Deconstructable Steel-Concrete Shear Connection for Sustainable Composite Floor Systems

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**Introduction**

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**

- Extraction → Manufacturing → Construction → Operation → Deconstruction → Disposal

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**Image from US Energy Information Administration (2011)**
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.

### Figure 1: Deconstructable composite beam prototype

- **Precast concrete plank**
- **Steel beam**
- **Cast-in channels**
- **Tongue and groove side joint**
- **Clamps**
- **Bolts**

### Figure 2: Precast concrete plank cross section

- **a) Plank perpendicular to the steel beam**
- **b) Plank parallel to the steel girder**

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Design for Deconstruction: Prototype Structural System

Typical floor plan for DfD system

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**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 Tests: Experimental Test Setup

Elevation view

Plan view

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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

<table>
<thead>
<tr>
<th>Name</th>
<th>Number of channels</th>
<th>Rebar configuration</th>
<th>Loading</th>
<th>Pretension</th>
<th>Shim</th>
<th>Intended Failure modes</th>
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**Introduction**

**DfD Floor System**

**Clamp Connector Behavior**

**Conclusions**
**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)

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[Graphs showing stress-strain curves for C30 concrete and bolt material]
Pushout Tests: Computational Simulation Results

-200
-100
0
100
200
300
400
500
600

-15 -10 -5 0 5 10 15

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
3-RH-LM-PS-SN

Bolt bearing
Concrete crushing
Bolt bearing
Slip
Bolt bearing

Load (kN)
Displacement (mm)
**Pushout Tests: Limit States Observed in Computational Simulation**

- Slip of clamp and shim
- Local yielding of channel lips
- Compressive damage in the concrete plank with three channels
- Bolt bearing against the channel

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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.
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Questions?