PEER Tall Building Seismic Design Guidelines

Performance Analysis
(Loss Estimation)

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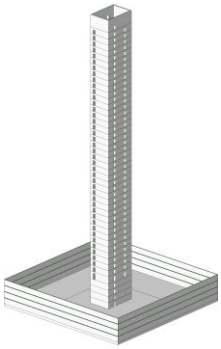
PBEE and Its Application to Tall Building Design – Long Beach – 10 September 2011

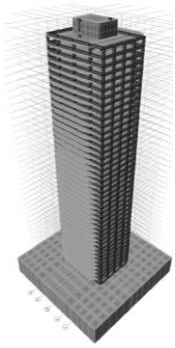
Purpose

- Determine if performance-based criteria would provide comparable or better performance than code-based designs
- Permit cost-benefit judgments

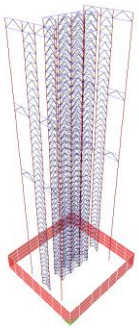
3 Example Buildings



42-story
Concrete Core Wall
Residence



42-story
Concrete Dual System
Residence



39-story
BRB
Office Structure

- All located on same Los Angeles site
- All have T_1= 4.5 seconds

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3 Buildings – 3 Designs

- Case 1
  - Code-conforming (almost)
    - Exceed system height limits
- Case 2
  - Performance-based
    - Using LA Tall Buildings Criteria (similar to AB-083)
- Case 3
  - Performance-based
    - Using PEER Tall Buildings Guidelines

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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

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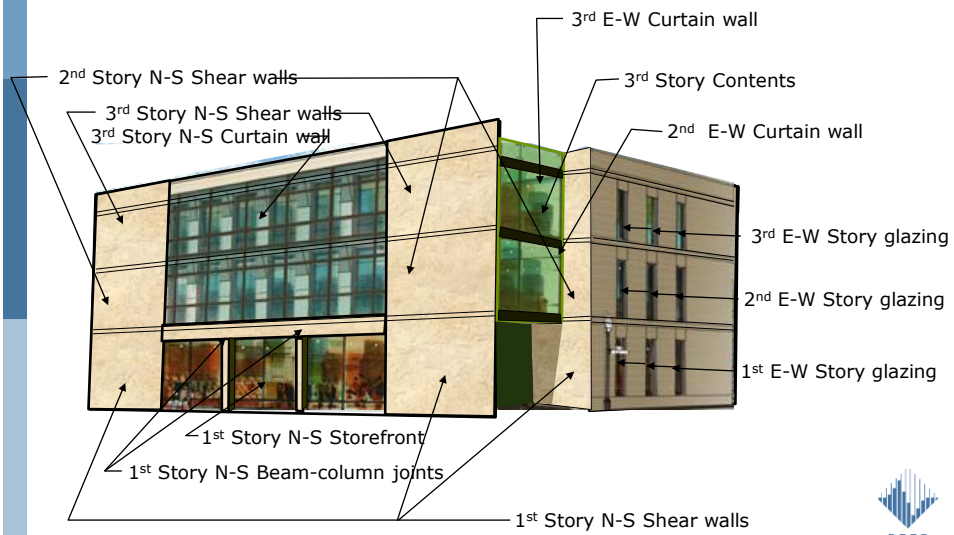
Loss Assessment Procedure

1. Develop building performance model



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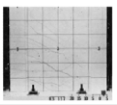
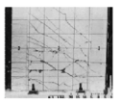
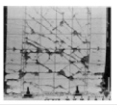
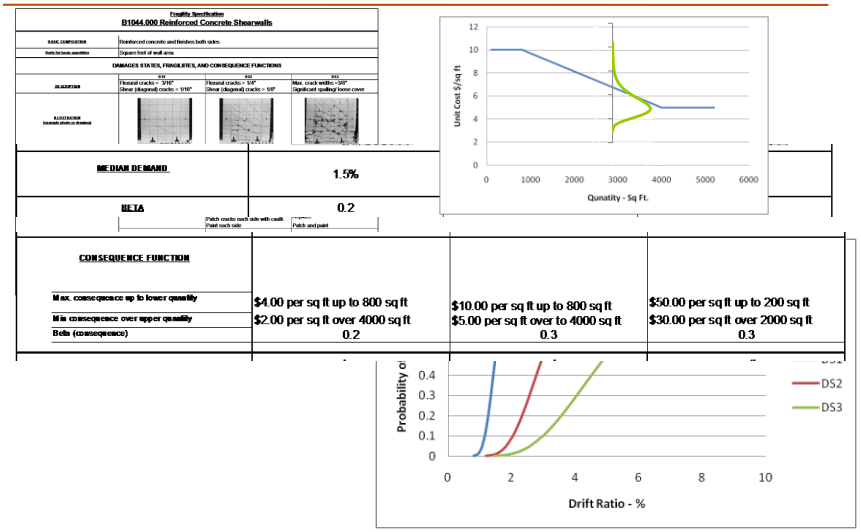
Building Performance Model

- Number of damageable components
- Location in building
- Fragility
  - Possible damage states
  - Probability of damage
- Consequences
  - Repair cost
  - Repair time

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%	3.0%	5.0%
BETA	0.2	0.3	0.4
CORRELATION (%)	70%		
DAMAGE FUNCTIONS	Patch cracks each side with caulk Paint each side	Remove loose concrete Patch spalls with NS grout Patch cracks each side with caulk Paint each side	Shore Demo existing wall Replace 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
TIMEFRAME TO ADDRESS CONSEQUENCES	days	weeks	months

Building Performance Model



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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

Note – this does not represent a complete inventory of all damageable items

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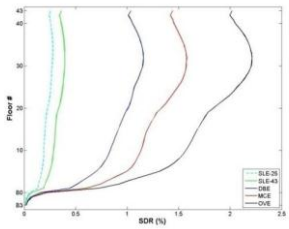
Loss Assessment Procedure

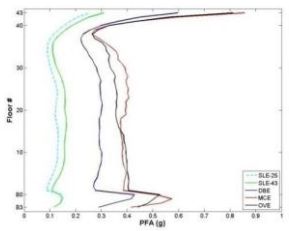
2. Select series of ground motion intensity levels
   - Service Level 1 - 25-year
   - Service Level 2 - 43-year
   - Design Earthquake - 500-year
   - Maximum Considered 2,500-year
   - Over the Top 5,000-year

Loss Assessment Procedure

3. For each intensity level, select and scale a suite of representative ground motions
4. Develop a structural model and perform NLRH analysis for each ground motion

Analysis Results





- Median values of peak transient:
  - Story drift
  - Floor acceleration

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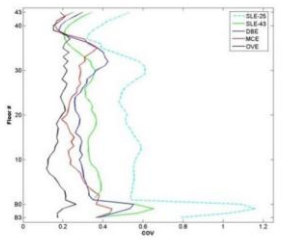
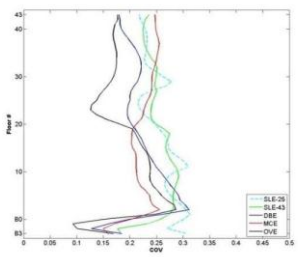
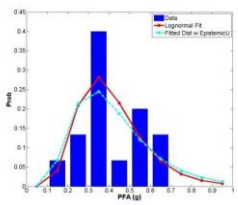
Analysis Results





- Logarithmic standard deviation of:
  - Peak story drift
  - Peak floor acceleration



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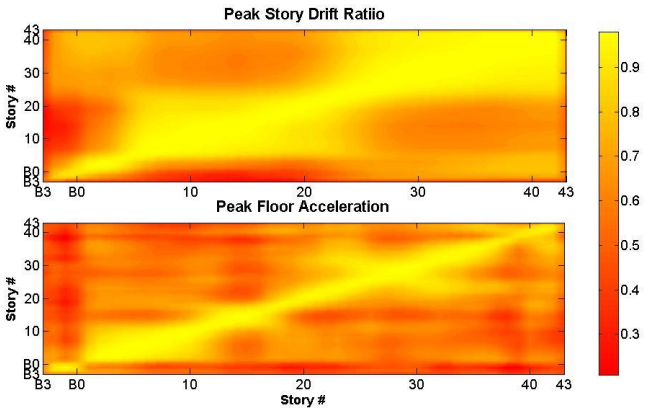
Analysis Results

- Covariance matrix



Loss Assessment Procedure

5. Generate a series of 1,000s of synthetic analysis results "realizations" consistent with:

   - Statistical median and variability
   - Correlation of demand parameters

   observed in actual analyses

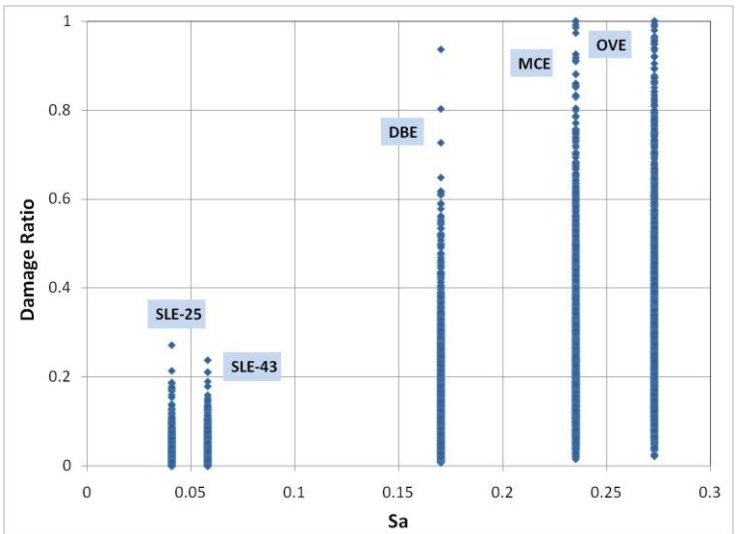
Loss Assessment Procedure

6. For each "realization", determine:
   - If collapse occurs
     - Results in total loss
   - If not -
     - Damage state of each vulnerable component
     - Repair cost for each vulnerable component
     - Total building repair cost

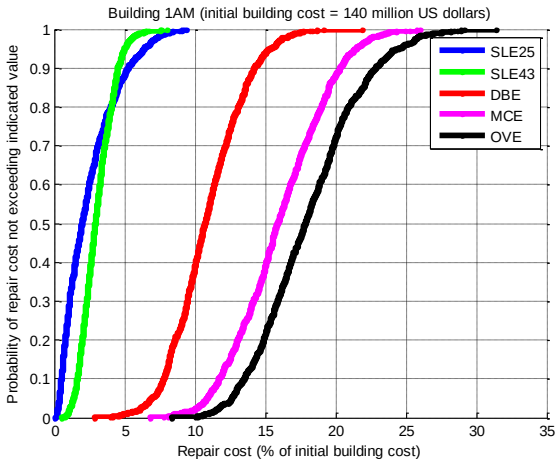
Provides one possible outcome

By viewing all realizations, distribution of loss at each intensity level

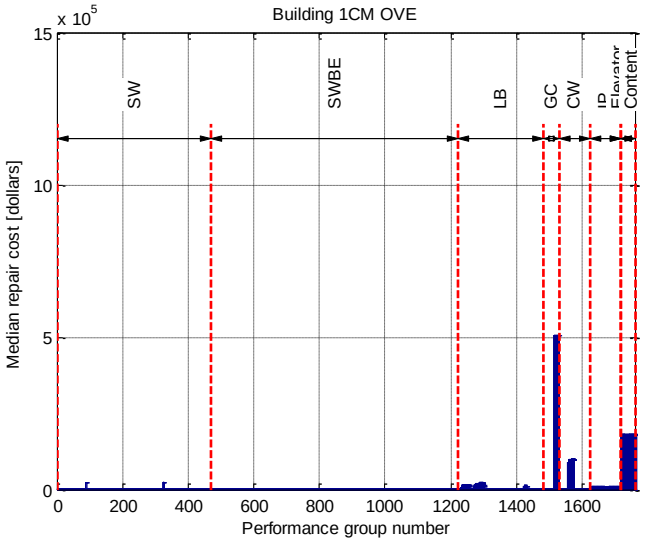
Loss Distributions



Loss Results



Loss Results

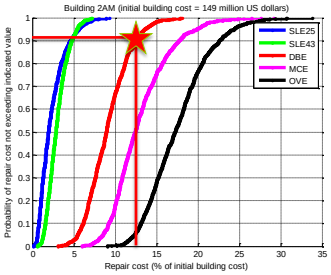


Loss Assessment Procedure

7. Average annual loss =

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

8. PML-500



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Summary Results

- Probable Maximum Loss – 500 year

	Core Wall	Dual System	BRB
Code Design	14%	13%	3%
PBE-1	15%	8%	3%
PBE-2	12%	8%	2%

Note – BRBs does not include effect of residual drift

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Summary Results

- Average Annual Loss
- Annual Insurance Premium

	Core Wall	Dual System	BRBF
Code	$326,000	$336,000	$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 – 10%
  - Normalized to code building cost

	Core Wall	Dual System	BRB
Code	1.0	1.0	1.0
PBE-1	1.02	.90	.88
PBE-2	0.91	.90	.86

Conclusions

- Performance-based approach:
  - Significant advantage for all systems, given significant building life
- TBI Guidelines
  - Generally results in better performance than prior approaches
  - May or may not cost more to implement