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

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Capacity based design of BRBs

Ultimate capacity governed by:

- Core tensile fracture
- Restrainer buckling
- Restrainer bulging
- Connection buckling

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.


AIJ (2018) *AIJ recommendations for stability design of steel structures*.

\[
\frac{N_{cr}}{N_{cr}} = \frac{K_{rg} (1 - 2\xi)}{\xi L_0 (1 - \xi)}
\]

\[
N_{cr} = \min \left( \frac{M_r P}{a_r N_{cr} B + 1}, \frac{(1-2\xi)M_p^g + M_r^p - 2M_0^r)}{a_r N_{cr} B + 1} \right)
\]

\[
N_{lim1} = \frac{(M_r^p - M_0^r)}{a_r + N_{cr}} + N_{cr} \frac{M_r^p - M_0^r}{a_r N_{cr} B + 1}
\]

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


\[
\beta \omega = 1.0 - 1.65
\]

\[
\text{Mean} = 0.4, \quad \text{Stdev} = 0.2
\]

\[
\text{Mean} = 1.0, \quad \text{Stdev} = 0.3
\]
Modified Eurocode

\[
\frac{N_{cr}^{calc}}{N_{cr}^{exp}} = \beta \omega = 1 \sim 1.65
\]

- **Unsafe**
- **Safe**

\[
\text{Mean } = 0.8 \quad \text{Stdev } = 0.2
\]

Perry-Robertson yield limit

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

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

- **P\delta** moment factor
- debonding gap imperf.


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>
Design Implications

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

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

Torsional bracing + Gusset stiffeners

Restraint end insert length ratio: $L_{in} > 2B_n$
Similar conn. & rest. stiffness $\gamma EI_r > EI_r$
Long insert length / stiff connections

Gusset stiffeners

Full-depth stiffeners

and/or

Connection O.O.P. stiffness $\gamma EI_r$
Core area $A_c$
Neck area $A_e$

$B_n$ $L_{in}$

Restrainer end continuity

$A_e / A_c \approx 2.0 \sim 3.6$

Large neck area

Increase restrainer end continuity

(i.e. monolithic simply simply supported)
Come see my Poster!

**Today Poster Session:**

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