Analysis of Case Study Buildings

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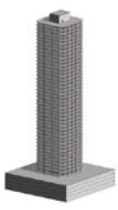
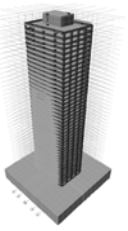
Building Systems

Three Building Systems

42-story Reinforced Concrete Core Wall	42-story Reinforced Concrete Dual System	40-story Buckling-restrained Braced Frame





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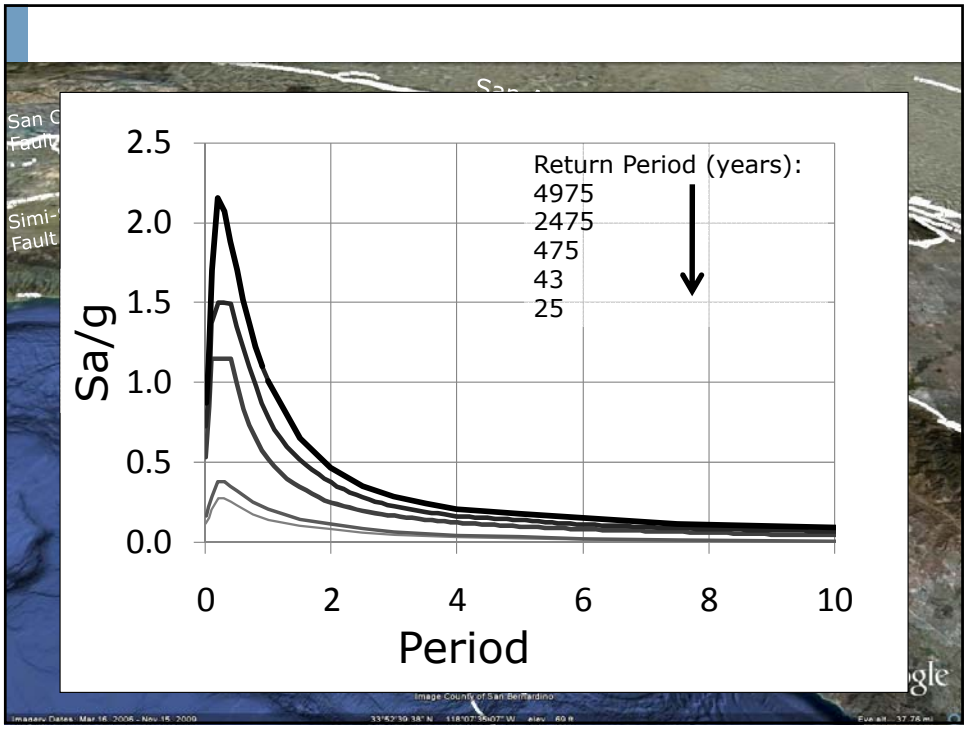


Process and Discussion

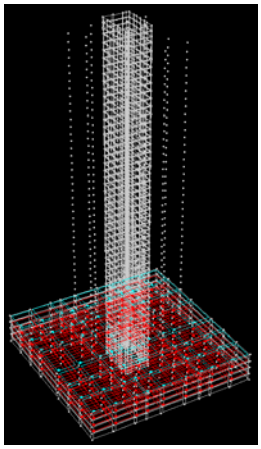
- Modeling
  - General considerations
  - System specific
- Analysis results
  - Drift ratios & Accelerations
  - Shear & Moment
  - Localized Demands (strain and rotations)
- Sensitivity
  - Ground motions
  - Material Properties

Modeling – General considerations

- 3-D nonlinear models
  - Perform 3D [practice oriented program]
  - Lateral force resisting system only
  - Soil-structure interaction is neglected
  - P-Delta effects are included
- 2.5% viscous Rayleigh damping
  - $0.2T_1$ & $1.5T_1$

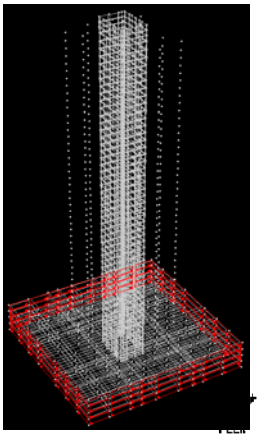
Modeling – General considerations

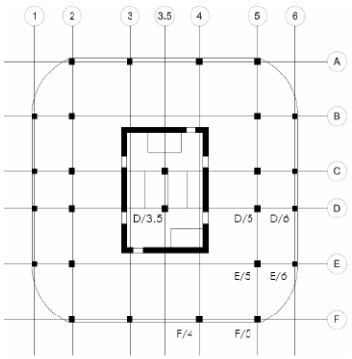
Podium Level Slabs & Basement Walls



Slabs below grade were modeled using elastic shear shell element ($E_{eff} = 0.25E_c$)

Basement walls below grade were modeled using elastic shear wall elements ($E_{eff} = 0.8E_c$)





42-story reinforced concrete core wall

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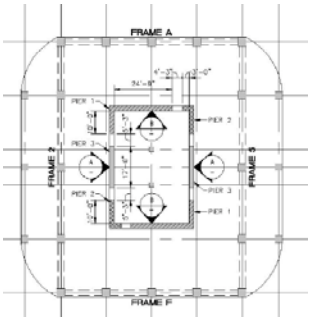
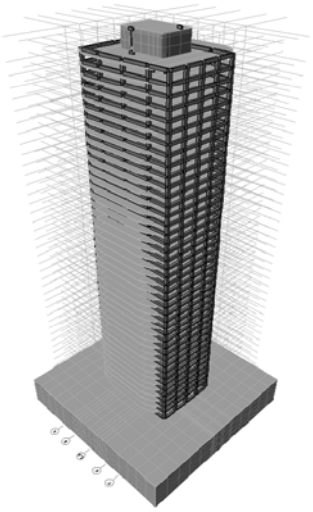


42-story reinforced concrete dual system



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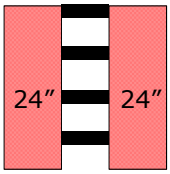
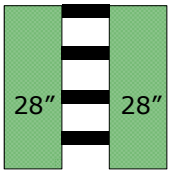
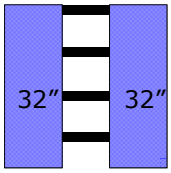
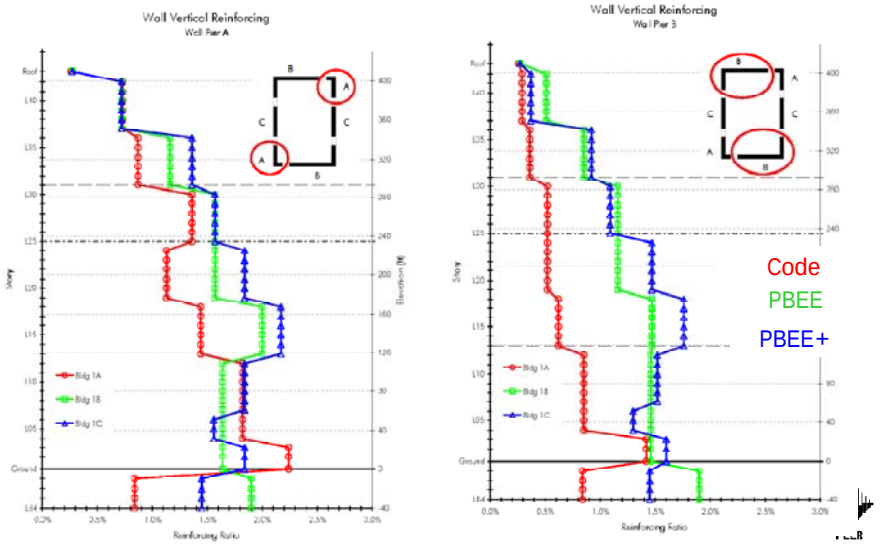
Modeling – Core Wall Structure

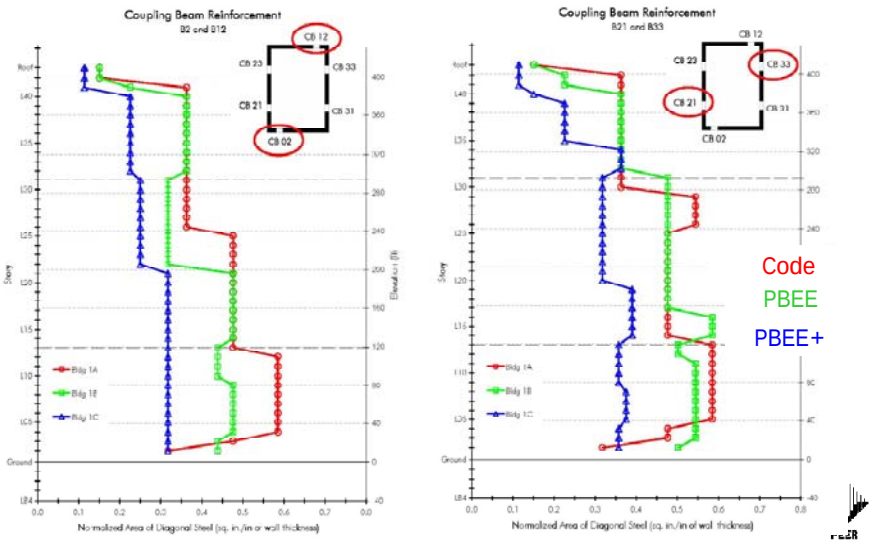
Design Summary

	1A: Code	1B: PBEE	1C: PBEE+
			
Wall:	Strong	Stronger	Strongest
Coupling beam:	Stronger	Stronger	Strong
1st mode Period:	T_{1EW} = 5.2 sec T_{1NS} = 4.0 sec	T_{1EW} = 4.8 sec T_{1NS} = 3.6 sec	T_{1EW} = 4.6 sec T_{1NS} = 3.5 sec

Core Wall – Wall Vert. Reinforce.

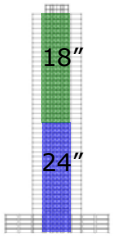
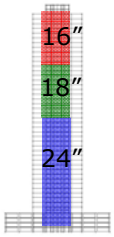


Core Wall – CB Reinforcement



Modeling – Dual System

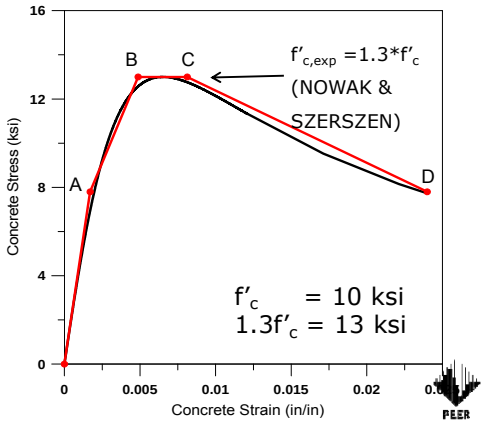
Design Summary

	2A: Code	2B: PBEE 1C: PBEE+
	 Columns: 36 X 36; 42 X 42; 46 X 46	 Columns: 36 X 36; 42 X 42; 46 X 46
Wall:	Strongest	Strong
Coupling beam:	Strong	Strong
1st mode Period:	T_{1EW} = 4.5 sec T_{1NS} = 4.0 sec	T_{1EW} = 4.3 sec T_{1NS} = 3.9sec

Modeling – Core Wall

Concrete stress-strain relationship
(Mander et al., 1988)

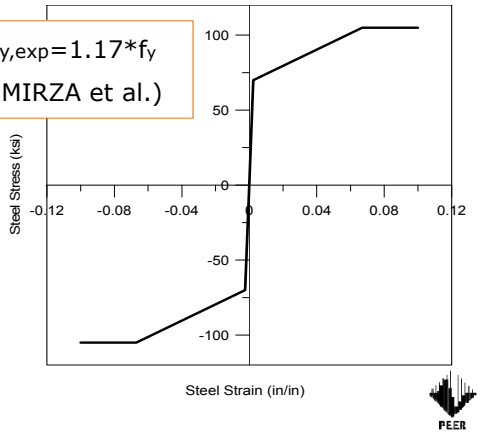
- A: ($0.6f_{cc}/E_c$, $0.6f_{cc}$)
- B: ($0.75\varepsilon_{cc}$, f_{cc})
- C: ($1.25\varepsilon_{cc}$, f_{cc})
- D: (0.024, $0.6f_{cc}$)



Modeling – Core Wall

Steel stress-strain relationship

- A706 steel
- f_y= 1.17(60) = 70 ksi
- f_u= 105 ksi
- Post-yield stiffness and cyclic degradation by Orakcal et al. (2006)



Modeling – Core Wall

Shear stress-strain relationship

$$v_{\exp} = 1.5 v_n = 1.5\left(\alpha_c \sqrt{f'_c} + \rho_t f_y\right) \text{ ACI 318-08 §21.9.4.1}$$

$f_c' \le 6000$ psi

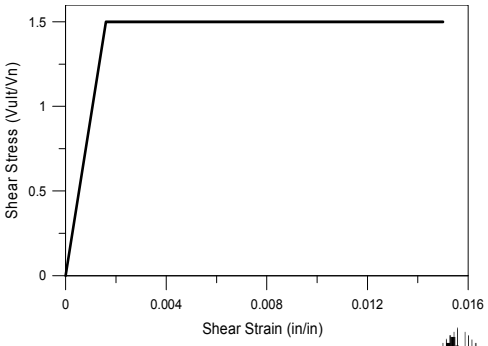
$E_c = 57,000\sqrt{f_c'}$ psi

$f_c' > 6000$ psi

$E_c = 40,000\sqrt{f_c'} + 1.0E6$ psi

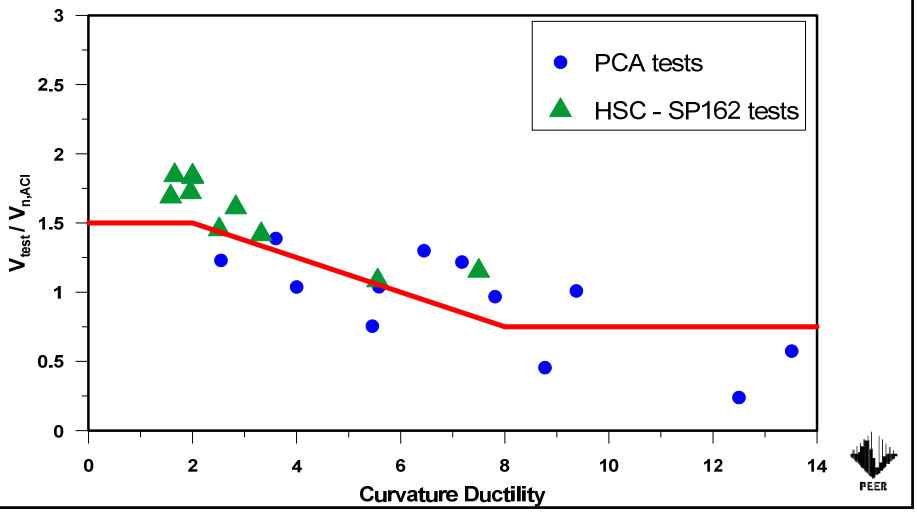
ACI Committee 363

$G_c = 0.2E_c$



Modeling – Core Wall

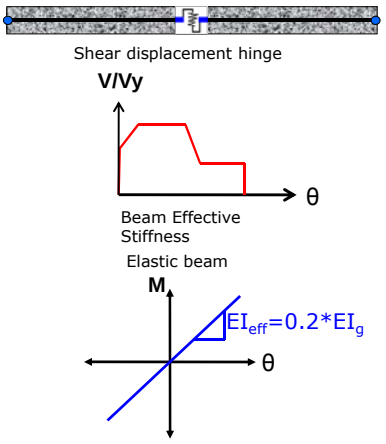
Shear Capacity (Test results)

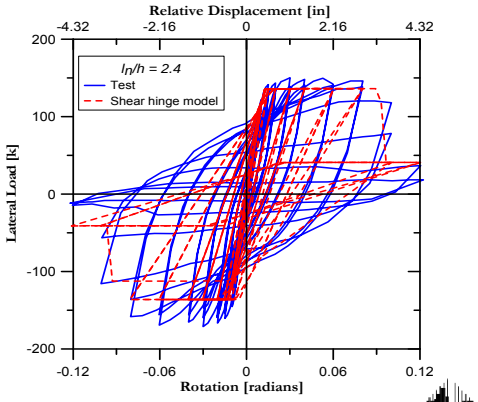


Modeling – Core Wall

Link Beam

Elastic beam + Nonlinear displacement shear hinge



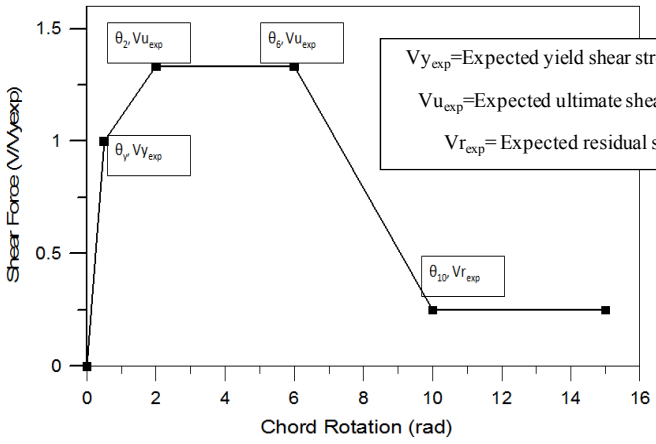


(Naish et al.)

Modeling – Core Wall

Link Beam

Elastic beam + Nonlinear displacement shear hinge

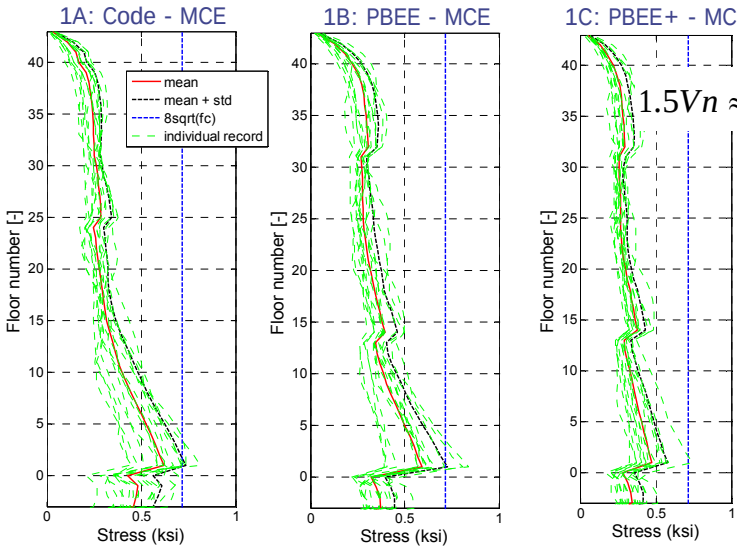


Vy_{exp}=Expected yield shear strength ($2*As*fy_{exp}*\sin(\alpha)$)

Vu_{exp}=Expected ultimate shear strength ($1.33*Vy_{exp}$)

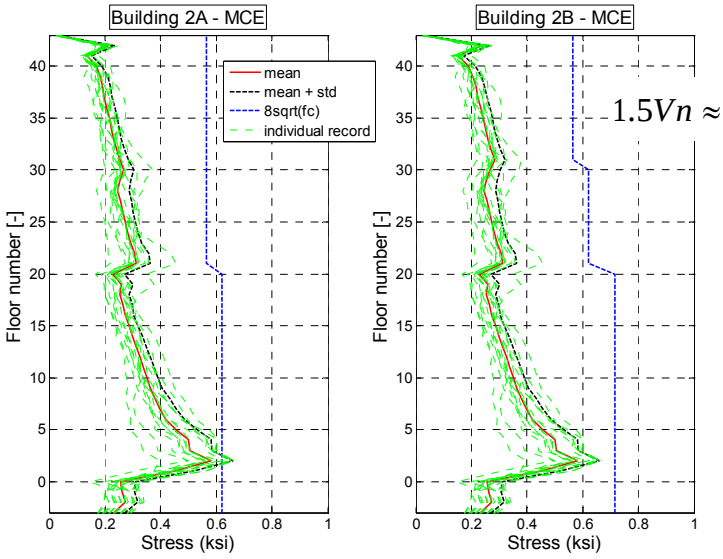
Vr_{exp}= Expected residual strength ($0.25*V_{uexp}$)

Core Wall - Wall Shear Stress



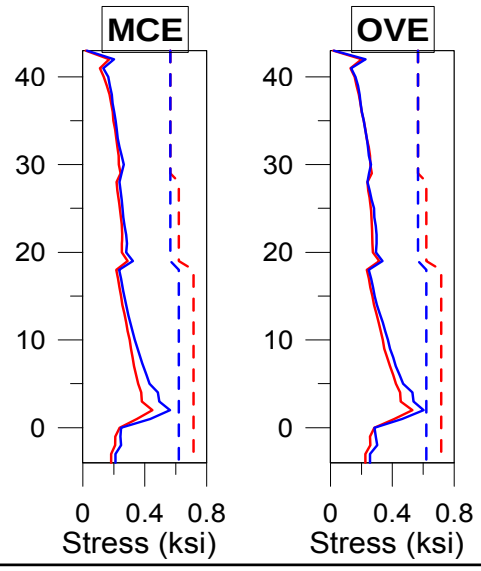
$$1.5Vn \approx 8\sqrt{f'_c}$$

Dual System - Wall Shear Stress



$$1.5Vn \approx 8\sqrt{f'_c}$$

Dual System - Wall Shear v_n

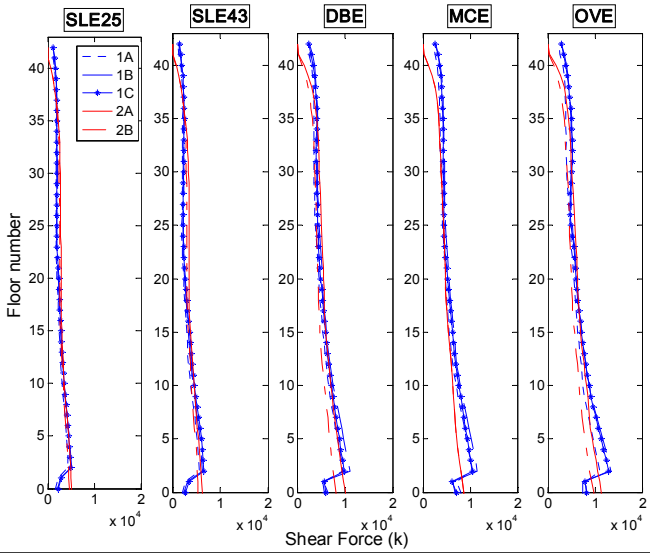


2A: Code
2B/2C: PBEE

$$1.5Vn \approx 8\sqrt{f'_c}$$

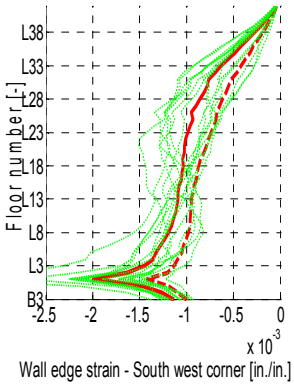
2A/Code
Shear Failure
OVE (1%/50yr)

Core Wall (1) vs Dual System (2)



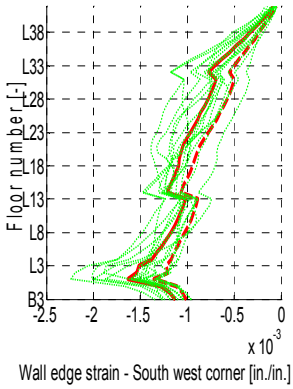
Core Wall – Wall Strains ε_c

1A: Code



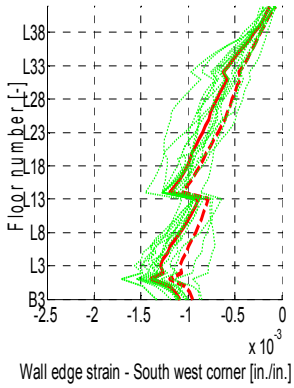
ε_c = 0.0014/0.002

1B: PBEE



ε_c = 0.0013/0.0016

1C: PBEE+

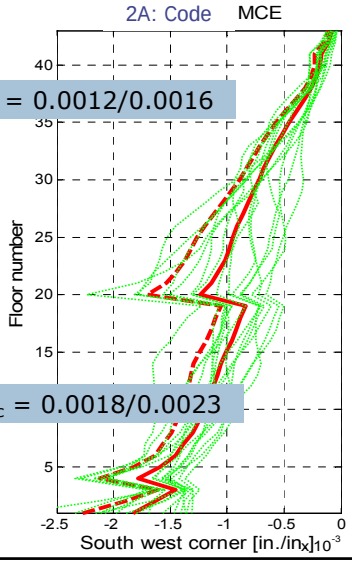


ε_c = 0.0012/0.0014

Wall concrete compressive strain x 2; Wallace, SDTB (2007)
PEER/ATC -72 Report: Modeling & Acceptance Criteria

Dual System – Wall Strains ε_c

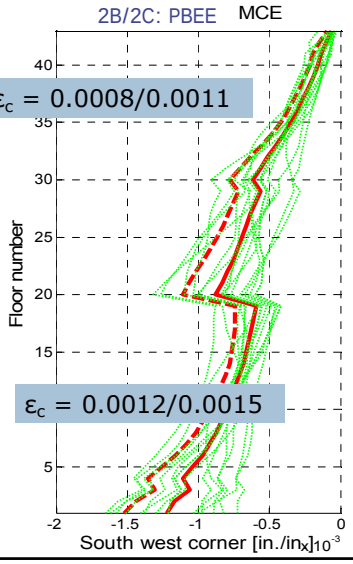
2A: Code MCE



ε_c = 0.0012/0.0016

ε_c = 0.0018/0.0023

2B/2C: PBEE MCE

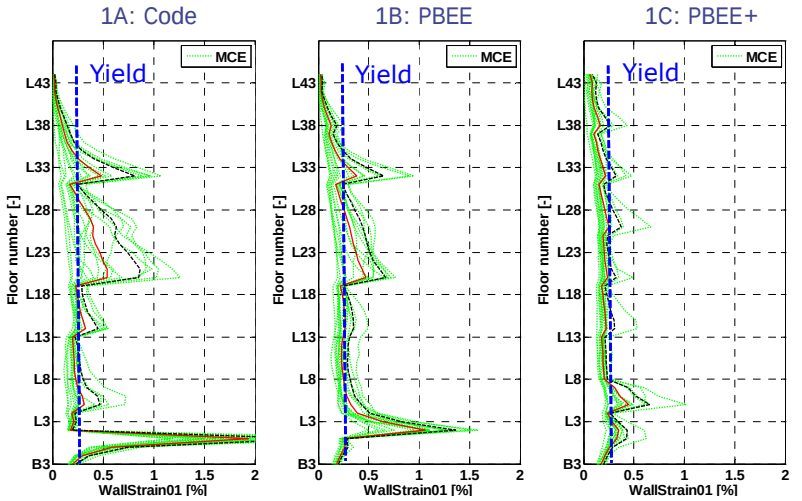


ε_c = 0.0008/0.0011

ε_c = 0.0012/0.0015

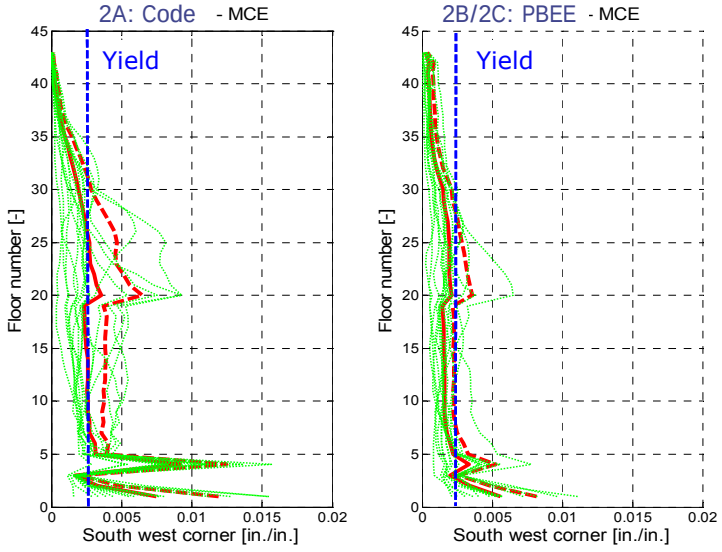
x2

Core Wall – Wall Strains ε_t

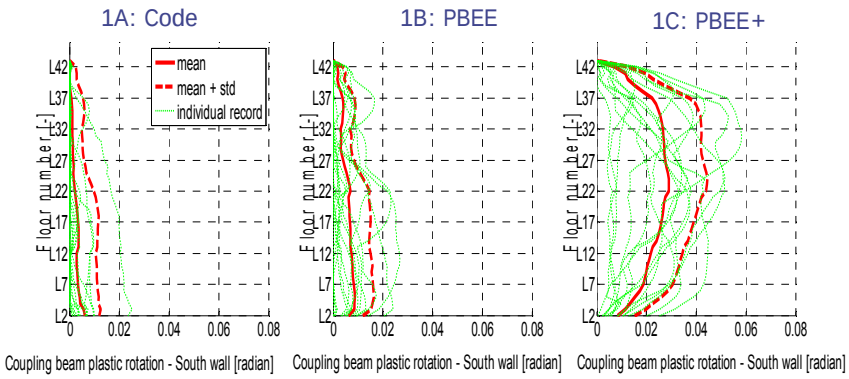


$\varepsilon_{t,max}$ = 0.02 $\varepsilon_{t,max}$ = 0.01 $\varepsilon_{t,max}$ = 0.004

Dual System – Wall Strains ε_t



Core Wall – CB Rotations θ_{cb}



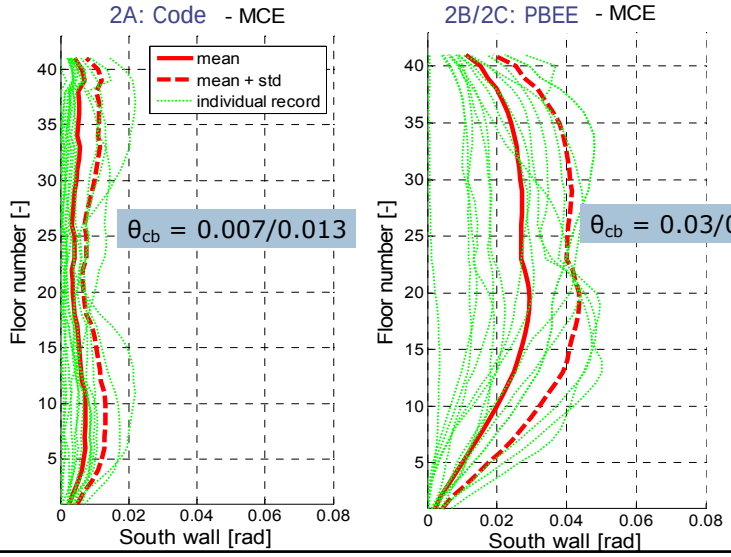
θ_{cb} = 0.008/0.013

θ_{cb} = 0.009/0.017

θ_{cb} = 0.028/0.043

Coupling beam plastic rotations

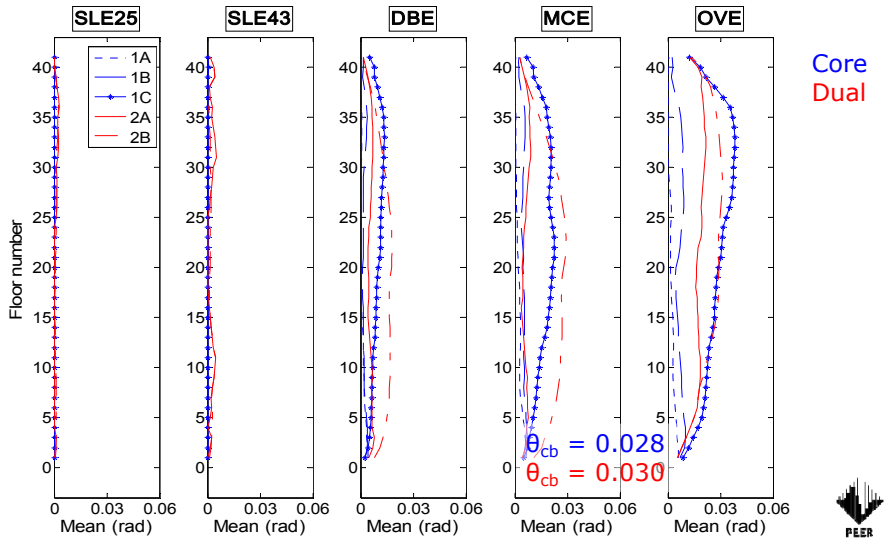
Dual System – CB Rotations θ_{cb}



θ_{cb} = 0.007/0.013

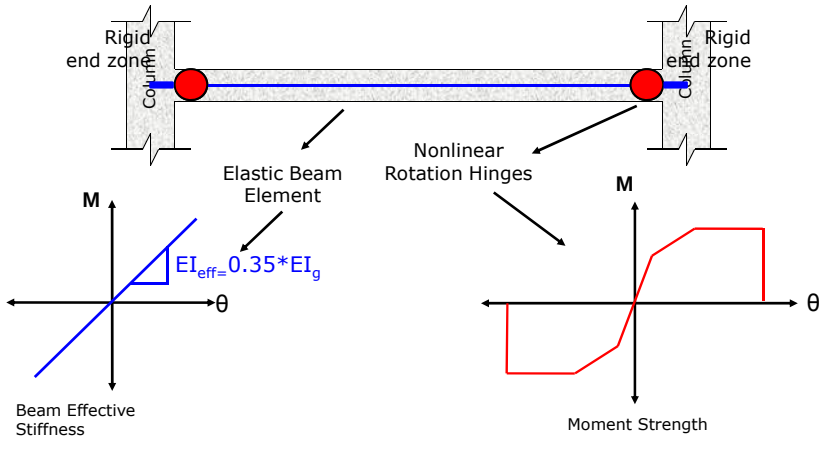
θ_{cb} = 0.03/0.042

Core Wall (1) vs Dual System (2)



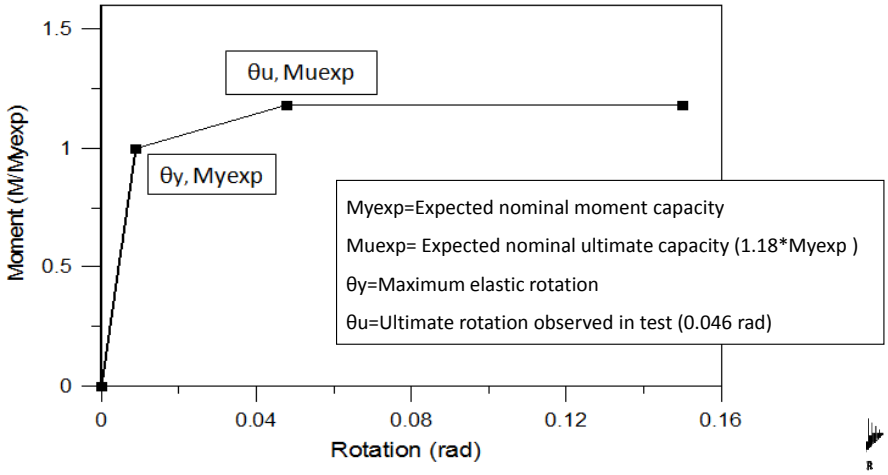
Modeling – Dual System

SMF Beam



Modeling – Dual System

SMF Beam



Myexp=Expected nominal moment capacity

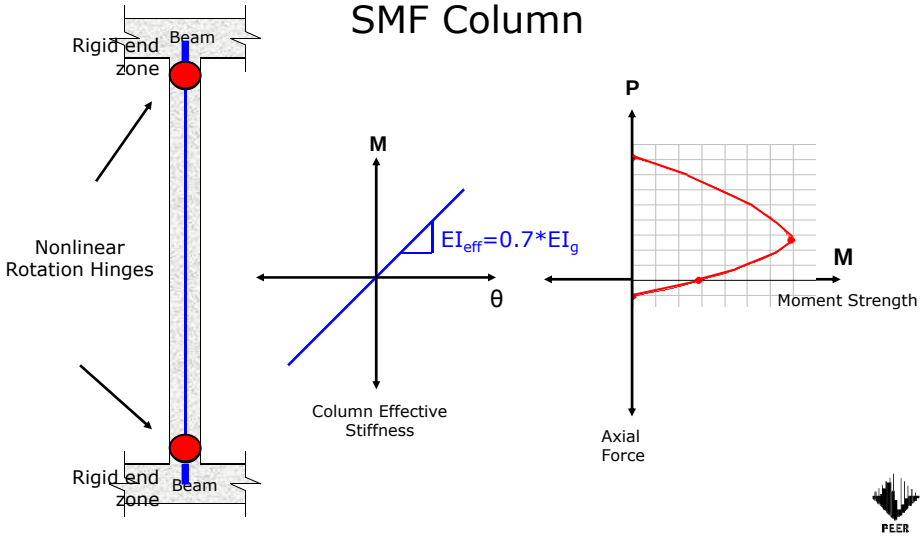
Muexp= Expected nominal ultimate capacity (1.18*Myexp)

θy=Maximum elastic rotation

θu=Ultimate rotation observed in test (0.046 rad)

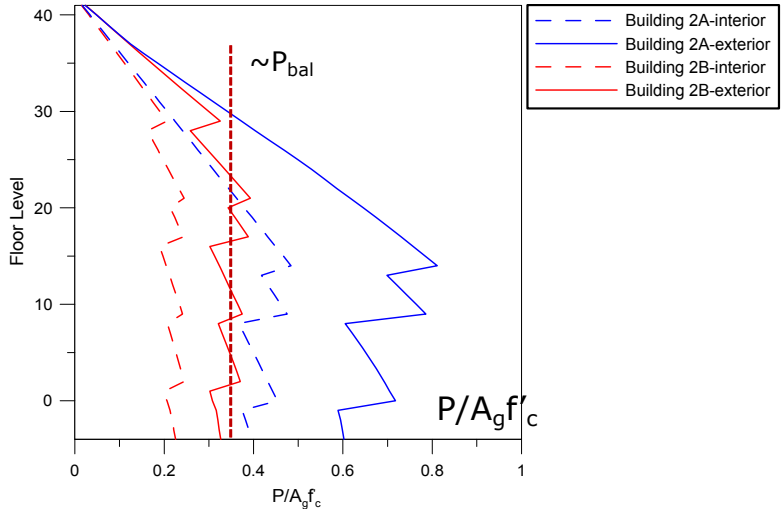
Modeling – Dual System

SMF Column



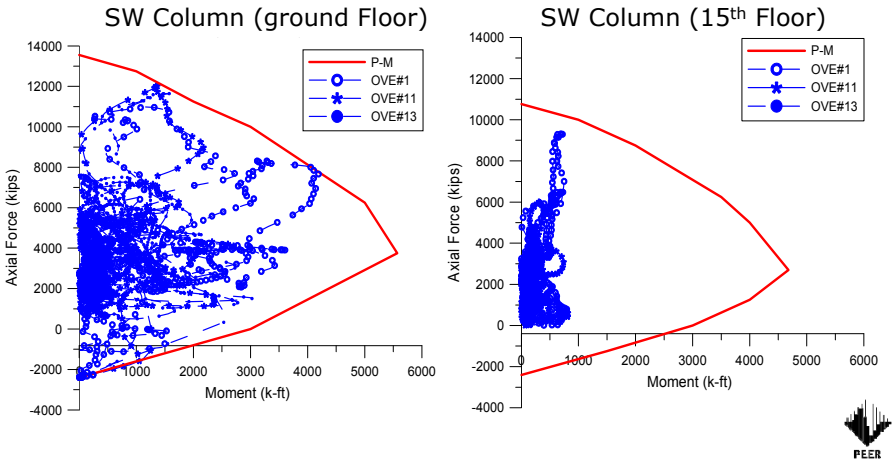
Dual System – SMF Columns

- At OVE level

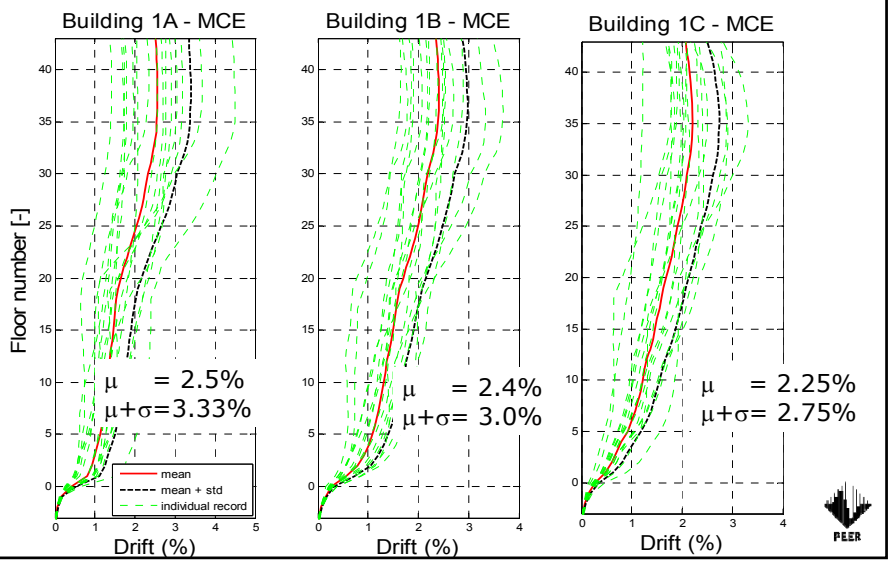


Dual System – SMF Columns

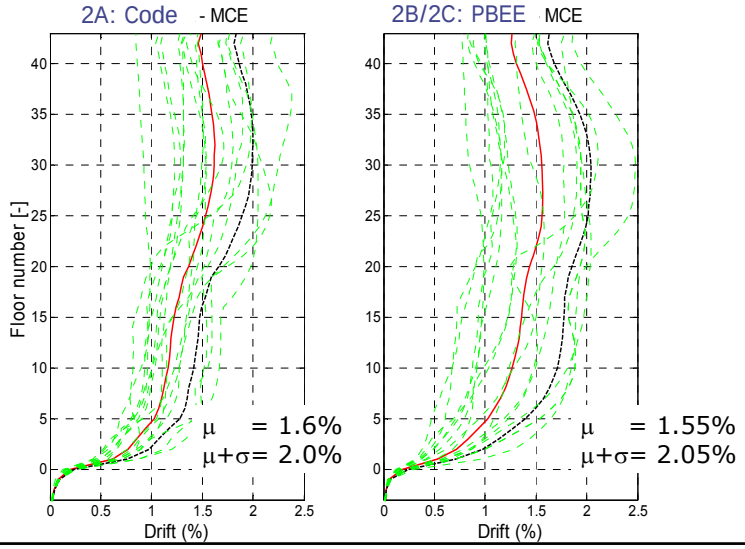
- Building 2A Code (OVE)



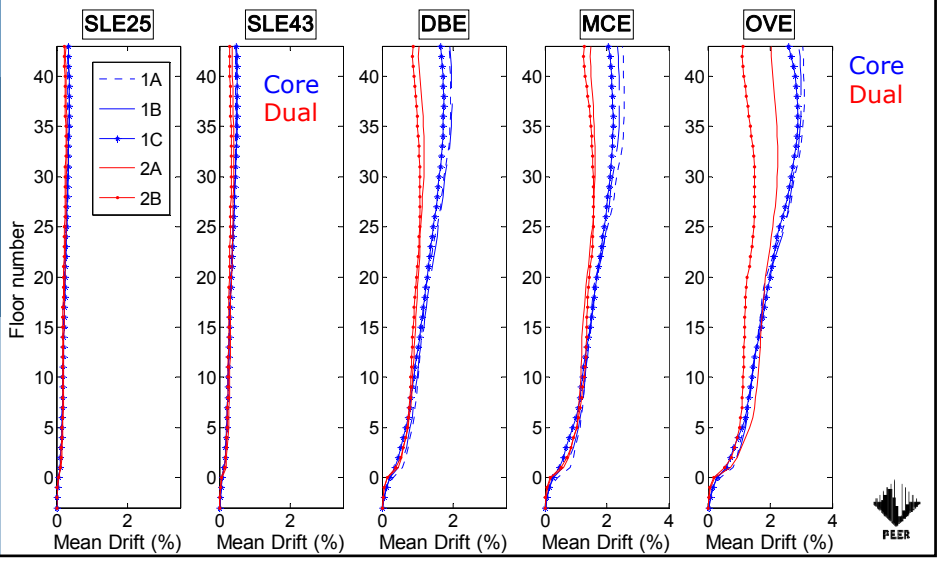
Core Wall – Drift (%)



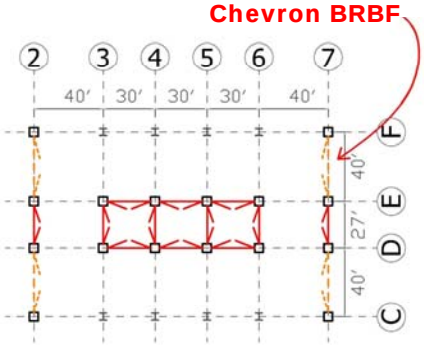
Dual System – Drift (%)



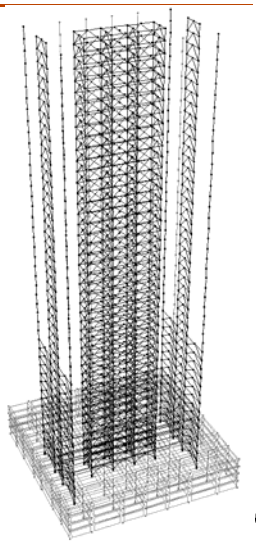
Core Wall (I) vs Dual System (II)



Core
Dual

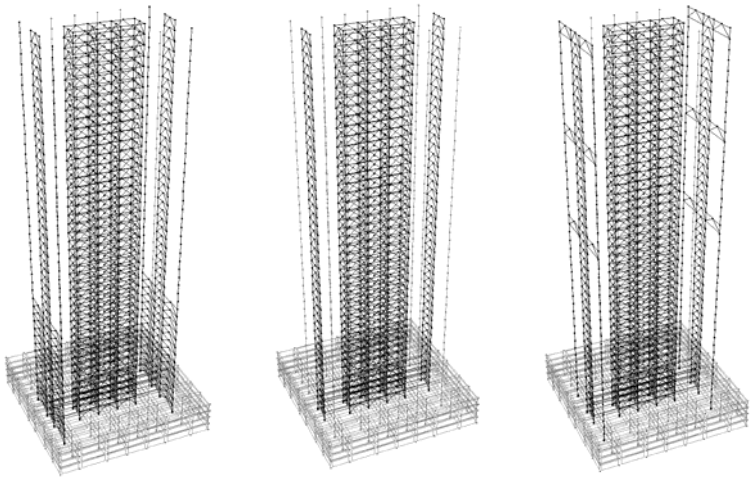


40-story steel Buckling-restrained braced frame



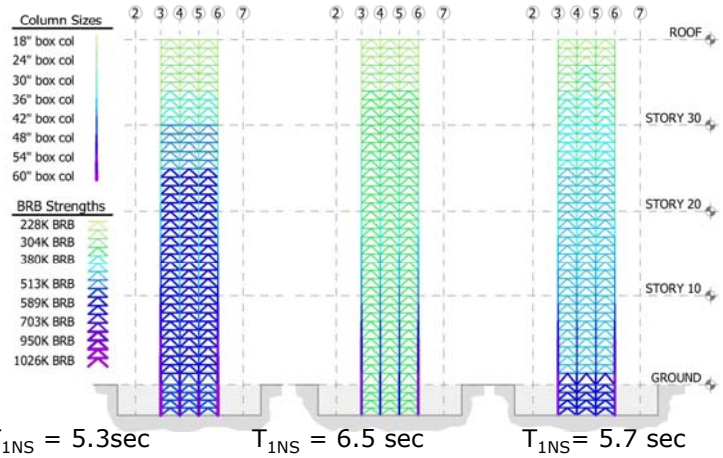
Modeling – BRBF

Design Summary



Modeling – BRBF

Design Summary



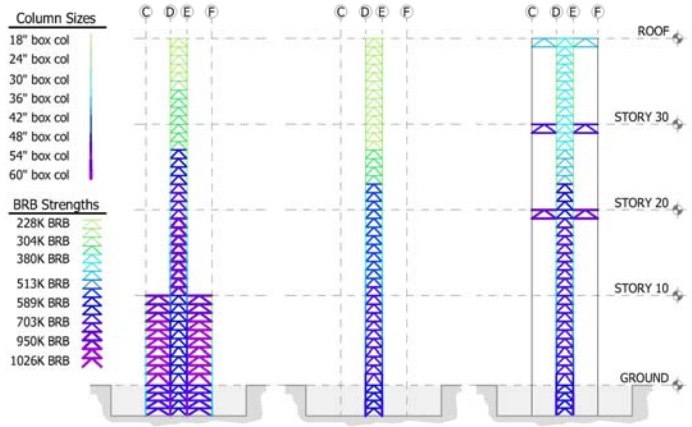
T_{1NS} = 5.3sec
T_{1EW} = 3.8 sec

T_{1NS} = 6.5 sec
T_{1EW}= 4.5 sec

T_{1NS}= 5.7 sec
T_{1EW} = 4.2 sec

Modeling – BRBF

Design Summary



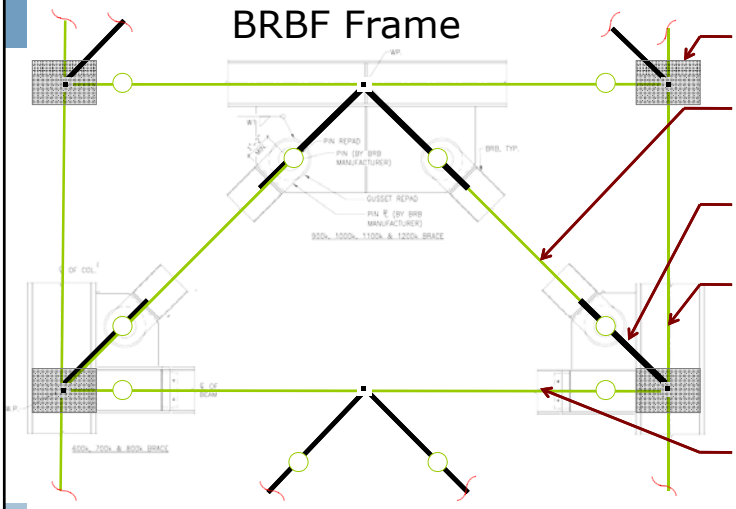
T_{1NS} = 5.3sec
T_{1EW} = 3.8 sec

T_{1NS} = 6.5 sec
T_{1EW}= 4.5 sec

T_{1NS}= 5.7 sec
T_{1EW} = 4.2 sec

Modeling – BRBF

BRBF Frame



Rigid panel zone

BRBF "brace" element, nonlinear. Connections modeled as pins.

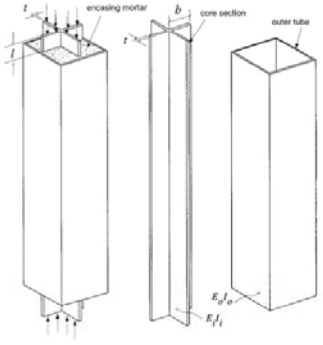
BRBF "stiff endzone" 30% length linear elastic bar

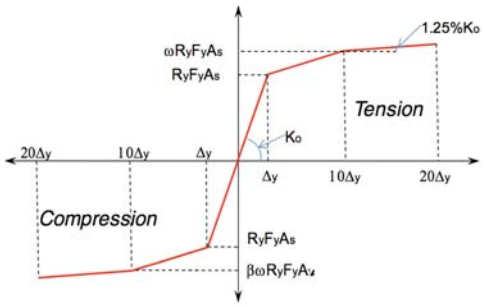
Elastic Column element, equivalent steel cross section used (axial, torsional, and bending stiffness modified to account for concrete)

Elastic Beam Element with pinned connections to columns

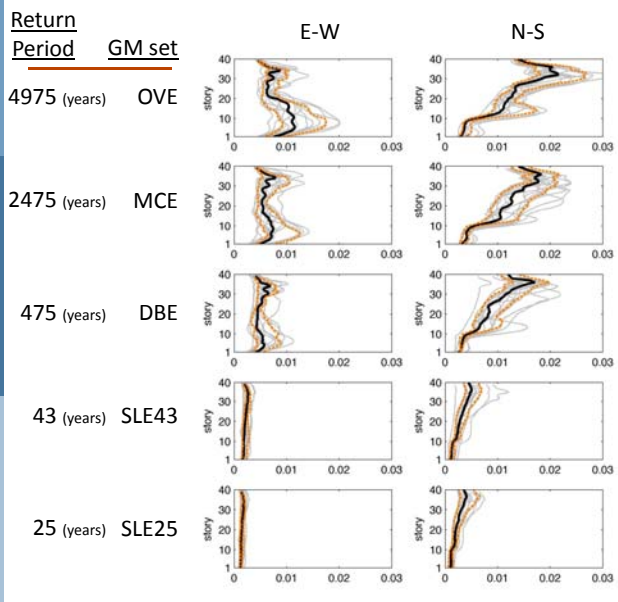
Modeling – BRBF

BRBF Element

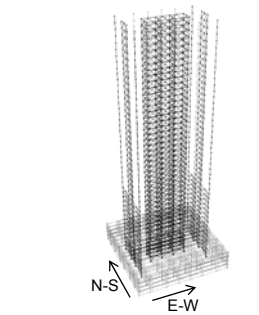


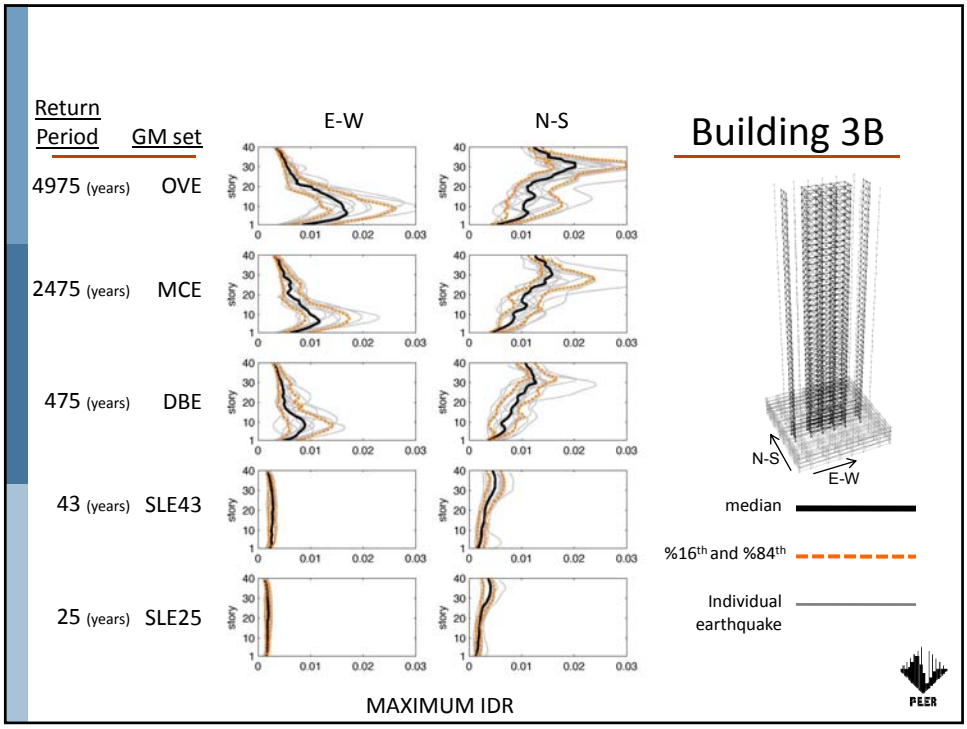


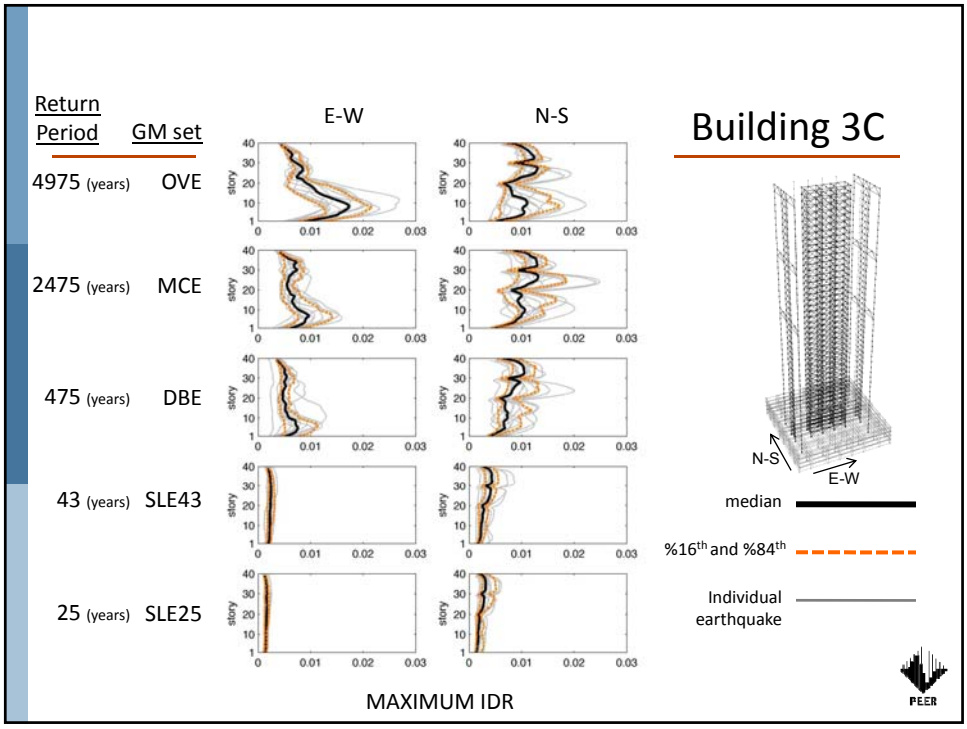
- R_y = 1.1, ω = 1.25, and β = 1.1.
- Maximum deformation capacity of ($20\varepsilon_y$)



Building 3A

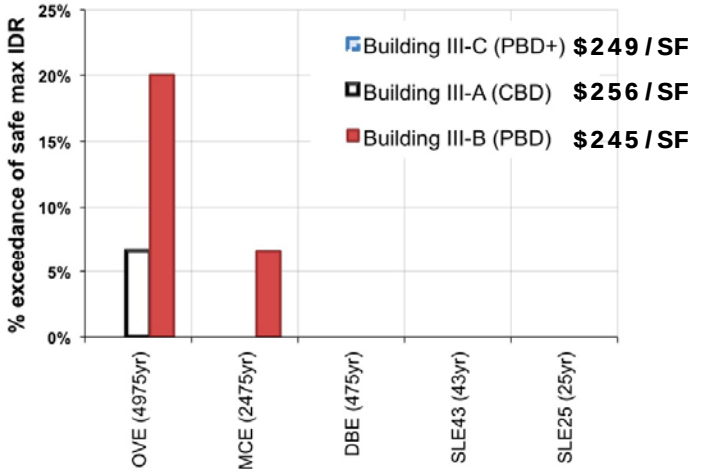



Return Period
GM set
E-W
N-S
Building 3B
4975 (years) OVE
2475 (years) MCE
475 (years) DBE
43 (years) SLE43
25 (years) SLE25
story
0 0.01 0.02 0.03
N-S
E-W
median
%16th and %84th
Individual earthquake
MAXIMUM IDR
PEER


Return Period
GM set
E-W
N-S
Building 3C
4975 (years) OVE
2475 (years) MCE
475 (years) DBE
43 (years) SLE43
25 (years) SLE25
story
0 0.01 0.02 0.03
N-S
E-W
median
%16th and %84th
Individual earthquake
MAXIMUM IDR
PEER

Results – BRBF

%Exceedance Of 3% Drift Ratio



Return Period | GM set

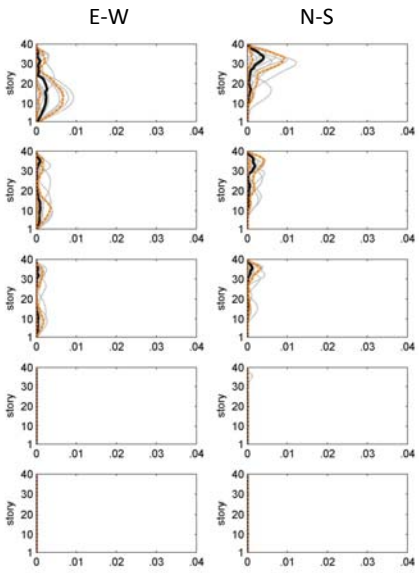
4975 (years) OVE

2475 (years) MCE

475 (years) DBE

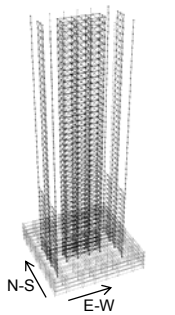
43 (years) SLE43

25 (years) SLE25



Res IDR

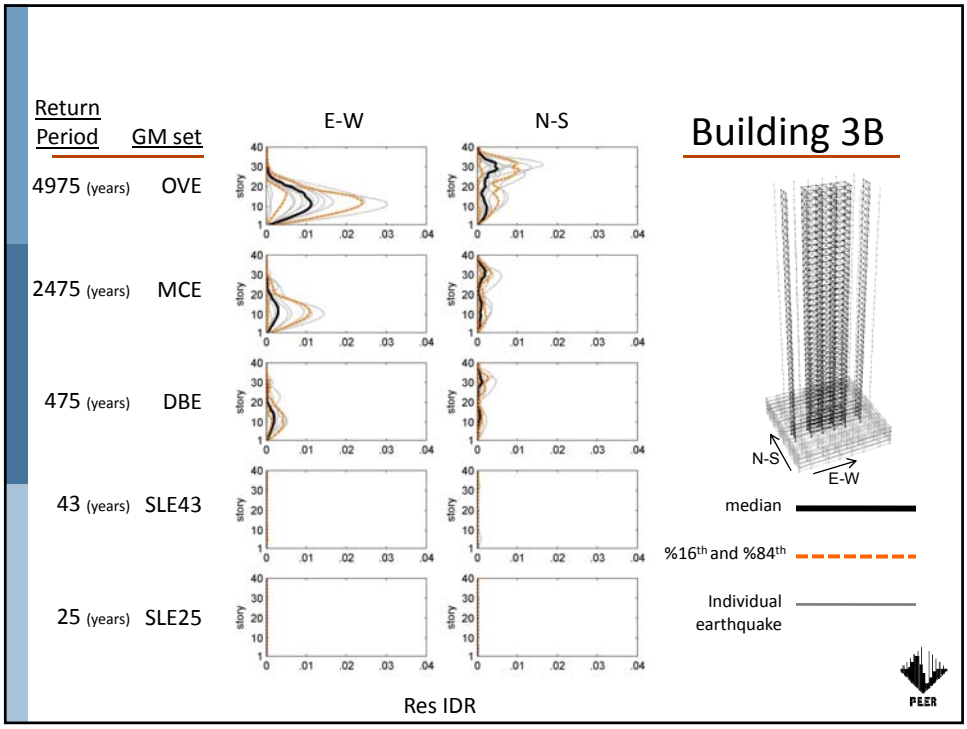
Building 3A

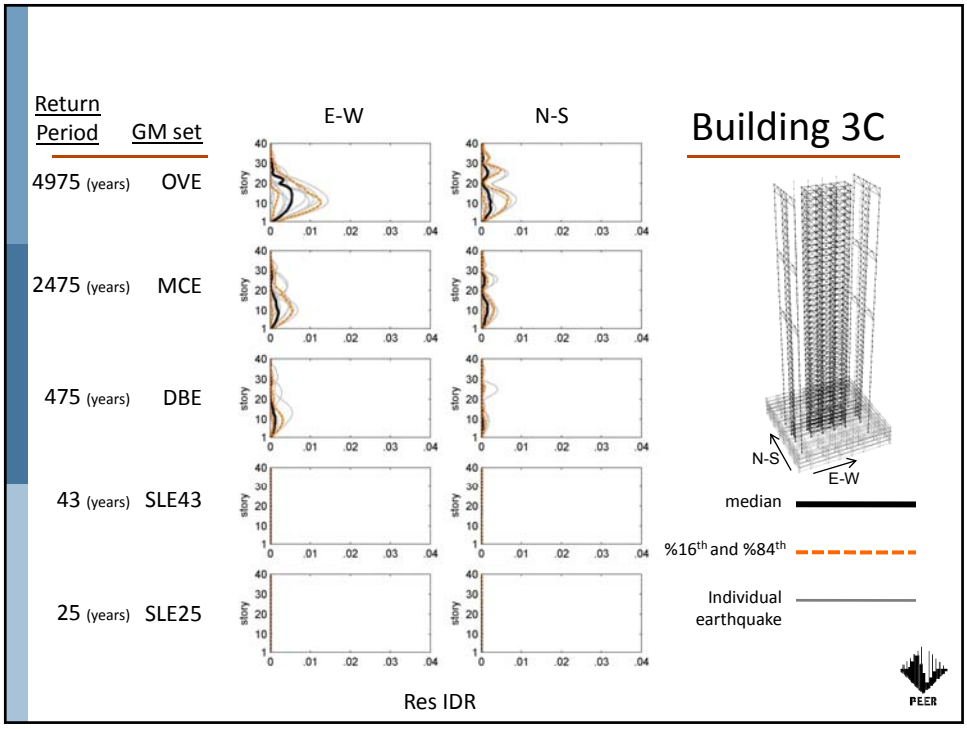


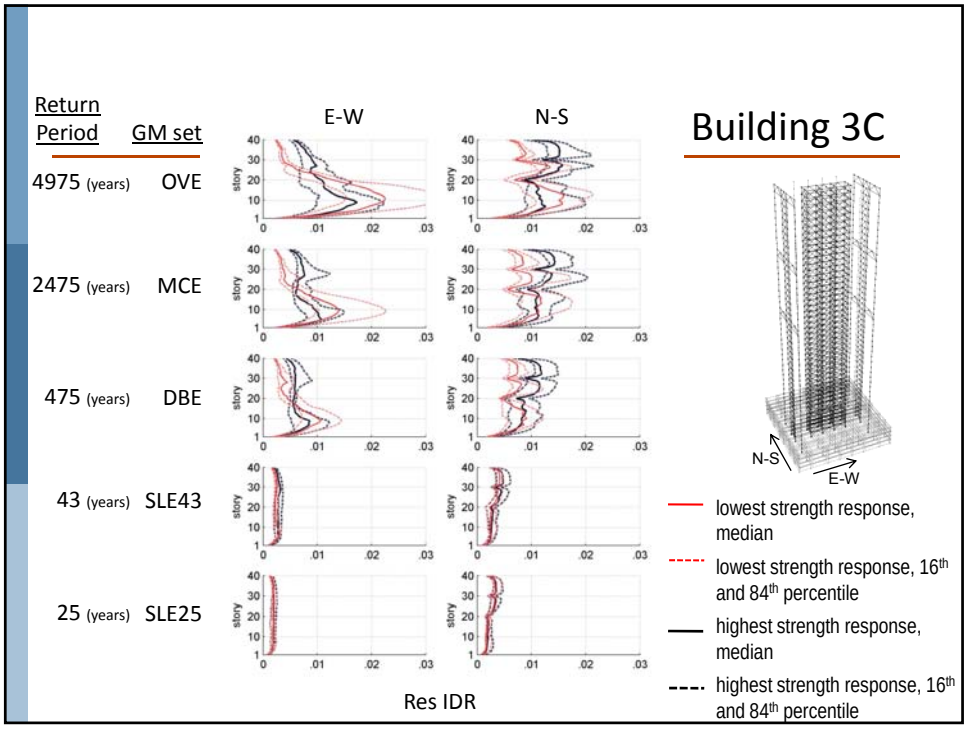
median

%16th and %84th

Individual earthquake


Return Period
GM set
4975 (years) OVE
2475 (years) MCE
475 (years) DBE
43 (years) SLE43
25 (years) SLE25
E-W
N-S
Building 3B
N-S
E-W
median
%16th and %84th
Individual earthquake
PEER
Res IDR


Return Period
GM set
4975 (years) OVE
2475 (years) MCE
475 (years) DBE
43 (years) SLE43
25 (years) SLE25
E-W
N-S
Building 3C
N-S
E-W
median
%16th and %84th
Individual earthquake
PEER
Res IDR



Summary of Case Study Analysis

- **Three systems: Core Wall, Dual System, and Buckling-restrained Braced Frame.**
  - **1A (code), 1B (PBEE), and 1C (PBEE+)**
  - **2A (code), 2B / 2C (PBEE+)**
  - **3A (code), 3B (PBEE), and 3C (PBEE+)**
- **PERFORM 3D nonlinear models**
  - **Consistent modeling approaches**
  - **Expected values, best-available information**
- **Subjected to 5 Hazard levels, 15 GM**
  - **SLE25, SLE43, DBE, MCE, OVE**
- **Engineering Demand Parameters**
  - **Drift, Accelerations, for loss studies**
  - **Local EDPs**

PEER