



NEESR-SG: Controlled Rocking of Steel-Framed Buildings with Replaceable Energy Dissipating Fuses

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E-Defense



JISF

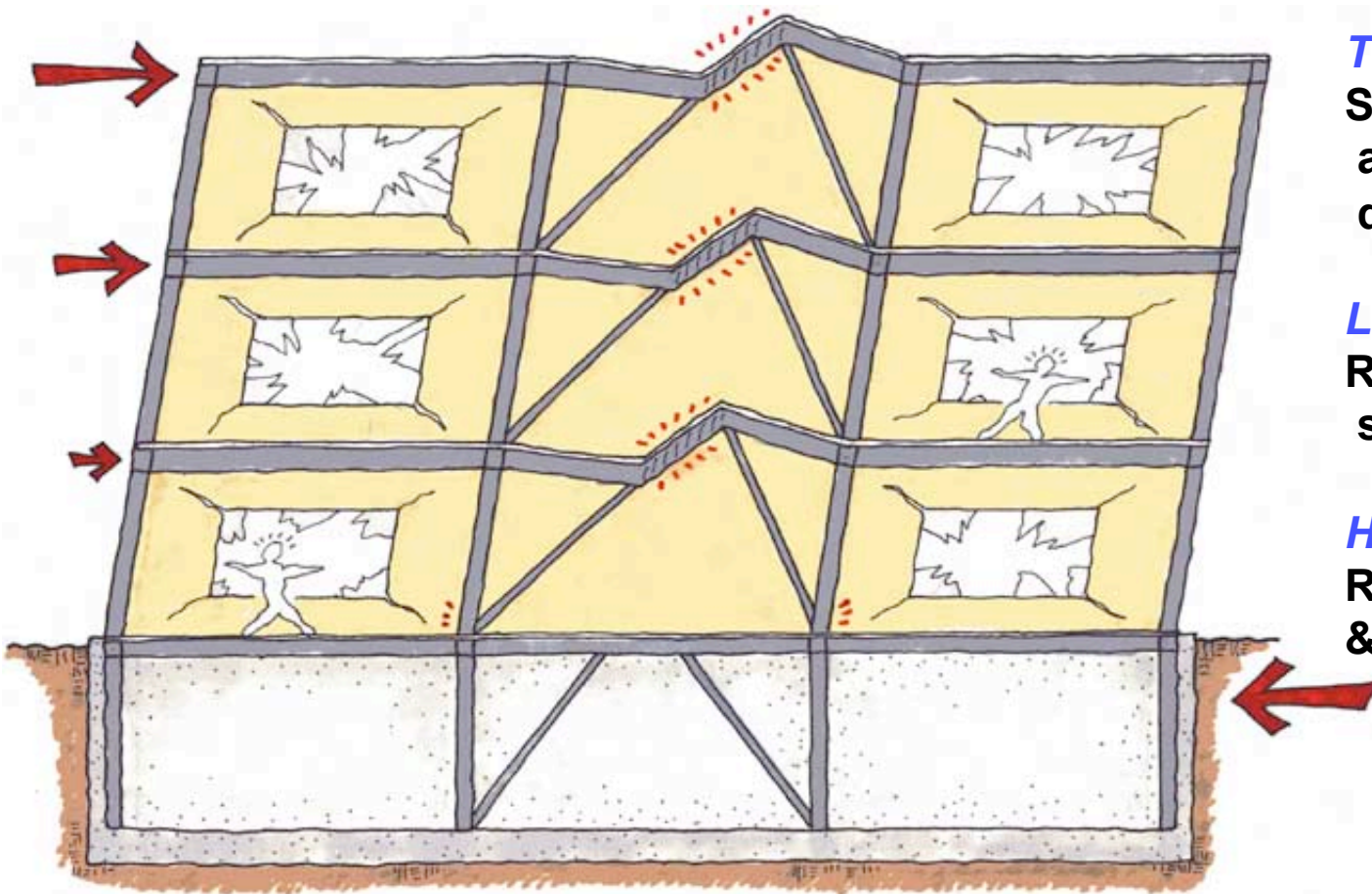


NEES

George E. Brown, Jr. Network for Earthquake Engineering Simulation



Code Seismic Design Protect Life Safety



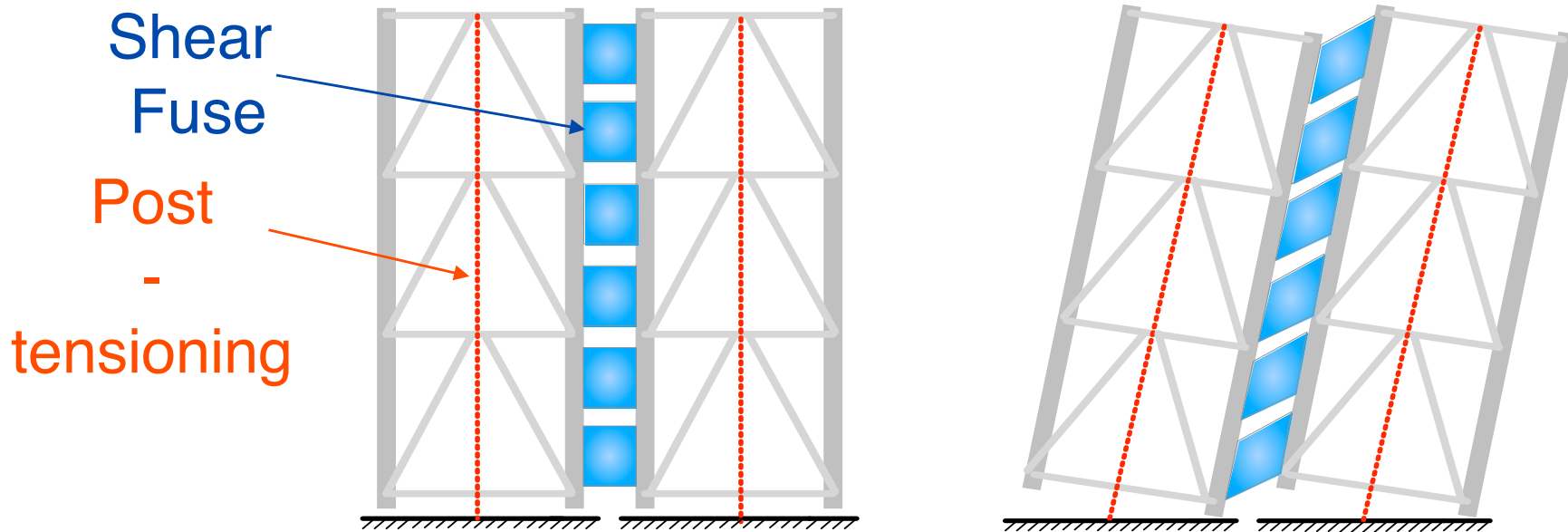
Throw-away technology:
Structure and Architecture
absorbs energy through
damage

Large Inter-story Drifts:
Result in architectural &
structural damage

High Accelerations:
Result in content damage
& loss of function

Deformed Section – Eccentric Braced Frame

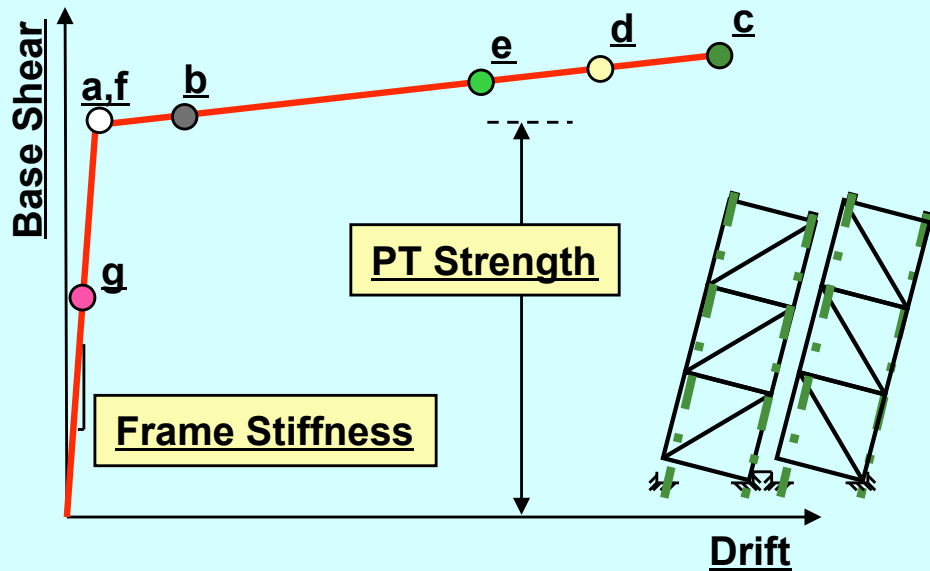
New Rocking Frame System



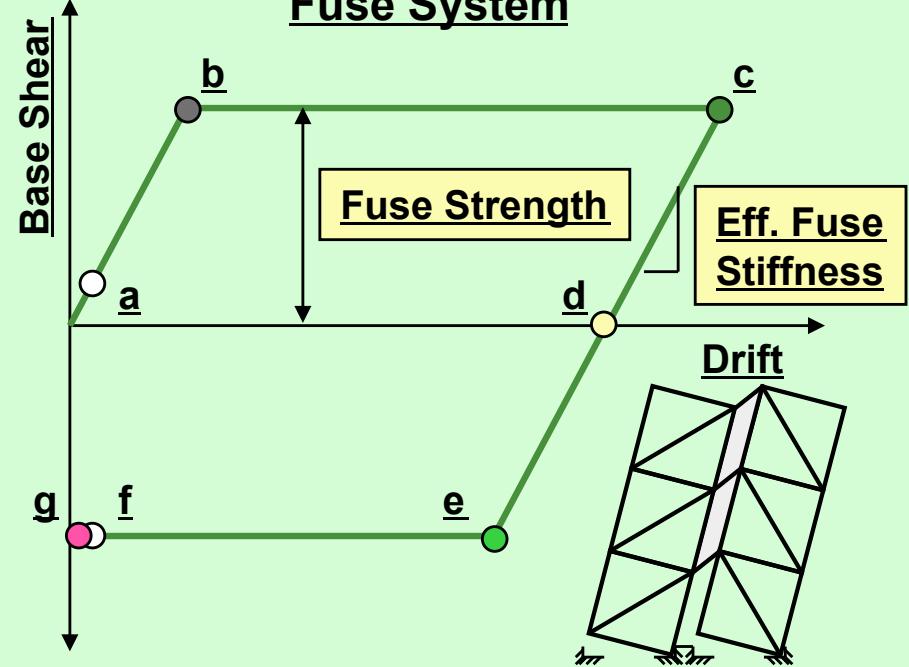
Develop a new structural building system that employs *self-centering rocking* action and *replaceable** fuses to provide safe and cost effective earthquake resistance.

**Key Concept – design for repair*

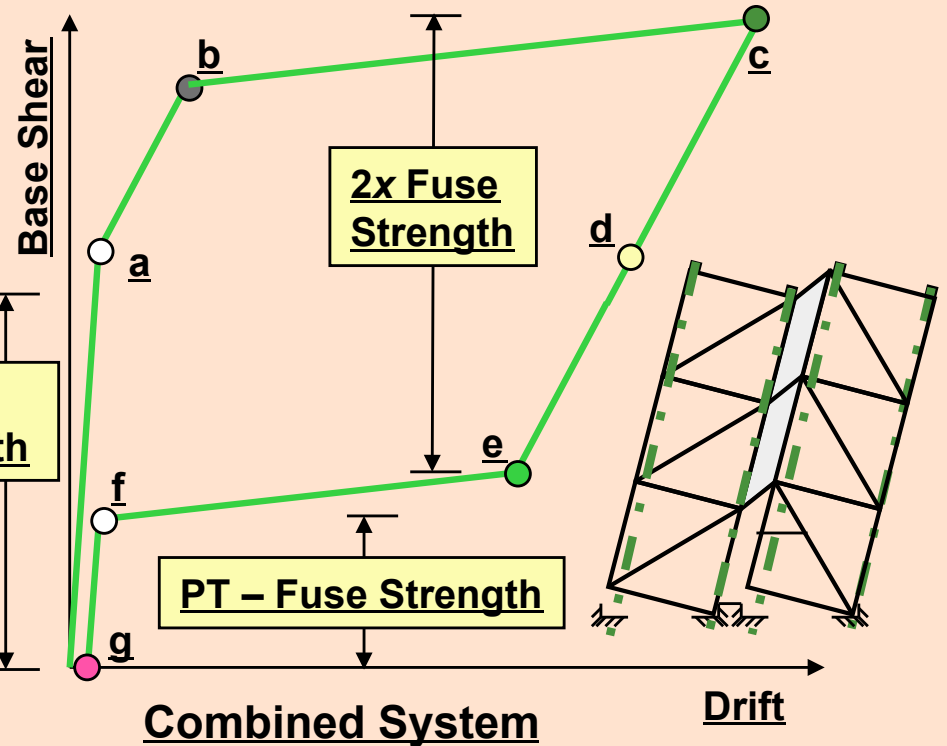
Pretension/Brace System



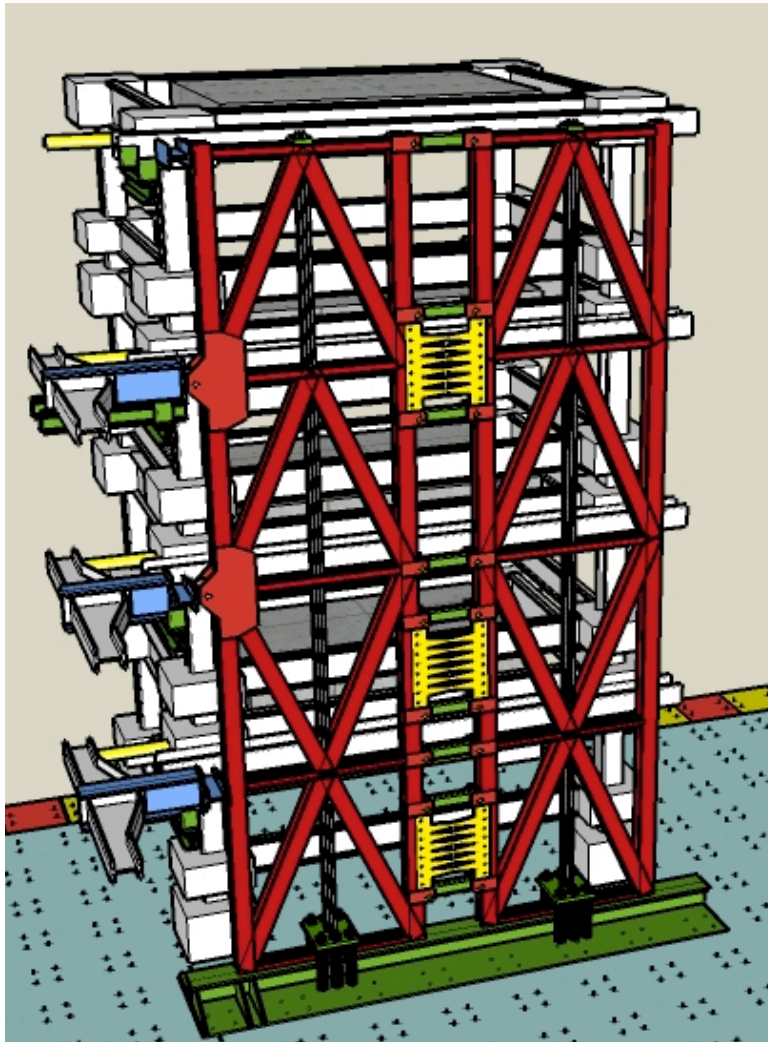
Fuse System



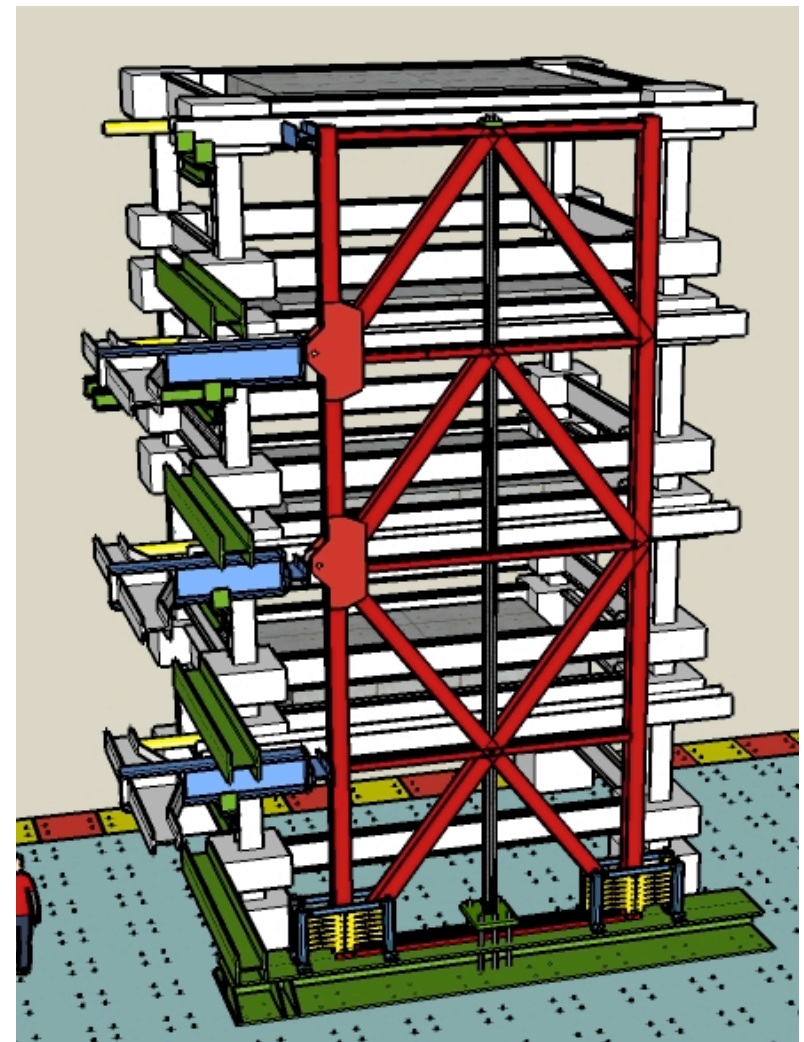
- Origin-a – frame strain + small distortions in fuse
- a – frame lift off, elongation of PT
- b – fuse yield (+)
- c – load reversal
- d – zero force in fuse
- e – fuse yield (-)
- f – frame contact
- f-g – frame relaxation
- g – strain energy left in frame and fuse, small residual displacement



Alternative Implementations



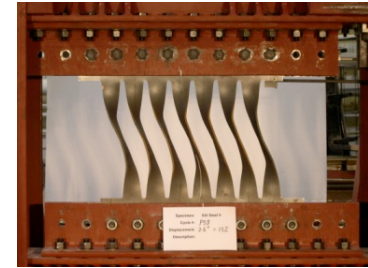
Dual Frame



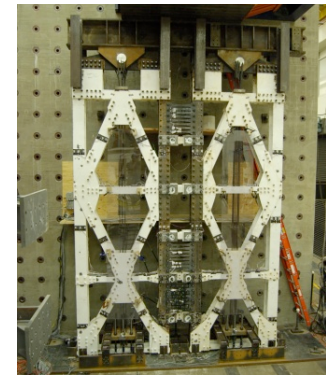
Single Frame

Research Scope

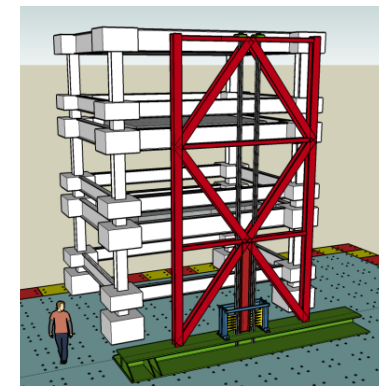
- **System Design Development**
 - parametric design studies
 - shear panel fuse design and testing
 - building simulation studies
- **Subassembly Frame/Fuse Tests**
 - quasi-static cyclic loading
 - PT rocking frame details & response
 - fuse/frame interaction
 - model calibration
- **Shake Table System Tests**
 - proof-of-concept
 - large scale validation



Stanford

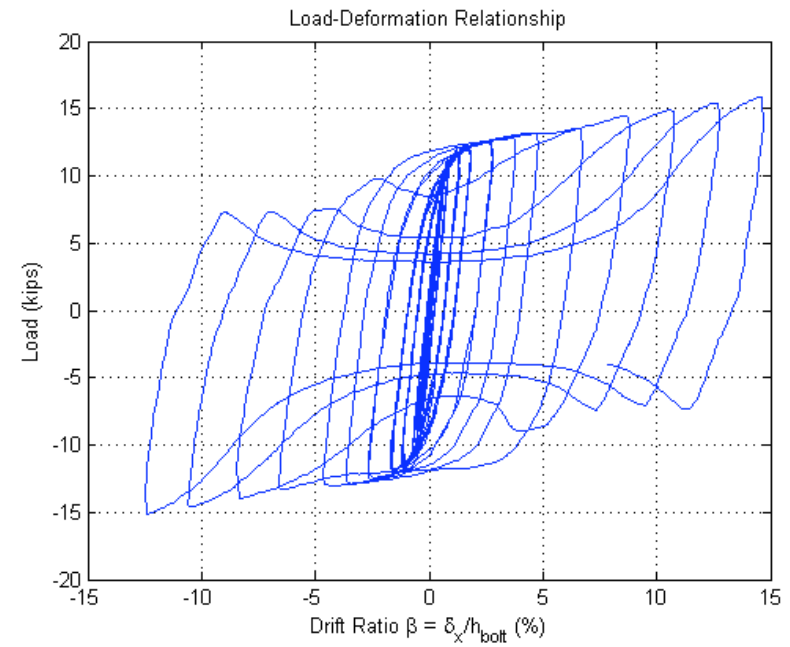
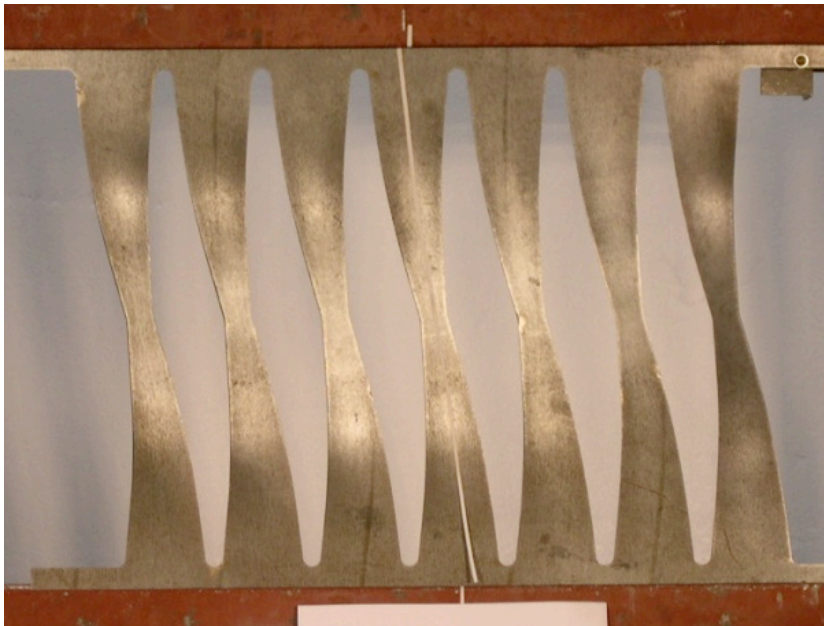
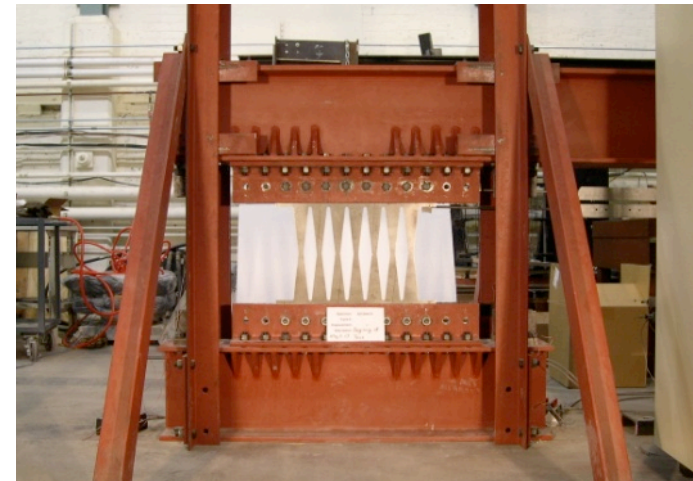
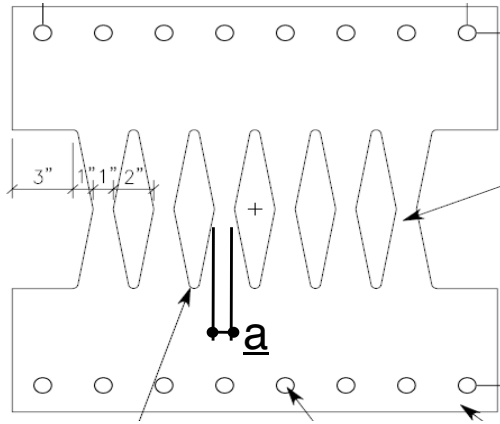


NEES - Illinois

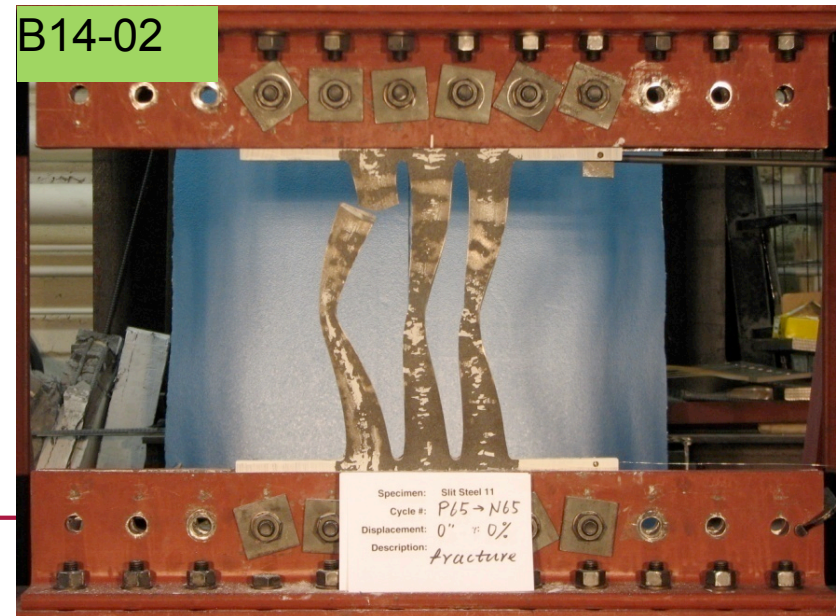
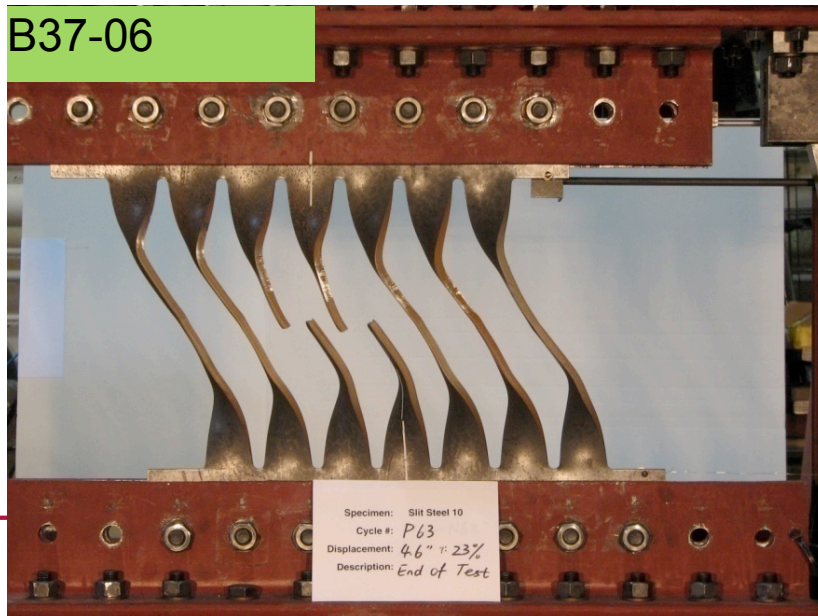
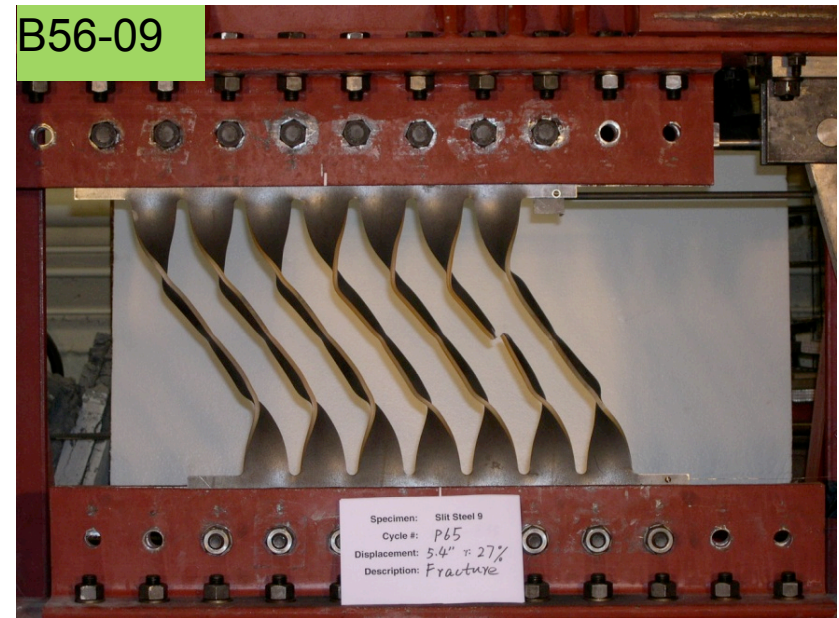
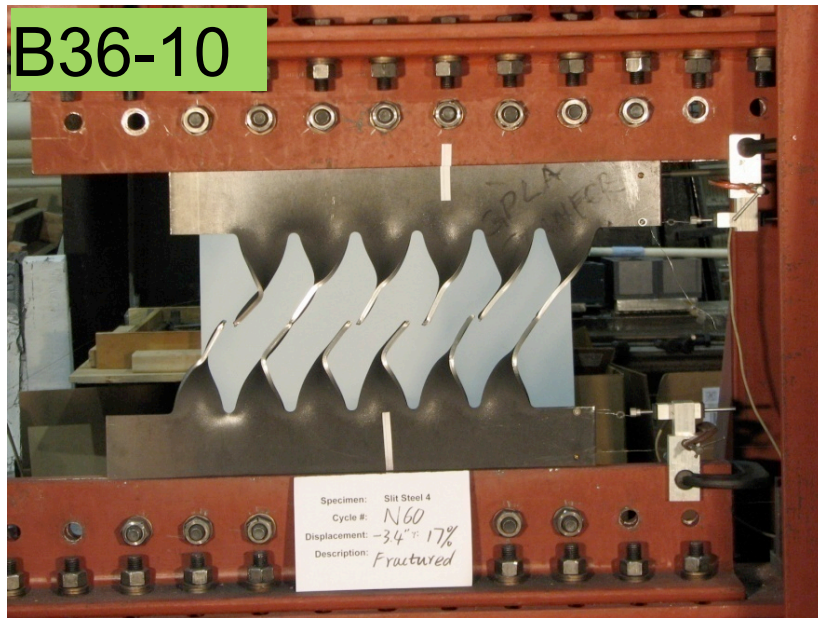


E-Defense

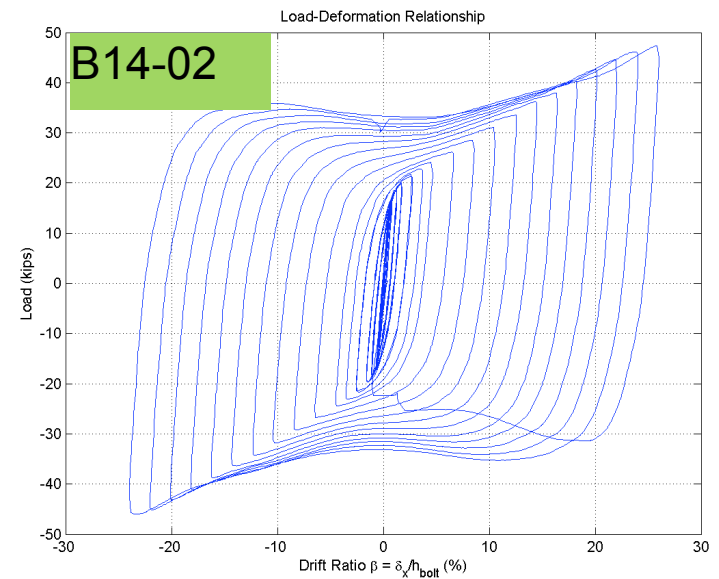
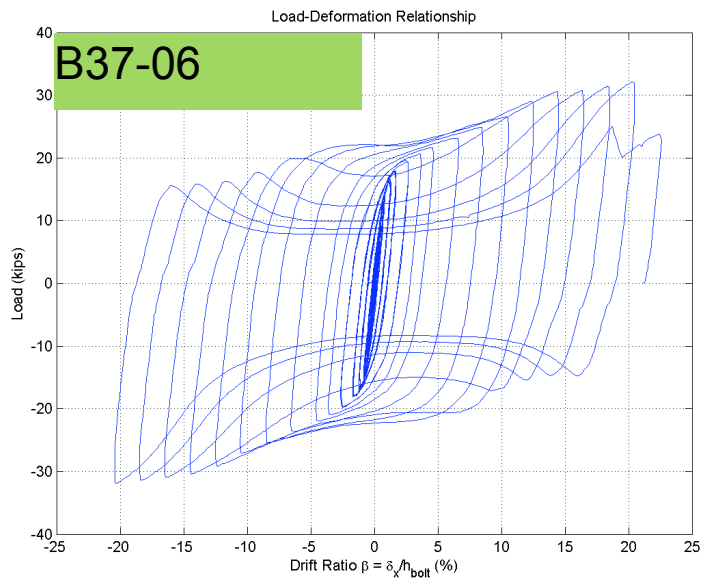
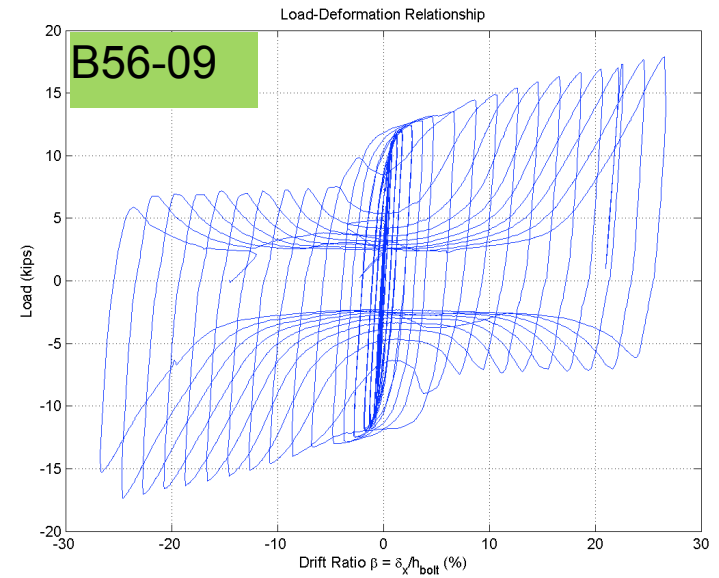
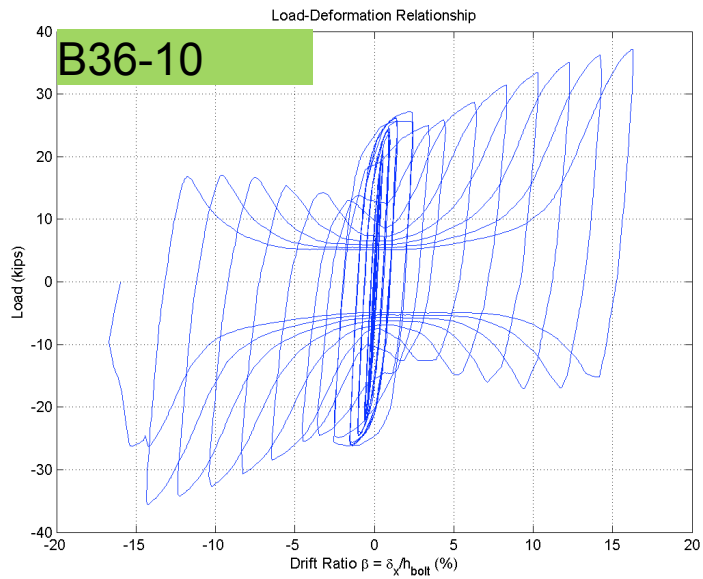
Energy Dissipating Steel Fuse Tests



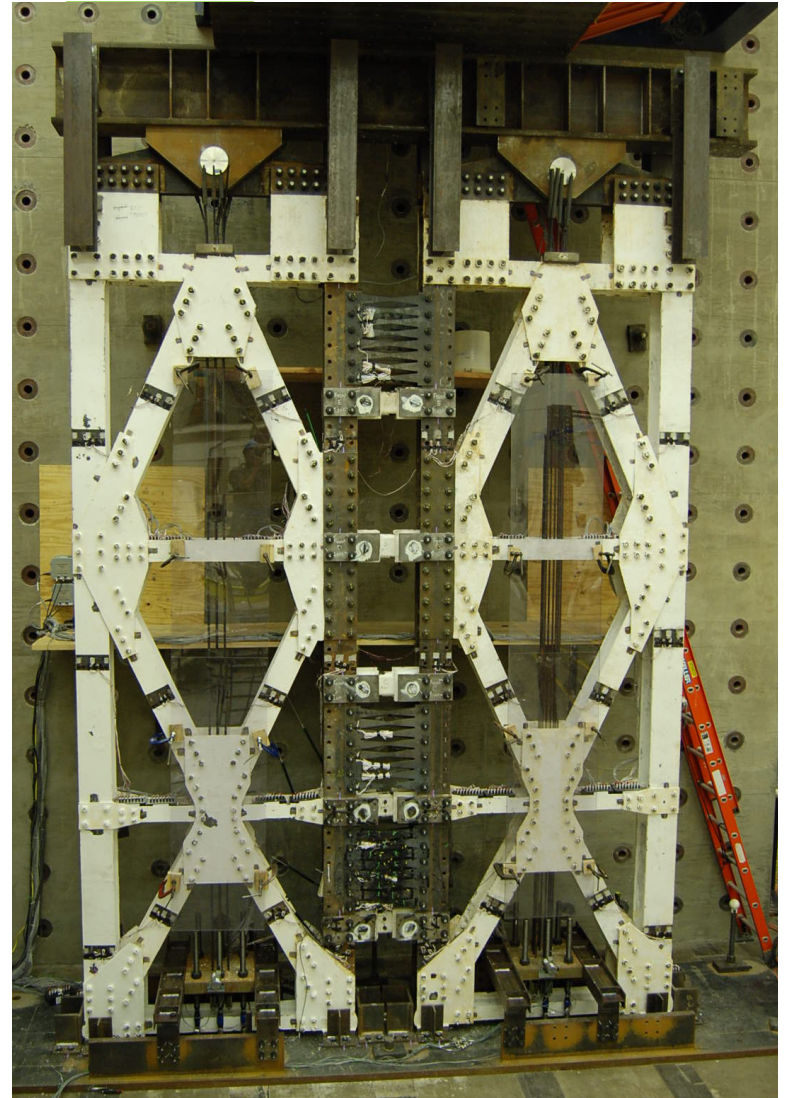
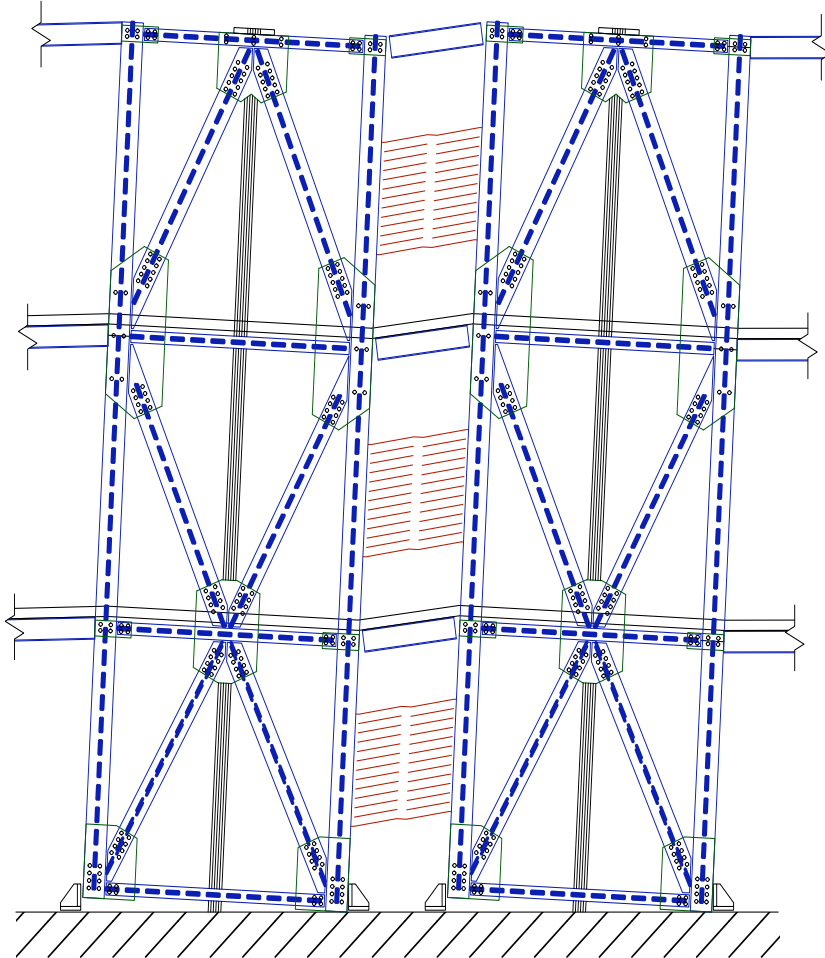
Testing Results: Butterfly links



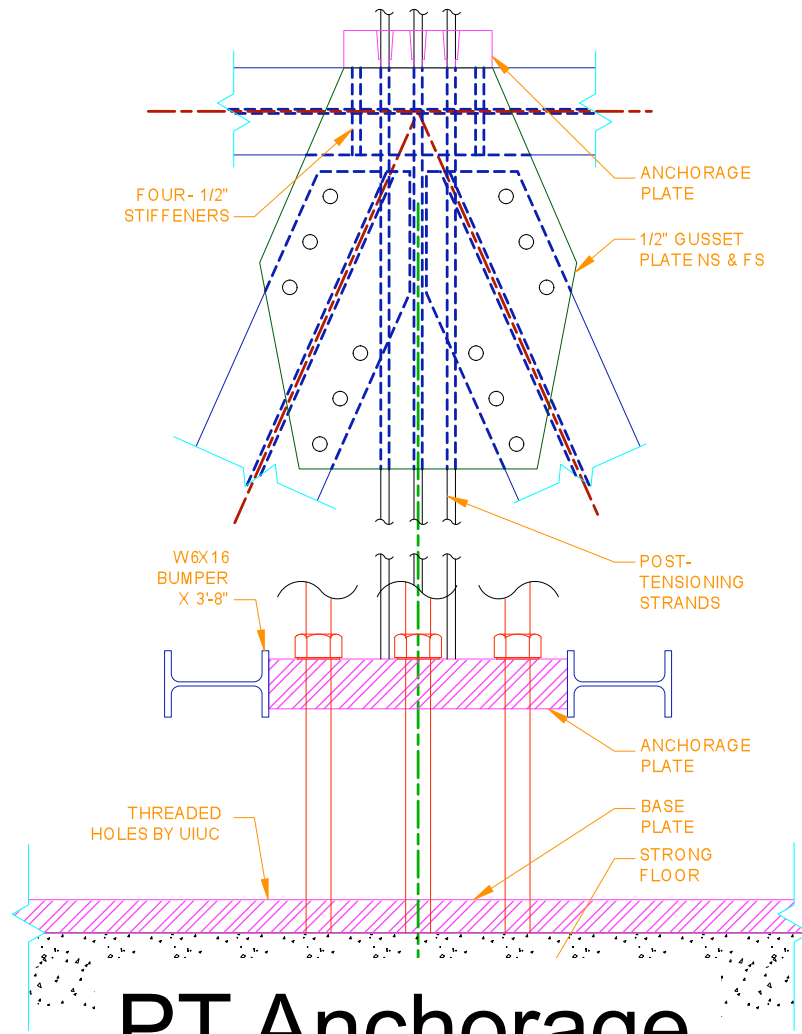
Butterfly Links: Load-deformation



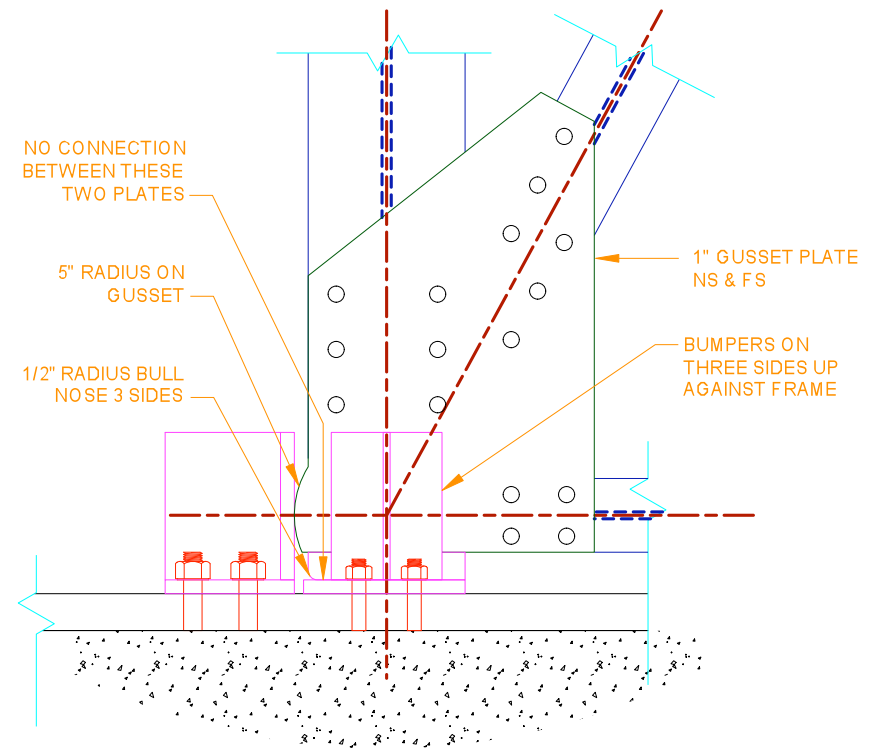
Dual Frame Test (1/2 scale) – U. Illinois



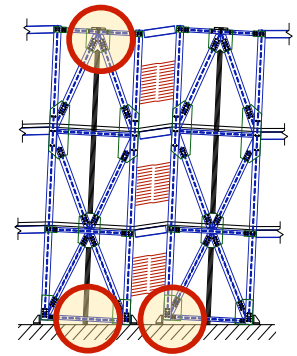
Key Details



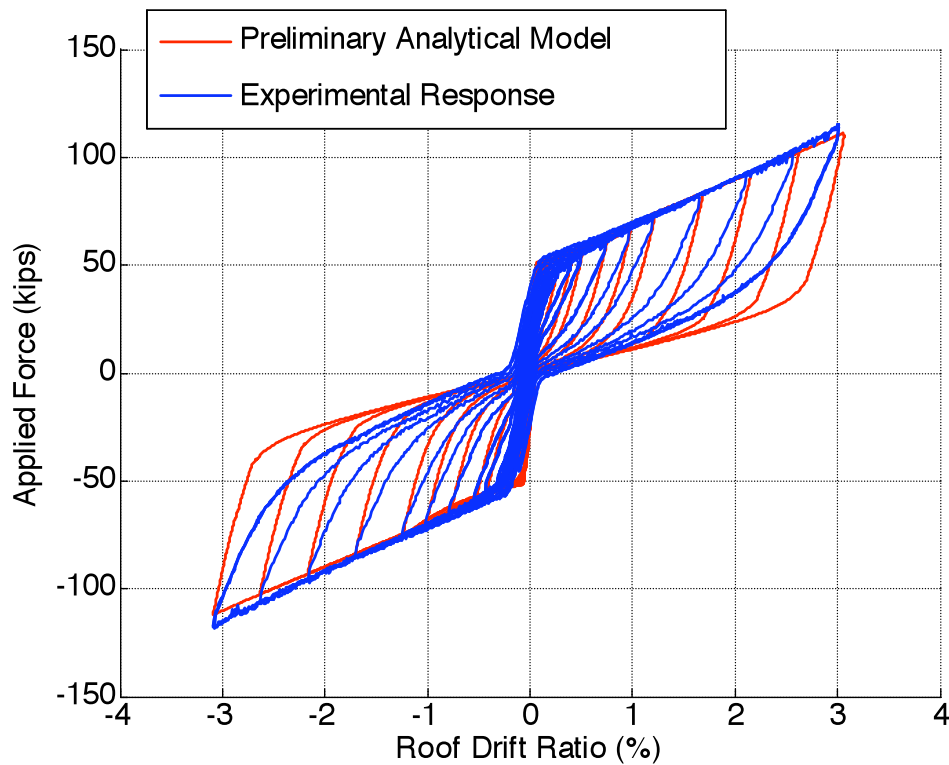
PT Anchorage



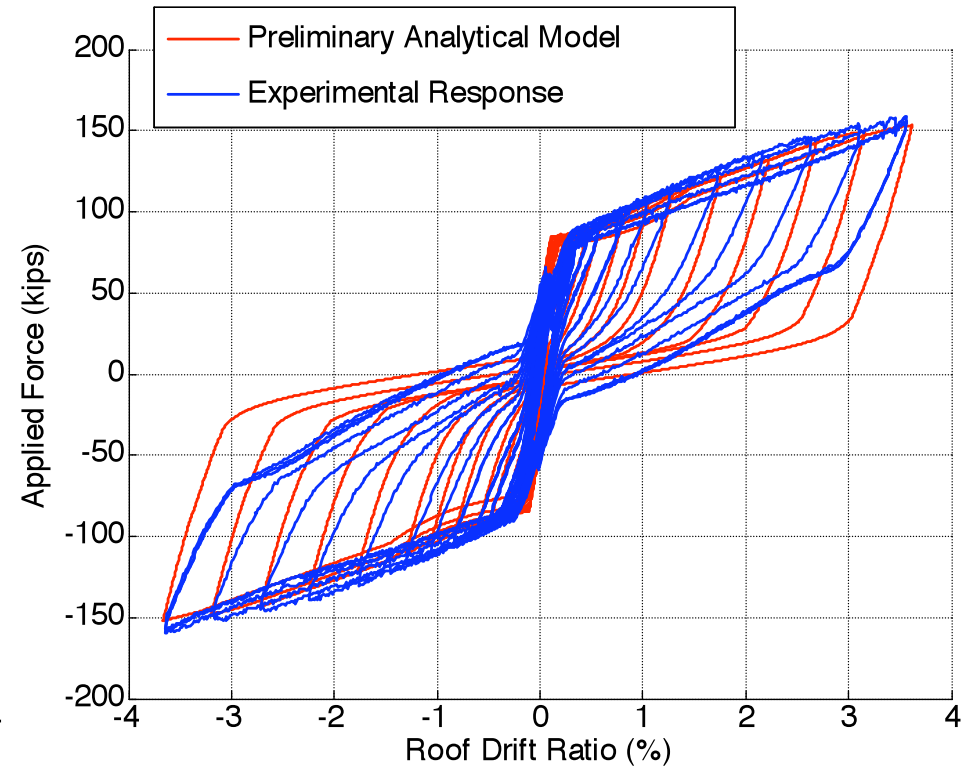
Rocking Base



Preliminary Results: Cyclic Loading

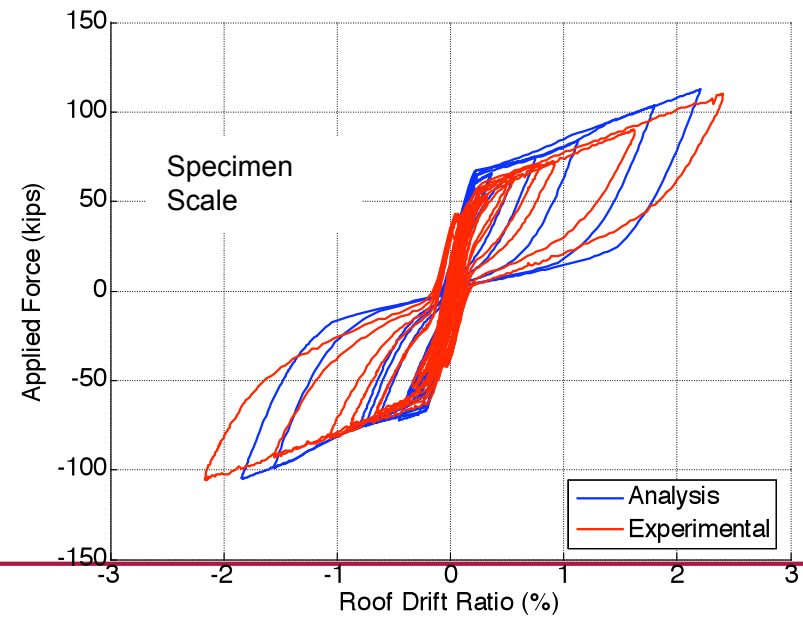
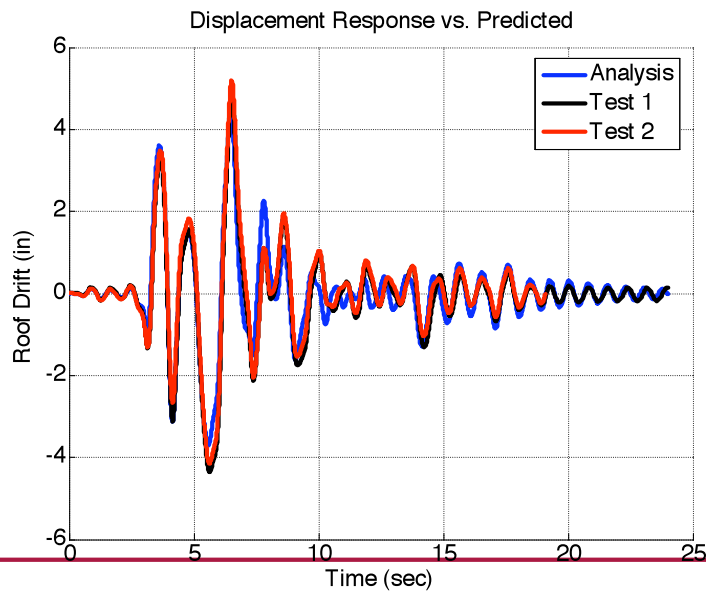
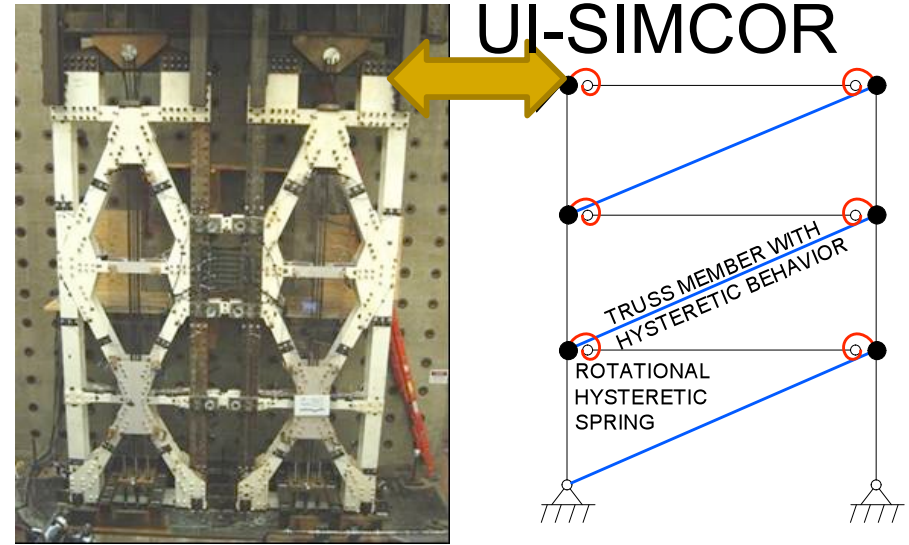
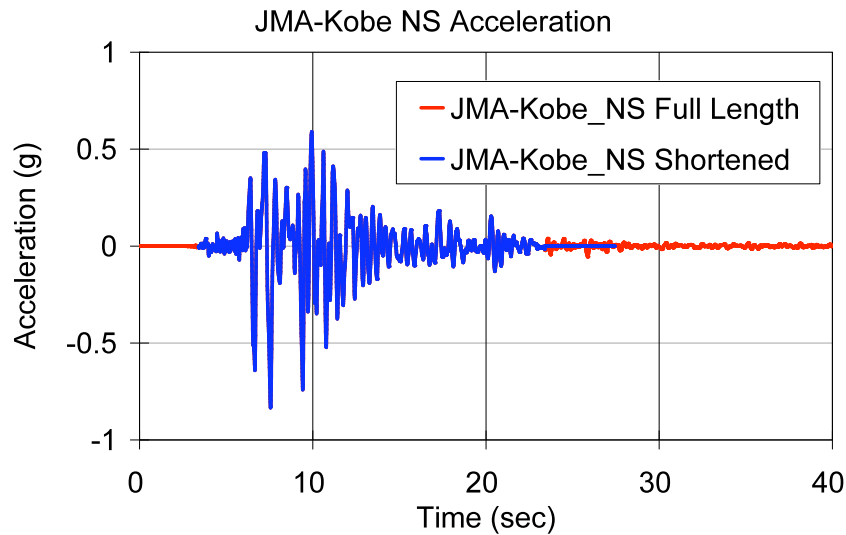


Weaker Fuse

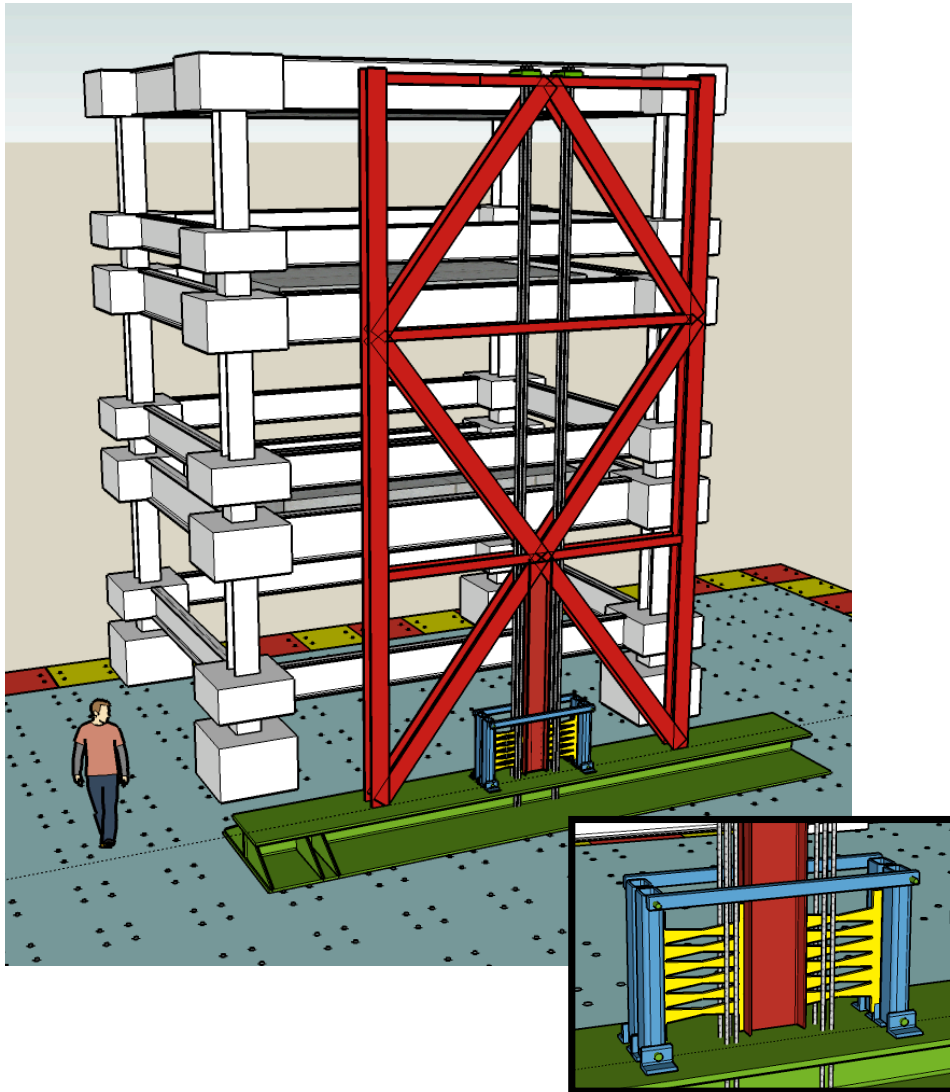


Stronger Fuse

Preliminary Results: Hybrid Simulation

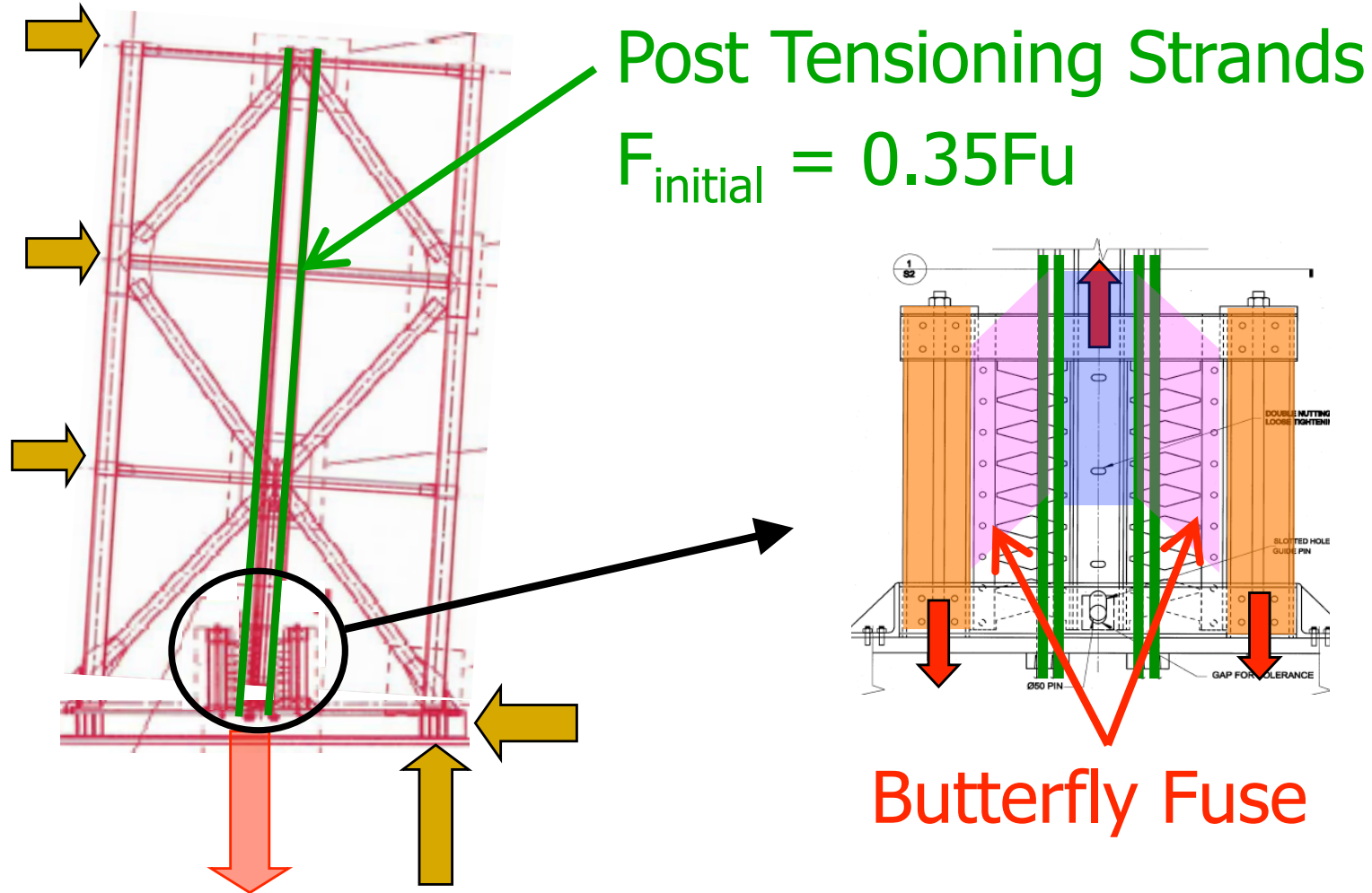


E-Defense Shake Table Test (August 2009)



- **Large-Scale Validation**
 - fuse/rocking frame interaction
 - rocking base details
 - post tensioning
 - replaceable fuses
- **Proof-of-Concept**
 - design concept & criteria
 - constructability
- **Performance Assessment**
 - nonlinear computer simulation

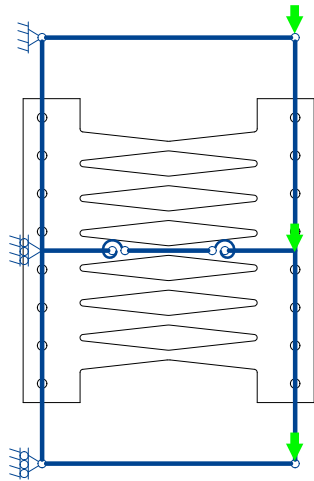
Rocking Frame Behavior



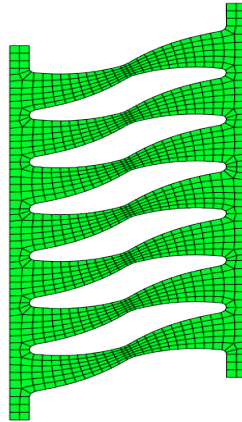
$$M_{OT, \text{resistance}} = (F_{PT} + F_{fuse}) * e$$

Nonlinear Time History Analysis

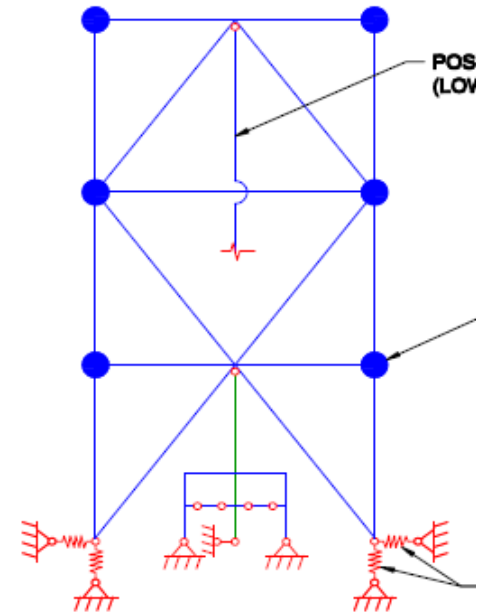
- Modeled with OpenSees & ABAQUS



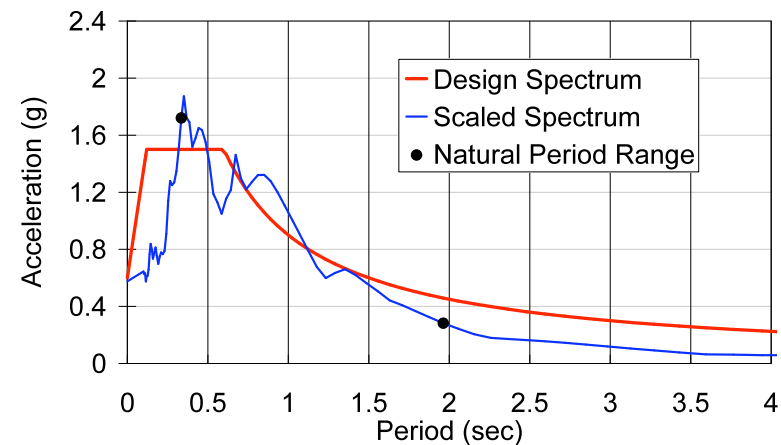
OpenSees



ABAQUS



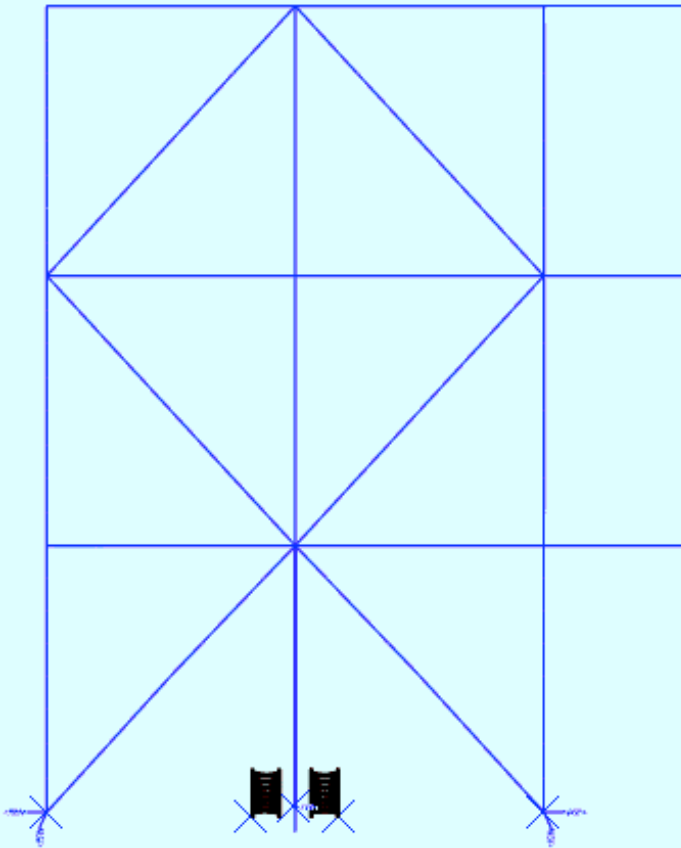
- JMA Kobe Ground Motion
 - 50% in 50 yr (0.20)
 - 10% in 50 yr (0.46)
 - 2% in 50 yr (0.69)



ABAQUS – NL Dynamic Analysis

Viewport: 1 ODB: C:/Work/E-Def/C1-TH.odb

Step: step-1 Frame: 7

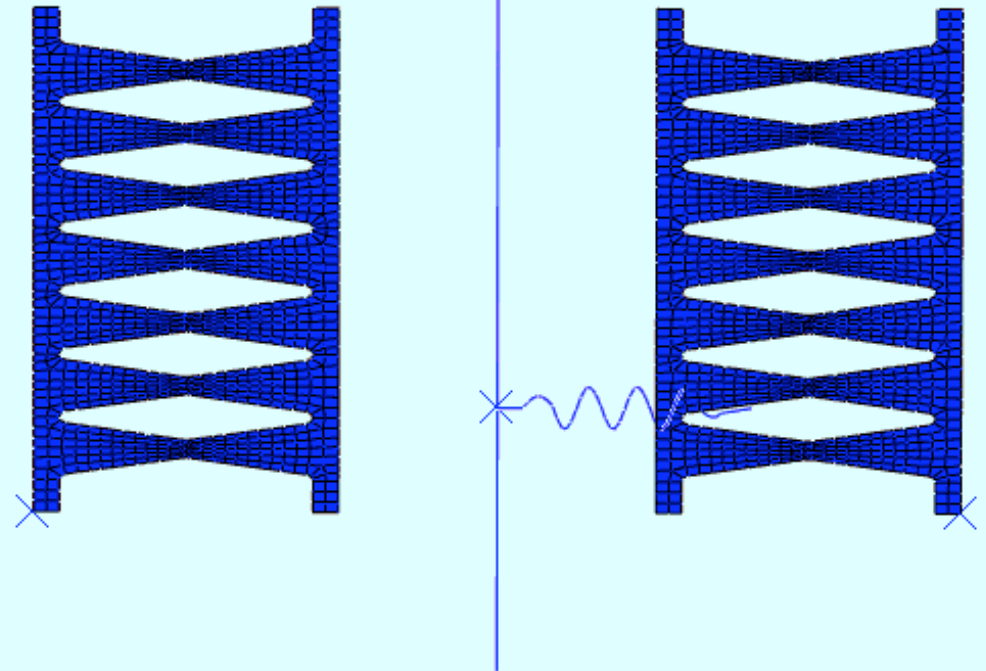


Step: step-1
Increment 7: Step Time = 1.000

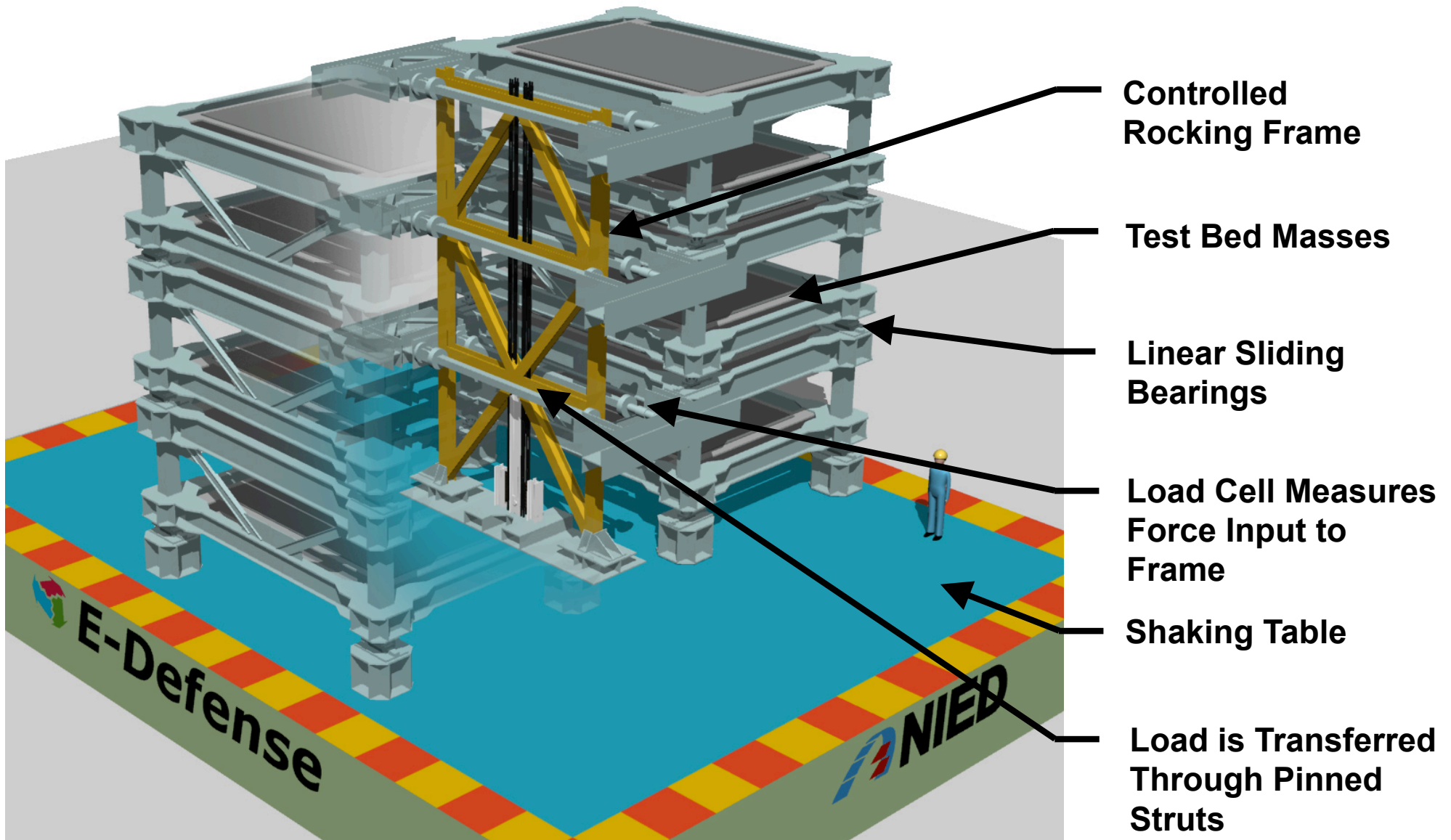
Deformed Var: U Deformation Scale Factor: +1.000e+00

Viewport: 2 ODB: C:/Work/E-Def/C1-TH.odb

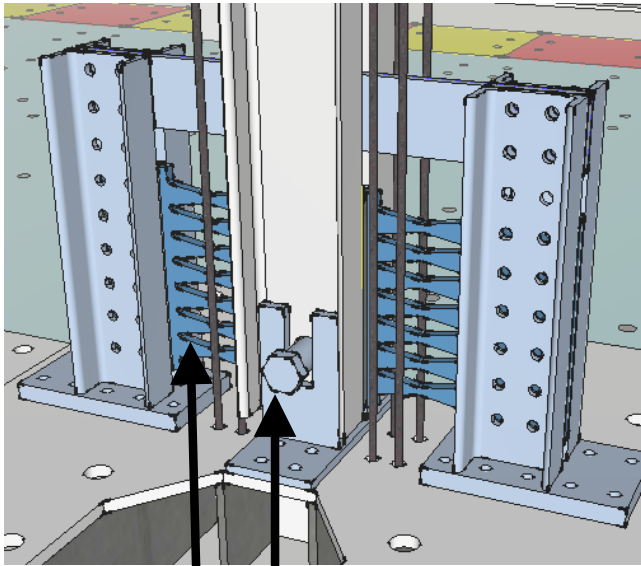
Step: step-1 Frame: 7



E-DEFENSE TEST SETUP



TEST A1 CONFIGURATION



Pin Moves Center of Fuse Up and Down

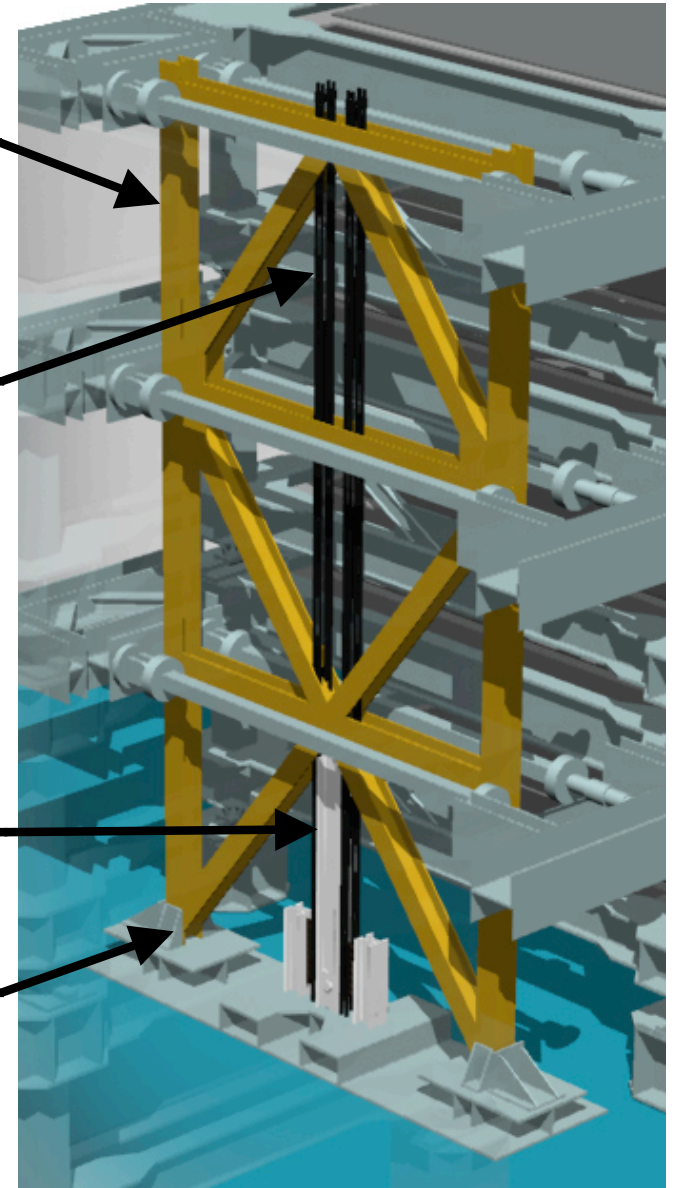
Fuse is Steel Plate with Specially Designed Cutouts

Steel Frame Remains Essentially Elastic, but is Allowed to Rock at the Base

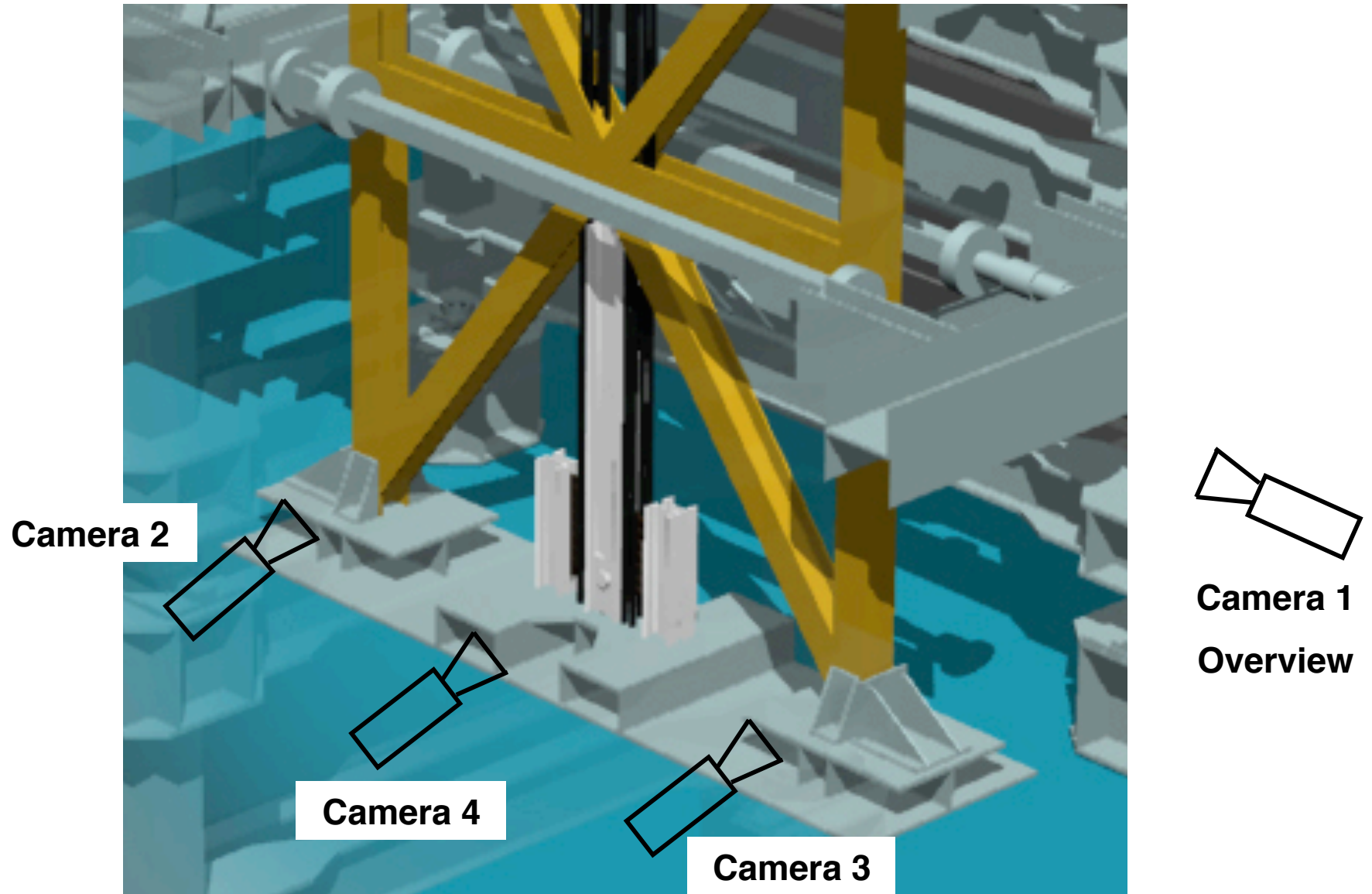
Post-Tensioning Strands Bring Frame Back to Center After Shaking Stops

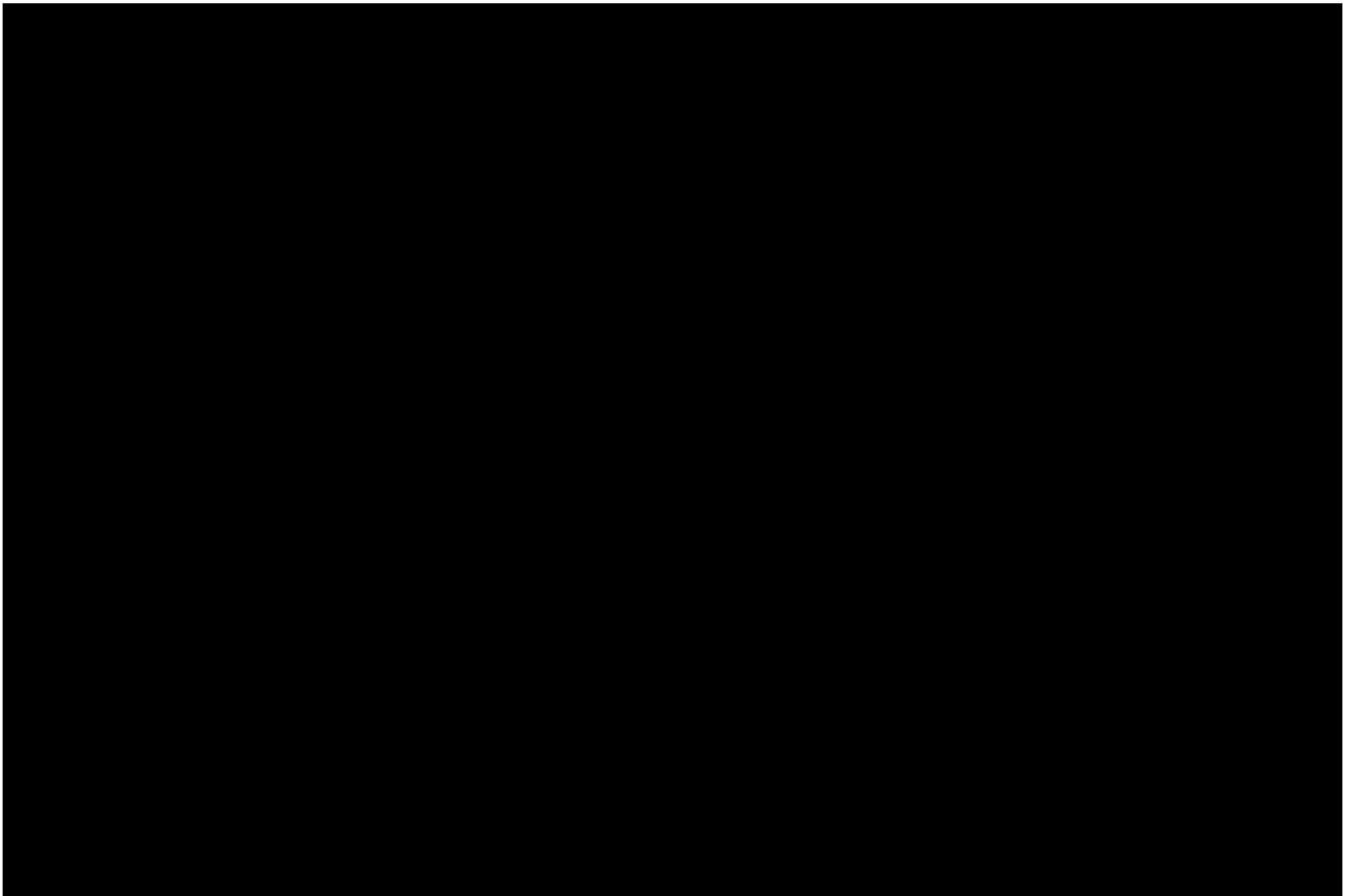
Center Column Connects Frame to Fuse

Base of Frame is Free to Uplift

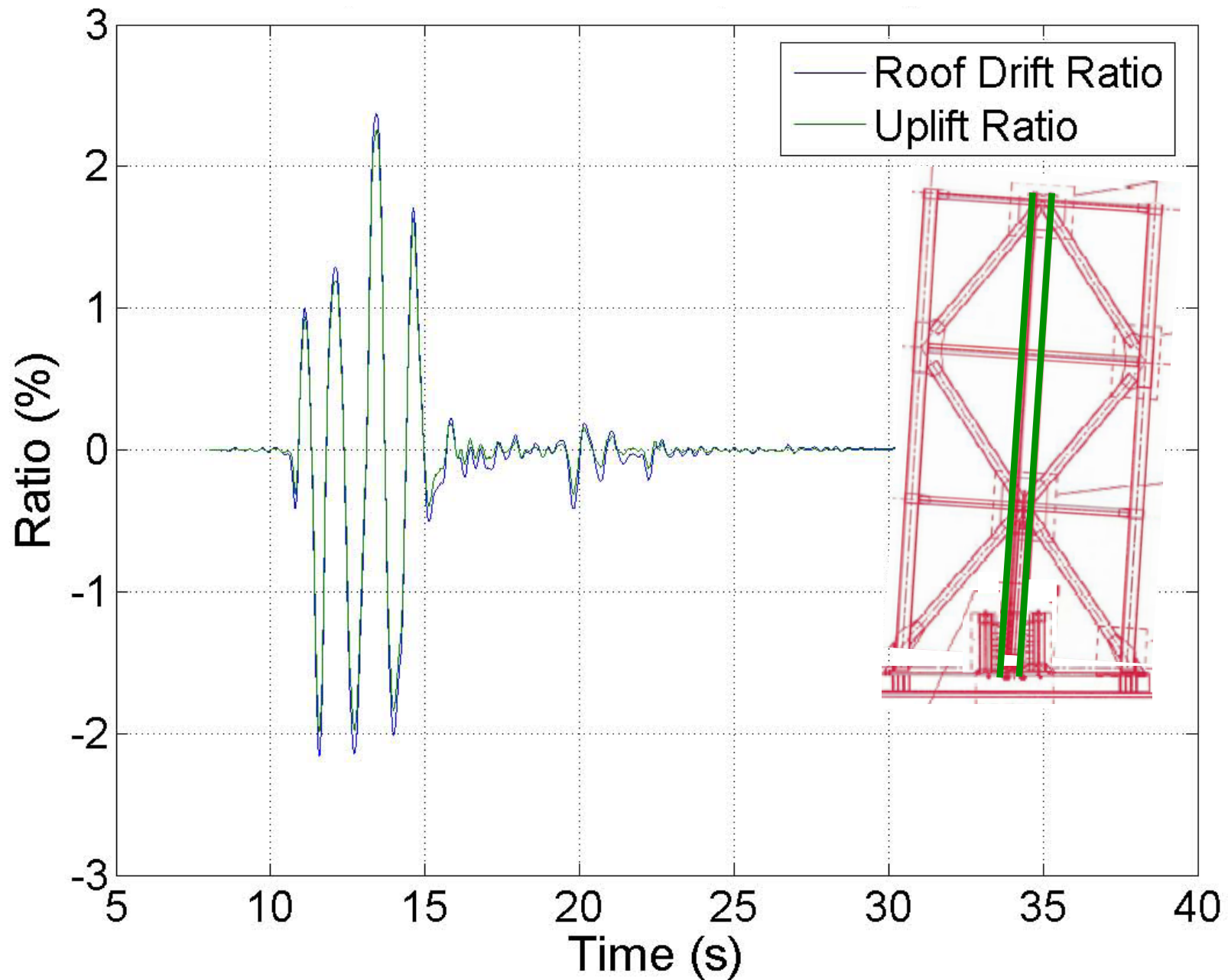


CAMERA LOCATIONS

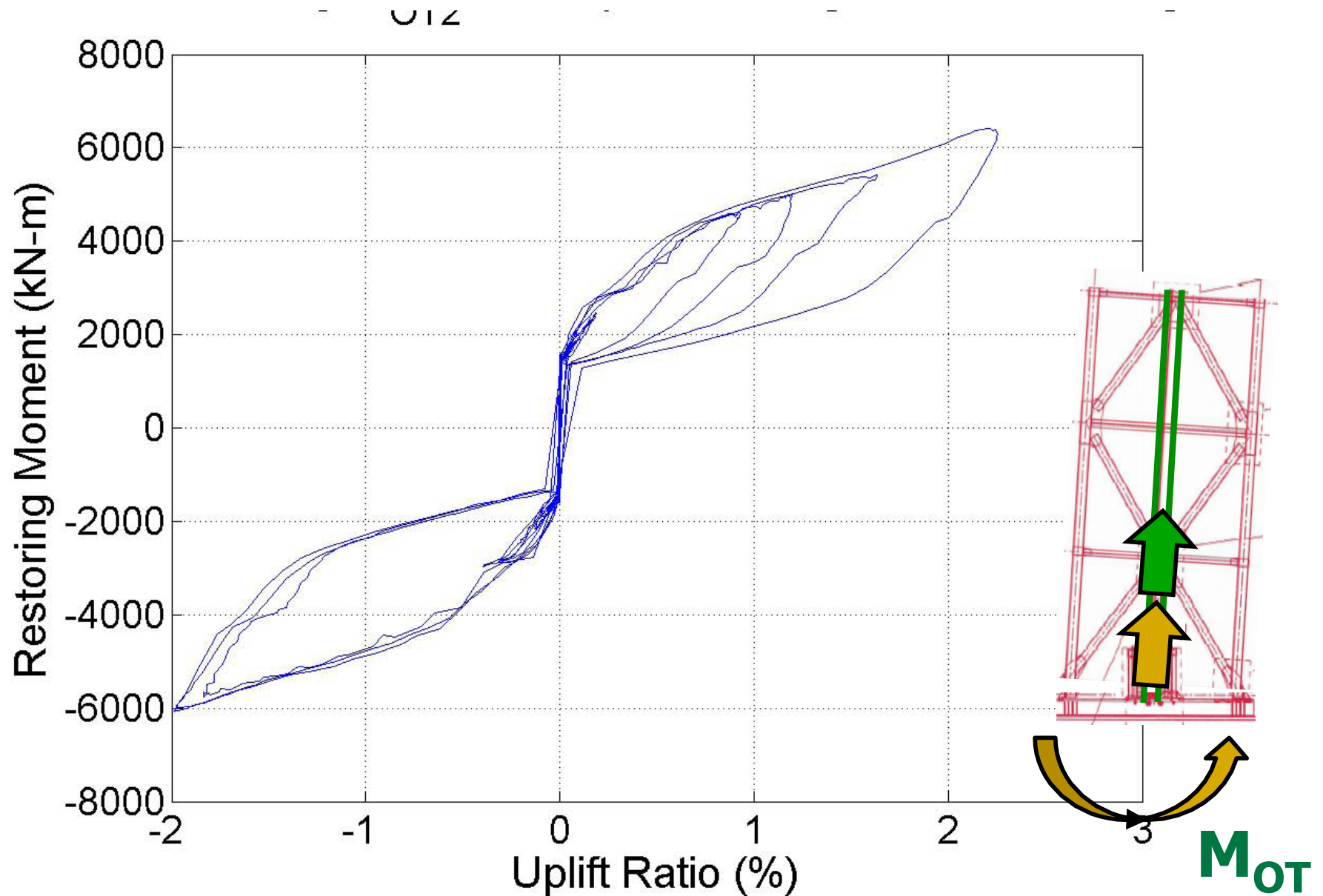




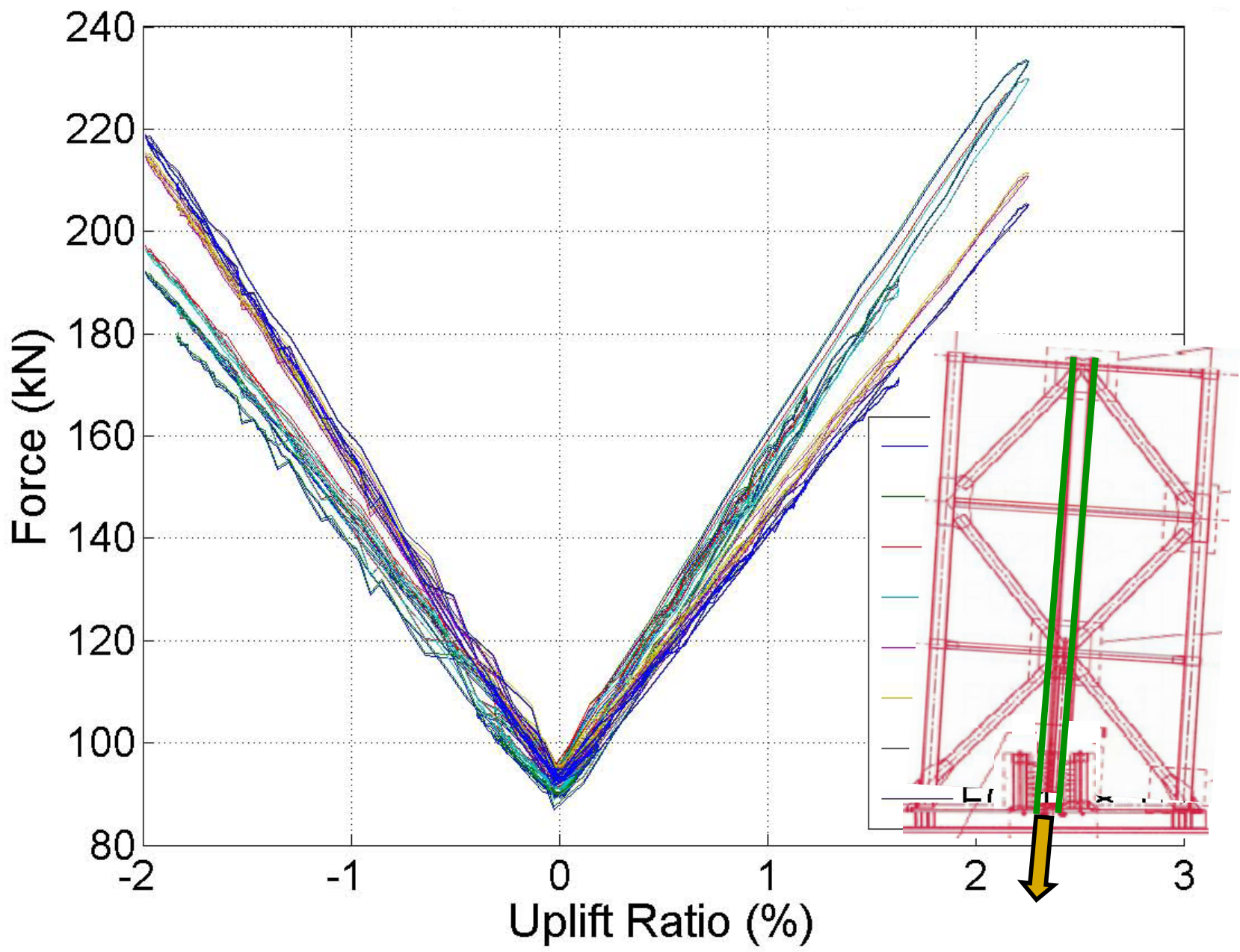
MCE (65% Kobe JMA) – Drift and Uplift



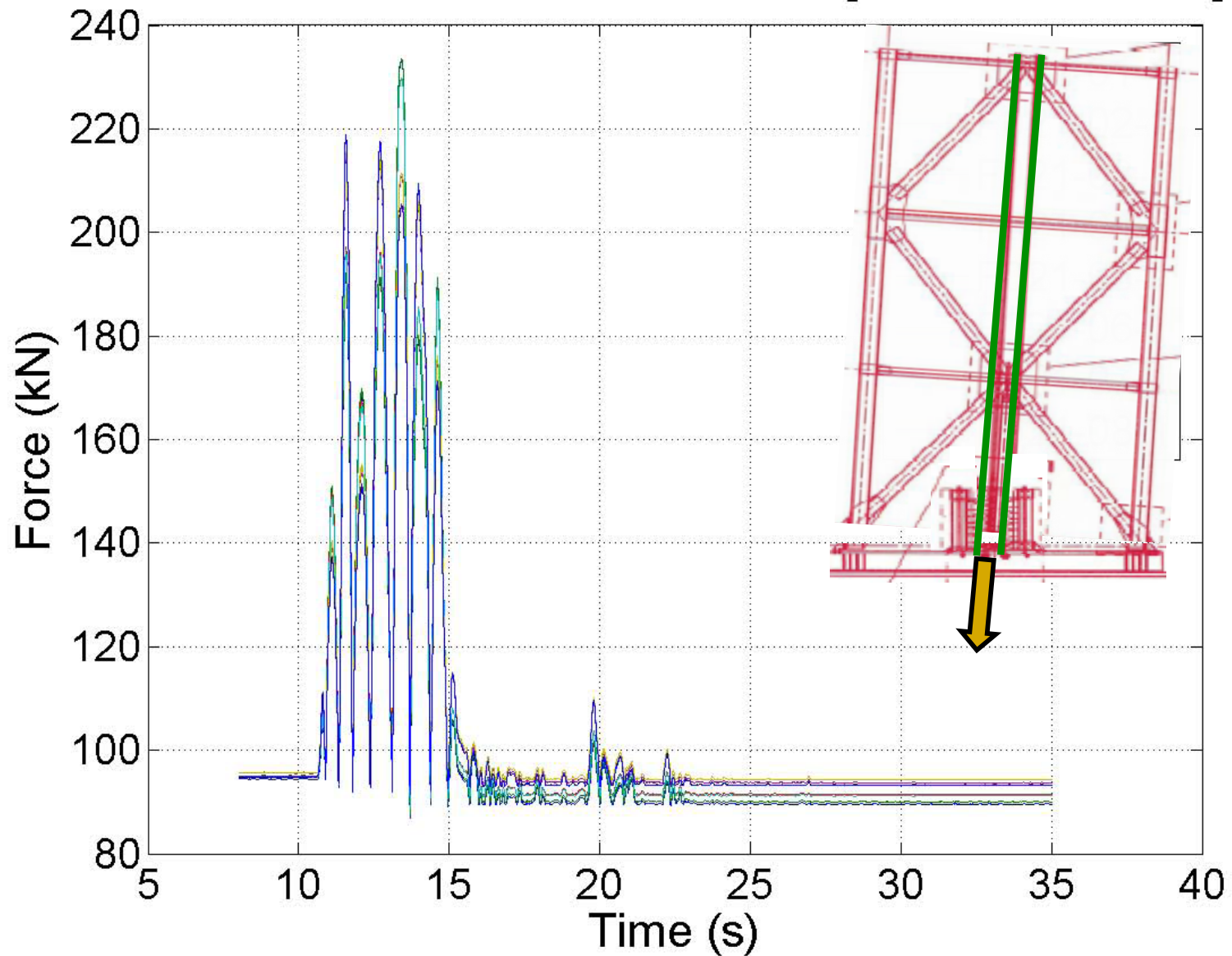
MCE (65% Kobe JMA) – $M_{OT,R}$ versus Uplift



MCE (65% Kobe JMA) – PT force versus Uplift



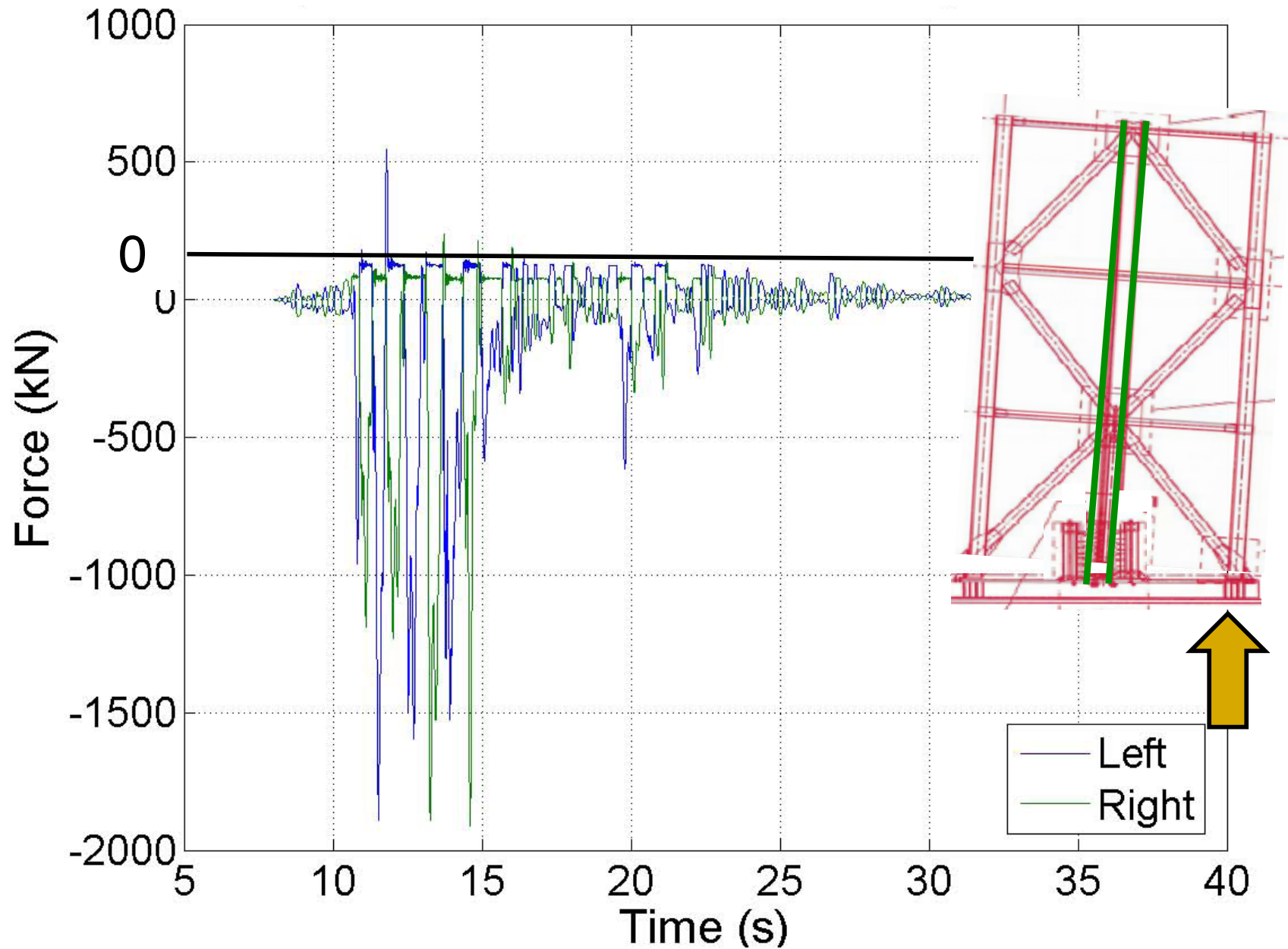
MCE (65% Kobe JMA) – PT Force



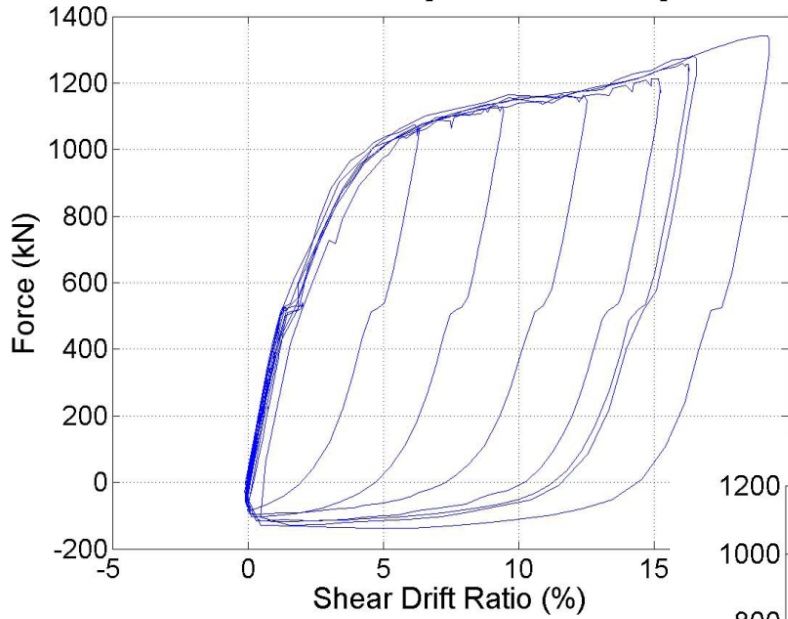
MCE (65% Kobe JMA) – Fuse Response



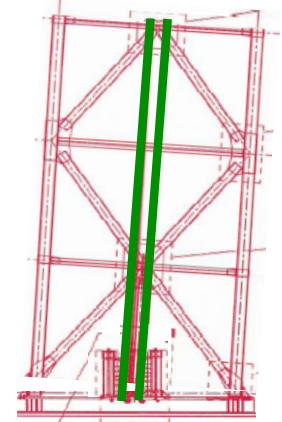
MCE (65% Kobe JMA) – Column Force



Fuse #20-14 [A1J5-JMA 65%]

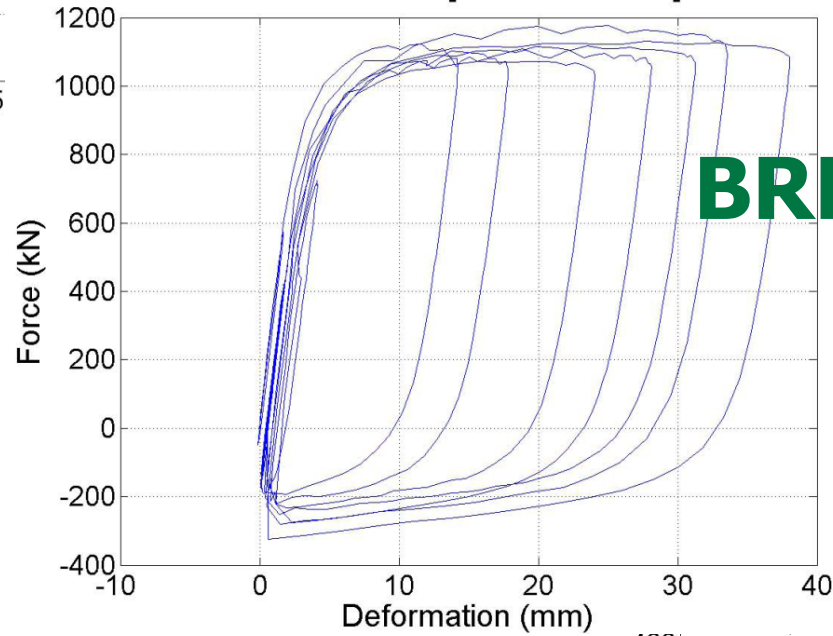


FUSE RESPONSE



**Butterfly
(thick)**

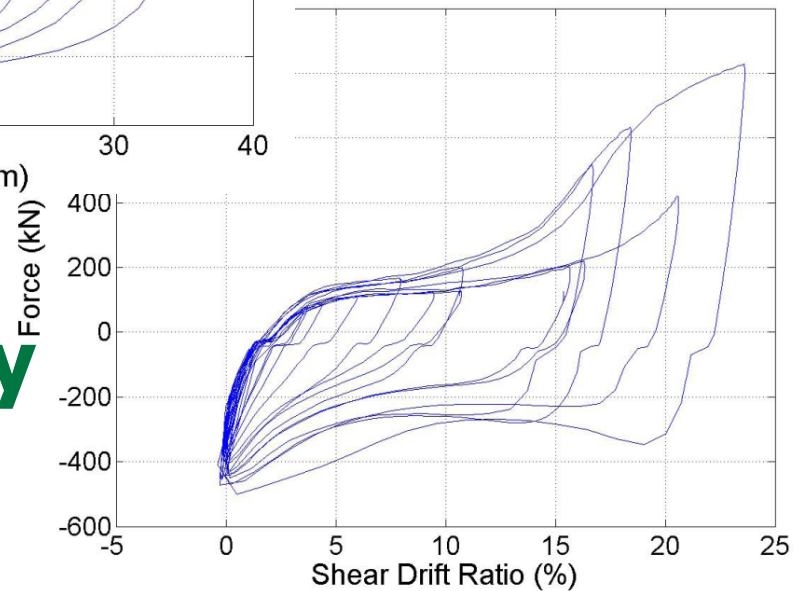
BRB #20-14 [CJ7-JMA 65%]



BRB

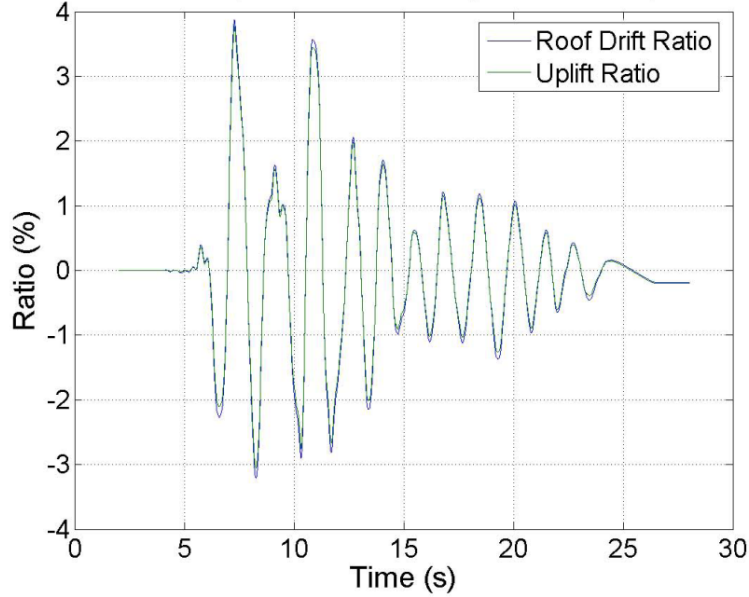
**Butterfly
(thin)**

e #20-14 [BJ6-JMA 60%]

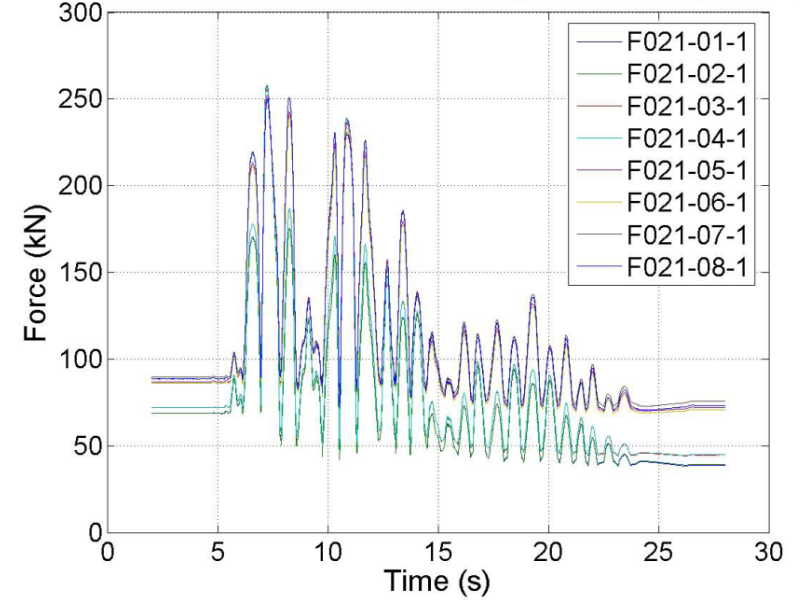


Shake Table Simulation Data (1.75 NR)

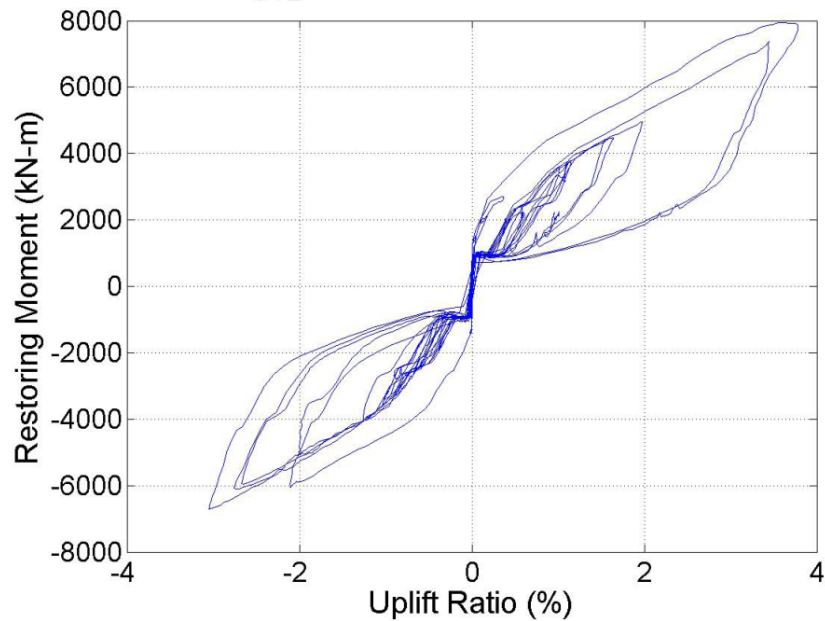
Roof Drift & Uplift Ratio #20-1 [A2N8-NRcnp 175%]



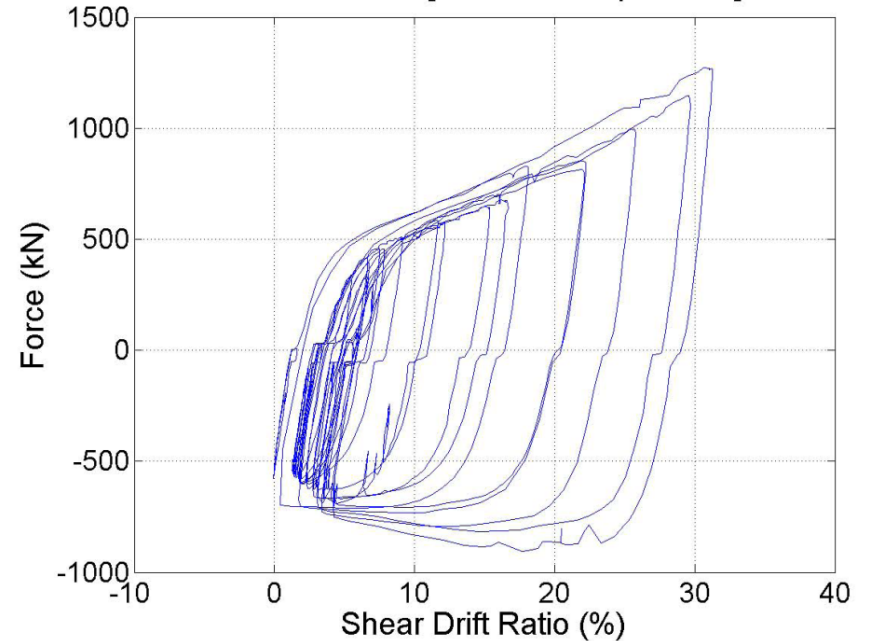
Force in Each PT Strand #20-3 [A2N8-NRcnp 175%]



Restoring M_{OT2} and Uplift #20-9 [A2N8-NRcnp 175%]

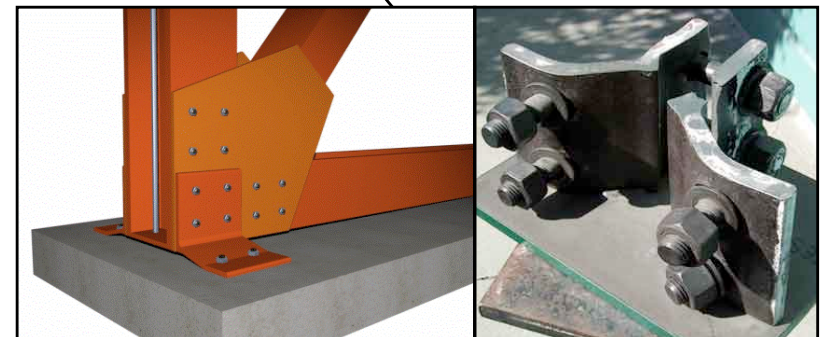
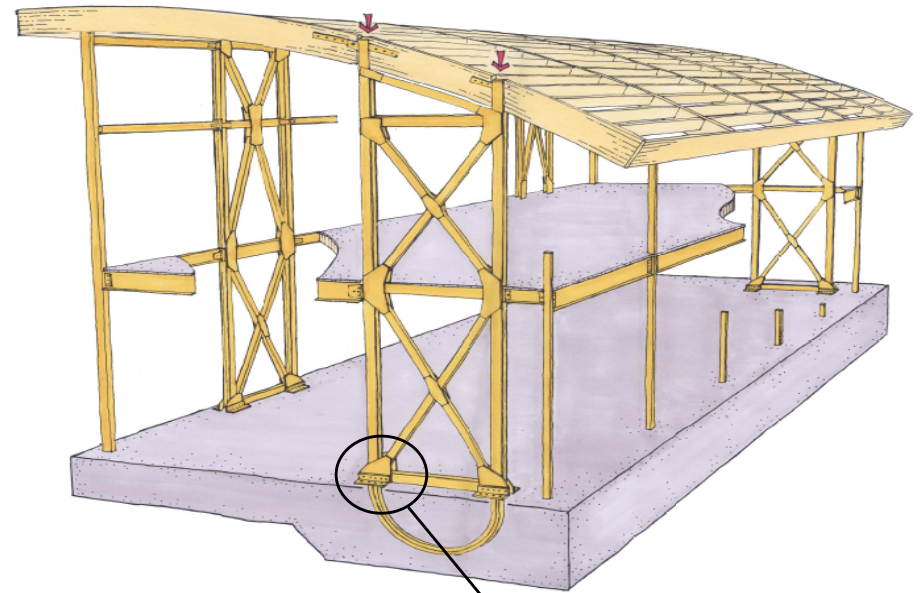


Fuse #20-14 [A2N8-NRcnp 175%]



Collaboration with Industry Partners

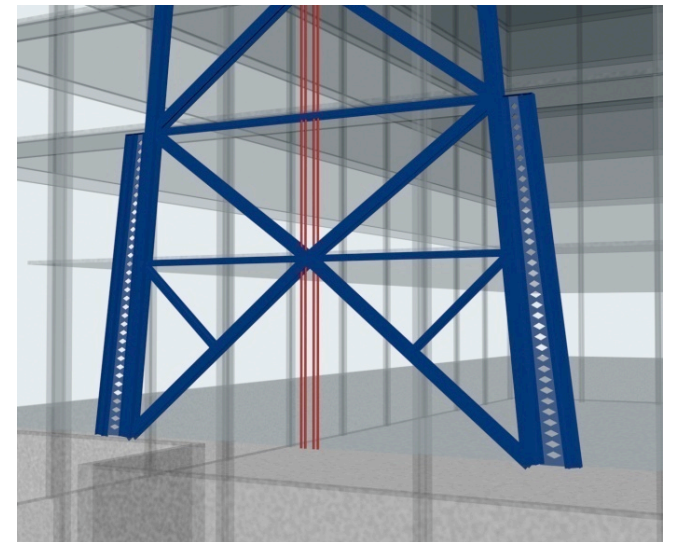
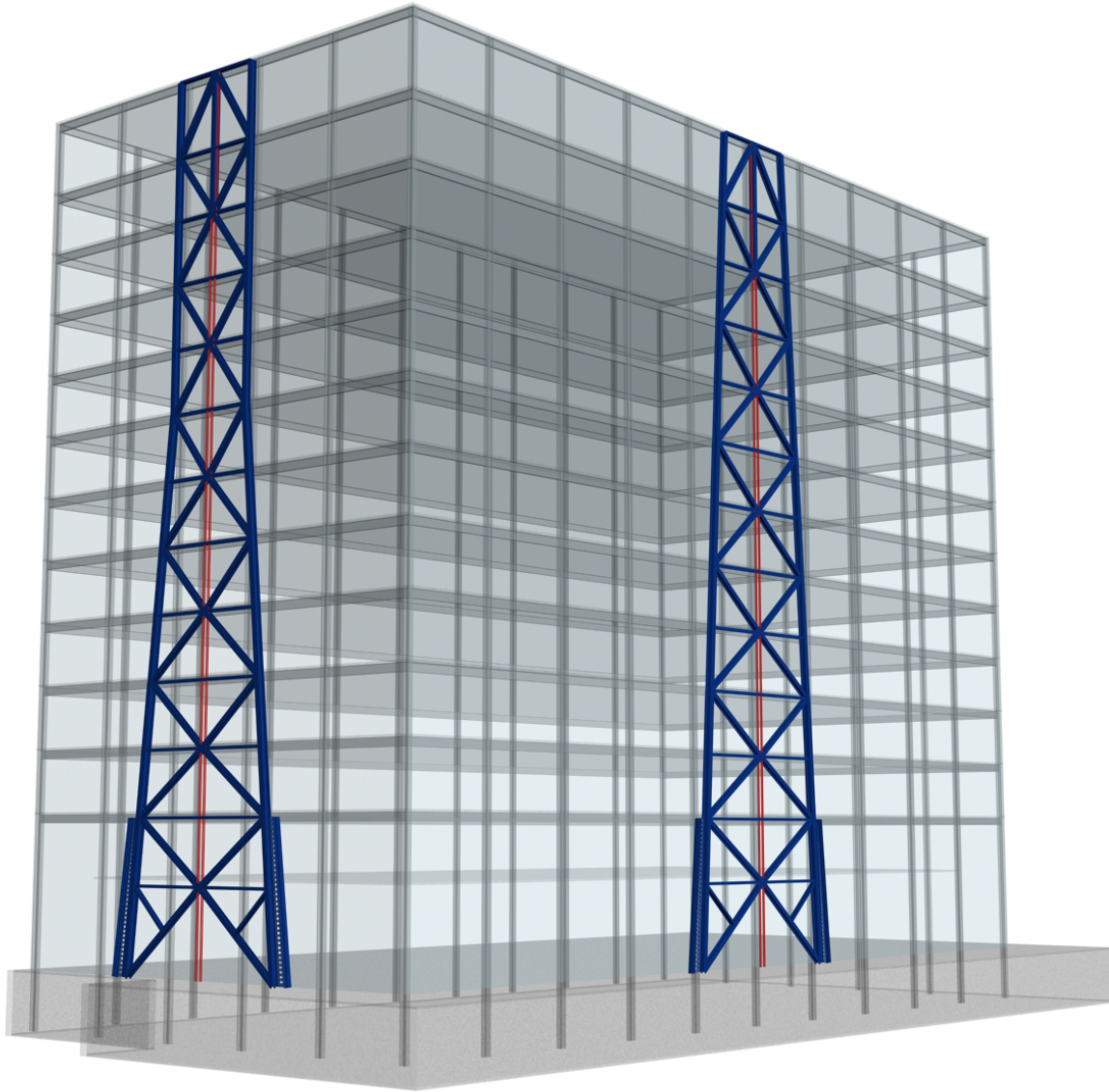
"Early Adopters" of System Innovations



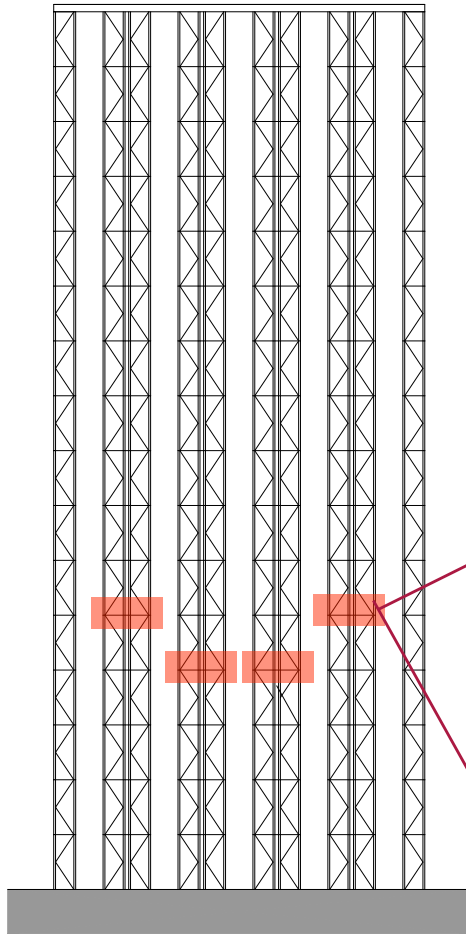
Orinda City Offices
Architect: Siegel and Strain Architects

TIPPING • MAR + associates
structural engineers

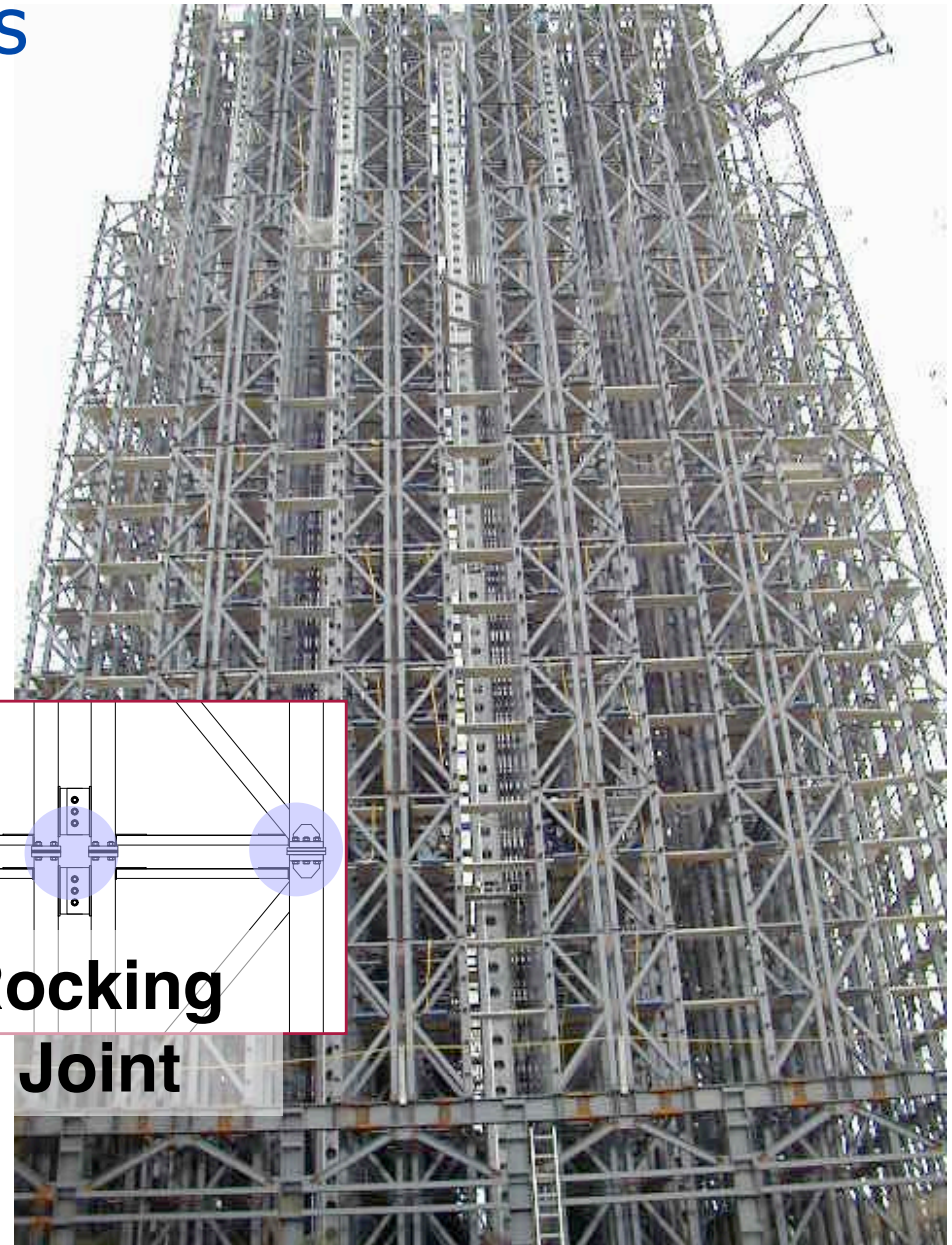
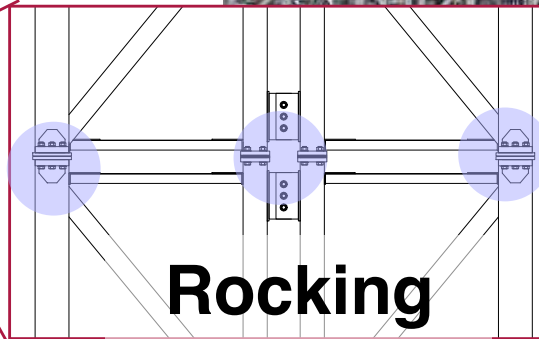
Concept for Single Rocking Frame Retrofit



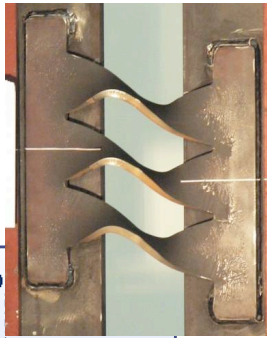
Rack Storage Structures



Height: 50 m



Structural System: Composite RC-Steel Pivoting Walls with Fuses



Energy
Dissipating
Fuse



USC School of
Cinematic Arts

Steel Boundary Member

RC Wall Panel

Gregory P. Luth & Assoc.
Santa Clara, CA

Innovation and Design Research

- **Thematic Concept**

- life cycle design for earthquake effects
- damage control & design for repair

- **Engineering Design Features**

- controlled rocking & self-centering
- energy dissipating replaceable fuses

- **Performance-Based Engineering Framework**

- quantification of decision variables (losses, downtime)
- integration of hazard, response, damage, loss

- **Development & Validation**

- large scale testing and computational simulation
-