Laboratory Performance and Implementation of UHPC Connections in Oklahoma

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GALLOGLY COLLEGE OF ENGINEERING
CIVIL ENGINEERING & ENVIRONMENTAL SCIENCE
The UNIVERSITY of OKLAHOMA

OKLAHOMA Transportation

ABC UTC
ACCELERATED BRIDGE CONSTRUCTION UNIVERSITY TRANSPORTATION CENTER

Ultra-High Performance Concrete (UHPC)

- Developed over the last 30 years
- Compressive strength typically greater than 18 ksi
- Post-cracking flexural strength greater than 0.72 ksi
- Very low to negligible permeability
- Resistant to freeze-thaw
- Strong bond to base concrete
- Short reinforcement development length
- Potential to increase service life

Ultra-High Performance Concrete (UHPC)

- Low w/cm
- Optimized particle packing
- High flowability
- Typically 2% by volume high strength steel fibers
- High mixing energy required

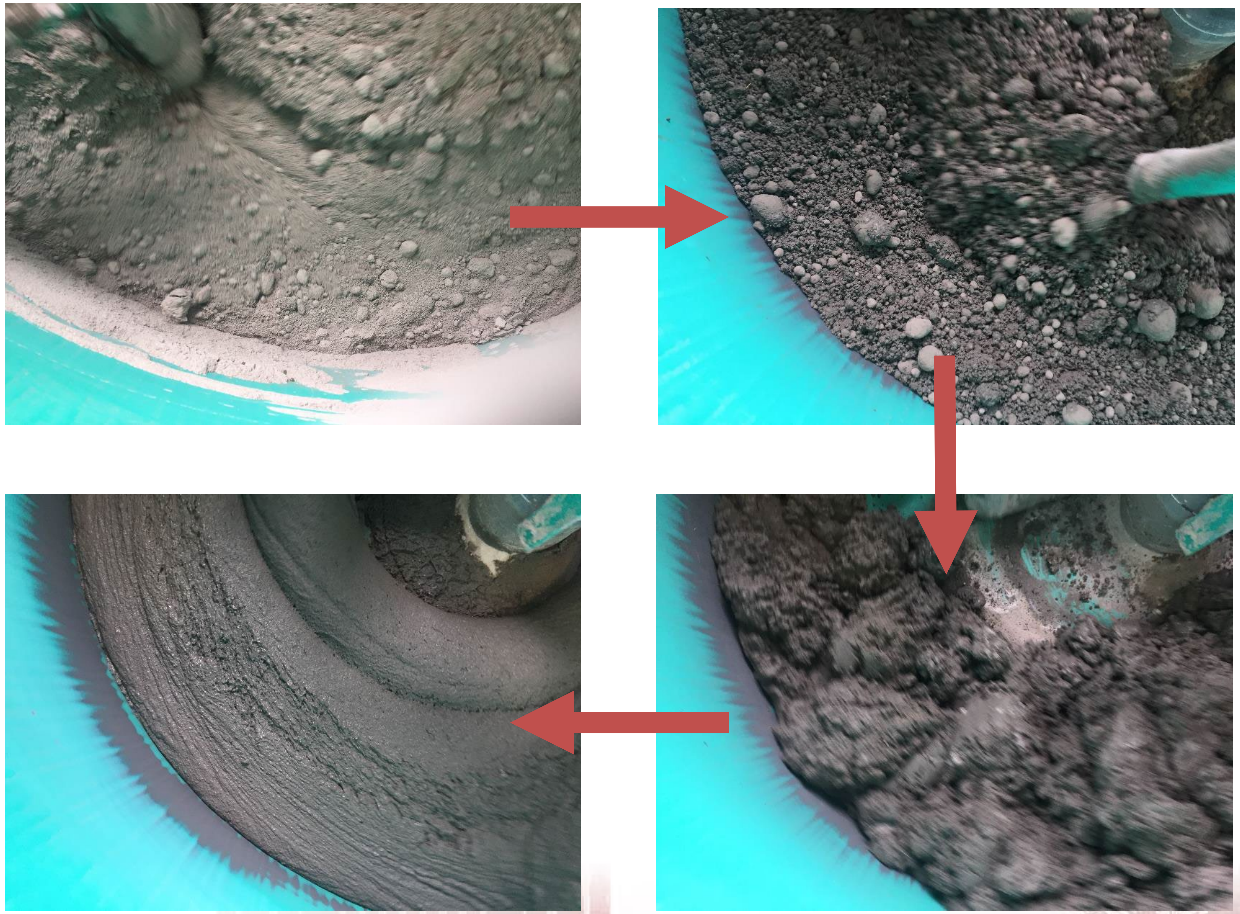


Illustration of the UHPC mixing process

UHPC Research in Oklahoma

- 8 projects over the last 6 years sponsored by ODOT and ABC-UTC
  - Mix development
  - Panel connections
  - Link slabs
  - Girder continuity
  - Repair/rehabilitation
  - Implementation
- Several bridge projects using UHPC are currently underway

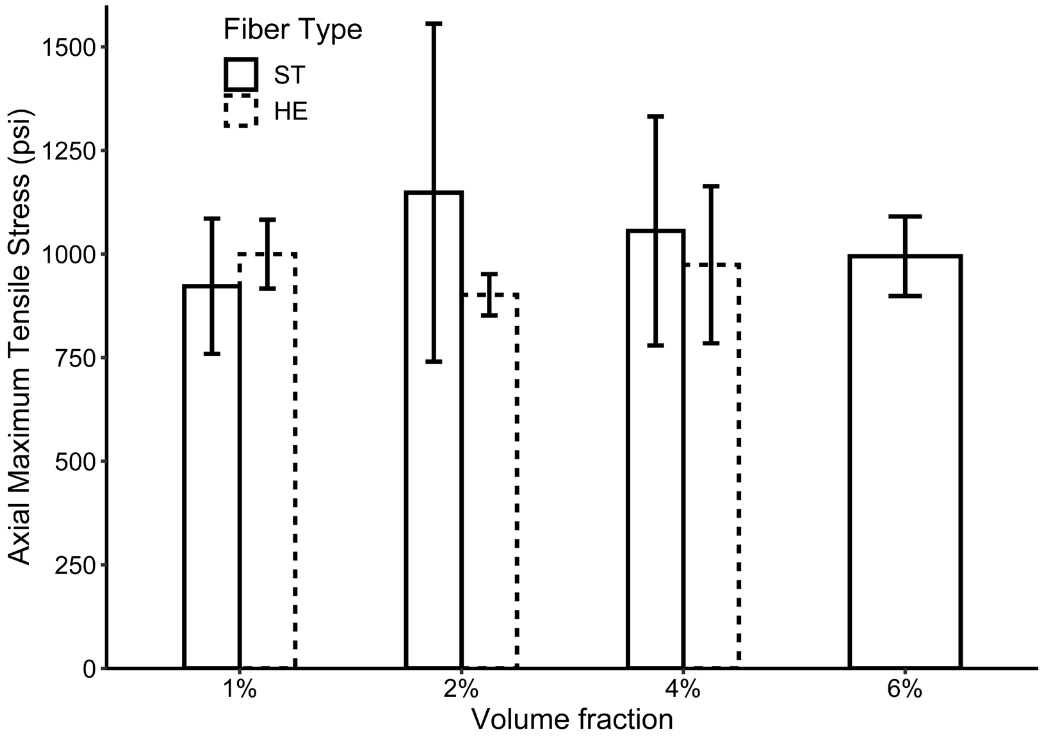
Non-Proprietary UHPC in Oklahoma

- Developed through ODOT and ABC-UTC support
- 8-10 in. flow
- Compressive strength of 18 ksi
- Approximately 1 ksi post-cracking tensile strength
- Cost approximately $800/yd^3
- Excellent bond strength
- Very low to negligible permeability
- High freeze-thaw resistance

Constituent	Mix Proportion
Type I Cement	0.6
Silica Fume	0.1
Slag Cement	0.3
Masonry Sand (1:1 agg/cm)	1.0
w/cm	0.2
Steel Fibers	2% by Volume
HRWR	20-28 oz/cwt

Non-Proprietary UHPC Properties

- J3 non-proprietary UHPC tensile strength



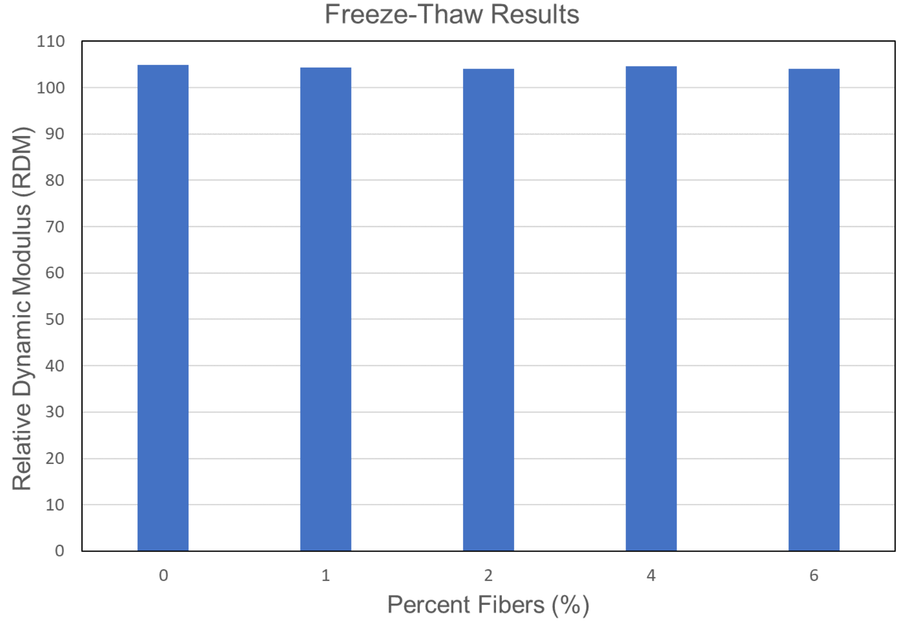
Direct tension strengths with different fiber types

Non-Proprietary UHPC Properties

- Freeze-thaw durability and chloride penetration
  - Conventional concrete (ODOT Class AA) and UHPC
  - J3 non-proprietary UHPC with varying fiber content
  - No fibers for Rapid Chloride testing

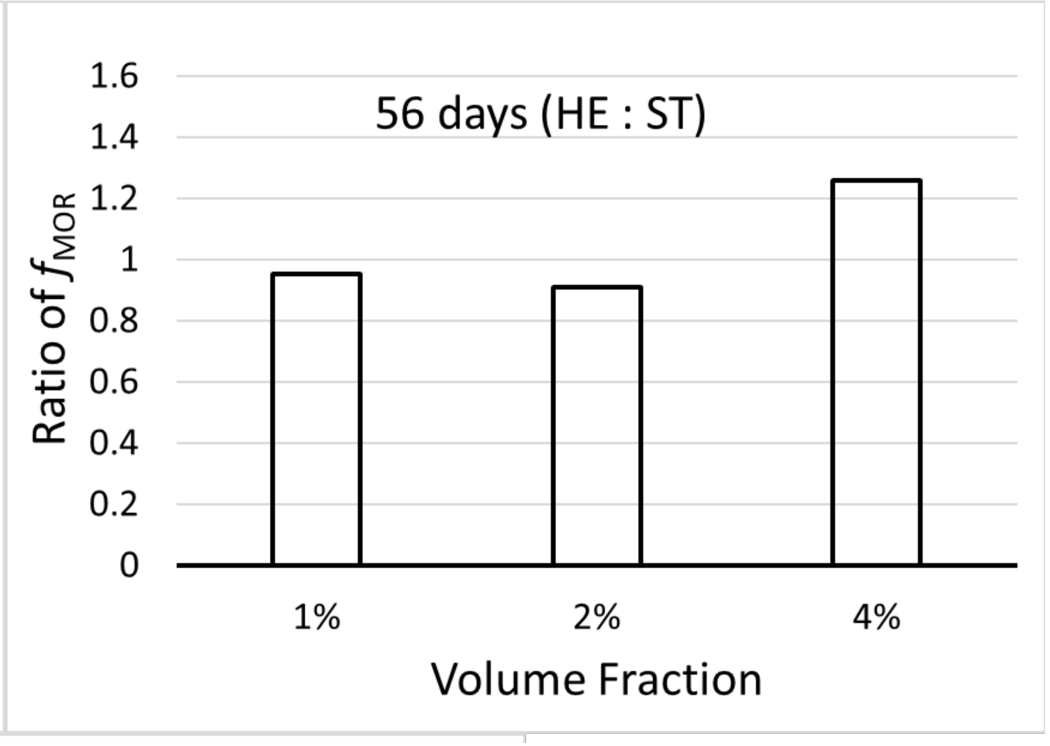
Summary of Measured Durability Properties

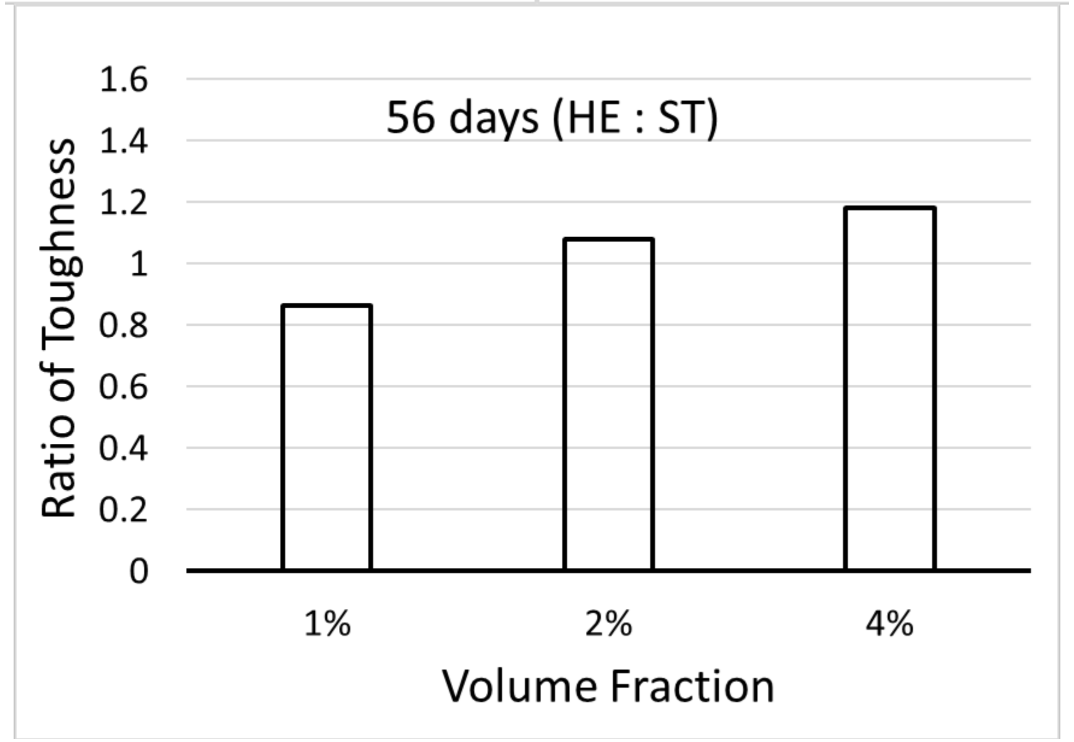
Property	AA	Proprietary UHPC	Non-Proprietary UHPC
Rapid Chloride (28-day)	2465 C	61 C	251 C
Rapid Chloride (56-day)	1832 C	28 C	63 C
Freeze-Thaw (350 cycles)	99.1%	102.5%	103.1%



Non-Proprietary UHPC Properties

- J3 non-proprietary UHPC flexural tension strength





Connections of Slab Panels

Precast deck panels during joint casting

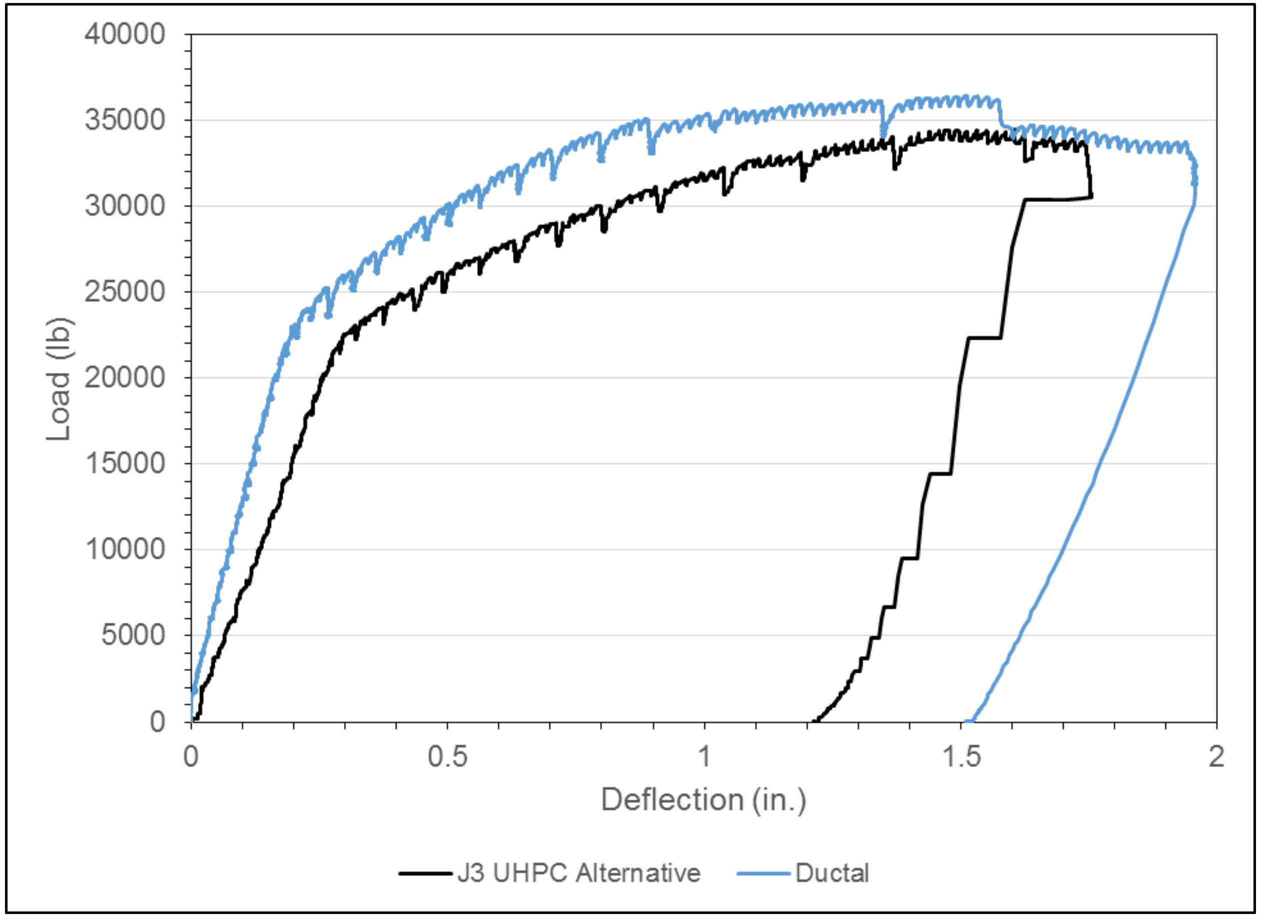
Close-up of panel connection bar splices

Slab Joints

Slab Joint Testing

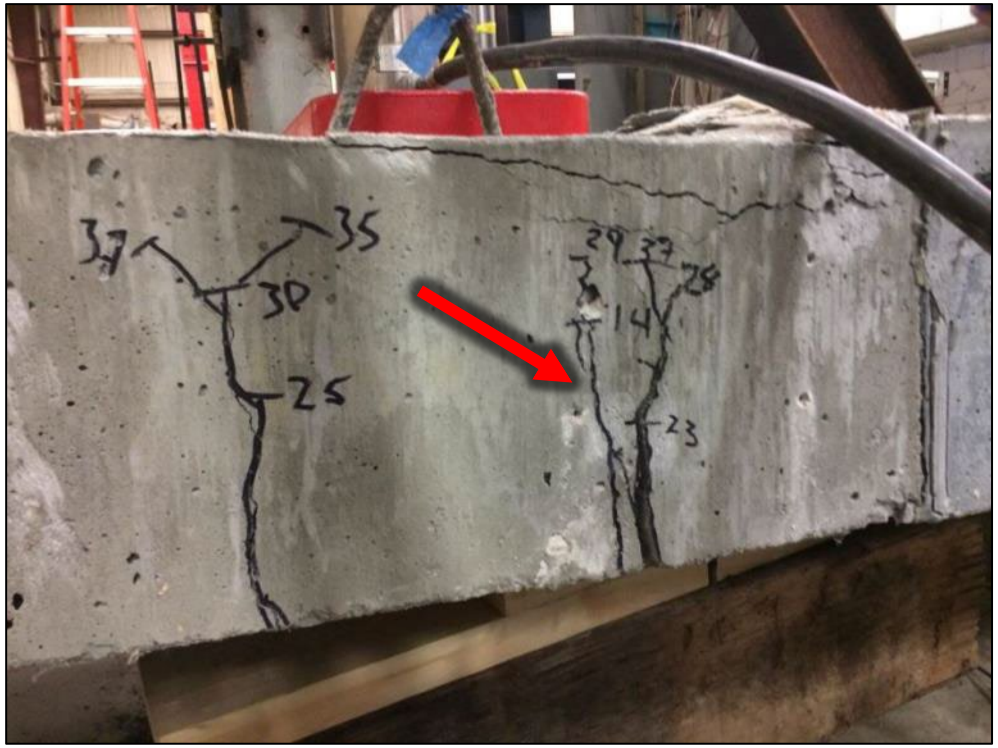
Static & Cyclic Loading

Slab Joint Testing Results



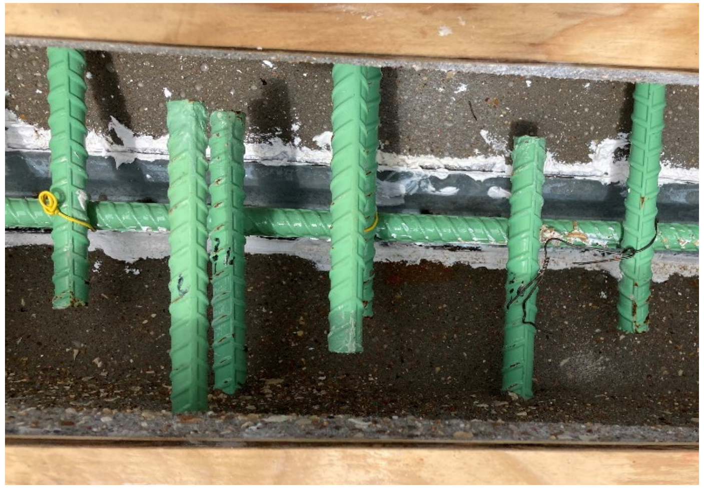
Slab Joint Testing Results

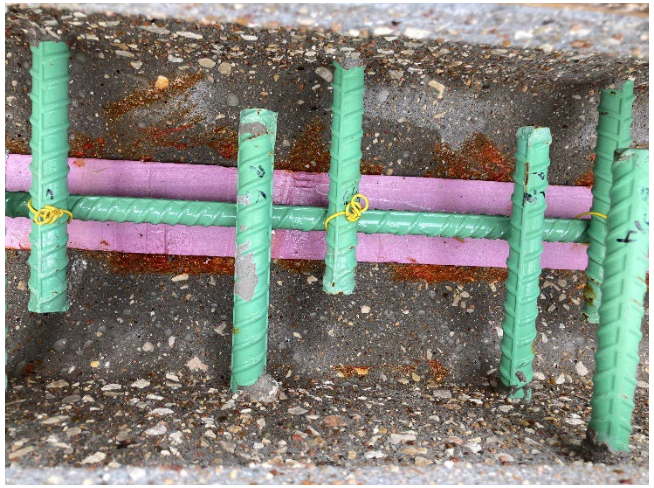
Ductal® Slab 2 Static Loading



Lake Eufaula Overflow Bridge

Lake Eufaula Overflow Bridge Mock-up





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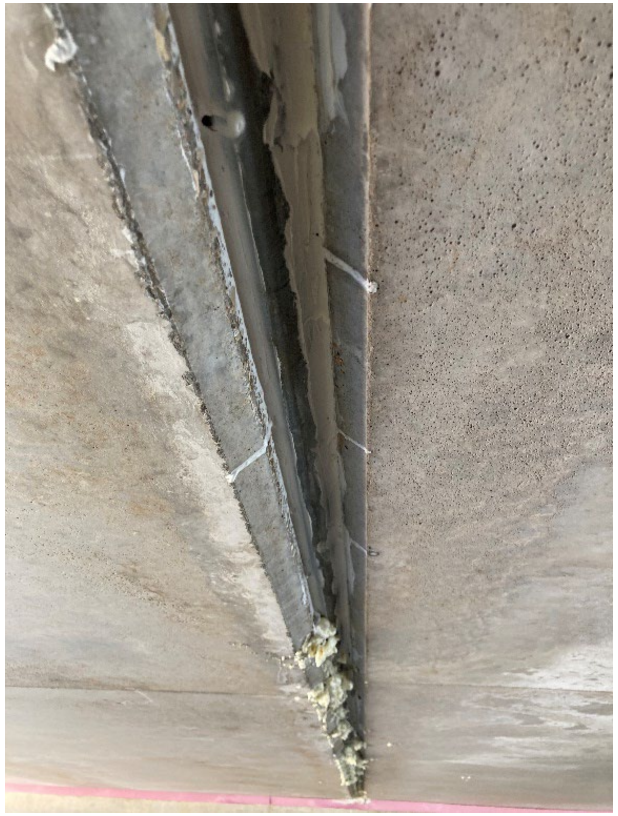
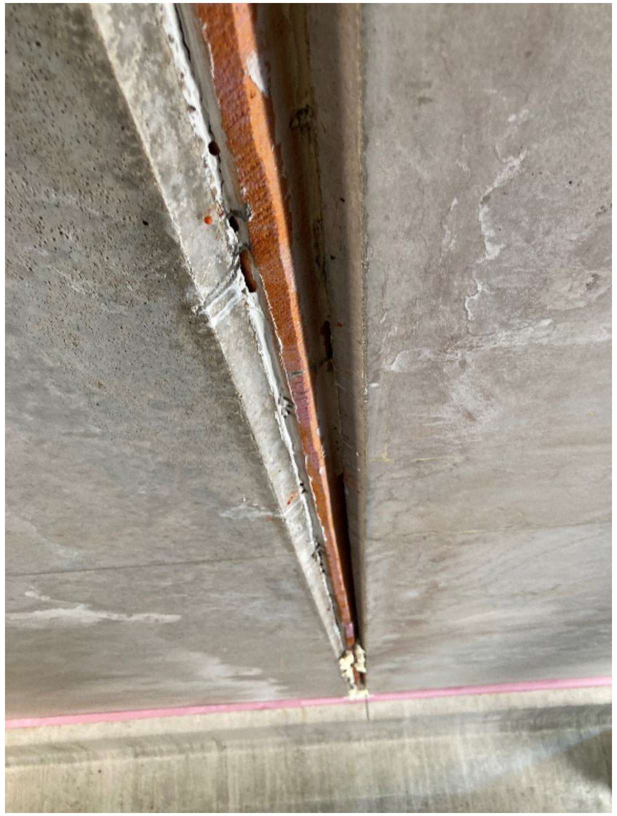


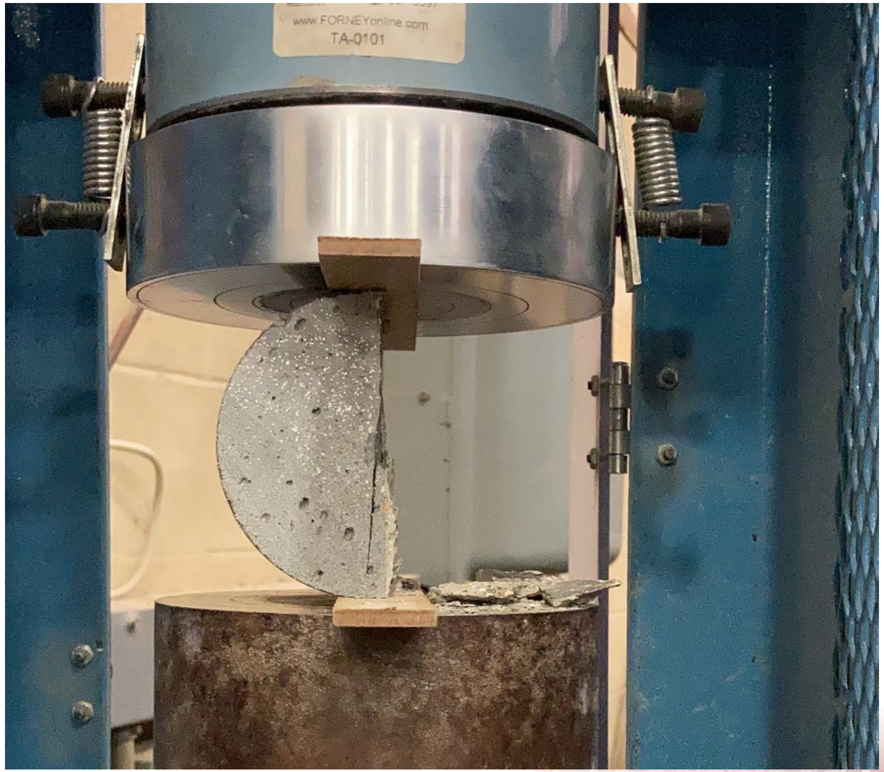


Lake Eufaula Overflow Bridge Mock-up

Lake Eufaula Overflow Bridge Mock-up

Lake Eufaula Overflow Bridge Mock-up

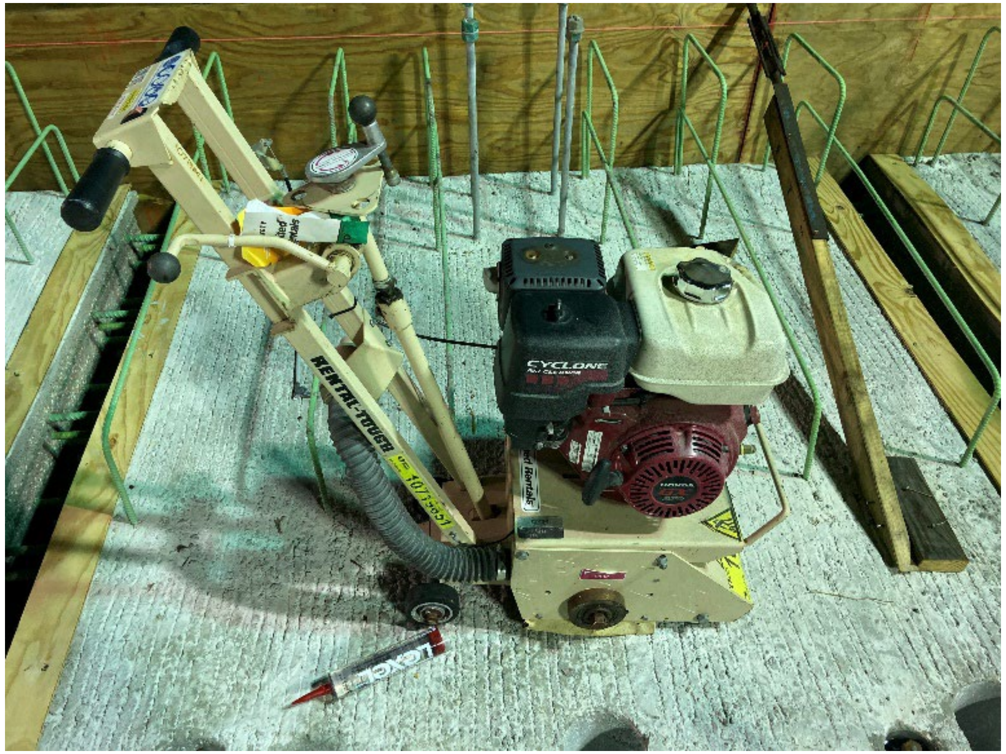
- Failure stress approximately 800 psi
- Greater than expected splitting tensile strength of deck concrete



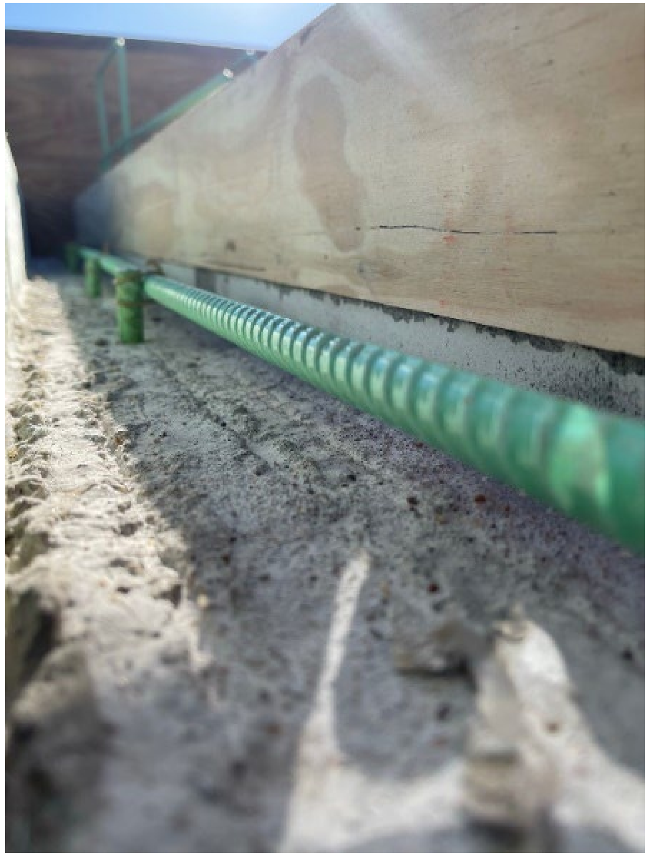
Deck Joint Preparation

Deck Joint Placement

Completed Deck Joint



Expansion Joint Headers

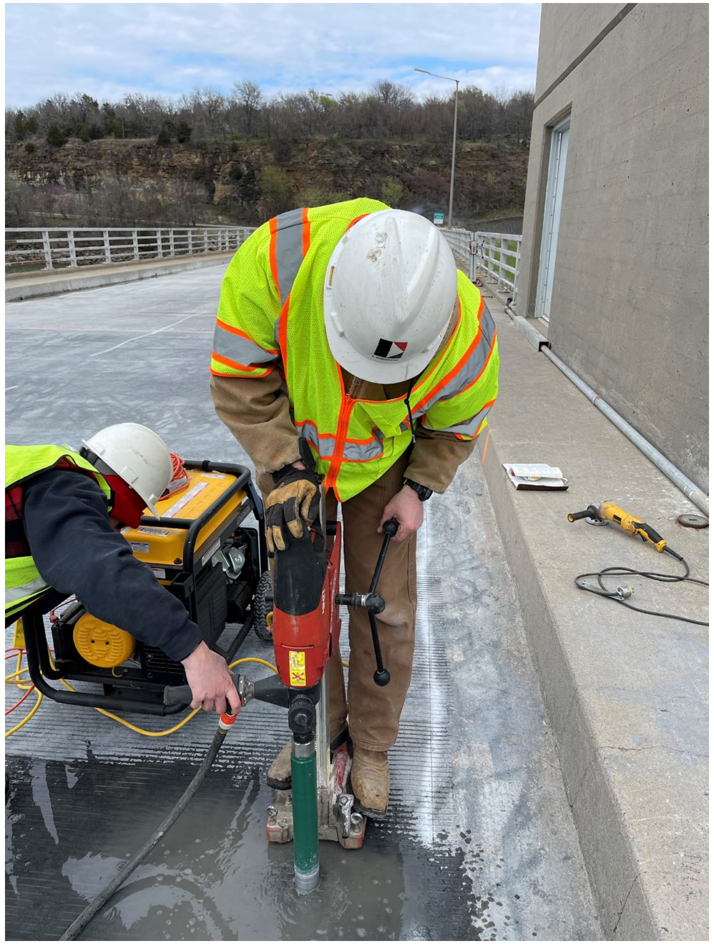


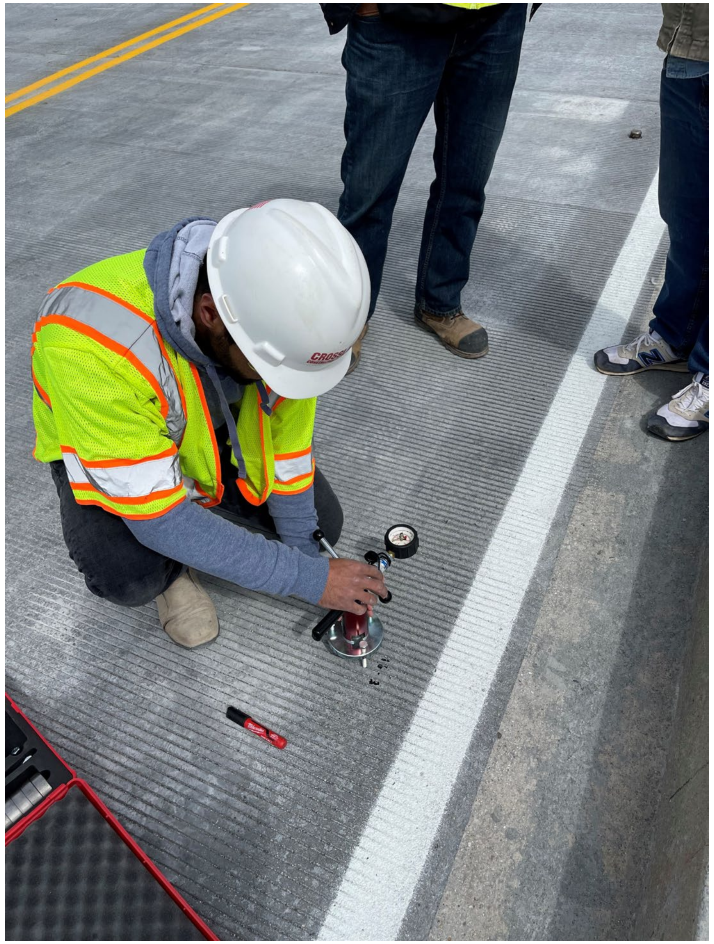
Lake Eufaula Overflow Bridge Overlay

Lake Eufaula Overflow Bridge Overlay

Lake Eufaula Overflow Bridge Overlay

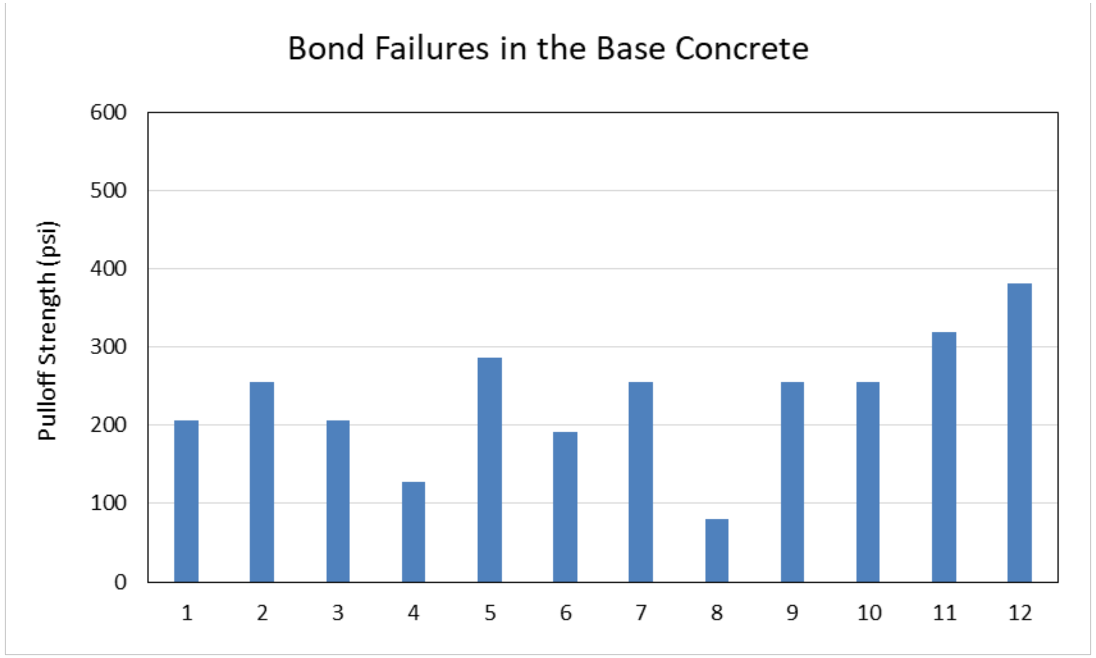
Overlay Bond Strength

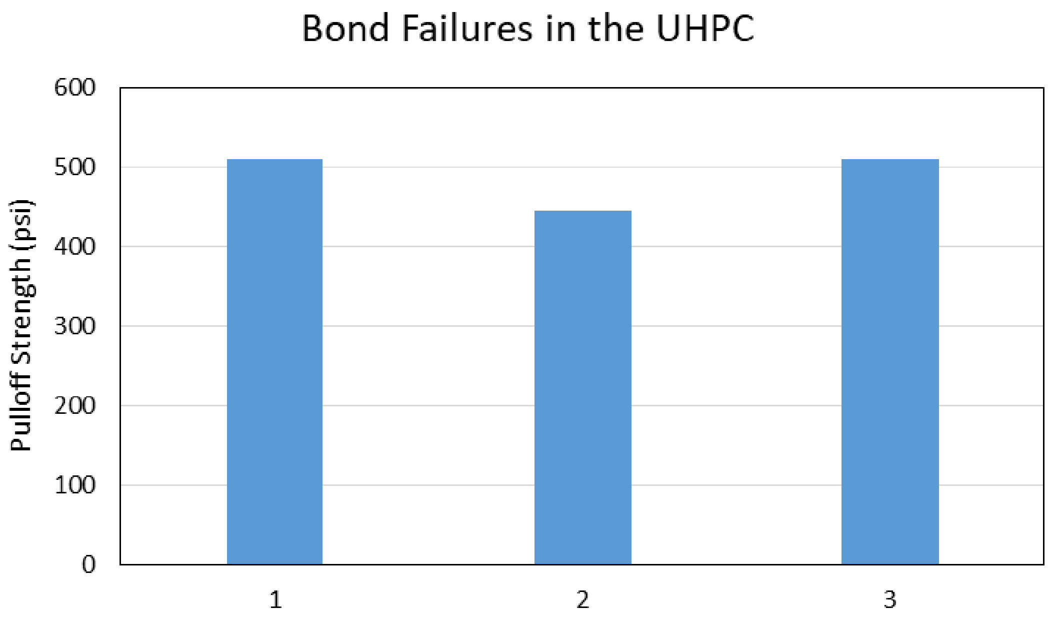




Overlay Bond Strength

- Three specimens failed near the interface
  - 190 to 315 psi





Live Load Continuity

Typical cracking in continuity connection on U.S. 283 over S. Canadian River (Photo courtesy of Walt Peters)

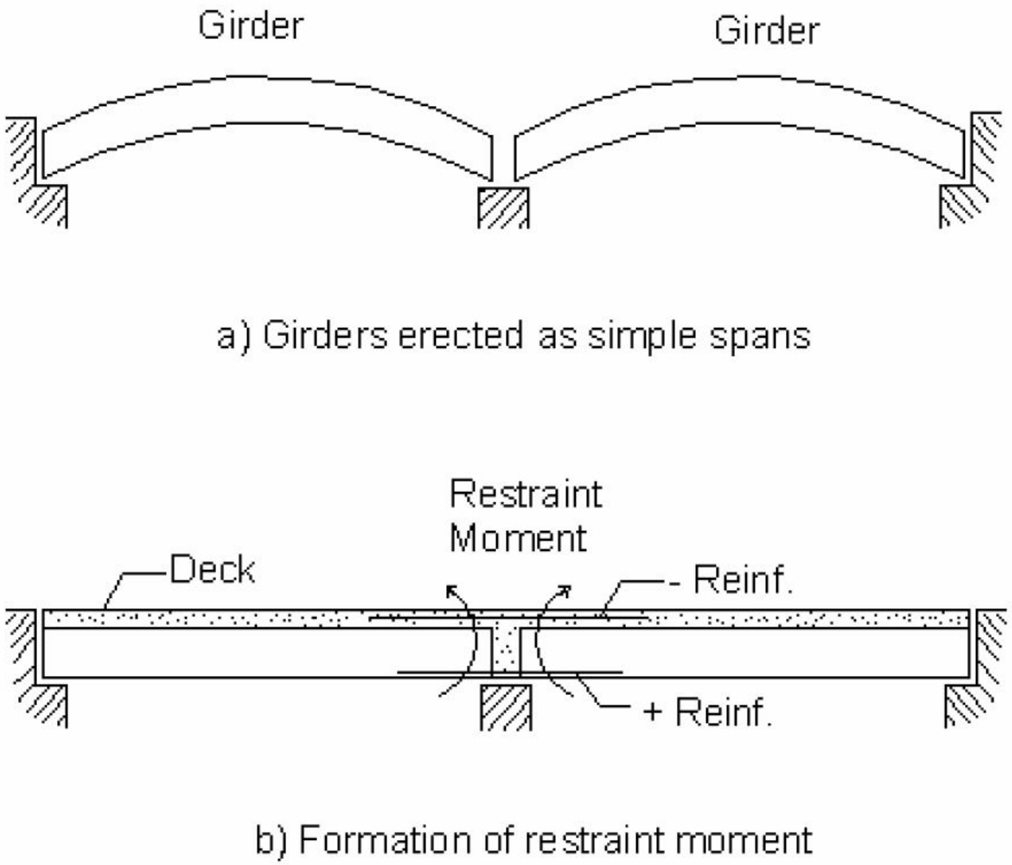
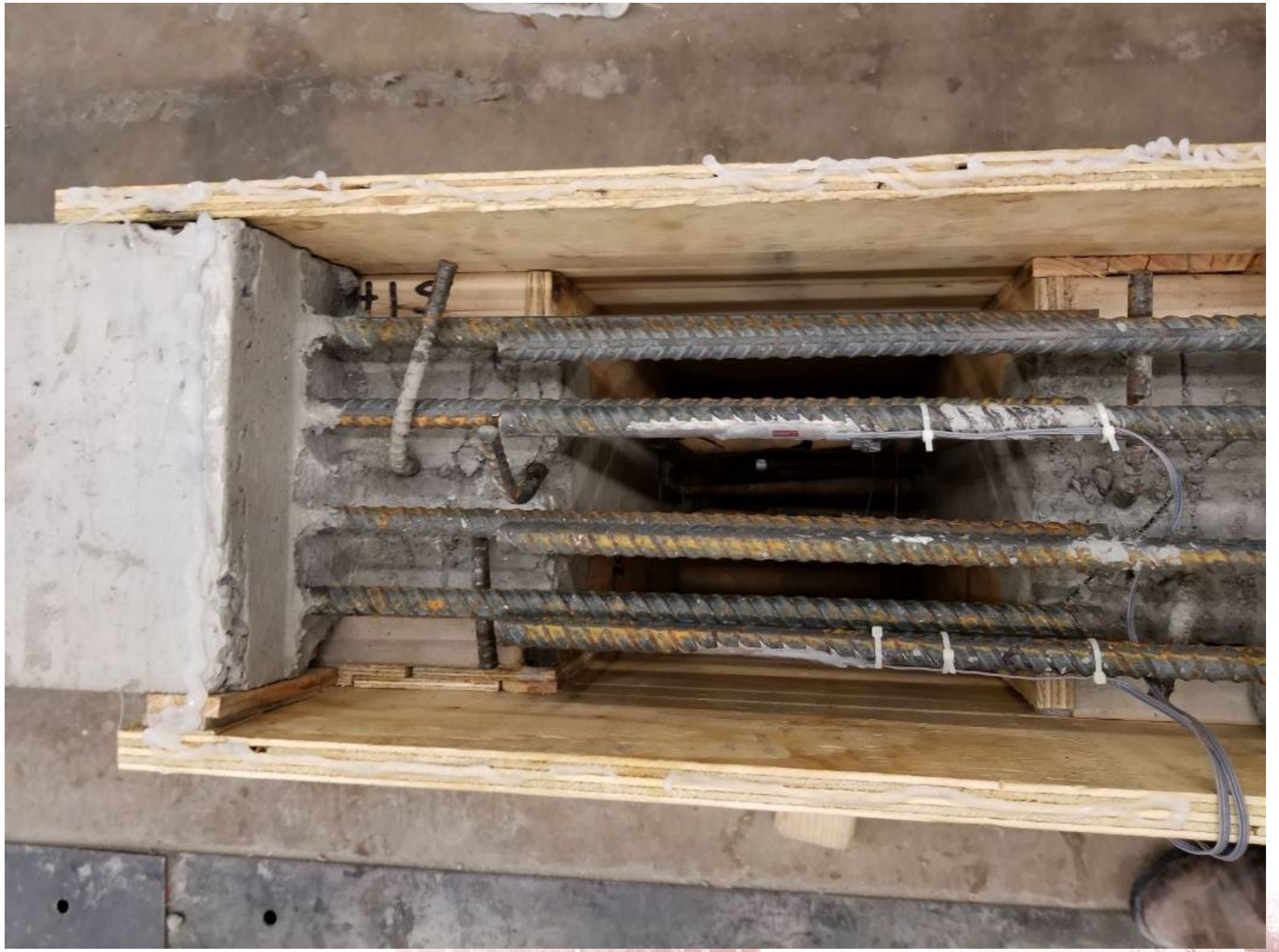


Illustration of restraint moment development (Saadeghvaziri et al., 2004)

Continuity Joint Construction

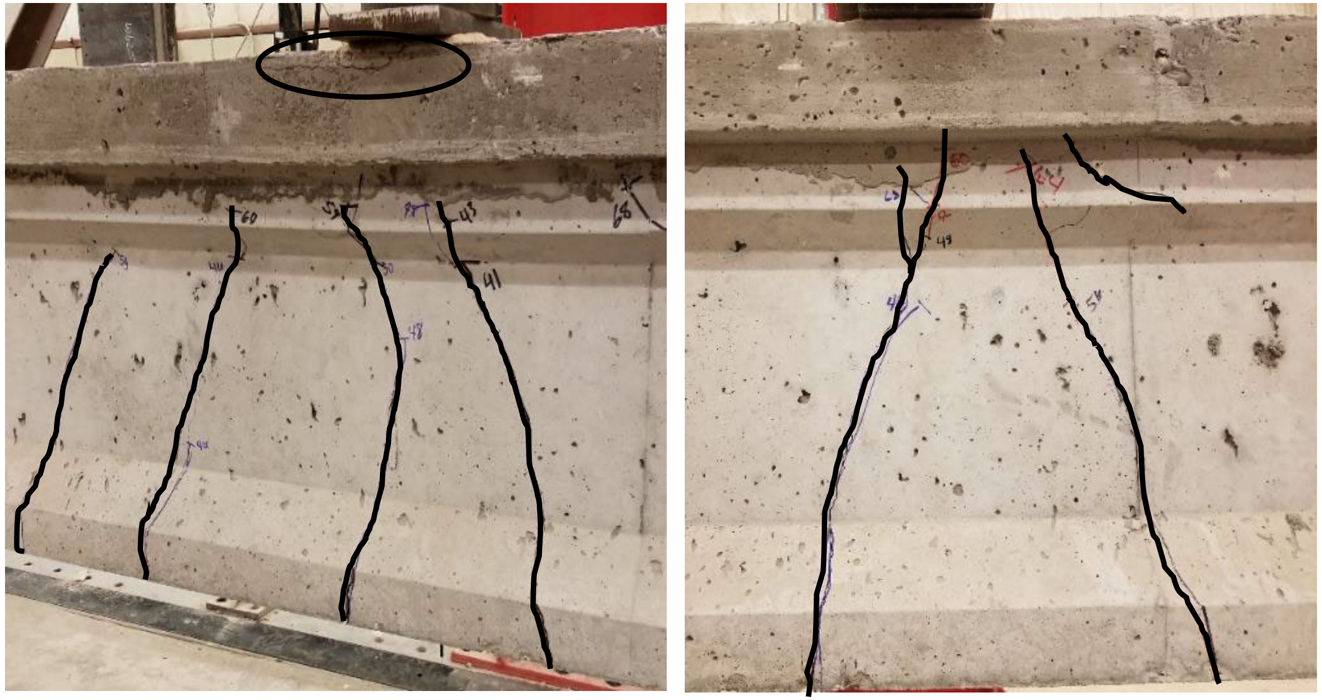


New construction continuity joint reinforcement immediately before casting

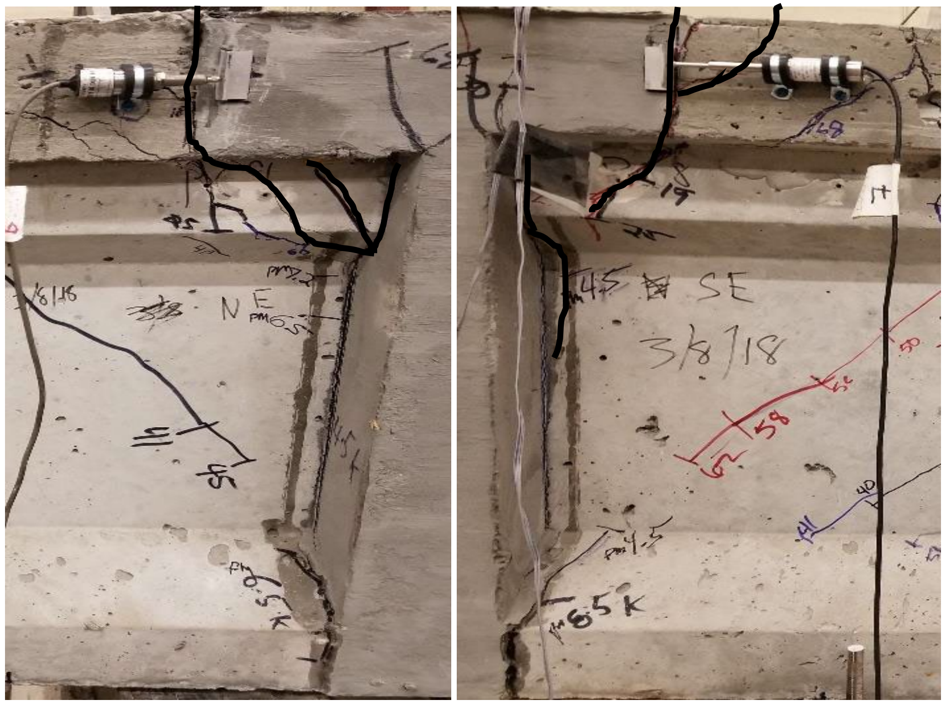
Testing Procedure

Two-span loading configuration used for testing continuity joints showing loads applied at mid-span of each beam

Typical Cracking

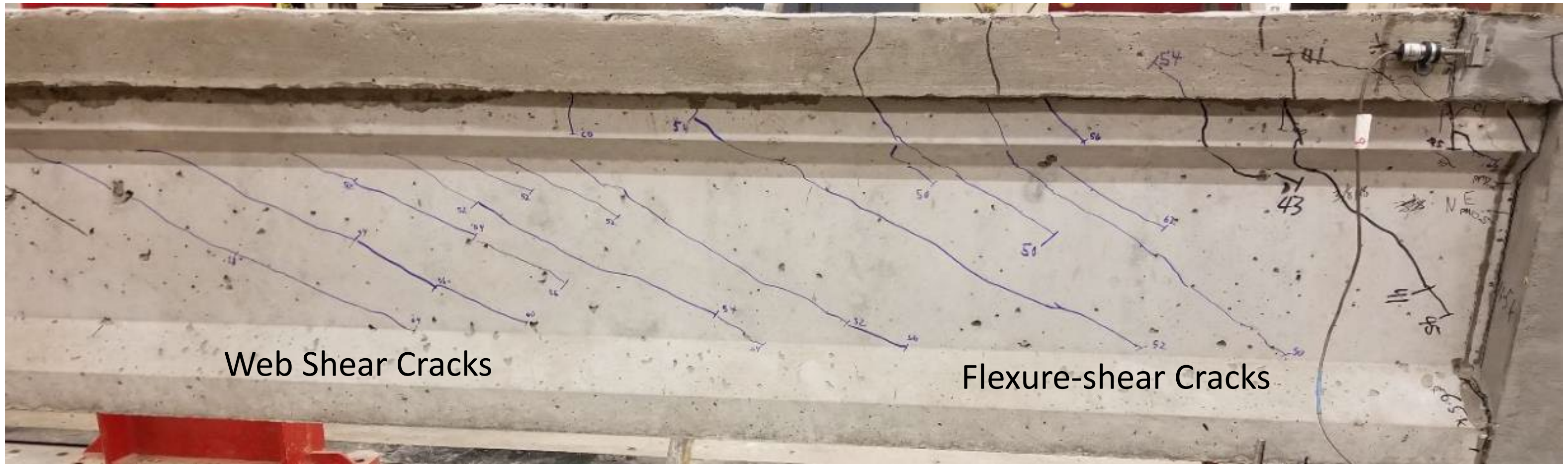


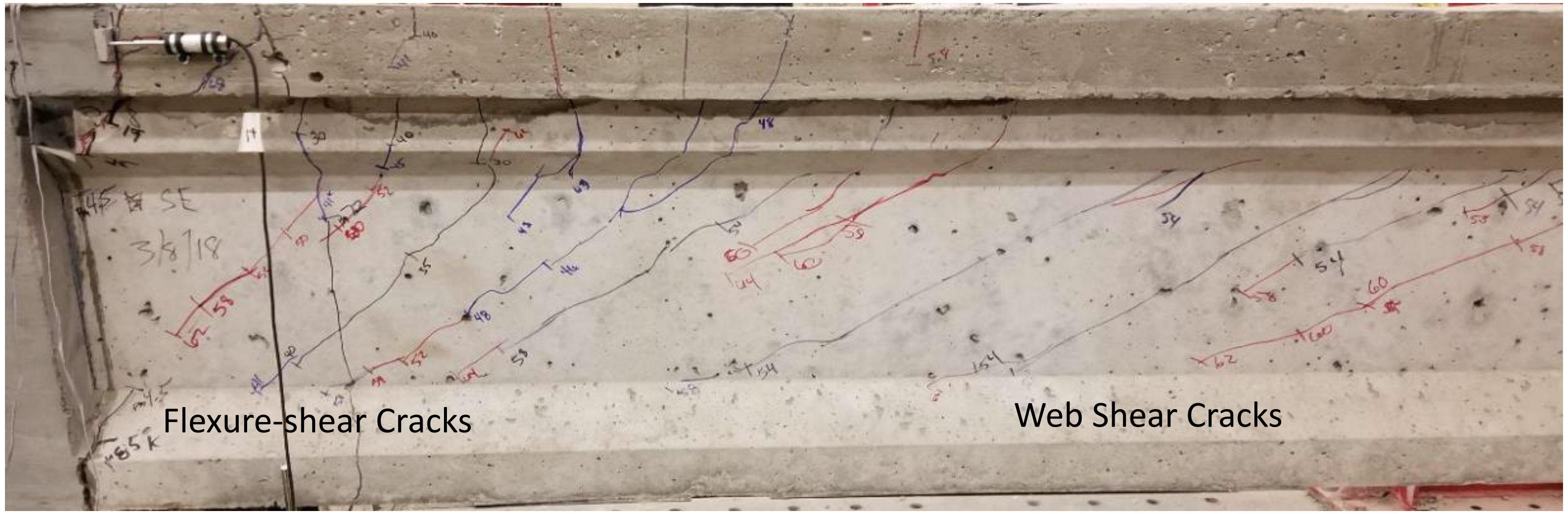
Flexural cracking under load point



Flexural and flexure-shear cracking at joint interface

Typical Cracking





Cracking between load point and joint on each side of the joint due to negative moment, top shows north beam and bottom shows the south beam

NC Summary

Specimen	NC1		NC2		NC3	
Girder	NC1-N	NC1-S	NC2-N	NC2-S	NC3-N	NC3-S
Experimental Max Load w/ Continuity Joint, kips	72.5	73.8	71.5	72	69.8	70.2
Theoretical Max Moment w/ Continuity Joint, kip-ft	211.9	215.6	208.9	210.4	204	205.1
M_n single span girder, kip-ft	145.7		145.7		145.7	
Moment percentage increase w/Continuity Joint	31.2	32.4	30.3	30.8	28.6	29.0

U.S. 183/412 Bridge over Wolf Creek, Fort Supply, OK

Panoramic view of U.S. 183/412 Bridge over Wolf Creek, Fort Supply, OK

Close-up view of continuity connection

U.S. 183/412 Bridge over Wolf Creek, Fort Supply, OK

In-service condition (April 2019)

Cracking in continuity connections on U.S. 183/412 Bridge over Wolf Creek, Fort Supply, OK

Field Implementation

Joint construction (November 2019)

UHPC Placement through the deck

Completed UHPC joint

Joint Condition After 1 Year (December 2020)

Joint Condition After 3 years (October 2022)

Lessons Learned

- A mock-up or at least trial batch is a critical step when working with UHPC for the first time
- Watertight and reinforced formwork is needed for working with UHPC and a water test helps saturate the substrate
- Insulation foam made the best sealant for the bottom of the slab joints
- Placements should be covered when possible to reduce drying
- Plastic sheeting on the bridge deck reduced cleanup

Conclusions

- Hooked end fibers provided limited benefit to tension strength, but increased flexural toughness
- UHPC connections provided flexural capacity exceeding the conventional slab capacity even with limited preparation
- UHPC connections of precast bridge deck panels have been used successfully in Oklahoma
- UHPC continuity connections provided increased capacity in the laboratory
- UHPC was successfully used to replace cracked connections of precast bridge girders made continuous for live load

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Thank you!

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