TBI

Tall Buildings Initiative

Guidelines for Performance-Based Seismic Design of Tall Buildings

Version 1.0
November 2010

Developed by
Pacific Earthquake Engineering Research Center
Report No. 2010/05

Sponsored by
Charles Pankow Foundation
California Seismic Safety Commission
California Emergency Management Agency
Los Angeles Department of Building and Safety

PEER

(ATC 58)

Next-Generation Performance-Based Seismic Design Guidelines

Program Plan for New and Existing Buildings

FEMA-445 / August 2006

FEMA

nehrp

TBI Partners

- Applied Technology Council
- California Geological Survey
- California Emergency Management Agency
- California Seismic Safety Commission
- FEMA
- Los Angeles Dept. of Buildings & Safety
- Los Angeles Tall Buildings Council
- National Science Foundation
- Pankow Foundation
- PEER
- San Francisco Building Department
- SCEC
- SEAOC
- USGS

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- TBI Guidelines Development Team
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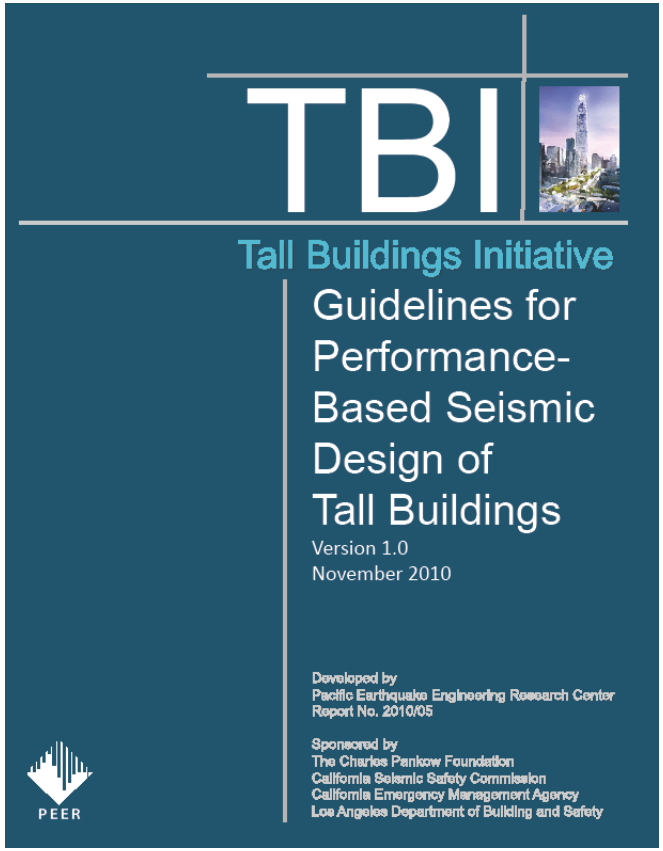
    - UCI – F. Zareian, P. Zhong, P. Jones
  - Loss Studies
    - ATC 58 – R. Hamburger, J. Hooper, P. Morris, T. Yang, J. Moehle
    - RMS – N. Shome, M. Rahnama, P. Seneviratna; H. Aslani

TBI Guidelines Chapters

1. Introduction
2. Performance objectives
3. Design process
4. Design criteria documentation
5. Seismic input
6. Preliminary design
7. Service level evaluation
8. MCE level evaluation
9. Presentation of results
10. Project review



1. Introduction

2. Seismic performance objectives

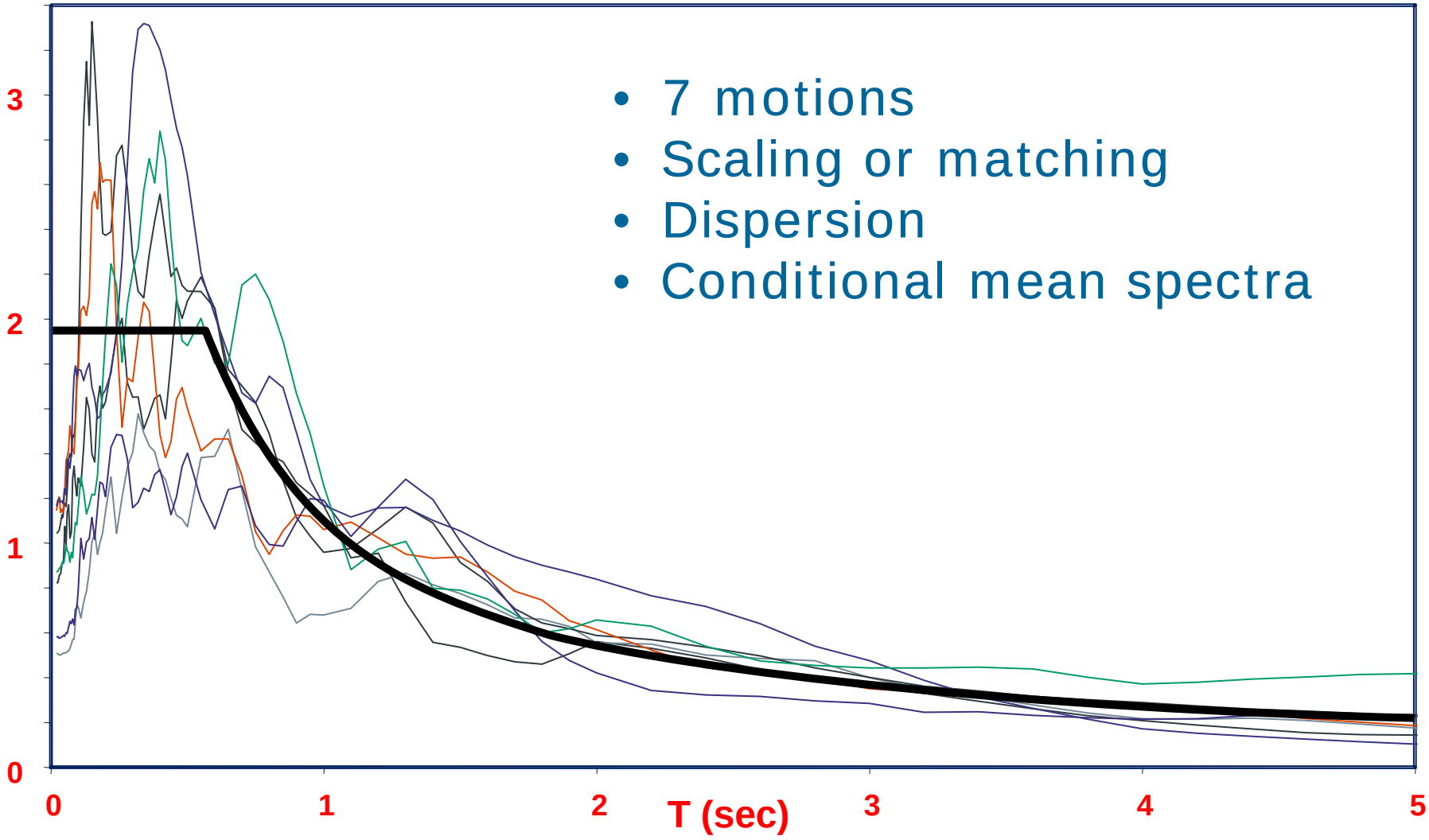
after SEAOC Vision 2000

		Earthquake Performance Level			
		Fully Operational	Operational	Life Safe	Near Collapse
Earthquake Design Level	Frequent (43 years)	Basic Objective	Unacceptable	Unacceptable	Unacceptable
	Occasional (72 years)	Essential/Hazardous Objective	Basic Objective	Unacceptable	Unacceptable
	Rare (475 years)	Safety Critical Objective	Essential/Hazardous Objective	Basic Objective	Unacceptable
	Very Rare (975 years)	Not Feasible	Safety Critical Objective	Essential/Hazardous Objective	Basic Objective

Serviceability check

Stability check

5. Ground motion selection and scaling

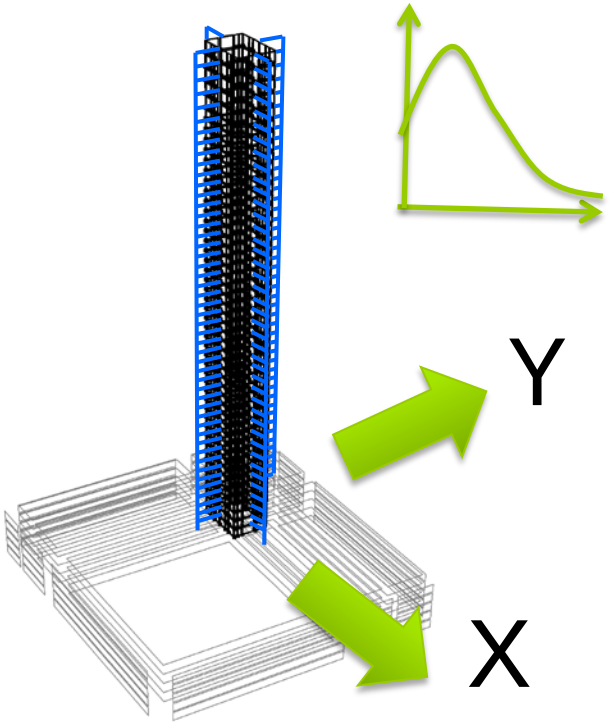


- 7 motions
- Scaling or matching
- Dispersion
- Conditional mean spectra

Service Level Analysis

- Performance Goal: Minor structural damage
- Model
  - All components that provide strength and stiffness
- Analysis
  - Linear response spectrum analysis
  - 43-yr return period, 2.5% damping
- Acceptance criterion
  - Effectively linear response

Load Combinations & Acceptance



$$Q = D + L_{\text{exp}} + 1.0E_X + 0.3E_Y$$

$$Q = D + L_{\text{exp}} + 0.3E_X + 1.0E_Y$$

$$L_{\text{exp}} = 0.25L$$

$$Q < 1.5\phi C_n$$

Story Drift < 0.005h

- C_n = nominal capacity (per code)
- ϕ = resistance factor per ACI or AISC

Maximum Considered Level Analysis

- Performance goals:
  - Minor implicit risk of collapse
  - Modest residual drift
  - Limited potential for failure of cladding
- Model
  - All components that provide strength and stiffness
- Analysis
  - Nonlinear dynamic analysis
  - MCE level
- Acceptance criteria
  - Force and deformation demands within limits
  - Transient and residual drifts within limits

Transient and residual drift

- Transient story drift
  - Mean of 7 runs < 0.03
  - Maximum of any run < 0.045
- Residual story drift
  - Mean of 7 runs < 0.01
  - Maximum of any run < 0.015

Non-ductile actions

$$F_u \le \phi F_{n,e}$$

$$F_u = 1.5\bar{F}$$

$$F_u = \bar{F} + 1.3\sigma \ge 1.2\bar{F}$$

- ϕ = 1 for inconsequential failures
- ϕ = per code otherwise

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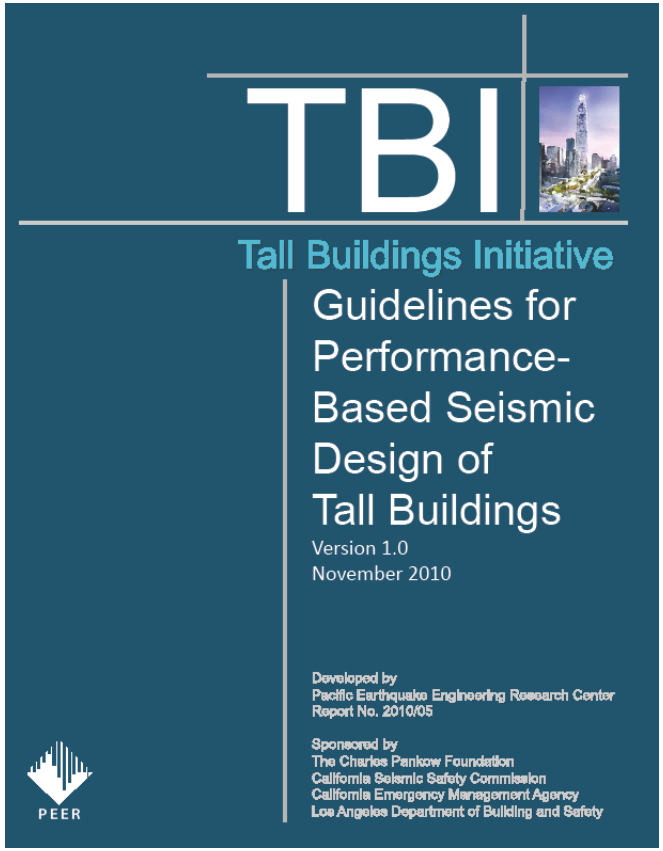


TBI Case Studies

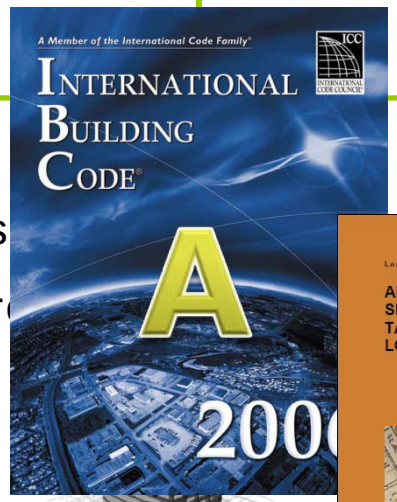
Building Design and Modeling

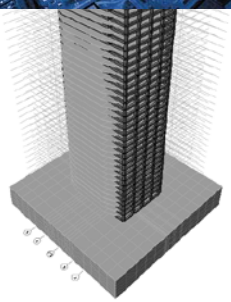
Three Building Systems

42-story reinforced concrete core wall

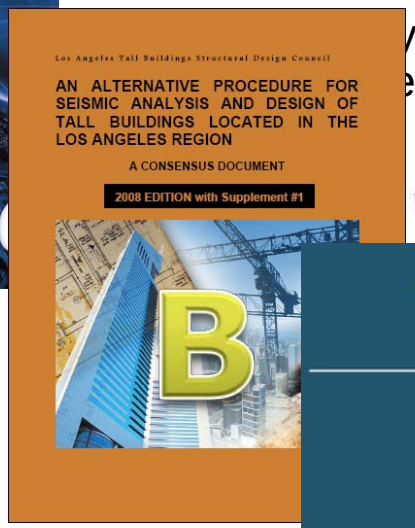
1

42-s… concr…



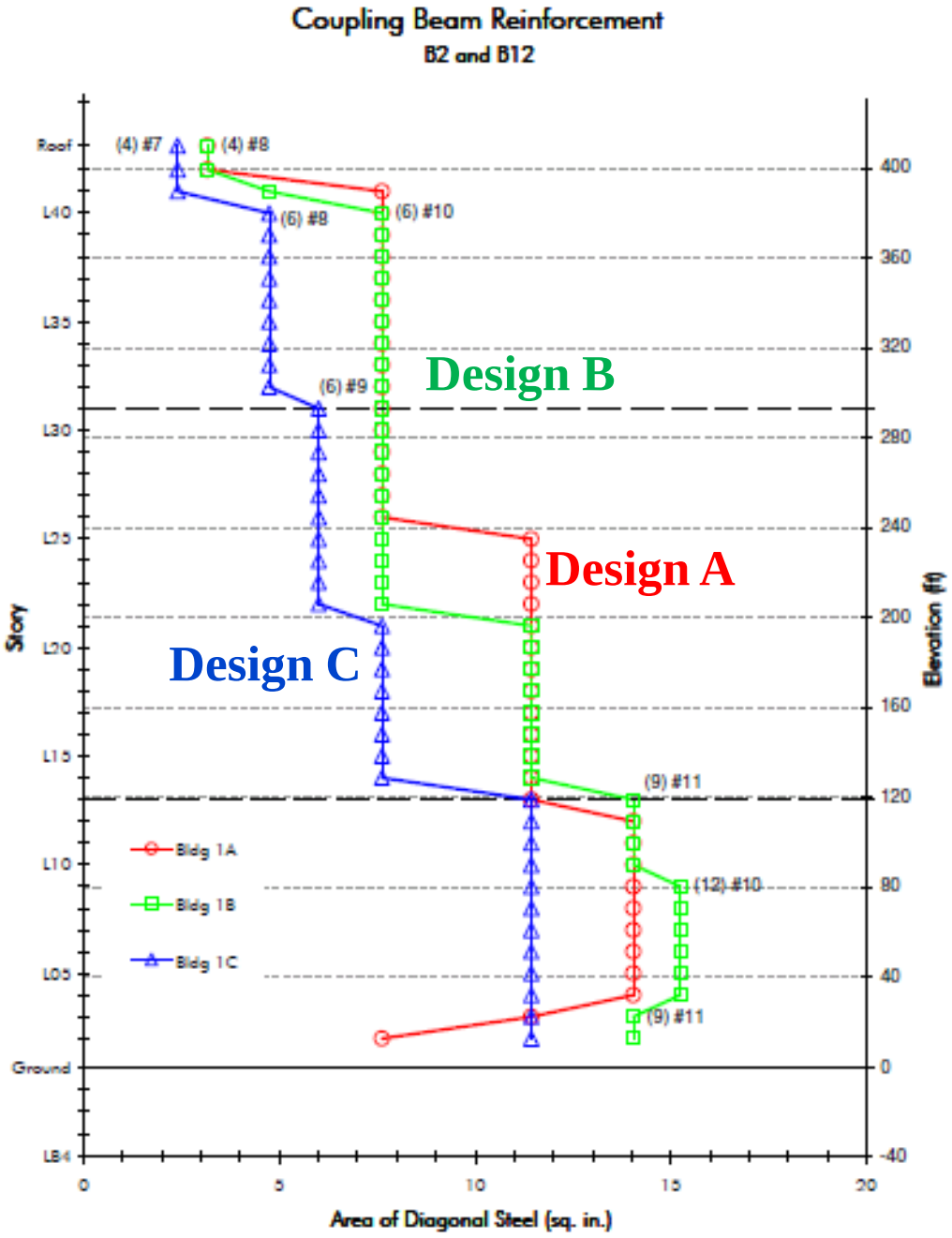


2

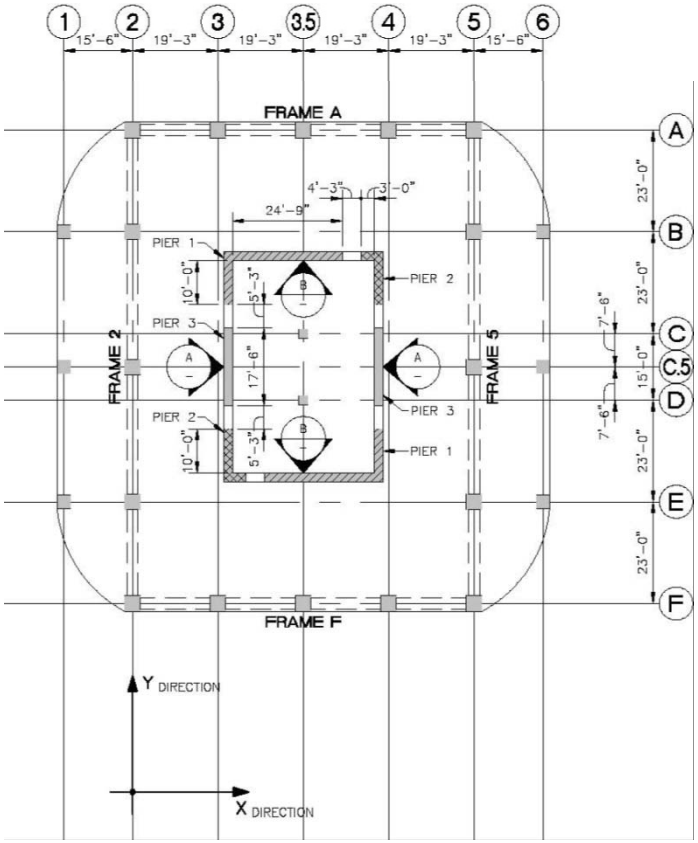


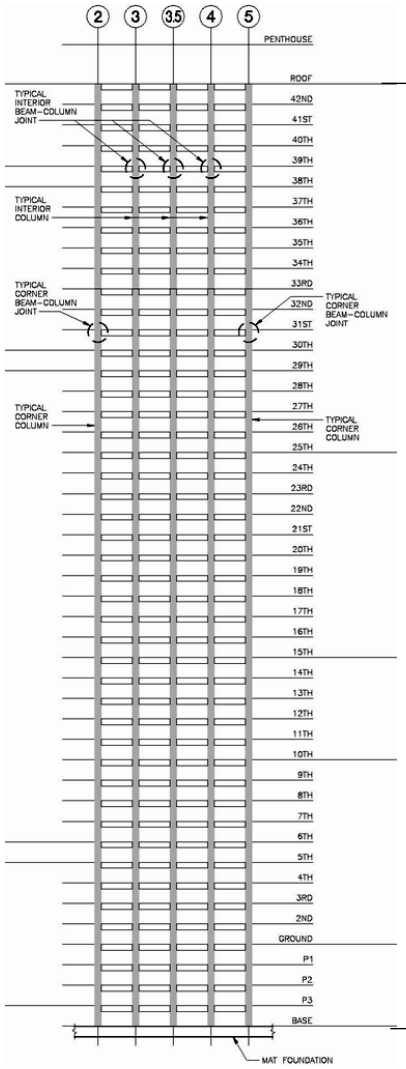
…y steel buckling-…ed braced frame

Building 1 – Core only



Building 2 – Dual system





Design A

Design B/C

36” x 36”

36” x 36”

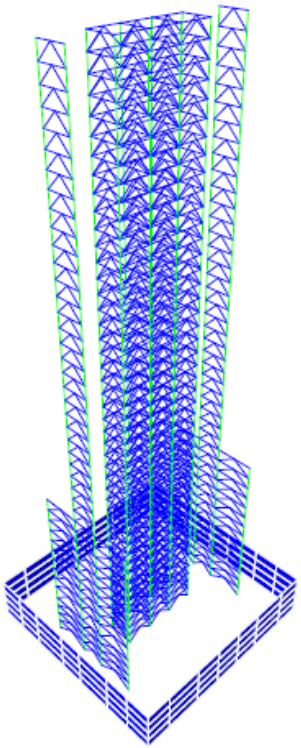
30th

42” x 42”

10th

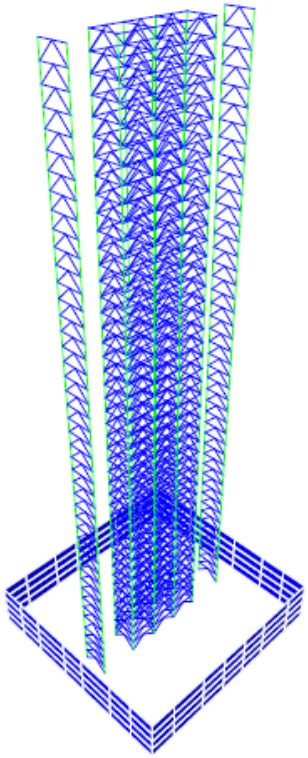
46” x 46”

Building 3 - Buckling Restrained Braced Frame



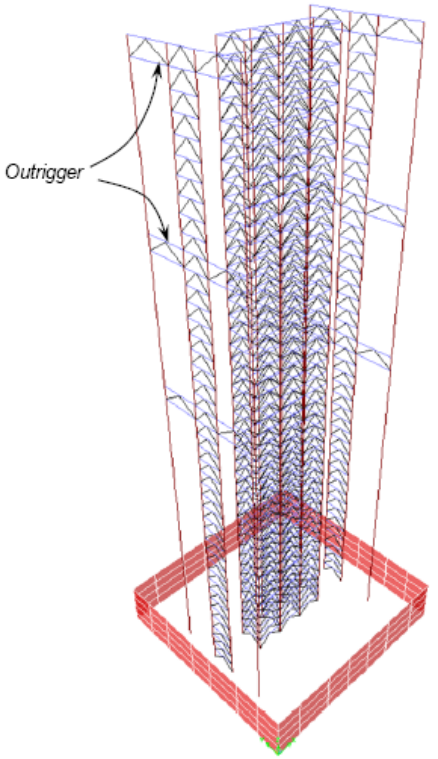
Bldg. 3A

T_{1NS} = 5.3sec



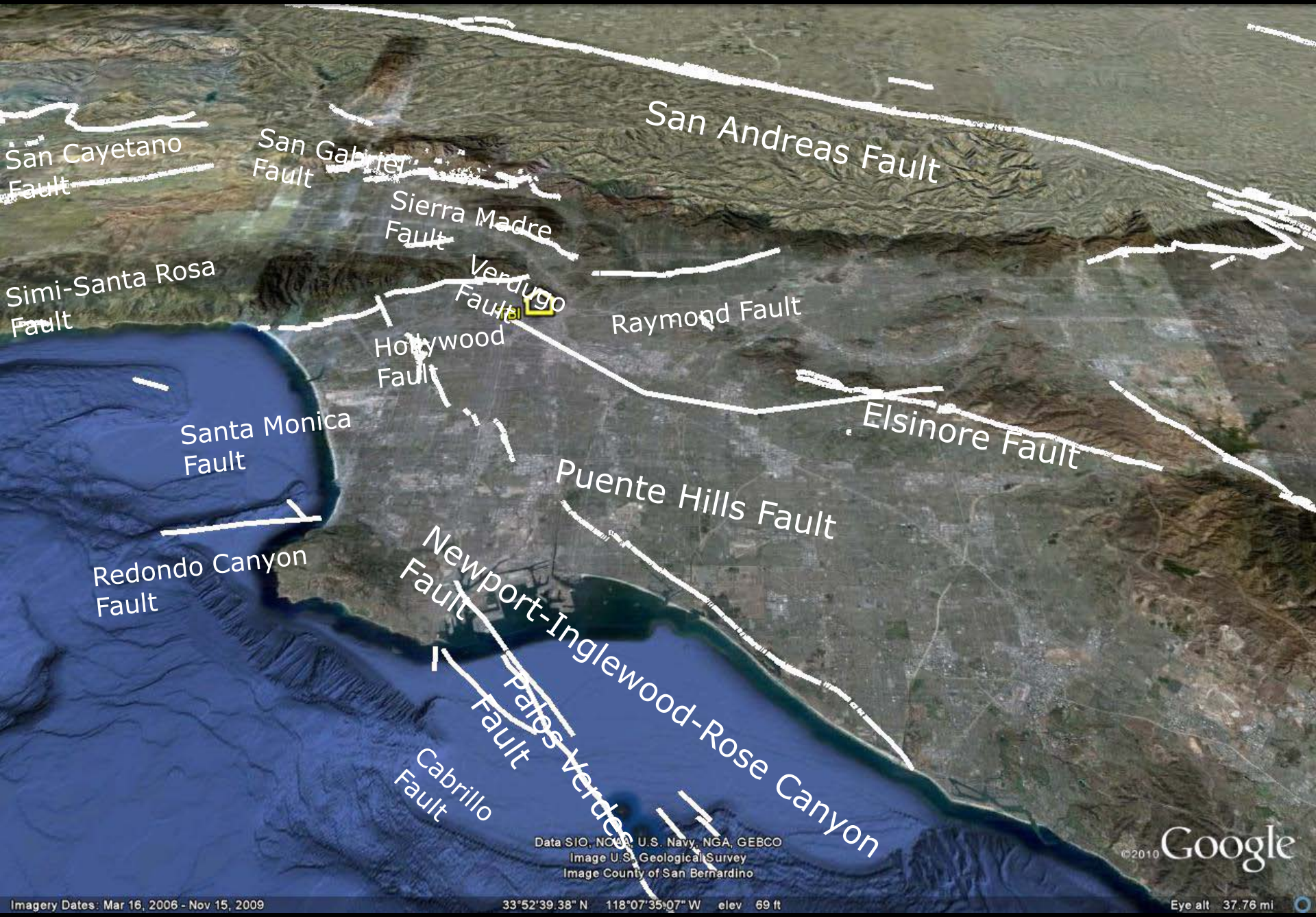
Bldg. 3B

T_{1NS} = 6.5 sec

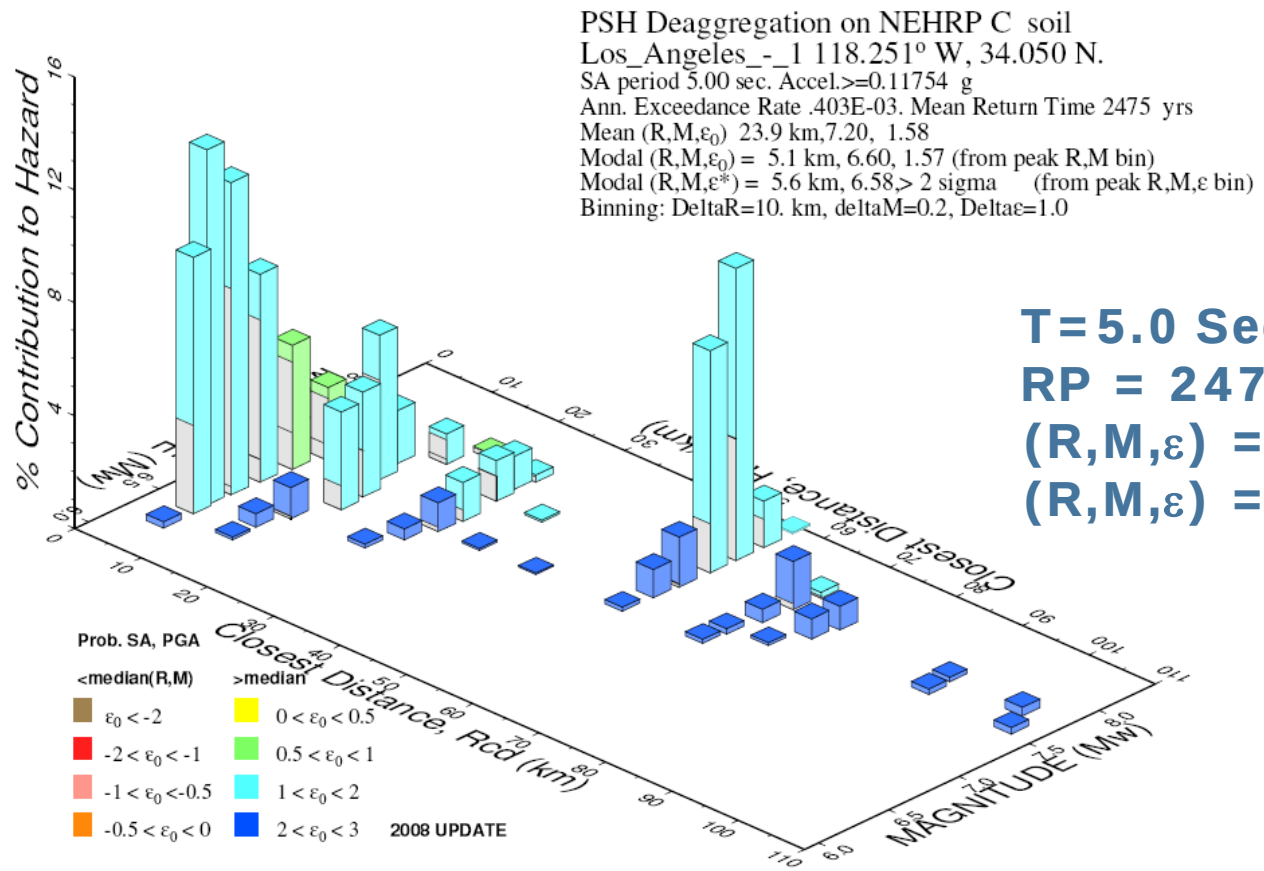


Bldg. 3C

T_{1NS}= 5.7 sec


San Andreas Fault
San Cayetano Fault
San Gabriel Fault
Sierra Madre Fault
Verdugo Fault
Simi-Santa Rosa Fault
Raymond Fault
Hollywood Fault
Santa Monica Fault
Elsinore Fault
Puente Hills Fault
Redondo Canyon Fault
Newport-Inglewood Fault
Palos Verdes Fault
Cabrillo Fault
Rose Canyon
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image U.S. Geological Survey
Image County of San Bernardino
©2010 Google
Imagery Dates: Mar 16, 2006 - Nov 15, 2009
33°52'39.38" N 118°07'35.07" W elev 69 ft
Eye alt 37.76 mi

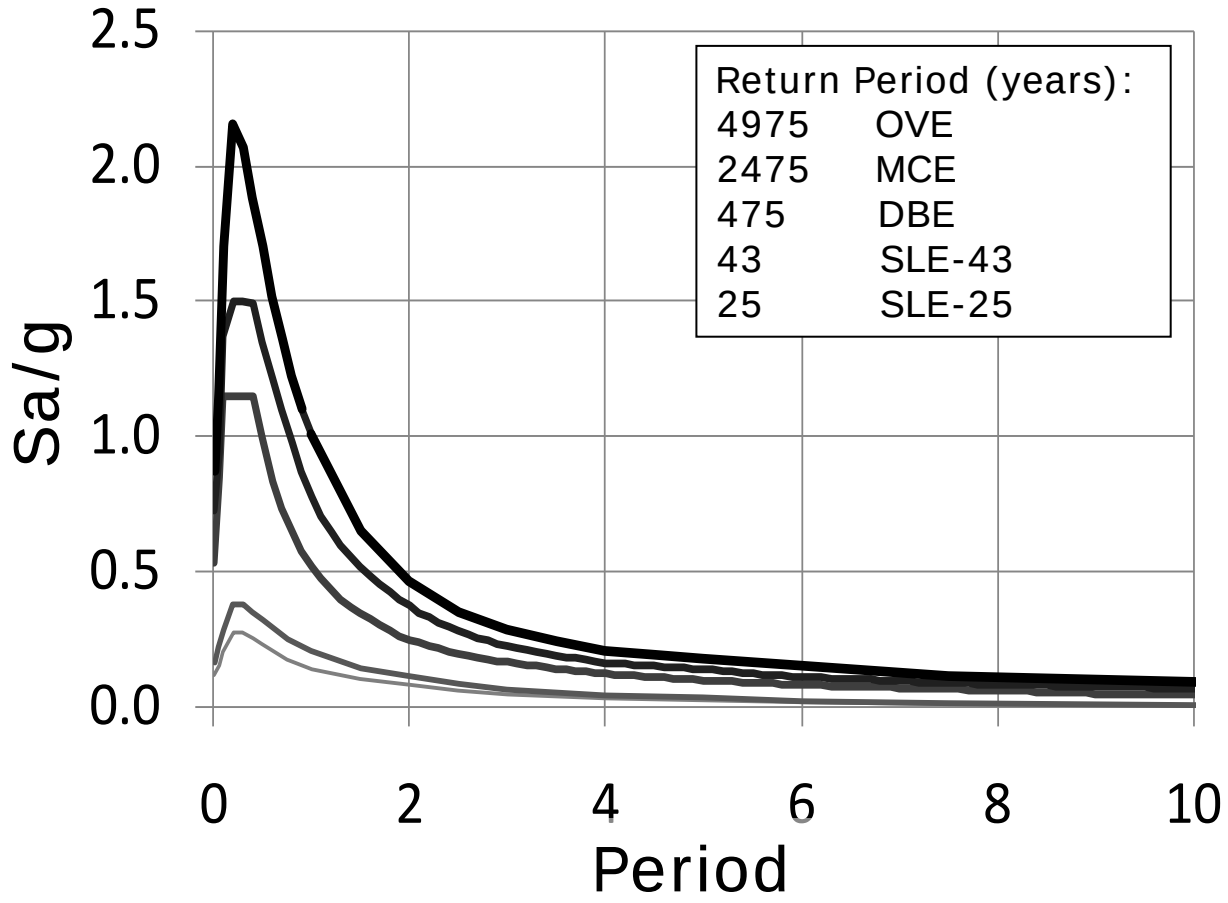
Disaggregation of Seismic Hazard

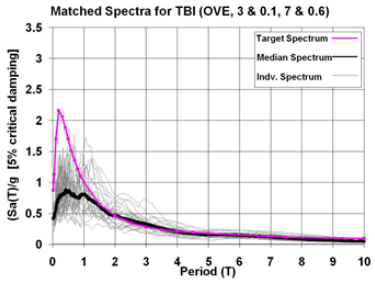


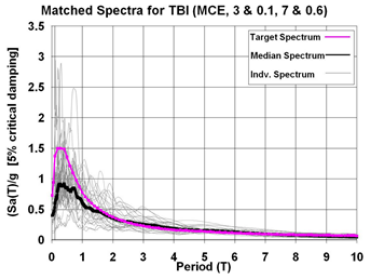
T=5.0 Sec.
RP = 2475 Years
(R,M,ε) = 5.1, 6.6,1.6
(R,M,ε) = 60., 8.0,2.0

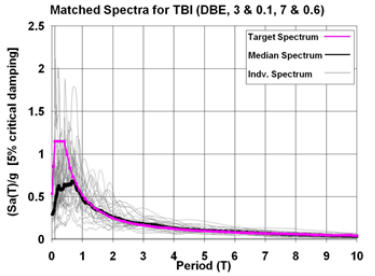
GMT 2009 Jul 3 23:55:30 Distance (R), magnitude (M), epsilon (E0,E) deaggregation for a site on soil with average vs= 525. m/s top 30 m. USGS CGHT PSHA2008 UPDATE Bins with lt 0.05% contrib. omitted

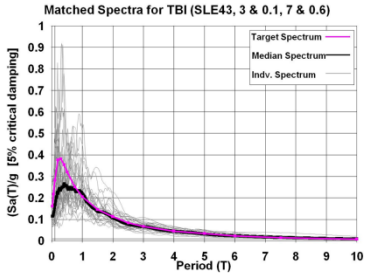
Response Spectra

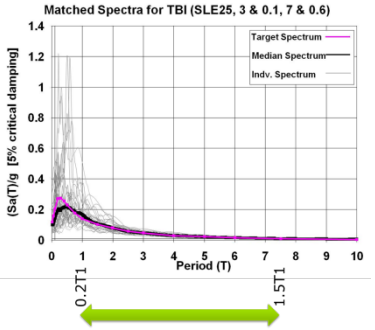






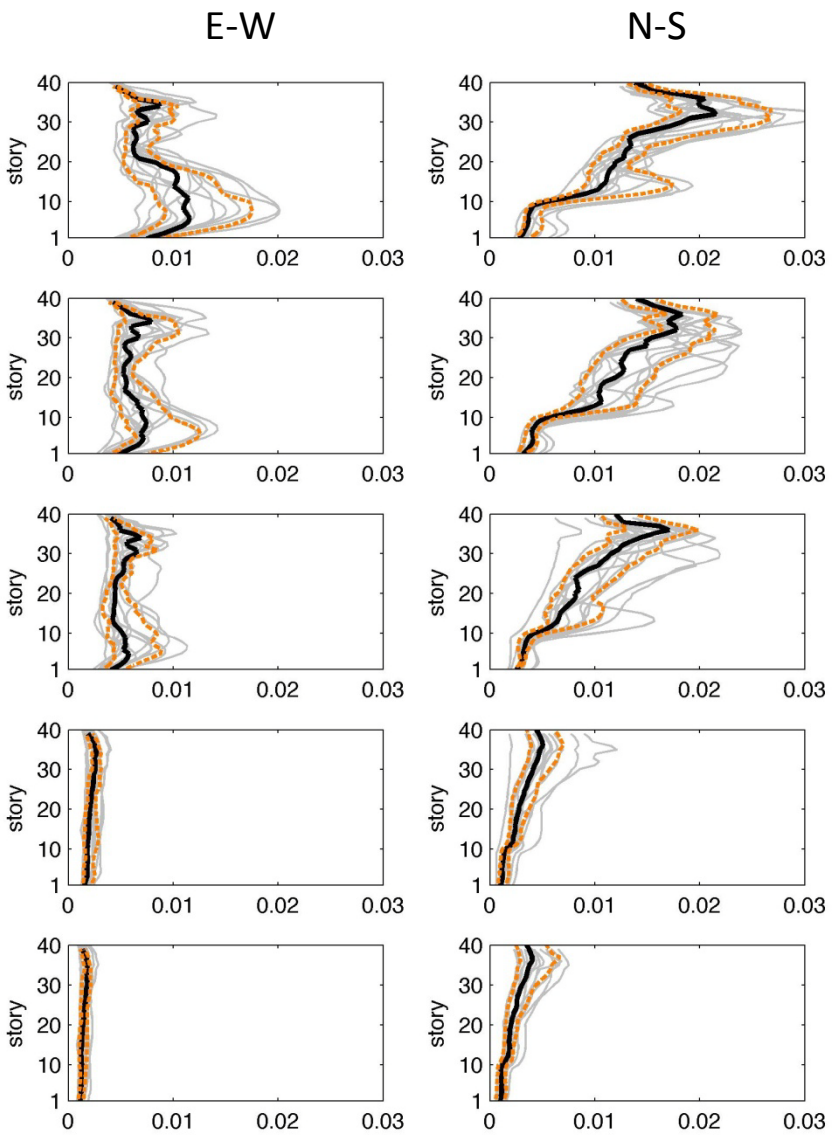




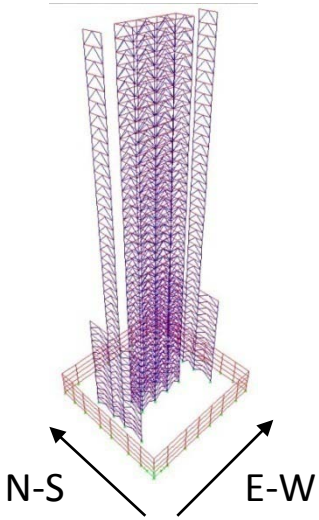


Example results

Return Period	GM set
4975 (years)	OVE
2475 (years)	MCE
475 (years)	DBE
43 (years)	SLE43
25 (years)	SLE25



Building 3A



median

%16th and %84th

Individual earthquake

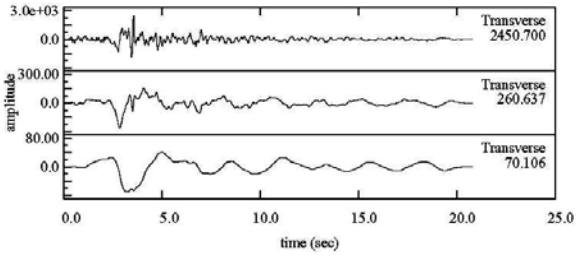
Base Building Costs

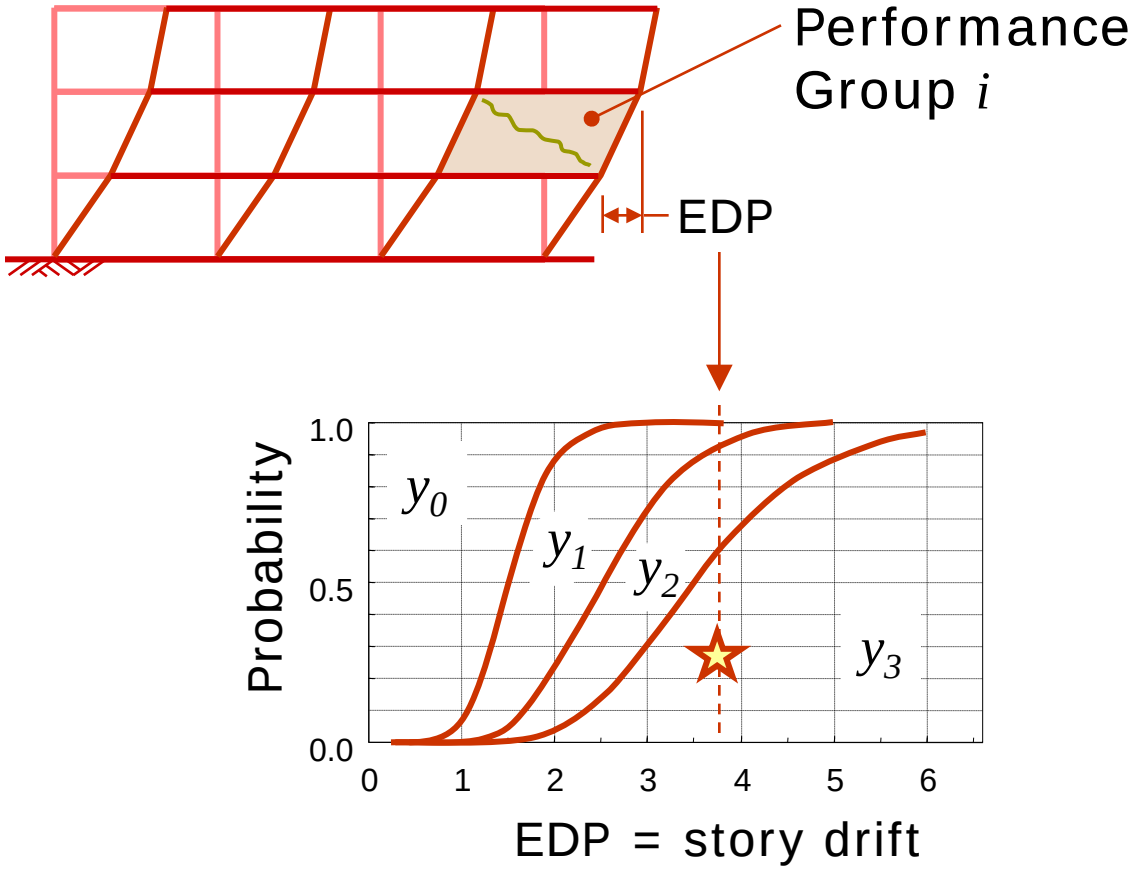
	Core Wall 683,000 sq ft	Dual System 683,000 sq ft	BRB 959,000 sq ft
Code Design	$140 M $326/ sq ft	$149 M $350/ sq ft	$341 M $370/ sq ft
PBE-1	$140 M	$174 M	$329 M
PBE-2	$143 M	$174 M	$333 M

Davis Langdon

- Structural system selection has significant impact on construction cost (13%)
- Design basis has relatively little impact on construction cost

Conceptual damage calculation



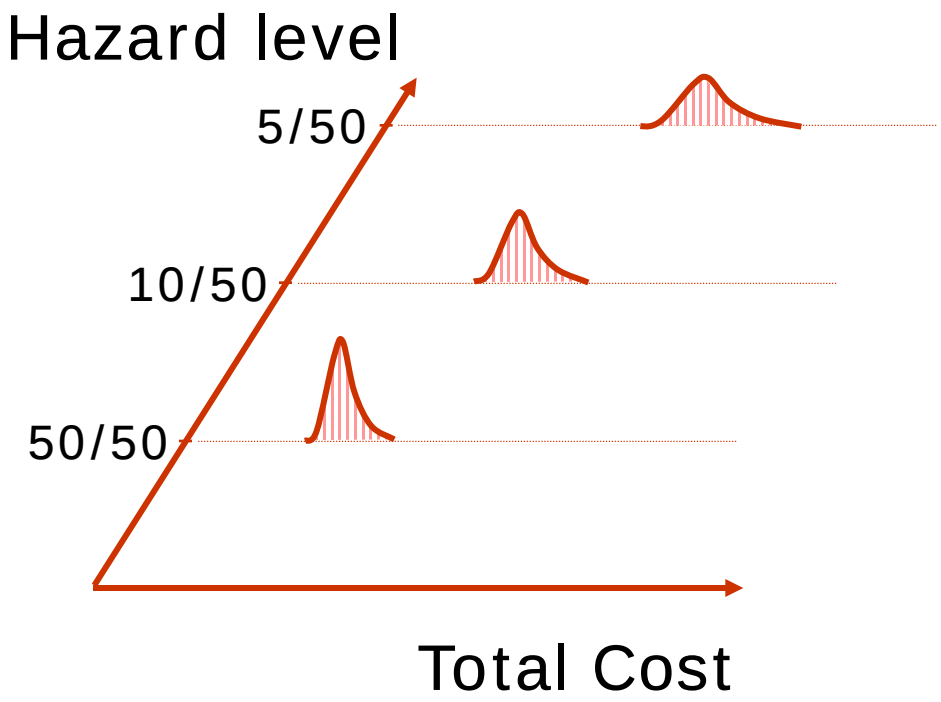


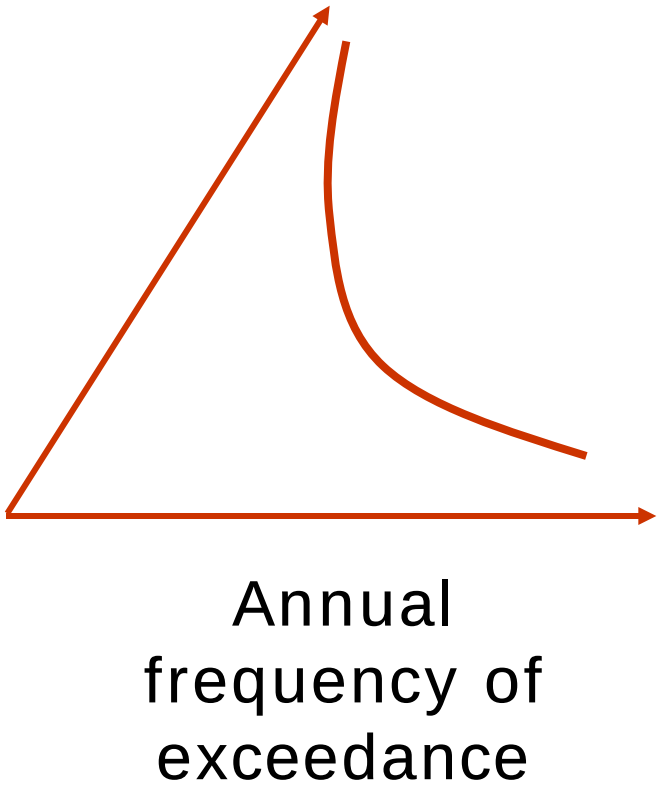
Conceptual repair quantities calculation

Performance Group *i*

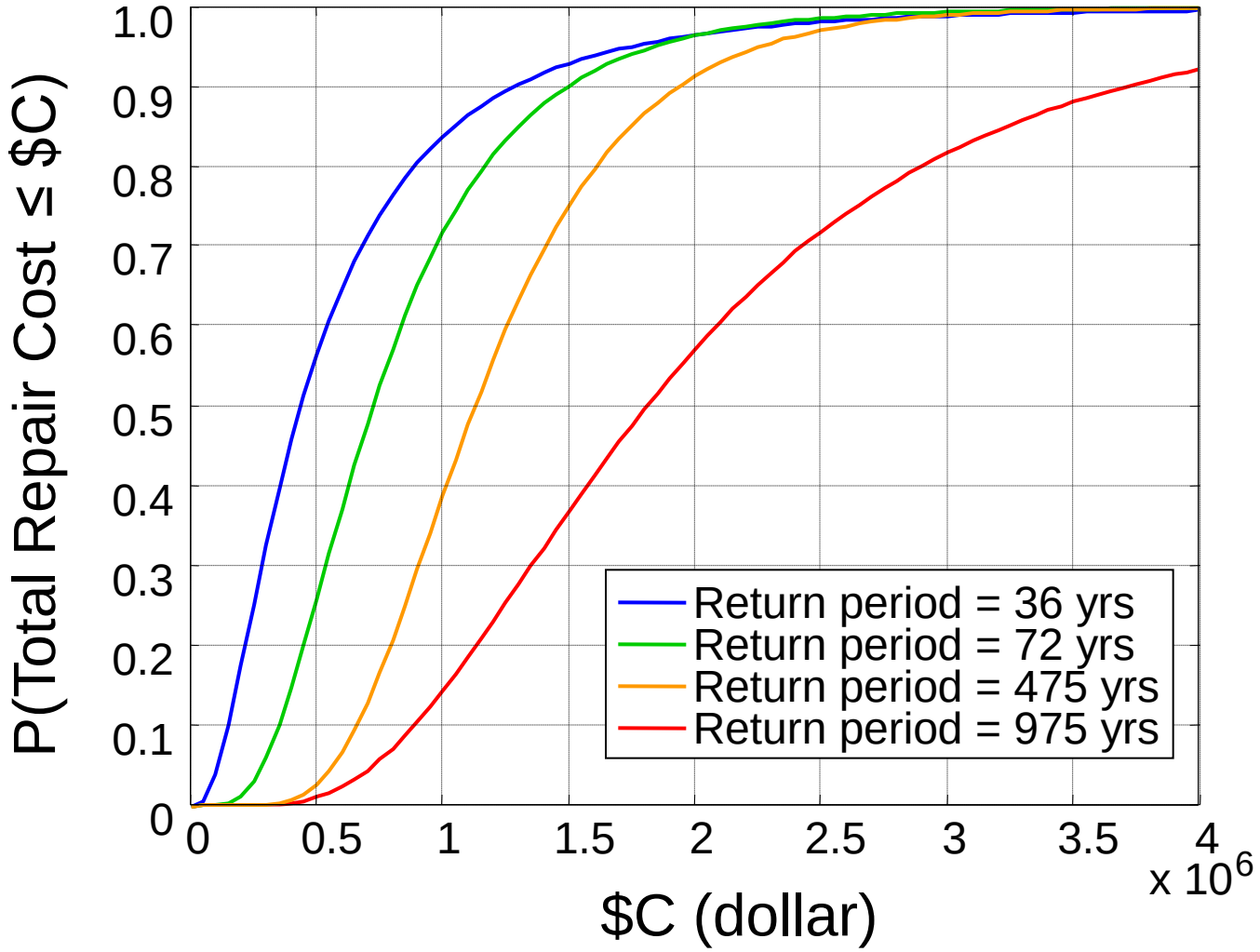
Quantities	Damage State			
	y_0	y_1	y_2	y_3
concrete	0	0	0	0
steel	0	0	0	0
wallboard	0	0	100	10,000
paint	0	100	1000	10,000
electrical	0	0	0	0
...				

Conceptual repair cost calculation





Summary repair costs



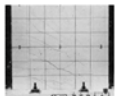
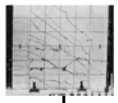
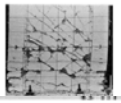
Building Performance Model

Fragility Specification

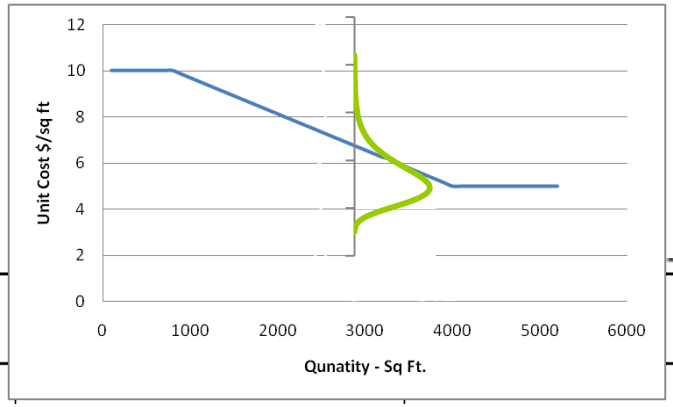
B1044.000 Reinforced Concrete Shearwalls

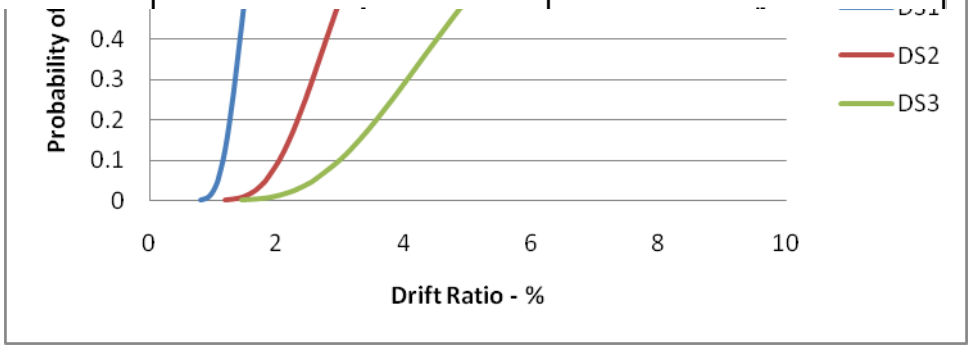
BASIC COMPOSITION	Reinforced concrete and finishes both sides
Units for basic quantities	Square feet of wall area

DAMAGES STATES, FRAGILITES, AND CONSEQUENCE FUNCTIONS

	DS1	DS2	DS3
DESCRIPTION	Flexural cracks < 3/16" Shear (diagonal) cracks < 1/16"	Flexural cracks > 1/4" Shear (diagonal) cracks > 1/8"	Max. crack widths >3/8" Significant spalling/ loose cover
ILLUSTRATION (example photo or drawing)			
MEDIAN DEMAND	1.5%		
BETA	0.2		
REPAIR DESCRIPTION	Patch cracks each side with caulk Paint each side		Patch and paint

CONSEQUENCE FUNCTION			
Max. consequence up to lower quantity	$4.00 per sq ft up to 800 sq ft	$10.00 per sq ft up to 800 sq ft	$50.00 per sq ft up to 200 sq ft
Min consequence over upper quantity	$2.00 per sq ft over 4000 sq ft	$5.00 per sq ft over to 4000 sq ft	$30.00 per sq ft over 2000 sq ft
Beta (consequence)	0.2	0.3	0.3

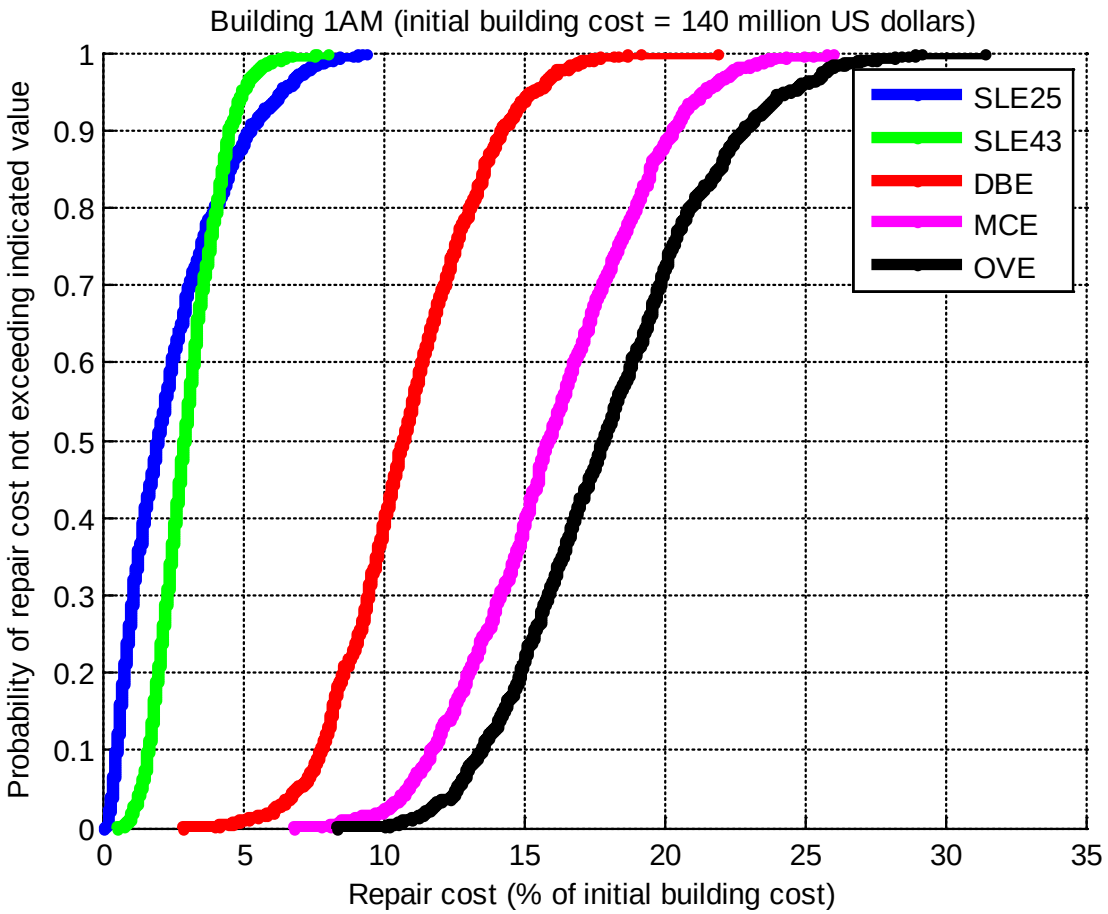




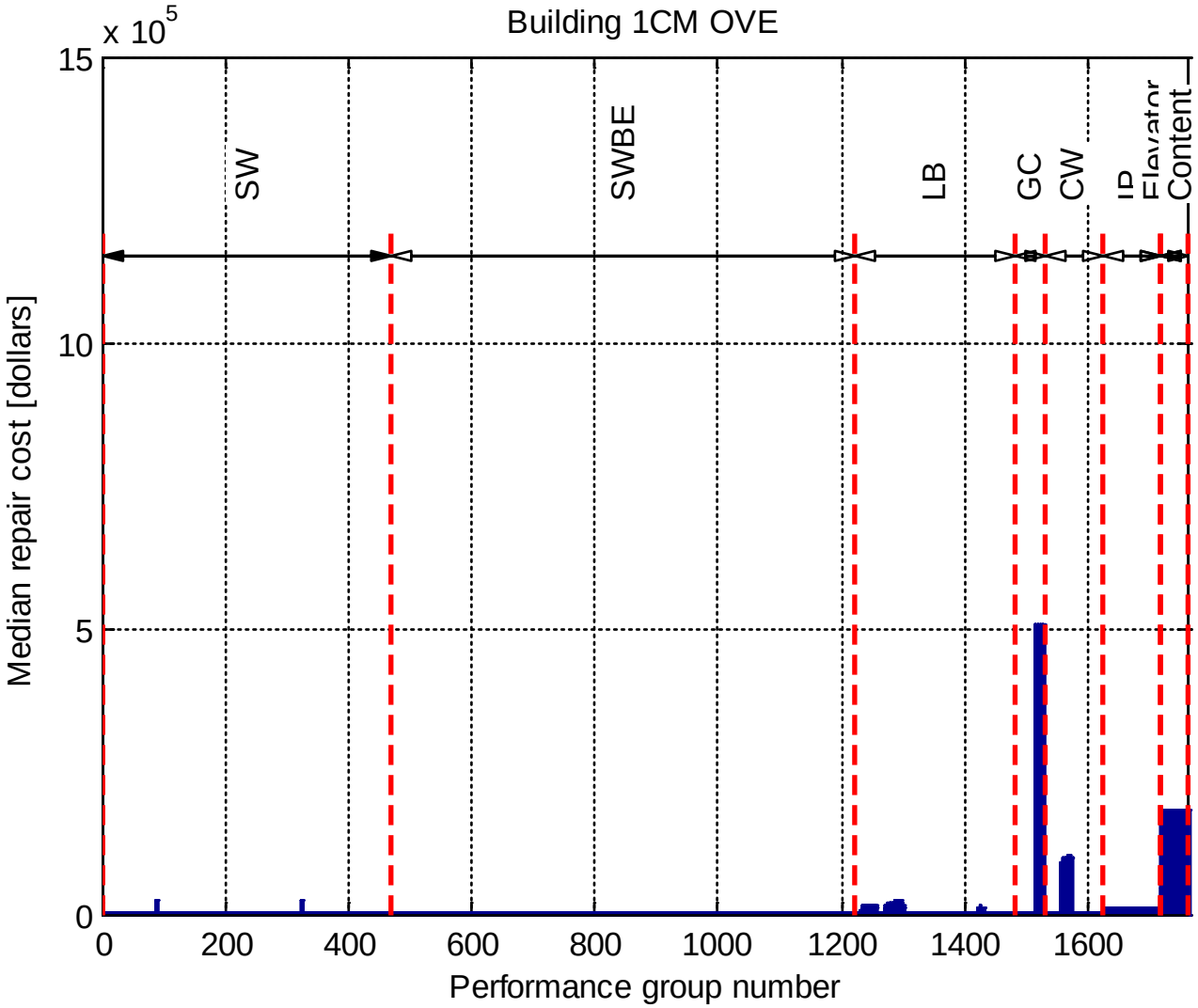
Building Performance Models

- Structural
  - Shear walls
    - Shear cracking
    - Flexural damage
  - Link beams
  - Gravity columns
  - Moment joints
  - Buckling restrained braces
- Nonstructural
  - Curtain walls
  - Interior partitions
  - Ceilings
  - Elevators
  - Contents

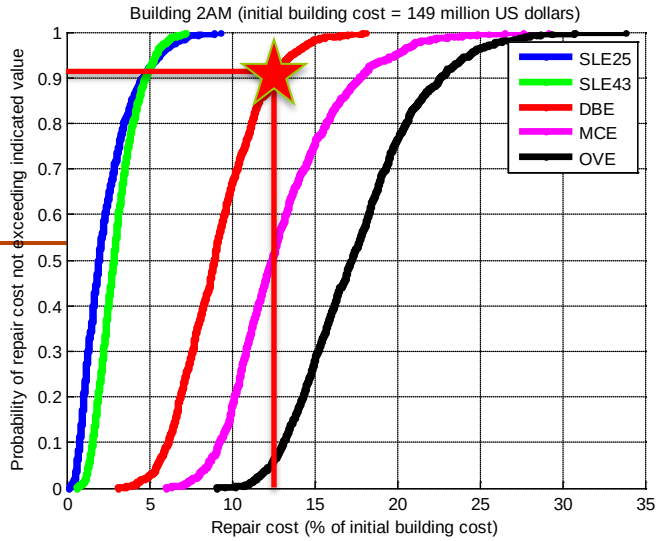
Loss Results



Loss Results



Summary Results



- Probable Maximum Loss – 500 year

	Core Wall	Dual System	BRB
Code Design	14%	13%	3%
PBE-1	15%	9%	3%
PBE-2	12%	9%	3%

Note – BRBs does not include effect of residual drift

Summary Results

$$\sum_i \left(\overline{Loss}_{GM\,i}\right)\left(P\left(GM_i\right)\right)$$

- Average Annual Loss
- Annual Insurance Premium

	Core Wall	Dual System	BRBF
Code	$326,000	$323,000	$206,000
PBE-1	$336,000	$269.000	$157,000
PBE-2	$282,000	$269,000	$141,000

Summary Results

- Cost-Benefit Analysis
  - Initial Construction Cost
  - Net Present Value of Insurance Premium (50 years)
  - Time value of money – 5%
  - Normalized to code-based building cost

	Core Wall	Dual System	BRB
Code	1.0	1.0	1.0
PBE-1	1.0	1.1	1.0
PBE-2	1.0	1.1	1.0

PEER Tall Buildings Initiative

PEER