Design Optimization and Structural Application of High Strength Fiber Reinforced Concrete

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Project Overview

Mix Development

- Prior Research Influences
- Mix Proportions
- Aggregate Gradations

Structural Application

- Composite Beam Designs
- Construction
- Beam Tests

UHPC Mix Design Characteristics

- Proprietary UHPC (e.g., Ductal®)
  - Compressive strength
  - Fine aggregates

- **Goal**: Manipulate aggregate gradations to reach UHPC-quality compressive strength with locally available aggregates.

Table 1. Typical composition of Ductal®

Material	lb/yd^3	kg/m^3	Percentage by Weight
Portland Cement	1,200	712	28.5
Fine Sand	1,720	1,020	40.8
Silica Fume	390	231	9.3
Ground Quartz	355	211	8.4
HRWR	51.8	30.7	1.2
Accelerator	50.5	30.0	1.2
Steel Fibers	263	156	6.2
Water	184	109	4.4

(Russel and Graybeal 2013)

Prior Research Influences

- Prior research by Swenty et al. (2019)
  - HSFRC mix designs with f_c = 15,000 psi
  - HSFRC laminate placed on bottom of normal concrete beams
- Aggregate gradations based on prior research
  - Control mix (Swenty et al. 2019)
  - "Tarantula" mix (Ley et al. 2014)
  - "Fuller" mix (Fuller and Thompson 1907)
  - Quartz sand mix

(Swenty et al. 2019)

Common Mix Proportions

Constituent	Weight (lbs/yd^3)	Percentage by Weight
Water*	350	8.56
Fine Aggregate	1687	41.24
Portland Cement	1750	42.78
Steel Fibers (2% by Volume)	264	6.45
Superplasticizer*	40	0.98

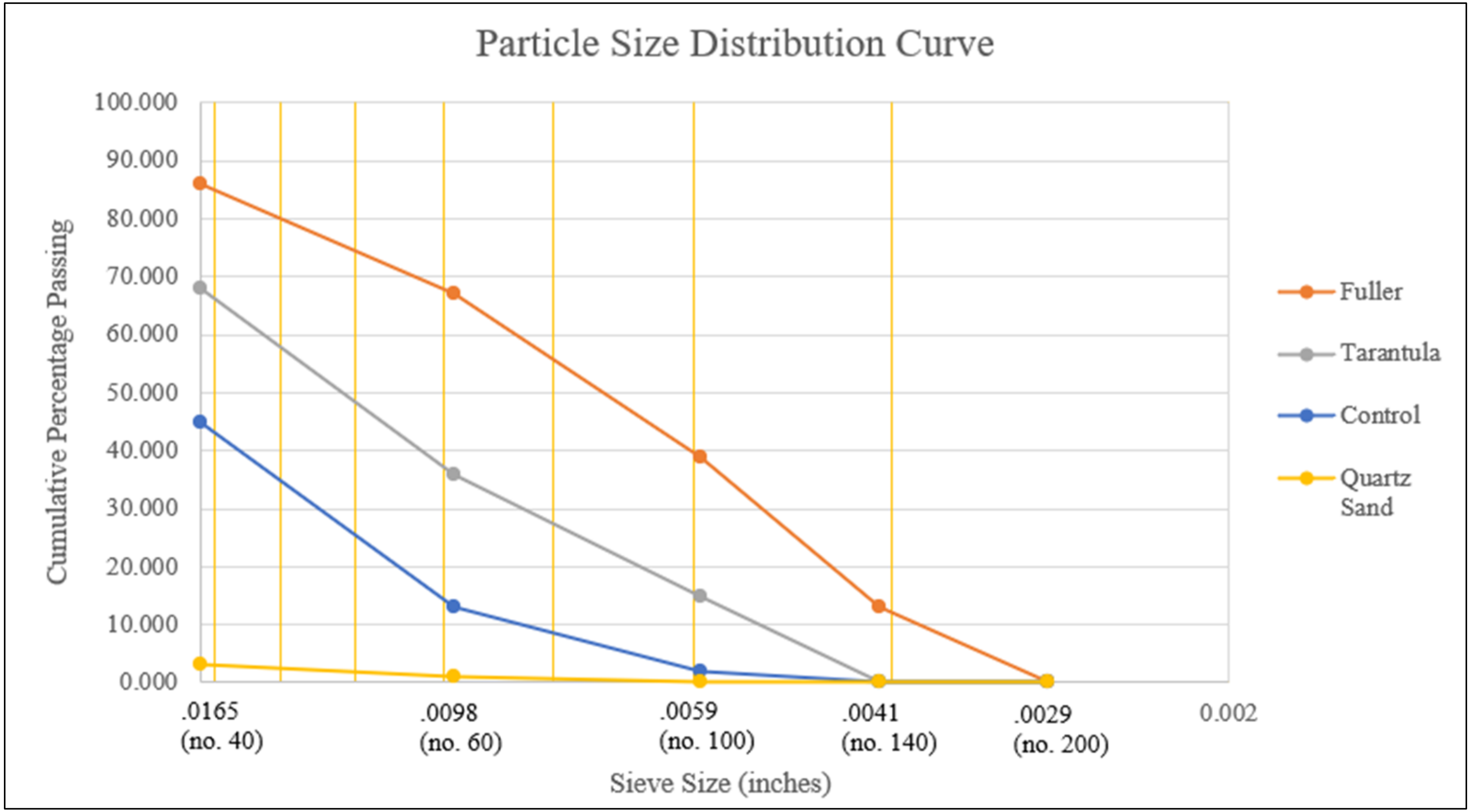
*Quartz Mixes used 2/3 of superplasticizer due to excess workability
*Fuller Mixes used double superplasticizer and 12.5% more water

Aggregate Gradations

Sieve	Control* (%)	Fuller (%)	Tarantula (%)	Quartz (%)
No. 40	55	14	32	97
No. 60	32	19	32	2
No. 100	11	28	21	1
No. 140	2	26	15	0
No. 200	0	13	0	0
Sum	100	100	100	100

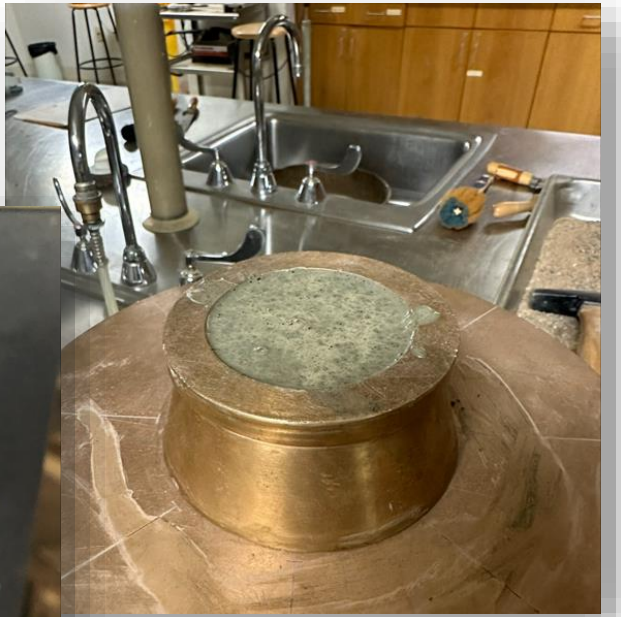
*Control mix was based on Swenty et al. (2019)

Particle Size Distribution Curves

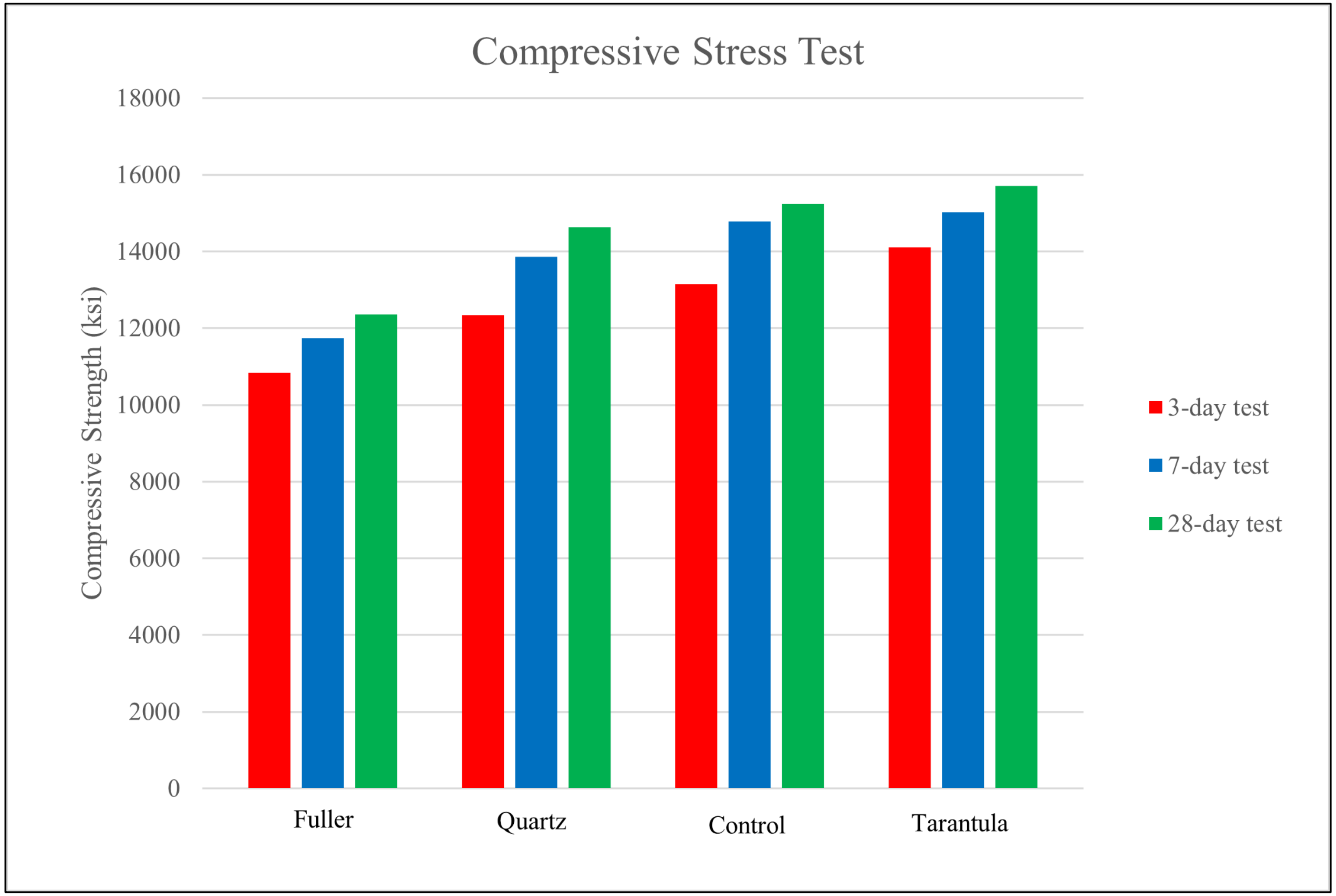


Mixing and Testing HSFRC

- Mixed using typical UHPC methods
- Static Flow Test (ASTM C1437)
- Compressive Stress Test (ASTM C109)



Compressive Stress



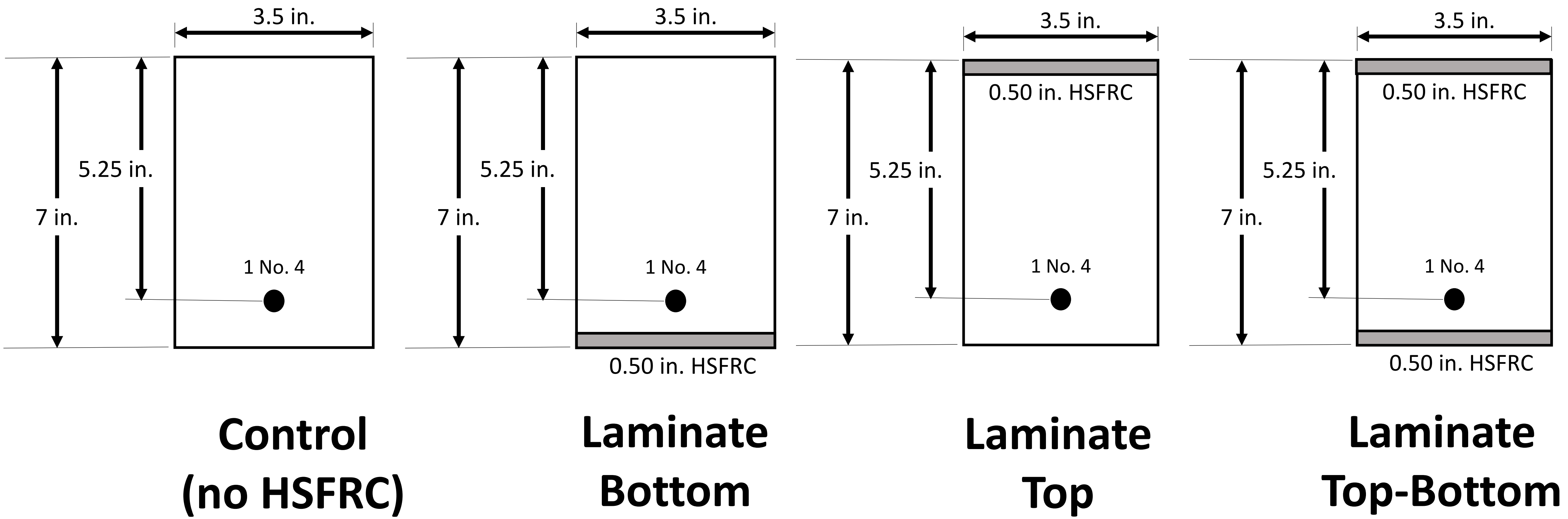
95% Confidence Interval for 28-day Strength Calculations

Control		Fuller		Tarantula		Quartz Sand	
Sample Mean (psi)	15235.3	**Sample Mean (psi)**	12364.6	**Sample Mean (psi)**	15715.8	**Sample Mean (psi)**	14637.5
Sample Standard Deviation (psi)	781.5	**Sample Standard Deviation (psi)**	593.2	**Sample Standard Deviation (psi)**	928.0	**Sample Standard Deviation (psi)**	1002.4
Upper Limit (psi)	16055.5	**Upper Limit (psi)**	12987.2	**Upper Limit (psi)**	16690.0	**Upper Limit (psi)**	17214.5
Lower Limit (psi)	14415.0	**Lower Limit (psi)**	11741.9	**Lower Limit (psi)**	14741.7	**Lower Limit (psi)**	12060.5

Results of Mix Development

- Maximum strength with Tarantula gradation → f_c = 15,700 psi
- Aggregate gradations affect the compressive strength
- Gradations may be an essential component to reaching UHPC strengths.

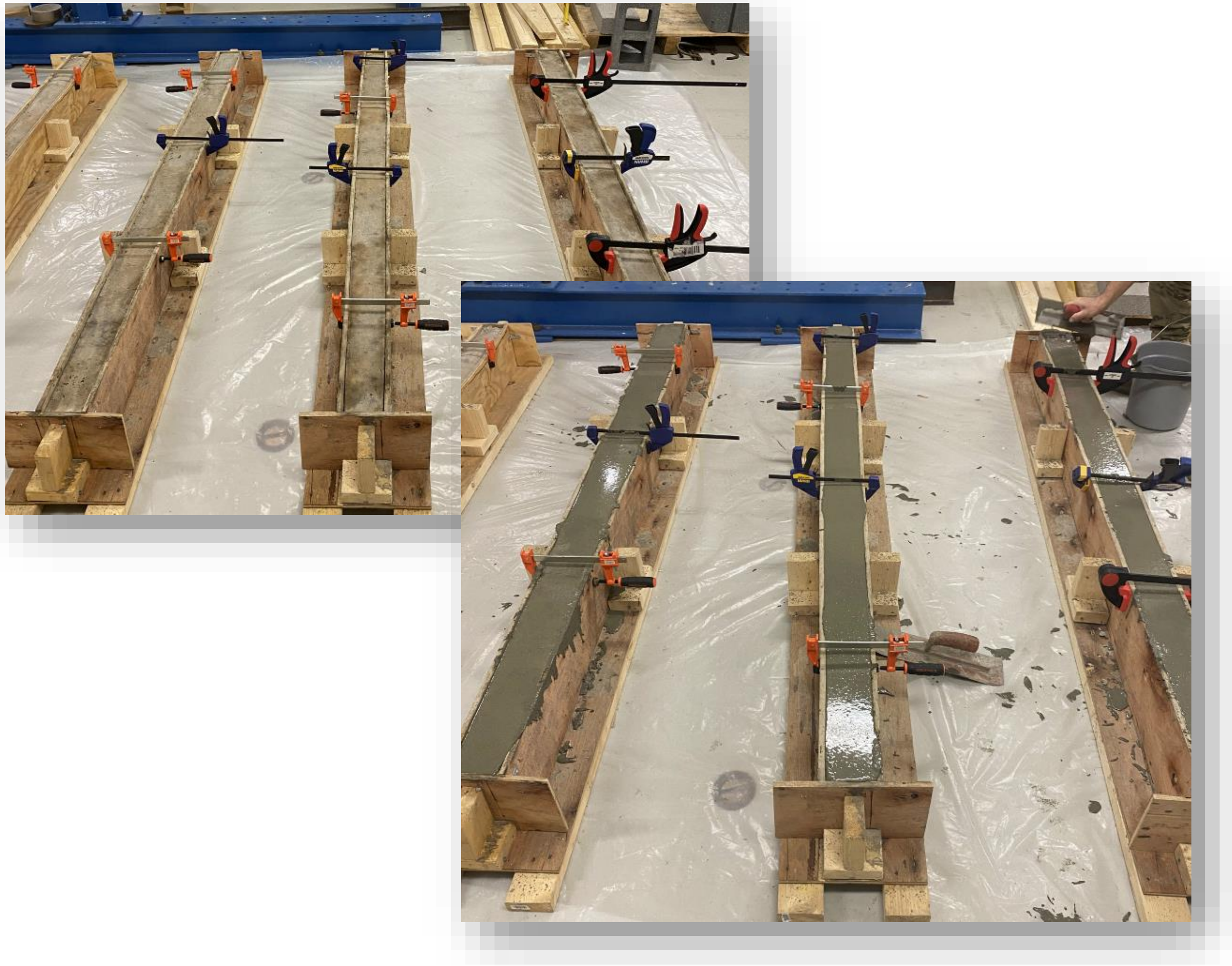
Composite Beam Designs



Beam Construction

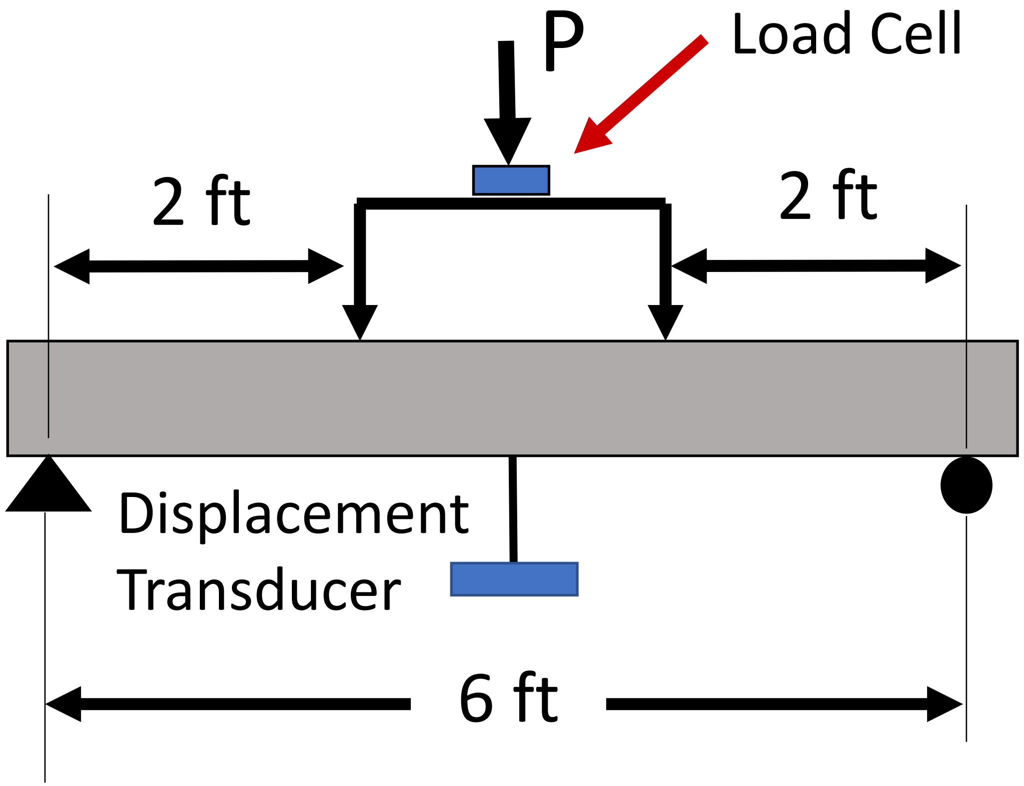
Beam Construction

Surface Treatment and HSFRC



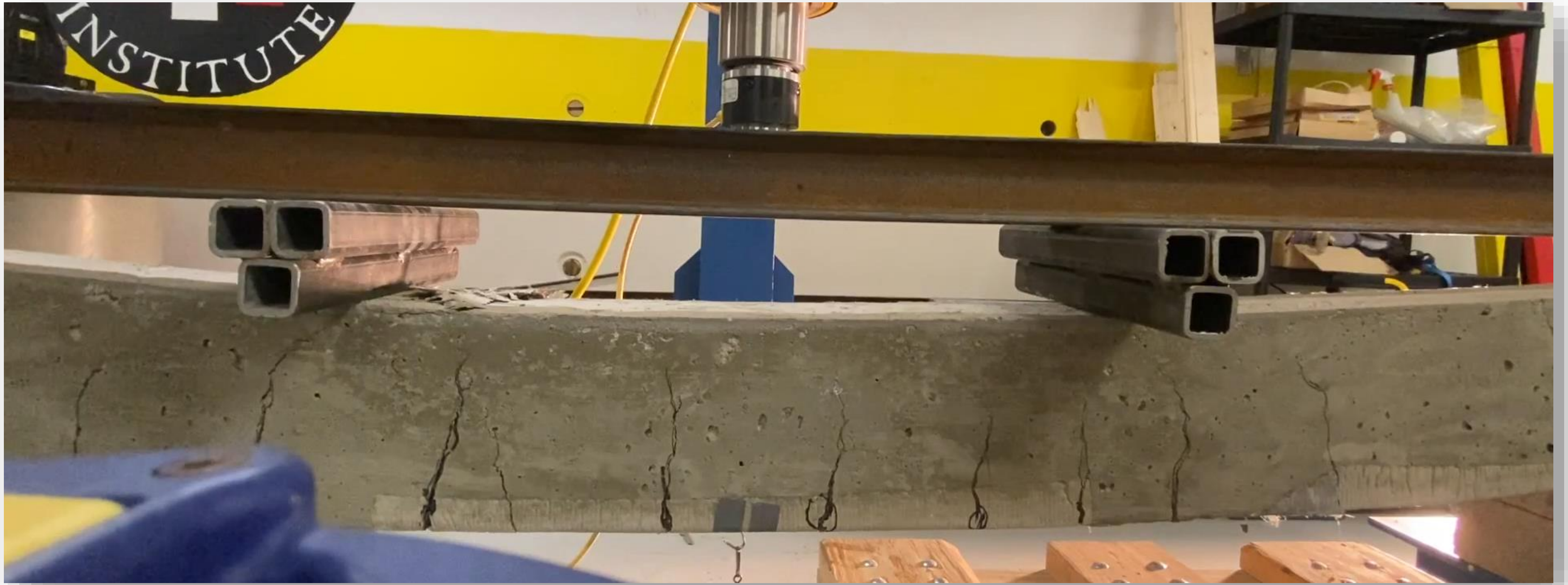
Acid Wash and Steel Brush
Surface Treatment

Beam Tests



Test Observations

Control Beam

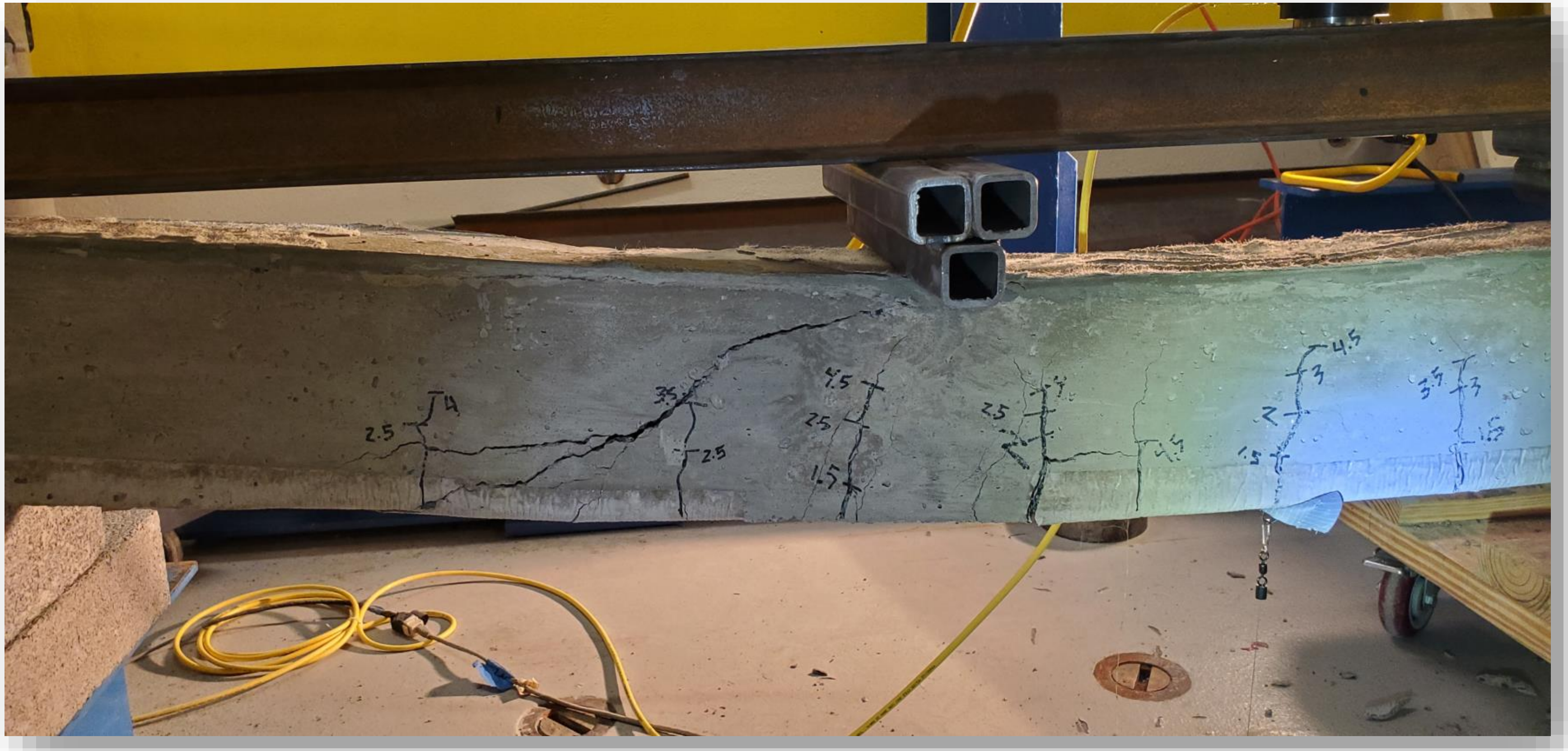


Test Observations

Laminate Bottom

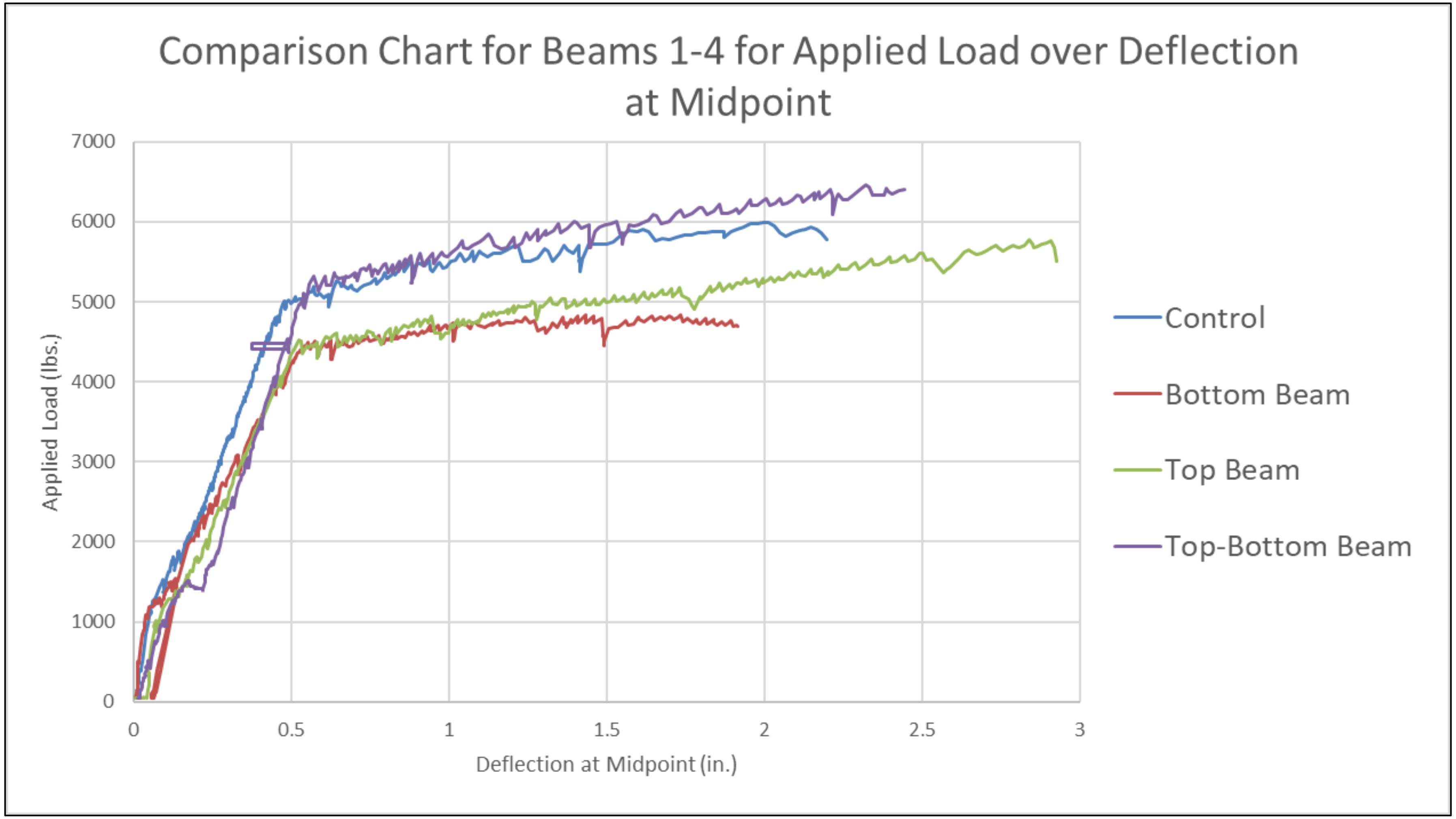
Test Observations

Laminate Top



Test Observations
Laminate Top-Bottom

Load vs. Deflection of Beams



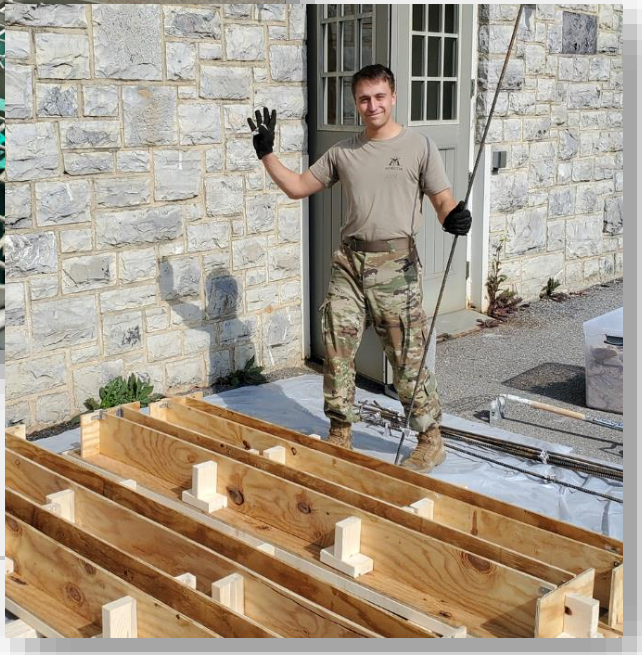
Results of Structural Tests

- Top-bottom beam reached the highest overall capacity
- Top beam demonstrated the highest ductility
- All laminate beams fail in shear rather than flexure

Future Recommendations

- Petrographic analysis of concrete
- Additional material property tests
- Consider Fuller model alterations
- Consider aggregate combinations

- Add shear reinforcement to beams
- Vary laminate thickness
- Use UHPC as laminate



Acknowledgements

- Faculty Advisors: Dr. D'Alessandro, Dr. Ramniceanu, Dr. Swenty, Dr. Timmes
- VMI Institute Honors Program
- VMI SURI – Summer Undergraduate Research Institute
- VMI Undergraduate Research (VMI VCUR)
- Our Fellow VMI Cadets

Questions?

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Resources

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