TEXAS A&M UNIVERSITY
Zachry Department of
Civil & Environmental Engineering

Texas Department of Transportation

Texas A&M Transportation Institute

Development and Application of Non-proprietary UHPC Mixtures for Pretensioned Bridge Girders

ACI / JCI – 6th Joint Seminar

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Research Objectives

1. Development of Nonproprietary UHPC Mixtures
2. Production of Full-Scale Precast Pretensioned Bridge Girders
3. Full-Scale UHPC Girder Testing

High Compressive and Tensile Strength and More Durable	Nonproprietary Mix from Materials Available in Texas	Precast Pretensioned UHPC Tx girders with Cast-in-Place Decks	Structural Performance Tested
Longer span High prestress Fewer girder lines Long service life	Locally available and commonly used materials at precast plant in Texas	Fabrication of UHPC girder at a precast plant while keeping current production practices	Full Scale Testing: Flexure Test Shear Test

Part I: Development of Nonproprietary UHPC Mixture and Plant Production

Requirements for UHPC Mixture Development

Questionnaire Results

- Constituent materials
  - Currently used materials
  - Type III cement, fly ash, HRWR, natural sand
- Curing
  - No heat treatment
- Prestressing transfer
  - Within 16 – 20 hours
- Mixing and Placement
  - Use existing mixer (50-60% of capacity) and standard transporters

Properties and Durability

- Workability
  - Sufficient flow spread
- Mechanical Properties
  - f'_{ci} at release = 12 – 14 ksi
  - f'_{c} at service = 18 – 20 ksi
- Durability
  - Superior transport properties

Challenge: achieving 12 – 14 ksi within 20 hours without heat treatment

Selected Mixture Optimized with Precast Plant Materials

Mixture Proportion Comparison

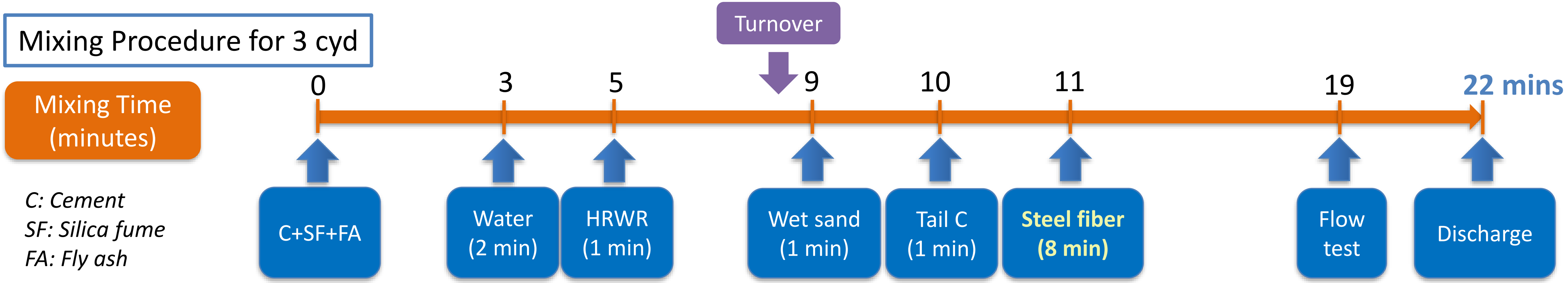
Constituent	Proprietary UHPC[1]	Developed Plant UHPC	Material used in Study
Cement	1.00	1.00	Type III
Silica fume	0.33	0.08	Densified
GQ / Fly ash	0.30 (GQ)	0.10	Class F fly ash
Sand	1.43	1.12	Natural sand, #4
Water	0.15	0.21	--
HRWR	0.04	0.024	--
Accelerator	0.04	--	--
Steel fiber	2.0% by volume	1.5% by volume	0.008" diameter 0.5" long

Mix proportion by cement weight

1. FHWA-HRT-06-103
2. GQ: Ground Quartz

Steel fibers

Production of UHPC Girder at Precast Plant



UHPC Mixing using existing twin shaft mixer

Vibrating the screen for steel fiber addition (2 in. spacing screen)

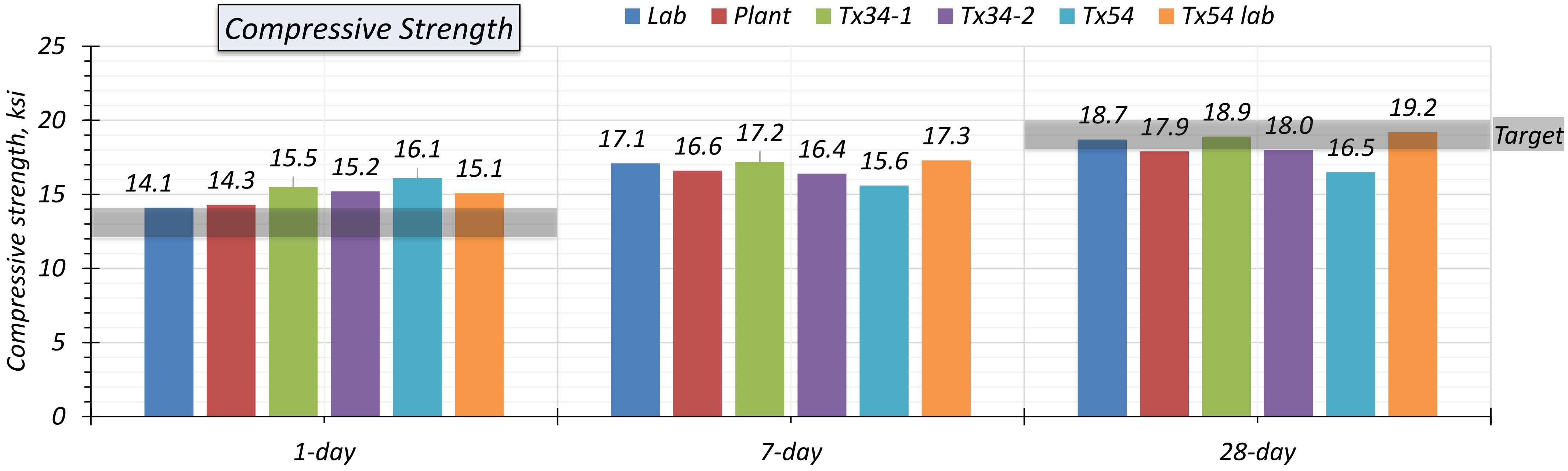
Placement using Tuckerbuilt

Production of UHPC Girder at Precast Plant

Tx34-2 Girder,
50 ft long

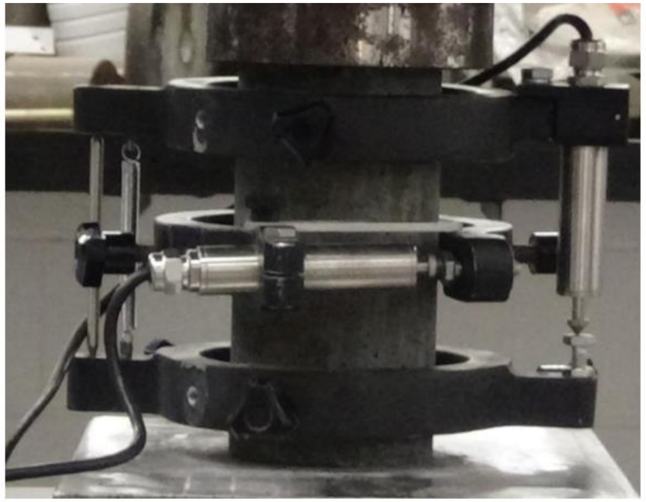
Compressive Strength

Property	Target	Average Value (cast samples at plant)	Comment
Compressive strength	• 12 – 14 ksi (release) • 18 – 20 ksi (service)	• > 12 ksi at release (20 hours) • 14.3 – 16.1 ksi (24 hours) • 17.9 – 19.2 ksi (28 days)	✓ Target met



Additional Hardened Properties

Property	Target	Average Value (cast samples at plant)	Comment
Modulus of Elasticity	–	• 6300 – 7400 ksi	Consistent with literature
Uniaxial Tensile Strength	• 0.75 ksi at release • 1.0 ksi at service	• 0.55 – 0.81 ksi (7 days) • 0.31 – 1.28 ksi (28 days)	Average is slightly less than target, but individual specimens met the target.
Inferred Flexural Tension Strength	• 2.0 ksi at service (PCI recommendation)	• 1.9 – 2.0 ksi (3 days) • 2.0 – 2.4 ksi (28 days)	✓ Strength target met



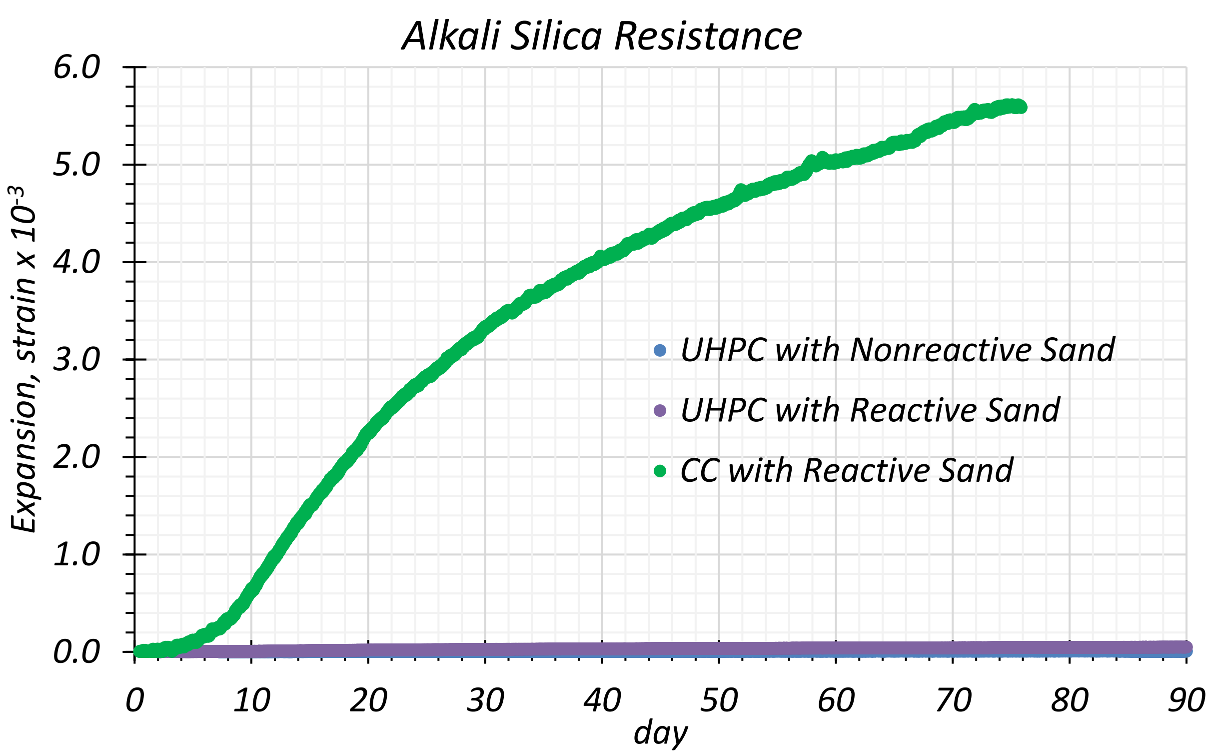
Modulus of Elasticity Test Setup

Uniaxial Tensile Strength Test Setup

Inferred Tension Bending Test Setup

Durability

Bulk / Surface Resistivity at 56 days (kΩ-cm)	RCPT (Coulombs)	ASR (with reactive sand)	Freeze-Thaw Resistance	Scaling Resistance	Abrasion Resistance (mass loss)	Service Life Prediction*
210 / 214 (Very Low)	54 (Negligible)	0.049×10^{-3} at 90 days (Negligible)	No degradation (Mass Change: 0.04%)	Rating 1 (Very slight scaling)	Top: 0.07% Bottom: 0.03%	> 150 years



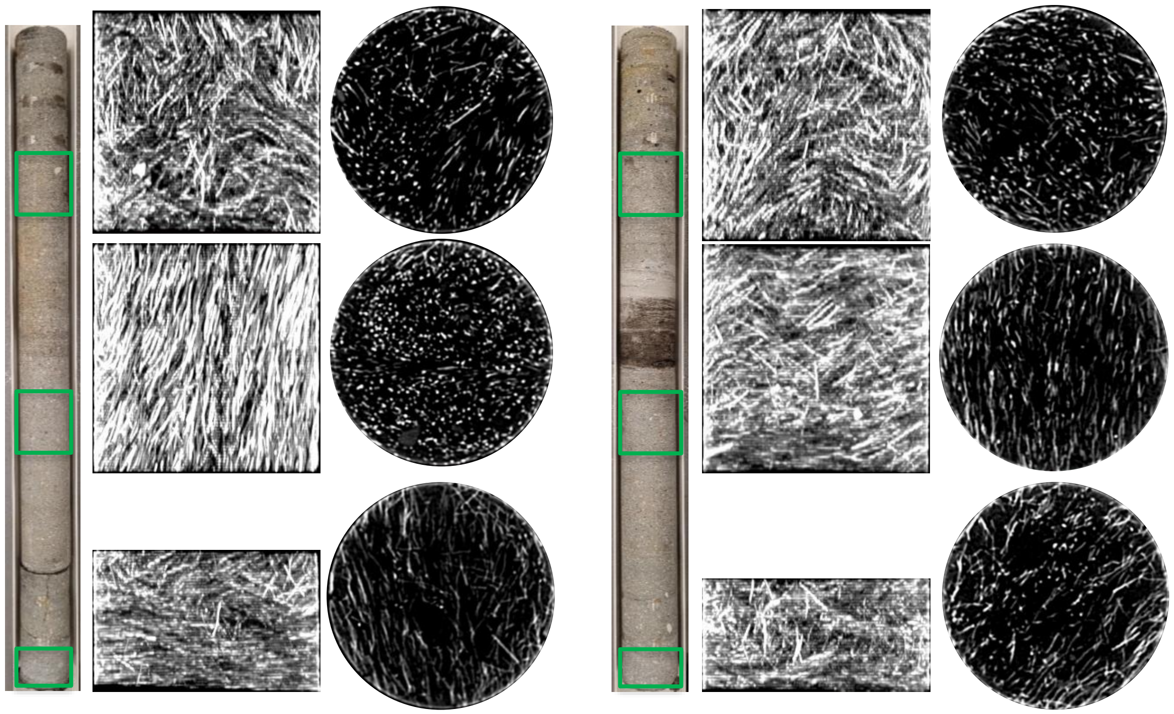
* *Service life prediction analyzed using Fick's 2nd law with bulk resistivity data.*
* *Diffusion coefficient: 2.75×10^{-14} m^2/s*

Surface resistivity testing

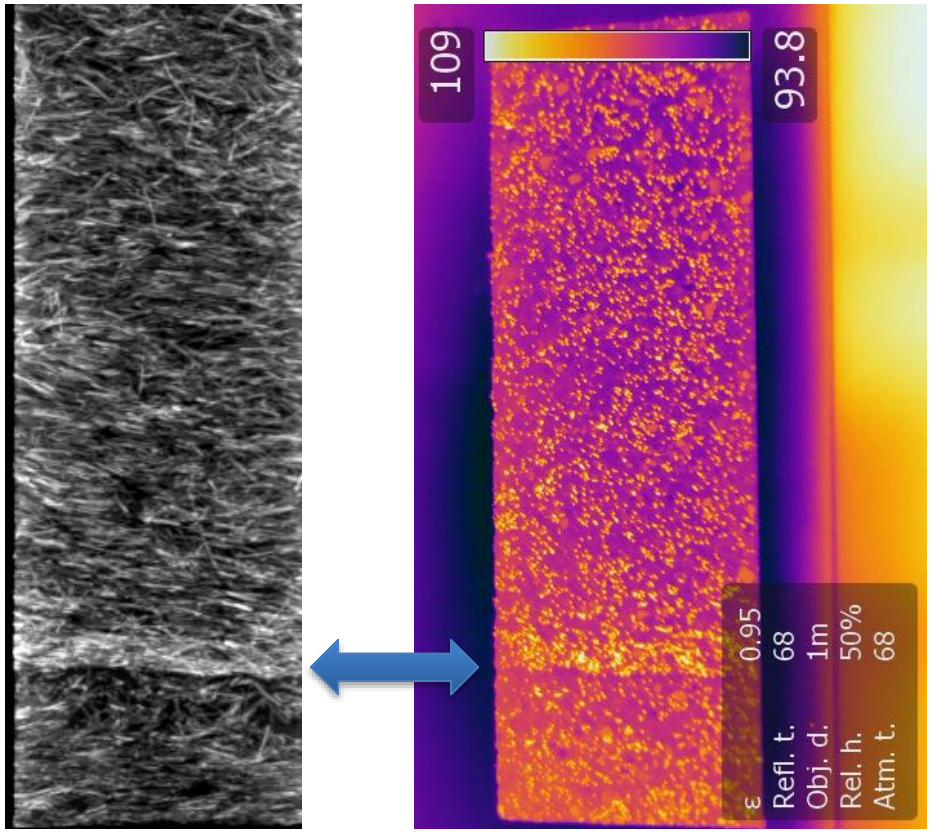
Abrasion resistance testing (left) and samples after abrasion (right)

Fiber Distribution and Orientation

- Fiber distribution was investigated using cored samples from the girders with X-ray CT scanning and infrared images.



Well Distributed and Randomly Oriented Fibers



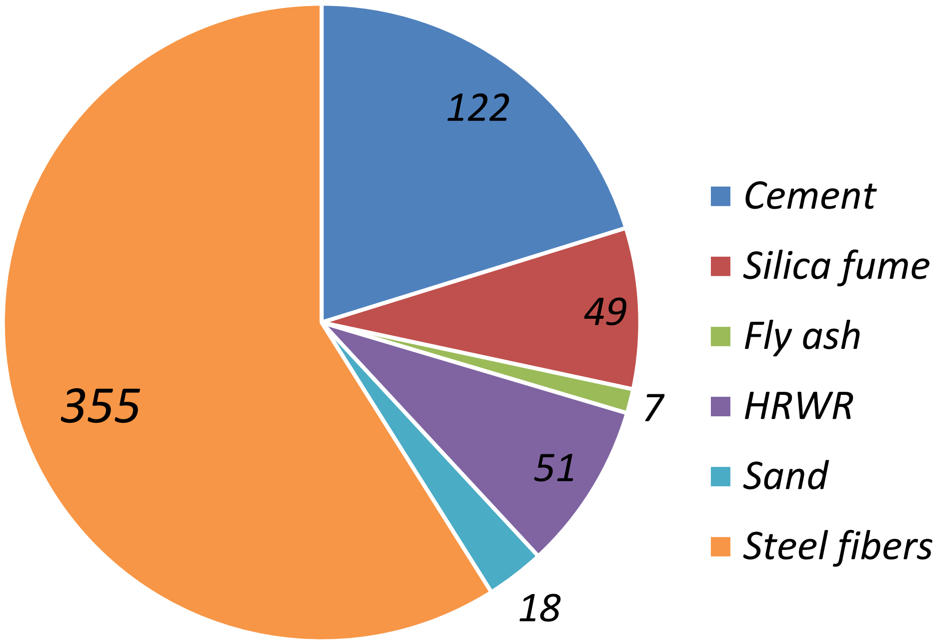
Possible Formation of Elephant Skin for Tx54 Girder Specimen

Cost Analysis

Cost Comparison

UHPC	$ / cyd	Materials (Fiber volume)	Source
TxDOT	**$602**	Type III, natural sand (1.5%)	This research study
Michigan DOT	$893	Type I, quartz sand (2.0%)	El-Tawil et al. (2018)
Montana DOT	$561	Type I/II, masonry sand (2.0%)	Berry et al. (2017)
Missouri DOT	$1017	Type III, natural sand (2.0%)	Khayat and Valipour (2018)
FHWA	$730	Type II/V, natural sand (1.5%)	Wille (2013)
	$965	White, natural sand (1.5%)	
	$1122	White, quartz sand (1.5%)	
Proprietary	$2000	Not listed	Tadros (2019)

Cost of Developed Mix ($/cyd)*

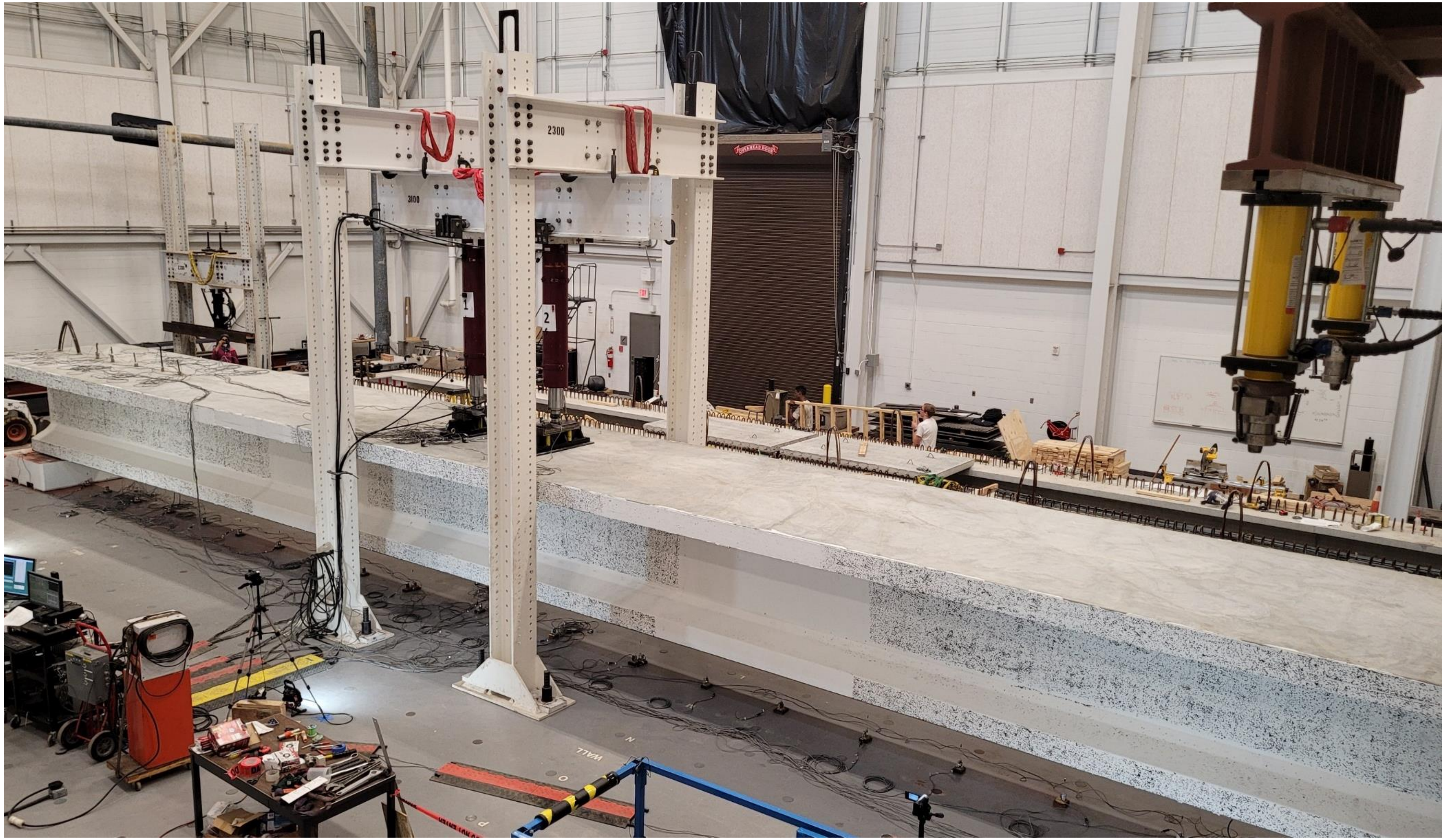


**Cost analysis was conducted in 2020.*

Part I: Development of UHPC Mixture: Summary and Conclusions

- *Development of Nonproprietary UHPC Mixture*
  - ✓ Locally available and commonly used materials at precast plant in Texas.
  - ✓ Reduction in steel fiber content (1.5 percent) for cost-effectiveness.
  - ✓ High early strength (12–14 ksi within 20 hours) without heat treatment and accelerator.
  - ✓ Superior durability: high resistivity and freeze-thaw, scaling, abrasion, and ASR resistance.
  - ✓ Long service life span (150+ years)
- *Production and Fabrication*
  - ✓ Successful use of existing mixer (50–60% mixer capacity)
  - ✓ Girder fabrication with multiple batches and placements using Tuckerbuilt
  - ✓ Release at 20 hours (compressive strength > 12 ksi)
- *Fiber Distribution and Orientation*
  - ✓ Overall, steel fibers were well-distributed with random orientation.
  - ✓ Possible risk of fiber segregation due to a high flow spread (> 11 in.) or elephant skin formation

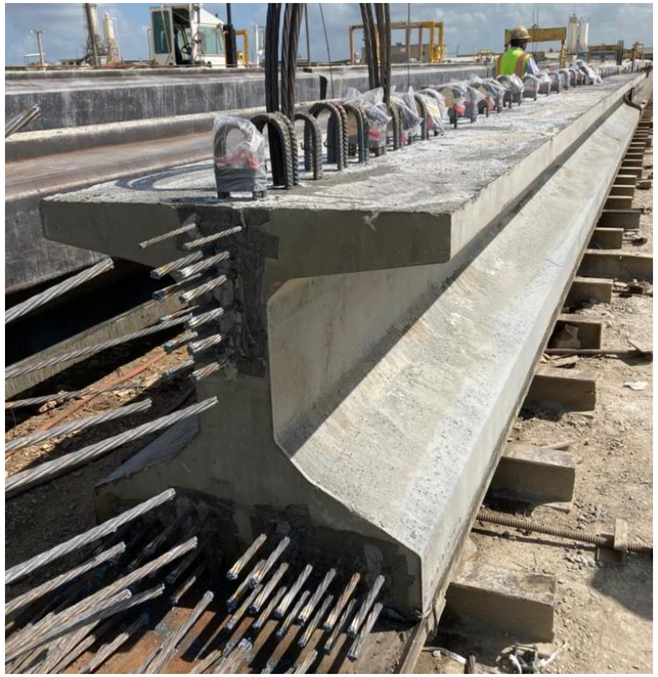
Part 2: Structural Full-Scale Testing



Structural Full-Scale Testing

- **Major Technical Objectives**
  - ✓ Conduct ***flexure test*** at midspan each girder specimen
  - ✓ Conduct ***shear test*** at each end of girder specimen
  - ✓ Compare the ***experimental*** observations with the ***predicted*** capacity and ***design*** strength

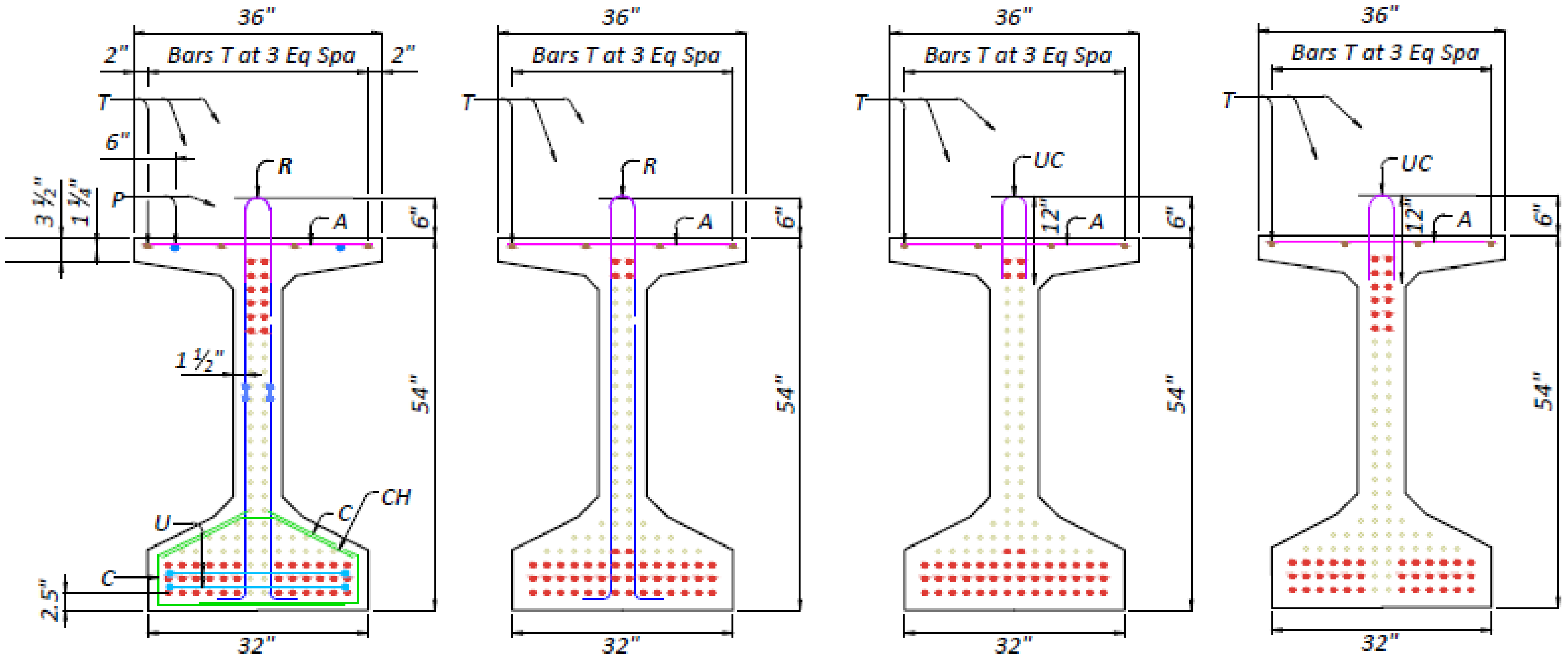
Tx34-1 Girder Test Setup



Tx34-2 Girder Specimen

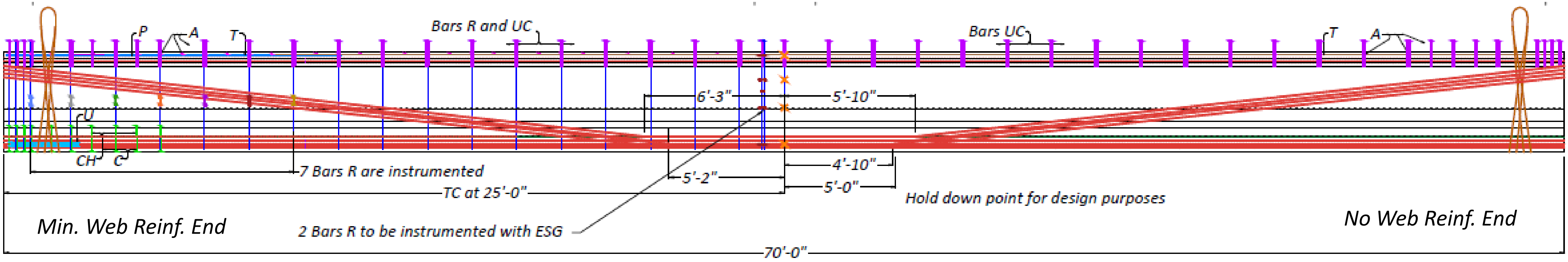
Tx54 Girder Test Setup

Tx54 Girder Specimen: Harped Tendon Profile



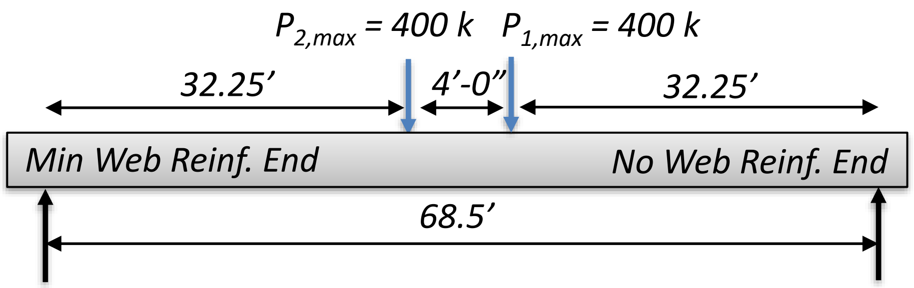
Parameter	Tx54
Prototype Span Length	121 ft
Specimen Length	68.5 ft
No. of Strands	48 total (8 harped)

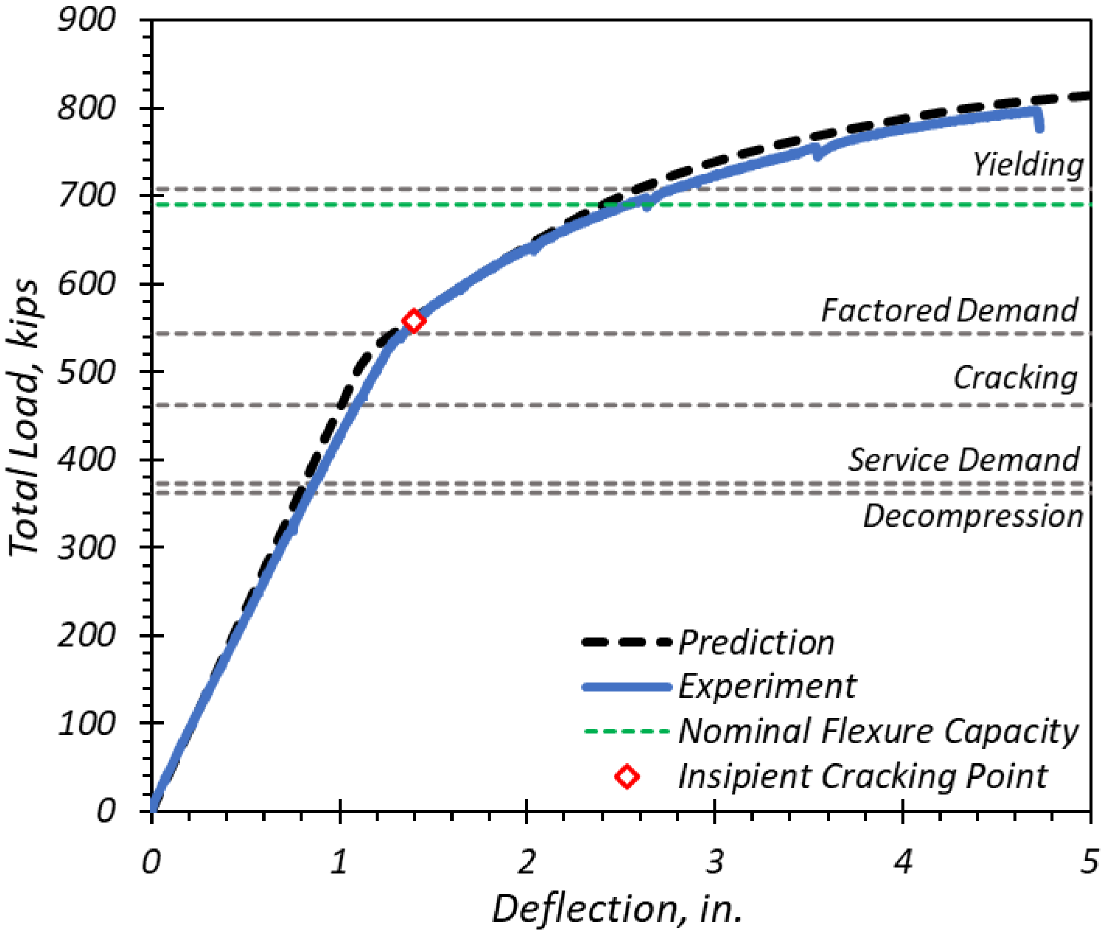
- *R-bars = #4: spacing = 24 in. spacing in half span and 3 in. at end*
- *UC-bars = #5: spacing = 24 in. (midspan), 12 in. and 3 in. at end*



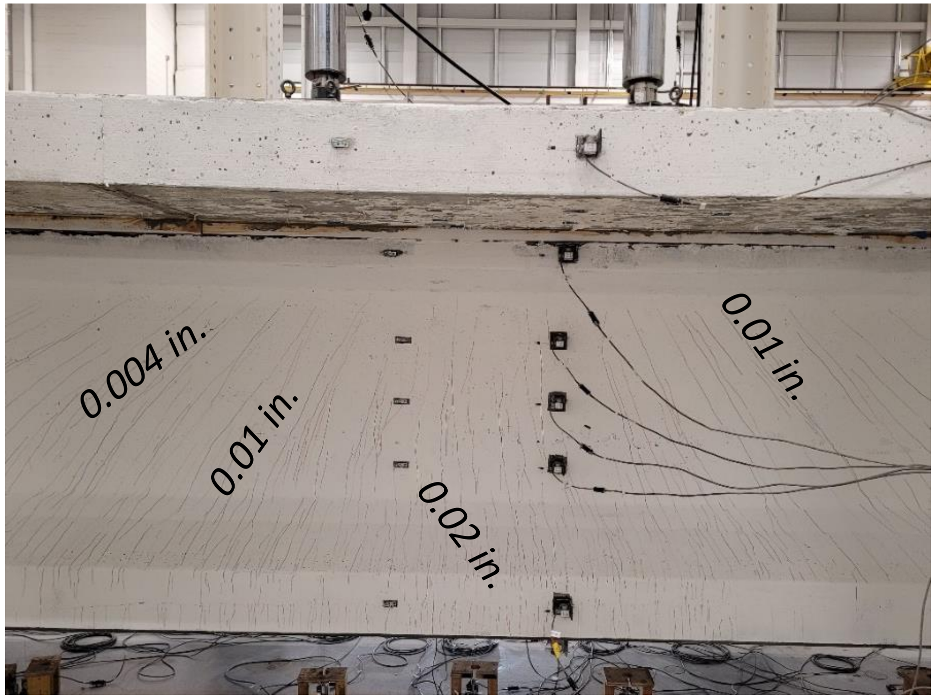
Tx54 Flexure Test

- *Flexure crack occurred at 560 kips (total actuator load)*
- *Shear crack developed at the ends at 698 kips*
- *Flexure and shear crack formation increased at 720 kips*





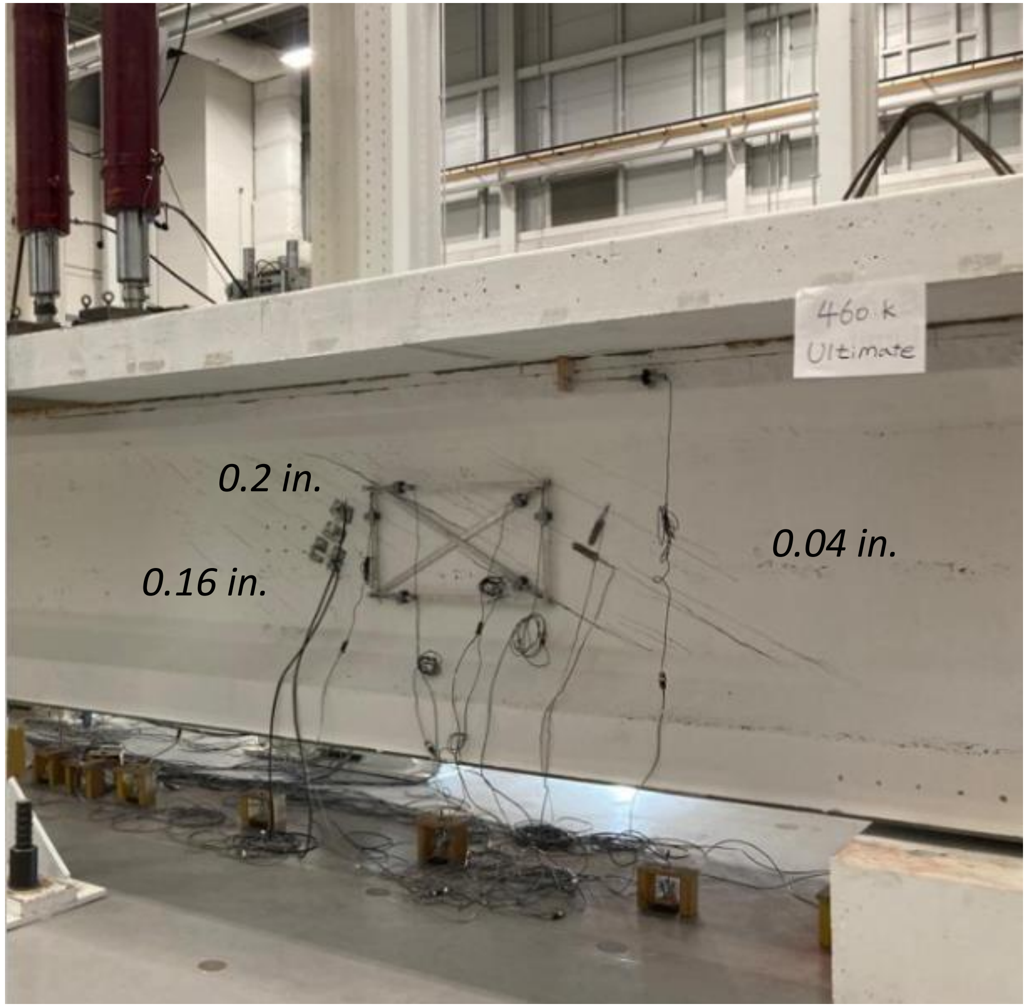
$$\frac{M_{n,exp}}{M_{n,pred}} = 0.98$$



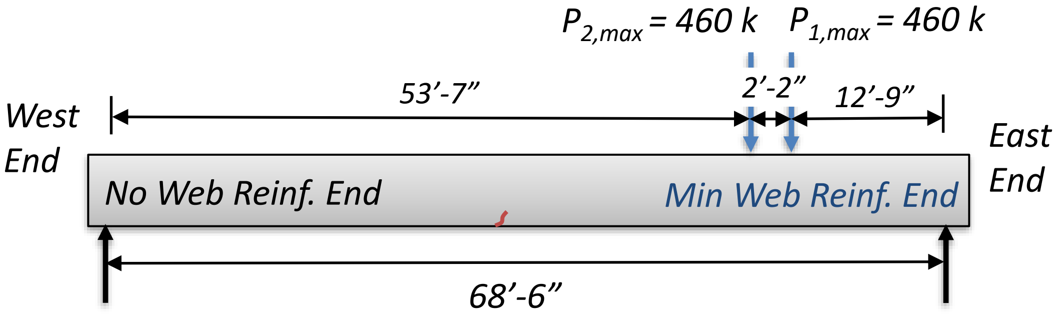
Flexure Cracks Tx54

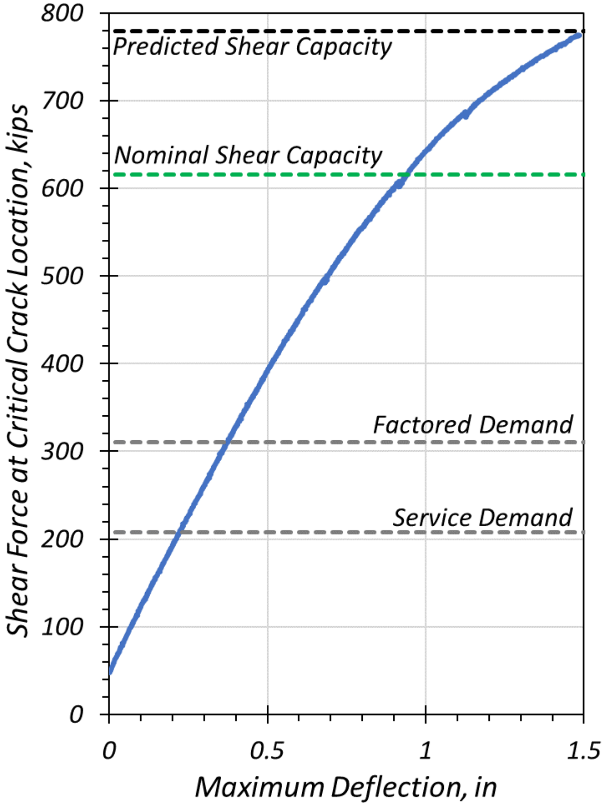
Tx54 Minimum Web Reinf. End - Shear Test

- *Shear Span-to-Depth Ratio = 2.37*
- *Uniaxial Tensile Strength = 0.95 ksi*



Tx54: Shear Crack at Minimum Web Reinforcement End



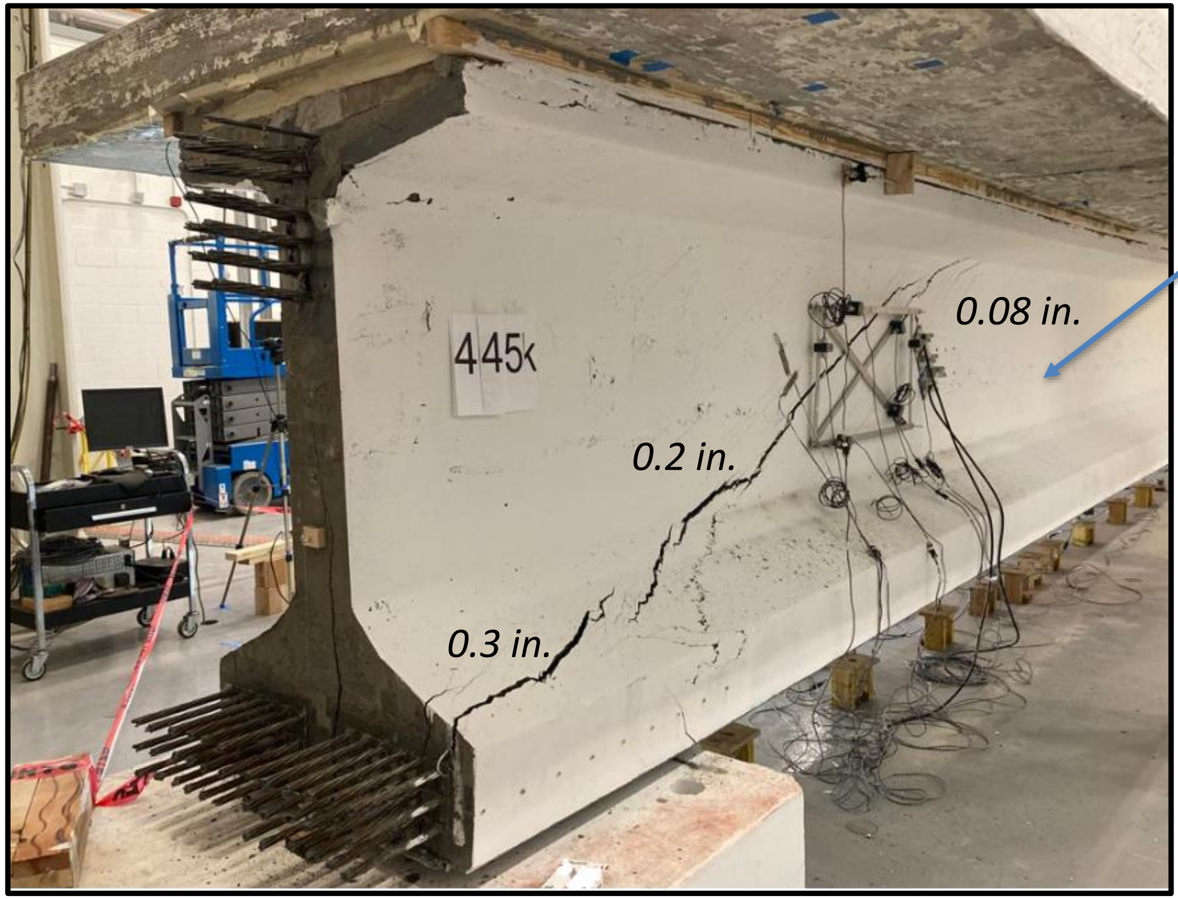


$$\frac{V_{n,exp}}{V_{n,pred}} = 1.00$$

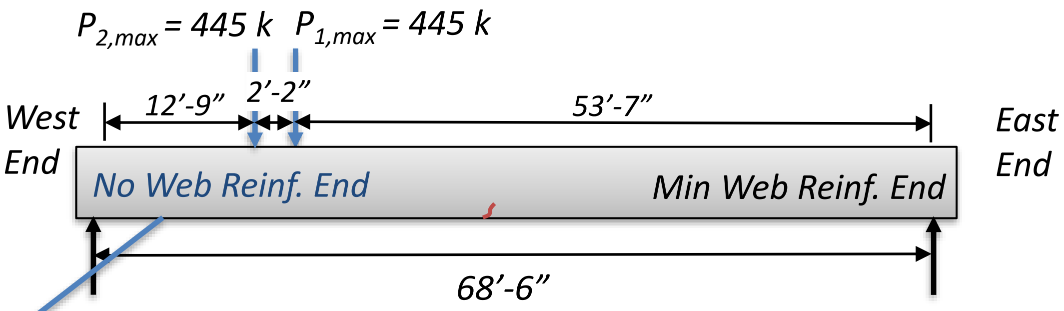
Shear Force vs Maximum Deflection

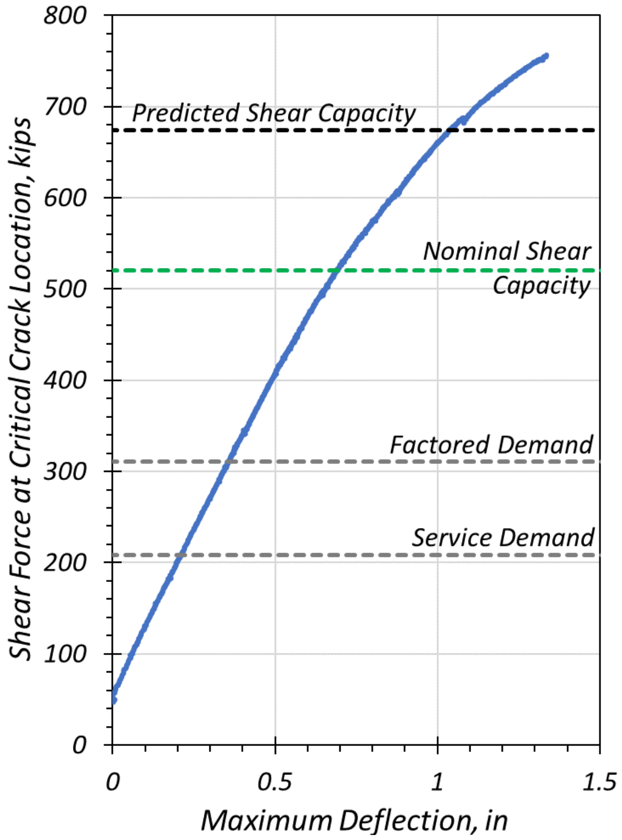
Tx54 No Web Reinf. End - Shear Test

- *Shear Span-to-Depth Ratio = 2.37*
- *Uniaxial Tensile Strength = 0.95 ksi*



Tx54: Shear Crack at No Web Reinforcement End

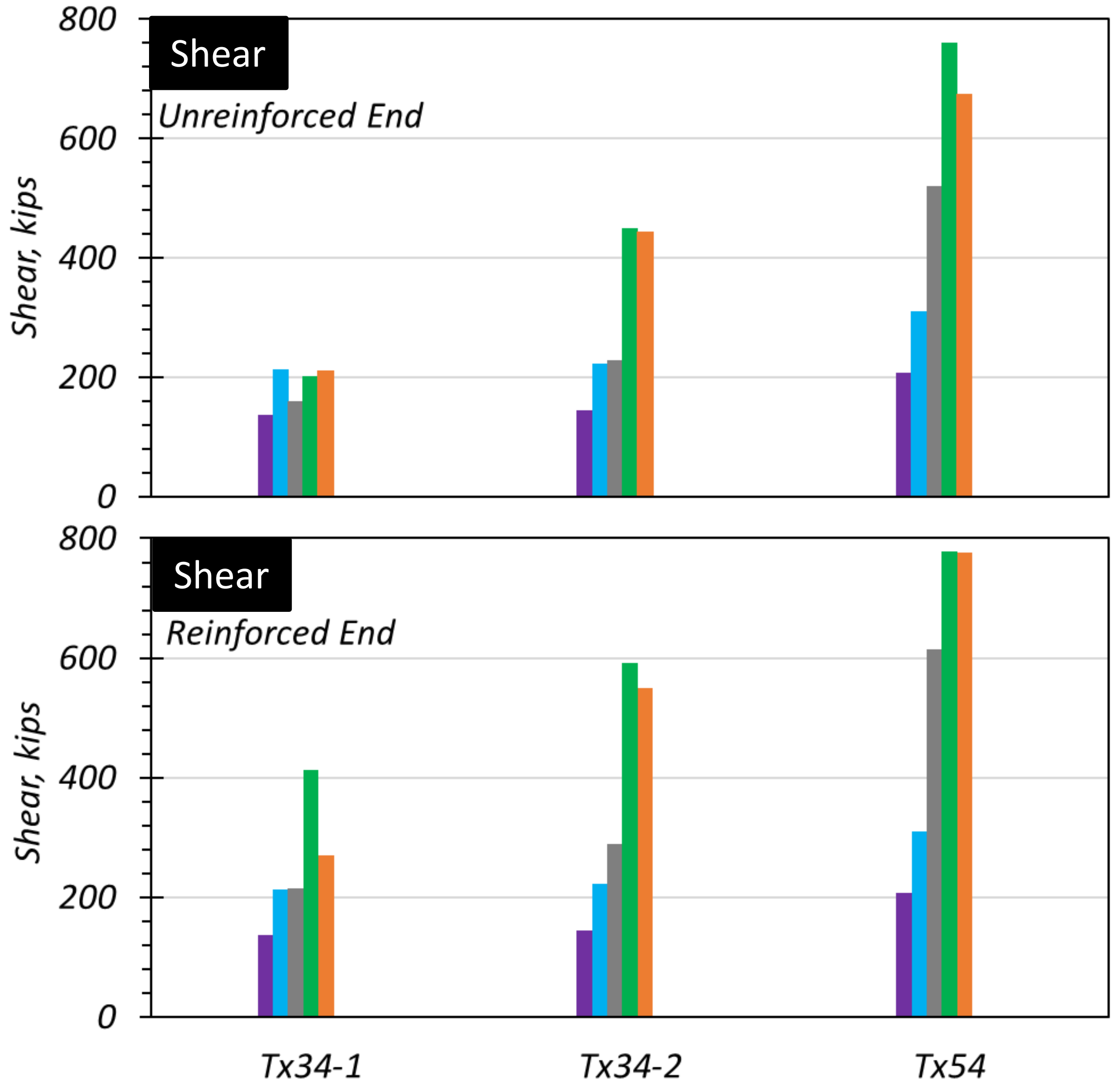


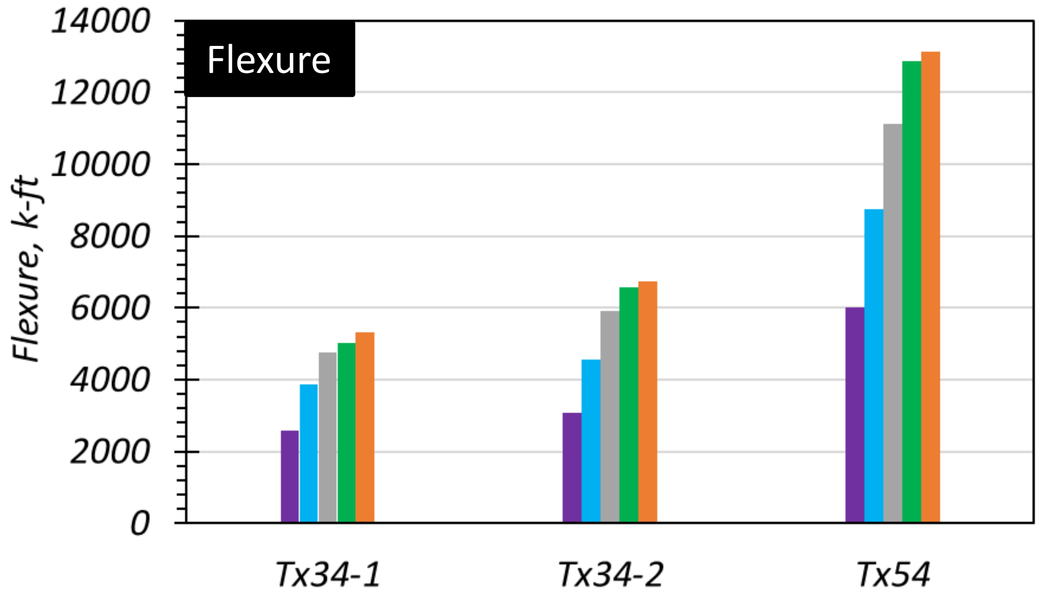


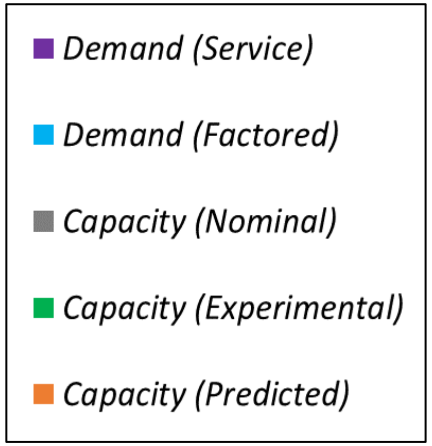
Shear Force vs Maximum Deflection

$$\frac{V_{n,exp}}{V_{n,pred}} = 1.13$$

Girder Specimens – Demand and Capacity







Flexure:

- Experimental capacity is well predicted (slightly overestimated)
- Sufficient capacity for design loads

Shear:

- Experimental capacity exceeds predicted capacity except for Tx34-1 unreinforced end
- Minimum shear reinforcement and harped strands enhance strength

Girder Testing: Summary and Conclusions

- *Design*
  - ✓ AASHTO Draft Recommendations for UHPC: nominal flexure and shear strengths are conservative relative to measured strengths
  - ✓ UHPC bridge girders provide increased design efficiency compared to CC girders with reduced cross-sections, longer spans, and larger girder spacings.
- *Flexure Performance*
  - ✓ No cracking observed up to factored load demand.
  - ✓ Applied moment demand on girder specimens ranged from 30–47 percent higher than factored design moment.
- *Shear Performance*
  - ✓ Minimum transverse reinforcement and harped tendons enhance shear performance.
  - ✓ All girder ends provided at least twice the shear capacity of the factored demand [except Tx34-1 end with no web reinforcement and low uniaxial tensile strength].
- *Composite Action*
  - ✓ Interface shear reinforcement controlled the interface slip up to factored design loads.
  - ✓ Limited slip was observed at higher loads.

Thank you!

Acknowledgments

Research Sponsor:
Texas Department of Transportation
(Project 0-6982)

Final Report

- *Vol. 1 – UHPC Mixture Development and Material-Level Experiments*
- *Vol. 2 – Structural Analysis, Design, and Full-scale Testing of Precast, Pretensioned Girders*
- *Vol. 3 – UHPC Production Guidelines and Design Recommendations with Design Examples*

Appendix

UHPC Project Team

Texas Department of Transportation

- Tom Schwerdt (TxDOT, Project Manager)
- Robert Owens (TxDOT, Project Director)
- TxDOT Project Monitoring Committee: Ahmed Al-Basha, Biniam Aregawi, Rachel Cano, Geetha Chandar, Chad Dabbs, Jamie Farris, Igor Kafando, Andy Naranjo, Joe Roche, Prapti Sharma, Jason Tucker

TAMU/TTI Research Team

- Mary Beth Hueste – RS
- Anol Mukhopadhyay, Stefan Hurlebaus, John Mander
- Amreen Fatima, Hyeonki Hong, Tevfik Terzioglu, Brittni Cooper, Jay Shah

Recommended Flow Spread Value for Qualification and Acceptance Testing

Flow Spread Range, in.	Color Code	Description	Comments
$\text{flow} < 9.5$	Red	Unacceptable	• Poor workability • Higher risk of elephant skin formation
$9.5 \leq \text{flow} < 10.0$	Orange	Acceptable	• Relatively low workability • Some risk of elephant skin formation
$10.0 \leq \text{flow} \leq 10.5$	Green	Desirable	• Good workability • None or negligible risk of elephant skin • Negligible fiber segregation*
$10.5 < \text{flow} \leq 11.0$	Yellow	Acceptable	• Some risk of fiber segregation • Better acceptability compared to mixture with flow < 10.0 in.
$\text{flow} > 11.0$	Red	Unacceptable	• High risk of fiber segregation

Recommended Values for Qualification and Acceptance Testing

Property	Recommended Value
Temperature at discharge	80 – 100 °F is recommended. A high discharge temperature near 100 °F demands placement within a relatively short period (less than 10 minutes).
Density	150 – 155 lb/ft^3 is recommended for 1.5 percent fiber volume.
Compressive strength	$f'_{c\ at\ release} \geq$ 65% of $f'_{c\ at\ service}$ [$f'_{c\ at\ release} \geq$ 12 ksi when $f'_{c\ at\ service}$ =18 ksi]
Direct uniaxial tension test	0.70 – 0.75 ksi at release, 0.85 – 1.0 ksi at service