ABCD Susquehanna Chapter

2016 Technical Conference

September 14, 2016

Ductal

LAFARGE

Building better cities™

Ultra-High Performance Concrete (UHPC) & Bridge Applications in Pennsylvania

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Definition

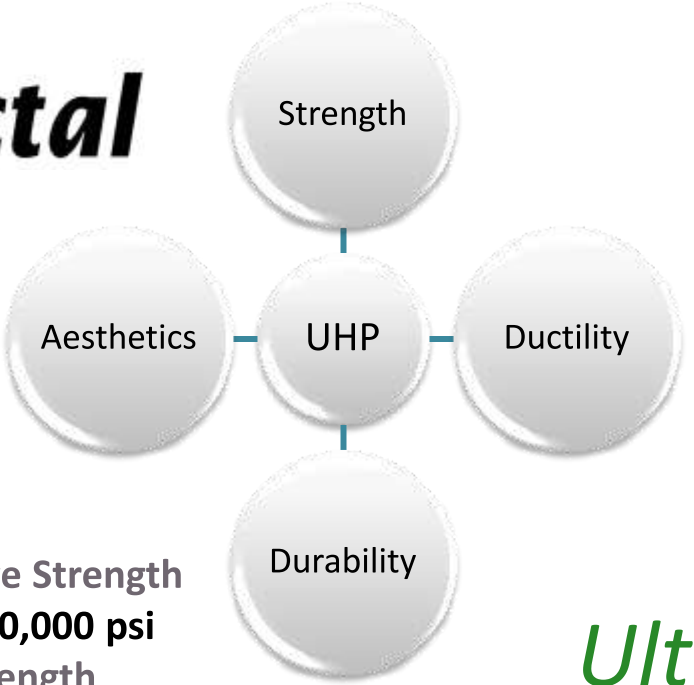
- Ultra-High Performance Concrete (UHPFRC)
  - UHPC is a cementitious composite material composed of an optimized gradation of granular constituents, a water-to-cementitious materials ratio less than 0.25, and a high percentage of discontinuous internal fiber reinforcement. The mechanical properties 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. –FHWA

  - Concrete that has a minimum specified compressive strength of 150 Mpa (22,000 psi) with specified durability, tensile ductility and toughness requirements; fibers are generally included to achieve specified requirements. –ACI 239

- Reactive Powder Concrete (RPC)
- Engineered Cementitious Composite (ECC)

Ultra-High Performance

Ductal



UHP

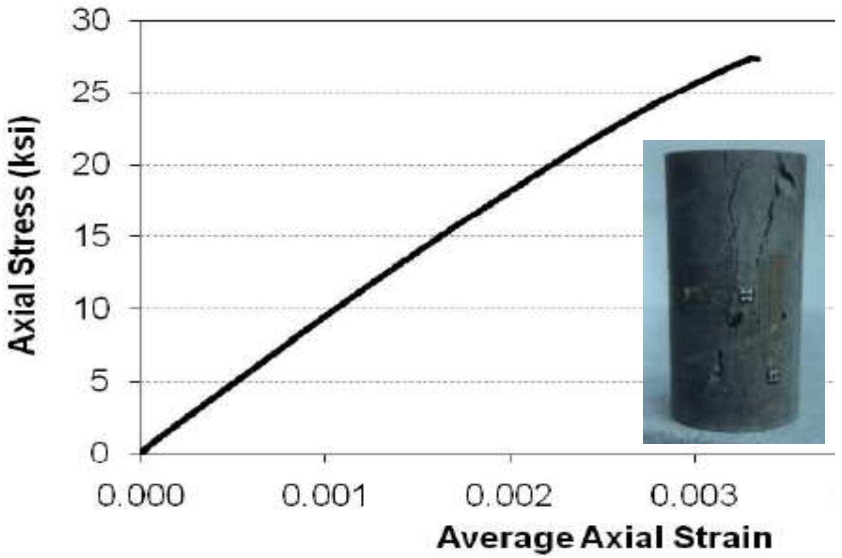
Strength

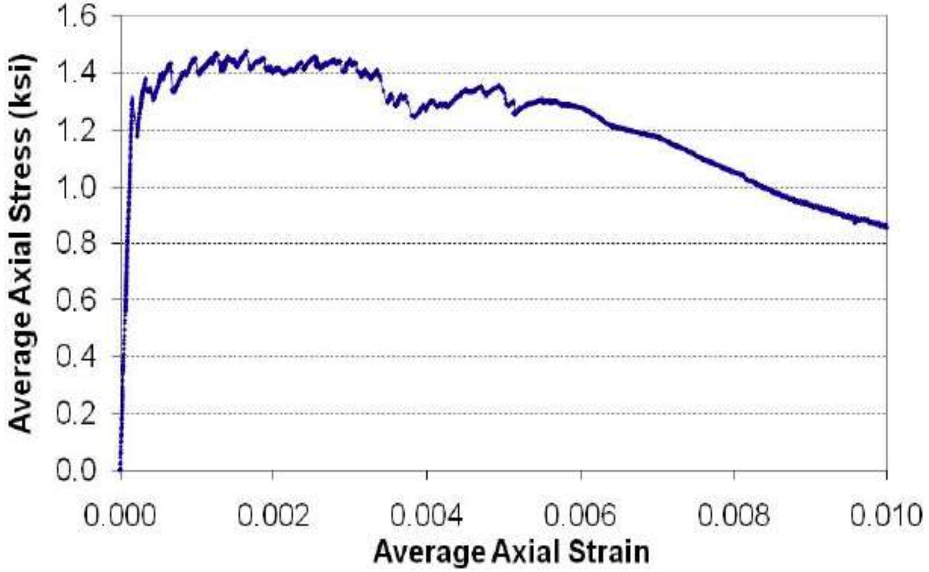
Aesthetics

Ductility

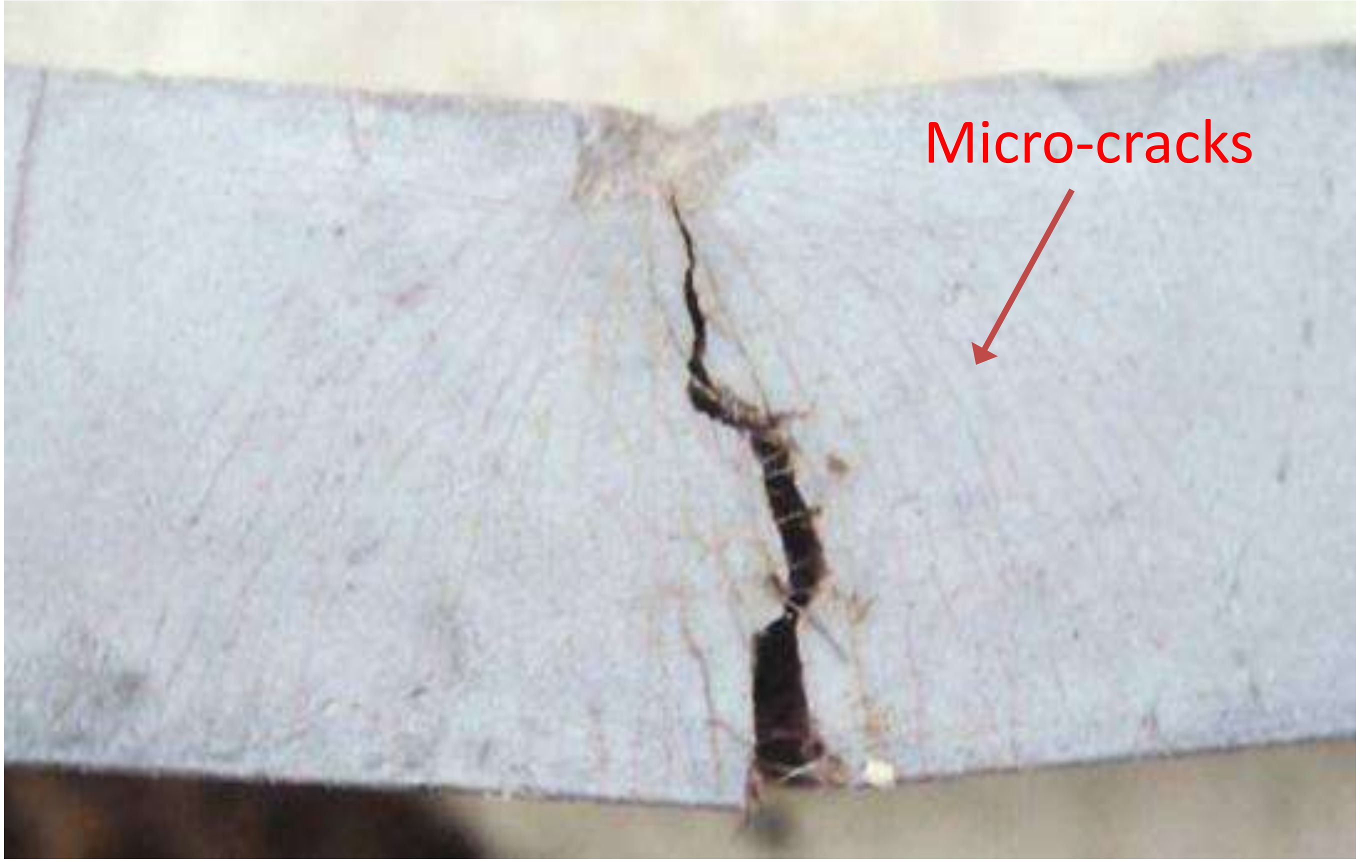
Durability

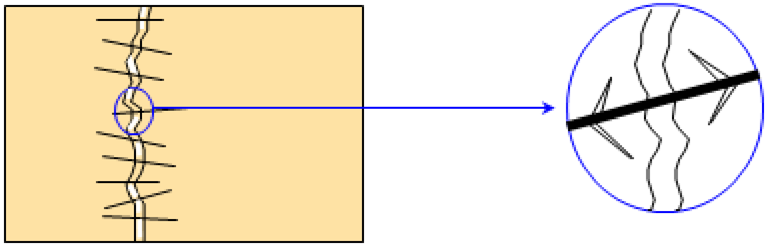
- **Compressive Strength**
  up to 30,000 psi
- **Flexural Strength**
  up to 6,000 psi
- **Direct Tension**
  up to 1,450 psi
- **Ductility**
  Greater capacity to deform and support flexural and tensile loads, even after initial cracking.
- **Abrasion Resistance**
  Similar to natural rock
- **Impermeability**
  Almost no carbonation or penetration of chlorides.



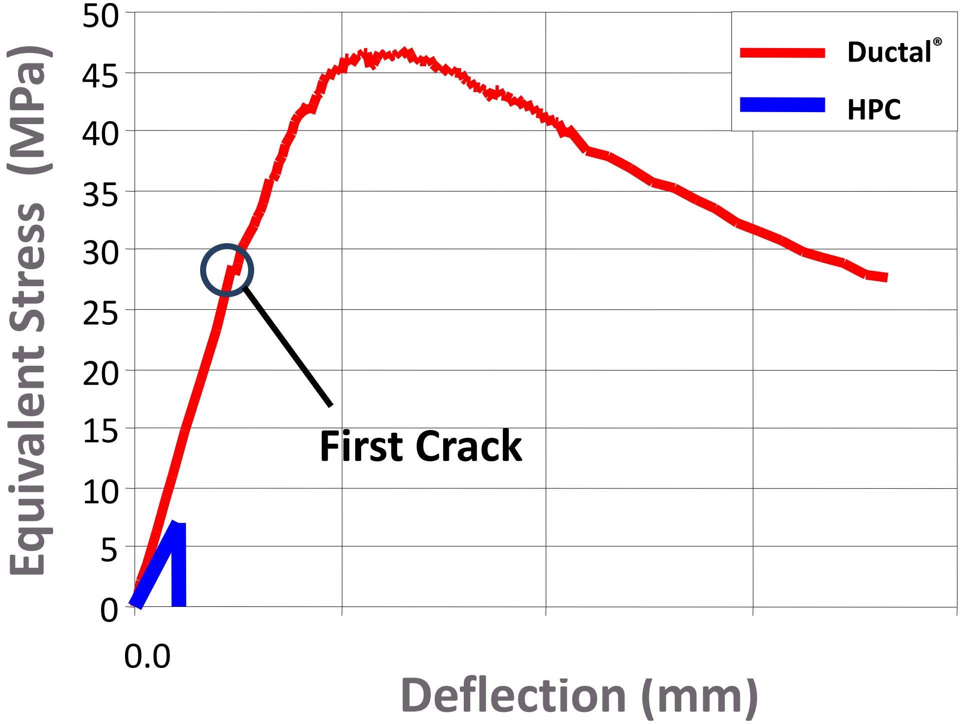


Crack-Bridging Fibers

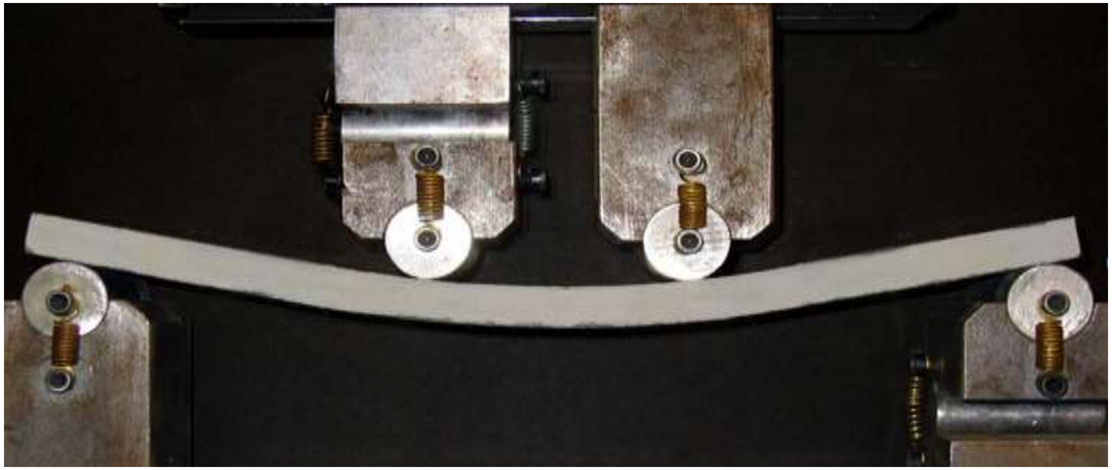




Ductility



2,000 lb car on a
1 ¼ -inch sheet of Ductal®



University of Michigan,
Engineered Cementitious
Composite (ECC)

Exceptional Durability

Treat Island, Maine, USA

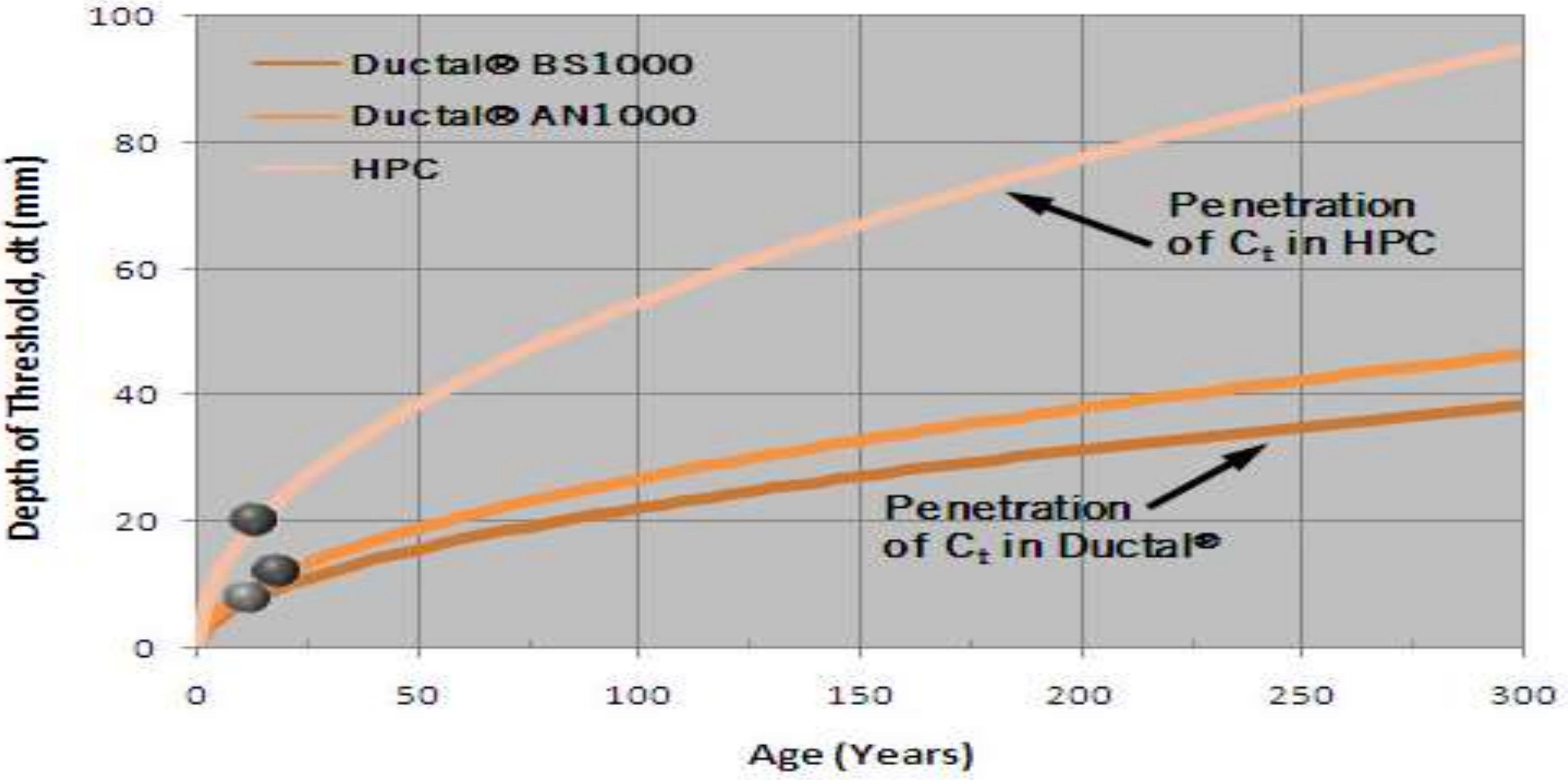
U.S Army Corp. of Engineers
Long-term Exposure Site

Three samples of Ductal® installed in 1996

EXPOSURE [2010]

- **1400 freeze/thaw cycles,**
- **10500 wet/dry cycles in saturated sea water**
- **High abrasion from waves and ice**
- **No sign of corrosion on rebar with only 10mm (3/8”) cover**

Impermeability & Longevity



Exposure Test at Oyashirazu Seashore

P10-P11 Installed in June 2002

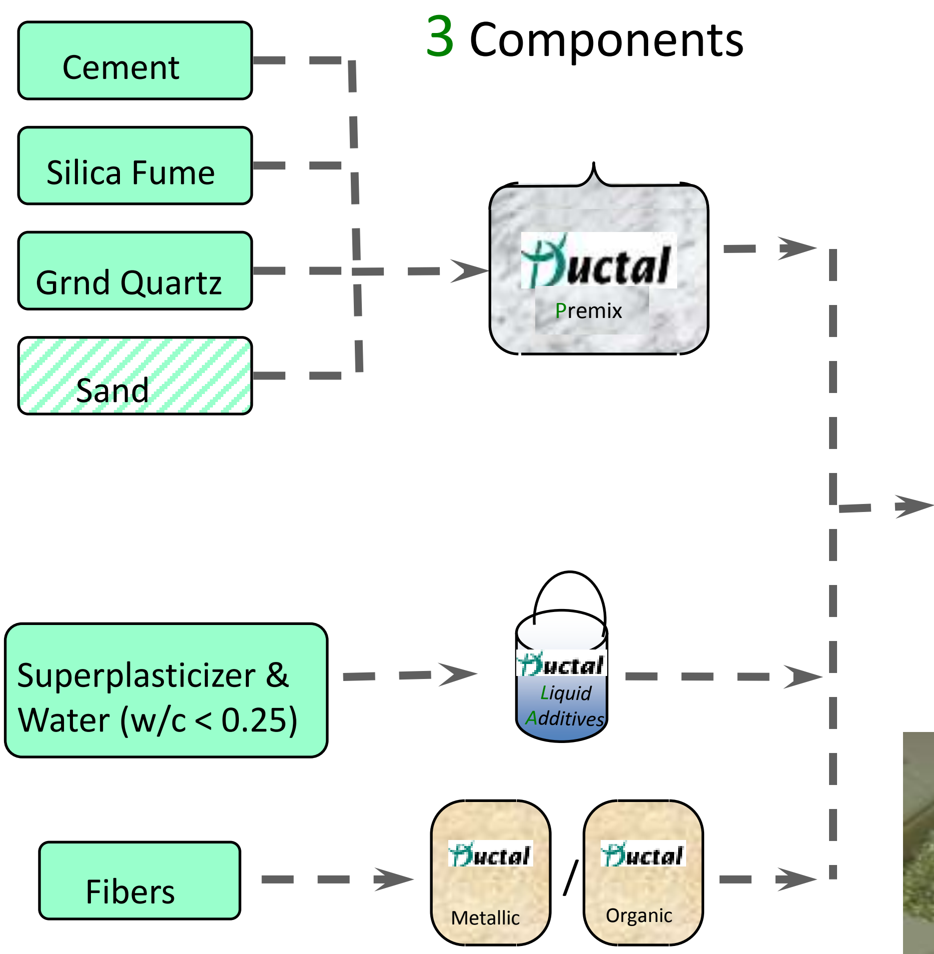
Close-up View of Specimen after 10 Months Exposure

Ductal-FM

Ordinary Concrete

Exposure of aggregate about 40-50%

Ductal® - UHPC Components



3 Components

Cement

Silica Fume

Grnd Quartz

Sand

Ductal

Premix

Superplasticizer &
Water (w/c < 0.25)

Ductal

Liquid
Additives

Fibers

Ductal

Metallic

/

Ductal

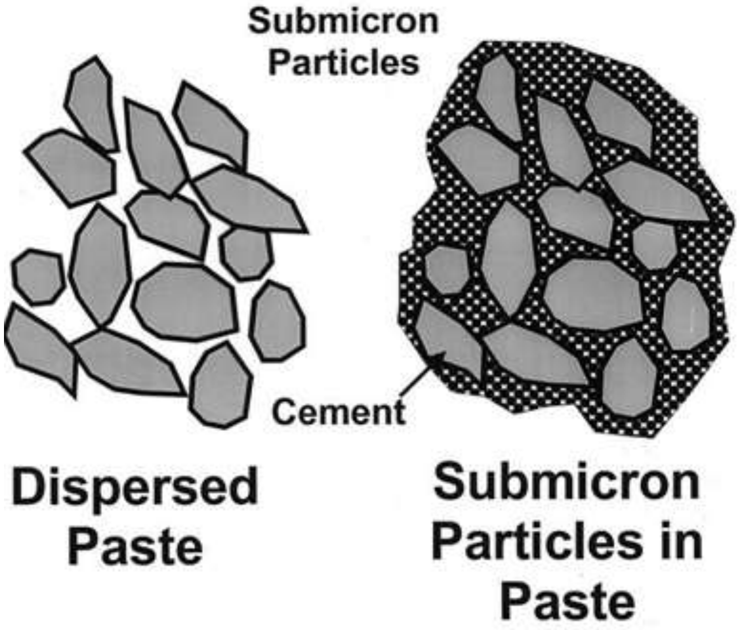
Organic

Self-leveling

12mm long
0.2mm diameter

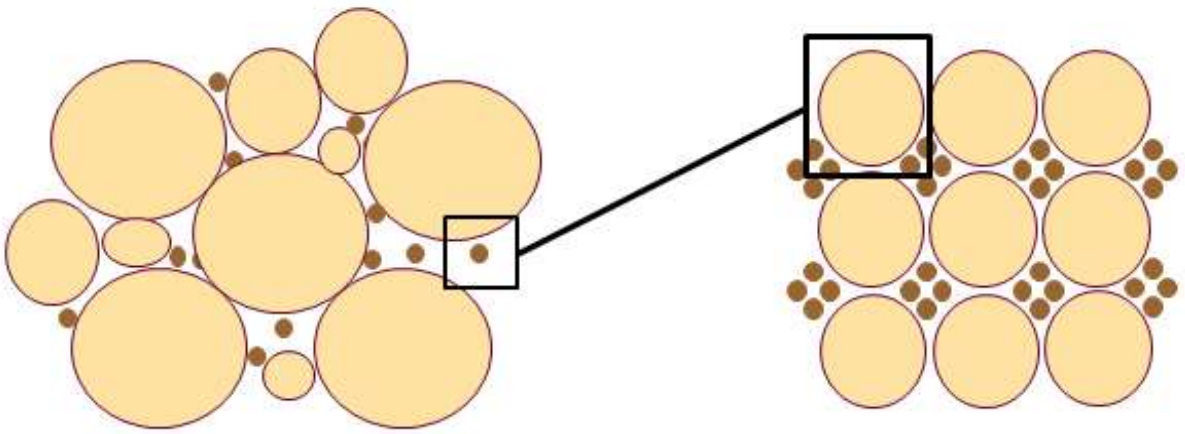
UHPC Mixing

Optimum Particle-Packing Matrix



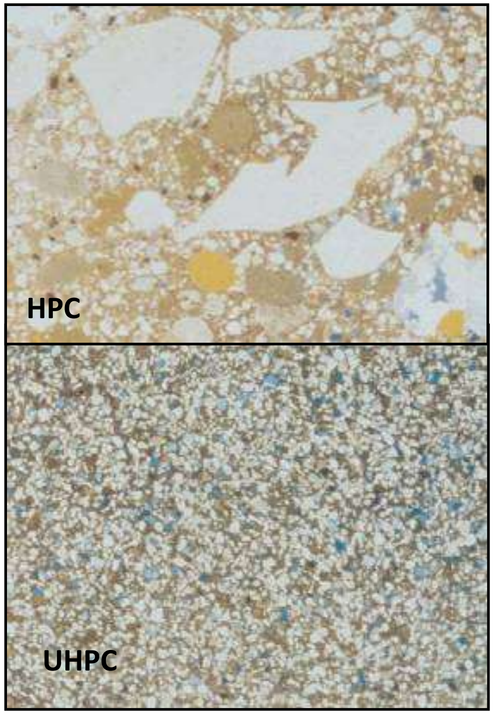
Concrete

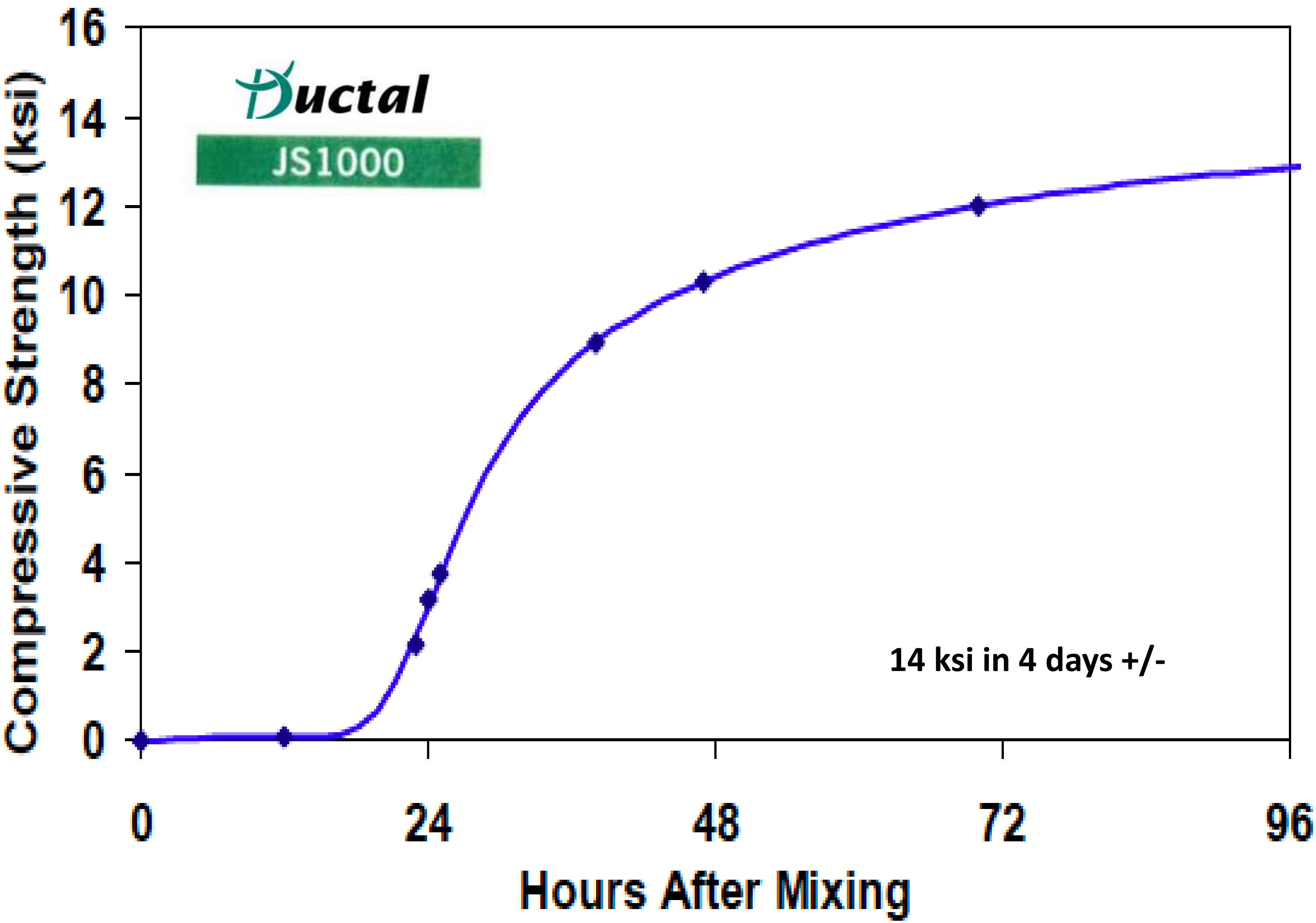
Ductal



Aggregate ¼ to ¾ inch
Sand
Cement

Sand 500 microns
Cement
Quartz
Silica Fume 1 micron

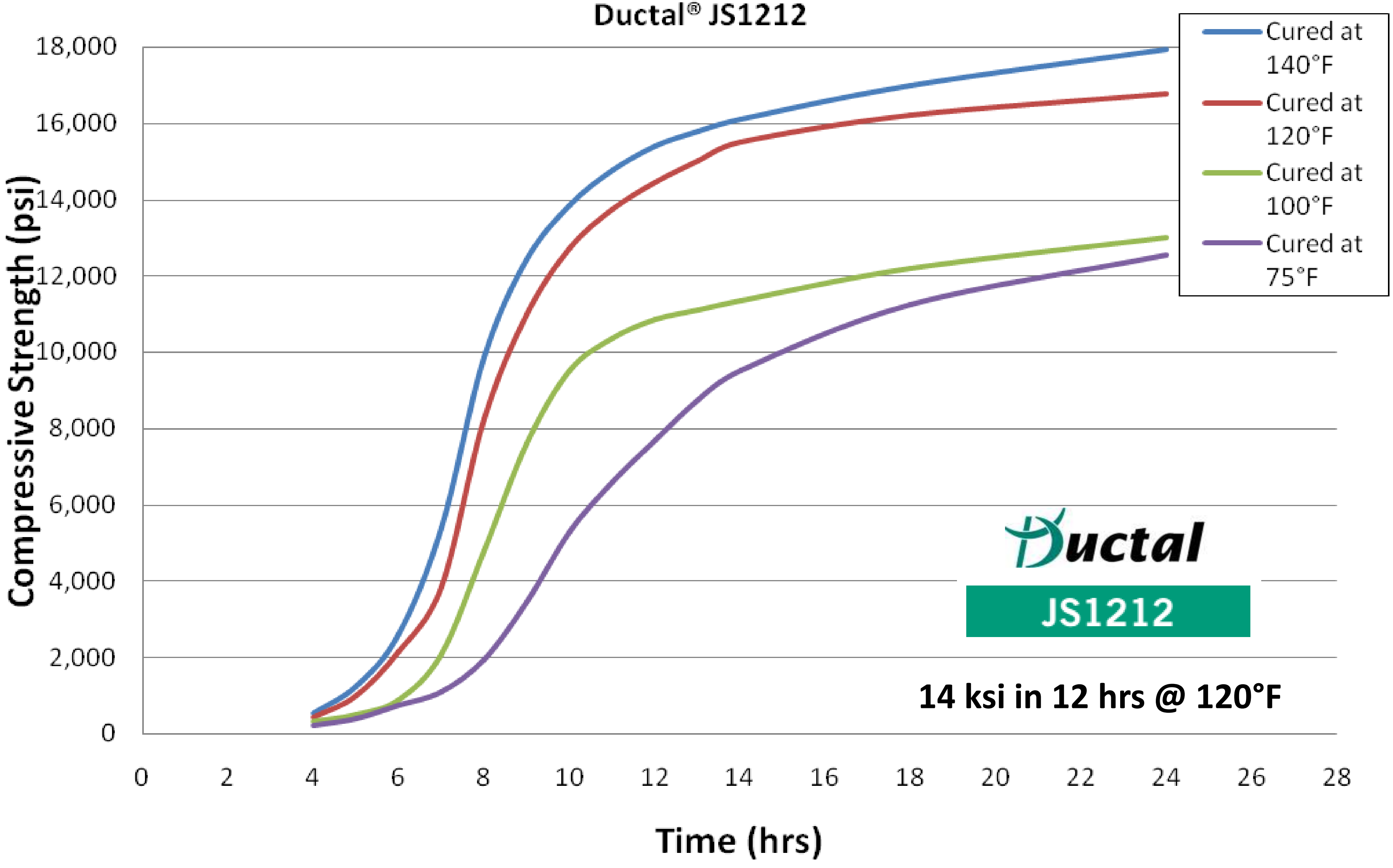




14 ksi in 4 days +/-

Temperature VS Strength Gain Curve

Ductal® JS1212



U.S. Department of Transportation
Federal Highway Administration

Accelerating Innovation | Every Day Counts | STIC Network | AID Demonstration | Resources

Every Day Counts

Better, Faster, Smarter

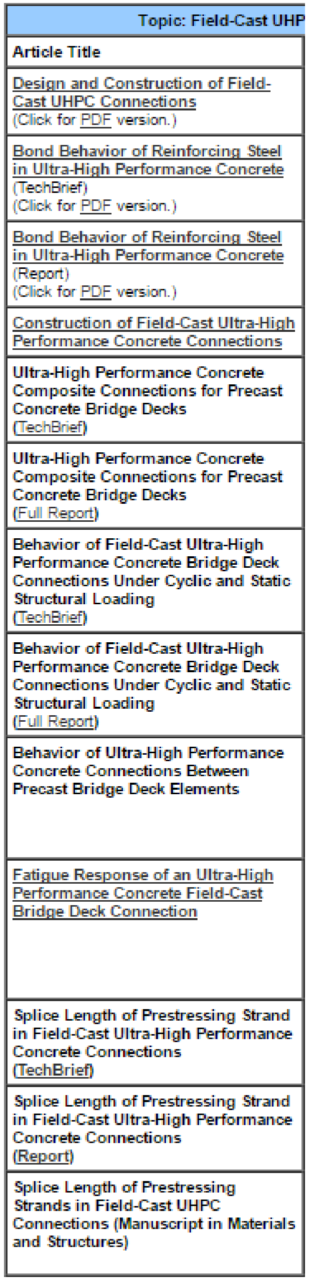
EDC Rounds

EDC-4 *(2017 - 2018)*
EDC-3 *(2015 - 2016)*
EDC-2 *(2013 - 2014)*
EDC-1 *(2011 - 2012)*

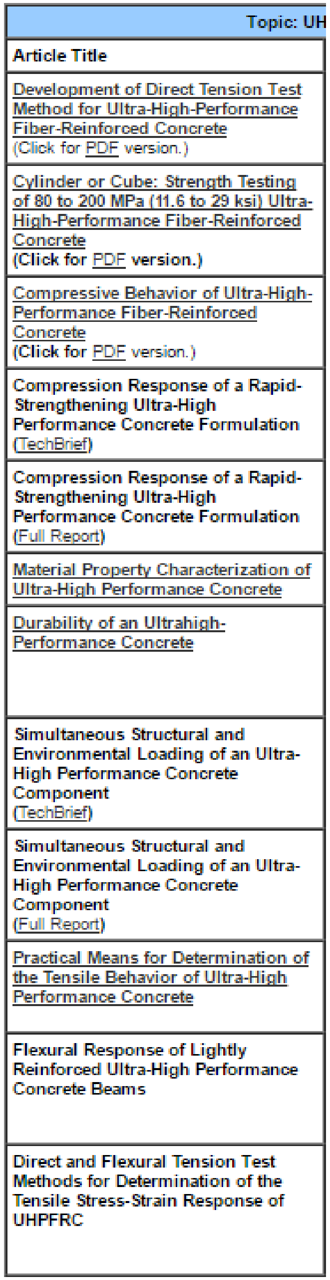
Learn more about Every Day Counts >>

Benefits

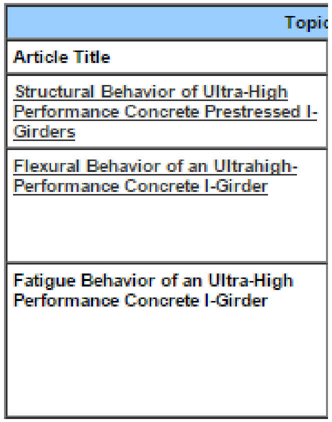
- **Accelerated Construction.** UHPC offers durable and simplified details that facilitate the fabrication and construction efforts needed to connect prefabricated bridge elements.
- **Simplified Connection Details.** UHPC allows for significant simplification to the design of the component connections. Its properties allow for the redesign of common connection details in ways that promote both ease and speed of construction.
- **Improved Long-Term Performance.** Field casting of UHPC connections between prefabricated components results in a strong connection that provides better long-term performance.



Topic: Field-Cast UHP
Article Title
Design and Construction of Field-Cast UHPC Connections (Click for PDF version.)
Bond Behavior of Reinforcing Steel in Ultra-High Performance Concrete (TechBrief) (Click for PDF version.)
Bond Behavior of Reinforcing Steel in Ultra-High Performance Concrete (Report) (Click for PDF version.)
Construction of Field-Cast Ultra-High Performance Concrete Connections
Ultra-High Performance Concrete Composite Connections for Precast Concrete Bridge Decks (TechBrief)
Ultra-High Performance Concrete Composite Connections for Precast Concrete Bridge Decks (Full Report)
Behavior of Field-Cast Ultra-High Performance Concrete Bridge Deck Connections Under Cyclic and Static Structural Loading (TechBrief)
Behavior of Field-Cast Ultra-High Performance Concrete Bridge Deck Connections Under Cyclic and Static Structural Loading (Full Report)
Behavior of Ultra-High Performance Concrete Connections Between Precast Bridge Deck Elements
Fatigue Response of an Ultra-High Performance Concrete Field-Cast Bridge Deck Connection
Splice Length of Prestressing Strand in Field-Cast Ultra-High Performance Concrete Connections (TechBrief)
Splice Length of Prestressing Strand in Field-Cast Ultra-High Performance Concrete Connections (Report)
Splice Length of Prestressing Strands in Field-Cast UHPC Connections (Manuscript in Materials and Structures)



Topic: UH
Article Title
Development of Direct Tension Test Method for Ultra-High-Performance Fiber-Reinforced Concrete (Click for PDF version.)
Cylinder or Cube: Strength Testing of 80 to 200 MPa (11.6 to 29 ksi) Ultra-High-Performance Fiber-Reinforced Concrete (Click for PDF version.)
Compressive Behavior of Ultra-High-Performance Fiber-Reinforced Concrete (Click for PDF version.)
Compression Response of a Rapid-Strengthening Ultra-High Performance Concrete Formulation (TechBrief)
Compression Response of a Rapid-Strengthening Ultra-High Performance Concrete Formulation (Full Report)
Material Property Characterization of Ultra-High Performance Concrete
Durability of an Ultrahigh-Performance Concrete
Simultaneous Structural and Environmental Loading of an Ultra-High Performance Concrete Component (TechBrief)
Simultaneous Structural and Environmental Loading of an Ultra-High Performance Concrete Component (Full Report)
Practical Means for Determination of the Tensile Behavior of Ultra-High Performance Concrete
Flexural Response of Lightly Reinforced Ultra-High Performance Concrete Beams
Direct and Flexural Tension Test Methods for Determination of the Tensile Stress-Strain Response of UHPFRC



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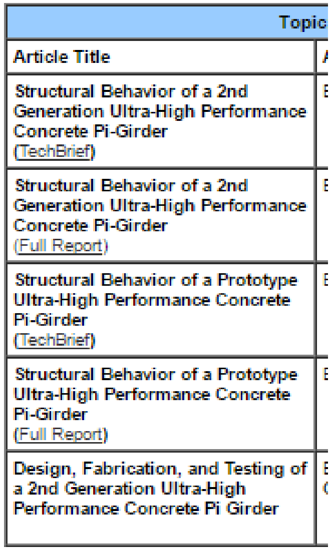
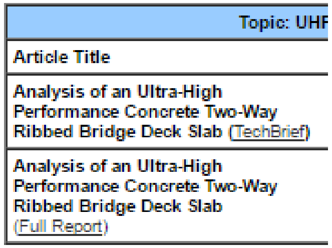
Article Title
Structural Behavior of Ultra-High Performance Concrete Prestressed I-Girders
Flexural Behavior of an Ultrahigh-Performance Concrete I-Girder
Fatigue Behavior of an Ultra-High Performance Concrete I-Girder



Topic	
Article Title	A
Structural Behavior of a 2nd Generation Ultra-High Performance Concrete Pi-Girder (TechBrief)	E
Structural Behavior of a 2nd Generation Ultra-High Performance Concrete Pi-Girder (Full Report)	E
Structural Behavior of a Prototype Ultra-High Performance Concrete Pi-Girder (TechBrief)	E
Structural Behavior of a Prototype Ultra-High Performance Concrete Pi-Girder (Full Report)	E
Design, Fabrication, and Testing of a 2nd Generation Ultra-High Performance Concrete Pi Girder	E (



Topic: UHF
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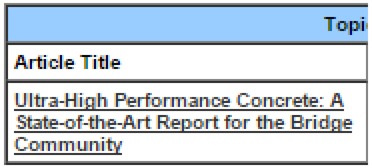
Analysis of an Ultra-High Performance Concrete Two-Way Ribbed Bridge Deck Slab (TechBrief)
Analysis of an Ultra-High Performance Concrete Two-Way Ribbed Bridge Deck Slab (Full Report)



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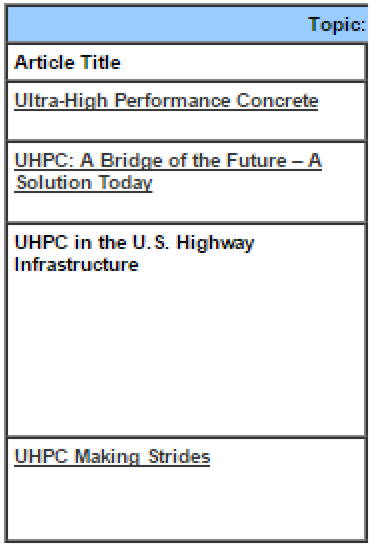
Article Title
Ultra-High Performance Concrete: A State-of-the-Art Report for the Bridge Community



Topic:
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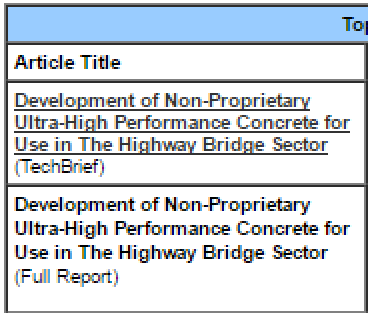
Ultra-High Performance Concrete
UHPC: A Bridge of the Future – A Solution Today
UHPC in the U.S. Highway Infrastructure
UHPC Making Strides



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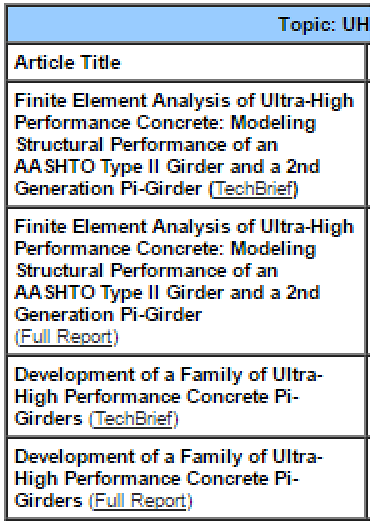
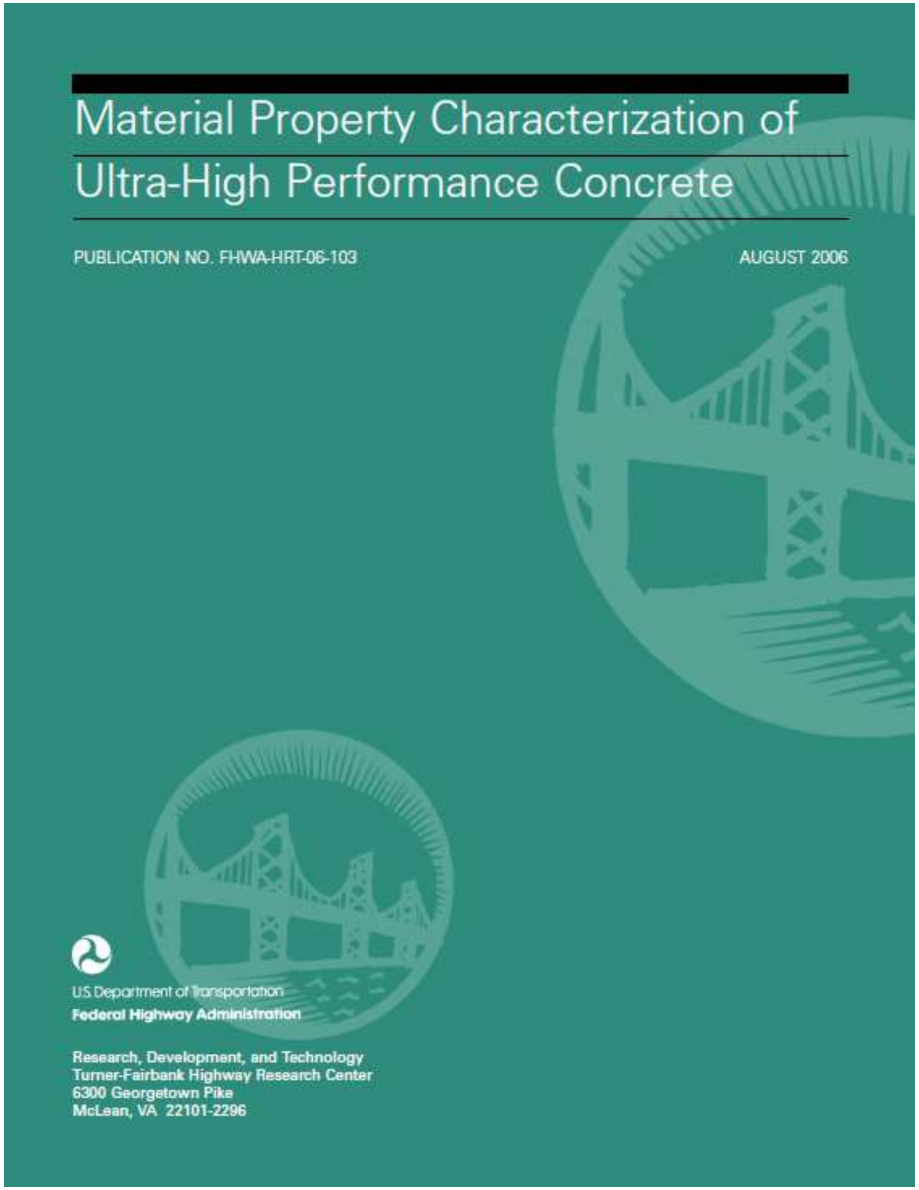
Article Title
Development of Non-Proprietary Ultra-High Performance Concrete for Use in The Highway Bridge Sector (TechBrief)
Development of Non-Proprietary Ultra-High Performance Concrete for Use in The Highway Bridge Sector (Full Report)



Topic: UH
Article Title
Finite Element Analysis of Ultra-High Performance Concrete: Modeling Structural Performance of an AASHTO Type II Girder and a 2nd Generation Pi-Girder (TechBrief)
Finite Element Analysis of Ultra-High Performance Concrete: Modeling Structural Performance of an AASHTO Type II Girder and a 2nd Generation Pi-Girder (Full Report)
Development of a Family of Ultra-High Performance Concrete Pi-Girders (TechBrief)
Development of a Family of Ultra-High Performance Concrete Pi-Girders (Full Report)

https://www.fhwa.dot.gov/research/resources/uhpc/publications.cfm



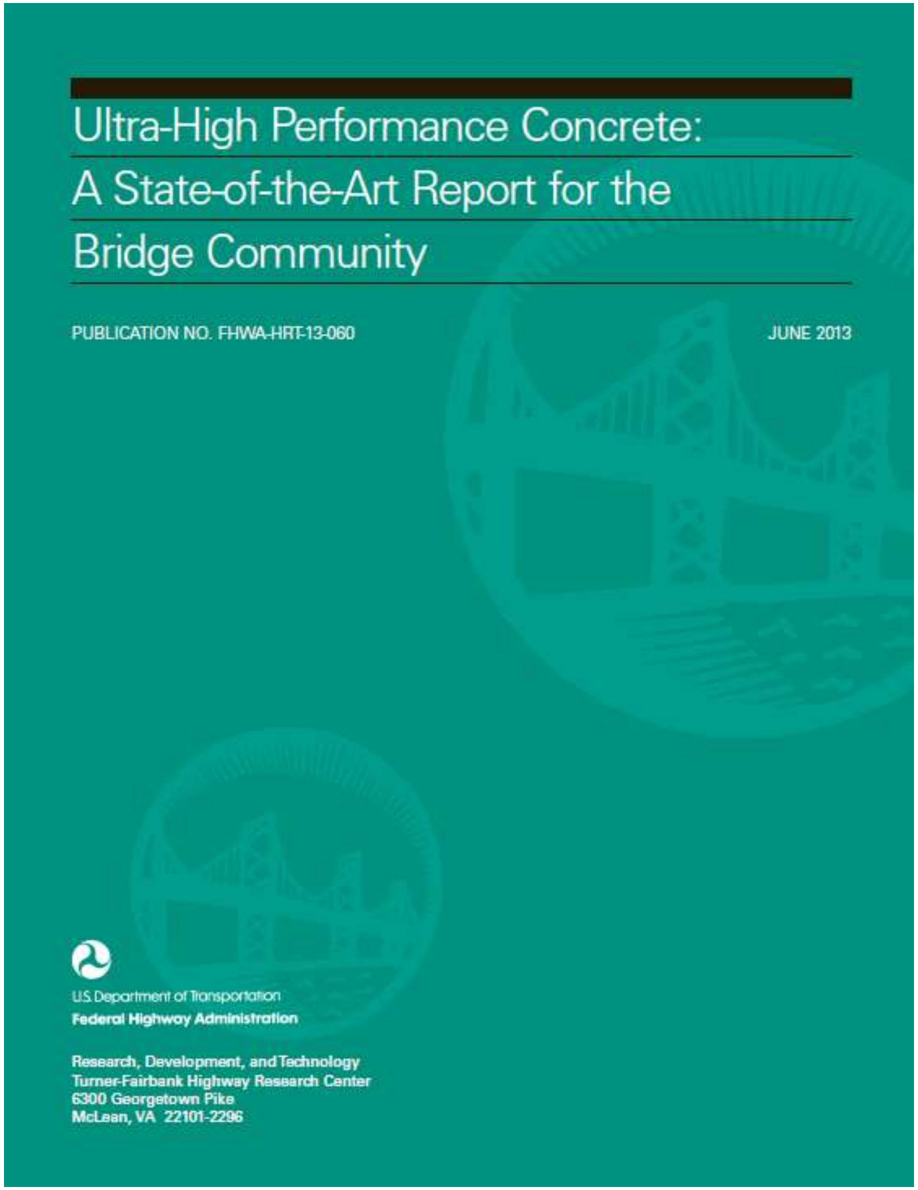
Material Property Characterization of Ultra-High Performance Concrete

PUBLICATION NO. FHWA-HRT-06-103

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

https://www.fhwa.dot.gov/research/resources/uhpc/publications.cfm

FHWA 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.(3)

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[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

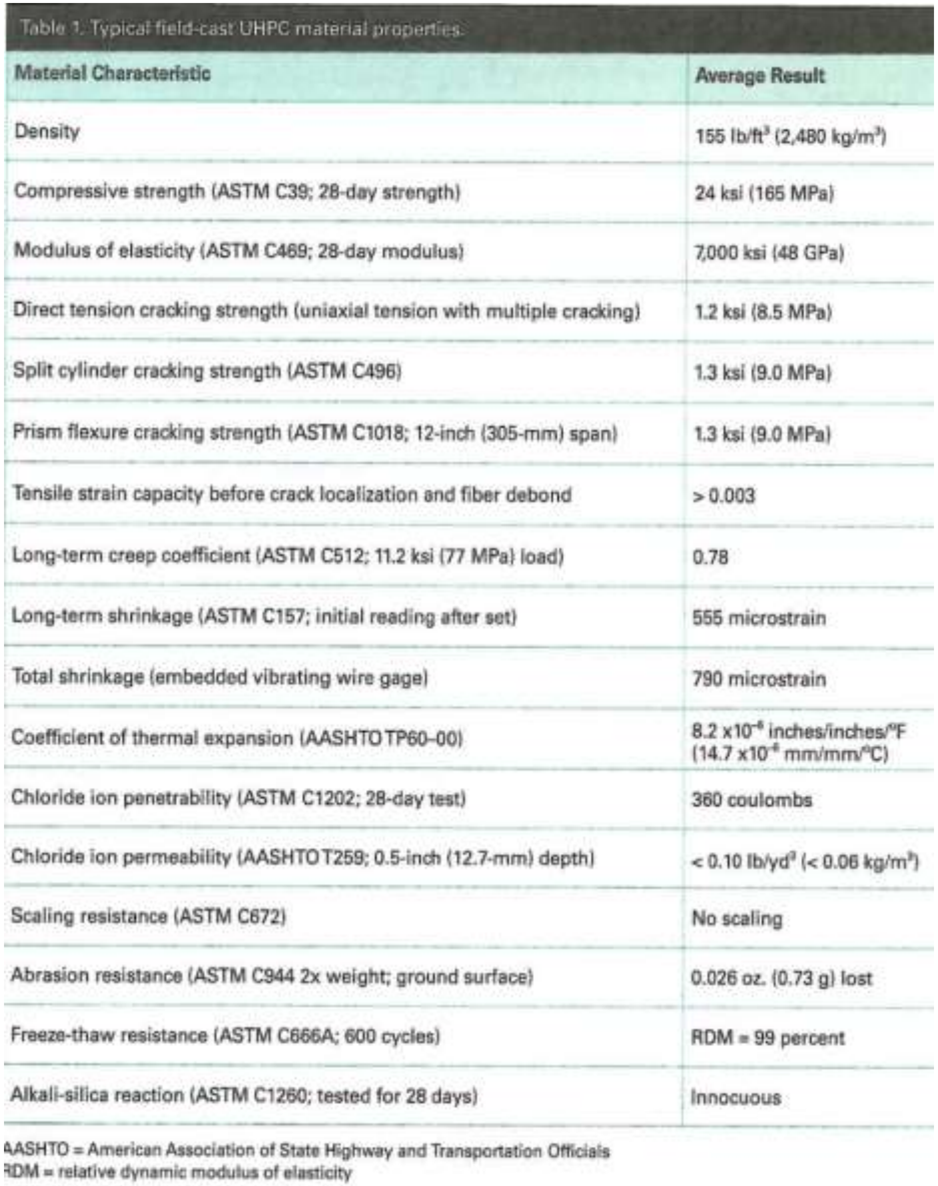


Table 1. Typical field-cast UHPC material properties.

Material Characteristic	Average Result
Density	155 lb/ft^3 (2,480 kg/m^3)
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/yd^3 (< 0.06 kg/m^3)
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

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

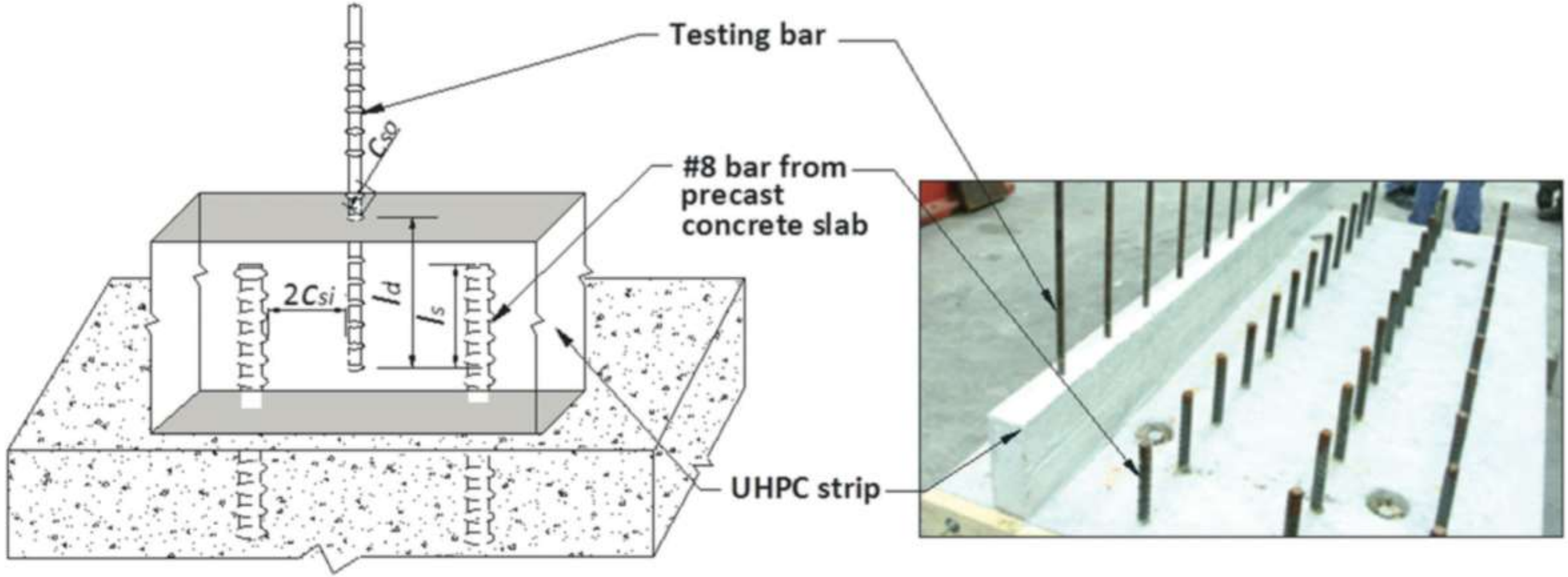
TECHBRIEF

Bond Behavior of Reinforcing Steel in Ultra-High Performance Concrete

FHWA Publication No.: FHWA-HRT-14-089

FHWA Contact: Ben Graybeal, HRDI-40, 202-493-3122,
benjamin.graybeal@dot.gov

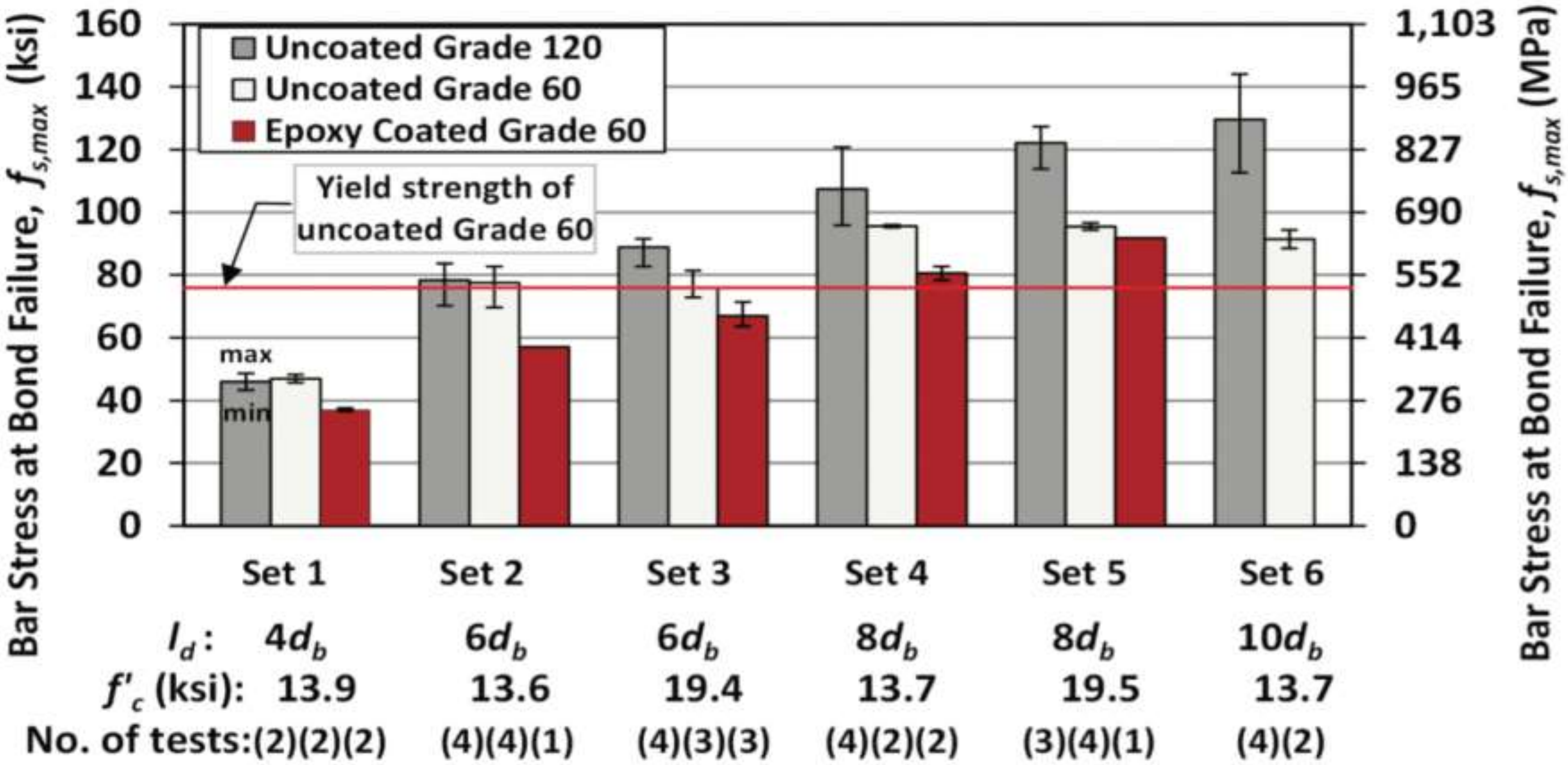
Figure 1. Overall configuration of test specimens.



Note: c_{so}, side cover; $2c_{si}$, bar clear spacing to the adjacent No.8 bar; l_d, embedment length; l_s, lap splice length

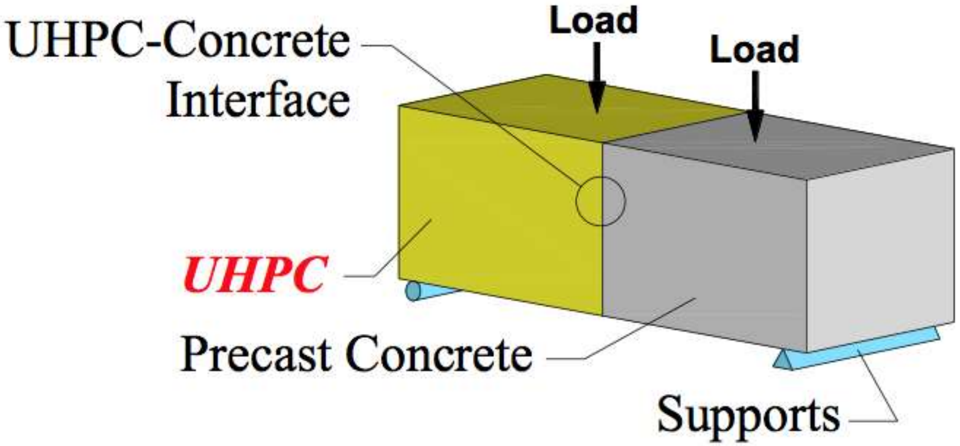
Rebar Bond Behavior

Figure 7. Average bar stress at bond failure for different types of reinforcing bar.



Note: specimens in each set had the same design except for reinforcing bar type

#5 Epoxy-Coated Gr. 60 Rebar Yields with only **5 inches** of Embedment!



(a) ASTM C78 (Modified) – Flexural Beam Test

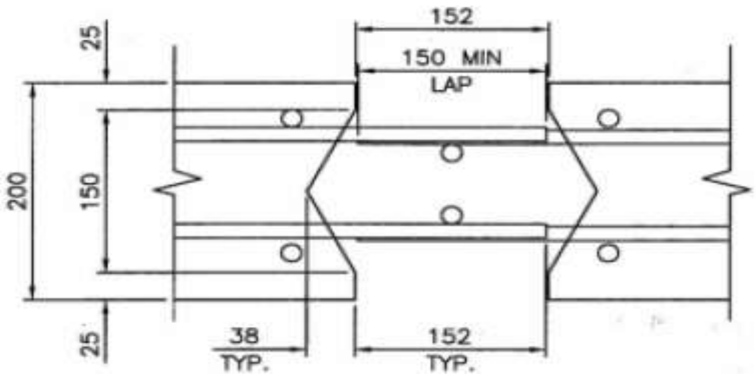
Surface Prep Requirements

- ➢ Saturated Surface Dry (SSD) Surface
- ➢ Exposed Aggregate Finish

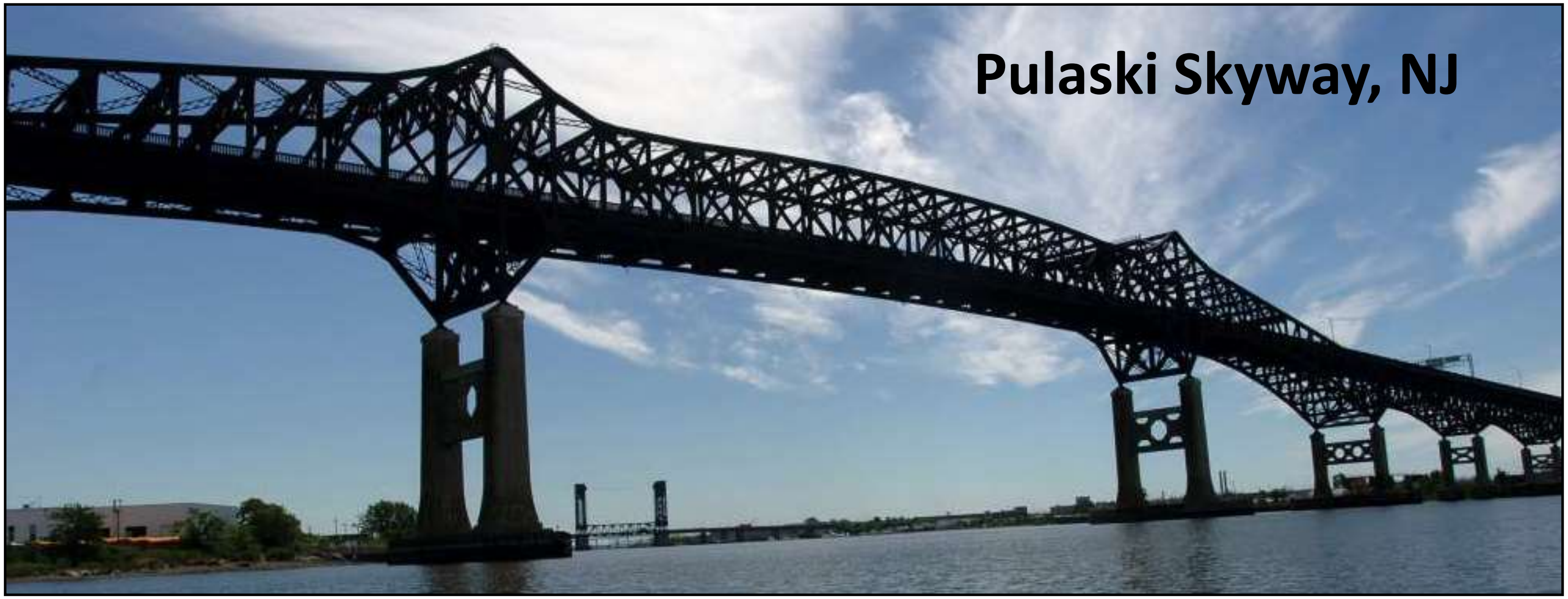
Fatigue Testing of UHPC for Joint Fill

"No Leakage through the Joint"

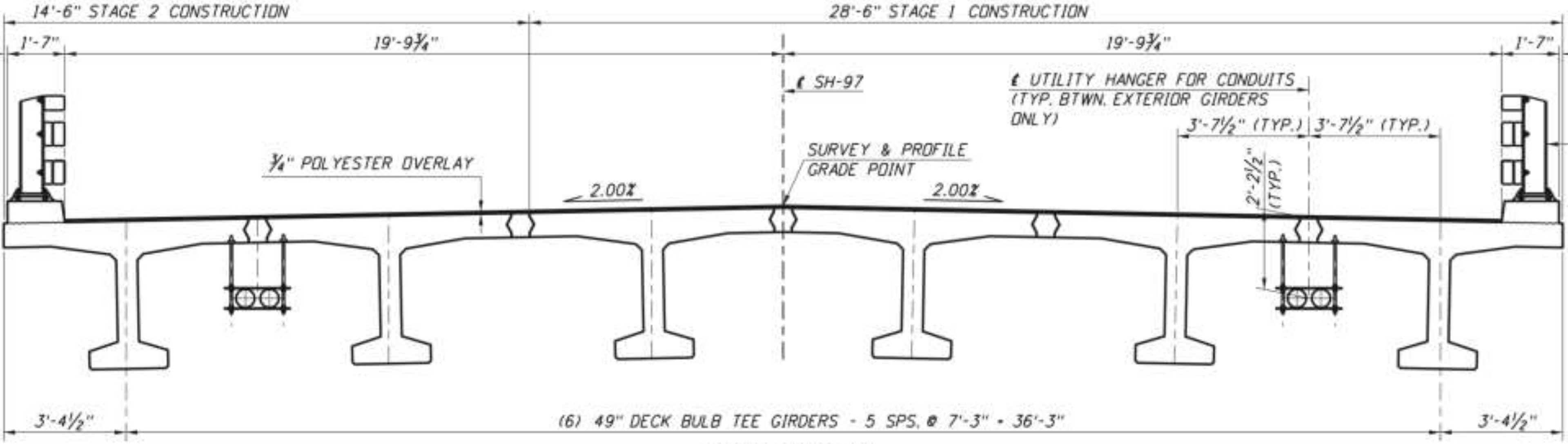
PBES Connections



Pulaski Skyway, NJ

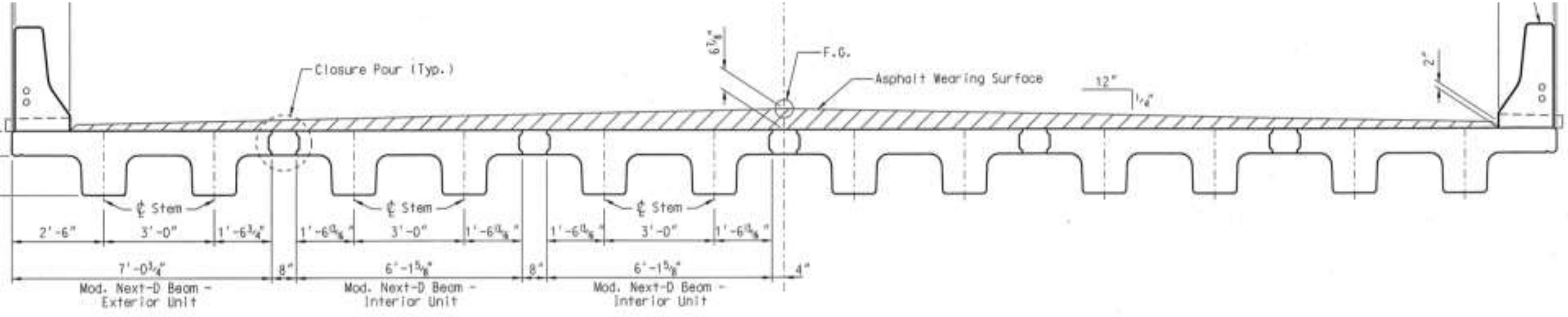


Deck Bulb Tees:



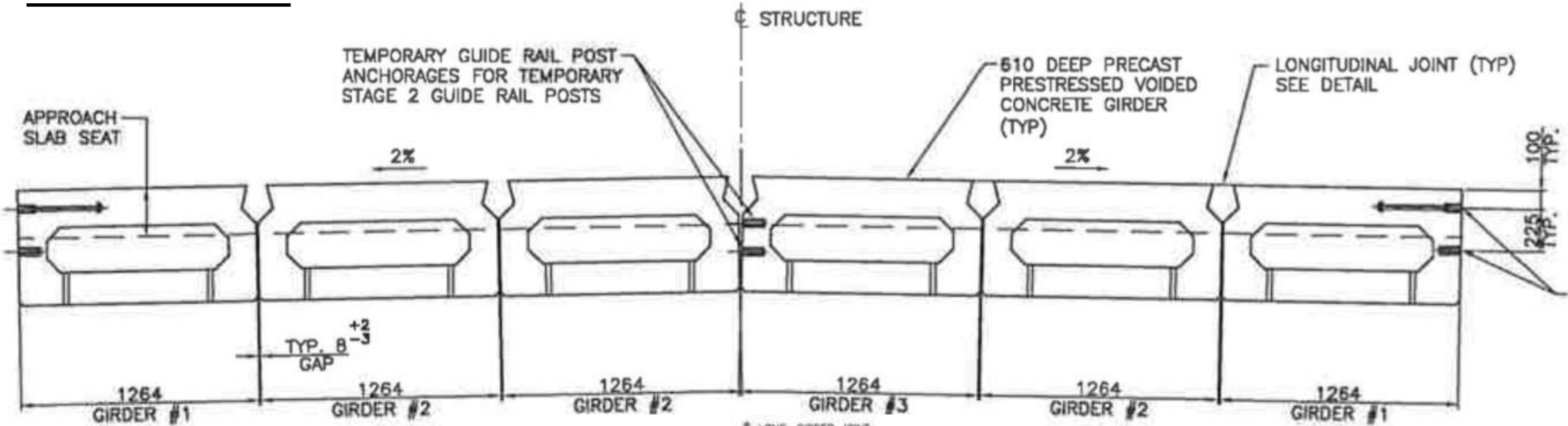
TYPICAL SECTION

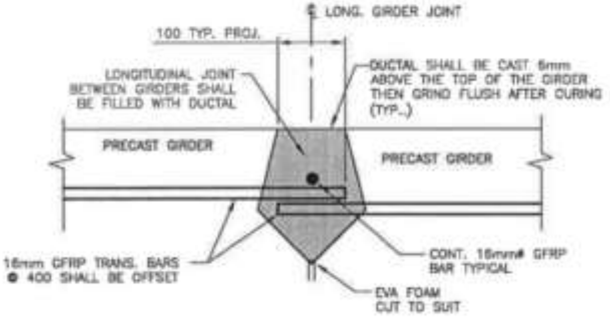
Next Beams:



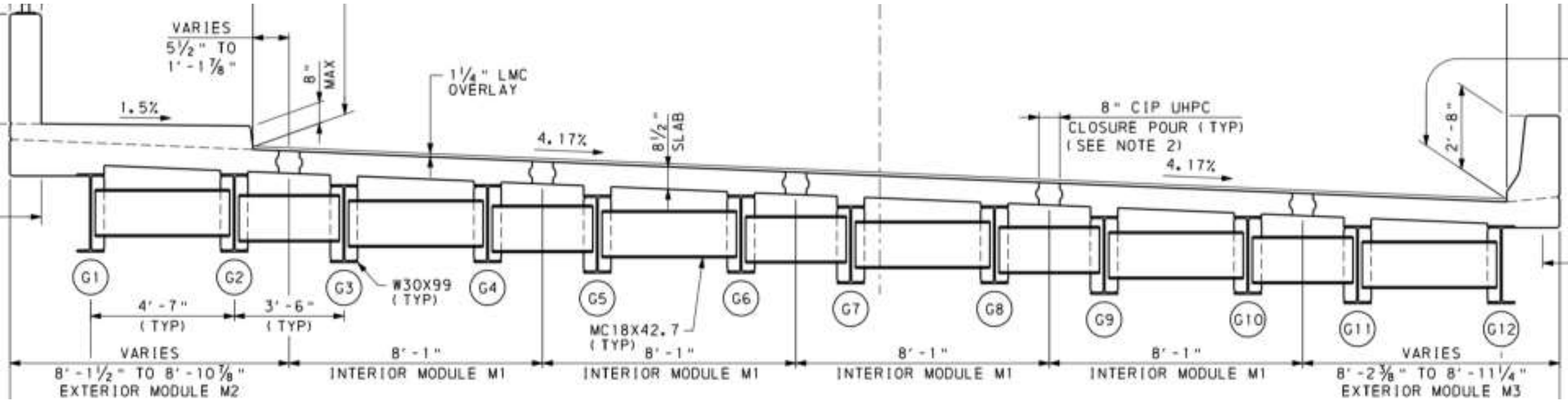
SECTION THRU SUPERSTRUCTURE

Box Girders:

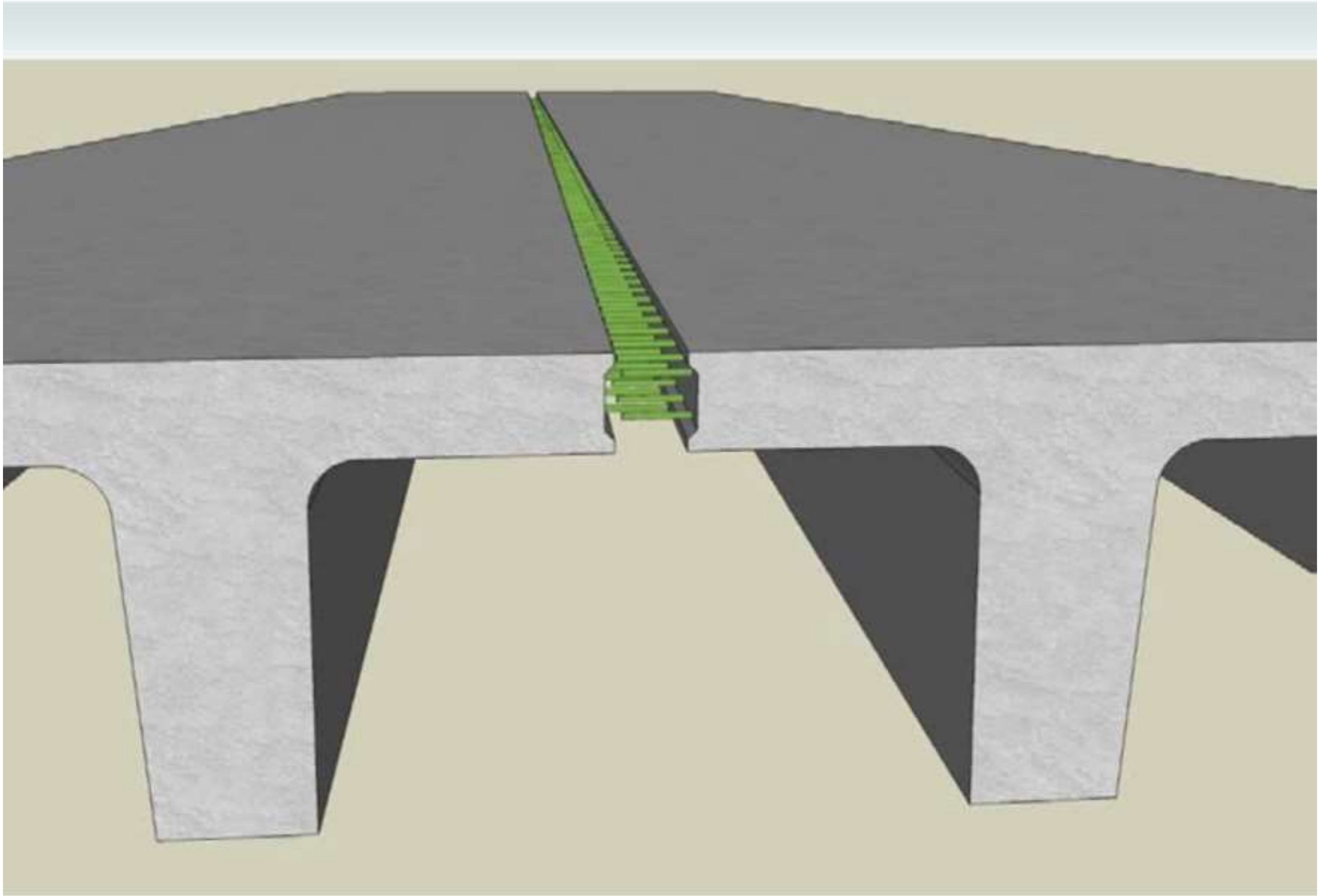


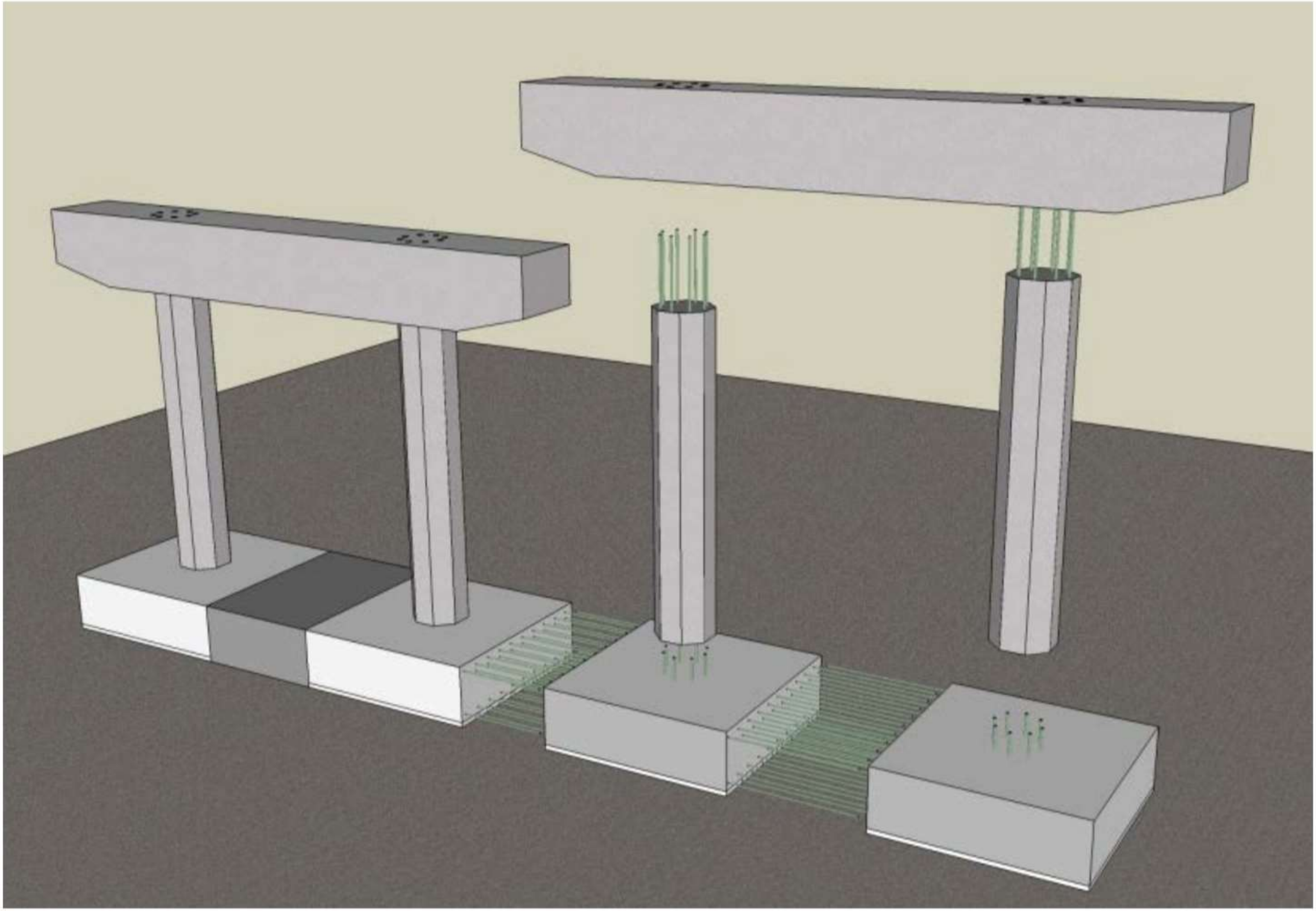


Modular Units:



3D Representation





Cast-in-place pier/column connections

Erection

Splice detail

Using ready made colum steel forms

Completed repair before painting

Mission Bridge - Pier Retrofit

Iowa DOT – structural overlay pilot project – May 2016

Phase 3 – overlay grinding and grooving

Grinding

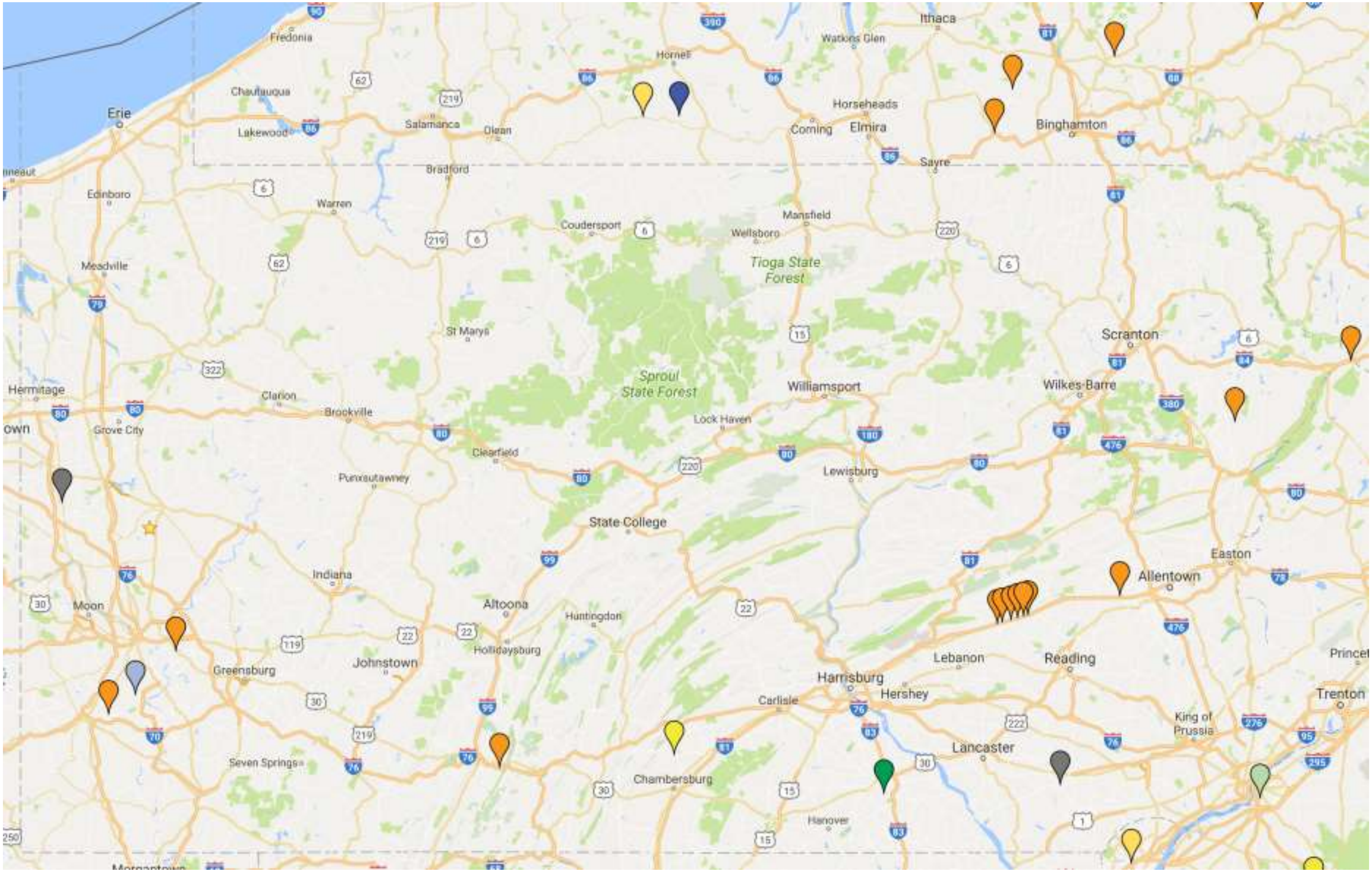
Grooving

Surface finish

MuCEM
Marseille, France

- 90 projects since 2014
- 200+ projects since 2006

Pennsylvania



Our Services

Ductal

- Engineering Expertise
- Project Development
- Technical Support and Assistance
- Innovative Research
- Quality Control

On-Site QA/QC

Slump Flow

- Mini-slump cone
- Flow – 7” to 10”

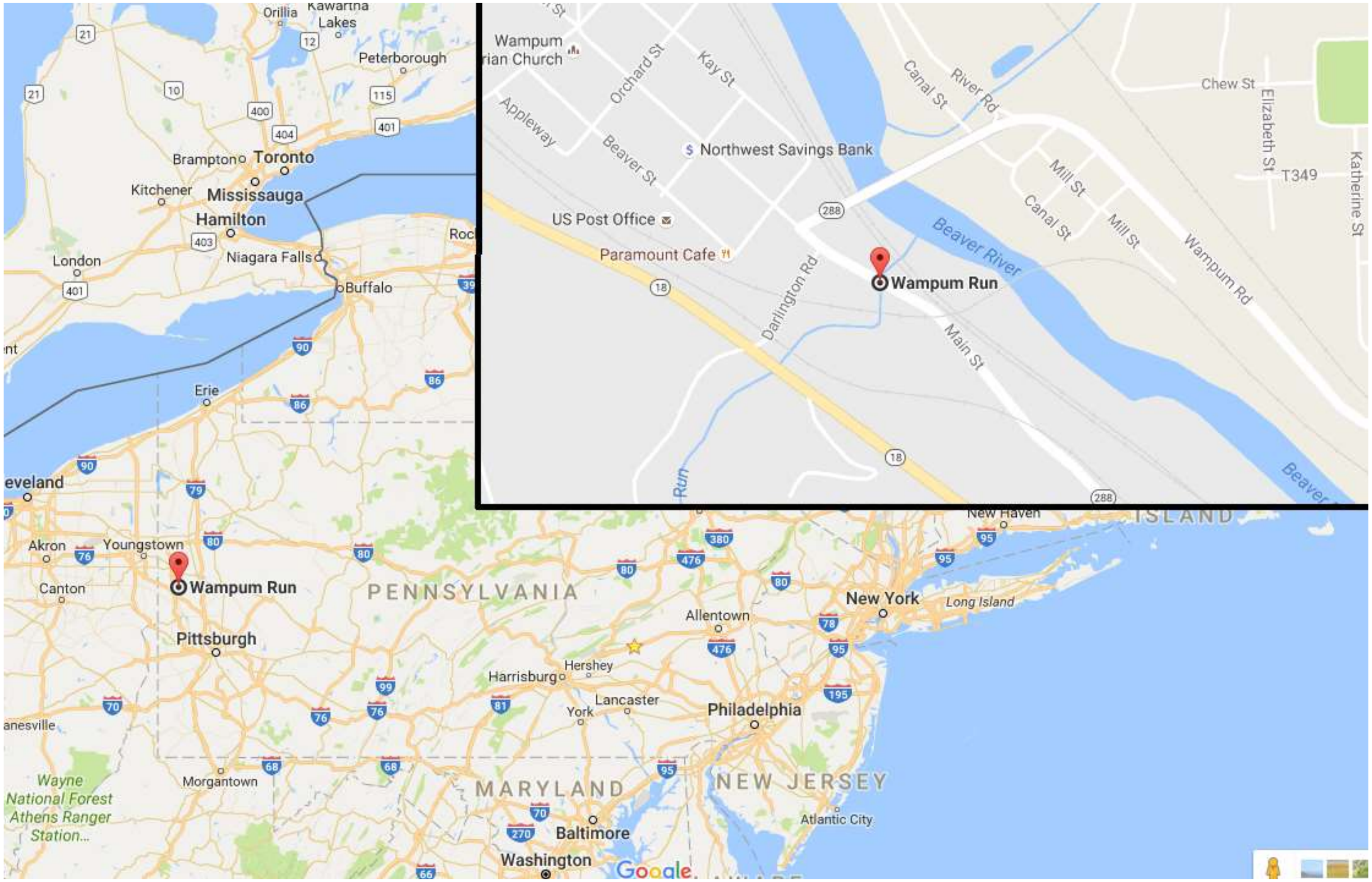
Compressive Strength

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

➢ A Ductal representative provides on-site QA/QC for all projects

Wampum Run (2014)

Wampum Run (2014)



Lawrence County: PennDOT District 11, SR288 over Wampum Run

Wampum Run (2014)

Structural Engineers: *JMT (Johnsoin, Mirmiran & Thompson)*

Contractor: *Joseph B Frey Company (Terentum PA)*

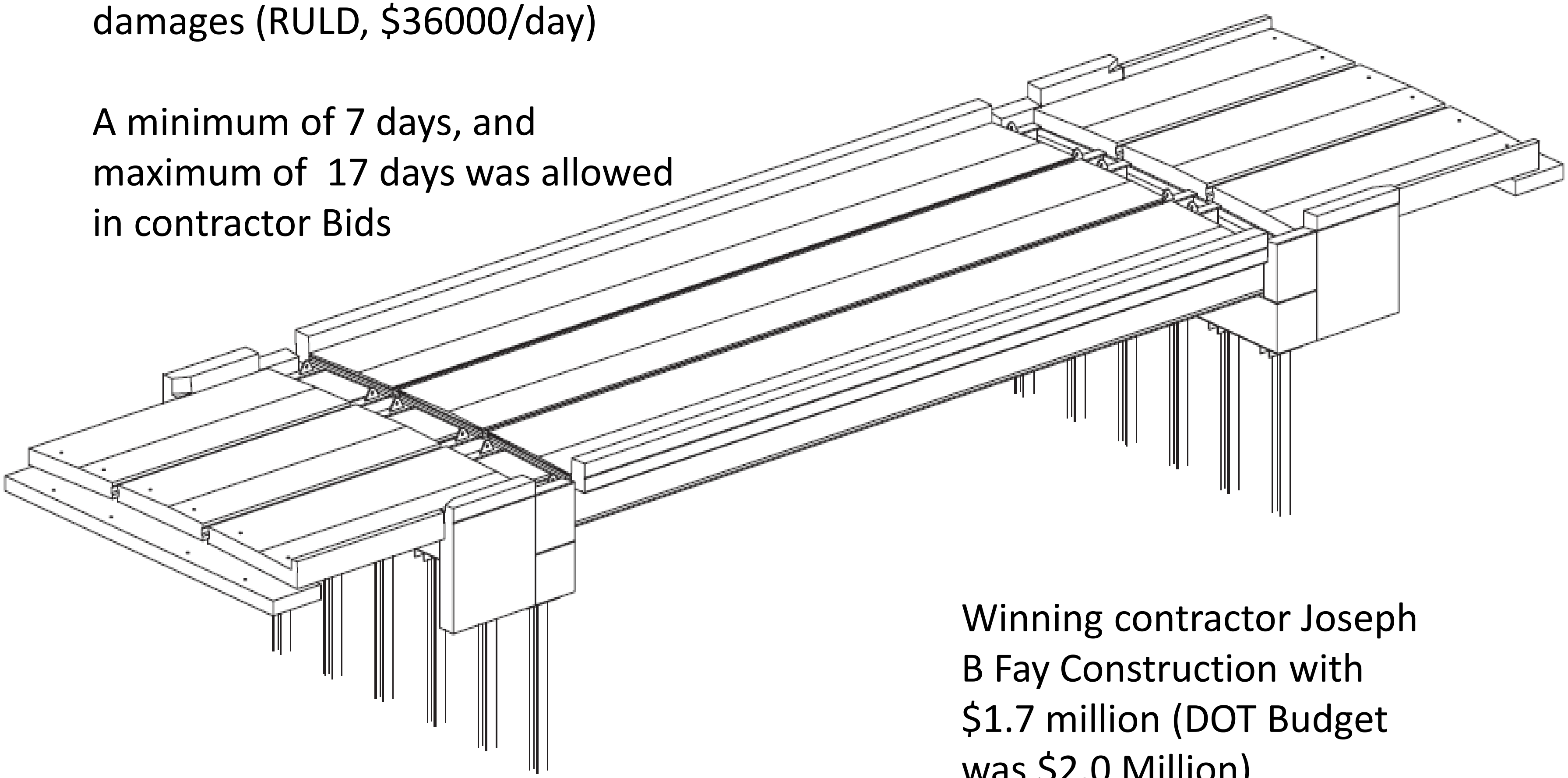
Existing bridge was a 60 foot, concrete arch bridge in poor condition.

Choosen as a first application location due to the rural location and low ADT of 4500 vehicles. However a 22 mile detour and heavy industry truck traffic

Wampum Run (2014)

Project was tendered using A+Bx
- A: Dollar value of contract
- B: Days to finish
- x: Road user liquidated damages (RULD, $36000/day)

A minimum of 7 days, and maximum of 17 days was allowed in contractor Bids



Winning contractor Joseph B Fay Construction with $1.7 million (DOT Budget was $2.0 Million)

Wampum Run (2014)

Construction Notes

Started: August 18, 2014
Finished: August 24, 2014

Total Closure of **7 days**, two days earlier than planned. (Received RULD Bonus of $72,000)

Epoxy overlay applied 28 days later.

Construction cost of fell within District 11's normal range (per sq ft)

Contractor performed a **prefit** before construction

Lightweight concrete used to keep pick weights down.

Wampum Run (2014)

UHPC Notes

Acccelerated Mix: **JS1212**

Casting of the UHPC joints occured August 23, 2014.

Started at 8am

Finished by 1pm.

10 batches, 6.65 yards placed.

Compressive strength
14,500 psi @ 24 hours
24,070 psi @ 28 days.

Ultimate compressive strength 28,700 psi.

Wampum Run (2014)

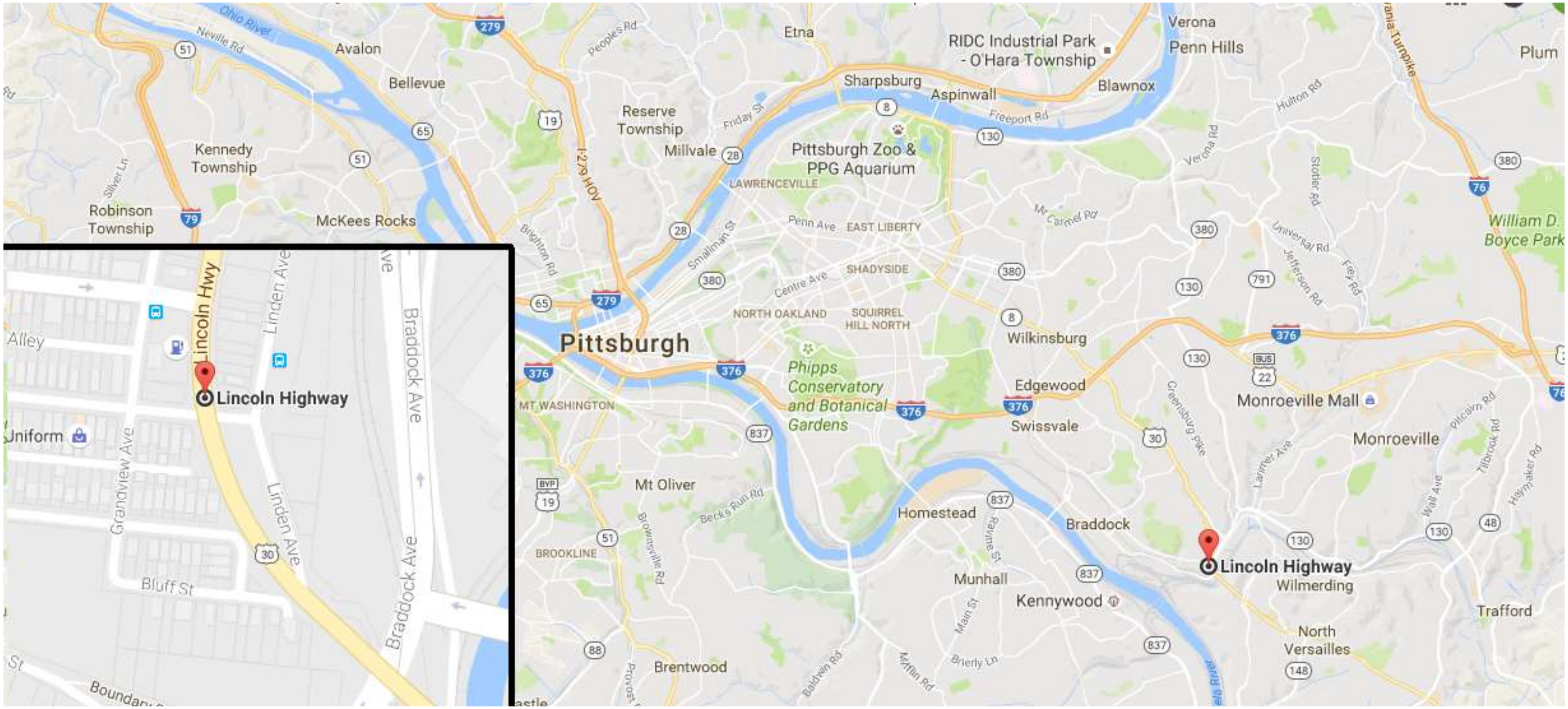
Additional Reading:

https://www.roadsbridges.com/sites/rb/files/24_Traveling_relief_RB0615.pdf

http://www.ductal.com/en/engineering/sr-288-main-st-bridge-wampum-usa

Route 30 over Bessemer, East Pittsburgh (2016)

Route 30 over Bessemer, East Pittsburgh (2016)



Allegheny County: PennDOT District 11, SR0030 over Bessemer Ave

Route 30 over Bessemer, East Pittsburgh (2016)

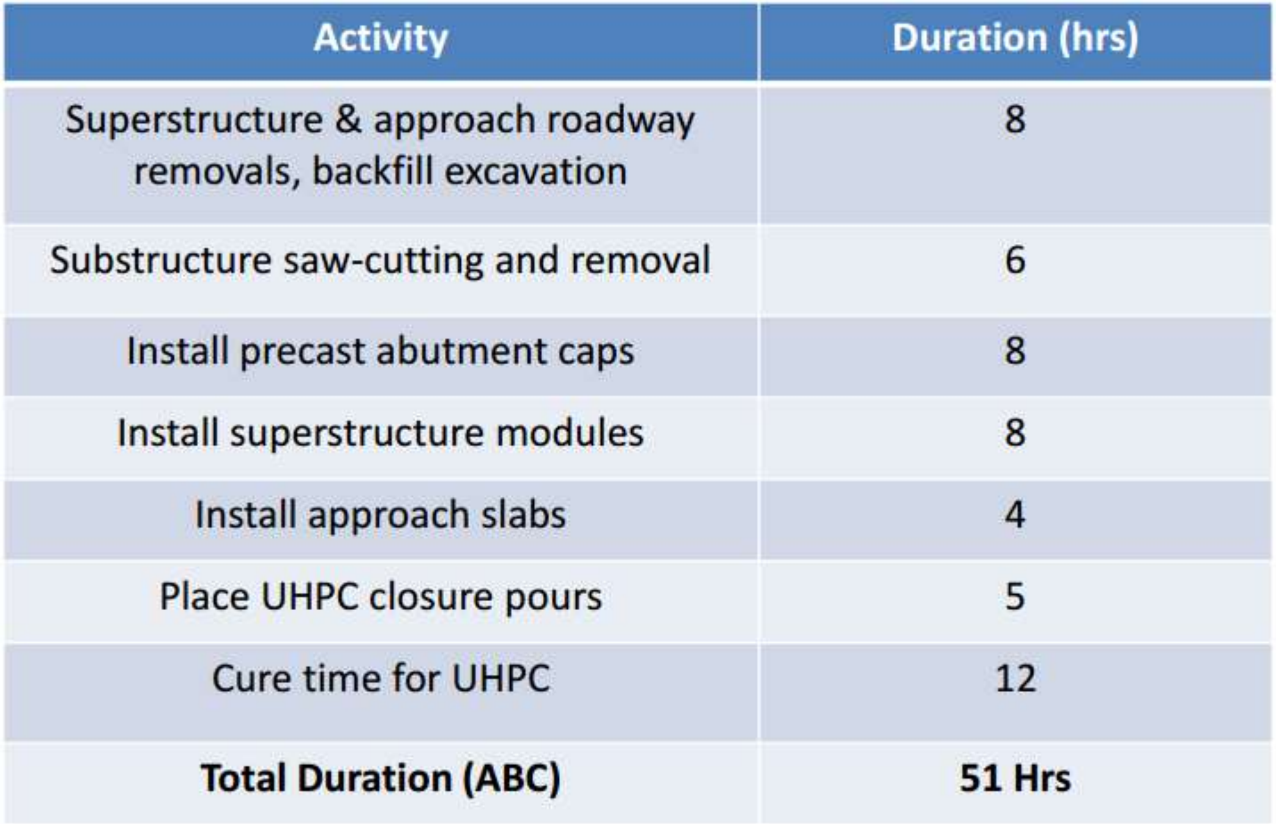
Structural Engineers: HNTB Corporation

Contractor: *Brayman Construction (Saxonburg PA) ($2,333,212)*

Existing bridge was a 52 foot, concrete T-beam superstructure. In poor condition.

ADT of 22,000 vehicles, major commuting route into and out of the city.

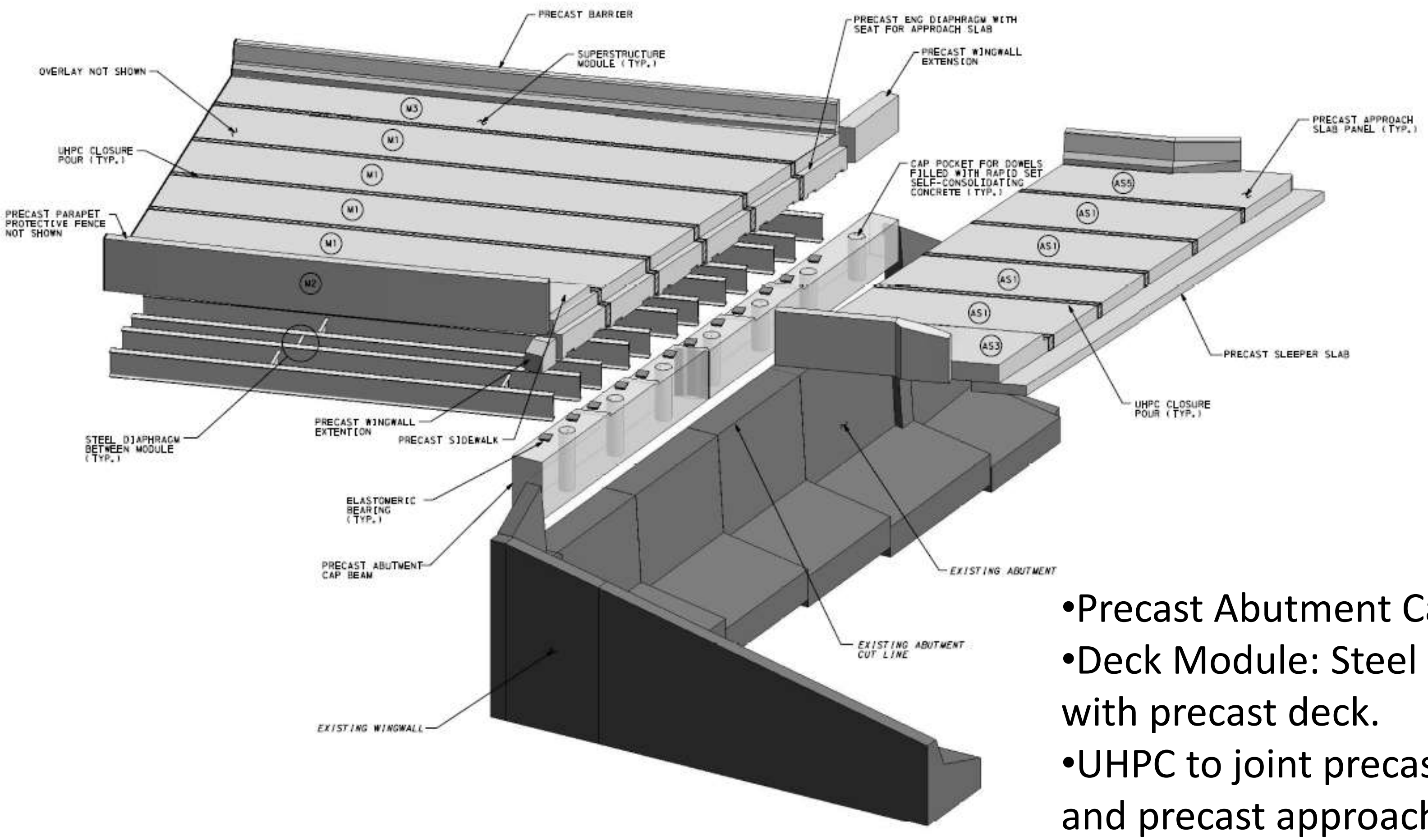
Route 30 over Bessemer, East Pittsburgh (2016)



Activity	Duration (hrs)
Superstructure & approach roadway removals, backfill excavation	8
Substructure saw-cutting and removal	6
Install precast abutment caps	8
Install superstructure modules	8
Install approach slabs	4
Place UHPC closure pours	5
Cure time for UHPC	12
Total Duration (ABC)	**51 Hrs**

57 hours was allowed. Friday 9pm – Monday 6am

Route 30 over Bessemer, East Pittsburgh (2016)



- Precast Abutment Caps
- Deck Module: Steel girder with precast deck.
- UHPC to joint precast deck and precast approach elements.

Route 30 over Bessemer, East Pittsburgh (2016)

Construction Notes

Started: May 20,2016 9:00 pm

Finished: May 23, 2016 6:00 am

Weather was a factor, heavy rain slowed the process

LMC overlay applied post weekend closure.

Backfilled abutments under approach slabs with flowable fill post weekend closure.

Contractor was also the precaster

All pieces were built in a mockup fashion in contractors yard

Lightweight concrete used to keep pick weights down.

Route 30 over Bessemer, East Pittsburgh (2016)

East End Precast Abutment Cap In Place

Route 30 over Bessemer, East Pittsburgh (2016)

Deck Module Waiting To be Installed

Route 30 over Bessemer, East Pittsburgh (2016)

First Deck Module Being Installed.

Route 30 over Bessemer, East Pittsburgh (2016)

UHPC Notes

Accelerated Mix: **JS1212**

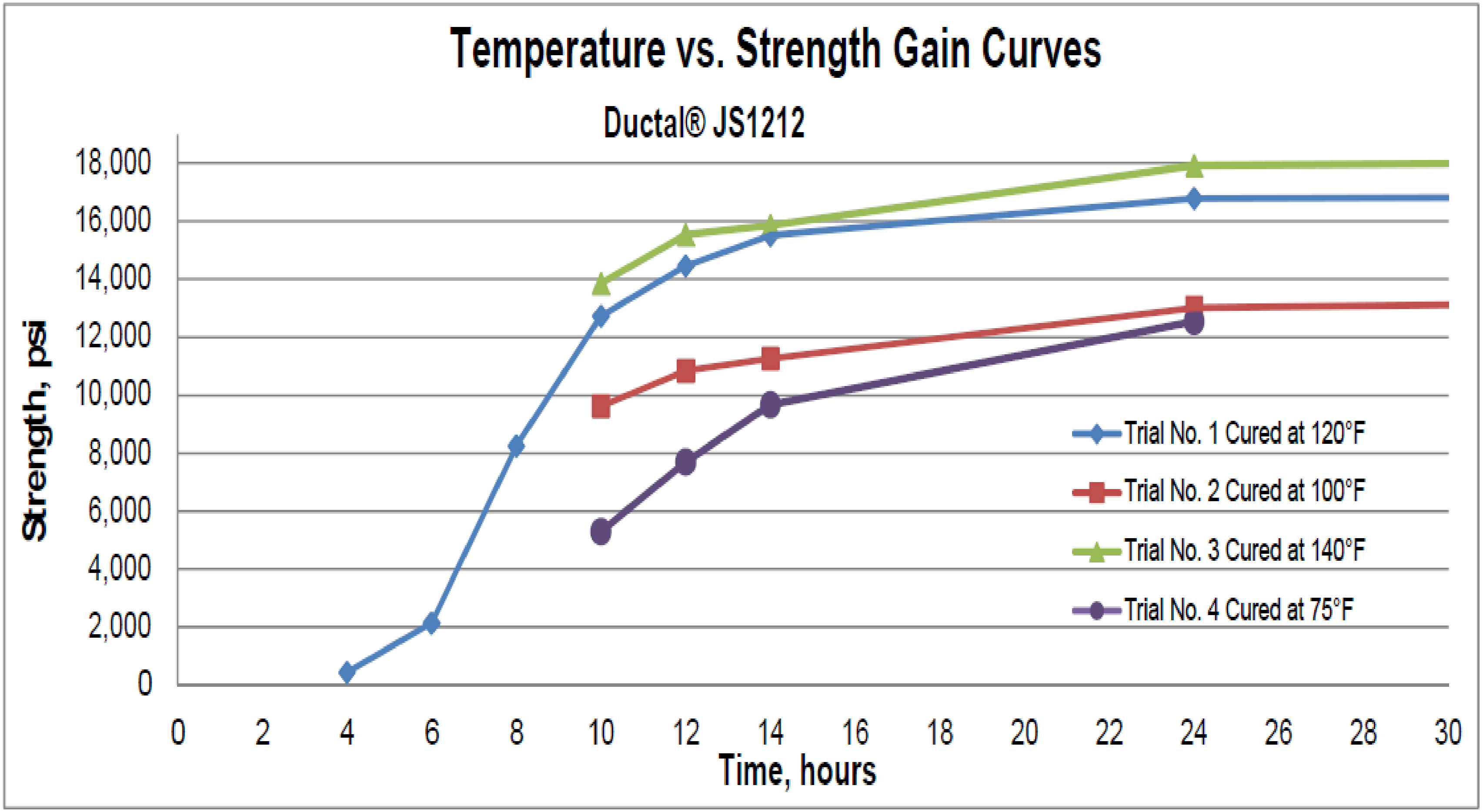
Curing was accelerated with increased curing temperature.

19.3 yards placed by conventional methods

6 hours mixing and placing

12 hours of accelerated cure to reach **12,000 psi**

Route 30 over Bessemer, East Pittsburgh (2016)



Js1212 12,000 psi in 12 hours when cured at 120° F

Route 30 over Bessemer, East Pittsburgh (2016)

**Route 30 Partially opened by Monday May 23, at 6:00 am.
Fully opened by 9:00 am.**

Route 30 over Bessemer, East Pittsburgh (2016)

Additional Reading:

FIU ABC Webinar & Presentation
https://abc-utc.fiu.edu/mc-events/penndot-sr-30-over-bessemer-avenue-bridge-replacement-in-one-weekend/?mc_id=165

https://abc-utc.fiu.edu/wp-content/uploads/sites/52/2016/08/2016-08-25_PennDOT_SR30-Over-Bessemer-Ave_08-19-16.pdf

Time Lapse Video
https://www.youtube.com/watch?v=WoPV7YHAnTM&feature=youtu.be

PA 997 Over Lehman Run

Franklin County

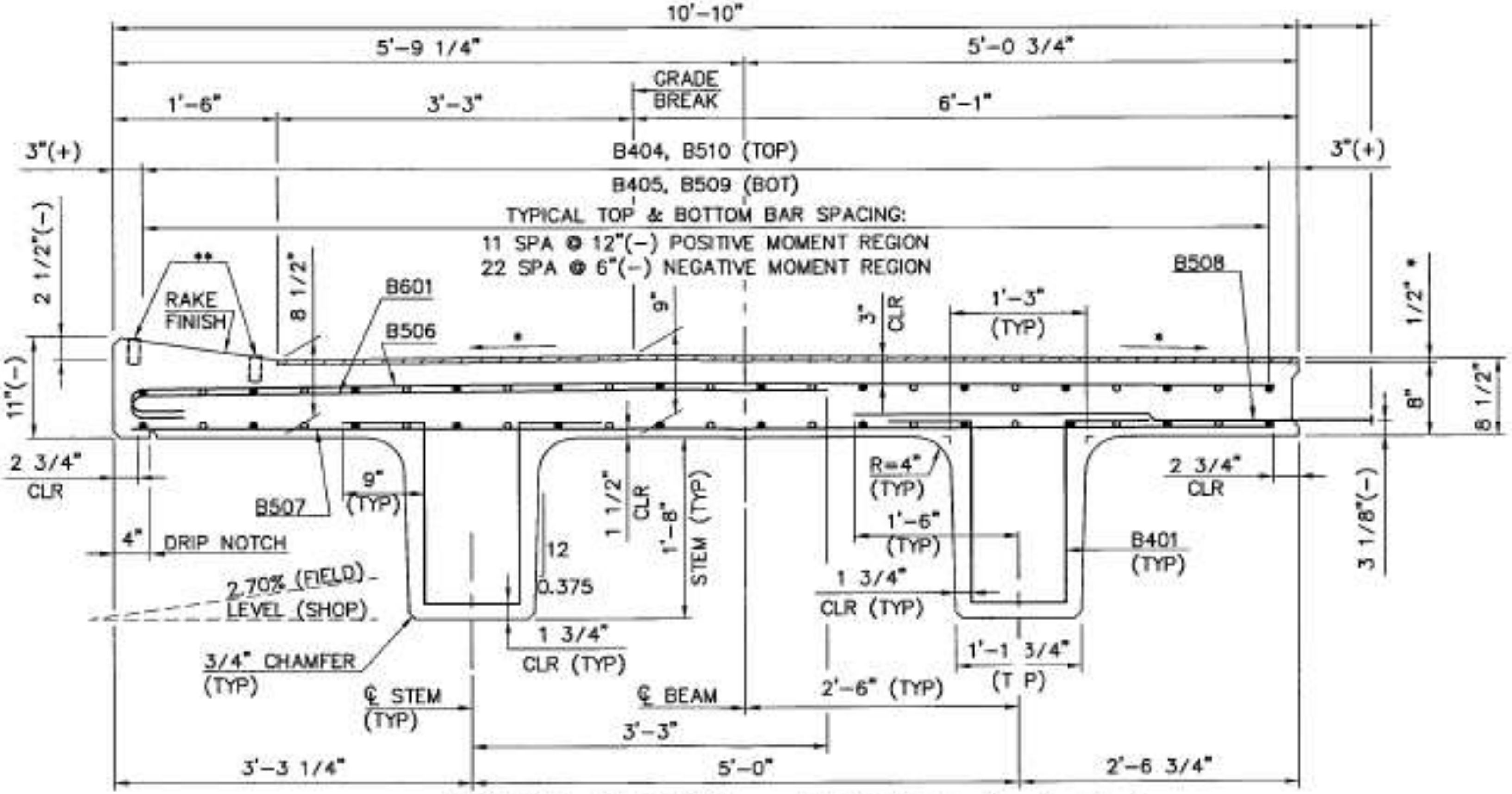
PA 997 Over Lehman Run

Structural Engineers: *Wilson Consulting Group (Mechanicsburg Pa)*

Contractor: *Lobar Construction (*DillsburgPA*) ($2,333,212)*

Existing bridge was a twin 26 ft span concrete beam superstructure. In poor condition.

PA 997 Over Lehman Run

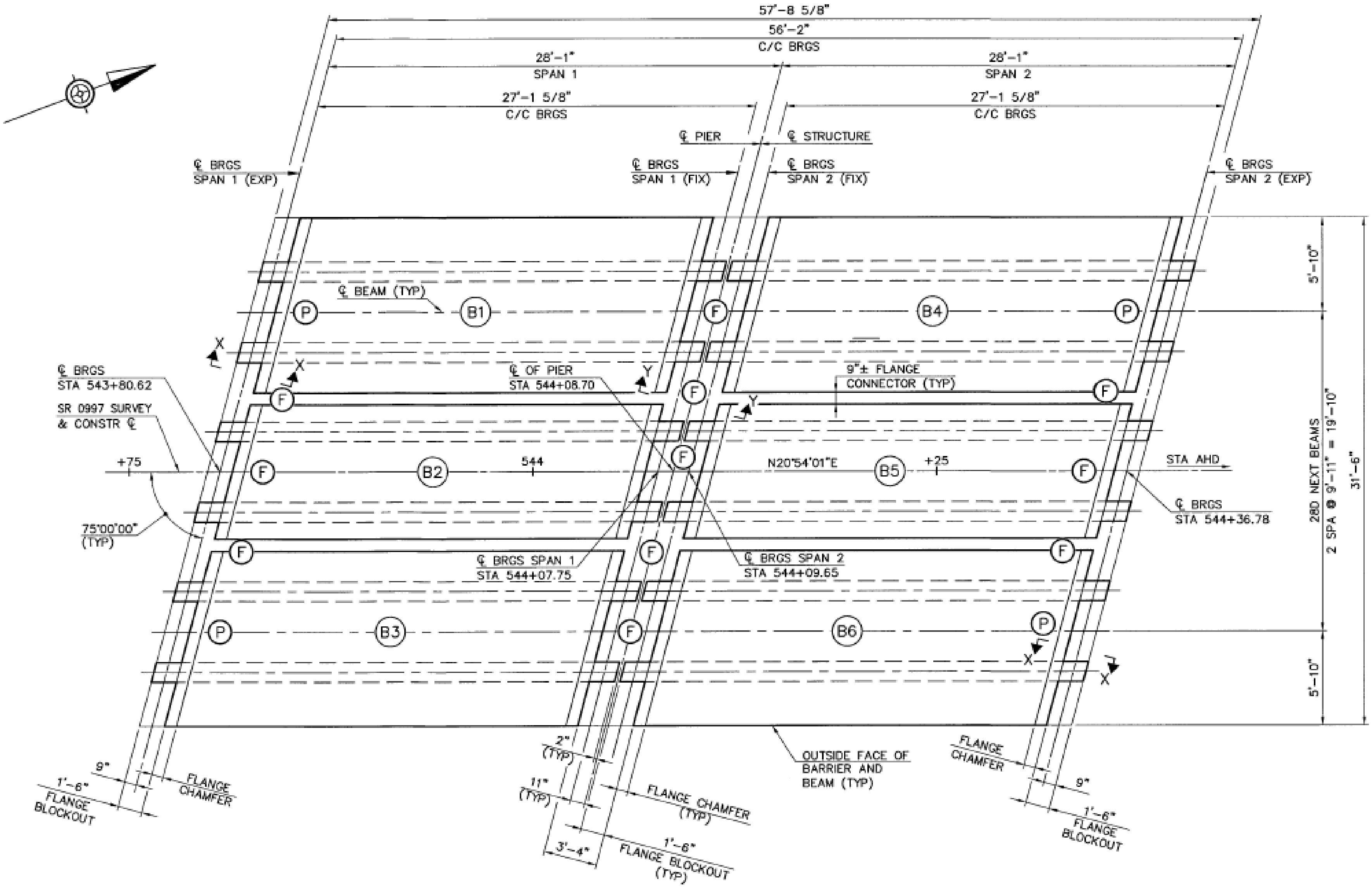


TYPICAL SECTION – BEAMS 1, 3, 4, & 6

1 0 1

SCALE: 1" = 1'

PA 997 Over Lehman Run



PA 997 Over Lehman Run

Non Accelerated Mix: **JS1000**

14,500 psi in 4 days (96 hours) / 21,700 psi in 28 days

9.3 yards placed by conventional methods over 2 days

PA 997 Over Lehman Run

Smaller mixers used to match bridge and crew size.

PA 997 Over Lehman Run

Link slab detail above pier

Questions?