Ground Motions for Design

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Thailand Seismic Hazard Workshop
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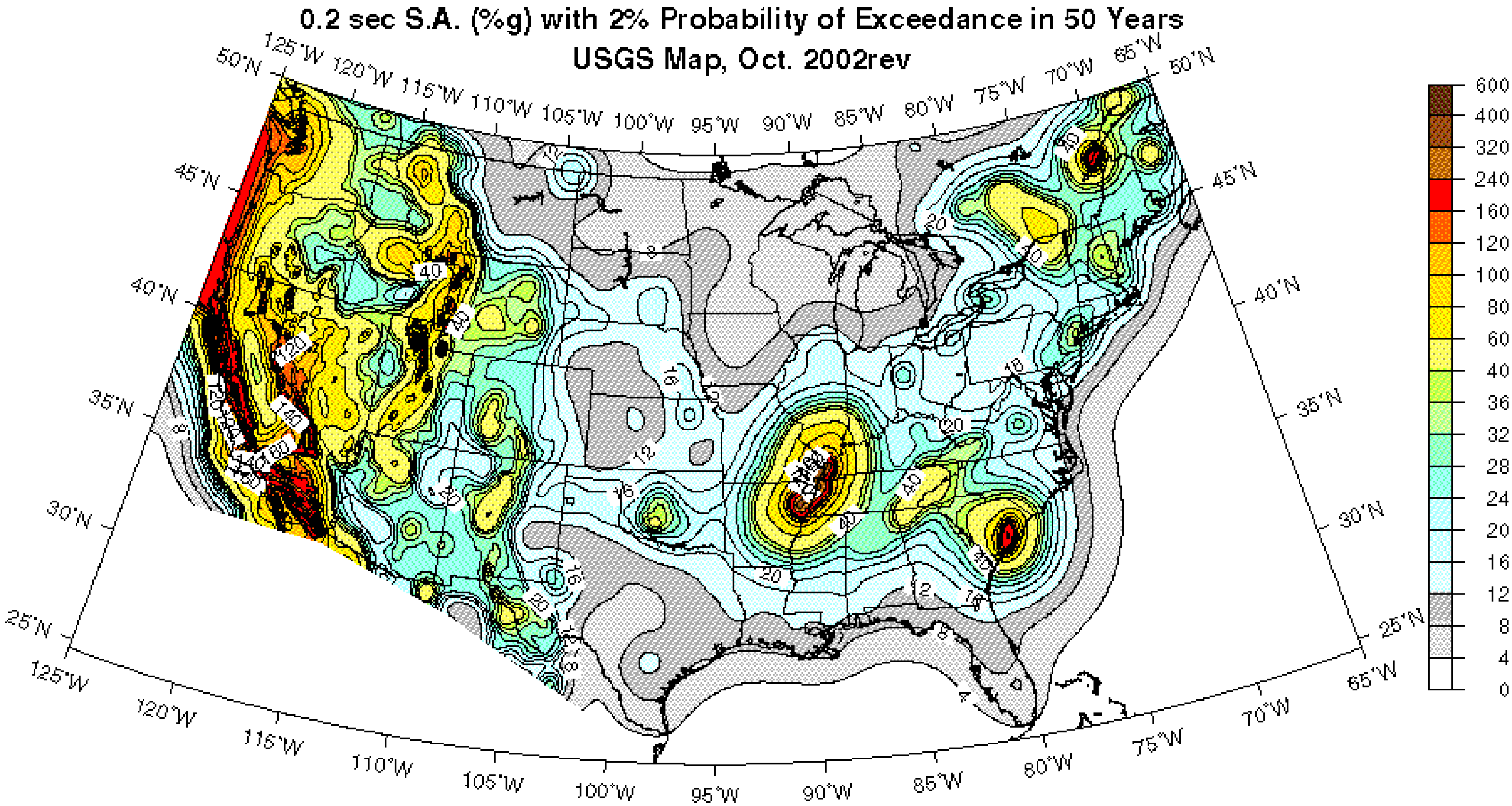
Outline of Material

- Derivation of "International" Building Code (IBC) *Design* Maps from USGS *Hazard* Maps
- Use of IBC Design Maps (i.e., procedure)
- Computer software for IBC Design Maps
- Potential updates of IBC Design Maps

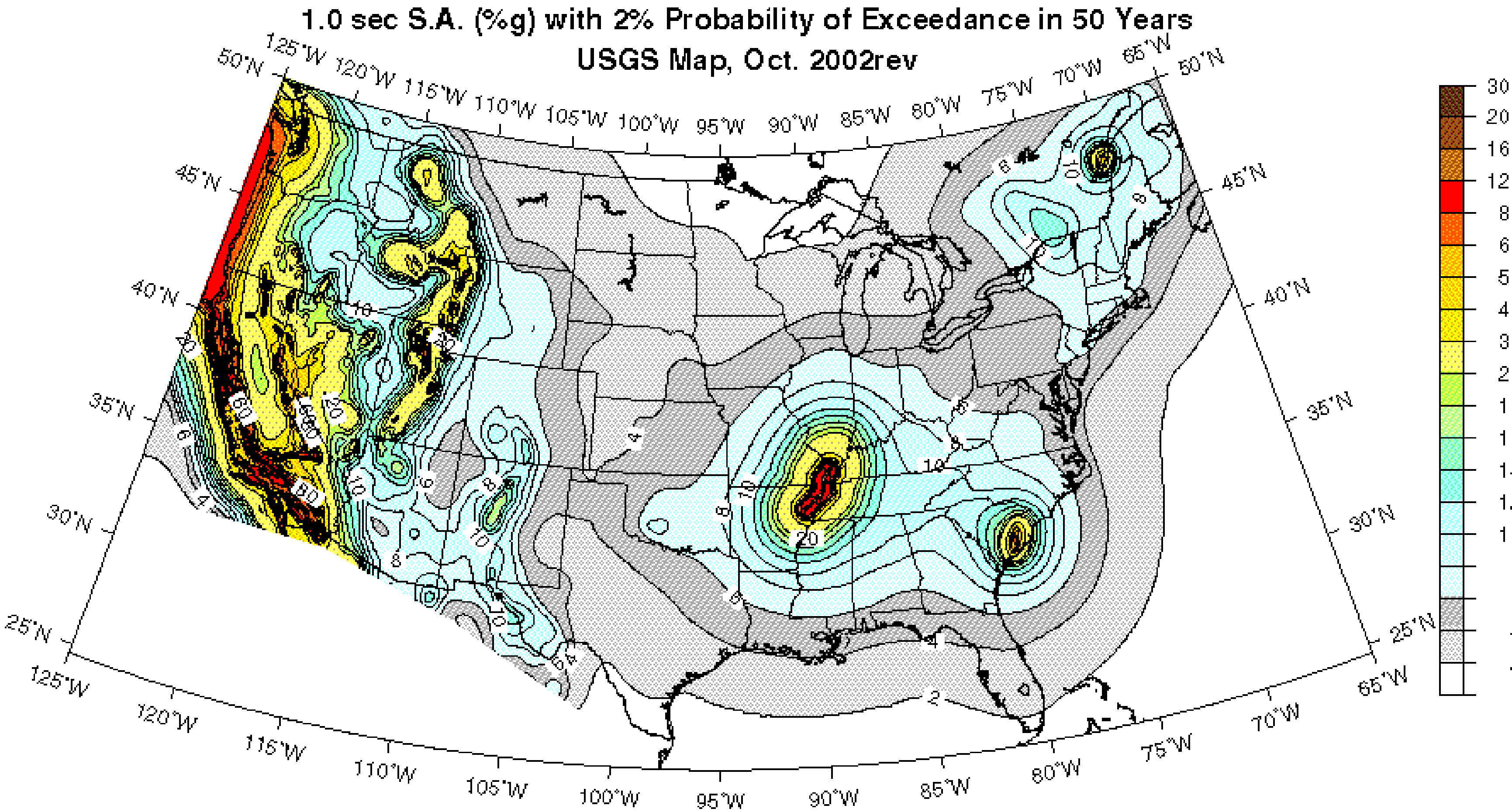
Derivation of IBC Design Maps

- The ground motions for design that are mapped in the IBC are based on, but not identical to, the USGS Probabilistic Seismic Hazard Analysis (PSHA) Maps for …
  - **2% in 50 years probability of exceedance**
  - **0.2- and 1.0-second spectral acceleration (*SA*)**
  - **(Vs30=760m/s, i.e., boundary of Site Classes B/C)**

The design maps in the IBC are based on, but not identical to, the USGS PSHA Maps …



The design maps in the IBC are based on, but not identical to, the USGS PSHA Maps …



Derivation of IBC Design Maps

- The ground motions for design that are mapped in the IBC are based on, but not identical to, the USGS Probabilistic Seismic Hazard Analysis (PSHA) Maps for …
  - **2% in 50 years probability of exceedance**
  - **0.2- and 1.0-second spectral acceleration (*SA*)**
- The site-specific ground motion procedure in the building code explains the link between the two.

Derivation of IBC Design Maps

- "The **probabilistic MCE** [Maximum Considered Earthquake] spectral response accelerations shall be taken as the spectral response accelerations represented by a 5 percent damped acceleration response spectrum having a <u>2 percent probability of exceedance within a 50-yr. period</u>."

Derivation of IBC Design Maps

- "The **deterministic MCE** response acceleration at each period shall be calculated as <u>150 percent of the largest median</u> 5 percent damped spectral response acceleration computed at that period <u>for characteristic earthquakes on all known active faults within the region</u>."

Derivation of IBC Design Maps

- "…, the ordinates of the **deterministic MCE** ground motion response spectrum shall not be taken lower than the corresponding ordinates of the response spectrum determined in accordance with Fig. 21.2-1 [on the next slide], where F_a and F_v are [the site coefficients], with the value of [the 0.2-second *SA*] taken as 1.5 and the value of [the 1.0-second *SA*] taken as 0.6."

- **0.6g = 1.5 * 0.4g (from UBC), 1.5g = 2.5 * 0.6g**

Derivation of IBC Design Maps

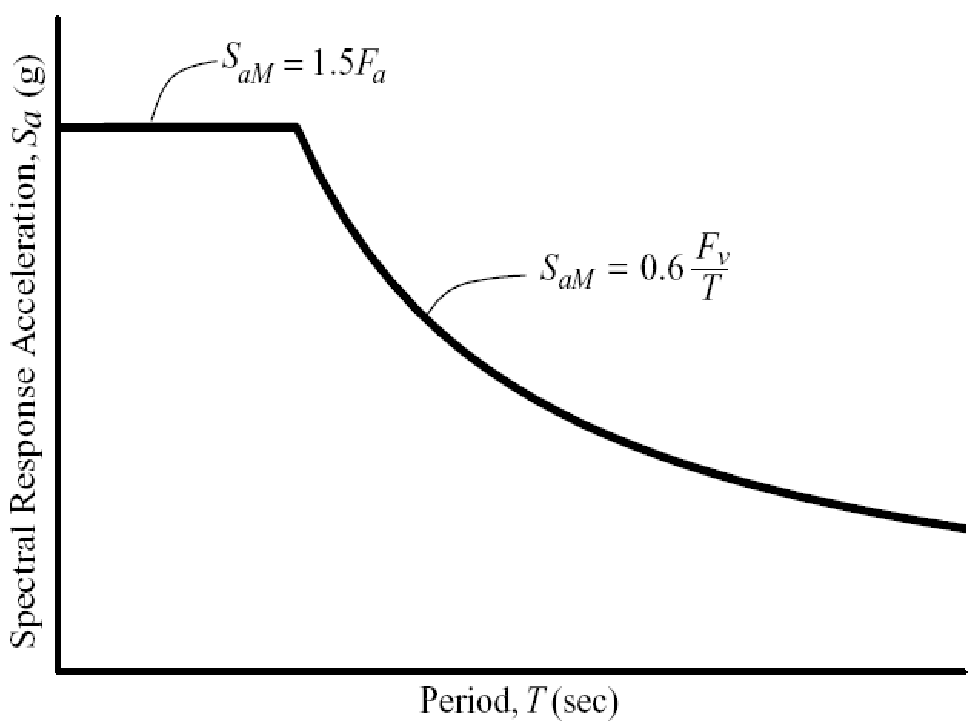


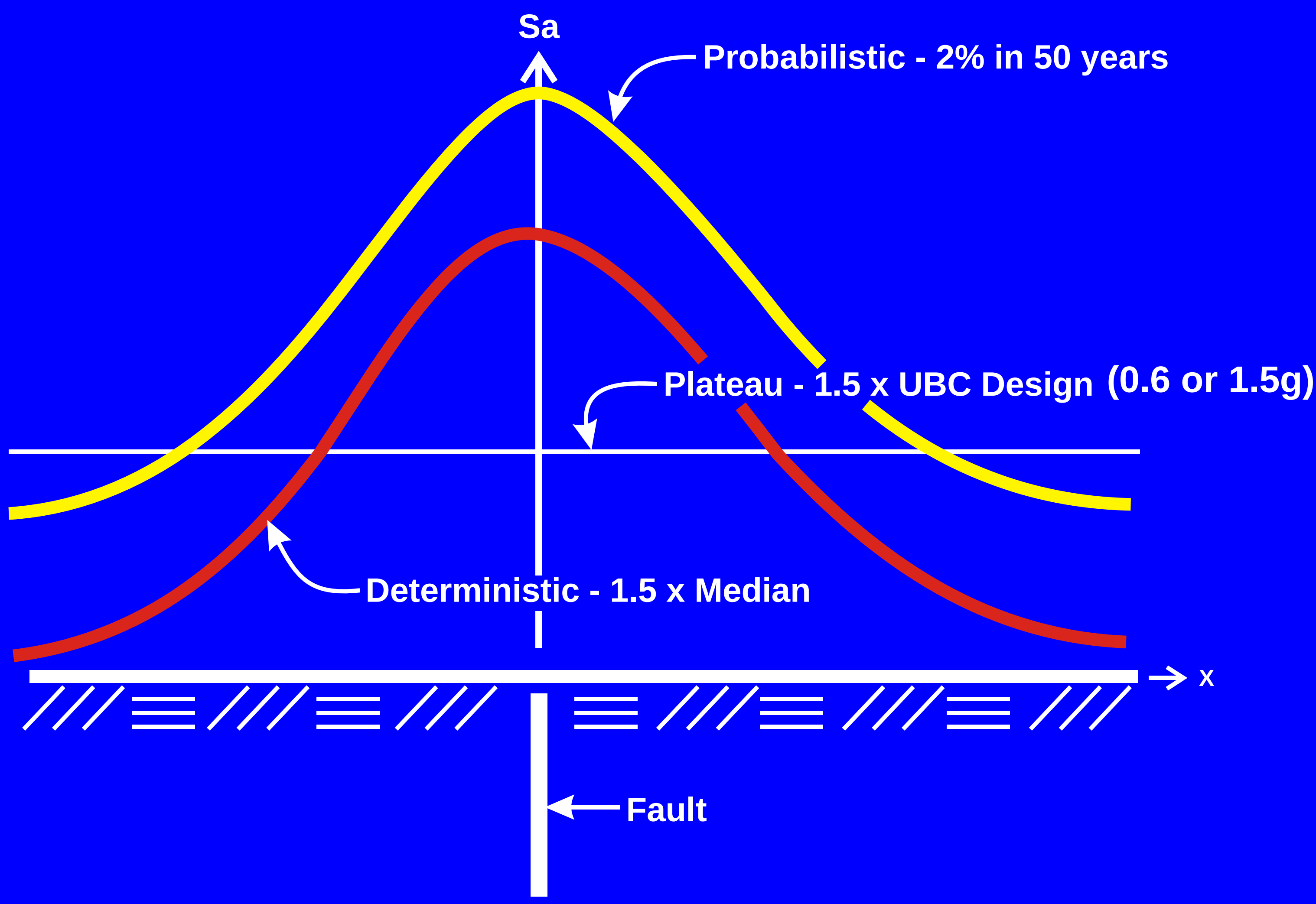
FIGURE 21.2-1 DETERMINISTIC LOWER LIMIT ON MCE RESPONSE SPECTRUM

- **Note: For the USGS Hazard Maps, F_a & F_v = 1**

Derivation of IBC Design Maps

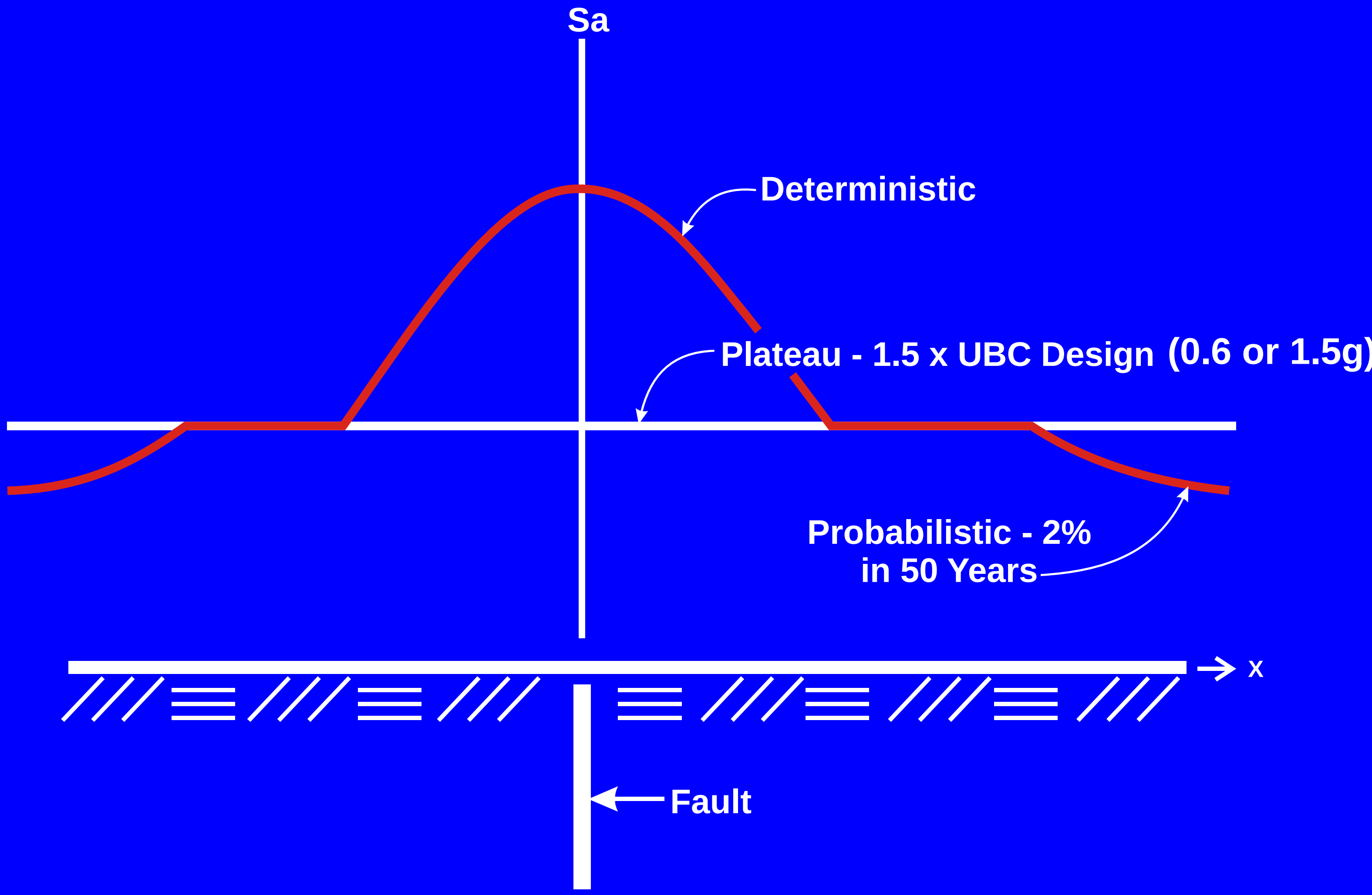
- "The site-specific MCE spectral response acceleration at any period … shall be taken as the lesser of the spectral response accelerations from the probabilistic MCE … and the deterministic MCE."

Near-Fault Criteria



(Source: E.V. Leyendecker)

Near-Fault MCE



(Source: E.V. Leyendecker)

Development of Maximum Considered Earthquake Ground Motion Maps

Edgar V. Leyendecker, M.EERI, R. Joe Hunt, M.EERI,
Arthur D. Frankel, M.EERI, and Kenneth S. Rukstales

The *1997 NEHRP Recommended Provisions for Seismic Regulations for New Buildings* use a design procedure that is based on spectral response acceleration rather than the traditional peak ground acceleration, peak ground velocity, or zone factors. The spectral response accelerations are obtained from maps prepared following the recommendations of the Building Seismic Safety Council's (BSSC) Seismic Design Procedures Group (SDPG). The SDPG-recommended maps, the Maximum Considered Earthquake (MCE) Ground Motion Maps, are based on the U.S. Geological Survey (USGS) probabilistic hazard maps with additional modifications incorporating deterministic ground motions in selected areas and the application of engineering judgement. The MCE ground motion maps included with the *1997 NEHRP Provisions* also serve as the basis for the ground motion maps used in the seismic design portions of the *2000 International Building Code* and the *2000 International Residential Code*. Additionally the design maps prepared for the *1997 NEHRP Provisions*, combined with selected USGS probabilistic maps, are used with the *1997 NEHRP Guidelines for the Seismic Rehabilitation of Buildings*.

(EVL,ADF,KSR) U.S. Geological Survey, MS 966, Denver Federal Center, Denver, CO 80225
(RJH) Lockheed Martin Energy Systems, PO Box 2009, Oak Ridge, TN 37831-8218

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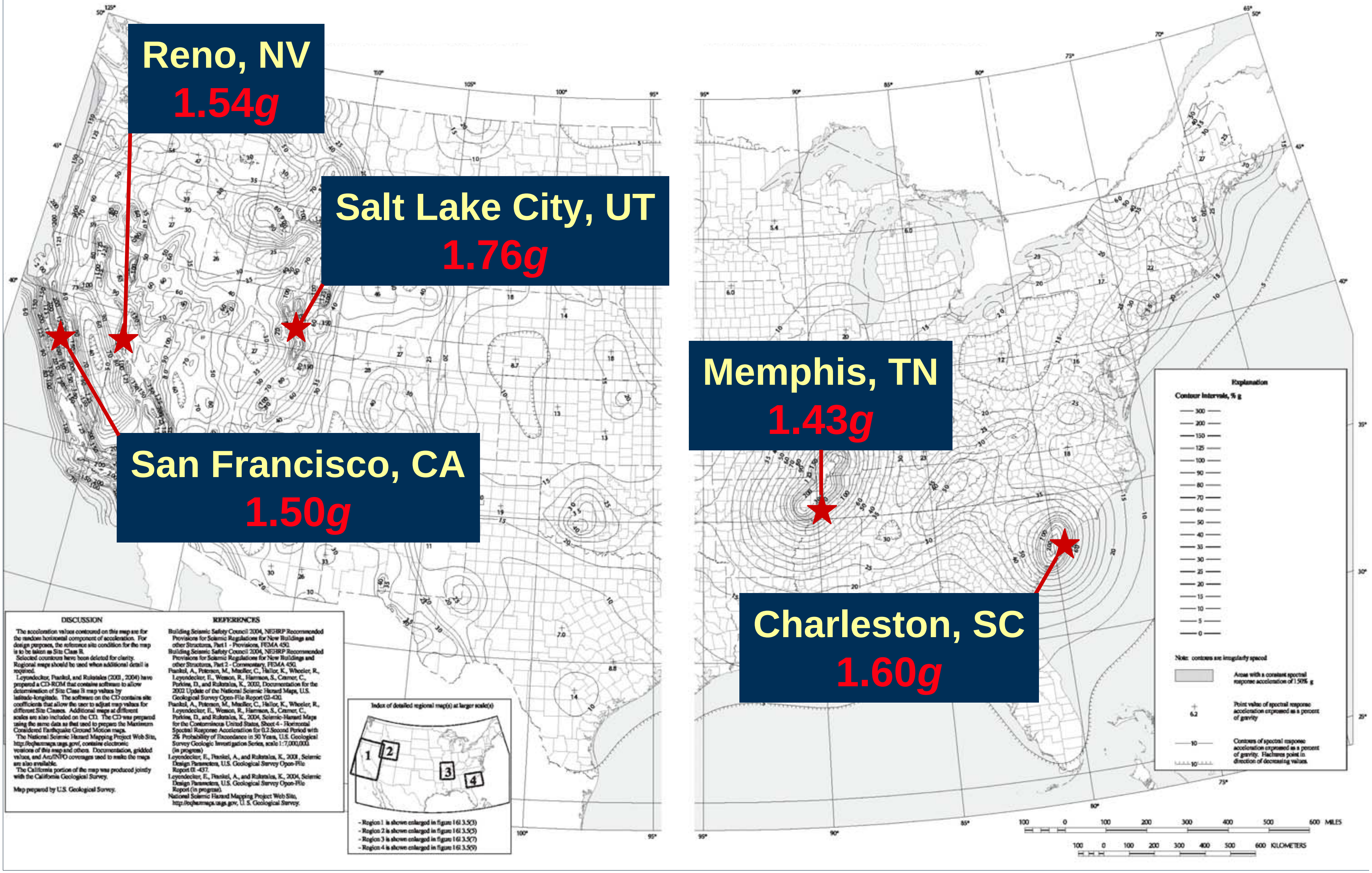
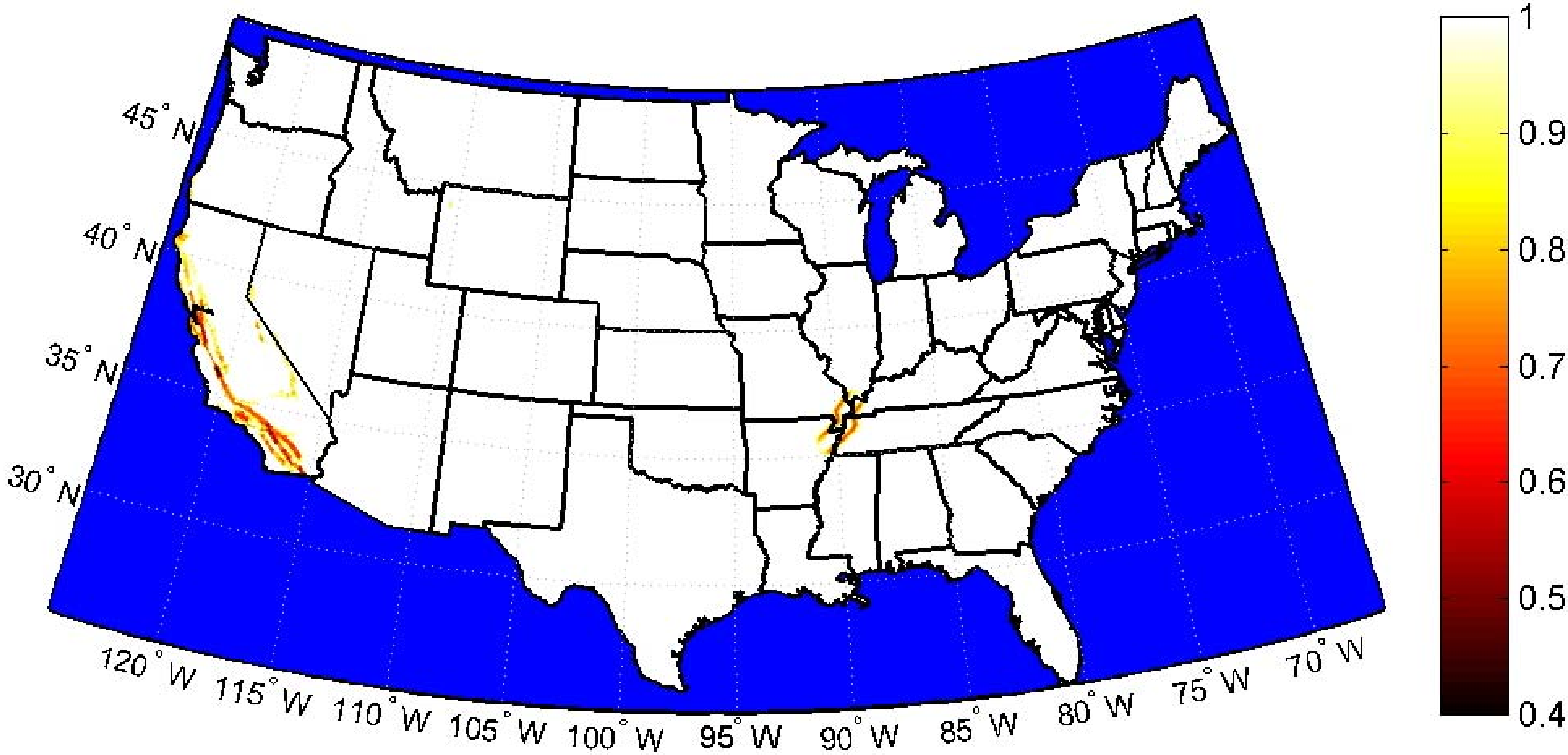
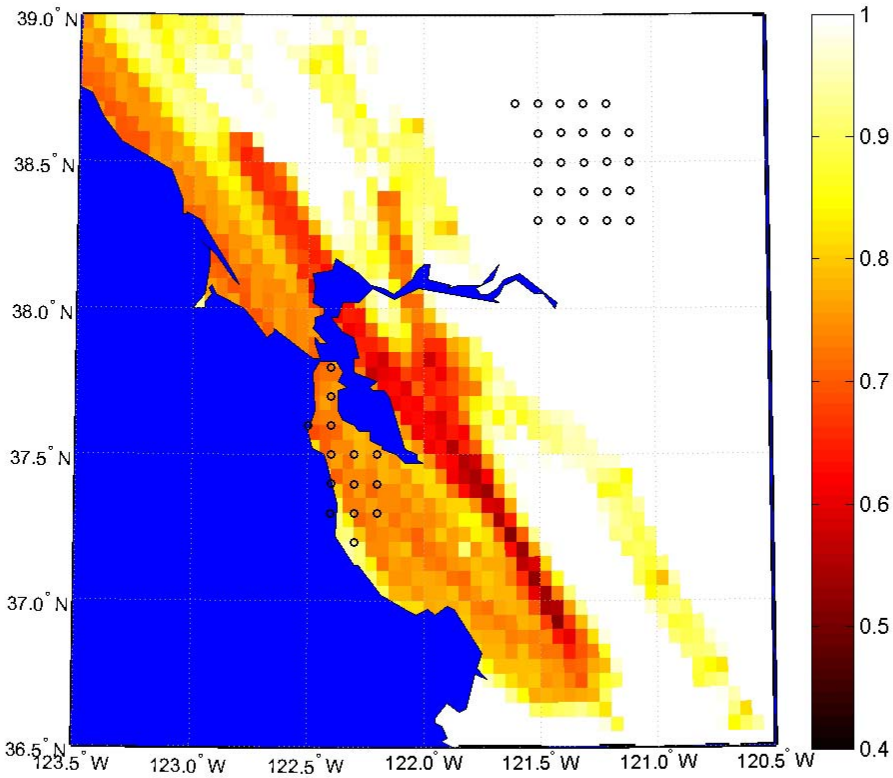
Maximum Considered Earthquake (MCE) Ground Motion for 0.2-sec Spectral Acceleration



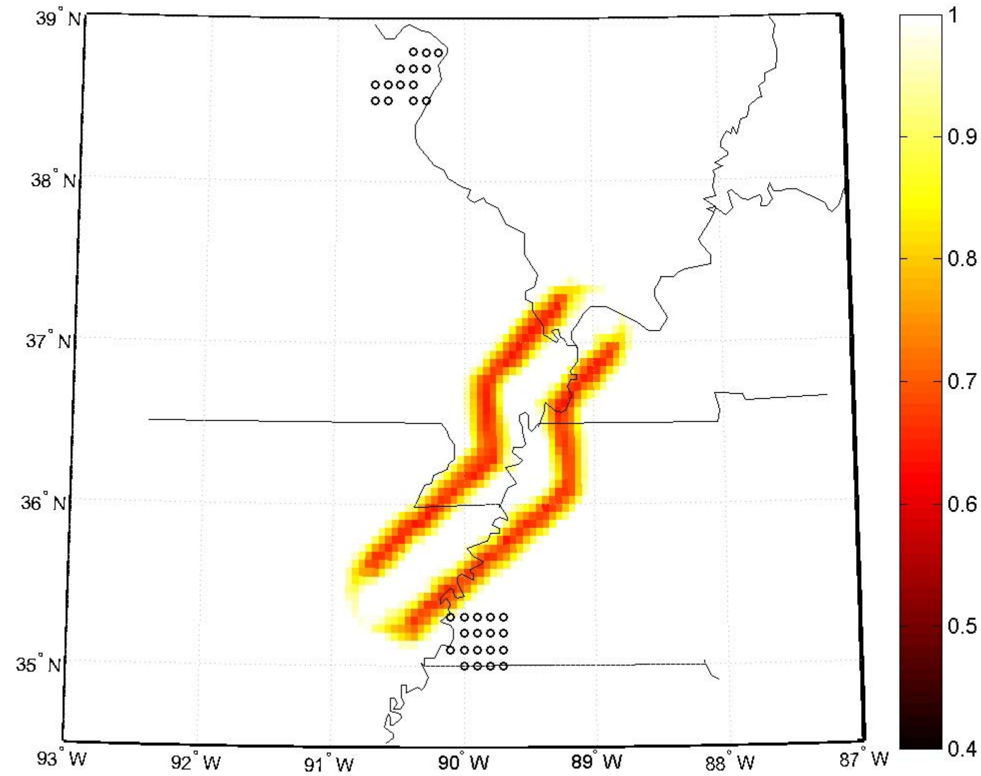
Design Maps vs. Hazard Maps (0.2s)



Design Maps vs. Hazard Maps (0.2s)



San Francisco Bay Area



New Madrid Seismic Zone

Outline of Material

- Derivation of "International" Building Code (IBC) *Design* Maps from USGS *Hazard* Maps
- Use of IBC Design Maps (i.e., procedure)
- Computer software for IBC Design Maps
- Potential updates of IBC Design Maps

SECTION 1613
EARTHQUAKE LOADS

1613.1 Scope. Every structure, and portion thereof, including nonstructural components that are permanently attached to structures and their supports and attachments, shall be designed and constructed to resist the effects of earthquake motions in accordance with ASCE 7, excluding Chapter 14 and Appendix 11A. The seismic design category for a structure is permitted to be determined in accordance with Section 1613 or ASCE 7.

Exceptions:

1. Detached one- and two-family dwellings, assigned to Seismic Design Category A, B or C, or located where the mapped short-period spectral response acceleration, S_S, is less than 0.4 g.
2. The seismic-force-resisting system of wood-frame buildings that conform to the provisions of Section 2308 are not required to be analyzed as specified in this section.
3. Agricultural storage structures intended only for incidental human occupancy.
4. Structures that require special consideration of their response characteristics and environment that are not addressed by this code or ASCE 7 and for which other regulations provide seismic criteria, such as vehicular bridges, electrical transmission towers, hydraulic structures, buried utility lines and their appurtenances and nuclear reactors.

Use of IBC Design Maps

- The Maximum Considered Earthquake (MCE) Ground Motion Maps in the IBC are in terms of …

  S_s = "short-period" (0.2-second) spectral acceleration

  S_1 = 1.0-second spectral acceleration

- Ground motions for other periods, and hence other buildings, are derived from these two spectral accelerations (as explained later)

Use of IBC Design Maps

- The S_s and S_1 values from the MCE ground motion maps are modified by "site coefficients" F_a and F_v that account for site class (soil or rock condition) amplification or deamplification, i.e., …

  $S_{MS} = F_a \times S_s$ **and** $S_{M1} = F_v \times S_1$

  where F_a and F_v vary with S_s and S_1, i.e., …

Use of IBC Design Maps

Reference Site Class = B (or B-C)

TABLE 1613.5.3(1)
VALUES OF SITE COEFFICIENT F_a [a]

SITE CLASS	MAPPED SPECTRAL RESPONSE ACCELERATION AT SHORT PERIOD				
	$S_s \leq 0.25$	$S_s = 0.50$	$S_s = 0.75$	$S_s = 1.00$	$S_s \geq 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	Note b	Note b	Note b	Note b	Note b

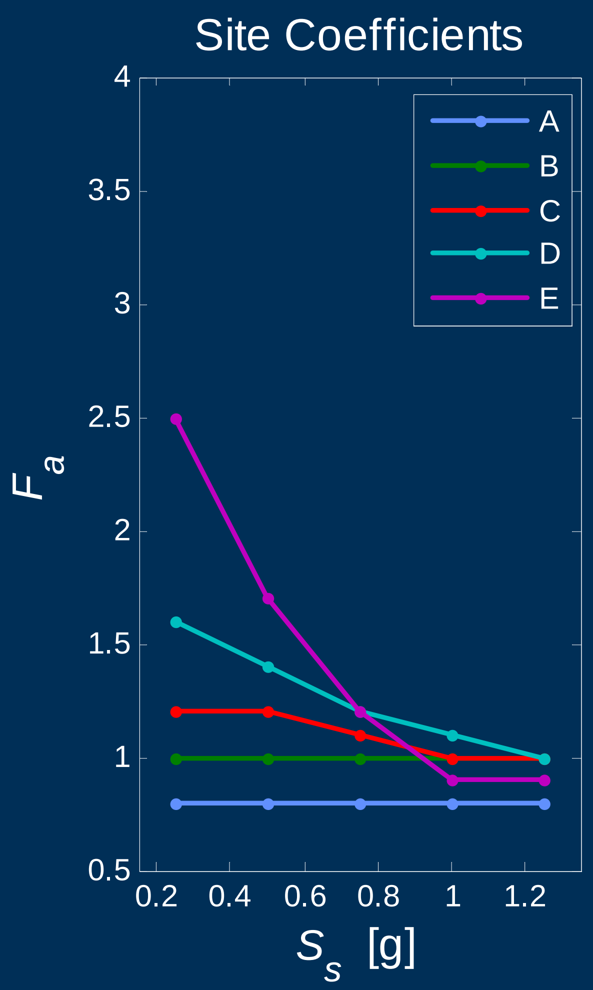
a. Use straight-line interpolation for intermediate values of mapped spectral response acceleration at short period, S_s.
b. Values shall be determined in accordance with Section 11.4.7 of ASCE 7.

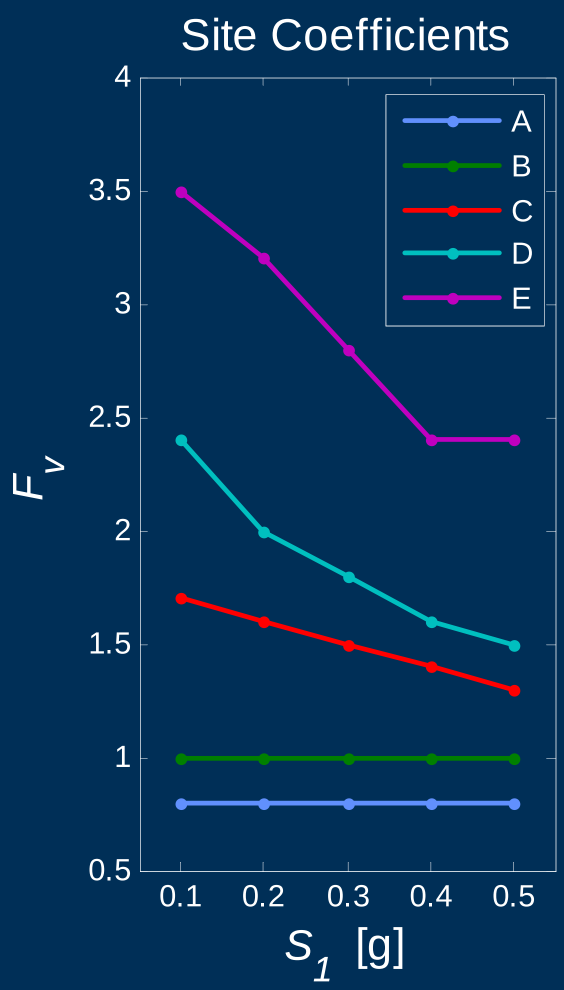
TABLE 1613.5.3(2)
VALUES OF SITE COEFFICIENT F_V [a]

SITE CLASS	MAPPED SPECTRAL RESPONSE ACCELERATION AT 1-SECOND PERIOD				
	$S_1 \leq 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \geq 0.5$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	Note b	Note b	Note b	Note b	Note b

a. Use straight-line interpolation for intermediate values of mapped spectral response acceleration at 1-second period, S_1.
b. Values shall be determined in accordance with Section 11.4.7 of ASCE 7.

Use of IBC Design Maps





Use of IBC Design Maps

Default Site Class = D

TABLE 1613.5.2
SITE CLASS DEFINITIONS

SITE CLASS	SOIL PROFILE NAME	AVERAGE PROPERTIES IN TOP 100 feet, SEE SECTION 1613.5.5		
		Soil shear wave velocity, $\bar{v}_s$, (ft/s)	Standard penetration resistance, $\bar{N}$	Soil undrained shear strength, $\bar{s}_u$, (psf)
A	Hard rock	$\bar{v}_s > 5,000$	N/A	N/A
B	Rock	$2,500 < \bar{v}_s \leq 5,000$	N/A	N/A
C	Very dense soil and soft rock	$1,200 < \bar{v}_s \leq 2,500$	$\bar{N} > 50$	$\bar{s}_u \geq 2,000$
D	Stiff soil profile	$600 \leq \bar{v}_s \leq 1,200$	$15 \leq \bar{N} \leq 50$	$1,000 \leq \bar{s}_u \leq 2,000$
E	Soft soil profile	$\bar{v}_s < 600$	$\bar{N} < 15$	$\bar{s}_u < 1,000$
E	—	Any profile with more than 10 feet of soil having the following characteristics: 1. Plasticity index $PI > 20$, 2. Moisture content $w \geq 40\%$, and 3. Undrained shear strength $\bar{s}_u < 500$ psf		
F	—	Any profile containing soils having one or more of the following characteristics: 1. Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils. 2. Peats and/or highly organic clays ($H >$ 10 feet of peat and/or highly organic clay where H = thickness of soil) 3. Very high plasticity clays ($H >$25 feet with plasticity index $PI >$75) 4. Very thick soft/medium stiff clays ($H >$120 feet)		

For SI: 1 foot = 304.8 mm, 1 square foot = 0.0929 m^2, 1 pound per square foot = 0.0479 kPa. N/A = Not applicable

Use of IBC Design Maps

- The "final" design ground motions, S_{DS} and S_{D1}, are simply 2/3rds of S_{MS} and S_{M1}, i.e., …

$$S_{DS} = 2/3 \times S_{MS} \quad \text{and} \quad S_{D1} = 2/3 \times S_{M1}$$

- Why 2/3rds? …

Use of IBC Design Maps

- Goal:

  Prevent building collapse under values of *SA* with 2% in 50 years probability of exceedance.

- Assumption:

  Buildings designed for *SA*=DGM actually have the capacity to prevent collapse at 1.5*DGM.

- Result:

  1.5*DGM = 2%-in-50yrs *SA*

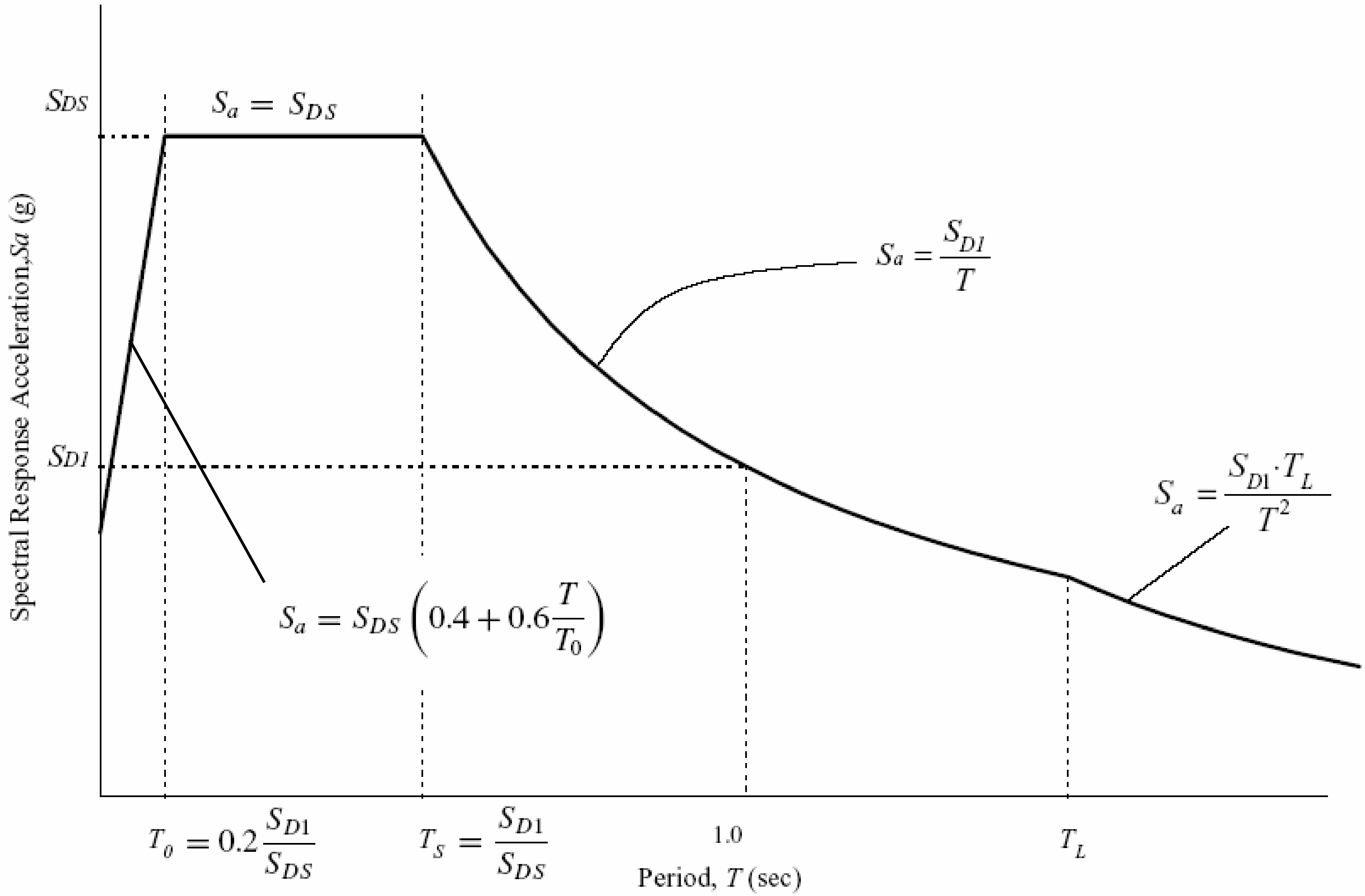
  ➔ DGM = 2/3 * (2%-in-50yrs SA)

Use of IBC Design Maps

- Design ground motions for other periods are found using an approximate Uniform-Hazard Response Spectrum (UHRS) shape, i.e., …

  (Note: UHRS is a plot of, e.g., 2%-in-50yrs *SA* values versus the vibration periods *T*.)

IBC Ground Motions for Design



Use of IBC Design Maps

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  (Note: UHRS is a plot of, e.g., 2%-in-50yrs *SA* values versus the vibration periods *T*.)

- S_s and S_1 were deemed by code developers to be sufficient to delineate the short-to-moderate period portion of the UHRS

Long-Period Transition Period, T_L (sec)

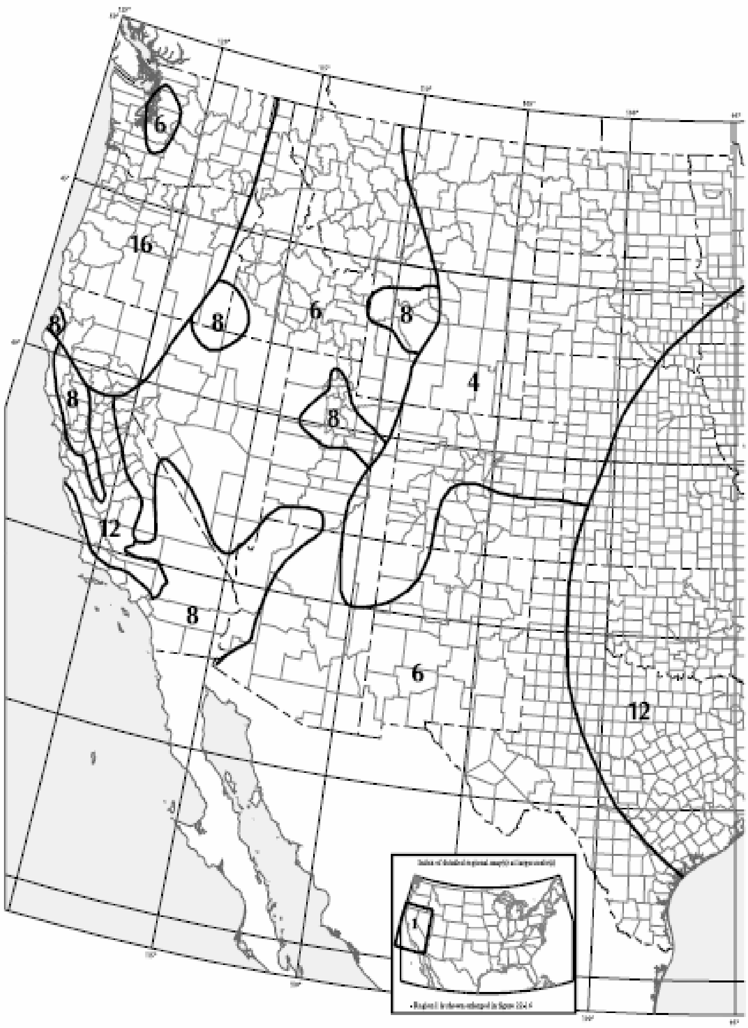

FIGURE 22-15 LONG-PERIOD TRANSITION PERIOD, T_L (SEC), FOR THE CONTERMINOUS UNITED STATES

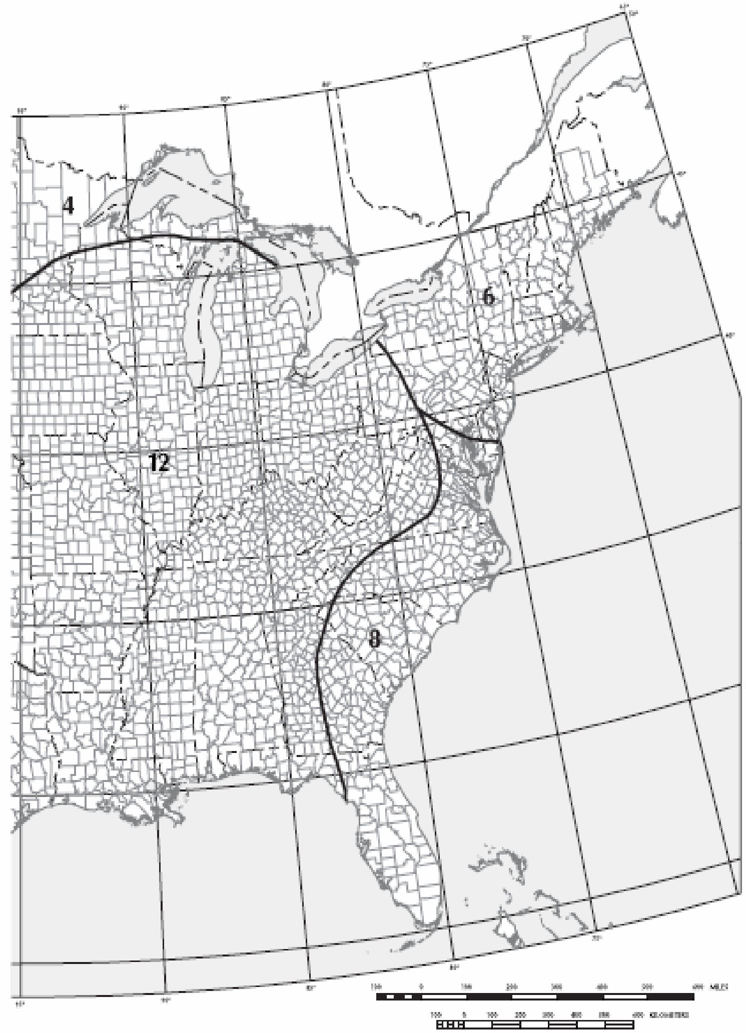

FIGURE 22-15 continued
LONG-PERIOD TRANSITION PERIOD, T_L (SEC), FOR THE CONTERMINOUS UNITED STATES

IBC Ground Motions for Design

- T_L is used to define the long-period part of the design response spectrum because USGS hazard maps are only produced for …

  <u>0</u> (PGA), <u>0.1</u>, <u>0.2</u>, <u>0.3</u>, <u>0.5</u>, <u>1.0</u>, & <u>2.0</u>-sec *SA*

- The maximum period is 2.0 seconds because of the available attenuation relations

IBC Ground Motions for Design

- The Pacific Earthquake Engineering Research (PEER) Center project entitled "Next Generation Attenuation (NGA)" has recently developed attenuation relations for periods up to 10 seconds.

- The difficulty in developing attenuation relations for long periods is that many of the available ground motion recordings are filtered at long periods when the raw data is processed

IBC Ground Motions for Design

- The T_L maps were produced by building code developers via the following procedure:
  - A relationship between earthquake magnitude (*M*) and T_L was established, based on seismic source theory, ground motion recordings, and simulations

Table 1. Moment magnitude versus corner period

M	T_c (sec)
6.0 – 6.5	4
6.5 – 7.0	6
7.0 – 7.5	8
7.5 – 8.0	12
8.0 – 8.5	16
8.5 – 9.0+	20

IBC Ground Motions for Design

- The T_L maps were produced by building code developers via the following procedure:
  - A relationship between earthquake magnitude (*M*) and T_L was established, based on seismic source theory, ground motion recordings, and simulations
  - A map of modal *M* was constructed via deaggregation of the 2%-in-50yrs, 2.0-second hazard
- See "Development of Seismic Ground-Motion Criteria for the ASCE 7 Standard" by C.B. Crouse *et al.* for details

Outline of Material

- Derivation of "International" Building Code (IBC) *Design* Maps from USGS *Hazard* Maps
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GROUND MOTION TOOL

http://earthquake.usgs.gov/research/hazmaps/

SEISMIC DESIGN VALUES FOR BUILDINGS

Ss and S1, Hazard Curves, Uniform Hazard Spectra, and Residential Design Category

USGS

(Source: E.V. Leyendecker)

Earthquake Research

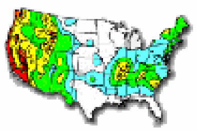
- Borehole Geophysics and Rock Mechanics
- Crustal Deformation
- Earthquake Geology & Paleoseismology
- **Earthquake Hazards**
- External Research Support
- Regional & Whole-Earth Structure
- Strong-motion Seismology, Site Response & Ground Motion

Monitoring Networks

Scientific Data

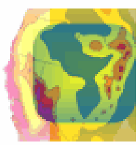
USGS National Seismic Hazard Maps

The USGS provides seismic hazard assessments for the U.S. and areas around the world. These hazard maps serve as the basis for seismic provisions used in building codes and influence billions of dollars of new construction every year. Learn more about seismic hazard analysis, the USGS maps, the underlying data, and the resulting building codes by browsing the links below.



Seismic Hazard Maps

US National and Regional Probabilistic Ground Motion Maps, Input and Output Data, and Documentation. Conterminous US , Alaska, Hawaii, Puerto Rico. **US Urban Maps and International Maps,** Fault Database. Compare the seismic hazard in your area with other parts of the US and the world.



Custom Mapping and Analysis Tools

Interactive Mapping, Hazard Value Lookup, Deaggregations, Earthquake Probability Mapping, Hazard Computer Codes.
Re-plot USGS probabilistic hazard maps for your area of interest, get hazard values using latitude/longitude or zip code, find predominant magnitudes and distances, map probability of given magnitude within a certain distance from a site.

Seismic Design Values for Buildings

Ss and S1, Hazard Curves, Uniform Hazard Spectra, and Residential Seismic Design Category Maps.
Find site design ground motion values for various building codes, using latitude/longitude or zip codes (coming soon). Display and download hazard curve or uniform hazard spectrum for a site (coming soon). Access seismic design maps. Learn about the process of incorporating seismic hazards into building codes.

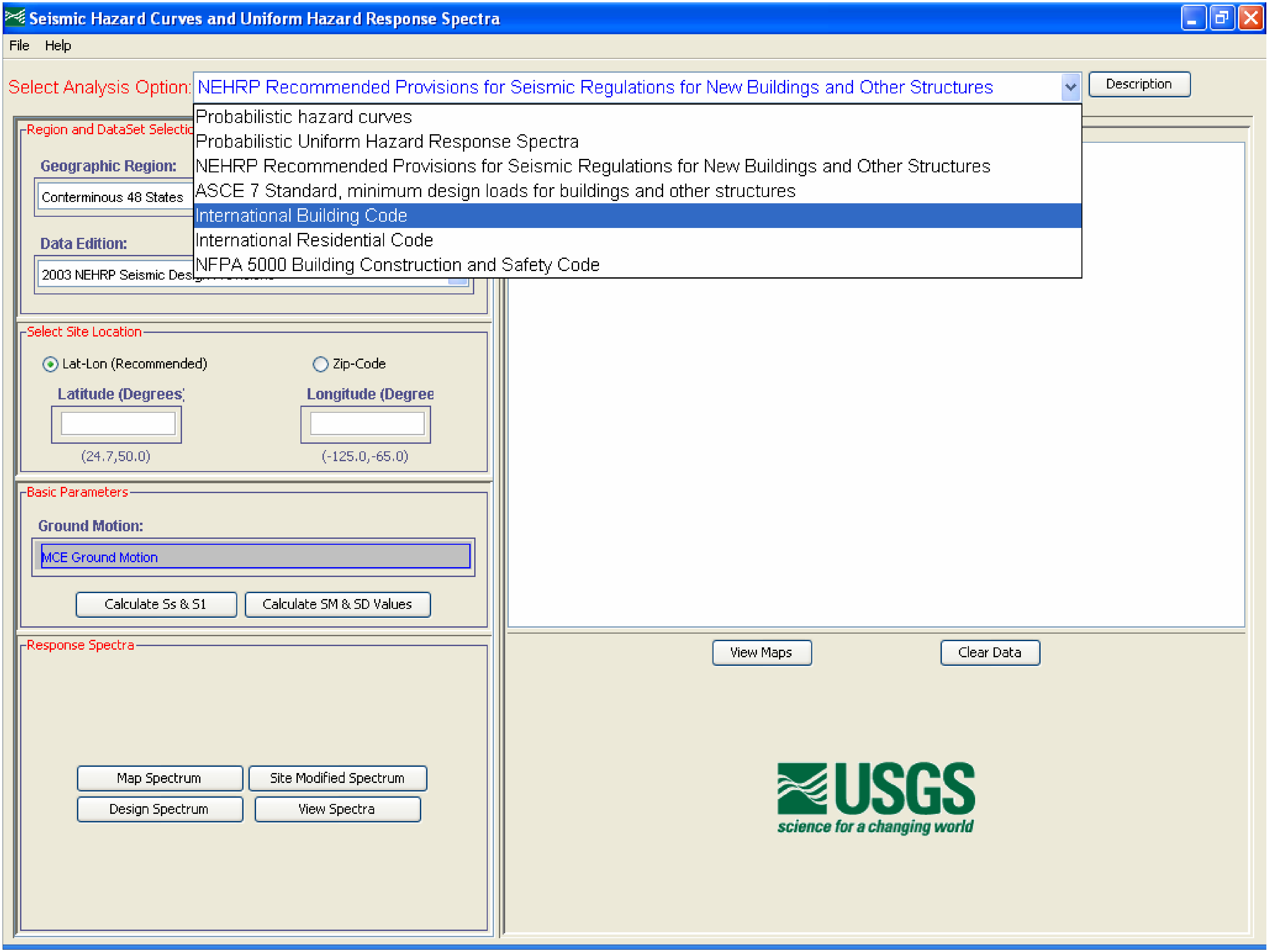
Earthquake Hazards 101

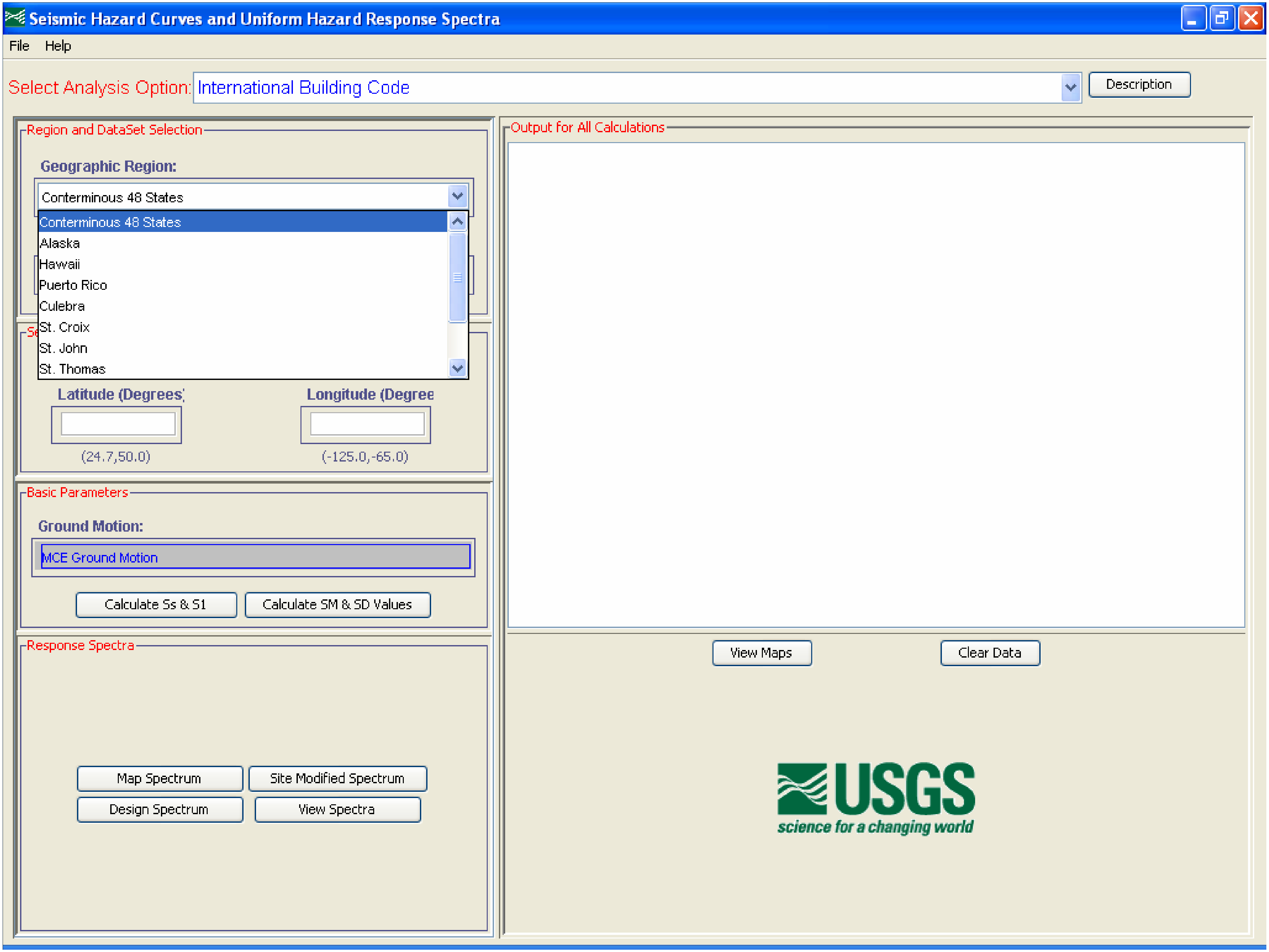
The basics, Easy Access to Maps and Faults, FAQ's

NSHM Links

- NSHM Home
- Seismic Hazard Maps
- Custom Mapping Analysis Tools
- Seismic Design Values for Buildings
- Earthquake Hazards 101
- Project Information and News
- Related Links

- NSHM FAQ
- NSHM Site Map
- A-Z Site Index


Seismic Hazard Curves and Uniform Hazard Response Spectra
File
Help
Select Analysis Option:
NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures
Description
Probabilistic hazard curves
Probabilistic Uniform Hazard Response Spectra
NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures
ASCE 7 Standard, minimum design loads for buildings and other structures
International Building Code
International Residential Code
NFPA 5000 Building Construction and Safety Code
Geographic Region:
Conterminous 48 States
Data Edition:
Select Site Location
Lat-Lon (Recommended)
Zip-Code
(24.7,50.0)
(-125.0,-65.0)
Basic Parameters
Ground Motion:
MCE Ground Motion
Calculate Ss & S1
Calculate SM & SD Values
Response Spectra
Map Spectrum
Site Modified Spectrum
Design Spectrum
View Spectra
View Maps
Clear Data
USGS
science for a changing world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Description
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Geographic Region:
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Conterminous 48 States
Alaska
Hawaii
Puerto Rico
Culebra
St. Croix
St. John
St. Thomas
Latitude (Degrees
Longitude (Degree
(24.7,50.0)
(-125.0,-65.0)
Basic Parameters
Ground Motion:
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Output for All Calculations
View Maps
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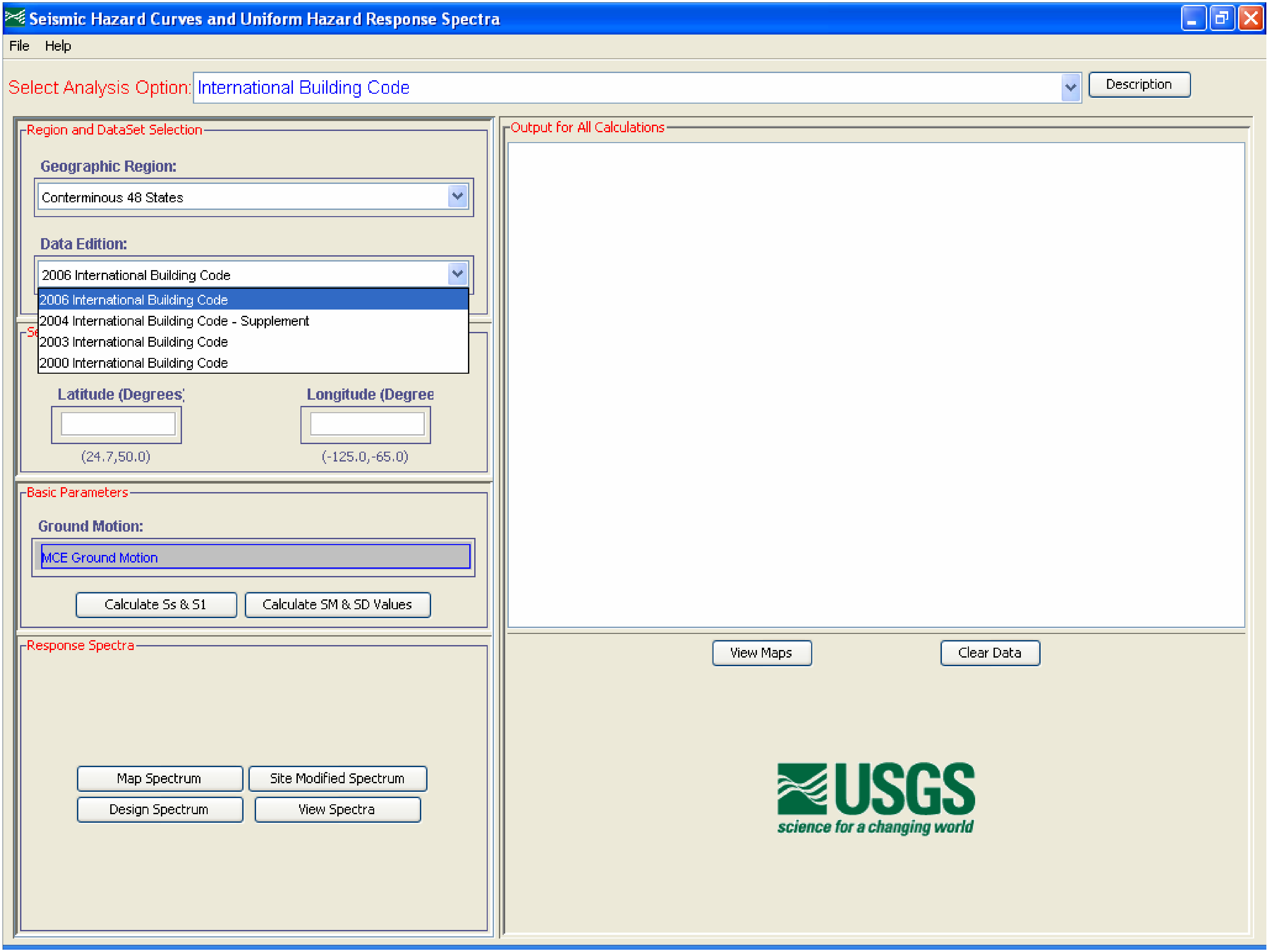
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Data Edition:
2006 International Building Code
2006 International Building Code
2004 International Building Code - Supplement
2003 International Building Code
2000 International Building Code
Latitude (Degrees
Longitude (Degree
(24.7,50.0)
(-125.0,-65.0)
Basic Parameters
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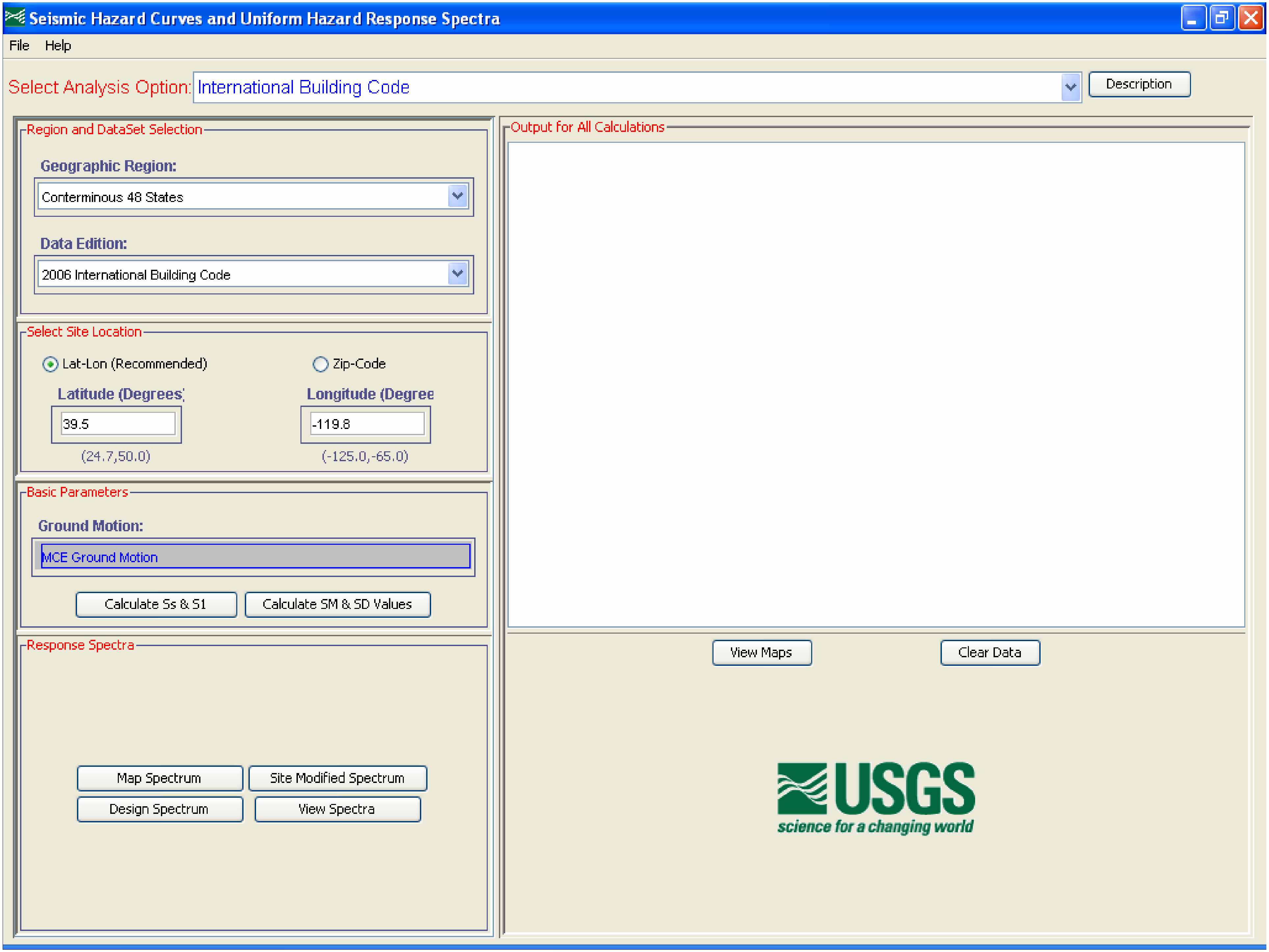
Seismic Hazard Curves and Uniform Hazard Response Spectra
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Select Analysis Option:
International Building Code
Description
Region and DataSet Selection
Geographic Region:
Conterminous 48 States
Data Edition:
2006 International Building Code
Select Site Location
Lat-Lon (Recommended)
Zip-Code
Latitude (Degrees
Longitude (Degree
39.5
-119.8
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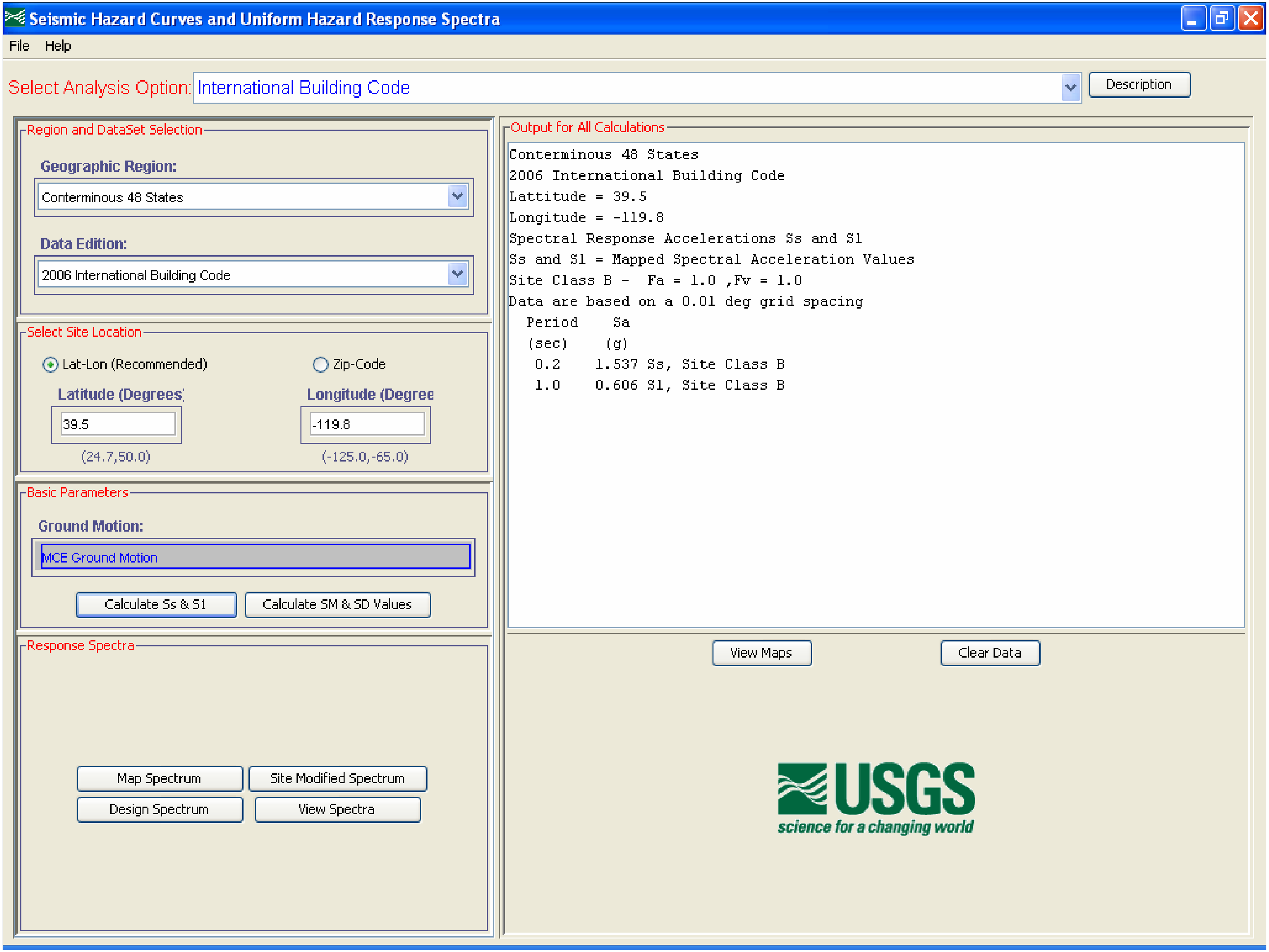

Seismic Hazard Curves and Uniform Hazard Response Spectra
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Description
Region and DataSet Selection
Geographic Region:
Conterminous 48 States
Data Edition:
2006 International Building Code
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Zip-Code
Latitude (Degrees
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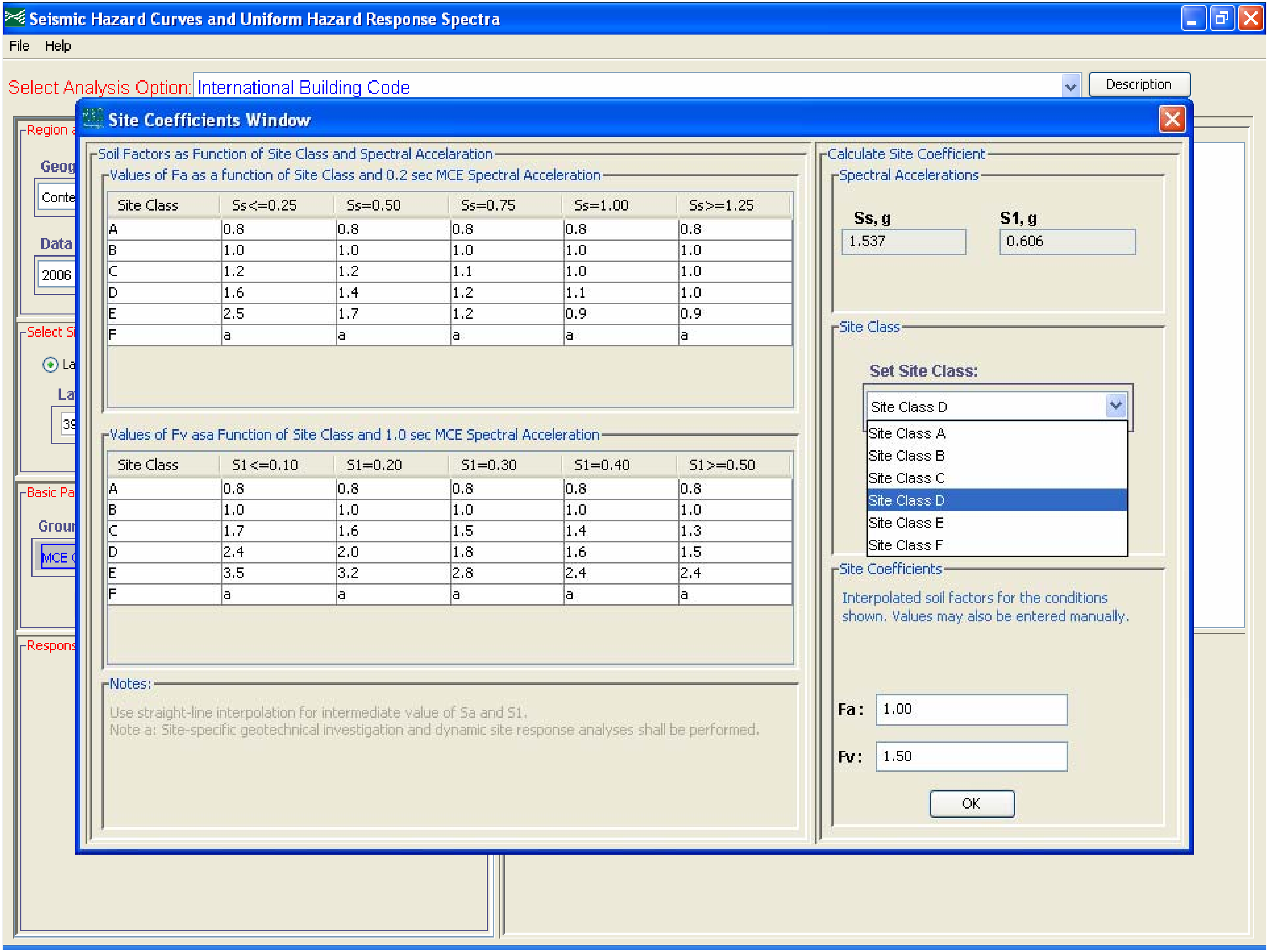
Calculate Ss & S1
Calculate SM & SD Values
Response Spectra
Map Spectrum
Site Modified Spectrum
Design Spectrum
View Spectra
Output for All Calculations
Conterminous 48 States
2006 International Building Code
Lattitude = 39.5
Longitude = -119.8
Spectral Response Accelerations Ss and S1
Ss and S1 = Mapped Spectral Acceleration Values
Site Class B - Fa = 1.0 ,Fv = 1.0
Data are based on a 0.01 deg grid spacing
Period Sa
(sec) (g)
0.2 1.537 Ss, Site Class B
1.0 0.606 S1, Site Class B
View Maps
Clear Data
USGS
science for a changing world



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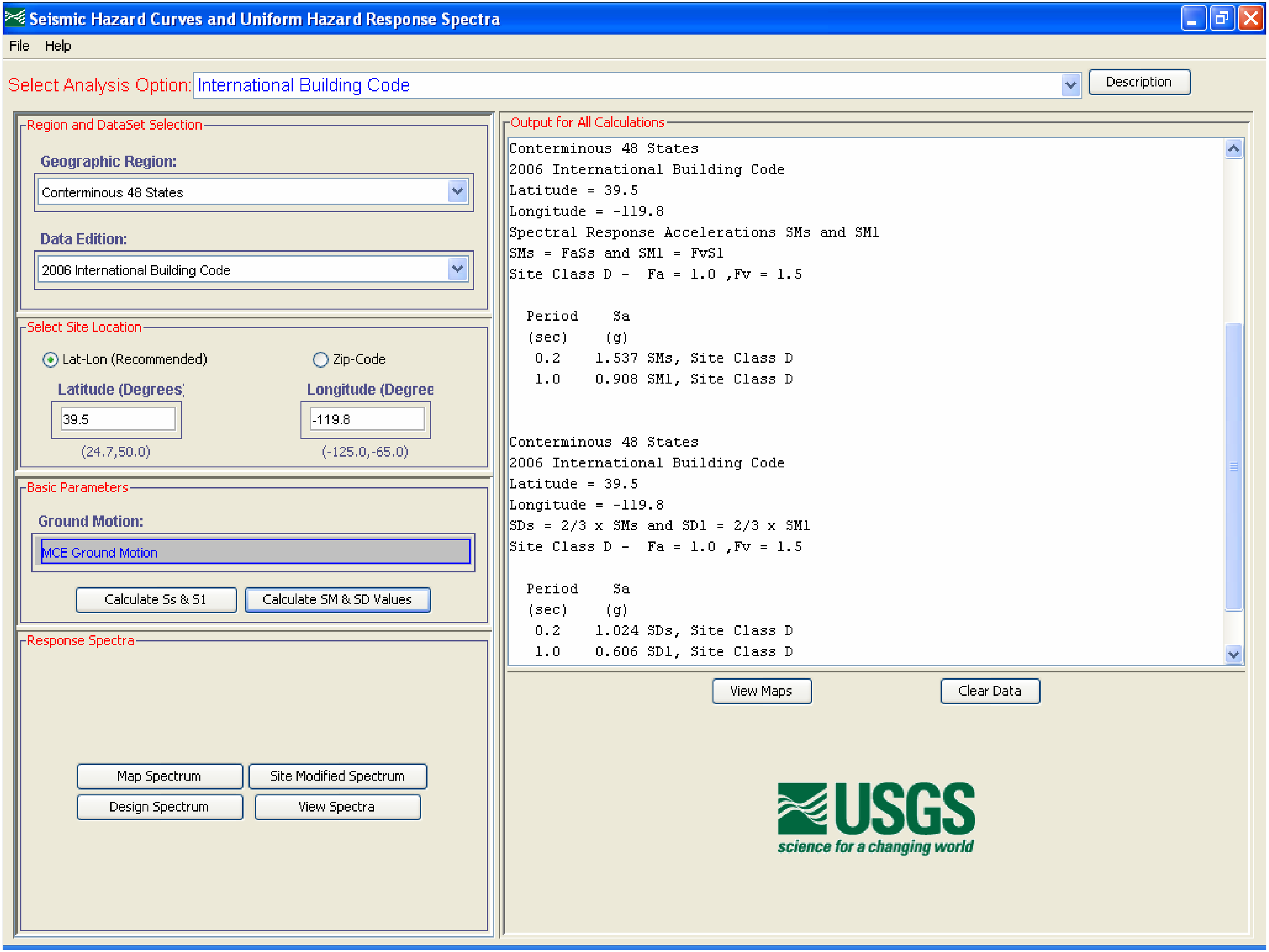
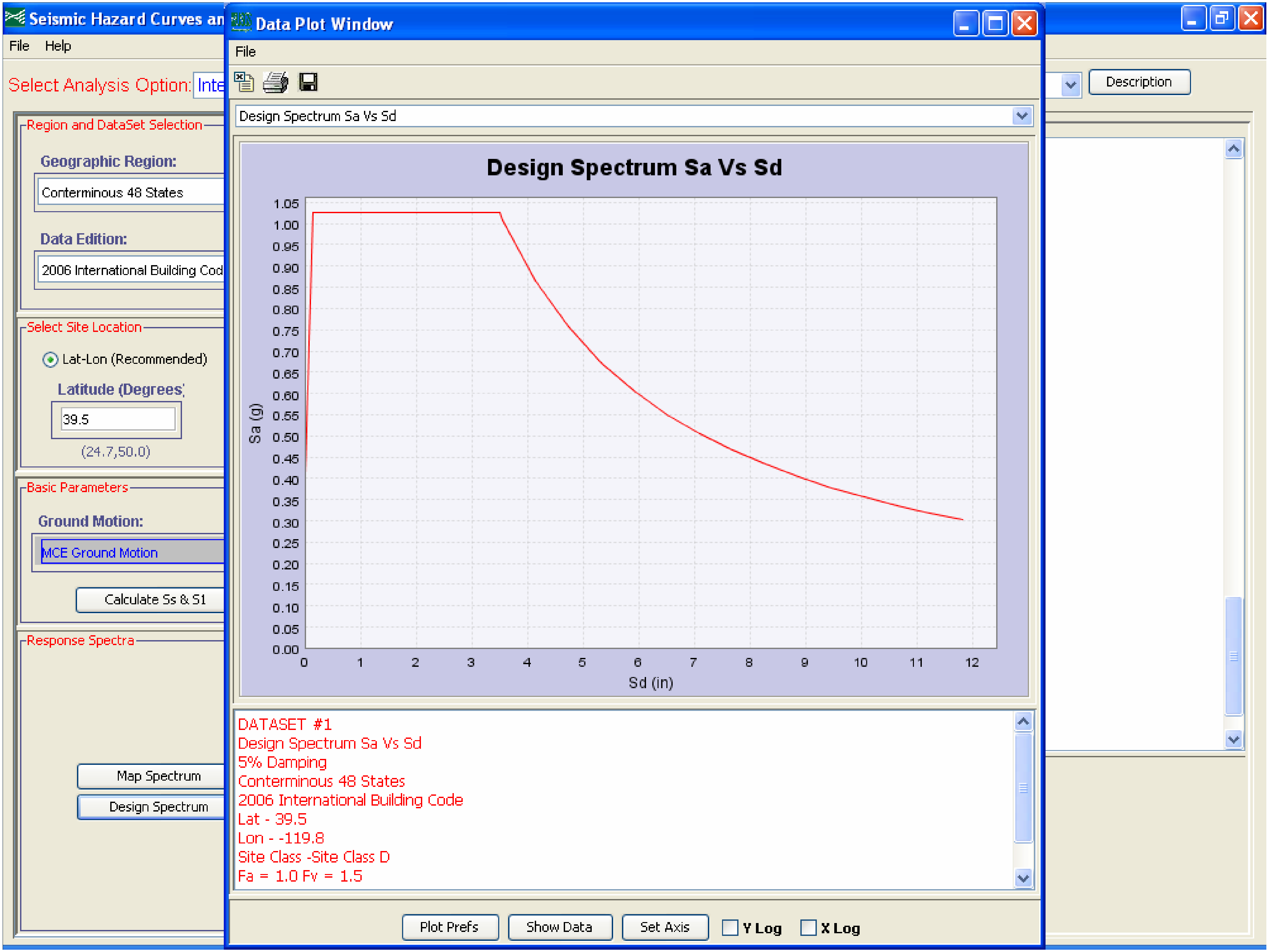
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	a	a	a	a	a

Site Class	S1<=0.10	S1=0.20	S1=0.30	S1=0.40	S1>=0.50
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	a	a	a	a	a


Seismic Hazard Curves and Uniform Hazard Response Spectra
File Help
Select Analysis Option: International Building Code
Description
Region and DataSet Selection
Geographic Region:
Conterminous 48 States
Data Edition:
2006 International Building Code
Select Site Location
Lat-Lon (Recommended)
Zip-Code
Latitude (Degrees)
Longitude (Degree
39.5
-119.8
(24.7,50.0)
(-125.0,-65.0)
Basic Parameters
Ground Motion:
MCE Ground Motion
Calculate Ss & S1
Calculate SM & SD Values
Response Spectra
Map Spectrum
Site Modified Spectrum
Design Spectrum
View Spectra
Output for All Calculations
Conterminous 48 States
2006 International Building Code
Latitude = 39.5
Longitude = -119.8
Spectral Response Accelerations SMs and SM1
SMs = FaSs and SM1 = FvS1
Site Class D - Fa = 1.0 ,Fv = 1.5
Period Sa
(sec) (g)
0.2 1.537 SMs, Site Class D
1.0 0.908 SM1, Site Class D
Conterminous 48 States
2006 International Building Code
Latitude = 39.5
Longitude = -119.8
SDs = 2/3 x SMs and SD1 = 2/3 x SM1
Site Class D - Fa = 1.0 ,Fv = 1.5
Period Sa
(sec) (g)
0.2 1.024 SDs, Site Class D
1.0 0.606 SD1, Site Class D
View Maps
Clear Data
USGS
science for a changing world


Seismic Hazard Curves an
File Help
Select Analysis Option: Inte
Region and DataSet Selection
Geographic Region:
Conterminous 48 States
Data Edition:
2006 International Building Cod
Select Site Location
Lat-Lon (Recommended)
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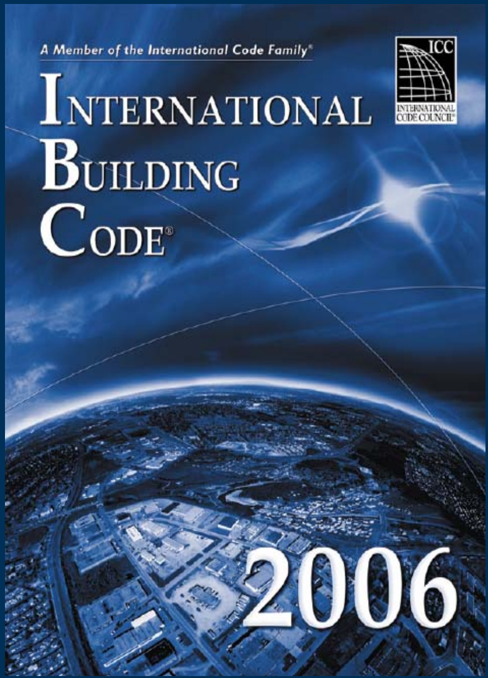
39.5
(24.7,50.0)
Basic Parameters
Ground Motion:
MCE Ground Motion
Calculate Ss & S1
Response Spectra
Map Spectrum
Design Spectrum
Description
Data Plot Window
File
Design Spectrum Sa Vs Sd
Design Spectrum Sa Vs Sd
Sa (g)
Sd (in)
DATASET #1
Design Spectrum Sa Vs Sd
5% Damping
Conterminous 48 States
2006 International Building Code
Lat - 39.5
Lon - -119.8
Site Class -Site Class D
Fa = 1.0 Fv = 1.5
Plot Prefs
Show Data
Set Axis
Y Log
X Log

Outline of Material

- Derivation of "International" Building Code (IBC) *Design* Maps from USGS *Hazard* Maps
- Use of IBC Design Maps (i.e., procedure)
- Computer software for IBC Design Maps
- Potential updates of IBC Design Maps

Development of IBC Design Maps

- **IBC Section 1613 on Earthquake Loads references "ASCE 7"**

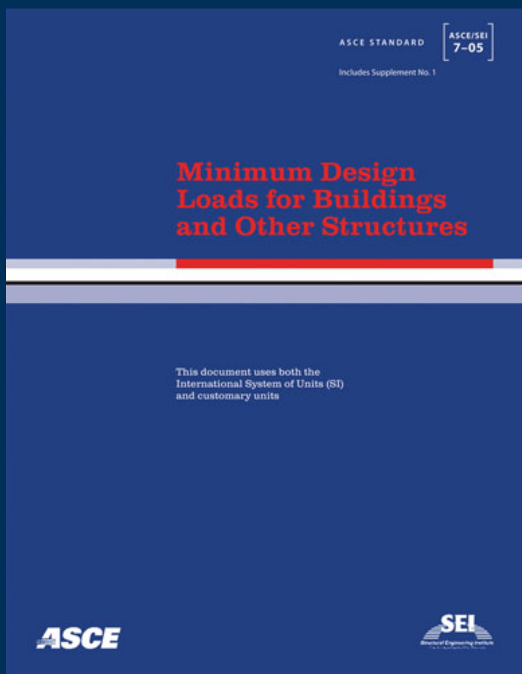


→ references →

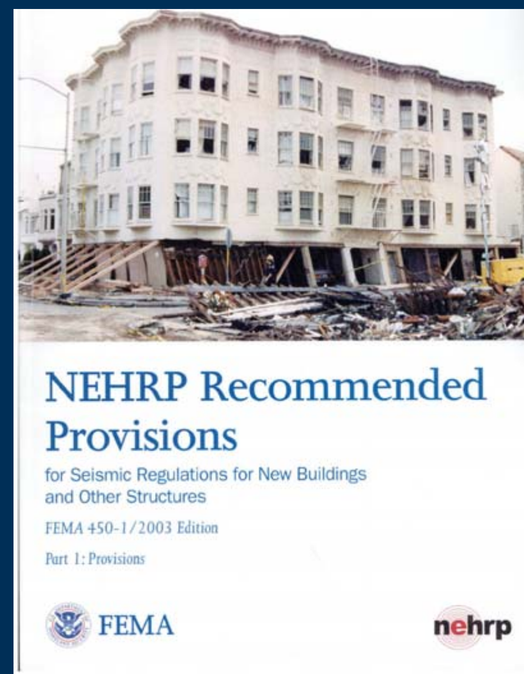
(ASCE = American Society of Civil Engineers)

Development of IBC Design Maps

- **ASCE 7 is based on the "NEHRP Provisions"**



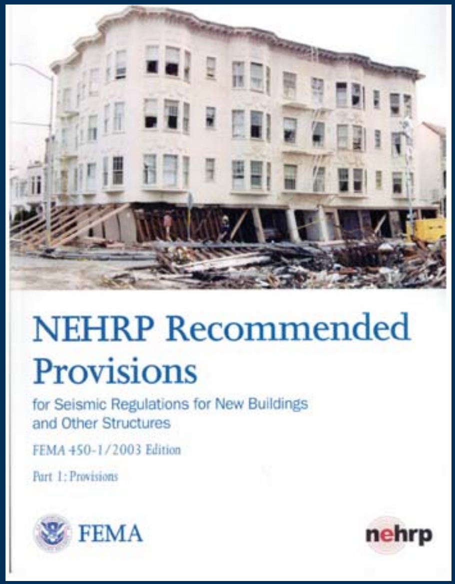
→ based on →



(NEHRP = National Earthquake Hazard Reduction Program)

Development of IBC Design Maps

- The NEHRP Provisions are prepared by the Building Seismic Safety Council (**BSSC**) with funding from **FEMA** (Federal Emergency Management Agency).



Building Seismic Safety Council

FEMA

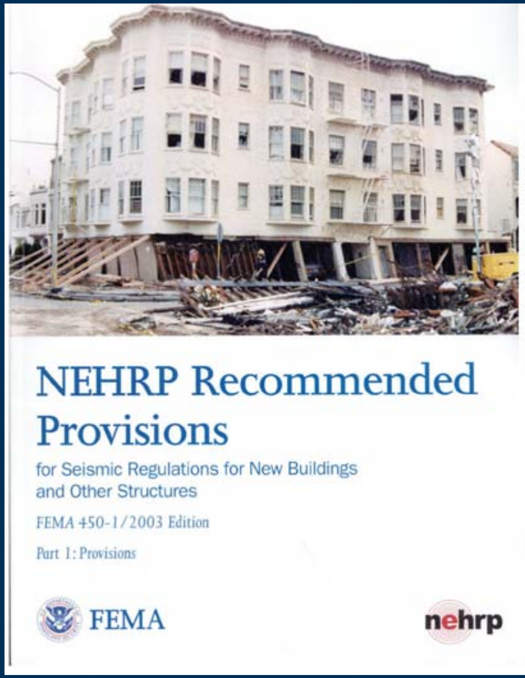
Development of IBC Design Maps

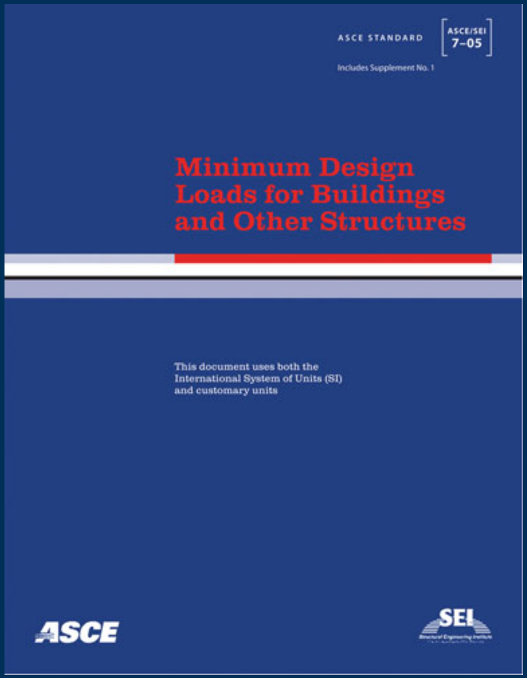
- In 1997: BSSC ***Seismic Design Procedures Group*** derived first MCE Ground Motion Maps from 1996 USGS Hazard Maps
- In 2003: MCE Maps were updated to reflect 2002 USGS Maps
- In 2007: BSSC ***Seismic Design Procedures Review Group*** is revisiting the methodology for deriving the MCE Maps ("**Project '07**")

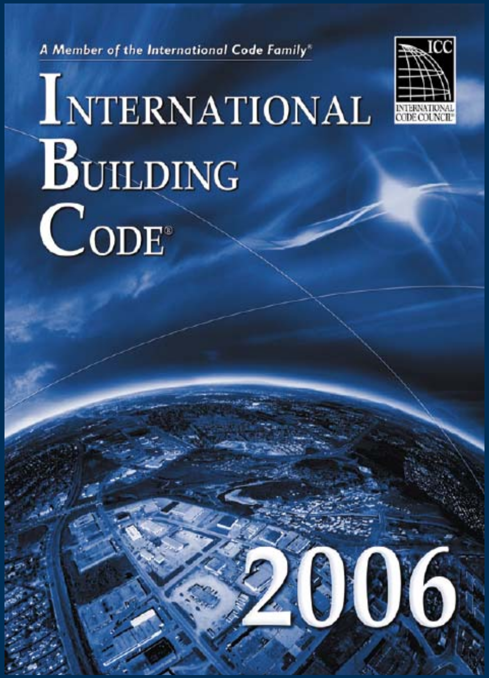
Update of IBC Design Maps

- **2007 Update of USGS Hazard Maps**

2008 → **2010** → **2012**







Update of IBC Design Maps

- **"Project '007, License to Build"**
- **C. Kircher (Chair)**

C.B. Crouse	**B. Ellingwood**
J. Hooper	**E.V. Leyendecker**
J. Kimball	**N. Luco** (Task 1 Leader)
R. Hamburger	**A. Whittaker** (Task 2 Leader)
W. Holmes	**J. Harris** (Task 3 Leader)

Update of IBC Design Maps

- **Task 1**: Consider "risk-targeted" instead of uniform-hazard basis for maps of ground motions for design
- **Task 2**: Consider using maximum instead of geometric mean of two horizontal components for deterministic MCE ground motions
- **Task 3**: Consider alternative ways to define the shape of the design response spectrum

Update of IBC Design Maps (Task 1)

- **What is the probability of collapse (e.g., in 50 years) for buildings designed using the current design ground motions?**

Quantifying Risk of Collapse

“Risk Integral” (total probability theorem app.)

$$P_f = \int_0^{\infty} P_f(a) \left| \frac{\mathrm{d}H(a)}{\mathrm{d}a} \right| \mathrm{d}a$$

where

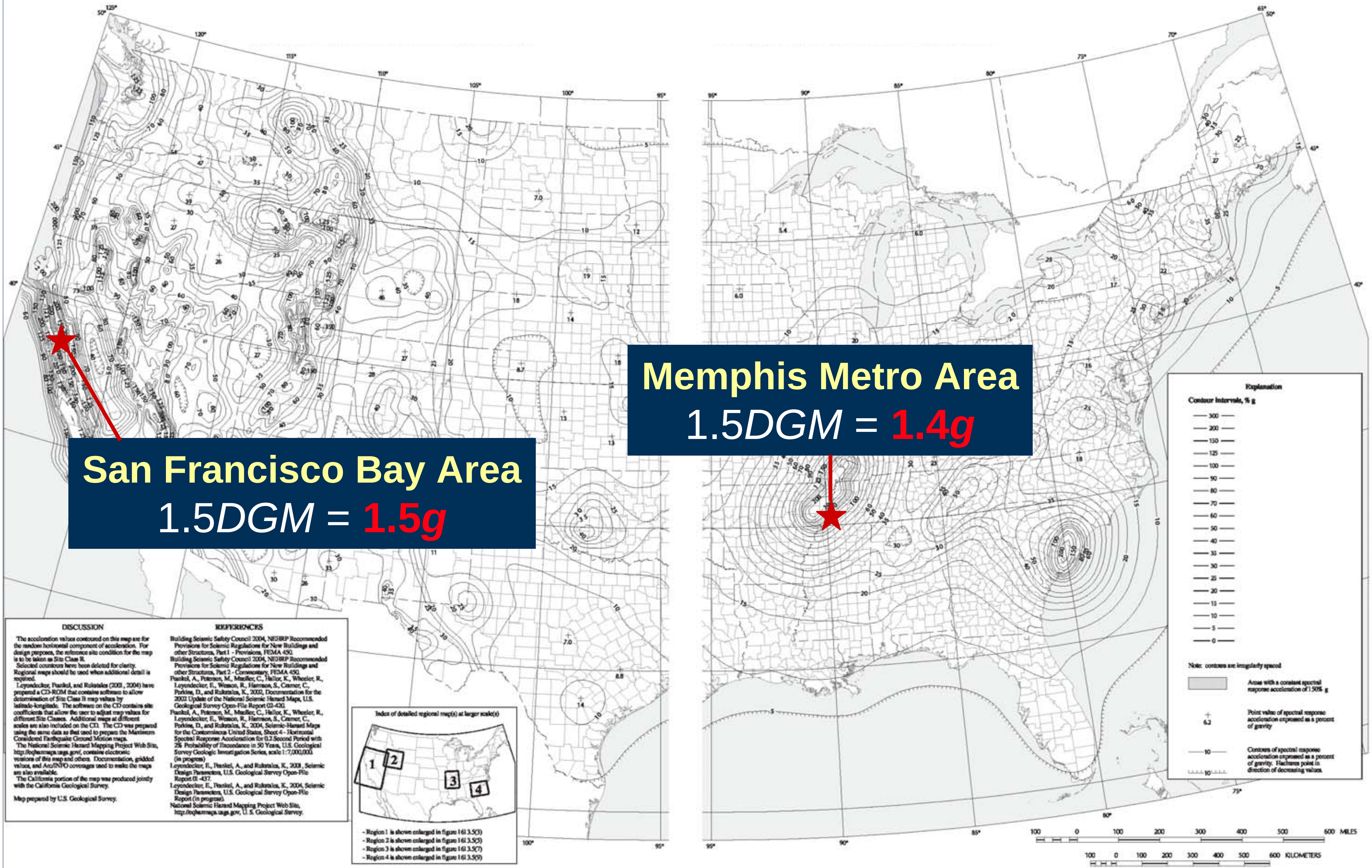
$\boldsymbol{P_f}$ = probability of “failure” (e.g., collapse) = **Risk**

$\boldsymbol{P_f(a)}$ = *conditional* (on a) prob. of failure = **Fragility**

$\boldsymbol{H(a)}$ = prob. of exceeding ground motion a = **Hazard**

(d$\boldsymbol{H(a)}$**/da** = prob. (density) of <u>equaling</u> g.m. a **)**

Example: "San Francisco vs. Memphis"



Example: Hazard Curves

USGS science for a changing world

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Earthquake Hazards Program

Home | Earthquake Center | Regional Information | Learning & Education | **Research & Monitoring** | Additional Resources

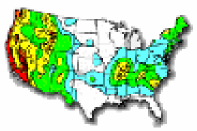
Home » Research & Monitoring » Natl Seismic Hazard Maps » USGS National Seismic Hazard Maps

Earthquake Research

- Borehole Geophysics and Rock Mechanics
- Crustal Deformation
- Earthquake Geology & Paleoseismology
- **Earthquake Hazards**
- External Research Support
- Regional & Whole-Earth Structure
- Strong-motion Seismology, Site Response & Ground Motion
- Monitoring Networks
- Scientific Data

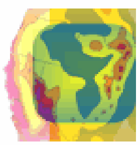
USGS National Seismic Hazard Maps

The USGS provides seismic hazard assessments for the U.S. and areas around the world. These hazard maps serve as the basis for seismic provisions used in building codes and influence billions of dollars of new construction every year. Learn more about seismic hazard analysis, the USGS maps, the underlying data, and the resulting building codes by browsing the links below.



Seismic Hazard Maps

US National and Regional Probabilistic Ground Motion Maps, Input and Output Data, and Documentation. Conterminous US , Alaska, Hawaii, Puerto Rico. **US Urban Maps and International Maps,** Fault Database. Compare the seismic hazard in your area with other parts of the US and the world.



Custom Mapping and Analysis Tools

Interactive Mapping, Hazard Value Lookup, Deaggregations, Earthquake Probability Mapping, Hazard Computer Codes.
Re-plot USGS probabilistic hazard maps for your area of interest, get hazard values using latitude/longitude or zip code, find predominant magnitudes and distances, map probability of given magnitude within a certain distance from a site.

Seismic Design Values for Buildings

Ss and S1, Hazard Curves, Uniform Hazard Spectra, and Residential Seismic Design Category Maps.
Find site design ground motion values for various building codes, using latitude/longitude or zip codes (coming soon). Display and download hazard curve or uniform hazard spectrum for a site (coming soon). Access seismic design maps. Learn about the process of incorporating seismic hazards into building codes.

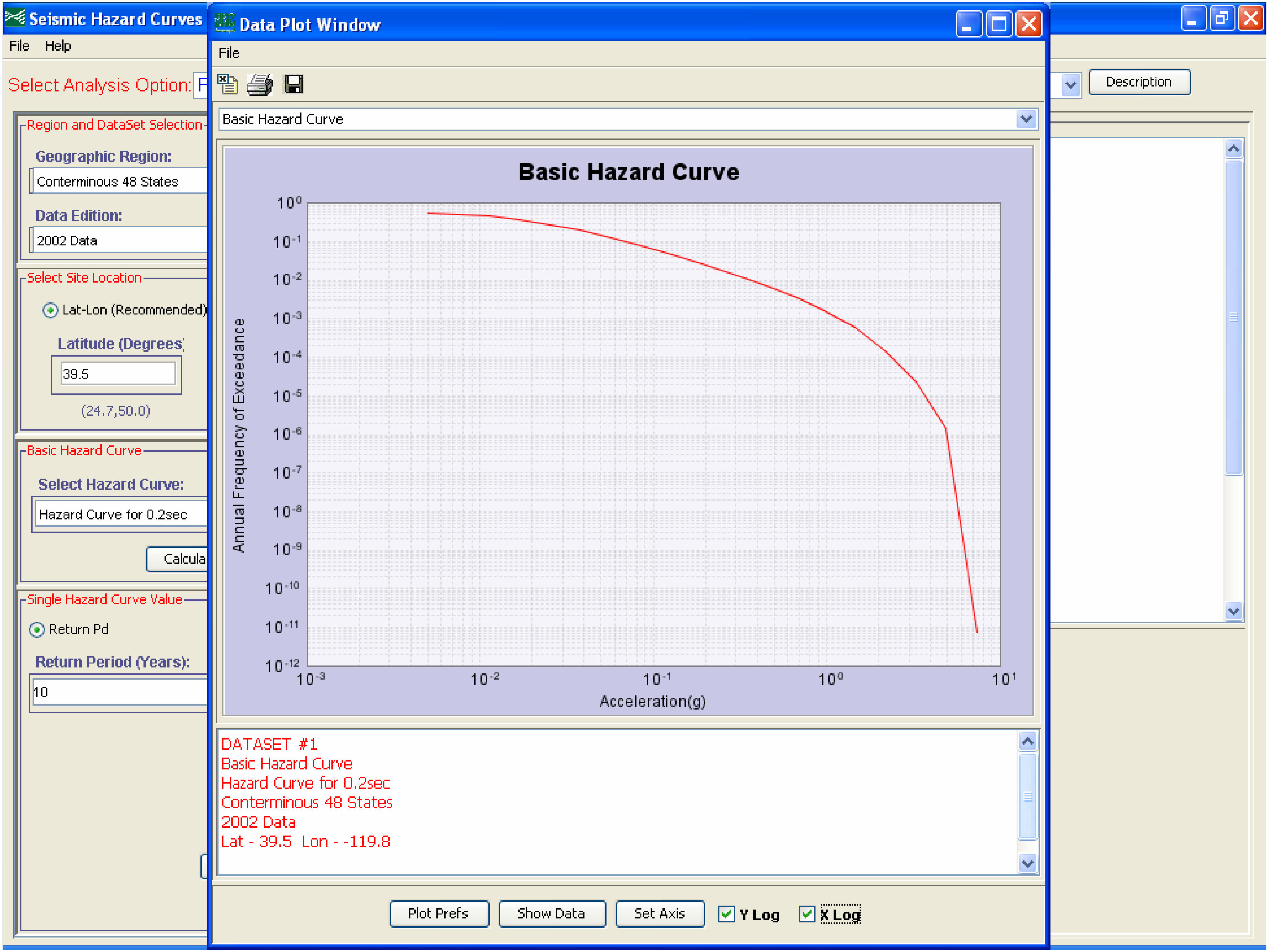
Earthquake Hazards 101

The basics, Easy Access to Maps and Faults, FAQ's

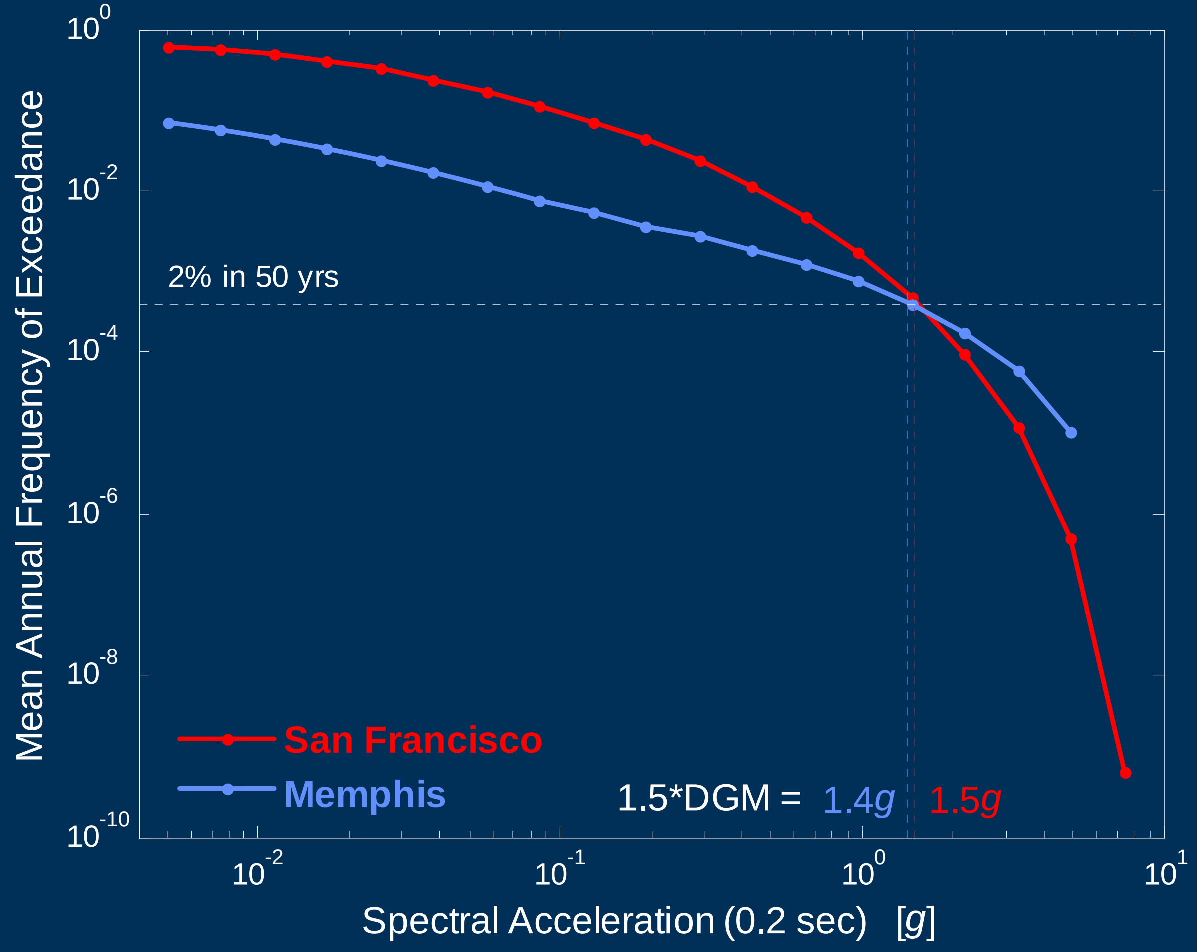
NSHM Links

- NSHM Home
- Seismic Hazard Maps
- Custom Mapping Analysis Tools
- Seismic Design Values for Buildings
- Earthquake Hazards 101
- Project Information and News
- Related Links

- NSHM FAQ
- NSHM Site Map
- A-Z Site Index


Seismic Hazard Curves
File Help
Select Analysis Option:
Region and DataSet Selection
Geographic Region:
Conterminous 48 States
Data Edition:
2002 Data
Select Site Location
Lat-Lon (Recommended)
Latitude (Degrees
39.5
(24.7,50.0)
Basic Hazard Curve
Select Hazard Curve:
Hazard Curve for 0.2sec
Single Hazard Curve Value
Return Pd
Return Period (Years):
10
Description
Data Plot Window
File
Basic Hazard Curve
Basic Hazard Curve
Annual Frequency of Exceedance
Acceleration(g)
DATASET #1
Basic Hazard Curve
Hazard Curve for 0.2sec
Conterminous 48 States
2002 Data
Lat - 39.5 Lon - -119.8
Plot Prefs
Show Data
Set Axis
Y Log
X Log

Example Hazard Curves, $H(a)$



Quantifying Fragility, $P_f(a)$

- **From *1998 NEHRP Provisions Commentary* …**

  "The collective opinion of the SDPG was that the seismic margin contained in the 1997 NEHRP Provisions provides, as a minimum, a margin of about 1.5 times the design earthquake ground motions. In other words, **if a structure is subjected to a ground motion 1.5 times the design level, the structure should have a low likelihood of collapse**. The SDPG recognized that quantification of this margin is dependent on the type of structure, detailing requirements, etc., but the 1.5 factor was considered a conservative judgment appropriate for structures designed in accordance with the 1997 NEHRP Provisions. This seismic margin estimate is supported by Kennedy et al. (1994), Cornell (1994), and Ellingwood (1994), who evaluated structural design margins and reached similar conclusions."

- **Corresponding assumption (ref. ATC-63):**

$$P_f(a = 1.5\,DGM) = 10\%$$

Quantifying Fragility, $P_f(a)$

- **Time-honored lognormality assumption:**

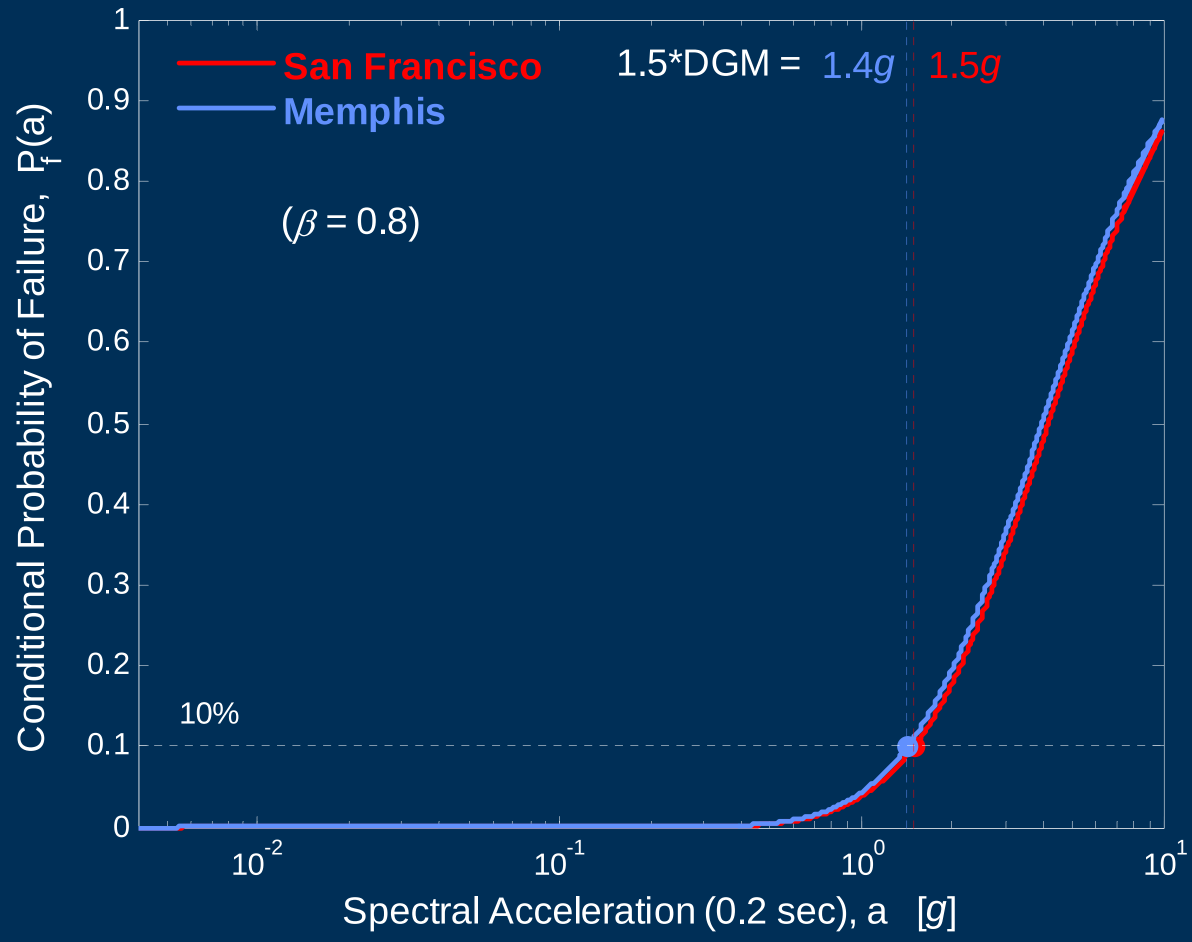
$$P_f(a) = \Phi\left[\frac{\ln a - (\ln 1.5\, DGM + 1.28\,\beta)}{\beta}\right]$$

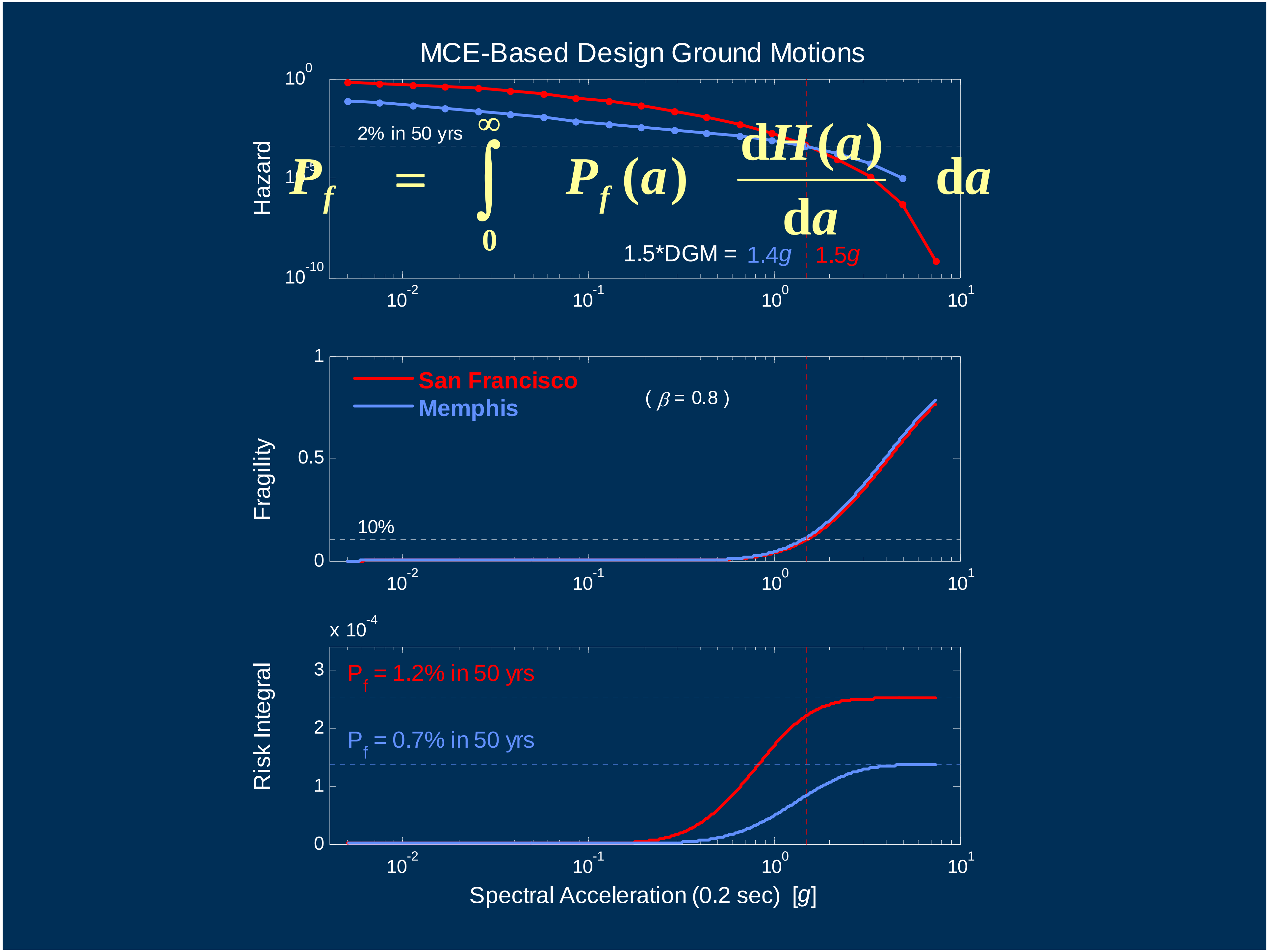
where

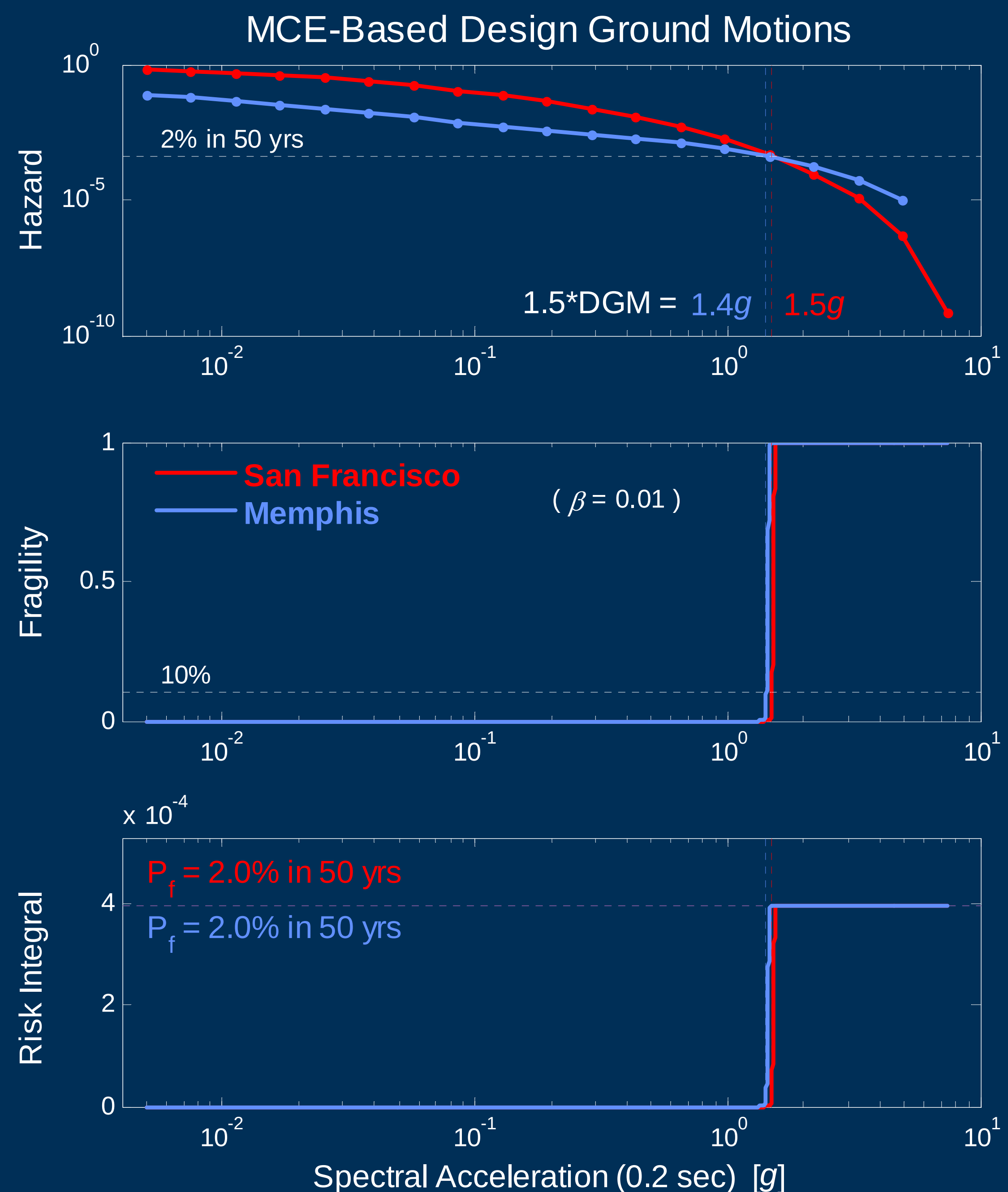
β = variability/uncertainty of ground motion value that induces failure

- **Assumption (again, ref. ATC-63):** $\boxed{\beta = 0.8}$

Example Fragilities, $P_f(a)$

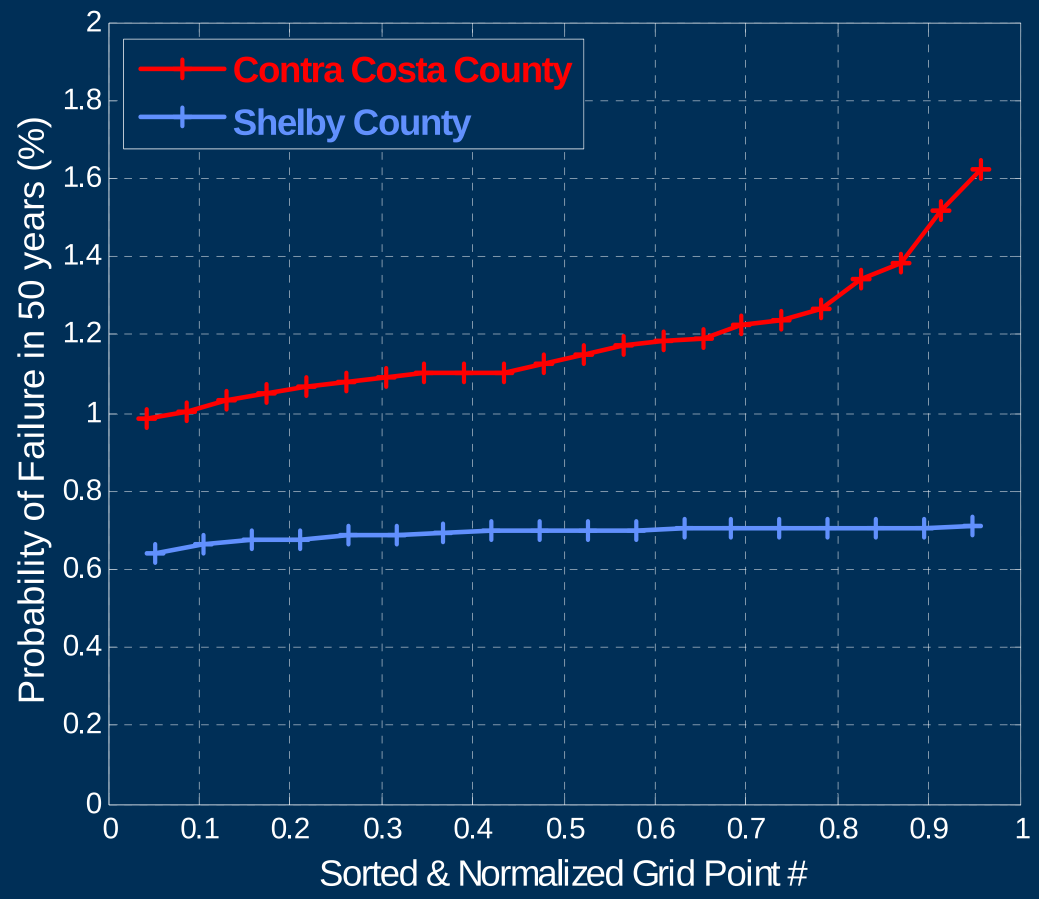



MCE-Based Design Ground Motions
Hazard
2% in 50 yrs
$P_f = \int_0^\infty P_f(a) \frac{dH(a)}{da} da$
1.5*DGM = 1.4g 1.5g
Fragility
San Francisco
Memphis
(β = 0.8)
10%
Risk Integral
x 10^-4
P_f = 1.2% in 50 yrs
P_f = 0.7% in 50 yrs
Spectral Acceleration (0.2 sec) [g]



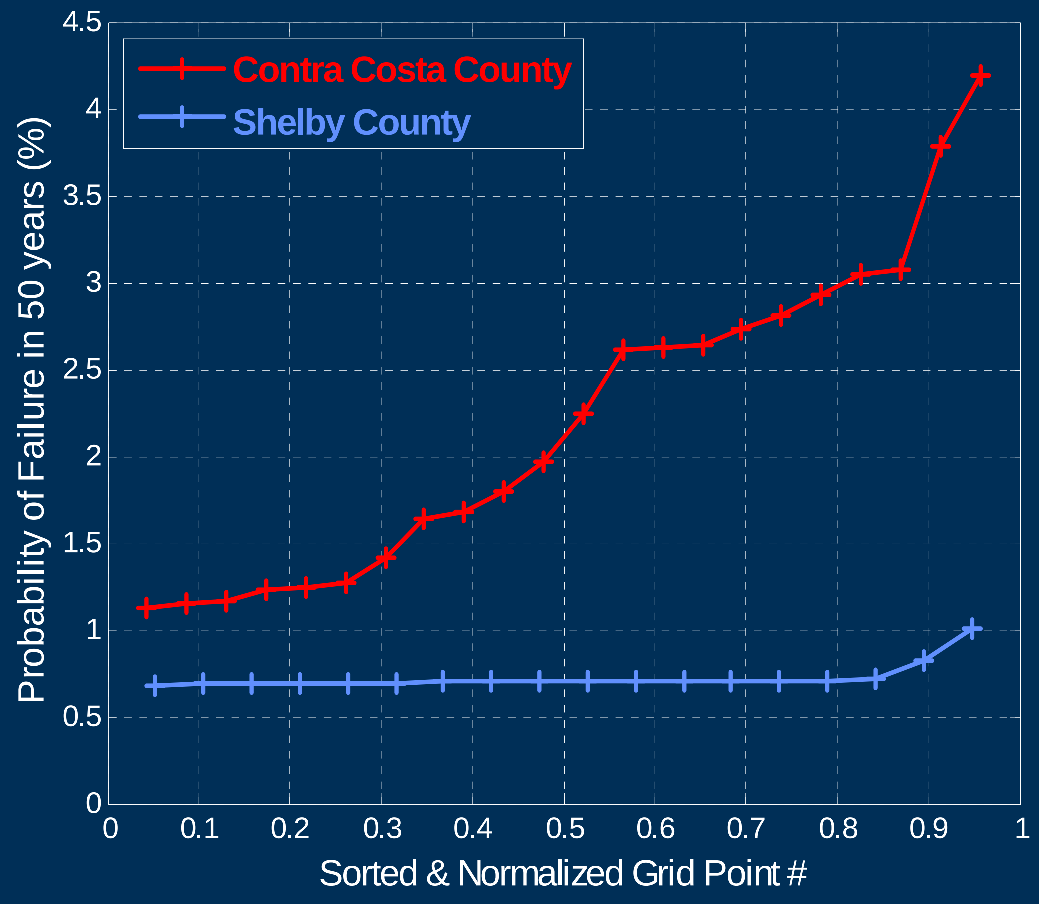
$$P_f = \int_0^\infty P_f(a) \frac{dH(a)}{da} da$$

Risk (P_f) at Additional Locations



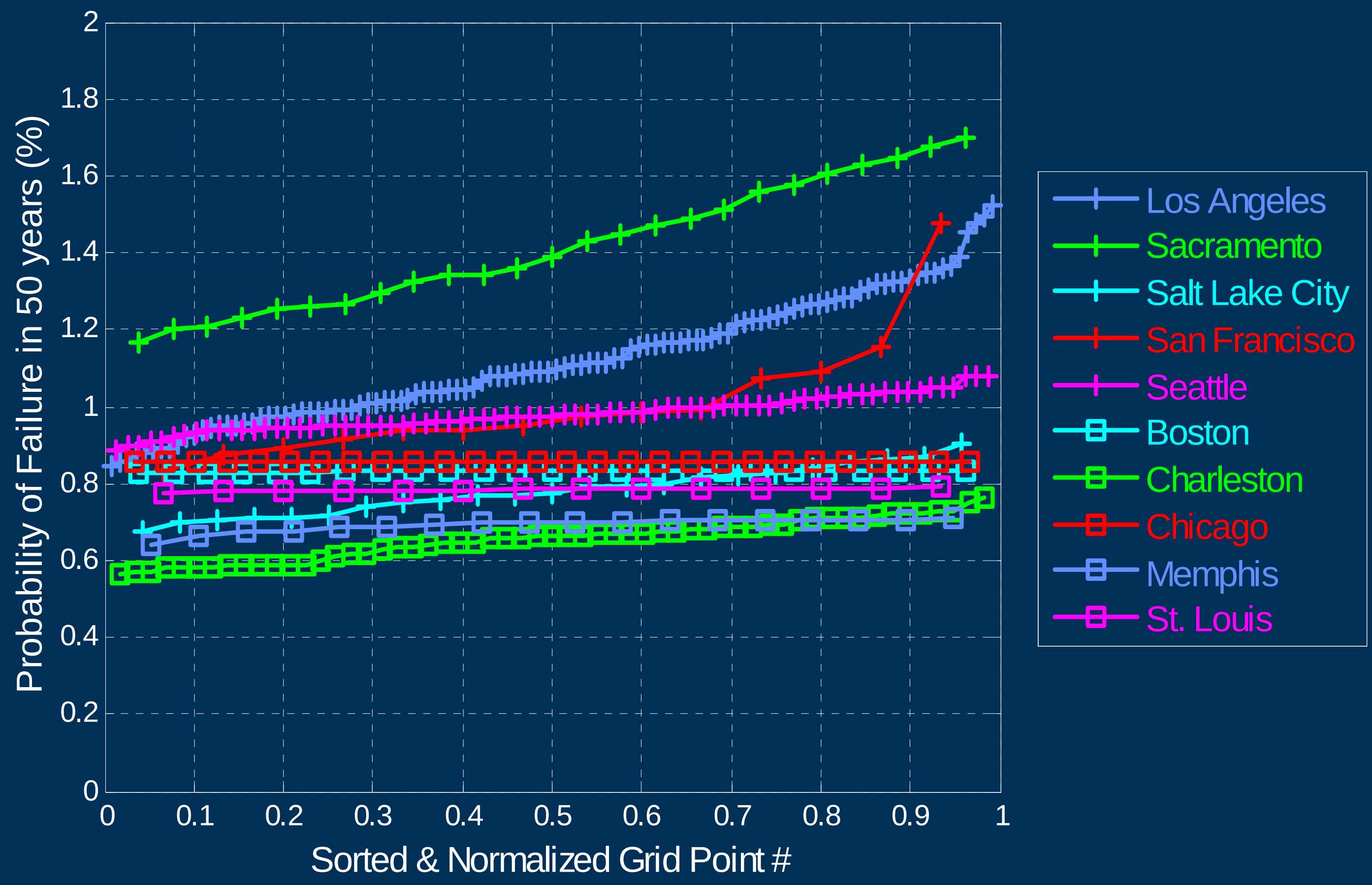
(Assuming DGM = 2/3 * 2%-in-50yrs S.A.)

Risk (P_f) at Additional Locations



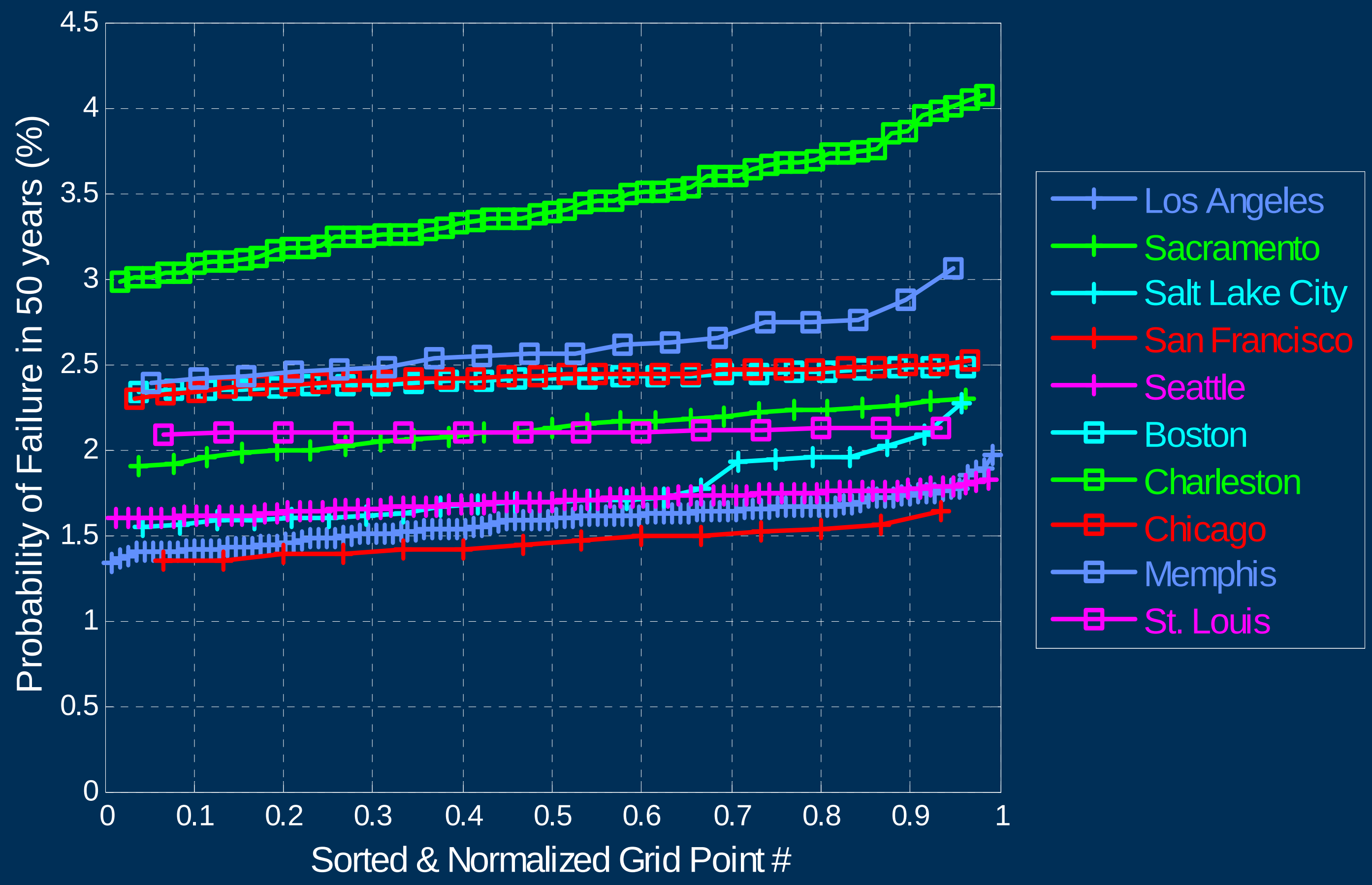
(For DGM = 2/3 * MCE S.A.)

Risk (P_f) at Additional Locations



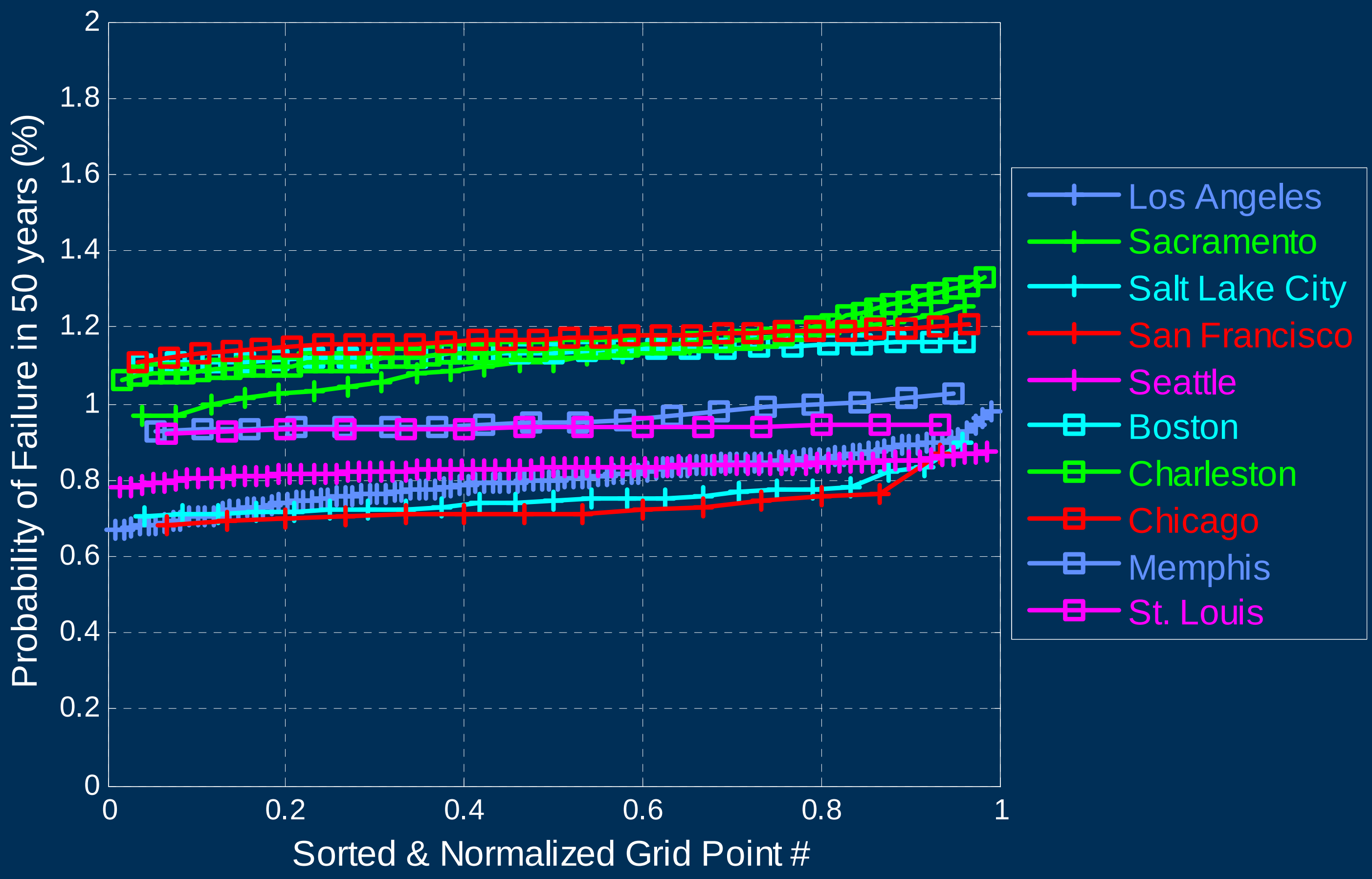
(Assuming DGM = 2/3 * 2%-in-50yrs S.A.)

Risk (P_f) at Additional Locations



(Assuming DGM = 10%-in-50yrs S.A.)

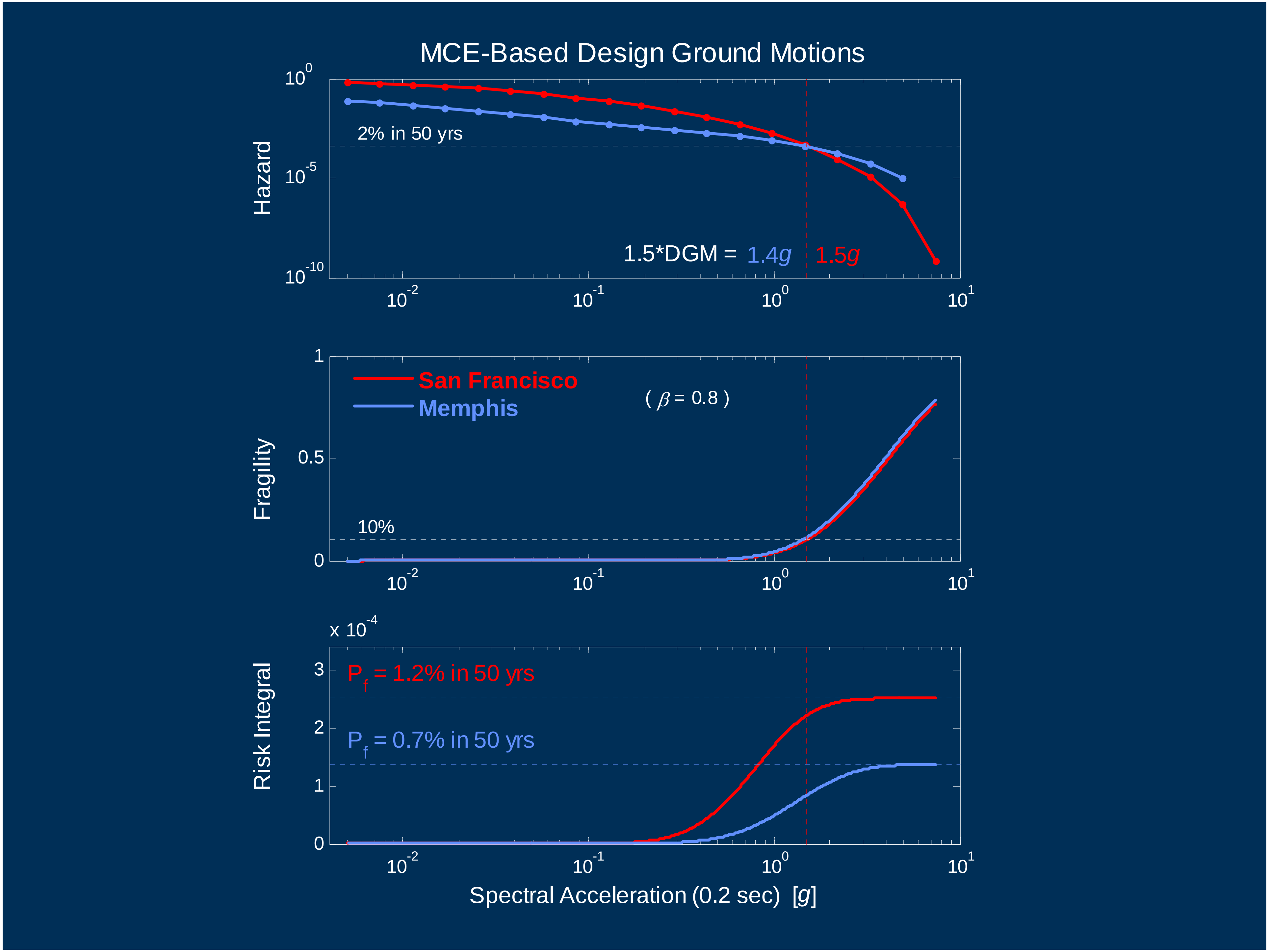
Risk (P_f) at Additional Locations



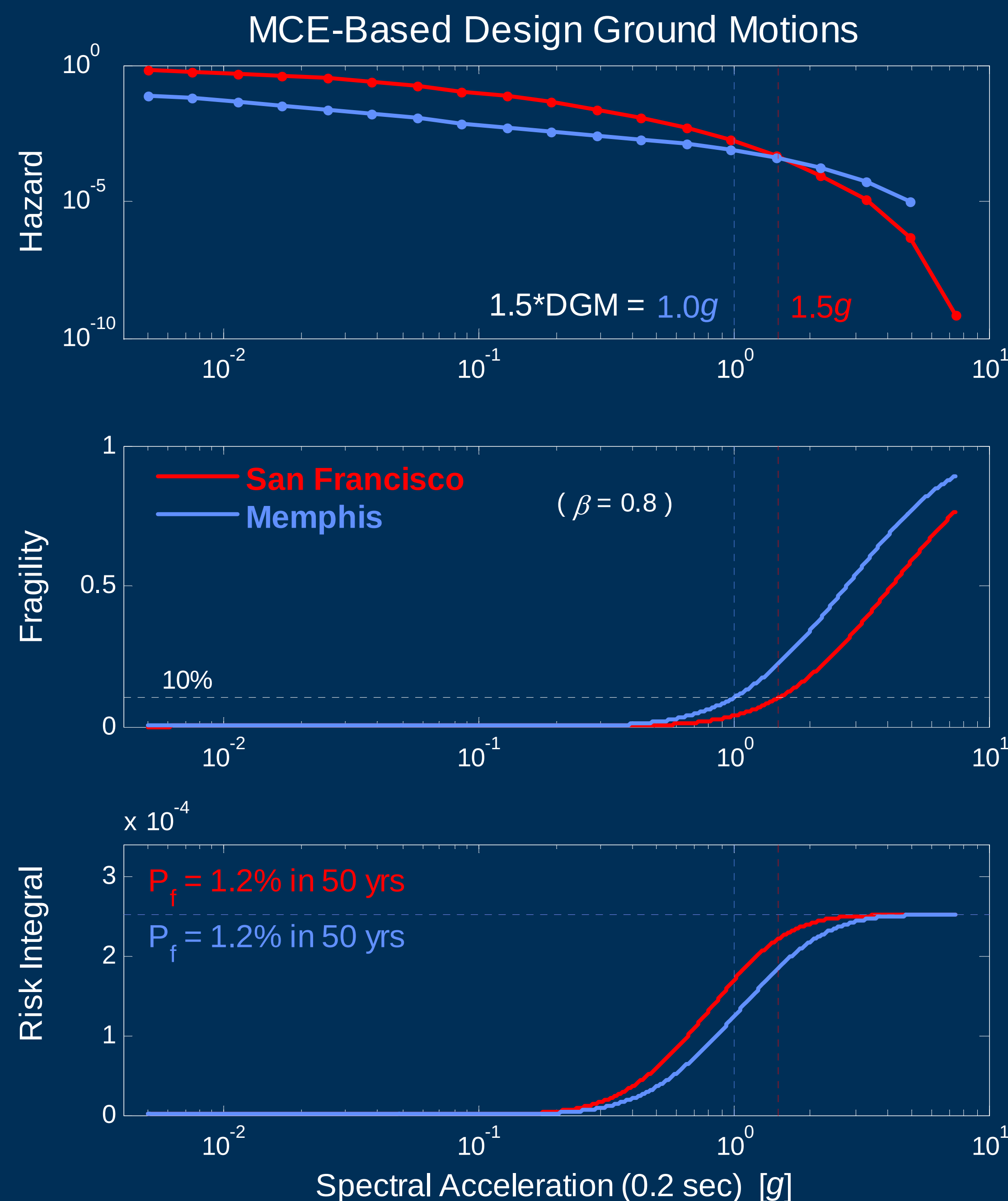
(Assuming DGM = 5%-in-50yrs S.A.)

Question

- **What design ground motion (DGM) values would lead to uniform probability of <u>collapse</u> (e.g., in 50 years) across locations and spectral acceleration vibration periods?**



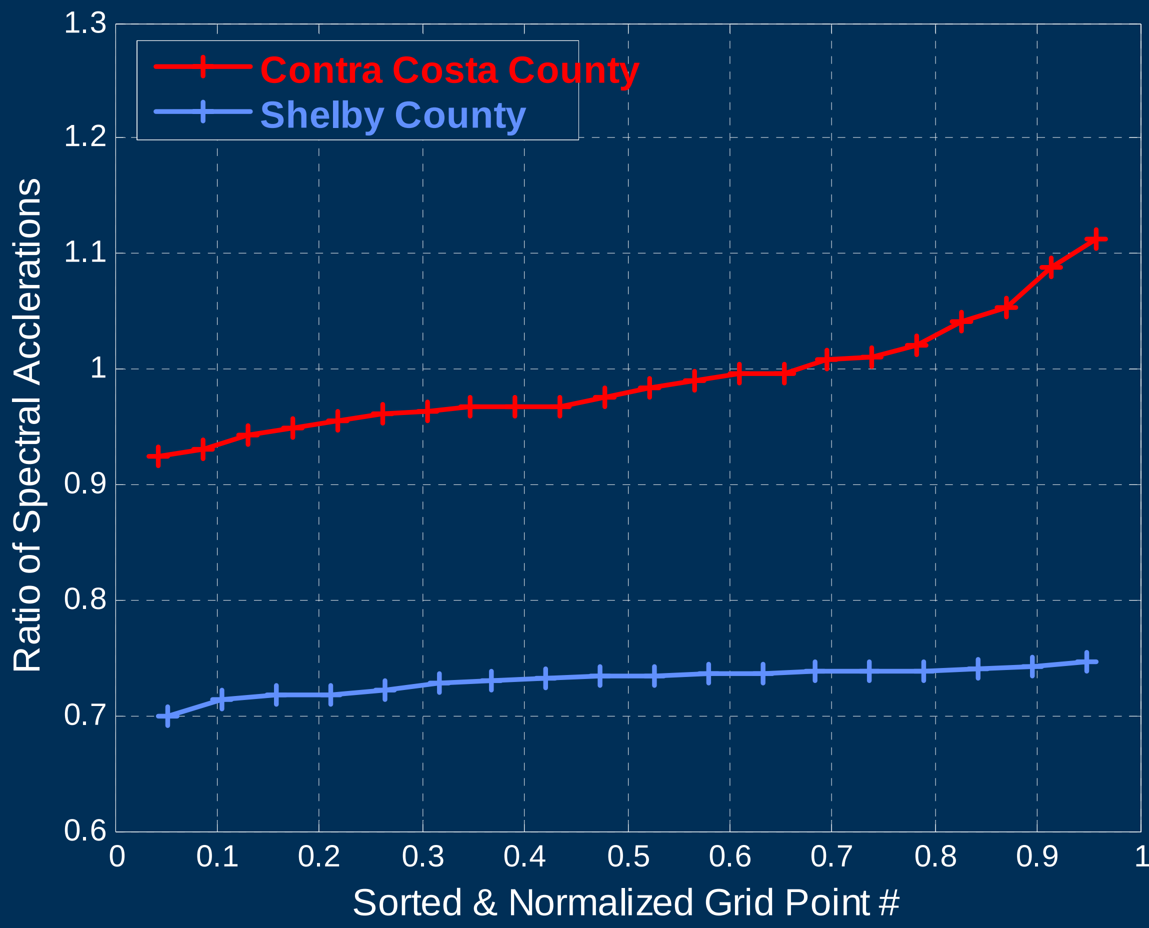
MCE-Based Design Ground Motions
Hazard
2% in 50 yrs
1.5*DGM = 1.4g 1.5g
Fragility
San Francisco
Memphis
(β = 0.8)
10%
Risk Integral
x 10^-4
Pf = 1.2% in 50 yrs
Pf = 0.7% in 50 yrs
Spectral Acceleration (0.2 sec) [g]



$$P_f = \int_0^\infty P_f(a) \frac{\mathrm{d}H(a)}{\mathrm{d}a} \mathrm{d}a$$

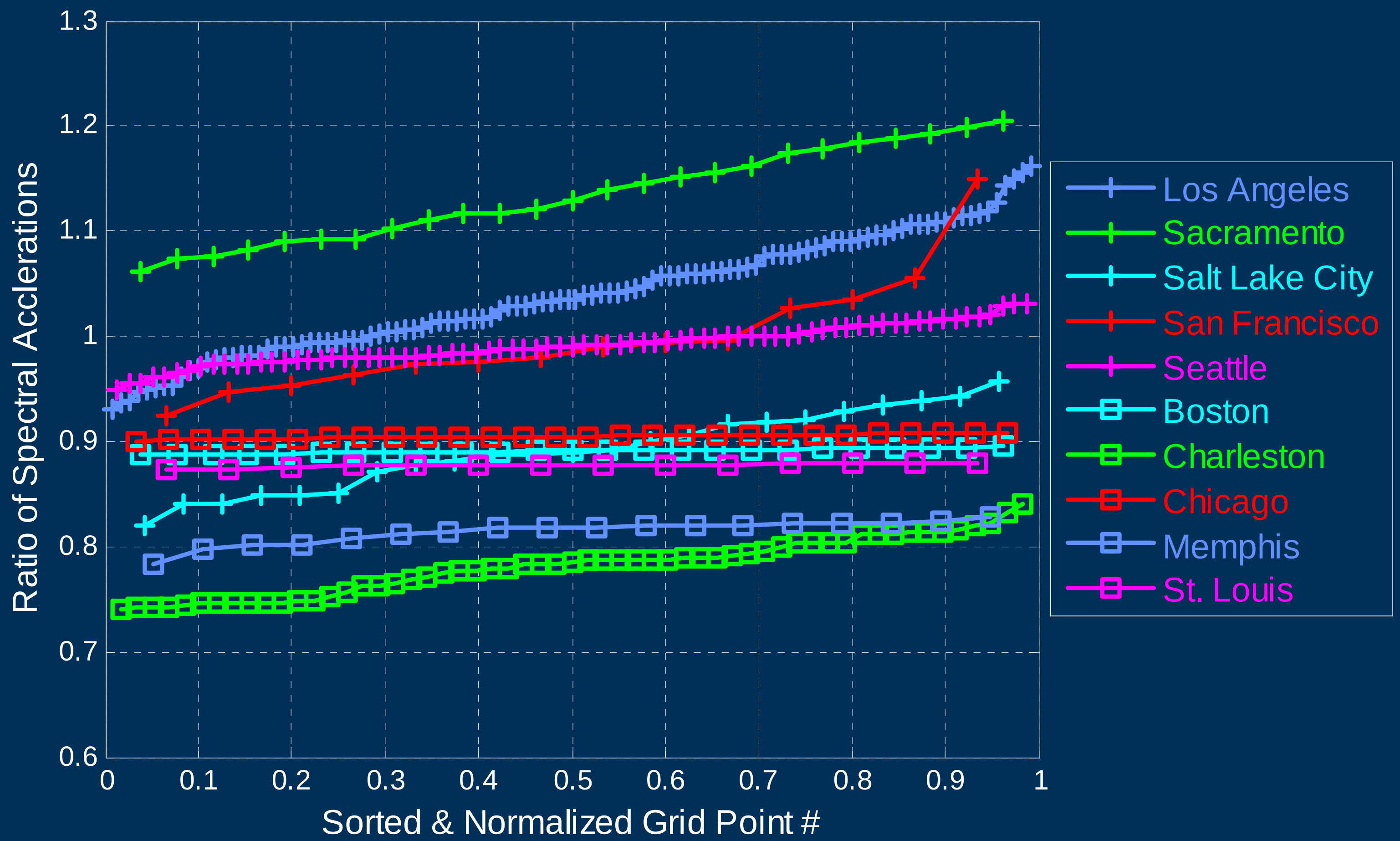
Risk-Targeted Design GMs

- **For P_f = 1.2% in 50yrs; vs. 2/3 * 2%-in-50yrs DGM**



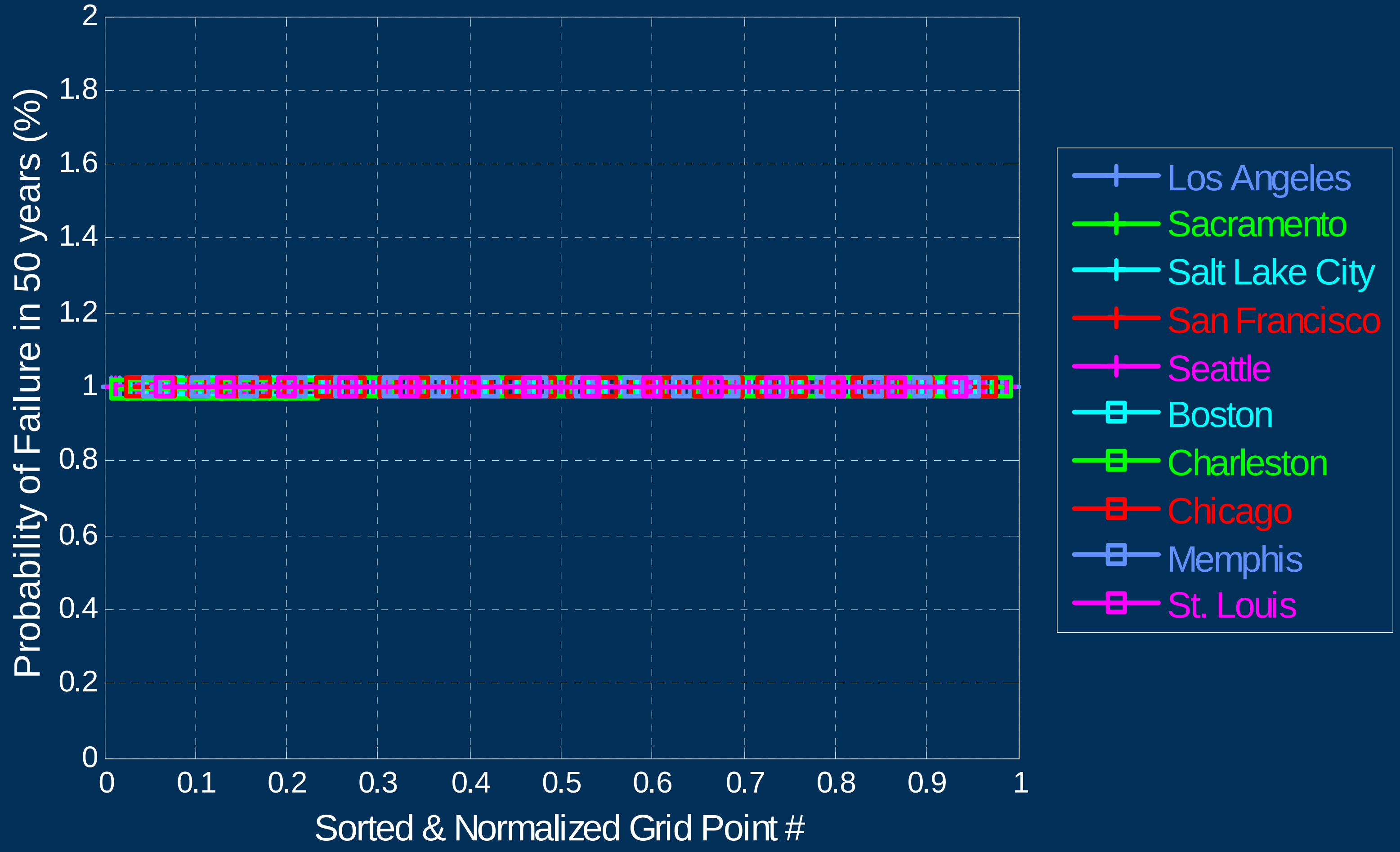
Risk-Targeted Design GMs

- For P_f = 1.0% in 50yrs; vs. 2/3 * 2%-in-50yrs DGM



Risk-Targeted Design GMs

- **Resulting risk (P_f) …**



Simplification *ala* ASCE 43-05?

(ASCE 43-05 = *Standard for Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities)*

- **GM Hazard Return Period = 10,000yrs**
- **"Design Factor" (applied to UHRS):**

$$DF = \max\{1.0, 0.6A_R^{0.8}\}$$

where A_R = 1 / (log hazard curve slope, k)

- **Recently adopted in NRC Draft Regulatory Guide 1146** (*A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion*)

Simplification *a la* ASCE 43-05?

- Re-calibrate DF for building codes?
- Regional k-values, e.g., from FEMA 350 …

Table A-2 Default Values of the Logarithmic Hazard Curve Slope *k* for Probabilisitc Ground Shaking Hazards

Region	*k*
Alaska, California and the Pacific Northwest	3
Intermountain Region, Basin & Range Tectonic Province	2
Other U.S. locations	1

Note: For deterministic ground shaking demands, use a value of $k = 4.0$

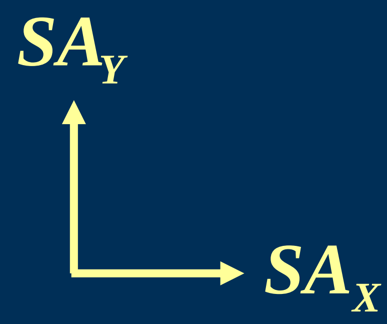
- Allow for site-specific evaluation

Update of IBC Design Maps (Task 1)

- **Current 2/3 * 2%-in-50yrs DGMs …**
  - **do not result in uniform risk (probability of collapse, e.g., in 50 years)**
  - **result in risks that are closer to uniform than 10%-in-50yrs DGMs**
- **Risk-targeted DGMs can be defined via …**
  - **maps of "design factors" to apply to uniform-hazard maps that account for hazard curve shapes**
  - **return period(s), and potentially factor(s), that result in somewhat uniform risk**

Update of IBC Design Maps (Task 2)

- The spectral accelerations from the attenuation relations used for both probabilistic and deterministic MCE ground motions are geometric means of the *SA*'s for the two orthogonal horizontal components, i.e., …



$$Geomean(SA) = \sqrt{SA_X \cdot SA_Y}$$

$$= \exp\left(\frac{\ln SA_X + \ln SA_Y}{2} \right)$$

$$= \exp(\ Mean(\ln SA)\ )$$

Update of IBC Design Maps (Task 2)

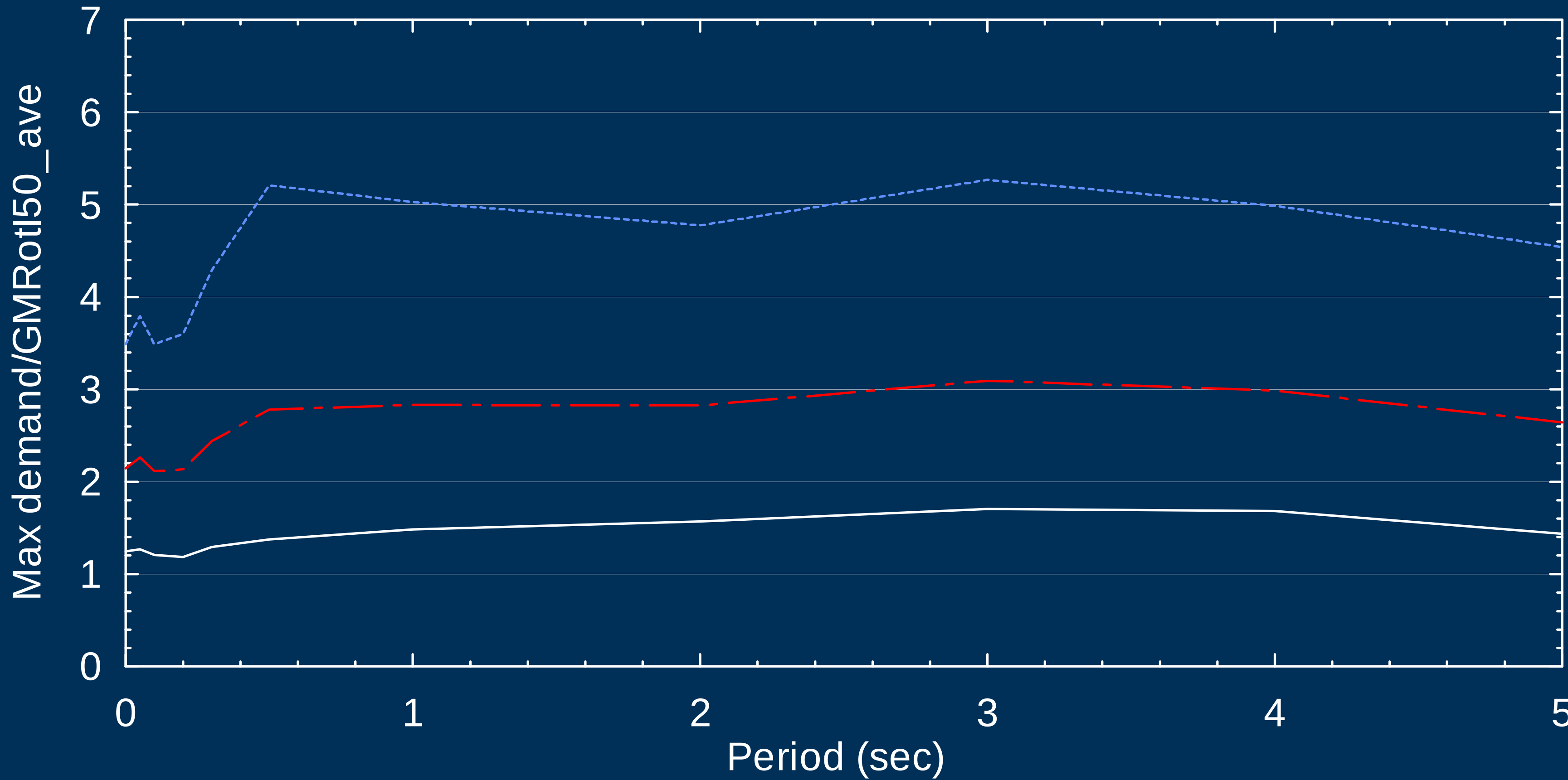
- Particularly near-fault (where the deterministic MCE governs), the maximum *SA* across the two horizontal components can be substantially larger than the geometric mean, i.e., …

$$Max(SA) >> Geomean(SA)$$

- The use of the maximum *SA* for the deterministic MCE ground motions is under consideration by Project '07.

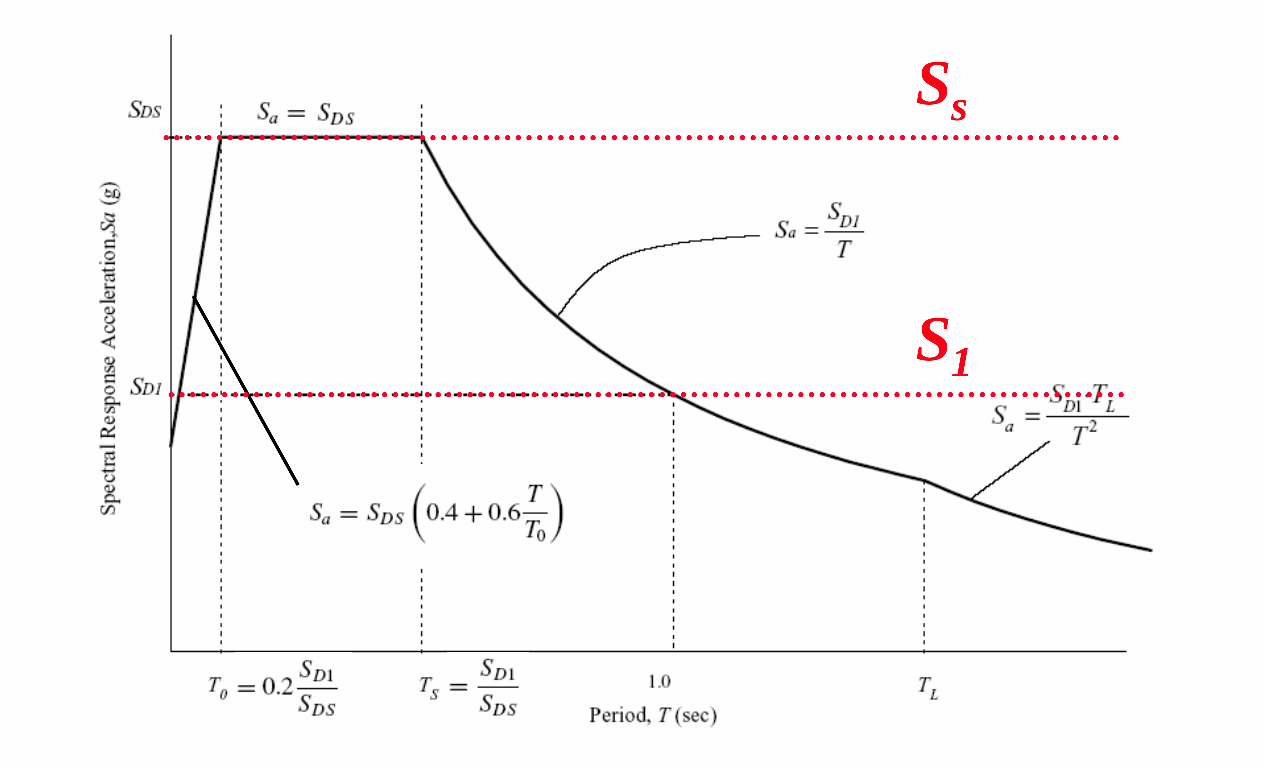
Update of IBC Design Maps (Task 2)

$$Max(SA) \div Geomean(SA)$$



Update of IBC Design Maps (Task 3)

- Recall that the Design Response Spectrum is defined by S_s, S_1, and T_L.



Update of IBC Design Maps (Task 3)

- Project '07 is considering alternative definitions of the design response spectrum, e.g., …
  - Use of PGA, 0.3-second, or 0.1-second instead of 0.2-second *SA.*
  - Use of more periods to better define the shape of the design response spectrum.
- A separate response spectrum for elastic modal response analysis and/or the selection and scaling of ground motion recordings is also being considered.

Other Potential Updates

- The BSSC Provisions Update Committee (PUC) Technical Subcommittee on Ground Motions is considering the following:
  - Vertical ground motions
  - Changes to the Site Class Coefficients

Outline of Material

- Derivation of "International" Building Code (IBC) *Design* Maps from USGS *Hazard* Maps
- Use of IBC Design Maps (i.e., procedure)
- Computer software for IBC Design Maps
- Potential updates of IBC Design Maps