EXPERIMENTAL & NUMERICAL RETROFIT OF NON-DUCTILE RC SHEAR WALLS

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Project Motivation

- Many structures in CA which were designed pre-1970’s.
- Pre-modern seismic codes.
- If a large earthquake occurs structures with non-ductile concrete shear walls are at risk of collapse.

Shear Wall Damage

- Diagonal Failure:
- Concrete Crushing/ Buckling of Bars:

2009 L'Aquilla
(Dazio 2009)

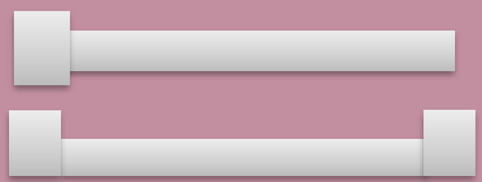
2011 Christchurch
(Kam et al. 2011)

2010 Chile
(Maffei et al. 2014)

2011 Christchurch
(Kam et al. 2011)

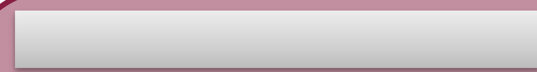
Shear Wall Background Research: 1950’s-1960’s in CA

W/ Pilasters



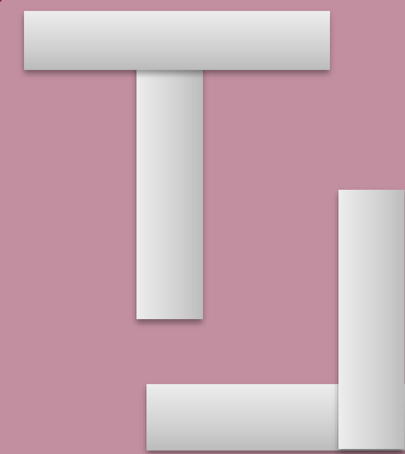
- Web
  thickness: 10-12”
  $\rho_v \approx 0.2\%$,
  $\rho_h \approx 0.2\text{-}0.3\%$
- Pilasters
  size: 24”-36”
  $\rho_v = 1.7\text{-}3.8\%$,
  $\rho_c = 0.4\text{-}1.4\%$

Rectangular walls



- thickness: 8”-16”
- $\rho_v = 0.2\text{-}0.5\%$
- $\rho_h \approx 0.3\%$
- Lap splices ($\approx 30d_b$)
- added bars around openings

Flanged walls



Materials:
- Concrete: $f'_c = 3{,}000\text{-}4{,}000$ psi
- Steel: $f_y = 40$ ksi, one case of $f_y = 60$ ksi

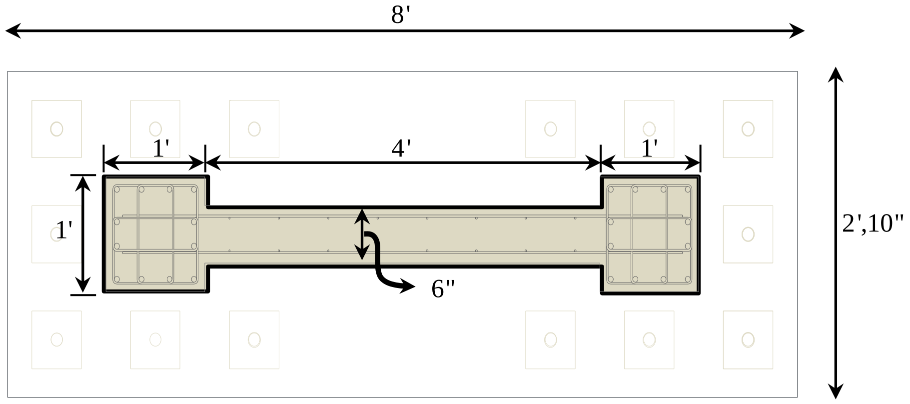
Objectives of Research

- Investigate anticipated damage patterns for currently active buildings on the West Coast that have been designed before (pre-1970, non-ductile) the advent of modern seismic design procedures.
- Study effectiveness of Fiber Reinforced Polymer and concrete retrofit methods for existing RC walls prone to shear failure.
- Further validate numerical models.
- ***Provide design recommendations for retrofitting techniques of shear walls.***

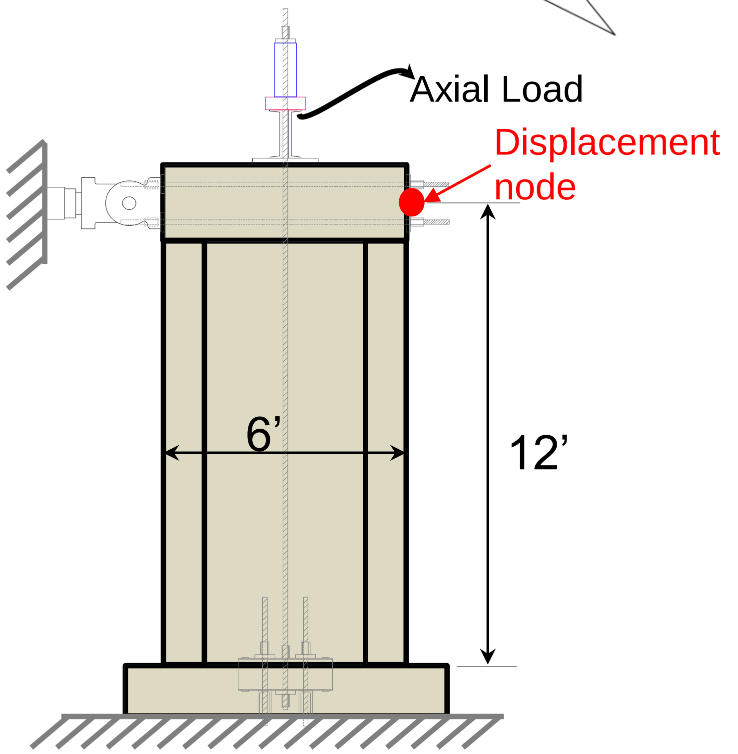
Specimen #	Retrofit Strategy
1	None, control
2	Fiber Reinforced Polymer
3	Shotcrete

complete

Specimen & Set Up



Plan View

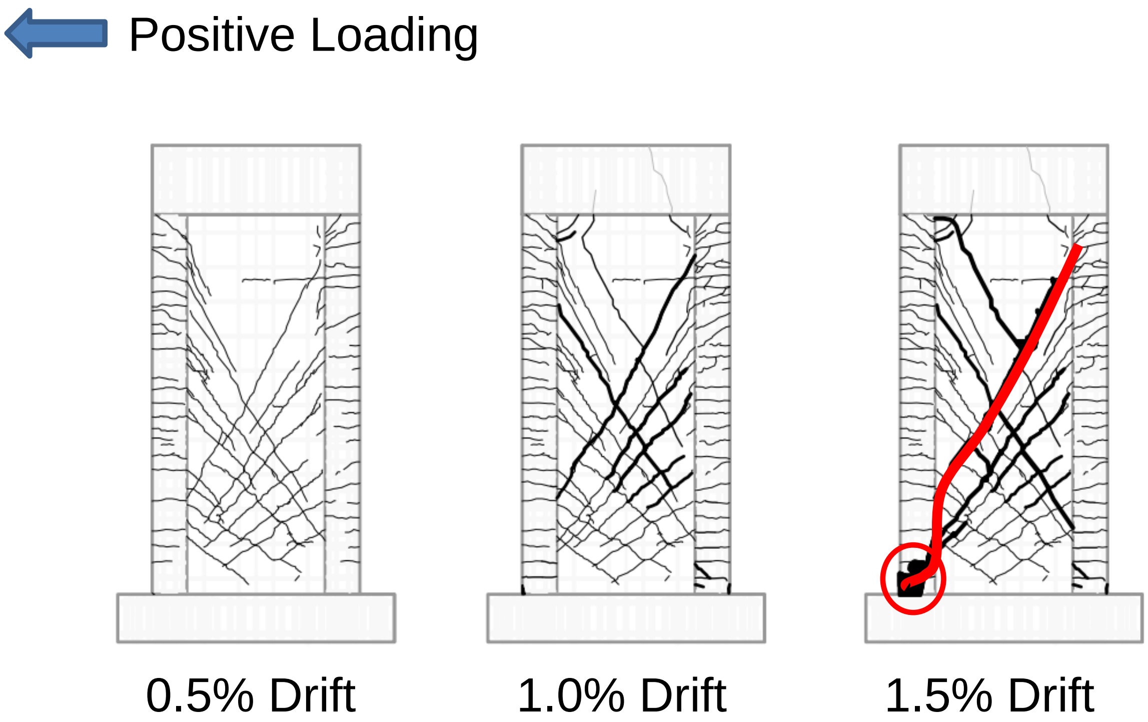


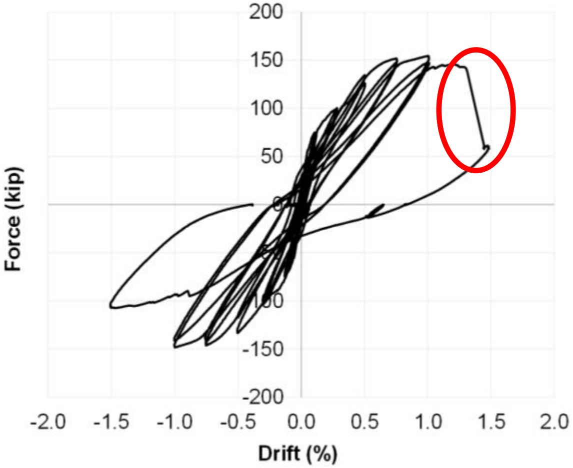
Elevation View

- Half Scale specimens
- Axial load ratio = 0.10 = 200 kips/Wall Area*f'c

Testing Specimen 1

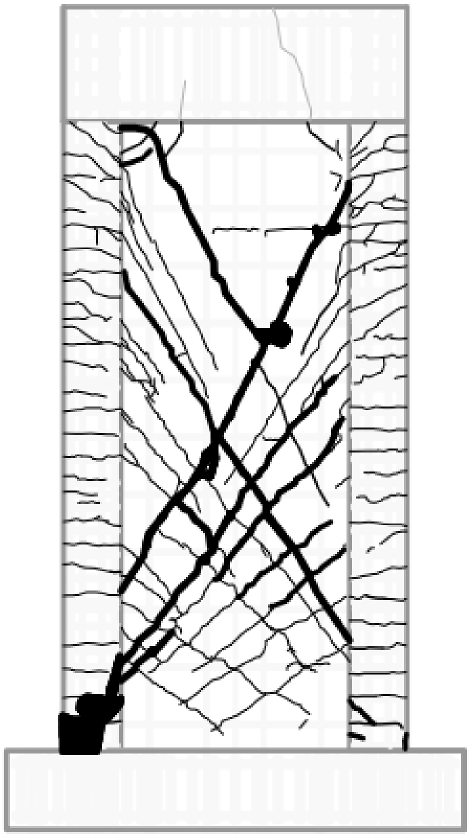
Testing Specimen 1

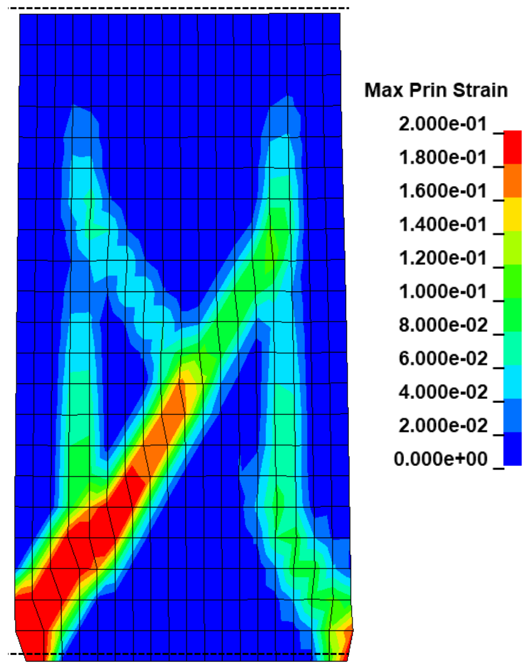




SHEAR CRUSHING FAILURE

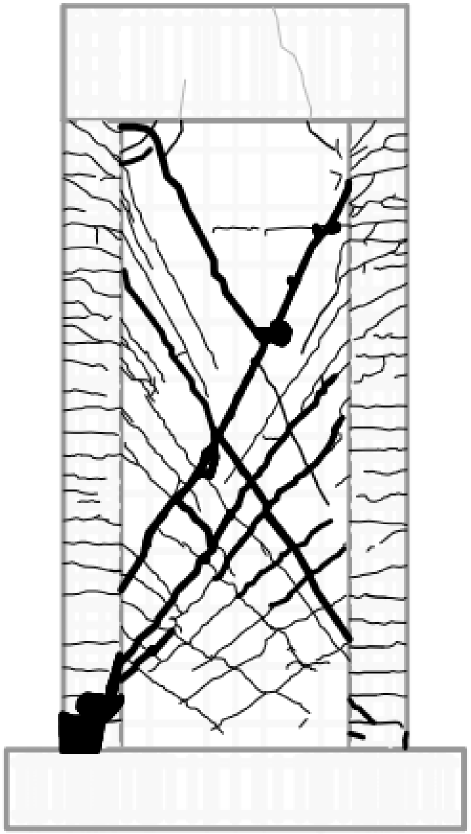
Analysis with actual material properties

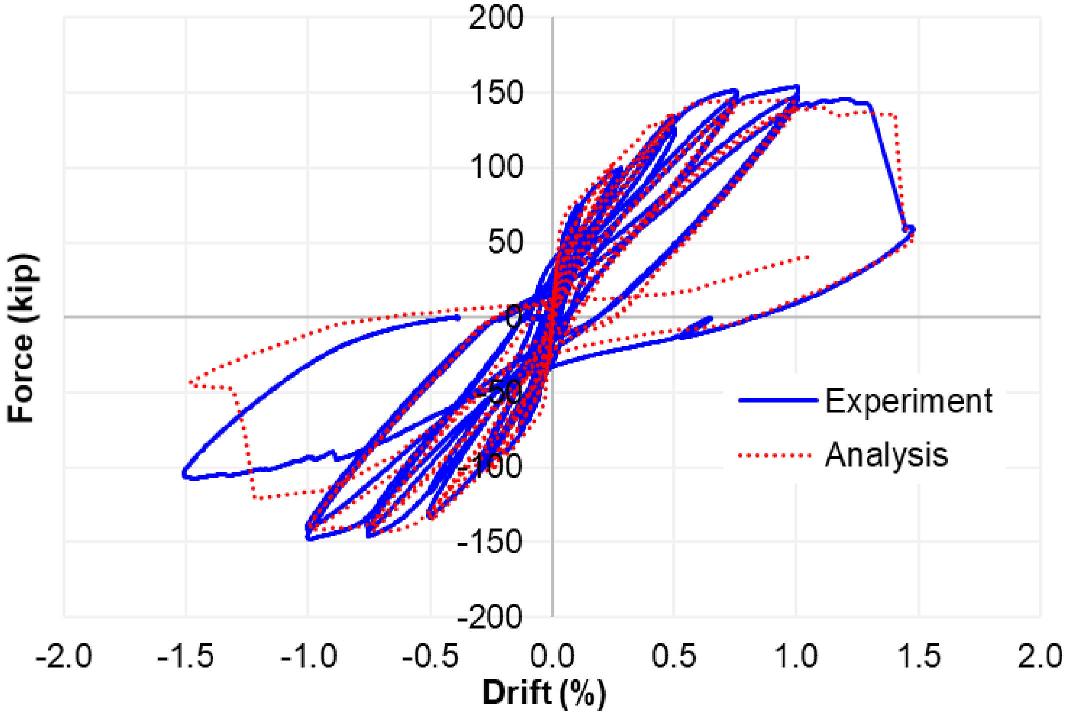




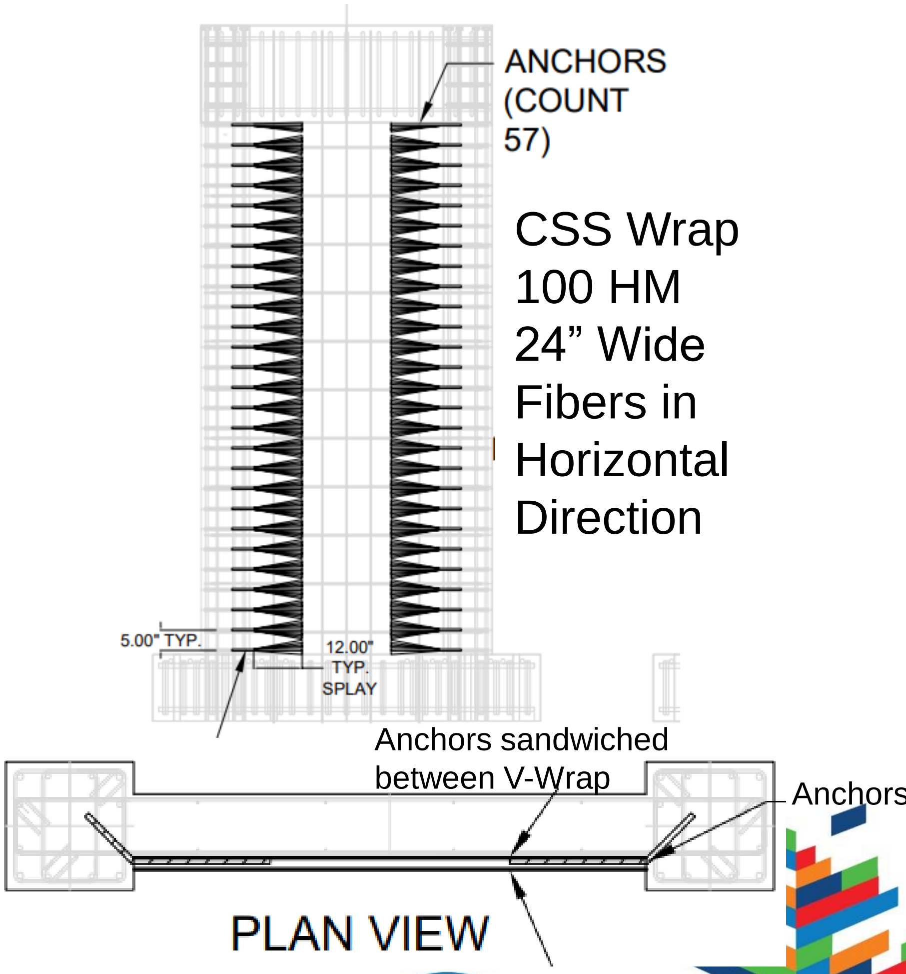
- Beam truss elements
- 500 elements
- Nonlinear

Analysis with <u>actual</u> material properties





Design of Specimen 2



CSS Wrap
100 HM
24” Wide
Fibers in
Horizontal
Direction

Testing of Specimen 2

- Back Face - Unretrofitted

Progress of Delamination of FRP

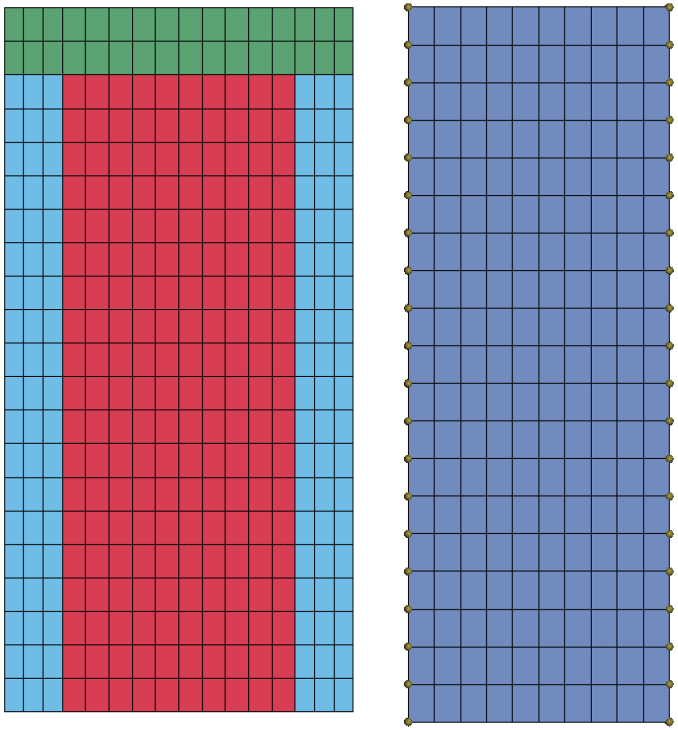
Actual Results of Specimen 2

At 2% Drift

Localized cracks in web

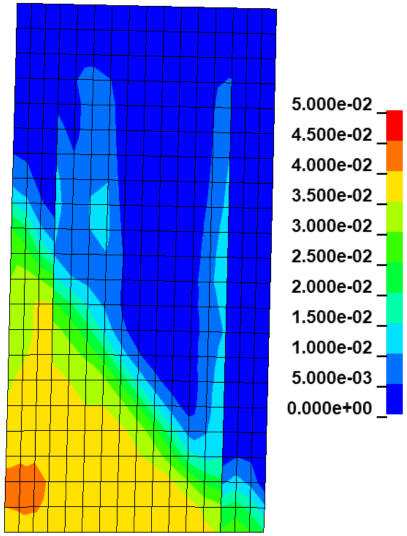
Truss Model Specimen 2

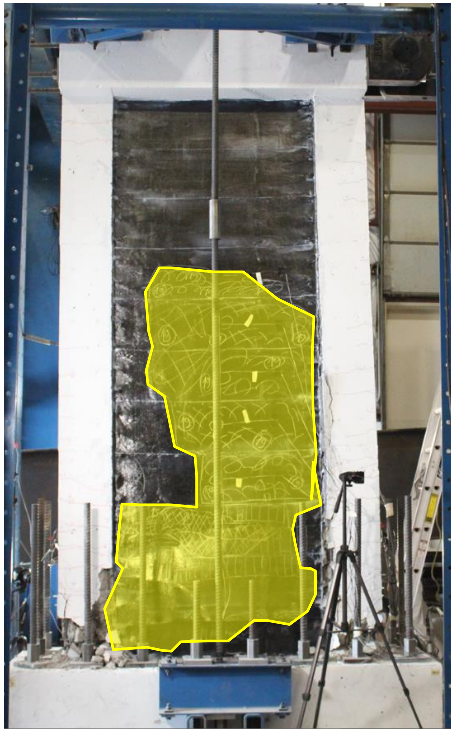
- Shell elements for FRP Overlay
- Adhesive interface elements used to account for the overlay debonding
- Spring elements for FRP anchors (elastic-brittle material)



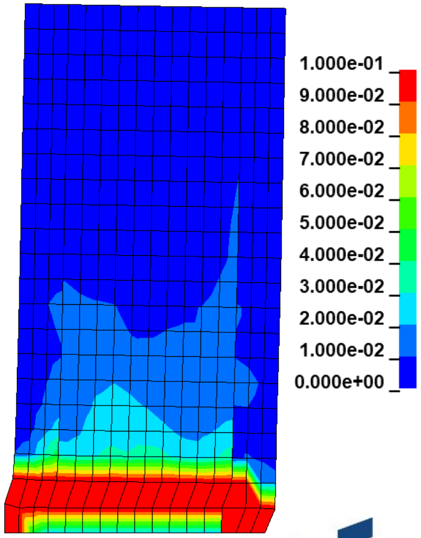
Truss Model Results

max principal strain @ drift = 2%



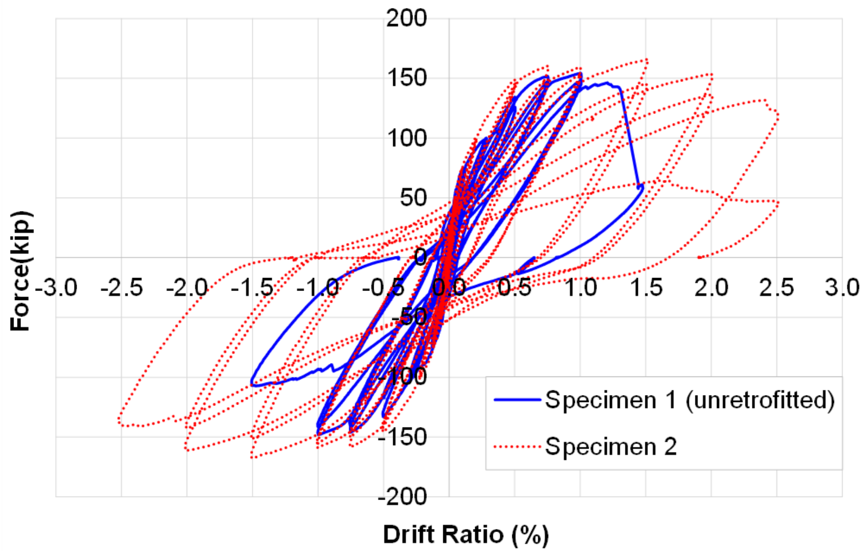


max principal strain @ end of analysis

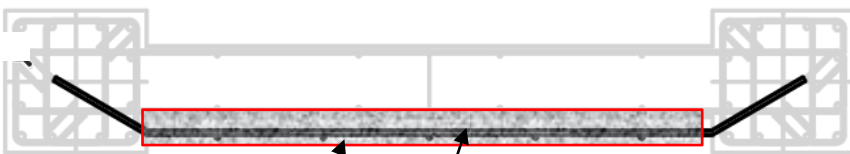


Comparison of Results

Specimen	Peak Load (kip)	Peak Drift (%)	Peak Strain in Vertical Rebar (in/in)	Peak Average Diagonal Strain (in/in)
1	154.3	1.5%	.0217	.008
2	165.7	2.5%	.055	.003



Future Work



3” concrete overlay - Shotcrete

9”x9” #3 rebar grid, embedded in pilasters 9”

Resources

- Deng, X., Koutromanos, I., Murcia-Delso, J., and Panagiotou, M. (2021). "Nonlinear truss models for strain-based seismic evaluation of planar RC walls," *Earthquake Engineering and Structural Dynamics* (open access), DOI: 10.1002/eqe.3480

- Deng, X., Murcia-Delso, J., Koutromanos, I., and Panagiotou, M. (2022). "Nonlinear truss modeling and strain-based evaluation of non-ductile RC walls, including the effect of lap-splice failures," *Proceedings of the 3rd European Conference on Earthquake Engineering and Seismology*, Bucharest, Romania.

- Panagiotou, M., et al. (2021). "Nonlinear Beam-Truss Model (BTM) for Seismic Performance Evaluation of Reinforced Concrete Wall Buildings," *Proceedings of the 2021 SEAOC Convention*, San Diego, CA.

Acknowledgements

- NIST
- Simpson Strong-Tie
- Professional Advisory Panel
- CRSI (especially Brett Lord)
- Commercial Metals Company (CMC Rebar)
- Headed Reinforcement Corp. West (HRC)
- Virginia Tech Structural Engineering Lab

Research Team

- Principal Investigators
    - I. Koutromanos, Virginia Tech (VT)
    - J. Murcia-Delso, UPC
- Graduate Students
    - Ann Albright, VT
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    - Colson Brandetsas, VT
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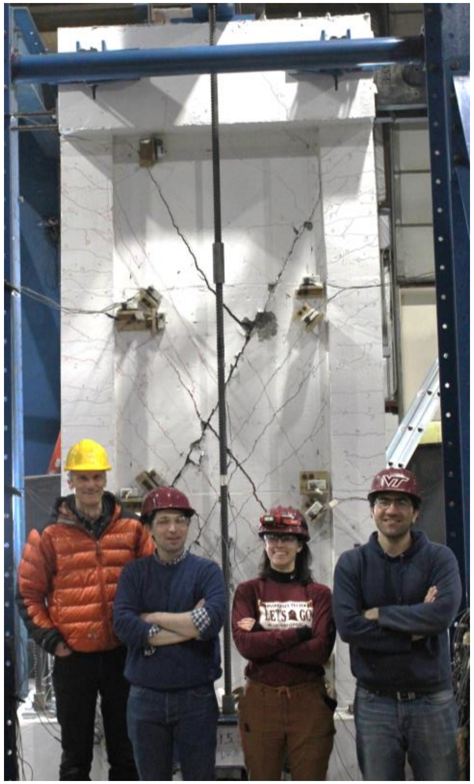
    - Brandon Pulido, UPC



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Thank you!

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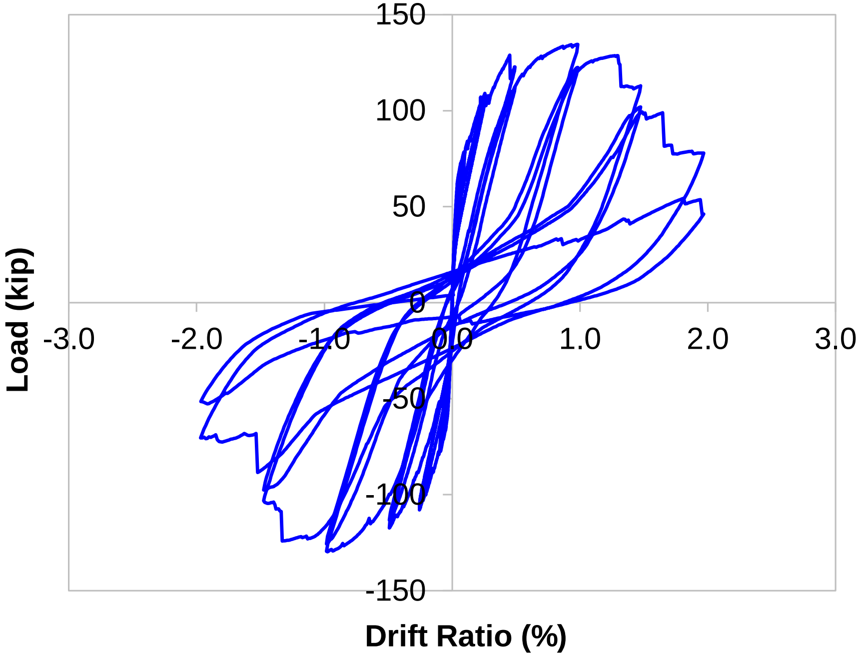
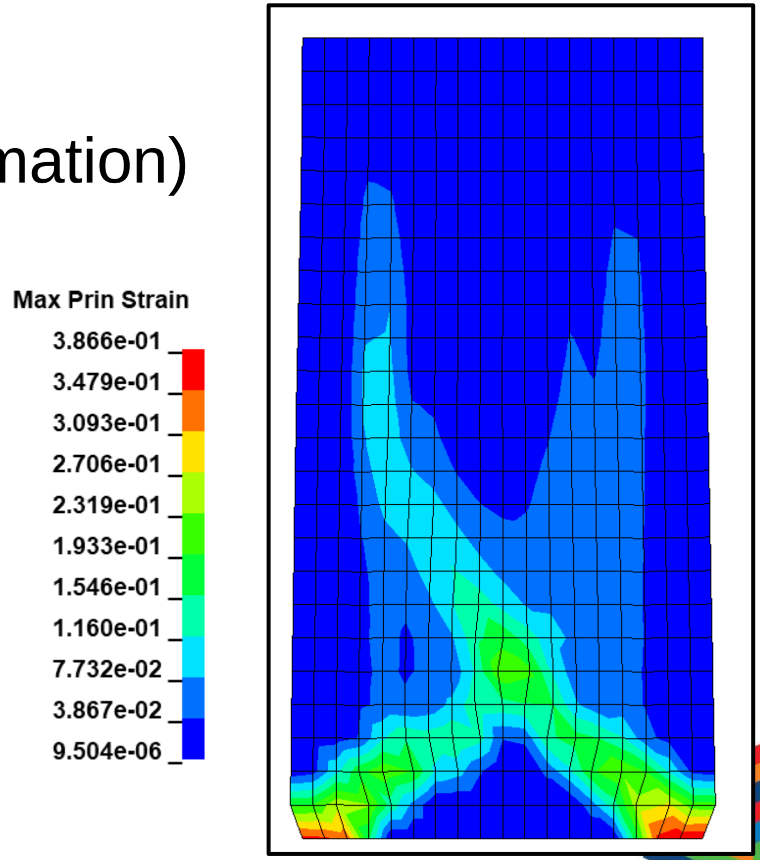
Pre-Test Analysis

- Conducted before experimental test – Beam Truss Model
- 500 elements
- V_{max}=135 kip (10% underestimation)





Pre-test Analysis of Specimen 2