Self-Consolidating Concrete Construction for Modular Units

Russell Gentry (PI)
Kimberly Kurtis (Co-PI)
Larry Kahn (Co-PI)
Giovanni Loreto (Researcher)
School of Civil and Environmental Engineering (CEE) – Georgia Institute of Technology

Bojan Petrovic (Co-PI)
Nuclear and Radiological Engineering – Georgia Institute of Technology

Westinghouse Electric
Jurie van Wyk
Bernd Laskewitz

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1. Intro
Objectives and outcomes

- Development of a self-consolidating concrete mixtures so that concrete placement can be made into steel plate composite (SC) modular structures without the need for continuous concrete placement.

Task 1: Development of SCC with Shear-Friction Capacity for Mass Placement

- SCC mixtures to ensure sufficient shear capacity across cold- joints (self-roughening), while minimizing shrinkage and temperature increase during curing to enhance concrete bonding with the steel plates.

Task 1: Development of SCC with Shear-Friction Capacity for Mass Placement
Task 2: Assessment of Cold Joint Shear-Friction Capacity

- SCC mixtures featuring a self-roughening capability to produce adequate shear friction between cold joints and to produce draft provisions addressing shear-friction, for consideration in the AISC N690-12 Appendix N9 code used for the design of SC modular structures.

Task 2: Assessment of Cold Joint Shear-Friction Capacity

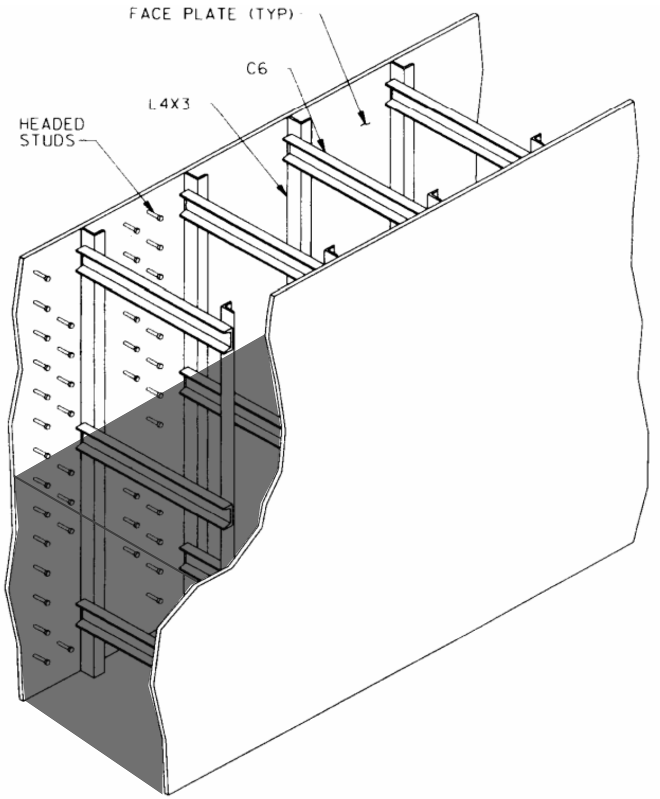
Task 3: Assessment of Shear and Flexural Performance

Task 4: Validation through Full-Scale Testing and Modeling

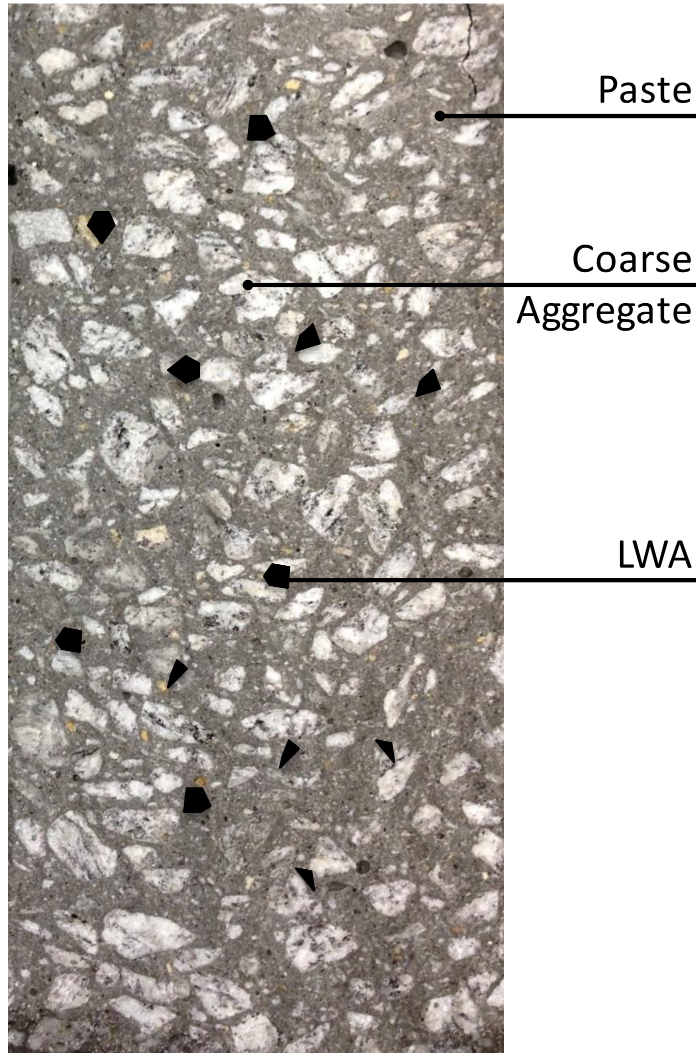
Task 5: Draft Code Requirement for Shear Friction Design of Cold Joints

1. Intro
Objectives

- Development of a self-consolidating concrete mixtures so that concrete placement can be made into steel plate composite (SC) modular structures without the need for continuous concrete placement.



1. Intro
Objectives



2. Development of SRC Mix Design
Strategies

Mix Component	**67M**
Cementitious (lb/yd^3)	
Cement Type II	617
Fly Ash, Class F	459
Total Powder	*1076*
Water (lb/yd^3)	343
w/cm	*0.319*
Coarse Aggregates (lb/yd^3)	
# 67	981
# 89	305
Total Coarse	*1286*
Fine Aggregates (lb/yd^3)	
Natural sand	679
Manufactured sand	679
Total Fine	*1357*
Total Aggregates	*2796*
Admixures (fl oz./cwt)	
HRWR	0.18
TOT	4063

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- Smaller aggregates and controlled gradation curve
- Use of #67 and #89 coarse aggregates
- Substitute 5%, 10% and 15% in volume of coarse aggregate with LWA

2. Development of SRC Mix Design
Proprieties and tests

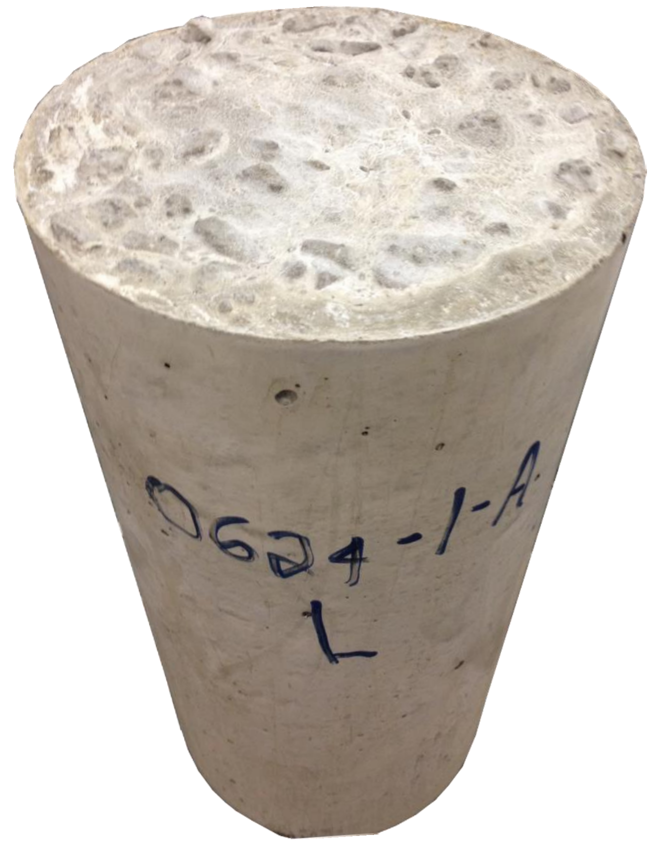

Self-Consolidating Concrete


Self-Roughening Concrete

Fresh SCC proprieties
- Flowability: flows easily at suitable speed into formwork (T20 = 4-5sec; Flow Slump = 24-26")
- S Groove test (good self-healing ability)
- Hardened Visual Stability Index (VSI = 0)

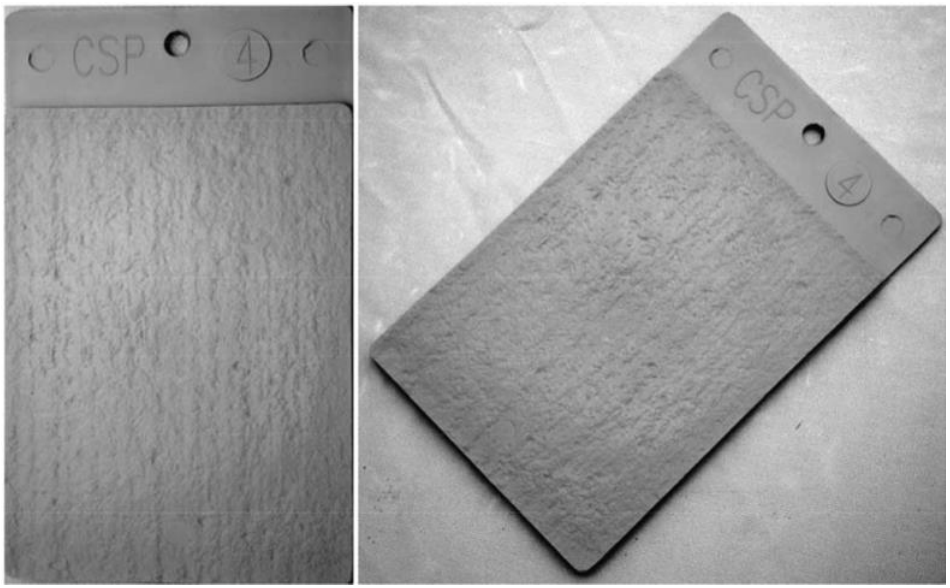
Hardened SRC proprieties
- Compressive strength: 6-7ksi
- Shrinkage: <250 με

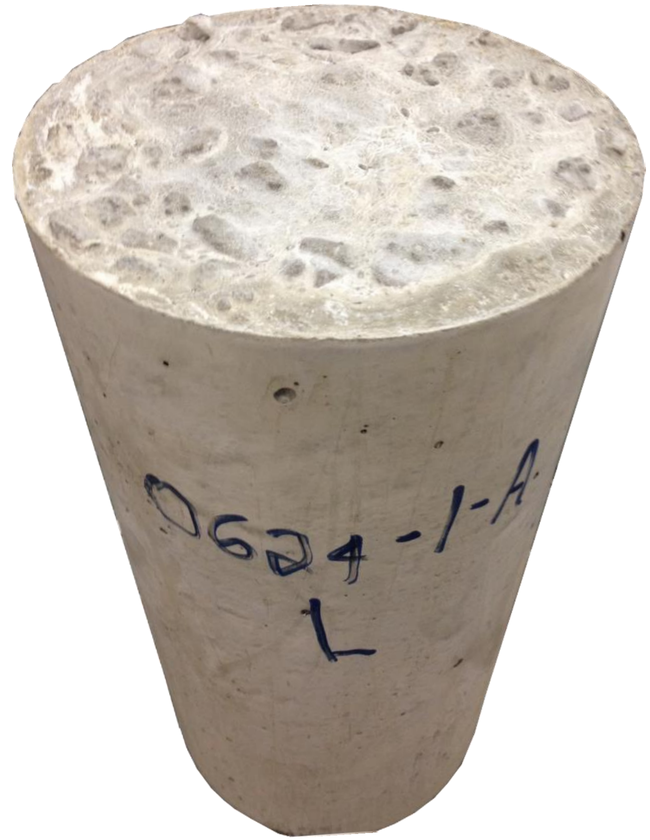
2. Development of SRC Mix Design
Measurements of Roughness



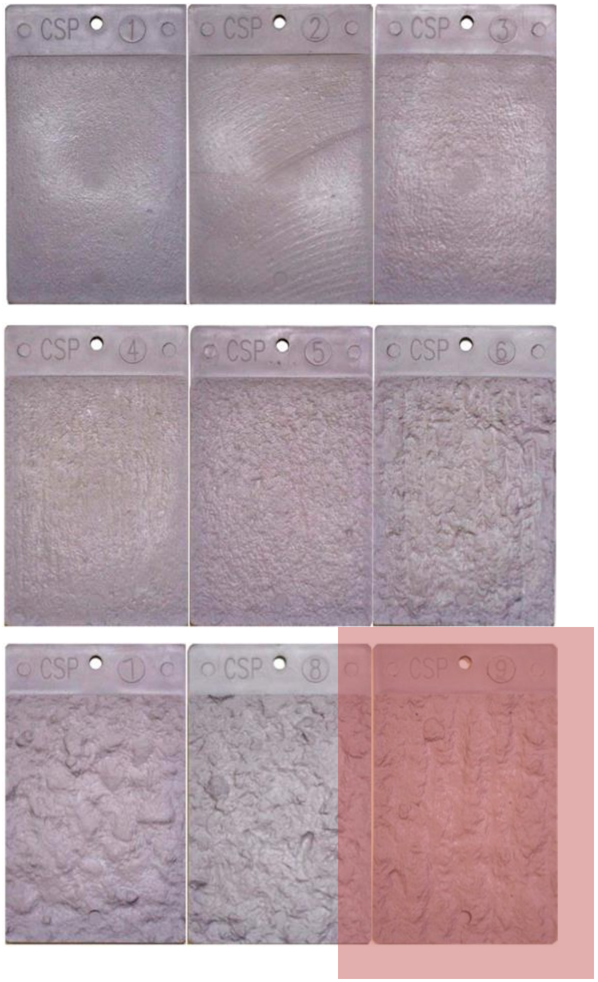
2. Development of SRC Mix Design
Roughness

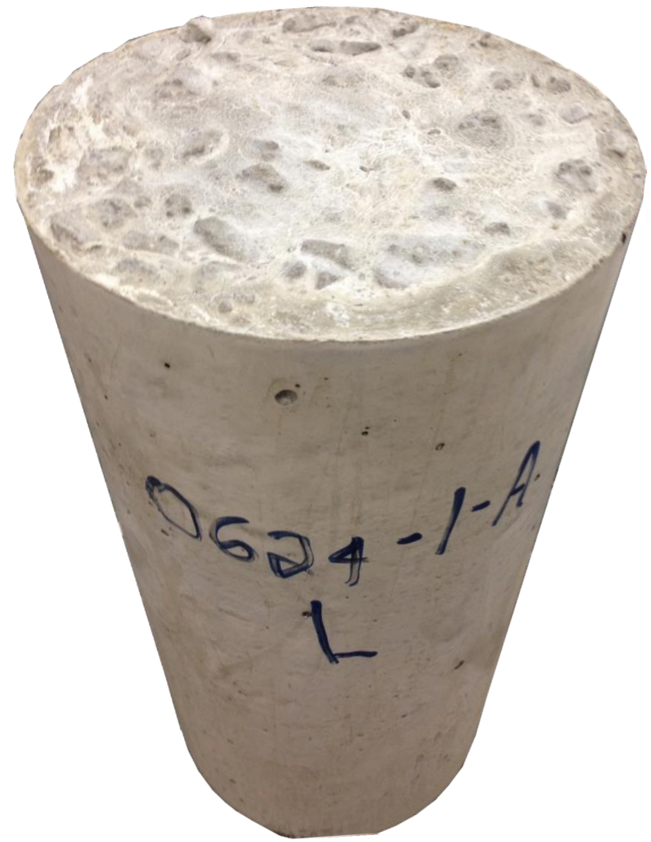
ICRI's CSPs





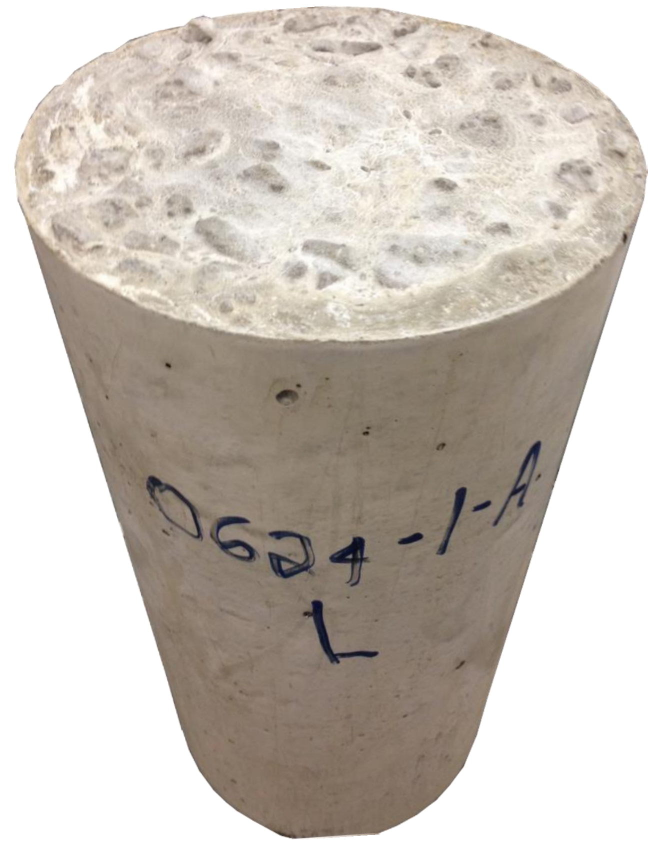
2. Development of SRC Mix Design
Roughness





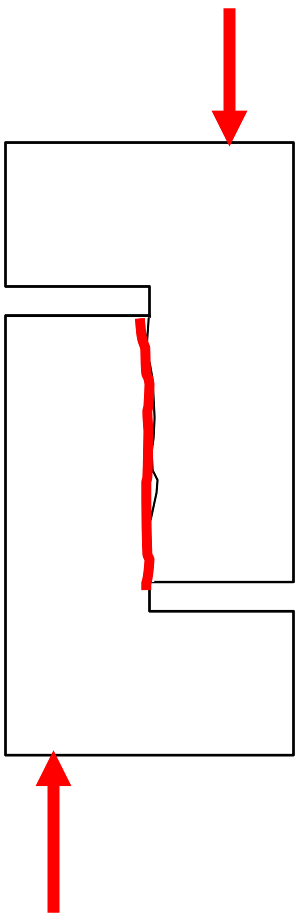
2. Development of SRC Mix Design
Measurements of Roughness

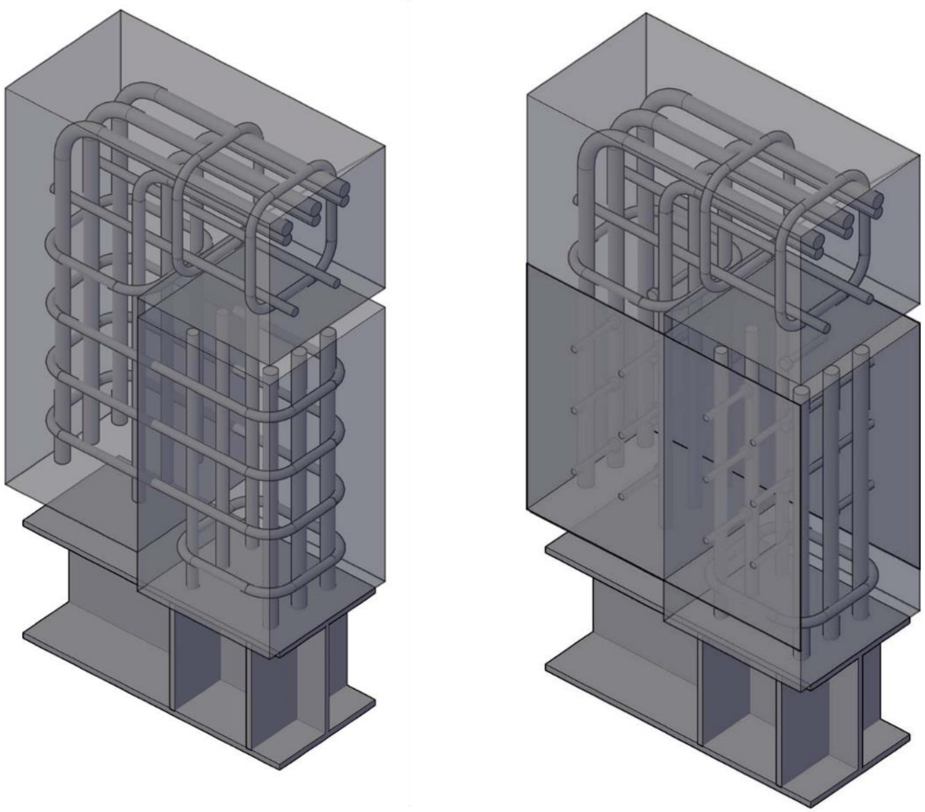
ACI 318-11 (11.6.9):
"...when concrete is placed against previously hardened concrete, the interface for shear transfer shall be clean and free of laitance. If μ is assumed equal to **1.0**λ, interface shall be roughened to a full amplitude of approximately 1/4 in."



3. Assessment of Cold Joint Shear Friction Capacity

Mechanical tests for shear friction characterization





Laboratory test

Kahn, L., Mitchell, A. D. (2002) “Shear friction test with high-strength concrete” ACI Structural Journal, 99 (1).

3. Assessment of Cold Joint Shear Friction Capacity

Mechanical tests for shear friction characterization

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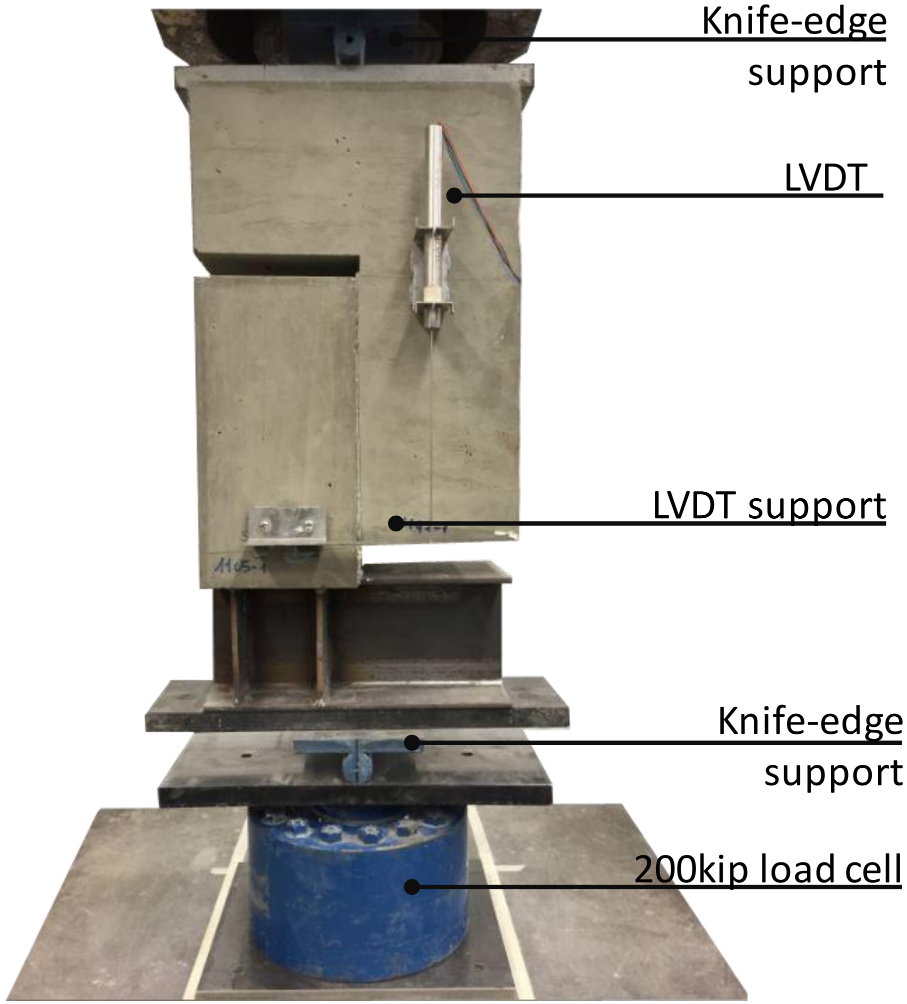


3. Assessment of Cold Joint Shear Friction Capacity

Failure modes

Internal Reinforcement
ρ=0.75%

External Steel Plate
ρ=0.25%
t=0.031 in.
(22 gage)

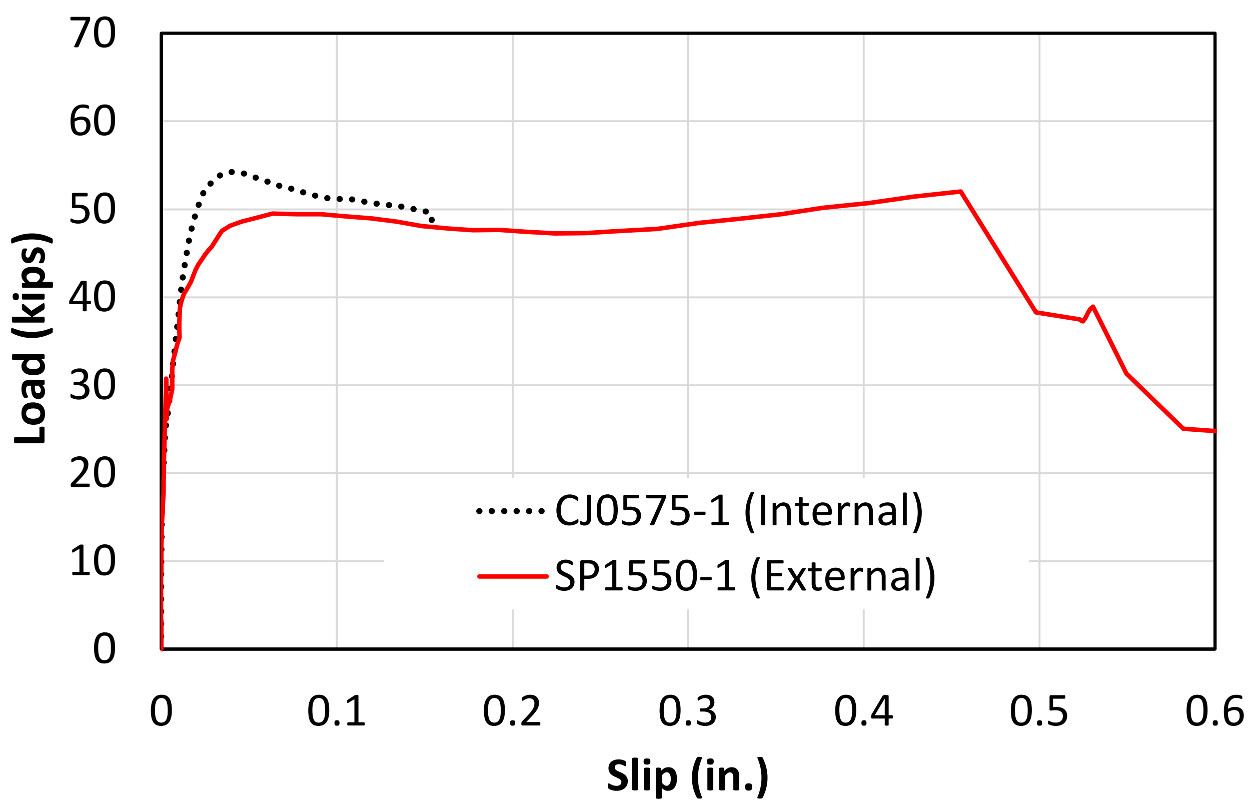
External Steel Plate
ρ=0.50%
t=0.063 in.
(16 gage)

External Steel Plate
ρ=0.75%
t=0.094 in.
(13 gage)

External Steel Strips
ρ=0.75%
t=0.375 in.

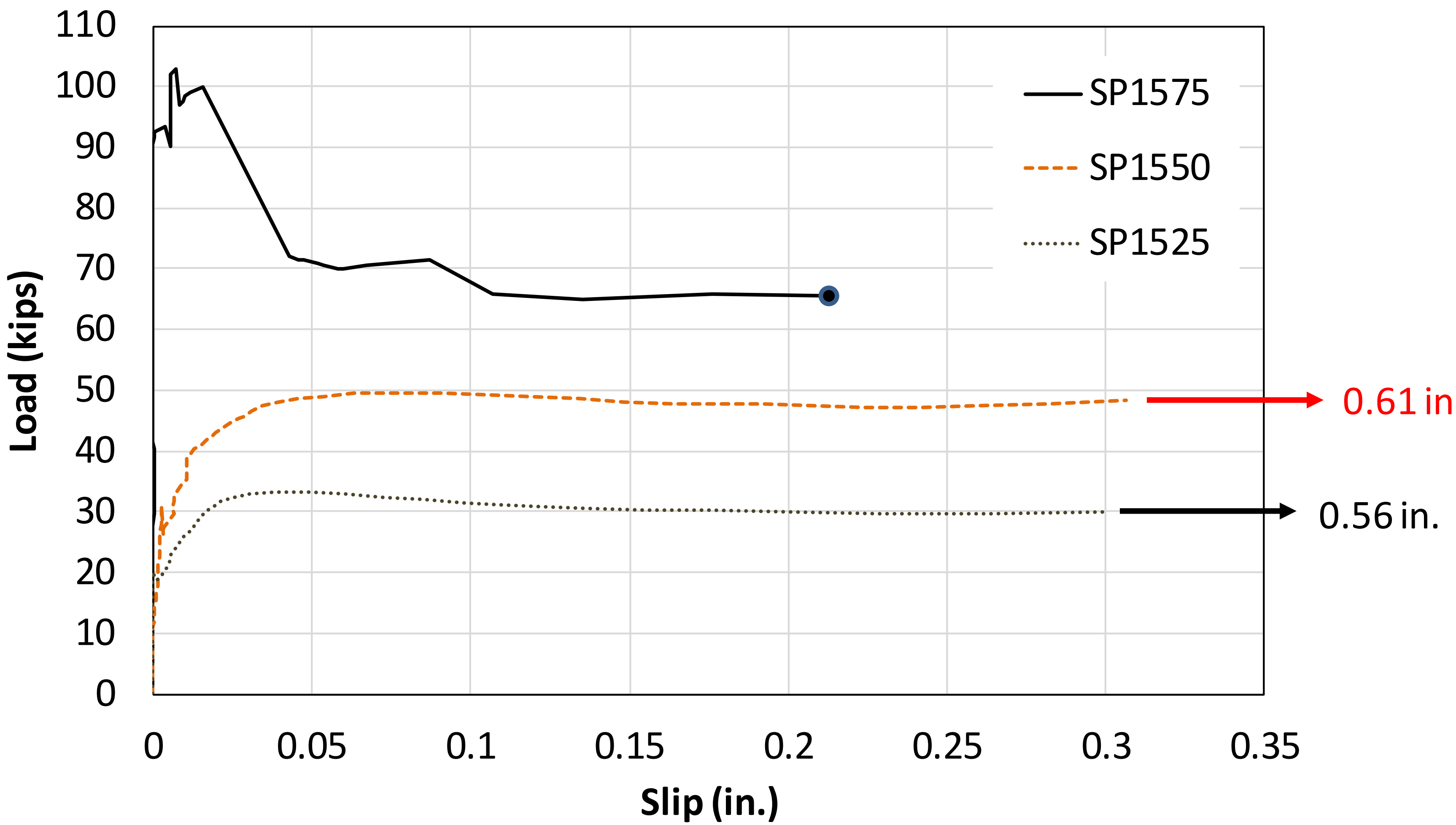
3. Assessment of Cold Joint Shear Friction Capacity

Test Results – Internal versus External Reinforcement



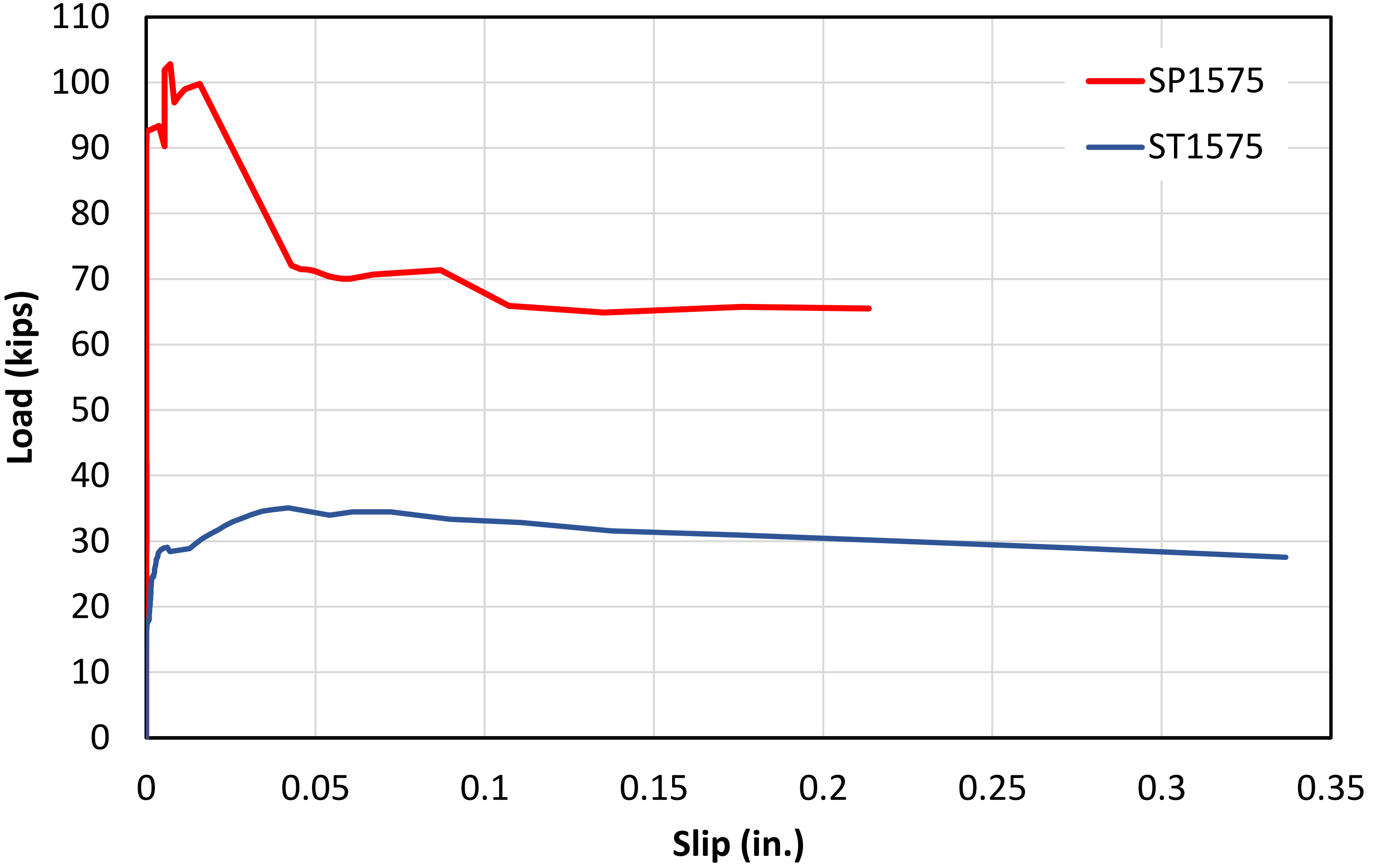
3. Assessment of Cold Joint Shear Friction Capacity

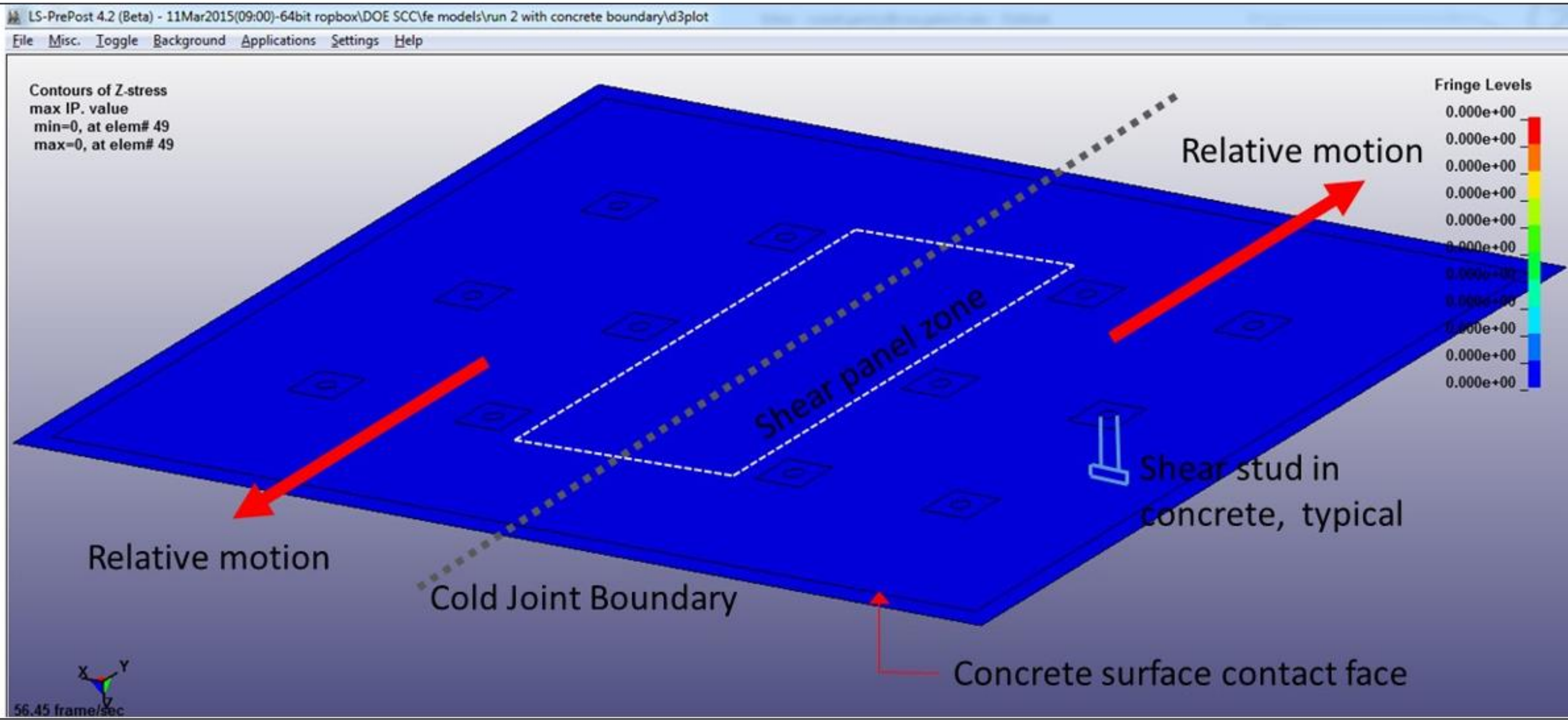
External Reinforcement – Effect of Reinforcement Ratio



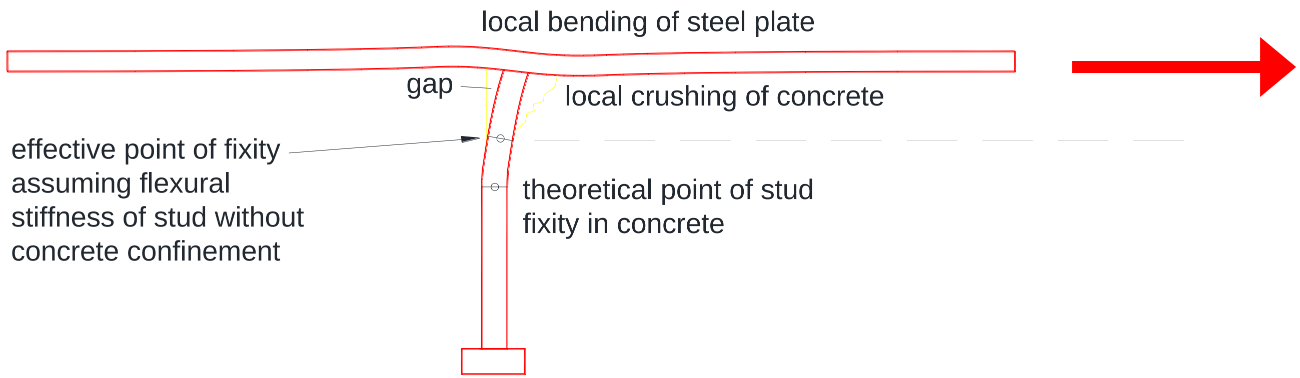
3. Assessment of Cold Joint Shear Friction Capacity

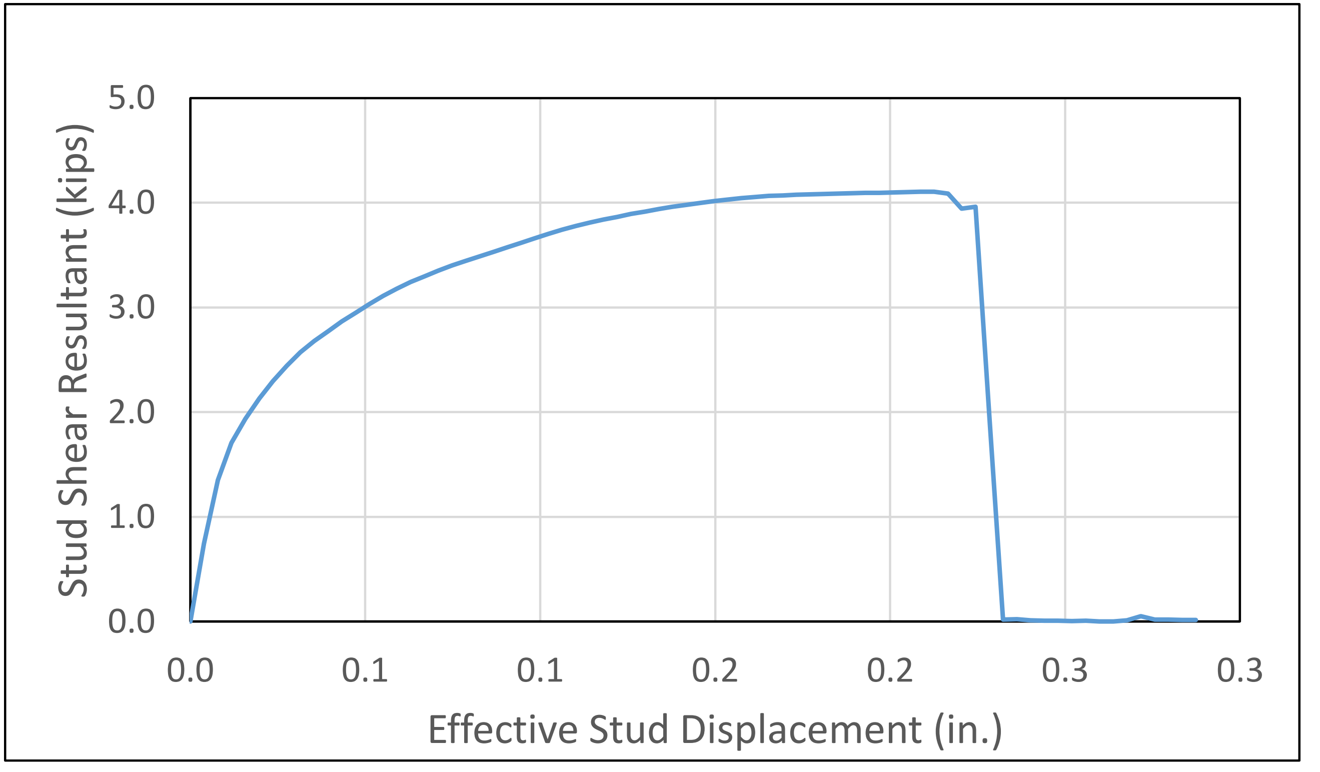
Test Results – External Plate versus Strip Reinforcement

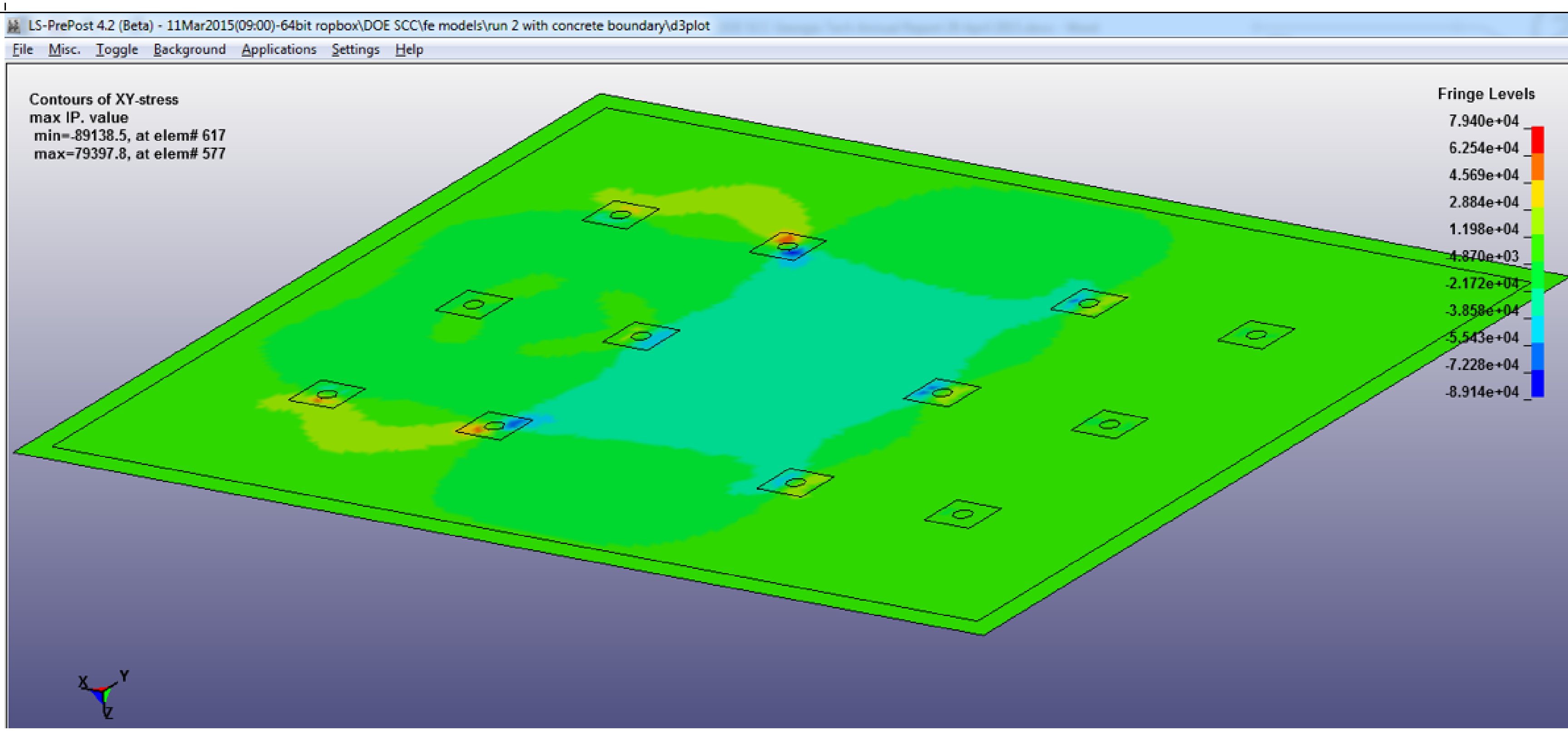




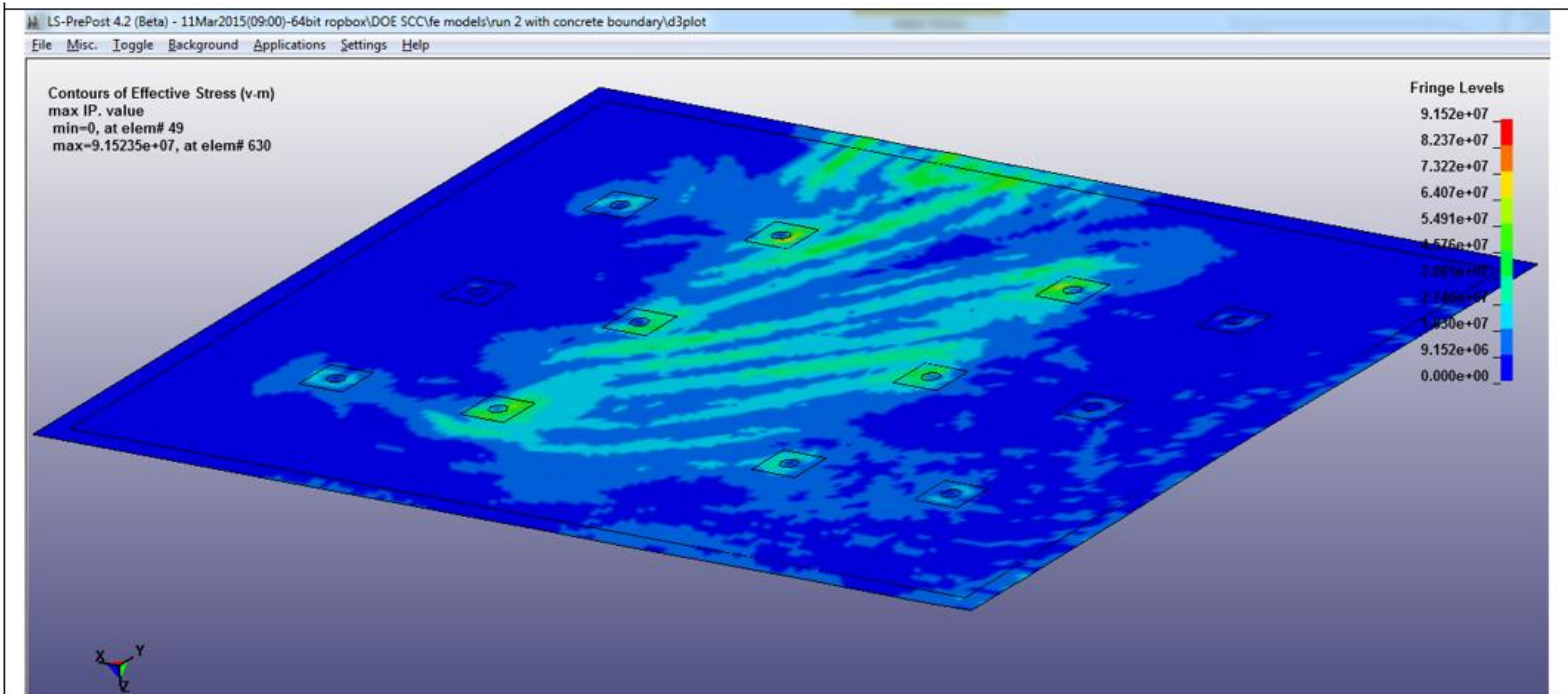
(a) Non-linear finite element model in LS-DYNA explicit. This initial model approximate the geometry of specimen SP 15 50-1 but with fewer Nelson studs.

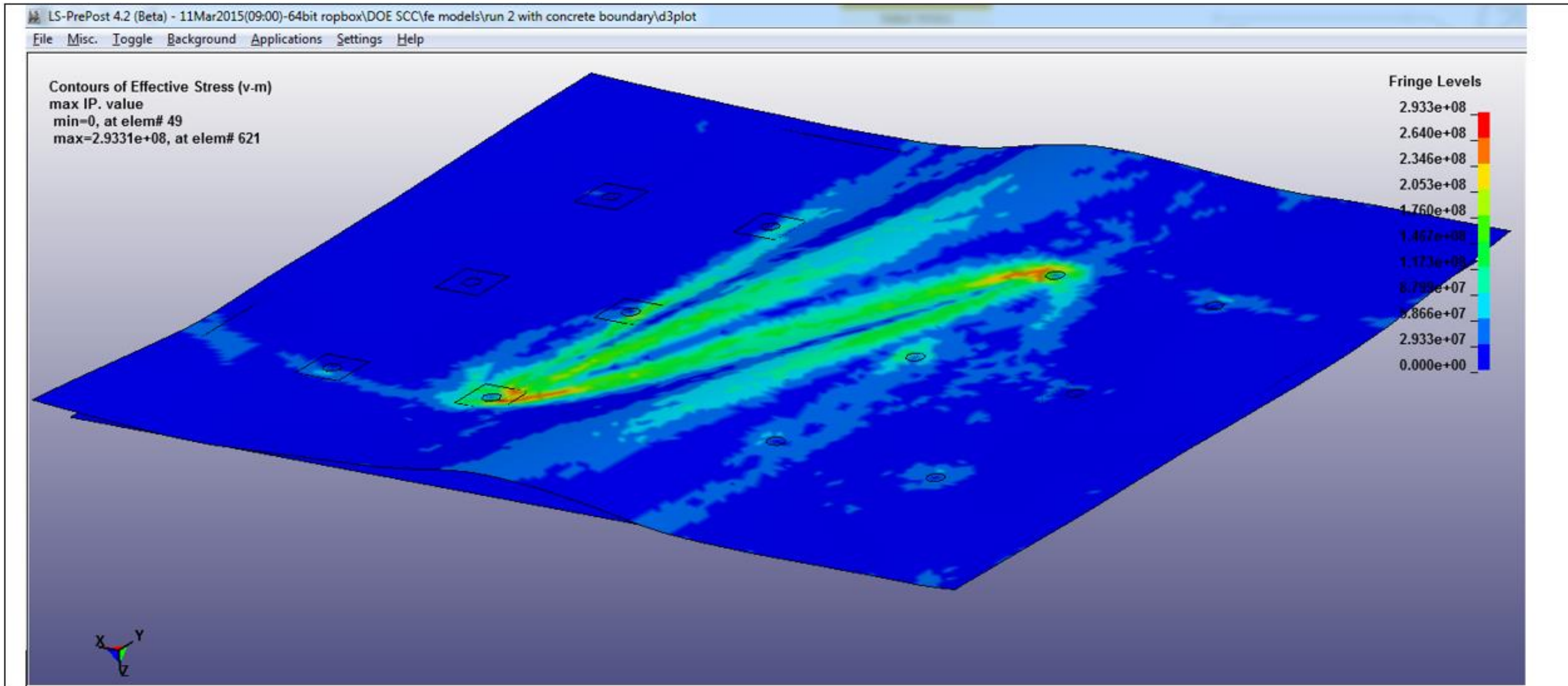

local bending of steel plate
gap
local crushing of concrete
effective point of fixity assuming flexural stiffness of stud without concrete confinement
theoretical point of stud fixity in concrete


Stud Shear Resultant (kips)
5.0
4.0
3.0
2.0
1.0
0.0
0.0
0.1
0.1
0.2
0.2
0.3
0.3
Effective Stud Displacement (in.)

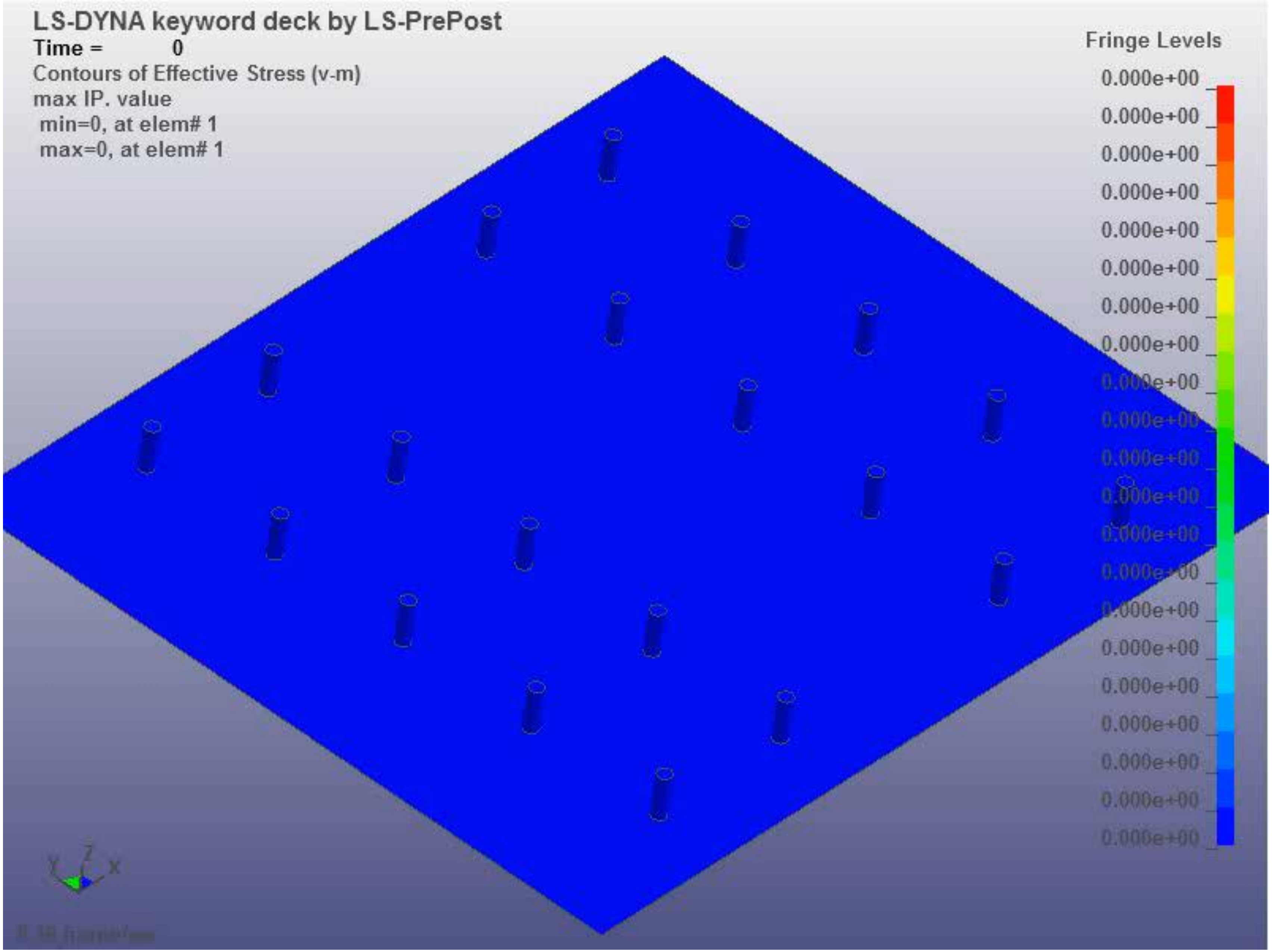


(b) Initital loading. Constant shear in the panel zone. In-plane shear stresses shown (all stresses in Pa).


LS-PrePost 4.2 (Beta) - 11Mar2015(09:00)-64bit ropbox\DOE SCC\fe models\run 2 with concrete boundary\d3plot
File Misc. Toggle Background Applications Settings Help
Contours of Effective Stress (v-m)
max IP. value
min=0, at elem# 49
max=9.15235e+07, at elem# 630
Fringe Levels
9.152e+07
8.237e+07
7.322e+07
6.407e+07
5.491e+07
9.152e+06
0.000e+00
X
Y
Z



(e) Buckling progresses. Steel plate begins to yield in the vicinity of two studs (see red on stress contour). Buckling distortion as the plate pulls away from the concrete visible.


LS-DYNA keyword deck by LS-PrePost
Time = 0
Contours of Effective Stress (v-m)
max IP. value
min=0, at elem# 1
max=0, at elem# 1
Fringe Levels
0.000e+00
0.000e+00
0.000e+00
0.000e+00
0.000e+00
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0.000e+00
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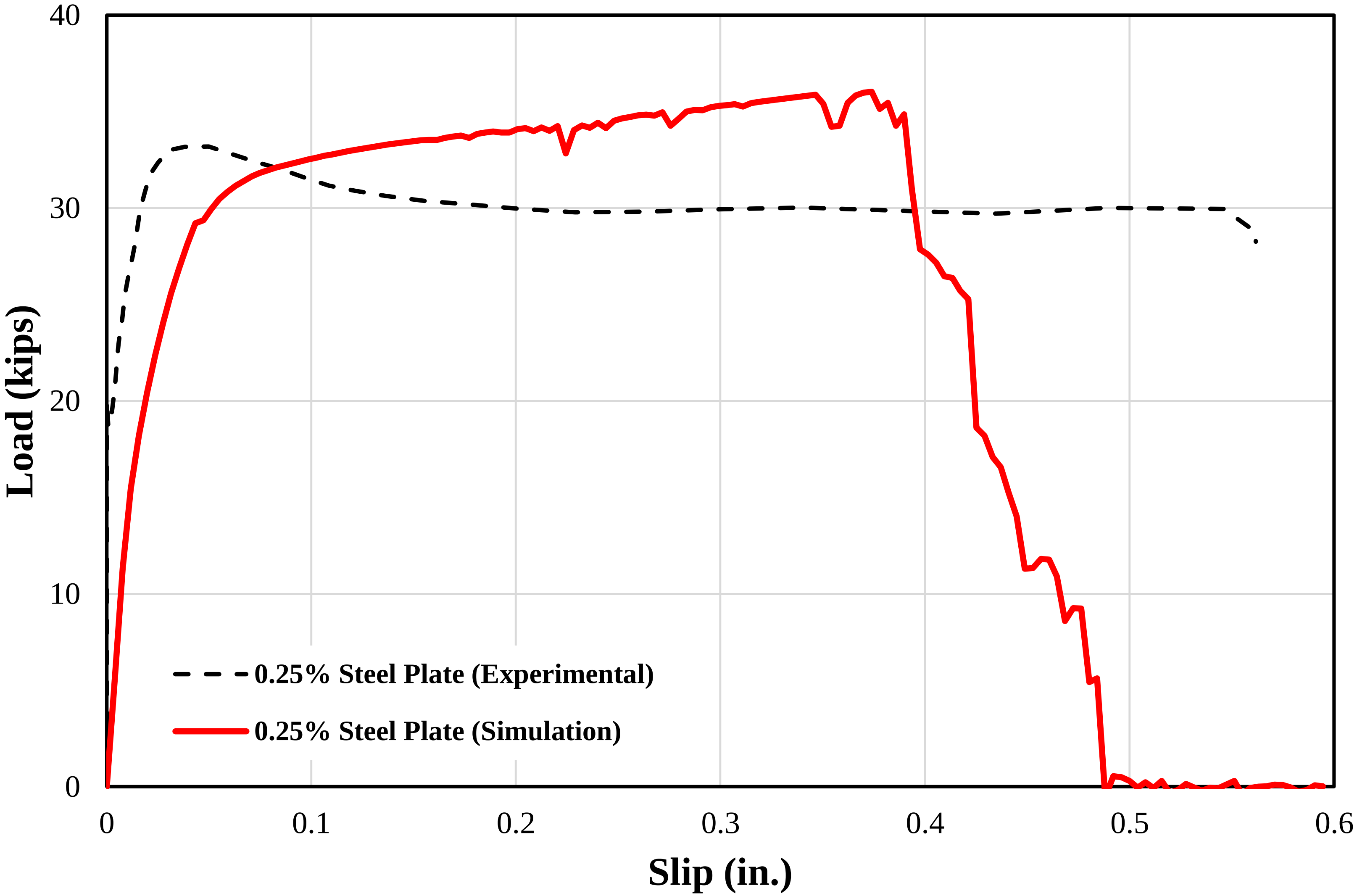
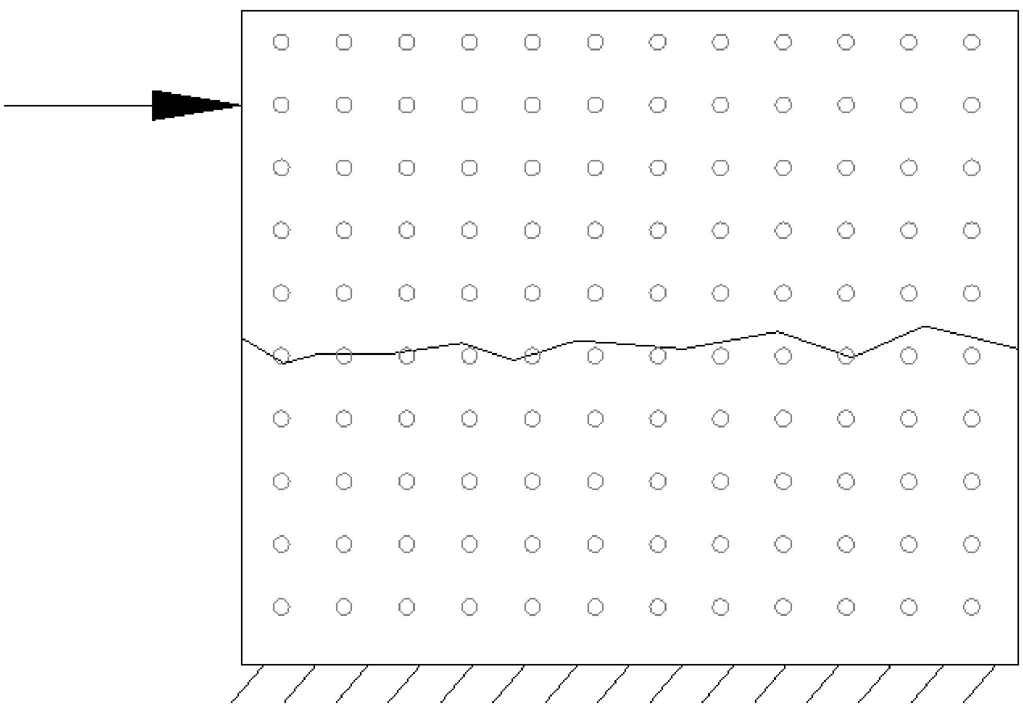
0.000e+00
Y
Z
X

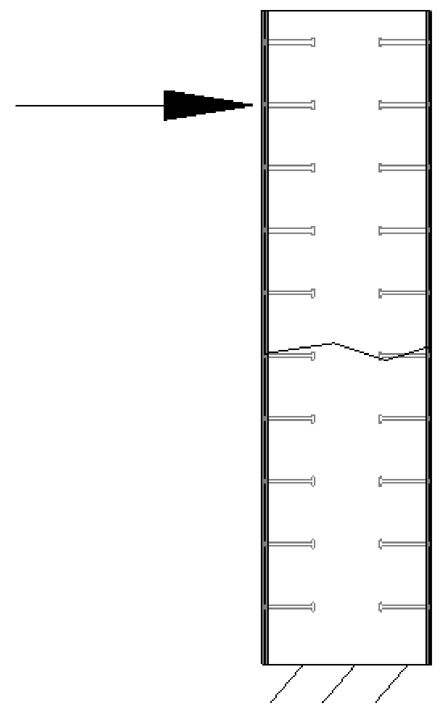

40
30
20
10
0
0
0.1
0.2
0.3
0.4
0.5
0.6
Load (kips)
Slip (in.)
0.25% Steel Plate (Experimental)
0.25% Steel Plate (Simulation)

4. Assessment of Shear and Flexural Performances

Specimens preparation



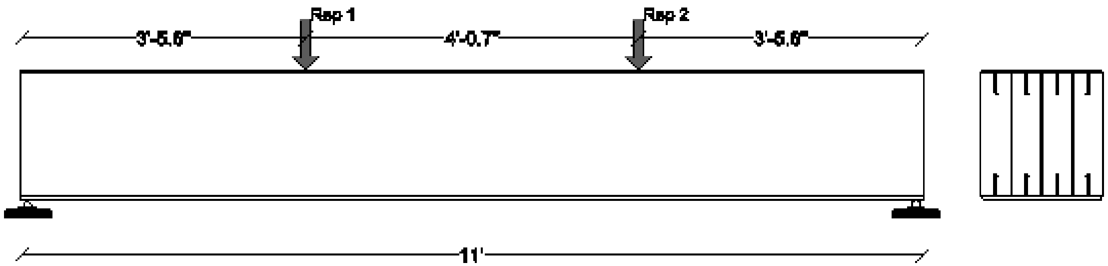
In-Plane Loading



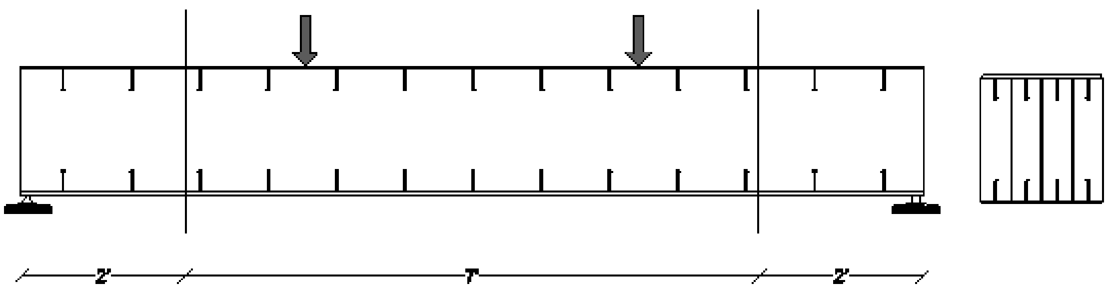
Out-of-Plane Loading

Task 3

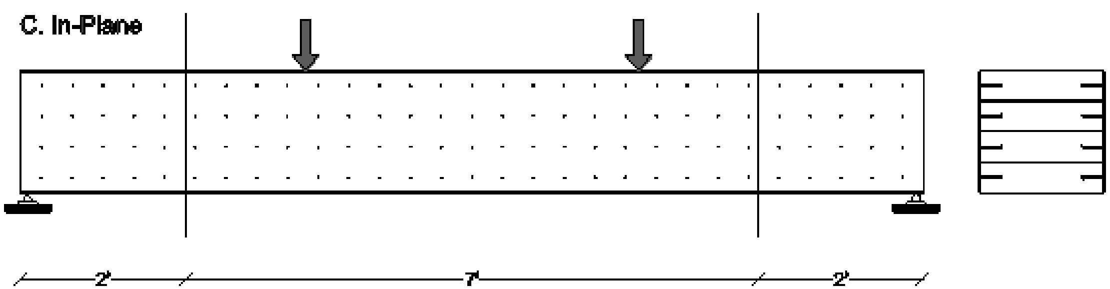
A. Control - No cold joint 1 in-plane and 1 out-of-plane

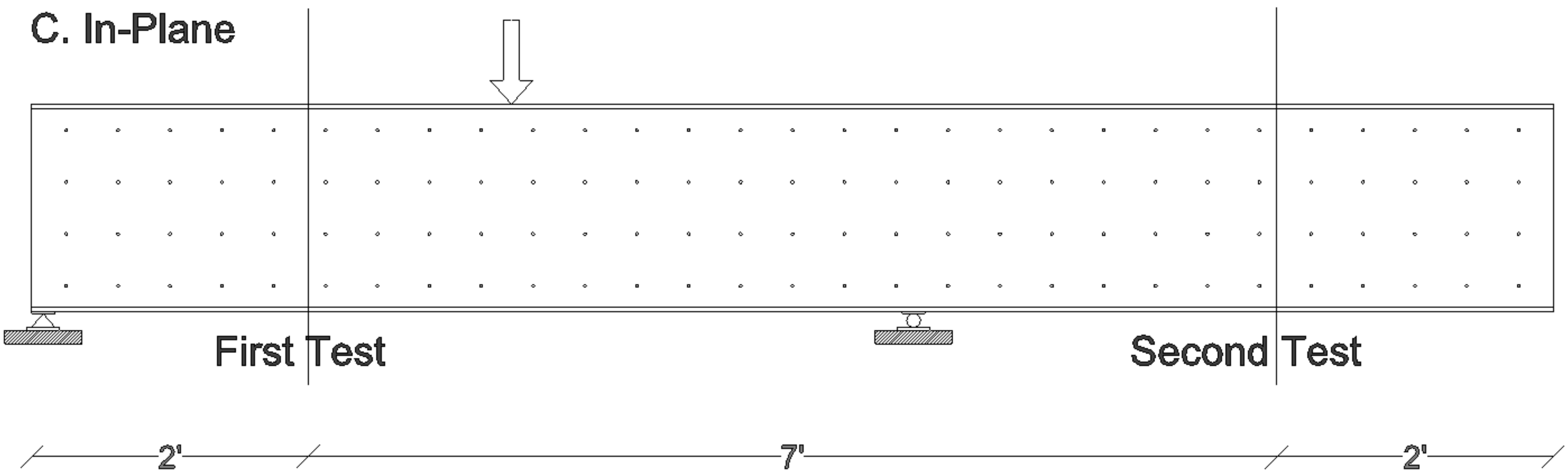


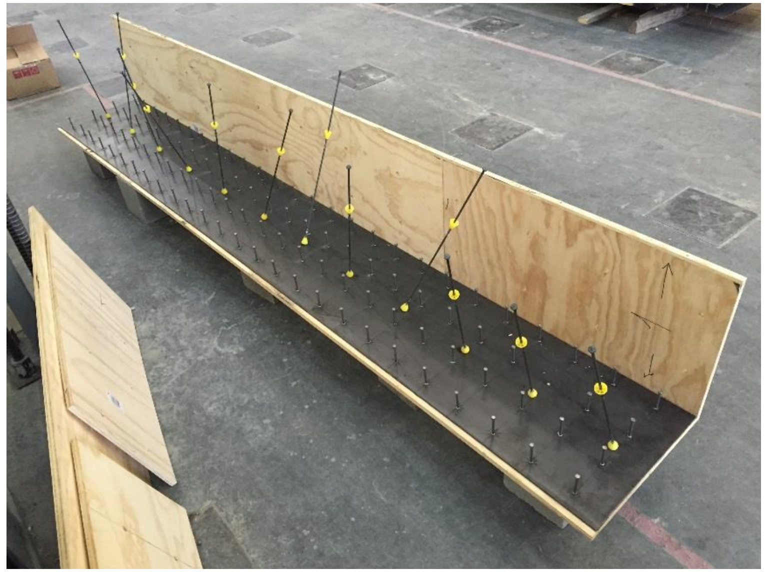
B. Out-of-Plane



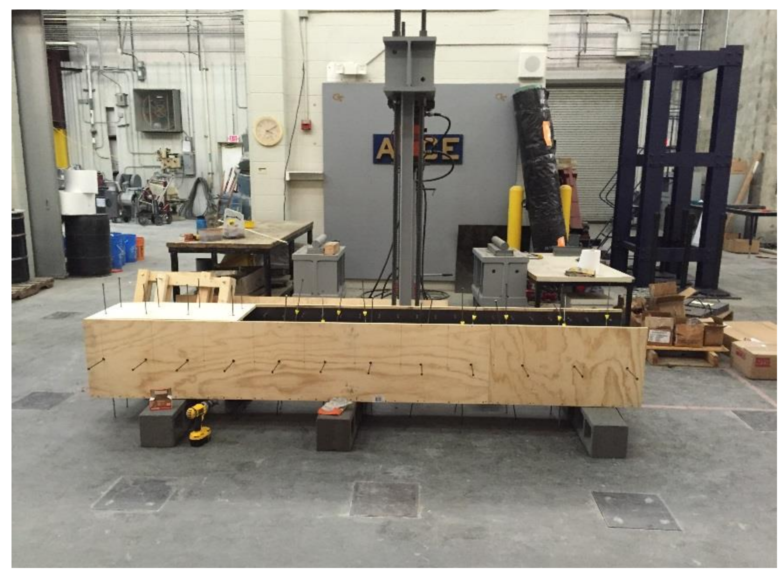
C. In-Plane




C. In-Plane
First Test
Second Test
2'
7'
2'

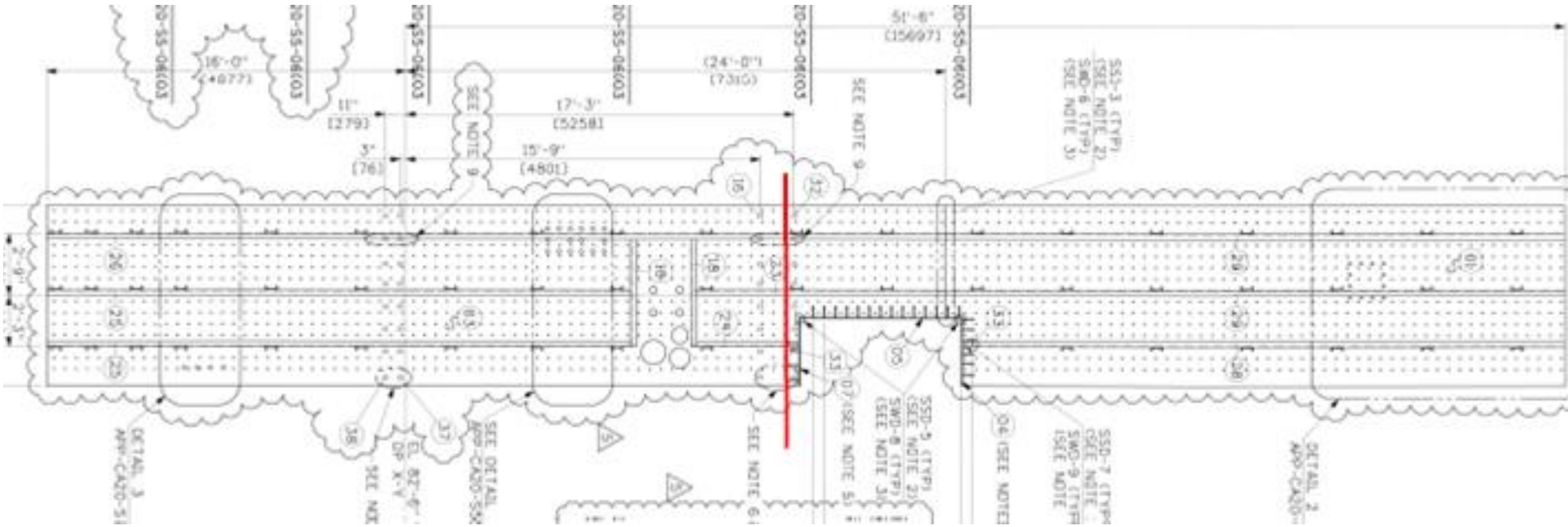








TRUCK 2
(Surface)

5. Validation through Full-scale Test and Modeling
Model

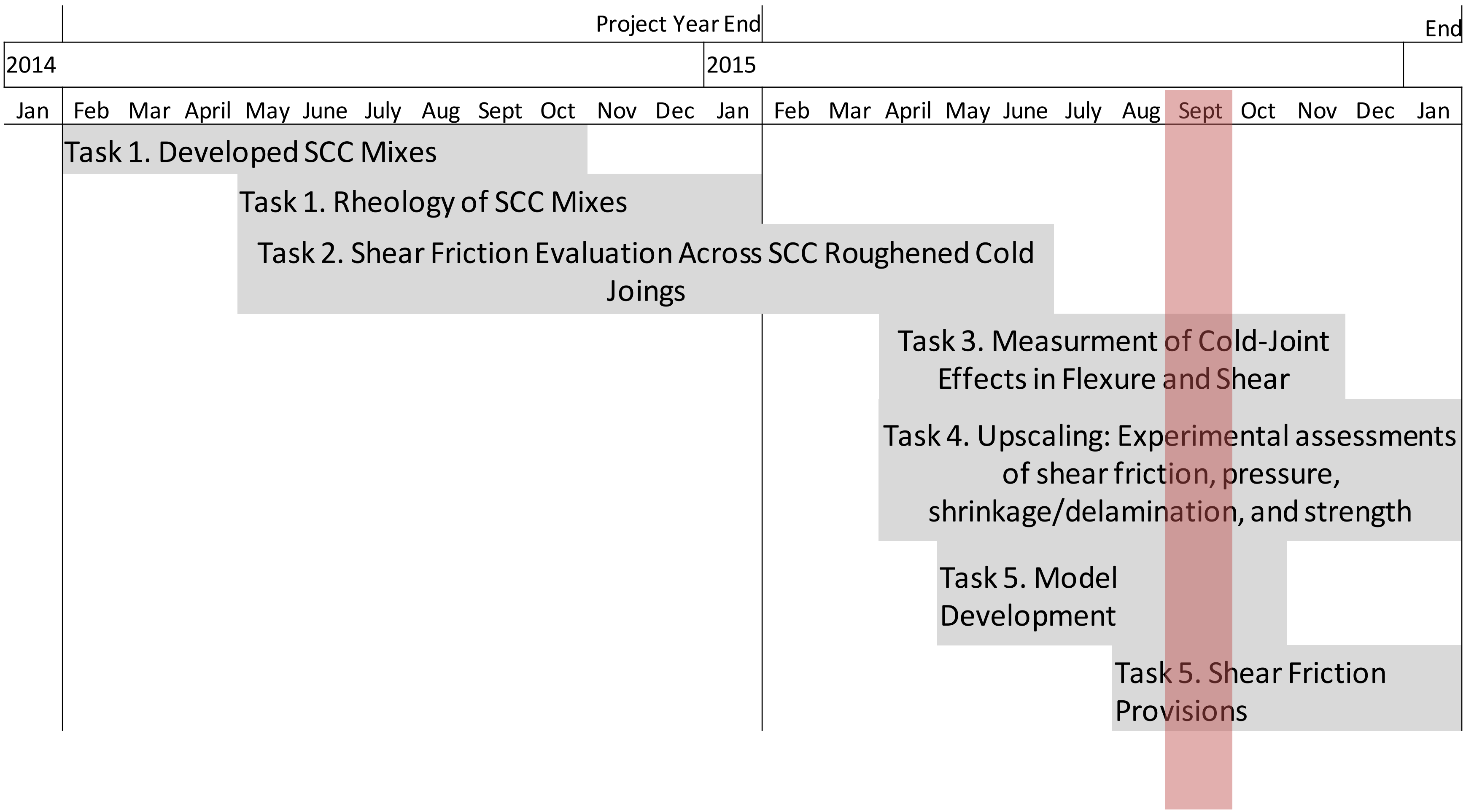


6. Conclusions and Outlooks

And future developments

1. Task 2 test results demonstrate the ability of steel plate composite construction to transfer in-plane forces across the cold-joint boundaries.
2. Results show that SC construction is more ductile than conventional internally-reinforced concrete.
3. Test results show that self-roughening concrete with at least 5% LWA provides shear friction coefficient (λ) of 1.0 or greater.
4. The test results do not conclusively demonstrate the relationship between LWA percentage and cold-joint shear capacity.
5. Non-linear FEA models are promising and may be used for parametric studies of joint behavior – but further calibration is needed.
6. Task 3 specimens will validate in-plane shear behavior and provide better guidance on the out-of-plane behavior of cold-joint behavior in SCC.
7. The Task 4 specimen will be a tremendous challenge and we are working closely with Westinghouse to procure the test article from CBI in a cost-effective and timely manner.

Timeline


Project Year End
End
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Task 1. Developed SCC Mixes
Task 1. Rheology of SCC Mixes
Task 2. Shear Friction Evaluation Across SCC Roughened Cold Joings
Task 3. Measurment of Cold-Joint Effects in Flexure and Shear
Task 4. Upscaling: Experimental assessments of shear friction, pressure, shrinkage/delamination, and strength
Task 5. Model Development
Task 5. Shear Friction Provisions

“This material is based upon work supported by the Department of Energy [DE-NE0000667 NEET]”

Thank you. Questions?