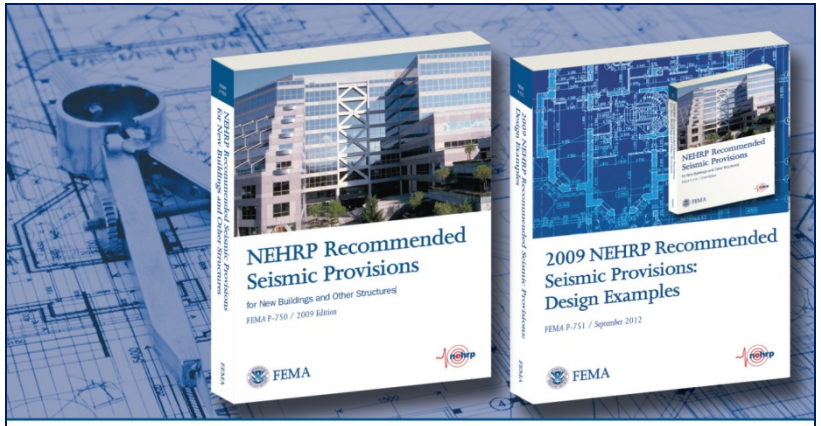


2009 NEHRP Recommended Seismic Provisions:

Training and Instructional Materials

FEMA P-752 CD / June 2013

FEMA

nehrp

3

Earthquake Ground Motion

Nicolas Luco, Ph.D., P.E., Michael Valley, S.E., and C.B. Crouse, P.E., Ph.D.

Slide set created by Finley A. Charney, Ph.D., P.E.

Topics Covered

- 2008 USGS Uniform Hazard Maps
- 2009 NEHRP *Provisions* Maps
- ASCE 7-10 Seismic Maps
- Determination of Ground Motion Values
- Horizontal Response Spectra
- Vertical Response Spectra
- Peak Ground Acceleration
- Selection and Scaling of Ground Motions

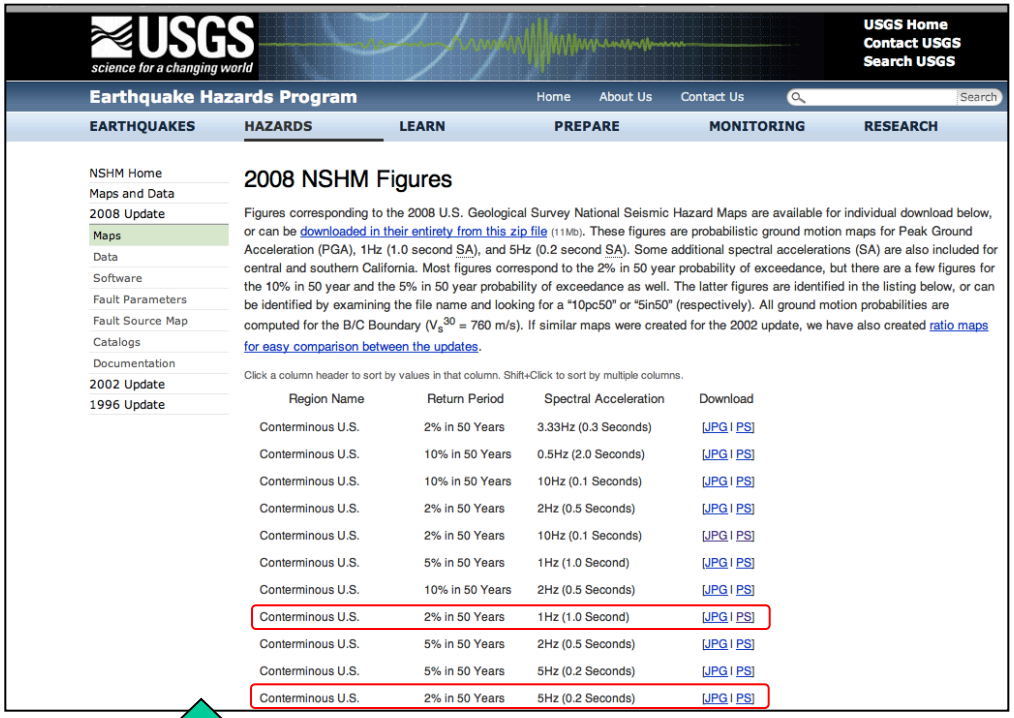
Topics Covered

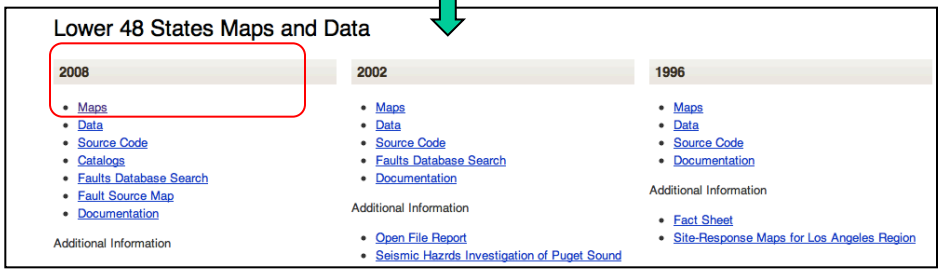
- **2008 USGS Uniform Hazard Maps**
- **2009 NEHRP *Provisions* Maps**
- **ASCE 7-10 Seismic Maps**
- Horizontal Response Spectra
- Vertical Response Spectra
- Peak Ground Acceleration
- Selection and Scaling of Ground Motions

2008 USGS Maps

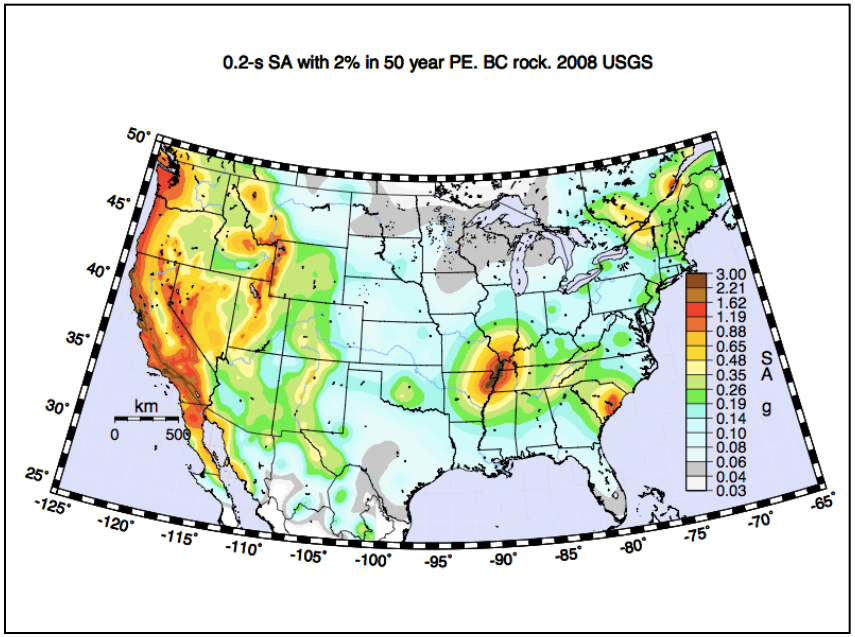
- Probabilistic
- Uniform Hazard (e.g. 2% in 50 year probability)
- Spectral Contours (T=0, 0.1, 0.2 sec…)
- 5 % Damping
- Site Class B/C Boundary
- Geomean Values

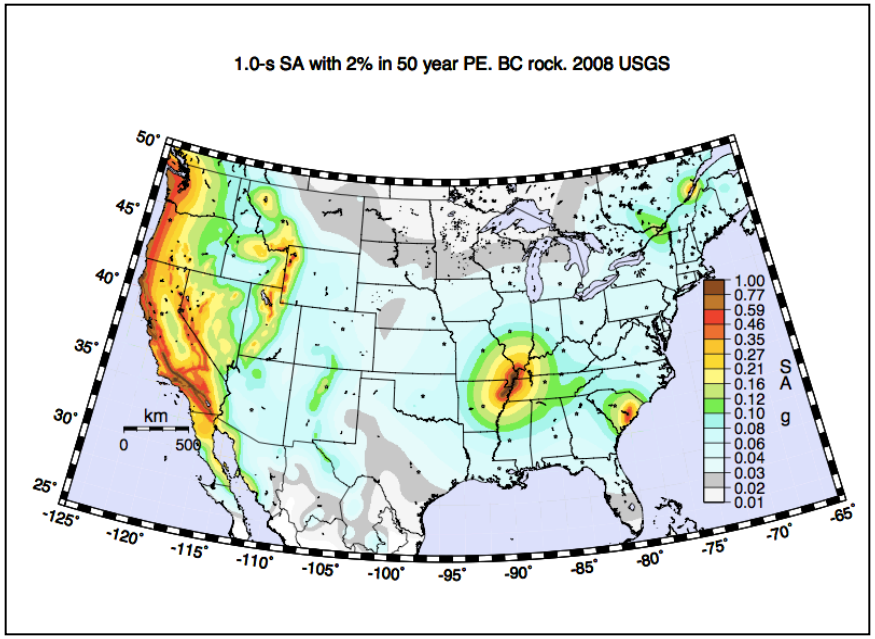
Obtaining 2008 Maps from USGS Seismic Hazard Data Website



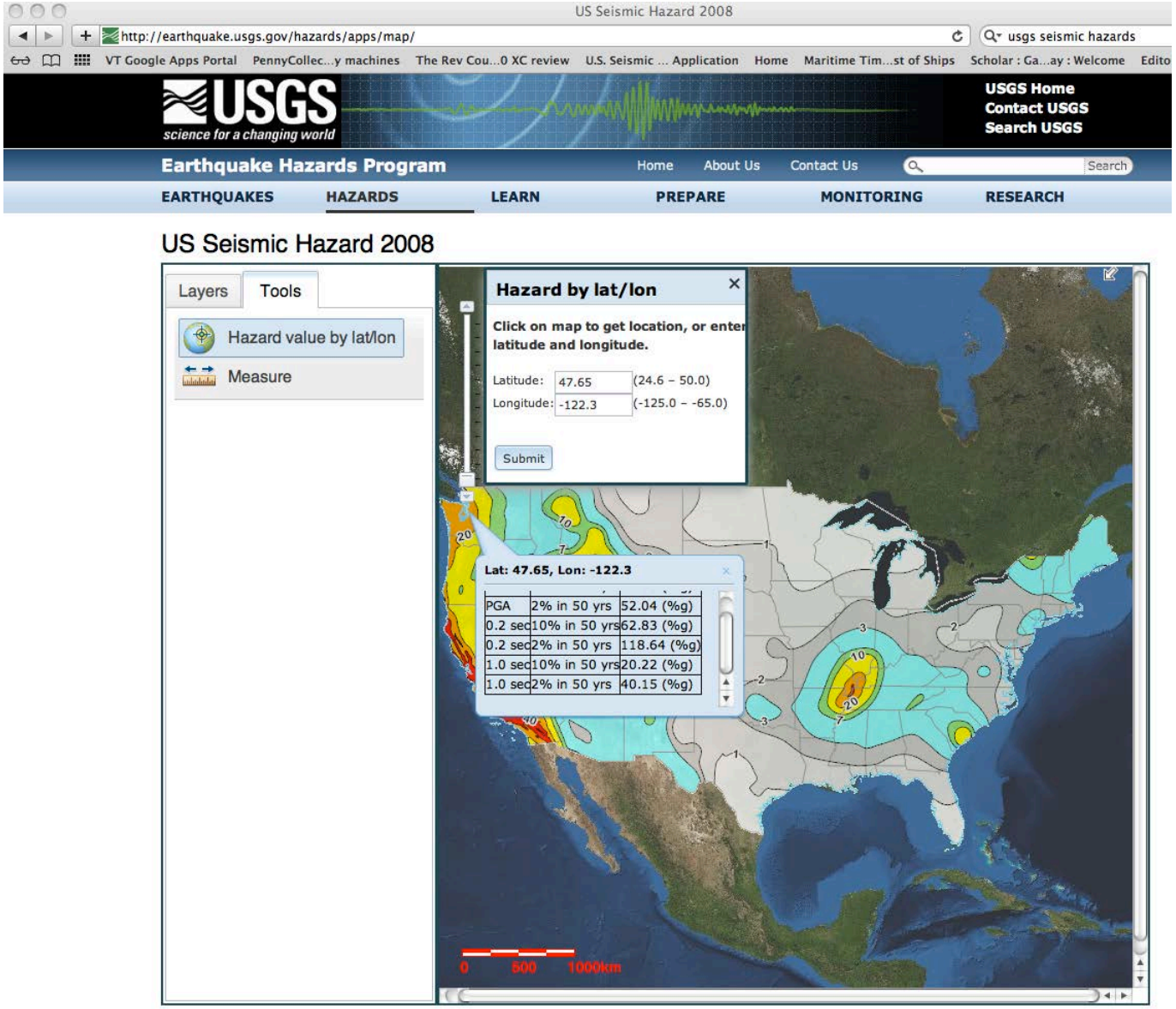


2008 USGS Seismic Hazard Maps





Obtain Accelerations for Given Lat-Lon

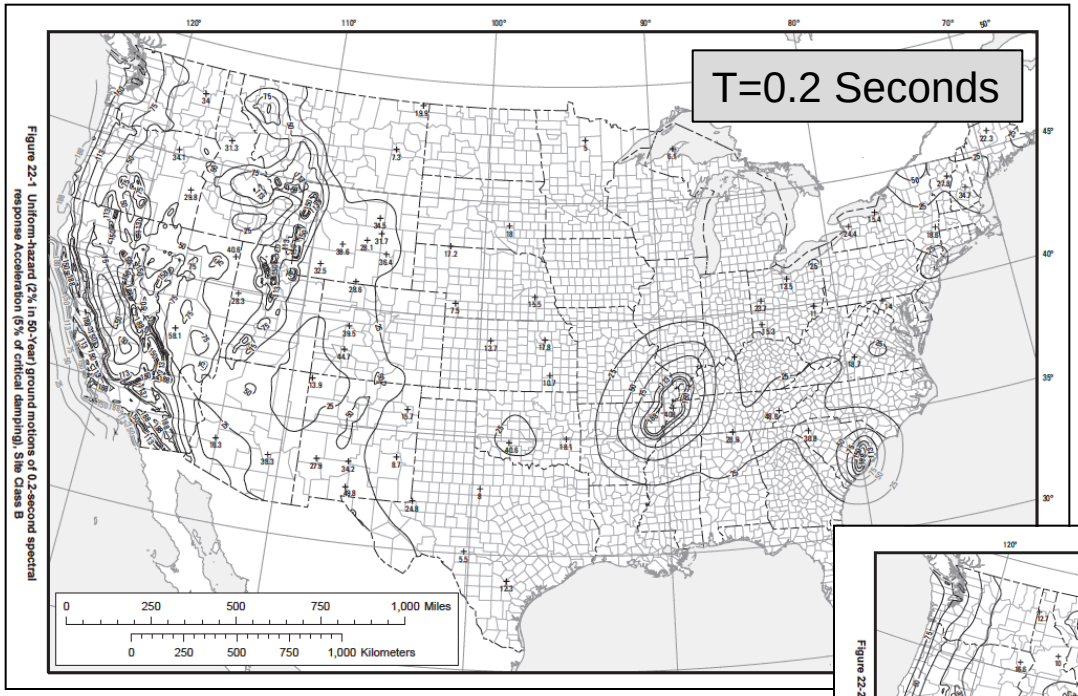


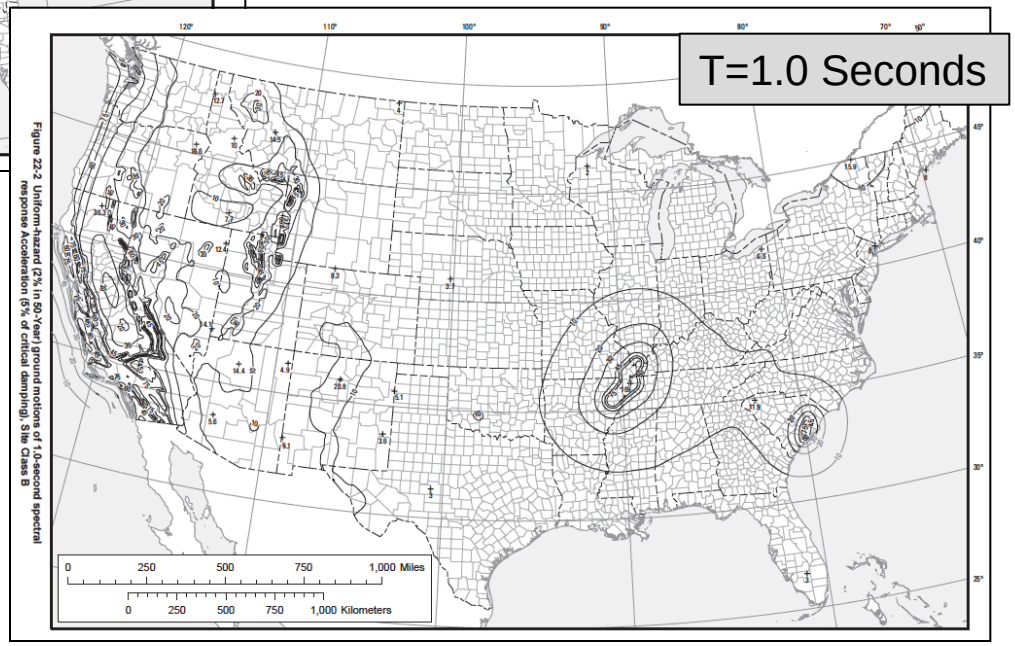
For Lat = 47.65
Lon = -122.3
2% in 50 year
GEOMEAN values:
PGA=0.520 g
0.2 sec=1.186 g
1.0 sec=0.4015 g

2009 NEHRP Maps

- Probabilistic / Deterministic (Separate Maps)
- Uniform Risk (Separate Maps)
- Spectral Contours (PGA, 0.1, 0.2 sec)
- 5 % Damping
- Site Class B/C Boundary
- Maximum Direction Values

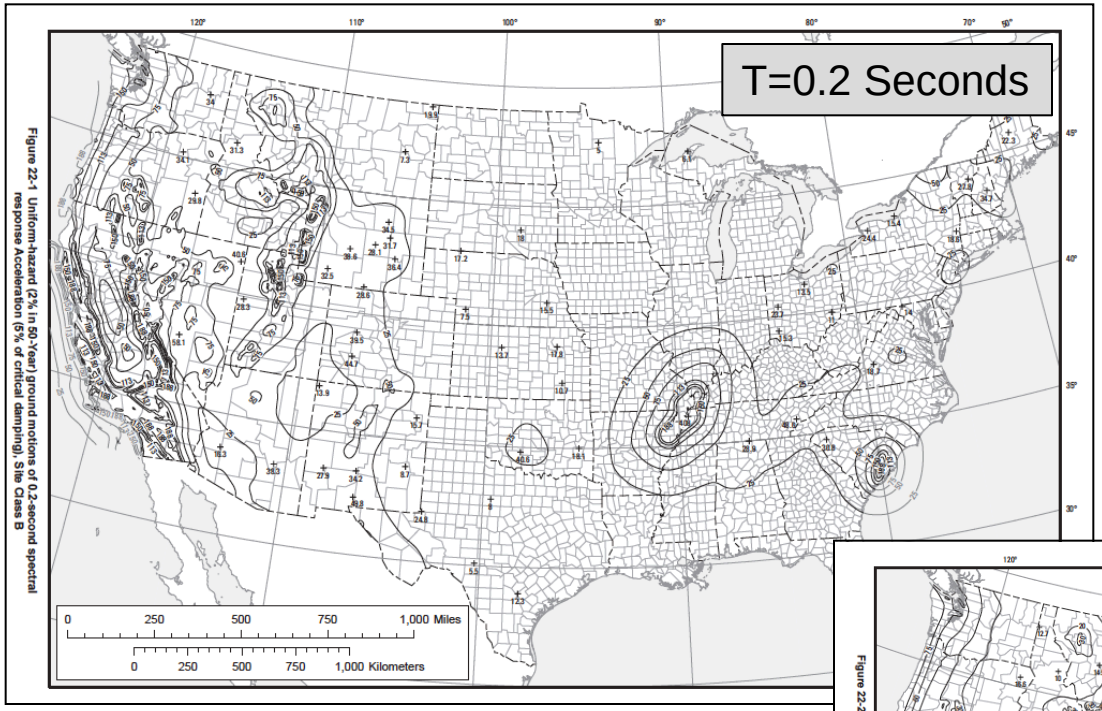
2009 NEHRP Probabilistic Maps





- Probabilistic / Deterministic (Separate Maps)
- Uniform Risk (Separate Maps)
- Spectral Contours (PGA, 0.1, 0.2 sec)
- 5 % Damping
- Site Class B/C Boundary
- Maximum Direction Values

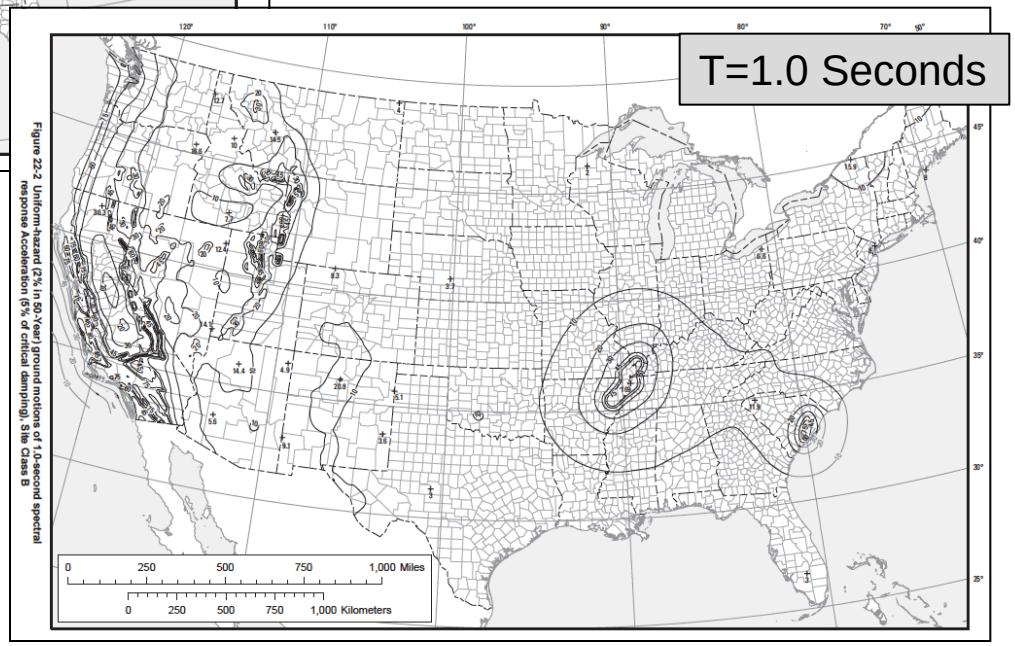
Maximum Direction Conversion



To convert from USGS Geomean to NEHRP ***Maximum Direction***

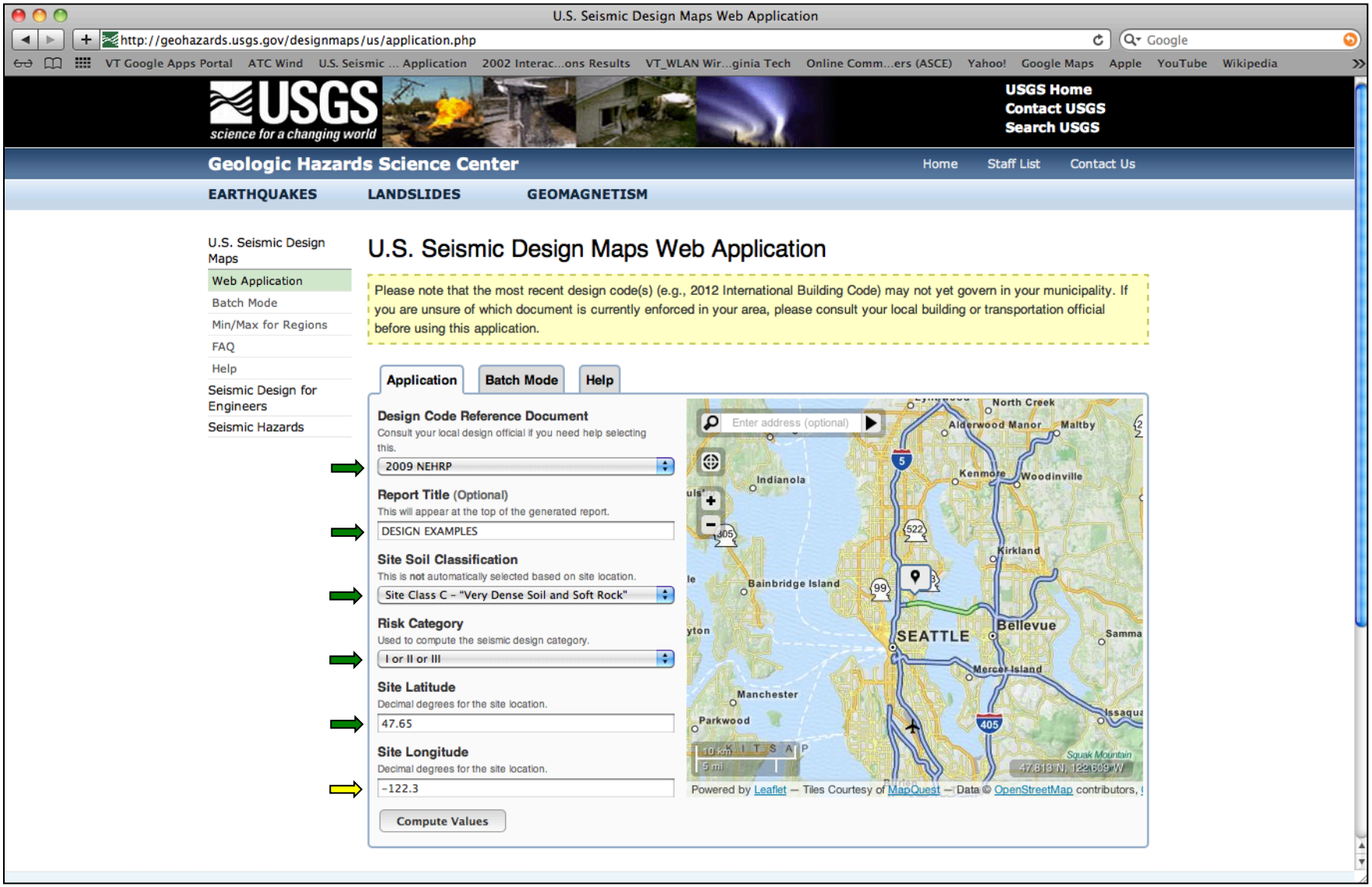
Multiply 0.2 Sec. values by 1.1

Multiply 1.0 Sec. values by 1.3



For Lat = 47.65
Lon = -122.3
2% in 50 year
Max Direction Values:
0.2 sec=1.186 x 1.1 = 1.305 g
1.0 sec=0.4015 x 1.3 = 0.522 g

Using the USGS Utility: 2009 NEHRP



Results from Detailed Report

Design Maps Detailed Report

USGS Design Maps Detailed Report

Print View Summary Report

2009 NEHRP Recommended Seismic Provisions (47.65°N, 122.3°W)

Section 11.4.1 — Mapped Acceleration Parameters and Risk Coefficients

Note: Ground motion values contoured on Figures 22-1, 2, 5, & 6 below are for the direction of maximum horizontal spectral response acceleration. They have been converted from corresponding geometric mean ground motions computed by the USGS by applying factors of 1.1 (to obtain S_{SUH} and S_{SD}) and 1.3 (to obtain S_{1UH} and S_{1D}). Maps in the 2009 NEHRP Provisions are provided for Site Class B. Adjustments for other Site Classes are made, as needed, in Section 11.4.3.

Figure 22–1: Uniform–Hazard (2% in 50–Year) Ground Motions of 0.2-Second Spectral Response Acceleration (5% of Critical Damping), Site Class B

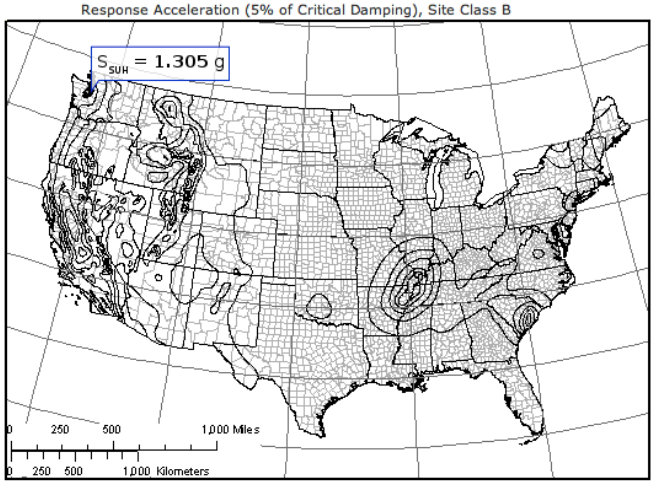
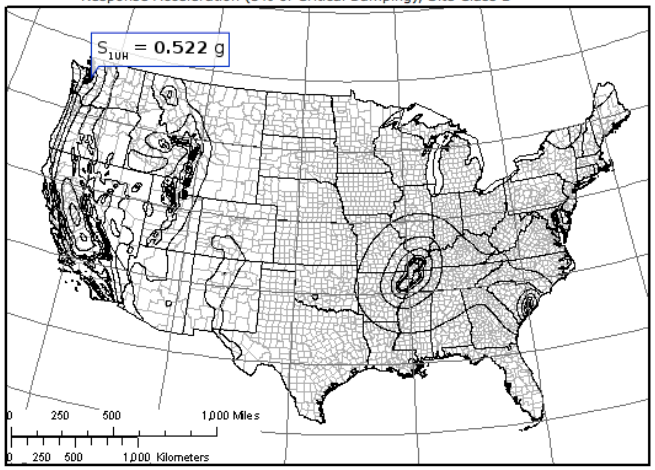


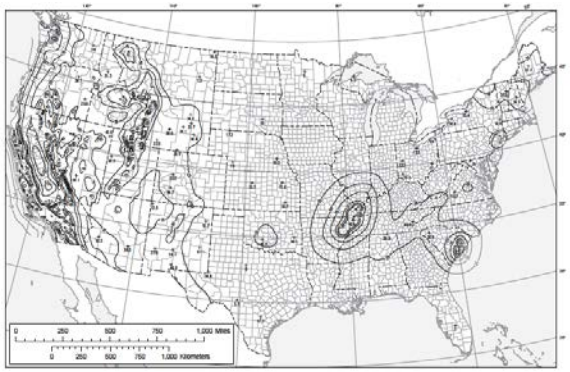
Figure 22–2: Uniform–Hazard (2% in 50–Year) Ground Motions of 1.0-Second Spectral Response Acceleration (5% of Critical Damping), Site Class B



S_{SUH}=1.305g
S_{1UH}=0.522g

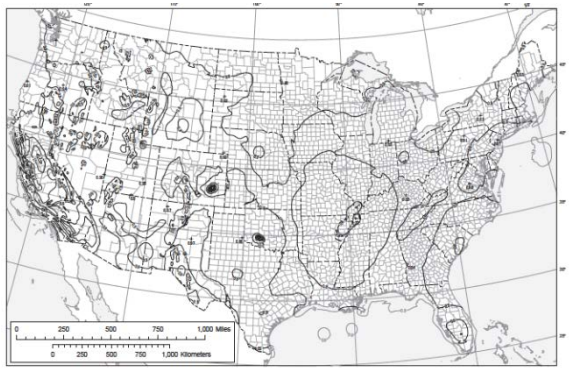
For Lat = 47.65
Lon = -122.3
2% in 50 year
Max Direction Values:
0.2 sec=1.186 x 1.1 = 1.305 g
1.0 sec=0.4015 x 1.3 = 0.522 g

Adjustment for Risk and Deterministic Cap



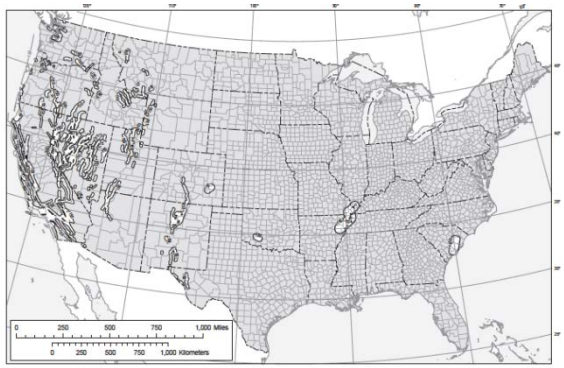
NEHRP Spectral Accelerations

+



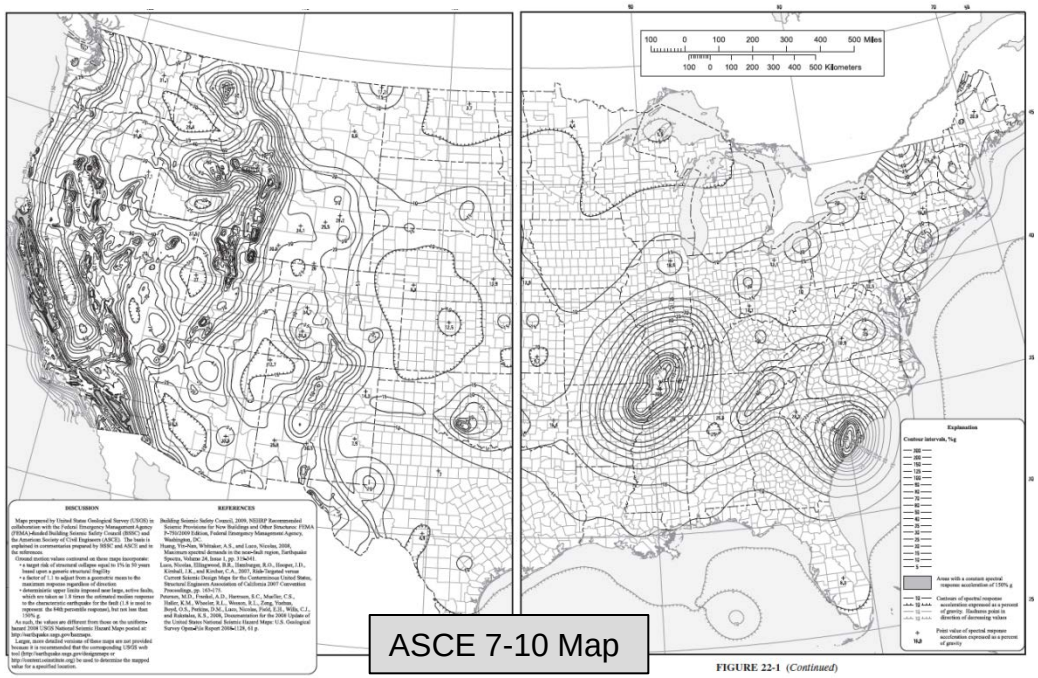
NEHRP Risk Coefficients

+



NEHRP Deterministic Peaks

=



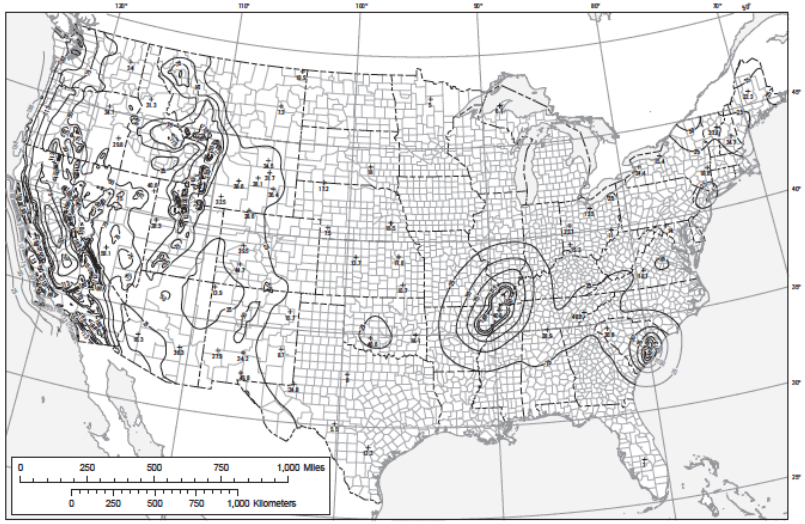
ASCE 7-10 Map

FIGURE 22-1 (*Continued*)

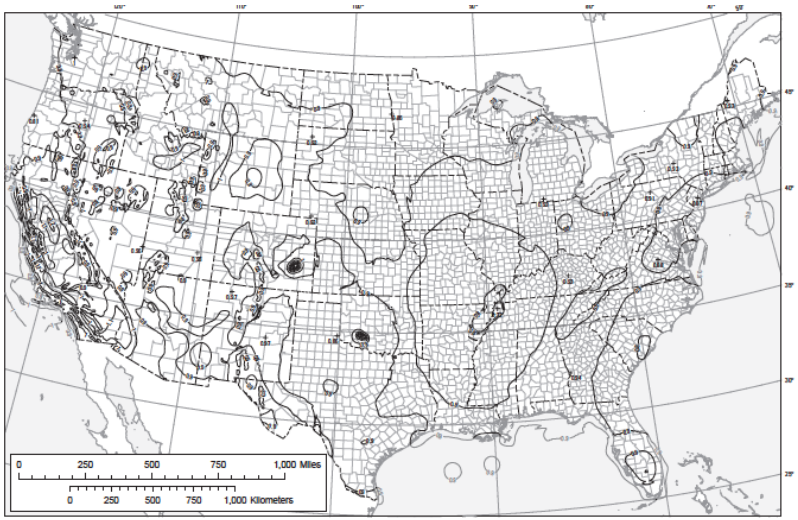
Adjustment for Risk

$$S_S = \min(S_{SUH} C_{RS}, S_{SD})$$

$$S_1 = \min(S_{1UH} C_{R1}, S_{1D})$$

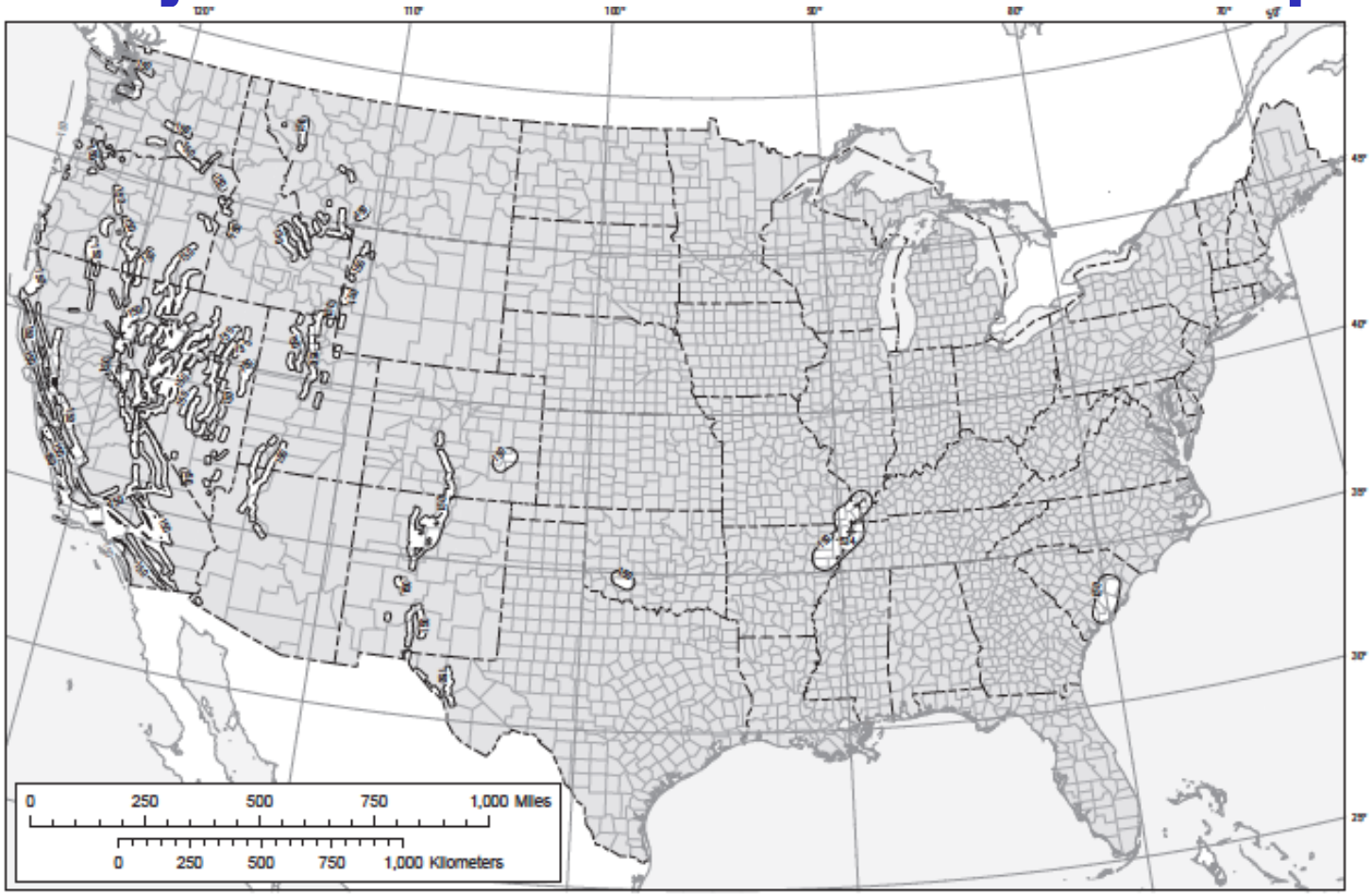


S_{UH} Maps (S_{1H} maps similar)



C_{RS} Maps (C_{R1} maps similar)

Adjustment for Deterministic Cap



S_{SD} Map (S_{1D} map is similar)

Deterministic Cap is 84th Percentile Ground Motion
But not less than 1.5g (S_{SD}) or 0.6g (S_{1D})

2009 NEHRP Intermediate Results

From Detailed Report

USGS Design Maps Detailed Report

Print View Summary Report

2009 NEHRP Recommended Seismic Provisions (47.65°N, 122.3°W)

Section 11.4.1 — Mapped Acceleration Parameters and Risk Coefficients

Note: Ground motion values contoured on Figures 22-1, 2, 5, & 6 below are for the direction of maximum horizontal spectral response acceleration. They have been converted from corresponding geometric mean ground motions computed by the USGS by applying factors of 1.1 (to obtain S_{SUH} and S_{SD}) and 1.3 (to obtain S_{1UH} and S_{1D}). Maps in the 2009 NEHRP Provisions are provided for Site Class B. Adjustments for other Site Classes are made, as needed, in Section 11.4.3.

Figure 22–1: Uniform–Hazard (2% in 50–Year) Ground Motions of 0.2-Second Spectral Response Acceleration (5% of Critical Damping), Site Class B

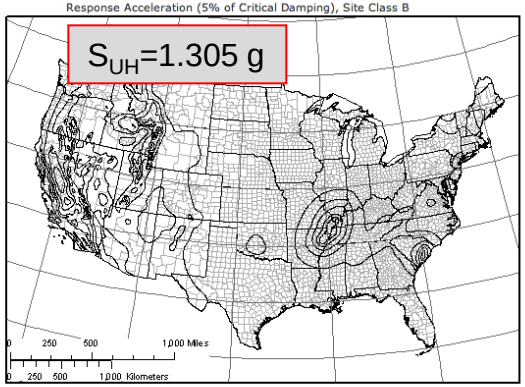


Figure 22–2: Uniform–Hazard (2% in 50–Year) Ground Motions of 1.0-Second Spectral Response Acceleration (5% of Critical Damping), Site Class B

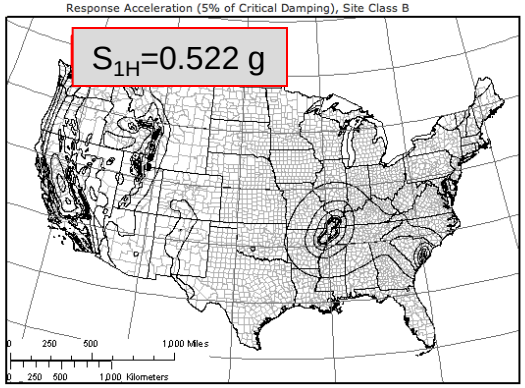


Figure 22–3: Risk Coefficient at 0.2-Second Spectral Response Period

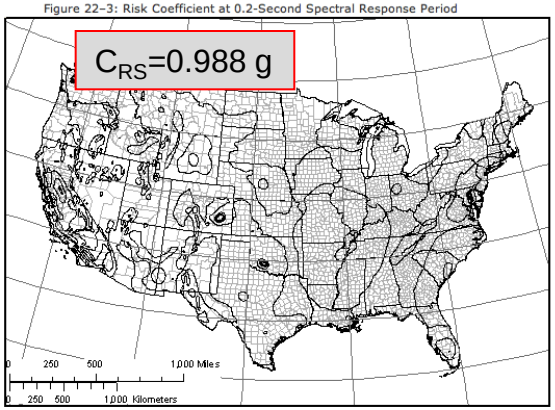


Figure 22–4: Risk Coefficient at 1.0-Second Spectral Response Period

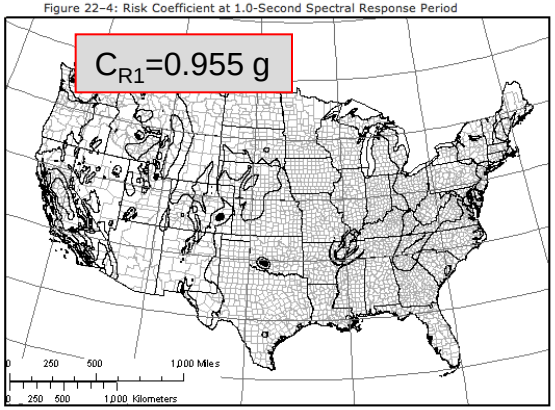


Figure 22–5: Deterministic Ground Motions of 0.2-Second Spectral Response Acceleration (5% of Critical Damping), Site Class B

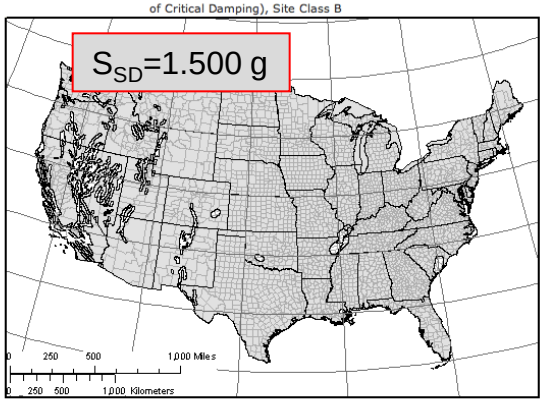
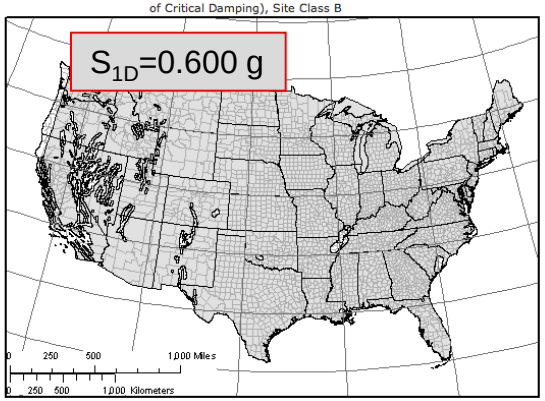


Figure 22–6: Deterministic Ground Motions of 1.0-Second Spectral Response Acceleration (5% of Critical Damping), Site Class B



$$S_S = \min(S_{SUH} C_{RS}, S_{SD}) = \min(1.305 \times 0.988, 1.5) = 1.289g$$

$$S_1 = \min(S_{1UH} C_{R1}, S_{1D}) = \min(0.522 \times 0.955, 0.6) = 0.498g$$

2009 NEHRP Results

From Standard Report

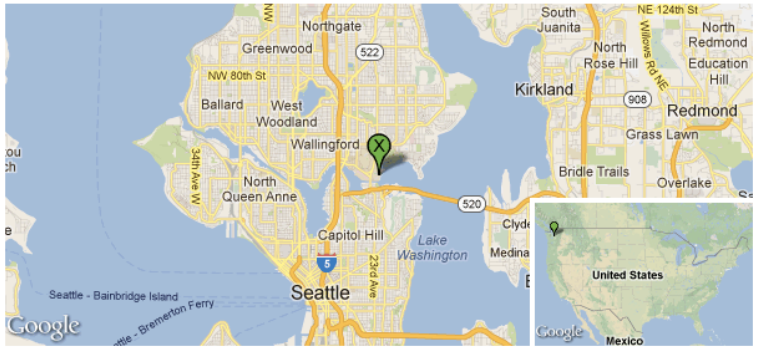
Design Maps Summary Report

USGS Design Maps Summary Report

Print View Detailed Report

User-Specified Input

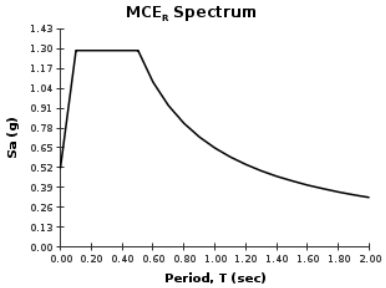
Report Title	DESIGN EXAMPLES Sat December 15, 2012 15:05:26 UTC
Building Code Reference Document	2009 NEHRP Recommended Seismic Provisions (which makes use of 2008 USGS hazard data)
Site Coordinates	47.65°N, 122.3°W
Site Soil Classification	Site Class C – "Very Dense Soil and Soft Rock"
Risk Category	I/II/III

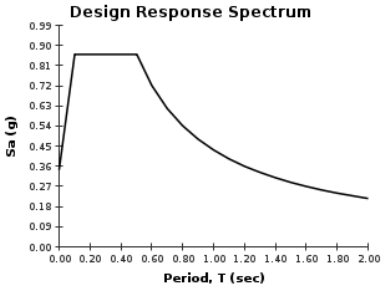


USGS-Provided Output

S_S =	1.289 g	S_{MS} =	1.289 g	S_{DS} =	0.860 g
S_1 =	0.498 g	S_{M1} =	0.649 g	S_{D1} =	0.433 g

For information on how the S_S and S_1 values above have been calculated from probabilistic (risk-targeted) and deterministic ground motions in the direction of maximum horizontal response, please view the detailed report.





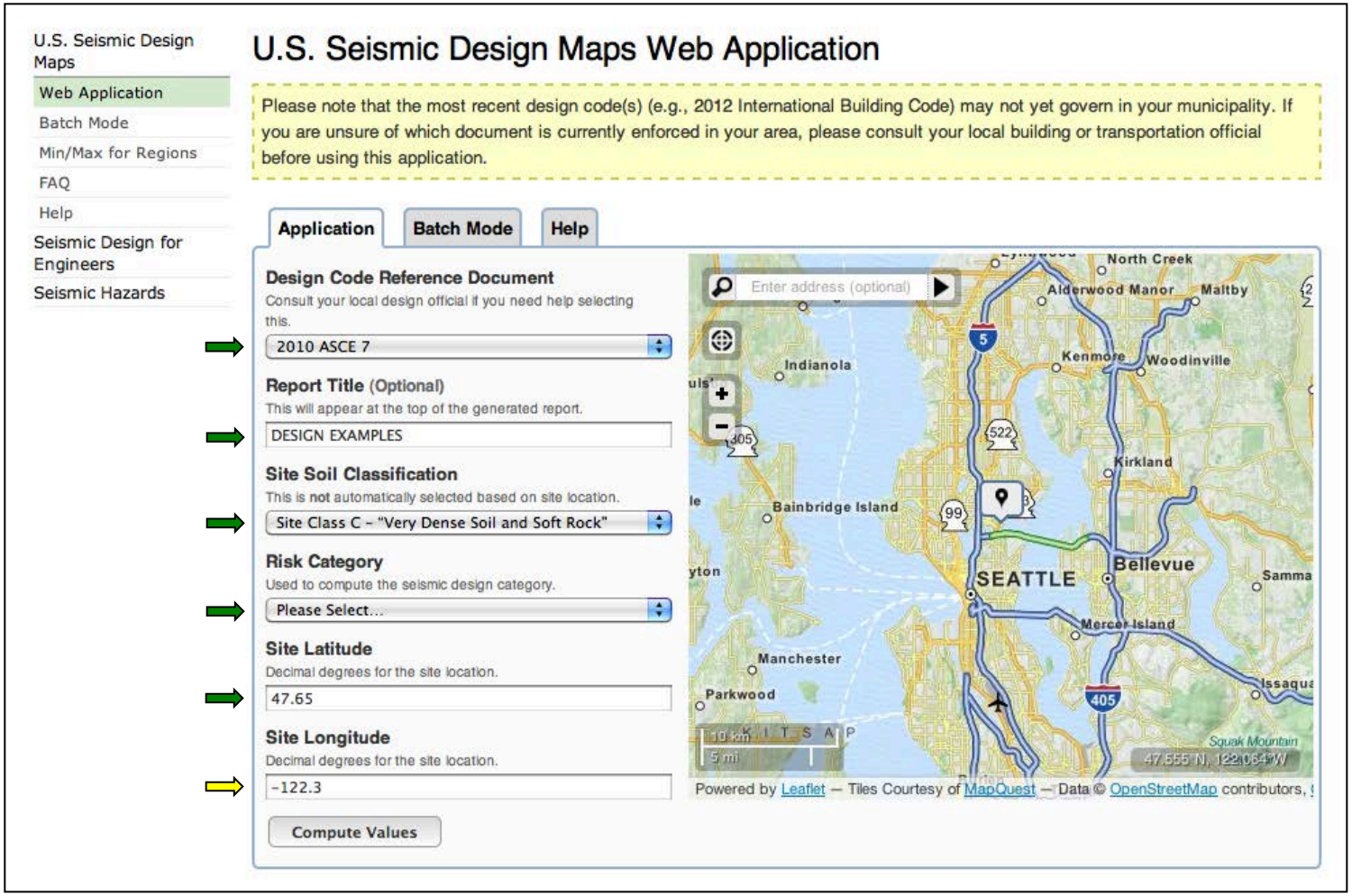
For PGA_M, T_L, C_{RS}, and C_{R1} values, please view the detailed report.

S_s=1.289g
S_1=0.498g

Summary of Differences between 2009 NEHRP and ASCE 7-10 Approaches

- NEHRP Starts with maximum direction maps and a uniform hazard and provides explicit values (C_{RS} and C_{R1}) for adjust to uniform risk.
- NEHRP Provides maps for deterministic cap
- When using NEHRP the user must manually (or via web utility) convert to MCE_R values.
- ASCE 7-10 Provides MCE_R values **Directly**

Using the USGS Utility: ASCE 7-10



ASCE 7-10 Results

From Standard Report

USGS Design Maps Summary Report

Print View Detailed Report

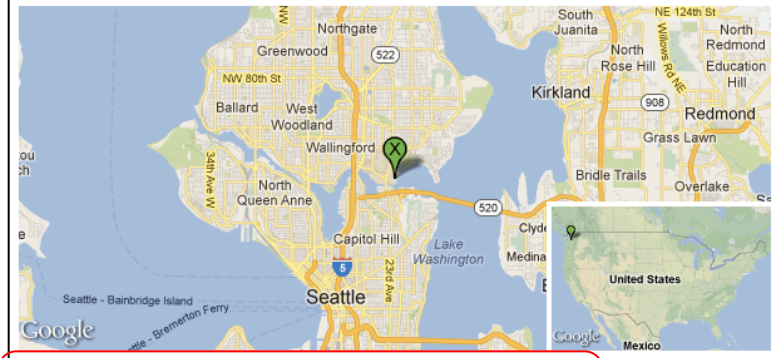
User–Specified Input

Report Title DESIGN EXAMPLES
Sat December 15, 2012 15:38:11 UTC

Building Code Reference Document ASCE 7-10 Standard
(which makes use of 2008 USGS hazard data)

Site Coordinates 47.65°N, 122.3°W

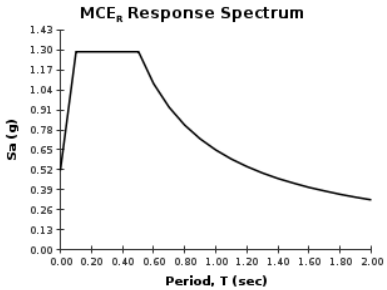
Site Soil Classification Site Class C – "Very Dense Soil and Soft Rock"

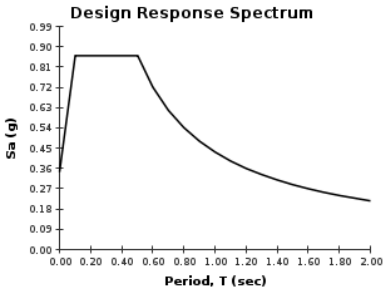


USGS–Provided Output

S_S =	1.289 g	S_{MS} =	1.289 g	S_{DS} =	0.860 g
S_1 =	0.498 g	S_{M1} =	0.649 g	S_{D1} =	0.433 g

For information on how the SS and S1 values above have been calculated from probabilistic (risk-targeted) and deterministic ground motions in the direction of maximum horizontal response, please return to the application and select the "2009 NEHRP" building code reference document.





For PGA_M, T_L, C_{RS}, and C_{R1} values, please view the detailed report.

From Detailed Report

USGS Design Maps Detailed Report

Print View Summary Report

ASCE 7-10 Standard (47.65°N, 122.3°W)

Section 11.4.1 — Mapped Acceleration Parameters

Note: Ground motion values provided below are for the direction of maximum horizontal spectral response acceleration. They have been converted from corresponding geometric mean ground motions computed by the USGS by applying factors of 1.1 (to obtain S_S) and 1.3 (to obtain S_1). Maps in the 2010 ASCE-7 Standard are provided for Site Class B. Adjustments for other Site Classes are made, as needed, in Section 11.4.3.

From Figure 22-1	S_S = 1.289 g
From Figure 22-2	S_1 = 0.498 g

S_s=1.289g
S_1=0.498g

Adjusting for Site Effects
2009 NEHRP and ASCE 7-10

From Detailed Report

Section 11.4.2 — Site Class

The authority having jurisdiction (not the USGS), site-specific geotechnical data, and/or the default has classified the site as Site Class C, based on the site soil properties in accordance with Chapter 20.

Table 20.3–1 Site Classification

Site Class	$\bar{v}_s$	$\bar{N}$ or $\bar{N}_{ch}$	$\bar{s}_u$
A. Hard Rock	>5,000 ft/s	N/A	N/A
B. Rock	2,500 to 5,000 ft/s	N/A	N/A
C. Very dense soil and soft rock	1,200 to 2,500 ft/s	>50	>2,000 psf
D. Stiff Soil	600 to 1,200 ft/s	15 to 50	1,000 to 2,000 psf
E. Soft clay soil	<600 ft/s	<15	<1,000 psf
	Any profile with more than 10 ft of soil having the characteristics: • Plasticity index $PI > 20$, • Moisture content $w \geq 40\%$, and • Undrained shear strength $\bar{s}_u < 500$ psf		
F. Soils requiring site response analysis in accordance with Section 21.1	See Section 20.3.1		

For SI: 1ft/s = 0.3048 m/s 1lb/ft² = 0.0479 kN/m²

Section 11.4.3 — Site Coefficients and Risk–Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameters

Table 11.4–1: Site Coefficient F_a

Site Class	Mapped MCE_R Spectral Response Acceleration Parameter at Short Period				
	$S_S \leq 0.25$	$S_S = 0.5$	$S_S = 0.75$	$S_S = 1$	$S_S \geq 1.25$
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	See Section 11.4.7 of ASCE 7				

Note: Use straight–line interpolation for intermediate values of S_S

For Site Class = C and S_s = 1.289 g, F_a = 1.000

Table 11.4–2: Site Coefficient F_v

Site Class	Mapped MCE_R Spectral Response Acceleration Parameter at 1–s 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	See Section 11.4.7 of ASCE 7				

Note: Use straight–line interpolation for intermediate values of S_1

For Site Class = C and S_1 = 0.498 g, F_v = 1.302

Equation (11.4–1):	$S_{MS} = F_a S_S = 1.000 \times 1.289 = 1.289$ g
Equation (11.4–2):	$S_{M1} = F_v S_1 = 1.302 \times 0.498 = 0.649$ g

Section 11.4.4 — Design Spectral Acceleration Parameters

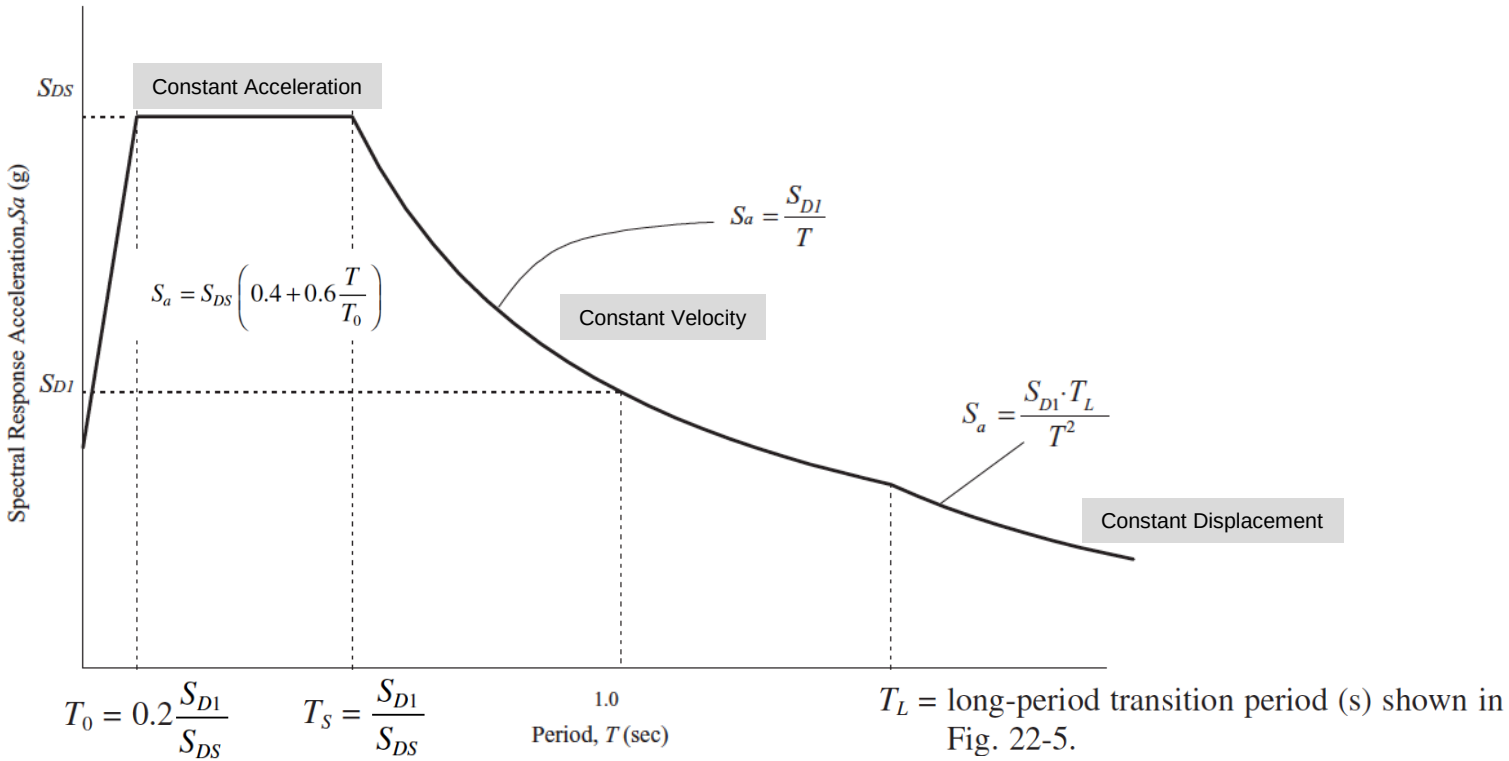
Equation (11.4–3):	$S_{DS} = ⅔\, S_{MS} = ⅔ \times 1.289 = 0.860$ g
Equation (11.4–4):	$S_{D1} = ⅔\, S_{M1} = ⅔ \times 0.649 = 0.433$ g

S_{DS}=0.860g
S_{D1}=0.433g

Topics Covered

- 2008 USGS Uniform Hazard Maps
- 2009 NEHRP *Provisions* Maps
- ASCE 7-10 Seismic Maps
- **Horizontal Response Spectra**
- **Vertical Response Spectra**
- **Peak Ground Acceleration**
- Selection and Scaling of Ground Motions

Development of Design Spectrum



Development of Design Spectrum

S_{DS}=0.860g
S_{D1}=0.433g

$$T_s = \frac{S_{D1}}{S_{DS}} = \frac{0.860}{0.433} = 0.503\,s$$

$$T_0 = 0.2T_s = 0.2(0.503) = 0.10\,s$$

T_L=6 s *(from map)*

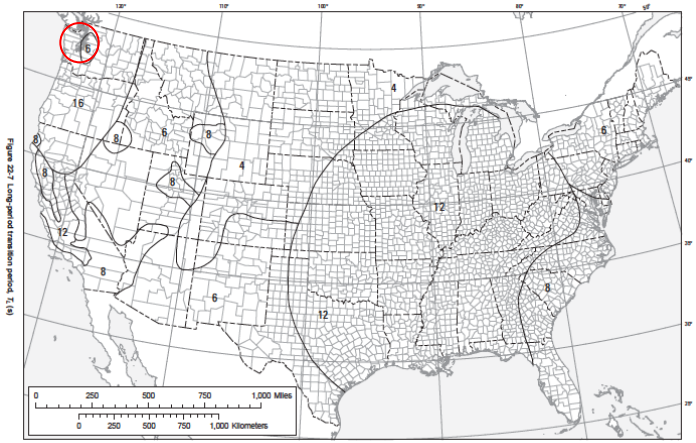
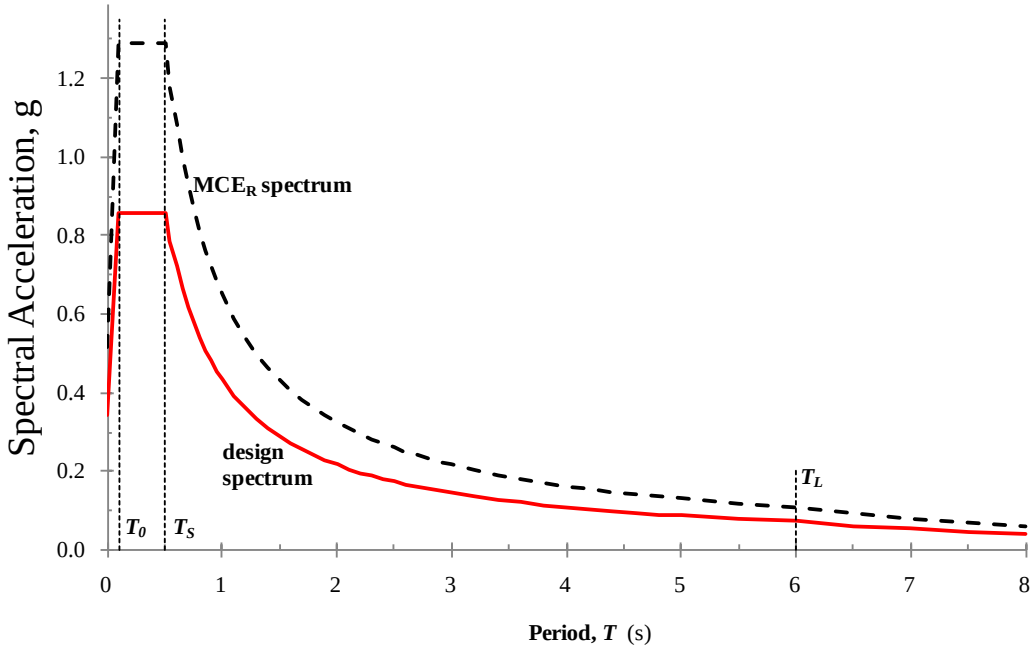


Fig. 22-7 Long Period Transition Maps

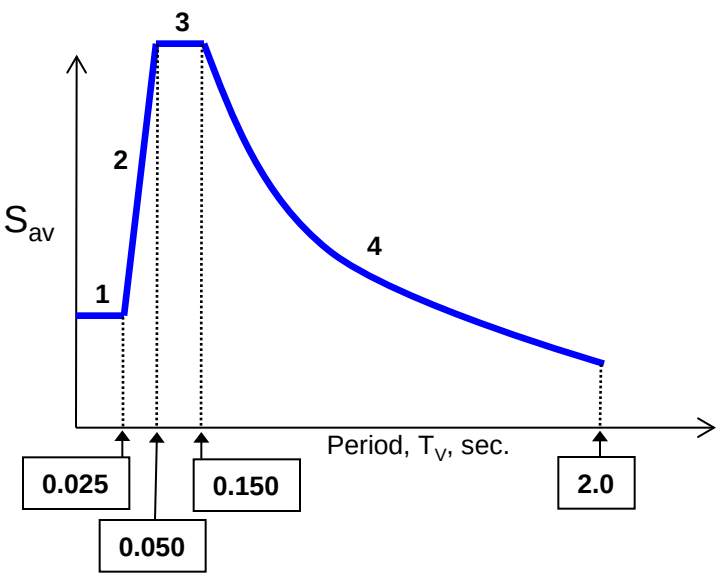


S_a @ T=0= 0.4(S_{DS})=0.4(0.860)=0.344g

Vertical Response Spectra

- New Chapter 23 of NEHRP Provisions
- Not yet incorporated into ASCE 7

Spectrum has Four Braches:



1 $$S_{av} = 0.3 C_v S_{DS}$$

2 $$S_{av} = 20 C_v S_{DS} (T_V - 0.025) + 0.3 C_v S_{DS}$$

3 $$S_{av} = 0.8 C_v S_{DS}$$

4 $$S_{av} = 0.8 C_v S_{DS} \left(\frac{0.15}{T_V} \right)^{0.75}$$

Table 23.1-1 Values of Vertical Coefficient C_V

MCE_R Spectral Response Parameter at Short Periods [a]	Site Class A, B	Site Class C	Site Class D, E, F
$S_s \geq 2.0$	0.9	1.3	1.5
$S_S = 1.0$	0.9	1.1	1.3
$S_S = 0.6$	0.9	1.0	1.1
$S_S = 0.3$	0.8	0.8	0.9
$S_S \leq 0.2$	0.7	0.7	0.7

[a] Use straight-line interpolation for intermediate values of S_S.

Vertical Response Spectra

For current example S_S=1.389g, S_{DS}=0.859g, Site Class D

$$S_{av} = 0.3C_v S_{DS} = 0.3(1.158)(0.859) = 0.298$$

$$S_{av} = 0.8C_v S_{DS} = 0.8(1.158)(0.859) = 0.796$$

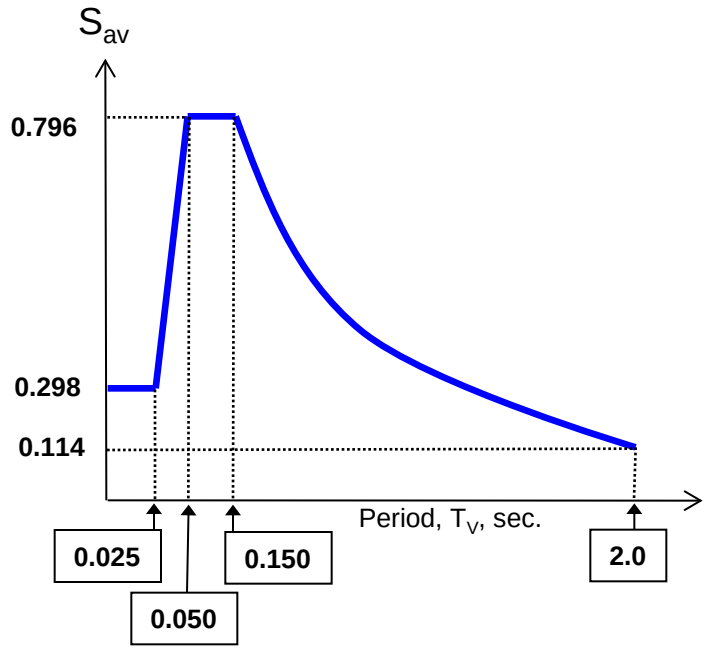
$$S_{av} = 0.8C_v S_{DS}\left(\frac{0.15}{T_V}\right)^{0.75} = 0.8(1.158)(0.859)\left(\frac{0.15}{2.0}\right)^{0.75} = 0.114$$

Table 23.1-1 Values of Vertical Coefficient C_V

MCE_R Spectral Response Parameter at Short Periods [a]	Site Class A, B	Site Class C	Site Class D, E, F
$S_s \geq 2.0$	0.9	1.3	1.5
$S_S = 1.0$	0.9	1.1	1.3
$S_S = 0.6$	0.9	1.0	1.1
$S_S = 0.3$	0.8	0.8	0.9
$S_S \leq 0.2$	0.7	0.7	0.7

[a] Use straight-line interpolation for intermediate values of S_S.

Interpolation gives C_V=1.158



Note: This is the DBE Spectra. Multiply all accelerations by 1.5 to obtain MCE Spectra

Peak Ground Acceleration

Section 11.8.3 of ASCE 7-10:

$$PGA_M = F_{PGA} PGA$$

Table 11.8-1 Site Coefficient F_{PGA}

	Mapped Maximum Considered Geometric Mean (MCE_G) Peak Ground Acceleration, PGA				
Site Class	PGA ≤ 0.1	PGA = 0.2	PGA = 0.3	PGA = 0.4	PGA ≥ 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	1.2	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	See Section 11.4.7				

Note: Use straight-line interpolation for intermediate values of PGA.

Peak Ground Acceleration

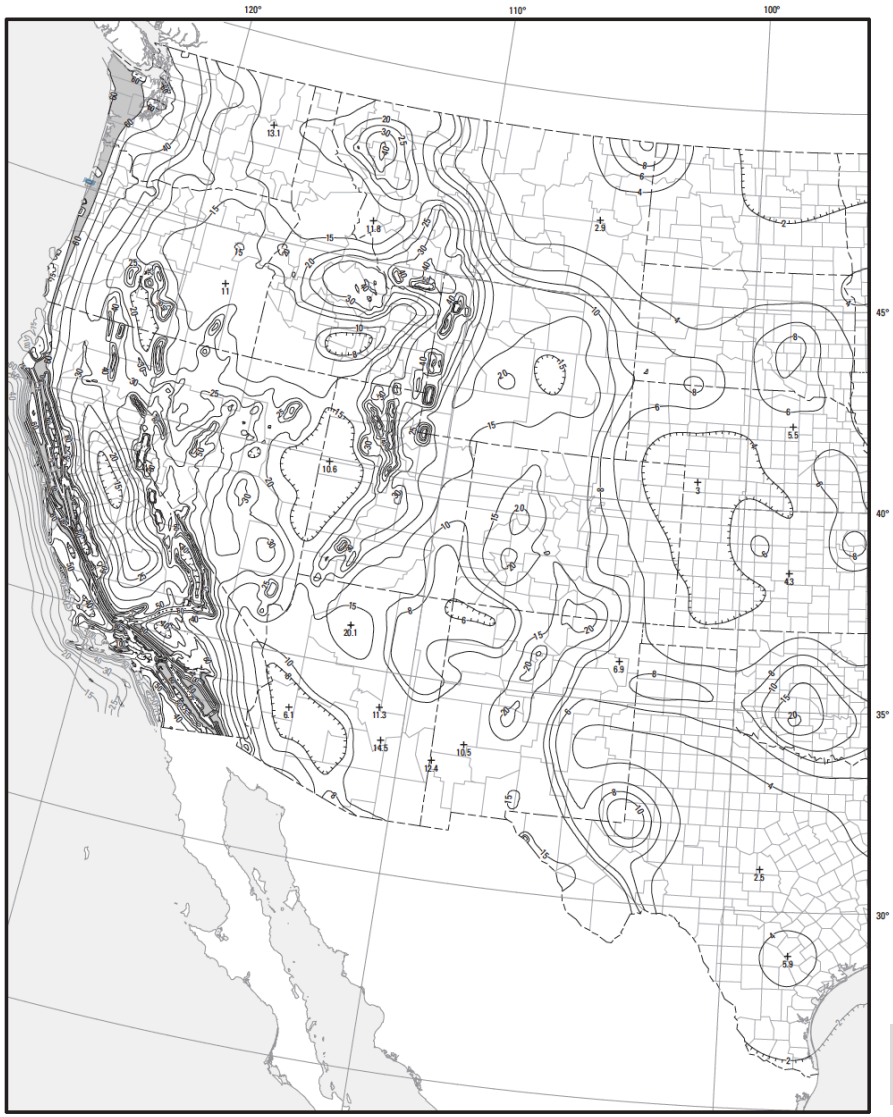


Figure 22-8 MCE geometric mean PGA, %g, Site Class B for the conterminous United States

Results from USGS Design Maps Utility (Detailed Report) for Seattle Location

From Figure 22-7 PGA=0.521 g

Equation (11.8–1): $PGA_M = F_{PGA}PGA = 1.000 \times 0.521 = 0.521$ g

Table 11.8–1: Site Coefficient F_{PGA}

Site Class	Mapped MCE Geometric Mean Peak Ground Acceleration, PGA				
	PGA ≤ 0.1	PGA = 0.2	PGA = 0.3	PGA = 0.4	PGA ≥ 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	1.2	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	See Section 11.4.7 of ASCE 7				

Note: Use straight–line interpolation for intermediate values of PGA

For Site Class = C and PGA = 0.521 g, F_{PGA}=1.0

$$PGA_M = F_{PGA}PGA = 1.0 \times 0.521 = 0.521g$$

Note: This is the MCE PGA. Design PGA (where used) = (2/3) PGA_M

Topics Covered

- 2008 USGS Uniform Hazard Maps
- 2009 NEHRP *Provisions* Maps
- ASCE 7-10 Seismic Maps
- Horizontal Response Spectra
- Vertical Response Spectra
- Peak Ground Acceleration
- **Selection and Scaling of Ground Motions**

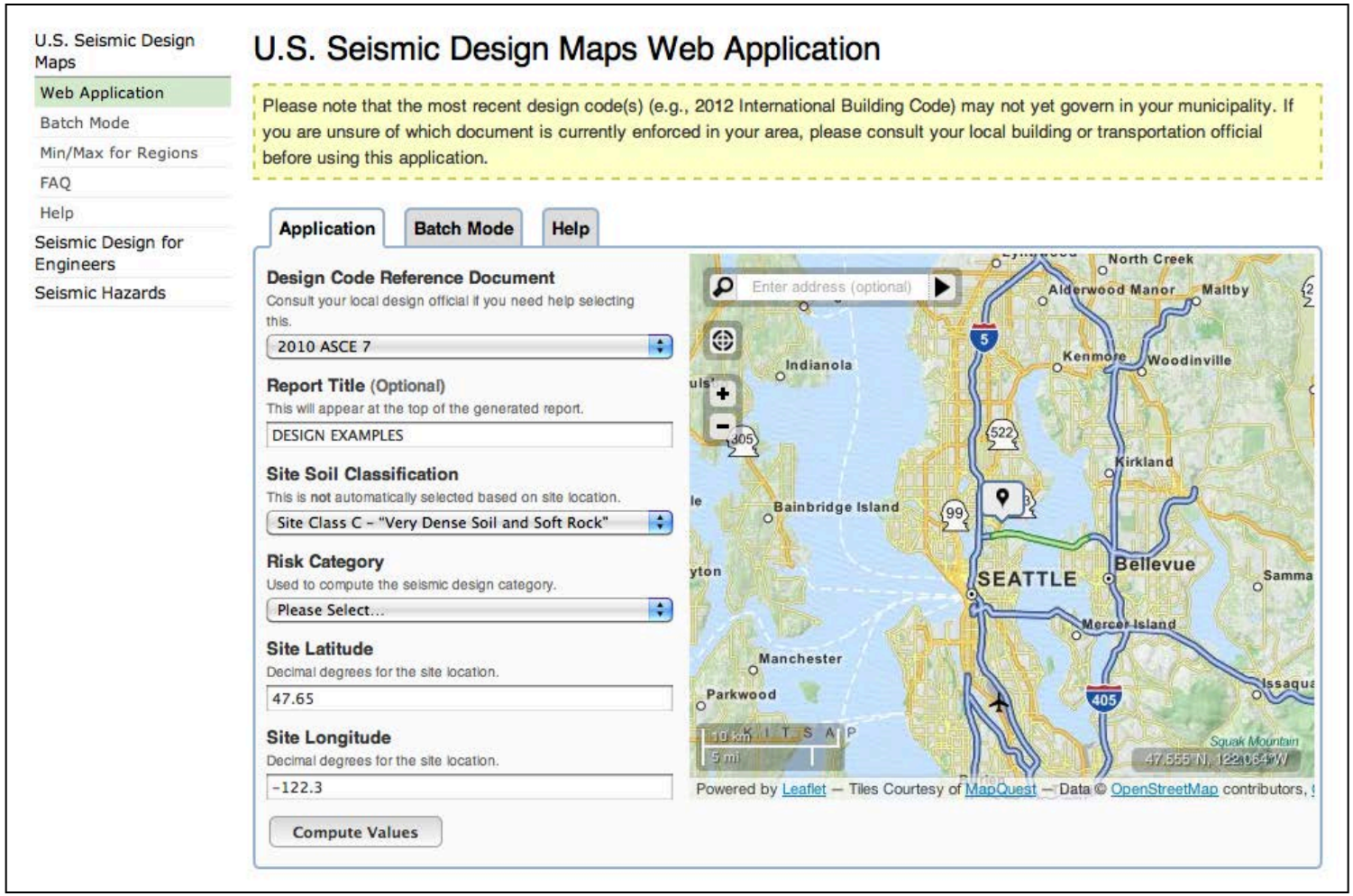
Selection and Scaling of Ground Motions

- Selection and Scaling procedures are Provided in Chapter 16 of ASCE 7-10: *Response History Analysis*
- Chapter 16 is usually used in association with nonlinear analysis of special structures or structures that do not conform to certain requirements (e.g. height limitations) in ASCE 7-10.
- This example will demonstrate procedure for a site in Seattle, Washington.
- Additional discussion of ground motion scaling and use in linear and nonlinear response history analysis is provided in Chapter 4 of P-751, *Structural Analysis.*

Ground Motion Nomenclature

- An "Event" refers to a given historical earthquake, such as the 1989 Loma Prieta California Earthquake
- A "Record" refers to the recorded ground acceleration histories at a particular recording station, such as the Saratoga-Aloha Ave. recording of the Loma Prieta event.
- Each record has (usually) three "Components" consisting of two (usually) orthogonal components and one vertical component. The horizontal components are often, but not always, oriented in N-S and E-W directions. In some cases fault-normal and fault-parallel values are provided. Records can be transformed to any direction (e.g. N-S and E-W recordings can be transformed to fault-normal and fault-parallel given the orientation of the fault.
- A "Suite" of ground motions consist of three or more records.

Location of Site

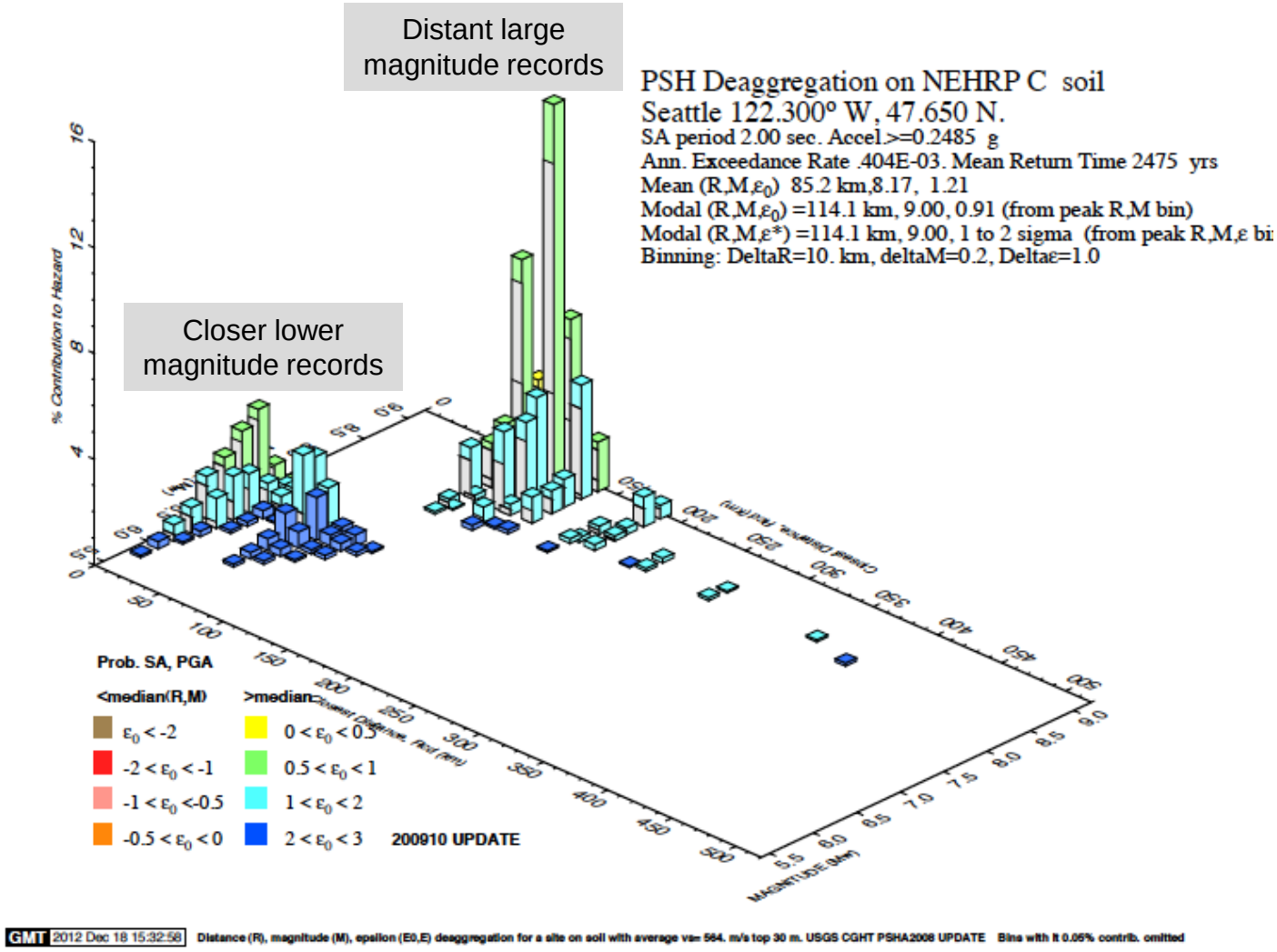


Selection of Appropriate Records

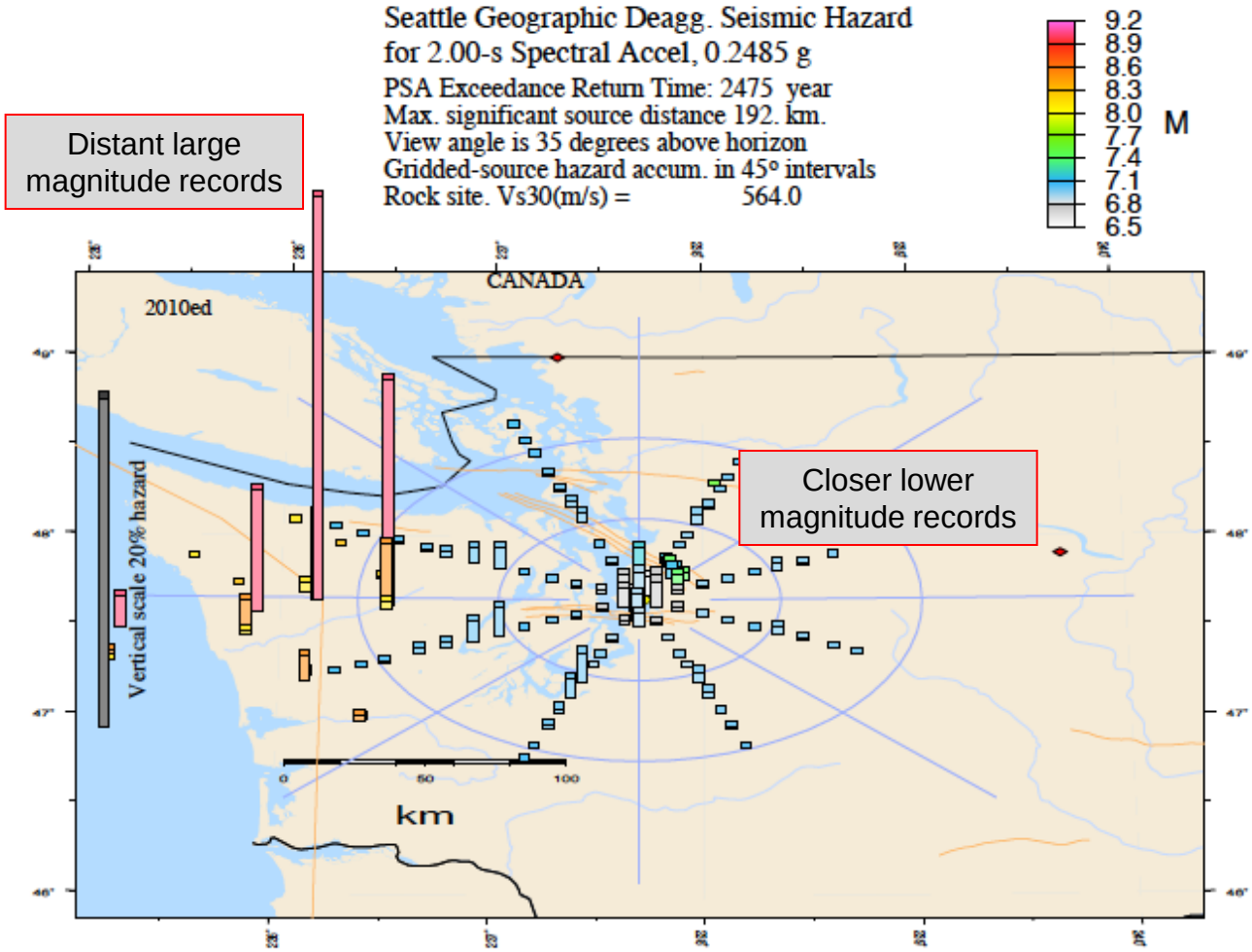
- Select from records of events having magnitude, fault distance, and source mechanisms that control the maximum considered earthquake (MCE)
- Pertinent information can be obtained from "Deaggregtion" of the seismic hazard

http://earthquake.usgs.gov/hazards/apps/#deaggint

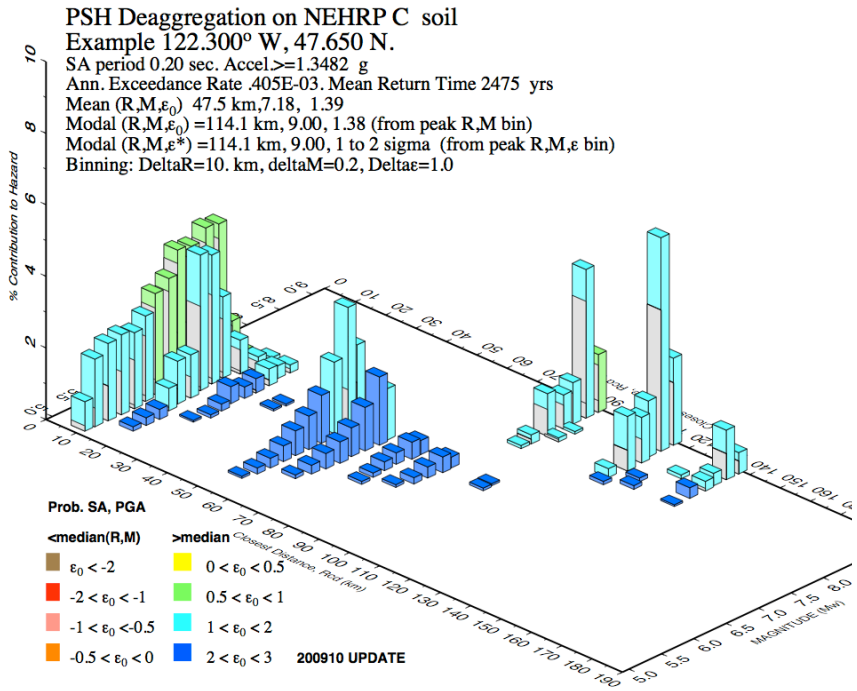
Deaggreagtion of Hazard (2.0 sec Accel)

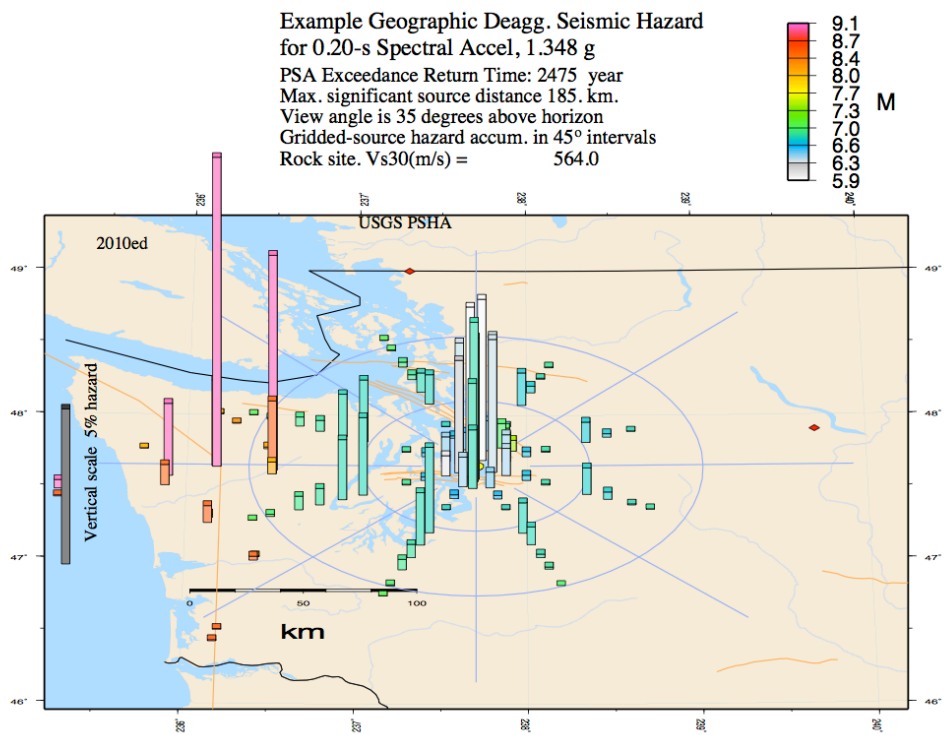


Deaggregation of Hazard (2.0 sec Accel)

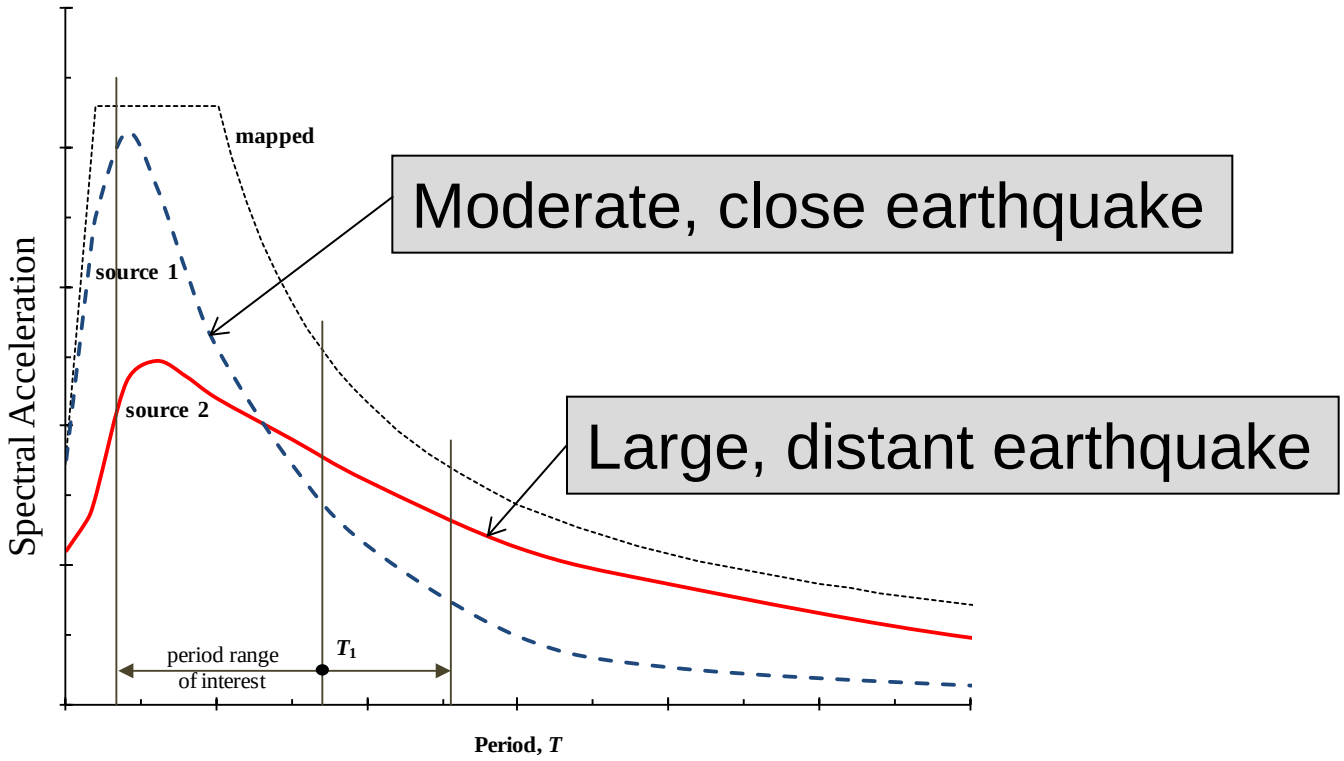


Deaggreagtion of Hazard (0.2 sec Accel)





Spectral Characteristics of Close and Far Records

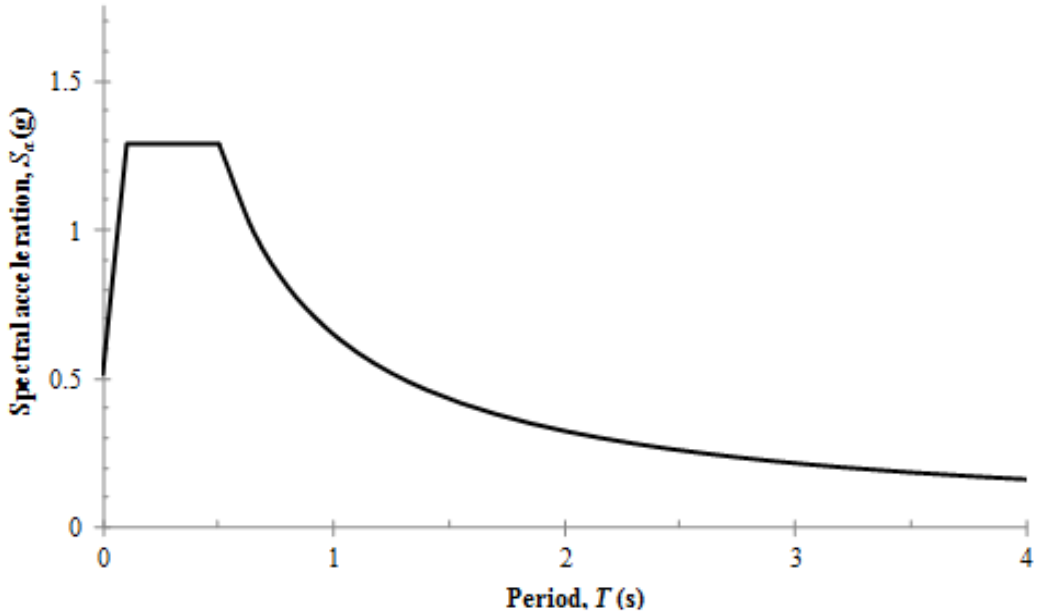


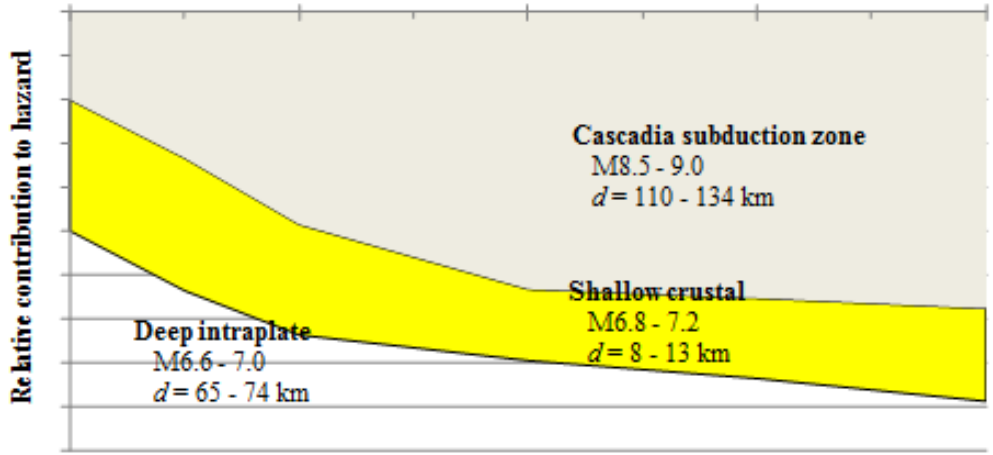
Deaggregation of Hazard (0.2 Sec Accel)

```
Principal sources (faults, subduction, random seismicity having > 3% contribution)
Source Category:                    % contr.  R(km)    M   epsilon0 (mean values).
Cascadia M8.3-M8.7 Floating           6.12   109.2   8.52    1.64
Cascadia Megathrust                  19.51   108.9   9.02    1.30
Wash-Oreg Cascades-West faults +     17.61    12.1   6.96    1.14
WUS Compr crustal gridded            17.51     9.4   6.14    1.13
50-km Deep Intraplate                21.72    60.6   6.79    2.07
Puget Lowlands gridded               16.55     9.4   6.32    1.03
Individual fault hazard details if its contribution to mean hazard > 2%:
Fault ID                            % contr.   Rcd(km)  M   epsilon0 Site-to-src azimuth(d)
Seattle fault zone, mid. GR           3.25    12.1   6.82    1.24    -172.2
Seattle fault zone, north, GR         5.14     9.9   6.82    1.01    -175.4
Seattle fault zone, N. Trace, Ch      4.55     8.0   7.16    0.72    -177.6
#*********End of deaggregation corresponding to Mean Hazard w/all GMPEs  *********#
```

Cascadia Subduction Zone=6.1+19.5=25.6%
Shallow Crustal=17.6+17.5=35.1%
Deep Intraplate=21.7+16.6=48.3%

Source Mechanisms for Selected Records





Scaling Requirements

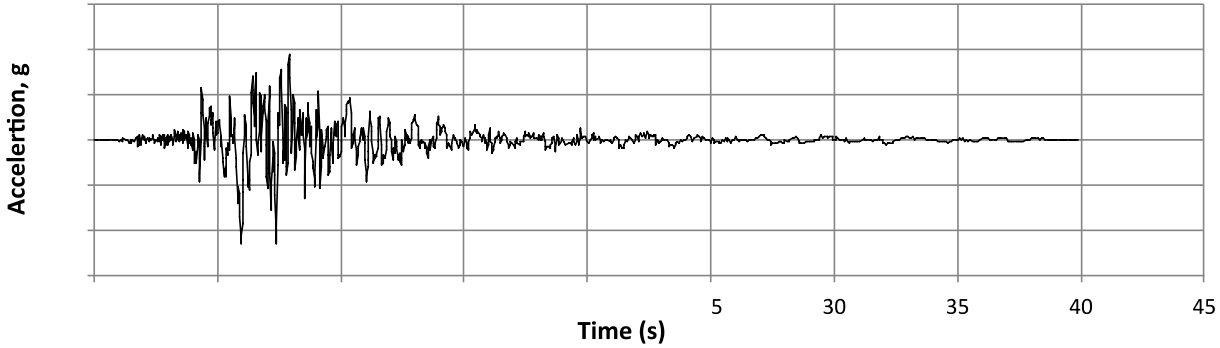
- 2D Analysis: The ground motions shall be scaled such that the average of the 5% damped response spectra is not less than the design spectrum over the period range 0.2T to 1.5T.
- 3D Analysis: The ground motions shall be scaled such that the average of the SRSS spectra from all horizontal component pairs does not fall below the design spectrum over the period range 0.2T to 1.5T.
- At sites within 5 km of the active fault each pair of components shall be rotated to fault-normal and fault-parallel directions and shall be scaled such that the ~~fault normal~~ dominant component is not less than the ~~MCE_R~~ design spectrum over the period range 0.2 to 1.5T.

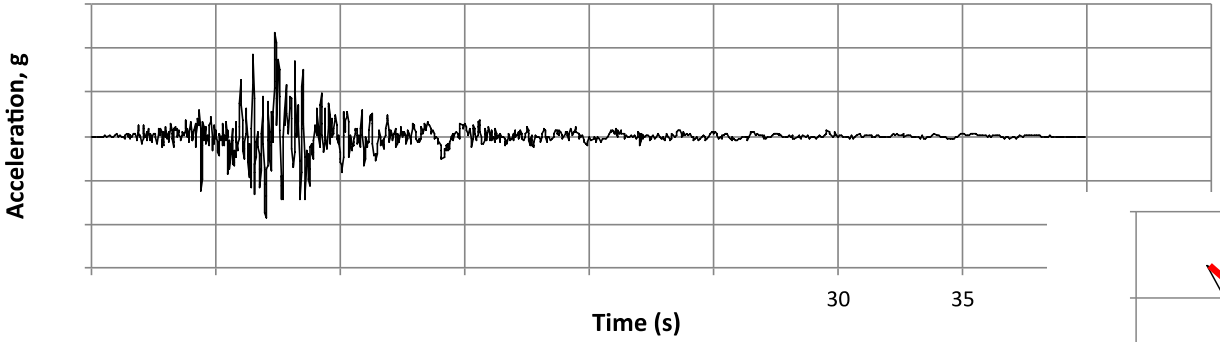
Ground Motion Scale Factors for 3D Analysis

Table 3-1 Selected and Scaled Ground Motions for Example Site

Record No.	Year	Earthquake name	M	Source type	Recording station	Distance (km)
1	2003	Tokachi-oki, Japan	8.3	Subduction zone	HKA 094	67
2	2003	Tokachi-oki, Japan	8.3	Subduction zone	HKD 092	46
3	1968	Tokachi-oki, Japan	8.2	Subduction zone	Hachinohe (S-252)	71
4	1949	Western Washington	7.1	Deep intraplate	Olympia	75
5	1989	Loma Prieta	6.9	Shallow crustal	Saratoga -- Aloha Ave	9
6	1999	Duzce, Turkey	7.1	Shallow crustal	Duzce	7
7	1995	Kobe, Japan	6.9	Shallow crustal	Nishi-Akashi	7

Components of the Northridge Earthquake



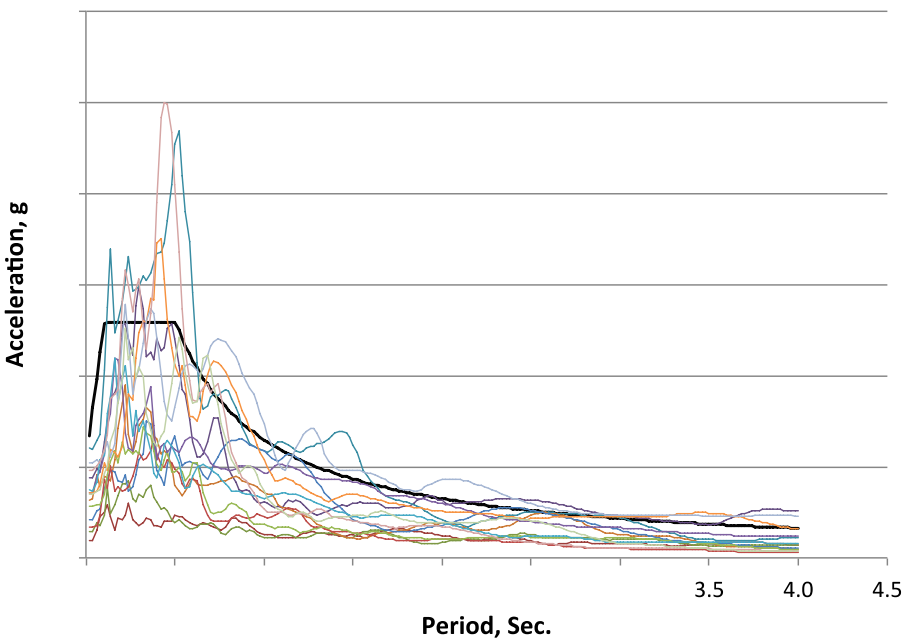


Ground Motion Spectra

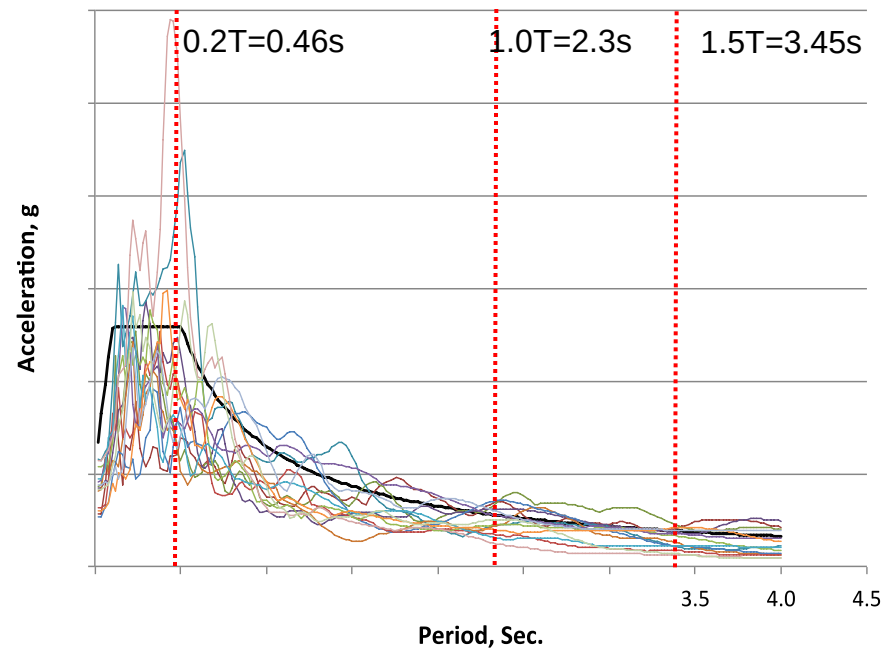
Table 3-1 Selected and Scaled Ground Motions for Example Site

Record No.	Year	Earthquake name	M	Source type	Recording station	Distance (km)	Scale factor
1	2003	Tokachi-oki, Japan	8.3	Subduction zone	HKA 094	67	2.99
2	2003	Tokachi-oki, Japan	8.3	Subduction zone	HKD 092	46	0.96
3	1968	Tokachi-oki, Japan	8.2	Subduction zone	Hachinohe (S-252)	71	1.28
4	1949	Western Washington	7.1	Deep intraplate	Olympia	75	1.92
5	1989	Loma Prieta	6.9	Shallow crustal	Saratoga – Aloha Ave	9	1.28
6	1999	Duzce, Turkey	7.1	Shallow crustal	Duzce	7	0.85
7	1995	Kobe, Japan	6.9	Shallow crustal	Nishi-Akashi	7	1.18

All Records, Unscaled

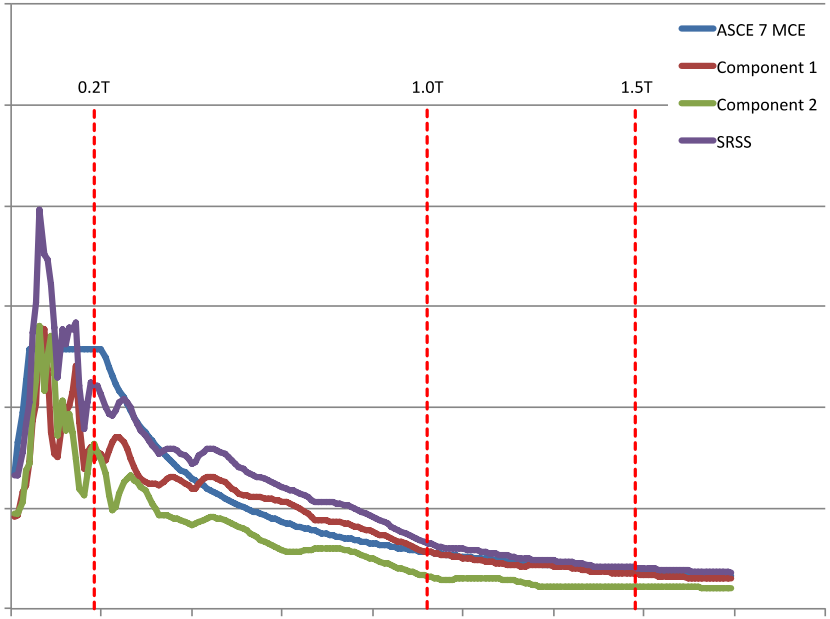


All Records, Scaled to MCE

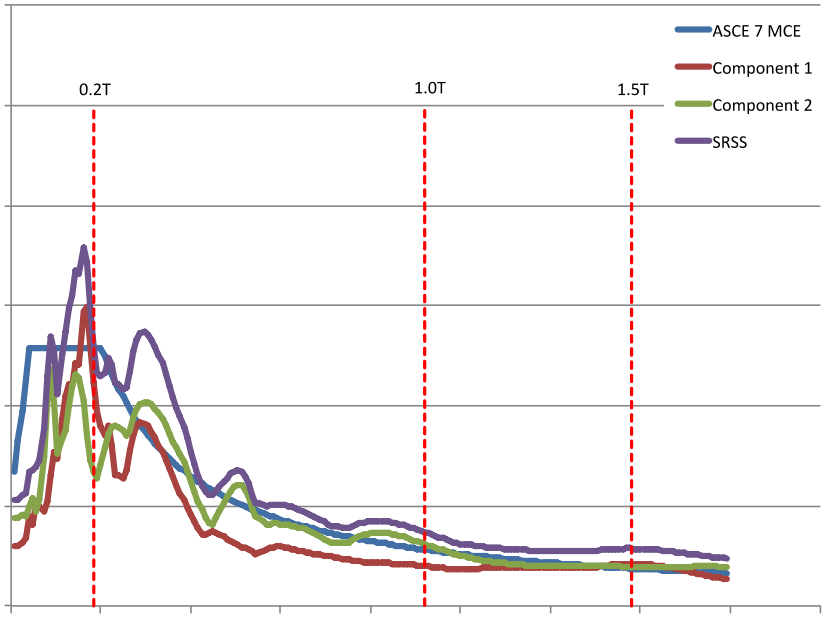


Response Spectra for Two Selected Scaled Motions

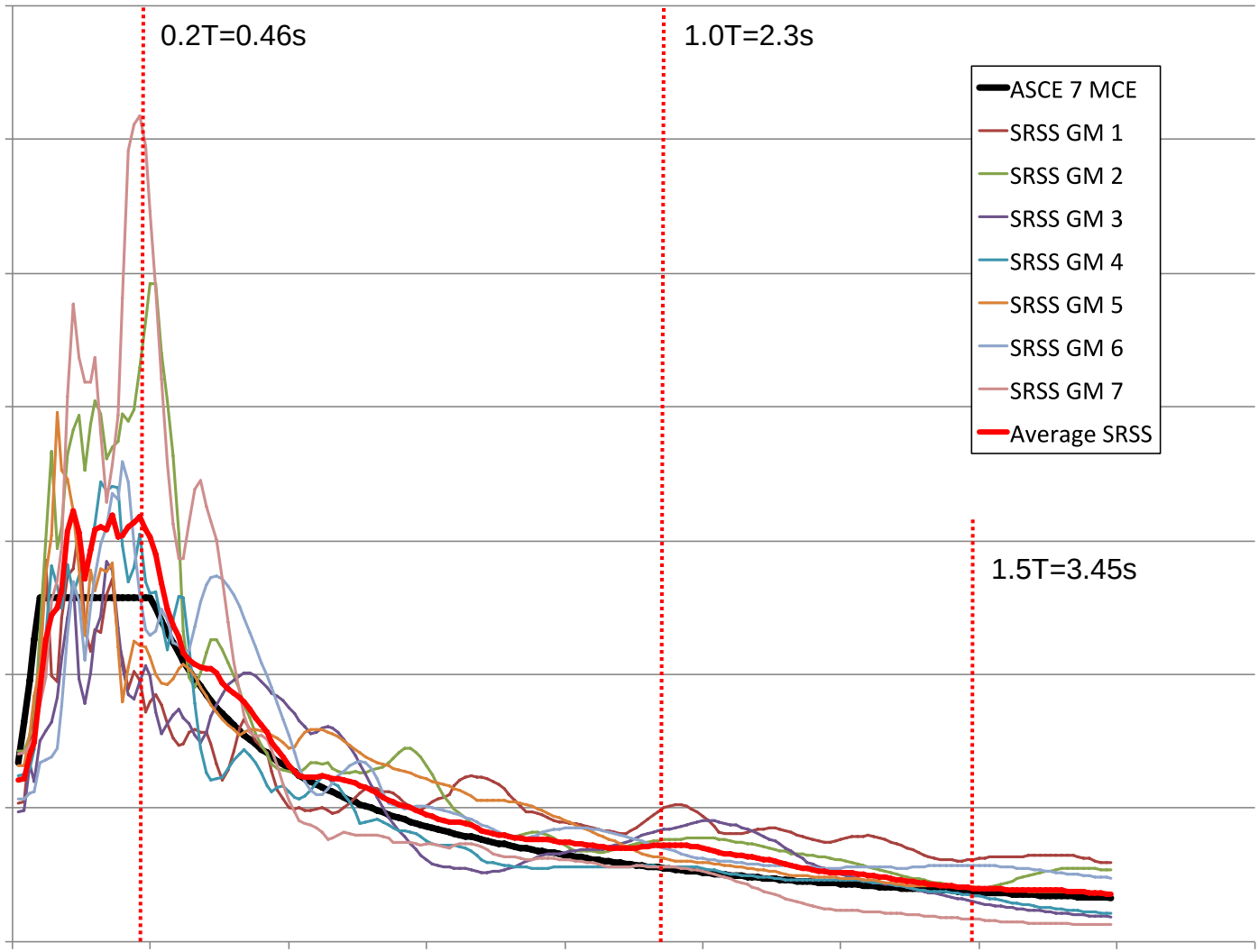
1989 Loma Prieta



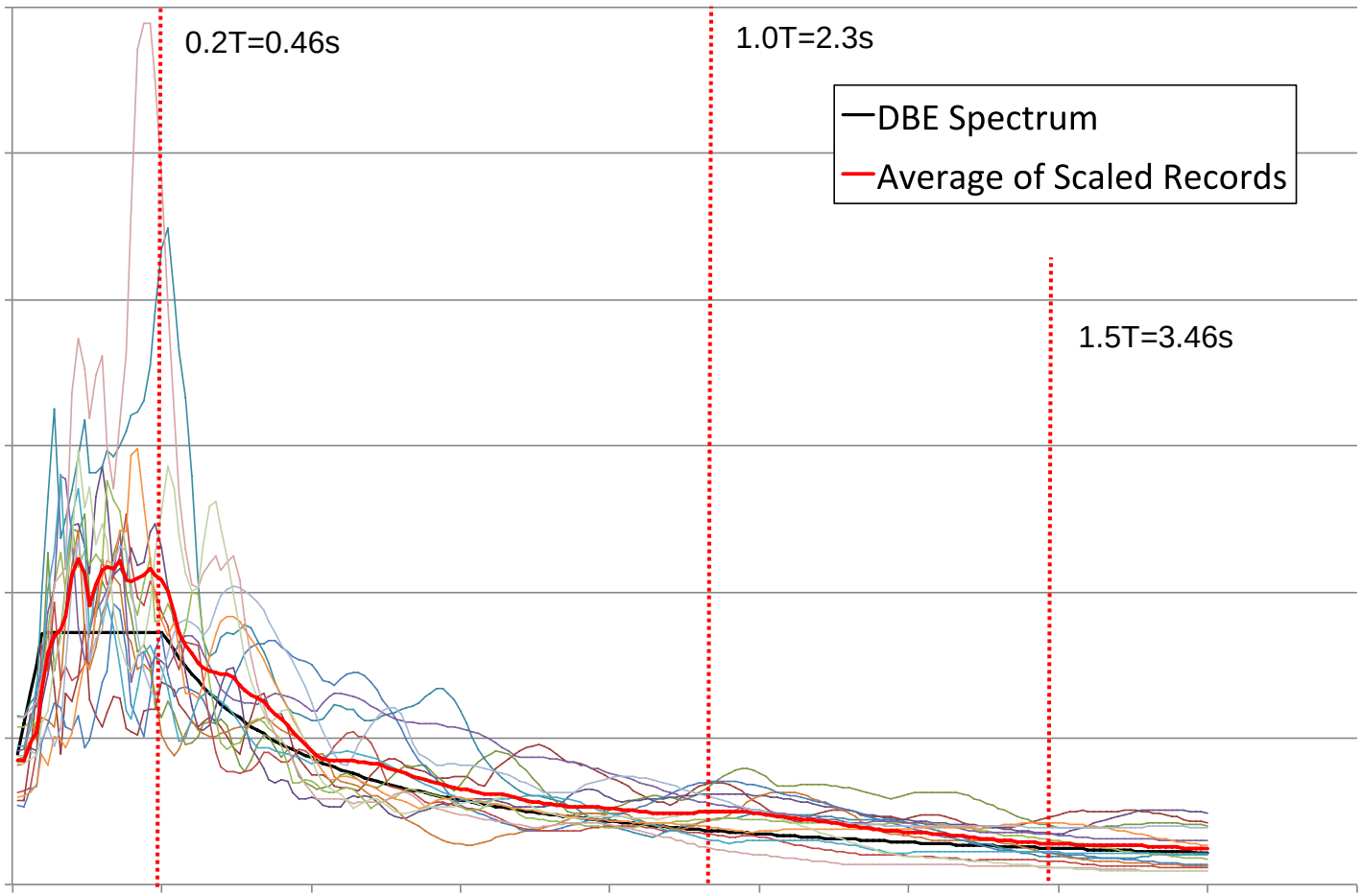
1999 Duzce, Turkey



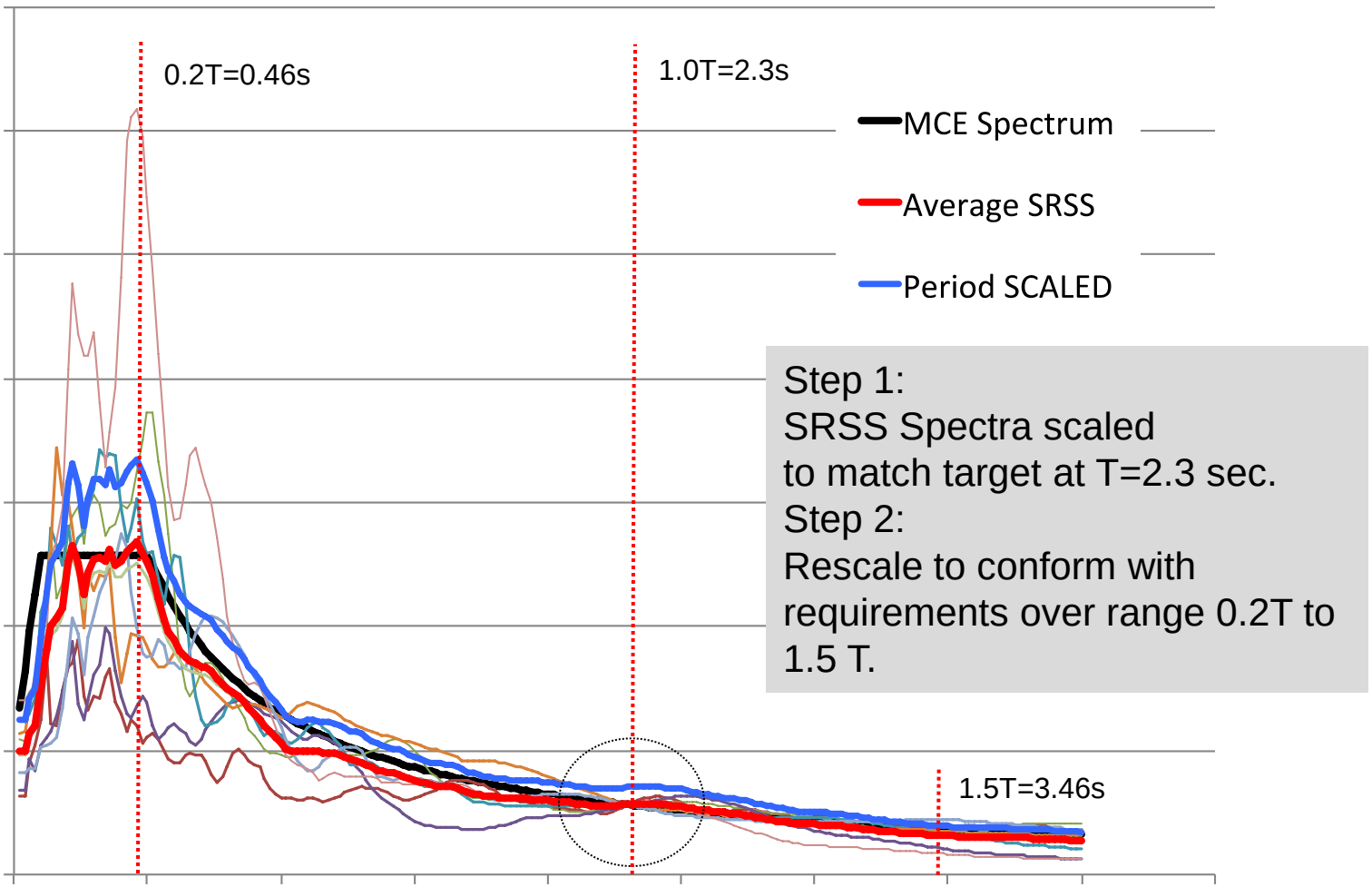
SRSS Scaled Spectra and MCE Spectrum



Scaled Records and DBE Spectrum

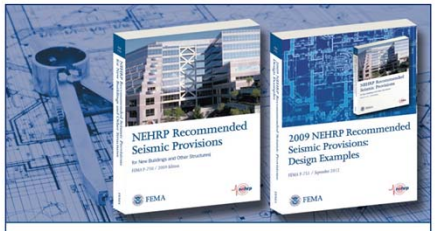


Alternate Scaling



Step 1:
SRSS Spectra scaled
to match target at T=2.3 sec.
Step 2:
Rescale to conform with
requirements over range 0.2T to
1.5 T.

Questions



2009 NEHRP Recommended Seismic Provisions:
Training and Instructional Materials

FEMA P-752 CD / June 2013

FEMA

3

Earthquake Ground Motion

Nicolas Luco, Ph.D., P.E., Michael Valley, S.E., and C.B. Crouse, P.E., Ph.D.

Slide set created by Finley A. Charney, Ph.D., P.E.

This topic covers Chapter 3 of FEMA P-751, Earthquake Ground Motion. The chapter is presented in two parts, the first being the theoretical basis of the 2008 USGS, the maps in 2009 NEHRP, and the maps in ASCE 7-10. The second part presents some examples for determining ground motion values for a site in Seattle, Washington. This slide sets is a based primarily on the examples. Note that most of the examples use various web-based utilities. It would be valuable for the instructor to have access to the internet so that the applications can be demonstrated live.

Topics Covered

- 2008 USGS Uniform Hazard Maps
- 2009 NEHRP *Provisions* Maps
- ASCE 7-10 Seismic Maps
- Determination of Ground Motion Values
- Horizontal Response Spectra
- Vertical Response Spectra
- Peak Ground Acceleration
- Selection and Scaling of Ground Motions

FEMA nehrp Instructional Material Complementing FEMA P-751, Design Examples Earthquake Ground Motions - 2

This slide presents a list of the topics covered.

Topics Covered

- **2008 USGS Uniform Hazard Maps**
- **2009 NEHRP *Provisions* Maps**
- **ASCE 7-10 Seismic Maps**
- Horizontal Response Spectra
- Vertical Response Spectra
- Peak Ground Acceleration
- Selection and Scaling of Ground Motions

FEMA nehrp Instructional Material Complementing FEMA P-751, Design Examples Earthquake Ground Motions - 3

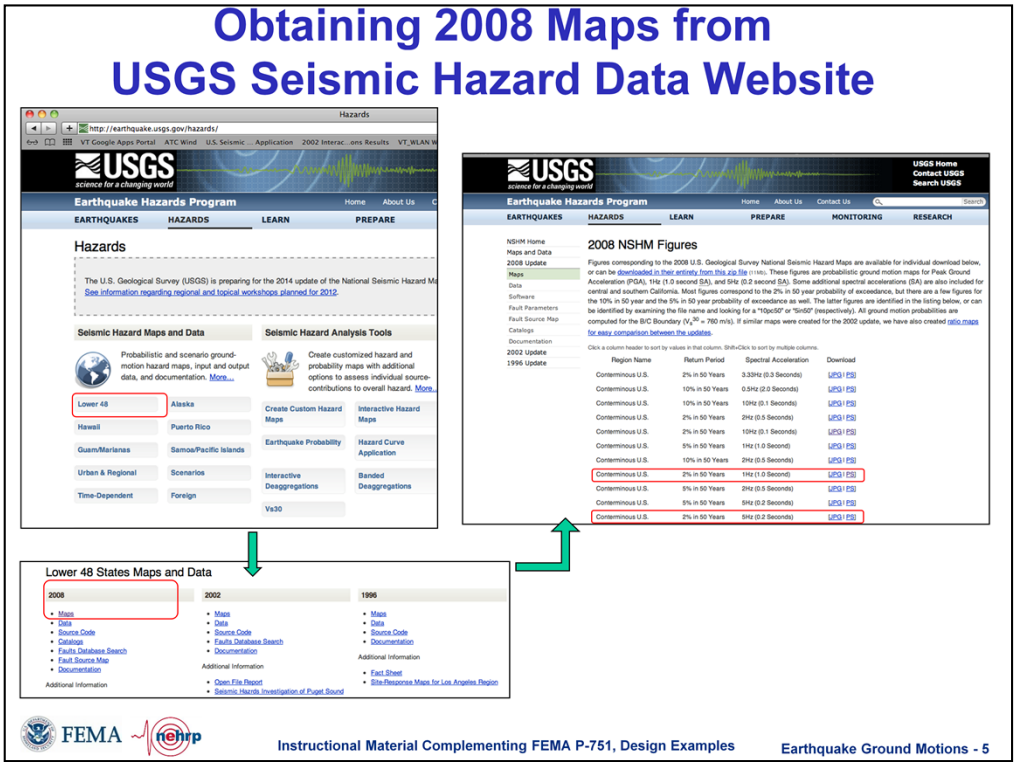
This slide presents a list of the first several topics covered.

2008 USGS Maps

- Probabilistic
- Uniform Hazard (e.g. 2% in 50 year probability)
- Spectral Contours (T=0, 0.1, 0.2 sec…)
- 5 % Damping
- Site Class B/C Boundary
- Geomean Values

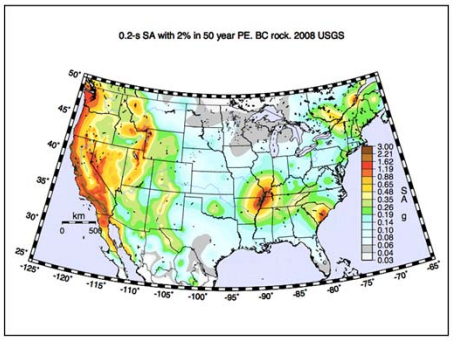
FEMA nehrp Instructional Material Complementing FEMA P-751, Design Examples Earthquake Ground Motions - 4

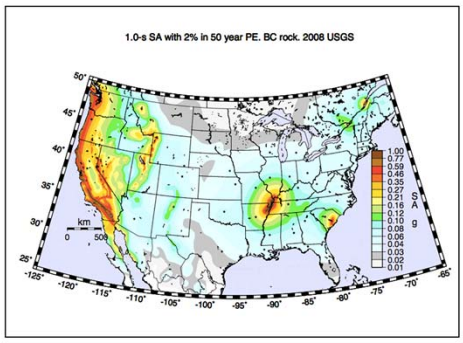
The maps in ASCE 7 and 2009 NEHRP are derived from the 2008 USGS maps. The USGS maps are purely probabilistic, represent a uniform hazard, and are based on geomean spectral values. The geomean is the square root of the product of the spectral values for the two components, at a particular period. The 2009 maps are split into three parts: Uniform hazard maps that have been converted to maximum direction ground motion, separate maps which provide coefficients to convert to uniform risk, and additional maps provide deterministic caps. This information must be combined to obtain the values of Ss and S1 that are provided directly by ASCE 7-10.



This slide shows a screen captured from a web site developed by USGS. In this instance the site was used to provide maps for the conterminous U.S. for a 2% in 50 year probability of occurrence. Maps for 0.2 second and 1.0 second periods are specified. Maps are then downloaded as PDF files or Postscript files.

2008 USGS Seismic Hazard Maps





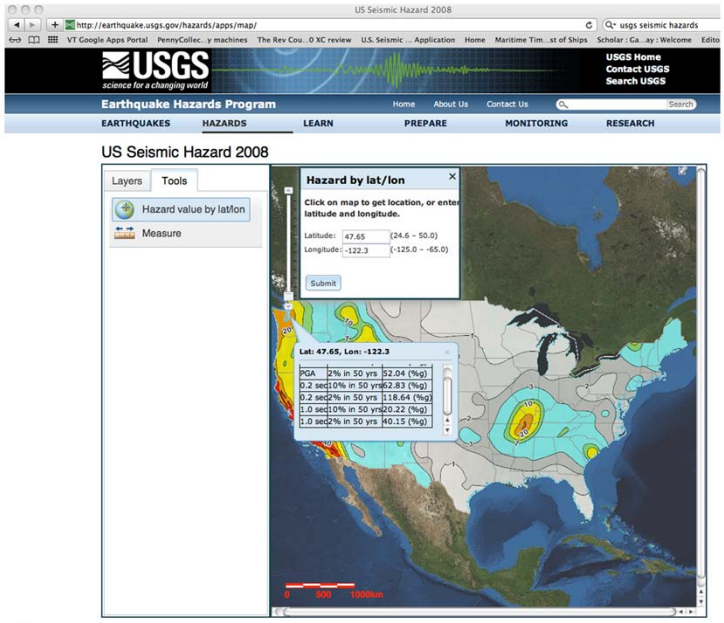
FEMA nehrp

Instructional Material Complementing FEMA P-751, Design Examples

Earthquake Ground Motions - 6

PDF files of the two requested maps are shown on this slide. Note that the maps are not particularly useful from a design perspective, but do show in some detail the distribution of shaking hazard across the U.S. In the western U.S. and certain areas in the central and eastern U.S. the ground shaking can be violent, with peak horizontal accelerations as high as 1.0 g. Peak ground acceleration is approximately 0.4 times the 0.2 second spectral acceleration. USGS also provide peak ground acceleration maps if needed.

Obtain Accelerations for Given Lat-Lon



For Lat = 47.65
Lon = -122.3
2% in 50 year
GEOMEAN values:
PGA=0.520 g
0.2 sec=1.186 g
1.0 sec=0.4015 g

FEMA nehrp

Instructional Material Complementing FEMA P-751, Design Examples

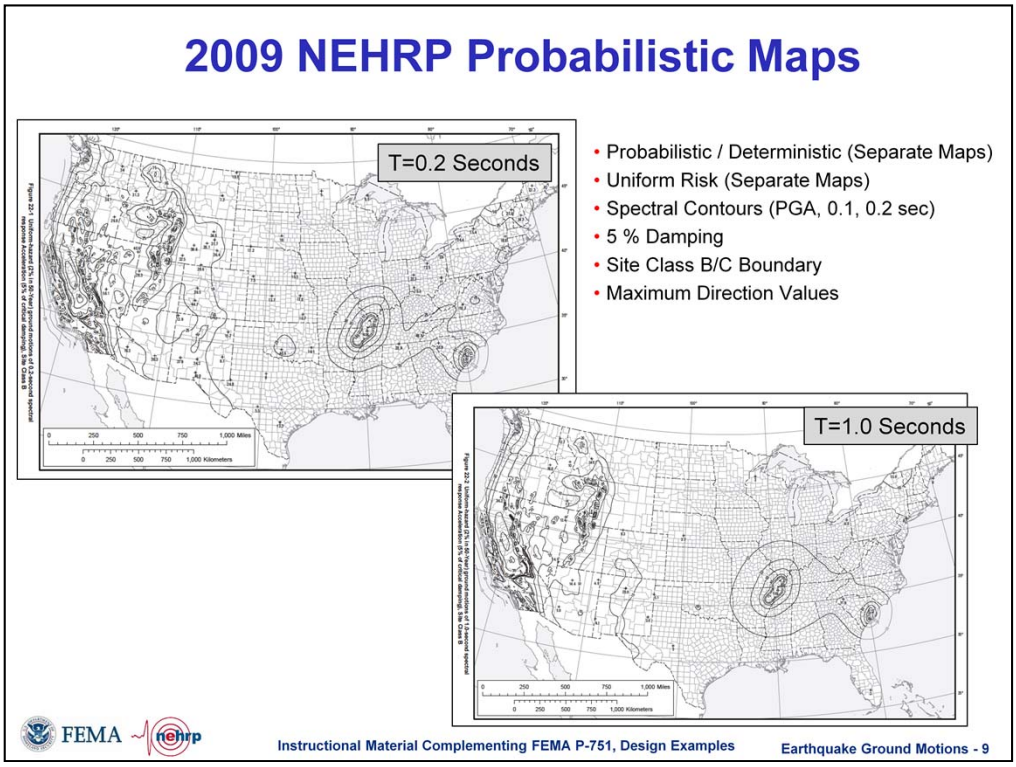
Earthquake Ground Motions - 7

This slide a screen capture for a USGS utility that provides geomean spectral acceleration by Longitude and Latitude. The given location is in Seattle, Washington. These values provided are purely probabilistic, and are based on a 2% in 50 year seismic hazard. Note that longitude must be entered as a negative number because Seattle is west of the prime meridian.

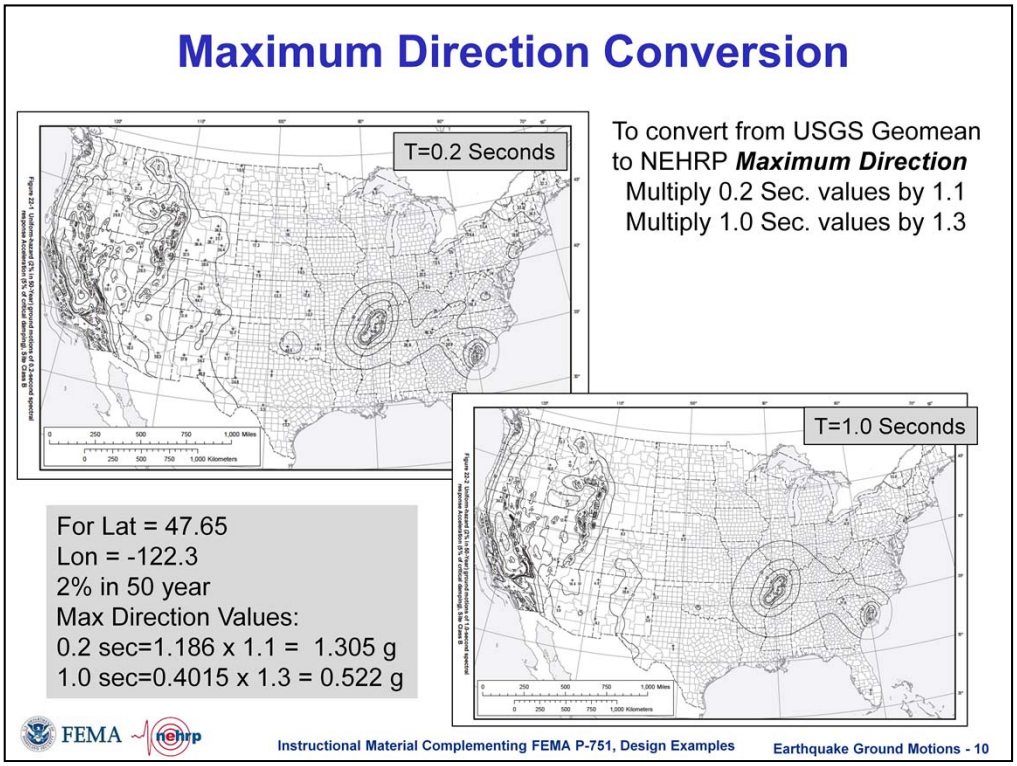
2009 NEHRP Maps

- Probabilistic / Deterministic (Separate Maps)
- Uniform Risk (Separate Maps)
- Spectral Contours (PGA, 0.1, 0.2 sec)
- 5 % Damping
- Site Class B/C Boundary
- Maximum Direction Values

The 2009 NEHRP provides three sets of maps that are used to provide design values. The first set is a based on a uniform hazard, but has been converted from geomean to maximum direction by use of a simple approximation. The second set of maps provide risk coefficients that are used to convert the maximum direction uniform hazard values to uniform risk values. The final set of maps is used to provide a "deterministic cap" on the probabilistic values where the probabilistic values are greater than the deterministic values.

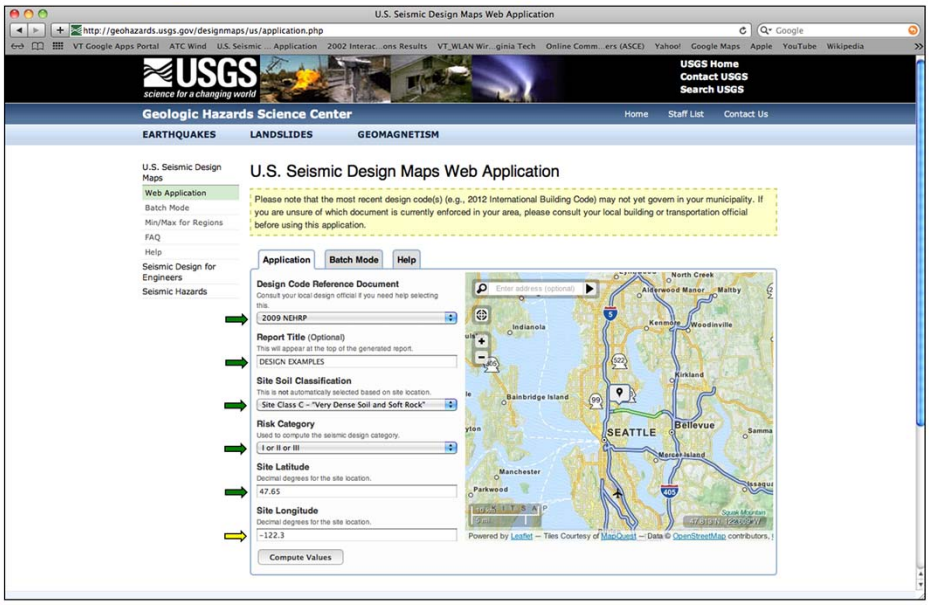


This slide shows the 2009 NEHRP Uniform Hazard maps which are based on maximum direction motions without a probabilistic cap. Maps are shown are for a 2% in 50 year hazard and for spectral accelerations at periods of 0.2 seconds and 1.0 seconds.



The maps that are shown on this page are the 2009 NEHRP Uniform Hazard Maximum Direction maps. These are obtained by multiplying values on the corresponding 2008 BSSC 0.2 second spectral values by 1.1, and the 2008 USGS 1.0 second spectral values by 1.3. This is an approximation to the maximum direction values.

Using the USGS Utility: 2009 NEHRP

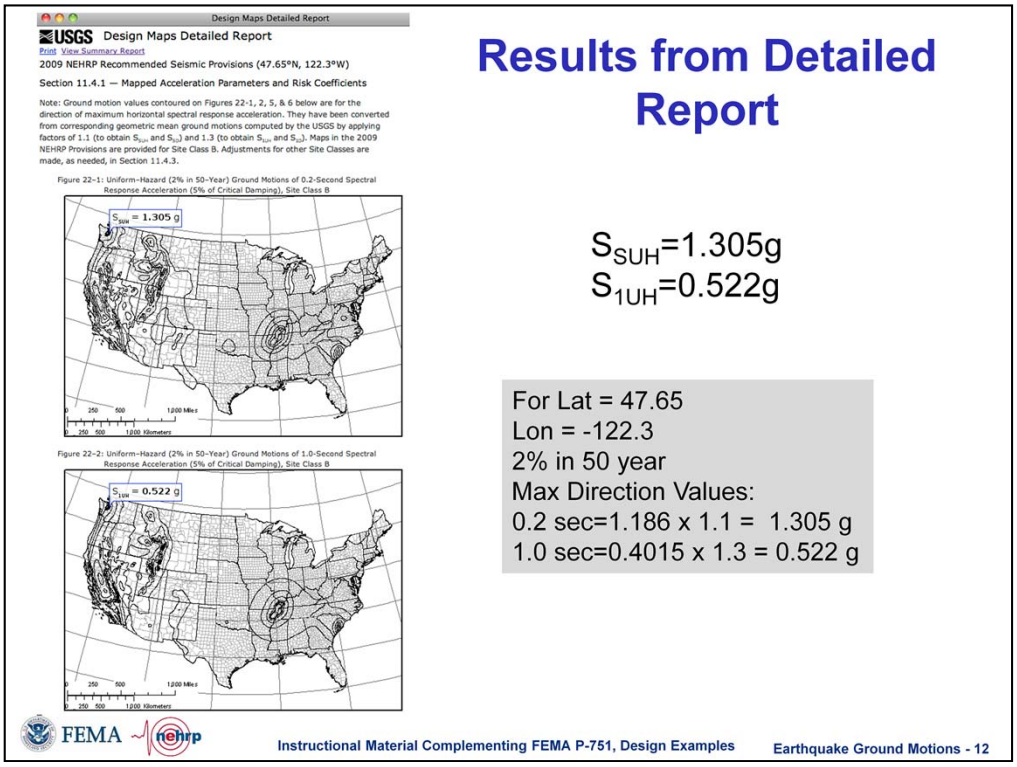


FEMA nehrp

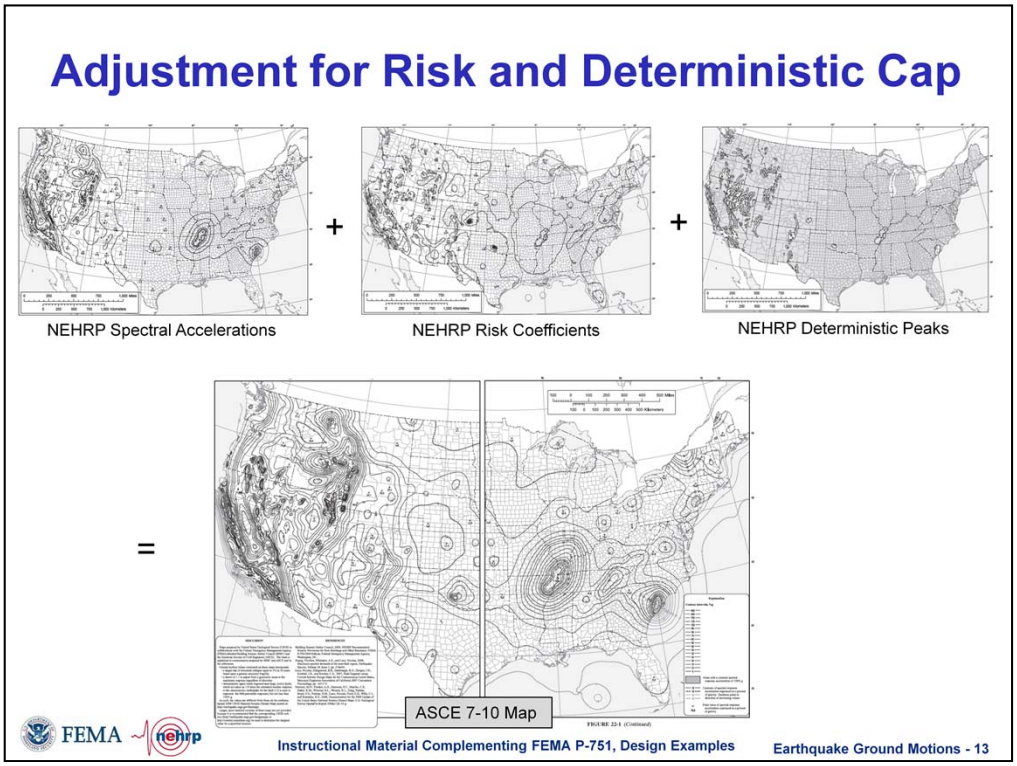
Instructional Material Complementing FEMA P-751, Design Examples

Earthquake Ground Motions - 11

The USGS Utility can be used to obtain values from the 2009 NEHRP Maps. This slide shows a screen capture of the U.S. Seismic Design Maps Web Application, with the Seattle ordinates of 47.65 Lat and -122.3 Lon keyed in.



The Detailed Report from the web application shows the 2009 NEHRP maps together with the computed values S sub SUH and S sub 1UH, where the "UH" in the subscript stands for Uniform Hazard". As can be seen the results are the same as computed "by hand" on Slide 10.

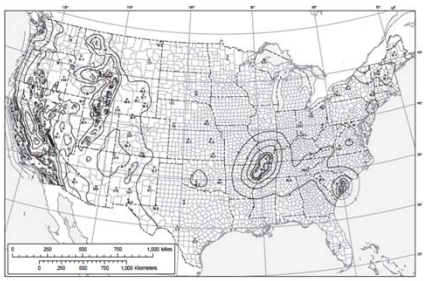


The next step to obtain the ASCE 7 values is to adjust for Uniform Risk by multiplying the Uniform Hazard values by Risk Coefficients. There is one map for 0.2 sec Risk Coefficients, and one Map for 1.0 sec Risk Coefficients.

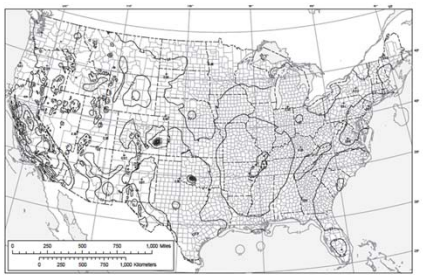
Adjustment for Risk

$$S_S = \min(S_{SUH} C_{RS}, S_{SD})$$

$$S_1 = \min(S_{1UH} C_{R1}, S_{1D})$$



S_{UH} Maps (S_{1H} maps similar)



C_{RS} Maps (C_{R1} maps similar)

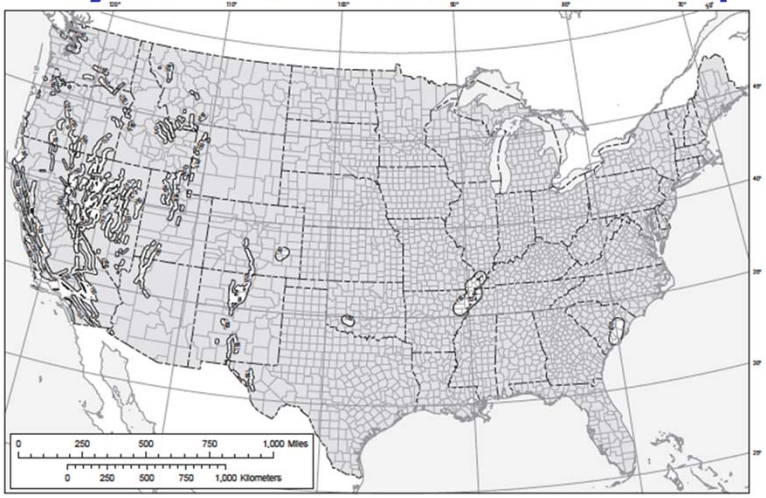
FEMA nehrp

Instructional Material Complementing FEMA P-751, Design Examples

Earthquake Ground Motions - 14

Before the final ASCE 7-10 mapped values can be determined, it is necessary to make sure the probabilistic Uniform Risk values do not exceed the deterministic cap values. 2009 NEHRP Provides the maps of the deterministic caps.

Adjustment for Deterministic Cap



S_{SD} Map (S_{1D} map is similar)

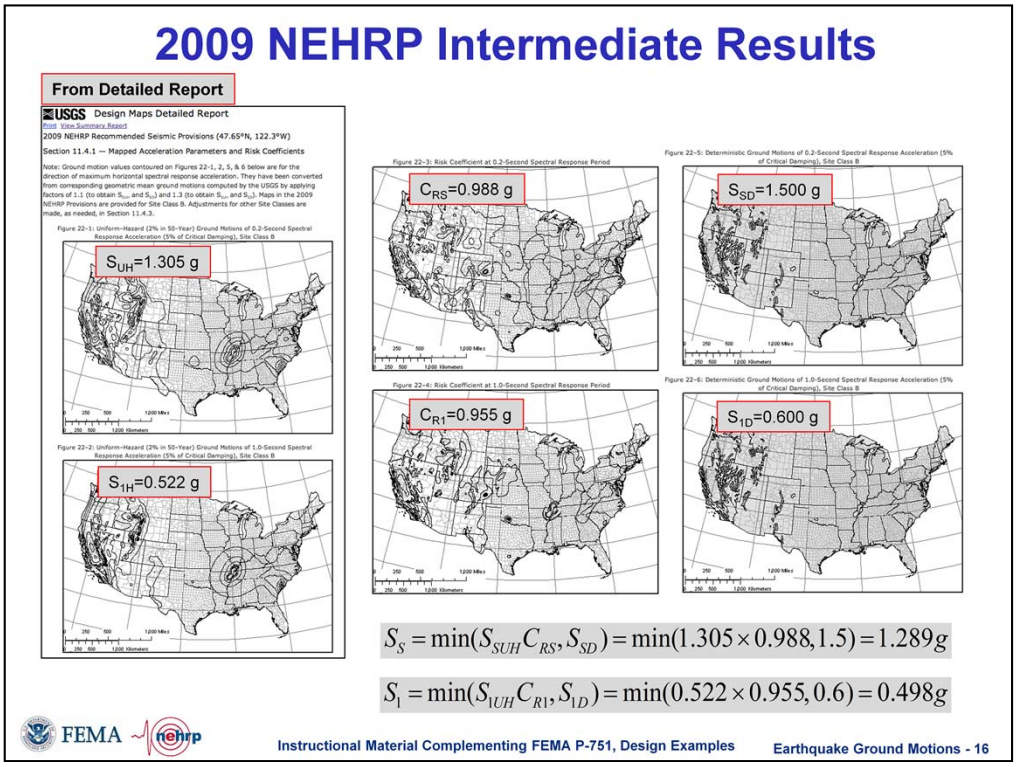
Deterministic Cap is 84th Percentile Ground Motion
But not less than 1.5g (S_{SD}) or 0.6g (S_{1D})

FEMA nehrp

Instructional Material Complementing FEMA P-751, Design Examples

Earthquake Ground Motions - 15

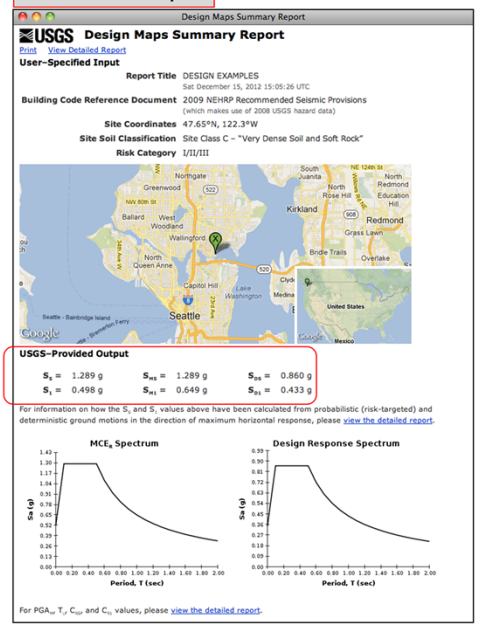
This slide shows the deterministic contours for the 0.2 second acceleration.



Finally, the values of S sub S and S sub 1 can be found. Values computed by hand are shown.

2009 NEHRP Results

From Standard Report



Design Maps Summary Report

USGS Design Maps Summary Report

Print View Detailed Report

User-Specified Input

Report Title DESIGN EXAMPLES
Sat December 15, 2012 15:05:26 UTC

Building Code Reference Document 2009 NEHRP Recommended Seismic Provisions
(which makes use of 2008 USGS hazard data)

Site Coordinates 47.65°N, 122.3°W

Site Soil Classification Site Class C - "Very Dense Soil and Soft Rock"

Risk Category I/II/III

USGS-Provided Output

S_s = 1.289 g	S_{ms} = 1.289 g	S_{ds} = 0.860 g
S_1 = 0.498 g	S_{m1} = 0.649 g	S_{d1} = 0.433 g

For information on how the S_s and S_1 values above have been calculated from probabilistic (risk-targeted) and deterministic ground motions in the direction of maximum horizontal response, please view the detailed report.

MCE_R Spectrum — Sa (g) — Period, T (sec)

Design Response Spectrum — Sa (g) — Period, T (sec)

For PGA_m, T_L, C_{RS} and C_{R1} values, please view the detailed report.

S_s=1.289g
S_1=0.498g

FEMA nehrp

Instructional Material Complementing FEMA P-751, Design Examples

Earthquake Ground Motions - 17

The values computed by the USGS Application are the same as those computed by hand, as shown on this screen capture from the detailed report.

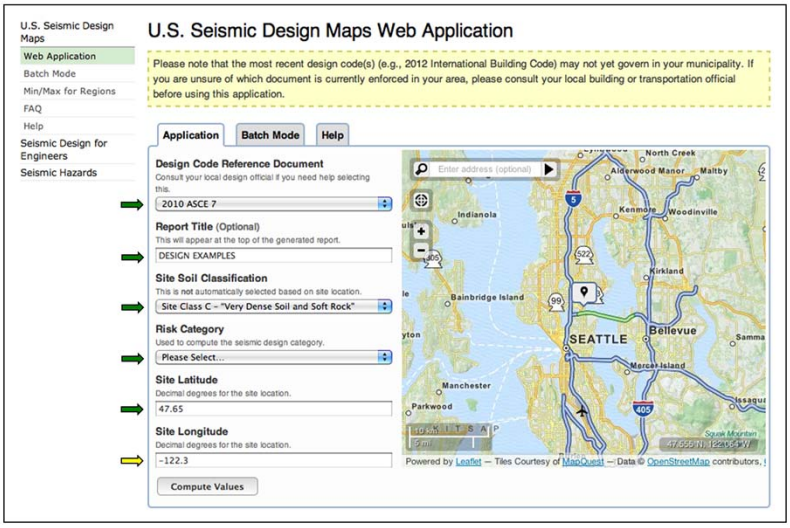
Summary of Differences between 2009 NEHRP and ASCE 7-10 Approaches

- NEHRP Starts with maximum direction maps and a uniform hazard and provides explicit values (C_{RS} and C_{R1}) for adjust to uniform risk.
- NEHRP Provides maps for deterministic cap
- When using NEHRP the user must manually (or via web utility) convert to MCE_R values.
- ASCE 7-10 Provides MCE_R values **Directly**

FEMA nehrp Instructional Material Complementing FEMA P-751, Design Examples Earthquake Ground Motions - 18

A summary of the differences between the 2009 NEHRP and the ASCE 7-10 Maps is provided on this slide.

Using the USGS Utility: ASCE 7-10



The USGS Utility can be used to determine the ASCE 7 Design Values (S sub s and S sub 1) directly. The slide shows a screen capture of the utility with the pertinent information keyed in for the Seattle location. Note again the negative value entered for longitude.

ASCE 7-10 Results

From Standard Report

USGS Design Maps Summary Report

Print View Detailed Report

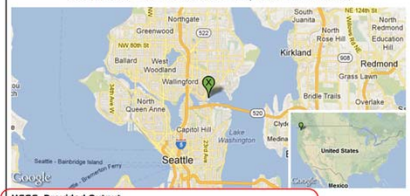
User-Specified Input

Report Title DESIGN EXAMPLES
Sat December 15, 2012 15:38:11 UTC

Building Code Reference Document ASCE 7-10 Standard
(which makes use of 2008 USGS hazard data)

Site Coordinates 47.65°N, 122.3°W

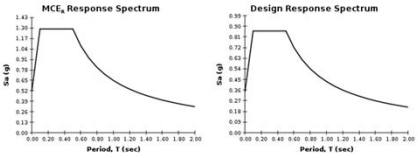
Site Soil Classification Site Class C - "Very Dense Soil and Soft Rock"



USGS-Provided Output

S_s = 1.289 g	S_{MS} = 1.289 g	S_{DS} = 0.860 g
S_1 = 0.498 g	S_{M1} = 0.649 g	S_{D1} = 0.433 g

For information on how the SS and S1 values above have been calculated from probabilistic (risk-targeted) and deterministic ground motions in the direction of maximum horizontal response, please return to the application and select the "2009 NEHRP" building code reference document.



For PGA$_M$, T_L, C_{RS}, and C_{R1} values, please view the detailed report.

From Detailed Report

USGS Design Maps Detailed Report

Print View Summary Report

ASCE 7-10 Standard (47.65°N, 122.3°W)

Section 11.4.1 — Mapped Acceleration Parameters

Note: Ground motion values provided below are for the direction of maximum horizontal spectral response acceleration. They have been converted from corresponding geometric mean ground motions computed by the USGS by applying factors of 1.1 (to obtain S_s) and 1.3 (to obtain S_1). Maps in the 2010 ASCE-7 Standard are provided for Site Class B. Adjustments for other Site Classes are made, as needed, in Section 11.4.3.

From Figure 22-1	S_S = 1.289 g
From Figure 22-2	S_1 = 0.498 g

S_s=1.289g
S_1=0.498g

FEMA nehrp

Instructional Material Complementing FEMA P-751, Design Examples

Earthquake Ground Motions - 20

The results from the USGS Utility are provided by the screen captures shown on this slide.

Adjusting for Site Effects
2009 NEHRP and ASCE 7-10

From Detailed Report

Section 11.4.2 — Site Class

The authority having jurisdiction (not the USGS), site-specific geotechnical data, and/or the default has classified the site as Site Class C, based on the site soil properties in accordance with Chapter 20.

Table 20.3–1 Site Classification

Site Class	$\bar{v}_s$	$\bar{N}$ or $\bar{N}_{ch}$	$\bar{s}_u$
A. Hard Rock	>5,000 ft/s	N/A	N/A
B. Rock	2,500 to 5,000 ft/s	N/A	N/A
C. Very dense soil and soft rock	1,200 to 2,500 ft/s	>50	>2,000 psf
D. Stiff Soil	600 to 1,200 ft/s	15 to 50	1,000 to 2,000 psf
E. Soft clay soil	<600 ft/s	<15	<1,000 psf
	Any profile with more than 10 ft of soil having the characteristics: • Plasticity index PI > 20, • Moisture content w ≥ 40%, and • Undrained shear strength $\bar{s}_u$ < 500 psf		
F. Soils requiring site response analysis in accordance with Section 21.1	See Section 20.3.1		

For SI: 1ft/s = 0.3048 m/s 1lb/ft² = 0.0479 kN/m²

Section 11.4.3 — Site Coefficients and Risk-Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameters

Table 11.4–1: Site Coefficient F_a

Site Class	Mapped MCE $_R$ Spectral Response Acceleration Parameter at Short Period				
	$S_S \le 0.25$	$S_S = 0.5$	$S_S = 0.75$	$S_S = 1$	$S_S \ge 1.25$
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	See Section 11.4.7 of ASCE 7				

Note: Use straight-line interpolation for intermediate values of S_S

For Site Class = C and S_S = 1.289 g, F_a = 1.000

Table 11.4–2: Site Coefficient F_v

Site Class	Mapped MCE $_R$ Spectral Response Acceleration Parameter at 1-s Period				
	$S_1 \le 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \ge 0.5$
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	See Section 11.4.7 of ASCE 7				

Note: Use straight-line interpolation for intermediate values of S_1

For Site Class = C and S_1 = 0.498 g, F_v = 1.302

Equation (11.4–1): $S_{MS} = F_a S_S = 1.000 \times 1.289 = 1.289$ g

Equation (11.4–2): $S_{M1} = F_v S_1 = 1.302 \times 0.498 = 0.649$ g

Section 11.4.4 — Design Spectral Acceleration Parameters

Equation (11.4–3): $S_{DS} = ⅔\, S_{MS} = ⅔ \times 1.289 = 0.860$ g

Equation (11.4–4): $S_{D1} = ⅔\, S_{M1} = ⅔ \times 0.649 = 0.433$ g

S_{DS}=0.860g
S_{D1}=0.433g

FEMA nehrp

Instructional Material Complementing FEMA P-751, Design Examples

Earthquake Ground Motions - 21

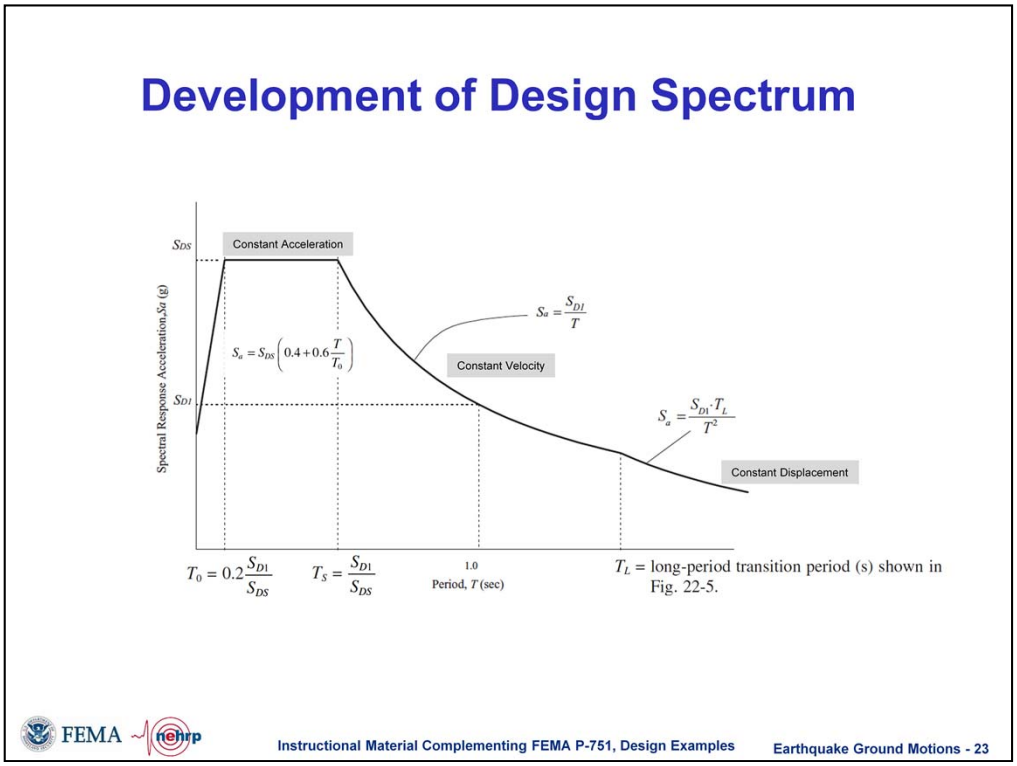
The USGS Web application also provides the interpolated values of the site coefficients F sub a and F sub v. Using these values, S sub MS and Sub sub M1 are obtained, where the "M" stands for Maximum Considered Earthquake. Dividing these values by 1.5 provides the Design values S sub DS and S sub D1.

Topics Covered

- 2008 USGS Uniform Hazard Maps
- 2009 NEHRP *Provisions* Maps
- ASCE 7-10 Seismic Maps
- **Horizontal Response Spectra**
- **Vertical Response Spectra**
- **Peak Ground Acceleration**
- Selection and Scaling of Ground Motions

FEMA nehrp Instructional Material Complementing FEMA P-751, Design Examples Earthquake Ground Motions - 22

This slide presents a list of the next three topics covered.



This slide shows the basic design spectrum, which is Figure 11.4-1 from ASCE 7-10. This spectrum would be used in Modal Response Spectrum Analysis as described in Section 12.9 of ASCE 7-10. The shape of this spectrum can be traced back to work done by Newmark in the 1960's. The Constant Velocity label indicates that if the spectrum were to be converted to a velocity spectrum, this segment of the spectrum would be constant. Similar for the Constant Displacement branch. Note the unit inconsistency of the values; for example, the division by T in the constant velocity region produces units inconsistency if the units of seconds are attached to T.

Development of Design Spectrum

S_{DS}=0.860g
S_{D1}=0.433g

$$T_s = \frac{S_{D1}}{S_{DS}} = \frac{0.860}{0.433} = 0.503\,s$$

$$T_0 = 0.2T_S = 0.2(0.503) = 0.10\,s$$

T_L=6 s *(from map)*

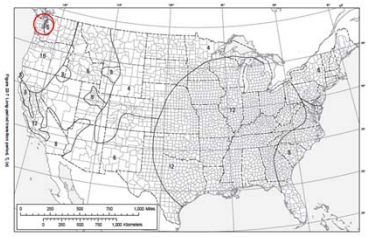
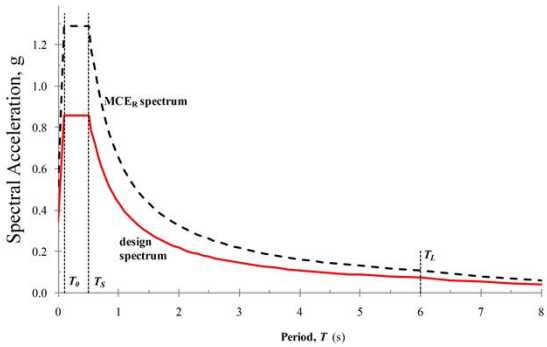


Fig. 22-7 Long Period Transition Maps



S_a @ T=0= 0.4(S_{DS})=0.4(0.860)=0.344g

FEMA nehrp Instructional Material Complementing FEMA P-751, Design Examples Earthquake Ground Motions - 24

This slide shows the calculation of the intermediate values needed to construct the design spectrum. Also shown is the long period transition map which provides the periods at which the constant displacement branch of the spectrum governs. For the location in Seattle, T sub L is 6 seconds. This represents (approximately) a building that is 30 to 40 stories in height, and is thus the spectrum beyond T sub L is not likely to control for most buildings.

Vertical Response Spectra

- New Chapter 23 of NEHRP Provisions
- Not yet incorporated into ASCE 7

Spectrum has Four Braches:

1. $S_{av} = 0.3 C_v S_{DS}$
2. $S_{av} = 20 C_v S_{DS} (T_V - 0.025) + 0.3 C_v S_{DS}$
3. $S_{av} = 0.8 C_v S_{DS}$
4. $S_{av} = 0.8 C_v S_{DS} \left(\frac{0.15}{T_V} \right)^{0.75}$

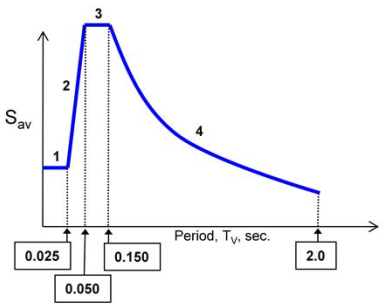


Table 23.1-1 Values of Vertical Coefficient C_v

MCE$_R$ Spectral Response Parameter at Short Periods [a]	Site Class A, B	Site Class C	Site Class D, E, F
$S_S \geq 2.0$	0.9	1.3	1.5
$S_S = 1.0$	0.9	1.1	1.3
$S_S = 0.6$	0.9	1.0	1.1
$S_S = 0.3$	0.8	0.8	0.9
$S_S \leq 0.2$	0.7	0.7	0.7

[a] Use straight-line interpolation for intermediate values of S_S.

FEMA nehrp

Instructional Material Complementing FEMA P-751, Design Examples

Earthquake Ground Motions - 25

The 2009 NEHRP Provisions provide a means for computing a vertical design spectrum. The spectrum contains four branches, as shown. Note that the period shown in the plot and used in the calculations is the vertical period of vibration of the structure. For vertical periods beyond 2 seconds (not likely for most buildings) a site specific analysis must be used to determine the vertical spectral values. The procedure for computing the vertical response spectrum is not adopted for use in ASCE 7-10.

Vertical Response Spectra

For current example S_S=1.389g, S_{DS}=0.859g, Site Class D

$$S_{av} = 0.3C_v S_{DS} = 0.3(1.158)(0.859) = 0.298$$

$$S_{av} = 0.8C_v S_{DS} = 0.8(1.158)(0.859) = 0.796$$

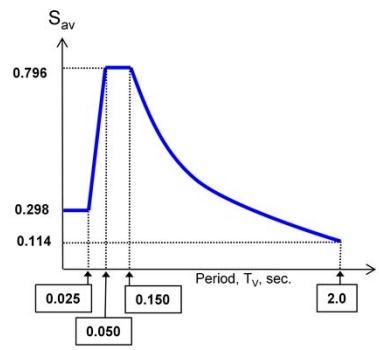
$$S_{av} = 0.8C_v S_{DS}\left(\frac{0.15}{T_V}\right)^{0.75} = 0.8(1.158)(0.859)\left(\frac{0.15}{2.0}\right)^{0.75} = 0.114$$

Table 23.1-1 Values of Vertical Coefficient C_V

MCE$_R$ Spectral Response Parameter at Short Periods [a]	Site Class A, B	Site Class C	Site Class D, E, F
$S_s \geq 2.0$	0.9	1.3	1.5
$S_S = 1.0$	0.9	1.1	1.3
$S_S = 0.6$	0.9	1.0	1.1
$S_S = 0.3$	0.8	0.8	0.9
$S_S \leq 0.2$	0.7	0.7	0.7

[a] Use straight-line interpolation for intermediate values of S_S.

Interpolation gives C_v=1.158



Note: This is the DBE Spectra. Multiply all accelerations by 1.5 to obtain MCE Spectra

FEMA nehrp

Instructional Material Complementing FEMA P-751, Design Examples

Earthquake Ground Motions - 26

This slide shows the computation steps for the vertical acceleration for the Seattle Site.

Peak Ground Acceleration

Section 11.8.3 of ASCE 7-10:

$$PGA_M = F_{PGA} PGA$$

Table 11.8-1 Site Coefficient F_{PGA}

	Mapped Maximum Considered Geometric Mean (MCE_G) Peak Ground Acceleration, PGA				
Site Class	PGA ≤ 0.1	PGA = 0.2	PGA = 0.3	PGA = 0.4	PGA ≥ 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	1.2	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	See Section 11.4.7				

Note: Use straight-line interpolation for intermediate values of PGA.

FEMA nehrp

Instructional Material Complementing FEMA P-751, Design Examples

Earthquake Ground Motions - 27

ASCE 7-10 provides a means to calculate the Peak Ground Acceleration. This values is used in determination of the potential for liquefaction. The PGA values are provided by the Map of Figure 22-7, or by the USGS Utility.

Peak Ground Acceleration

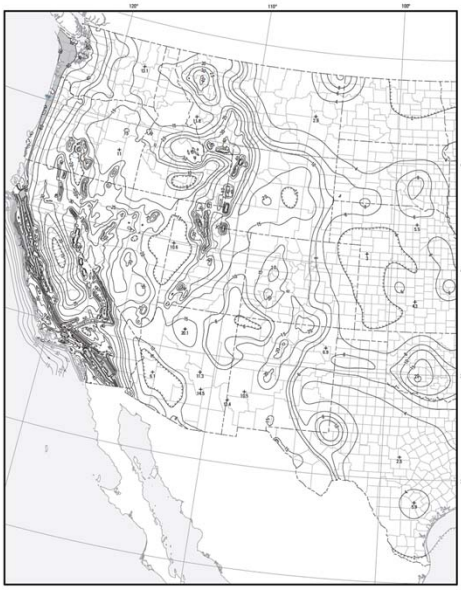


Figure 22-8 MCE geometric mean PGA, %g, Site Class B for the conterminous United States

Results from USGS Design Maps Utility (Detailed Report) for Seattle Location

From Figure 22-7 — PGA=0.521 g

Equation (11.8-1): $PGA_M = F_{PGA}PGA = 1.000 \times 0.521 = 0.521$ g

Table 11.8-1: Site Coefficient F_{PGA}

Site Class	Mapped MCE Geometric Mean Peak Ground Acceleration, PGA				
	PGA ≤ 0.1	PGA = 0.2	PGA = 0.3	PGA = 0.4	PGA ≥ 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	1.2	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	See Section 11.4.7 of ASCE 7				

Note: Use straight-line interpolation for intermediate values of PGA

For Site Class = C and PGA = 0.521 g, F_{PGA}=1.0

$$PGA_M = F_{PGA}PGA = 1.0 \times 0.521 = 0.521g$$

Note: This is the MCE PGA. Design PGA (where used) = (2/3) PGA_M

FEMA nehrp

Instructional Material Complementing FEMA P-751, Design Examples

Earthquake Ground Motions - 28

Computation of the MCE level PGA is shown for the Seattle site. The calculation was done using the USGS application, as indicated by the screen capture. Note that the mapped value of PGA, 0.521 g, is the same as provided by the USGS maps, not adjusted for maximum and not adjusted for risk.

Topics Covered

- 2008 USGS Uniform Hazard Maps
- 2009 NEHRP *Provisions* Maps
- ASCE 7-10 Seismic Maps
- Horizontal Response Spectra
- Vertical Response Spectra
- Peak Ground Acceleration
- **Selection and Scaling of Ground Motions**

FEMA nehrp Instructional Material Complementing FEMA P-751, Design Examples Earthquake Ground Motions - 29

This slide presents a list of the topics covered, and indicates that the next topic covered (the last topic) is Ground Motion Selection and Scaling. Selection and Scaling of ground motions is required whenever a response history analysis is to be used.

Selection and Scaling of Ground Motions

- Selection and Scaling procedures are Provided in Chapter 16 of ASCE 7-10: *Response History Analysis*
- Chapter 16 is usually used in association with nonlinear analysis of special structures or structures that do not conform to certain requirements (e.g. height limitations) in ASCE 7-10.
- This example will demonstrate procedure for a site in Seattle, Washington.
- Additional discussion of ground motion scaling and use in linear and nonlinear response history analysis is provided in Chapter 4 of P-751, *Structural Analysis.*

FEMA nehrp Instructional Material Complementing FEMA P-751, Design Examples Earthquake Ground Motions - 30

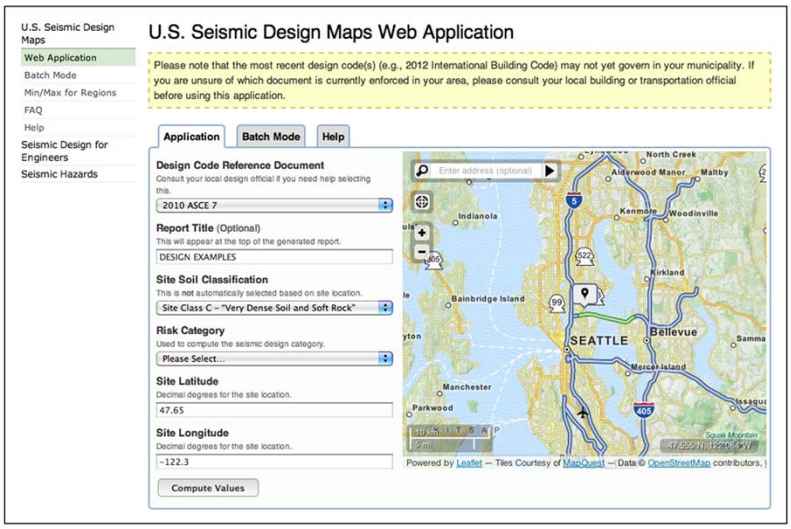
The slide provides several important points regarding selection and scaling of ground motions.

Ground Motion Nomenclature

- An "Event" refers to a given historical earthquake, such as the 1989 Loma Prieta California Earthquake
- A "Record" refers to the recorded ground acceleration histories at a particular recording station, such as the Saratoga-Aloha Ave. recording of the Loma Prieta event.
- Each record has (usually) three "Components" consisting of two (usually) orthogonal components and one vertical component. The horizontal components are often, but not always, oriented in N-S and E-W directions. In some cases fault-normal and fault-parallel values are provided. Records can be transformed to any direction (e.g. N-S and E-W recordings can be transformed to fault-normal and fault-parallel given the orientation of the fault.
- A "Suite" of ground motions consist of three or more records.

This slide provides nomenclature used in ground motion selection and scaling.

Location of Site



FEMA nehrp

Instructional Material Complementing FEMA P-751, Design Examples

Earthquake Ground Motions - 32

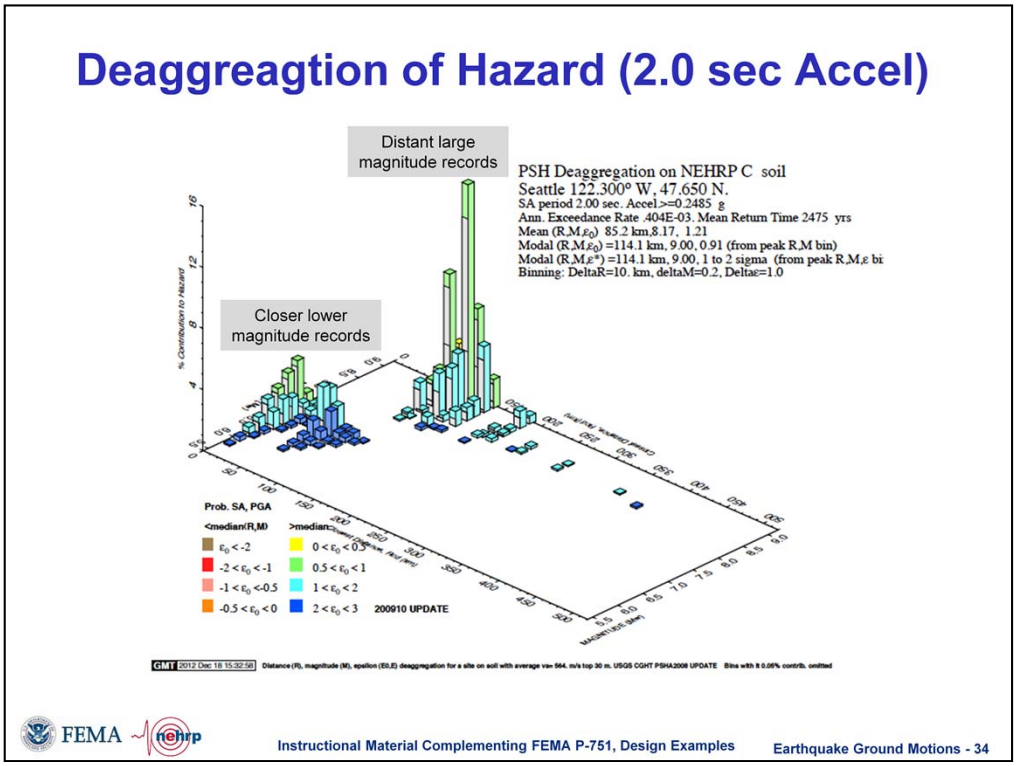
In the following example we will describe the procedures for selecting a suite of motions for the site in Seattle.

Selection of Appropriate Records

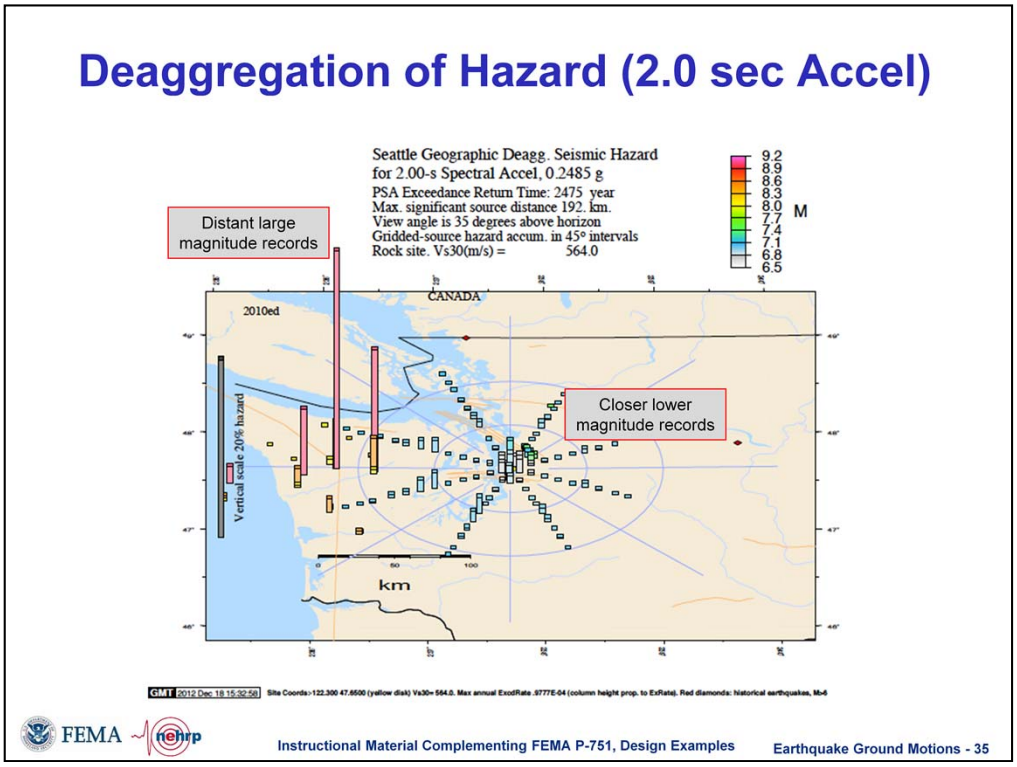
- Select from records of events having magnitude, fault distance, and source mechanisms that control the maximum considered earthquake (MCE)
- Pertinent information can be obtained from "Deaggregtion" of the seismic hazard

http://earthquake.usgs.gov/hazards/apps/#deaggint

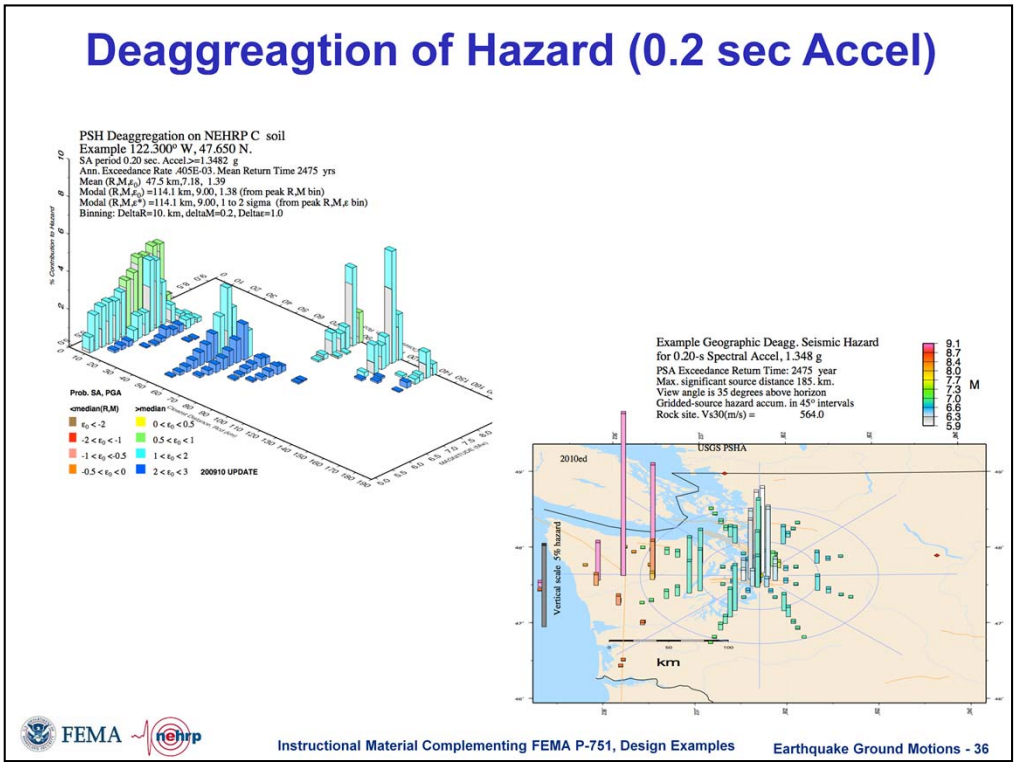
The first bullet is taken directly from Chapter 16 of ASCE 7-10. While there are thousands of recordings available (e.g. from the PEER NGA site), it is often difficult to find a suitable number of records that match the criterion listed. The USGS utility for hazard deaggregation provides information that can be used to detect the appropriate types of ground motions (but not the actual recordings themselves).



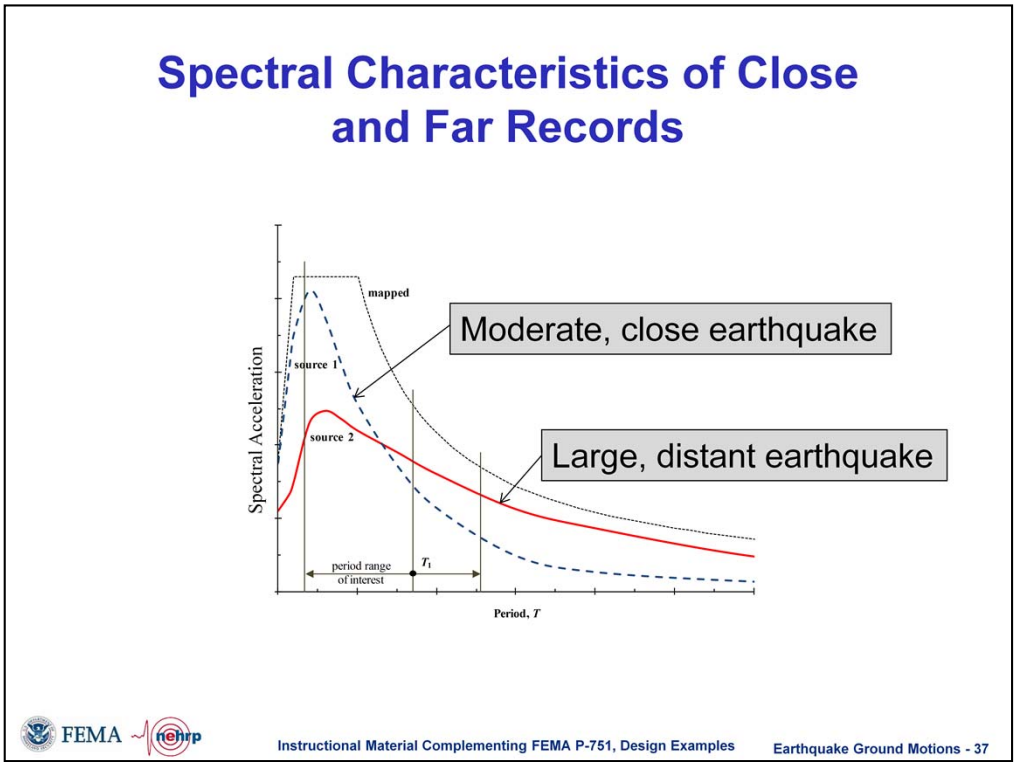
This slide is a screen capture of the results of the deaggregation for ground motions that affect the 2.0 second spectral acceleration for the site on Site Class C soils, and a 2% probability of occurrence (consistent with the MCE). The three axes are the distance from the site, the magnitude of the ground motion, and the percent contribution to 2.0 second spectral acceleration. In this case, there appear to be a cluster of events, 0 to 100 km from the site with a maximum magnitude of about 7 and which have moderate contribution. Somewhat further away (100 to 200 km) are higher magnitude events that contribute even more significantly to the 2.0 spectral acceleration.



This slide shows the 2.0 second deaggregation information on a map of the area surrounding the site.



The same USHS utility can provide deaggregation information at any period. In these screen captures the contribution to the 0.2 second spectral acceleration is shown. Note how the importance of the close-by motion has increased dramatically when compared to the deaggregation for the 2.0 second acceleration.



Similar information is shown on this plot, which shows response spectra for large distant earthquakes, for moderate close-by earthquakes, and the code design spectrum. The moderate, close-by earthquake dominates at lower periods, and the large distant earthquake dominates at the longer periods. The smooth ground motion curves were obtained from ground motion models called "attenuation relationships".

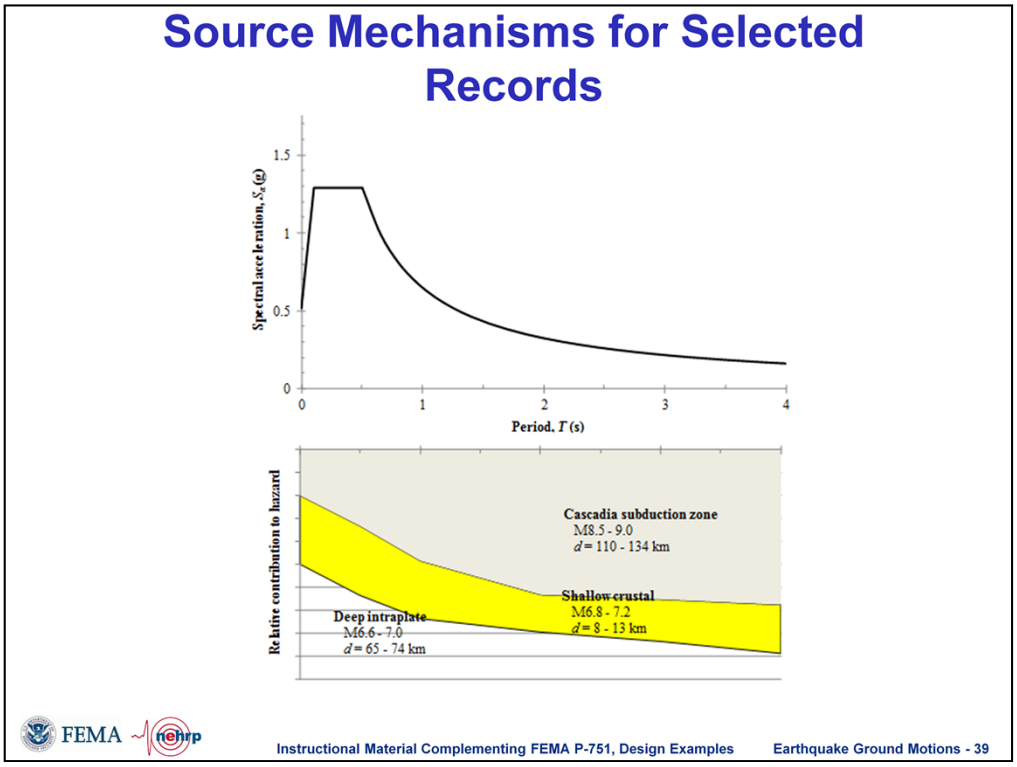
Deaggregation of Hazard (0.2 Sec Accel)

```
Principal sources (faults, subduction, random seismicity having > 3% contribution)
Source Category:                  % contr.  R(km)    M   epsilon0 (mean values).
Cascadia M8.3-M8.7 Floating          6.12   109.2   8.52    1.64
Cascadia Megathrust                 19.51   108.9   9.02    1.30
Wash-Oreg Cascades-West faults +    17.61    12.1   6.96    1.14
WUS Compr crustal gridded           17.51     9.4   6.14    1.13
50-km Deep Intraplate               21.72    60.6   6.79    2.07
Puget Lowlands gridded              16.55     9.4   6.32    1.03
Individual fault hazard details if its contribution to mean hazard > 2%:
Fault ID                          % contr.   Rcd(km)  M   epsilon0 Site-to-src azimuth(d)
Seattle fault zone, mid. GR          3.25    12.1   6.82    1.24    -172.2
Seattle fault zone, north, GR        5.14     9.9   6.82    1.01    -175.4
Seattle fault zone, N. Trace, Ch     4.55     8.0   7.16    0.72    -177.6
#*********End of deaggregation corresponding to Mean Hazard w/all GMPEs  *********#
```

Cascadia Subduction Zone=6.1+19.5=25.6%
Shallow Crustal=17.6+17.5=35.1%
Deep Intraplate=21.7+16.6=48.3%

FEMA nehrp Instructional Material Complementing FEMA P-751, Design Examples Earthquake Ground Motions - 38

The deaggregation utility provides detailed information on how different types of earthquake contribute to the hazard. A portion of the the text file that is provided with the deaggregation is shown.



The information shown on the previous slide can be used to create a graph as shown on the bottom of the current slide. As can be seen, the Cascadia subduction zone dominates at longer periods, and has relatively low influence at short periods. The influence of the deep intraplate events is just the opposite; dominant at lower periods and waning at longer periods. The shallow crustal contribution is somewhat constant along all periods.

Scaling Requirements

- 2D Analysis: The ground motions shall be scaled such that the average of the 5% damped response spectra is not less than the design spectrum over the period range 0.2T to 1.5T.
- 3D Analysis: The ground motions shall be scaled such that the average of the SRSS spectra from all horizontal component pairs does not fall below the design spectrum over the period range 0.2T to 1.5T.
- At sites within 5 km of the active fault each pair of components shall be rotated to fault-normal and fault-parallel directions and shall be scaled such that the ~~fault normal~~ dominant component is not less than the ~~MCE_R~~ design spectrum over the period range 0.2 to 1.5T.

FEMA nehrp Instructional Material Complementing FEMA P-751, Design Examples Earthquake Ground Motions - 40

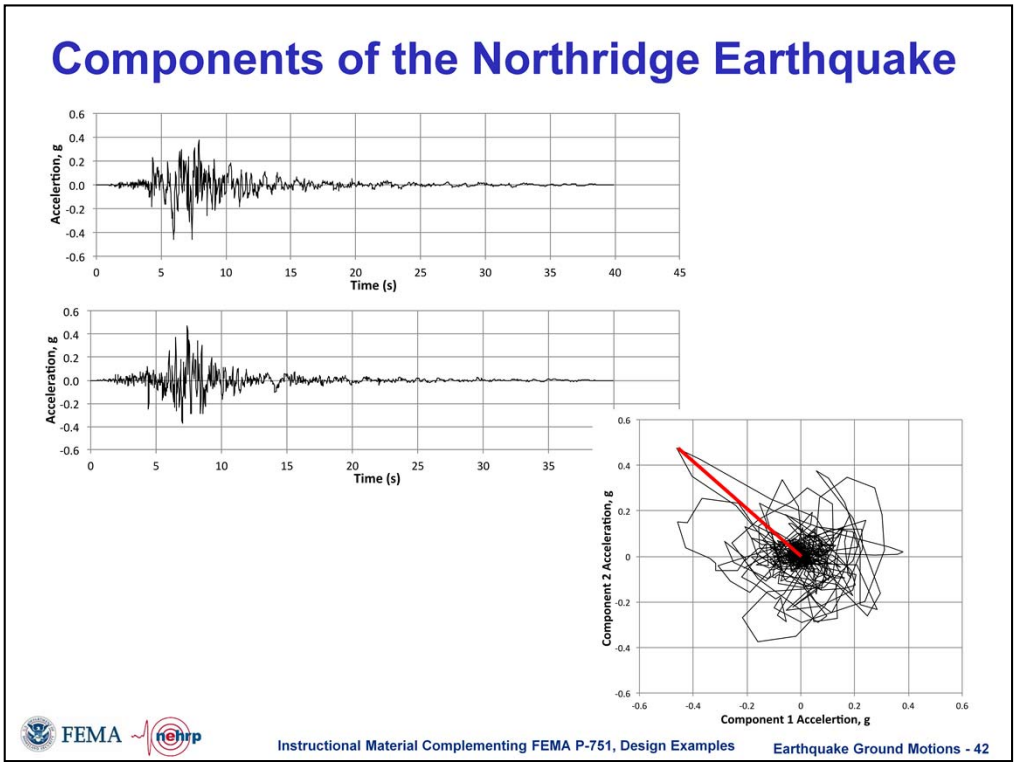
This slide provides a summary of the ASCE 7-10 ground motions scaling requirements. The strikeouts and rewording in the last bullet are discussed in the text of the example.

Ground Motion Scale Factors for 3D Analysis

Table 3-1 Selected and Scaled Ground Motions for Example Site

Record No.	Year	Earthquake name	M	Source type	Recording station	Distance (km)
1	2003	Tokachi-oki, Japan	8.3	Subduction zone	HKA 094	67
2	2003	Tokachi-oki, Japan	8.3	Subduction zone	HKD 092	46
3	1968	Tokachi-oki, Japan	8.2	Subduction zone	Hachinohe (S-252)	71
4	1949	Western Washington	7.1	Deep intraplate	Olympia	75
5	1989	Loma Prieta	6.9	Shallow crustal	Saratoga -- Aloha Ave	9
6	1999	Duzce, Turkey	7.1	Shallow crustal	Duzce	7
7	1995	Kobe, Japan	6.9	Shallow crustal	Nishi-Akashi	7

The table provides seven records that fit the characteristics derived from the deaggregation. As may be seen, the sources types, magnitudes, and distances are consistent with the deaggregation. (Other pertinent information, not shown in the example, is the site class at the recording station. This should be consistent with the site class for the building under consideration). Note that all distances are greater than 5km, so it is not necessary to rotate the components to fault-normal, fault parallel, or to find the dominant component.

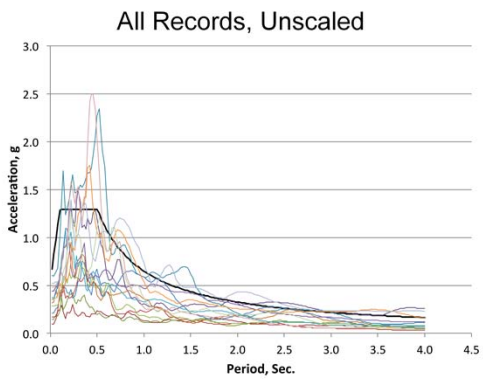


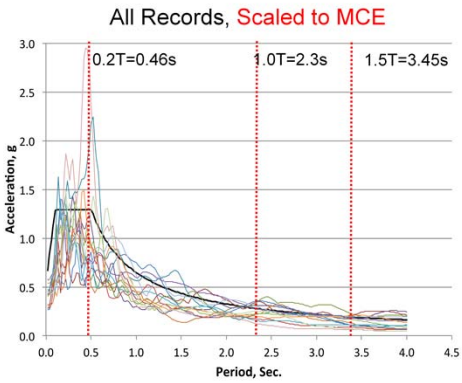
These ground motion acceleration histories are fault normal (upper) and fault parallel (lower). The orbit plot (lower right corner of slide) shows that the motions in the two directions are largely out of phase, and that the maximum resultant acceleration occurs at a 45 degree rotation.

Ground Motion Spectra

Table 3-1 Selected and Scaled Ground Motions for Example Site

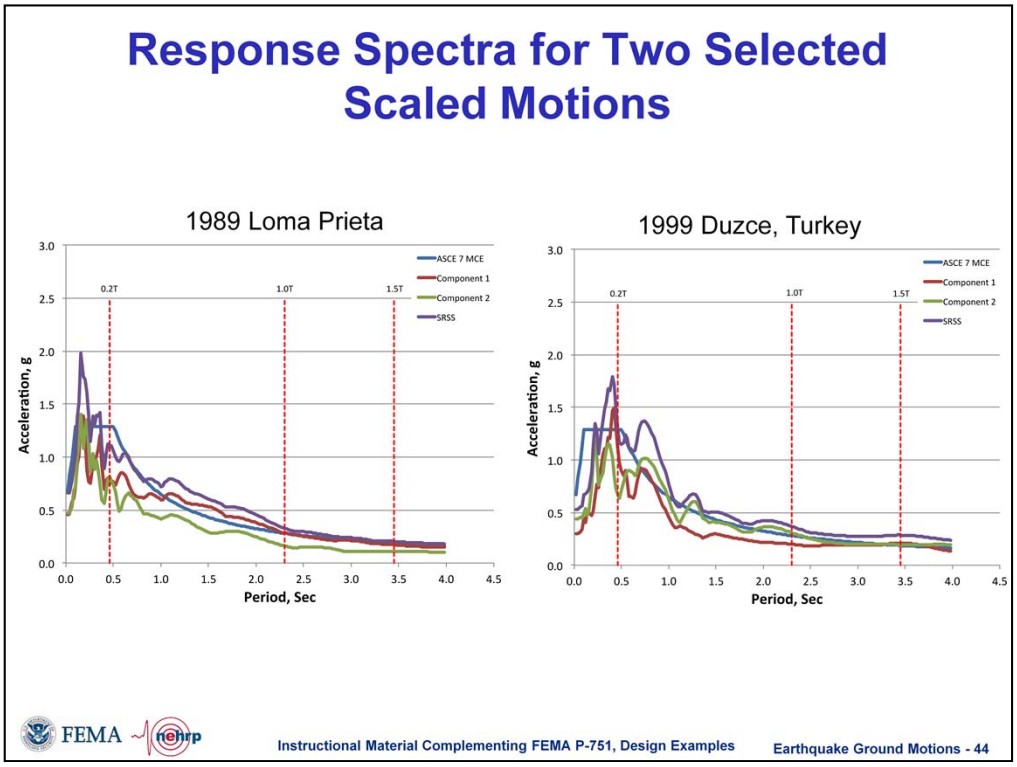
Record No.	Year	Earthquake name	M	Source type	Recording station	Distance (km)	Scale factor
1	2003	Tokachi-oki, Japan	8.3	Subduction zone	HKA 094	67	2.99
2	2003	Tokachi-oki, Japan	8.3	Subduction zone	HKD 092	46	0.96
3	1968	Tokachi-oki, Japan	8.2	Subduction zone	Hachinohe (S-252)	71	1.28
4	1949	Western Washington	7.1	Deep intraplate	Olympia	75	1.92
5	1989	Loma Prieta	6.9	Shallow crustal	Saratoga -- Aloha Ave	9	1.28
6	1999	Duzce, Turkey	7.1	Shallow crustal	Duzce	7	0.85
7	1995	Kobe, Japan	6.9	Shallow crustal	Nishi-Akashi	7	1.18



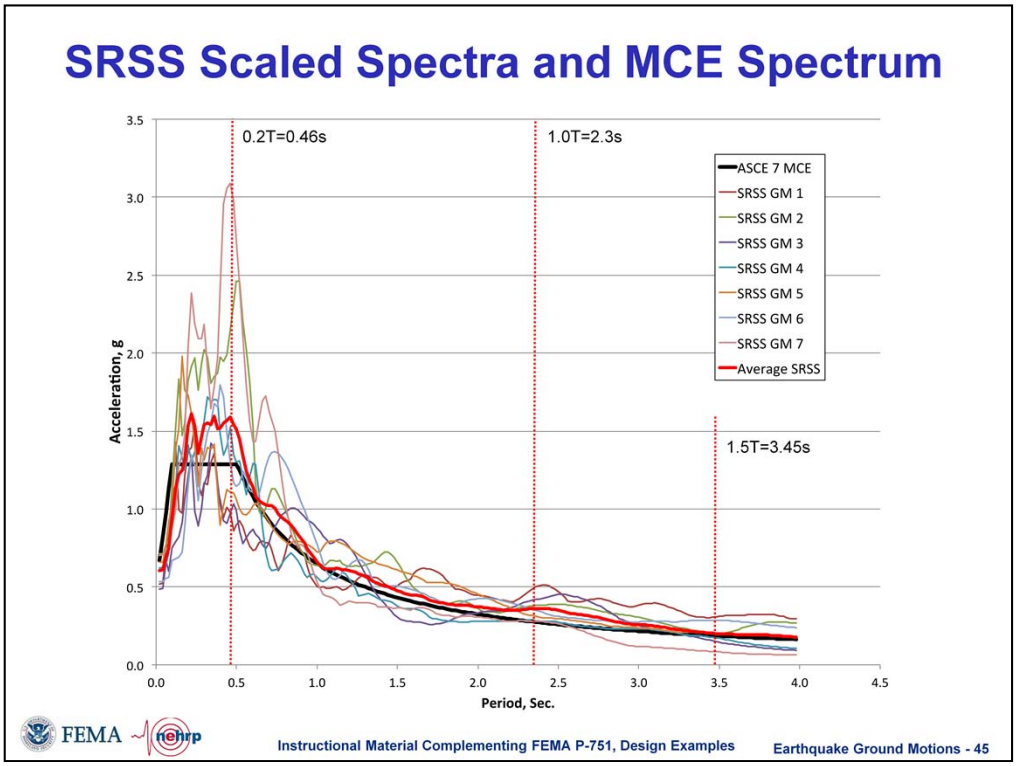


FEMA nehrp Instructional Material Complementing FEMA P-751, Design Examples Earthquake Ground Motions - 43

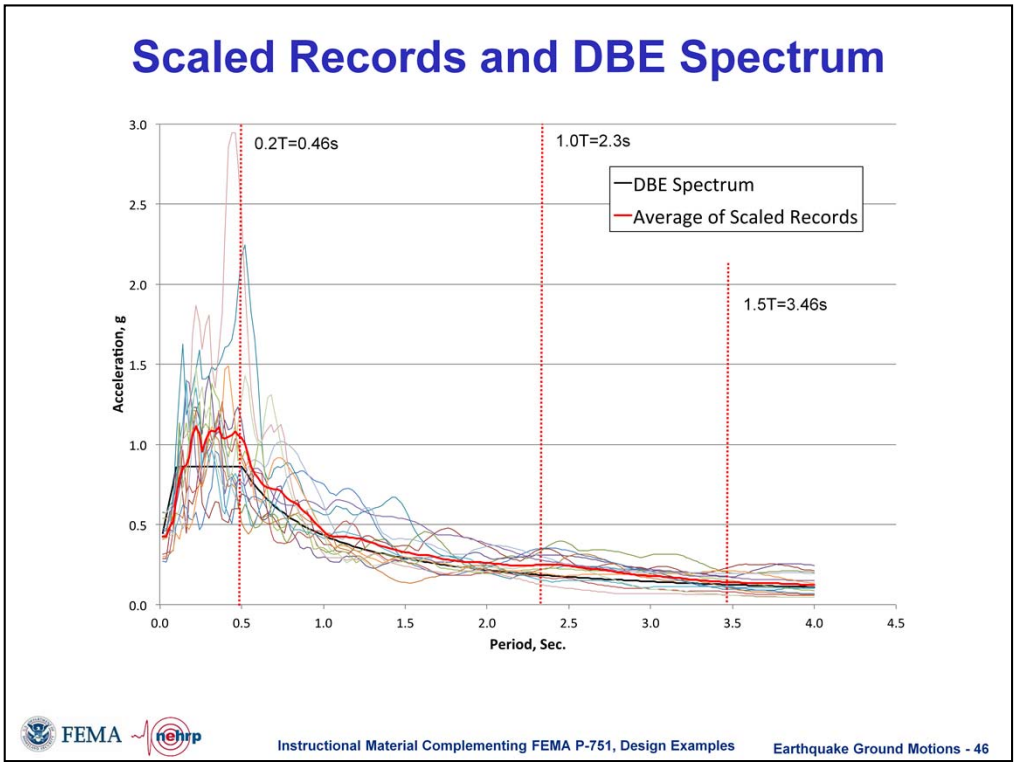
This slide shows the 5% damped response spectra for both components of each record, together with the MCE Target Spectrum. The plot on the left shows the unscaled records, and the plot on the right shows the record with the scale factors shown in the last column of the table. The vertical lines in the scaled plot indicates the period range over which the scaling applies, where the structural period is 2.3 seconds.



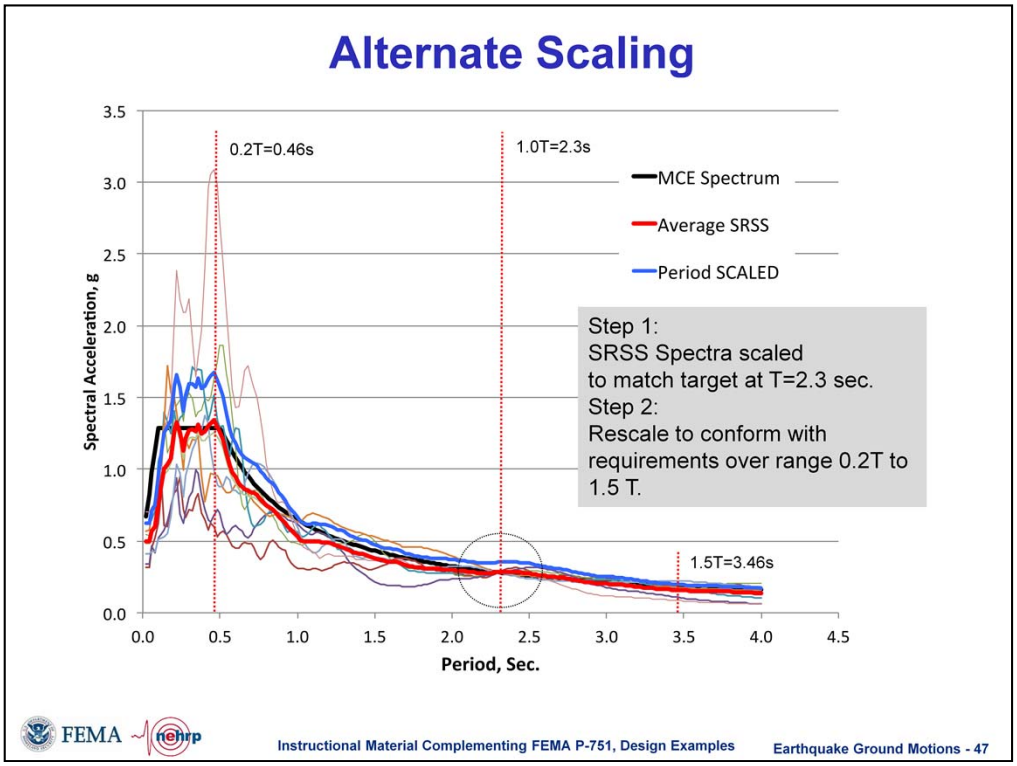
This slide shows the response spectra for two of the scaled records. Each individual component is shown, as is the SRSS and the MCE target spectrum. The individual component spectra as well as the SRSS spectra have a shape that is consistent with the target spectrum over the indicated period range.



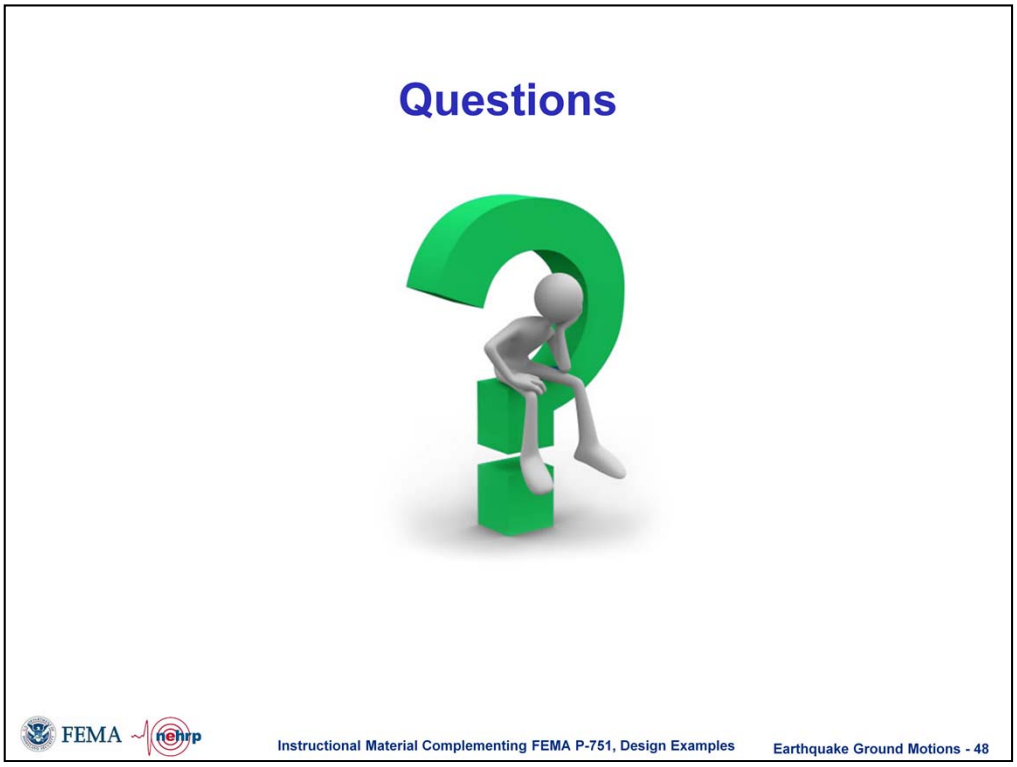
The plot on this slide shows the scaled SRSS spectra for the seven events, together with the average of the SRSS (heavy red line), and the target MCE spectrum (heavy black line). As can be seen, the Average SRSS falls above the target spectrum over the indicated period range, with the match point at about T=1.0 sec. Note that one of the SRSS spectra (for GM 7) has high amplitude at T=0.5 seconds. Thus, this record will have a larger higher mode influence than will the other records. Note also that the ordinate for GM 1 is nearly twice the ordinate of the design spectrum at the period of 2.3 seconds.



This plot shows the individual MCE scaled components together with the DBE target spectrum. On the average, the MCE scaled records are a good match for the DBE target spectrum, thus little additional scaling would be required if was desired to re-scale for analysis in 2-Dimensions, where the average of the individual component spectra is used instead of the average of the SRSS spectra.



In the Chapter 3 example the method for determining the individual record scale factors was not mentioned. In fact, there are an infinite number of sets of factors that will fit the ASCE 7 criterion. In this slide, an approach is used where the SRSS spectra are first scaled to match the target spectra at the design period (2.3 sec in this example), and then re-scaled such that the average of the SRSS spectra does not fall below the target over the period range 0.2 to 1.5 T. As may be seen, the fit is much better near the target period, but a few of the individual records have relatively low acceleration at the lower periods.



Slide to initiate questions from participants.

3

Earthquake Ground Motion

Nicolas Luco, Ph.D., P.E., Michael Valley, S.E., and C.B. Crouse, P.E., Ph.D.

Slide set created by Finley A. Charney, Ph.D., P.E.

Topics Covered

- 2008 USGS Uniform Hazard Maps
- 2009 NEHRP *Provisions* Maps
- ASCE 7-10 Seismic Maps
- Determination of Ground Motion Values
- Horizontal Response Spectra
- Vertical Response Spectra
- Peak Ground Acceleration
- Selection and Scaling of Ground Motions

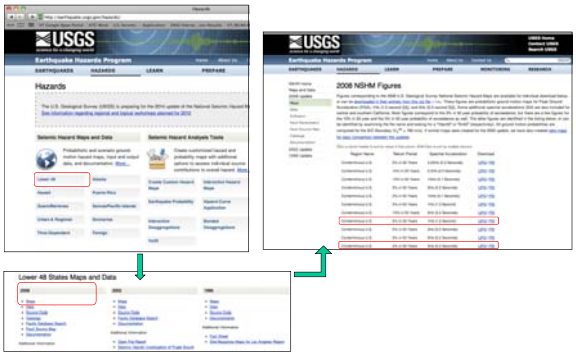
Topics Covered

- **2008 USGS Uniform Hazard Maps**
- **2009 NEHRP *Provisions* Maps**
- **ASCE 7-10 Seismic Maps**
- Horizontal Response Spectra
- Vertical Response Spectra
- Peak Ground Acceleration
- Selection and Scaling of Ground Motions

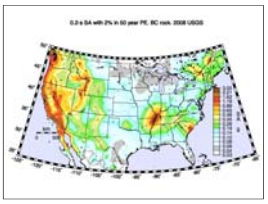
2008 USGS Maps

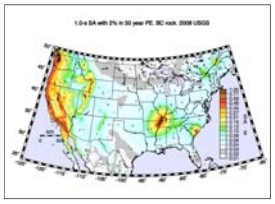
- Probabilistic
- Uniform Hazard (e.g. 2% in 50 year probability)
- Spectral Contours (T=0, 0.1, 0.2 sec…)
- 5 % Damping
- Site Class B/C Boundary
- Geomean Values

Obtaining 2008 Maps from USGS Seismic Hazard Data Website

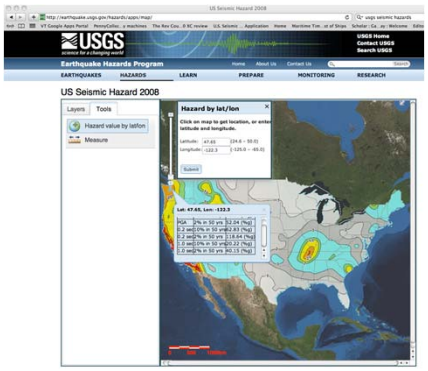


2008 USGS Seismic Hazard Maps





Obtain Accelerations for Given Lat-Lon

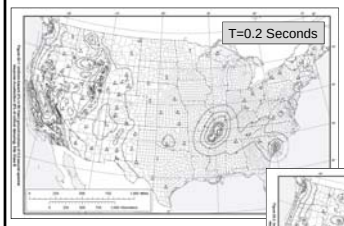


For Lat = 47.65
Lon = -122.3
2% in 50 year
GEOMEAN values:
PGA=0.520 g
0.2 sec=1.186 g
1.0 sec=0.4015 g

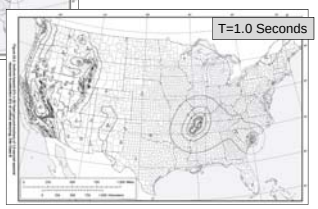
2009 NEHRP Maps

- Probabilistic / Deterministic (Separate Maps)
- Uniform Risk (Separate Maps)
- Spectral Contours (PGA, 0.1, 0.2 sec)
- 5 % Damping
- Site Class B/C Boundary
- Maximum Direction Values

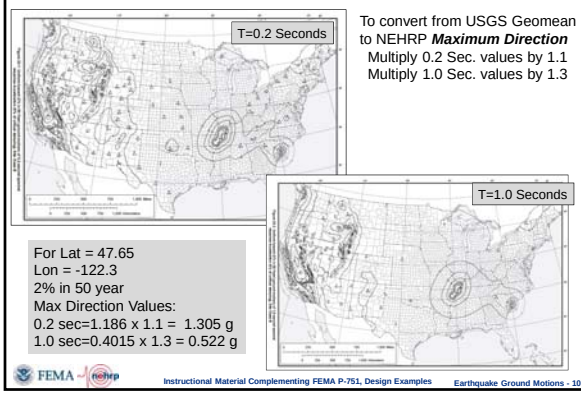
2009 NEHRP Probabilistic Maps



- Probabilistic / Deterministic (Separate Maps)
- Uniform Risk (Separate Maps)
- Spectral Contours (PGA, 0.1, 0.2 sec)
- 5 % Damping
- Site Class B/C Boundary
- Maximum Direction Values



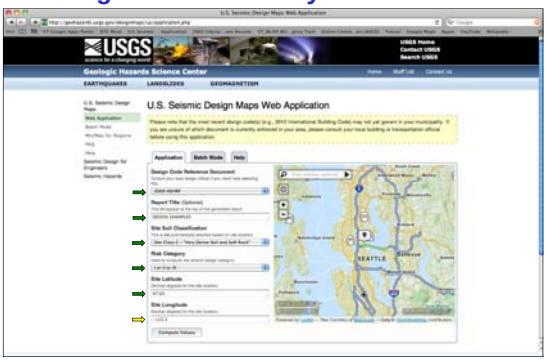
Maximum Direction Conversion



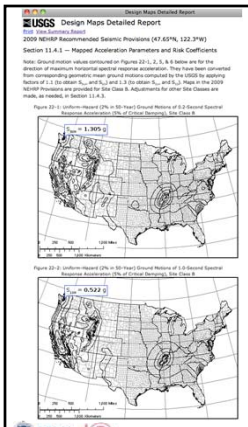
To convert from USGS Geomean to NEHRP ***Maximum Direction***
Multiply 0.2 Sec. values by 1.1
Multiply 1.0 Sec. values by 1.3

For Lat = 47.65
Lon = -122.3
2% in 50 year
Max Direction Values:
0.2 sec=1.186 x 1.1 = 1.305 g
1.0 sec=0.4015 x 1.3 = 0.522 g

Using the USGS Utility: 2009 NEHRP



Results from Detailed Report



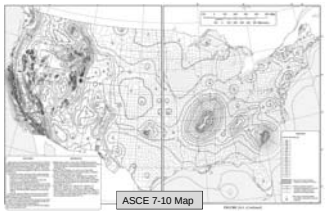
S_{SUH}=1.305g
S_{1UH}=0.522g

For Lat = 47.65
Lon = -122.3
2% in 50 year
Max Direction Values:
0.2 sec=1.186 x 1.1 = 1.305 g
1.0 sec=0.4015 x 1.3 = 0.522 g

Adjustment for Risk and Deterministic Cap

NEHRP Spectral Accelerations + NEHRP Risk Coefficients + NEHRP Deterministic Peaks

=



ASCE 7-10 Map

Adjustment for Risk

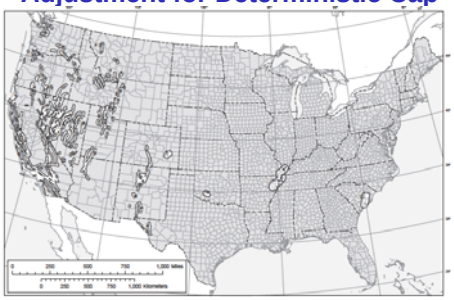
$$S_S = \min(S_{SUH} C_{RS}, S_{SD})$$

$$S_1 = \min(S_{1UH} C_{R1}, S_{1D})$$

S_{UH} Maps (S_{1H} maps similar)

C_{RS} Maps (C_{R1} maps similar)

Adjustment for Deterministic Cap

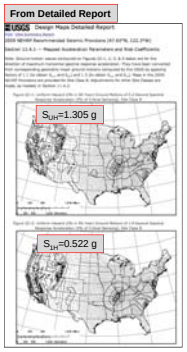


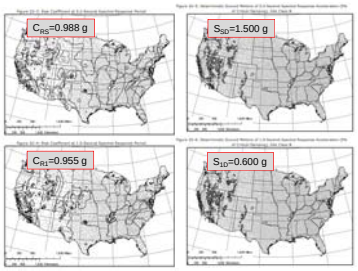
S_{SD} Map (S_{1D} map is similar)

Deterministic Cap is 84th Percentile Ground Motion
But not less than 1.5g (S_{SD}) or 0.6g (S_{1D})

2009 NEHRP Intermediate Results

From Detailed Report





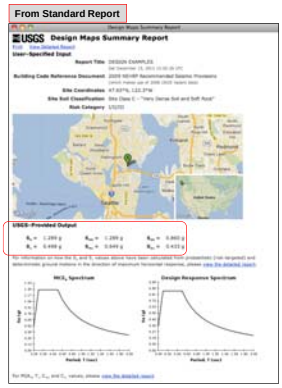
$$S_S = \min(S_{SUH} C_{RS}, S_{SD}) = \min(1.305 \times 0.988, 1.5) = 1.289g$$

$$S_1 = \min(S_{1UH} C_{R1}, S_{1D}) = \min(0.522 \times 0.955, 0.6) = 0.498g$$

FEMA nehrp Instructional Material Complementing FEMA P-751, Design Examples Earthquake Ground Motions - 16

2009 NEHRP Results

From Standard Report



S_S=1.289g
S_1=0.498g

FEMA nehrp Instructional Material Complementing FEMA P-751, Design Examples Earthquake Ground Motions - 17

Summary of Differences between 2009 NEHRP and ASCE 7-10 Approaches

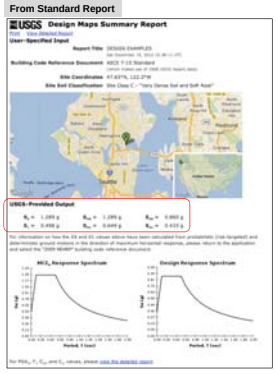
- NEHRP Starts with maximum direction maps and a uniform hazard and provides explicit values (C_{RS} and C_{R1}) for adjust to uniform risk.
- NEHRP Provides maps for deterministic cap
- When using NEHRP the user must manually (or via web utility) convert to MCE_R values.
- ASCE 7-10 Provides MCE_R values **Directly**

FEMA nehrp Instructional Material Complementing FEMA P-751, Design Examples Earthquake Ground Motions - 18

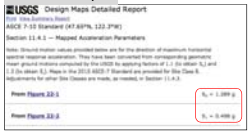
Using the USGS Utility: ASCE 7-10

ASCE 7-10 Results

From Standard Report



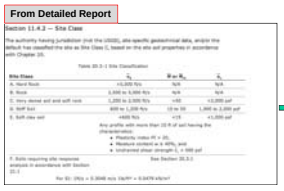
From Detailed Report

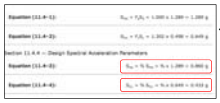


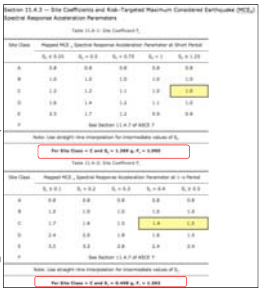
S_s=1.289g
S_1=0.498g

Adjusting for Site Effects
2009 NEHRP and ASCE 7-10

From Detailed Report





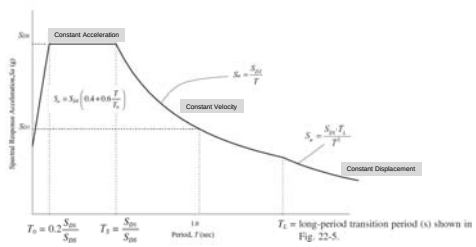


S_{DS}=0.860g
S_{D1}=0.433g

Topics Covered

- 2008 USGS Uniform Hazard Maps
- 2009 NEHRP *Provisions* Maps
- ASCE 7-10 Seismic Maps
- **Horizontal Response Spectra**
- **Vertical Response Spectra**
- **Peak Ground Acceleration**
- Selection and Scaling of Ground Motions

Development of Design Spectrum



Development of Design Spectrum

S_{DS}=0.860g
S_{D1}=0.433g

$$T_s = \frac{S_{D1}}{S_{DS}} = \frac{0.860}{0.433} = 0.503\,s$$

$$T_0 = 0.2T_S = 0.2(0.503) = 0.10\,s$$

T_L=6 s *(from map)*

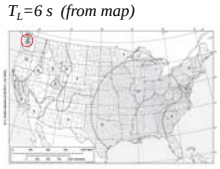
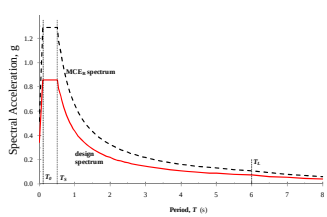


Fig. 22-7 Long Period Transition Maps



S_a @ T=0= 0.4(S_{DS})=0.4(0.860)=0.344g

Vertical Response Spectra

- New Chapter 23 of NEHRP Provisions
- Not yet incorporated into ASCE 7

Spectrum has Four Braches:

1. $S_{av} = 0.3C_vS_{DS}$
2. $S_{av} = 20C_vS_{DS}(T_V - 0.025) + 0.3C_vS_{DS}$
3. $S_{av} = 0.8C_vS_{DS}$
4. $S_{av} = 0.8C_vS_{DS}\left(\frac{0.15}{T_V}\right)^{0.75}$

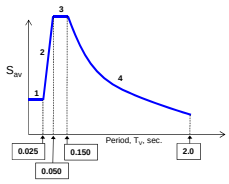


Table 23.1-1 Values of Vertical Coefficient C_v

MCE$_R$ Spectral Response Parameter at Short Periods *	Site Class A, B	Site Class C	Site Class D, E, F
$S_S \geq 2.0$	0.9	1.3	1.5
$S_S = 1.0$	0.9	1.1	1.3
$S_S = 0.6$	0.9	1.0	1.1
$S_S = 0.3$	0.8	0.8	0.9
$S_S \leq 0.2$	0.7	0.7	0.7

* Use straight-line interpolation for intermediate values of S_S.

Vertical Response Spectra

For current example S_S=1.389g, S_{DS}=0.859g, Site Class D

$$S_{av} = 0.3C_vS_{DS} = 0.3(1.158)(0.859) = 0.298$$

$$S_{av} = 0.8C_vS_{DS} = 0.8(1.158)(0.859) = 0.796$$

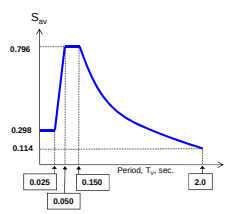
$$S_{av} = 0.8C_vS_{DS}\left(\frac{0.15}{T_V}\right)^{0.75} = 0.8(1.158)(0.859)\left(\frac{0.15}{2.0}\right)^{0.75} = 0.114$$

Table 23.1-1 Values of Vertical Coefficient C_v

MCE$_R$ Spectral Response Parameter at Short Periods *	Site Class A, B	Site Class C	Site Class D, E, F
$S_S \geq 2.0$	0.9	1.3	1.5
$S_S = 1.0$	0.9	1.1	1.3
$S_S = 0.6$	0.9	1.0	1.1
$S_S = 0.3$	0.8	0.8	0.9
$S_S \leq 0.2$	0.7	0.7	0.7

* Use straight-line interpolation for intermediate values of S_S.

Interpolation gives C_v=1.158



Note: This is the DBE Spectra. Multiply all accelerations by 1.5 to obtain MCE Spectra

Peak Ground Acceleration

Section 11.8.3 of ASCE 7-10:

$$PGA_M = F_{PGA}PGA$$

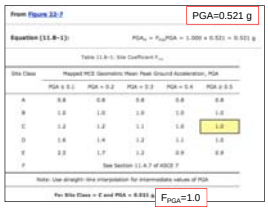
Table 11.8-1 Site Coefficient F_{PGA}

Site Class	Mapped Maximum Considered Geometric Mean (MCE$_G$) Peak Ground Acceleration, PGA				
	PGA ≤ 0.1	PGA = 0.2	PGA = 0.3	PGA = 0.4	PGA ≥ 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	1.2	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	See Section 11.4.7				

Note: Use straight-line interpolation for intermediate values of PGA.

Peak Ground Acceleration

Results from USGS Design Maps Utility (Detailed Report) for Seattle Location



PGA=0.521 g

F_{PGA}=1.0

$$PGA_M = F_{PGA} PGA = 1.0 \times 0.521 = 0.521g$$

Note: This is the MCE PGA. Design PGA (where used) = (2/3) PGA_M

Topics Covered

- 2008 USGS Uniform Hazard Maps
- 2009 NEHRP *Provisions* Maps
- ASCE 7-10 Seismic Maps
- Horizontal Response Spectra
- Vertical Response Spectra
- Peak Ground Acceleration
- **Selection and Scaling of Ground Motions**

Selection and Scaling of Ground Motions

- Selection and Scaling procedures are Provided in Chapter 16 of ASCE 7-10: *Response History Analysis*
- Chapter 16 is usually used in association with nonlinear analysis of special structures or structures that do not conform to certain requirements (e.g. height limitations) in ASCE 7-10.
- This example will demonstrate procedure for a site in Seattle, Washington.
- Additional discussion of ground motion scaling and use in linear and nonlinear response history analysis is provided in Chapter 4 of P-751, *Structural Analysis.*

Ground Motion Nomenclature

- An "Event" refers to a given historical earthquake, such as the 1989 Loma Prieta California Earthquake
- A "Record" refers to the recorded ground acceleration histories at a particular recording station, such as the Saratoga-Aloha Ave. recording of the Loma Prieta event.
- Each record has (usually) three "Components" consisting of two (usually) orthogonal components and one vertical component. The horizontal components are often, but not always, oriented in N-S and E-W directions. In some cases fault-normal and fault-parallel values are provided. Records can be transformed to any direction (e.g. N-S and E-W recordings can be transformed to fault-normal and fault-parallel given the orientation of the fault.
- A "Suite" of ground motions consist of three or more records.

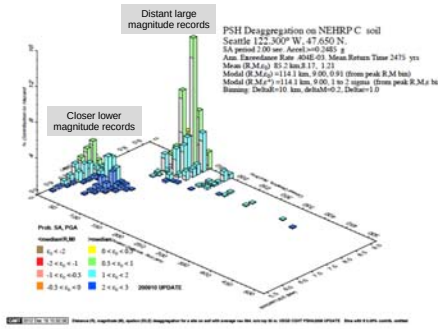
Location of Site

Selection of Appropriate Records

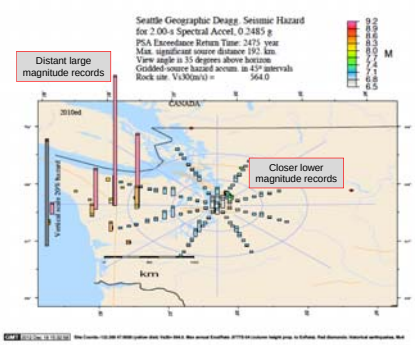
- Select from records of events having magnitude, fault distance, and source mechanisms that control the maximum considered earthquake (MCE)
- Pertinent information can be obtained from "Deaggregtion" of the seismic hazard

http://earthquake.usgs.gov/hazards/apps/#deaggint

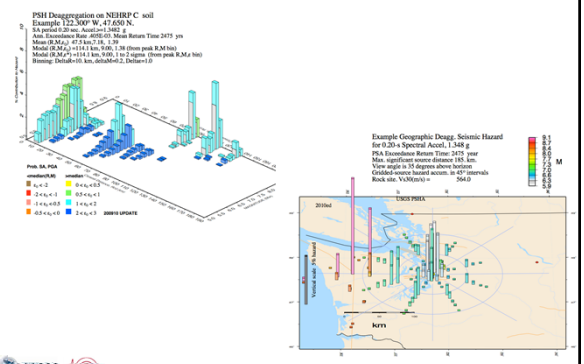
Deaggreagtion of Hazard (2.0 sec Accel)



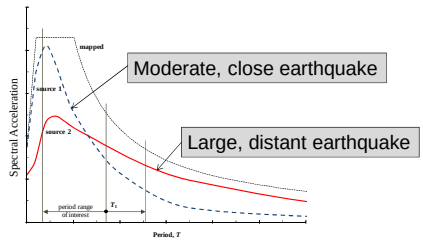
Deaggregation of Hazard (2.0 sec Accel)



Deaggreagtion of Hazard (0.2 sec Accel)



Spectral Characteristics of Close and Far Records

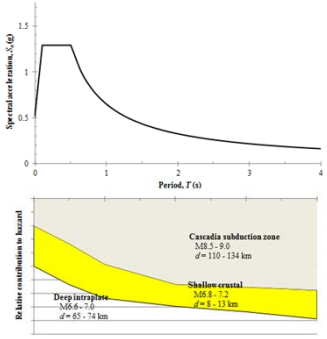


Deaggregation of Hazard (0.2 Sec Accel)

```
Principal sources (faults, subduction, random seismicity having > 3% contribution)
Source Category:                  % contr.  R(km)    M   epsilon0 (mean values).
Cascadia M8.3-M8.7 Floating         6.12   109.2   8.52    1.64
Cascadia Megathrust                19.51   108.9   9.02    1.30
Wash-Oreg Cascades-West faults +   17.61    12.1   6.96    1.14
WUS Compr crustal gridded          17.51     9.4   6.14    1.13
50-km Deep Intraplate              21.72    60.6   6.79    2.07
Puget Lowlands gridded             16.55     9.4   6.32    1.03
Individual fault hazard details if its contribution to mean hazard > 2%:
Fault ID                          % contr.   Rcd(km)  M   epsilon0 Site-to-src azimuth(d)
Seattle fault zone, mid. GR         3.25    12.1   6.82    1.24    -172.2
Seattle fault zone, north, GR       5.14     9.9   6.82    1.01    -175.4
Seattle fault zone, N. Trace, Ch    4.55     8.0   7.16    0.72    -177.6
#*********End of deaggregation corresponding to Mean Hazard w/all GMPEs  *********#
```

Cascadia Subduction Zone=6.1+19.5=25.6%
Shallow Crustal=17.6+17.5=35.1%
Deep Intraplate=21.7+16.6=48.3%

Source Mechanisms for Selected Records



Scaling Requirements

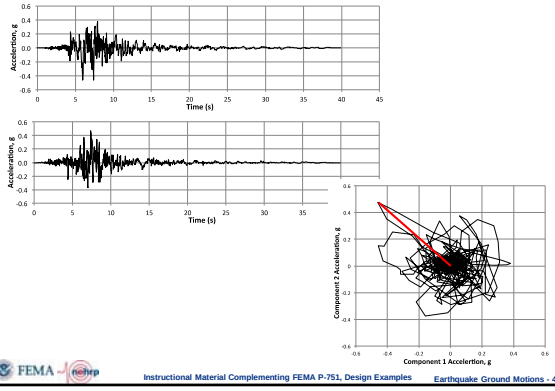
- 2D Analysis: The ground motions shall be scaled such that the average of the 5% damped response spectra is not less than the design spectrum over the period range 0.2T to 1.5T.
- 3D Analysis: The ground motions shall be scaled such that the average of the SRSS spectra from all horizontal component pairs does not fall below the design spectrum over the period range 0.2T to 1.5T.
- At sites within 5 km of the active fault each pair of components shall be rotated to fault-normal and fault-parallel directions and shall be scaled such that the ~~fault normal~~ dominant component is not less than the ~~MCE_R~~ design spectrum over the period range 0.2 to 1.5T.

Ground Motion Scale Factors for 3D Analysis

Table 3-1 Selected and Scaled Ground Motions for Example Site

Record No.	Year	Earthquake name	M	Source type	Recording station	Distance (km)
1	2003	Tokachi-oki, Japan	8.3	Subduction zone	HKA 094	67
2	2003	Tokachi-oki, Japan	8.3	Subduction zone	HKD 092	46
3	1968	Tokachi-oki, Japan	8.2	Subduction zone	Hachinohe (S-252)	71
4	1949	Western Washington	7.1	Deep intraplate	Olympia	75
5	1989	Loma Prieta	6.9	Shallow crustal	Saratoga -- Aloha Ave	9
6	1999	Duzce, Turkey	7.1	Shallow crustal	Duzce	7
7	1995	Kobe, Japan	6.9	Shallow crustal	Nishi-Akashi	7

Components of the Northridge Earthquake

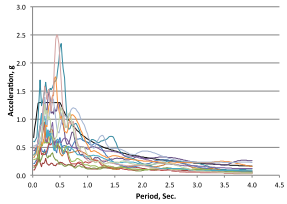


Ground Motion Spectra

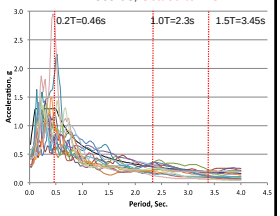
Table 3-1 Selected and Scaled Ground Motions for Example Site

Record No.	Year	Earthquake name	M	Source type	Recording station	Distance (km)	Scale factor
1	2003	Tokachi-oki, Japan	8.3	Subduction zone	HKA 094	67	2.99
2	2003	Tokachi-oki, Japan	8.3	Subduction zone	HKD 092	46	0.96
3	1968	Tokachi-oki, Japan	8.2	Subduction zone	Hachinohe (S-252)	71	1.28
4	1949	Western Washington	7.1	Deep intraplate	Olympia	75	1.92
5	1989	Loma Prieta	6.9	Shallow crustal	Saratoga – Aloha Ave	9	1.28
6	1999	Duzce, Turkey	7.1	Shallow crustal	Duzce	7	0.85
7	1995	Kobe, Japan	6.9	Shallow crustal	Nishi-Akashi	7	1.18

All Records, Unscaled



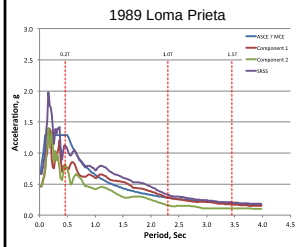
All Records, Scaled to MCE



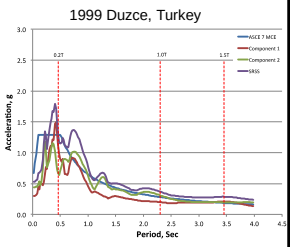
Instructional Material Complementing FEMA P-751, Design Examples Earthquake Ground Motions - 43

Response Spectra for Two Selected Scaled Motions

1989 Loma Prieta

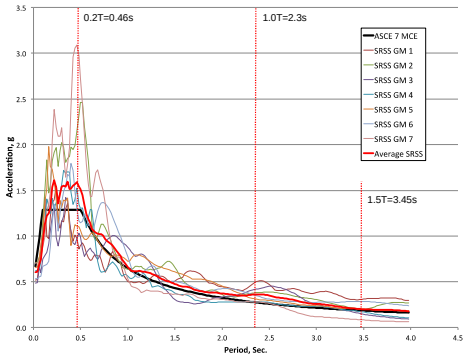


1999 Duzce, Turkey



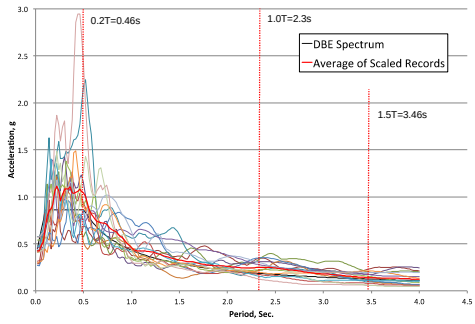
Instructional Material Complementing FEMA P-751, Design Examples Earthquake Ground Motions - 44

SRSS Scaled Spectra and MCE Spectrum

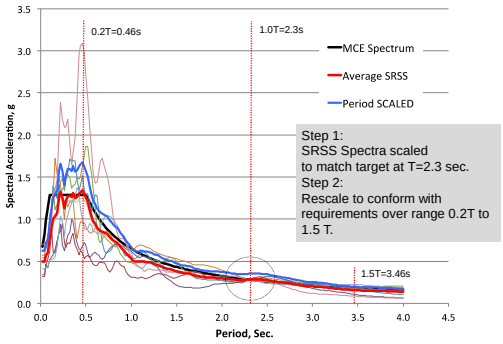


Instructional Material Complementing FEMA P-751, Design Examples Earthquake Ground Motions - 45

Scaled Records and DBE Spectrum



Alternate Scaling



Questions