Performance of Deconstructable Shear Connectors in Sustainable Composite Floor Systems

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Sustainable Building Systems

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:

1. Extraction → Manufacturing → Construction → Operation → Deconstruction → Disposal

Design for Deconstruction

Image from US Energy Information Administration (2011)
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.

### Diagrams

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

#### Deconstructable composite beam prototype

**Precast concrete plank cross section**

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

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| Introduction | DfD Floor System | Clamp Connector Behavior | Conclusions |
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

Example of deconstructable bolted connection

ConXtech moment connection

Image from ConXtech Website
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

Fixed BCs

Elevation View

Stiffened W6x25

Built-up steel guide

WT5x30 or WT4x15.5

Stiffened C15x50

Load

24"

60°

Fixed BCs

Pushout test setup and primary instrumentation

Plan View

Fixed BCs

Stiffened W6x25

Stiffened C15x50

Load

Fixed BCs

WT5x30 or WT4x15.5
# Pushout Test Matrix

<table>
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<tr>
<th>Name</th>
<th>Bolt diameter</th>
<th>Number of channels</th>
<th>Reinforcement configuration</th>
<th>Test parameters</th>
<th>Number of turns</th>
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<td>3</td>
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</table>
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:
  - Emulate AISC 341-10 K2.4b “Loading Sequences for Beam-to-Column Moment Connection”
  - Load control until a slip of 0.02”, then switch to displacement control
**Pretension Test Results**

- 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

Results of bolt pretension test

- A significant decrease in the average axial strain indicate that the bolt head or concrete has cracked
- Axial force is estimated assuming the material unloads elastically

Two complete turns after snug-tight position is recommended
Monotonic Test Results

- Average peak strength for one clamp connector is \(~22\) kips, comparable to \(~21.5\) kips for a \(\frac{3}{4}\)" shear stud embedded in 4 ksi solid concrete slab
- Clamps behave in a ductile manner
- High initial stiffness prior to sliding leads to reduced deflection under serviceability loading
- Test with shim oscillates due to stick-slip mechanism and used 3 turns-of-the-nut, resulting in premature bolt fracture

![Load-Slip Curve](image)

Cracks on concrete surface due to frictional forces
**Cyclic Test Results**

- The peak load reduces due to lowering of coefficient of friction, but through pinching behavior at larger slips retains much of its strength.
- No significant difference is observed between the load-slip curves of the heavy reinforcement and light reinforcement specimens.
- Clamps have the potential to connect composite diaphragms and collector beams because of the capacity to dissipate energy without damaging steel beams and concrete slabs.
Load Distribution Due to Clamps

- Transfer of force clearly seen based on force estimates at beam cross sections based on strain gages on flange and web of beam
- Measured estimation of axial forces approximate the estimated actuator force at each cross section (+ = pulling to the left; - = pushing to the right)
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 have been conducted to evaluate the effects of different parameters and formulate strength design equations for the clamping system; composite beam tests will be conducted in the next phase of work

• Two complete turns after snug-tight position is recommended for pretensioning the T bolts in the DfD plank system

• The usage of shims does not reduce the peak strength, but the using a steel shim exhibits undesirable stick-slip behavior

• The clamping connectors are highly robust under monotonic loading - compared to shear studs that fracture at much smaller slips, the clamping connectors can retain almost 80% of the peak strength even at 5 in. slip under monotonic loading

• Due to reduction of frictional coefficients as a result of the abrasion of the clamp teeth and steel flange, the strength of the specimens under cyclic loading reduces by about 20-30% at large slips compared to monotonic loading, but may be addressed in design
Thank You

Precast concrete plank

Cast-in channels

Steel beam

Tongue and groove side joint

Clamps

Deconstructable composite beam prototype

Spreader system

Bolts

Pre-cast Concrete Planks

Composite beam test setup