NASCC: THE STEEL CONFERENCE

# Deconstructable Systems for Sustainable Design of Steel and Composite Structures

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Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

# Course Description

A sustainable composite steel-concrete floor system for building structures is proposed to enable disassembly and reuse of the structural components, thereby reducing the environmental impacts associated with material extraction, production, fabrication, and waste disposal.

# Learning Objectives

**Learning Objective 1:**

Identify keys findings in recent studies in sustainable design through use of Design for Deconstruction (DfD).

**Learning Objective 2:**

Learn about recent experimental tests validating the performance of a DfD floor steel framing system.

**Learning Objective 3:**

List recommendations to implement in design based on test results of DfD floor steel framing system.

**Learning Objective 4:**

Identify key findings in the life cycle assessments of DfD structure and understand the resulting reduced environmental impact.

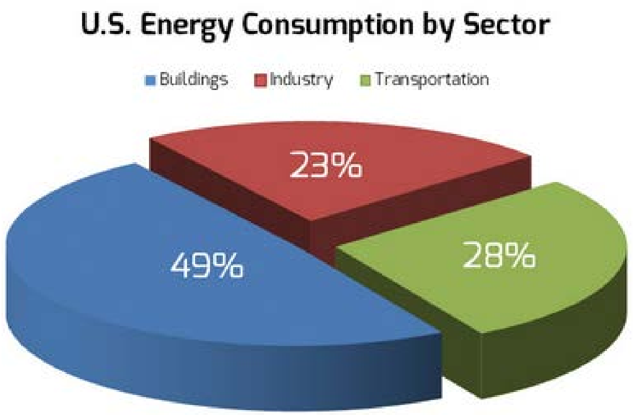
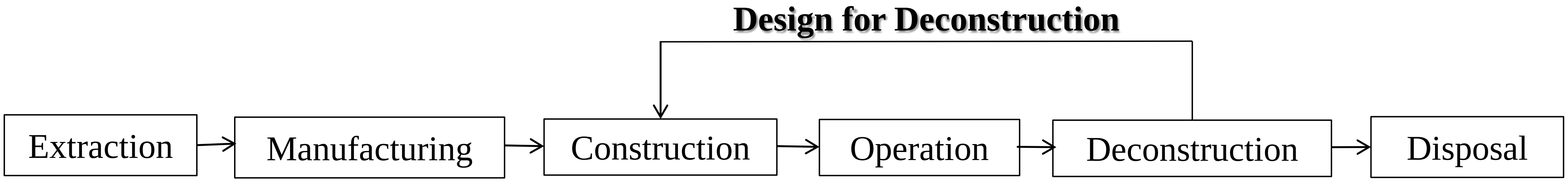



*Image from US Energy Information Administration (2011)*

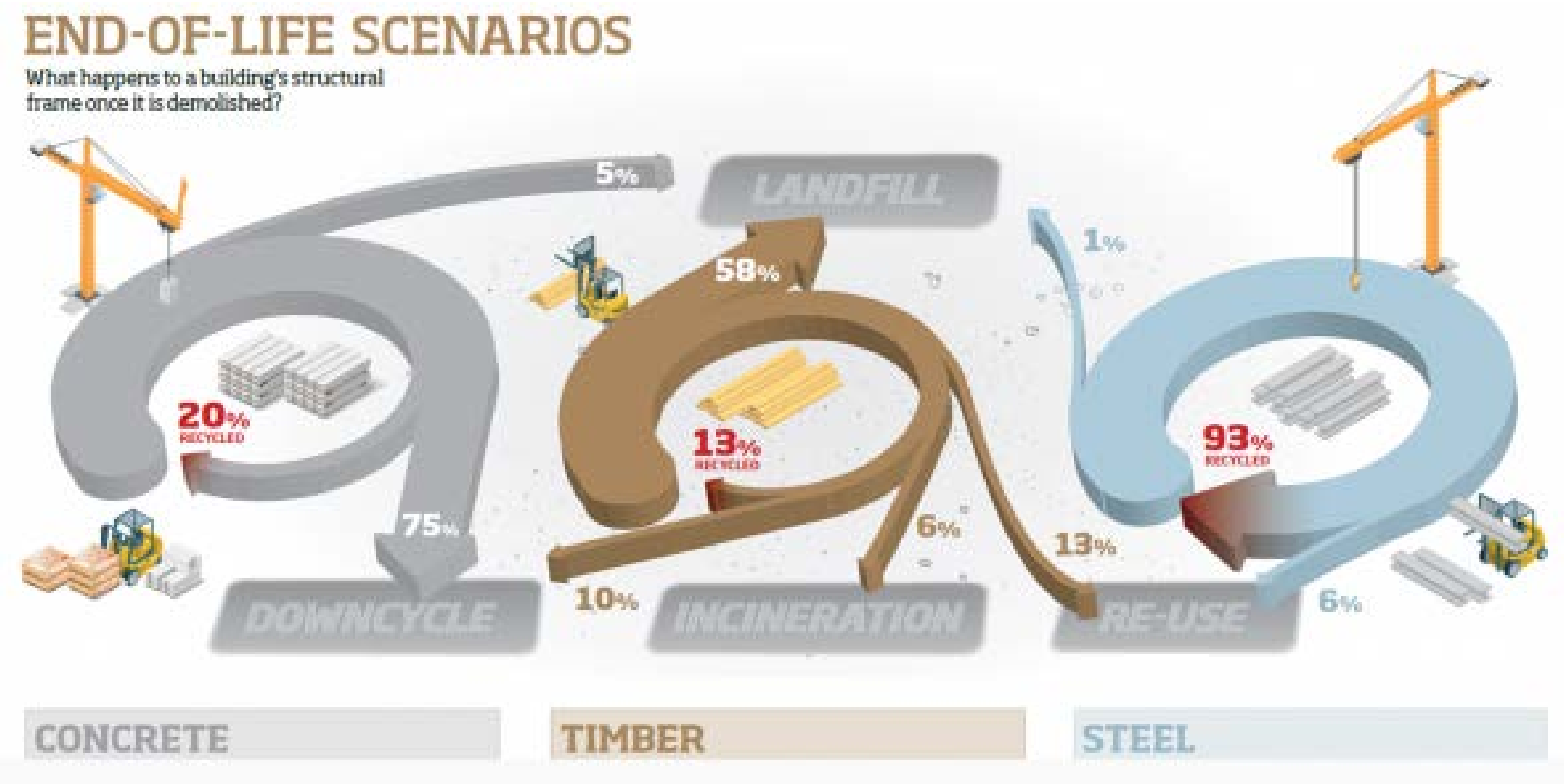
## Green buildings

- 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*



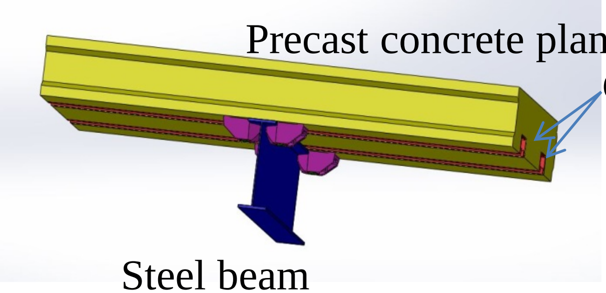

End-of-life of construction materials

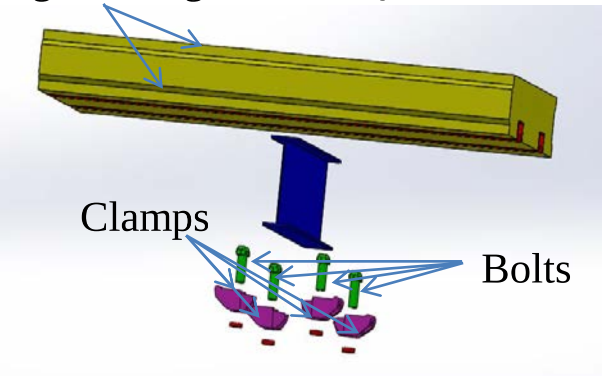
*Image from SteelConstruction.Info*

Design for Deconstruction

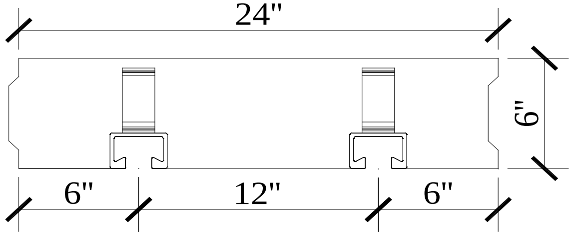
# *Composite Floor System*

- 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

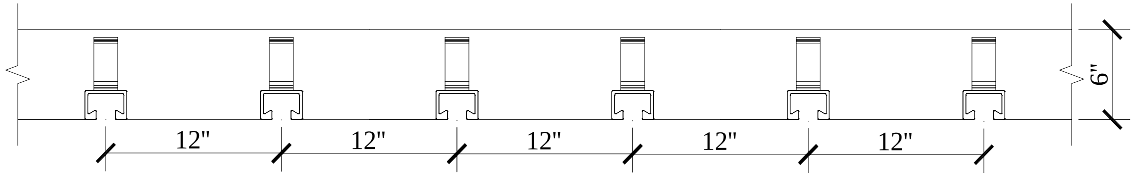



Deconstructable composite beam prototype




a) Plank perpendicular to the steel beam



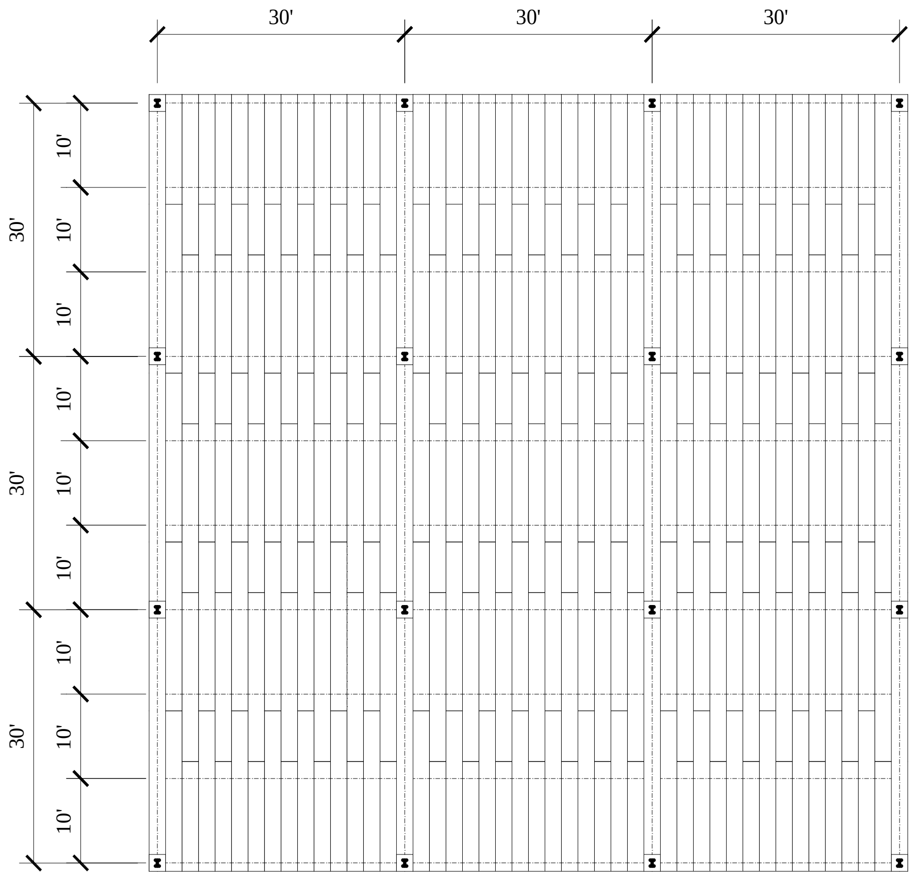

b) Plank parallel to the steel girder

Precast concrete plank cross section

Design for Deconstruction

# DfD Floor System

Goal: Achieve nearly 100% direct reusability for composite floor systems within the context of bolted steel framing systems

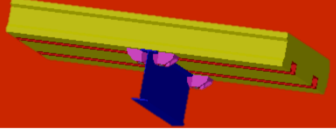



Typical floor plan for DfD system


ConXtech moment connection

*Image from ConXtech Website*

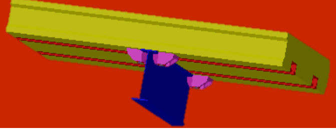
Example of deconstructable bolted





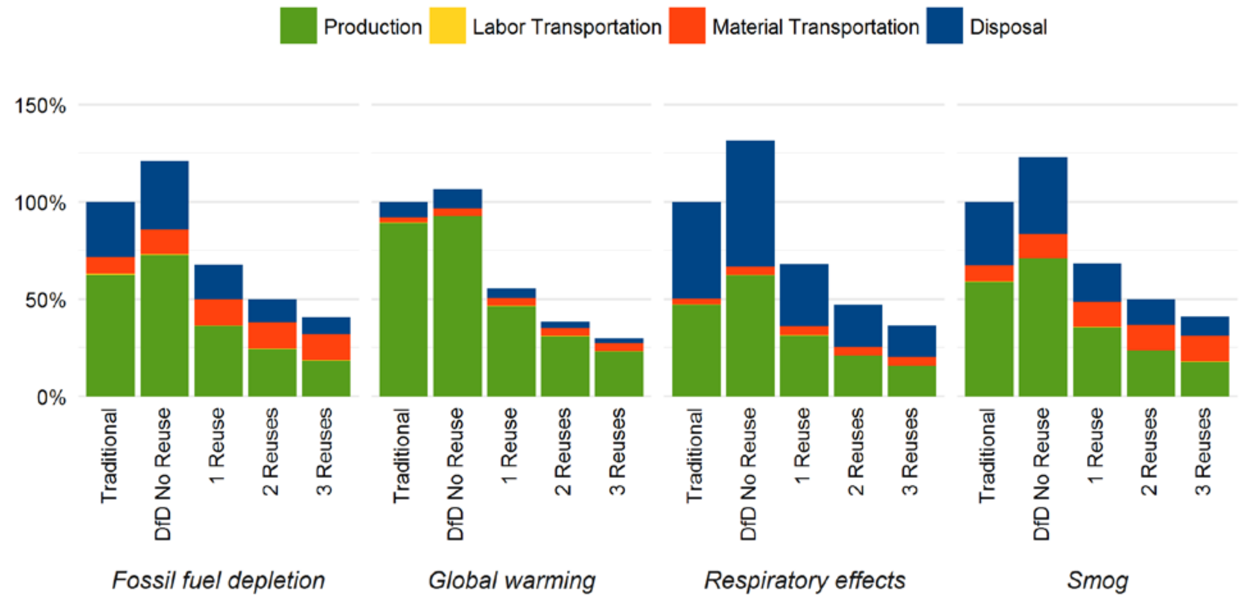
# *Life Cycle Assessment (LCA)*

- Aim:
  - Compare the environmental impacts of structures with deconstructable composite floor systems to those of buildings with conventional composite floors
  - Demonstrate whether DfD leads to environmental benefits, and, if so, how much
- Prototype structures:
  - 3 bays by 3 bays buildings
  - Structural systems
    - Floor systems: Traditional buildings using shear studs and DfD buildings using clamps
    - Special concentrically braced frames as lateral force-resisting systems
  - Parameters: Bay size (20 ft. or 30 ft.); Number of floors (3 floors or 9 floors); Floor thickness (6 in. or 8 in.)
- Life cycle: Production; Material transportation; Worker transportation; Disposal
- Environmental impact categories: Fossil Fuel Depletion; Global Climate Change; Human Health—Particulate (Respiratory Effects); Photochemical Smog Formation
- End-of-life scenarios:
  - Traditional buildings: No reuse and all materials are disposed of
  - DfD buildings: No reuse or a portion is disposed of and a portion is salvaged



# *Life Cycle Assessment (LCA)*

- Comparison Across Life Cycle Stages and Impact Categories (20-3-6 building)

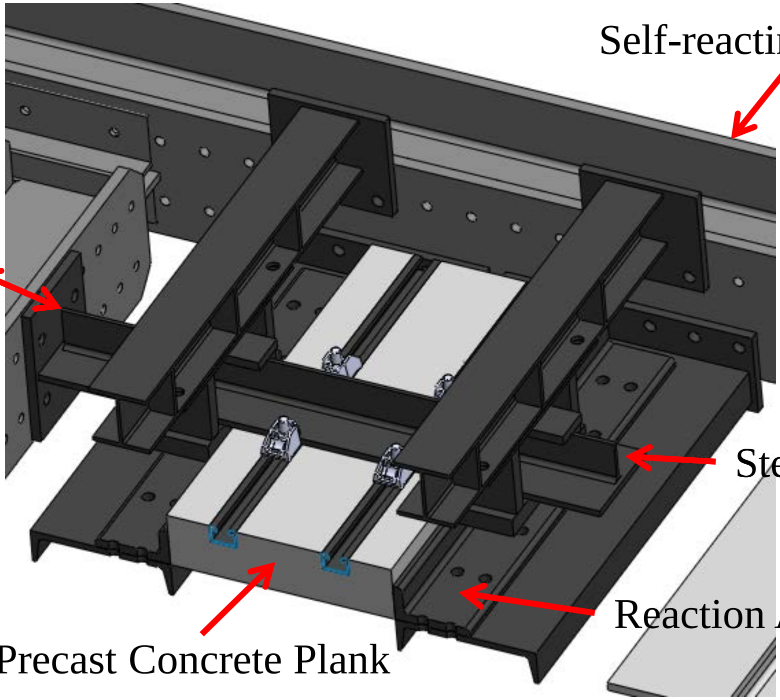



Observations:

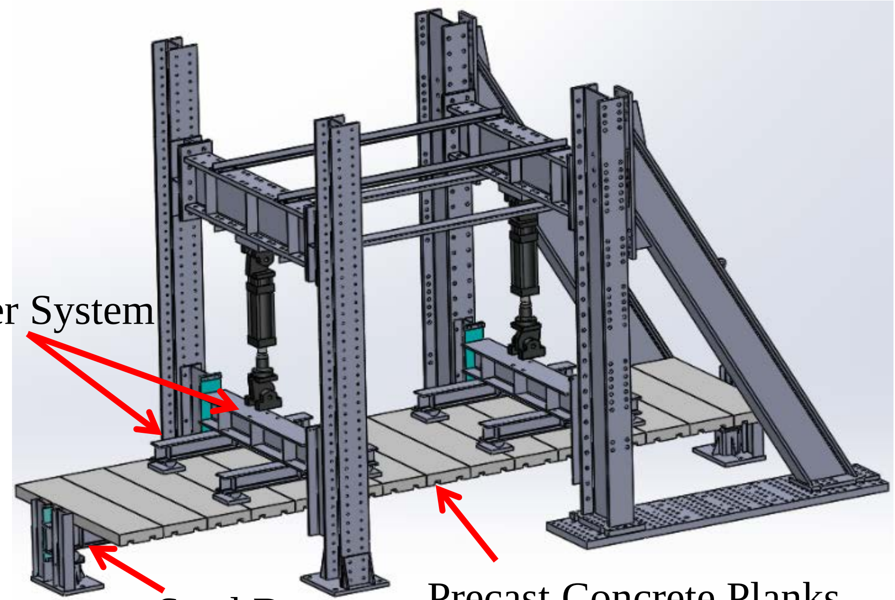
- Due to the greater mass and longer assembly time, DfD buildings without reuse may have higher impacts than traditional buildings in all categories.
- With each reuse, the impacts associated with production and disposal are spread across the DfD buildings. The impacts resulting from the additional labor and transportation are estimated to be minor.

# *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



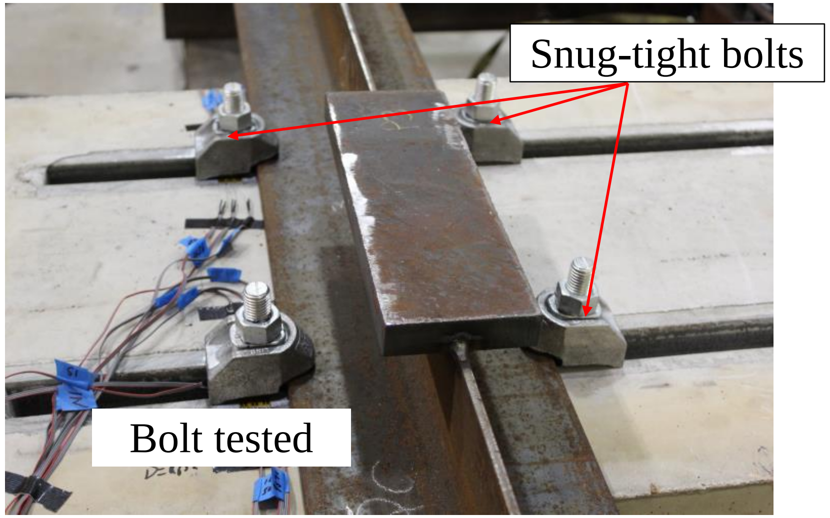

Pushout test setup



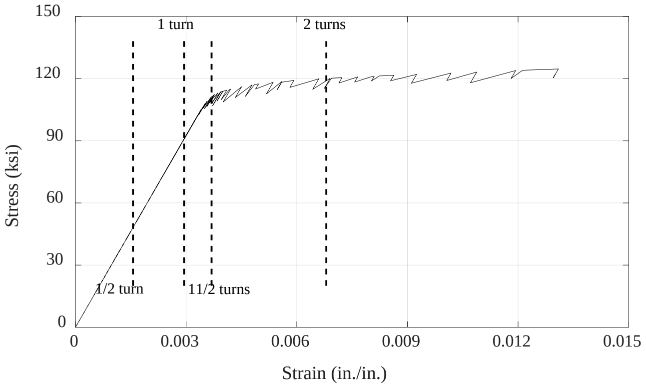

Composite beam test setup

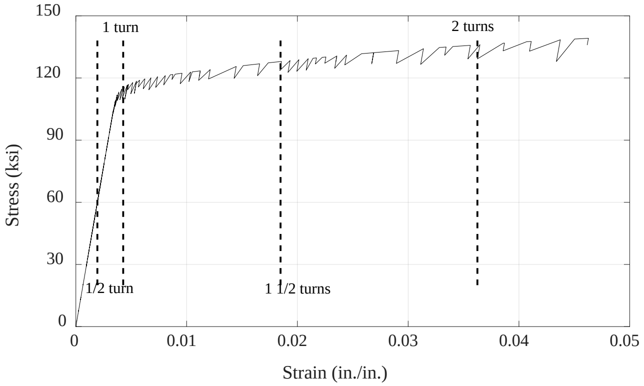
# *Pretension Test*

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




Pretension test setup



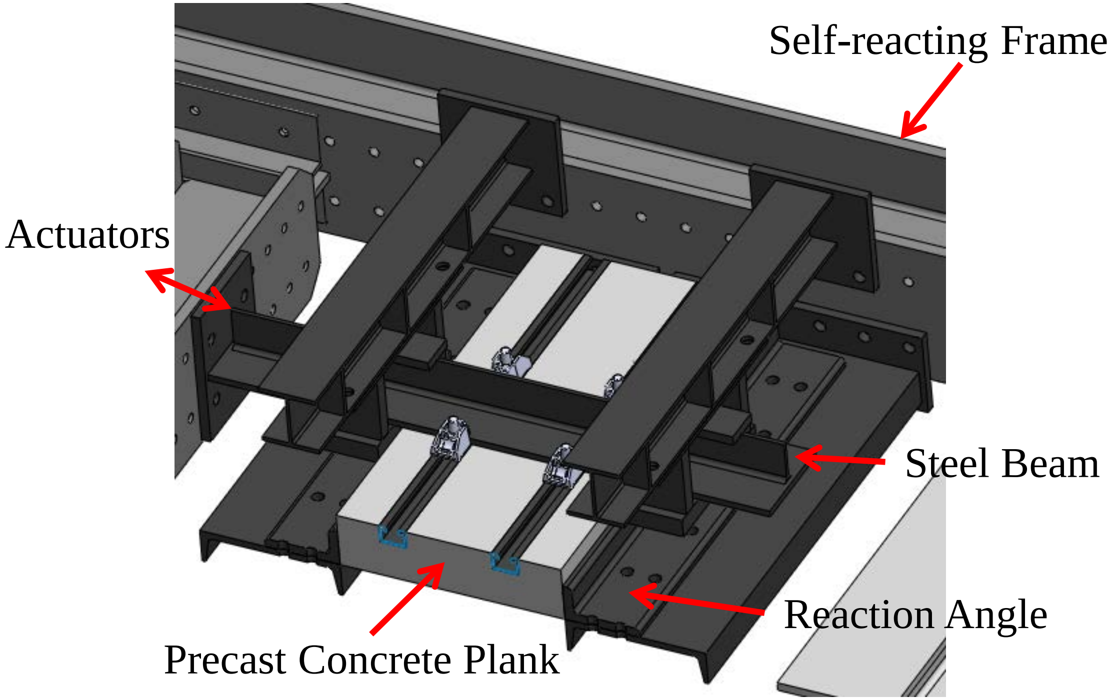

M24 bolts

M20 bolts

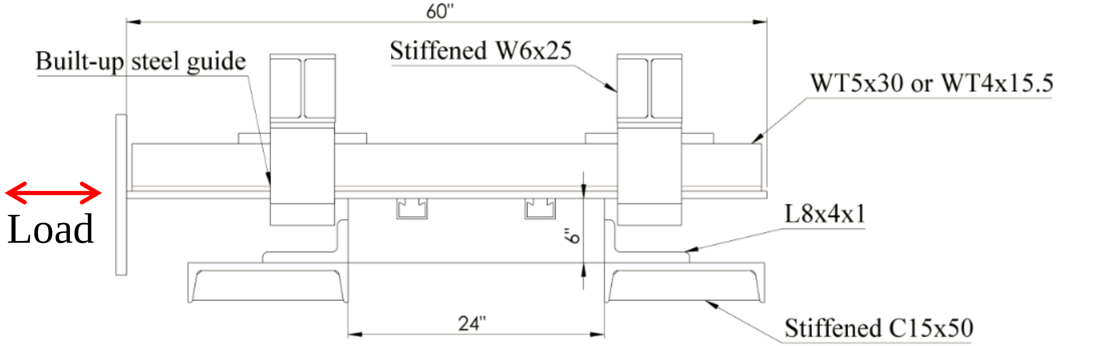
Fractured bolts

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

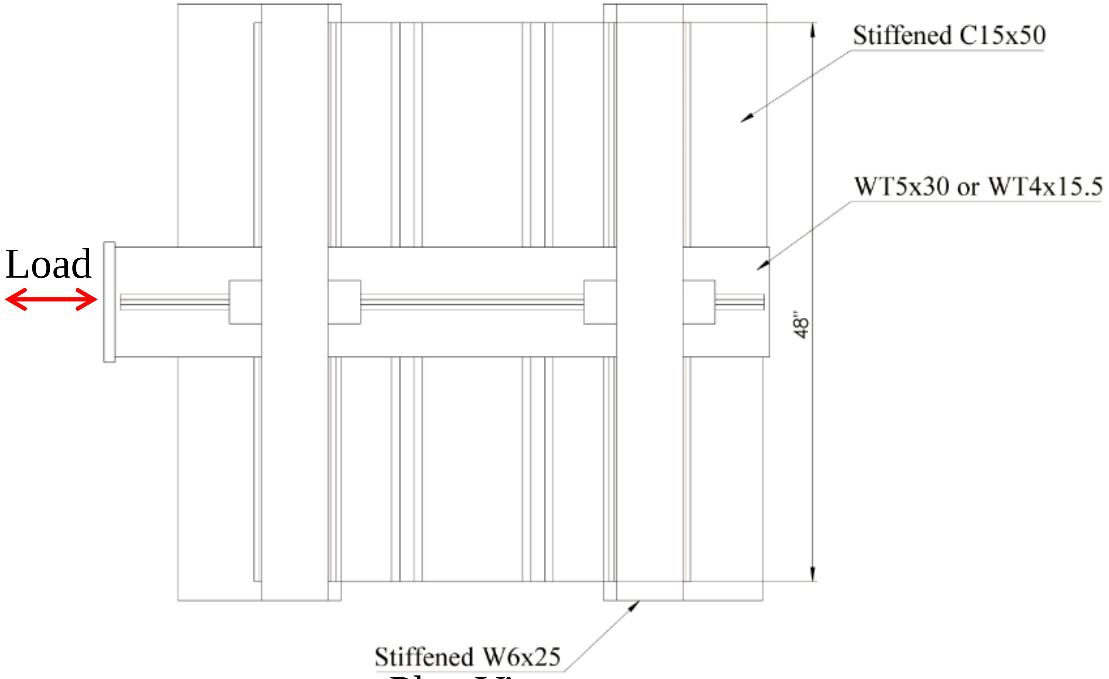
# *Pushout Test Configuration*




Pushout test setup



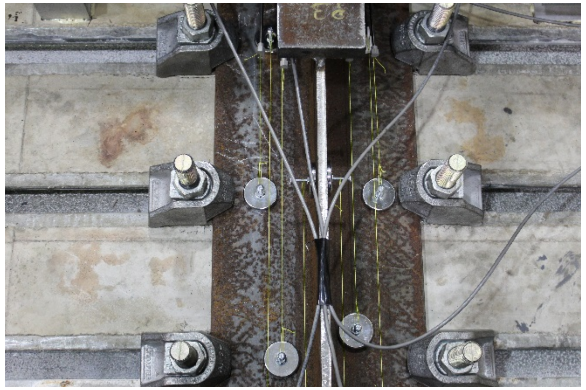

Elevation View



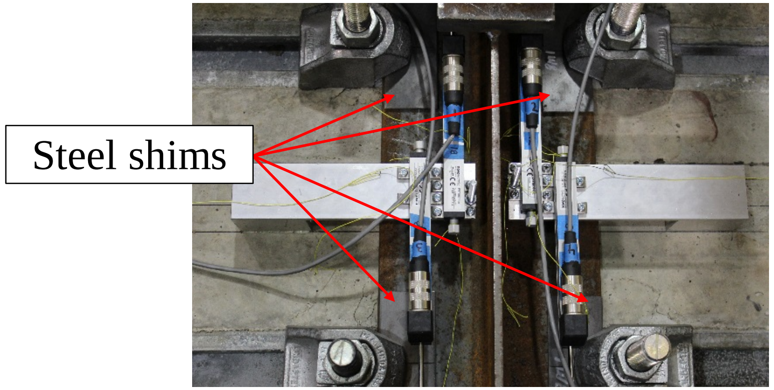

Plan View

# *Pushout Test Matrix*

| Series | Specimen | Test parameters | | | | Number of turns |
|---|---|---|---|---|---|---|
| | | Bolt diameter | # of T-bolts | Reinforcement configuration | Shim | |
| M | 2-M24-T4-RH | M24 | 4 | Heavy | No | 3 turns |
| M | 3-M24-T4-RH-S | M24 | 4 | Heavy | Yes | 3 turns |
| M | 4-M24-T6-RH | M24 | 6 | Heavy | No | 2 turns |
| M | 5-M20-T4-RH | M20 | 4 | Heavy | No | 1.5 turns |
| C | 6-C24-T4-RH | M24 | 4 | Heavy | No | 2 turns |
| C | 7-C24-T4-RL | M24 | 4 | Light | No | 2 turns |
| C | 8-C24-T4-RH-S | M24 | 4 | Heavy | Yes | 2 turns |
| C | 9-C24-T6-RH | M24 | 6 | Heavy | No | 2 turns |
| C | 10-C20-T4-RH | M20 | 4 | Heavy | No | 1.5 turns |



Three-channel specimen

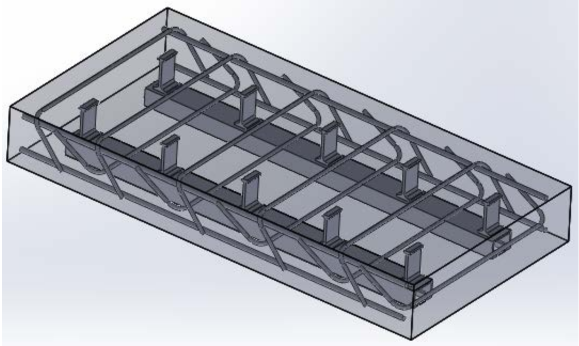



Two-channel specimen with shims

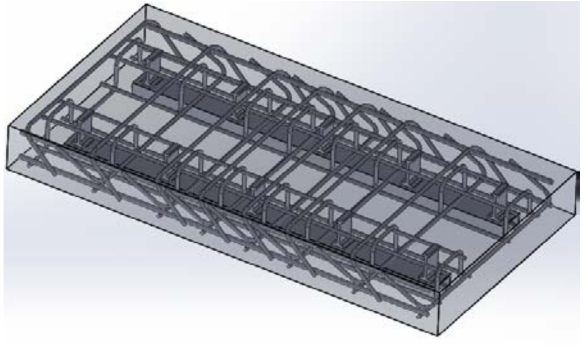
# Pushout Test Parameters

## Reinforcement pattern

- Light pattern: Contains reinforcement designed for gravity loading only

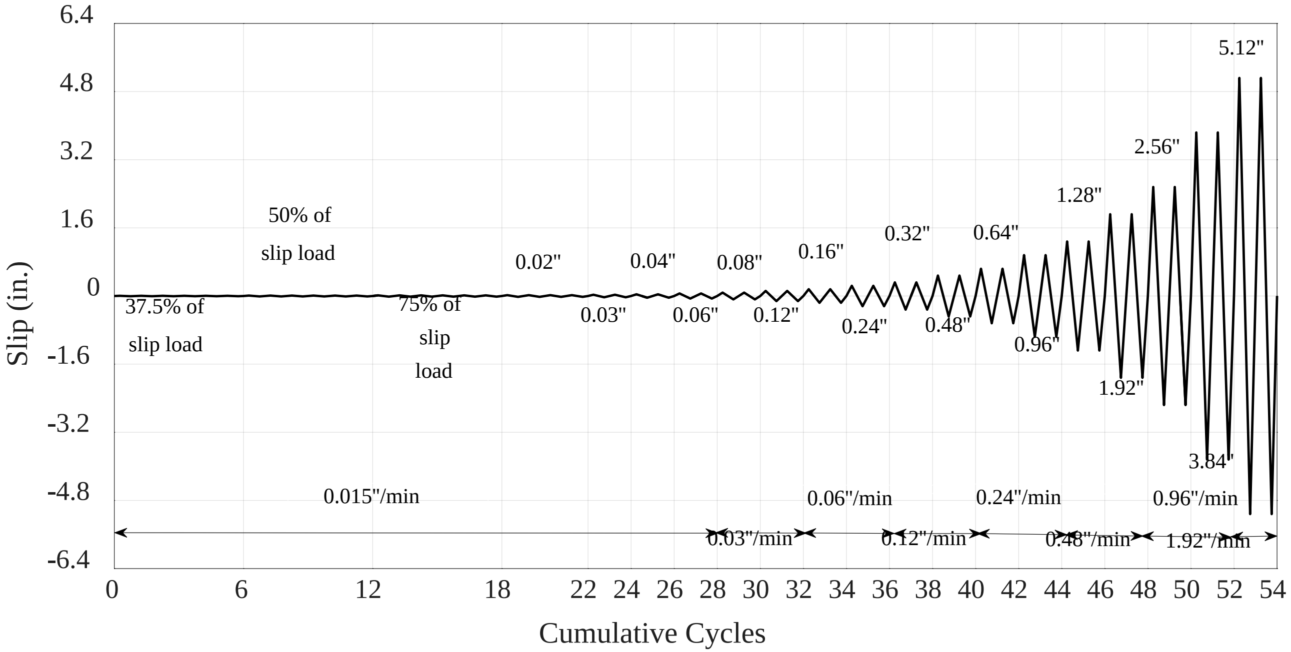


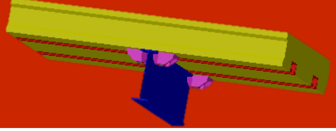
- Heavy pattern: Supplementary reinforcement bridges all potential concrete failure planes



## Loading protocols

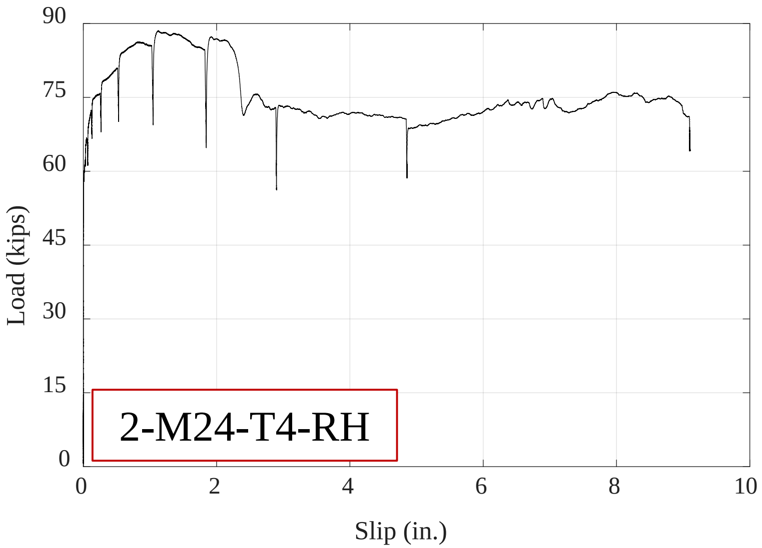
- Monotonic test: Displacement control
- Cyclic test:
  - Displacement control
  - Emulate AISC 341-10 K2.4b "Loading Sequences for Beam-to-Column Moment Connection"

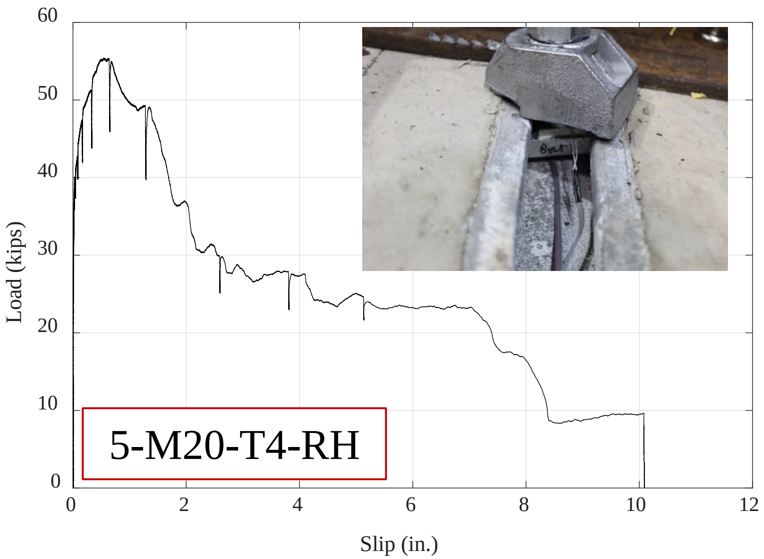






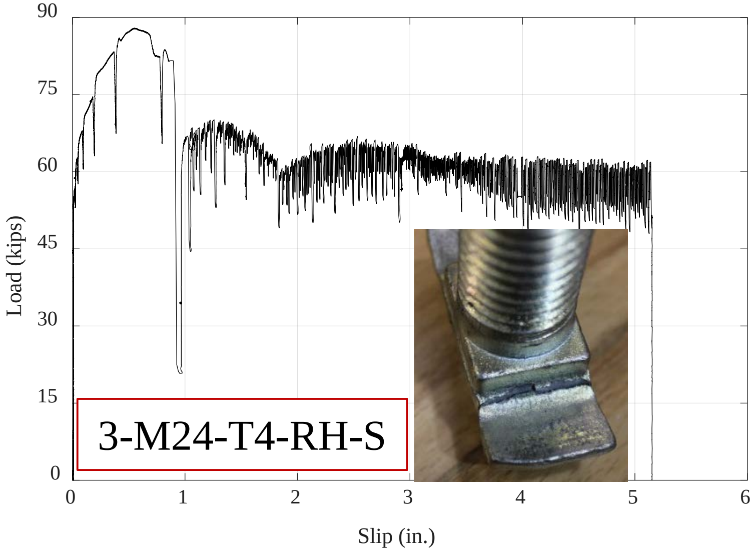
# *Monotonic Test Results*

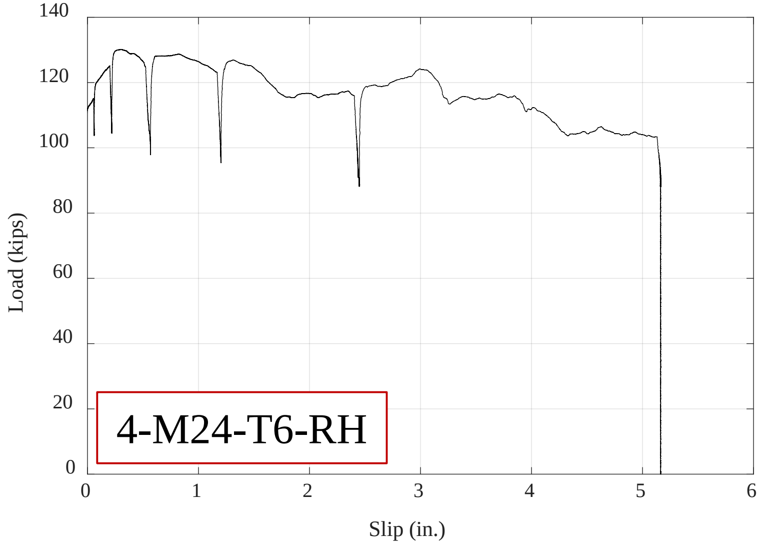



- The shear strength of a M24 clamp is 22.1 kips, while the strength of a 3/4 in. diameter shear stud embedded in a 4 ksi solid concrete slab is 21.5 kips.
- The very large initial stiffness of the clamps reduces the slip at the steel-concrete interface at the serviceability and enhances the elastic stiffness of the composite beams.
- The M24 clamps retain almost 80% of the peak strength even at a slip of 5 in., while shear studs usually fracture under much less deformation (~0.29 in.).
- The smaller M20 clamps are prone to rotate. The strength degradation starts at a slip of 0.68 in., which is usually much larger than the maximum slip demand on the shear connectors in composite beams.

# *Monotonic Test Results*



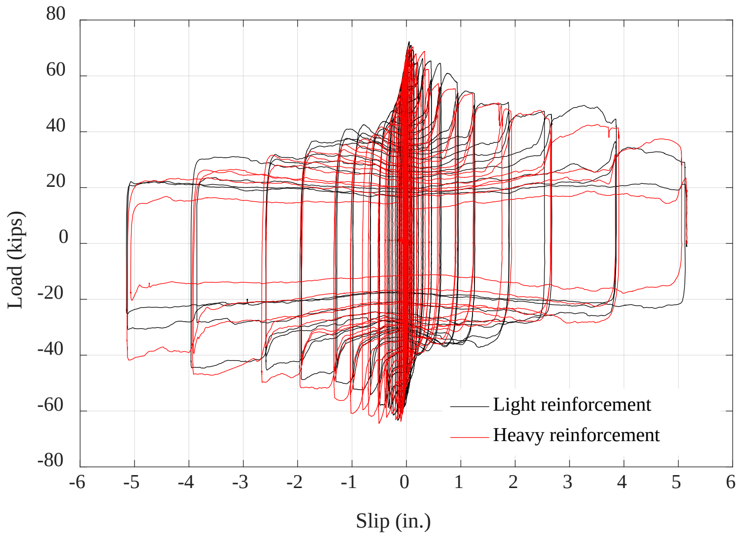

- Load oscillation caused by a stick-slip mechanism occurred in the test using shims, but little loss in the slip load and peak strength is seen.

**Summary of monotonic pushout test results**

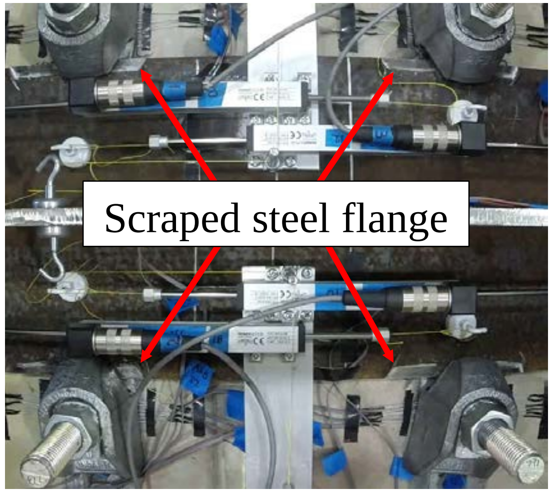
| Specimen | Slip load (kips) | | Peak load (kips) | | | Peak load/Slip load | Load at 5 in. slip (kips) | |
|---|---|---|---|---|---|---|---|---|
| | Absolute | Normalized | Absolute | Normalized | Slip (in.) | | Absolute | Percentage of peak load |
| 2-M24-T4-RH | 60.8 | 1.00 | 88.5 | 1.00 | 1.12 | 1.46 | 68.9 | 78% |
| 3-M24-T4-RH-S | 56.5 | 0.93 | 87.9 | 0.99 | 0.55 | 1.56 | 55.1 | 63% |
| 4-M24-T6-RH | 87.0 | 1.43 | 130.1 | 1.47 | 0.30 | 1.50 | 104.0 | 80% |
| 5-M20-T4-RH | 36.5 | 0.60 | 55.3 | 0.62 | 0.54 | 1.52 | 24.9 | 45% |

# Cyclic Load-Slip Curves

## *Cyclic Test Results*

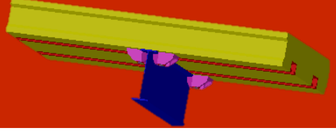



Specimens 6-C24-T4-RH and 7-C24-T4-RL



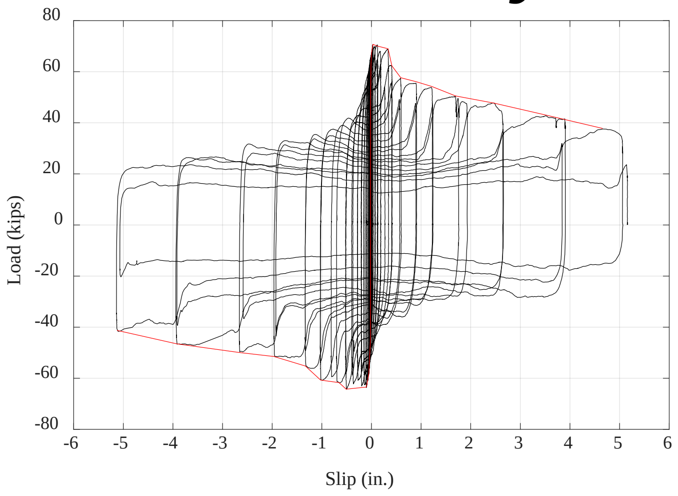

Damage of the steel flange in Specimen 6-C24-T4-RH at 1.28 in. slip

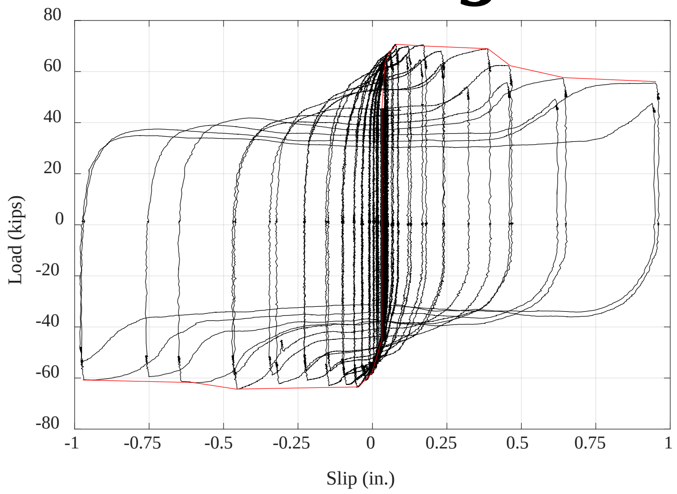
- Strength reduction similar to shear studs which exhibit lower strength and ductility when subjected to cyclic loading
- The elimination of the additional supplementary reinforcement did not induce a premature concrete failure mode and strength reduction.
- The peak load reduces due to lowering of frictional coefficients and release of bolt tension caused by abrasion between the components.
- Clamps have the potential to connect composite diaphragms and collector beams and could be designed as inelastic components to dissipate energy.





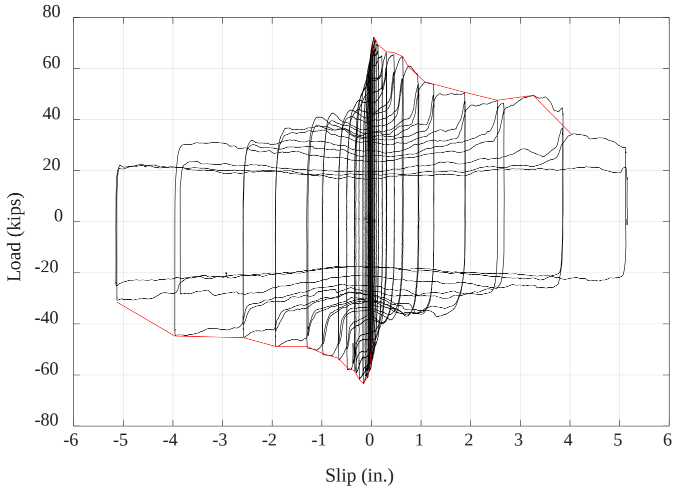
# *Cyclic Test Results: Heavy Reinforcement vs. Light Reinforcement*

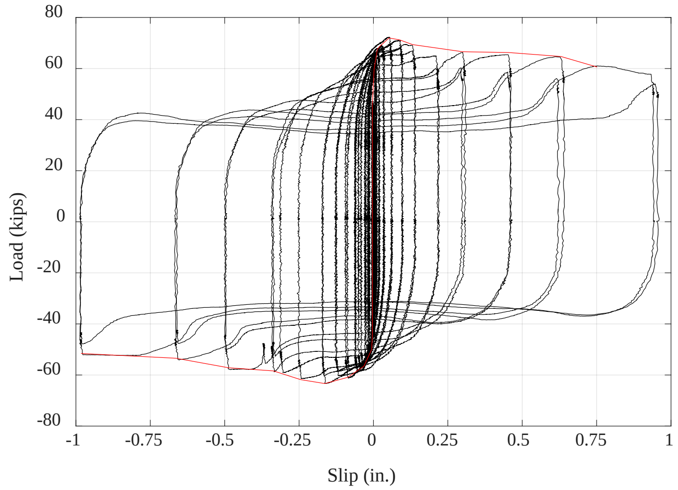



Slip +/- 1”

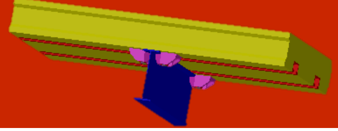
Specimen 6-C24-T4-RH



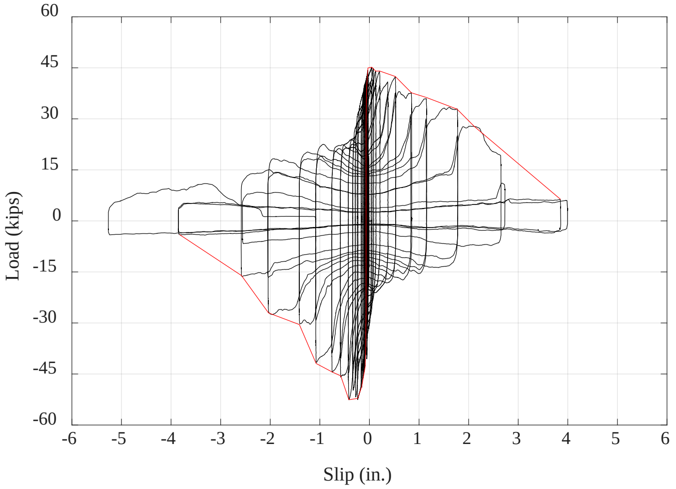



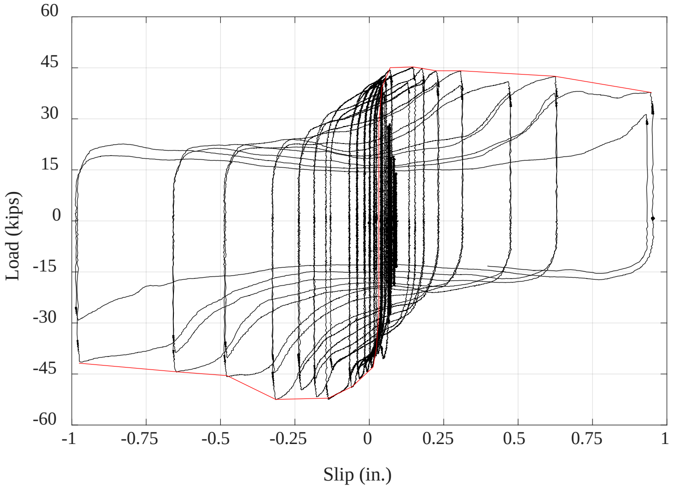

Slip +/- 1”

Specimen 7-C24-T4-RL



# *Cyclic Test Results*




Slip +/- 1"

Specimen 10-C20-T4-RH

**Peak strength reduction in cyclic pushout specimens**

| Specimen | Cyclic tests (kips) | | Monotonic tests (kips) | Cyclic/Monotonic | |
|---|---|---|---|---|---|
| | Positive | Negative | | Positive | Negative |
| 6-C24-T4-RH | 72.2 | 63.3 | 88.5 | 0.82 | 0.72 |
| 7-C24-T4-RL | 70.6 | 64.4 | 88.5 | 0.80 | 0.73 |
| 8-C24-T4-RH-S | 65.5 | 71.8 | 87.9 | 0.75 | 0.82 |
| 9-C24-T6-RH | 104.0 | 97.0 | 130.1 | 0.80 | 0.75 |
| 10-C20-T4-RH | 44.9 | 52.5 | 55.3 | 0.81 | 0.95 |
| | | | Average | 0.79 | 0.79 |

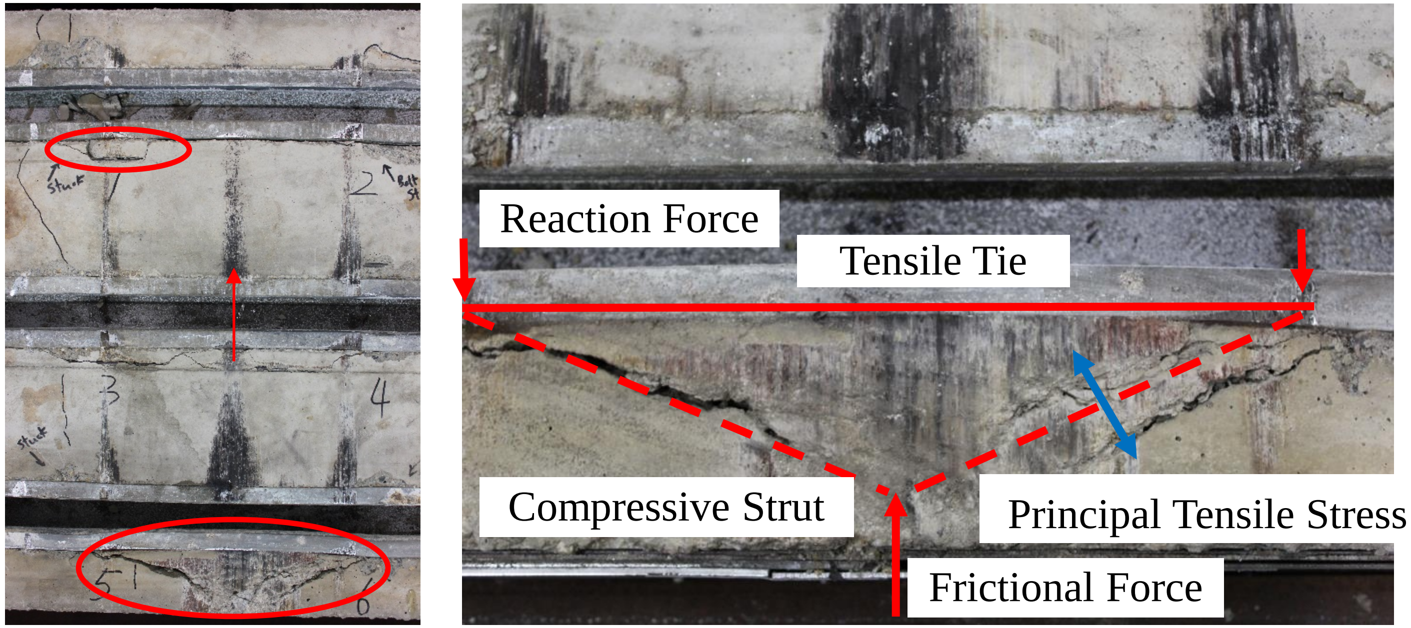
**A coefficient of 0.8 could be used to design clamps in shear under seismic loading.**

# *Formation of Cracks in Concrete*

## Influences of cracks

- Cracks mostly initiated around the slip load and remained localized at locations where contact occurred (i.e., in the vicinity of bolts and middle region of plank).
- Concrete cracking does not affect the overall behavior of the specimens, and is thus not regarded as a key limit state.
- The width and propagation of the cracks may affect the reusability and refabrication of the planks.

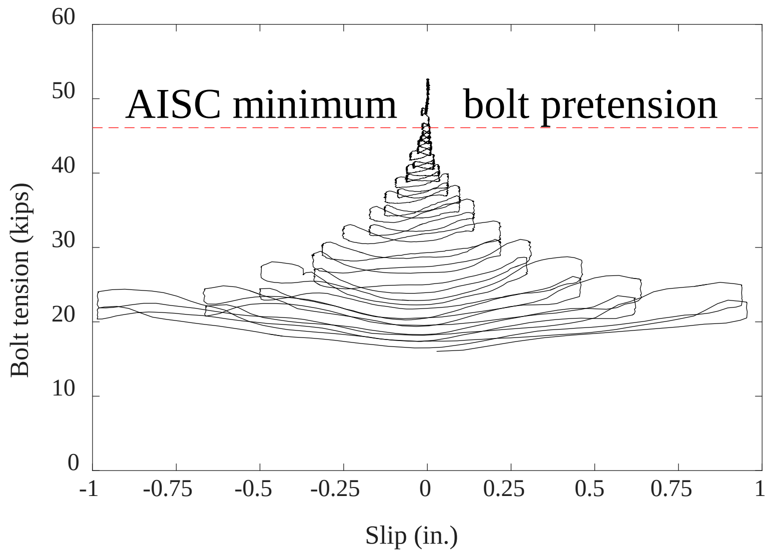
**Strut-and-tie model**



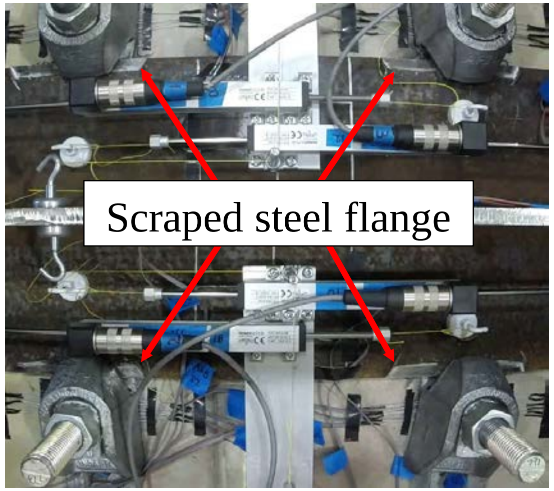

Specimen 4-M24-T6-RH

# *Bolt Tension Variation*

- After pretensioning, bolts were yielded and the tension met the AISC minimum pretension force requirements.
- Bolt tension gradually decreased as slip increased.
    - Shear force acting on bolts
    - Material removal due to abrasion between steel flanges and clamp teeth
- The strength of the system is affected by the bolt tension as well as the frictional coefficients at the slip planes.

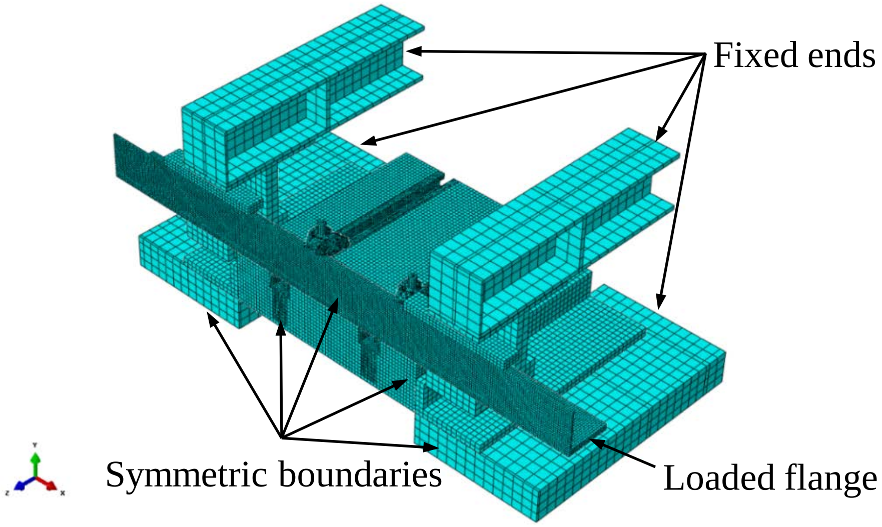


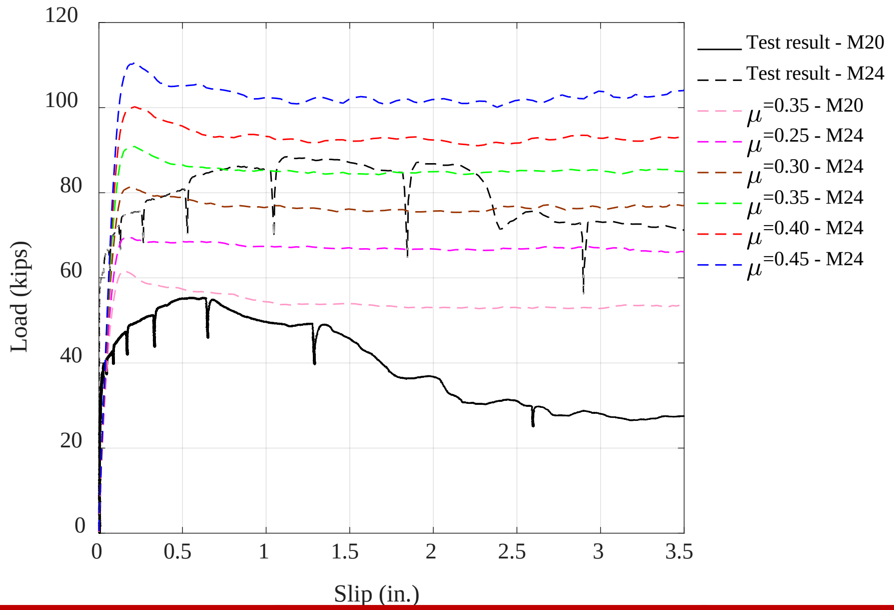

Specimen 7-C24-T4-RL




Damage of the steel flange in Specimen 6-C24-T4-RH at 1.28 in. slip

# *Finite Element Model*




FEM:

- ABAQUS/EXPLICIT
- Two analysis steps: bolt pretension applied using temperature method; displacement applied to steel flange
- A single frictional coefficient of 0.35 is assumed.

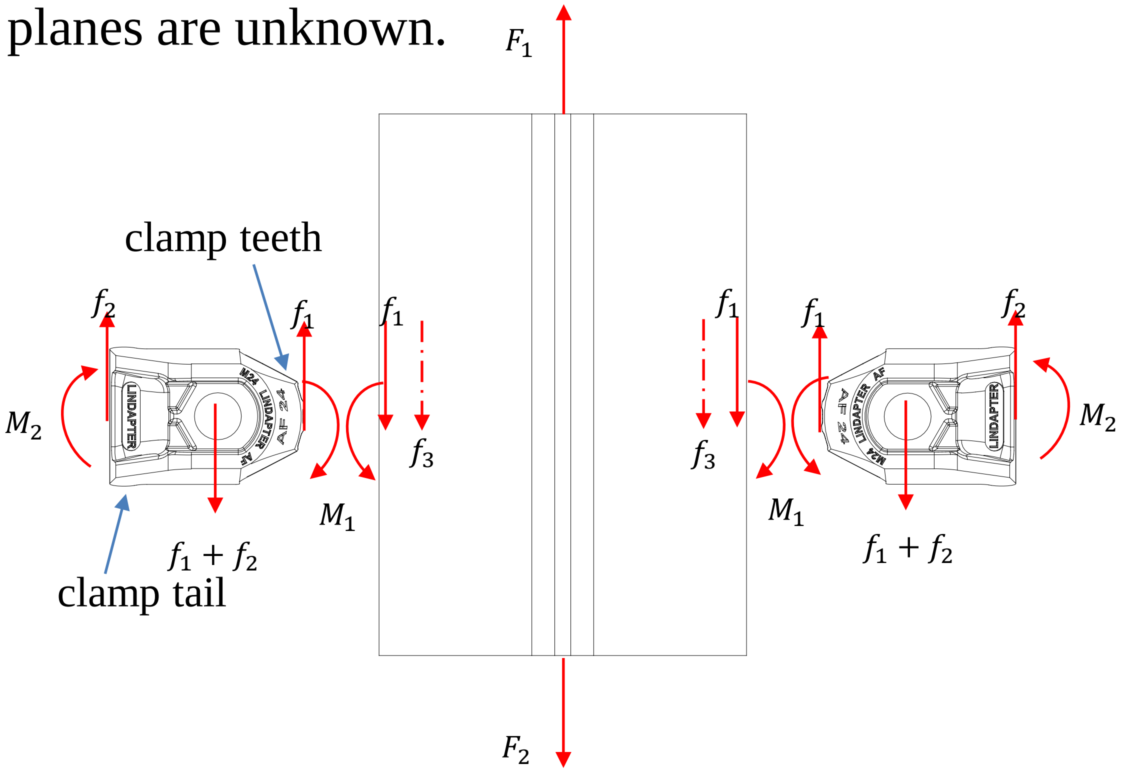

Impressions on steel flange in pretension test for M24 bolts

Specimen:

- Prior to slip, the shear resistance comes from static friction.
- After slip occurs, bearing, induced by clamp teeth digging into steel flanges, is another contributor to the shear resistance.

# System Indeterminacy

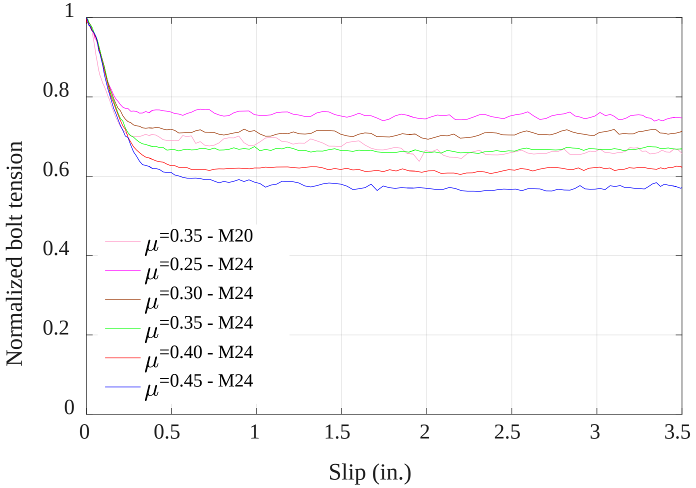
- Bolt tension transfers to clamp teeth and clamp tail; only the normal force at the clamp teeth contributes to the frictional resistance.
- Bolt tension reduces throughout the tests due to shear force.
- Frictional coefficients at slip planes are unknown.

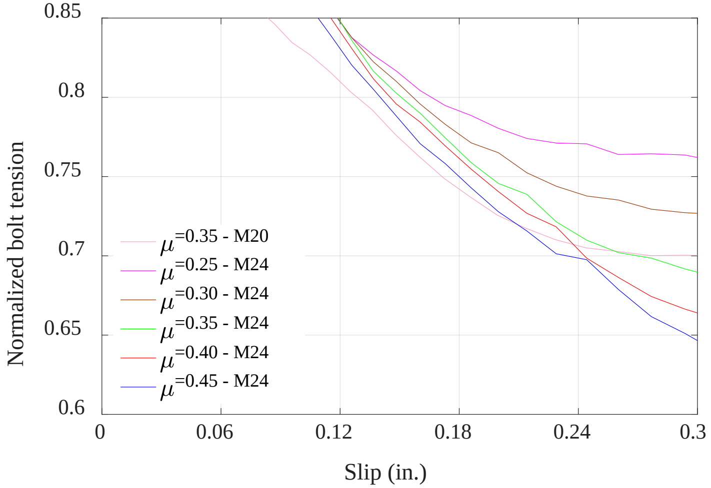



Free body diagram

# Finite Element Analysis Results

- Bolt tension versus slip




- Normal force at clamp teeth to bolt tension ratio versus slip

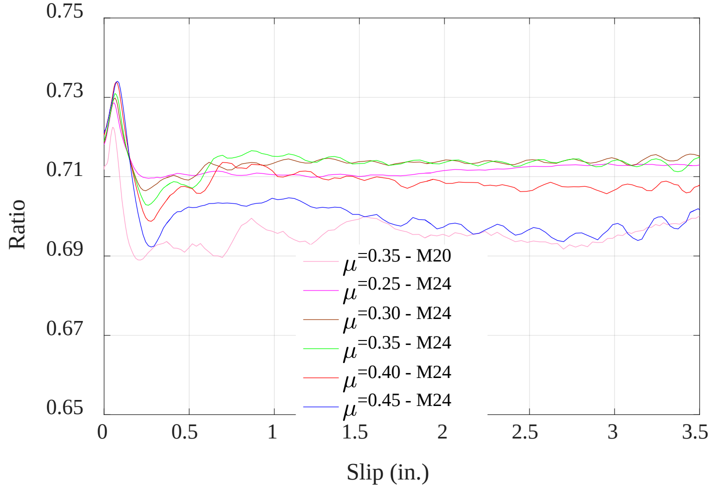



**Table 4.10 Mean Slip Coefficient in pushout specimens**

| Specimen | Slip load (kips) | Bolt tension (kips) | Mean slip coefficient |
|---|---|---|---|
| 2-M24-2C-RH-LM | 60.8 | 239.6 | 0.181 |
| 4-M24-2C-RH-LM-S | 56.5 | 239.6 | 0.168 |
| 7-M24-3C-RH-LM | 87.0 | 239.6 | 0.173 |
| 9-M20-2C-RH-LM | 36.5 | 166.0 | 0.157 |
| | | Mean | 0.170 |
| | | C.O.V. | 0.051 |

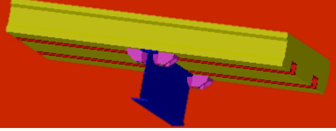
# *Shear Strength of Clamping Connectors*

**Monotonic shear strength:**

Slip strength: $Q_s = k_d \mu_s D_u T_b n_s$

Peak strength: $Q_p = k_d k_r \mu_p D_u T_b n_s$

- $k_d$ and $k_r$= coefficients accounting for the portion of bolt tension transferred to the clamp teeth and the bolt tension reduction at peak strength, which are 0.70 and 0.75, respectively
- $\mu_s$= mean slip coefficient, which is 0.17 in this test series
- $\mu_p$= idealized frictional coefficient at peak strength, which is 0.35 in this test series
- $D_u$=1.13, a multiplier representing the ratio of the mean installed bolt pretension to the specified minimum bolt tension
- $T_b$= minimum fastener tension given in AISC 360-16
- $n_s$= number of slip planes, which is 2



# Design Equations

**Tested-to-predicted strength ratio for pushout specimens**

| Specimen | Tested strength (kips) | | Predicted strength (kips) | | Ratio | |
|---|---|---|---|---|---|---|
| | $Q_s$ | $Q_p$ | $Q_s$ | $Q_p$ | Slip | Peak |
| 2-M24-T4-RH | 60.8 | 88.5 | 49.6 | 76.6 | 1.23 | 1.16 |
| 3-M24-T4-RH-S | 56.5 | 87.9 | 49.6 | 76.6 | 1.14 | 1.15 |
| 4-M24-T6-RH | 87.0 | 130.1 | 74.4 | 114.9 | 1.17 | 1.13 |
| 5-M20-T4-RH | 36.5 | 55.3 | 34.3 | 53.0 | 1.06 | 1.04 |

- The proposed design equations predict the strengths of the clamps conservatively.
- The difference mainly comes from $D_u$, which is about 1.30 in the pushout tests.

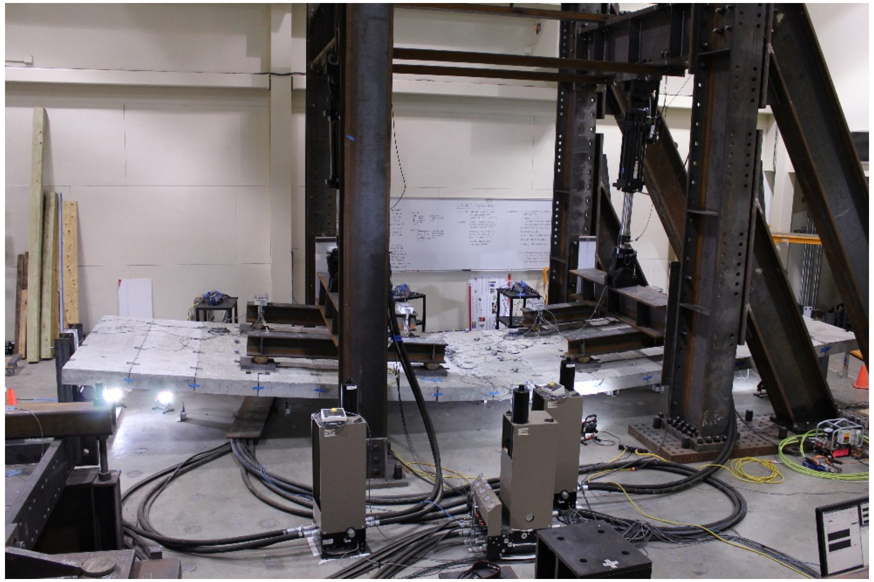
**Cyclic shear strength:**

**Peak strength reduction in cyclic pushout specimens**

| Specimen | Cyclic tests (kips) | | Monotonic tests (kips) | Cyclic/Monotonic | |
|---|---|---|---|---|---|
| | Positive | Negative | | Positive | Negative |
| 6-C24-T4-RH | 72.2 | 63.3 | 88.5 | 0.82 | 0.72 |
| 7-C24-T4-RL | 70.6 | 64.4 | 88.5 | 0.80 | 0.73 |
| 8-C24-T4-RH-S | 65.5 | 71.8 | 87.9 | 0.75 | 0.82 |
| 9-C24-T6-RH | 104.0 | 97.0 | 130.1 | 0.80 | 0.75 |
| 10-C20-T4-RH | 44.9 | 52.5 | 55.3 | 0.81 | 0.95 |
| | | | Average | 0.79 | 0.79 |

- A coefficient of 0.8 could be used with the monotonic shear strength.

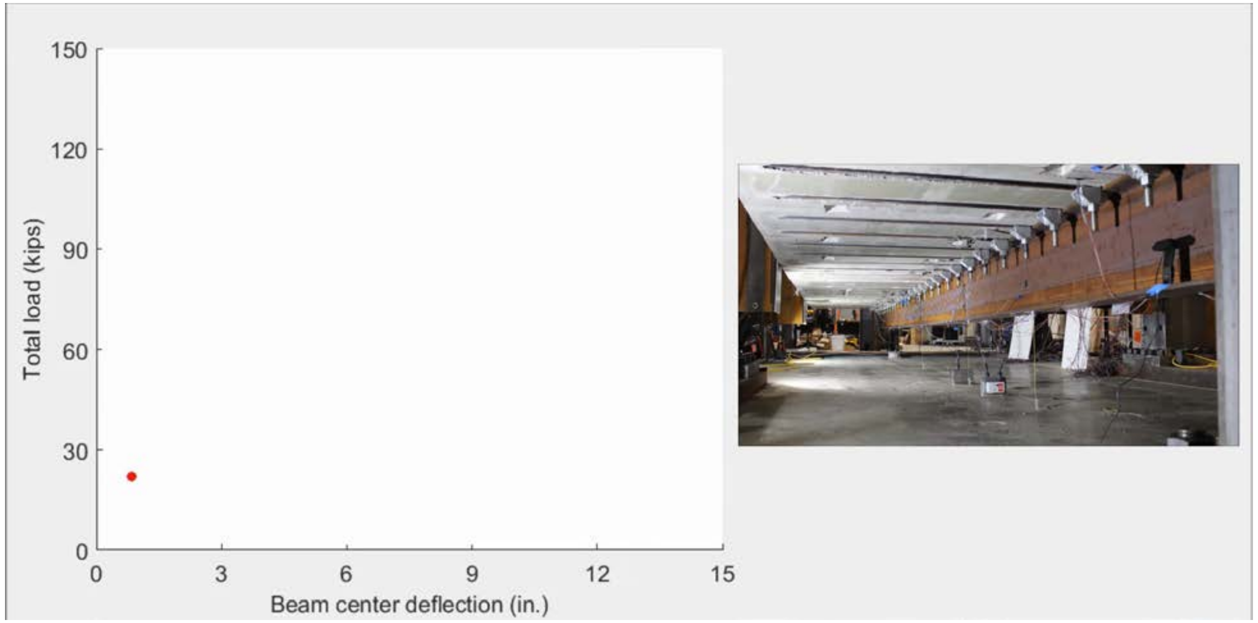
# Composite Beam Test



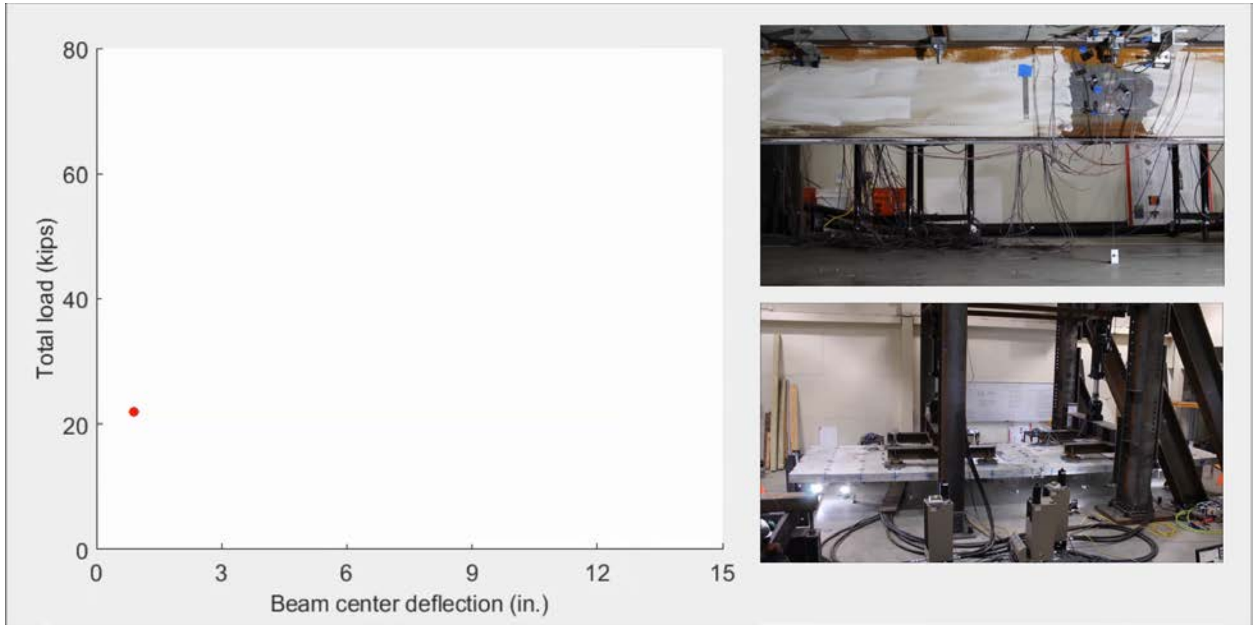
Composite beam test setup

| Composite beam # | Bolt size | # of channels per plank | Steel beam section | Reinforcement configuration | Number of bolts (clamps) | Percentage of composite action | |
|---|---|---|---|---|---|---|---|
| | | | | | | Nominal | Actual |
| 1-M24-2C-RH | M24 | 2 | W14x38 | Heavy | 56 | 86.7% | 82.7% |
| 2-M24-1C-RL | M24 | 1 | W14x38 | Light | 30 | 47.3% | 45.1% |
| 3-M20-3C-RL | M20 | 3 | W14x26 | Light | 90 | 129.2% | 137.8% |
| 4-M20-1C-RL | M20 | 1 | W14x26 | Light | 30 | 43.0 % | 43.8% |

# *Composite Beam Tests*

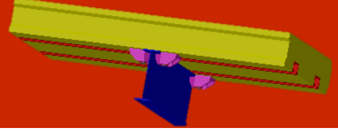



Test 1-M24-2C-RH



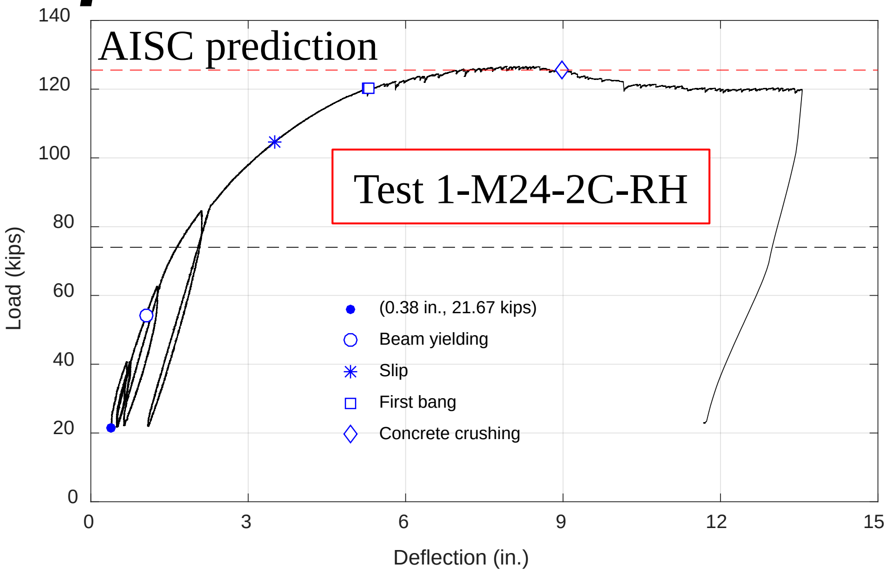

Test 4-M20-1C-RL

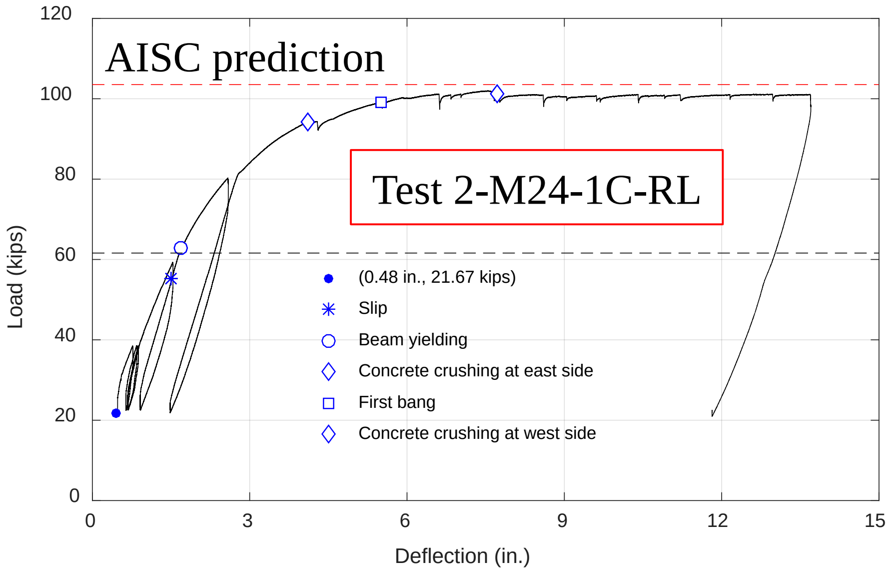
- Vertical load vs. vertical deflection
- Load transfer occurs through the clamps without causing damage to either the steel beam or concrete planks

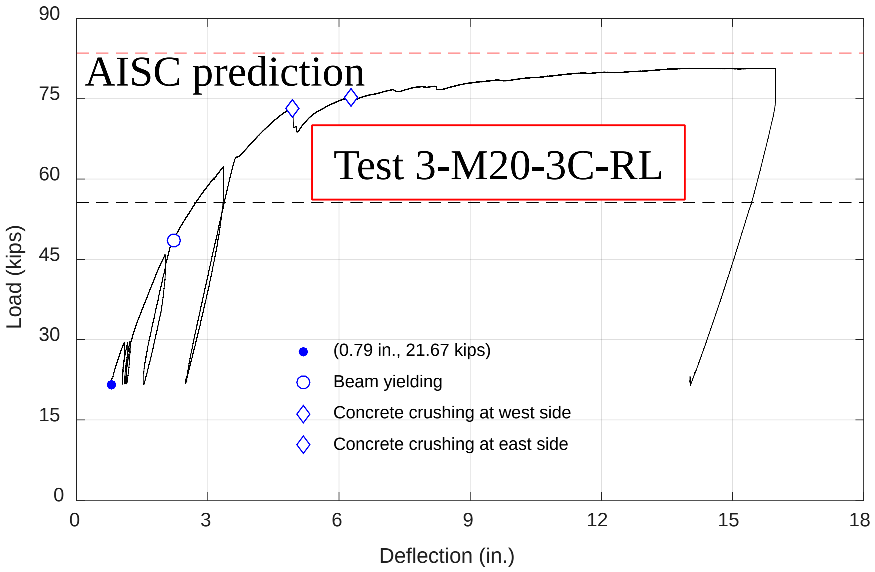


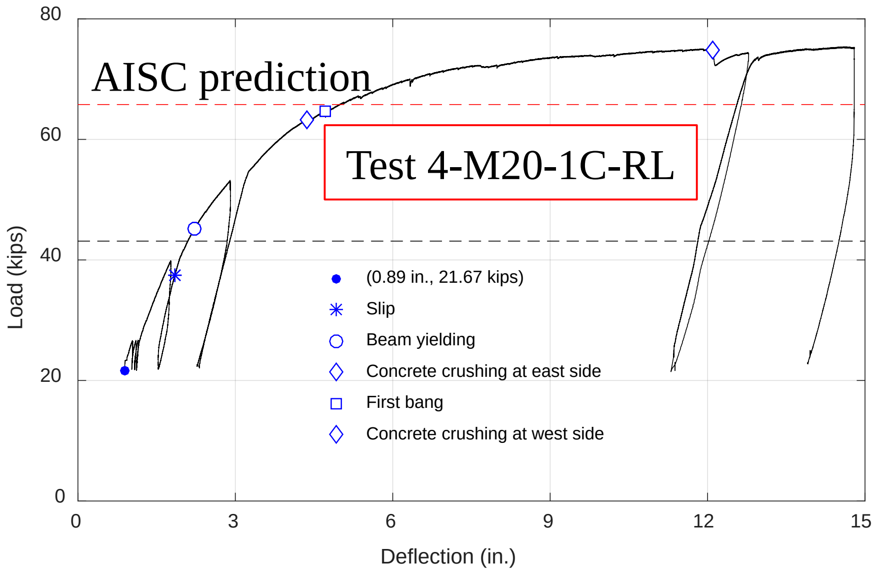


# *Load-Deflection Curves*



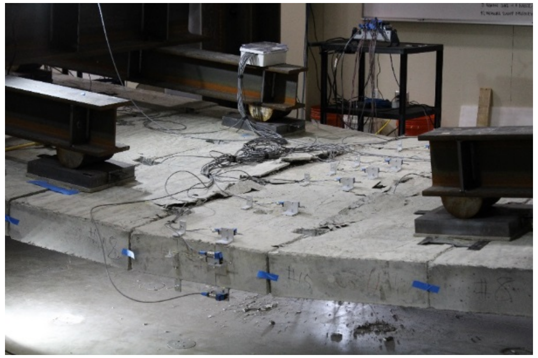



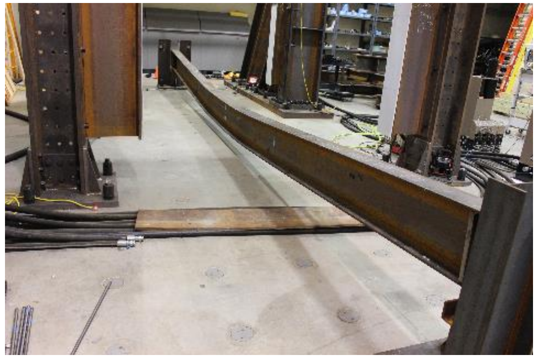



# Test Results

| Specimen # | Stiffness (kips/in.) | | | Moment (ft.-kips) | | | Maximum Slip (in.) | |
|---|---|---|---|---|---|---|---|---|
| | Test | AISC | Test/AISC | Test | AISC | Test/AISC | West Side | East Side |
| 1-M24-2C-RH | 52.8 | 49.5 | 1.07 | 571 | 565 | 1.01 | 0.234 | 0.253 |
| 2-M24-1C-RL | 44.3 | 38.9 | 1.14 | 469 | 464 | 1.00 | 0.322 | 0.254 |
| 3-M20-3C-RL | 36.9 | 34.2 | 1.08 | 364 | 376 | 0.97 | 0.018 | 0.009 |
| 4-M20-1C-RL | 34.7 | 25.3 | 1.37 | 351 | 296 | 1.19 | 0.346 | 0.318 |

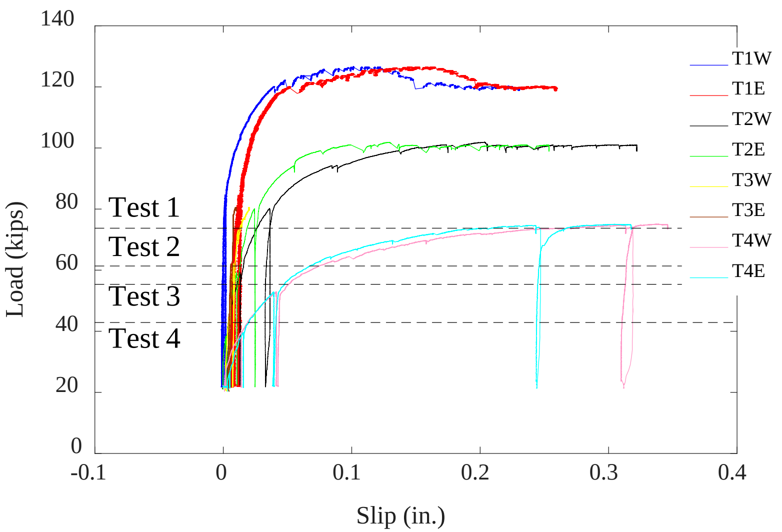

Localized concrete crushing


Deconstructed steel beam

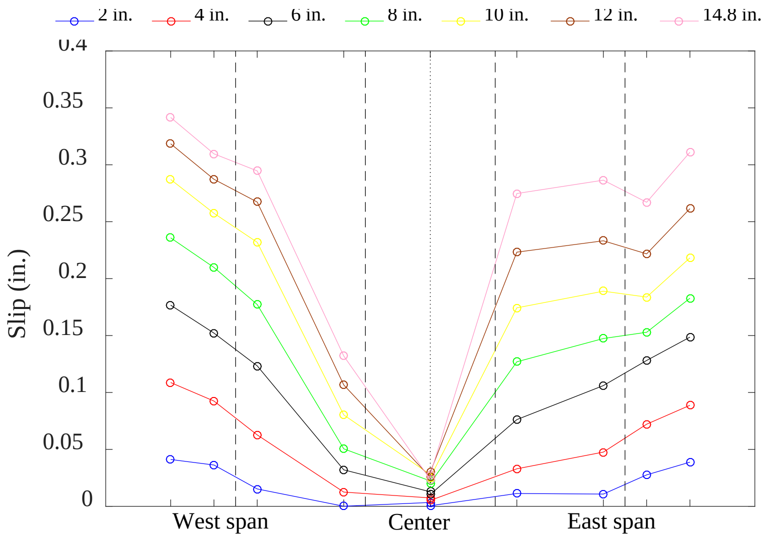
- The ultimate slip is inversely proportional to the degree of shear connection.
- All the beams were deflected to L/25 and behaved in a ductile manner with little or no strength reduction. All beams have a ductility of at least 3.
- Concrete crushing happened in all tests, even though the concrete strength does not control the design.

# *Load-Slip Relationship*

The dashed lines show the service loading on the beams



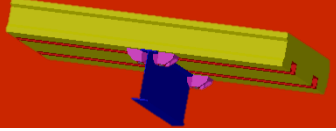

Load-slip curve




Slip distribution along beam 4-M20-1C-RL

The dashed lines show the positions of the applied loads. The dotted lines indicate the center sections of the beams.

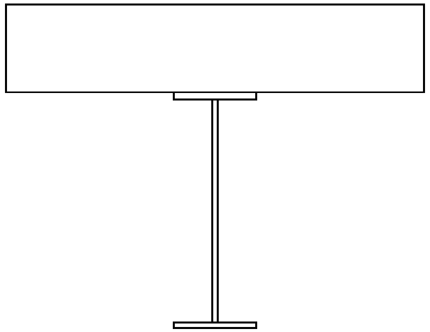
- Large initial stiffness demonstrated by the load-slip curves
- Maximum slip less than 0.05 in. at serviceability
- Slip of clamps observed in the partially composite beam specimens with low composite action during the loading/unloading cycles
- Trivial slip measured close to the beam center throughout the tests

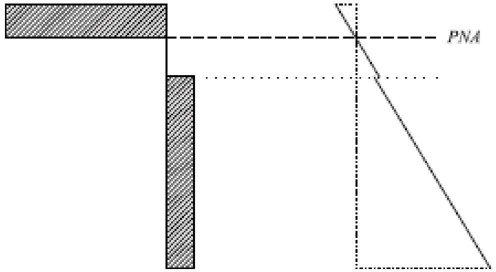




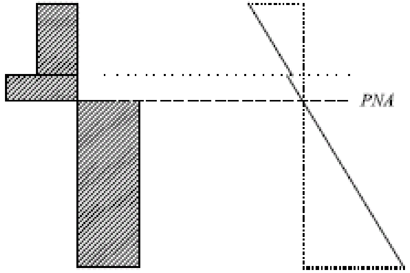
# *Beam Section Strain Distribution*

**Neutral axis in composite beams**

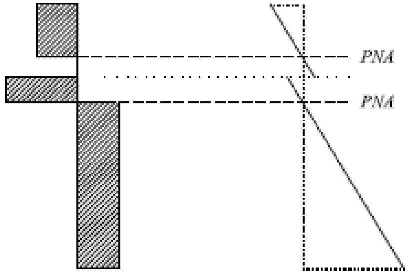




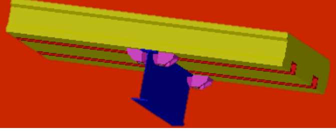

Case 1: full shear connection; $A_sF_y < 0.85f'_cA_c$ and $\sum Q_n$



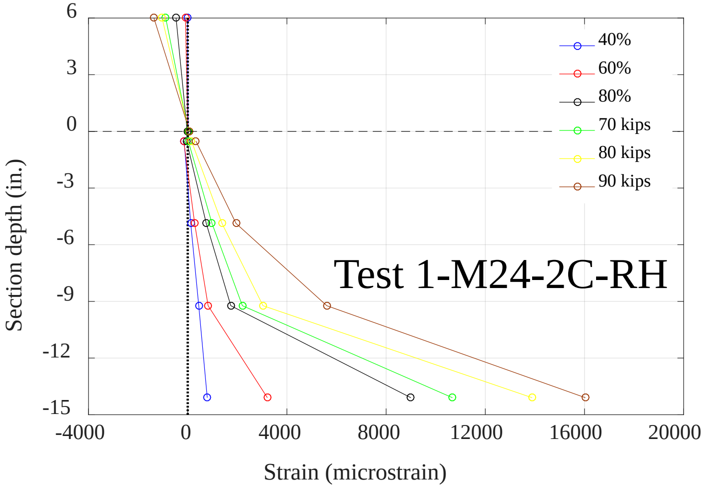

Case 2: full shear connection; $0.85f'_cA_c < A_sF_y$ and $\sum Q_n$

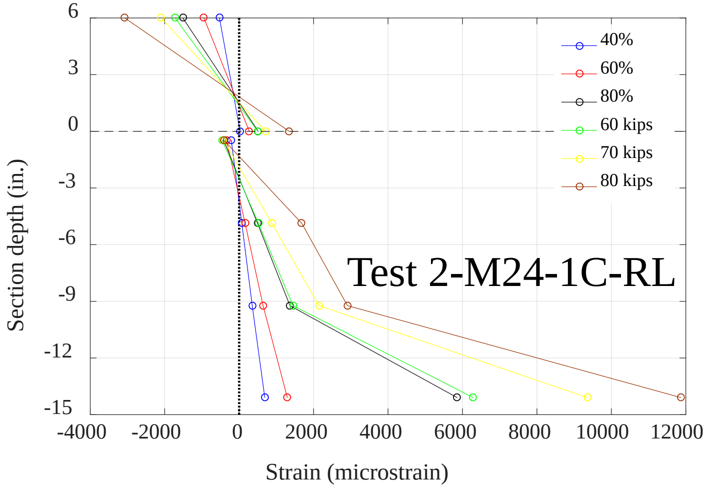


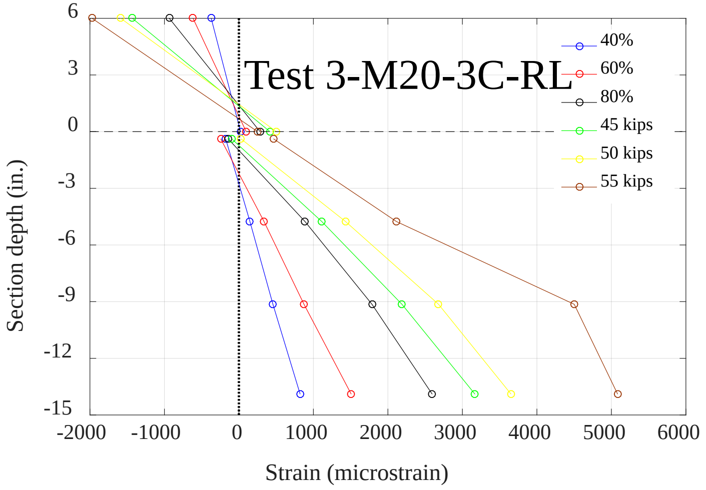

Case 3: partial shear connection; $\sum Q_n < A_sF_y$ and $0.85f'_cA_c$

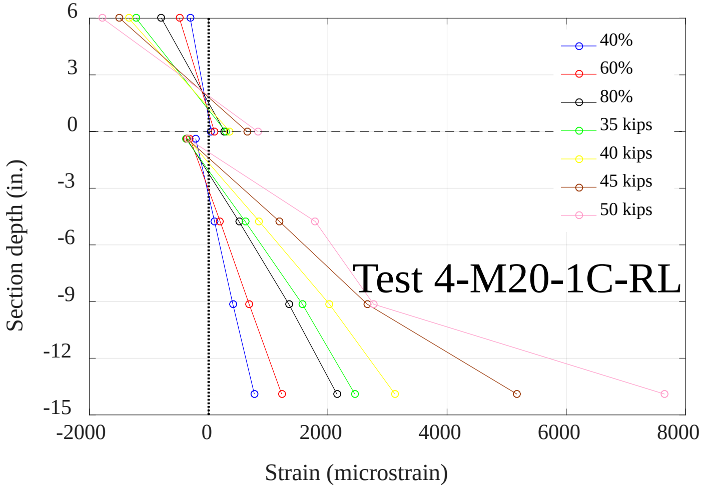


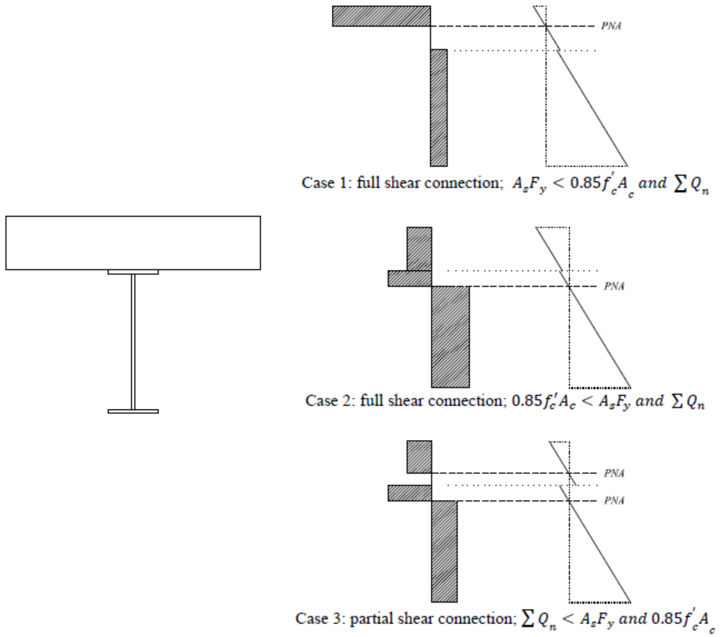
# Neutral Axis Migration



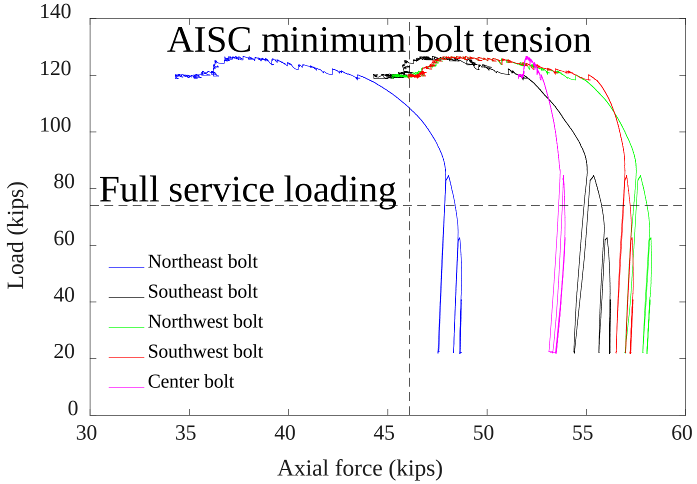



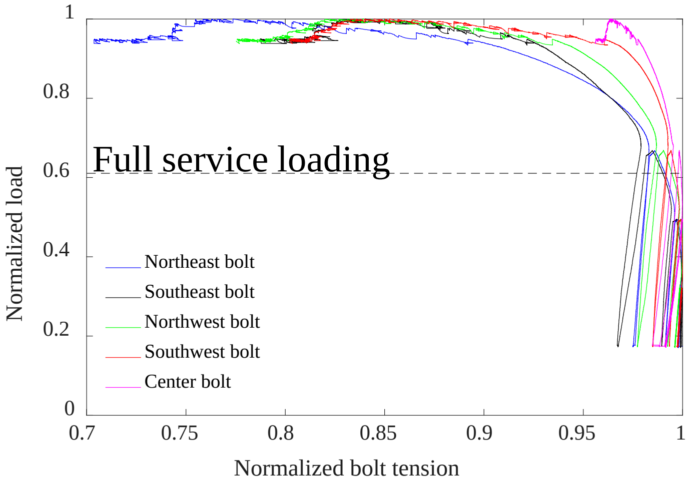



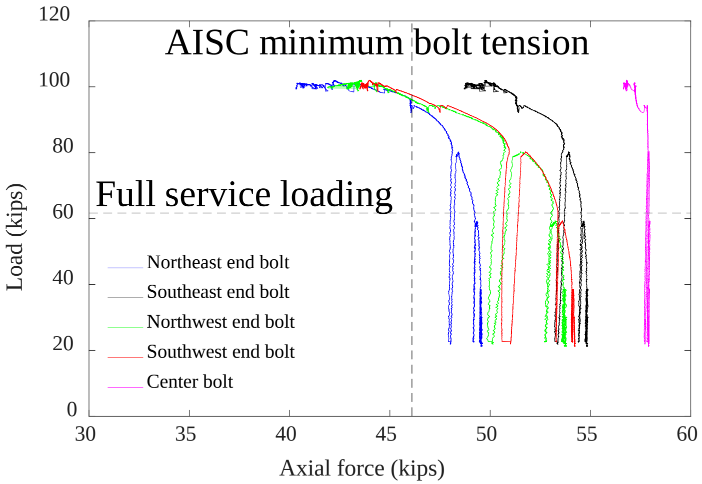

- Beams 1 and 3 behave like as fully composite beams as they approach ultimate strength
- Beams 2 and 4 clearly behave as partially composite beams

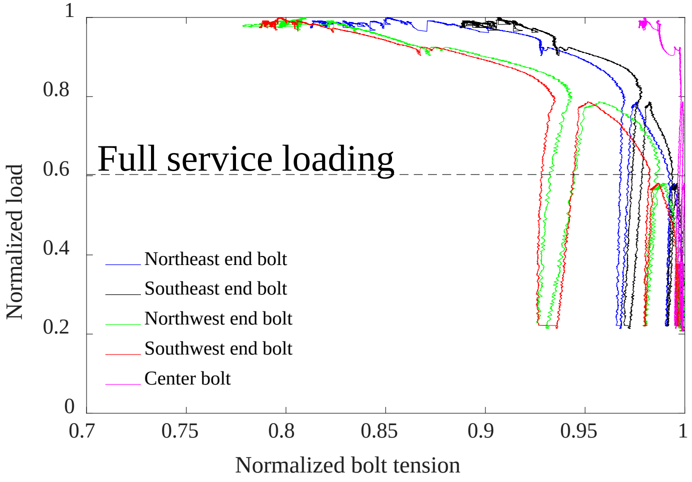
# *Load-Bolt Tension Relationship*




Test 1-M24-2C-RH




Test 2-M24-1C-RL

# Effective Width

**Shear lag**

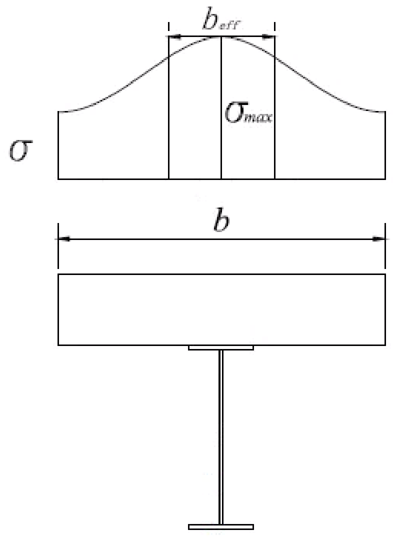
- Concrete slab subjected to combined in-plane normal stress and shear stress
- Plane section assumption invalid due to shear strain
- Nonuniform normal stress distribution along the width of the slab
- Effective width proposed to simply design

**Effective width**

- Definition

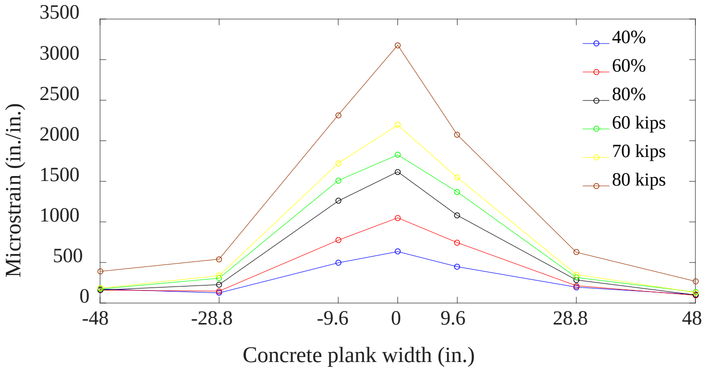
$$b_{eff} = \frac{\int_{-b/2}^{b/2} \sigma dx}{\sigma_{max}}$$

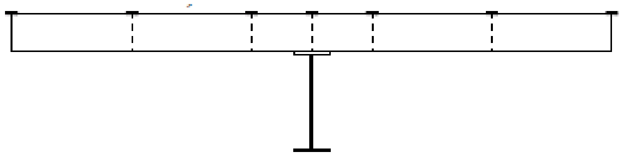
- AISC 360-16
  - 1/8 of the beam span
  - 1/2 of the distance to the centerline of the adjacent beam
  - the distance to the edge of the slab
- Same effective width used for both serviceability and ultimate states



Effective width

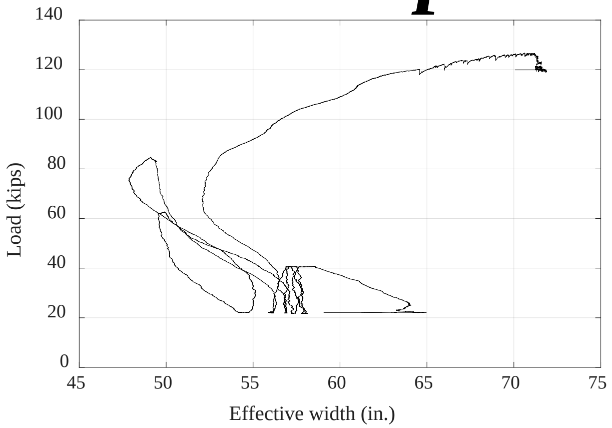
# *Effective Width of Deconstructable Composite Beams*



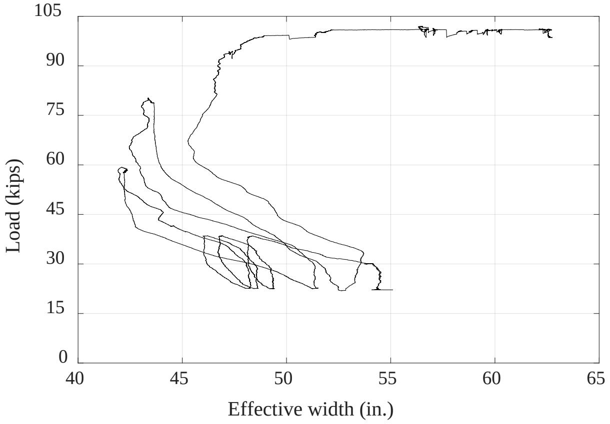



Senor layout at center section

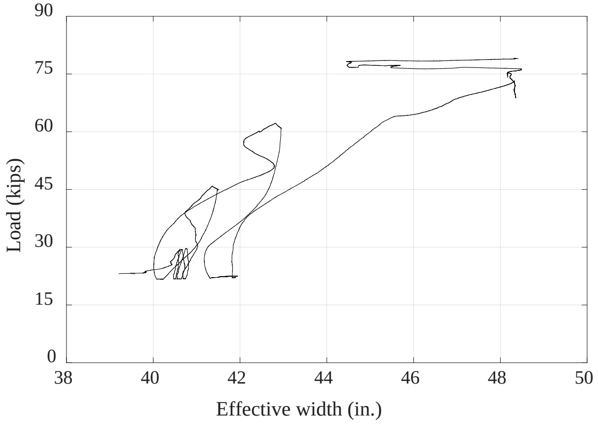
Test 2-M24-1C-RL



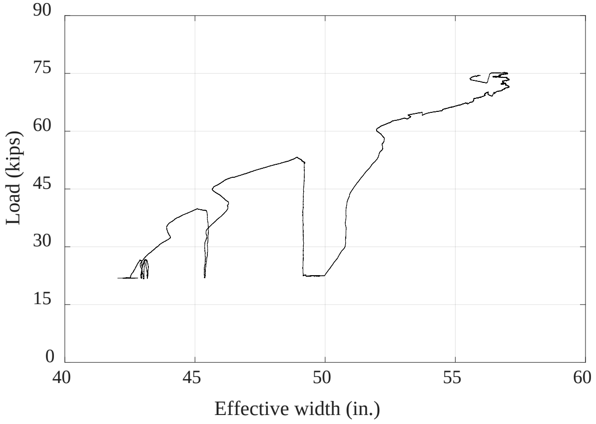

Test 1-M24-2C-RH




Test 2-M24-1C-RL



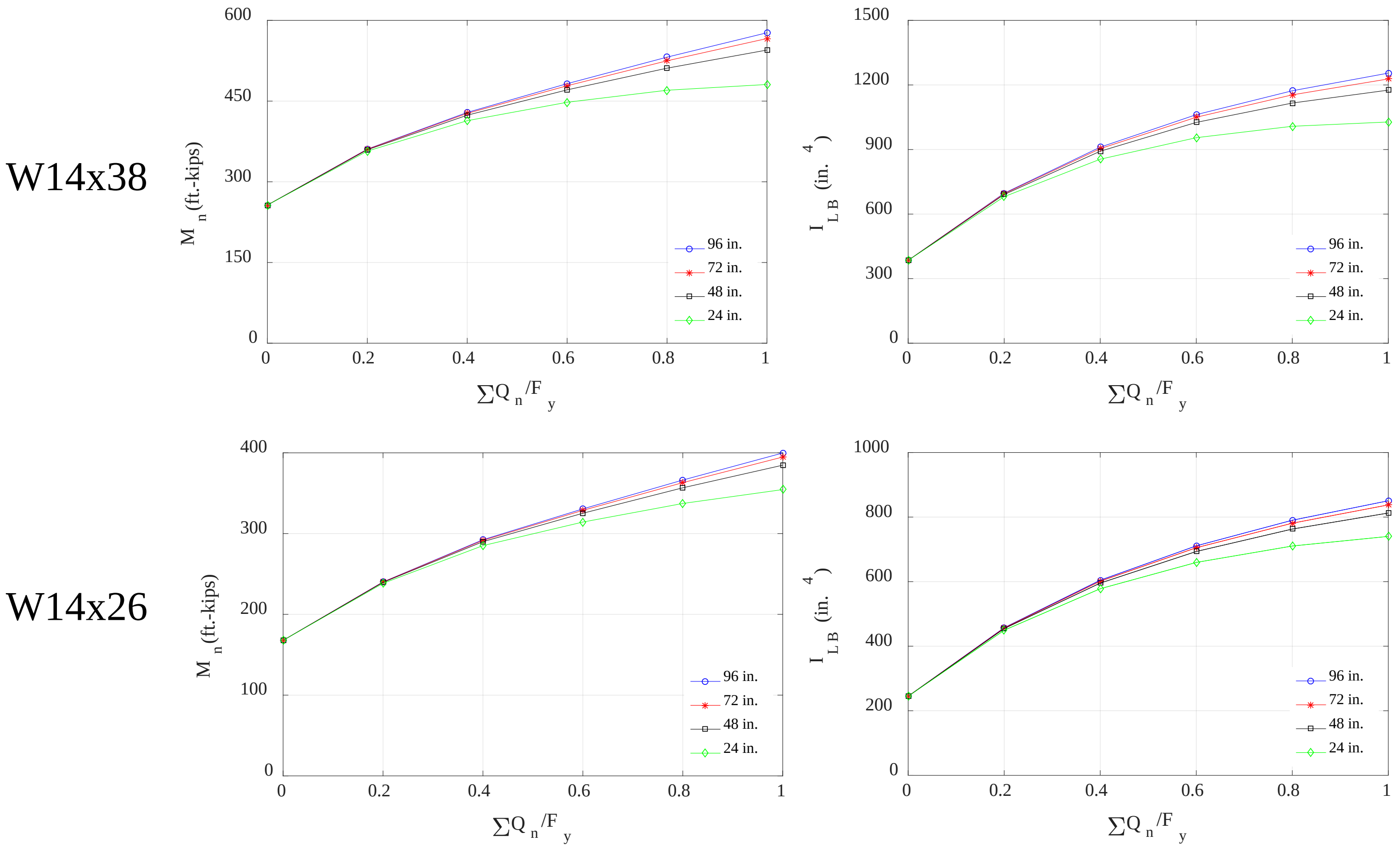

Test 3-M20-3C-RL




Test 4-M20-1C-RL

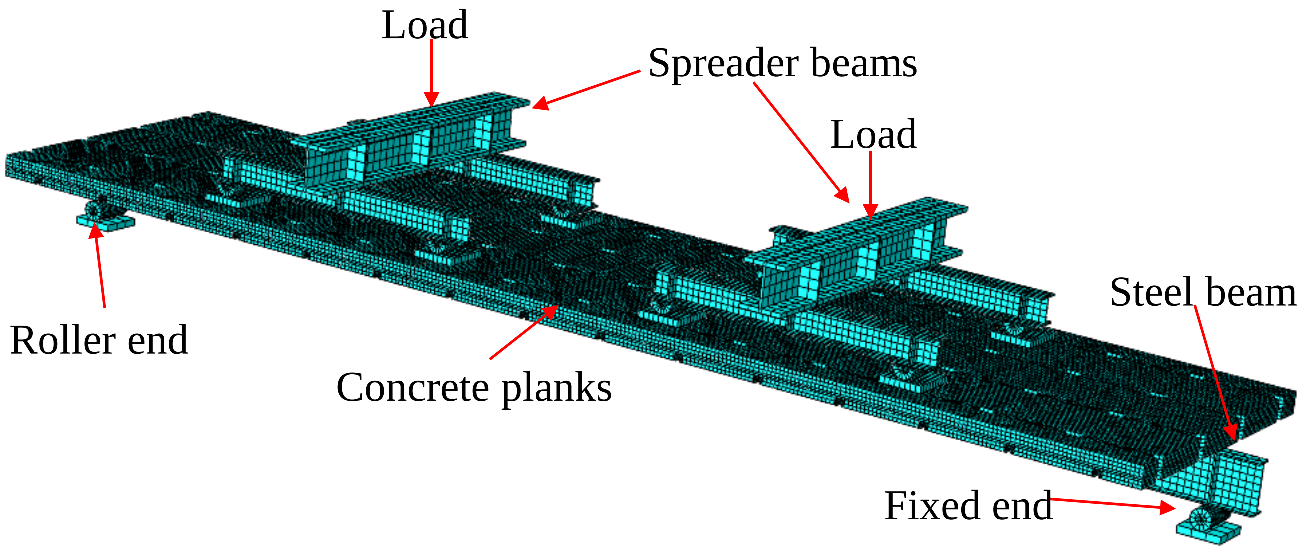
- At large deflections, effective widths increase along with increasing deflections.
- Effective widths are smaller than those calculated in accordance with the AISC provisions (90 in.), due to the cutouts and gaps between planks.

# *Influences of Effective Width*



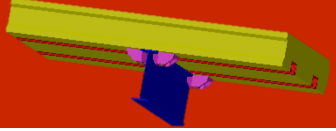

- Different effective widths have minimal impacts on the calculated strength and stiffness of the beams, especially for partially composite beams with low composite action.
- The ultimate flexural strengths of the composite beams are not very sensitive to the degree of shear connection.

# *Finite Element Model*



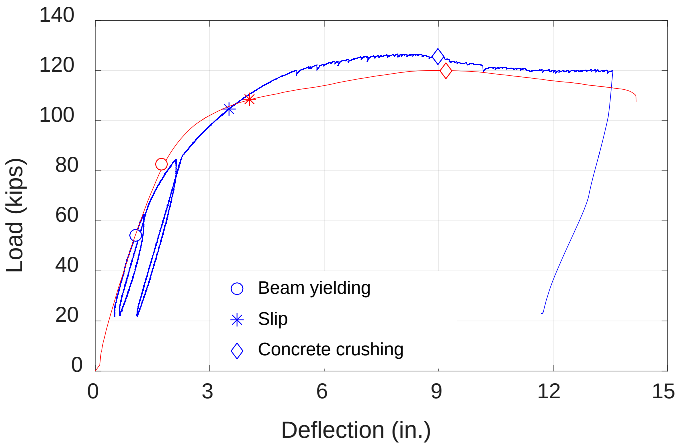

FEM:

- ABAQUS/EXPLICIT
- Two analysis steps:
  - Rod tension and bolt pretension applied using temperature method
  - Displacement applied to top spreader beams
- Assume the frictional coefficient is 0.35 which is the same as that used in the pushout tests.
- Material properties are based on the material testing results.

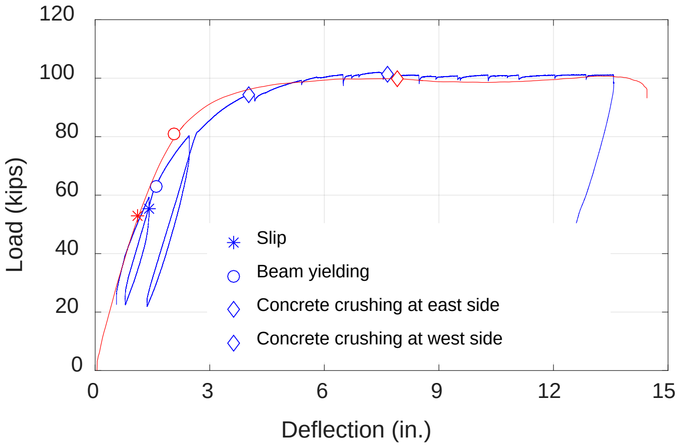




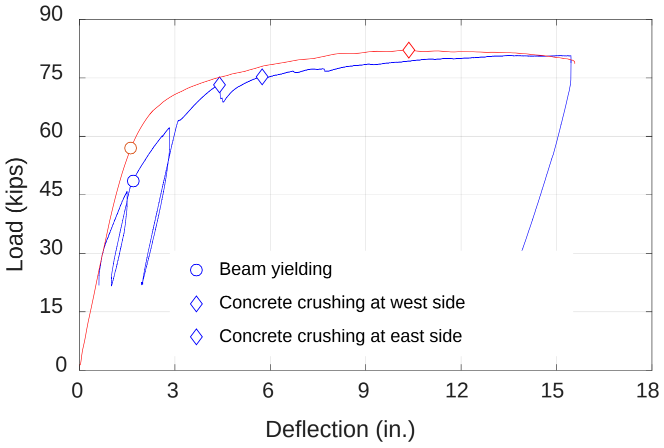
# *Load-Deflection Curve Comparison*



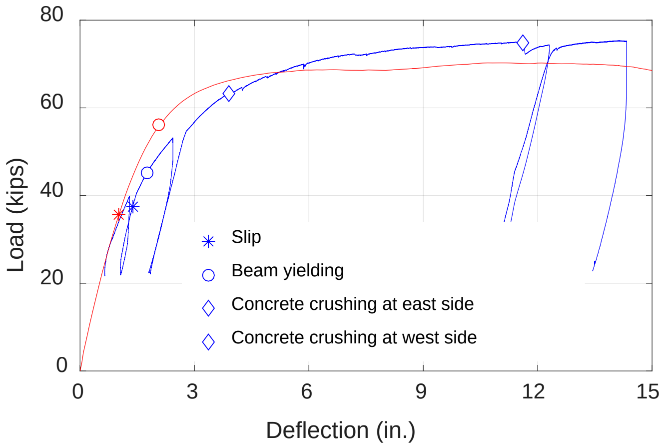

Test 1-M24-2C-RH




Test 2-M24-1C-RL

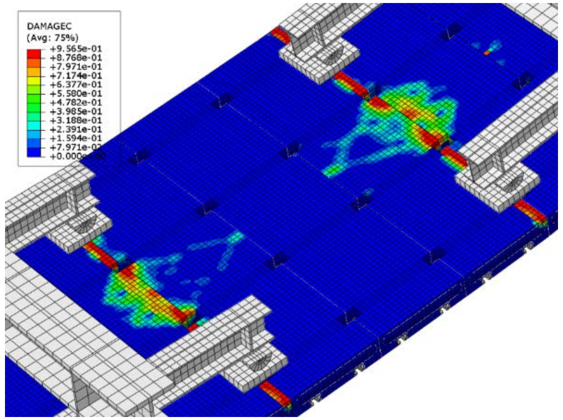



Test 3-M20-3C-RL



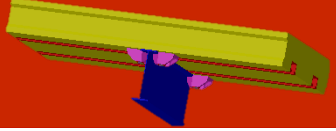

Test 4-M20-1C-RL

Test




FEM

Test 1-M24-2C-RH



# *Design Recommendations*

## Clamping Connectors

- Monotonic shear strength
    - Slip strength:

$$Q_s = k_d \mu_s D_u T_b n_s \text{ and } \emptyset = 0.9$$

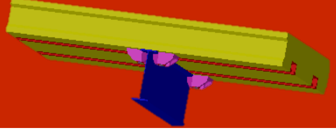
    - Peak strength:

$$Q_p = k_d k_r \mu_p D_u T_b n_s \text{ and } \emptyset = 0.9$$

- Cyclic shear strength: A coefficient of 0.8 could be used with the monotonic shear strength.

## Deconstructable Composite Beams

- Design provisions in AISC 360-16 are applicable
    - Effective width: can be determined as per AISC 360-16
    - Elastic stiffness: can be conservatively estimated using a lower-bound moment of inertia
    - Flexural strength: can be calculated using a rigid plastic design method
    - Resistance factor: a factor of 0.9 is proposed for the flexural strength design equation, assuming a reliability index of 3.0



# *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.
- Two 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. The strength of the M20 clamps declines quickly because the clamps are prone to rotate as the beam moves. Nonetheless, the slip at which the curve starts to descend is much larger than the slip demand on the clamping connectors in composite beams. Also, a properly sized channel may mitigate this behavior.
- The clamps could be utilized to connect composite diaphragms and collector beams due to their excellent energy dissipating capacity.
- All the beams are 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. The stiffness of the specimens is slightly underestimated by a lower-bound moment of inertia.
- Bolt tension reduction induced by shear force is insignificant at the serviceability of the beams.
- Design equations and resistance factors are proposed to estimated the shear strengths of the clamps and the flexural

# Acknowledgments

## Sponsors

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- Fastenal Company
- HALFEN
- Lindapter International
- Meadow Burke
- S&F Concrete
- Souza Concrete
- University of Cincinnati

# Learning Assessment Question

Which of the following statements is false?

a) Deconstructable clamping connectors are ductile, as seen by their ability to retain strengths near their peak value at significant slip
b) Over their lifespan and assuming that a majority of components are reusable, deconstructable systems have lower overall environmental impact than conventional framing.
c) In the deconstructable system, shear studs connect the concrete floor slab to the steel beams.
d) Most hot-rolled steel produced today is made from over 90% recycled steel.

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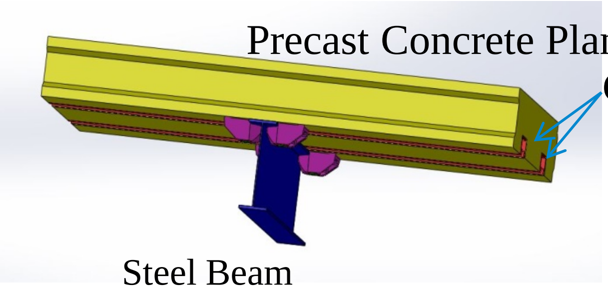
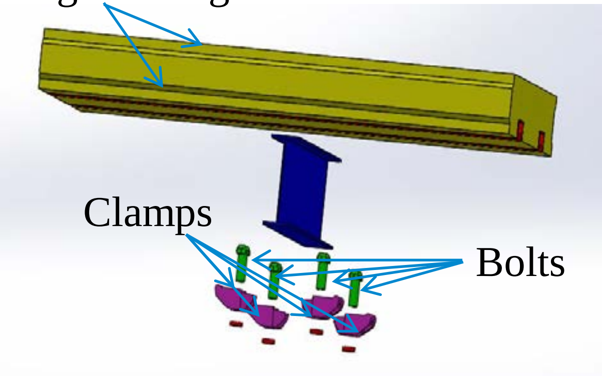
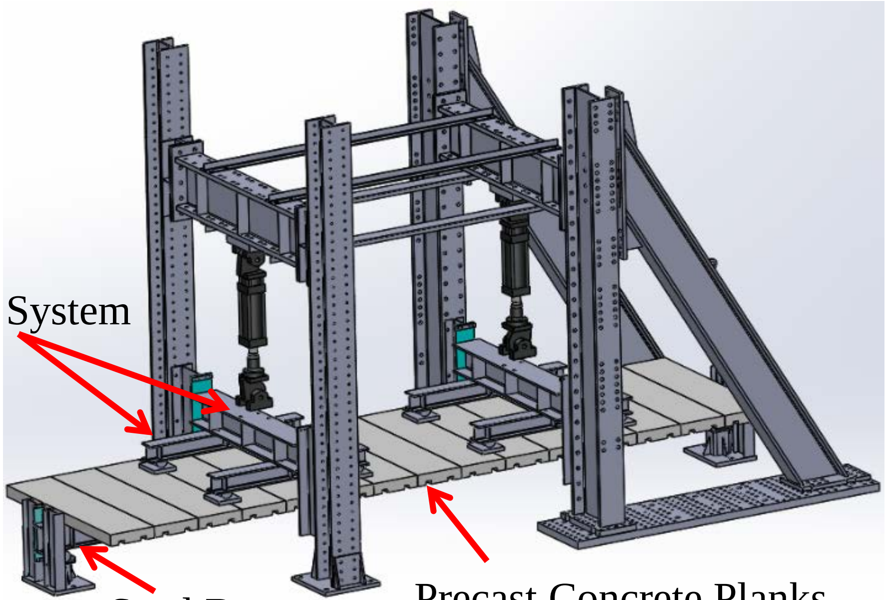
# Thank You




Deconstructable composite beam prototype




Composite beam test setup



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