INVESTIGATING INTERFACE SHEAR RESISTANCE THROUGH SLANT SHEAR TESTS: A CRITICAL REVIEW OF CURRENT DESIGN CODES

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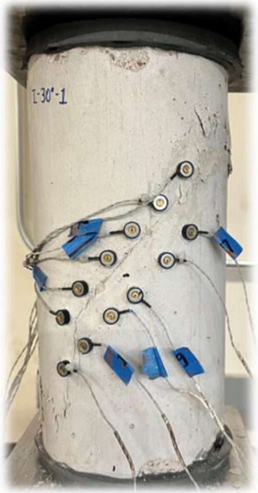
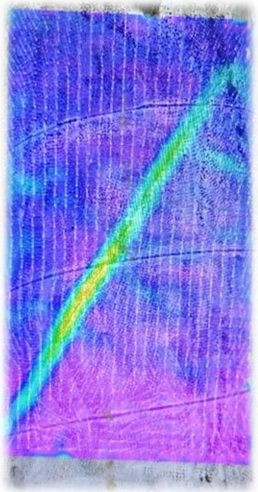
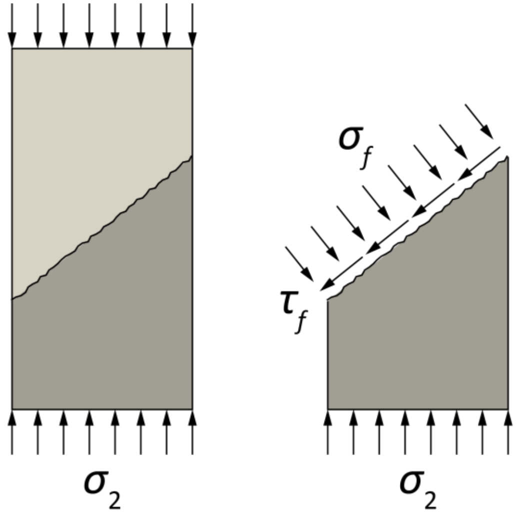






THE WORLD'S GATHERING PLACE FOR ADVANCING CONCRETE

aci CONCRETE CONVENTION

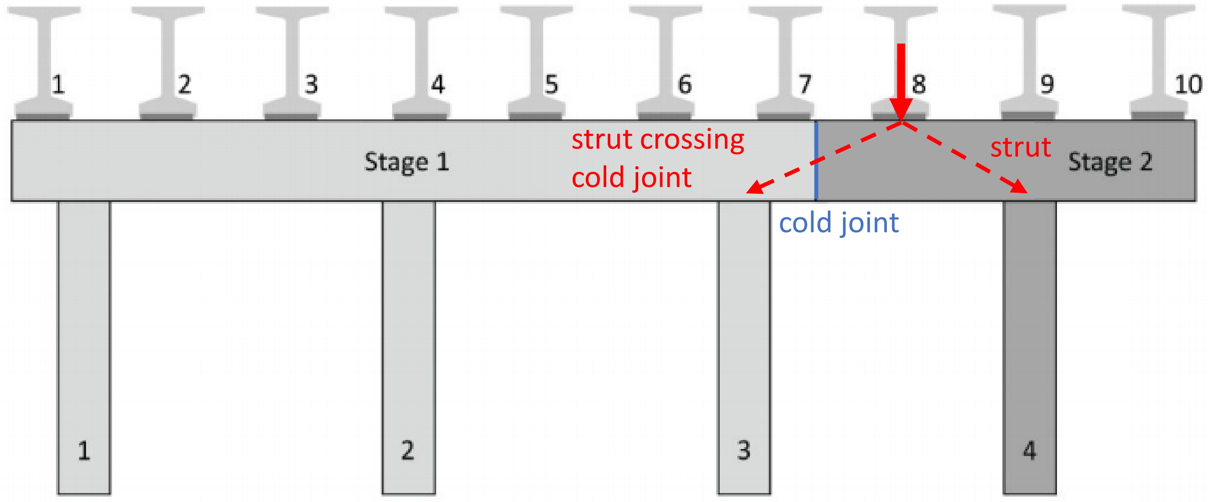
OUTLINE

- Introduction
- Experimental Program
- Code Evaluation
- Database Analysis
- Conclusions

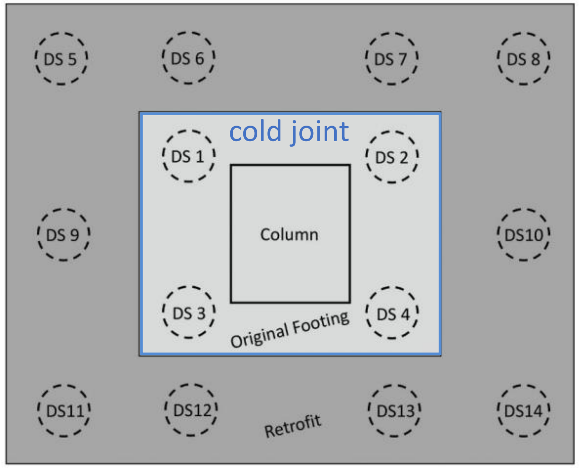
INTRODUCTION

"Cities are not static – they are growing"

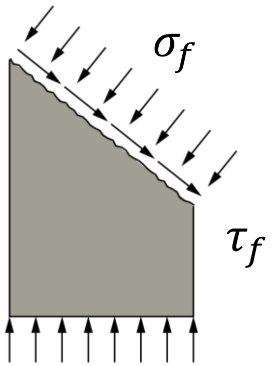
INTRODUCTION



Strut Crossing Cold Joint in Stage Construction (Bayrak, 2020)



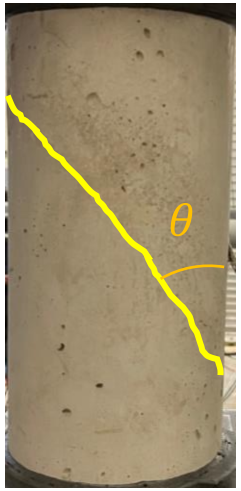
Strut Crossing Cold Joint in Retrofitted Pier Cap (Bayrak, 2020)



EXPERIMENTAL PROGRAM

Test Matrix – Series I: Angle

Series	Groups	Angle (°)	Interface Roughness	Concrete Strength	Casting Age	Agg. Size
I-Angle	I-30	30	R1	N-N	3 days	A1-A1
	I-38	38	R1	N-N	3 days	A1-A1
	I-45	45	R1	N-N	3 days	A1-A1
	I-60	60	R1	N-N	3 days	A1-A1
II-Interface Roughness	II-M	-	M	N-N	3 days	A1-A1
	II-NR	30	NR	N-N	3 days	A1-A1
	II-R1	30	R1	N-N	3 days	A1-A1
	II-R2	30	R2	N-N	3 days	A1-A1
III-Concrete Strength	III-H1	30	R1	N-H1	3 days	A1-A1
	III-H2	30	R1	N-H2	3 days	A1-A1
IV-Casting Age	IV-1/6	30	R1	N-N	4 hours	A1-A1
	IV-28	30	R1	N-N	28 days	A1-A1
	IV-56	30	R1	N-N	56 days	A1-A1
V-Aggregate Size	V-A2	30	R1	N-N	3 days	A1-A2
	V-A3	30	R1	N-N	3 days	A1-A3



30 °


38 °


45 °


60 °

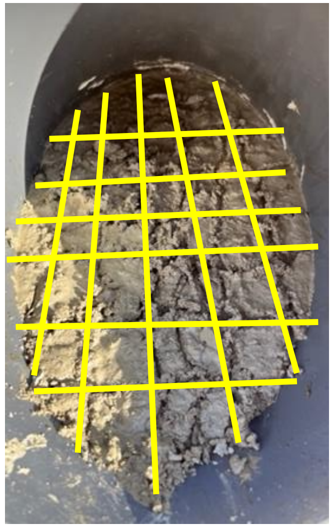
EXPERIMENTAL PROGRAM

Test Matrix – Series II: Interface Roughness

Series	Groups	Angle (°)	Interface Roughness	Concrete Strength	Casting Age	Agg. Size
I-Angle	I-30	30	R1	N-N	3 days	A1-A1
	I-38	38	R1	N-N	3 days	A1-A1
	I-45	45	R1	N-N	3 days	A1-A1
	I-60	60	R1	N-N	3 days	A1-A1
II-Interface Roughness	II-M	-	M	N-N	3 days	A1-A1
	II-NR	30	NR	N-N	3 days	A1-A1
	II-R1	30	R1	N-N	3 days	A1-A1
	II-R2	30	R2	N-N	3 days	A1-A1
III-Concrete Strength	III-H1	30	R1	N-H1	3 days	A1-A1
	III-H2	30	R1	N-H2	3 days	A1-A1
IV-Casting Age	IV-1/6	30	R1	N-N	4 hours	A1-A1
	IV-28	30	R1	N-N	28 days	A1-A1
	IV-56	30	R1	N-N	56 days	A1-A1
V-Aggregate Size	V-A2	30	R1	N-N	3 days	A1-A2
	V-A3	30	R1	N-N	3 days	A1-A3


NR

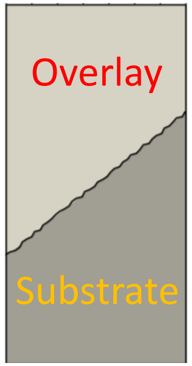

R1

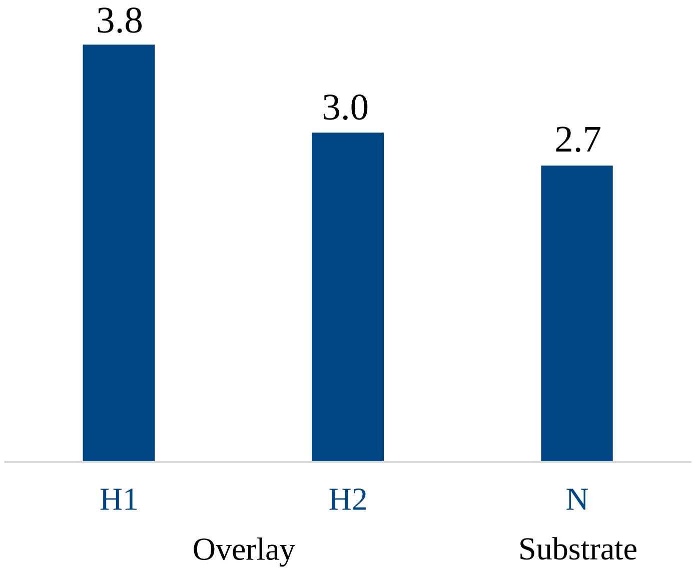

R2

EXPERIMENTAL PROGRAM

Test Matrix – Series III: Variation in Concrete Strength

Series	Groups	Angle (°)	Interface Roughness	Concrete Strength	Casting Age	Agg. Size
I-Angle	I-30	30	R1	N-N	3 days	A1-A1
	I-38	38	R1	N-N	3 days	A1-A1
	I-45	45	R1	N-N	3 days	A1-A1
	I-60	60	R1	N-N	3 days	A1-A1
II-Interface Roughness	II-M	-	M	N-N	3 days	A1-A1
	II-NR	30	NR	N-N	3 days	A1-A1
	II-R1	30	R1	N-N	3 days	A1-A1
	II-R2	30	R2	N-N	3 days	A1-A1
III-Concrete Strength	III-H1	30	R1	N-H1	3 days	A1-A1
	III-H2	30	R1	N-H2	3 days	A1-A1
IV-Casting Age	IV-1/6	30	R1	N-N	4 hours	A1-A1
	IV-28	30	R1	N-N	28 days	A1-A1
	IV-56	30	R1	N-N	56 days	A1-A1
V-Aggregate Size	V-A2	30	R1	N-N	3 days	A1-A2
	V-A3	30	R1	N-N	3 days	A1-A3

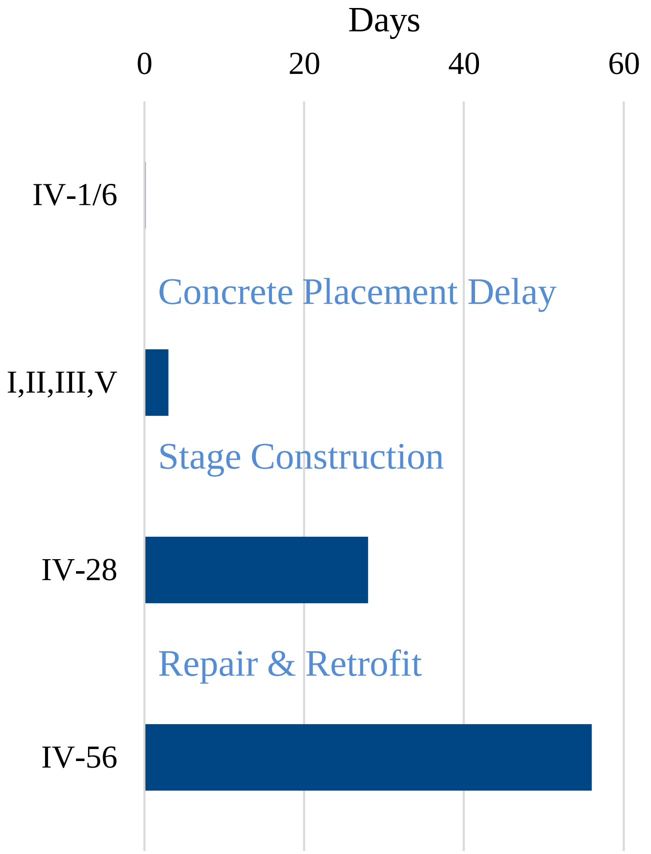




Experimental Program

Test Matrix – Series IV: Casting Age Difference

Series	Groups	Angle (°)	Interface Roughness	Concrete Strength	Casting Age	Agg. Size
I-Angle	I-30	30	R1	N-N	3 days	A1-A1
	I-38	38	R1	N-N	3 days	A1-A1
	I-45	45	R1	N-N	3 days	A1-A1
	I-60	60	R1	N-N	3 days	A1-A1
II-Interface Roughness	II-M	-	M	N-N	3 days	A1-A1
	II-NR	30	NR	N-N	3 days	A1-A1
	II-R1	30	R1	N-N	3 days	A1-A1
	II-R2	30	R2	N-N	3 days	A1-A1
III-Concrete Strength	III-H1	30	R1	N-H1	3 days	A1-A1
	III-H2	30	R1	N-H2	3 days	A1-A1
IV-Casting Age	IV-1/6	30	R1	N-N	4 hours	A1-A1
	IV-28	30	R1	N-N	28 days	A1-A1
	IV-56	30	R1	N-N	56 days	A1-A1
V-Aggregate Size	V-A2	30	R1	N-N	3 days	A1-A2
	V-A3	30	R1	N-N	3 days	A1-A3



Test Matrix – Series V: Aggregate Size

Series	Groups	Angle (°)	Interface Roughness	Concrete Strength	Casting Age	Agg. Size
I-Angle	I-30	30	R1	N-N	3 days	A1-A1
	I-38	38	R1	N-N	3 days	A1-A1
	I-45	45	R1	N-N	3 days	A1-A1
	I-60	60	R1	N-N	3 days	A1-A1
II-Interface Roughness	II-M	-	M	N-N	3 days	A1-A1
	II-NR	30	NR	N-N	3 days	A1-A1
	II-R1	30	R1	N-N	3 days	A1-A1
	II-R2	30	R2	N-N	3 days	A1-A1
III-Concrete Strength	III-H1	30	R1	N-H1	3 days	A1-A1
	III-H2	30	R1	N-H2	3 days	A1-A1
IV-Casting Age	IV-1/6	30	R1	N-N	4 hours	A1-A1
	IV-28	30	R1	N-N	28 days	A1-A1
	IV-56	30	R1	N-N	56 days	A1-A1
V-Aggregate Size	V-A2	30	R1	N-N	3 days	A1-A2
	V-A3	30	R1	N-N	3 days	A1-A3

Substrate A1-5/8”

Overlay A2-Sand

Overlay A3-3/8”

EXPERIMENTAL PROGRAM

Specimen Fabrication

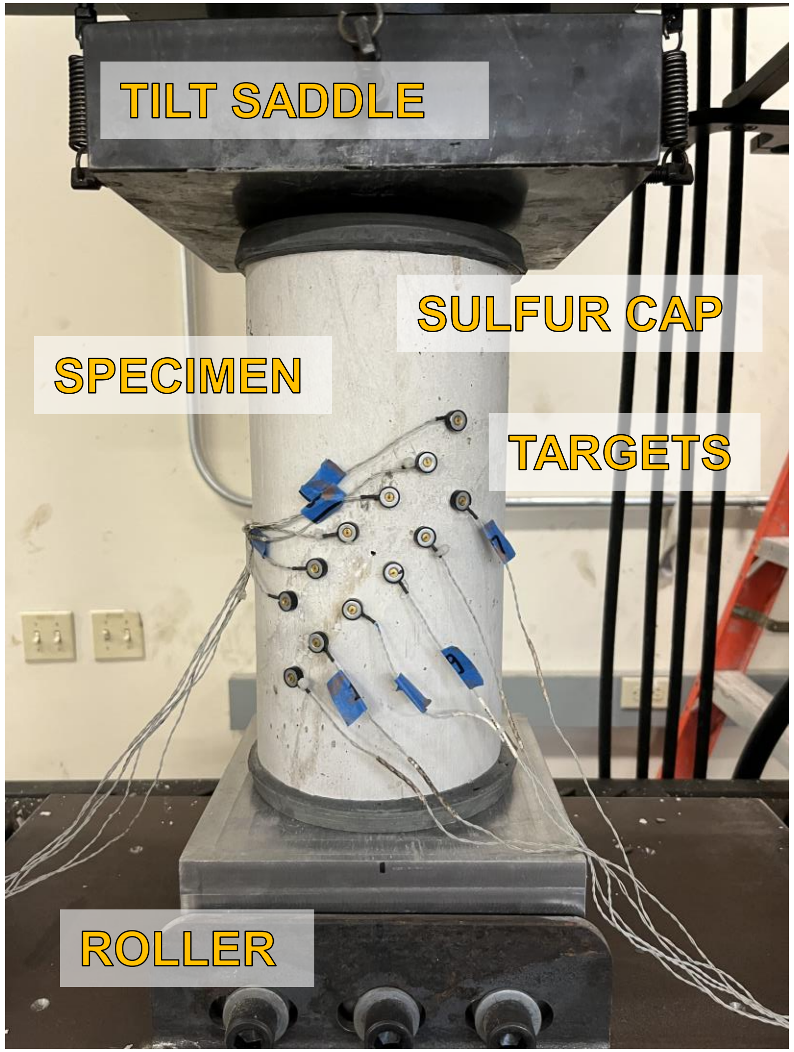
Preparation → 1st Cast → Intentional Roughening → 2nd Cast → Curing

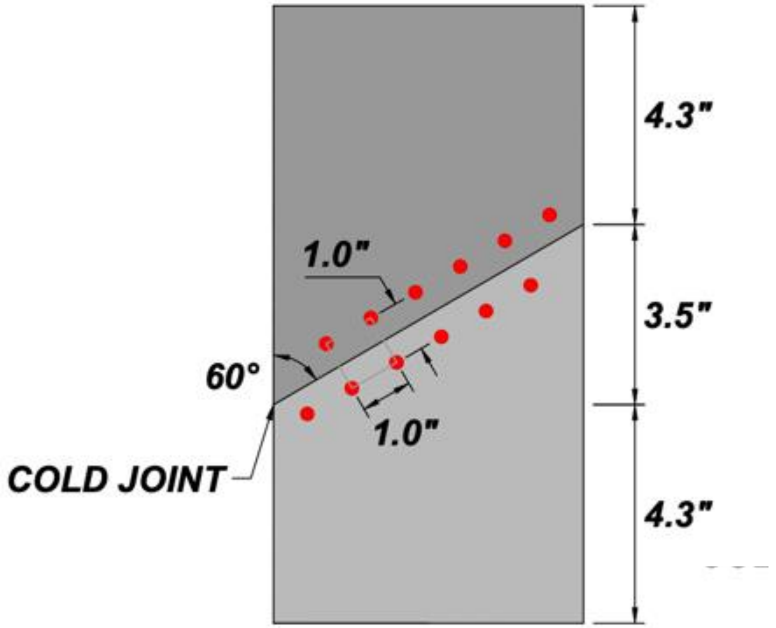
EXPERIMENTAL PROGRAM

Test Setup

NDI Optical Tracking System

Sulfur Cap for Contact Surface





Target Arrangement

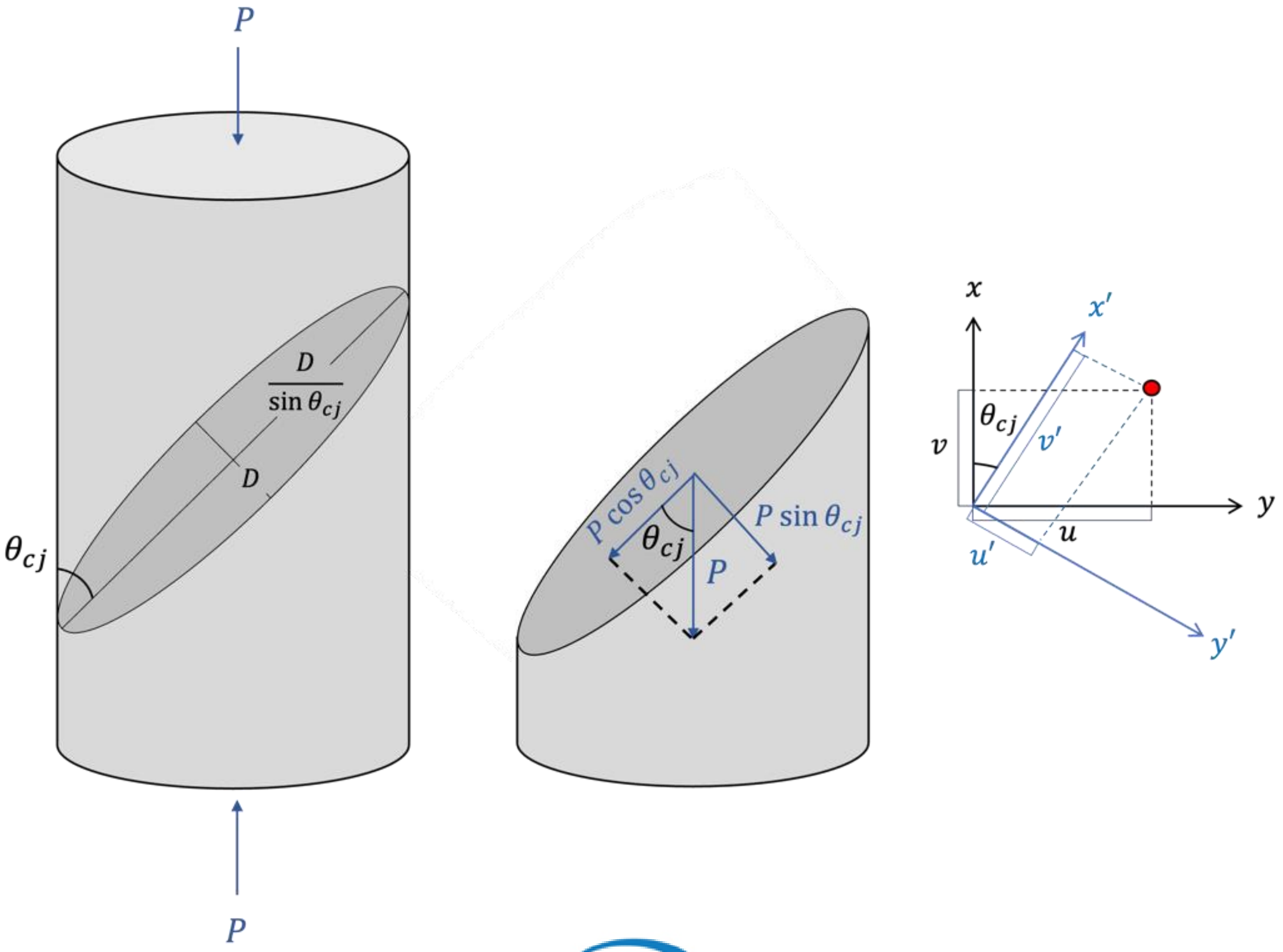
Failure Mechanisms

Slant shear failure

Crushing of concrete

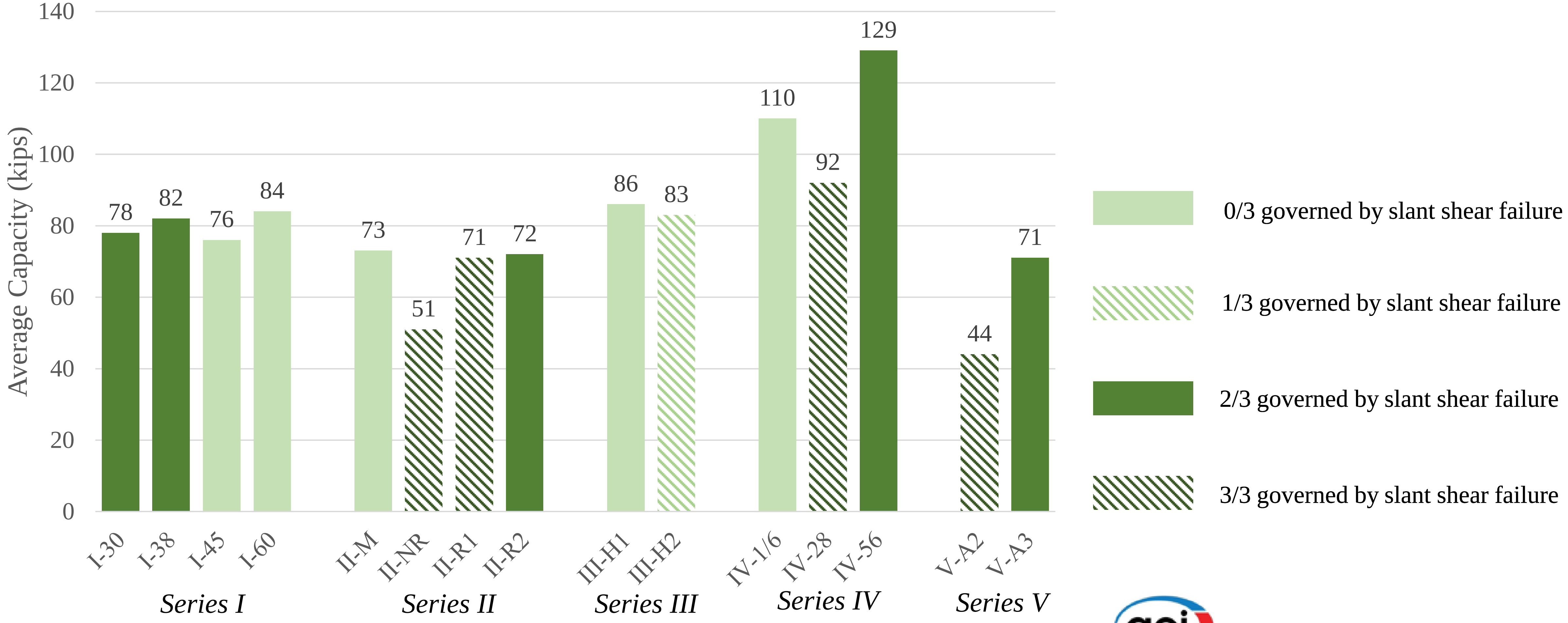
Hybrid failure

Data Processing Methodology



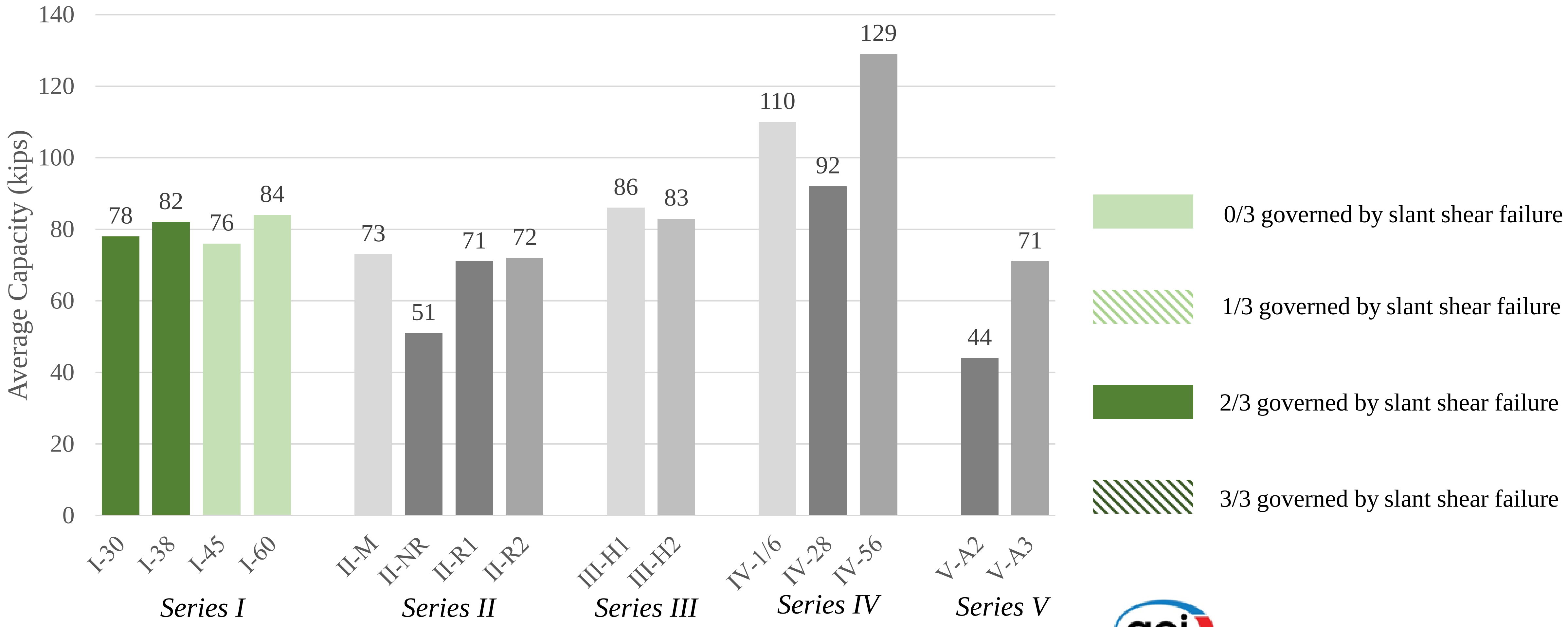
Experimental Results

Capacity and Failure Mode



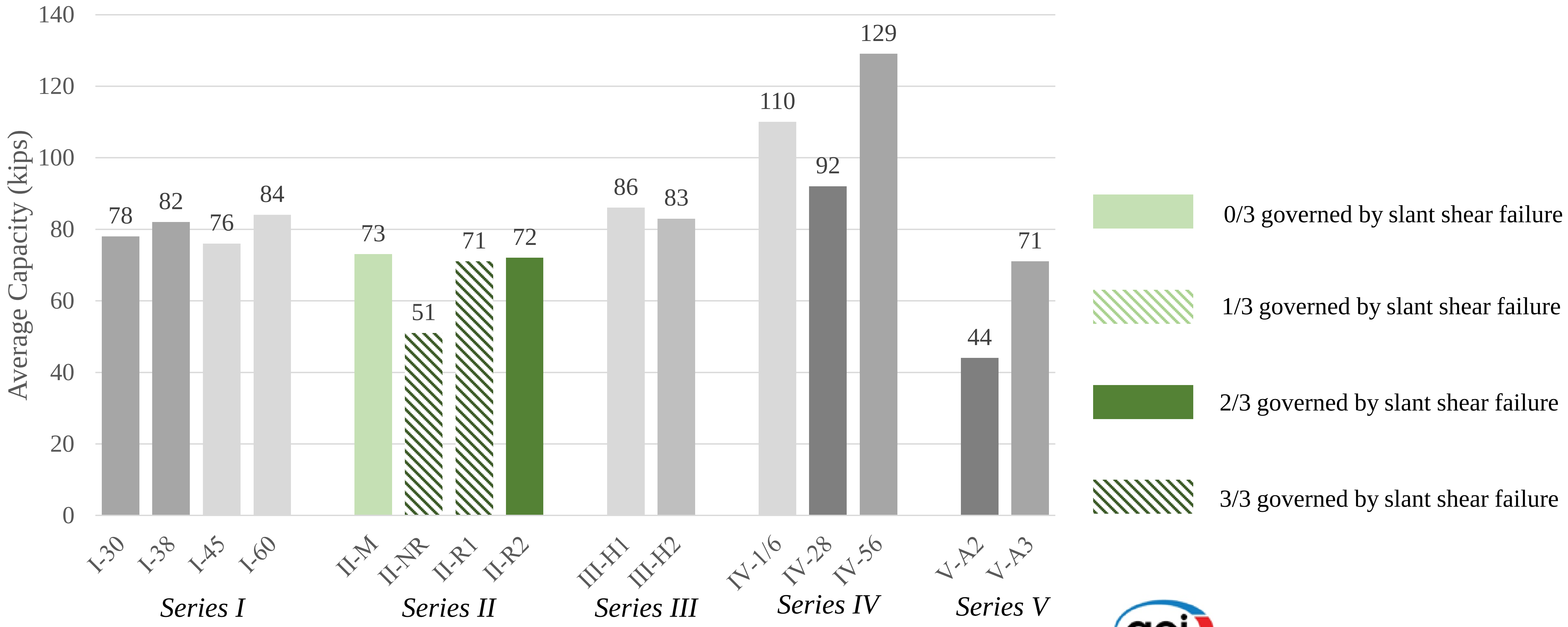
EXPERIMENTAL RESULTS

Series I – Inclination: Alternate Failure Mode



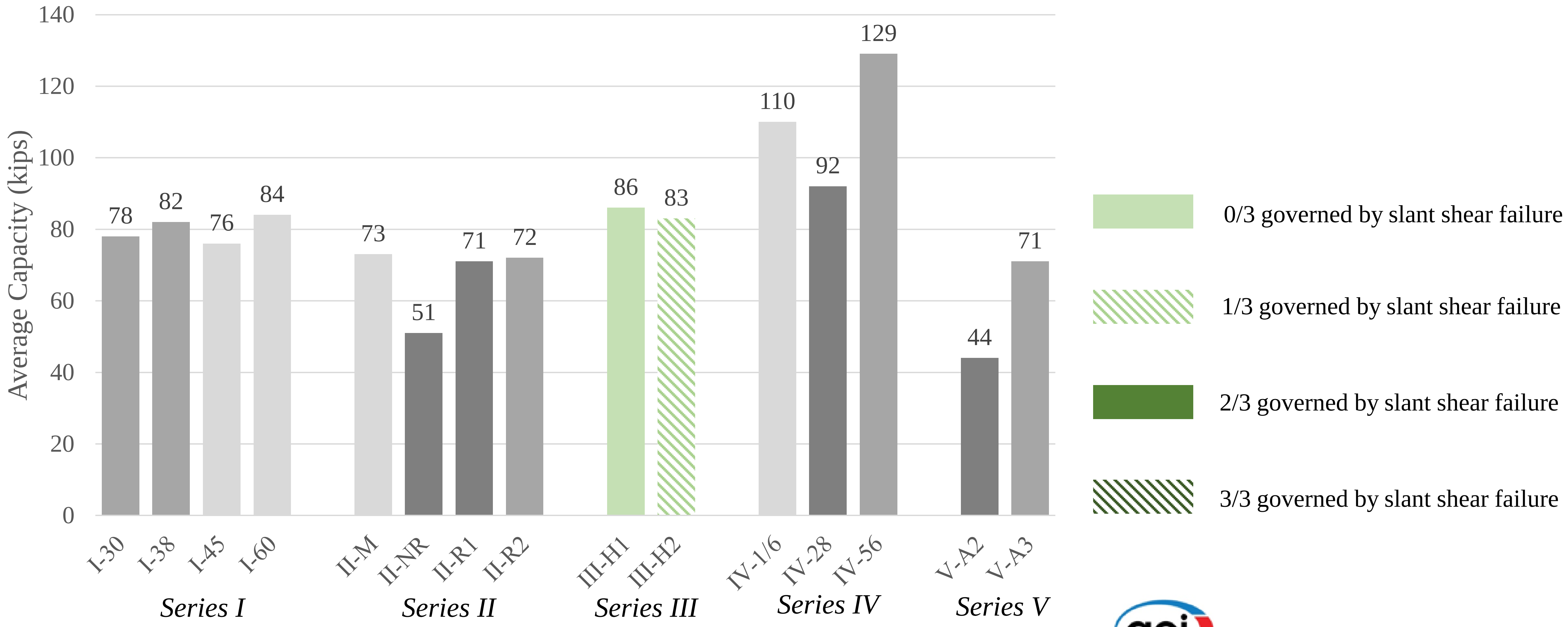
EXPERIMENTAL RESULTS

Series II – Interface Roughness: Capacity Decrease with Roughness



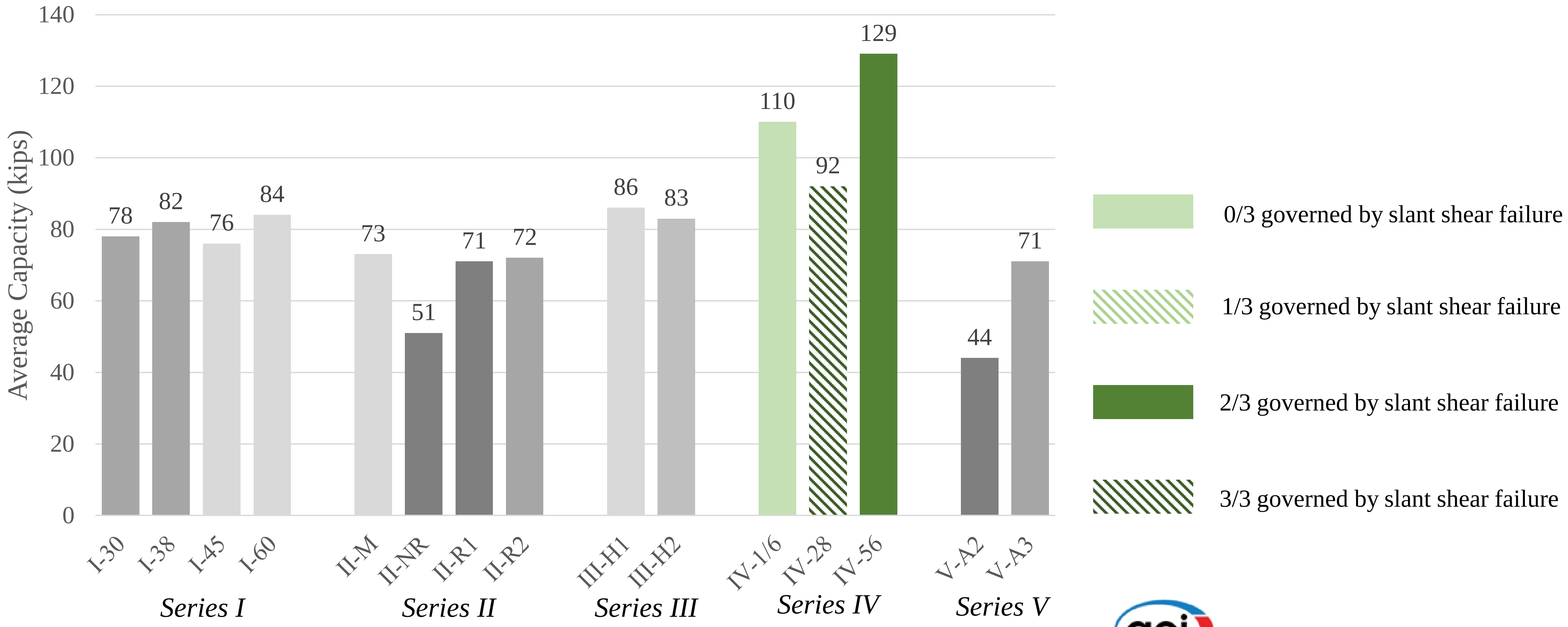
EXPERIMENTAL RESULTS

Series III – Variation of Concrete Strength: Crushing at Weaker Layer



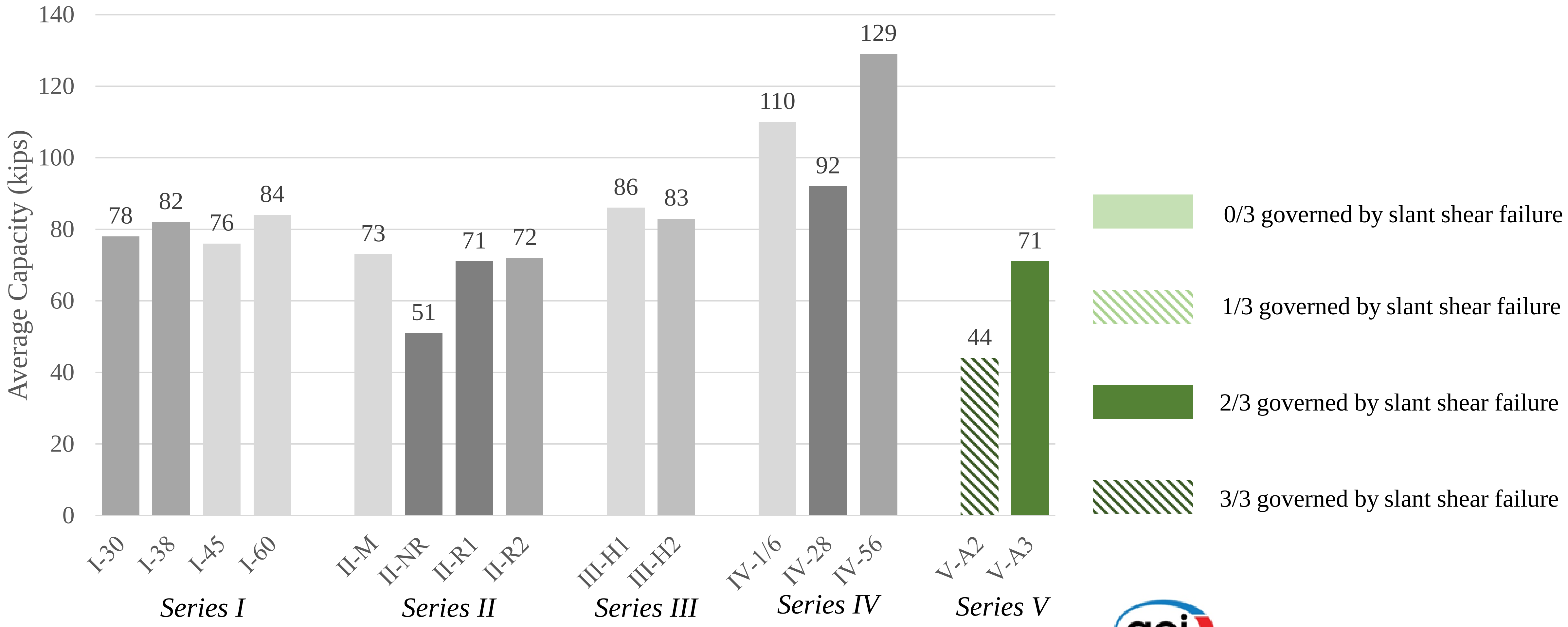
EXPERIMENTAL RESULTS

Series IV – Casting Age Difference: Capacity Increase with Age Difference



EXPERIMENTAL RESULTS

Series V – Aggregate Size: Capacity Decrease with Aggregate Size



CODE EVALUATION

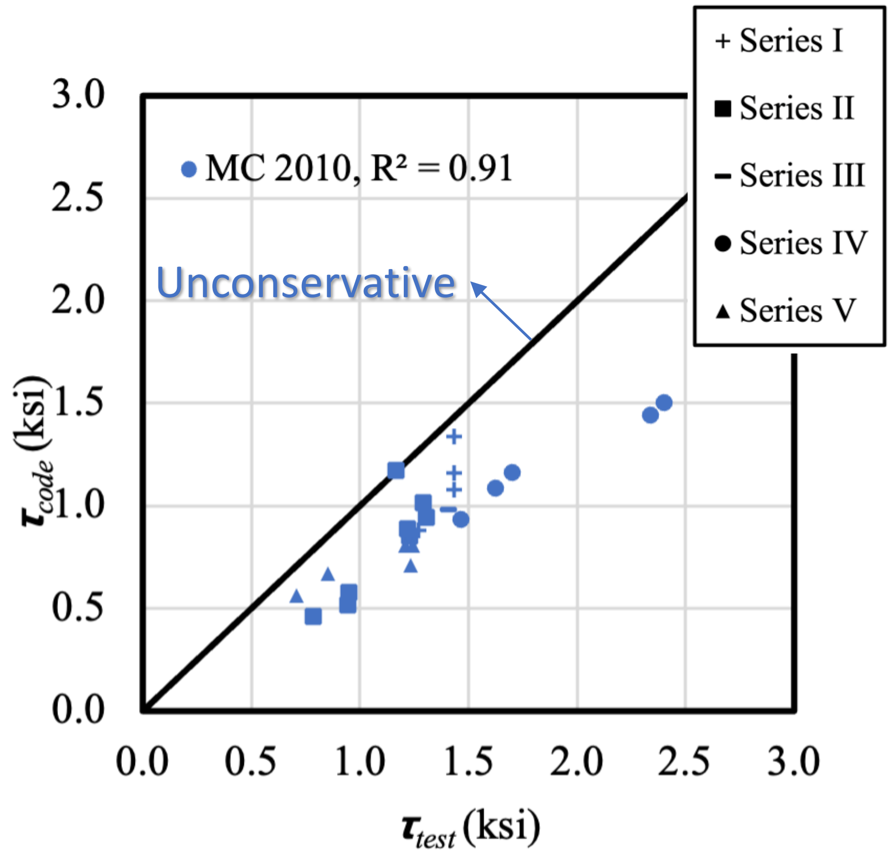
Roughening with 0.125-inch amplitude was applied to the specimens

Design code	Amplitude (in.)	c (ksi)	μ	Design Expression
AASHTO LRFD	< 0.25	0.075	0.6	$\tau_n = c + \mu(\rho f_y + \sigma_n)$
	≥ 0.25	0.24	1.0	
ACI 318-19	< 0.25	N/A	0.6λ	$\tau_n = \mu(\rho f_y sin\alpha + \sigma_n) + \rho f_y cos\alpha$
	≥ 0.25	N/A	1.0λ	
CSA A23.3:19	< 0.2	0.036	0.6	$\tau_n = \lambda[c + \mu(\rho f_y sin\alpha + \sigma_n)] + \rho f_y cos\alpha$
	≥ 0.2	0.073	1.0	

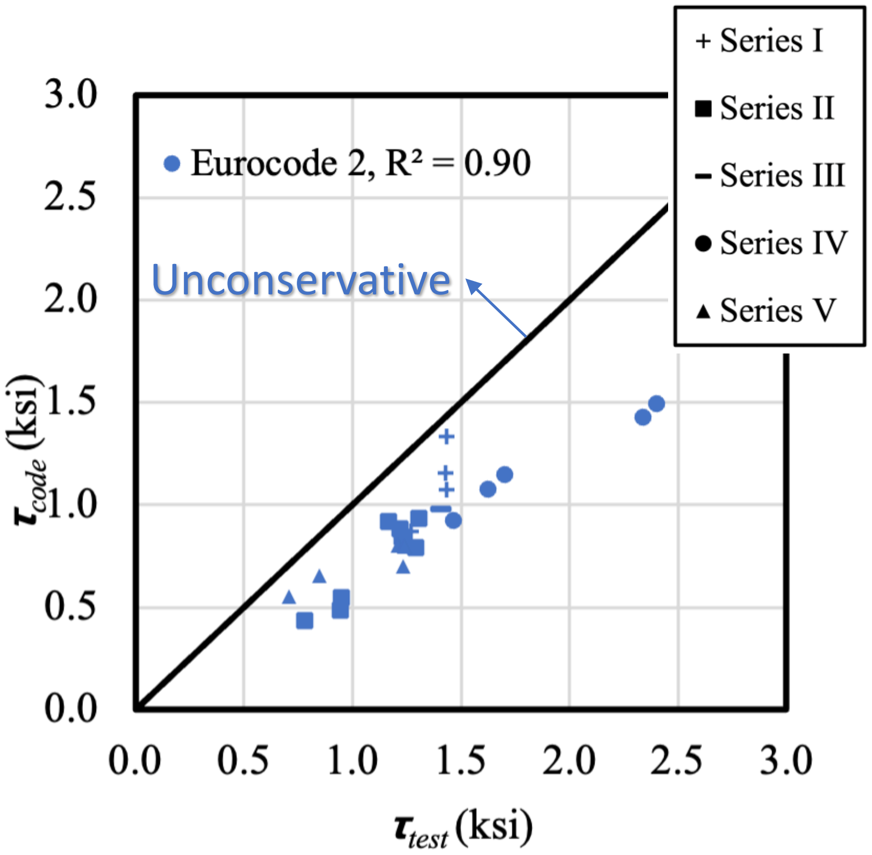
Design code	Amplitude (in.)	c_a	μ	Design Expression
fib MC2010	< 0.06	0.35	0.6	$\tau_n = c_a f_{ctd} + \mu(\rho f_y sin\alpha + \sigma_n) + \rho f_y cos\alpha$
	$\geq 0.06, < 0.12$	0.45	0.7	
	≥ 0.12	0.5	0.9	
Eurocode 2	< 0.12	0.2	0.6	$\tau_n = c_a f_{ctd} + \mu(\rho f_y sin\alpha + \sigma_n) + \rho f_y cos\alpha$
	≥ 0.12	0.4	0.7	

CODE EVALUATION

Current Design Code



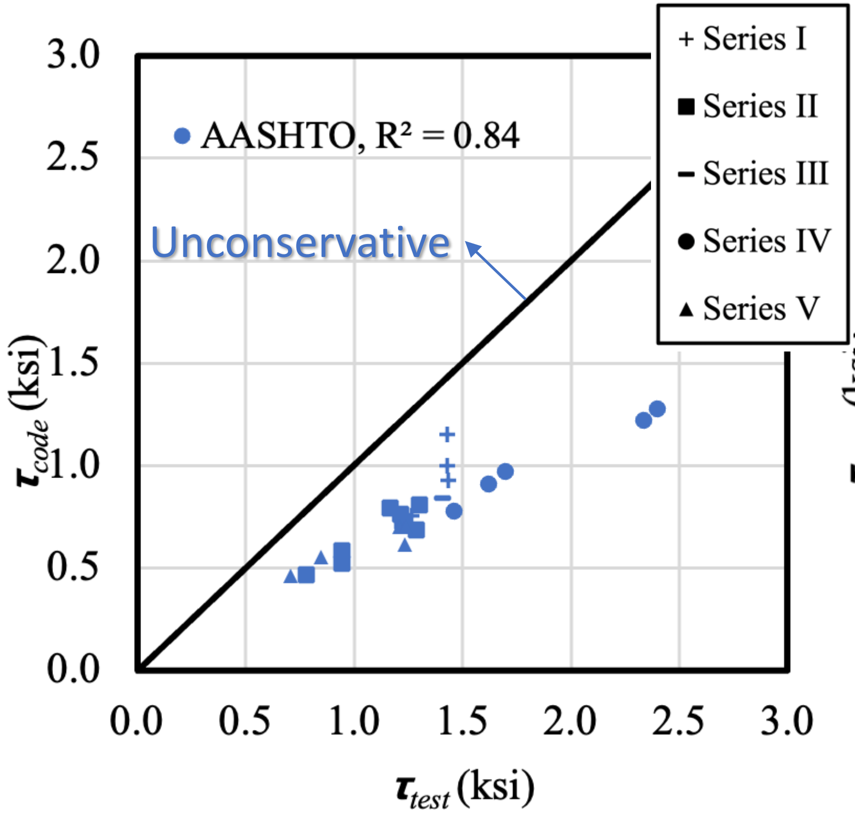
fib MC2010



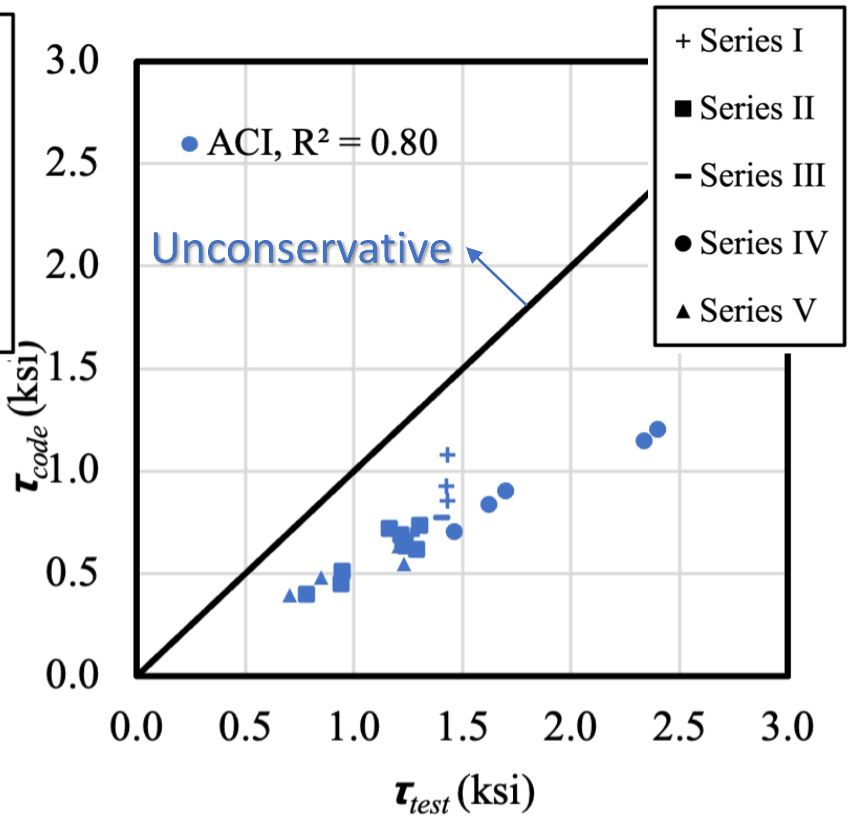
Eurocode 2

CODE EVALUATION

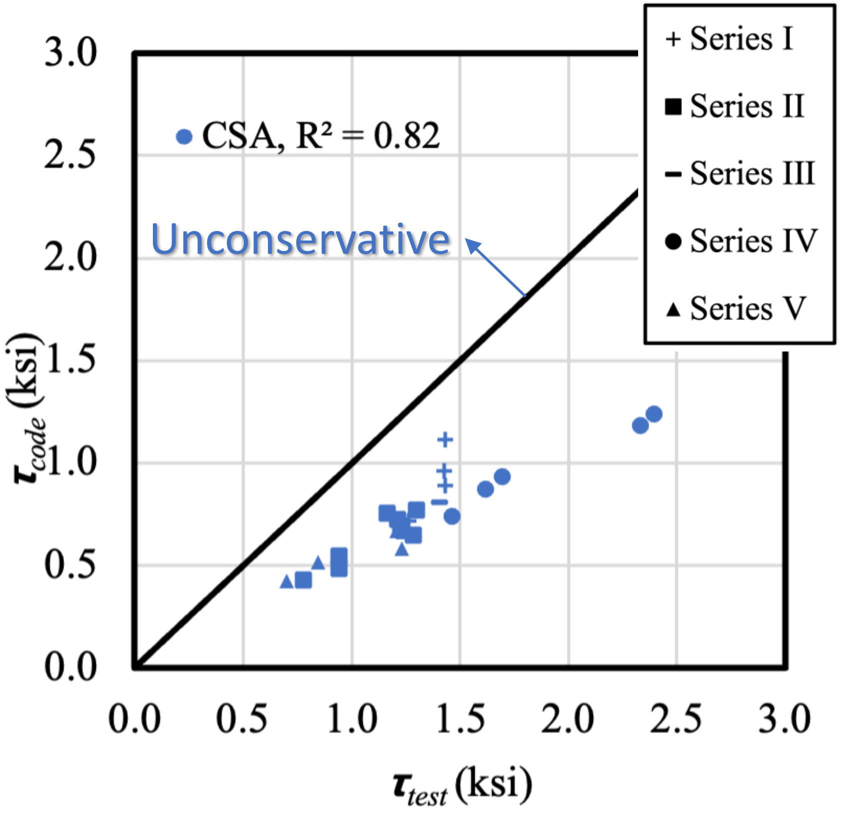
Current Design Code



AASHTO LRFD (2020)



ACI 318-19



CSA A23.3:19

CODE EVALUATION

RI Approach - define cold joint as roughened interface disregarding the amplitude

Design code	Amplitude (in.)	c (ksi)	μ	Design Expression
AASHTO LRFD	$<\ 0.25$	0.075	0.6	$\tau_n = c + \mu(\rho f_y + \sigma_n)$
	$\geq\ 0.25$	0.24	1.0	
ACI 318-19	$<\ 0.25$	N/A	0.6λ	$\tau_n = \mu(\rho f_y sin\alpha + \sigma_n) + \rho f_y cos\alpha$
	$\geq\ 0.25$	N/A	1.0λ	
CSA A23.3:19	$<\ 0.2$	0.036	0.6	$\tau_n = \lambda[c + \mu(\rho f_y sin\alpha + \sigma_n)] + \rho f_y cos\alpha$
	$\geq\ 0.2$	0.073	1.0	

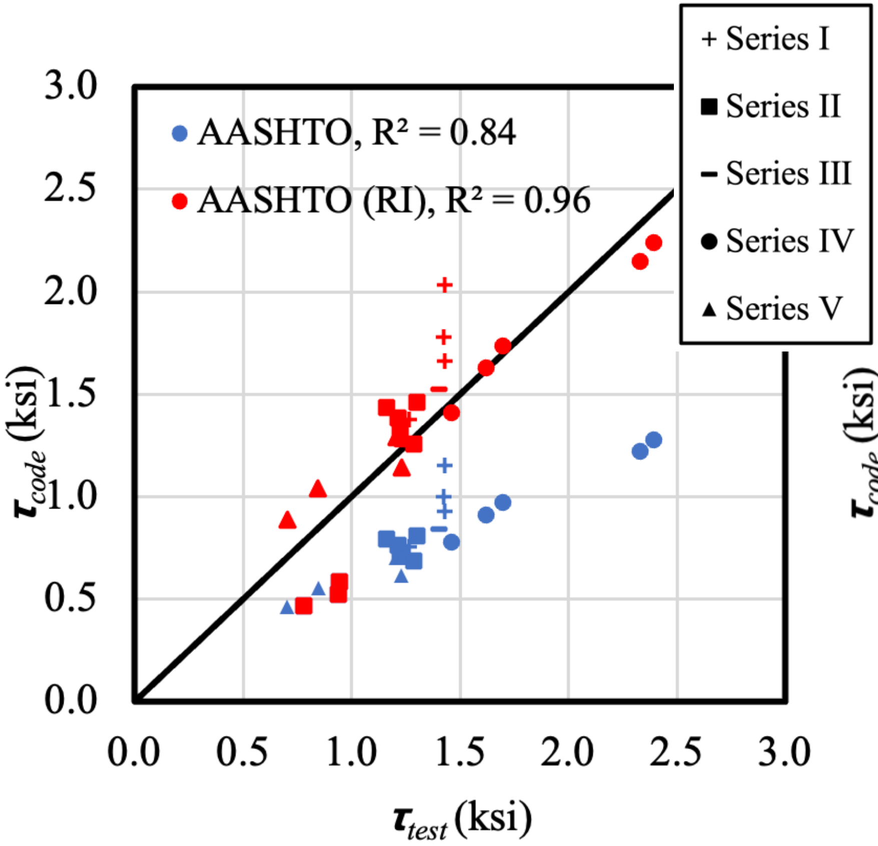
Design code	Amplitude (in.)	c_a	μ	Design Expression
fib MC2010	$<\ 0.06$	0.35	0.6	$\tau_n = c_a f_{ctd} + \mu(\rho f_y sin\alpha + \sigma_n) + \rho f_y cos\alpha$
	$\geq\ 0.06, < 0.12$	0.45	0.7	
	$\geq\ 0.12$	0.5	0.9	
Eurocode 2	$<\ 0.12$	0.2	0.6	$\tau_n = c_a f_{ctd} + \mu(\rho f_y sin\alpha + \sigma_n) + \rho f_y cos\alpha$
	$\geq\ 0.12$	0.4	0.7	

CODE EVALUATION

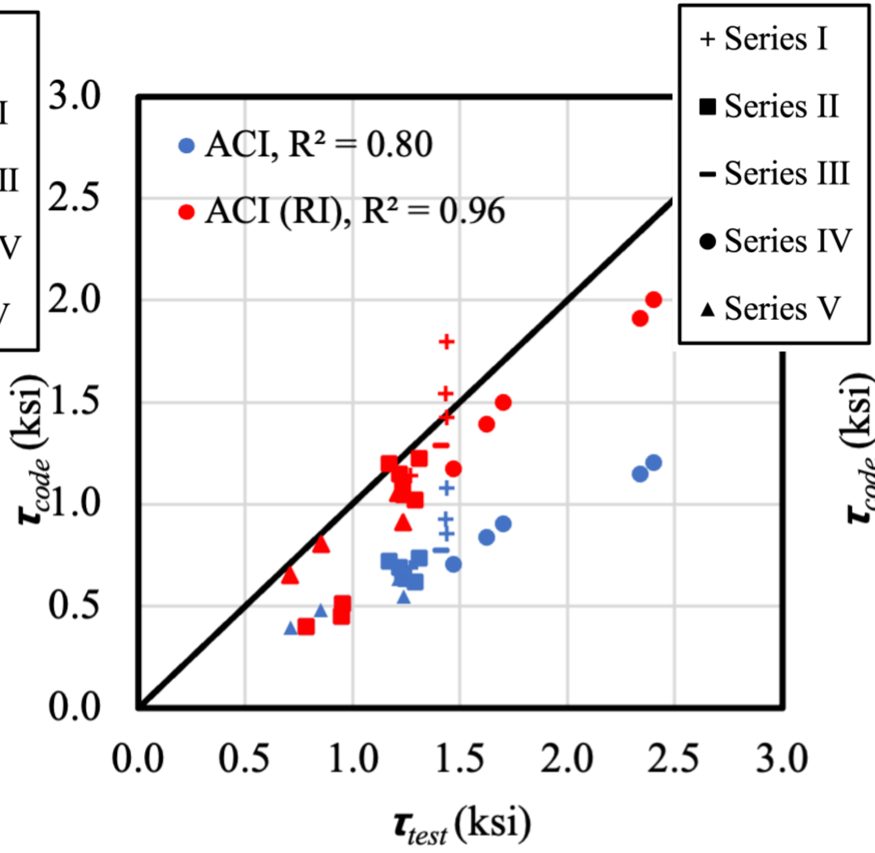
RI Approach

✓ Accuracy of estimations is improved

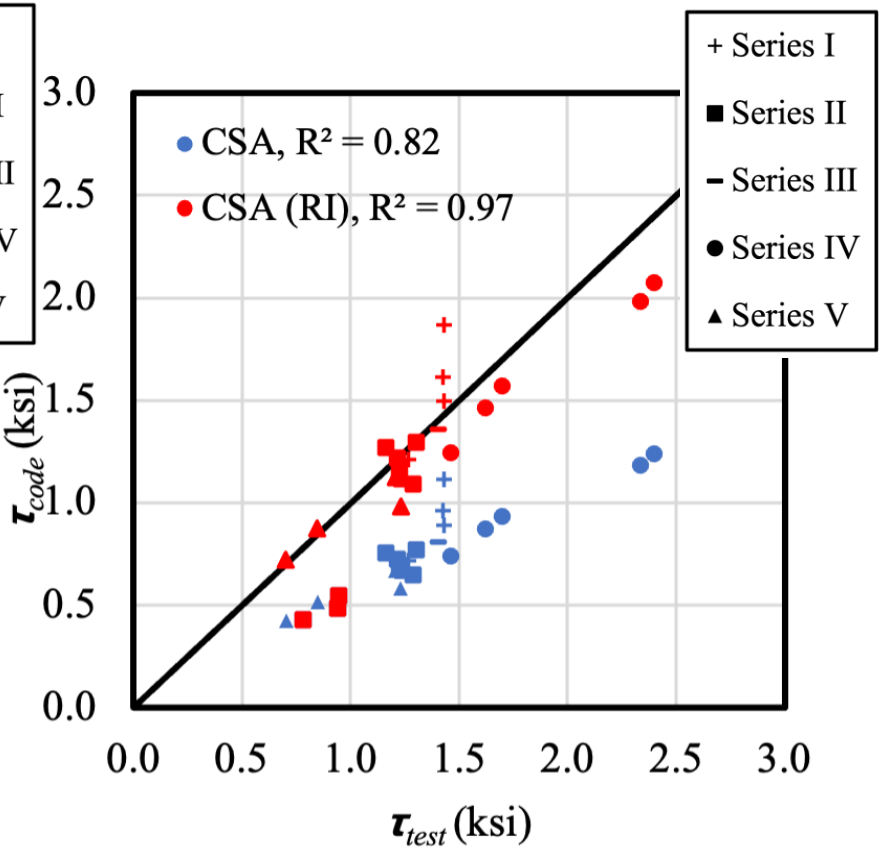
× Numerous unconservative cases were observed



AASHTO LRFD (2020)



ACI 318-19

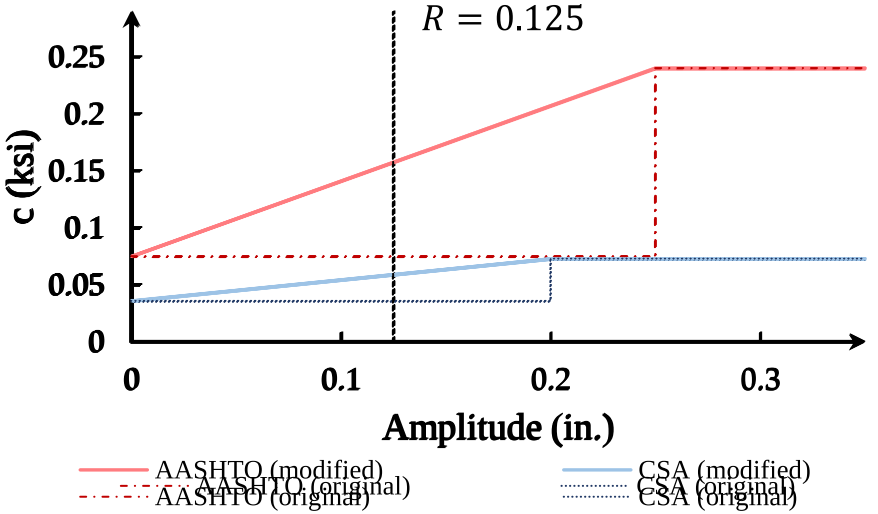


CSA A23.3:19

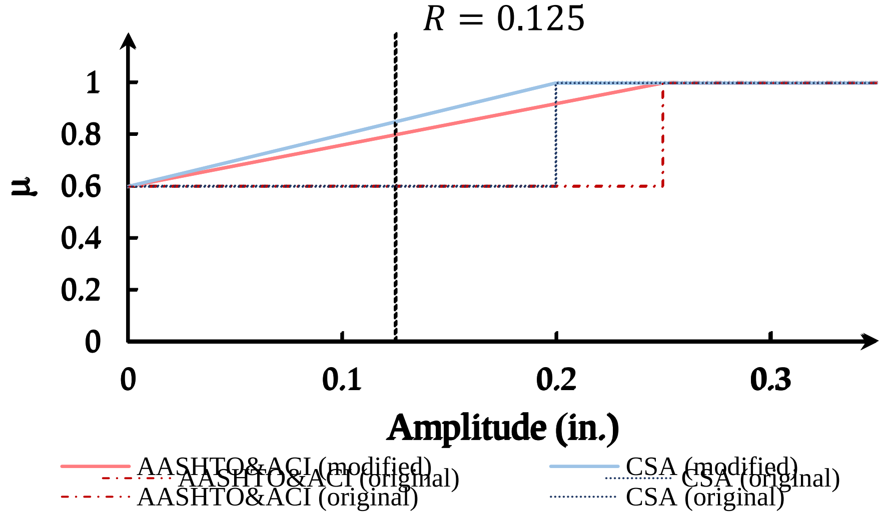
CODE EVALUATION

LIF Approach - factors are linear interpolated based on the roughness amplitude

Design code	Amplitude (in.)	*c* (ksi)	μ	Design Expression
AASHTO LRFD	< 0.25	0.075	0.6	$\tau_n = c + \mu(\rho f_y + \sigma_n)$
	≥ 0.25	0.24	1.0	
ACI 318-19	< 0.25	N/A	0.6λ	$\tau_n = \mu(\rho f_y sin\alpha + \sigma_n) + \rho f_y cos\alpha$
	≥ 0.25	N/A	1.0λ	
CSA A23.3:19	< 0.2	0.036	0.6	$\tau_n = \lambda[c + \mu(\rho f_y sin\alpha + \sigma_n)] + \rho f_y cos\alpha$
	≥ 0.2	0.073	1.0	



Cohesion Factor

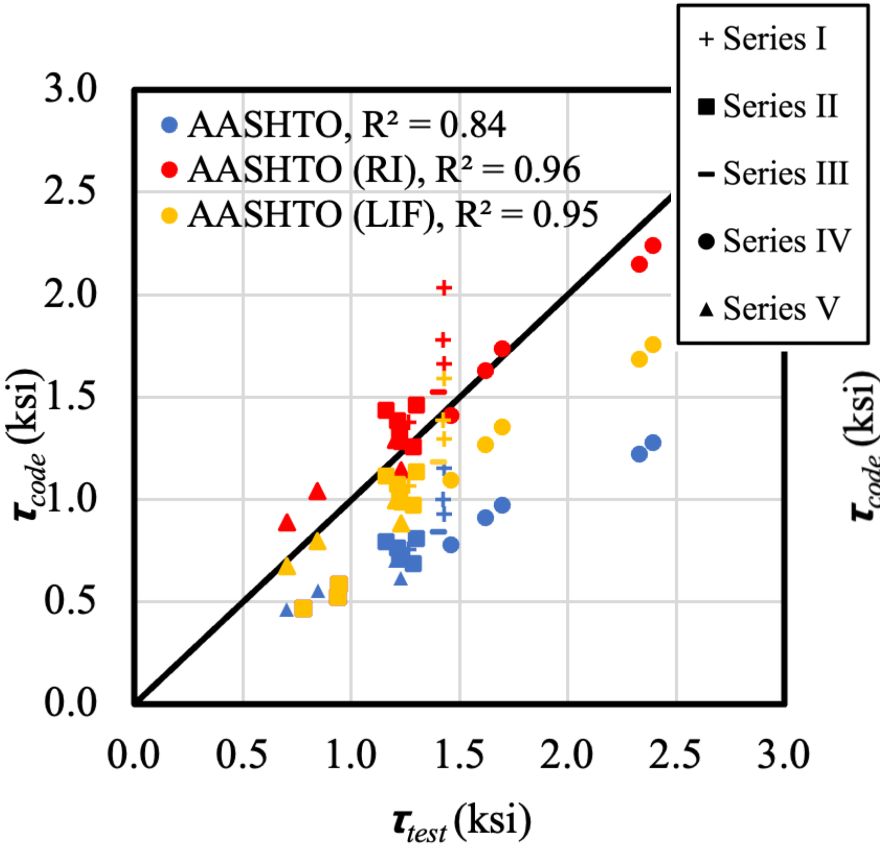


Friction Factor

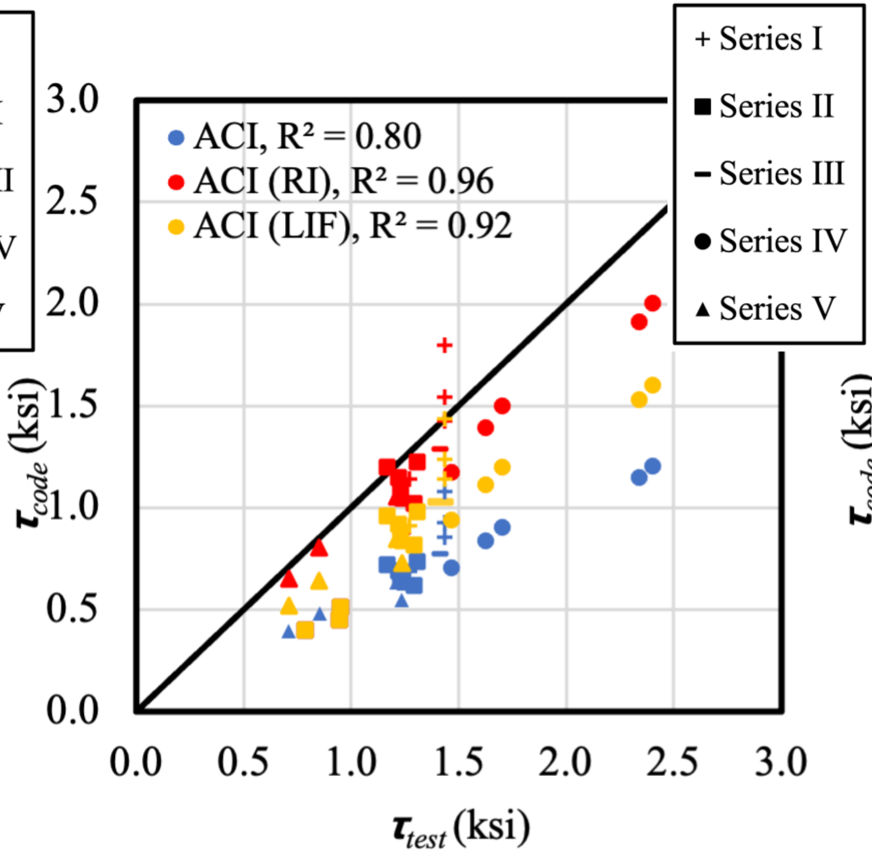
CODE EVALUATION

LIF Approach

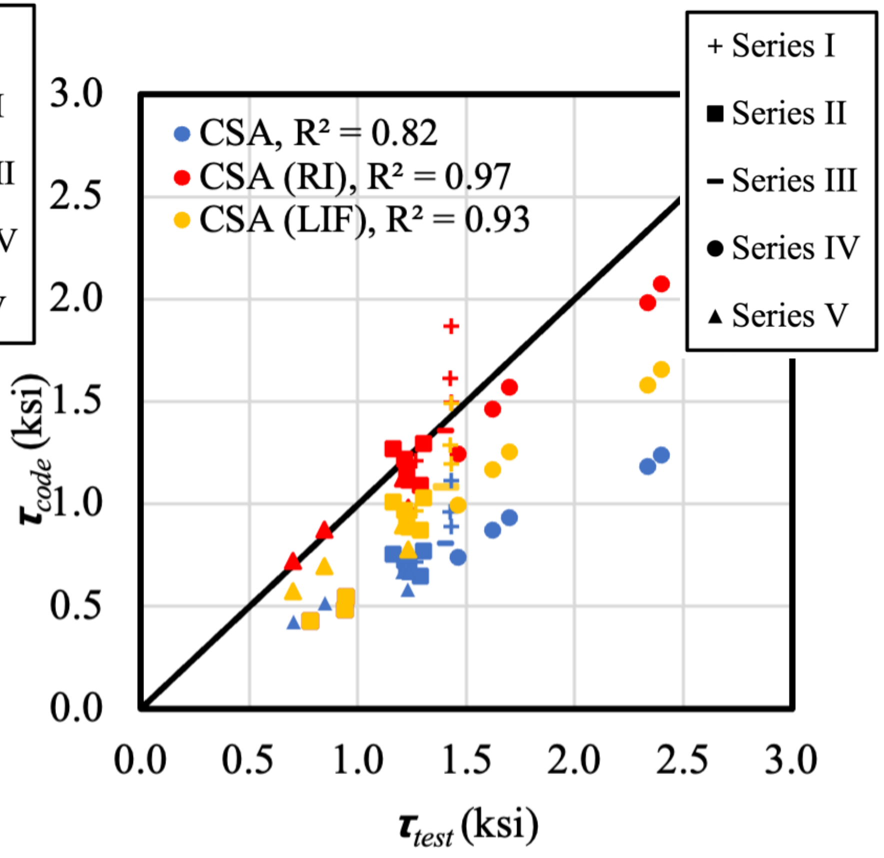
- ✓ Accuracy of estimations is improved
- ✓ Only a few unconservative cases were observed



AASHTO LRFD (2020)



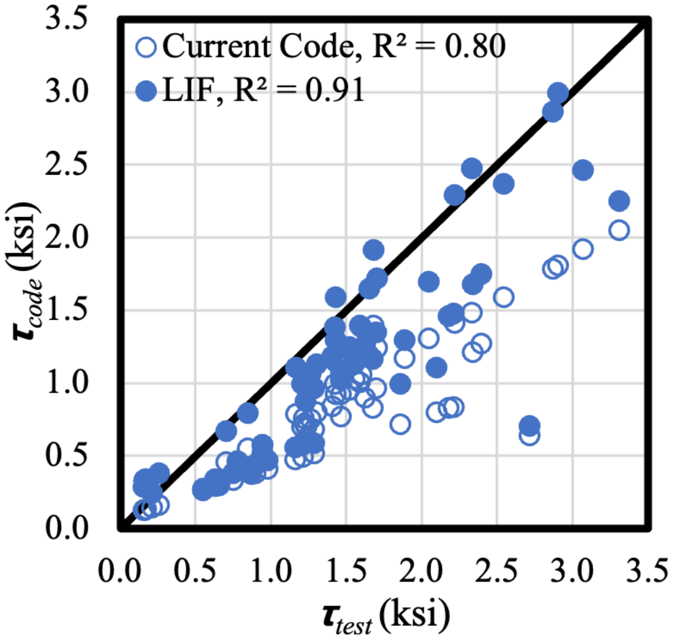
ACI 318-19



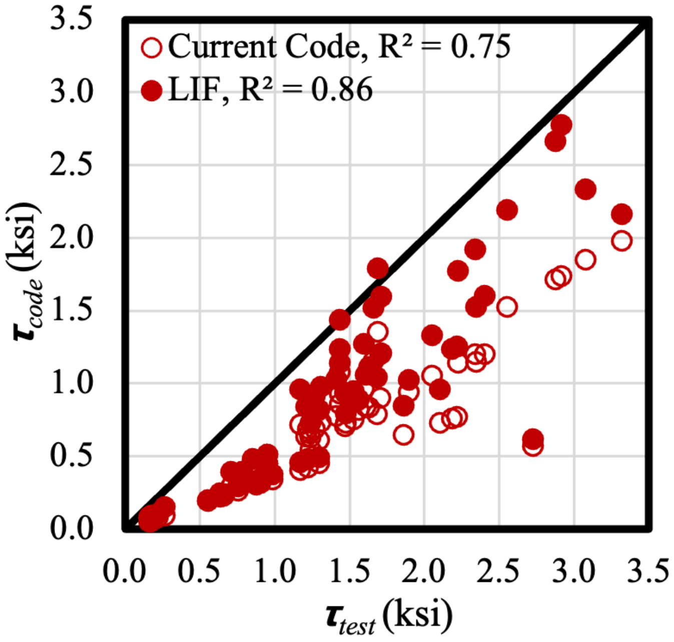
CSA A23.3:19

DATABASE ANALYSIS

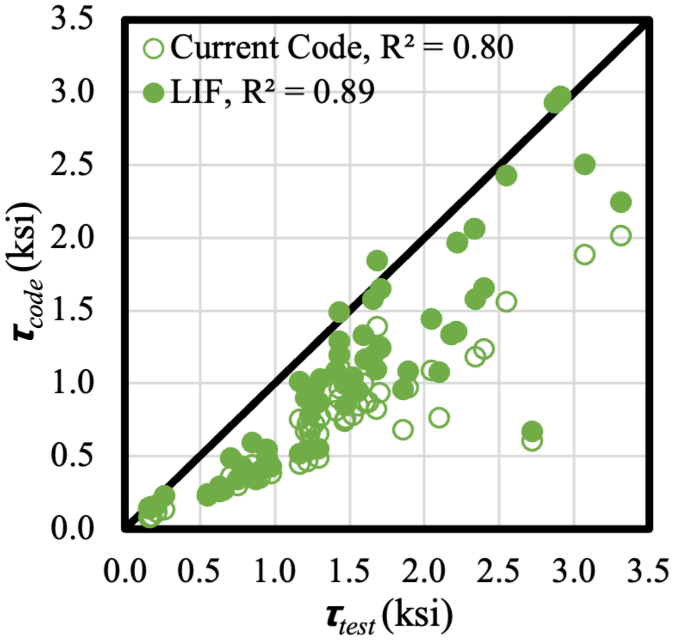
Source	Number of Specimens	Geometry	θ_{cj} (°)	R_a (in.)	D (in.)	Roughening Approach
Figueiredo et al.	75	cylindrical	30	0.034 – 0.22	5.51	hand-scrubbing; vibrating
Santos & Júlio	150	prismatic	30	0.01 – 0.048	5.91	wire-brushing; sandblasting; shotblasting; hand-scrubbing
Diab et al.	150	cylindrical	30	0.12, 0.24	5.91	patterned groves
Saldanha et al.	12	prismatic	30	0.197, 0.59	5.91	hand-scrubbing; patterned groves
Hu et al.	96	cylindrical	30, 40	0.12, 024	2.77	patterned groves



AASHTO LRFD (2020)



ACI 318-19



CSA A23.3:19

CONCLUSIONS & FUTURE WORK

CONCLUSIONS

- Applying intentional roughening and using larger aggregate size improve the capacity of cold joint significantly.
- The control failure mode switch from slant shear to compression failure by increase the inclination.
- Cold joint capacity estimated by LIF demonstrate better alignment with the experimental results.
- LIF is more impactful on intentionally roughened interface with higher shear capacity.

FUTURE WORK

- Large scale slant shear column
- Deep beam with cold joint
- Drill-shaft footing with expansion
- Shear-slip relationship of interface for FEA

Thank You!

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