Self-Consolidating Concrete for SC Modular Structures

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

Giovanni Loreto (Researcher/Presenter)
College of Architecture and Construction Management – Kennesaw State University (Atlanta, GA)

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

Jurie van Wyk (Industry partner)
Bernd Laskewitz (Industry partner)
Westinghouse Electric

Monday, OCTOBER 17, 2016 – Germantown, MD
AMM Workshop

1. Intro

2. Task 1 – Development of Self-Roughening Concrete (SRC) Mix Design

3. Task 2 – Assessment of Cold Joint Shear Friction Capacity

4. Task 3 – Assessment of Shear and Flexural Performances

5. Task 4 – Validation through Full-scale Test and Modeling

6. Conclusions and Outlooks

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 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

Some consideration

- Next 10 years 40% of NPP will approach their 40ys of service
- Average time for construction for existing NPPs: 9.3 years
- Longest time for construction: 23 years

1. Intro
Looking at Containment Buildings

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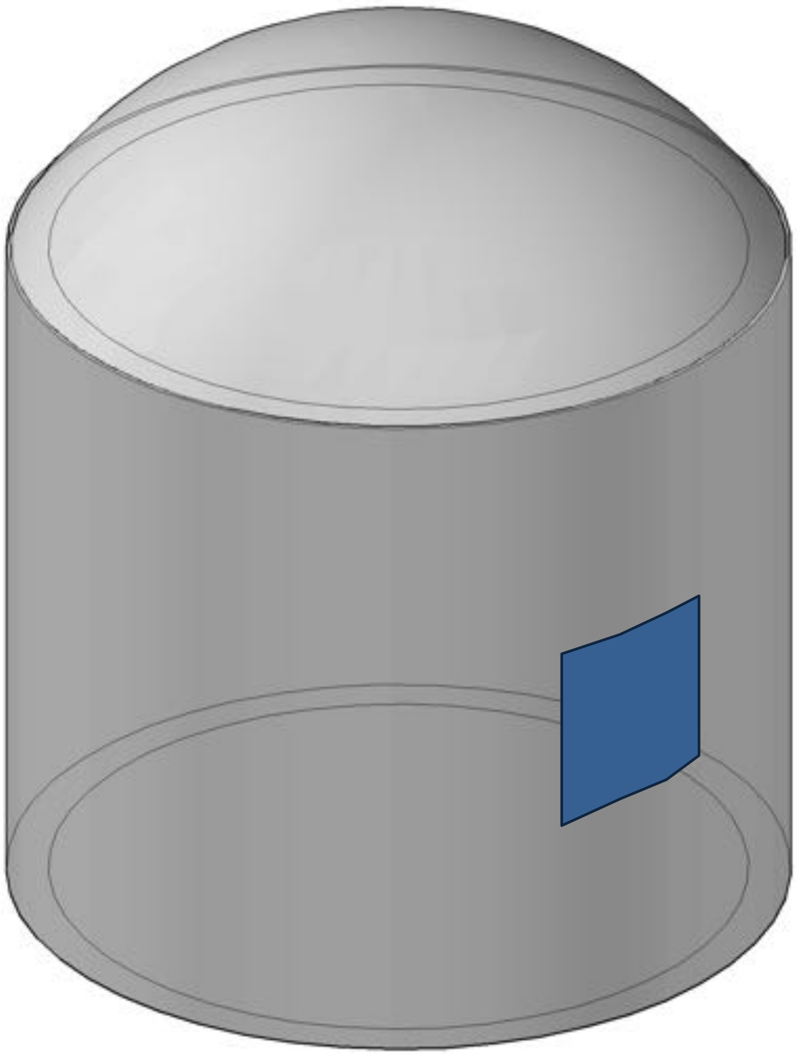
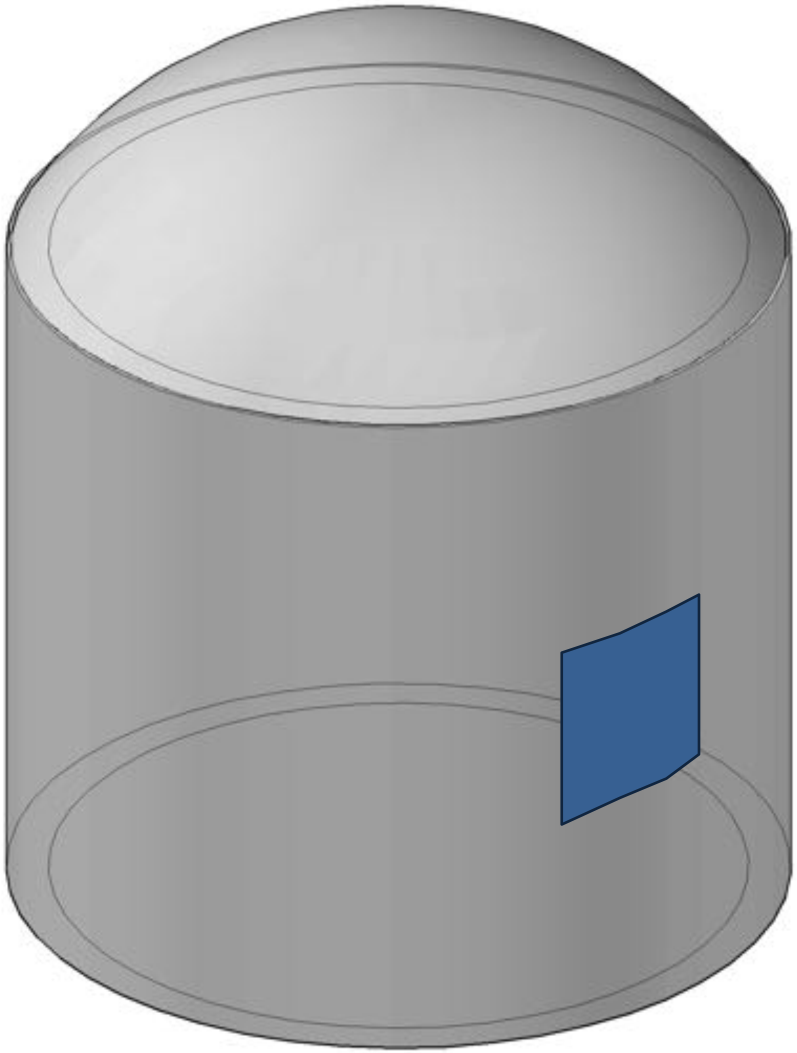
Looking at Confinement Buildings

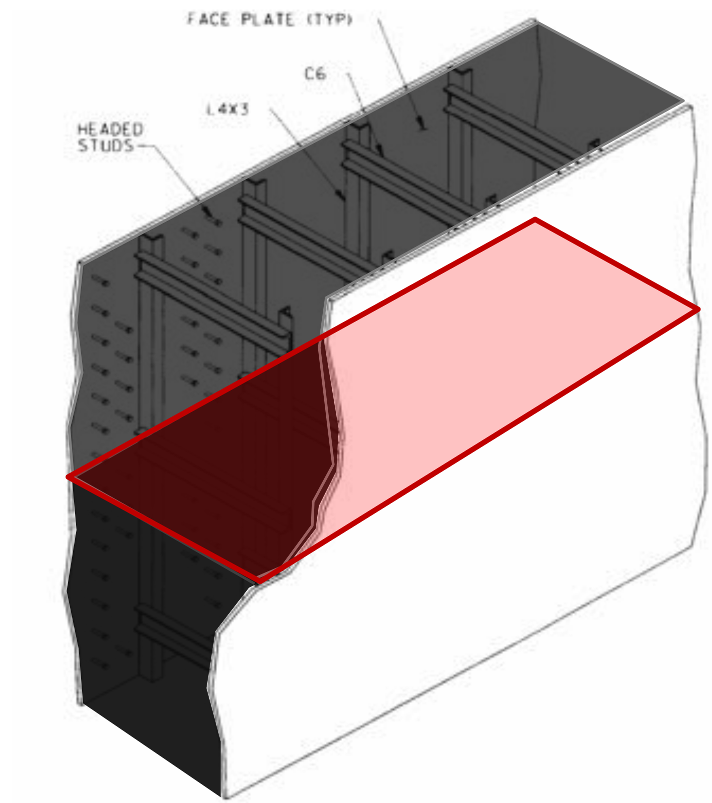


- In third generation modular (steel composite) construction of containment structures, concrete is placed between two steel plates, tied together

1. Intro
Facts



- In third generation modular (steel composite) construction of containment structures, concrete is placed between two steel plates, tied together



- To avoid cold joints, requires *continuous concrete placement* → 1200 trucks!

Some consideration

- Next 10 years 40% of NPP will approach their 40ys of service
- Average time for construction for existing NPPs: 9.3 years
- Longest time for construction: 23 years

Research need (DOE-NEET)

(1) Assembly and material innovation to enhance modular building techniques such as advances in high strength concrete and rebar, inspection equipment, and pre-assembled rebar systems; and

(2) Advances in modular construction to include improved design codes, improved methods for transport and delivery and advancements in integrated prefabrication.

1. Intro
Objectives

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Objectives

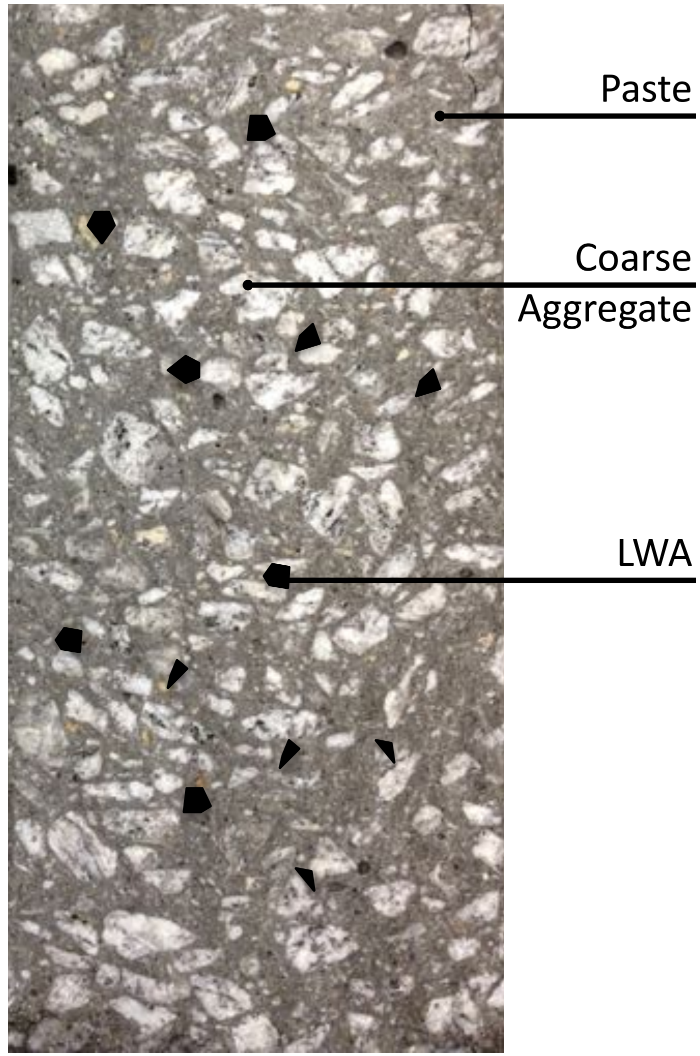
Task 1

- 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 (cold joint) .

Task 2, Task 3, Task 4

- 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.

2. Task 1 – Development of a Self-Roughening Concrete
Proposed idea



2. Task 1 – Development of a Self-Roughening Concrete
Strategies

2. Task 1 – Development of a Self-Roughening Concrete
Outcomes

Let's take a look!

2. Task 1 – Development of a Self-Roughening Concrete
Proprieties and tests

Self-Consolidating Concrete

Self-Roughening Concrete

Fresh SCC proprieties

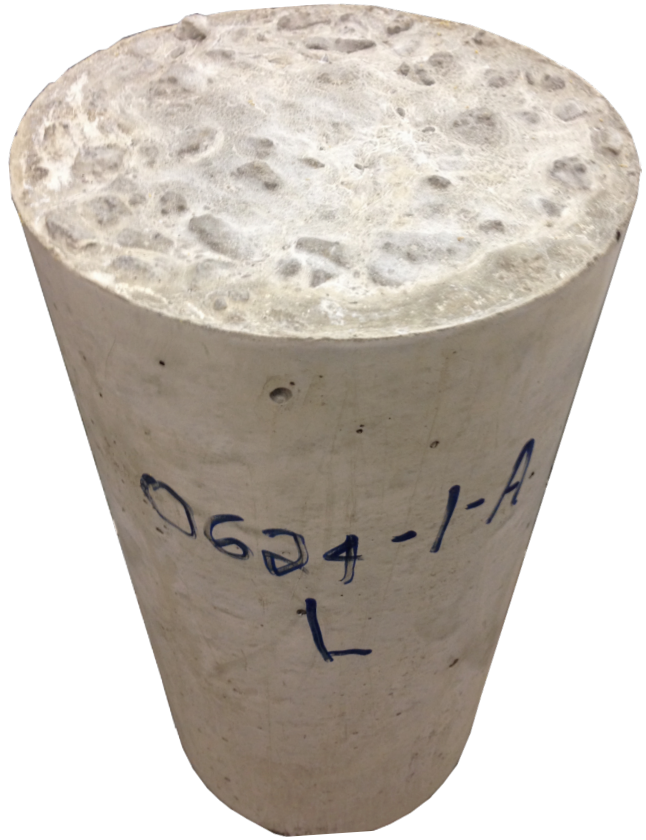
- Flowability: flows easily at suitable speed into formwork (T20 = 4-5sec; Flow Slump = 24-26”)
- S Groove test (good self-healing ability)
- Hardened Visual Stability Index (VSI = 0)

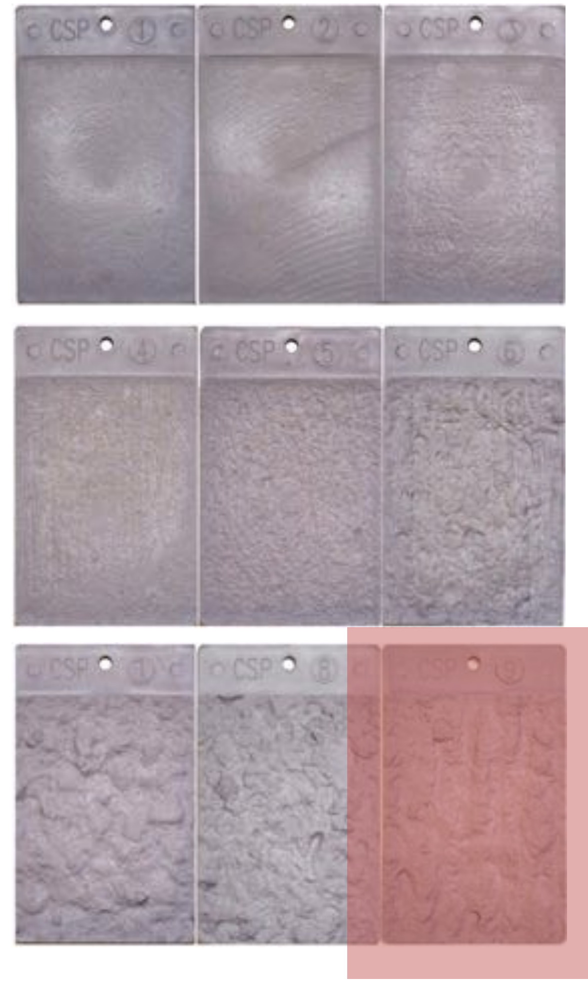
Hardened SRC proprieties

- Compressive strength: 6-7ksi
- Shrinkage: <250 $\mu\varepsilon$

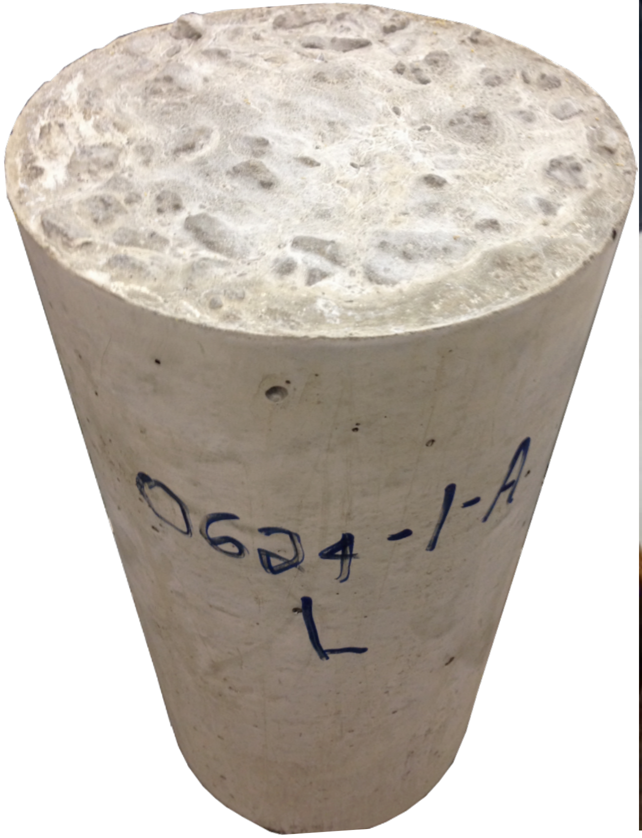
Measurement of Roughness

2. Task 1 – Development of a Self-Roughening Concrete
Measurements of Roughness - Qualitative





2. Task 1 – Development of a Self-Roughening Concrete
Measurements of Roughness - Quantitative



3. Task 2 - Assessment of Cold Joint Shear Friction Capacity

Mechanical tests for shear friction characterization

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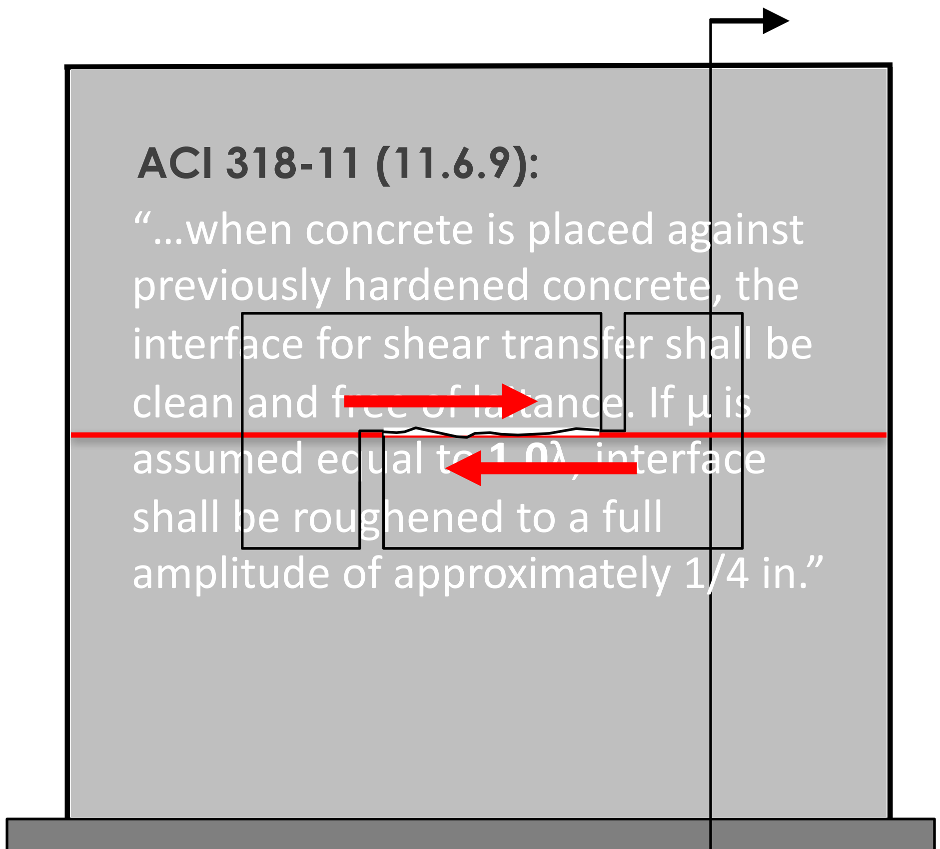
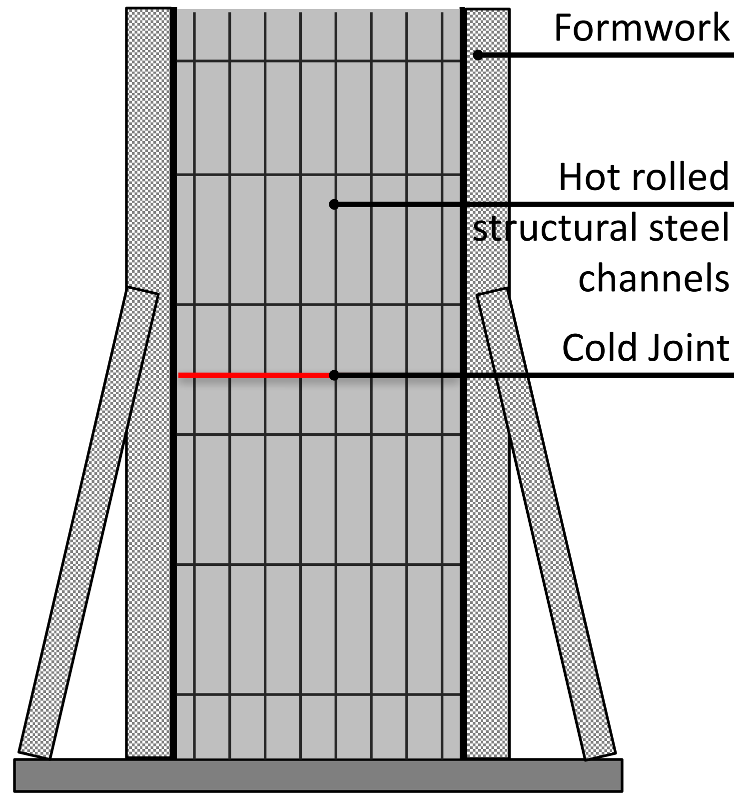
Mechanical tests for shear friction characterization



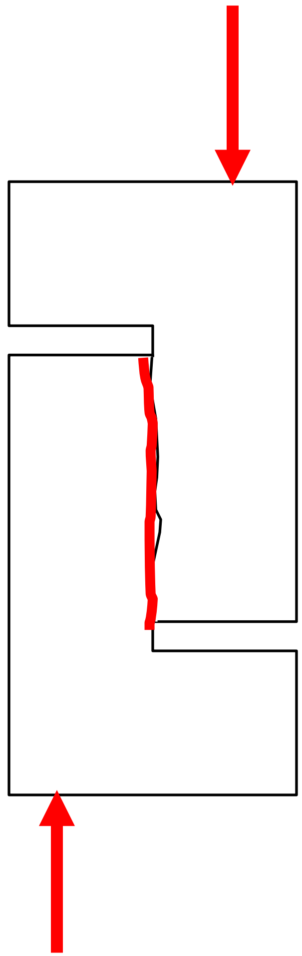
Wall Elevation

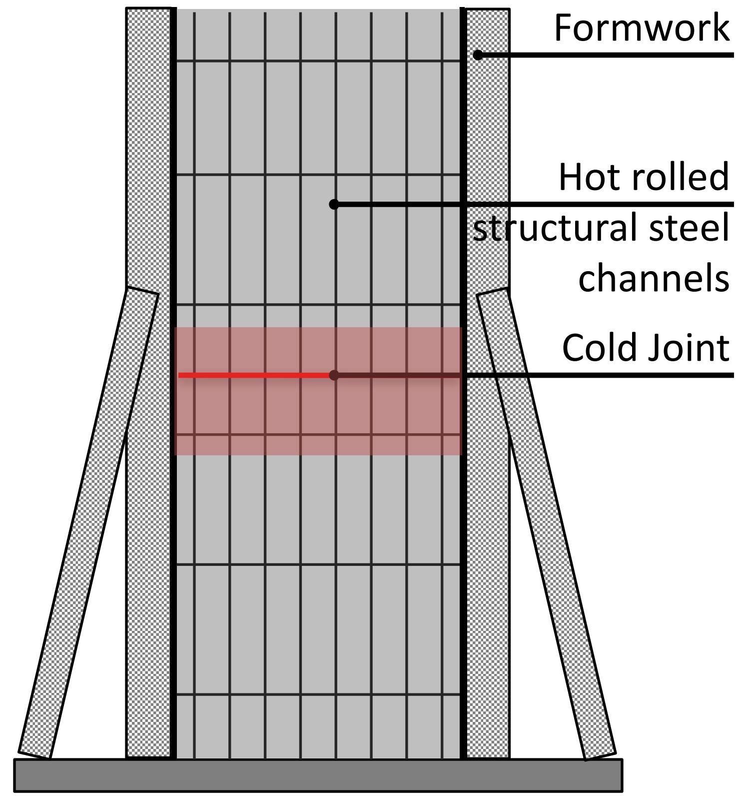


Wall Section

3. Task 2 - Assessment of Cold Joint Shear Friction Capacity

Mechanical tests for shear friction characterization





Wall Section

Cold Joint

When wet concrete is cast up to dry concrete.

3. Task 2 - Assessment of Cold Joint Shear Friction Capacity

Test Matrix

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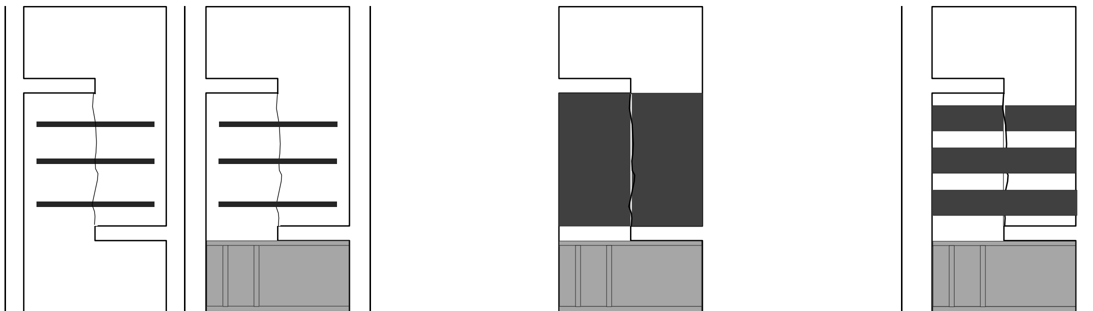
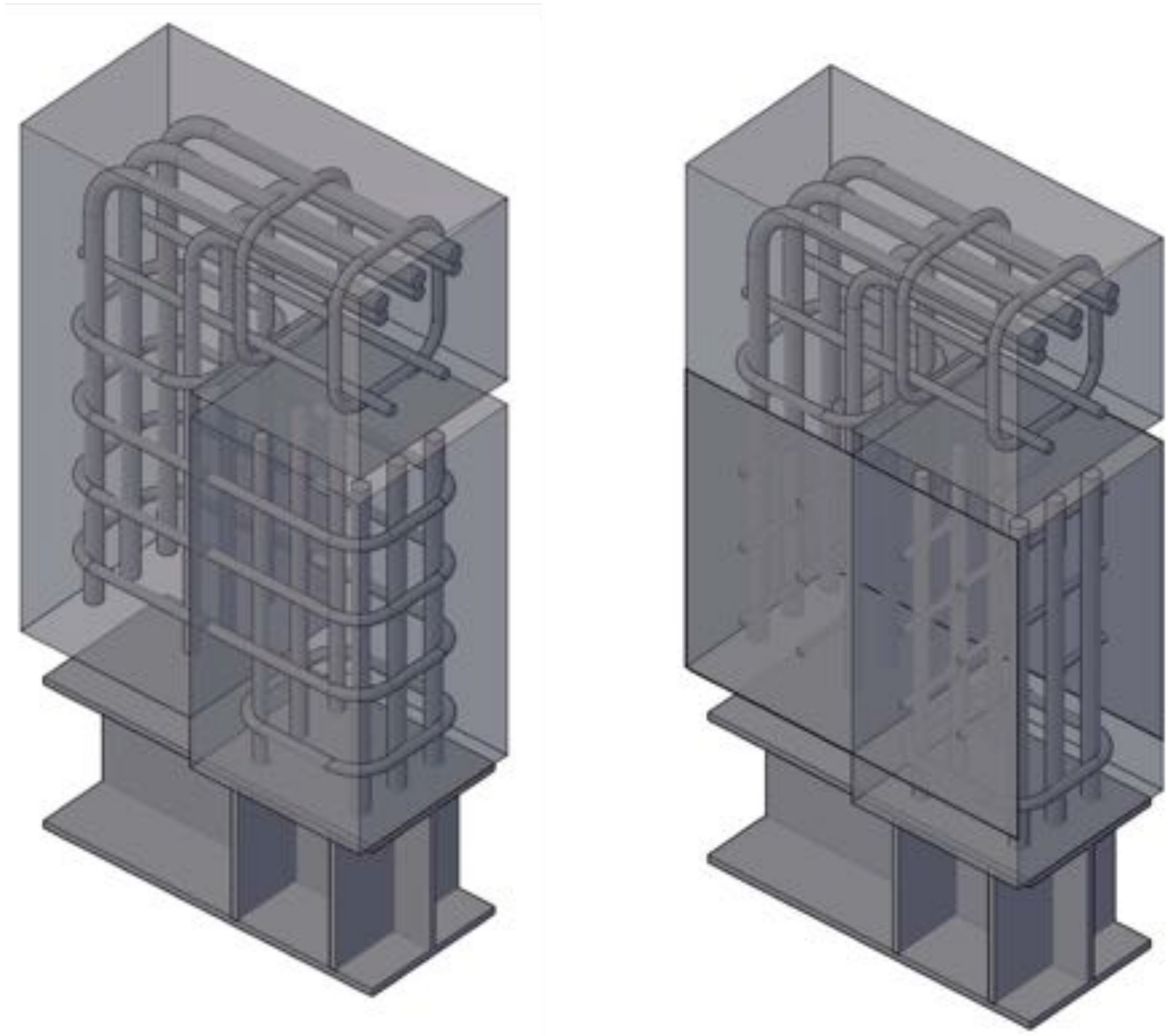
Test Matrix



Cold joint	No	Yes	Yes	Yes	Yes	Yes
Reinforcement ratio - ρ (%)	0.75	0.75	0.25	0.50	0.75	0.75
#3 shear reinforcement	Yes	Yes	No	No	No	No
Steel plate (thickness)	No	No	0.03125 in. (22 gauge)	0.0625 in. (16 gauge)	0.09375 in. (13 gauge)	0.375 in. (16 gauge) h= 2.90 in.
Repetition with 5% LWA	n/a	2	2	2	2	2
Repetition with 15% LWA	n/a	3	3	3	3	3
Tot. N. of repetitions	2	5	5	5	5	5

3. Task 2 - Assessment of Cold Joint Shear Friction Capacity
Test Matrix



3. Task 2 - Assessment of Cold Joint Shear Friction Capacity

Specimens preparation

Step 1

Step 2

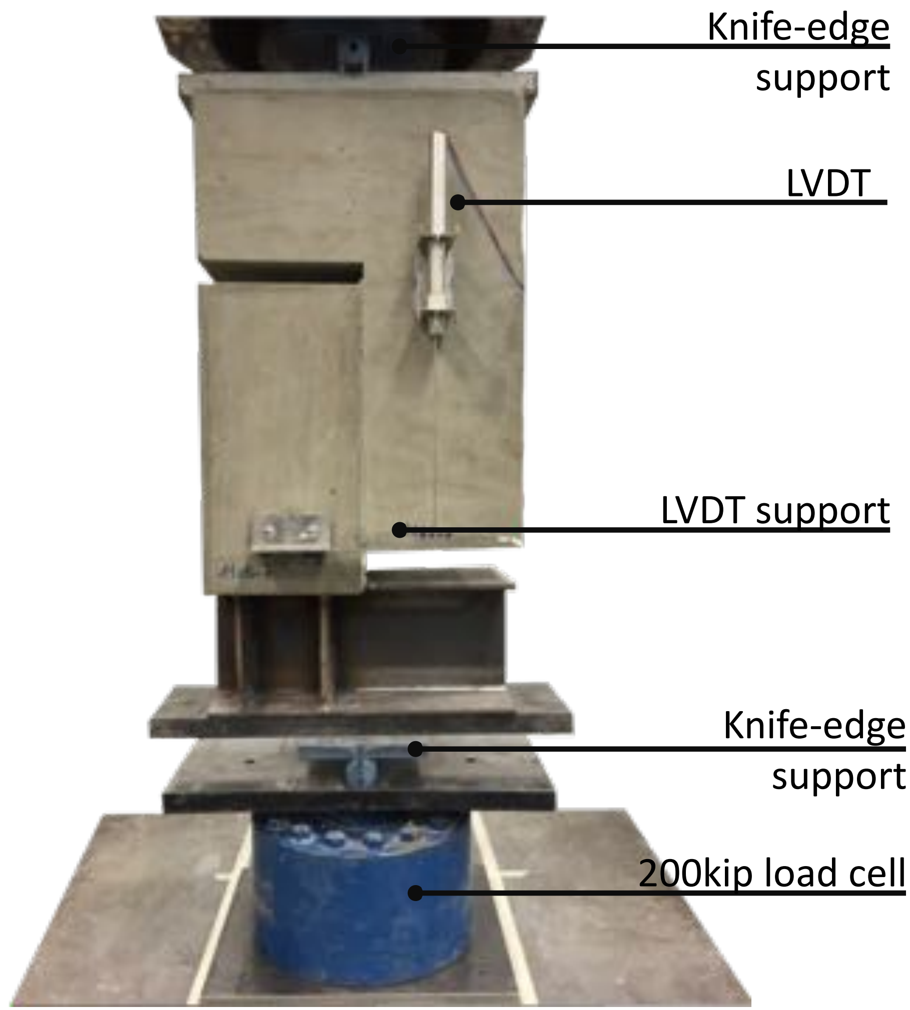
Step 3

Step 4

Step 5

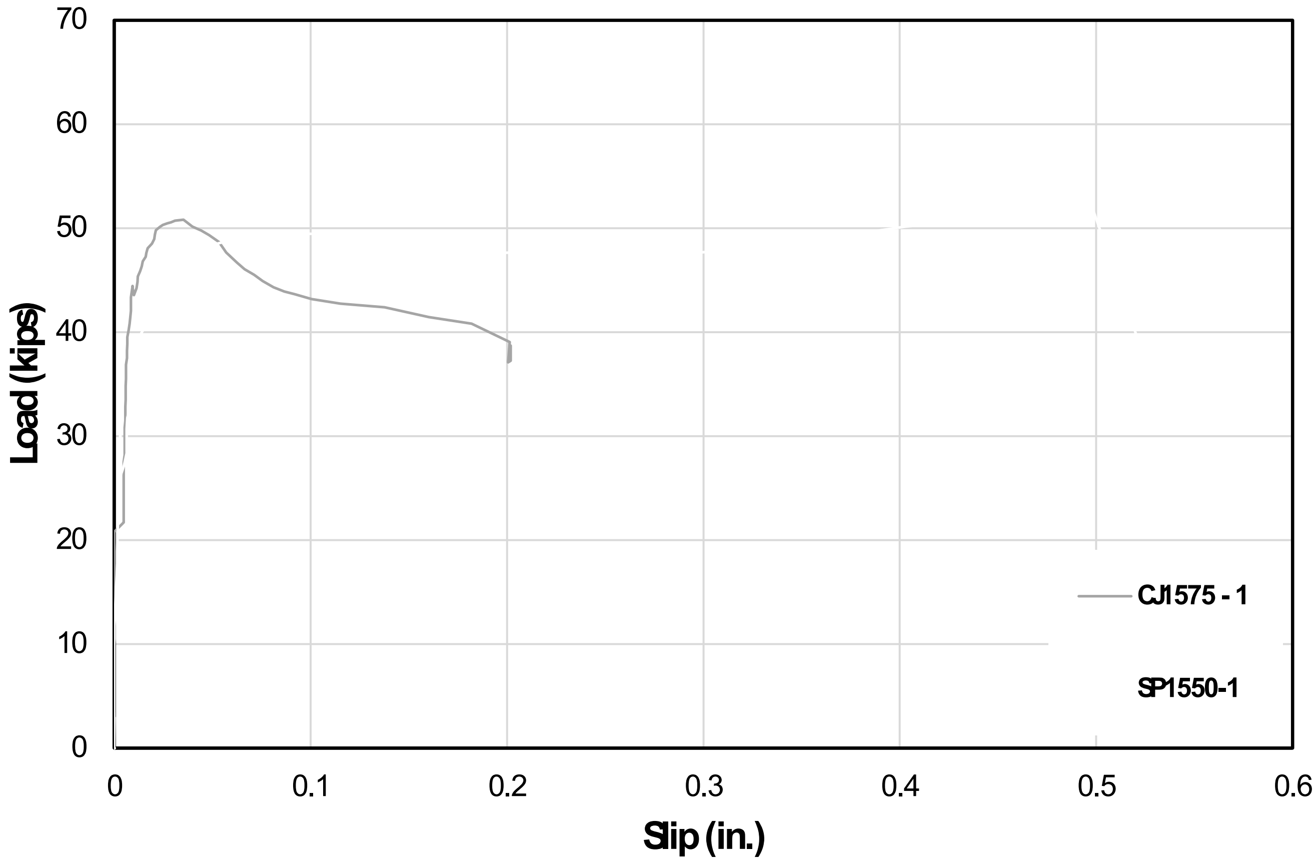
3. Task 2 - Assessment of Cold Joint Shear Friction Capacity

Test set up



3. Task 2 - Assessment of Cold Joint Shear Friction Capacity

Behavior at cold joint with internal reinforcement

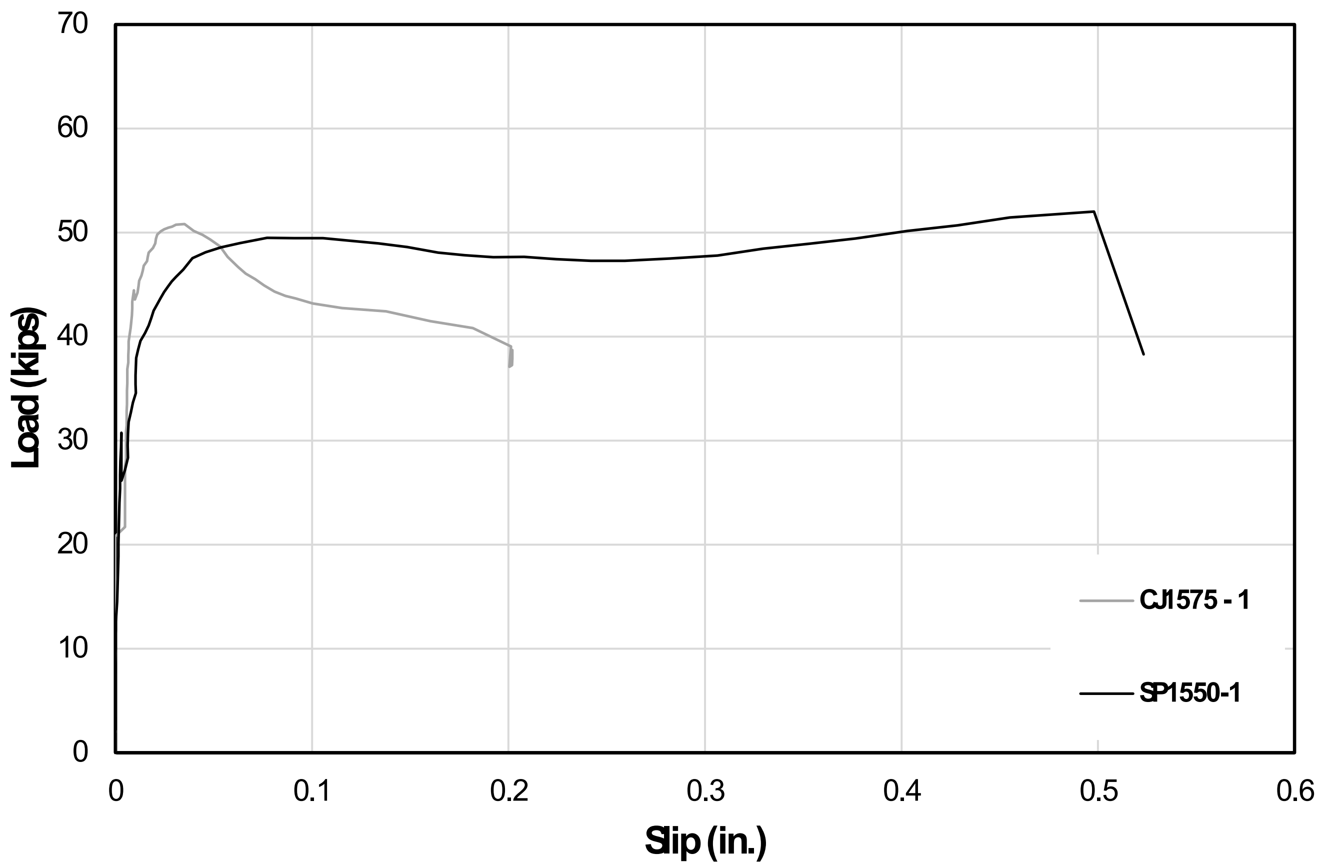


3. Task 2 - Assessment of Cold Joint Shear Friction Capacity

Behavior at cold joint with external steel plates

3. Task 2 - Assessment of Cold Joint Shear Friction Capacity

Behavior at cold joint comparing internal and external reinforcement.



3. Task 2 - Assessment of Cold Joint Shear Friction Capacity

Mechanical tests for shear friction characterization

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)

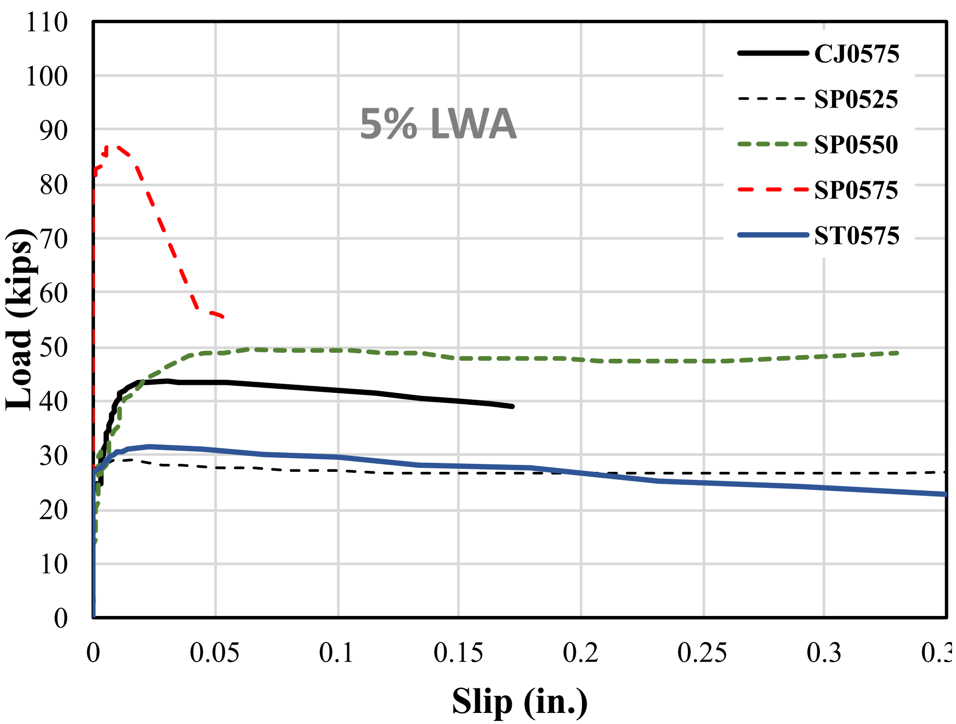
External Steel Plate
ρ=0.75%
t=0.094 in.
(13 gage)

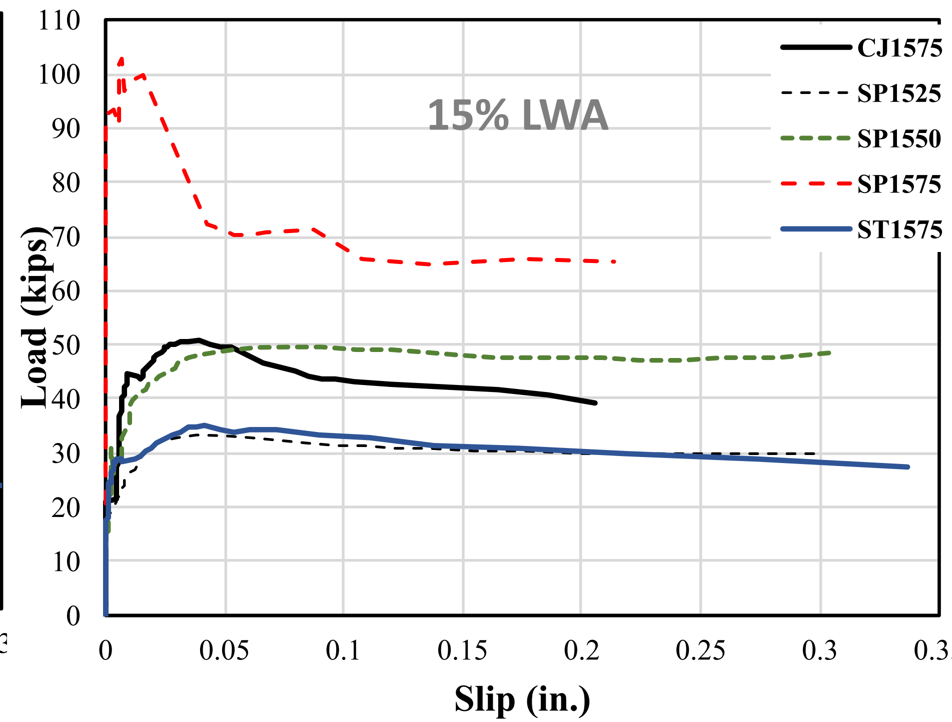
External Steel Strips
ρ=0.75%
t=0.375 in.

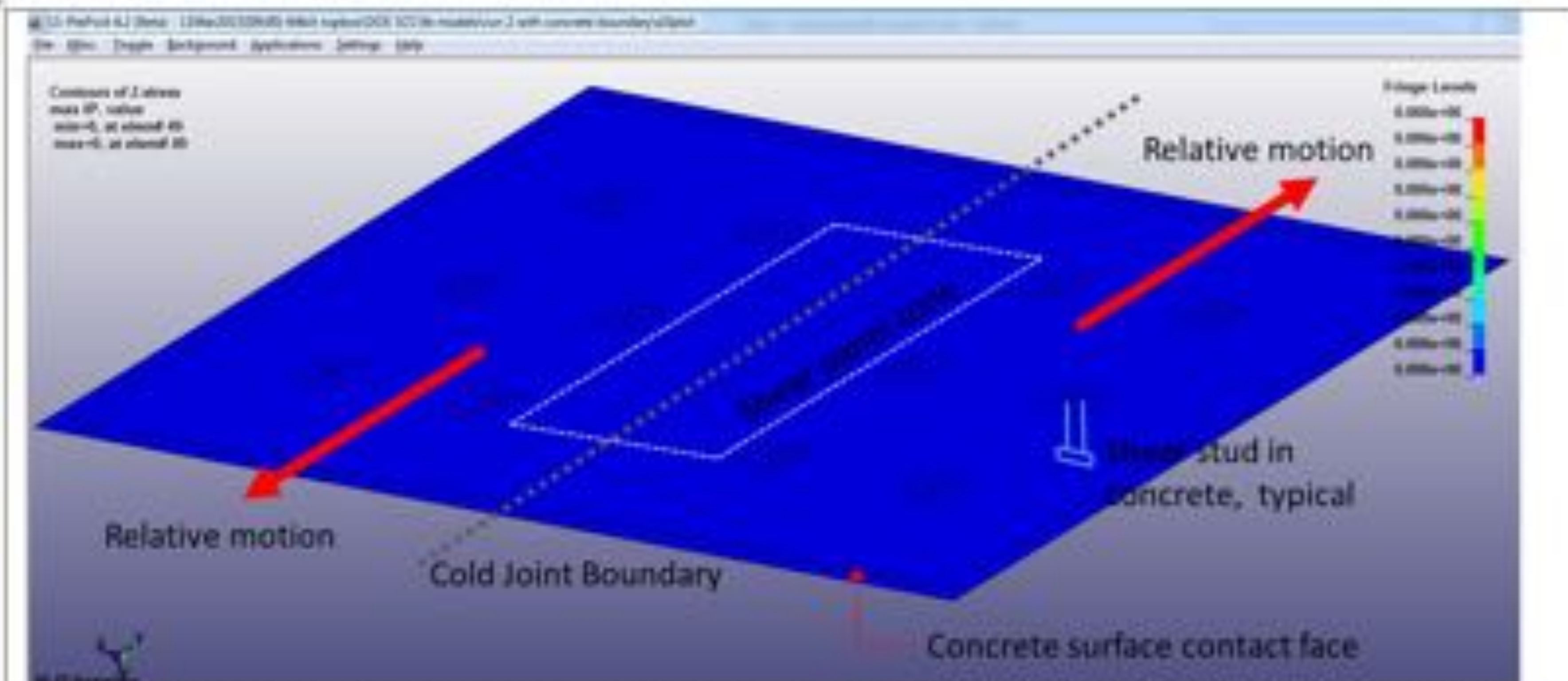
3. Task 2 - Assessment of Cold Joint Shear Friction Capacity

Behavior at cold joint comparing internal and external reinforcement.

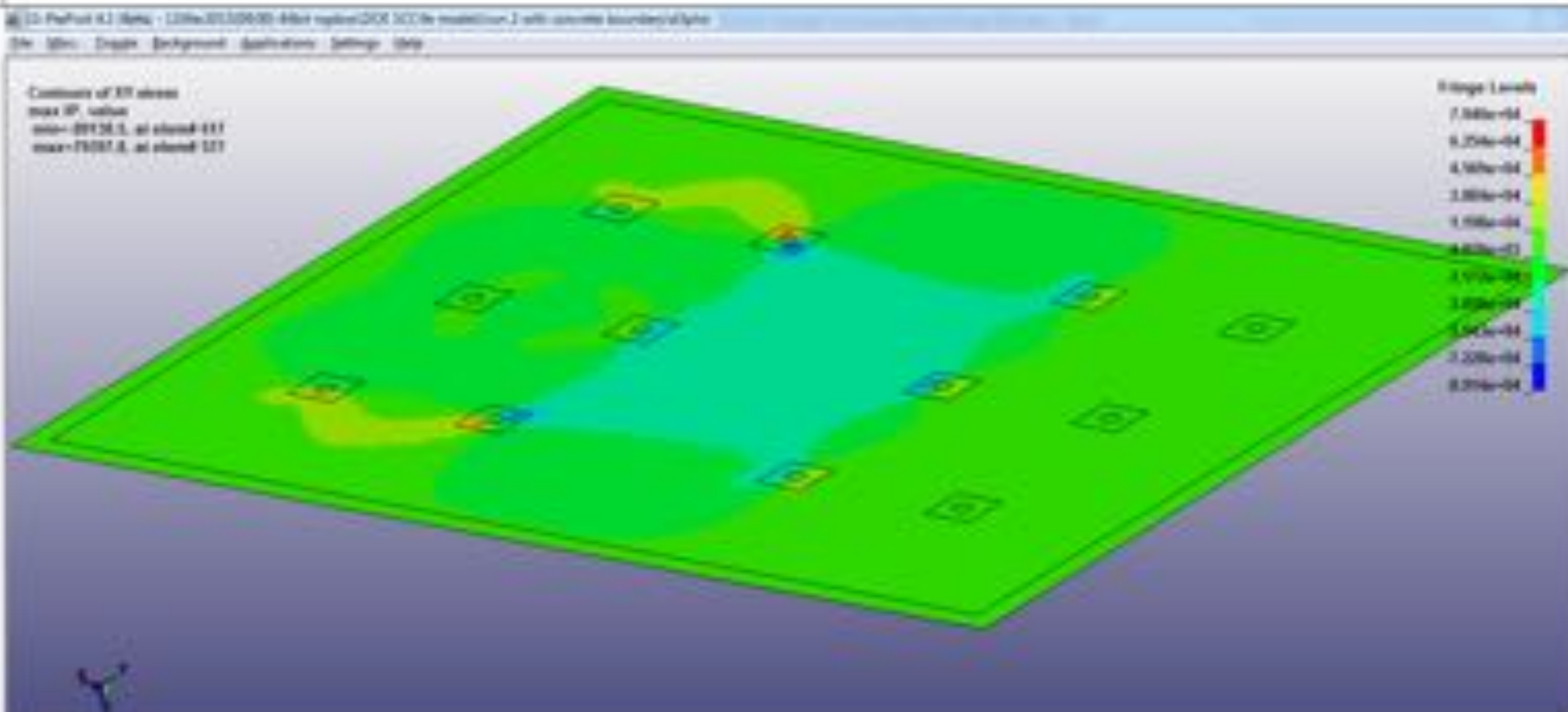
- Self-roughening concrete carries higher load.
- Higher load with greater fraction of LWA.



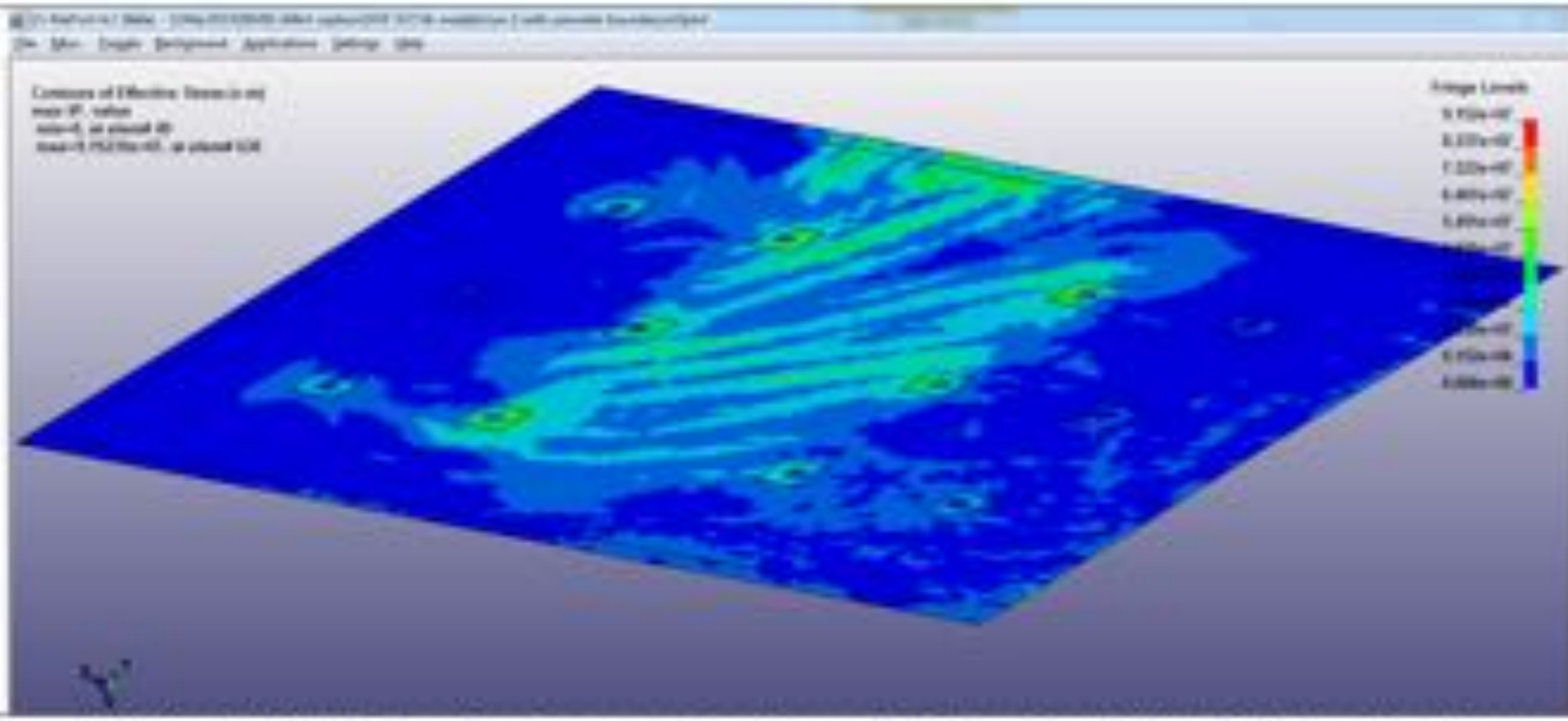




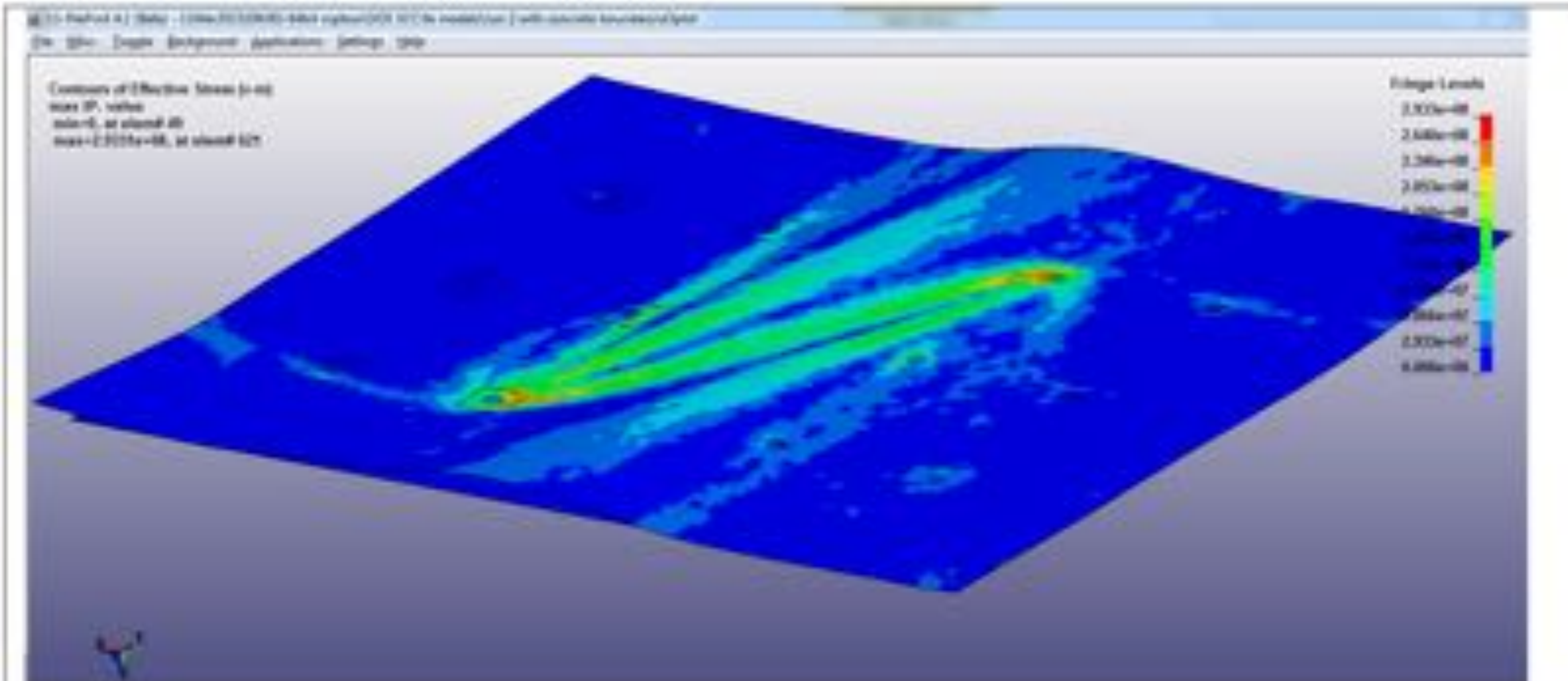
(a) Non-linear finite element model in LS-DYNA explicit. This initial model approximate the geometry of specimen SP 15 50-1 but with fewer Nelson studs.



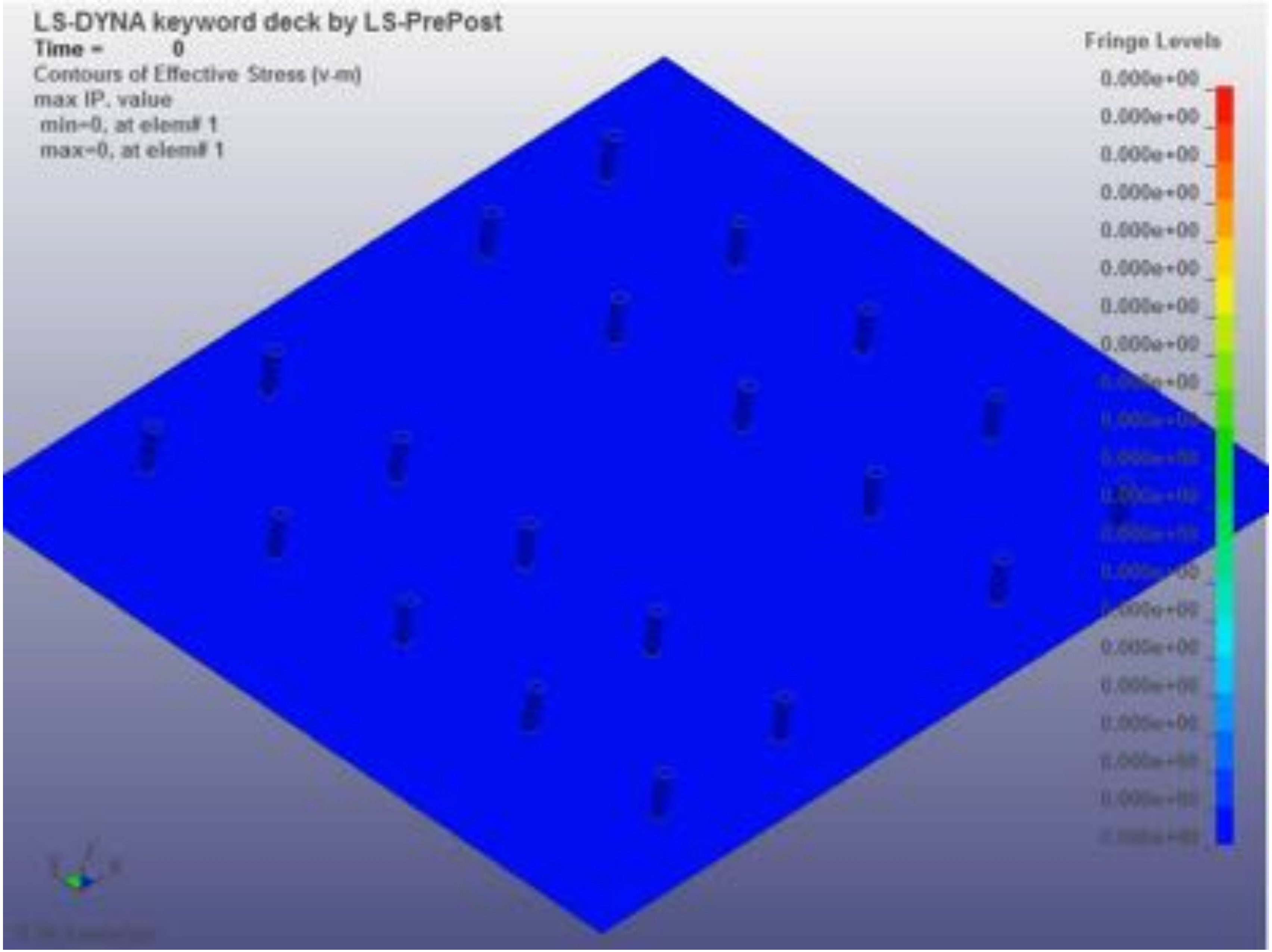
(b) Initital loading. Constant shear in the panel zone. In-plane shear stresses shown (all stresses in Pa).

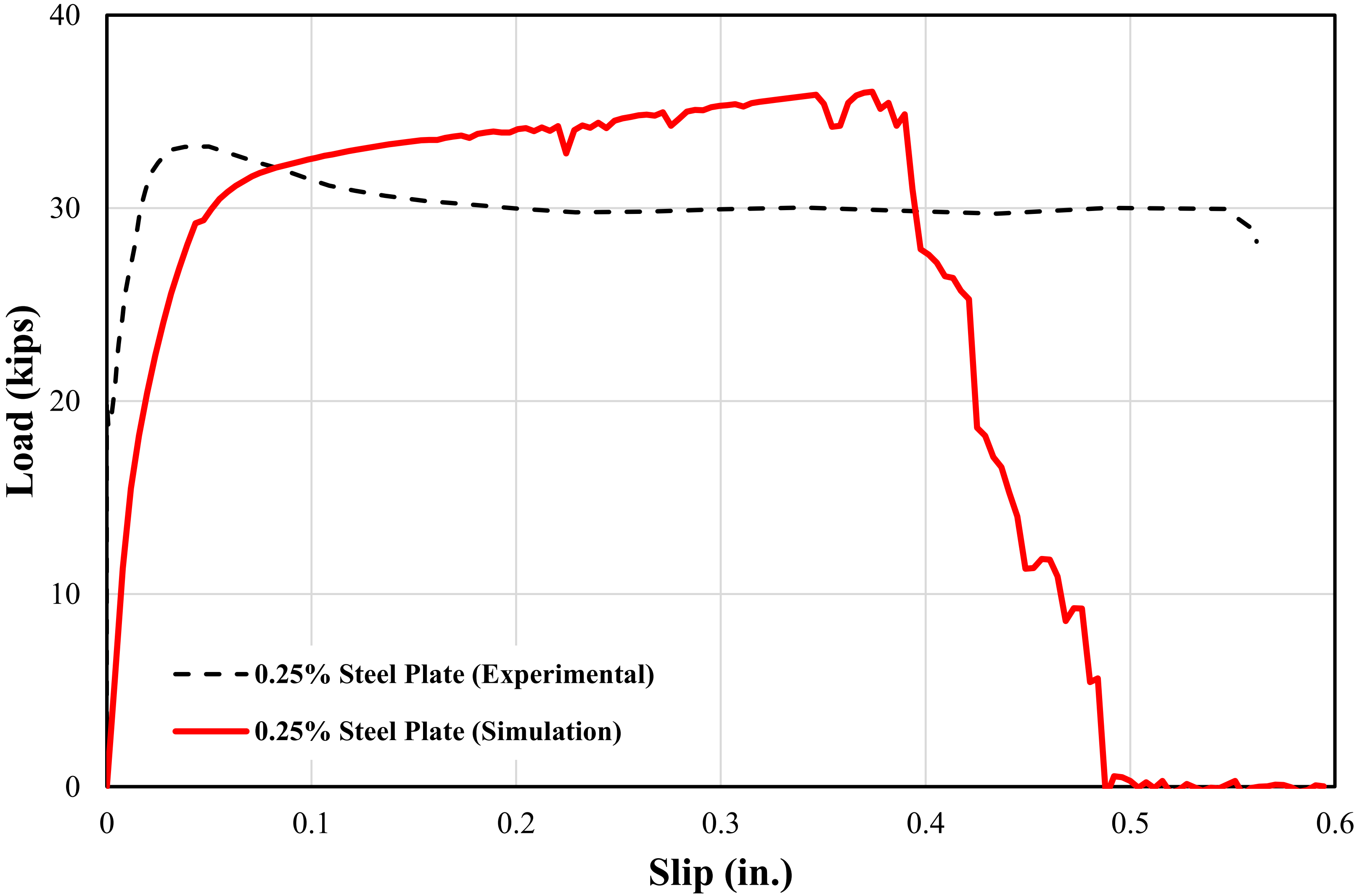


(d) Onset of buckling. Panel zone shear dramatically reduced. Principle tensile stresses align with buckling of plate steel. Buckling is elastic, that is, steel plate does not yield before the bucking initiates. Model also predicts the lifting of the edge of the steel plate.



(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

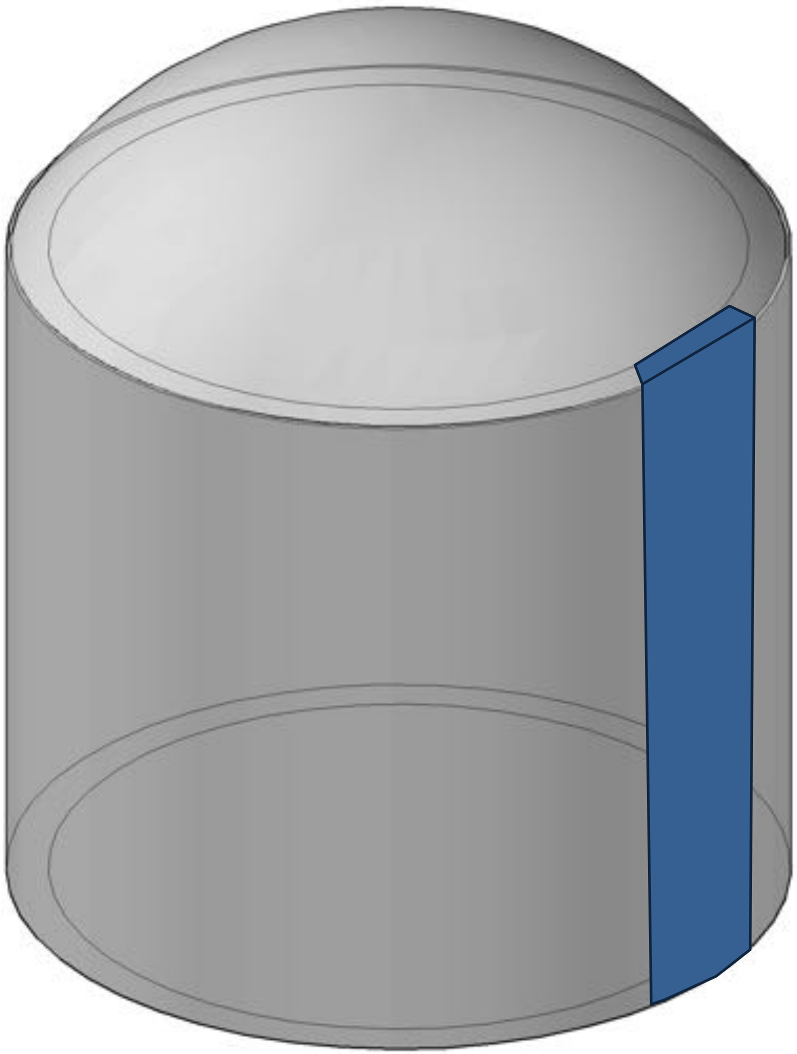


Load (kips)
40
30
20
10
0
0
0.1
0.2
0.3
0.4
0.5
0.6
Slip (in.)
0.25% Steel Plate (Experimental)
0.25% Steel Plate (Simulation)

Specimen Design

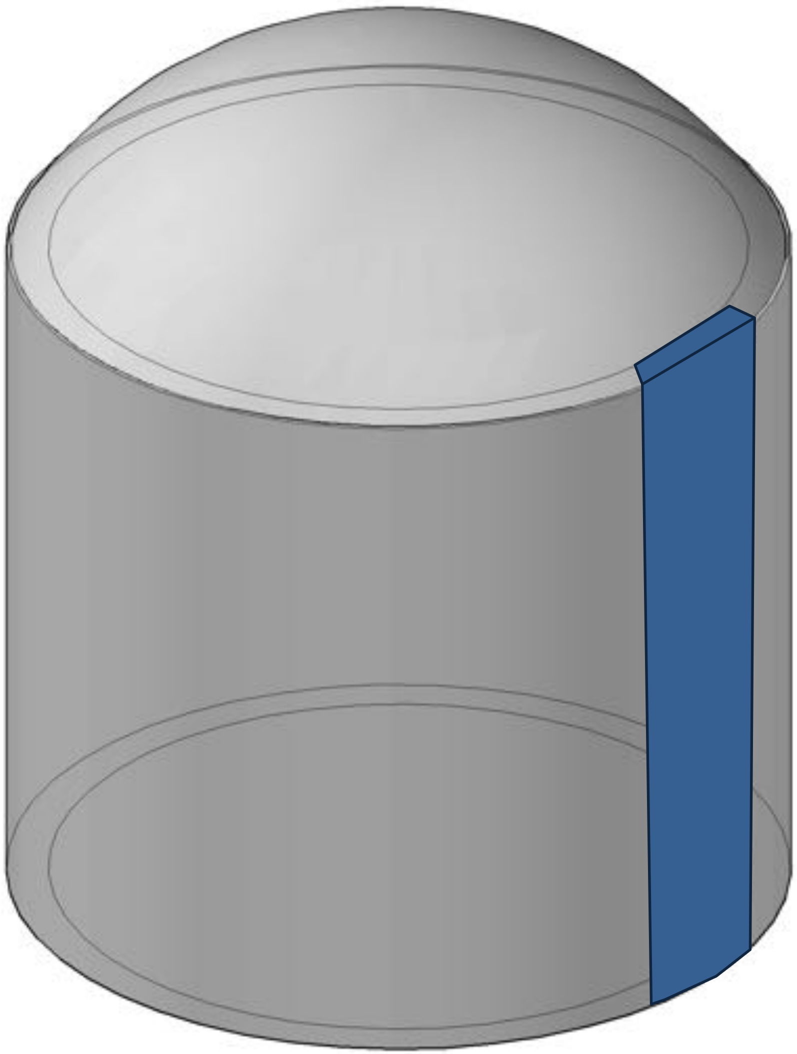
4. Task 3 – Assessment of Shear and Flexure Performances

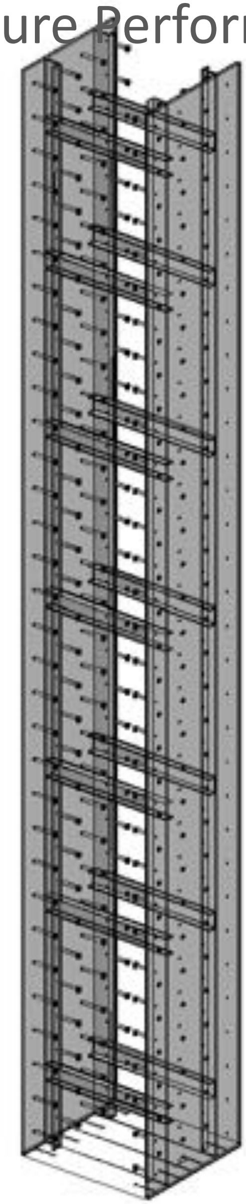
Specimen Design



4. Task 3 – Assessment of Shear and Flexure Performances

Specimen Design





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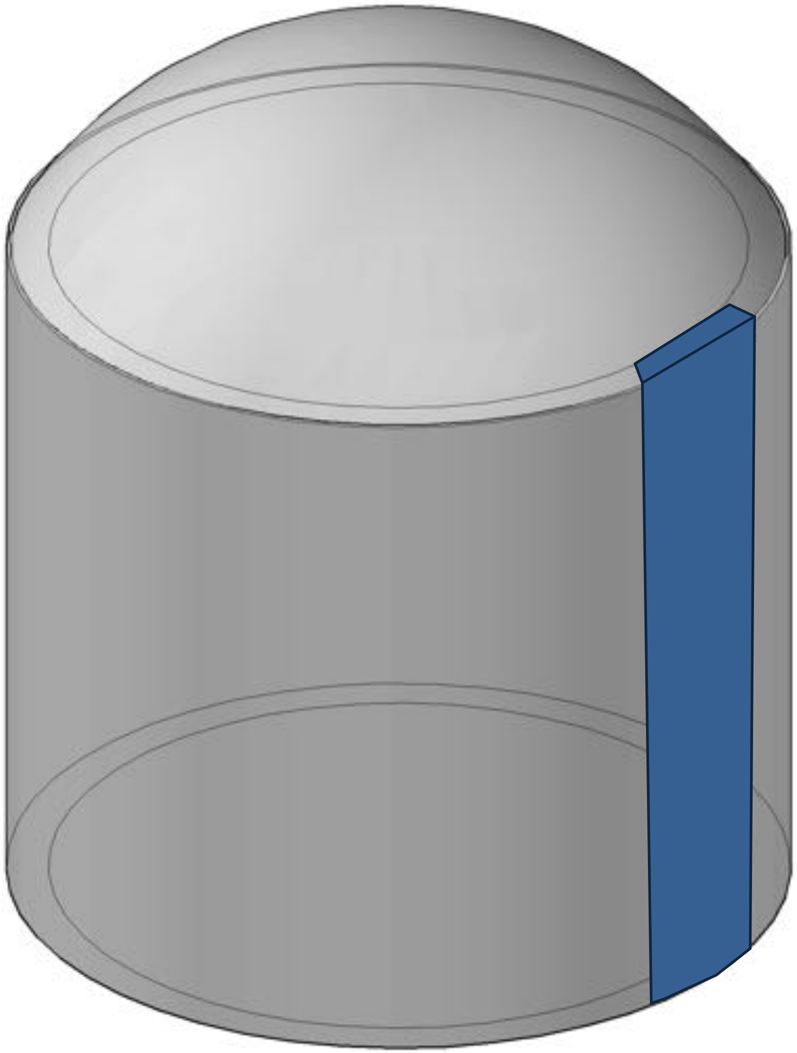
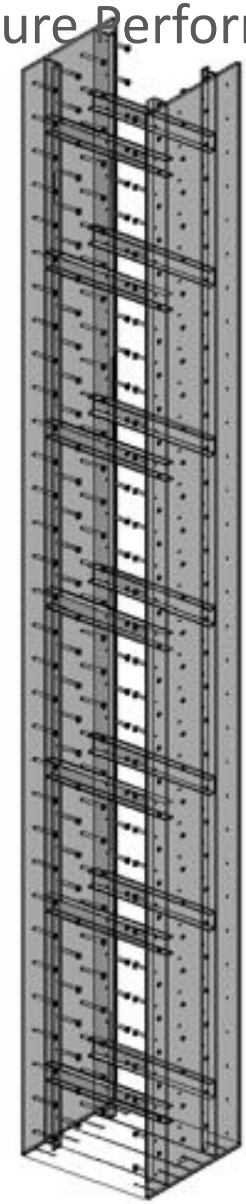
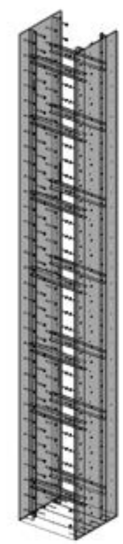
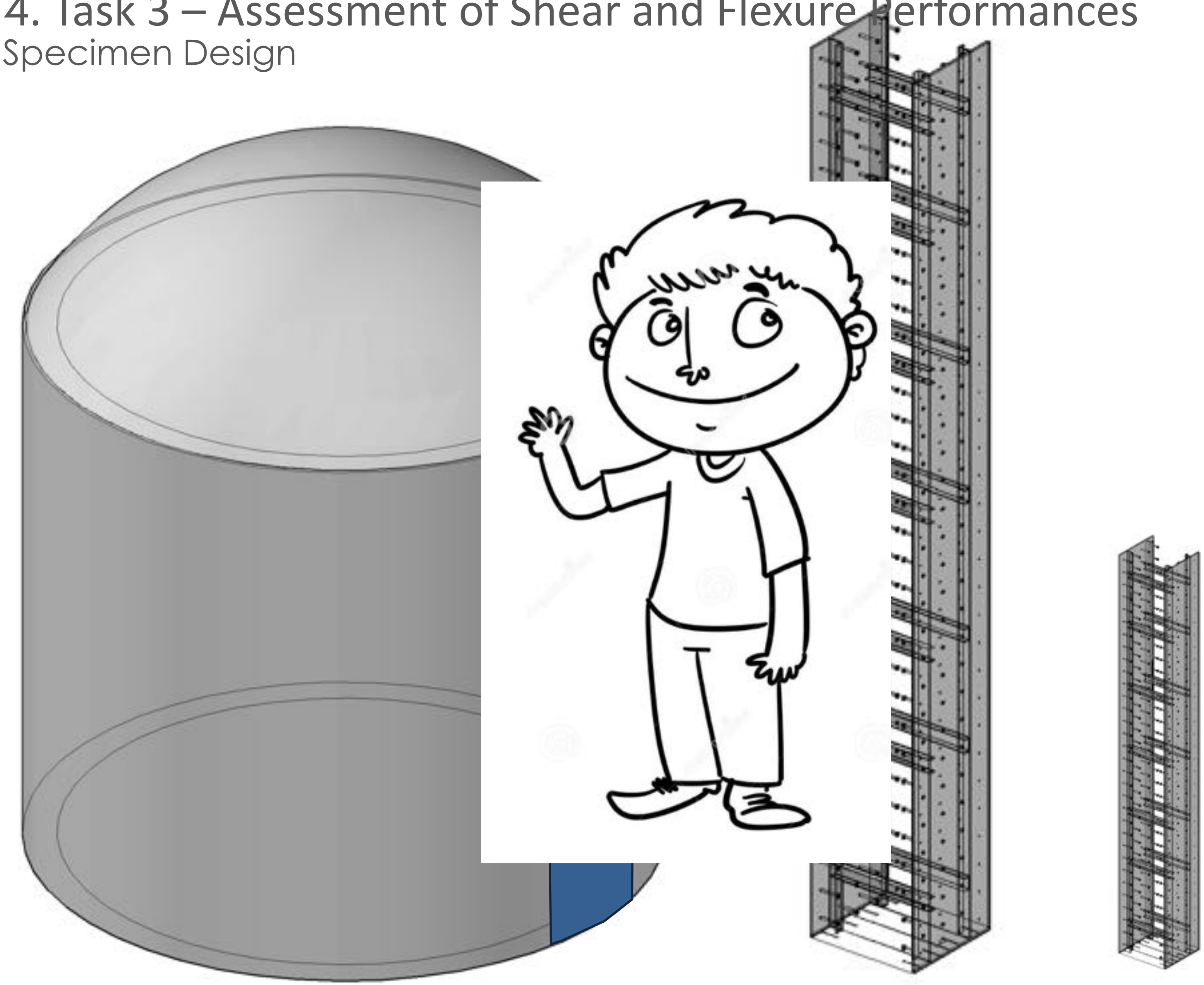
Specimen Design







4. Task 3 – Assessment of Shear and Flexure Performances
Specimen Design



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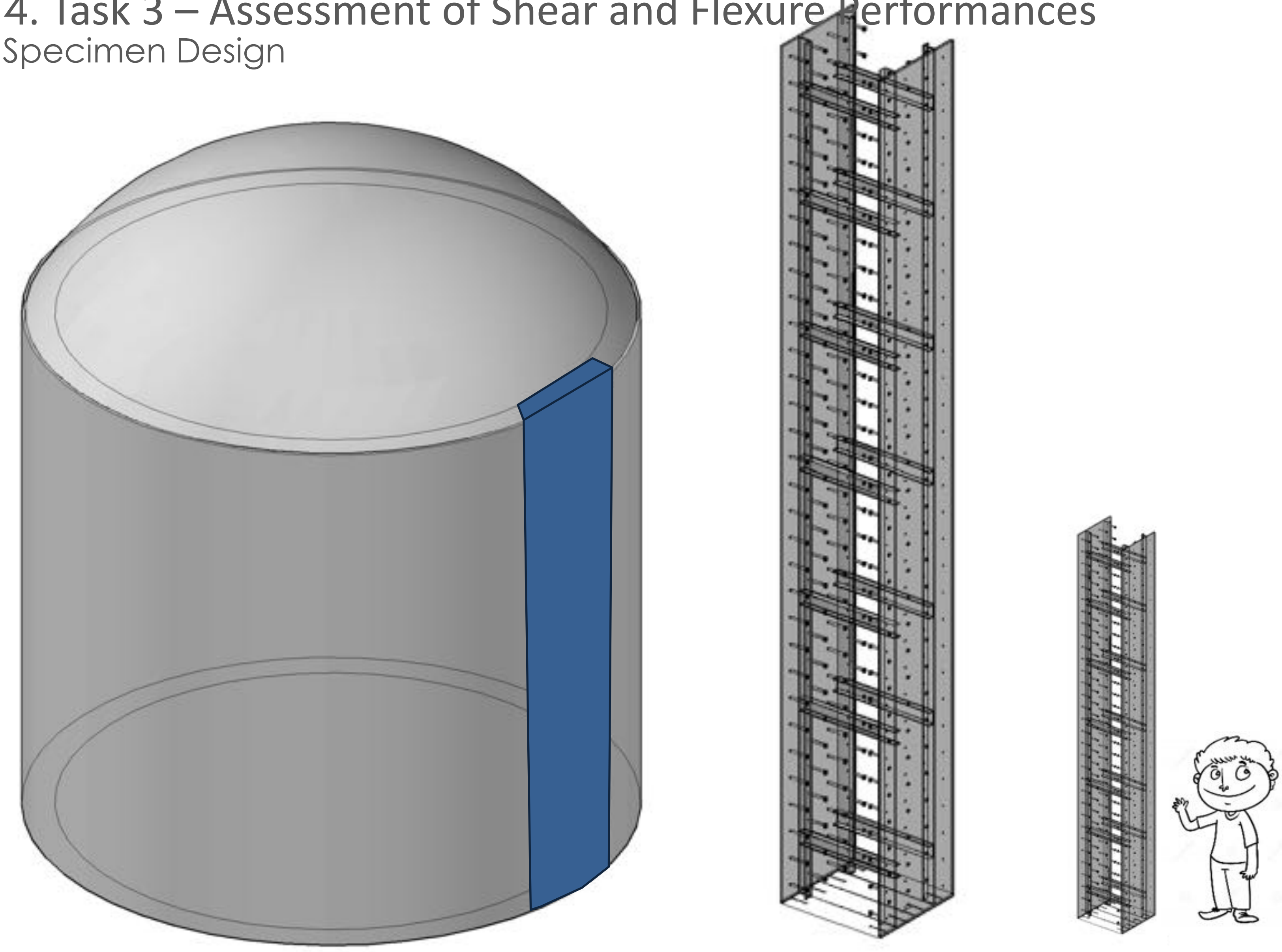

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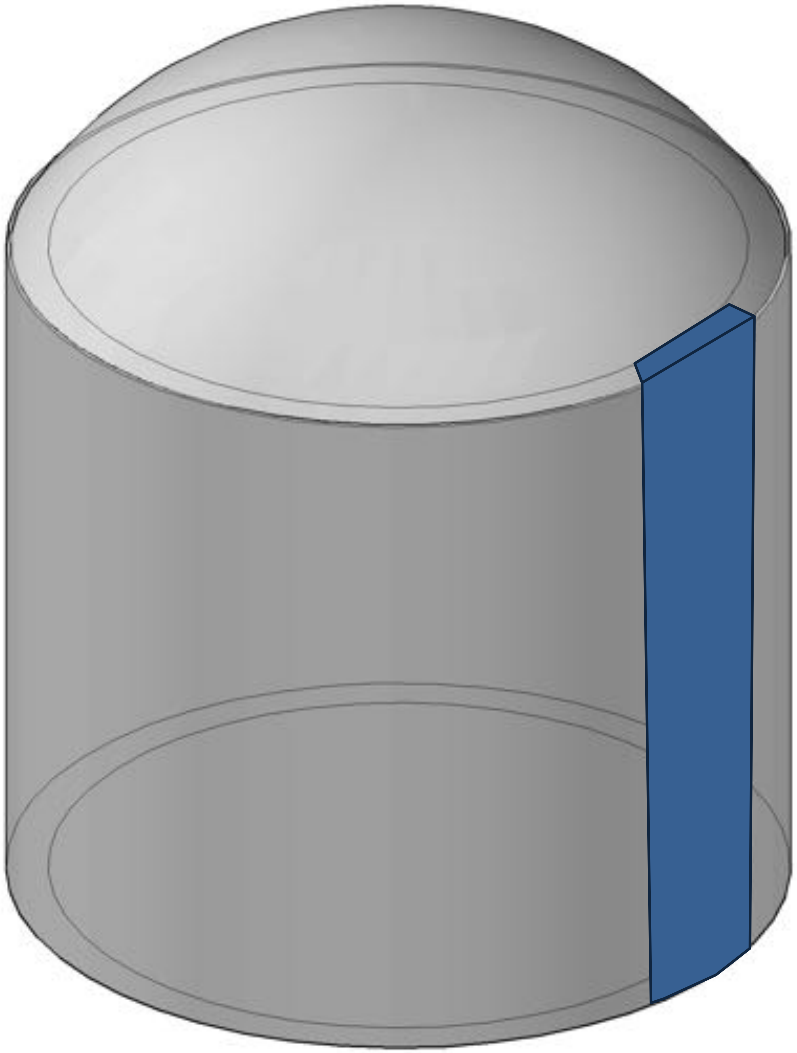
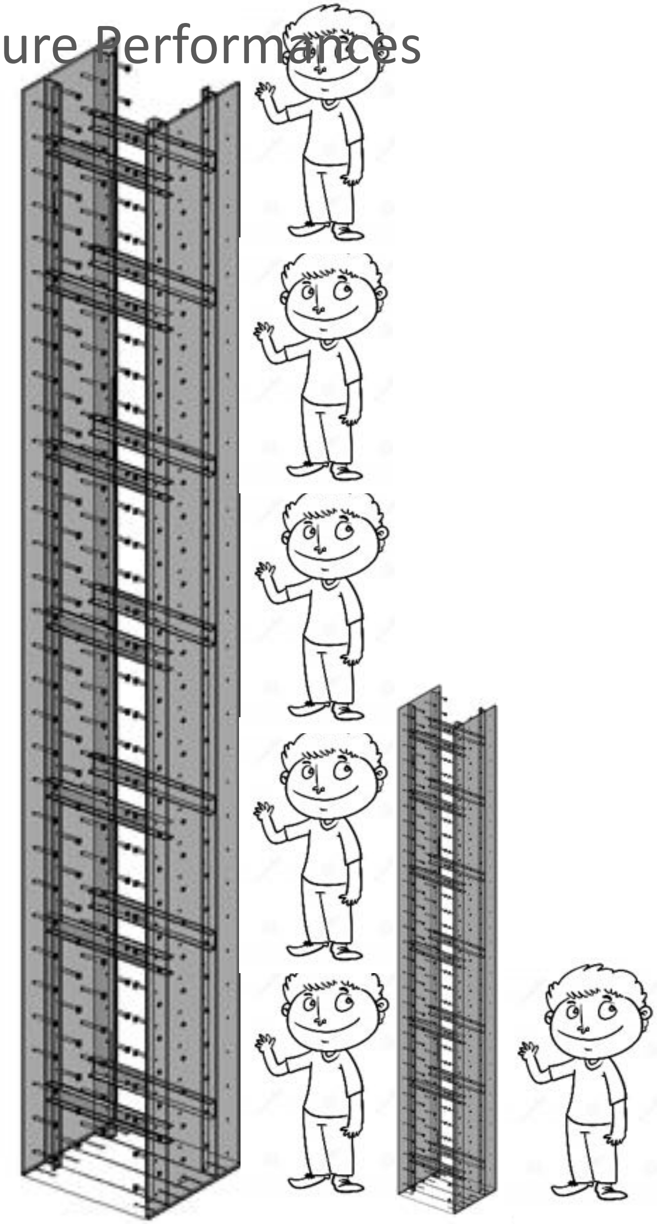
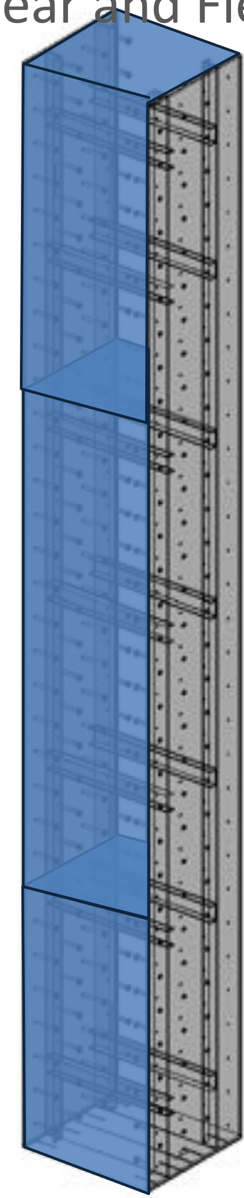
Specimen Design



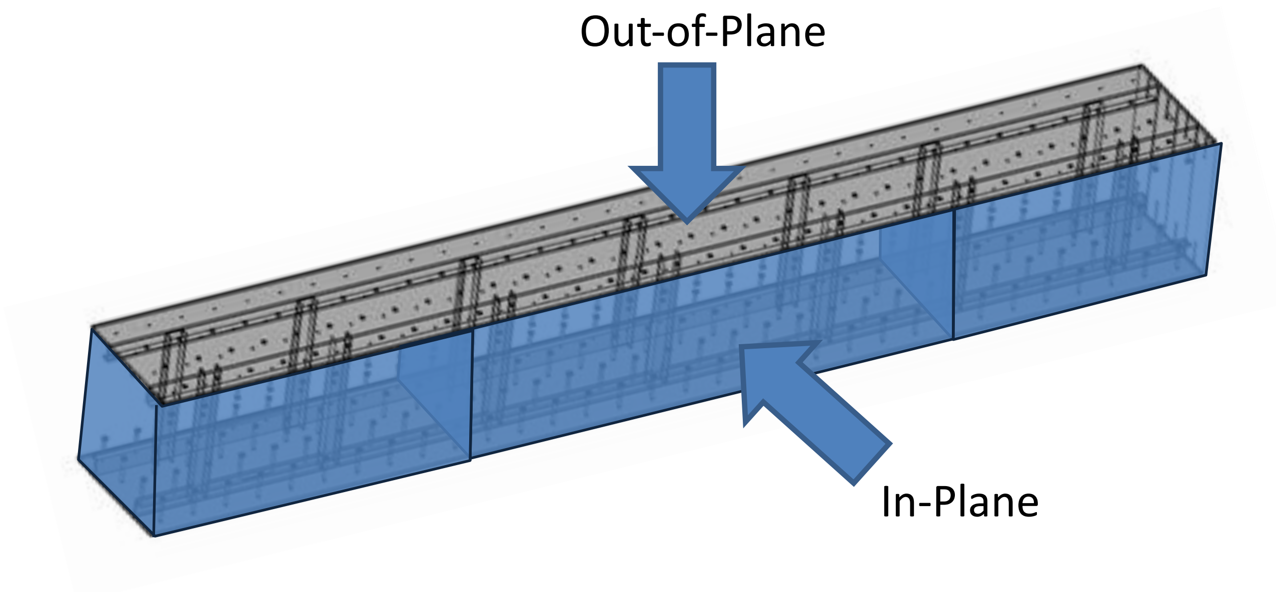


4. Task 3 – Assessment of Shear and Flexure Performances

Specimen Design



4. Task 3 – Assessment of Shear and Flexure Performances
Specimen Design



4. Task 3 – Assessment of Shear and Flexure Performances
Specimen Design

4. Task 3 – Assessment of Shear and Flexure Performances
Specimen construction – welding

4. Task 3 – Assessment of Shear and Flexure Performances

Specimen construction – welding

4. Task 3 – Assessment of Shear and Flexure Performances
Specimen construction – formwork

4. Task 3 – Assessment of Shear and Flexure Performances

Specimen construction – formwork

4. Task 3 – Assessment of Shear and Flexure Performances

Specimen construction – formwork

4. Task 3 – Assessment of Shear and Flexure Performances

Specimen construction

4. Task 3 – Assessment of Shear and Flexure Performances

Specimen construction – ready to be picked up

4. Task 3 – Assessment of Shear and Flexure Performances

Specimen construction – cast

4. Task 3 – Assessment of Shear and Flexure Performances

Casting day

Facing construction challenges

First Trial

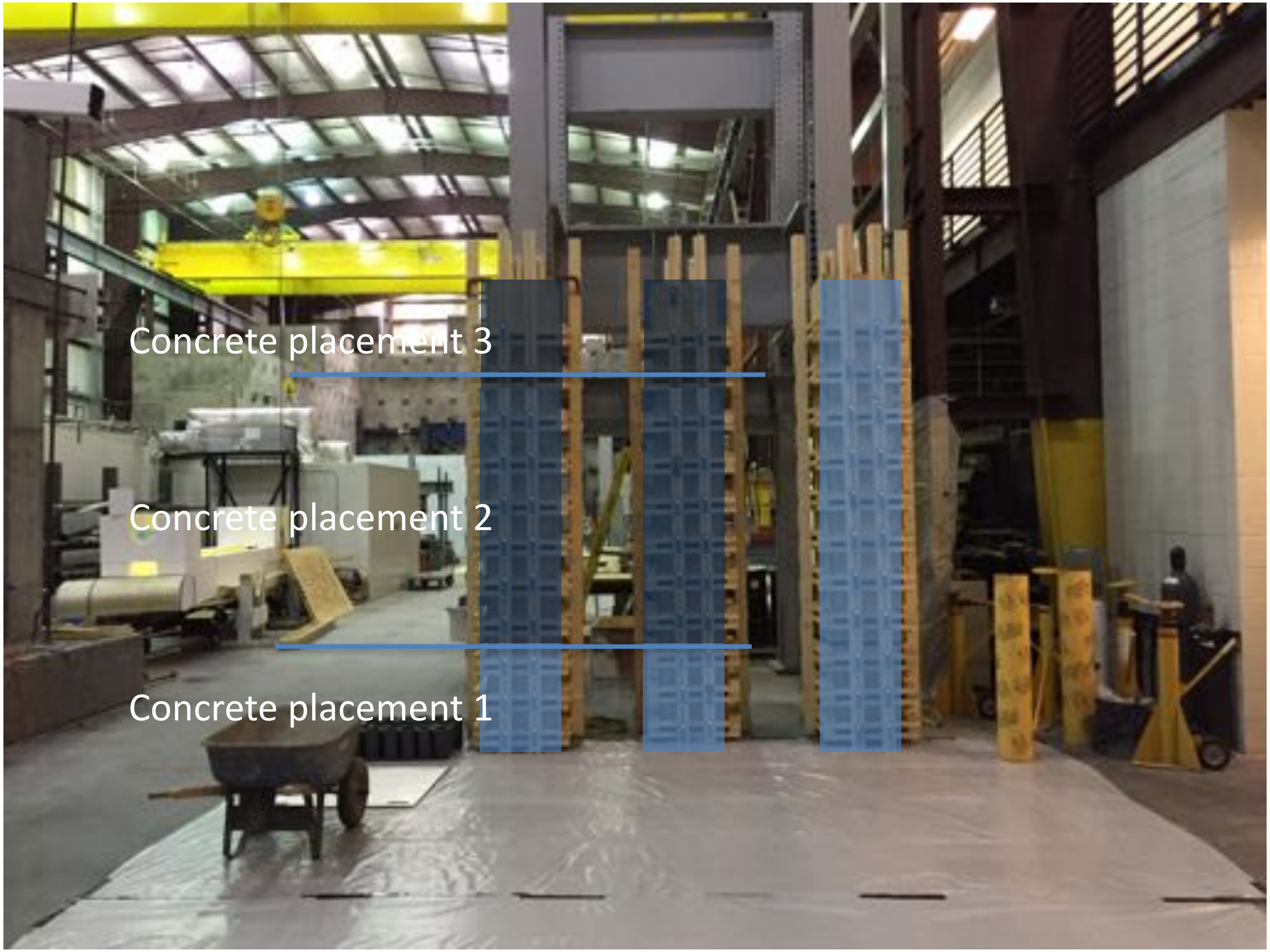
Second Trial

Third Trial

In the lab

4. Task 3 – Assessment of Shear and Flexure Performances

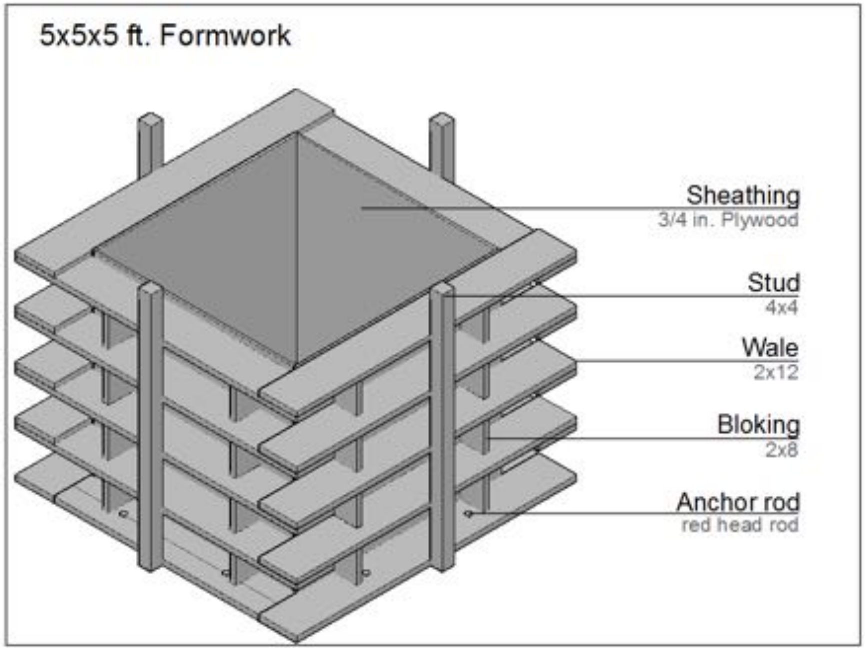
Specimen construction – cast

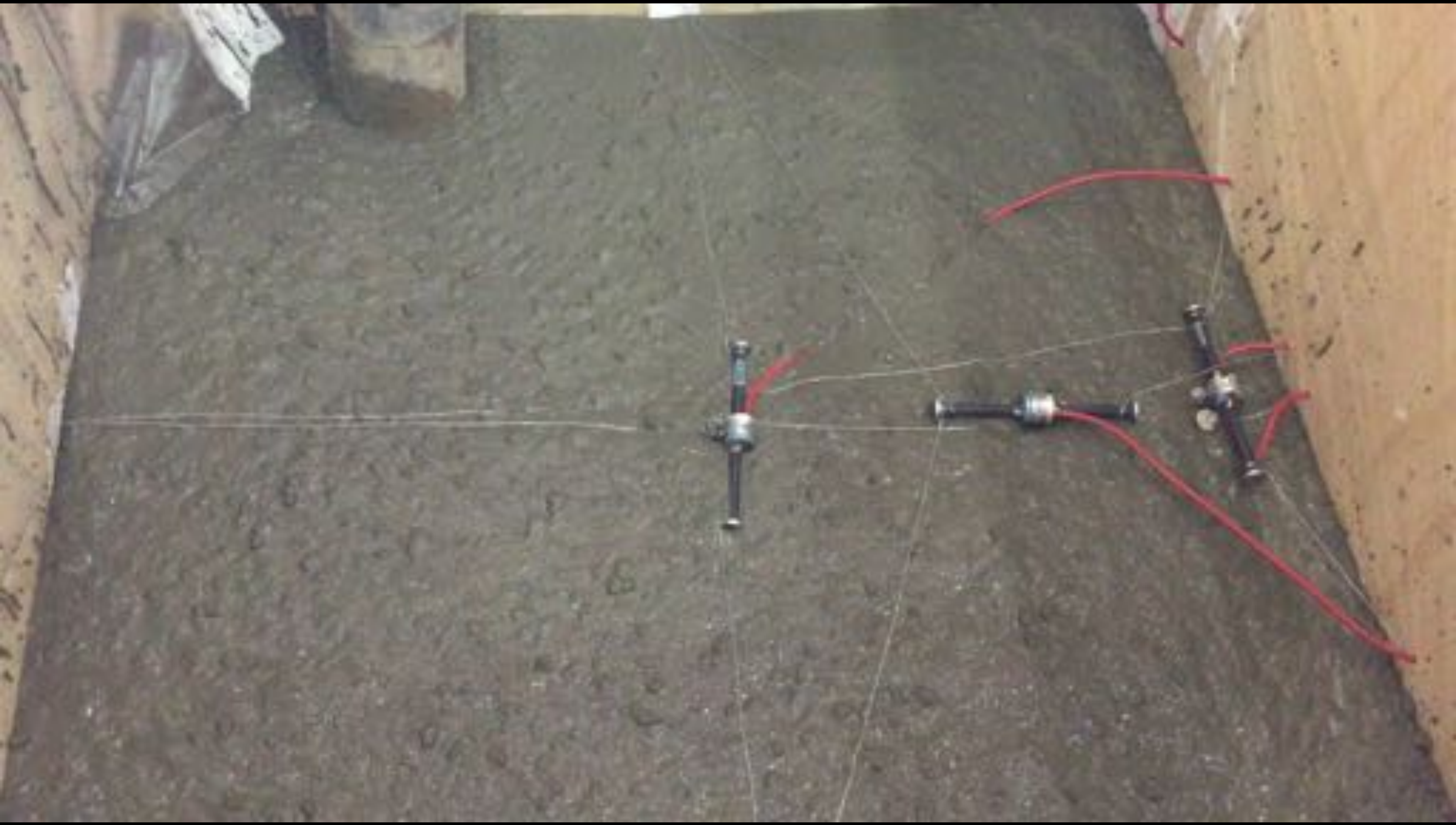


In the lab – After Casting

4. Task 3 – Assessment of Shear and Flexure Performances

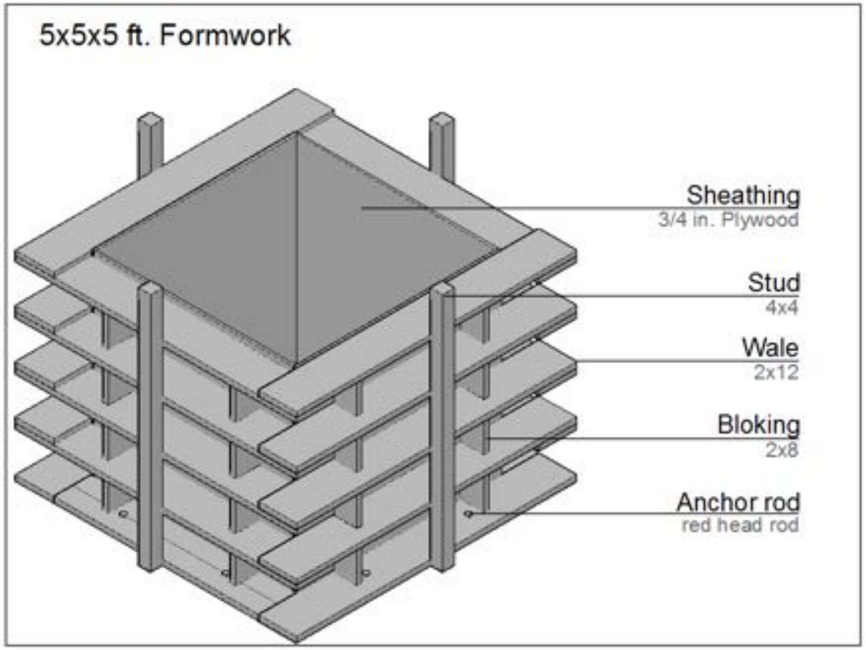
Measurements of Temperature

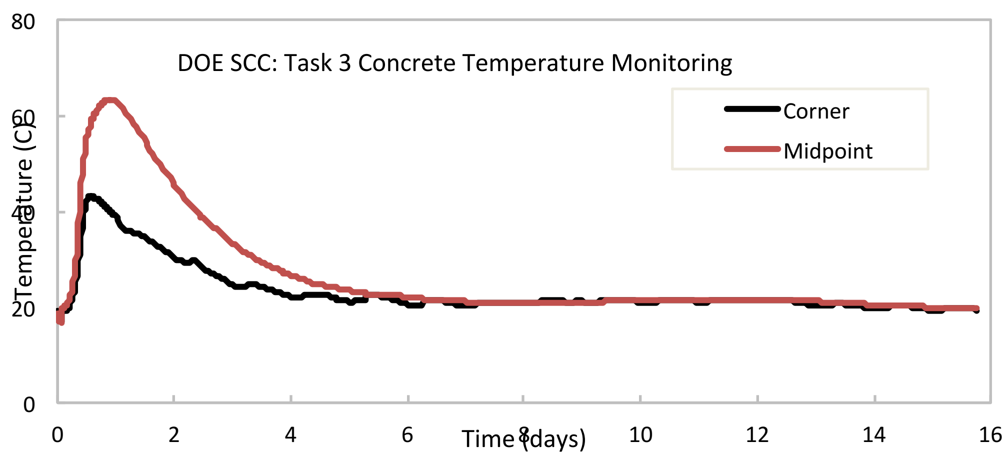




4. Task 3 – Assessment of Shear and Flexure Performances

Measurements of Temperature





Getting ready to test

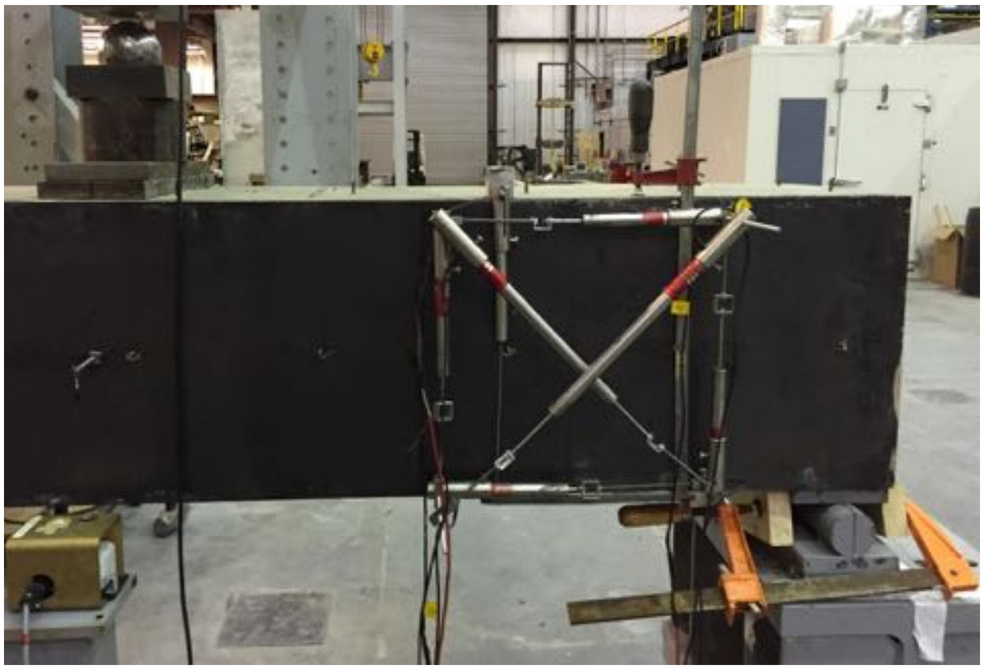
After 28dd

4. Task 3 – Assessment of Shear and Flexure Performances

Behavior at cold joint

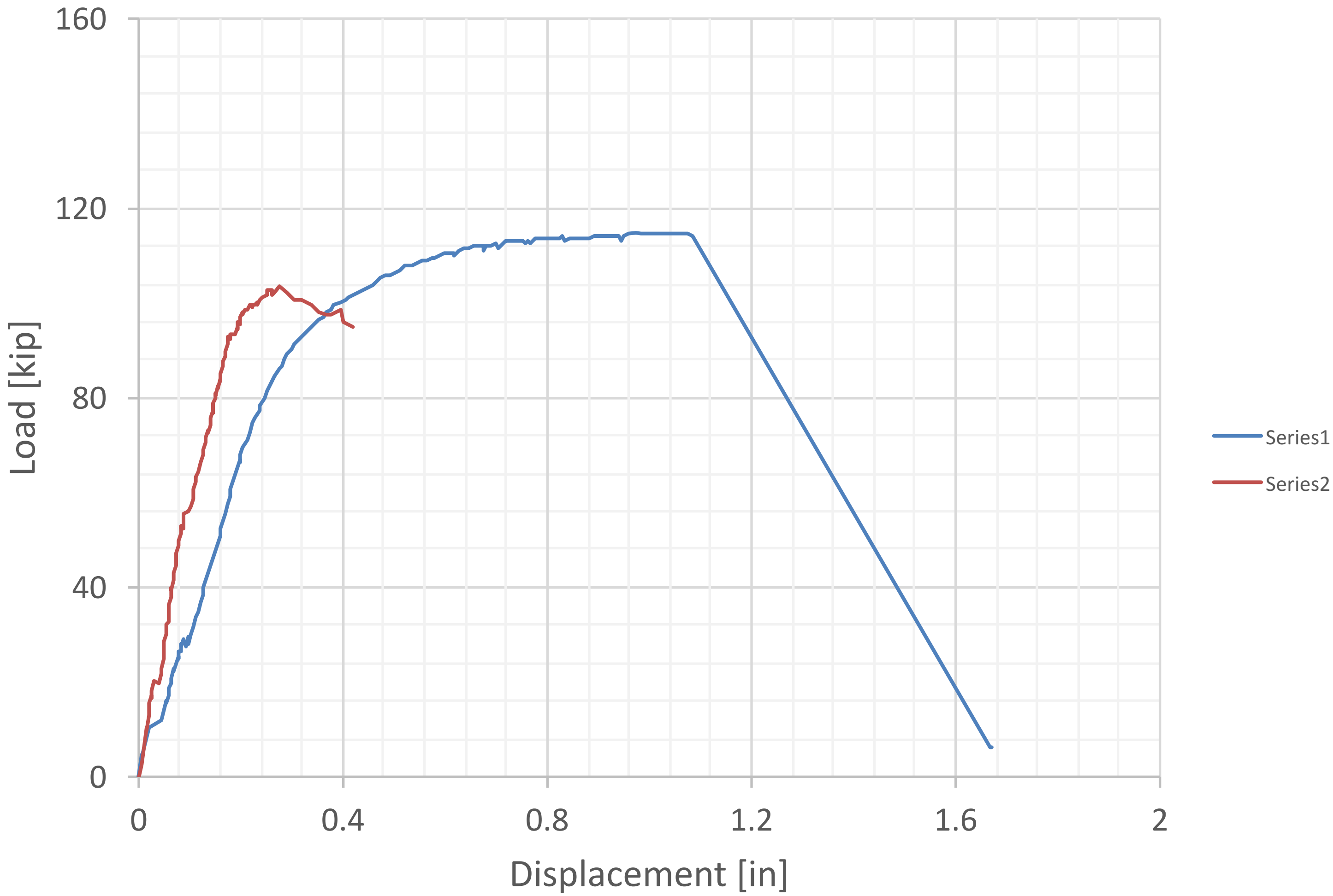
4. Task 3 – Assessment of Shear and Flexure Performances

In-Plane and Out-of-Plane set up



4. Task 3 – Assessment of Shear and Flexure Performances

Out-of-Plane behavior



4. Task 3 – Assessment of Shear and Flexure Performances

Monolithic Out-of-Plane failure mode

4. Task 3 – Assessment of Shear and Flexure Performances

Out-of-Plane failure mode

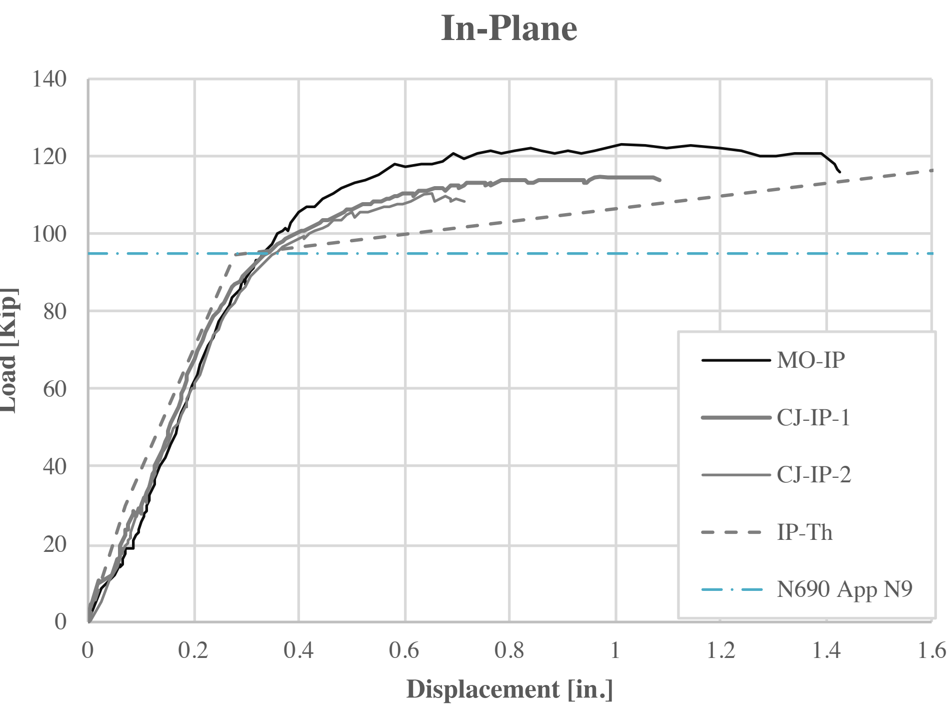
4. Task 3 – Assessment of Shear and Flexure Performances

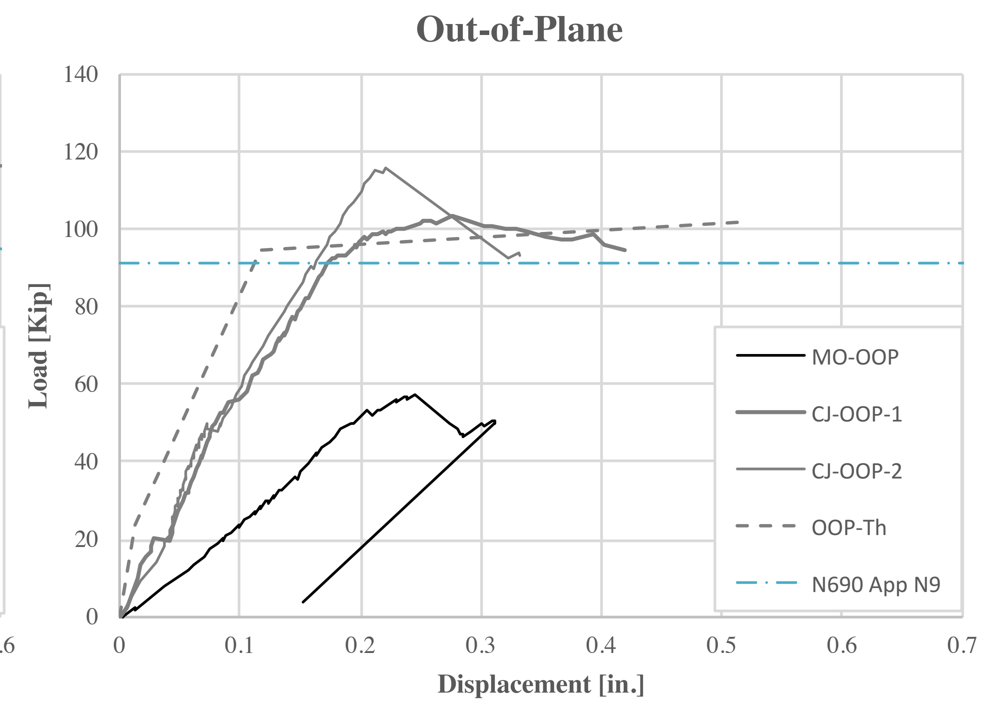
In-Plane and Out-of-Plane failure mode

4. Task 3 – Assessment of Shear and Flexure Performances

In-Plane and Out-of-Plane failure mode

4. Task 3 – Assessment of Shear and Flexure Performances
Test Results and Analytical Model





5. Task 4 – Validation through Full-Scale Testing
Specimen

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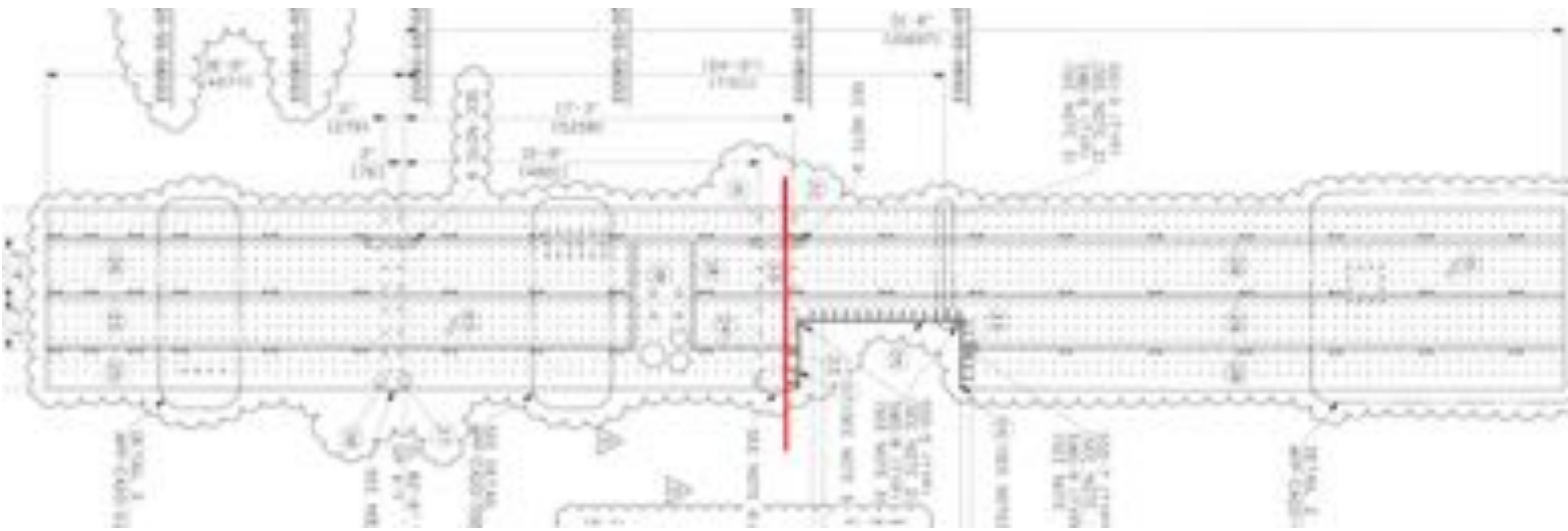
Specimen

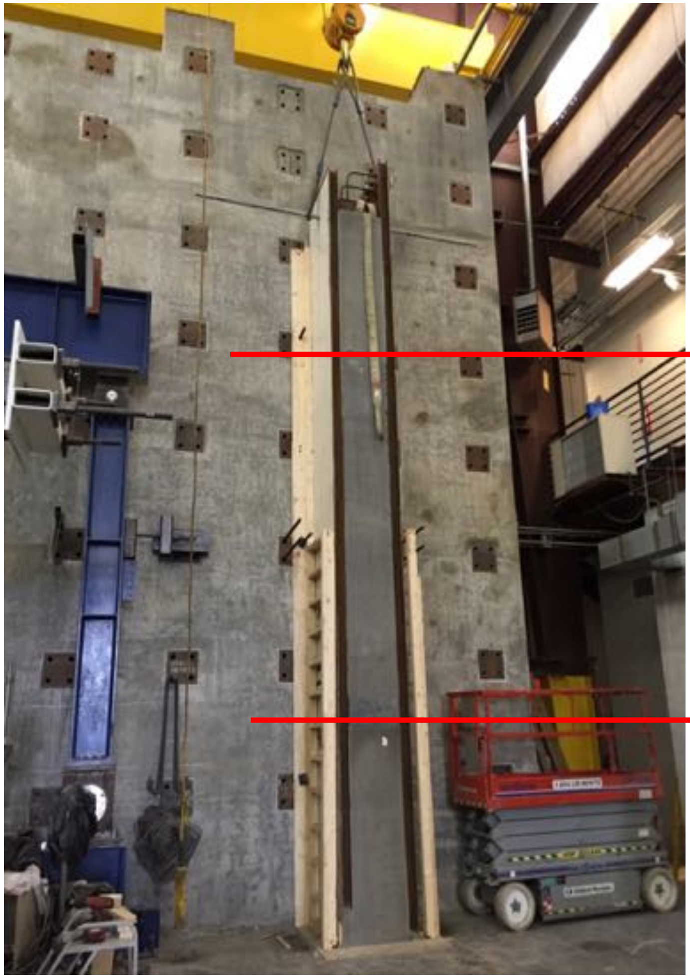


5. Task 4 – Validation through Full-Scale Testing
External steel plates

5. Task 4 – Validation through Full-Scale Testing
Vertical

3. Scaling things up

Three concrete lifts



Concrete Placement 3

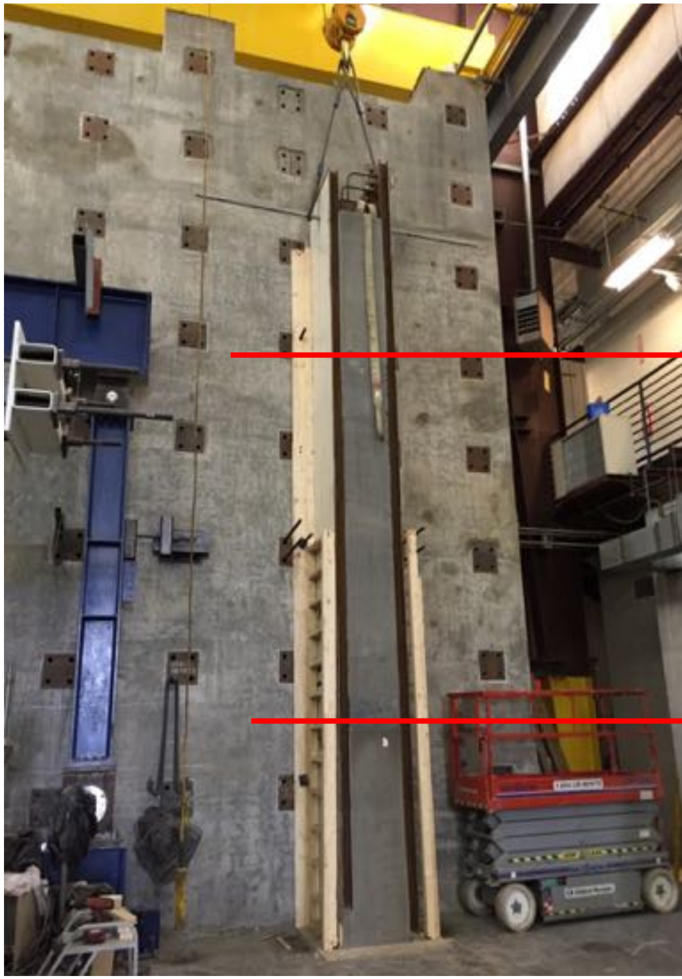
Cold Joint 2

Concrete Placement 2

Cold Joint 1

Concrete Placement 1

3. Scaling things up
Cold joint



Concrete Placement 3

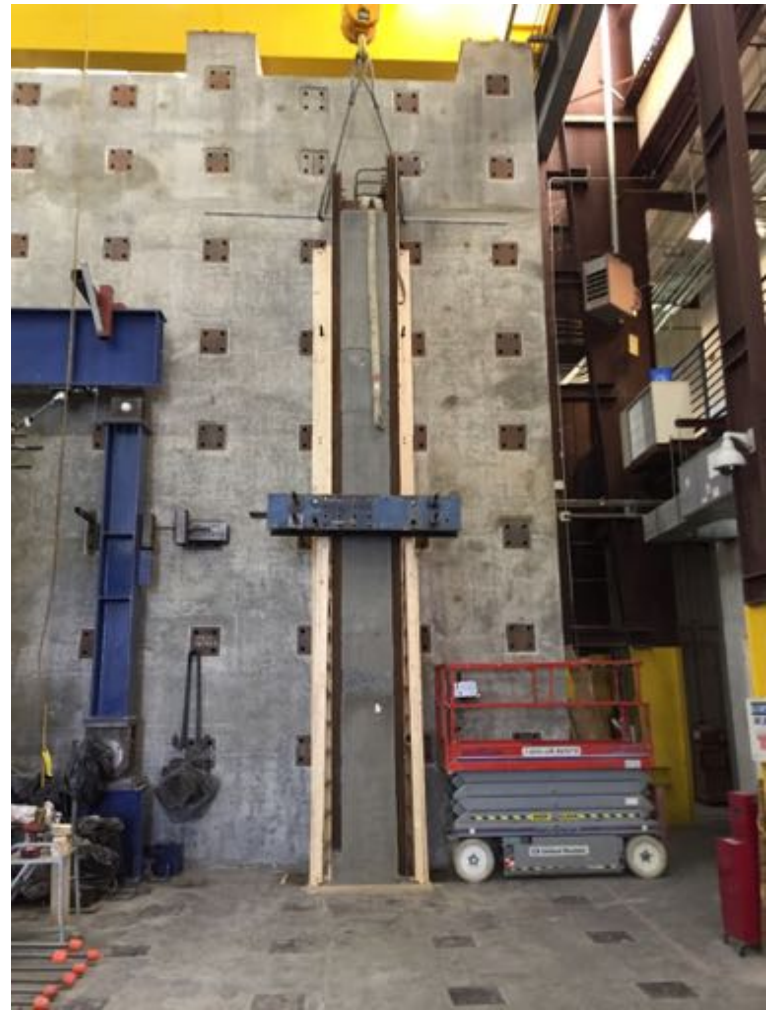
Cold Joint 2

Concrete Placement 2

Cold Joint 1

Concrete Placement 1

5. Task 4 – Validation through Full-Scale Testing

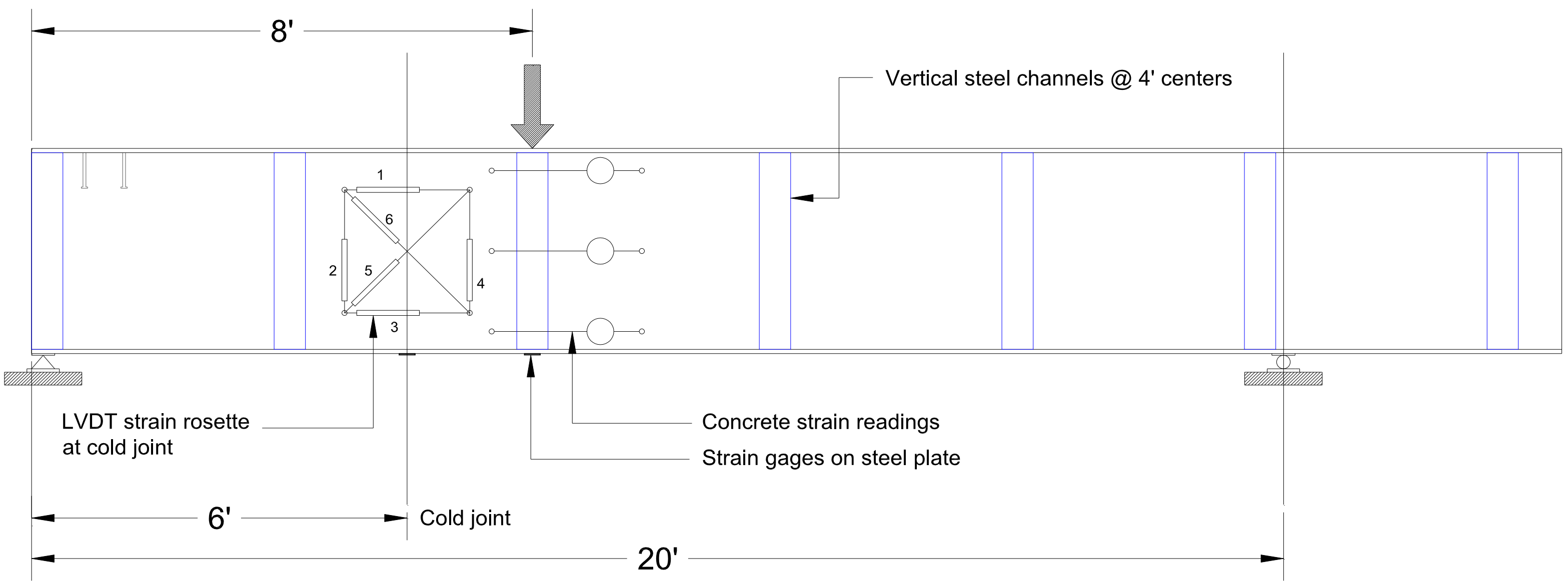


5. Task 4 – Validation through Full-Scale Testing

Moving the test specimen

5. Task 4 – Validation through Full-Scale Testing

Test setup

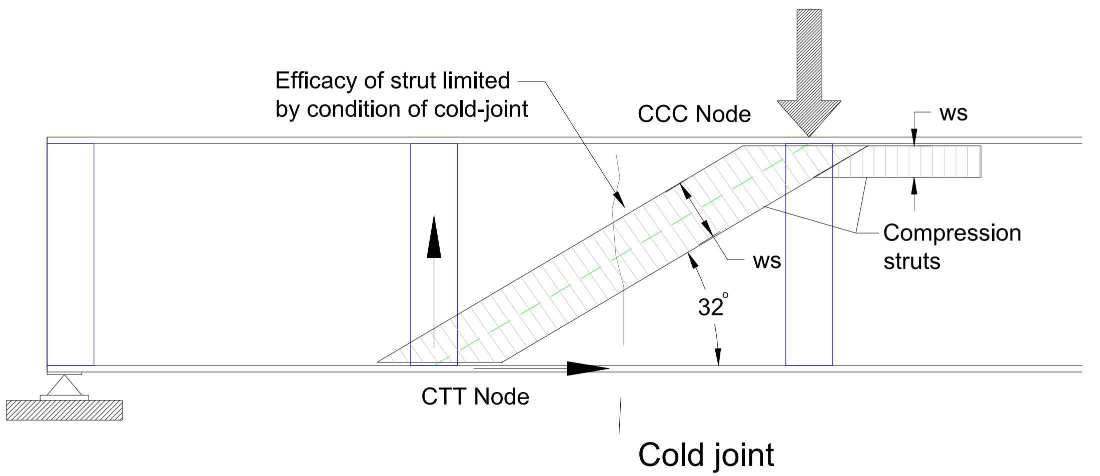


5. Task 4 – Validation through Full-Scale Testing

Test setup

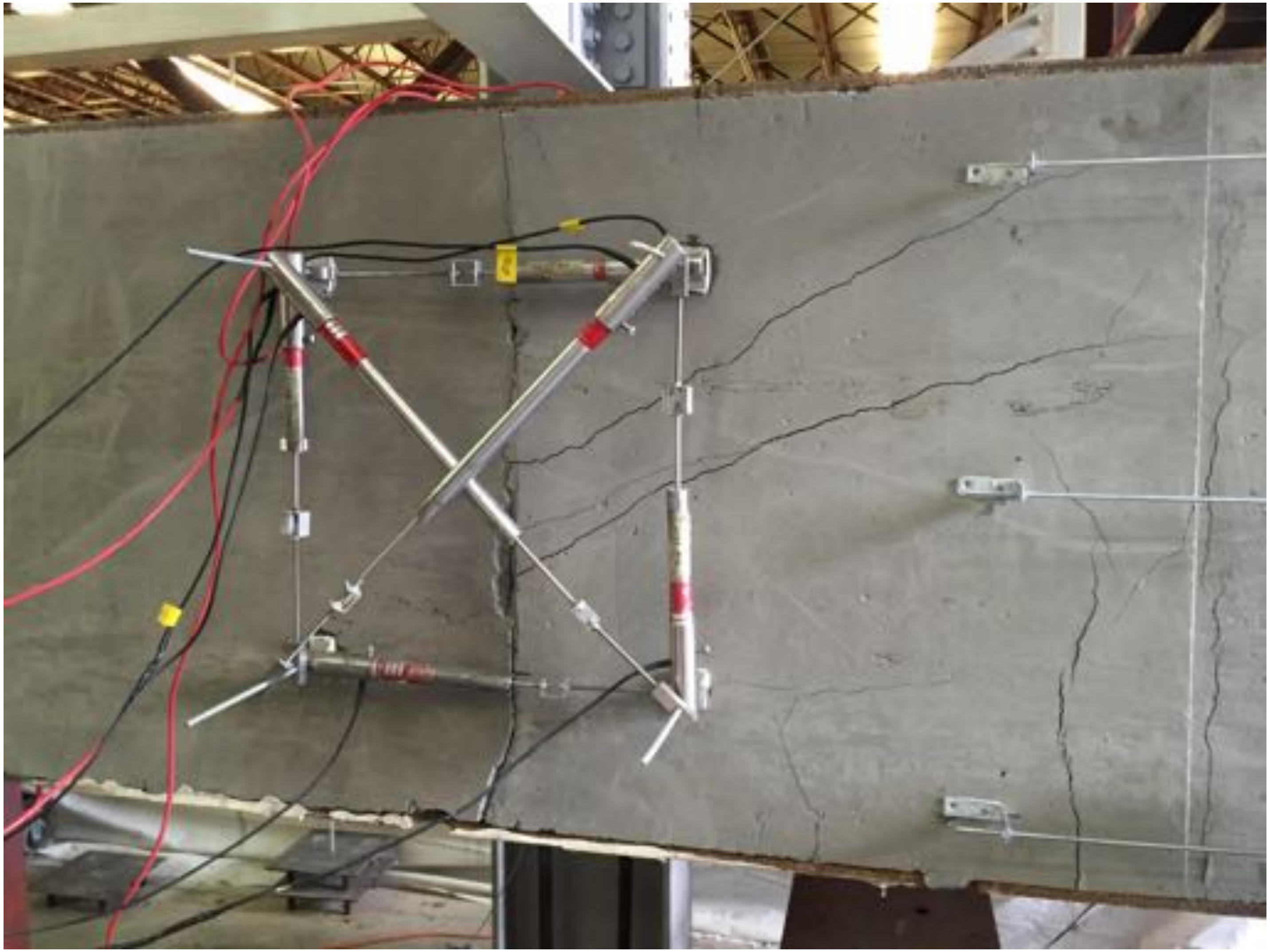
5. Task 4 – Validation through Full-Scale Testing

Expected behavior



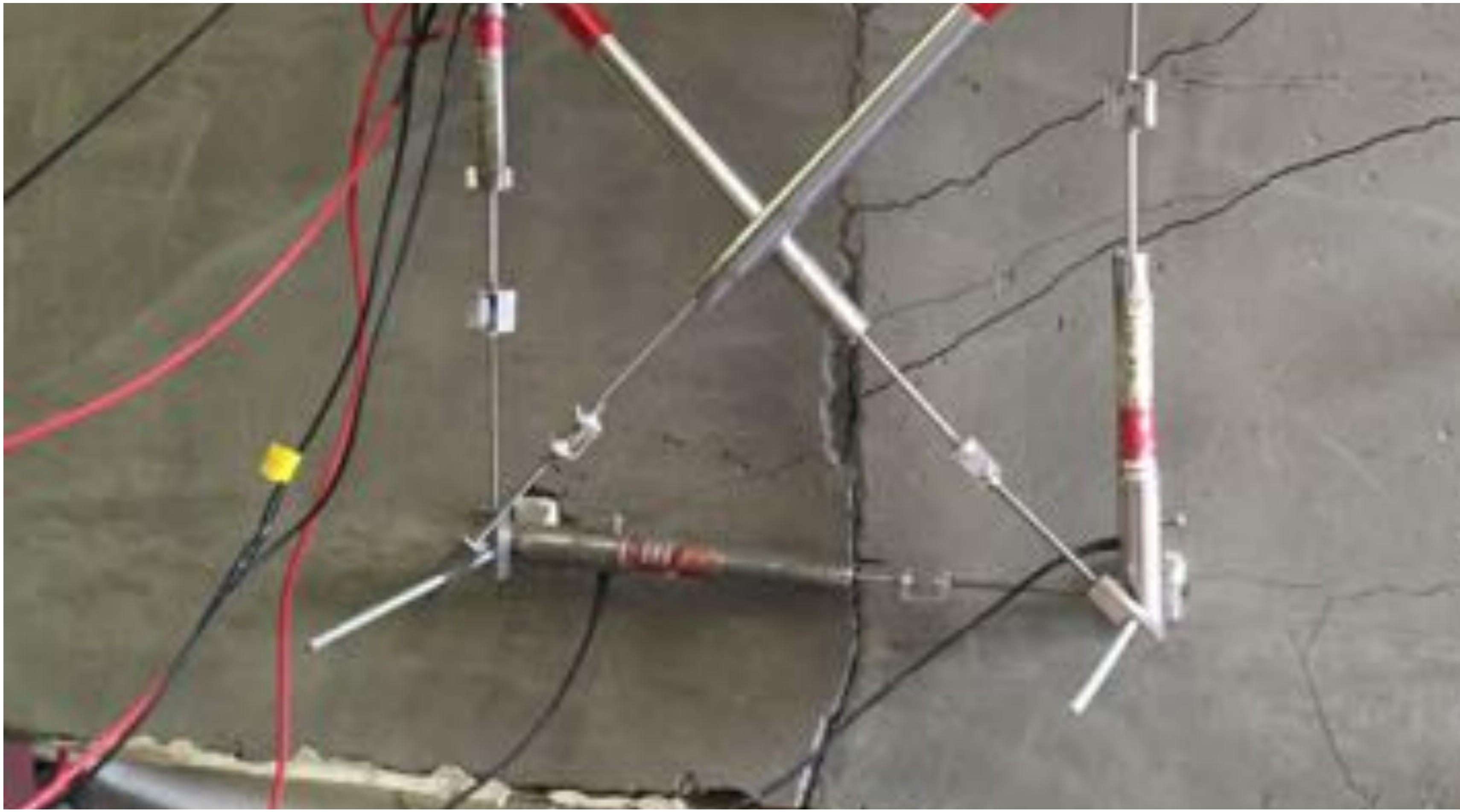
5. Task 4 – Validation through Full-Scale Testing

Cold joint detail



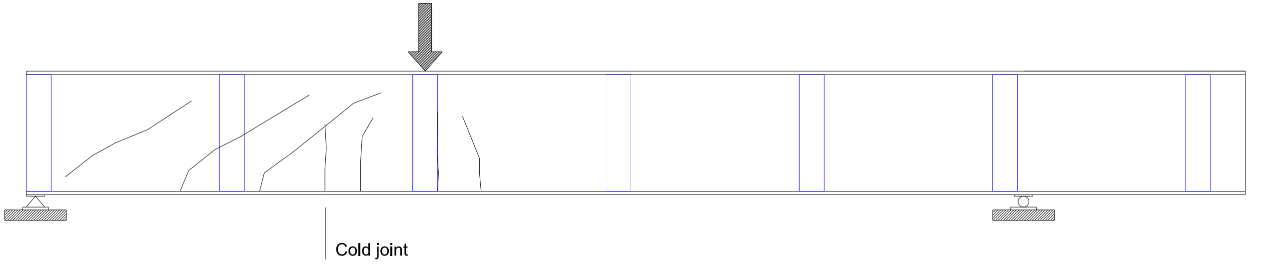
5. Task 4 – Validation through Full-Scale Testing

Cold joint detail



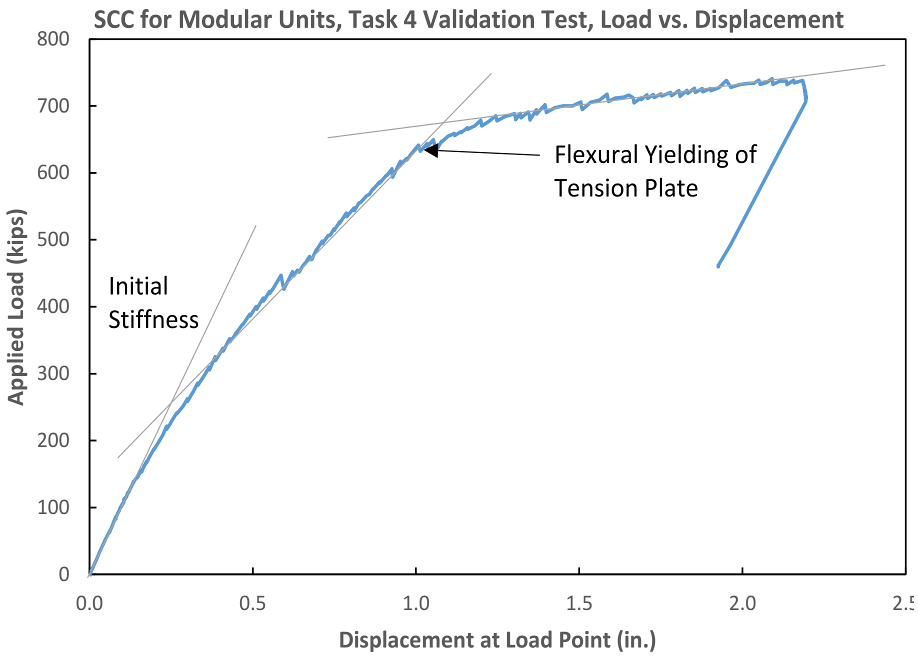
5. Task 4 – Validation through Full-Scale Testing
5. Task 4 – Validation through Full-Scale Testing

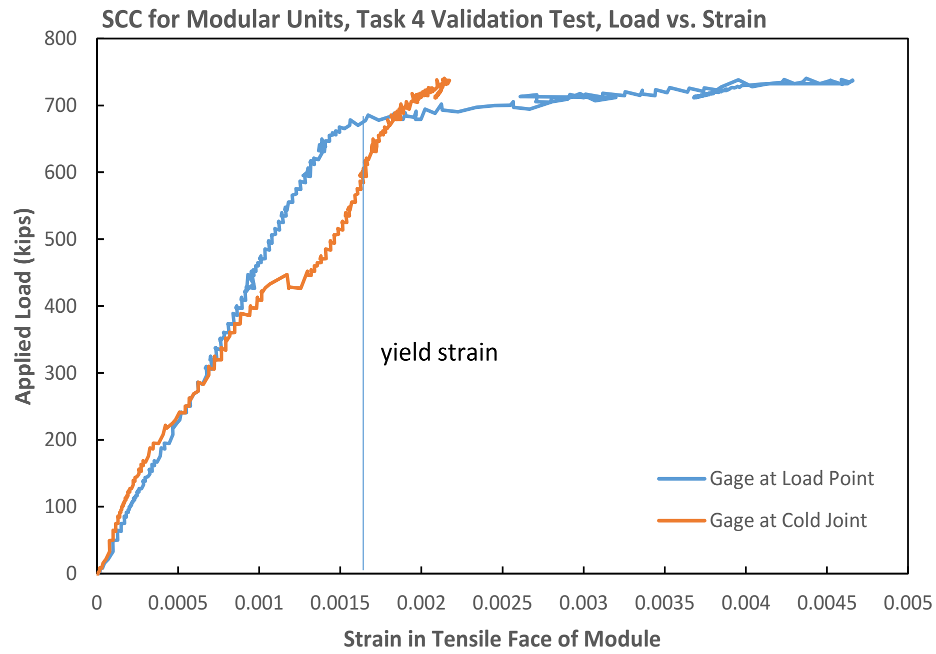
Cold joint detail
Cold joint detail



5. Task 4 – Validation through Full-Scale Testing

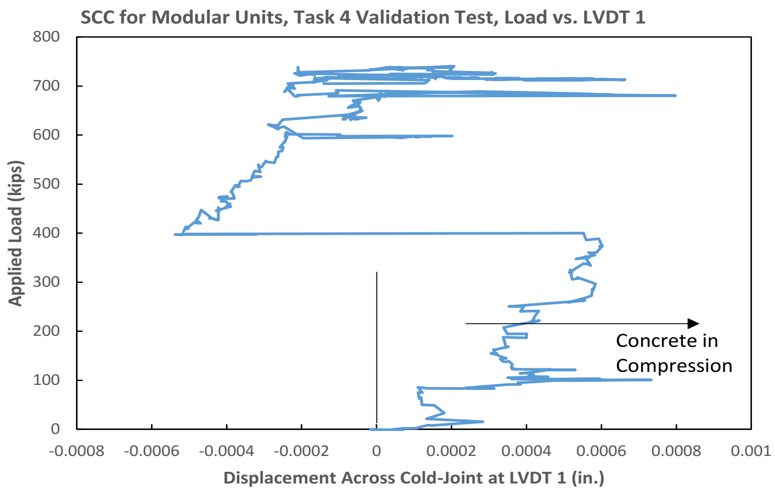
Load displacement curve

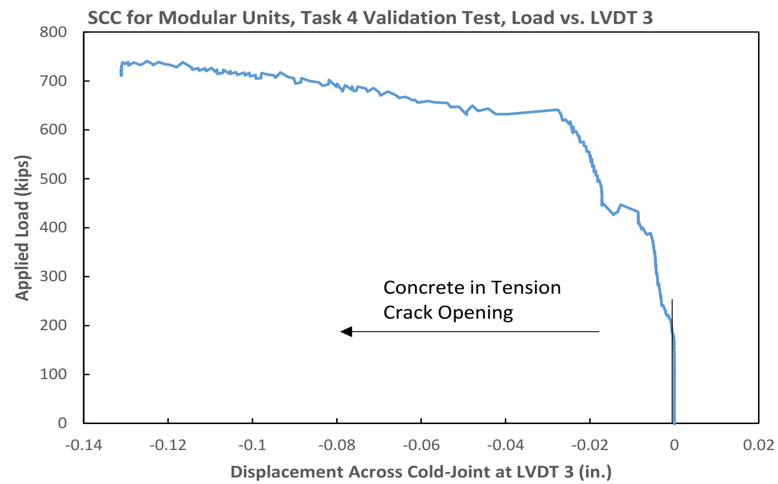


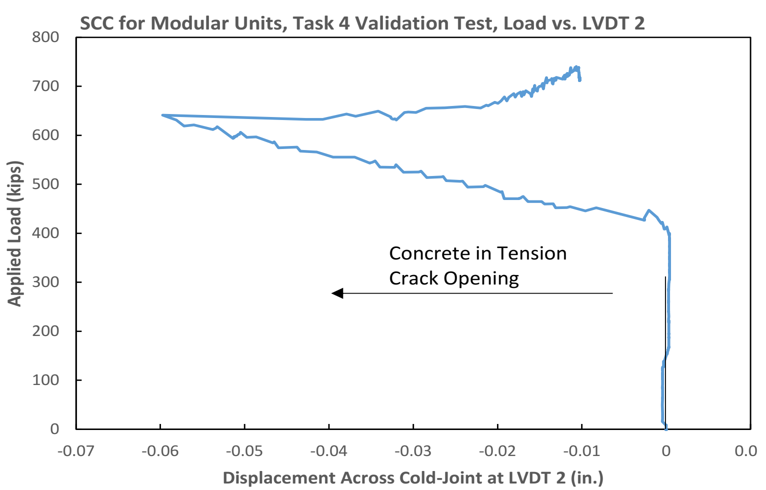


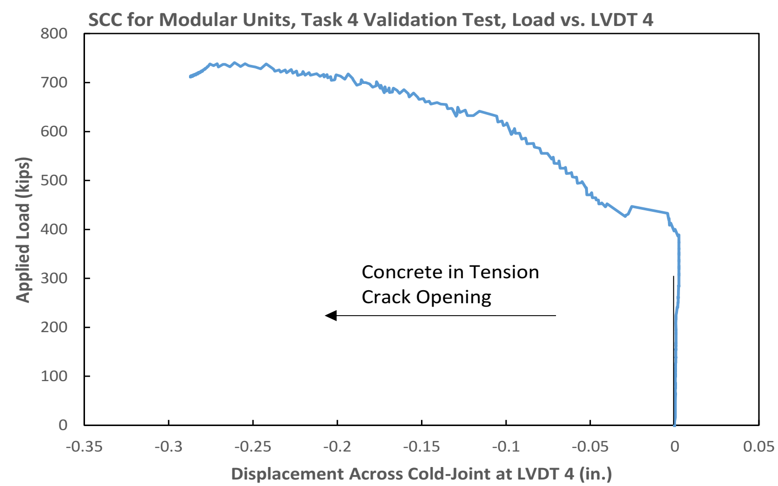
5. Task 4 – Validation through Full-Scale Testing

Load strain

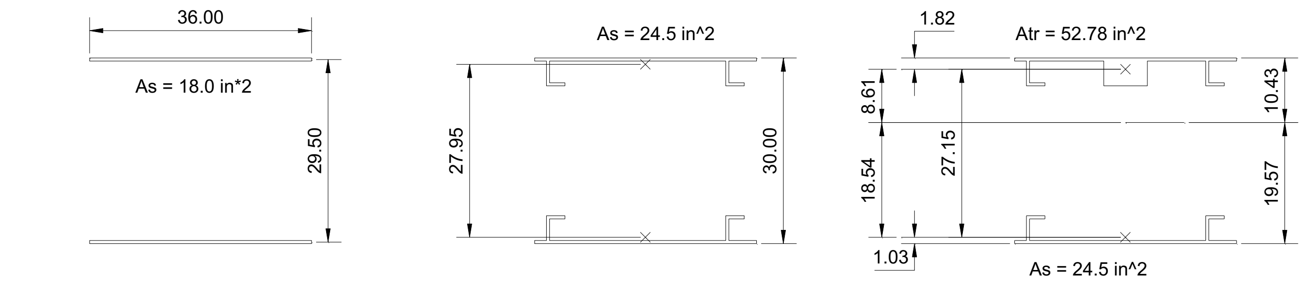








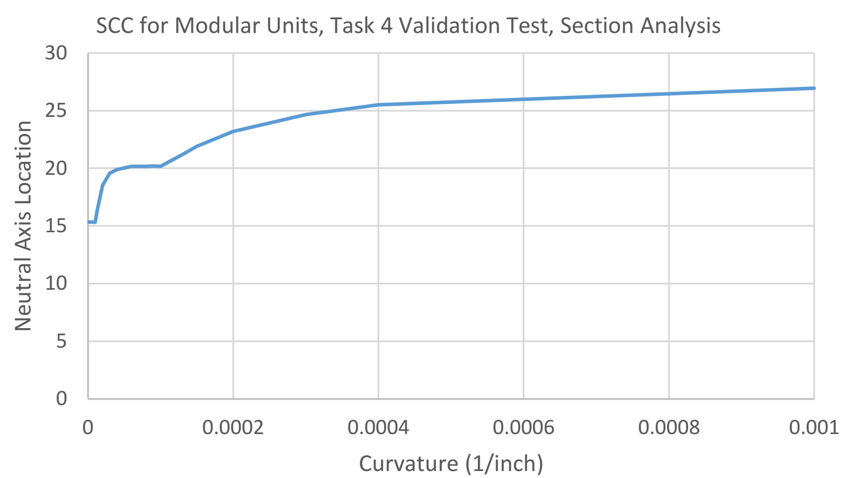
5. Task 4 – Validation through Full-Scale Testing
Model

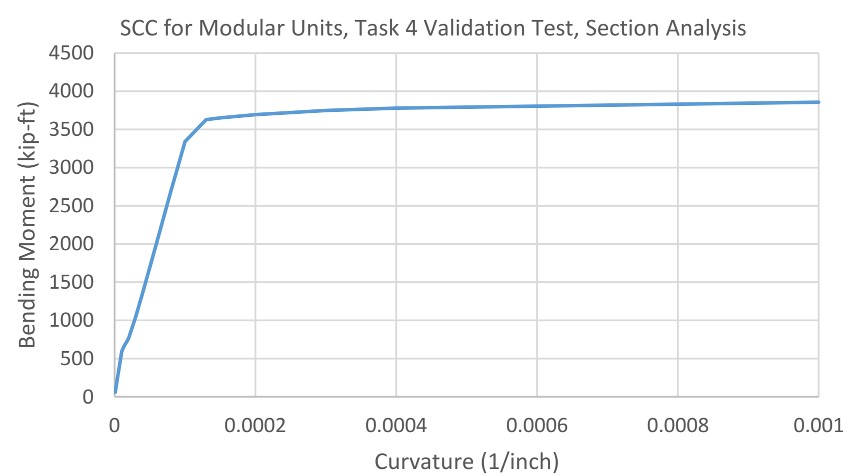


(a) faces only

(b) faces plus continuous angles

(c) faces plus continuous angles, compression concrete transformed





Concluding

6. Conclusions
And outlooks

- SCC which self-roughens has been developed by replacing small fraction of coarse with lightweight aggregate (LWA) → avoids need for continuous placement
- Achieve improved shear friction capacity, which scales with LWA fraction.
- Full scale convalidation
- Meet strength and shrinkage targets.

6. Acknowledgments

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1. Mr. **Ray Nixon and Ian Houston** of the **Nelson Stud Welding Company** provided significant support to our understanding of headed stud welding and quality control. Mr. Nixon spent countless hours teaching Georgia Tech faculty, students and staff to weld studs and arranged for a gift of a stud welder to Georgia Tech.
2. The **Carolina Stalite Company** provided expanded lightweight slate aggregate for the project. Mr. **Ken Harmon**, PE of the Stalite Company provided technical support during the design of concrete mixes using the lightweight aggregate.
3. **Thomas Concrete** provided ready-mix concrete for casting of the Task 3 and 4 specimens. Mr. **John Cook** and **Justin Lazenby** provided technical assistance in scaling the laboratory mixes used in Tasks 1 and 2 into self-roughening SCC mixes capable of being batched in a ready-mix plant.
4. The **Vulcan Materials Company** provided alluvial sand, crushed man-made sand, and crushed granite aggregate for the laboratory mixes used in Task 1 and Task 2 of the project.

6. Disclaimer

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

Thank you. Questions?


Questions?