast UHPC material properties.

<table>
<thead>
<tr>
<th>Material Characteristic</th>
<th>Average Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>155 lb/ft³ (2,480 kg/m³)</td>
</tr>
<tr>
<td>Compressive strength (ASTM C39; 28-day strength)</td>
<td>24 ksi (165 MPa)</td>
</tr>
<tr>
<td>Modulus of elasticity (ASTM C469; 28-day modulus)</td>
<td>7,000 ksi (48 GPa)</td>
</tr>
<tr>
<td>Direct tension cracking strength (uniaxial tension with multiple cracking)</td>
<td>1.2 ksi (8.5 MPa)</td>
</tr>
<tr>
<td>Split cylinder cracking strength (ASTM C496)</td>
<td>1.3 ksi (9.0 MPa)</td>
</tr>
<tr>
<td>Prism flexure cracking strength (ASTM C1018; 12-inch (305-mm span)</td>
<td>1.3 ksi (9.0 MPa)</td>
</tr>
<tr>
<td>Tensile strain capacity before crack localization and fiber debond</td>
<td>&gt; 0.003</td>
</tr>
<tr>
<td>Long-term creep coefficient (ASTM C512; 11.2 ksi (77 MPa) load)</td>
<td>0.78</td>
</tr>
<tr>
<td>Long-term shrinkage (ASTM C157; initial reading after set)</td>
<td>555 microstrains</td>
</tr>
<tr>
<td>Total shrinkage (embedded vibrating wire gage)</td>
<td>790 microstrains</td>
</tr>
<tr>
<td>Coefficient of thermal expansion (AASHTO TP60-00)</td>
<td>8.2 x 10⁻⁶ inches/inches/F (14.7 x 10⁻⁶ mm/mm/°C)</td>
</tr>
<tr>
<td>Chloride ion penetrability (ASTM C1202; 28-day test)</td>
<td>360 coulombs</td>
</tr>
<tr>
<td>Chloride ion permeability (AASHTO TP259; 0.6-inch (12.7-mm depth))</td>
<td>&lt; 0.10 lb/yr² (&lt; 0.06 kg/m²)</td>
</tr>
<tr>
<td>Scaling resistance (ASTM C672)</td>
<td>No scaling</td>
</tr>
<tr>
<td>Abrasion resistance (ASTM C944 2x weight; ground surface)</td>
<td>0.026 oz. (0.73 g) lost</td>
</tr>
<tr>
<td>Freeze-thaw resistance (ASTM C666A; 600 cycles)</td>
<td>RDM = 99 percent</td>
</tr>
<tr>
<td>Alkali-silica reaction (ASTM C1280; tested for 28 days)</td>
<td>Innocuous</td>
</tr>
</tbody>
</table>

Table 1: Typical field-cast UHPC material properties.

FHWA Publication No: FHWA-HRT-14-084
FHWA Contact: Ben Graybeal, HRDI-40, 202-483-3122, benjamin.graybeal@dot.gov

Introduction
Advancements in the science of concrete materials have led to the development of a new class of cementitious composites called ultra-high performance concrete (UHPC). UHPC exhibits mechanical and durability properties that make it an ideal candidate for use in developing new solutions to pressing concerns about highway infrastructure deterioration, repair, and replacement. Field-cast UHPC details connecting prefabricated structural elements used for bridge construction have proven to be an application that has captured the attention of owners, specifiers, and contractors across the country. These connections can be simpler to construct and can provide more robust long-term performance than connections constructed through conventional methods. This document provides guidance on the design and deployment of field-cast UHPC connections.

UHPC
UHPC is a fiber-reinforced, portland cement-based product with advantageous fresh and hardened properties. Through the appropriate combination of advancements in superplasticizers, dry constituent gradation, fiber reinforcements, and supplemental cementitious materials, UHPC is able to deliver performance that far exceeds conventional concrete. Developed in the late 20th century, this class of concrete has emerged as a capable replacement for conventional structural materials in a variety of applications. The Federal Highway Administration (FHWA) defines UHPC as follows:

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). UHPC has a discontinuous pore structure that reduces liquid ingress, significantly enhancing durability compared to conventional concrete.

The tensile behavior of UHPC may generally be defined as "strain-hardening," a broad term defining concretes in which the sustained post-cracking strength provided by the fiber reinforcement is greater than the cementitious matrix cracking strength. Note that the post-cracking tensile strength and strain capacity of UHPC is highly dependent on the type, quantity, dispersion, and orientation of the internal fiber reinforcement.

U.S. Department of Transportation
Federal Highway Administration
Research, Development, and Technology
Turner Fairbank Highway Research Center
6301 Georgetown Pike, McLean, VA 22102-2296

AASTHO = American Association of State Highway and Transportation Officials
RDM = relative dynamic modulus of elasticity
Design Aids

Table 2. Material tests commonly applied to UHPC used in field-cast connections.

<table>
<thead>
<tr>
<th>Test Method</th>
<th>ASTM</th>
<th>Material Vetting</th>
<th>QA/QC</th>
<th>QA/QC Frequency</th>
<th>Acceptance Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>C1437</td>
<td>Yes</td>
<td>Yes</td>
<td>Once per mix</td>
<td>• Flow diameter before and after drops—project specific</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Flow range from 7 to 10 inches (178 to 254 mm).</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>C39, C109</td>
<td>Yes</td>
<td>Yes</td>
<td>At least once per 25 yd³ (19 m³) or once per 12-h shift</td>
<td>• &gt; 14 ksi (97 MPa) after 4 days</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• &gt; 21 ksi (145 MPa) after 28 days</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• &gt; 14 ksi (97 MPa) before application of construction or live loads</td>
</tr>
<tr>
<td>Chloride ion</td>
<td>C1202</td>
<td>Yes</td>
<td>Not Common</td>
<td>N/A</td>
<td>• ≤ 250 coulombs by 28 days</td>
</tr>
<tr>
<td>penetrability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freeze-thaw</td>
<td>C666A</td>
<td>Yes</td>
<td>Not Common</td>
<td>N/A</td>
<td>• RDM ≥ 95 percent after 300 cycles</td>
</tr>
<tr>
<td>resistance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shrinkage</td>
<td>C157</td>
<td>Yes</td>
<td>Not Common</td>
<td>N/A</td>
<td>• ≤ 800 microstrain at 28 days</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Consider curing scenarios</td>
</tr>
</tbody>
</table>

N/A = not applicable
QA/QC = quality assurance/quality control
RDM = relative dynamic modulus of elasticity
Field Batching of UHPC

UHPC may be mixed in any type of mixer with proper mixer adjustments and optimization but best performance is achieved in high shear mixers.

Most precast plant mixers work fine.

0.2 yd$^3$ batches (0.8 m$^3$ per hour)  
0.65 yd$^3$ batches (2.6 yd$^3$ per hour)  
6 yd$^3$ batches
Casting
Quality Control

Slump Flow
- Mini-slump cone
- Flow – 7” to 10”

Compressive Strength
- 3” x 6” Cylinders
- Ends cut to length and machined to <0.5°

Material supplier provides on-site QA/QC for all projects.
High Early Strength UHPC for ABC

Temperature VS Strength Gain Curve

Ductal® JS1212

- Cured at 140°F
- Cured at 120°F
- Cured at 100°F
- Cured at 75°F

Compressive Strength (psi)

Time (hrs)
Applications

- Precast deck panel connections
- Link slabs
- Beam connections
- Beams
- Pier elements
- Precast substructure connections
- Bridge rehabilitation, repair and retrofit
- Thin bonded overlays
Engineering With UHPC

Precast Concrete Connections

- 3” Dia Port For Placing UHPC
- 3” Dia Corrugated Pipe Sleeve Around Reinforcing Steel
- Precast Concrete Pier Cap
- Precast Concrete Column

* UHPC Collar – Form and Pour Through 3” Port

Shown is One of Many Types of Possible Connections
Engineering with UHPC

As Built

Required Embedment Length

\[ l \geq 8d \] for \( f_c \leq 75 \text{ ksf} \) bars
UHPC Field Connections
For Full-Depth Precast Deck Panels

[Diagram of UHPC field connections for full-depth precast deck panels]

[Images of construction site showing workers installing and monitoring the precast deck panels]
Typical Concrete Panel Joint Details

All units in inches

Design longitudinal reinforcement

Exposed aggregate finish

Continuous form (typical)

Presoak and clean connection interface

Note 1: Distance could be increased based on construction tolerance

Note 2: Required lap length based on bar type and size

All units in inches
UHPC Field Cast Joints for Live-Load Continuity

* Courtesy of Hatch Mott McDonald & Ministry of Transportation Ontario
Side-by-Side Box Girder UHPC Field Connections

Straight Bars with off-set laps!

* Courtesy of Ministry of Transportation of Ontario
Abutment to Pile Connections for ABC

* Courtesy of Delcan & Ministry of Transportation Ontario
Pulaski Skyway, New Jersey/New York
Pulaski Skyway, New Jersey/New York
Pulaski Skyway, New Jersey/New York
Pulaski Bridge UHPC Details

Typical Shear Connector Details

TYPICAL CROSS BEAM SHEAR CONNECTOR BLOCKOUT DETAIL
SCALE: 2" = 1' - 0"
Pulaski Bridge UHPC Details

Typical Transverse Joint Details

- Fill shear key with cast-in-place ultra high performance concrete (UHPC)
- 8" nominal (see notes)
- Precast deck panel rebar (typ.)
- Top of precast panel
- Limits of pay item concrete bridge deck, UHPC
- End of precast panel (typ.)

Section A

3" = 1'-0"
Nipigon Bridge UHPC Details
Nipigon Bridge UHPC Details

Phase 1 Construction - Westbound
Nipigon Bridge UHPC Details

Typical Joint Details
Nipigon Bridge UHPC Details

Typical PBES/UHPC Portion Completed
Deck Bulb-Tee UHPC Field Connections

* Courtesy of NY State Department of Transportation
Deck Bulb-Tee UHPC Field Connections
UHPC Field Connections
For UHPC Waffle Deck Bridge Panels
Hodder Avenue Underpass, Thunder Bay, ON
Hodder Avenue Underpass
Hodder Avenue Underpass
Mission Bridge – Pier Retrofit, Mission, BC
Mission Bridge - Pier Retrofit
Mission Bridge - Pier Retrofit
Mission Bridge - Pier Retrofit
CN Rail - Column Jacketing, QC
CN Rail - Column Jacketing
CN Rail Column Jacketing