Steel Structures

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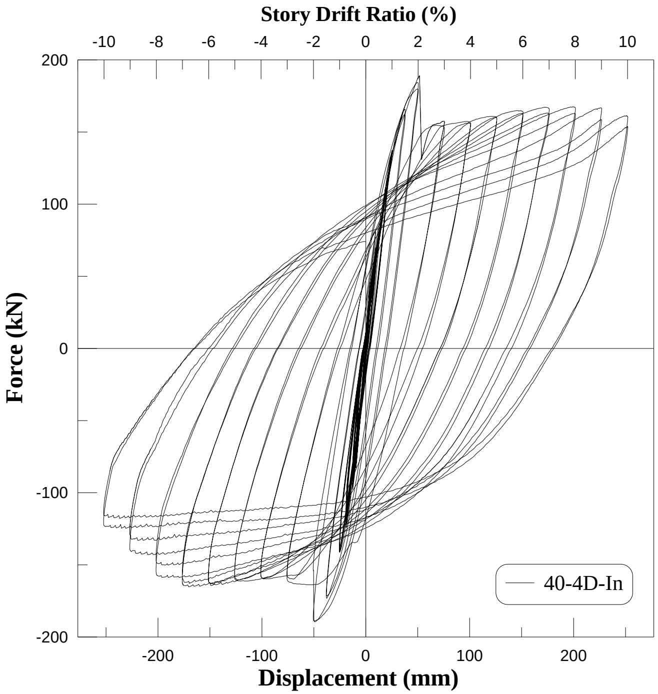
Basic requirements

- Strength
- Stiffness
- Ductility

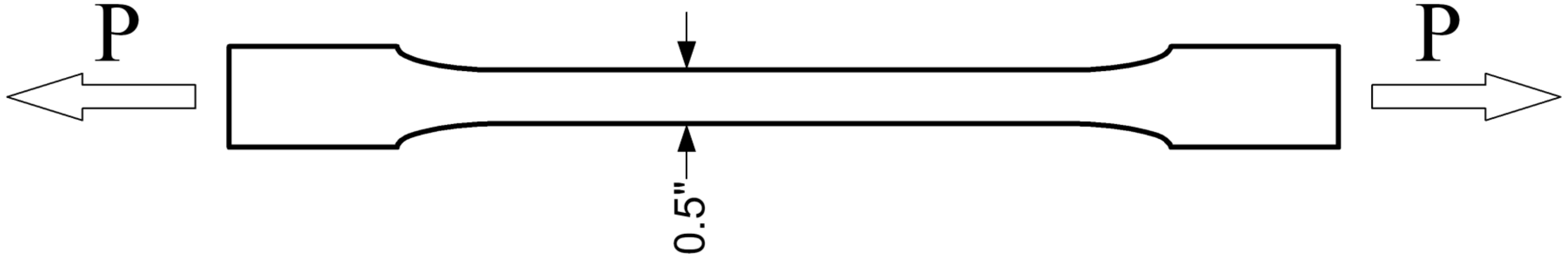


Steel Structures

- Applications→ Buildings, Bridges, etc.
- Composition of steel
  - Mild Carbon Steel→Iron≧98%, Carbon: 0.15~0.29%
  - Categorization of carbon steel
    - Low Carbon (C<0.15%)
    - Mild Carbon (C:0.15%~0.29%)
    - Medium Carbon (C:0.30%~0.59%)
    - High Carbon (C:0.6%~1.7%)
      - The higher the carbon is, the higher yield strength the steel is.

Determination of strength

- Coupon Test



Property of steel

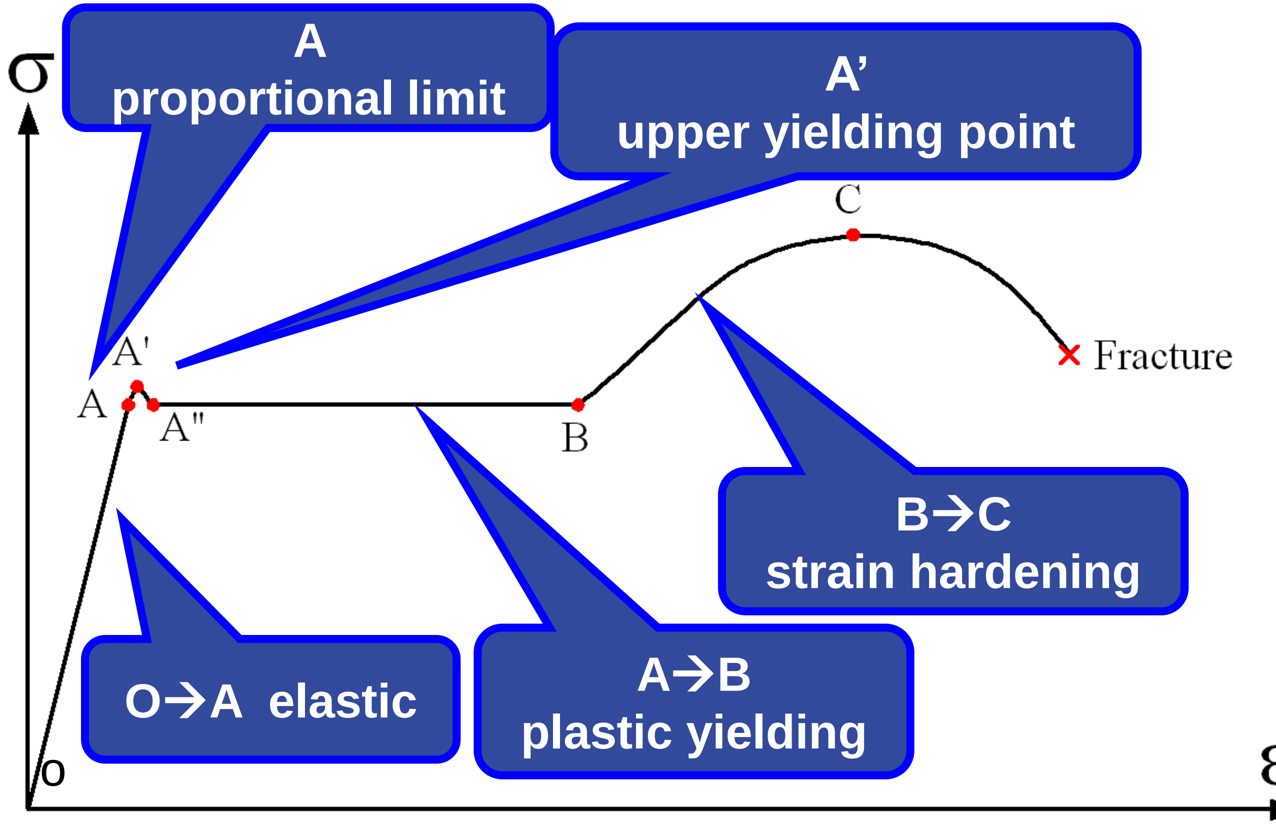
- Stress-strain

$$\sigma = P/A$$

$$\varepsilon = \Delta L/L$$

- Young's modulus

$$E = \sigma/\varepsilon$$



Steel shapes

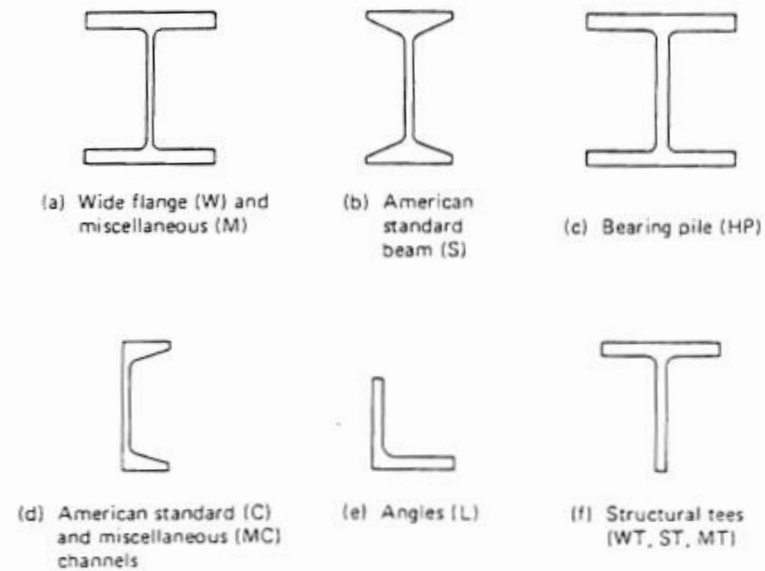


Figure 1-6 Hot-rolled steel shapes

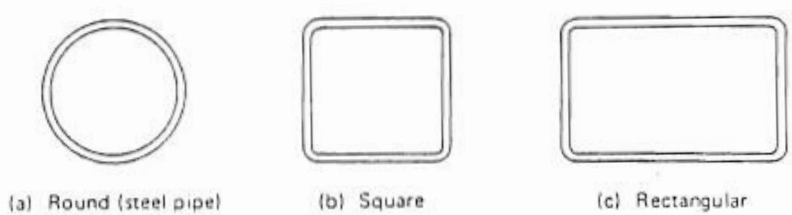


Figure 1-8 Structural steel tubing

Characteristics of steel

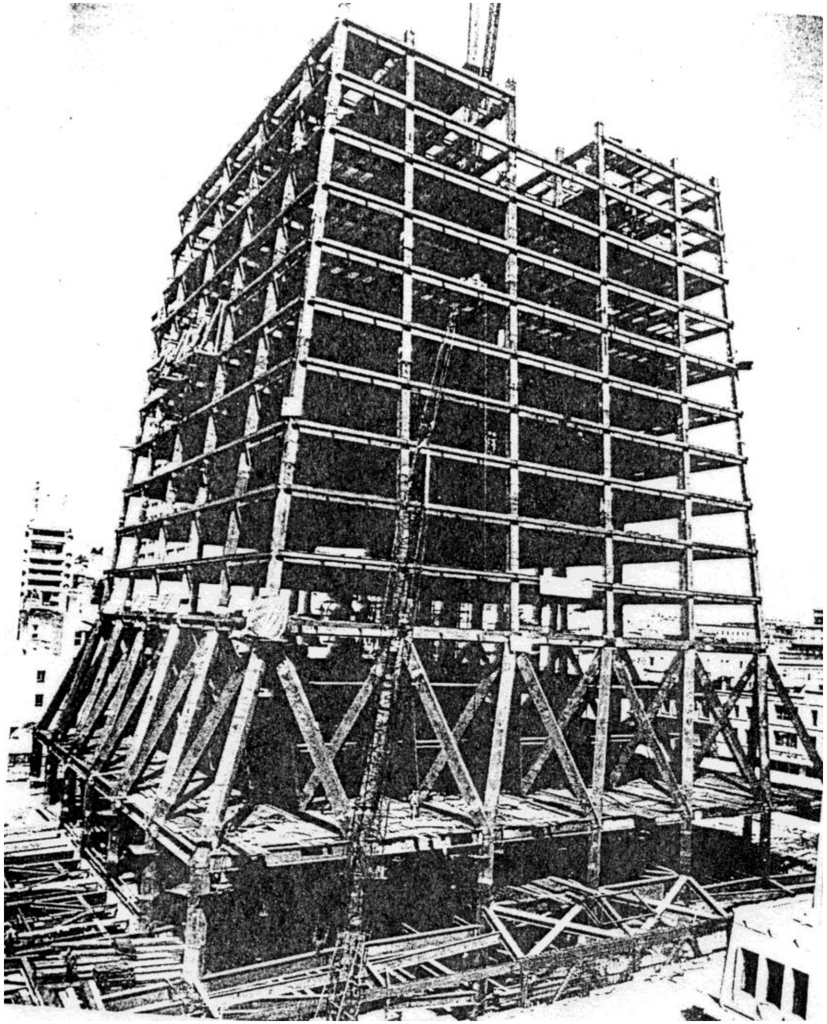
- **Advantages:**
  - High strength
  - Uniformity
  - Ductility
  - Ease of fabrication
  - Speed of erection

- **Disadvantages:**
  - Corrosion
  - Fireproofing
  - Buckling
  - Fatigue

By adequate design and maintenance
→Steel structures are effective structural forms.

Major components of steel structures

- Beams
- Columns
- Beam-Columns
- Bracings
- Connections



Major design concerns

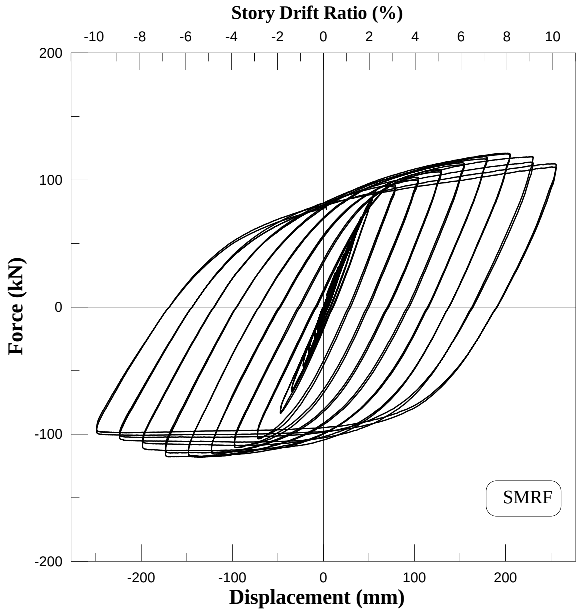
- Beam: Lateral torsional buckling
- Column: buckling (elastic, inelastic)
- Beam-column: P-Δ effect
- Brace: buckling
- Connection: strength, rigidity

Seismic design of steel structures

- Major concerns
  - Light weight →High Strength/Weight ratio
  - Structural symmetry should be considered
  - Adequate planning to avoid torsion
  - Center of mass should be close to center of rigidity
  - Avoid unnecessary opening

Ductility concern

- Structures should be able to dissipate seismic energy.
- If structural members are not strong enough to resist input force (remain elastic), they will enter inelastic stage and dissipate energy through inelastic deformation.
- Structures should sustain adequate strength (say, 80%) at large deformation.



Ductility concern

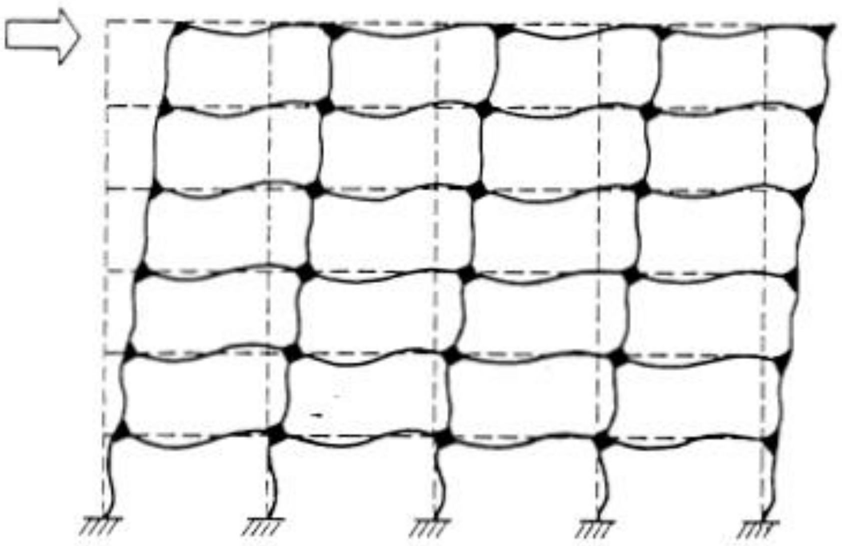
- Connection failures should be avoided.
- Select adequate structural forms and connection details.

Failure in welded connections.
(Source: Earthquake Engineering Research Institute)

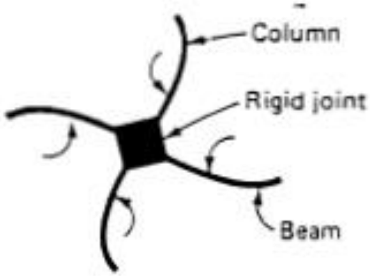
Typical steel structures

Rigid frames

- Beams and columns connected by rigid joints.
- Joints remain same shape when subject to bending.
- Earthquake energy dissipated through deformation of structural members.
- Story drift becomes too large when the structure is taller than 30 story.
- Heavy size of members will be used to reduce the drift when structure is taller than 30 story.
  - Less competitive in economy

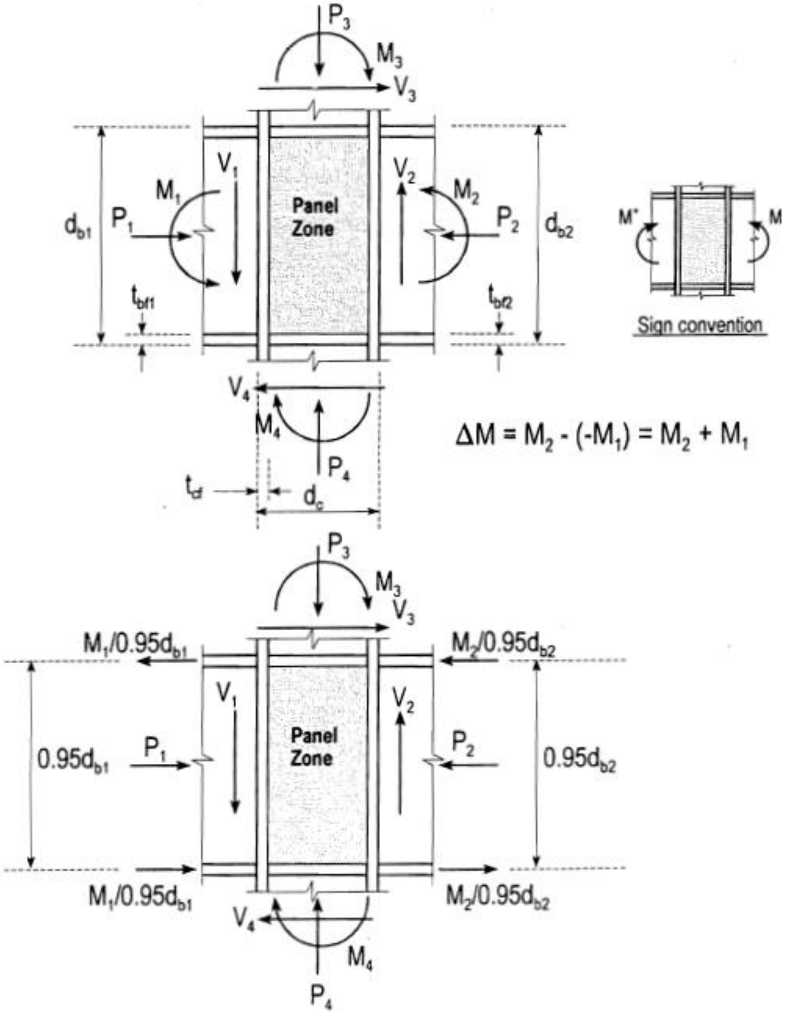


(a)

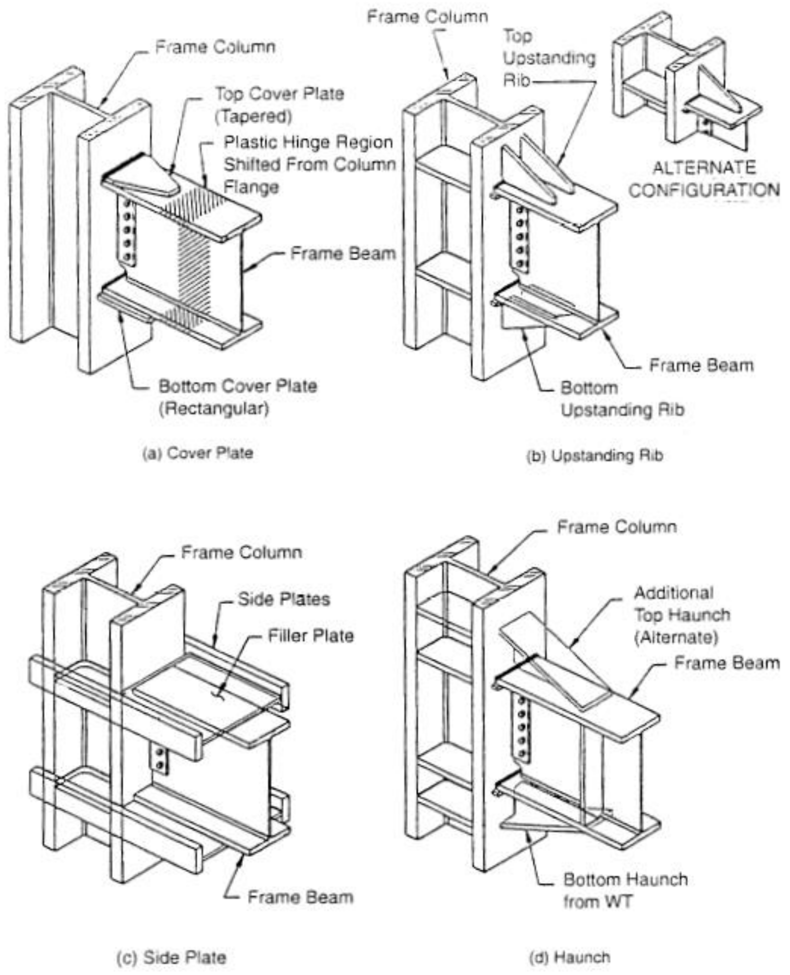


(b)

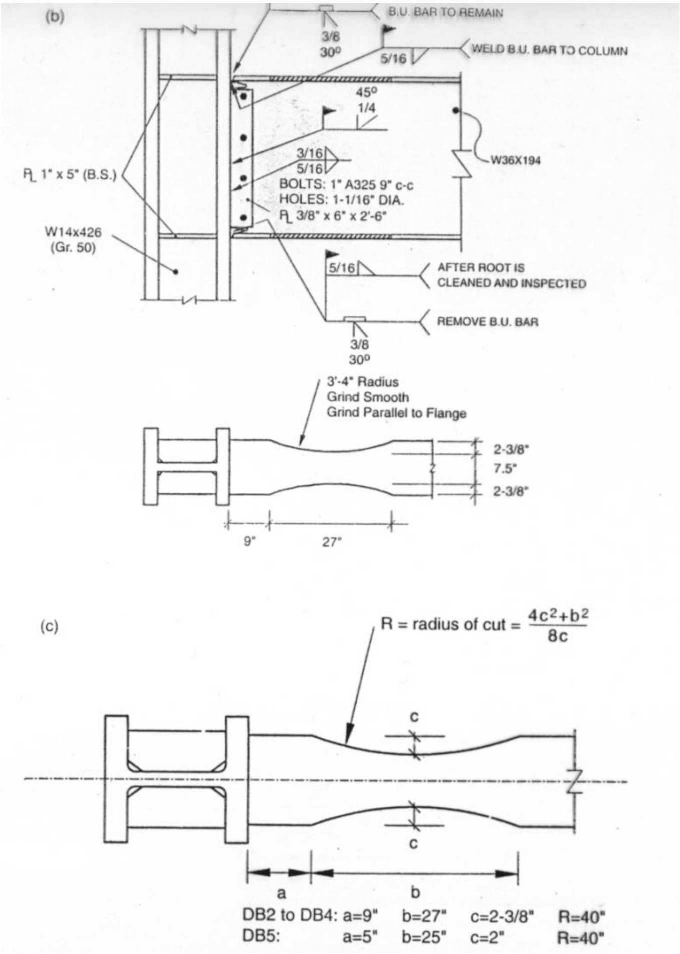
Beam-column connection behavior

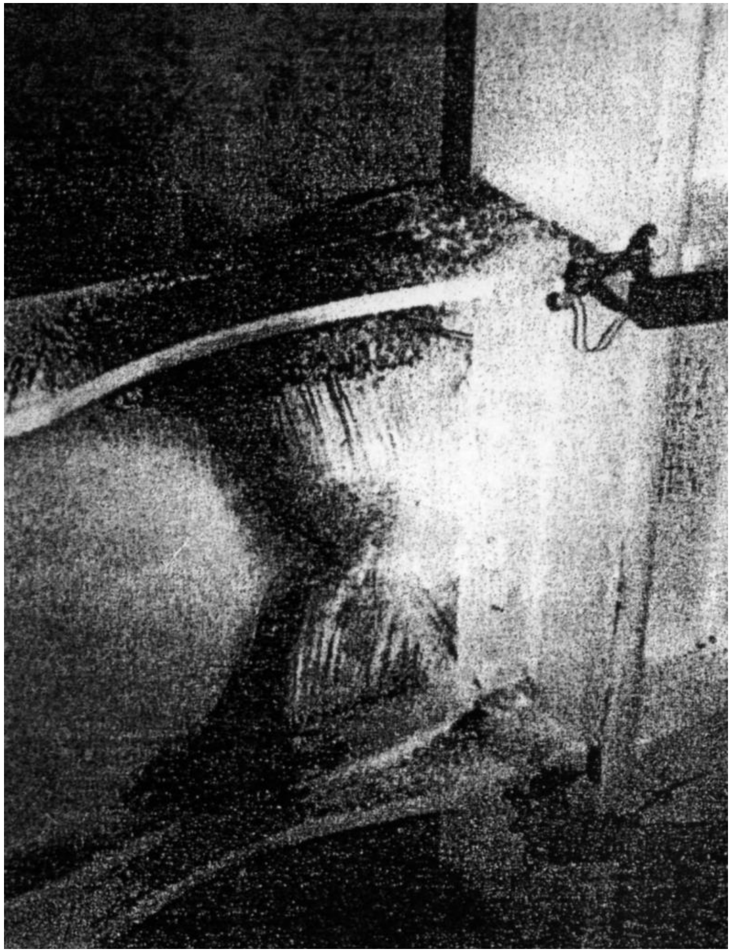


Strengthening of connections



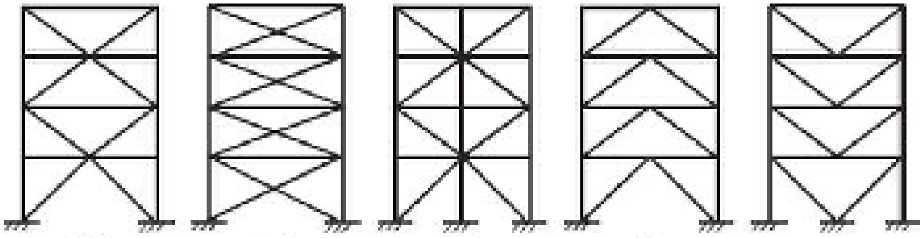
Reduced beam sections

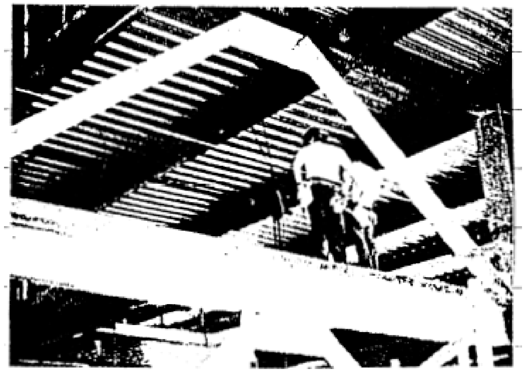




Concentrically Braced Frames (CBF)

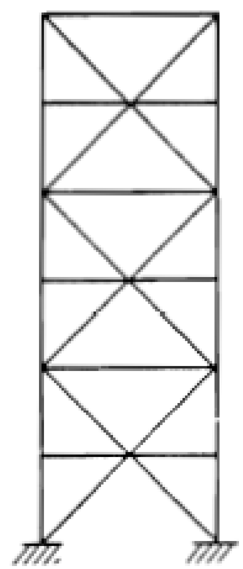
- Braced frames can be used to reduce excessive drift in rigid moment frame.
- Axial strength of brace members provide lateral resistance, which is more efficient than using the beams to resist shear and bending.
- K-brace and x-brace are commonly used.

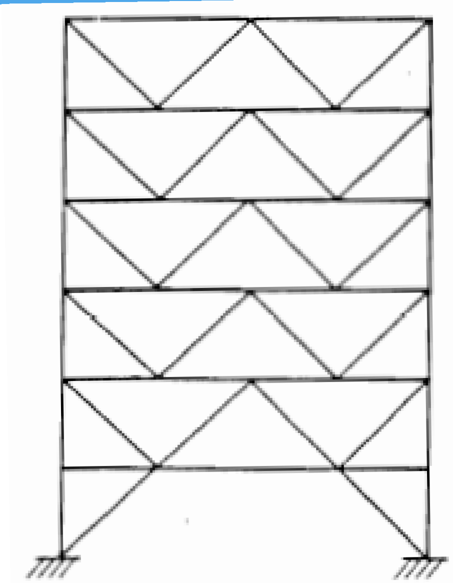




Concerns in braced frames

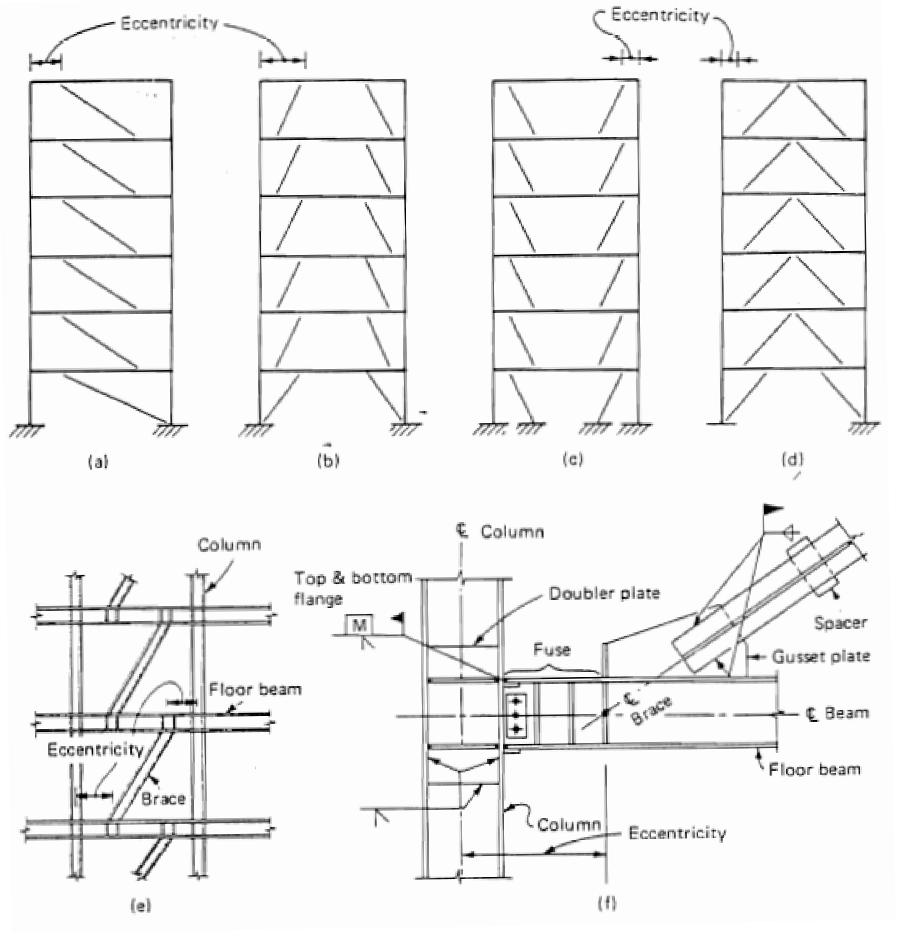
- Slenderness ratio of brace
- Brace-connection
- Gusset plate design
- Composite brace
- Buckling Restrained Brace
- Adopt low-yield steel





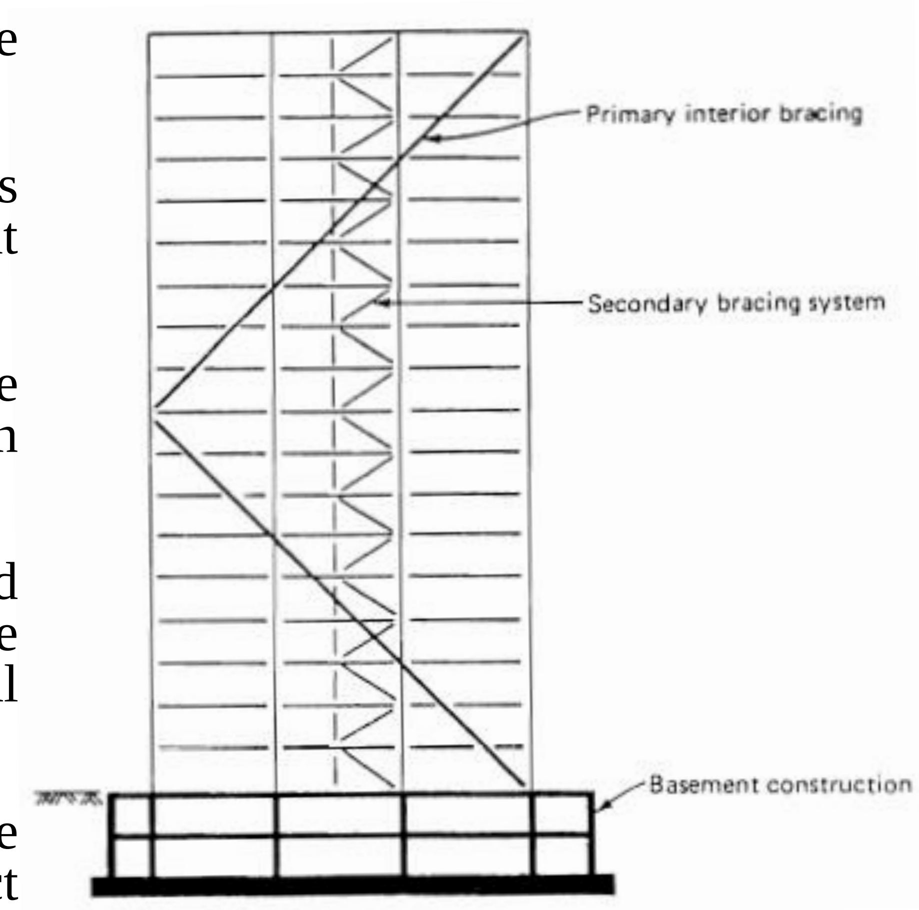
Eccentrically Braced Frames (EBF)

- Brace members connect top and bottom beams of the story with an eccentricity.
- Large axial force from the brace member will cause yielding (shear or flexural) of the beam segment within the eccentricity.
  - Shear link or moment link
- The eccentric beam segment is used as the energy dissipation mehanism.
- Structural stability is sustained at large deformation.
- Weight of EBF can be reduced to achieve similar structural performance of rigid moment frame.



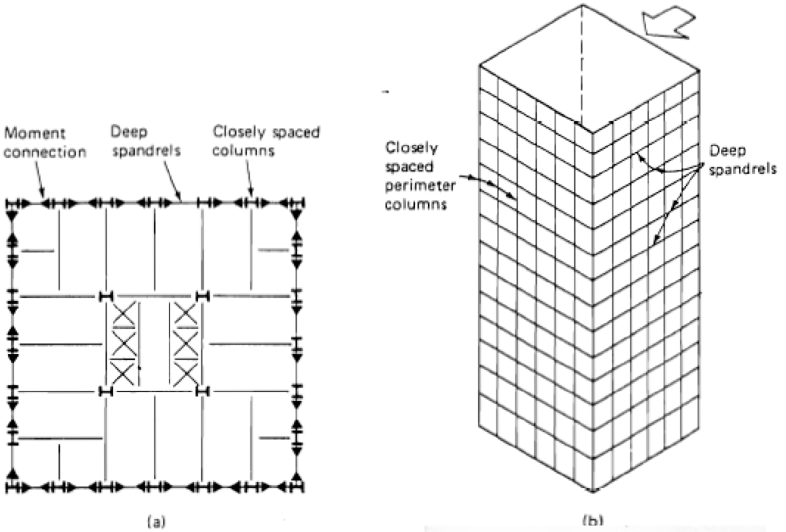
Interacting System of Braced and Rigid Frames

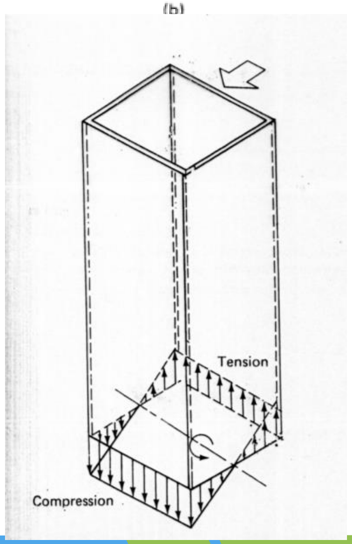
- Number of brace members should be reduced to minimize impact on space.
- However, sizes of columns and beams will be increased if pure moment frames are used.
- Overturning moment will cause large uplift force on the foundation in moment frames.
- Combine rigid frames and braced frames can improve the competitiveness of the structural designs.
- Can try to arrange braced frames in the central regions to minimize the impact on the space.



Framed Tube Systems

- Columns with small spacing connected with deep beams by rigid connections.
- Behavior of the system is similar to a hollow tube when subject to lateral force.
- Moment induced by lateral force produces axial compression and axial tension on the walls.
- Axial strength of the columns is high, therefore, the system is effective in resisting the moment caused by the lateral force.

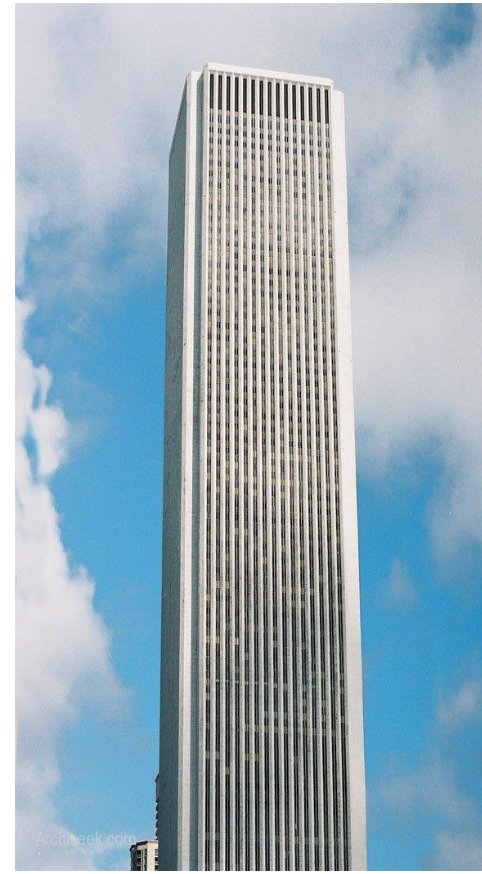




Framed Tube Systems

Sears Tower
(110 stories)

John Hancock Building
(100 stories)

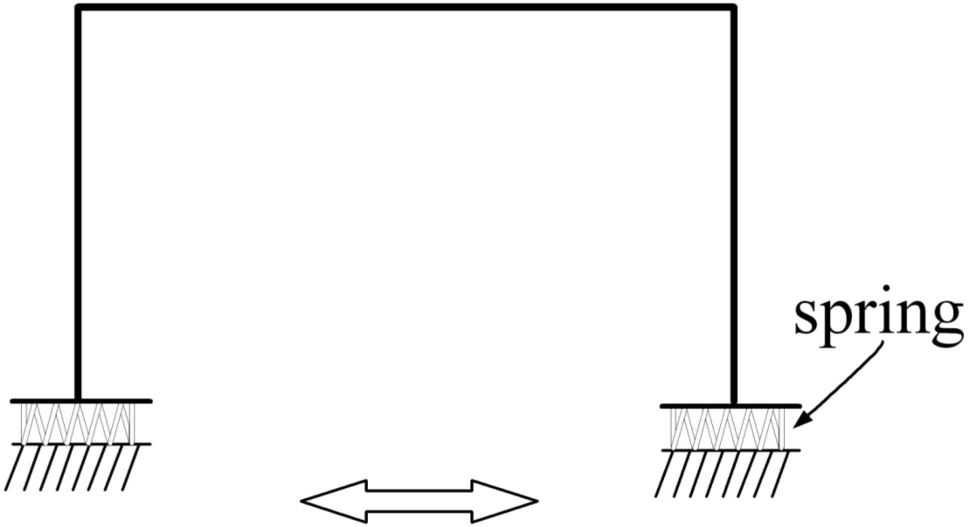


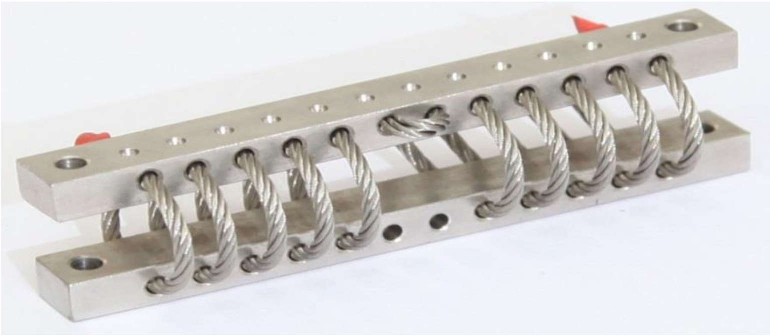
Standard Oil Building
(83 stories)

Alternative methods to improve structural performance

Base-isolated structures

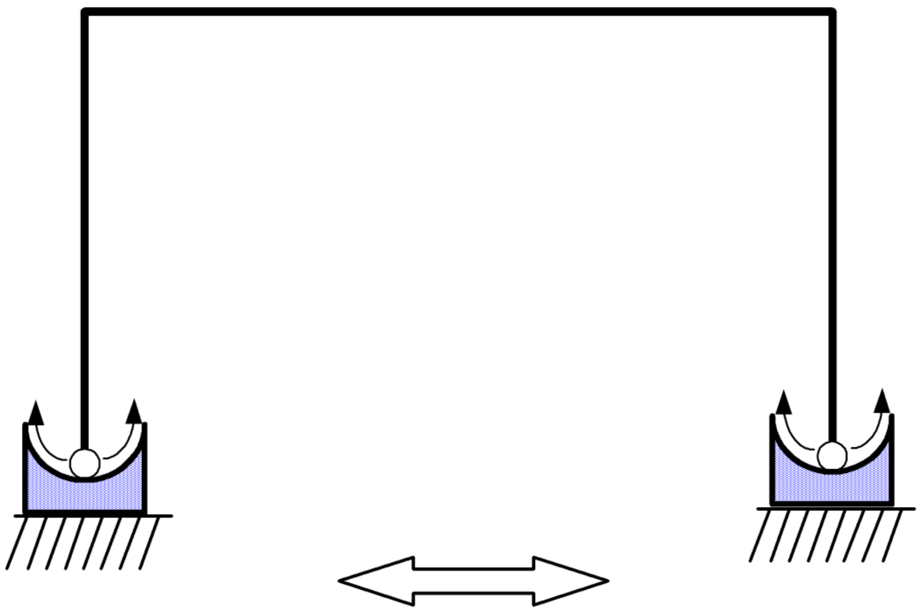
- To prevent energy from transmitting to the structures

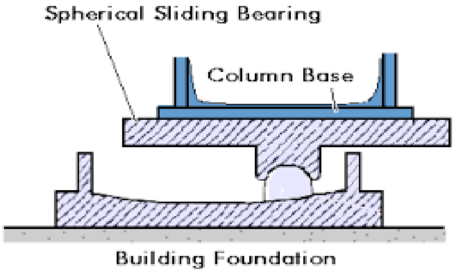




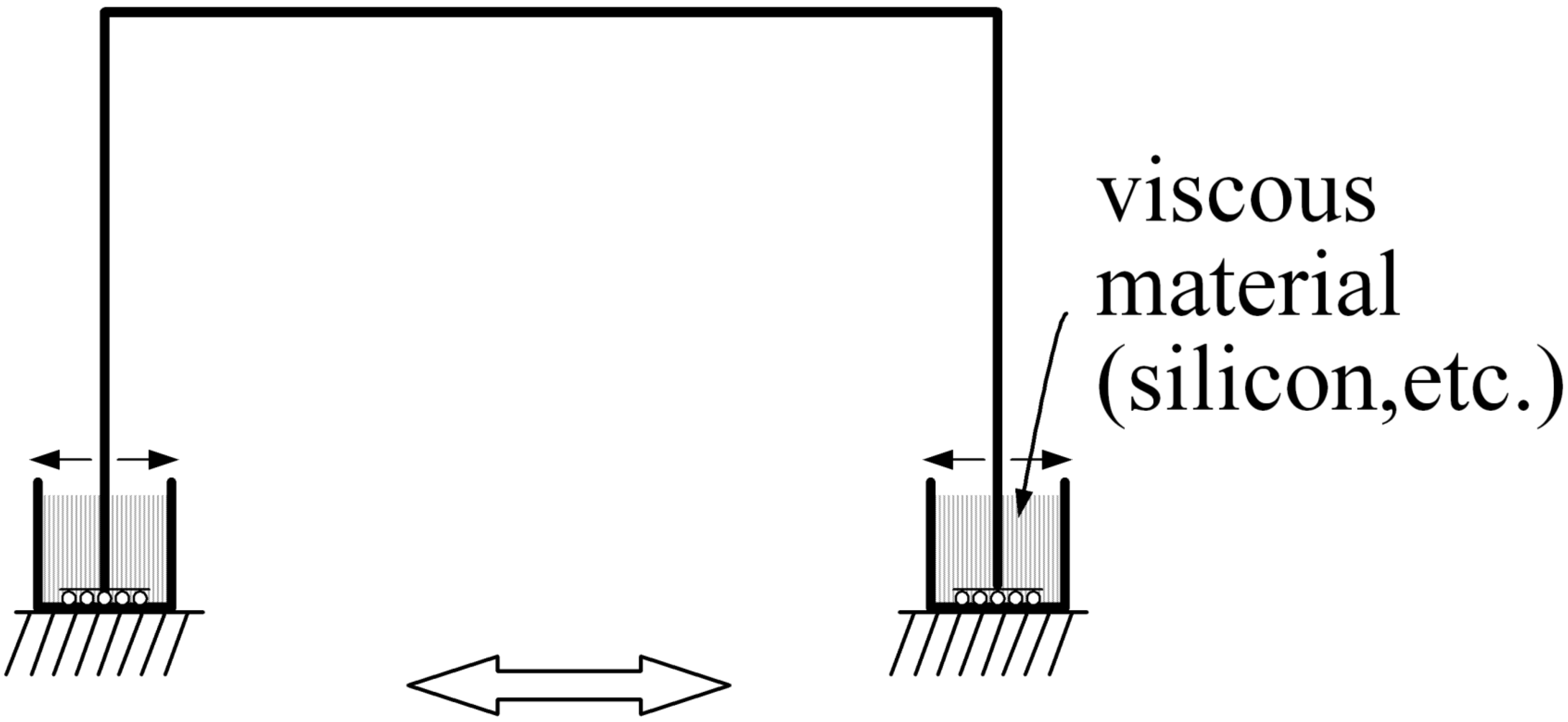
Base-isolation devices

Base-isolated structures

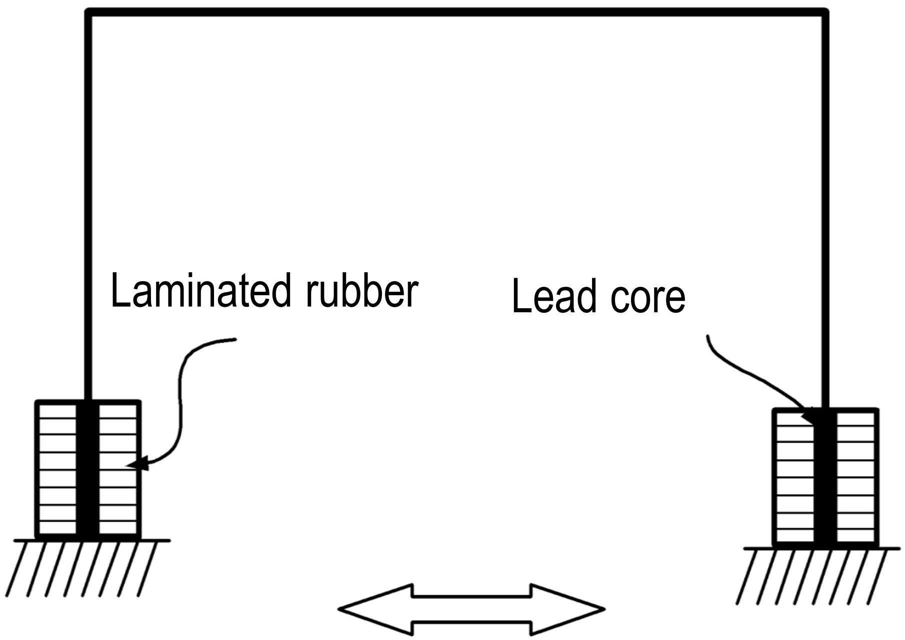


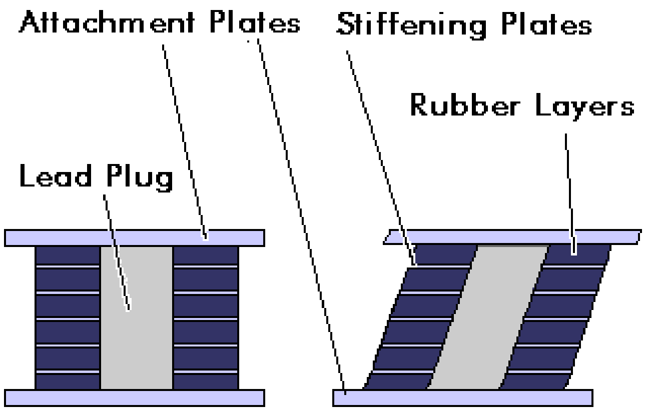


Energy-dissipation system

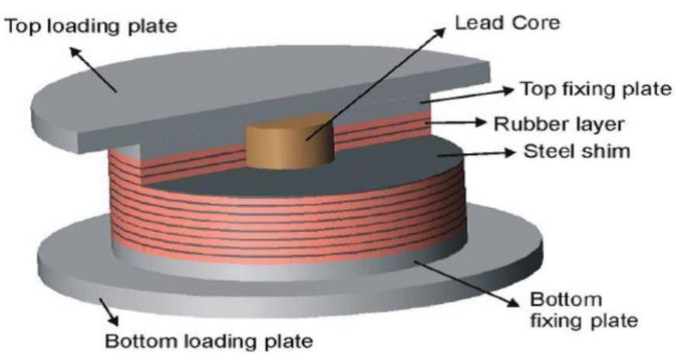


LRB (Lead Rubber Bearing)

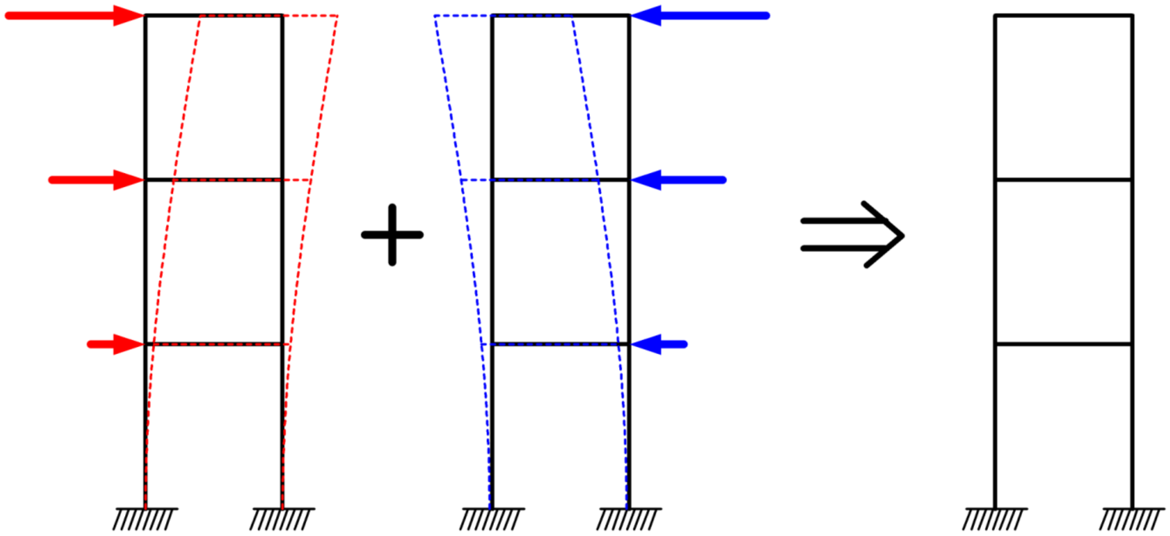


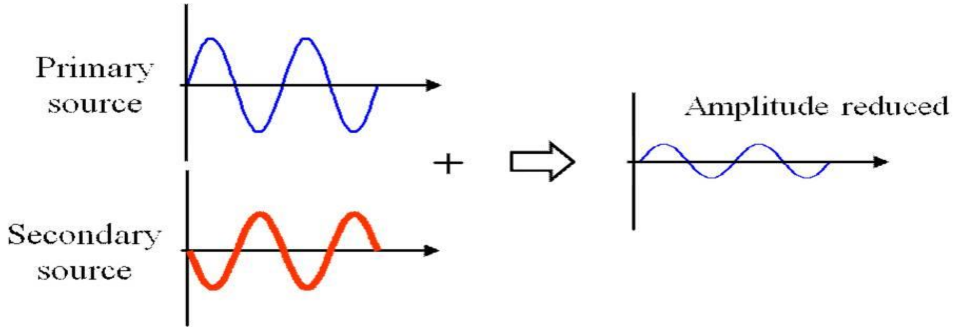


LRB
(Lead Rubber Bearing)

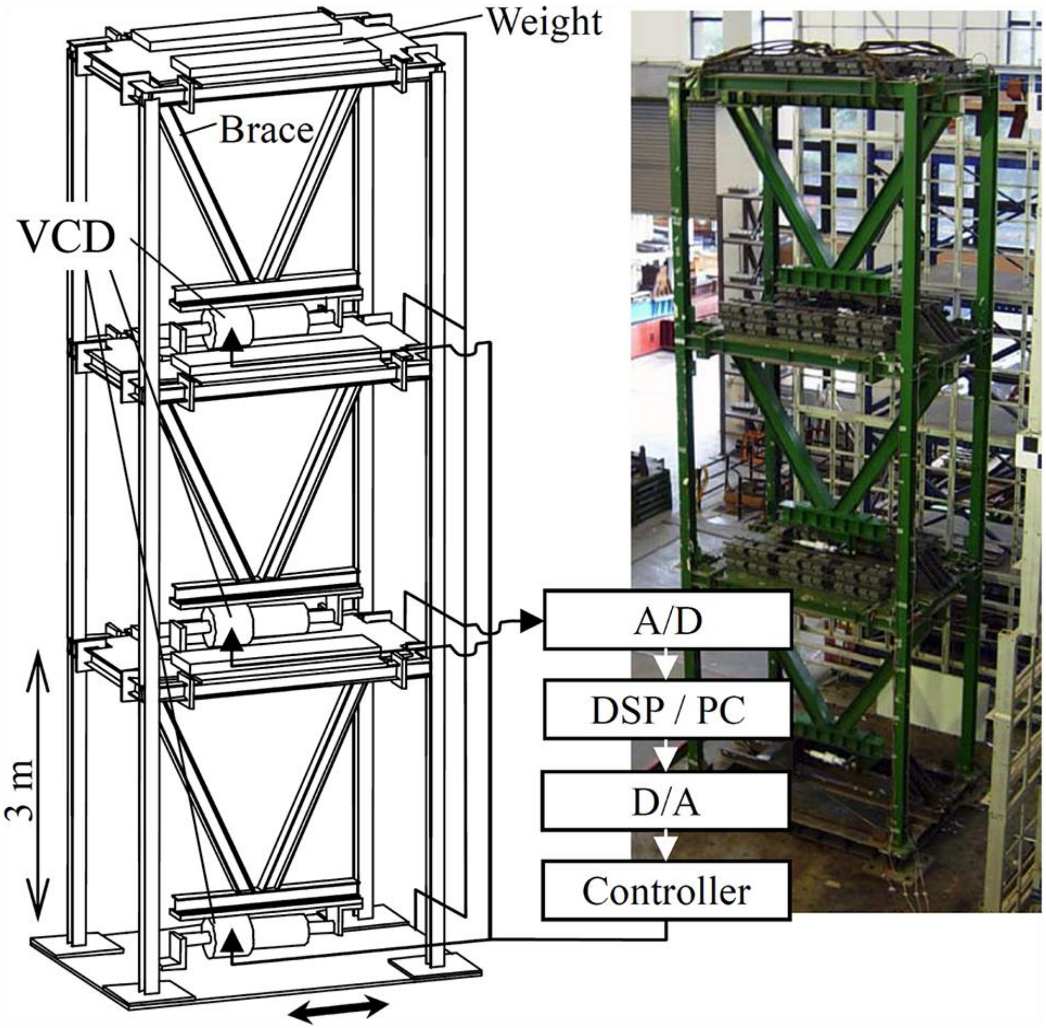


Active control



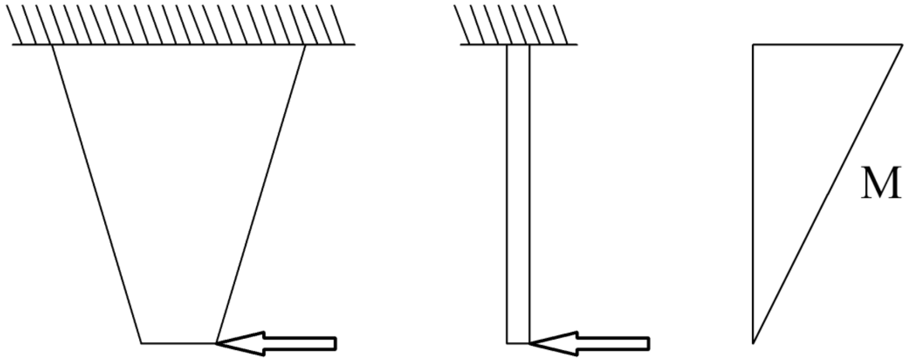


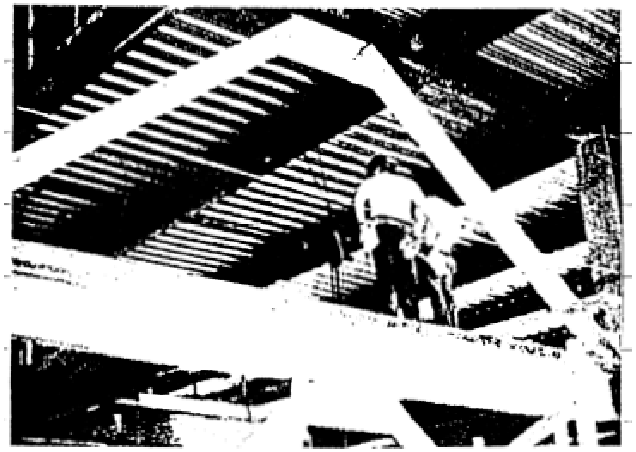
Active control

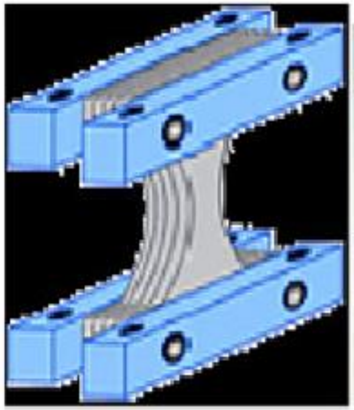


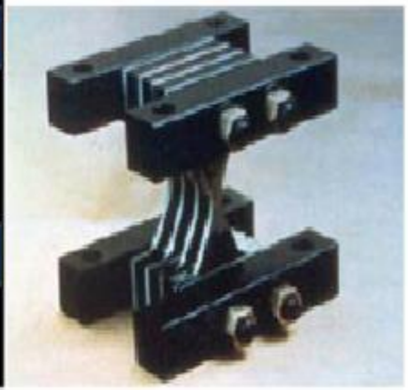
Damper (ADAS)

- Added Damping, Added Stiffness

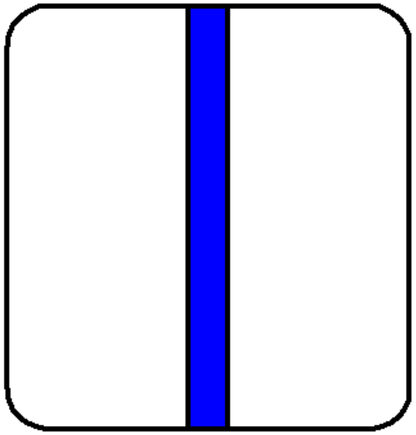


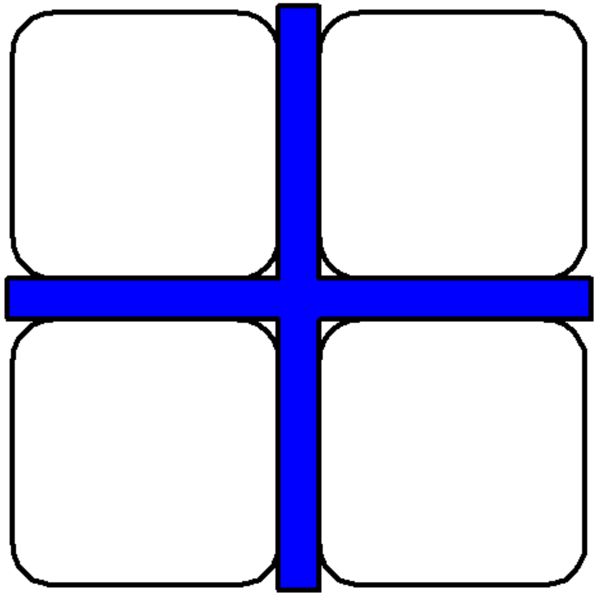




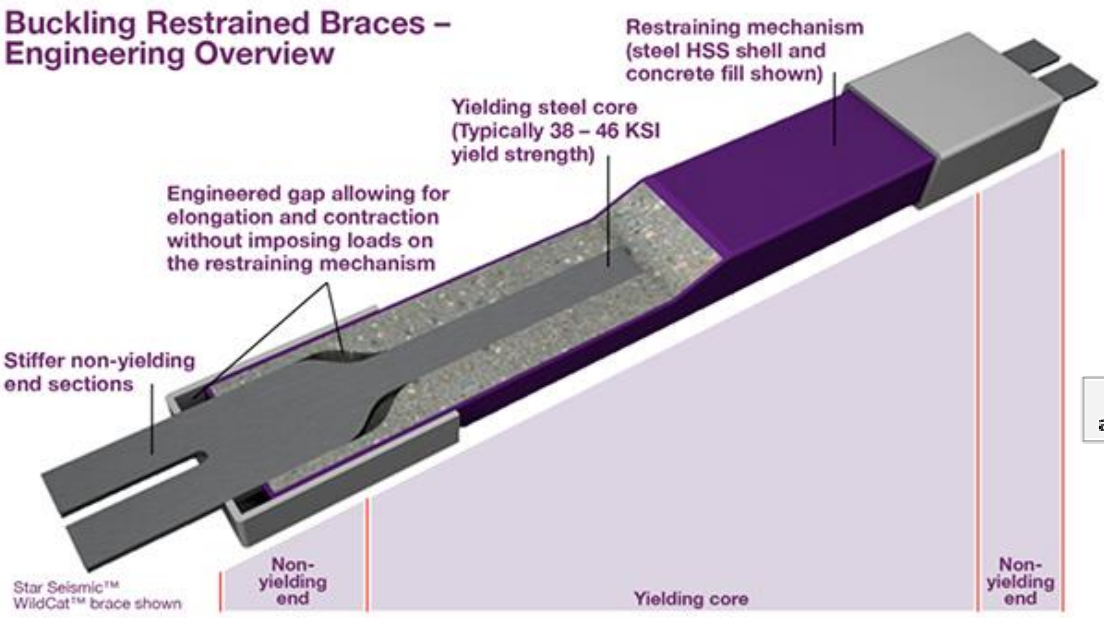


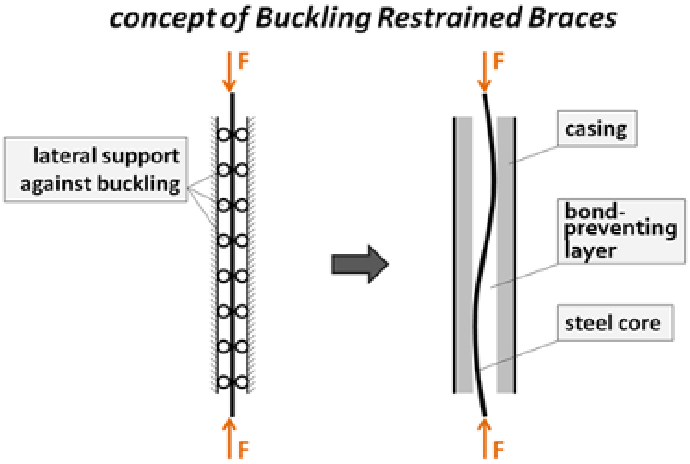
Buckling Restrained Braces



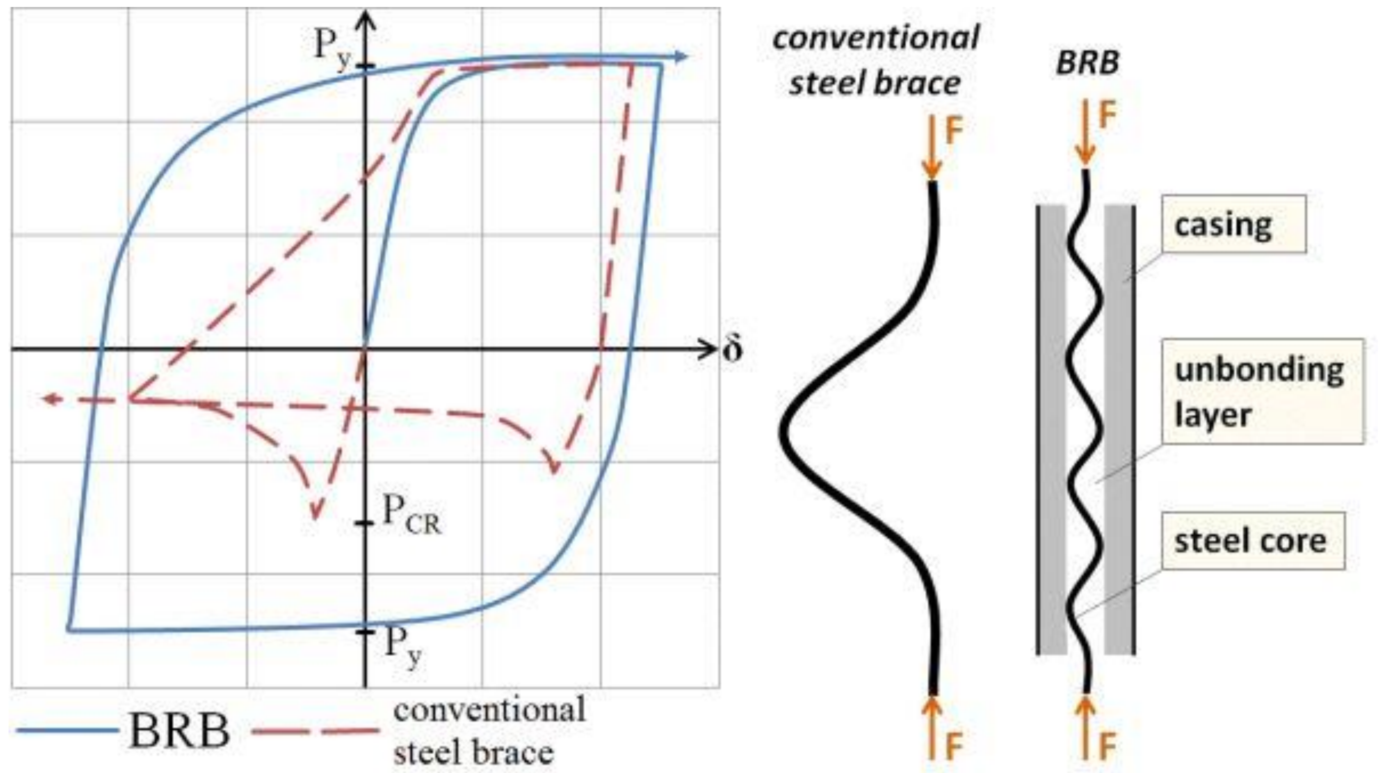


Buckling Restrained Braces

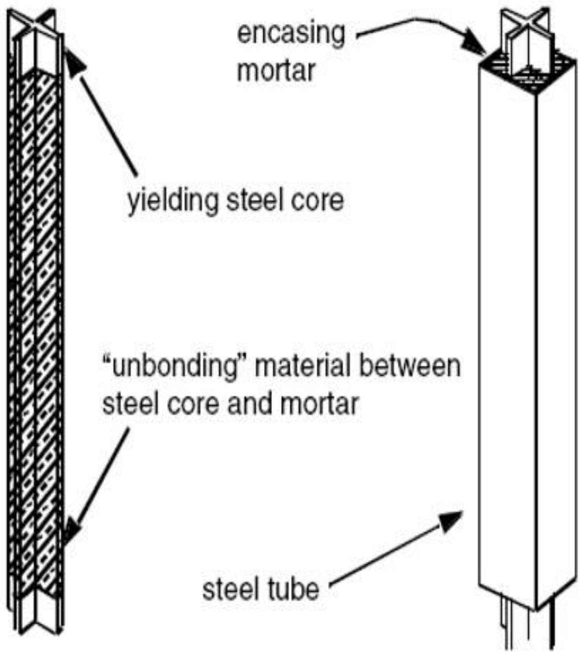


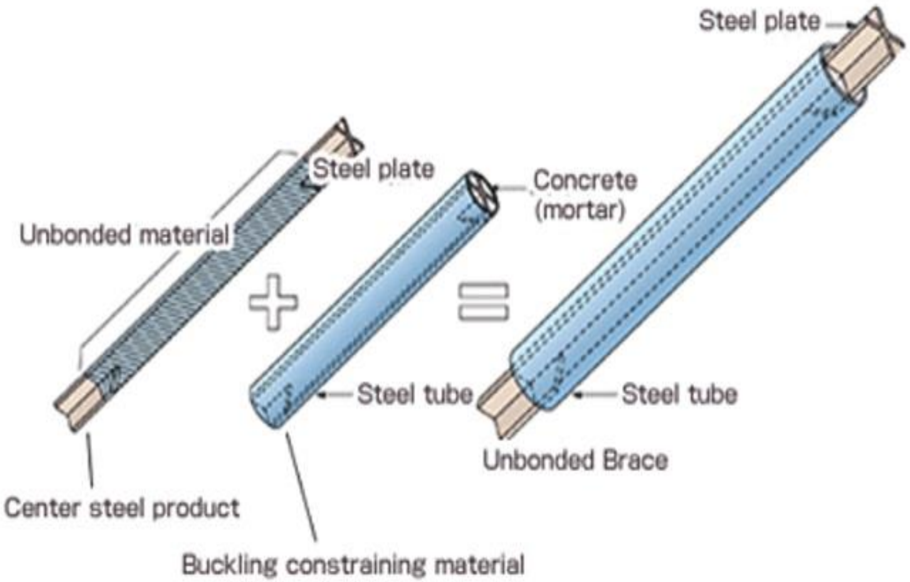


Buckling Restrained Braces



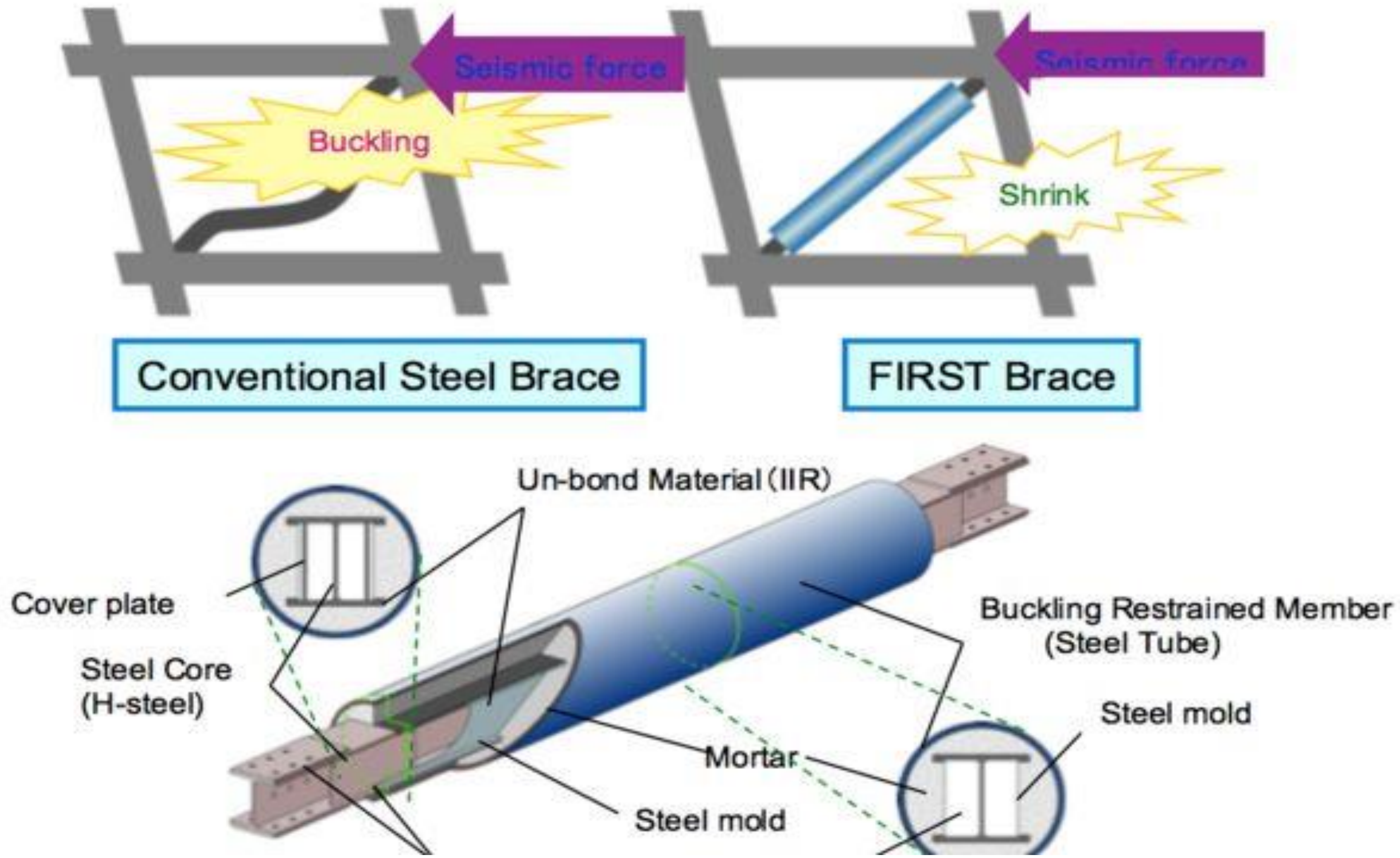
Buckling Restrained Braces





Components of a BRB using a rectangular steel tube casing on the left and a cylindrical steel tube casing on the right

Buckling Restrained Braces

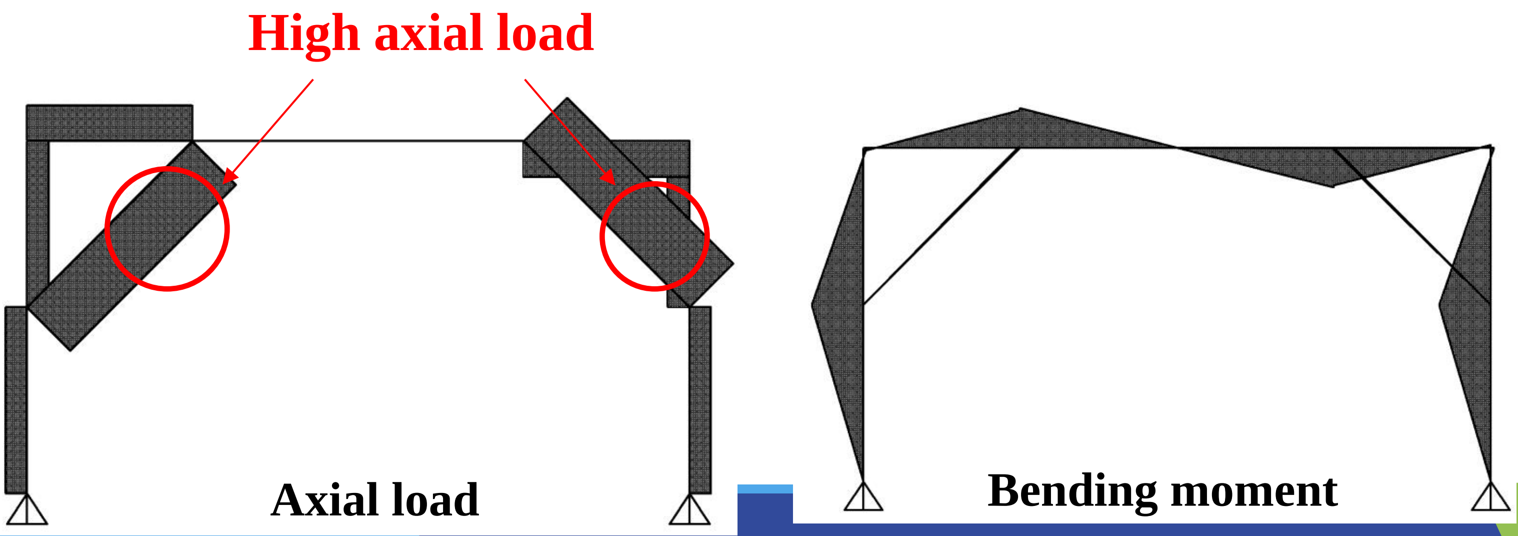


Example of Research in Steel Structures

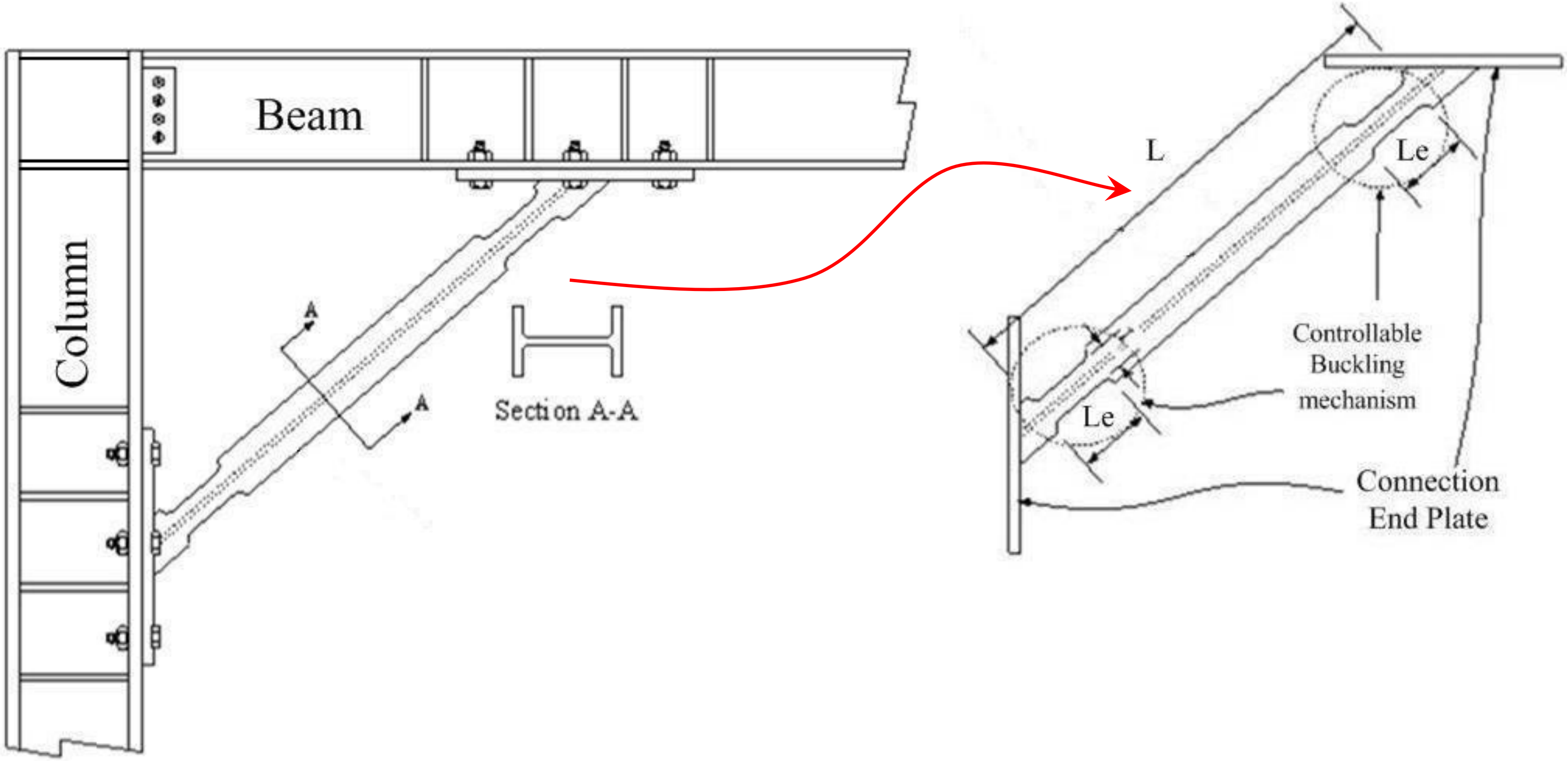
Performance of steel frames with various buckling modes in the braces

Loading distribution

- Possible Failure Mode of KBRF
  - Buckling of knee brace
  - Bending of gusset plate
  - Distortion of beam
- Loading Distribution of KBRF



Knee Brace Design Proposal



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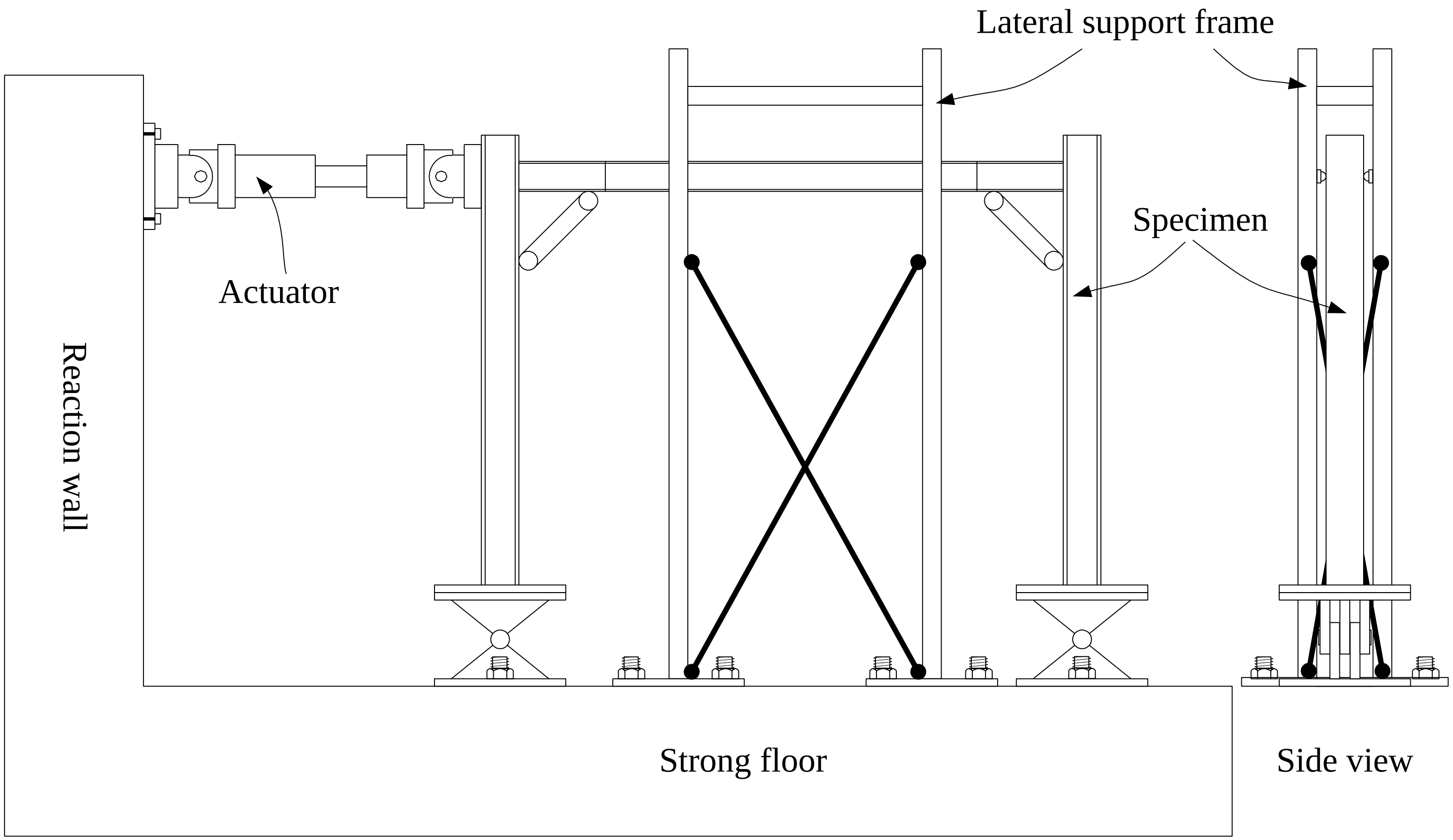
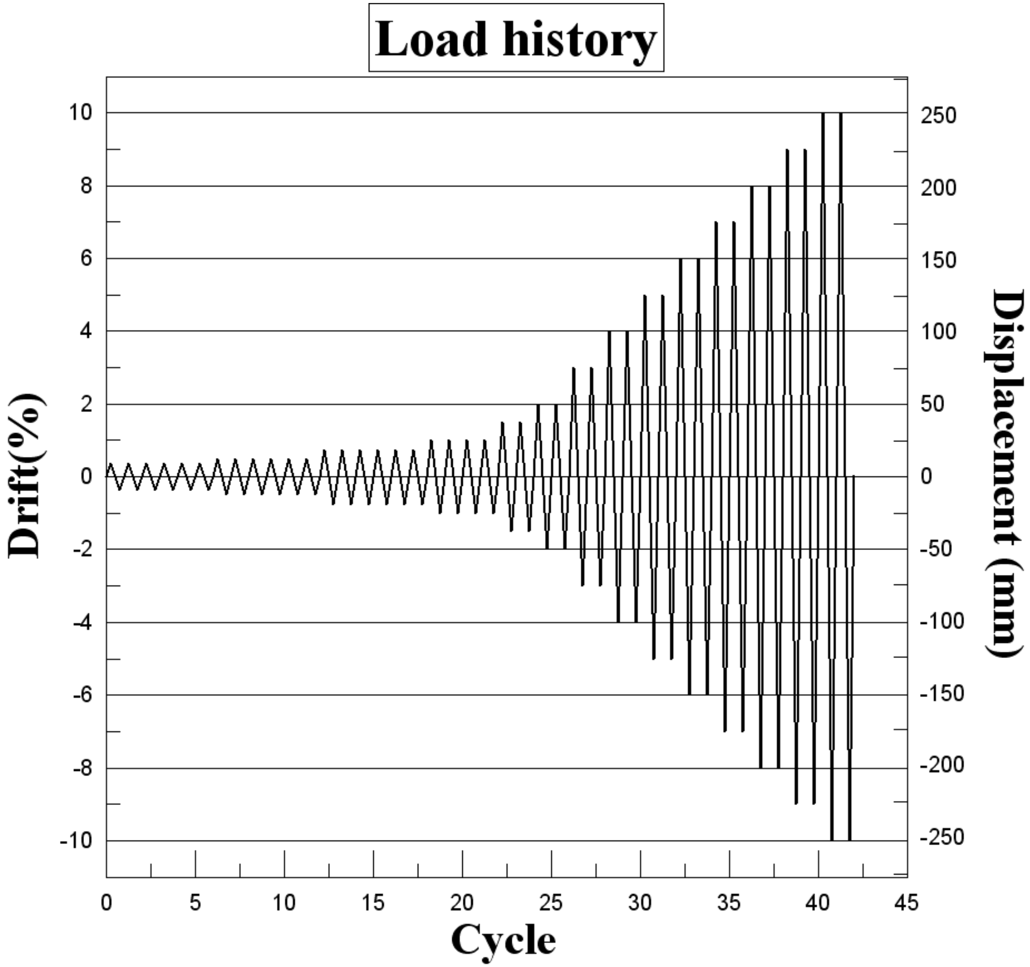
Test setup



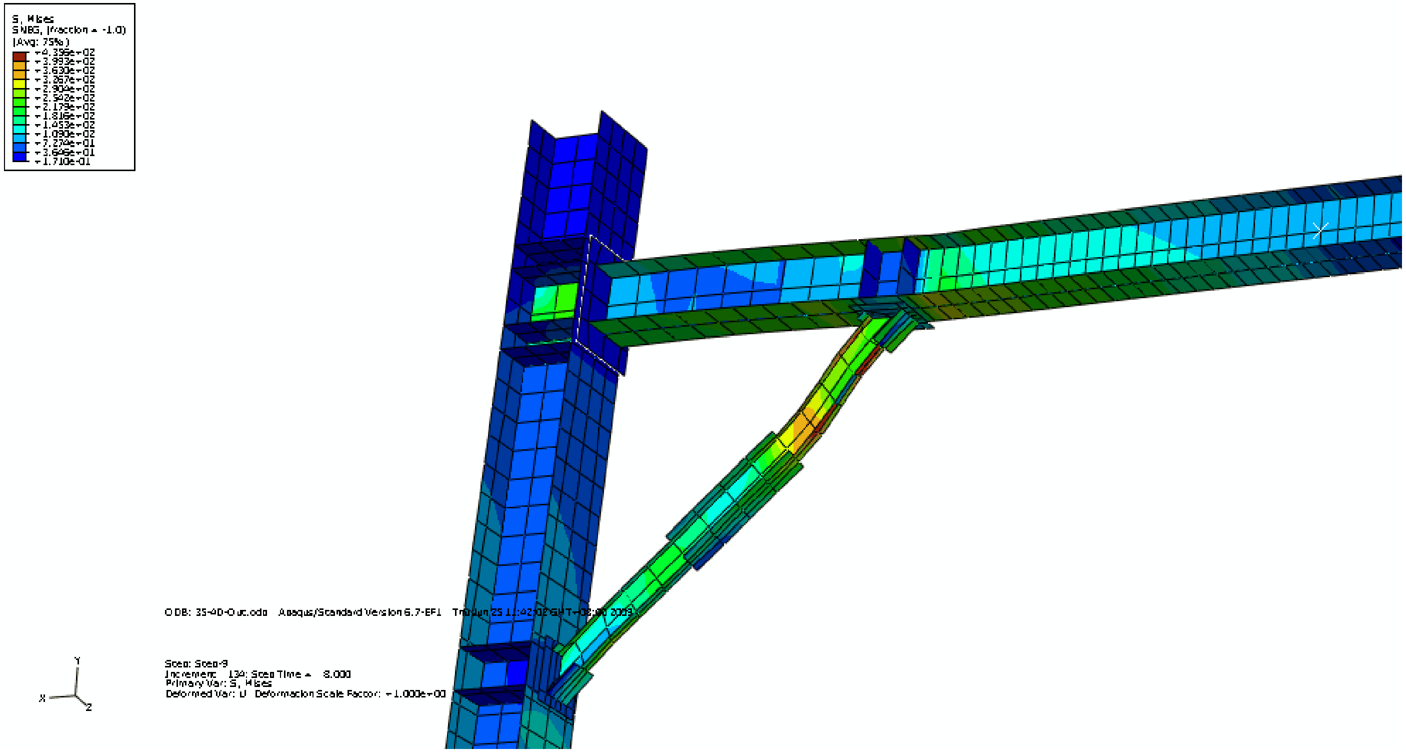
Lateral support frame
Specimen
Actuator
Reaction wall
Strong floor
Side view

Loading pattern ⇨ Displacement Control



Arrangement of Knee Braces

Out-of-plane Buckling

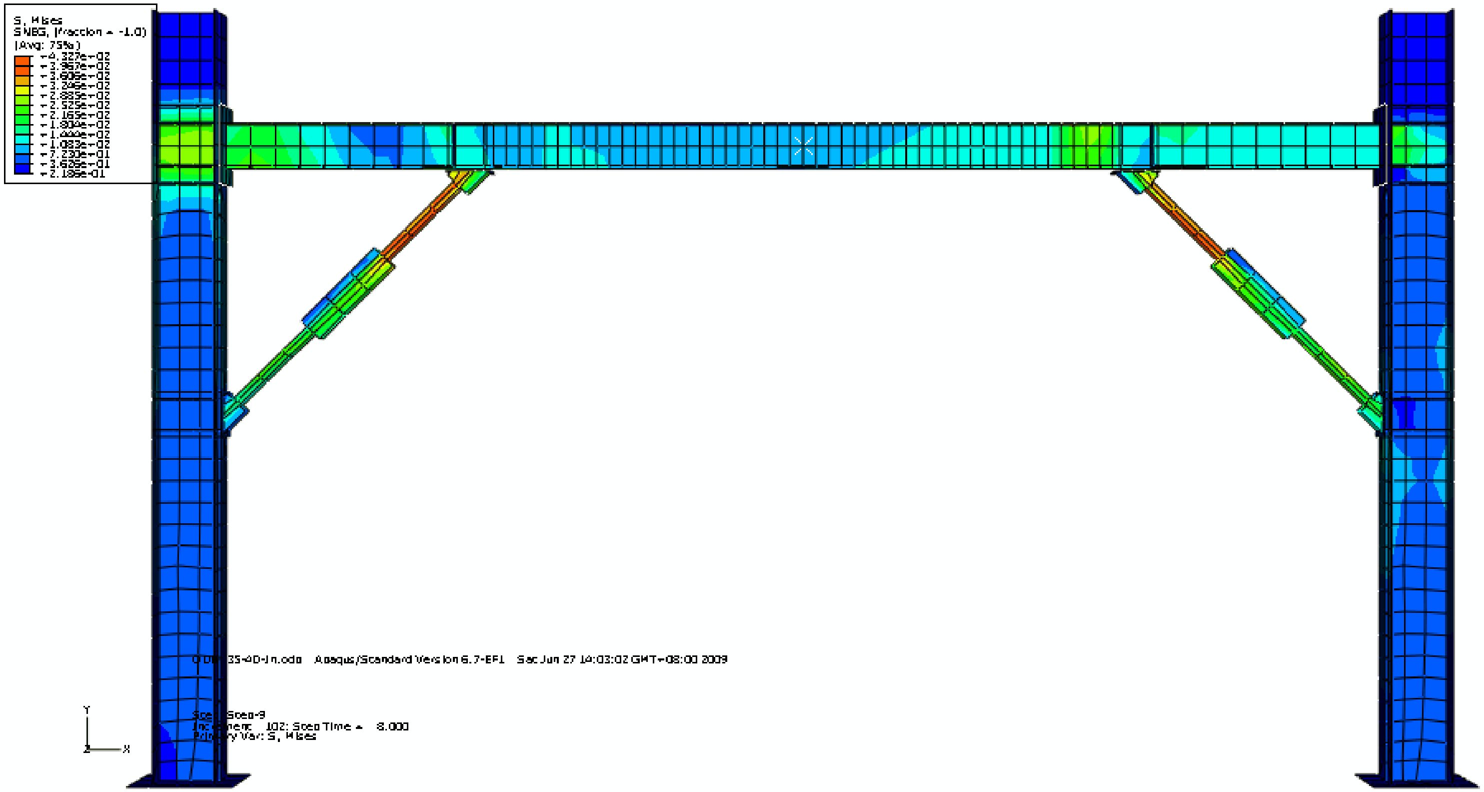


Cyclic responses of KBRF

Out-of-plane Buckling

Cyclic responses of KBRF

In-plane Buckling

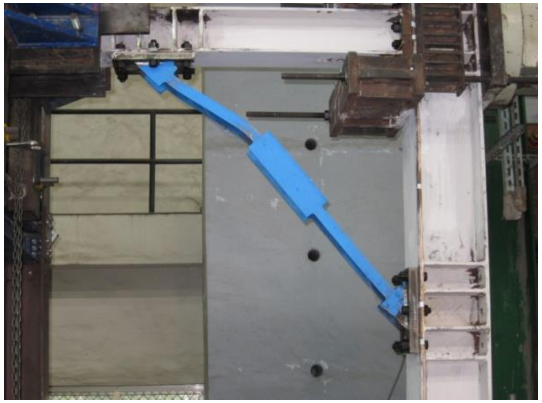


Cyclic responses of KBRF

In-plane Buckling

Failure patterns

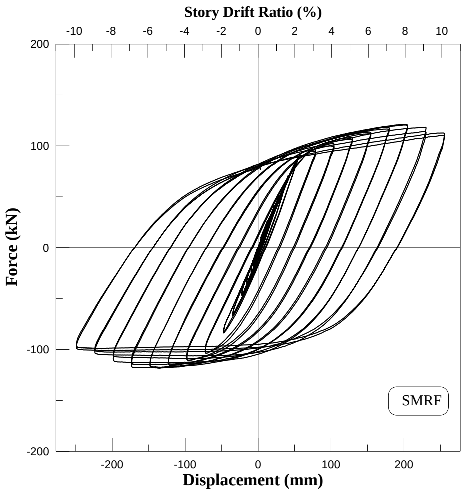
SMRF



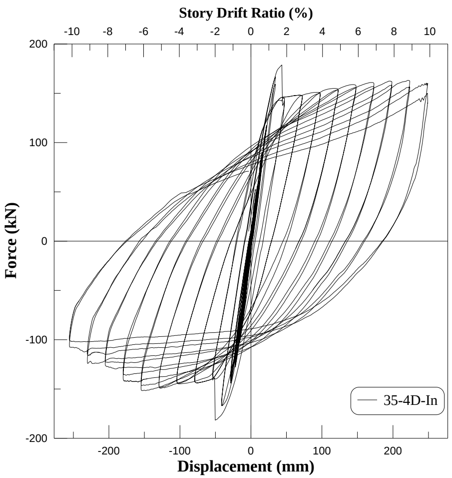
KBRF with in-plane buckling

KBRF with out-of-plane buckling

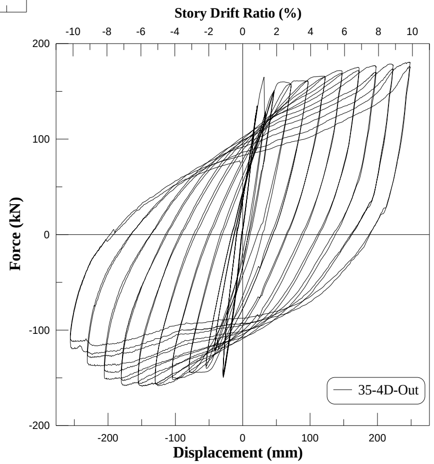
Hysteretic behavior



SMRF

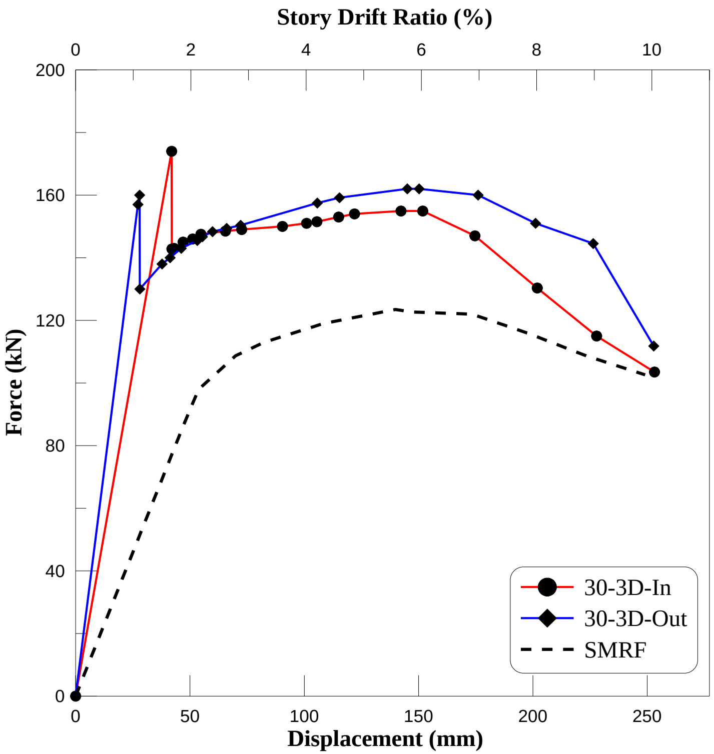


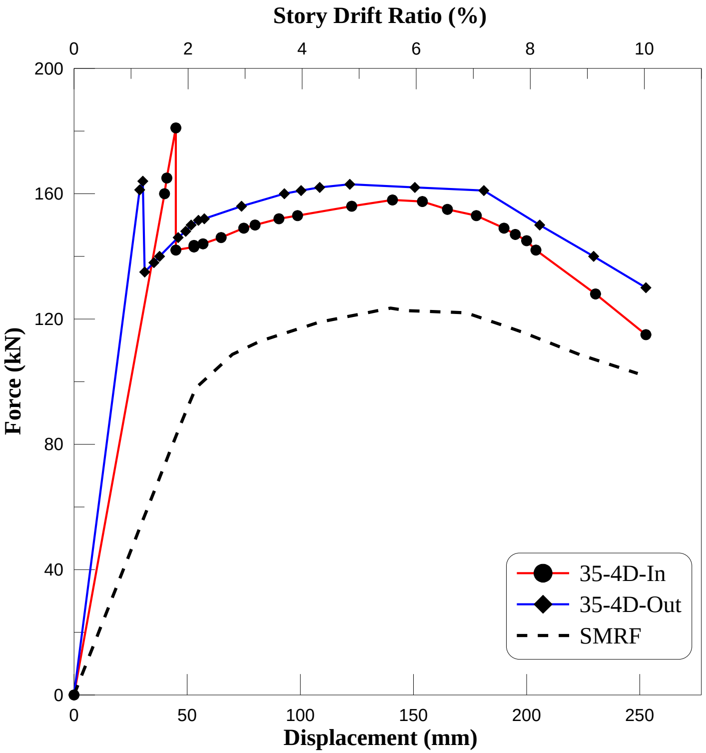
KBRF with in-plane buckling



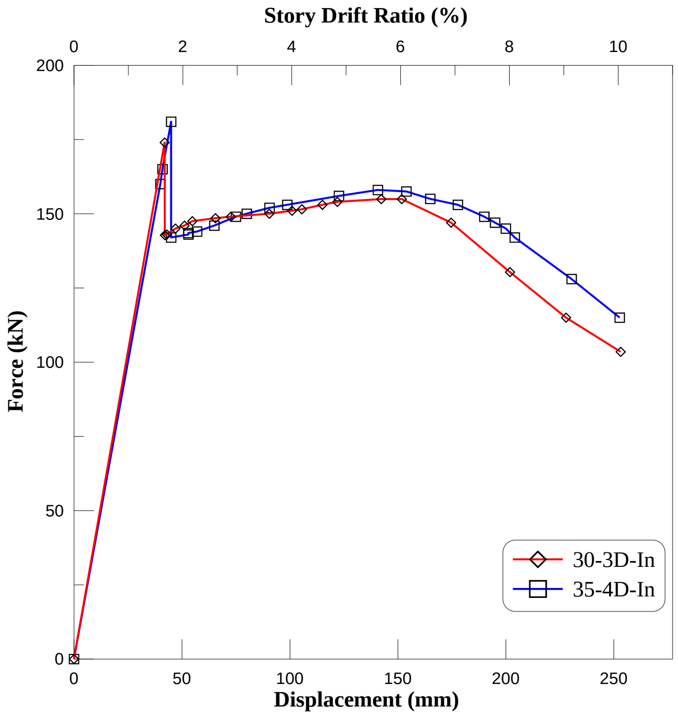
KBRF with out-of-plane buckling

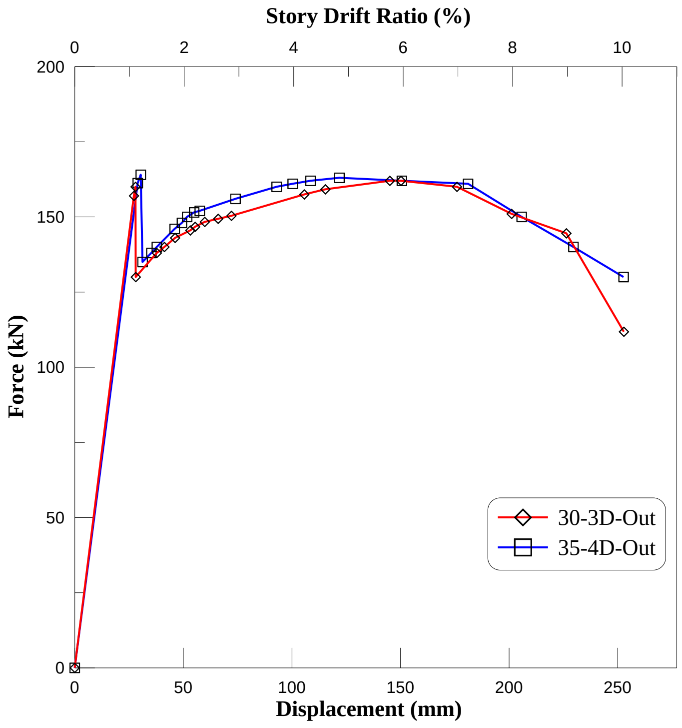
Comparisons of performance





Backbone curves (same buckling modes)





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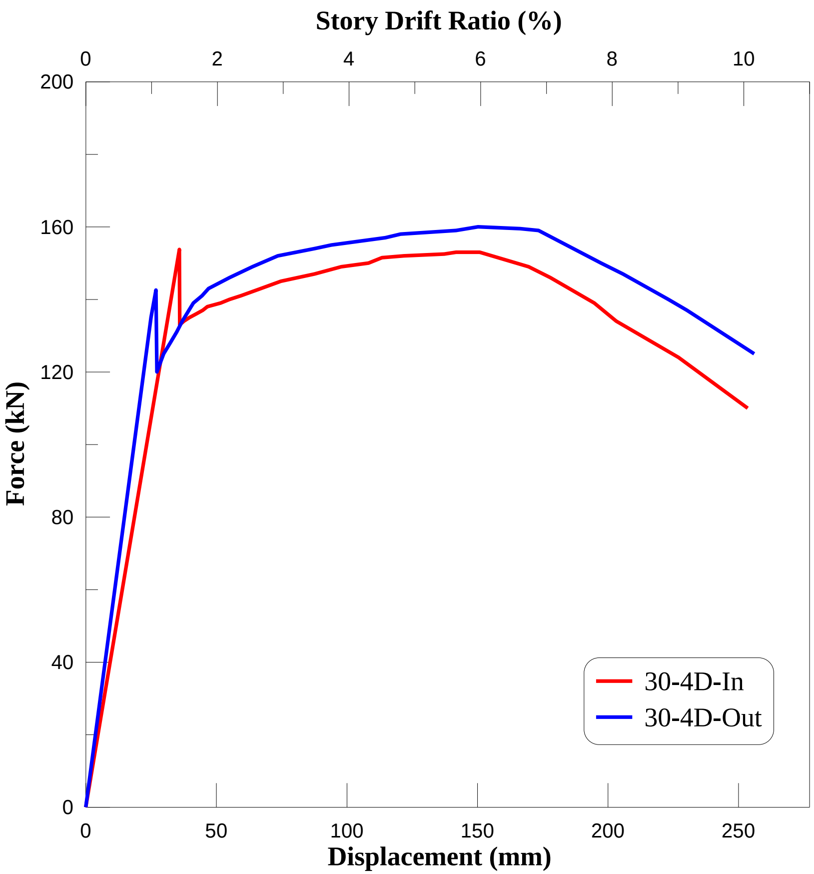
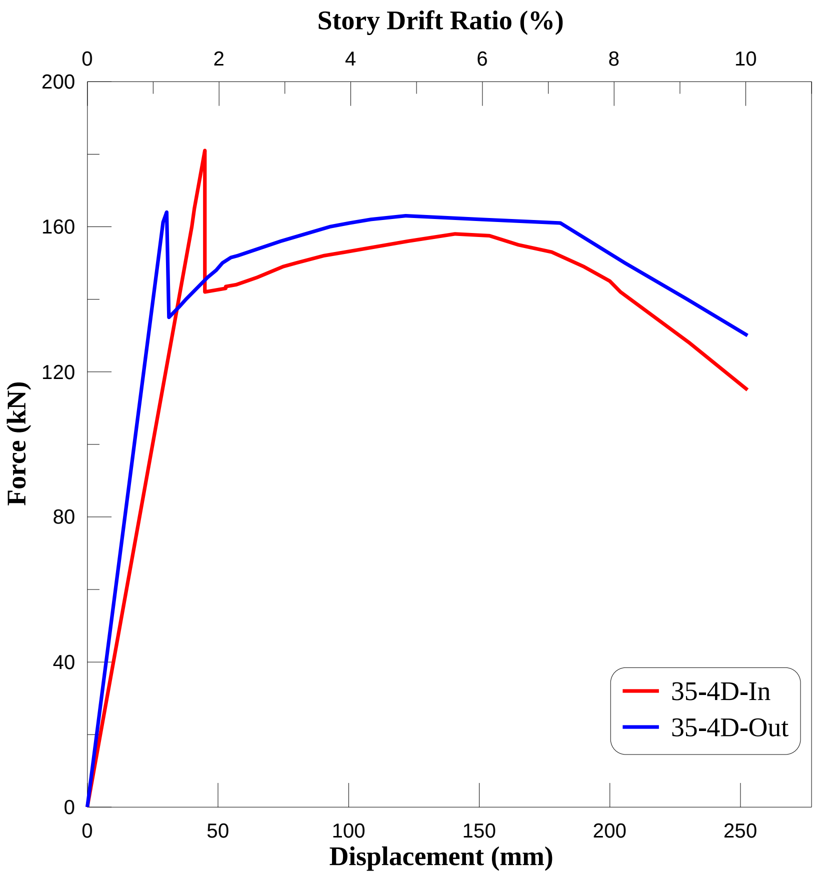
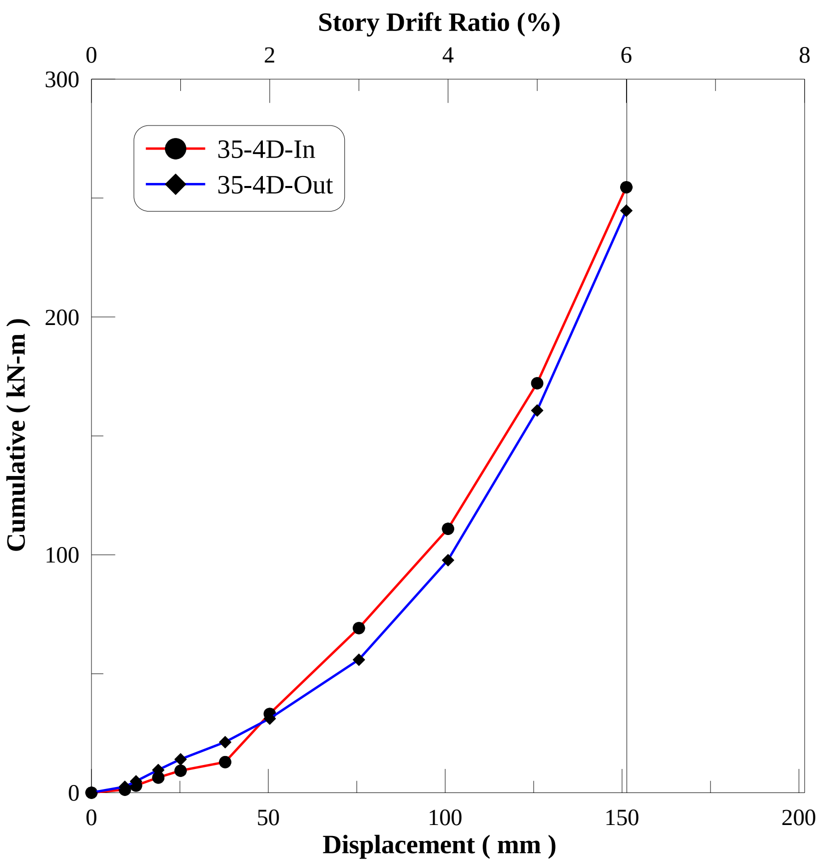
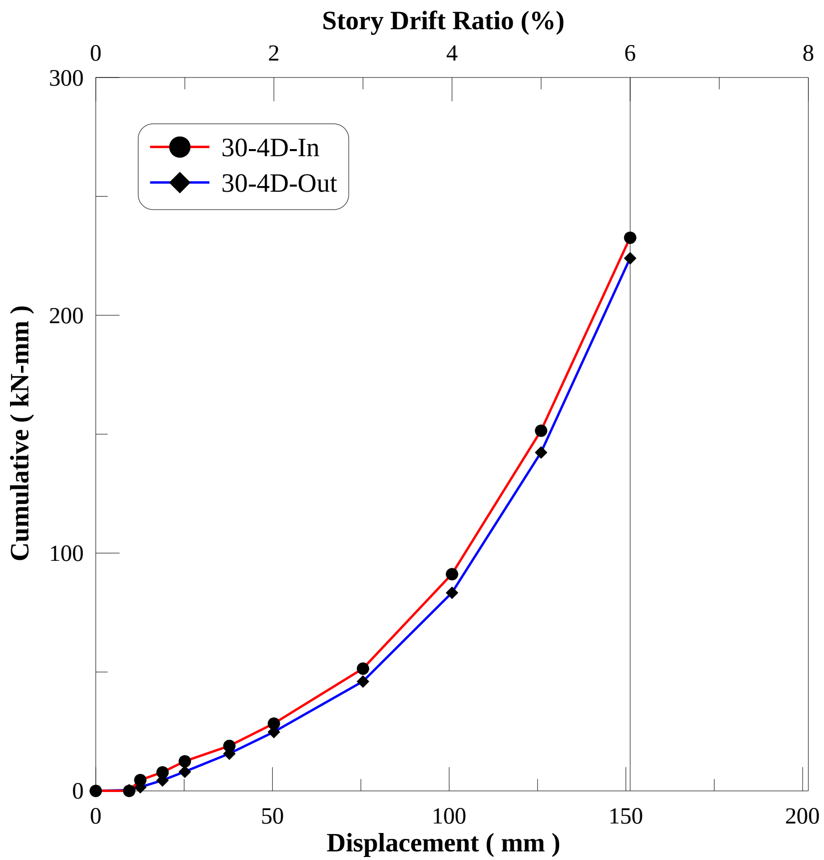
Effect of various buckling modes



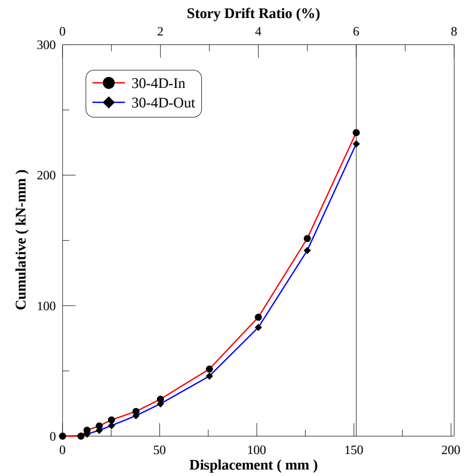


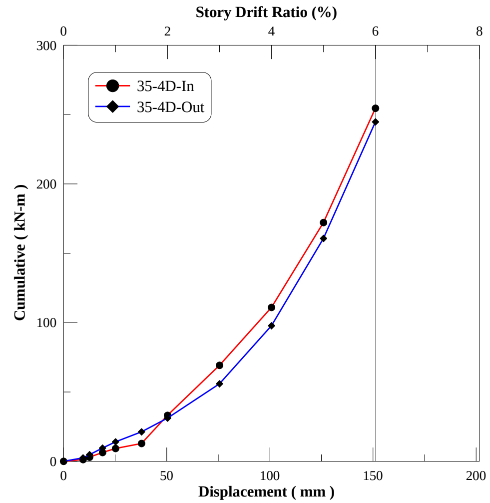
Effect of buckling modes (energy)

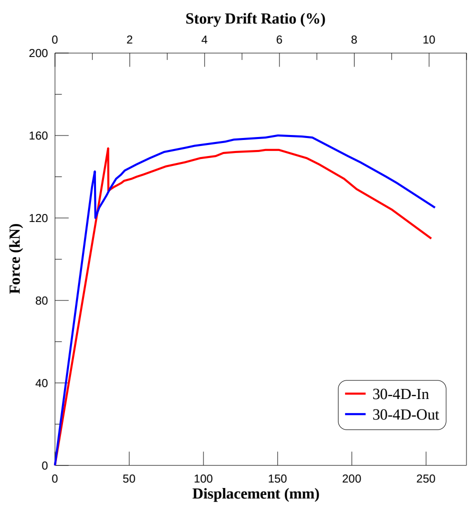


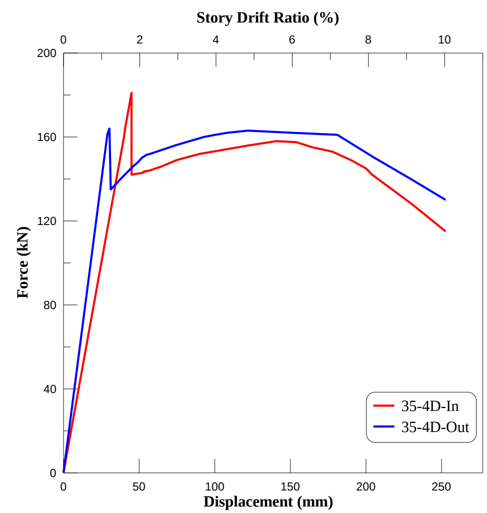


Energy Dissipation vs. Drift









Conclusions

- Strength and stiffness of the KBRFs were significantly enhanced no matter the knee braces buckled in the in-place or out-of-plane direction.
- Drift at which the knee braces reached the buckling stage was higher for KBRF frames with braces installed in the in-plane buckling direction.
- Braces with in-plane buckling is suggested should the architectural function is a concern.

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Homework

Brace members have been used in many structural designs for earthquake-resistant purposes.

Please explain how the brace members function to resist the earthquake load.

Please also describe the difference in response between the buckling restrained braces (BRB) and the traditional braces when they are subject to earthquake load.