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"Mechanics for Sustainable and Resilient Systems"

Deconstructable Steel-Concrete Shear Connection for Sustainable Composite Floor Systems

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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

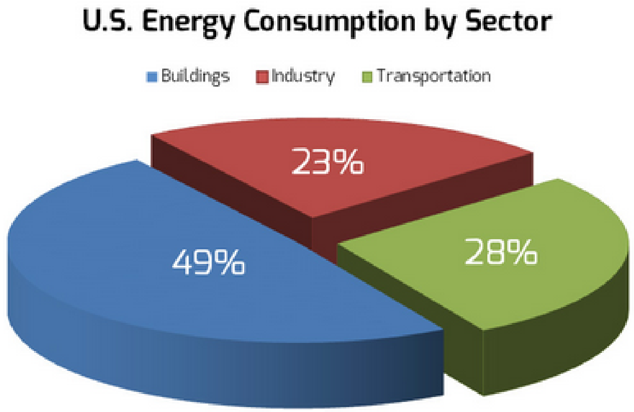
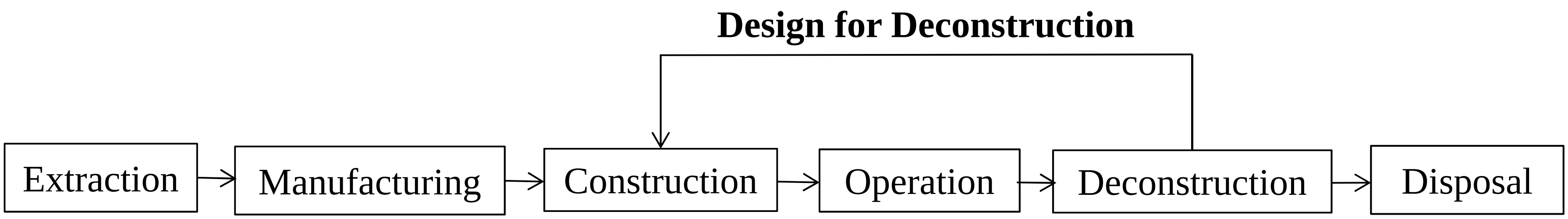


Image from US Energy Information Administration (2011)

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

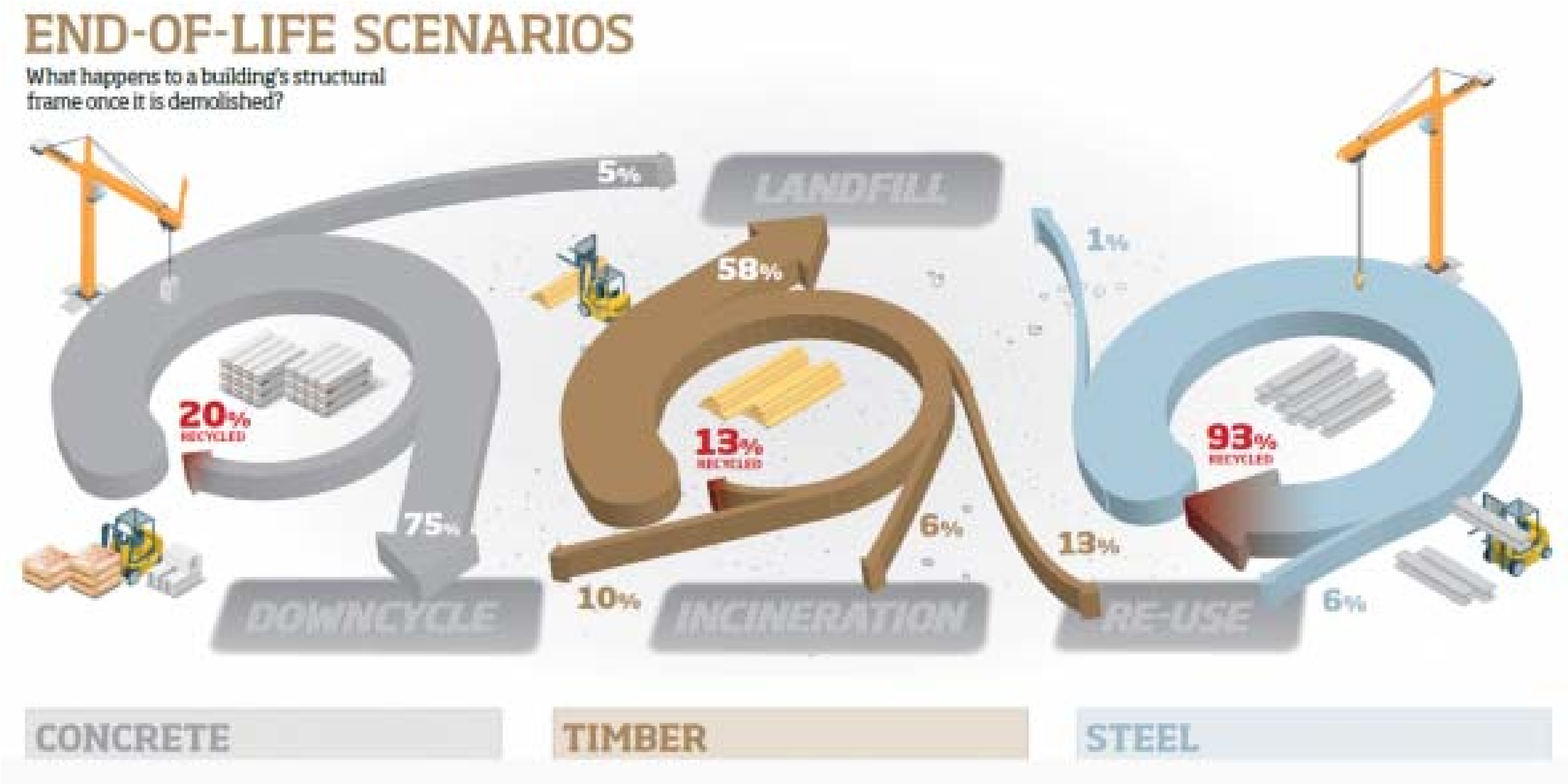
Material flow of current buildings



Design for Deconstruction

Extraction → Manufacturing → Construction → Operation → Deconstruction → Disposal

End-of-life of Construction Materials

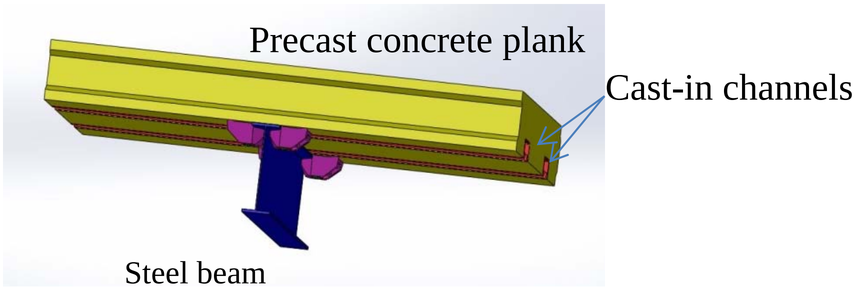


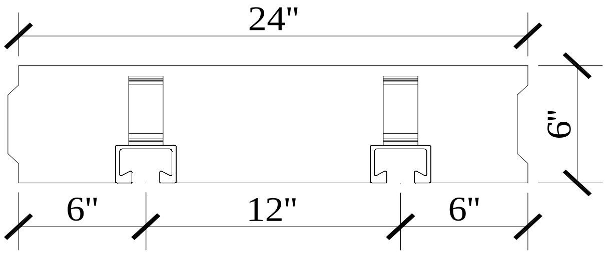
End-of-life of construction materials

Image from SteelConstruction.Info

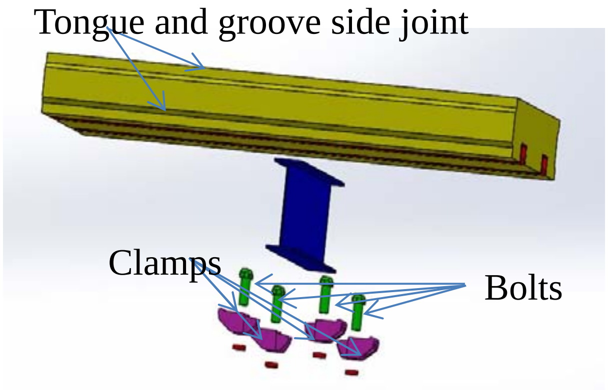
Composite Floor System in Multi-Story Frames

- Conventional composite floor systems are cost-effective solutions for multi-story buildings.
- The integration of steel beams and concrete slab prevents separation and reuse of the components.

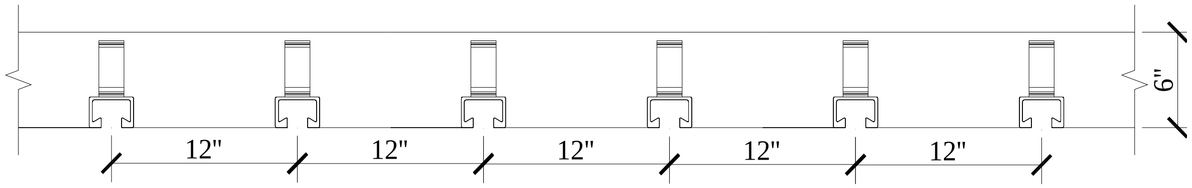




a) Plank perpendicular to the steel beam



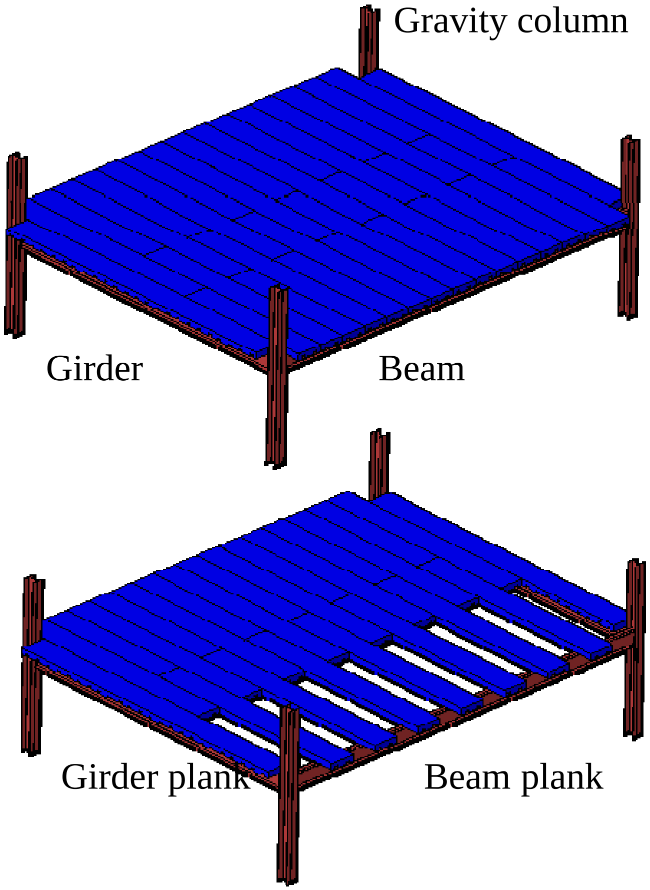
Deconstructable composite beam prototype

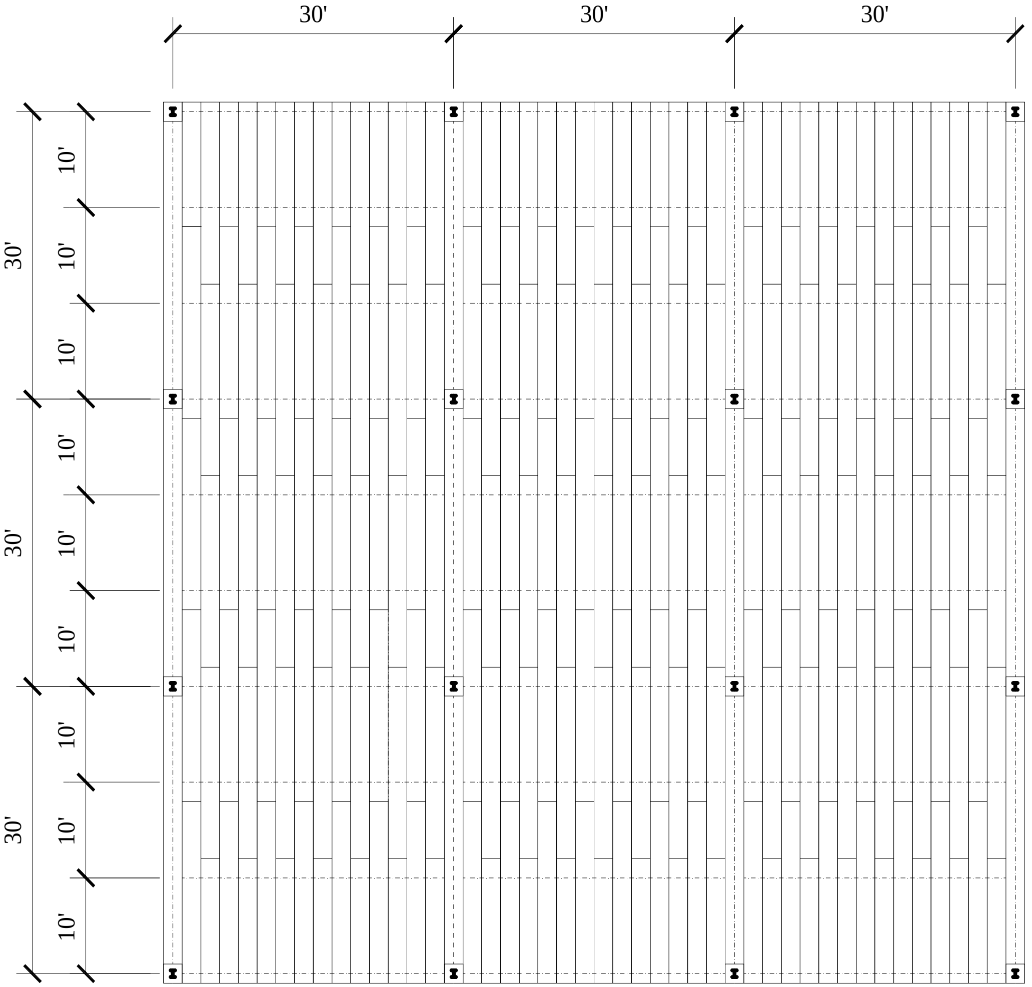


b) Plank parallel to the steel girder

Precast concrete plank cross section

Design for Deconstruction: Prototype Structural System

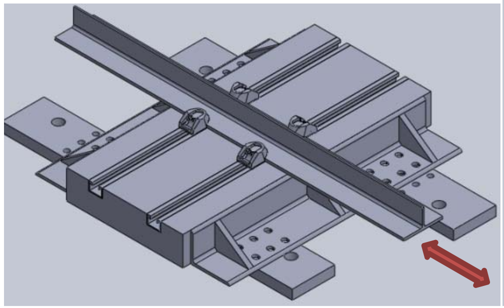




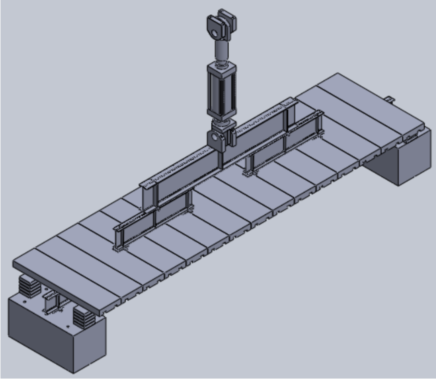
Typical floor plan for DfD system

Design for Deconstruction: Experimental Testing Program

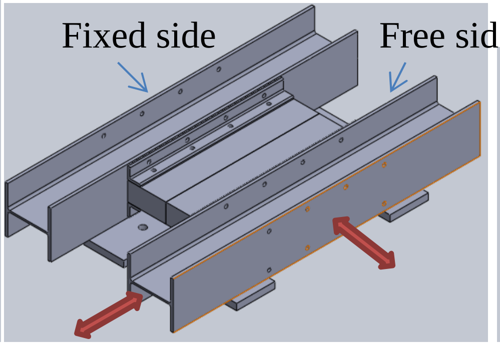
- Pushout test: evaluate a wide range of parameters and formulate strength design equations
- Beam test: study the clamp connector behavior in a realistic manner
- Precast connector test: test the strength and ductility of the plank connectors under tensile and shear loading
- Diaphragm test: investigate the in-plane seismic behavior of the composite floor system



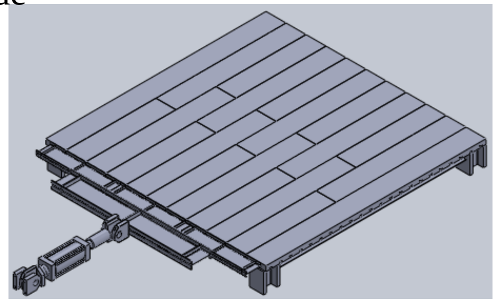
Pushout test



Beam test

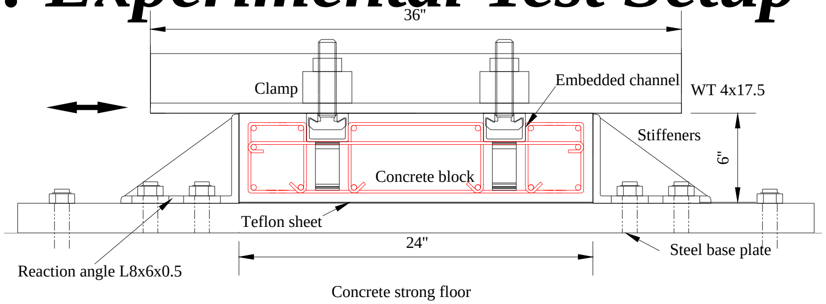


Precast connector test

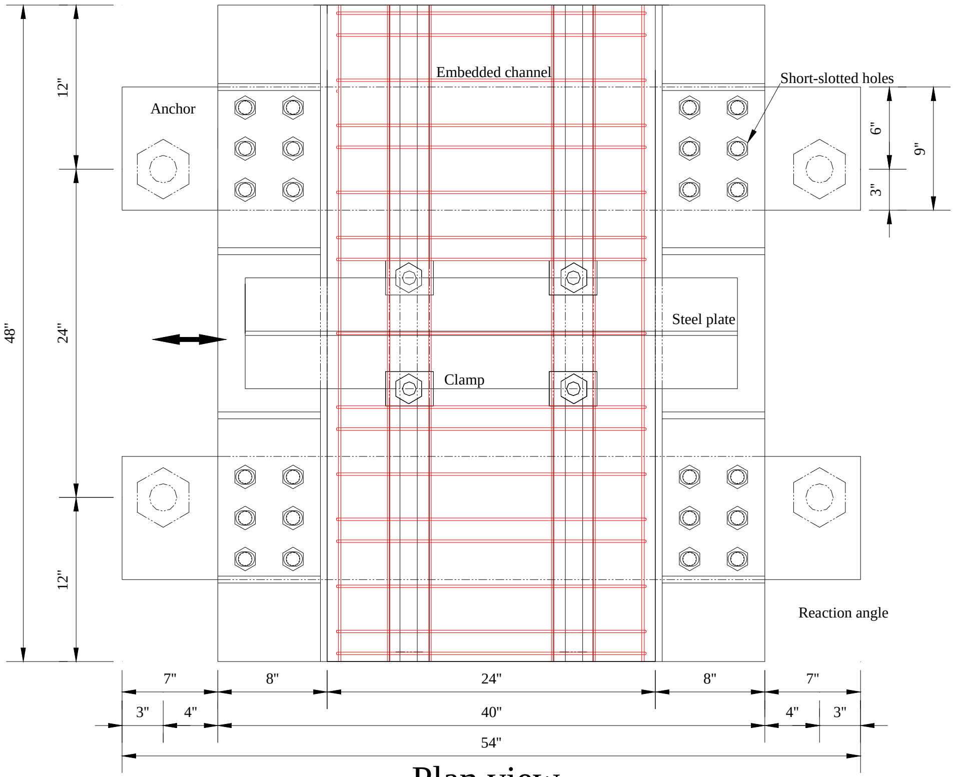


Diaphragm test

Pushout Tests: Experimental Test Setup



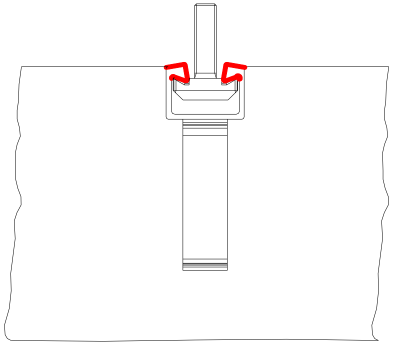
Elevation view



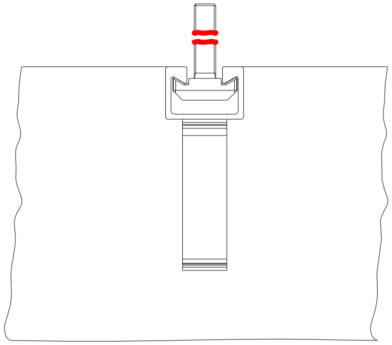
Plan view

Limit States for Cast-in Channels

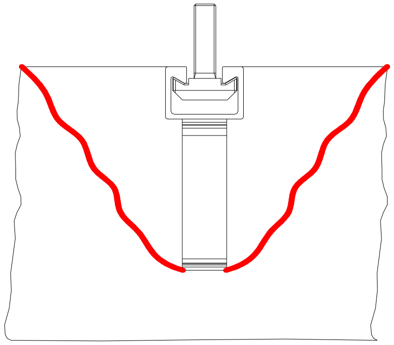
- Tensile loading



Local flexure of channel lips

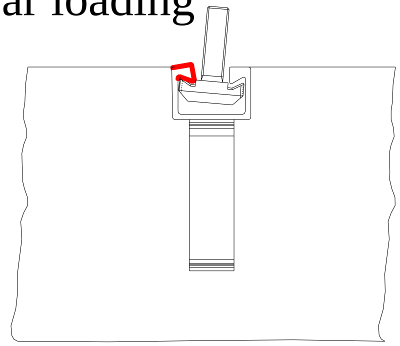


Bolt failure

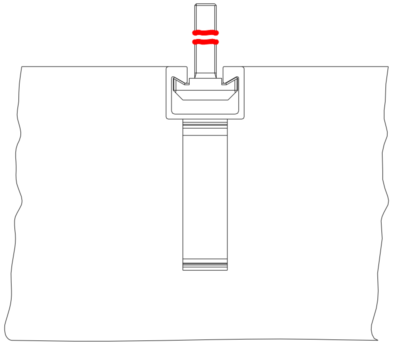


Concrete cone failure

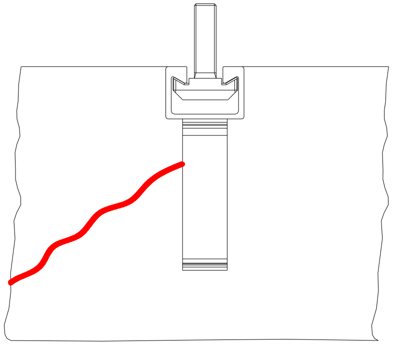
- Shear loading



Local flexure of channel lips



Bolt failure



Concrete edge failure

Pushout Tests: Experimental Test Matrix

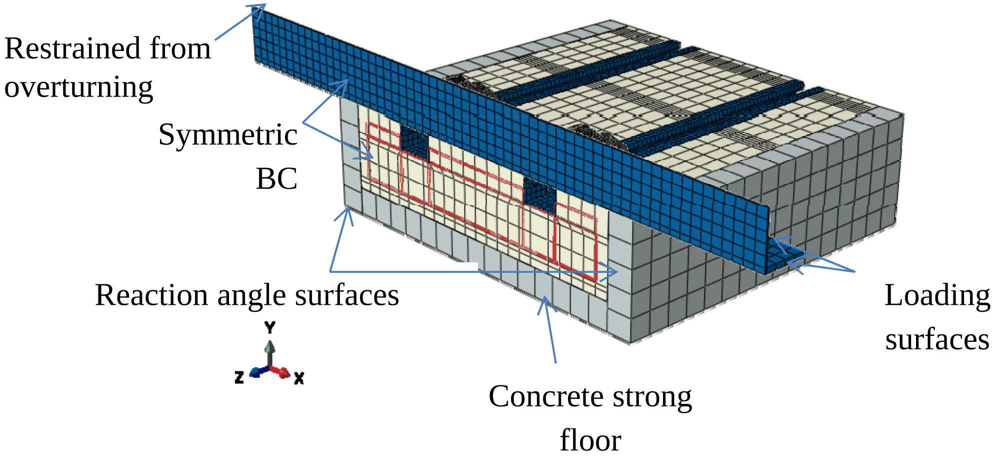
Name	Number of channels		Rebar configuration		Loading		Pretension		Shim		Intended Failure modes		
	2	3	Light	Heavy	Monotonic	Cyclic	Small	Large	Yes	No	Concrete failure	Channel lips failure	Slip of clamps
2-RH-LM-PS-SN	✓			✓	✓		✓			✓			✓
2-RL-LM-PS-SN	✓		✓		✓		✓			✓	✓		
2-RH-LM-PL-SN	✓			✓	✓			✓		✓		✓	
2-RH-LM-PS-SY	✓			✓	✓		✓		✓				✓
2-RH-LC-PS-SN	✓			✓		✓	✓			✓			✓
2-RH-LC-PS-SY	✓			✓		✓	✓		✓				✓
3-RH-LM-PS-SN		✓		✓	✓		✓			✓			✓
3-RH-LM-PS-SY		✓		✓	✓		✓		✓				✓

Pushout Tests: Computational Simulation

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.

Boundary conditions and load application



Interaction

- Frictional coefficient: 0.3, except for the contact between the plank and the concrete strong floor, which is frictionless
- Rebar: embedded in the concrete plank

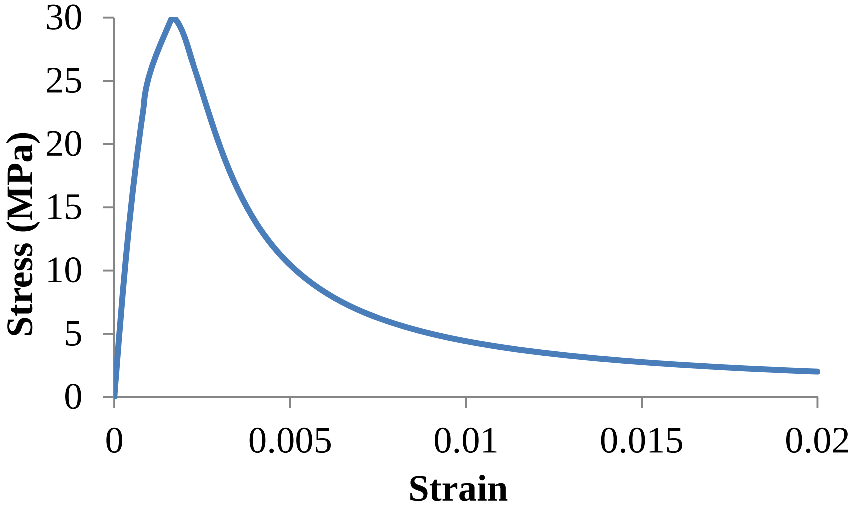
Pushout Tests: Constitutive Relations

Material constitutive model

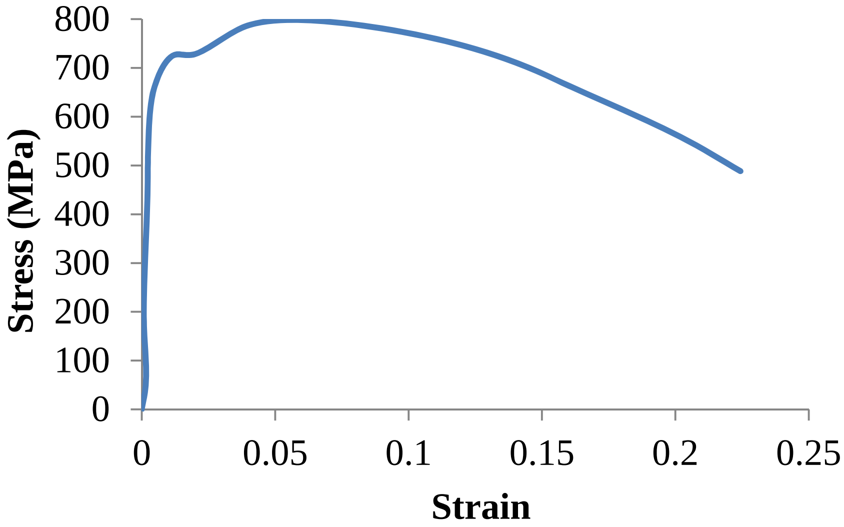
- Concrete damaged plasticity model
  - Failure mechanism: tensile cracking and compressive crushing
  - Capture stiffness recovery due to crack opening and closing under cyclic loading

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

- Bolts: A325 bolts (Grade 8.8 bolts)

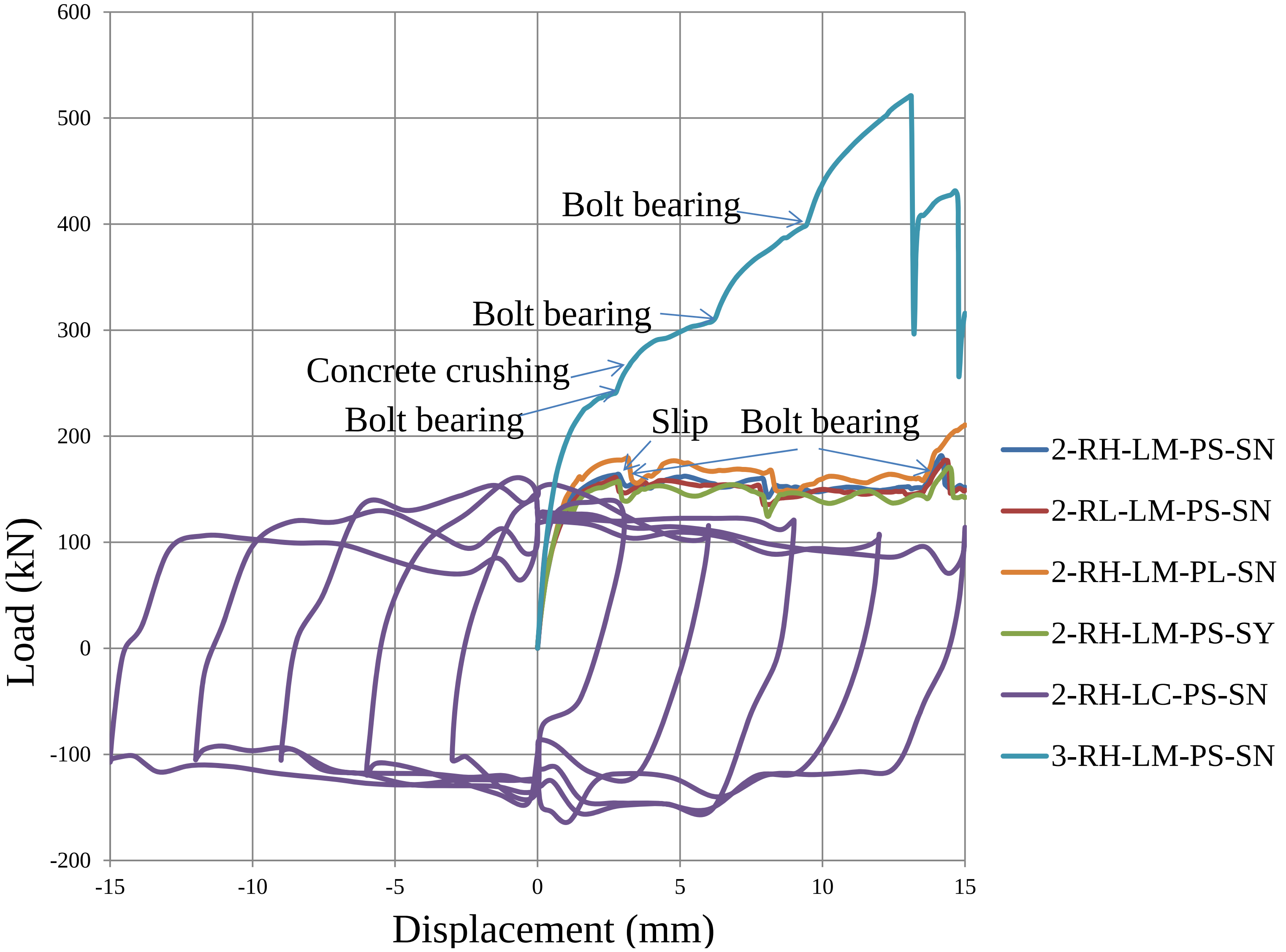


C30 concrete compressive behavior

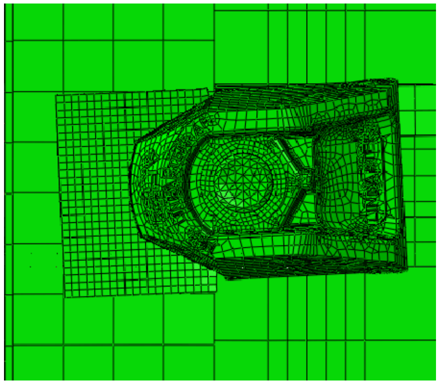


Bolt material stress-strain curve

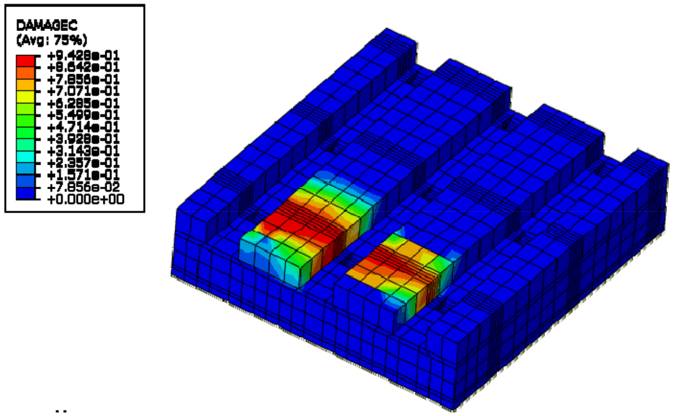
Pushout Tests: Computational Simulation Results



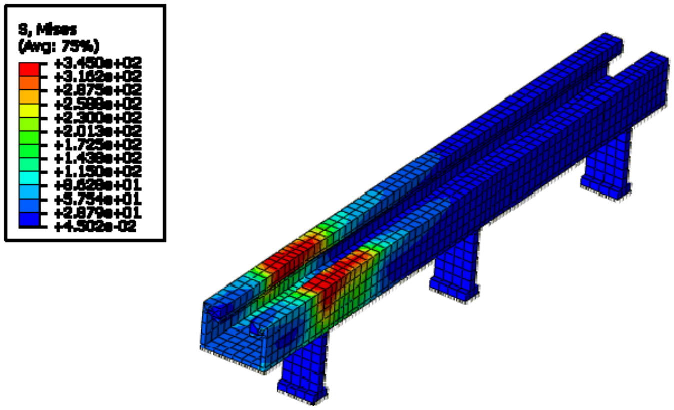
Pushout Tests: Limit States Observed in Computational Simulation



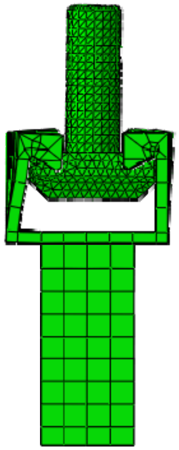
Slip of clamp and shim



Compressive damage in the concrete plank with three channels



Local yielding of channel lips



Bolt bearing against the channel

Conclusions

- A new deconstructable composite floor system, consisting of steel framing, precast concrete planks and clamping connectors, is presented.
- The clamping connector has a relatively high ultimate strength and behave ductile; therefore, they can be used as connectors in composite beams.
- Using shims for thin flange sections reduces the frictional strength slightly.
- As a result of damage accumulation in concrete, the strength of the connector reduces under cyclic loading. Three channel configuration fails by concrete crushing.

Acknowledgement

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- **American Institute of Steel Construction**
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- **Simpson Gumpertz and Heger, Inc.**

Questions?