Improvement of Design Codes to Account for Accident Thermal Effects on Seismic Performance

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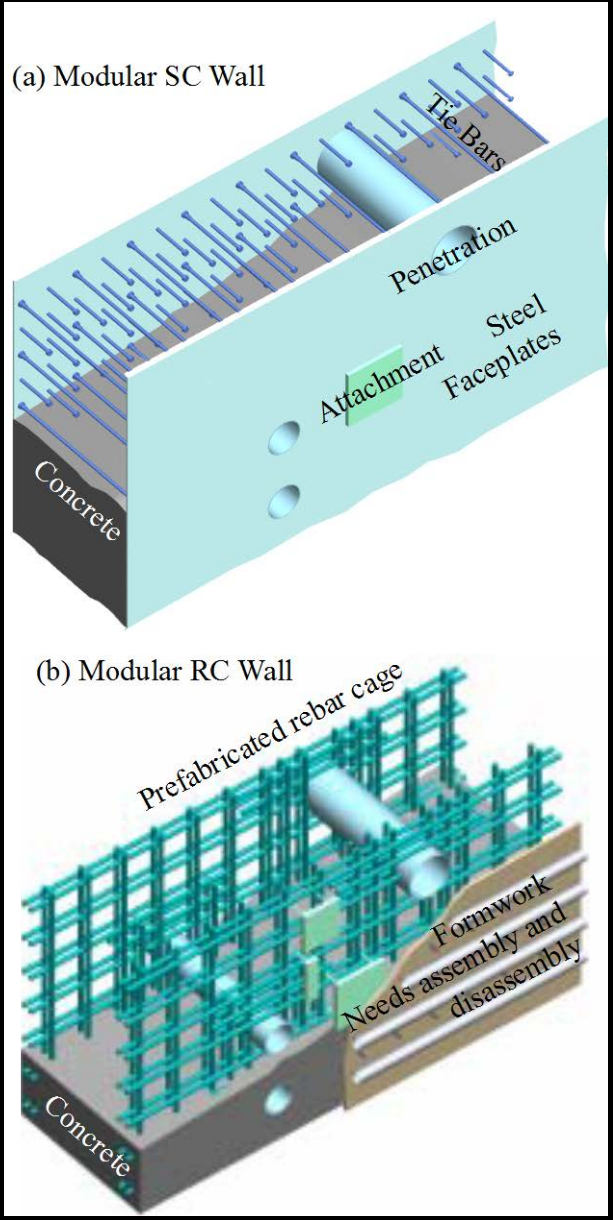
INTRODUCTION

- Project focuses on the effects of accident thermal conditions on the seismic performance of:
  a) Innovative steel-plate composite SC walls, and
  b) Conventional reinforced concrete RC walls.



MOTIVATION

- Steel faceplates are directly exposed to elevated temperatures resulting from accident thermal conditions. The resulting differential temperatures and nonlinear thermal gradients lead to concrete cracking
- Potential overstressing of the steel faceplates (primary reinforcement) during seismic events. Need to address the effects of accident thermal loading on seismic performance.
- ACI 349 for safety-related RC structures also does not address the effects of accident thermal loading on seismic performance of RC walls.
- Guidance is needed for regulators, designers, utilities and NSSS vendors.

PROJECT OBJECTIVES

- Evaluate the seismic performance of structural walls subjected to accident thermal loading. Parameters:
  (i) Wall type: SC and RC,
  (ii) Maximum accident temperature,
  (iii) Duration of the accident thermal loading before seismic
  (iv) Details like reinforcement ratio, clear cover, etc.
- Develop and benchmark numerical models for predicting the seismic performance of structural walls subjected to accident thermal loading
- Conduct analytical parametric studies to evaluate effects of wide range of material, geometric, structural detailing, thermal loading, and seismic loading parameters including those identified in 1.

Project Objectives (Cont'd)

- Develop design guidelines and recommendations for accident thermal + seismic loading
  - (i) Recommendations for calculating design demands, and
  - (ii) Calculating the strength and post-peak response
- To disseminate this knowledge and information, and update upcoming design and analysis codes particularly
  - ACI 349 App. E
  - ACI 349.1R
  - AISC N690
  - ASCE 4 and ASCE 43 to include research findings and guidelines.

PROJECT TASKS

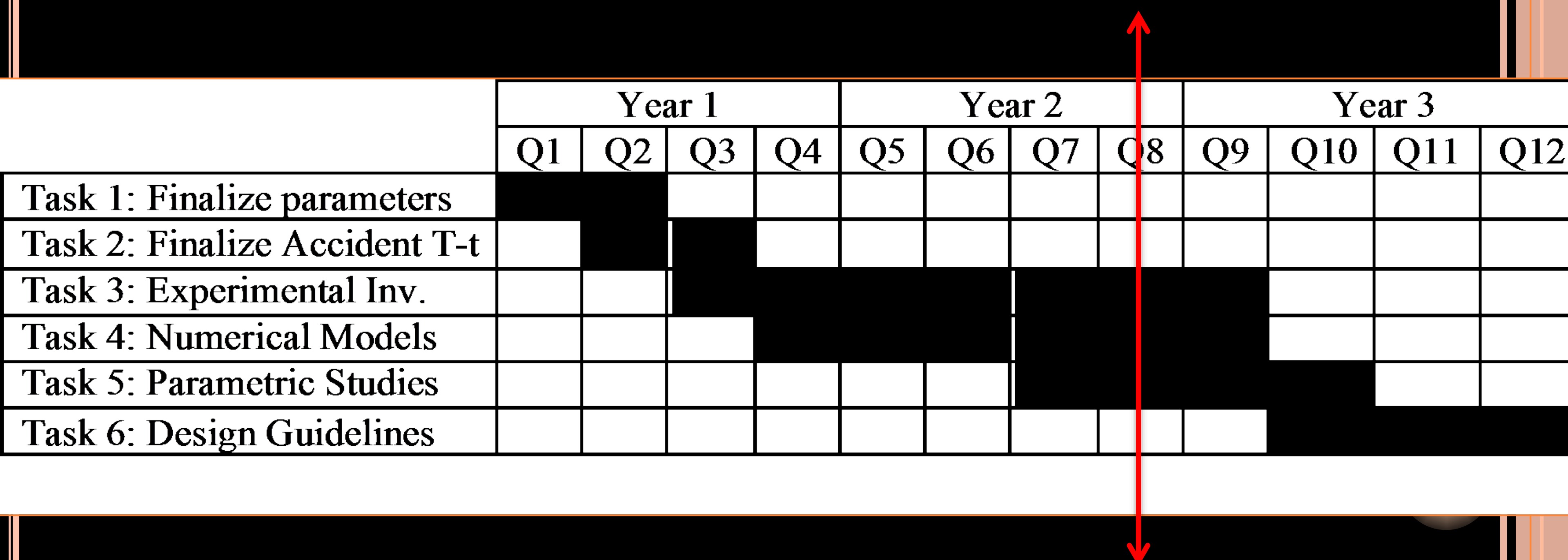
- Task 1 – Review and Finalization of Parameters
  - Industry Partners: Westinghouse Electric, AECOM, Bechtel
  - Status – Complete
- Task 2 – Accident Thermal Loading and History
  - Industry Partners, and Review of DCDs, Public NRC documents for AP1000, US-APWR, SMRs etc.
  - Status – Complete
- Task 3 – Experimental Investigations of SC and RC Walls
  - Bowen Laboratory using Specialized Heating and Hydraulic Equipment
  - Status – Ongoing

Project Tasks

- Task 4: Development & Benchmarking of Models
  - Using LS-DYNA, ABAQUS, and other software
  - Status – Ongoing rigorously
- Task 5 – Analytical Parametric Studies
  - Using Parameters from Task 1, and Models from Task 4
  - Status – Ongoing
- Task 6 – Dissemination to Codes / Standards
  - ACI 349.1R, AISC N690, ASCE 4/43, etc.
  - Status - Ongoing

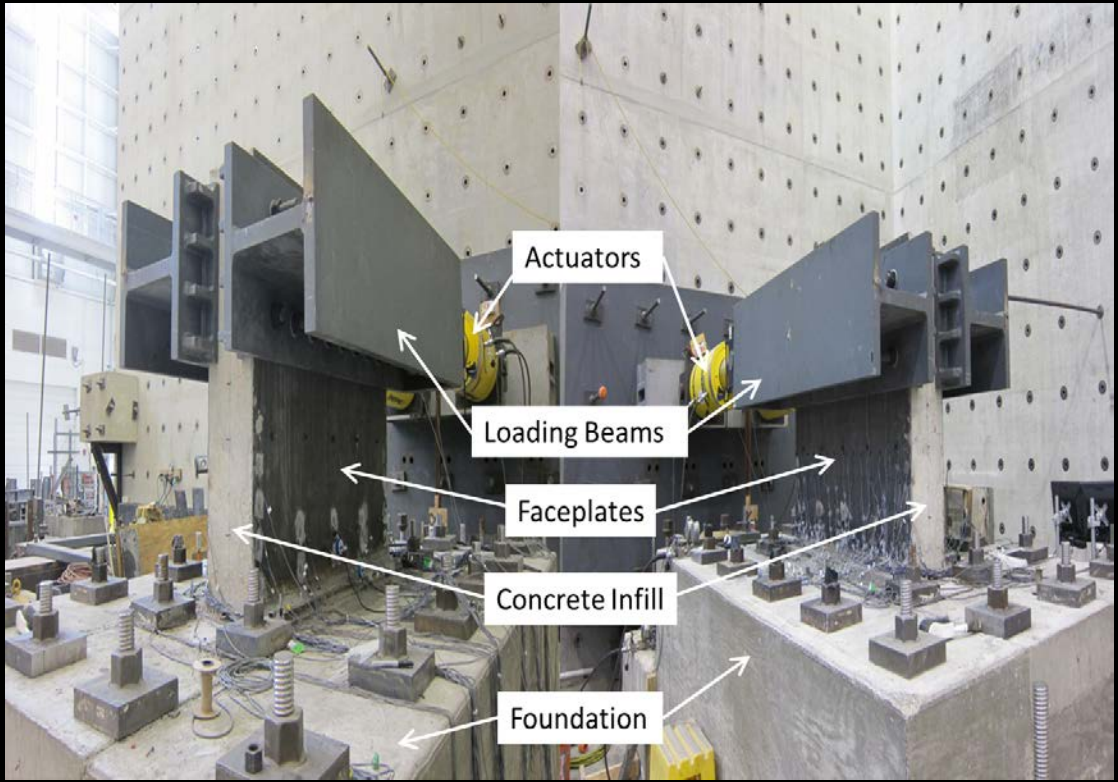
PROJECT SCHEDULE

- Project progressing as planned
- No significant deviations or issues so far

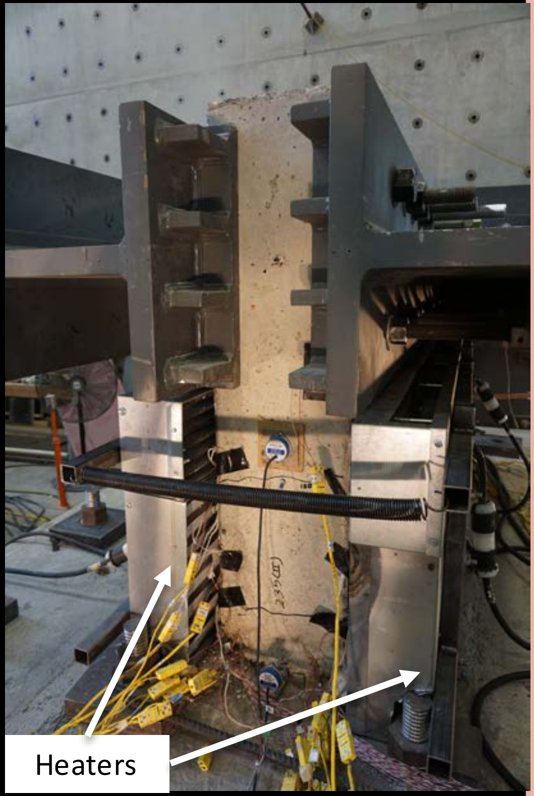


Experimental Progress

- SC-Wall Pier Specimens: Cyclic In-plane Shear
- Tested at Ambient and Elevated Temperatures



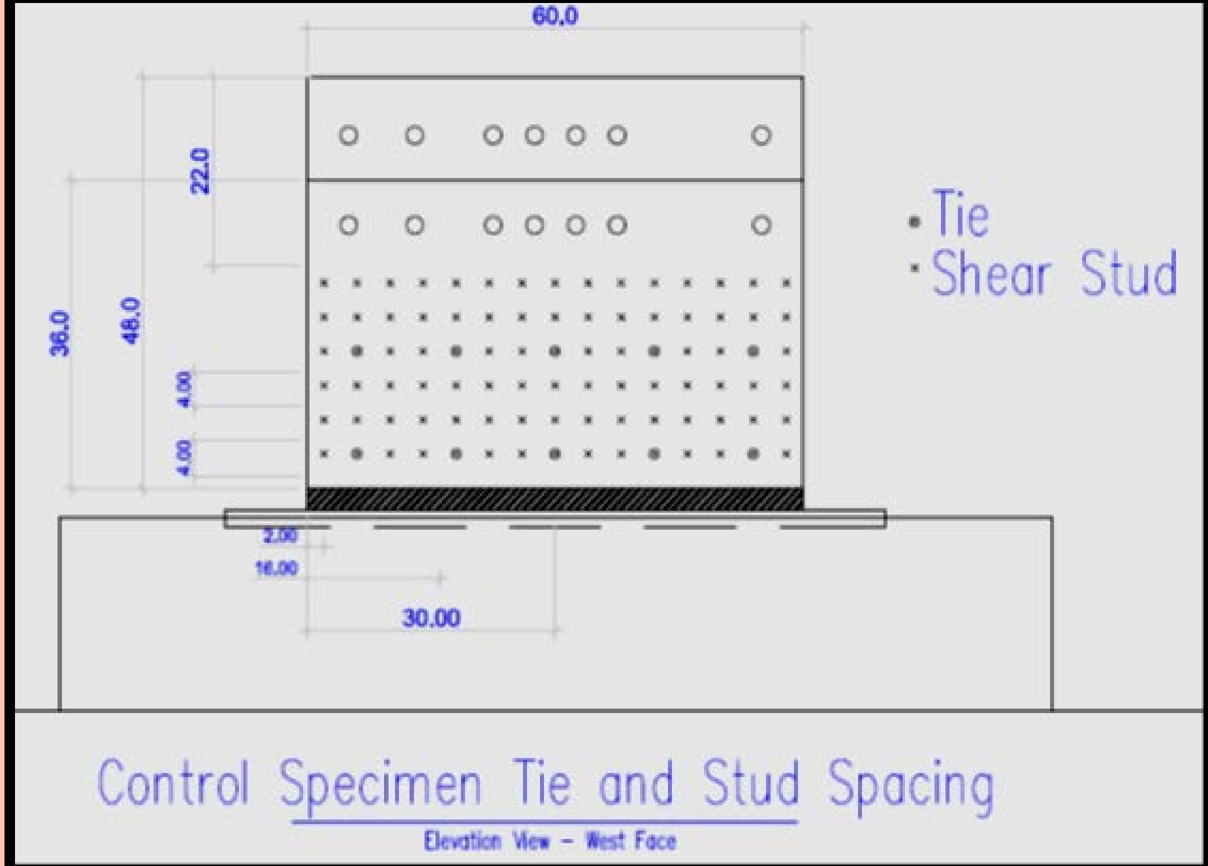
Ambient Test



Elevated Temp.

Experimental Progress

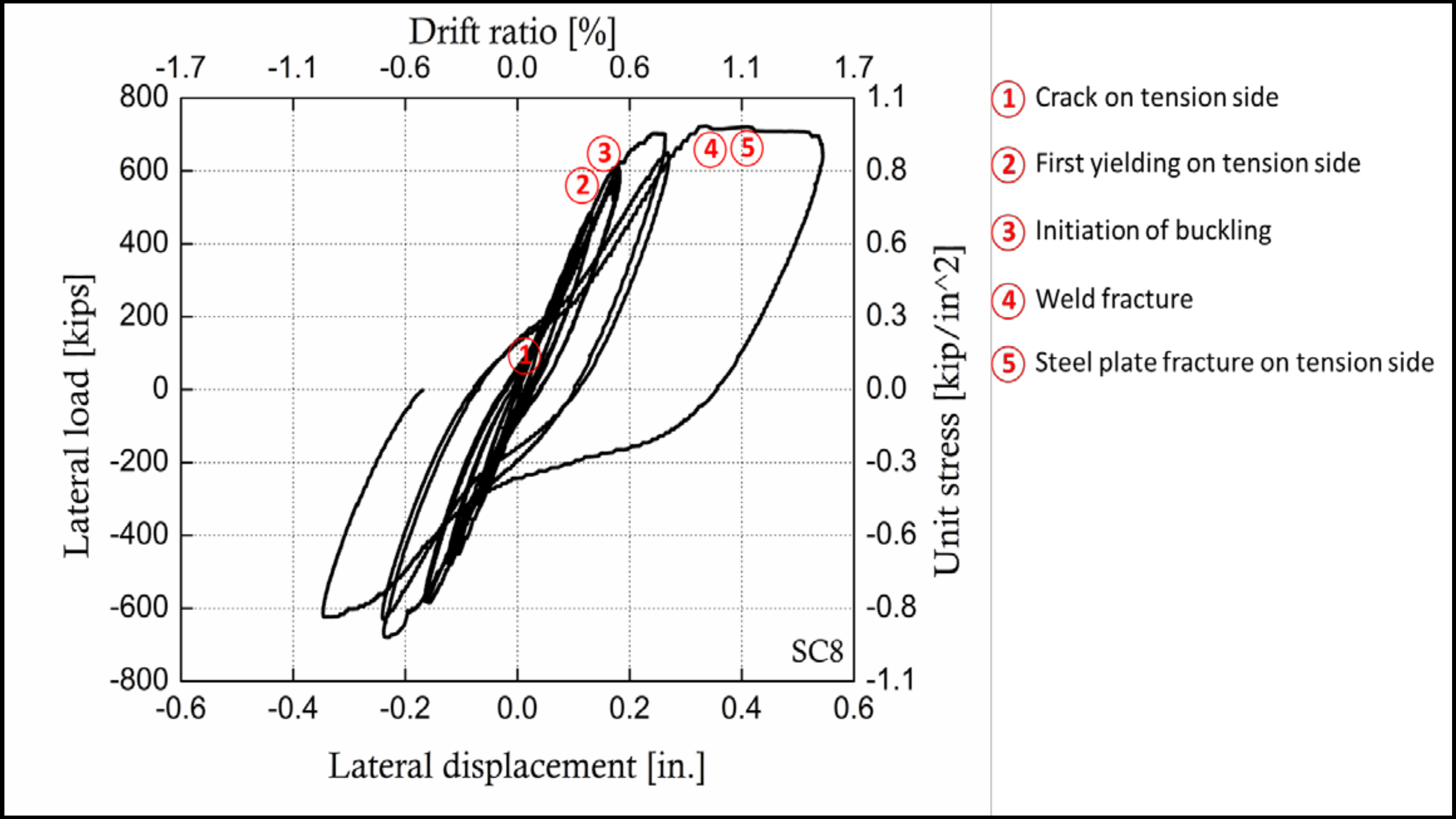
- SC-Wall Pier Specimens: Cyclic In-plane Shear at Ambient Condition – Specimen Geometry



L = 60 in.
H = 36 in. (H/L = 0.6)
t_{sc} = 12 in.
t_p = 3/16" = 0.1875 in.

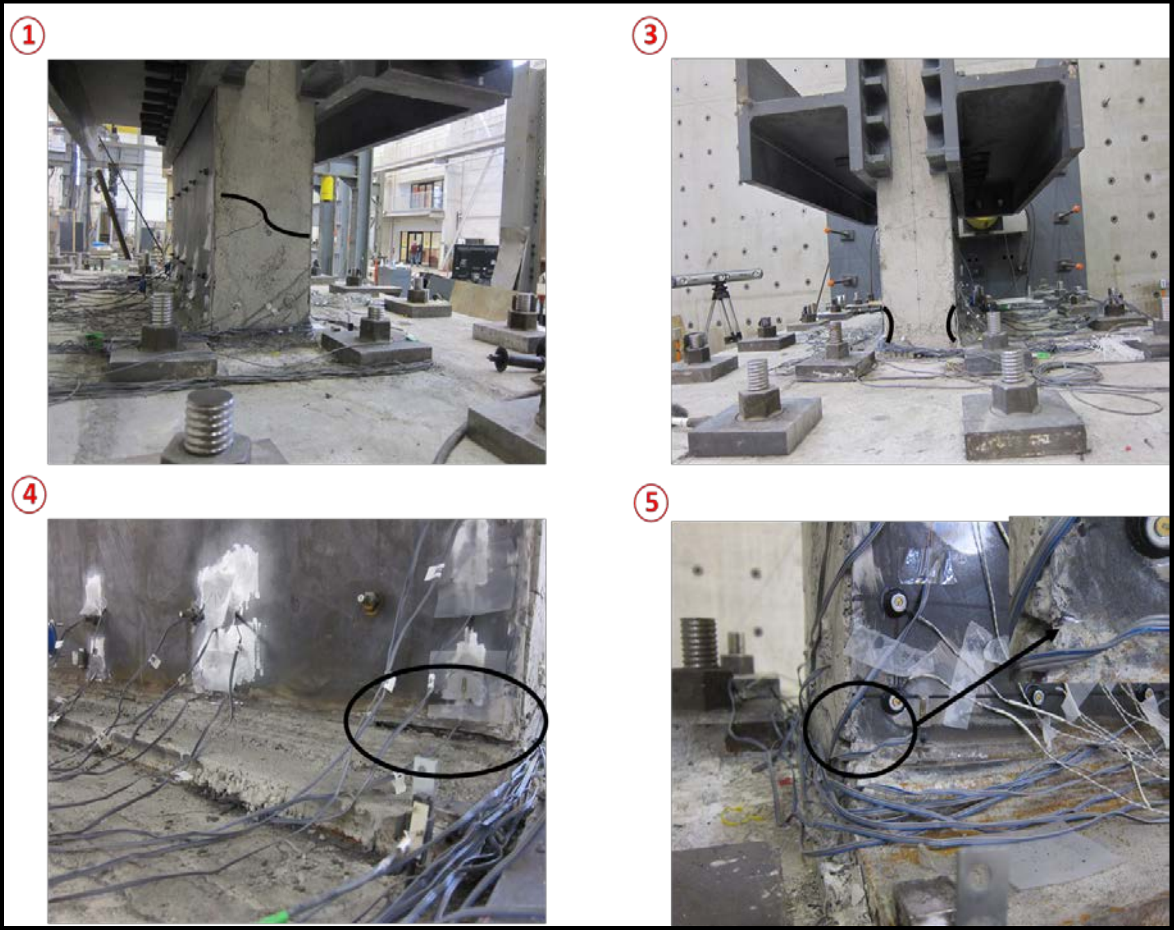
Experimental Progress

- SC-Wall Pier Specimens: Cyclic In-plane Shear at Ambient Condition – Cyclic Hysteresis



Experimental Progress

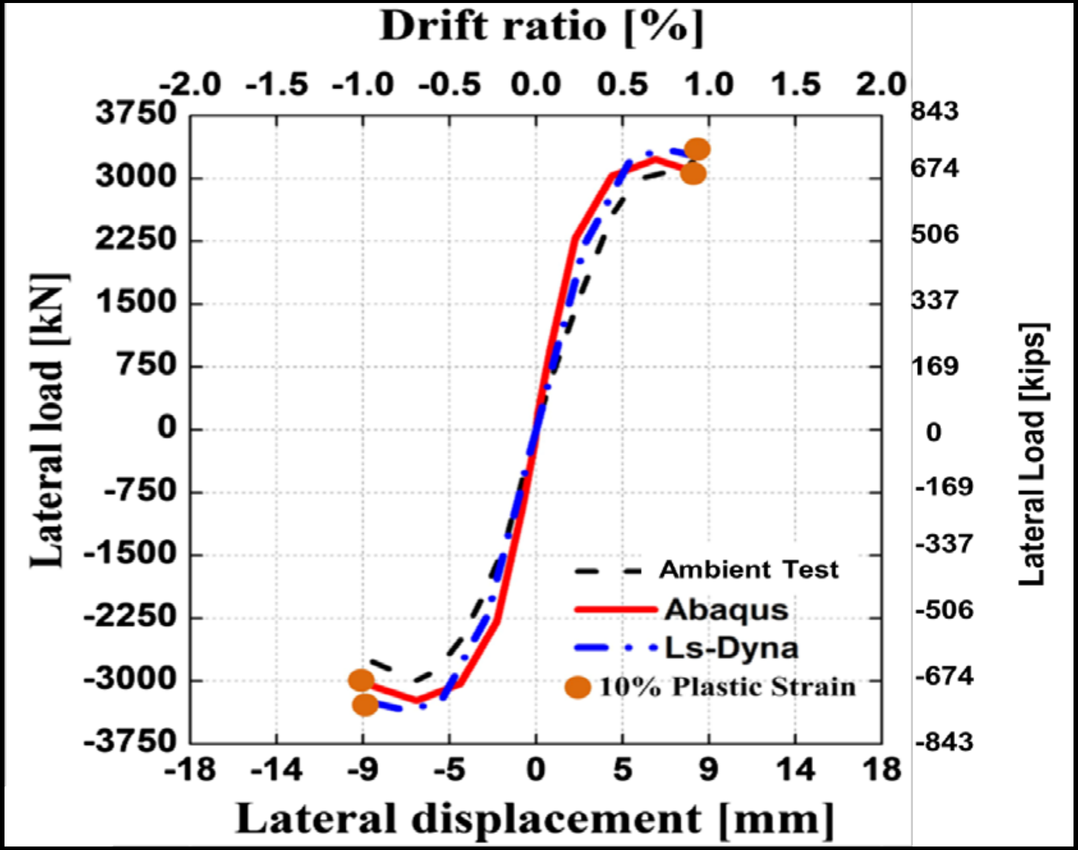
- SC-Wall Pier Specimens: Cyclic In-plane Shear at Ambient Condition – Experimental Observations



1. Crack on tension side
2. First yielding on tension side
3. Initiation of buckling
4. Weld fracture
5. Steel plate fracture on tension side

Experimental Progress

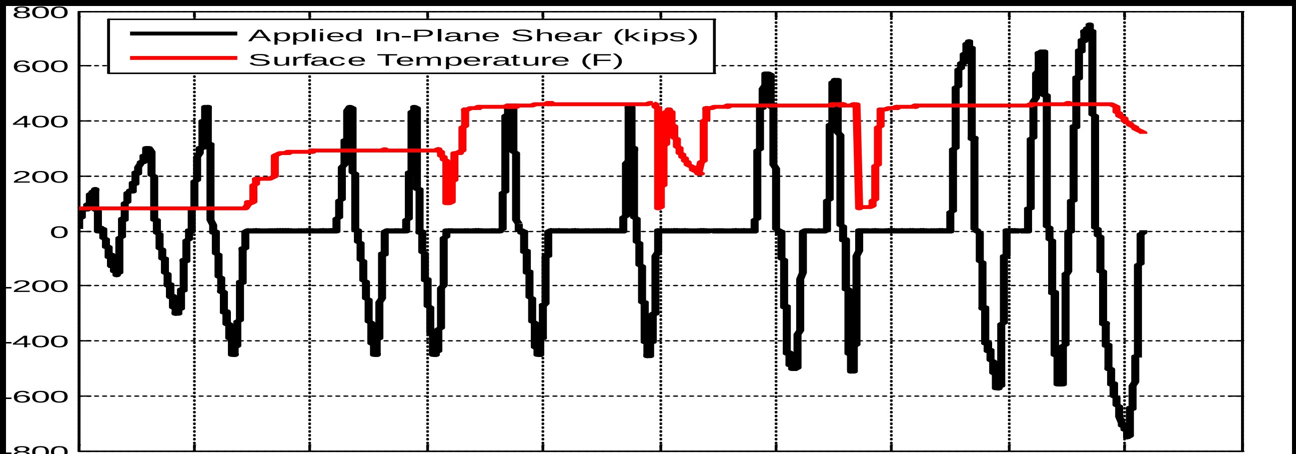
- SC-Wall Pier Specimens: Cyclic In-plane Shear at Ambient Condition – Experiment vs. FE Analysis



EXPERIMENTAL PROGRESS

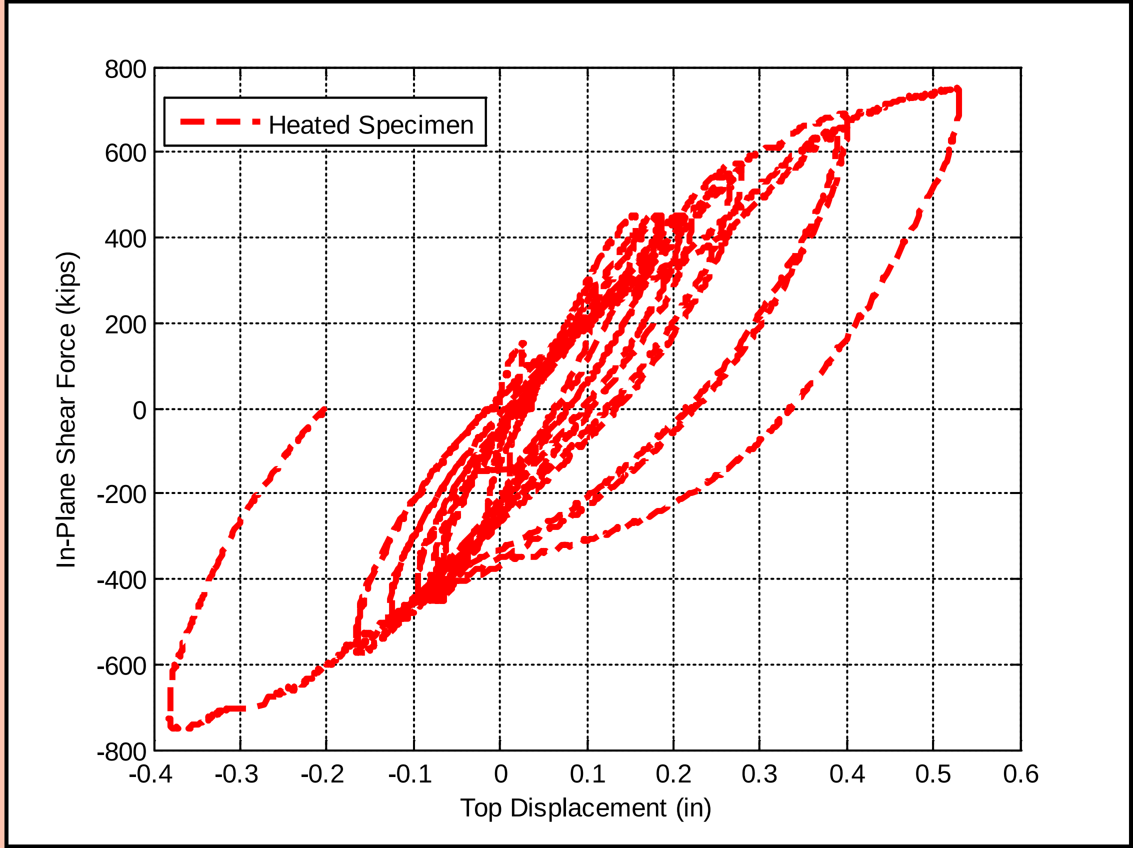
- SC-Wall Pier Specimens: Cyclic In-plane Shear at Elevated Temperature – Loading Protocol

Force Cycle No.	Surface Temperature	Heating Duration	Target Force Level	Target Displacement Level	Corresponding Max. Load – Push (Pull)
1	Ambient	-	150 kips	-	
2	Ambient	-	300 kips	-	
3	Ambient	-	450 kips	-	
4	300°F	1 hr	450 kips	-	
5	300°F	3 hr	450 kips		
6	450°F	1 hr	450 kips	0.75 Δ_y	
7	450°F	3 hr	450 kips	0.75 Δ_y	
8	450°F	1 hr		1.0 Δ_y	572 kips (503 kips)
9	450°F	3 hr		1.0 Δ_y	548 kips (508 kips)
10	450°F	1 hr	-	1.5 Δ_y	689 kips (575 kips)
11	450°F	3 hr	-	1.5 Δ_y	653 kips (557 kips)
12	450°F	4 hr	-	2.0 Δ_y	749 kips (750 kips)



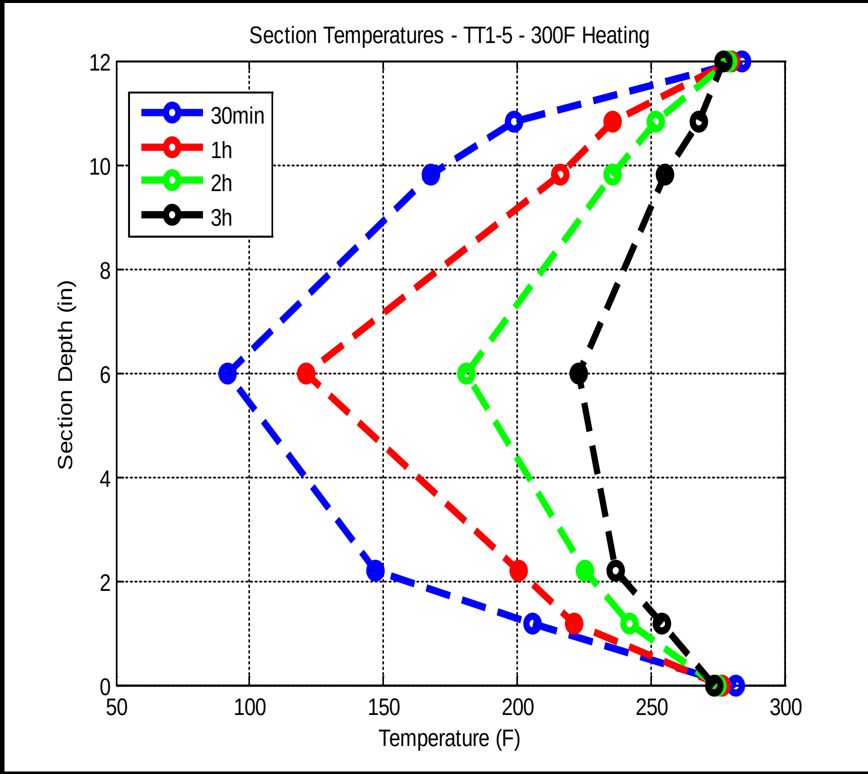
Experimental Progress

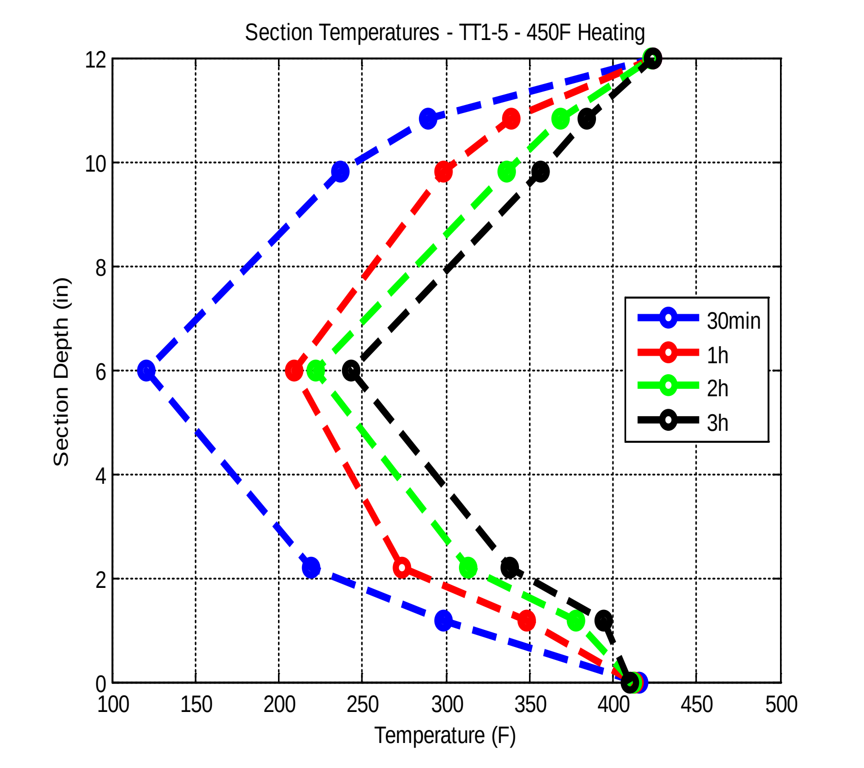
- SC-Wall Pier Specimens: Cyclic In-plane Shear at Elevated Condition – Cyclic Hysteresis



Experimental Progress

- SC-Wall Pier Specimens: Cyclic In-plane Shear at Elevated Condition – Temperature Profiles Through Cross Section for 300ºF and 450ºF





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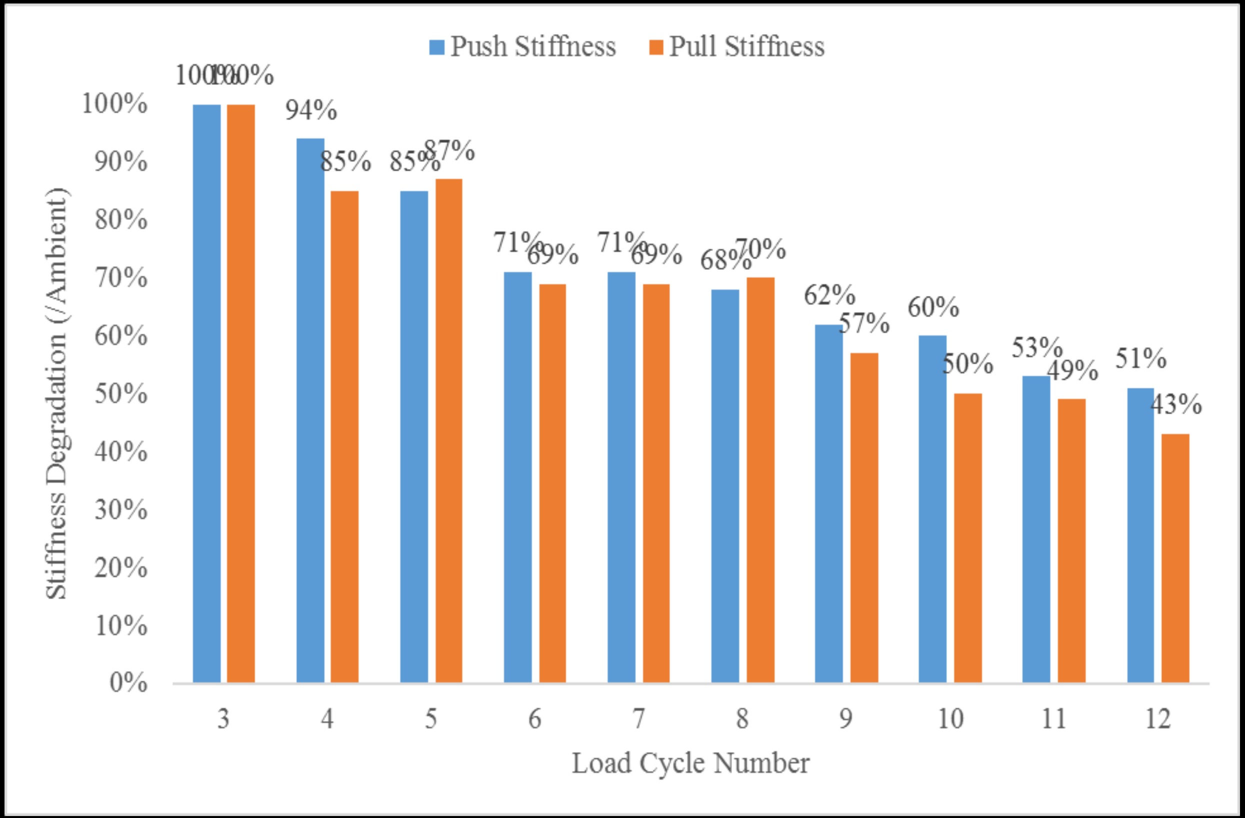
EXPERIMENTAL PROGRESS

- SC-Wall Pier Specimens: Cyclic In-plane Shear at Elevated Condition – Stiffness Degradation

Force Cycle No.	Secant Stiffness – Push (kip/in)	Secant Stiffness – Pull (kip/in)	Change (/Ambient) - Push	Change (/Ambient) - Pull
3	3435	3435	100%	100%
4	3214	2903	94%	85%
5	2903	3000	85%	87%
6	2432	2368	71%	69%
7	2432	2419	71%	69%
8	2334	1960	68%	70%
9	2115	2040	62%	57%
10	2059	1714	60%	50%
11	1818	1689	53%	49%
12	1750	1480	51%	43%

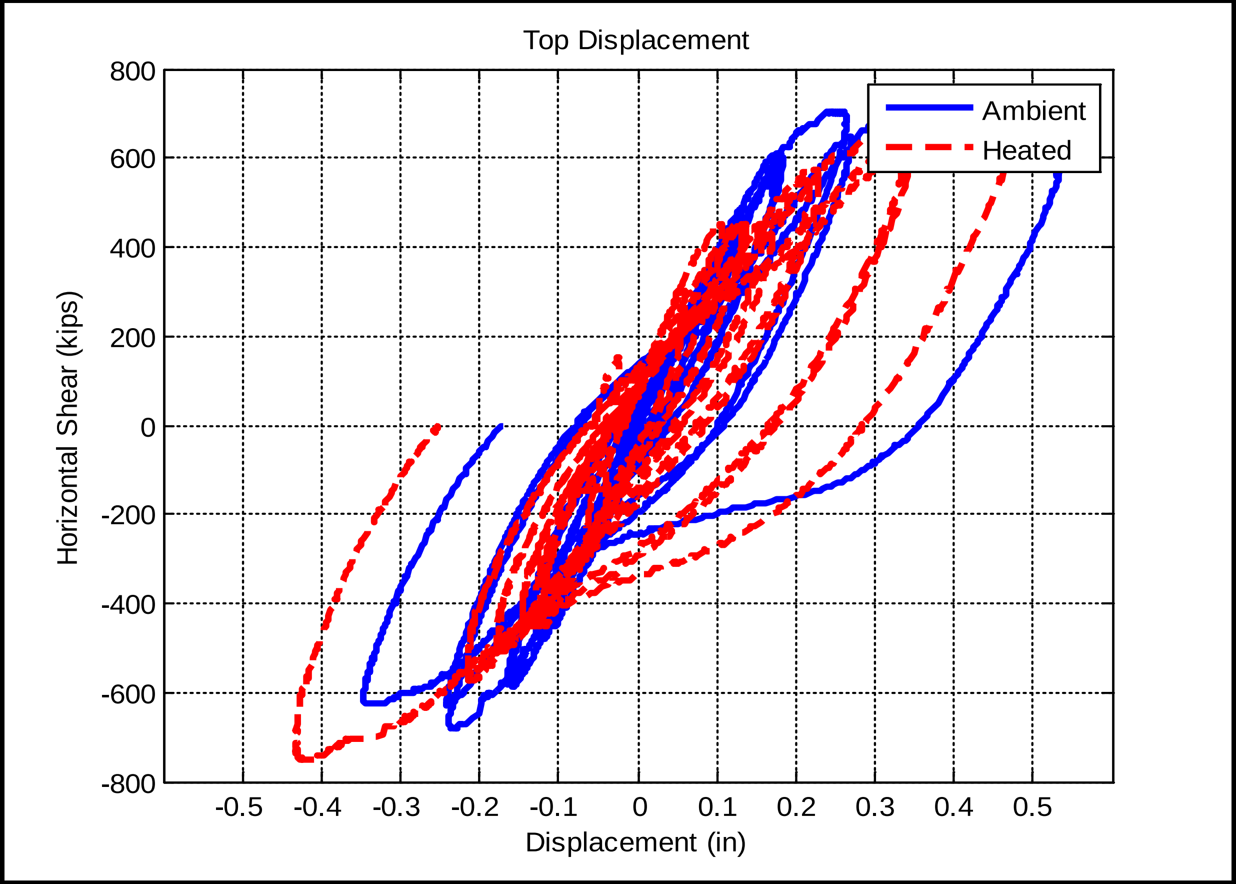
Experimental Progress

- SC-Wall Pier Specimens: Cyclic In-plane Shear at Elevated Condition – Stiffness Degradation



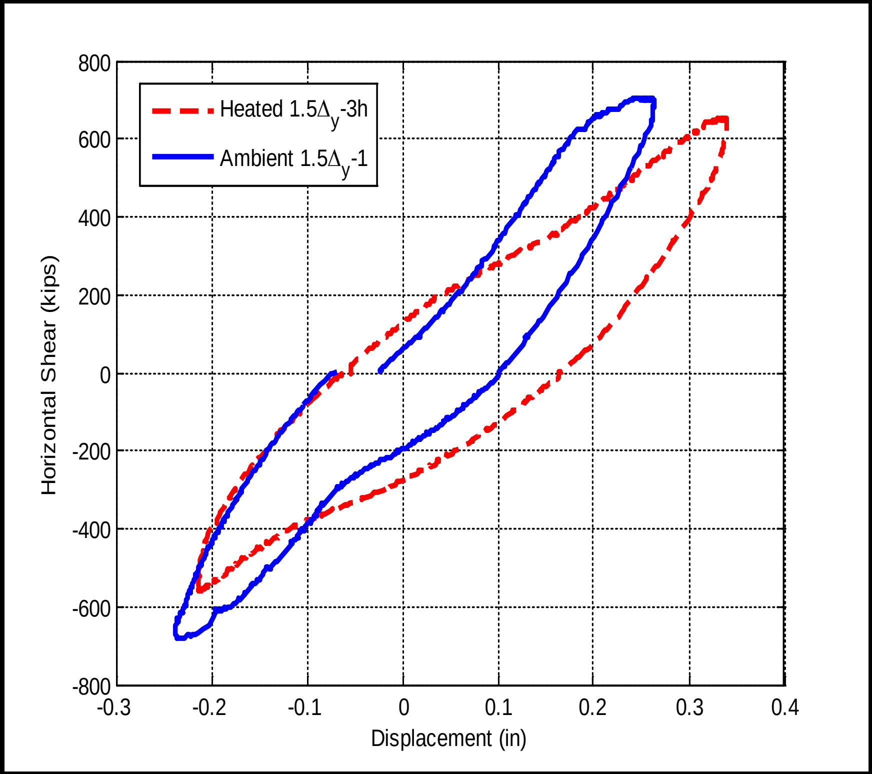
Experimental Progress

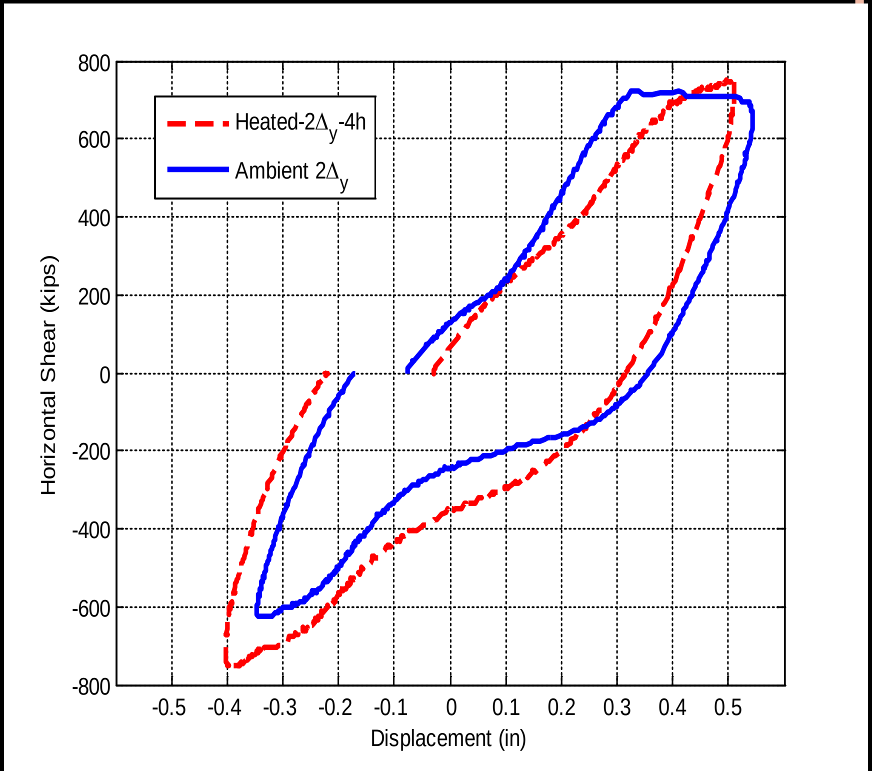
- SC-Wall Pier Specimens: Cyclic In-plane Shear at Elevated Condition – Cyclic Hysteresis Comparison



Experimental Progress

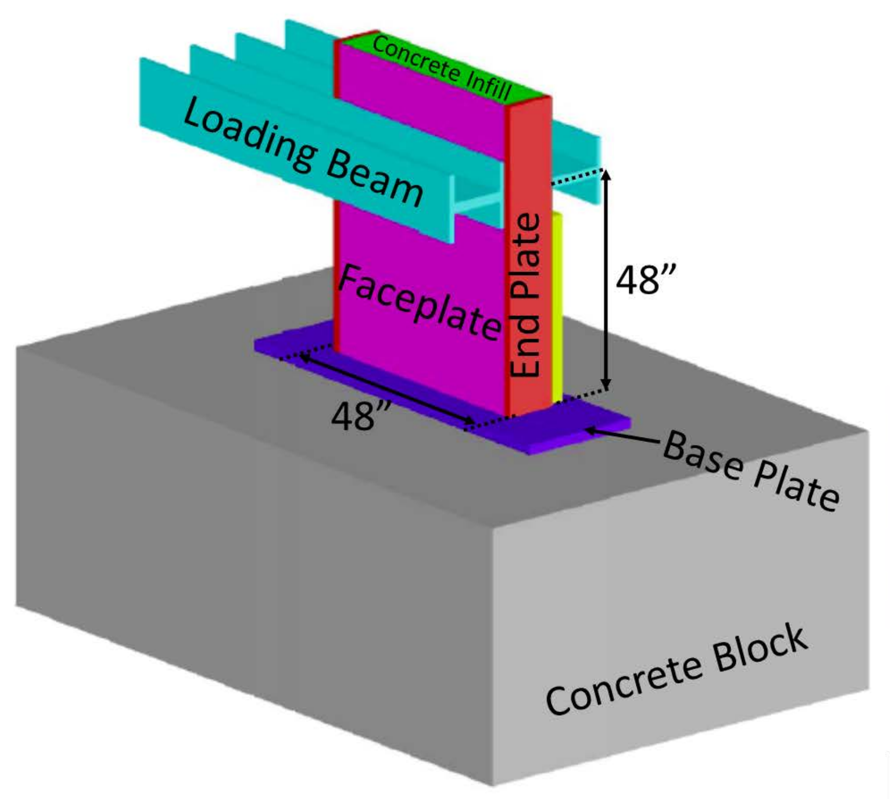
- SC-Wall Pier Specimens: Cyclic In-plane Shear at Elevated Condition – Cyclic Hysteresis Comparison

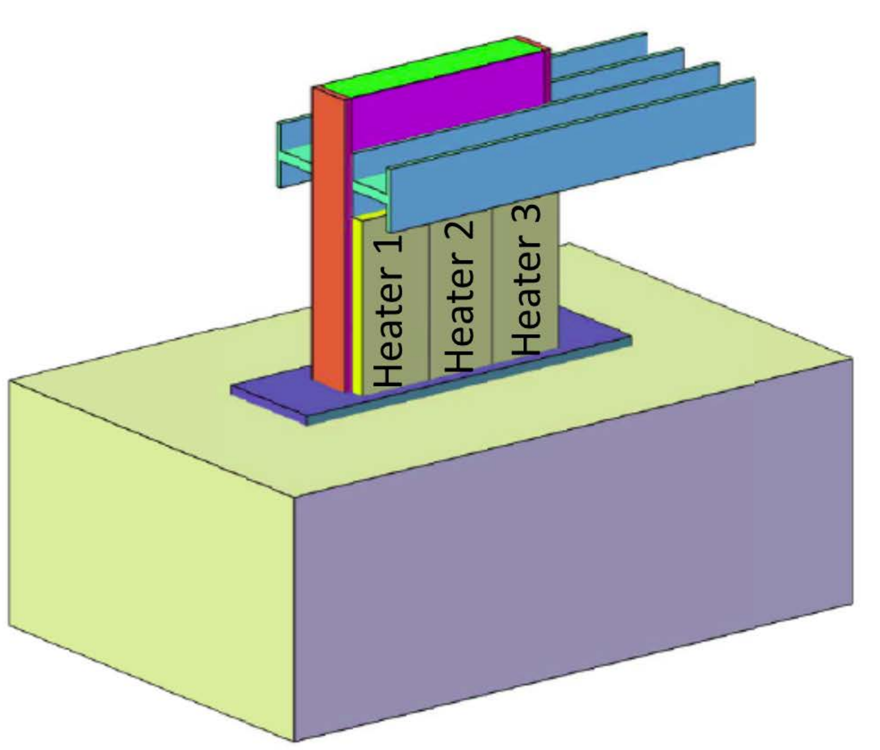




Experimental Progress

- SC-Flanged Wall Specimens: Cyclic In-plane Shear at Ambient and Elevated Condition – Specimen Design





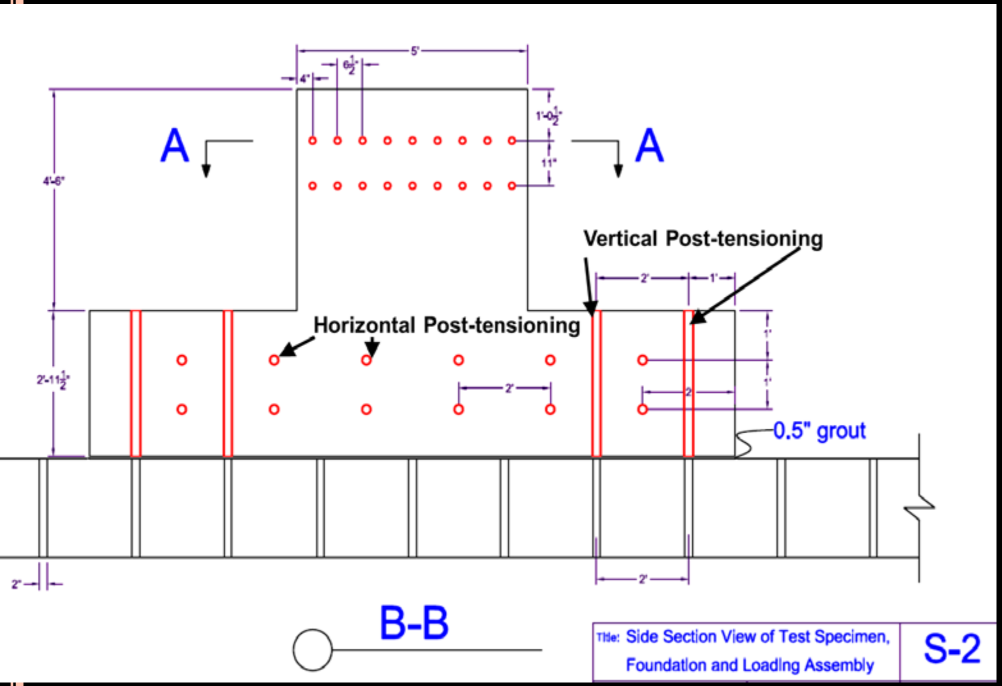
Experimental Progress

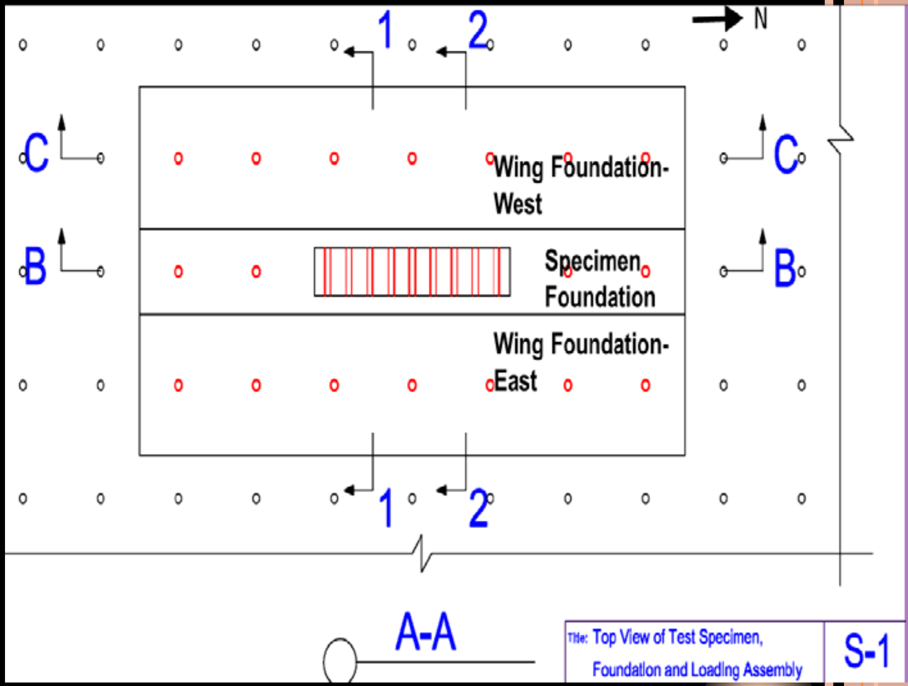
- SC-Flanged Wall Specimens: Cyclic In-plane Shear at Ambient and Elevated Condition – Loading Protocol

Specimen ID	Heating Cycles	Wall thick. T (in.)	Plate Thick. (in.)	Reinf. ratio %	End plate thick. (in.)	Tie Spacing (S), in.	Shear stud s/t_p ratio	Max. temp. (^oF)	Heating Duration (hour)	Comment
SW-H	300-1	10	0.1046 (12ga)	2.1	0.75	5	24	300	1	Effect of heating
	300-3							300	3	Duration of heating
	450-1							450	1	Max. temperature
	450-3							450	3	Max. temperature-duration of heating
	300-24							300	24	Long term heating
SW-A	N.A	10	0.1046 (12ga)	2.1	0.75	5	24	Amb.	-NA-	Control Specimen

Experimental Progress

- RC Wall Specimens: Cyclic In-plane Shear at Ambient and Elevated Condition – Specimen Design





EXPERIMENTAL PROGRESS

- RC Wall Specimens: Cyclic In-plane Shear at Ambient and Elevated Condition – Loading Protocol

Specimen ID	Heating Cycles	Wall thick. (T)	Rebar size & spacing	Reinf. ratio %	Max. temp.	Heating duration	Comment
R-1-H	300-1	10 in.	#6@4in.	2%	300ºF	1 hour	Effect of heating
	300-3				300ºF	3 hour	Duration of heating
	450-1				450ºF	1 hour	Max. temperature
	450-3				450ºF	3 hour	Max. temperature-duration of heating
	300-24				300ºF	24 hour	Long term heating
R-2-H	300-1	10 in.	#4@4in.	1%	300ºF	1 hour	Effect of heating
	300-3				300ºF	3 hour	Duration of heating
	450-1				450ºF	1 hour	Max. temperature
	450-3				450ºF	3 hour	Max. temperature-duration of heating
	300-24				300ºF	24 hour	Long term heating
R-1-A	N.A	10 in.	#6@4in.	2%	Amb.	-NA-	Control Specimen
R-2-A	N.A	10 in.	#4@4in.	1%	Amb.	-NA-	Control Specimen

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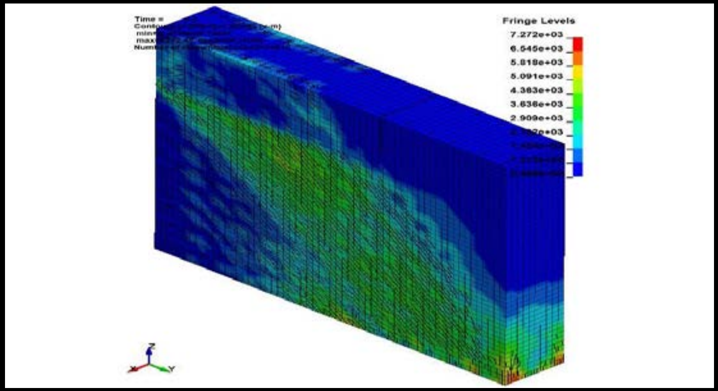
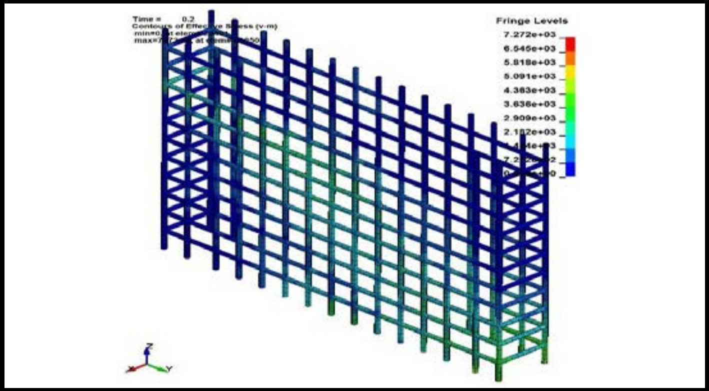
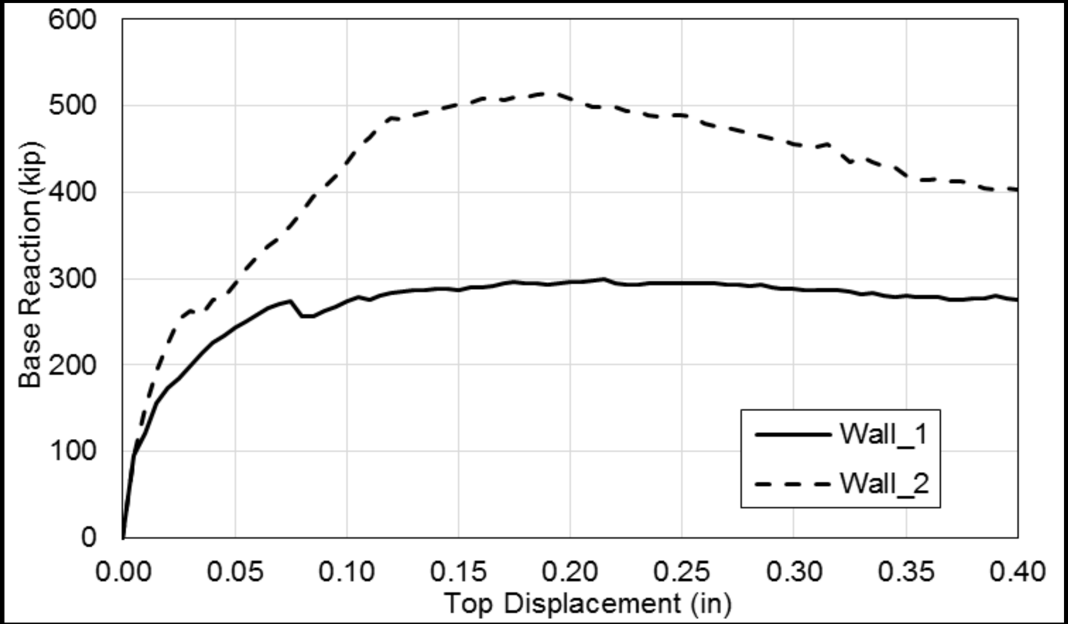
Experimental Progress

- RC Wall Specimens: Cyclic In-plane Shear at Ambient and Elevated Condition – Preliminary FE Analysis







Summary & Conclusions

- SC Wall Pier Tests are Completed
  - Stiffness degradations were more severe for the heated specimen
  - Strength remained unchanged from the ambient specimen
- SC Flanged-Wall Specimen design is completed. Testing is expected to be completed in the next quarter.
- RC Wall Specimen design is completed. Testing is expected to be completed in the next quarter.