Improvement of the Cyclic Bending Behavior of HSS Members Through Foam Fill

C. Flores Carreras\textsuperscript{1}, L. Alfaro\textsuperscript{1}, D. Wei\textsuperscript{1}, and J. McCormick\textsuperscript{2}

\textsuperscript{1}Graduate Student Researcher
\textsuperscript{2}Assistant Professor

\textsuperscript{1,2}Dept. of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI 48109-2125
Agenda

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- Experimental Test Setup
  - Test Specimens
  - Instrumentation
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  - Filled to Unfilled Comparison
  - Hysteretic Behavior
  - Energy Dissipation
Hollow Structural Sections

- HSS have various favorable properties for seismic applications:
  - Good compressive, bending, and torsional strength
  - High strength to weight ratio
  - Provide voids that can be easily filled

- Previous work shows potential for HSS-based seismic moment frames:
  - HSS bending studies
  - HSS-to-HSS seismic moment connection development
Motivation behind the Research

• Steel moment frames rely on the formation of plastic hinges to dissipate seismic input energy.

• Local buckling in the plastic hinge region can severely limit the performance of steel moment frames.

• A lightweight polyurethane-based foam fill can help inhibit local buckling of HSS members and provide added energy dissipation capacity.
Research Objectives

- Better understand the behavior of a foam-filled HSS member.
- Determine potential benefits of a polyurethane-based foam fill in steel moment frames.
- Address effectiveness of a foam fill with regards to potentially relaxing width-thickness and depth-thickness requirements.
Polyurethane Foam

- Polyurethane-based expanding foam that is unique to structural engineering applications.
- High strength to weight ratio and energy absorption properties.
- Consists of two liquid components that are mixed together.

Manufacturer Reported Mechanical Properties – 256 kg/m³

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Parallel Compressive Strength</td>
<td>4.00 MPa</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>3.10 MPa</td>
</tr>
<tr>
<td>Shear Strength</td>
<td>1.59 MPa</td>
</tr>
<tr>
<td>Flexural Strength</td>
<td>5.17 MPa</td>
</tr>
<tr>
<td>Expansion Rate (at 26.7°C)</td>
<td>4.0 x Vol.</td>
</tr>
</tbody>
</table>

Properties from: [www.uscomposites.com/foam.html](http://www.uscomposites.com/foam.html)
Characterization of Mechanical Properties

- 38.1 mm cube specimens tested under monotonic and increasing cyclic compression.
- Overall behavior categorized by three phases: initial elastic phase, intermediate plateau due to crushing, and stiffening phase due to consolidation after crushing.
Test Specimens

- The different section sizes allow different width-thickness and depth-thickness ratios to be considered.
- For each section size, an empty and polyurethane-based foam filled beam is considered.

### Relevant HSS Member Properties

<table>
<thead>
<tr>
<th>HSS Member</th>
<th>t</th>
<th>b</th>
<th>h</th>
<th>A</th>
<th>Expected $M_p$</th>
<th>Theoretical $L_p$</th>
<th>b/t</th>
<th>h/t</th>
</tr>
</thead>
<tbody>
<tr>
<td>203.2x152.4x6.4</td>
<td>6.4</td>
<td>152.4</td>
<td>203.2</td>
<td>3980</td>
<td>123</td>
<td>247.7</td>
<td>22.8</td>
<td>31.3</td>
</tr>
<tr>
<td>203.2x203.2x6.4</td>
<td>6.4</td>
<td>203.2</td>
<td>203.2</td>
<td>4580</td>
<td>149</td>
<td>121.4</td>
<td>31.3</td>
<td>31.3</td>
</tr>
<tr>
<td>254.0x152.4x6.4</td>
<td>6.4</td>
<td>152.4</td>
<td>254.0</td>
<td>4580</td>
<td>172</td>
<td>271.5</td>
<td>22.8</td>
<td>39.9</td>
</tr>
</tbody>
</table>

Meet moderately ductile slenderness limits.
Experimental Test Setup

- Lateral displacements are applied through a slotted hole connection at the free end.

- Foam length spans 1.5 times the theoretical plastic hinge length of the HSS, starting at the fixed end.

- Loading protocol follows the AISC Seismic Provisions for prequalifying connections for seismic frames.
Instrumentation

- Multiple strain gauges on the top and bottom flanges of the beams.

- Grid of optical tracking markers is used to measure the displacement and rotation of the specimen.

- Whitewash is applied to the back and sides of the HSS to visualize yielding.
Experimental Test Results

- All specimens experience the onset of local buckling and moment capacity degradation.
- At the 0.06 rad. cycle, the extent of the local buckling is restrained in the foam-filled beams.
- Typically, the filled specimens experience less tearing by the end of the test.

Unfilled HSS 254.0x152.4x6.4

Filled HSS 254.0x152.4x6.4
Hysteretic Behavior

- Foam has little influence on maximum strength, initial stiffness, and unloading stiffness.
- The foam fill leads to less degradation of the moment capacity with continued cycling.
- Clear connection between element slenderness ratio and degree of influence of the foam fill.
Hysteretic Behavior (cont.)

Moment vs. Rotation – HSS 203.2x203.2x6.4

Moment vs. Rotation – HSS 254.0x152.4x6.4
Hysteretic Behavior (cont.)

Moment vs. Rotation – HSS 203.2x203.2x6.4

Moment vs. Rotation – HSS 254.0x152.4x6.4
Energy Dissipation

- Clear increase in energy dissipation due to foam fill.
- The foam fill allows for larger moments to be maintained, leading to large hysteresis curves and more dissipated energy.
- At large rotations, the foam starts to crush and dissipates energy.
Energy Dissipation (cont.)

Dissipated Energy vs. Rotation
HSS 203.2x203.2x6.4

Dissipated Energy vs. Rotation
HSS 254.0x152.4x6.4
Conclusions

- HSS beams filled with a polyurethane-based foam exhibit less moment capacity degradation and dissipate more energy.

- The foam fill helps inhibit local buckling in the member.

- Results suggest a foam infill can potentially lead to a relaxation of current slenderness requirements.
Acknowledgements

• National Science Foundation
  • CMMI – 1334272
  • CMMI – 1350605

• Students
  • Carolyn McCann
Thank You