Herbert Wertheim College of Engineering
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Ultra-High Performance Concrete Quality Control Testing

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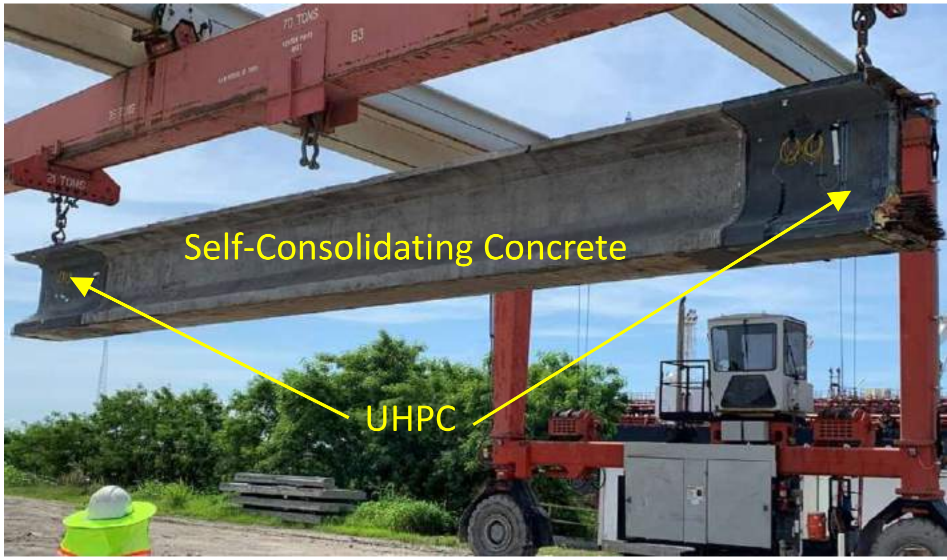
POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE

UHPC Applications



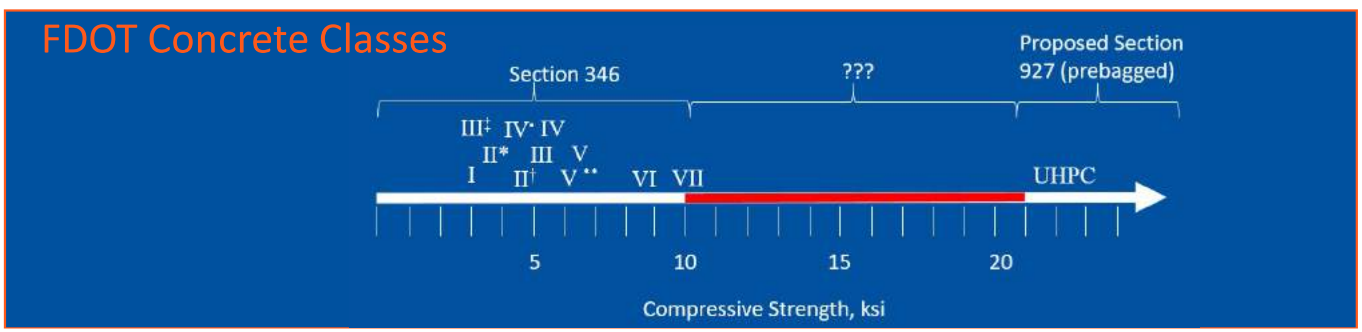
Benefits of UHPC

- Tensile performance can allow you to reduce amount of steel reinforcement
- Increase member length or capacity
- Can optimize geometry for lighter member to reduce shipping costs and crane size
- Reduce cover dimensions?
- Dense and discontinuous microstructure can give very high durability – alternative to stainless steel and FRP reinforcement

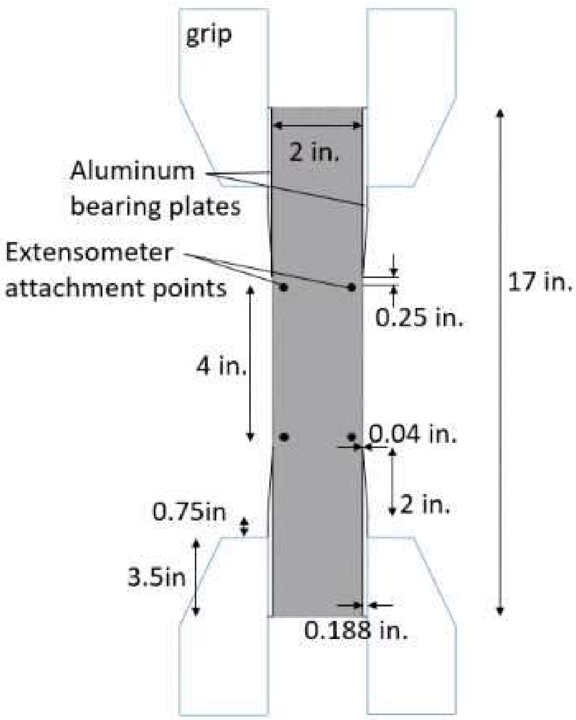
Ultra-High Performance Concrete

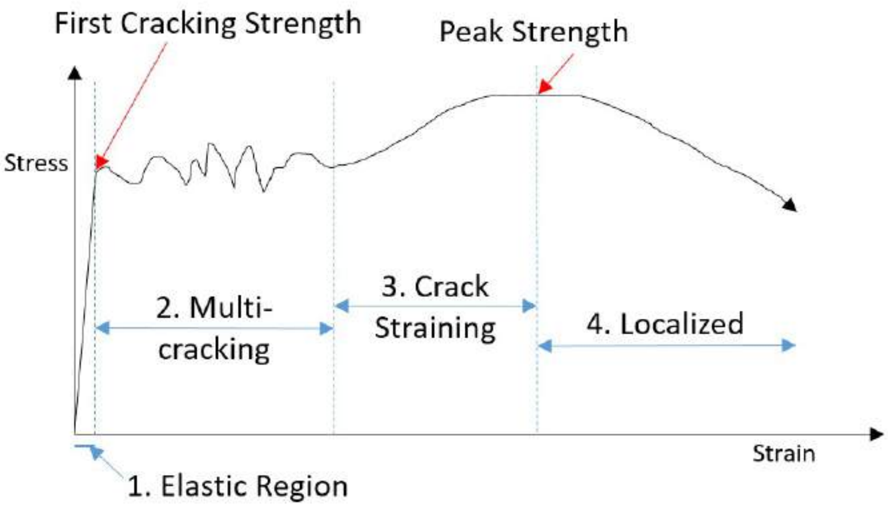
- ACI 239:
  - Very high strength: ≥ 22 ksi
  - Specified durability – very low permeability
  - Tensile ductility – high volumes of fibers (1 – 4% by volume)
- PCI:
  - Will define very high strength: ≥ 17.4 ksi

Typically has ≥ 2% Steel Fibers for strain-hardening



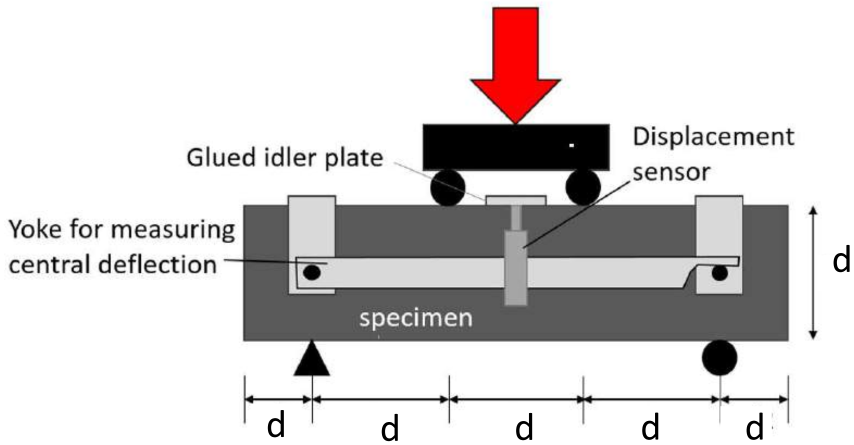
Qualification Test: Direct Tension Test





Qualification Test: Flexural Strength- ASTM C1609

- PCI is considering recommending First-peak (first crack) flexural strength f_1, peak flexural strength, and residual flexural strength at L/150



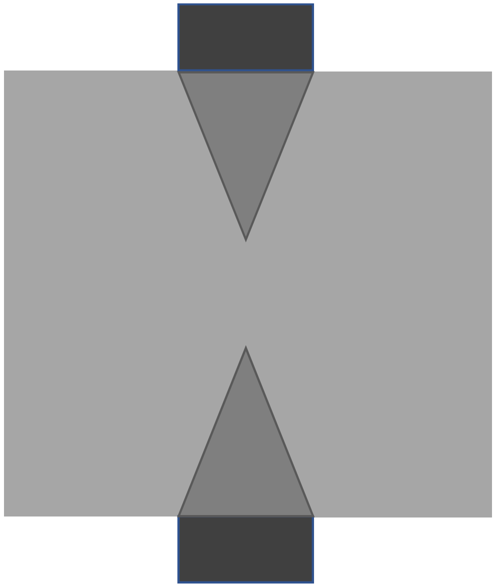
$$f_1 = \frac{PL}{bd^2}$$

P=load
L=span length
b=specimen width
d=span depth

What About Quality Control Tensile Testing?

- Many current requirements do not require tensile QC testing
- PCI UHPC materials guide is currently considering requiring ASTM C1609 testing of 3 beams from one batch per day per mix, with an additional 3 beams required if volume exceeds 25 yd^3
- Because tensile strength is so integral to performance and in some cases safety, what test should be used at production facilities?
- Ideal QC test would:
  - Accurately characterize tensile strength
  - Provide a measure of ductility or toughness
  - Can be performed with equipment commonly available at precast concrete plants & local testing laboratories
  - Simple to perform, easy for technicians to learn

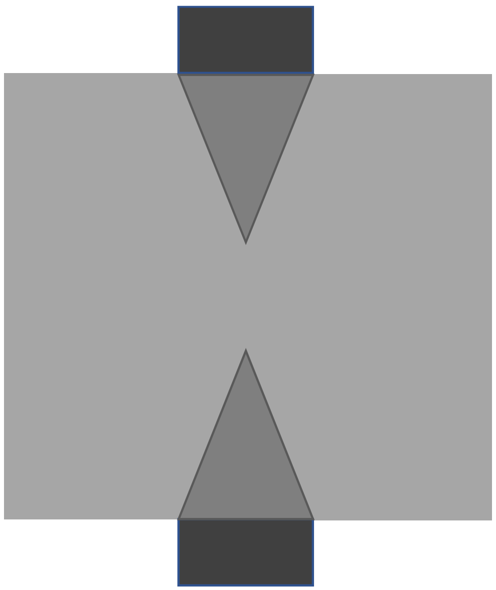
Double Punch Test

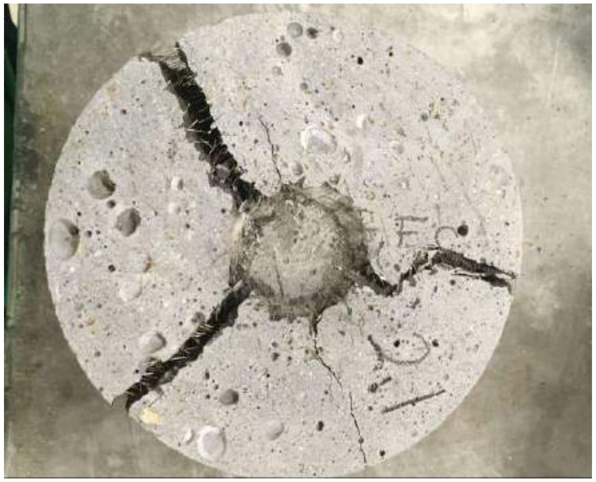


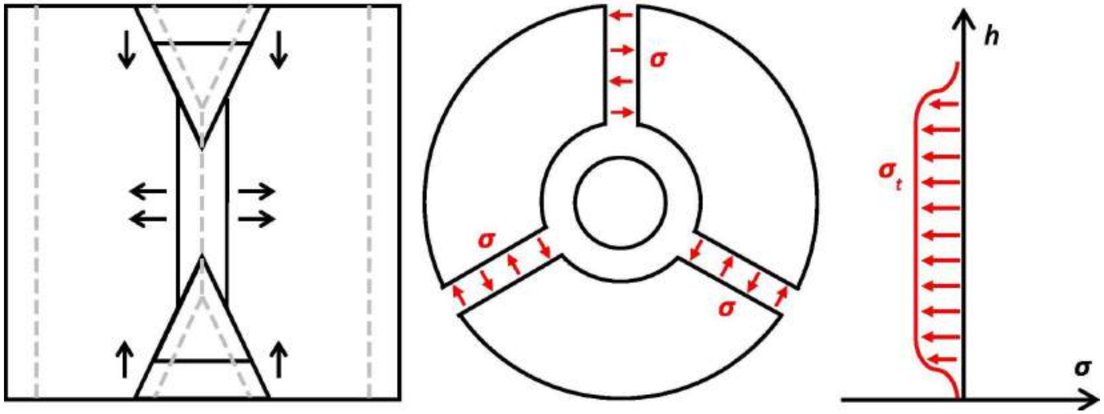
- 6 in. x 6 in. cylindrical specimen
- Specimen is loaded axially through 2 central punches of 1.5 in. diameter.
- Load is applied at displacement-controlled rate

Choumanidis, D., E. Badogiannis, P. Nomikos, and A. Sofianos. (2017). Barcelona test for the evaluation of the mechanical properties of single sand hybrid FRC, exposed to elevated temperature. *Construction and Building Materials, 138*. 296-305.

Double Punch Test







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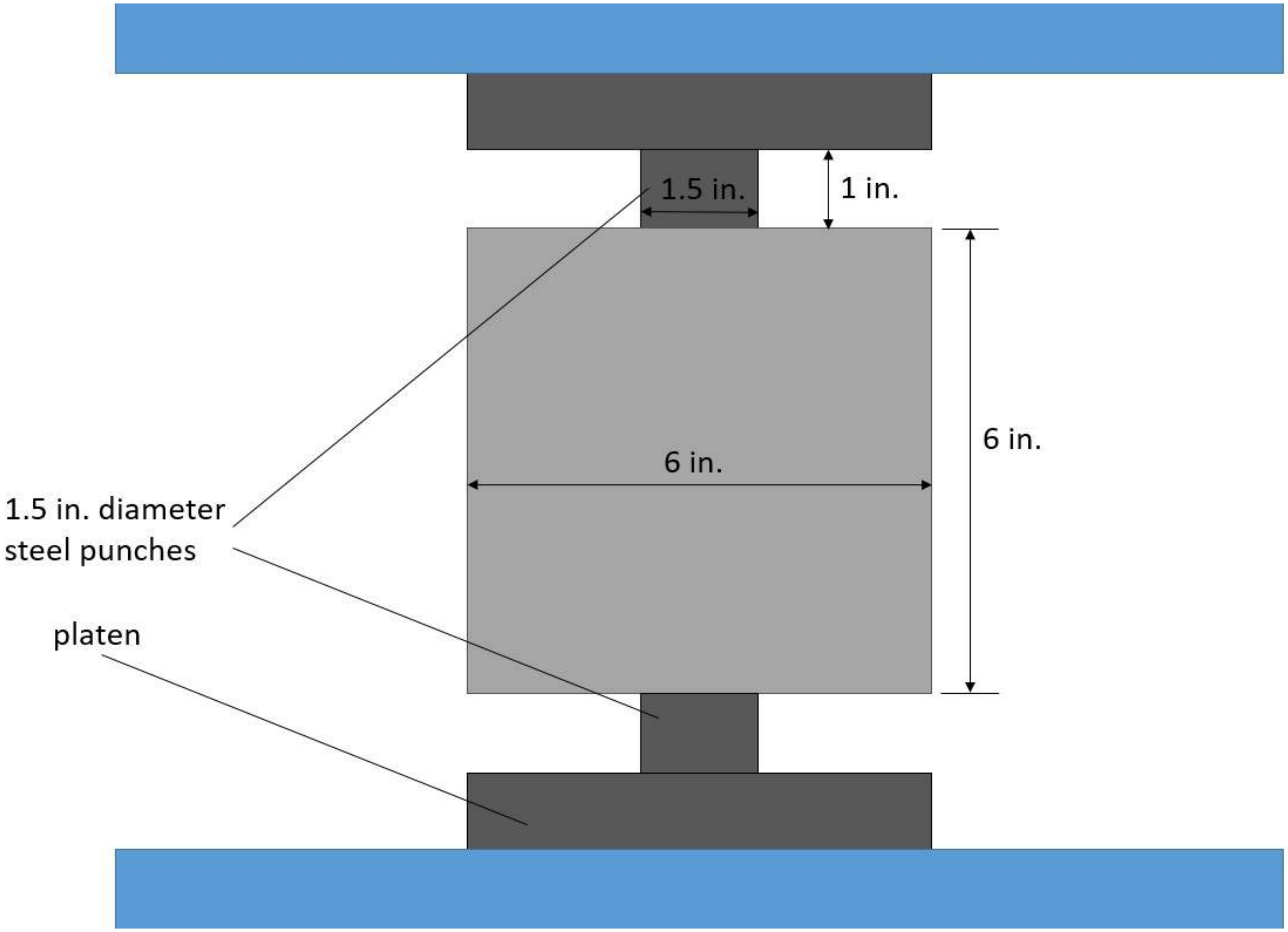
Engineering School or Sustainable Infrastructure & Environment

Barcelona Testing at UF



Research Questions

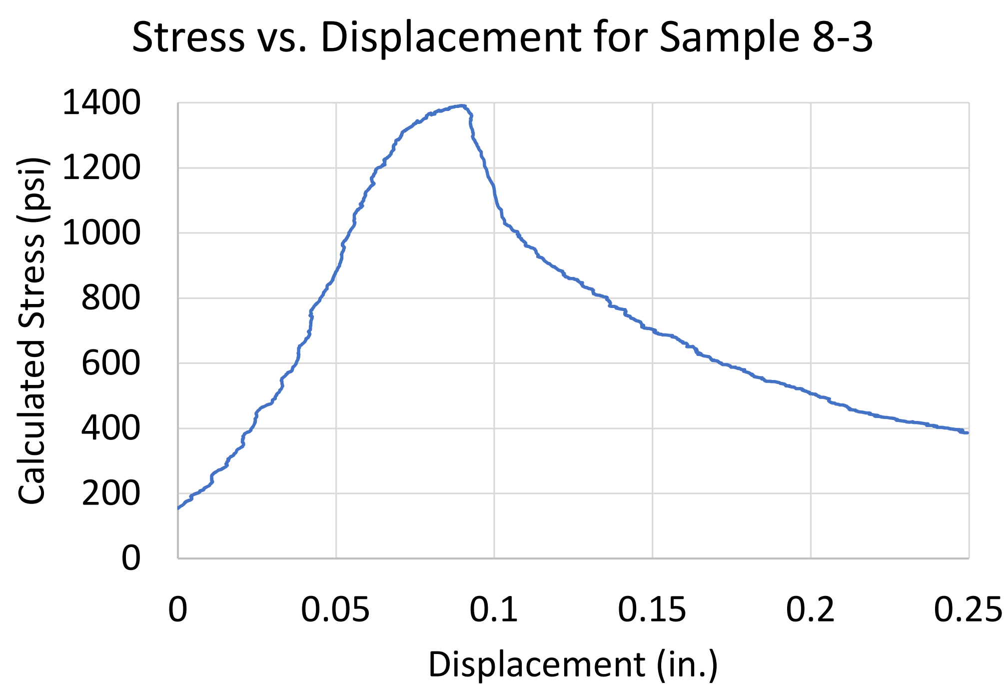
- Can this test be simplified to be performed in a simple compression machine for QC purposes?
- What parameters of the test method must be controlled in the specification?
  - Finishing, casting, punch alignment, load rate
- Do the simplified double punch measured parameters correlate with those of the direct tension test and ASTM C1609, giving confidence that it can be used as a QC index test?

Ruggedness test design (ASTM E1169)

- Casting method
  - Filled with a scoop (slow filling)
  - Filled with a bucket (fast filling)
- Surface
  - Ground with cylinder grinder
  - Not ground
- Loading Rates
  - Fast: 700-800 lb/second
  - Slow: 200-300 lb/second
- Punch centering
  - Centered
  - Top punch 5mm off-center

Results investigated

- Max stress
- Toughness
- Displacement location at which peak load occurs



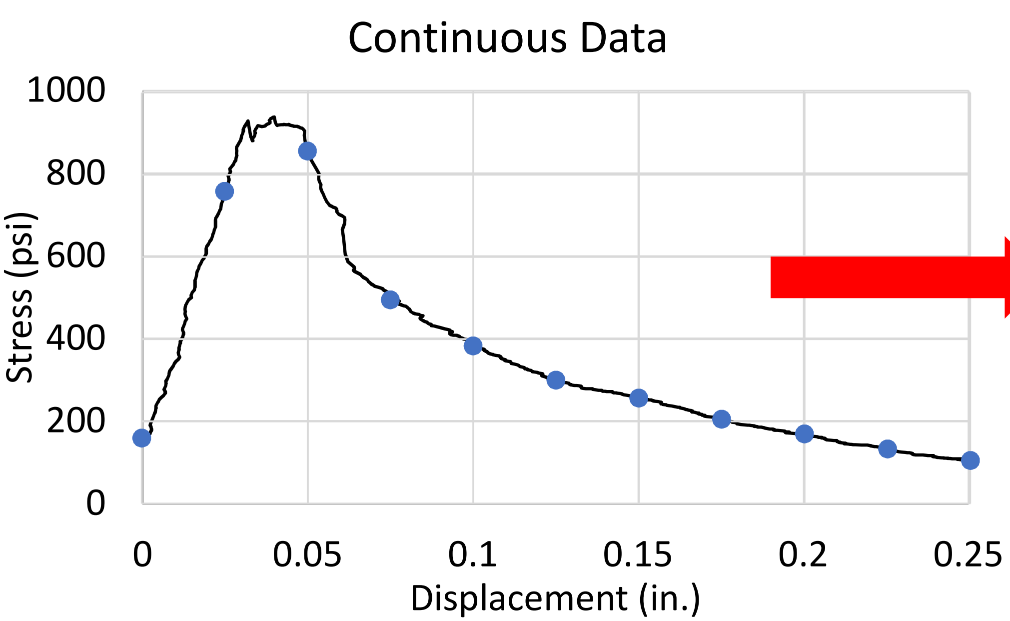
Significant factors (percent confidence intervals for two factor T test)

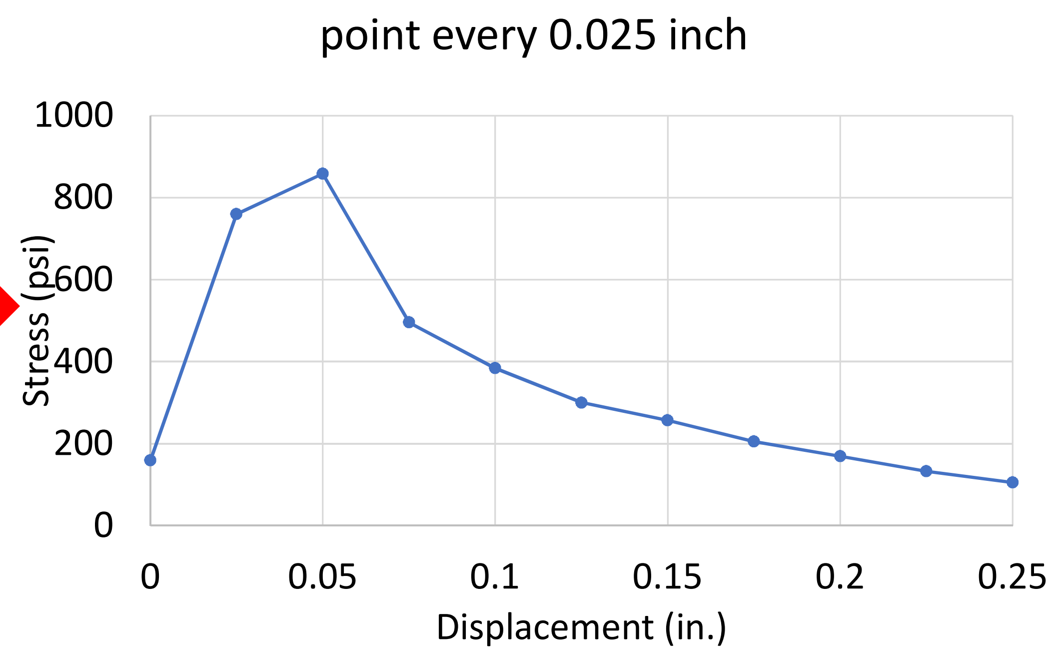
	Max stress	Toughness	displacement at peak load
scoop vs. bucket	99.99	100.00	96.72
surface grinding	53.60	56.68	99.47
load rate	1.79	32.91	14.30
centering	67.56	56.61	44.07

95% confidence chosen as threshold for significance

Results - Simplifying for Dial Gauge

- Continuous axial displacement data was taken with string potentiometers
- Discrete data points at different displacement intervals were selected from continuous measurements to simulated manual recording of strength at these displacement values





Toughness results

Data point displacement interval	Maximum toughness deviation from continuous data
0.050 in.	4%
0.025 in.	1.5%
0.010 in.	2%

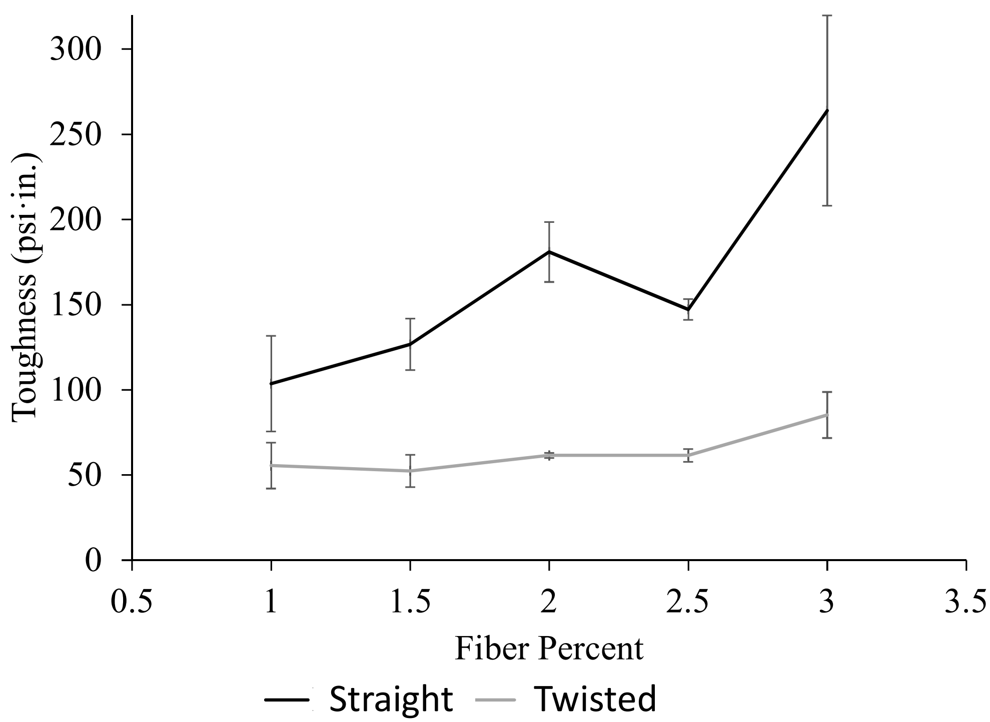
Simplified Setup with Dial Gauge

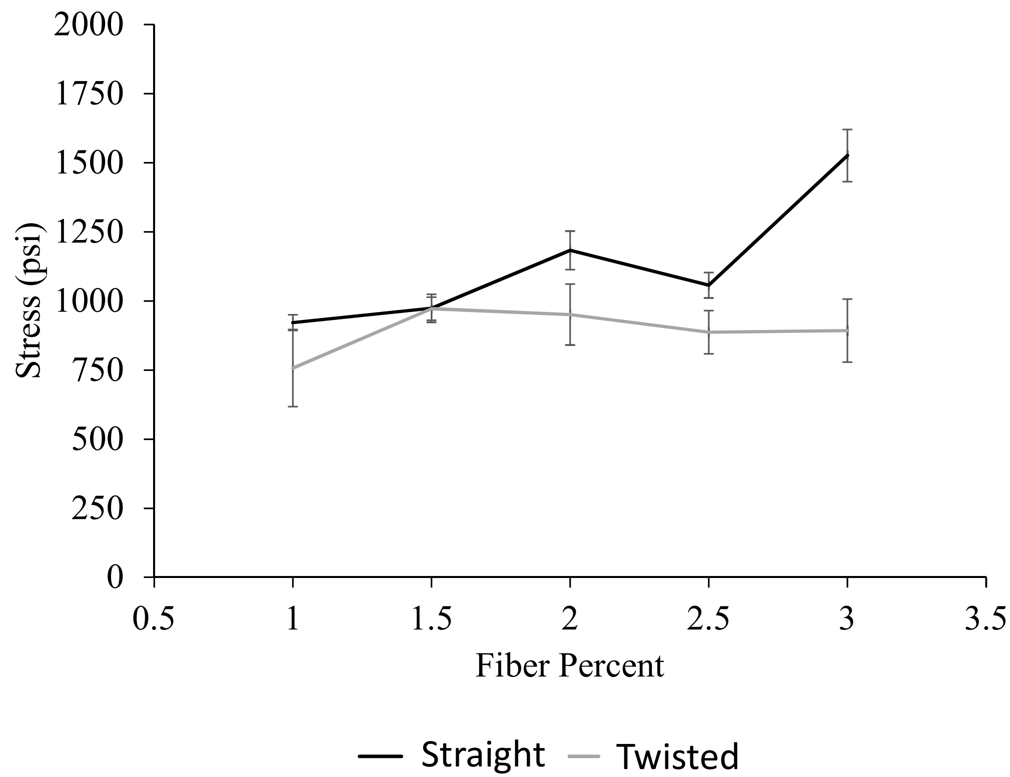
Axial displacement measurements used instead of circumferential

A dial gage or other simple displacement device can be used.

Templates to align punches

Double Punch Response to Fiber Percentage



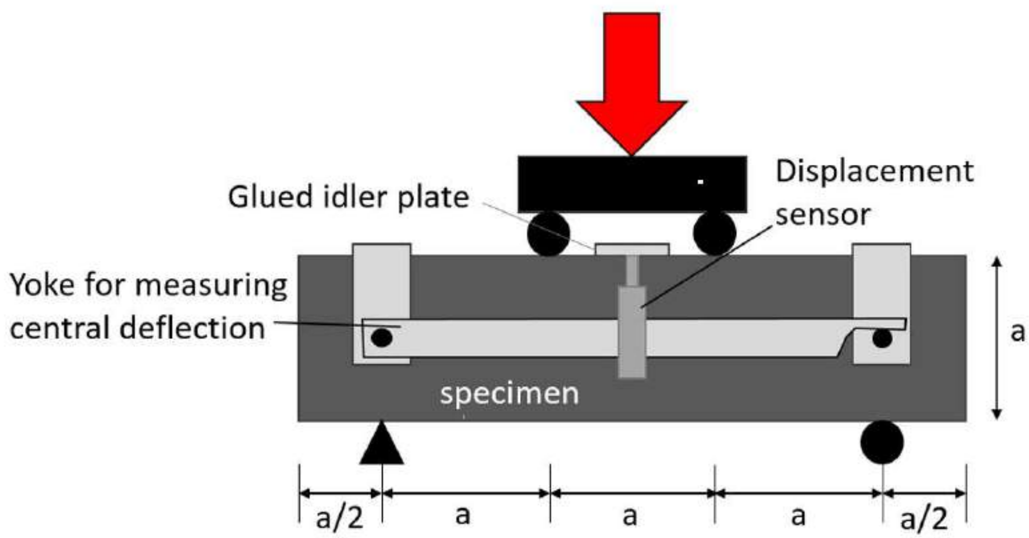


Both fiber types were 13mm long. Straight fibers had diameter of 0.2 mm, twisted had diameter of 0.5mm

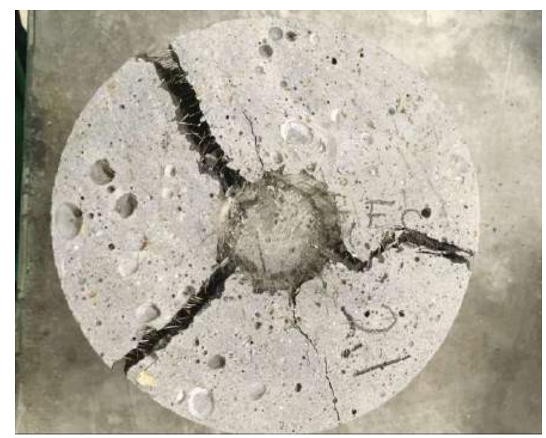
Simplified Double Punch Test Compared to Direct Tension Test and ASTM C1609

Direct Tension Test

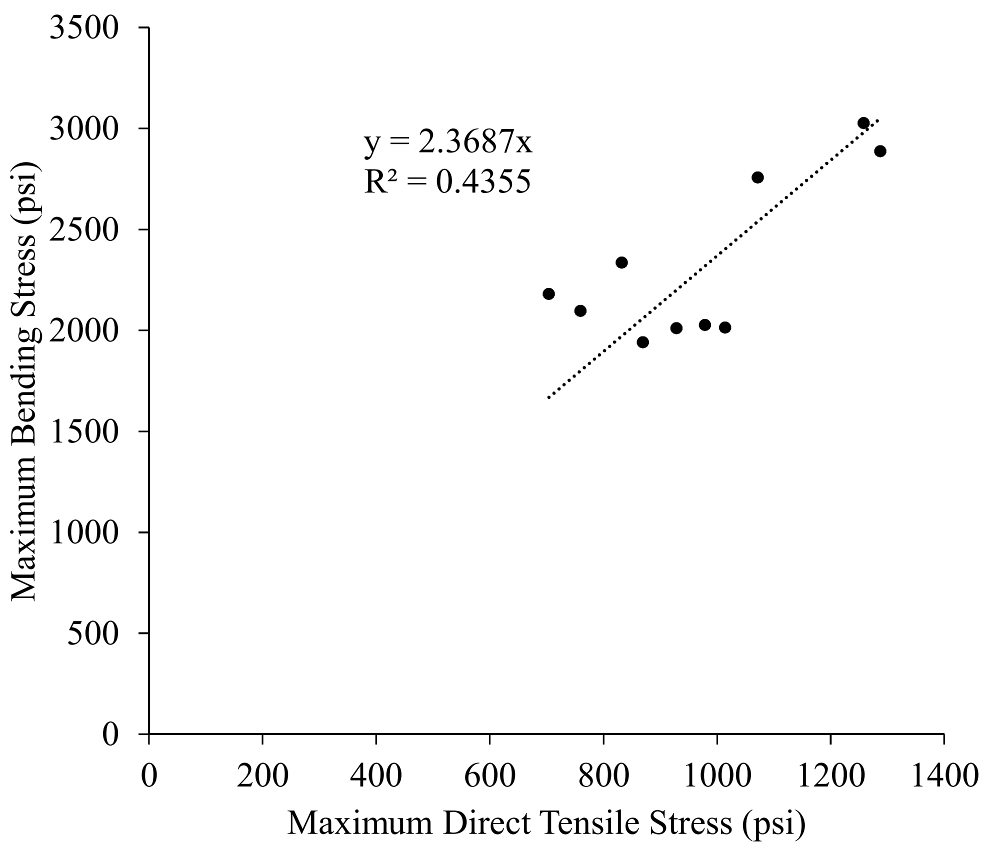
ASTM C1609

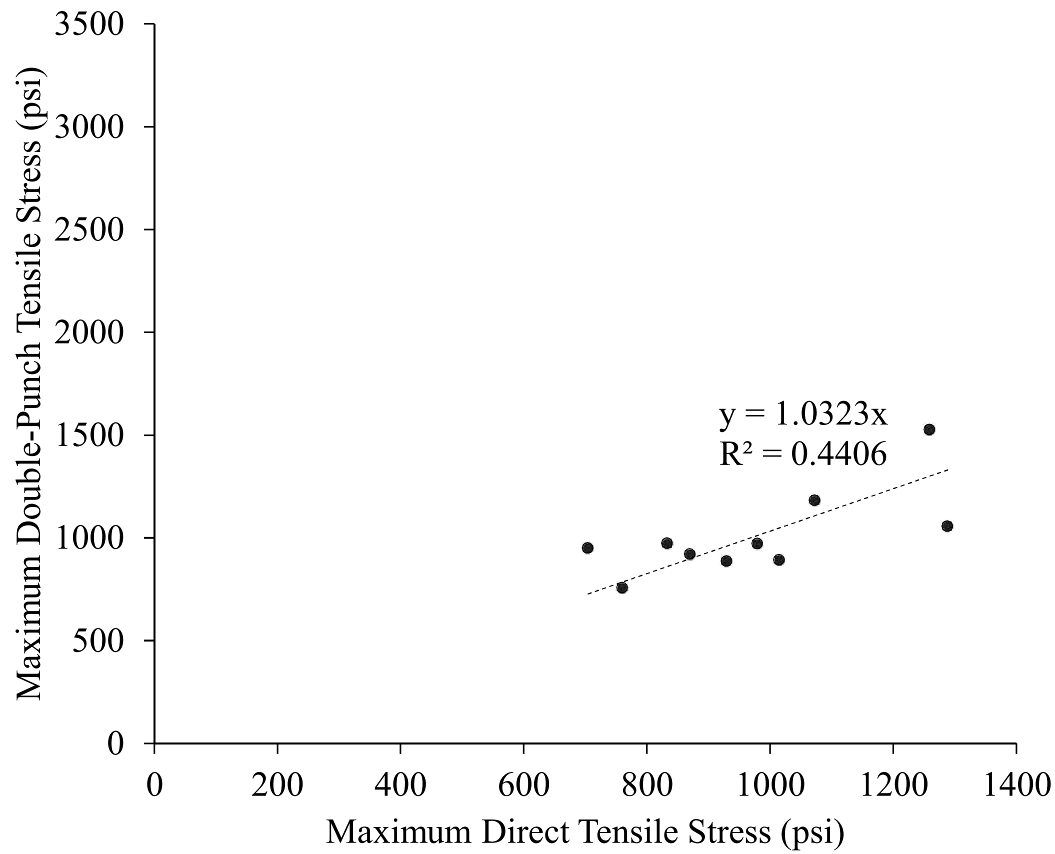


Double Punch

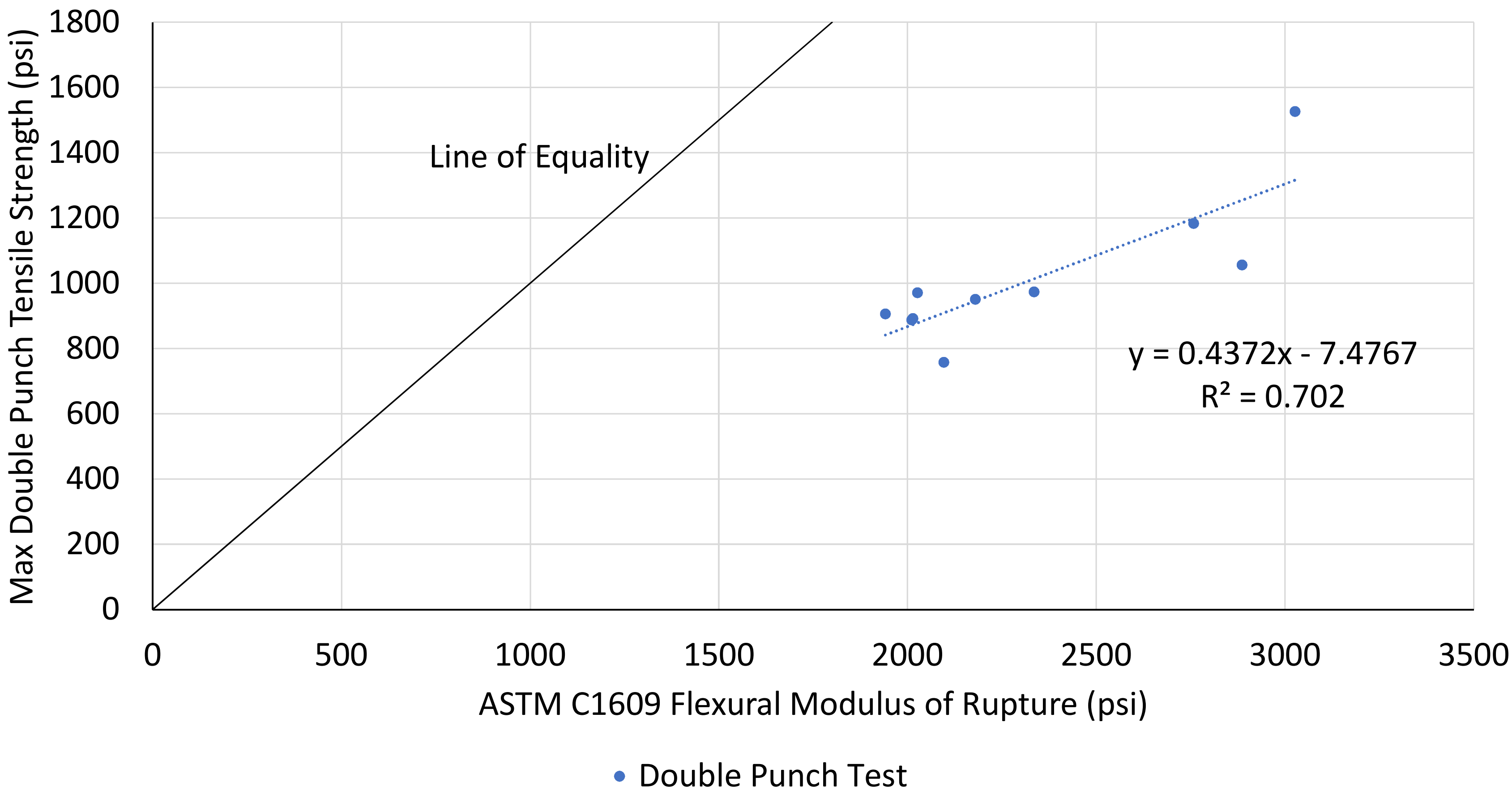


Test Method Comparison

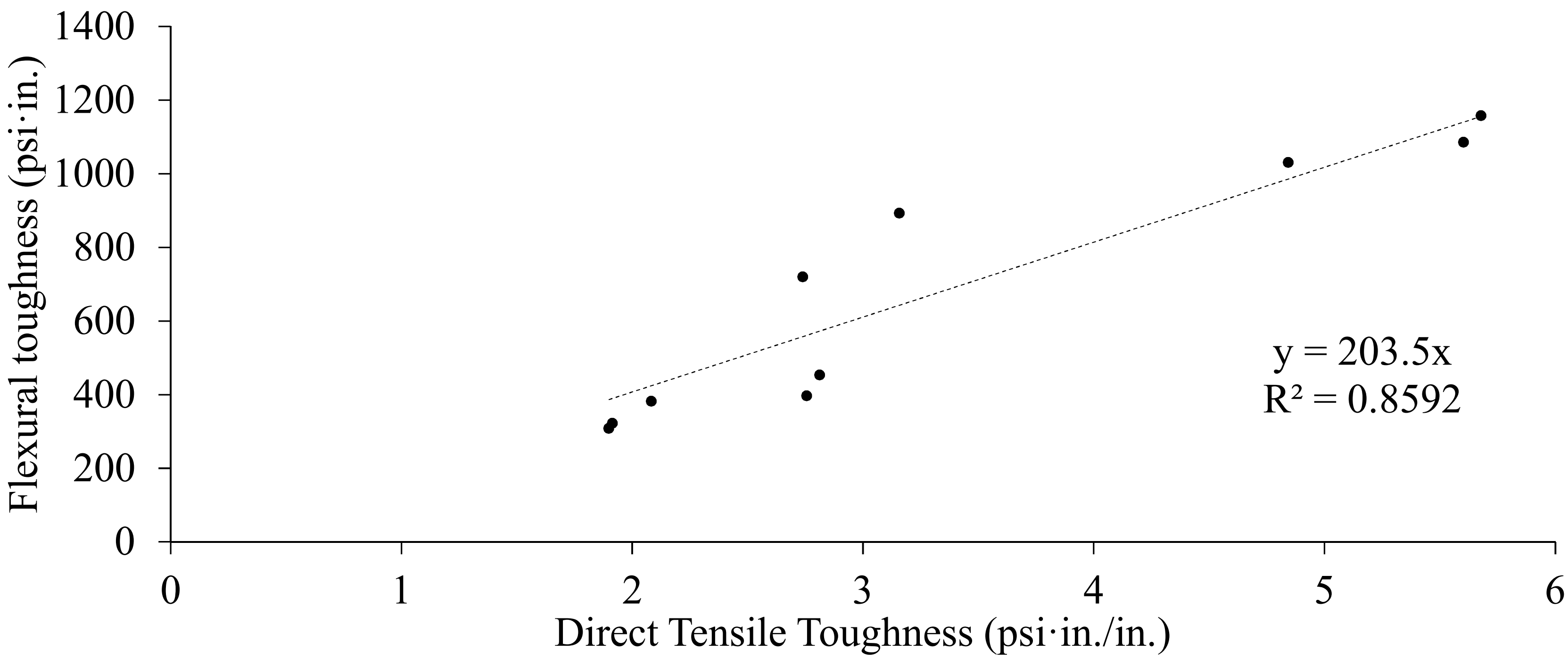




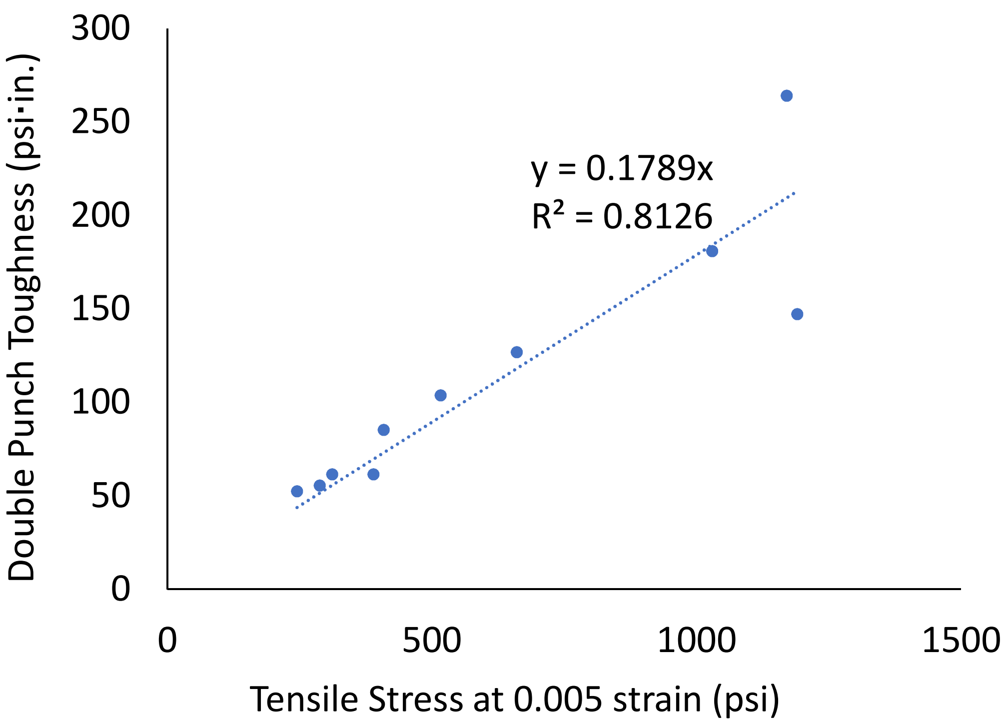
Flexure vs Double Punch

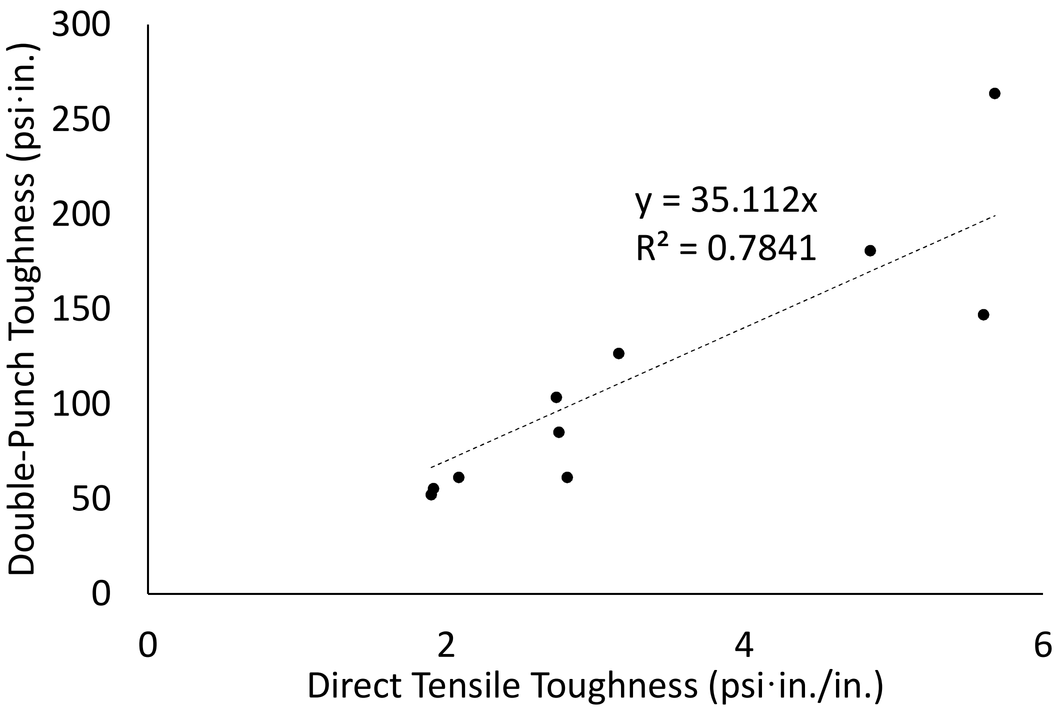


Toughness: Direct Tension vs. ASTM C1609



Relation to Direct Tension Ductility Parameters





Tensile Testing Summary

- QC Tensile test method MUST have a measure of toughness/ ductility
- Ideal QC test would: ✓
  - Accurately characterize tensile strength ✓
  - Provide a measure of ductility or toughness ✓
  - Can be performed with equipment commonly available ✓
  - Simple to perform, easy for technicians to learn ✓
- Round robin study is recommended to implement this test
- Recommendation: Qualify mixtures with direct tension test or ASTM C1609, use new simplified double punch test as QC test at the plant

Acknowledgements

- FDOT for providing funding for this work. Dale DeFord and Steve Nolan for serving as project monitors.

Ultra-High Performance Concrete and Innovative Concrete Materials for Prestressed Concrete Girder Repair

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Motivation

Bridge Joint Deterioration

Photo curtesy of Walt Peters

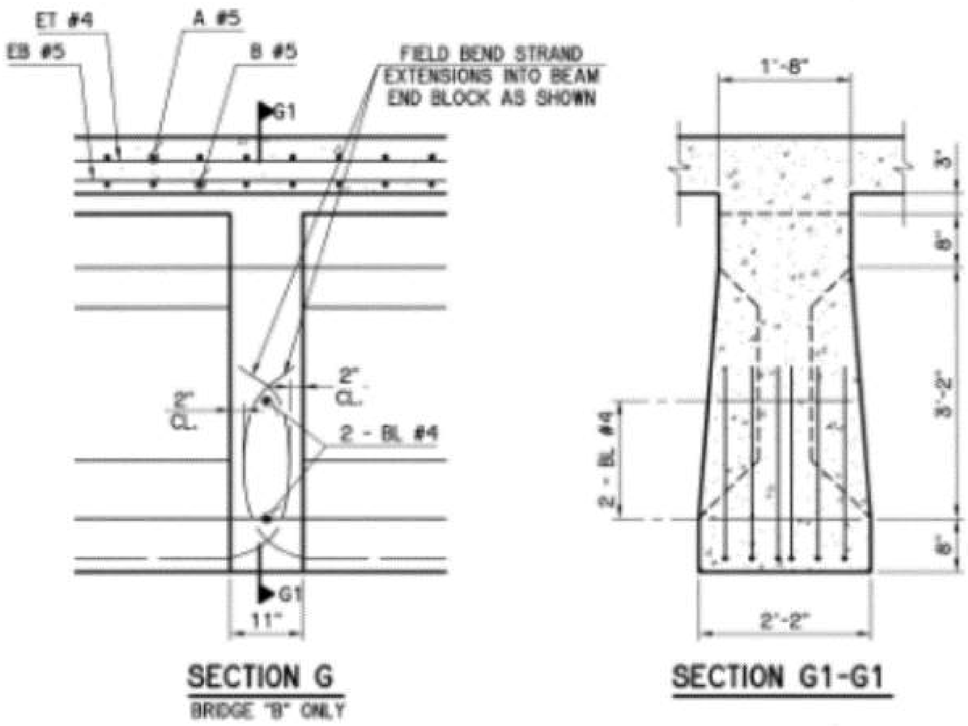
http://www.toledoblade.com/local/2011/07/08/Defective-bridge-expansion-joint-causes-I-75-delays.html

Corrosion and Spalling of Simply Supported Girders

Motivation

Cracking of Continuity Connection Blocks

Photo curtesy of Walt Peters



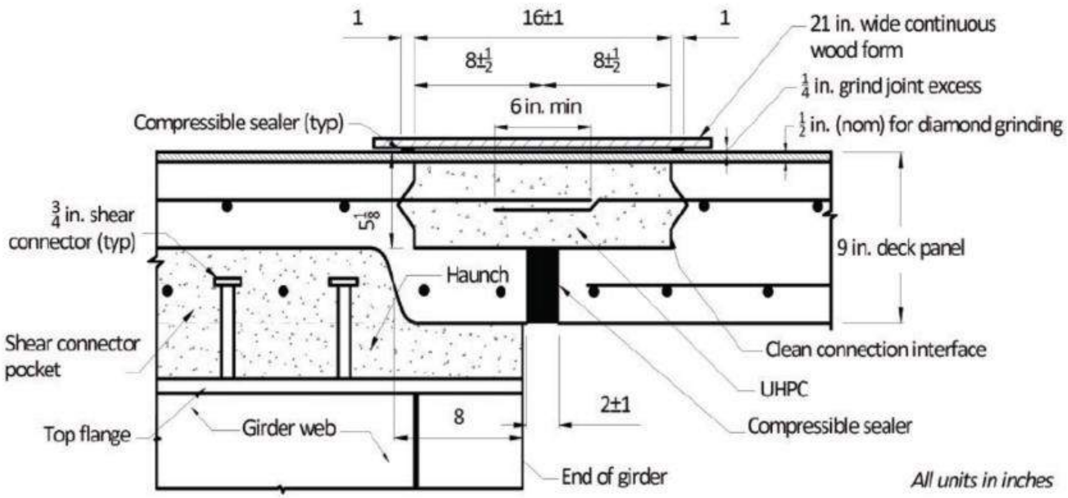
UHPC

- General Definition
  - Compressive strength of 18 – 30 ksi
  - Post-cracking strength of 700 – 900 psi
- High flowability
- Very low to negligible permeability
- High freeze-thaw resistance
- Durability

UHPC Repair Applications

Expansion Joint Headers

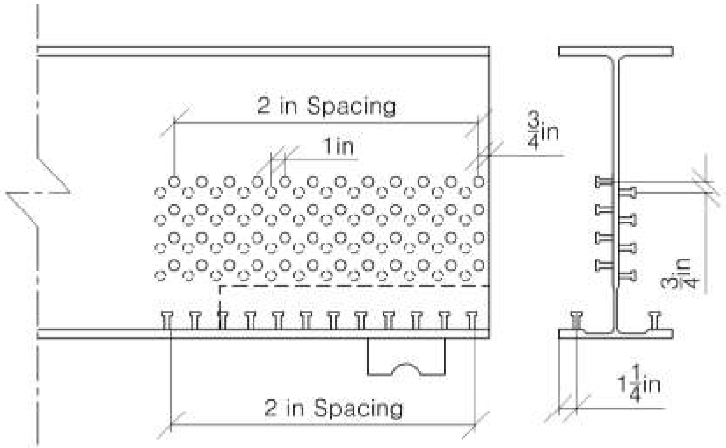
Link Slabs



(Graybeal 2014)

UHPC Repair Applications

Steel girder ends



(Zmetra 2015)

Concrete girder ends

(Shafei et al. 2020)

FR-SCC

- Fiber reinforced self-consolidating concrete
- Flowable and easy to cast
- Good for complex geometry and congested reinforcement
- Fiber reinforcement for restrained shrinkage
- Expansive agent for reduced shrinkage

FR-SCC Repair Applications

- Retaining wall

Jarry/Querbes Underpass, Montreal (Khayat et al. 2005)

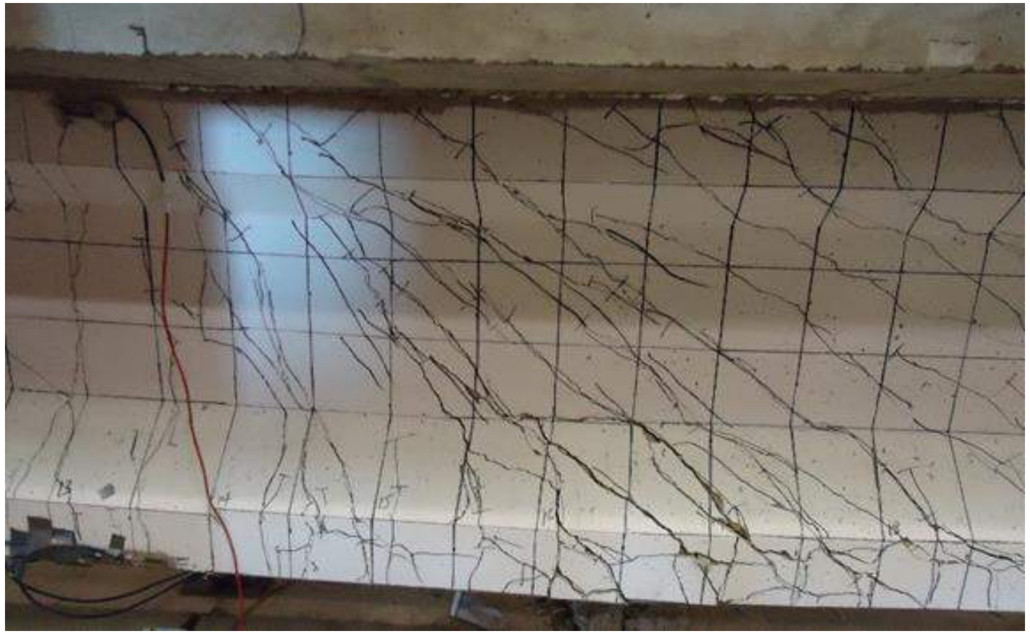
FR-SCC Repair Applications

- Bridge Pier

Ozyildirim 2013

FR-SCC Repair Applications

- Bridge Girder
  - Restored 80% of capacity



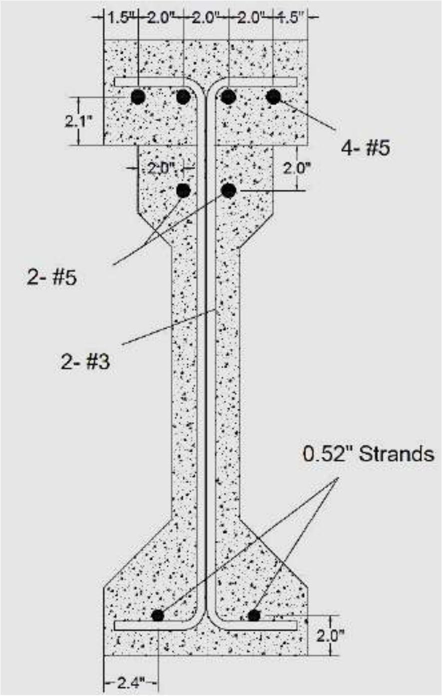
MALP Concrete

- Magnesium-alumina-aggregate dry powder
- Mono-aluminum-liquid phosphate activator
- Rapid setting and rapid strength gain
- Chemically bonds with base concrete
- Acidic environment reduces halo effect
- Used successfully by other states (Washington, Oregon, North Carolina, Florida, Kentucky, California, New York)

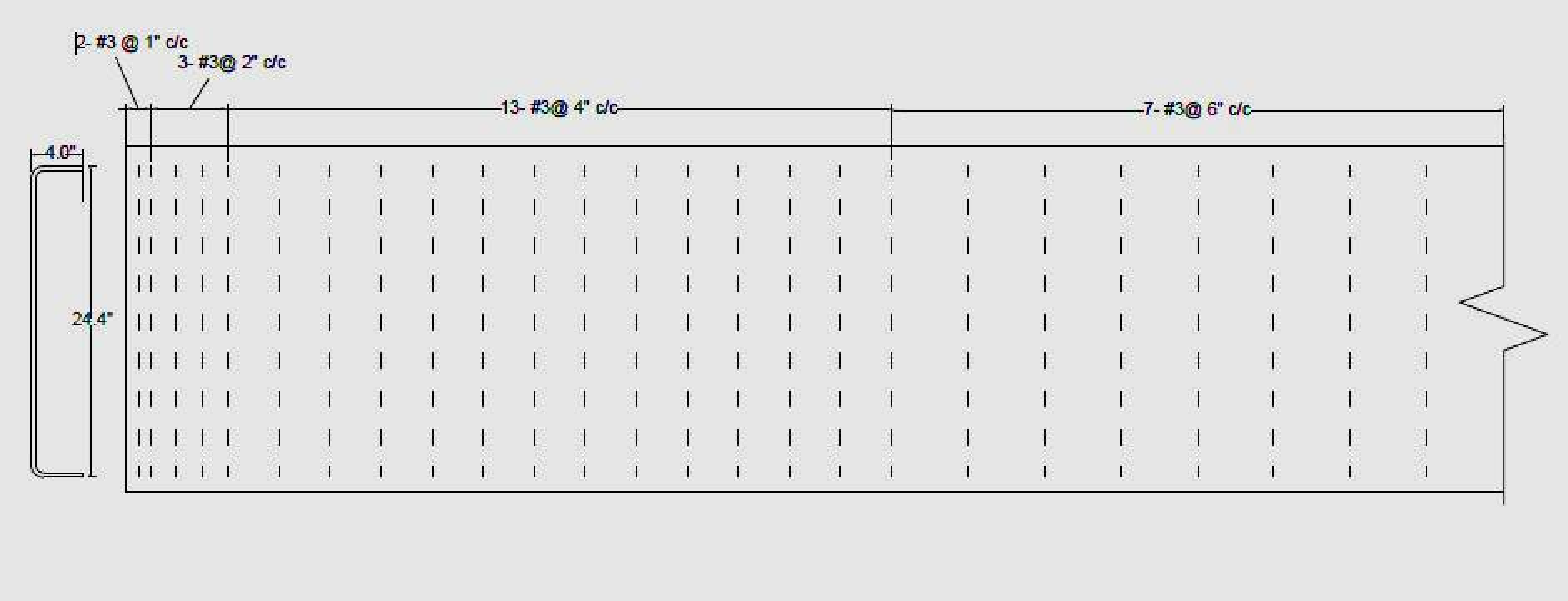
Objectives

- Examine UHPC, FR-SCC, and MALP as repair material
  - Girder end region with shear damage
  - Girder end region with corrosion damage
  - Continuity connection
- Examine effectiveness of UHPC as continuity connection replacement

Girder Design



Cross-Section



Elevation

Girder Construction

Girder Construction

Repair Materials

- FR-SCC developed by previous research (Wirkman 2016)
- Non-proprietary UHPC developed at OU (Looney et al. 2019)
- MALP was proprietary product Phoscrete

FR-SCC

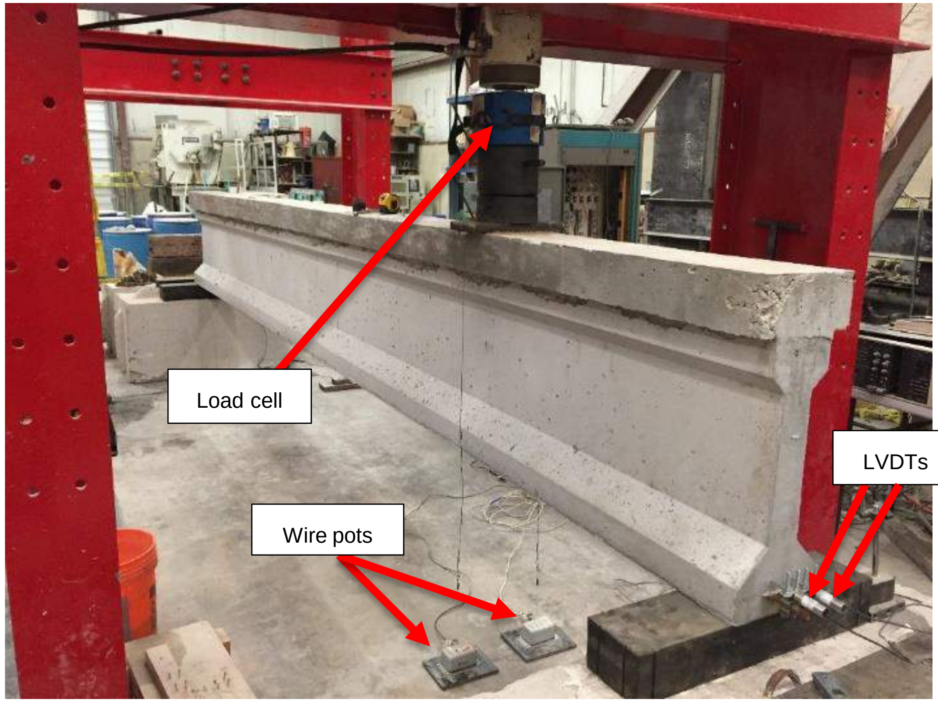
Material	Quantity (lb/yd^3)
Portland cement (Type I) (lb/yd^3)	412.5
Fly Ash	225
Type K Cement (Komponent)	112.5
Coarse Aggregate (3/8 in. River Rock)	1276
Fine Aggregate	1441
Water	230
Polypropylene Fibers	7.70
Air Entrainer (Master Builders AE-90)	0.54
High Range Water Reducer (Glenium 7920)	4.02
Citric Acid	0.41

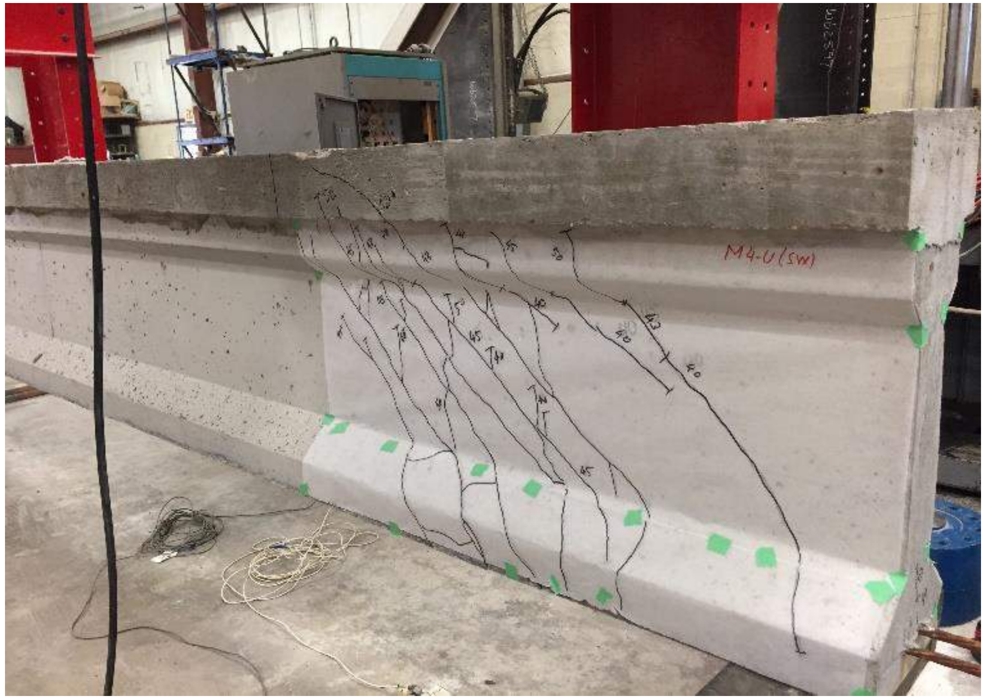
UHPC

Material	Quantity
Type I Cement (lb/yd^3)	1180
GGBFS (lb/yd^3)	590
Silica Fume (lb/yd^3)	197
Steel Fibers (lb/yd^3)	265
Fine Masonry Sand (lb/yd^3)	1966
Water (lb/yd^3)	393
Glenium 7920 (oz/cwt)	18

End Region Repair

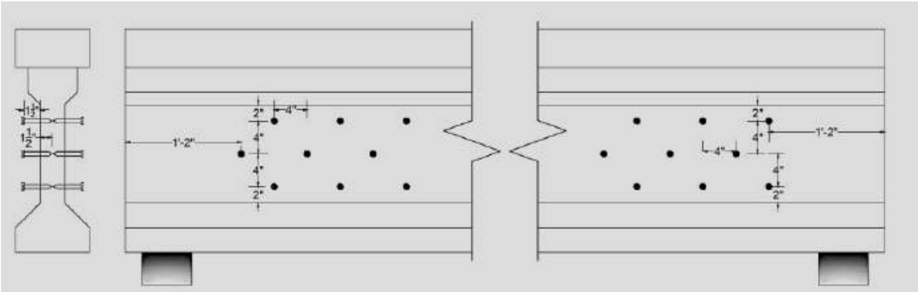
- Initial test to induce bond-shear failure

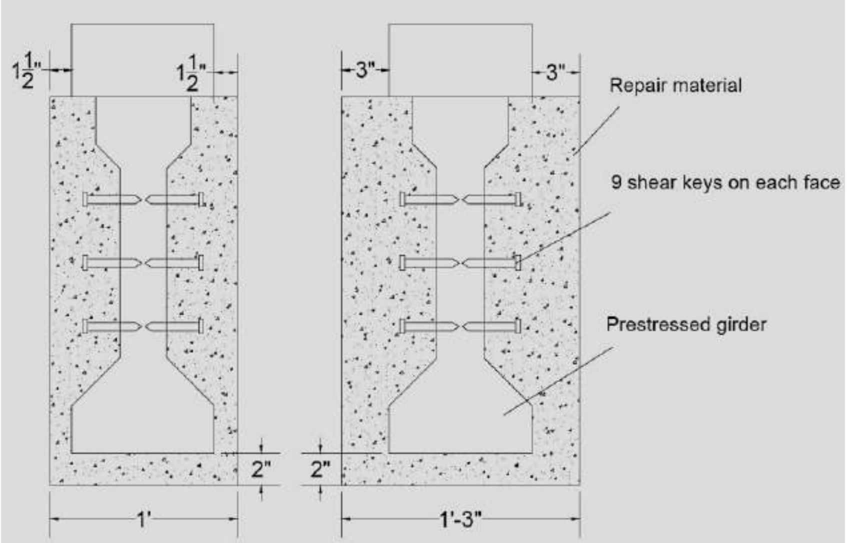




End Region Repair

- Encapsulate end with UHPC, FR-SCC, or MALP
- Concrete screw anchors as shear studs
  - Designed using shear friction





UHPC FR-SCC and MALP

End Region Repair

- Completed repairs

UHPC

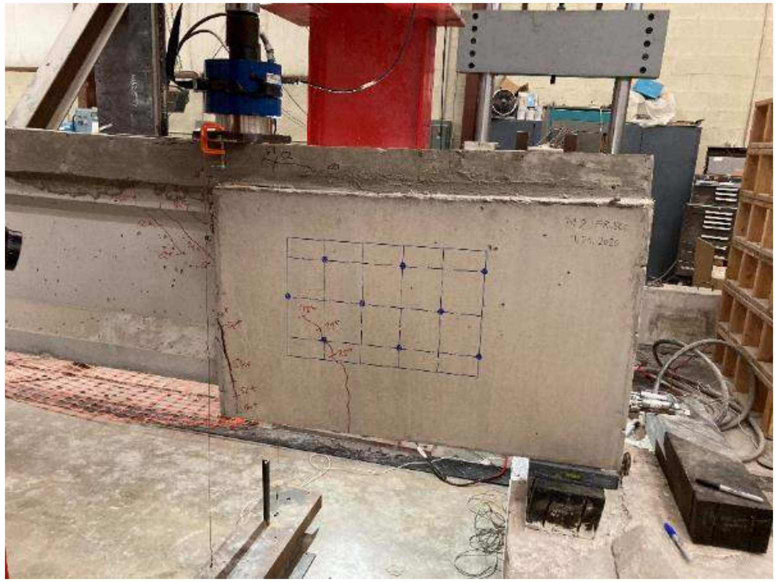
FR-SCC

MALP

End Region Repair

- Post-repair load tests

UHPC

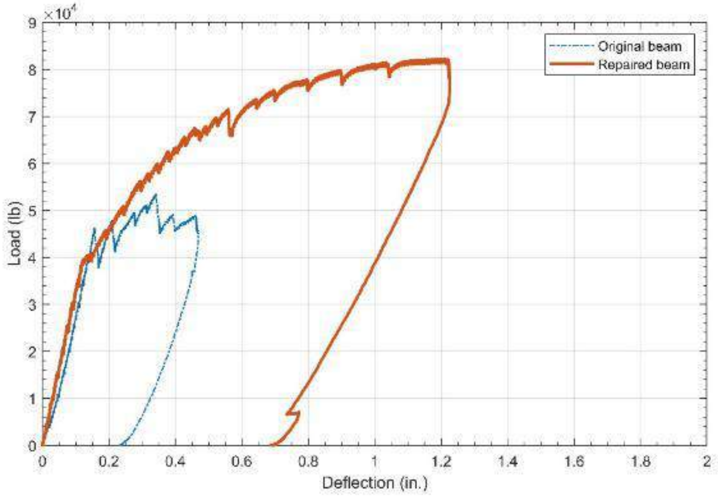


FR-SCC

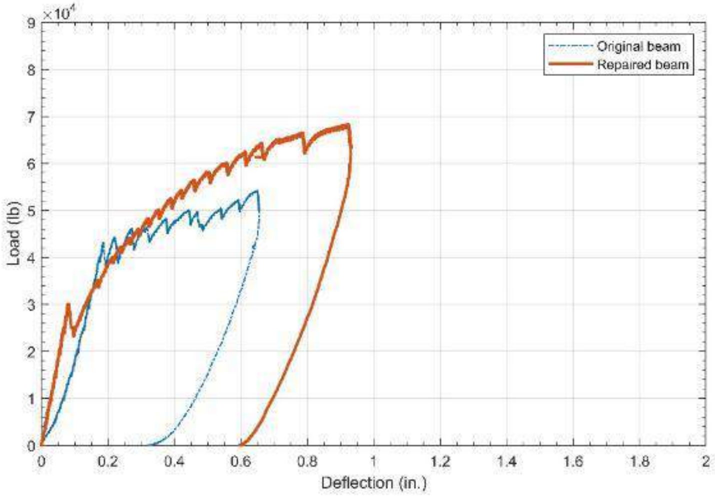
MALP

End Region Repair

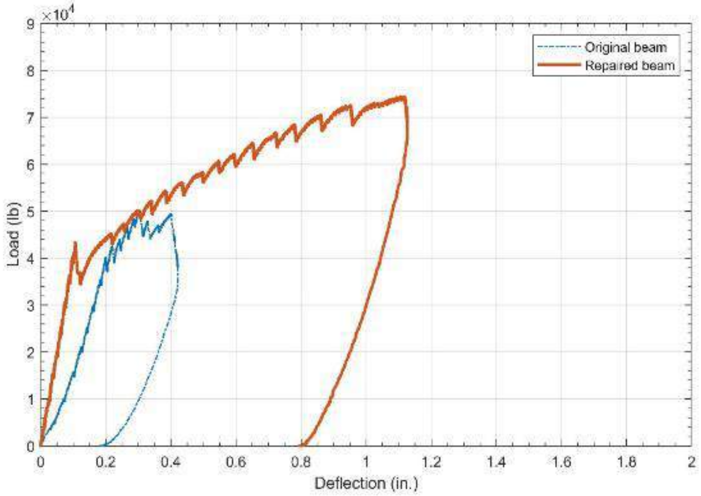
- Load-deflection comparison



UHPC



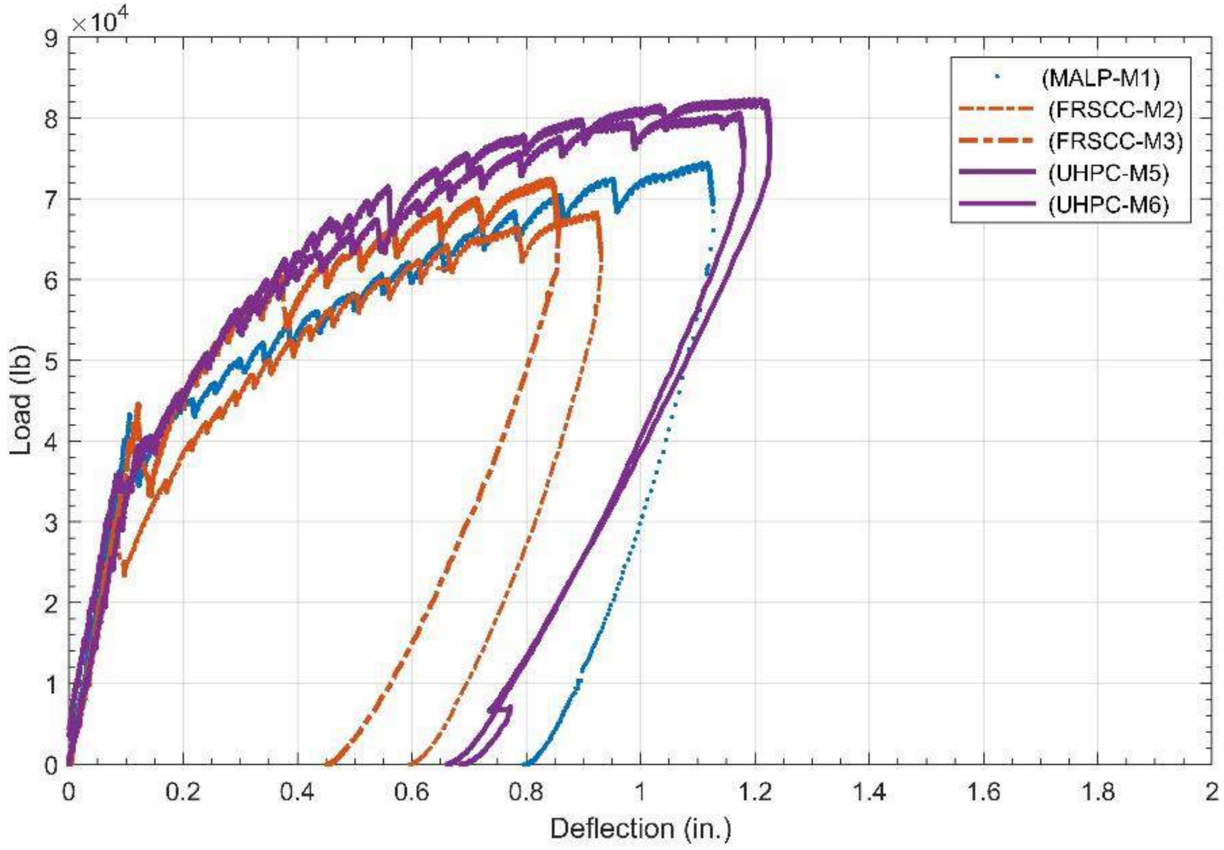
FR-SCC



MALP

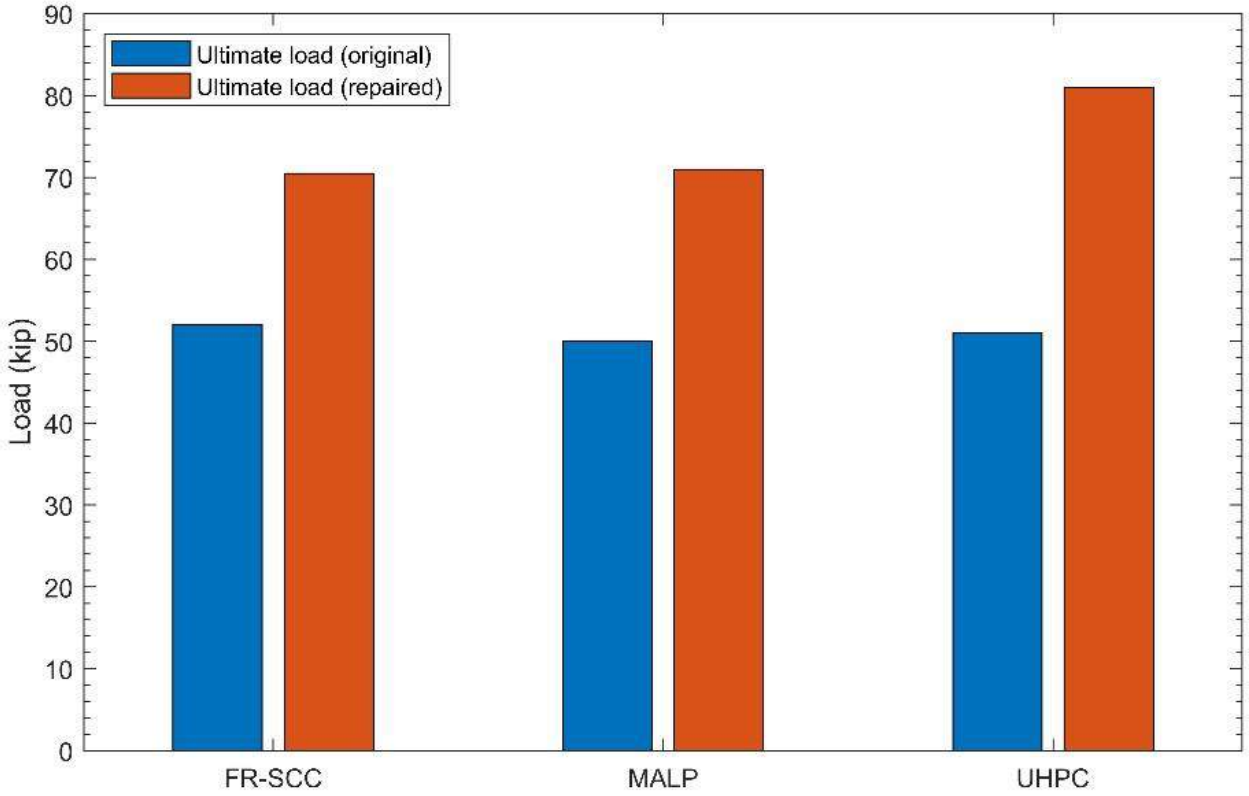
End Region Repair

- Load-deflection for all repaired specimens



End Region Repair

- Maximum load comparison



Field Implementation

Five Spans, three continuous

Field Implementation

In-service condition

Field Implementation

Pre-repair load test

Field Implementation

Joint demolition and instrumentation

Field Implementation

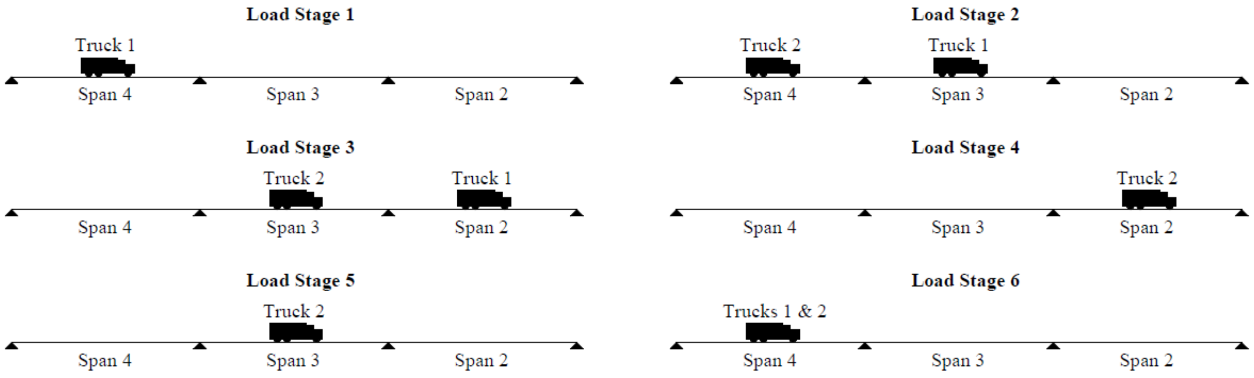
Joint construction

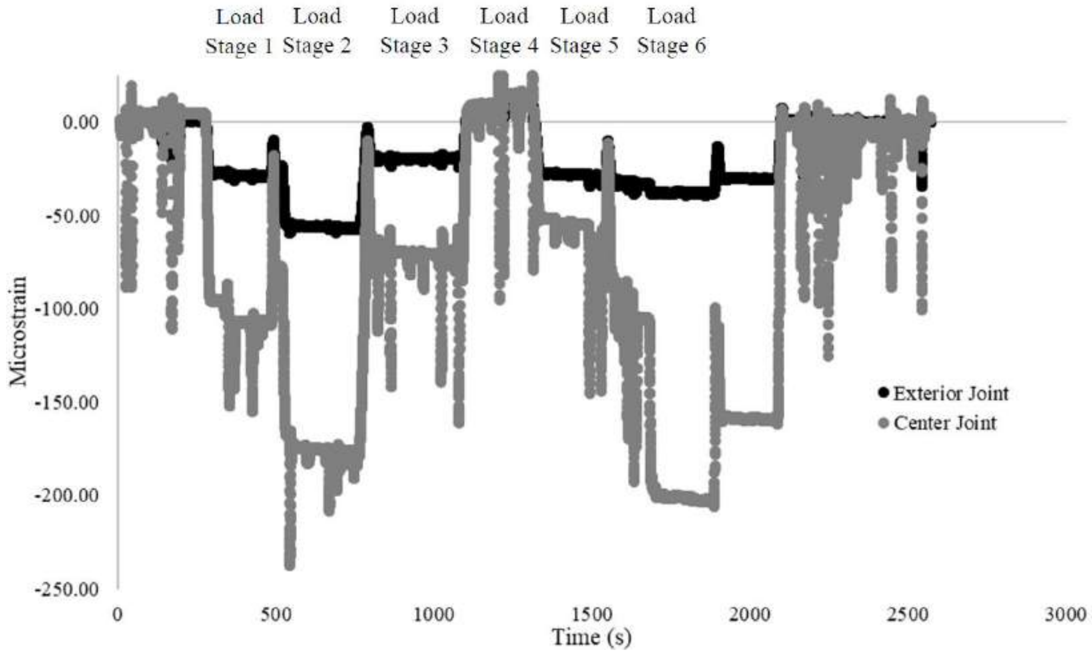
Field Implementation

Condition after 1 year

Field Implementation

Post-repair load test





Load Stage	Measured Before Repair	Calculated for Simple Span	Measured After Repair	Calculated for Continuous Spans
1	-1	-2	-2	-1.5
2	-2	NA	-1	-1.0
3	0	NA	0	0.3
4	0	NA	0	-0.2
5	-1	NA	1	0.5
6	-4	-4	-3	-3.1

Conclusions

- All three repair materials provided increased capacity when used to encapsulate shear damaged end region
- UHPC provided the greatest increase in capacity, even with a smaller thickness
- Repaired specimens exhibited significantly less cracking which could lead to improved longevity
- UHPC was successfully used to replace existing precast concrete girder continuity connections and appears to be functioning as expected

Future Work

- Examine repair of concrete loss below the prestressing strands
- Examine effects of creep, shrinkage, and temperature on the joint when prestressed girders are connected shortly after prestress
- Develop design guidance for UHPC continuity connections

Thank you!

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