UHPC 101

An Introduction to Ultra-High Performance Concrete

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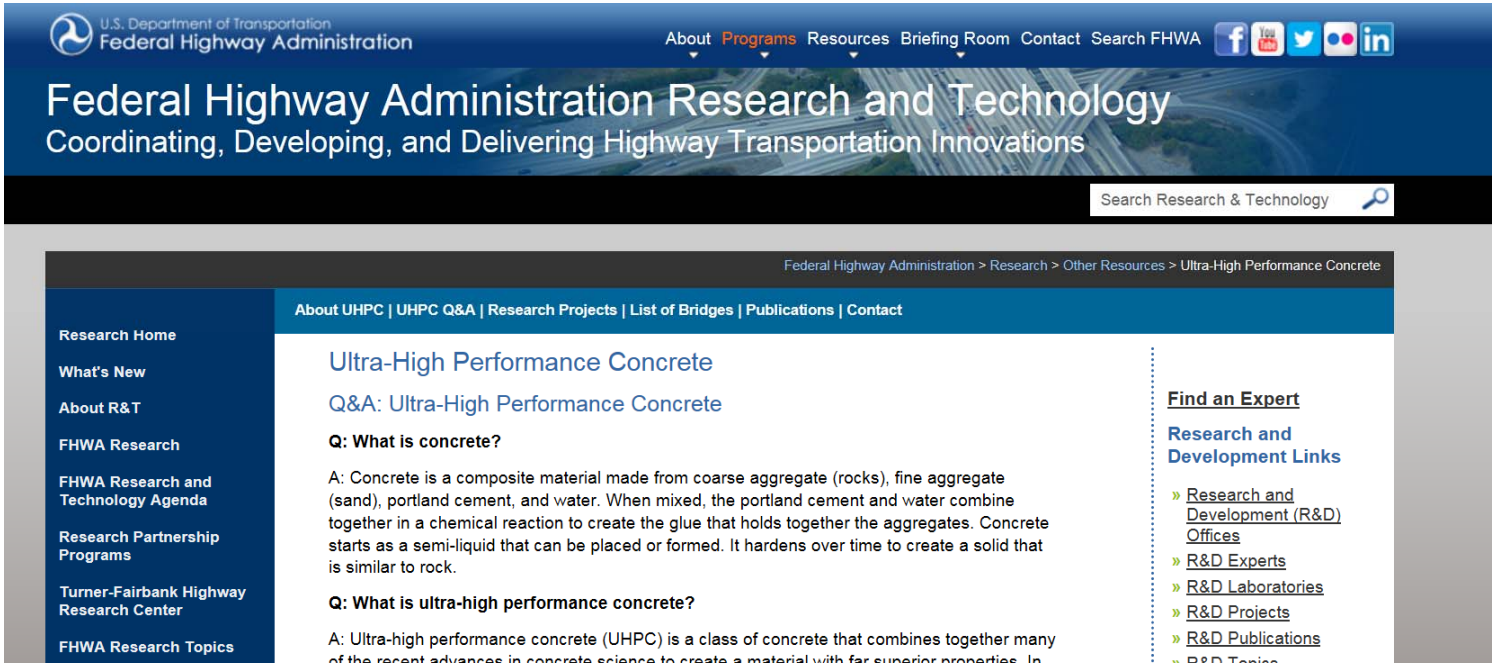
Illinois Transportation and Highway Engineering Conference

February 28, 2017

FHWA UHPC Web Resources

- Web Search: **FHWA UHPC**
- *https://www.fhwa.dot.gov/research/resources/uhpc/*

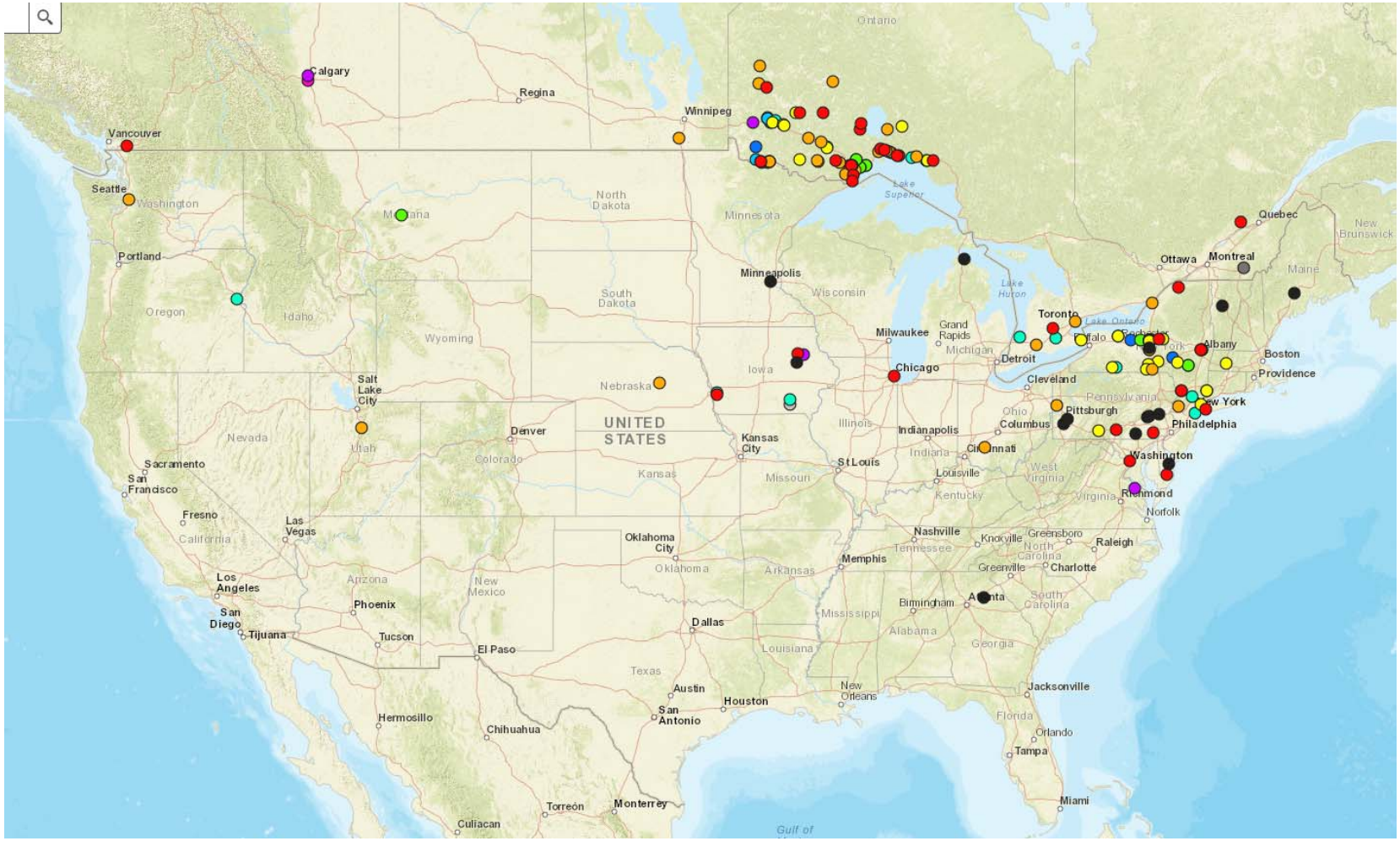


UHPC State-of-the-Art Report

- FHWA HRT-13-060
  - Published in June 2013
  - 300+ references
  - 600+ item bibliography

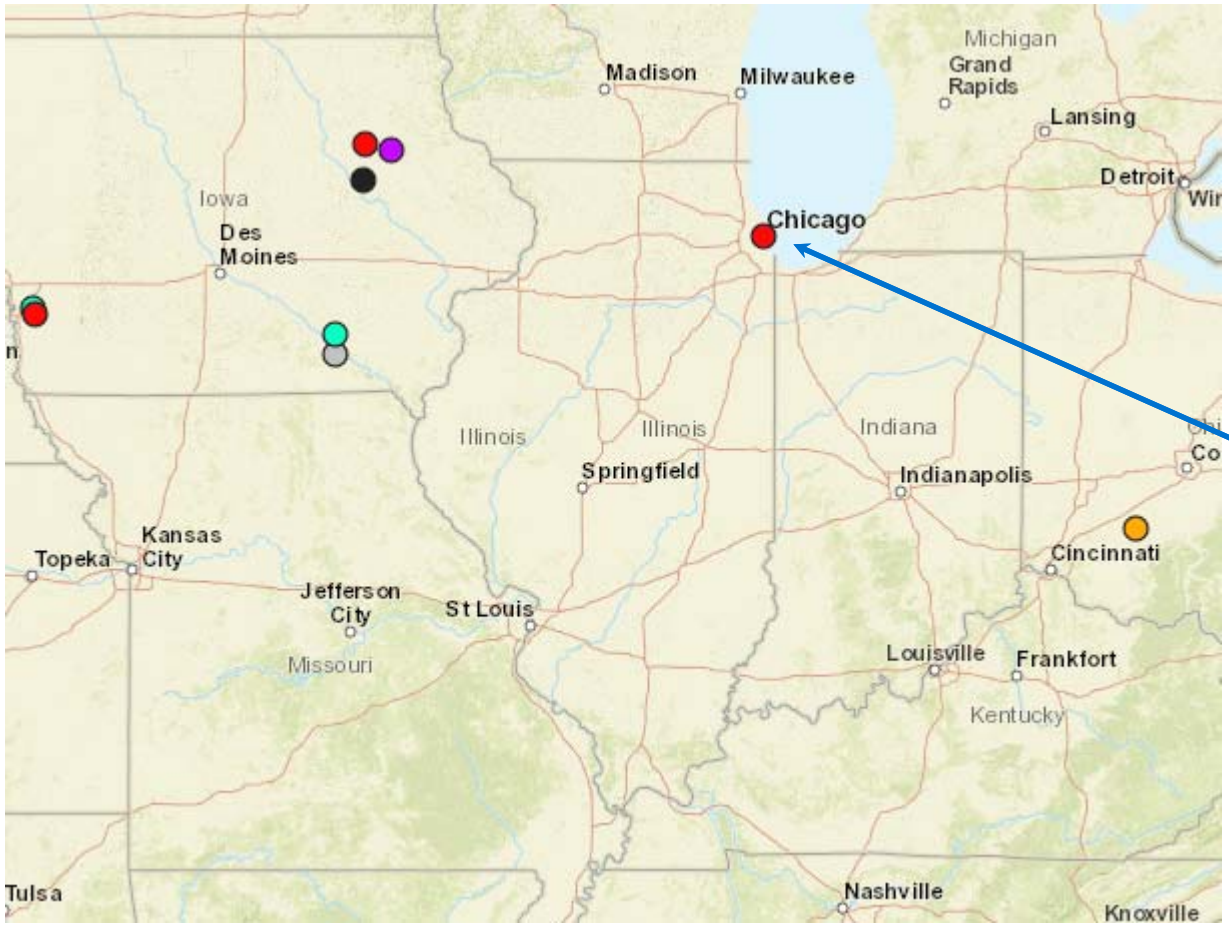
Mix Designs, Material Properties, Design Guidelines, Deployment, etc.

UHPC Deployments Across US and Canada



http://usdot.maps.arcgis.com/apps/webappviewer/index.html?id=41929767ce164eba934d70883d775582

UHPC Deployments Across US and Canada



S. Peoria Street Bridge

Bridge Name / Route: S. Peoria Street

Crossing Feature: I-290

Country: United States

State or Province: IL

City or County: Chicago

Owner: Illinois Department of Transportation

UHPC Application: Deck-level connections between full-depth precast concrete deck panels (pedestrian bridge).

Year Constructed: 2015

GPS Latitude: 41.88

GPS Longitude: -87.65

http://usdot.maps.arcgis.com/apps/webappviewer/index.html?id=41929767ce164eba934d70883d775582

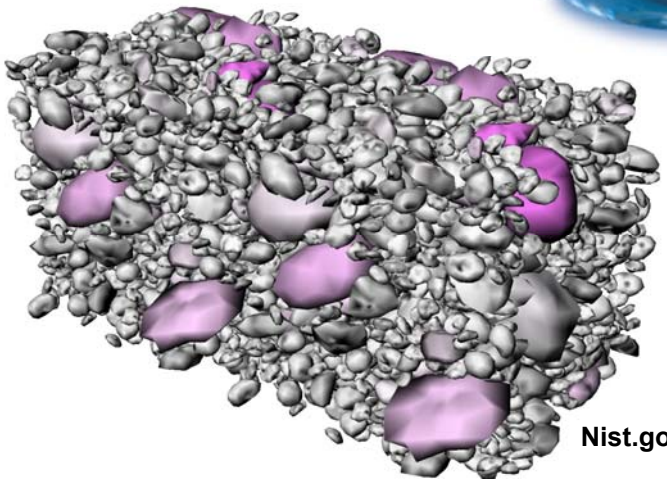
What is Ultra-High Performance Concrete?

What is Ultra-High Performance Concrete?

Fiber Reinforcement

Superplasticizers

Particle Packing Theory



Nist.gov

Supplementary Cementitious Materials

American Coal Ash Association

What is Ultra-High Performance Concrete?

- ACI 239 – Ultra-High Performance Concrete
  - Concrete, ultra-high performance - 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.

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?

Highly durable, strain-hardening concrete

What is Ultra-High Performance Concrete?

Micro-Reinforced Concrete

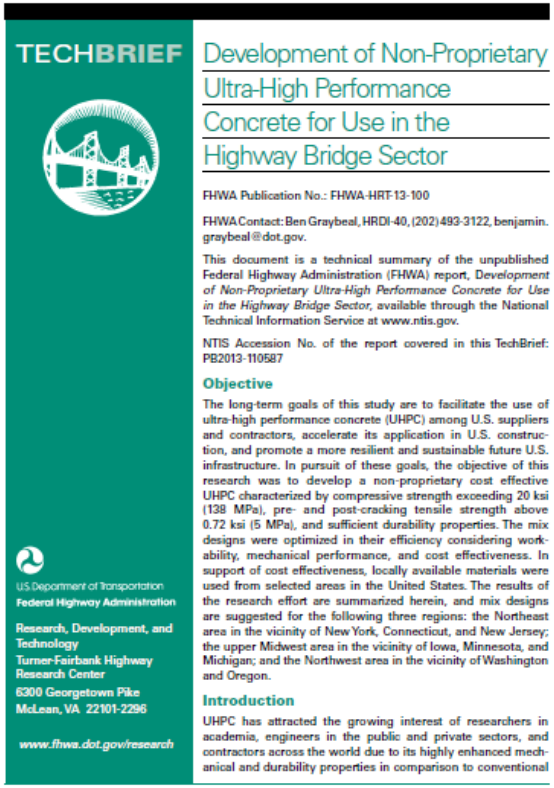
What is Ultra-High Performance Concrete?

Resilient Cementitious Composite

Availability of UHPC-Class Materials

Example Proprietary Versions

Non-Proprietary Versions



TECHBRIEF

Development of Non-Proprietary Ultra-High Performance Concrete for Use in the Highway Bridge Sector

FHWA Publication No.: FHWA-HRT-13-100

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

This document is a technical summary of the unpublished Federal Highway Administration (FHWA) report, *Development of Non-Proprietary Ultra-High Performance Concrete for Use in the Highway Bridge Sector*, available through the National Technical Information Service at www.ntis.gov.

NTIS Accession No. of the report covered in this TechBrief: PB2013-110587

Objective

The long-term goals of this study are to facilitate the use of ultra-high performance concrete (UHPC) among U.S. suppliers and contractors, accelerate its application in U.S. construction, and promote a more resilient and sustainable future U.S. infrastructure. In pursuit of these goals, the objective of this research was to develop a non-proprietary cost effective UHPC characterized by compressive strength exceeding 20 ksi (138 MPa), pre- and post-cracking tensile strength above 0.72 ksi (5 MPa), and sufficient durability properties. The mix designs were optimized in their efficiency considering workability, mechanical performance, and cost effectiveness. In support of cost effectiveness, locally available materials were used from selected areas in the United States. The results of the research effort are summarized herein, and mix designs are suggested for the following three regions: the Northeast area in the vicinity of New York, Connecticut, and New Jersey; the upper Midwest area in the vicinity of Iowa, Minnesota, and Michigan; and the Northwest area in the vicinity of Washington and Oregon.

Introduction

UHPC has attracted the growing interest of researchers in academia, engineers in the public and private sectors, and contractors across the world due to its highly enhanced mechanical and durability properties in comparison to conventional

U.S. Department of Transportation
Federal Highway Administration

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

www.fhwa.dot.gov/research

FHWA-HRT-13-100:
Dr. Kay Willie at UCONN

Example Composition of a UHPC

Constituent	Amount (lb/yd^3)	Amount (kg/m^3)
Portland Cement	1235	733
Silica Fume	388	230
Ground Quartz	308	183
Fine Sand	1699	1008
Steel Fibers	327	194
Superplasticizer	56	33
Water	271	161

* Teichmann and Schmidt report titled “Mix Design and Durability of UHPC” from the Proceedings of the 4th Intl Ph.D. Symposium in Civil Engineering

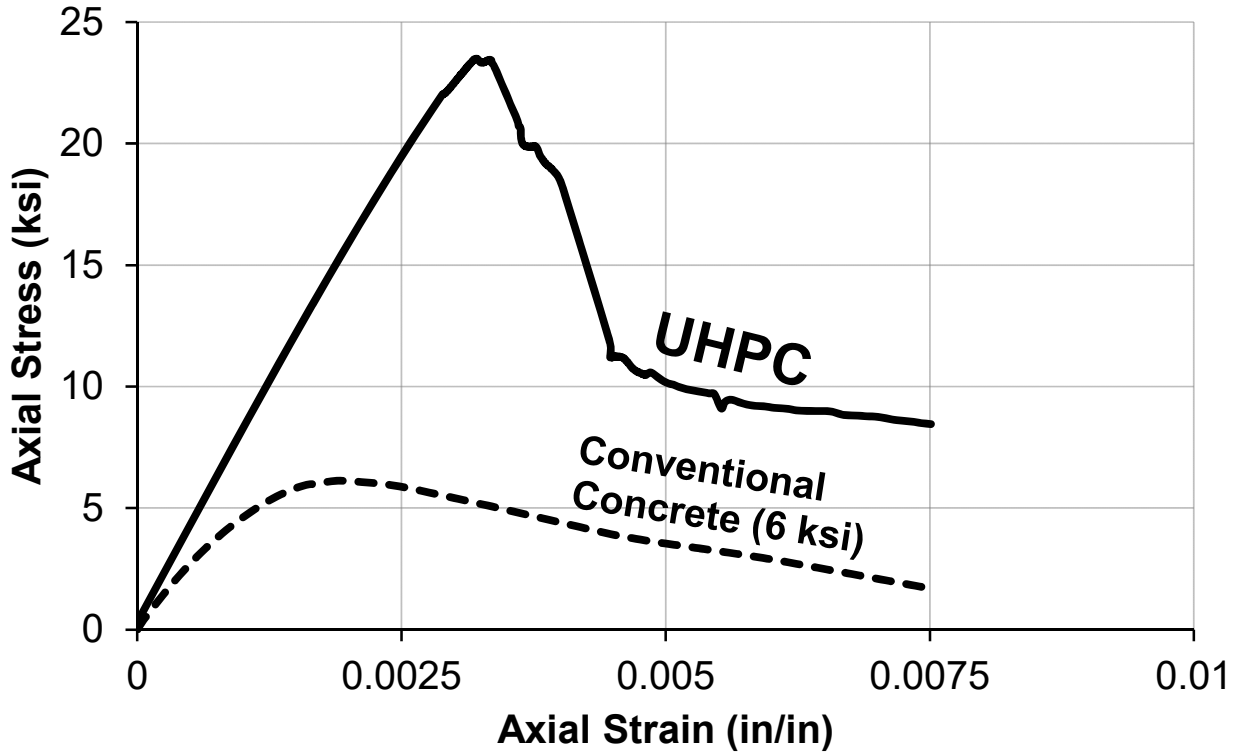
Example Composition of a UHPC

Constituent	Amount (lb/yd^3)	Amount (kg/m^3)
Portland Cement	1331	790
Silica Fume	334	198
Fly Ash (Class F)	324	192
Fine Basalt	1923	1141
Steel Fibers	199	118
Superplasticizer	47	28
Water	246	146

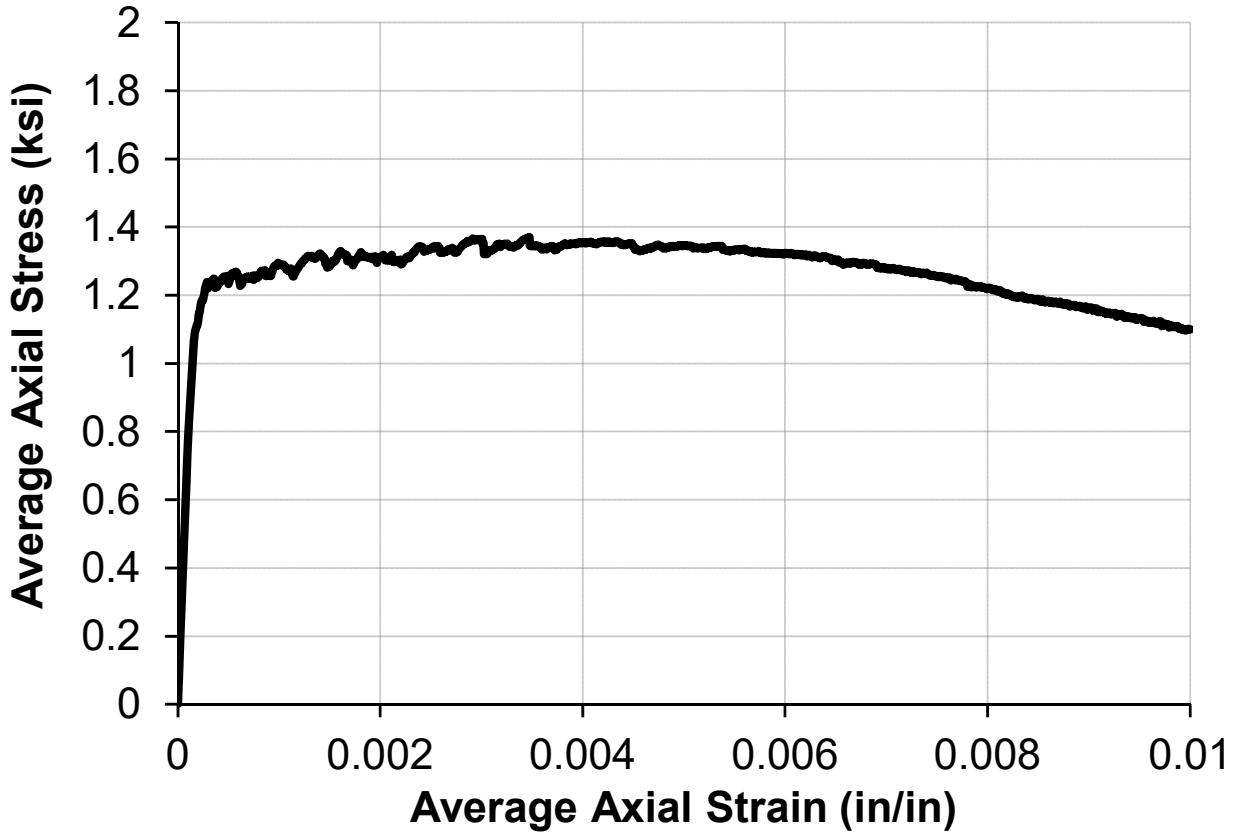
* Wille and Boisvert-Cotulio report titled “Development of Non-Proprietary UHPC for Use in the Highway Bridge Sector” (FHWA NTIS-PB2013-100587)

Fiber Reinforcement

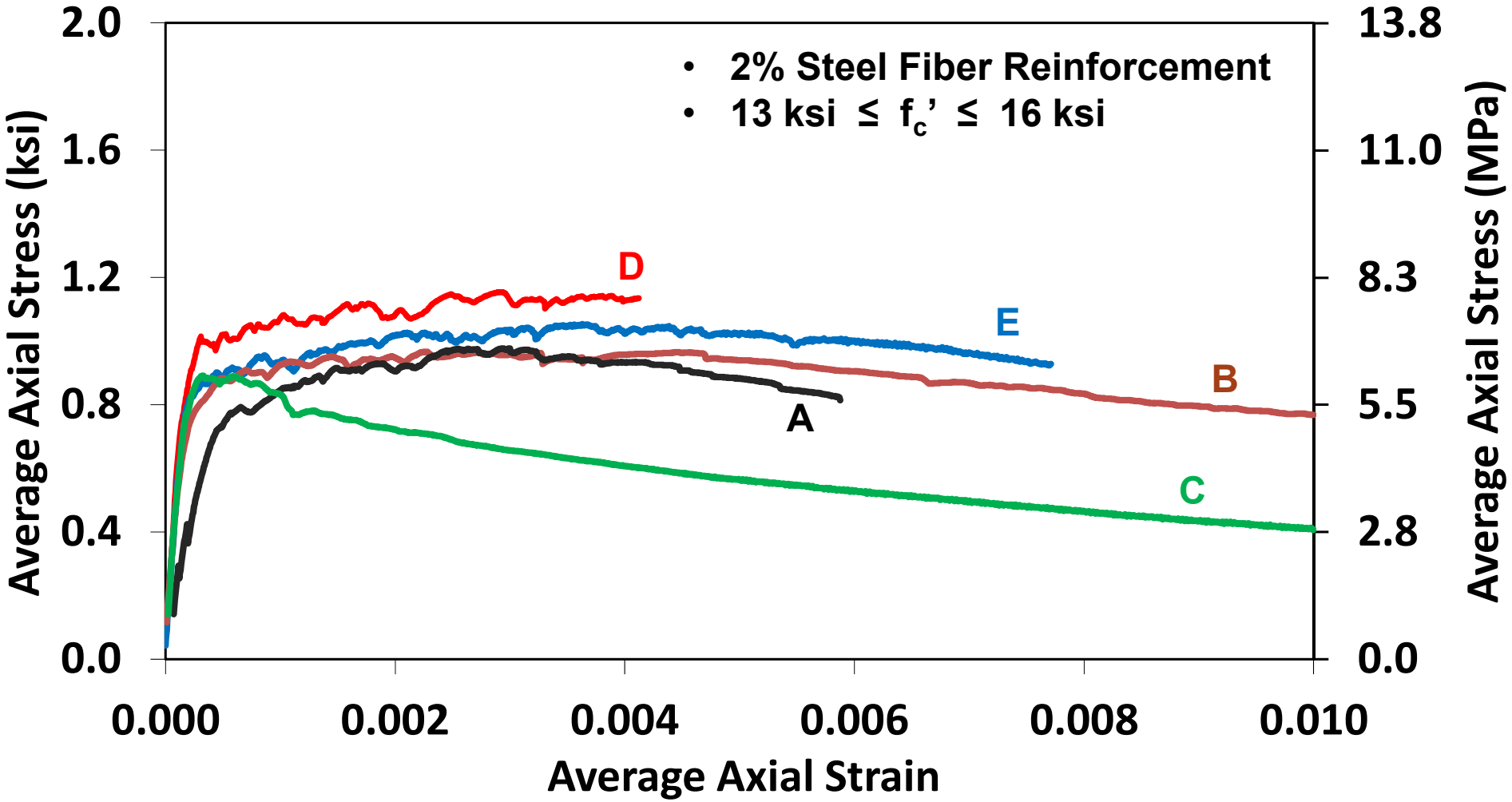
Compression Behavior



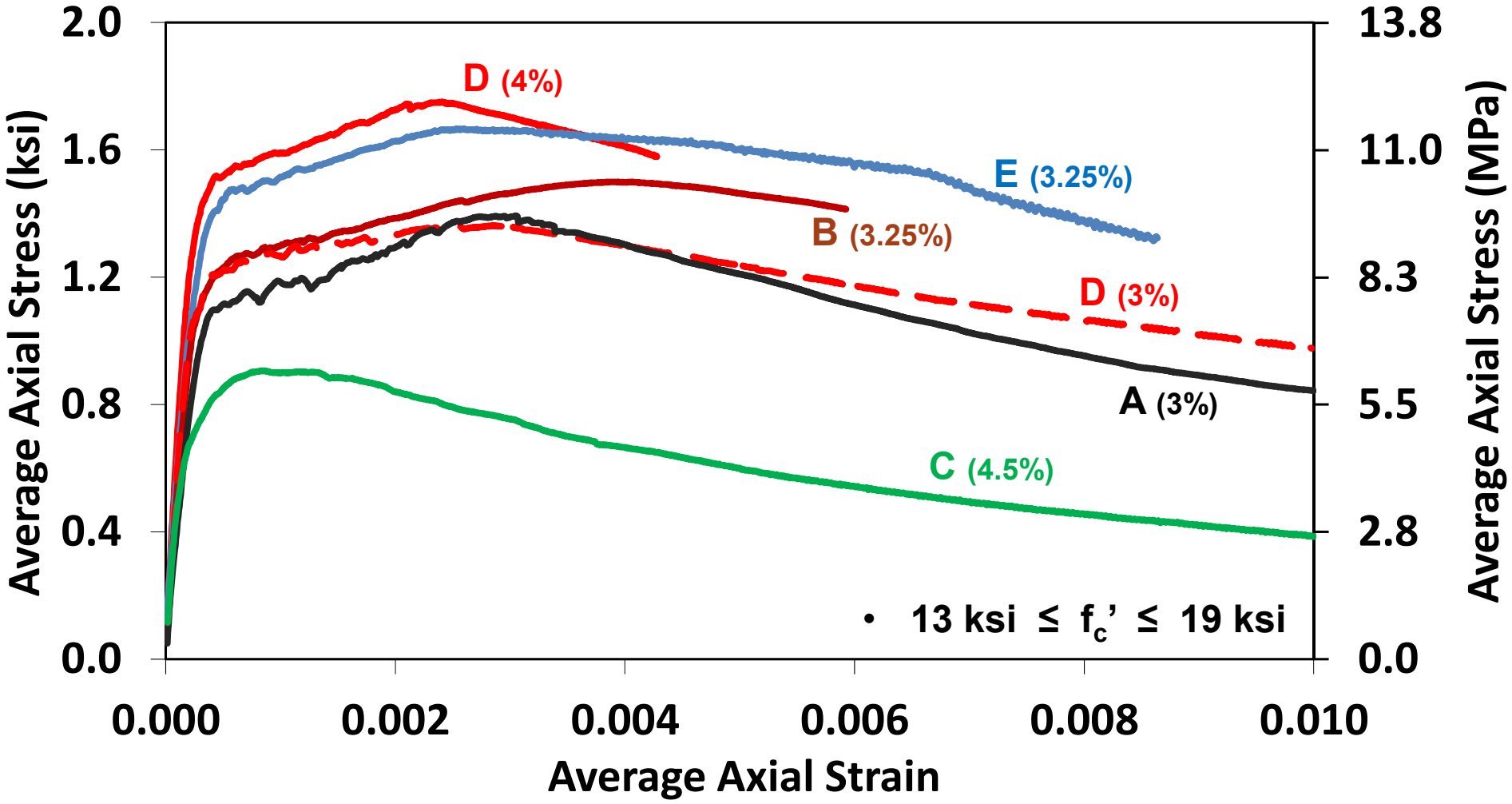
Tensile Behavior



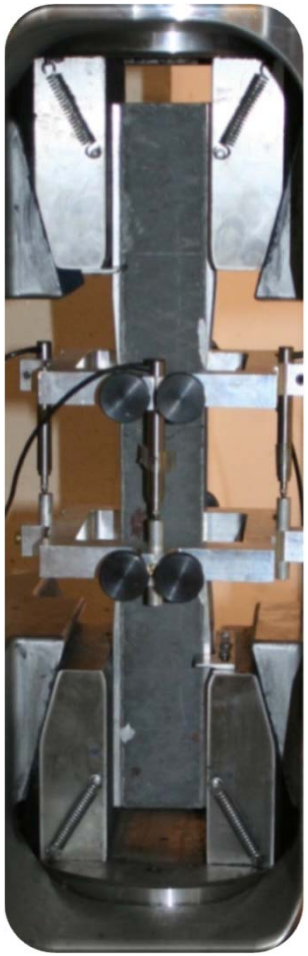
Tensile Behavior

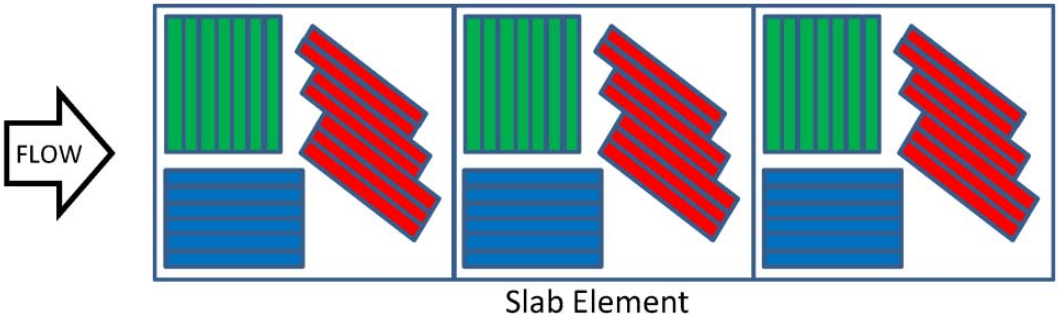


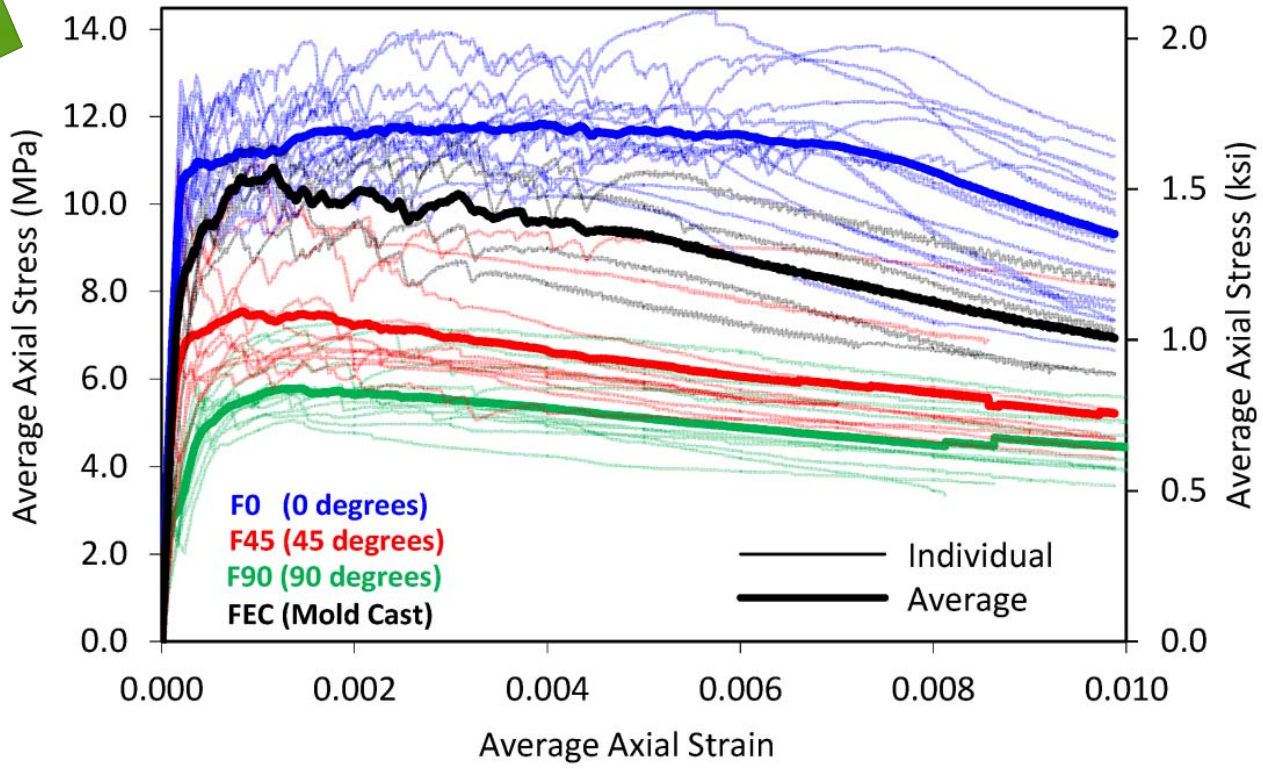
Tensile Behavior



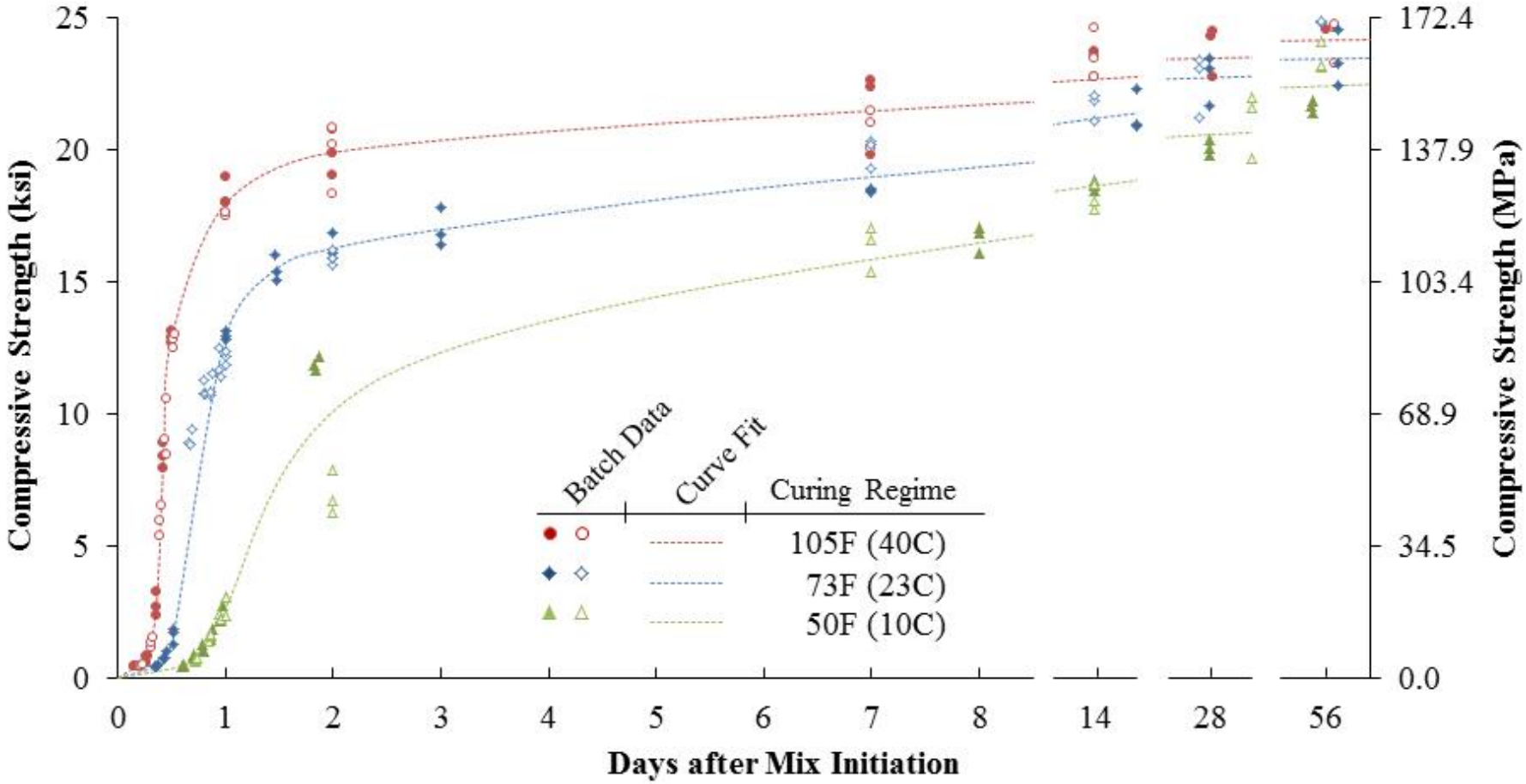
Tensile Behavior



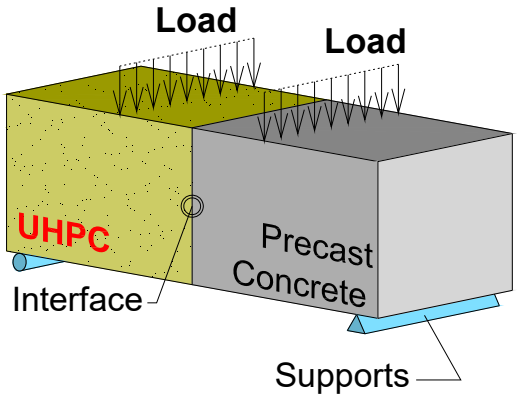


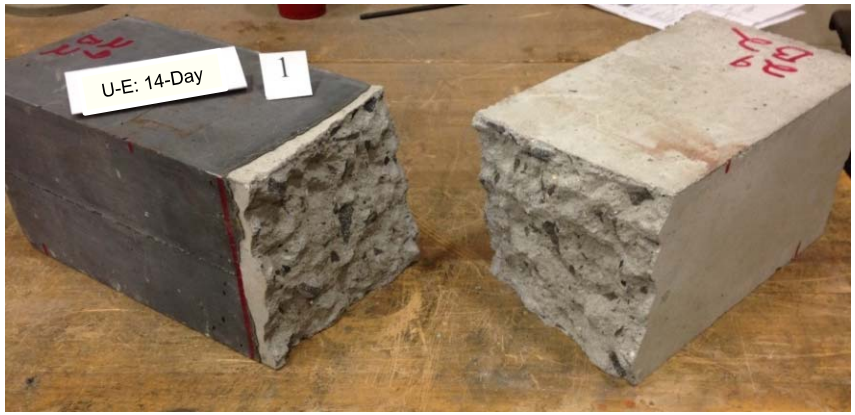


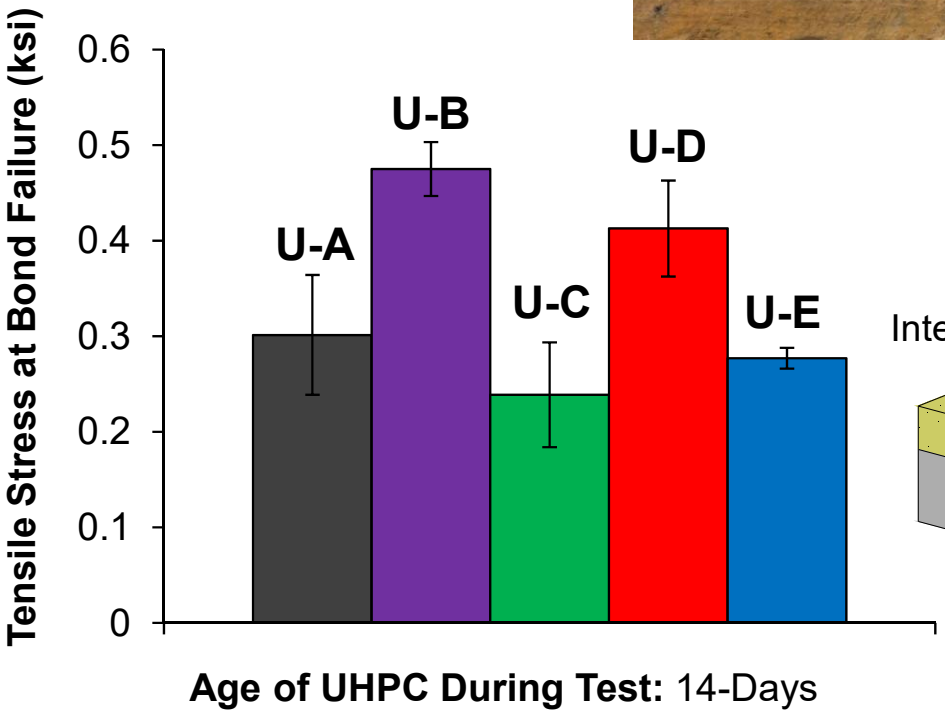
Compression Strength Gain

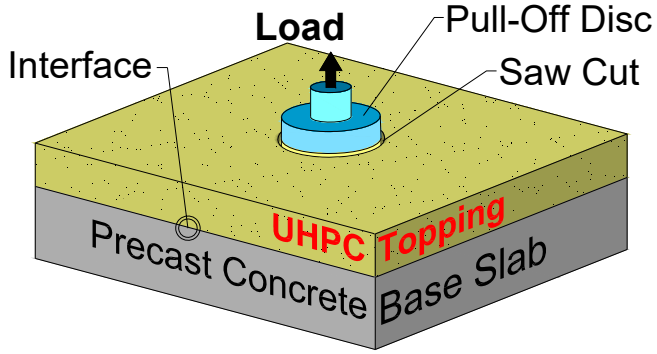


Interface Bond

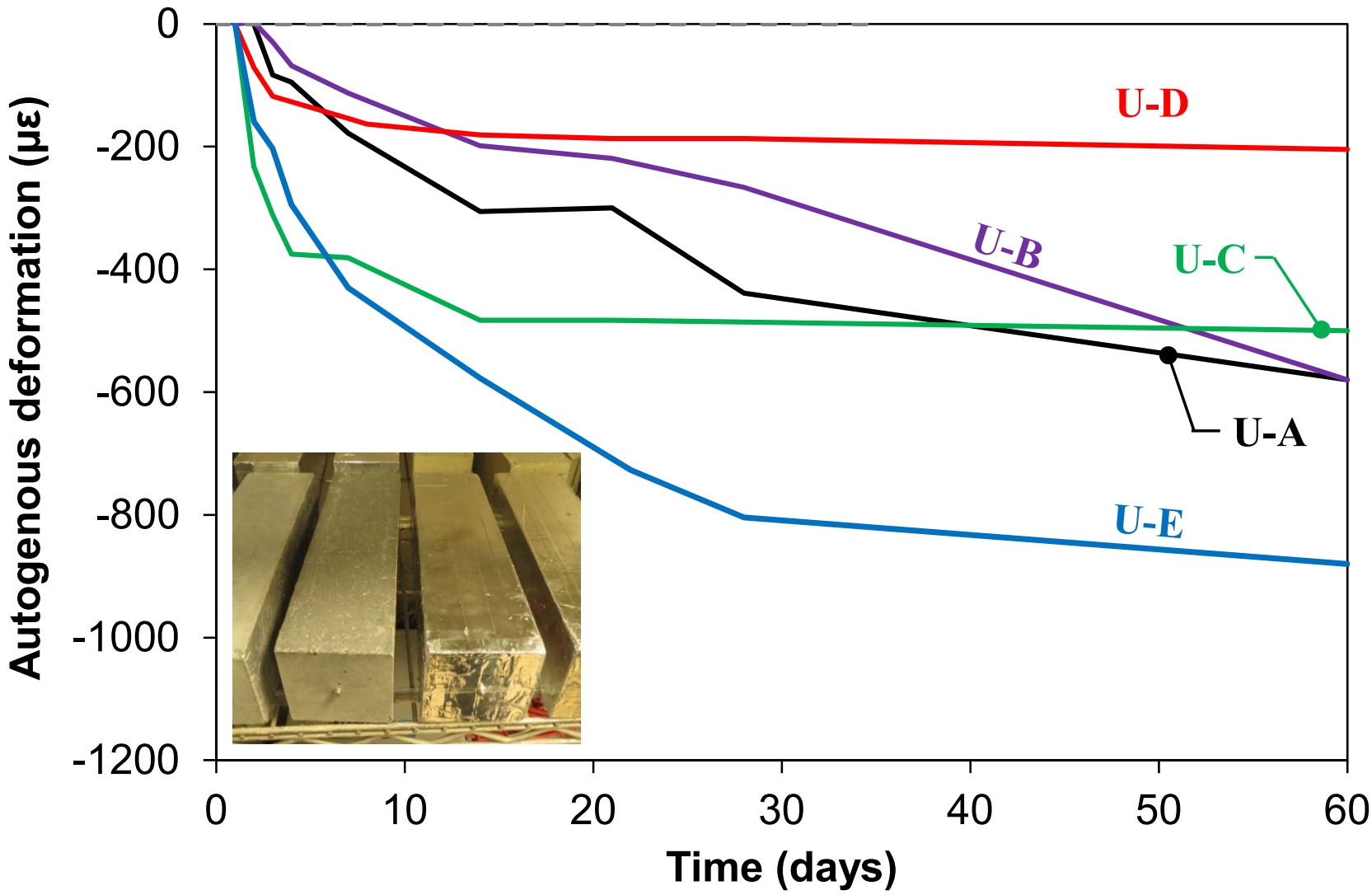




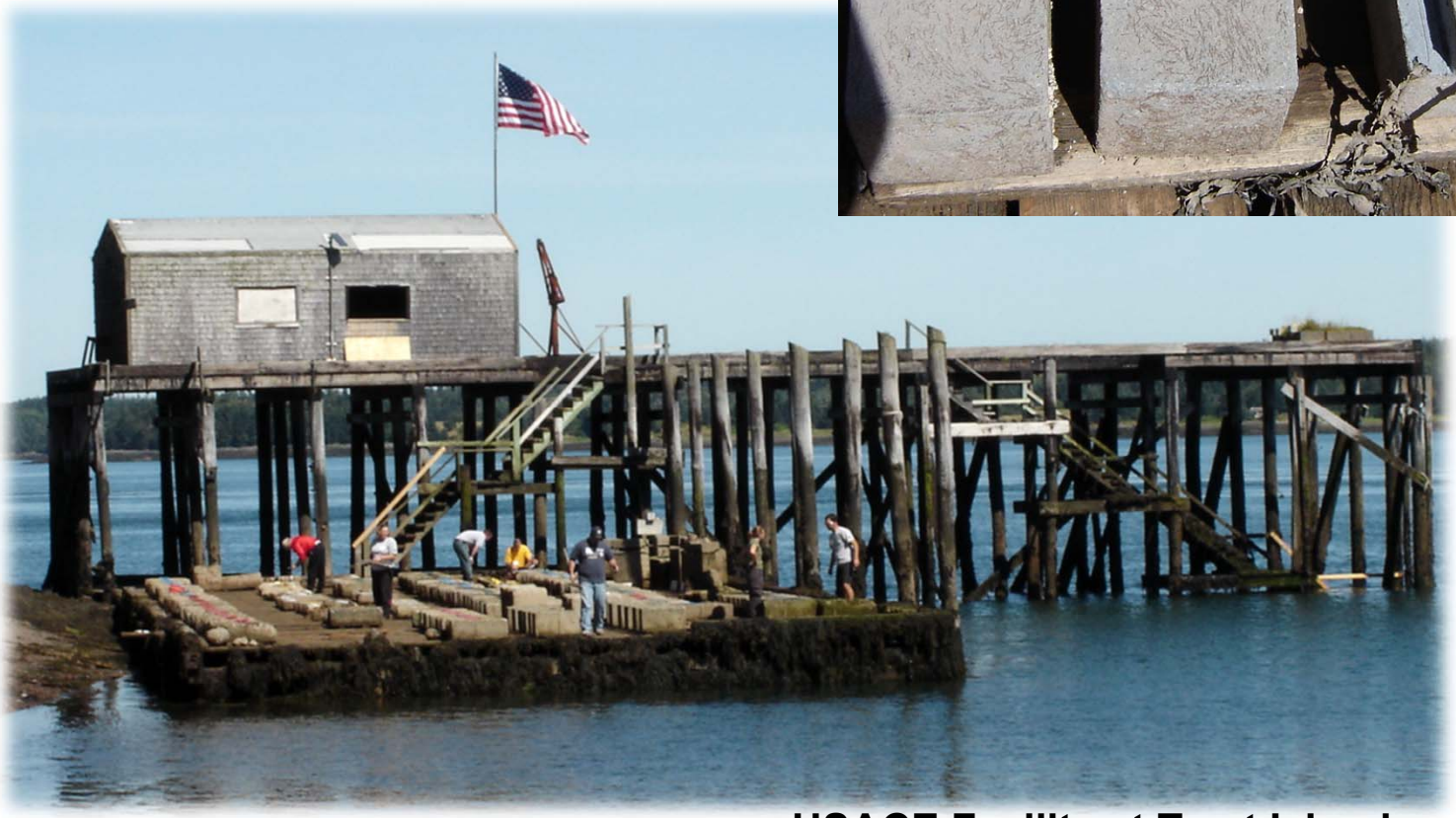




Shrinkage Behavior



Durability



USACE Facility at Treat Island

UHPC Permeability

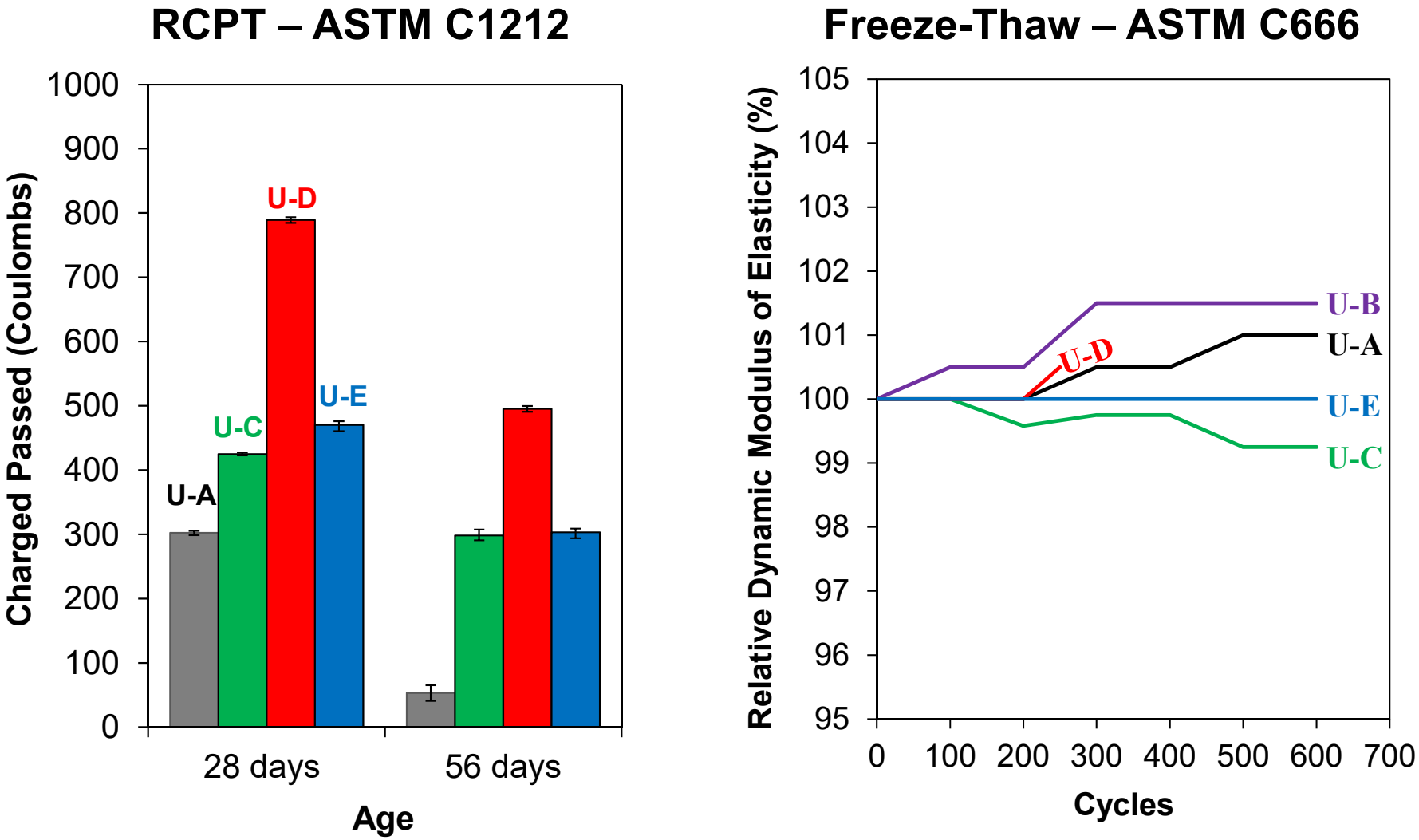
- Chloride Ion Diffusion Coefficient

  2×10^{-11} m^2/s for conventional concrete

  2×10^{-12} m^2/s for HPC

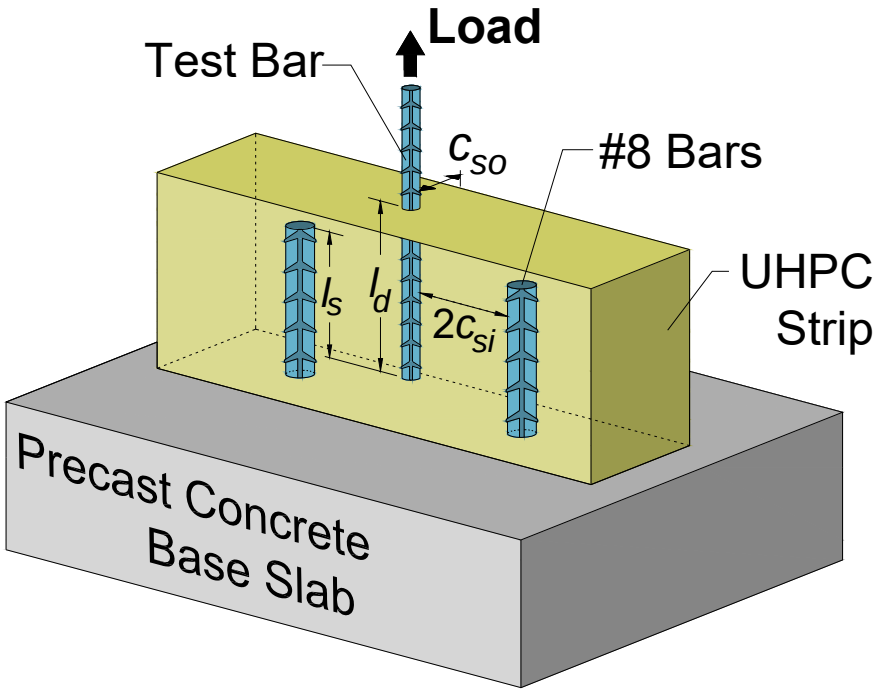
  2×10^{-13} m^2/s for UHPC

Durability


RCPT – ASTM C1212
Charged Passed (Coulombs)
1000
900
800
700
600
500
400
300
200
100
0
U-A
U-C
U-D
U-E
28 days
56 days
Age
Freeze-Thaw – ASTM C666
Relative Dynamic Modulus of Elasticity (%)
105
104
103
102
101
100
99
98
97
96
95
U-B
U-A
U-D
U-E
U-C
0
100
200
300
400
500
600
700
Cycles

Bond to Steel Reinforcing Bars

TEST CONFIGURATION



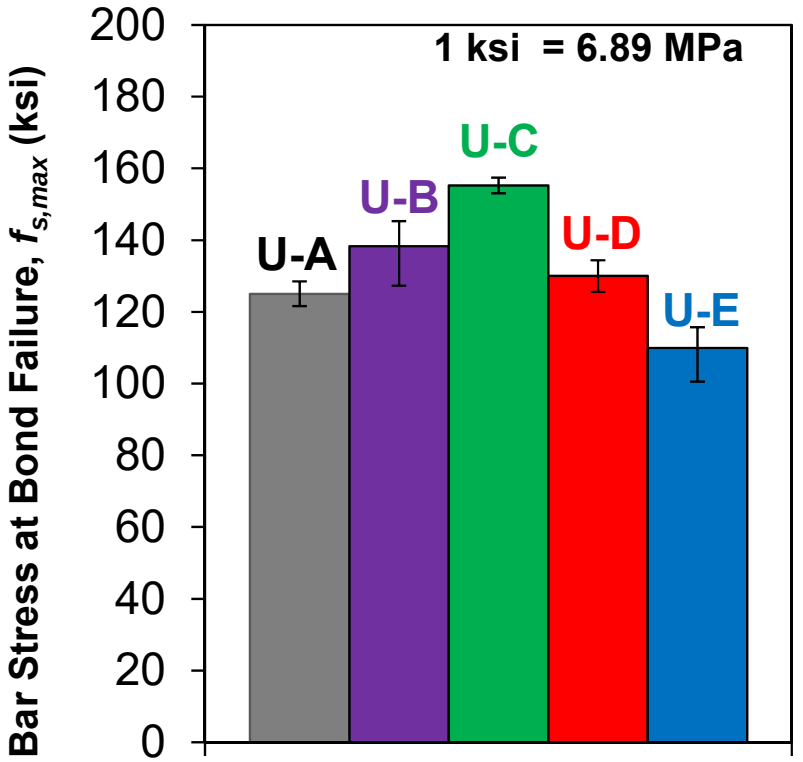
EXAMPLE RESULT

Gr. 120 Bars (Uncoated)

Side Cover : $c_{so} = 3d_b$

Embedment Length: $l_d = 8d_b$

Splice Length: $l_s = 6.4d_b$



Manufacturer-Recommend Fiber Vol.

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
- Interface Bond – Can surpass substrate tensile strength
- Permeability – 100x less than conventional concrete
- Freeze/Thaw Resistance – RDM > 95%
- Rebar Bond – $8d_b$ embedment can deliver yield

UHPC Mixing

UHPC Mixing

UHPC Mixing

UHPC Mixing

UHPC Casting

UHPC Casting

UHPC Casting (Video)

UHPC Casting (Video)

UHPC Structural Design

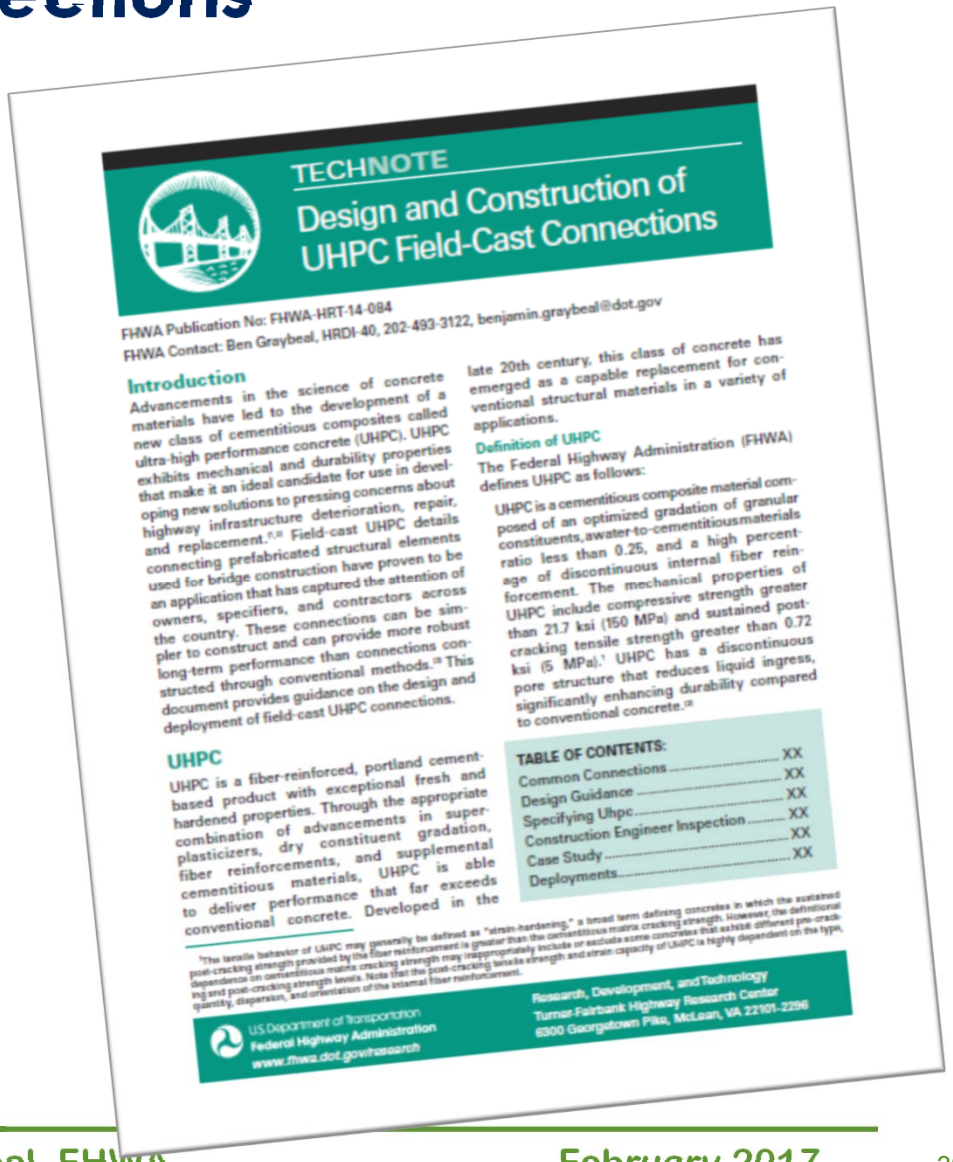
Specifications Published
- France
- Switzerland

Development Underway
- Canada
- US

Design and Construction of UHPC Field-Cast Connections

- FHWA-HRT-14-084

- What is UHPC?
- Example Connections
- Structural Design
- Construction
- Quality Assurance
- Deployments



TECHNOTE

Design and Construction of UHPC Field-Cast 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 exceptional 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.

Definition of UHPC

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]

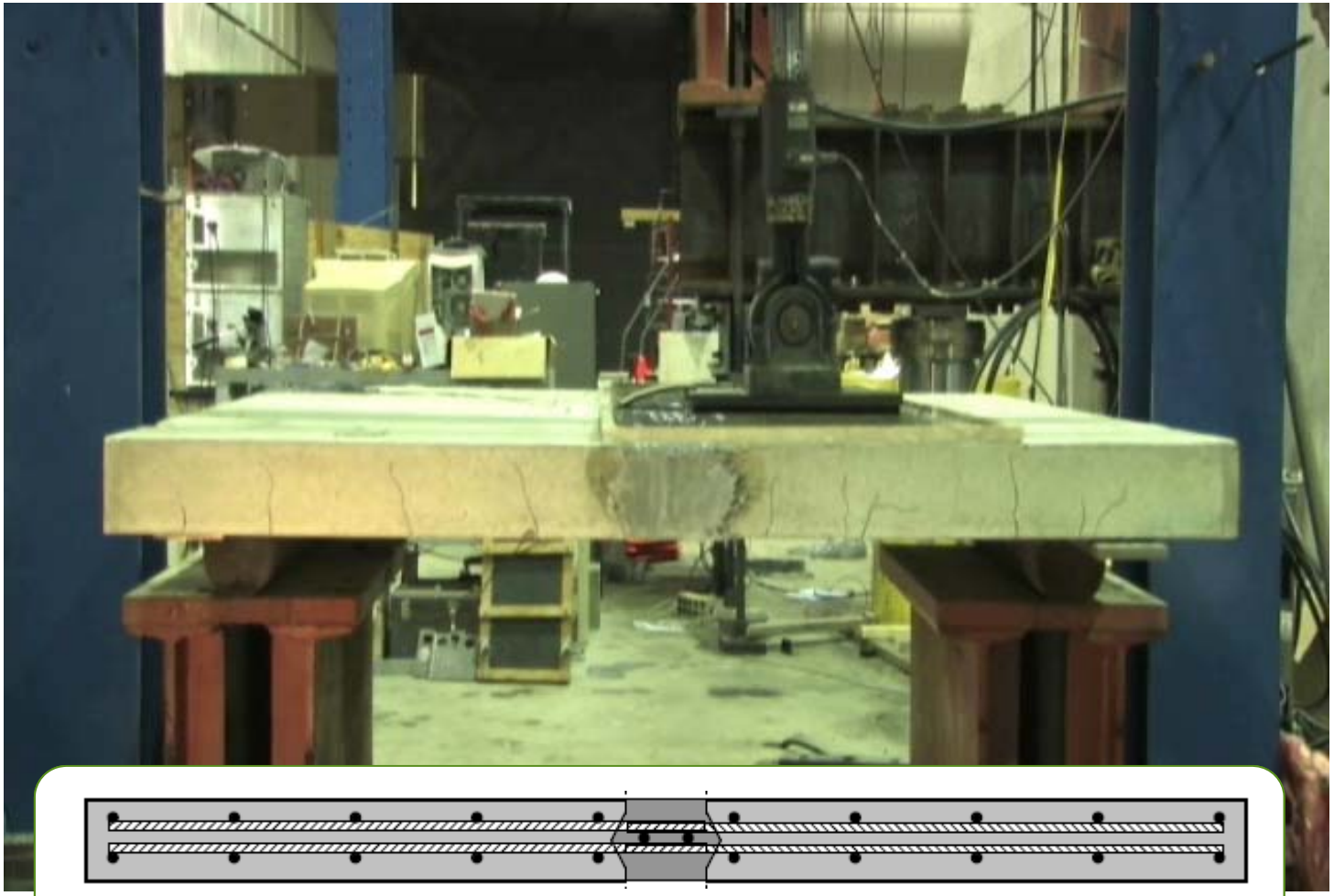
TABLE OF CONTENTS:

[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. However, the definitional dependence on cementitious matrix cracking strength may inappropriately include or exclude some concretes that exhibit different pre-cracking and post-cracking strength levels. 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

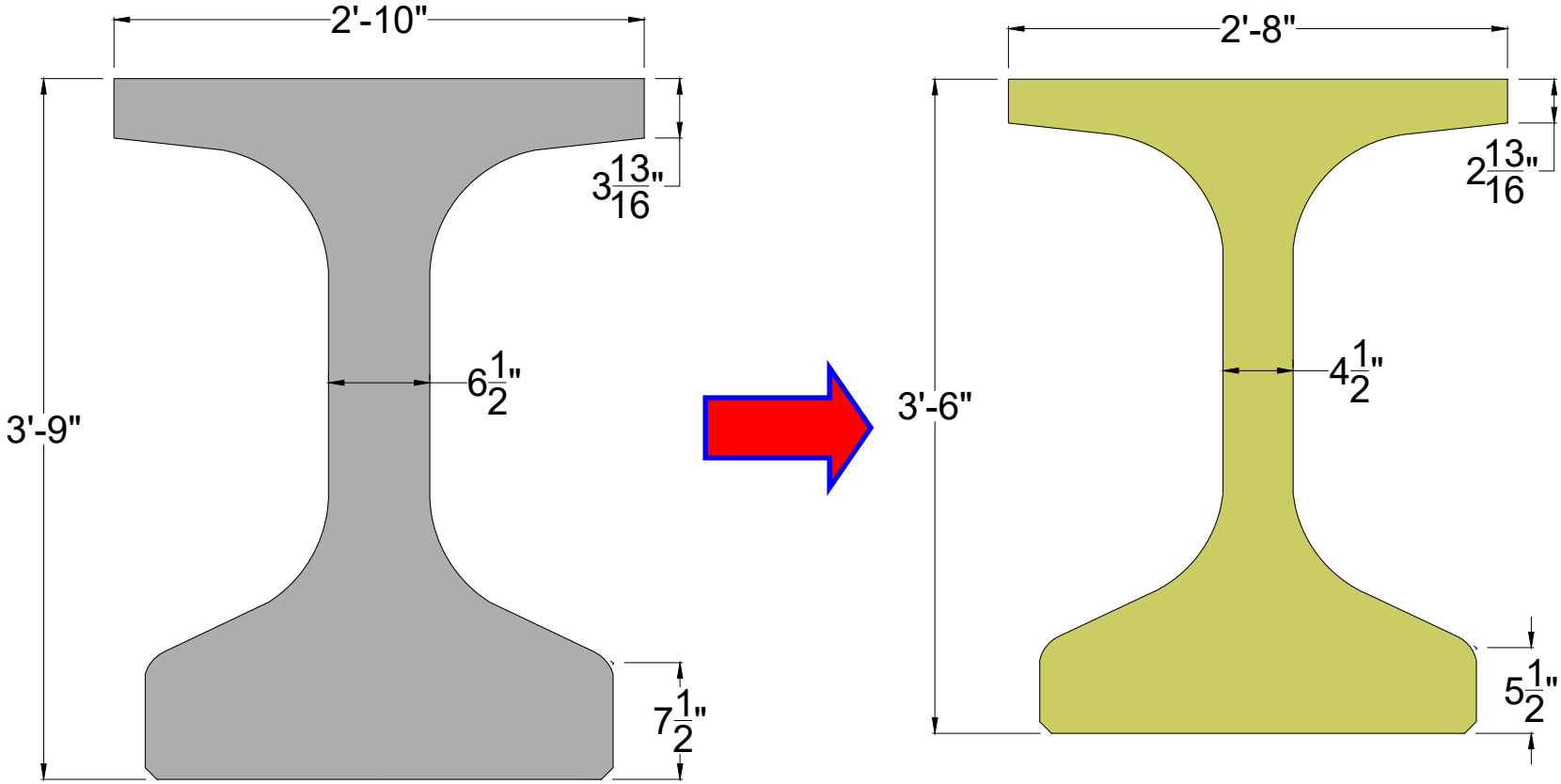
UHPC Structural Behavior



#5 Rebar Lap Splice

Mars Hill Bridge

Mars Hill Bridge



Iowa 45” Bulb Tee

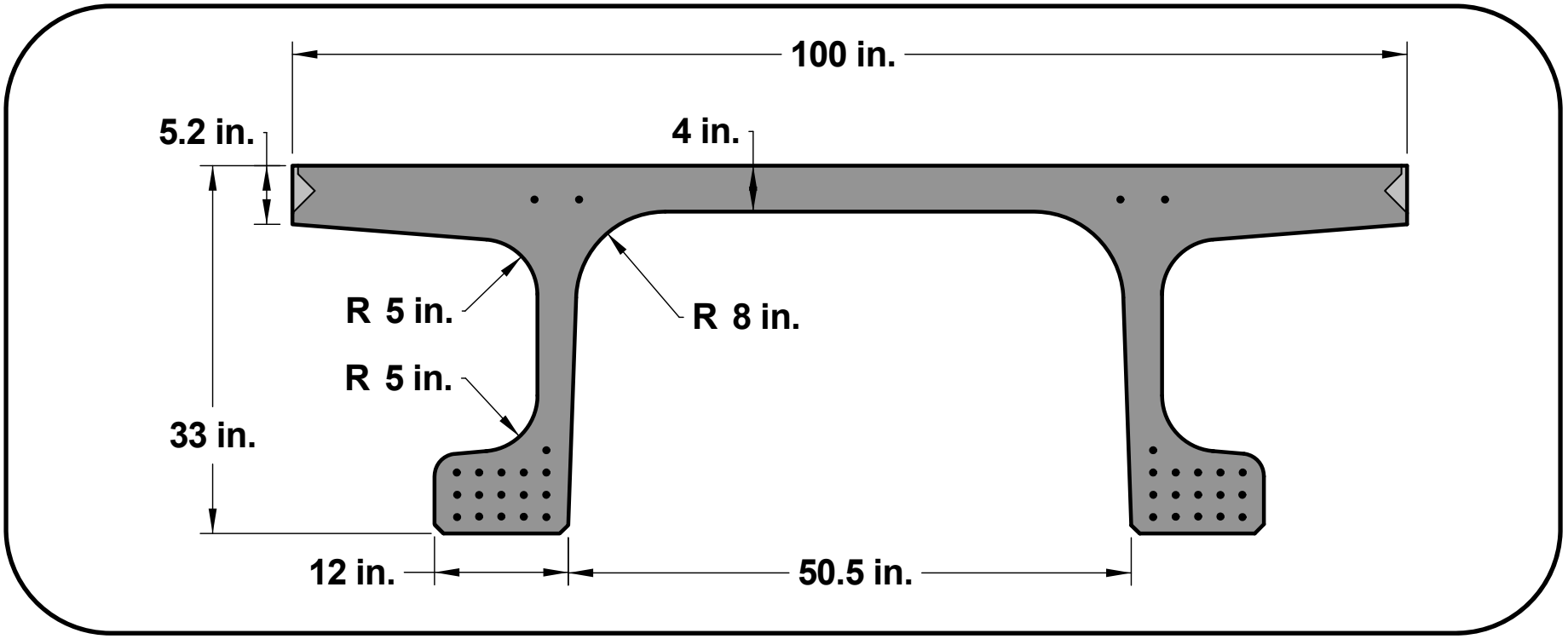
SW ≈ 0.7 kip/ft

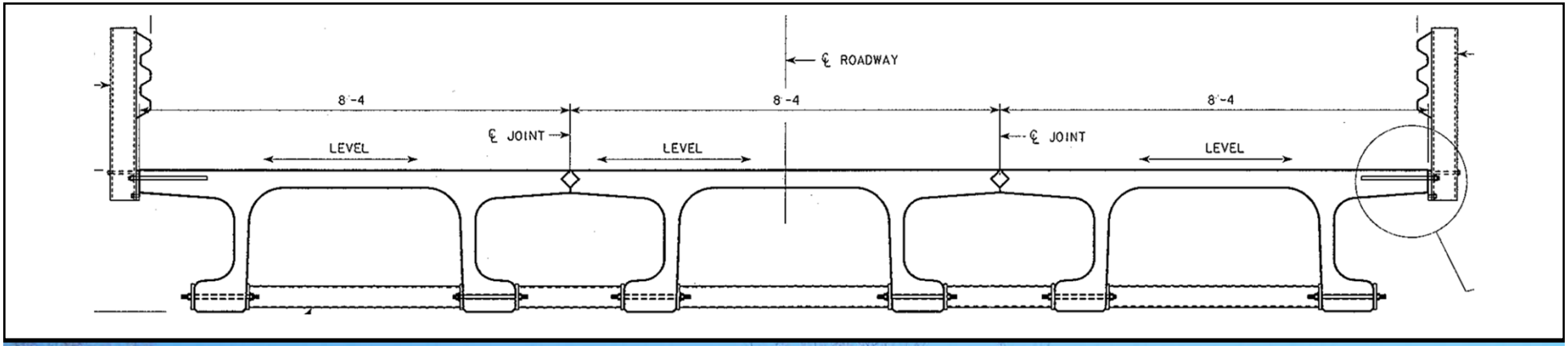
Modified Bulb Tee

SW ≈ 0.56 kip/ft

π-Girder

- 33” depth spans 80’; weight = 932 lb/ft
- Family of girders up to 47” depth





Jakway Bridge
Buchanan County, Iowa

UHPC for Bridge Decks

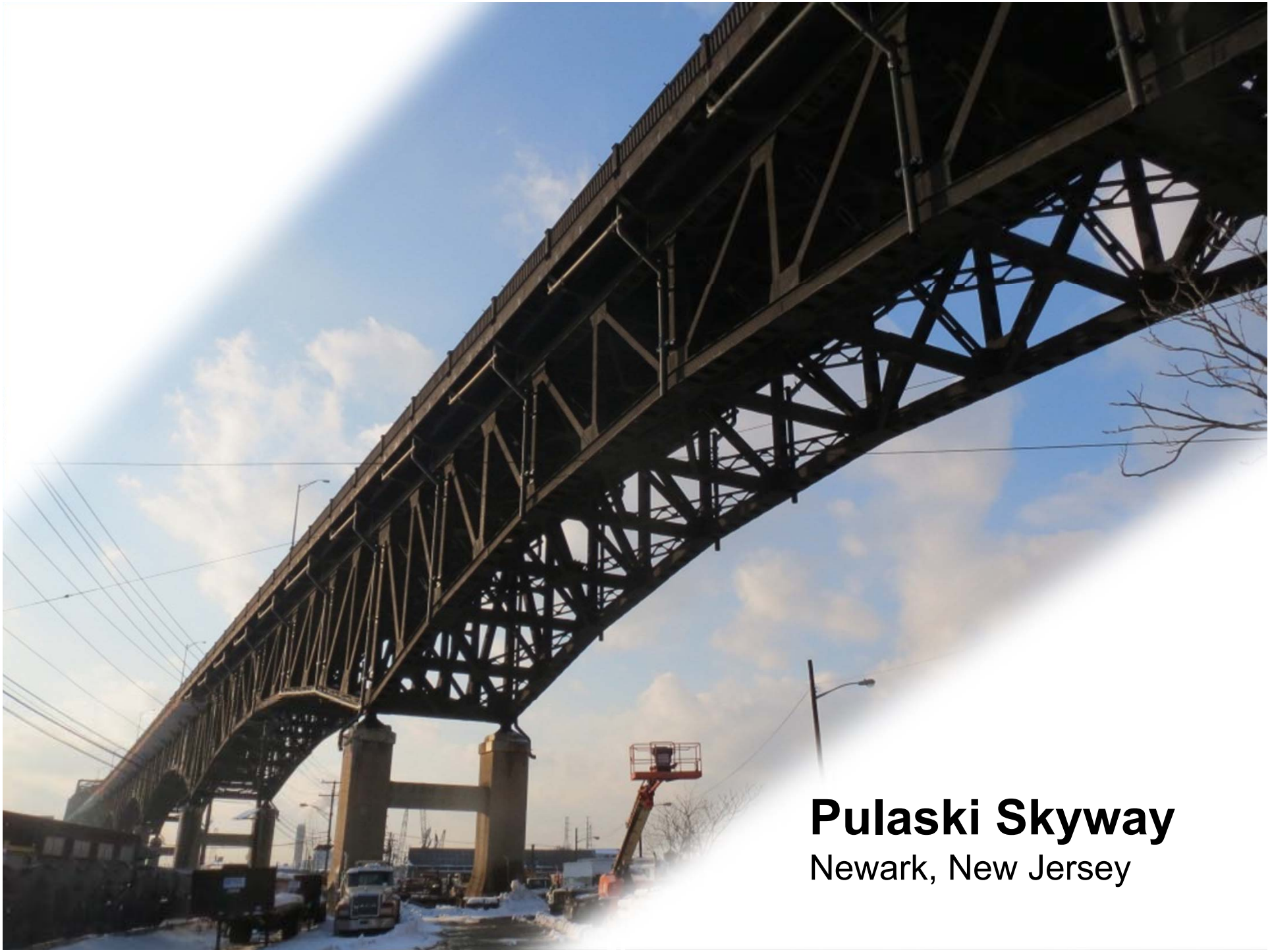
Dahlonega Road Bridge in Wapello County, Iowa

Footbridge – Marseille, France

Foot Bridge of Peace – Seoul, South Korea

MuCEM – Marseille, France

Bourg-les-Valence



Pulaski Skyway

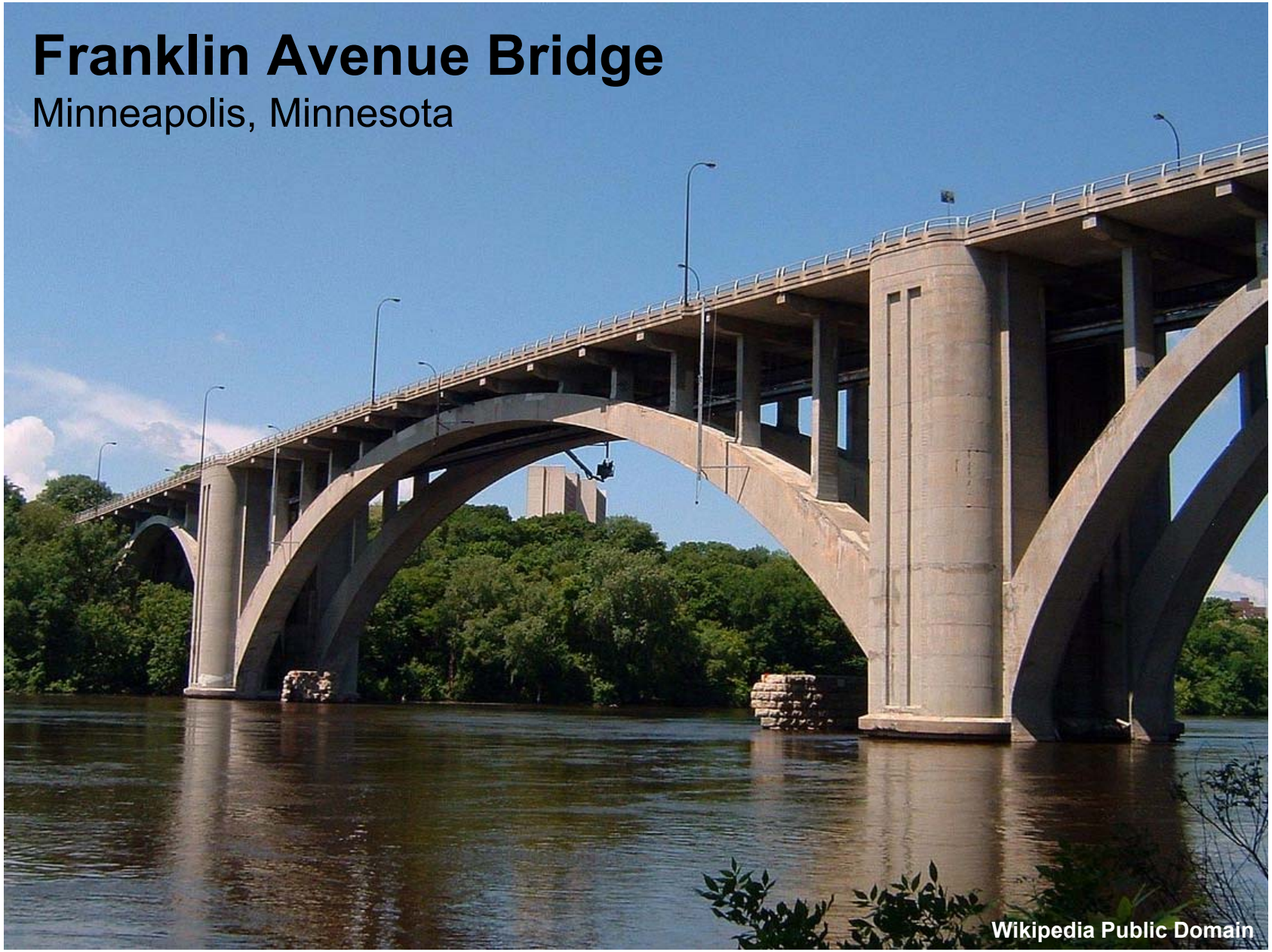
Newark, New Jersey

Precast Deck Panel Connections

Pulaski Skyway
Newark, New Jersey

Franklin Avenue Bridge

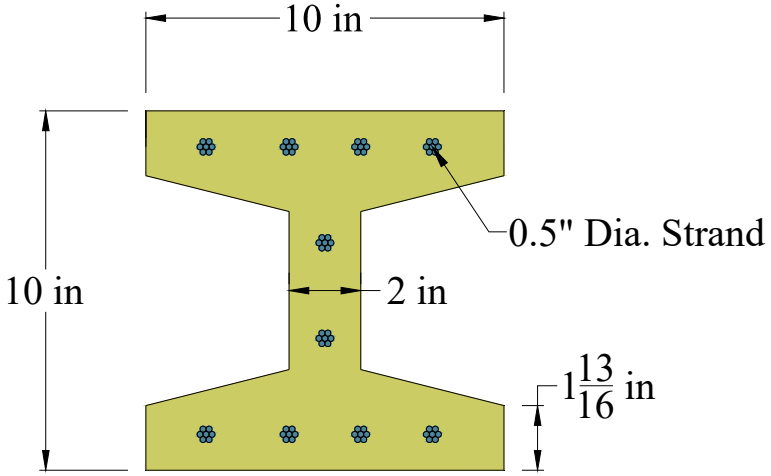
Minneapolis, Minnesota

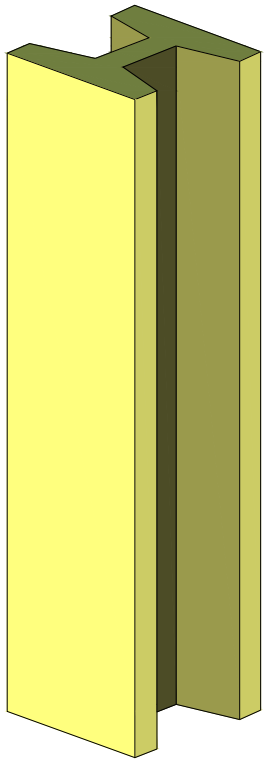


Deck Panel Connections

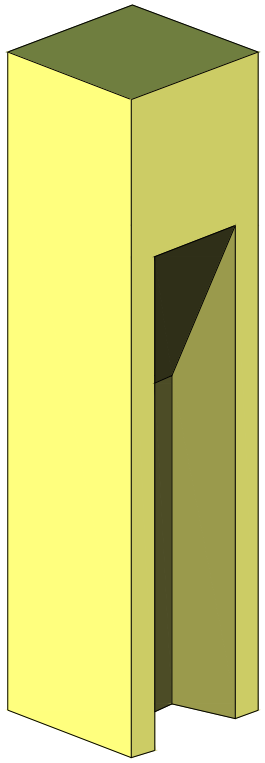
Franklin Ave. Bridge
Minneapolis, MN

UHPC for Pile Foundations





Without Taper



With Taper – Minimize Driving Stresses

UHPC Pile Design – Vande Voort et al. 2008, Iowa State University

UHPC for Seismic Retrofit

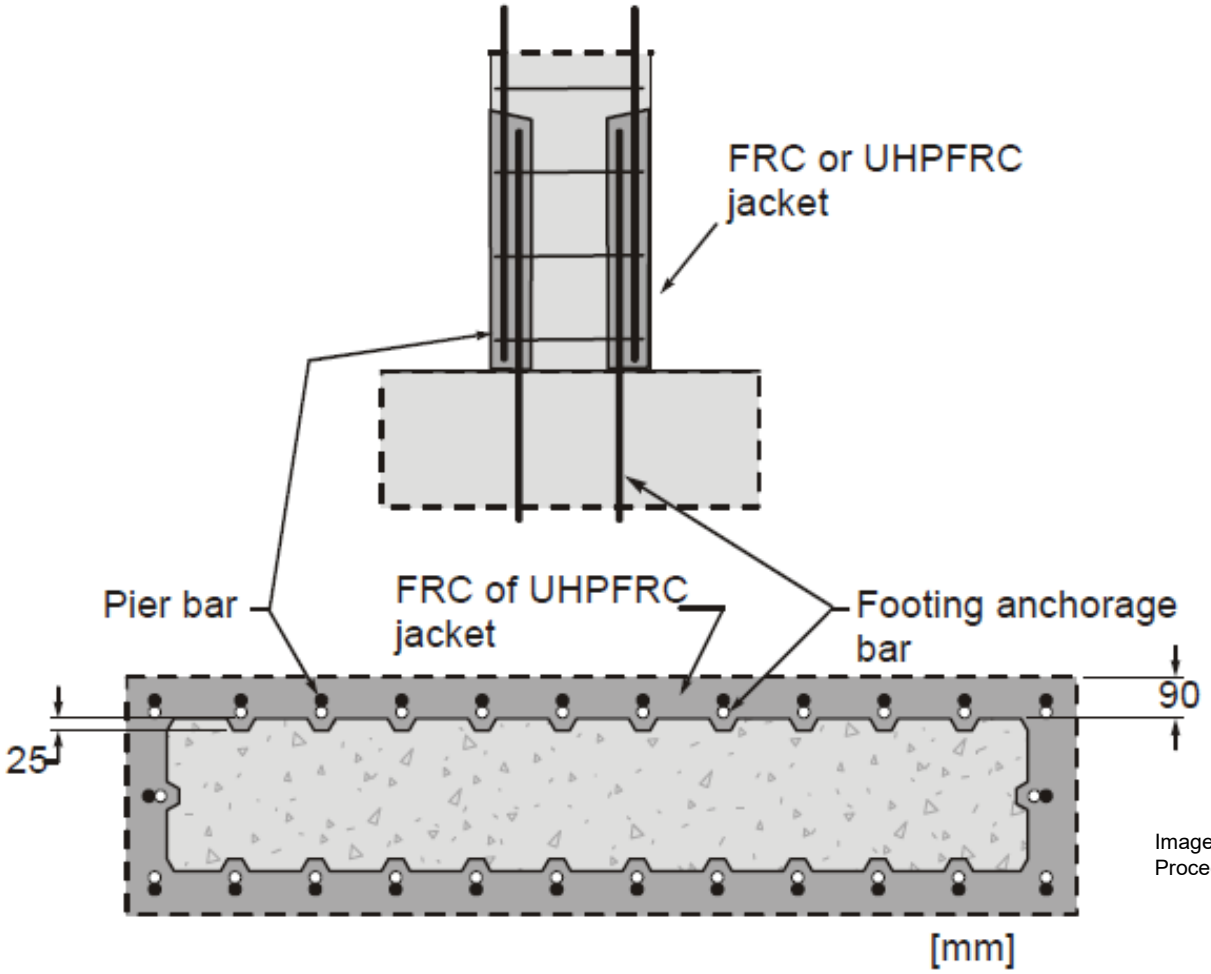
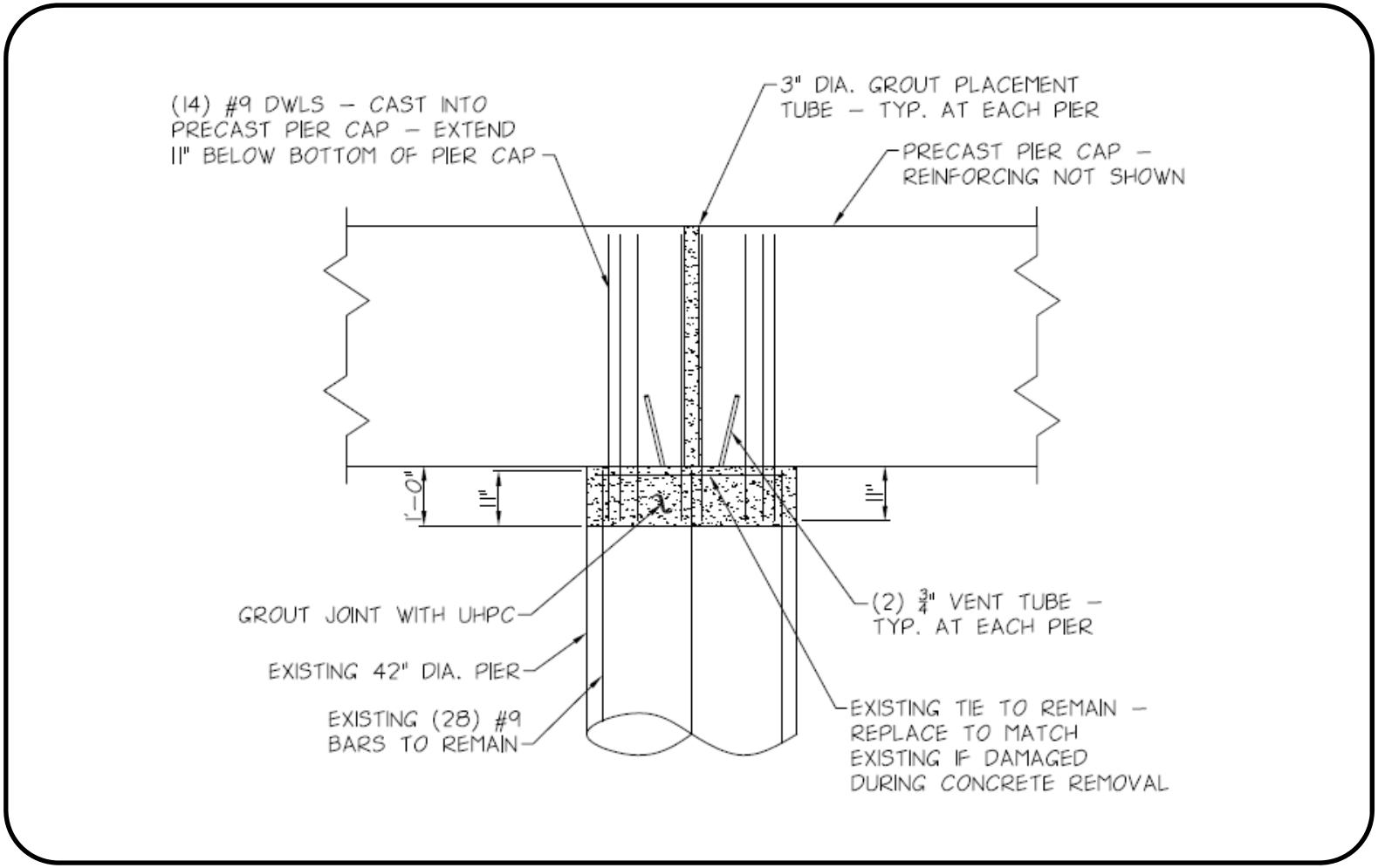


Image Credit:
Proceedings, 2009 UHPFRC, Marseille

Bruno Massicotte, Polytechnique Montreal

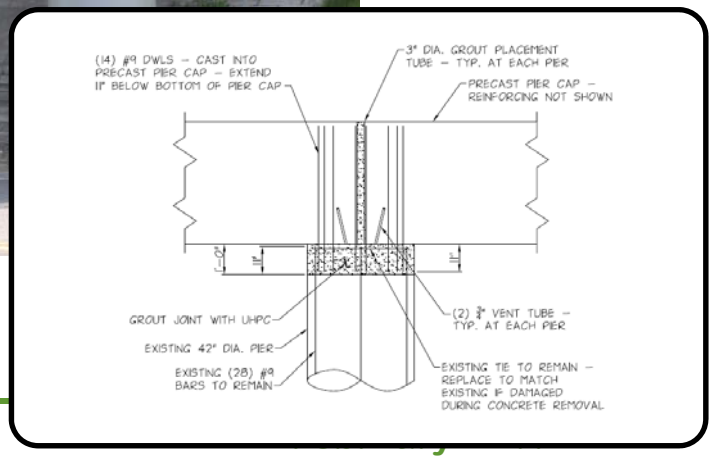
UHPC Connection for Substructures



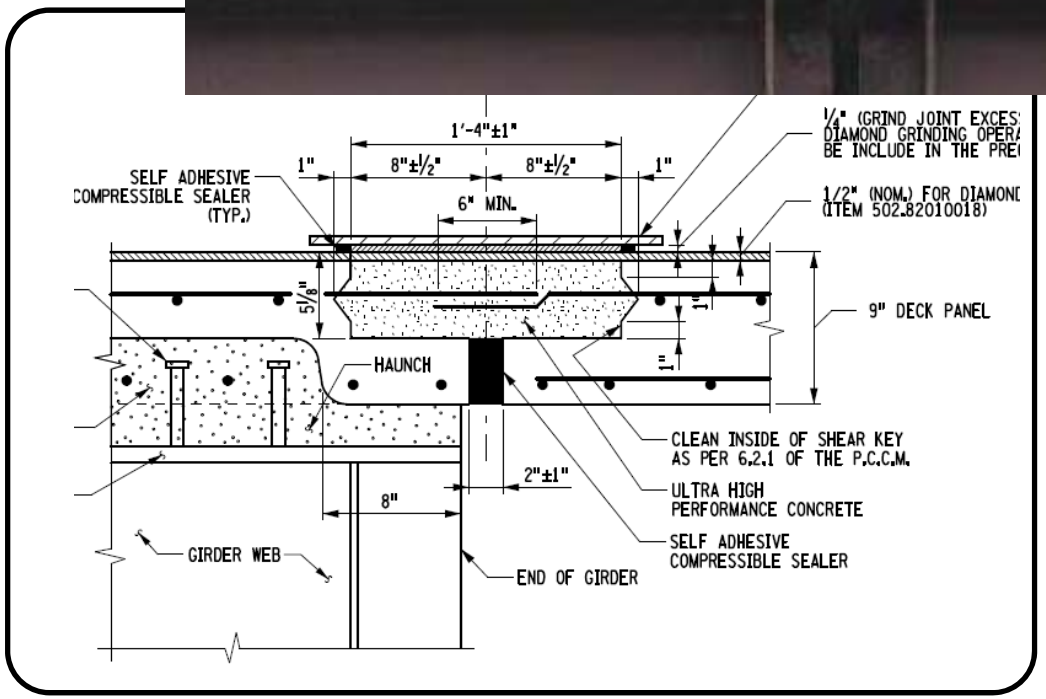
Hooper Road over US 17C in Union, New York

Pier Column to Cap Connection

Hooper Road over Route 17C
Union, New York



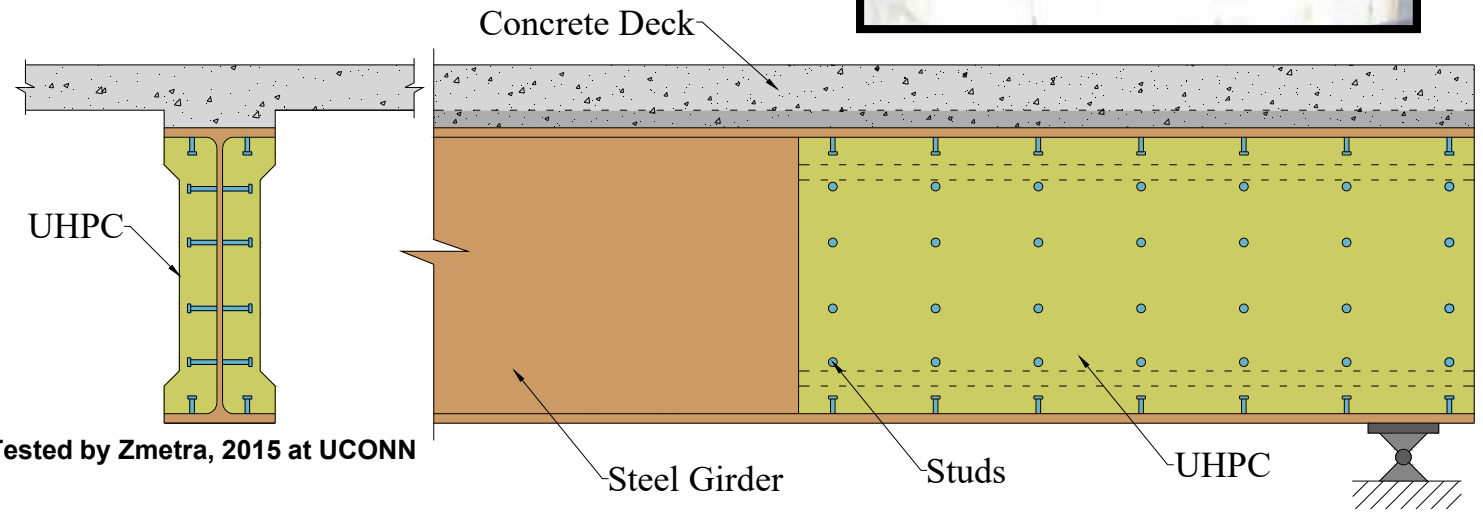
UHPC for Replacing Failing Expansion Joints



SR 96 over I-86 near Owego, NY

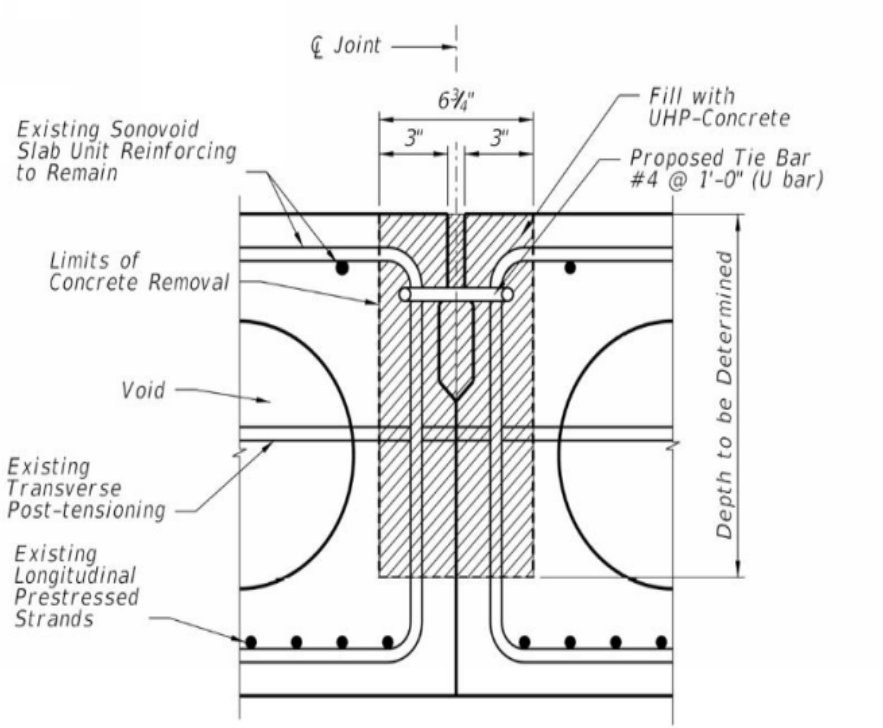
UHPC for Steel Girder Rehabilitation

Photos from Rose & Picard, NYSDOT



Tested by Zmetra, 2015 at UCONN

UHPC for Adjacent Box Beam Repair

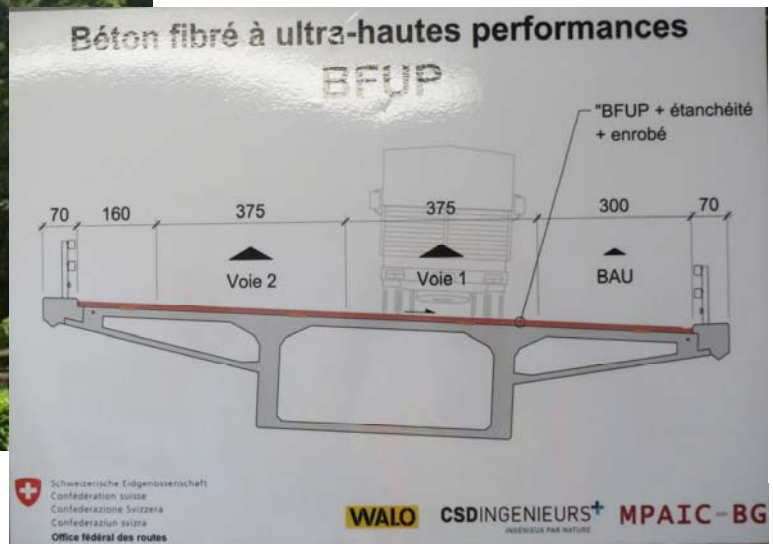


SLAB UNIT CONNECTION DETAIL USING UHP-CONCRETE

Florida DOT

Florida DOT Rehabilitation of SR-714 at Danforth Creek in Fall 2016

UHPC for Bridge Deck Rehabilitation



Chillon Viaduct near Lausanne, Switzerland

UHPC for Bridge Deck Rehabilitation

Chillon Viaduct near Lausanne, Switzerland

UHPC for Bridge Deck Rehabilitation

CR L over Mud Creek near Brandon, Iowa

What is Ultra-High Performance Concrete?

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Resilient Cementitious Composite

What is Ultra-High Performance Concrete?

Capable Solution
for Today's Challenges
and Tomorrow's Opportunities

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UHPC 101

An Introduction to Ultra-High Performance Concrete

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Illinois Transportation and Highway Engineering Conference

February 28, 2017