Bridge Engineering/Construction
Ultra High Performance Concrete (UHPC)

Ductal® UHPC

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LafargeHolcim

October, 2016

UHPC Premix/Constituents

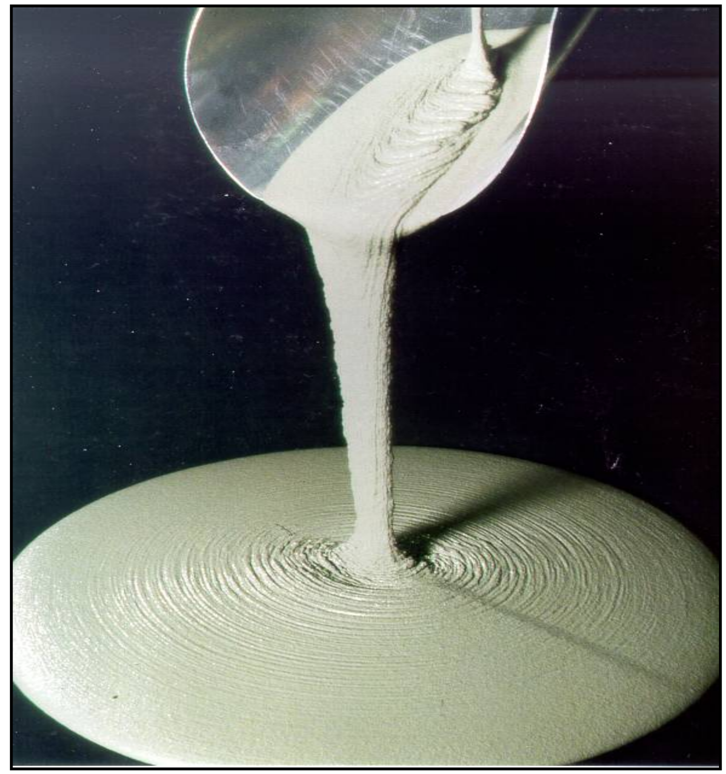
- **Premix**
  - Blend of cement, silica sand, quartz flour and silica fume
  - Largest “aggregate” less than 1 mm
- **Superplasticizer**
- **Water**
  - w/c ratio less than 0.25
- **Fibers**
  - Steel (structural)
  - Organic (architectural)


Organic fibers

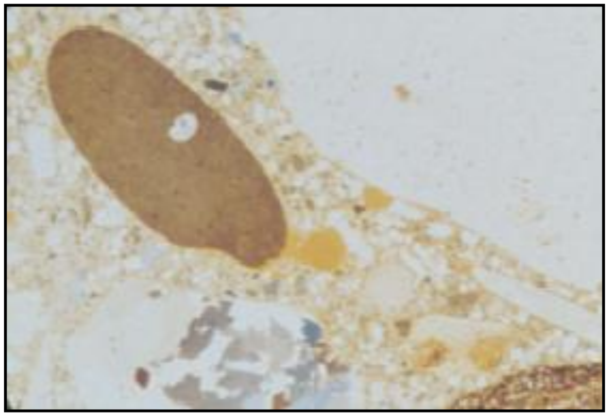

Metallic fibers

Properties of UHPC

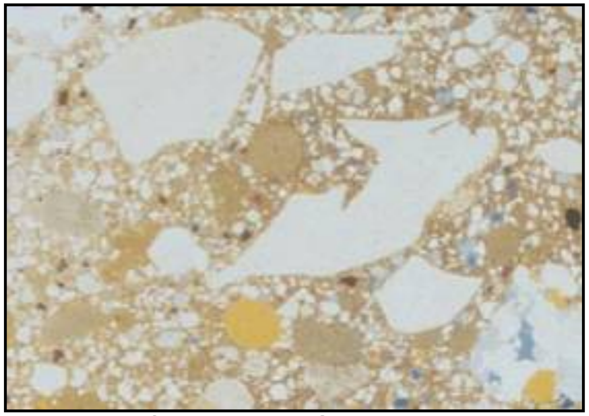
- **Compressive Strength**
  - 140 to 225 MPa
    (20,000 to 33,000 psi)
- **Flexural Strength**
  - 20 to 50 MPa
    (3,000 to 7,000 psi)
- **Ductility**
  - Greater capacity to deform and support flexural and tensile loads even after initial cracking
- **Abrasion Resistance**
  - Similar to natural rock
- **Impermeability**
  - Almost no carbonation and penetration of chlorides



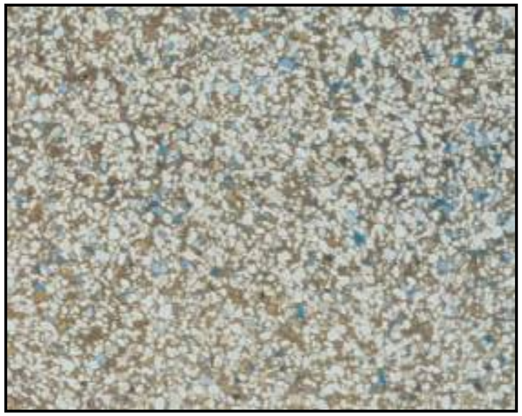
UHPC Matrix



Conventional Concrete – 4000 psi



High Performance Concrete – 10,000 psi

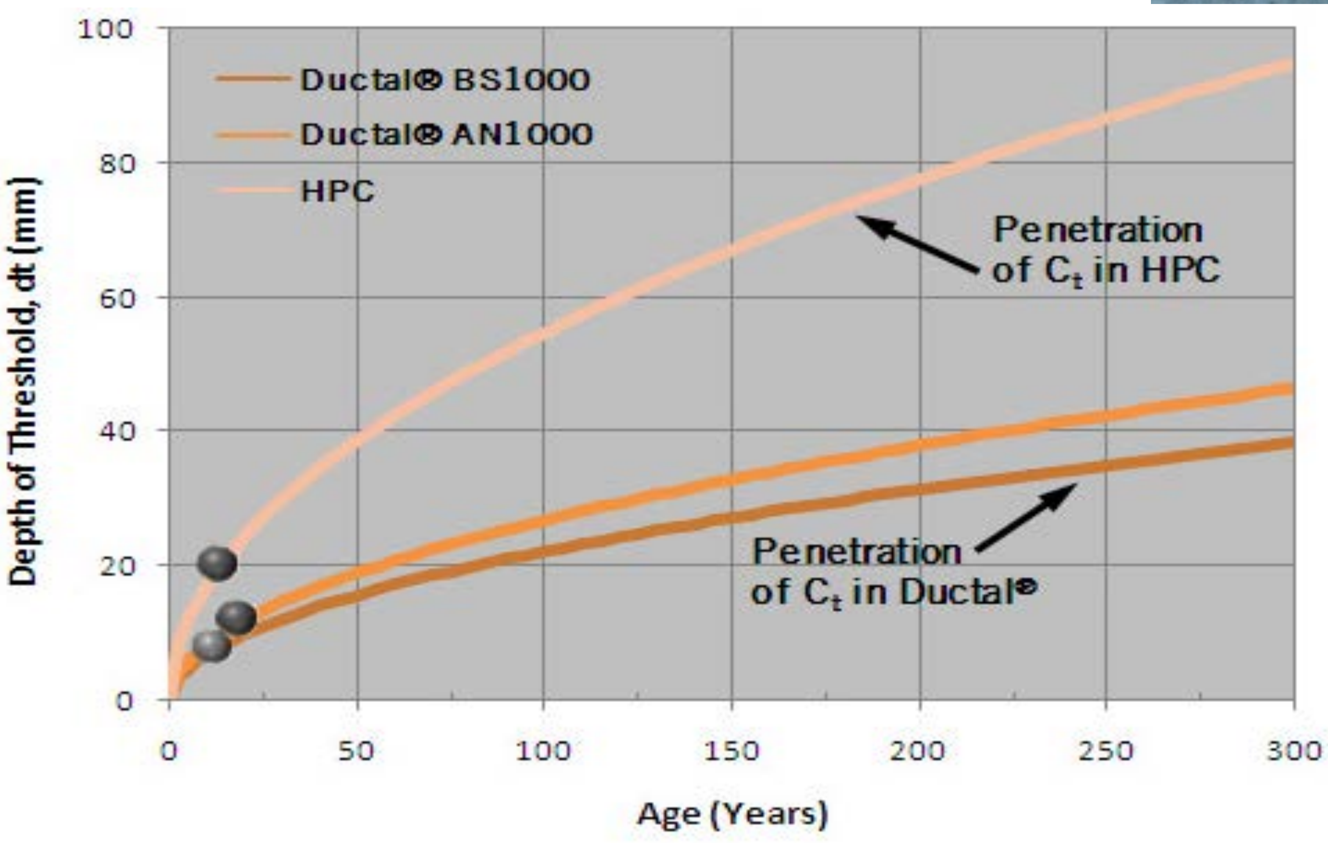


Ultra High Performance Concrete – 21,000 psi

Impermeability & Longevity

US Army Corp, Exposure Site
Treat Island, Maine

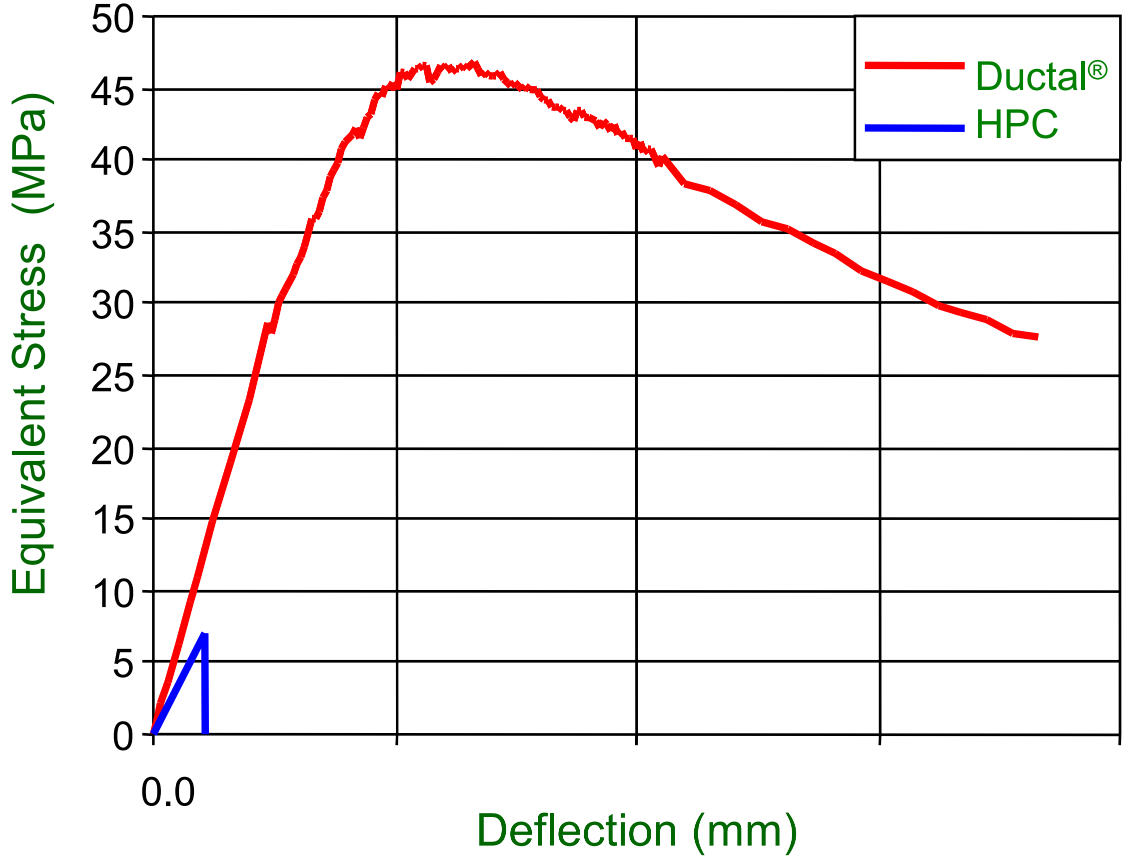
August 14, 2002



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

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):

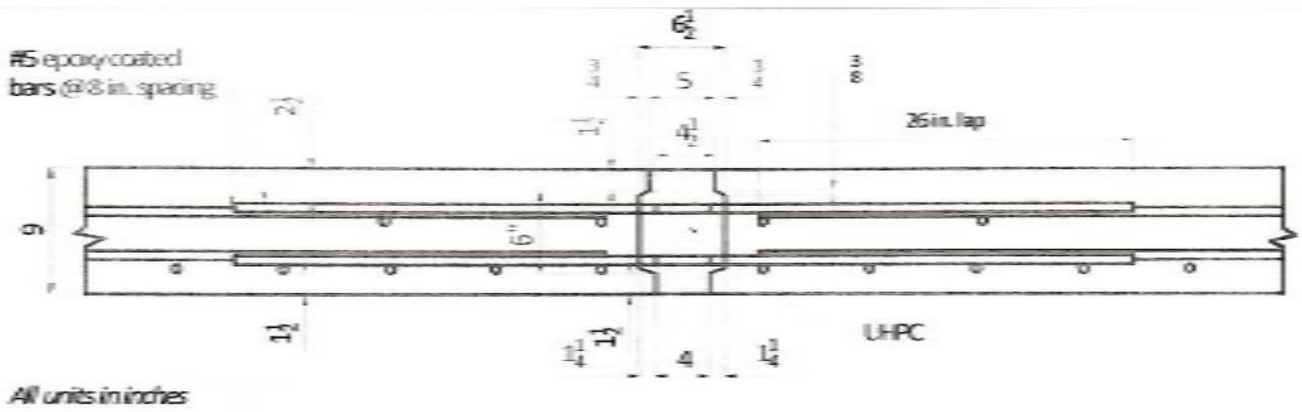
- 2000 to 16,000 pounds
  for 8,900,0000 cycles

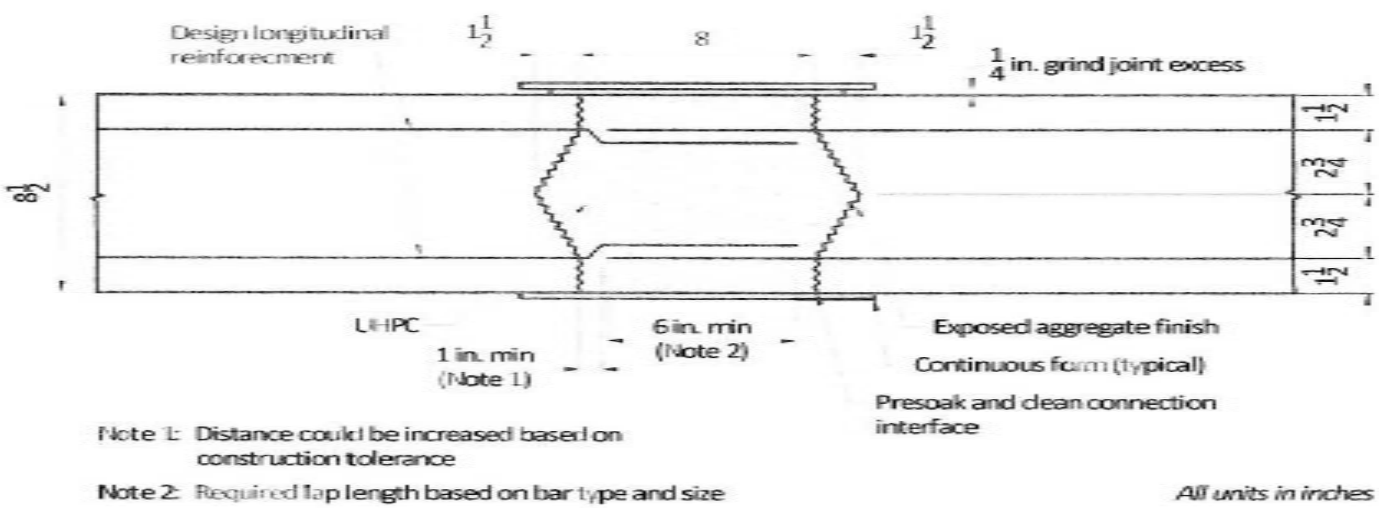
- 2000 to 21,300 pounds
  for 5,200,000 cycles

"No leakage through the joint"

Design

Details



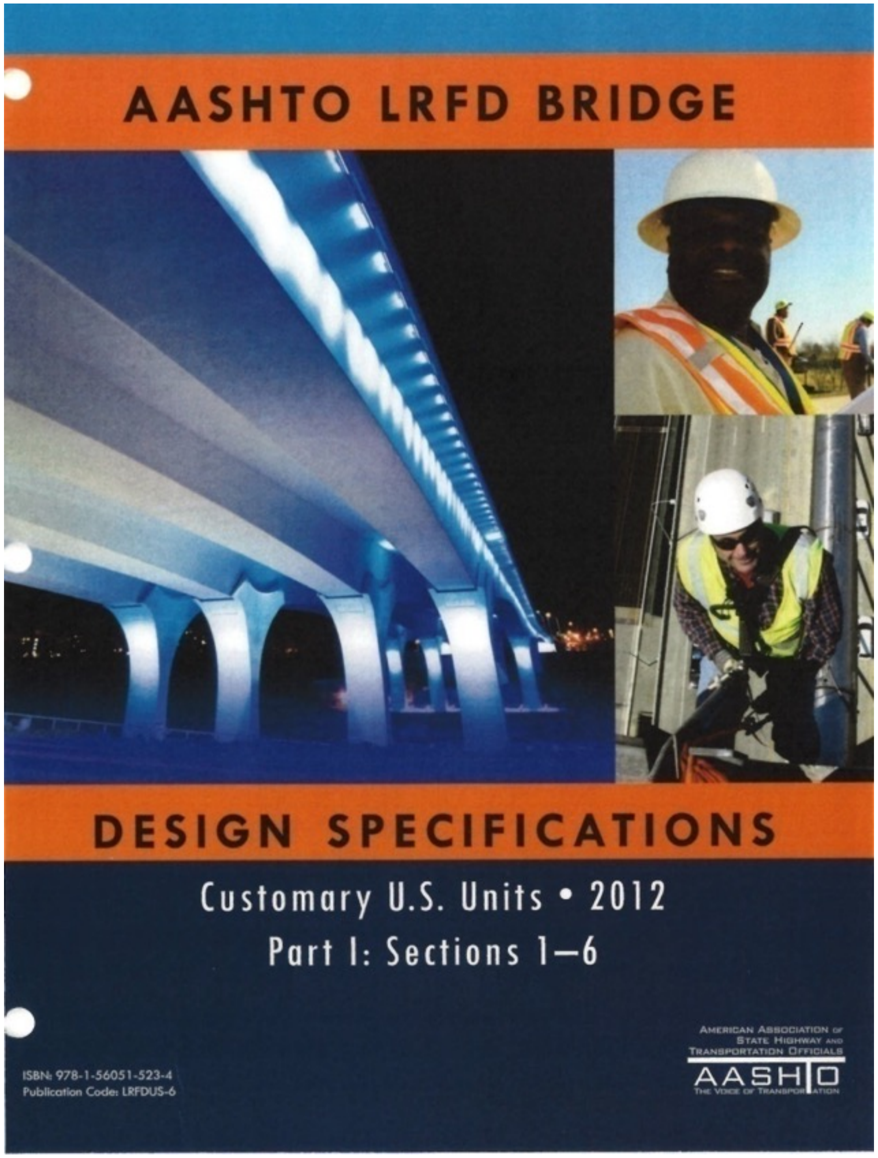


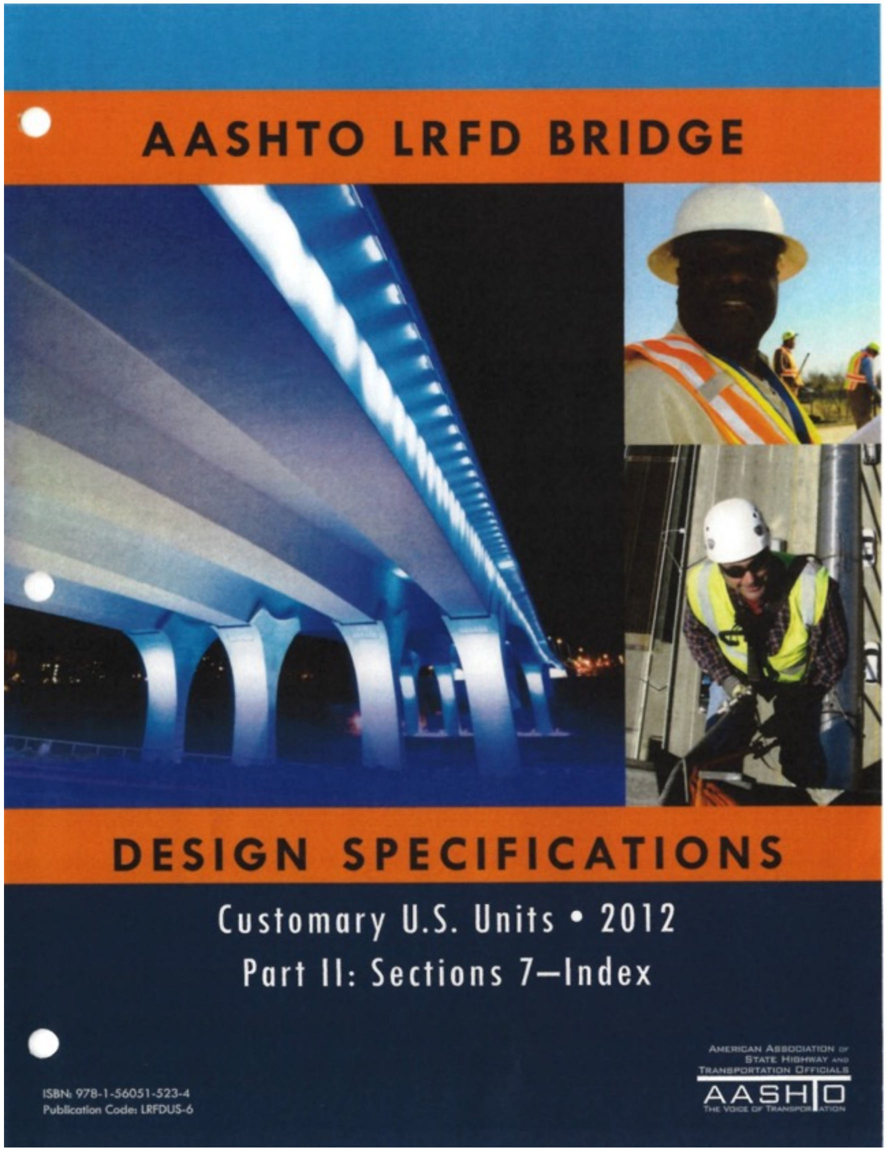
Design Aids

French Association Civil Engineering

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

Design Aids


AASHTO LRFD BRIDGE
DESIGN SPECIFICATIONS
Customary U.S. Units • 2012
Part I: Sections 1–6
ISBN: 978-1-56051-523-4
Publication Code: LRFDUS-6
American Association of State Highway and Transportation Officials
AASHTO
The Voice of Transportation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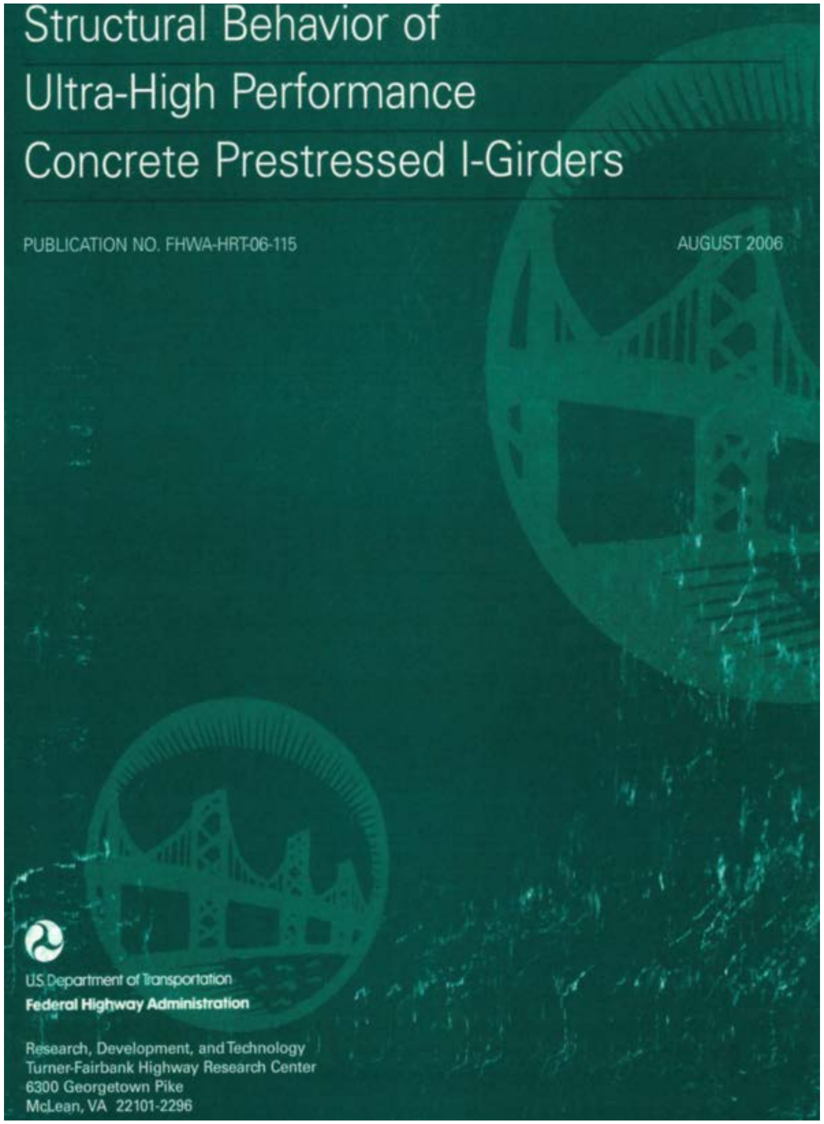
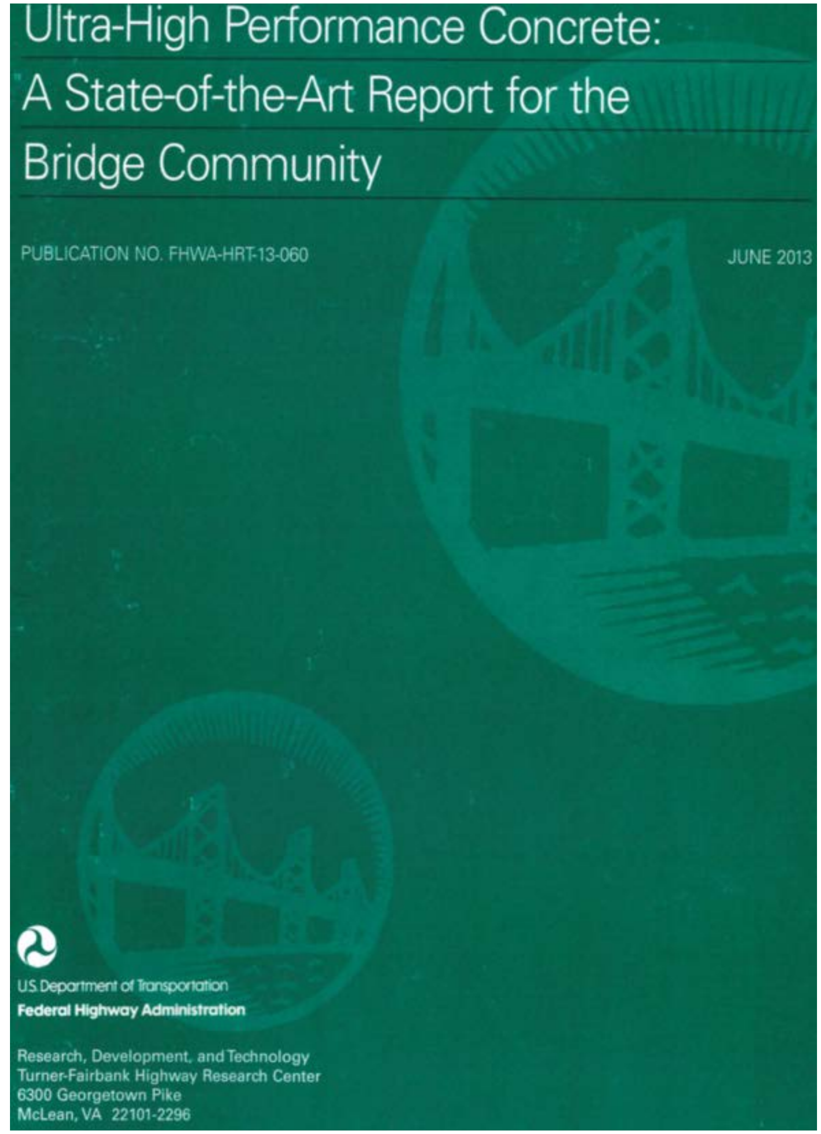
Design Aids


Structural Behavior of
Ultra-High Performance
Concrete Prestressed I-Girders
PUBLICATION NO. FHWA-HRT-06-115
AUGUST 2006
U.S. Department of Transportation
Federal Highway Administration
Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296


Ultra-High Performance Concrete:
A State-of-the-Art Report for the
Bridge Community
PUBLICATION NO. FHWA-HRT-13-060
JUNE 2013
U.S. Department of Transportation
Federal Highway Administration
Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

Design Aids

TECHNOTE

Design and Construction of Field-Cast UHPC Connections

FHWA Publication No: FHWA-HRT-14-084

FHWA Contact: Ben Graybeal, HRDI-40, 202-493-3122, 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.[1,2] 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.[3] 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).[1] UHPC has a discontinuous pore structure that reduces liquid ingress, significantly enhancing durability compared to conventional concrete.[2]

TABLE OF CONTENTS:

[1]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
www.fhwa.dot.gov/research

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike, McLean, VA 22101-2296

Table 1. Typical field-cast UHPC material properties.

Material Characteristic	Average Result
Density	155 lb/ft³ (2,480 kg/m³)
Compressive strength (ASTM C39; 28-day strength)	24 ksi (165 MPa)
Modulus of elasticity (ASTM C469; 28-day modulus)	7,000 ksi (48 GPa)
Direct tension cracking strength (uniaxial tension with multiple cracking)	1.2 ksi (8.5 MPa)
Split cylinder cracking strength (ASTM C496)	1.3 ksi (9.0 MPa)
Prism flexure cracking strength (ASTM C1018; 12-inch (305-mm) span)	1.3 ksi (9.0 MPa)
Tensile strain capacity before crack localization and fiber debond	> 0.003
Long-term creep coefficient (ASTM C512; 11.2 ksi (77 MPa) load)	0.78
Long-term shrinkage (ASTM C157; initial reading after set)	555 microstrain
Total shrinkage (embedded vibrating wire gage)	790 microstrain
Coefficient of thermal expansion (AASHTO TP60-00)	8.2 x10^{-6} inches/inches/°F (14.7 x10^{-6} mm/mm/°C)
Chloride ion penetrability (ASTM C1202; 28-day test)	360 coulombs
Chloride ion permeability (AASHTO T259; 0.5-inch (12.7-mm) depth)	< 0.10 lb/yd³ (< 0.06 kg/m³)
Scaling resistance (ASTM C672)	No scaling
Abrasion resistance (ASTM C944 2x weight; ground surface)	0.026 oz. (0.73 g) lost
Freeze-thaw resistance (ASTM C666A; 600 cycles)	RDM = 99 percent
Alkali-silica reaction (ASTM C1260; tested for 28 days)	Innocuous

AASHTO = 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.

Test Method	ASTM	Material Vetting	QA/QC	QA/QC Frequency	Acceptance Criteria
Flow	C1437	Yes	Yes	Once per mix	• Flow diameter before and after drops—project specific • Flow range from 7 to 10 inches (178 to 254 mm).
Compressive strength	C39 C109	Yes	Yes	At least once per 25 yd^3 (19 m^3) or once per 12-h shift	• > 14 ksi (97 MPa) after 4 days • > 21 ksi (145 MPa) after 28 days • > 14 ksi (97 MPa) before application of construction or live loads
Chloride ion penetrability	C1202	Yes	Not Common	N/A	• ≤ 250 coulombs by 28 days
Freeze-thaw resistance	C666A	Yes	Not Common	N/A	• RDM ≥ 95 percent after 300 cycles
Shrinkage	C157	Yes	Not Common	N/A	• ≤ 800 microstrain at 28 days • Consider curing scenarios

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 yd³ batches (0.8 m3 per hour)

0.65 yd³ batches (2.6 yd³ per hour)

6 yd³ batches

Casting

Quality Control

Slump Flow

- **Mini-slump cone**
- **Flow – 7" to 10"**

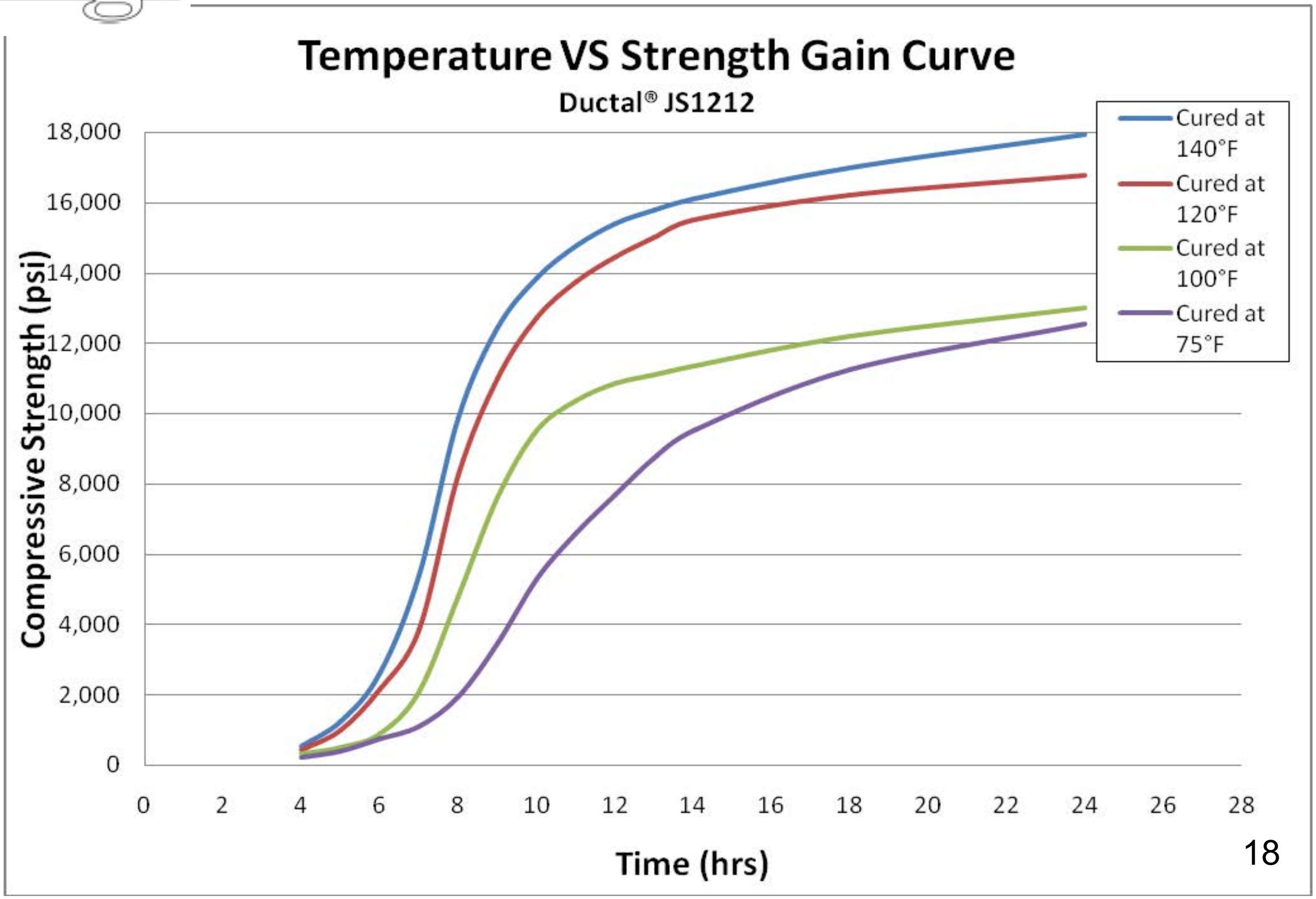
Compressive Strength

- **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

Advance Testing
Campbell Hall, NY

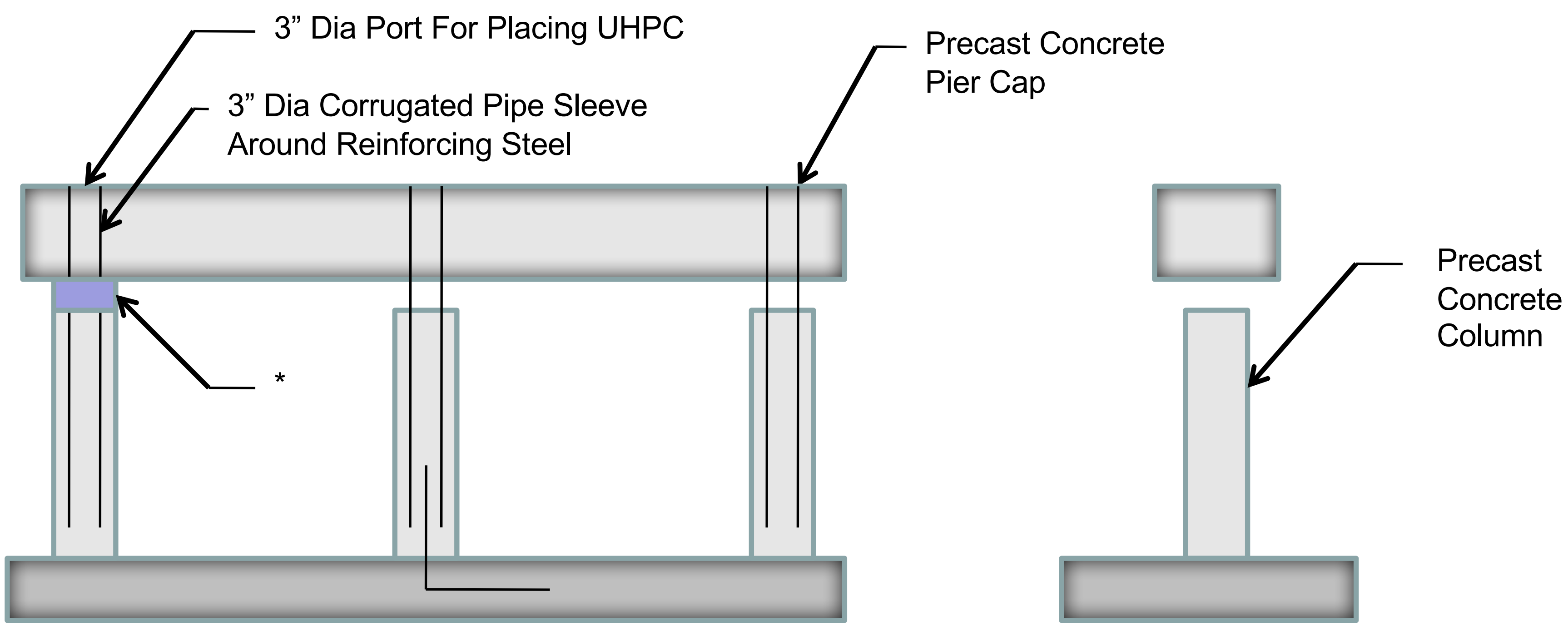


Applications

- 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

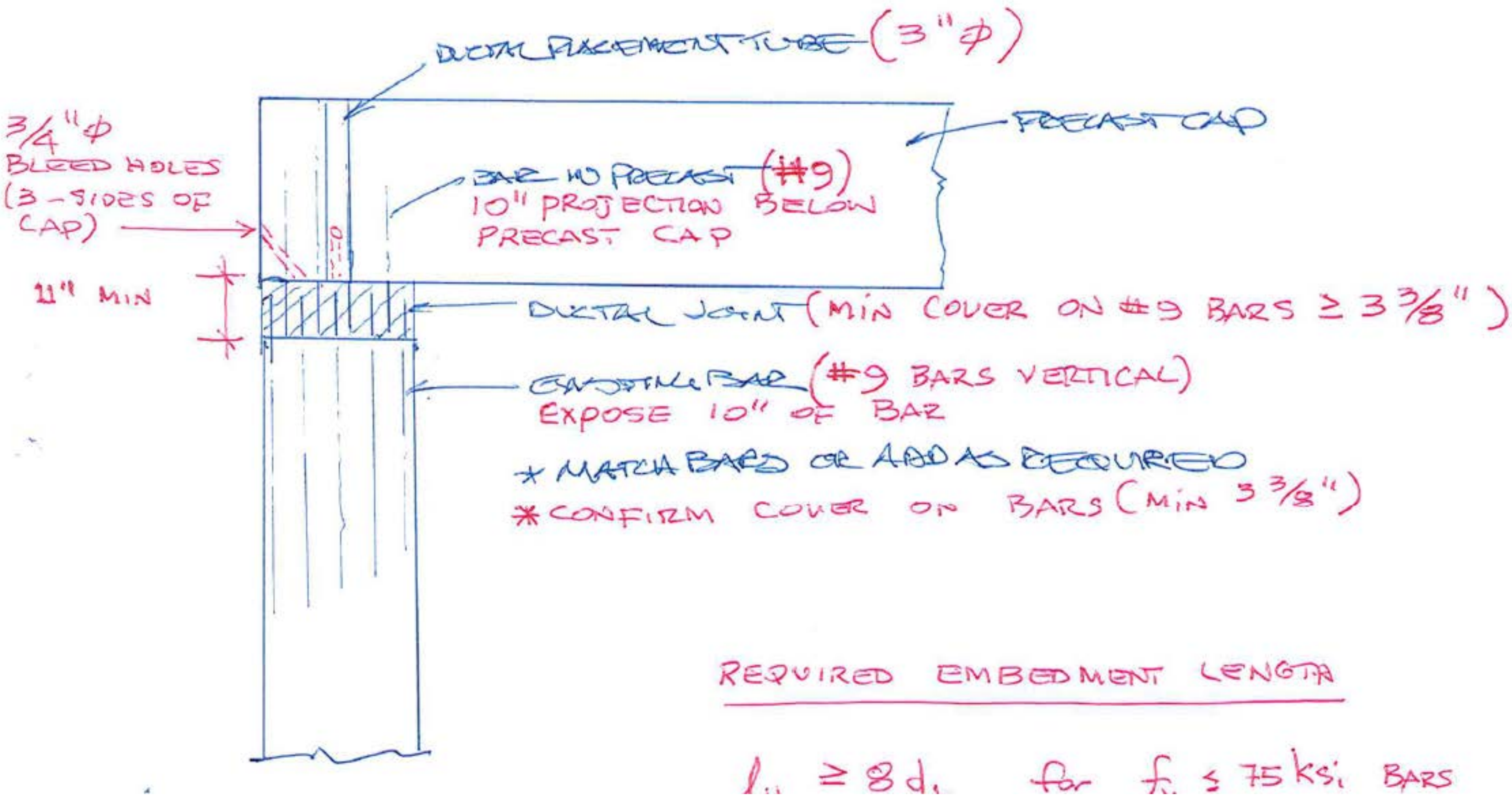


* UHPC Collar – Form and Pour Through 3” Port

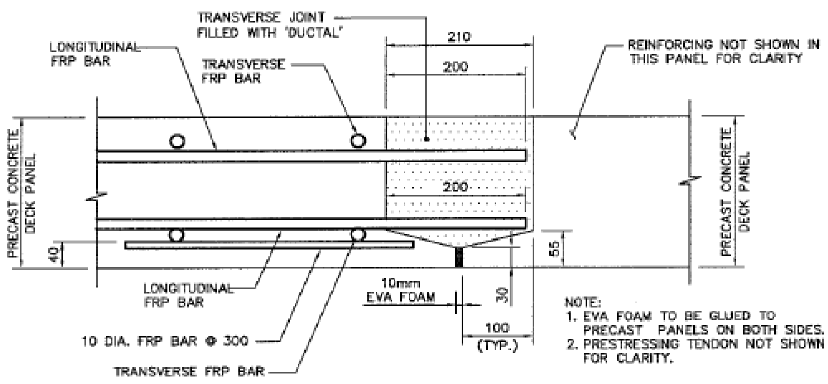
Shown is One of Many Types of Possible Connections

Engineering with UHPC

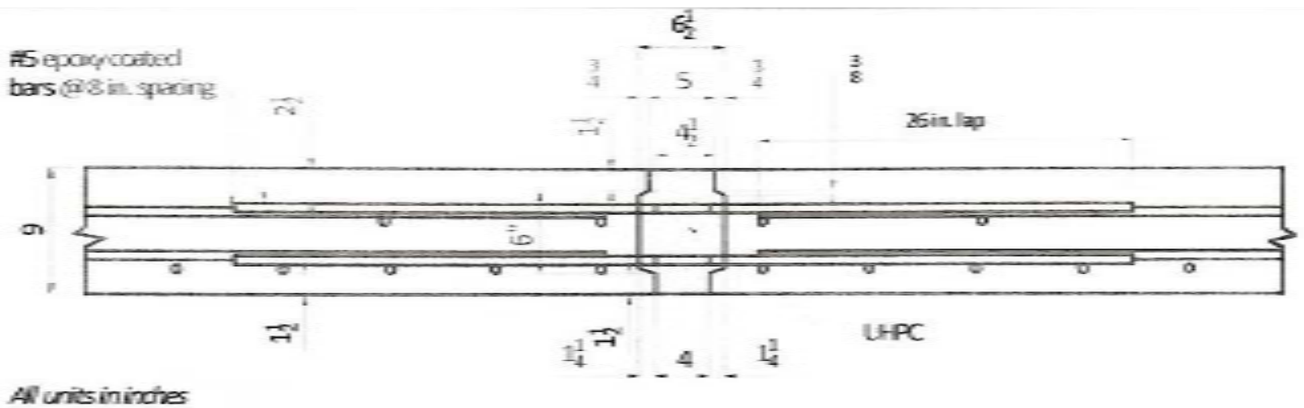
As Built

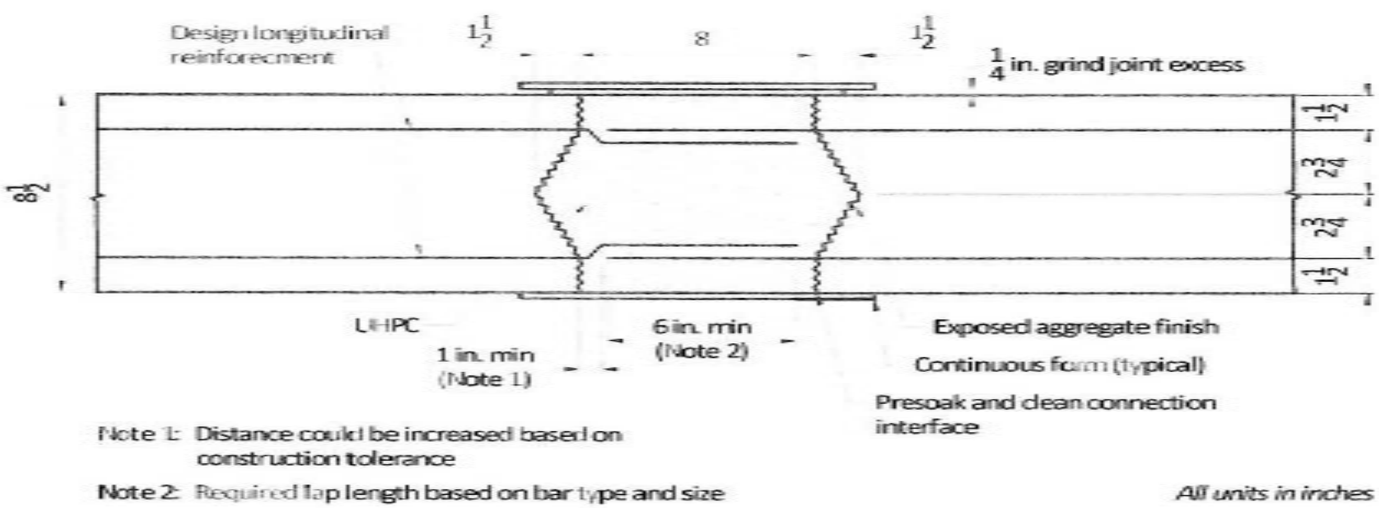


UHPC Field Connections For Full-Depth Precast Deck Panels

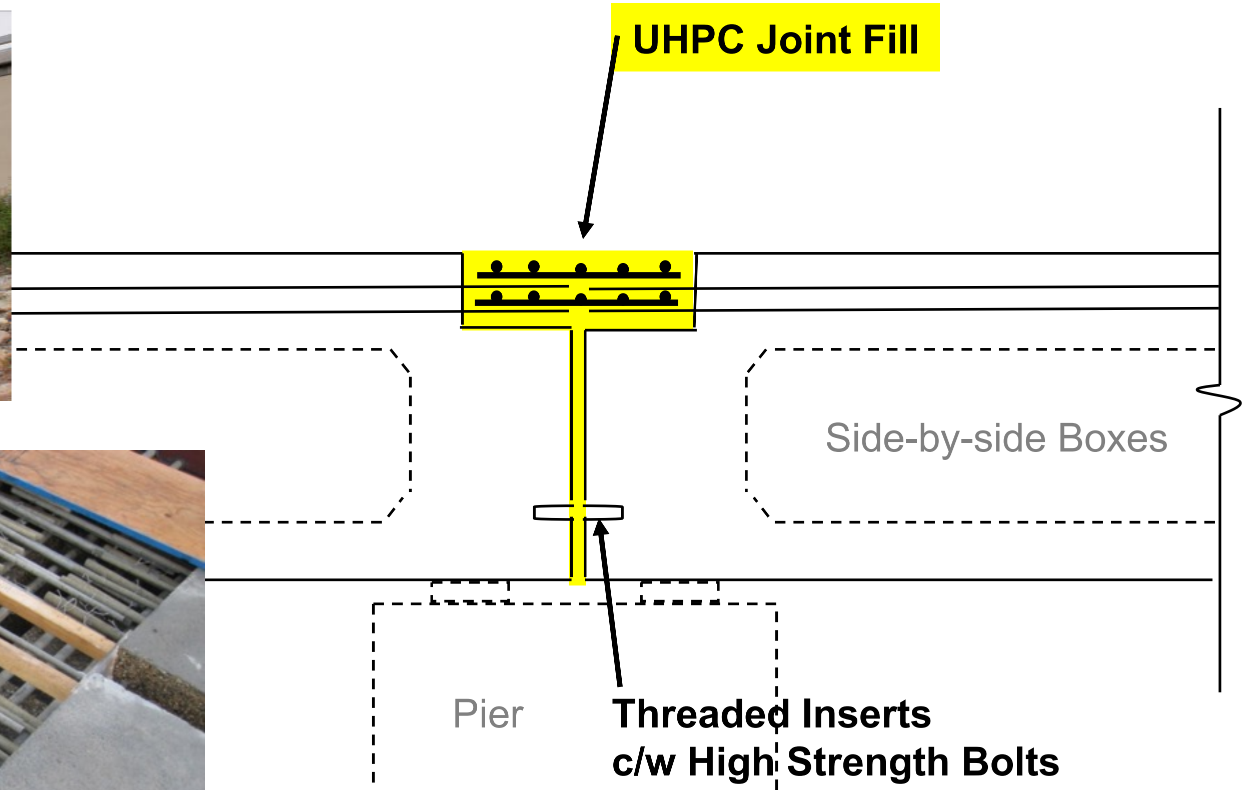


Typical Concrete Panel Joint Details



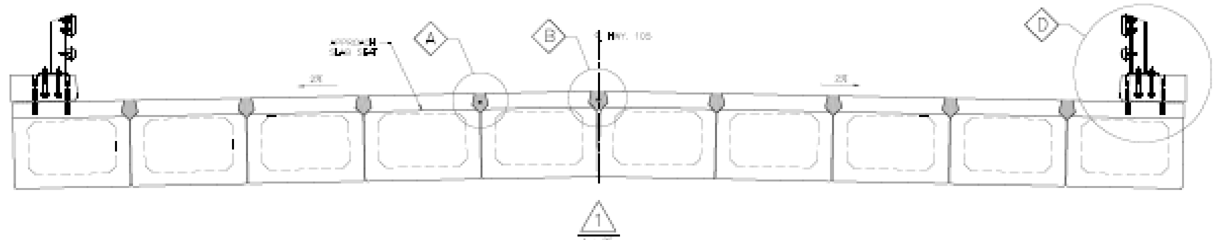


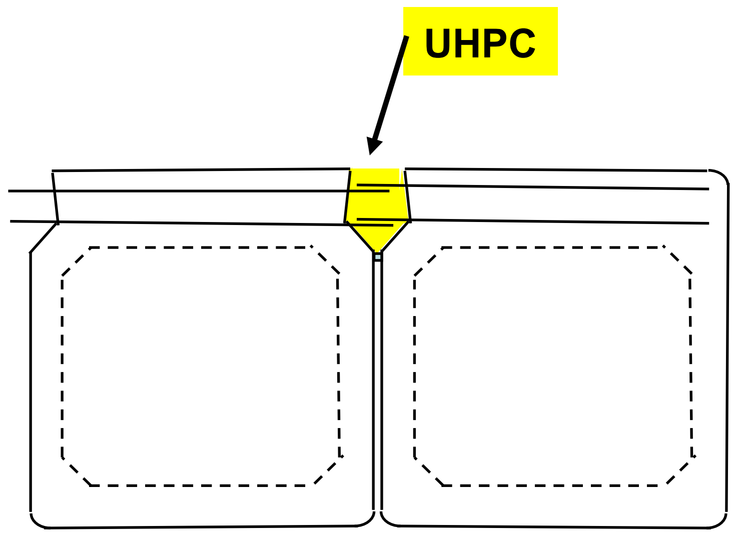
UHPC Field Cast Joints for Live-Load Continuity



* Courtesy of Hatch Mott McDonald & Ministry of Transportation Ontario

Side-by-Side Box Girder UHPC Field Connections



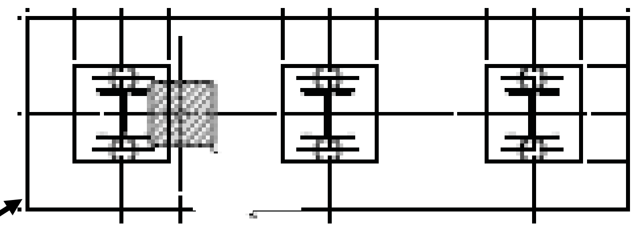


Straight Bars with off-set laps!

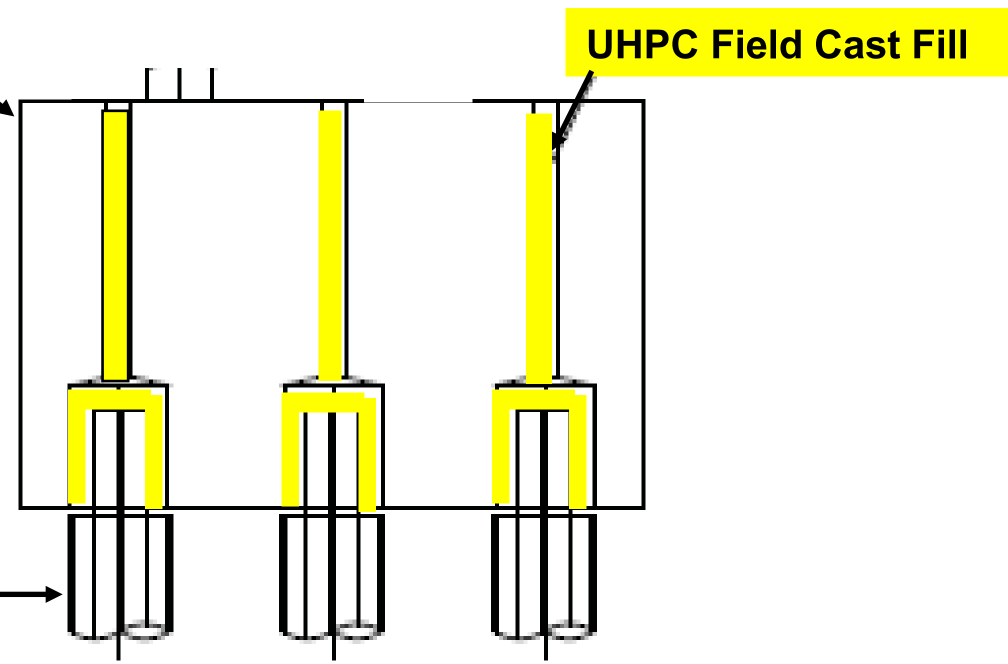
* Courtesy of Ministry of Transportation of Ontario

Abutment to Pile Connections for ABC

Precast Abutment



Plan View



Precast Piles

* Courtesy of Delcan & Ministry of Transportation Ontario

Section

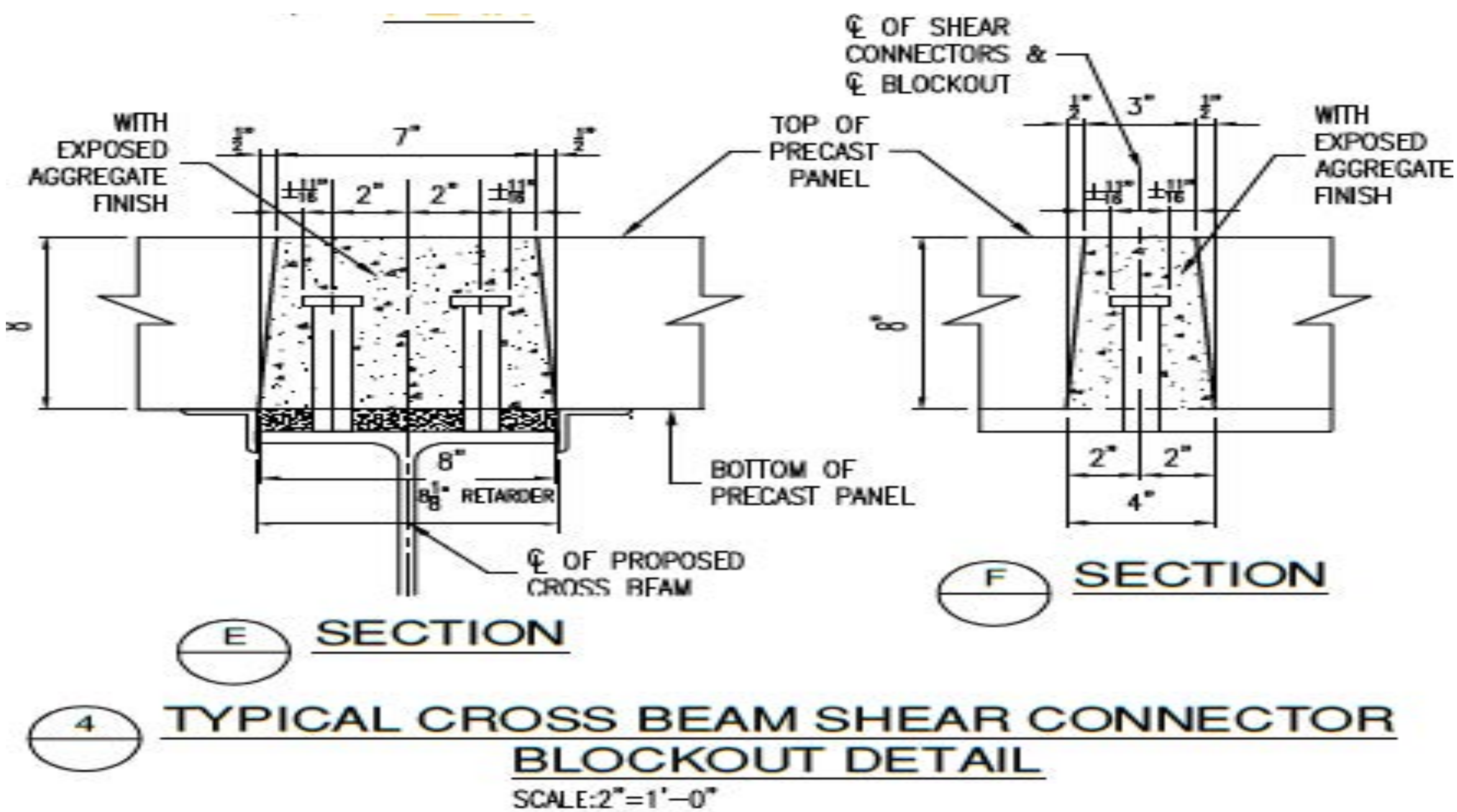
Pulaski Skyway, New Jersey/New York

Pulaski Skyway, New Jersey/New York

Pulaski Skyway, New Jersey/New York

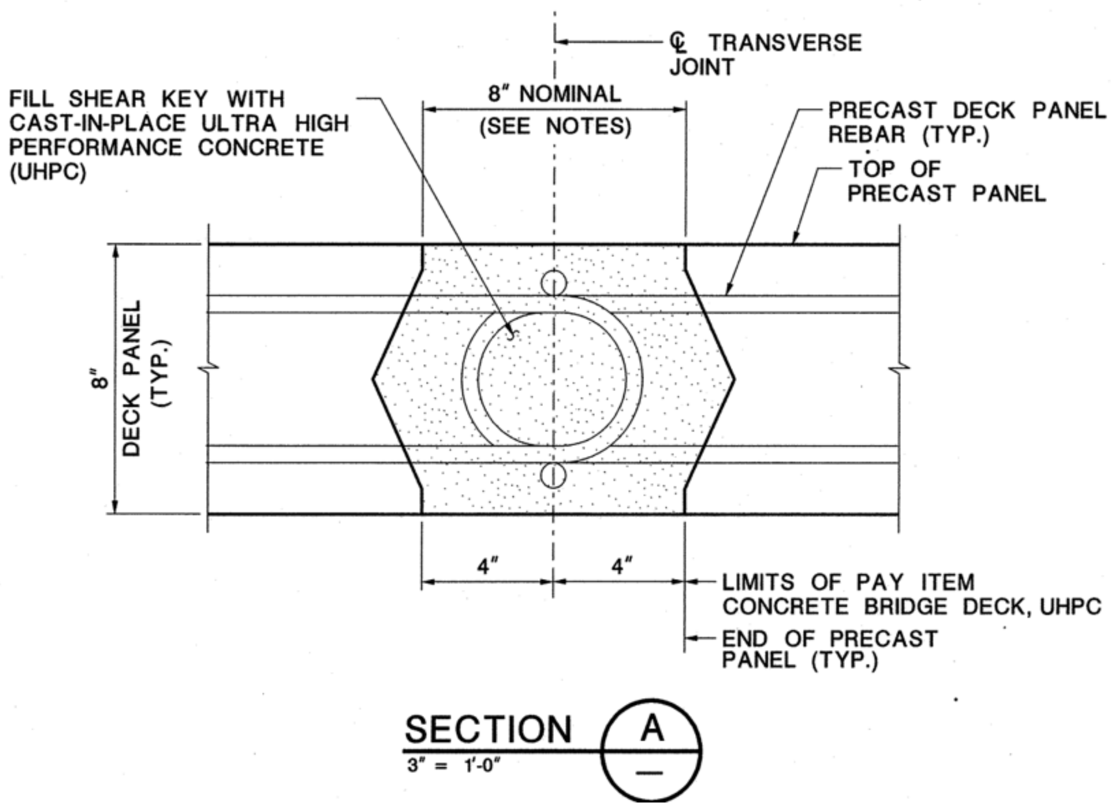
Pulaski Bridge UHPC Details

Typical Shear Connector Details

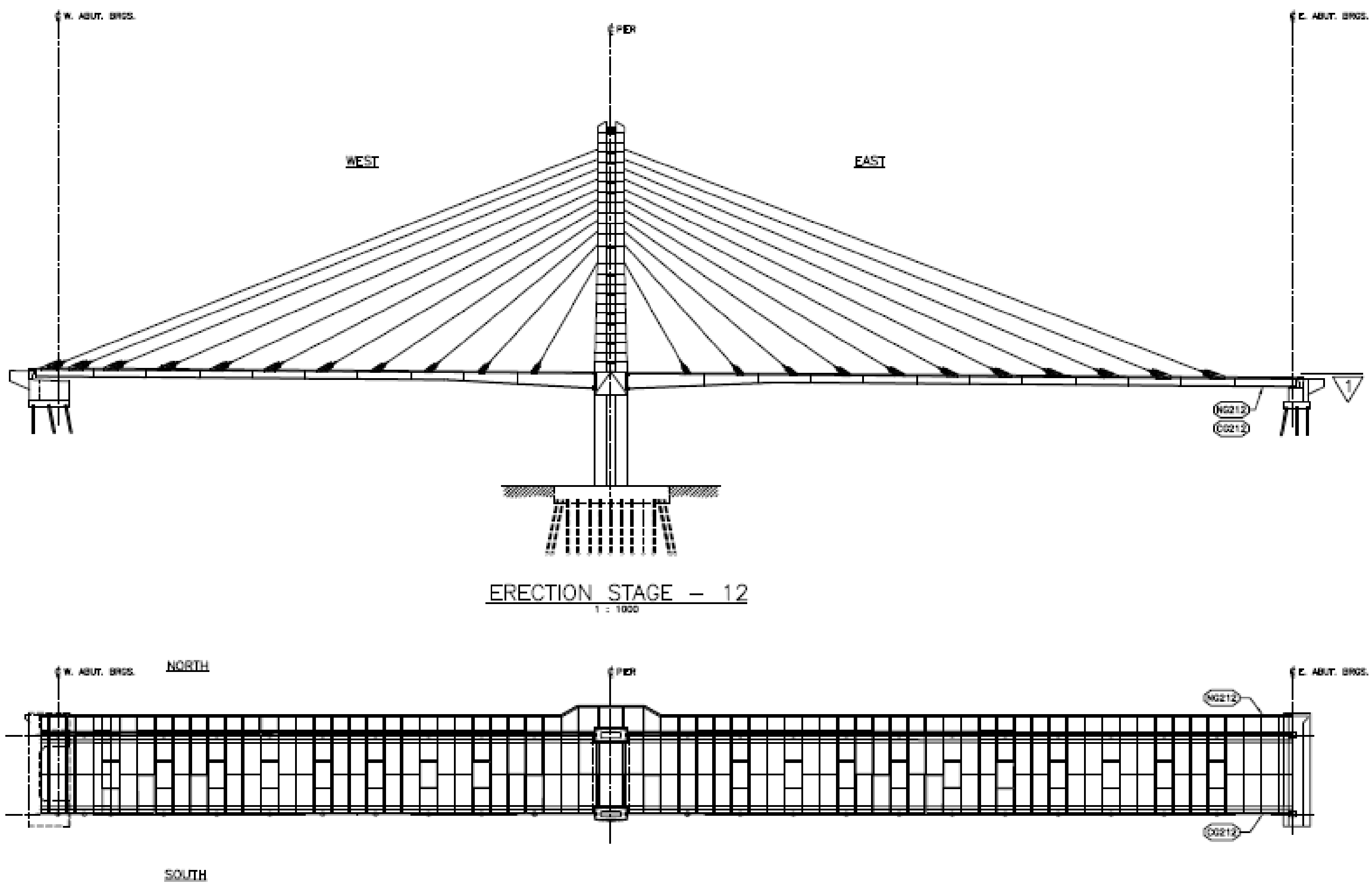


Pulaski Bridge UHPC Details

Typical Transverse Joint Details



Nipigon Bridge UHPC Details



Nipigon Bridge UHPC Details

Phase 1 Construction - Westbound

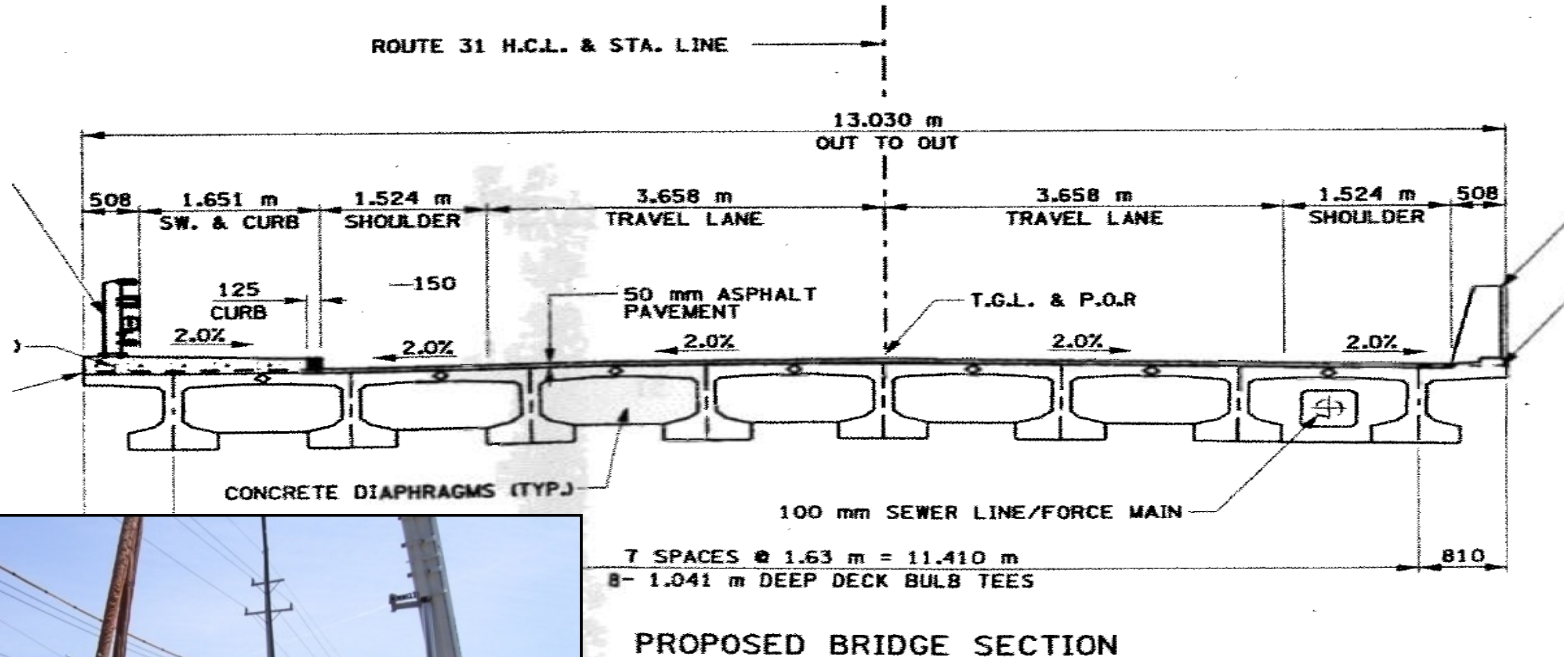
Nipigon Bridge UHPC Details

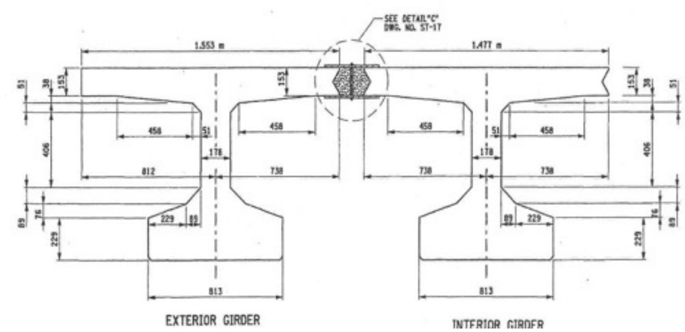
Typical Joint Details

Nipigon Bridge UHPC Details

Typical PBES/UHPC Portion Completed

Deck Bulb-Tee UHPC Field Connections

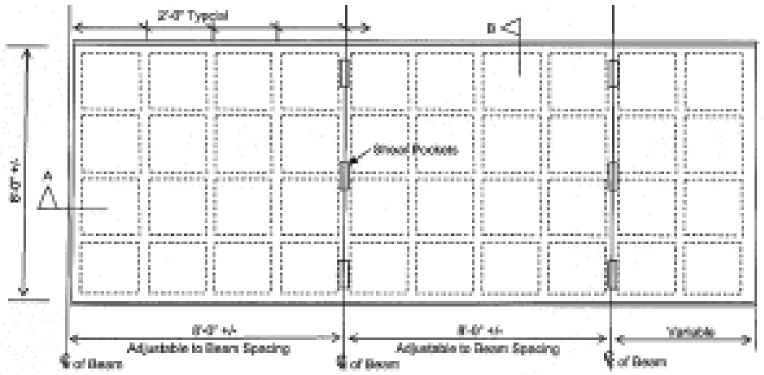




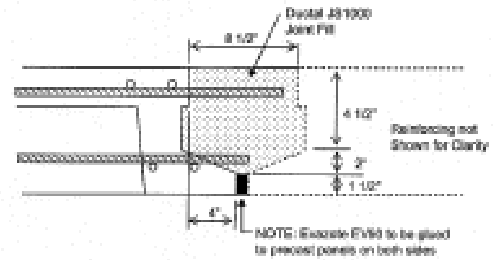
* Courtesy of NY State Department of Transportation

Deck Bulb-Tee UHPC Field Connections

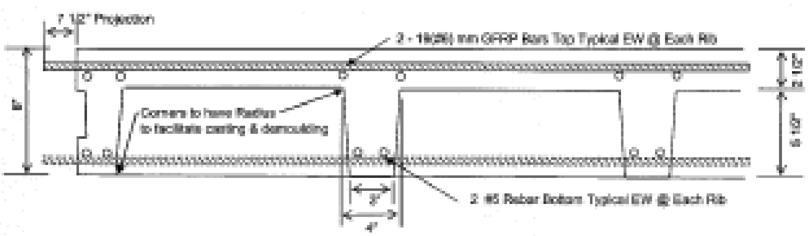
UHPC Field Connections
For UHPC Waffle Deck Bridge Panels



PLAN(Typical Panel)



SECTION B (Typical Transverse Joint)



SECTION A

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

Q & A