Probabilistic Ground Motions in Earthquake-resistant Design of Buildings

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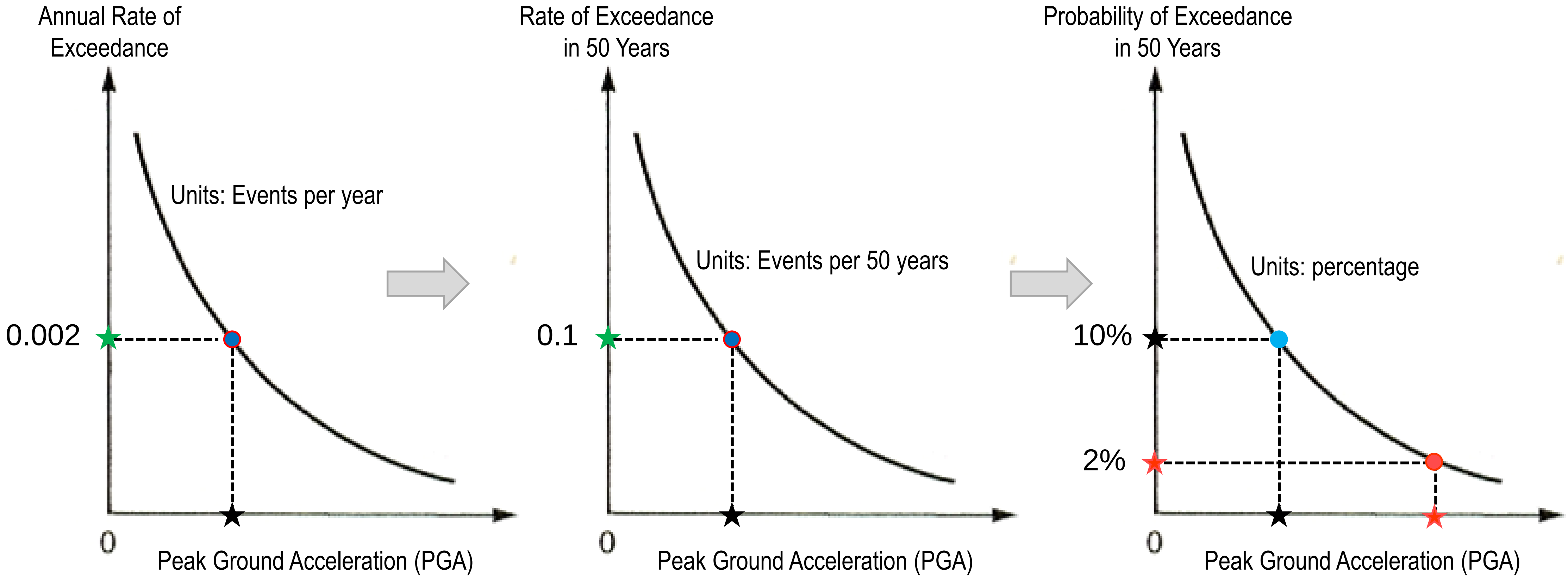
Use of Probabilistic Ground Motions in Earthquake-resistant Design of Buildings

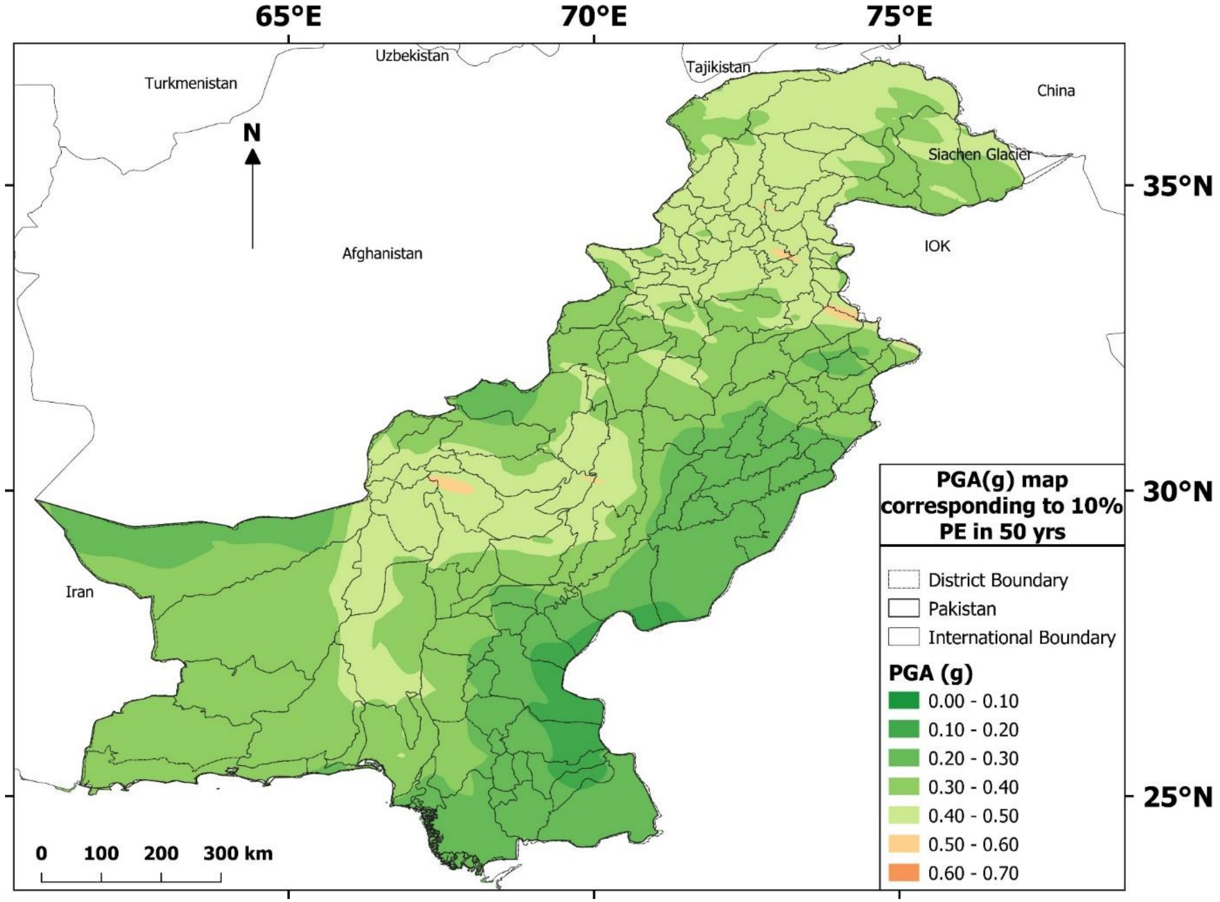
Different Forms of Hazard Curves



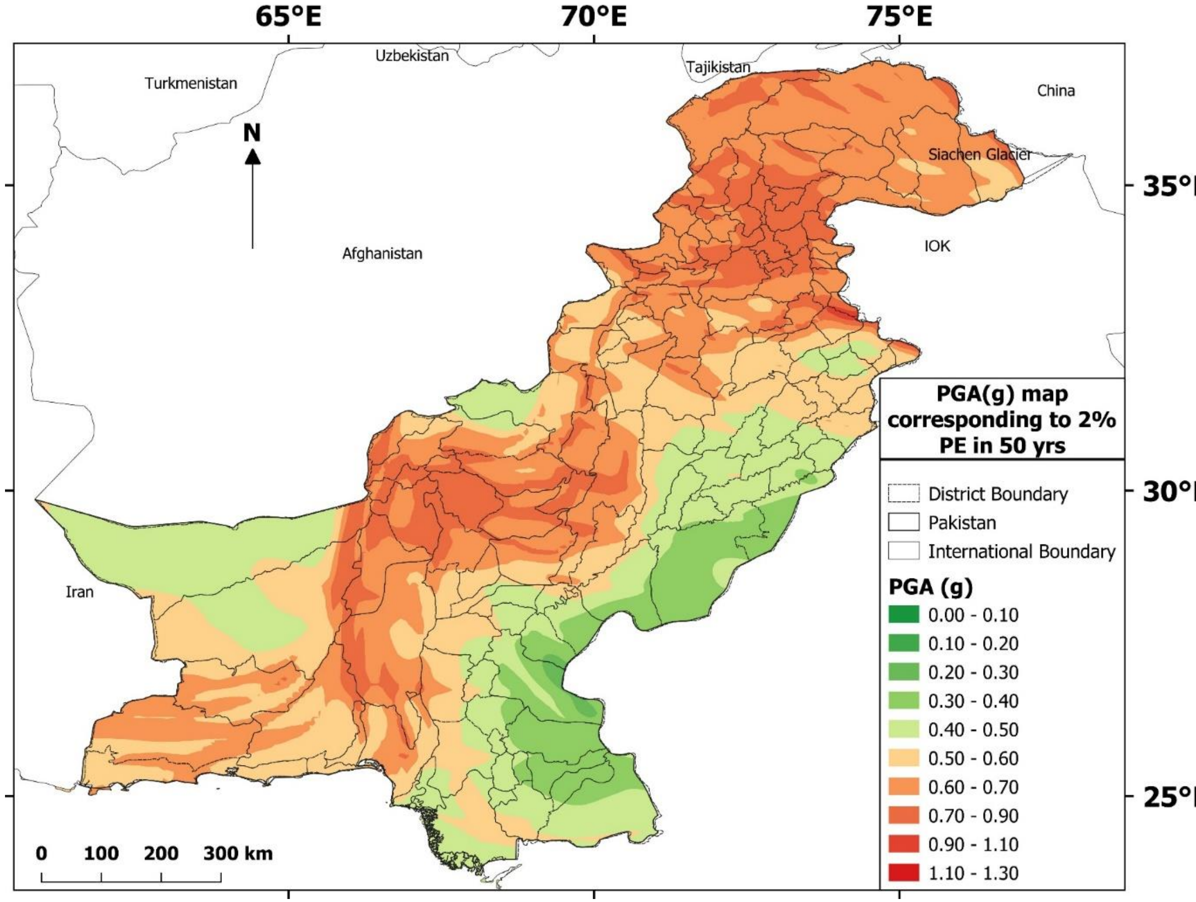
Probabilistic Seismic Hazard Analysis

Seismic Hazard Map of Pakistan

10% PE in 50 Years (475 Years Return Period)



2% PE in 50 Years (2475 Years Return Period)



Use of Probabilistic Ground Motions in Earthquake-resistant Design of Buildings

- The expected performance of buildings in modern earthquake-resistant design codes are:

1) Resist **a minor level of earthquake** ground shaking (SE) without damage

   SE = Serviceability earthquake—50% probability of exceedance in 30 years (43-year return period)

2) Resist **the design level of eart**hquake ground shaking (DBE) with damage (which may or may not be economically repaired) but without causing extensive loss of life.

   DBE = Design basis earthquake—10% probability of exceedance in 50 years (475-year return period)

3) Resist **the strongest earthquake** shaking expected at the site (MCE) without collapse, but potentially with extreme damage.

   MCE = Maximum considered earthquake—2% probability of exceedance in 50 years (2475-year return period)

Seismic Design Criteria of Major Dam Projects

- According to ICOLD (International Commission of Large Dams) Bulletin 72 (1989), large dams have to be able to withstand the effects of **the Maximum Credible Earthquake Shaking Level (MCE)**.
- This MCE is the strongest earthquake shaking level that could occur in the region of a dam, and is considered to have **a return period of several thousand years (typically 10,000 years in regions of low to moderate seismicity)**.

MCE = Maximum considered earthquake—0.5% probability of exceedance in 50 years (about 10,000-year return period)

Probabilistic Ground Motion Parameters: PGA, PGV, SA

- Traditionally **Peak Ground Acceleration (PGA)** has been used to quantify ground motion in PSHA. PGA is a good index to hazard for low-rise buildings, up to about 7 stories.
- **PGV, peak ground velocity,** is a good index to hazard to taller buildings. However, it is not clear how to relate velocity to force in order to design a taller building.
- Today the preferred parameter is **Response Spectral Acceleration (SA)**.
- While **PGA (peak acceleration)** is what is experienced by a particle on the ground, **SA** is approximately what is experienced by a building, as modeled by a particle mass on a massless vertical rod having the same natural period of vibration as the building.

SA = The maximum acceleration experienced by a damped, single-degree-of-freedom oscillator (a crude representation of building response).

Max. Earthquake Force in the Building = Building Mass x SA

Response Spectrum Parameters: SA, SD, SV

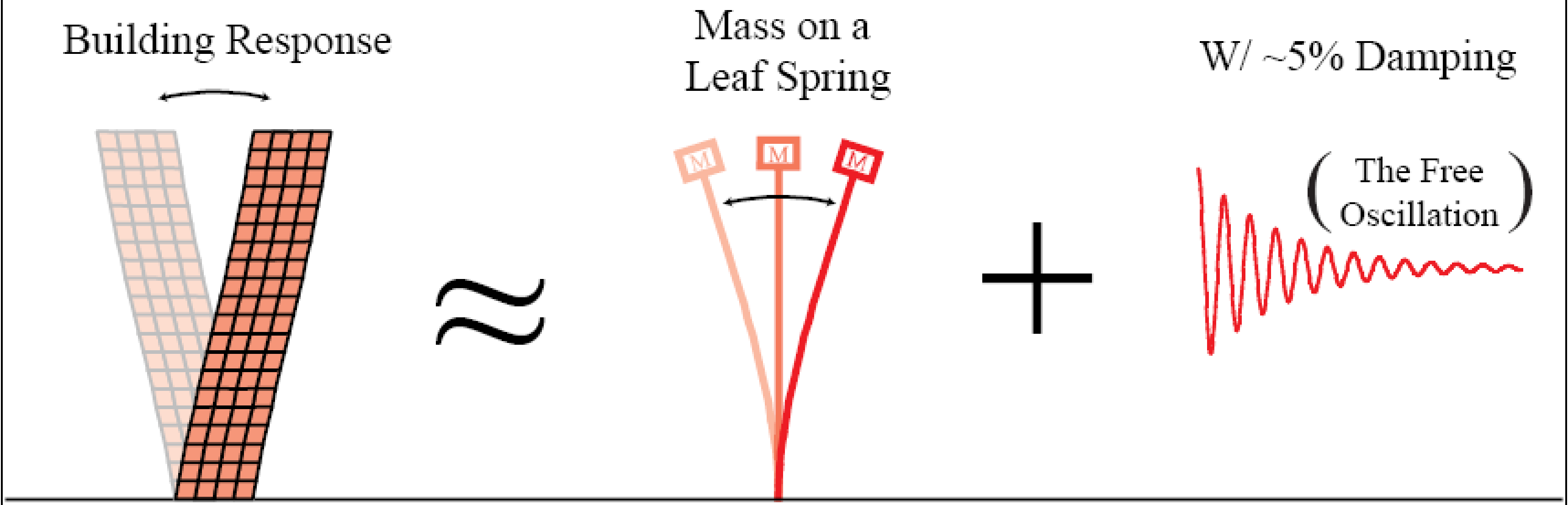


Figure 1. The response-spectrum value is the peak motion (displacement, velocity, or acceleration) of a damped single-degree of freedom harmonic oscillator (with a particular damping and resonant period) subjected to a prescribed ground motion.

If we look at the displacement response, we can identify the maximum displacement. If we take the derivative (rate of change) of the displacement response with respect to time, we can get the velocity response. The maximum velocity can likewise be determined. Similarly for response acceleration (rate of change of velocity) also called response spectral acceleration (SA).

Construction of Response Spectra (for Past Earthquakes)

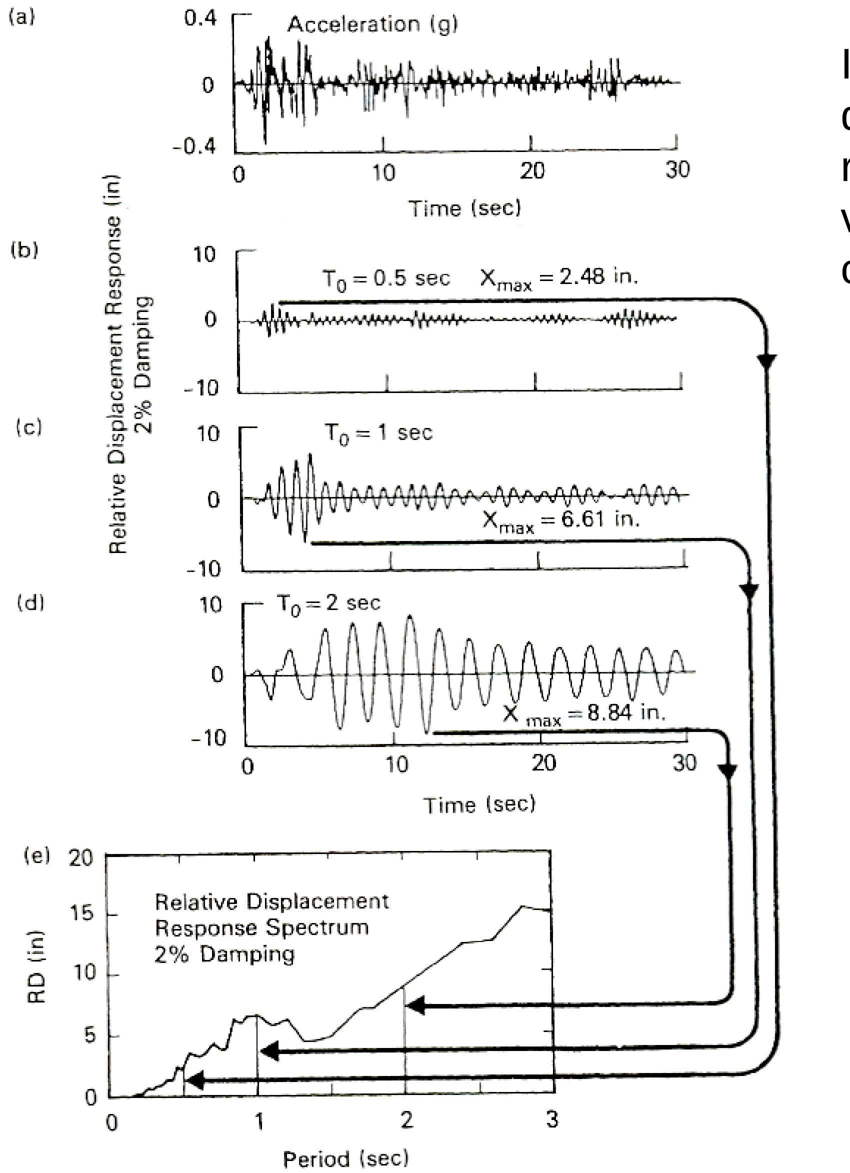
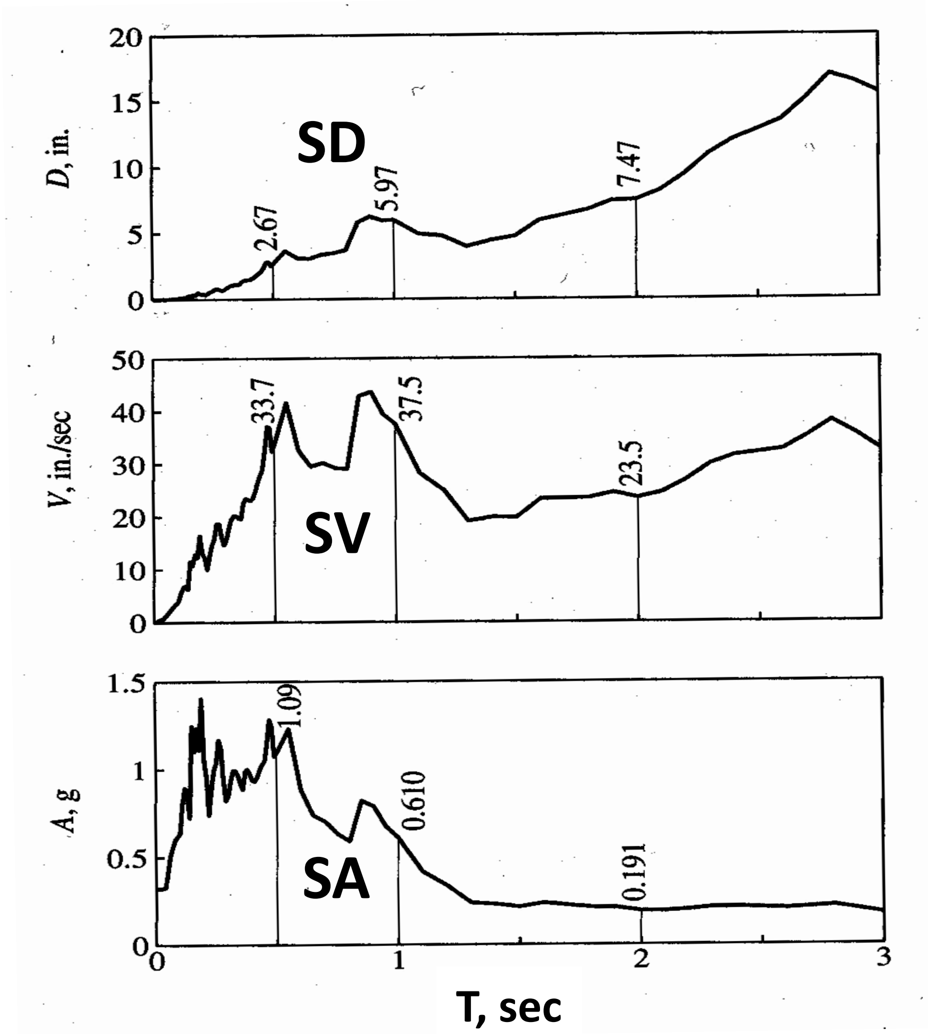
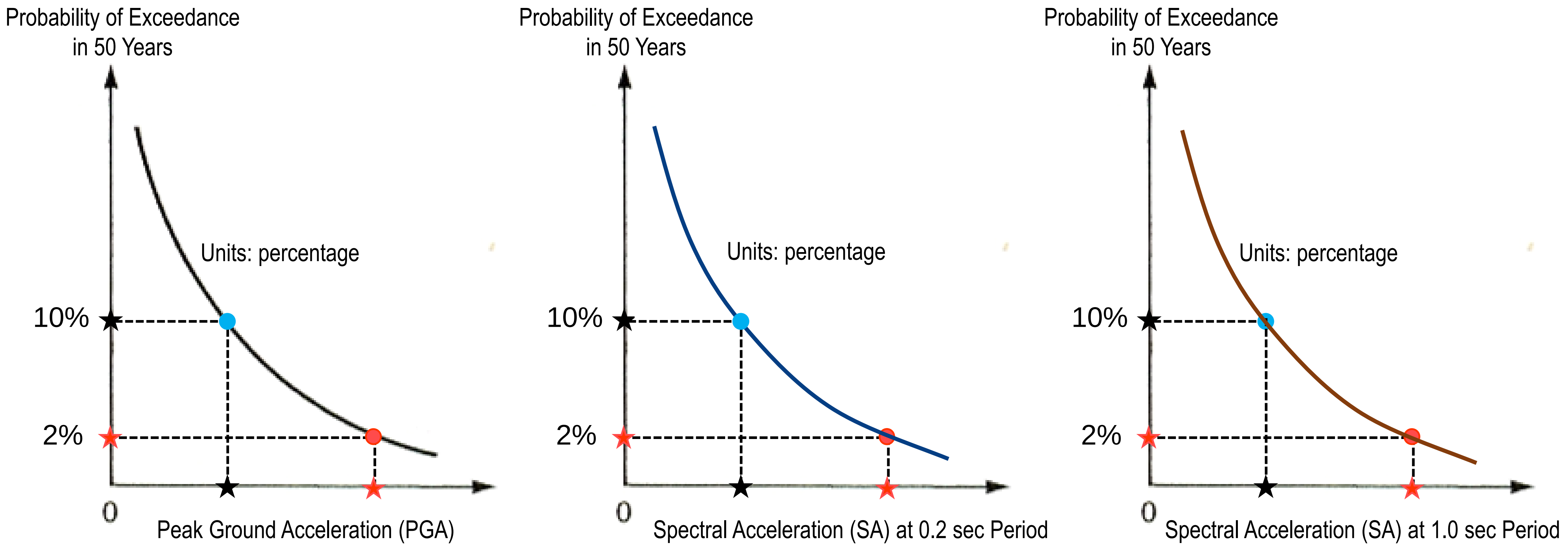


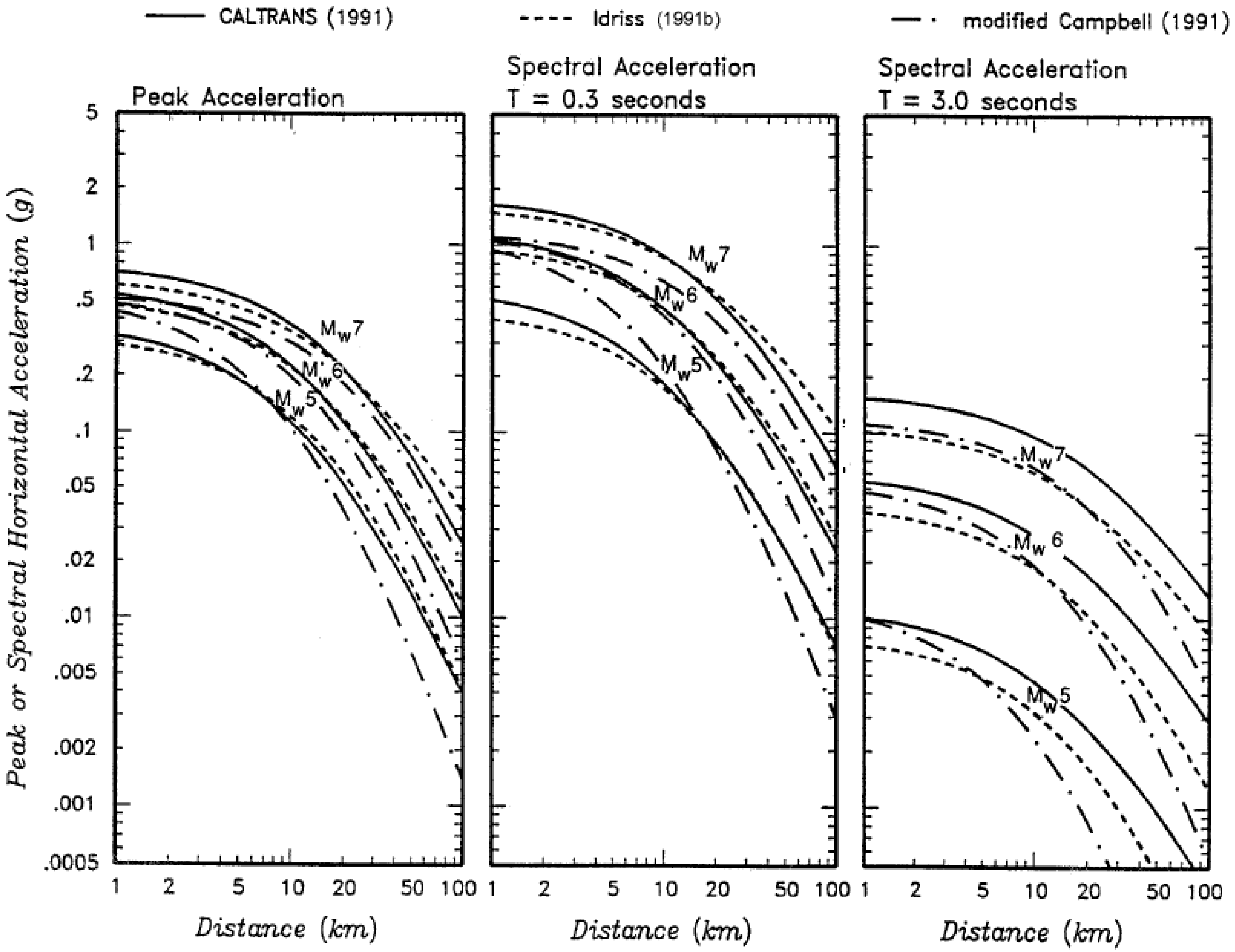
FIGURE 6.3 Construction of a response spectrum. (a) earthquake acceleration time history (El Centro, California 1940) used as input, (b) relative displacement response of a 2% damped oscillator with a natural period of 0.5 seconds, (c) relative displacement response of a 2% damped oscillator with a natural period of 1.0 seconds, (d) relative displacement response of a 2% damped oscillator with a natural period of 2.0 seconds and (e) maxima of b, c and d become points on the 2% damped relative displacement response spectrum (after Chopra 1981).



Hazard Curves for Spectral Acceleration



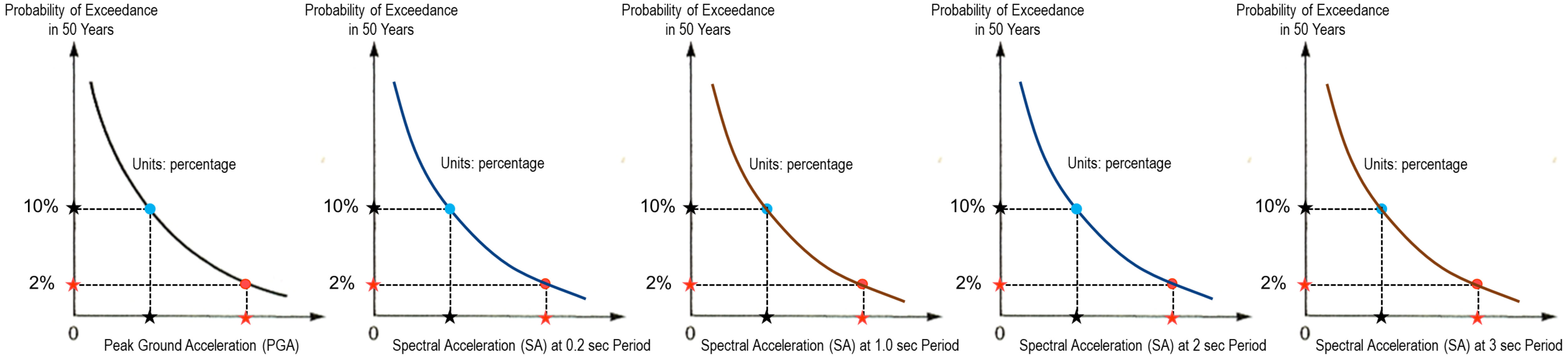
Attenuation Model for SA



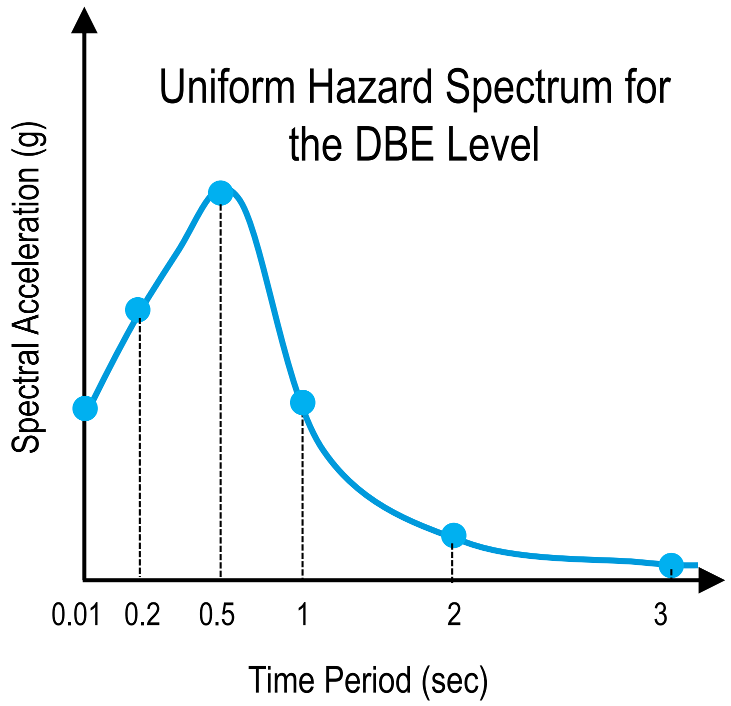
Coefficients of an attenuation relationship

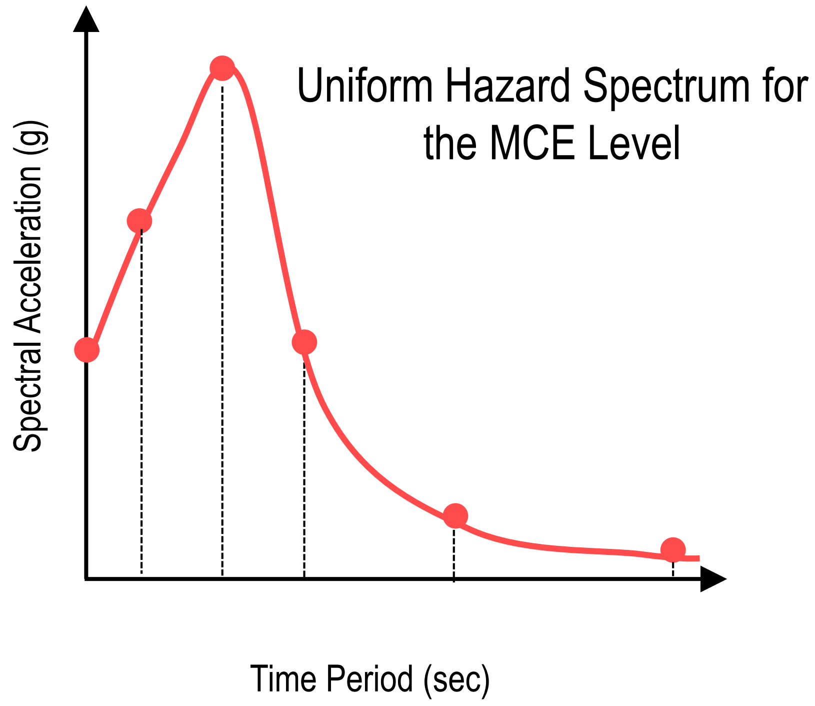
TABLE 5.11 Coefficients for Sadigh et al. Rock Attenuation Relation: Horizontal Component

T_n (s)	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	c_{10}	c_{11}	c_{12}	c_{13}	c_{14}
						$M_W \leq 6.5$								
PGA	0.182	–0.624	1.0	0	–2.100	0	3.6564	0.250	0	1.39	0.14	0.38	0	7.21
0.05	0.182	–0.090	1.0	0.006	–2.128	–0.082	3.6564	0.250	0	1.39	0.14	0.38	0	7.21
0.07	0.182	0.110	1.0	0.006	–2.128	–0.082	3.6564	0.250	0	1.40	0.14	0.39	0	7.21
0.09	0.182	0.212	1.0	0.006	–2.140	–0.052	3.6564	0.250	0	1.40	0.14	0.39	0	7.21
0.10	0.182	0.275	1.0	0.006	–2.148	–0.041	3.6564	0.250	0	1.41	0.14	0.40	0	7.21
0.12	0.182	0.348	1.0	0.005	–2.162	–0.014	3.6564	0.250	0	1.41	0.14	0.40	0	7.21
0.14	0.182	0.307	1.0	0.004	–2.144	0	3.6564	0.250	0	1.42	0.14	0.41	0	7.21
0.15	0.182	0.285	1.0	0.002	–2.130	0	3.6564	0.250	0	1.42	0.14	0.41	0	7.21
0.17	0.182	0.239	1.0	0	–2.110	0	3.6564	0.250	0	1.42	0.14	0.41	0	7.21
0.20	0.182	0.153	1.0	–0.004	–2.080	0	3.6564	0.250	0	1.43	0.14	0.42	0	7.21
0.24	0.182	0.060	1.0	–0.011	–2.053	0	3.6564	0.250	0	1.44	0.14	0.43	0	7.21
0.30	0.182	–0.057	1.0	–0.017	–2.028	0	3.6564	0.250	0	1.45	0.14	0.44	0	7.21
0.40	0.182	–0.298	1.0	–0.028	–1.990	0	3.6564	0.250	0	1.48	0.14	0.47	0	7.21
0.50	0.182	–0.588	1.0	–0.040	–1.945	0	3.6564	0.250	0	1.50	0.14	0.49	0	7.21
0.75	0.182	–1.208	1.0	–0.050	–1.865	0	3.6564	0.250	0	1.52	0.14	0.51	0	7.21
1.0	0.182	–1.705	1.0	–0.055	–1.800	0	3.6564	0.250	0	1.53	0.14	0.52	0	7.21
1.5	0.182	–2.407	1.0	–0.065	–1.725	0	3.6564	0.250	0	1.53	0.14	0.52	0	7.21
2.0	0.182	–2.945	1.0	–0.070	–1.670	0	3.6564	0.250	0	1.53	0.14	0.52	0	7.21
3.0	0.182	–3.700	1.0	–0.080	–1.610	0	3.6564	0.250	0	1.53	0.14	0.52	0	7.21
4.0	0.182	–4.230	1.0	–0.100	–1.570	0	3.6564	0.250	0	1.53	0.14	0.52	0	7.21
5.0	0.182	–4.714	1.0	–0.100	–1.540	0	3.6564	0.250	0	1.53	0.14	0.52	0	7.21
7.5	0.182	–5.530	1.0	–0.110	–1.510	0	3.6564	0.250	0	1.53	0.14	0.52	0	7.21



Construction of Uniform Hazard Spectra (UHS) (for Design against Future Earthquakes)





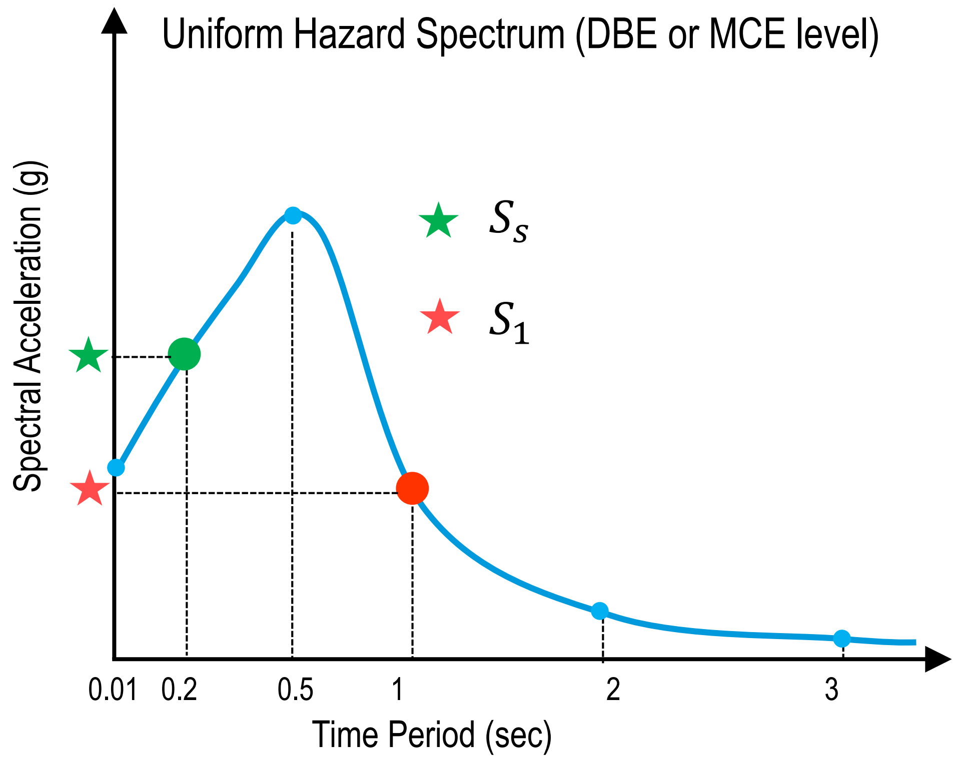
S_s and S_1 in Building Codes

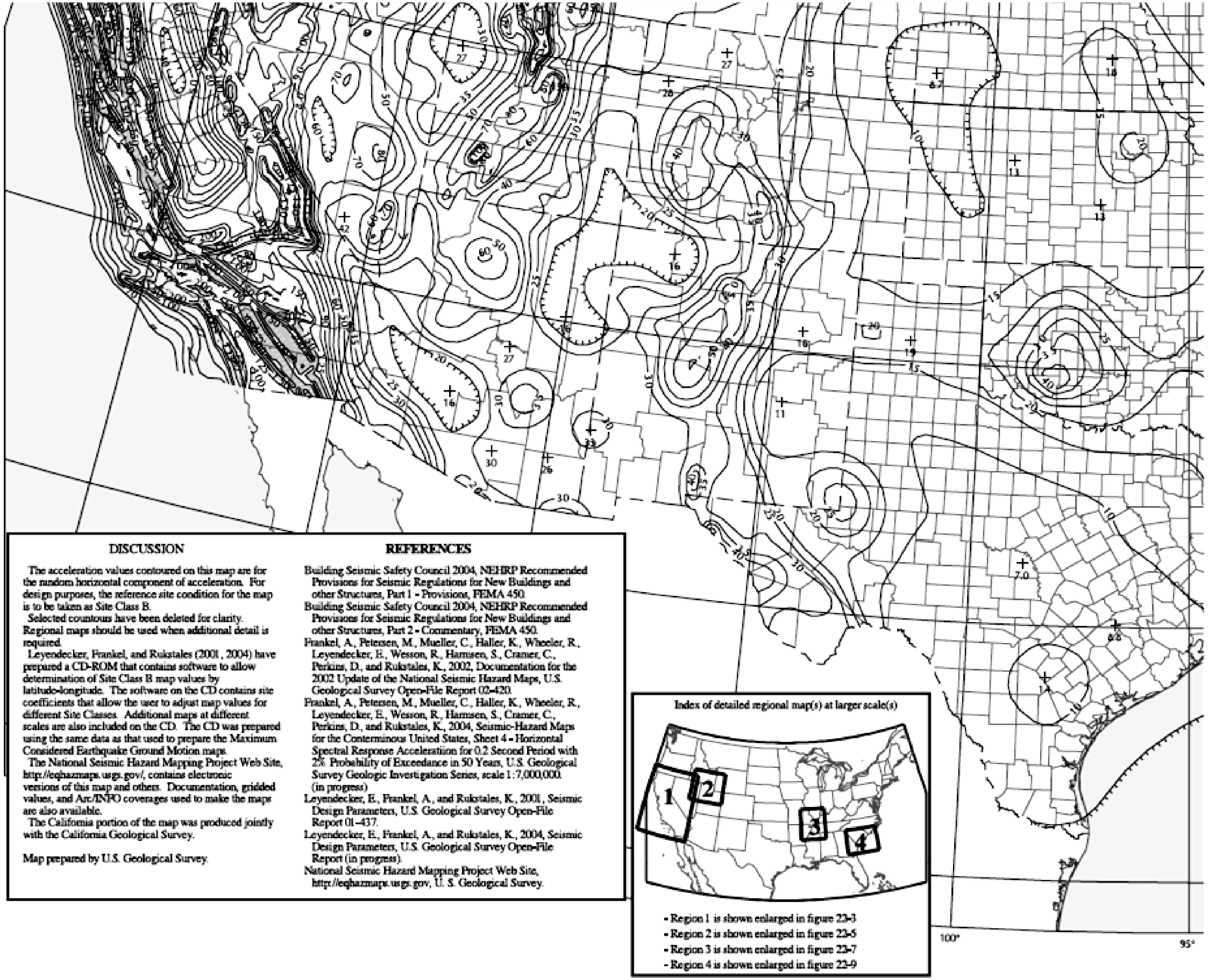
S_s = Short-period Spectral Acceleration

= SA (0.2 sec Time Period)

S_1 = Short-period Spectral Acceleration

= SA (1.0 sec Time Period)





DISCUSSION

The acceleration values contoured on this map are for the random horizontal component of acceleration. For design purposes, the reference site condition for the map is to be taken as Site Class B.

Selected countours have been deleted for clarity. Regional maps should be used when additional detail is required.

Leyendecker, Frankel, and Rukstales (2001, 2004) have prepared a CD-ROM that contains software to allow determination of Site Class B map values by latitude-longitude. The software on the CD contains site coefficients that allow the user to adjust map values for different Site Classes. Additional maps at different scales are also included on the CD. The CD was prepared using the same data as that used to prepare the Maximum Considered Earthquake Ground Motion maps.

The National Seismic Hazard Mapping Project Web Site, http://eqhazmaps.usgs.gov/, contains electronic versions of this map and others. Documentation, gridded values, and Arc/INFO coverages used to make the maps are also available.

The California portion of the map was produced jointly with the California Geological Survey.

Map prepared by U.S. Geological Survey.

REFERENCES

Building Seismic Safety Council 2004, NEHRP Recommended Provisions for Seismic Regulations for New Buildings and other Structures, Part 1 - Provisions, FEMA 450.

Building Seismic Safety Council 2004, NEHRP Recommended Provisions for Seismic Regulations for New Buildings and other Structures, Part 2 - Commentary, FEMA 450.

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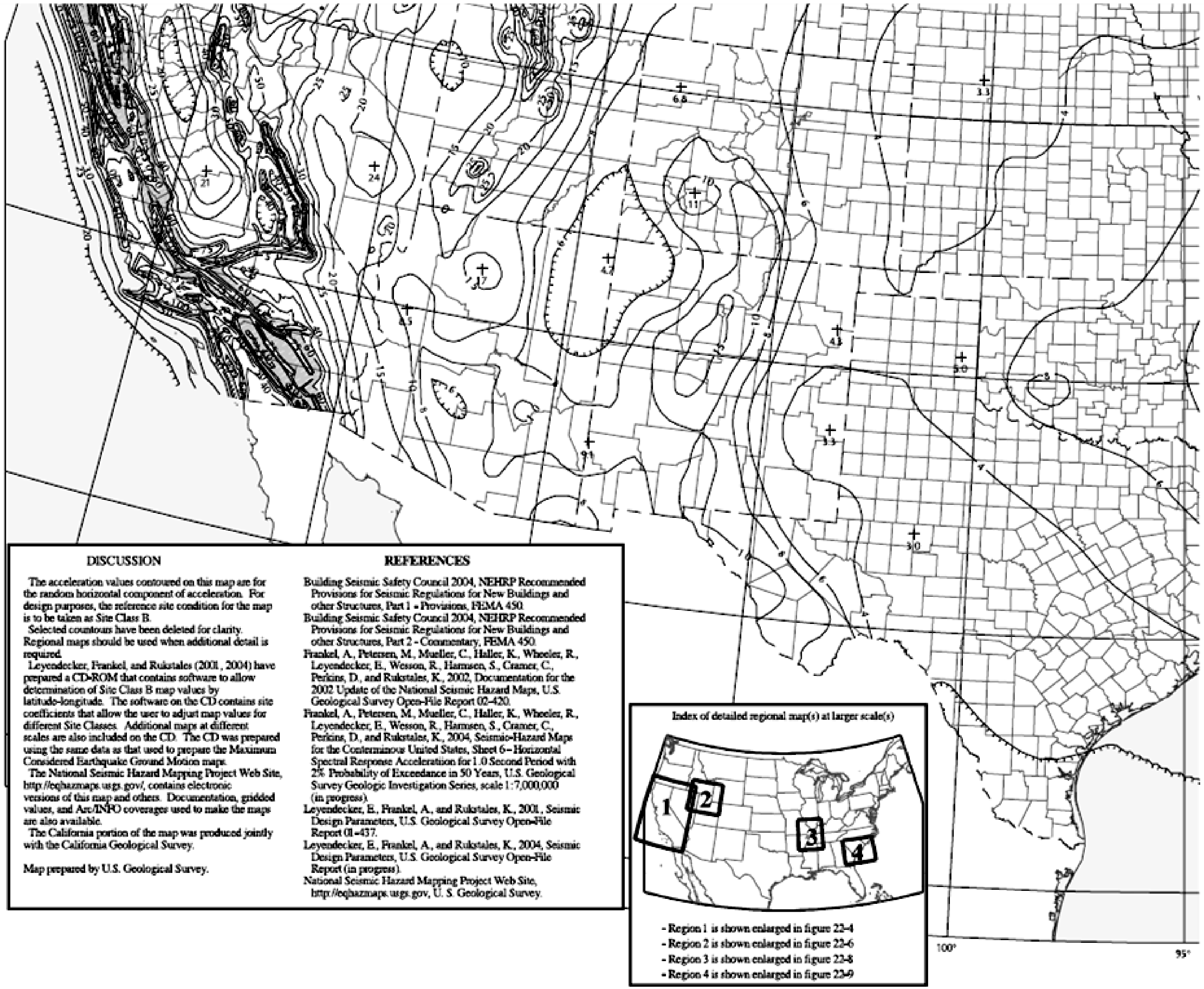
FIGURE 22-1 MAXIMUM CONSIDERED EARTHQUAKE GROUND MOTION FOR THE CONTERMINOUS UNITED STATES OF 0.2 SEC SPECTRAL RESPONSE ACCELERATION (5% OF CRITICAL DAMPING), SITE CLASS B



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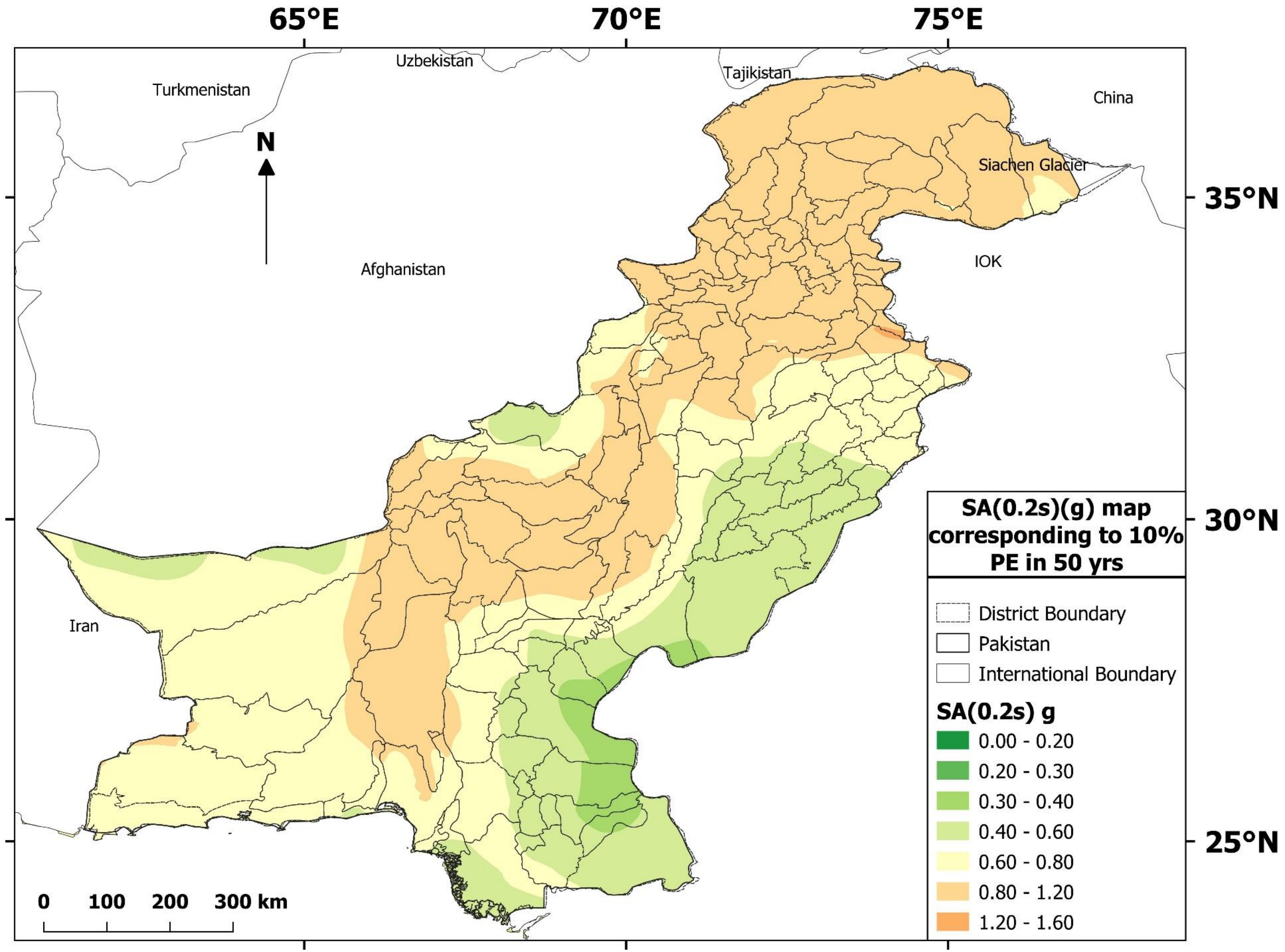
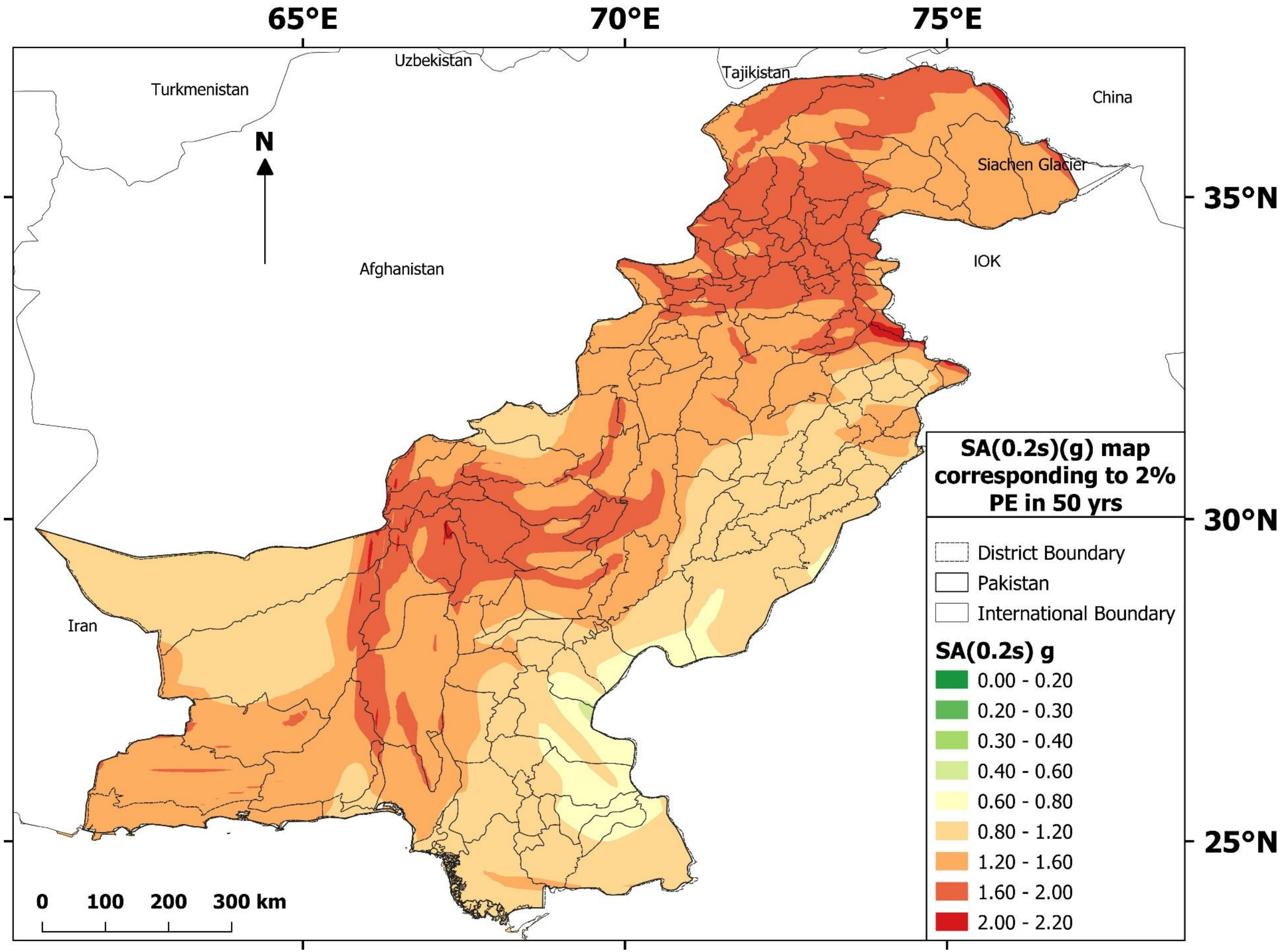
National Seismic Hazard Mapping Project Web Site, http://eqhazmaps.usgs.gov, U. S. Geological Survey.

FIGURE 22-2 MAXIMUM CONSIDERED EARTHQUAKE GROUND MOTION FOR THE CONTERMINOUS UNITED STATES OF 1.0 SEC SPECTRAL RESPONSE ACCELERATION (5% OF CRITICAL DAMPING), SITE CLASS B

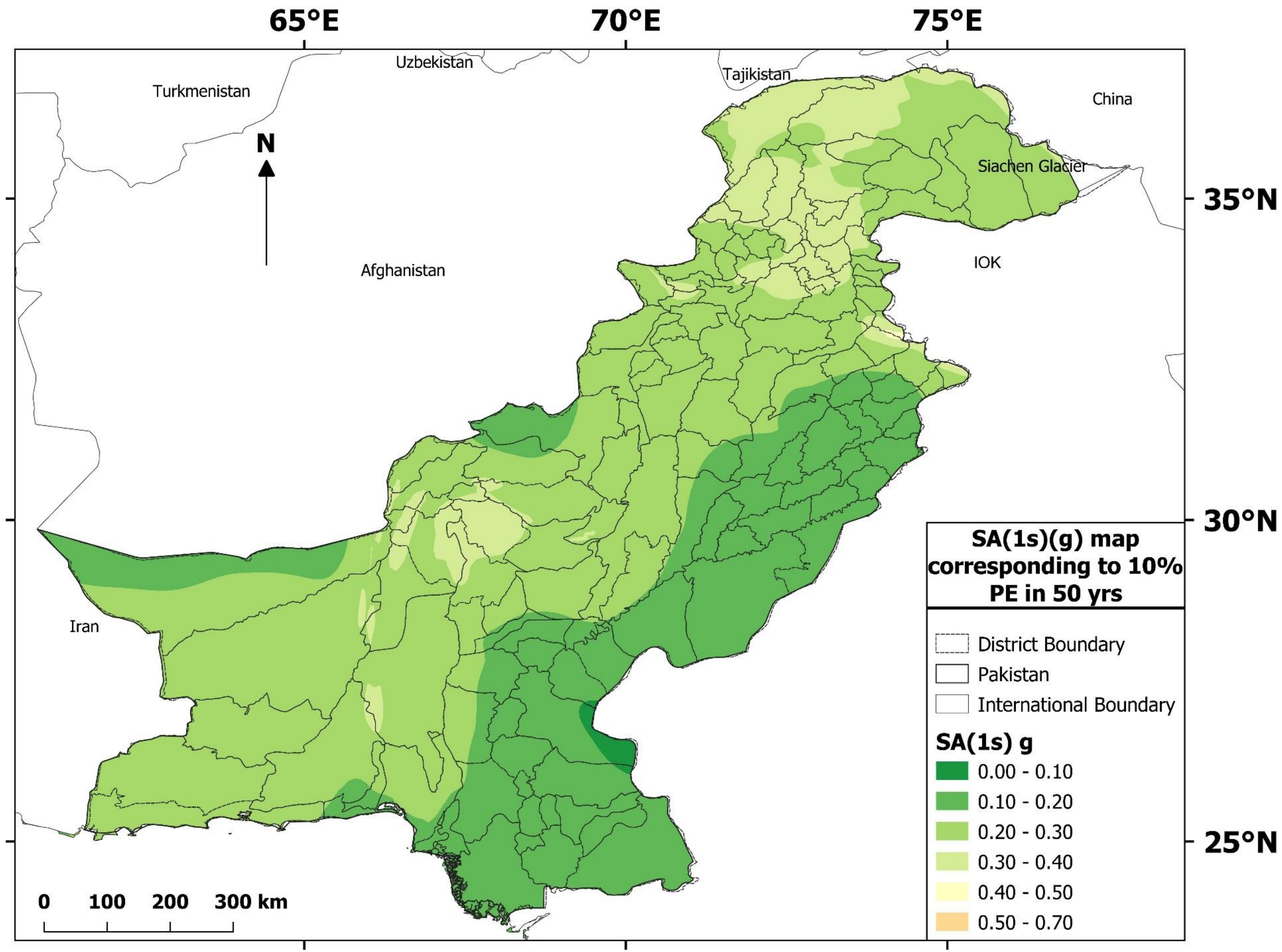
Spectral Acceleration (SA) at 0.2 sec. map for 475 years RP (10% PE in 50 years)



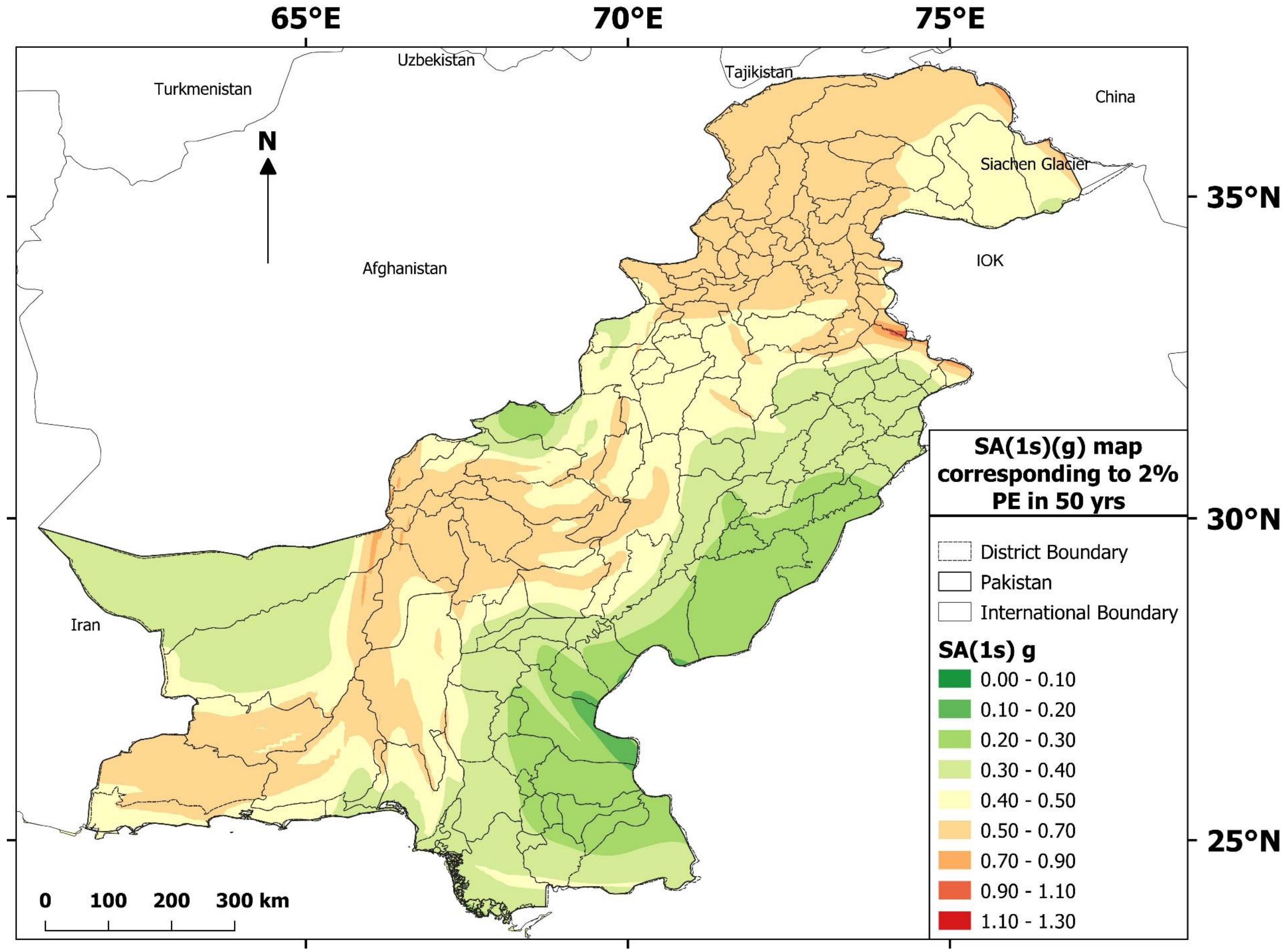
Spectral Acceleration (SA) at 0.2 sec. map for 2475 years RP (2% PE in 50 years)



Spectral Acceleration (SA) at 1.0 sec. map for 475 years RP (10% PE in 50 years)



Spectral Acceleration (SA) at 1.0 sec. map for 2475 years RP (2% PE in 50 years)

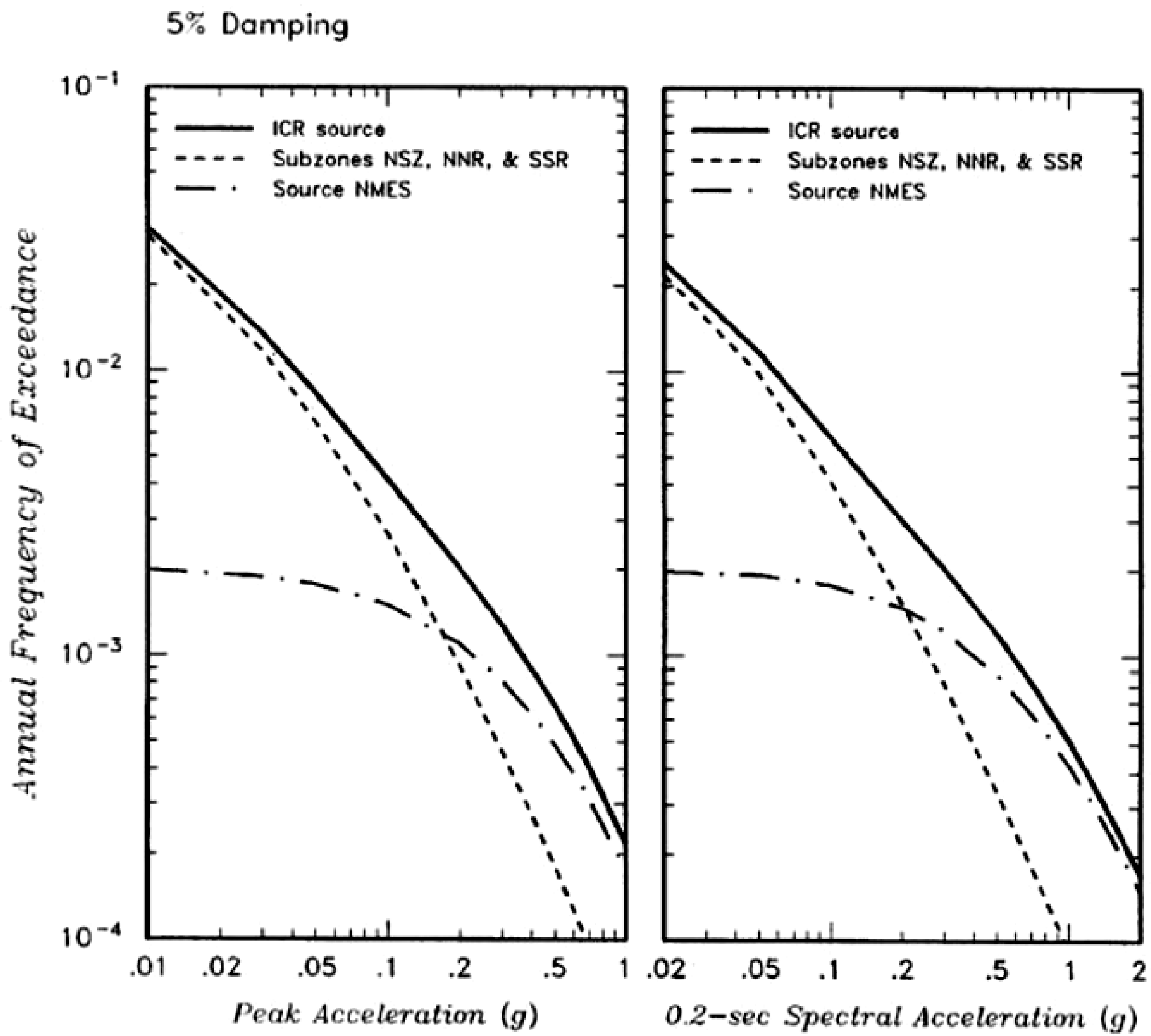


Deaggregation of Seismic Hazard

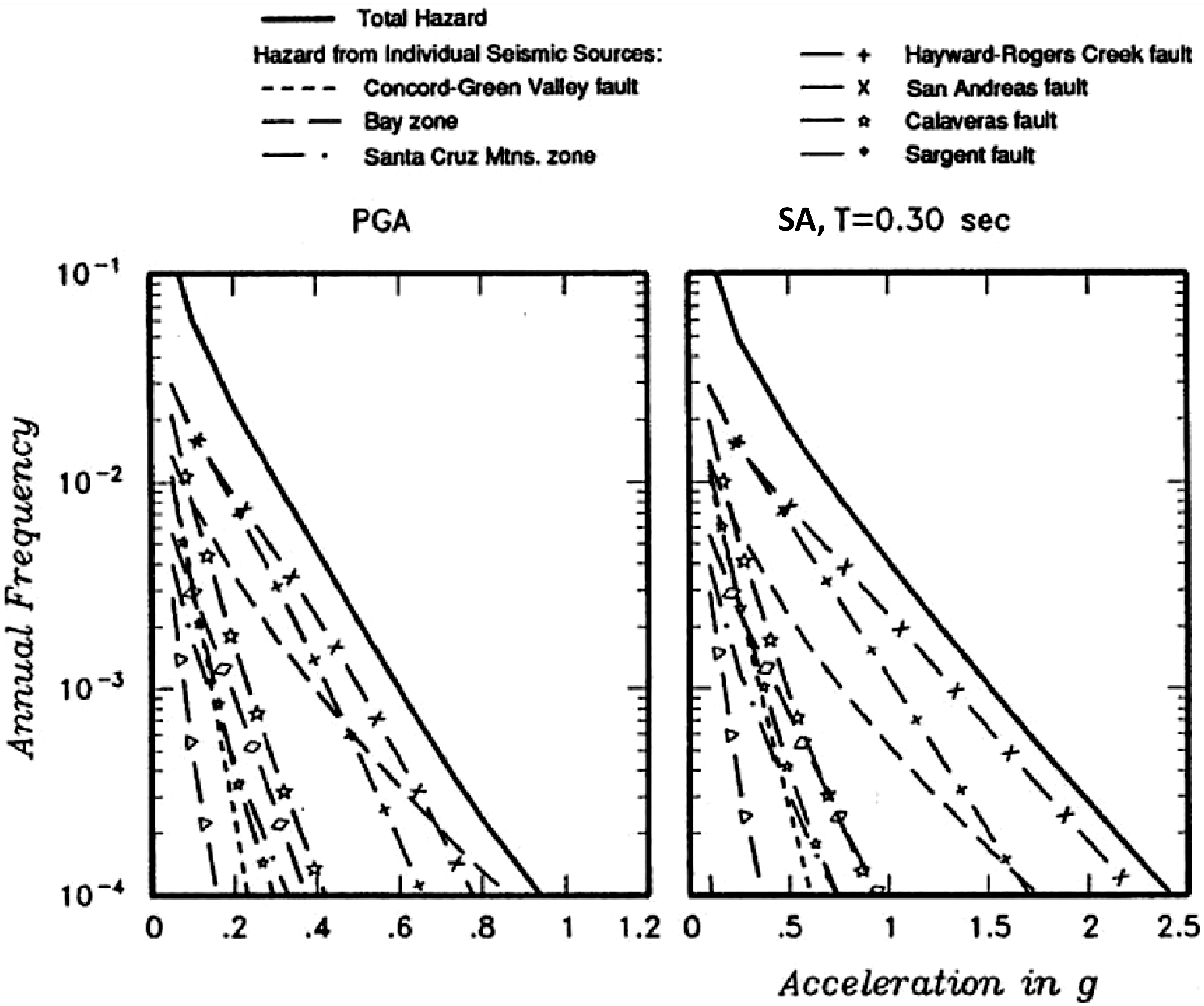
Deaggregation of Seismic Hazard

- The hazard curve gives the **combined effect** of all the seismic sources, magnitudes and distances on the probability of exceeding a given ground motion level.
- Since all of the sources, magnitudes, and distances are mixed together, it is difficult to get an intuitive understanding of what is controlling the hazard from the hazard curve by itself.
- To provide insight into what events are the most important for the hazard at a given ground motion level, **the hazard curve is broken down into its contributions from different earthquake scenarios**.
- This process is called '**Deaggregation of Hazard**'.

Example of Contributions of Various Seismic Sources to the Total Seismic Hazard at the Site



Example of Contributions of Various Seismic Sources to the Total Seismic Hazard at the Site



Example of Contributions of Various Seismic Sources to the Total Seismic Hazard at the Site

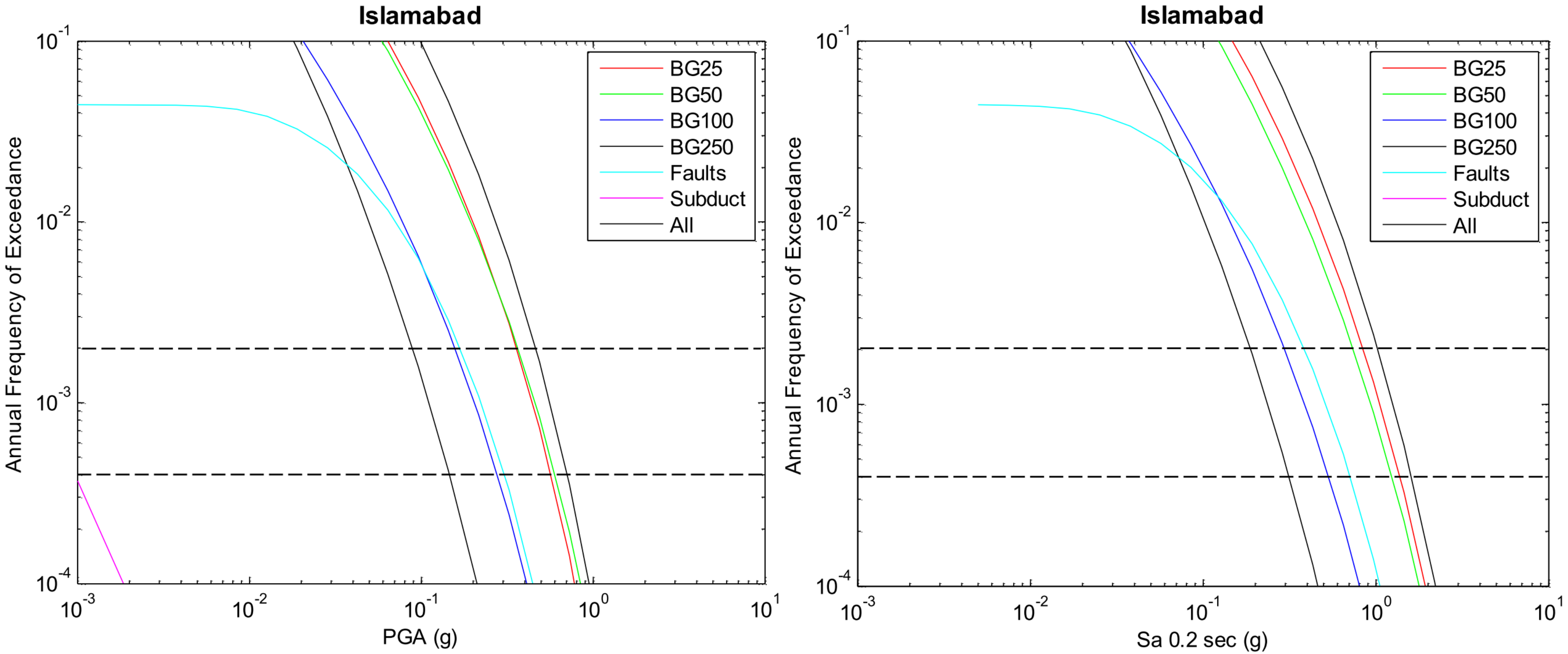
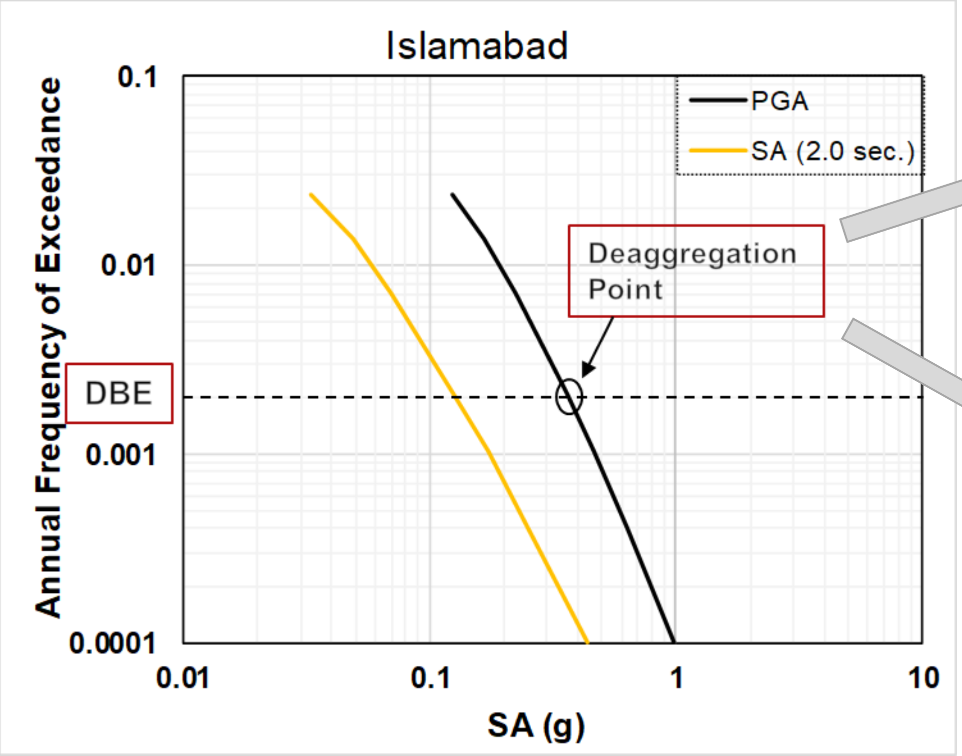


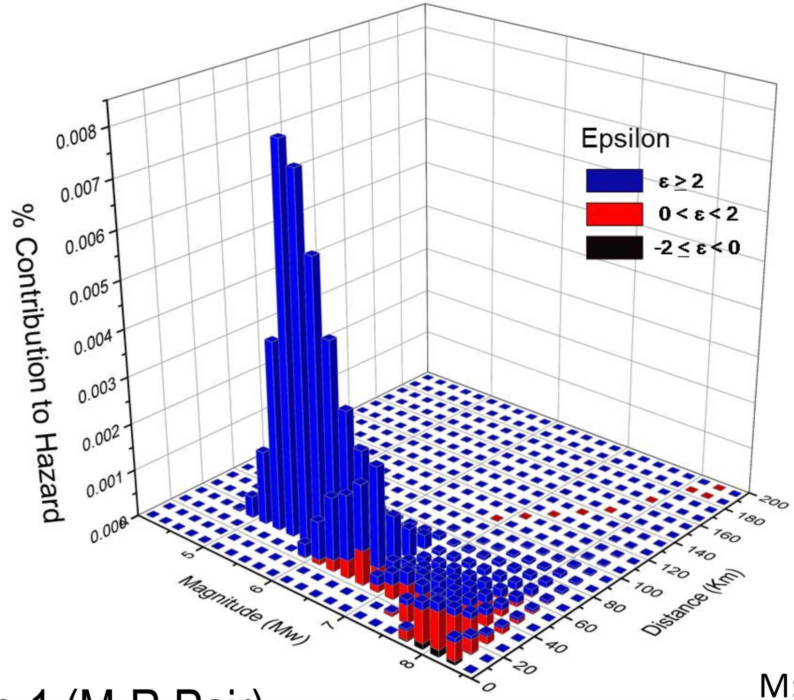
Figure. 3.17 (a) Seismic hazard curves for PGA and 0.2-second SA for Islamabad and contributions of six different earthquake sources to the hazard (BG25: Background shallow seismicity (0-25 km), (BG50: Background shallow seismicity (25-50km), BG100: Background intermediate depth seismicity (50-100 km), BG250: Background deep seismicity (100-250 km), Faults, Makran Subduction zone (Subduct) and All Source (All)).

Source: Zaman (2016)

Probabilistic Seismic Hazard Deaggregation

M-R-ε Deaggregation





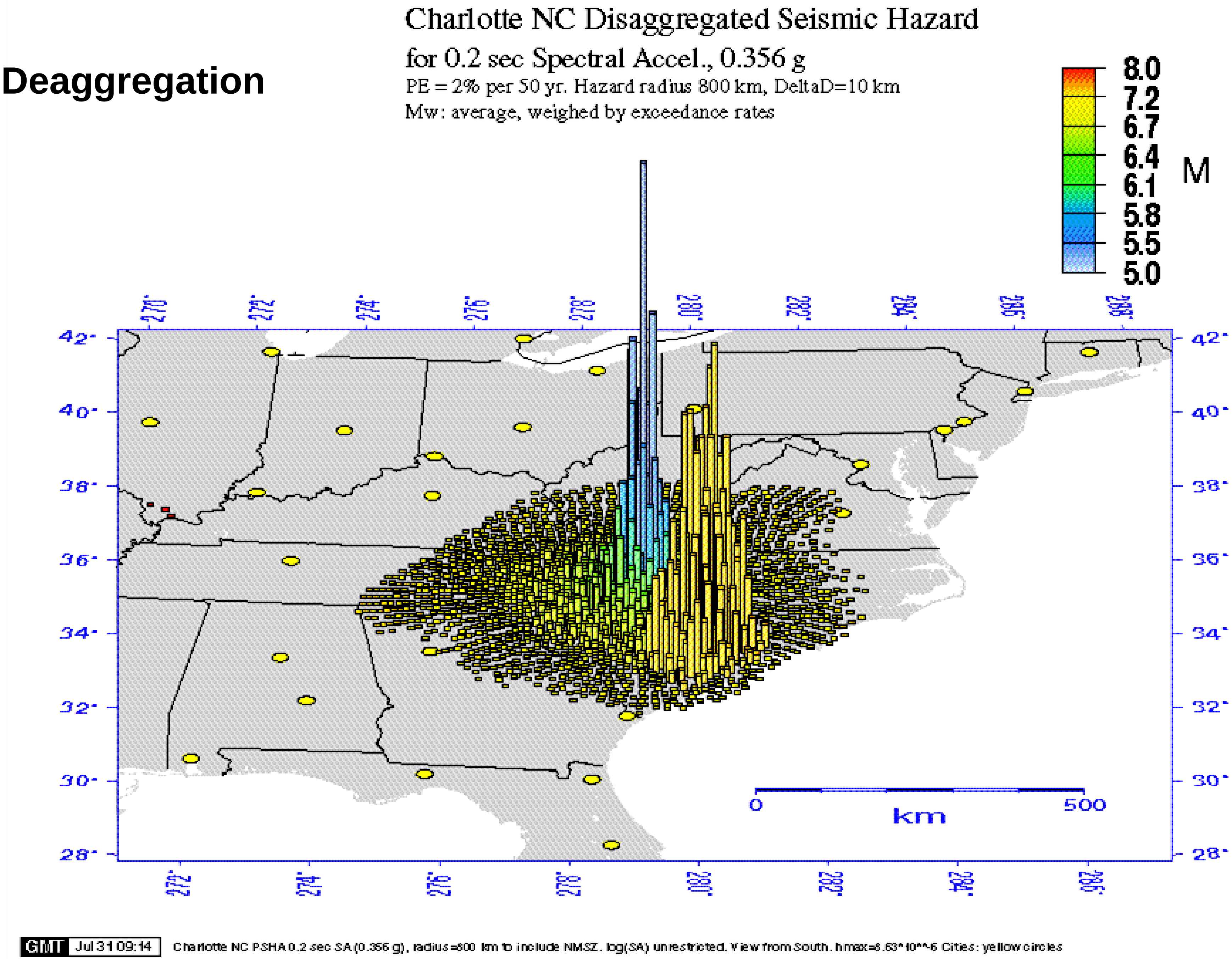
70% Source 1 (M-R Pair)

20% Source 2 (M-R Pair)

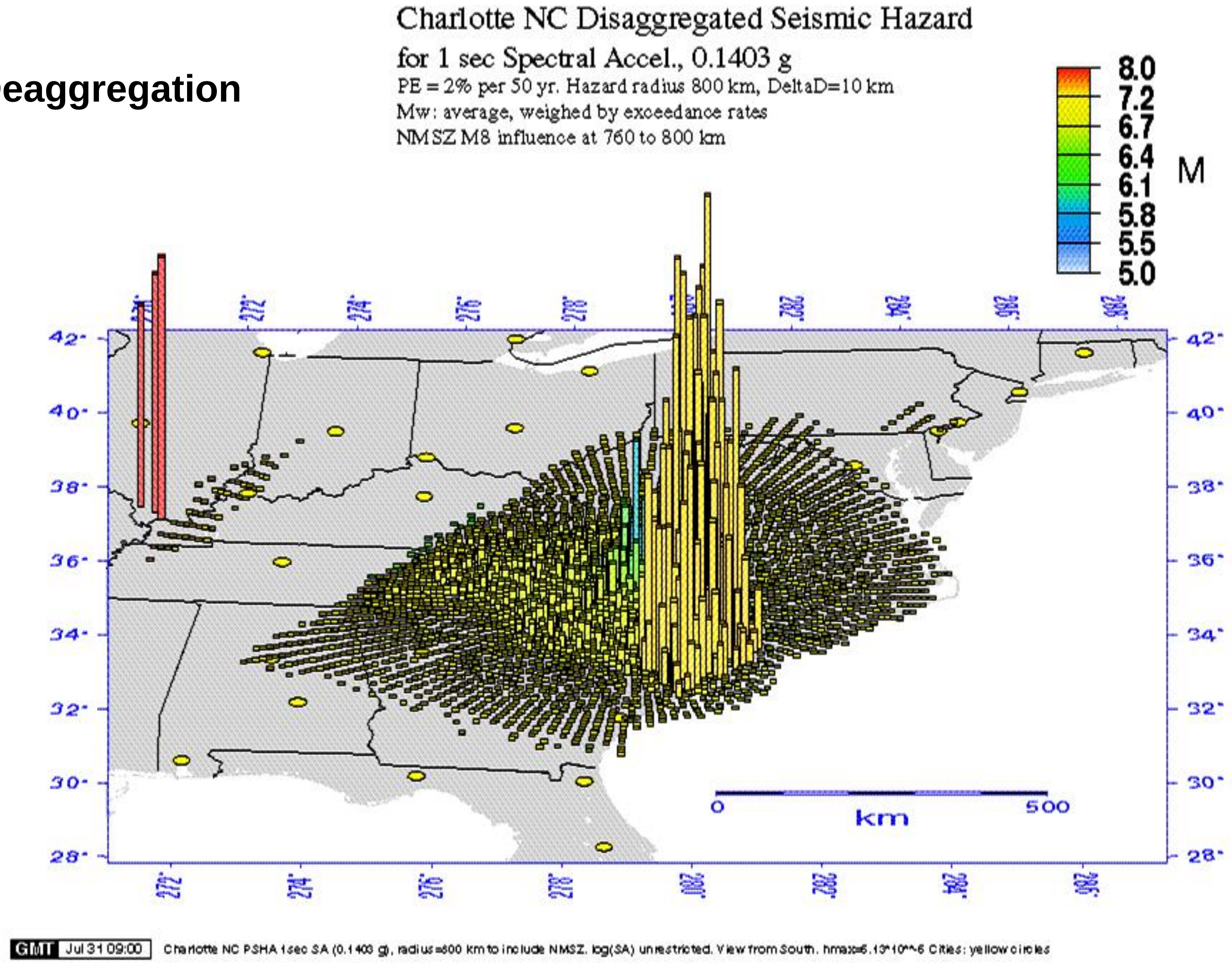
10% Source 3 (M-R Pair)

M: Magnitude
R Distance

Geographic Deaggregation



Geographic Deaggregation



Deaggregation of Seismic Hazard at Islamabad (Pakistan)

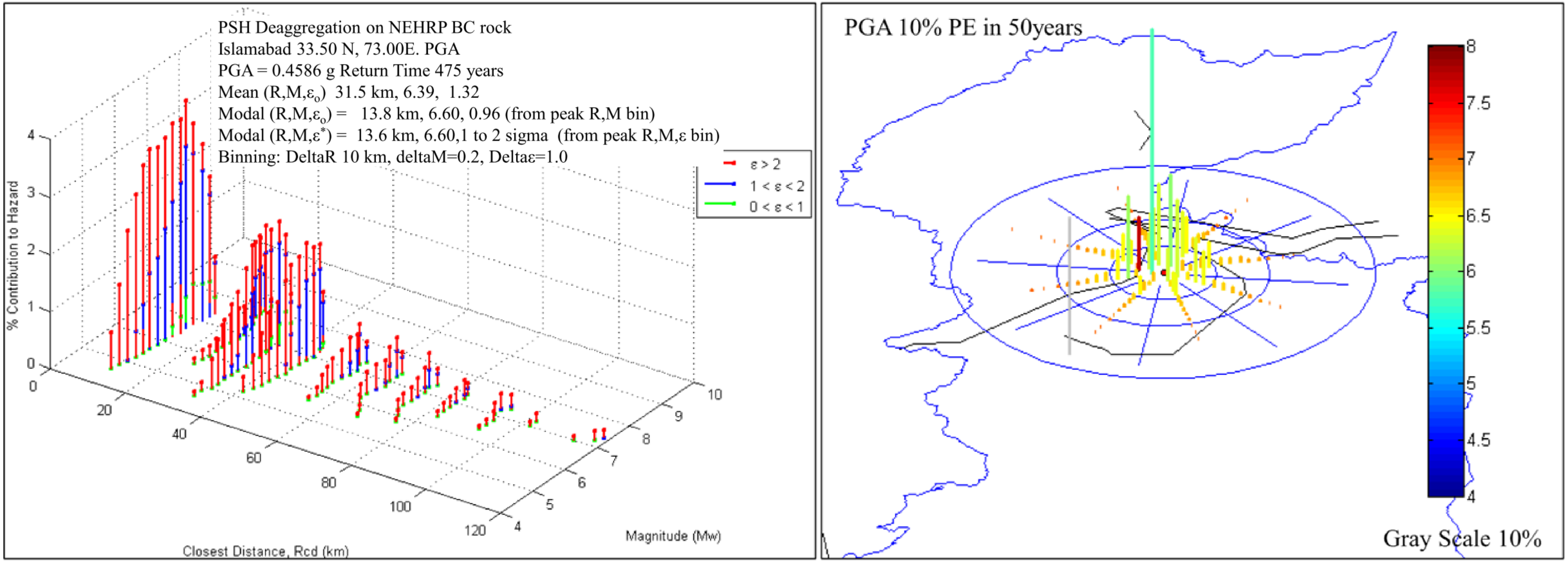


Figure 4.3 Deaggregation plots for Islamabad. PGA (10% PE in 50years): M-R-ε_o (left) and Geographic (right). The red dot and black line in Geographic Plot shows the location of Islamabad and crustal faults, respectively.

Source: Zaman (2016)

Mean and Modal values of M-R-ε for 10% PE in 50-years

Source: Zaman (2016)

Table 4.1 Mean and Modal values of M-R-ε_o for 10% PE in 50-years

Site	T (s)	SA (g) at 475-years	Mean			Modal		
			M	R (km)	ε_o	M	R (km)	ε_o
Islamabad	0	0.4586	6.39	31.5	1.32	6.6	13.8	0.96
	0.2	1.0214	6.41	28.0	1.36	6.6	14.1	0.83
	1.0	0.2691	6.91	37.4	1.29	7.78	23.6	0.88
	2.0	0.1096	7.08	42.0	1.24	7.79	23.6	0.54
Peshawar	0	0.3908	6.56	51.6	1.26	6.80	44.6	0.57
	0.2	0.8160	6.59	32.5	1.31	7.78	32.5	1.09
	1	0.2283	7.01	68.8	1.34	7.65	32.5	0.85
	2	0.0938	7.10	81.7	1.36	7.78	32.5	0.45
Quetta	0	0.4548	6.45	34.7	1.28	6.6	35.2	0.71
	0.2	0.9923	6.46	31.6	1.34	6.6	14.2	0.81
	1	0.2602	6.94	36.9	1.25	7.44	23.2	1.14
	2	0.1090	7.19	55.8	1.16	7.57	22.8	0.7
Karachi	0	0.2918	6.43	53.2	1	5.8	37.2	0.99
	0.2	0.6141	6.56	56.7	1.14	5.8	37.1	1.12
	1	0.1778	7.25	92.9	1.25	8.11	122.1	0.76
	2	0.0792	7.51	145	1.35	8.11	125.5	0.76

Mean and Modal values of M-R-ε for 2% PE in 50-years

Source: Zaman (2016)

Table 4.2 Mean and Modal values of M-R-ε_o for 2% PE in 50-years

Site	T (s)	SA (g) at 2475-years	Mean			Modal		
			M	R (km)	ε_o	M	R (km)	ε_o
Islamabad	0	0.7092	6.58	29.9	1.68	6.6	13	1.61
	0.2	1.6212	6.58	25.5	1.74	6.6	13.3	1.5
	1	0.4413	7.01	28.3	1.66	6.8	13.7	1.35
	2	0.1880	7.19	30.5	1.60	7.77	23.6	1.36
Peshawar	0	0.6206	6.74	45.8	1.58	7.00	35.4	0.75
	0.2	1.3194	6.75	43	1.63	7.00	35.2	0.95
	1	0.3781	7.14	52.6	1.70	7.65	32.5	1.63
	2	0.1629	7.26	58.2	1.64	7.81	32.5	1.26
Quetta	0	0.706	6.63	33.3	1.63	7.2	35.3	0.72
	0.2	1.5795	6.62	29.4	1.71	6.6	13.4	1.47
	1	0.4295	7.02	29.9	1.69	7.45	23.2	1.92
	2	0.1903	7.26	37	1.63	7.59	22.8	1.47
Karachi	0	0.4978	6.62	46.1	1.29	6.6	35.6	0.83
	0.2	1.0652	6.71	48.9	1.43	6.6	35.4	0.95
	1	0.3082	7.36	81.5	1.62	8.04	118.6	1.72
	2	0.1385	7.61	126.5	1.73	8.09	122.5	1.70

Contribution from individual seismic sources to Islamabad (10% PE in 50-years)

Source: Zaman (2016)

Table 4.3 Contribution from individual seismic sources to Islamabad (10% PE in 50-years)

PGA 10% PE in 50-years					
Details of principal seismic sources (shallow, intermediate & deep seismicity, faults, subduction) if its contribution to seismic hazard >10%					
Seismic Source	**% Contribution**	**R [km]**	**M**	**Eps0 [mean values]**	
Shallow seismicity	92.03	29.9	6.32	1.28	
Details of Individual fault having seismic hazard contribution > 2%					
ID & Fault Name	**% Contribution**	**R [km]**	**M**	**Eps0**	**Site-to-source azimuth [degree (d)]**
3, MBT Charac	3.89	29.9	7.78	1.53	-41.5
0.2sec SA 10% PE in 50-years					
Details of principal seismic sources (shallow, intermediate & deep seismicity, faults, subduction) if its contribution to seismic hazard >10%					
Seismic Source	**% Contribution**	**R [km]**	**M**	**Eps0 [mean values]**	
Shallow seismicity	92.19	26.8	6.32	1.33	
Crustal Faults	5.67	25.4	7.64	1.58	
Details of Individual fault having seismic hazard contribution > 2%					
ID & Fault Name	**% Contribution**	**R [km]**	**M**	**Eps0**	**Site-to-source azimuth [d]**
3, MBT Charac	4.56	23.6	7.77	1.45	-41.5

Contribution from individual seismic sources to Islamabad (10% PE in 50-years)

Source: Zaman (2016)

1.0sec SA 10% PE in 50-years

Details of principal seismic sources (shallow, intermediate & deep seismicity, faults, subduction) if its contribution to seismic hazard >10%

Seismic Source	% Contribution	R [km]	M	Eps0 [mean values]
Shallow seismicity	73.59	33.4	6.72	1.25
Crustal Faults	20.61	33	7.60	1.28
Intermediate & Deep seismicity (50 to 200 km)	5.80	103.6	6.95	1.84

Details of Individual fault having seismic hazard contribution > 2%

ID & Fault Name	% Contribution	R (km)	M	Eps0	Site-to-source azimuth [d]
3, MBT Charac	13.37	23.6	7.79	0.89	-41.5

2.0sec SA 10% PE in 50-years

Details of principal seismic sources (shallow, intermediate & deep seismicity, faults, subduction) if its contribution to seismic hazard >10%

Seismic Source	% Contribution	R [km]	M	Eps0 [mean values]
Shallow seismicity	58.13	23.5	6.88	1.58
Crustal Faults	35.18	29.3	7.73	1.53
Intermediate & Deep seismicity (50 to 200 km)	6.69	97.7	7.07	2.13

Details of Individual fault having seismic hazard contribution > 2%

ID & Fault Name	% Contribution	R (km)	M	Eps0	Site-to-source azimuth [d]
3, MBT Charac	18.80	23.6	7.78	0.58	-41.5
MBT GR	2.58	31.2	7.25	1.36	-37.1
5, HFT Charac	2.50	74	7.81	1.62	64.8
2, Salt range Charac	2.11	48	7.11	1.92	88.5

Thank you for your attention