Project 07 - Reassessment of Seismic Design Procedures and Development of New Ground Motions for Building Codes

EERI Seminar on Next Generation Attenuation Models

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USGS science for a changing world

FEMA

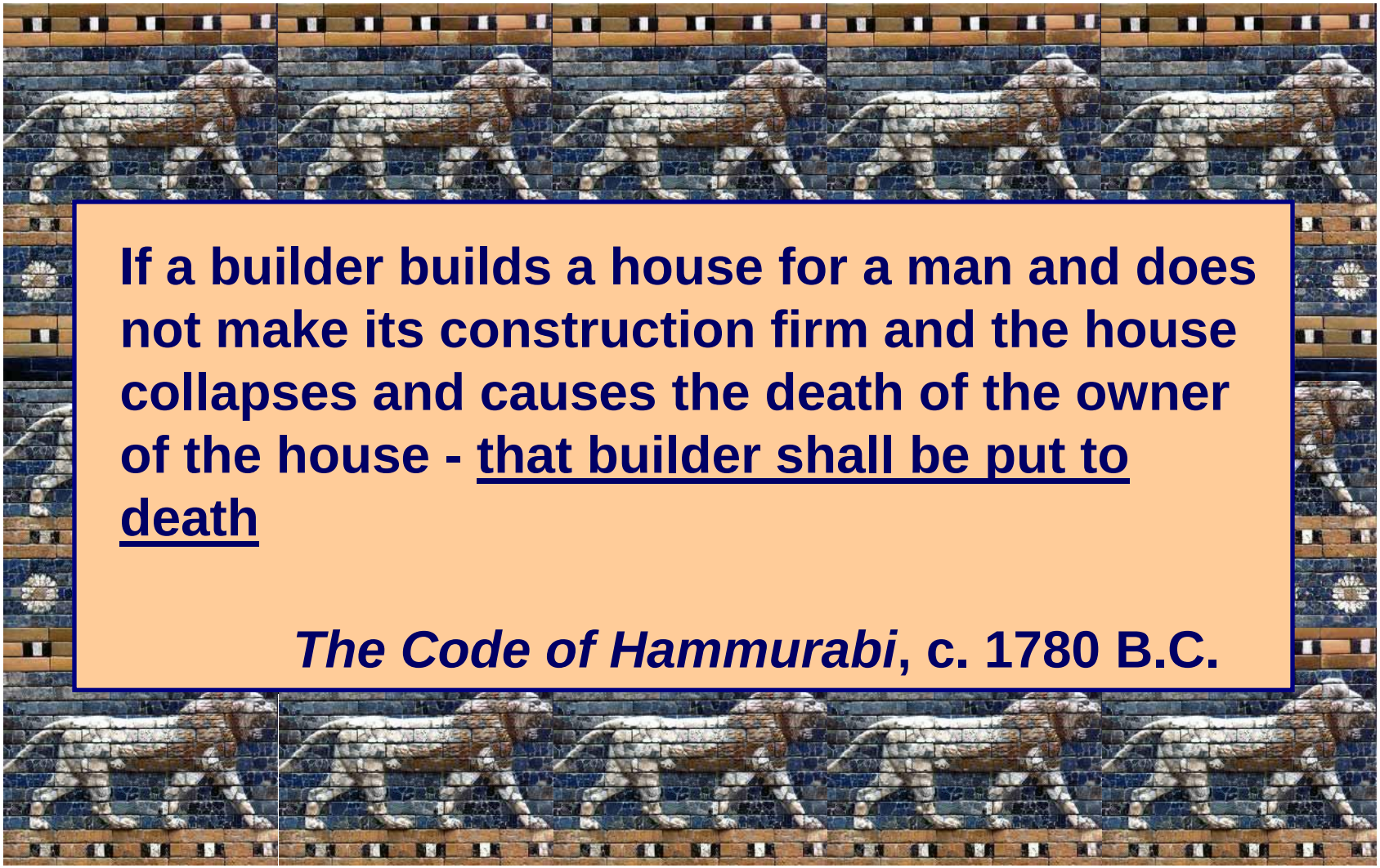
Building Seismic Safety Council

EERI

Topics

- Background – Building Code Seismic Criteria
  - Seismic Codes and Resource Documents
  - Ground Motion Development Process
  - Current ground motion criteria – *Project 97*
- New Ground Motion Criteria – *Project 07*
  - Seismic Design Procedures Reassessment Group
- Discussion of Key Concepts
  - Risk-Targeted Ground Motions
  - Maximum Direction Ground Motion Intensity
  - 84th Percentile Deterministic Ground motions
- Example Values of New Ground Motions
  - 34 United States City Sites

Very Early Building Code – Life Safety POV



If a builder builds a house for a man and does not make its construction firm and the house collapses and causes the death of the owner of the house - <u>that builder shall be put to death</u>

***The Code of Hammurabi*, c. 1780 B.C.**

2009 *NEHRP Provisions* – Life Safety (+) POV

- **Provisions are minimum recommended requirements** for design and construction of buildings and other structures to resist earthquake ground motions
- **Intent of these Provisions** is to provide reasonable assurance of seismic performance:
  - **Avoid serious injury and life loss**
  - **Avoid loss of function in critical facilities**
  - **Minimize nonstructural repair costs (where practical to do so)**
- **Objectives addressed by:**
  - **Avoiding structural collapse in very rare, extreme ground shaking**
  - **Limiting damage to structural and nonstructural systems** that could lead to injury, economic loss or loss of functions **for smaller more frequent ground motions.**

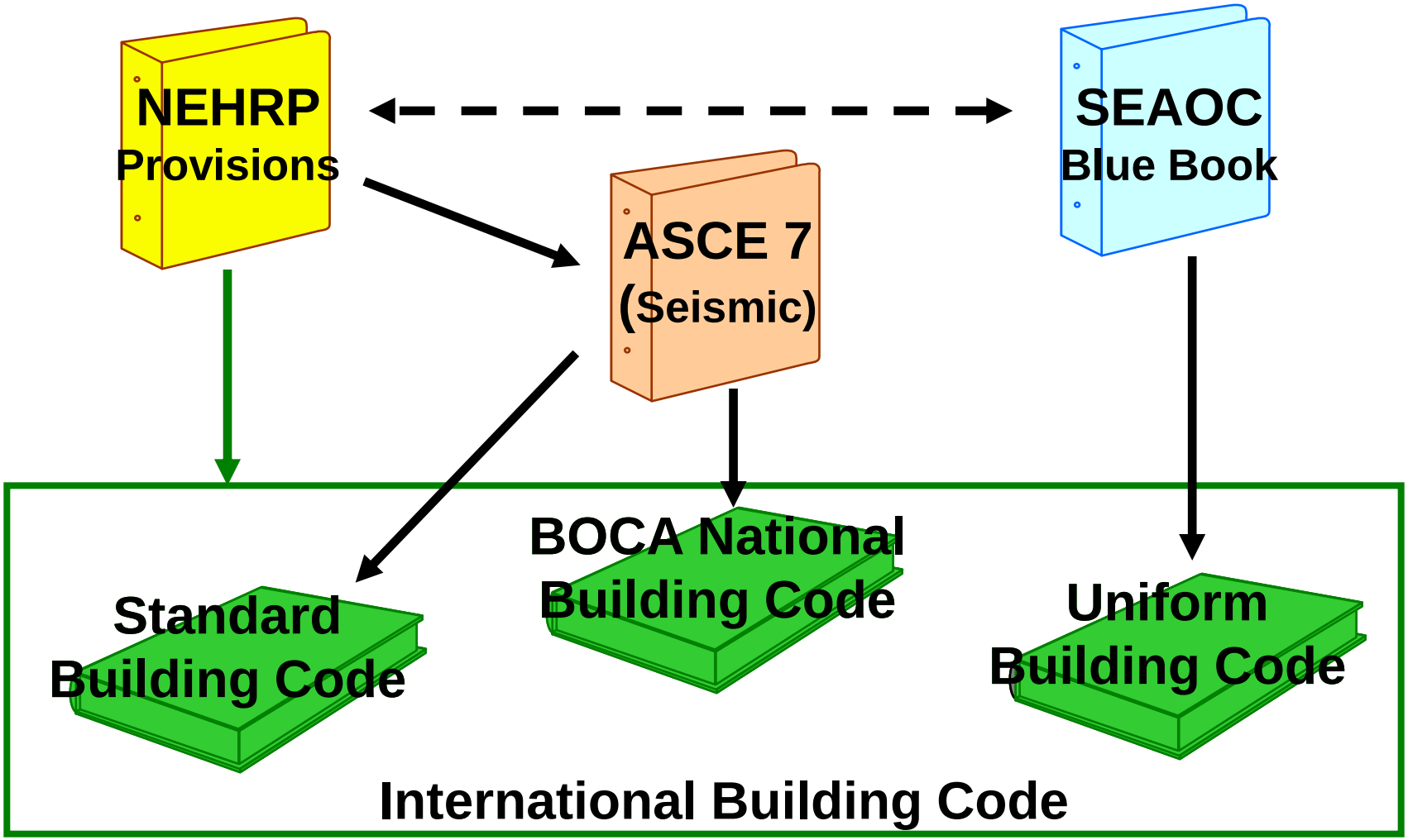
Current Model Building Codes

- National:
  - ***2006 IBC*** - *2006 International Building Code*, International Code Council, Birmingham AL. (next edition ***2012 IBC***)
  - ***2006 NFPA 5000*** - *2006 Building Construction and Safety Code*, *NFPA 5000*, National Fire Protection Association, Quincy MA.
- Regional:
  - ***2006 CBC*** - *2006 California Building Code*, California Building Standards Commission, (previous, *2001 CBC*, based on the *1997 Uniform Building Code,* International Conference of Building Officials, Whittier, CA.

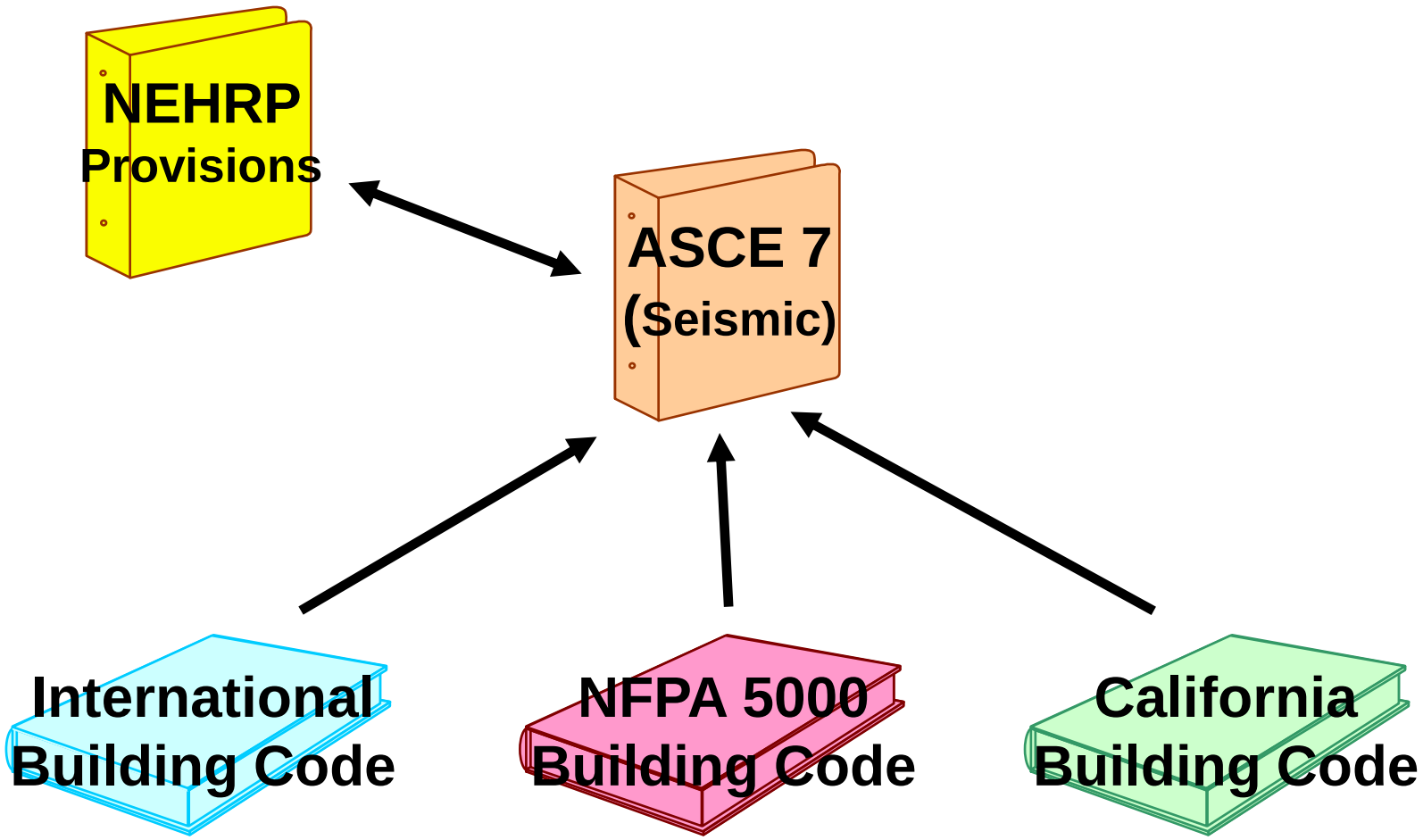
Source Documents – Model Building Codes

- National:
  - ***NEHRP Provisions*** *- 2003 NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures*, Federal Emergency Management Agency, *FEMA 450.* (next edition – ***2009 Provisions***)
  - ***ASCE 7*** *- Minimum Design Loads for Buildings and Other Structures*, ASCE 7-05, American Society of Civil Engineers, Reston, VA. 2006 (next edition – ***ASCE 7-10***)
- Regional:
  - **SEAOC *Blue Book*** *- Recommended Lateral Force Requirements and Commentary, Seismology Committee*, Structural Engineers Association of California, 1996 Sixth Edition and 1999 Seventh Edition.

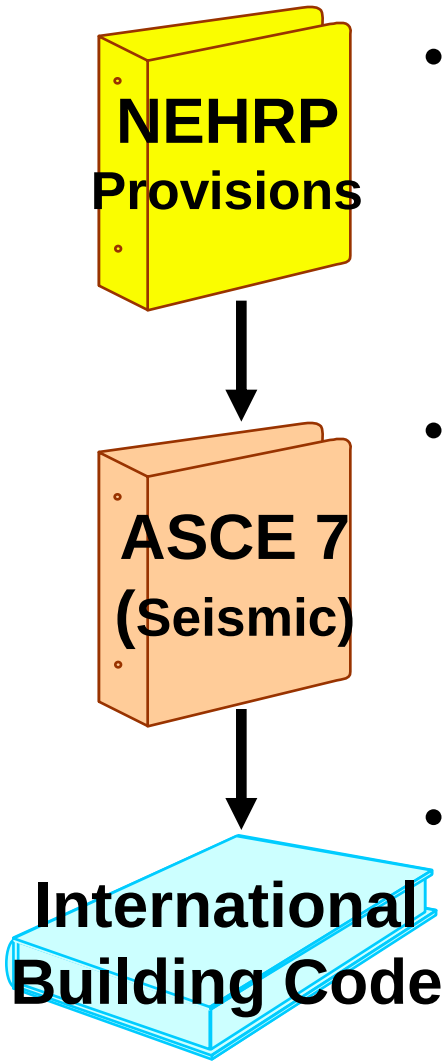
Seismic Codes and Source Documents - Past



Seismic Codes and Source Documents – Current



Code Development Process – Ground Motions



- Building Seismic Safety Council (BSSC) for the Federal Emergency Management Agency (FEMA)
  - **Provisions Update Committee (PUC)**
    - **Seismic Design Procedures Reassessment Group (SDPRG)**
- Structural Engineering Institute (SEI) of the American Society of Civil Engineers (ASCE)
  - **Minimum Design Loads on Buildings and Other Structures Committee (ASCE 7 MC)**
    - **Task Com. Seismic Provisions (ASCE 7 SSC)**
- International Code Council (ICC)
  - **Codes and Standards, International Building Code - Structural Committee (IBC-S)**
    - **Public Hearings (2009/2010 for 2012 IBC)**

Seismic Design Procedures Reassessment Group

Project 07 – Joint effort of the BSSC, FEMA and USGS

Scope/Objectives

- **Revisit products of *Project 97*** in light of new seismic hazard information (developed by the USGS)
- **Develop revised seismic design maps and procedures** reflecting these new data for inclusion in the *2009 NEHRP Procedures* (and ASCE/SEI 7-10 and model building codes)

Members

Dr. Charles A. Kircher, PE (SDPRG Chair)
Dr. C. B. Crouse, PE (PUC TS-3 Chair)
Prof. Bruce R. Ellingwood, PE, Georgia Tech
Mr. Ronald O. Hamburger, SE (PUC Chair)
Prof. Robert D. Hanson, *FEMA (tech. advisor)*
Dr. James R. Harris, SE (ASCE 7 past Chair)
Dr. John "Jack" R. Hayes, *PE, NIST (NEHRP)*
Mr. William T. Holmes, SE (PUC past Chair)
Mr. John D. Hooper, SE (ASCE 7 SSC Chair)
Dr. Jeffrey K. Kimball, DOE NNSA
Dr. Nicolas Luco, USGS
Prof. Andrew Whittaker, SE, SUNY Buffalo
Mr. Michael Mahoney, *FEMA*

Proposal Development Activities and Schedule

- Technical Topics Investigated by SDPRG (task leaders):
  - **Level of Uniform Hazard or Risk? (Dr. Nicolas Luco)**
  - **Ground Motion Intensity Parameter? (Prof. Andrew Whittaker)**
  - **Spectral Shape Definition? (Dr. James Harris)**
- Proposal SDPRG-1R4 – *2009 NEHRP Provisions* (Done):
  - **SDPRG Proposal Development – June '06 – Sep. '07**
  - **BSSC PUC Review and Approval – Oct. '07 – Sep. '08**
  - **BSSC Membership Review and Approval - March 2009**
- Proposal GM-CH11-1R1 – *ASCE 7-10* (Done):
  - **ASCE 7 SSC Review and Approval – Sep. '08 – May '09**
  - **ASCE 7 MC Review and Approval – July 2009**
- Ground Motion Proposal – 2012 *IBC* (in the works)

New Ground Motions

Approach and Key Components

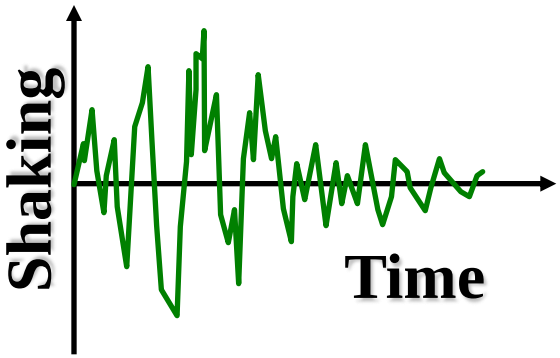
- Revise Seismic Design Criteria:
  - **Seismic ground motion values (ASCE 7-10, Section 11.4) and related seismic ground motion maps (ASCE 7-10, Chapter 22)**
  - **Site-specific ground motion procedures (ASCE 7-10, Chap. 21)**
- Incorporate USGS Seismic Hazard Data – New ground motions incorporate updated seismic hazard data and related maps developed by the USGS
- Key Technical Improvements – New ground motions include changes in three topical areas:
  - **Risk-targeted ground motions (probabilistic regions)**
  - **Direction of ground motions (Maximum direction)**
  - **Near-fault (deterministic) ground motions (84th percentile)**

ASCE 7-10 and 2009 *NEHRP Provisions* – Differences?

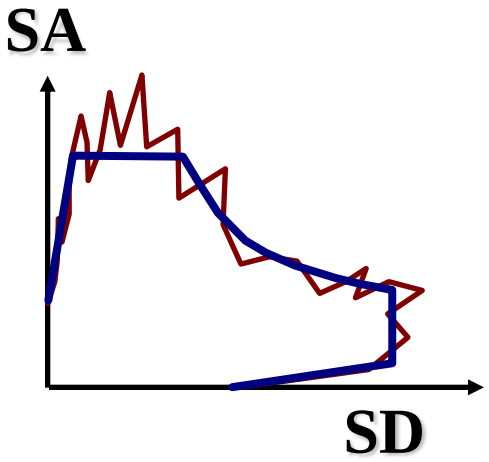
- Technical – None, same concepts, same design values
  - **Seismic design coefficients of *ASCE 7-10* are exactly the same as those of the 2009 *NEHRP Provisions***
- Editorial – Slightly different MCE symbol and definition (red underline indicates text not used by *ASCE 7-10*):
  - **RISK-TARGETED MAXIMUM CONSIDERED EARTHQUAKE (MCE_R) GROUND MOTIONS: The most severe earthquake effects considered by this standard as defined in Section 11.4.**
  - **Other minor edits**
- Section 11.4 formulas (and referenced MCE maps):
  - ***ASCE 7-10* – Simpler: *ASCE 7-10* defines ground motion values (Section 11.4) consistent with formulas of *ASCE 7-05***
  - **2009 *NEHRP Provisions* – More Transparent: 2009 *Provisions* define ground motion values (Section 11.4) that are consistent with site-specific ground motion process (Chapter 21)**

Ground Motion Characterization

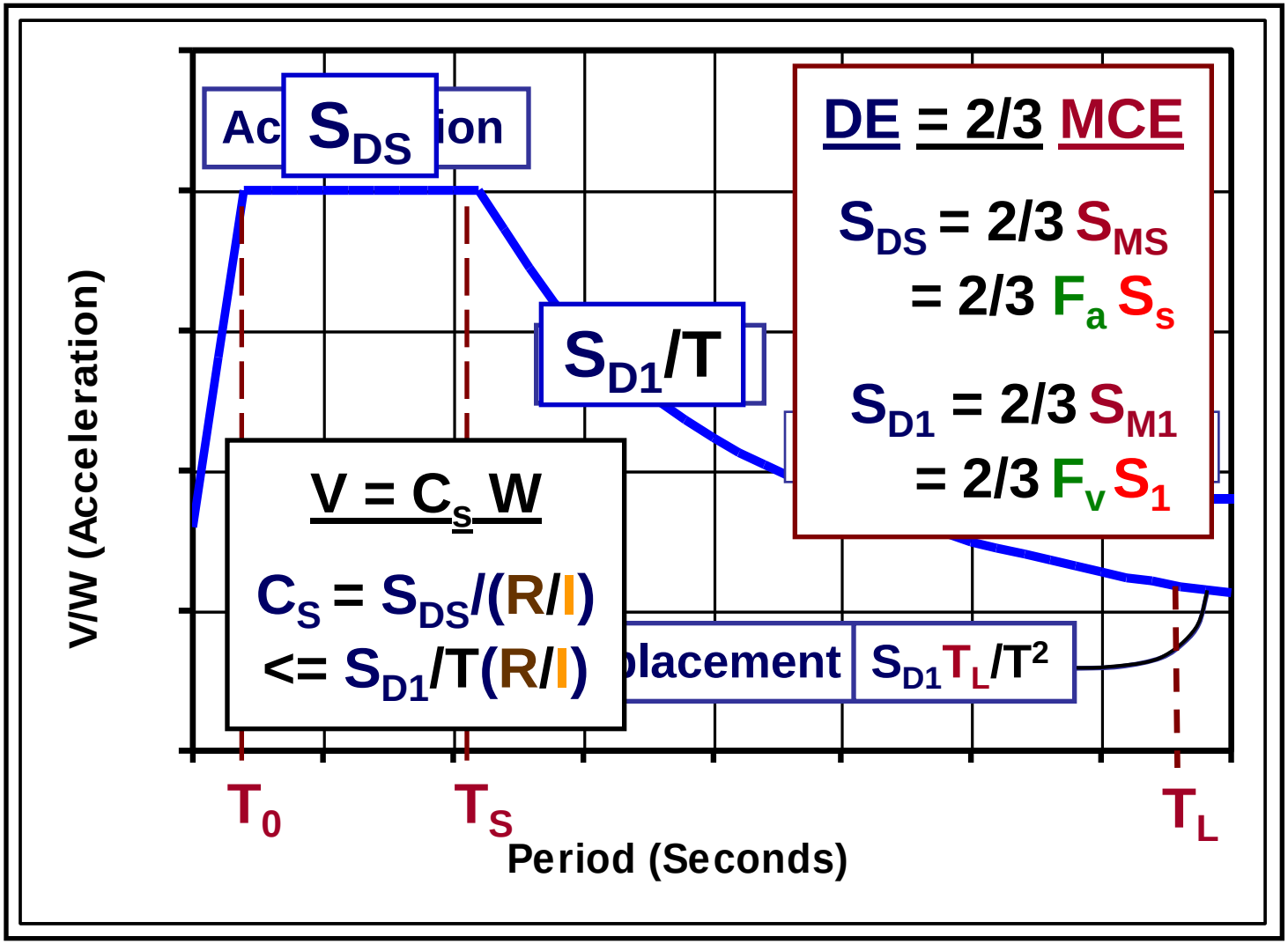
- Ground Motion Time Histories
  - **Acceleration (including PGA)**
  - Velocity (including PGV)
  - Displacement (including (PGD)



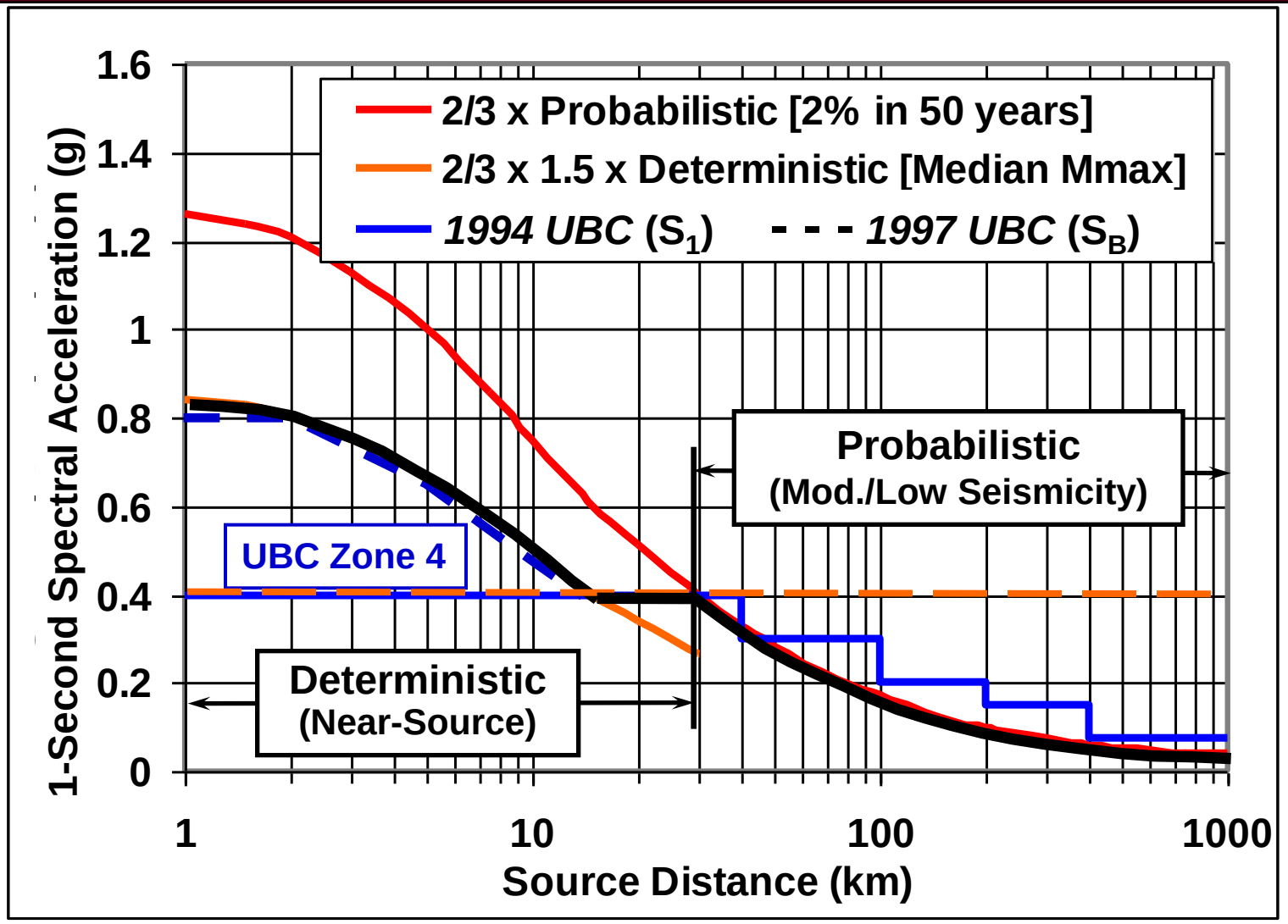
- Elastic Response Spectra
  - Peak response of a collection of linear single-degree-of-freedom systems with 5% viscous damping
  - **"Smooth" spectra used for design (to represent many different possible ground motion time histories)**



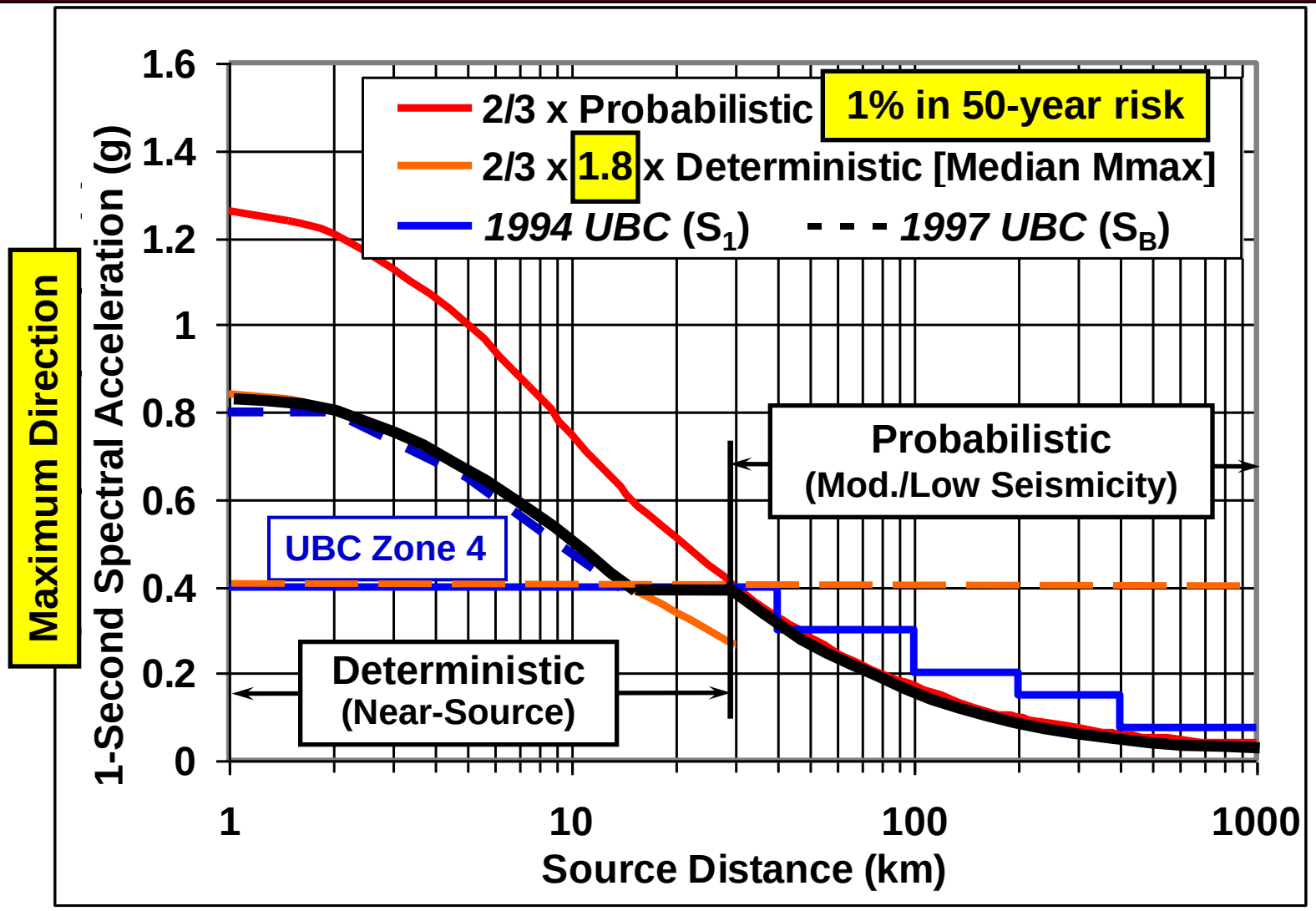
Design Spectrum Shape and Parameters



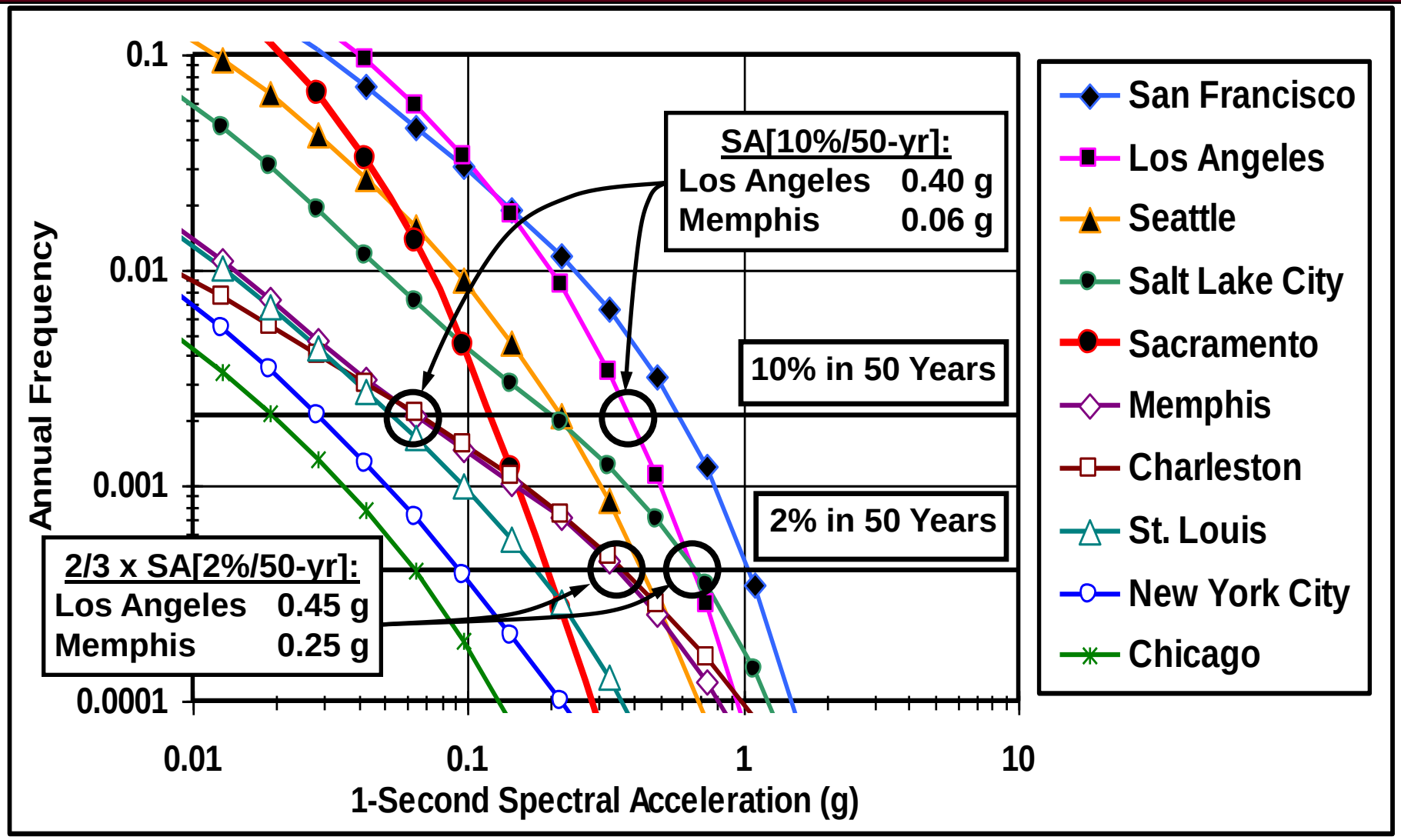
Notional Illustration of Design Earthquake (*Project 97*)



Notional Illustration of Design Earthquake *(Project '07)*



Example Hazard Curves (USGS, 2003)



Probabilistic MCE Ground Motions

- Previous probabilistic MCE ground motions have a 2% probability of being exceeding in 50 years (i.e., they are of "uniform-hazard")

- But as recognized in ATC 3-06 (1978), …

> "*It really is the probability of structural failure with resultant casualties that is of concern, and the geographical distribution of that probability is not necessarily the same as the distribution of the probability of exceeding some ground motion*"

Probabilistic MCE Ground Motions

- In other words, …

  Designing for uniform-hazard (e.g., 2% in 50 years) ground motions does not necessarily result in buildings with uniform probability of collapse in 50 years (i.e., “uniform risk”).

- New risk-targeted ground motions are based on a uniform collapse risk objective:

  Collapse Risk Objective – 1% in 50 years

- New risk-targeted ground motions are calculated assuming a generic collapse fragility that has:

  10% collapse probability given MCE ground motions

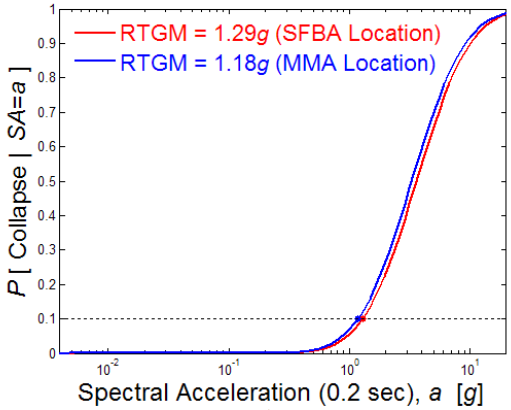
Risk-Targeted Ground Motions

Calculated iteratively by combining …

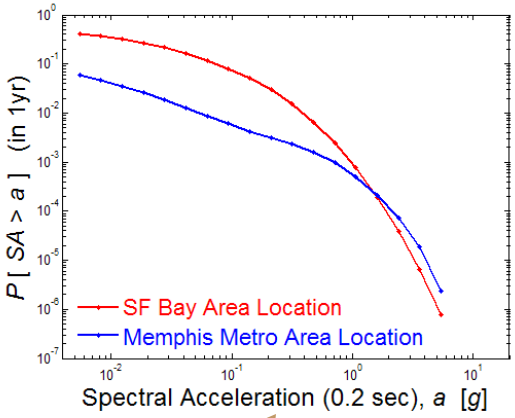
Risk Target from Project '07

Prob. of Collapse in 50 yrs = 1%

Building Fragility Curves defined by Project '07



GM Hazard Curves (e.g., from USGS)



… via "Risk Integral" (e.g. ATC 3-06), i.e., …

$$P[Collapse] = \int_0^\infty \frac{dP[Collapse|SA=a]}{da} P[SA>a]\,da$$

Generic Collapse Capacity / Fragility

- Based on nonlinear response history analysis by ATC-63 Project (FEMA P695) and others …

  Log. std. deviation of collapse capacity, $\beta \approx 0.6$

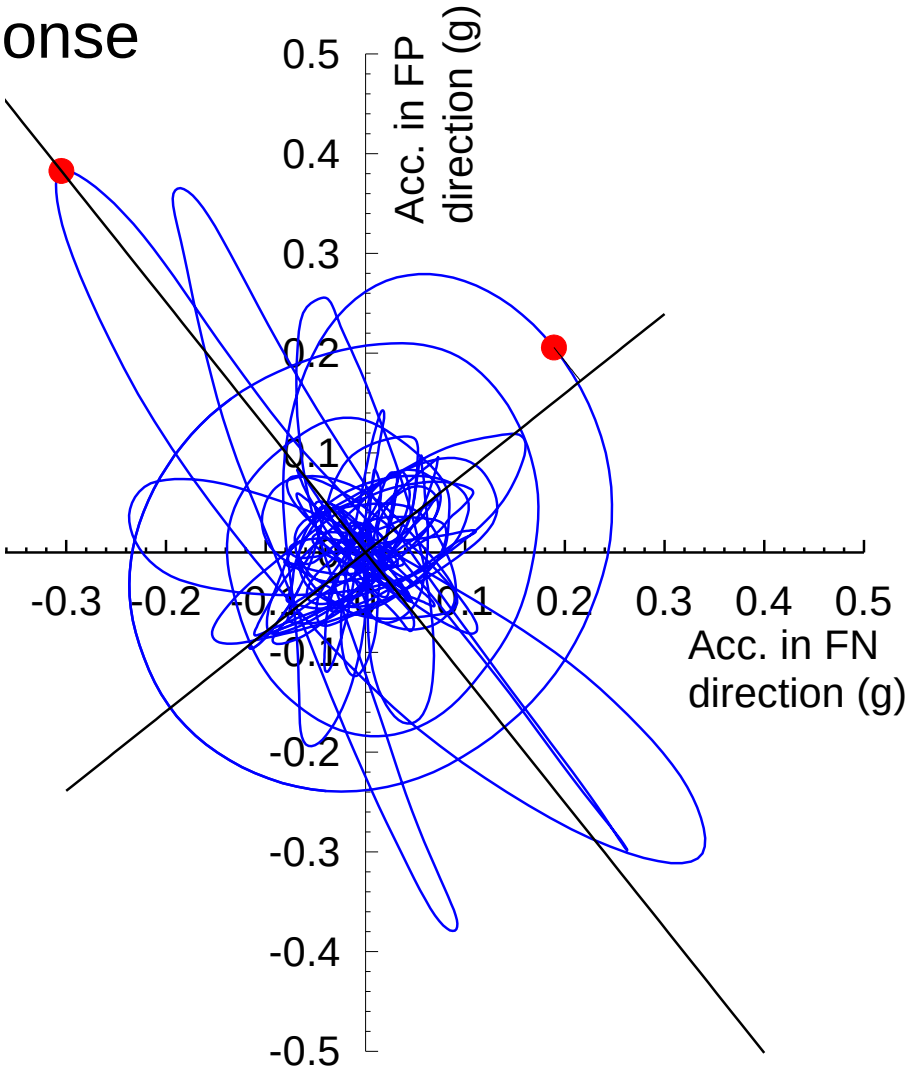
  10^{th} percentile collapse capacity, $c_{10\%} \approx$ MCE (T_1)

- The latter is consistent with performance expectation expressed in the *NEHRP Provisions:*

  "If a structure experiences a level of ground motion 1.5 times the design level [i.e., the MCE level], the structure should have a low likelihood of collapse" (p. 320 of 2003 *NEHRP Provisions* Commentary)

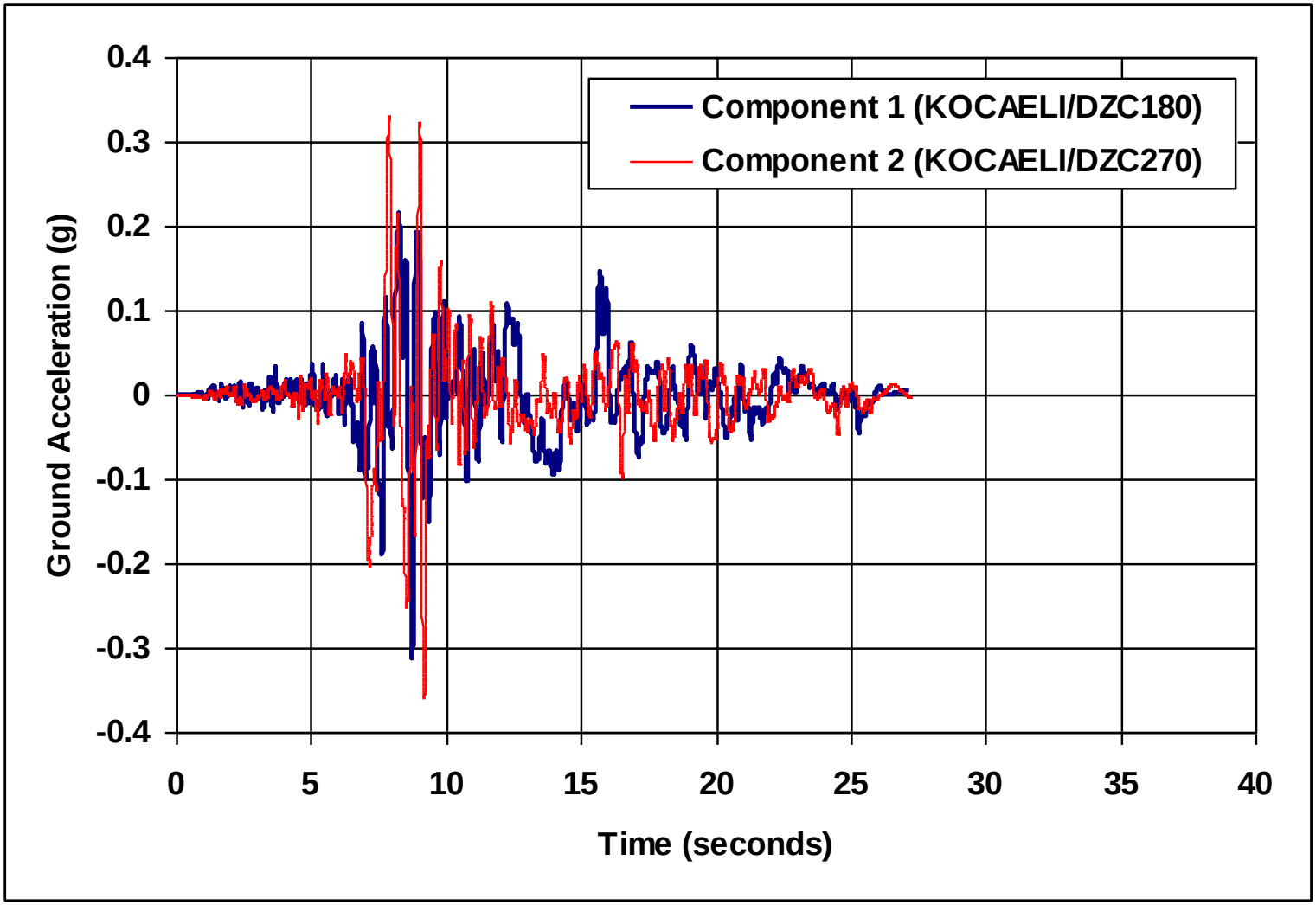
Ground Motion Intensity - Background

- Traditionally defined by response spectral acceleration:
  - Period dependent
- Geomean definition:
  - SQRT [Sa(X)*Sa(Y)]
  - Varies with X-Y orientation
- GMRotI50 definition (NGA):
  - Complex definition
  - About equal to geomean
- Maximum direction
  - Simple definition
  - Peak X-Y resultant response
  - Independent of X-Y orientation



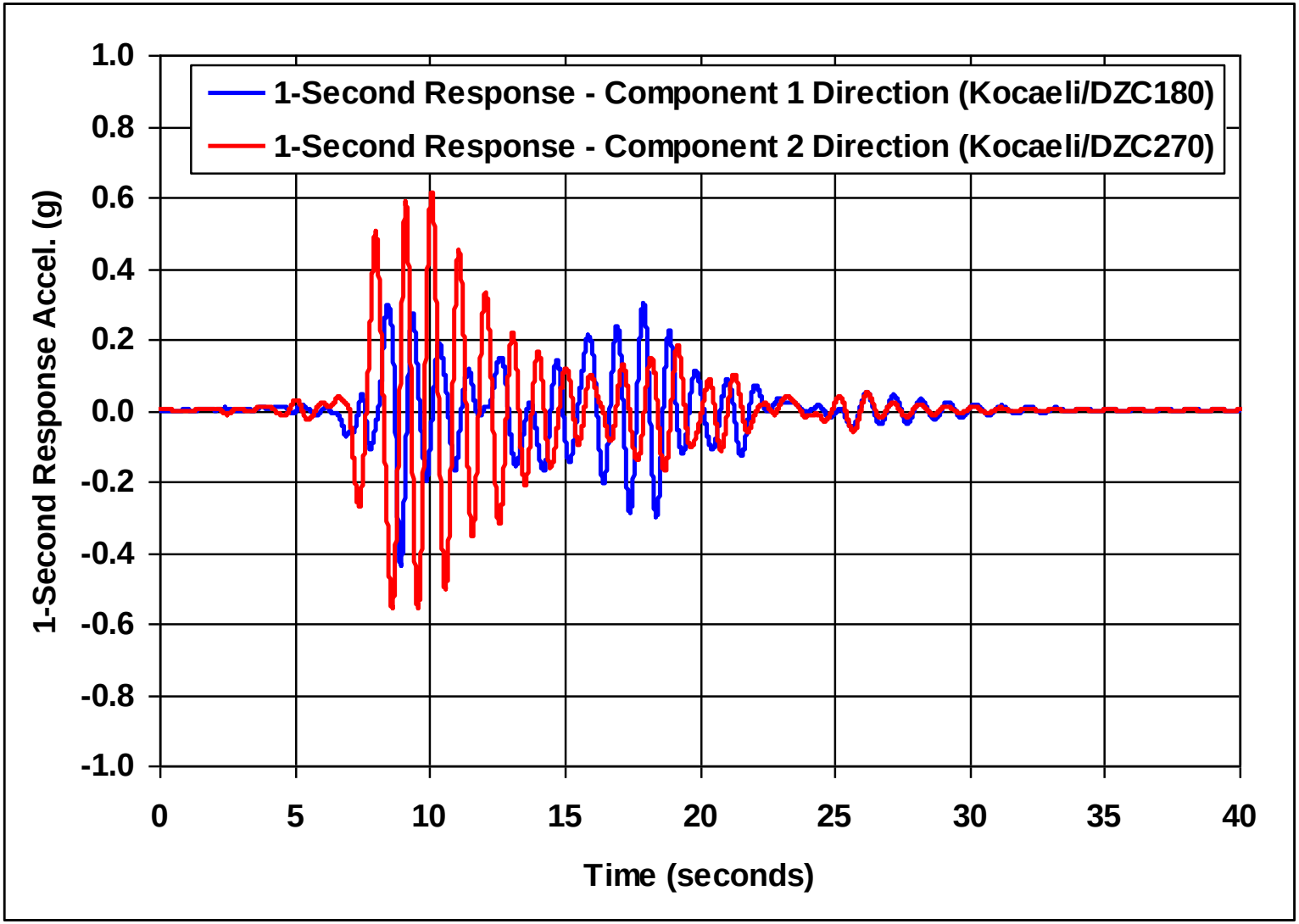
Intensity Example – 1999 Kocaeli Earthquake – Duzce Record

(M_w = 7.5, Strike-Slip, D_f = 15.4 km, $v_{s,30}$ < 276 m/s)



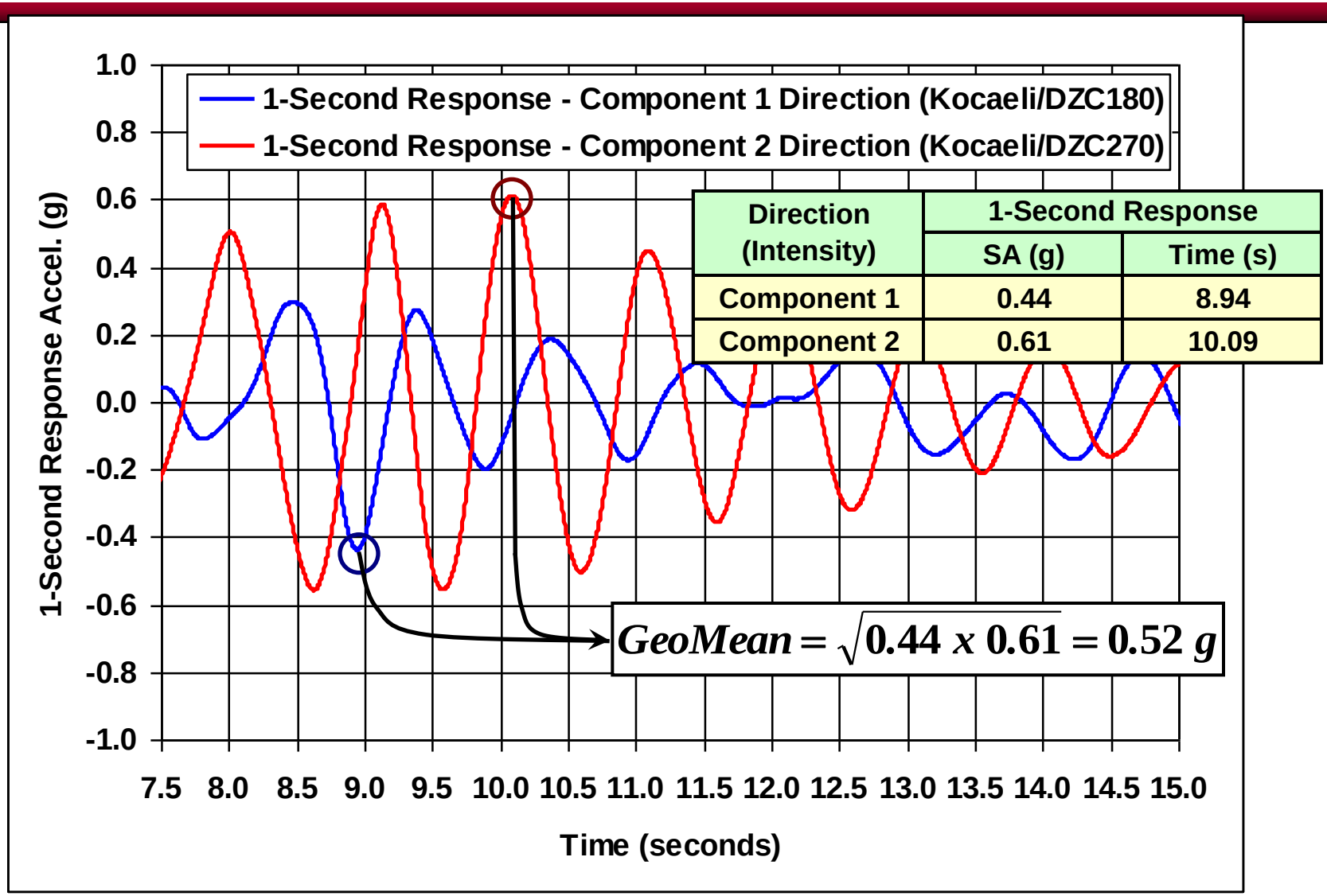
Intensity Example – 1-Second Response of SDOF System (5% Damping)

(1999 Kocaeli Earthquake – Duzce Record)



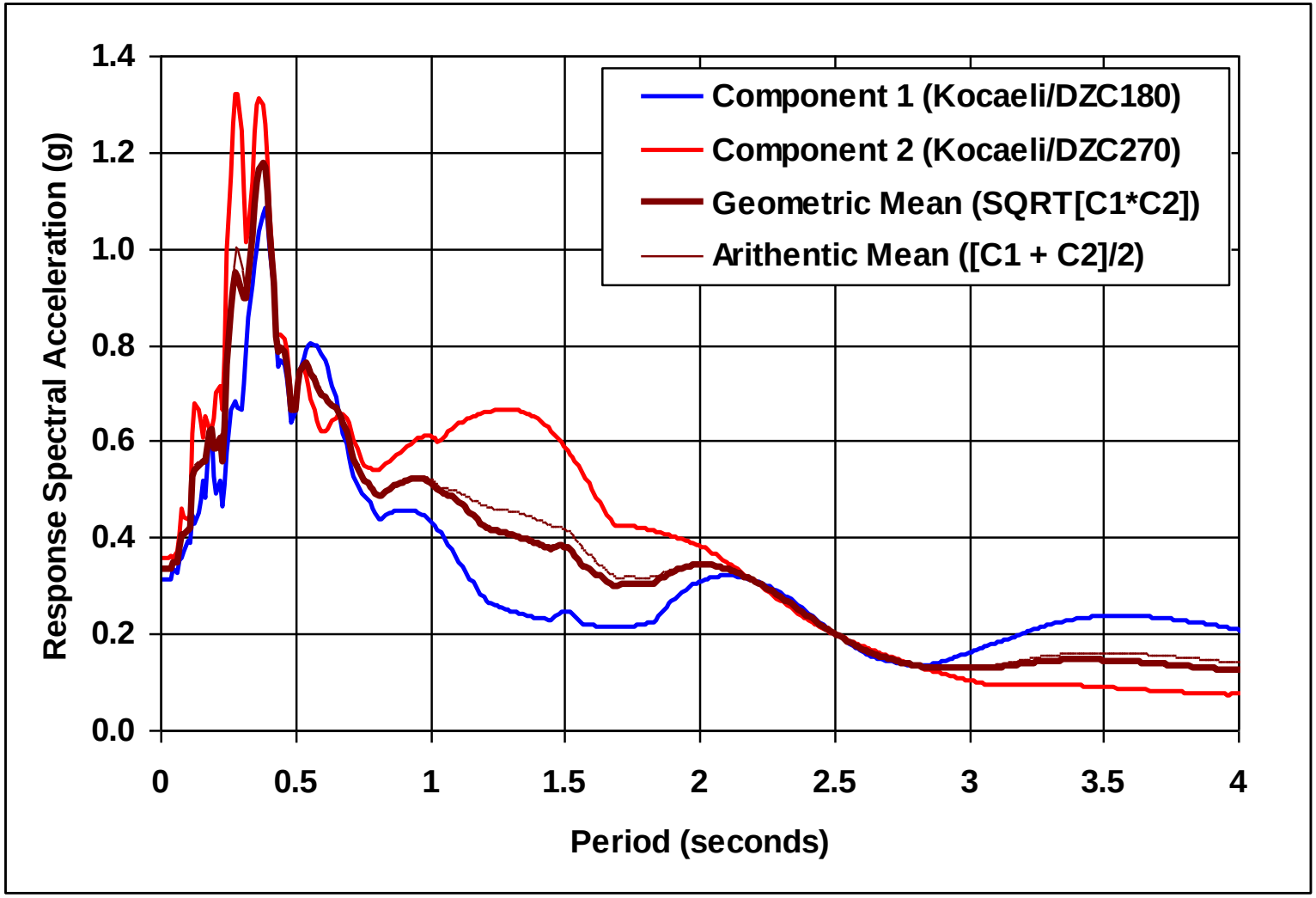
Intensity Example – Calculation of Geometric Mean Intensity

(1-Second Response of the Kocaeli-Duzce Record)



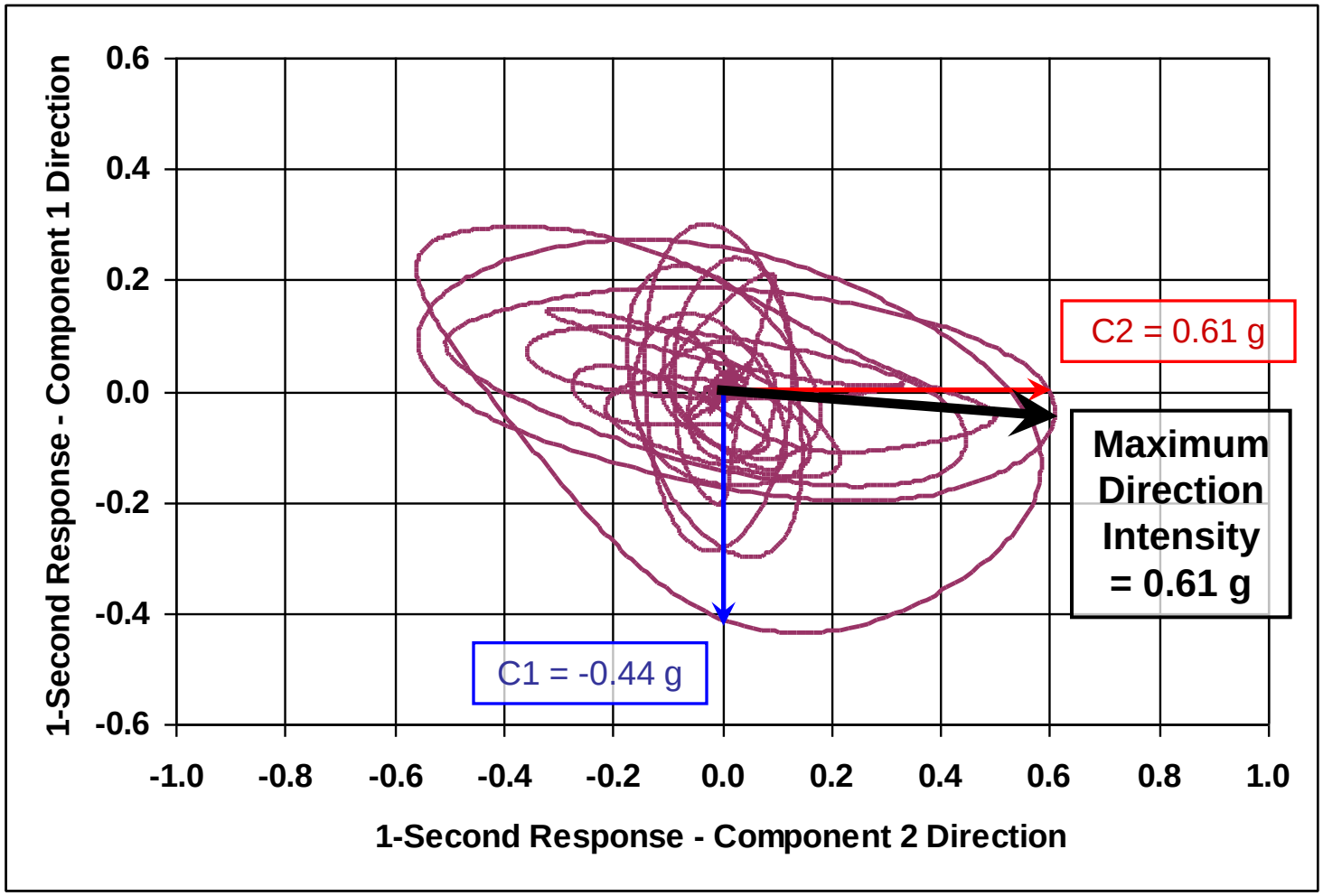
Direction (Intensity)	1-Second Response	
	SA (g)	Time (s)
Component 1	0.44	8.94
Component 2	0.61	10.09

Intensity Example – Comparison of Individual Component, Geometric Mean and Arithmetic Mean Response Spectra (Kocaeli-Duzce Record)

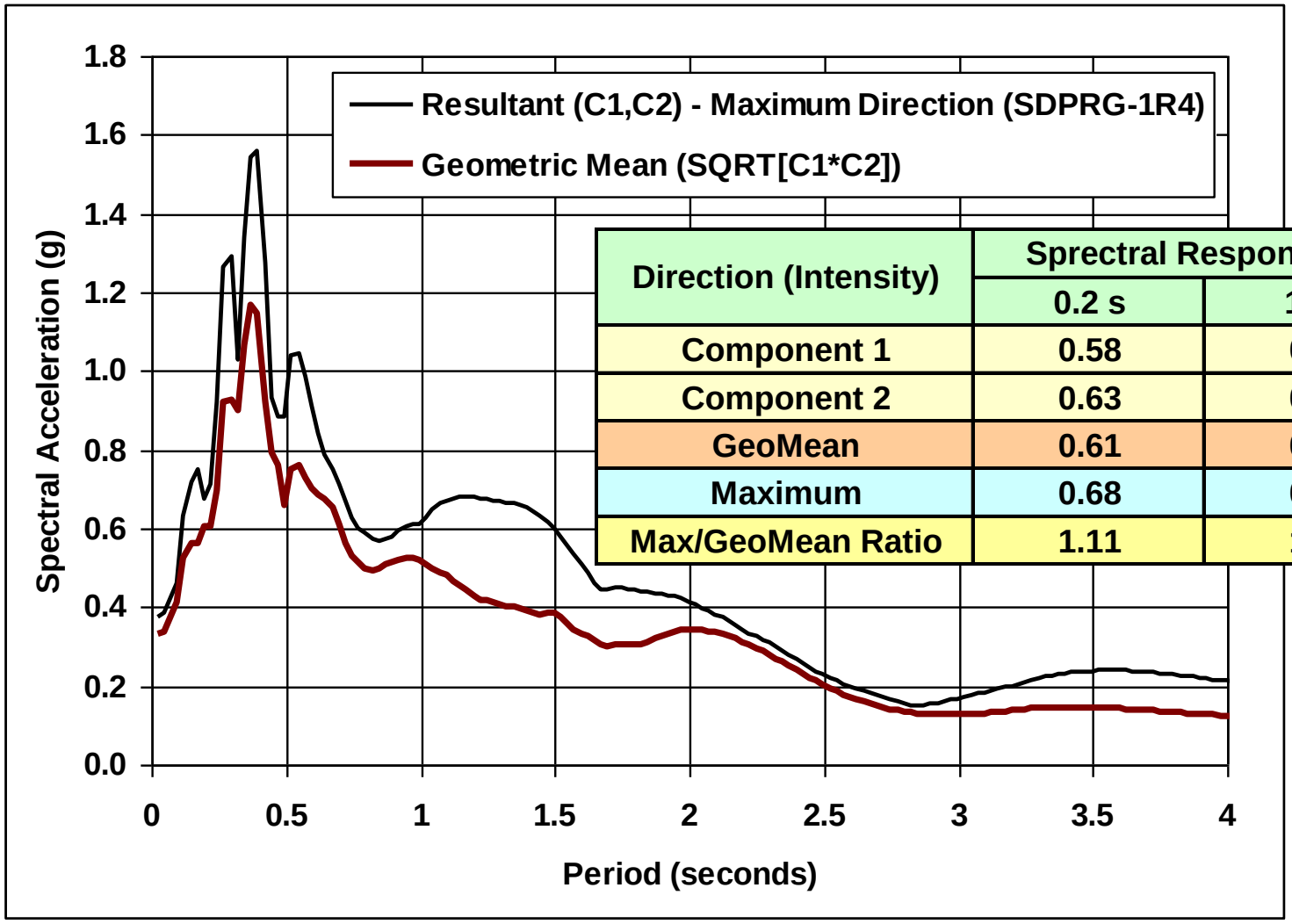


Intensity Example – Calculation of Maximum Direction Intensity

(1-Second Response of the Kocaeli-Duzce Record)



Intensity Example - Comparison of Geometric Mean and Maximum Direction Response Spectra (Kocaeli-Duzce Record)



Direction (Intensity)	Sprectral Response (g)	
	0.2 s	1.0 s
Component 1	0.58	0.44
Component 2	0.63	0.61
GeoMean	0.61	0.52
Maximum	0.68	0.61
Max/GeoMean Ratio	1.11	1.18

Near-Fault/Maximum Direction Ground Motions

(from Huang, Whittaker, Luco, 2008)

- Max/geomean ratios based on:
  - **Large magnitudes (M > 6.5)**
  - **Close distance (R < 15 km)**
  - **Average directivity (all records)**
- 84th percentile response:
  - **1.8 (2.0/1.1) times median response at short periods**
  - **1.8 (2.3/1.3) times median response at 1 second**
- Proposed deterministic MCE:
  - **84th percentile (1.8 x median) in lieu of 1.5 x median**

Maximum/Geomean Ratios

Period (sec.)	All Records		Forward Directivity	
	Median	84th%	Median	84th%
0	1	1.8	1.3	2.2
0.05	1	1.8	1.3	2.3
0.1	0.9	1.7	1.2	2.1
0.2	0.9	1.7	1.2	2.2
0.3	1	1.9	1.3	2.5
0.5	1.2	2.1	1.4	2.8
1	1.3	2.3	1.5	2.9
2	1.3	2.3	1.6	2.9
3	1.4	2.6	1.7	3.1
4	1.4	2.7	1.7	3

1.1

2.0 (1.1*1.8)

1.3

2.3 (1.3*1.8)

Building Collapse – Design Considerations

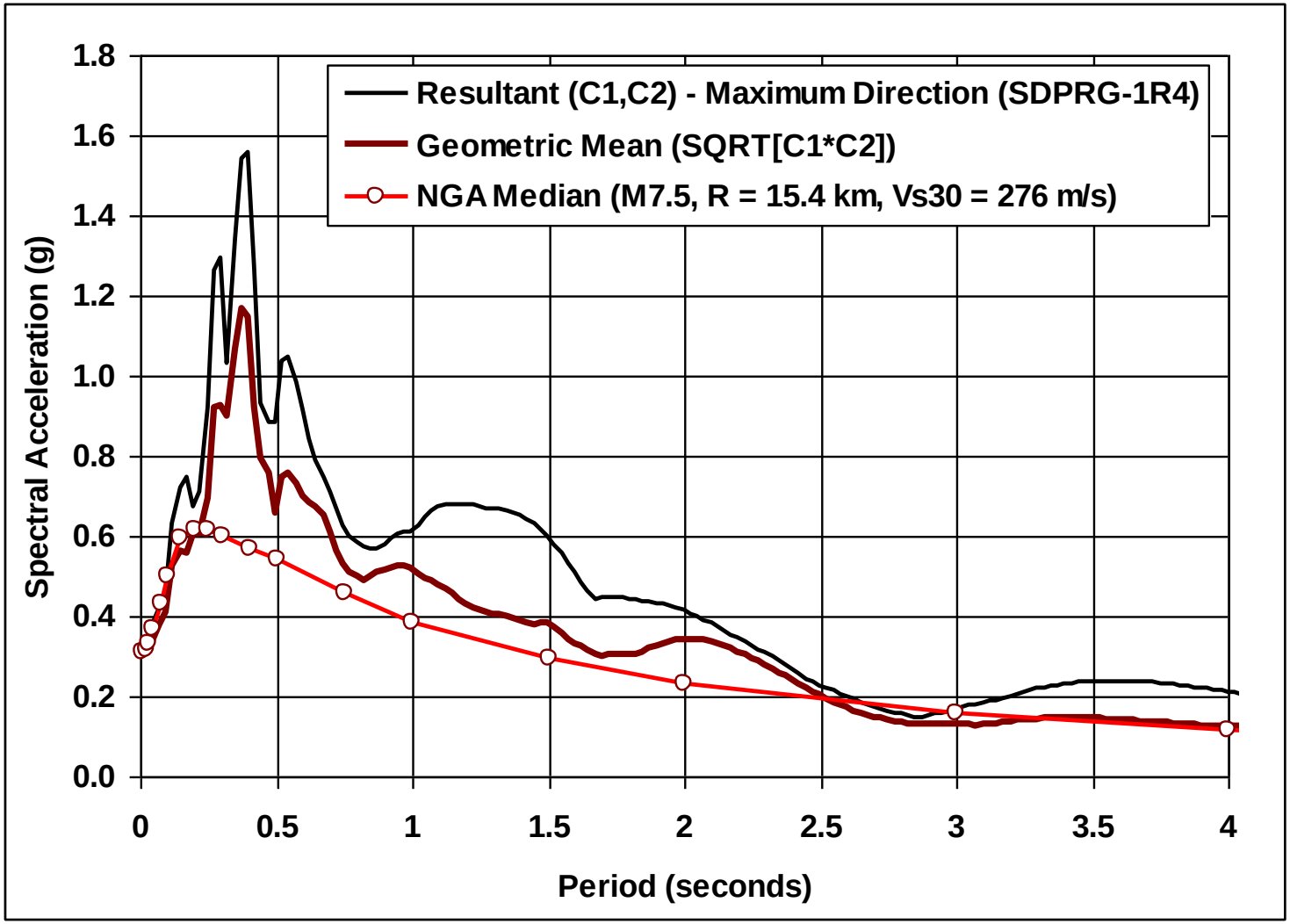
Bi-directional versus uni-axial application of ground motions

- Records applied along a single axis are approximately 20% less likely to collapse a structure as compared to a bi-axial application of the same records:
  - **"Incremental dynamic analysis of wood frame buildings" study (Christovasilis et al., EESD, 2008)**
  - **ATC-63 Project - Based on studies of light wood frame, SMF RC and OMF RC buildings (C_{3D} = 1.2)**
- Why (are bi-directional ground motions more critical)?
  - **In general, 3-D models (and real structures), can fail in any direction (e.g., collapse can occur due to failure of framing on either the X or Y axis, or other X-Y orientation)**
  - **The stronger component (of each record) tends to govern collapse and fails the structure in the direction of application**

Maximum Direction Intensity

- Simple, record-orientation independent measure of ground motion record intensity
  - **Peak response of bi-directional SDOF (2DOF) lollypop**
  - **Readily converted from relations based on geomean intensity**
- Appropriate for ELF (2-D) Design:
  - **Peak X-Y response appropriate for design of structures to resist possible collapse in any horizontal direction**
- Appropriate for scaling records for time history analysis:
  - ***ASCE 7-10*** **(and the 2009** ***NEHRP Provisions*****) now scale records to match target spectrum by a factor of 1.0 (rather than 1.3 factor of** ***ASCE 7-05*****)**

Comparison of Geomean and Maximum Direction Response Spectra of the Kocaeli-Duzce Record and NGA ground motions

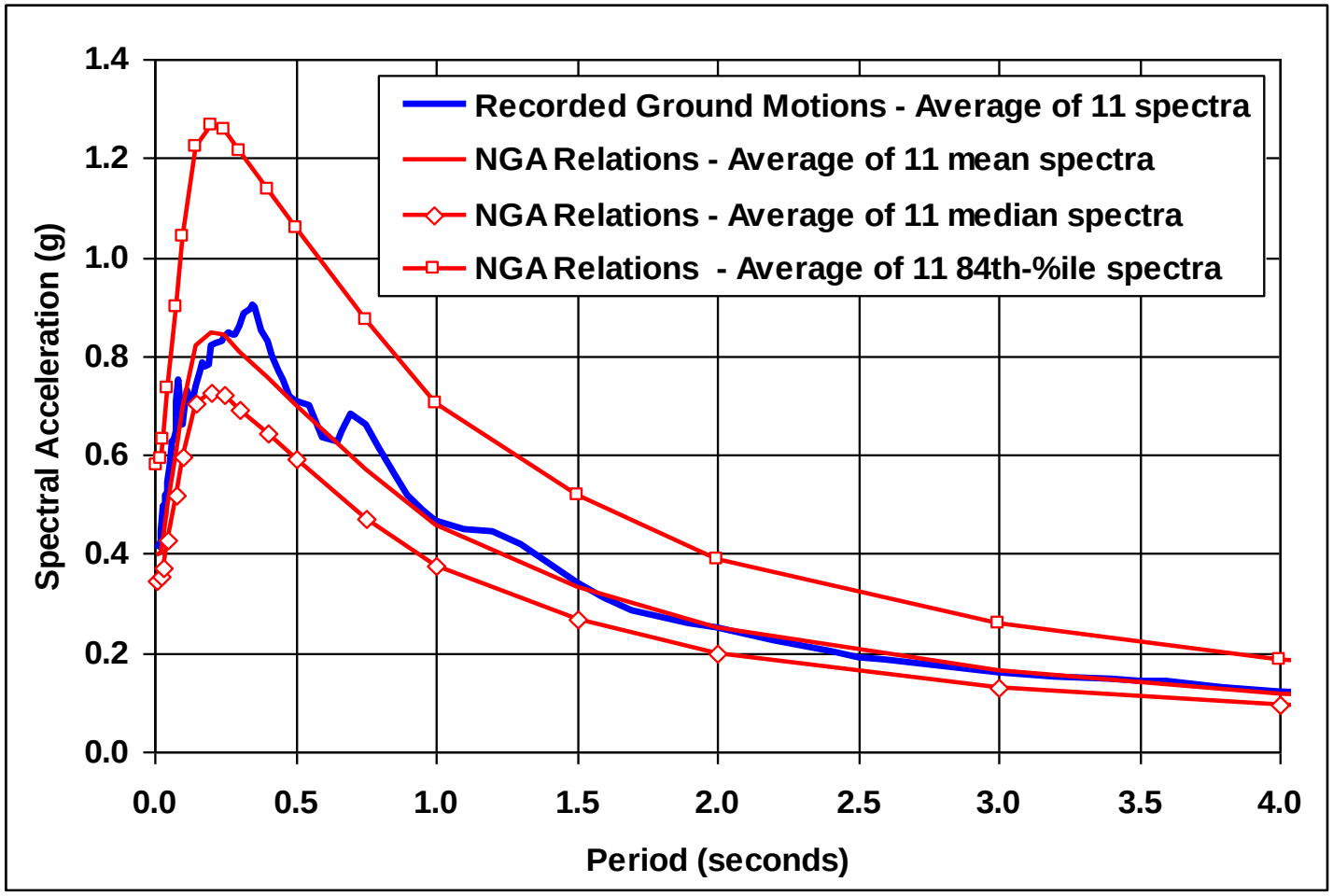


Properties of (all) 11 Strike-Slip Records in the PEER NGA Database of $M_w > 7$, $D_f < 20$ km, 180 m/sec < $v_{s,30}$ < 760 m/s

Earthquake			Source Characterisitcs				Site Conditions	
Year	Name	Record Station	Mag. (M_w)	Distance D_f (km)		Fault Mechanism	Site Class	$v_{s,30}$ (m/sec.)
				BJ	Campbell			
1992	Landers	Coolwater	7.3	19.7	20.0	Strike-slip	D	271
1992	Landers	Joshua Tree	7.3	11.0	11.4	Strike-slip	C	379
1992	Landers	Lucerne	7.3	2.2	3.7	Strike-slip	C	685
1999	Kocaeli, Turkey	Arcelik	7.5	10.6	13.5	Strike-slip	C	523
1999	**Kocaeli, Turkey**	**Duzce**	**7.5**	**13.6**	**15.4**	**Strike-slip**	**D**	**276**
1999	Kocaeli, Turkey	Yarimca	7.5	1.4	5.3	Strike-slip	D	297
1999	Duzce, Turkey	Bolu	7.1	12.0	12.4	Strike-slip	D	326
1999	Duzce, Turkey	Duzce	7.1	0.0	6.6	Strike-slip	D	276
1990	Manjil, Iran	Abbar	7.4	12.6	13.0	Strike-slip	C	724
1999	Hector Mine	Hector	7.1	10.4	12.0	Strike-slip	C	685
2002	Denali, Alaska	TAPS Pump St. #10	7.9	0.2	3.8	Strike-slip	D	329
Average Value of Eleven Records			**7.37**	**8.5**	**10.6**			**434**

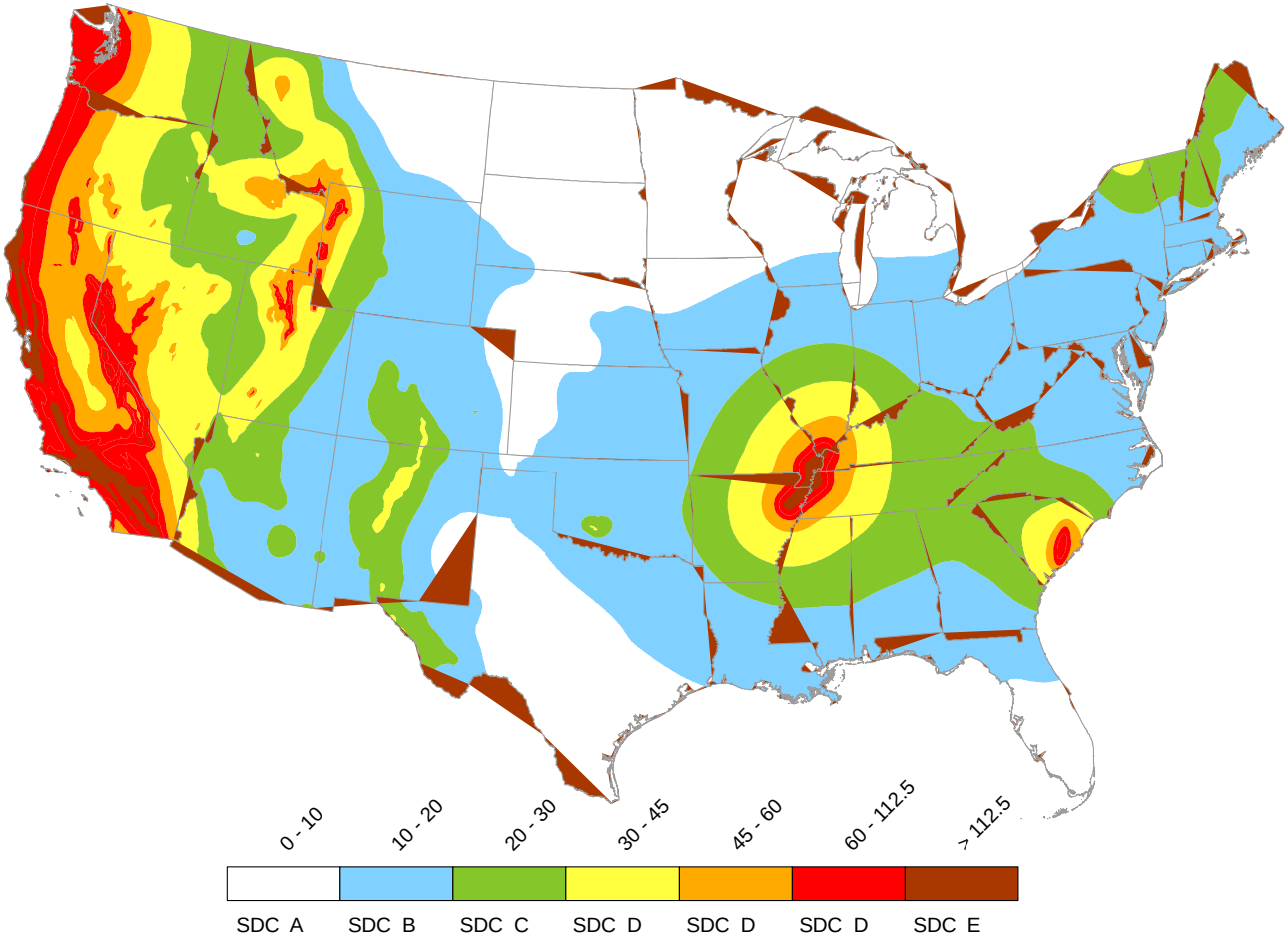
Comparison of Spectra (Geomean Intensity)

All Strike-Slip Records (11) in the PEER NGA Database of M_w > 7, D_f < 20 km, 180 m/sec < $v_{s,30}$ < 760 m/s and NGA Ground Motions



Example – Map of New Ground Motions

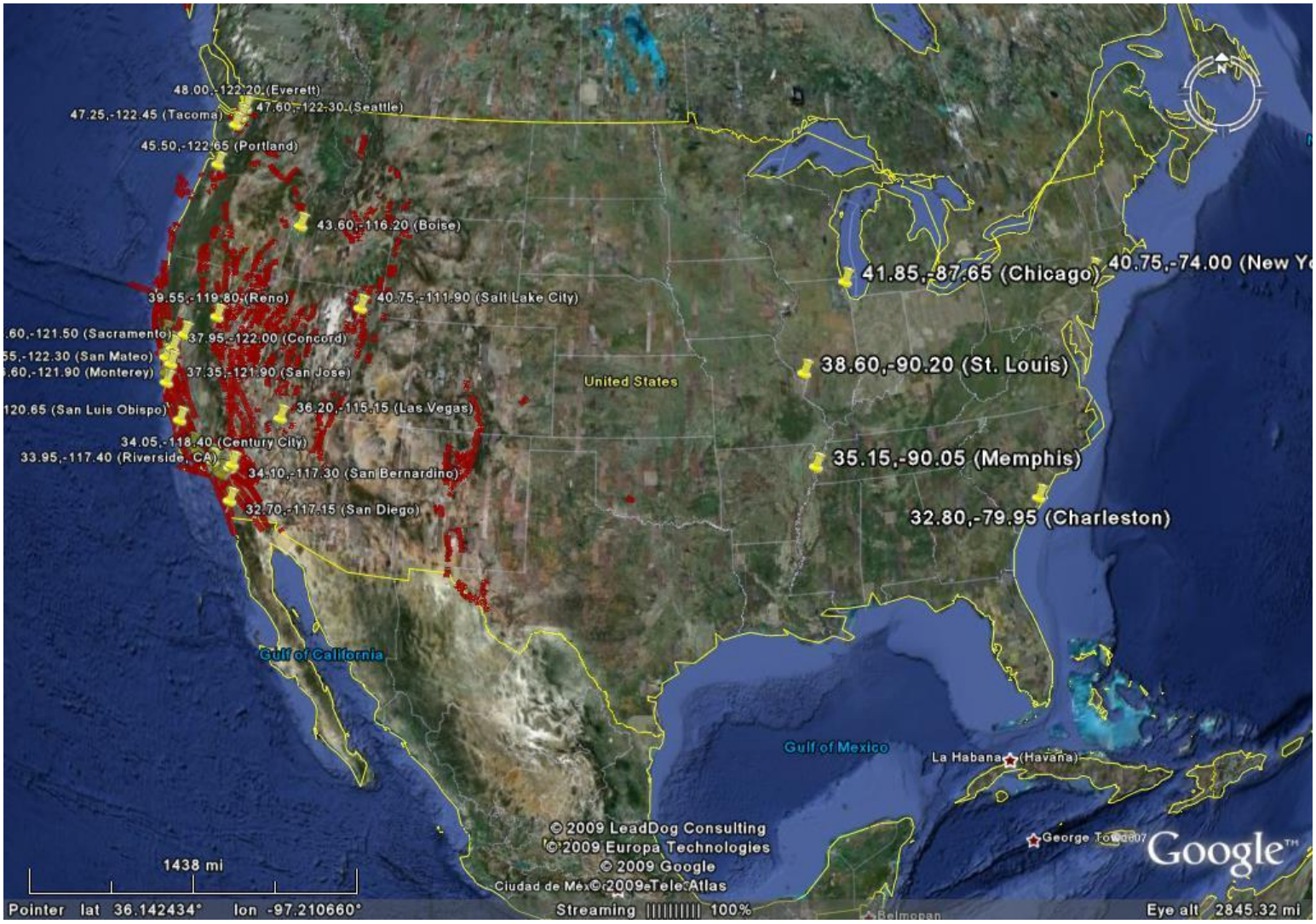
1-Second MCE Spectral Acceleration (Site Class D)



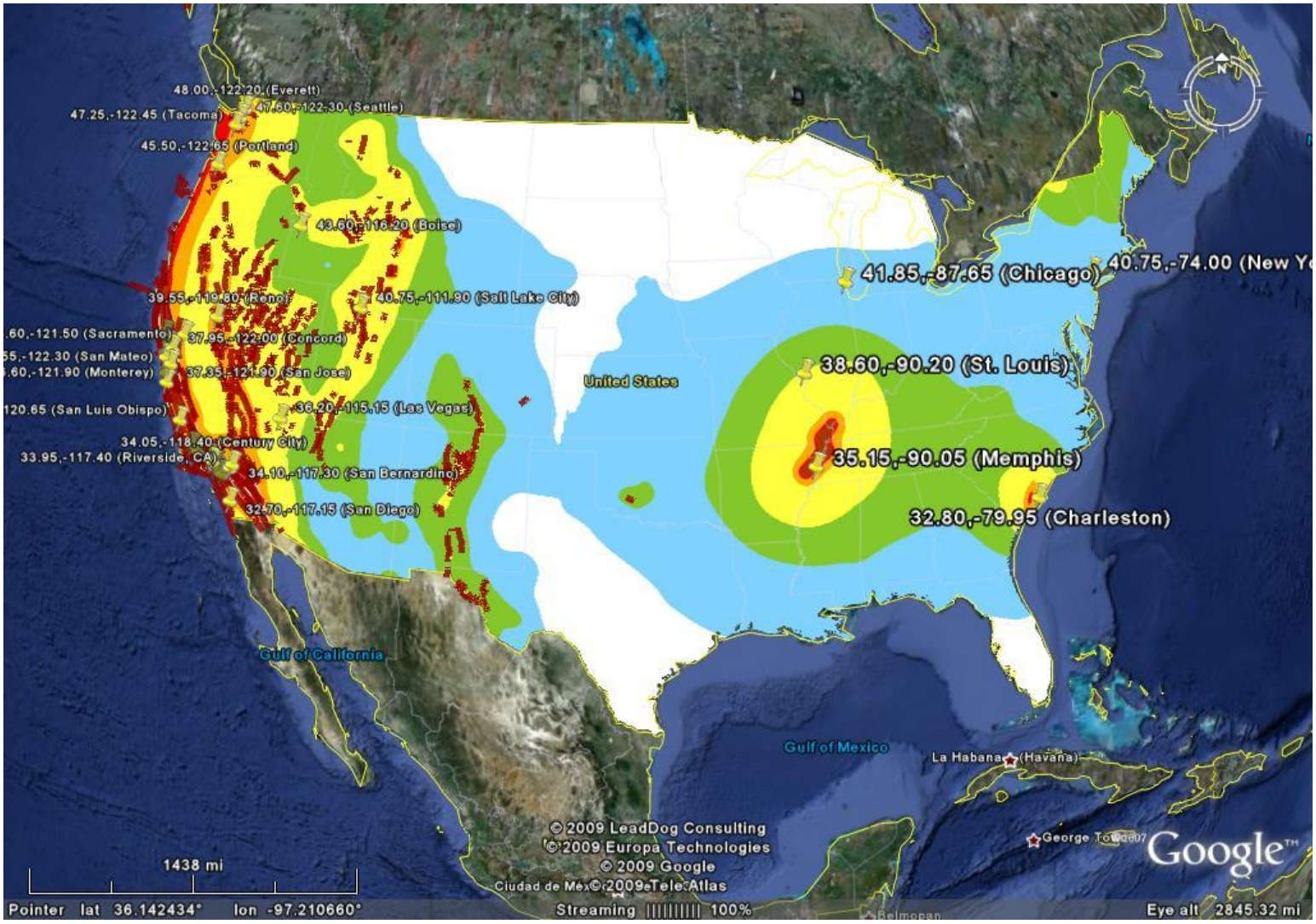
Comparison of Seismic Design Values

- 34 City Sites in the Continental United States
  - Selection of regions most at risk:
    - High seismic regions (Nor Cal, So Cal, PNW)
    - High population areas of high/moderate/low seismic regions (Intermountain and CEUS)
  - Selection of City sites:
    - Major city of regional county or metropolitan area
    - Nearest USGS hazard grid point to center of city
- Average Regional or National values:
  - Weight seismic design value of associated county or metropolitan area population
- Assume Default Soil Type (Site Class D)

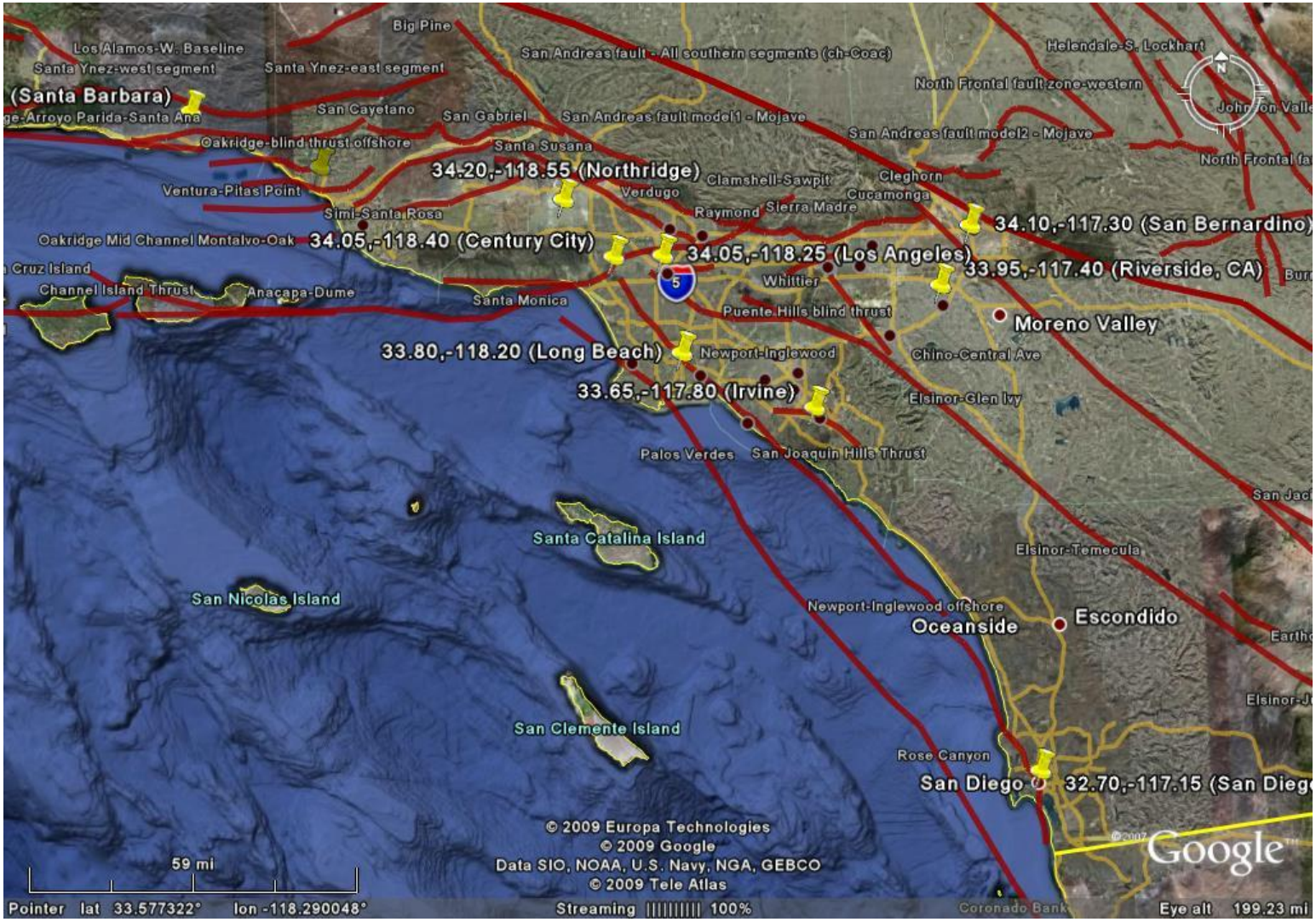
Map showing selected United States city sites (34) used to compare ground motions (WUS faults shown with red lines)



Map showing selected United States city sites (34) and new 1-second MCE ground motions (WUS faults shown with red lines)



Map showing selected Southern California city sites (11) used to evaluate proposed ground motions (WUS faults shown with red lines)



Southern California City Sites

Location and associated county population data

City and Location of Site			County	
Name	Latitude	Longitude	Name	Population
Los Angeles	34.05	-118.25	Los Angeles	9,948,081
Century City	34.05	-118.40		
Northridge	34.20	-118.55		
Long Beach	33.80	-118.20		
Irvine	33.65	-117.80	Orange	3,002,048
Riverside	33.95	-117.40	Riverside	2,026,803
San Bernardino	34.10	-117.30	San Bernardino	1,999,332
San Luis Obispo	35.30	-120.65	San Luis Obispo	257,005
San Diego	32.70	-117.15	San Diego	2,941,454
Santa Barbara	34.45	-119.70	Santa Barbara	400,335
Ventura	34.30	-119.30	Ventura	799,720
Total Pop. - S. California		22,349,098	Total Pop. - 8 Counties	21,374,778

Map showing Los Angeles City Site and Nearby Faults

Southern California City Sites

Comparison of 1-second design values (S_{D1}) and MCE parameters for Site Class D, return periods and 50-year collapse risk probabilities

City (Site Location)	Design	MCE (2009 *NEHRP Provisions*)				Return Period (years)	50-Year Collapse Prob.
	S_{D1} (g)	F_v	S_{1UH} (g)	C_{R1}	S_{1D} (g)		
Los Angeles	**0.84**	**1.50**	**0.88**	**0.96**	1.01	**2,228**	**1.0%**
Century City	**0.80**	**1.50**	**0.84**	**0.96**	1.05	**2,240**	**1.0%**
Northridge	**0.60**	**1.50**	0.69	1.04	**0.60**	**1,558**	**1.6%**
Long Beach	**0.62**	**1.50**	**0.65**	**0.96**	0.98	**2,233**	**1.0%**
Irvine	**0.57**	**1.50**	**0.56**	**1.01**	1.24	**2,556**	**1.0%**
Riverside	**0.60**	**1.50**	0.67	1.07	**0.60**	**1,657**	**1.6%**
San Bernardino	**1.08**	**1.50**	1.43	0.96	**1.08**	**1,155**	**1.7%**
San Luis Obispo	**0.45**	**1.57**	**0.43**	**0.98**	0.60	**2,349**	**1.0%**
San Diego	**0.49**	**1.52**	**0.56**	**0.87**	1.05	**1,940**	**1.0%**
Santa Barbara	**0.99**	**1.50**	**1.10**	**0.90**	1.17	**1,863**	**1.0%**
Ventura	**0.90**	**1.50**	**0.97**	**0.93**	1.27	**2,096**	**1.0%**
So Cal Average	**0.70**	1.50	0.77	0.97	0.98	**1,993**	**1.2%**

Southern California City Sites

Comparison of 1-second design ground motions (S_{D1}) with prior (*ASCE 7-05*) values and older Code Values (Site Class D)

City (Site Location)	1.25(1.5)Z	C_v	S_{D1} - ASCE 7		
	1994 UBC	1997 UBC	ASCE 7-98	ASCE 7-05	ASCE 7-10
Los Angeles	0.75	0.72	0.60	0.72	0.84
Century City	0.75	0.93	0.62	0.72	0.80
Northridge	0.75	0.64	0.65	0.61	0.60
Long Beach	0.75	1.02	0.75	0.70	0.62
Irvine	0.75	0.64	0.48	0.53	0.57
Riverside	0.75	0.64	0.60	0.60	0.60
San Bernardino	0.75	0.93	0.60	0.62	1.08
San Luis Obispo	0.75	0.77	0.49	0.48	0.45
San Diego	0.75	1.02	0.67	0.64	0.49
Santa Barbara	0.75	1.02	0.78	0.81	0.99
Ventura	0.75	1.02	0.82	0.86	0.90
SoCal Average	0.75	0.83	0.63	0.65	0.70

Southern California City Sites

Comparison of short-period design ground motions (S_{DS}) with prior (*ASCE 7-05*) values and older Code values (Site Class D)

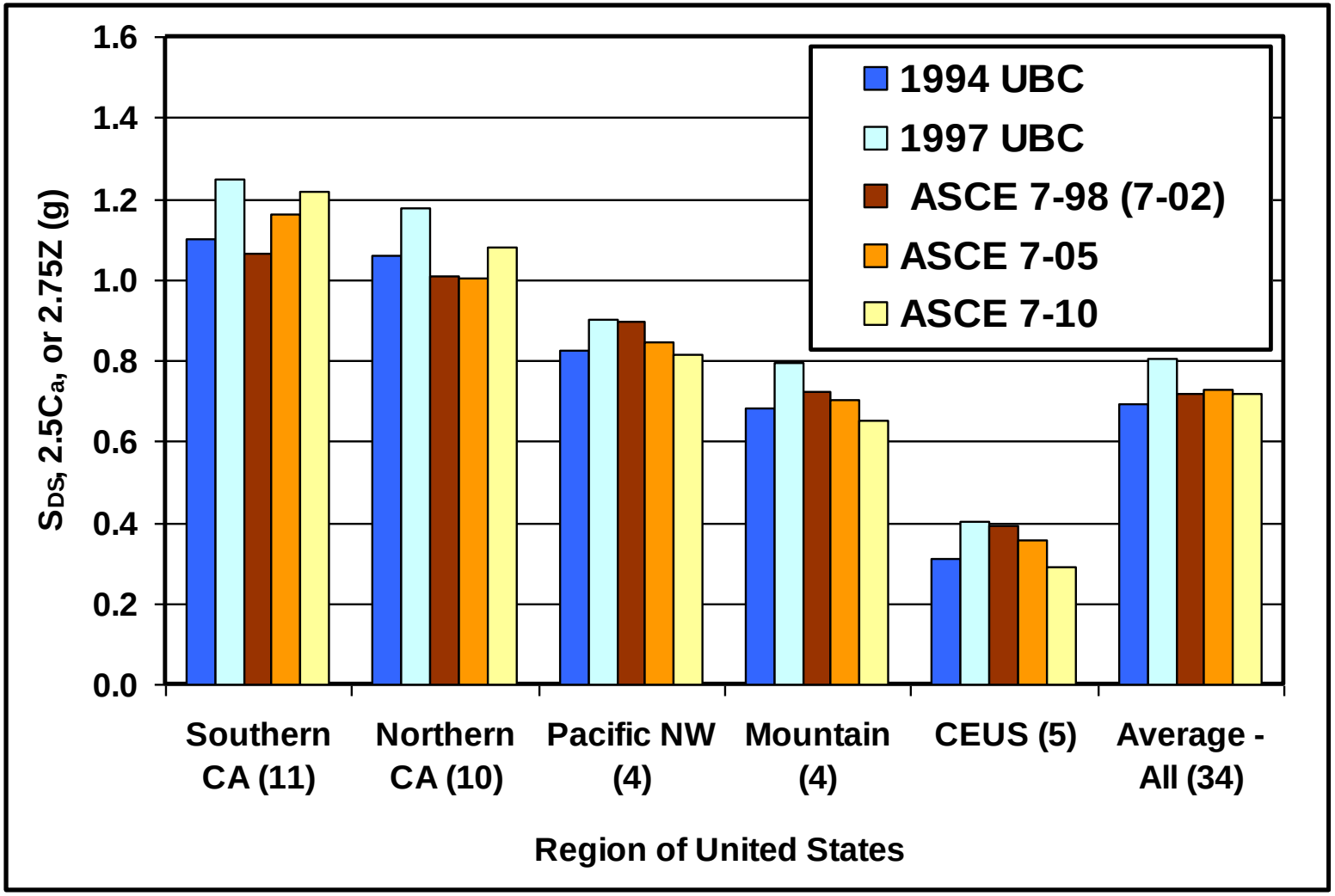
City (Site Location)	2.75*Z	C_a	S_{DS} - ASCE 7		
	1994 UBC	1997 UBC	ASCE 7-98	ASCE 7-05	ASCE 7-10
Los Angeles	1.10	1.10	1.00	1.44	1.60
Century City	1.10	1.32	1.13	1.22	1.44
Northridge	1.10	1.10	1.00	1.09	1.13
Long Beach	1.10	1.43	1.31	1.20	1.10
Irvine	1.10	1.10	0.84	1.00	1.03
Riverside	1.10	1.10	1.00	1.00	1.00
San Bernardino	1.10	1.32	1.08	1.13	1.58
San Luis Obispo	1.10	1.10	0.85	0.83	0.78
San Diego	1.10	1.43	1.01	1.07	0.84
Santa Barbara	1.10	1.43	1.58	1.38	1.89
Ventura	1.10	1.43	1.45	1.64	1.59
SoCal Average	1.10	1.25	1.06	1.16	1.22

Comparison of Short-Period Design Ground Motions

Comparison of average values of current (*ASCE 7-10*) and prior (*ASCE 7-05*) ground motions, and older Codes for each region and all 34 selected sites in the continental United States

United States Region	2.75*Z	C_a	S_{DS} - ASCE 7		
	1994 UBC	1997 UBC	7-98(7-02)	7-05	7-10
Southern CA	1.10	1.25	1.06	1.16	1.22
Northern CA	1.06	1.18	1.01	1.00	1.08
Pacific NW	0.83	0.90	0.90	0.84	0.83
Intermountain	0.68	0.80	0.72	0.70	0.65
CEUS	0.31	0.40	0.39	0.36	0.29
All Regions	0.69	0.80	0.72	0.73	0.72

Comparison of Short-Period Design Ground Motions

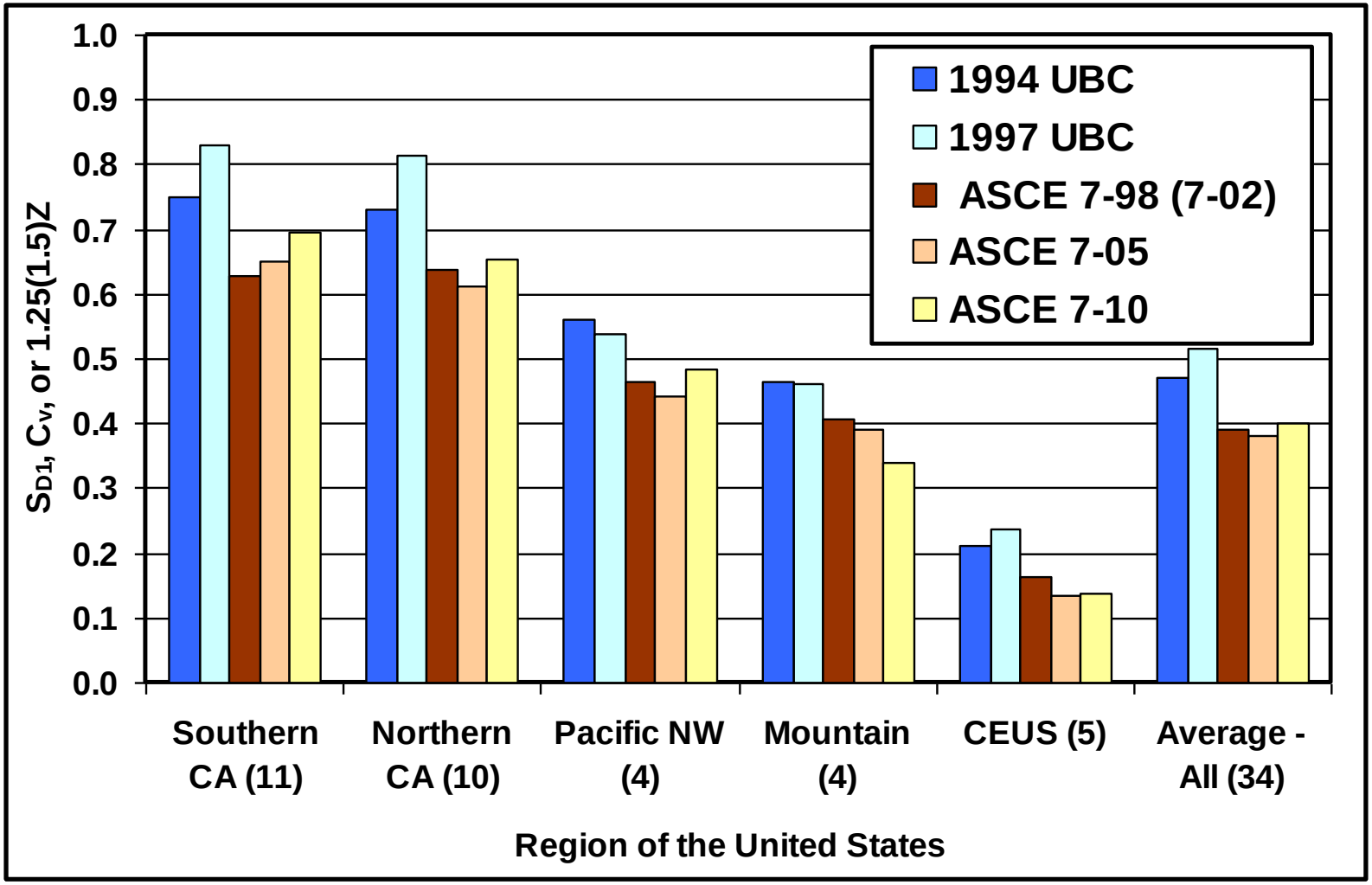


Comparison of 1-Second Design Ground Motions

Comparison of average values of current (*ASCE 7-10*) and prior (*ASCE 7-05*) ground motions, and older Codes for each region and all 34 selected sites in the continental United States

United States Region	1.25(1.5)Z	C_v	S_{D1} - ASCE 7		
	1994 UBC	1997 UBC	7-98 (7-02)	7-05	7-10
Southern CA	0.75	0.83	0.63	0.65	0.70
Northern CA	0.73	0.81	0.64	0.61	0.65
Pacific NW	0.56	0.54	0.46	0.44	0.49
Intermountain	0.47	0.46	0.41	0.39	0.34
CEUS	0.21	0.24	0.16	0.14	0.14
All Regions	0.47	0.52	0.39	0.38	0.40

Comparison of 1-Second Design Ground Motions



Closing Comments

- On-Going Process
  - New ground motions of *ASCE 7-10* (and the 2009 *NEHRP Provisions*) must still be approved for use in model building codes (e.g., 2012 *IBC*)
- A Word of Caution (for building design)
  - New USGS hazard data and maps (e.g., based on new NGA relations, etc.) should be used with new building design procedures (*ASCE 7-10*)
- User Friendly
  - GIS tools (Google) and web-based software (USGS) will greatly simplify implementation of new design values maps and procedures