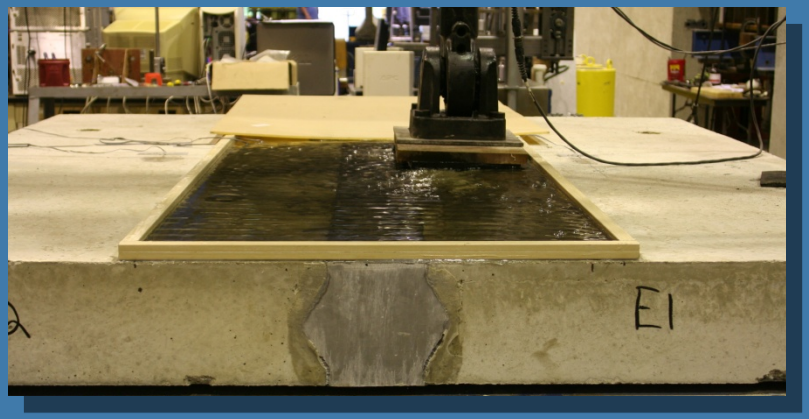
Ultra-High Performance Concrete: A Bridge of the Future Solution



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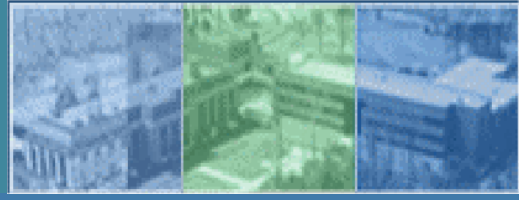
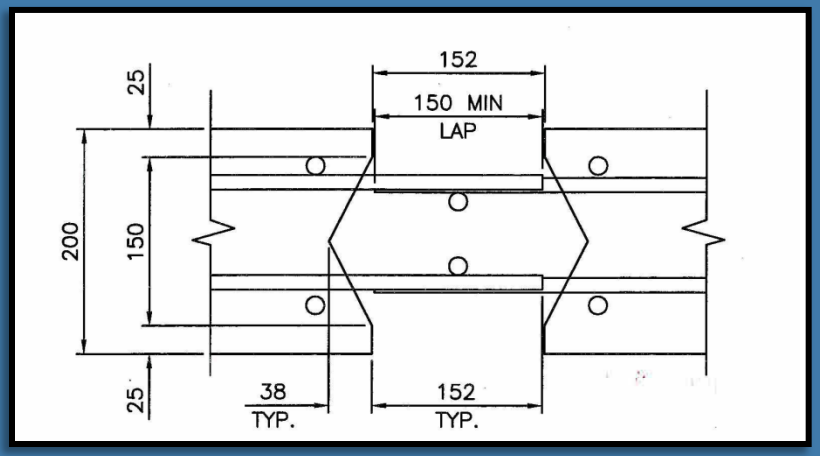
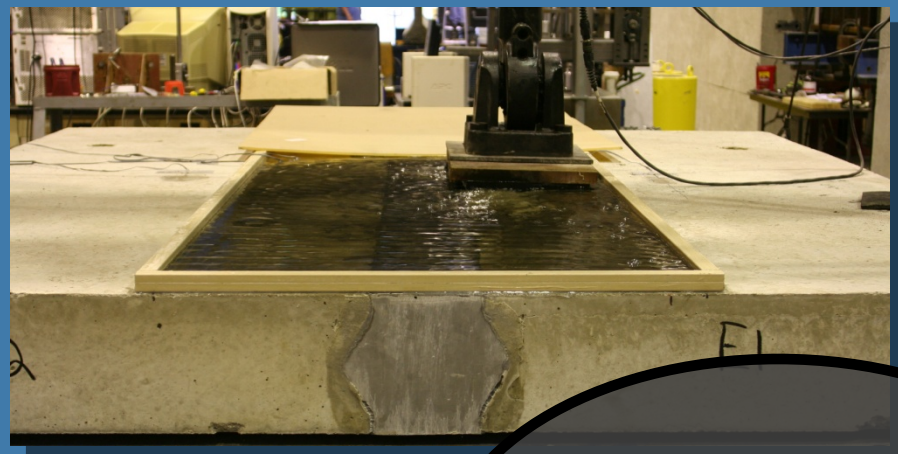


UHPC: Introduction and Applications

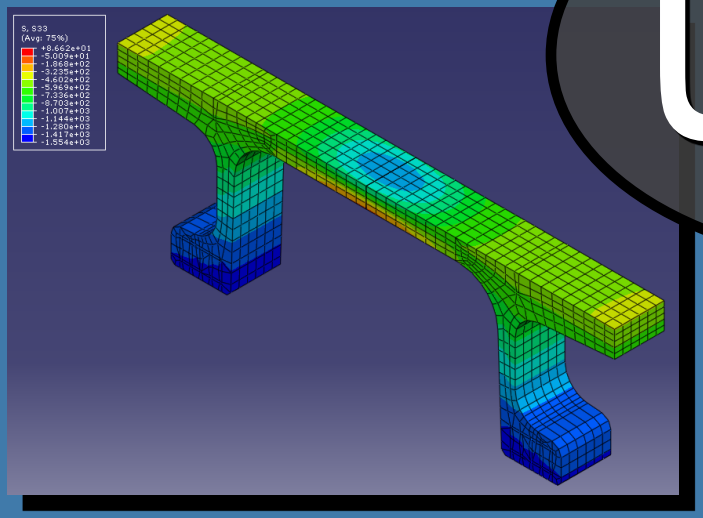
- Overview of UHPC
- Potential Applications
  - Girders, Decks, Joints
- Field-Cast Joints
  - Deployed Applications
  - Experimental Testing and Outlook
- Conclusions



TURNER-FAIRBANK HIGHWAY RESEARCH CENTER



UHPC



U.S. Department of Transportation
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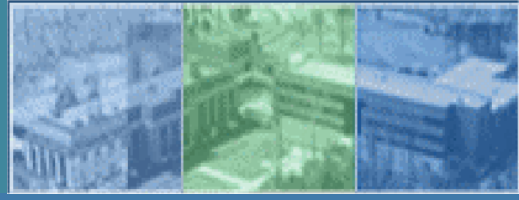
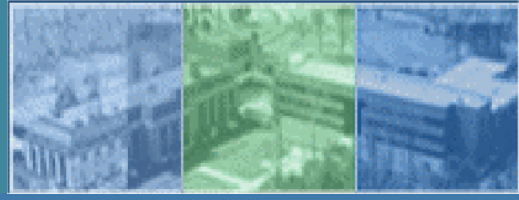


What is Ultra-High Performance Concrete?

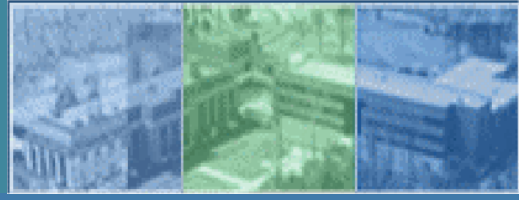
- Advanced cementitious material
- High strength, high stiffness
- Exceptional durability
- Internal steel fiber reinforcement for added ductility
- Self-consolidating

Cementitious Powder
Fine Filler Materials
Steel Fibers
Superplasticizer
Water



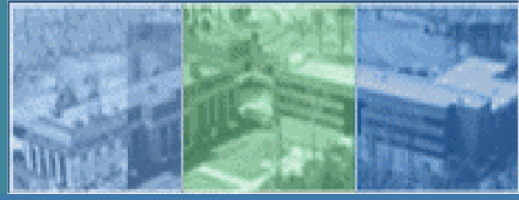
UHPC Properties: Some Ballpark Values

- Compressive Strength – 18 to 35 ksi
- Modulus of Elasticity – 6200 to 8000 ksi
- Creep Coefficient – 0.3 to 0.8
- Sustained Tensile Capacity – 0.9 to 1.5 ksi or more
- Rapid Chloride Permeability – 20 to 350 Coulombs
- Freeze/Thaw Resistance – RDM > 95%



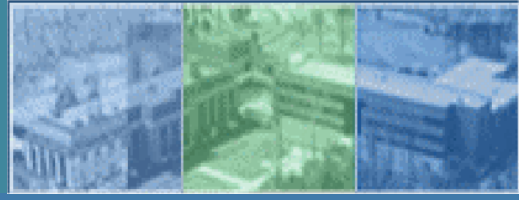
Typical Composition of UHPC

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



Important Points

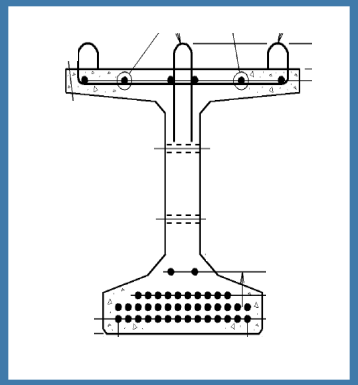
- Fiber-reinforced cementitious composite
- Strength is impressive
  …durability is even better.
- Cost (by volume) is high
  - Consider optimized use
  - Consider life-cycle costs
  - Increased familiarity and competition will help

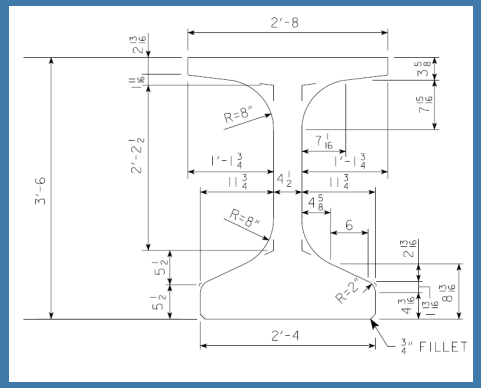


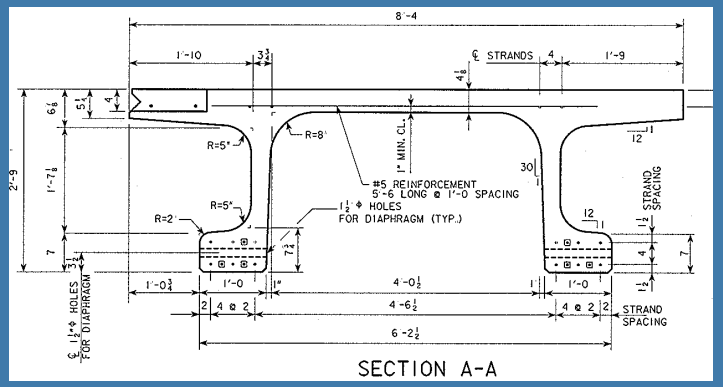
Potential Applications for UHPC in Highway Transportation Infrastructure

- Prestressed Girders
- Precast Deck Panels, Orthotropic Decks
- Field-Cast Joint Fill
  - Deck Joints, Composite Connections, Link Slab, etc.
- Columns, Piles
- Claddings, Overlays
- Decorative Elements

UHPC Prestressed Girders







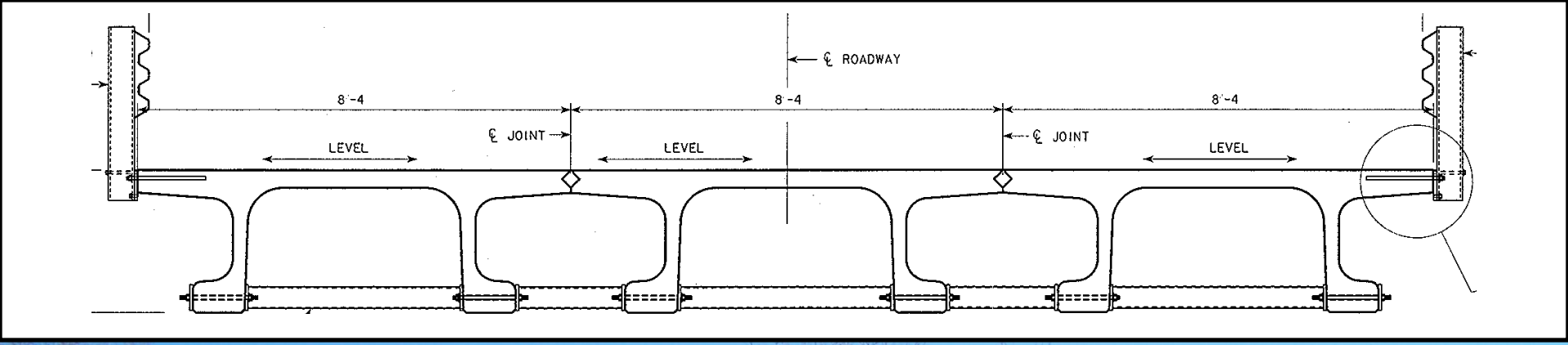
- Longer Spans
- Shallower Depths
- Integral Deck
- Accelerated Construction
- Lighter Weight
- Enhanced Durability
- Greater Resilience

Mars Hill Bridge
Wapello County, Iowa

U.S. UHPC Highway Bridges

Jakway Bridge
Buchanan County, Iowa

Cat Point Creek Bridge
Richmond County, Virginia

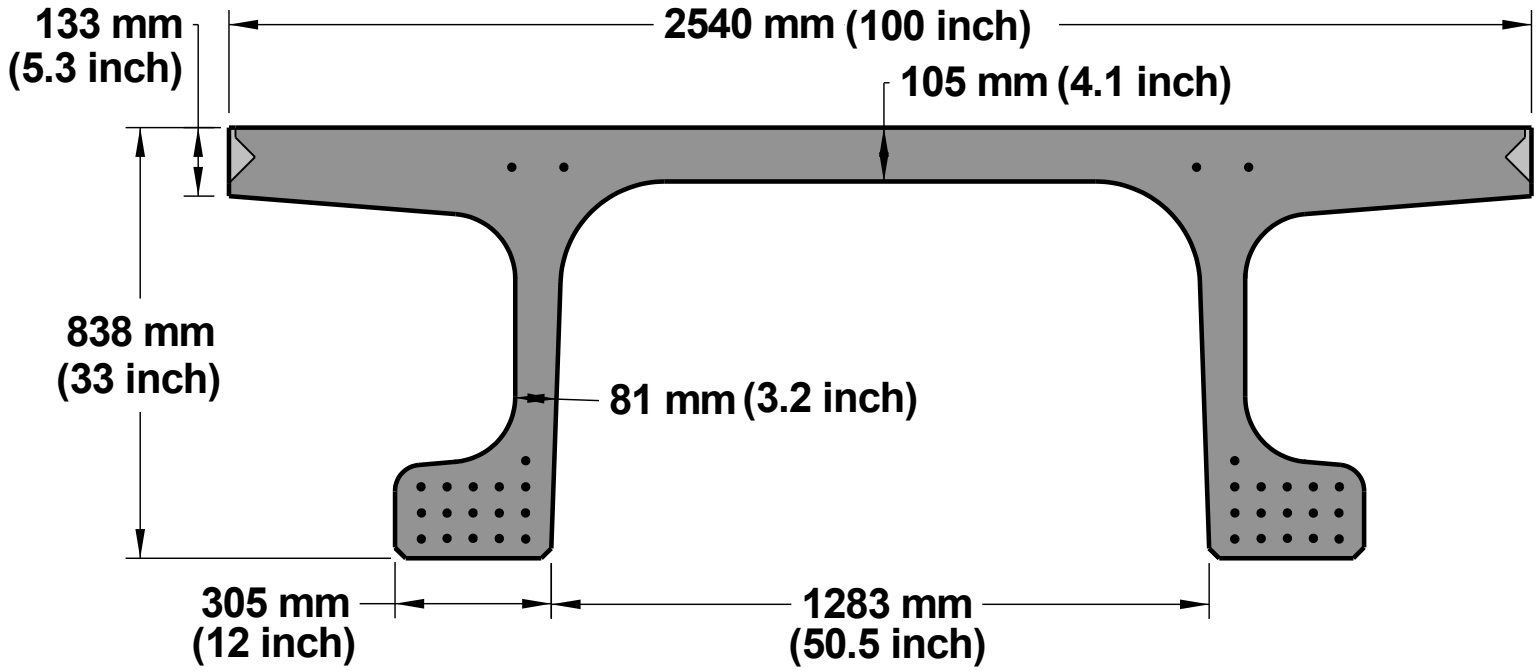


UHPC π-Girder Bridge

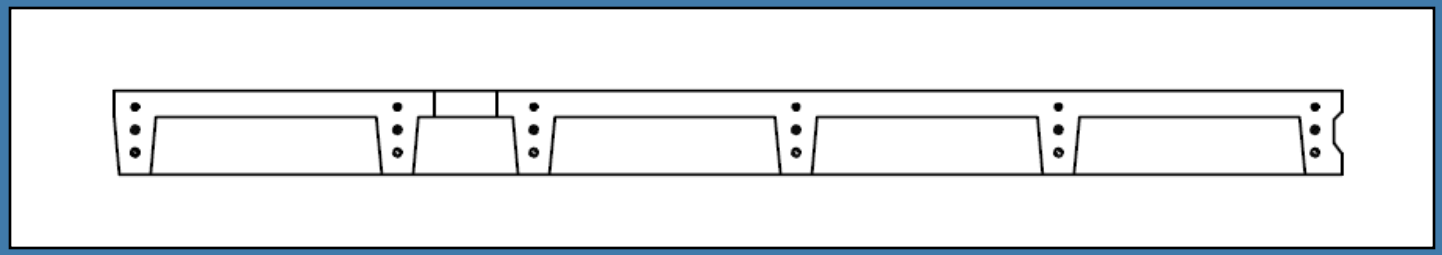
Jakway Bridge
Buchanan County, Iowa

π-Girder

- Decked Bulb Double-Tee
- 0.84 m (33”) depth spans up to 26.5 m (87’)
- Weight = 1390 kg/m (932 lb/ft)
- Designed to carry AASHTO LRFD loads

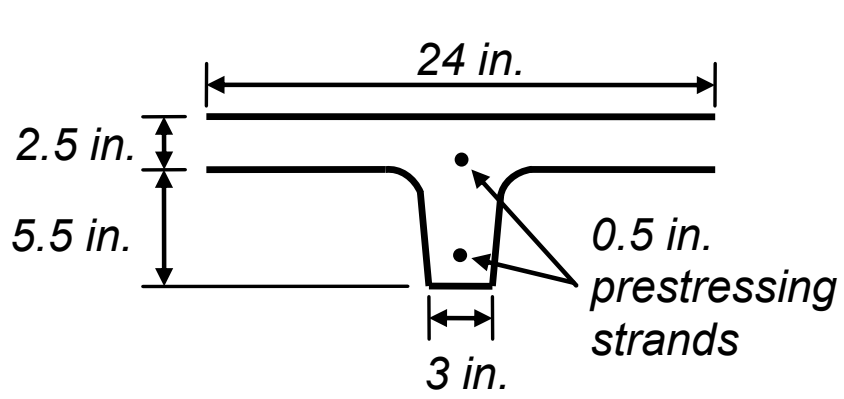


UHPC Precast Decks

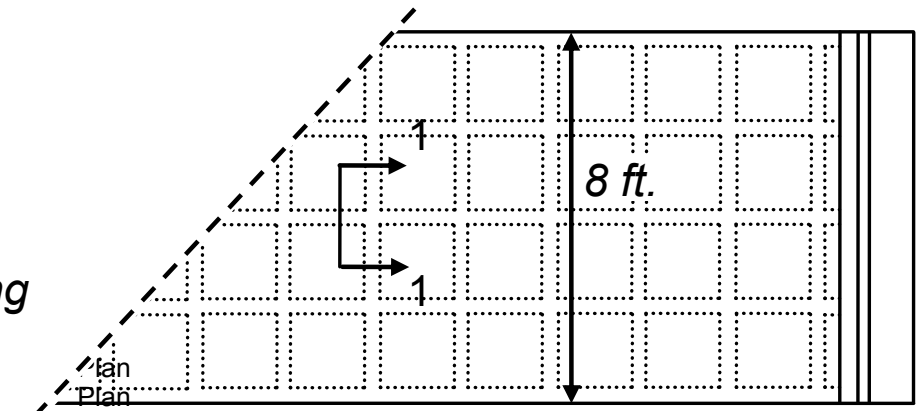


- Enhanced Durability
- Lighter Weight
- Greater Resilience
- Accelerated Construction
- Simplified Construction

UHPC Waffle Slab

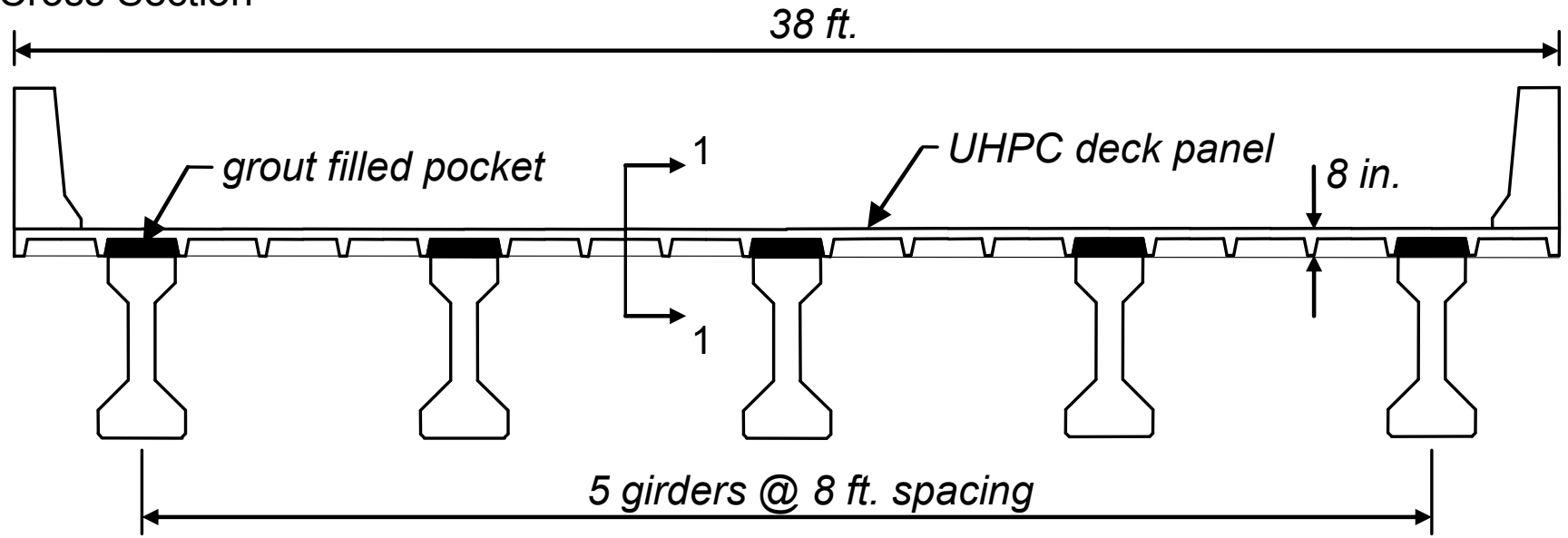


Detail 1-1



Plan

Cross Section



UHPC Waffle Slab Bridge Deck & Joints

Bridge over Little Cedar Creek
Wapello County, Iowa

- Prestressed I-girders
- Precast UHPC Waffle Slabs
- Field-Cast UHPC Joints b/t Modular Components

Construction pending appropriate weather conditions

Panel Fabrication at Coreslab Structures, Omaha Nebraska in July-Sept. 2010

Test Panel Photo Courtesy of Iowa State University

FHWA Highway for Life grant to Coreslab (Omaha) for development of concept.

UHPC Orthotropic Deck Replacement

Research and Development at LCPC in France

Referred to as the MIKTI deck

Intended to replace steel orthotropic decks

First deployment pending

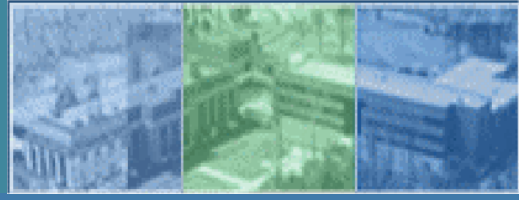
- Ribbed in 2 directions
- 15” total depth
- 2” deck, 13” ribs
- 23.6” rib spacing

- Testing completed
  - Global Bending
  - Fatigue
  - PT Anchorage
  - Punching Shear
  - Composite Cxn
  - Panel Joints

Photo Courtesy of Francois Toutlemonde, LCPC.

UHPC Connections b/t Modular Components

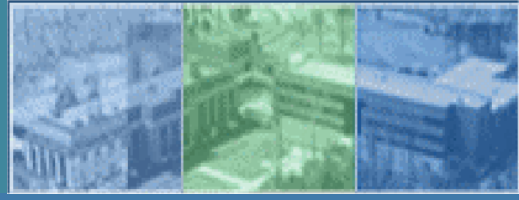
- Enhanced Durability
- Simplified Construction
- Greater Resilience
- Accelerated Construction



Connections are a Problem…

- Prefabricated components can:
  - Accelerate construction
  - Increase quality and safety
  - Enhance Durability
- But…
  Prefabricated components require connections.

- Connections tend to be:
  - Difficult to Construct
  - Expensive
  - Less Durable

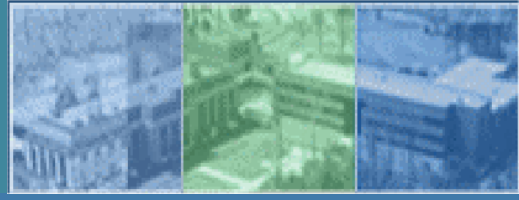


Solution: Rethink the Connection

- **Goals:**
  - Simplify construction
  - Minimize expense
  - Increase mechanical strength
  - Increase durability

} Greater Than Prefab!

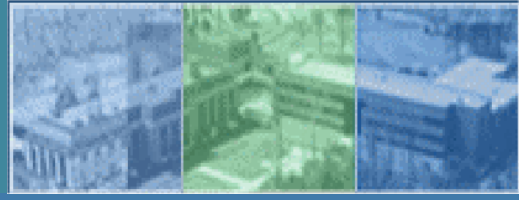
- **What we need:**
  - Strong, Durable Material
  - Good Bond to Concrete
  - Good Bond to Rebar



Concept: UHPC Connection

- Use lapped rebar connection as the starting point
- UHPC mechanical properties allow:
  - Reduced width through shortened development length
  - Reduced cracking through higher strengths
  - Reduced interface cracking through good cementitious bond
- UHPC durability properties allow:
  - Greatly reduced permeability and enhanced longevity

Simple, field-cast connection between modular precast concrete components

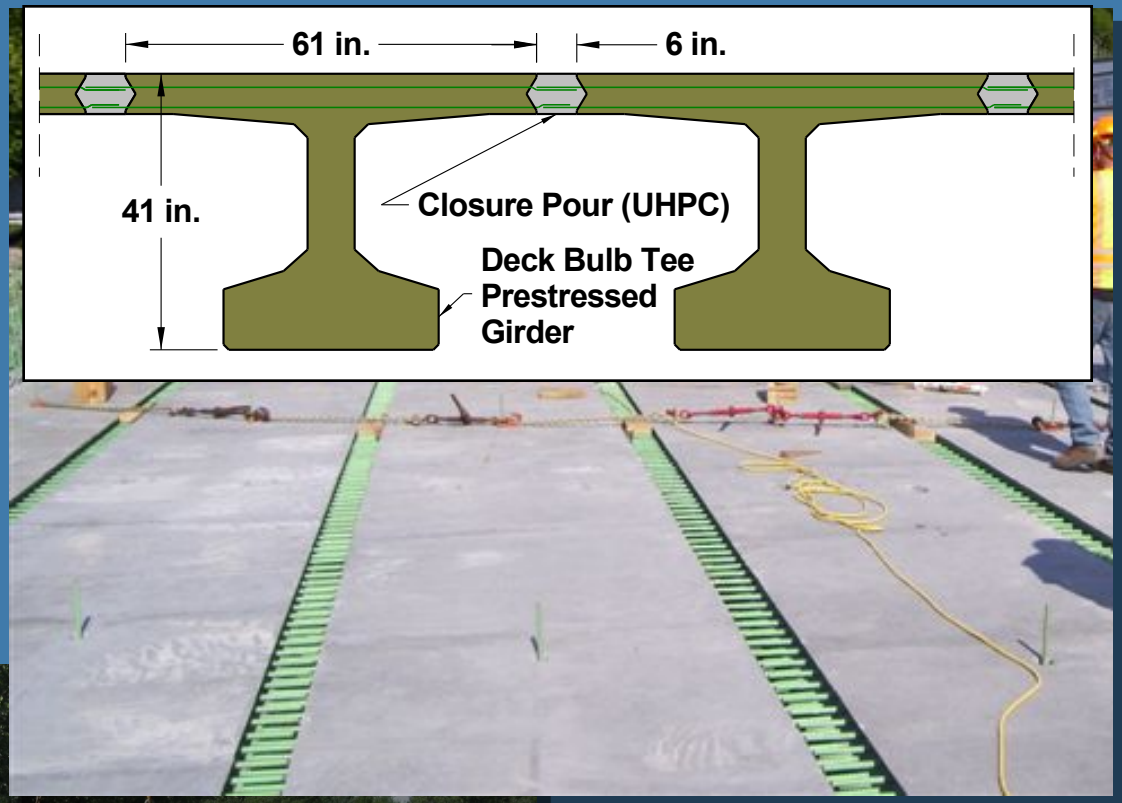


Field-Cast UHPC Properties

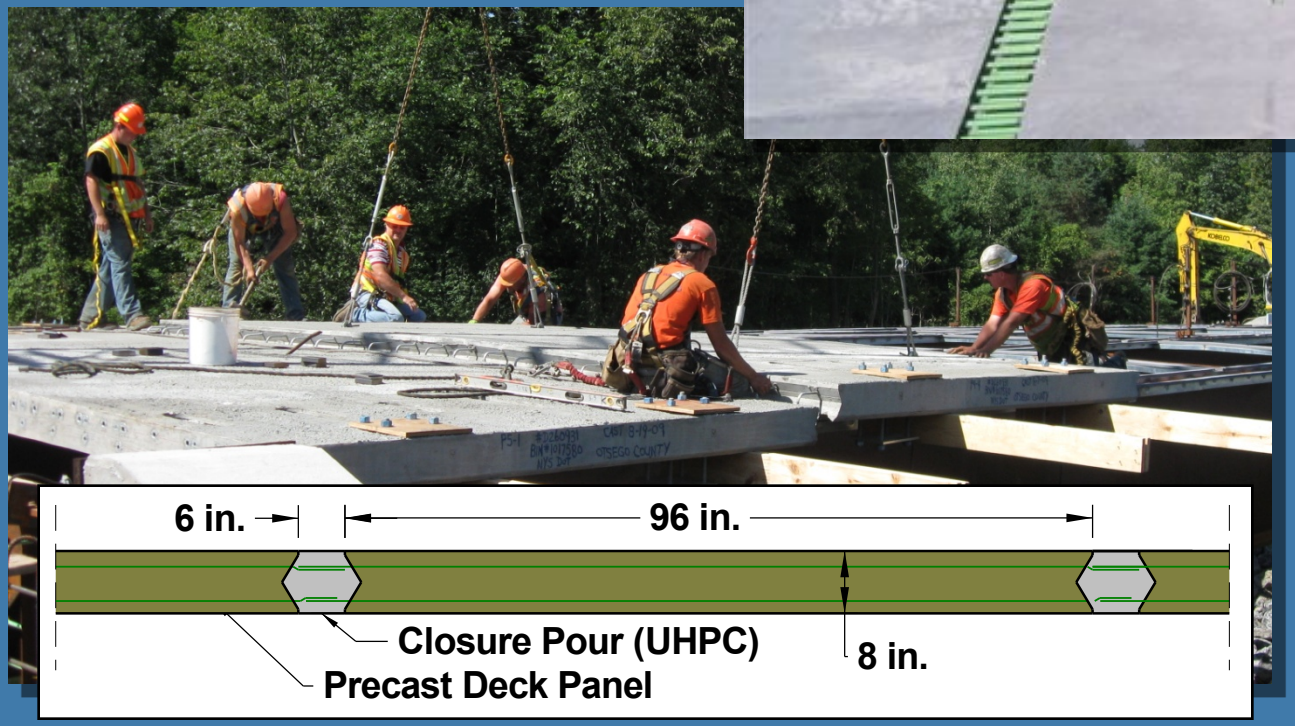
- Compressive Strength → 18 to 25 ksi
- Modulus of Elasticity → 6200 to 6500 ksi
- Creep Coefficient → 0.8
- Sustained Tensile Capacity → 0.9 ksi or more
- Rapid Chloride Permeability → 350 Coulombs
- Freeze/Thaw Resistance → RDM > 100%

Source: *FHWA Report FHWA-HRT-06-103*
Material Property Characterization of Ultra-High Performance Concrete

UHPC Modular Connections



SR 31 over
Canandaigua Outlet
Lyons, New York



SR 23 over Otego Creek
Oneonta, New York

Photos Courtesy of NYSDOT.

Field-Cast Connections for Modular Components

U.S. Department of Transportation
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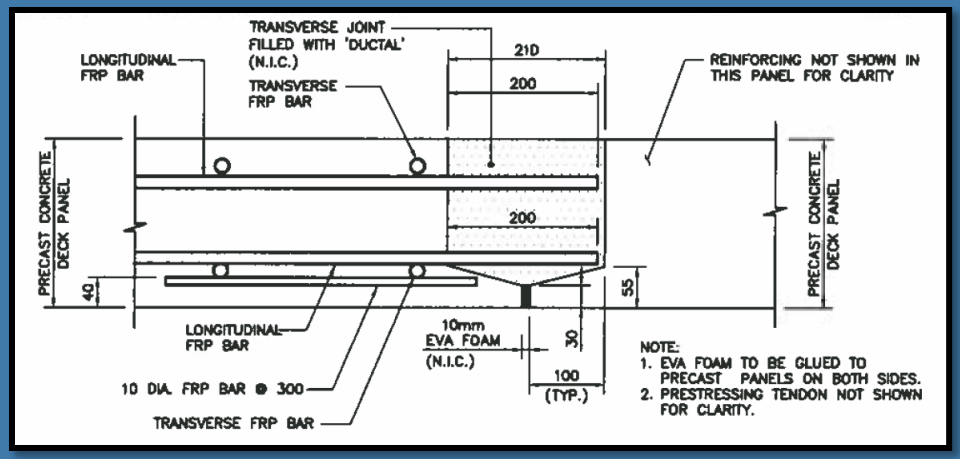
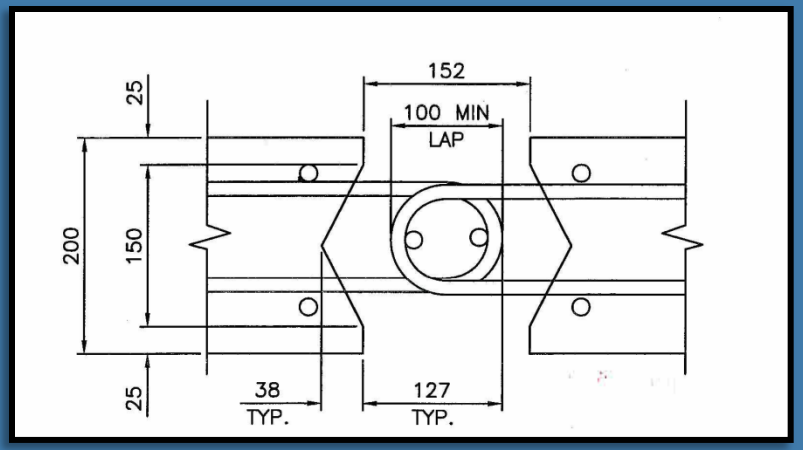
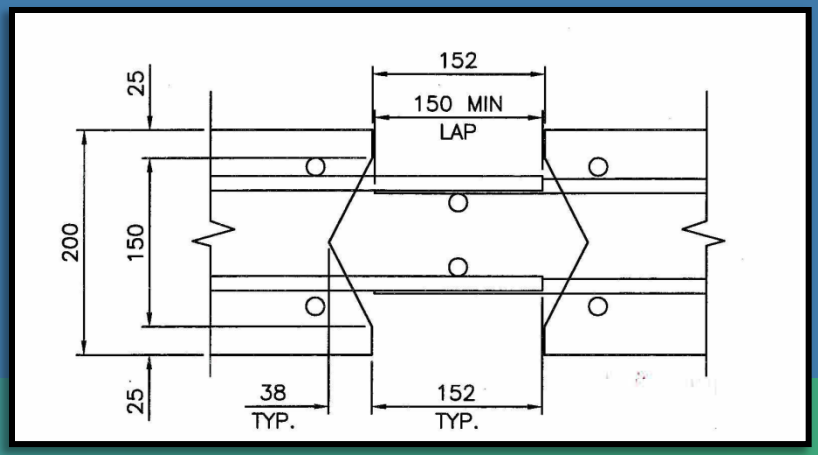
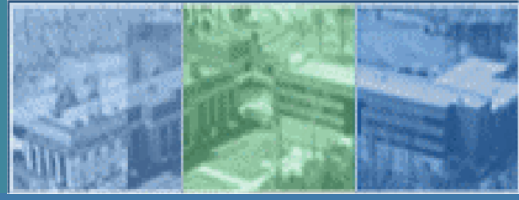
Photos Courtesy of NYSDOT.

Field-Cast UHPC Connections









… But Does It Really Work?

- **NYSDOT**
  - Already deploying field-cast UHPC joints
  - Strong interest in proof testing of concept
- **FHWA-TFHRC**
  - Significant experience w/ UHPC R&D
  - Desire to facilitate Accel. Bridge Construction
- **Pooled Fund: TPF-5(217) w/ NYSDOT, FHWA, Iowa DOT**

Assess Structural Performance of Field-Cast UHPC Joints

UHPC Joint Testing Project

- Full-scale subcomponents
- Simulated wheel loading
- 4 deck panel transverse joint specimens
- 2 deck-bulb-tee longitudinal joint specimens
- 12 months of testing completed
  - Cyclic testing below static cracking
  - Cyclic testing above static cracking
  - Static loading to flexural failure

Panel 6B - Cycling from 3 to 21.3 kips

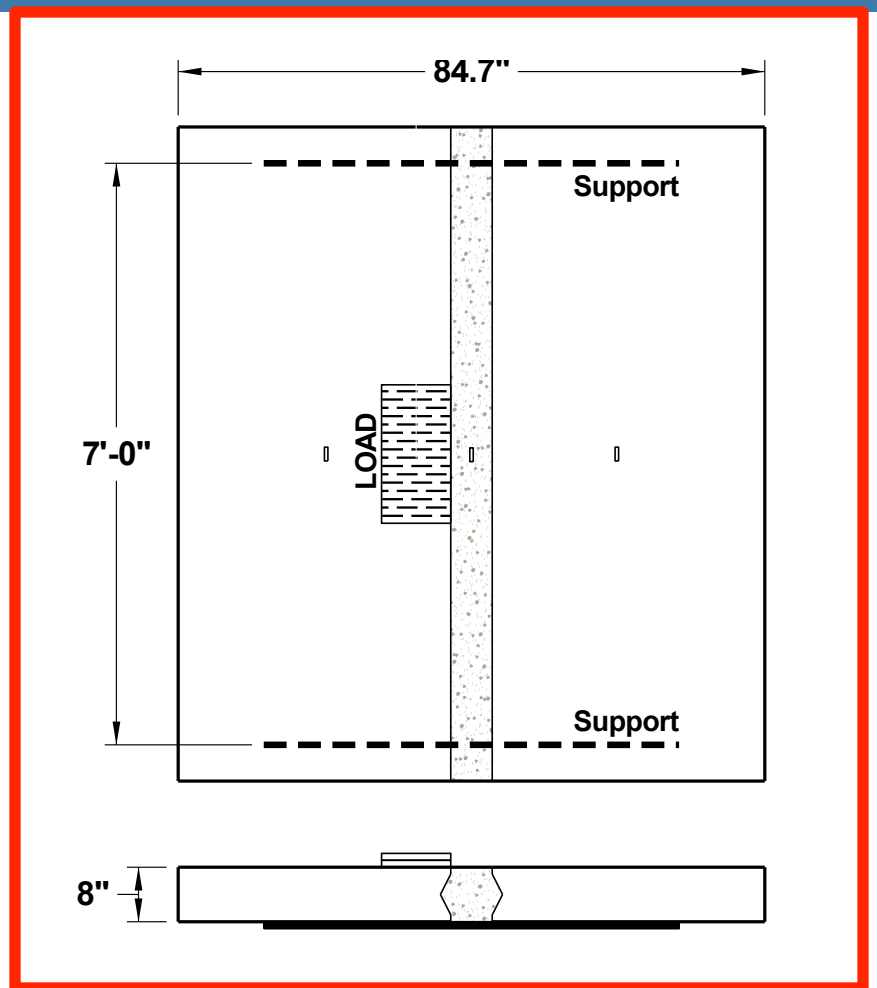
Panel 6B - Cycling from 3 to 40 kips

UHPC Joint Testing

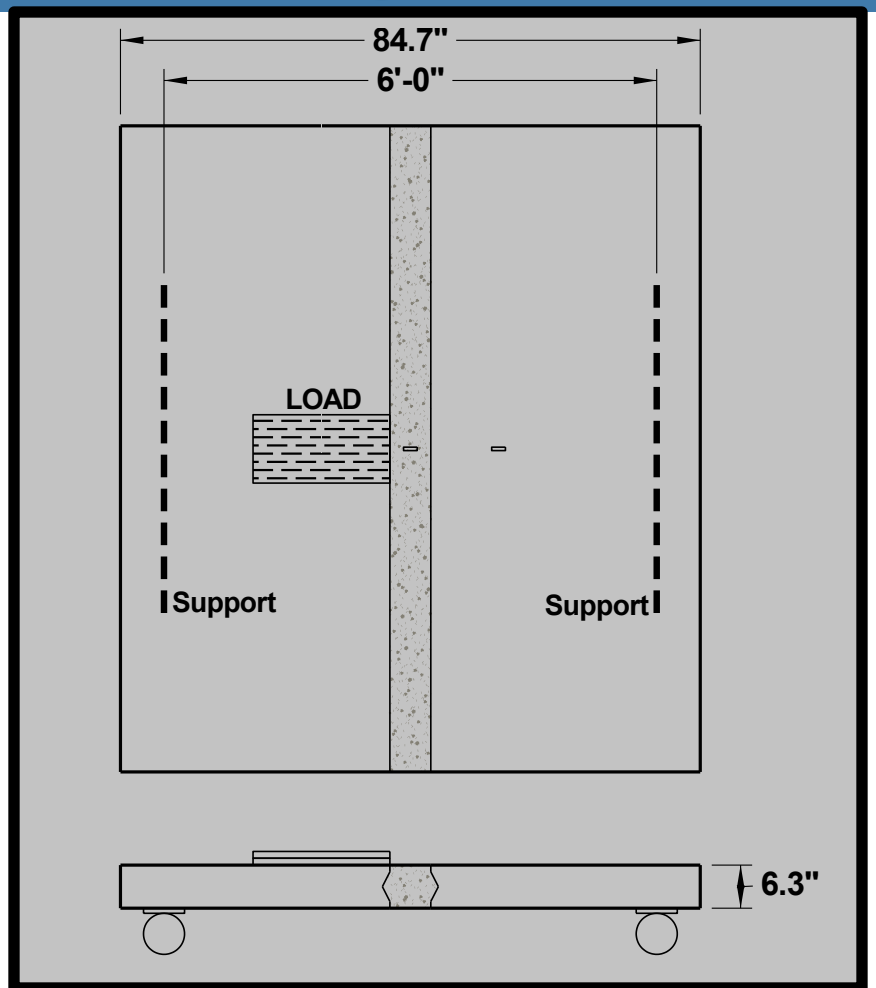
- **Joint Designs Investigated**
  - Hairpins, headed bars, and straight bars
  - Epoxy coated, galvanized, and black bars
- **Load Levels**
  - Uncracked cycling ← Does interface debond?
  - Cracked cycling ← Interface debond? Rebar debond?

UHPC Joint Testing

Simulating Deck Panel Cxn

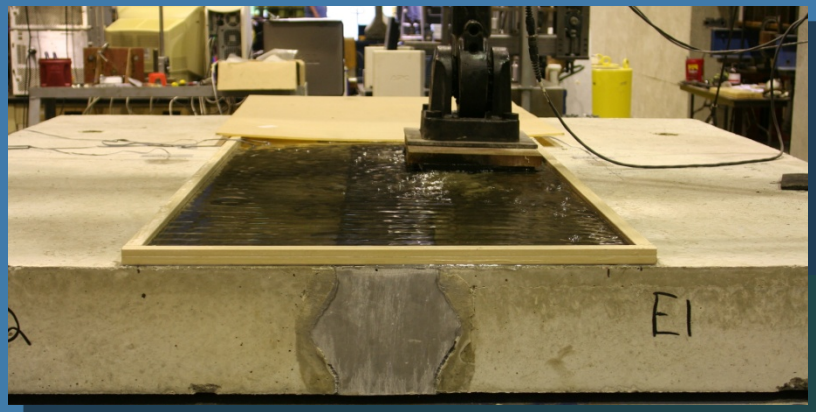


Simulating DBTee Cxn



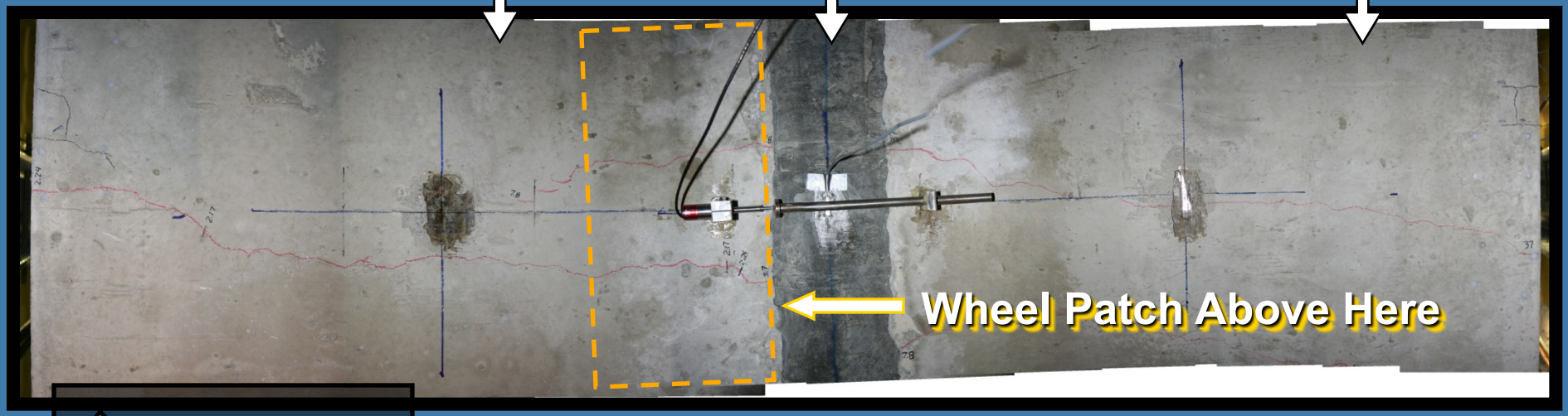
UHPC Transverse Joint Testing

	Peak Cyclic Load		
Panel	16 kip	21.3 kip	Rebar
8E	8.9M	5.2M	#4 epoxy-coated hairpins
8G	2.1M	5.8M	#5 straight galvanized bars
8B	2.1M	5.2M	#5 straight black bars
8H	2.0M	5.1M	#5 headed black bars



- **No Interface Debonding**
- **No Leakage**
- **Midspan Flexural Cracking at Higher Loads**

UHPC Transverse Joint Testing

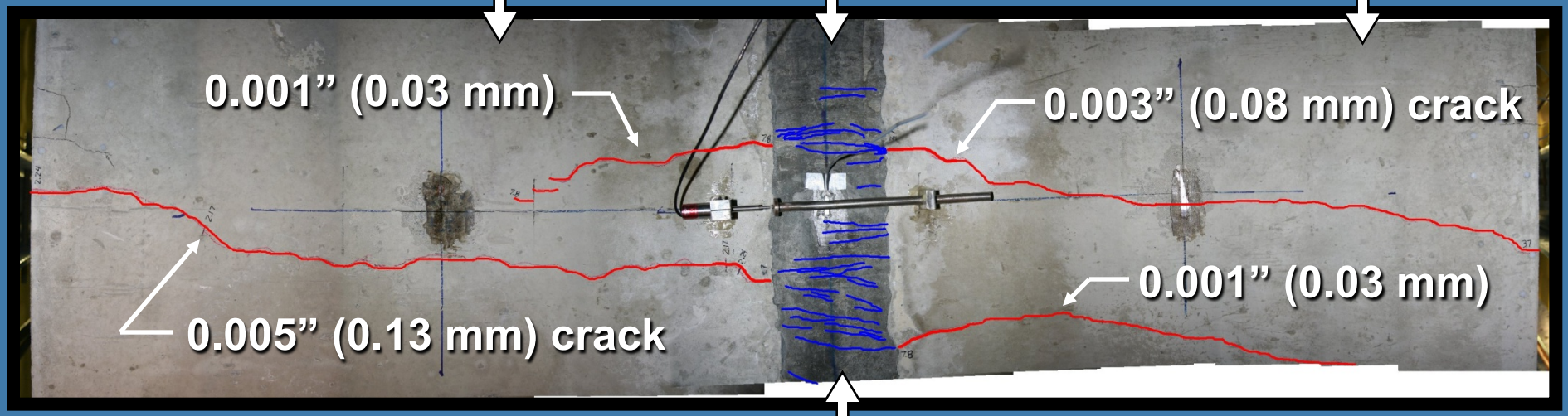


7' between Simple Supports

7' Wide Specimen

Panel 8G – After 5.8 Million Cycles to 21.3 kips

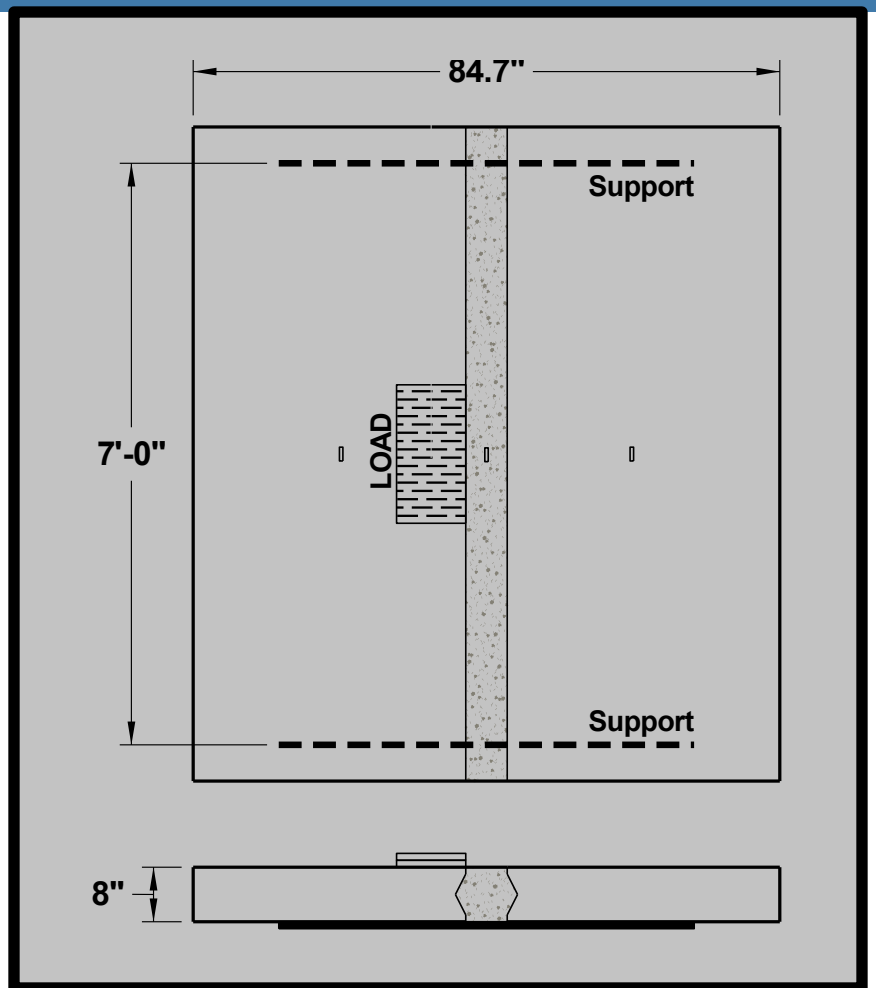
UHPC Transverse Joint Testing



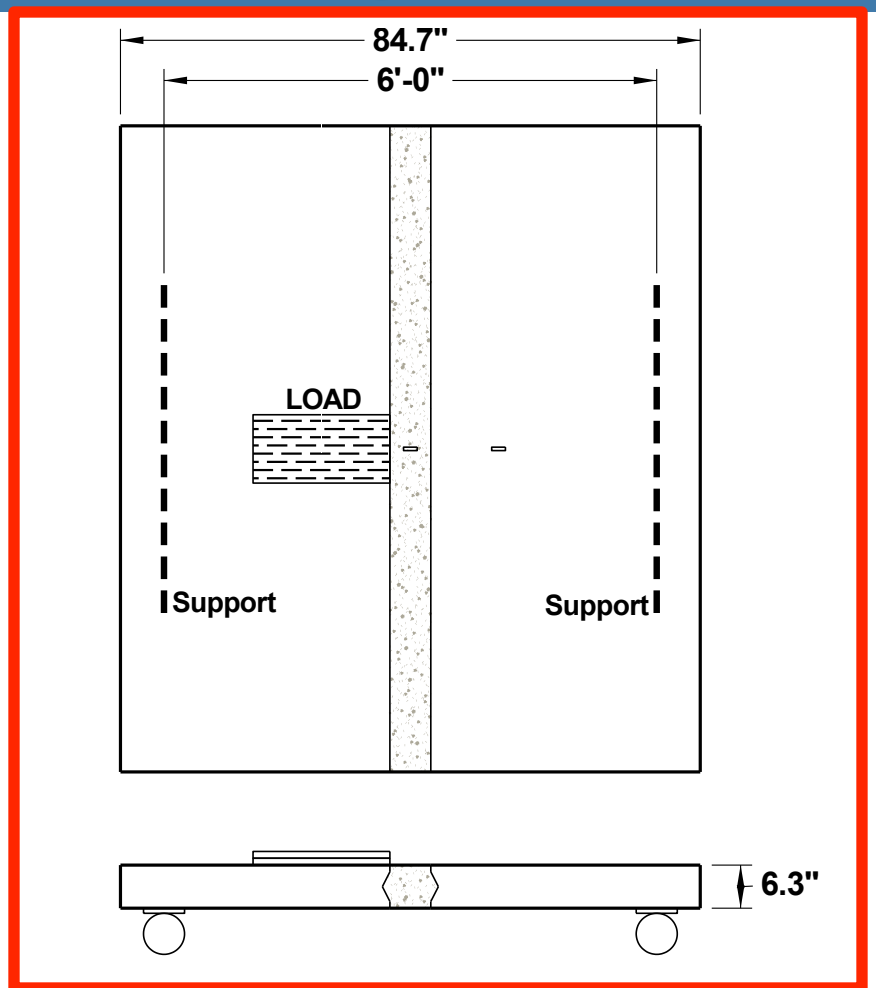
Panel 8G – After 5.8 Million Cycles to 21.3 kips

UHPC Joint Testing

Simulating Deck Panel Cxn



Simulating DBTee Cxn



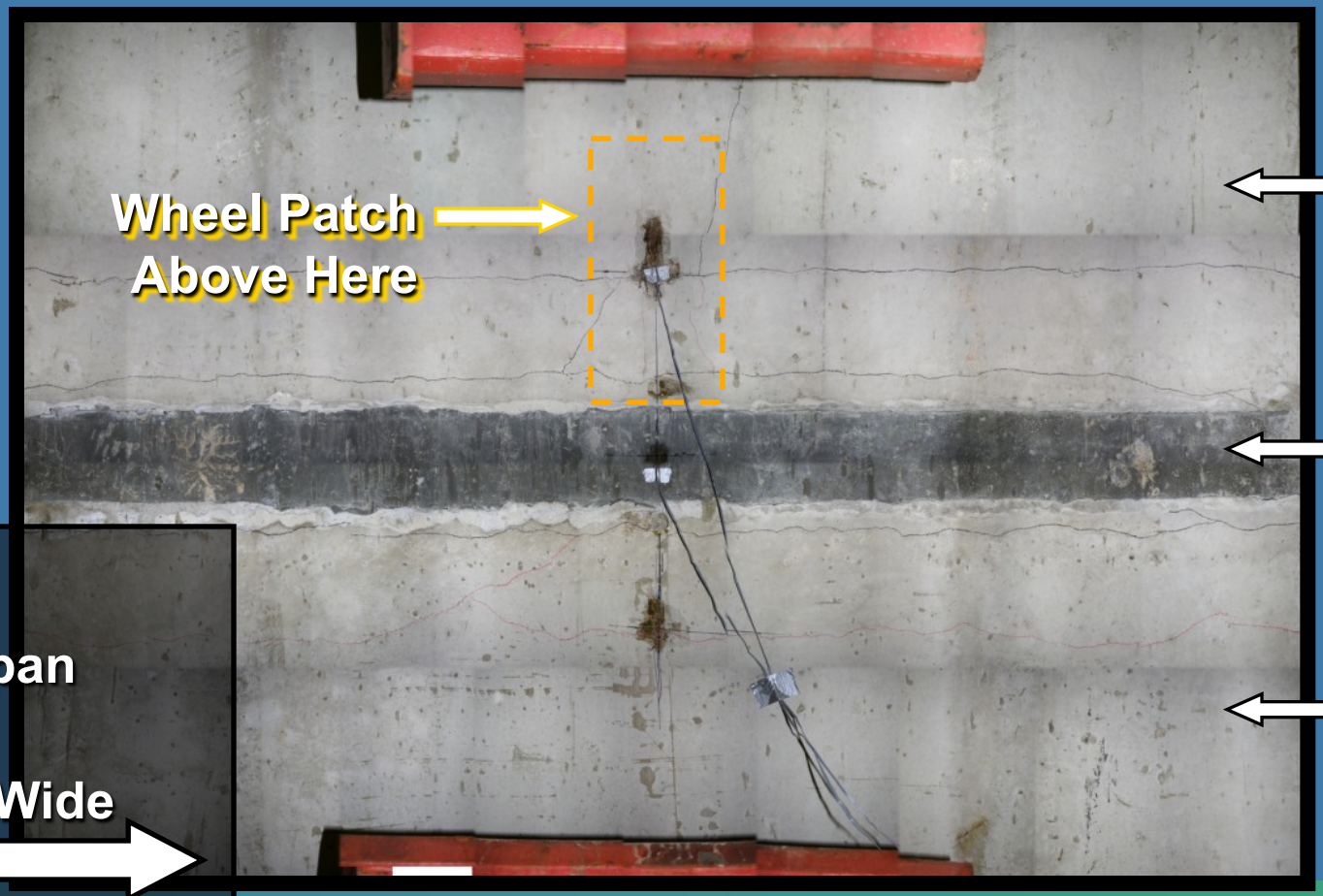
UHPC Longitudinal Joint Testing

	Peak Cyclic Load (kip)				
Panel	16	21.3	32	40	Rebar
6H	2.0M	7.0M			#5 headed black bars
6B	60k *	10.1M	1.1M	340k	#5 straight black bars

* Overload to 70 kip…significant cracking

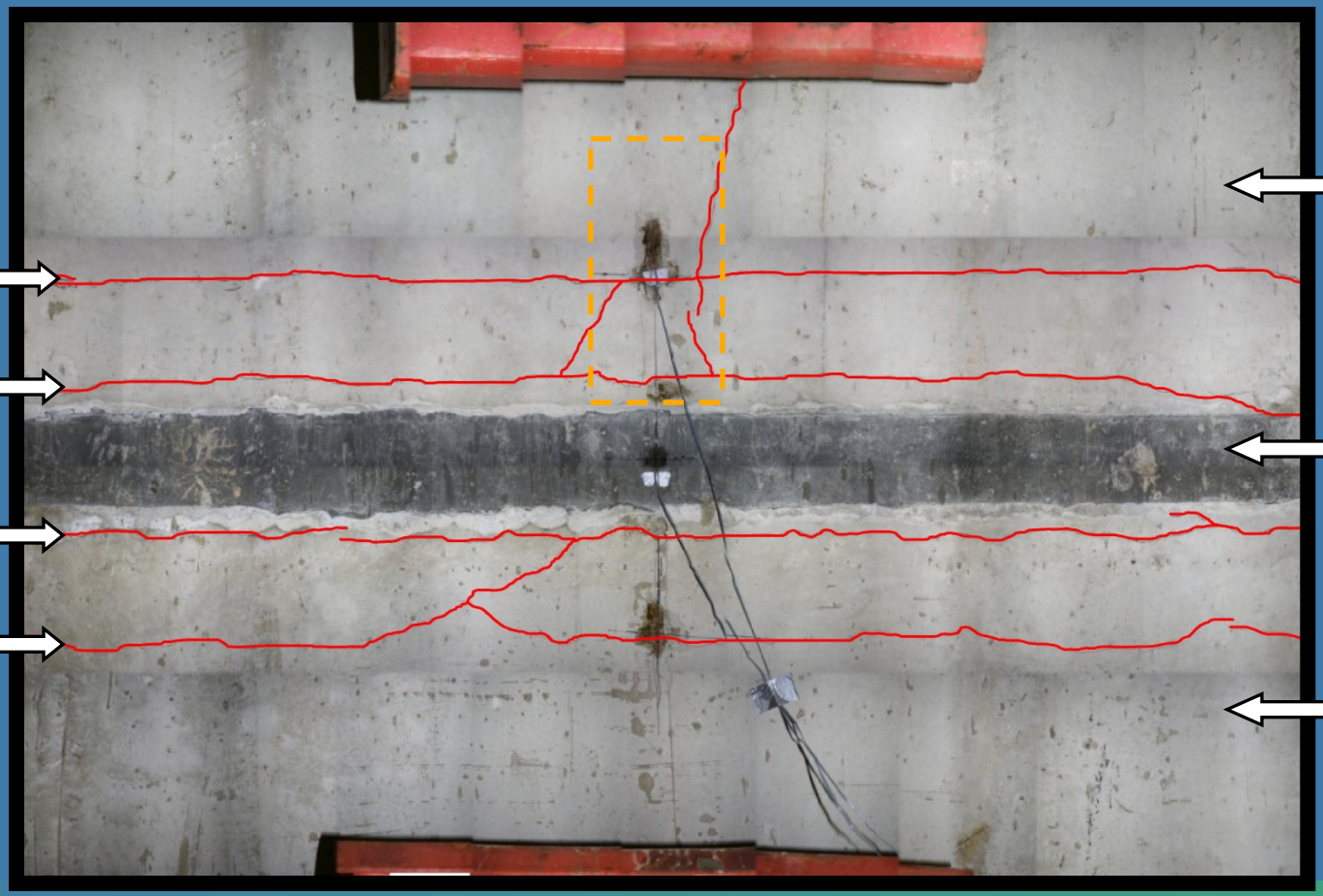
- 6H: No interface debond
  No Leakage
- 6B: No rebar debond
  Rebar fatigue fracture

UHPC Longitudinal Joint Testing – 6H



Panel 6H After 7.0 Million Cycles to 21.3 kips

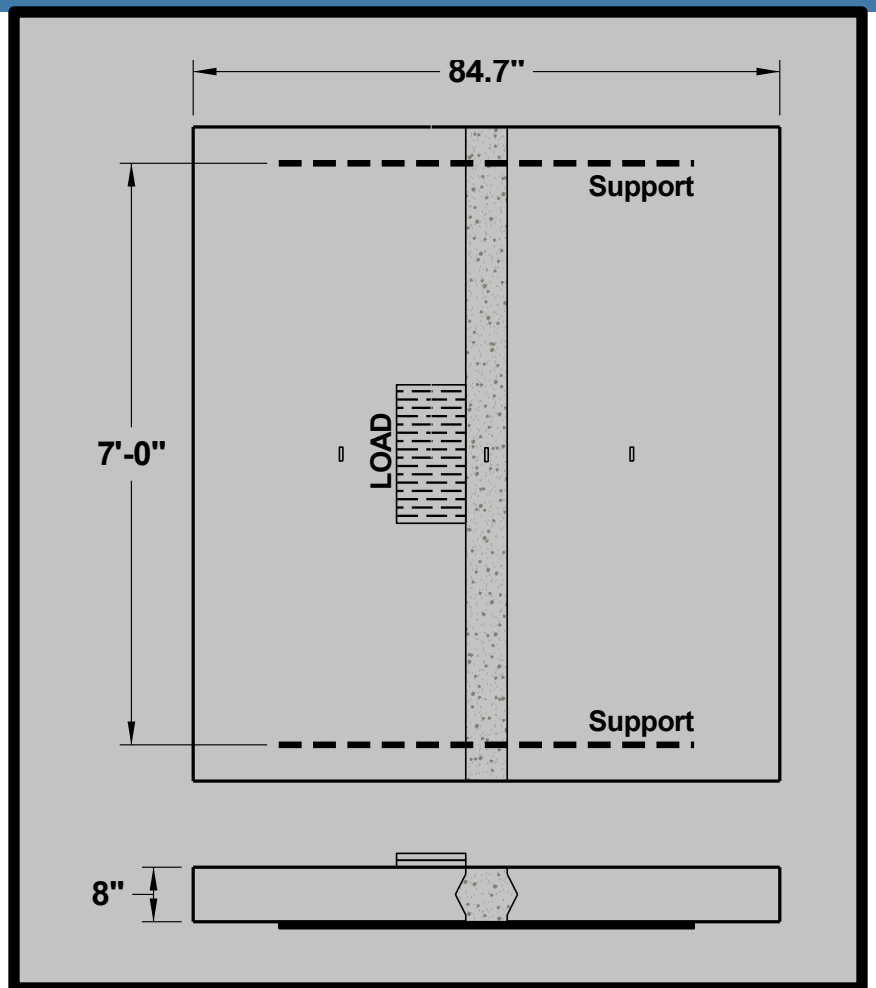
UHPC Longitudinal Joint Testing – 6H



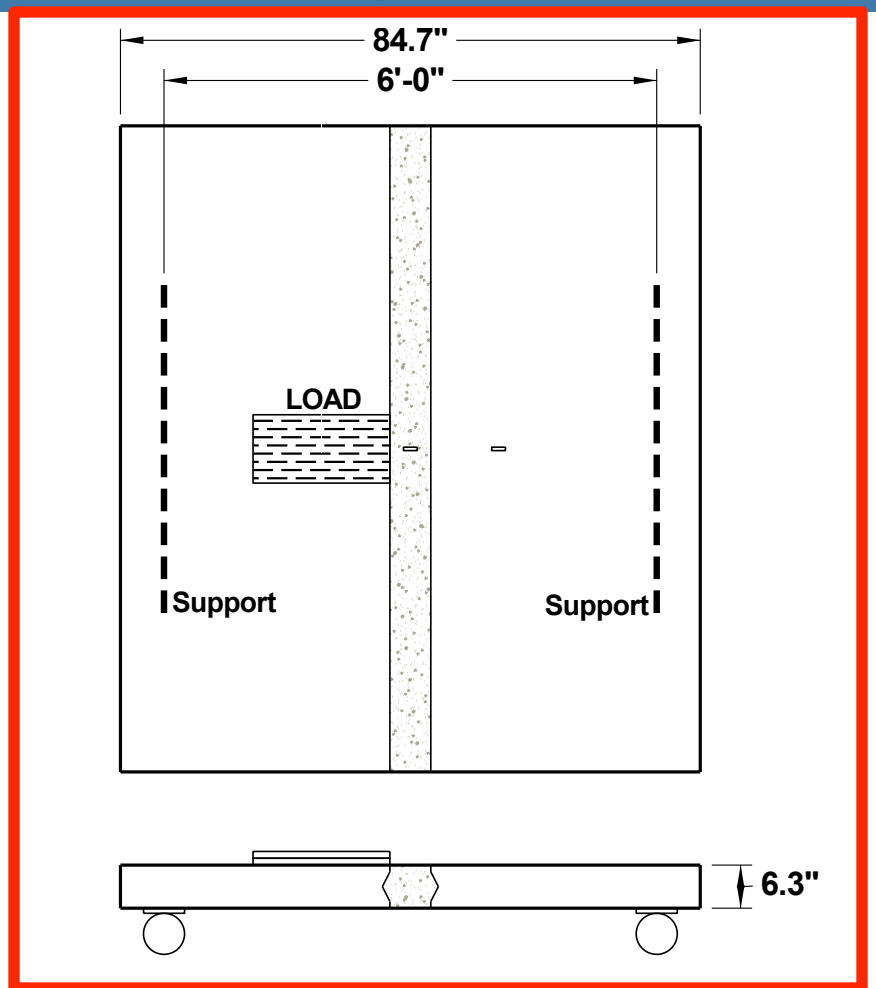
Panel 6H After 7.0 Million Cycles to 21.3 kips

UHPC Joint Testing

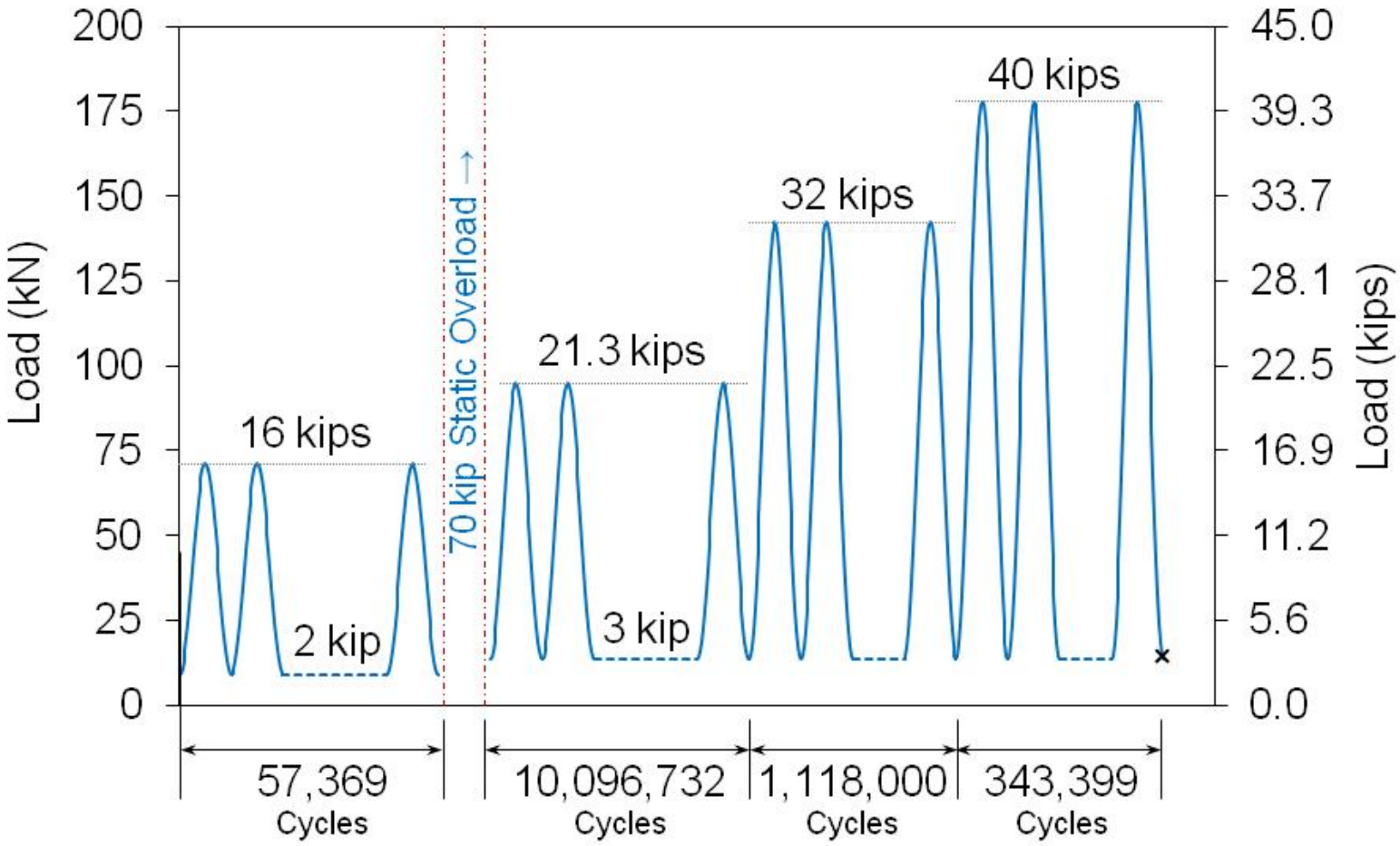
Simulating Deck Panel Cxn



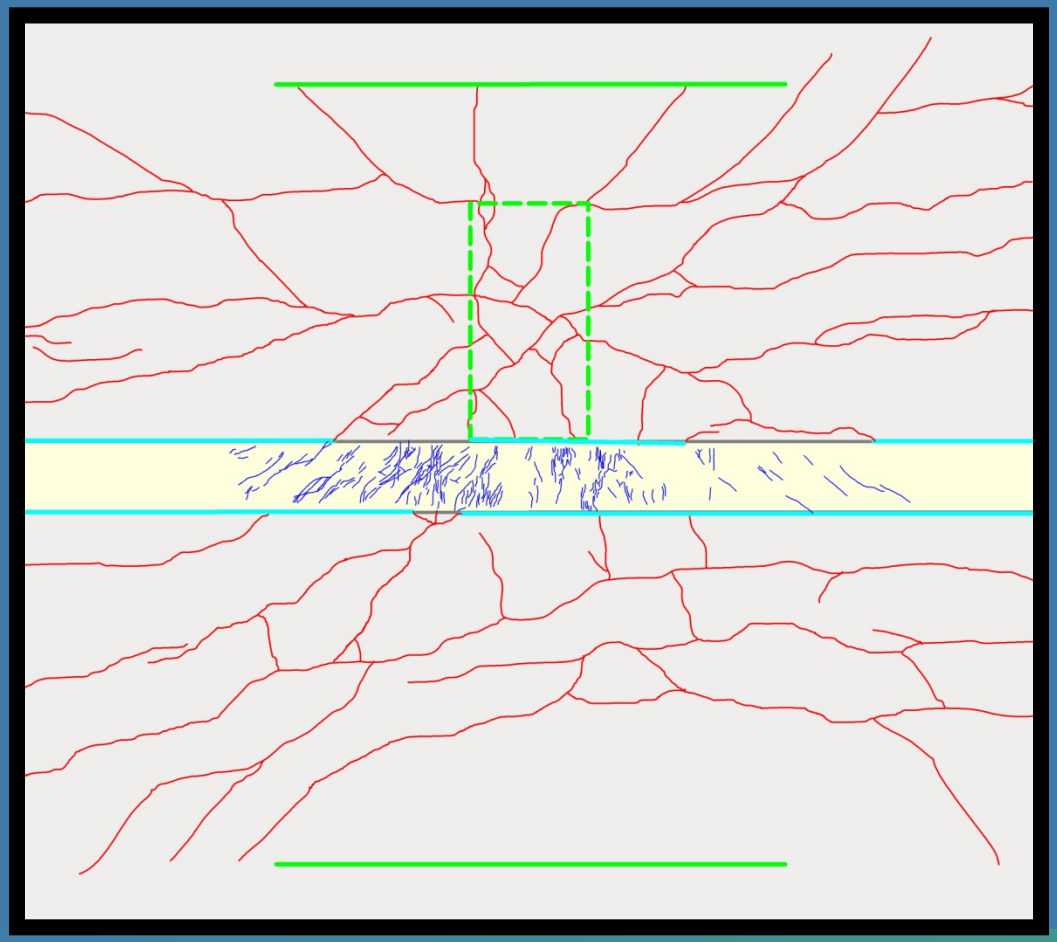
Simulating DBTee Cxn



UHPC Longitudinal Joint Testing – **6B**



UHPC Longitudinal Joint Testing – 6B



Crack Map
- Precast Panel
- UHPC
- Interface

No interface crack widening over 10 million cycles

Panel 6B After 70 kip Overload and 10M Cycles to 21.3 kips

UHPC Longitudinal Joint Testing – **6B**

Rebar Fracture

Stress range in rebar was at least 28 ksi during final 340,000 cycles.

9 of 18 rebar failed in metal fatigue before test had to be halted.

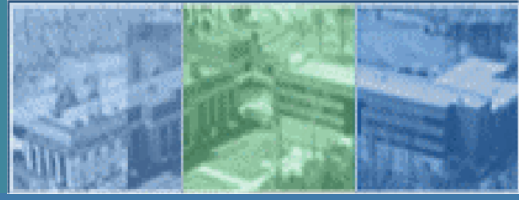
Fatigue then Mating Surface Impact

UHPC Joints – Static Testing to Failure

Failures emulated monolithic construction.

Rebar yielding and concrete crushing.

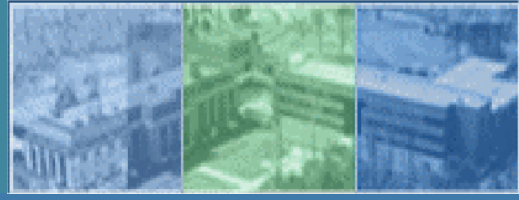
No rebar debonding.



Field-Cast UHPC Connections

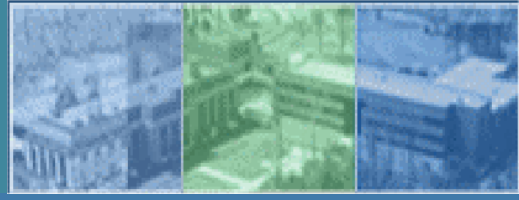
- **Testing Observations:**
  - Good interface bond performance between HPC and UHPC
  - HPC cracks intersecting UHPC become tight, parallel UHPC cracks
  - Transverse cracks did not cause interface debonding
  - Cyclic loading did not debond lapped rebar in joint
  - Overload + cyclic loading did not debonded lapped rebar in joint
  - Static failures of panels emulated monolithic construction

Bottom Line: ***UHPC connections are a viable solution.***



Field-Cast UHPC Connections

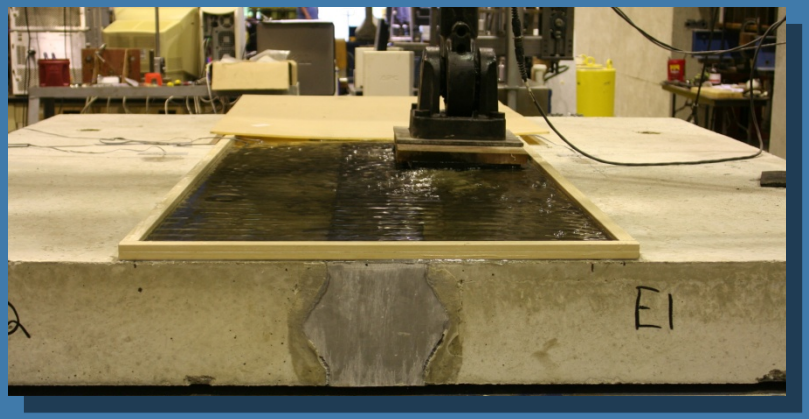
- **Deployments:**
  - 2 bridges in NY constructed in 2009
  - ~12 bridges in Western Ontario including 7 in 2010
  - Bridge in Wapello County, Iowa
    - UHPC Waffle Panels & UHPC Joints and Connections
    - Construction in late 2010 or early 2011
  - Highway 11/17N Mackenzie River Bridge
    - 3 spans w/ 120 total precast deck panels – UHPC Joints and Connections
    - Construction scheduled for 2011



Potential Benefits of Using Field-Cast UHPC for Transportation Structure Connection Details

- Eliminate post-tensioning
- Reduce conflict points b/t joint reinforcements
- Simplify joint details to ease prefabrication and construction
- Eliminate concerns of unintended void spaces in joints, shear pockets, and haunches
- Better long-term joint performance (strength, durability)

Ultra-High Performance Concrete: A Bridge of the Future Solution



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