MODULAR CONNECTION TECHNOLOGIES FOR SC WALLS OF SMRs

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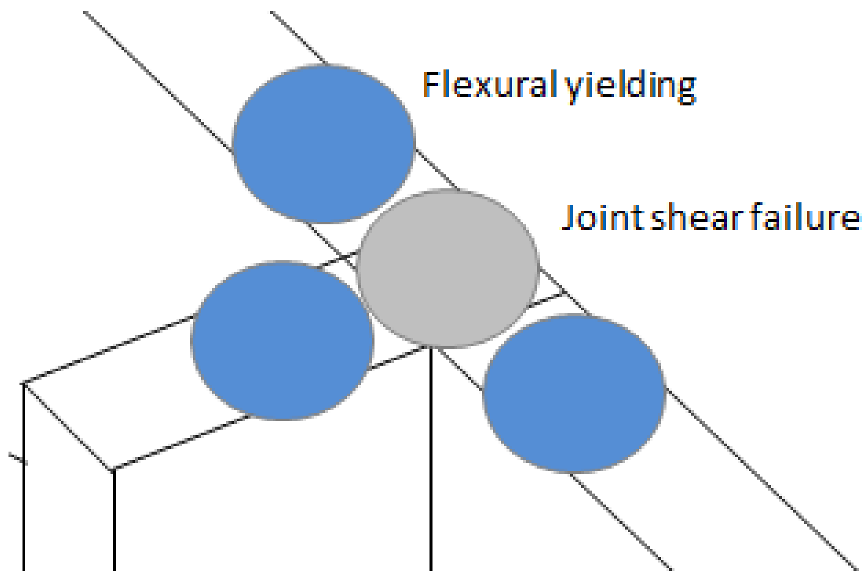
OUTLINE

- SC Wall-to-Wall T Connection
- SC Wall-to-Wall L Connection
- Benchmarking Analysis
- SC Slab-to-Wall Connection
- Findings

SC WALL-TO-WALL T CONNECTION
DESIGN PHILOSOPHY

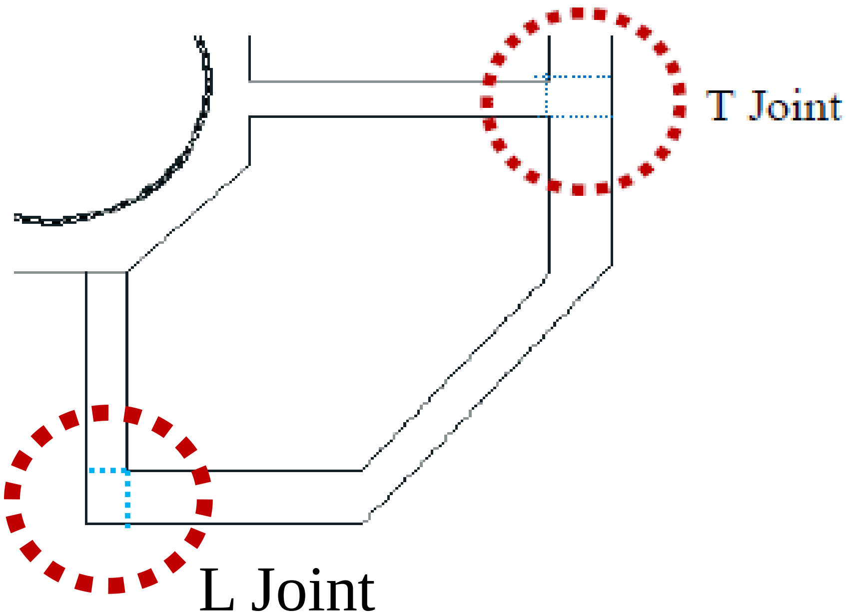
- Full-strength connection design philosophy
  - Develops the expected strength
- Implementation of full-strength design
  - Two parts in SC wall joints
    - SC wall and SC wall joints
  - Desired failure mode
    - Flexural yielding (ductile) – plastic hinges



SC WALL-TO-WALL T CONNECTION
DESIGN PHILOSOPHY

- SC wall-to-wall joints in the CIS
  - Common joint configurations (T and L)
- Implementation of full-strength design
  - The required joint shear strength
    - Based on the force transfer mechanism
  - Calculation of the available joint shear strength
    - ACI 349-06 equation
    - γ = 12 for SC wall T-joints
    - γ = 8 for SC wall L-joints
    - Verification is required

$$V_n = \gamma\sqrt{f_c'}A_j$$



SC WALL-TO-WALL T CONNECTION

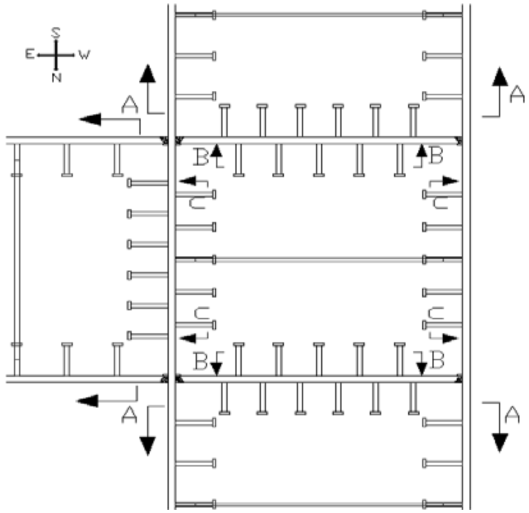
Experimental Program

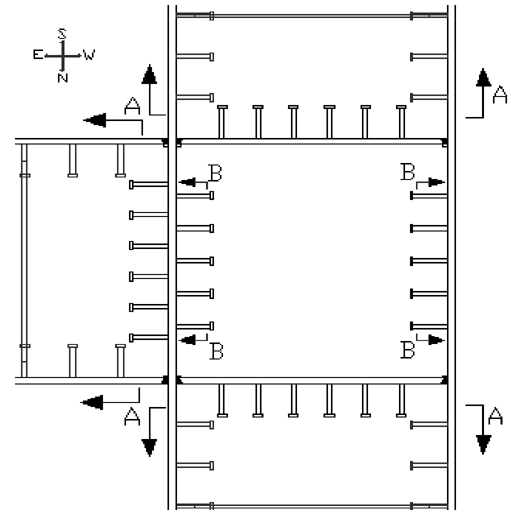
- Four full-scale SC wall T-joint shear specimens
  - T = 30 in.
  - To evaluate the influence of (i) the shear reinforcement ratio and (ii) The steel headed stud layout
  - Designed to undergo joint shear failure

Specimen	Steel faceplate thickness, t_p (in.)	Steel tie plate dimension		No. of tie plates in the Joint	Shear Stud Layout
		Continuous SC wall	Discontinuous SC wall		
JS-T1-F	0.75	$3^3/_4$ x $^5/_{16}$ in.	$3^3/_4$ x $^1/_2$ in.	1	F
JS-T0-F	0.75	$3^3/_4$ x $^5/_{16}$ in.	$3^3/_4$ x $^1/_2$ in.	0	F
JS-T0-P	0.75	$3^3/_4$ x $^5/_{16}$ in.	$3^3/_4$ x $^1/_2$ in.	0	P
JS-T2-F	0.75	$3^3/_4$ x $^5/_{16}$ in.	$3^3/_4$ x $^1/_2$ in.	2	F

SC WALL-TO-WALL T CONNECTION

Experimental Program





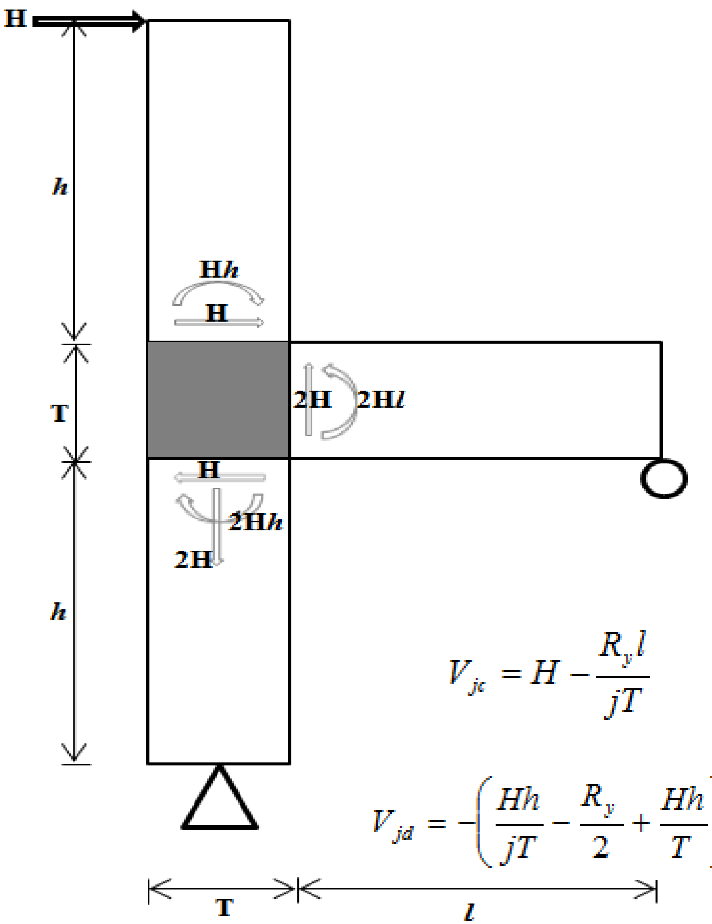
- Material properties

Specimen	Faceplates		Tie plates		Studs	Concrete, psi
	F_y, ksi	F_u, ksi	F_y, ksi	F_u, ksi	F_u, ksi	
JS-T1-F	58.6	83.9	60.4	69.1	74.0	6,473
JS-T0-F	58.0	77.0	62.7	73.5	80.9	6,402
JS-T0-P	58.0	77.0	62.7	73.5	80.9	6,502
JS-T2-F	58.5	78.6	62.7	73.5	80.9	6,504
						Avg = 6,502

SC WALL-TO-WALL T CONNECTION

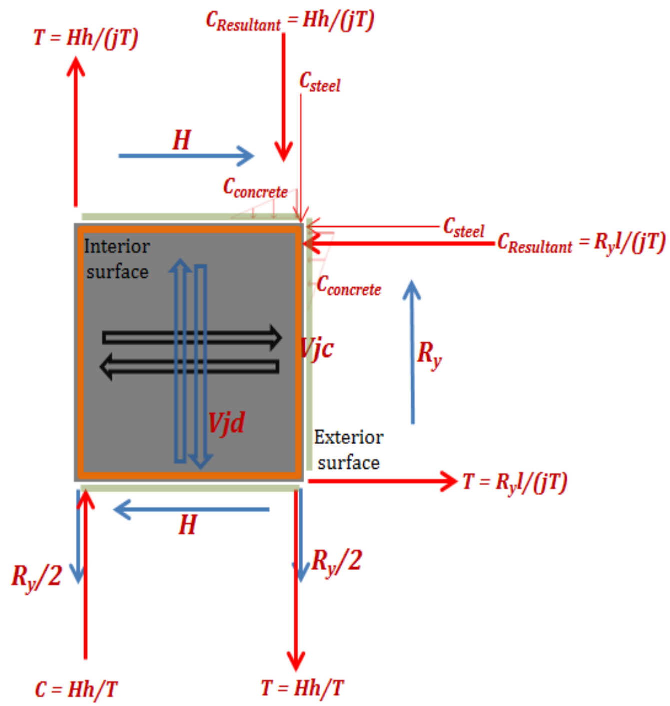
Experimental Program

- Boundary conditions and joint shear force terms



$$V_{jc} = H - \frac{R_y l}{jT}$$

$$V_{jd} = -\left(\frac{Hh}{jT} - \frac{R_y}{2} + \frac{Hh}{T}\right)$$

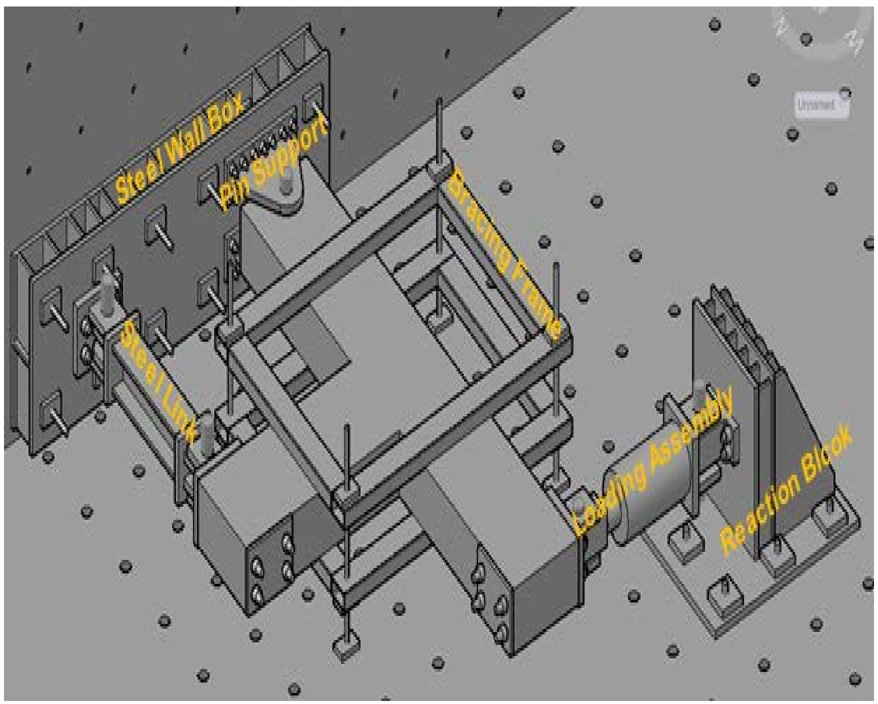


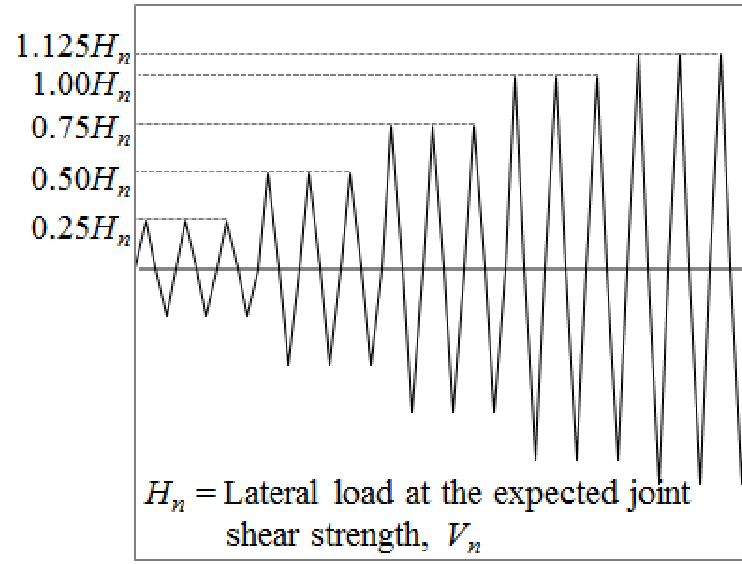
$$V_{jc} = H - \frac{R_y l}{jT}$$

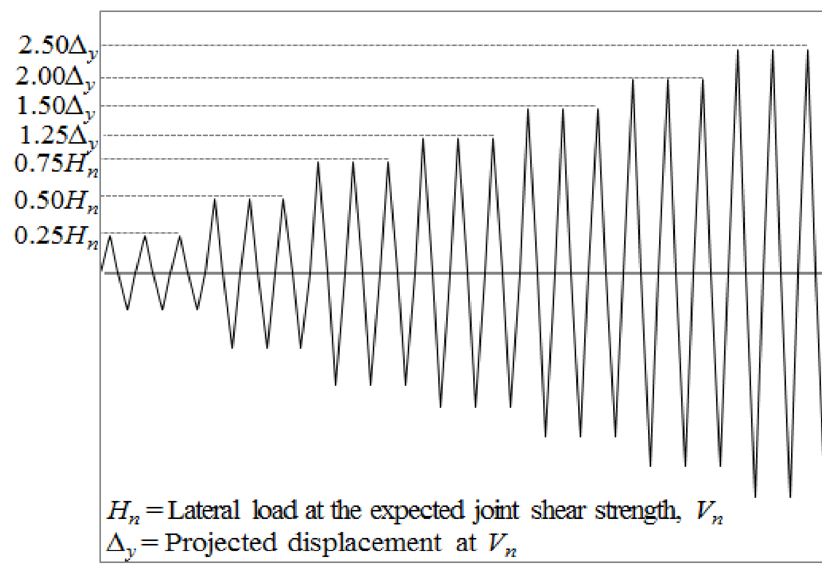
$$V_{jd} = -\left(\frac{Hh}{jT} - \frac{R_y}{2} + \frac{Hh}{T}\right)$$

SC WALL-TO-WALL T CONNECTION
Experimental Program

- Test-setup and loading protocol







SC WALL-TO-WALL T CONNECTION

Experimental Program

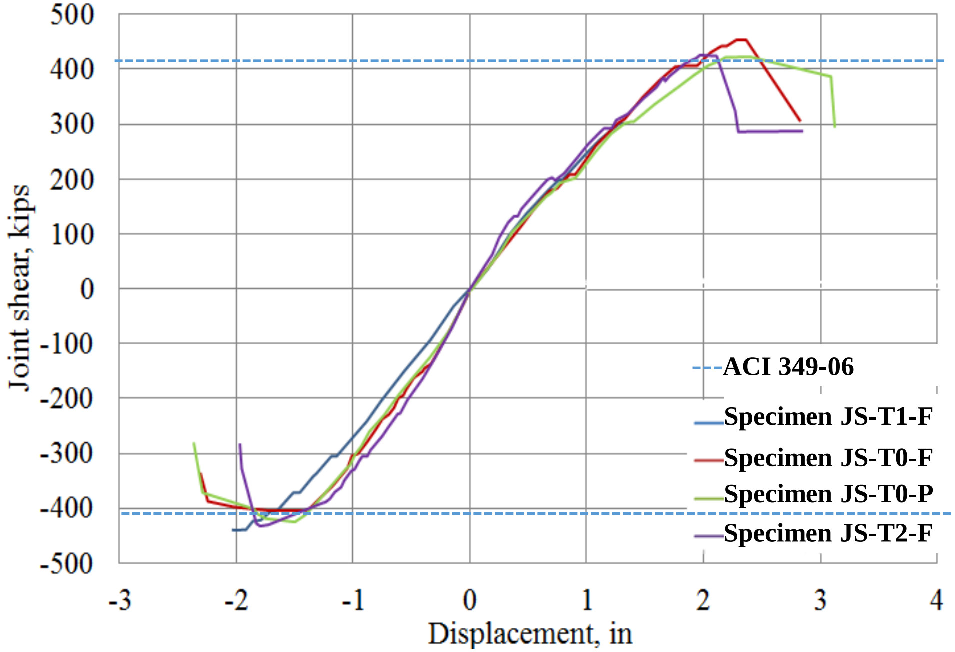
- Summary of experimental results

Specimen	Ultimate joint shear, kips	Shear strain at the ultimate joint shear	Governing failure mode	Event order in the Joint region
JS-T1-F	438.4	0.0049	Joint shear	Concrete crack ↓ Yielding of steel tie plate ↓ Extensive concrete cracking
JS-T0-F	455.5	0.0070	Joint shear	Concrete crack ↓ Extensive concrete cracking
JS-T0-P	427.8	0.0069	Joint shear	Concrete crack ↓ Extensive concrete cracking
JS-T2-F	431.6	0.0060	Joint shear	Concrete crack ↓ Yielding of steel tie plates ↓ Extensive concrete cracking

SC WALL-TO-WALL T CONNECTION

Experimental Program

- Joint shear – displacement response



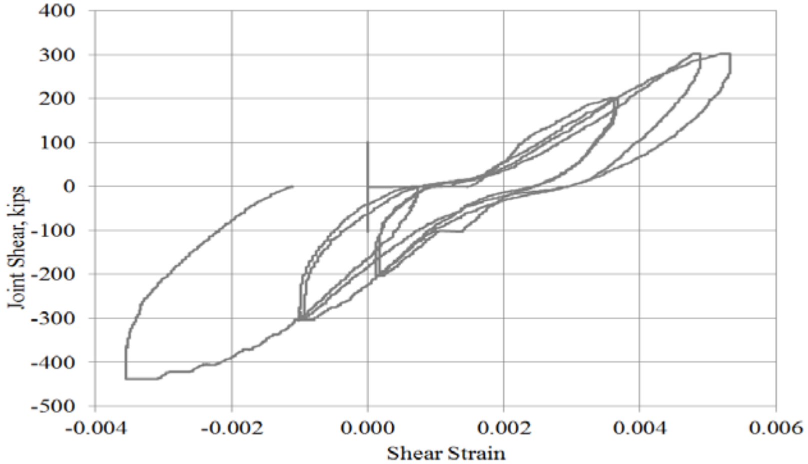
$V_{js} – \Delta'$

- V_{njs}^{TEST} within the range of 426.7 - 454 kips
- Greater than $V_{njs}^{ACI\text{-}exp}$ (413 kips) by 3.1 - 10.3%.

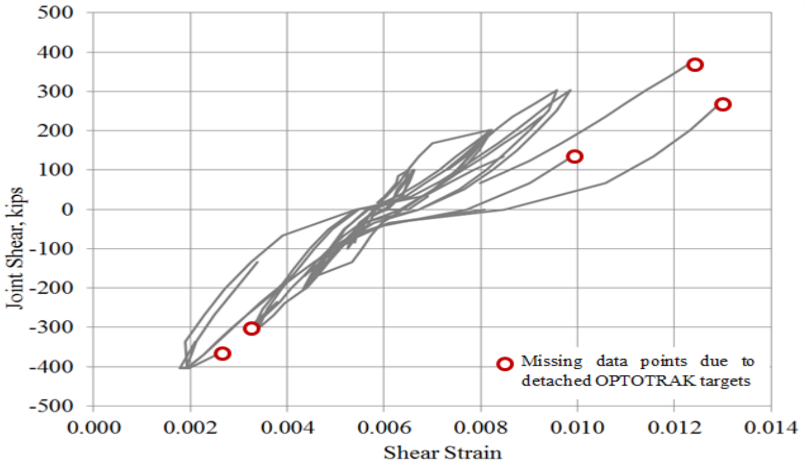
SC WALL-TO-WALL T CONNECTION

Experimental Program

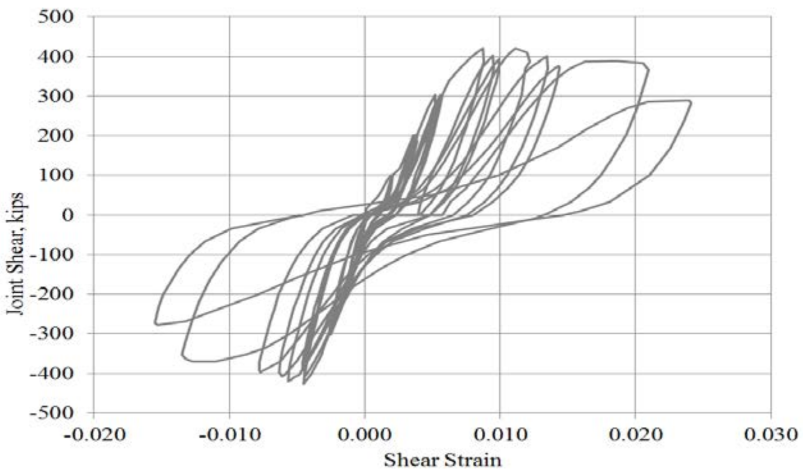
- Joint shear – shear strain response



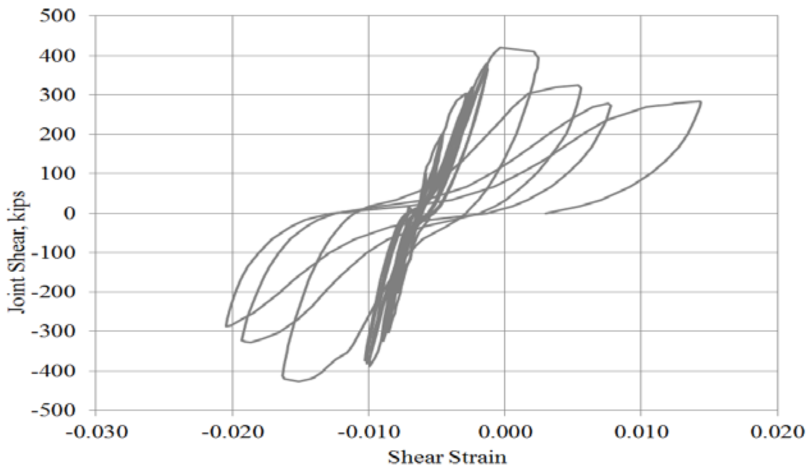
JS-T1-F



JS-T0-F



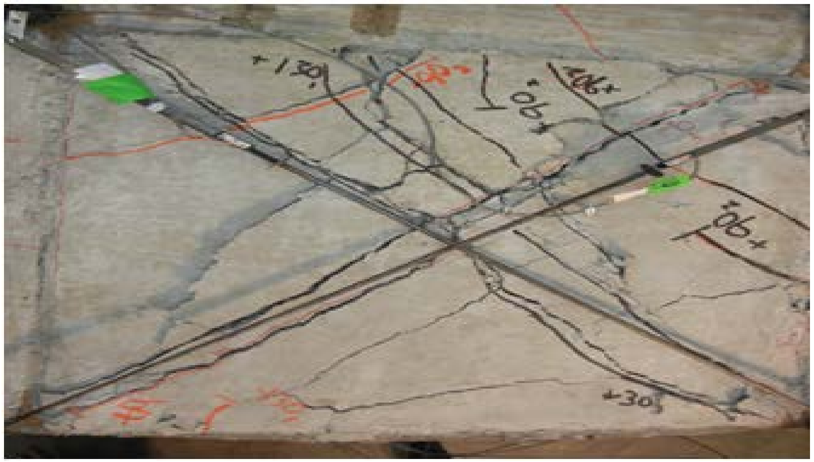
JS-T0-P



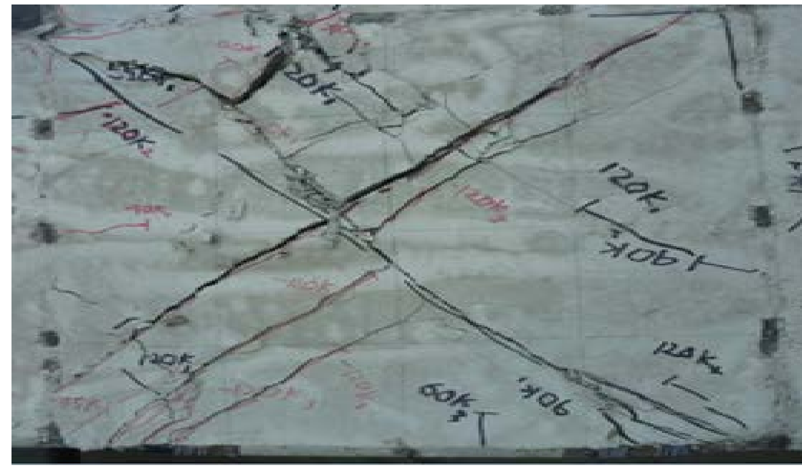
JS-T2-F

SC WALL-TO-WALL T CONNECTION
Experimental Program

- Crack pattern at the ultimate joint shear : all specimens



JS-T1-F



JS-T0-F

JS-T0-P

JS-T2-F

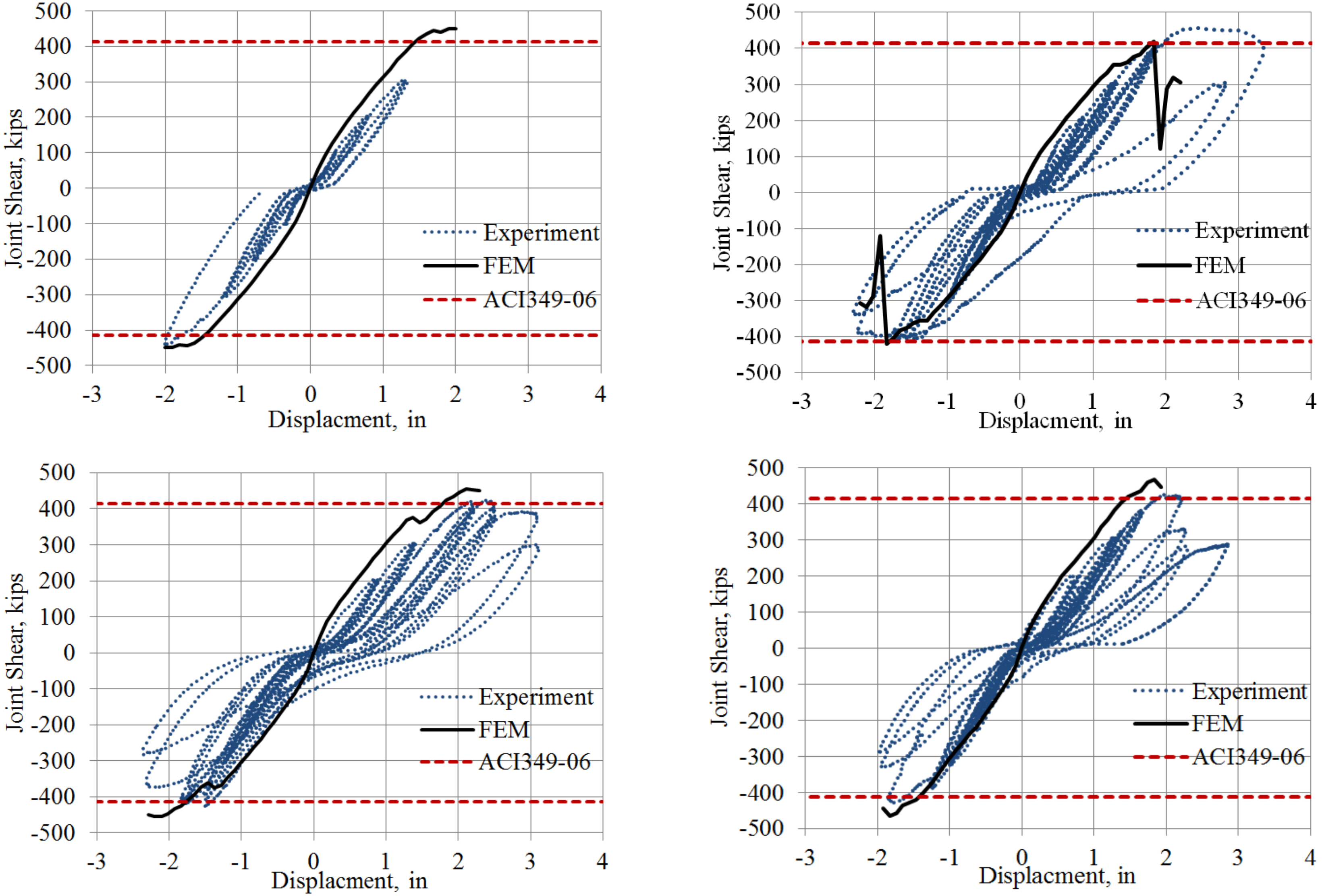
SC WALL-TO-WALL T CONNECTION
Benchmarking Analysis

- 3-D FE analysis for additional insights
- Comparison with experimental results
- ABAQUS explicit
  - The quasi static analysis
  - Shell (S4R) elements for steel, solid (C3D8R) elements for concrete, and Timoshenko beam elements (B32) for stud
  - Connector elements (CONN3D2)
- CEF concrete model
  - Elastic in compression, Uniaxial tension strength and post-peak behavior defined in CEB-FIP mc 90 (1993)
  - Element deletion to prevent excessive deformation
- Steel material model
  - Multi-axial plasticity theory
  - Idealized uniaxial stress-strain curve

SC WALL-TO-WALL T CONNECTION

Analysis Results

- Joint shear – displacement response



SC WALL-TO-WALL T CONNECTION

Benchmarking Analysis

- Summary

Specimen	Ultimate joint shear, kips	Shear strain at the ultimate joint shear	Governing failure mode	Event Order in the Joint region
JS-T1-F	450.0	0.0157	Joint shear	Concrete crack ↓ Yielding of steel tie plate ↓ Extensive concrete cracking
JS-T0-F	418	0.0142	Joint shear	Concrete crack ↓ Extensive concrete cracking
JS-T0-P	455.4	0.0164	Joint shear	Concrete crack ↓ Extensive concrete cracking
JS-T2-F	465.6	0.0147	Joint shear	Concrete crack ↓ Yielding of steel tie plates ↓ Extensive concrete cracking

SC WALL-TO-WALL L CONNECTION

Experimental Program

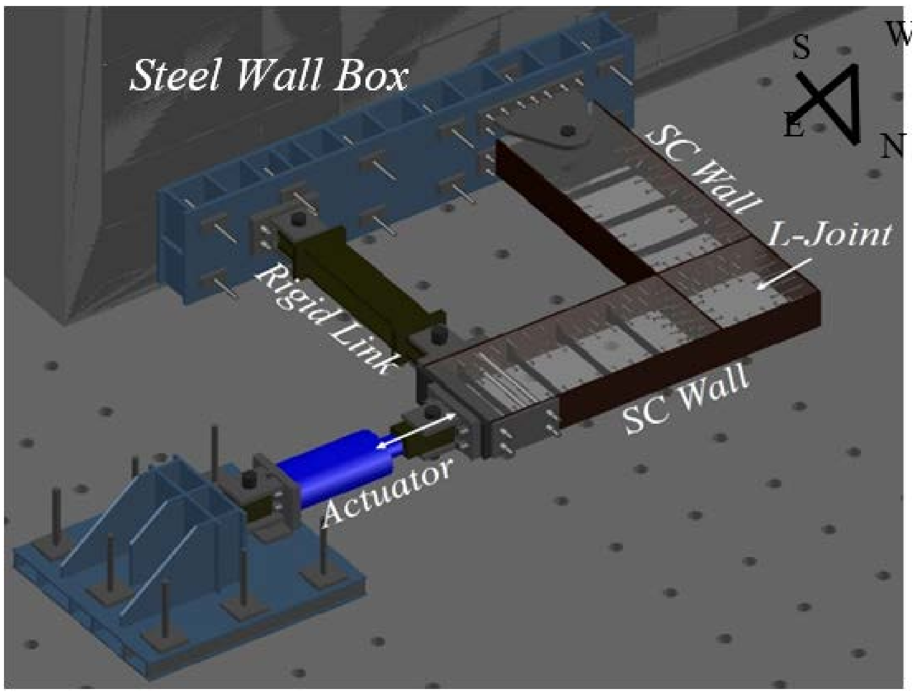
- One full-scale SC wall L-joint shear specimens
  - T = 30 in.
  - To experimentally investigate the joint shear behavior of SC wall-to-wall L joint
  - The same specimen design approach and test procedure from SC wall-to-wall T joint specimens

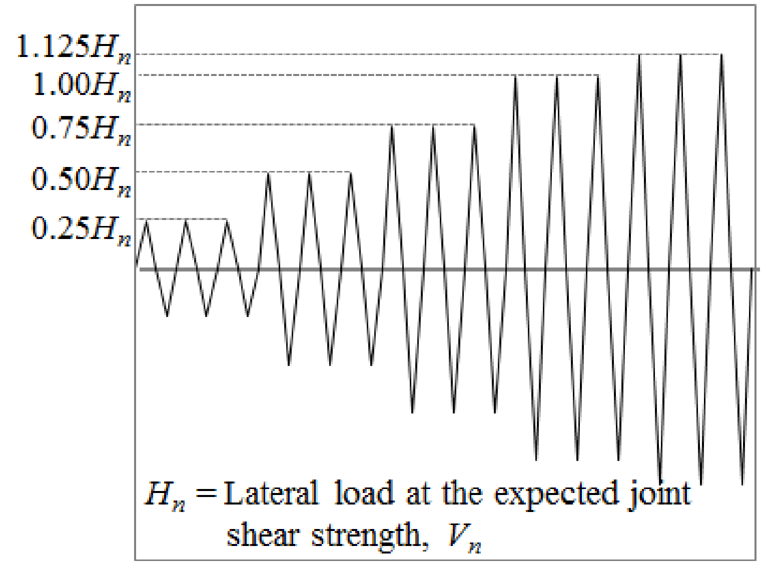
Specimen	Steel faceplate thickness, t_p (in.)	Steel tie plate dimension		No. of tie plates in the Joint	Shear Stud Layout
		Continuous SC wall	Discontinuous SC wall		
JS-L-T0-F	0.75	$3^3/_4$ x $^5/_{16}$ in.	$3^3/_4$ x $^1/_2$ in.	0	F

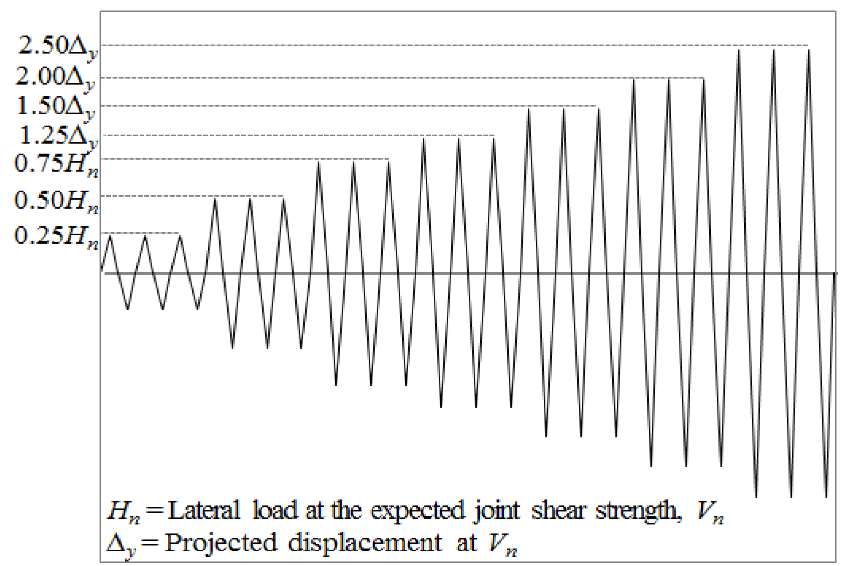
SC WALL-TO-WALL L CONNECTION

Experimental Program

- Test-setup and loading protocol



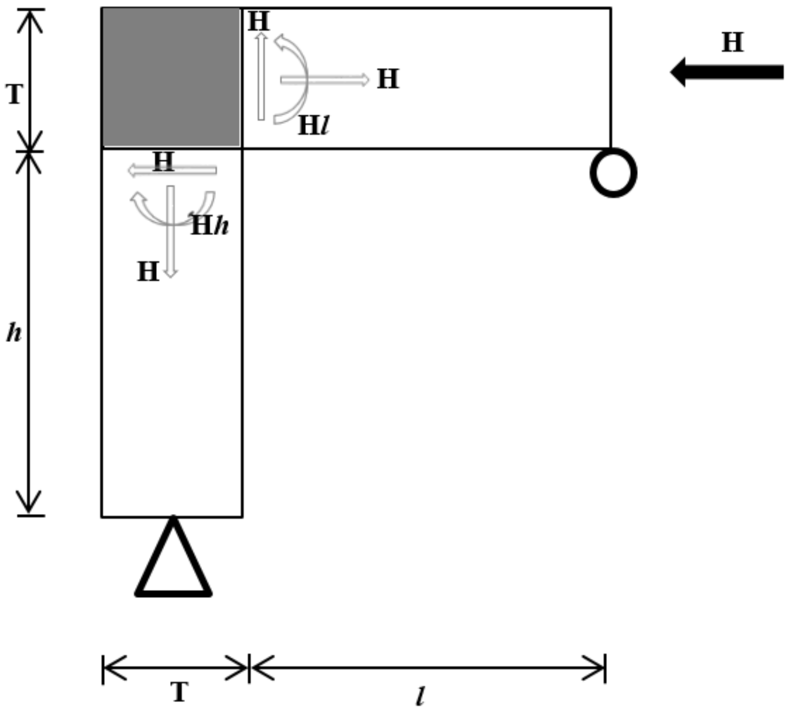


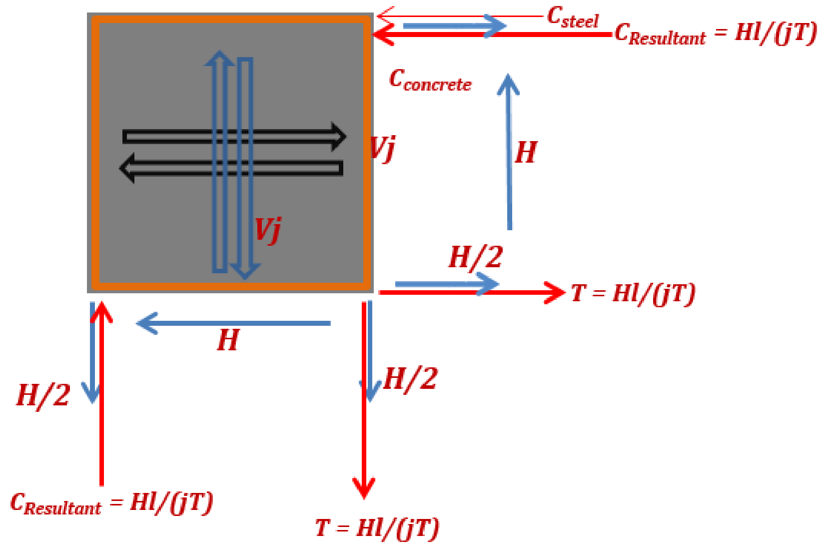


SC WALL-TO-WALL L CONNECTION

Experimental Program

- Boundary conditions and joint shear force terms



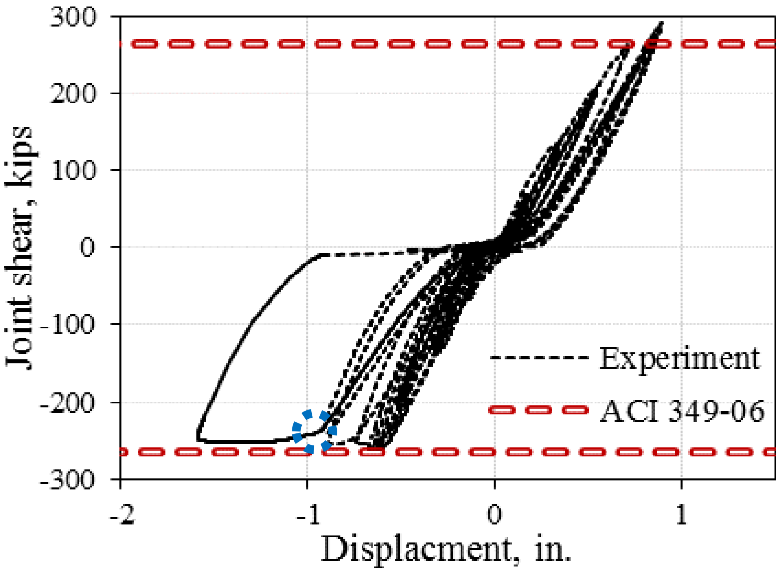


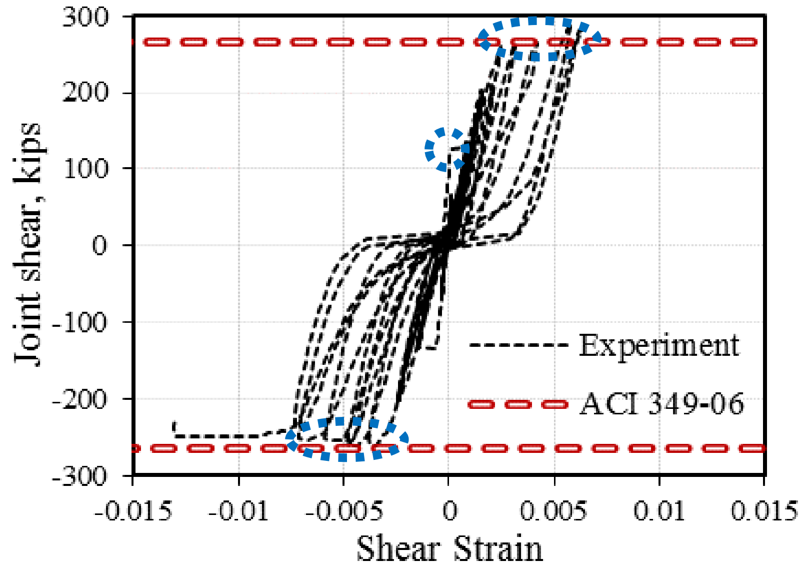
$$V_j = H\left(\frac{1}{2} - \frac{l}{jT}\right)$$

SC WALL-TO-WALL L CONNECTION

Experimental Program

- Joint shear – displacement response



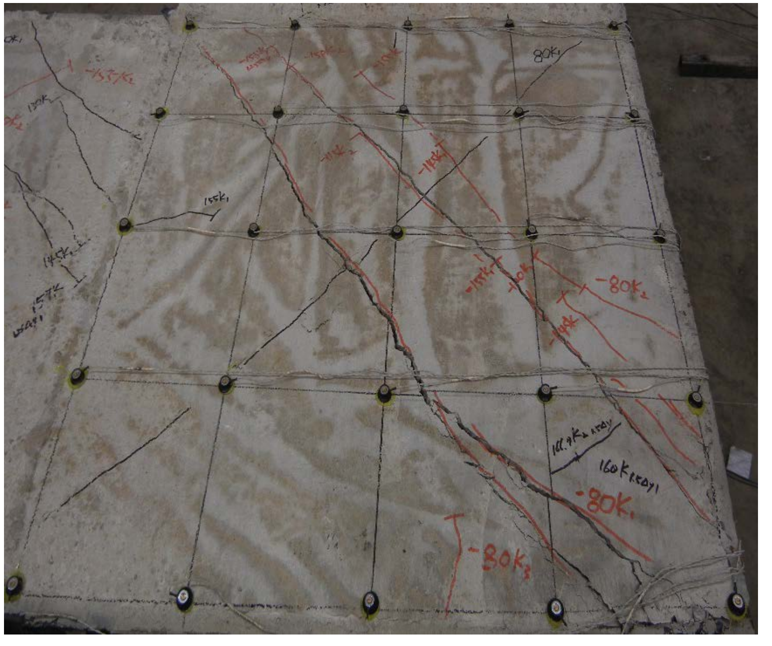


Ultimate joint shear, kips	Shear strain at the ultimate joint shear	Governing failure mode	Event order in the Joint region
261.7 (-) 290.3 (+)	- 0.0071 (-) 0.0089 (+)	Joint Shear Failure	Concrete crack ↓ Extensive concrete cracking ↓ Yielding of diaphragm plates

V_{njs}^{TEST} = 276 kips $V_{njs}^{ACI\text{-}exp}$ (262.7 kips)

SC WALL-TO-WALL L CONNECTION
Experimental Program

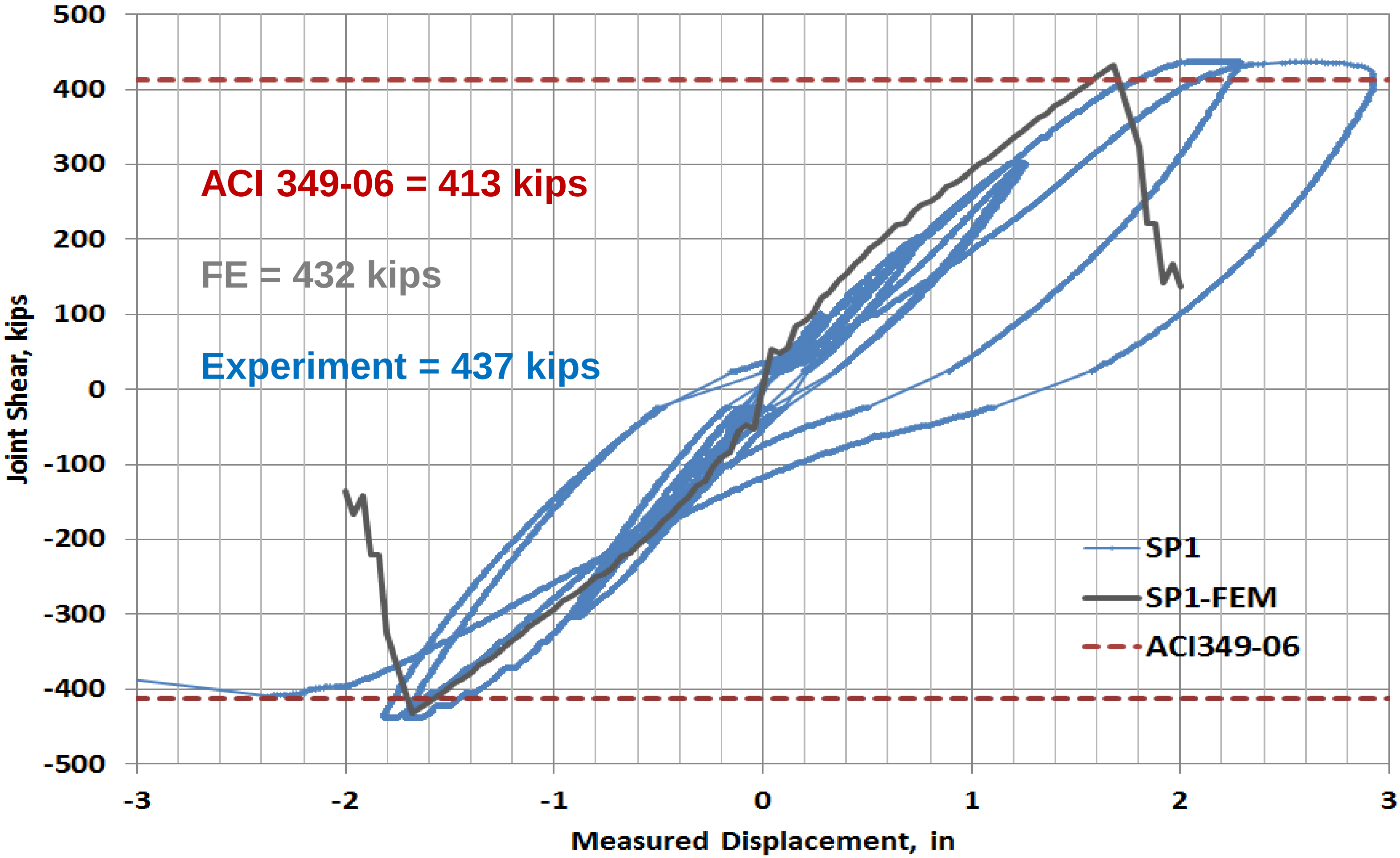
- Crack pattern at the ultimate joint shear



JS-L-T0-F

BENCHMARKING ANALYSIS

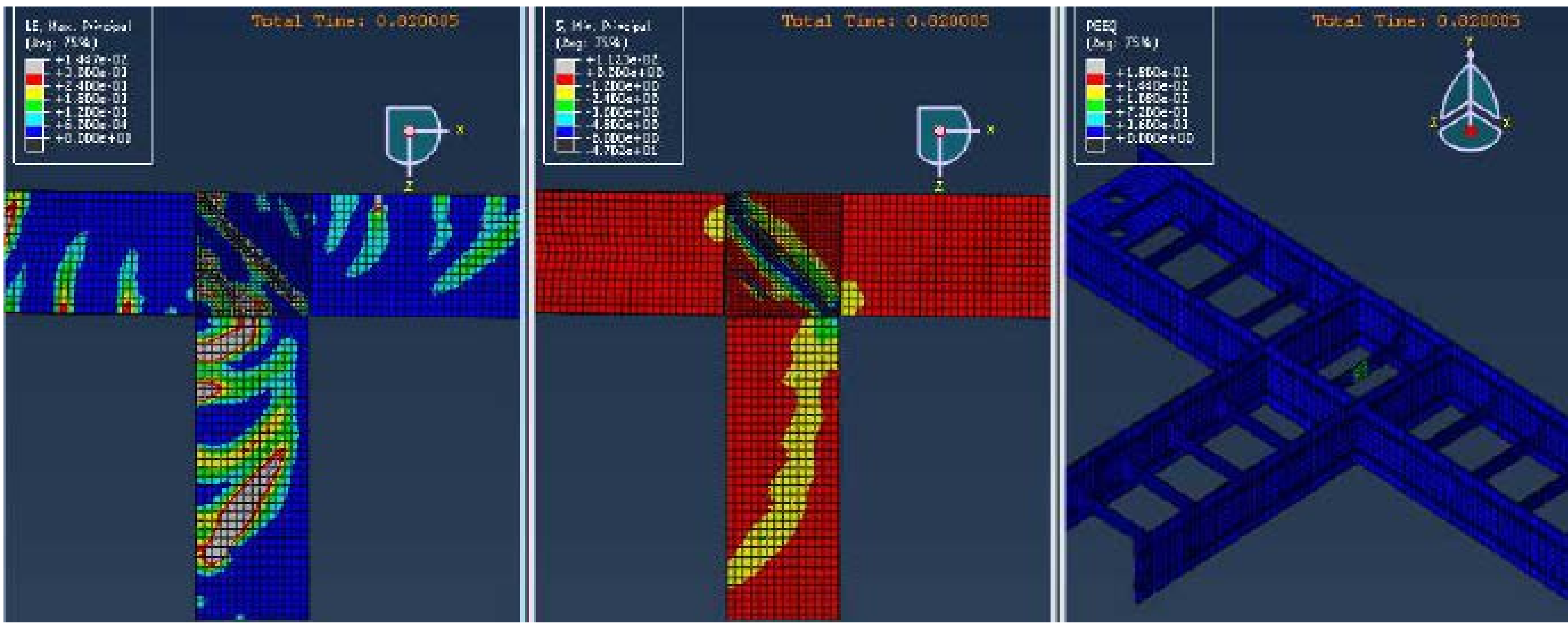
- Analysis results – Specimen JS-T1-F
  - Joint shear – displacement response



BENCHMARKING ANALYSIS

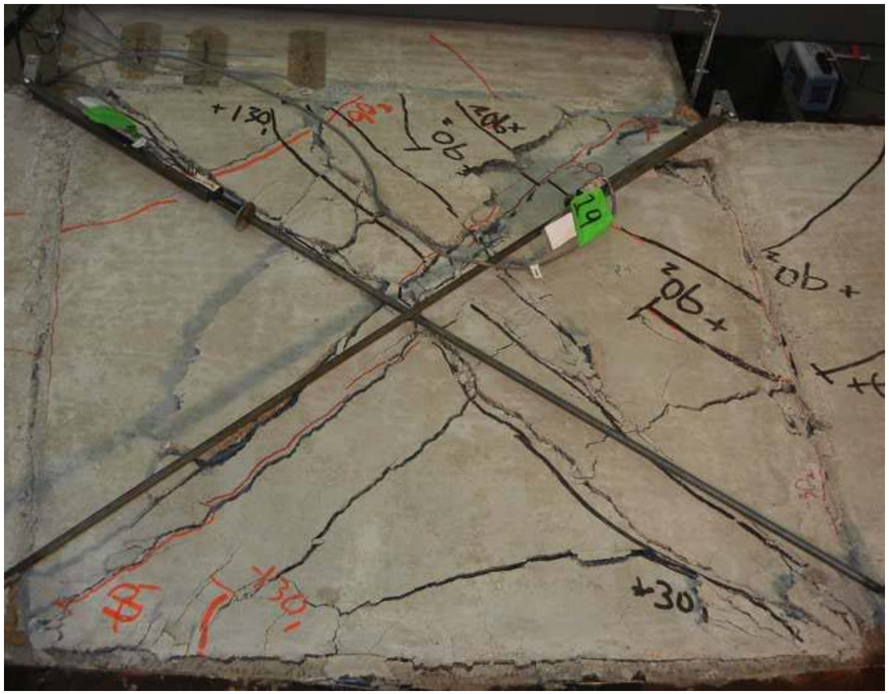
- Analysis results – Specimen JS-T1-F
  - Stress and strain distribution

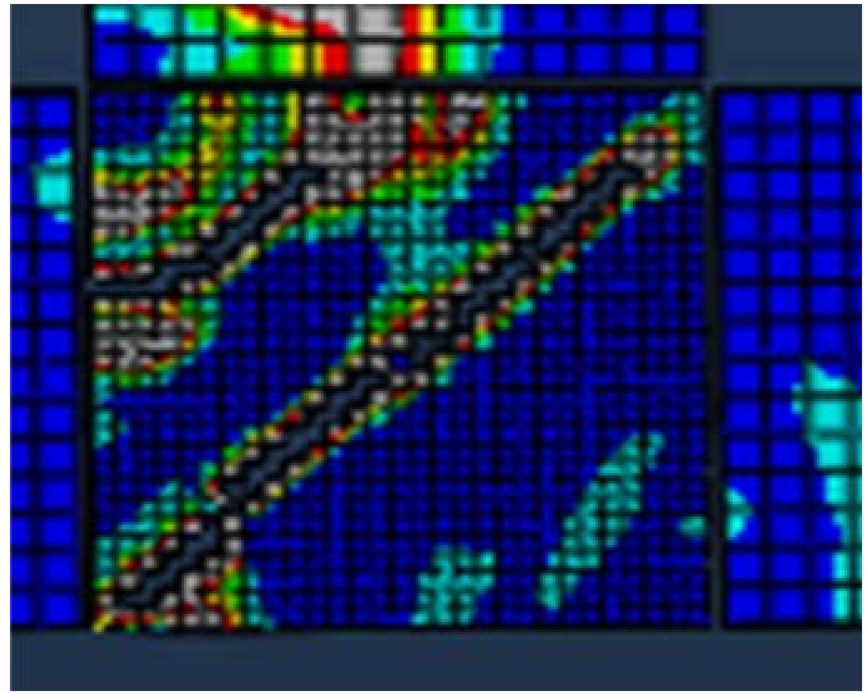
LE max　　　　S min　　　　PEEQ



BENCHMARKING ANALYSIS

- Analysis results – Specimen JS-T1-F
  - Crack pattern

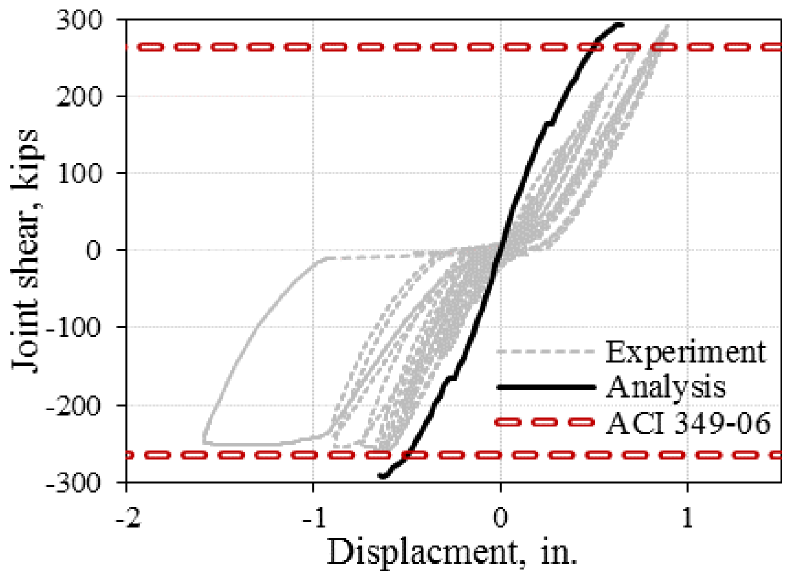




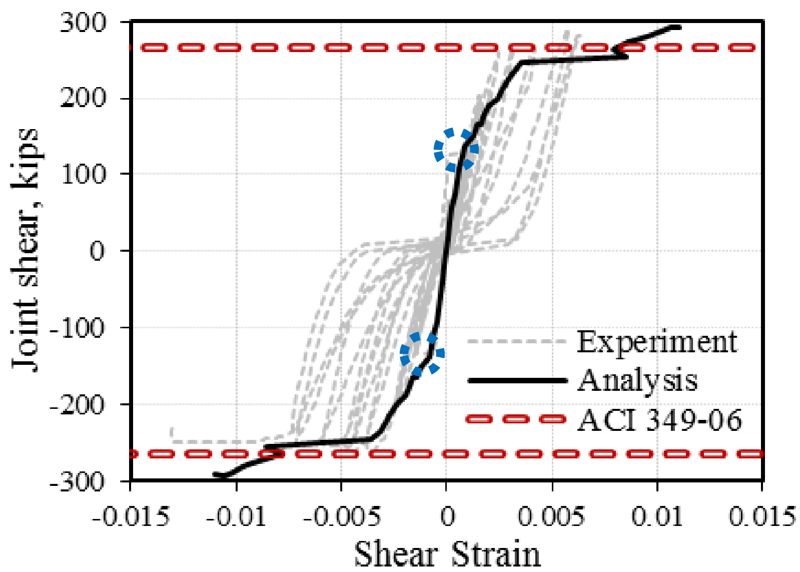
BENCHMARKING ANALYSIS

- Analysis results – Specimen JS-L-T0-F

Joint shear – displacement response



Joint shear – shear strain response

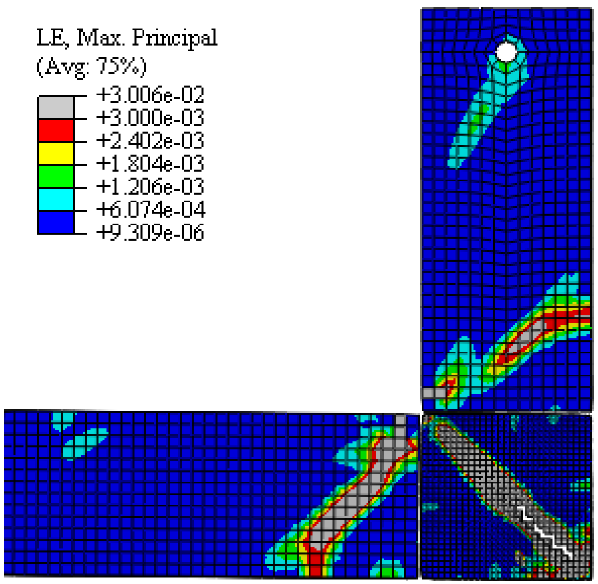


- $V_{js}^{ACI349\text{-}06}$ = 262.7 Kips (1.17MN)
- V_{js}^{FEM} = 292.3 Kips (1.3 MN) (+ 29.6 kips)
- V_{js}^{Exp} = 276 Kips (1.22 MN) (+ 13.3 kips)
- Joint shear failure

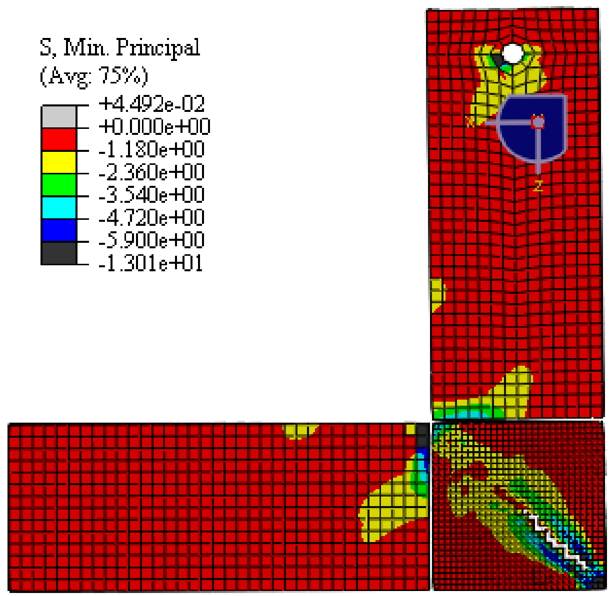
BENCHMARKING ANALYSIS

- Analysis results – Specimen JS-L-T0-F
  - Stress and strain distribution

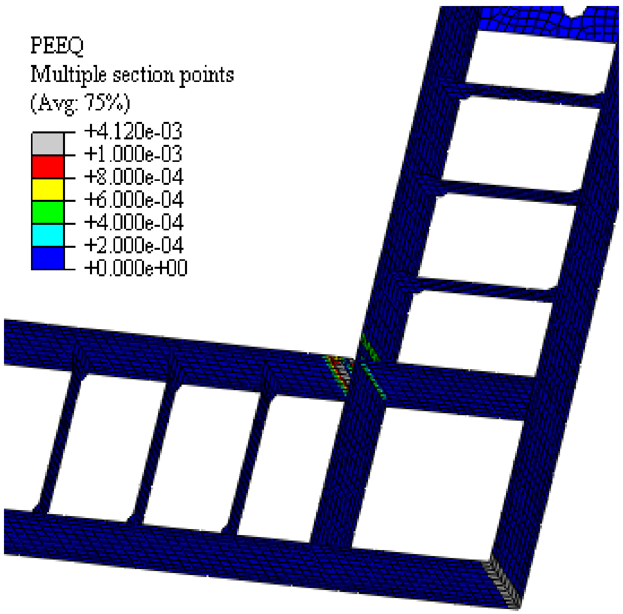
LE max



S min



PEEQ

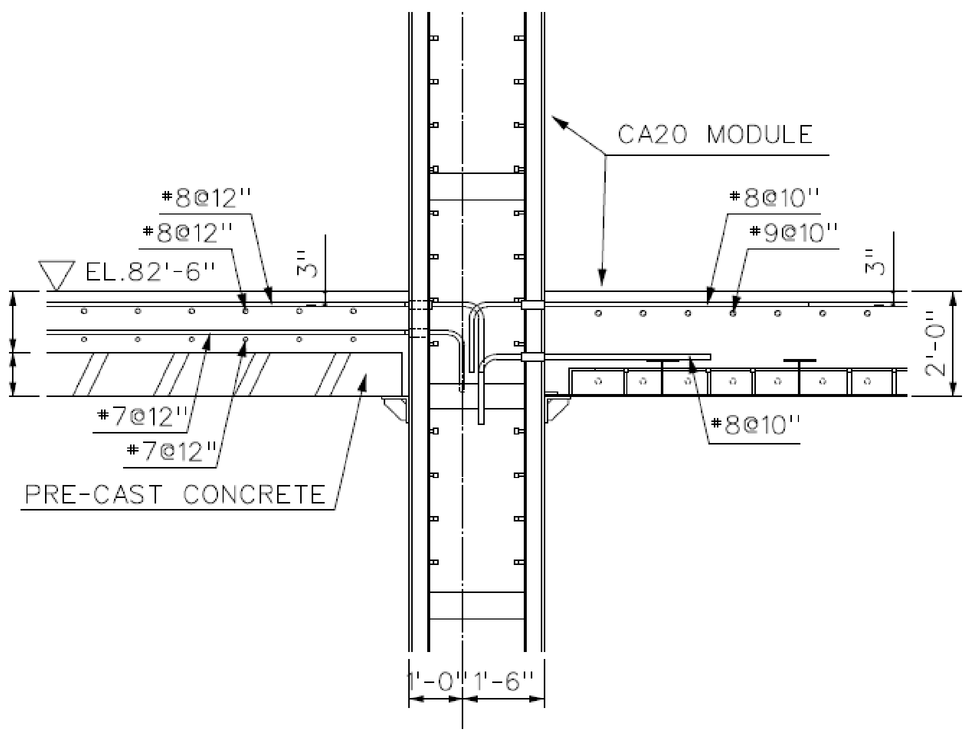


SC SLAB-TO-WALL CONNECTION
Experimental Program

- Background
  - Existing design recommendations and aids for RC slab (column) to slab connections
  - No existing design recommendation for SC slab-to-wall connection
  - The applicability of existing code provisions for RC slab (column) to slab connection on SC slab-to-wall connection
- Design philosophy
  - The full strength connection design philosophy
  - The connection region should not be the weakest point
  - Capability of transferring both shear and flexural demand

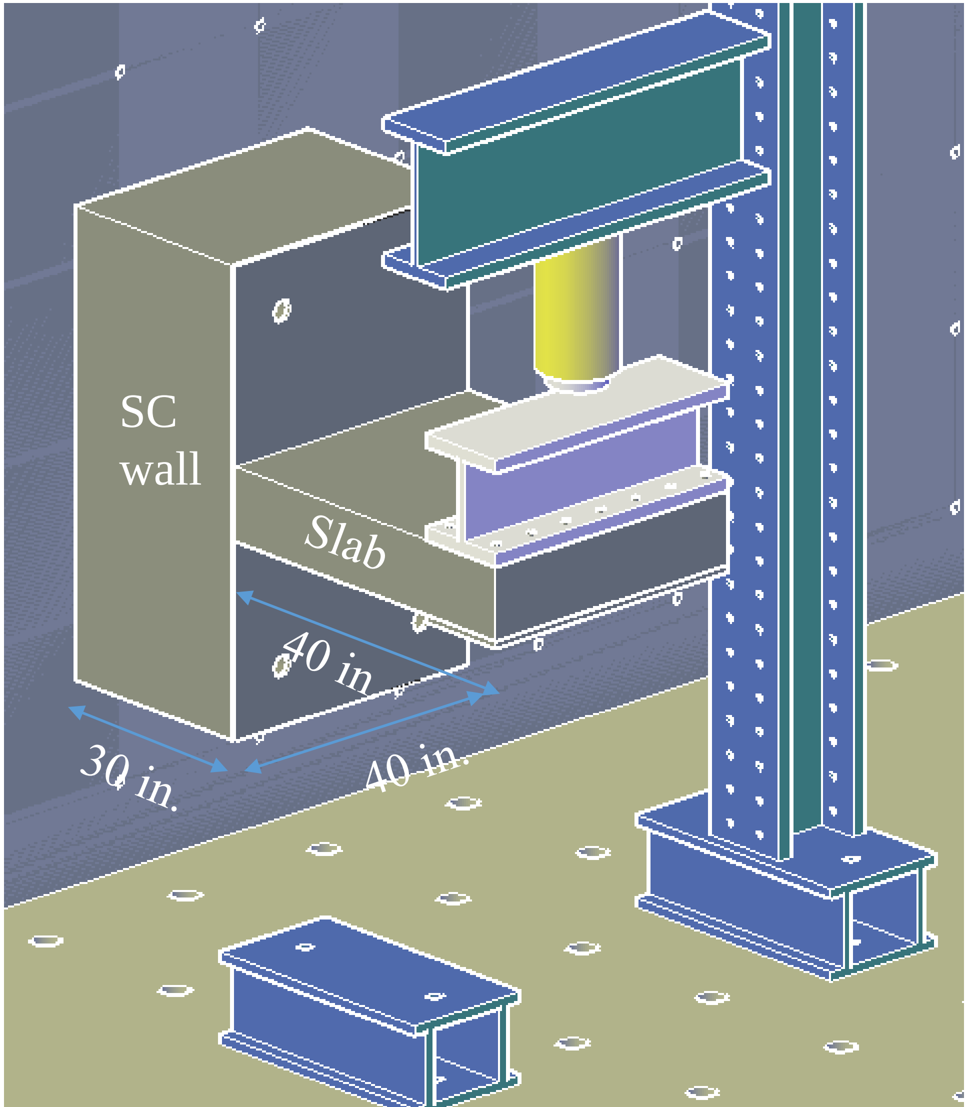
SC SLAB-TO-WALL CONNECTION
Experimental Program

- Test parameters
  - Slab type : RC or half SC (HSC)
  - Rebar : rebar type (Hooked bar or T headed rebar), Reinforcement ratio, Embedded length, and Rebar location in the SC wall portion



SC SLAB-TO-WALL CONNECTION
Experimental Program

- Test setup



FINDINGS

- SC wall-to-wall T connection test
  - The joint shear failure mode for all test specimens
  - No significant effects of the shear reinforcement ratio and the steel headed stud layout
  - V_{njs}^{TEST} within the range of 426.7 kips - 454 kips Greater than $V_{njs}^{ACI-exp}$ (413 kips) by 3.1% - 10.6%
  - The ACI 349-06 (2006) code equation is applicable and conservative for estimating the joint shear strength of SC wall-to-wall T joints with γ of 12
- SC wall-to-wall L connection test
  - The joint shear failure mode
  - V_{njs}^{TEST} of 261.7 kips close to $V_{njs}^{ACI-exp}$ (262.7 kips)
  - The ACI 349-06 (2006) code equation is applicable for estimating the joint shear strength of SC wall-to-wall L joints with γ of 8

Publications

- Seo, J., Varma, A.H., and Winkler, D. (2013). “Preliminary Investigations of the Joint Shear Strength of SC Wall-to-Wall T-Joints.” Transactions of SMiRT 22, IASMIRT, NCSU, Raleigh, NC, pp. 1-10. http://www.iasmirt.org/transactions/22/Pap_863_ver_3.pdf
- Seo, J., and Varma, A.H. (2015). "Behaviour and Design of Corner or L-Joints in SC Walls." Transactions of SMiRT 23 in Manchester, UK, Paper ID 695, IASMIRT, North Carolina State University, Raleigh, NC, pp. 1-10, http://smirt23.uk/attachments/SMiRT-23_Paper_695.pdf