

UHPC 101

An Introduction to Ultra-High Performance Concrete



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Mid-Atlantic Quality Assurance Workshop – February 2017

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.



FHWA UHPC Web Resources

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

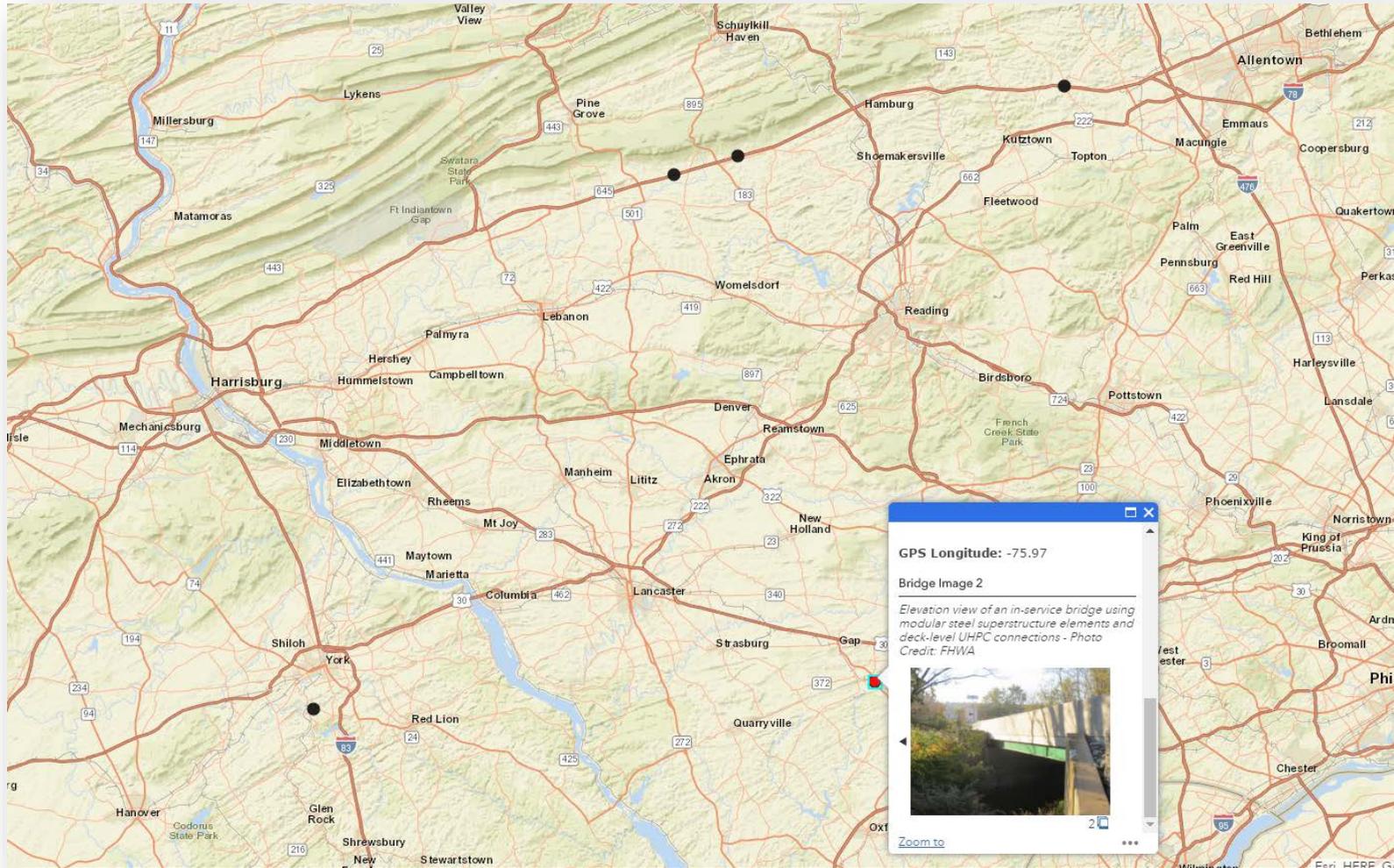
The screenshot displays the FHWA UHPC web page. At the top, the U.S. Department of Transportation Federal Highway Administration logo is on the left, and navigation links for About, Programs, Resources, Briefing Room, Contact, and Search FHWA are on the right. Social media icons for Facebook, YouTube, Twitter, and LinkedIn are also present. The main header reads "Federal Highway Administration Research and Technology" with the tagline "Coordinating, Developing, and Delivering Highway Transportation Innovations". Below this is a search bar labeled "Search Research & Technology". The breadcrumb trail indicates the current location: "Federal Highway Administration > Research > Other Resources > Ultra-High Performance Concrete". A secondary navigation bar includes "About UHPC | UHPC Q&A | Research Projects | List of Bridges | Publications | Contact". The left sidebar contains a menu with items: Research Home, What's New, About R&T, FHWA Research, FHWA Research and Technology Agenda, Research Partnership Programs, Turner-Fairbank Highway Research Center, and FHWA Research Topics. The main content area features the title "Ultra-High Performance Concrete" and a "Q&A: Ultra-High Performance Concrete" section. It includes a question "Q: What is concrete?" and an answer "A: Concrete is a composite material made from coarse aggregate (rocks), fine aggregate (sand), portland cement, and water. When mixed, the portland cement and water combine together in a chemical reaction to create the glue that holds together the aggregates. Concrete starts as a semi-liquid that can be placed or formed. It hardens over time to create a solid that is similar to rock." Below this is another question "Q: What is ultra-high performance concrete?" and the start of an answer "A: Ultra-high performance concrete (UHPC) is a class of concrete that combines together many of the recent advances in concrete science to create a material with far superior properties. In". To the right of the main content is a "Find an Expert" section with the heading "Research and Development Links" and a list of links: Research and Development (R&D) Offices, R&D Experts, R&D Laboratories, R&D Projects, R&D Publications, and R&D Topics.

UHPC Deployments Across US and Canada



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

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<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



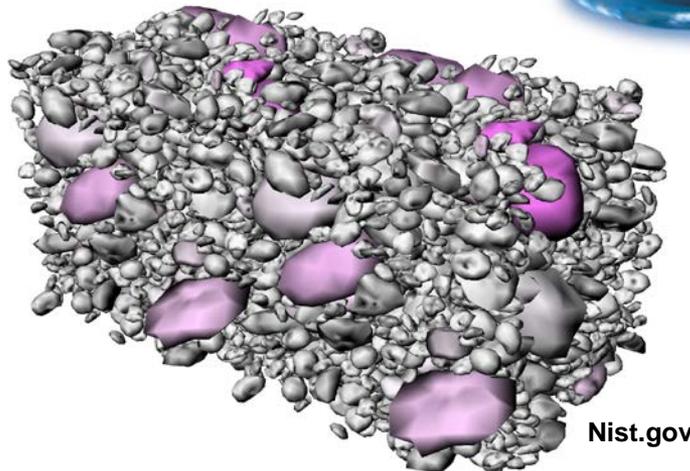
Superplasticizers



Supplementary Cementitious Materials



Particle Packing Theory



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

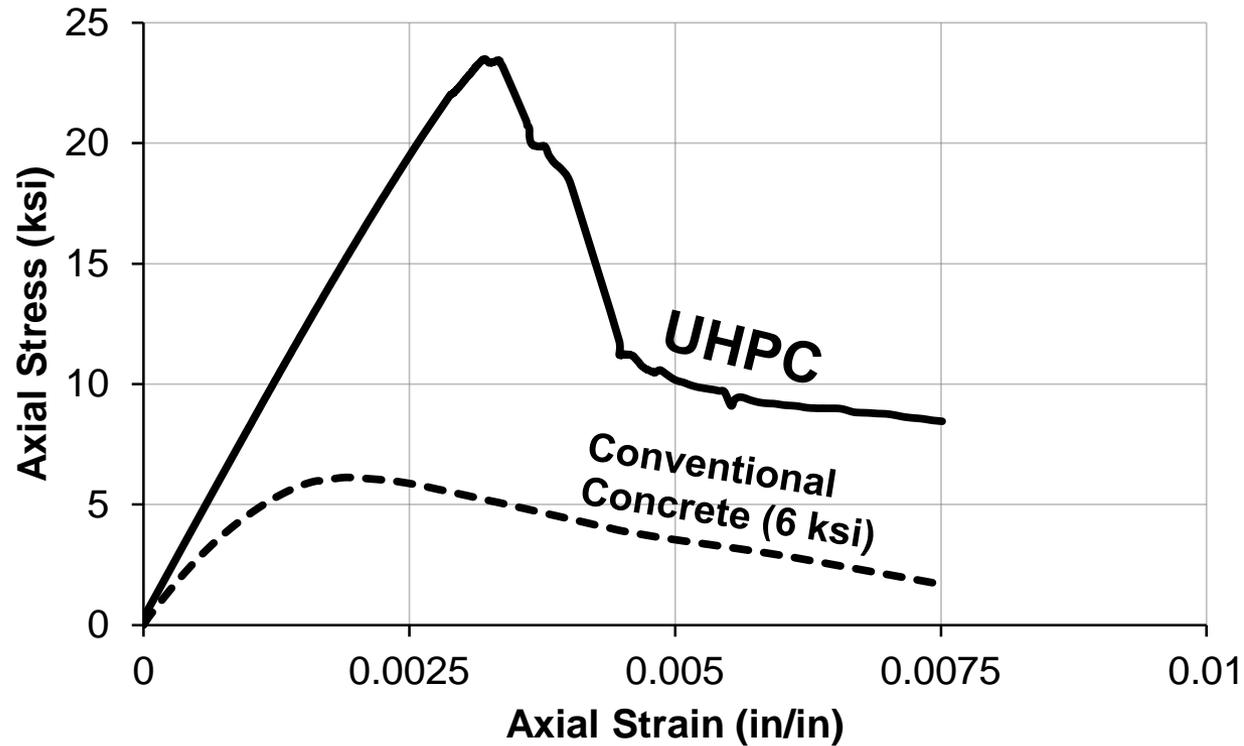
Constituent	Amount (lb/yd ³)	Amount (kg/m ³)
Portland Cement	1331	790
Silica Fume	334	198
Fly Ash (Class F)	324	192
Fine Basalt	1923	1141
Steel Fibers	199	118
Superplasticizer	47	28
Water	246	146

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

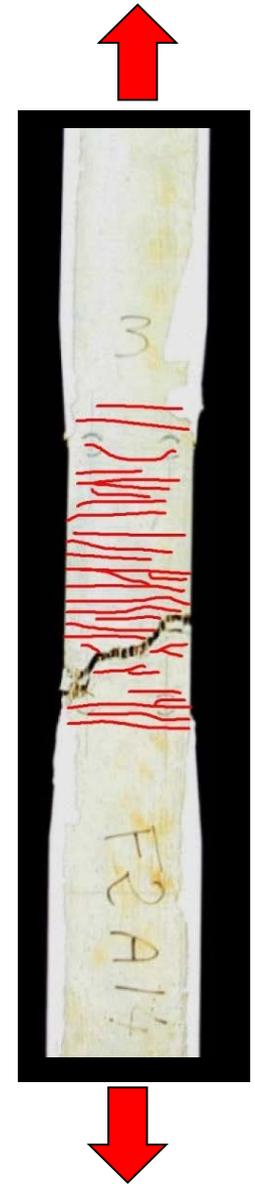
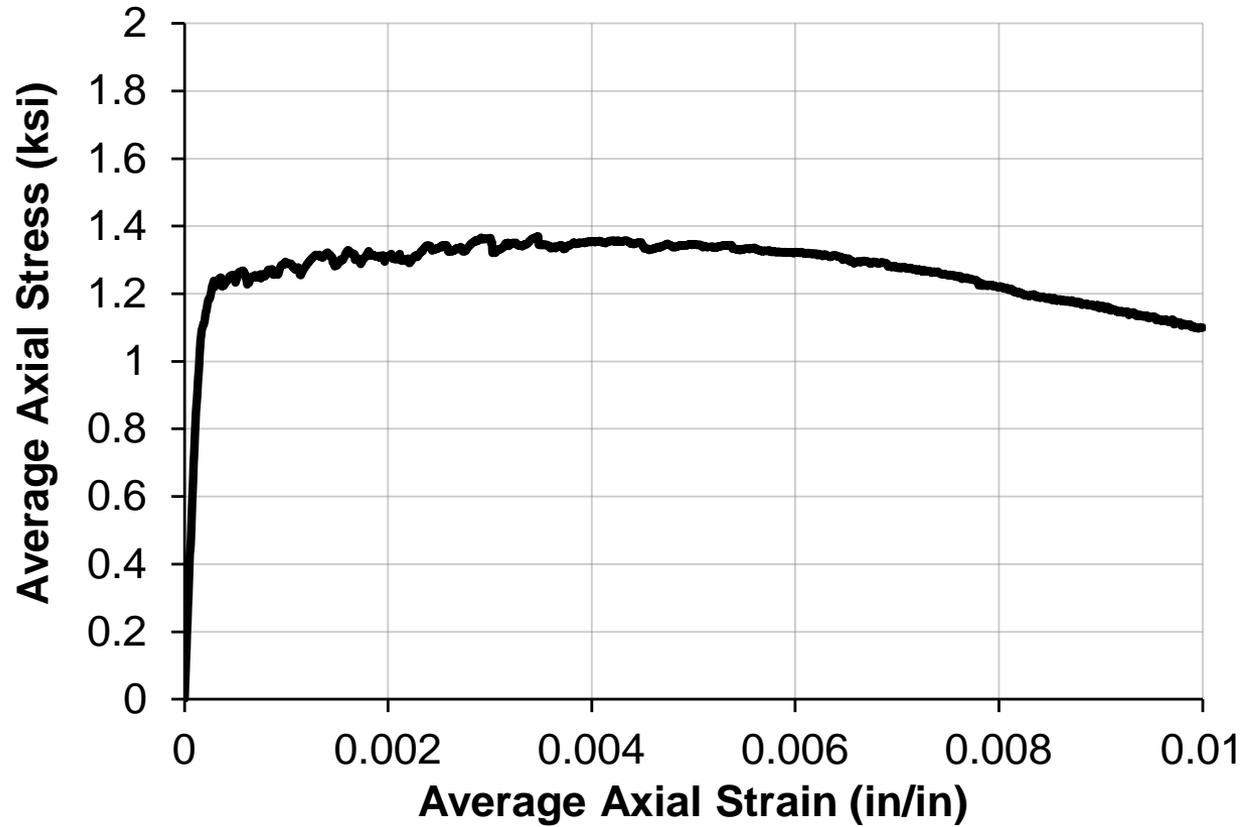
Fiber Reinforcement



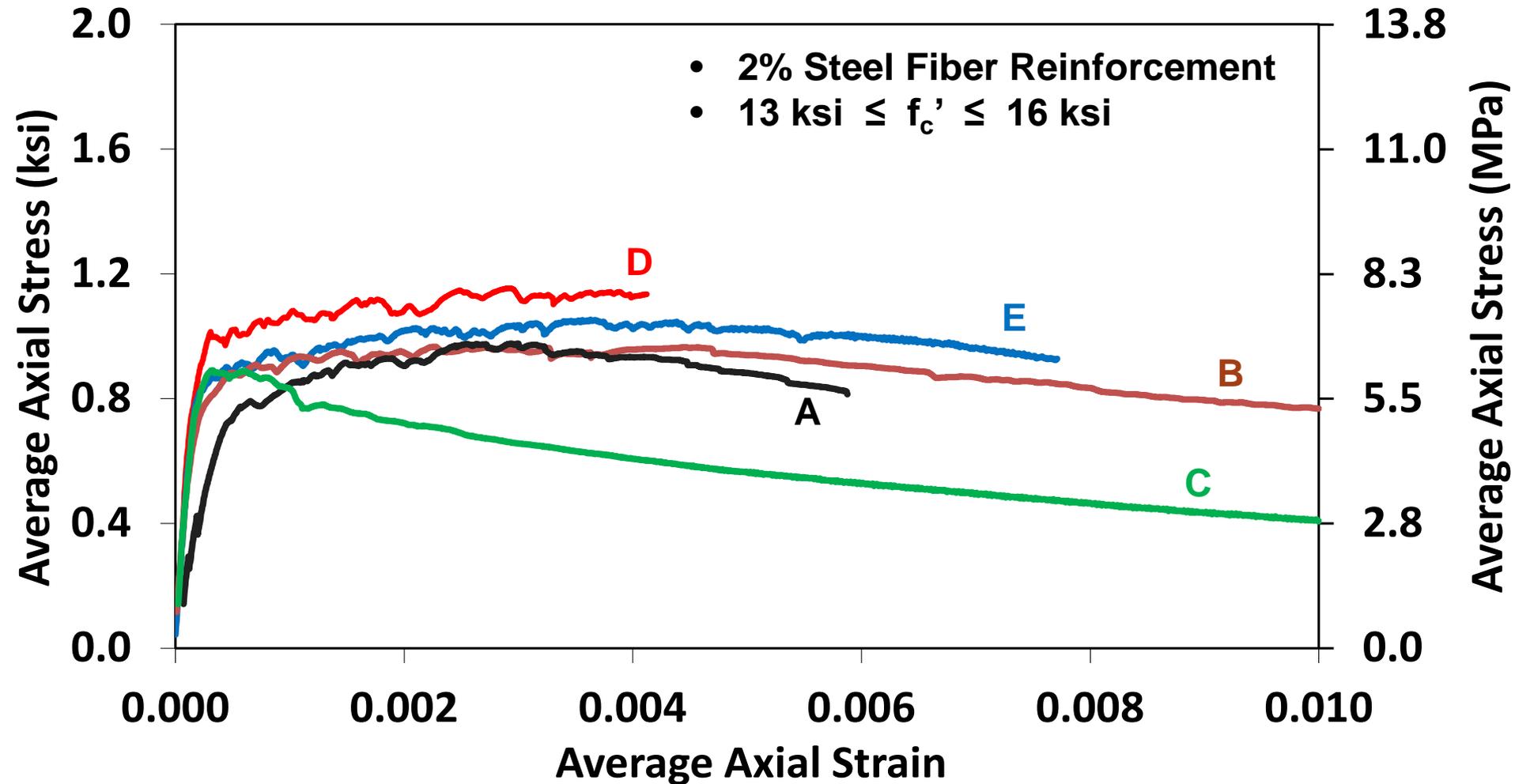
Compression Behavior



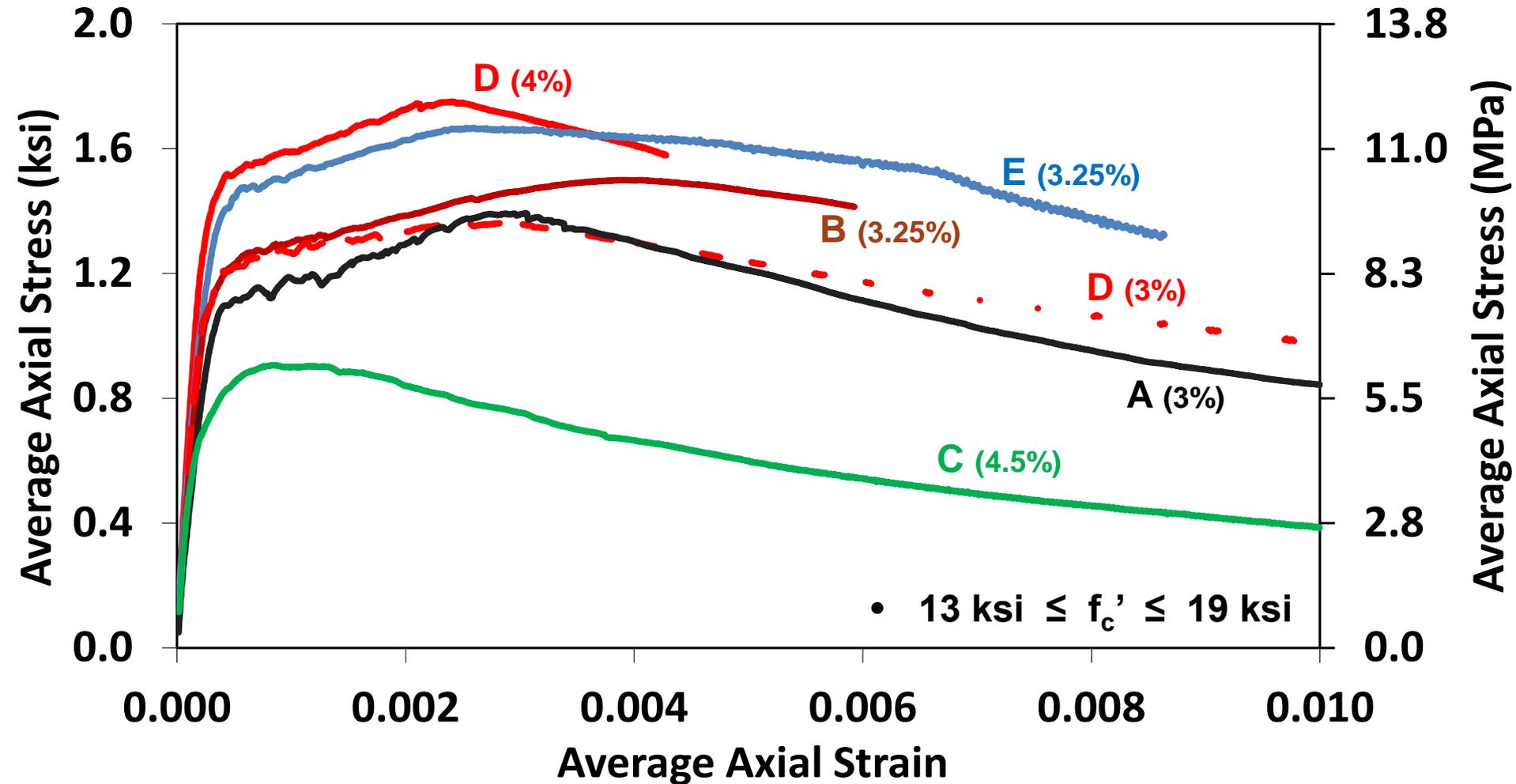
Tensile Behavior



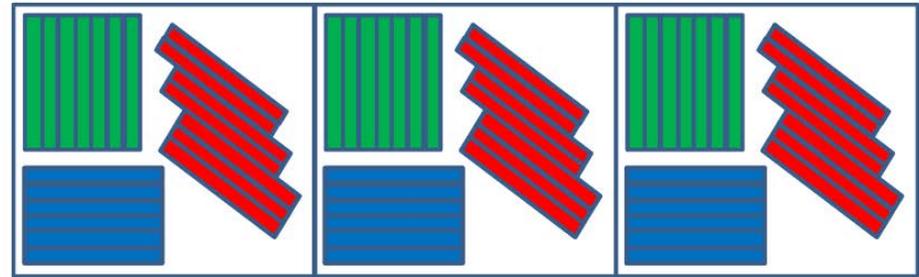
Tensile Behavior



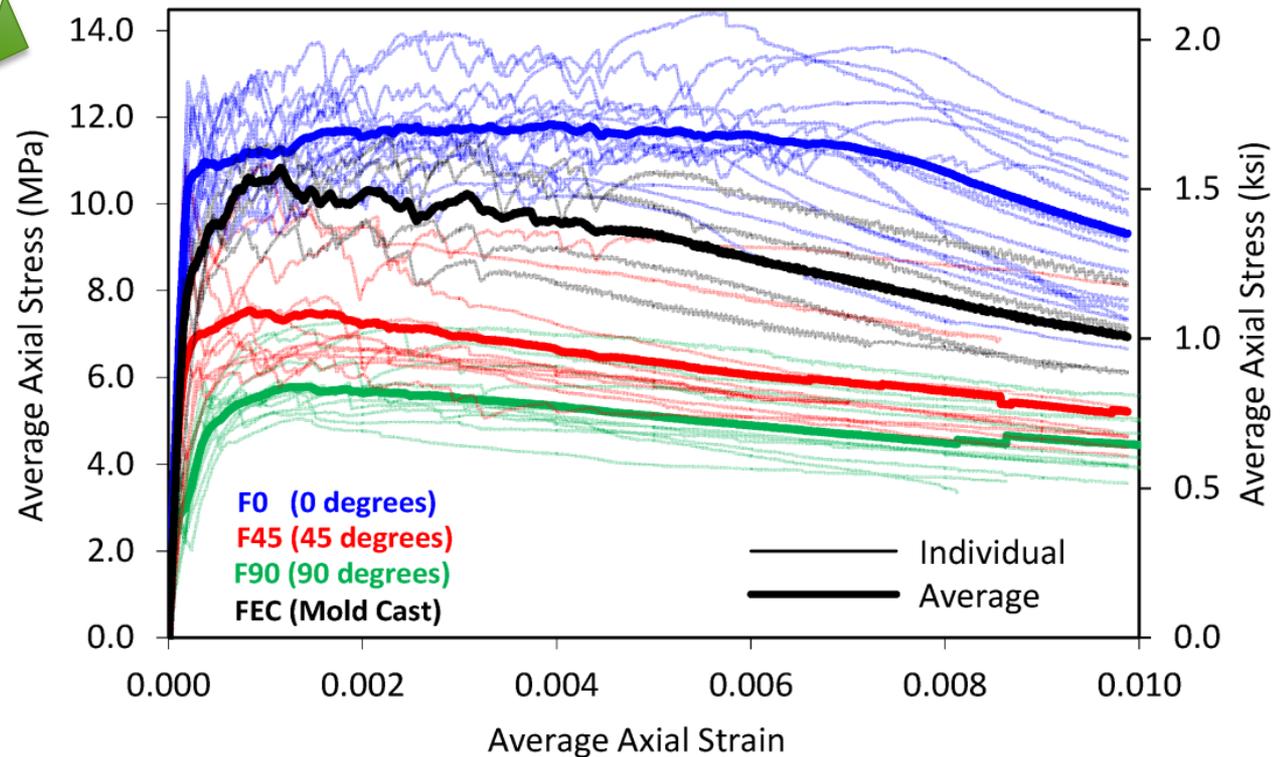
Tensile Behavior



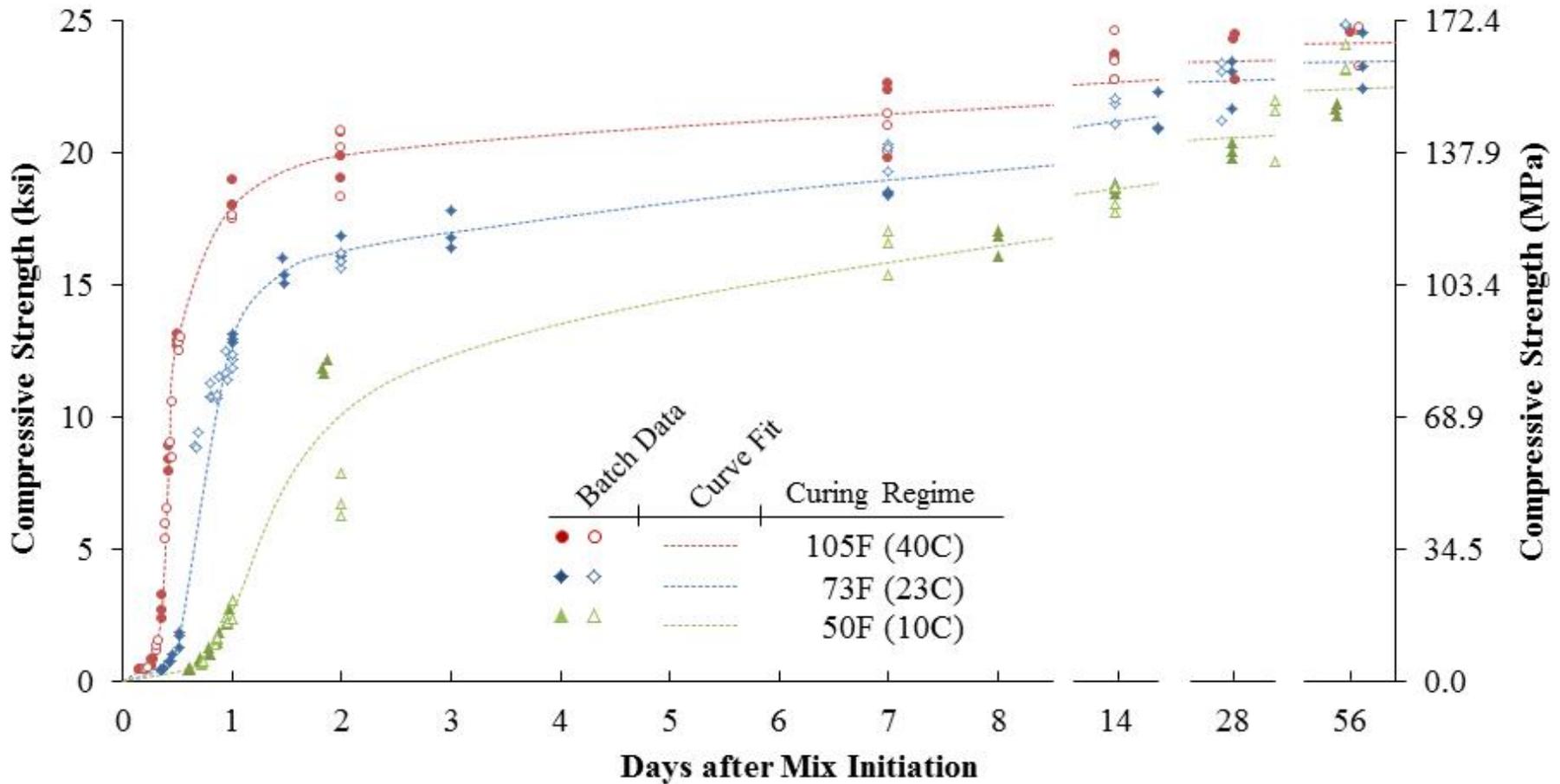
Tensile Behavior



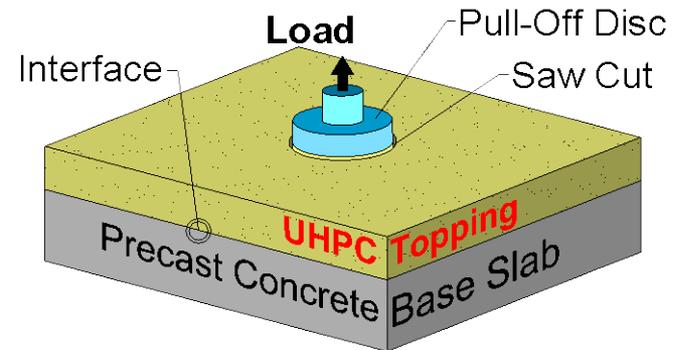
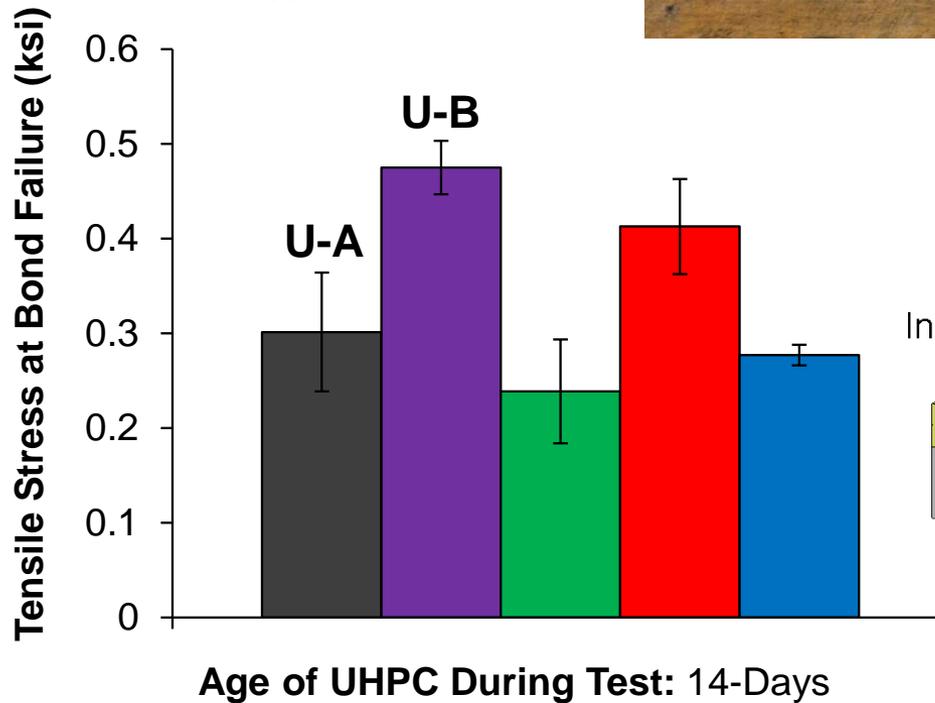
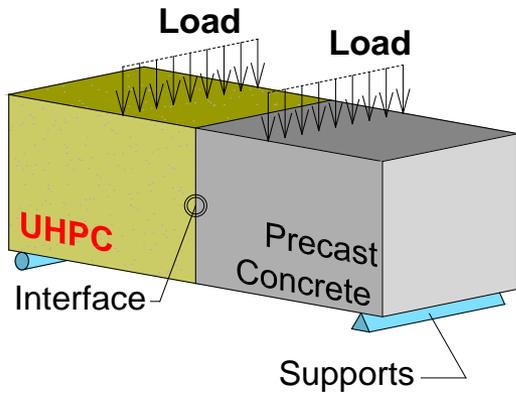
Slab Element



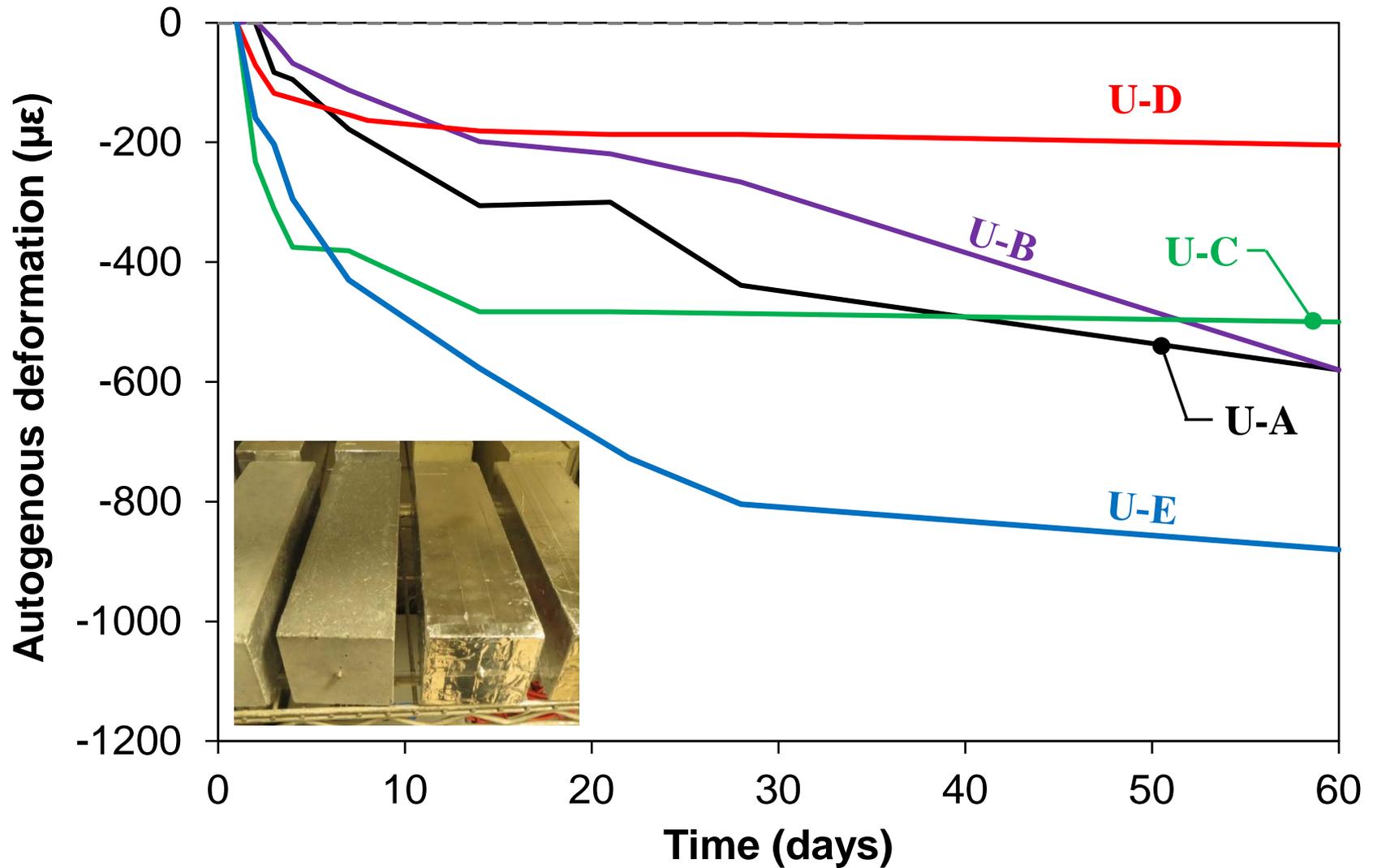
Compression Strength Gain



Interface Bond



Shrinkage Behavior



Durability



USACE Facility at Treat Island

UHPC Permeability

- Chloride Ion Diffusion Coefficient

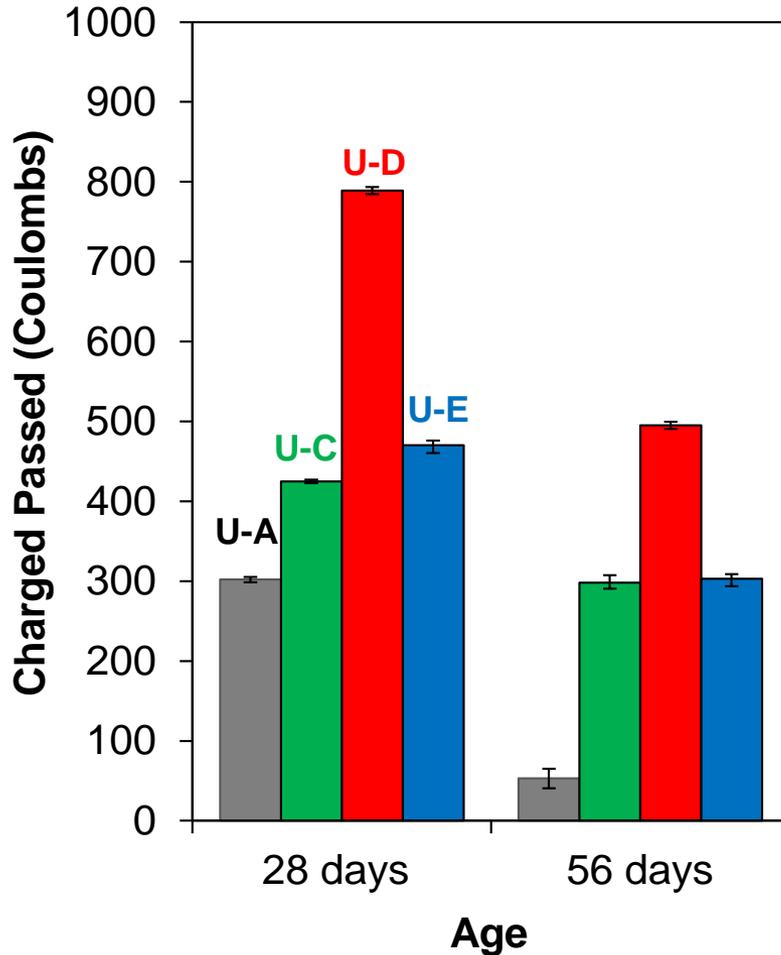
$2 \times 10^{-11} \text{ m}^2/\text{s}$ for conventional concrete

$2 \times 10^{-12} \text{ m}^2/\text{s}$ for HPC

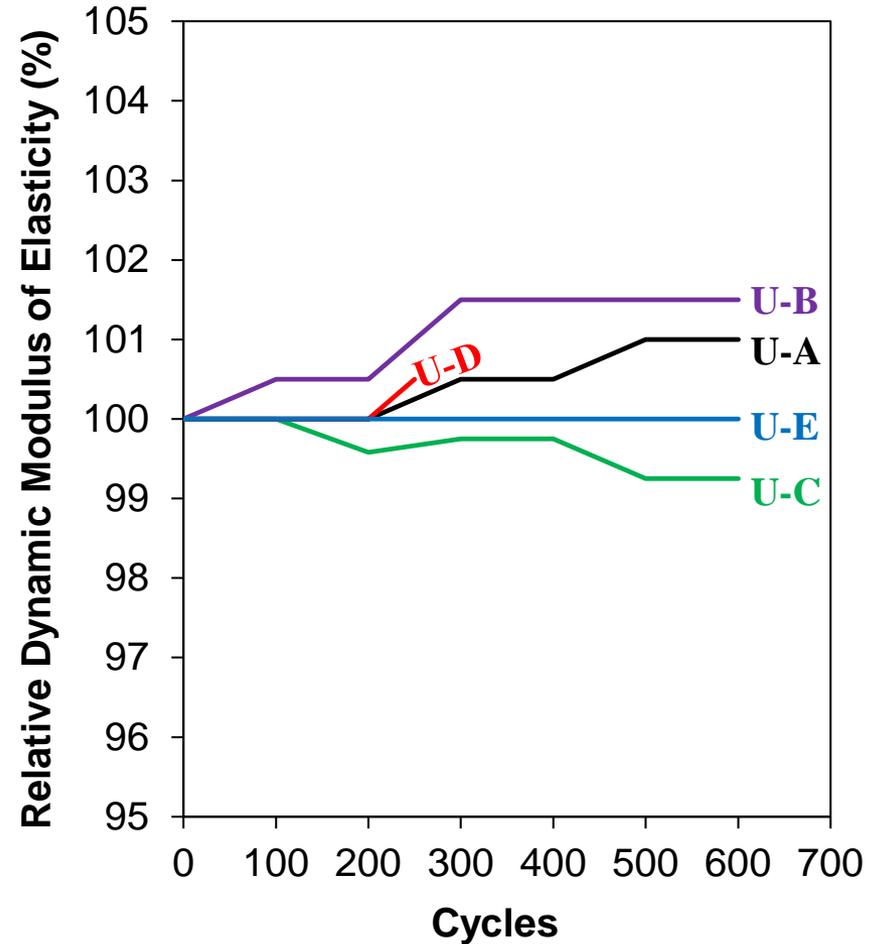
$2 \times 10^{-13} \text{ m}^2/\text{s}$ for UHPC

Durability

RCPT – ASTM C1212

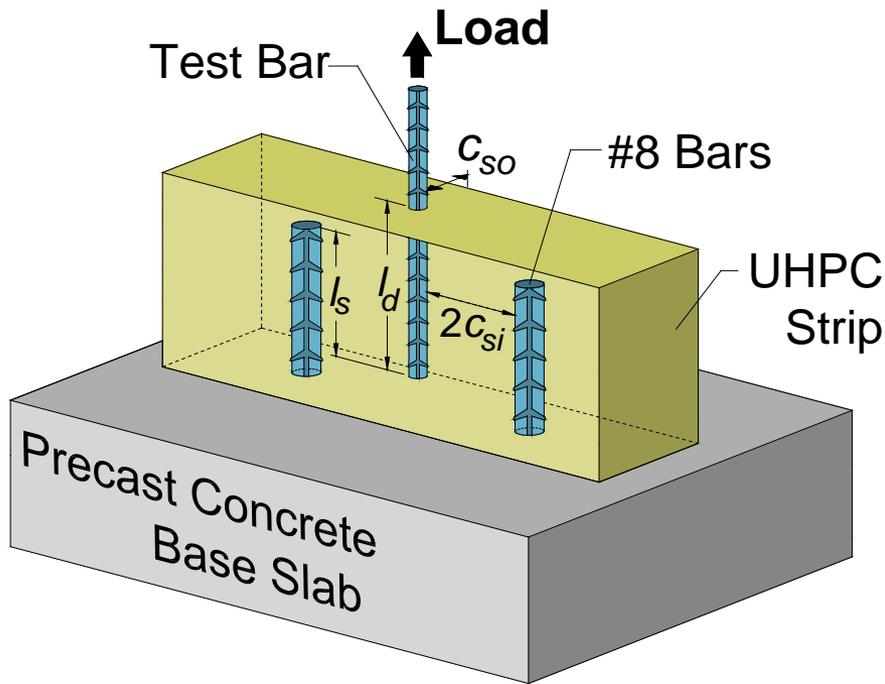


Freeze-Thaw – ASTM C666



Bond to Steel Reinforcing Bars

TEST CONFIGURATION



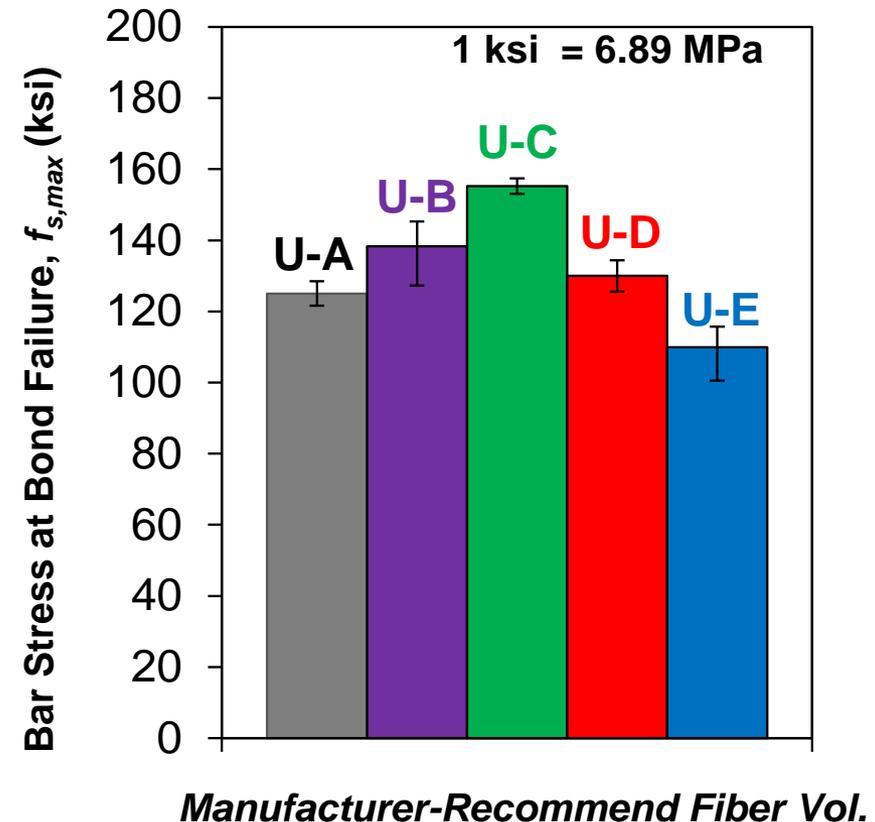
EXAMPLE RESULT

Gr. 120 Bars (Uncoated)

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

Embedment Length: $l_d = 8d_b$

Splice Length: $l_s = 6.4d_b$



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

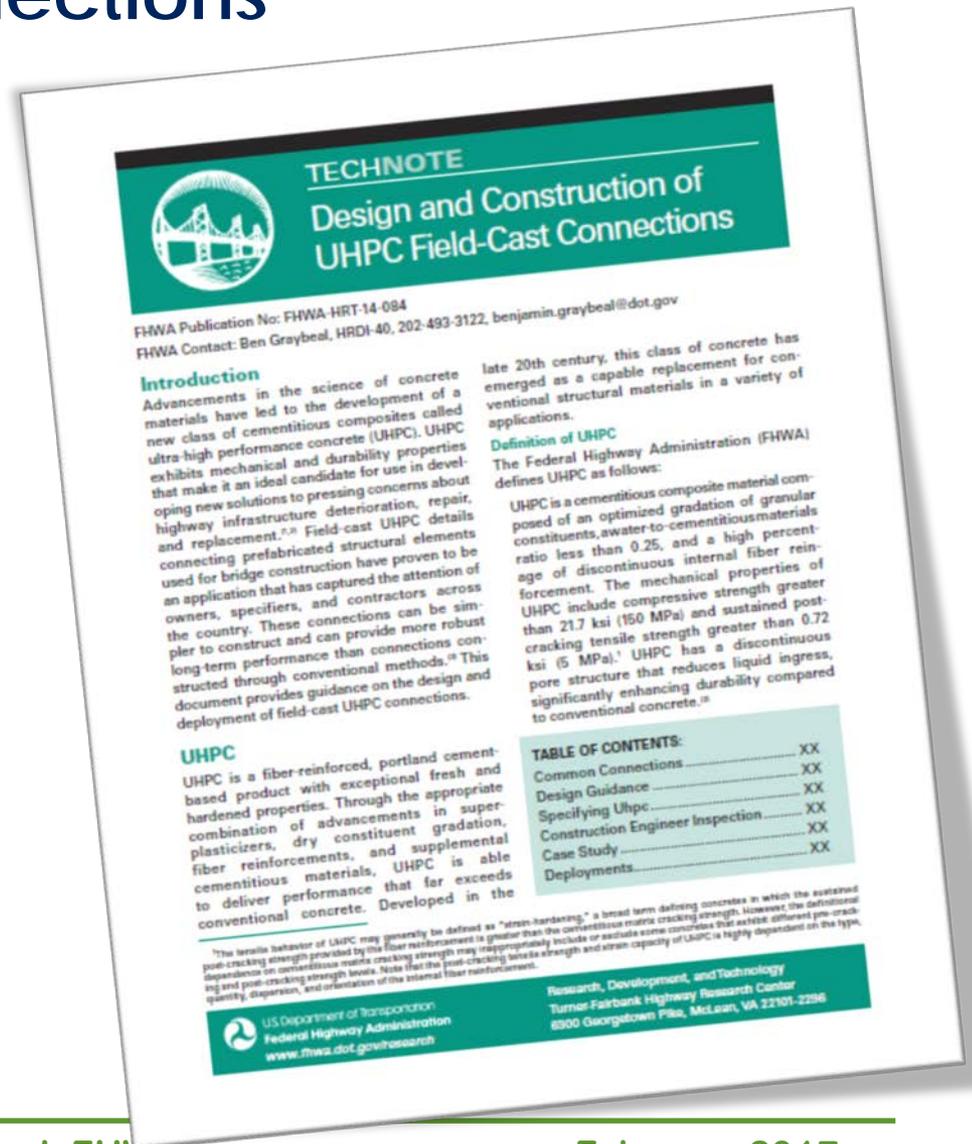
Development Underway

- Canada
- US

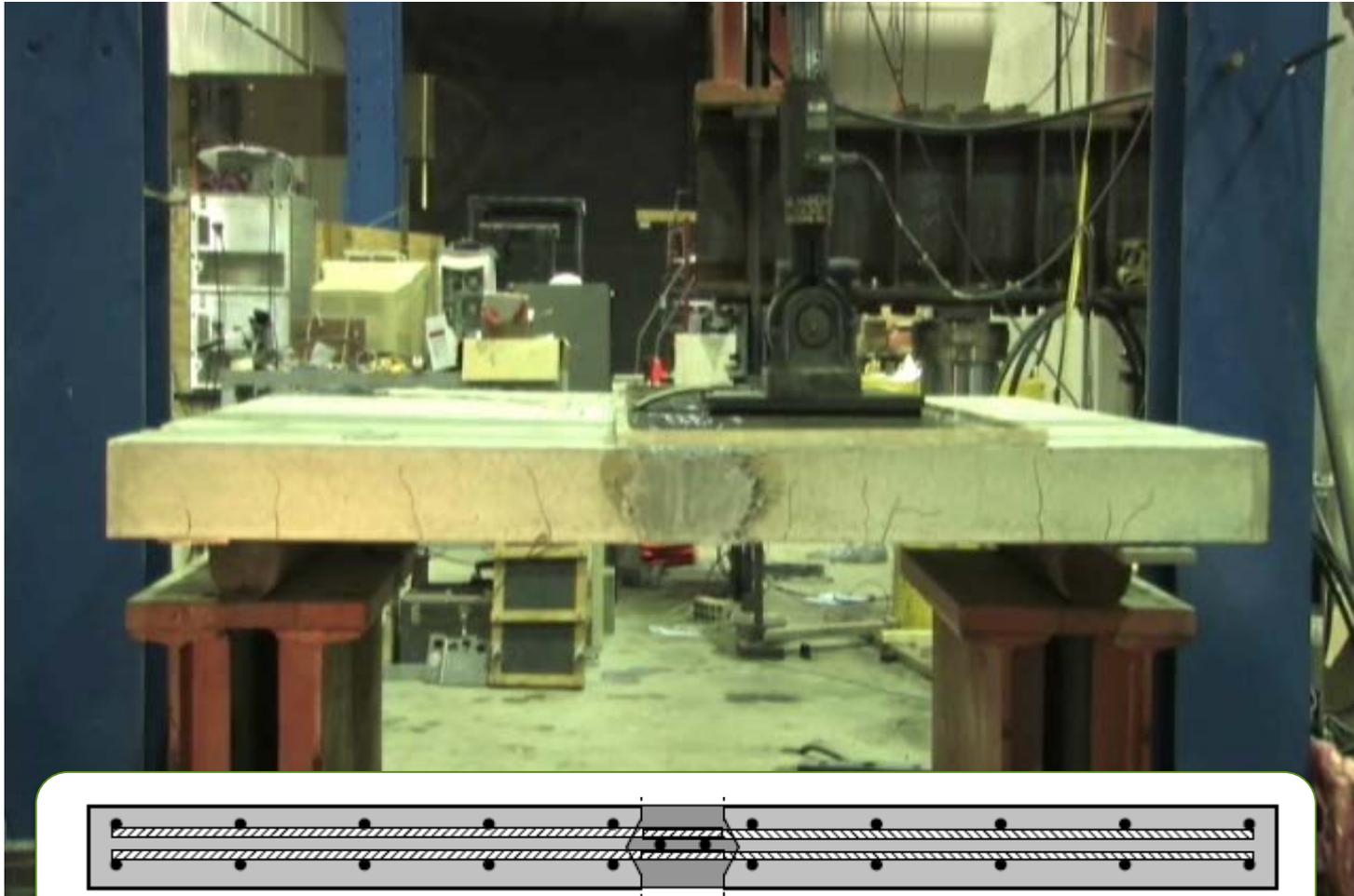


Design and Construction of UHPC Field-Cast Connections

- FHWA-HRT-14-084
- What is UHPC?
- Example Connections
- Structural Design
- Construction
- Quality Assurance
- Deployments



UHPC Structural Behavior

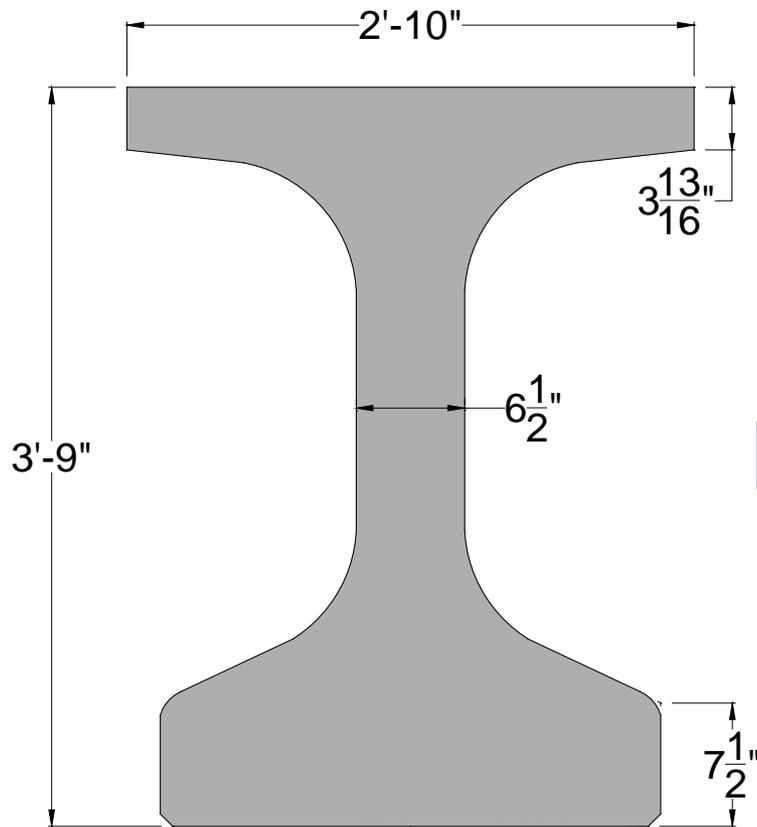


#5 Rebar Lap Splice

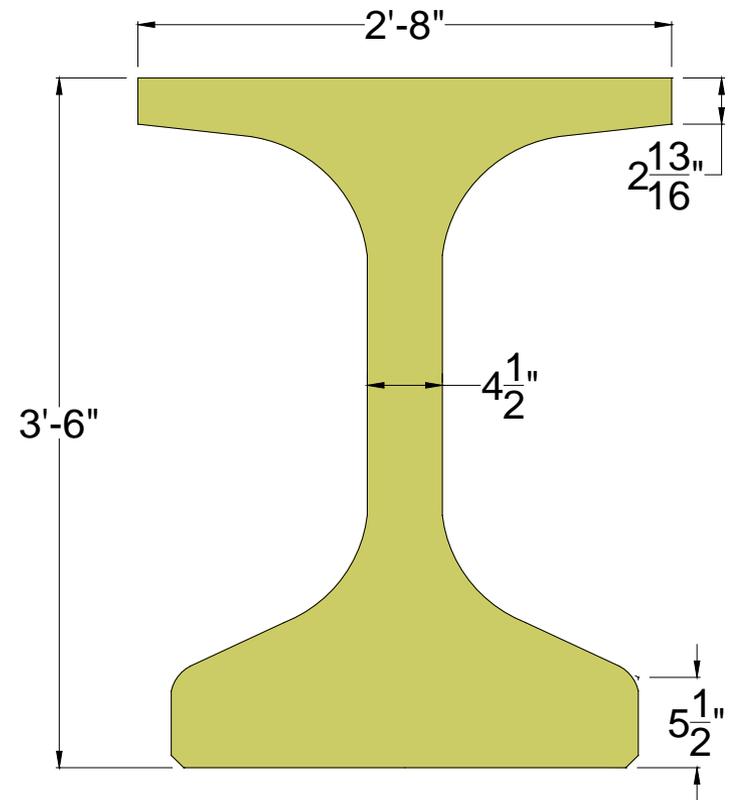
Mars Hill Bridge



Mars Hill Bridge



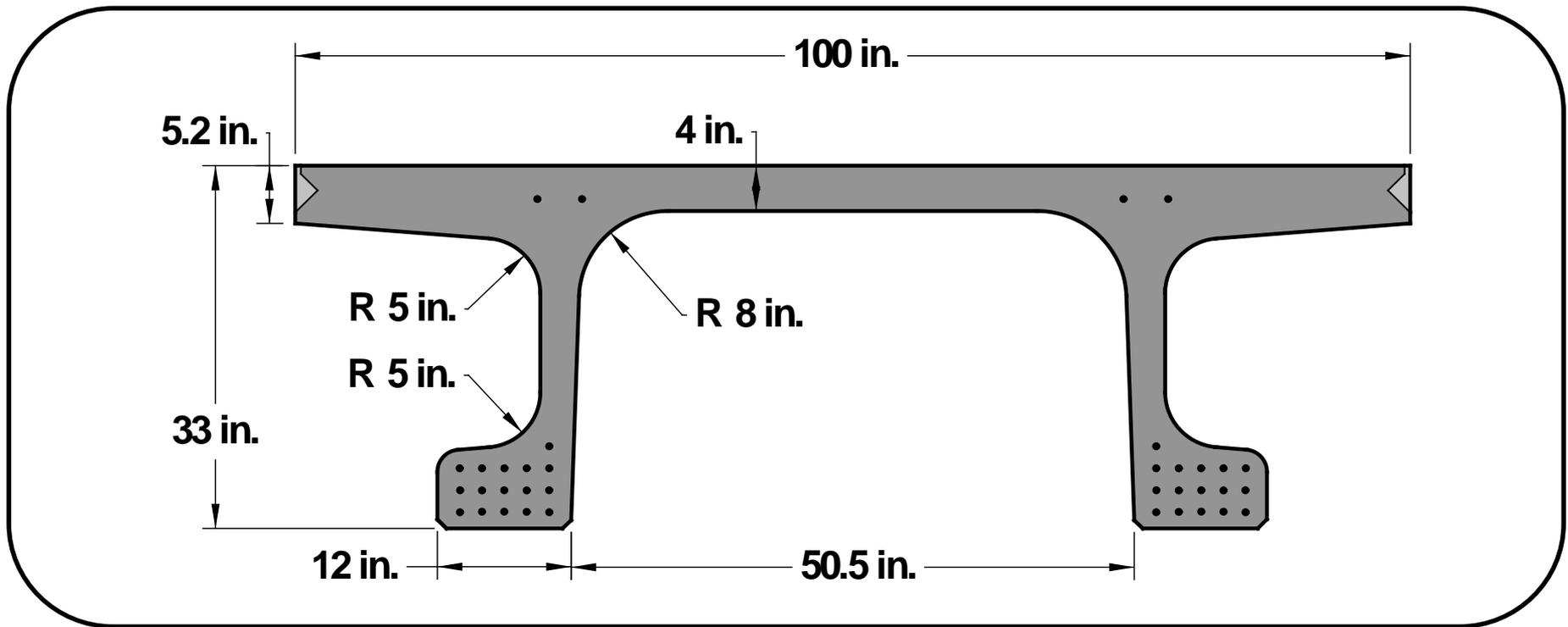
Iowa 45" Bulb Tee
SW \approx 0.7 kip/ft

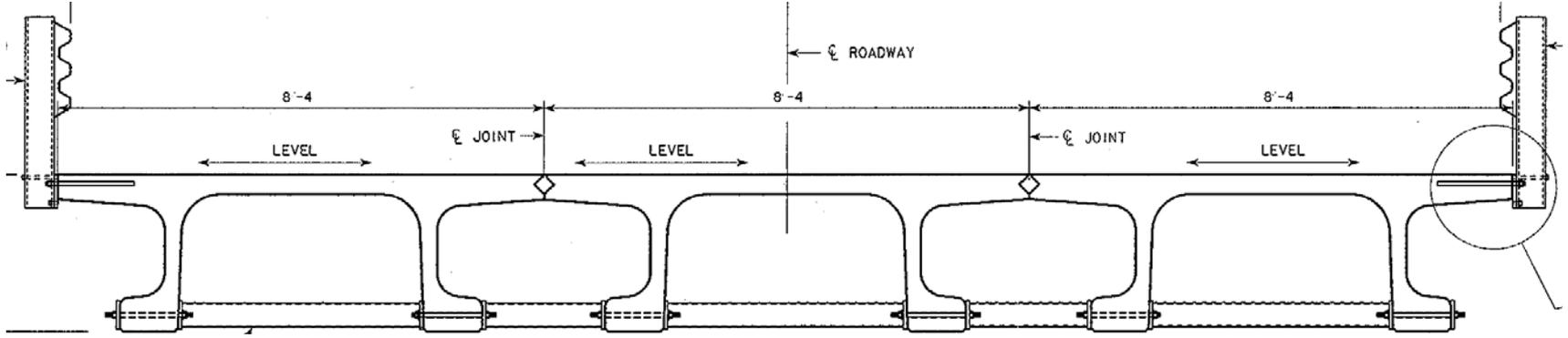


Modified Bulb Tee
SW \approx 0.56 kip/ft

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



Dahlonge 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



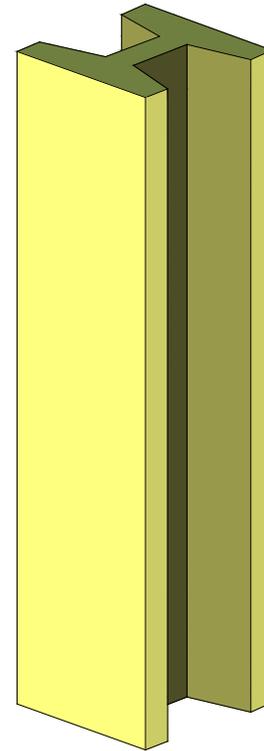
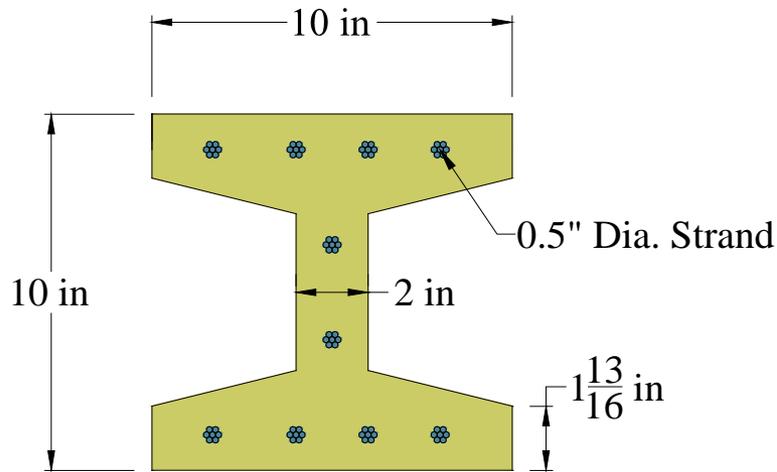
Wikipedia Public Domain

Deck Panel Connections

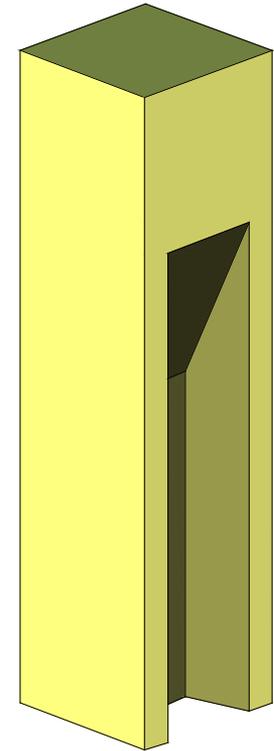


Franklin Ave. Bridge
Minneapolis, MN

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

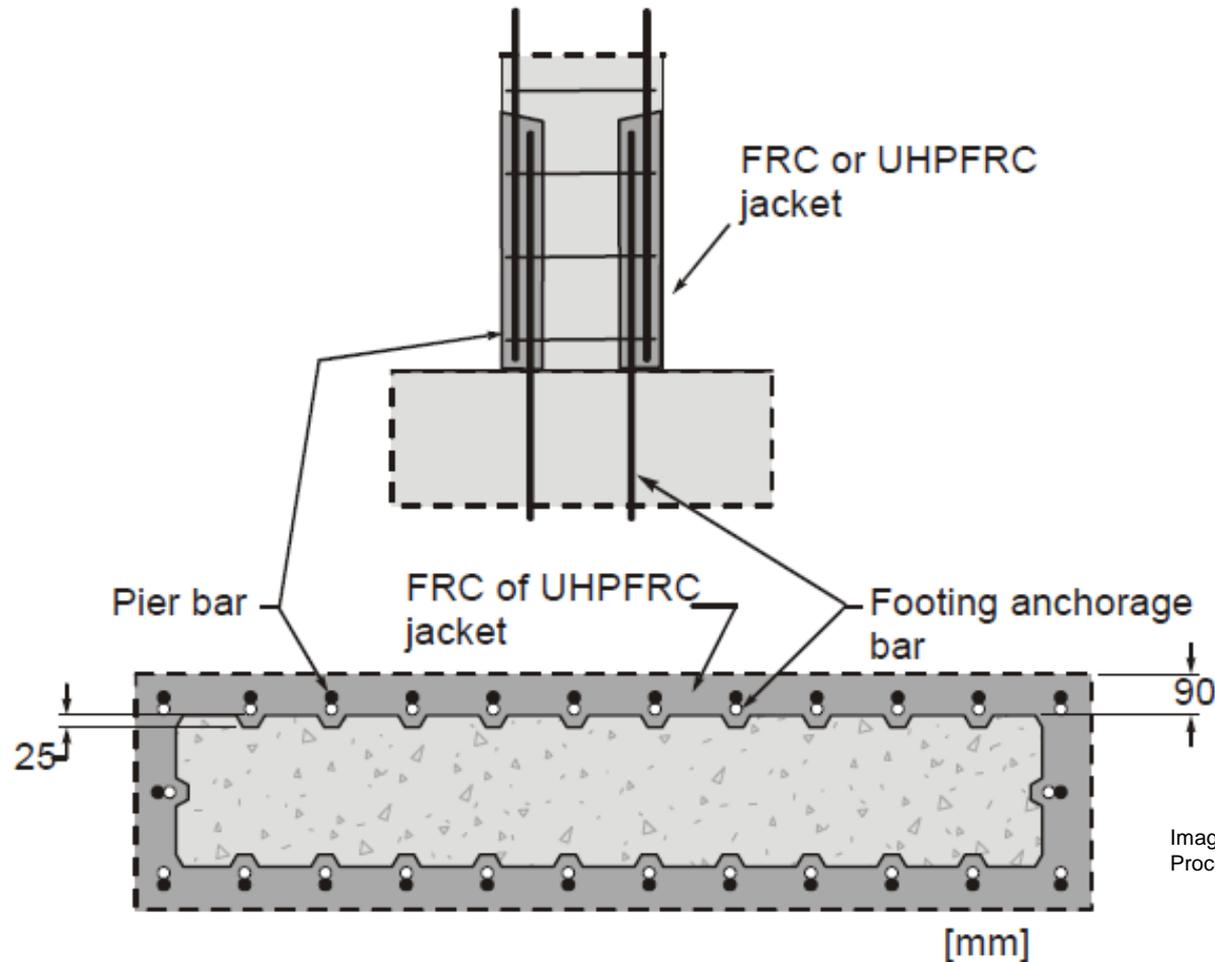
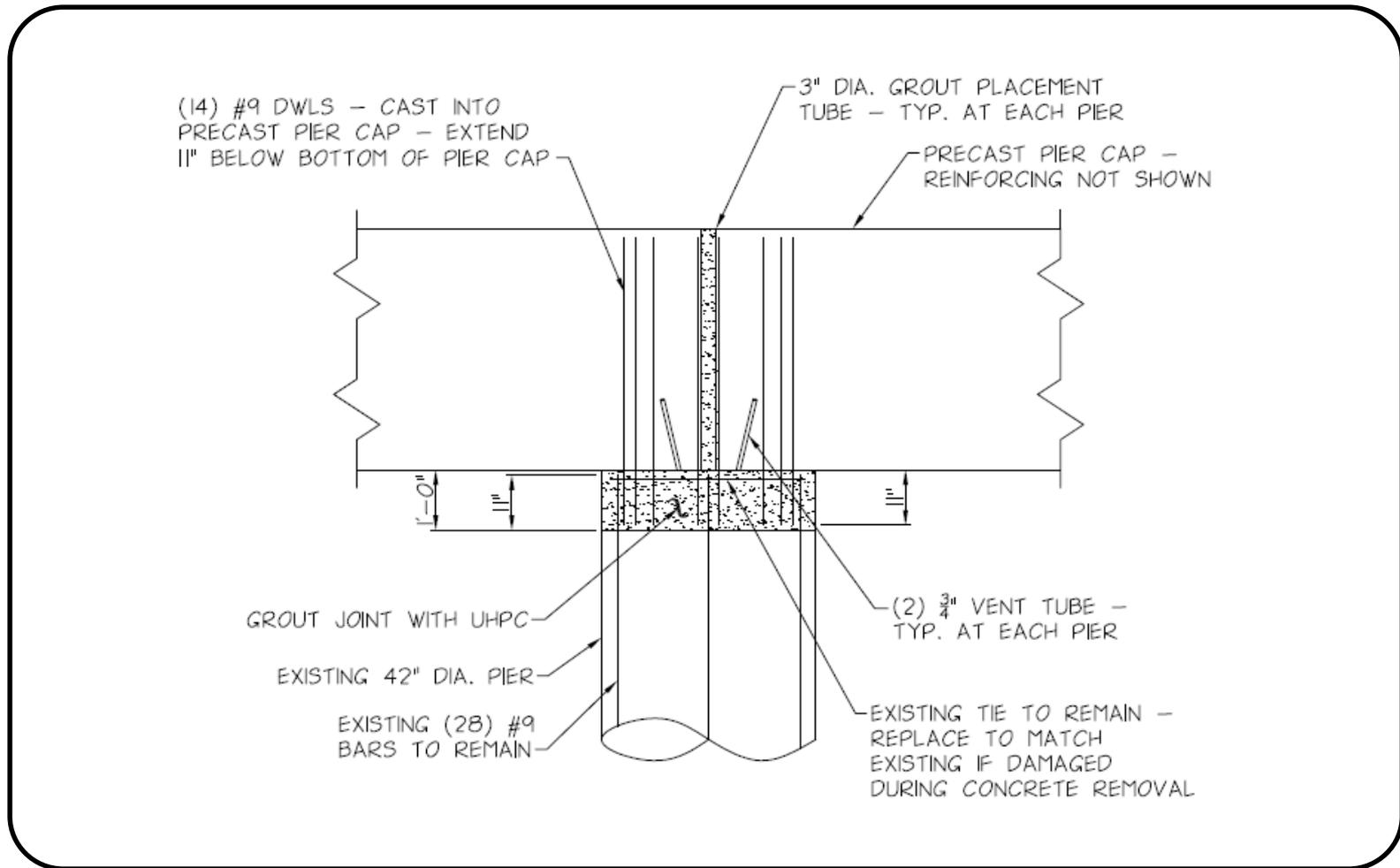


Image Credit:
Proceedings, 2009 UHPFRC, Marseille

Bruno Massicotte, Polytechnique Montreal

UHPC Connection for Substructures

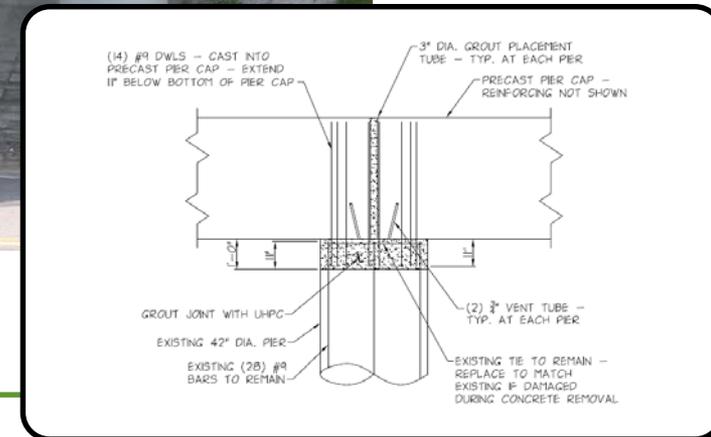


Hooper Road over US 17C in Union, New York

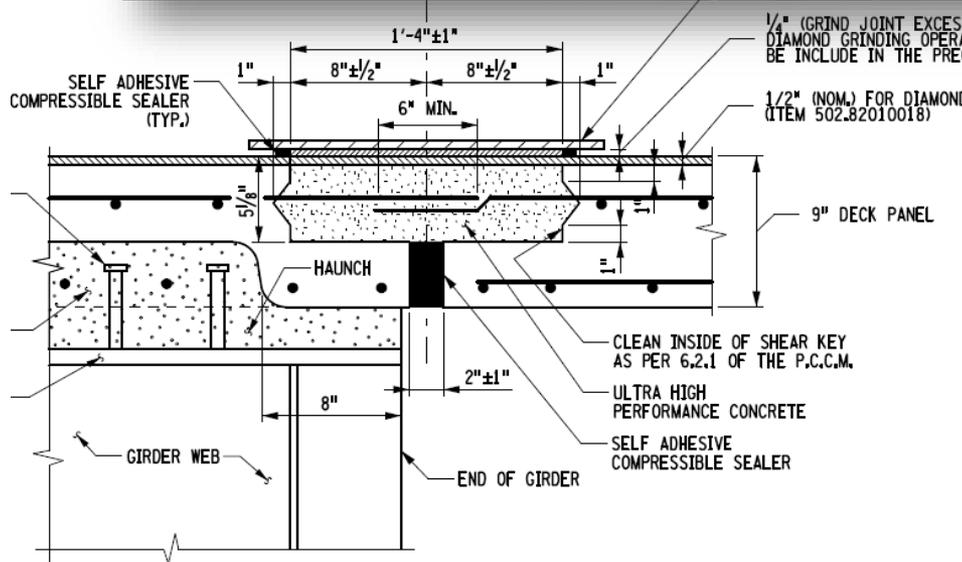
Pier Column to Cap Connection



**Hooper Road over Route 17C
Union, New York**



UHPC for Replacing Failing Expansion Joints

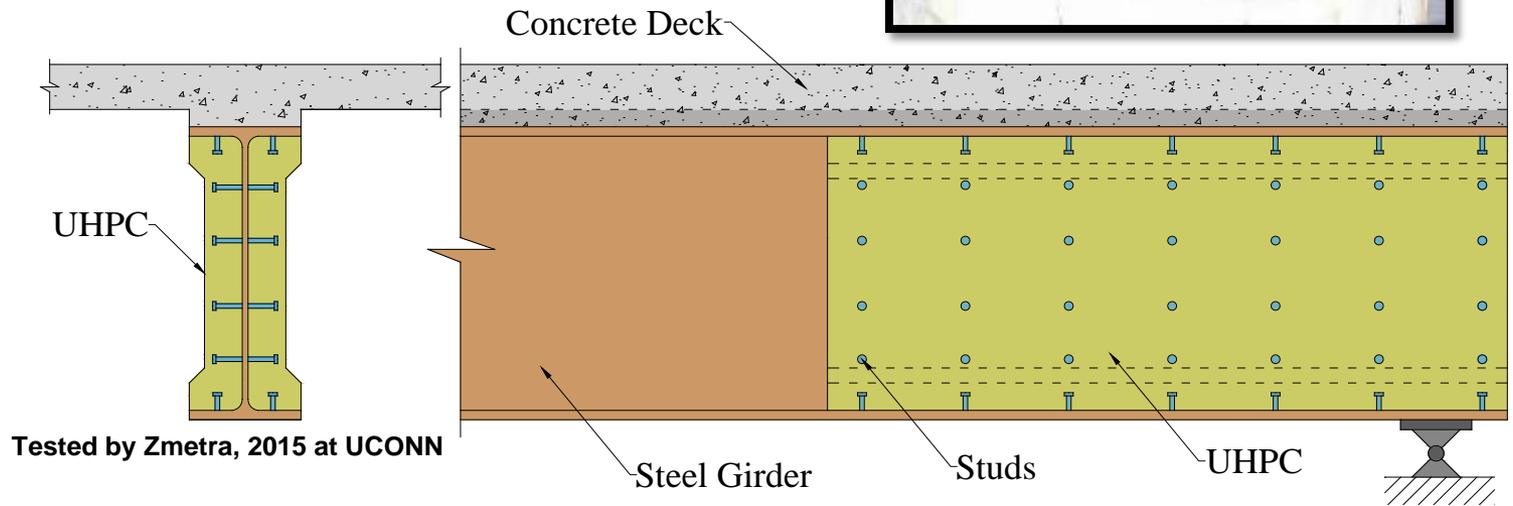
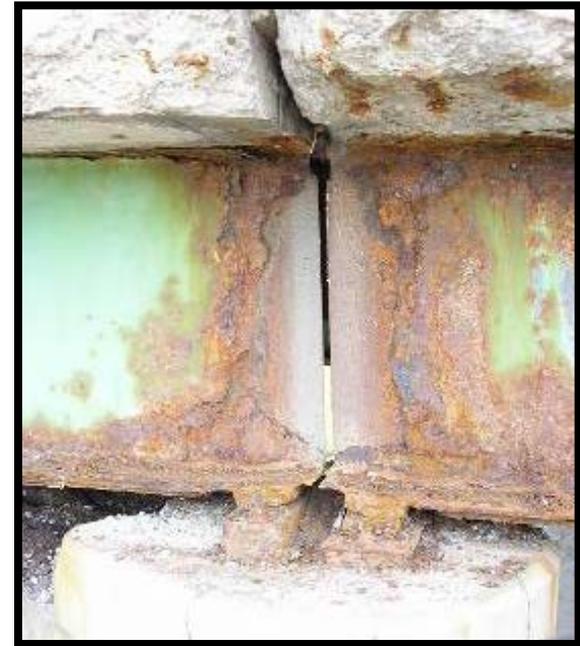


SR 96 over I-86 near Owego, NY

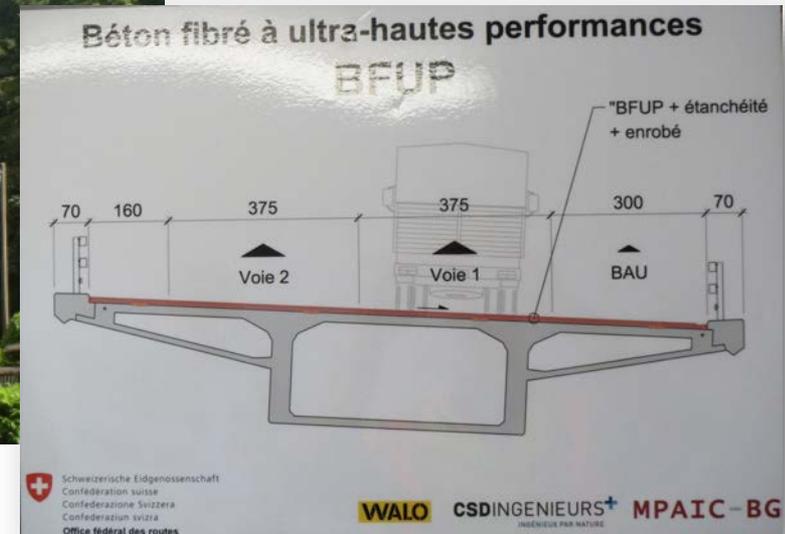
UHPC for Steel Girder Rehabilitation



Photos from Rose & Picard, NYSDOT



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?

What is Ultra-High Performance Concrete?

Resilient Cementitious Composite

What is Ultra-High Performance Concrete?

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

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