Experimental Investigation of Deconstructable Steel-Concrete Shear Connections in Sustainable Composite Beams

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Acknowledgements

Sponsors

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- Simpson Gumpertz & Heger

In-Kind Support

- Benevento Companies
- Capone Iron Corporation
- Fastenal Company
- HALFEN
- Lindapter International
- Meadow Burke
- S&F Concrete
- Souza Concrete

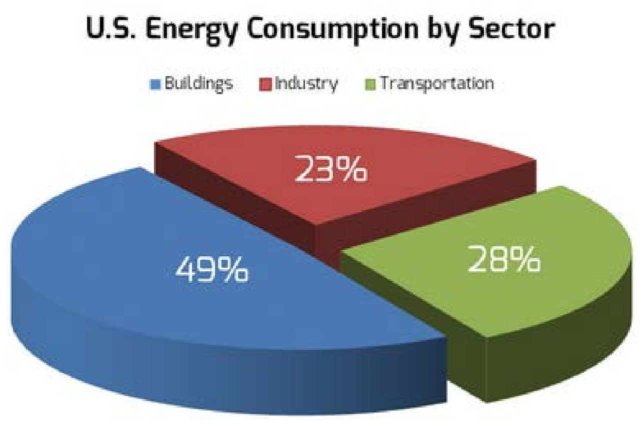
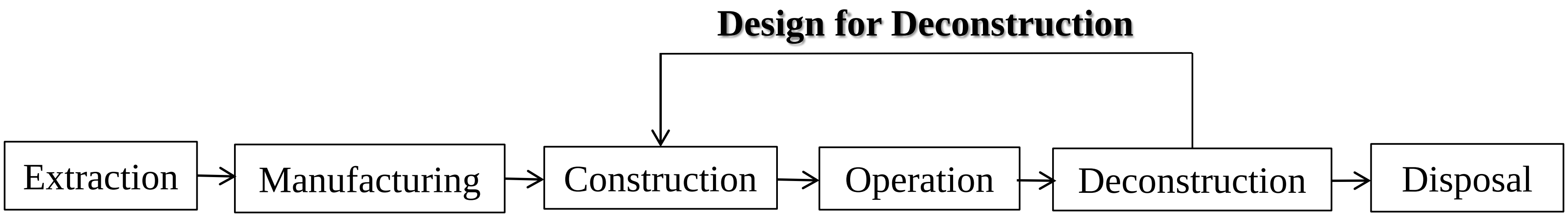


Image from US Energy Information Administration (2011)

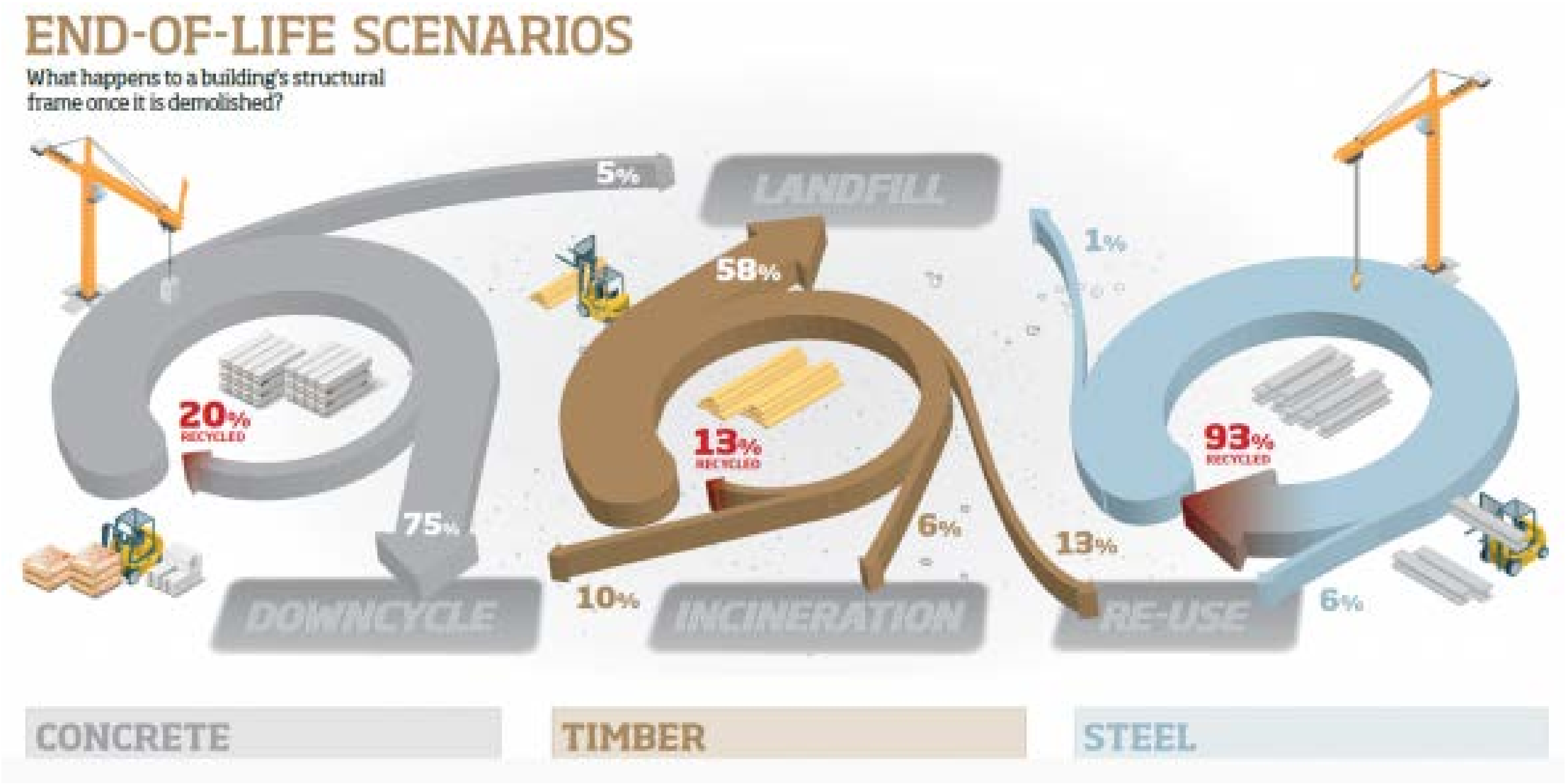
Green buildings

- Material manufacture:
  - Environmentally friendly, renewable and low embodied energy materials
- Building use:
  - Efficient heating, ventilating and lighting systems
  - Adaptation or reconfiguration
- End of life
  - Minimum amount of waste and pollution
  - Reusable and recyclable materials

Material flow of current buildings:



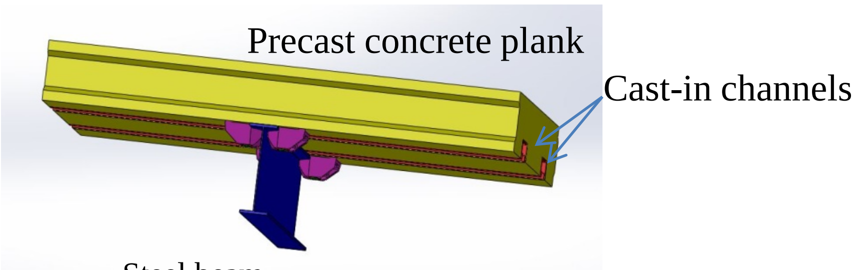
End-of-life of Construction Materials

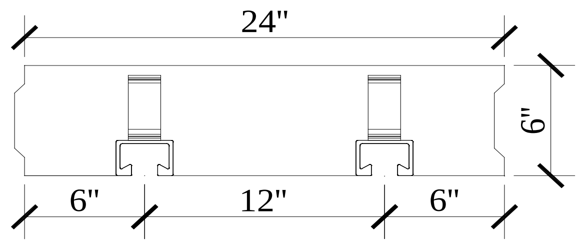


End-of-life of construction materials
Image from SteelConstruction.Info

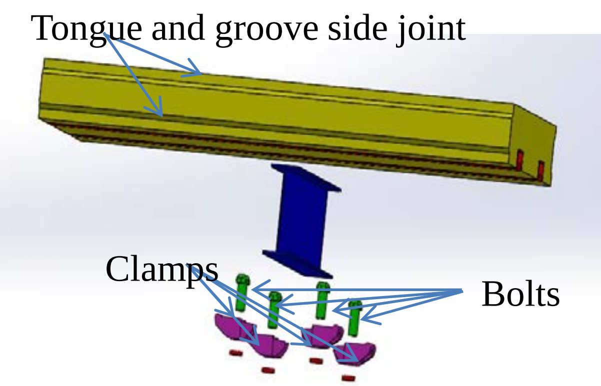
Composite Floor System

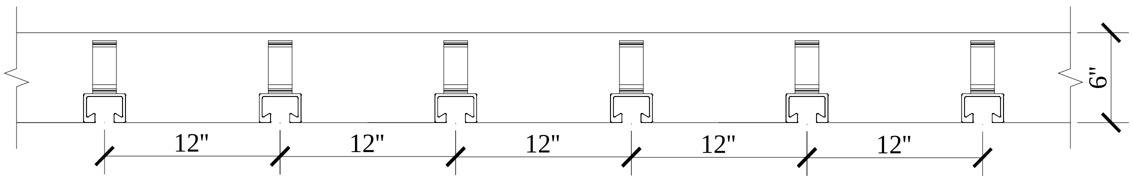
- Conventional composite floor systems are cost-effective solutions for multi-story buildings
- The integration of steel beams and concrete slab limits separation and reuse of the components
- Proposed DfD System: Clamp precast planks to steel beams/girders in a steel framing system
  - Both the steel members and the precast planks may be reused





a) Plank perpendicular to the steel beam





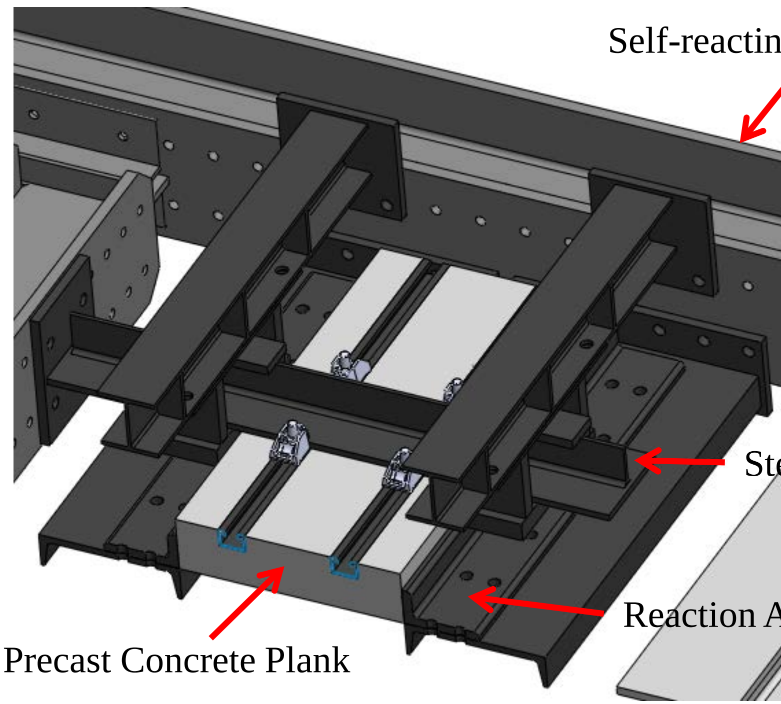
b) Plank parallel to the steel girder

Deconstructable composite beam prototype

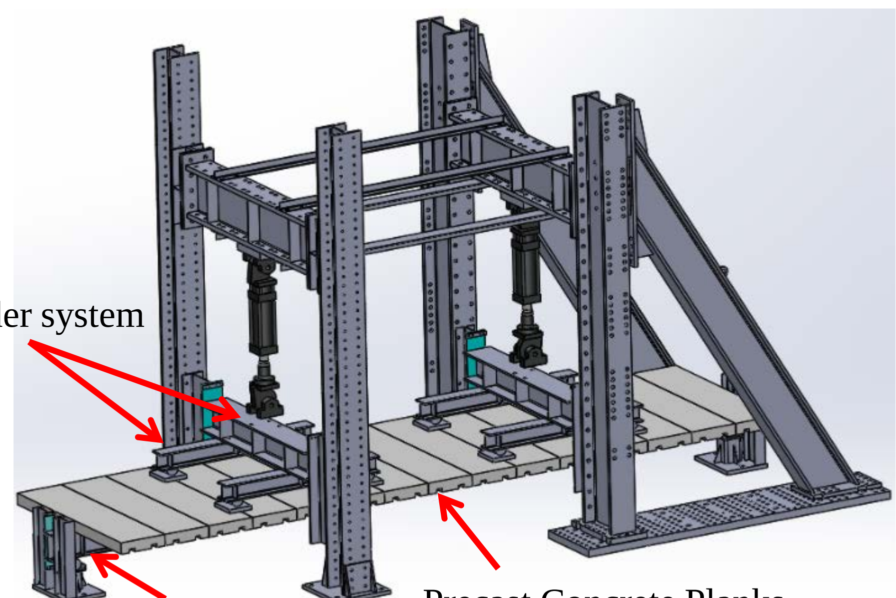
Precast concrete plank cross section

Test Program

- Pushout tests: evaluate a wide range of parameters and formulate strength design equations for the clamping connectors
- Beam tests: study the clamp connector behavior and associated composite beam strength and stiffness for different levels of composite action



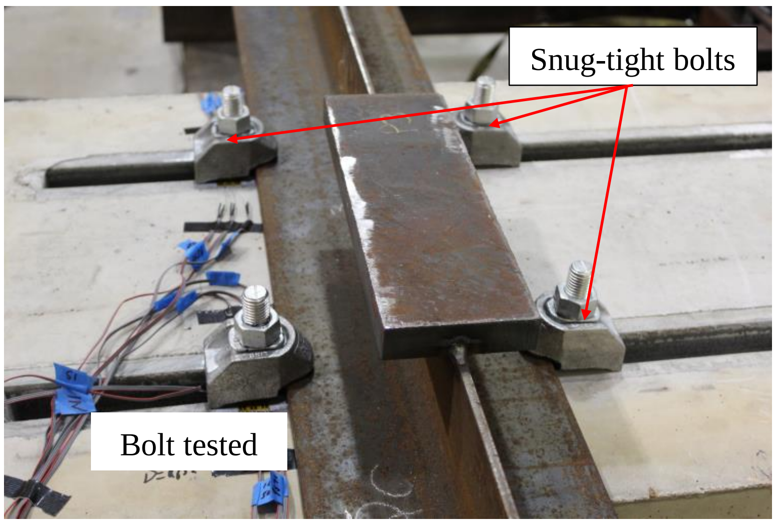
Pushout test setup



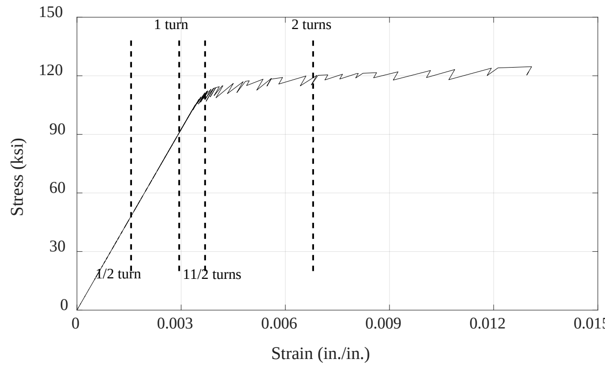
Composite beam test setup

Pretension Test

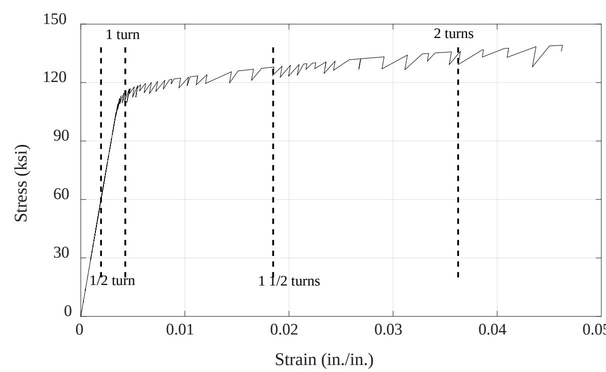
- Determine the number of turns needed for pretensioning the T bolts
- Round coupons are first tested to obtain the stress-strain curve of the bolt material



Pretension test setup



M24 bolts

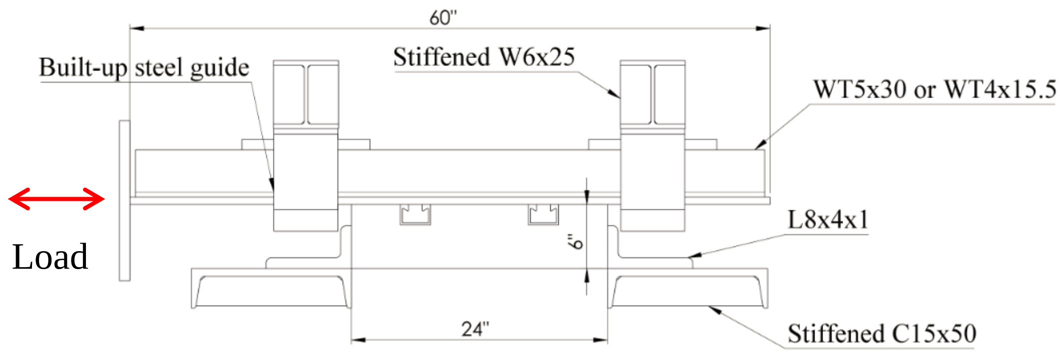


M20 bolts

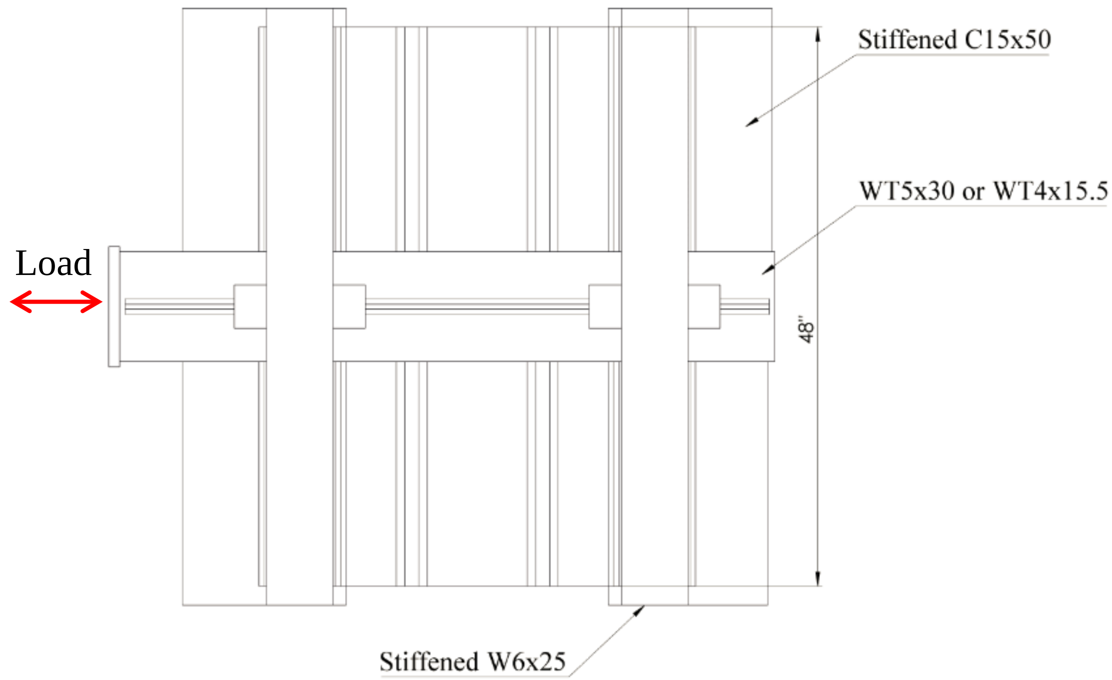
Fractured bolts

Two turns and 1.5 turns after a snug-tight condition are recommended for pretensioning the M24 and M20 bolts, respectively.

Pushout Test Configuration



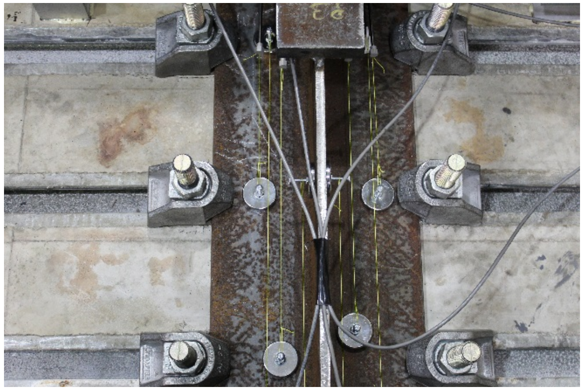
Elevation View

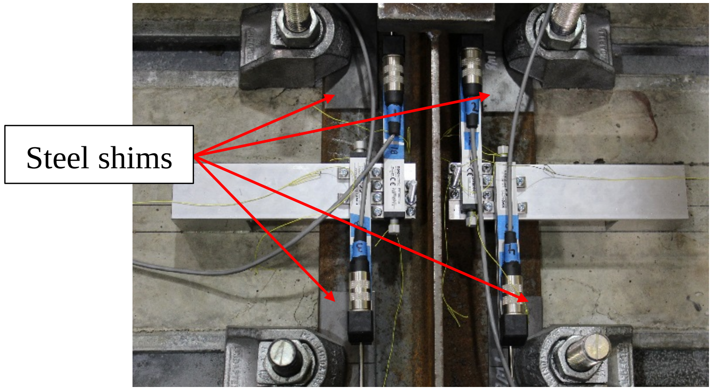


Plan View

Pushout Test Matrix

Series	Specimen	Test parameters			
		Bolt diameter	Number of T bolts	Reinforcement configuration	Shim
M	2-M24-T4-RH	M24	4	Heavy	No
M	3-M24-T4-RH-S	M24	4	Heavy	Yes
M	4-M24-T6-RH	M24	6	Heavy	No
M	5-M20-T4-RH	M20	4	Heavy	No
C	6-C24-T4-RH	M24	4	Heavy	No
C	7-C24-T4-RL	M24	4	Light	No
C	8-C24-T4-RH-S	M24	4	Heavy	Yes
C	9-C24-T6-RH	M24	6	Heavy	No
C	10-C20-T4-RH	M20	4	Heavy	No


Three-channel specimen

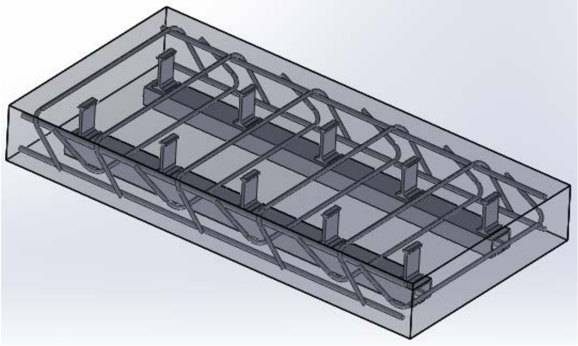


Two-channel specimen with shims

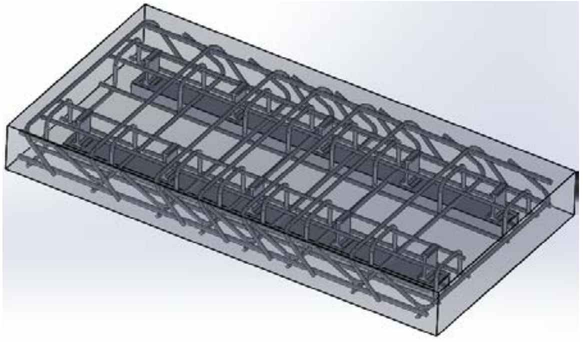
Pushout Test Parameters

Reinforcement pattern

- Light pattern: Contains reinforcement designed for gravity loading only

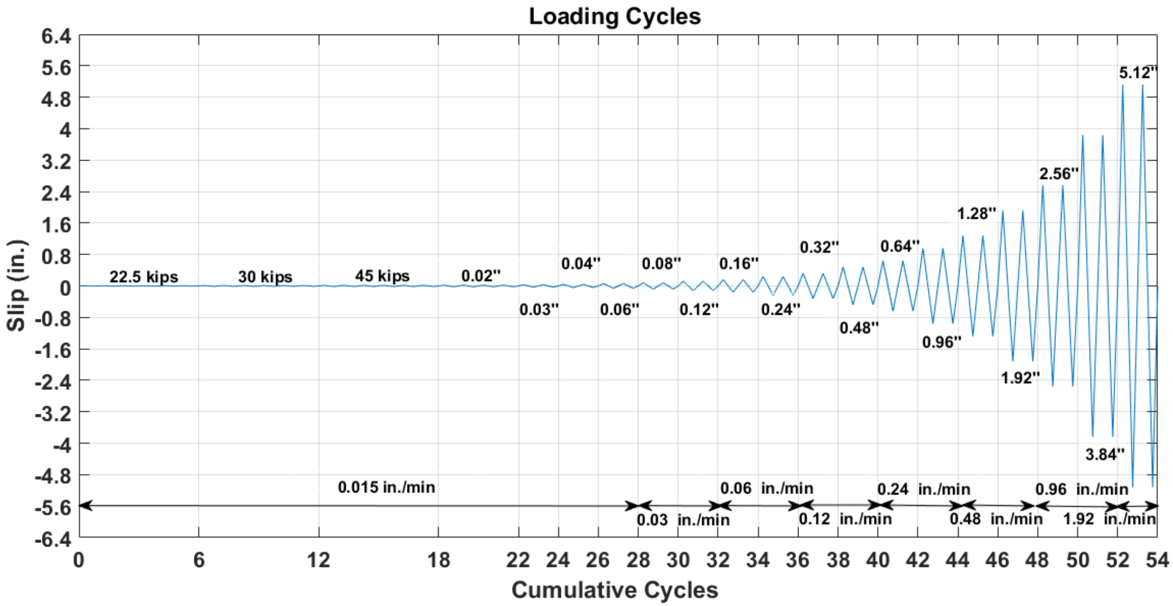


- Heavy pattern: Supplementary reinforcement bridges all potential concrete failure planes



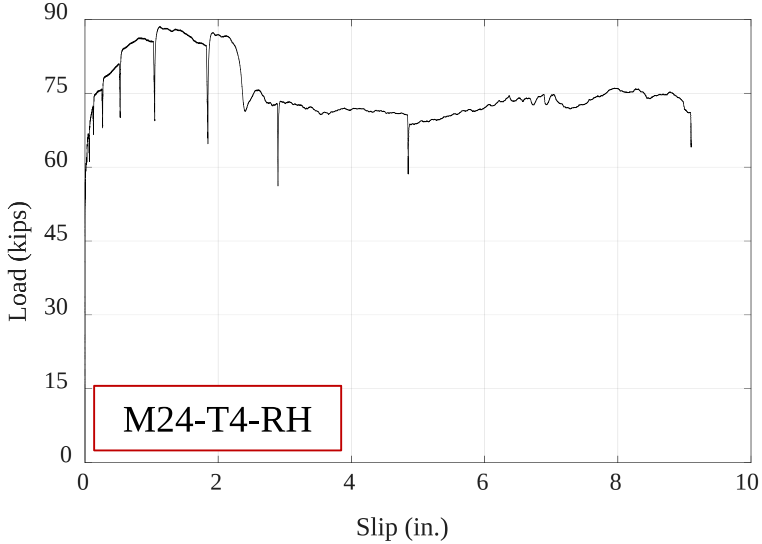
Loading protocols

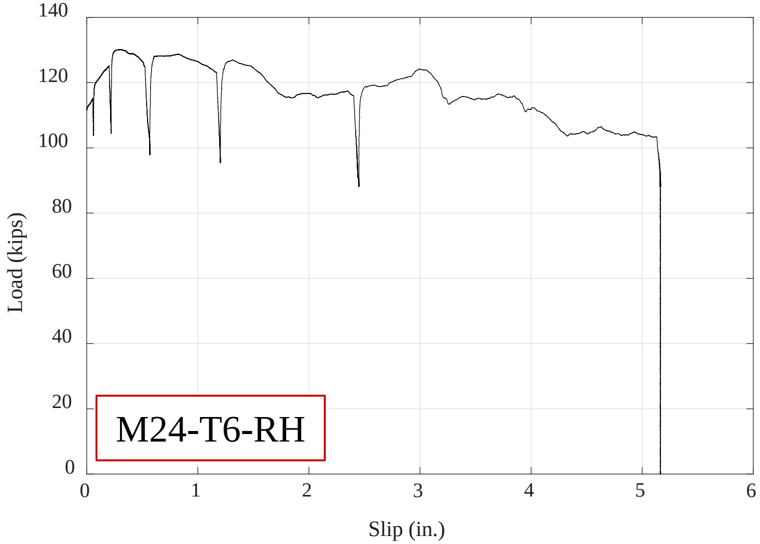
- Monotonic test: Displacement control
- Cyclic test:
  - Displacement control
  - Emulate AISC 341-10 K2.4b “Loading Sequences for Beam-to-Column Moment Connection”

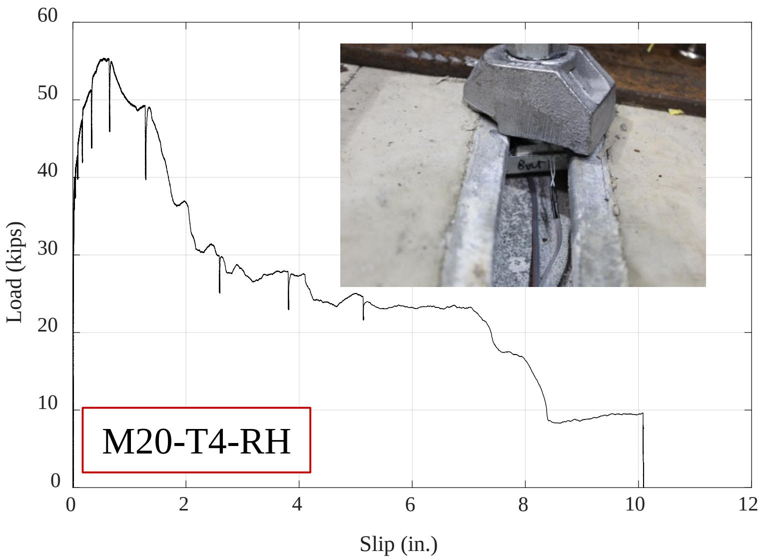


Pushout Test Results

Monotonic Test Results



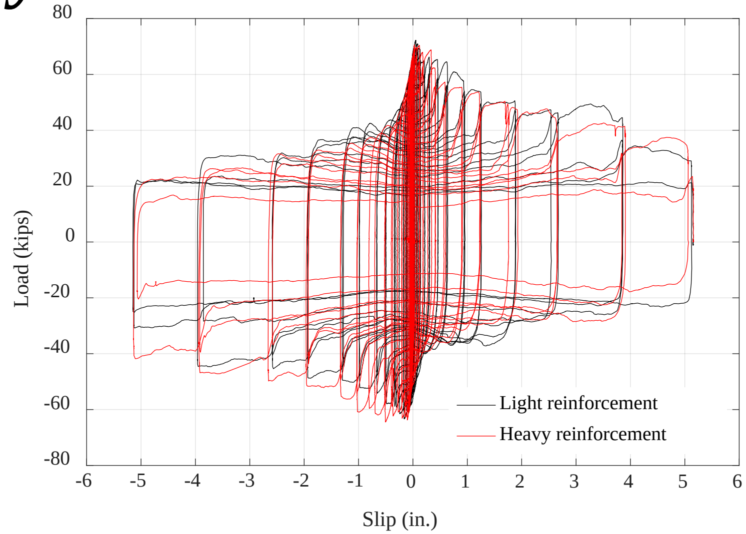




- Smaller M20 clamps are prone to rotate and cannot hold their positions as stably as the M24 clamps
- It is recommended to reduce the rotation of the M20 clamps to maintain the bolt tension, which could be achieved by locking the clamp tails into the channels
- The strength degradation starts at a slip of 0.54 in., which is usually larger than the slip demand on shear connectors in composite beams

Pushout Test Results

Cyclic Test Results



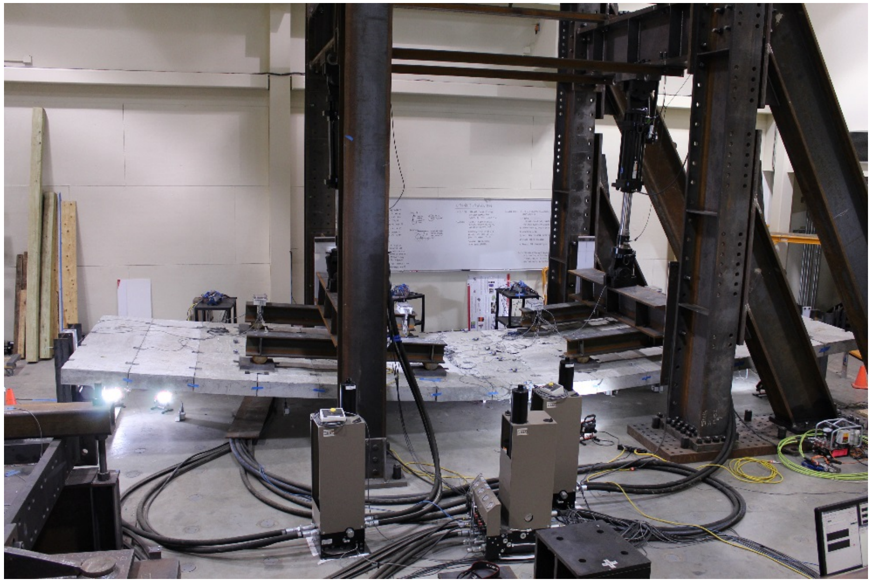
Specimens C24-T4-RH and C24-T4-RL

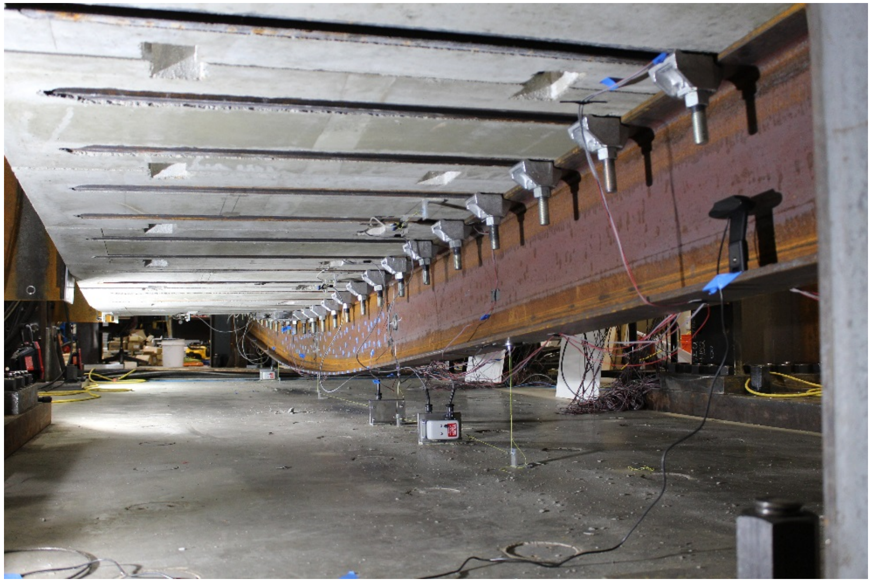
Abrasion on steel flanges

- Strength reduction similar to shear studs which exhibit lower strength and ductility when subjected to cyclic loading (25% strength reduction in design)
- The peak load reduces due to lowering of frictional coefficients and release of bolt tension, but through pinching behavior at larger slips retains much of its strength
- Shear studs have limited slip capacity before fracture (~0.3 in.); clamps have the potential to connect composite diaphragms and collector beams and could be designed as inelastic components to dissipate energy

Beam Test Setup

Composite Beam Test



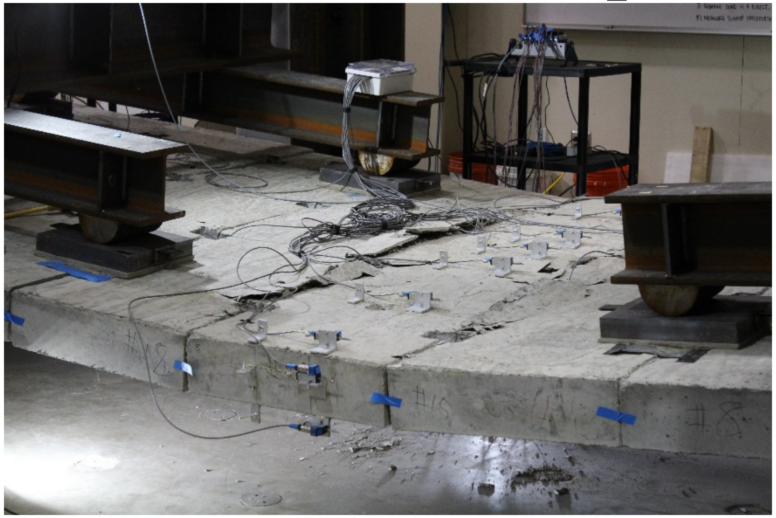


Composite beam test setup

Composite beam #	Bolt size	# of channels per plank	Steel beam section	Reinforcement configuration	Number of bolts (clamps)	Percentage of composite action
1-M24-2C-RH	M24	2	W14x38	Heavy	56	82.7%
2-M24-1C-RL	M24	1	W14x38	Light	30	45.1%
3-M20-3C-RL	M20	3	W14x26	Light	90	164.5%
4-M20-1C-RL	M20	1	W14x26	Light	30	43.8%

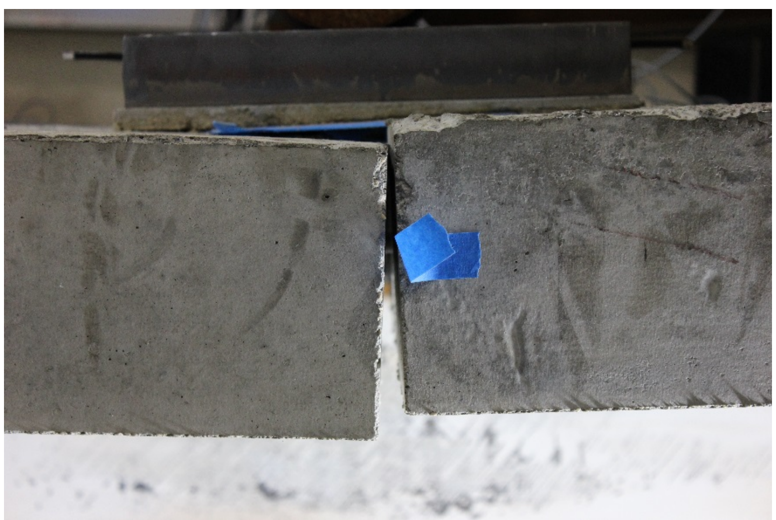
Beam Test Results

Observed Beam Response

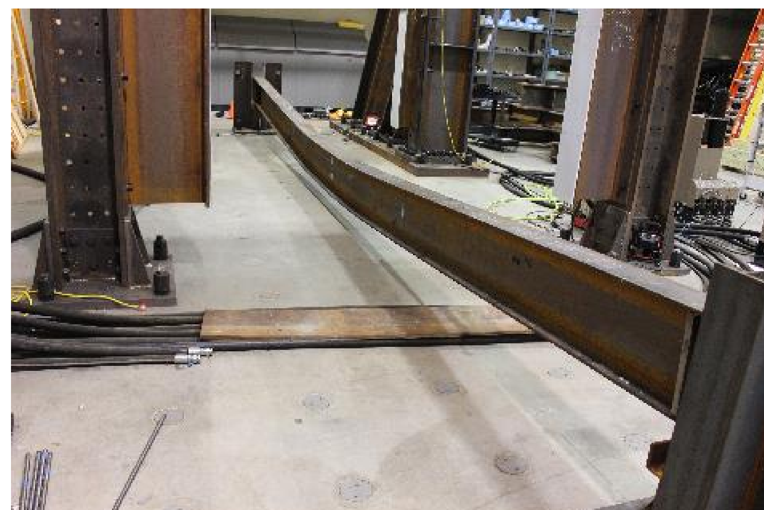


Concrete crushing

Longitudinal cracking (parallel to the steel beam)



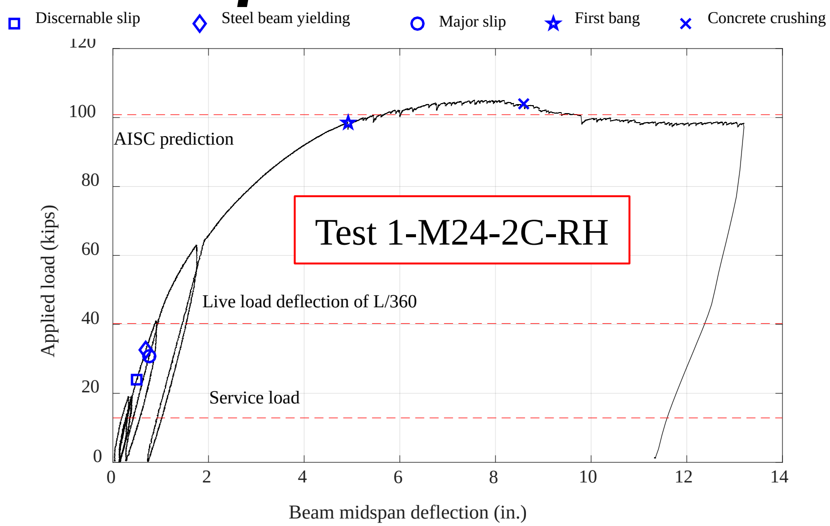
Contact between planks at ultimate deflection



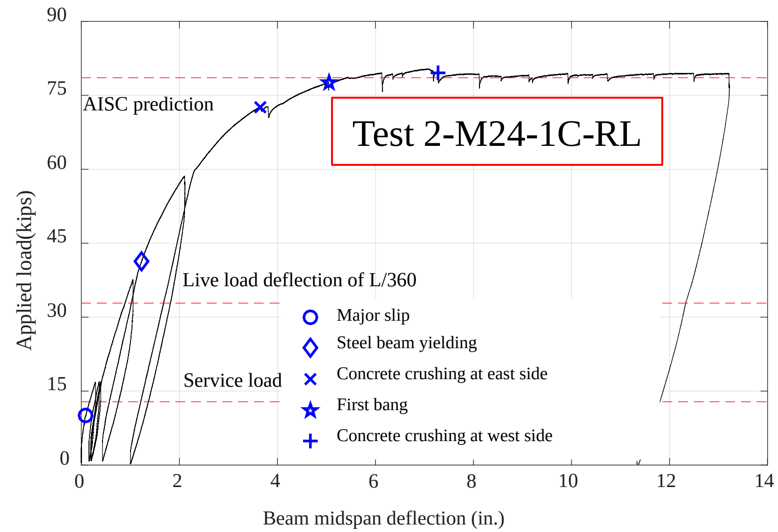
Deconstructed steel beam

Beam Test Results

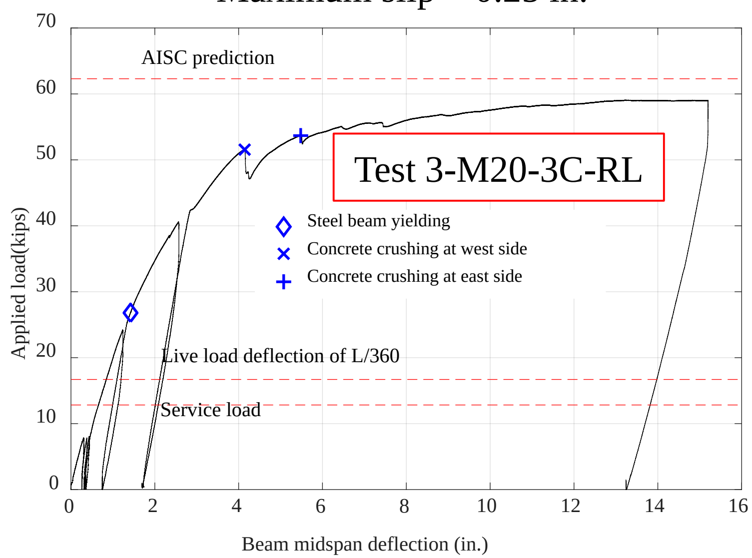
Load-Deflection Curves



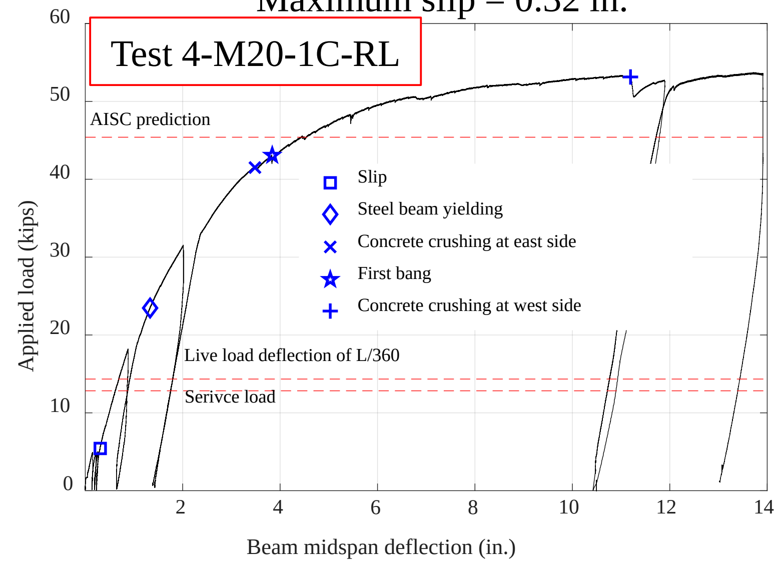
Maximum slip = 0.25 in.



Maximum slip = 0.32 in.



Maximum slip = 0.02 in.

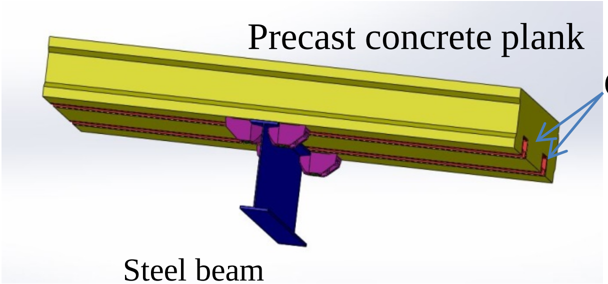


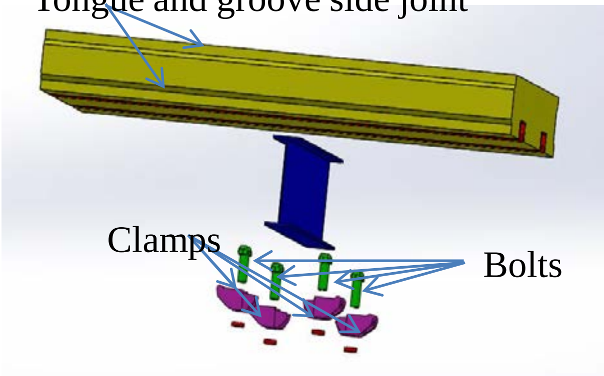
Maximum slip = 0.35 in.

Conclusions

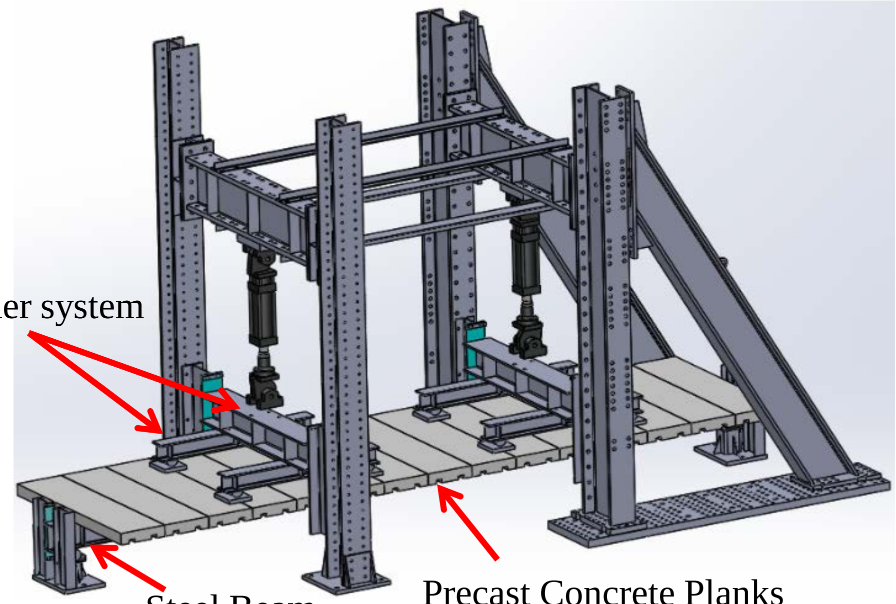
- A new deconstructable composite floor system is proposed to promote sustainable design of composite floor systems within bolted steel building construction through comprehensive reuse of all key structural components.
- Pushout tests are conducted to evaluate the effects of different parameters and formulate strength design equations for the clamping system; composite beam tests are performed to investigate the strength, stiffness and ductility of the beams.
- 2 turns and 1.5 turns after a snug-tight condition are recommended for pretensioning the M24 and M20 bolts in the DfD plank system.
- The M24 clamps are highly robust under monotonic loading - compared to shear studs that fracture at much smaller slips (~0.3 in.), the clamping connectors can retain almost 80% of the peak strength even at 5 in. slip under monotonic loading.
- The strength of the M20 clamps declines quickly because the clamps are prone to rotate as the beam moves. As such, the size of the clamp relative to the channel is an important design consideration. Also, the slip at which the strength starts to descend is much larger than the slip demand on the clamping connectors in composite beams.
- All the beams deflected to L/25 and behave in a ductile manner. The tested flexural strength of the beams is close to that predicted by the AISC design equations.

Thank You





Deconstructable composite beam prototype



Composite beam test setup

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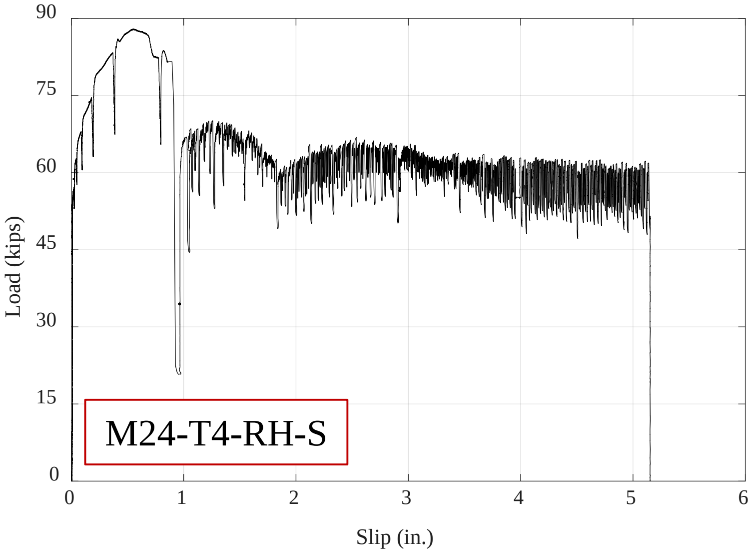
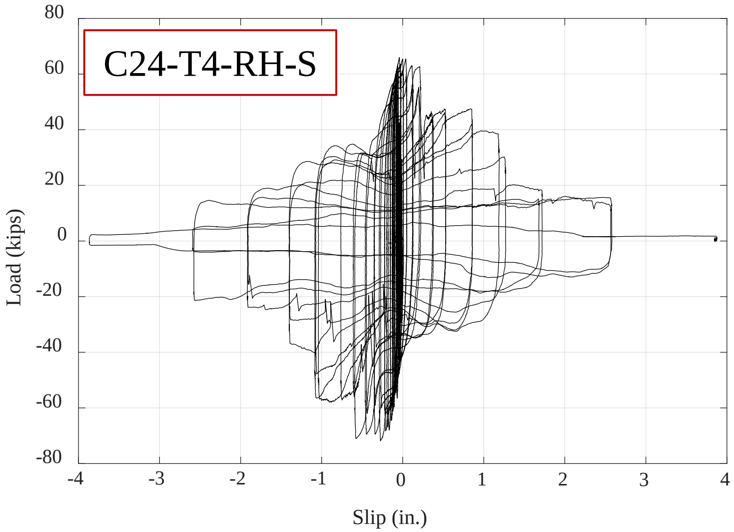
Laboratory for Structural Testing of Resilient and Sustainable Systems
SIMPSON GUMPERTZ & HEGER
Engineering of Structures and Building Enclosures

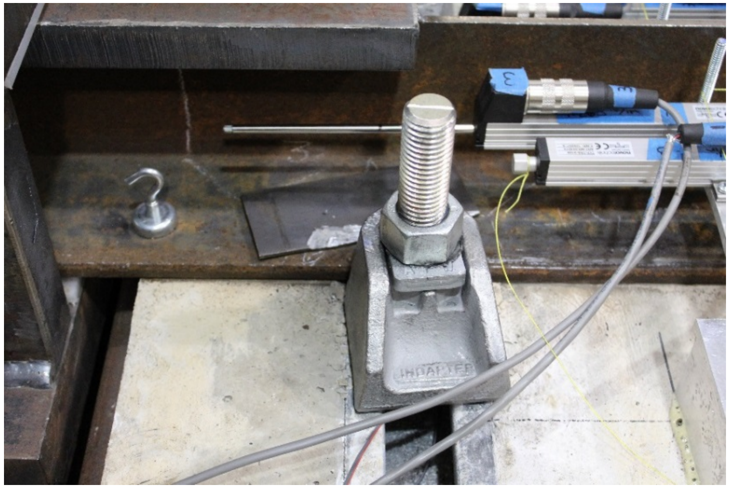
Pushout Test Results

Test Results



Bolt head fracture

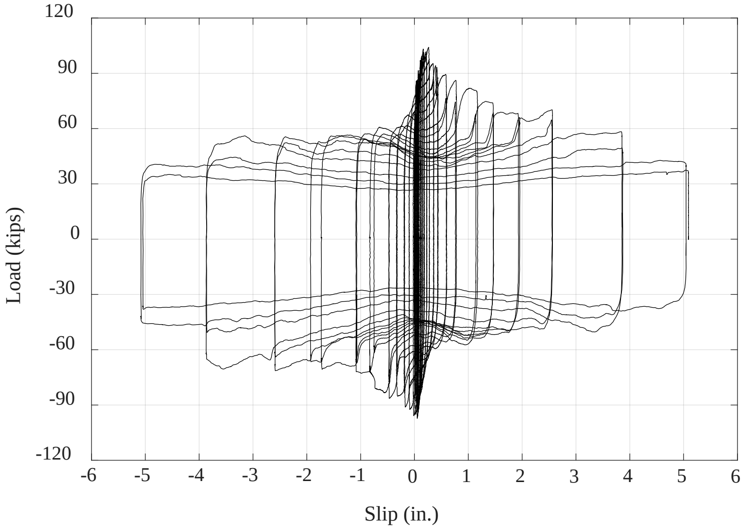




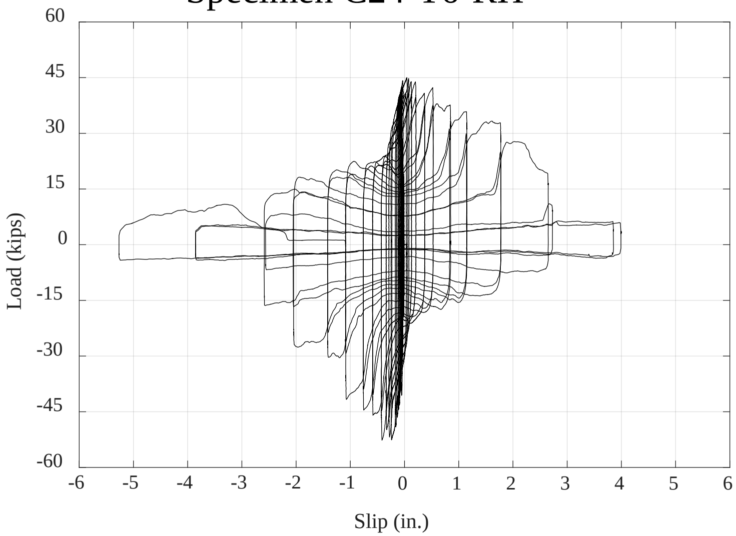
Separation of shims from clamps

Pushout Test Results

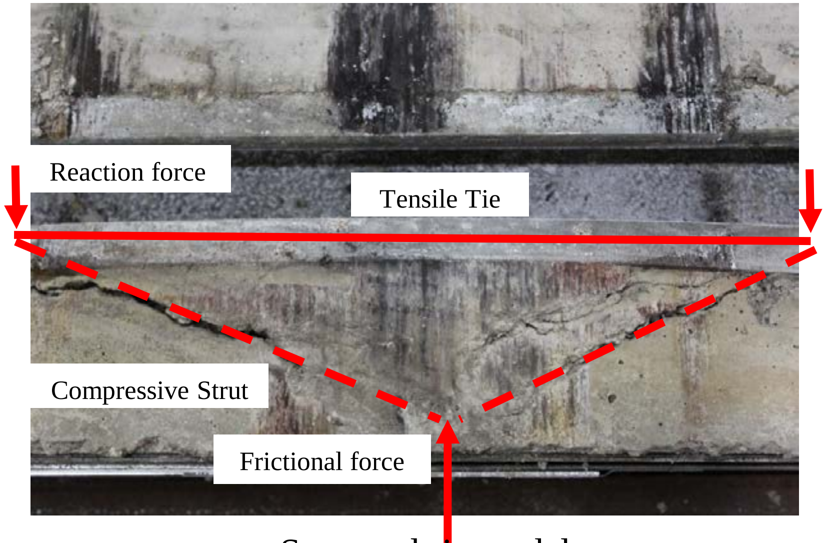
Test Results



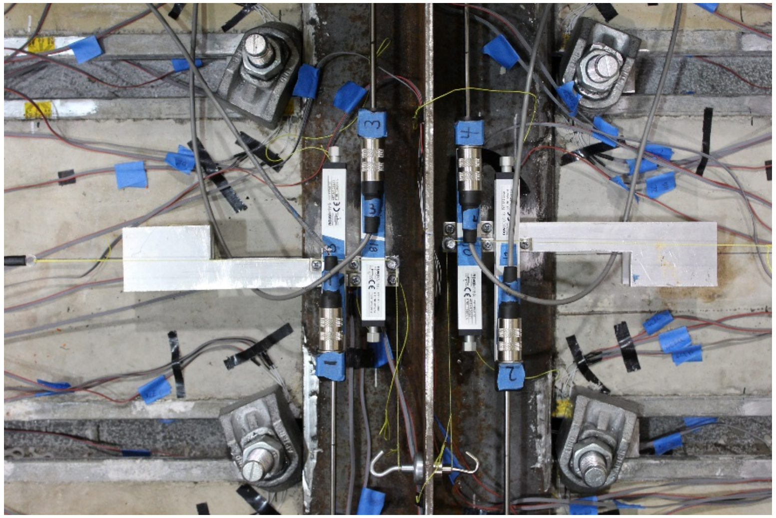
Specimen C24-T6-RH



Specimen C20-T4-RH



Strut-and-tie model



Complete disengagement of clamps