Benefits of Adopting High-Strength High-Resilience Concrete in Prestressed Crossties

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RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

2016 International
Crosstie & Fastening System Symposium

14-16 June 2016

Outline

- Historical Background
- Hypothesis
- Material Development and Characterization
- Prototype Tie Design and Fabrication
- Product Qualification
- Conclusions

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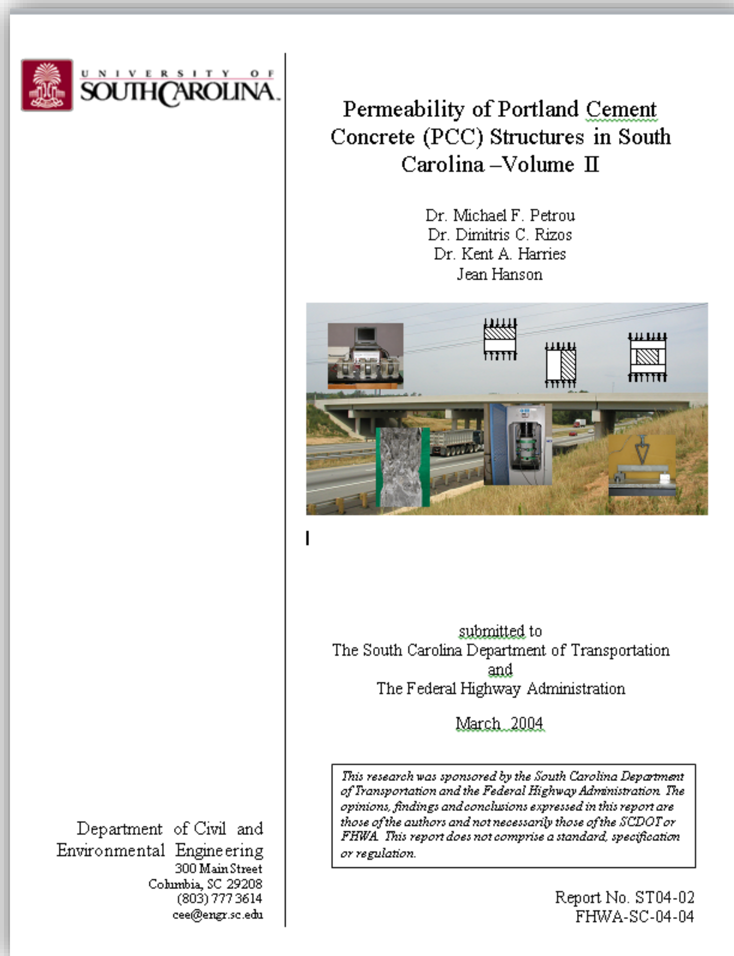

UNIVERSITY OF SOUTH CAROLINA

Permeability of Portland Cement Concrete (PCC) Structures in South Carolina –Volume II

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submitted to
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and
The Federal Highway Administration

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SCDOT Research Project

- HPC for Highway Bridges
- Local Aggregates
- SCDOT Mixture Designs

Table 2.1 Grades of Performance Characteristics for High Performance Structural Concrete (Goodspeed et al., 1996)

Performance Characteristic	Standard Test Method	FHWA HPC Performance Grade			
		1	2	3	4
Strength (x=compressive strength)	AASHTO T22 ASTM C39	41≤x<55 MPa (6≤x<8 ksi)	55≤x<69 MPa (8≤x<10 ksi)	69≤x<97 MPa (10≤x<14 ksi)	x≥97 MPa (x≥14 ksi)
Elasticity (x=modulus of elasticity)	ASTM C469	28≤x<40 GPa (4≤x<6·10^6 psi)	40≤x<50 GPa (6≤x<7.5·10^6 psi)	x≥50 GPa (x≥7.5·10^6 psi)	
Shrinkage (x=microstrain)	ASTM C157	800>x≥600	600>x≥400	400>x	
Creep (x=microstrain/pressure unit)	ASTM C512	75≥x≥60/MPa (0.52≥x≥0.41/psi)	60≥x>45/MPa (0.41≥x>0.31/psi)	45≥x>30/MPa (0.31≥x>0.21/psi)	30/MPa≤x (0.21/psi≤x)
Freeze-thaw durability (x=relative dynamic modulus of elasticity at 300 cycles)	AASHTO T161 ASTM C666 (Procedure A)	60%≤x<80%	80%≤x		
Scaling (x= visual rating of the surface after 50 cycles)	ASTM C672	x=4,5	x=2,3	x=0,1	
Abrasion (x= average depth of wear)	ASTM C944	2.0>x>1.0 mm (0.08>x>0.04 in.)	1.0>x≥0.5 mm (0.04>x>0.02 in.)	x<0.5 mm (x<0.02 in.)	
Chloride Penetration (x=Coulombs)	AASHTO T277 ASTM C1202	3000≥x>2000	2000≥x>800	800≥x	

- Aggregates from specific quarries
- HPC Classified as Grade 1 or 2 based on most properties
- Did not meet Grade based on Elastic Modulus
- HPC Rejected

Performance Characteristic	Standard Test Method	Batch No.	Experimental Results	FH Perfor Grade
Strength (MPa (psi))	ASTM C39	1	47.5 (6890)	1
		2	51.9 (7525)	1
		3	55.2 (8003)	2
		4	57.6 (8360)	2
Elasticity (GPa (ksi))	ASTM C469	1	21.3 (3089)	< 1
		2	19.4 (2811)	< 1
		3	24.1 (3492)	< 1
		4	24.1 (3501)	< 1
Shrinkage (microstrain)	ASTM C157	Shrinkage tests were not performed		
Creep (microstrain/pressure unit)	ASTM C512	Creep tests were not performed.		
Freeze-thaw durability (relative dynamic modulus of elasticity at 300 cycles, %)	ASTM C666 (Procedure A)	1	---	---
		2	---	---
		3	---	---
		4	>90	2
Scaling (visual rating of the surface after 50 cycles)	ASTM C672	1	4	1
		2	3	2
		3	---	---
		4	---	---
Abrasion (average depth of wear, mm (in.))	ASTM C944	1	1.410 (0.0555)	1
		2	1.711 (0.0674)	1
		3	---	---
		4	---	---
loride Penetration Coulombs)	ASTM C1202	1	2144	1
		2	2632	1
		3	2683	1
		4	1065	2

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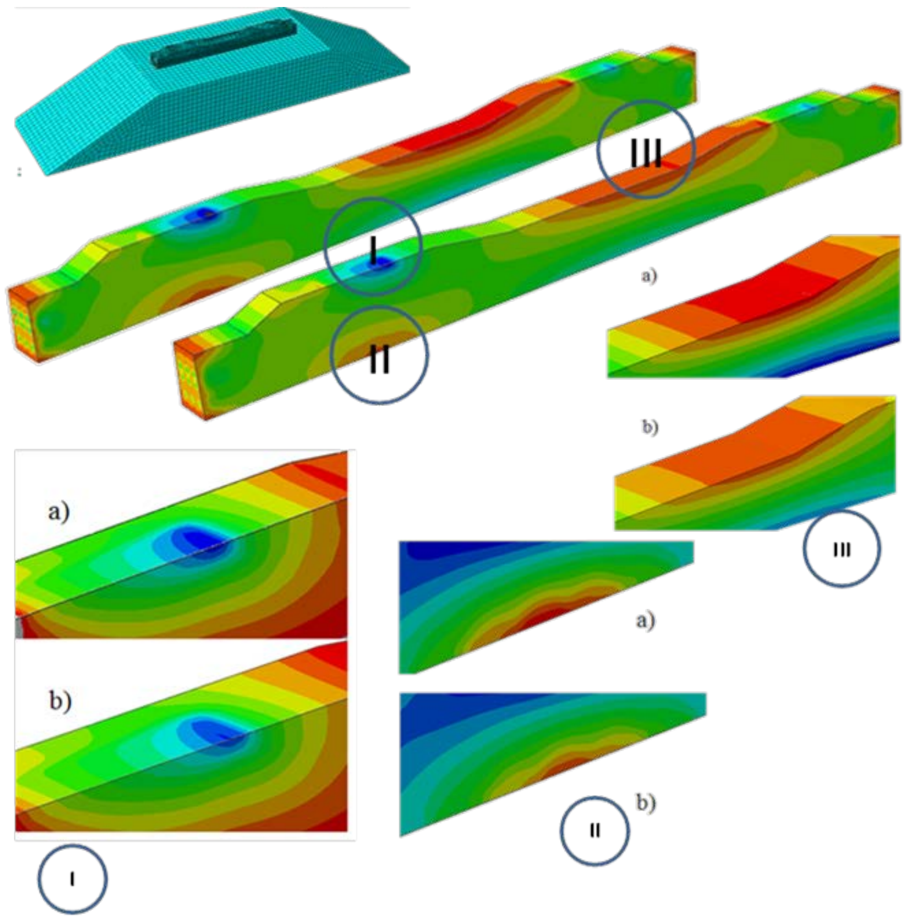
Hypothesis

Benefits of Using Higher Resilience Concrete in Prestressed Ties:

- Better load distribution
- Smoother stress gradient
- Lower stress amplitudes
- Delay of onset of damage
- Relative rigidity

Critical Location	Stress Reduction due to HSRM-HPC (%)
I	15%
II	50%
III	48%



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Concrete Mix Designs

- Rocla Design
  - Min. 28 Day = 7000psi
  - Min. Transfer Strength = 4000psi
- Direct substitution of aggregates
- 4 Aggregate Sources
  - CA1: Plum Run Stone (ROCLA)
  - CA2: Weathered Granite Source A
  - CA3: Weathered Granite Source B
  - CA4: Weathered Granite Source C

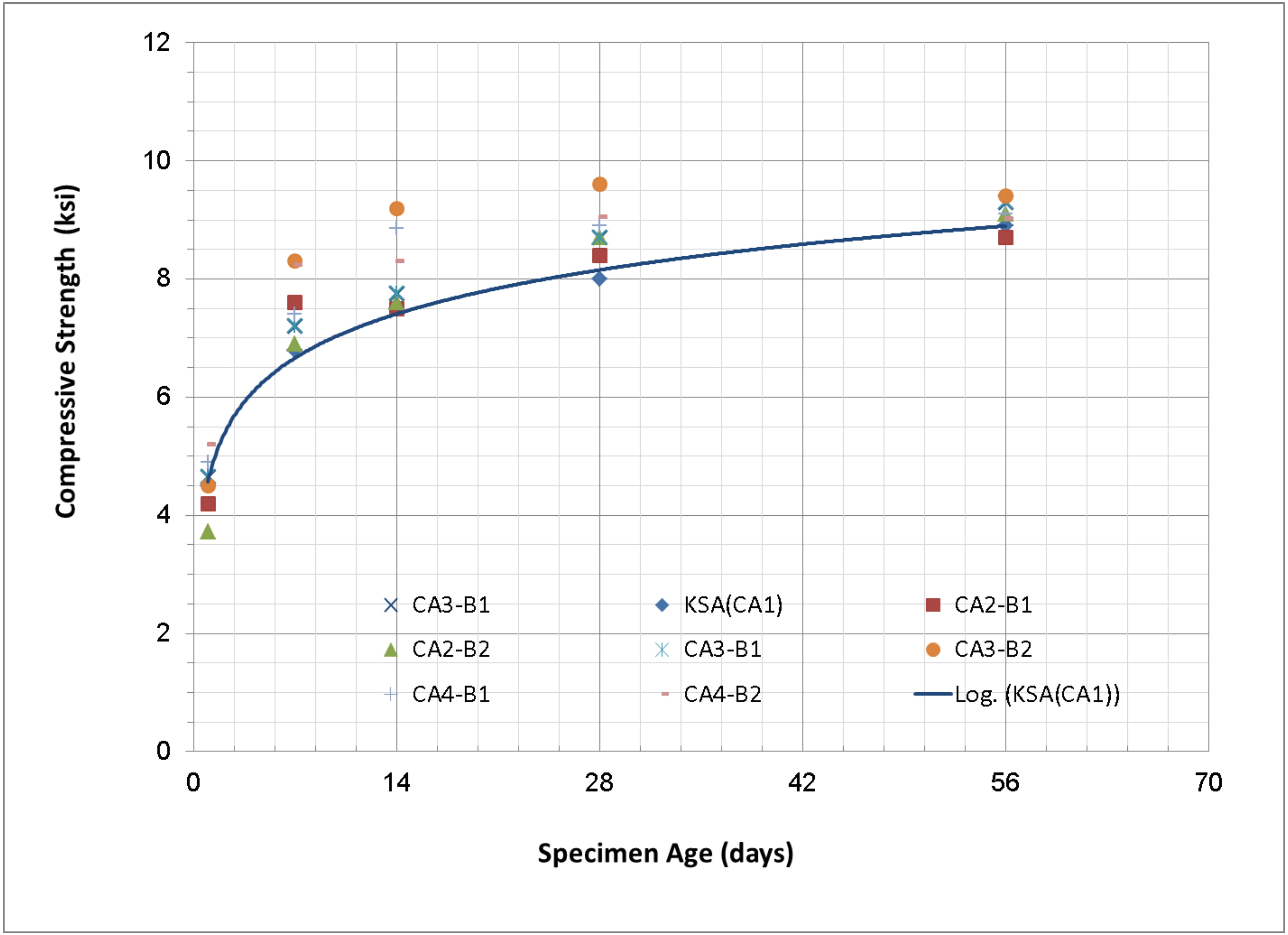
Material Development and Characterization

Material Development and Characterization

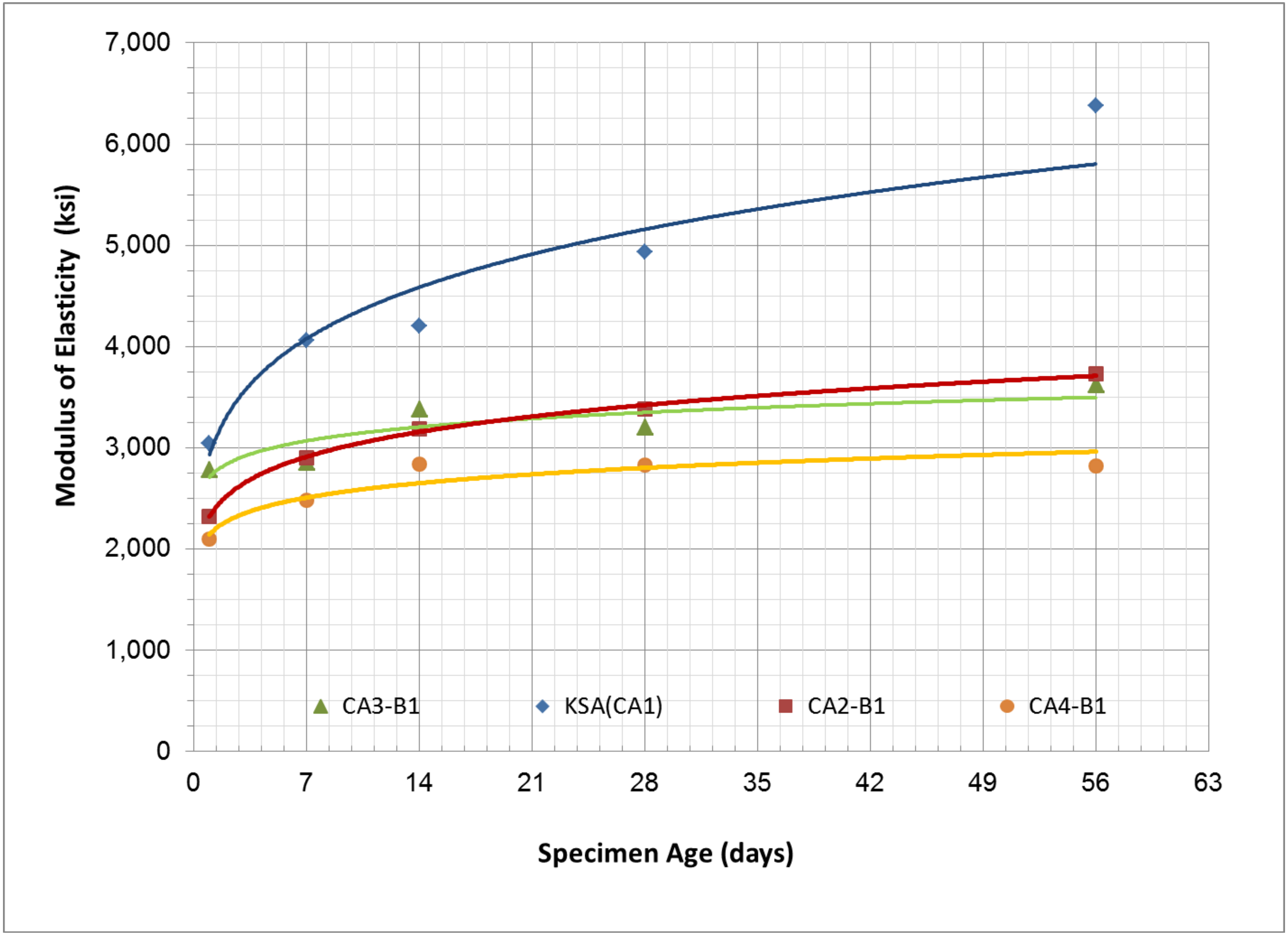
Tests on Rock, Aggregate, Mortar and Concrete

	Test	ASTM
Coarse Ag.	Los Angles Abrasion Test	C131
	Sieve Analysis (Particle Size Distribution)	C136
	Bulk Density and Voids	C29
	Density, Specific Gravity and Absorption	C127
Rock	Compressive Strength	D7012 - 14
	Modulus of Elasticity	D7012 - 14
Concrete	Slump	C143
	Density	C138
	Air Content by pressure method	C231
	Compressive Strength of Concrete	C39
	Flexural Strength of Concrete	C78
	Modulus of Elasticity of Concrete	C469
	Shrinkage	C157
Mortar	Compressive Strength	C 109- 13
	Tensile Strength	C 307-12
	Modulus of Elasticity	C 580-02
	Setting Time (Initial and Final)	C191 - 13

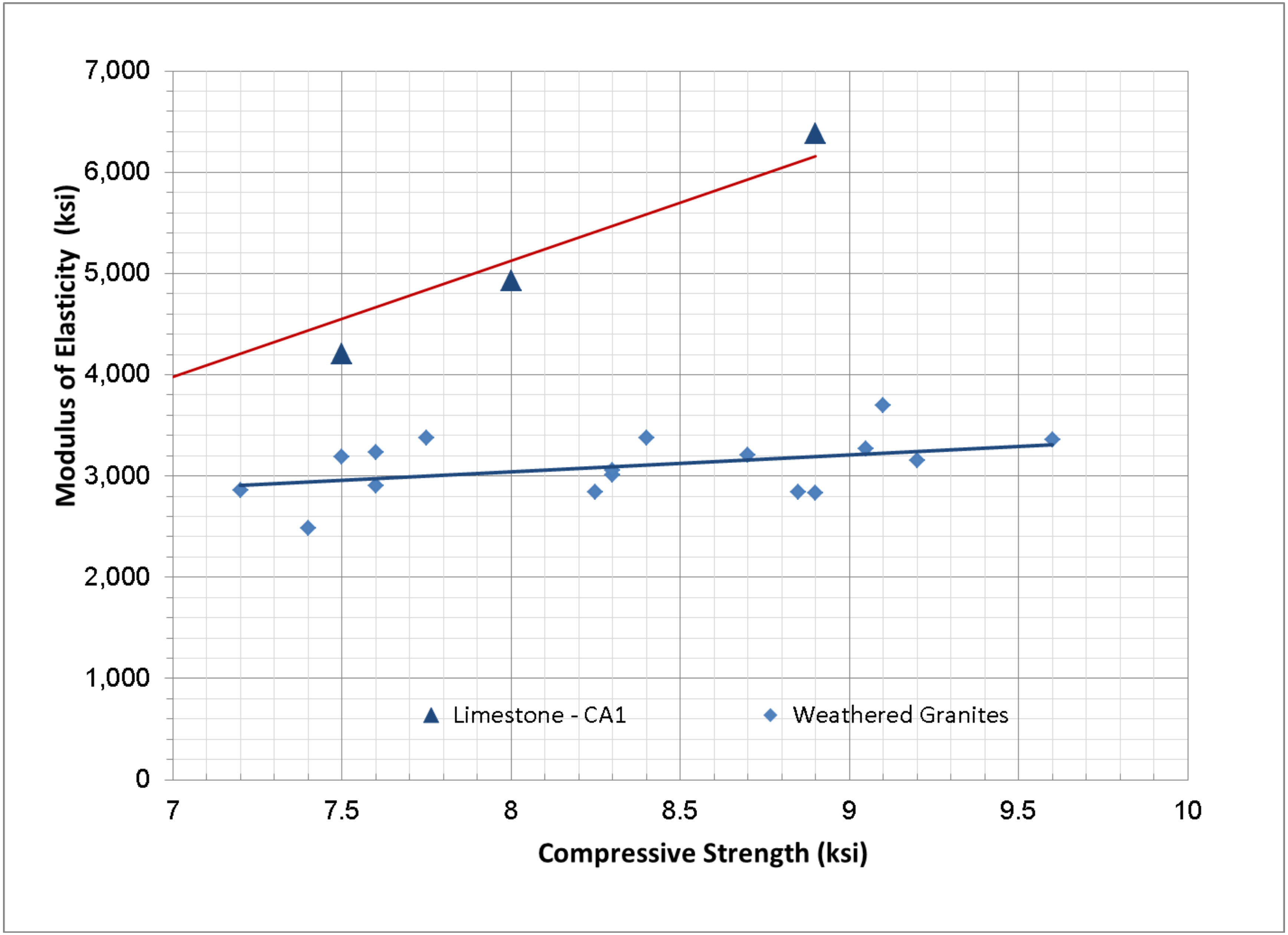
Concrete Strength vs Age



Elastic Modulus of Concrete vs Age



Concrete Modulus vs Strength (fc'>7 ksi)



Properties Comparison

	Property	AGGREGATE			
		KSA (CA1)	CA2	CA3	CA4
Aggreg	Voids	42.73	42.51	39.90	39.10
	Density (lb/ft^3)	161.65	164.50	165.00	167.50
	Relative Density	2.58	2.60	2.65	2.69
	LA Abrasion	27.5%	33.9%	44.3%	46.0%
Fresh Concr	Density (lb/ft^3)	152.90	153.73	154.14	158.55
	Yield (yd^3)	0.15	0.15	0.14	0.14
	Cement Content (lb/yd^3)	618.23	621.53	623.21	632.05
	Slump (in)	7.00	6.50	7.50	4.00
	Air Content (%)	5.0%	5.9%	4.8%	4.0%
Concrete	Compressive Strength (psi)	8.8E+03	8.8E+03	9.2E+03	8.7E+03
	Increase/Reduction %	***0%***	***0%***	***4%***	***-1%***
	Flexural Strength (psi)	0.13fc'	0.125fc'	0.12fc'	-
	Elastic Modulus (psi)	5.6E+06	3.6E+06	3.2+06	2.8E+06
	Elastic Modulus Reduction %	***0%***	***-37%***	***-43%***	***-50%***
	Lapping Test Abrasion Rate (mm/min)	0.042	0.023	0.029	0.039

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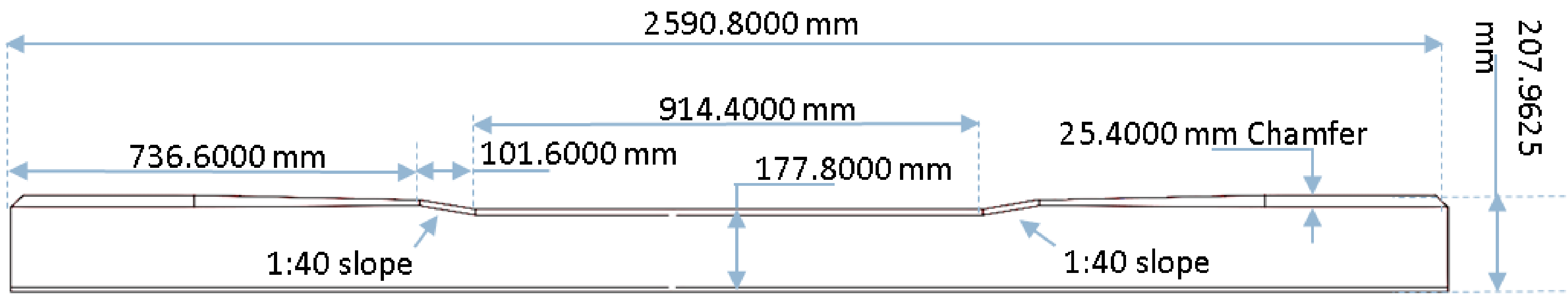
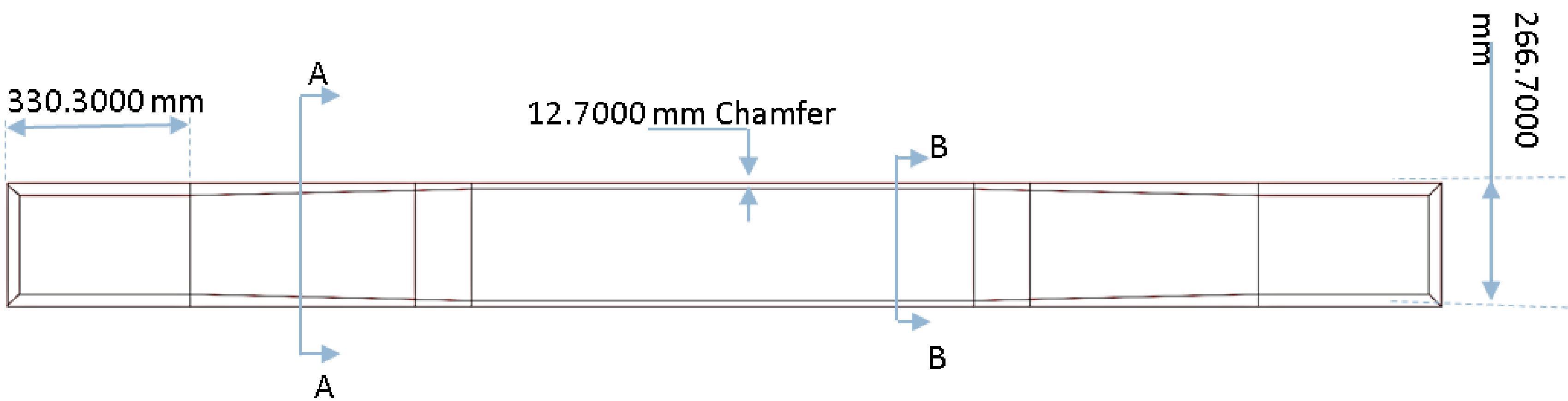
Prototype Tie Geometry



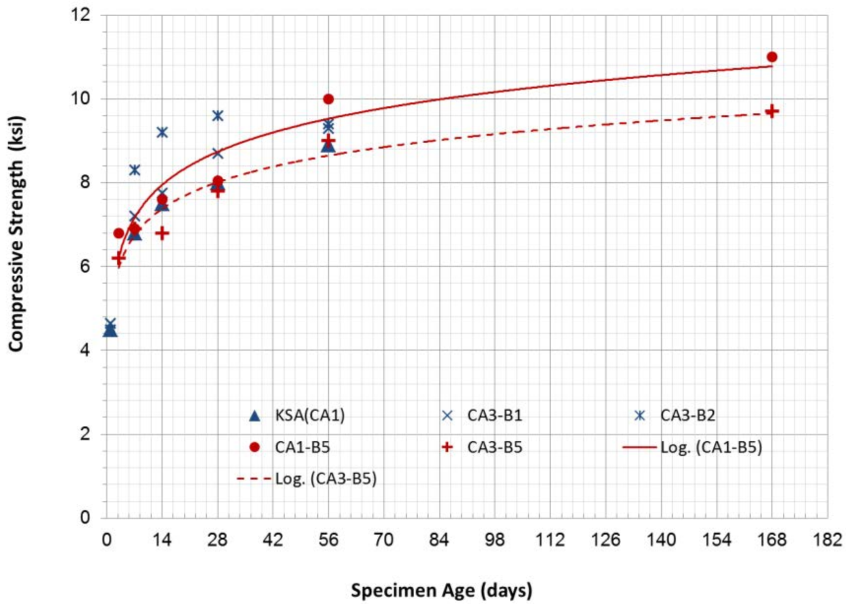


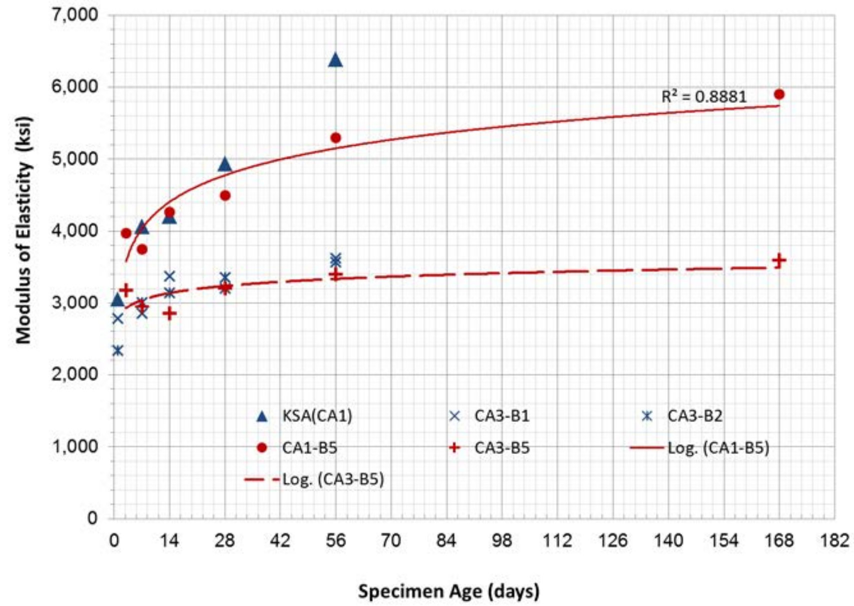
Prototype Fabrication: 9/25

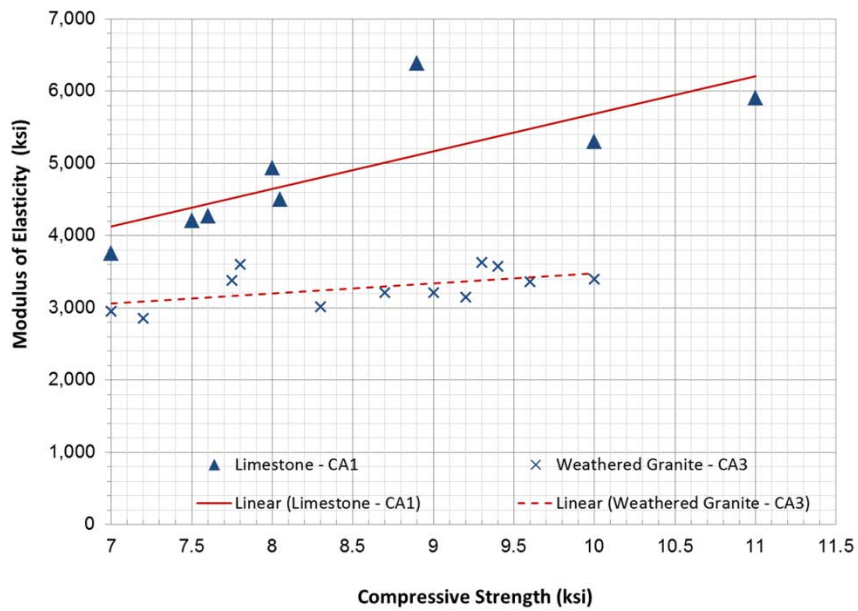
Prototype Fabrication: 9/25

Prototype Fabrication: 9/26

Concrete Properties – Plant Batch



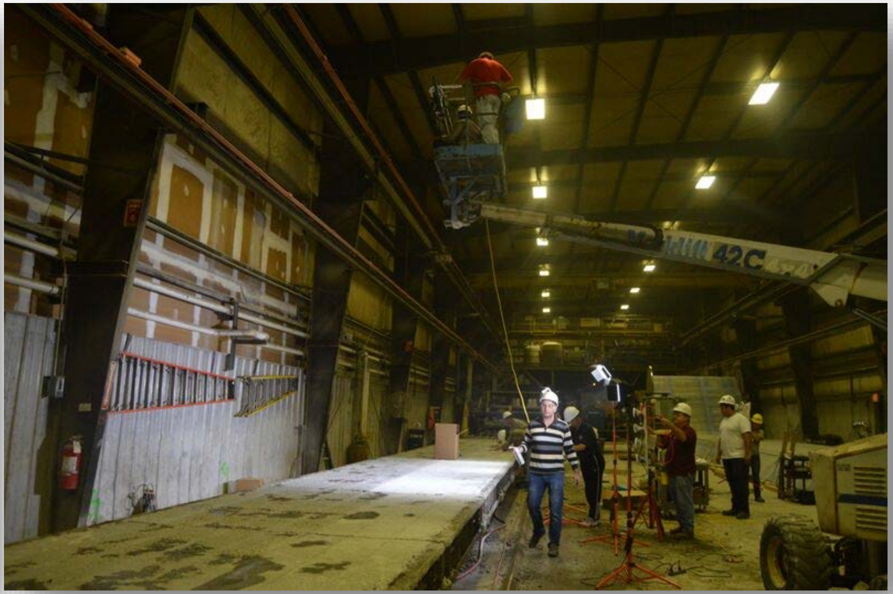




Prototype Fabrication: 9/26

Transfer Length	HSRM-HPC	Standard
Average	11.9 in	16.2 in
Std. Deviation	1.0 in	2.5 in
Coeff. Var.	8.4%	15.4%

Prototype Fabrication: 9/26



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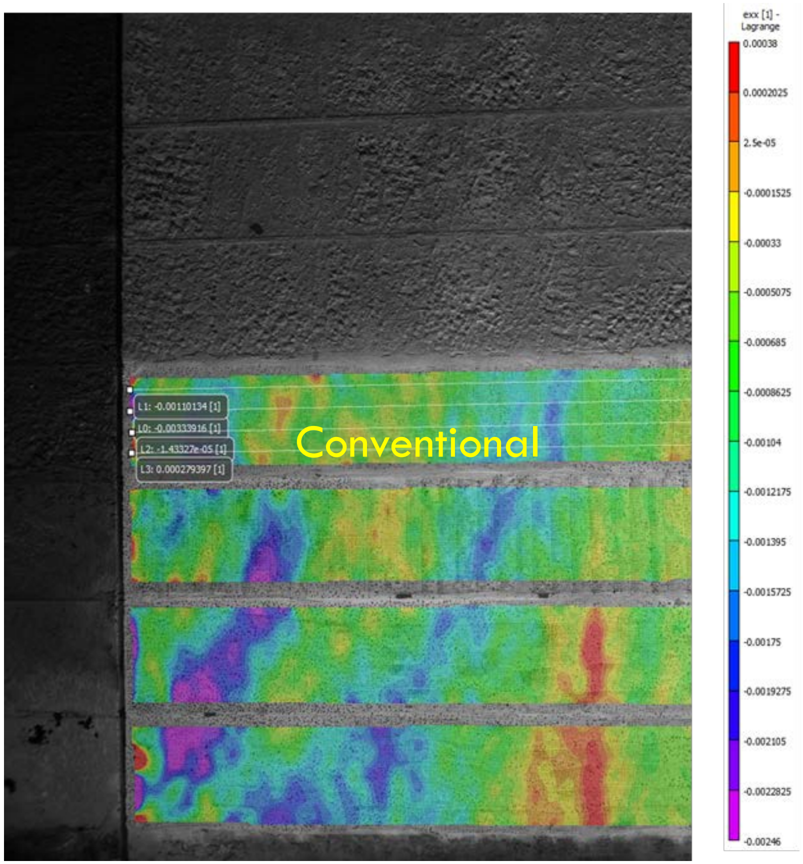

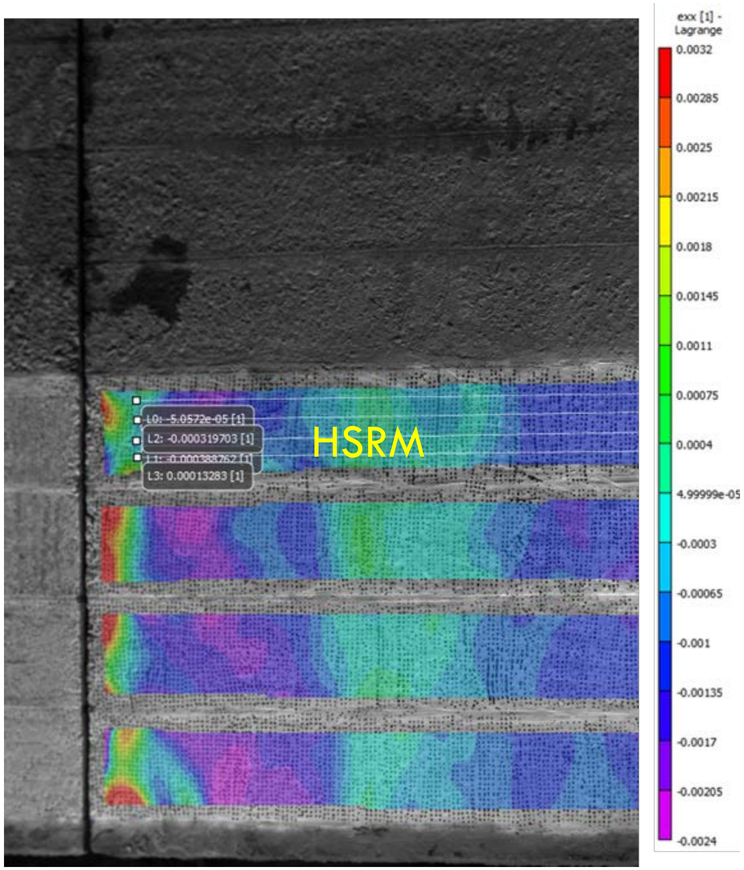

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4.9.1.1 Sequence of Design Tests (Tie "1")

Completed

a. Rail Seat Vertical Load Test - Rail seat A (4.9.1.4)
b. Center Negative Bending Moment Test (4.9.1.6)
c. Center Positive Bending Moment Test (4.9.1.7)
d. Rail Seat Vertical Load Test – Rail seat B (4.9.1.4)
e. Bond Development, Tendon Anchorage, and Ultimate Load Test – Rail seat A (4.9.1.8)

In Progress

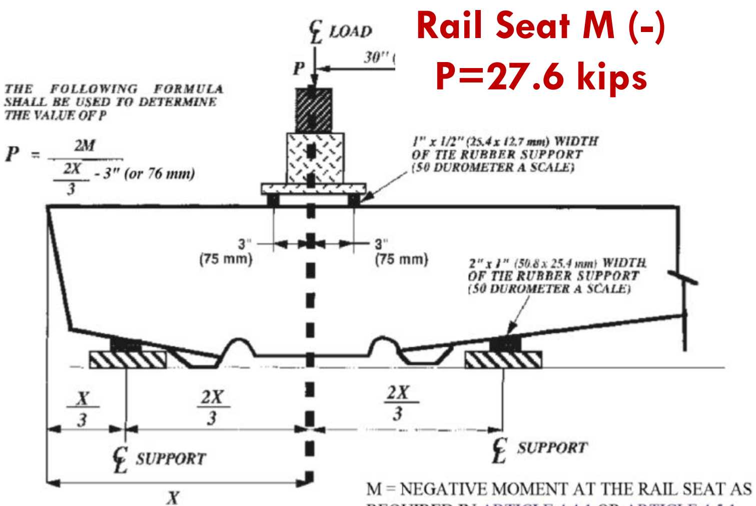
a. Rail Seat Repeated Load Test – Rail seat B(4.9.1.5)

4.9.1.2 Sequence of Design Tests (Tie "2")

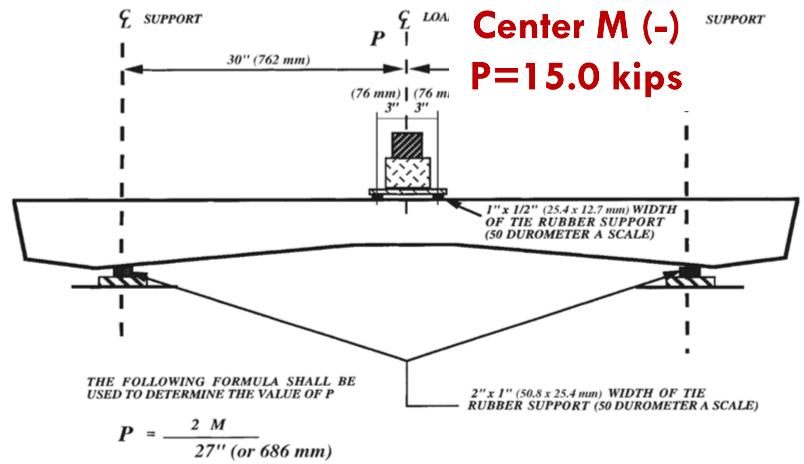
Completed

a. Fastening Insert Test (4.9.1.9)
b. Fastening Uplift Test (4.9.1.10)
c. Electrical Resistance and Impedance Test (4.9.1.14)

AREMA Sequence of Design Tests (Tie "1")

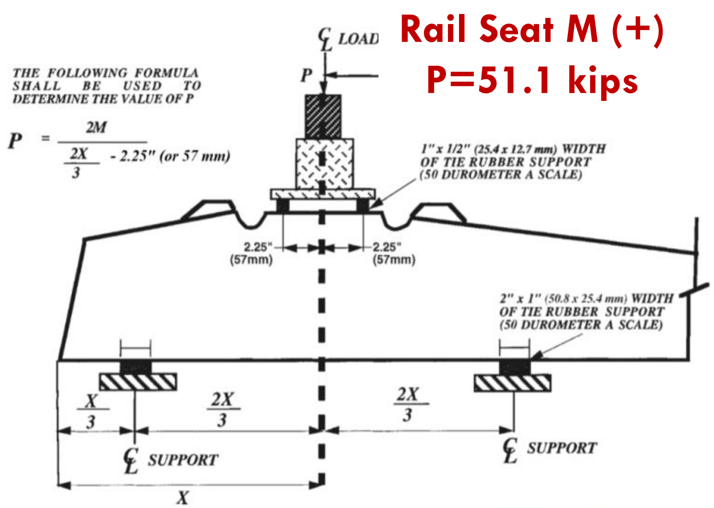


M = NEGATIVE MOMENT AT THE RAIL SEAT AS REQUIRED IN ARTICLE 4.4.1 OR ARTICLE 4.5.1



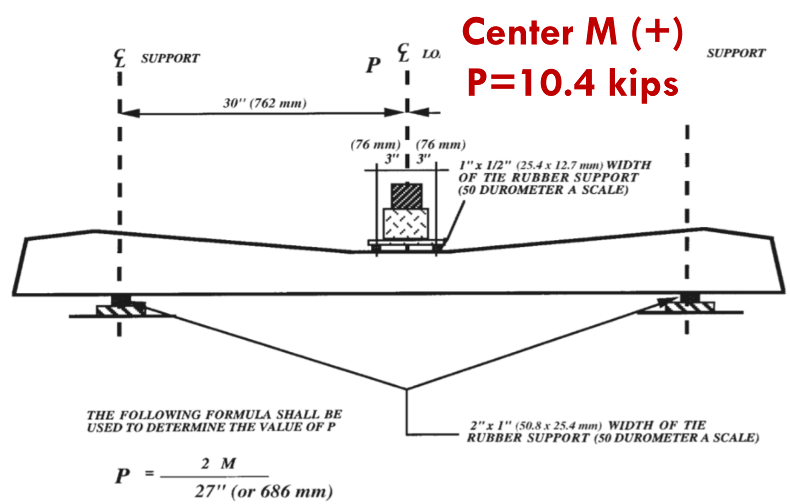
M = NEGATIVE MOMENT AT THE CENTER OF THE TIE AS REQUIRED IN ARTICLE 4.4.1

Figure 30-4-10. Tie Center Negative Moment Test



M = POSITIVE MOMENT AT THE RAIL SEAT AS REQUIRED IN ARTICLE 4.4.1 FOR PRESTRESSED MONOBLOCK TIES OR ARTICLE 4.5.1 FOR TWO BLOCK TIES

Figure 30-4-8. Rail Seat Positive Moment Test

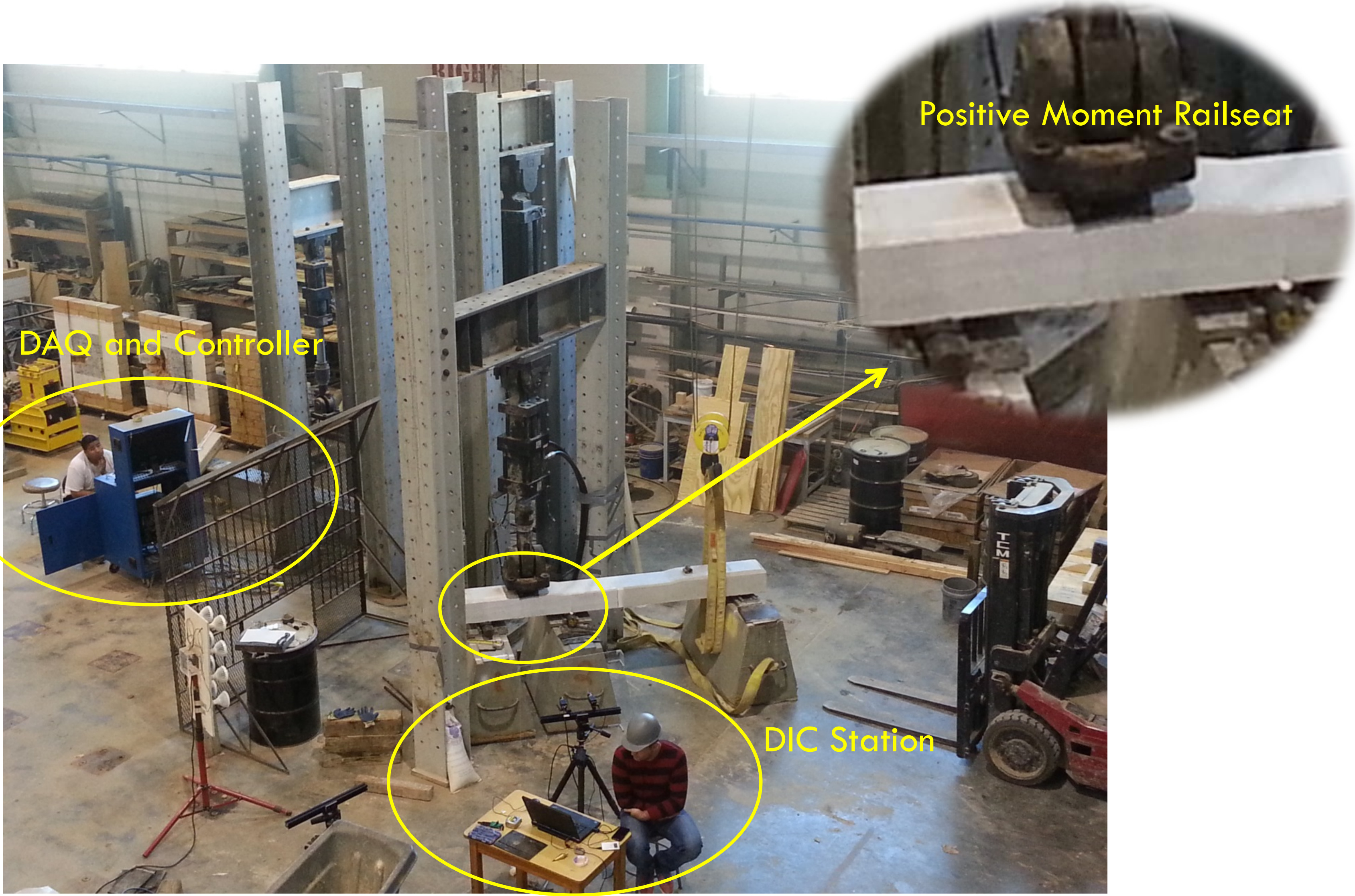


M = POSITIVE MOMENT AT THE CENTER OF THE TIE AS REQUIRED IN ARTICLE 4.4.1

Figure 30-4-11. Tie Center Positive Moment Test

AREMA Sequence of Design Tests (Tie "1")

3-D Stereovision System for Strain Field Measurements



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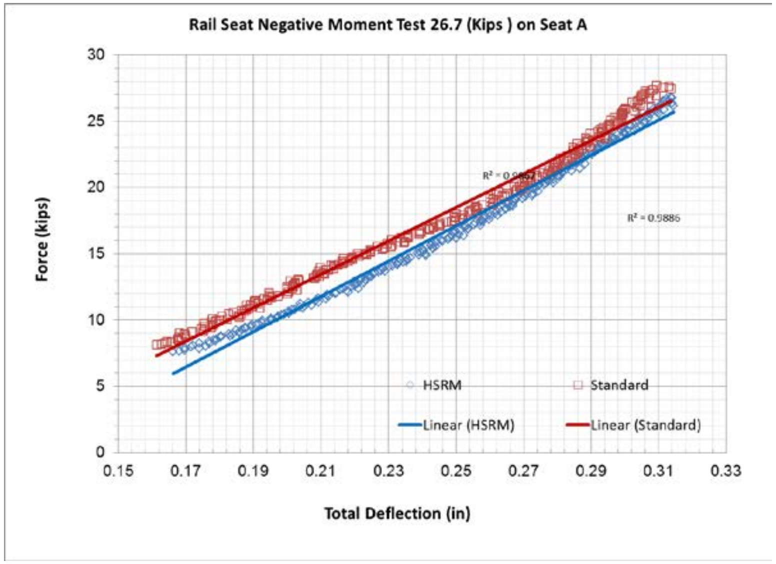
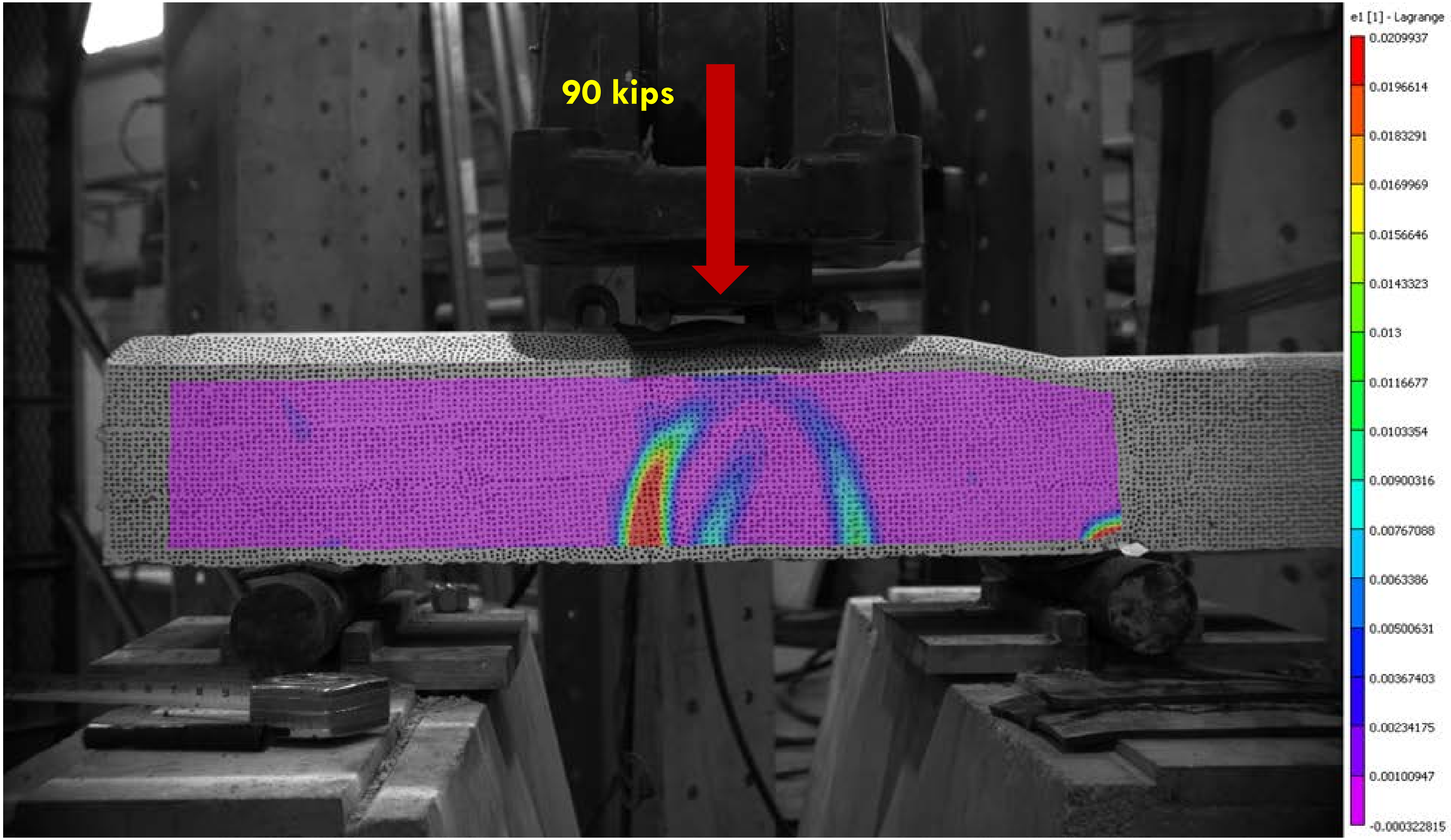
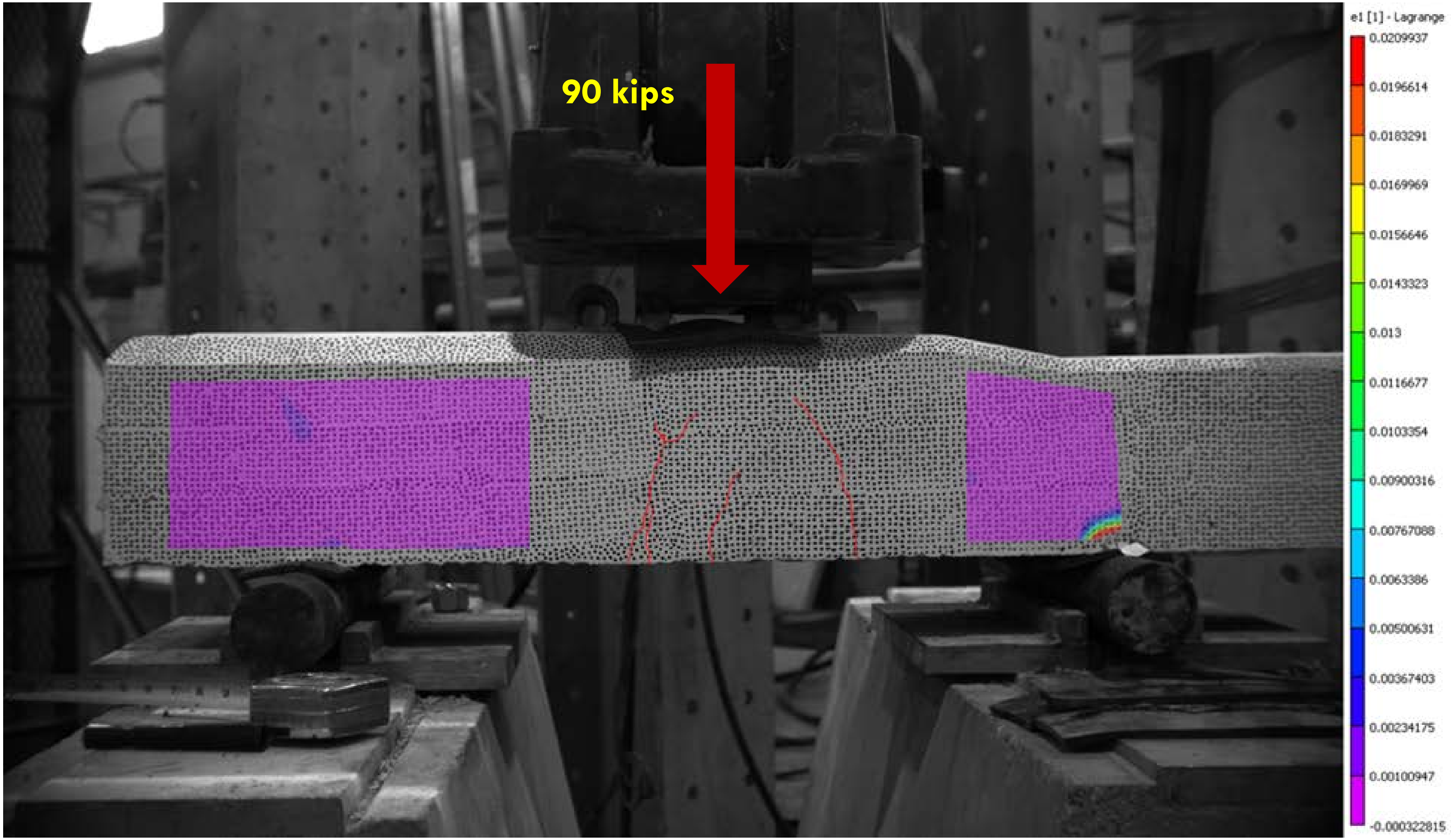


Design Performance – AREMA: Ultimate Load Tests (In Progress)



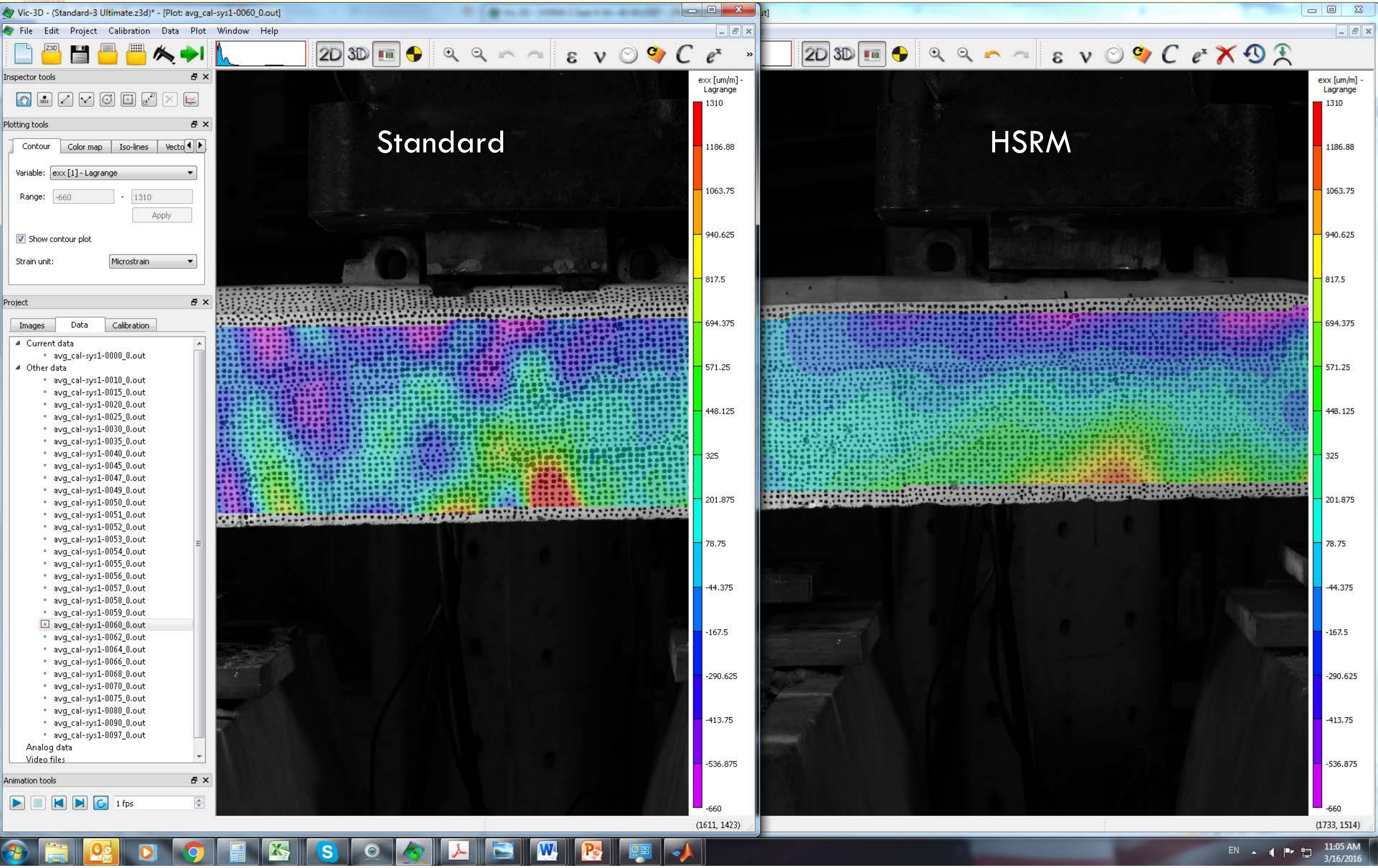
Design Performance – AREMA: Ultimate Load Tests (In Progress)



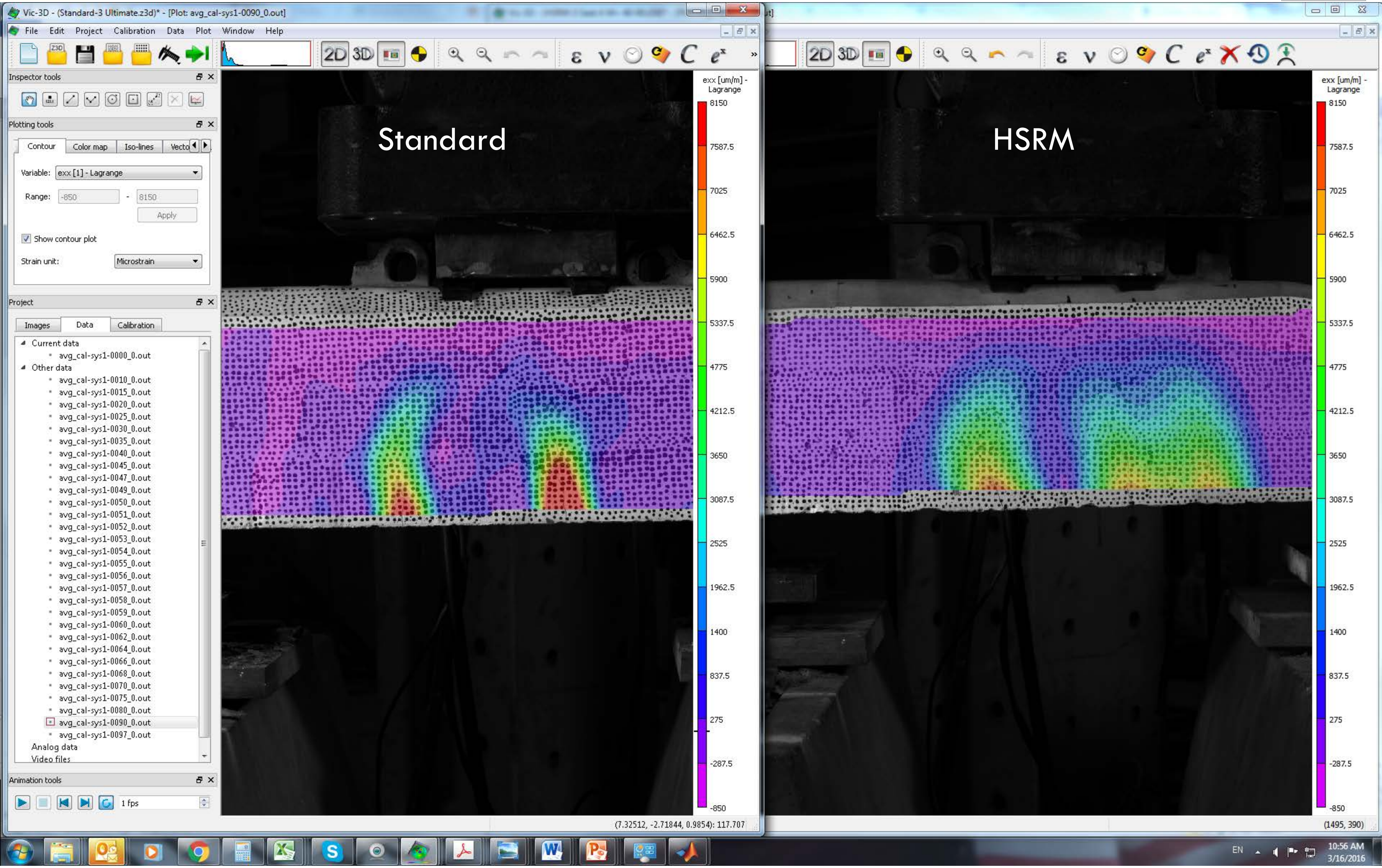
Ultimate Load Tests

	Tie ID	Rail Seat A					
		$\varepsilon_{prestress}$ (+/- 10%)	ε_{crack}	P_{crack}	1.5P	Pu	Strand Slippage
Prototype	HSRM-Q1	~800 µε	~320µε	56	Pass	>100	No
	HSRM-Q2						
	HSRM-Q3			57	Pass	>100	No
	HSRM-Q4						
	HSRM-Q5			52	Pass	96	No
Baseline	STND-Q1	~500 µε	~220 µε				
	STND-Q2						
	STND-Q3 (9-1)			57.9	Pass	88.9	No
	STND-Q4 (11-3)			52.1	Pass	105.3	No
	STND-Q7			49	Pass	97	No
Other	STND-Q5-A						
	STND-Q6-A						

P=60 kips Same Scale



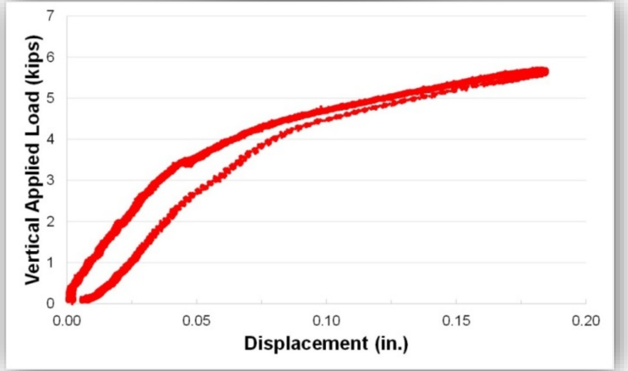
P=90 kips – Same Scale



Fastener Pullout and Torque Tests

Crosstie	Rail Seat	Location	Pull-out (12kips)	Torque (250lb-ft)
Rocla	A	Field	PASS	PASS
		Gauge	PASS	PASS
	B	Field	PASS	PASS
		Gauge	PASS	PASS
USC Prototype	A	Field	PASS	PASS
		Gauge	PASS	PASS
	B	Field	PASS	PASS
		Gauge	PASS	PASS

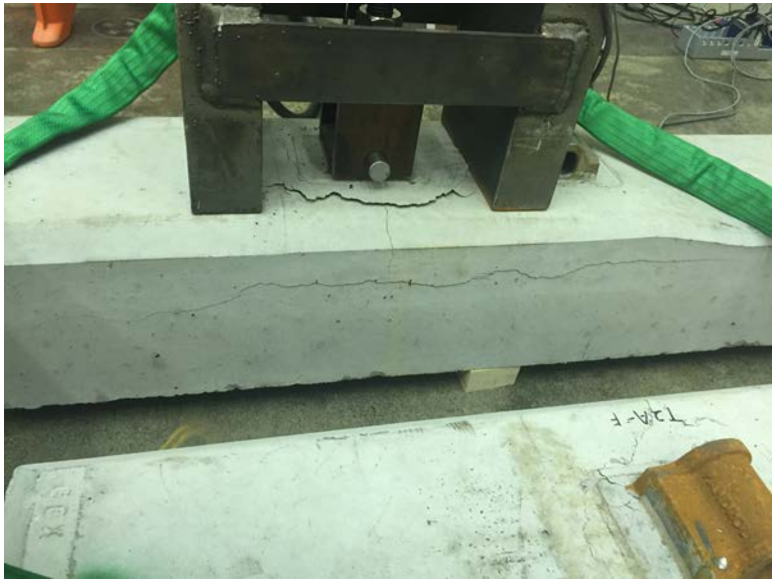
Fastener Uplift Tests



Crosstie	Rail Seat	Result
Standard Crosstie	A	PASS
	B	PASS
USC Prototype Crosstie	A	PASS
	B	PASS

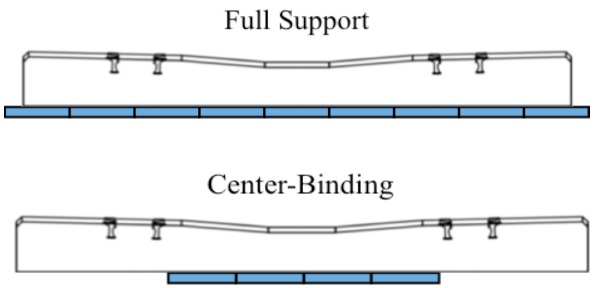
Crosstie	Level of Distress	Load (kips)
Standard	Crack Initiation at	31.6
	Insert Pulled out	34.6
HSRM	Crack Initiation	33.2
	Insert Pulled out	35.1

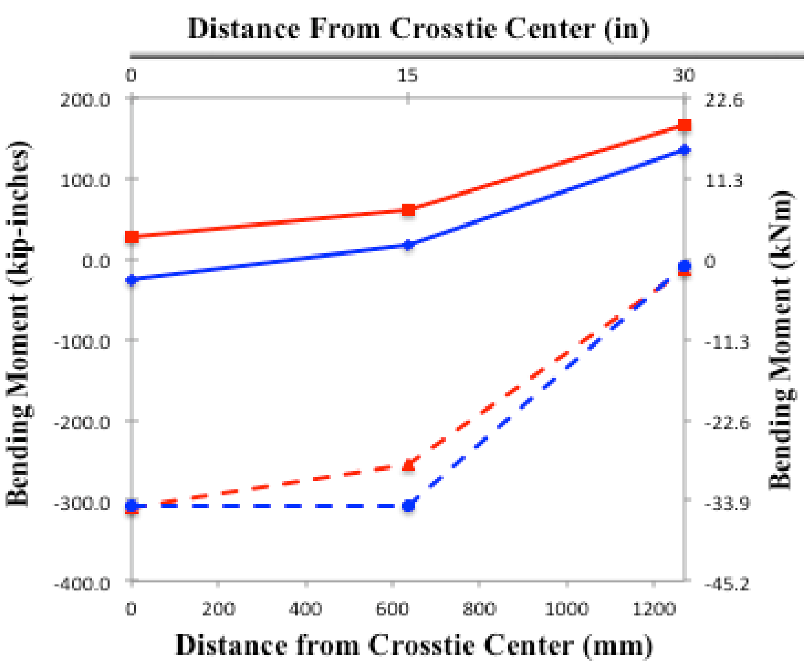
Standard

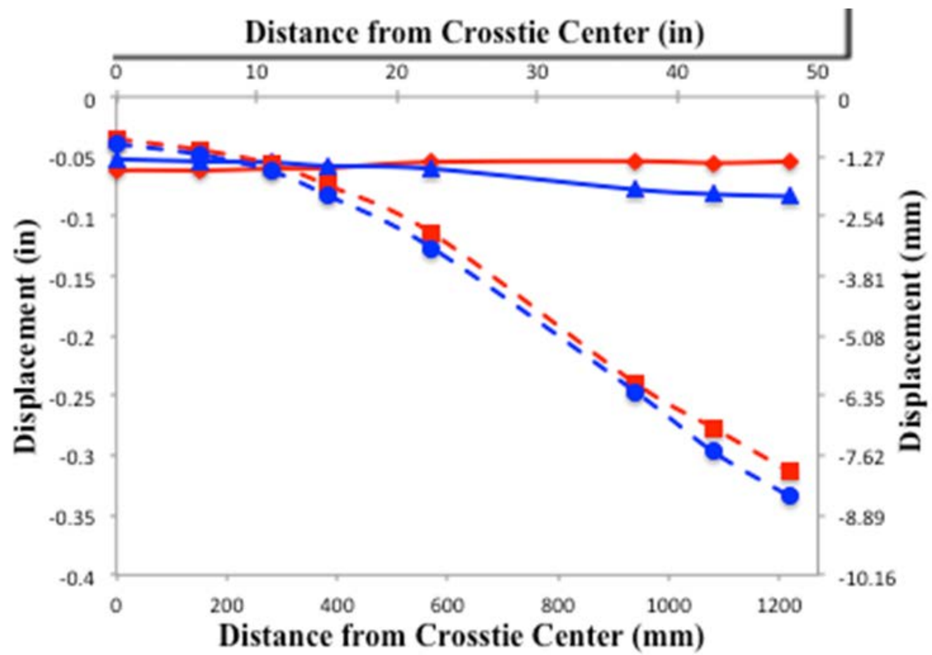


HSRM

Tie Performance – Flexural tests

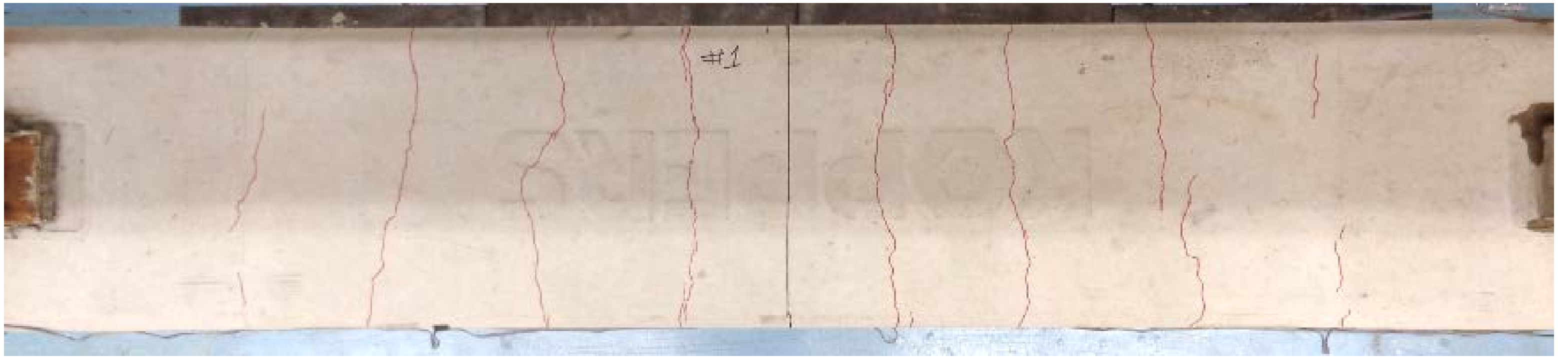




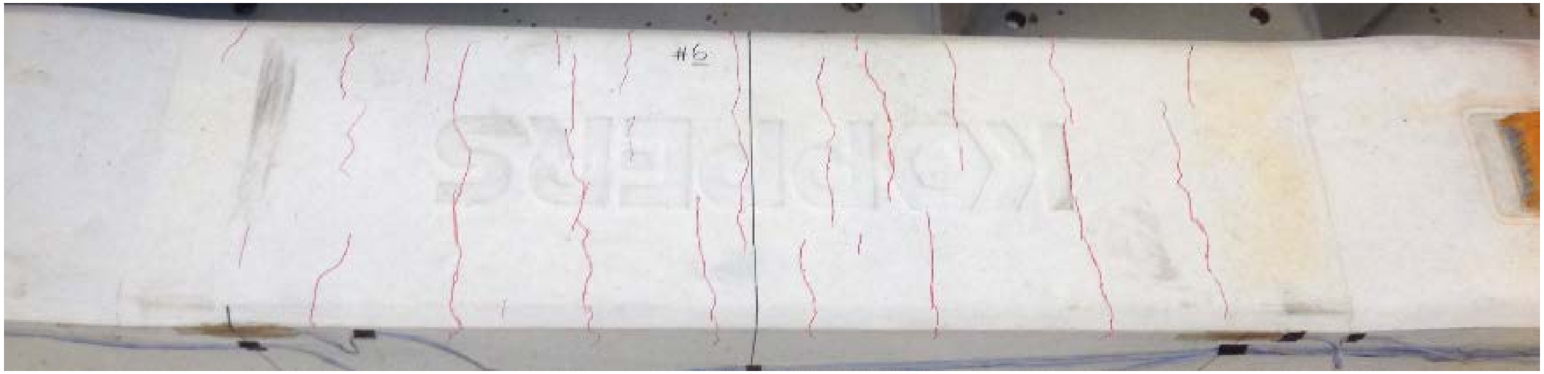


Tie Performance – Flexural tests

Standard Tie



HSRM Tie



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Conclusions

- HSRM-HPC similar properties as Limestone HPC except Elastic Modulus (up to 50% reduction)
- HSRM Ties Passed all AREMA Qualification Tests and meets or exceeds standard tie performance
- HSRM Tie provides
  - Better load distribution
  - Stress reduction
  - Delay onset of damage
- A technology based modification in concrete tie technology that will improve the safety of rail service and maintenance operations without impacting fabrication cost and process

Acknowledgments

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CSX

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