30-years from the first application, BRBs are still actively researched and expanding in applications. This book is the first devoted specifically to BRBs.
Contents

Chapter 1: Composition and history of buckling-restrained braces
Chapter 2: Restrainer design and clearances
Chapter 3: Local bulging failure
Chapter 4: Connection design and global stability
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  7.5 Direct Connections to RC Frames
  7.6 Applications for truss and spatial structures
  7.7 Spine frame concepts

Appendix
  A1 Typical BRB details
  A2 Rotational spring at connections
  A3 BRB buckling capacity
1.1 Composition of buckling-restrained Braces (BRB)

Appearance of typical BRB

Concept of Buckling-restrained Brace

Types of restrainer
Chapter 1: Composition and history of Buckling-restrained Braces

Buckling-restrained Braces and Applications

Clearance and eccentricity

Development of higher buckling mode

Hysteresis of well-designed BRB
1.2 History of Development

The first application of Buckling-restrained Brace (Unbonded Brace, 1987)

Chapter 2: Restrainer Design and Clearances

**Quality Requirement for Hysteresis models**

- Inappropriate clearance
- Plastic strain concentration
- Local buckling
- Local bulging
- Uneven stiffness
- Uneven strength
- Degradation in compression side

**Bulging-induced failure**

- Slack (pin connection)
- Buckling
- Fracture
- Tearing

**Buckling-induced failure**
2. Restrainer Design and Clearance

Failure pattern and stability conditions

1. **Restrainer** successfully suppresses core first-mode buckling *(Chapter 2)*
2. **Debonding mechanism** decouples axial demands and allows for Poisson effects *(Chapter 2)*
3. **Restrainer wall bulging** due to higher mode buckling is suppressed *(Chapter 3)*
4. **Global out-of-plane stability** is ensured, including connection *(Chapter 4)*
5. **Low-cycle fatigue capacity** is sufficient for expected demands *(Chapter 5)*
3. Local Bulging Failure

in-plane local bulging failure

out-of-plane local bulging failure

(Tokyo Institute of Technology)

(National Center for Research on Earthquake Engineering)
4. Connection design and global stability

The AIJ Recommendations provide rigorous evaluation methods for BRB connection out-of-plane buckling. Two concepts below are presented:

1: Cantilevered gusset

2: Restrainer end continuity

### 5. Cumulative deformation capacity

(a) Ordinary Tube Brace

(b) Incomplete Buckling-restrained Brace

(c) Complete Buckling-restrained Brace

Local buckling distribution until fracture
6. Performance test specification for BRB

(a) ANSI/AISC 341-05 and US practice

<table>
<thead>
<tr>
<th>Cycle (Story drift angle)</th>
<th>Inelastic Deformation ( (\Delta_{by} = 4\Delta_{by}) )</th>
<th>Cumulative strain ( (\Delta_{by} = 0.25%) )</th>
<th>Cumulative Inelastic strain</th>
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<tbody>
<tr>
<td>( \Delta_{by} \times 2 )</td>
<td>( = 2 \times 4 \times (\Delta_{by} - \Delta_{by}) = 0\Delta_{by} )</td>
<td>( = 2 \times 4 \times 0.25 = 2% )</td>
<td>( = 2 \times 4 \times 0 = 0% )</td>
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<tr>
<td>( 0.5\Delta_{bm} \times 2 )</td>
<td>( = 2 \times 4 \times (2\Delta_{by} - \Delta_{by}) = 8\Delta_{by} )</td>
<td>( = 2 \times 4 \times 0.5 = 4% )</td>
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<tr>
<td>( 1.0\Delta_{bm} \times 2 )</td>
<td>( = 2 \times 4 \times (4\Delta_{by} - \Delta_{by}) = 24\Delta_{by} )</td>
<td>( = 2 \times 4 \times 1.0 = 8% )</td>
<td>( = 2 \times 4 \times 0.75 = 6% )</td>
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<tr>
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<td>( = 2 \times 4 \times (6\Delta_{by} - \Delta_{by}) = 40\Delta_{by} )</td>
<td>( = 2 \times 4 \times 1.5 = 12% )</td>
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<tr>
<td>( 2.0\Delta_{bm} \times 2 )</td>
<td>( = 2 \times 4 \times (8\Delta_{by} - \Delta_{by}) = 56\Delta_{by} )</td>
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<td>( = 2 \times 4 \times 1.75 = 14% )</td>
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<tr>
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<td>( = 4 \times 4 \times 1.5 = 24% )</td>
<td>( = 4 \times 4 \times 1.25 = 20% )</td>
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Total = \( 208\Delta_{by} \) = 56\% = 52\%

(b) BCJ and Japanese practice

<table>
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<th>Cycle (Plastic length strain)</th>
<th>Inelastic Deformation ( (\Delta_{by} = 0.25%) )</th>
<th>Cumulative strain ( (\Delta_{by} = 0.25%) )</th>
<th>Cumulative Inelastic strain</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta_{by} \times 3 )</td>
<td>( = 3 \times 4 \times (\Delta_{by} - \Delta_{by}) = 0\Delta_{by} )</td>
<td>( = 3 \times 4 \times 0.25 = 3% )</td>
<td>( = 3 \times 4 \times 0 = 0% )</td>
</tr>
<tr>
<td>( 0.5% \times 3 )</td>
<td>( = 3 \times 4 \times (2\Delta_{by} - \Delta_{by}) = 8\Delta_{by} )</td>
<td>( = 3 \times 4 \times 0.5 = 6% )</td>
<td>( = 3 \times 4 \times 0.25 = 3% )</td>
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<tr>
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<td>( = 3 \times 4 \times 0.75 = 9% )</td>
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<td>( = 3 \times 4 \times 3.0 = 36% )</td>
<td>( = 3 \times 4 \times 2.75 = 33% )</td>
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</table>

Total = \( 264\Delta_{by} \) = 81\% = 66\%
Chapter 7.1: Damage Tolerant Concept

7.1 Damage tolerant concept

Triton Square Project
Chapter 7.1: Damage Tolerant Concept

Following Damage Tolerant Projects

Grand Tokyo North Tower

Election of Large BRBF
Grid skin structures

- Main Frame
  - Spiral Layout of Energy-dissipation
  - Fuses around Perimeter zones

- Open Space

- Energy Dissipation Brace

Solar-panel Envelope Structure
- Flexible and Lightweight structure over the main frame
7.3 Seismic retrofit with BRBs

Before Retrofit

5F
4F Laboratory Offices
3F
2F Drawing Rm.
1F Class Rm.
B1F Laboratories

Midorigaoka-1st Building Retrofit concept

Continuously Occupied
Adding Damper only

Inner Work in Summer Vacation
Carbon-fiber Reinforcement
+Additional Damper
Chapter 7.3: Seismic retrofit with BRBs

After Retrofit
7.5 Direct connections to RC frames

![Diagram of Braced frame with BRB connections]

- Out-of-plane restrained
- 2000 kN Actuator
- 1000 kN Actuator
- 40.4º
- Right BRB (Upper story)
- Left BRB (Lower story)
- For strut
- RC corbel
- Gusset plate
- Pre-stressing bolt

![Graphs showing force vs. axial deformation]
7.6 Applications for truss and spatial structures

a) Truss structures

Response Control for Truss Structures

Device Layout Types for Response-controlled Truss Structures
b) Roof structures

Horizontal Acceleration
Vertical Acceleration
Horizontal Input
Seismic Response of Raised Roof

(R-1) Roof with Dampers (R-2) Base Isolated
(R-3) Substructure with Dampers (R-4) Entire Base Isolation

Device Layout for Response-controlled Roof Structures
Chapter 7.7: Spine frame concepts

7.7 Spine frame concepts

- Buckling-restrained Braces and Applications