New Analytical Models and Tools for Nonlinear Modeling of Reinforced Concrete Wall Structures

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2019 PEER Annual Meeting
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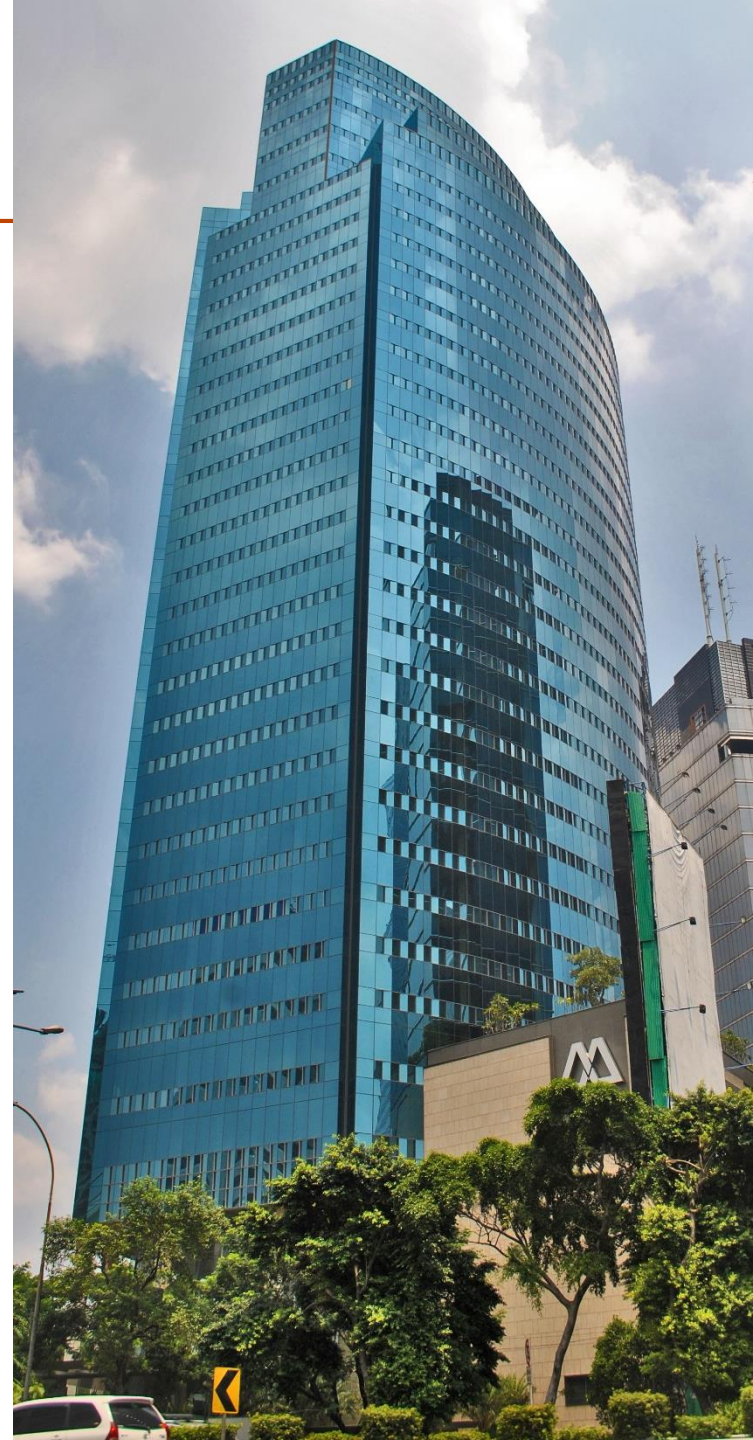
Presentation Outline

- Description and validation of new 3D models for RC walls
  - MVLEM_3D
  - SFI_MVLEM_3D
  - quadWall
- Convert ETABS to OpenSees
  - Description
  - Example
- Summary and future work

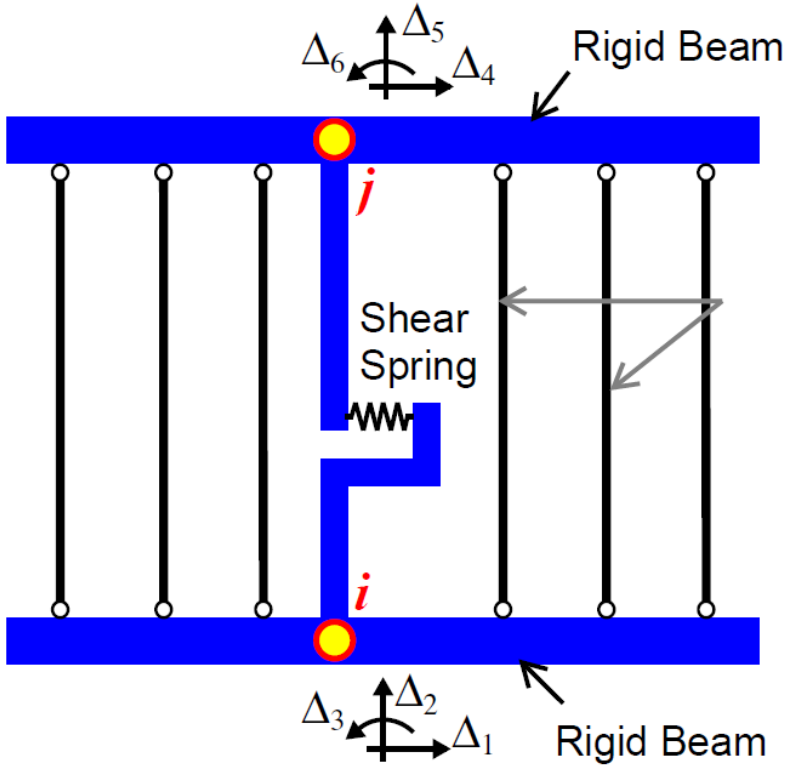


Background

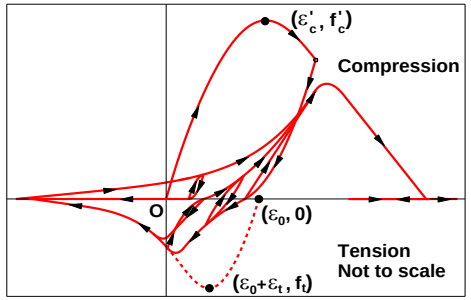
Existing OpenSees RC Wall Models

MVLEM

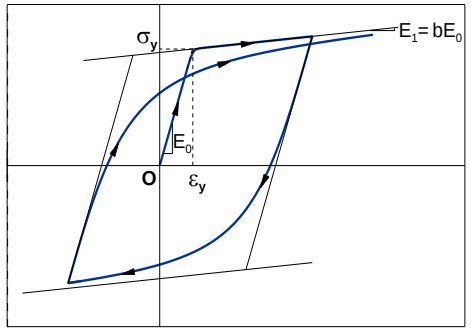
- P-M fiber section
- V - shear spring
- P-M and V uncoupled



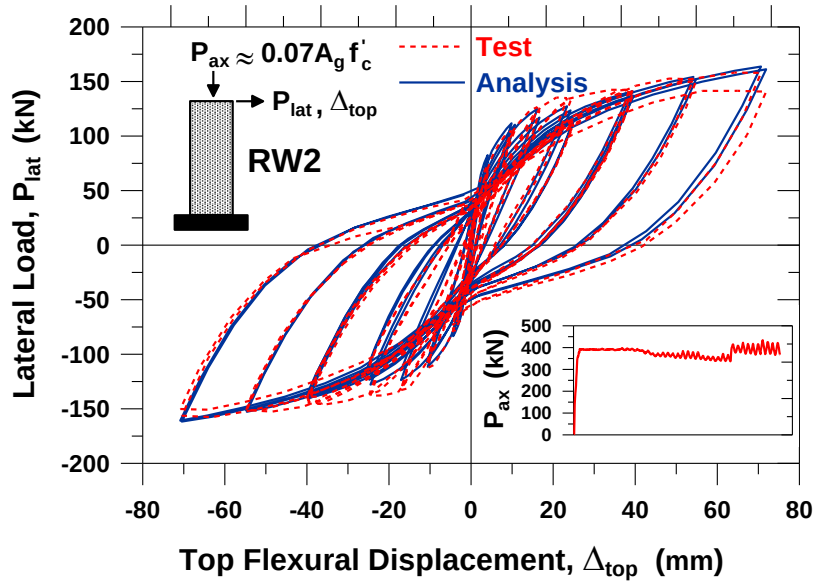
Concrete

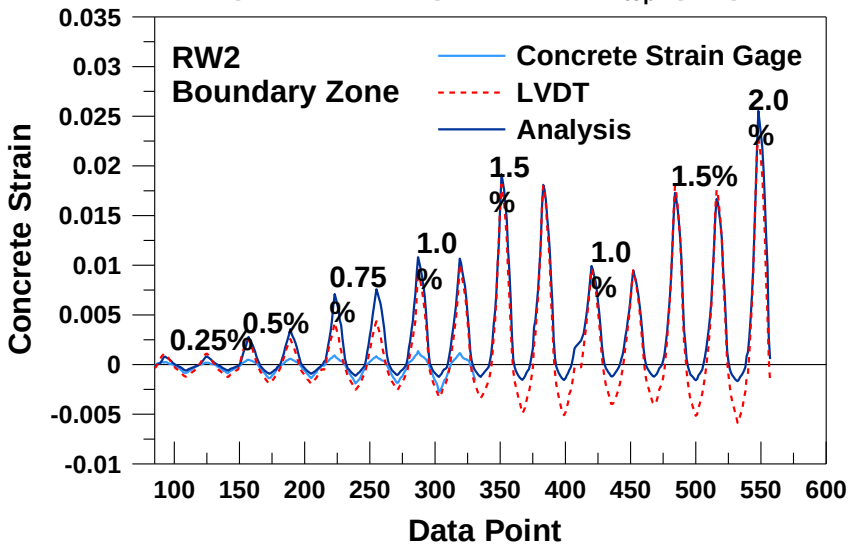


Steel



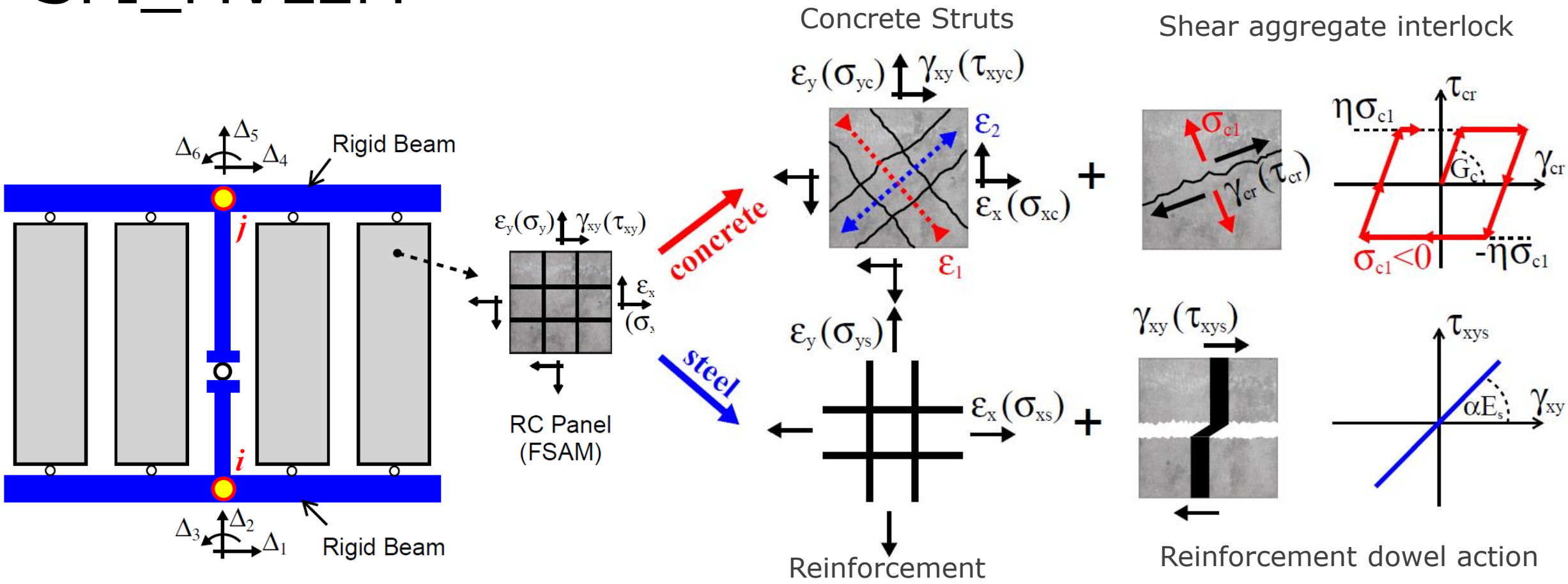
RW2, Thomsen and Wallace (1994)





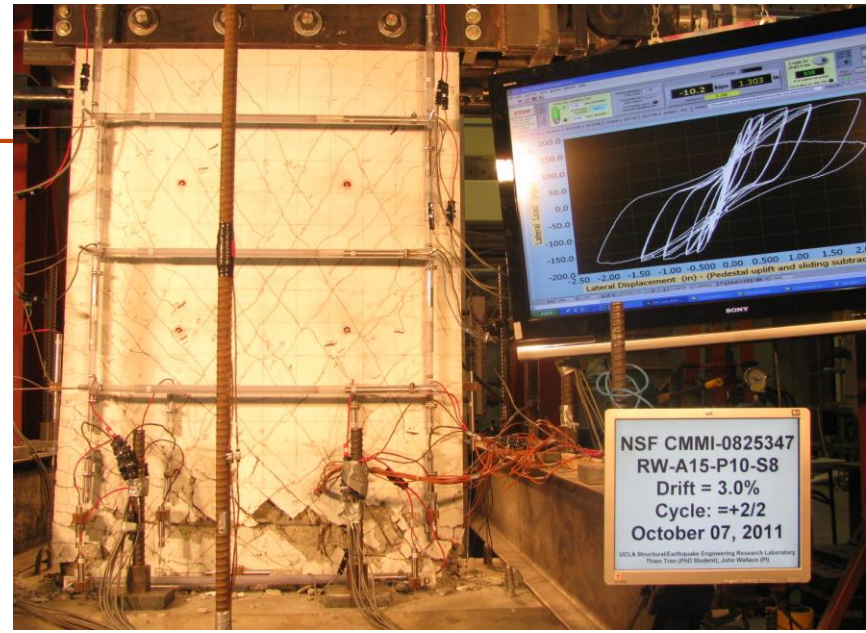
Existing OpenSees RC Wall Models

SFI_MVLEM



Existing RC Wall Models

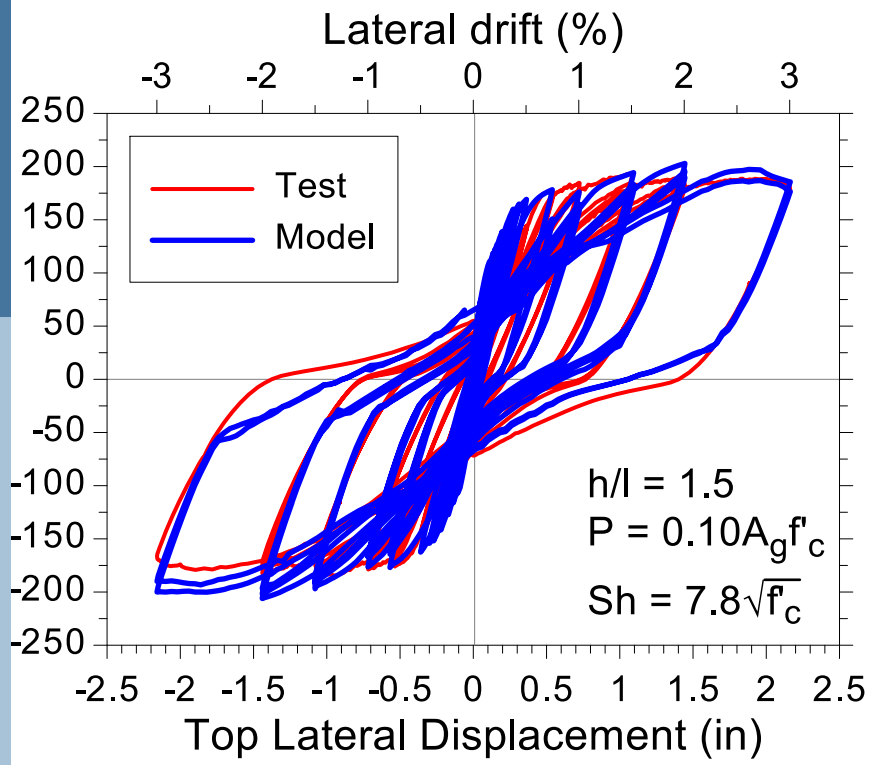
Tran and Wallace (2015)

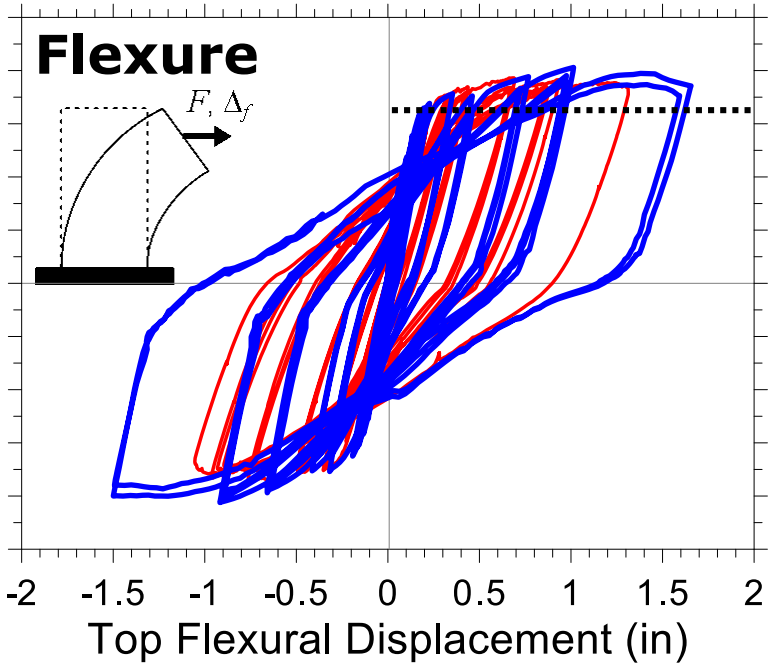


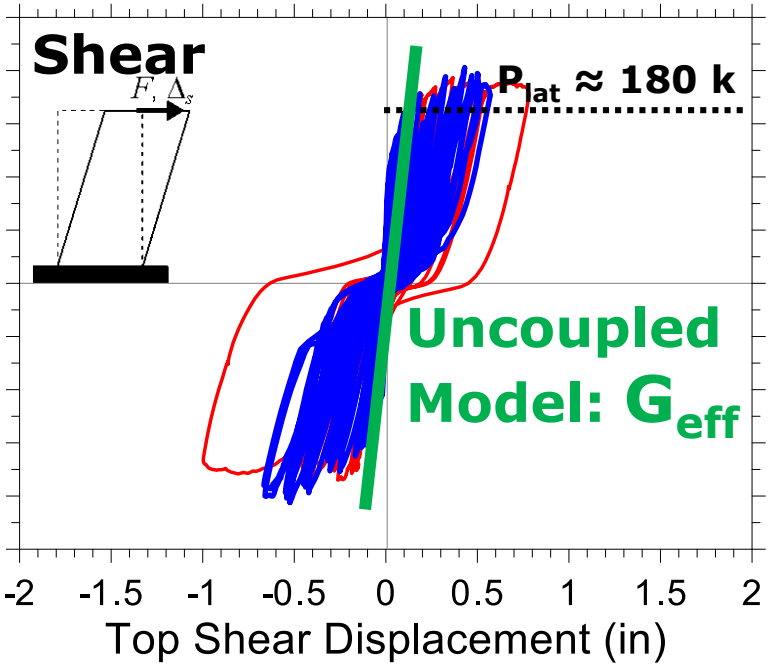
Good prediction of hysteretic behavior

Nonlinear shear deformations

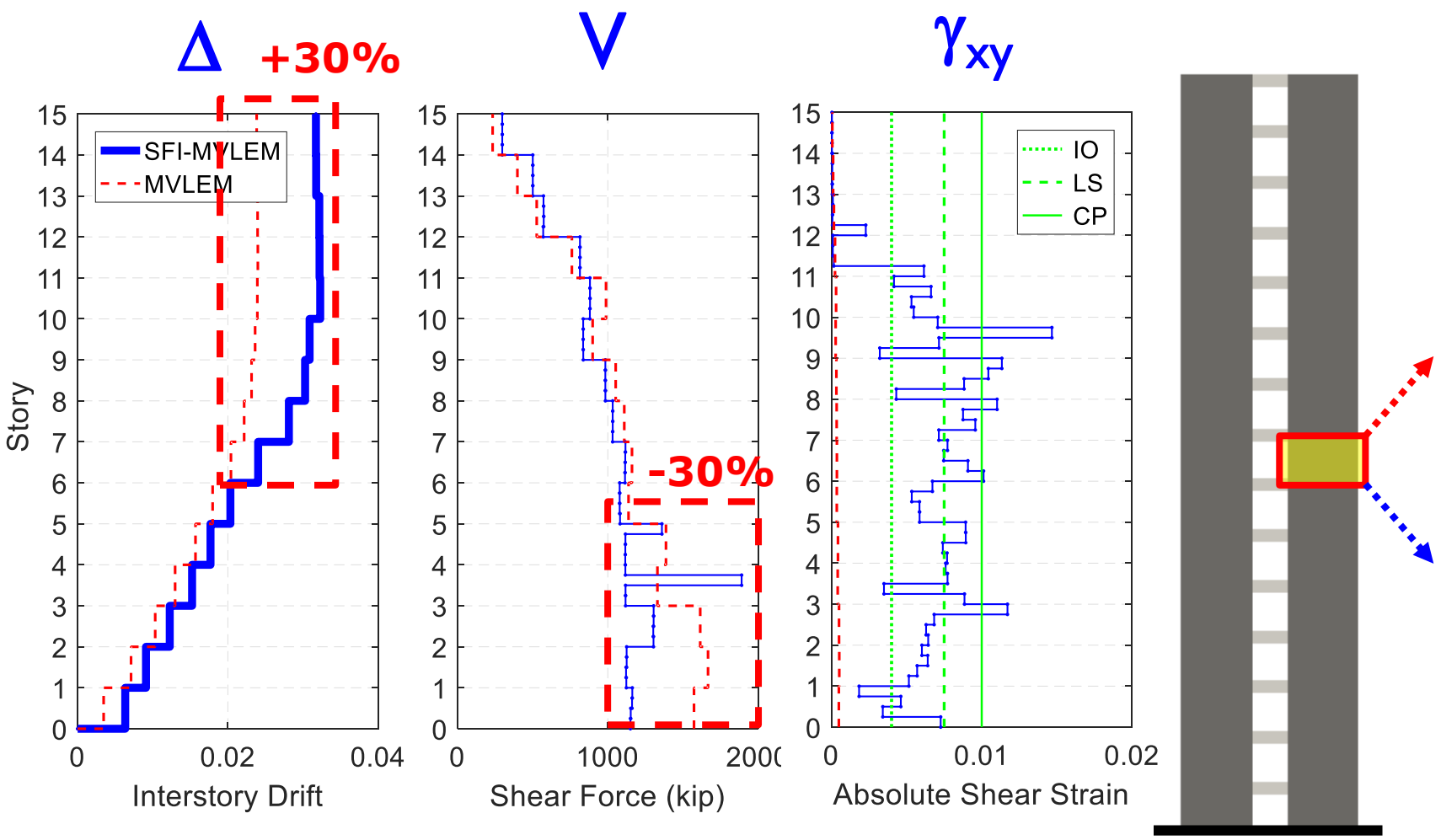
Shear-flexural interaction

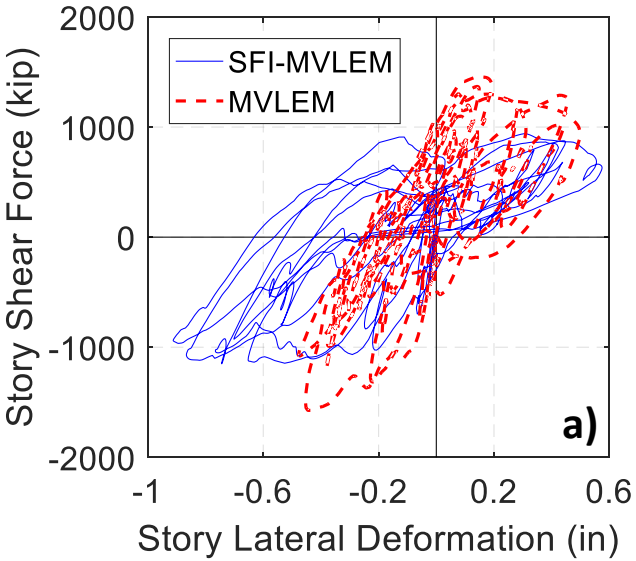


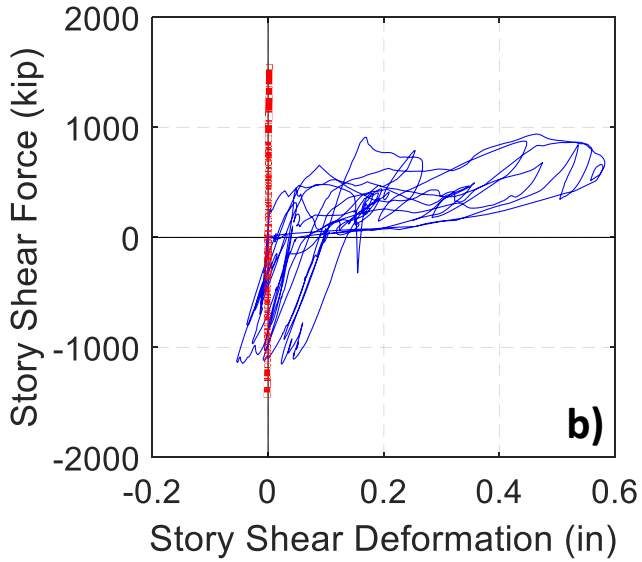




Coupled versus Uncoupled Wall Models

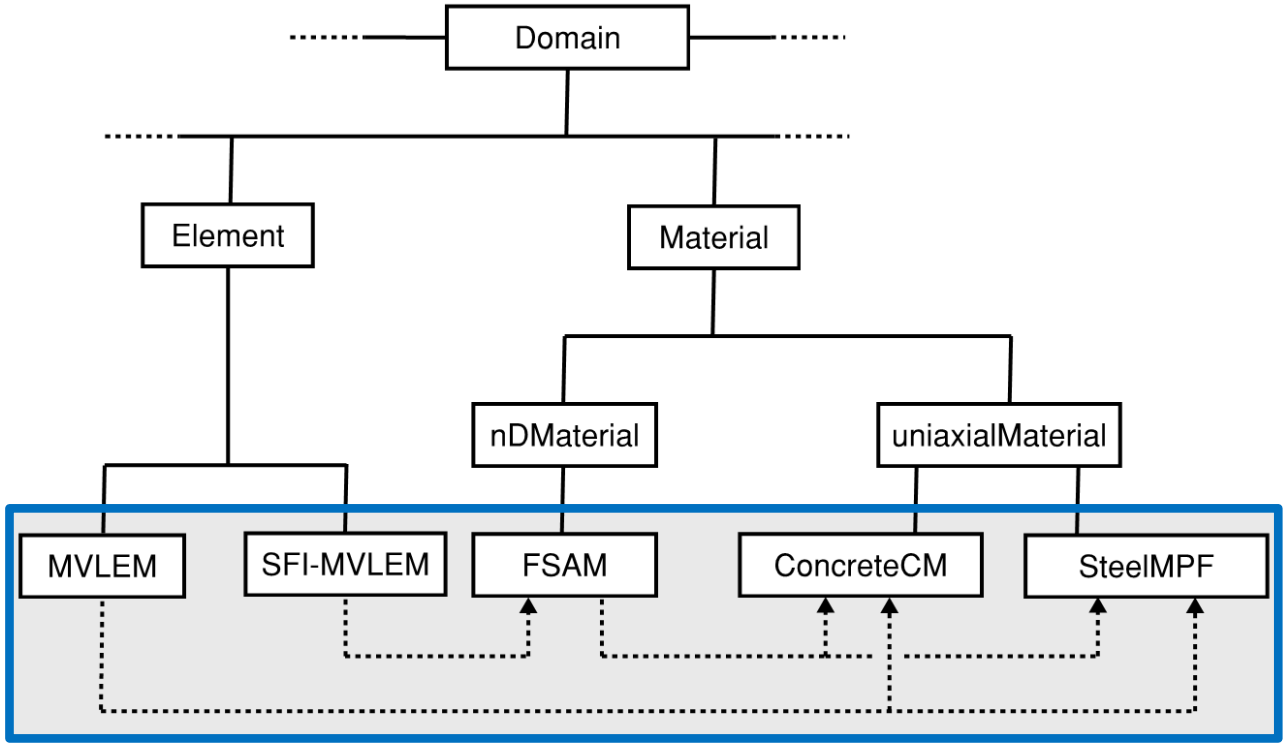






Existing OpenSees RC Wall Models

- Extensive Documentation
  - OpenSeesWiki (manuals, examples) - 15,000+ visits
  - Kolozvari et al. (2015) ASCE Structural. Journal
  - Kolozvari et al. (2015) PEER Report 2015/12
  - Kolozvari et al. (2018) Computers and Structures Jour.



PEER Report

PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

Shear-Flexure Interaction Modeling for Reinforced Concrete Structural Walls and Columns under Reversed Cyclic Loading

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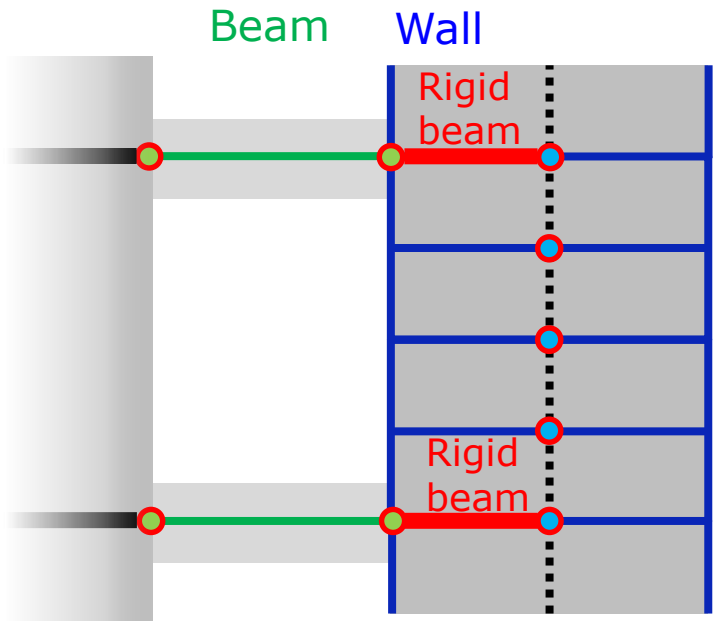
PEER Report No. 2015/12
Pacific Earthquake Engineering Research Center
Headquarters at the University of California, Berkeley

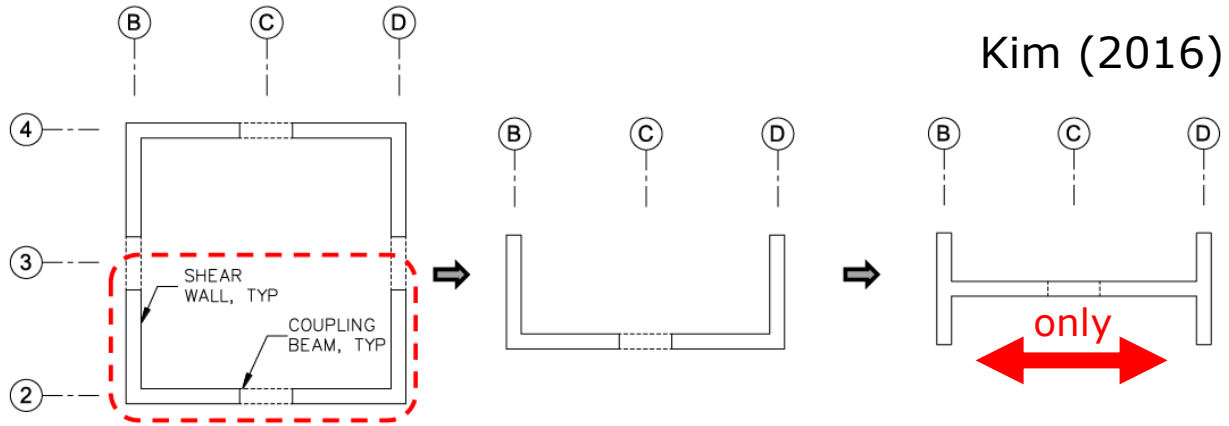
December 2015

PEER 2015/12
December 2015

Model Shortcomings & Objectives

- Models are 2-node
  - Cumbersome connecting wall and frame elements (requires rigid beams)
- Models are 2-D
  - Limited ability in modeling nonplanar walls
  - Impossible to model 3D behavior of walls
  - Impossible to model 3D building systems



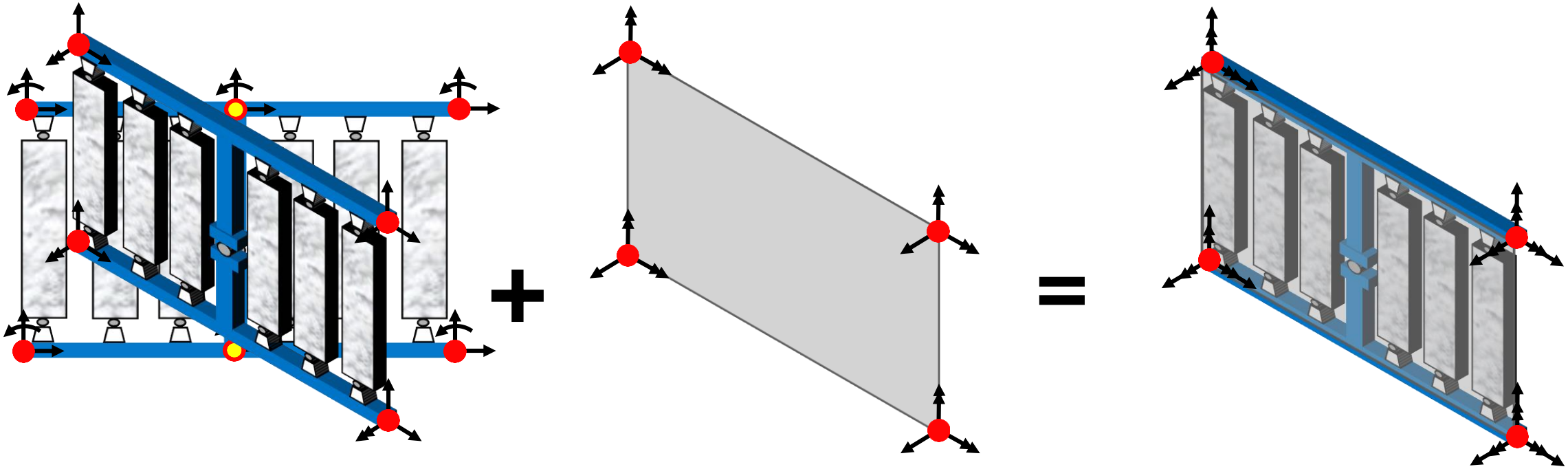


Kim (2016)

Models Description and Validation

Macroscopic Models

4-Node 3D MVLEM Elements



4-node 2D Element
12 in-plane DOFs

4-node Elastic Plate
12 out-of-plane DOFs

3D Wall Element
24 DOFs

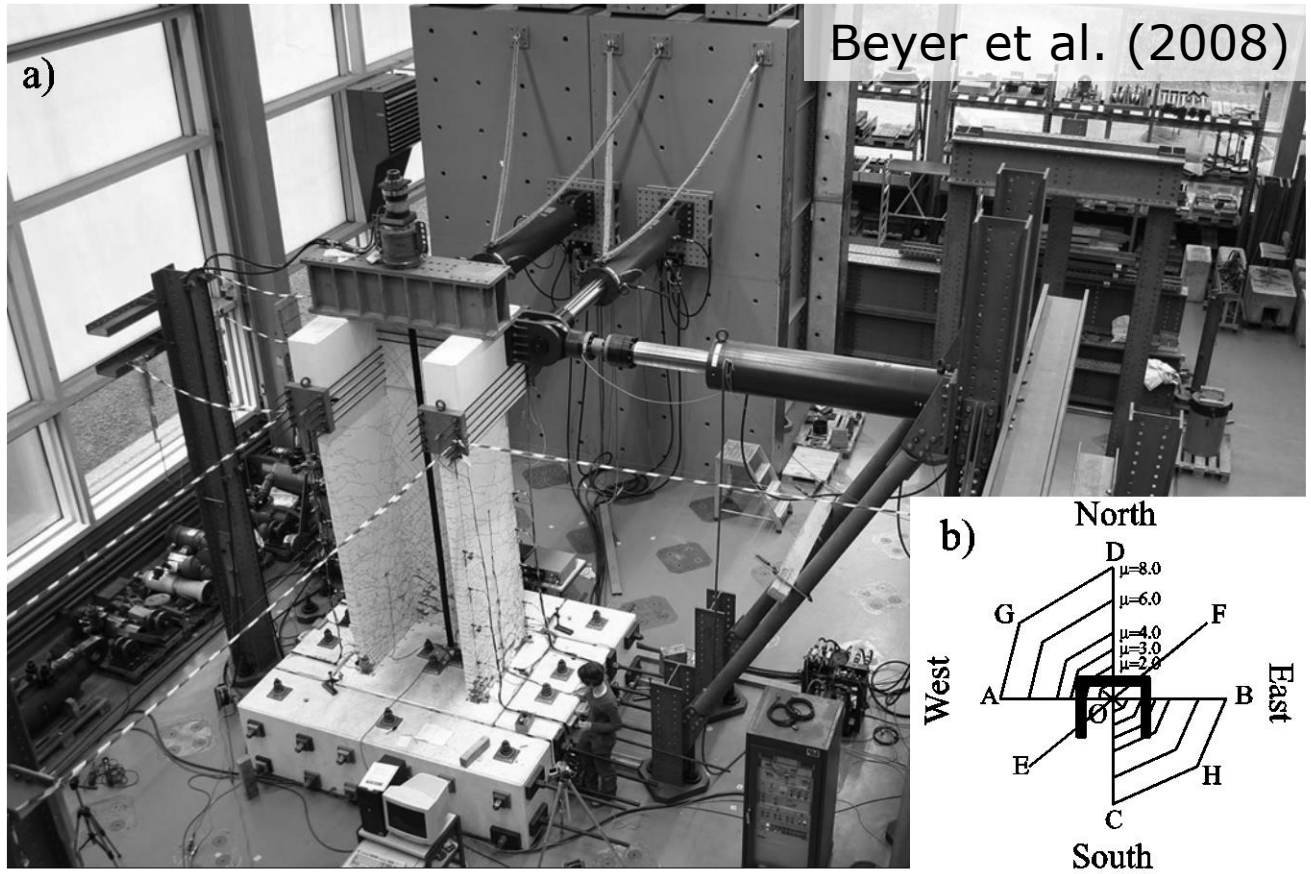
- MVLEM_3D
- SFI_MVLEM_3D

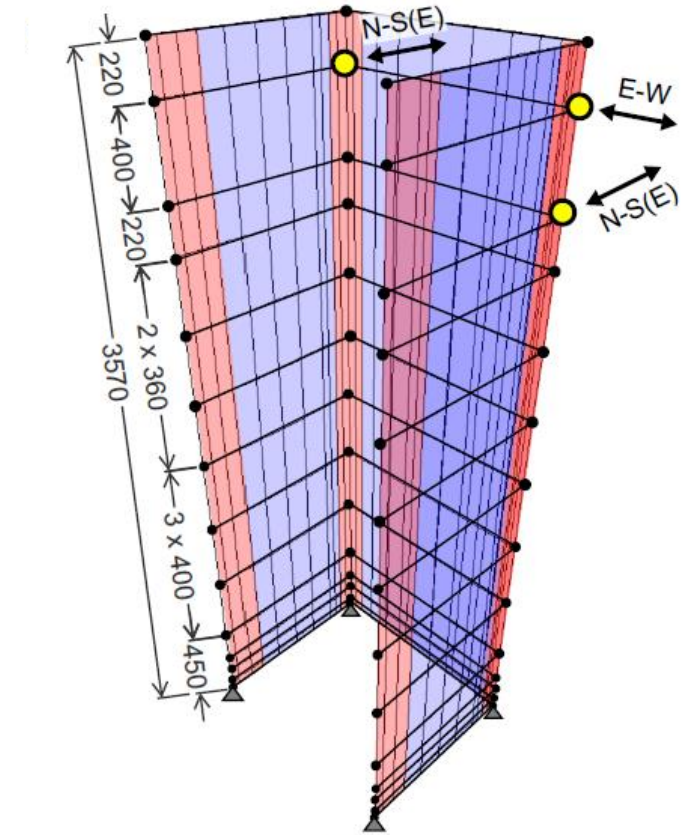
NEW

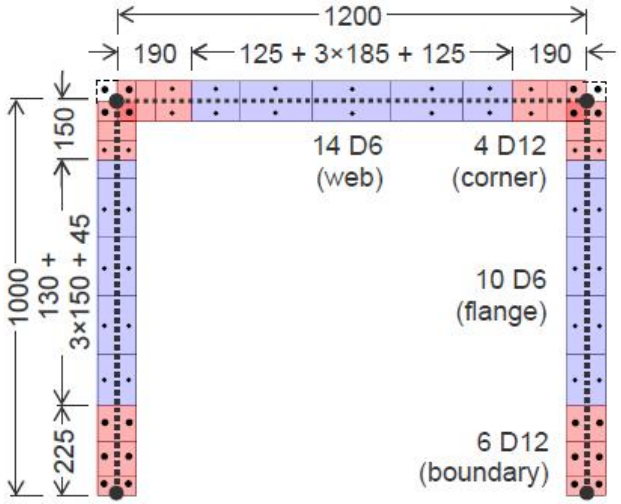
Publicly available in 2019

Models Validation

- Planar walls
- T-shaped walls under uniaxial loading
- U-shaped walls under biaxial loading

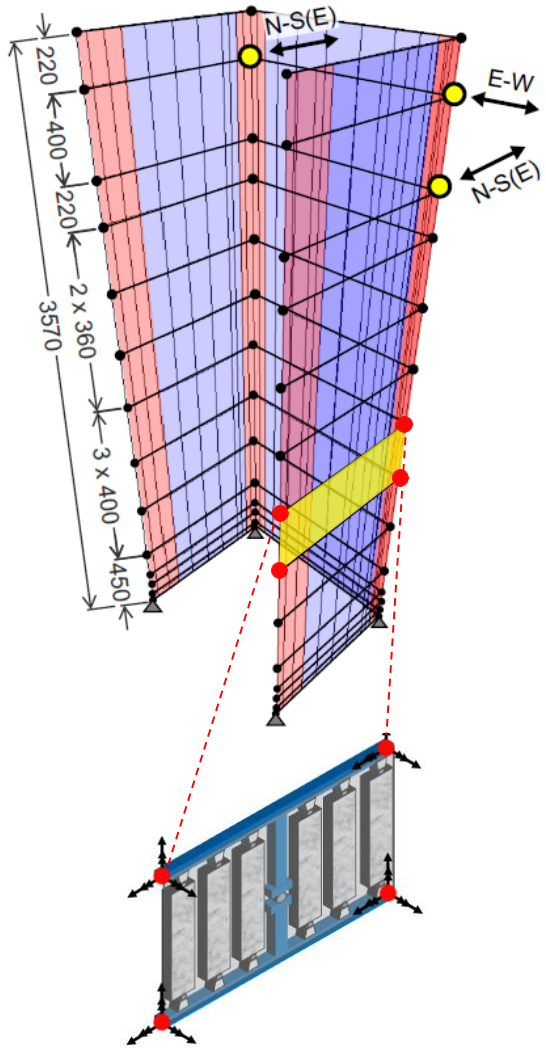


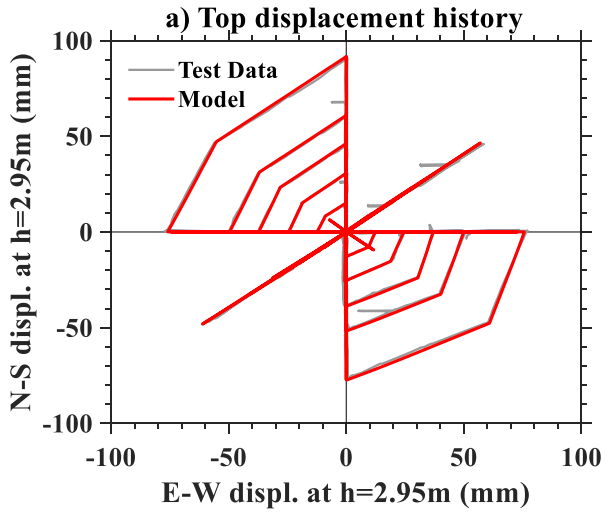


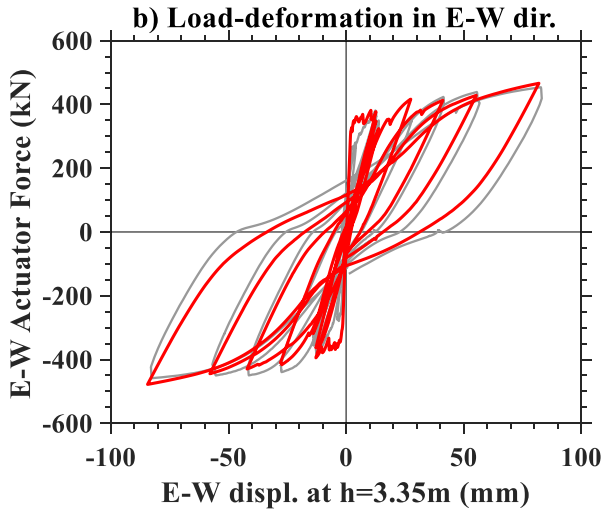


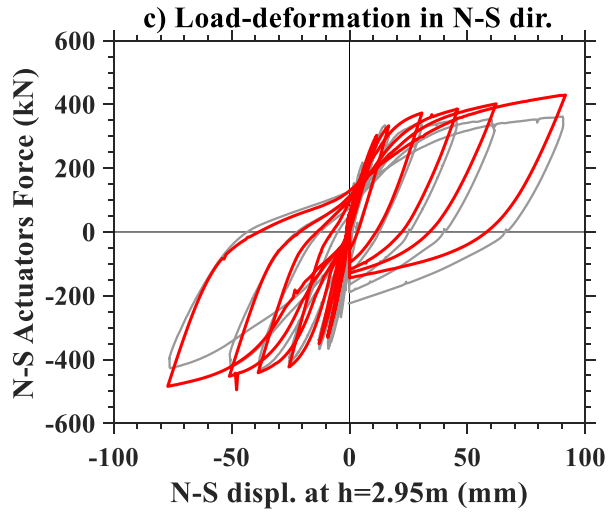
TUB (Beyer et al., 20018)

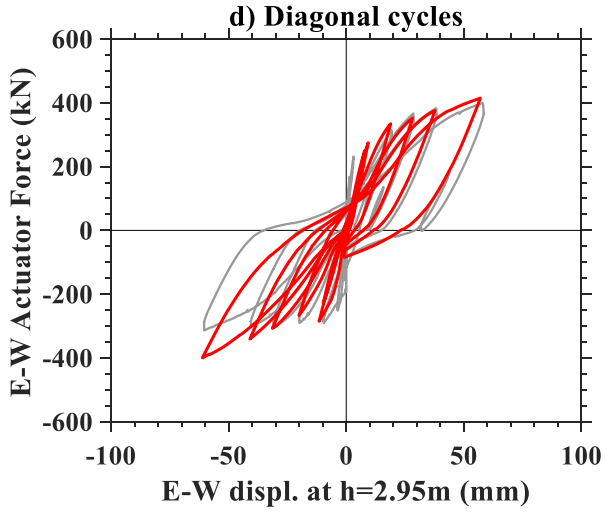
- SFI-MVLEM-3D

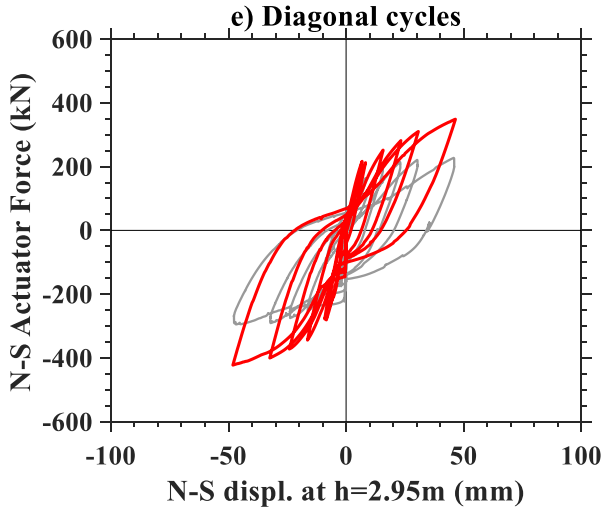


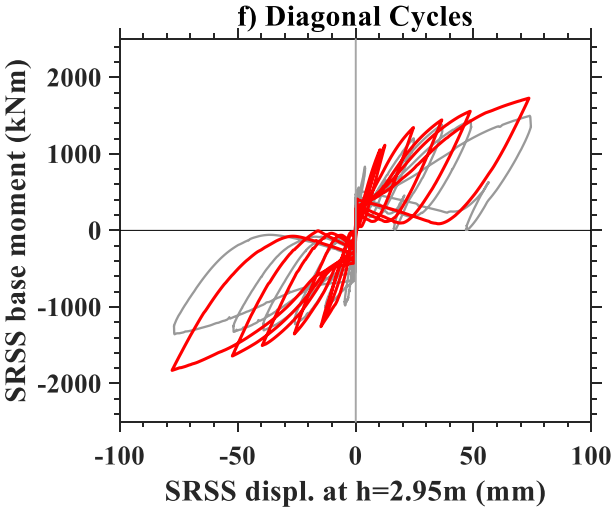










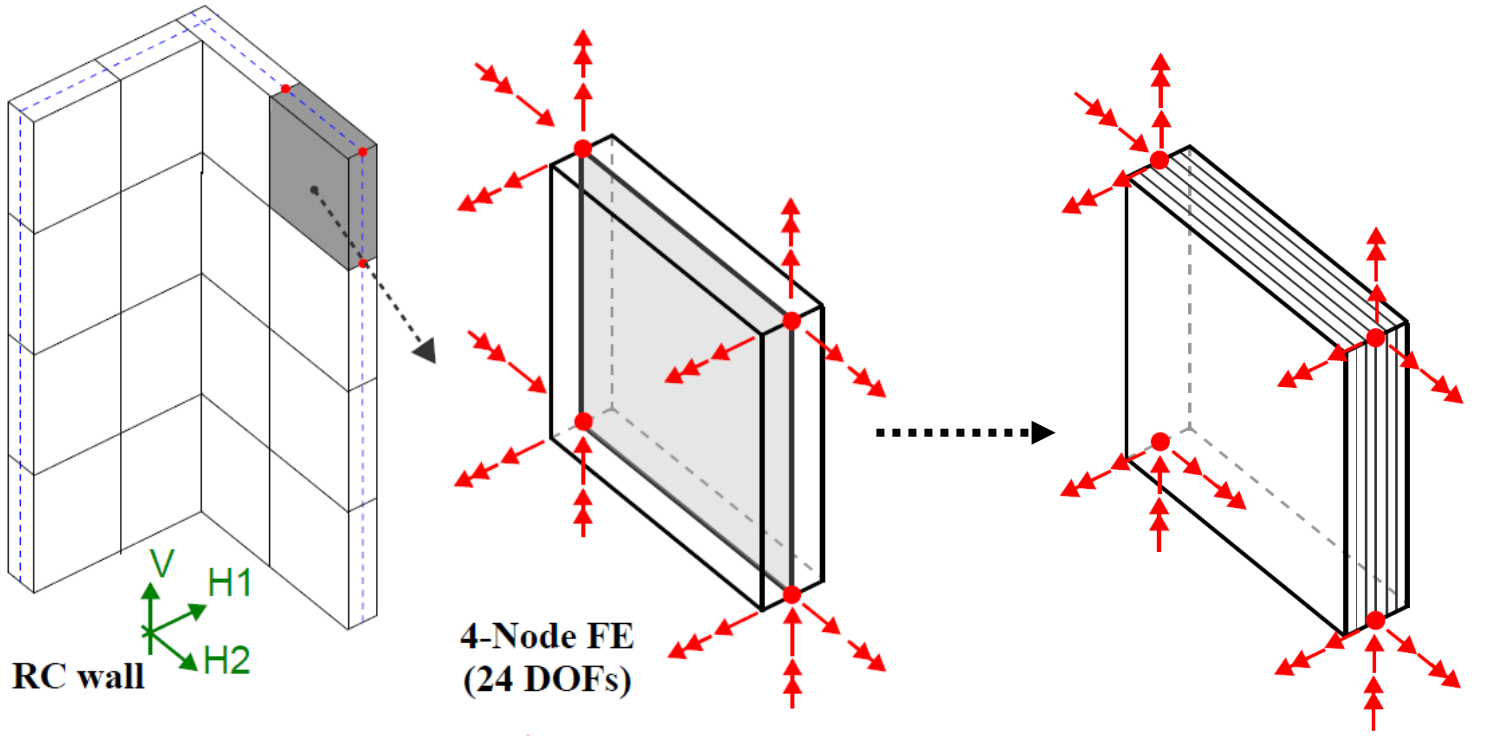


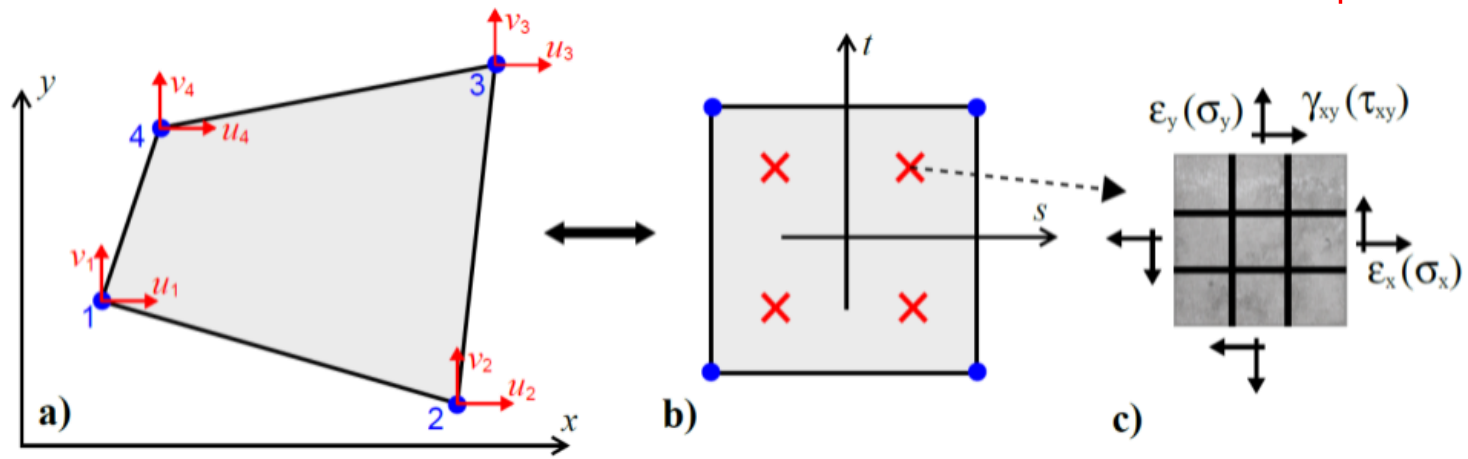
Models Description and Validation

Finite Element Models

Finite Element Models

- 4-Node FE
  - Bilinear
  - FSAM material
- 3D behavior
  - In-Plane
  - Out-of-plane
- Single layer
- Multi layer



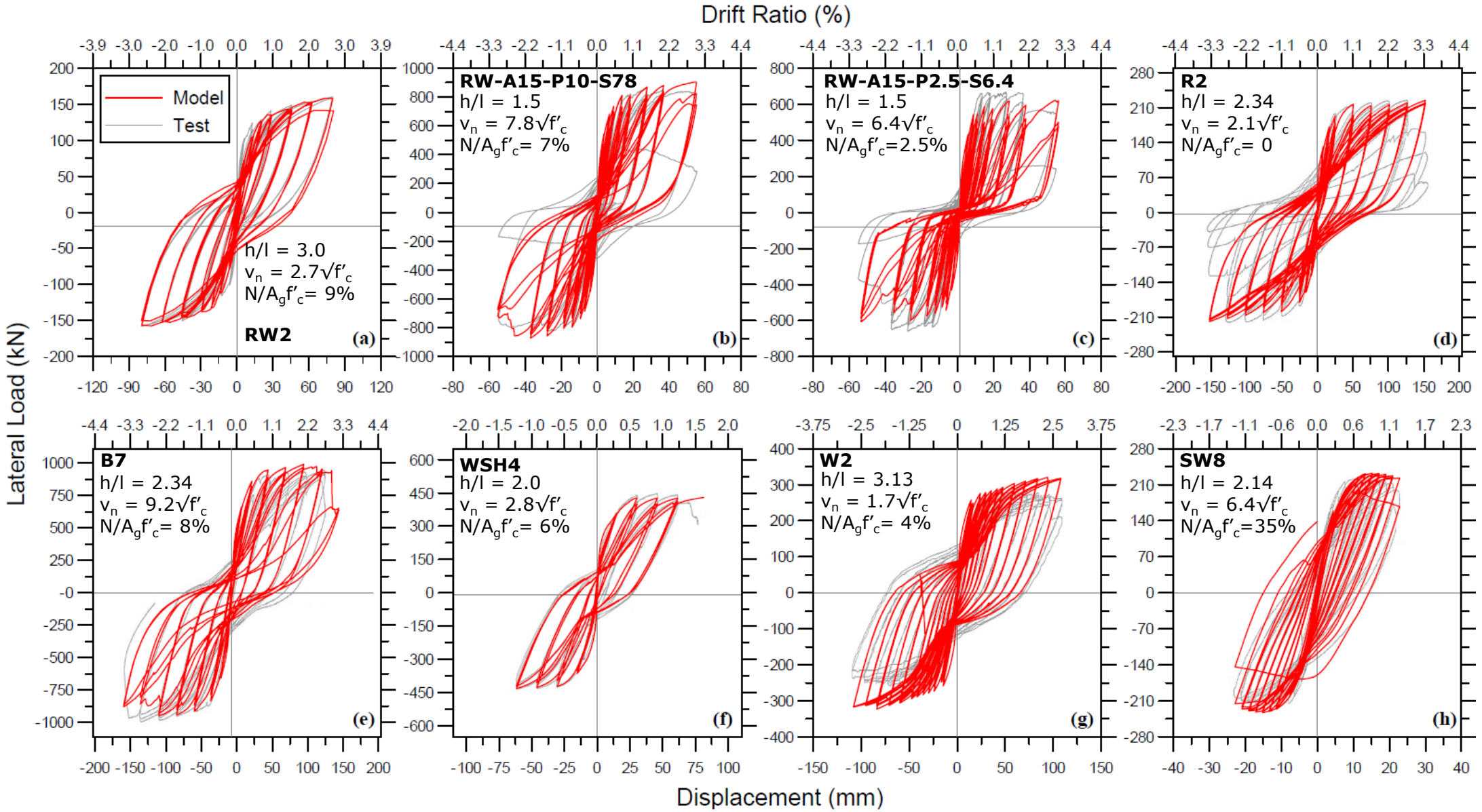


Validation

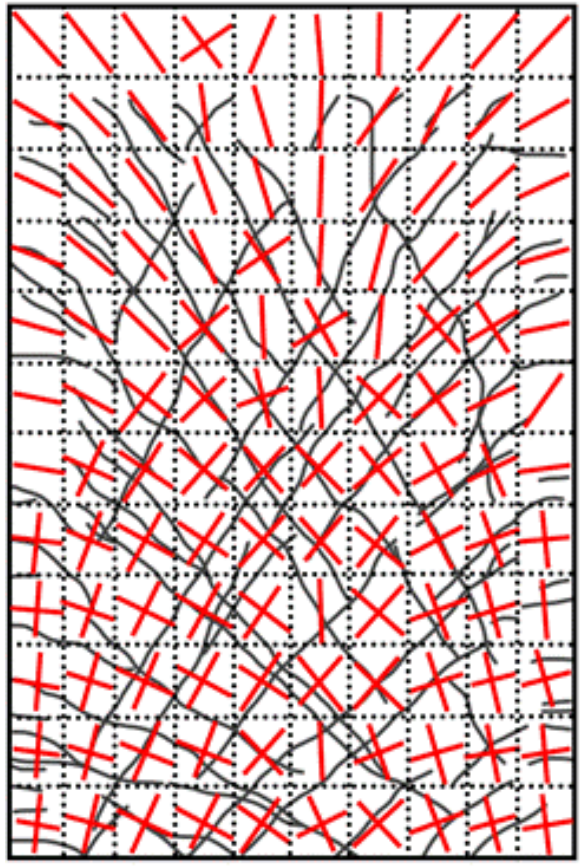
- Planar Walls
- 40 specimens
- 8 experimental programs
- Range of parameters
  - h_w/l_w = 1.50 - 3.13
  - $N/A_g f'_c$ = 0.00 - 0.35
  - $V_{n,psi}$ = 1.1 – 12.3 $\sqrt{f'_c}$
- Failure modes

Spec. No.	Spec. ID	Author	Cross-section	h/l_w	f_{yBE} (MPa)	$\rho_{b,v}$ (%)	$\rho_{w,v}$ (%)	$\rho_{w,h}$ (%)	$M/(Vl_w)$	$P/(A_g f'_c)$	$V_{max}/(A_{cv}\sqrt{f'_c})$ (psi)	Failure Mode [1]
1	RW1	Thomsen and Wallace	R	3.00	434	1.15	0.33	0.33	3.13	0.11	2.6	BR
2	RW2	Thomsen and Wallace	R	3.00	434	1.15	0.33	0.33	3.13	0.09	2.7	CB
3	SP1	Tran and Wallace	R	2.00	472	3.23	0.27	0.27	2.00	0.10	3.8	DT
4	SP2	Tran and Wallace	R	2.00	477	7.11	0.61	0.61	2.00	0.10	6.3	CB
5	SP3	Tran and Wallace	R	1.50	472	3.23	0.32	0.32	1.50	0.10	5.1	CB
6	SP4	Tran and Wallace	R	1.50	477	6.06	0.73	0.73	1.50	0.10	7.8	DC
7	SP5	Tran and Wallace	R	1.50	477	6.06	0.61	0.61	1.50	0.03	6.4	DC
8	R1	Oesterle et al	R	2.34	512	1.47	0.25	0.31	2.40	0.00	1.1	BR
9	R2	Oesterle et al	R	2.34	450	4.00	0.25	0.31	2.40	0.00	2.1	BR
10	B1	Oesterle et al	B	2.34	449.5	1.11	0.29	0.31	2.40	0.00	2.4	R
11	B2	Oesterle et al	B	2.34	410.2	3.67	0.29	0.63	2.40	0.00	6.0	BR
12	B3	Oesterle et al	B	2.34	437.8	1.11	0.29	0.31	2.40	0.00	2.6	BR
13	B4	Oesterle et al	B	2.34	450.2	1.11	0.29	0.31	2.40	0.00	2.8	CB
14	B5	Oesterle et al	B	2.34	444.0	3.67	0.29	0.63	2.40	0.00	7.1	BR
15	B6	Oesterle et al	B	2.34	441	3.67	0.29	0.63	2.40	0.13	12.9	CB
16	B7	Oesterle et al	B	2.34	458	3.67	0.29	0.63	2.40	0.08	9.2	R
17	B8	Oesterle et al	B	2.34	447	3.67	0.29	1.38	2.40	0.09	10.1	BR
18	B9	Oesterle et al	B	2.34	430	3.67	0.29	0.63	2.40	0.09	9.7	BR
19	B10	Oesterle et al	B	2.34	447	1.97	0.29	0.42	2.40	0.09	7.2	CB
20	F1	Oesterle et al	F	2.34	444.7	3.89	0.30	0.71	2.40	0.00	8.4	BR
21	F2	Oesterle et al	F	2.34	430	4.35	0.31	0.63	2.40	0.07	9.2	CB
22	WSH1	Dazio et al	R	2.02	548	1.32	0.30	0.25	2.28	0.06	2.0	R
23	WSH2	Dazio et al	R	2.02	583	1.32	0.30	0.25	2.28	0.06	2.3	BR
24	WSH3	Dazio et al	R	2.02	601	1.54	0.54	0.25	2.28	0.06	2.9	BR
25	WSH4	Dazio et al	R	2.02	576	1.54	0.54	0.25	2.28	0.06	2.8	CB
26	WSH5	Dazio et al	R	2.02	584	0.67	0.27	0.25	2.28	0.14	2.8	BR
27	WSH6	Dazio et al	R	2.02	576	1.54	0.54	0.25	2.26	0.11	3.6	CB
28	W1	Liu	R	3.13	458	1.24	0.54	0.40	3.13	0.08	2.3	CB
29	W2	Liu	R	3.13	458	1.24	0.27	0.47	3.13	0.04	1.7	BR
30	W3	Tupper	R	3.13	458	1.24	0.54	0.40	3.13	0.08	2.3	CB
31	SW4	Pilakoutas and Elnashai	R	2.00	500	6.30	0.79	0.39	2.00	0.00	5.1	CB
32	SW5	Pilakoutas and Elnashai	R	2.00	530	9.60	0.79	0.35	2.00	0.00	5.0	DC
33	SW6	Pilakoutas and Elnashai	R	2.00	500	6.30	0.79	0.35	2.00	0.00	4.7	DC
34	SW7	Pilakoutas and Elnashai	R	2.00	530	9.60	0.79	0.39	2.00	0.00	6.6	BR
35	SW8	Pilakoutas and Elnashai	R	2.00	530	6.50	0.79	0.42	2.00	0.00	5.0	BR
36	SW9	Pilakoutas and Elnashai	R	2.00	530	6.50	0.79	0.60	2.00	0.00	6.6	CB
37	SW7	Zhang and Wang	R	2.14	305	0.88	0.67	1.01	1.80	0.24	6.0	BR
38	SW8	Zhang and Wang	R	2.14	305	0.65	0.67	1.01	1.80	0.35	6.4	CB
39	SW9	Zhang and Wang	R	2.14	305	1.80	0.67	1.01	1.80	0.24	8.3	CB
40	SRCW12	Zhang and Wang	R	2.14	305	1.53	0.67	1.01	1.80	0.35	8.2	CB

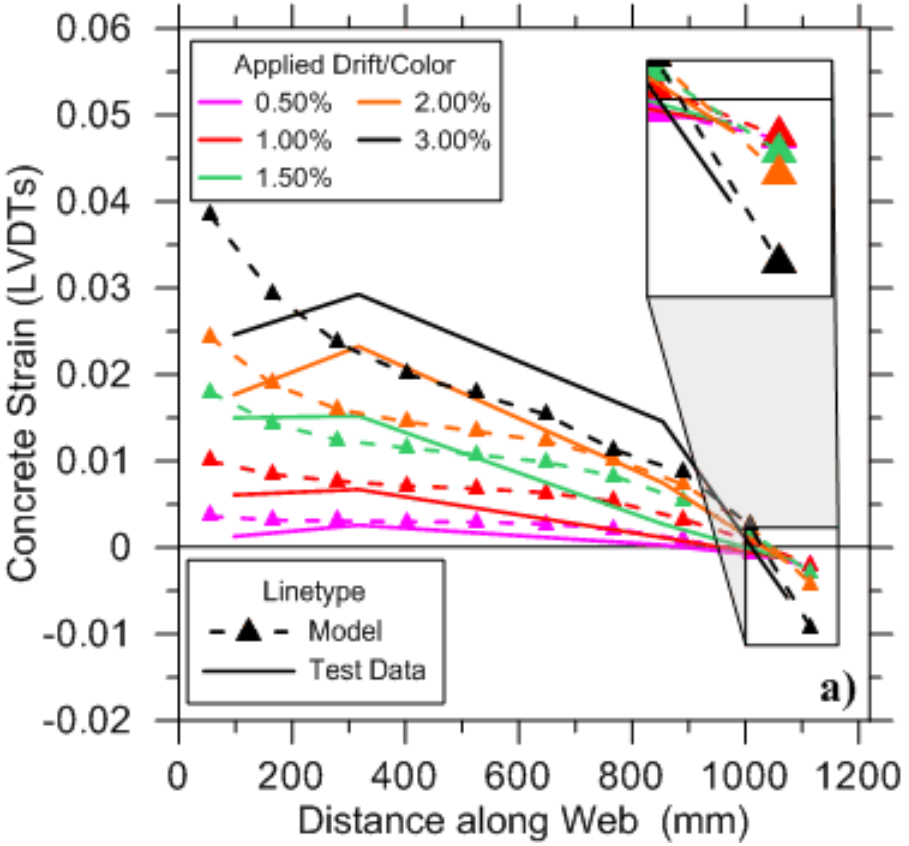
Validation: Planar Walls



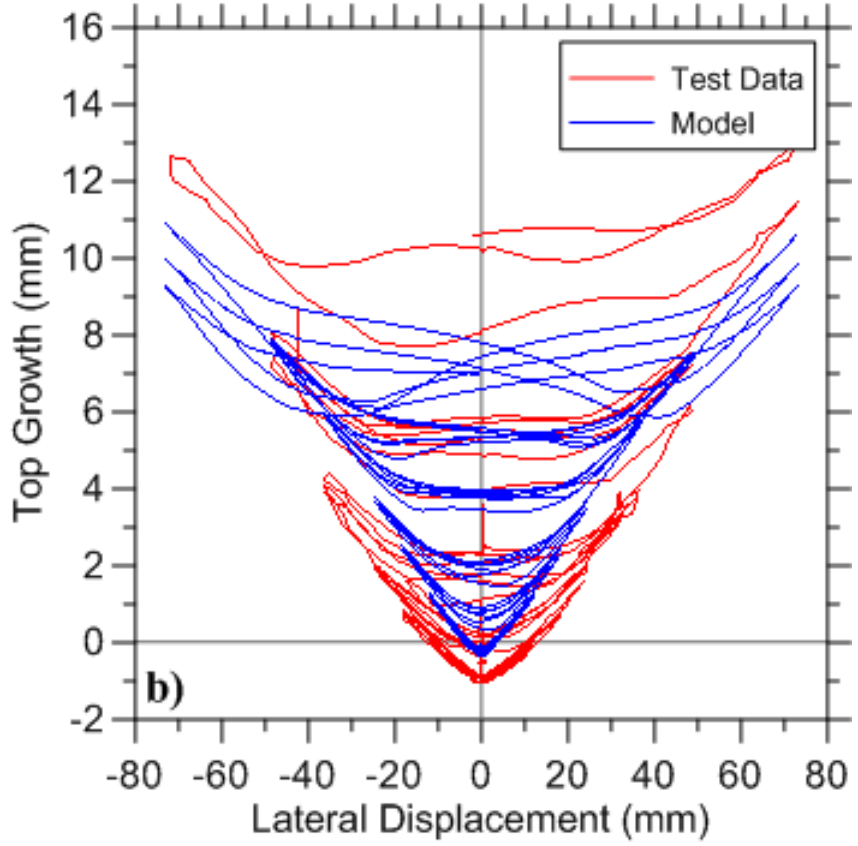
Validation: Planar Walls



Cracking Pattern



Vertical Strain Profiles at Wall Base



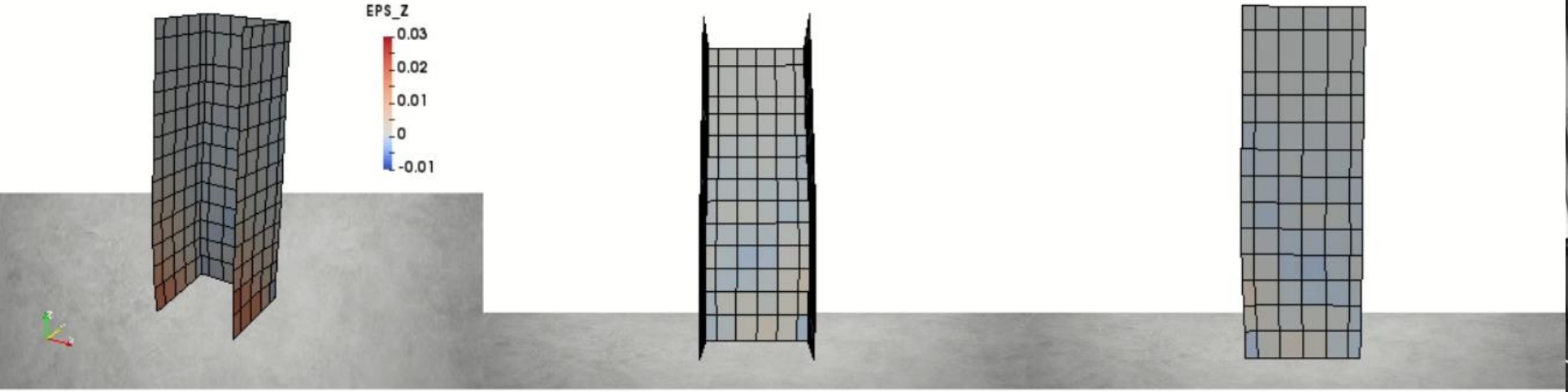
Axial Growth at Wall Top

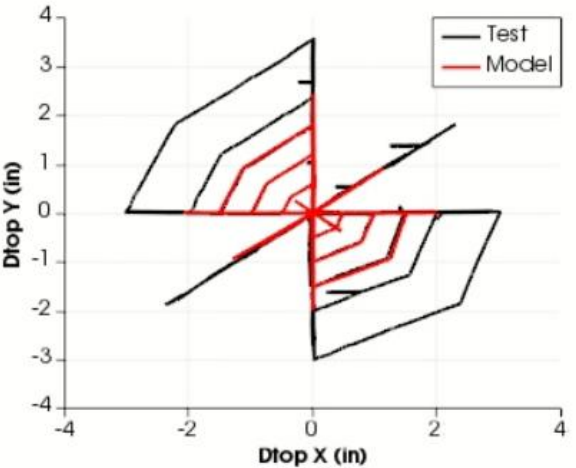
3D Models for RC Walls

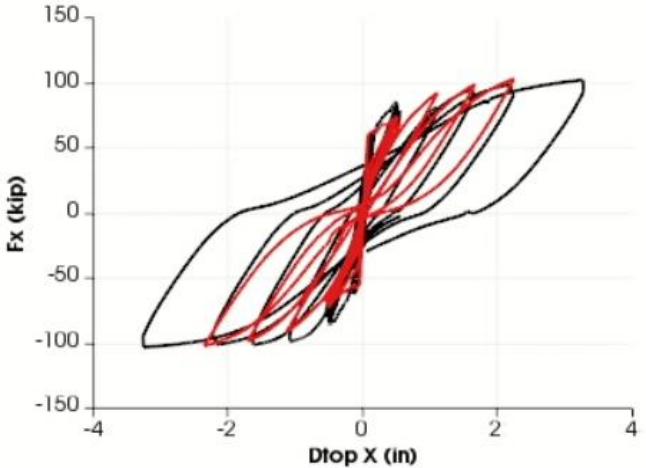
- Validation
  - Nonplanar walls under biaxial loading

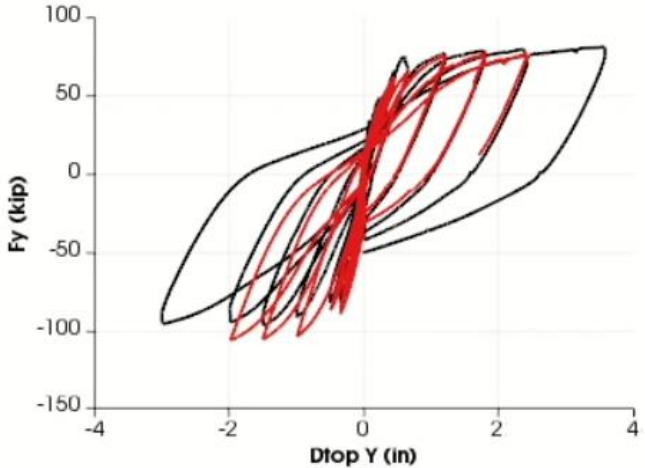
Beyer et al. (2008)

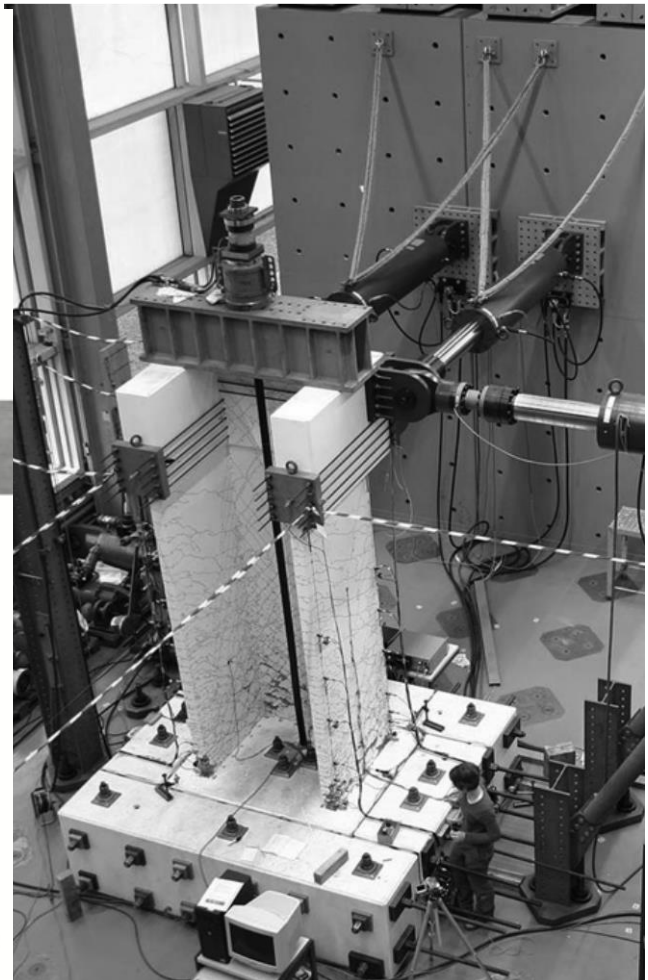
Constantin (2013)





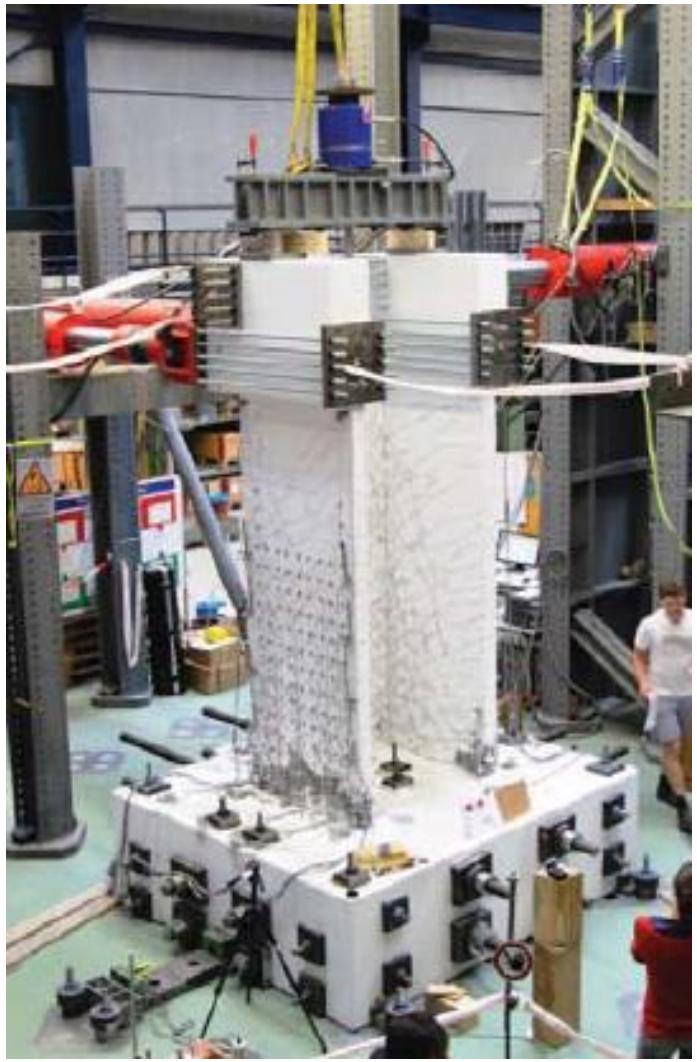


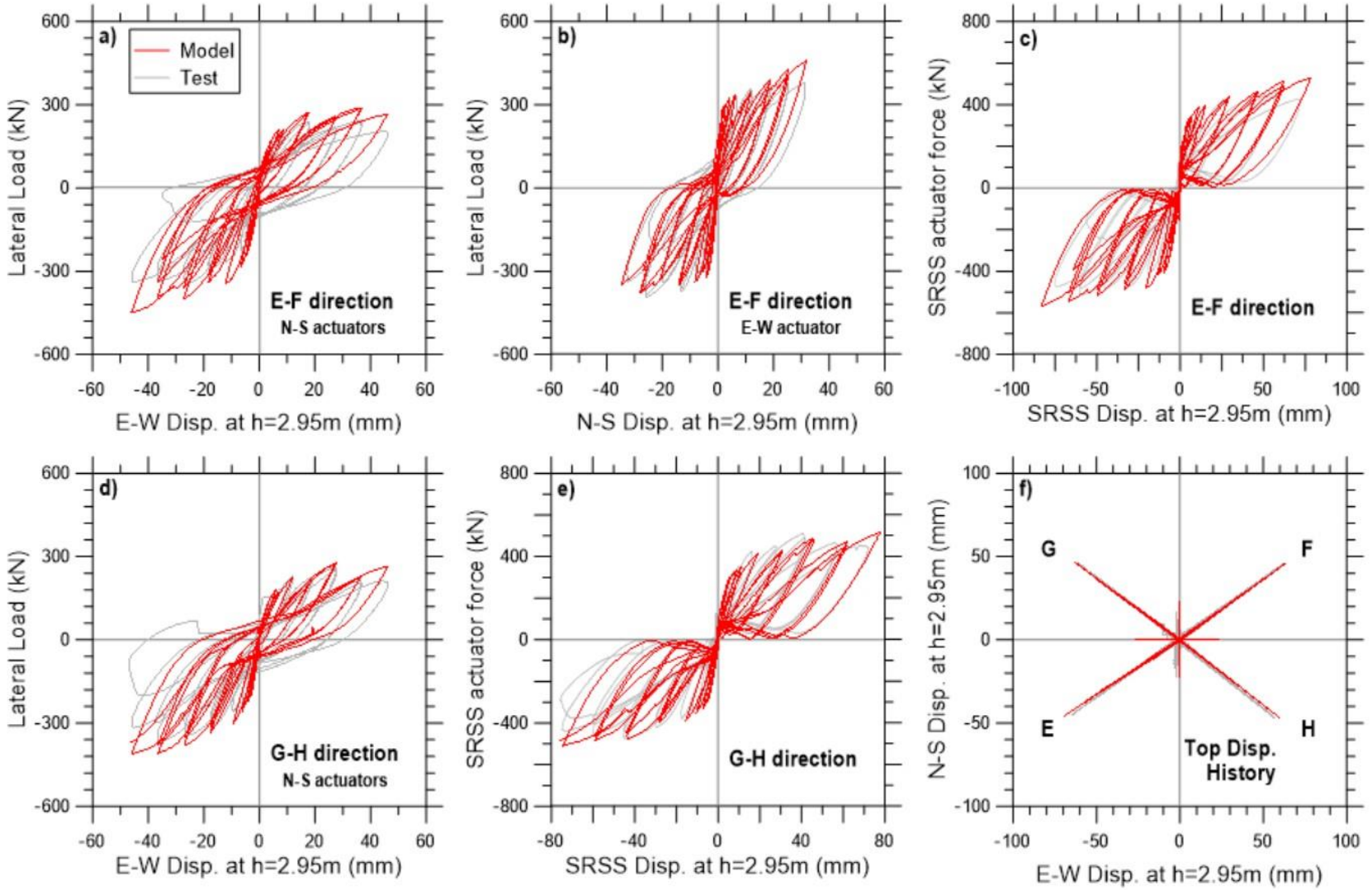




3D Models for RC Walls

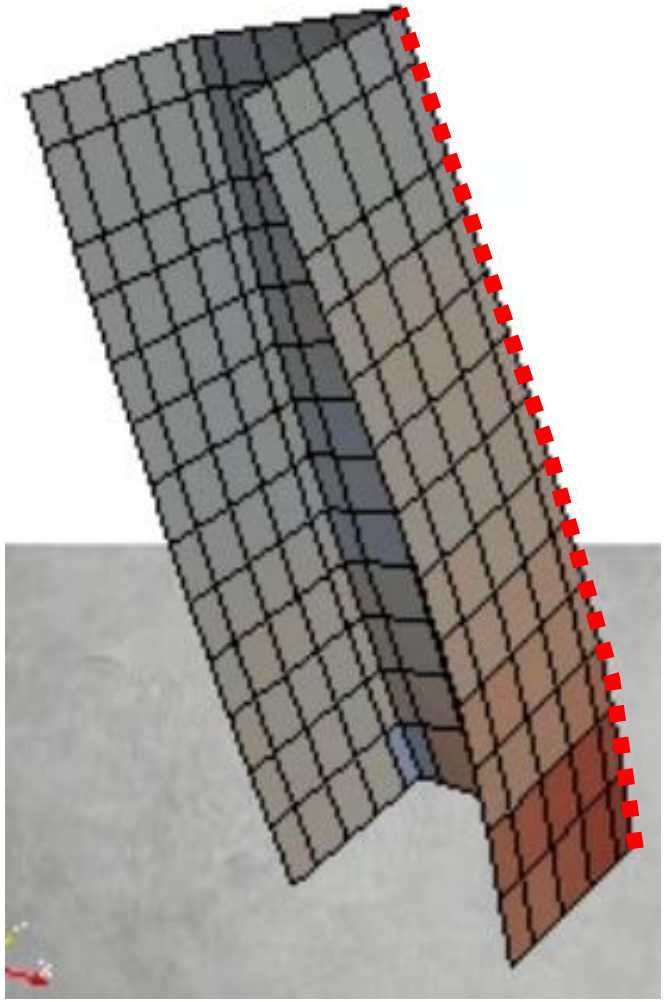
- TUC (Constantin, 2016)

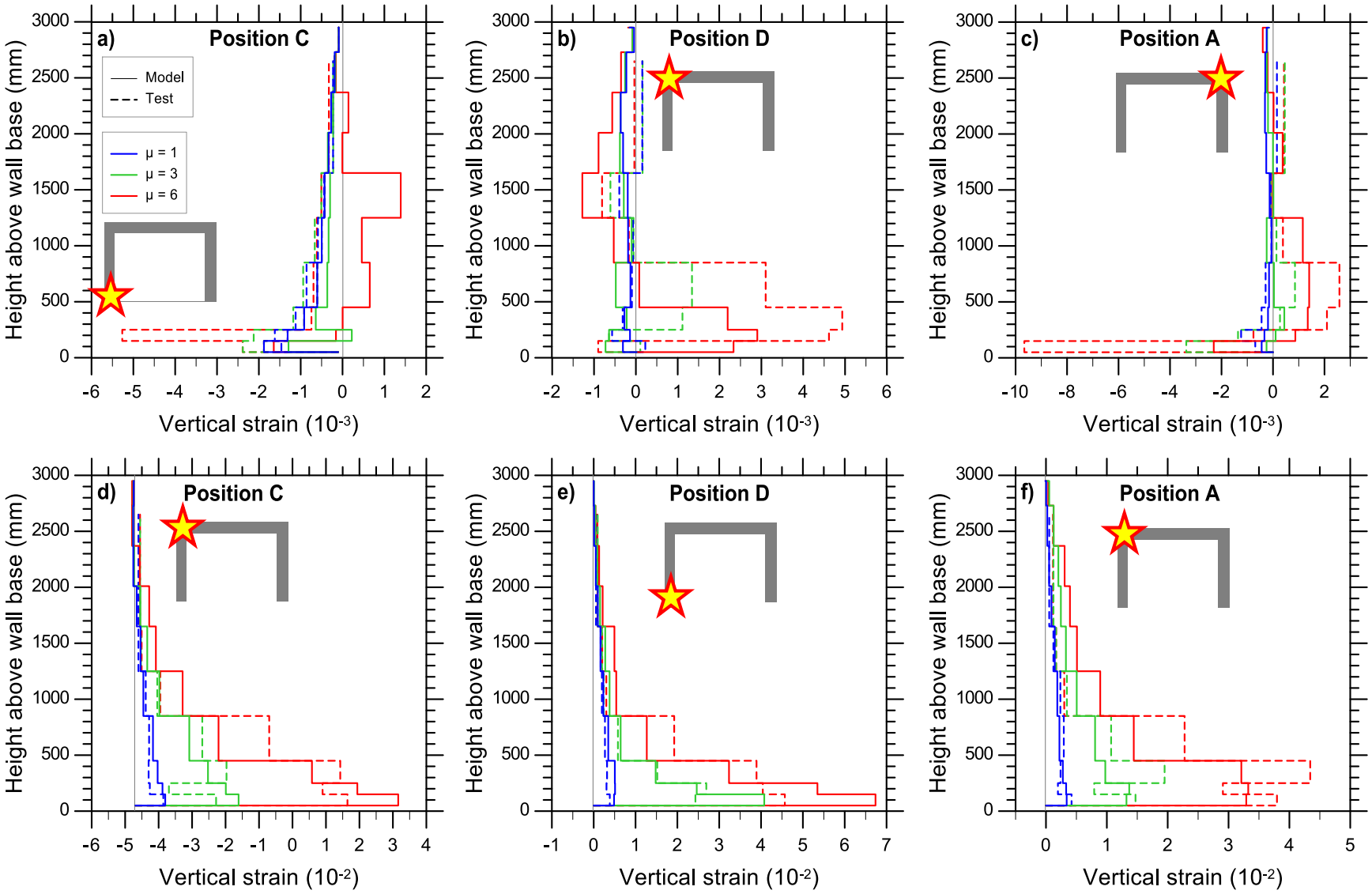




3D Models for RC Walls

- Validation





Development & Validation

- New 3D OpenSees Models for RC Walls
  - MVLEM_3D
  - SFI_MVLEM_3D
  - quadWall

  Macro models

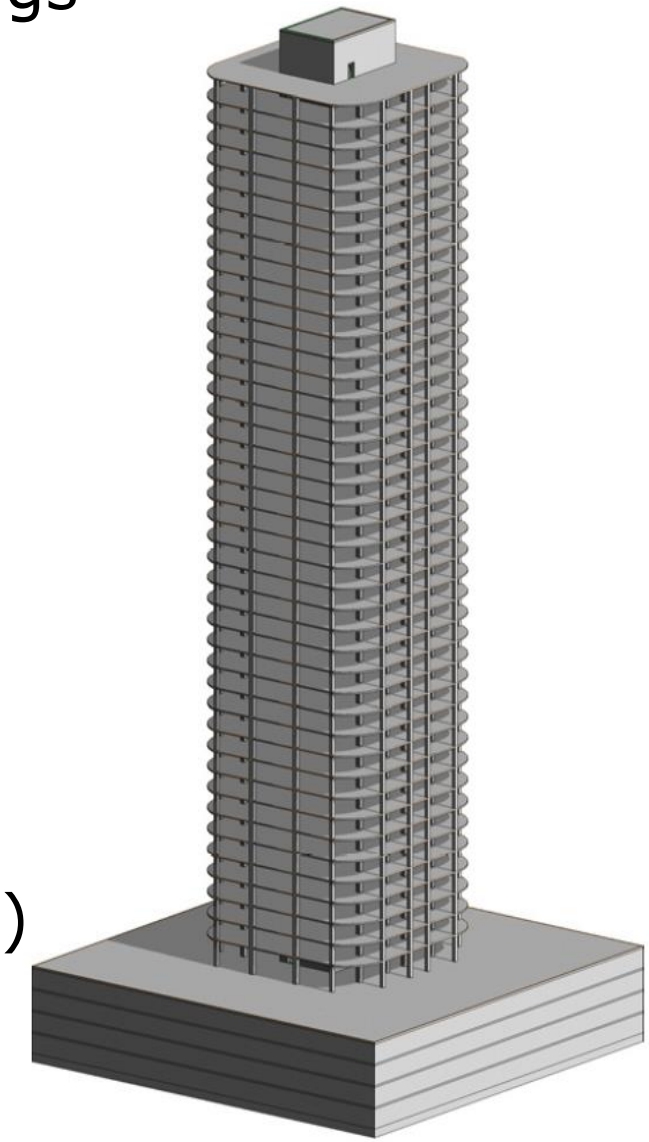
  FE model
- Validation
  - Planar wall subjected to uni-directional loading
  - Nonplanar walls subjected to multi-directional loading
  - Reasonable prediction of global and local responses
- Implementation and public release in 2019
  - Wiki Pages
  - Examples

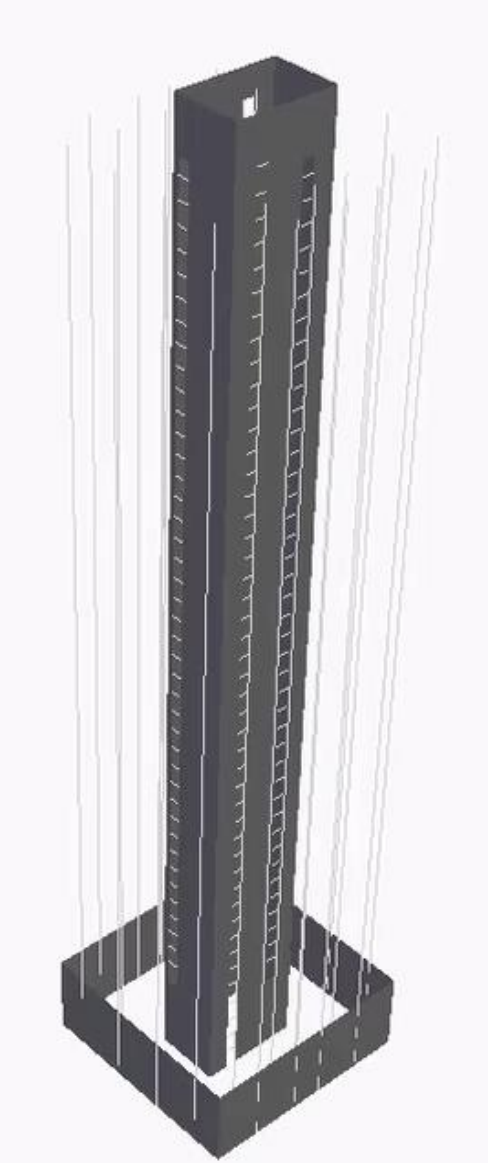
Related Ongoing Work

Resilient-Based Design of Tall Buildings

- Analysis of tall RC core wall buildings using new OpenSees model
- Assessment of structural and nonstructural components
- Loss and downtime estimation
- Varying design parameters to find optimal design solution
- Applications of new materials and technology
- Collaboration Vesna Terzic (CSULB)

CMMI: 1563428 & 1563577





System-Level Analysis

- System-level behavior
- Component interactions
- 3D System Tests
  - E-Defense tests:
    - 4-story (2011)
    - 10-story (2015, 2019)
  - IZIIS tests:
    - 3-story coupled walls (2019)

Acknowledgements

- CSUF Students
  - Carlos Garcia
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