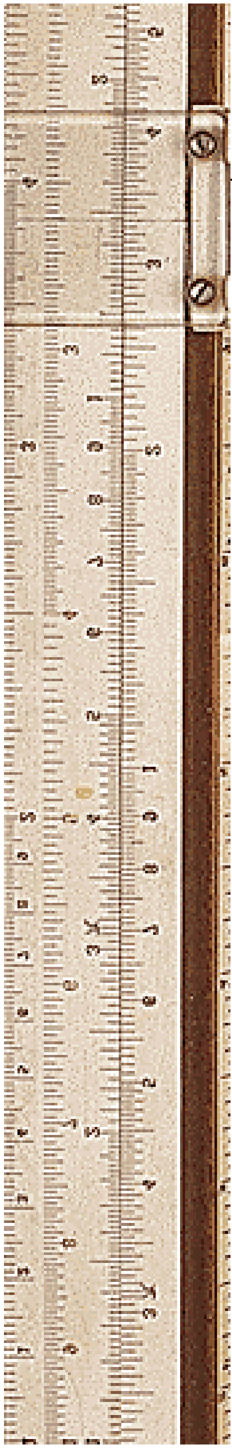

Los Angeles Tall Buildings Structural Design Council

AN ALTERNATIVE PROCEDURE FOR SEISMIC ANALYSIS AND DESIGN OF TALL BUILDINGS LOCATED IN THE LOS ANGELES REGION

A Consensus Document

December 2005

The Council expresses its gratitude to the following distinguished experts who also contributed to the development of this document:

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Prof. Graham Powell, *Professor Emeritus, University of California, Berkeley, Berkeley, CA*
Mr. Gary Searer, *Structural Engineer, Wiss, Janney, Elstner Associates, Emeryville, CA*
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Prof. John Wallace, *University of California, Los Angeles, CA*

Introductory Remarks

Simple Facts

- Historical evidence shows that collapse is not a function of building height and flexibility but a result of configuration, detailing, workmanship, engineering, and construction issues.
- Examples from all earthquakes show this.
- Here are a few examples


Kobe 1995
Photo Courtesy of Dr. Charles Kircher


Chi Chi, Taiwan 1999

Most Typical Damage


240E


雅姿韻律世界
日立冷氣
金門
十大書坊
出租
普騰
精緻家電
中興保全
玉山銀行
ESUN BANK
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髮型設計
月麗
書坊
600元
營業時間


喜相逢資訊社


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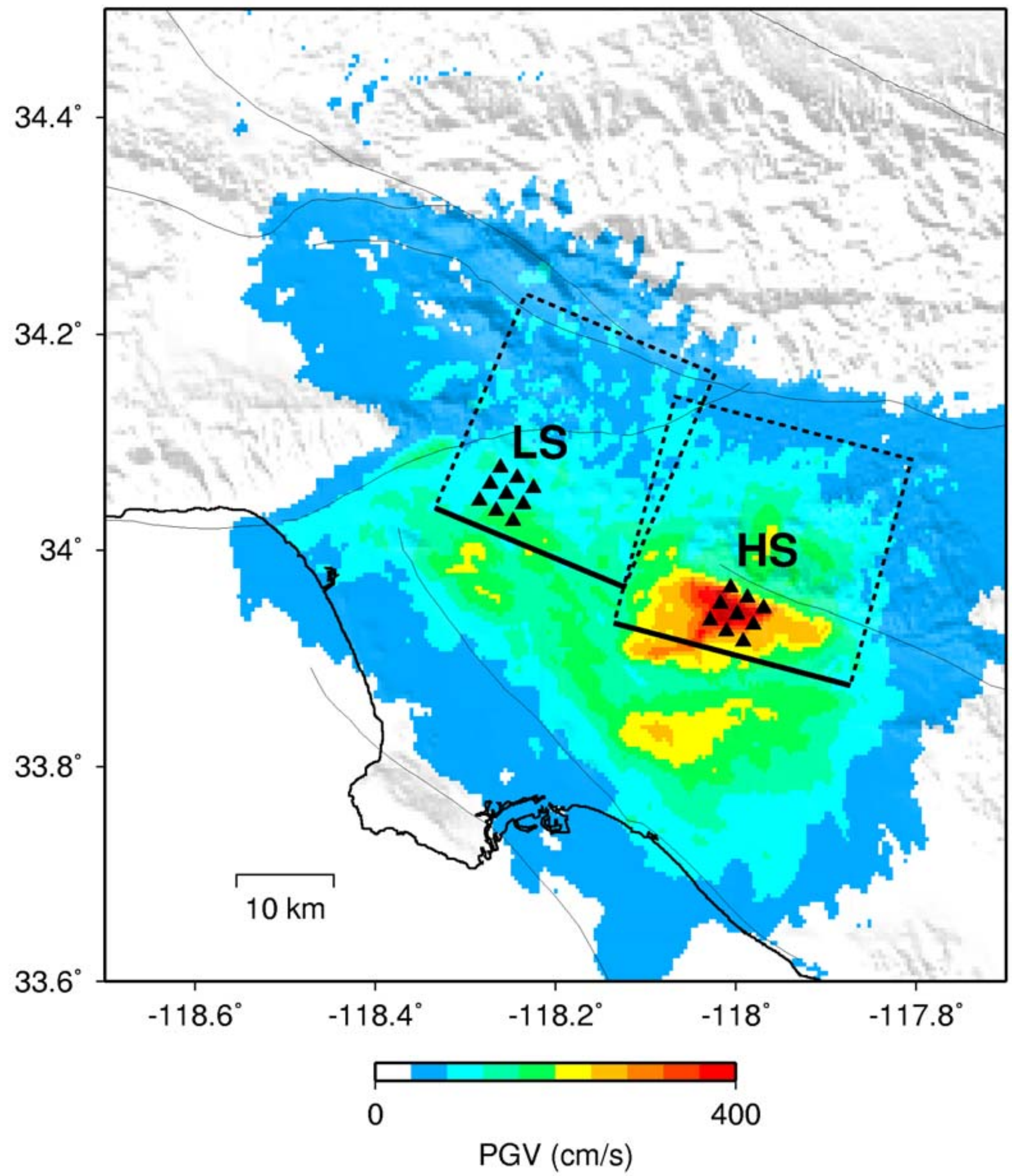
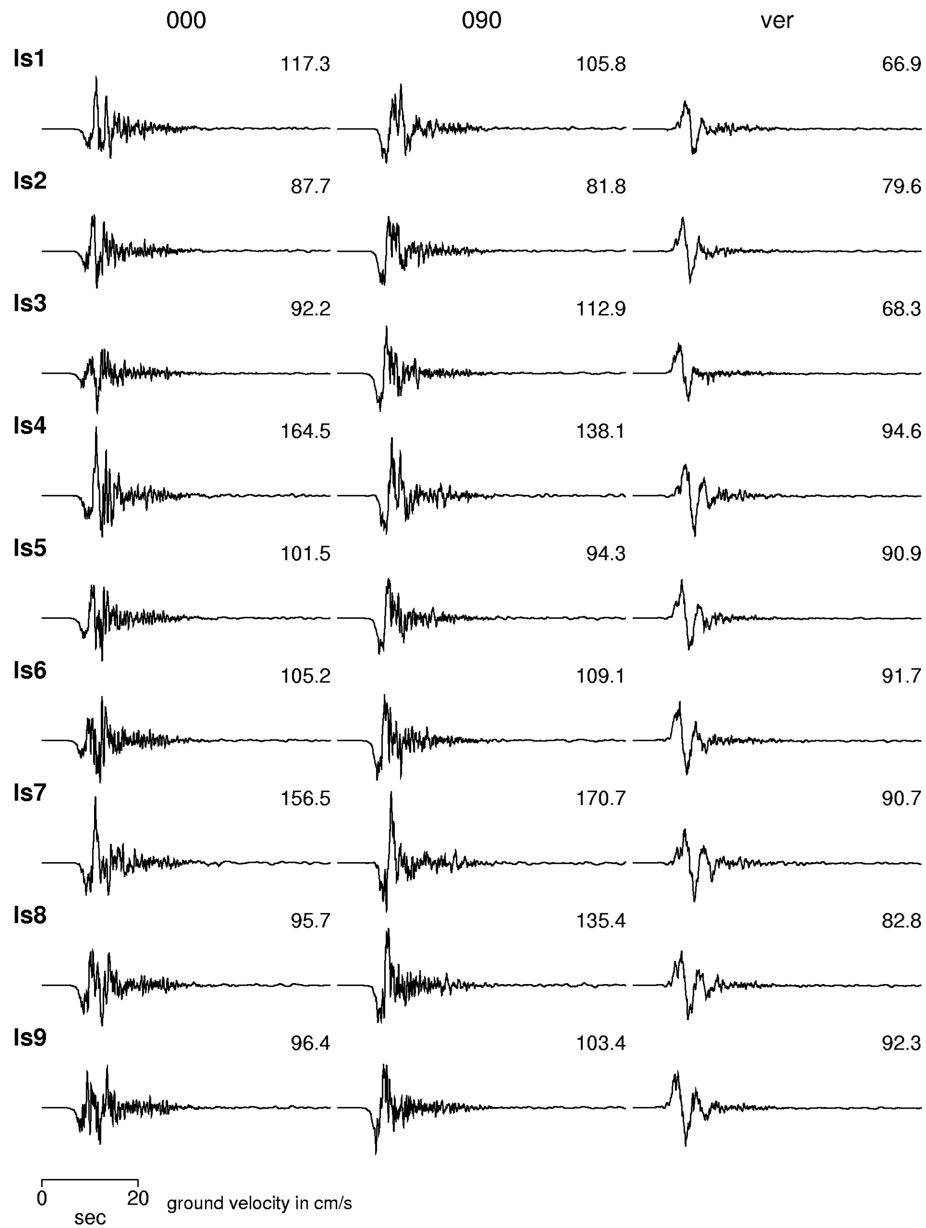
How Would Various Well-Engineered Buildings Perform During a Large Event Affecting the Los Angeles Region?

Results of a detailed study by Naeim and Graves (2005)
to be published in:
Structural Design of Tall and Special Buildings

Puente Hills All (Mw 7.15): PGV

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20
sec
ground velocity in cm/s

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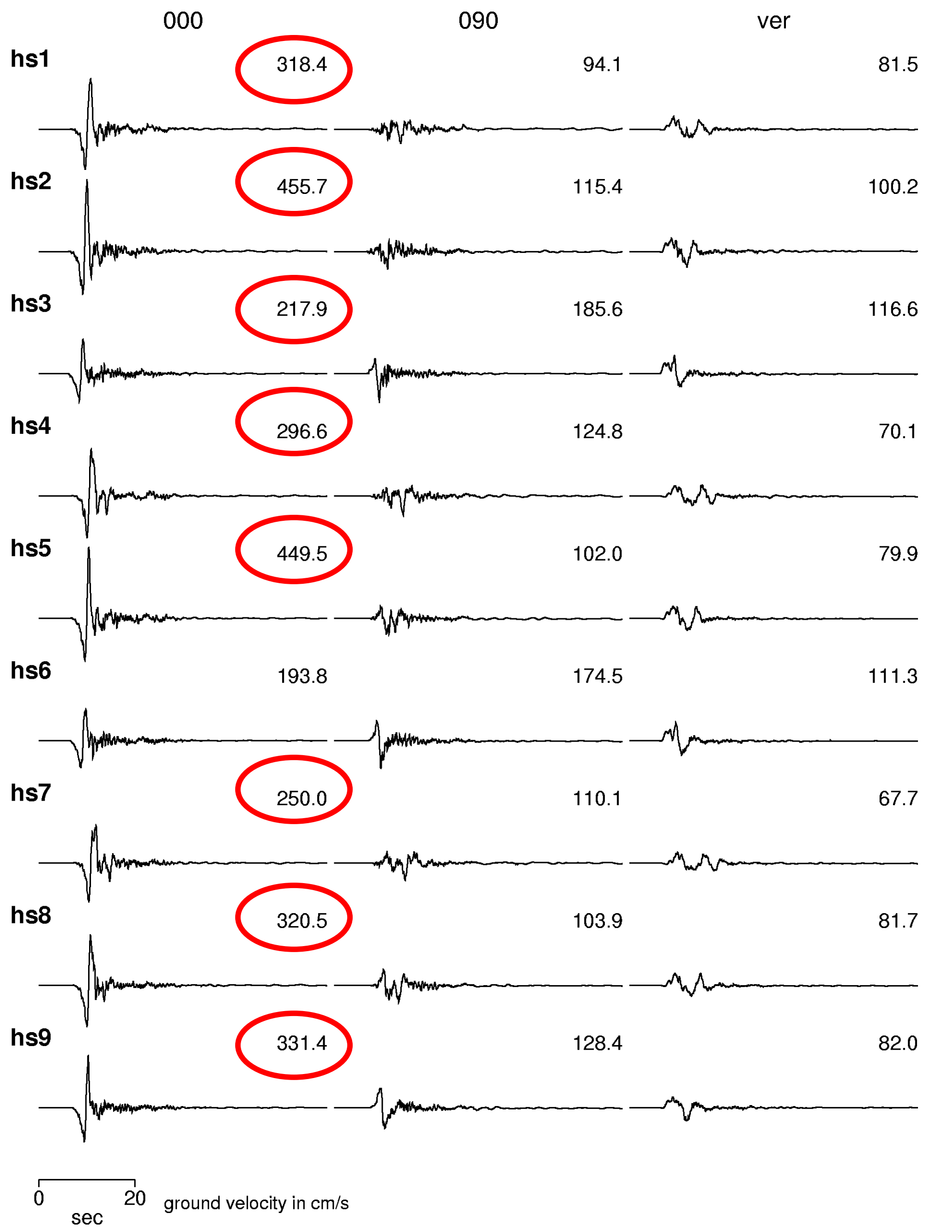
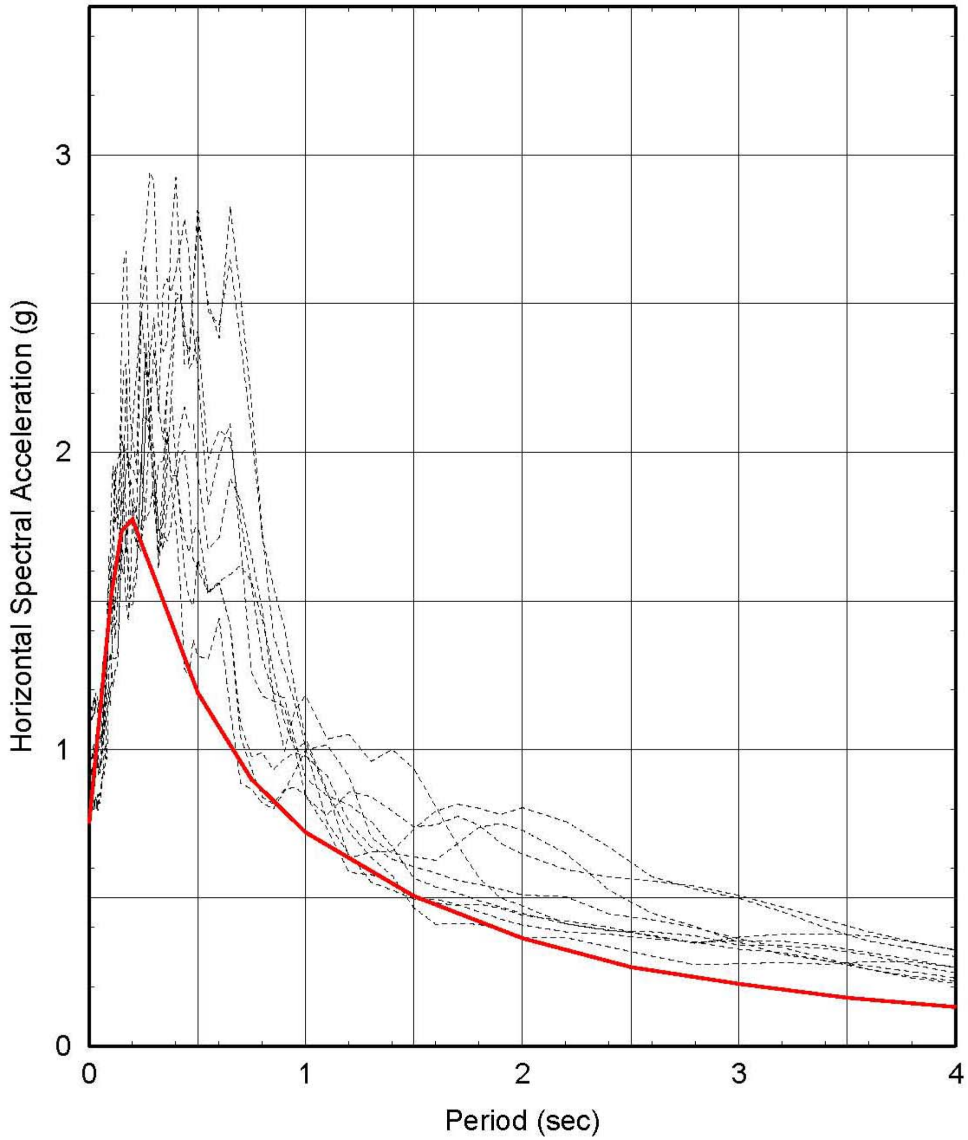
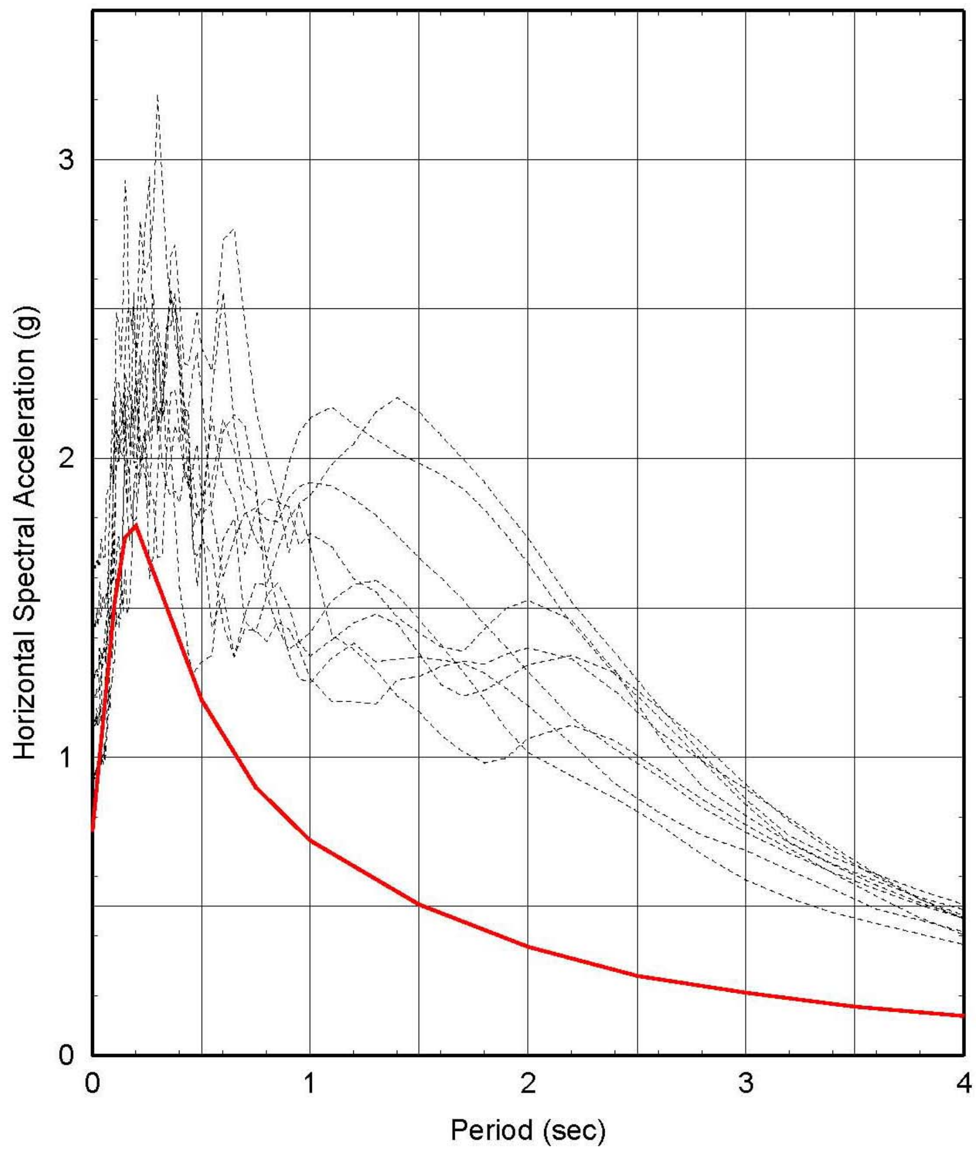


Low-Slip Area Compared with Equal Hazard Spectra (475 Year – 5% Damping)



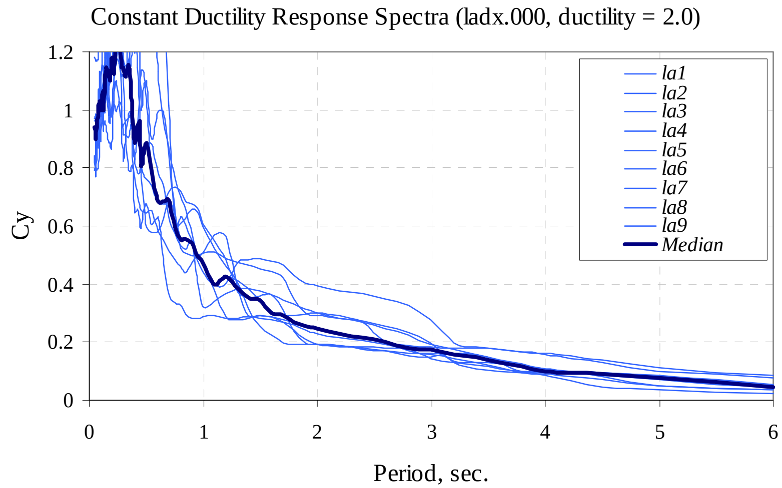
High-Slip Area Compared with Equal Hazard Spectra (475 Year – 5% Damping)



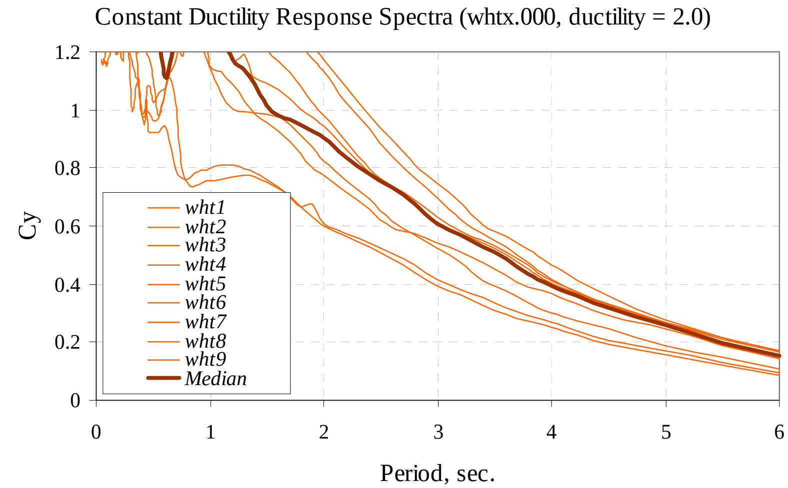
Constant Ductility Spectra

Los Angeles Tall Buildings Structural Design Council

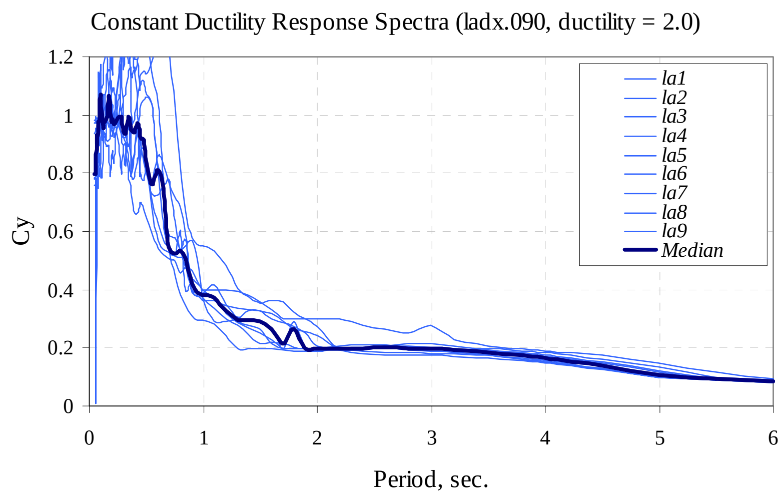
Constant Ductility Response Spectra (Ductility = 2.0)



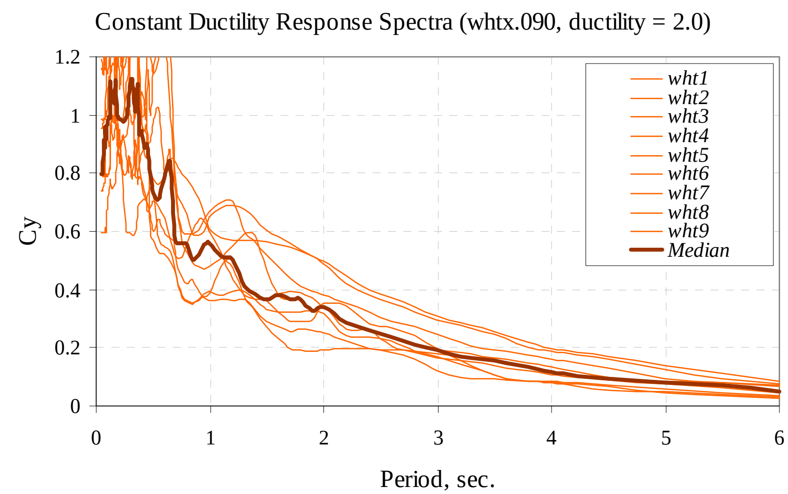
Low-Slip Area N-S



High-Slip Area N-S

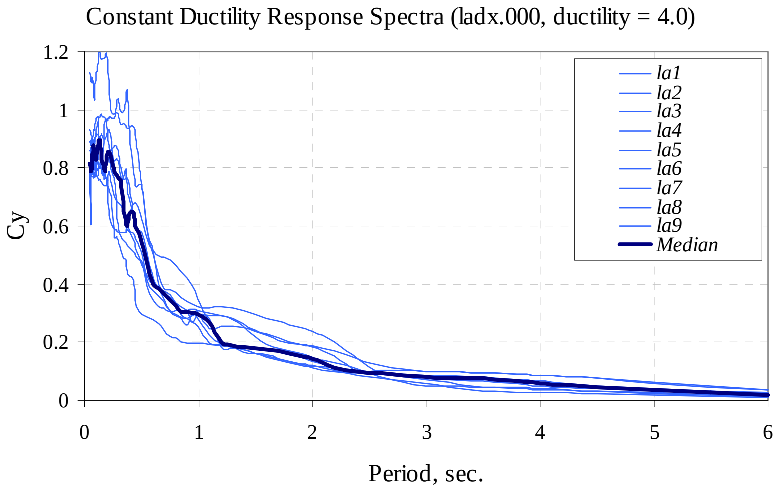


Low-Slip Area E-W

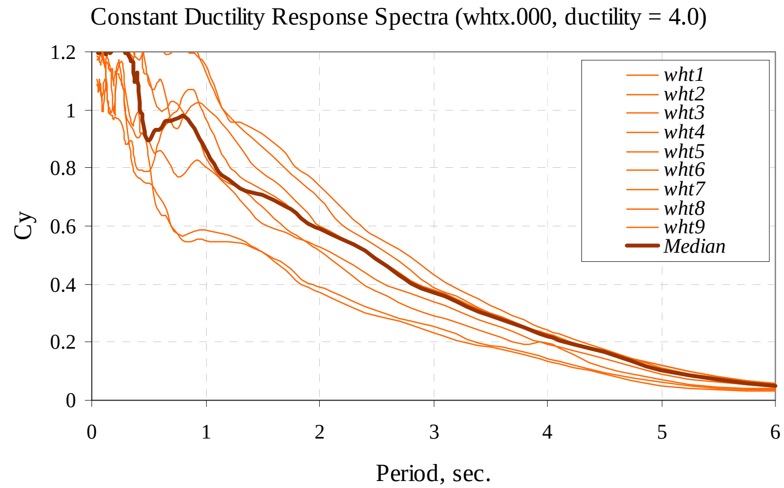


High-Slip Area E-W

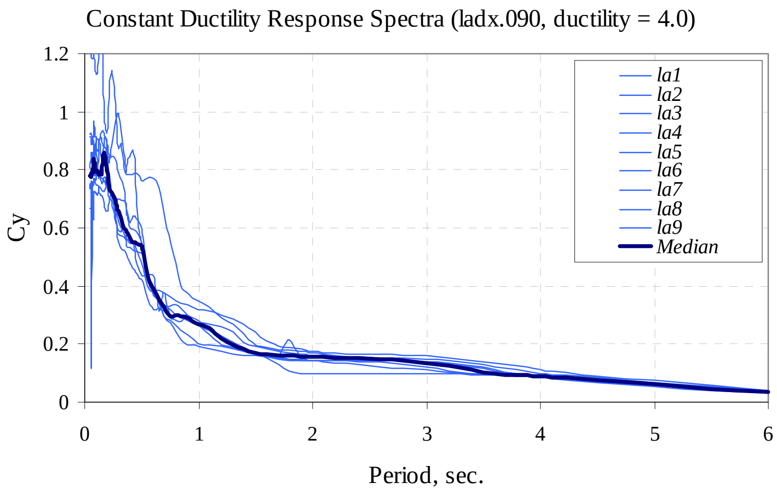
Constant Ductility Response Spectra (Ductility = 4.0)



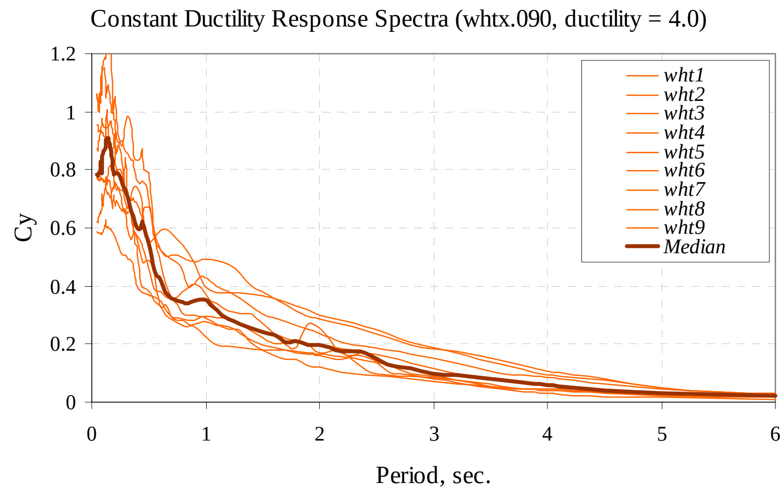
Low-Slip Area N-S



High-Slip Area N-S



Low-Slip Area E-W



High-Slip Area E-W

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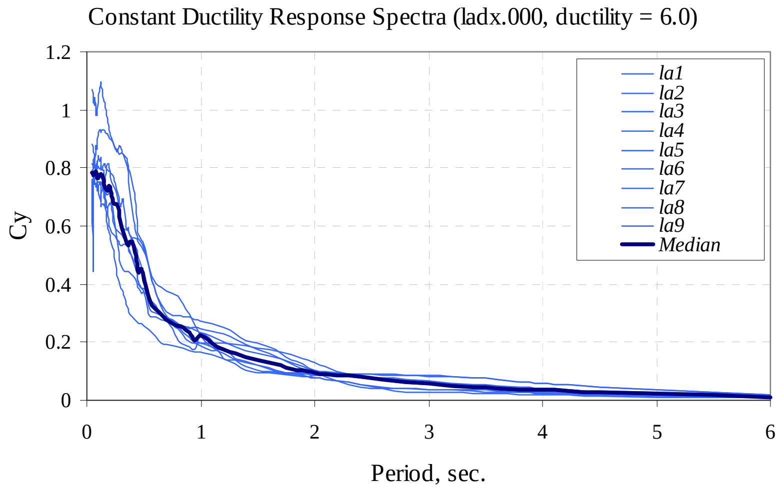
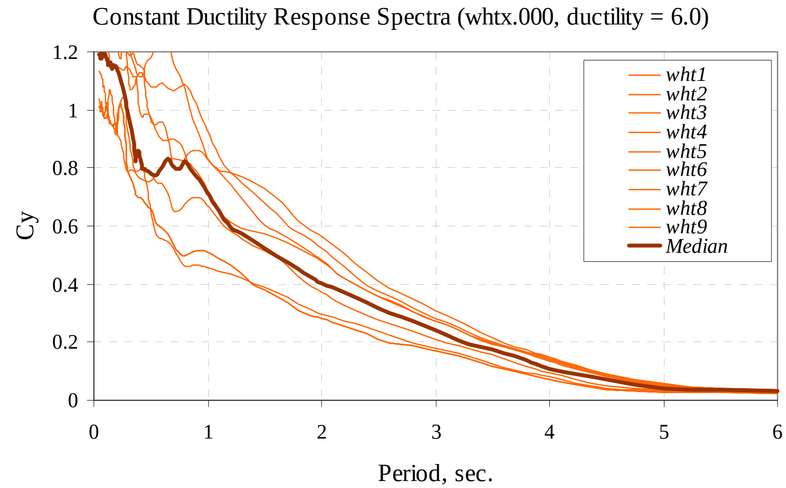
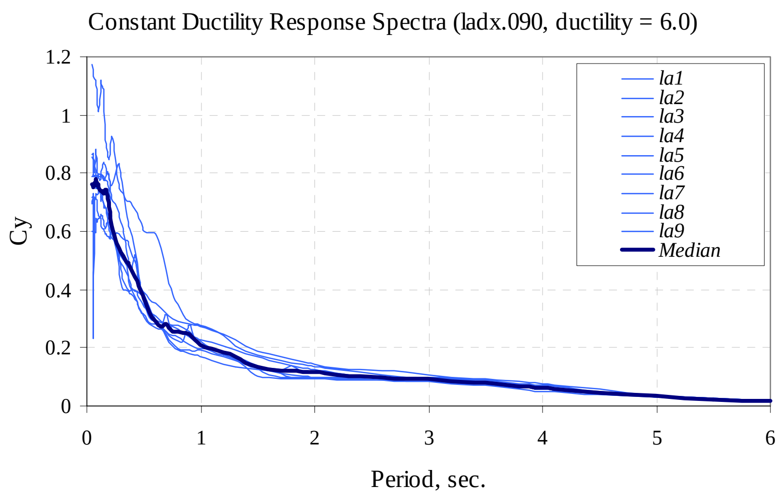
Constant Ductility Response Spectra (Ductility = 6.0)



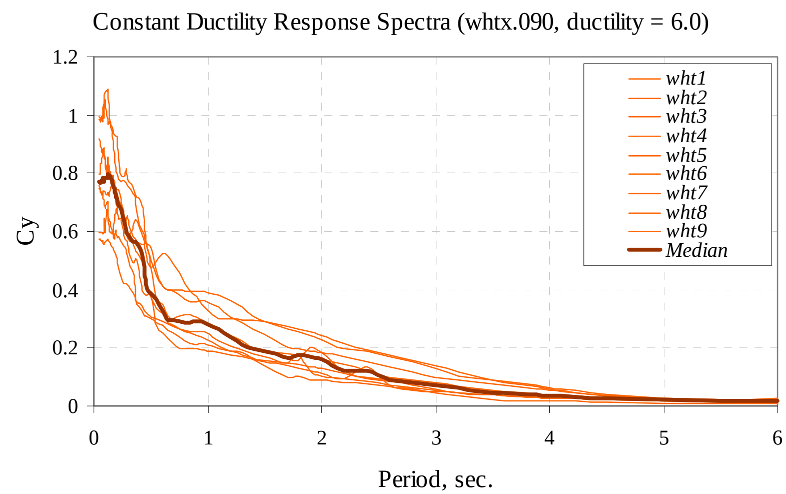
Low-Slip Area N-S



High-Slip Area N-S

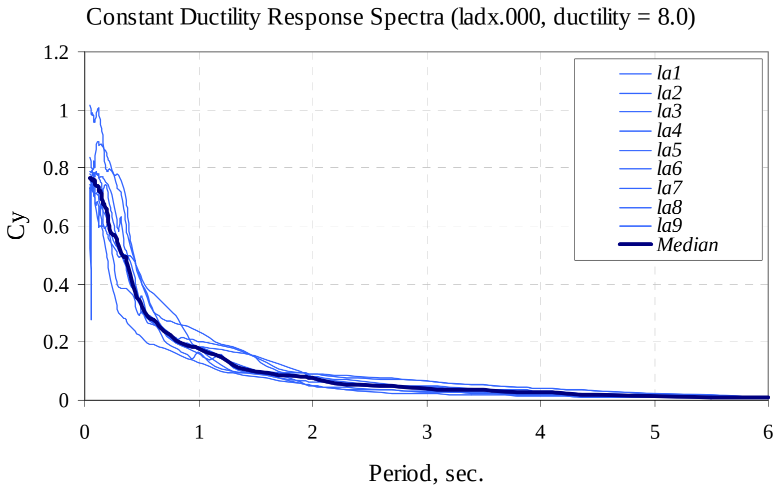


Low-Slip Area E-W

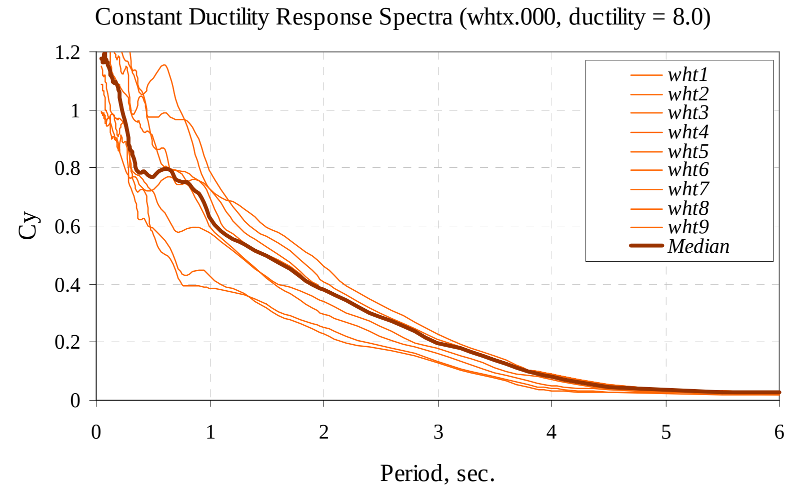


High-Slip Area E-W

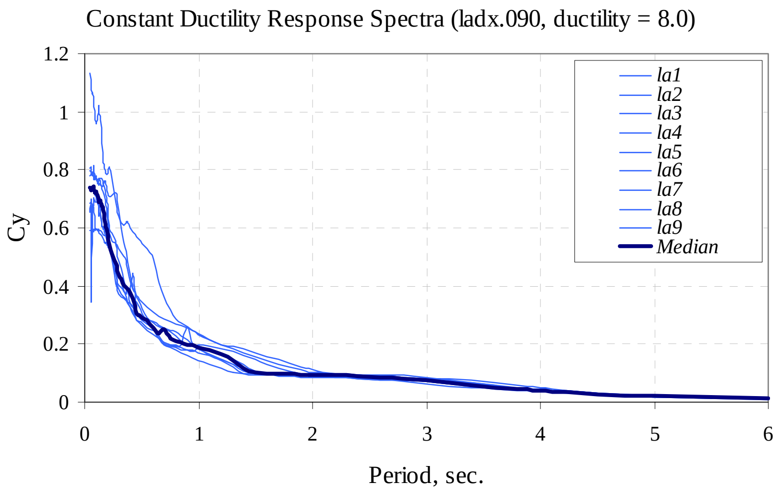
Constant Ductility Response Spectra (Ductility = 8.0)



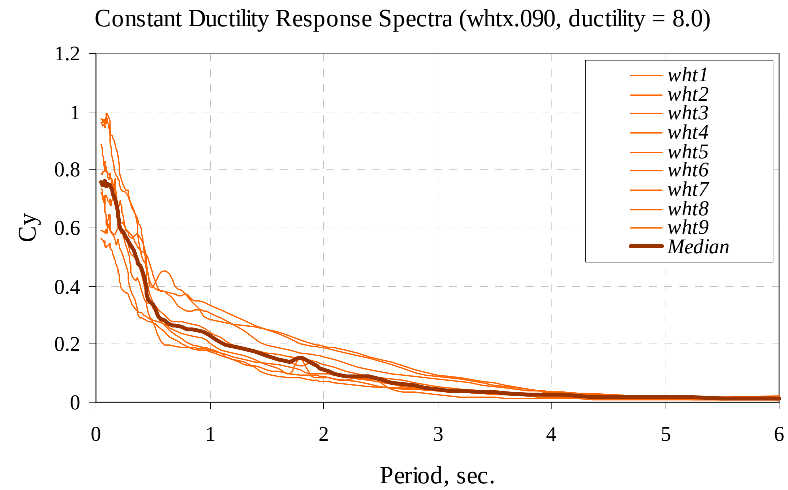
Low-Slip Area N-S



High-Slip Area N-S



Low-Slip Area E-W



High-Slip Area E-W

Constant Strength Spectra

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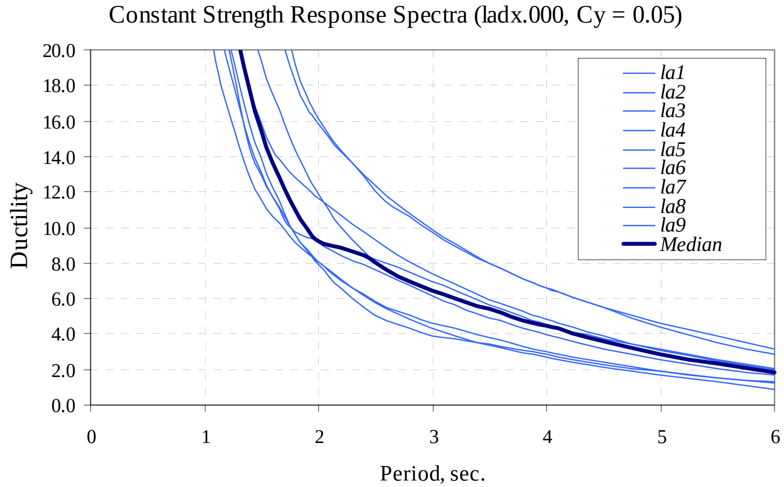
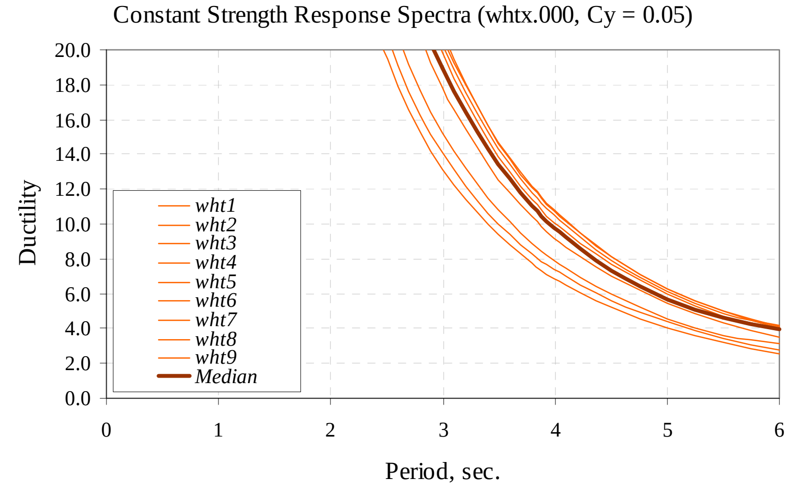
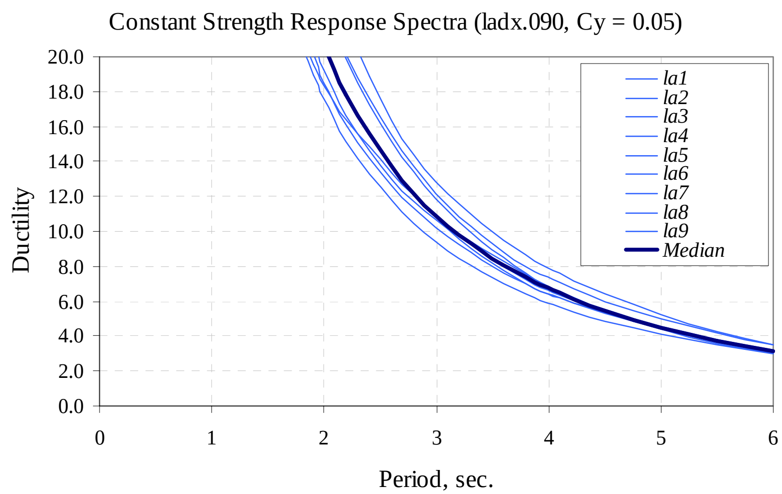
Constant Strength Response Spectra (Cy = 0.05)



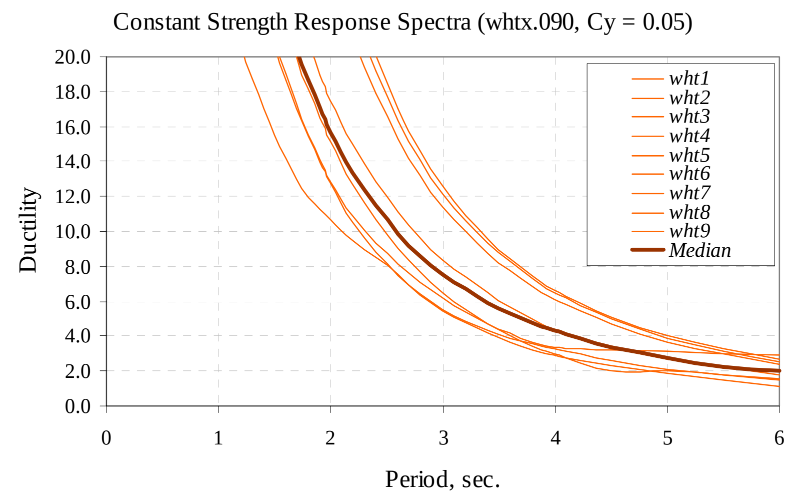
Low-Slip Area N-S



High-Slip Area N-S



Low-Slip Area E-W



High-Slip Area E-W

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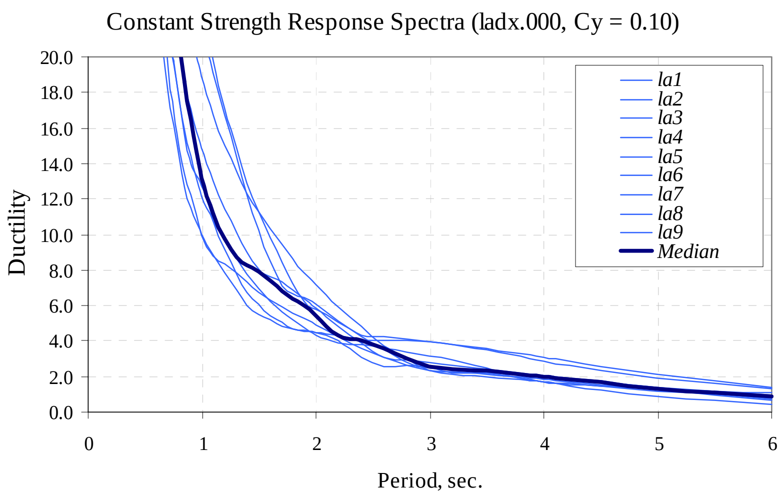
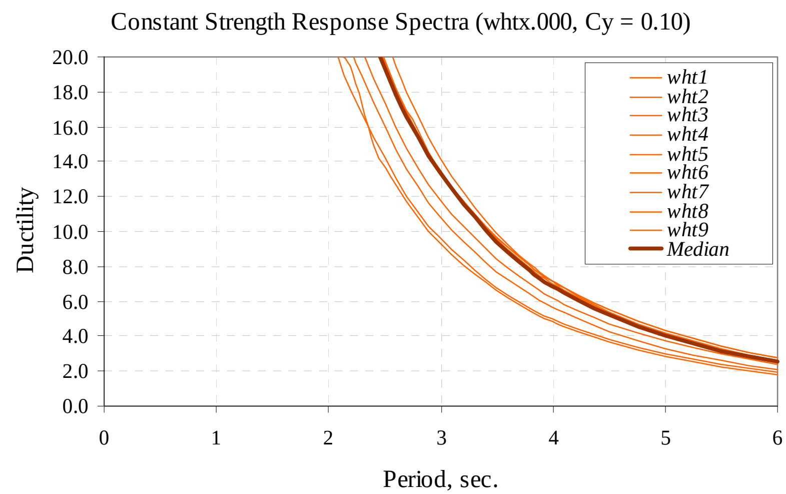
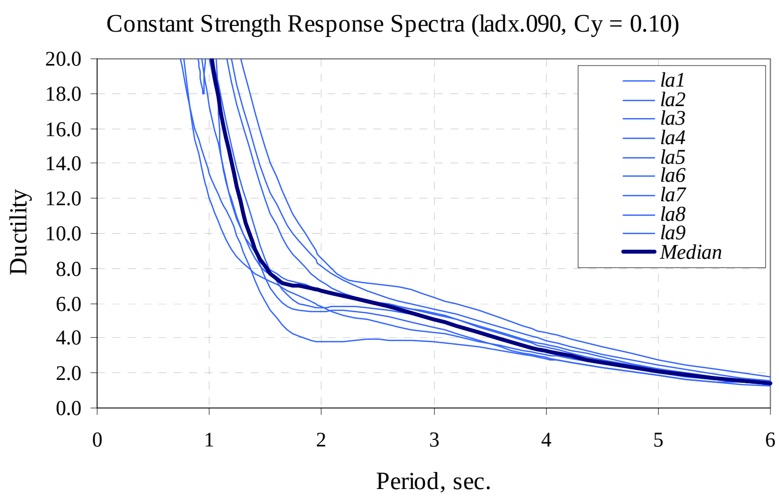
Constant Strength Response Spectra (Cy = 0.10)



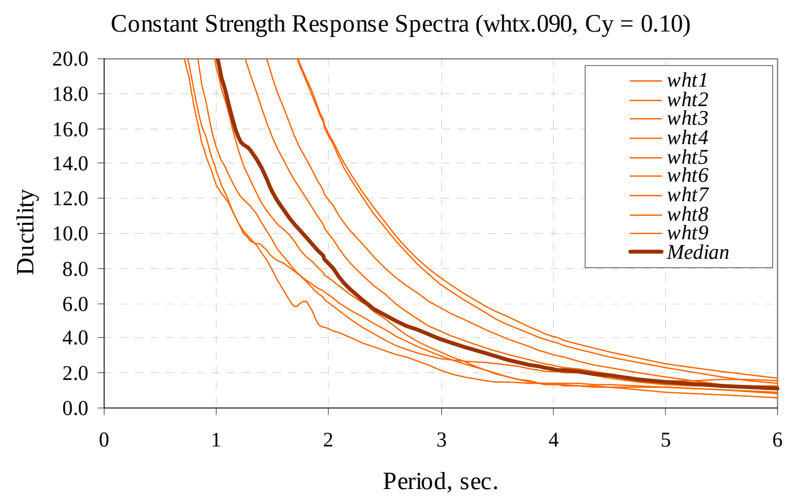
Low-Slip Area N-S



High-Slip Area N-S

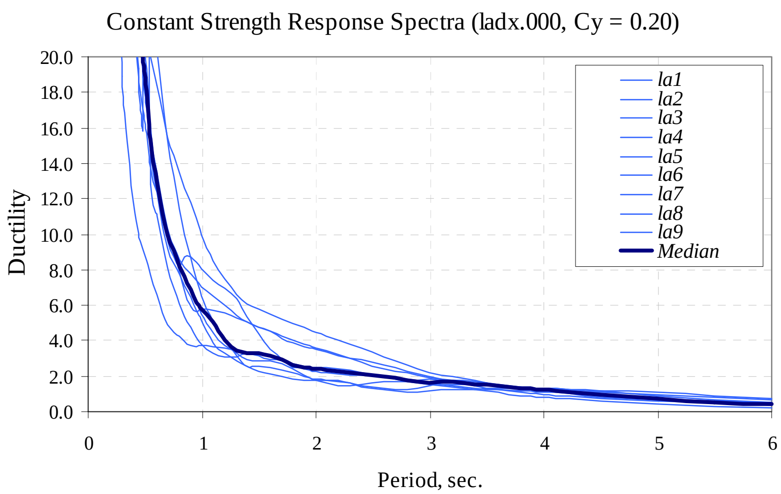


Low-Slip Area E-W

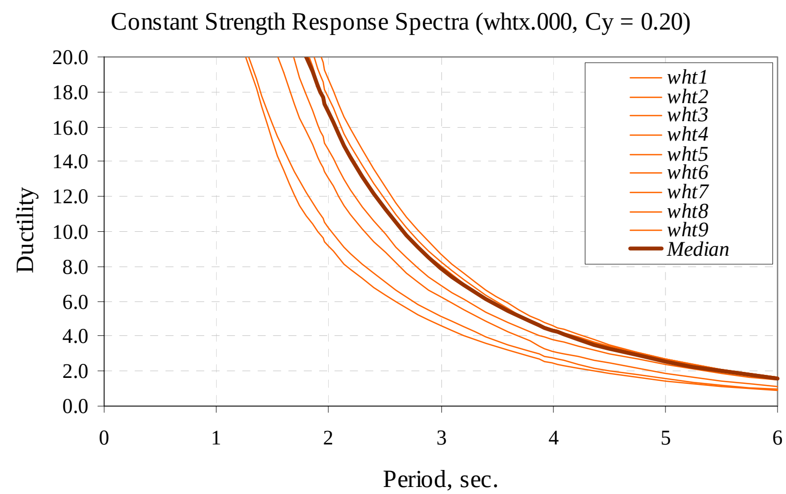


High-Slip Area E-W

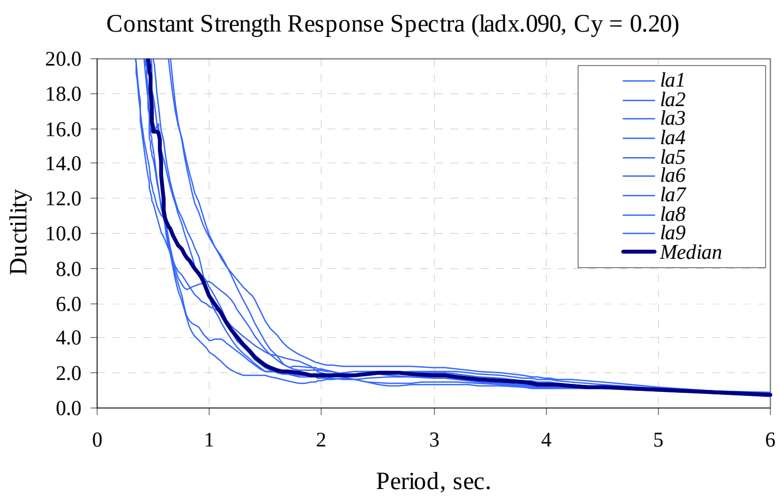
Constant Strength Response Spectra (Cy = 0.20)



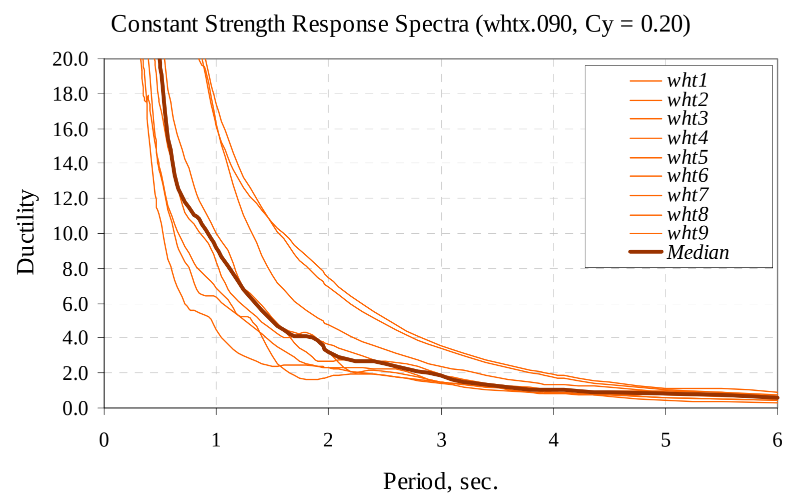
Low-Slip Area N-S



High-Slip Area N-S



Low-Slip Area E-W



High-Slip Area E-W

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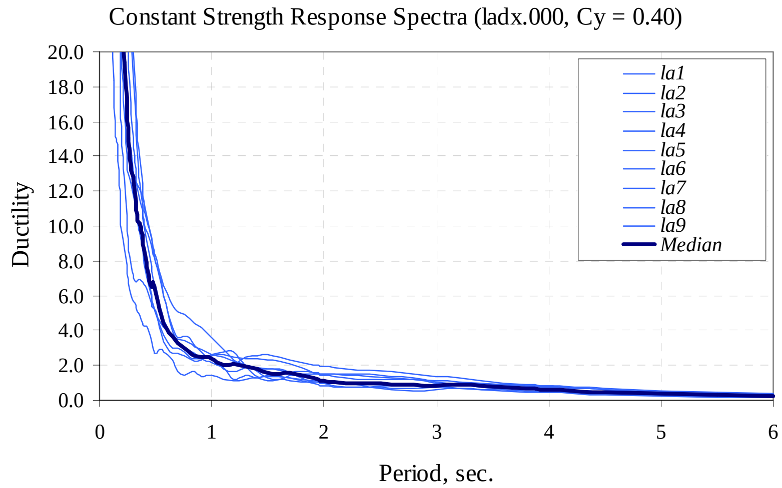
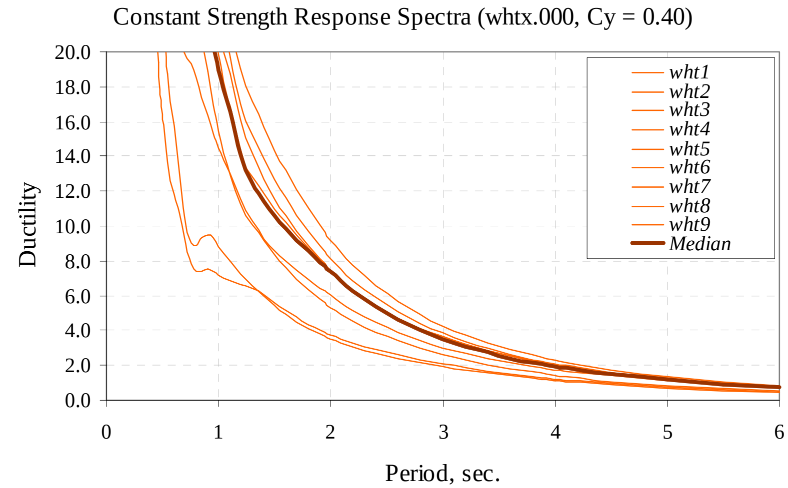
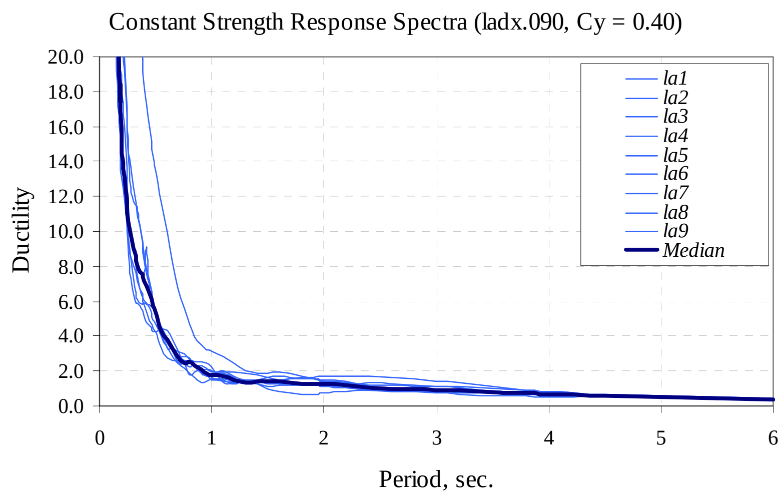
Constant Strength Response Spectra (Cy = 0.40)



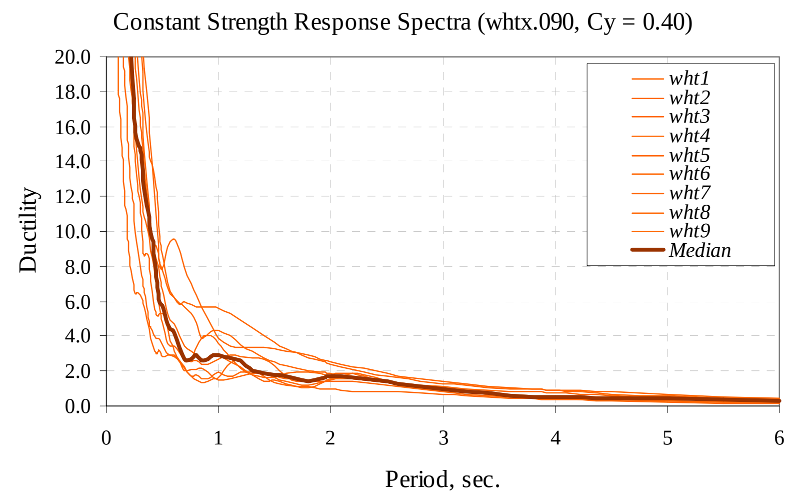
Low-Slip Area N-S



High-Slip Area N-S



Low-Slip Area E-W

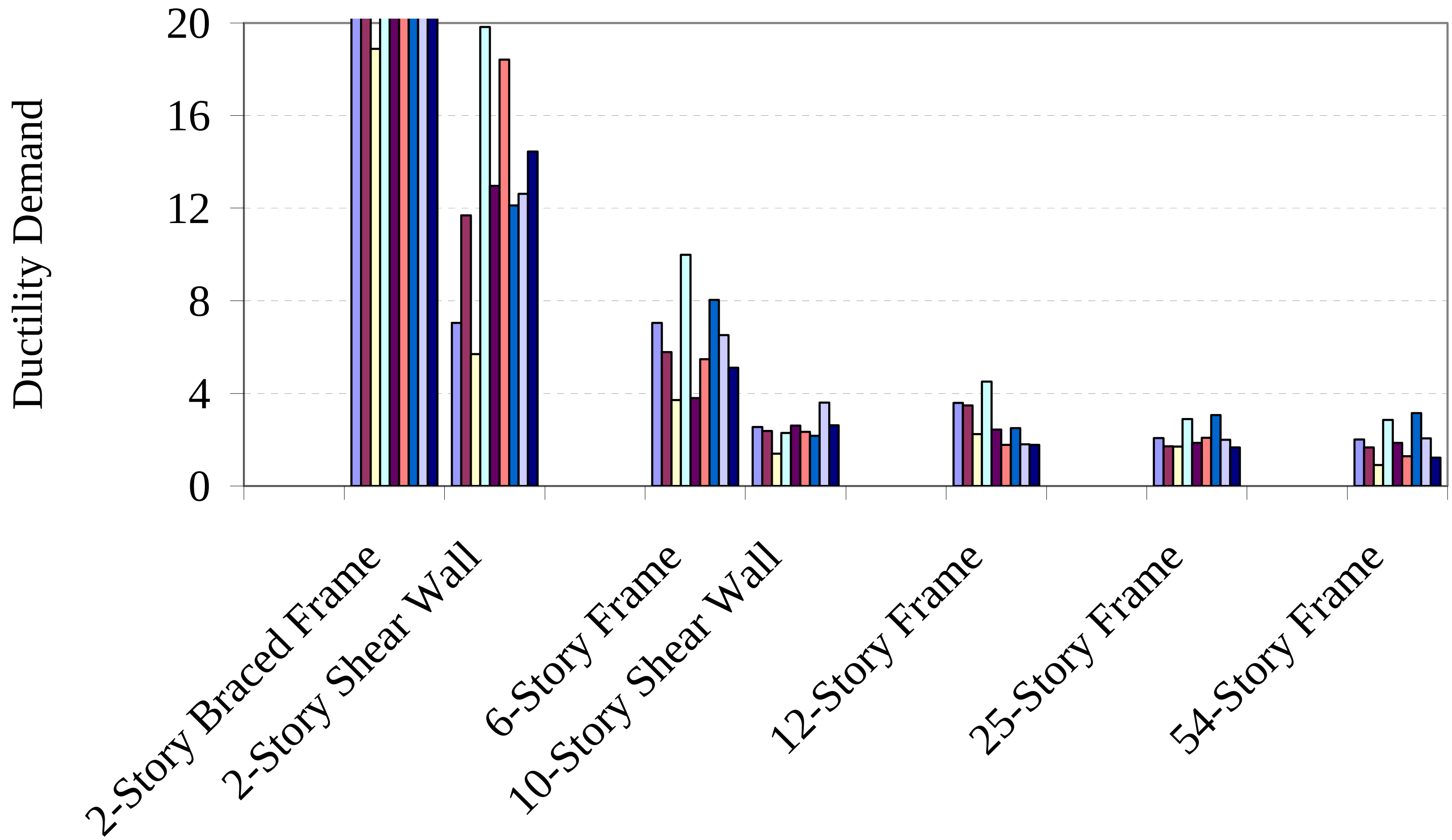


High-Slip Area E-W

Table 1. Typical Building Types Considered to Measure Ductility Demands Imposed by a Postulated M_W 7.15 Puente Hills Earthquake

Building Type	Fundamental Period (sec.)	Yield Seismic Base Shear Coefficient
2-Story Braced Frame System	0.30	0.20
2-Story Shear Wall System	0.30	0.40
6-Story Moment Frame System	1.0	0.20
10-Story Shear Wall System	1.0	0.40
12-Story Moment Frame System	2.0	0.20
25-Story Moment Frame System	4.0	0.10
54-Story Moment Frame System	6.0	0.05

Low-Slip Region (N-S)



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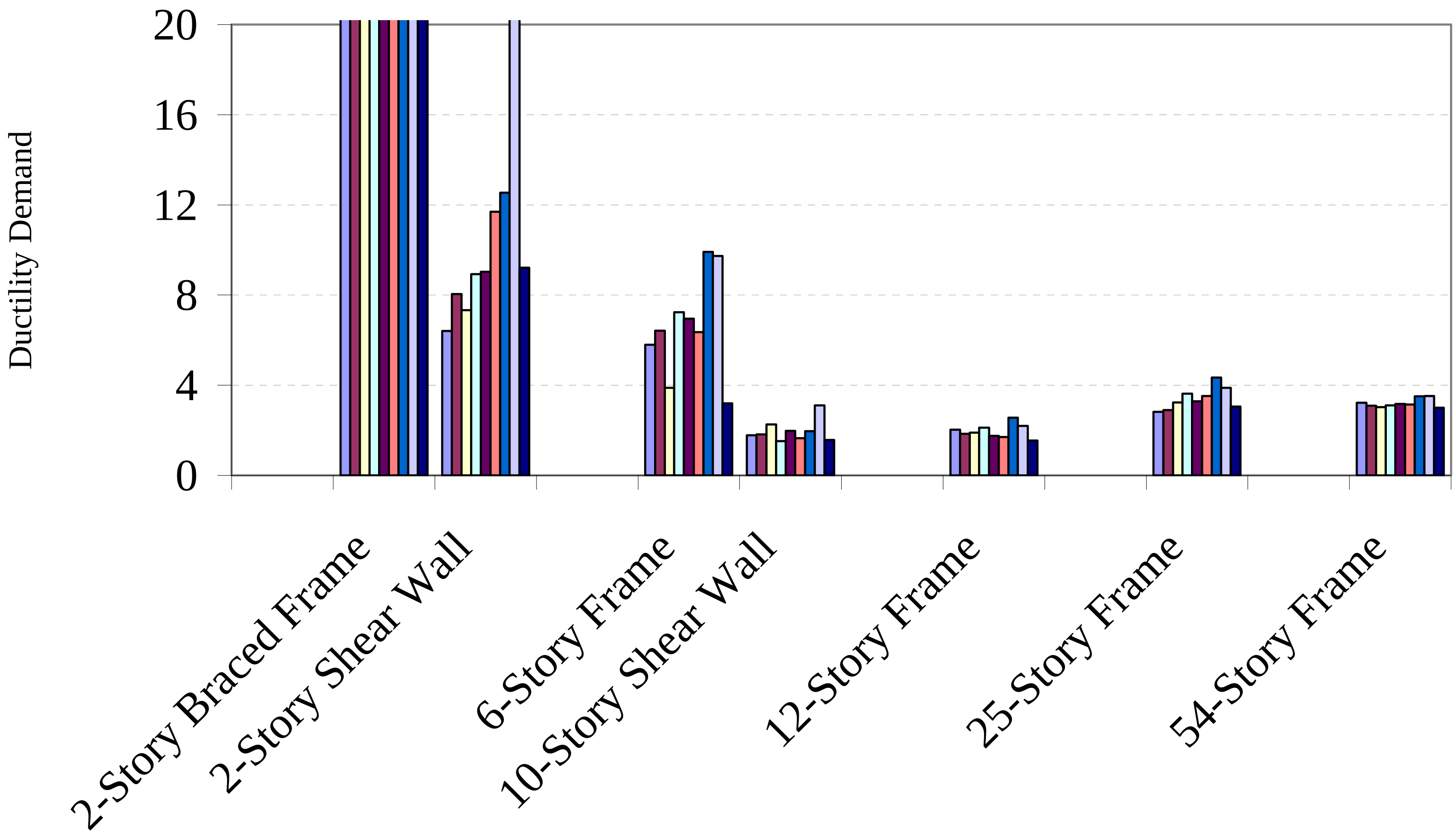
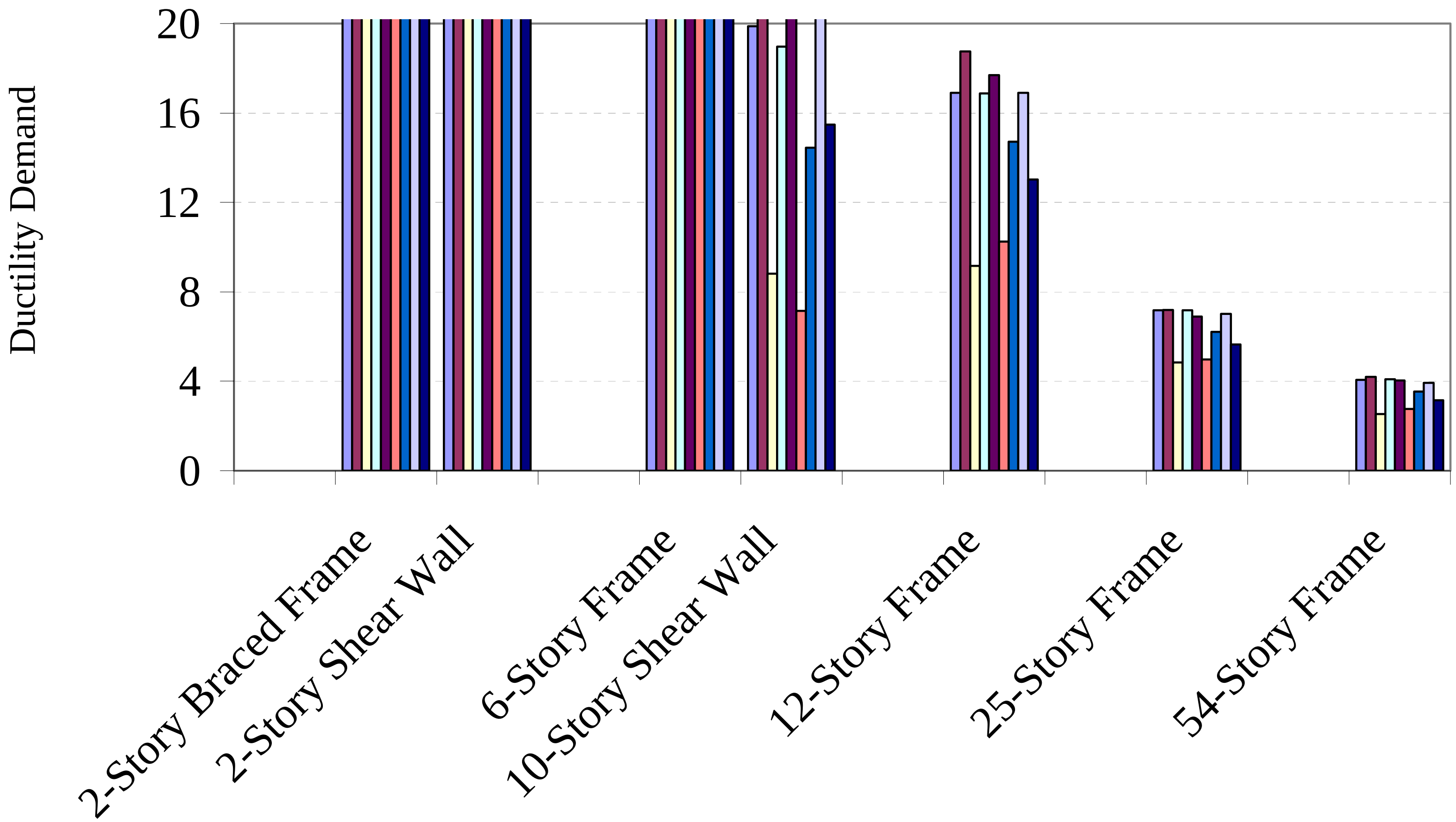
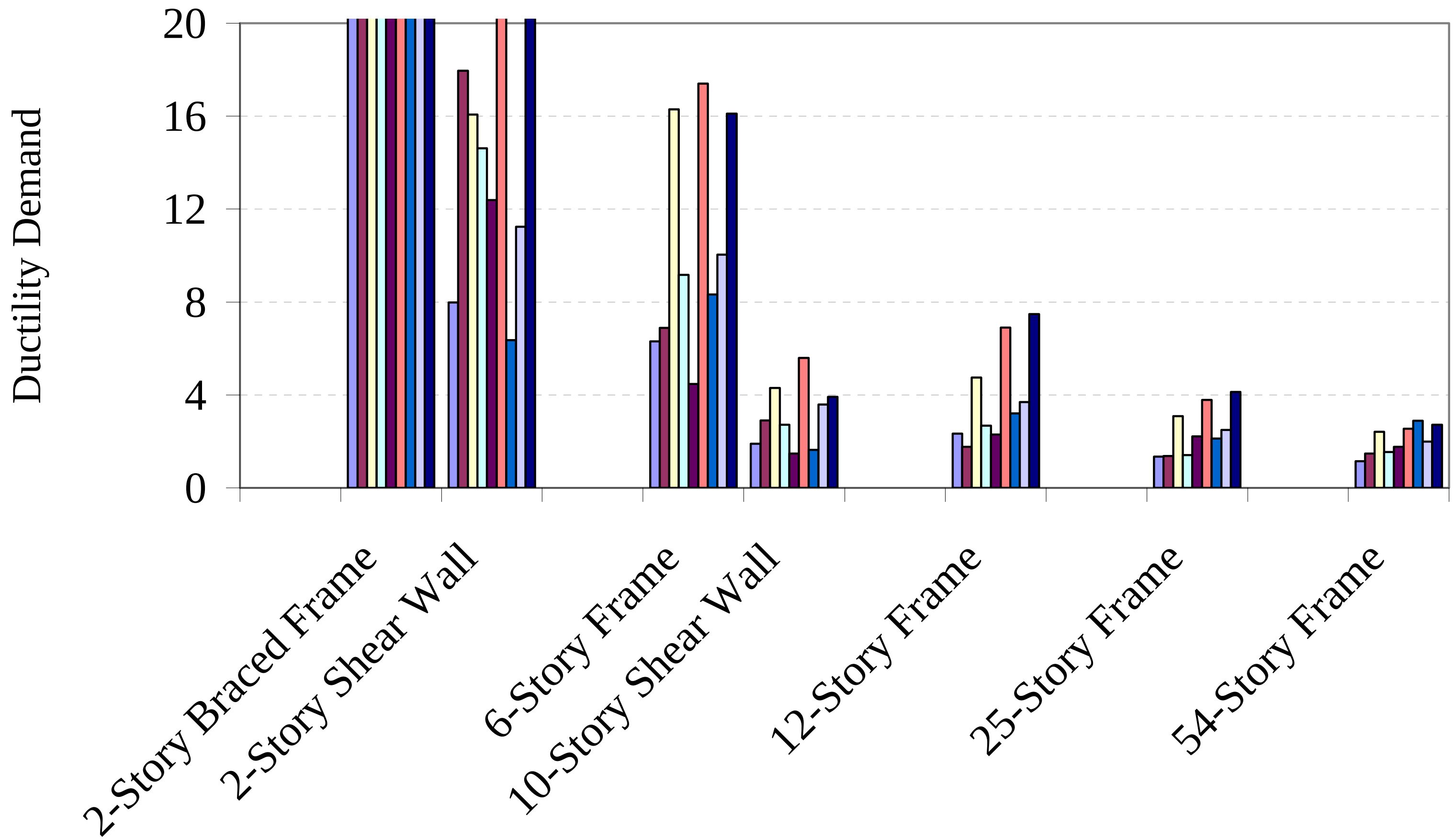
Low-Slip Region (E-W)



High-Slip Region (N-S)



High-Slip Region (E-W)



Conclusions

- Demands from the simulated Puente Hills event are indeed extreme
- Demands imposed by such an event on shorter, more stiff structures, will be significantly larger than that imposed on taller, more flexible buildings.

AN ALTERNATIVE PROCEDURE FOR SEISMIC ANALYSIS AND DESIGN OF TALL BUILDINGS LOCATED IN THE LOS ANGELES REGION

A Consensus Document

December 2005

1. INTENT, SCOPE, JUSTIFICATION, AND METHODOLOGY

- INTENT: Provide an alternate, performance-based approach for seismic design and analysis of tall buildings
- SCOPE: Limited to tall buildings (total height of 160 feet or more).
- JUSTIFICATION: Code's Alternative Analysis Clause (Section 16.29.10.1 of the 2002 City of Los Angeles Building Code (2002-LABC).
- METHODOLOGY: Performance Based Approach with three levels of analysis.

METHODOLOGY:

- Essentially a performance based approach which embodies the performance goals provided in:
  - The 1999 SEAOC BlueBook
  - A number of latest provisions from the ASCE 7-05, the upcoming 2006-IBC, and the FEMA-356 documents.
  - Three levels of ground motion and performance are considered:
    - Serviceability
    - Life-Safety
    - Collapse Prevention

SERVICEABILITY:

- The service level design earthquake is taken as an event having a 50% probability of being exceeded in 30 years (43 year return period).
- For this level, the building structural members are designed without a reduction factor (R = 1).
- This evaluation is not contained in current code requirements.
- The objective is to produce a structure that remains serviceable following such event.

LIFE-SAFETY:

- This is a code-level seismic evaluation.
- The life-safety level design earthquake is taken as an event having a 10% probability of being exceeded in 50 years (475 year return period).
- For this level of earthquake, building code requirements are strictly followed with a small number of carefully delineated exceptions and modifications.
- The prescriptive connection detailing conforms to the requirements of the code.
- Standard code load combinations and material code standards are used.

COLLAPSE-PREVENTION:

- The collapse-prevention level earthquake is taken as an event having a 2% probability of being exceeded in 50 years (2,475 year return period) with a deterministic limit.
- This is larger than the current 2002-LABC MCE event which has a return period of 975 years.
- Evaluation is performed using nonlinear response history analyses.
- Demands are checked against both structural members of the lateral force resisting system and other structural members.
- Nonstructural components are not evaluated at this level.

SEAOC PBD Framework (1999)

Earthquake Design Level	Fully Operational	Operational	Life Safe	Near Collapse
	Earthquake Performance 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

- Our procedure is consistent with, but more stringent than SEAOC PBD Framework (1999)
- MCE level event is consistent with ASCE 7-05

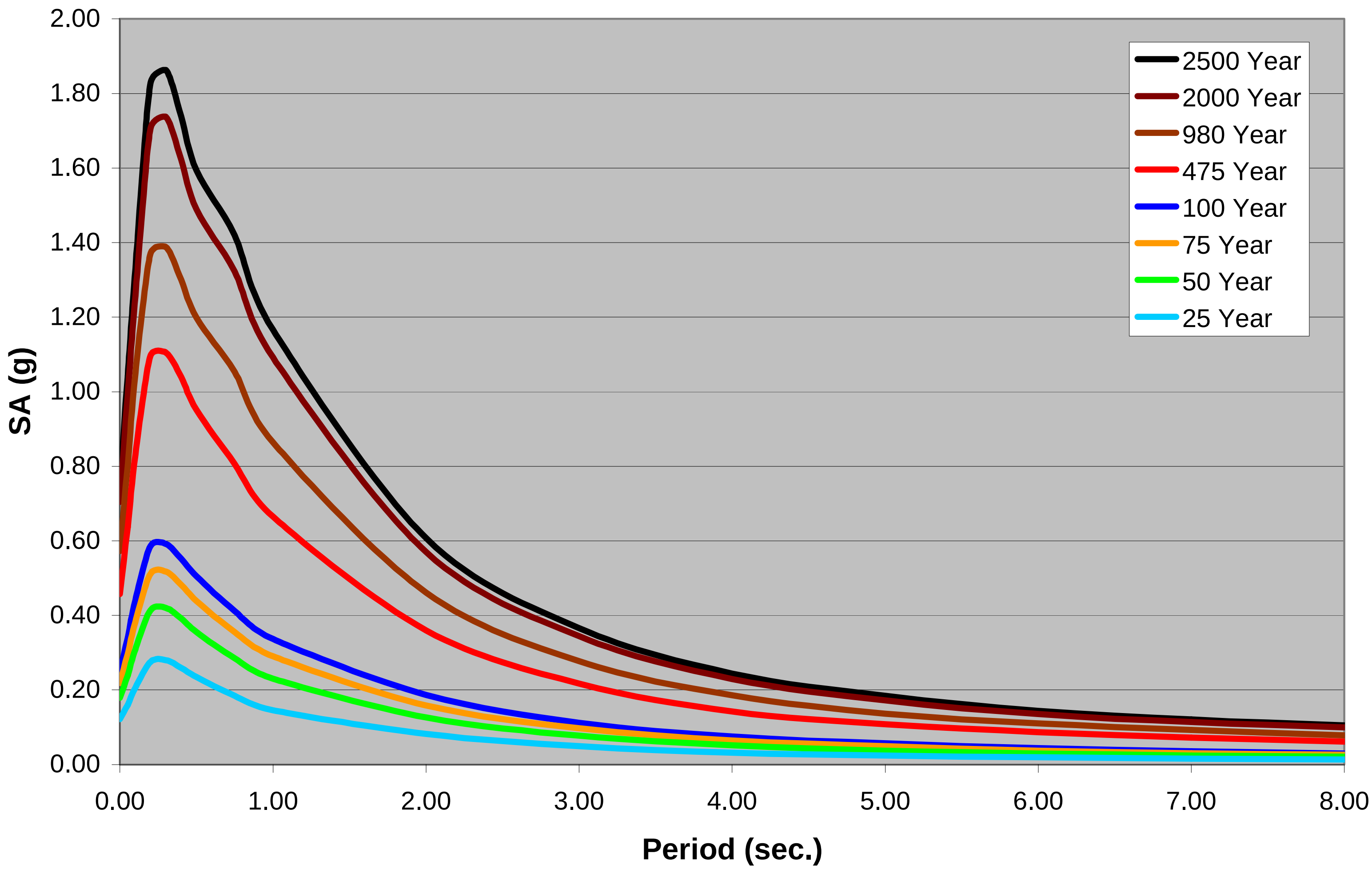
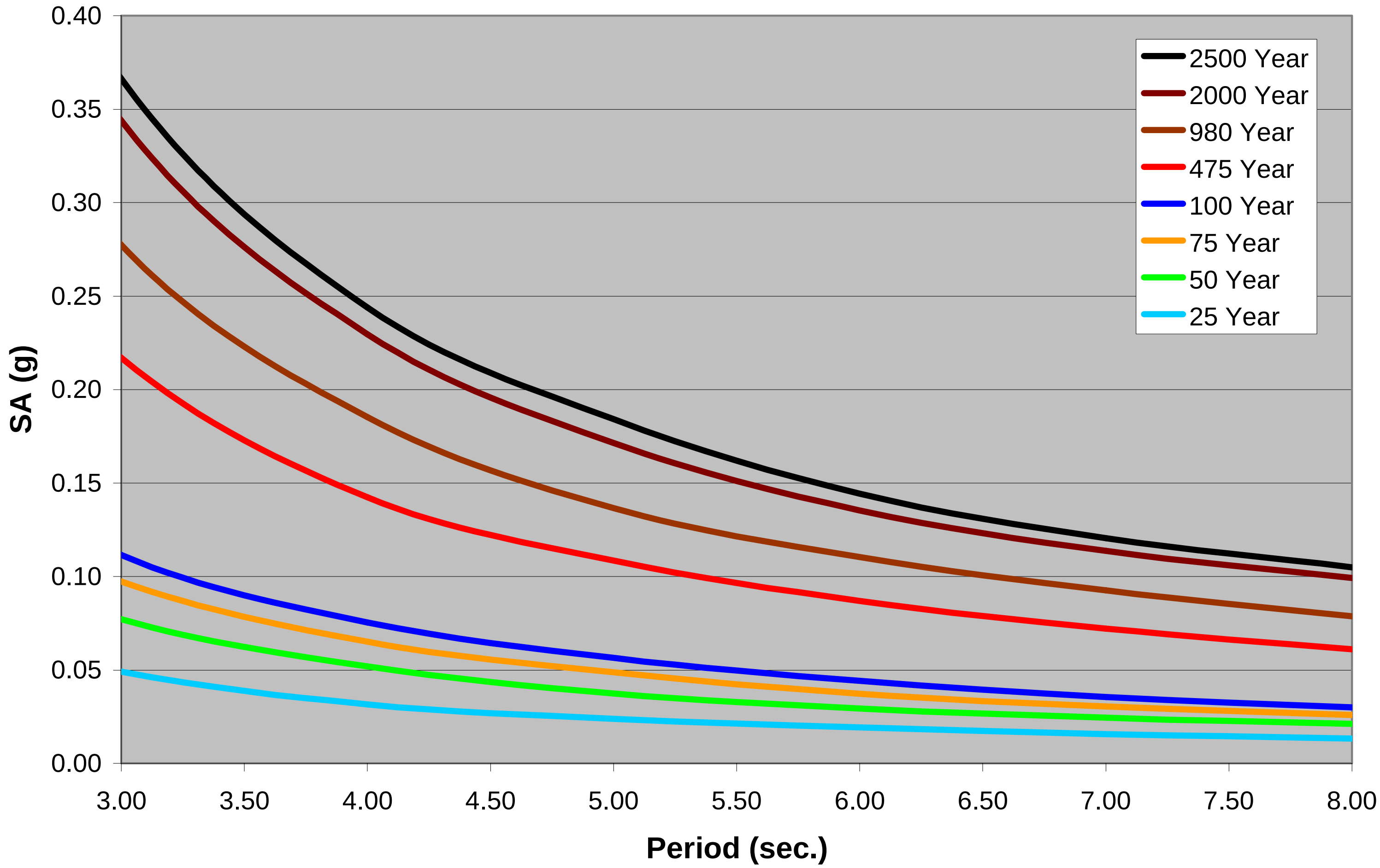


Figure C.2-1. Mean values of spectral acceleration obtained from three attenuation relations.

1. Abrahamson and Silva (1997)
2. Boore, Joyner and Fumal (1997)
3. Sadigh (1997)



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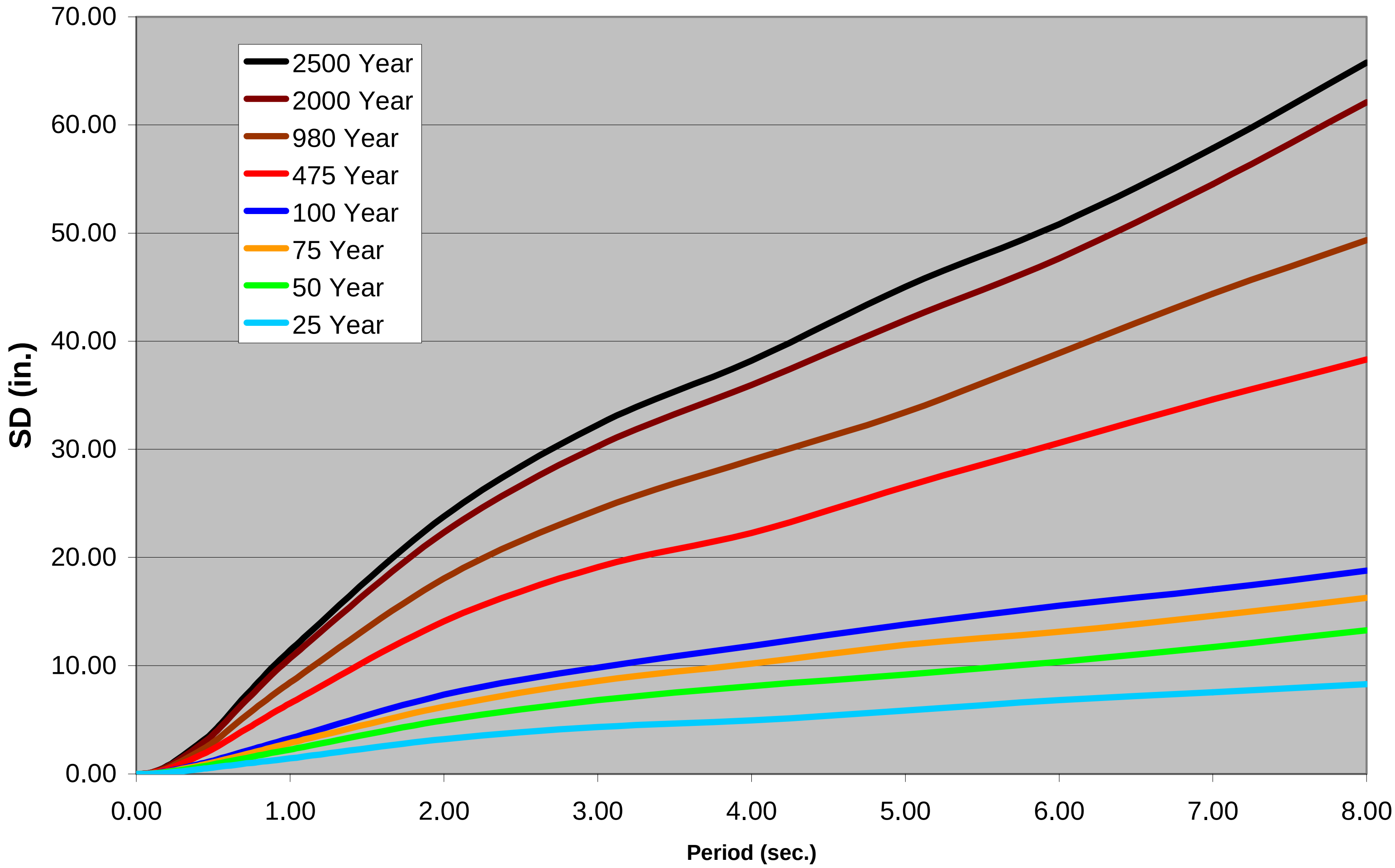

Figure C.2-1. Mean values of spectral displacement (inches) from three attenuation relations.

1. Abrahamson and Silva (1997)
2. Boore, Joyner and Fumal (1997)
3. Sadigh (1997)

Summary of Basic Requirements

Evaluation Step	**Ground Motion Intensity**[1]	**Type of Analysis**	**Type of Mathematical Model**	**Reduction Factor (*R*)**	**Accidental Torsion Considered?**	**Material Reduction Factors (ϕ)**	**Material Strength**
1	50/30	LDP[2]	3D[4]	1.0	No	1.0	Expected
2	10/50	LDP[2]	3D[4]	Per 2002-LABC	Yes	Per 2002-LABC	Specified
3	2/50[5]	NDP[3]	3D[4]	N/A	No.	1.0	Expected

[1] probability of exceedance in percent / number of years
[2] linear dynamic procedure
[3] nonlinear dynamic procedure
[4] three-dimensional
[5] with deterministic limit per ASCE 7-05 and 2006-IBC

Step 1: Serviceability Requirement

- Ground Motion:
  - 50% probability of being exceeded in 30 years
  - Not be reduced by the quantity R.
  - Site-specific elastic design response spectrum
  - The spectrum shall be developed for 5% damping, unless a different value is shown to be consistent with the anticipated structural behavior at the intensity of shaking established for the site.
- Mathematical Model
  - 3D mathematical model required
  - The stiffness properties used in the analysis and general mathematical modeling shall be in accordance with 2002-LABC Section 1630.1.2.
  - Expected material strengths may be used.

Step 1: Serviceability Requirement

- Description of Analysis Procedure
  - Elastic response spectrum analysis
  - At least 90 percent of the participating mass included
  - Complete Quadratic Combination (CQC) method used.
  - Response Parameters shall not be reduced.
  - Inclusion of accidental torsion is not required.
  - The following load combinations shall be used:

$$1.0D + 0.5L + 1.0E_x + 0.3E_y \quad (1)$$

$$1.0D + 0.5L + 0.3E_x + 1.0E_y \quad (2)$$

Step 1: Serviceability Requirement

- Acceptability Criteria

  - None of the members exceed the applicable LRFD limits for steel members or USD limits for concrete members (ϕ = 1.0).

  - Note that the design spectral values shall not be reduced by the quantity R.

Step 2: Life-Safety Requirement

- Ground Motion:
  - Code DBE
  - Reduced by the quantity R per Code.
  - Site-specific elastic design response spectrum
- Mathematical Model
  - 3D mathematical model
- Description of Analysis & Design Procedure
  - Elastic response spectrum analysis
  - Structural analysis and design shall be performed in accordance with all relevant 2002-LABC provisions except for the provisions specifically excluded in Section 2.4 of this document.
- Acceptability Criteria
  - The structure shall satisfy all relevant 2002-LABC requirements except the provisions explicitly identified in Section 2.4 of this document

Step 3: Collapse-Prevention Requirement

- Ground Motion:
  - ASCE 7-05 MCE
  - 7 Pairs or more time-histories required
  - Selection and scaling according to ASCE 7-05
- Mathematical Model
  - 3D nonlinear model
  - P-Δ effects included
  - All elements and components that in combination represent more than 15% of the total initial stiffness of the building, or a particular story, shall be included in the mathematical model.
  - The hysteretic behavior of elements shall be modeled consistent with suitable laboratory test data or applicable modeling parameters for nonlinear response analyses published in FEMA-356.
  - Various degradations must be modeled if relevant Exception invoked.
  - Use expected strength considering material overstrength.

Table 2.3.2-1. Expected Material Strengths

Material		Expected Strength
		Strength (ksi)
Structural steel*		
	Hot-rolled structural shapes and bars	
	ASTM A36/A36M	$1.5F_y$
	ASTM A572/A572M Grade 42 (290)	$1.3F_y$
	ASTM A992/A992M	$1.1F_y$
	All other grades	$1.1F_y$
	Hollow Structural Sections	
	ASTM A500, A501, A618 and A847	$1.3F_y$
	Steel Pipe	
	ASTM A53/A53M	$1.4F_y$
	Plates	$1.1F_y$
	All other products	$1.1F_y$
Reinforcing steel**		1.17 times specified f_y
Concrete**		1.3 times specified f'_c

* based on 2002 AISC Seismic Provisions

** based on FEMA-356

Step 3: Collapse-Prevention Requirement

- Description of Analysis Procedure:
  - 3D nonlinear response history analyses
  - For each ground motion pair, the structure shall be analyzed for the effects of the following loads and excitations:

    1.0D + 0.5L + 1.0Ex + 1.0Ey (1)

    1.0D + 0.5L + 1.0Ex - 1.0Ey (2)

    1.0D + 0.5L - 1.0Ex + 1.0Ey (3)

    1.0D + 0.5L - 1.0Ex - 1.0Ey (4)
  - Inclusion of accidental torsion is not required.

- Acceptability Criteria
  - Capacity > Demand
    - Demand = Average of 7.
    - Capacity = FEMA-356 Primary CP values for NL response unless Exception invoked.

Step 3: Collapse-Prevention Requirement

- Acceptability Criteria
  - EXCEPTION
    - Larger deformation capacities may be used only if substantiated by appropriate laboratory tests and approved by the Peer Review Panel and the Building Official.
    - If FEMA-356 Primary Collapse Prevention deformation capacities are exceeded, strength degradation, stiffness degradation and hysteretic pinching shall be considered **and**
    - base shear capacity of the structure shall not fall below 90% of the base shear capacity at deformations corresponding to the FEMA-356 Primary Collapse Prevention limits.

Step 3: Collapse-Prevention Requirement

- Acceptability Criteria
  - Collector elements shall be provided and must be capable of transferring the seismic forces originating in other portions of the structure to the element providing the resistance to those forces.
  - Every structural component not included in the seismic force–resisting system shall be able to resist the gravity load effects, seismic forces, and seismic deformation demands identified in this section.
  - Components not included in the seismic force resisting system shall be deemed acceptable if their deformation does not exceed the corresponding Secondary Life Safety values published in FEMA-356 for nonlinear response procedures.

EXCLUSIONS

- For buildings analyzed and designed according to the provisions of this document:
  1. The seismic force amplification factor, Ω_0, in 2002-LABC formula 30-2 is set to unity (Ω_0 = 1.0).
  2. The Reliability/Redundancy Factor, ρ, as provided by 2002-LABC formula 30-3 is set to unity (ρ = 1.0).
  3. Static 2002-LABC formulas 30-6 and 30-7 do not apply. Instead in Step 2, the seismic base shear (*V*) shall not be taken less than 0.025*W* where *W* is the effective seismic weight.

$$V = 0.11 C_a I W$$

$$V = \frac{0.8 Z N_V I}{R} W$$

$$V = 0.025 W$$

EXCLUSIONS

- For buildings analyzed and designed according to the provisions of this document:
  4. Method A (2002-LABC Sec. 1630.2.2.1) does not apply. Results obtained by Method B or more advanced analysis are not bound by the results obtained from Method A.
  5. The limit on calculated story drift of $0.020/T^{1/3}$ specified in 2002-LABC 1630.10.2 does not apply.
  6. The height limitations of 2002-LABC Table 16-N do not apply.

Design Review

- Peer Review Panel:
  - Design review shall be conducted according to the provisions of 2002-LABC Section 1631.6.3.2.
  - In addition, the review need not be limited to lateral system and may include review of the
    - the gravity system
    - acceptance criteria
    - configuration of structural elements
    - performance/design philosophy
    - design ground motions, and
    - quality assurance measures.
  - The cost for the peer review process shall be borne by the owner

Design Review

- <u>Assurance of Consistency and Quality of the Peer Review Process:</u>
  - An advisory board appointed by the region's building and safety authorities to be formed.
  - This advisory board shall consist of widely respected and recognized experts in
    - structural engineering
    - performance-based design
    - nonlinear analysis techniques, and
    - geotechnical engineering.
  - The advisory board members to be elected to serve for a predetermined period of time on a staggered basis.
  - The advisory board shall
    - oversee the design review process across multiple projects periodically;
    - assist the building department in developing criteria and procedures spanning similar design conditions, and
    - resolve disputes arising under peer review.

Link to the Document