

# Ultra-High Performance Concrete (UHPC)

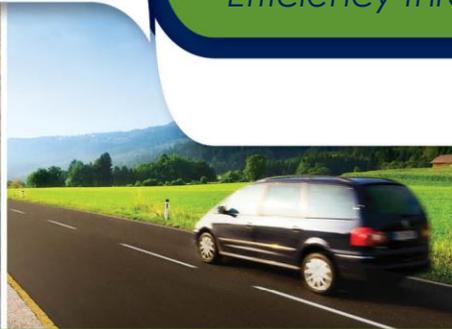
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*Efficiency through technology and collaboration*



2016 FDOT Design Training Expo  
Daytona Beach, FL, June 13-15, 2016



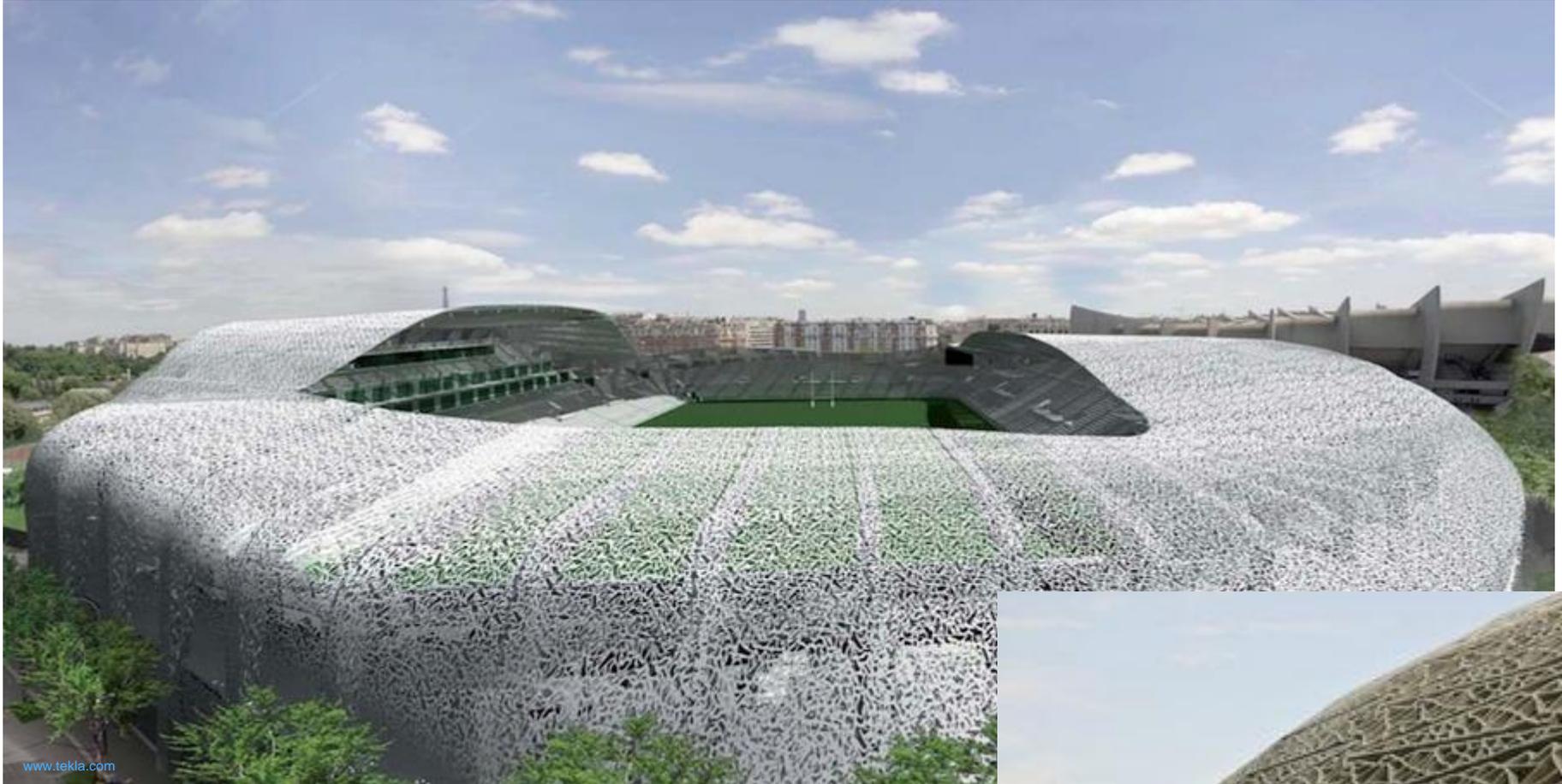
U.S. Department of Transportation  
**Federal Highway Administration**

# Foot Bridge of Peace – Seoul, South Korea



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# Jean Bouin Stadium Façade – Paris, France



[www.tekla.com](http://www.tekla.com)



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# Hawkeye UHPC Bridge – Buchanan County, IA



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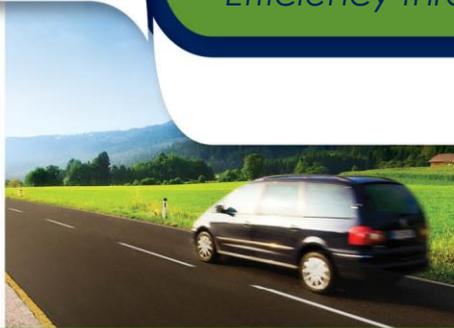
# Pulaski Skyway – Newark, New Jersey





# What is UHPC?

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**Federal Highway Administration**

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# What is Ultra-High Performance Concrete?

**Portland Cement-Based**



**Self-Consolidating**



**Castable**



# What is Ultra-High Performance Concrete?

## Fiber Reinforcement



## Superplasticizers

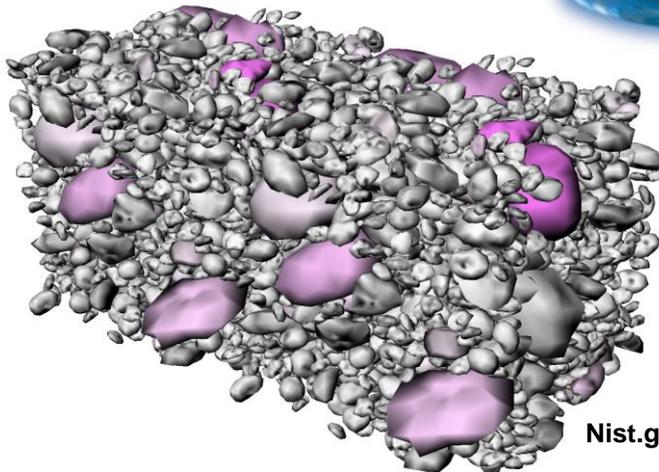


## Supplementary Cementitious Materials



American Coal Ash Association

## Particle Packing Theory



Nist.gov



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# What is Ultra-High Performance Concrete?

**Advanced Cement-Based Composite**

**Highly Durable, Strain-Hardening Concrete**

**State-of-the-Art Concrete**

**Numerous Potential Applications**



# Typical Composition of UHPC

Constituent	Amount	% by Weight
Portland Cement	1200 lb/yd <sup>3</sup>	28.5
Silica Fume	390 lb/yd <sup>3</sup>	9.3
Fine Sand	1720 lb/yd <sup>3</sup>	41.0
Ground Quartz	355 lb/yd <sup>3</sup>	8.5
Superplasticizer	51 lb/yd <sup>3</sup>	1.2
Water	218 lb/yd <sup>3</sup>	5.2
Steel Fibers	263 lb/yd <sup>3</sup>	6.3

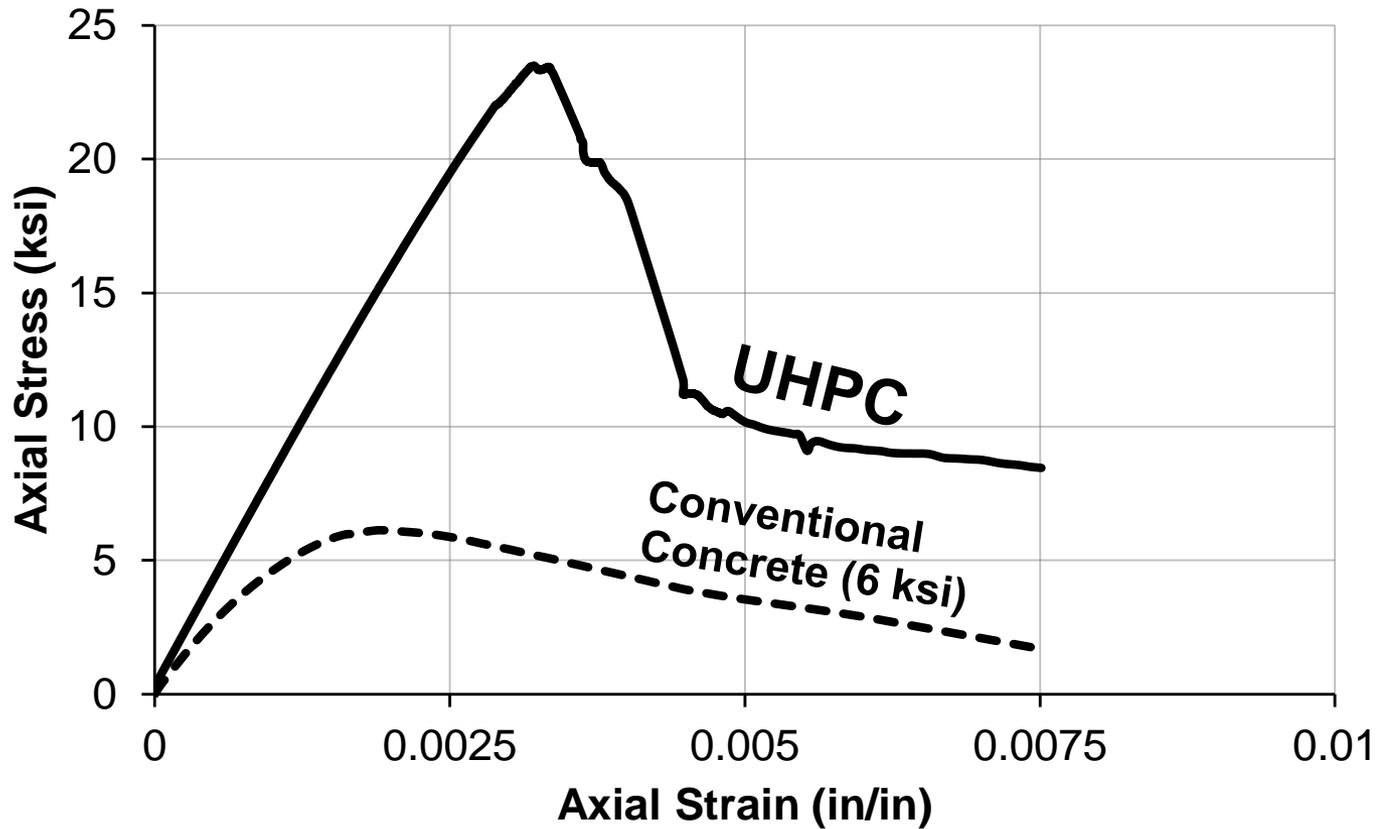


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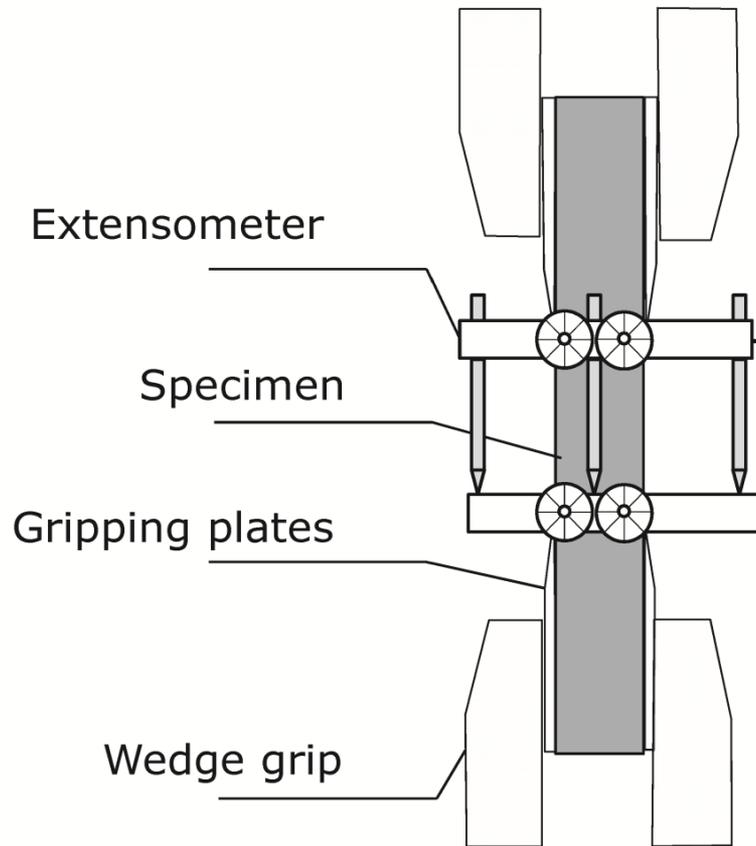
# Steel Fibers



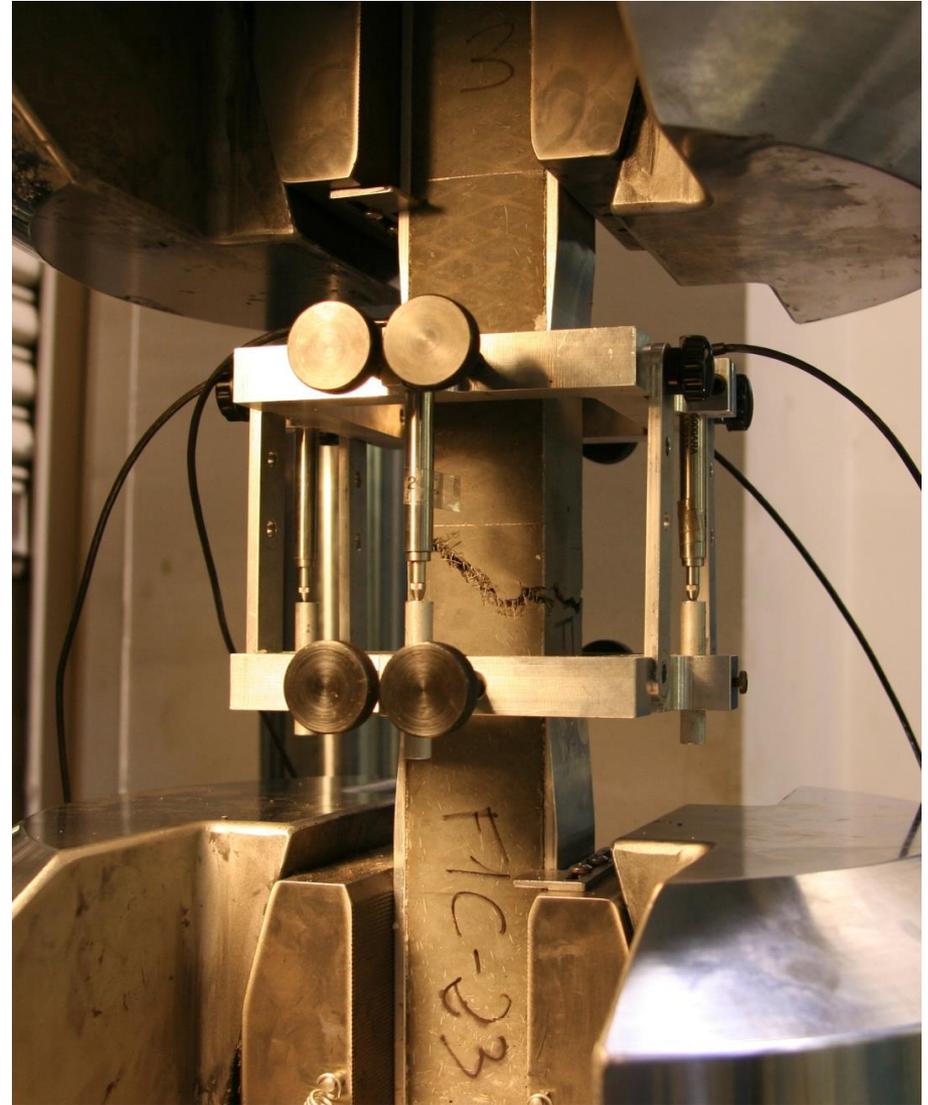
# Compression Behavior



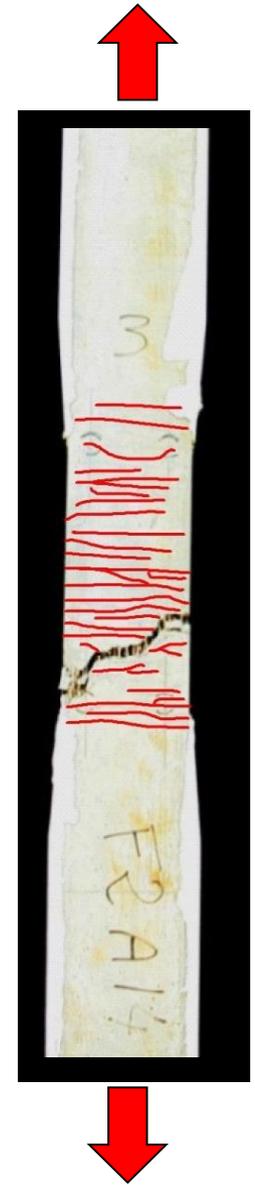
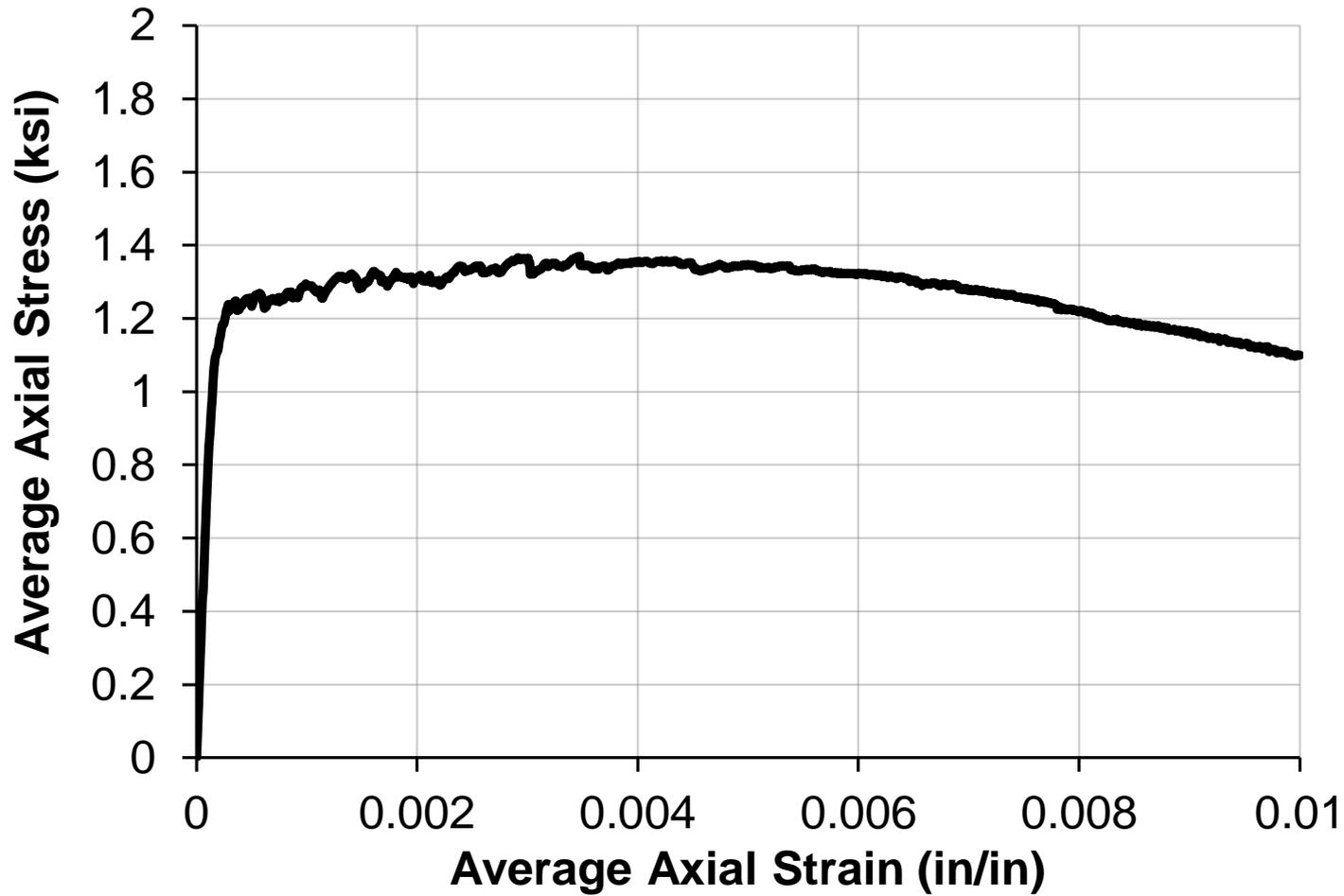
# Tensile Behavior



**Specimen: 2" x 2" x 17"**



# Tensile Behavior



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# UHPC Properties: Some Ballpark Values

- Compressive Strength – 18 to 35 ksi
- Modulus of Elasticity – 6000 to 8000 ksi
- Sustained Tensile Capacity – 0.75 to 1.5 ksi
- Rapid Chloride Test – 20 to 360 Coulombs
- Freeze/Thaw Resistance – RDM > 95%
- Permeability -  $2 \times 10^{-13}$  m<sup>2</sup>/s (Chloride Ion Diffusion Coefficient)



# UHPC Mixing

## Pre-Bagged Powder Constituents



# UHPC Mixing



# UHPC Mixing



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# UHPC Casting (Video)



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# UHPC Casting (Video)



# Availability of UHPC-Class Materials

## 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](http://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

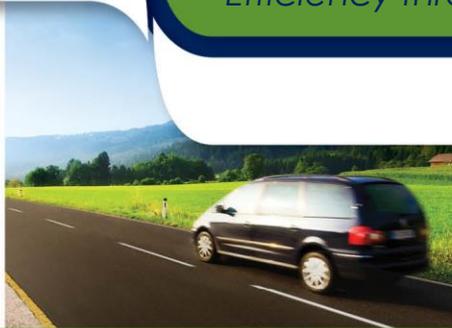
[www.fhwa.dot.gov/research](http://www.fhwa.dot.gov/research)

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

# UHPC:

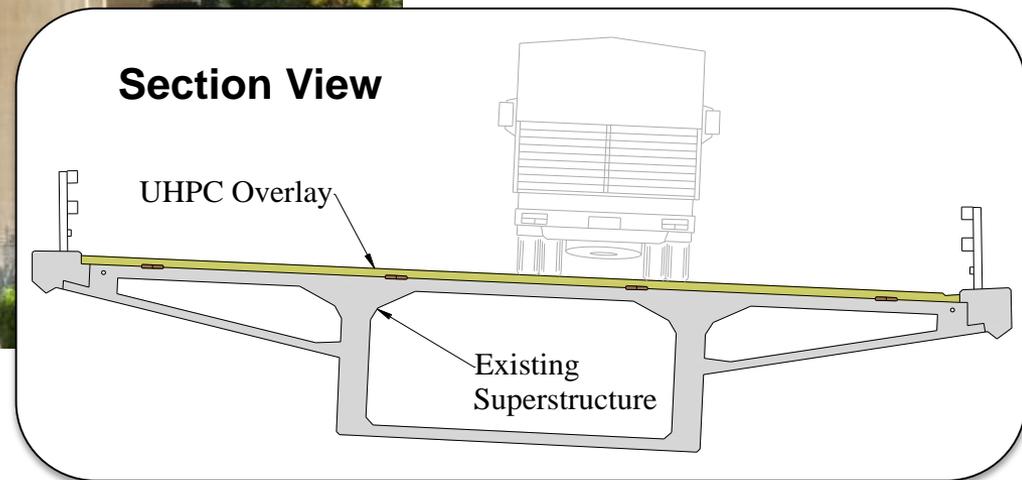
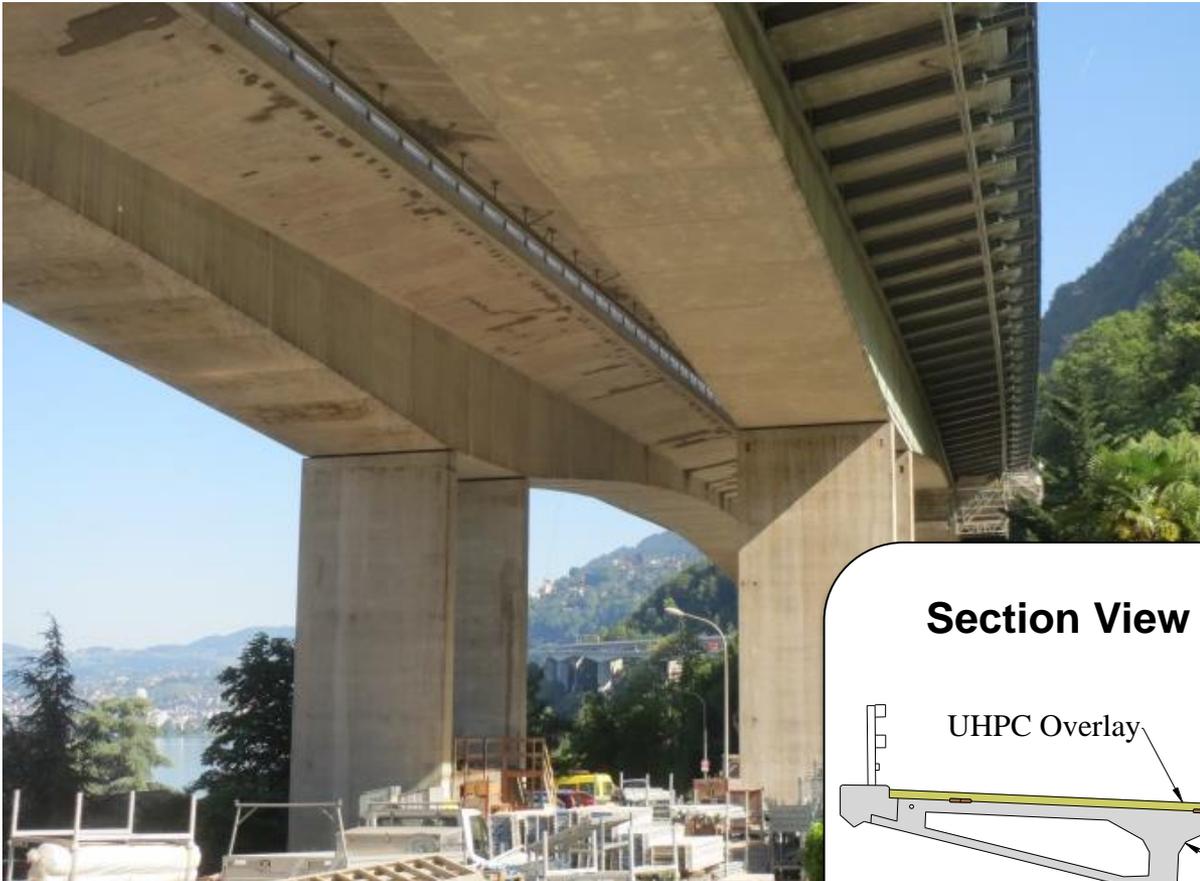
## Applications in the Highway Sector

*Efficiency through technology and collaboration*



U.S. Department of Transportation  
**Federal Highway Administration**

# UHPC for Bridge Deck Rehabilitation



Chillon Viaduct near Lausanne, Switzerland

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# UHPC for Bridge Deck Rehabilitation



**Chillon Viaduct near Lausanne, Switzerland**

# Casting for Bridge Deck Rehabilitation



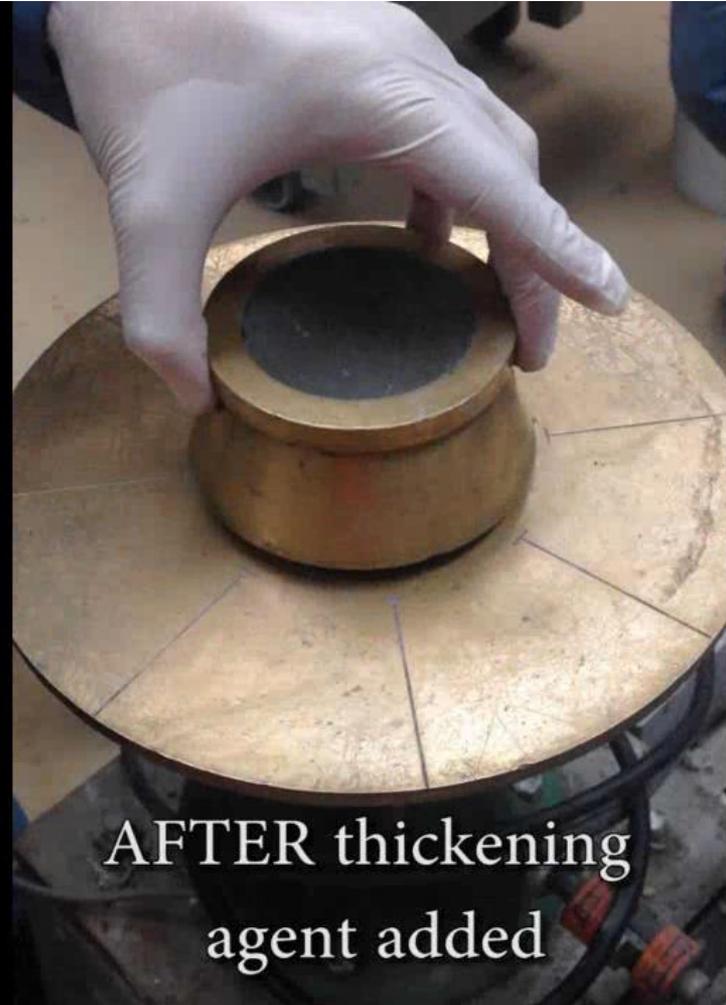
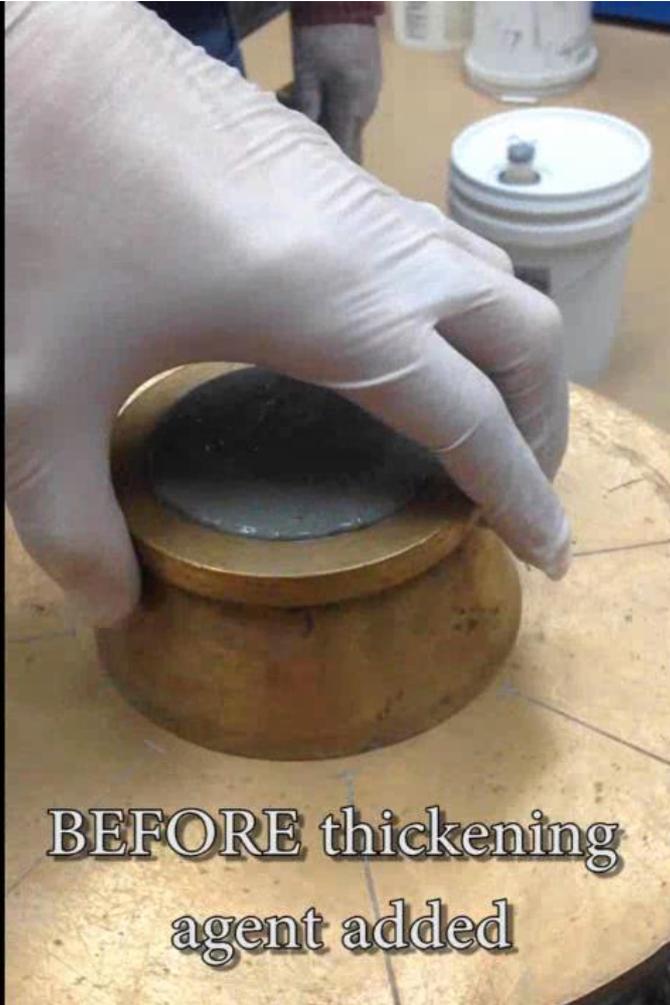
Chillon Viaduct near Lausanne, Switzerland

# UHPC for Bridge Deck Rehabilitation



Chillon Viaduct near Lausanne, Switzerland

# UHPC for Bridge Deck Rehabilitation



# UHPC for Bridge Girders



Jakway Bridge  
Buchanan County, Iowa



Mars Hill Bridge  
Wapello County, Iowa



Cat Point Creek Bridge  
Richmond County, Virginia



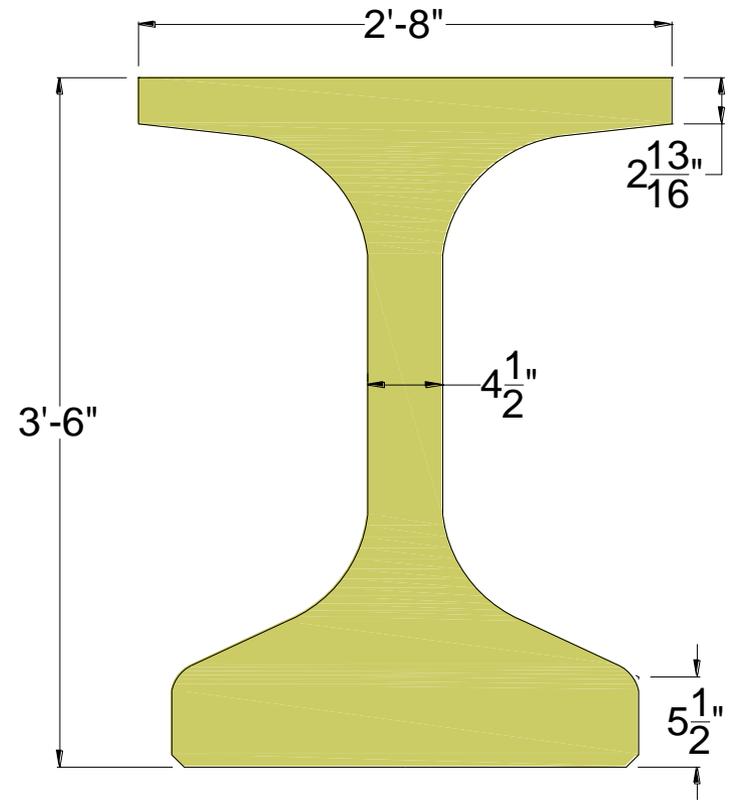
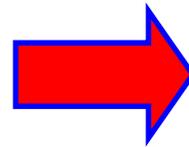
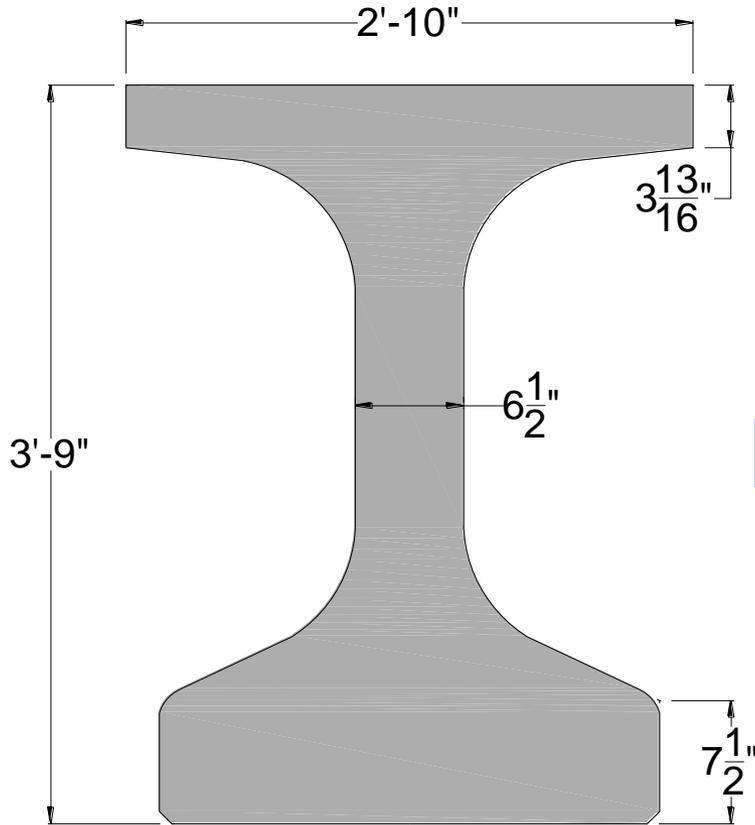
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# Mars Hill Bridge

- UHPC prestressed girder superstructure
- 110' span with 9.6' girder spacing
- Opened to traffic in early 2006



# Mars Hill Bridge

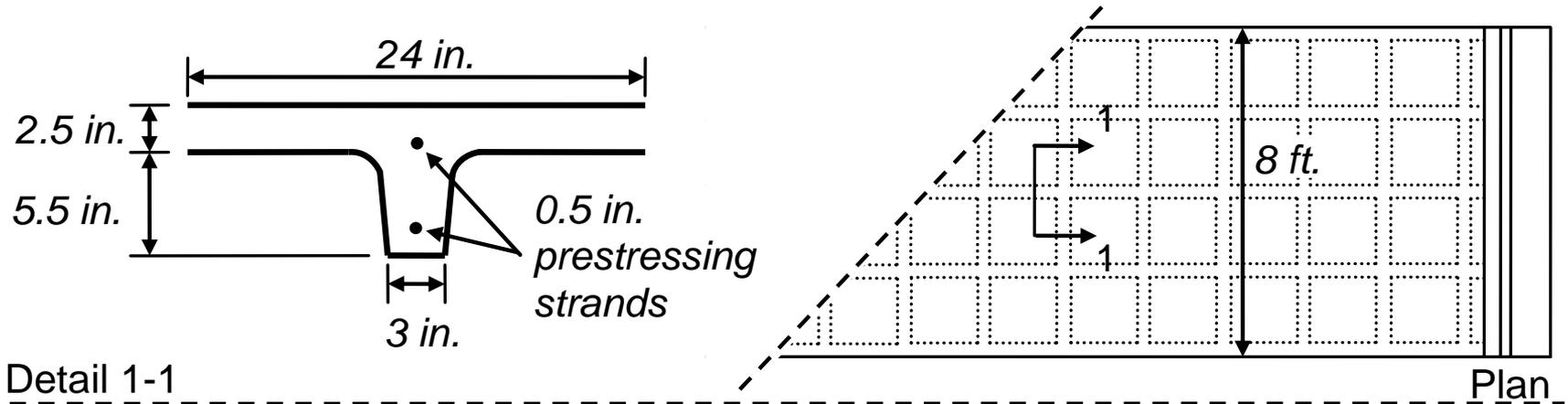


**Iowa 45" Bulb Tee**  
SW  $\approx$  0.7 kip/ft

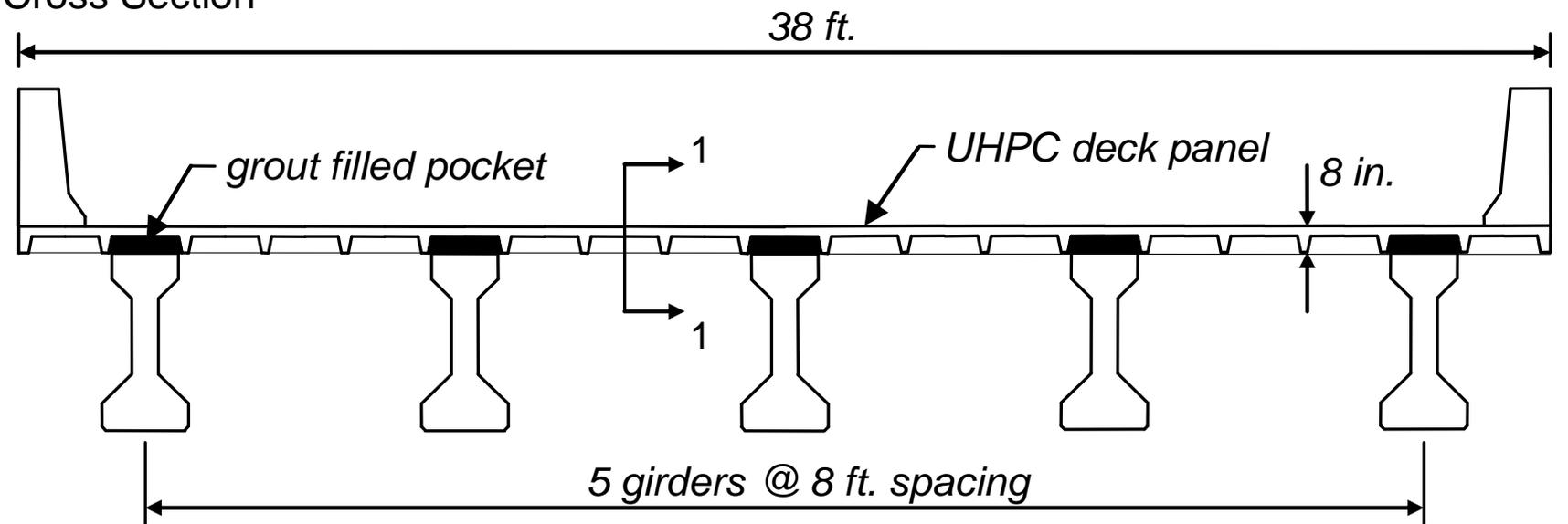
**Modified Bulb Tee**  
SW  $\approx$  0.56 kip/ft



# UHPC for Bridge Decks



Detail 1-1  
Cross Section



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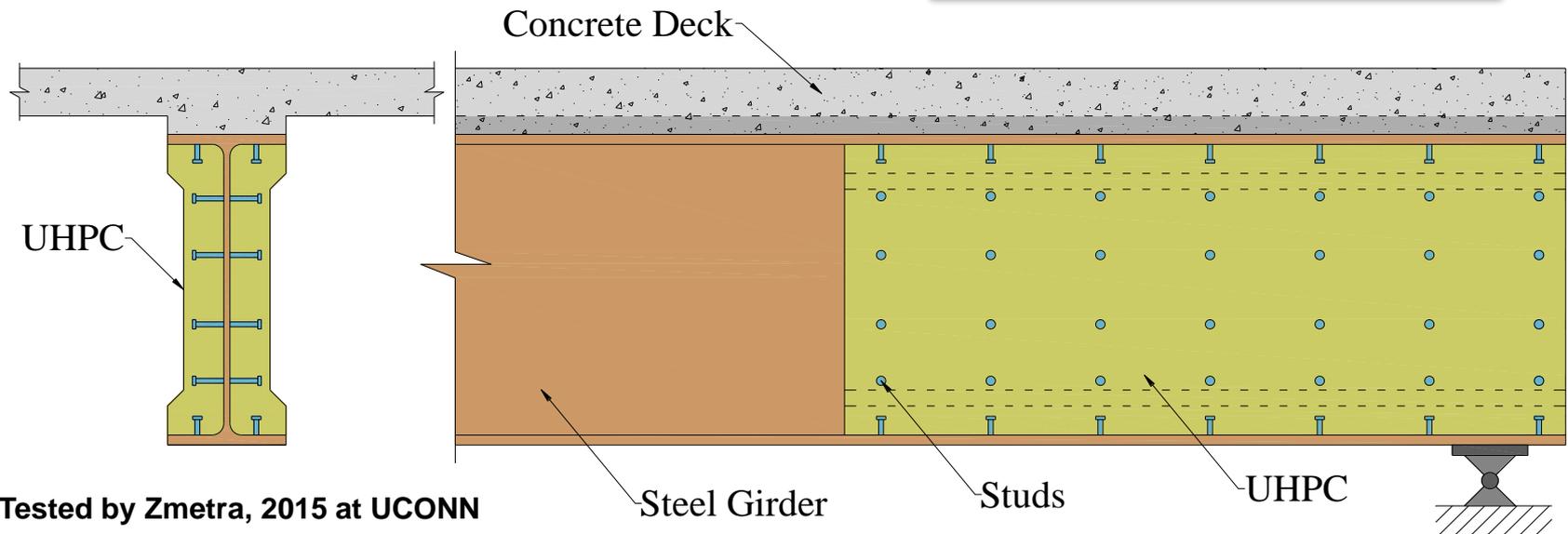
# UHPC for Bridge Decks



Dahlongea Road Bridge in Wapello County, Iowa

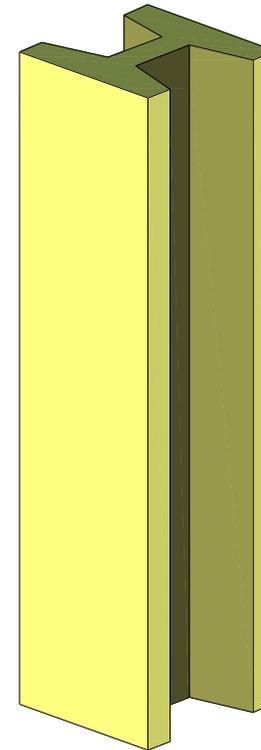
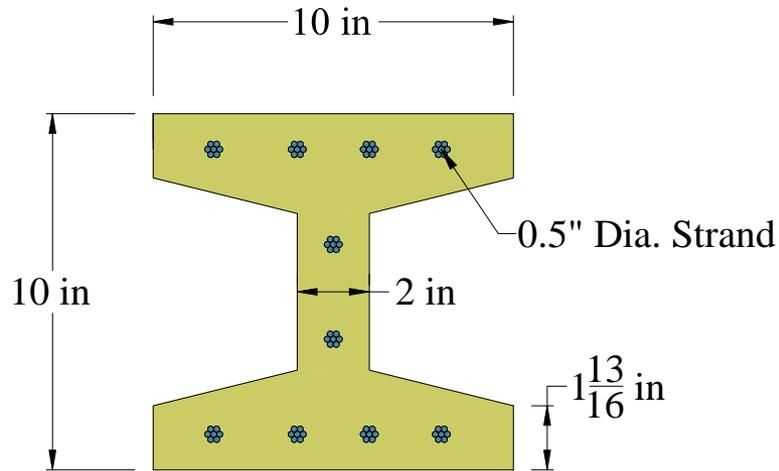


# UHPC for Steel Girder Rehabilitation

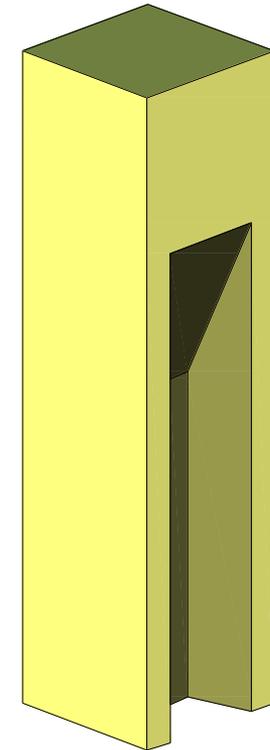


Tested by Zmetra, 2015 at UCONN

# UHPC for Pile Foundations



Without Taper



With Taper –  
Minimize Driving  
Stresses

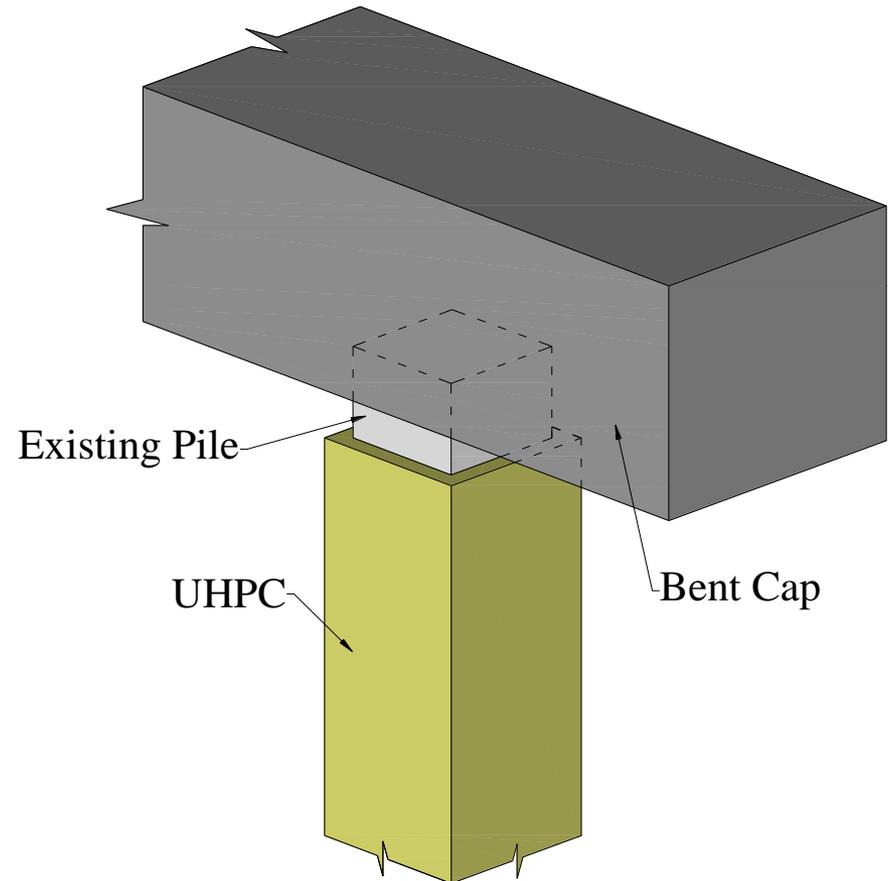
Vande Voort et al. 2008, Iowa State University



# UHPC for Pile Foundation Rehabilitation

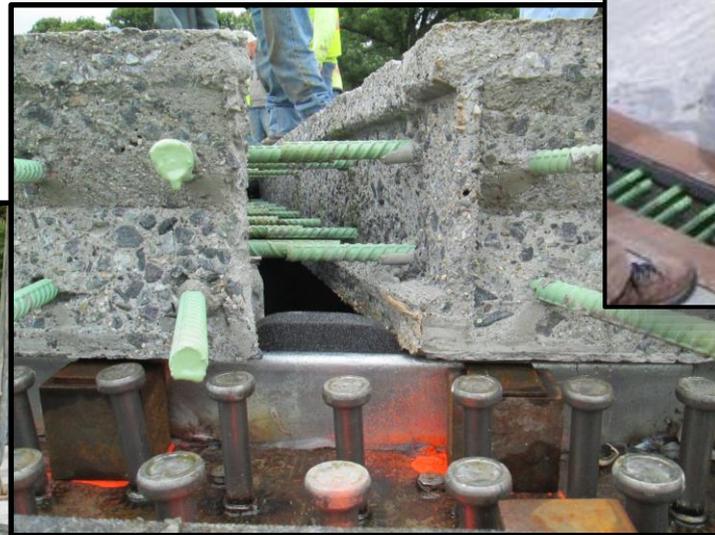


Nace.org



# UHPC for PBE Connections

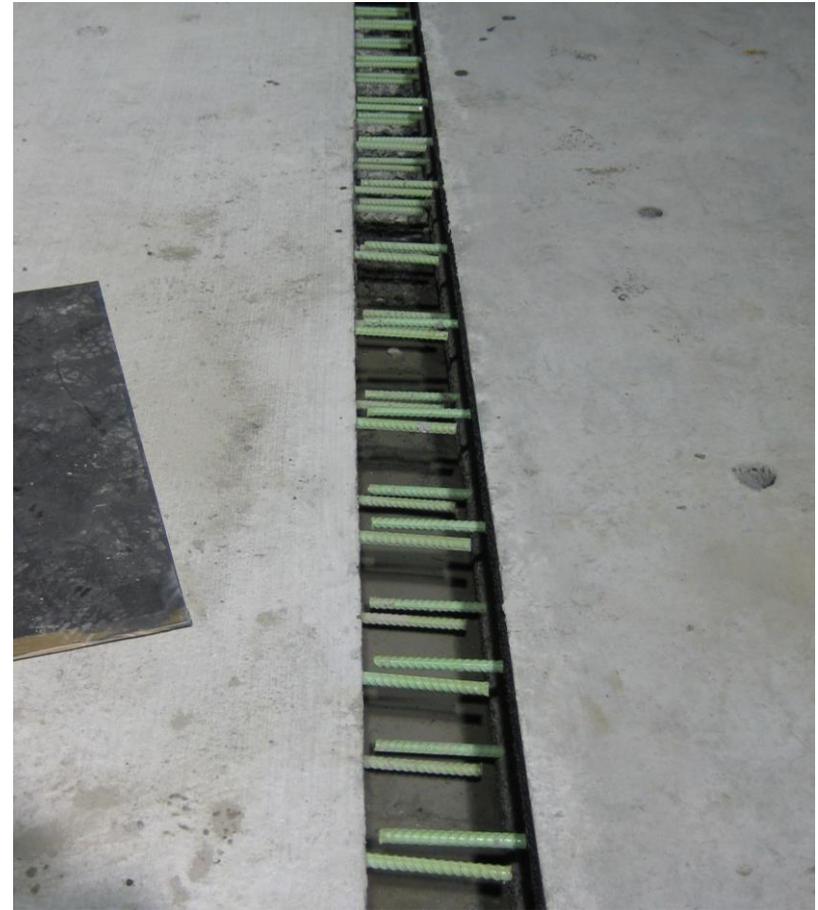
- Ultra-High Performance Concrete
- Prefabricated Bridge Elements
- Bridge Construction



# Conventional vs UHPC Connections



**Conventional Detail**



**UHPC Detail**

# Design and Construction of UHPC Field-Cast Connections

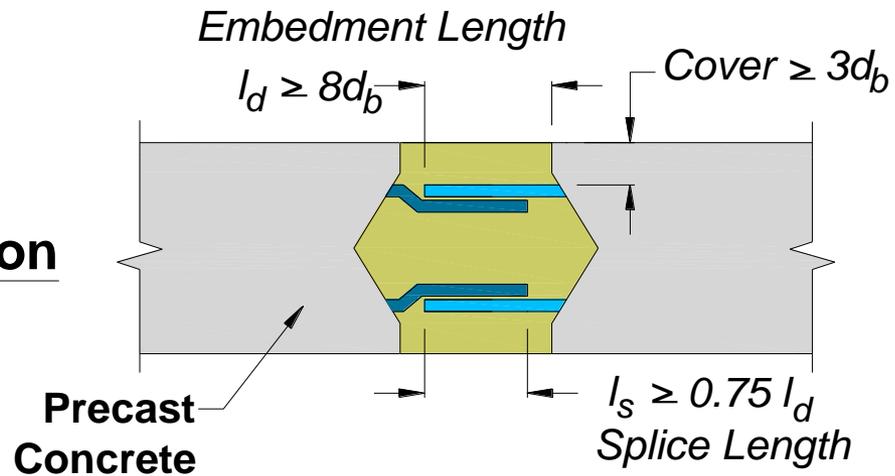
## FHWA-HRT-14-084

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

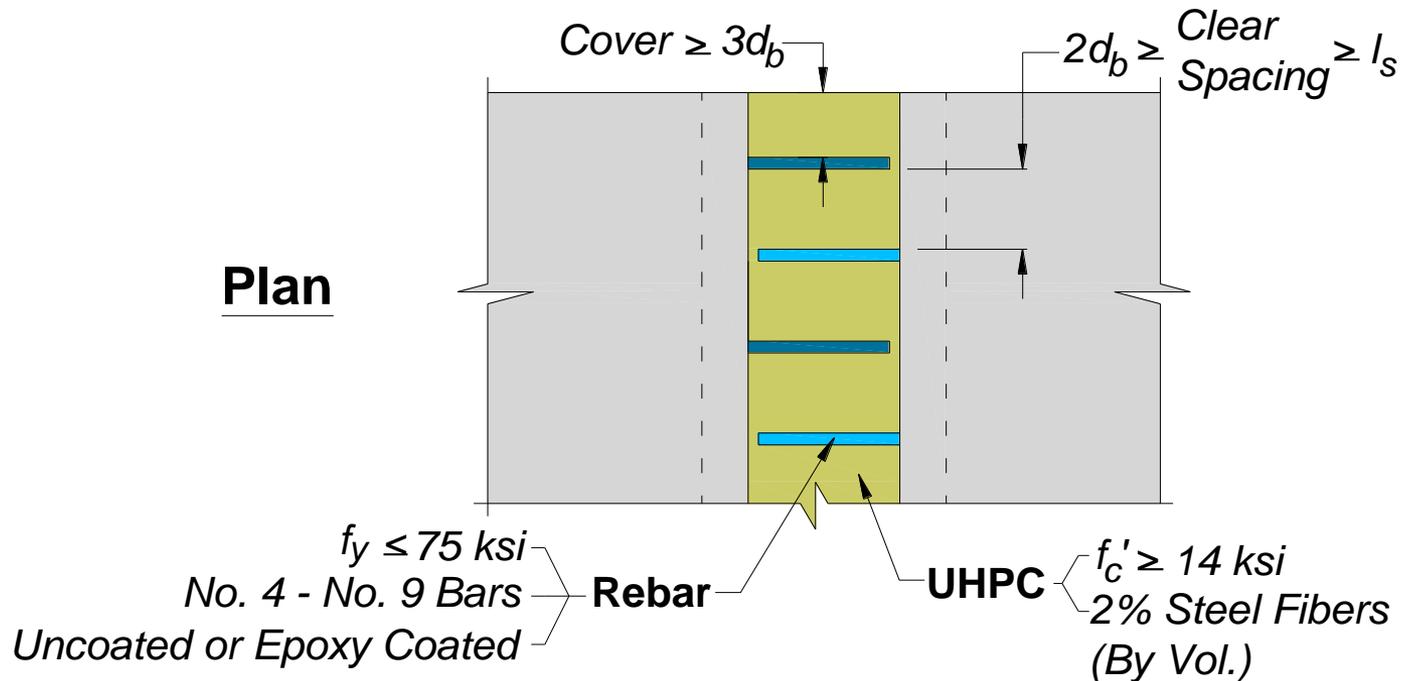


# Design Guidance: Rebar Lap Splice

**Elevation**



**Plan**



# Deck-to-Deck Connections



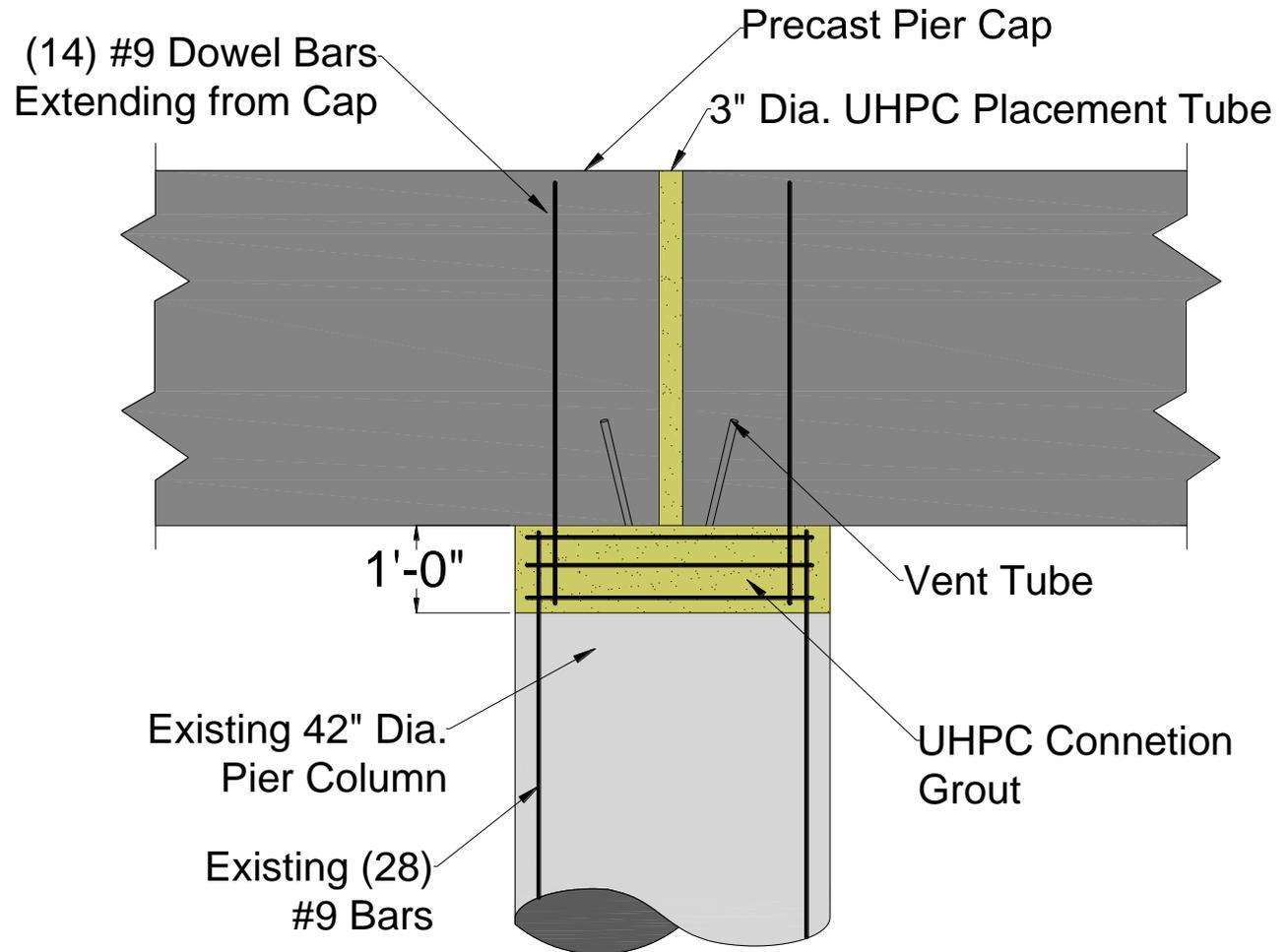
# Deck-to-Girder Connections



# Connections for Deck-Barrier Units



# Pier Column to Cap Connection



Hooper Road over Route 17C  
Union, New York



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# Pier Column to Cap Connection

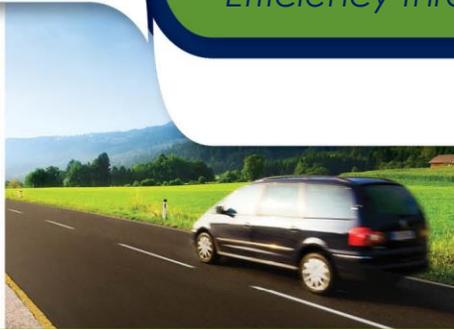


**Hooper Road over Route 17C  
Union, New York**



# So, What Does a UHPC Connections Project Look Like?

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U.S. Department of Transportation  
**Federal Highway Administration**

# Example Project

New York State DOT  
I-87 SB at Exit 4, Albany, NY

- Casting Prep
- UHPC Placement
- UHPC Mixing
- Finishing + Curing
- Field Testing
- Form Removal + Profiling
- Open to Traffic



# 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". A search bar is located below the header. The breadcrumb trail indicates the current location: "Federal Highway Administration > Research > Other Resources > Ultra-High Performance Concrete". The left sidebar contains a navigation menu with links to 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 a blue header with links: "About UHPC | UHPC Q&A | Research Projects | List of Bridges | Publications | Contact". The primary heading is "Ultra-High Performance Concrete", followed by "Q&A: Ultra-High Performance Concrete". A question is posed: "Q: What is concrete?". The answer states: "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." Another question is asked: "Q: What is ultra-high performance concrete?". The answer begins: "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, a "Find an Expert" section lists "Research and Development Links" with sub-links for "Research and Development (R&D) Offices", "R&D Experts", "R&D Laboratories", "R&D Projects", "R&D Publications", and "R&D Topics".



# Ultra-High Performance Concrete (UHPC)

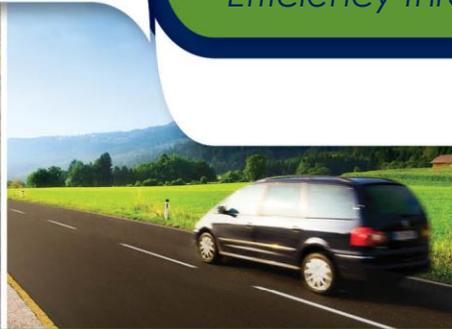
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Daytona Beach, FL, June 13-15, 2016



U.S. Department of Transportation  
**Federal Highway Administration**

# 1<sup>st</sup> Intl. Interactive Symposium on UHPC

- July 18-20, 2016
- Des Moines, Iowa
- ABC
- Structural Design
- Material Design
- Repair & Retrofit
- Bridge Site Visits

<http://register.extension.iastate.edu/uhpc2016>

DES MOINES, IOWA

**FIRST INTERNATIONAL INTERACTIVE SYMPOSIUM ON UHPC**

DES MOINES, IOWA JULY 18-20, 2016

The organizing committee is pleased to announce the First International Interactive Symposium on Ultra-High Performance Concrete in North America. The three day symposium will be held in Des Moines, Iowa, at the Downtown Marriott, July 18-20, 2016. Under the theme "UHPC unites" the goal of the symposium is to share knowledge and experiences in the field of UHPC material and structural design for continuous advancements of the technology.

The symposium will provide a platform to present recent UHPC activities and innovations as well as to participate in thematic workshops, led by various topic leaders, where active participation is encouraged.

The symposium will include topics related to a) latest developments in UHPC material and structural design emphasizing enhanced performance, sustainability, durability, resiliency and cost efficiency, b) material characterization methods adapted to UHPC, c) numerical material and structural modelling, d) small and large scale applications, e) repair and retrofiting, and other aspects to further broaden theoretical knowledge and practical experiences.

The submission of abstracts is encouraged and will close by **October 15, 2015 (Extended)**.

<http://register.extension.iastate.edu/uhpc2016>

**organizing committee**

Sri Satharan	Co-Chair	Iowa State University
Kay Wille	Co-Chair	University of Connecticut
Benjamin Graybeal	Co-Chair	Federal Highway Administration
Vic Perry	Treasurer	V-Concrete Inc.
Toss Atkisson	Scientific Chair	Michigan Technological University
Eric Steinberg	Scientific Co-Chair	Ohio University
Larry Rowland	Secretary	Lehigh White Cement Co.
Mary Christensen	Student Competition	University of Minnesota Duluth
Michael McDonagh	Tours	WSP   Parsons Brinckerhoff
Dominique Corvez	International Liaison	LargeHolcim

**sponsors & partners**

IOWA STATE UNIVERSITY, Federal Highway Administration, IOWA DOT, Lotoflex, BEKAERT, LEHIGH, acl, PCI



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# Cost of PBE Grouts including UHPC...

- **Products on the Market**

Grout Type	Approximate Cost per yd <sup>3</sup>
Portland Cement Grouts	\$1000 to \$2000
Repair Mortars	\$1500 to \$3000
Epoxy Grouts	\$5000
UHPCs	\$2500 to \$3500

- **Non-Proprietary Versions**

- At least \$800 for UHPC raw constituents



# UHPC for Steel Girder Rehabilitation



From: Zmetra, 2015

# UHPC Connections for Shear Interfaces



Steel Girder Connection



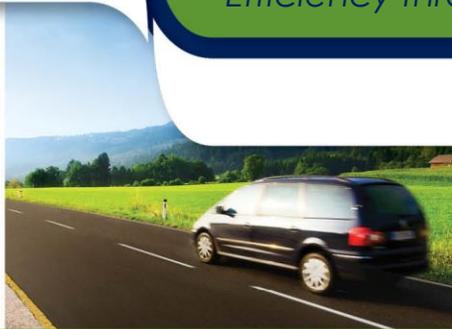
Concrete Girder Connection

# Session 5:

# UHPC Connections:

## Construction, Monitoring & Testing

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U.S. Department of Transportation  
**Federal Highway Administration**

# PBE Installation



# PBE Installation



# PBE Installation



# PBE Installation



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# Connection Formwork



# Connection Formwork



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# Connection Formwork



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# Preparing to Cast (Video)



# Pre-Wetting Connection Interfaces



# UHPC Mixing



# UHPC Mixing

## Pre-Bagged Powder Constituents



# UHPC Mixing



# UHPC Mixing



# UHPC Casting



# UHPC Casting



# Connection Overfilling and Top Forming



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# Connection Overfilling and Top Forming



# Connection Overfilling and Top Forming



# Connection Overfilling and Top Forming



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# Forms Removed – Full Bridge View



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# Forms Removed – Close Up View



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# Riding Surface Preparation – Grinding



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# Construction Engineer Inspection

- Familiarity with specs and special provisions
- Worker safety equipment and procedures.
- Prior coordination of construction activities.
- Constituent materials...lot, date, storage.
- Mixing process...weighing, timing, discharge.
- Formwork
- Connection interface surface preparation.
- Pour locations and volume per pour.



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# Construction Engineer Inspection

- Placement procedure.
- Form closure including overpressure.
- Curing requirements.
- Surface preparation of hardened UHPC.
- Field testing for fresh properties.
- Lab testing for hardened properties.



# Constituent Measurement



# Flow Testing



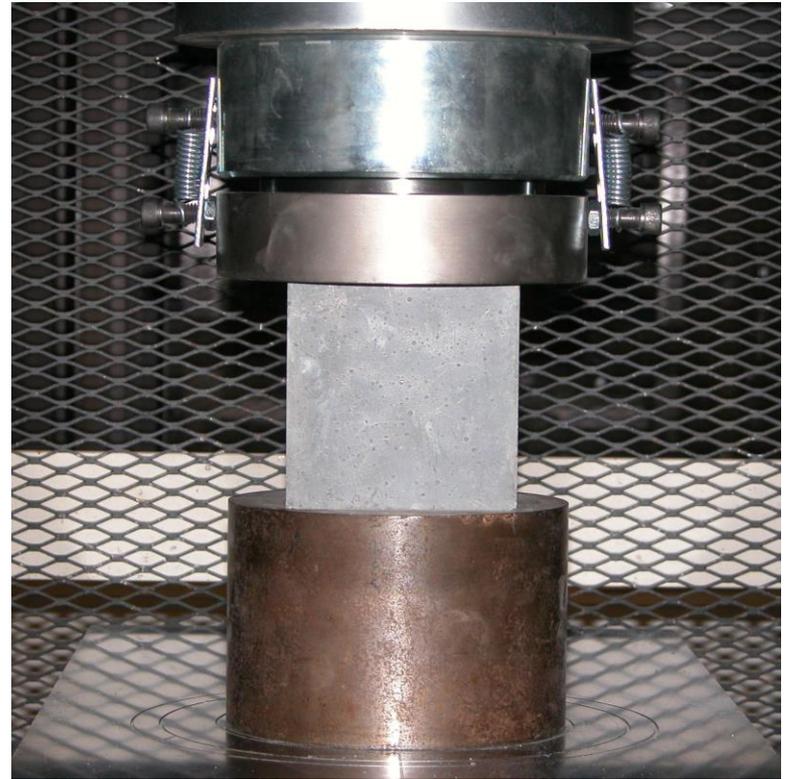
# Flow Testing



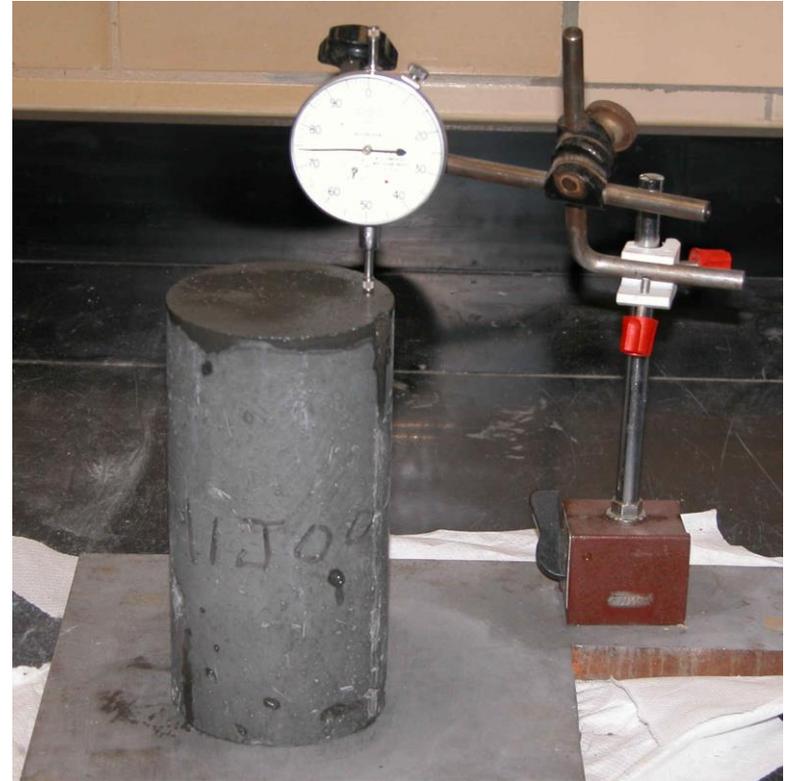
# Flow Testing (Video)



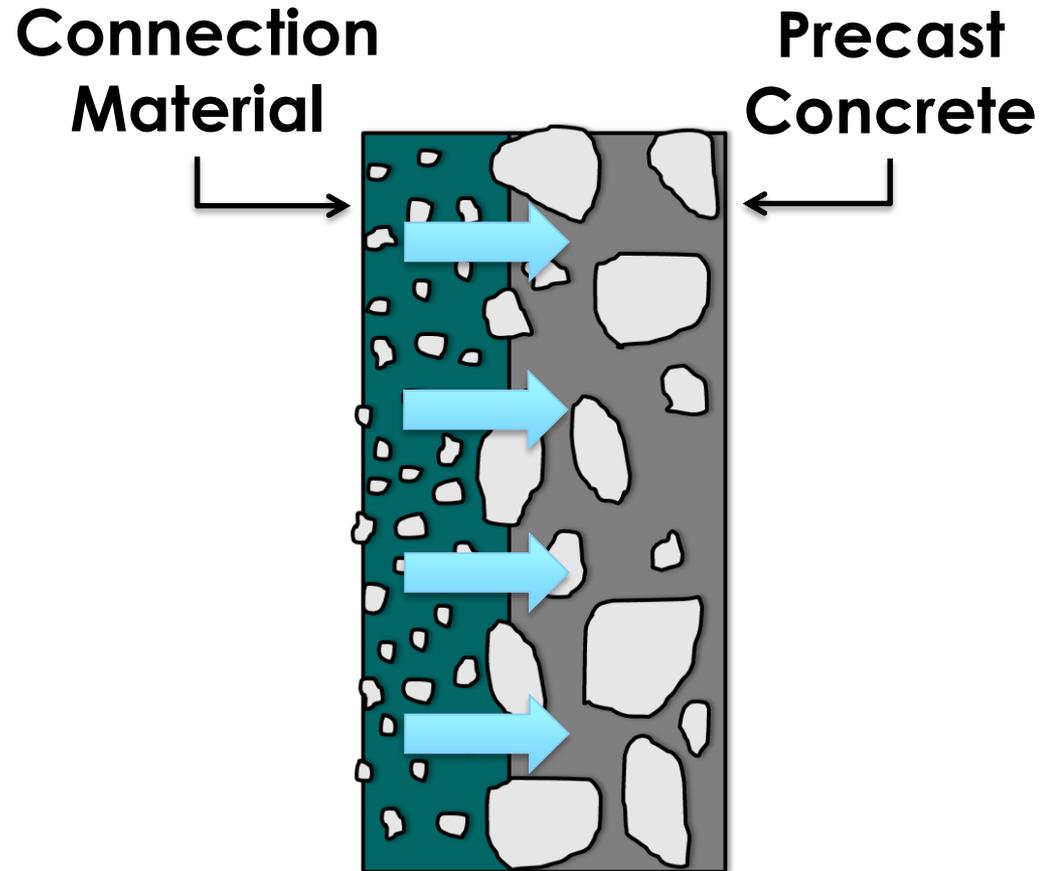
# Compression Testing



# Cylinder Preparation for Compression Testing

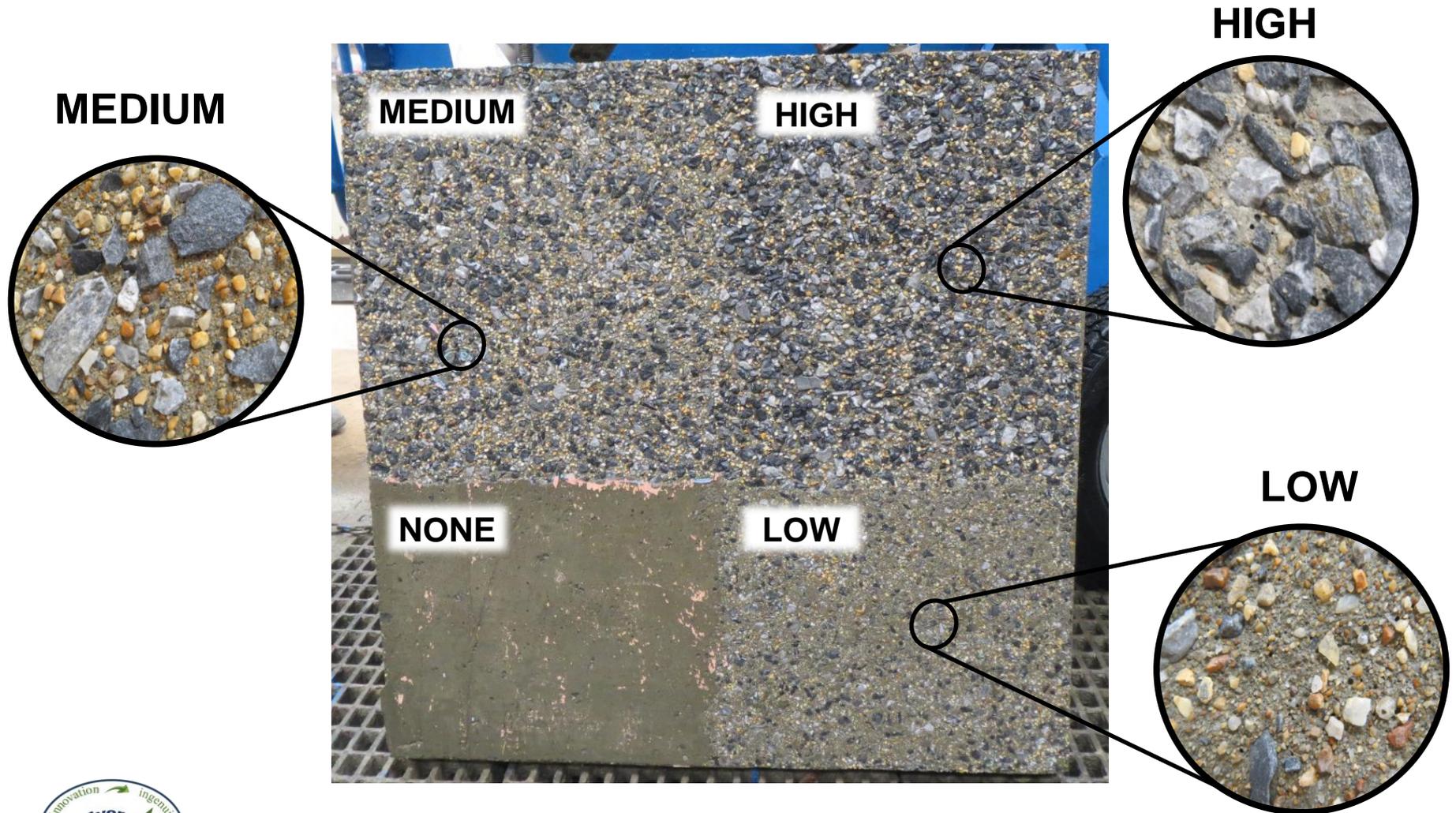


# Pre-Wetting Connection Interfaces

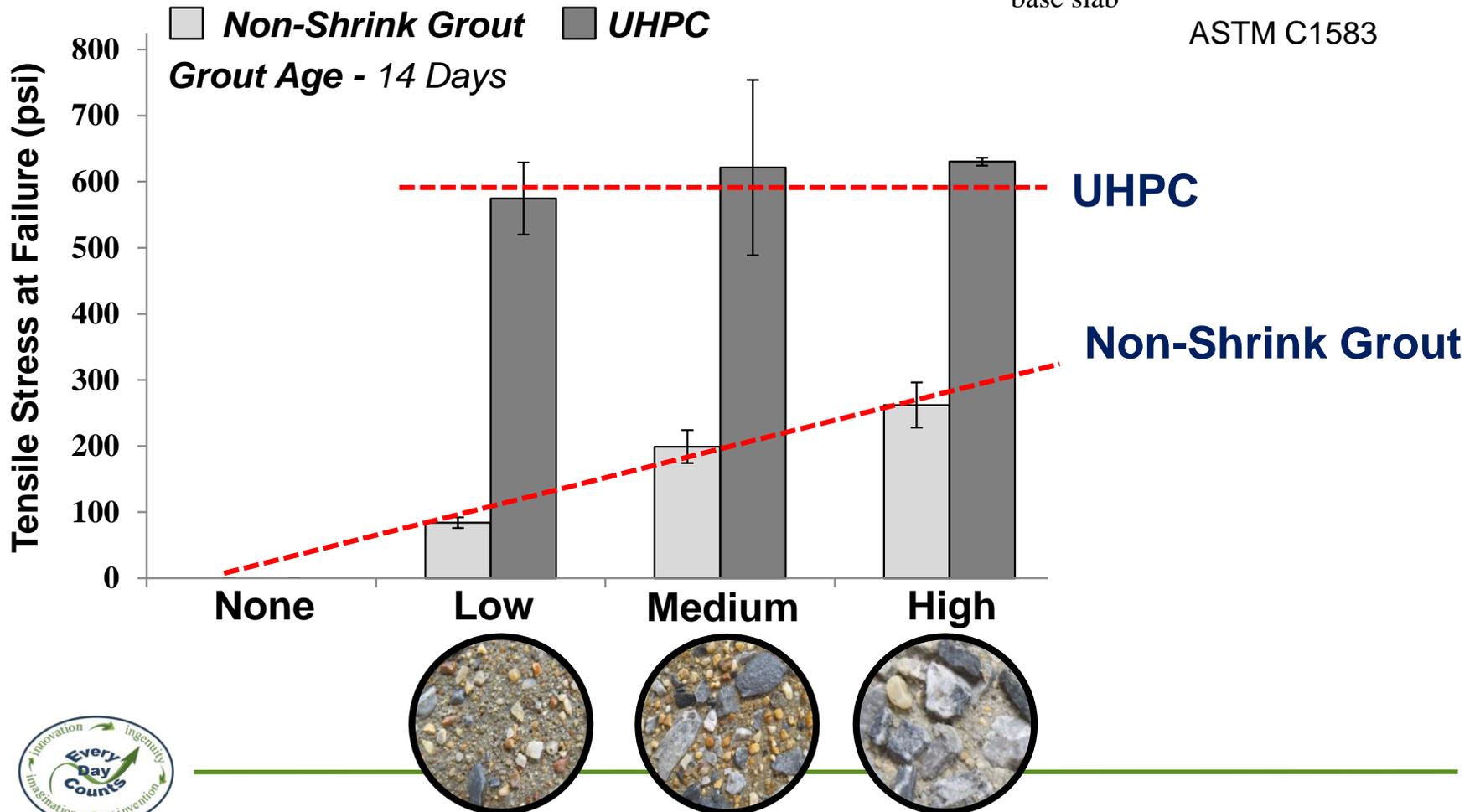
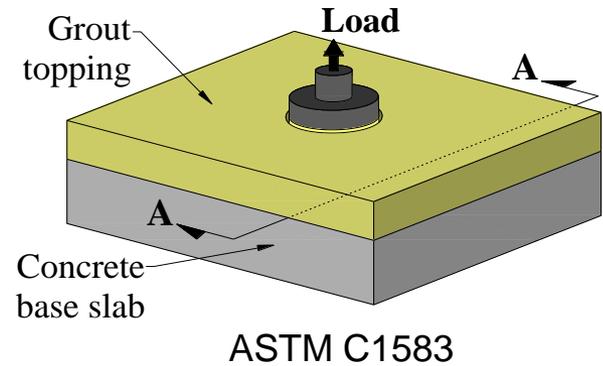


**No Moisture → Reduced Bond**

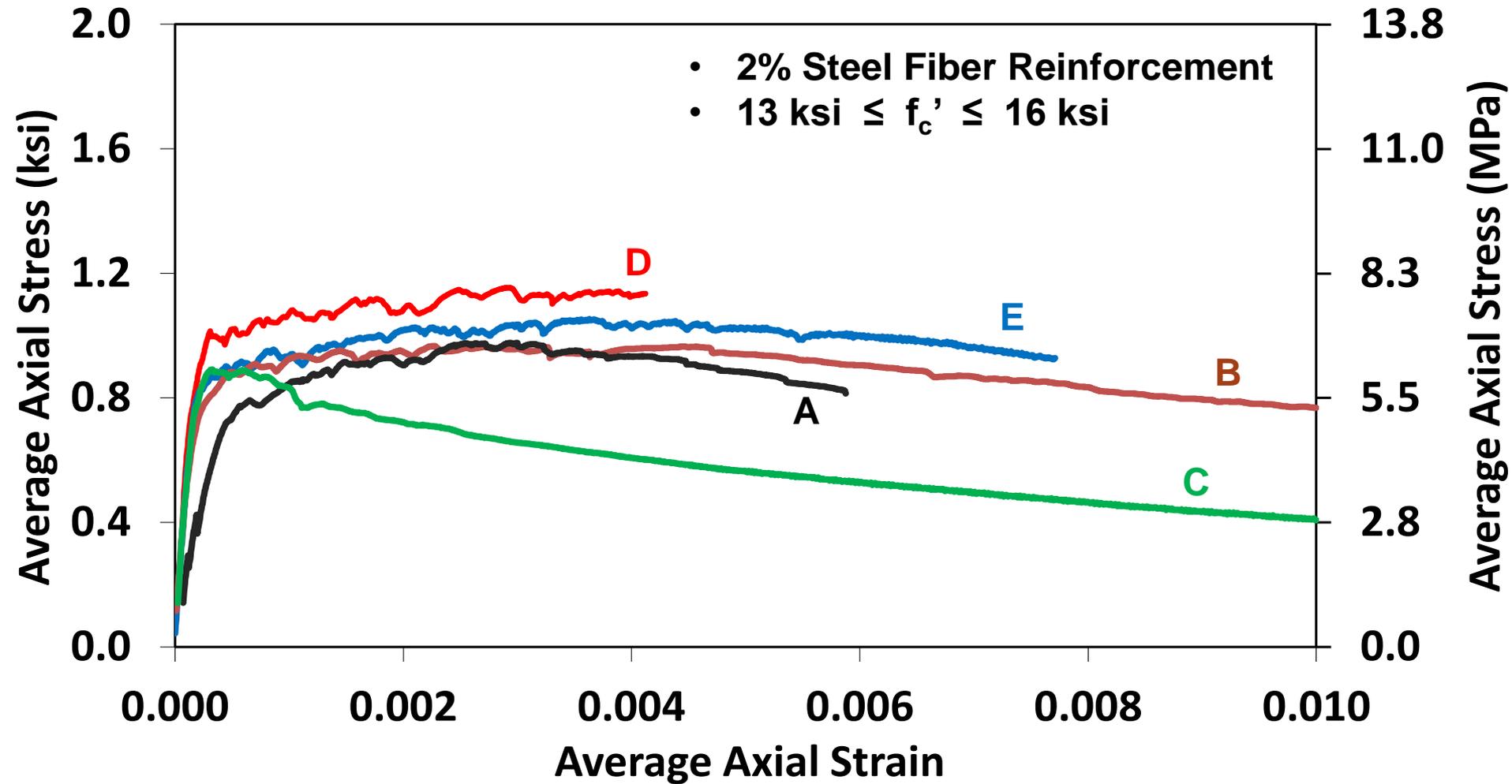
# Bondable Interface to Reduce Leakage



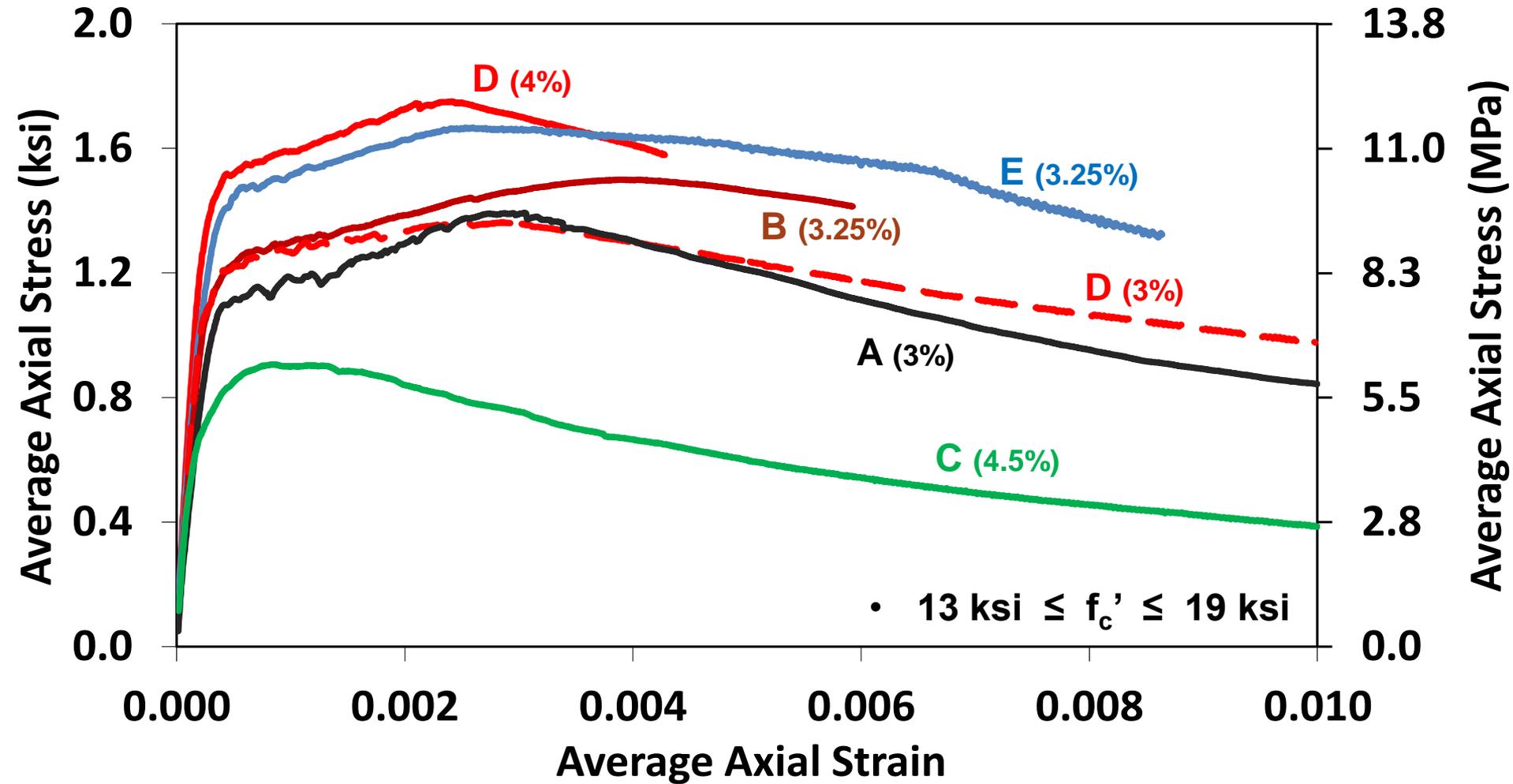
# Bondable Interface



# Tensile Behavior



# Tensile Behavior



# Compression Behavior

