Appendix C
Ground Motion Example Problems

Section I: Manual Calculations

C-1. Example problem 1

This problem will demonstrate the development of a 5% damping horizontal standard response spectrum for an Operational Basis Earthquake (OBE).

a. Project data

Name: Mud Mountain Dam
Location: King County, WA
Latitude: 47.1 deg
Longitude: -121.9 deg
Site Conditions: Soft rock foundation (site class C)

b. Mapped spectral values.

Accessing the USGS web site with the appropriate site location information, we obtain the corresponding PGA and spectral acceleration values corresponding to 0.2 seconds and 1 second:

	10% PE in 50 years	**2% PE in 50 years**
PGA [g]	0.2666	0.4858
S_S [g]	0.5951	1.1005
S_1 [g]	0.1918	0.3601

c. Return period for design earthquake

If the OBE is defined as an event with 50% chance of exceedance in 100 years, then the corresponding return period is given by

$$T_R = -\frac{100\,\text{years}}{\ln(1-0.50)} = 144\,\text{years}$$

d. Adjust spectral values to specified return period

For the spectral acceleration at 0.2 seconds:

$$m_S = \frac{\log(S_S^{T_R=2475}) - \log(S_S^{T_R=475})}{0.7169}$$

$$m_S = \frac{\log(1.1005) - \log(0.5951)}{0.7169} = 0.3724$$

$$\log(b_S) = 4.7338\log(S_S^{T_R=475}) - 3.7338\log(S_S^{T_R=2475})$$
$$\log(b_S) = 4.7338\log(0.5951) - 3.7338\log(1.1005)$$
$$\log(b_S) = -1.2223$$
$$b_S = 10^{\log(b_S)} = 0.0599$$

Therefore

$$S_S^{T_R=144} = 0.0599(144)^{0.3724}$$
$$S_S^{T_R=144} = 0.3815$$

For the spectral acceleration at 1 second:

$$m_1 = \frac{\log(S_1^{T_R=2475}) - \log(S_1^{T_R=475})}{0.7169}$$
$$m_1 = \frac{\log(0.3601) - \log(0.1918)}{0.7169} = 0.3816$$

$$\log(b_1) = 4.7338\log(S_1^{T_R=475}) - 3.7338\log(S_1^{T_R=2475})$$
$$\log(b_1) = 4.7338\log(0.1918) - 3.7338\log(0.3601)$$
$$\log(b_1) = -1.7386$$
$$b_1 = 10^{\log(b_1)} = 0.0183$$

Therefore

$$S_1^{T_R=144} = 0.0183(144)^{0.3816}$$
$$S_1^{T_R=144} = 0.1216$$

e. Construct standard spectrum

Adjust for site conditions

$$\overline{S}_S = F_a S_S^{T_R=144} = (1.20)0.3815$$
$$\overline{S}_S = 0.4578$$
$$\overline{S}_1 = F_v S_1^{T_R=144} = (1.69)0.1216$$
$$\overline{S}_1 = 0.2041$$

Compute periods defining the amplification plateau

$$T_S = \frac{B_S \bar{S}_1}{B_1 \bar{S}_S} = \frac{(1.00)0.2041}{(1.00)0.4578} = 0.45\,\text{sec}$$

$$T_0 = \frac{1}{5}T_S = \frac{0.45}{5} = 0.09\,\text{sec}$$

Define the horizontal standard spectrum

$$S_A[g] = \begin{cases} 3.0806\,T + 0.1831 & \text{for } 0 \le T < 0.09\,\text{sec} \\ 0.4578 & \text{for } 0.09\,\text{sec} \le T < 0.45\,\text{sec} \\ 0.2041/T & \text{for } 0.45\,\text{sec} \le T \end{cases}$$

Therefore the spectrum exhibits a maximum value of 0.4578 g between the periods of 0.09 and 0.45 seconds. The following figure shows the resulting horizontal standard spectrum:

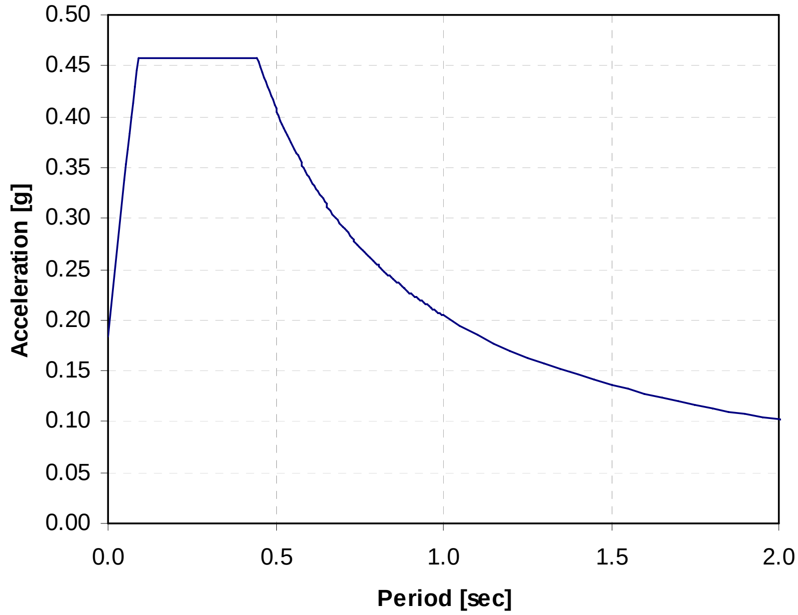


Figure C-1. Standard horizontal acceleration response spectrum for example C-1

C-2. Example problem 2

This problem will demonstrate the development of 6% damping horizontal and vertical standard response spectra for a Maximum Design Earthquake (MDE) characterized by a return period of 1,000 years.

a. Project data

Name: Blue River Dam
Location: Lane County, OR
Latitude: 44.2 deg
Longitude: -122.3 deg
Site Conditions: Rock foundation (site class B)

b. Mapped spectral values

Accessing the USGS web site with the appropriate site location information, we obtain the corresponding PGA and spectral acceleration values corresponding to 0.2 seconds and 1 second:

	10% PE in 50 years	**2% PE in 50 years**
PGA [g]	0.1020	0.2216
S_S [g]	0.2371	0.5262
S_1 [g]	0.0987	0.2231

c. Return period for design earthquake

For this case the specified MDE is characterized by a return period of 1,000 years.

d. Adjust spectral values to specified return period

For the spectral acceleration at 0.2 seconds:

$$m_S = \frac{\log(S_S^{T_R=2475}) - \log(S_S^{T_R=475})}{0.7169}$$

$$m_S = \frac{\log(0.5262) - \log(0.2371)}{0.7169} = 0.4830$$

$$\log(b_S) = 4.7338\log(S_S^{T_R=475}) - 3.7338\log(S_S^{T_R=2475})$$

$$\log(b_S) = 4.7338\log(0.2371) - 3.7338\log(0.5262)$$

$$\log(b_S) = -1.9178$$

$$b_S = 10^{\log(b_S)} = 0.0121$$

Therefore

$$S_S^{T_R=1000} = 0.0121(1000)^{0.4830}$$
$$S_S^{T_R=1000} = 0.3397$$

For the spectral acceleration at 1 second:

$$m_1 = \frac{\log(S_1^{T_R=2475}) - \log(S_1^{T_R=475})}{0.7169}$$
$$m_1 = \frac{\log(0.2231) - \log(0.0987)}{0.7169} = 0.4941$$

$$\log(b_1) = 4.7338\log(S_1^{T_R=475}) - 3.7338\log(S_1^{T_R=2475})$$
$$\log(b_1) = 4.7338\log(0.0987) - 3.7338\log(0.2231)$$
$$\log(b_1) = -2.3281$$
$$b_1 = 10^{\log(b_1)} = 0.0047$$

Therefore

$$S_1^{T_R=1000} = 0.0047(1000)^{0.4941}$$
$$S_1^{T_R=1000} = 0.1426$$

e. Construct standard spectra

Adjust for site conditions

$$\overline{S}_S = F_a S_S^{T_R=1000} = (1.00)0.3397$$
$$\overline{S}_S = 0.3397$$
$$\overline{S}_1 = F_v S_1^{T_R=1000} = (1.00)0.1426$$
$$\overline{S}_1 = 0.1426$$

Compute periods defining the amplification plateau

$$T_S = \frac{B_S \overline{S}_1}{B_1 \overline{S}_S} = \frac{(1.06)0.1426}{(1.04)\,0.3397} = 0.43\sec$$
$$T_0 = \frac{1}{5}T_S = \frac{0.43}{5} = 0.086\sec$$

Define the horizontal standard spectrum

$$S_A[g] = \begin{cases} 2.1573\,T + 0.1359 & \text{for } 0 \le T < 0.086\,\text{sec} \\ 0.3205 & \text{for } 0.086\,\text{sec} \le T < 0.43\,\text{sec} \\ 0.1371/T & \text{for } 0.43\,\text{sec} \le T \end{cases}$$

Therefore, the horizontal response spectrum exhibits a maximum value of 0.3205 g between the periods of 0.086 and 0.43 seconds. A source-to-site distance of 25 km is assumed to define the vertical standard spectrum. Considering the corresponding conversion factor $F_V = 0.84$, the periods defining the vertical amplification plateau are given by

$$T_{SV} = \frac{0.67}{F_V} T_S = \frac{0.67}{0.84} 0.43 = 0.34\,\text{sec}$$

Define the vertical standard spectrum

$$S_{AV}[g] = \begin{cases} 0.84\,S_A & \text{for } 0 \le T < 0.34\,\text{sec} \\ 0.0919/T & \text{for } 0.34\,\text{sec} \le T \end{cases}$$

The vertical response spectrum shows a maximum value of 0.2692 g between the periods of 0.086 and 0.34 seconds. The following figure displays both horizontal and vertical standard response spectra:

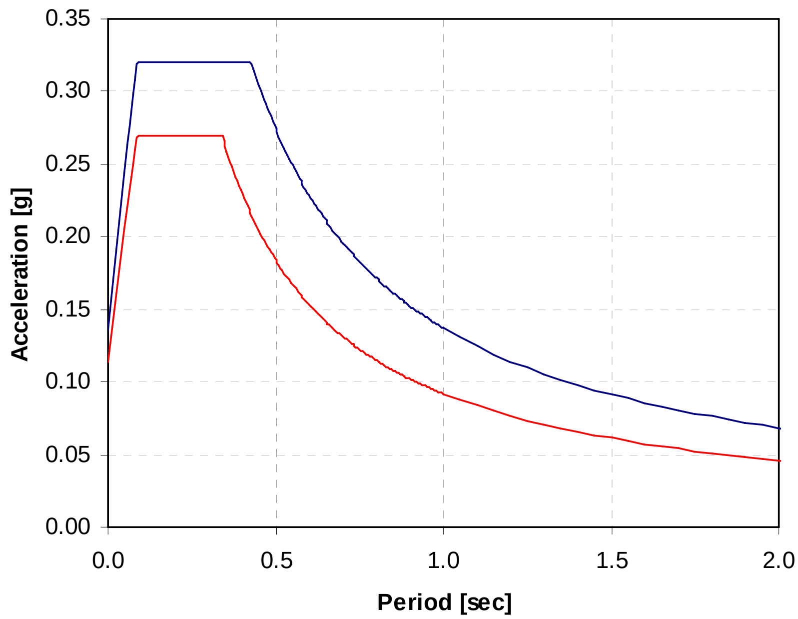


Figure C-2. Standard horizontal (blue) and vertical (red) acceleration response spectra for example C-2

C-3. Example problem 3

This problem will demonstrate the determination of Effective Peak Ground Acceleration (EPGA) values for different return periods (100, 500, 1000, 2000, 5000, and 10000 years).

a. Project data

Name: Montgomery Point Lock and Dam
Location: AR
Latitude: 33.9 deg
Longitude: -91.1 deg
Site Conditions: Stiff soil (site class D)

b. Mapped spectral values

Accessing the USGS web site with the appropriate site location information, we obtain the corresponding PGA and spectral acceleration values corresponding to 0.2 seconds and 1 second:

	10% PE in 50 years	**2% PE in 50 years**
PGA [g]	0.0612	0.2008
S_S [g]	0.1417	0.4562
S_1 [g]	0.0452	0.1553

c. Compute short-period spectral values for specified return periods

For the spectral acceleration at 0.2 seconds:

$$m_S = \frac{\log(S_S^{T_R=2475}) - \log(S_S^{T_R=475})}{0.7169}$$

$$m_S = \frac{\log(0.4562) - \log(0.1417)}{0.7169} = 0.7083$$

$$\log(b_S) = 4.7338 \log(S_S^{T_R=475}) - 3.7338 \log(S_S^{T_R=2475})$$
$$\log(b_S) = 4.7338 \log(0.1417) - 3.7338 \log(0.4562)$$
$$\log(b_S) = -2.7446$$
$$b_S = 10^{\log(b_S)} = 0.0018$$

Therefore, the spectral acceleration values can be approximated as follows:

$$S_S^{T_R} = 0.0018\left(T_R\right)^{0.7083}$$

d. Determine effective peak ground acceleration values

To adjust for site conditions, we determine the site coefficients based on the short-period spectral accelerations corresponding to the different return periods:

Return Period [years]	S_s [g]	F_a	$\overline{S}_s$ [g]
100	0.0470	1.60	0.0752
500	0.1469	1.60	0.2351
1000	0.2401	1.60	0.3841
2000	0.3923	1.49	0.5830
5000	0.7507	1.20	0.9006
10000	1.2266	1.01	1.2381

Finally, the EPGA values for the required return periods can be tabulated as follows:

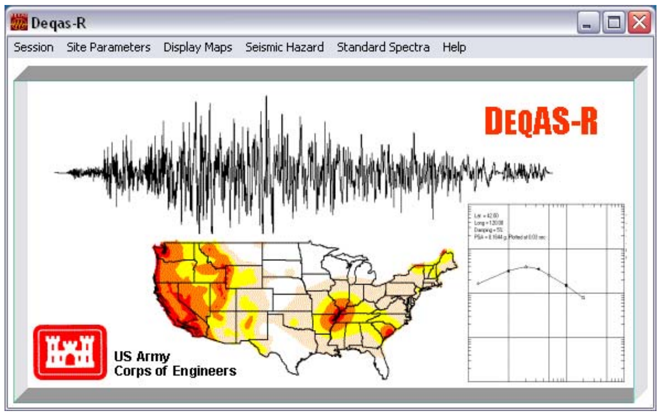
Return Period [years]	EPGA [g]	Site Specific PGA [g]
100	0.0301	0.0180
500	0.0940	0.0390
1000	0.1537	0.0520
2000	0.2332	0.0700
5000	0.3603	0.1100
10000	0.4952	---

For the same return periods, the table also shows the associated PGA values obtained by a site-specific probabilistic seismic hazard study as described in EM 1110-2-6050 (Appendix G, Example 3). The results show that the computed EPGA values are much larger than the site-specific PGA values. The local site condition (deep soil site) was included in the site-specific study by employing special ground motion attenuation relationships for deep-soil-site motions. This site condition was consistently taken into account in the determination of the EPGA values by using the corresponding site coefficient F_a .

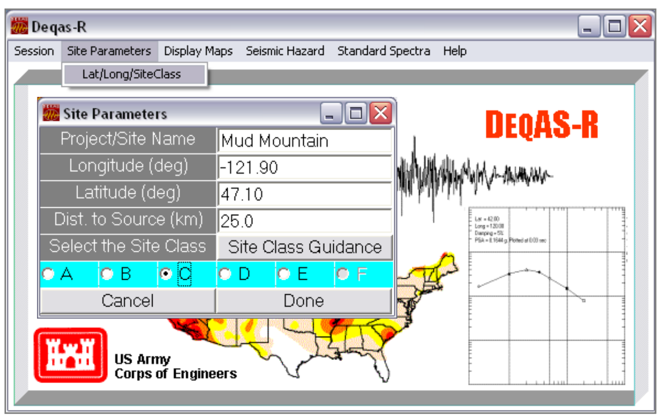
SECTION II: Use of Computer Program DEQAS-R

C-4. Solution of example problem C-1 using the program DEQAS-R

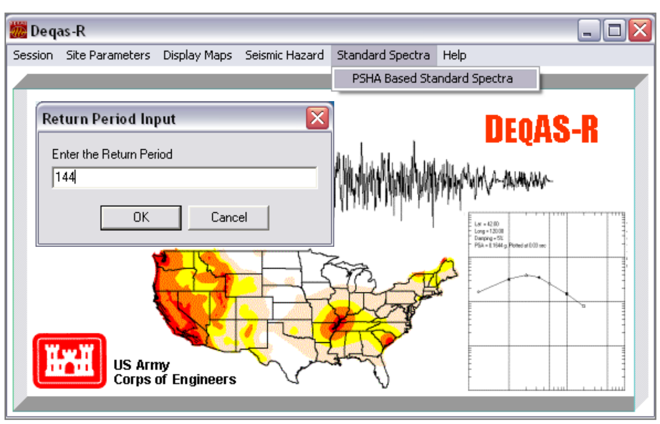
a. Start the program



b. Enter site location and site class



c. Define return period



d. Plot horizontal standard spectrum

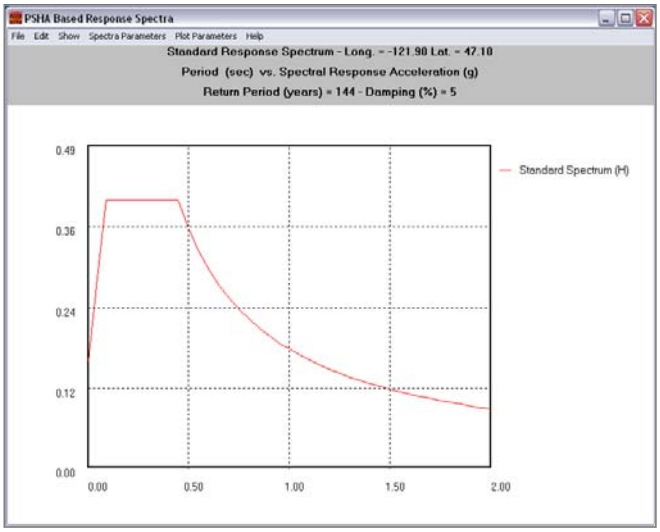


Figure C-3. Standard horizontal acceleration response spectrum for example C-1 obtained using the program DEQAS-R

e. Discussion

(1) As shown in Figure C-3, the program plots the horizontal standard spectrum for the required location, site class and return period. If required, the spectral data can be saved in a text file for future use. The spectrum shows an amplification plateau that extends between the periods of 0.09 and 0.44 seconds, with a maximum spectral value of 0.4043 g. This value is about 88% of the maximum spectral acceleration obtained with the previous procedure (0.4578 g).

(2) By taking advantage of the fact that the program can also display the 0.2- and 1.0-second period seismic hazard curves for the specified location, an explanation for the difference in the spectral results can be found by examining these curves. These hazard curves are shown in Figure B-2. These two curves represent the actual seismic hazard data used by the program to compute the spectral values S_S and S_1 that are used in the construction of the standard response spectrum. To obtain the values corresponding to the specified return period (e.g., $S_S^{T_R=144}$ and $S_1^{T_R=144}$), the program performs a linear log-log interpolation using the two closest available values. This is a “local” interpolation scheme which is adopted to represent a return period interval in the vicinity of the available data points. The resulting values may be different from those obtained based on direct interpolation of the data available from the USGS website, which offers only two spectral acceleration values (for return periods of 475 and 2,475 years). The values in this case are then based on a “global” 2-point interpolation that is used to represent the entire return period range.

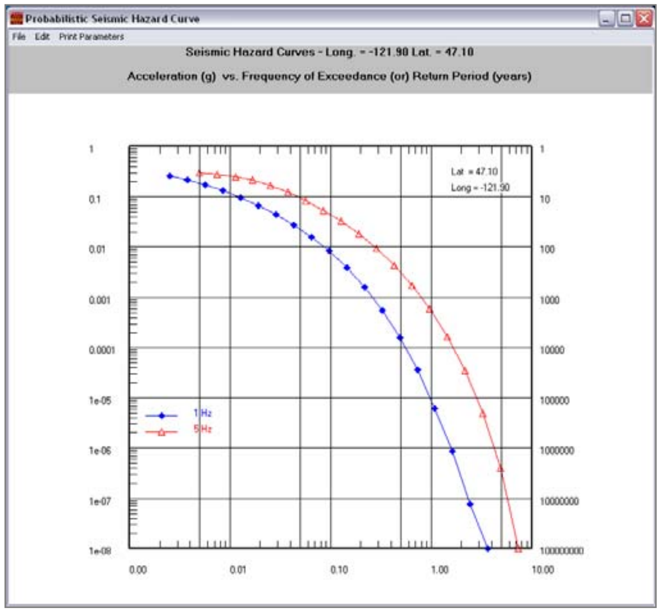


Figure C-4. Seismic hazard curves for example C-1 obtained using the program DEQAS-R

(3) Figure C-5 depicts this situation for the case of the S_S spectral acceleration. The figure shows that the 144-year value (0.3815 g) computed based on the values for return periods of 475 and 2475 years is different from the 144-year value (0.3369 g) determined by the **DEQAS-R** program by interpolating the two closest data points in the database (which for this case correspond to approximate return periods of 107 and 232 years).

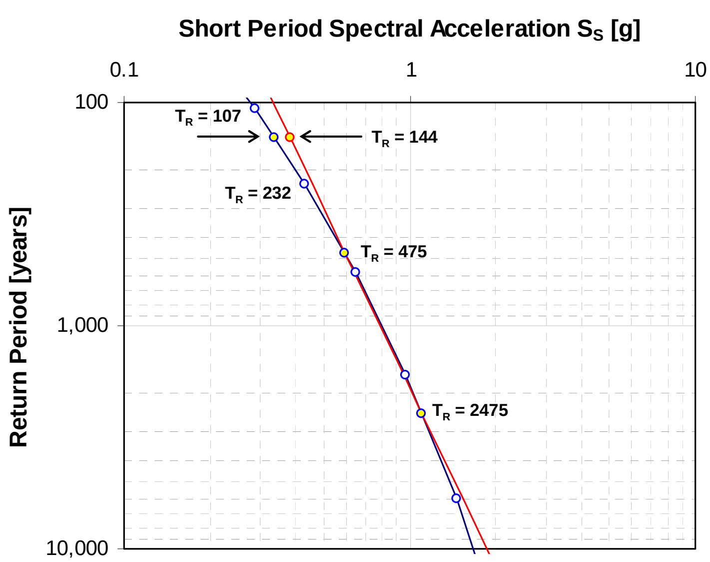


Figure C-5. Comparison of 0.2-second seismic hazard curves for example C-1 obtained by local (red) and global (blue) log-log interpolation

(4) Figure C-6 shows the same situation for the S_1 spectral acceleration. The 144-year value (0.1216 g) computed based on the values for return periods of 475 and 2475 years is different from the 144-year value (0.1060 g) determined by the **DEQAS-R** program by interpolating the two closest data points available in the database (which for this case correspond to approximate return periods of 120 and 253 years).

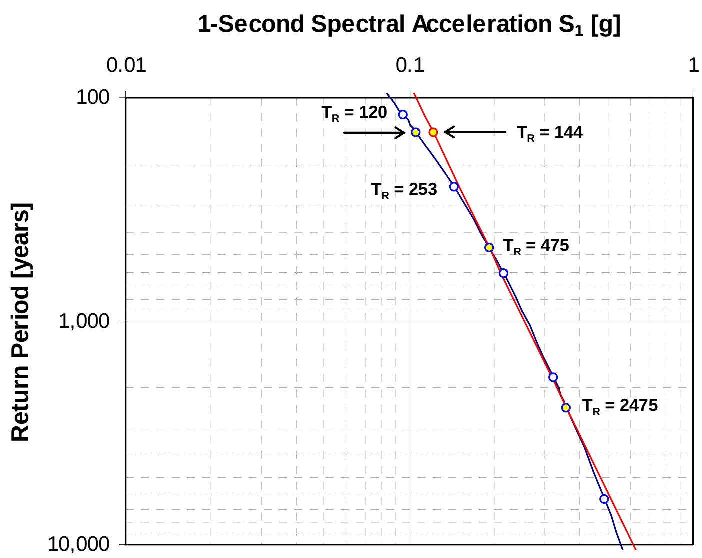
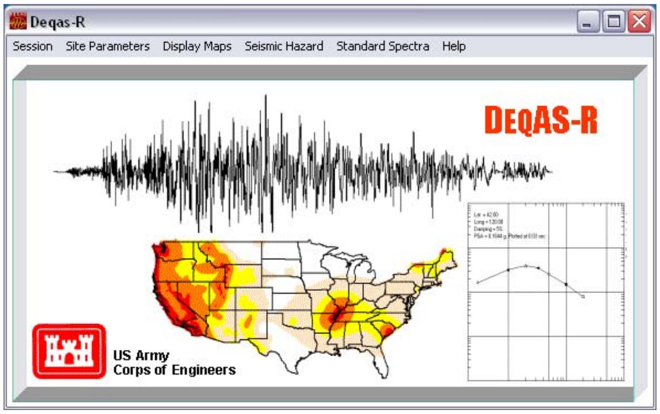


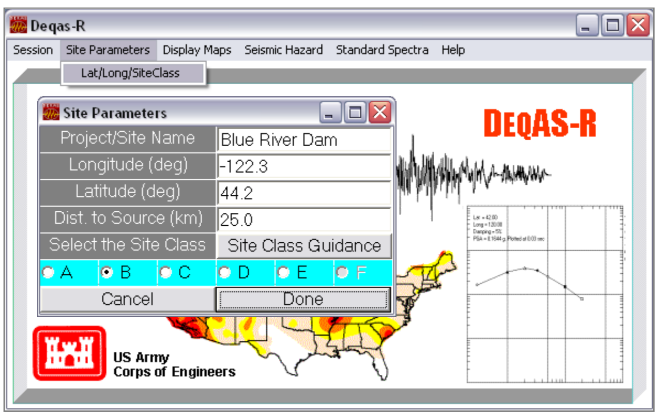
Figure C-6. Comparison of 1-second seismic hazard curves for example C-1 obtained by local (red) and global (blue) log-log interpolation

C-5. Solution of example problem C-2 using the program DEQAS-R

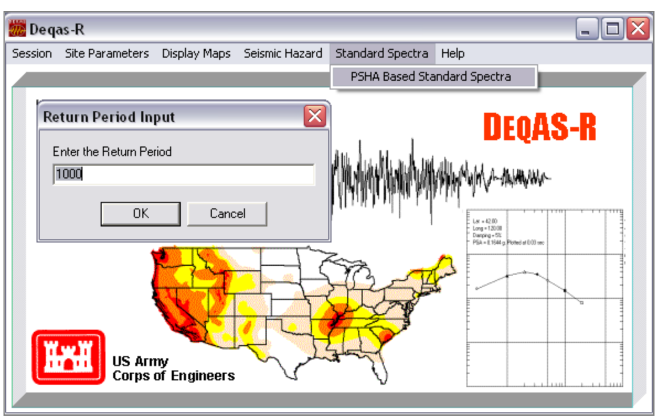
a. Start the program



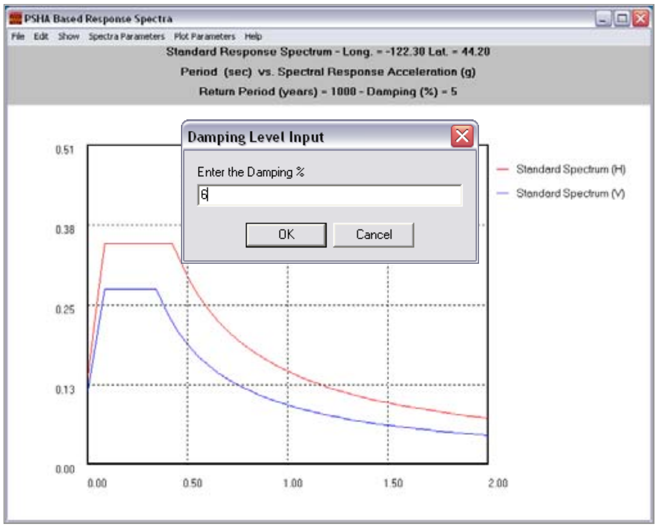
b. Enter site location and site class



c. Define return period



d. Adjust damping level



e. Plot horizontal and vertical response spectra

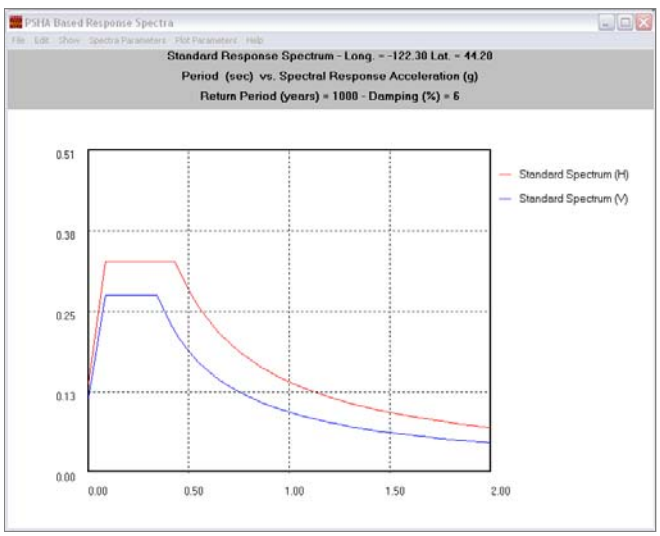


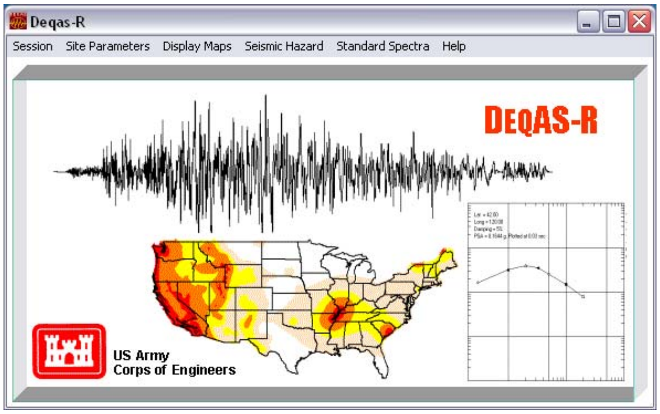
Figure C-7. Standard horizontal and vertical response spectra for example C-2 obtained using the program DEQAS-R

f. Discussion

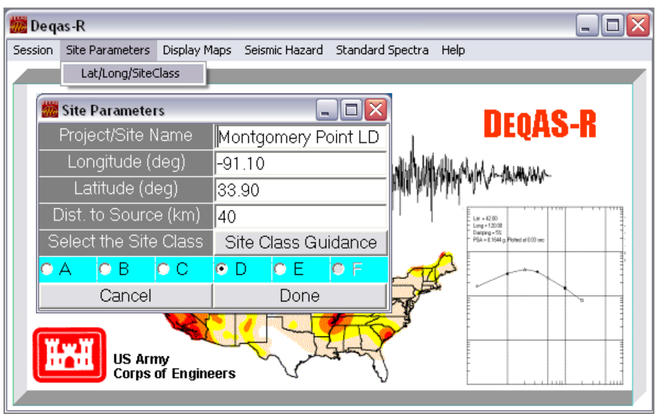
As shown in Figure C-7, the horizontal response spectrum computed by the program exhibits a maximum value of 0.3313 g between the periods of 0.086 and 0.43 seconds. The vertical response spectrum shows a maximum spectral value of 0.2783 g between the periods of 0.086 and 0.34 seconds. Therefore, these maximum horizontal and vertical spectral values represent an increase of about 3% with respect to those values previously computed manually in Section I.

C-6. Solution of example problem C-3 using the program DEQAS-R

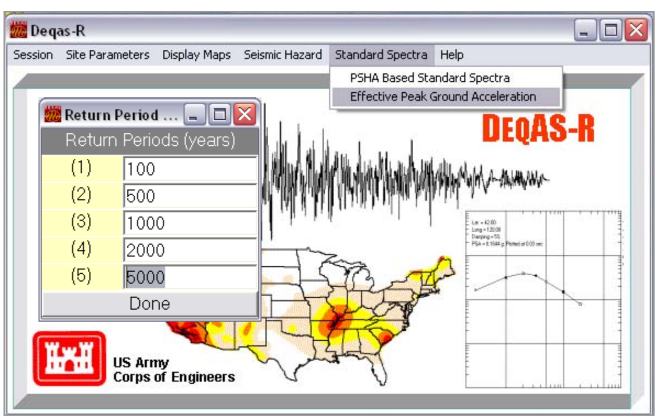
a. Start the program



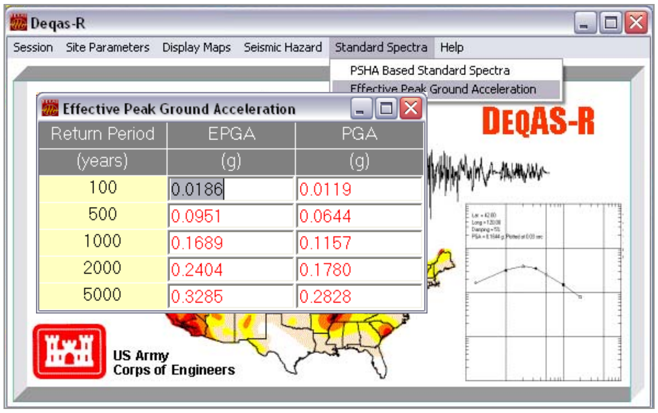
b. Enter site location and site class



c. Enter required return periods



d. Obtain EPGA values



e. Discussion

(1) The EPGA values computed by the program DEQAS-R are based on a more accurate interpolation of the data in the database, and this explains the differences between these results and those previously obtained in Section I.

(2) For reference purposes, the program also outputs the PGA values corresponding to the required return periods. However, it must be considered that these PGA values are only available for the default site class (firm rock). On the other hand, the EPGA values are calculated as a function of the short-period spectral value modified by site conditions.