Buckling-Restrained Brace Stability Evaluation, Empirical Basis and Design Implications

B. Sitler¹, T. Takeuchi², R. Matsui²

¹PhD Candidate, Tokyo Institute of Technology
²Professor, Tokyo Institute of Technology
³Assistant Professor, Tokyo Institute of Technology

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Capacity based design of BRBs

Ultimate capacity governed by:

1. Connection buckling
2. Restrainer bulging
3. Restrainer buckling
4. Other

Undesirable failure modes:

1. Connection buckling
2. Restrainer bulging
3. Restrainer buckling
4. Other:
   - Gusset buckling
   - Connection/splice tensile fracture
   - Adj. frame fracture
Thornton with $k_e = 2.0$


Nakamura’s proposal


Lanning J. (2012) *Using BRBs on long-span bridges near faults.* PhD, UCSD.

Hikino T, et al. (2013) *O.O.P. stability of BRBs placed in chevron arr., EESD.*


\[ N_{cr} = \frac{K_{rg}}{\xi L_0 (1 - \xi)} \]

\[ \text{Ultimate plastic capacity} \]

\[ N_{lim1} = \frac{(M_P^r - M_0^r)}{a_r N_{cr}^r} + N_{cr}^r \]

\[ N_{lim2} = \frac{((1-2\xi)M_P^g + M_P^r - 2M_0^r))}{a_r N_{cr}^g + 1} \]

\[ N_{cr} = \min \left( N_{lim1}, N_{lim2} \right) \]
Modified Eurocode

Summary

- **Global** buckling, not local gusset buckling
- Key parameters: rotational end fixity (gusset stiffness), restrainer end continuity, neck area
- Two widely used methods are **unconservative**:

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean</th>
<th>Stdev</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thornton ($k_e=2.0$)</td>
<td>$+70%$</td>
<td>$70%$</td>
<td>not safe</td>
</tr>
<tr>
<td>Nakamura</td>
<td>$+40%$</td>
<td>$70%$</td>
<td>not safe</td>
</tr>
<tr>
<td>Koetaka / Hikino / Lanning</td>
<td>$-60%$</td>
<td>$20%$</td>
<td>(usually) very safe, simple</td>
</tr>
<tr>
<td>Takeuchi / Zaboli</td>
<td>$+0%$</td>
<td>$30%$</td>
<td>safe, complex</td>
</tr>
<tr>
<td>Modified Euro.</td>
<td>$-20%$</td>
<td>$20%$</td>
<td>safe, simple</td>
</tr>
</tbody>
</table>

\[ N_{cr} = \frac{N_y^n}{\phi + \sqrt{\phi^2 - \lambda^2}} \]

\[ \phi = 0.5(1 + c(\alpha + \alpha_{slack})(\lambda - 0.2) + \lambda) \]

\[ \beta \omega = 1 - 1.65 \]

\[ P\delta \text{ moment factor} \]

\[ \text{Perry-Robertson yield limit} \]

\[ \text{Unsure Safe} \]

Design Implications

Increase rotational end fixity (i.e. cantilever connection off of frame)

- Full-depth stiffeners
- Transverse beam
- chevron BRB

Increase restrainer end continuity (i.e. monolithic simply supported)

- Restrainer end insert length ratio: $L_{in} > 2 \cdot B_n$
- Similar conn. & rest. stiffness $\gamma EI_r > EI_r$
- Long insert length / stiff connections
- Neck ($A_e$) to core ($A_c$) areas $A_e / A_c \approx 2.0 ~ 3.6$
- Neck area $A_e$

- Full-depth stiffeners
- Gusset stiffeners

Gusset stiffeners

Connection O.O.P. stiffness $\gamma EI_r$

Core area $A_c$

Restrainer O.O.P. stiffness $EI_r$

$B_n$

$L_{in}$
Come see my Poster!

Today Poster Session:

- **Time**: 5:15 – 7:00 pm
- **Room**: Pasadena (Exhibit Hall)
- **Poster location**: Number 017