NORTHRIDGE 20
SYMPOSIUM

Buckling Restrained Braced Frames

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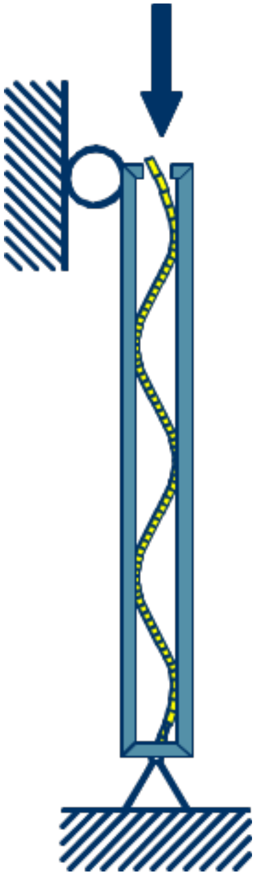
Buckling Restrained Braced Frames

- Background
- Introduction to US practice
- Use today
- Ongoing issues

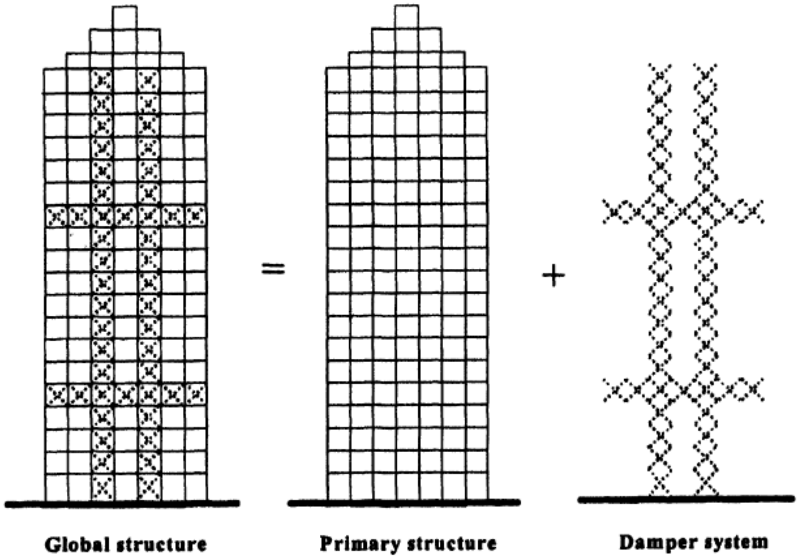
Background

- Concept in India
  - Sleeved column
    - Decoupled stress and flexural buckling
    - Minimum-weight compression member
    - Energy absorption in compression (later)

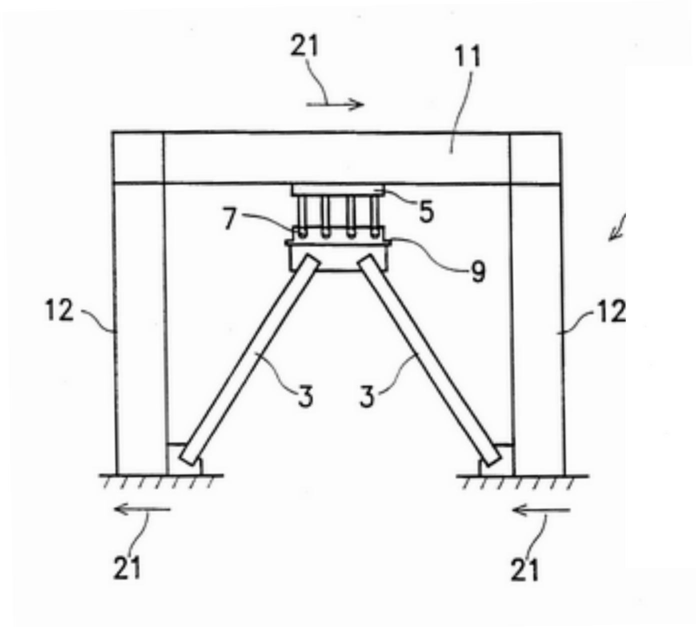


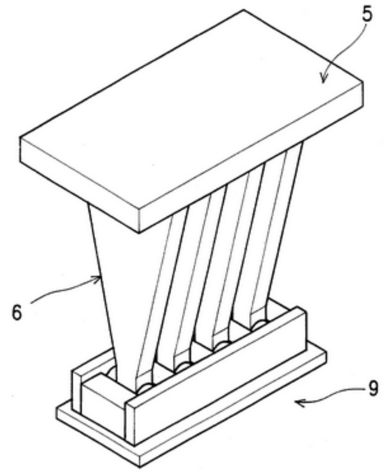
Background

- Use in Japan
  - 1970s
    - Developmental research on unbonded braces
  - 1980s
    - Use as hysteretic damping device
      - Similar to ADAS devices



Background





ADAS

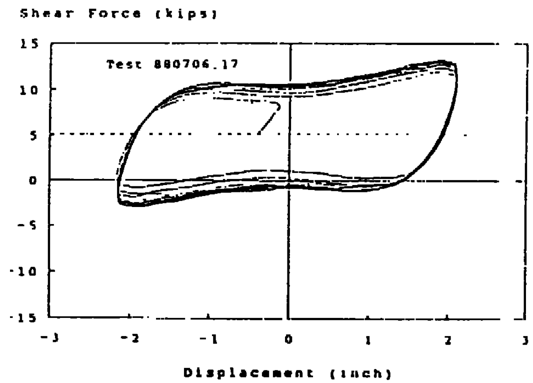
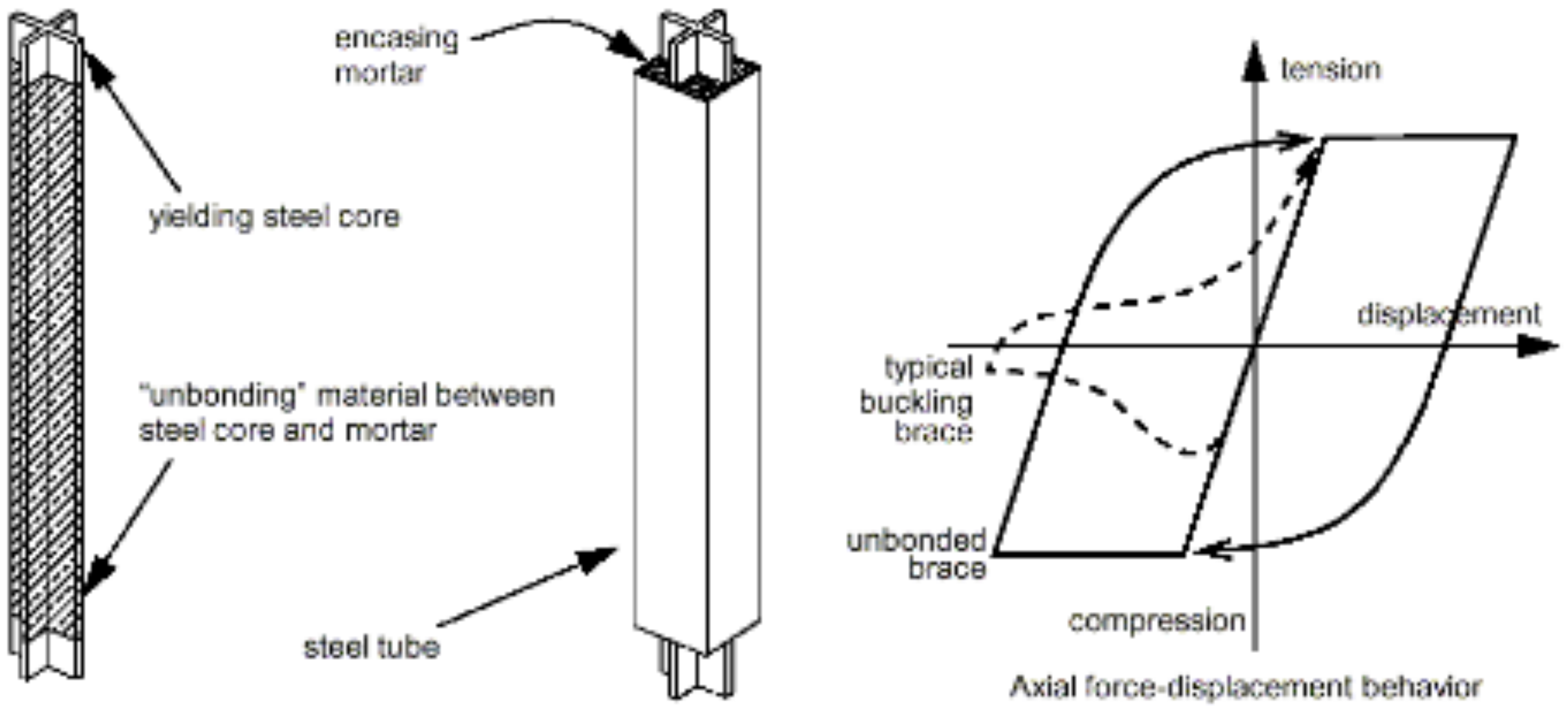


Figure 30a. ADAS devices hysteresis loops [Whittaker, 1991]

Background



Unbonded brace

Nippon Steel

Introduction to US practice

- First applications
  - New construction
    - 1999: Plant & Environmental Sciences Building, UC Davis

ARUP

Introduction to US practice

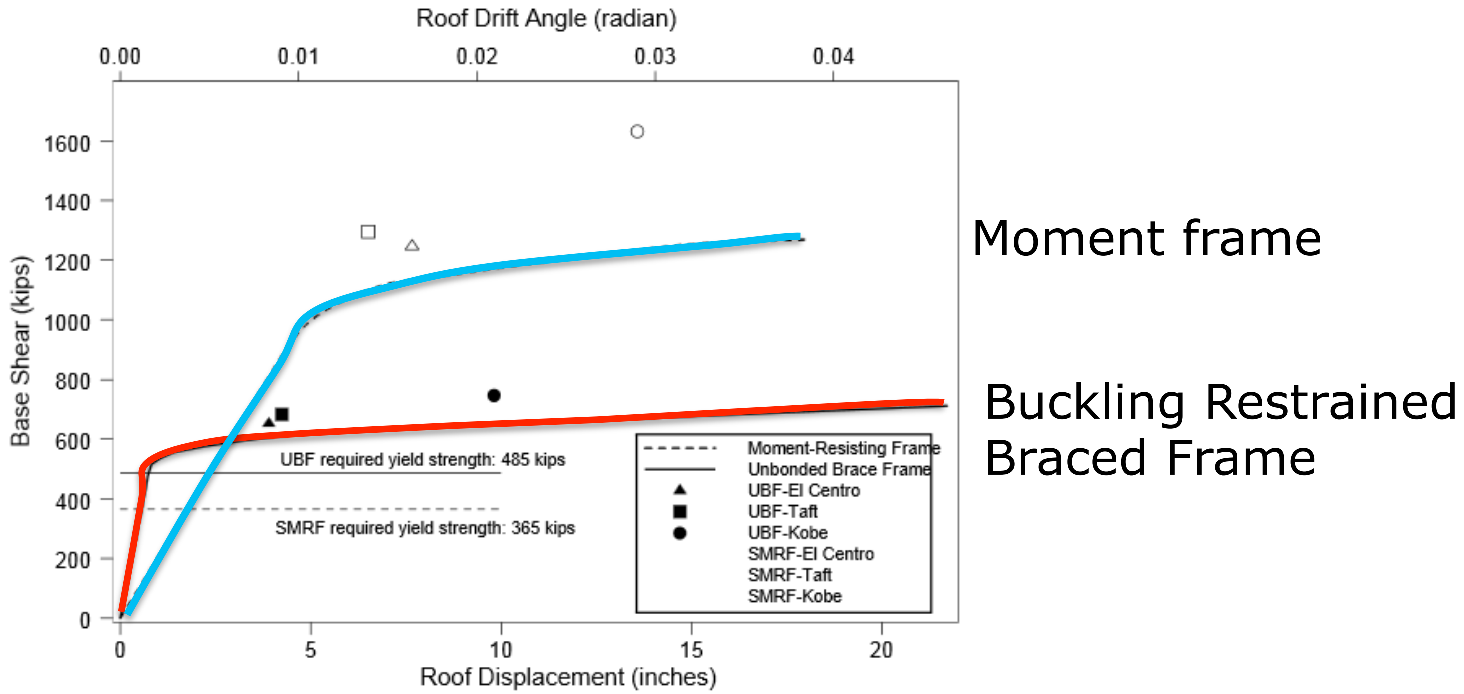
- First applications
  - Retrofit
    - 2000: Marin County Civic Center Hall of Justice
    - 2002: Wallace F. Bennett Federal Building, Salt Lake City

Crosby Group

Reaveley Engineering

Introduction to US practice

- US Design approach
  - Primary lateral-load resisting system
    - Not as supplemental damping
  - Controlled (limited) overstrength



Clark

Introduction to US practice

- US Design approach
  - Decoupled strength and stiffness

An alternative design approach for sizing the unbonded braces could be to use smaller L'_{br} as long as the increase of ε_{br} is acceptable. Such an approach will produce a higher brace stiffness K_{br} and better drift control. This demonstrates how variations in L'_{br} can be investigated to control the stiffness of the unbonded brace independent of its strength. Similarly, steels of various yield strengths can be considered, giving designers the opportunity to modify the strength of a braced frame while keeping its stiffness constant.

    - Fine print: as long as the strain is acceptable
      - (Often it is not!)
      - (Stiffness better achieved through more or larger braces)
  - Design similar to Eccentrically Braced Frames

Introduction to US practice

- Post-Northridge context
  - Less reliance on building code
  - Testing basis
    - Project-specific testing
    - Limited extrapolation
  - Focus on material issues
    - Large strains
    - Low-cycle fatigue
  - Skepticism of calculated drift
    - Minimum drift (rotation) requirements for moment frames

Introduction to US practice

- Code context
  - Testing basis
  - Design basis
    - 1997 UBC & 2000 IBC
      - "Design Basis Earthquake"
        - Life safety
      - "Maximum Considered Earthquake"
        - Collapse prevention
        - Important buildings
    - 2003 IBC
      - Maximum Considered Earthquake
        - Collapse prevention
      - 2/3 MCE?
        - Byproduct/artifact of process?

Introduction to US practice

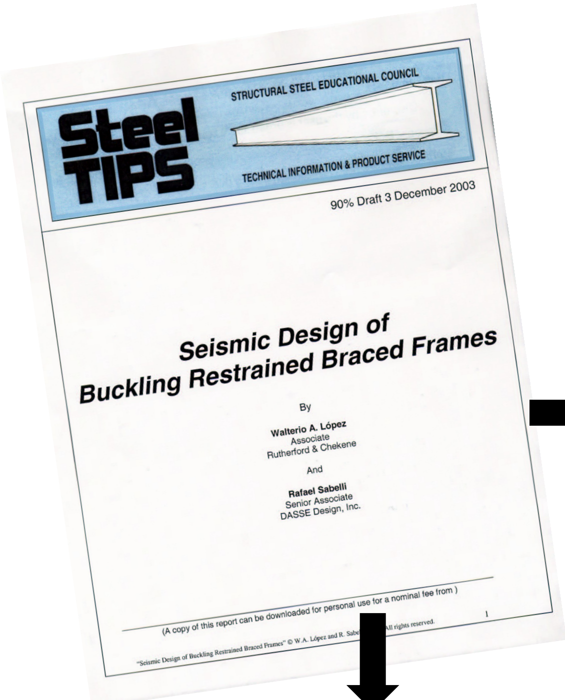
- Code context
  - Design basis
    - Hazard level and performance goal pairing not consistently understood
    - Translation of system performance goal into element performance requirement not clear
  - Move to make Buckling Restrained Braced Frames an available codified system

Introduction to US practice

- Code context
  - SEAOC
    - Prominent role in UBC
    - Prominent role in SAC
    - Unclear role in ASCE 7/IBC
  - SEAOC BRBF design provisions
    - Originated with SEAONC working group
    - Revised by AISC
    - Published 2003
    - Incorporated in to *AISC Seismic* 2005
    - *AISC Seismic* updated 2010

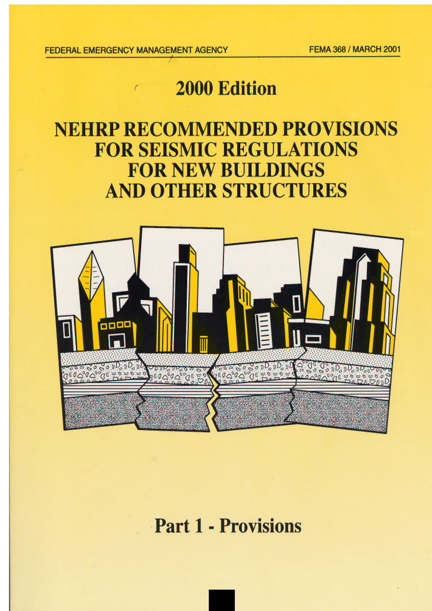
Introduction to US practice

Steel Tips



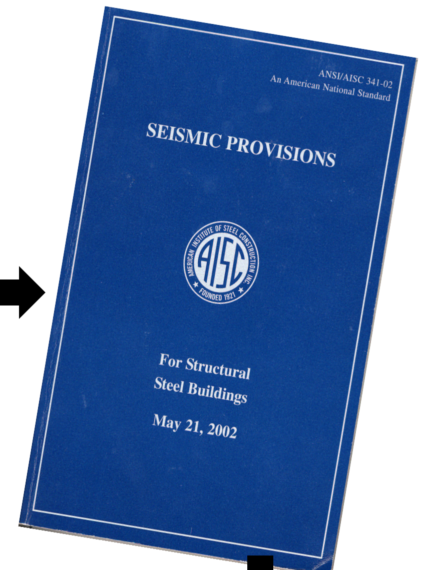
Design Guide to Aid Designers and Plan Reviewers

FEMA 450 (2003)



Guideline Includes BRBF Provisions

AISC Seismic (2005)

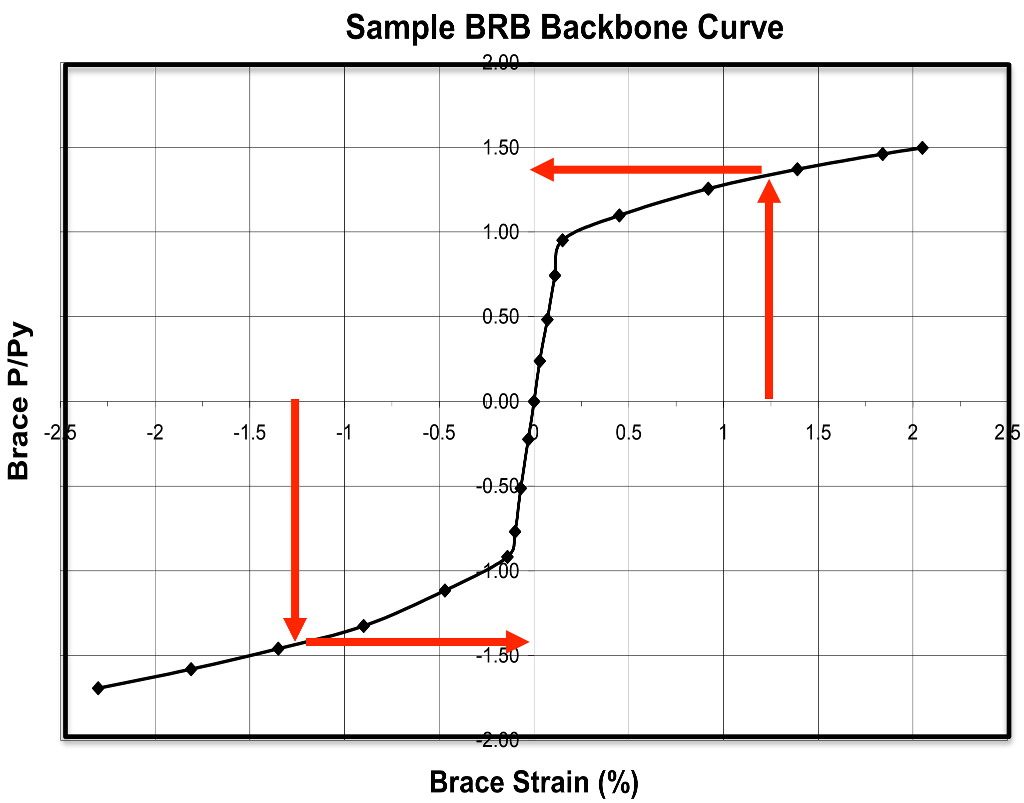


Standard to be Adopted into IBC 2006

Introduction to US practice

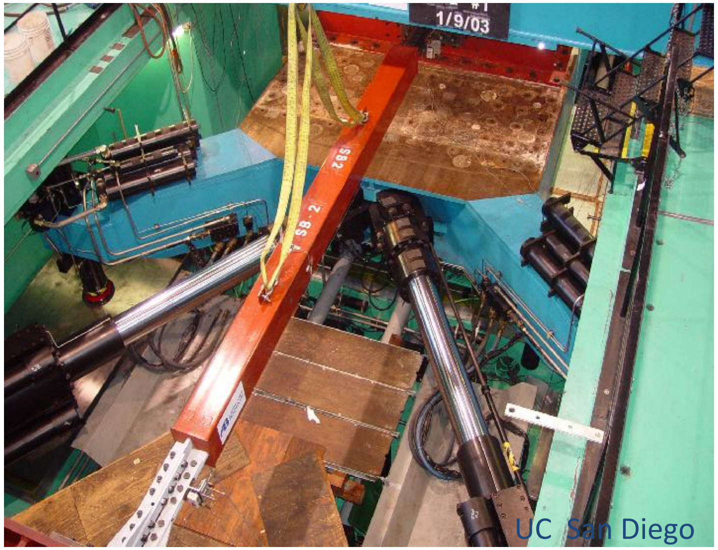
- Code context
  - 2003 BRBF design provisions
    - Strain-based overstrength
    - Amplified displacements used
      - 1.5 x C_d
        - $R/C_d \sim 1.5$
    - Equivalent properties to Eccentrically Braced Frames
      - R
        - Reasonable
      - Ω_o
        - Reasonable; superseded for frame
      - C_d
        - Too low, but consistent with other systems
        - Adjusted by 1.5 for strain and stroke

Introduction to US practice



Introduction to US practice

- Code context
  - 2003 BRBF design provisions
    - Testing required
      - Rotations
      - Limited extrapolation
      - "Similitude"
      - Maximum ductility
      - Cumulative ductility



Introduction to US practice

- Code context
  - 2003 BRBF design provisions
    - Minimum drift not considered for strain-hardening
      - Concentration of ductility not explicitly addressed for strain-hardening
      - Dependence on code-calculated drift
    - Amplification based on limited study
      - Design Basis Earthquake

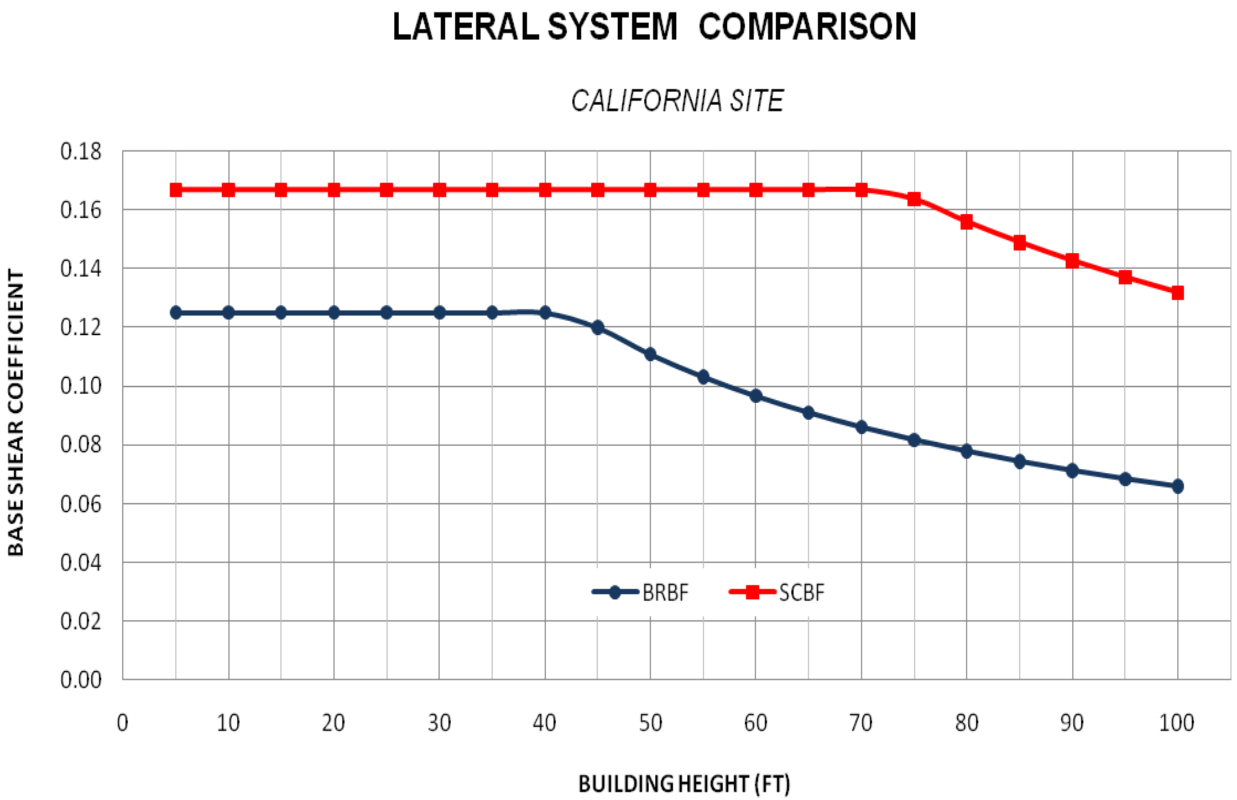
Introduction to US practice

- Code context
  - 2005 BRBF design provisions
    - Amplified displacements used
      - 2 x C_d
        - MCE/DBE ~1.5
        - R/C_d ~ 1.5
      - 2% minimum drift considered for brace stroke
    - Strain-based overstrength
      - 2 x C_d
  - 2010 BRBF design provisions
    - 2% minimum drift considered
      - Stroke
      - Strain hardening

Use today

- Codified system
  - One of the last systems not facing FEMA P-695
- Competing manufacturers
  - Competitive bid
  - Interchangeable products?
    - Strength/stiffness characteristics may be different
- Range of building types

Use today



Code provisions offer significant advantages for BRBF compared to other concentrically braced frames

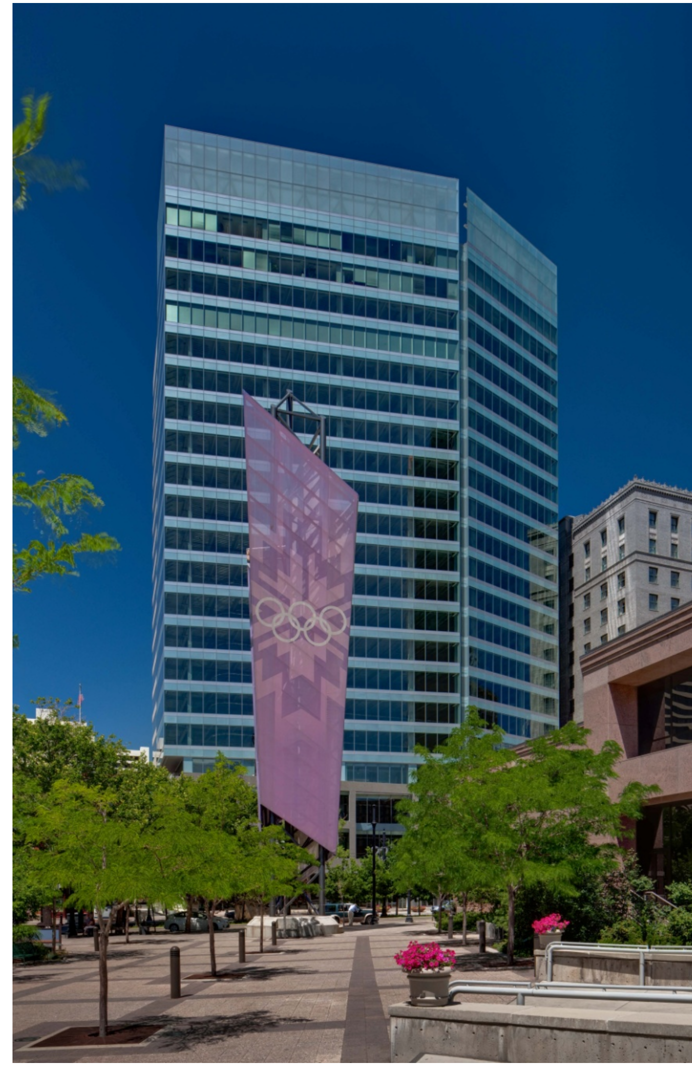
Use today

- Low-rise concentrically braced frames

STAR Seismic

Use today

- Large buildings



CoreBrace

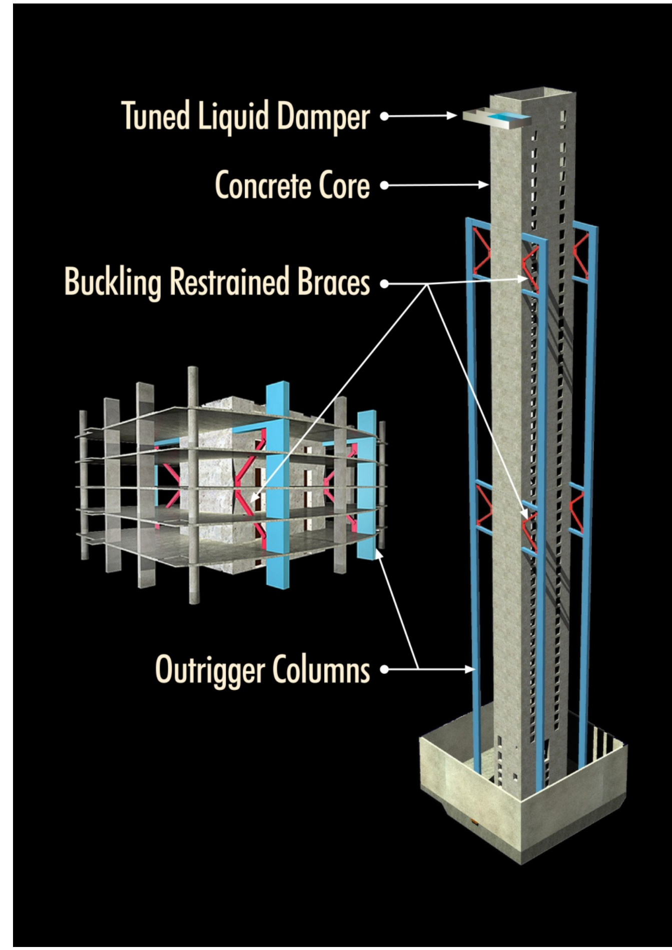
Use today

- Large buildings

Stadia

Use today

- Force-limiting applications



Outriggers

CoreBrace

Use today

- Force-limiting applications

Outriggers

STAR Seismic

Use today

- Unusual applications

Vertical brace in rocking frame

CoreBrace

Use today

- Unusual applications

Dam structure

Use today

- Unusual applications

Horizontal buttress

Ongoing issues

- Maximum Considered Earthquake
  - Demands
    - Elongation
    - Maximum strain
  - Performance
    - Collapse-prevention
      - Is ideal brace behavior necessary at MCE?
    - Appropriate reliability
      - ϕ
      - Ω

Ongoing issues

- Maximum Considered Earthquake
  - Appropriate protocol
    - Strain-based overstrength
    - Current protocol may be too stringent
  - Safeguard against under-prediction of strain
    - Short yield lengths
      - Result of (mentally) decoupling strength and stiffness
    - Minimum drift
    - Amplification of calculated maximum drift
  - Utilization of existing test data

Thank you