PEER Tall Building Seismic Design Guidelines

Preliminary Design Recommendations & Performance Studies

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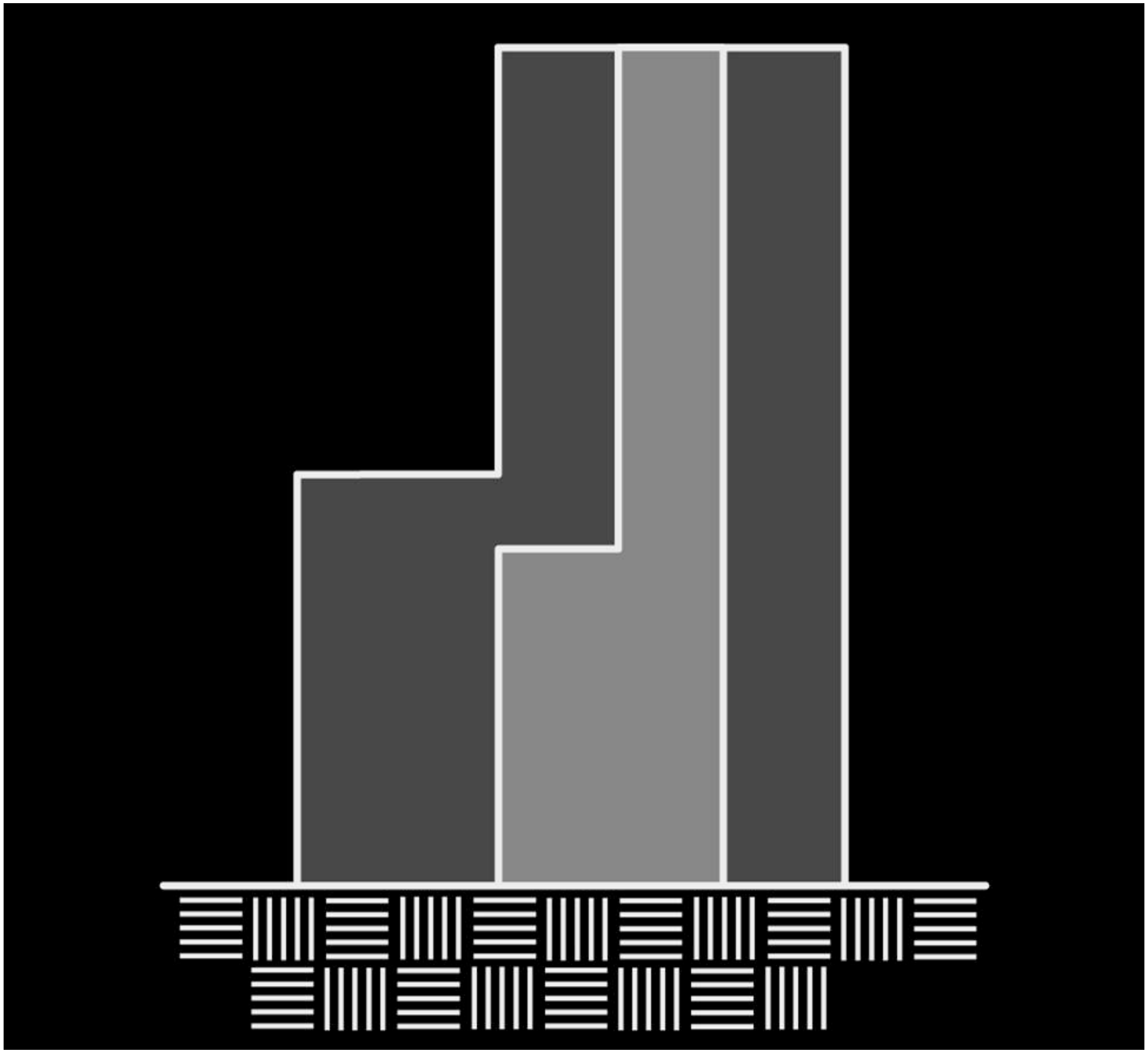
PEER

SEAW **November 30, 2010**

Structural Configuration

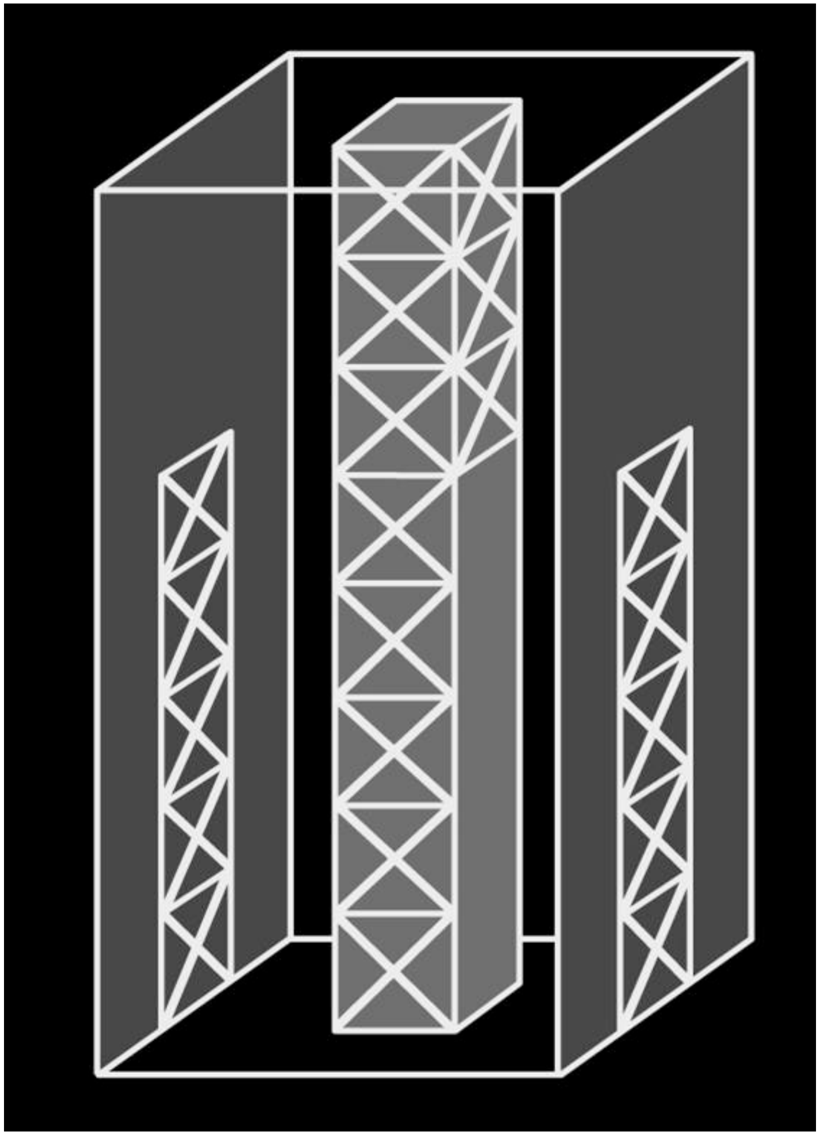
- Simple arrangement of structural elements
- Clearly defined load paths
- Complicated configurations and geometries complicate behavior—avoid to the extent possible

System Configuration



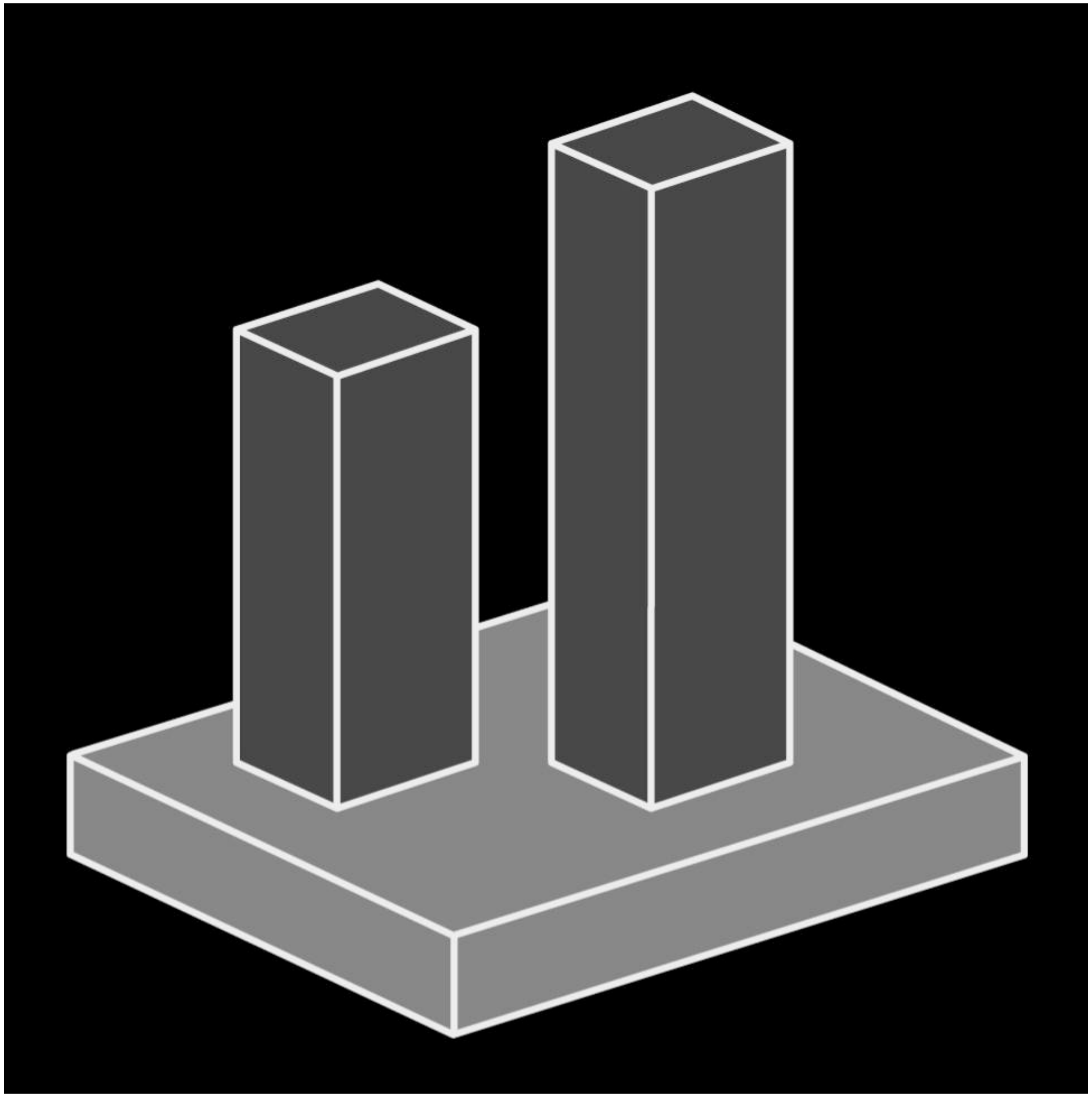
Changes in Building Stiffness and Mass

System Configuration



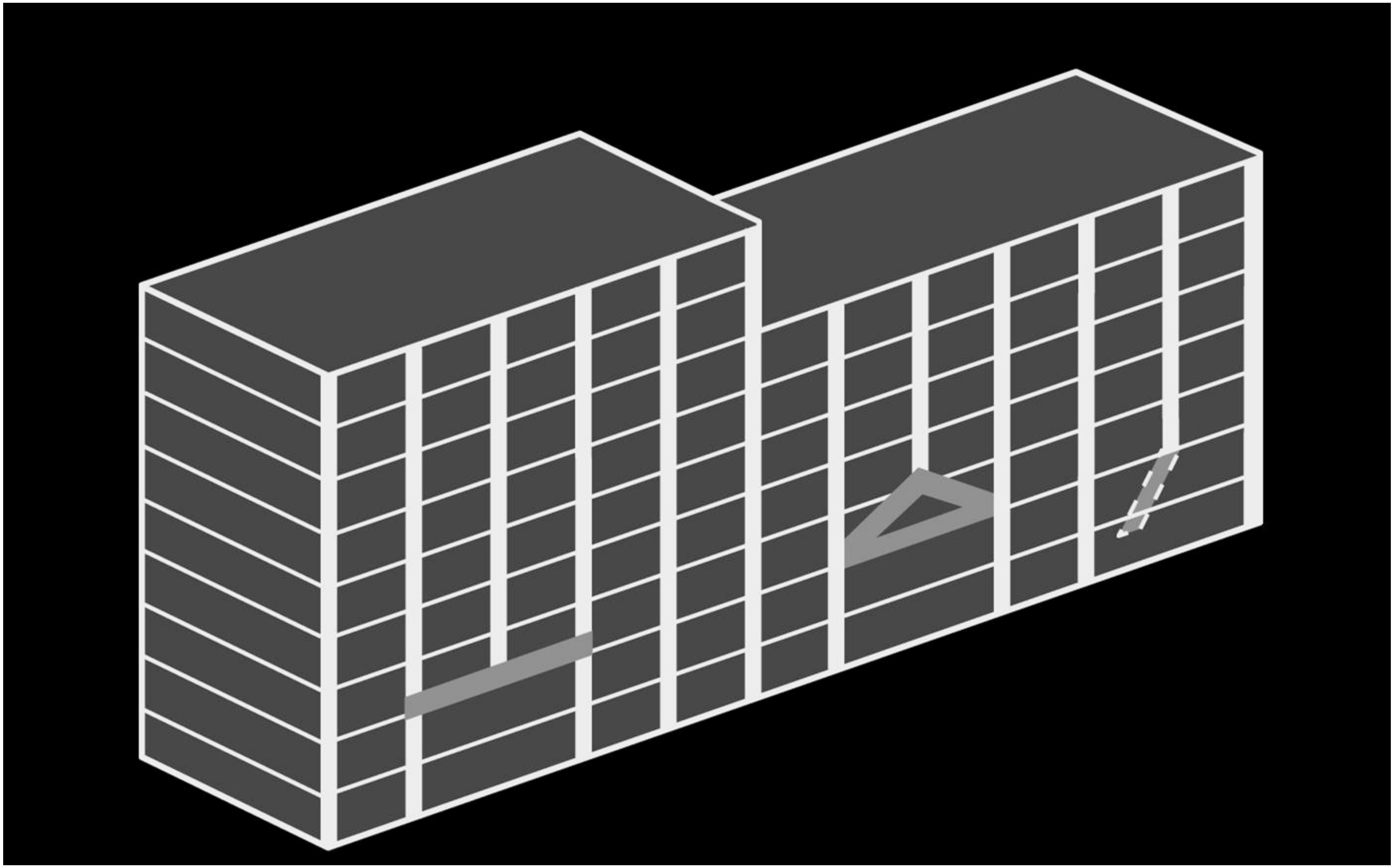
Repositioning of Bracing Elements

System Configuration



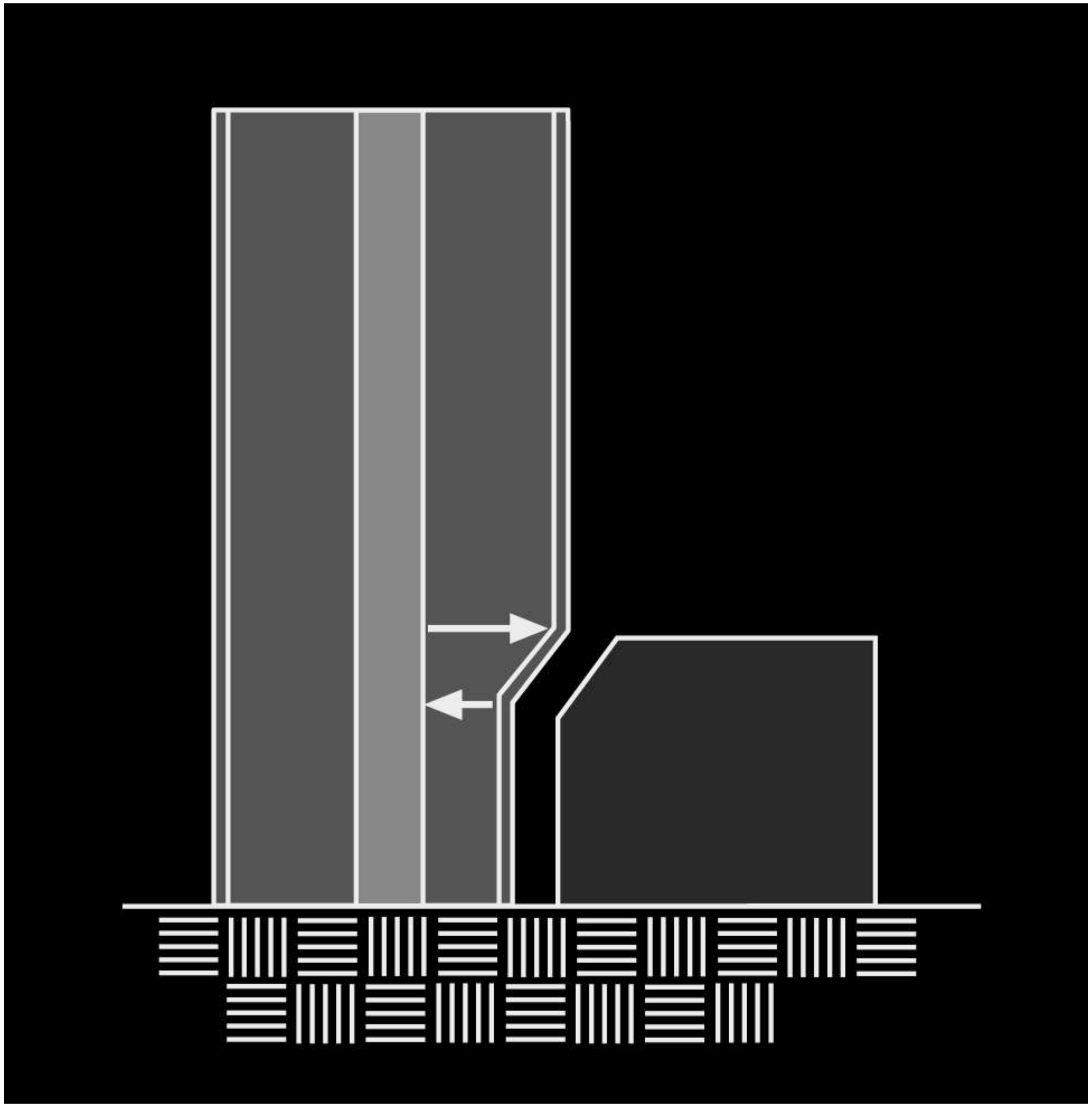
Multiple Towers on a Common Base

System Configuration



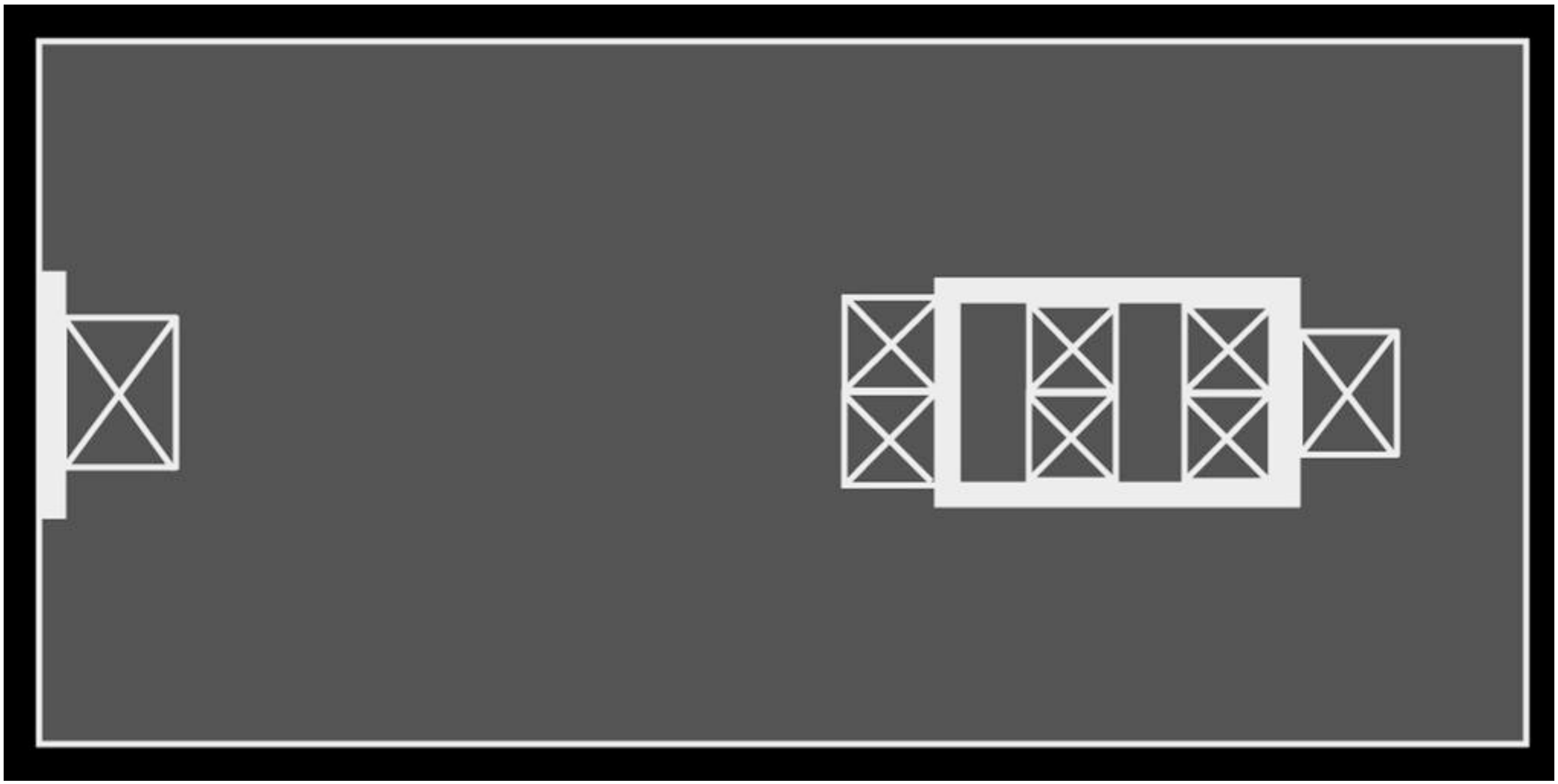
Column Transfers and Offsets

System Configuration



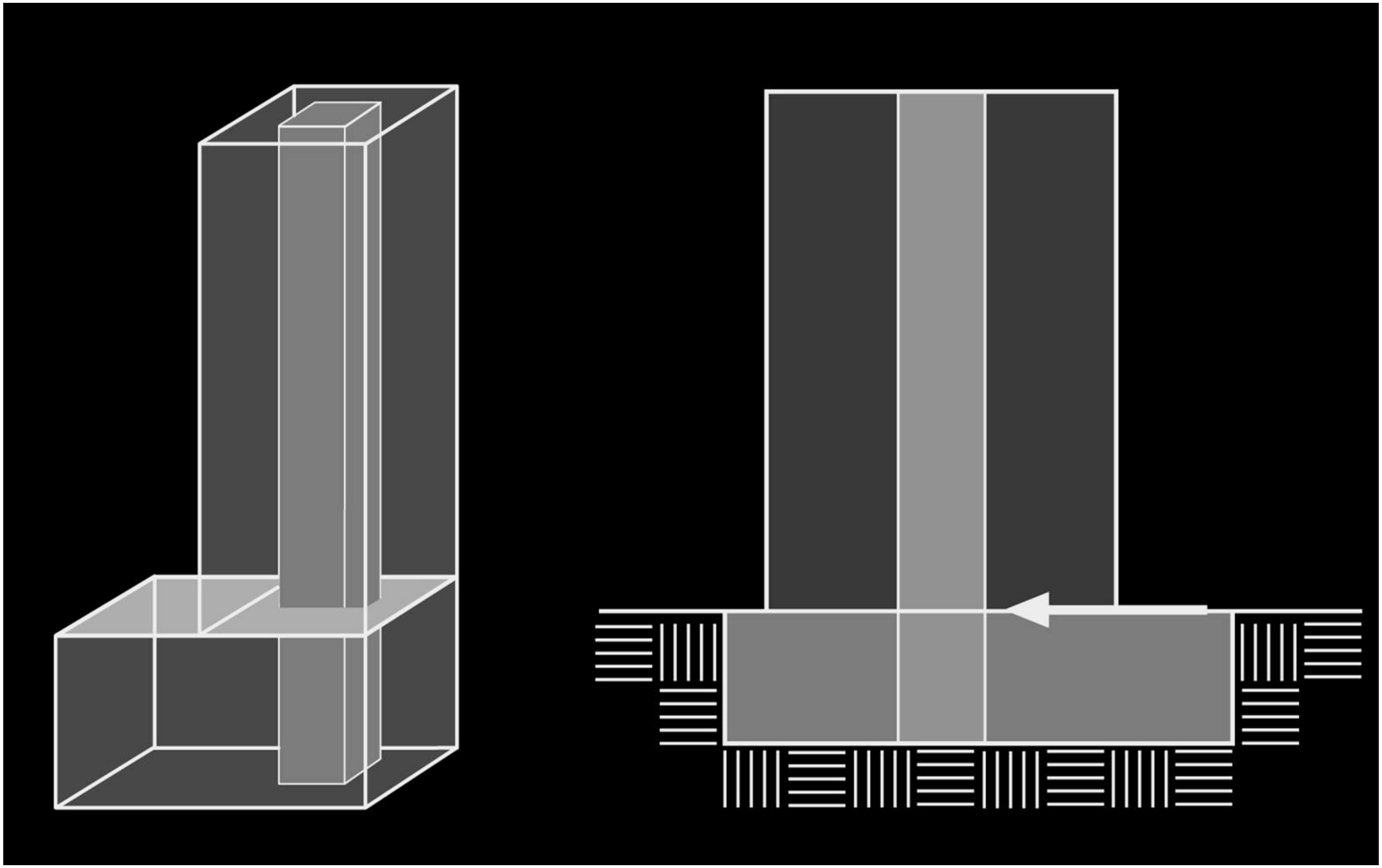
Gravity Induced Shear Forces

System Configuration



Limited Connectivity of Floor Diaphragms

System Configuration



Concentration of Diaphragm Demands

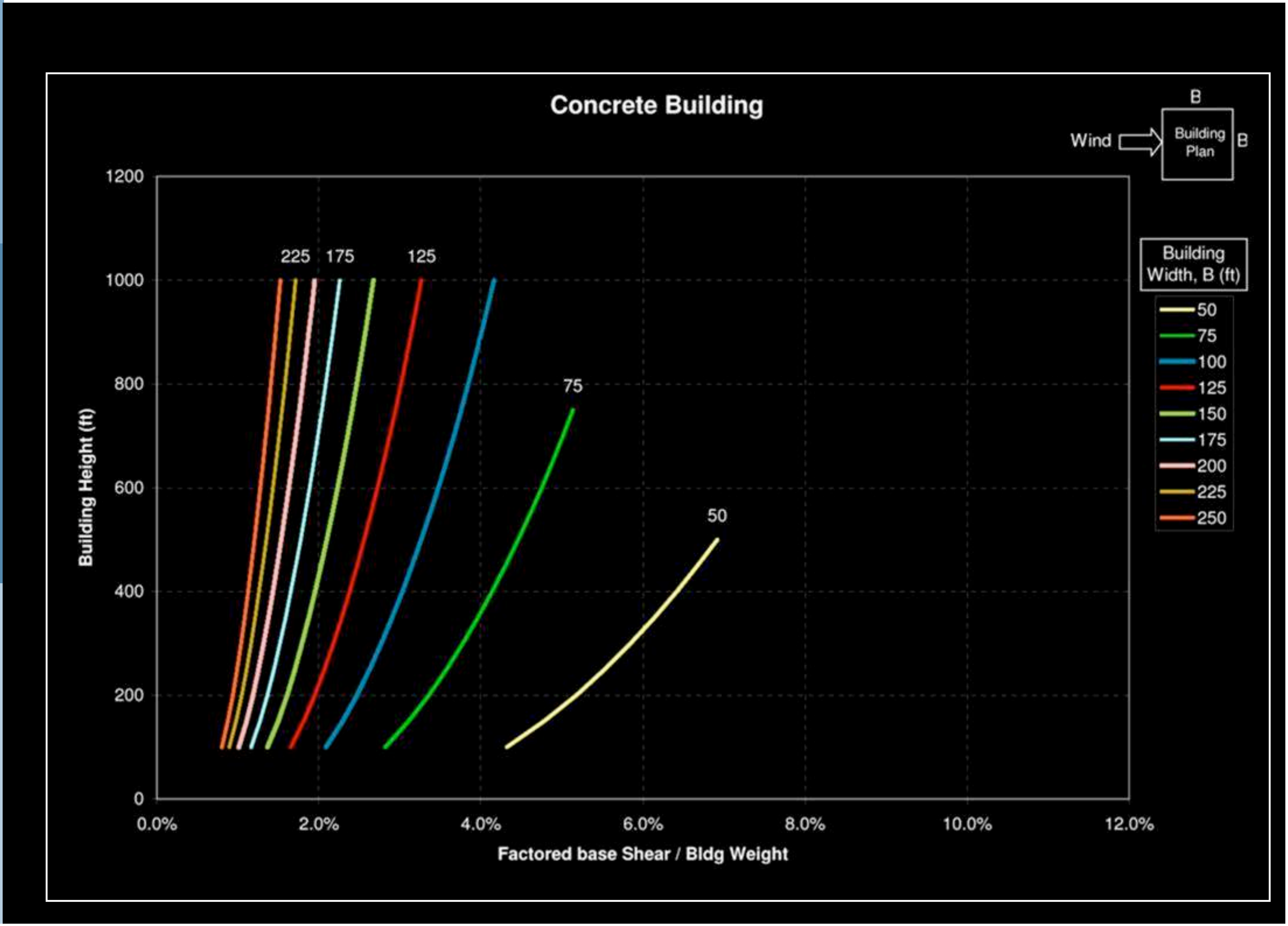
Structural Performance Hierarchy

- Identify zone or elements of nonlinear response
- Establish hierarchy of the nonlinear elements
- Incorporate capacity design concepts as appropriate for remaining elements
- Confirm hierarchy through nonlinear response history analysis

Structural Performance Hierarchy

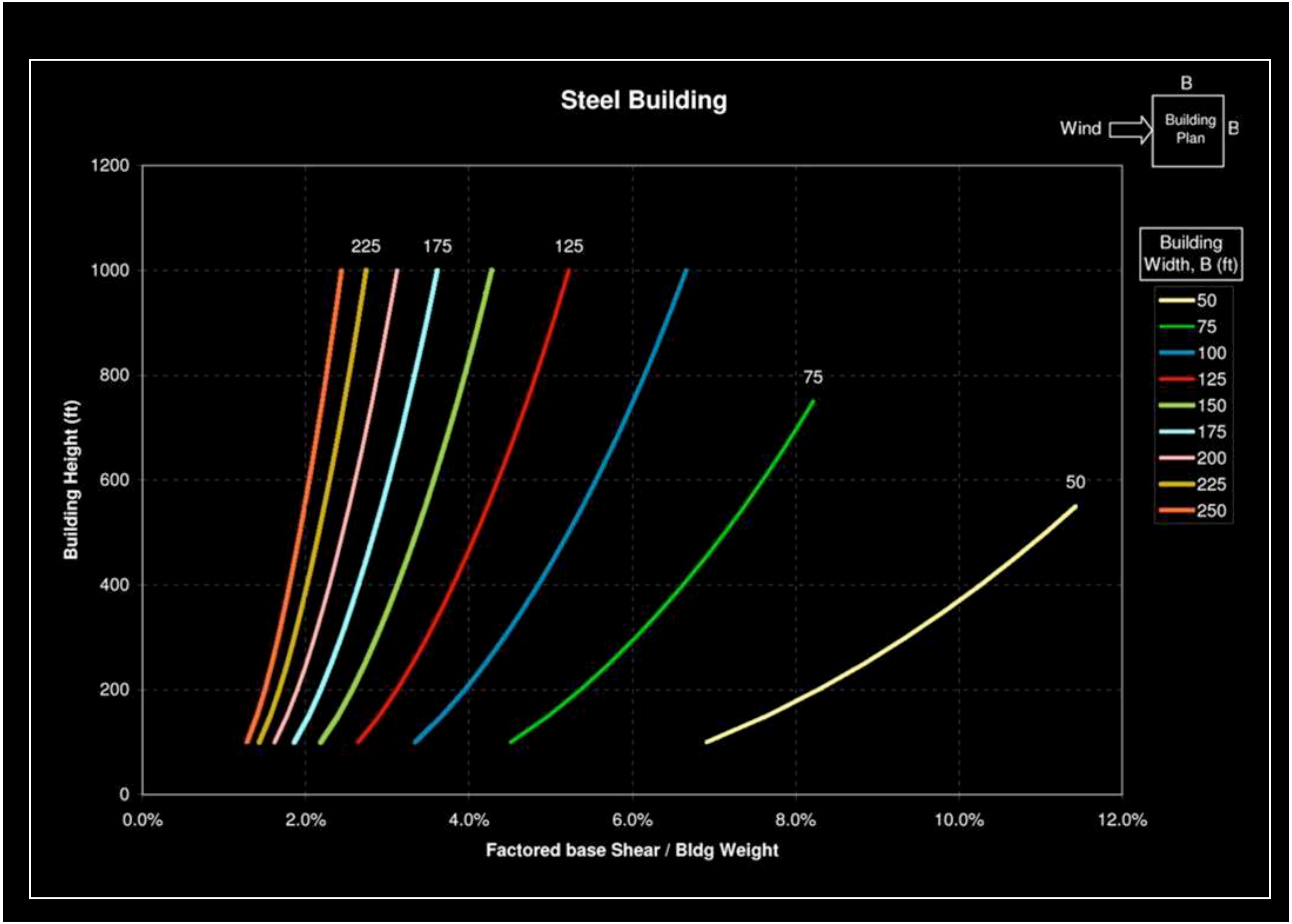
- Desirable Modes of nonlinear response inlcude:
  - Flexural yielding of beams, slabs and shear walls
  - Yielding of diagonal reinforcement in coupling beams
  - Tension yielding in steel braces and steel plate shear walls
  - Post-buckling compression in steel braces that don’t support gravity
  - Tension/compression yielding in BRBs

Wind



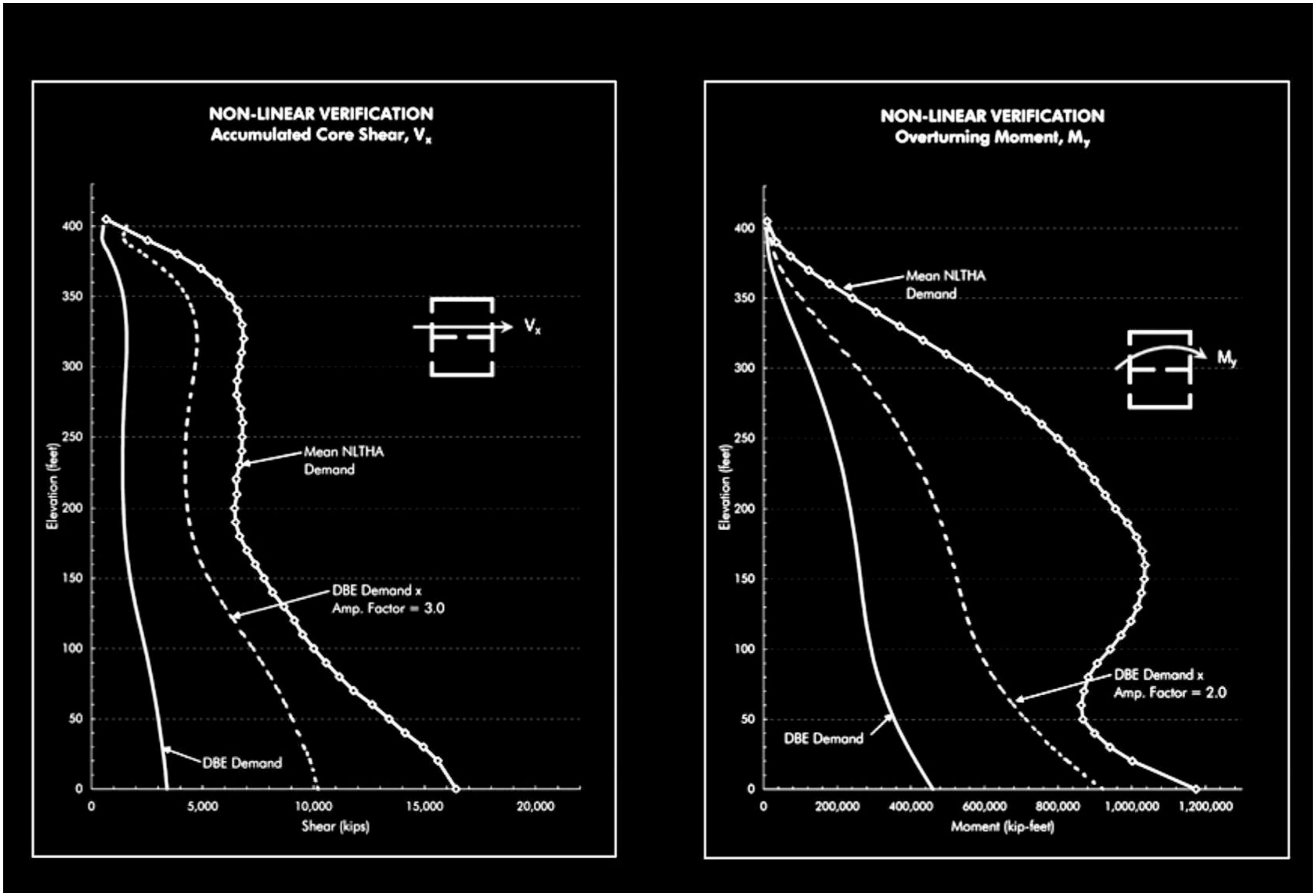
Concrete Building
B
Wind
Building Plan
B
1200
1000
800
600
400
200
0
Building Height (ft)
225
175
125
75
50
0.0%
2.0%
4.0%
6.0%
8.0%
10.0%
12.0%
Factored base Shear / Bldg Weight
Building Width, B (ft)
50
75
100
125
150
175
200
225
250

Wind



Steel Building
B
Wind
Building Plan
B
Building Height (ft)
1200
1000
800
600
400
200
0
225
175
125
75
50
0.0%
2.0%
4.0%
6.0%
8.0%
10.0%
12.0%
Factored base Shear / Bldg Weight
Building Width, B (ft)
50
75
100
125
150
175
200
225
250

Higher Mode Effects



Significantly Impact Shear and Flexural Demands

Higher Mode Effects

PEER/CSSC SAMPLE DESIGN

CORE WALL ONLY BUILDING 1B
June 8, 2009

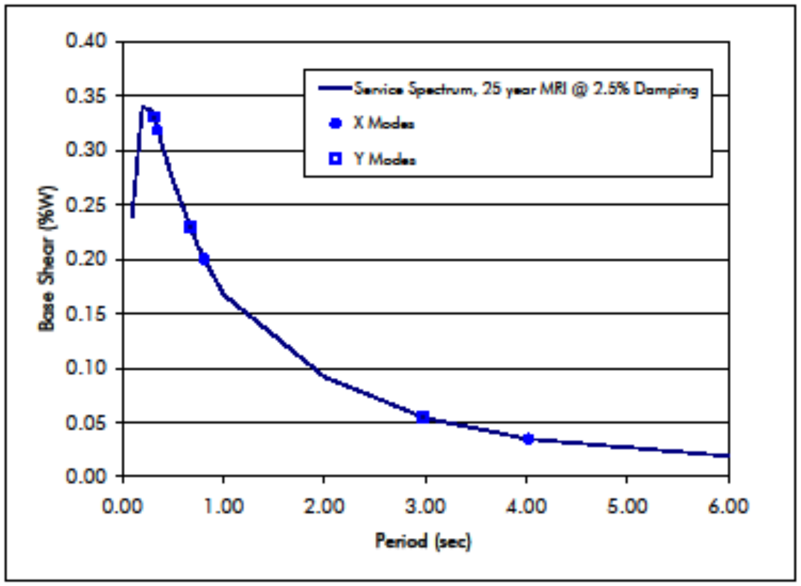
Service Level Base Shear, Unscaled from ETABS

Vx	4,636	kips	5.5%
Vy	5,642	kips	6.7%

Approximate Base Shear	1st mode	2nd mode	3rd mode	SRSS
Vx	2.3%	4.1%	2.0%	5.1%
Vy	3.7%	4.8%	1.9%	6.3%

Building Weight

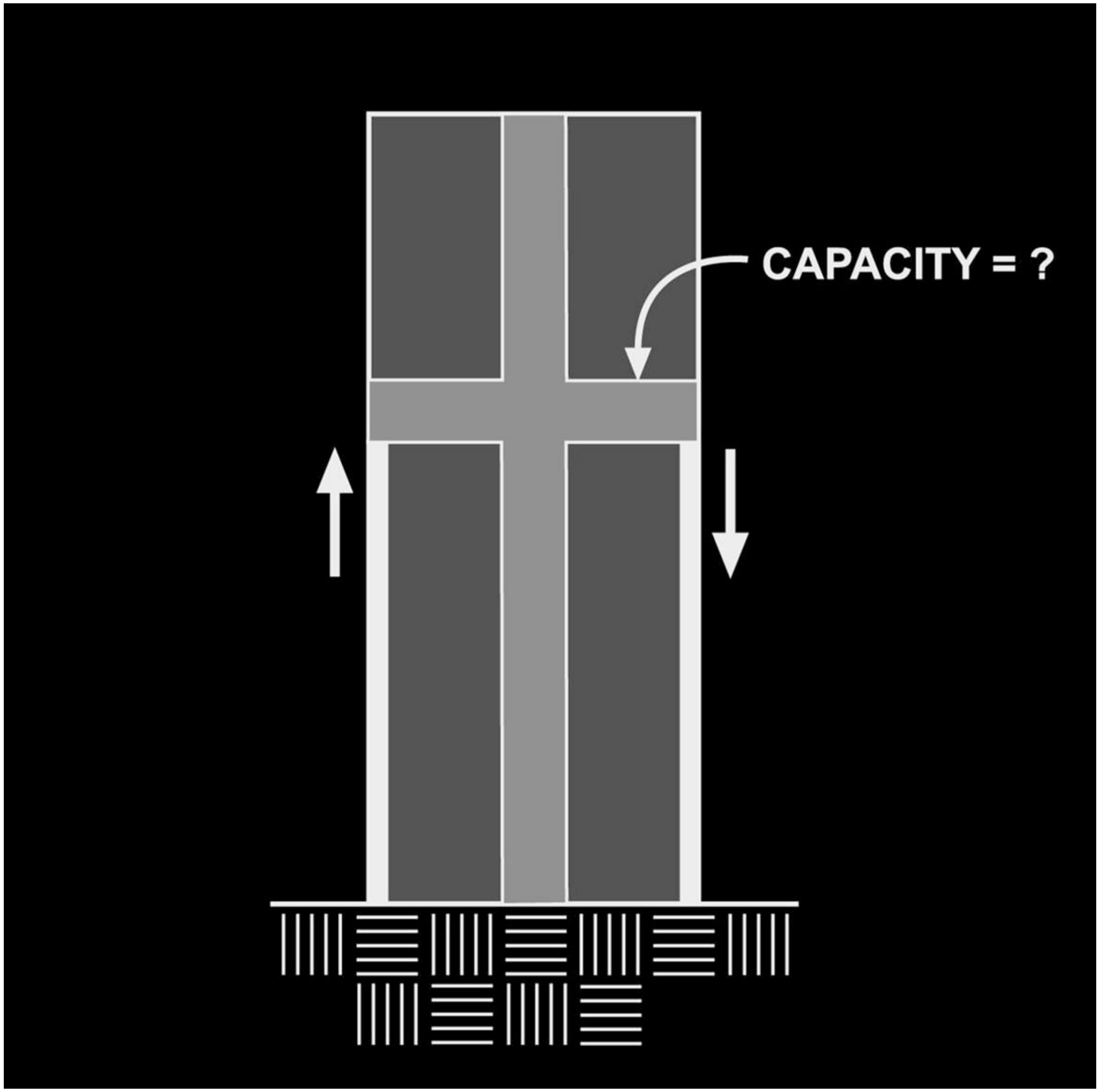
W 84,670 kips



DATA	
Service Spectrum, 25 year MRI @ 2.5% Damping	
Period	Sa (g)
0.00	0.120
0.05	0.158
0.10	0.239
0.20	0.340
0.30	0.336
0.40	0.303
0.50	0.273
0.75	0.212
1.00	0.168
2.00	0.092
3.00	0.054
4.00	0.035
5.00	0.027
6.00	0.019

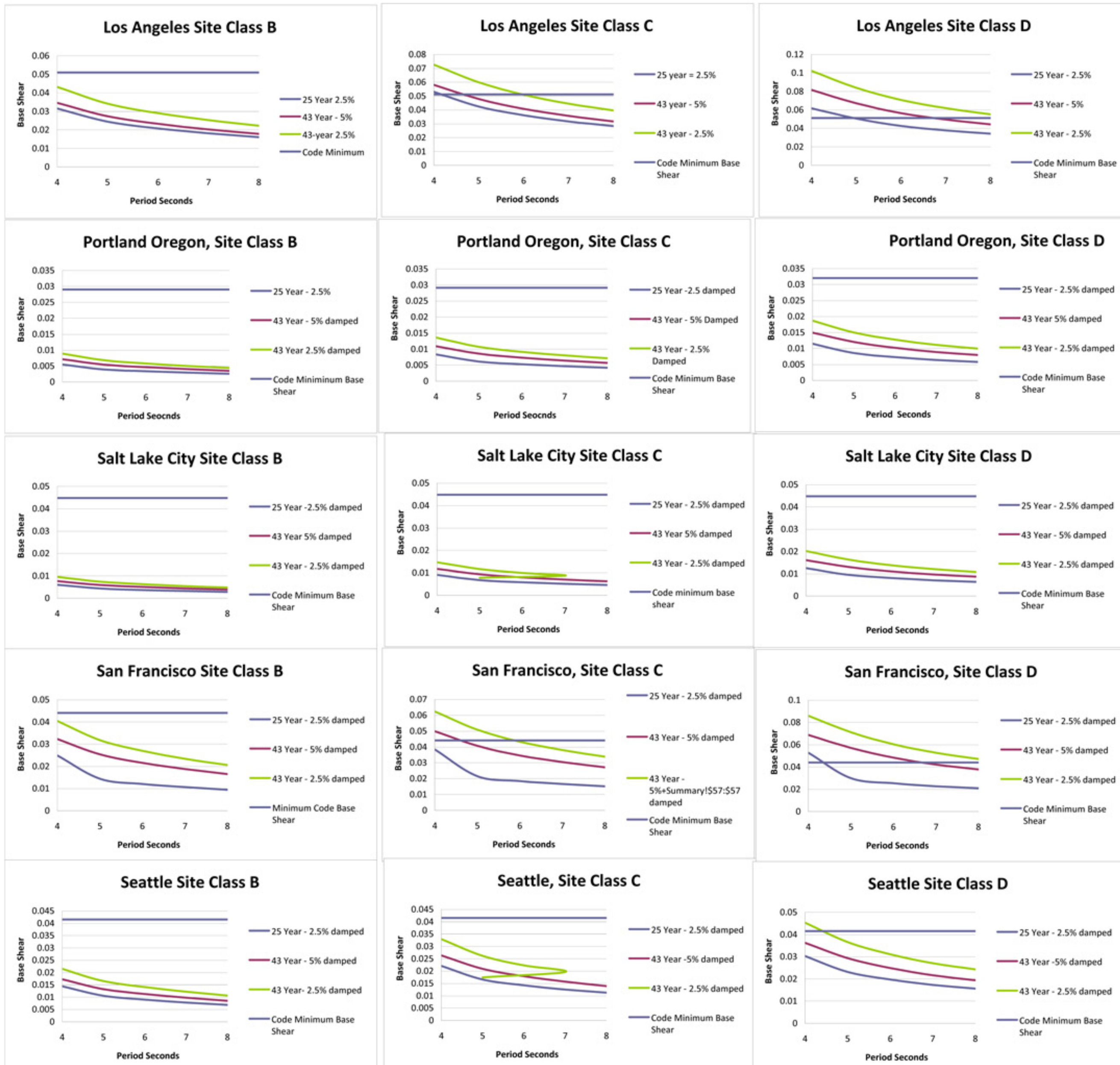
Building 1B Modal Data					
Mode	Period	UX	UY	SumUX	SumUY
1	4.022	65.611	0.034	65.611	0.034
2	2.961	0.058	66.749	65.669	66.783
3	1.516	0.000	0.000	65.669	66.783
4	0.818	20.618	0.000	86.287	66.783
5	0.678	0.013	20.773	86.299	87.556
6	0.513	0.000	0.000	86.299	87.556
7	0.353	6.360	0.098	92.659	87.653
8	0.316	0.193	5.773	92.851	93.426
9	0.300	0.000	0.000	92.851	93.426
10	0.213	2.334	0.399	95.185	93.825

Outrigger Elements



Column Demands Due to Outrigger Over Strength

Serviceability Base Shears



The Performance Study

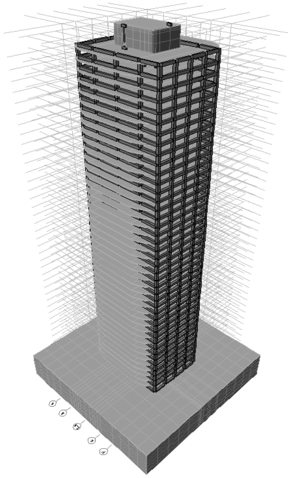
Three Building Systems

42-story concrete core wall

Designs
A
B
C

Building 1
(MKA)

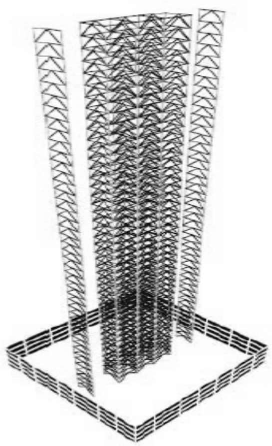
42-story concrete dual system



Designs
A
B
C

Building 2
(REI)

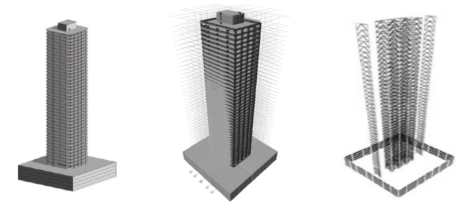
40-story steel buckling restrained braced frame



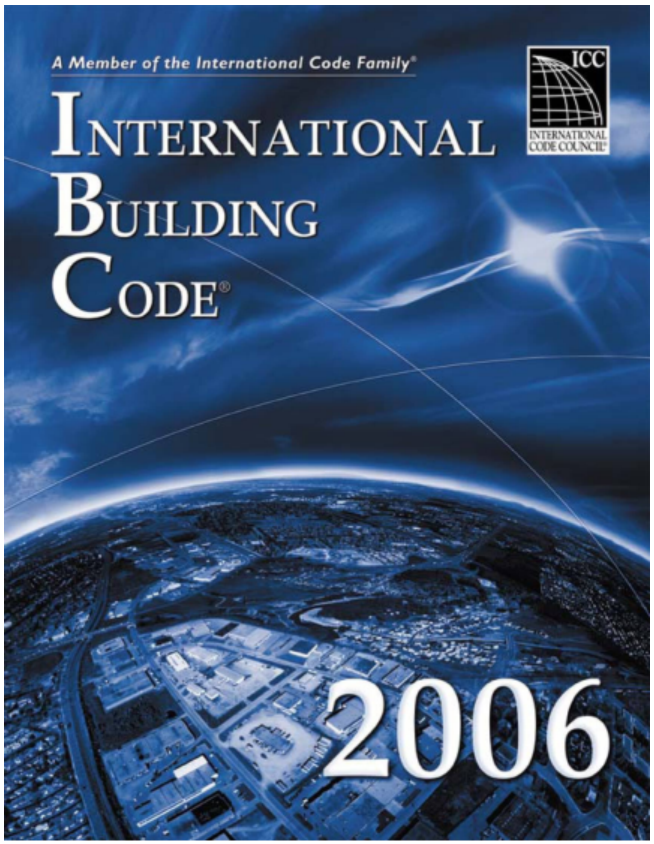
Designs
A
B
C

Building 3
(SGH)

The Performance Study

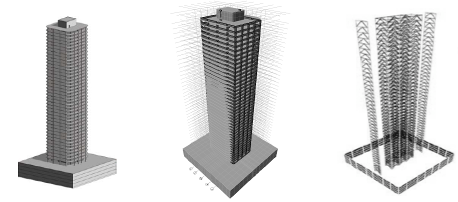


Design A

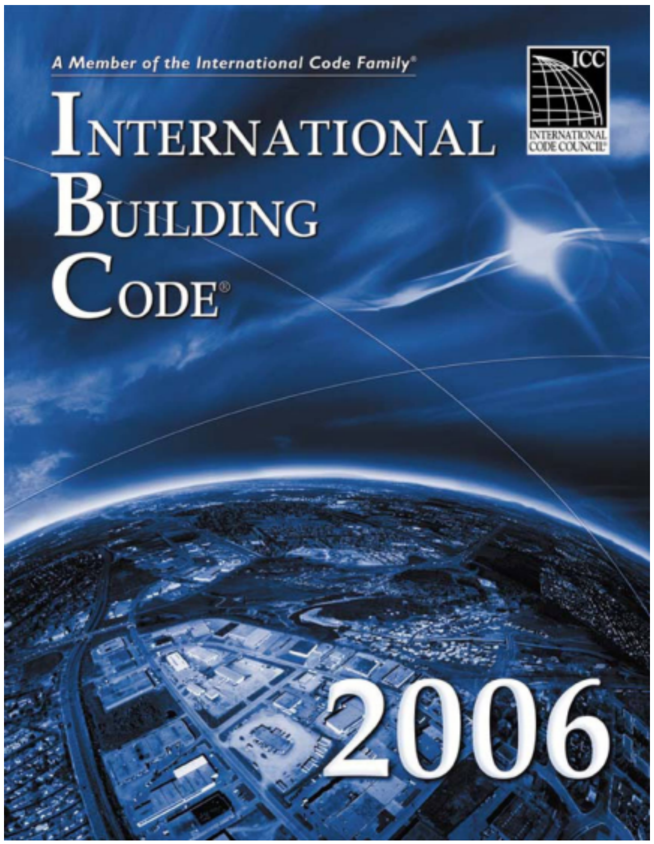


- All provisions followed except height limits

The Performance Study

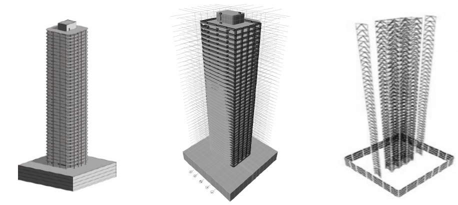


Design A

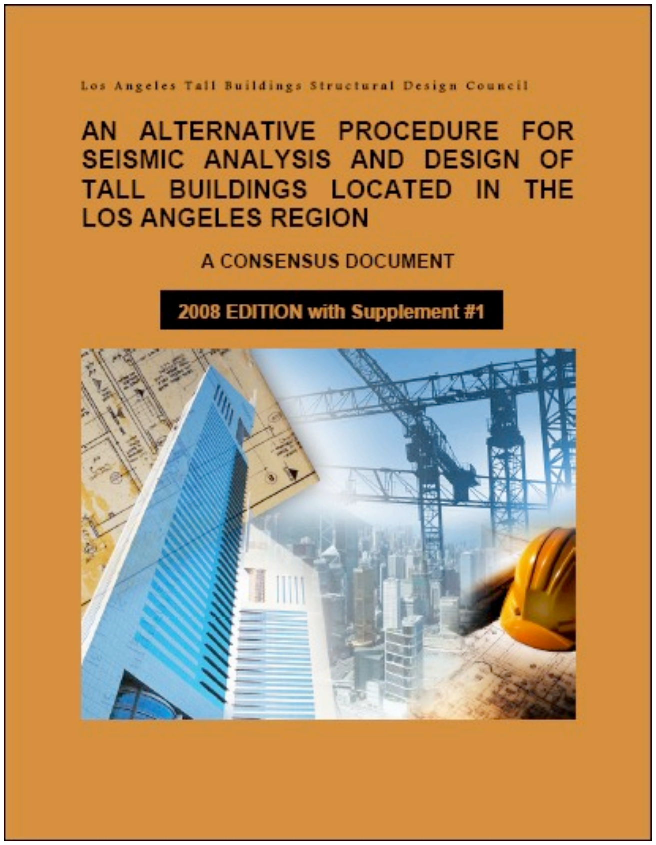


- All provisions followed except height limits
- Seismic
  - $S_s = 2.1$, $S_1 = 0.7$
  - Site class C
  - SDC D
- Wind
  - 85 mph, exposure B

The Performance Study

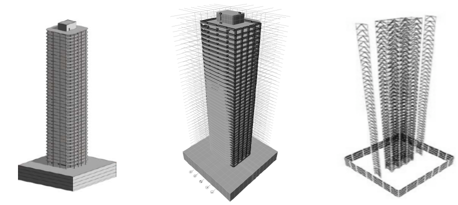


Design B

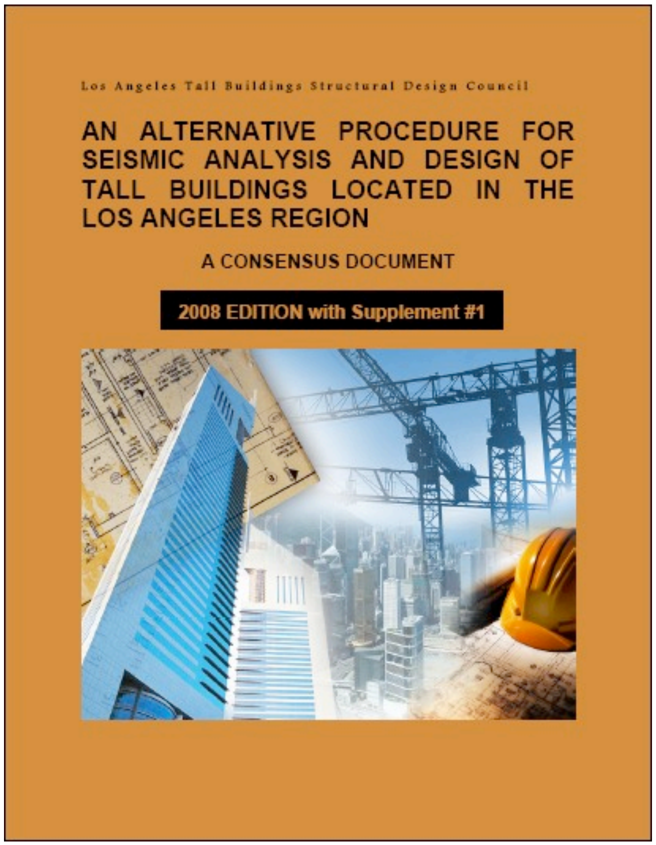


- PBD based on LA Tall Buildings Guidelines (2008)
- Seismic design to disregard all code requirements
- Design verified by nonlinear analysis
- Wind and gravity design to follow code

The Performance Study

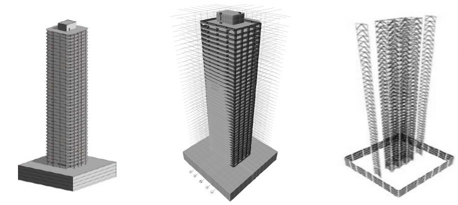


Design B

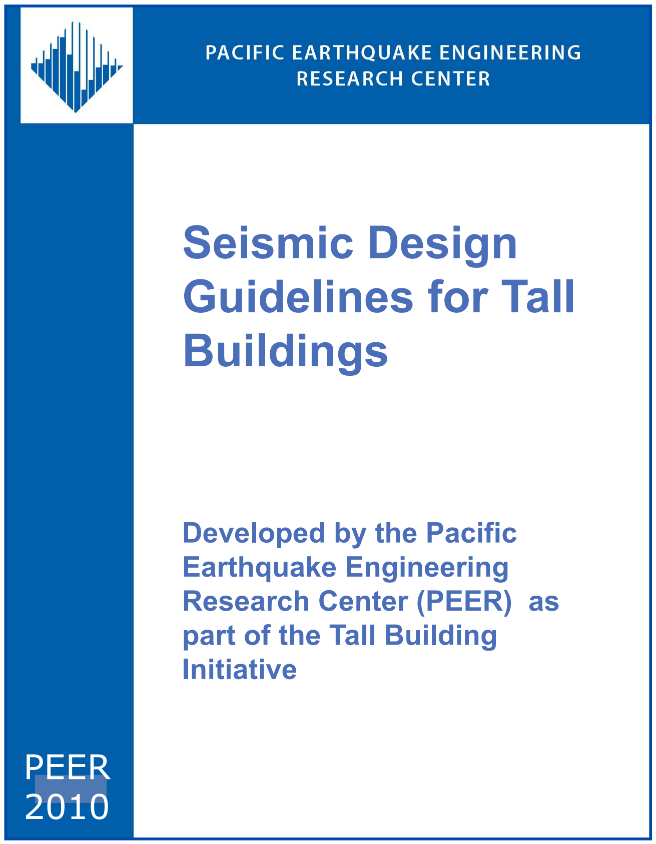


- 2 Design Levels
  - Serviceability
  - MCE
- Serviceability check
  - 25-yr return period
  - response spectrum analysis
  - essentially elastic
  - transient drift ≤ 0.005
- MCE
  - per ASCE 7-05
  - seven ground motion pairs
  - ductile actions
    - mean demands
    - expected materials, ϕ = 1
  - brittle actions
    - 1.5 x mean demands
    - specified materials, ϕ = 1
  - transient drift ≤ 0.03
- Minimum base shear
  - waived
  - strength controlled by 25-yr EQ and Wind

The Performance Study



Design C



PACIFIC EARTHQUAKE ENGINEERING
RESEARCH CENTER

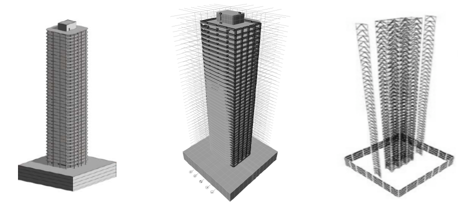
Seismic Design Guidelines for Tall Buildings

Developed by the Pacific Earthquake Engineering Research Center (PEER) as part of the Tall Building Initiative

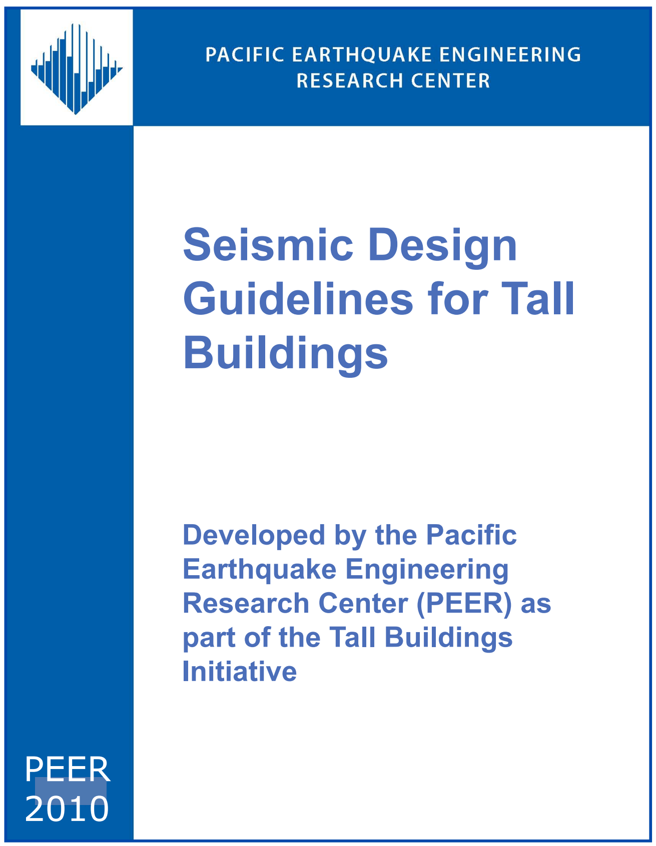
PEER
2010

- Substitute TBI Guidelines for LA Tall Building Guidelines (2008)
- Seismic design to disregard all code requirements
- Design verified by nonlinear analysis
- Wind and gravity design to follow code

The Performance Study



Design C


PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

Seismic Design Guidelines for Tall Buildings

Developed by the Pacific Earthquake Engineering Research Center (PEER) as part of the Tall Buildings Initiative

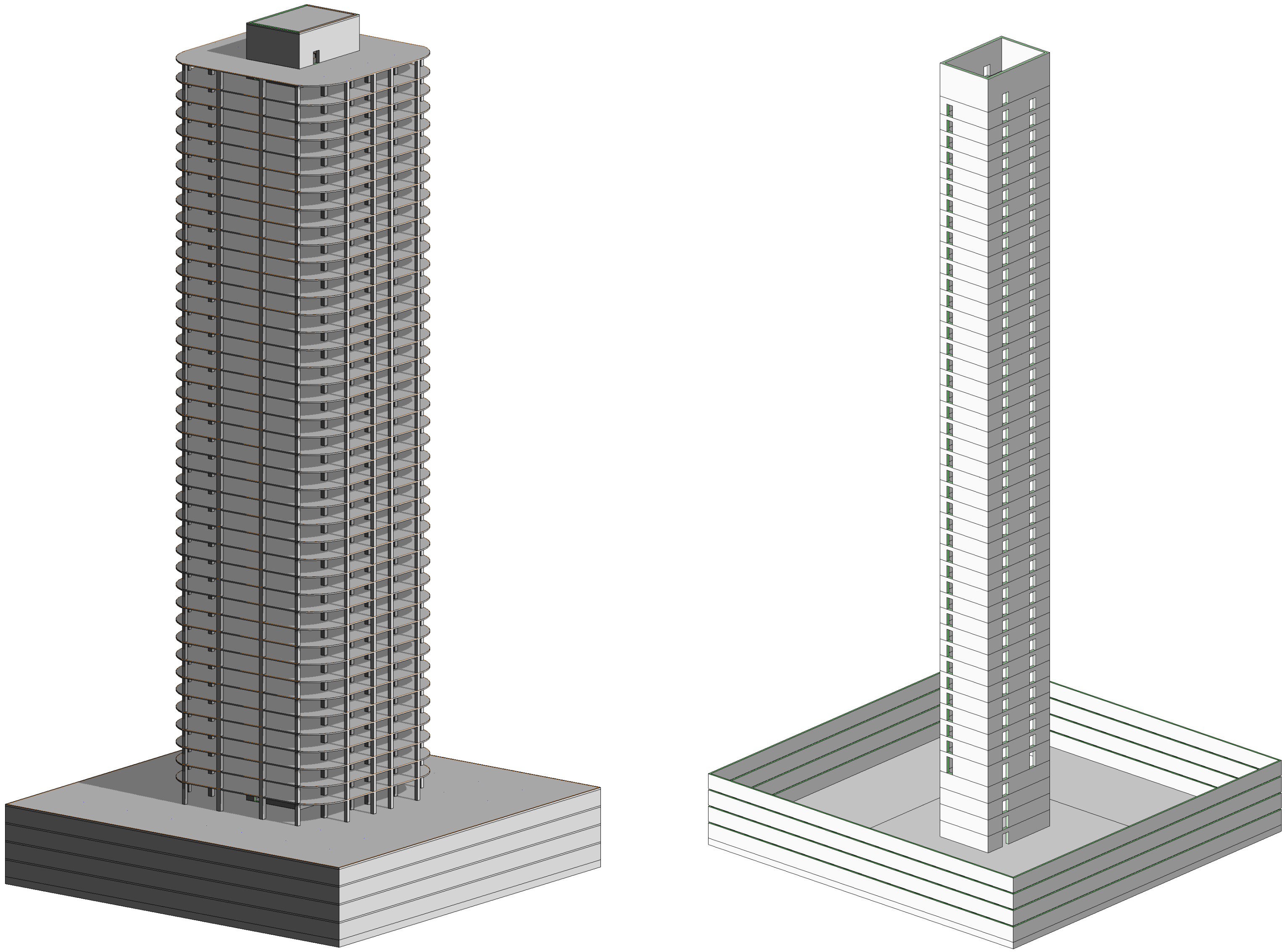
PEER 2010

- 2 Design Levels
  - Serviceability
  - MCE
- Serviceability check
  - 43-yr return period
  - response spectrum analysis (or nonlinear analysis)
  - essentially elastic: D/C ≤ 1.5
  - C based on nominal strength & code ϕ
  - transient drift ≤ 0.005
- MCE
  - per ASCE 7-05
  - seven ground motion pairs
  - ductile actions
    - mean demands
    - expected materials, $\phi = 1$
  - brittle actions
    - 1.5 x mean demands
    - expected materials, ϕ per code
  - transient story drifts
    - mean ≤ 0.03
    - max ≤ 0.045
  - residual story drifts
    - mean ≤ 0.01
    - max ≤ 0.015
- Minimum base shear
  - waived
  - strength controlled by 43-yr EQ and Wind

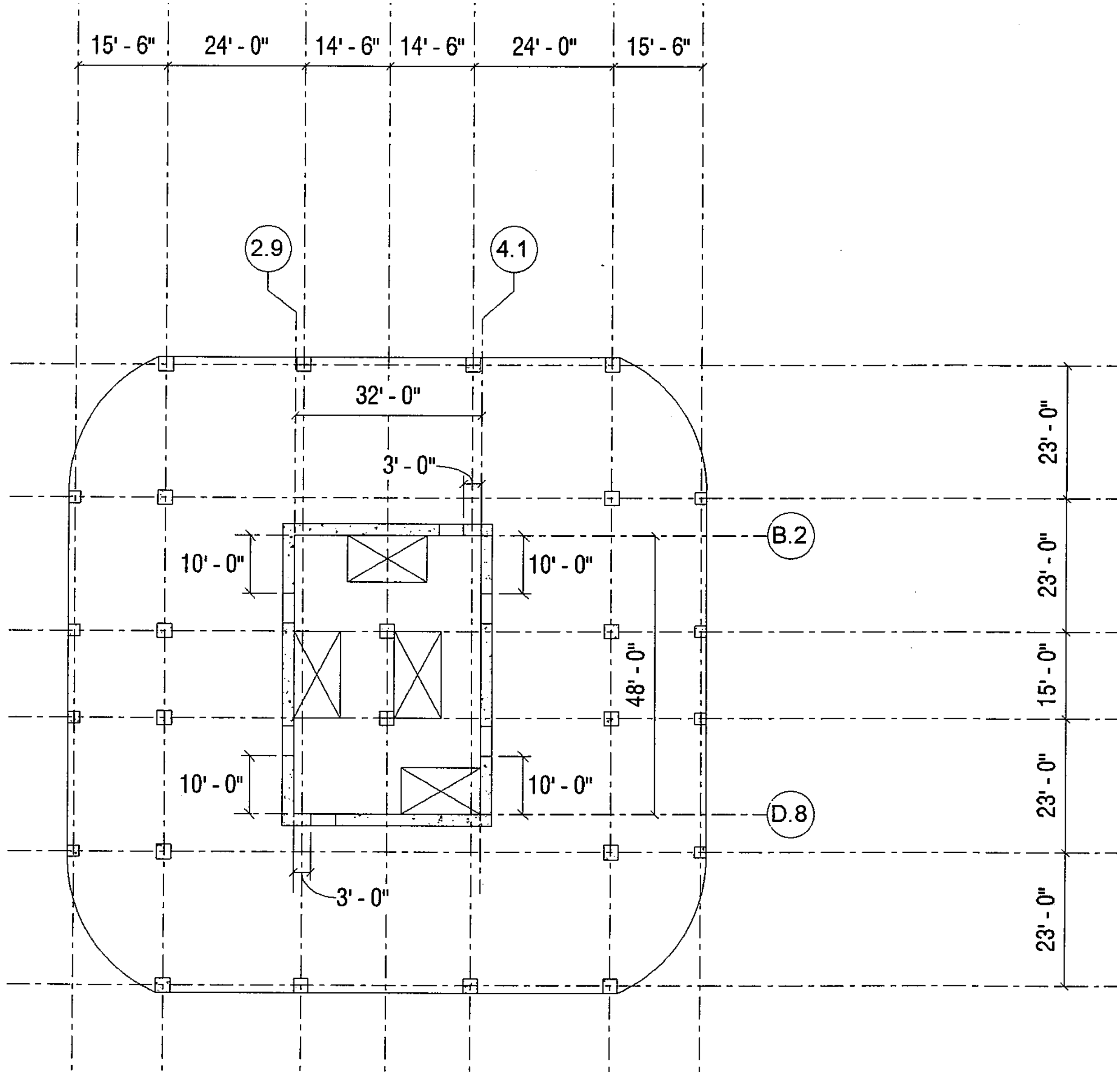
Building 1 Example—Information

- Located in Los Angeles
- 42-Story Residential Building
- 410 ft Tall
- 108 ft X 107 ft Plan Dimensions
- Core Wall System
- Approximate Period: 5 Sec

Tower and Core Wall Isometric

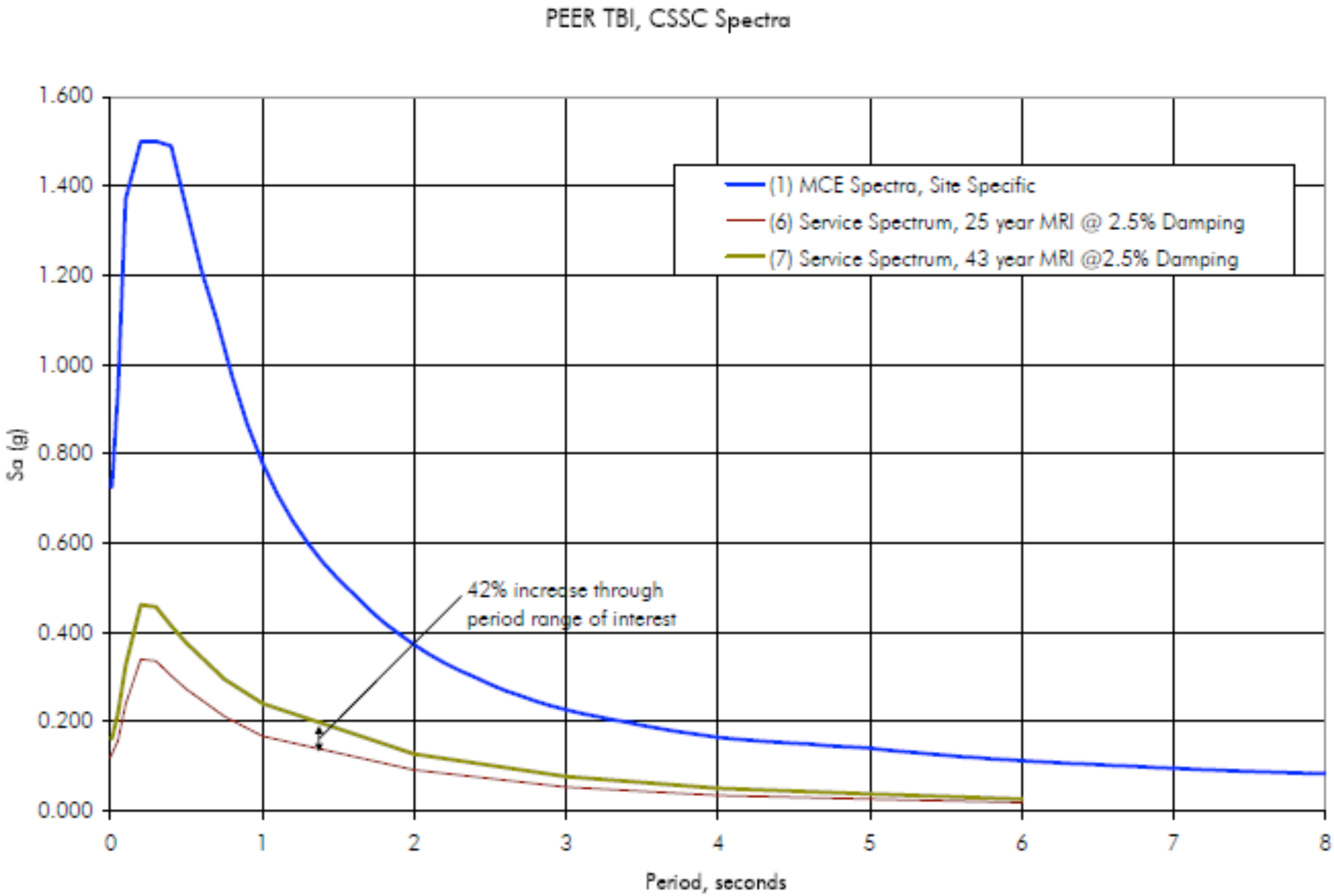


Tower Plan



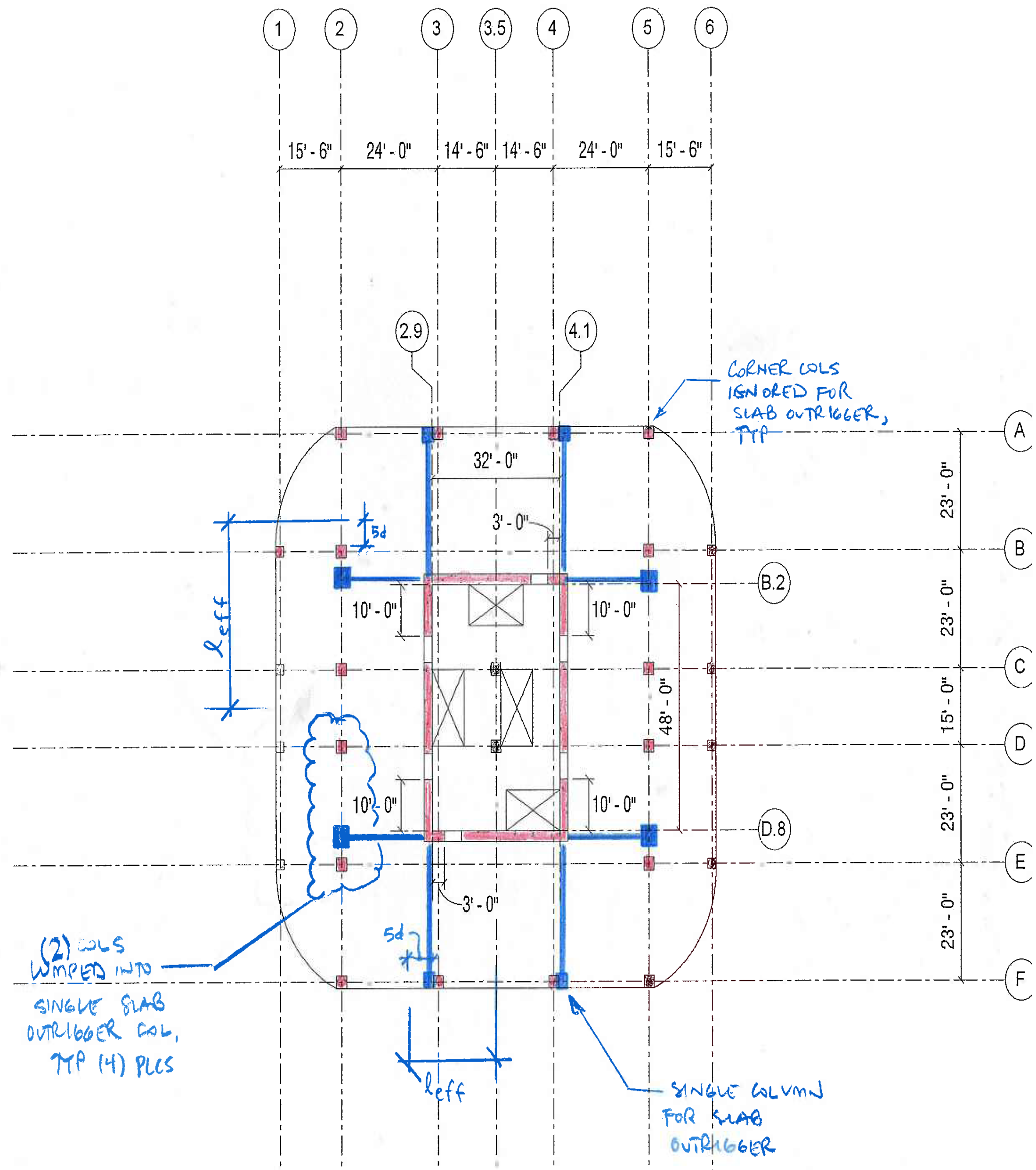
15' - 6"
24' - 0"
14' - 6"
14' - 6"
24' - 0"
15' - 6"
2.9
4.1
32' - 0"
3' - 0"
B.2
D.8
10' - 0"
10' - 0"
10' - 0"
10' - 0"
48' - 0"
3' - 0"
23' - 0"
23' - 0"
15' - 0"
23' - 0"
23' - 0"

Design B & C Seismic Hazard Spectra



Design B & C—Serviceability Model

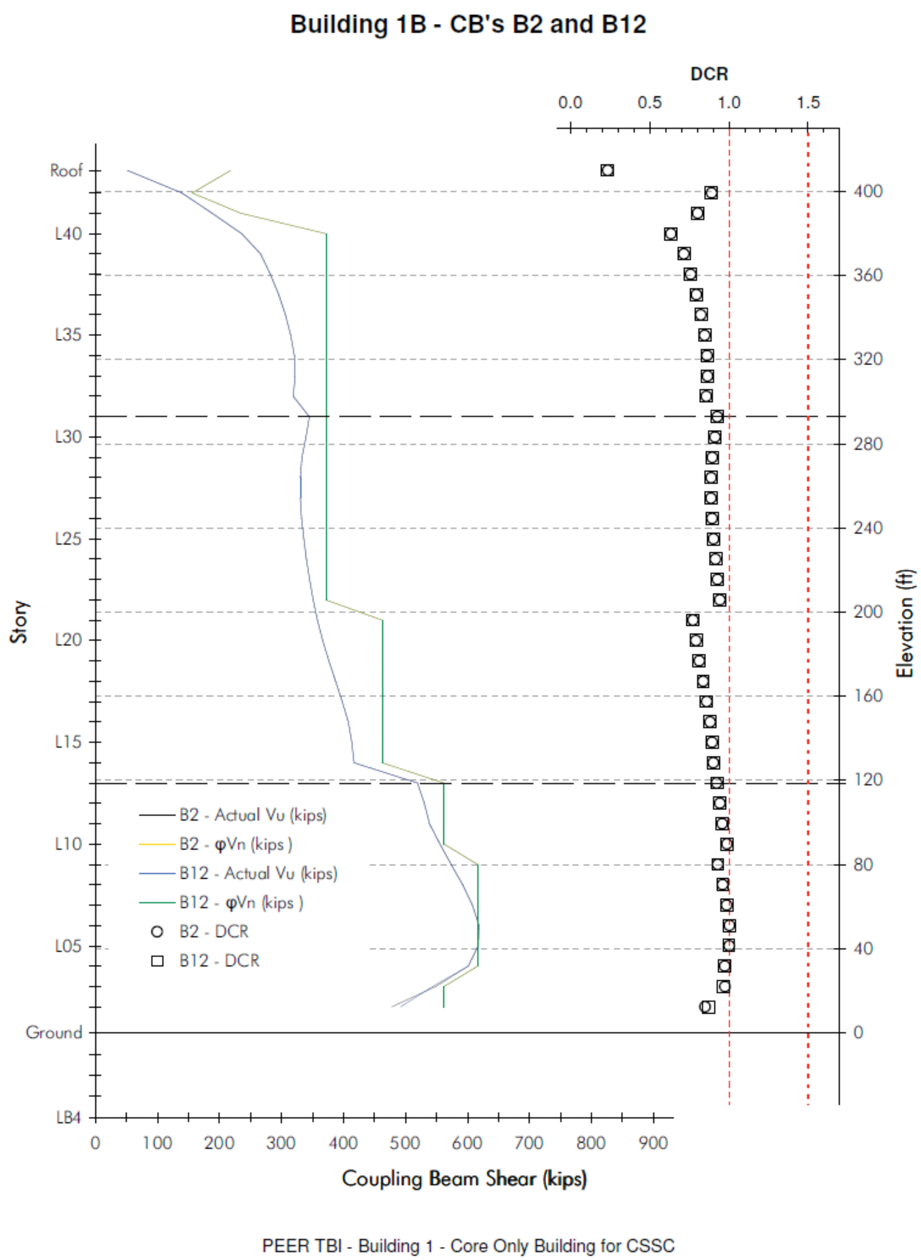
- 3-D Model using ETABS
- Elastic RSA
- Model Included Slab Outriggers

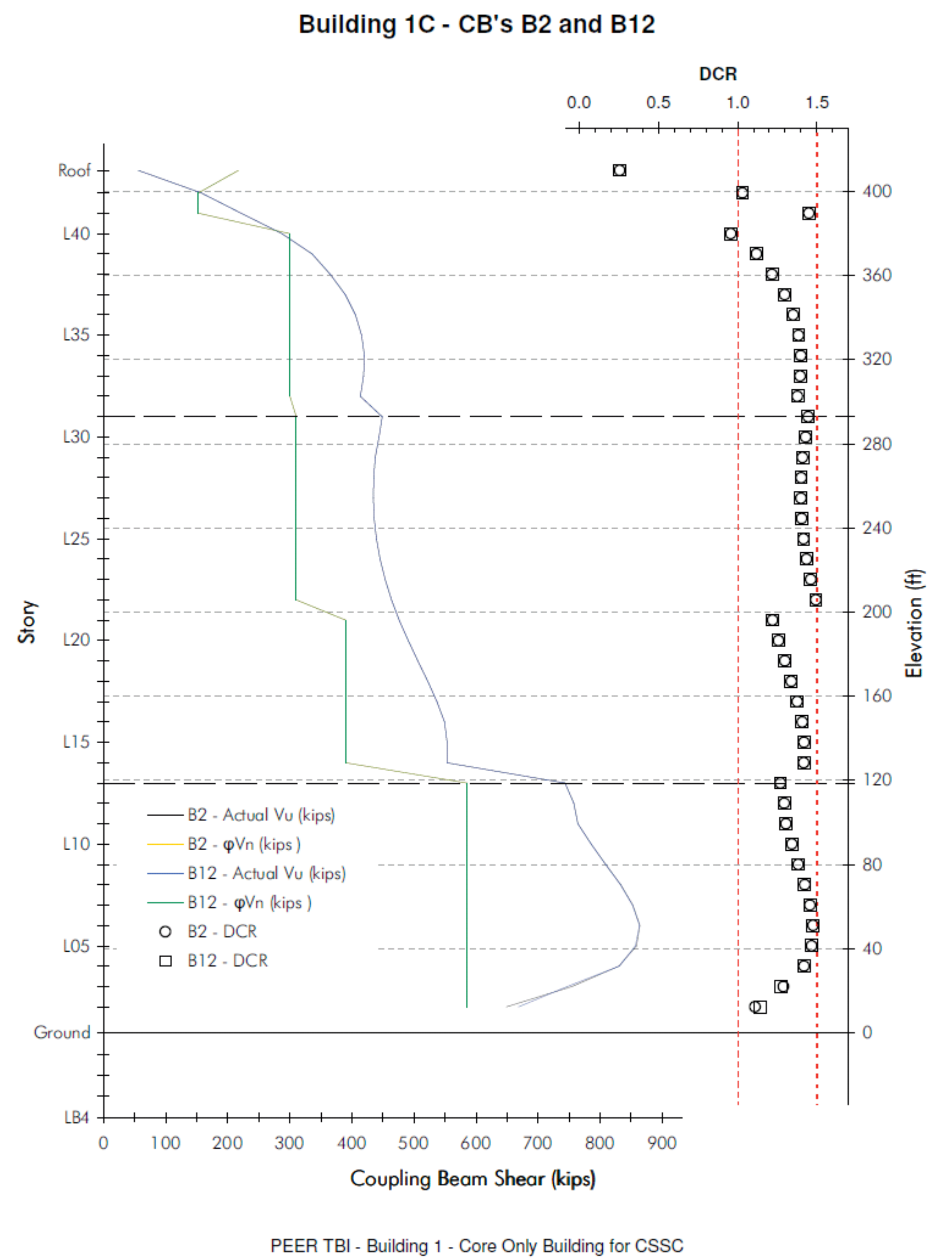


Summary of Results—Code & Serviceability

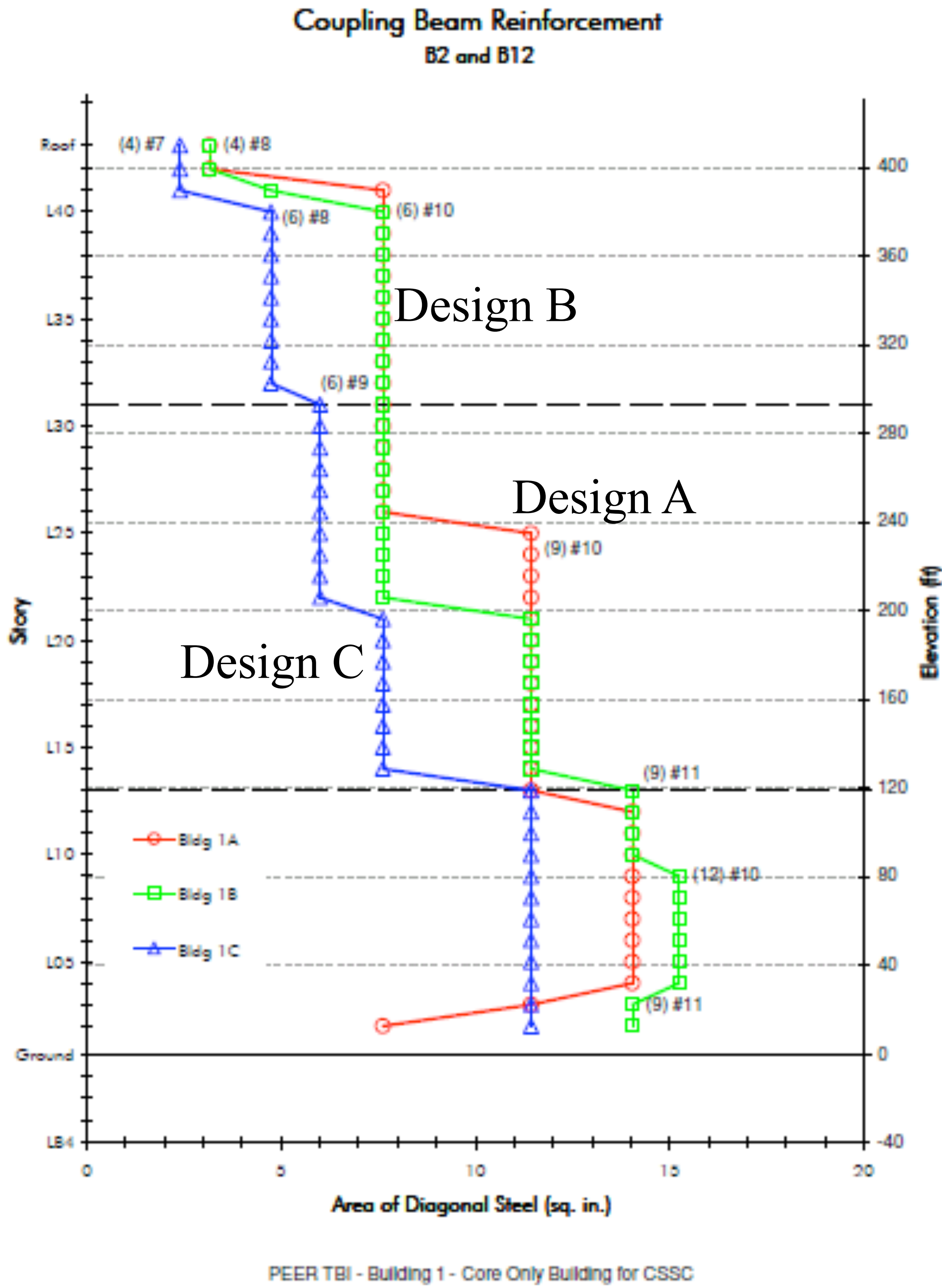
	Design A	Design B	Design C
	Building 1A	Building 1B	Building 1C
Code/Service EQ Base Shear (kips)	Vx = 4,581 Vy = 4,581	Vx = 5,013 Vy = 6,018	Vx = 6,686 Vy = 8,151
Service EQ Overturning Moment (kip-ft)	My = 587,000 Mx = 697,000	My = 591,000 Mx =921,000	My = 892,000 Mx =1,371,000
Wall thicknesses	Grade – Lvl 25 = 24 in Lvl 25 – Roof = 21 in	Grade – Lvl 13 = 28 in (E-W) and 32 in (N-S) Lvl 13 – Lvl 31 = 24 in Lvl 31 – Roof = 21 in	Grade – Lvl 13 = 32 in (E-W) and 36 in (N-S) Lvl 13 – Lvl 31 = 24 in Lvl 31 – Roof = 21 in
Periods (sec)	6.7 4.8 2.6 (ETABS)	4.2 3.4 2.3 (PERFORM)	4.0 3.2 2.2 (PERFORM)

Design B Design C

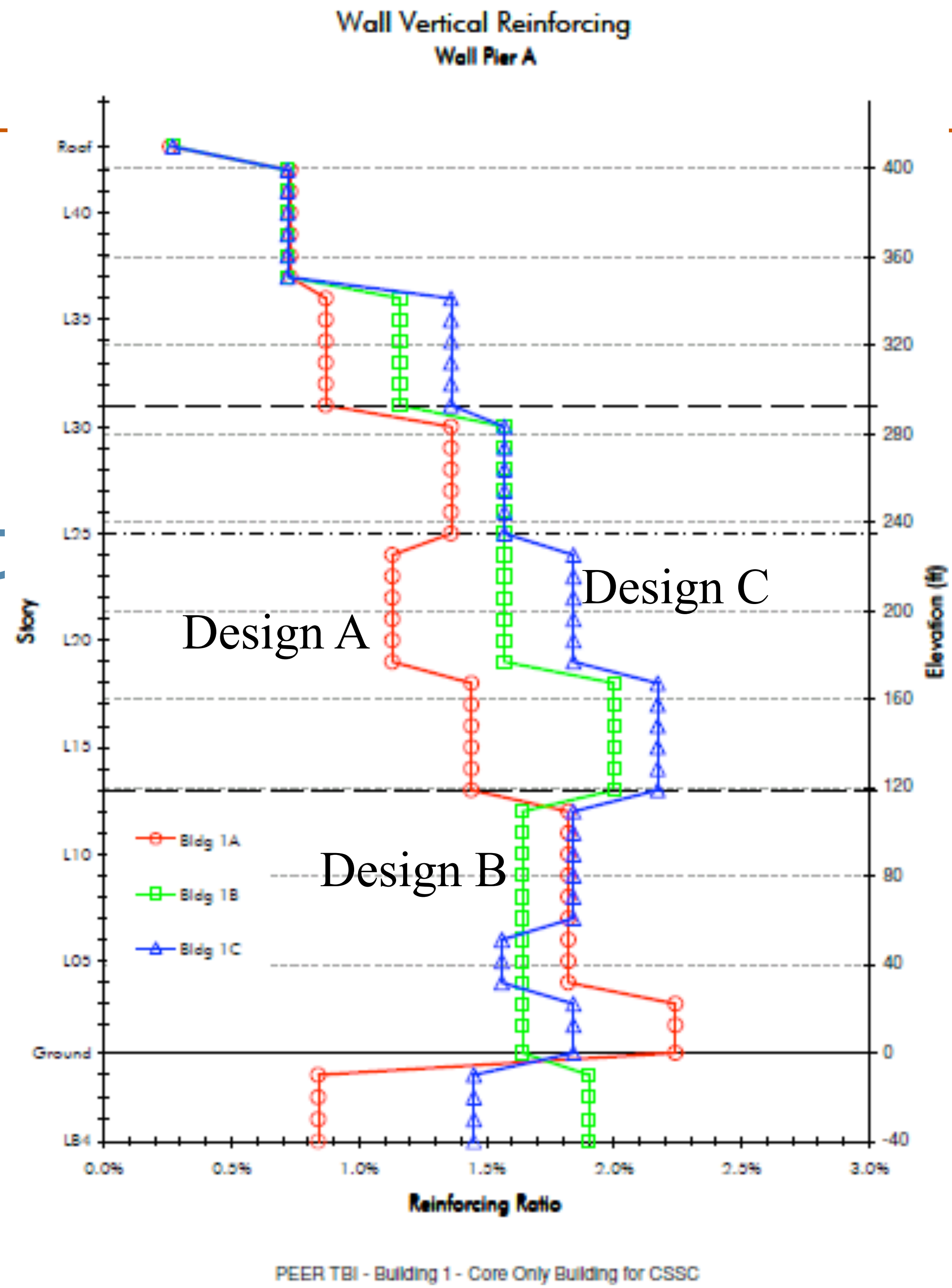




Coupling Beam Reinforcement



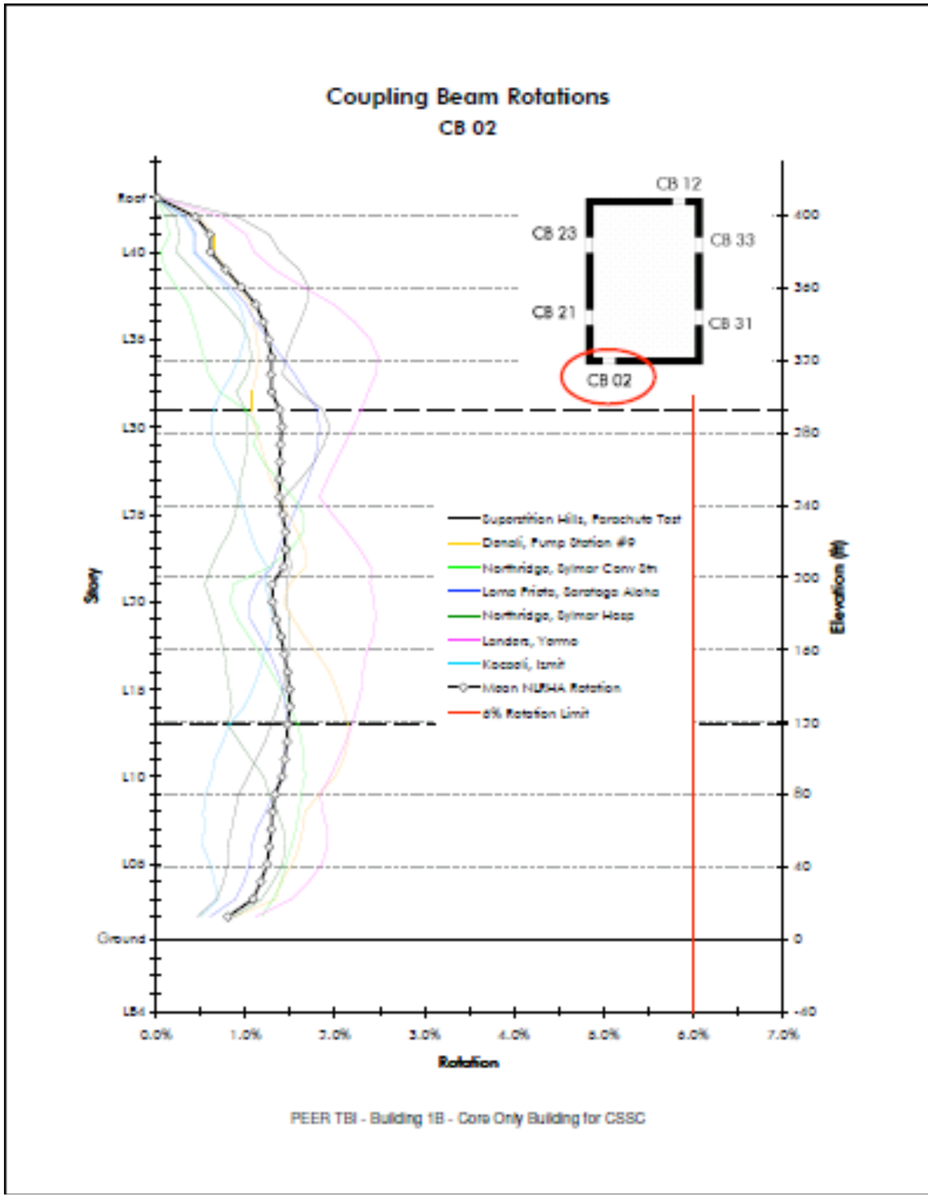
Vertical Wall Reinforcement

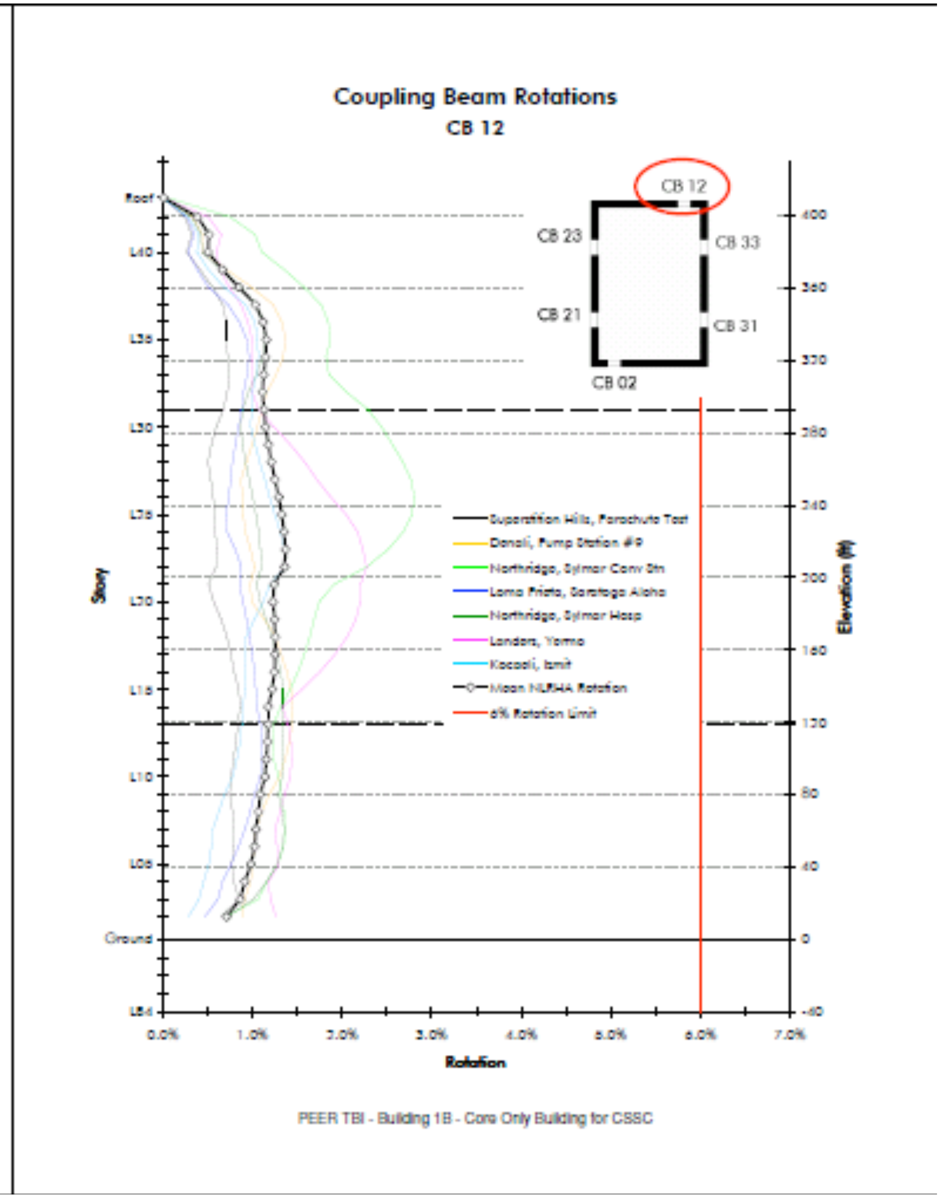


Design B & C—MCE Model

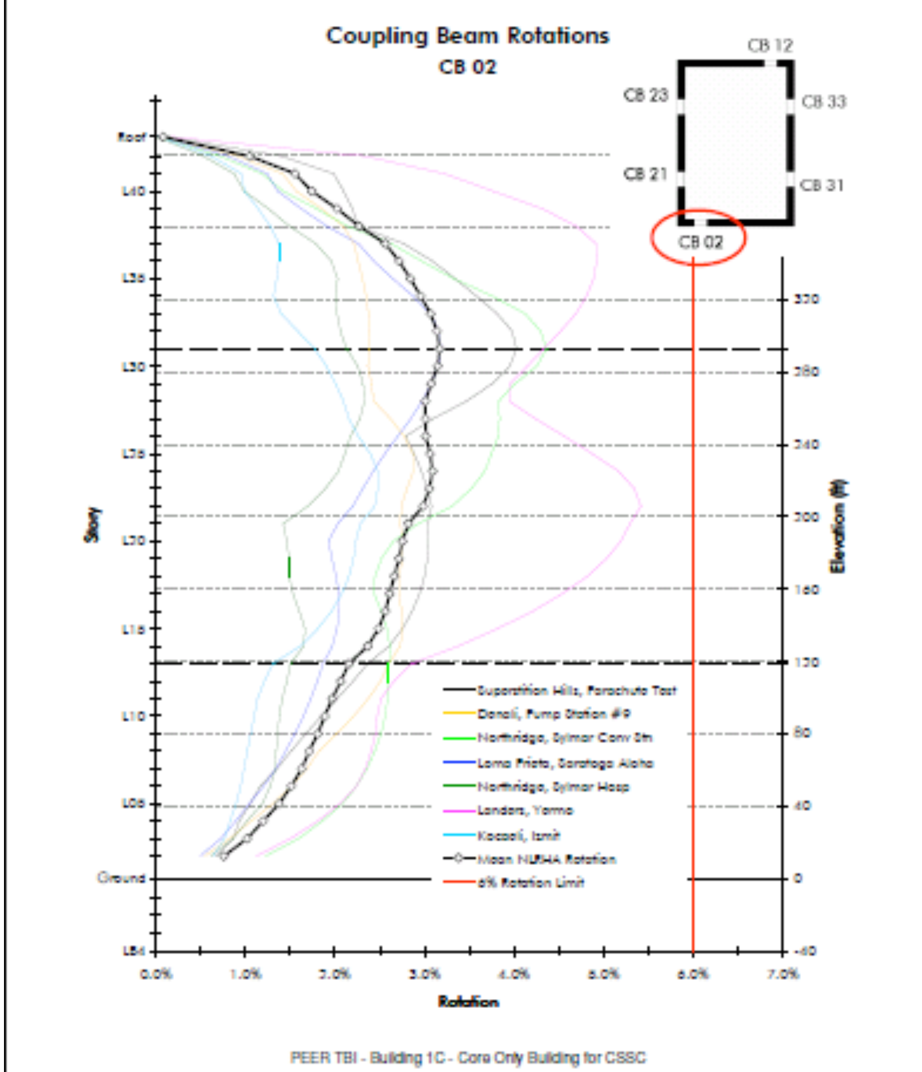
- 3-D model using CSI Perform-3D
- Modeled as inelastic:
  - Coupling beams
  - Core wall flexural behavior
  - “Slab-beams”
- Modeled as elastic:
  - Core wall shear behavior
  - Diaphragm slabs
  - Columns
  - Basement walls
- Model extended to mat

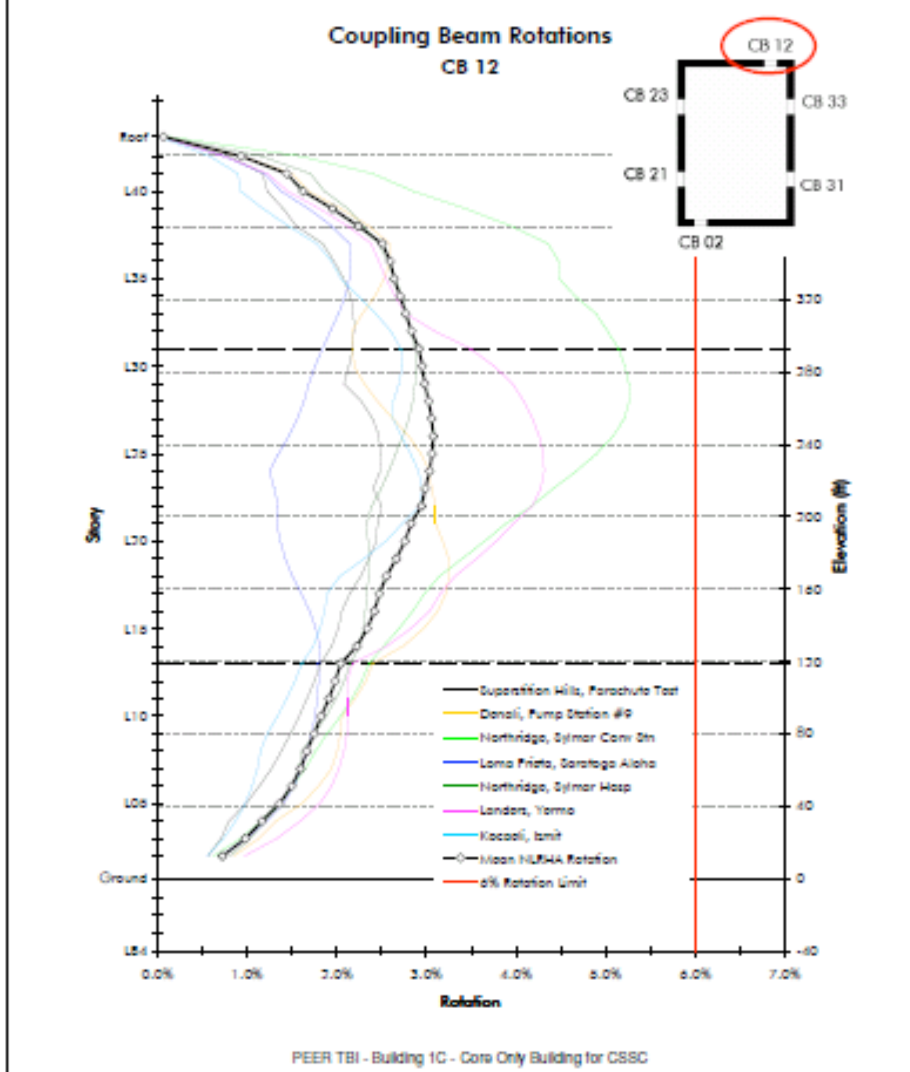
Design B Coupling Beam Rotations



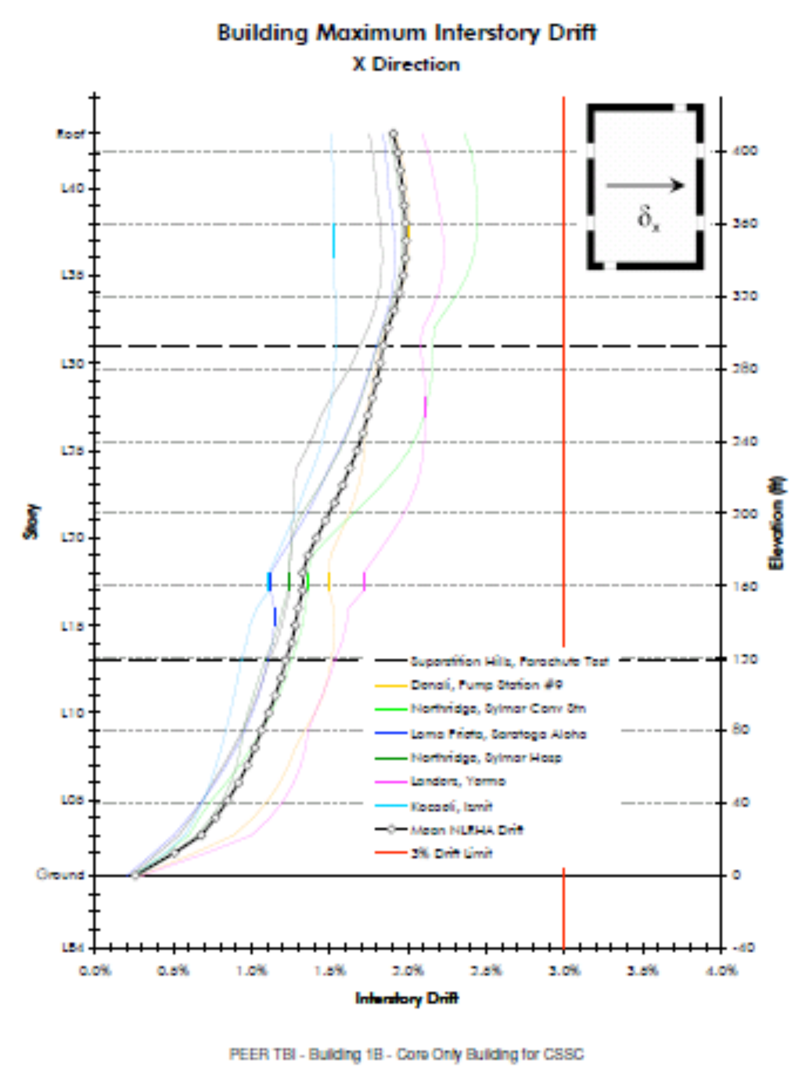


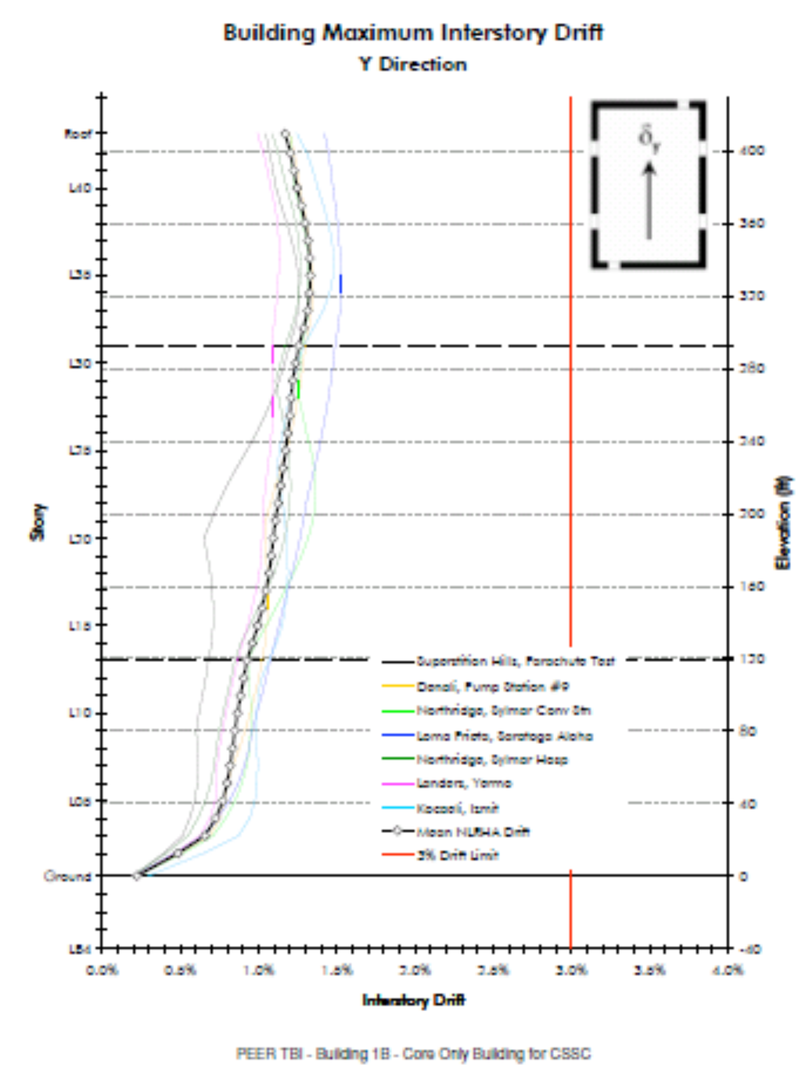
Design C Coupling Beam Rotations



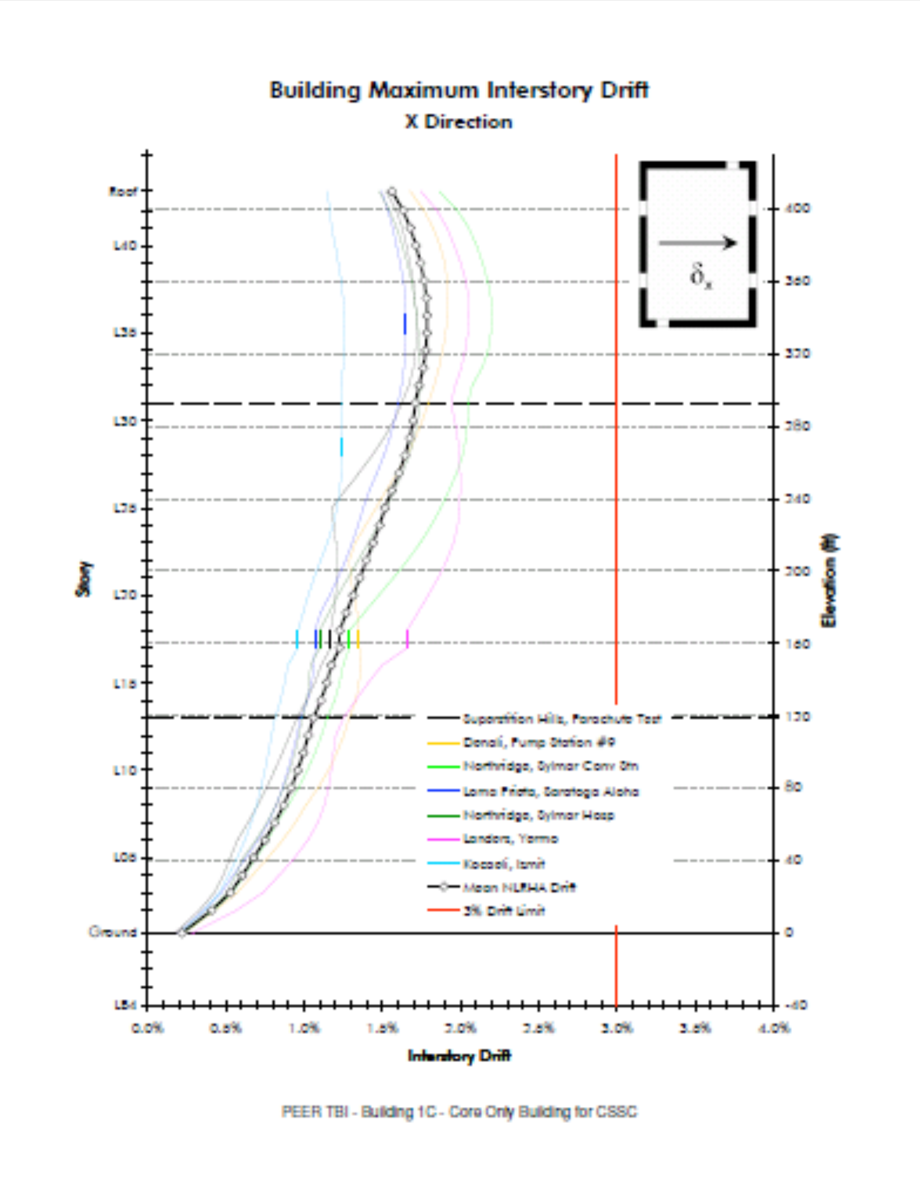


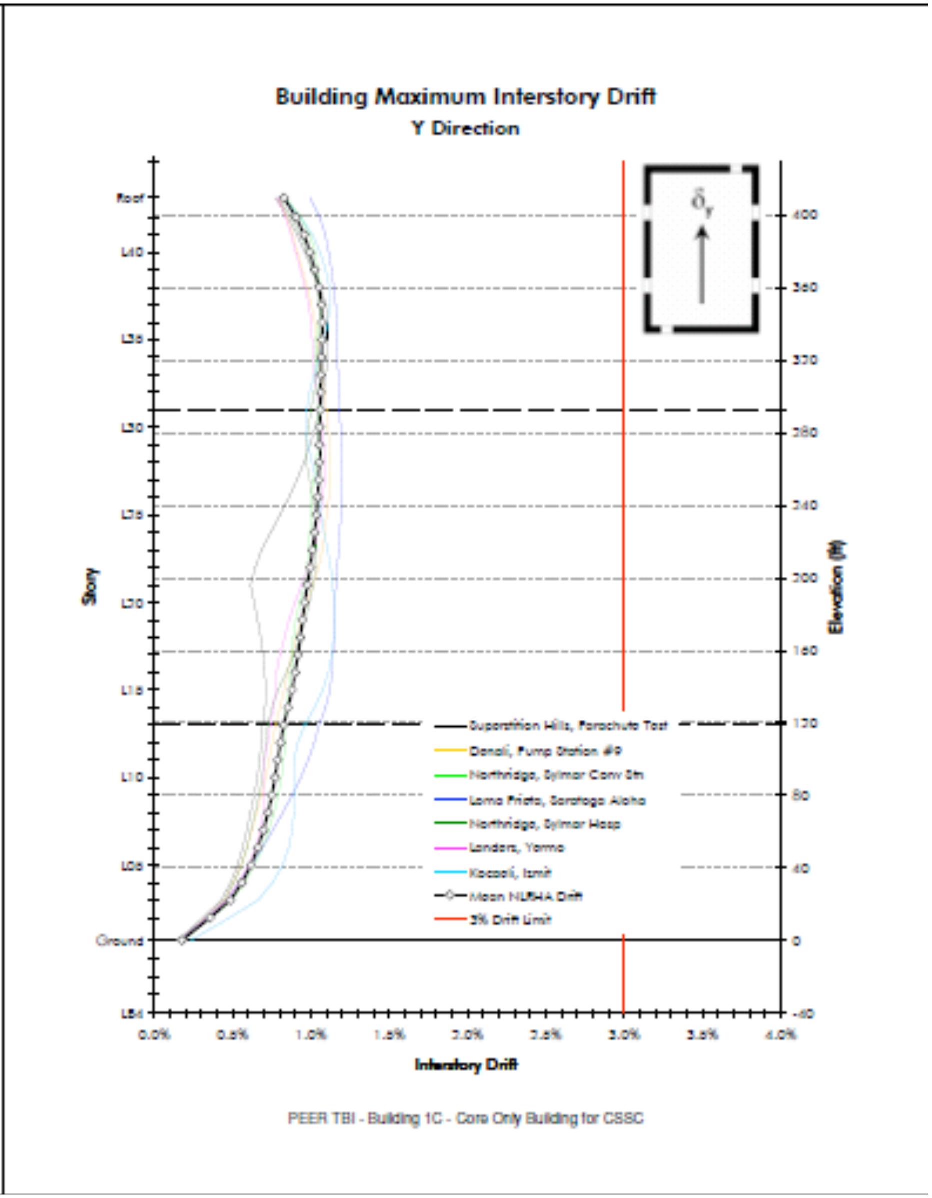
Design B Story Drifts





Design C Story Drifts





Building 1 Observations

- Core wall shear is the governing design parameter & governs wall thickness

- Serviceability Design governed over Wind Design for Design B & C

- Walls thicker for Design C vs. Design B vs. Design A

- Serviceability Demands of Design C > Design B > Design A

Building 1 Observations

- Coupling Beam Reinforcement for Design C < Design B ~ Design A
- Vertical Wall Reinforcement for Design C > Design B > Design A
- Design C Results in Greater Strong Pier—Weak Coupling Beam Performance than Design A & B