Northeastern University

Behavior of Deconstructable Steel-Concrete Shear Connection in Composite Beams

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STReSS LAB
Laboratory for Structural Testing of Resilient and Sustainable Systems

SIMPSON GUMPERTZ & HEGER
Engineering of Structures and Building Enclosures

Introduction

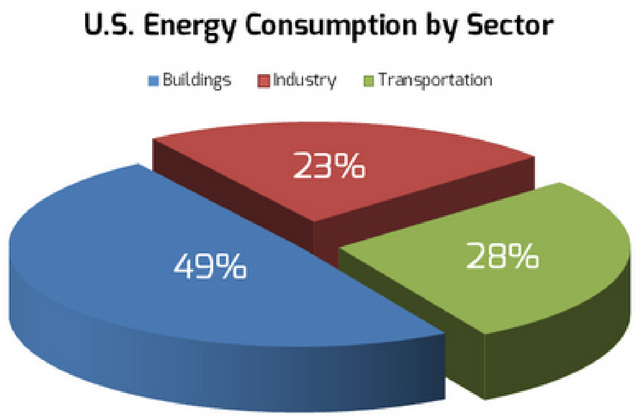
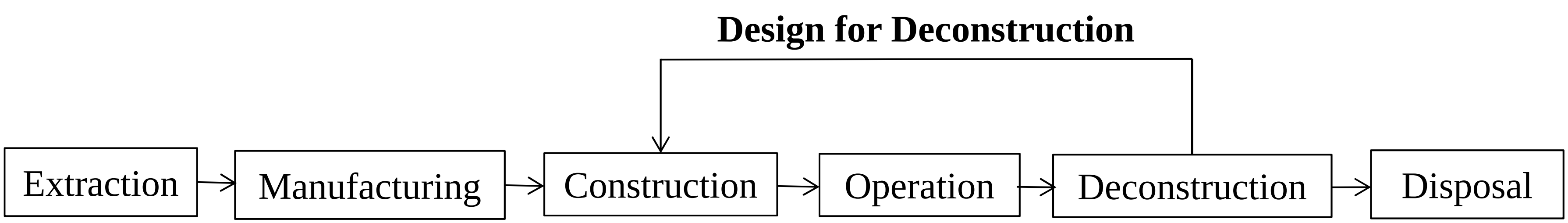


Image from US Energy Information Administration (2011)

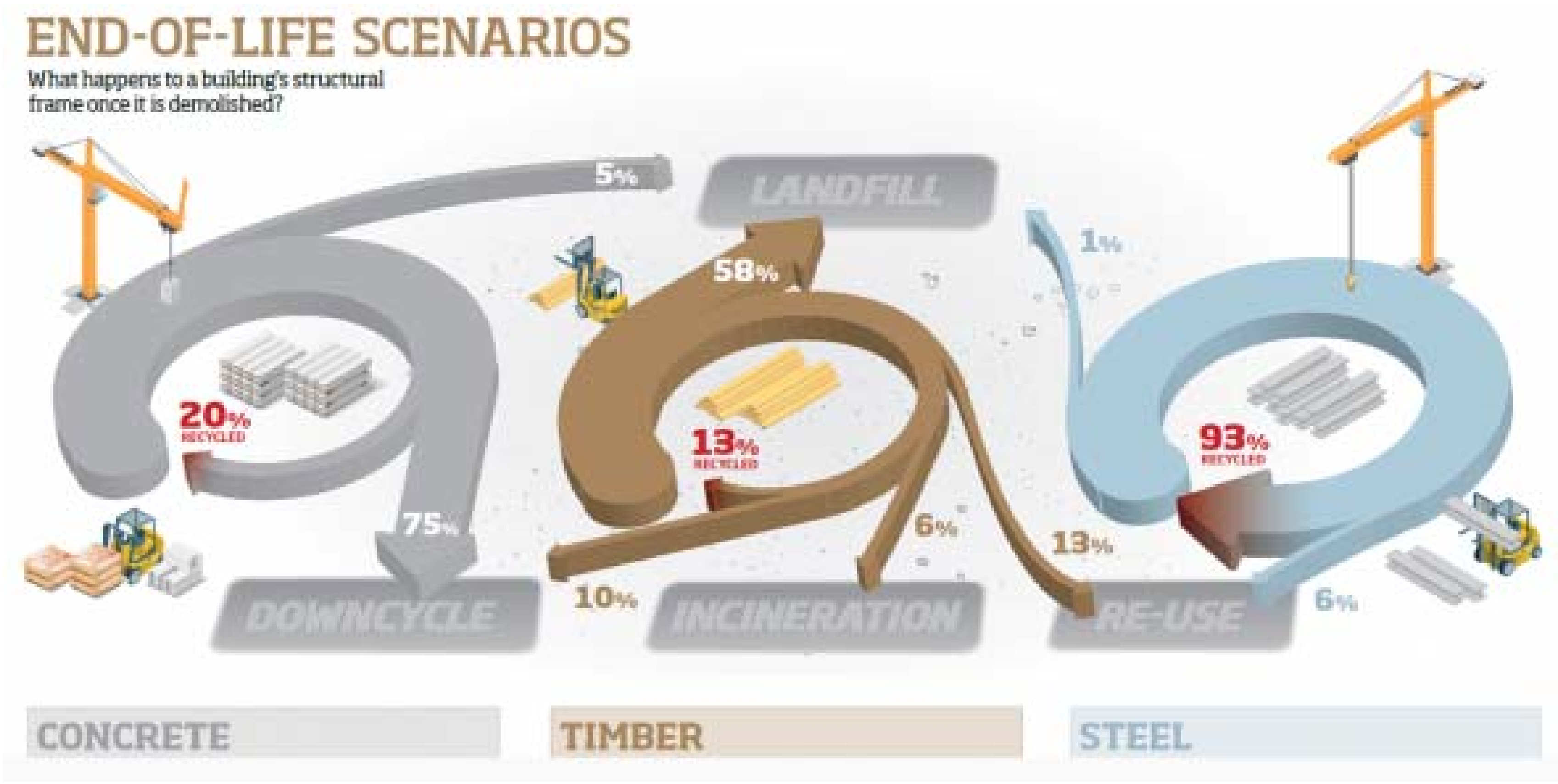
Green buildings

- Material manufacture
  - Environmentally friendly, renewable and low embodied energy materials
- Use phase
  - 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



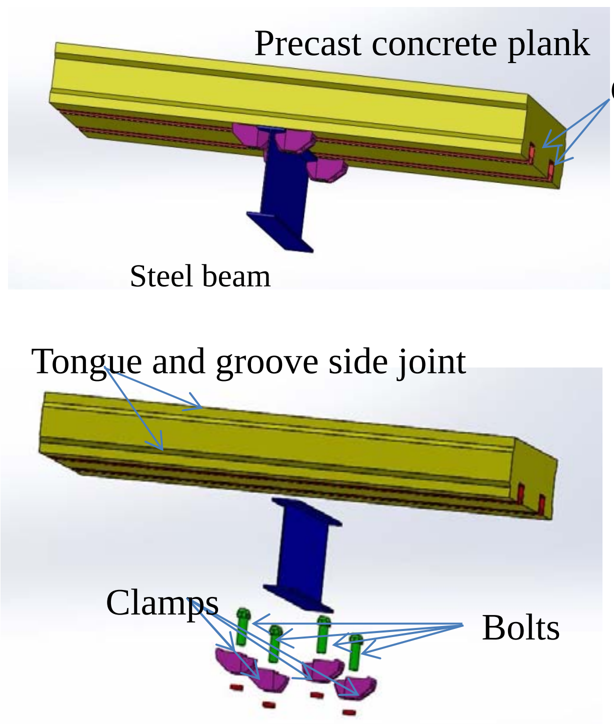
End-of-life of Construction Materials



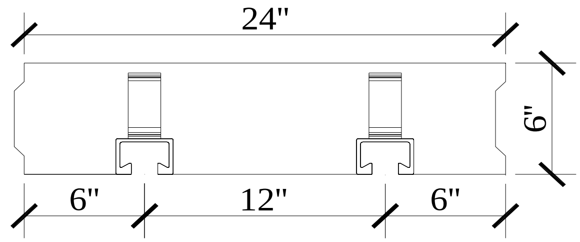
End-of-life of construction materials
Image from SteelConstruction.Info

Composite Floor System

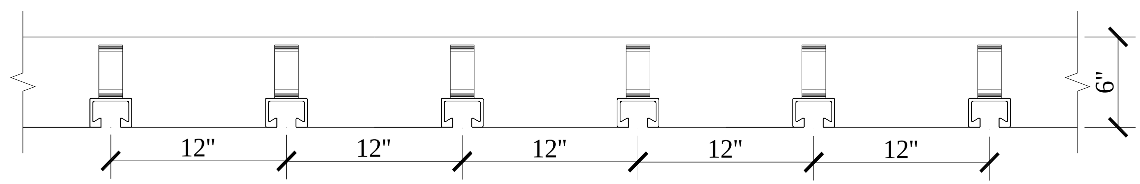
- Conventional composite floor systems are cost-effective solutions for multi-story buildings
- The integration of steel beams and concrete slab limits separation and reuse of the components
- Proposed DfD System: Clamp precast planks to steel beams/girders in a steel framing system
  - Both the steel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



Deconstructable composite beam prototype



a) Plank perpendicular to the steel beam

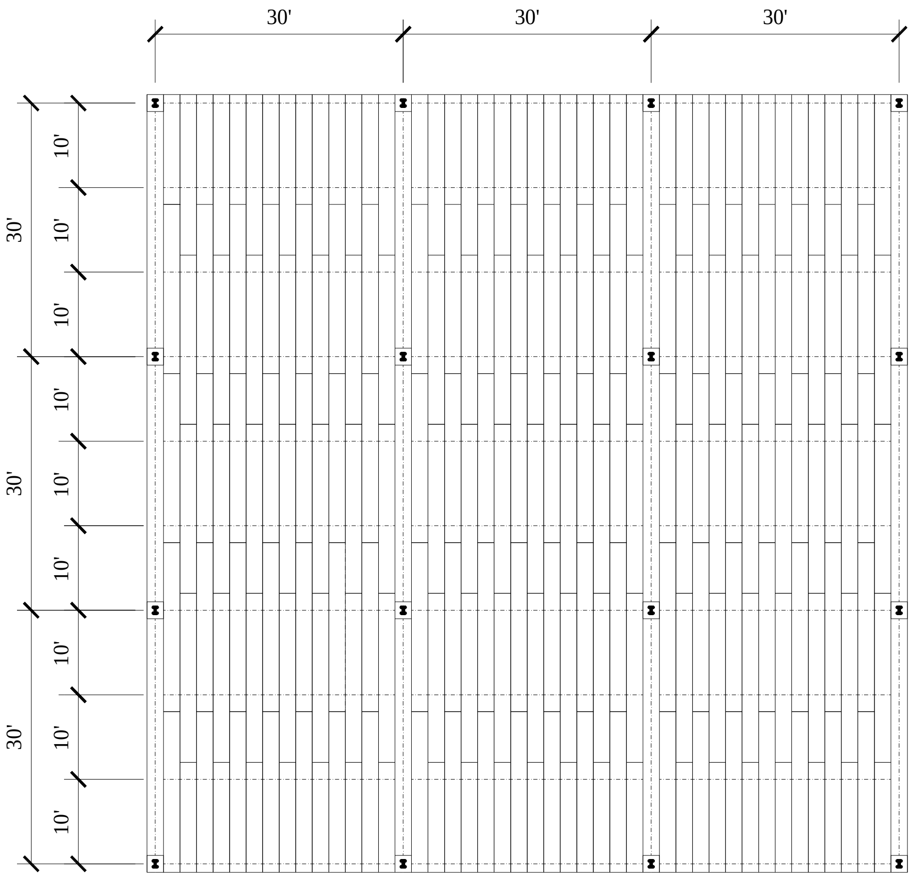


b) Plank parallel to the steel girder

Precast concrete plank cross section

DfD Floor System

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



Typical floor plan for DfD system

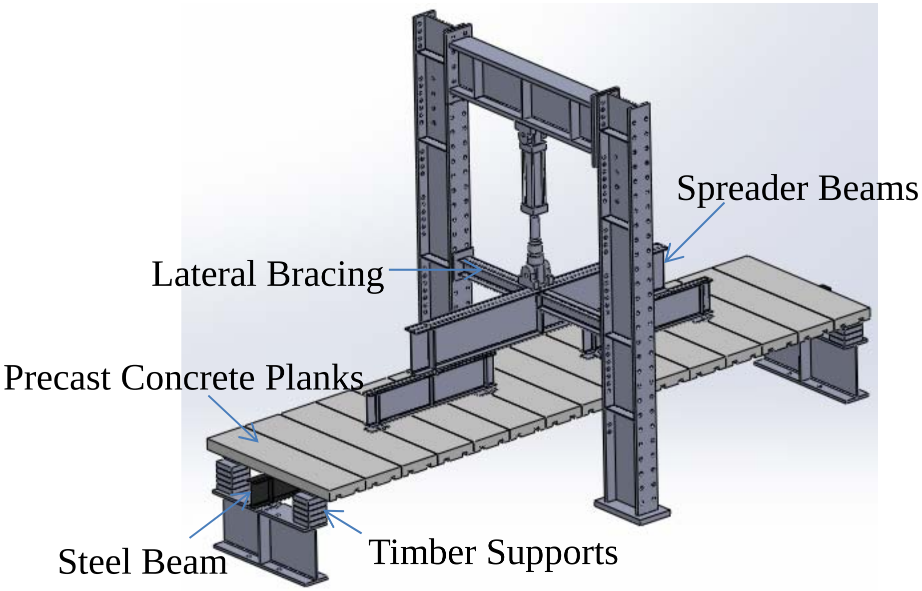
ConXtech moment connection

Image from ConXtech Website

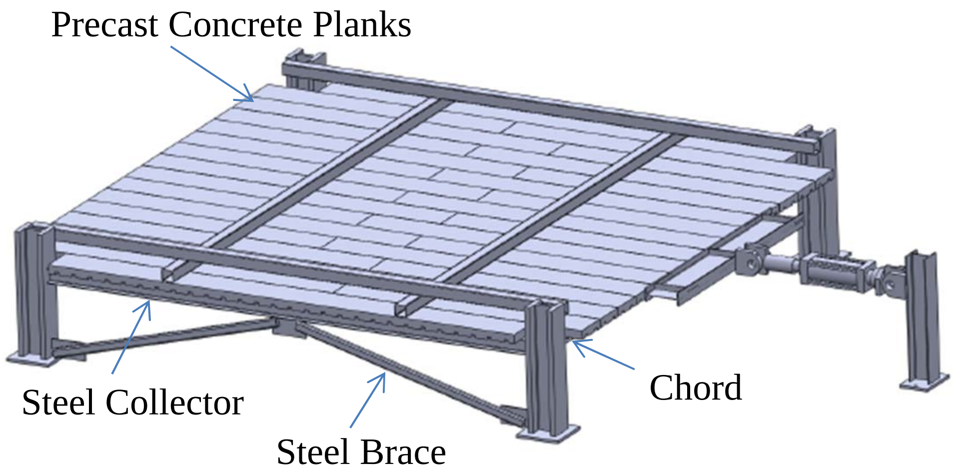
Example of deconstructable bolted connection

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
- Diaphragm tests: investigate the in-plane seismic behavior of the deconstructable composite floor system

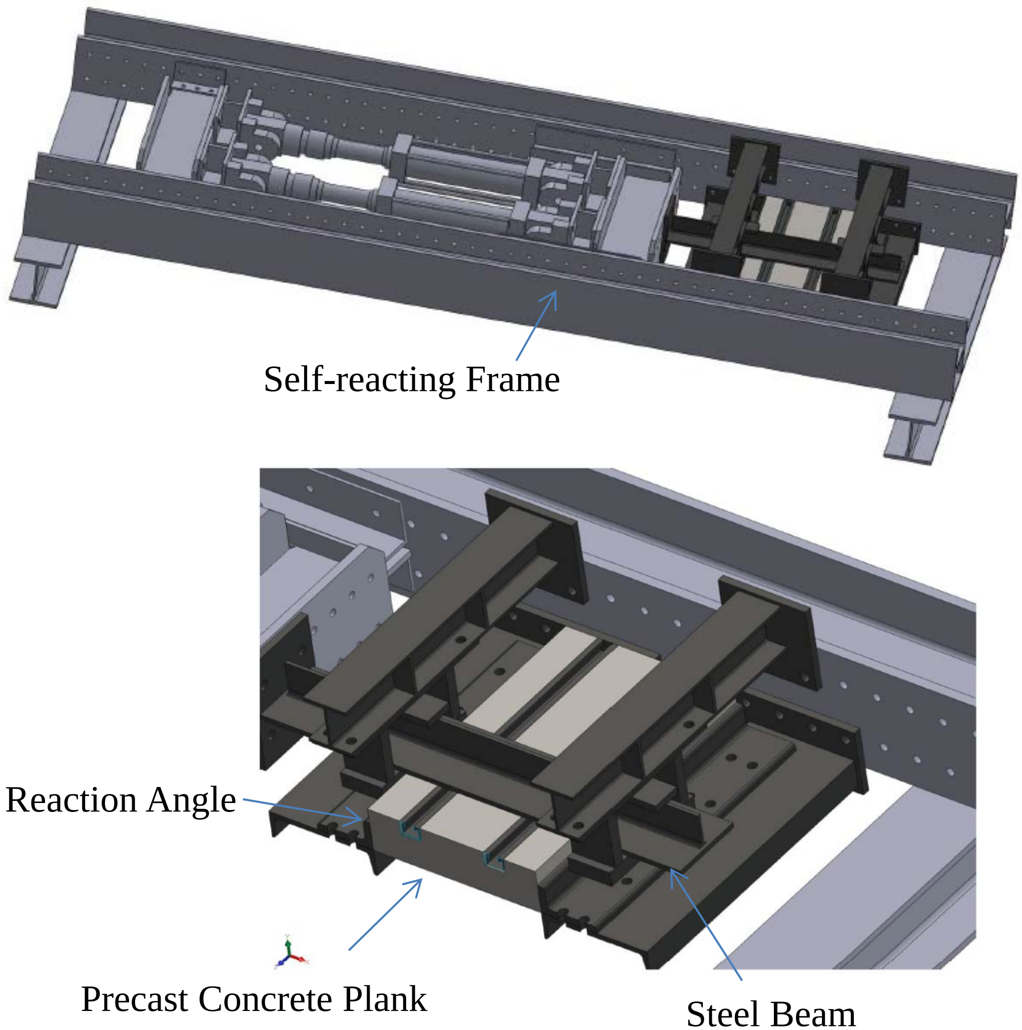


Composite Beam Test



Composite Diaphragm Test

Pushout Test Setup



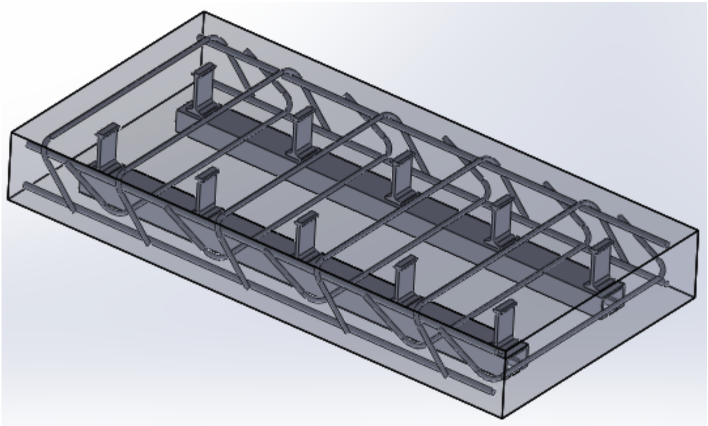
Pushout Test

Specimen components

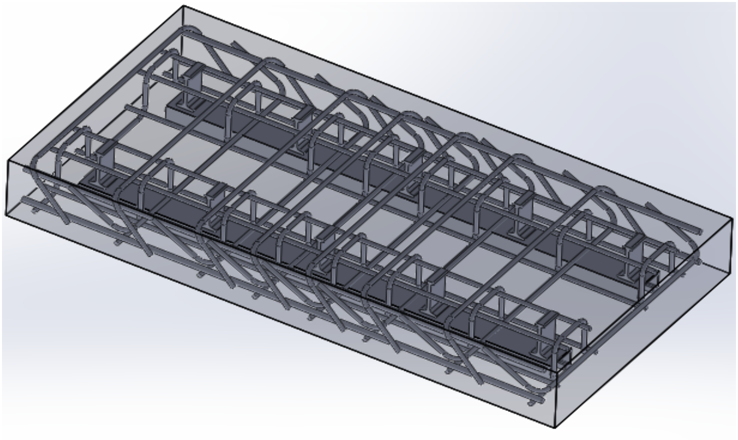
- Precast concrete plank
  - Dimension: 6 in. x 2 ft. x 4 ft.
- Reaction angle: L8x6x1
  - Provide realistic compressive stress distributions within the concrete
- Steel beam: WT5x30 and WT4x15.5
  - Smaller WT requires shims between the clamp and steel flange
- Overturning of the system is restrained vertically

Steel Reinforcement Patterns for Pushout Specimens

- Light reinforcement pattern:
  - Contains reinforcement designed for gravity loading only
- Heavy reinforcement pattern:
  - Supplementary reinforcement bridges all potential concrete failure planes
  - Pattern is slightly changed when three channels are used in the concrete specimen to achieve a high level of composite action
- Reinforcement:
  - No.4 bars are selected for the longitudinal reinforcement designed for plank flexure under gravity loading
  - Transverse and supplementary reinforcement use No.3 bars



Light reinforcement pattern



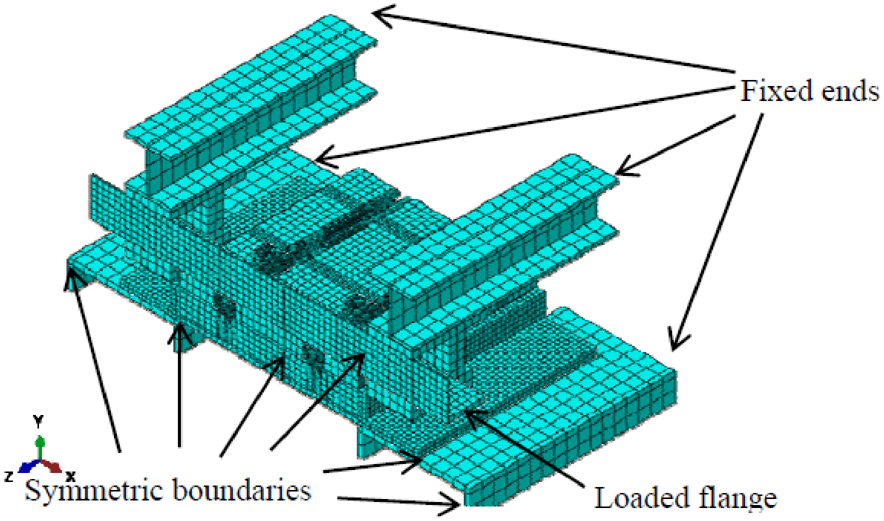
Heavy reinforcement pattern

Pushout Test Matrix

Name	Test parameters											
	Bolt diameter		Number of channels		Rebar configuration		Loading		Pretension		Shim	
	1’’	¾’’	2	3	Light	Heavy	Monotonic	Cyclic	Small	Large	Yes	No
1-2-RH-PL-SN	✓		✓			✓				✓		✓
2-2-RL-LM-PS-SN	✓		✓		✓		✓		✓			✓
3-2-RH-LM-PS-SN	✓		✓			✓	✓		✓			✓
4-2-RH-LM-PS-SY	✓		✓			✓	✓		✓		✓	
5-2-RH-LC-PS-SN	✓		✓			✓		✓	✓			✓
6-2-RH-LC-PS-SY	✓		✓			✓		✓	✓		✓	
7-3-RH-LM-PS-SN	✓			✓		✓	✓		✓			✓
8-3-RH-LC-PS-SN	✓			✓		✓		✓	✓			✓
9-2-RH-LM-PS-SN		✓	✓			✓	✓		✓			✓
10-2-RH-LC-PS-SN		✓	✓			✓		✓	✓			✓

Pushout Test Simulation

Boundary conditions and load application



Loading process

- Pretension in the bolt is obtained by assigning thermal coefficient to the shank and decreasing the temperature
- The steel beam is then loaded in the axial direction using displacement control

Interaction between parts

- Contact frictional coefficient of steel beam to concrete slab and steel clamp to steel beam: 0.3
- Reinforcement: modeled explicitly and embedded in the concrete slab

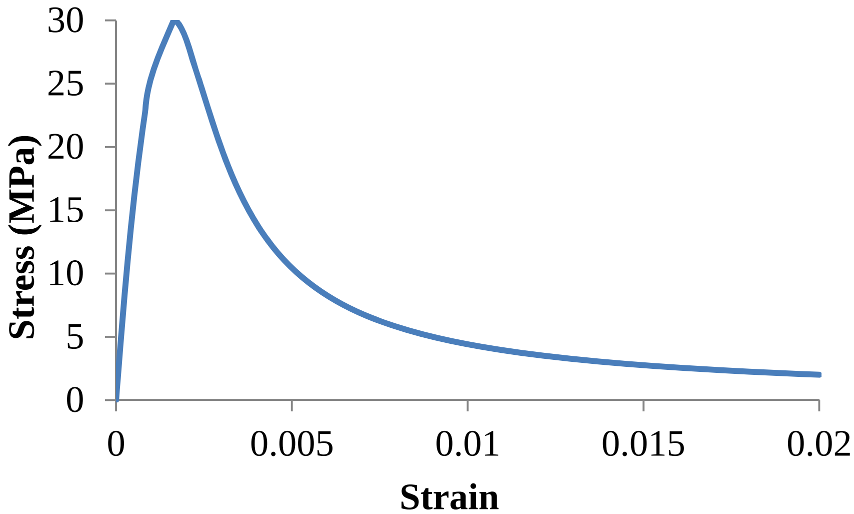
Pushout Test Simulation

Material constitutive model

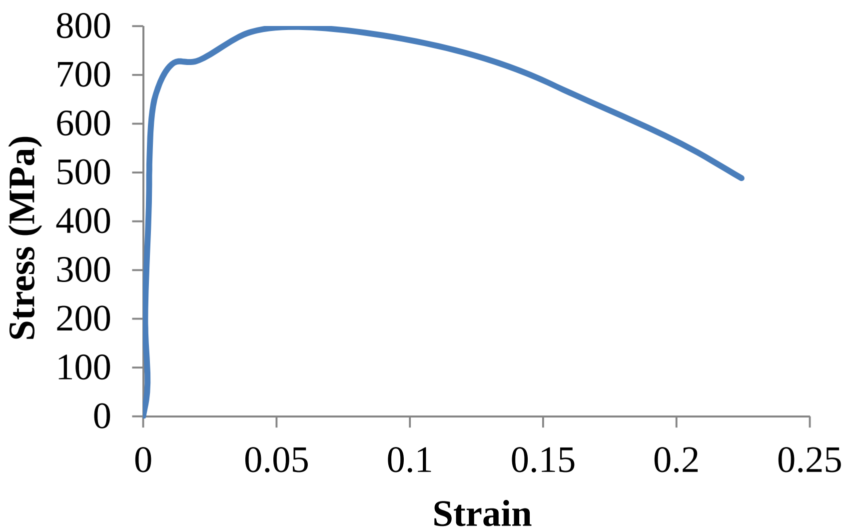
- Concrete damaged plasticity model
  - Failure mechanism: tensile cracking and compressive crushing
  - Capture stiffness recovery due to crack opening and closing under cyclic loading

- Steel beam, reinforcement and cast-in channels: elastic-perfectly-plastic material

- Bolts: A325 bolts (Grade 8.8 bolts)



C30 concrete compressive behavior



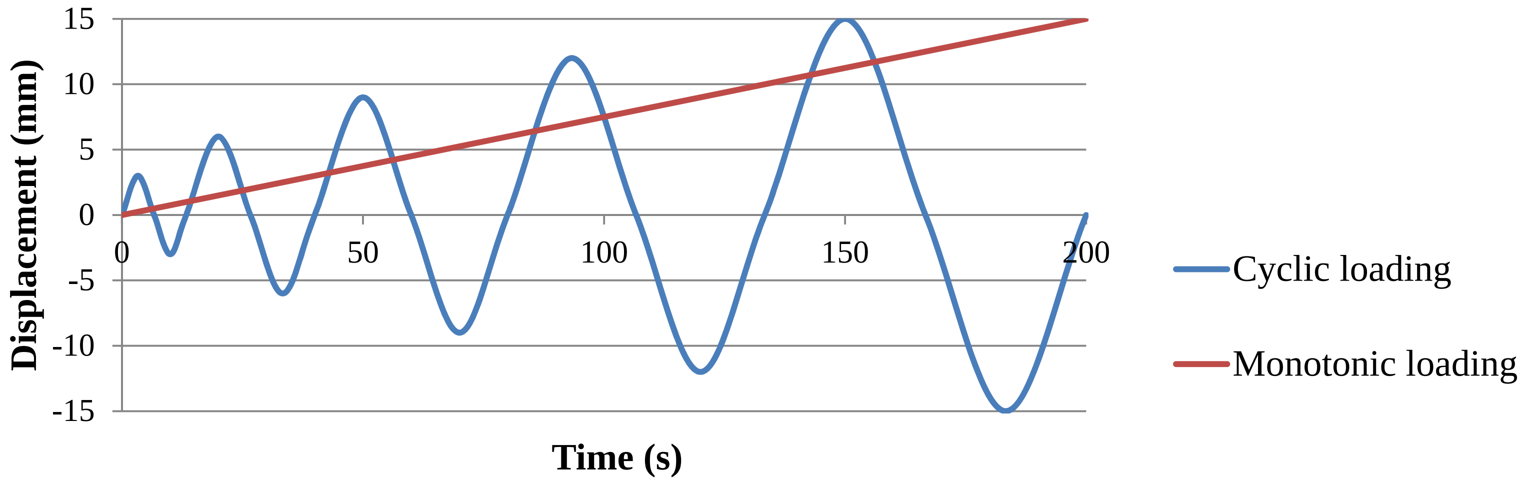
Bolt material stress-strain curve

Pushout Test Simulation

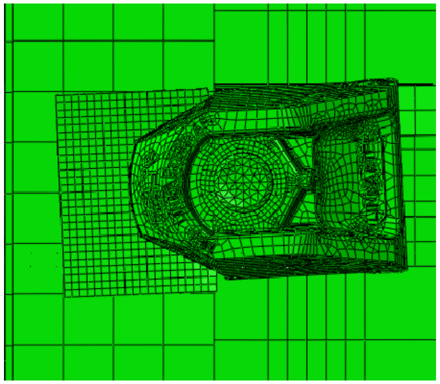
Computational models

Model Number	Loading protocol	Usage of shim	Amount of bolt pretension	Reinforcement pattern
1	Monotonic	No	Small	Heavy
2	Monotonic	No	Small	Light
3	Monotonic	No	Large	Heavy
4	Monotonic	Yes	Small	Heavy
5	Cyclic	No	Small	Heavy

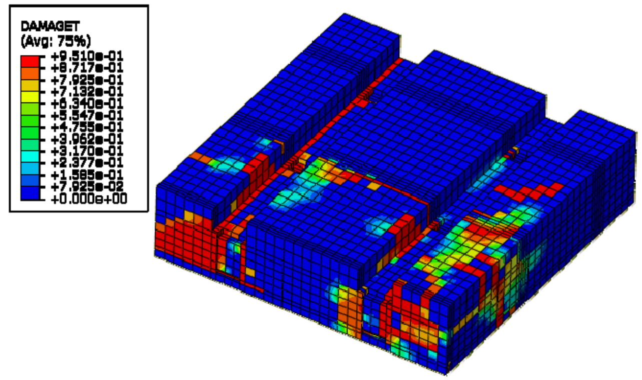
Loading protocols



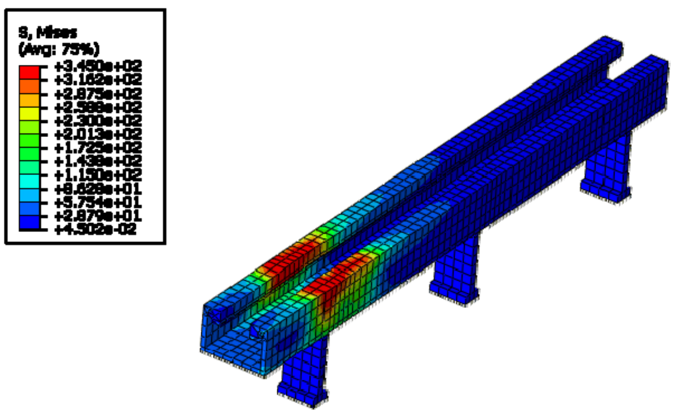
Limit States for Pushout Specimens



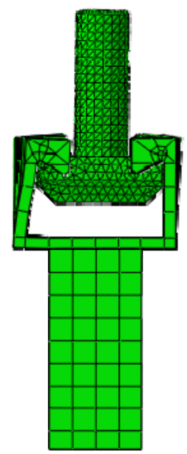
Slip of clamp and shim



Damage due to concrete cracking

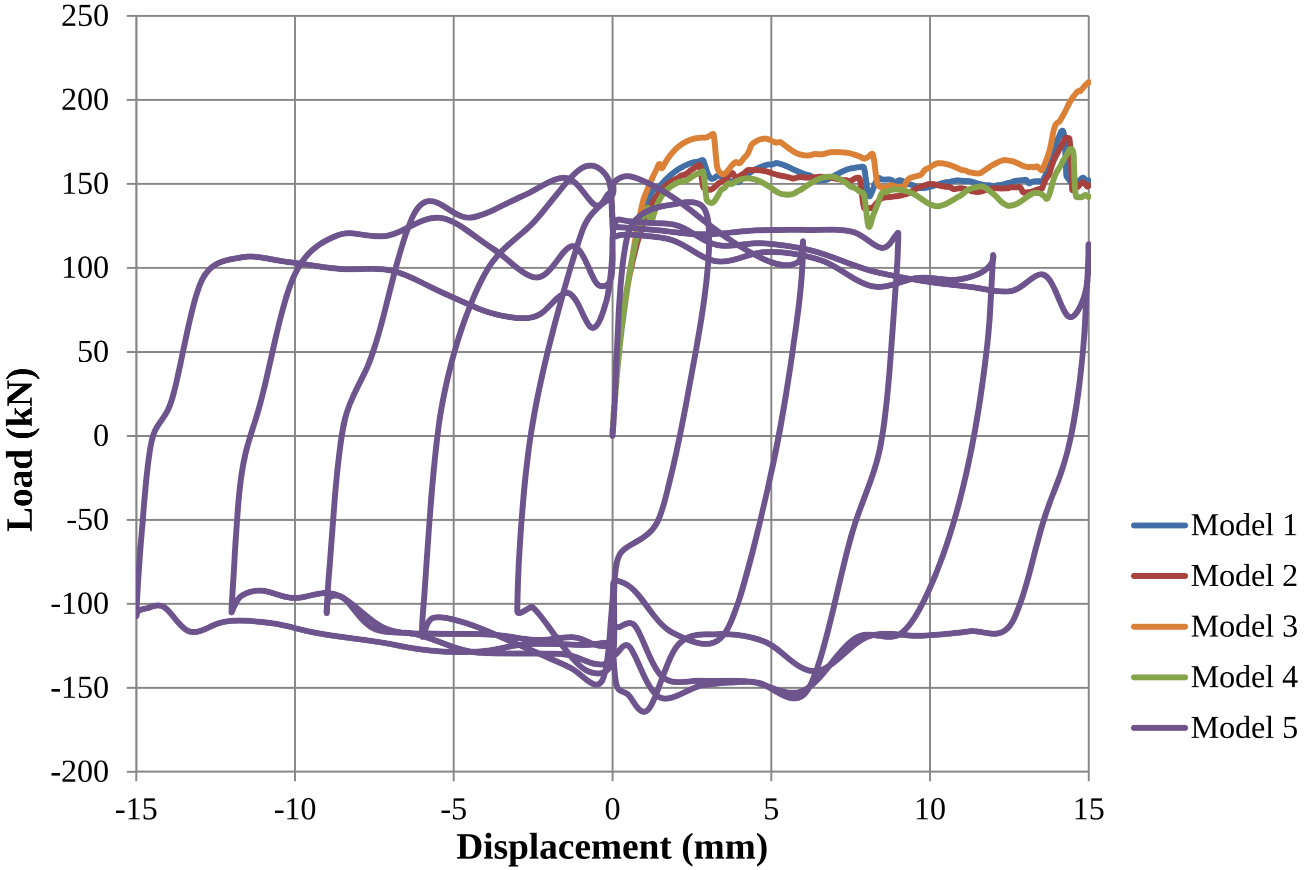


Local yielding of channel lips



Bolt bearing against the channel

Simulation Results



Summary of the analysis results:

- Clamping connectors in the light reinforcement specimens yield almost the same strength as those in the heavy reinforcement specimen
- Using shims reduces the connector slip strength slightly
- The connectors retain 70% of their strength after significant cyclic loading

Conclusions

- A new deconstructable composite floor system, consisting of steel framing, precast concrete planks and clamping connectors, 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 designed to evaluate the effects of different parameters and formulate strength design equations for the clamping system. This research also includes composite beam tests and composite diaphragm tests to investigate the flexural and in-plane seismic behavior of the system.

- FE analysis results show that the clamping connectors have an ultimate strength comparable to that of headed stud anchors and behave in a ductile manner; therefore, they have the potential for being used in lieu of headed stud anchors in composite beams.

- The influence of different reinforcement patterns on the ultimate strength of the clamping connectors is negligible. The connector strength is reduced slightly when shims are used, and it decreases when cyclic loading is applied.

Questions?