Experiments on Braced Thin-Walled Cold-Formed Steel C and Z Beams in Flexure

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acknowledgments

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  – AISI and MBMA
  – CECO Buildings, VP Buildings, Clark Steel

• People
  – Cheng Yu - graduate RA
  – Sam Phillips - undergraduate RA
  – Liakos Ariston - undergraduate RA
  – Jack Spangler - technician
  – Chuck Pearson - Prosser Steel
overview

- Background
- Objective
- Setup
- Typical results
- Influence of details
- Preliminary results
- Continuing work
background / motivation

• Effective width of a web of a cold-formed steel beam?
• Unification of design? North American Specification
• American (AISI) vs. Canadian (S136) method
• AISI expressions inconsistent and discontinuous
• AISI predicted strength > S136 predicted strength
• Industry skeptical of academic test data showing problems with AISI predicted strength
• Definitive testing needed
local buckling with web/flange interaction

\[ \xi = 3 \]
\[ \xi = 2 \]
\[ \xi = 1.4 \]
\[ \xi = 1 \]

\[ \xi = 2, \text{ pure bending} \]

Plate buckling coefficient for the flange \( k \)

Ratio of web height to flange width (\( h/b \))
objective

• New tests are needed to provide direction for the Specification and definitively determine the role of local web/flange interaction for the web effective width

• Requirements
  – Simple repeatable tests on industry ‘C’s and ‘Z’s
  – Account for issues in practice related to local buckling of these members, such as attachment to sheeting
  – Focus on local buckling limit states
  leave distortional and lateral buckling issues for later
### Testing Matrix

- **Dimensions:** h, b, d, t.
- **Isolation of h/t variation sought**
- **MBMA ‘Z’s (purlins):** h,b,d, fixed, t varied
- **SSMA ‘C’s (studs, joists):** b,d fixed, h and t varied

<table>
<thead>
<tr>
<th>Tests to be performed</th>
<th>num</th>
<th>h/t min</th>
<th>max</th>
<th>h/b min</th>
<th>max</th>
<th>b/t min</th>
<th>max</th>
<th>d/t min</th>
<th>max</th>
<th>d/b min</th>
<th>max</th>
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</thead>
<tbody>
<tr>
<td>bracing configuration</td>
<td>3</td>
<td>71</td>
<td>144</td>
<td>3.4</td>
<td>same</td>
<td>21</td>
<td>42</td>
<td>8</td>
<td>13</td>
<td>0.28</td>
<td>0.41</td>
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<tr>
<td>Z: h,b,~d fixed, t varied</td>
<td>7</td>
<td>96</td>
<td>158</td>
<td>3.3</td>
<td>same</td>
<td>29</td>
<td>48</td>
<td>8</td>
<td>13</td>
<td>0.26</td>
<td>0.29</td>
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<tr>
<td>Z: h,b,~d fixed, t varied</td>
<td>5</td>
<td>82</td>
<td>242</td>
<td>4.0</td>
<td>same</td>
<td>21</td>
<td>61</td>
<td>6</td>
<td>19</td>
<td>0.31</td>
<td>same</td>
</tr>
<tr>
<td>C: h,b,d fixed, t varied</td>
<td>5</td>
<td>67</td>
<td>222</td>
<td>1.8</td>
<td>6.0</td>
<td>37</td>
<td>same</td>
<td>12</td>
<td>same</td>
<td>0.31</td>
<td>same</td>
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<tr>
<td>miscellaneous</td>
<td>4</td>
<td>67</td>
<td>242</td>
<td>1.8</td>
<td>6.0</td>
<td>21</td>
<td>61</td>
<td>6</td>
<td>19</td>
<td>0.26</td>
<td>0.41</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>29</td>
<td>67</td>
<td>242</td>
<td>1.8</td>
<td>6.0</td>
<td>21</td>
<td>61</td>
<td>6</td>
<td>19</td>
<td>0.26</td>
<td>0.41</td>
</tr>
</tbody>
</table>
members

8.5° Z Typical

11.5° Z Typical

Minimum Depth C

Maximum Depth C

Cross-Section of C and Z Members to be Tested

BWS
16 October 2000
testing setup

standard decking fastened through flanges of purlins to retard lateral and distortional buckling. Fastener patterns and spacing investigated.

spreader beam to apply the load at 1/3 points

tubes at ends and at support points bolting the two specimens together, top of tube flush with top of purlin to avoid crippling at loading point.

1 1/4 x 1 1/4 x 0.057 angles connecting tension flanges of 2 specimens to insure they act as a unit 12” on center

4x4x1/4 angles bolted to end plates and specimens to avoid crippling at ends.

each span is 5’ 4” on center. Length is selected considering: shear demands, actuator capacity, actuator stroke, and future testing (dist. buckling when panel is removed)
typical online results
elastic buckling modes

local
\( \frac{1}{2} \lambda \sim 5 \text{ in.} \)

distortional
\( \frac{1}{2} \lambda \sim 20 \text{ in.} \)
elastic buckling

- Local Elastic
- Distortional Elastic

h=8.5 in.
b=2.5 in.
d=0.8 to 1.0 in.
t=0.059 in. to 0.120 in.
\( f_y = 60 \text{ ksi} \)
continuous spring analysis (finite strip)
fe (elastic) model to develop detail
distortional predicted as lowest eigenmode
(single screw pattern, t=0.073 in.)

panels removed for visual purposes only
influence of details
local predicted as lowest eigenmode
(paired screw pattern, t=0.073 in.)

panels removed for visual purposes only
influence of details

<table>
<thead>
<tr>
<th>Specimen</th>
<th>$M_{\text{test}}/M_y$</th>
<th>$M_{\text{test}}/M_{\text{aisi}}$</th>
<th>note</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.5Z073-5E6W</td>
<td>0.78</td>
<td>0.86</td>
<td>single panel-to-purlin screws - 12&quot; o.c.</td>
</tr>
<tr>
<td>8.5Z073-1E2W</td>
<td>0.80</td>
<td>0.88</td>
<td>single panel-to-purlin screws on both sides of raised corrugation</td>
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<tr>
<td>8.5Z073-4E3W</td>
<td>0.86</td>
<td>0.96</td>
<td>paired panel-to-purlin screws on both sides of raised corrugation</td>
</tr>
</tbody>
</table>
prediction of 8.5 in. ‘Z’s

web slenderness (h/t)

M/M_y

AISI (1996)
direct strength: distortional
direct strength: local
prediction of 8.5 in. ‘Z’s
comments

• web/flange interaction
• details
• ongoing work
  – testing on ‘C’\’s
  – improved monitoring of testing
  – numerical modeling and extension of results
  – refining design methodology
• future
  – remove panels, allow distortional buckling
  – move away from effective width?
### Detailed Testing Plan

<table>
<thead>
<tr>
<th>Out-to-out-dimensions</th>
<th>Inner Dimensions</th>
<th>Non-dimensional Ratios Studied</th>
</tr>
</thead>
<tbody>
<tr>
<td>h (in.)</td>
<td>b (in.)</td>
<td>d (in.)</td>
</tr>
<tr>
<td>8.5</td>
<td>2.5</td>
<td>0.71</td>
</tr>
<tr>
<td>8.5</td>
<td>2.5</td>
<td>0.78</td>
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<td>8.5</td>
<td>2.5</td>
<td>0.92</td>
</tr>
<tr>
<td>8.5</td>
<td>2.5</td>
<td>0.94</td>
</tr>
<tr>
<td>8.5</td>
<td>2.5</td>
<td>0.96</td>
</tr>
<tr>
<td>8.5</td>
<td>2.5</td>
<td>0.98</td>
</tr>
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<td>2.5</td>
<td>1.01</td>
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<tr>
<td>11.5</td>
<td>3.5</td>
<td>0.92</td>
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<tr>
<td>11.5</td>
<td>3.5</td>
<td>0.94</td>
</tr>
<tr>
<td>11.5</td>
<td>3.5</td>
<td>0.96</td>
</tr>
<tr>
<td>11.5</td>
<td>3.5</td>
<td>0.98</td>
</tr>
<tr>
<td>11.5</td>
<td>3.5</td>
<td>1.01</td>
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<tr>
<td>8</td>
<td>2</td>
<td>0.63</td>
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<tr>
<td>8</td>
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<td>0.63</td>
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<td>0.63</td>
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<tr>
<td>12</td>
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<td>0.63</td>
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<tr>
<td>10</td>
<td>2</td>
<td>0.63</td>
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<tr>
<td>8</td>
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<td>0.63</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>0.63</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>0.63</td>
</tr>
<tr>
<td>3.62</td>
<td>2</td>
<td>0.63</td>
</tr>
</tbody>
</table>

AISI and S136 different
typical results

Result of test 85Z059-2E1W at LVDT

North (1.371e+000, 3.090e+000)
South (1.346e+000, 3.090e+000)

North k=2.276e+000 (kips/in.)
South k=2.265e+000 (kips/in.)
influence of details

<table>
<thead>
<tr>
<th>Specimen</th>
<th>$M_{test}/M_y$</th>
<th>$M_{test}/M_{aisi}$</th>
<th>note</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.5Z059-1E2W</td>
<td>0.81</td>
<td>0.95</td>
<td><strong>paired</strong> panel-to-purlin screws on both sides of raised corrugation and in pan</td>
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<tr>
<td>8.5Z059-4E3W</td>
<td>0.83</td>
<td>0.99</td>
<td><strong>paired</strong> panel-to-purlin screws on both sides of raised corrugation</td>
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</table>
## Industry vs. Academia?

<table>
<thead>
<tr>
<th></th>
<th>h/t</th>
<th>b/t</th>
<th>d/t</th>
<th>h/b</th>
<th>d/b</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>min</td>
<td>max</td>
<td>min</td>
<td>max</td>
<td>min</td>
</tr>
<tr>
<td>MBMA Z’s</td>
<td>53</td>
<td>170</td>
<td>17</td>
<td>47</td>
<td>5</td>
</tr>
<tr>
<td>SSMA members</td>
<td>25</td>
<td>318</td>
<td>11</td>
<td>132</td>
<td>1</td>
</tr>
<tr>
<td>Rack members</td>
<td>23</td>
<td>136</td>
<td>16</td>
<td>45</td>
<td>6</td>
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<tr>
<td>Elhouar and Murray (1985)</td>
<td>68</td>
<td>165</td>
<td>24</td>
<td>52</td>
<td>3</td>
</tr>
<tr>
<td>Schafer and Peköz (1999)</td>
<td>43</td>
<td>270</td>
<td>15</td>
<td>75</td>
<td>3</td>
</tr>
</tbody>
</table>

### Available Members

- h/b = 1.0
- 3.3
- 10.0

### Experimental Data