Development of Risk-Targeted Earthquake Ground Motions for use in ASCE 7

National Earthquake Hazards Reduction Program (NEHRP) Advisory Committee (ACEHR) Meeting

Nicolas Luco, Research Structural Engineer

USGS, Golden, Colorado

Acknowledgements

- USGS Hazard Mapping Project, particularly …
  - Mark Petersen (Project Chief)
  - Steve Harmsen (Modeler)
  - Ken Rukstales (GIS)
  - Eric Martinez (Web)
  - Greg Smoczyk (DB)
  - Sean McGowan (QA)
- FEMA-Funded BSSC Project '07
  - Charlie Kircher (Chair)
  - See seminar presentation by Kircher for member list
- ASCE 7 SSC Ad-Hoc Ground Motion Committee
  - Charlie Kircher (Chair)
  - John Hooper (SSC Chair)
  - C.B. Crouse (TC1 Chair)
  - Jim Harris (ASCE 7 MC)

New *ASCE 7-10* "Design Maps"

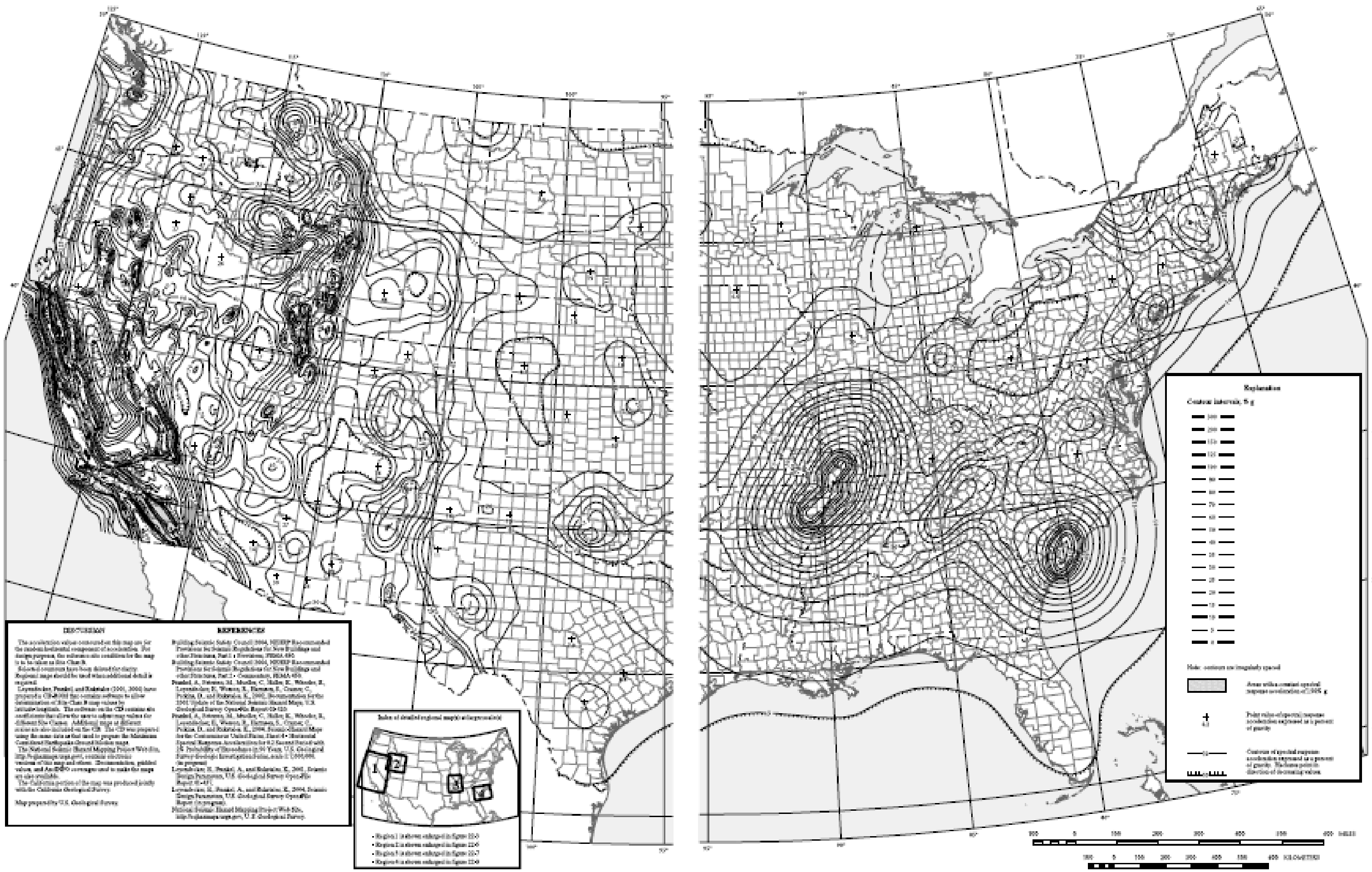


FIGURE 22-1 RISK-TARGETED MAXIMUM CONSIDERED EARTHQUAKE (MCE_R) GROUND MOTION OF 0.2 SEC SPECTRAL RESPONSE ACCELERATION, SITE CLASS B

Google "EERI NGA Seminar Presentations" for Video or email nluco@usgs.gov for just PowerPoint

Outline of Presentation

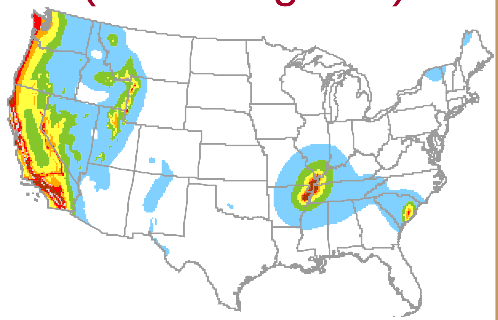
- Preparation of new design maps using …
  - Seismic hazard computed by USGS
    - Probabilistic hazard curves
    - Deterministic median ground motions
  - Procedures developed by Project '07
    - Stipulated in site-specific procedures (Ch. 21) of *ASCE 7-10 & 2009 NEHRP Provisions*
- Design maps **web application** and other associated products prepared by USGS

Preparation of New Design Maps

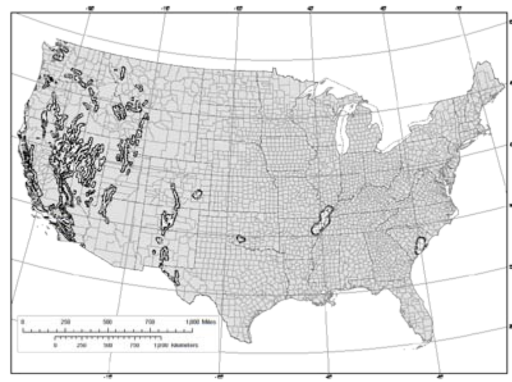
- Consistent with site-specific procedures (Ch. 21) of *ASCE 7-10* & *2009 NEHRP* …
  - **Probabilistic ground motion**
    - Method 1: Uniform-hazard GM x Risk Coefficient
    - Method 2: Risk-targeted probabilistic GM directly
  - **Deterministic ground motion**
    - 84^{th}-%ile GM, but not < $1.5F_a$ or $0.6F_v / T$
  - **MCE_R GM = min(Prob. GM, Det. GM)**
  - All GMs are max-direction spectral accel.'s
- Ground motions computed by USGS

Preparation of New Design Maps

min (**Probabilistic GMs** (Risk-Targeted)

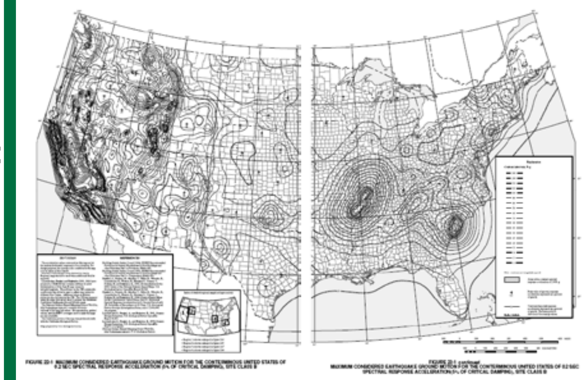


Deterministic GMs

)

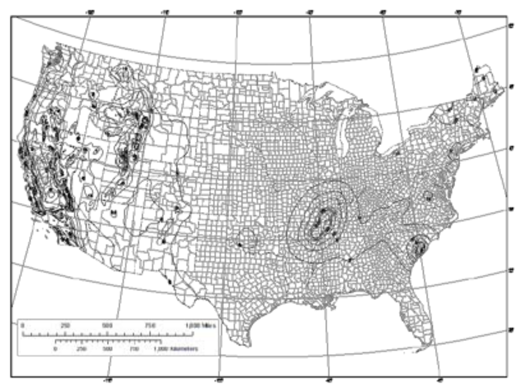
=

New MCE_R GMs



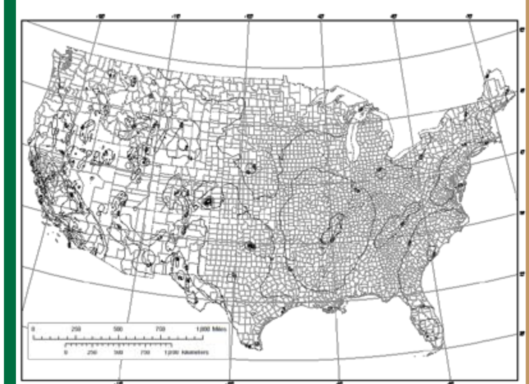
To relate back to conventional uniform-hazard (2500-yr) GMs …

(**Uniform-Hazard GMs**



X

Risk Coefficients

)

— In *ASCE 7-10*

— In 2009 NEHRP

Probabilistic Ground Motions

From site-specific procedures (Chapter 21) of *ASCE 7-10 & 2009 NEHRP Provisions* …

21.2.1, Probabilistic Ground Motion: *The probabilistic spectral response accelerations shall be taken as the spectral response accelerations in the direction of maximum horizontal response represented by a 5 percent damped acceleration response spectrum that is expected to achieve a 1 percent probability of collapse within a 50-yr. period.*

Probabilistic Ground Motion = Risk-Targeted GM

21.2.1.2, Method 2: *At each spectral response period for which the acceleration is computed, ordinates of the probabilistic ground motion response spectrum shall be determined from iterative integration of a site-specific hazard curve with a lognormal probability density function representing the collapse fragility (i.e., probability of collapse as a function of spectral response acceleration). The ordinate of the probabilistic ground-motion response spectrum at each period shall achieve a 1 percent probability of collapse within a 50-yr. period for a collapse fragility having (i) a 10 percent probability of collapse at said ordinate of the probabilistic ground-motion response spectrum and (ii) a logarithmic standard deviation values of 0.6.*

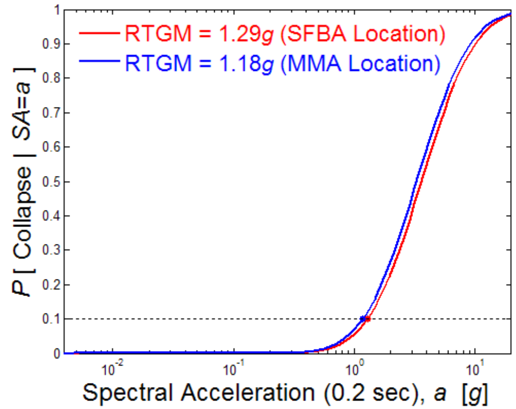
Risk-Targeted Ground Motions

Calculated iteratively by combining …

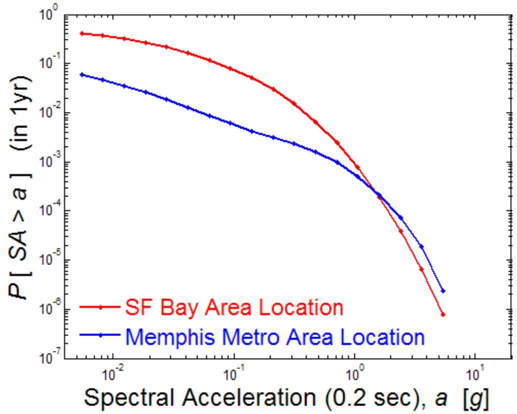
Risk Target defined by Project ‘07

Prob. of Collapse in 50 yrs = 1%

Building Fragility Curves defined by Project ‘07



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

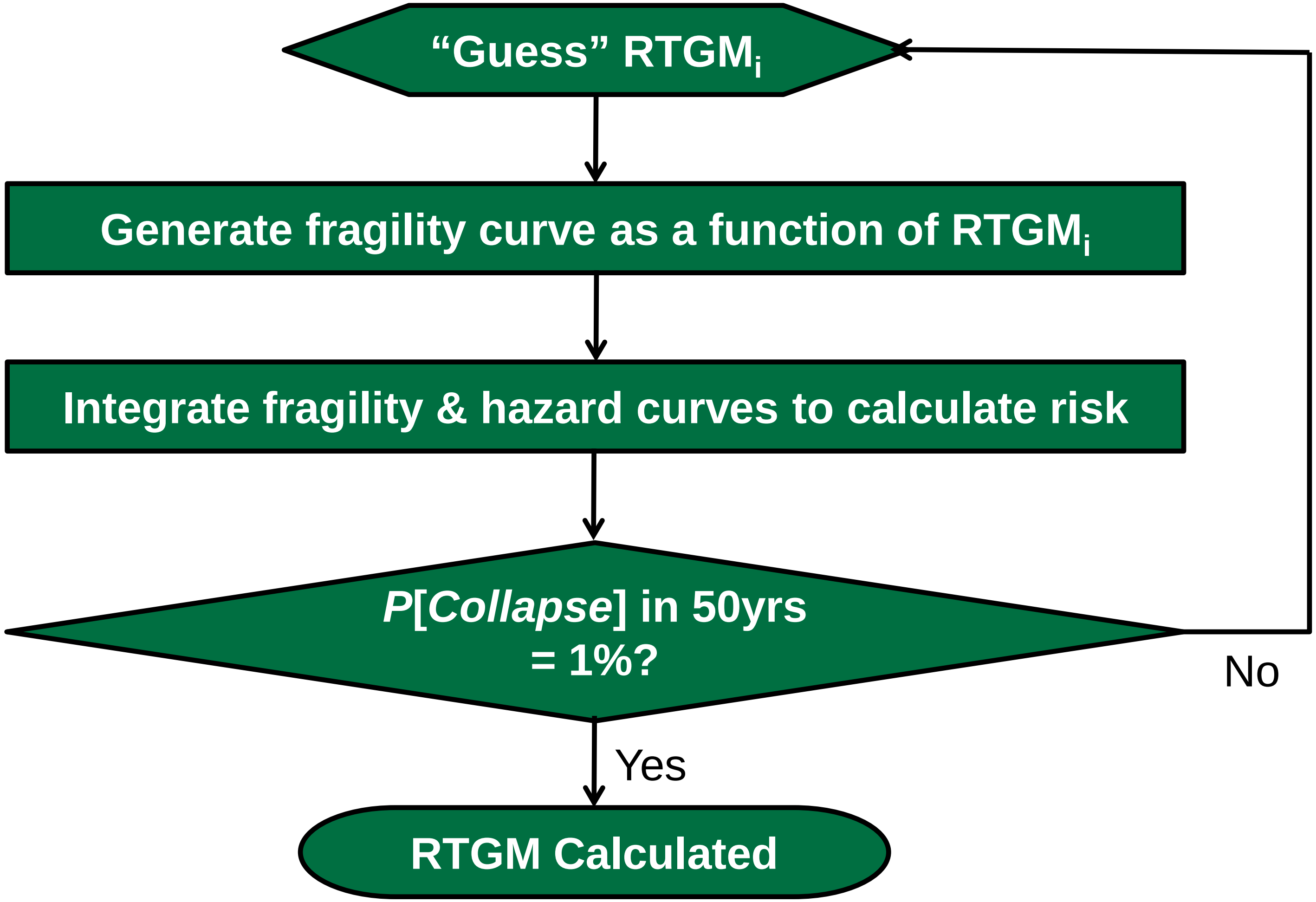


… via “Risk Integral” (e.g. ATC 3-06), i.e., …

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

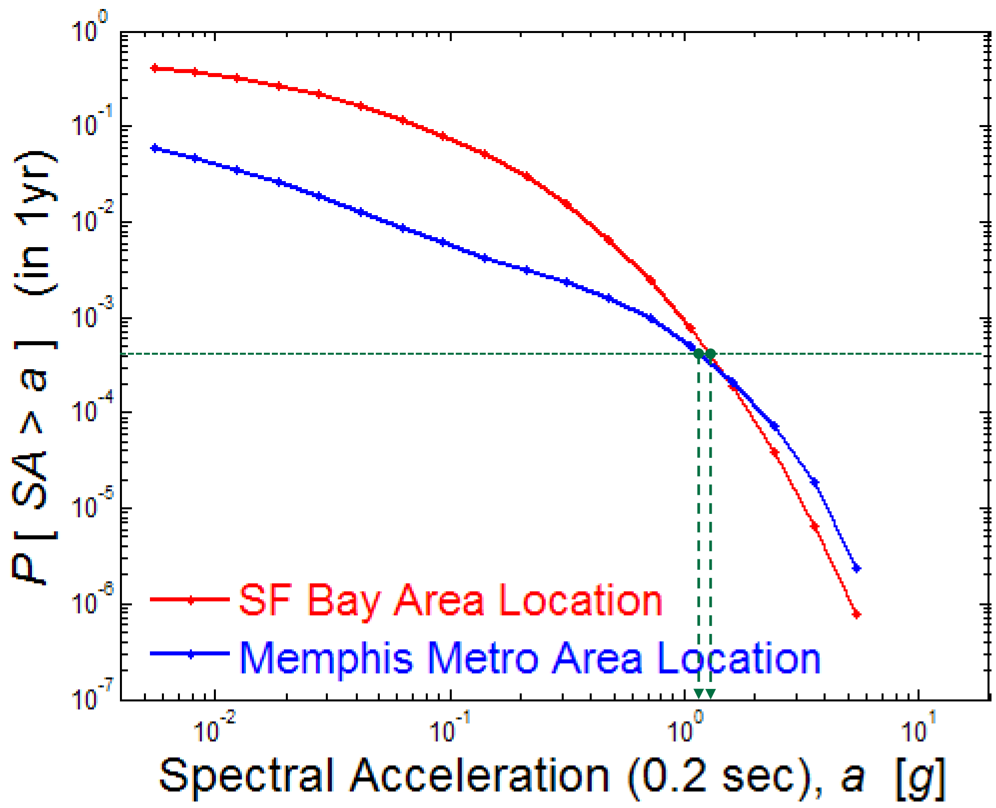
Risk-Targeted Ground Motions

For a given location …



Risk-Targeted GMs – Example

GM hazard curves from USGS …



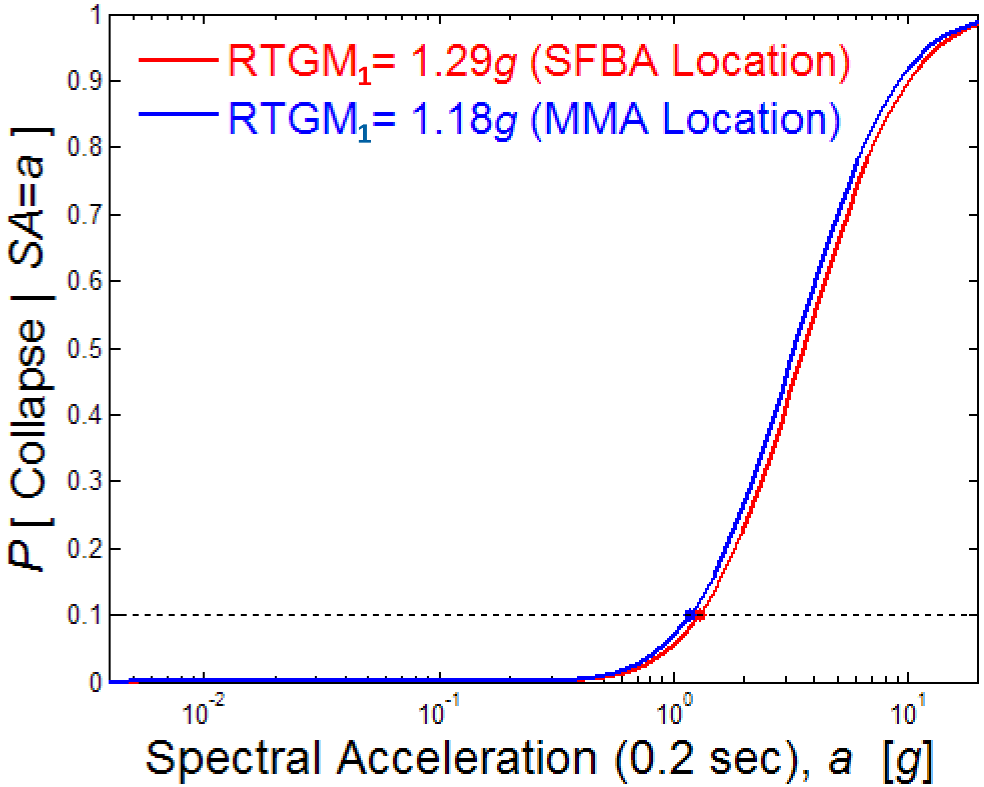
<u>Notes</u>:

The *SA* values from USGS have been factored by 1.1 for 0.2s or 1.3 for 1.0s to convert (approximately) to max direction.

Conventional "2500-yr" GMs are interpolated from such hazard curves.

Risk-Targeted GMs – Example

Generic fragility curves assuming, for our 1st iteration, that RTGMs = 2500-yr GMs …



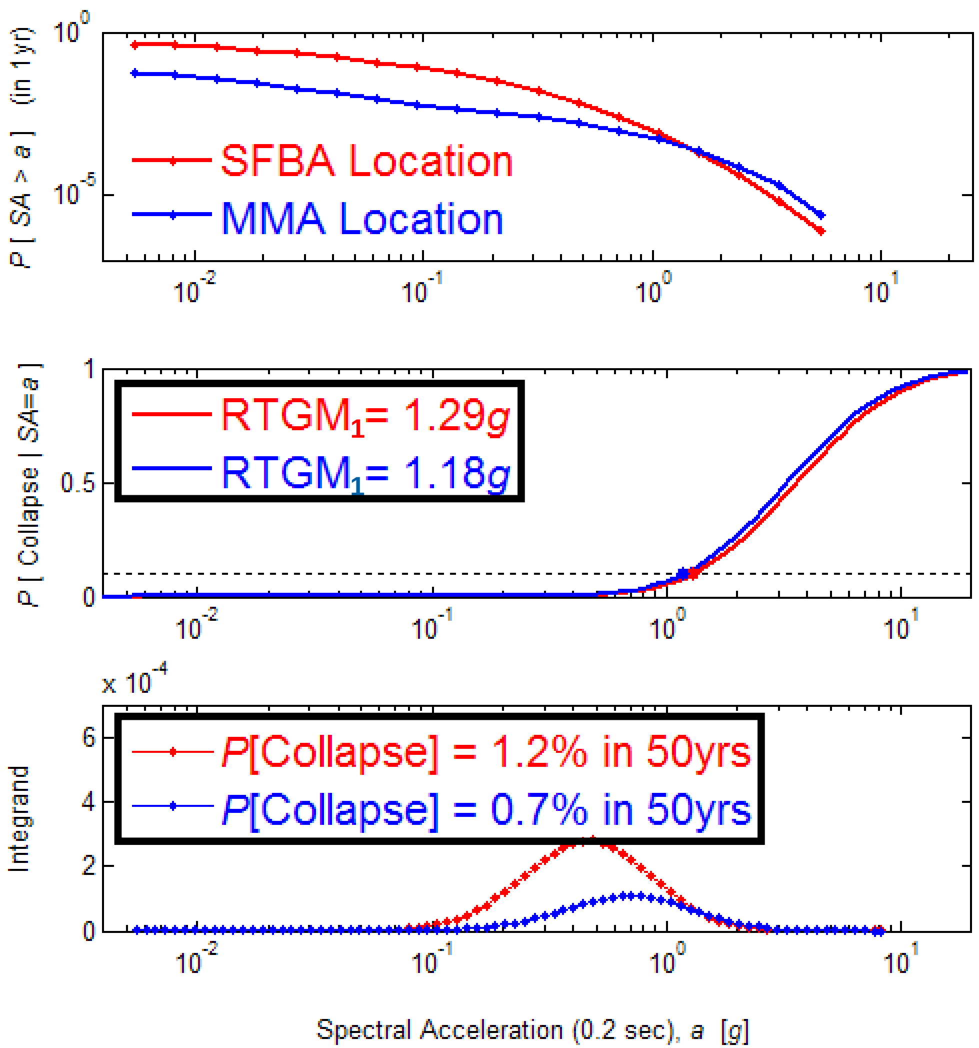
Generic fragility curve equation:

$$P[Collapse|SA = a] = \Phi\left[\frac{\ln a - (\ln RTGM + 1.28 \times 0.8)}{0.8}\right]$$

where

$$\Phi[\cdot] \equiv \text{Normal/Gaussian CDF}$$

Risk-Targeted GMs – Example

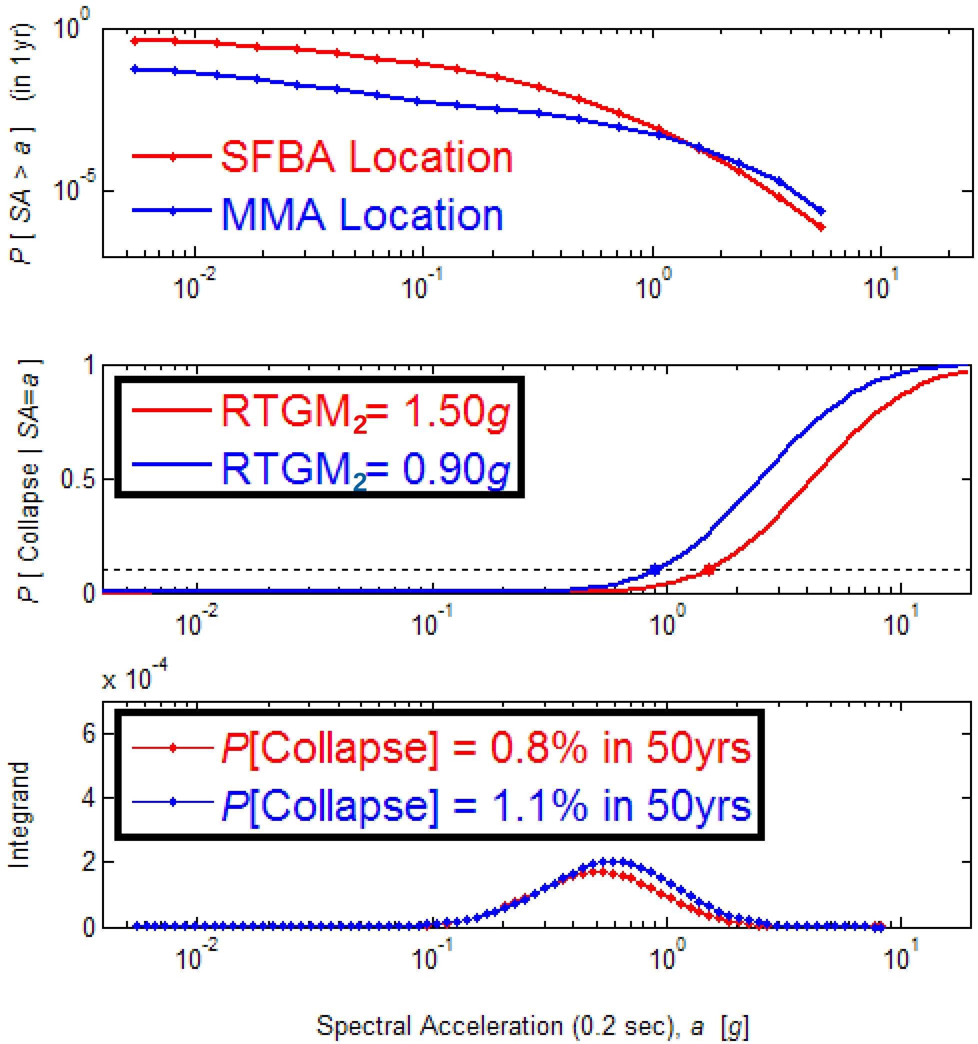


Risk-Targeted GMs – Example

Hazard

Fragility

Risk



Risk Integration:

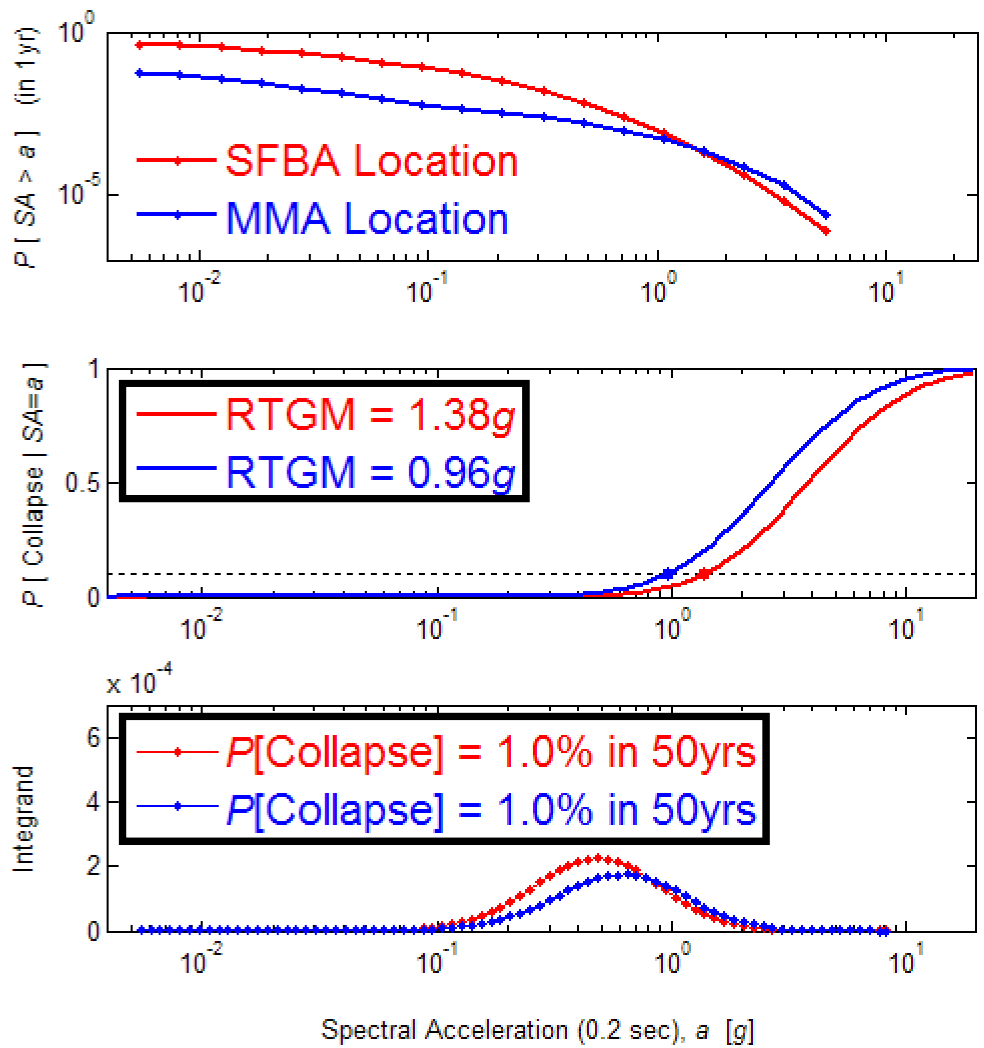
$$\mathbf{P[Collapse]} = \int_0^\infty \frac{\mathrm{d}\mathbf{P}[\boldsymbol{Collapse}|\boldsymbol{SA} = \boldsymbol{a}]}{\mathrm{d}\boldsymbol{a}} \mathbf{P}[\boldsymbol{SA} > a]\, \mathrm{d}\boldsymbol{a}$$

Risk-Targeted GMs – Example

Hazard

Fragility

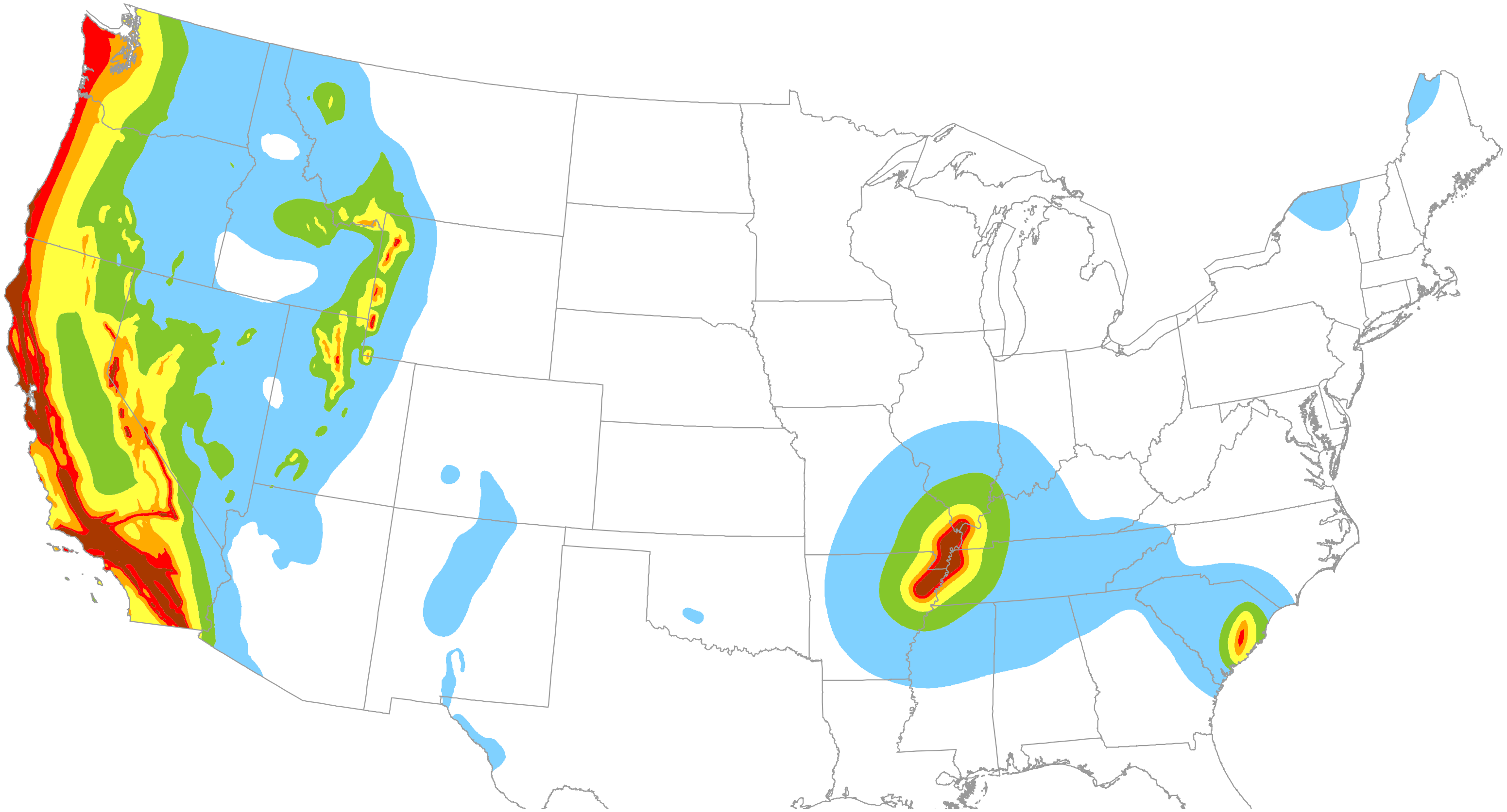
Risk



Risk Integration:

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

Risk-Targeted GM (RTGM) Maps



Reminder: These RTGM maps are coupled with deterministic maps to produce the MCE_R maps in ASCE 7-10

Risk-Targeted Ground Motions

From site-specific procedures (Chapter 21) of *ASCE 7-10 & 2009 NEHRP Provisions* …

21.2.1, Probabilistic Ground Motion: *The probabilistic spectral response accelerations shall be taken as the spectral response accelerations <u>in the direction of maximum horizontal response represented by a 5 percent damped acceleration response spectrum that is expected to achieve a 1 percent probability of collapse within a 50-yr. period.</u>*

Probabilistic Ground Motion = Risk-Targeted GM

21.2.1.1, Method 1: *At each spectral response period for which the acceleration is computed, ordinates of the probabilistic ground motion response spectrum shall be determined as the product of the risk coefficient, C_R, and the spectral response acceleration from a [illegible] spectrum having a 2 percent probability of exceedance within a 50-yr. period. The value of the risk coefficient, C_R, shall be determined using values of C_{RS} and C_{R1} from Figs. 22-3 and 22-4, respectively. …*

Risk-Targeted GM =
Uniform-Hazard (2500-yr) GM
x Risk Coefficient

Risk Coefficients (C_R's)

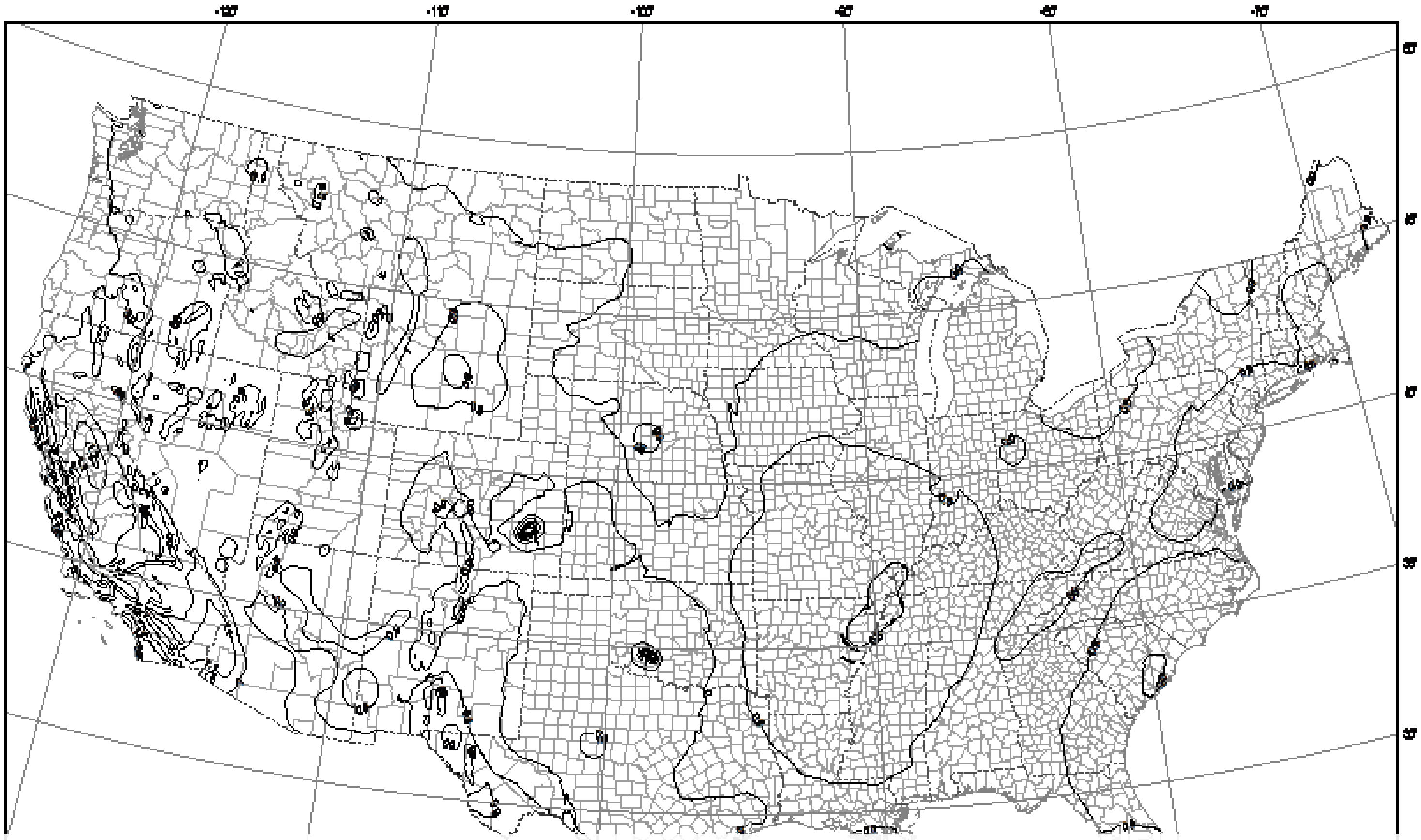
- Conventional uniform-hazard (2500-yr) GMs interpolated from hazard curves

- C_R's = $\dfrac{\text{Risk-Targeted GMs}}{\text{Uniform-Hazard GMs}}$

- e.g.,

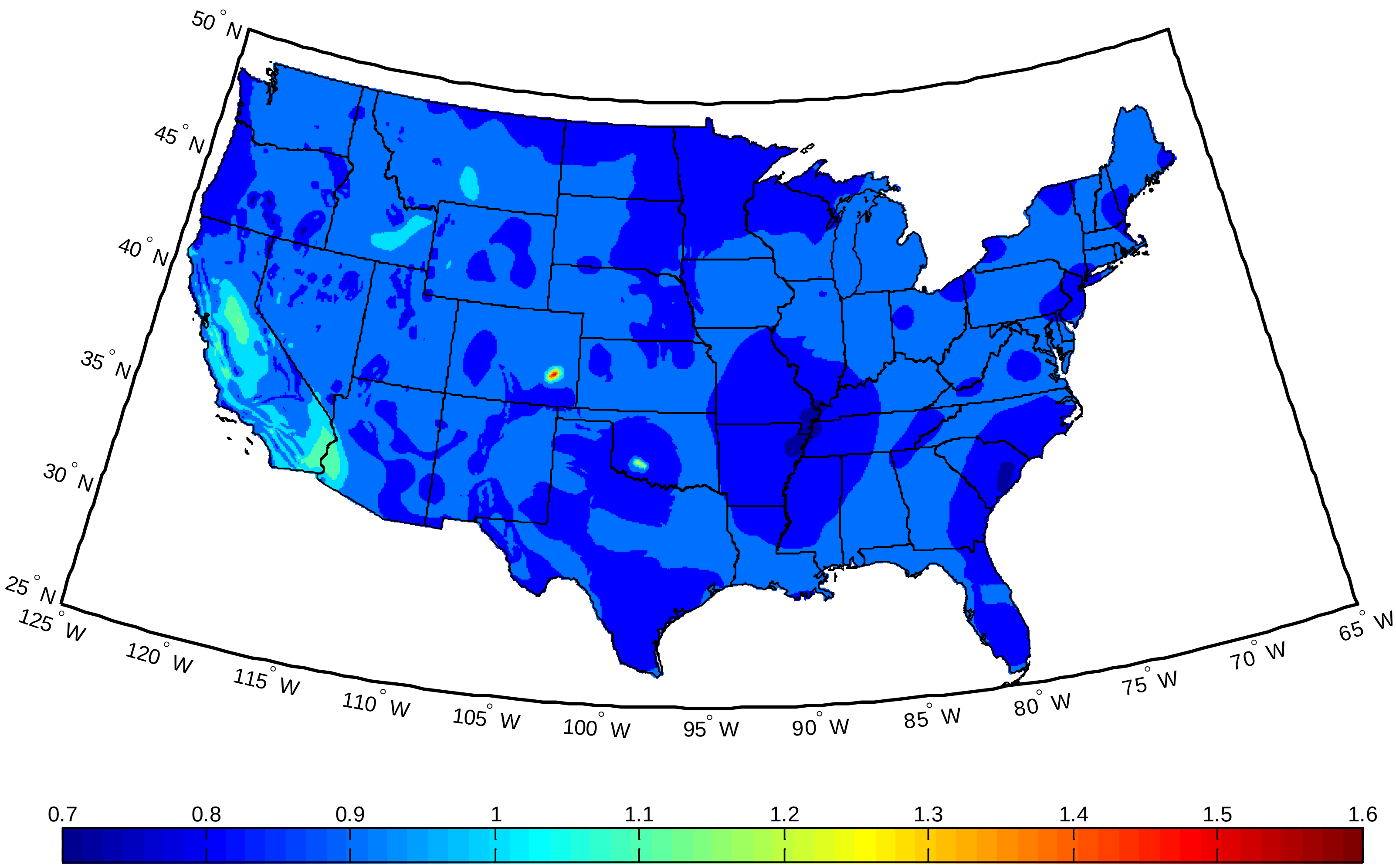
	SFBA Location	MMA Location
Risk-Targeted GM	1.38*g*	0.96g
Uniform-Hazard GM	1.29*g*	1.18g
Risk Coefficient (C_R)	1.07	0.82

Risk Coefficient (C_R) Maps

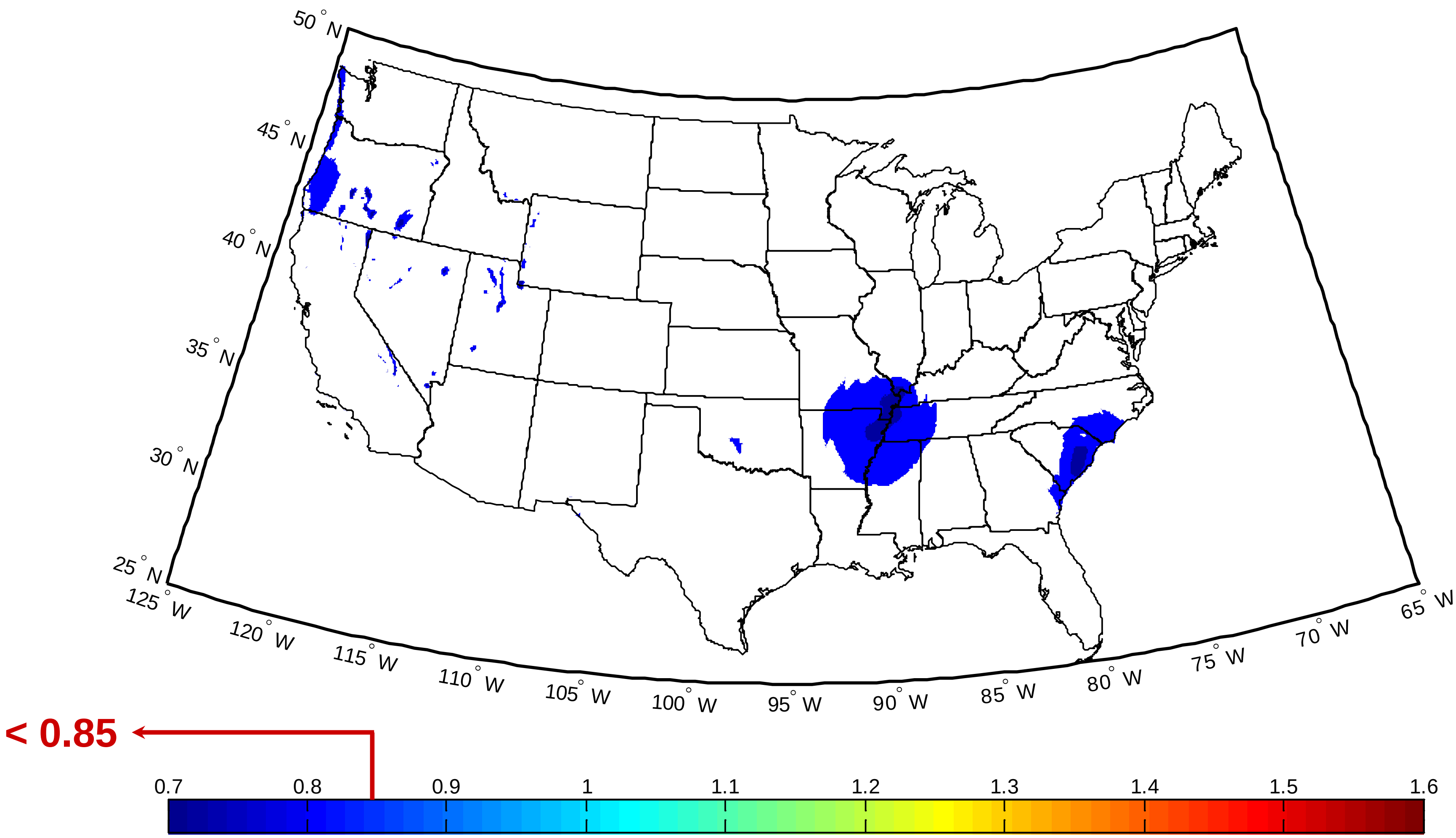


These intermediate maps <u>are</u> included in *ASCE 7-10* (for Ch. 21) <u>and</u> *2009 NEHRP*

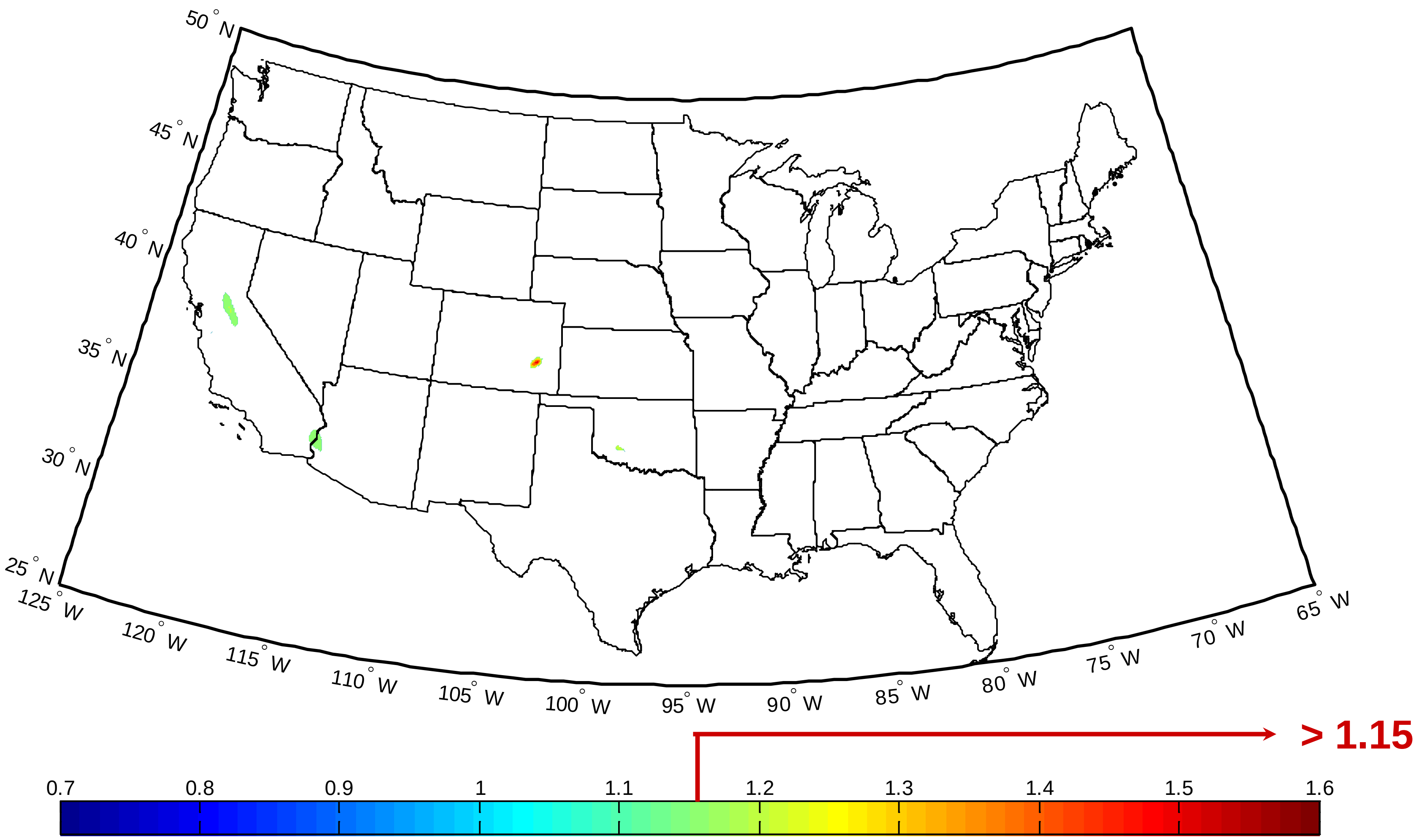
Risk Coefficient (C_R) Maps



Risk Coefficient (C_R) Maps



Risk Coefficient (C_R) Maps



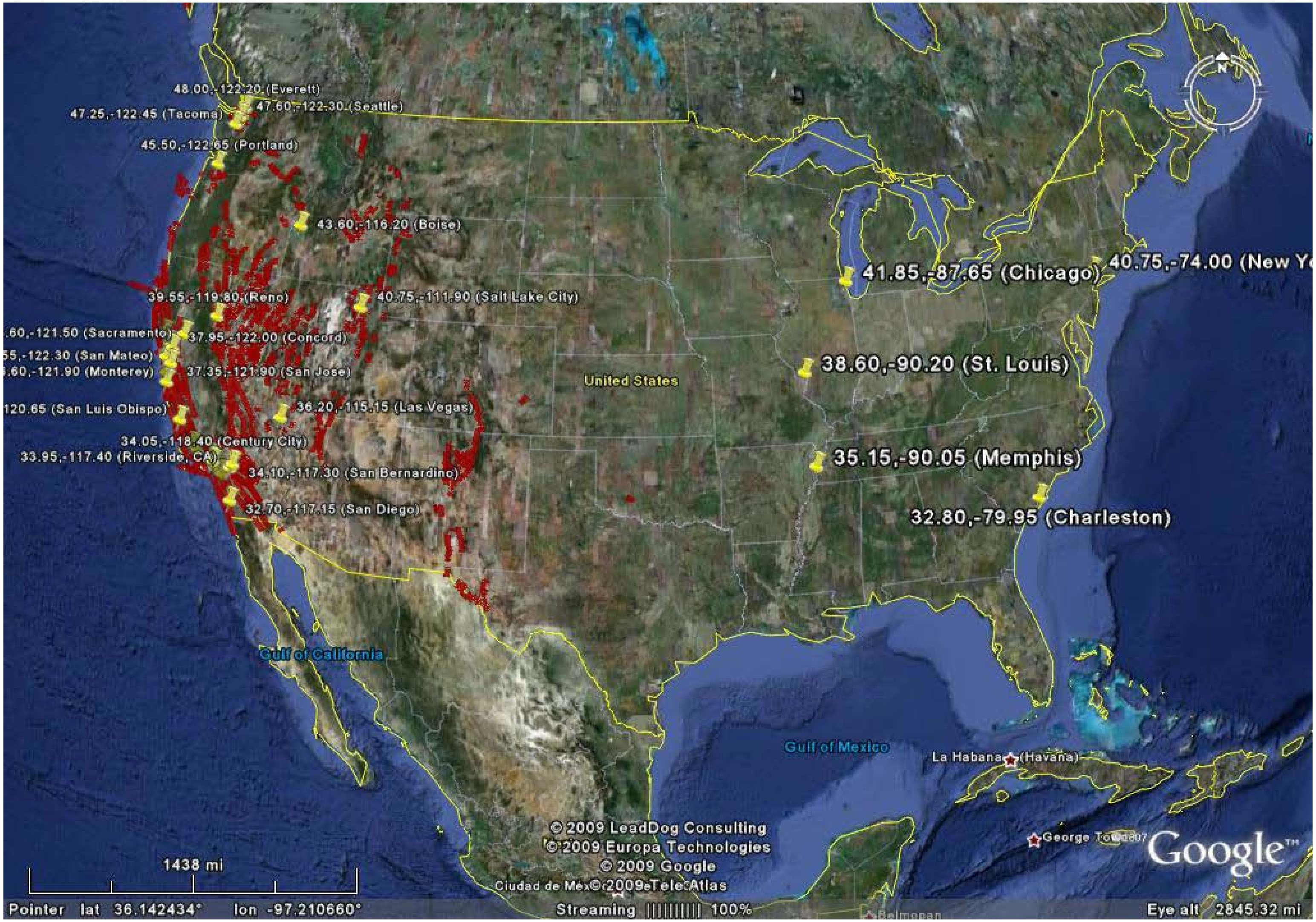
Summary: Probabilistic GMs

- **Probabilistic GMs = Risk-Targeted GMs**
- Risk-Targeted GMs calculated from …
  - GM hazard curves (from USGS)
  - Building fragility curves (def. by Project ’07)
  - Risk target (defined by Project ‘07)
- Risk Coefficients = $\dfrac{\text{Risk-Targeted GMs}}{\text{Uniform-Hazard GMs}}$
- Risk Coeff. Maps included in *ASCE 7-10* for combination with site-specific UHGMs

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 Central and Eastern United states (CEUS) city sites (5) used to compare ground motions

Central and Eastern United States city sites

Location and associated county population data (and total population for all United States counties)

City and Location of Site			Metropolitan Statistical Area	
Name	**Latitude**	**Longitude**	**Name**	**Population**
St. Louis	38.60	-90.20	St. Louis MSA (16)	2,786,728
Memphis	35.15	-90.05	Memphis MSA (8)	1,269,108
Charleston	32.80	-79.95	Charleston MSA (3)	603,178
Chicago	41.85	-87.65	Chicago MSA (7)	9,505,748
New York	40.75	-74.00	New York MSA (23)	18,747,320
Total Pop - MO/TN/SC/IL/NY		48,340,918	Total Pop - 57 Counties	32,912,082
Total State Population All Regions		101,407,080	Total County Population All Regions	71,381,030

Central and Eastern United States City Sites

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

CEUS City (Site Location)	Design	MCE (2009 *NEHRP Provisions*)				Return Period (years)	50-Year Collapse Prob.
	S_{DS} (g)	F_a	S_{SUH} (g)	C_{RS}	S_{SD} (g)		
St. Louis	0.42	1.45	0.51	0.87	1.50	1,838	1.0%
Memphis	0.74	1.10	1.24	0.81	1.50	1,680	1.0%
Charleston	0.80	1.04	1.46	0.79	2.99	1,747	1.0%
Chicago	0.14	1.60	0.15	0.92	1.50	2,155	1.0%
New York	0.29	1.58	0.32	0.87	1.50	2,058	1.0%
CEUS Average	0.29	1.54	0.34	0.88	1.53	2,047	1.0%

Central and Eastern United States 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
St. Louis	0.41	0.55	0.53	0.52	0.42
Memphis	0.83	0.90	0.92	0.93	0.74
Charleston	0.41	0.55	0.95	1.01	0.80
Chicago	0.00	0.00	0.20	0.18	0.14
New York	0.41	0.55	0.41	0.37	0.29
CEUS Average	0.31	0.40	0.39	0.36	0.29

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	(+5%)
Northern CA	1.06	1.18	1.01	1.00	1.08	(+8%)
Pacific NW	0.83	0.90	0.90	0.84	0.83	(-1%)
Intermountain	0.68	0.80	0.72	0.70	0.65	(-7%)
CEUS	0.31	0.40	0.39	0.36	0.29	(-19%)
All Regions	0.69	0.80	0.72	0.73	0.72	(-1%)

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	(+8%)
Northern CA	0.73	0.81	0.64	0.61	0.65	(+7%)
Pacific NW	0.56	0.54	0.46	0.44	0.49	(+11%)
Intermountain	0.47	0.46	0.41	0.39	0.34	(-13%)
CEUS	0.21	0.24	0.16	0.14	0.14	(0%)
All Regions	0.47	0.52	0.39	0.38	0.40	(+5%)

From "Project 07 - Reassessment of Seismic Design Procedures ... for Building Codes," C. Kircher et al

Summary

- Previous uniform-hazard (2%-in-50yr) probabilistic ground motions …
  - Resulted in spatially-variable collapse risk, due to variations in hazard curve shapes
  - Considered only a single selected point (2%-in-50yr) on hazard curves
  - Were similar in value in Memphis Metro Area and San Francisco Bay Area
- New risk-targeted probabilistic ground motions address these issues

Summary (continued)

- New risk-targeted probabilistic ground motions (RTGMs) …
  - Explicitly & uniformly target 1% probability of collapse in a building's lifetime, ~50 years
  - Consider all points on & spatial variations in shapes of hazard curves
  - Require a generic fragility that depends on RTGM & effectively considers shapes of hazard curves
  - Changes uniform-hazard (2%-in-50yr) ground motions by factor of 0.85-1.15 generally, but as low as 0.70 near New Madrid and Charleston