Structural Fuses

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EARTHQUAKE ENGINEERING TO EXTREME EVENTS

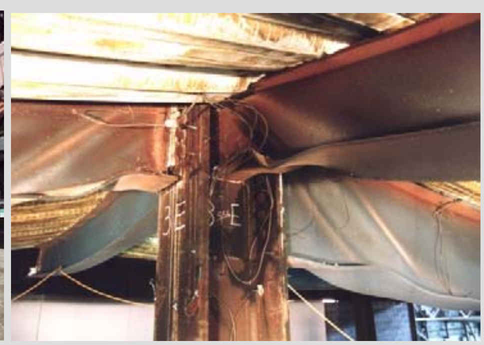
Energy Dissipation

- Earthquake-resistant design has long relied on hysteretic energy dissipation to provide life-safety level of protection
- Advantages of yielding steel
  - Stable material properties well known to practicing engineers
  - Not a mechanical device (no special maintenance)
  - Reliable long term performance (resistance to aging)
- For traditional structural systems, ductile behavior achieved by stable plastic deformation of structural members = damage to those members
- In conventional structural configurations, serves life-safety purposes, but translates into property loss, and need substantial repairs

Energy Dissipation

Ductility

Brittle (↓) (Somewhat) Ductile (↓)

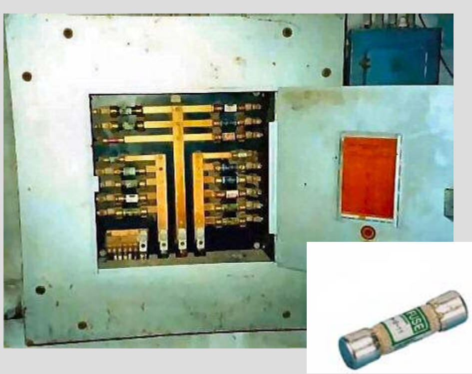


Structural Fuses

- From Energy Dissipation to Structural Fuse
  - Researchers have proposed that hysteretic energy dissipation should instead occur in “disposable” structural elements (i.e., structural fuses)

Analogy

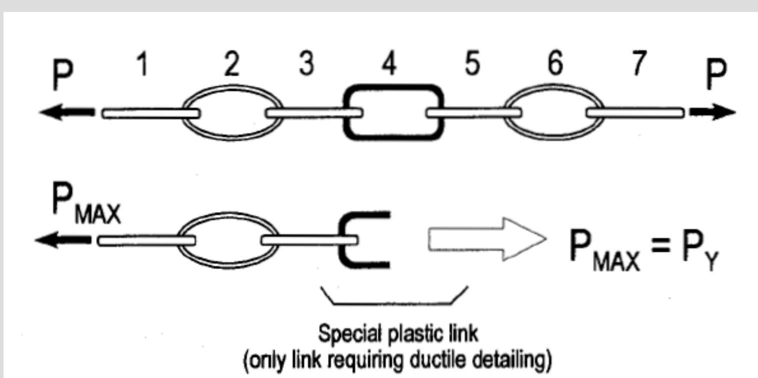
- Sacrificial element to protect the rest of the system.



Weak Link

Brittle (↓) (Somewhat) Ductile (↓)

Capacity Design



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Eccentrically Braced Frames with Tubular Links

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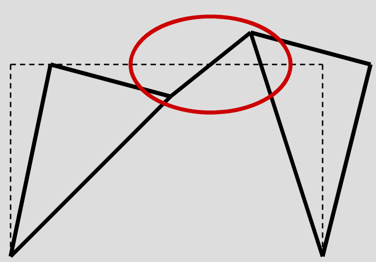
Roeder and Popov (1977)

"Ductile Fuse"



Eccentrically Braced Frame

- Ductile seismic behavior
- Concentrating energy dissipation in special elements + capacity design
- Links not literally disposable

Other studies:

- Fintel and Ghosh (1981)
- Aristizabal-Ochoa (1986)
- Basha and Goel (1996)
- Carter and Iwankiw (1998)
- Sugiyama (1998)
- Rezai et al. (2000)

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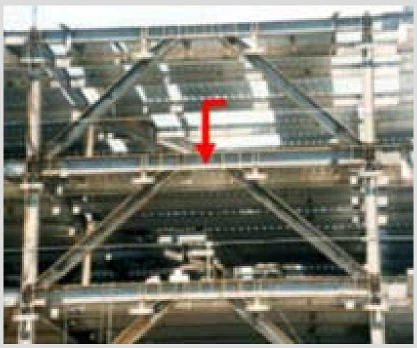
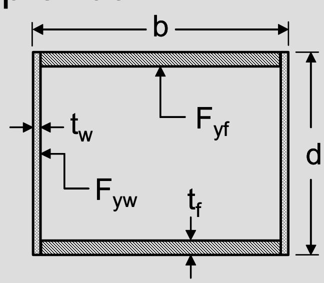
Eccentrically Braced Frame



Tubular Eccentrically Braced Frame

- EBFs with wide-flange (WF) links require lateral bracing of the link to prevent lateral torsional buckling
- Lateral bracing is difficult to provide in bridge piers
- Development of a laterally stable EBF link is warranted
- Consider rectangular cross-section – No LTB



Proof-of-Concept Testing

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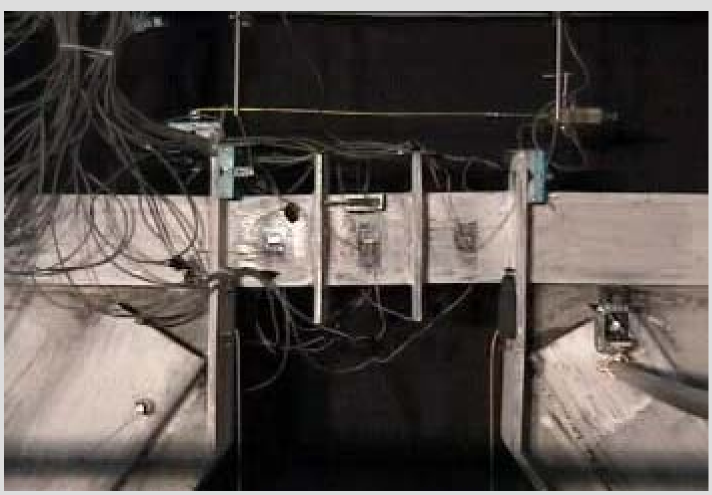
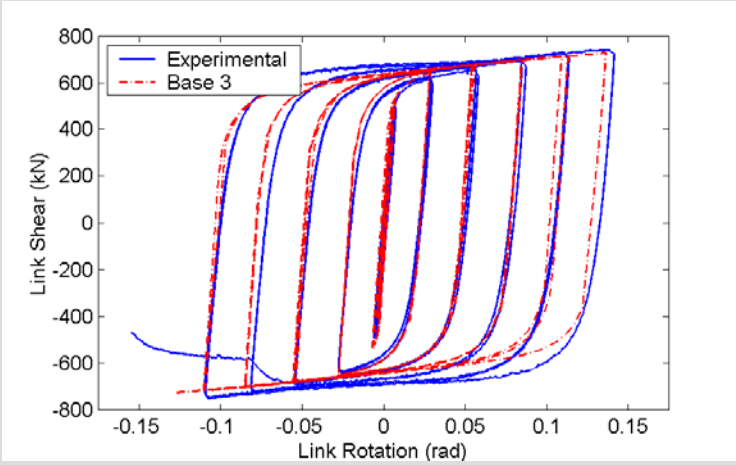


Finite Element Modeling of Proof-of-Concept Testing



Hysteretic Results for Refined ABAQUS Model and Proof-of-Concept Experiment

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Link Testing – Results

Large Deformation Cycles of Specimen X1L1.6

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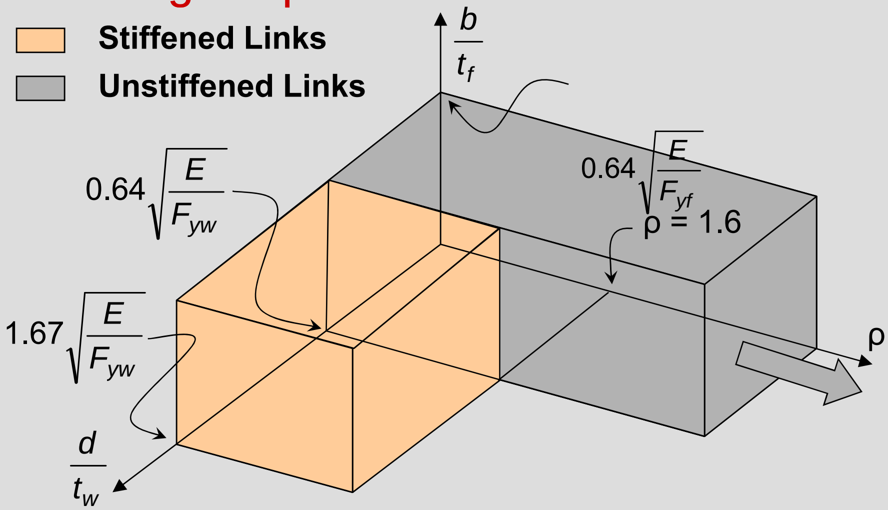
Design Space



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Buckling Restrained Braces in Structural Fuse Application

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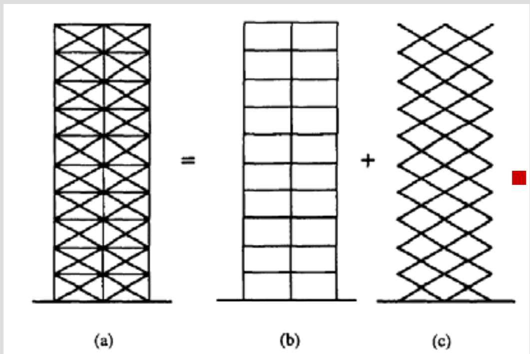
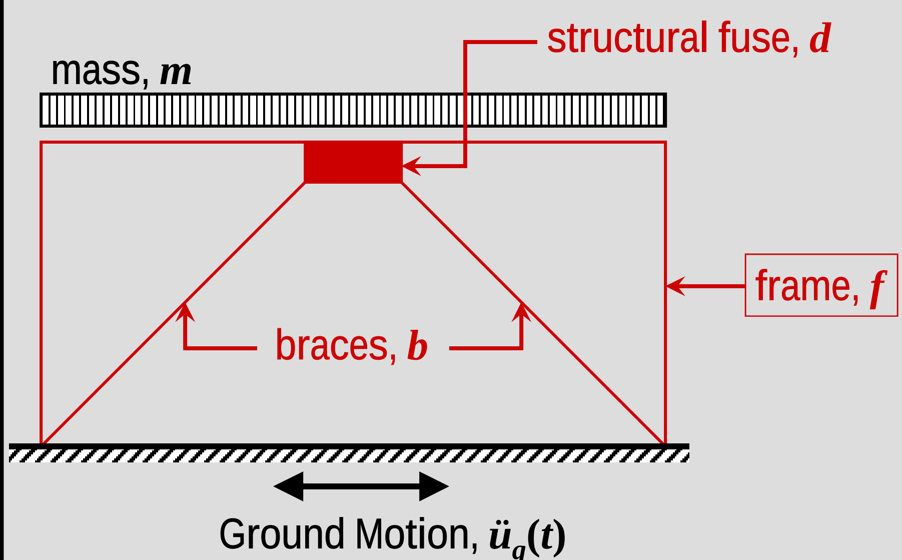
Wada et al. (1992)
Damage-controlled or Damage-tolerant Structures



- Ductile elements were used to reduce inelastic deformations of the main structure
- Concept applied to high rise buildings (T > 4 s)

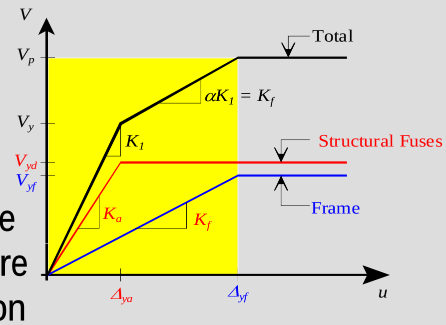
Other studies:

- Connor et al. (1997)
- Shimizu et al. (1998)
- Wada and Huang (1999)
- Wada et al. (2000)
- Huang et al. (2002)



Benefits of Structural Fuse Concept:

- Seismically induced damage is concentrated on the fuses
- Following a damaging earthquake only the fuses would need to be replaced
- Once the structural fuses are removed, the elastic structure returns to its original position (self-recentering capability)



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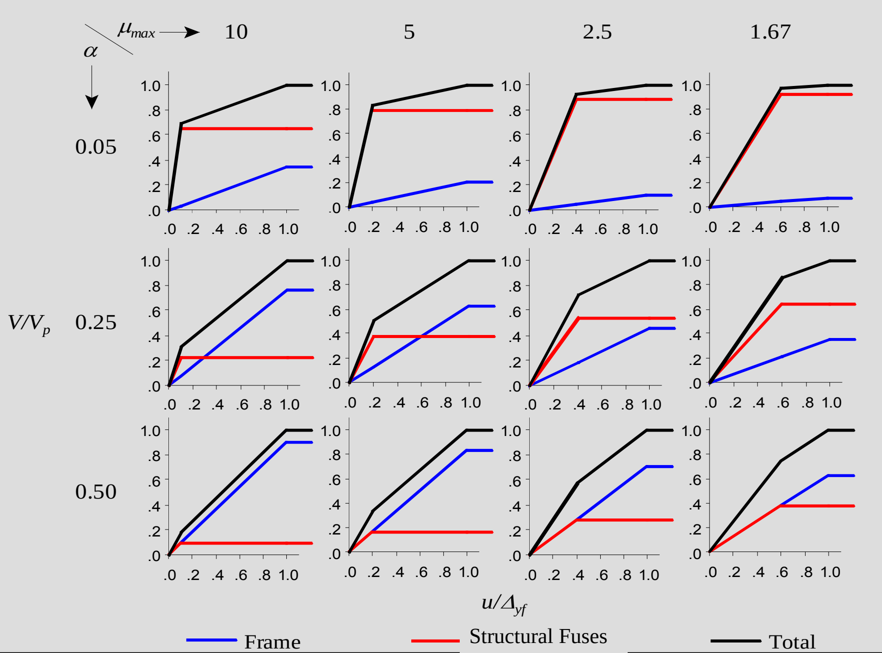

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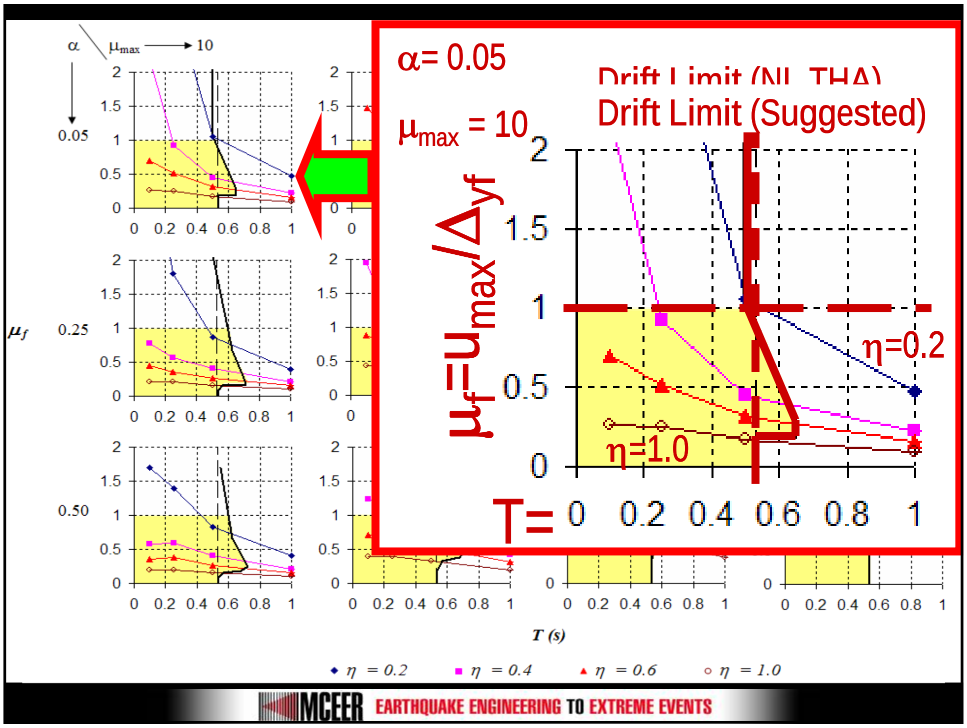
α= 0.05
μmax = 10
Drift Limit (NL THA)
Drift Limit (Suggested)
μf=umax/Δyf
η=0.2
η=1.0
T= 0 0.2 0.4 0.6 0.8 1
T (s)
η = 0.2
η = 0.4
η = 0.6
η = 1.0
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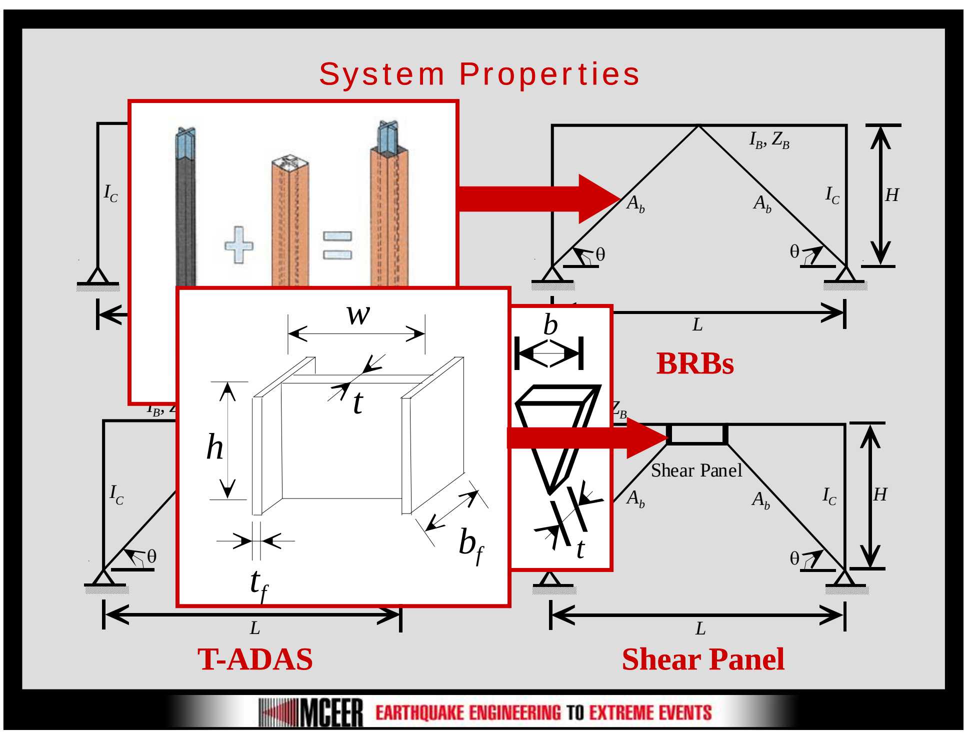
System Properties
BRBs
Shear Panel
T-ADAS
Shear Panel
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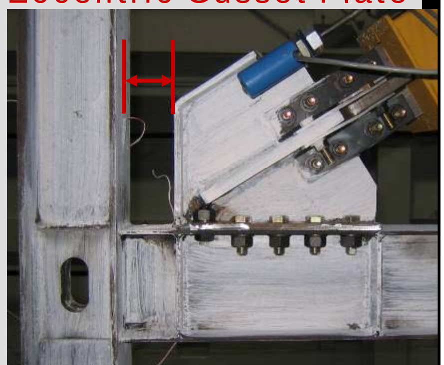
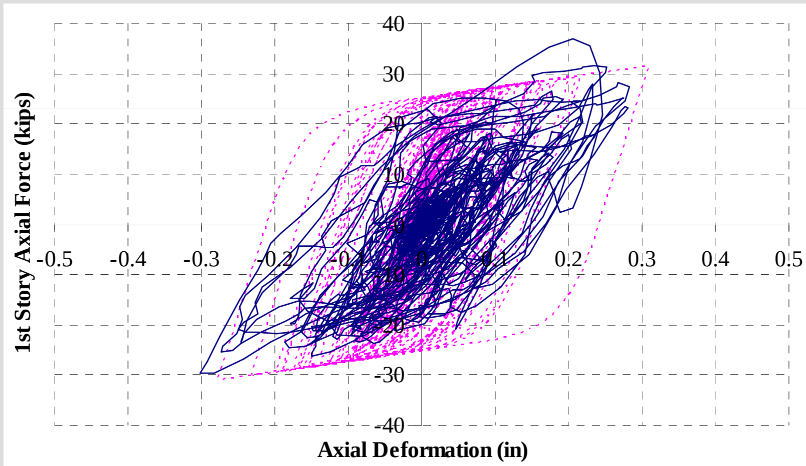
Model with
Nippon Steel BRBs

Eccentric Gusset-Plate

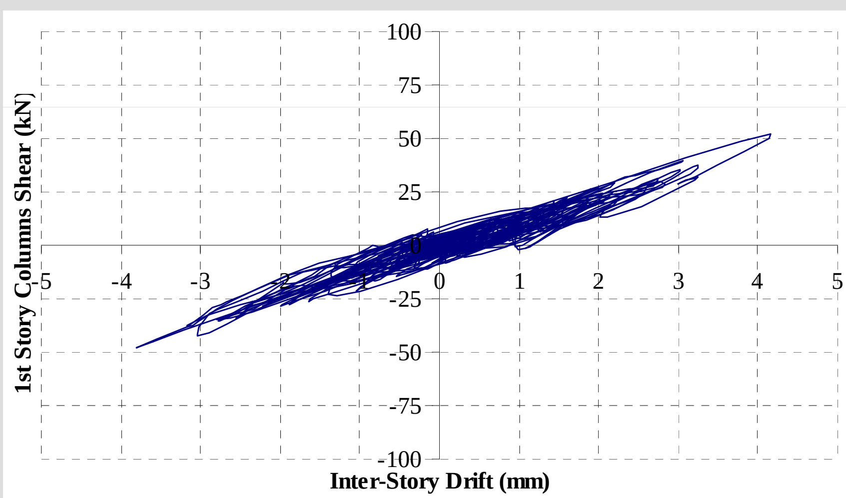


Test 1
(PGA = 1g)

Test 1
First Story BRB



Test 1 (Nippon Steel BRB Frame)
First Story Columns Shear



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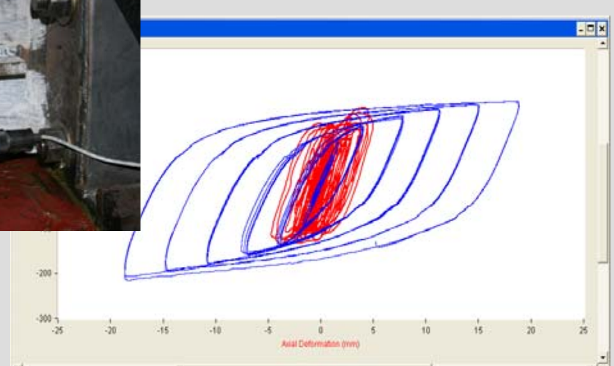
Static Test - Nippon Steel BRBs

Note: Replacement is to re-center the building (not due to BRB fracture life)



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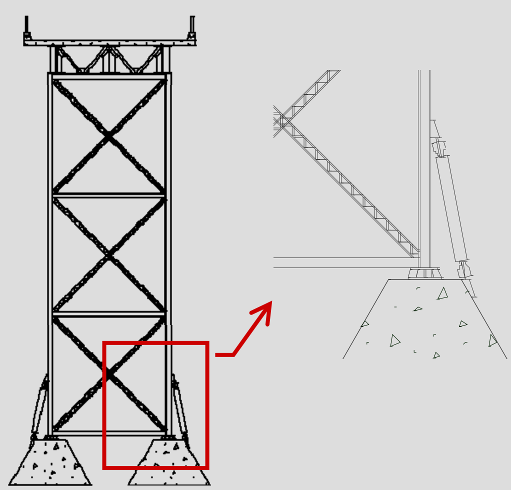
Rocking Trusses
(Rocking Braced Frames)

Controlled Rocking/Energy Dissipation System

- Absence of base of leg connection creates a rocking bridge pier system partially isolating the structure
- Installation of steel yielding devices (buckling-restrained braces) at the steel/concrete interface controls the rocking response while providing energy dissipation



Retrofitted Tower

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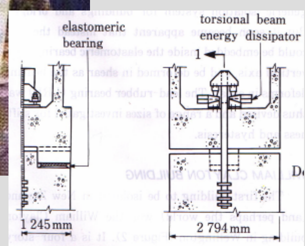
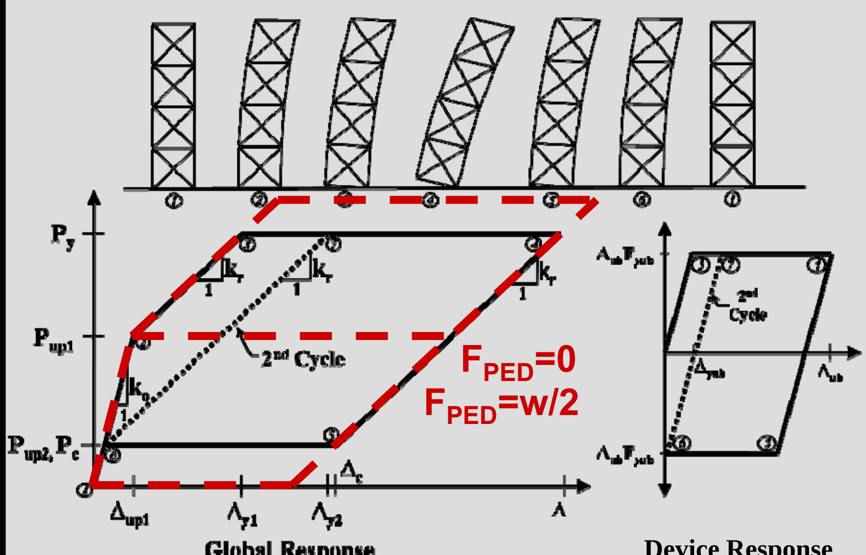
Existing Rocking Bridges

South Rangitikei Rail Bridge



Lions Gate Bridge North Approach

Static, Hysteretic Behavior of Controlled Rocking Pier



General Design Constraints for Controlled Rocking System

- (1) Deck-level displacement limits need to be established on a case-by-case basis
  - Maintain pier stability
  - Bridge serviceability requirements
- (2) Strains on buckling-restrained brace (uplifting displacements) need to be limited such that it behaves in a stable, reliable manner
- (3) Capacity Protection of existing, vulnerable resisting elements considering 3-components of excitation and dynamic forces developed during impact and uplift
- (4) Allow for self-centering of pier

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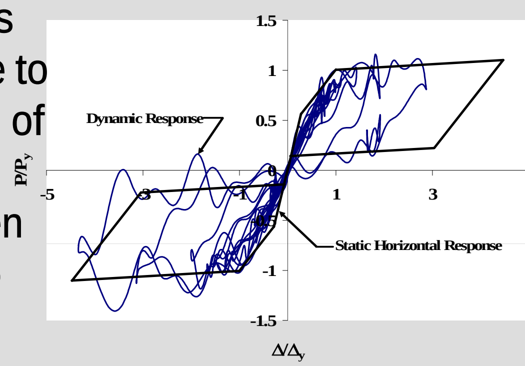
(3) Capacity Protection (cont.)

- An increase from the static response has been observed due to dynamic excitation of vertical modes of vibration even when subjected solely to horizontal base accelerations



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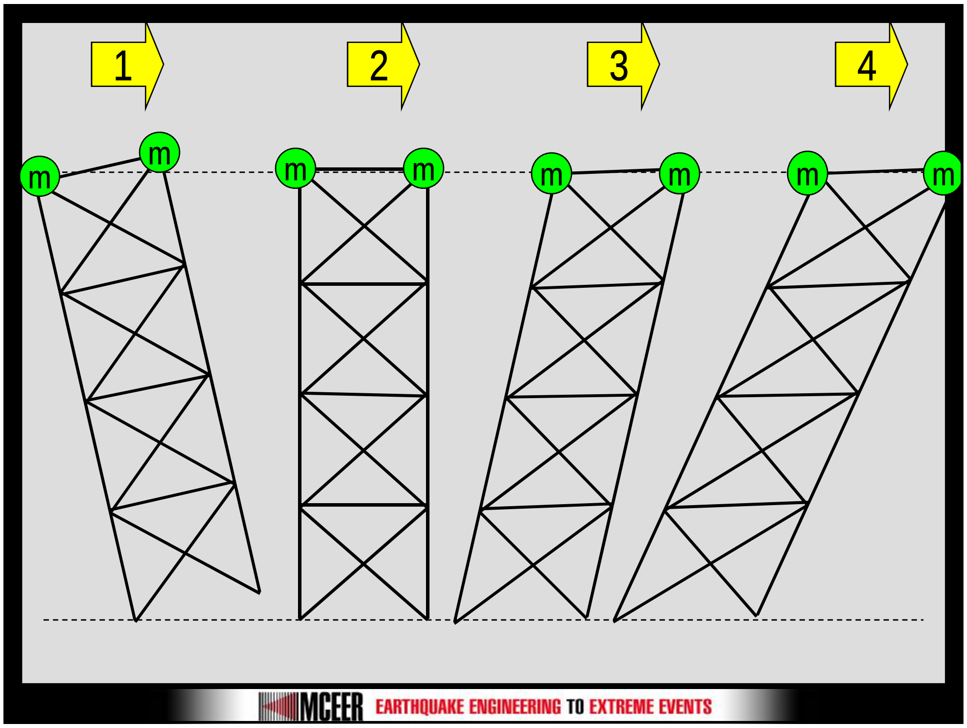
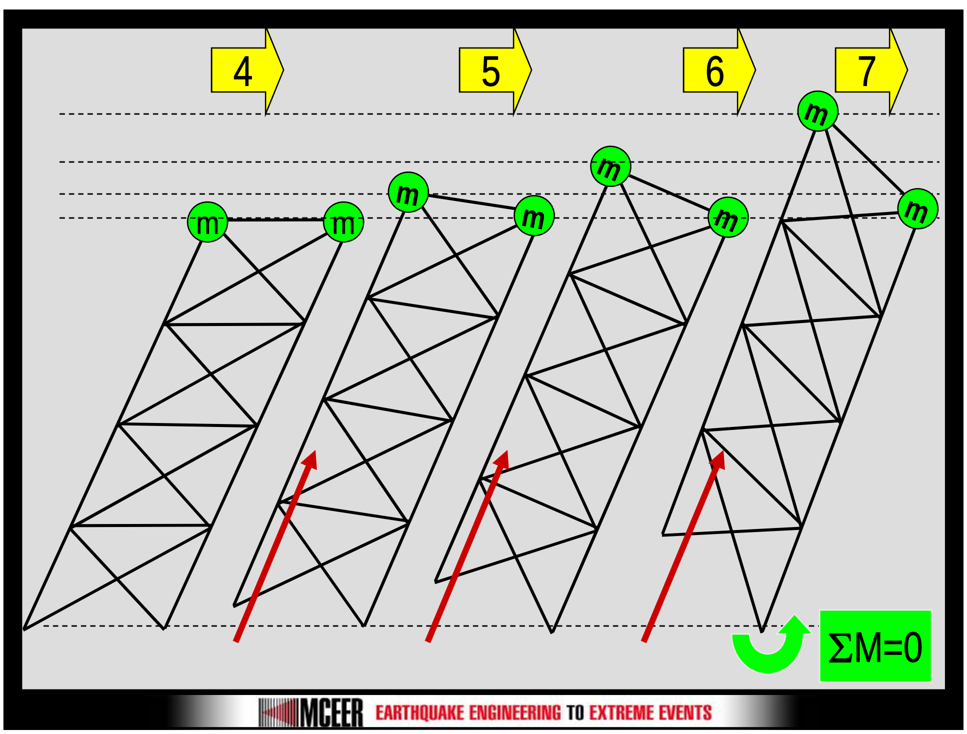

1
2
3
4
m
MCEER EARTHQUAKE ENGINEERING TO EXTREME EVENTS


4
5
6
7
m
ΣM=0
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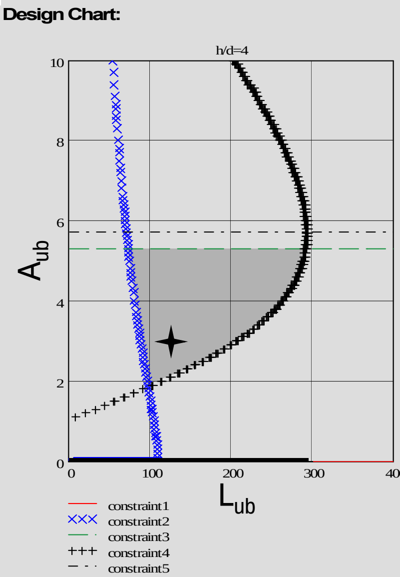
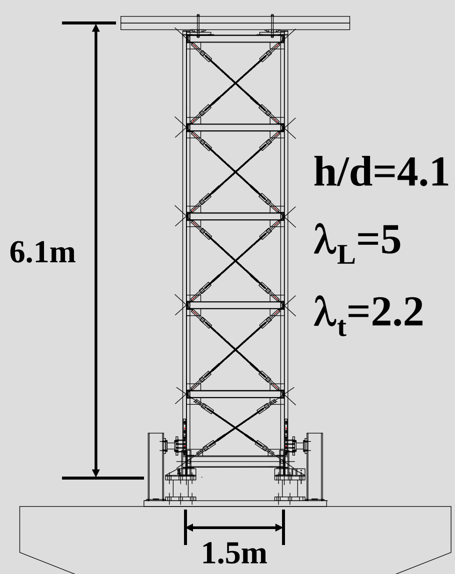
Design Procedure

- Design Constraints
  - Acceleration
    Limit forces through vulnerable members using structural “fuses”
  - Velocity
    Control impact energy to foundation and impulsive loading on tower legs by limiting velocity
  - Displacement Ductility
    Limit μ_L of specially detailed, ductile “fuses”
  - β<1 Inherent re-centering (Optional)



Experimental Testing

- Artificial Mass Simulation Scaling Procedure
  - λ_L>5 (Crane Clearance)
  - λ_A=1.0 (1-g Field)
  - W_m=70kN (W_e=76kN)
  - T_{om}=0.34sec (T_{oe}=0.40sec)
- Loading System
  - Phase I
    - 5DOF Shake Table
  - Phase II
    - 6DOF Shake Table



Synthetic EQ 150% of Design
Free Rocking

Synthetic EQ 150% of Design
TADAS Case η_L=1.0

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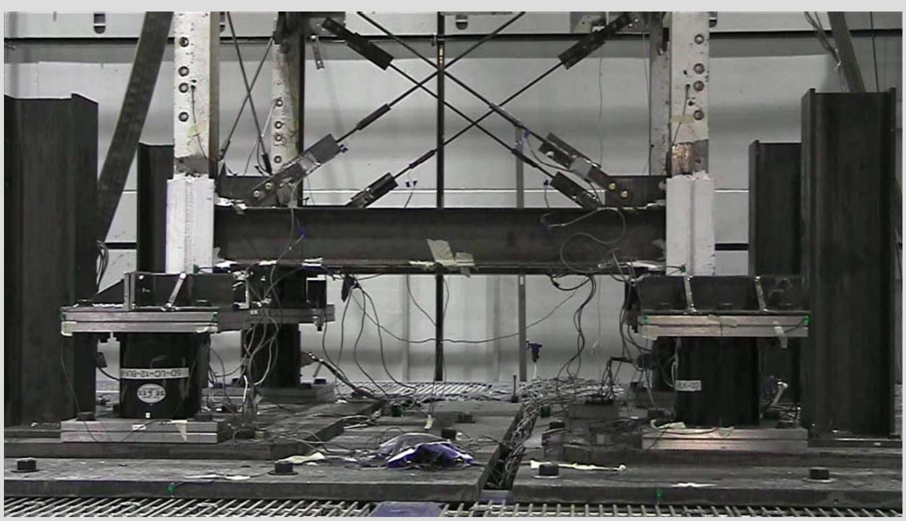

Synthetic EQ 150% of Design – Free Rocking

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Synthetic EQ 175% of Design - Viscous Dampers

ABC Bridge Pier with Structural Fuses

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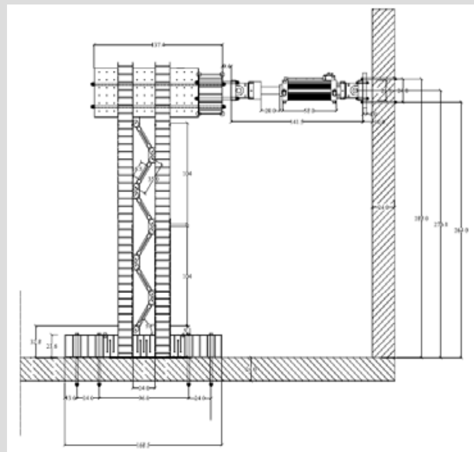
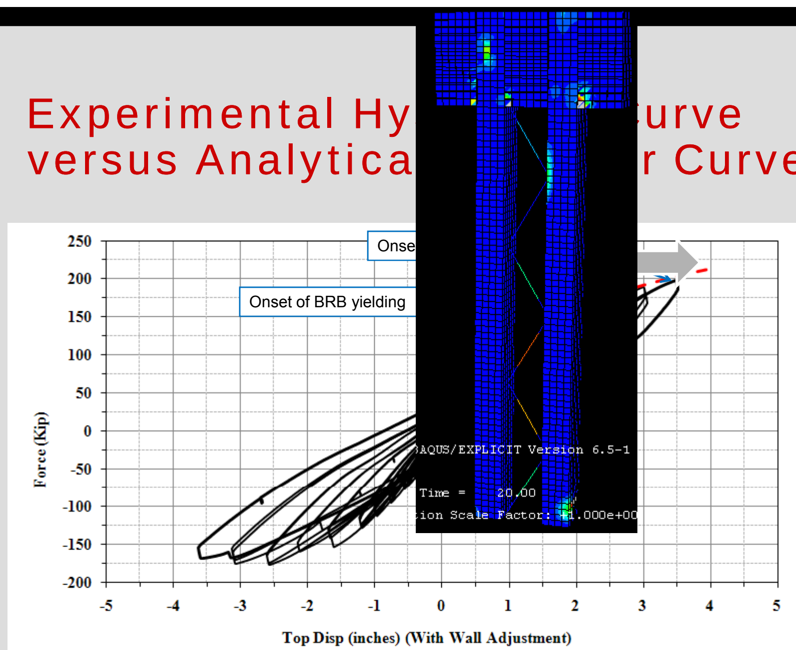
Specimen S2-1



Experimental Hy urve versus Analytica r Curve



Specimen with BRB Fuses

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Specimen with BRB Fuses

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Conclusions

- Recently developed options for seismic design and retrofit illustrated (BRB with Fuse, TEBF, Rocking)
- Instances for which replacement of sacrificial structural members (considered to be structural fuses dissipating hysteric energy) was accomplished, in some cases repeatedly.
- Article/Clauses for the design of some of these systems are being considered by:
  - CSA-S16 committee for 2009 Edition of S16
  - AISC TC9 Subcommittee for the 2010 AISC Seismic Provisions
- Emerging field: opportunities to develop structural fuse concepts still exist

Acknowledgments

- Ph.D. Students:
  - Michael Pollino – *Rocking Steel Framed Systems*
  - Jeffrey Berman – *Seismic Retrofit of Large Bridges Braced Bent*
  - Ramiro Vargas – *Enhancing Resilience using Passive Energy Dissipation Systems*
  - *Samer El-Bahey – Structural Fuses for Bridges*

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Thank you!

Questions?

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