Bond Behavior of Epoxy-Coated Reinforcing Bars in Non-Proprietary Ultra-High Performance Concrete

Sanjeeb Thapa
Dr. David Darwin
Dr. Matthew O'Reilly
Dr. Rémy D. Lequesne

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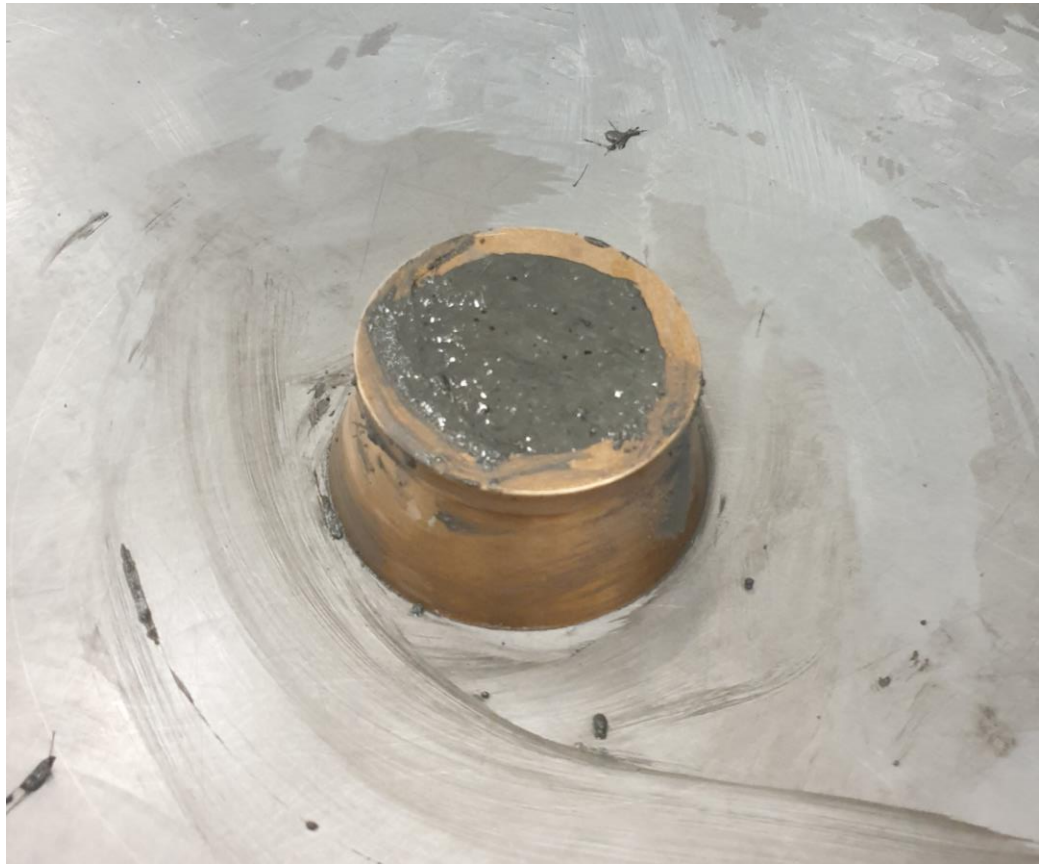
Outline

- What is Ultra-High Performance Concrete (UHPC)?
- Objectives and Scope
- Research
- Findings

UHPC

- Advanced construction material
- Very high early compressive strength (often > 20 ksi)
- High tensile strength (> 1 ksi)
- 1-3% by volume of steel fibers (most often 2%)
- Contains no coarse aggregate
- Low water-to-cementitious material ratio (*w/cm* < 0.22)
- Very workable – Spread = 8-10 in.

Spread Test



Mold

Spread

Advantages of UHPC

- High compressive strength and fiber performance allow for the development of reinforcing steel with very short embedment lengths
- Viable option for use in bridge-deck closure strips

Bridge-Deck closure strips (Source: Castine, 2017; New York State DOT)

Existing knowledge

- Most UHPC mixtures are proprietary = $$
- Existing design approaches for bond strength in UHPC based on pullout tests – this test method is not recommended for determining bond strength

Objectives

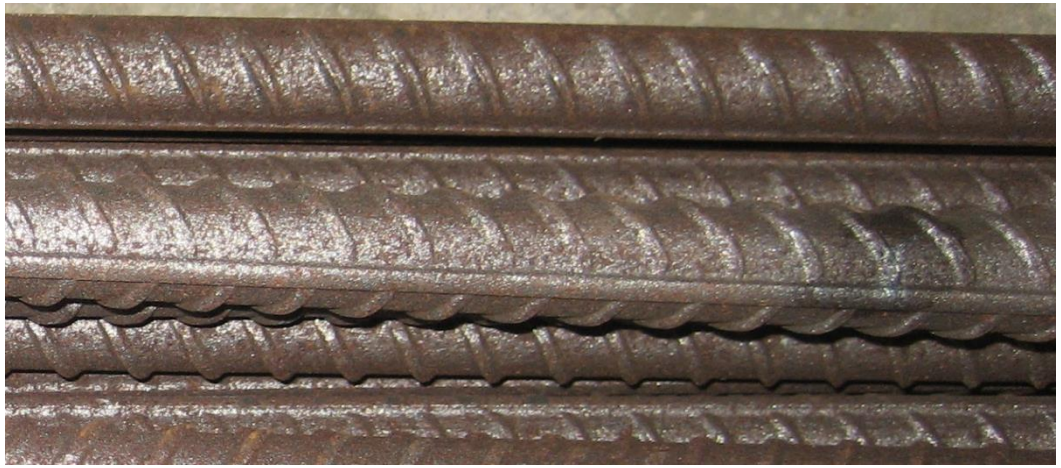
- Develop non-proprietary UHPC
- Perform realistic bond tests for use in design to determine effect of bar size, cover, splice length, spacing, and surface properties of reinforcing steel
- Develop design recommendations for splice length in non-proprietary UHPC

Scope

- 144 UHPC batches
- 92 modified pullout tests
- 24 modified beam-end specimens
- 28 beam-splice specimens
- No. 4, No. 5, No. 8 bars
- Uncoated, Epoxy-coated and Textured epoxy-coated bars

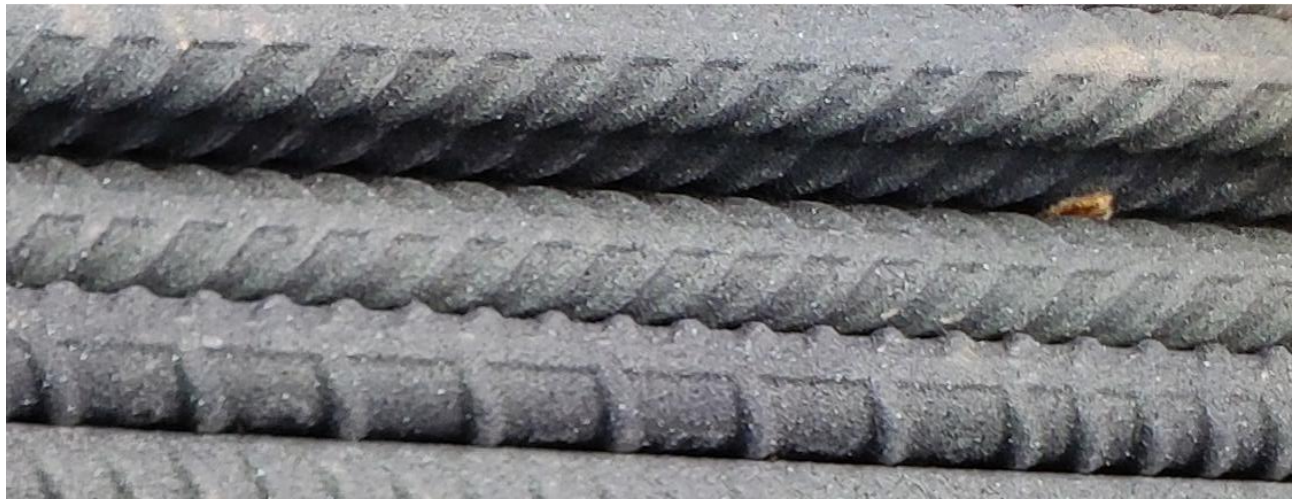
Research

Uncoated bars



Epoxy-coated bars

Textured epoxy-coated bars



Non-proprietary UHPC

Material/Properties	Mix A	Mix B
w/cm ratio	0.183	0.183
Spread (in.)	10.13	9.75
Fiber Distribution	Not well-distributed	Well-distributed

w/cm ratio: water to cementitious materials ratio

- Each mix had two superplasticizers from the same company
- Mix B had a set accelerator

Strength

- Compressive

Age (days)	Strength (ksi)	
	Mix A	Mix B
1	9.56	8.57
3	12.13	11.89
7	14.95	14.40

- Flexural

Age (days)	Peak Strength (ksi)	
	Mix A	Mix B
3	1.90	2.89
7	2.78	3.60

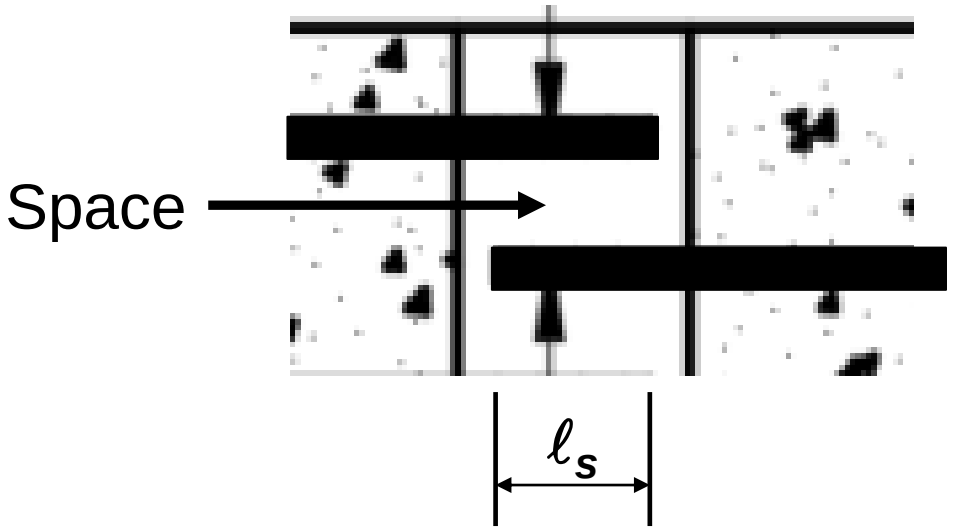
Bond tests

Non-contact splices

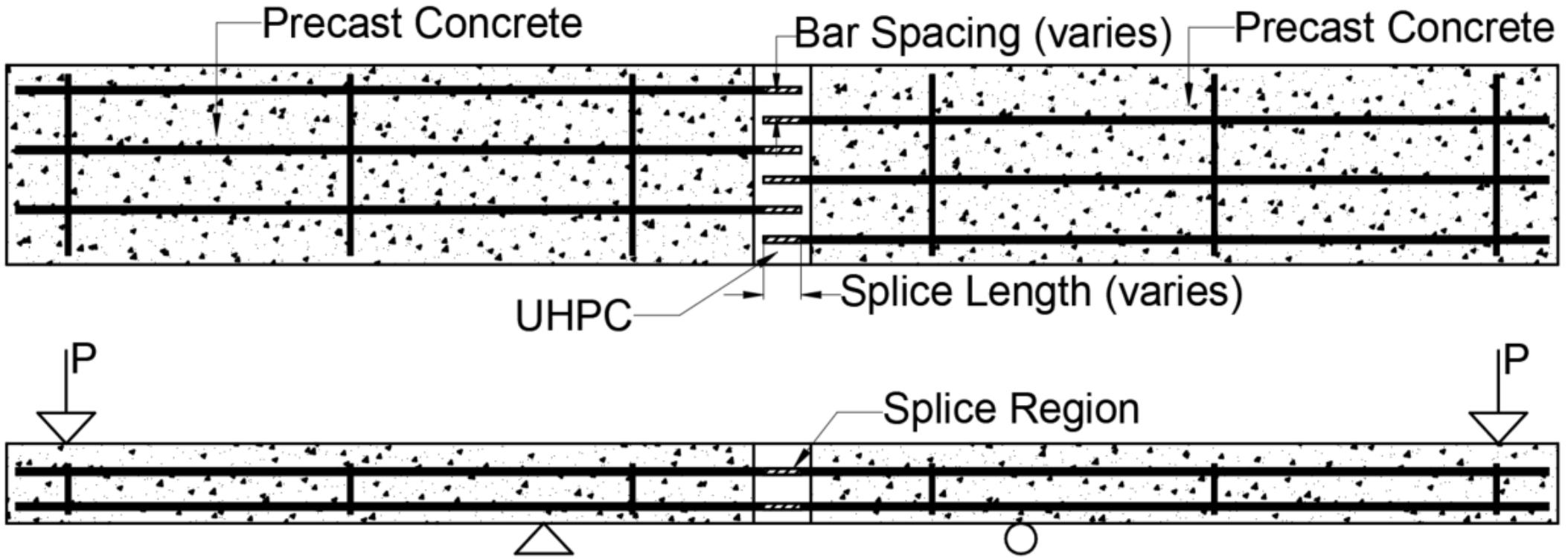
- Bars spliced by noncontact lap splices

  Space $\leq \ell_s/5$

  Space $\leq$ 6.0 in.



Splice tests



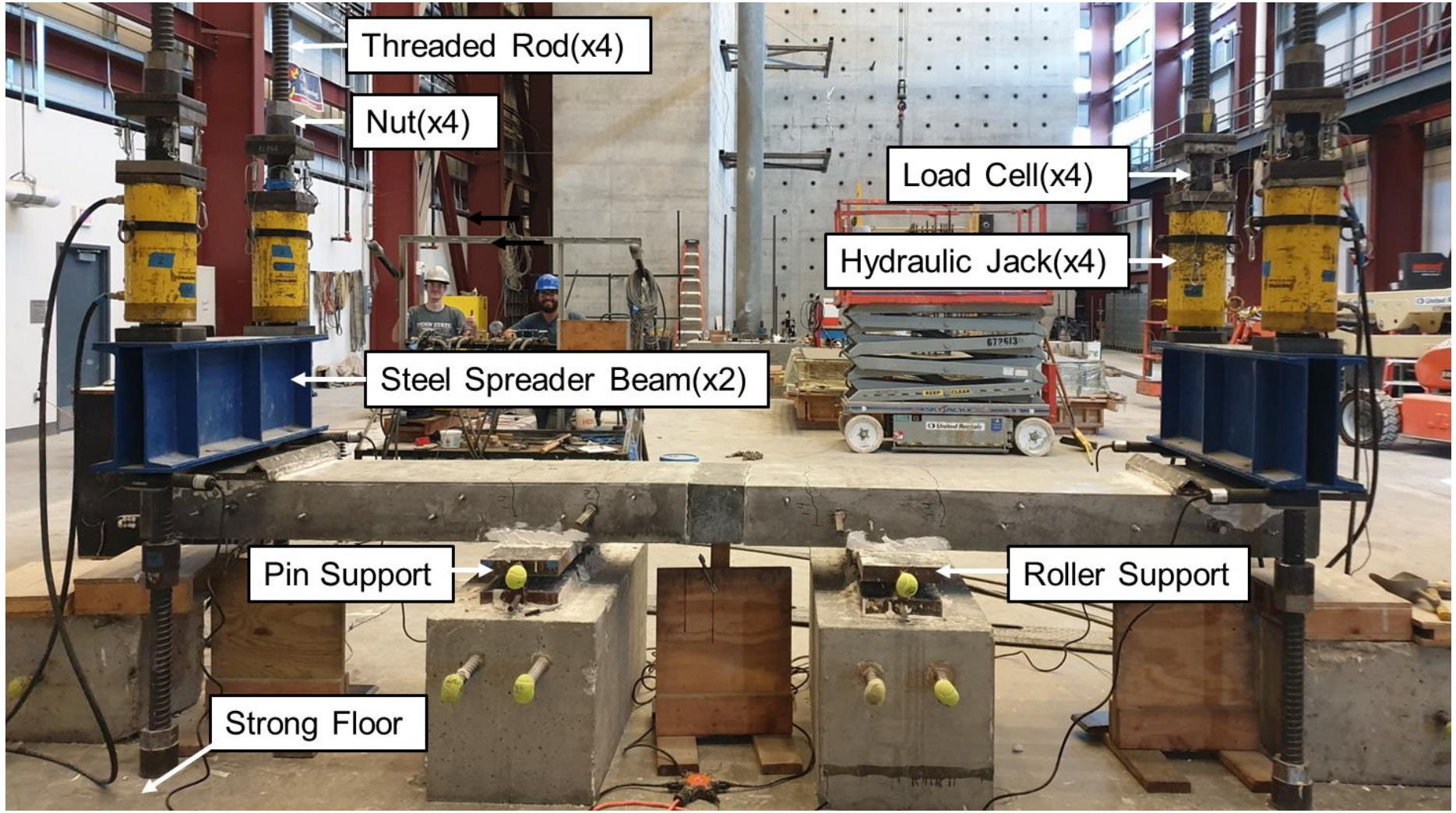
Beam-splice specimen with UHPC closure strip

Splice tests – Key Variables

Parameters	Range
Bar Size	No. 4, 5, 8
Bar Type	U, E, T
Splice length, ℓ_s (in.)	$6d_b$ to $10d_b$
Bar spacing (in.)	1.5 to 3
Concrete cover (in.)	1, 2.5

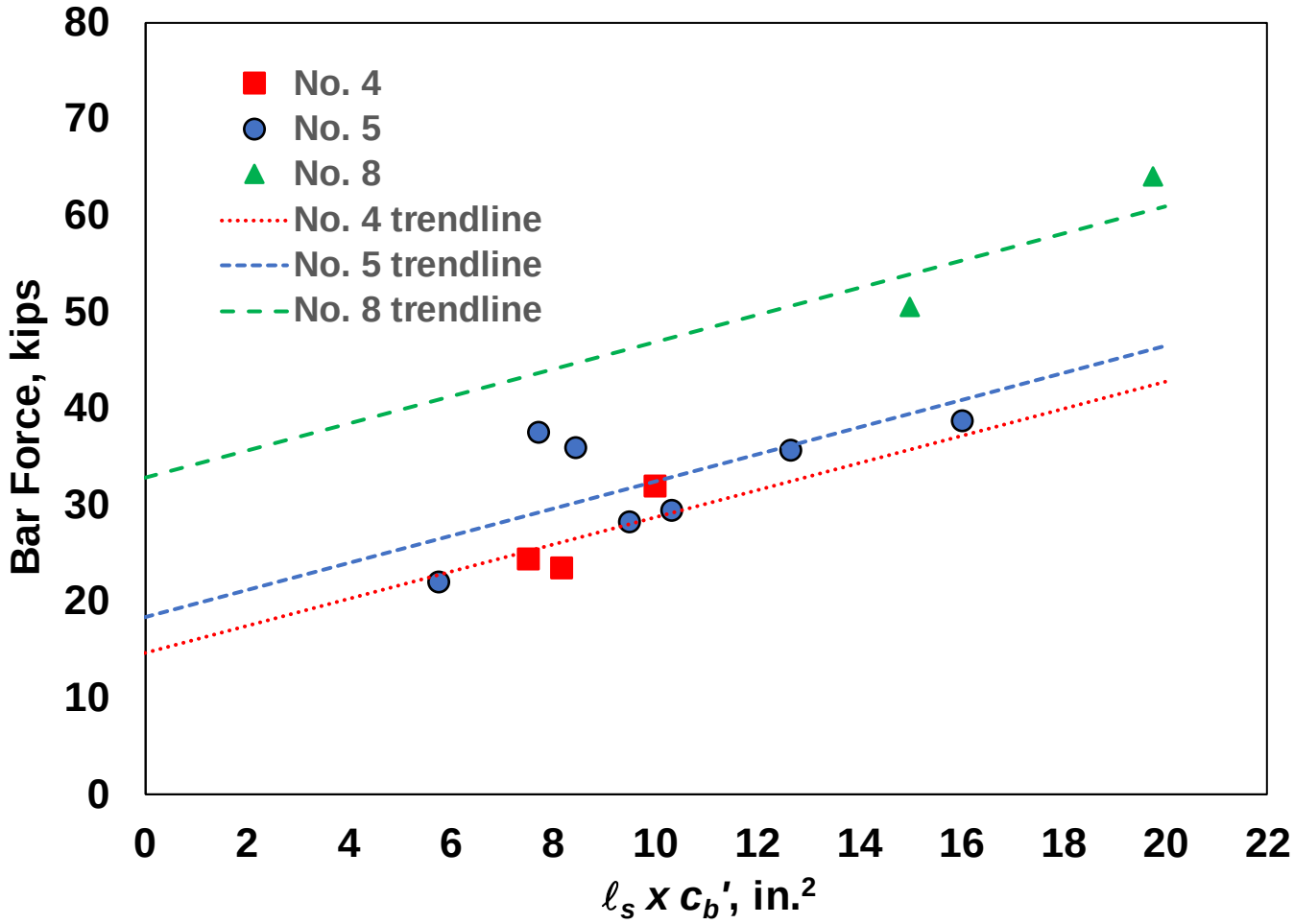
U = Uncoated, E = Epoxy-coated, T = Textured epoxy-coated

Splice tests – No. 4, No. 5, and No. 8 bars



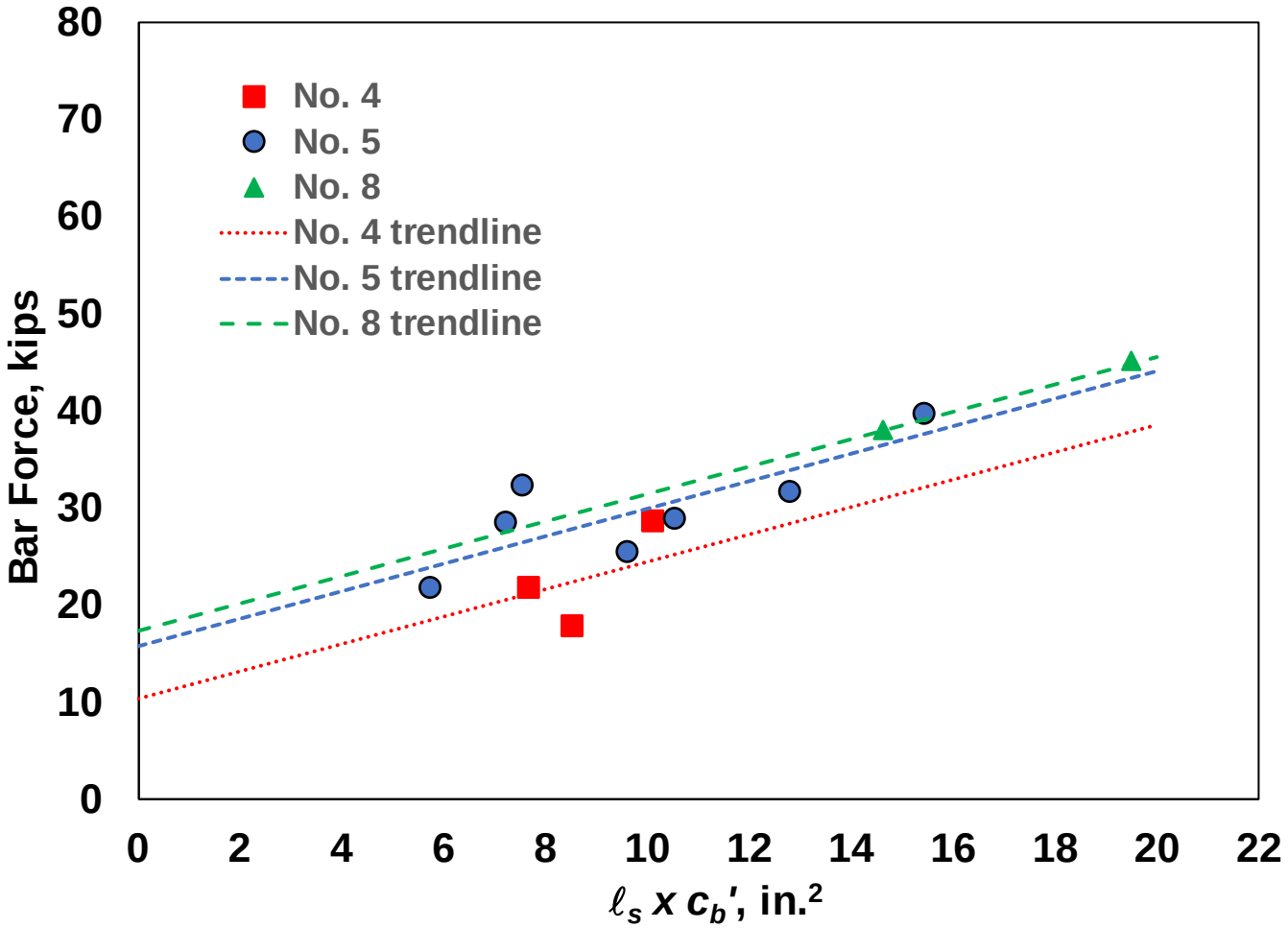
Splice test results - Uncoated bars

c_b' = cover to center of bar being developed to nearest concrete surface



Splice test results - Epoxy-coated bars

c_b' = cover to center of bar being developed to nearest concrete surface



Comparisons to spliced bars in conventional concrete – Use ACI Committee 408 database

- Uncoated: $f_{s\ test}/f_{s\ ACI\ 408} = 2.23$
- Epoxy-coated: $f_{s\ test}/f_{s\ ACI\ 408} = 1.94$
- Textured epoxy-coated: $f_{s\ test}/f_{s\ ACI\ 408} = 2.37$
- $f_{s\ Epoxy\text{-}coated}/f_{s\ Uncoated} = 0.87$ vs. < 0.7 in conventional concrete

Proposed Design Equation: ℓ_s

Design equation: $$\ell_s = \frac{A_b f_y - 24\lambda_{cfu} d_b}{1.1 c_b'} \geq 6 d_b$$

λ_{cfu} = coated bar factor for spliced bars in UHPC

= 1.0 for uncoated and textured-epoxy-coated bars

= 0.7 for epoxy-coated bars

c_b' = cover to center of bar being developed to nearest concrete surface

Evaluating proposed design provisions: ℓ_s

	$f_{s\ test} / f_{s\ design}$		
	U	E	T
MAX	1.60	1.71	1.62
MIN	1.03	1.00	0.96
MEAN	1.26	1.32	1.32
STDEV	0.172	0.193	0.289
COV	0.136	0.146	0.218

Summary of findings

- UHPC can be made from local materials
- Admixtures play a big role in UHPC
- Bond strength in UHPC is two times that of conventional concrete without confining reinforcement at same compressive strength

Summary of findings

- Negative effects of epoxy coating are less in UHPC than in conventional concrete
- Textured epoxy-coated bars have the same bond strength as uncoated bars

Questions?