

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

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

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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
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 - C.B. Crouse (TC1 Chair)
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Preparation of Seismic Design Maps for Codes \$45.00

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Presented by:
 Nicolas Luco, Research Structural Engineer
 USGS, Golden, Colorado



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About this Seminar Series

Next Generation Attenuation (NGA) Models
 This seminar informs structural and geotechnical engineers about the implications for engineering practice of the recently developed next generation attenuation (NGA) models. Significant changes are coming to the USGS Hazard Maps and Seismic Design Maps that are part of the ASCE 7 and IBC design process. These changes need to be understood by geotechnical, seismological, and structural engineers; not only will they impact site-specific studies, but they will also become a part of the 2010 ASCE 7 and 2012 IBC design provisions. This seminar provides the background and basis for the NGA models and how they impact the new USGS Hazard Maps. It also summarizes the technical basis of the three major changes to Seismic Design Maps. It provides examples of applications of the new NGA models.

The NGA models that are now incorporated in the new USGS Hazard Maps were developed by the Pacific Earthquake Engineering Research (PEER) Center over a five-year period to update the ground motion predictive equations for shallow crustal earthquakes in the western United States and similar active tectonic regions. The expansion of the strong motion database

Preparation of New Seismic Design Maps for Building Codes

EERI Seminar on Next Generation Attenuation Models

Nicolas Luco, Research Structural Engineer
USGS, Golden, Colorado







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

Outline of Presentation

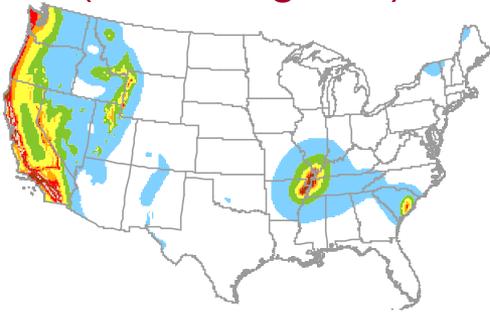
- Preparation of new design maps using ...
 - Seismic hazard computed by USGS
 - Probabilistic hazard curves
 - Deterministic median ground motions
 - Procedures developed by Project '07
 - Stipulated in site-specific procedures (Ch. 21) of *ASCE 7-10 & 2009 NEHRP Provisions*
- Design maps **web application** 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**
 - 84th-^oile 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

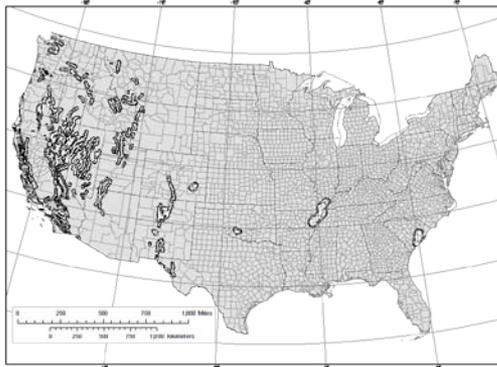
Preparation of New Design Maps

Probabilistic GMs (Risk-Targeted)

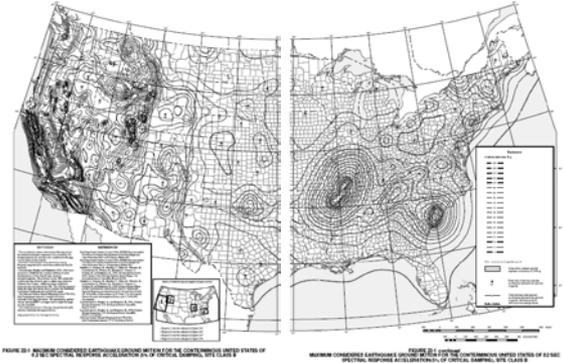


min

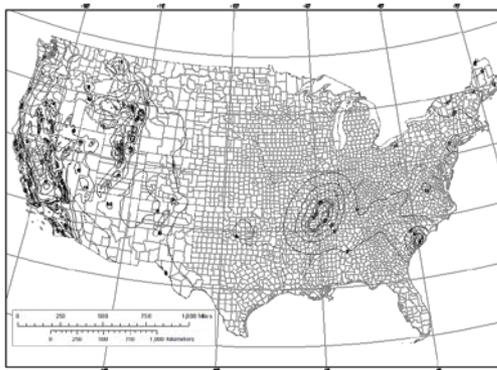
Deterministic GMs



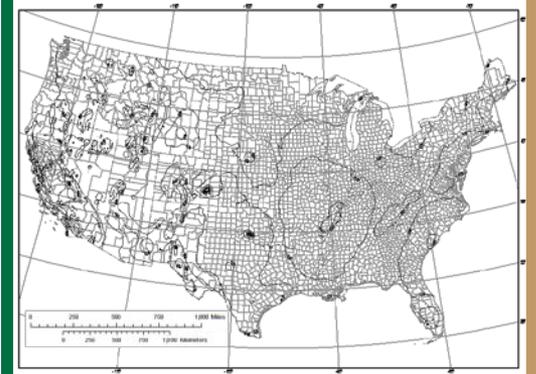
New MCE_R GMs



Uniform-Hazard GMs



Risk Coefficients



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

- In **ASCE 7-10**
- In **2009 NEHRP**

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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.

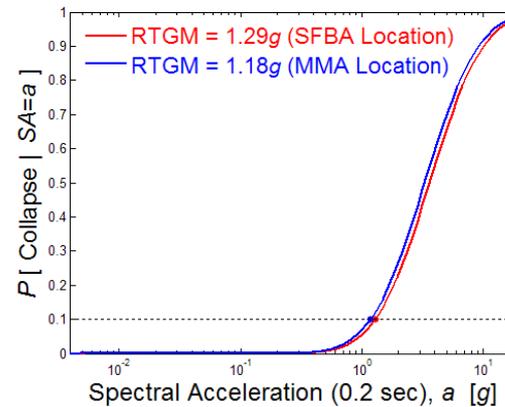
Risk-Targeted Ground Motions

Calculated iteratively by combining ...

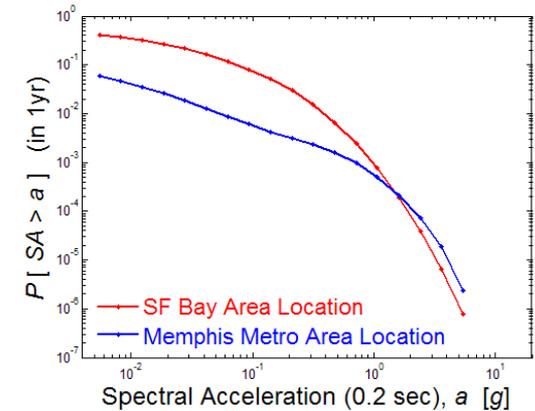
Risk Target
defined by Project '07

Prob. of Collapse
in 50 yrs = 1%

Building Fragility Curves
defined by Project '07



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

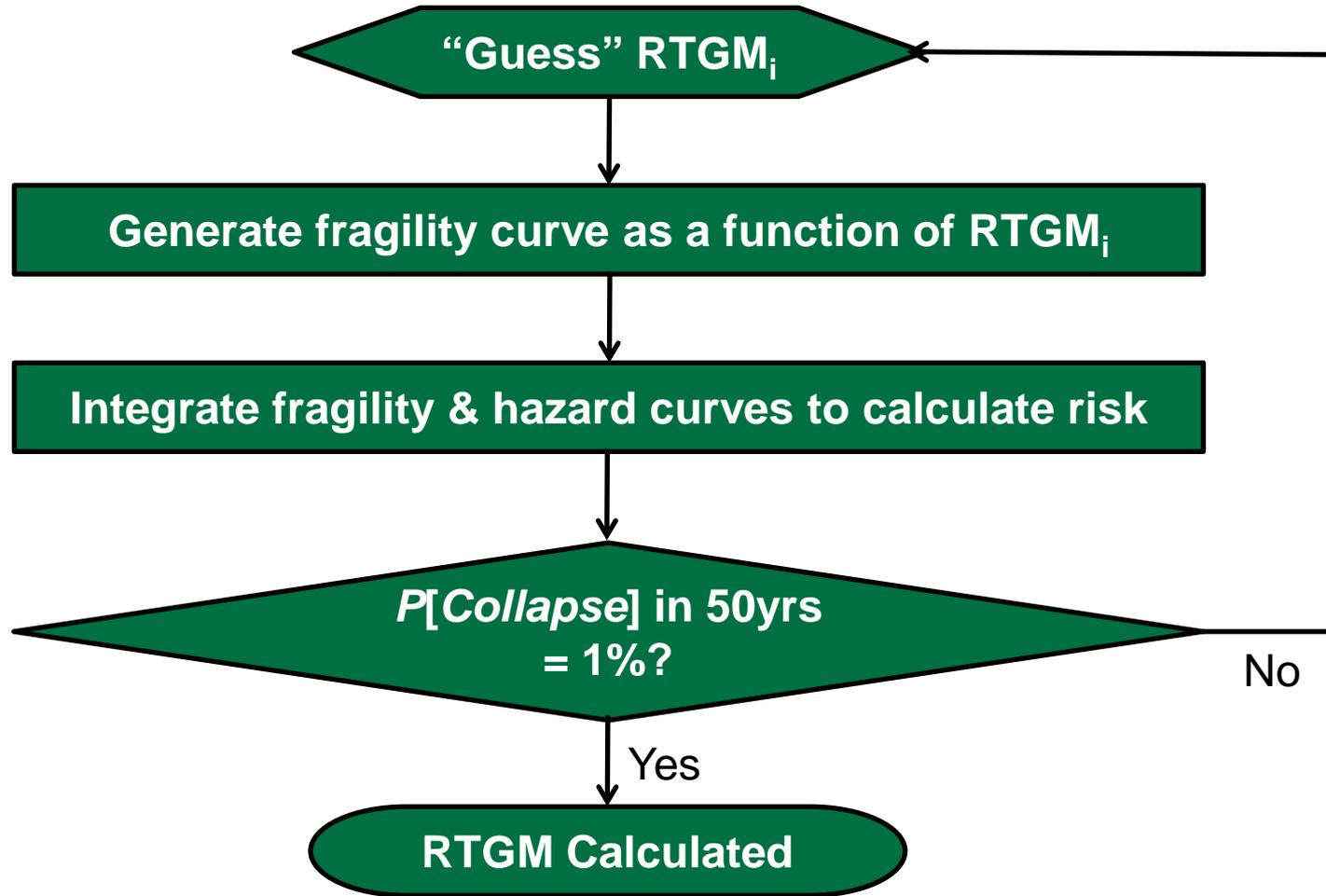


... via "Risk Integral" (e.g. ATC 3-06), i.e., ...

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

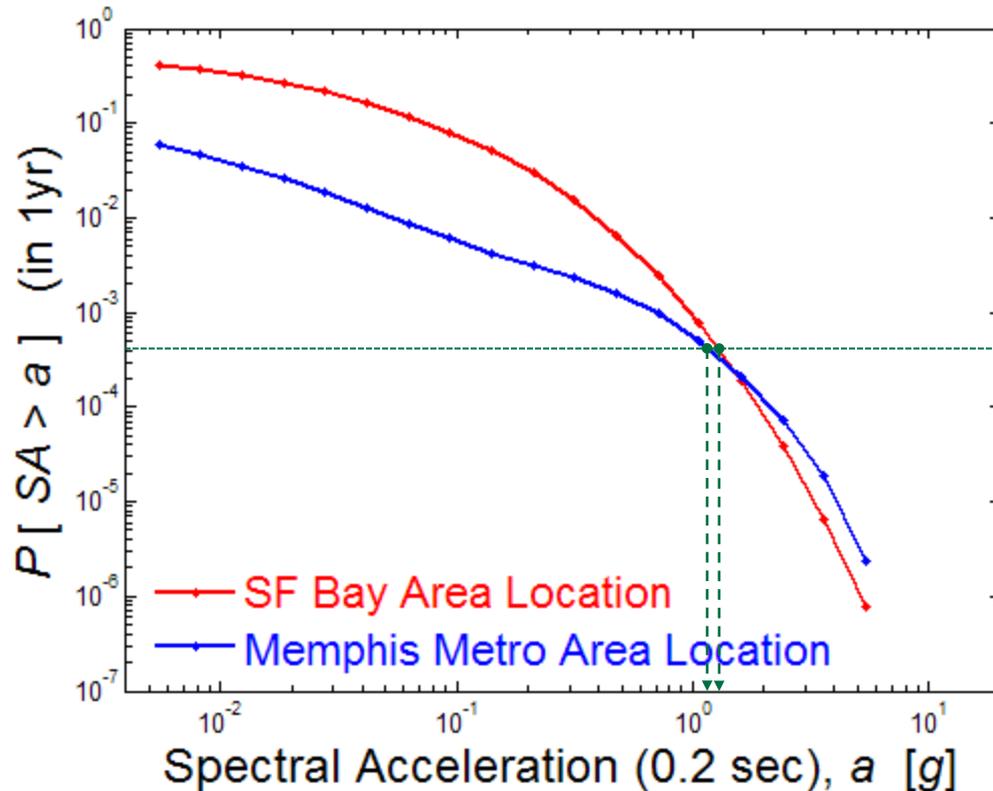
Risk-Targeted Ground Motions

For a given location ...



Risk-Targeted GMs – Example

GM hazard curves from USGS ...



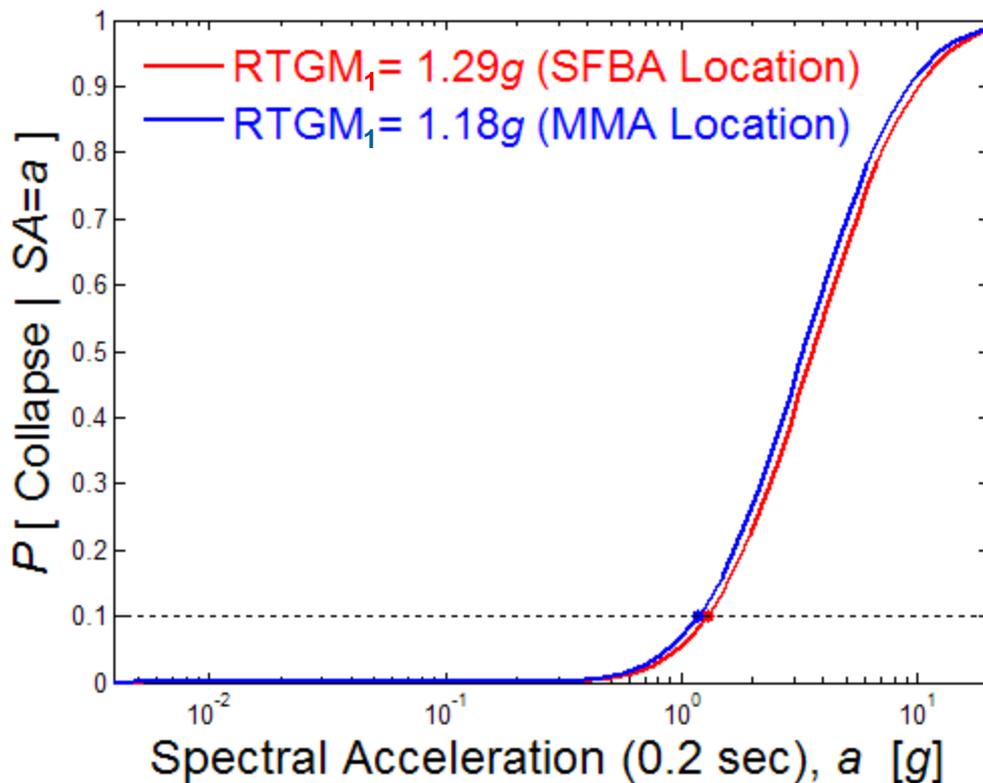
Notes:

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 ...



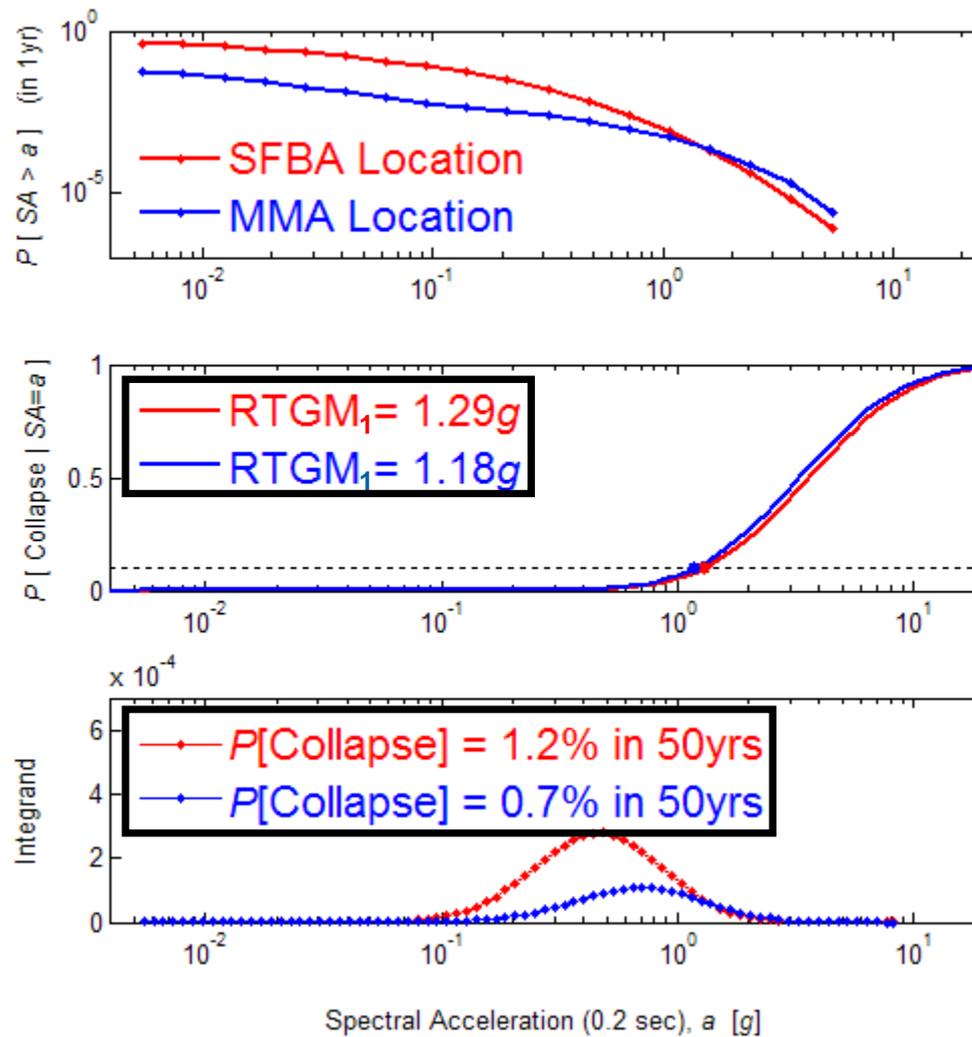
Generic fragility curve equation:

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

where

$\Phi[\cdot] \equiv$ Normal/Gaussian CDF

Risk-Targeted GMs – Example



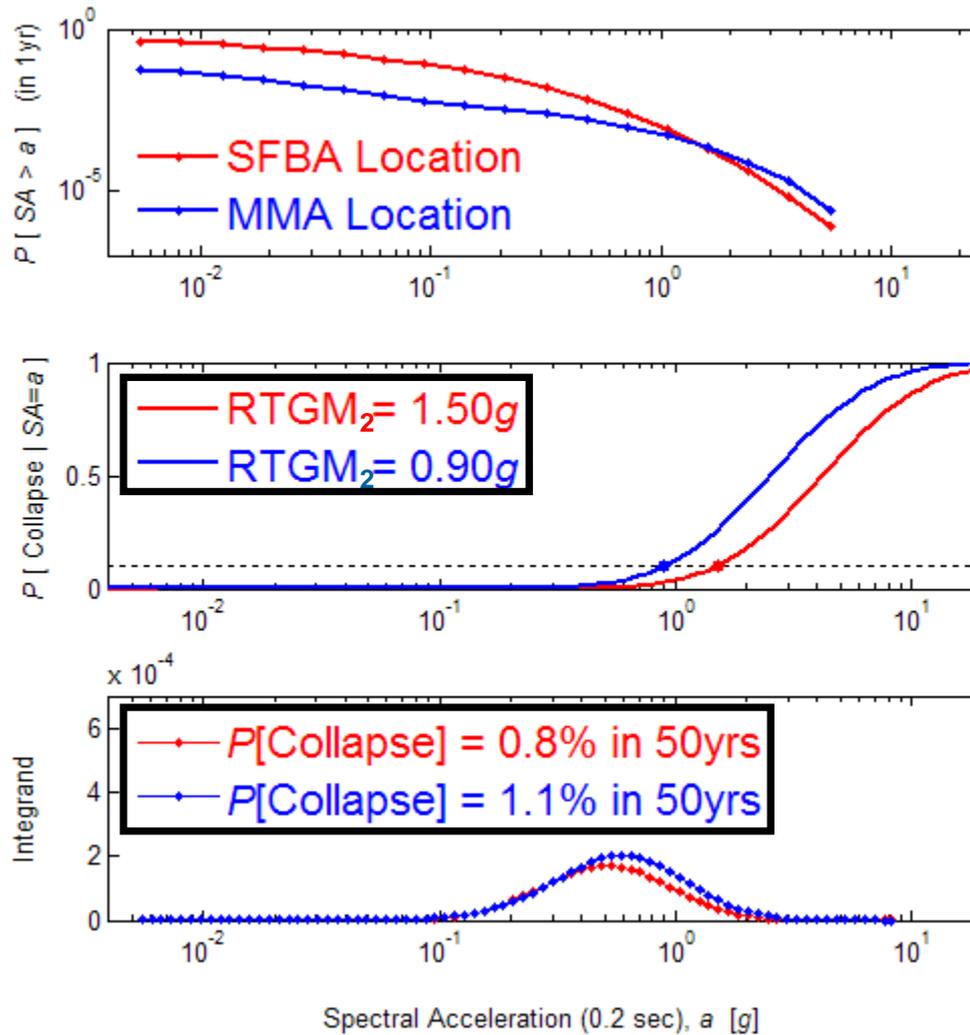
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Risk-Targeted GMs – Example

Hazard

Fragility

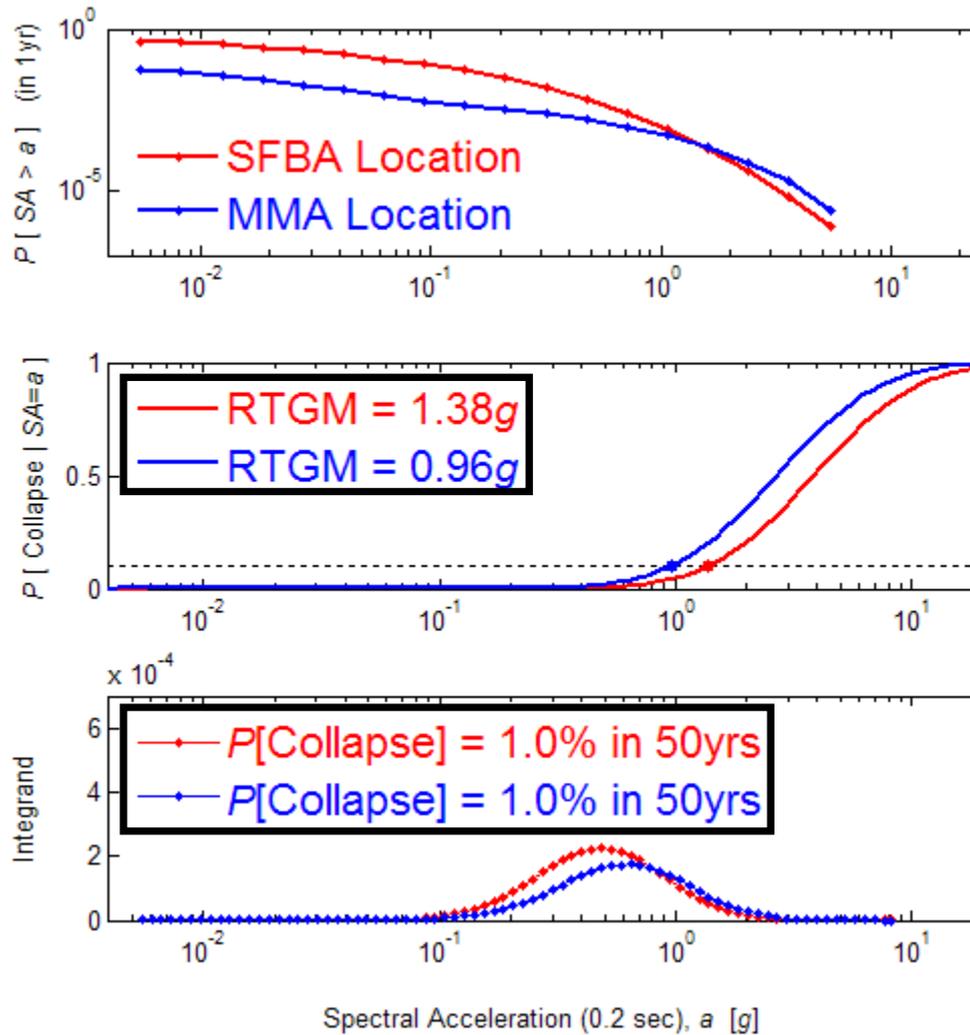
Risk



Risk Integration:

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

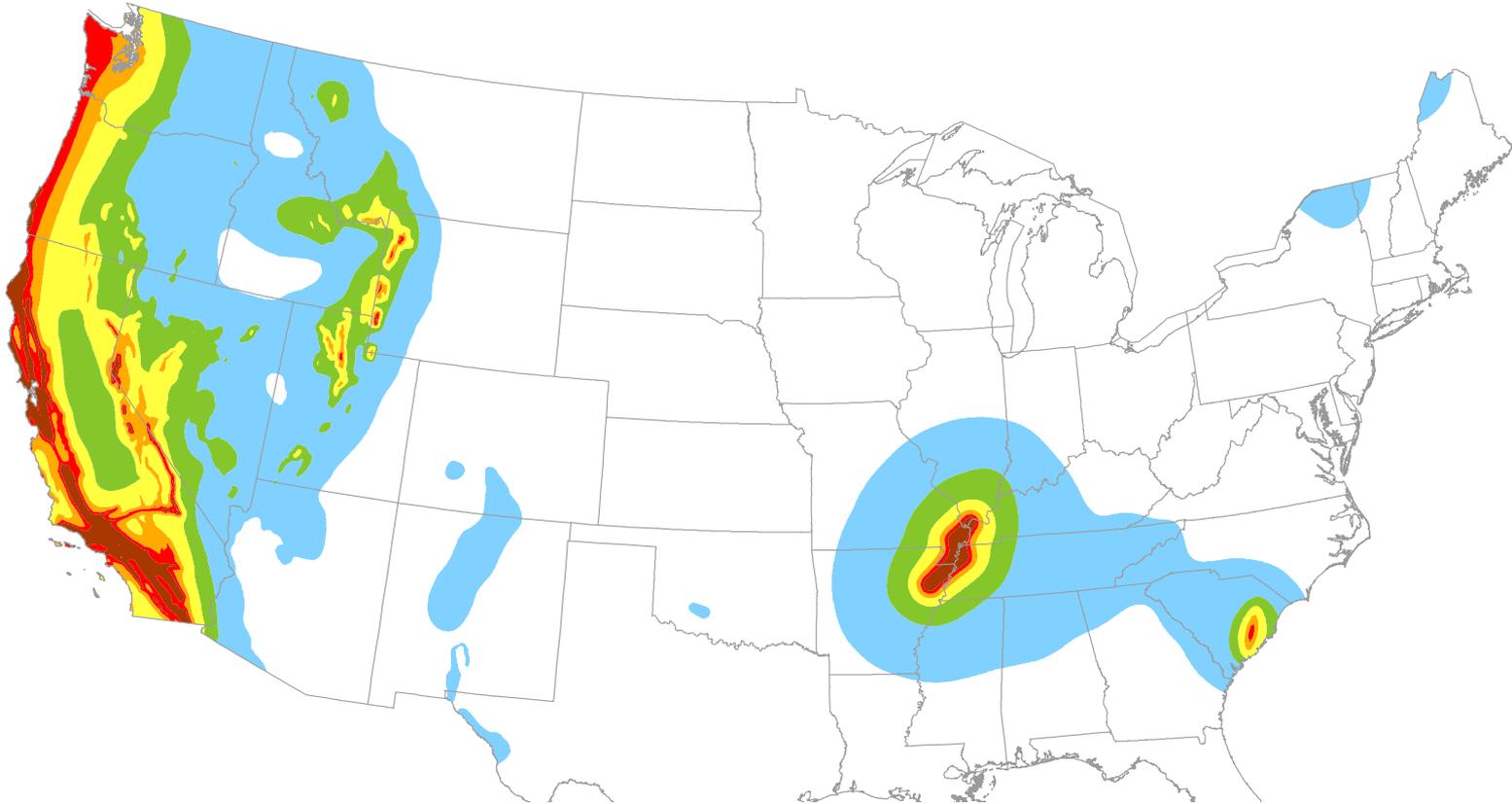
Risk-Targeted GMs – Example



Risk Integration:

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

Risk-Targeted GM (RTGM) Maps



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

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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 in the direction of maximum horizontal response represented by a 5 percent damped acceleration*

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_{R1} , and the spectral response acceleration from a uniform-hazard (2500-yr) GM spectrum having a 2 percent probability of exceedance within a 50-yr period. The value of the risk coefficient, C_{R1} , shall be determined using values of C_{RS} and C_{R1} from Figs. 22-3 and 22-4, respectively. ...*

Risk Coefficients (C_R 's)

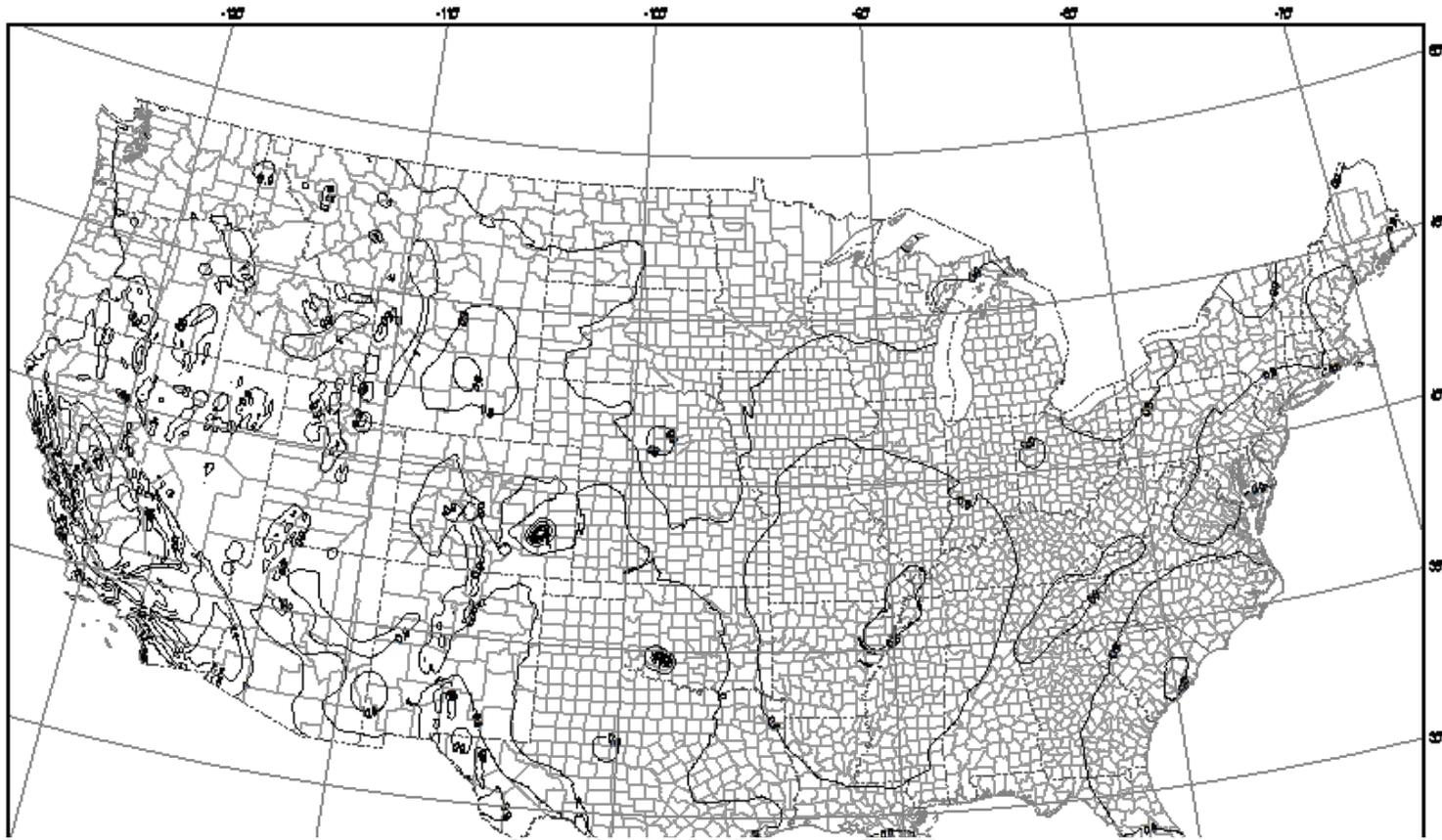
- Conventional uniform-hazard (2500-yr) GMs interpolated from hazard curves

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

- e.g.,

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

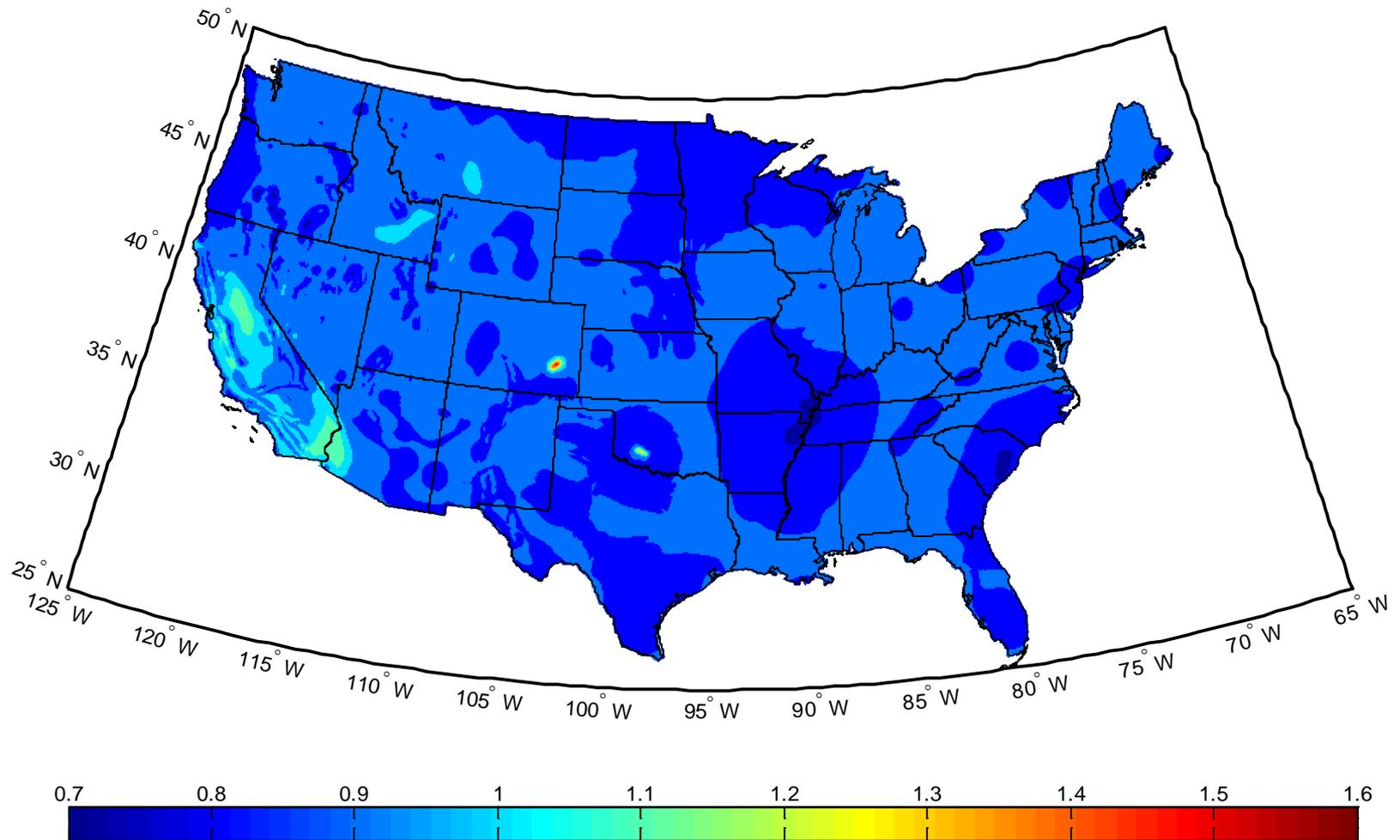
Risk Coefficient (C_R) Maps



These intermediate maps are included in ASCE 7-10 (for Ch. 21) and 2009 NEHRP

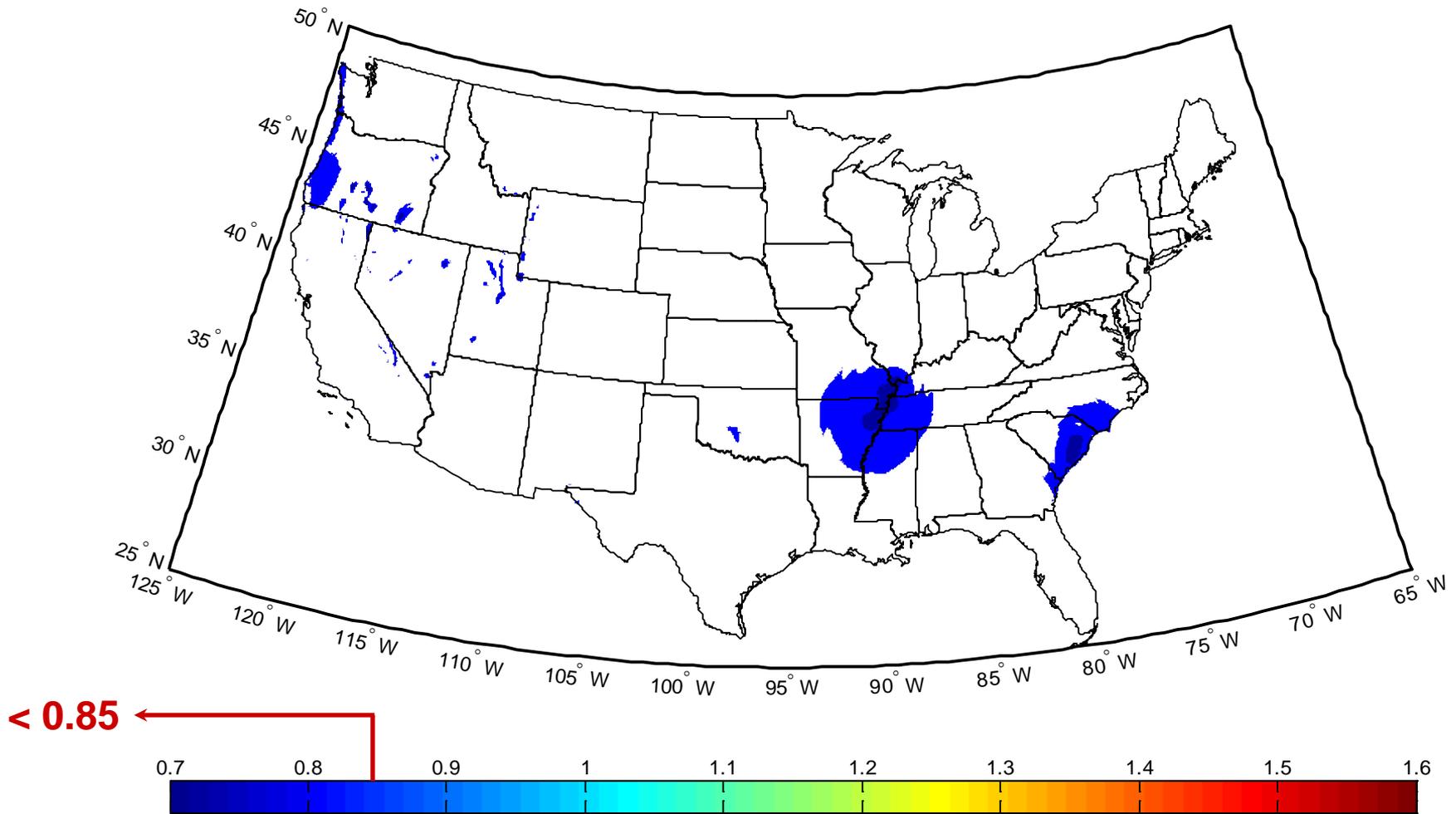
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Risk Coefficient (C_R) Maps



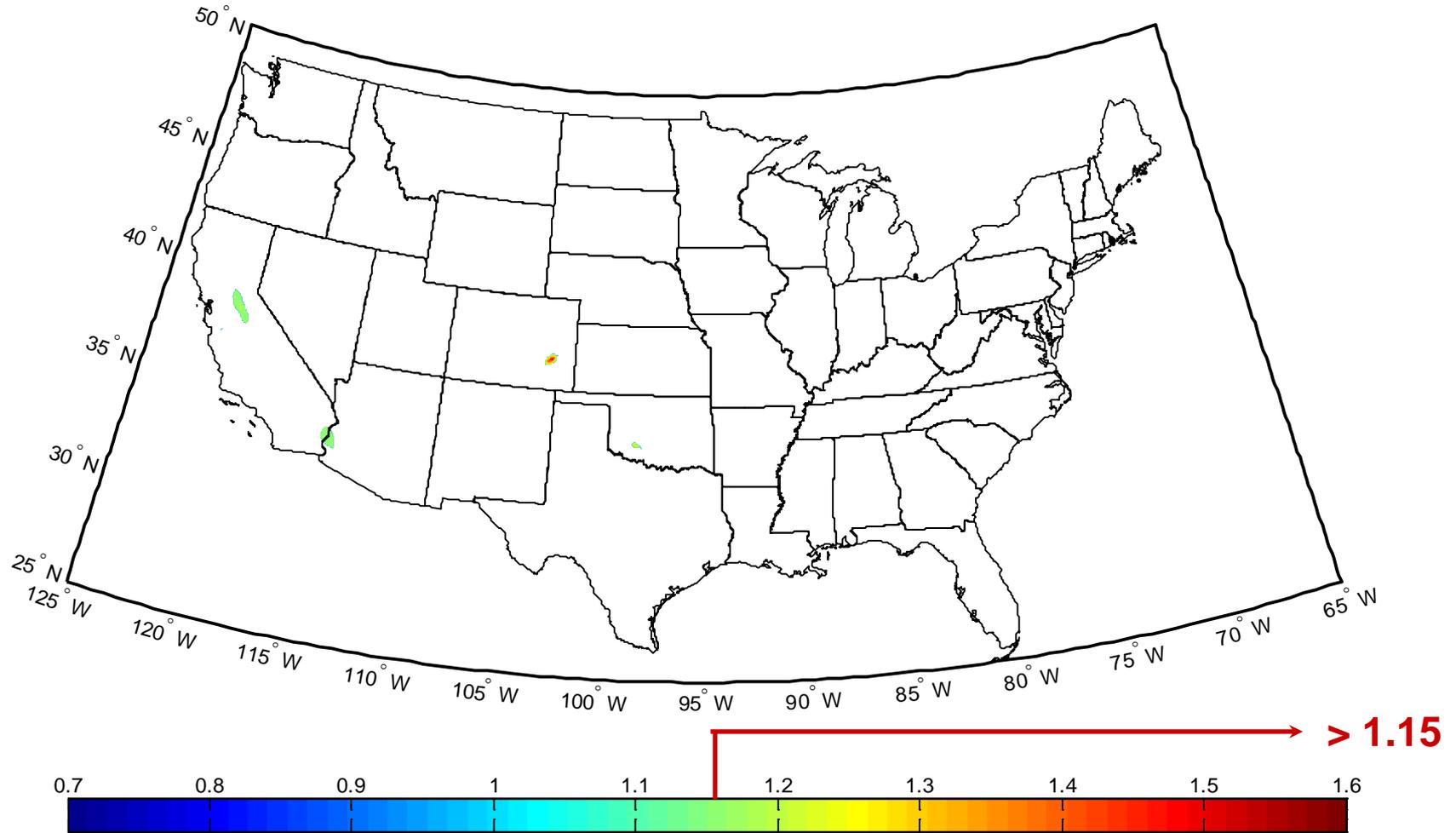
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Risk Coefficient (C_R) Maps



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Risk Coefficient (C_R) Maps



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Summary: Probabilistic GMs

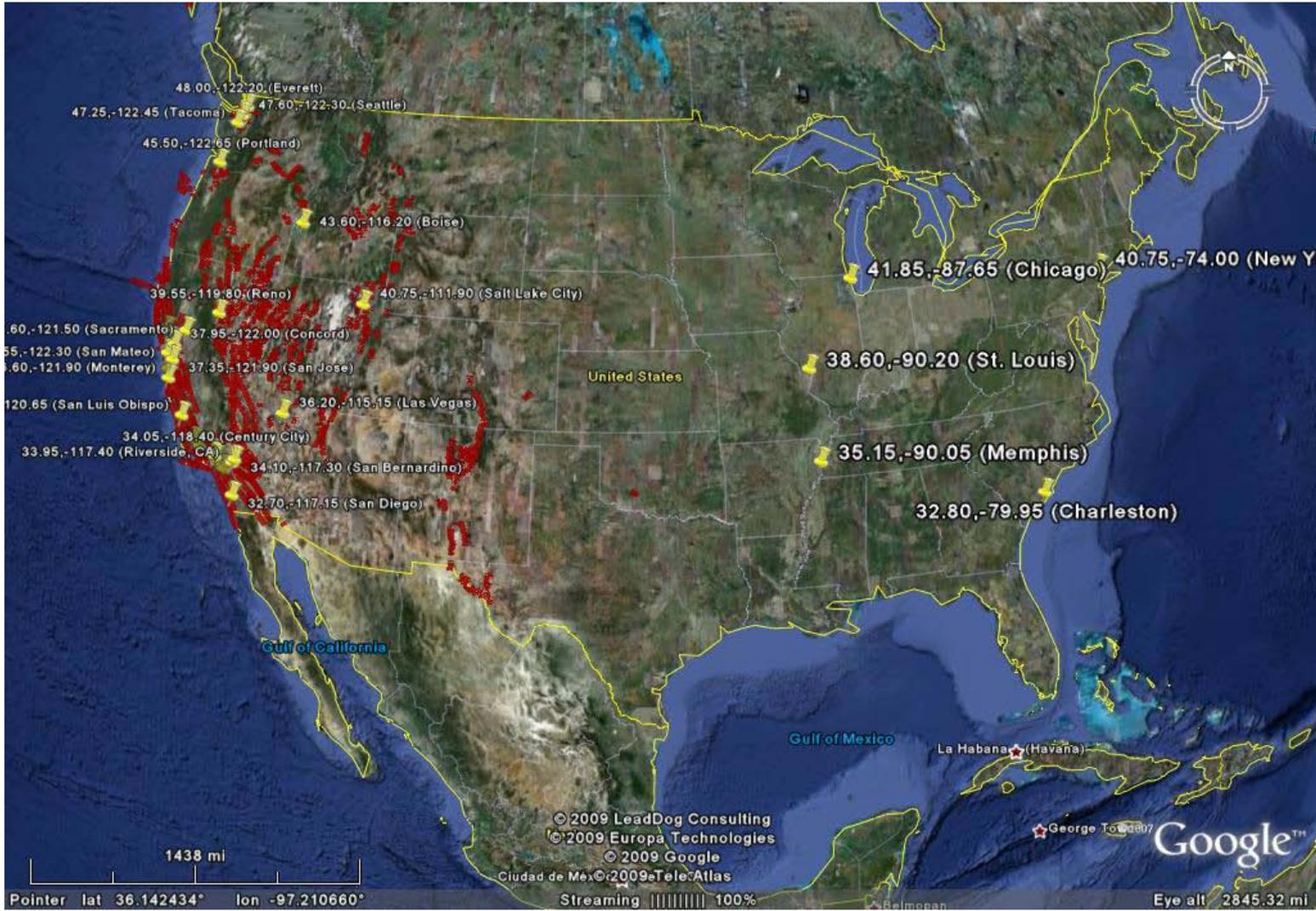
- **Probabilistic GMs = Risk-Targeted GMs**
- Risk-Targeted GMs calculated from ...
 - GM hazard curves (from USGS)
 - Building fragility curves (def. by Project '07)
 - Risk target (defined by Project '07)
- Risk Coefficients = $\frac{\text{Risk-Targeted GMs}}{\text{Uniform-Hazard GMs}}$
- Risk Coeff. 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)



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



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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%)



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