American Concrete Institute®
Advancing concrete knowledge

Composite and Modular Structures, Part 2

ACI Spring 2012 Convention
March 18 – 21, Dallas, TX

Steven J. Mitchell received his Bachelors of Science degree in Civil Engineering from Trine (formerly Tri-State) University in 2009. Before enrolling in graduate school at the University of Cincinnati in September, 2010, he worked for a consulting firm in South Bend, IN, where he is originally from, called Lawson-Fisher Associates P.C. He is currently in his second year of graduate studies at the University of Cincinnati, pursuing his Masters of Science in Civil Engineering. A Research Experience for Undergraduates (REU) experience at UC during the summer of 2007 instilled in him the desire to pursue graduate studies, and most notably research within academics. Upon completion of his master's degree, he is considering pursuing a doctorate degree at the University of Cincinnati, while at the same time searching for future employment as a civil engineer in the Midwest and elsewhere in the United States.

University of Cincinnati

The development of a replaceable (steel fuse) coupling beam for coupled core wall systems

Steven J. Mitchell – Graduate student, University of Cincinnati

Gian A. Rassati – Associate professor, University of Cincinnati

Bahram M. Shahrooz – Professor, University of Cincinnati

University of Cincinnati

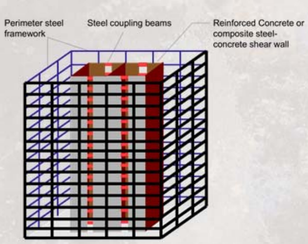
Presentation Outline

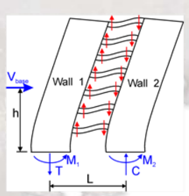
- Background: Steel Coupling Beams (SCBs), and Steel Fuse Coupling Beams (SFCBs)
- Methodology of SFCBs
- Previous SFCB experiment
- Proposed design procedure
- Prototype Design and Analytical modeling
- Preliminary results
- Half-scale testing of SFCB

University of Cincinnati

Background

- Efficient Lateral Force Resisting System (LFRS)





University of Cincinnati

Background

- Efficient Lateral Force Resisting System (LFRS)
- Application to building structures

Background

- Efficient Lateral Force Resisting System (LFRS)
- Application to building structures
- Types of coupling beams
  - Reinforced concrete
  - Diagonally reinforced concrete
  - Conventional steel

Background

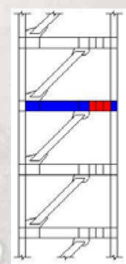
- Efficient Lateral Force Resisting System (LFRS)
- Application to building structures
- Types of coupling beams – Conventional Steel
  - Significant advantages include:
    - Superior strength and stiffness in coupled core wall systems
    - Ductility and energy dissipation capacities
    - Performance under cyclic loads

Background

- Efficient Lateral Force Resisting System (LFRS)
- Application to building structures
- Types of coupling beams
- Methodology for a Steel Fuse Coupling Beam, how will it perform, and why is this desirable?

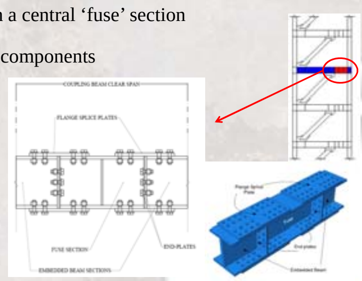
Methodology

- Seismic response of structures
  - Localized, controlled damage
  - Steel links in eccentrically braced frames (EBFs)
  - Protect the elements surrounding the link from yielding



Methodology

- Localize damage in a central 'fuse' section
- Surrounding beam components remain elastic
- Has the same advantages as conventional steel coupling beams



Previous SFCB Experiment

- First generation developed at the University of Cincinnati (Fortney, 2005)
- Design procedure based on 'arbitrary' strength values to achieve performance.

Proposed Design Procedure

1. Determine the load demands on a single coupling beam, both shear and moment
   a) The fuse section is designed to resist these forces and must be designed FIRST
2. Design the fuse
   a) Shear Capacity: $\phi V_{nf} = \phi(0.6 F_y h_{wf} t_{wf})$
   b) Flexural Capacity: $\phi M_{nf} = \phi M_{pf} = \phi F_y z_f$

Check limiting width-thickness ratios: ✓ ✓

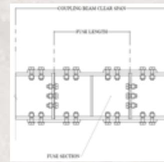
Proposed Design Procedure

3. Determine fuse length to ensure it is shear-critical:

$$e \leq \frac{(1.6)M_p}{V_p}$$

Where: $M_p = M_{pf}$

$V_p = V_{nf}$

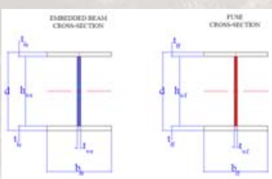


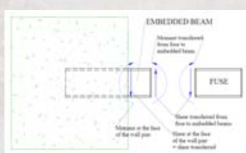
4. Use the EXPECTED shear strength of the fuse to determine the loads imparted to the surrounding embedded beams:

Proposed Design Procedure

4. Use the EXPECTED shear strength of the fuse to determine the loads imparted to the surrounding embedded beams:

$$V_{f,\exp} = V_{u,emb} = 1.1 R_y V_{nf}$$



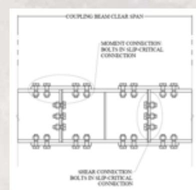


Proposed Design Procedure

5. Design the embedded beams
   a) Shear Capacity: $\phi V_{ne} = \phi(0.6 F_y h_{we} t_{we})$
   b) Flexural Capacity: $M_y = F_y S_e$

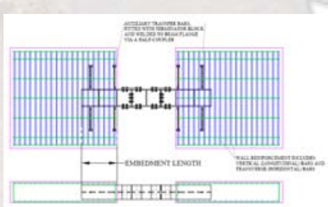
Check limiting width-thickness ratios: ✓ ✓

6. Design the bolted and welded connections



Proposed Design Procedure

7. Design the coupling beam within the reinforced concrete wall piers
   a) Embedment length
   b) Auxiliary transfer bars
   c) Detailing
8. Perform necessary limit-state checks on beam elements and connecting elements.



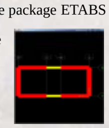
Analytical Modeling

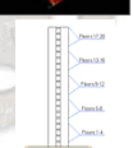
Elastic design/analysis completed using software package ETABS

Adaptive pushover analysis completed using the software package Ruaumoko.

Dynamic response history analyses completed using the software package Ruaumoko, with the following ground motions considered (further records to be added later):

Ruaumoko Building Model	Dynamic Forces	Analysis Time (s)	Peak Acceleration (g)
1	Adaptive Pushover	100	N/A
2	ASCE Design Earthquake	30	1.050
3	ASCE MC Earthquake	30	1.575
4	El Centro Earthquake	20	0.348
5	Northridge Earthquake @ Sylmar Hospital	40	0.798
6	Northridge Earthquake @ Pacoima Dam	60	1.492

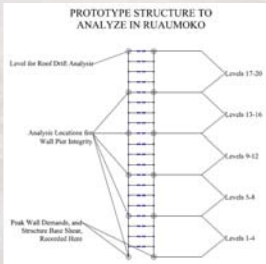




Analytical Modeling

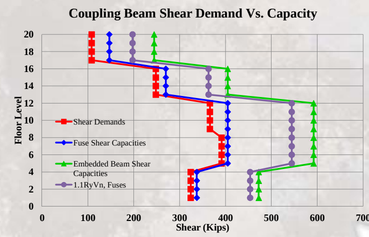
The following response quantities are of interest in the analyses:

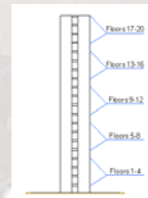
1. Building drift information – residual effects
2. Status of coupling beams throughout the ground motion
3. Peak rotations witnessed by coupling beams
4. Load demands on wall piers – base shears and moments



Prototype Building Design

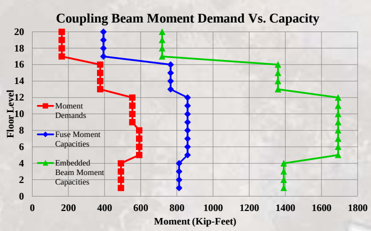
Each floor level coupling beam is designed such that the fuse is capable of resisting design-level demands.

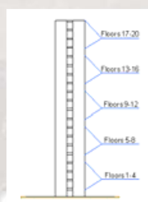




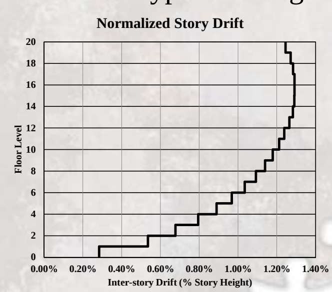
Prototype Building Design

Each floor level coupling beam is designed such that the fuse is capable of resisting design-level demands.

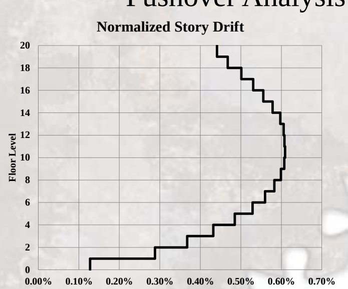




Prototype Building Design

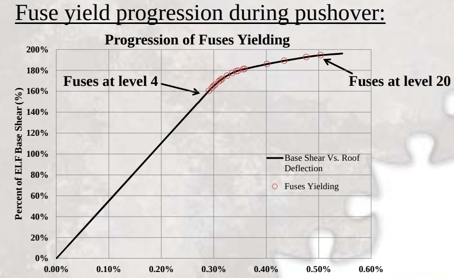


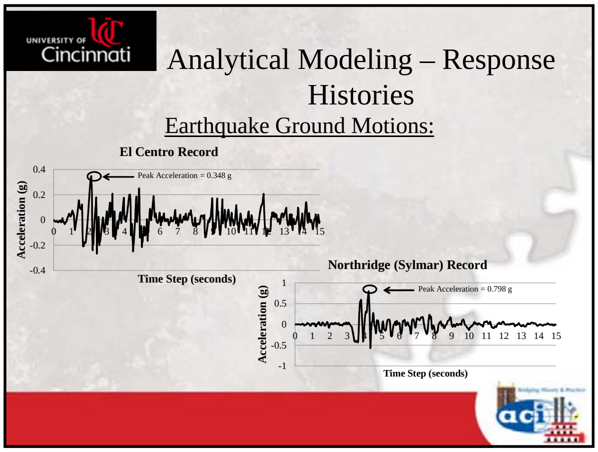
Analytical Modeling – Pushover Analysis



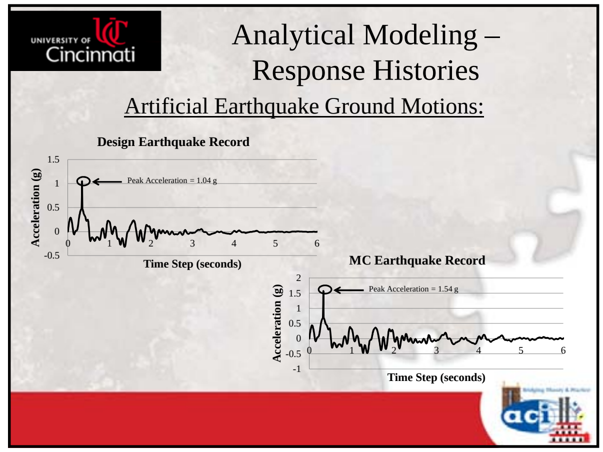
Analytical Modeling – Pushover Analysis

Fuse yield progression during pushover:

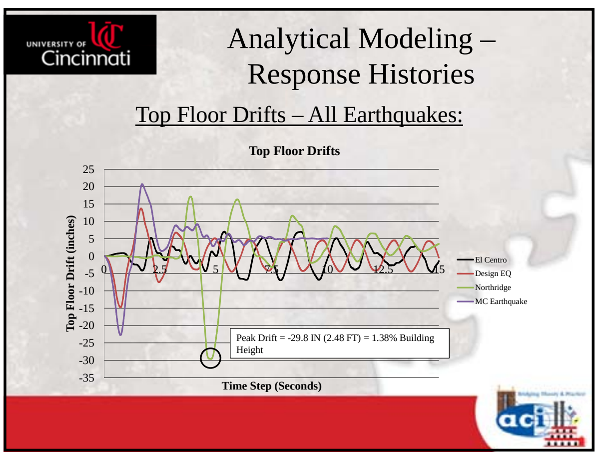




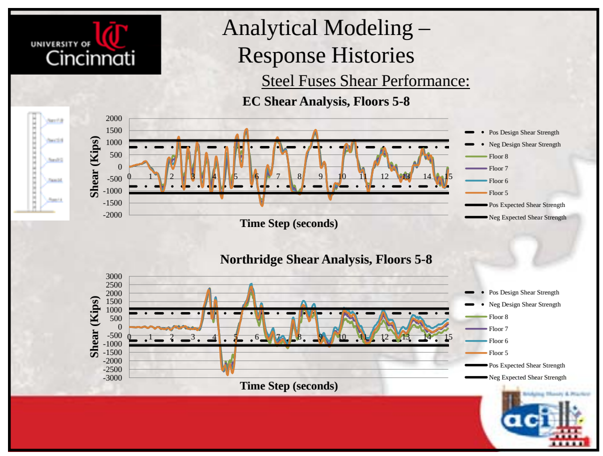
Analytical Modeling – Response Histories
Earthquake Ground Motions:
El Centro Record
Peak Acceleration = 0.348 g
Acceleration (g)
Time Step (seconds)
Northridge (Sylmar) Record
Peak Acceleration = 0.798 g
Acceleration (g)
Time Step (seconds)



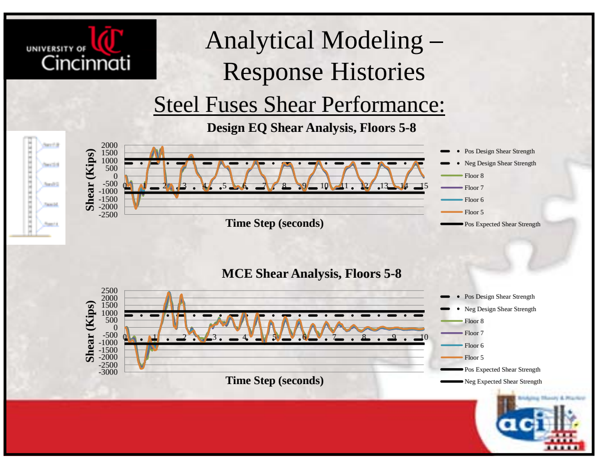
Analytical Modeling – Response Histories
Artificial Earthquake Ground Motions:
Design Earthquake Record
Peak Acceleration = 1.04 g
Acceleration (g)
Time Step (seconds)
MC Earthquake Record
Peak Acceleration = 1.54 g
Acceleration (g)
Time Step (seconds)



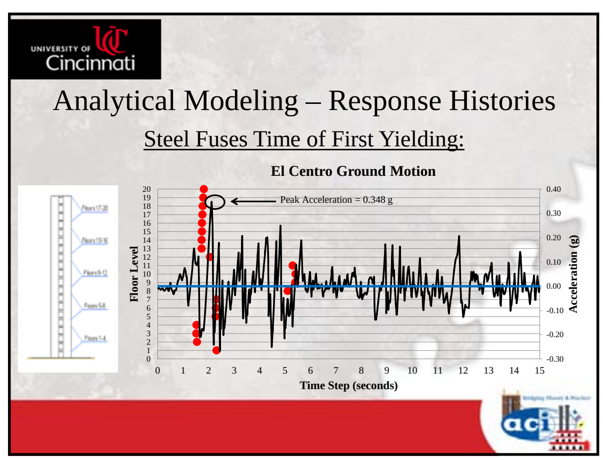
Analytical Modeling – Response Histories
Top Floor Drifts – All Earthquakes:
Top Floor Drifts
Top Floor Drift (inches)
El Centro
Design EQ
Northridge
MC Earthquake
Peak Drift = -29.8 IN (2.48 FT) = 1.38% Building Height
Time Step (Seconds)



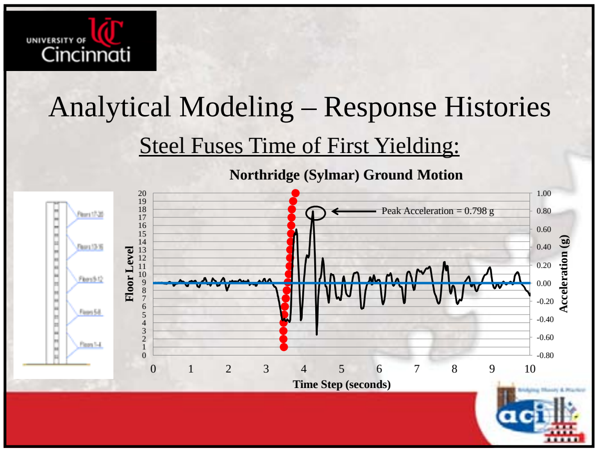
Analytical Modeling – Response Histories
Steel Fuses Shear Performance:
EC Shear Analysis, Floors 5-8
Shear (Kips)
Time Step (seconds)
Northridge Shear Analysis, Floors 5-8
Shear (Kips)
Time Step (seconds)

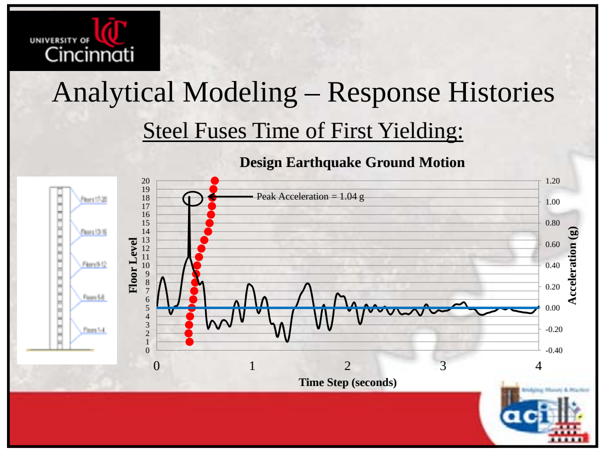


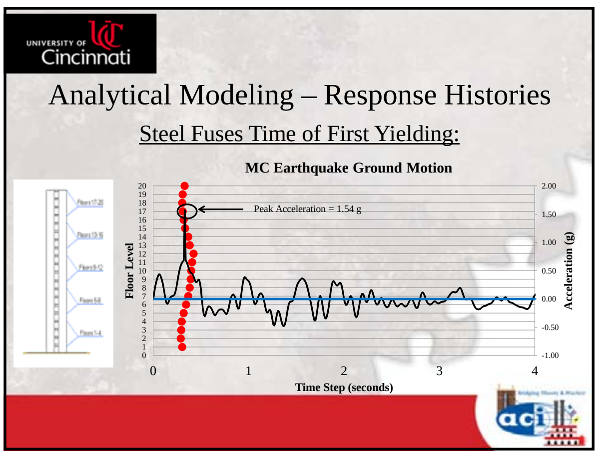
Analytical Modeling – Response Histories
Steel Fuses Shear Performance:
Design EQ Shear Analysis, Floors 5-8
Shear (Kips)
Time Step (seconds)
MCE Shear Analysis, Floors 5-8
Shear (Kips)
Time Step (seconds)

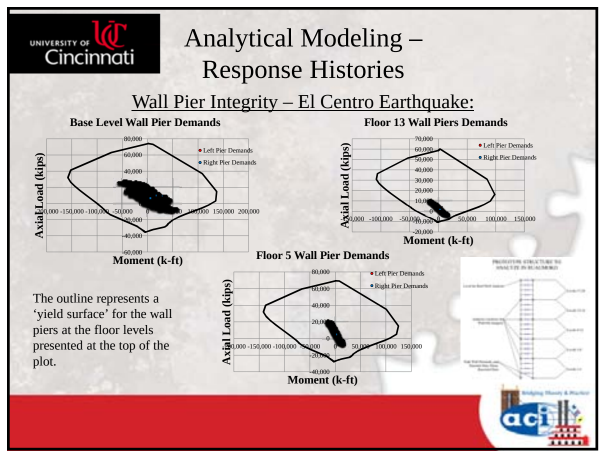


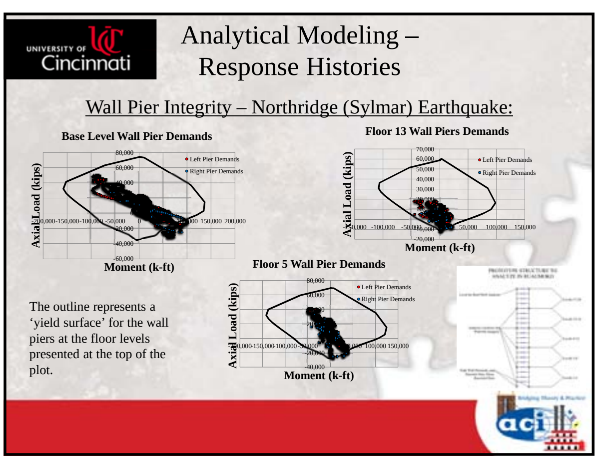
Analytical Modeling – Response Histories
Steel Fuses Time of First Yielding:
El Centro Ground Motion
Peak Acceleration = 0.348 g
Floor Level
Acceleration (g)
Time Step (seconds)

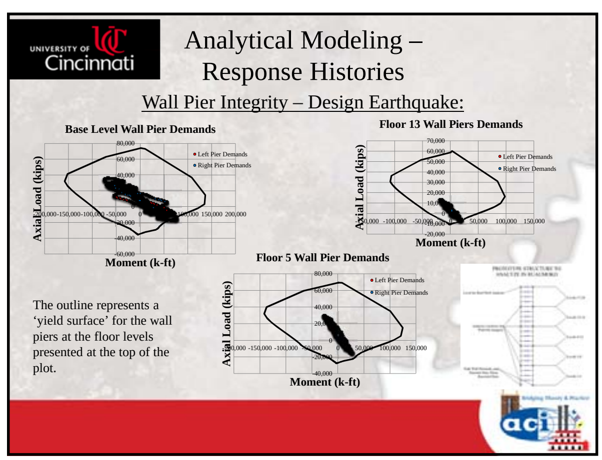

UNIVERSITY OF Cincinnati
Analytical Modeling – Response Histories
Steel Fuses Time of First Yielding:
Northridge (Sylmar) Ground Motion
Peak Acceleration = 0.798 g
Floor Level
Acceleration (g)
Time Step (seconds)


UNIVERSITY OF Cincinnati
Analytical Modeling – Response Histories
Steel Fuses Time of First Yielding:
Design Earthquake Ground Motion
Peak Acceleration = 1.04 g
Floor Level
Acceleration (g)
Time Step (seconds)


UNIVERSITY OF Cincinnati
Analytical Modeling – Response Histories
Steel Fuses Time of First Yielding:
MC Earthquake Ground Motion
Peak Acceleration = 1.54 g
Floor Level
Acceleration (g)
Time Step (seconds)

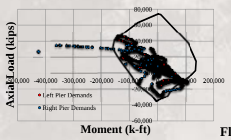

UNIVERSITY OF Cincinnati
Analytical Modeling – Response Histories
Wall Pier Integrity – El Centro Earthquake:
Base Level Wall Pier Demands
Floor 13 Wall Piers Demands
Floor 5 Wall Pier Demands
Axial Load (kips)
Moment (k-ft)
The outline represents a 'yield surface' for the wall piers at the floor levels presented at the top of the plot.

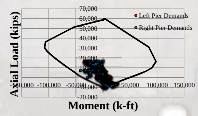

UNIVERSITY OF Cincinnati
Analytical Modeling – Response Histories
Wall Pier Integrity – Northridge (Sylmar) Earthquake:
Base Level Wall Pier Demands
Floor 13 Wall Piers Demands
Floor 5 Wall Pier Demands
Axial Load (kips)
Moment (k-ft)
The outline represents a 'yield surface' for the wall piers at the floor levels presented at the top of the plot.


UNIVERSITY OF Cincinnati
Analytical Modeling – Response Histories
Wall Pier Integrity – Design Earthquake:
Base Level Wall Pier Demands
Floor 13 Wall Piers Demands
Floor 5 Wall Pier Demands
Axial Load (kips)
Moment (k-ft)
The outline represents a 'yield surface' for the wall piers at the floor levels presented at the top of the plot.

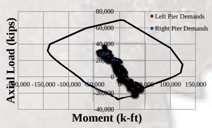
Analytical Modeling – Response Histories

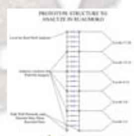
Wall Pier Integrity – MC Earthquake:





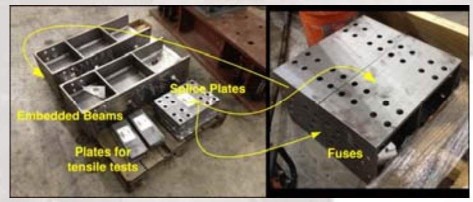
The outline represents a 'yield surface' for the wall piers at the floor levels presented at the top of the plot.





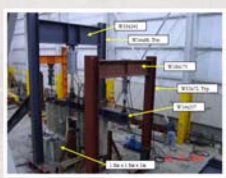
Half-Scale Experimental Test

- Half-scale test coupling beam designed from floors 5-8 of the prototype structure
- Experimental steel fuse coupling beam already fabricated



Half-Scale Experimental Test

- Half-scale test coupling beam designed from floors 5-8 of the prototype structure
- Experimental steel fuse coupling beam already fabricated
- Instrumentation packages will be used on the fuses, and the embedded beams both outside and inside the reinforced concrete walls
- Testing schedule is likely for April-May, 2012
- Data from experiment will help guide future analytical modeling



Previous test at the University of Cincinnati Large Scale Testing Facility

Questions ?