11-4-2002

Development of Response Spectra for the HBPP ISFSI

Norma Abraham

Marcia McLaren

Lloyd Claff

HUMBOLDT BAY POWER PLANT
CALCULATION COVER SHEET

File No. : ____________
Calculation No.: GEO.HBIP.02.04

☐ Preliminary

☒ Final

Department/Group: HBPP/Geosciences

Unit(s) 0 Structure, System or Component: ISFSI Geotechnical

Type or Purpose of Calculation: Development of Response Spectra for the HBPP ISFSI

No. of Sheets: 101

	Signature	Discipline/Dept	Date
Prepared by:	*By Geosciences*		11/4/2002
Checked by:	*By Geosciences*		11/7/2002
Approved by (Supv):	[signature]	[signature]	12/26/2002

Registered Engineer Approval: (Complete section A for Civil calcs. Complete A or B for others)

A. Insert Engineer Stamp or Seal Below	B.
By Geosciences	Engineer's full name: ____________
	Registration Number: ____________
	Expiration Date: ____________
Expiration Date:	

RECORDS OF REVISIONS

Revision Number	Date	Reasons for Revision	Prepared By	Checked By	Approval Regis. Engr.	Approval Supvr.
0	12/26/02	Initial Issue	*Geosci.*	*Geosci.*	*Geosc.i*	[signature]

PACIFIC GAS AND ELECTRIC COMPANY
GEOSCIENCES DEPARTMENT
CALCULATION DOCUMENT

Calc Number:GEO.HBIP.02.04
Revision: 0
Date: 11/4/02
Calc Pages: 101
Verification Method: B

TITLE:_Development of Response Spectra for the HBPP ISFSI

PREPARED BY: [signature] DATE 11/4/02

Norman Abrahamson — Printed Name
Geosciences — Organization

VERIFIED BY: [signature] DATE 11/7/02

MARCIA MCLAREN — Printed Name
GEOSCIENCES — Organization

APPROVED BY: [signature] DATE 11/7/02

Lloyd Cluff — Printed Name
Geosciences — Organization

REGISTERED GEOLOGIST
LLOYD S. CLUFF
No. EG567
CERTIFIED ENGINEERING GEOLOGIST
STATE OF CALIFORNIA

Expiration Sept 30, 2003

Rev. No.	Reason for Revision	Revision Date
00	Initial Issue	11/4/02

2. PURPOSE

The purpose of this calculation is to develop 84th percentile response spectra from the maximum credible earthquake acceleration for the HBPP ISFSI incorporating the site-specific soil response that satisfy the requirements specified in the Work Plan (GEO_2002-2, rev. 0)

The resulting spectra are to be used as the basis for the development of spectrum compatible time histories (see GEO.HBPP.02.05).

3. ASSUMPTIONS

3.1 Horizontal Component Attenuation Relationships for Rock Site Conditions for Crustal Earthquakes

The Abrahamson and Silva (1997), Sadigh et al. (1993), Idriss (1991; 1994; 1995), and Campbell (1997) attenuation relationships for horizontal response spectral values are assumed to be representative attenuation relations for rock sites close to large earthquakes. The basis for this assumption is that these attenuation relations represent the state-of-the practice and are widely used.

One other commonly used attenuation model is the Boore et al., 1997 model. This model is not considered applicable for this case. The Boore et al (1997) model produces very low ground motions on rock for sites close to the rupture. This is a result of the very sparse near-fault data used to derive the model and the assumption of linear site response. Therefore, this model is not included. If this model were included, the ground motions would be lower than estimated using the other four models.

3.2 Vertical Component Attenuation Relationships for Soil Site Conditions

There has been very little research on non-linear vertical component site response. As an alternative to a site response study, it is assumed that the empirical attenuation relations for the vertical component can be reasonably extrapolated to very high ground motion levels. The basis for this assumption is that empirical attenuation relations (e.g. Abrahamson and Silva, 1997) indicate that the nonlinear effects for the vertical component are much smaller than the for the horizontal component.

The Abrahamson and Silva (1997) attenuation relation for the vertical component on deep soil site conditions is assumed to be appropriate for soil sites close to large magnitude earthquakes.

The basis for this assumption is that of the four empirical attenuation relations selected for the horizontal component (assumption 3.1), only the Campbell (1997) and Abrahamson and Silva (1997) models include the models for the vertical component on deep soil sites. Since the Campbell vertical component model is based on vertical to horizontal ratios which are then scaled by the horizontal spectrum, it is sensitive to the non-linear response of the horizontal component. Therefore, this model is not considered appropriate. The only remaining model is Abrahamson and Silva (1997).

3.3 Depth to Seismogenic Zone

The Campbell (1997) attenuation relation uses the seismogenic distance which is defined as the closest distance between the recording site and the zone of seismogenic rupture on the fault (Campbell, 1997, page 155). Campbell (1997, page 156) states that the depth to the top of the seismogenic zone should be no less than about 2 to 4 km. For the HBPP region, the depth to the top of the seismogenic zone is assumed to be 3 km. The basis for this assumption is that it is in average of the range recommended by Campbell (1997).

3.4 Depth to Basement Rock

The Campbell (1997) attenuation relationship includes a term based on the depth to basement rock. For a hard rock site, the depth to basement rock is zero. For soft-rock sites, there may be weathered rock or shallow soil over the basement rock. Campbell (1997) does not give a recommended value for the depth to basement rock for soft-rock sites. The depth to basement rock is assumed to be 1.0 km. The basis for this assumption is that the depth of the weathering or of the shallow soil is likely to be much less than 1 km. Since the Campbell (1997) model has increasing long period ground motion for increasing depth to basement rock, this assumption is conservative in terms of the resulting ground motion.

3.5 Rupture Distance

The Bay Entrance Fault is the closest of the main traces of the Little Salmon fault zone to the ISFSI site. It passes under the ISFSI site at a rupture distance of 0.5 km (see Input 4.1). For computing the deterministic ground motion, the rupture distance is assumed to be zero and the seismogenic distance is assumed to be 3 km.

The basis for this assumption is that it is slightly conservative (using 0 km rather than 0.5 km results in about a 1 to 2% increase in the ground motions). This assumption avoids the uncertainty in the location of the Bay Entrance Fault impacting the ground motion calculations.

3.6 Horizontal Component Attenuation for Subduction Zone Earthquakes

The Youngs et al (1997) attenuation relation is used for subduction earthquakes. The basis for this assumption is given below.

There are two types of subduction zone earthquakes: interface earthquakes and intraslab earthquakes. Although the ground motions for a given magnitude and distance can be very different for these two types of earthquakes, most ground motion attenuation studies for subduction zone earthquakes have not distinguished between these two source types. The exceptio is Youngs et al (1997). By separating the two source types for subduction zone earthquakes, Youngs et al found a significant difference in the ground motions (ground motions from intraslab earthquakes are about 60% larger than those from interface earthquakes for the same magnitude and distance). This difference is considered to be important, so te Youngs et al (1997) attenuation relation is selected for use in this study.

3.7 Spectral Period Extrapolation to 10.0 second

The four empirical attenuation relationships are defined between the period range of 0.01 seconds (i.e., PGA) and 4.0 seconds. The spectral values from these attenuation relations are extrapolated to a period of 10 seconds using linear interpolation on the log-log values (see 5.2.7).

The basis for this assumption is that it is conservative. At long periods, the spectra typically exhibit an increasing slope as a function of period in the period range of 4 to 10 seconds. Therefore, using a constant slope leads to some conservatism in the long periods range.

3.8 Extrapolation of the directivity effects to 10 seconds period

The directivity effects models by Somerville et al (1997) are defined for periods up to 5 seconds. For periods between 5 and 10 seconds, the directivity scale factors are assumed to be equal to the value at T=5 seconds.

The basis for this assumption is the earthquake magnitude of interest is 7.8 which will have a rise-time on the order of 6 seconds. The directivity effects are expected to be observed at periods up to about twice the rise-time. For the fault normal/AveH ratio, Calculations GEO.DCPP.01.11 showed that the effect extended out periods of 10 seconds.

3.9 Spectrum for Synchronous Rupture

For the case of synchronous rupture of two sources (e.g. Cascadia and Little Salmon fault zone), the response spectrum of the combined ground motion is assumed to be the square root of the sum of the squares (SRSS) of the spectra of the individual sources.

The basis for this assumption is that SRSS is the appropriate method for combining the response spectra from independent events (random vibration theory).

3.10 Hypocenter location for directivity
The rupture is assumed to begin at the bottom of the Little Salmon fault.

The basis for this assumption is that the Little Salmon fault is modeled as a splay off of the main subduction interface. If the rupture starts on the interface at depth, the rupture would transfer to the LSF at the bottom of the fault and continue to rupture updip.

3.11 Hypocenter depth for the Cascadia Interface event
The depth of the Cascadia Interface event is assumed to be at a depth of 20 km. The basis for this assumption is that it is the depth of the bottom of the interface. Using the Youngs et al (1997) attenuation relation, the ground motion increases as the hypocentral depth increases for the same rupture distance. Therefore, this is a conservative assumption.

3.12 V/H ratio
The Vertical to horizontal ratio computed using the Abrahamson and Silva (1997) attenuation relation for M=8, R_{rup}=7, Strike-slip, and soil site condition is assumed to be applicable to a M=8.8, R_{rup}=7, interface source, and soil site conditions. The basis for this assumption is given below.

The vertical / horizontal ratio is dependent on magnitude , distance, soil class, and spectral period. The Youngs et al (1997) model does not include a model for a vertical component. Therefore, a crustal model needs to be used to capture the magnitude and distance dependence of the V/H ratio. The Abrahamson and Silva (1997) model can be used with a distance of 7 km to capture the magnitude dependence of the ratio, but it is not applicable to M=8.8. The main effects of the magnitude dependence of the ratio can be captured using M=8 in the Abrahamson and Silva (1997) model. A strike-slip mechanism is selected because the spectral shape for Abrahamson and Silva (1997) is more stable for the strike-slip case than it is for the reverse case.

3.13 Interpolation of Damping Scale Factors to Other Damping Values
The scale factor for 4% damping is assumed to be equal to the square root of the arithmetic value of the scale factor for 3% damping.

The basis for this assumption is that it corresponds to linear interpolation on the log of the scale factor. The log is used because the scale factors can be approximated by alog normal distribution (Abrahamson and Silva, 1996). Since the scale factor at 5% damping is unity by definition and the logarithm of 1.0 is 0, a linear interpolation of the log values is just one-half of the log value at 3% damping. One half of the log value corresponds to the square root of the arithmetic value.

3.14 Extrapolation of Damping Scale Factors to Long Periods
The Abrahamson and Silva (1996) damping scale factors are given for spectral periods up to 5 seconds. The values are not given for longer spectral periods because the ground motion data beyond 5 seconds is generally not reliable (See Abrahamson and Silva, Figure 1, page 96). For long period periods, the damping scale factors are assumed to be

equal to the value for T=5 seconds. The basis for this assumption is that it is the simplest assumption that can be made and we have no basis for a more complex model.

3.15 Earthquake Magnitude for the Damping Scale Factors

The Abrahamson and Silva (1996) models for the damping scale factors include a dependence on the earthquake magnitude. It is assumed that a magnitude of 8.0 is appropriate for use in the damping scale factor models to estimate the scale factors for the synchronous rupture case.

The basis for this assumption is that the magnitude of the synchronous rupture, approximately 8.8 (see Input 4.1), is outside of the range of applicability of the Abrahamson and Silva (1996) model. The largest magnitude in the data set used by Abrahamson and Silva is M=7.4 and the regression equation does not properly extrapolate for magnitudes greater than 8.5 due to the selected functional form. As a co-developer of the model, it is my judgment that it can be reasonably extrapolated up to magnitude 8.0 but it is not reliable for extrapolation of the equations to larger magnitudes. Therefore, magnitude 8.0 is used for earthquakes with magnitude greater than 8.0

3.16 Short Periods for Youngs et al (1997)

The Youngs et al (1997) attenuation relation for subduction earthquakes gives equations for the peak acceleration and for a spectral period of 0.075 sec, but it does not include equations for periods less than 0.075 sec. The response spectral values for spectral periods less than or equal to 0.03 seconds are assumed to be equal to the peak acceleration.

The basis for this assumption is that the response spectra from large subduction earthquakes (e.g. 1985 Michoacan and 1985 Chile) are approximately flat (equal to the peak acceleration) for spectral periods less than 0.03 sec (see PEER strong motion data base).

4. DESIGN INPUTS

4.1 Earthquake Magnitudes and Distances

As described in GEO.HBPP.02.03, two seismic sources are considered in developing the deterministic ground motions: the Little Salmon Fault and the Cascadia interface. The mean magnitudes and distances for the two sources based on the Carver model are taken from GEO.HBPP.02.03 (Table 8-1). These values are listed in Tables 4-1 and 4-2.

Table 4-1. Source parameters for deterministic events for the Little Salmon Fault zone subsource

	Little Salmon fault zone	Reference
Magnitude	7.7	GEO.HBIP.02.03, Table 8-1
Rupture Distance (km)	0.0	Assumption 3-5
Seismogenic Distance (km)	3.0	Assumption 3-3, 3-5
Mechanism	Reverse	GEO.HBIP.02.03, Table 8-1

Table 4-2. Source parameters for deterministic events for the Cascadia Interface subsource

	Cascadia Interface	Reference
Magnitude	8.8	GEO.HBIP.02.03, Table 8-1
Rupture Distance (km)	7	GEO.HBIP.02.03, Table 8-1
Mechanism	Interface	GEO.HBIP.02.03, Table 8-1

4.2 Northridge High Frequency Spectral Shapes

The acceleration response spectral shape (i.e., SA/PGA) from 5 strong ground motion sites on soil site conditions which recorded large horizontal PGA motions (i.e., average horizontal ground motions of 0.6 g and larger) from the Northridge earthquake was computed in GEO.HBIP.02.06 (Table 8-2). These values are listed in Table 4-3 below.

Table 4-3. Average horizontal rock spectral shape based on 12 Northridge strong motion recordings. (from GEO.HBIP.02.06 Table 8-2)

Period (sec)	Average Spectral Shape (Sa/pga)
0.010	1.000
0.020	1.000
0.030	1.016
0.050	1.095
0.075	1.225
0.100	1.384
0.150	1.690
0.200	1.911
0.300	2.368
0.500	1.980
0.750	2.049
1.000	1.682
1.500	1.036
2.000	0.765
3.000	0.451
4.000	0.208

4.3 Site specific soil amplification factors

As described in GEO.HBIP.02.06, the site specific soil amplification factors were developed based on three soil profiles: median, lower bound, and upper bound. For each profile three sets of time histories were used and the average amplification factors for a rock PGA value of 1.6 g are given below in Table 4-4.

Table 4-4. Average amplification factors for an input PGA of 1.6 g (From GEO.HBIP.02.06, Table 8-1)

Period (sec)	Median Profile	Lower Profile	Upper Profile
0.010	0.608	0.383	0.813
0.030	0.615	0.387	0.822
0.050	0.434	0.273	0.581
0.075	0.352	0.221	0.473
0.100	0.324	0.201	0.444
0.150	0.292	0.182	0.435
0.200	0.376	0.193	0.602
0.300	0.563	0.325	0.924
0.420	0.940	0.481	1.011
0.500	0.882	0.677	0.948
0.600	0.900	0.811	1.258
0.640	0.885	0.734	1.342
0.750	1.053	0.678	1.416
0.860	1.214	0.766	1.368
1.000	1.262	0.823	1.468
1.200	1.342	1.117	1.903
1.450	1.580	1.181	2.419
1.700	1.904	1.309	2.681
2.200	2.381	1.809	2.194
2.600	2.305	2.083	1.893
3.200	1.922	2.373	1.605
3.500	1.926	2.324	1.622
4.100	1.692	2.102	1.384
4.300	1.521	1.915	1.250
5.400	1.451	1.724	1.250
6.200	1.322	1.484	1.211
7.800	1.209	1.351	1.165
10.000	1.258	1.330	1.174

5. METHOD AND EQUATION SUMMARY

5.1 Methods

5.1.1 Horizontal Spectrum

The method used to develop the HBPP horizontal spectra uses the following steps.

1. The 84th percentile spectrum for reference rock site conditions is computed for the Little Salmon fault zone source using the average spectrum computed from four empirical attenuation relations for crustal sources.

2. The LSF average horizontal spectrum is extrapolated to a spectral period of 10.0 seconds.

3. The LSF horizontal rock spectrum is modified to include the effects of directivity. This results in separate spectra for the fault normal and fault parallel components.

4. The 84th percentile spectrum for reference rock site conditions is computed for the Cascadia Interface source using the Youngs et al. (1997) empirical attenuation relation for subduction sources.

5. The Cascadia horizontal spectrum is extrapolated to a spectral period of 10.0 seconds.

6. The horizontal rock spectra for the LSF and Cascadia interface sources are combined to estimate the spectrum for synchronous rupture.

7. The horizontal spectrum for soil site conditions is computed by scaling the combined rock spectra by the site-specific soil amplification factors.

8. The short period part of the horizontal soil spectrum is modified to envelope the empirical spectral shape from large amplitude recordings from soil sites in the Northridge earthquake.

9. Smooth design spectra are developed for the fault normal and fault parallel components.

5.1.2 Vertical Spectrum

The method used to develop the HBPP vertical spectrum uses the following steps.

1. The 84th percentile vertical component spectrum for deep soil site conditions is computed for the Little Salmon fault zone source using the Abrahamson and Silva (1997) empirical attenuation relation.

2. The LSF vertical soil spectrum is extrapolated to a period of 10 seconds.

3. The 84th percentile horizontal spectrum for deep soil site conditions is computed for the Cascadia Interface source using the Youngs et al (1997) empirical attenuation relation for subduction sources.

4. The V/H ratio for soil sites is computed using the Abrahamson and Silva (1997) attenuation relations.

5. The Cascadia vertical soil spectrum is computed by multiplying the horizontal spectrum (step 3) by the V/ ratio (step 4).

6. The Cascadia vertical soil spectrum is extrapolated to a period of 10 seconds.

7. The vertical soil spectra for the LSF and Cascadia interface sources are combined to estimate the vertical spectrum for synchronous rupture.

5.1. 3 Spectra for Damping Values Other than 5%

1. Scale factors for scaling the 5% damped horizontal to damping values of 2%, 3%, and 7% are computed using the Abrahamson and Silva (1996) model.

2. The horizontal scale factors at 4% damping are estimated from the scale factors for 3% damping

3. Scale factors for scaling the 5% damped vertical to damping values of 2%, 4%, and 7% are computed using the Abrahamson and Silva (1996) model.

4. The vertical scale factors at 4% damping are estimated from the scale factors for 3% damping.

5. The horizontal scale factors are applied to the 5% damped fault normal spectrum to compute the fault normal spectra at 2%, 4%, and 7% damping.

6. The horizontal scale factors are applied to the 5% damped fault parallel spectrum to compute the fault parallel spectra at 2%, 4%, and 7% damping.

7. The vertical scale factors are applied to the 5% damped vertical spectrum to compute the vertical spectra at 2%, 4%, and 7% damping.

5.2 Equations

5.2.1 Sadigh et al. (1993,1997) Attenuation Equation

The Sadigh et al. (1997) attenuation relation for rock sites is identical to the Sadigh et al. (1993) relation with two exceptions. First, the 1997 paper has fewer spectral periods listed. Second, there is a small change to the standard deviation model. In the 1993 model, the standard deviation becomes independent of magnitude for M>7.25. In the 1997 model, the standard deviation becomes independent of magnitude for M>7.2. This change in the standard deviation model results in a slight increase in the standard deviation for earthquakes with magnitudes greater than 7.21.

To avoid unnecessary interpolations, the 1993 relation is used for the coefficients for the median. The revised standard deviation model given in Sadigh et al (1997) is used.

The Sadigh et al (1993) median horizontal spectral acceleration attenuation relation for a strike-slip earthquake (Sa_{SS}) at a rock site is given by (Sadigh et al, 1993, page 66)

$$\ln(Sa_{SS}) = C_1 + 1.1\,M + C_3(8.5-M)^{2.5} + C_4\ln(R+\exp(C_5+C_6M)) + C_7\ln(R+2) \qquad (5\text{-}1)$$

where R is the rupture distance, and M is the magnitude. The coefficients for this model are listed in Table 5-1. Ground motions for reverse faults are computed by scaling the strike-slip values by a factor of 1.2 at all spectral periods (Sadigh et al, 1993, page 66).

For M<7.21, the standard deviation is given by the equation in the last column of Table 5-1. For M>=7.21, the standard deviation is given by using M=7.2 in the equation.

Table 5-1. Coefficients for the Sadigh et al. (1993) attenuation relation for horizontal spectral acceleration for M > 6.5 (from Sadigh, 1993, Table 1, page 66)

Period(s)	C_1	C_3	C_4	C_5	C_6	C_7	σ (M<7.21) (1997)
0.0	-1.274	0.000	-2.100	-0.48451	0.524	0.0	1.39 - 0.14M
0.05	-0.740	0.006	-2.128	-0.48451	0.524	-0.082	1.39 - 0.14M
0.07	-0.540	0.006	-2.128	-0.48451	0.524	-0.082	1.40 - 0.14M
0.09	-0.438	0.006	-2.140	-0.48451	0.524	-0.052	1.40 - 0.14M
0.10	-0.375	0.006	-2.148	-0.48451	0.524	-0.041	1.41 - 0.14M
0.15	-0.365	0.002	-2.130	-0.48451	0.524	0.0	1.42 - 0.14M
0.20	-0.497	-0.004	-2.080	-0.48451	0.524	0.0	1.43 - 0.14M
0.30	-0.707	-0.017	-2.028	-0.48451	0.524	0.0	1.45 - 0.14M
0.40	-0.948	-0.028	-1.990	-0.48451	0.524	0.0	1.48 - 0.14M
0.50	-1.238	-0.040	-1.945	-0.48451	0.524	0.0	1.50 - 0.14M
0.75	-1.858	-0.050	-1.865	-0.48451	0.524	0.0	1.52 - 0.14M
1.00	-2.355	-0.055	-1.800	-0.48451	0.524	0.0	1.53 - 0.14M
1.50	-3.057	-0.065	-1.725	-0.48451	0.524	0.0	1.53 - 0.14M
2.00	-3.595	-0.070	-1.670	-0.48451	0.524	0.0	1.53 - 0.14M
3.00	-4.350	-0.080	-1.610	-0.48451	0.524	0.0	1.53 - 0.14M
4.00	-4.880	-0.100	-1.570	-0.48451	0.524	0.0	1.53 - 0.14M
5.00	-5.364	-0.100	-1.540	-0.48451	0.524	0.0	1.53 - 0.14M
7.50	-6.180	-0.110	-1.510	-0.48451	0.524	0.0	1.53 - 0.14M

5.2.2 Idriss (1991,1994,1995) Attenuation Equation

The Idriss (1991) median horizontal spectral acceleration attenuation relations for rock sites use the form:

$$\ln(Sa) = \alpha_0 + \exp(\alpha_1 + \alpha_2 M) + (\beta_0 - \exp(\beta_1 + \beta_2 M))*\ln(R+20) + 0.2F \quad (5\text{-}2a)$$

where R is the rupture distance and F is the style-of-faulting (F=1 for reverse, F=0.5 for reverse/oblique, F=0, otherwise). Idriss (1991), which is summarized in the Idriss (1992) review paper, developed coefficients for peak acceleration and response spectral acceleration. The coefficients for this model are listed in Table 5-2.

Subsequently, the peak acceleration model was updated in Idriss (1995). For $M \geq 6$, the updated peak acceleration is given by(Idriss, 1995, page 2114):

$$\ln(PGA_{95}) = \exp(\alpha_1 + \alpha_2 M) - \exp(\beta_1 + \beta_2 M)*\ln(R+10) + F\phi \quad (5\text{-}2b)$$

where $\alpha_1 = 2.763$, $\alpha_2 = -0.262$, $\beta_1 = 2.215$, $\beta_2 M = -0.288$, and $\phi = 0.28$.

The spectral shape is given by the ratio of the spectral acceleration to the peak acceleration: Sa(T)/ pga. If the spectral shape is unchanged, then at each spectral period, T,

$$Sa_{95}(T) / pga_{95} = Sa_{91}(T) / pga_{91} \quad (5\text{-}3)$$

Therefore,

$$Sa_{95} = Sa_{91} * (PGA_{95} / PGA_{91}) \quad (5\text{-}4)$$

Using eq.(5-4), the updated model for the response spectral values is computed by scaling the 1991 spectral values by the ratio of the 1995 pga to the 1991 pga.

The standard deviation for the response spectral values was updated by Idriss (1994). The equations for the updated standard deviations are given in Table 5-2. For M<7.25, the standard deviation is given by the equation in the last column of Table 5-2. For M>=7.25, the standard deviation is given by using M=7.25 in the equation.

Table 5-2. Coefficients for the Idriss (1991) attenuation relation for horizontal spectral acceleration for M > 6.0

Period (s)	α_0	α_1	α_2	β_0	β_1	β_2	σ (1994) for M<7.25	σ (1994) for M>=7.25
0.0	-0.050	3.477	-0.284	0	2.475	-0.286	1.29-0.12M	0.42
0.03	-0.050	3.477	-0.284	0	2.475	-0.286	1.29-0.12M	0.42
0.05	-0.278	3.426	-0.269	0.066	2.475	-0.286	1.29-0.12M	0.42
0.075	-0.308	3.359	-0.252	0.070	2.475	-0.286	1.29-0.12M	0.42
0.10	-0.318	3.327	-0.243	0.072	2.475	-0.286	1.32-0.12M	0.45
0.15	-0.348	3.185	-0.216	0.076	2.475	-0.286	1.35-0.12M	0.48
0.20	-0.358	3.100	-0.201	0.078	2.475	-0.286	1.37-0.12M	0.50
0.30	-0.486	2.982	-0.182	0.082	2.475	-0.286	1.39-0.12M	0.52
0.40	-0.577	2.906	-0.173	0.092	2.475	-0.286	1.41-0.12M	0.54
0.50	-0.648	2.850	-0.169	0.099	2.475	-0.286	1.42-0.12M	0.55
0.70	-0.754	2.765	-0.165	0.111	2.475	-0.286	1.44-0.12M	0.57
0.80	-0.796	2.728	-0.164	0.115	2.475	-0.286	1.45-0.12M	0.58
1.00	-0.867	2.662	-0.162	0.123	2.475	-0.286	1.47-0.12M	0.60
1.50	-0.970	2.536	-0.160	0.136	2.475	-0.286	1.47-0.12M	0.60
2.00	-1.046	2.447	-0.160	0.146	2.475	-0.286	1.47-0.12M	0.60
3.00	-1.143	2.295	-0.159	0.160	2.475	-0.286	1.47-0.12M	0.60
4.00	-1.177	2.169	-0.159	0.169	2.475	-0.286	1.47-0.12M	0.60
5.00	-1.214	2.042	-0.157	0.177	2.475	-0.286	1.47-0.12M	0.60

5.2.3 Abrahamson and Silva (1997) Attenuation Equation

The Abrahamson and Silva (1997) median spectral acceleration attenuation relation is given by (Abrahamson and Silva, 1997, eq. 3, page 105):

$$\ln(Sa(g)) = f_1(M,R_{rup}) + Ff_3(M,R_{rup}) + HWf_4(M,R_{rup}) + Sf_5(PGA_{rock}) \qquad (5\text{-}5)$$

where M is the moment magnitude, R_{rup} is the rupture distance, F is the style of faulting factor (F=1 for reverse, F=0.5 for reverse/oblique, and F=0 otherwise), S is a site factor (S=0 for rock, S=1 for soil), and HW is a hangingwall factor (HW=1 for sites on the hanging wall and HW=0 otherwise).

For M>c_1 the $f_1(M,R)$ equation is given by (Abrahamson and Silva, 1997, eq. 4, page 105):

$$f_1(M,R) = a_1 + a_4(M - c_1) + a_{12}(8.5 - M)^n + [a_3 + a_{13}(M - c_1)]\ln R \qquad (5\text{-}6)$$

where $c_1 = 6.4$ (Abrahamson and Silva, 1997, table 3, page 108). The distance R is given by (Abrahamson and Silva, 1997, eq. 5, page 105):

$$R = \sqrt{R_{rup}^2 + c_4^2} \qquad (5\text{-}7)$$

For M> c_1, the effect of the style-of-faulting on the spectral acceleration is given by Abrahamson and Silva, 1997, eq. 6, page 106):

$$f_3(M) = a_6 \qquad (5\text{-}8)$$

The hanging wall term, $f_4(M,R_{rup})$, is zero for R_{rup} < 4 km (Abrahamson and Silva, 1997, eq. 9, page 106).

The non-linear soil response (Abrahamson and Silva, 1997, eq. 10, page 106) is modeled by:

$$f_5(PGA_{rock}) = a_{10} + a_{11}\ln(PGA_{rock} + c_5) \qquad (5\text{-}9)$$

Substituting eq. 5-6, 5-7, and 5-8 into eq. 5-5, the median spectral acceleration for M>6,4, R_{rup}<4 km, on rock (S=0), is

$$\ln(Sa(g)) = a_1 + a_4(M - c_1) + a_{12}(8.5 - M)^n + [a_3 + a_{13}(M - c_1)]\ln(\sqrt{R_{rup}^2 + c_4^2}) + Fa_6 \qquad (5\text{-}10)$$

Substituting eq. 5-6, 5-7, 5-8 and 5-9 into eq. 5-5, the median spectral acceleration for M>6,4, R_{rup}<4 km, on soil (S=1), is

$$\ln(Sa(g)) = a_1 + a_4(M - c_1) + a_{12}(8.5 - M)^n + [a_3 + a_{13}(M - c_1)]\ln(\sqrt{R_{rup}^2 + c_4^2}) + Fa_6 + a_{10} + a_{11}\ln(PGA_{rock} + c_5) \qquad (5\text{-}11)$$

The coefficients for eq. 5-10 and 5-11 are listed in Tables 5-3 and 5-4 for the horizontal and vertical components, respectively.

The standard deviations, for M ≥7.0 are given by (Abrahamson and Silva, 1997, eq. 13, page 106).

$$\sigma = b_5 - 2b_6 \qquad (5\text{-}12)$$

The coefficients for the standard deviation for the horizontal and vertical components are also listed in Tables 5-3 and 5-4.

Table 5-3. Coefficients for the Abrahamson and Silva (1997) attenuation relation for horizontal spectral acceleration (from Abrahamson and Silva, Table 3 and 4, pages 108 and 109)

Period (s)	c_4	a_1	a_3	a_4	a_5	a_6	a_9	a_{10}	a_{11}	a_{12}	a_{13}	n	c_5	b_5	b_6
0.0	5.60	1.640	-1.1450	-0.144	0.610	0.260	0.370	-0.417	-0.230	0.000	0.17	2	0.03	0.70	0.135
0.03	5.60	1.690	-1.1450	-0.144	0.610	0.260	0.370	-0.470	-0.230	0.014	0.17	2	0.03	0.70	0.135
0.05	5.60	1.870	-1.1450	-0.144	0.610	0.260	0.370	-0.620	-0.267	0.0280	0.17	2	0.03	0.71	0.135
0.075	5.58	2.037	-1.1450	-0.144	0.610	0.260	0.370	-0.628	-0.280	0.0300	0.17	2	0.03	0.73	0.135
0.10	5.50	2.160	-1.1450	-0.144	0.610	0.260	0.370	-0.598	-0.280	0.0280	0.17	2	0.03	0.74	0.135
0.15	5.27	2.407	-1.1450	-0.144	0.610	0.260	0.370	-0.577	-0.280	0.0050	0.17	2	0.03	0.75	0.135
0.20	5.10	2.406	-1.1150	-0.144	0.610	0.260	0.370	-0.445	-0.245	-0.0138	0.17	2	0.03	0.77	0.135
0.30	4.80	2.114	-1.0350	-0.144	0.610	0.198	0.370	-0.219	-0.195	-0.0360	0.17	2	0.03	0.78	0.135
0.40	4.52	1.860	-0.9880	-0.144	0.610	0.154	0.370	-0.065	-0.160	-0.0518	0.17	2	0.03	0.79	0.135
0.50	4.30	1.615	-0.9515	-0.144	0.581	0.119	0.370	0.085	-0.121	-0.0635	0.17	2	0.03	0.80	0.130
0.75	3.90	1.160	-0.8852	-0.144	0.528	0.057	0.331	0.320	-0.050	-0.0862	0.17	2	0.03	0.81	0.123
1.00	3.70	0.828	-0.8383	-0.144	0.490	0.013	0.281	0.423	0.000	-0.1020	0.17	2	0.03	0.83	0.118
1.50	3.55	0.260	-0.7721	-0.144	0.438	-0.049	0.210	0.600	0.040	-0.1200	0.17	2	0.03	0.84	0.110
2.00	3.50	-0.150	-0.7250	-0.144	0.400	-0.094	0.160	0.610	0.040	-0.1400	0.17	2	0.03	0.85	0.105
3.00	3.50	-0.690	-0.7250	-0.144	0.400	-0.156	0.089	0.630	0.040	-0.1726	0.17	2	0.03	0.87	0.097
4.00	3.50	-1.130	-0.7250	-0.144	0.400	-0.200	0.039	0.640	0.040	-0.1956	0.17	2	0.03	0.88	0.092
5.00	3.50	-1.460	-0.7250	-0.144	0.400	-0.200	0.000	0.664	0.040	-0.2150	0.17	2	0.03	0.89	0.087

Table 5-4. Coefficients for the Abrahamson and Silva (1997) attenuation relation for vertical spectral acceleration for M > 6.4 (from Abrahamson and Silva, page 116)

Period (sec)	c_4	a_1	a_3	a_4	a_5	a_6	a_9	a_{10}	a_{11}	a_{12}	a_{13}	n	c_5	b_5	b_6
0.0	6.00	1.642	-1.2520	0.275	0.390	-0.050	0.630	-0.140	-0.22	0.0000	0.06	3	0.3	0.76	0.085
0.03	6.00	2.100	-1.3168	0.275	0.432	-0.050	0.630	-0.140	-0.22	0.0000	0.06	3	0.3	0.76	0.085
0.05	6.00	2.620	-1.3700	0.275	0.496	-0.050	0.630	-0.140	-0.22	-0.0002	0.06	3	0.3	0.76	0.085
0.075	6.00	2.750	-1.3700	0.275	0.545	-0.050	0.630	-0.129	-0.22	-0.0007	0.06	3	0.3	0.76	0.085
0.10	6.00	2.700	-1.3700	0.275	0.580	-0.050	0.630	-0.114	-0.22	-0.0010	0.06	3	0.3	0.76	0.085
0.12	6.00	2.480	-1.2986	0.275	0.580	-0.017	0.630	-0.104	-0.22	-0.0015	0.06	3	0.3	0.74	0.075
0.15	6.00	2.170	-1.2113	0.275	0.580	0.024	0.630	-0.093	-0.22	-0.0022	0.06	3	0.3	0.72	0.063
0.17	5.72	1.960	-1.1623	0.275	0.580	0.047	0.604	-0.087	-0.220	-0.0025	0.06	3	0.3	0.70	0.056
0.20	5.35	1.648	-1.0987	0.275	0.580	0.076	0.571	-0.078	-0.22	-0.0030	0.06	3	0.3	0.69	0.050
0.24	4.93	1.312	-1.0274	0.275	0.580	0.109	0.533	-0.069	-0.22	-0.0035	0.06	3	0.3	0.69	0.050
0.30	4.42	0.878	-0.9400	0.275	0.580	0.150	0.488	-0.057	-0.22	-0.0042	0.06	3	0.3	0.69	0.050
0.40	3.77	0.478	-0.8776	0.275	0.539	0.150	0.428	-0.043	-0.22	-0.0050	0.06	3	0.3	0.69	0.050
0.50	3.26	0.145	-0.8291	0.275	0.471	0.150	0.383	-0.031	-0.22	-0.0060	0.06	3	0.3	0.69	0.050
0.75	2.50	-0.344	-0.7488	0.275	0.348	0.150	0.299	-0.010	-0.22	-0.0083	0.06	3	0.3	0.69	0.050
1.00	2.50	-0.602	-0.7404	0.275	0.260	0.150	0.240	0.004	-0.22	-0.0115	0.06	3	0.3	0.69	0.050
1.50	2.50	-0.966	-0.7285	0.275	0.260	0.058	0.240	0.025	-0.22	-0.0180	0.06	3	0.3	0.69	0.050
2.00	2.50	-1.224	-0.7200	0.275	0.260	-0.008	0.240	0.040	-0.22	-0.0240	0.06	3	0.3	0.69	0.050
3.00	2.50	-1.581	-0.7200	0.275	0.260	-0.100	0.240	0.040	-0.22	-0.0431	0.06	3	0.3	0.72	0.050
4.00	2.50	-1.857	-0.7200	0.275	0.260	-0.100	0.240	0.040	-0.22	-0.0565	0.06	3	0.3	0.75	0.050
5.00	2.50	-2.053	-0.7200	0.275	0.260	-0.100	0.240	0.040	-0.22	-0.0670	0.06	3	0.3	0.78	0.050

5.2.5 Campbell (1997) Attenuation Equations

Campbell (1997) develops a relation for peak acceleration and a relation for spectral acceleration based on the peak acceleration. For a soft-rock site (S_{SR} =1 and S_{HR} =0), the mean horizontal component of peak acceleration is given by (Campbell, eq 3, page 164)

$$\begin{aligned}\ln(A_H) = &-3.512 + 0.904M - 1.328\ln\sqrt{R_{SEIS}^2 + [0.149\exp(0.647M)]^2} \\ &+ [1.125 - 0.112\ln(R_{SEIS}) - 0.0957M]F \\ &+ [0.440 - 0.171\ln(R_{SEIS})]\end{aligned} \quad (5\text{-}13)$$

For a reverse-slip earthquake, F=1 (Campbell, 1997, page 156)

The median horizontal spectral acceleration attenuation relations for strike-slip earthquakes use the form (Campbell eq. 8, page 170):

$$\begin{aligned}\ln(Sa(g)) = &\ln(A_H) + c_1 + c_2\tanh[c_3(M-4.7)] + (c_4+c_5M)R_{SEIS} + 0.5c_6S_{SR} + c_6S_{HR} \\ &+ c_7\tanh(c_8D)(1 - S_{HR}) + f_{SA}(D)\end{aligned} \quad (5\text{-}14)$$

where M is magnitude, R_{SEIS} is the seismogenic distance, D is the depth to basement rock, S_{SR} =1 for soft-rock and 0 otherwise, and S_{HR} =1 for hard-rock sites and 0 otherwise. For D< 1 km, the function $f_{sa}(D)$ is given by

$$f_{sa}(D) = c_6(1-S_{SR})(1-D) + 0.5\, c_6(1-D)S_{SR} \quad (5\text{-}15)$$

(Campbell, 1997, page 170, part of eq. 8). Note that Campbell (1997) contains an error in the equation for $F_{sa}(D)$. The term (1-S_{SR} in eq. (5-15) above is incorrectly given as (1-S_{HR}) in Campbell (1997).

For a soft-rock site, (S_{SR}=1, S_{HR}=0), equation (5-14) becomes

$$\begin{aligned}\ln(Sa(g)) = &\ln(A_H) + c_1 + c_2\tanh[c_3(M-4.7)] + (c_4+c_5M)R_{SEIS} + 0.5c_6 \\ &+ c_7\tanh(c_8D) + 0.5c_6(1-D)\end{aligned} \quad (5\text{-}16)$$

The standard deviation for the horizontal component, σ_H, is given by (Campbell eq 10, page 171 and eq 5, page 164)

$$\sigma_H = \sqrt{\sigma_{pga}^2 + 0.27^2} \quad (5\text{-}17)$$

where

$$\sigma_{pga} = \begin{cases} 0.889 - 0.0691\,M & \text{for } M < 7.4 \\ 0.38 & \text{for } M >= 7.4 \end{cases} \quad (5\text{-}18)$$

Table 5-5. Coefficients for the Campbell (1997) attenuation relation for horizontal spectral acceleration (from Campbell, page 170)

Period (sec)	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8
0.05	0.05	0	0	-0.0011	0.000055	0.20	0	0
0.075	0.27	0	0	-0.0024	0.000095	0.22	0	0
0.10	0.48	0	0	-0.0024	0.000007	0.14	0	0
0.15	0.72	0	0	-0.0010	-0.00027	-0.02	0	0
0.20	0.79	0	0	0.0011	-0.00053	-0.18	0	0
0.30	0.77	0	0	0.0035	-0.00072	-0.40	0	0
0.50	-0.28	0.74	0.66	0.0068	-0.00100	-0.42	0.25	0.62
0.75	-1.08	1.23	0.66	0.0077	-0.00100	-0.44	0.37	0.62
1.0	-1.79	1.59	0.66	0.0085	-0.00100	-0.38	0.57	0.62
1.5	-2.65	1.98	0.66	0.0094	-0.00100	-0.32	0.72	0.62
2.0	-3.28	2.23	0.66	0.0100	-0.00100	-0.36	0.83	0.62
3.0	-4.07	2.39	0.66	0.0108	-0.00100	-0.22	0.86	0.62
4.0	-4.26	2.03	0.66	0.0112	-0.00100	-0.30	1.05	0.62

5.2.6 Computation of 84th Percentile Spectral Values

For a log-normal distribution, the 84th percentile corresponds to 1.0 standard deviations above the median. The 84th percentile response spectral values are given by:

$$Ln(Sa_{84th}) = \ln(Sa_{med}) + \sigma \qquad (5\text{-}19)$$

5.2.7 Equation for log-log interpolation/extrapolation of response spectra

The interpolation or extrapolation of the response spectral values is done using linear interpolation on the log spectral acceleration – log period. Given the spectral values Sa_1 and Sa_2 at periods T_1 and T_2, respectively, then using linear interpolation on the log-log values, the spectral acceleration at period T is given by

$$\ln(Sa(T)) = \ln(Sa(T_1)) + (\ln(T) - \ln(T_1)) \frac{\ln(Sa(T_2)) - \ln(Sa(T_1))}{[\ln(T_2) - \ln(T_1)]} \qquad (5\text{-}20)$$

5.2.8 Somerville et al (1997) Rupture Directivity Model

The Somerville et al (1997) model for rupture directivity has two effects: a scale factor for the average horizontal component and a scale factor for the fault normal (FN) and fault parallel (FP) components. The equation for the scale factor for the average horizontal component for dip-slip earthquakes is given by (Somerville et al 1997, page 210):

$$\ln(Dir\,(Y, \phi, T\,)) = c_1(T) + c_2(T)\,Y\cos(\phi) \qquad (5\text{-}21)$$

where $C_1(T) + C_2(T)$ are listed in Table 5-6, and Y and ϕ are directivity parameters defined by Somerville et al. (1997). (See Somerville et al 1997 figure 5).

The Somerville et al (1997, page 214) model for the difference between the fault normal and fault parallel components of the horizontal ground motion is given by (Somerville et al, 1997, page 214)

$$\ln(FN/Ave_H) = \cos(2\phi)\,[C_1 + C_2\ln(R+1) + C_3(M-6)] \quad \text{for } M>6 \text{ and } \phi<45 \qquad (5\text{-}22)$$
$$\ln(FN/Ave_H) = 0 \quad \text{otherwise}$$

The coefficients for this model are listed in Table 5-7. (note: Somerville et al uses the variable ξ in eq. (5-22). They state that $\xi=\phi$ for dip-slip earthquakes. Only the dip-slip model is shown here.)

Table 5-6. Coefficients for the Somerville et al (1997) directivity model for the average horizontal component for dip-slip earthquakes (from Somerville et al 1997, Table 4 part b, page 208).

Period (sec)	C_1	C_2
0.0 -0.60	0.000	0.000
0.75	-0.045	0.008
1.00	-0.104	0.178
1.50	-0.186	0.318
2.00	-0.245	0.418
3.00	-0.327	0.559
4.00	-0.386	0.659
5.00	-0.431	0.737

Table 5-7. Model Coefficients for the Somerville et al. (1997) Directivity Effects Including the dependence on the angle ϕ (from Somerville et al, 1997, Table 7, Page 209)

Period (sec)	C_1	C_2	C_3
0.0 -.50	0.000	0.000	0.000
0.60	0.027	-0.007	0.000
0.75	0.061	-0.016	0.000
1.00	0.104	-0.026	0.000
1.50	0.164	-0.049	0.034
2.00	0.207	-0.061	0.059
3.00	0.353	-0.101	0.093
4.00	0.456	-0.128	0.118
5.00	0.450	-0.127	0.137

The average horizontal component is based on the geometric mean of the two horizontals (Abrahamson and Silva, 1997, page 105). That is $Ave_H = FP*FN$. Therefore the ratio of the FP/Ave_H is given by

$$\ln(FP/Ave_H) = -\ln(FN/Ave_H) \qquad (5\text{-}23)$$

where $\ln(FN/Ave_H)$ is given in eq. 5-22.

5.2.9 Combination of directivity factors

The two directivity scale factors are combined to give the total effect. The scale factors for the FN and FP components are:

$$Scale_{FN}(T) = Dir(T) * FN/Ave_H(T) \quad (5\text{-}24)$$

$$Scale_{FP}(T) = Dir(T) * FP/Ave_H(T) \quad (5\text{-}25)$$

Where Dir is from eq. 5-21 and FN/Ave_H is from eq. 5-22, and FP/Ave_H is from eq. 5-23.

5.2.10 Computation of fault normal and fault parallel ground motion

The directivity factors are scale factors that are used to scale ground motions from standard attenuation relations for the average horizontal component. The response spectrum for the fault normal component, including directivity effects, is computed using the following equation:

$$Sa_{FN}(T) = Sa_{AveH}(T) * Scale_{FN}(T) \quad (5\text{-}26)$$

The response spectrum for the fault parallel component, including directivity effects, is computed using the following equation:

$$Sa_{FP}(T) = Sa_{AveH}(T) * Scale_{FP}(T) \quad (5\text{-}27)$$

5.1.11 Youngs et al. (1997) Attenuation Relation

The Youngs et al. (1997) attenuation relation for subduction zone earthquakes for rock sites is given by (Youngs et al, 1997, listed in Table 2, page 67):

$$\ln(Sa)=0.2418+1.414M+C_1+C_2(10-M)^3 \\ +C_3\ln(R_{rup}+1.7818e^{0.554M})+0.00607H+0.3846Z_T \tag{5-28a}$$

where H=hypocentral depth in km and Z_T is the source Type (Z_T=0 for interface and Z_T=1 for intraslab).

The Youngs et al. (1997) attenuation relation for subduction zone earthquakes for soil sites is given by (Youngs et al, 1997, listed in Table 2, page 67):

$$\ln(Sa)=-0.6687+1.438M+C_1+C_2(10-M)^3 \\ +C_3\ln(R_{rup}+1.097e^{0.617M})+0.00648H+0.3643Z_T \tag{5-28b}$$

The standard deviation is given by (Youngs et al, 1997, listed in Table 2, page 67):

$$\sigma=\begin{cases} C_4+C_5M & for\ M\leq 8 \\ C_4+8C_5 & for\ M>8 \end{cases} \tag{5-29}$$

The coefficients for eq. (5-28a) and (5-28b) are given in Tables 5-8 and 5-9 for rock sites and soil sites, respectively.

Table 5-8. Coefficients for the Youngs et al (1997) attenuation relations for subduction earthquakes on rock sites (From Youngs et a. 1997, Table 2, page 67)

Period (sec)	c_1	c_2	c_3	c_4	c_5
0.00	0	0	-2.552	1.45	-0.1
0.075	1.275	0	-2.707	1.45	-0.1
0.1	1.188	-0.0011	-2.655	1.45	-0.1
0.2	0.722	-0.0027	-2.528	1.45	-0.1
0.3	0.246	-0.0036	-2.454	1.45	-0.1
0.4	-0.115	-0.0043	-2.401	1.45	-0.1
0.5	-0.400	-0.0048	-2.360	1.45	-0.1
0.75	-1.149	-0.0057	-2.286	1.45	-0.1
1.0	-1.736	-0.0064	-2.234	1.45	-0.1
1.5	-2.634	-0.0073	-2.160	1.50	-0.1
2.0	-3.328	-0.0080	-2.107	1.55	-0.1
3.0	-4.511	-0.0089	-2.033	1.65	-0.1

Table 5-9. Coefficients for the Youngs et al (1997) attenuation relations for subduction earthquakes on soil sites (From Youngs et a. 1997, Table 2, page 67)

Period (sec)	c_1	c_2	c_3	c_4	c_5
0.00	0	0.0	-2.329	1.45	-0.1
0.075	2.400	-0.0019	-2.697	1.45	-0.1
0.1	2.516	-0.0019	-2.697	1.45	-0.1
0.2	1.549	-0.0019	-2.464	1.45	-0.1
0.3	0.793	-0.0020	-2.327	1.45	-0.1
0.4	0.144	-0.0020	-2.230	1.45	-0.1
0.5	-0.438	-0.0035	-2.140	1.45	-0.1
0.75	-1.704	-0.0048	-1.952	1.45	-0.1
1.0	-2.870	-0.0066	-1.785	1.45	-0.1
1.5	-5.101	-0.0114	-1.470	1.50	-0.1
2.0	-6.433	-0.0164	-1.290	1.55	-0.1
3.0	-6.672	-0.0221	-1.347	1.65	-0.1

5.1.12 Converting Spectral Acceleration to Psuedo-Spectral velocity response spectrum

A spectral acceleration response spectrum can be converted to a psuedo-spectral velocity response spectrum based on the following equation (Hudson, 1979, page 60):

$$PSV(cm/s) = \frac{T * Sa(g)}{2\pi}\left(\frac{980.5\ cm/s}{g}\right) \quad (5\text{-}30)$$

where PSV is in units of cm/sec and Sa is in units of g, and T is the spectral period in seconds. The inverse conversion from PSV to Sa is given by solving eq. 5-30 for Sa:

$$Sa(g) = \frac{PSV * 2\pi}{T}\left(\frac{g}{980.5\ cm/s}\right) \quad (5\text{-}31)$$

5.2.13 Equations for Scale Factors for Damping values other than 5%

The Abrahamson and Silva (1996) model for natural log of the scale factors for response spectral values at dampings other than 5% is given by

$$\ln\left(\frac{Sa_{x\%}}{Sa_{5\%}}\right) = C_1 + G_2(M - 6.0) + G_3(8.5 - M)^2 \quad (5\text{-}32)$$

where x% is the desired damping percentage (e.g. 2% or 5% or 7%). The coefficients for the horizontal component are given in Tables 5-10a, 5-10b, and 5-10c. The coefficients for the vertical component are given in Tables 5-11a, 5-11b, and 5-11c.

The scale factor for the different damping ratio is given by

$$Scale_{damp}(T,x\%) = \exp(\ \ln(Sa_{x\%}(T)/Sa_{5\%}(T))\ ), \quad (5\text{-}33)$$

where ($\ln(Sa_{x\%}(T)/Sa_{5\%}(T))$ is given in equation (5-32). The damping scale factors are applied to the 5% damped spectrum. That is, the spectral values at x% damping are computed using the following equation:

$$Sa_{x\%}(T) = Sa_{5\%}(T) * Scale_{damp}(T,x\%) \quad (5\text{-}34)$$

Table 5-10a. Abrahamson and Silva (1996) coefficient C_1 for damping scale factors for the horizontal component (from Abrahamson and Silva 1996, Table 4-4a)

Period (sec)	2% damping	3% damping	7% damping
0.000	0	0	0
0.020	0	0	0
0.030	0.0462	0.0273	-0.0205
0.040	0.0828	0.0490	-0.0367
0.050	0.1094	0.0648	-0.0486
0.075	0.1580	0.0936	-0.0701
0.100	0.1922	0.1138	-0.0853
0.120	0.2141	0.1268	-0.0950
0.150	0.2284	0.1353	-0.1014
0.170-0.750	0.2379	0.1409	-0.1056
1.000	0.2365	0.1401	-0.1050
1.500	0.2309	0.1368	-0.1025
2.000	0.2239	0.1326	-0.0994
3.000	0.2095	0.1241	-0.0930
4.000	0.1957	0.1159	-0.0869
5.000	0.1830	0.1084	-0.0812

Table 5-10b. Abrahamson and Silva (1996) coefficient G_2 for damping scale factors for the horizontal component (from Abrahamson and Silva 1996, Table 4-5a)

Period (sec)	2% damping	3% damping	7% damping
0.000	0	0	0
0.020	0	0	0
0.030	0	0	0
0.040	0	0	0
0.050	0	0	0
0.075	0	0	0
0.100	0	0	0
0.120	0	0	0
0.150	0	0	0
0.170 – 0.750	0	0	0
1.000	0.0016	0.001	-0.0007
1.500	0.0039	0.0023	-0.0017
2.000	0.0055	0.0032	-0.0024
3.000	0.0078	0.0046	-0.0034
4.000	0.0094	0.0055	-0.0042
5.000	0.0106	0.0063	-0.0047

Table 5-10c. Abrahamson and Silva (1996) coefficient G_3 for damping scale factors for the horizontal component (from Abrahamson and Silva 1996, Table 4-6a)

Period (sec)	2% damping	3% damping	7% damping
0.000	0	0	0
0.020	0	0	0
0.030	0	0	0
0.040	0	0	0
0.050	0	0	0
0.075	0	0	0
0.100	0	0	0
0.120	0	0	0
0.150	0	0	0
0.170-0.750	0	0	0
1.000	-0.0012	-0.0007	0.0006
1.500	-0.0030	-0.0018	0.0013
2.000	-0.0042	-0.0025	0.0019
3.000	-0.0060	-0.0036	0.0027
4.000	-0.0072	-0.0043	0.0032
5.000	-0.0082	-0.0049	0.0036

Table 5-11a. Abrahamson and Silva (1996) coefficient C_1 for damping scale factors for the vertical component (from Abrahamson and Silva 1996, Table 4-4b)

Period (sec)	2% damping	3% damping	7% damping
0.000	0	0	0
0.020	0	0	0
0.030	0.1232	0.0725	-0.0528
0.040	0.1844	0.1085	-0.0790
0.050	0.2072	0.1220	-0.0888
0.075	0.2488	0.1464	-0.1067
0.100	0.2818	0.1658	-0.1208
0.120	0.2890	0.1701	-0.1239
0.150	0.2932	0.1726	-0.1257
0.170	0.2910	0.1713	-0.1247
0.200	0.2839	0.1671	-0.1217
0.240	0.2776	0.1634	-0.1190
0.300 – 0.750	0.2727	0.1605	-0.1169
1.000	0.2709	0.1594	-0.1161
1.500	0.2637	0.1552	-0.1131
2.000	0.2549	0.1500	-0.1093
3.000	0.2366	0.1393	-0.1014
4.000	0.2193	0.1291	-0.0940
5.000	0.2033	0.1196	-0.0871

Table 5-11b. Abrahamson and Silva (1996) coefficient G_2 for damping scale factors for the vertical component (from Abrahamson and Silva 1996, Table 4-5b)

Period (sec)	2% damping	3% damping	7% damping
0.000	0	0	0
0.020	0	0	0
0.030	0	0	0
0.040	0	0	0
0.050	0	0	0
0.075	0	0	0
0.100	0	0	0
0.120	0	0	0
0.150	0	0	0
0.170	0	0	0
0.200	0	0	0
0.240	0	0	0
0.300 - 0750	0	0	0
1.000	0.0018	0.0011	-0.0008
1.500	0.0044	0.0026	-0.0019
2.000	0.0063	0.0037	-0.0027
3.000	0.0089	0.0052	-0.0038
4.000	0.0107	0.0063	-0.0046
5.000	0.0122	0.0072	-0.0052

Table 5-11c. Abrahamson and Silva (1996) coefficient G_3 for damping scale factors for the vertical component (from Abrahamson and Silva 1996, Table 4-6b)

Period (sec)	2% damping	3% damping	7% damping
0.000	0	0	0
0.020	0	0	0
0.030	0	0	0
0.040	0	0	0
0.050	0	0	0
0.075	0	0	0
0.100	0	0	0
0.120	0	0	0
0.150	0	0	0
0.170	0	0	0
0.200	0	0	0
0.240	0	0	0
0.300 – 0.750	0	0	0
1.000	-0.0014	-0.0008	0.0006
1.500	-0.0034	-0.0020	0.0015
2.000	-0.0049	-0.0029	0.0021
3.000	-0.0069	-0.0040	0.0029
4.000	-0.0083	-0.0049	0.0036
5.000	-0.0094	-0.0055	0.0040

6. SOFTWARE

No specialized computer software was used in these calculations.

7. BODY OF CALCULATIONS

7.1. Horizontal Spectra for Synchronous Rupture

7.1.1 Step1: 84th Percentile Horizontal Spectra for the LSF Subsource

The 84th percentile 5% spectral damping acceleration response spectra from the four empirical attenuation relationships are computed for a magnitude 7.7 reverse earthquake on the Little Salmon fault zone at a rupture distance of 0 km and a seismogenic distance of 3 km (input 4-1) using the Abrahamson and Silva (1997), Sadigh et al (1993), Idriss (1991,1994,1995) and Campbell (1997) attenuations relations (assumption 3.1).

The computed spectra for each relation is described below.

7.1.1.1 Abrahamson and Silva (1997)

From the inputs listed in Table 4-1:

$M = 7.7$
$R_{rup} = 0$
Mech = Reverse

For a reverse mechanism, F=1. Using these inputs, the horizontal spectral acceleration based on the Abrahamson and Silva (1997) relation is given in Table 7-1. In this table, the median spectral acceleration (column #1) is computed using eq. (5-10) with coefficients from Table 5-3.

The standard deviation (column #2) is computed using eq. (5-12) with coefficients from Table 5-3.

The 84th percentile spectral acceleration (column #3) is computed using eq. (5-19) with the median spectral acceleration from column #1 and the standard deviation from column #2.

Table 7-1. 5% damped spectral acceleration on reference rock for the Little Salmon fault zone using the Abrahamson and Silva (1997) attenuation model.

	#1	#2	#3
Period (sec)	Median Spectral Acc (g)	Standard Deviation (Natural Log Units)	84th Percentile Spectral Acc (g)
0.000	1.129	0.43	1.735
0.020	1.129	0.43	1.735
0.030	1.197	0.43	1.841
0.050	1.446	0.44	2.245
0.075	1.716	0.46	2.718
0.100	1.965	0.47	3.144
0.150	2.579	0.48	4.168
0.200	2.754	0.5	4.541
0.300	2.281	0.51	3.799
0.500	1.554	0.54	2.667
0.750	1.074	0.564	1.887
1.000	0.803	0.594	1.455
1.500	0.472	0.62	0.877
2.000	0.316	0.64	0.599
3.000	0.169	0.676	0.333
4.000	0.103	0.696	0.206

7.1.1.2 Sadigh et. al. (1993,1997)

From the inputs listed in Table 4-1:

$M = 7.7$, $R_{rup} = 0$

Mech = Reverse

For a reverse mechanism, F=1. Using these inputs, the horizontal spectral acceleration based on the Sadigh et al (1993) relation is given in Table 7-2. In this table, the median spectral acceleration (column #1) is computed using eq. (5-1) with coefficients from Table 5-1. The spectral accelerations in column #1 are for a strike-slip earthquake. To compute the spectral acceleration for a reverse earthquake (column #2), the values in column #1 are multiplied by 1.2.

The standard deviation (column #3) is computed using equation listed in the last column of Table 5-1 with M=7.2 (the upper limit of M for the standard deviation equations).

The 84th percentile spectral acceleration (column #4) is computed using eq. (5-19) with the median spectral acceleration for reverse faulting from column #2 and the standard deviation from column #3.

Table 7-2. 5% damped spectral acceleration on reference rock for the Little Salmon fault zone using the Sadigh et al. (1993) attenuation model.

		#1	#2	#3	#4
Period (sec)		Median Spectral Acc (g) strike-slip	Median Spectral Acc (g) Reverse	Standard Deviation (Natural Log Units)	84th Percentile Spectral Acc (g)
0.000		0.771	0.926	0.38	1.354
0.020		0.771	0.926	0.38	1.354
0.030		0.771	0.926	0.38	1.354
0.050		1.129	1.355	0.38	1.982
0.070	Used only to interpolate	1.379		0.39	
0.075	Interpolated	1.410	1.692	0.39	2.499
0.090	Used only to interpolate	1.494		0.39	
0.100		1.559	1.871	0.40	2.791
0.150		1.723	2.068	0.41	3.115
0.200		1.797	2.156	0.42	3.282
0.300		1.739	2.087	0.44	3.240
0.500		1.355	1.626	0.49	2.654
0.750		0.963	1.155	0.51	1.924
1.000		0.736	0.883	0.52	1.485
1.500		0.473	0.568	0.52	0.955
2.000		0.335	0.402	0.52	0.676
3.000		0.194	0.232	0.52	0.391
4.000		0.130	0.156	0.52	0.262

7.1.1.3 Idriss (1991,1994,1995)

From the inputs listed in Table 4-1:

$M = 7.7$
$R_{rup} = 0$
Mech = Reverse

For a reverse mechanism, F=1.

The peak acceleration is computed for the 1991 model using eq. (5-2a) with the coefficients given in Table 5-2. The PGA for the 1995 model is computed using eq. 5-2b. The resulting PGA values are:

$PGA_{91} = 0.859$ (from eq. 5-2a)
$PGA_{95} = 1.095$ (from eq. 5-2b)

The ratio of the PGA values is

$$\frac{PGA_{95}}{PGA_{91}} = \frac{1.095}{0.859} = 1.275$$

The horizontal spectral acceleration based on the Idriss (1991) attenuation relation is given in column #1 of Table 7-3. These values are computed using eq. (5-2a) with coefficients from Table 5-2.

The spectral acceleration, Sa_{95} (column #2) is computed using eq. 5-4 with the PGA ratio listed above and the Sa_{91} spectral acceleration listed in column #1.

The standard deviation (column #3) is computed using equation listed in the last column of Table 5-2 with M=7.25 (the upper limit of M for the standard deviation equations).

The 84^{th} percentile spectral acceleration (column #4) is computed using eq. (5-19) with the median spectral acceleration from column #2 and the standard deviation from column #3.

Table 7-3. 5% damped spectral acceleration on reference rock for the Little Salmon fault zone using the Idriss (1991,1994,1995) attenuation model.

	#1	#2	#3	#4
Period (sec)	Median Spectral Acc (g) Sa91	Median Spectral Acc (g) Sa95	Standard Deviation (Natural Log Units)	84^{th} Percentile Spectral Acc (g)
0.000	0.859	1.095	0.420	1.667
0.020	0.859	1.095	0.420	1.667
0.030	0.859	1.095	0.420	1.667
0.050	1.062	1.354	0.420	2.060
0.075	1.347	1.717	0.420	2.613
0.100	1.569	2.000	0.450	3.137
0.150	2.065	2.632	0.480	4.254
0.200	2.370	3.021	0.500	4.981
0.300	2.416	3.080	0.520	5.180
0.500	1.857	2.367	0.550	4.102
0.750	1.247	1.589	0.575	2.824
1.000	0.888	1.131	0.600	2.062
1.500	0.542	0.691	0.600	1.258
2.000	0.377	0.481	0.600	0.877
3.000	0.228	0.290	0.600	0.528
4.000	0.160	0.204	0.600	0.372

7.1.1.4 Campbell (1997)

From the inputs listed in Table 4-1 and assumption 3.4:

$M = 7.7$
$R_{seis} = 3$ km
Mech = Reverse
$D = 1$ km (assumption 3.4)

For a reverse mechanism, F=1. Using these inputs, the peak acceleration, A_H, is computed using eq. (5-13). For M=7.7, R_{seis}=3, and F=1, the median peak acceleration is

$$A_H = 0.874g$$

The standard deviation of the peak acceleration is computed using eq. 5-17 and 5-18. Using M=7.7, the standard deviation is

$$\sigma_{PGA} = 0.38 \quad \text{natural log units.}$$

The horizontal spectral acceleration based on the Campbell (1997) attenuation relation is given in Table 7-4. In this table, the median spectral acceleration (column #1) is computed using eq. (5-16) with coefficients from Table 5-5 with M=7.7, R_{seis}=0, D=1 and the PGA value of $A_H = 0.874g$.

The standard deviation of the spectral acceleration (column #2) is computed using eq. 5-19 with $\sigma_{PGA} = 0.38$.

The 84th percentile spectral acceleration (column #3) is computed using eq. (5-19) with the median spectral acceleration from column #1 and the standard deviation from column #2.

Table 7-4. 5% damped spectral acceleration on reference rock for the Little Salmon fault zone using the Campbell (1997) attenuation model.

	#1	#2	#3
Period (sec)	Median Spectral Acc (g)	Standard Deviation (Natural Log Units)	84^{th} Percentile Spectral Acc (g)
0.000	0.874	0.380	1.279
0.020	0.874	0.380	1.279
0.030	0.874	0.380	1.279
0.050	1.014	0.466	1.616
0.075	1.272	0.466	2.028
0.100	1.505	0.466	2.399
0.150	1.762	0.466	2.809
0.200	1.745	0.466	2.781
0.300	1.537	0.466	2.449
0.500	1.250	0.466	1.992
0.750	0.955	0.466	1.522
1.000	0.766	0.466	1.220
1.500	0.529	0.466	0.843
2.000	0.374	0.466	0.596
3.000	0.216	0.466	0.345
4.000	0.135	0.466	0.215

7.1.1.5 Average Horizontal Spectrum

The average horizontal response spectra from the Abrahamson and Silva (1997), Campbell (1997), Idriss (1991;1995) and Sadigh et al. (1997) attenuation relationship is given the last column on the right in Table 7-5. The 84th percentile response spectra based on the four attenuation models are taken from the Tables 7-1, 7-2, 7-3, and 7-4. The spectral values for the four attenuation relations are compared in Figure 1.

Table 7-5. 84th Percentile horizontal rock spectra for the Little Salmon fault zone subsource (M=7.7).

Period (sec)	Abrahamson & Silva (1997)	Campbell (1997)	Idriss (1991;1995)	Sadigh et al. (1993,1997)	Average
0.000	1.735	1.279	1.667	1.354	1.509
0.020	1.735	1.279	1.667	1.354	1.509
0.030	1.841	1.279	1.667	1.354	1.535
0.050	2.245	1.616	2.060	1.982	1.976
0.075	2.718	2.028	2.613	2.499	2.465
0.100	3.144	2.399	3.137	2.791	2.868
0.150	4.168	2.809	4.254	3.115	3.587
0.200	4.541	2.781	4.981	3.282	3.896
0.300	3.799	2.449	5.180	3.240	3.667
0.500	2.667	1.992	4.102	2.654	2.854
0.750	1.887	1.522	2.824	1.924	2.039
1.000	1.455	1.220	2.062	1.485	1.556
1.500	0.877	0.843	1.258	0.955	0.983
2.000	0.599	0.596	0.877	0.676	0.687
3.000	0.333	0.345	0.528	0.391	0.399
4.000	0.206	0.215	0.372	0.262	0.264

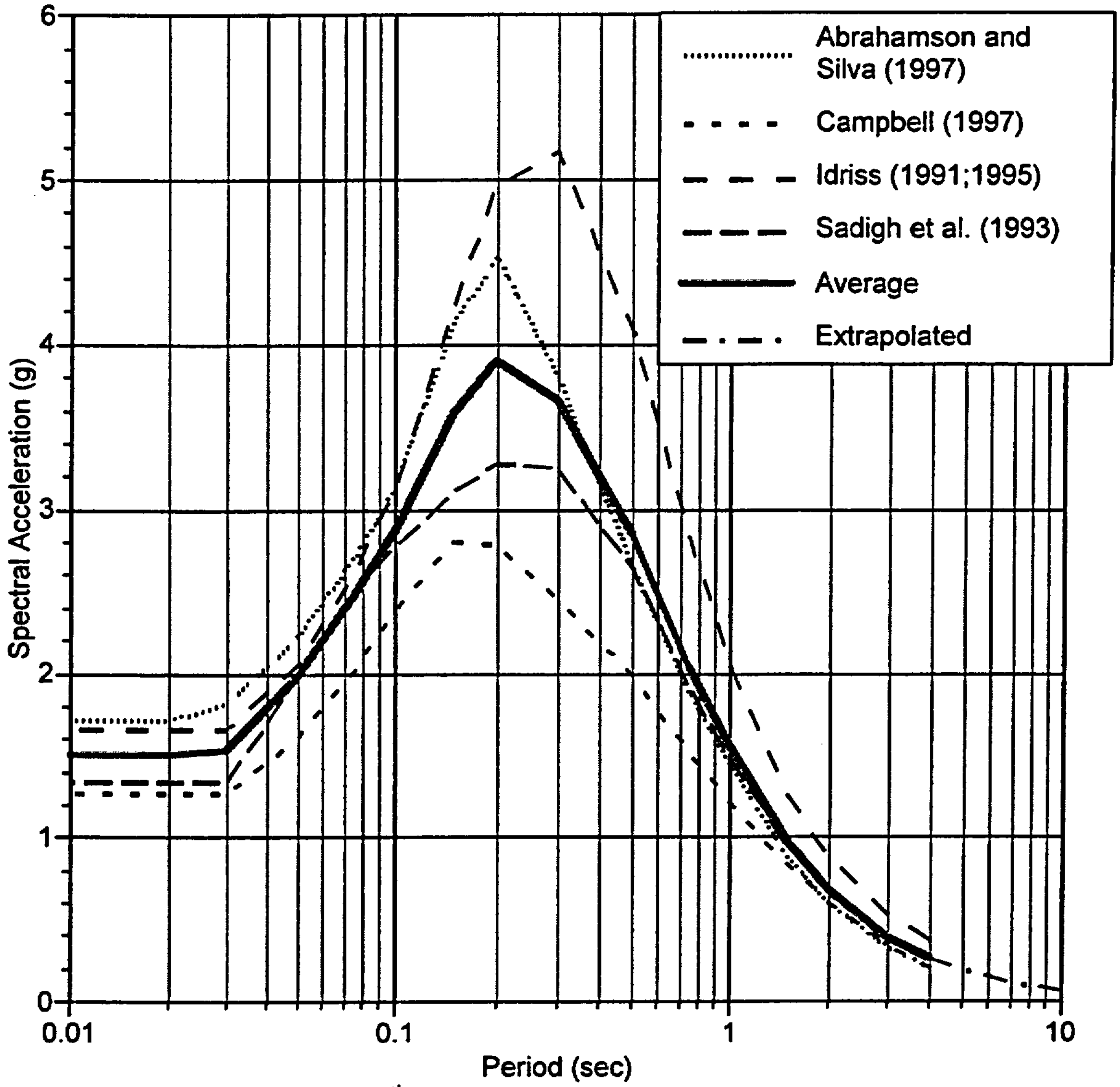

Figure 1. Comparison of the 84th percentile horizontal spectra for the Little Salmon fault subsource for rock site based on the alternative attenuation relations,

7.1.2 Step 2: Extrapolation of the LSF Subsource Spectrum from 5 seconds to 10 seconds

For periods greater than 5 seconds, the average spectrum given in Table 7-5 is extrapolated using eq. (5-20) with the following values (from the last two rows of Table 7-5)

$T_1 = 3.0$
$T_2 = 4.0$
$Sa_1 = 0.399$ g
$Sa_2 = 0.264$ g

The computed spectral values at periods greater than 5 seconds are listed in Table 7-6. These values give the average horizontal component without directivity effects. The extrapolated spectra values are also show in Figure 1.

Table 7-6. 84th Percentile horizontal spectra for the Little Salmon fault zone extrapolated to 10 seconds period. (5% damping)

	#1	#2	#3
Period (sec)	Average SA (g) (from Table 7-5)		Average Sa (g)
0.000	1.509		1.509
0.020	1.509		1.509
0.030	1.535		1.535
0.050	1.976		1.976
0.075	2.465		2.465
0.100	2.868		2.868
0.150	3.587		3.587
0.200	3.896		3.896
0.300	3.667		3.667
0.500	2.854		2.854
0.750	2.039		2.039
1.000	1.556		1.556
1.500	0.983		0.983
2.000	0.687		0.687
3.000	0.399		0.399
4.000	0.264		0.264
5.000		Extrapolated	0.192
7.000		Extrapolated	0.118
10.000		Extrapolated	0.071

7.1.3 Step 3: Directivity Effects for the LSF subsource

The rupture is assumed to begin at the bottom of the fault (assumption 3.10). This corresponds to the full rupture width. Therefore the directivity parameter, Y, is 1.0 in Somerville et al (1997). For the site located at zero distance, then second directivity parameter, ϕ, is 0 degrees.

From the inputs in Table 4-2 and the hypocenter location discussed above,

$M = 7.7$
$Y = 1.0$
$\phi = 0$

7.1.3.1 Directivity Effects for the Average Horizontal Component

The directivity scale factor for the average horizontal component (Table 7-6, col. #3) is computed using eq. (5-21) with coefficients from Table 5-6 and the input parameters listed above. The results are given in column #2 of Table 7-7. The scale factors at periods of 7 and 10 seconds are based on the assumption (3.8) that the factor is constant for periods > 5 seconds.

7.1.3.2 Directivity Effects for the Fault Normal Component

The directivity scale factor for the FN/Ave_H component is computed using eq. (5-22) with the input parameters listed above and coefficients from Table 5-7. The results are given in column #3 of Table 7-7. The scale factors at periods of 7 and 10 seconds are based on the assumption (3.8) that the factor is constant for periods > 5 seconds.

The scale factor for the FN component (column #5) is computed using eq. 5-24 (column #2 times column #3).

The spectral acceleration on the FN component including directivity (column #7) is computed using eq. 5-26 (column #1 time column #5). This spectrum is plotted in Figure 2.

7.1.3.3 Directivity Effects for the Fault Parallel Component

The directivity effects for the FP/Ave_H (column #4) is computed using eq. 5-23 with the FN/Ave_H value from column #3 of Table 7-7. The scale factors at periods of 7 and 10 seconds are based on the assumption (3.8) that the factor is constant for periods > 5 seconds.

The scale factor for the FP component (column #6) is computed using eq. 5-25 (column #2 times column #4).

The spectral acceleration on the FN component including directivity (column #8) is computed using eq. 5-27 (column #1 time column #6). This spectrum is plotted in Figure 2.

Table 7-7. Horizontal Rock Spectra with directivity effects for the Little Salmon Fault event.

	#1	#2	#3	#4	#5	#6	#7	#8
Period (sec)	AveH Spectral Acc (g) (From Table 7-6)	Directivity Scale Factor for The Average Horizontal DIR	FN/Ave_H	FP/Ave_H	$Scale_{FN}$	$Scale_{FP}$	Rock Spectrum (g) FN Component	Rock Spectrum (g) FP Component
0.000	1.509	1	1	1.000	1.000	1.000	1.509	1.509
0.020	1.509	1	1	1.000	1.000	1.000	1.509	1.509
0.030	1.535	1	1	1.000	1.000	1.000	1.535	1.535
0.050	1.976	1	1	1.000	1.000	1.000	1.976	1.976
0.075	2.465	1	1	1.000	1.000	1.000	2.465	2.465
0.100	2.868	1	1	1.000	1.000	1.000	2.868	2.868
0.150	3.587	1	1	1.000	1.000	1.000	3.587	3.587
0.200	3.896	1	1	1.000	1.000	1.000	3.896	3.896
0.300	3.667	1	1	1.000	1.000	1.000	3.667	3.667
0.5	2.854	1	1.000	1.000	1.000	1.000	2.854	2.854
0.75	2.039	1.00**	1.063	0.941	1.063	0.941	2.167	1.918
1.0	1.556	1.077	1.110	0.901	1.195	0.970	1.860	1.510
1.5	0.983	1.141	1.248	0.801	1.424	0.914	1.400	0.899
2.0	0.687	1.189	1.360	0.735	1.617	0.874	1.111	0.601
3.0	0.399	1.261	1.667	0.600	2.102	0.757	0.839	0.302
4.0	0.264	1.314	1.928	0.519	2.533	0.682	0.669	0.180
5.0	0.192	1.358	1.980	0.505	2.689	0.686	0.516	0.132
7.0	0.118	1.358*	1.980*	0.505	2.689	0.686	0.317	0.081
10.0	0.071	1.358*	1.980*	0.505	2.689	0.686	0.191	0.049

* Extrapolated to long periods assuming a constant factor.

** Value fixed to 1.0 (see text)

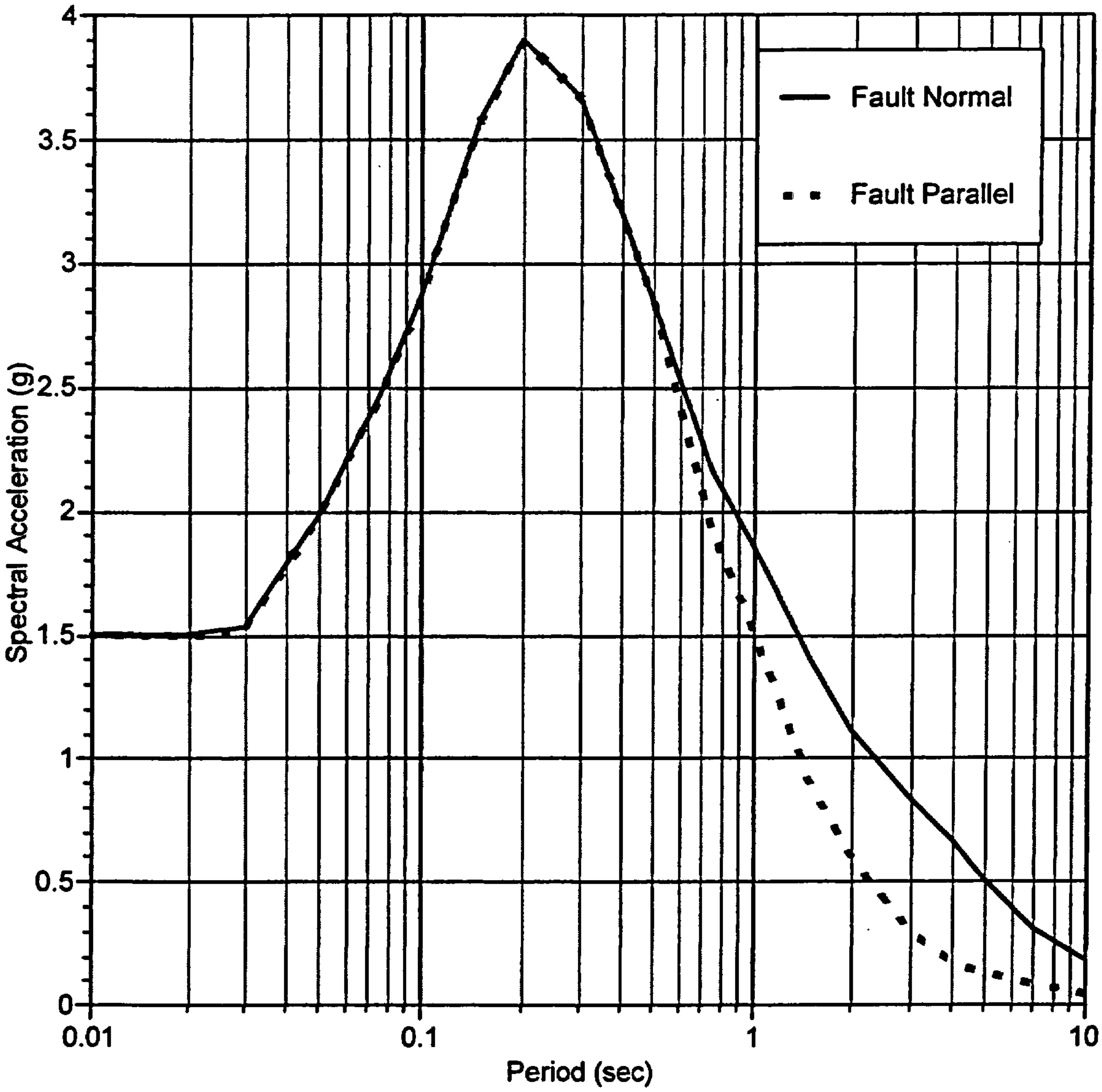

Figure 2. Comparison of the fault normal and fault parallel spectra for the LSF after accounting for the effects of directivity.

7.1.4 Step 4: Horizontal Spectrum for Rock for the Cascadia Subsource

The parameters for the Cascadia interface subsource are given below:

$M = 8.8$ (Table 4-2)
$R_{rup} = 7$ km (Table 4-2)
$Z_T = 0$ (for interface sources) (table 4-2)
$H = 20$ km (Assumption 3-11)

The 84th percentile 5% spectral damping acceleration response spectra for a subduction zone earthquake is computed based on the Youngs et al. (1997) empirical attenuation relationship (assumption 3.6). The horizontal spectral acceleration based on these input parameters is given below in Table 7-8. The median spectral acceleration values for a rock site are given in column #1 as a function of spectral period. These values were computed using equation (5-28) with the regression coefficients given in Table 5-8.

The standard deviation (column #2) is computed using equation (5-29).

The 84th percentile spectral acceleration (column #3) is computed using equation (5-19) with the median spectral acceleration from column #1 and the standard deviation from column #2.

Table 7-8. 5% damped spectral acceleration on reference rock for the Cascadia interface event using Youngs et al. (1997) attenuation model.

	#1	#2	#3
Period (sec)	Median Spectral Acc (g)	Standard Deviation (LN units)	84th Percentile Spectral Acc (g)
0.00	0.306	0.65	0.586
0.075	0.468	0.65	0.896
0.1	0.569	0.65	1.091
0.2	0.715	0.65	1.369
0.3	0.665	0.65	1.274
0.4	0.619	0.65	1.186
0.5	0.583	0.65	1.116
0.75	0.413	0.65	0.790
1.0	0.305	0.65	0.584
1.5	0.186	0.70	0.375
2.0	0.124	0.75	0.263
3.0	0.057	0.85	0.133

7.1.5 Step 5: Extrapolation of Cascadia Subsource Spectrum from 3 to 10 Seconds

The acceleration response spectrum for spectral periods of 0.02 and 0.03 seconds are set equal to the PGA spectral acceleration value (assumption 3.16).

The acceleration response spectra values for spectral periods of 0.05 and 0.15 seconds were computed by interpolation using eq. 5-20.

For spectral periods greater than 3.0 seconds, the acceleration response values were computed by extrapolation using eq. 5-20 using the spectral acceleration values at T=2 and T=3 seconds.

Table 7-9. 84th percentile horizontal response spectrum for the Cascadia Interface event extrapolated to 10 seconds period (5% spectral damping).

	#1	#2	#3
Period (sec)	84th Percentile Spectral SA (g) (From Table 7-8)		Extrapolated 84th Percentile Spectral SA (g)
0.00	0.586		0.586
0.02		Assumption 3.16	0.586
0.03		Assumption 3.16	0.586
0.05		Interpolated	0.743
0.075	0.896		0.896
0.10	1.091		1.091
0.15		Interpolated	1.246
0.2	1.369		1.369
0.3	1.274		1.274
0.5	1.116		1.116
0.75	0.790		0.790
1.0	0.584		0.584
1.5	0.375		0.375
2.0	0.263		0.263
3.0	0.133		0.133
4.0		Extrapolated	0.082
5.0		Extrapolated	0.057
7.0		Extrapolated	0.032
10.0		Extrapolated	0.018

7.1.6 Step 6: Combined Synchronous Rupture Rock Spectra

The horizontal rock spectra for the Little Salmon Fault (see Table 7-7) and the Cascadia Interface event (see Table 7-9) are combined based on assumption 3.9 (i.e., SRSS).

The combined synchronous rupture rock acceleration response spectrum for the fault normal component is given in Table 7-10. The third column is the SRSS of the #1 and #2 columns. The spectra are plotted in Figure 3.

The corresponding combined synchronous rupture rock acceleration response spectrum for the fault parallel component is given in Table 7-11. The spectra are plotted in Figure 4.

Table 7-10. Combined synchronous rupture rock acceleration response spectrum for the fault normal component of motion.

	#1	#2	#3
Period (sec)	Little Salmon Fault Rock Fault Normal Sa(g) (from Table 7-7)	Cascadia Interface Rock Sa(g) (from Table 7-9)	Synchronous Rock Fault Normal Sa(g)
0.000	1.509	0.586	1.619
0.020	1.509	0.586	1.619
0.030	1.535	0.586	1.643
0.050	1.976	0.743	2.111
0.075	2.465	0.896	2.623
0.100	2.868	1.091	3.069
0.150	3.587	1.246	3.797
0.200	3.896	1.369	4.130
0.300	3.667	1.274	3.882
0.500	2.854	1.116	3.064
0.750	2.167	0.790	2.307
1.000	1.860	0.584	1.950
1.500	1.400	0.375	1.449
2.000	1.111	0.263	1.142
3.000	0.839	0.133	0.849
4.000	0.669	0.082	0.674
5.000	0.516	0.057	0.519
7.000	0.317	0.032	0.319
10.000	0.191	0.018	0.192

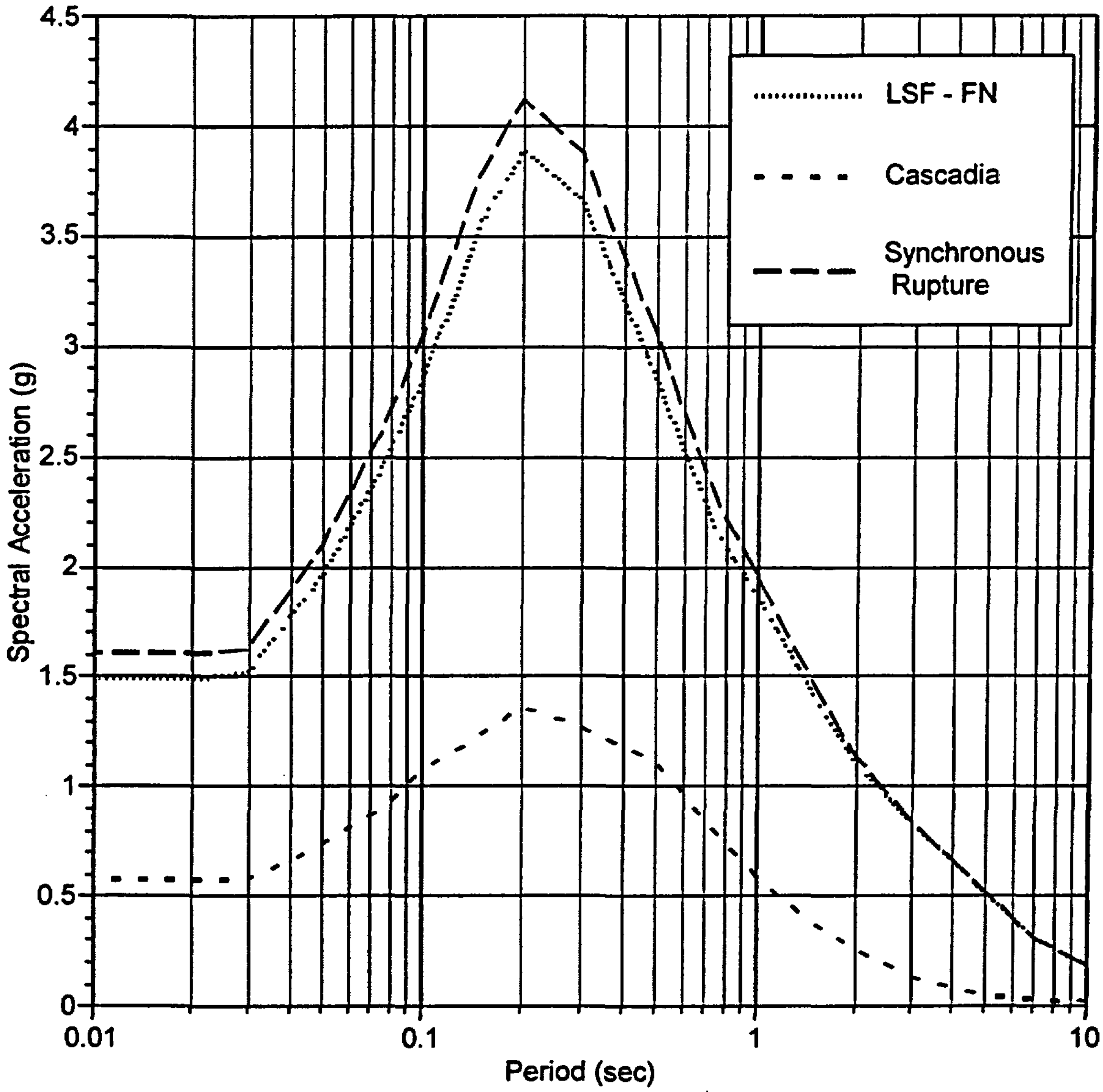

Figure 3. Fault normal spectra for the individual subsources and for synchronous rupture.

Table 7-11. Combined synchronous rupture outcropping rock acceleration response spectrum for the fault parallel component of motion.

	#1	#2	#3
Period (sec)	Little Salmon Fault Rock Fault Parallel Sa(g) (from Table 7-7)	Cascadia Interface Rock Sa(g) (from Table 7-9)	Synchronous Rock, Fault Parallel Sa(g)
0.000	1.509	0.586	1.619
0.020	1.509	0.586	1.619
0.030	1.535	0.586	1.643
0.050	1.976	0.743	2.111
0.075	2.465	0.896	2.623
0.100	2.868	1.091	3.069
0.150	3.587	1.246	3.797
0.200	3.896	1.369	4.130
0.300	3.667	1.274	3.882
0.500	2.854	1.116	3.064
0.750	1.918	0.790	2.074
1.000	1.510	0.584	1.619
1.500	0.899	0.375	0.974
2.000	0.601	0.263	0.656
3.000	0.302	0.133	0.330
4.000	0.180	0.082	0.198
5.000	0.132	0.057	0.144
7.000	0.081	0.032	0.087
10.000	0.049	0.018	0.052

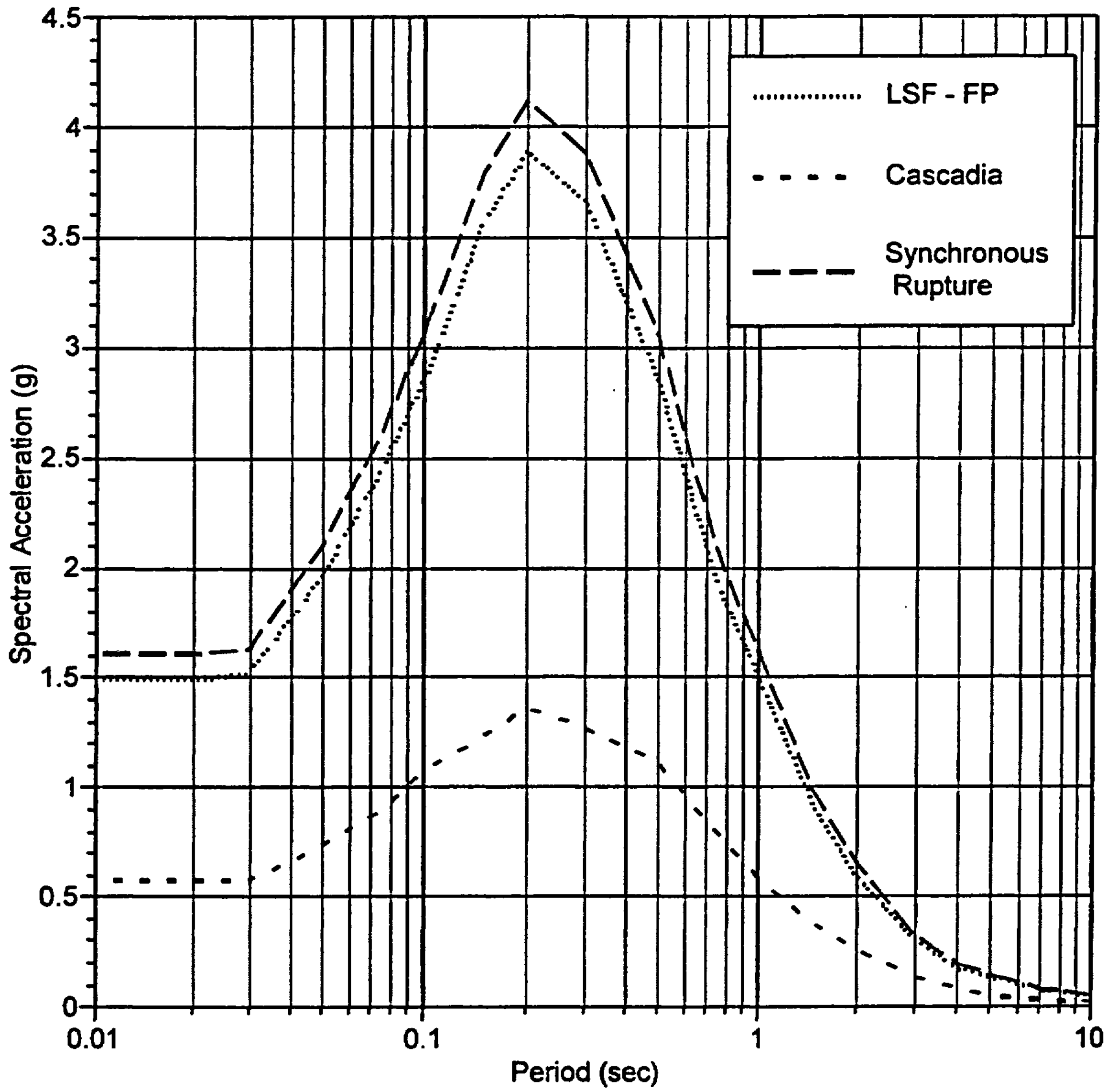

Figure 4. Fault parallel spectra for the individual subsources and for synchronous rupture.

7.1.7 Step 7: Scaling of Combined Spectra by Site Specific Soil Amplification Factors

The soil spectra for the FN and FP components are computed by multiplying the horizontal rock acceleration response spectra by the soil site-specific amplification factors . The horizontal spectra (Tables 7-10 and 7-11) are first interpolated to match the spectral periods used to define the soil amplification (Table 4-4) using eq. 5-19. The interpolated values are listed in Table 7-12.

For each of the three profiles (Median, Lower Bound, and Upper Bound), the amplification factors from Table 4-4 are multiplied by the horizontal rock spectra given in Tables 7-12 to compute the soil ground motion for the synchronous rupture. The computed spectral acceleration values for soil are given in Tables 7-13, 7-14, and 7-15 for the median, lower bound, and upper bound profiles, respectively. In each of these three tables, the FN soil spectrum (column #4) is computed by multiplying the FN rock (column #1) by the amplification factor (column #3). Similarly, the FP soil spectrum is (column #5) is computed by multiplying the FP rock (column #2) by the amplification factor (column #3).

The FN spectra for the rock site and for each of the three soil profiles is shown in Figure 5. The FP spectra for the rock site and for each of the three soil profiles is shown in Figure 6.

Table 7-12. 5% damped spectra for the synchronous rupture. Interpolated to the periods from the amplification factors.

Period (sec)		Fault Normal	Fault parallel
0.00		1.619	1.619
0.02		1.619	1.619
0.03		1.643	1.643
0.05		2.111	2.111
0.075		2.623	2.623
0.1		3.069	3.069
0.15		3.797	3.797
0.2		4.130	4.130
0.3		3.882	3.882
0.42	Interpolated	3.322	3.322
0.5		3.064	3.064
0.6	Interpolated	2.697	2.571
0.64	Interpolated	2.578	2.416
0.75		2.307	2.074
0.86	Interpolated	2.130	1.843
1		1.950	1.619
1.2	Interpolated	1.706	1.288
1.45	Interpolated	1.485	1.016
1.5		1.449	0.974
1.7	Interpolated	1.306	0.820
2		1.142	0.656
2.2	Interpolated	1.065	0.558
2.6	Interpolated	0.943	0.421
3		0.849	0.330
3.2	Interpolated	0.806	0.294
3.5	Interpolated	0.750	0.251
4		0.674	0.198
4.1	Interpolated	0.655	0.191
4.3	Interpolated	0.619	0.179
5		0.519	0.144
5.4	Interpolated	0.464	0.128
6.2	Interpolated	0.380	0.104
7		0.319	0.087
7.8	Interpolated	0.273	0.074
10		0.192	0.052

Table 7-13. Soil Spectrum for synchronous rupture using the site-specific amplification factors for the median profile

	#1	#2	#3	#4	#5
Period (sec)	Rock, Fault Normal Sa(g) (Table 7-12)	Rock, Fault Parallel Sa(g) (Table 7-12)	Amplification Factor, Median Profile PGA=1.6 g (Table 4-4)	Soil, Fault Normal Sa (g)	Soil, Fault Parallel Sa(g)
0.00	1.619	1.619	0.608	0.984	0.984
0.02	1.619	1.619	0.608*	0.984	0.984
0.03	1.643	1.643	0.615	1.010	1.010
0.05	2.111	2.111	0.434	0.916	0.916
0.075	2.623	2.623	0.352	0.923	0.923
0.1	3.069	3.069	0.324	0.994	0.994
0.15	3.797	3.797	0.292	1.109	1.109
0.2	4.130	4.130	0.376	1.553	1.553
0.3	3.882	3.882	0.563	2.186	2.186
0.42	3.322	3.322	0.940	3.123	3.123
0.5	3.064	3.064	0.882	2.702	2.702
0.6	2.697	2.571	0.900	2.427	2.314
0.64	2.578	2.416	0.885	2.281	2.138
0.75	2.307	2.074	1.053	2.429	2.184
0.86	2.130	1.843	1.214	2.585	2.238
1	1.950	1.619	1.262	2.461	2.043
1.2	1.706	1.288	1.342	2.290	1.729
1.45	1.485	1.016	1.580	2.347	1.606
1.7	1.306	0.820	1.904	2.487	1.562
2.2	1.065	0.558	2.381	2.536	1.329
2.6	0.943	0.421	2.305	2.173	0.969
3.2	0.806	0.294	1.922	1.549	0.566
3.5	0.750	0.251	1.926	1.445	0.483
4.1	0.655	0.191	1.692	1.108	0.323
4.3	0.619	0.179	1.521	0.942	0.272
5.4	0.464	0.128	1.451	0.674	0.186
6.2	0.380	0.104	1.322	0.503	0.138
7.8	0.273	0.074	1.209	0.331	0.090
10	0.192	0.052	1.258	0.242	0.065

* Set to be equal to amplification at T=0.00

Table 7-14. Scaled combined synchronous rupture spectra for the lower bound site specific soil profile

	#1	#2	#3	#4	#5
Period (sec)	Rock, Fault Normal Sa(g) (Table 7-12)	Rock, Fault Parallel Sa(g) (Table 7-12)	Amplification Factor, Lower Bound profile PGA=1.6 g (Table 4-4)	Soil, Fault Normal Sa (g)	Soil, Fault Parallel Sa(g)
0.00	1.619	1.619	0.383	0.620	0.620
0.02	1.619	1.619	0.383*	0.620	0.620
0.03	1.643	1.643	0.387	0.636	0.636
0.05	2.111	2.111	0.273	0.576	0.576
0.075	2.623	2.623	0.221	0.580	0.580
0.10	3.069	3.069	0.201	0.617	0.617
0.15	3.797	3.797	0.182	0.691	0.691
0.2	4.130	4.130	0.193	0.797	0.797
0.3	3.882	3.882	0.325	1.262	1.262
0.42	3.322	3.322	0.481	1.598	1.598
0.5	3.064	3.064	0.677	2.074	2.074
0.6	2.697	2.571	0.811	2.187	2.085
0.64	2.578	2.416	0.734	1.892	1.773
0.75	2.307	2.074	0.678	1.564	1.406
0.86	2.130	1.843	0.766	1.631	1.412
1.0	1.950	1.619	0.823	1.605	1.332
1.2	1.706	1.288	1.117	1.906	1.439
1.45	1.485	1.016	1.181	1.754	1.200
1.7	1.306	0.820	1.309	1.710	1.074
2.2	1.065	0.558	1.809	1.927	1.010
2.6	0.943	0.421	2.083	1.964	0.876
3.2	0.806	0.294	2.373	1.913	0.698
3.5	0.750	0.251	2.324	1.744	0.583
4.1	0.655	0.191	2.102	1.376	0.402
4.3	0.619	0.179	1.915	1.186	0.342
5.4	0.464	0.128	1.724	0.800	0.221
6.2	0.380	0.104	1.484	0.564	0.155
7.8	0.273	0.074	1.351	0.369	0.101
10.0	0.192	0.052	1.330	0.255	0.069

* Set to be equal to amplification at T=0.00

Table 7-15. Scaled combined synchronous rupture spectra for the upper bound site specific soil profile.

	#1	#2	#3	#4	#5
P	Rock, Fault Normal Sa(g) (Table 7-12)	Rock, Fault Parallel Sa(g) (Table 7-12)	Amplification Factor, Upper Bound Profile PGA=1.6 g (Table 4-4)	Soil, Fault Normal Sa (g)	Soil, Fault Parallel Sa(g)
0.00	1.619	1.619	0.813	1.316	1.316
0.02	1.619	1.619	0.813	1.316	1.316
0.03	1.643	1.643	0.822	1.351	1.351
0.05	2.111	2.111	0.581	1.226	1.226
0.075	2.623	2.623	0.473	1.241	1.241
0.10	3.069	3.069	0.444	1.363	1.363
0.15	3.797	3.797	0.435	1.652	1.652
0.20	4.130	4.13	0.602	2.486	2.486
0.30	3.882	3.882	0.924	3.587	3.587
0.42	3.322	3.322	1.011	3.359	3.359
0.50	3.064	3.064	0.948	2.905	2.905
0.60	2.697	2.571	1.258	3.393	3.234
0.64	2.578	2.416	1.342	3.459	3.242
0.75	2.307	2.074	1.416	3.267	2.937
0.86	2.130	1.843	1.368	2.913	2.522
1.0	1.950	1.619	1.468	2.863	2.377
1.2	1.706	1.288	1.903	3.247	2.452
1.45	1.485	1.016	2.419	3.593	2.458
1.7	1.306	0.820	2.681	3.502	2.199
2.2	1.065	0.558	2.194	2.337	1.225
2.6	0.943	0.421	1.893	1.784	0.796
3.2	0.806	0.294	1.605	1.294	0.472
3.5	0.750	0.251	1.622	1.217	0.407
4.1	0.655	0.191	1.384	0.906	0.265
4.3	0.619	0.179	1.25	0.774	0.223
5.4	0.464	0.128	1.25	0.580	0.160
6.2	0.380	0.104	1.211	0.460	0.126
7.8	0.273	0.074	1.165	0.319	0.087
10.0	0.192	0.052	1.174	0.225	0.061

* Set to be equal to amplification at T=0.00

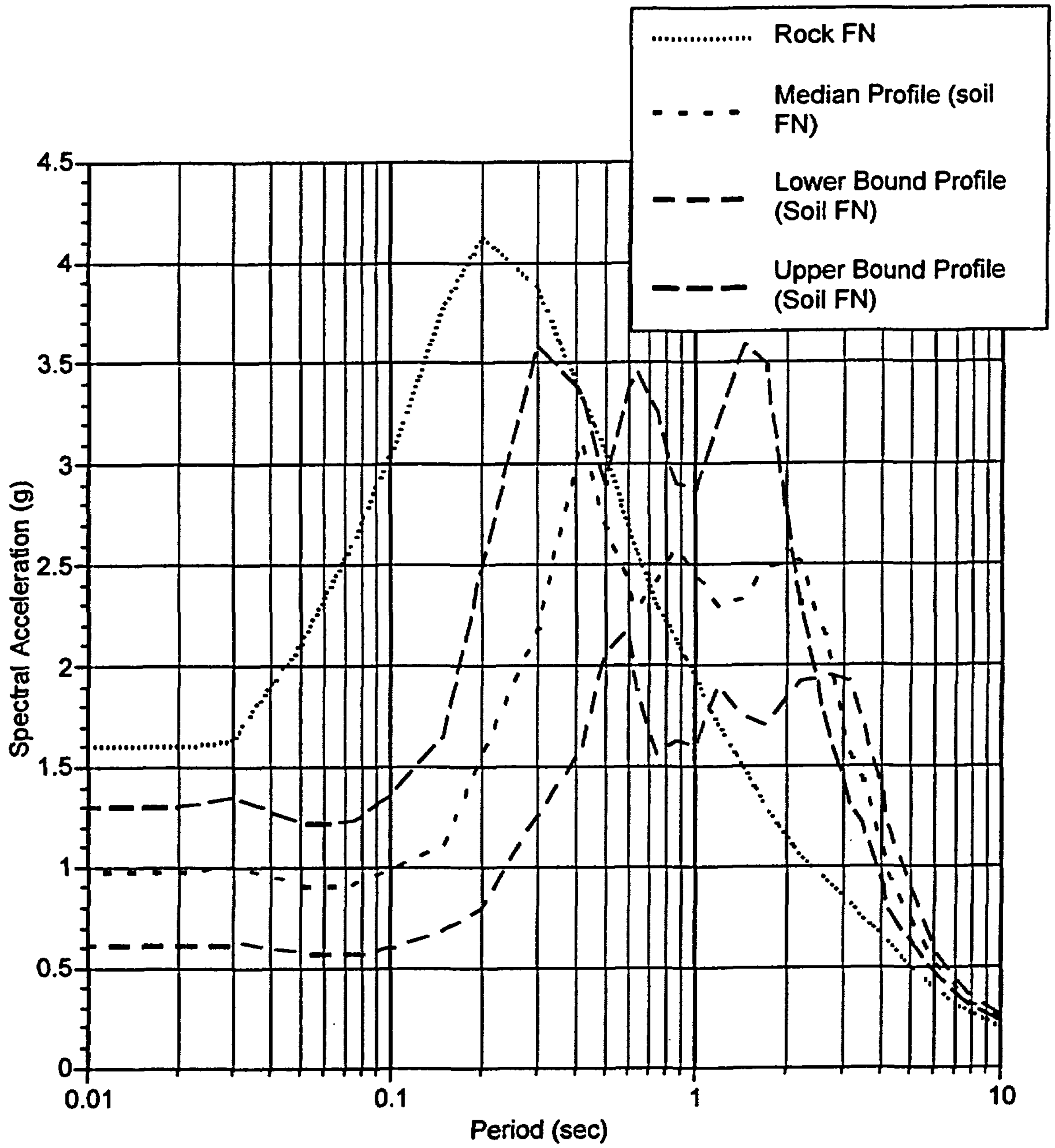

Figure 5. Comparison of the rock spectra and the soil spectra for the three profiles for the FN component for the synchronous rupture.

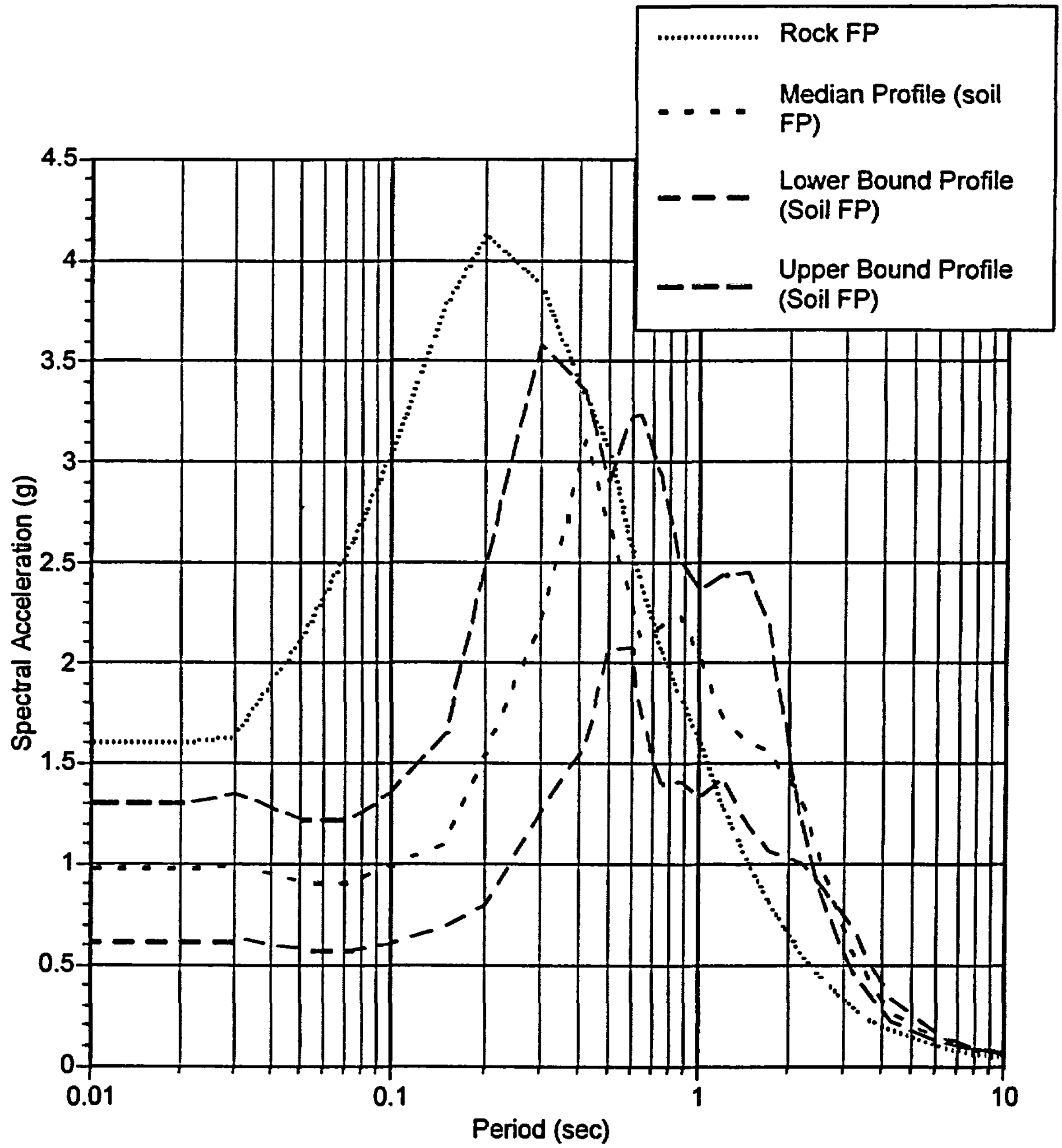

Figure 6. Comparison of the rock spectra and the soil spectra for the three profiles for the FP component for the synchronous rupture.

7.1.8 Step 8: Northridge High Frequency Spectrum and Corresponding Envelope Spectrum

The spectral shape from the Northridge recordings is used as a constraint on the high frequency portion of the site-specific soil spectra. This spectral shape (see Table 4-3) is scaled by the largest soil PGA value from the three soil profiles (first row of Column #4 in Tables 7-13, 7-14, and 7-15). The largest PGA is 1.316g from the upper bound profile (Table 7-15). The scaled spectral shape is listed in the last column (#3) in Table 7-16.

Table 7-16. Constraint on the high frequency spectrum from the Northridge spectral shape.

	#1	#2	#3
Period (sec)	Spectral Shape	Largest PGA (g)	High Frequency Constraint Sa(g)
0.000	1.000	1.316	1.316
0.020	1.000	1.316	1.316
0.030	1.016	1.316	1.337
0.050	1.095	1.316	1.441
0.075	1.225	1.316	1.612
0.100	1.384	1.316	1.821
0.150	1.690	1.316	2.224
0.200	1.911	1.316	2.515
0.300	2.368	1.316	3.116
0.500	1.980	1.316	2.606
0.750	2.049	1.316	2.696
1.000	1.682	1.316	2.214
1.500	1.036	1.316	1.363
2.000	0.765	1.316	1.007
3.000	0.451	1.316	0.594
4.000	0.208	1.316	0.274

For both the fault normal and fault parallel cases, the envelope of the following spectra was computed:

1. Soil spectrum based on the amplification factors from the median profile
2. Soil spectrum based on the amplification factors from the lower bound profile
3. Soil spectrum based on the amplification factors from the upper bound profile
4. The scaled spectral shape from Northridge.

For the fault normal case, the four spectra listed above are given in Table 7-17. The envelope of these four spectra is listed in column #5. The spectra are plotted in Figure 7.

For the fault parallel case, the four spectra listed above are given in Table 7-18. The envelope of these four spectra is listed in column #5. The spectra are plotted in Figure 8.

Table 7-17. Envelope acceleration response spectrum (5% spectral damping) for synchronous rupture for the fault normal component.

	#1	#2	#3	#4	#5
Period (sec)	Synchronous Soil Fault Normal (Median profile) (Table 7-13)	Synchronous Soil Fault Normal (Lower Bound profile) (Table 7-14)	Synchronous Soil Fault Normal (Upper Bound Profile) (Table 7-15)	High Frequency Constraint	Envelope Fault Normal
0.00	0.984	0.620	1.316	1.316	1.316
0.02	0.984	0.620	1.316	1.316	1.316
0.03	1.010	0.636	1.351	1.337	1.351
0.05	0.916	0.576	1.226	1.441	1.441
0.075	0.923	0.580	1.241	1.612	1.612
0.10	0.994	0.617	1.363	1.821	1.821
0.15	1.109	0.691	1.652	2.224	2.224
0.20	1.553	0.797	2.486	2.515	2.515
0.30	2.186	1.262	3.587	3.116	3.587
0.42	3.123	1.598	3.359		3.359
0.50	2.702	2.074	2.905	2.606	2.905
0.60	2.427	2.187	3.393		3.393
0.64	2.281	1.892	3.459		3.459
0.75	2.429	1.564	3.267	2.696	3.267
0.86	2.585	1.631	2.913		2.913
1.0	2.461	1.605	2.863	2.214	2.863
1.2	2.290	1.906	3.247		3.247
1.45	2.347	1.754	3.593		3.593
1.7	2.487	1.710	3.502		3.502
2.2	2.536	1.927	2.337		2.536
2.6	2.173	1.964	1.784		2.173
3.2	1.549	1.913	1.294		1.913
3.5	1.445	1.744	1.217		1.744
4.1	1.108	1.376	0.906		1.376
4.3	0.942	1.186	0.774		1.186
5.4	0.674	0.800	0.580		0.800
6.2	0.503	0.564	0.460		0.564
7.8	0.331	0.369	0.319		0.369
10.0	0.242	0.255	0.225		0.255

Table 7-18. Envelope acceleration response spectrum (5% spectral damping) for synchronous rupture for the fault parallel component.

	#1	#2	#3	#4	#5
Period (sec)	Synchronous Soil Fault Parallel (Median profile) (Table 7-13)	Synchronous Soil Fault Parallel (Lower Bound profile) (Table 7-14)	Synchronous Soil Fault Parallel (Upper Bound Profile) (Table 7-15)	Average High Frequency Spectra	Envelope Fault Parallel
0.000	0.984	0.620	1.316	1.316	1.316
0.020	0.984	0.620	1.316	1.316	1.316
0.030	1.010	0.636	1.351	1.337	1.351
0.050	0.916	0.576	1.226	1.441	1.441
0.075	0.923	0.580	1.241	1.612	1.612
0.100	0.994	0.617	1.363	1.821	1.821
0.150	1.109	0.691	1.652	2.224	2.224
0.200	1.553	0.797	2.486	2.515	2.515
0.300	2.186	1.262	3.587	3.116	3.587
0.420	3.123	1.598	3.359		3.359
0.500	2.702	2.074	2.905	2.606	2.905
0.600	2.314	2.085	3.234		3.234
0.640	2.138	1.773	3.242		3.242
0.750	2.184	1.406	2.937	2.696	2.937
0.860	2.238	1.412	2.522		2.522
1.000	2.043	1.332	2.377	2.214	2.377
1.200	1.729	1.439	2.452		2.452
1.450	1.606	1.200	2.458		2.458
1.700	1.562	1.074	2.199		2.199
2.200	1.329	1.010	1.225		1.329
2.600	0.969	0.876	0.796		0.969
3.200	0.566	0.698	0.472		0.698
3.500	0.483	0.583	0.407		0.583
4.100	0.323	0.402	0.265		0.402
4.300	0.272	0.342	0.223		0.342
5.400	0.186	0.221	0.160		0.221
6.200	0.138	0.155	0.126		0.155
7.800	0.090	0.101	0.087		0.101
10.000	0.065	0.069	0.061		0.069

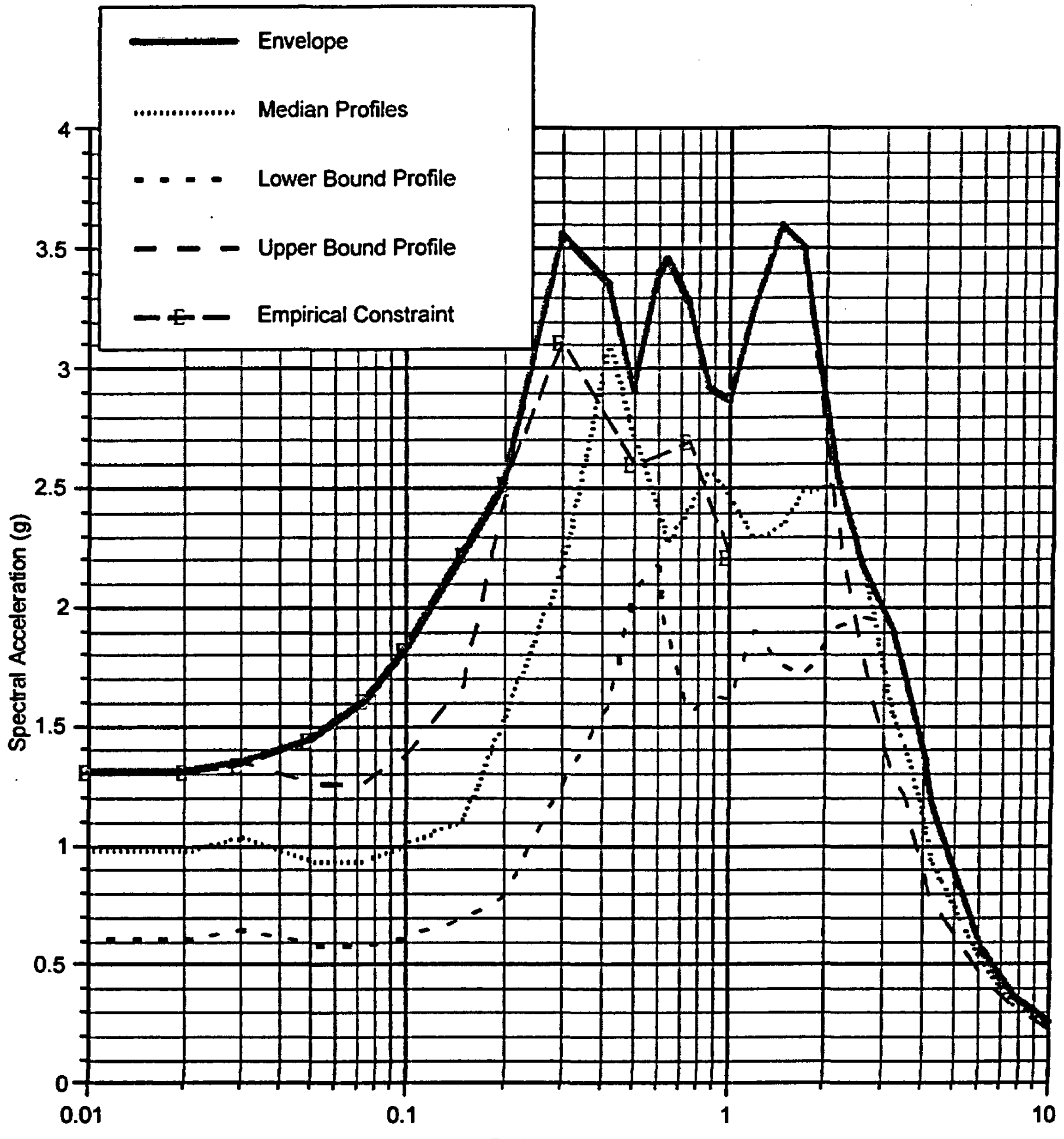

Figure 7. Development of the envelope for the soil spectrum for synchronous rupture for the FN component. (Table 7-17)

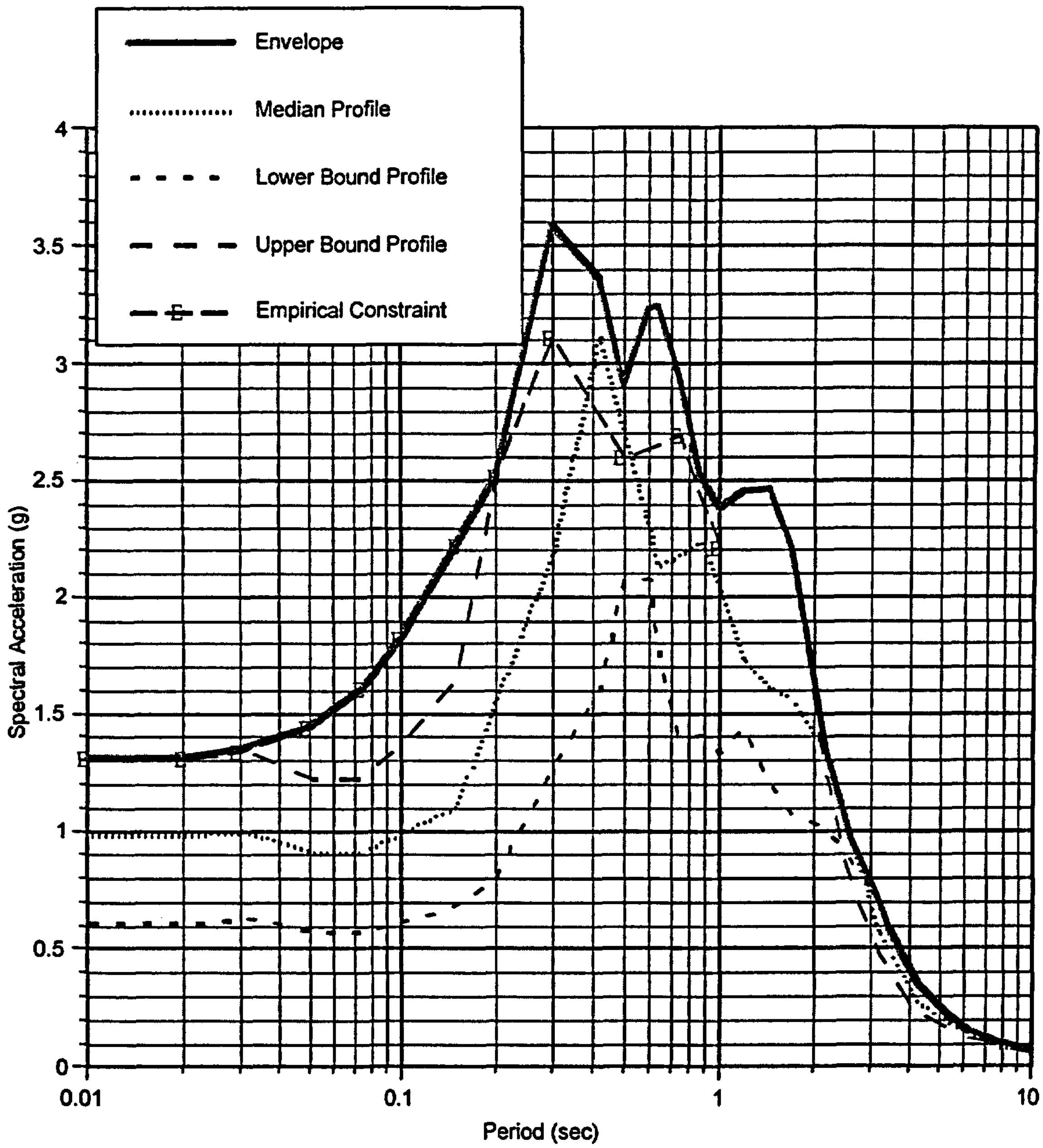

Figure 8. Development of the envelope for the soil spectrum for synchronous rupture for the FP component. (Table 7-18)

7.1.9 Step 9: Horizontal Design Spectra

The envelope spectra shown in Figures 7 and 8 (from Tables 7-17, 7-18) are smoothed to develop design spectra. This smoothing is to avoid peaks and troughs in the spectra. The smoothed spectra are shown in Figures 9 and 10. The values are listed in Table 7-19. For the design spectra, the periods are selected to be commonly used periods.

Table 7-19. Smoothed design spectra (5% damping) for the horizontal components on soil.

	Spectral Acc (g)	
Period (sec)	Fault Normal	Fault Parallel
0.000	1.316	1.316
0.020	1.316	1.316
0.030	1.351	1.351
0.050	1.441	1.441
0.075	1.612	1.612
0.100	1.821	1.821
0.150	2.224	2.224
0.200	2.515	2.515
0.300	3.600	3.587
0.640	3.600	3.242
0.750	3.600	3.100
1.000	3.600	2.800
1.500	3.600	2.460
1.700	3.502	2.199
2.000	3.000	1.800
2.400	2.400	1.200
3.000	2.050	0.800
4.000	1.500	0.450
5.000	1.000	0.270
7.000	0.460	0.130
10.000	0.255	0.069

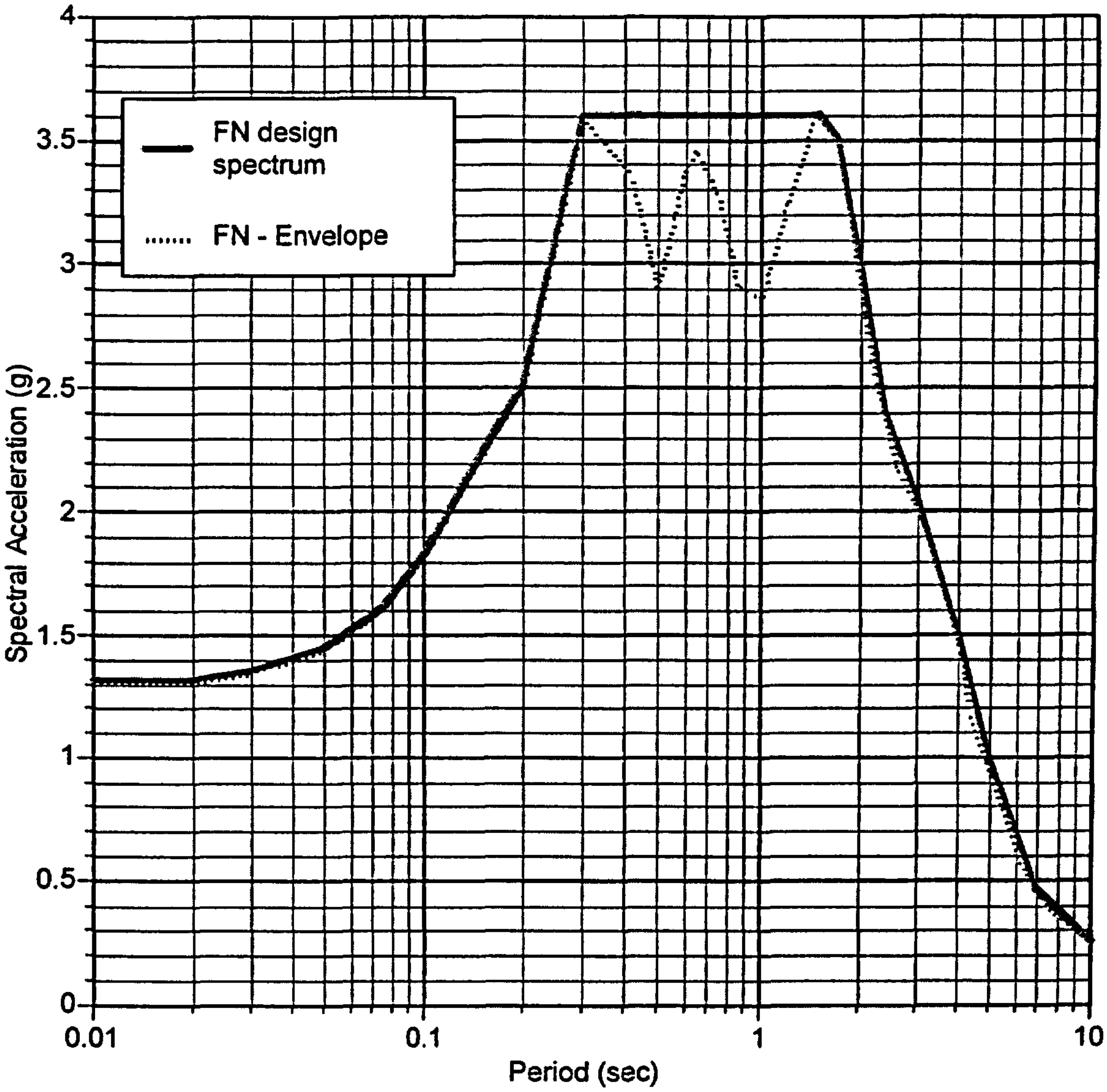

Figure 9. Design spectrum for synchronous rupture for the FN component. (Tables 7-17 and 7-19)

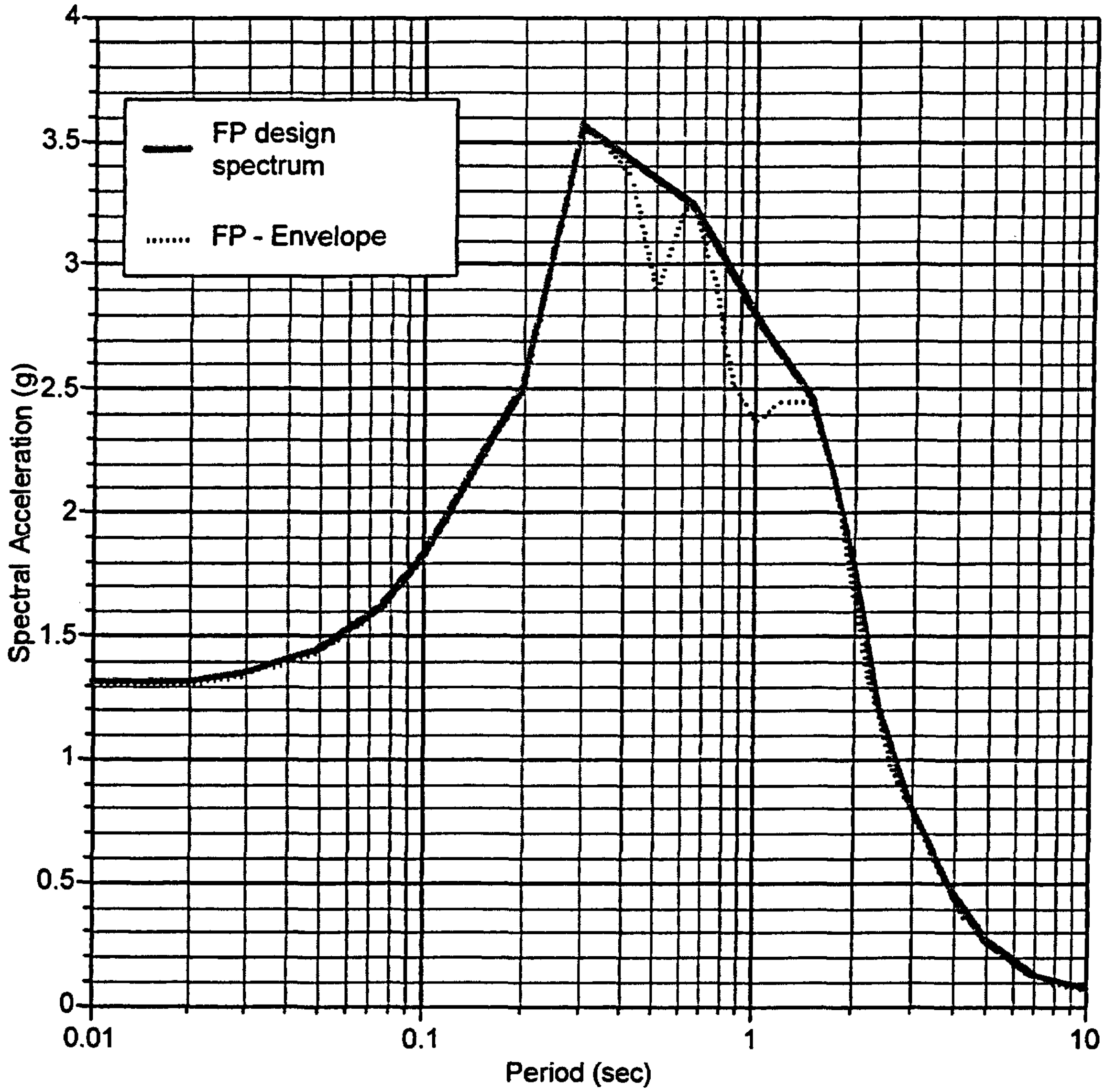

Figure 10. Design spectrum for synchronous rupture for the FP component. (Tables 7-18 and 7-19)

7.2 Vertical Spectra for the Synchronous Rupture

7.2.1 Step 1: 84th Percentile Vertical Spectra for Soil Sites for the LSF Subsource

The same input parameters (see Table 4-1) that were used to develop the horizontal acceleration response spectrum for the Little Salmon Fault subsource were used for the vertical component. From the inputs listed in Table 4-1:

$M = 7.7$
$R_{rup} = 0$
Mech = Reverse

For a reverse mechanism, F=1. The difference here is that the spectrum is computed for a soil site (S=1). Using these inputs, the vertical spectral acceleration based on the Abrahamson and Silva (1997) relation (assumption 3.2) is given in Table 7-20. In this table, the median spectral acceleration (column #1) is computed using equation (5-11) with the coefficients from Table 5-4 with M=7.7, R_{rup} =0 km, F=1, and S=1.

Equation (5-11) has the peak acceleration on rock (PGA_{rock}) as a parameter. Using Equation (5-10), the median PGA_{rock} is computed with the coefficients from Table 5-4 with M=7.7, R_{rup} =0 km, and F=1.

$PGA_{rock} = 0.857$ g

The standard deviation (column #2) is computed using equation (5-12) with coefficients from Table 5-4.

The 84th percentile spectral acceleration (column #3) is computed using equation (5-19) with the median spectral acceleration from column #1 and the standard deviation from column #2.

Table 7-20. 5% damped vertical spectral acceleration for the Little Salmon Fault using the Abrahamson and Silva (1997) relationship for deep soil site conditions.

	#1	#2	#3
Period (sec)	Median Spectral Acc (g)	Standard Deviation (Natural Log units)	84th Percentile Spectral Acc (g)
0.000	0.722	0.590	1.302
0.020	0.722	0.590	1.302
0.030	1.015	0.590	1.832
0.050	1.553	0.590	2.802
0.075	1.788	0.590	3.225
0.100	1.726	0.590	3.114
0.120	1.642	0.590	2.962
0.150	1.485	0.594	2.689
0.170	1.424	0.588	2.564
0.200	1.296	0.590	2.338
0.240	1.175	0.590	2.120
0.300	1.013	0.590	1.828
0.400	0.857	0.590	1.547
0.500	0.740	0.590	1.335
0.750	0.608	0.590	1.097
1.000	0.479	0.590	0.865
1.500	0.312	0.590	0.564
2.000	0.231	0.590	0.416
3.000	0.146	0.620	0.271
4.000	0.110	0.650	0.210
5.000	0.090	0.680	0.177

7.2.2 Step 2: Extrapolation from 5.0 seconds to 10 seconds for the LSF subsource

For periods greater than 5.0 seconds an extrapolation of the 84th percentile vertical acceleration response spectra was performed. The spectral velocities for the last 3 periods (3, 4, and 5 seconds) show a slight increase with period (see Figure 11 and discussion below). This trend is not expected to continue to longer periods. Therefore, spectrum was extrapolated to long periods by using a constant PSV for long periods.

The acceleration response spectrum given in Table 7-20 was converted to PSV (cm/sec) using equation (5-30). The resulting PSV values are listed in Table 7-21 (column #2). The PSV is plotted in Figure 11.This figure shows that the spectral velocity is approximately constant for periods greater than 2.0 seconds.

The geometric mean of the PSV values between the period range of 2.0 and 5.0 seconds was computed: 131.50 cm/s

The vertical spectrum is set to be equal to this constant PSV value for spectral periods of 2.0 and greater. This extended vertical PSV spectrum was then converted back to spectral acceleration based on equation (5-31) and the corresponding values are listed in Table 7-22 (column #2).

Table 7-21. Little Salmon fault vertical spectral acceleration and psuedo-spectral velocity response spectra.

	#1	#2
Period (sec)	84th Percentile Spectral Acc (g) (From Table 7-20)	84th Percentile Spectral PSV (cm/s)
0.000	1.302	2.032
0.020	1.302	4.063
0.030	1.832	8.576
0.050	2.802	21.862
0.075	3.225	37.750
0.100	3.114	48.594
0.120	2.962	55.467
0.150	2.689	62.944
0.170	2.564	68.024
0.200	2.338	72.979
0.240	2.120	79.414
0.300	1.828	85.574
0.400	1.547	96.548
0.500	1.335	104.153
0.750	1.097	128.354
1.000	0.865	134.974
1.500	0.564	131.934
2.000	0.416	129.821
3.000	0.271	126.829
4.000	0.210	131.324
5.000	0.177	138.301

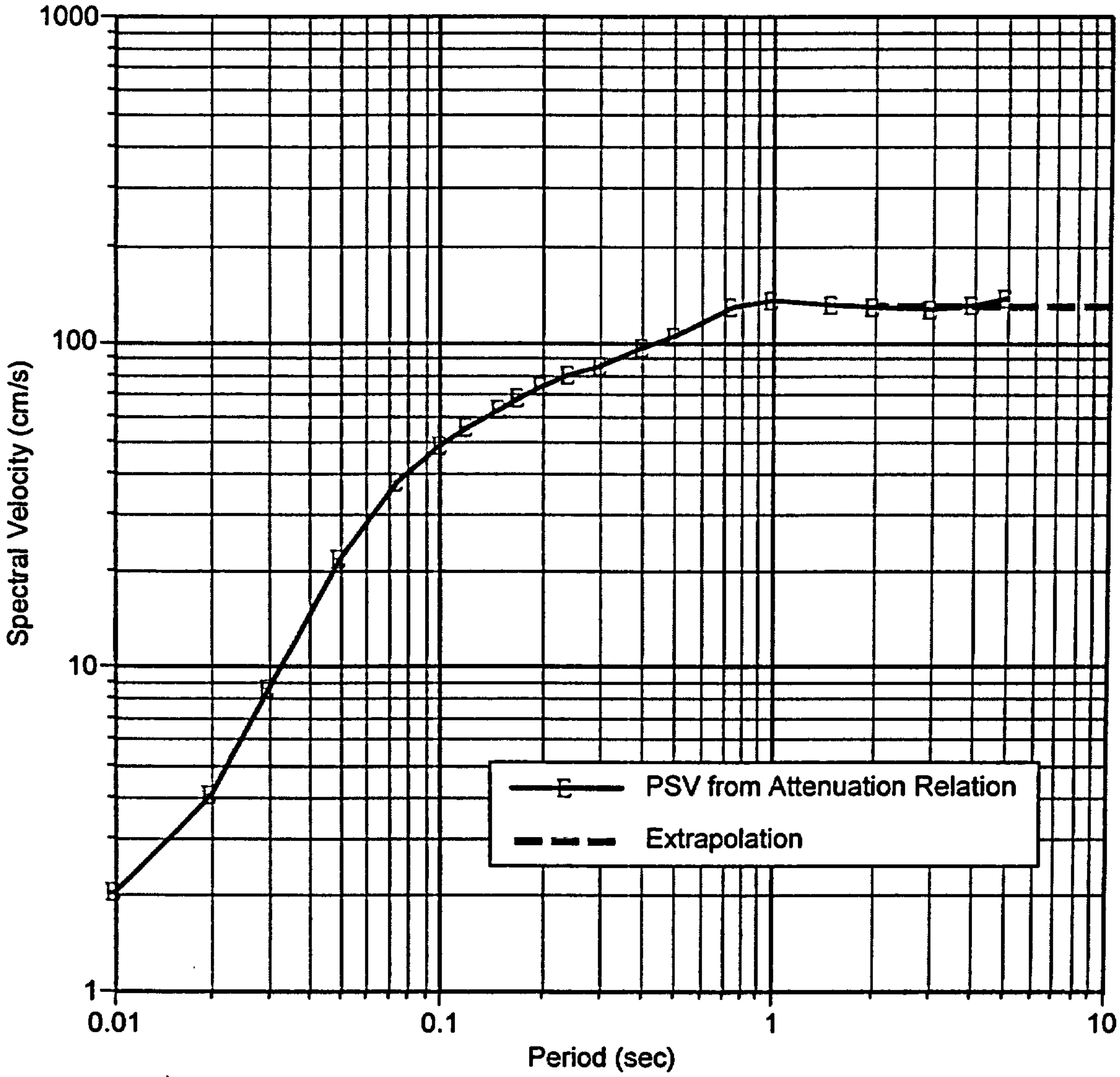

Figure 11. Extrapolation of the vertical spectrum for the LSF to long spectral periods.

Table 7-22. Extended vertical spectral acceleration and psuedo-spectral velocity response spectra for the Little Salmon fault.

	#1	#2	#3
Period (sec)	Extended 84th Percentile Spectral PSV (cm/s) (From Table 7-21)		Extended 84th Percentile Spectral Acc (g)
0.000	2.032		1.302
0.020	4.063		1.302
0.030	8.576		1.832
0.050	21.862		2.802
0.075	37.750		3.225
0.100	48.594		3.114
0.120	55.467		2.962
0.150	62.944		2.689
0.170	68.024		2.564
0.200	72.979		2.338
0.240	79.414		2.120
0.300	85.574		1.828
0.400	96.548		1.547
0.500	104.153		1.335
0.750	128.354		1.097
1.000	134.974		0.865
1.500	131.934		0.564
2.000	131.50	Constant PSV	0.421
3.000	131.50	Constant PSV	0.281
4.000	131.50	Constant PSV	0.211
5.000	131.50	Constant PSV	0.169
7.000	131.50	Constant PSV	0.120
10.000	131.50	Constant PSV	0.084

7.2.3 Step 3: Cascadia Interface Event Horizontal Soil Spectrum

The same input parameters used in the development of the horizontal rock spectrum (see 7.1.4) from the Cascadia interface event were used for the soil spectrum:

$M = 8.8$	(Table 4-2)
$R_{rup} = 7$ km	(Table 4-2)
$Z_T = 0$ (for interface sources)	(table 4-2)
$H = 20$ km	(Assumption 3-11)

The horizontal soil spectral acceleration computed using the Youngs et al (1997) attenuation relation and the input parameters given above are summarized in Table 7-23.

The median spectral acceleration values (column #1) are computed using eq. 5-28b with coefficients given in Table 5-9.
The standard deviation (column #2) is computed using equation (5-29) with coefficients given in Table 5-9.

The 84th percentile spectral acceleration (column #3) is computed using equation (5-19) with the median spectral acceleration from column #1 and the standard deviation from column #2.

Table 7-23. 5% damped horizontal spectral acceleration on soil for the Cascadia interface event using Youngs et al. (1997) attenuation model.

	#1	#2	#3
Period (sec)	Median Spectral Acc (g)	Standard Deviation (LN units)	84th Percentile Spectral Acc (g)
0.00	0.445	0.650	0.852
0.075	0.634	0.650	1.214
0.100	0.712	0.650	1.364
0.200	0.986	0.650	1.890
0.300	0.991	0.650	1.897
0.400	0.887	0.650	1.699
0.500	0.814	0.650	1.560
0.750	0.650	0.650	1.246
1.000	0.510	0.650	0.978
1.500	0.312	0.700	0.629
2.000	0.222	0.750	0.470
3.000	0.126	0.850	0.295
4.000	0.074	0.850	0.173

7.2.4 Step 4: V/H Ratio for the Cascadia Interface subsource

The Youngs et al (1997) attenuation relation for ground motion from subduction zone earthquakes does not include a model for the vertical component. The Abrahamson and Silva (1997) attenuation relation is used to estimate the V/H ratio that can then be applied to the horizontal spectrum for the Cascadia earthquake.

The inputs for the Cascadia event are:

M=8.8
R_{rup} = 7 km
Source type = interface

For computing the horizontal and vertical soil spectra using Abrahamson and Silva (1997), it is assumed that the following inputs will approximate the V/H ratio for the subduction events (assumption 3-12):

M = 8.0
R_{rup} = 7 km
Source type = strike-slip
S = 1 (soil)

The horizontal and vertical median response spectra for soil sites are computed using (eq. 5-11) with the above inputs. First, the PGA_{rock} is computed for the horizontal component using eq. 5-10 with coefficients from Table 5-3 and for the vertical component using eq. 5-10 with coefficients from Table 5-4. He resulting PGA_{rock} values are:

horizontal PGA_{rock} = 0.603g
vertical PGA_{rock} = 0.615g

For the horizontal component, the coefficients from Table 5-3 are used with eq. 5-11 and with the PGA_{rock} =0.603g, M = 8.0, R_{rup} = 7 km, Source type = strike-slip, and S = 1. The results are listed in column #1 of Table 7-24.

For the vertical component, the coefficients from Table 5-4 are used with eq. 5-11 and with the PGA_{rock} =0.615g, M = 8.0, R_{rup} = 7 km, Source type = strike-slip, and S = 1.. The results are listed in column #2 of Table 7-24.

The V/H ratio (column #3) is computed by dividing column #2 by column #1,

Table 7-24. Horizontal, vertical, and V/H ratio for a magnitude 8.0 strike-slip earthquake at a distance of 7 km from Abrahamson and Silva (1997).

	#1	#2	#3
Period (sec)	Median Horizontal Soil Spectra SA(g)	Median Vertical Soil Spectra SA (g)	V/H Spectral Ratio
0.000	0.442	0.545	1.233
0.020	0.442	0.545	1.233
0.030	0.442	0.746	1.688
0.075	0.549	1.285	2.341
0.100	0.643	1.240	1.928
0.200	1.019	0.858	0.842
0.300	1.119	0.604	0.540
0.400	1.113	0.483	0.434
0.500	1.081	0.396	0.366
0.750	0.976	0.300	0.307
1.000	0.838	0.239	0.285
1.500	0.638	0.173	0.271
2.000	0.470	0.138	0.294
3.000	0.277	0.096	0.347
4.000	0.179	0.073	0.408

7.2.5 Step 5: Cascadia Vertical Soil Spectrum

The V/H ratio (Table 7-24, column #3) was then use to scale the previously developed 84th percentile horizontal soil acceleration response spectrum for the Cascadia interface event (Table 7-23, column #3). The V/H spectral ratio, horizontal soil spectrum, and corresponding scaled vertical soil spectrum are listed in Table 7-25 in columns #1, #2, and #3, respectively..

Table 7-25. V/H spectral ratio, horizontal, and vertical soil spectrum for the Cascadia interface event.

	#1	#2	#3
Period (sec)	V/H Spectral Ratio (from Table 7-24)	84th Percentile Horizontal Spectra SA (g) (from Table 7-23)	84th Percentile Vertical Spectra SA (g)
0.000	1.233	0.852	1.051
0.020	1.233	0.852	1.051
0.030	1.688	0.852	1.438
0.075	2.341	1.214	2.842
0.100	1.928	1.364	2.630
0.200	0.842	1.890	1.591
0.300	0.540	1.897	1.024
0.400	0.434	1.699	0.737
0.500	0.366	1.560	0.571
0.750	0.307	1.246	0.383
1.000	0.285	0.978	0.279
1.500	0.271	0.629	0.171
2.000	0.294	0.470	0.138
3.000	0.347	0.295	0.102
4.000	0.408	0.173	0.071

7.2.6 Step 6: Extrapolation/Interpolation of the Cascadia Vertical Soil Spectrum

The vertical soil spectrum from table 7-25 (column #3) is extrapolated to 10 seconds period using eq. 5-20 (with T_1=3 sec and T_2=4 sec). The extrapolated values are listed in Table 7-26 (column #2).

The vertical soil spectrum from Table 7-25 are also interpolated to the same spectral periods used for the LSF vertical soil spectrum (Table 7-22) using eq. 5-20.

Table 7-26. Vertical soil spectrum for the Cascadia interface event.

	#1		#2
Period (sec)	84th Percentile Vertical Soil Spectra SA (g) (from Table 7-25)		84th Percentile Vertical Soil Spectra SA (g)
0.000	1.051		1.051
0.020	1.051		1.051
0.030	1.438		1.438
0.050		Interpolated	2.102
0.075	2.842		2.842
0.100	2.630		2.630
0.120		Interpolated	2.304
0.150		Interpolated	1.960
0.170		Interpolated	1.790
0.200	1.591		1.591
0.240		Interpolated	1.305
0.300	1.024		1.024
0.400	0.737		0.737
0.500	0.571		0.571
0.750	0.383		0.383
1.000	0.279		0.279
1.500	0.171		0.171
2.000	0.138		0.138
3.000	0.102		0.102
4.000	0.071		0.071
5.000		extrapolated	0.054
7.000		extrapolated	0.035
10.000		extrapolated	0.022

7.2.7 Step 7: Combined Synchronous Rupture Vertical Soil Spectra

The vertical soil spectra for the Little Salmon Fault (see column #3 of Table 7-22) and the Cascadia Interface event (see Table 7-26) are combine based on assumption 3.9 (i.e., SRSS).

The combined synchronous rupture vertical soil acceleration response spectrum is given in Table 7-27. The third column is the SRSS of the #1 and #2 columns. These spectra are plotted in Figure 12.

Figure 13 compares the vertical and horizontal spectra for 5% damping.

Table 7-27. Combined synchronous rupture vertical soil acceleration response spectrum.

	#1	#2	#3
Period (sec)	Little Salmon Fault Vertical Soil SA (g) (from Table 7-22)	Cascadia Interface Event, Vertical Soil SA(g) (from Table 7-26)	Synchronous Vertical Soil SA(g)
0.000	1.302	1.051	1.673
0.020	1.302	1.051	1.673
0.030	1.832	1.438	2.329
0.050	2.802	2.102	3.503
0.075	3.225	2.842	4.299
0.100	3.114	2.630	4.076
0.120	2.962	2.304	3.753
0.150	2.689	1.960	3.328
0.170	2.564	1.790	3.127
0.200	2.338	1.591	2.828
0.240	2.120	1.305	2.489
0.300	1.828	1.024	2.095
0.400	1.547	0.737	1.714
0.500	1.335	0.571	1.452
0.750	1.097	0.383	1.162
1.000	0.865	0.279	0.909
1.500	0.564	0.171	0.589
2.000	0.421	0.138	0.443
3.000	0.281	0.102	0.299
4.000	0.211	0.071	0.223
5.000	0.169	0.054	0.177
7.000	0.120	0.035	0.125
10.000	0.084	0.022	0.087

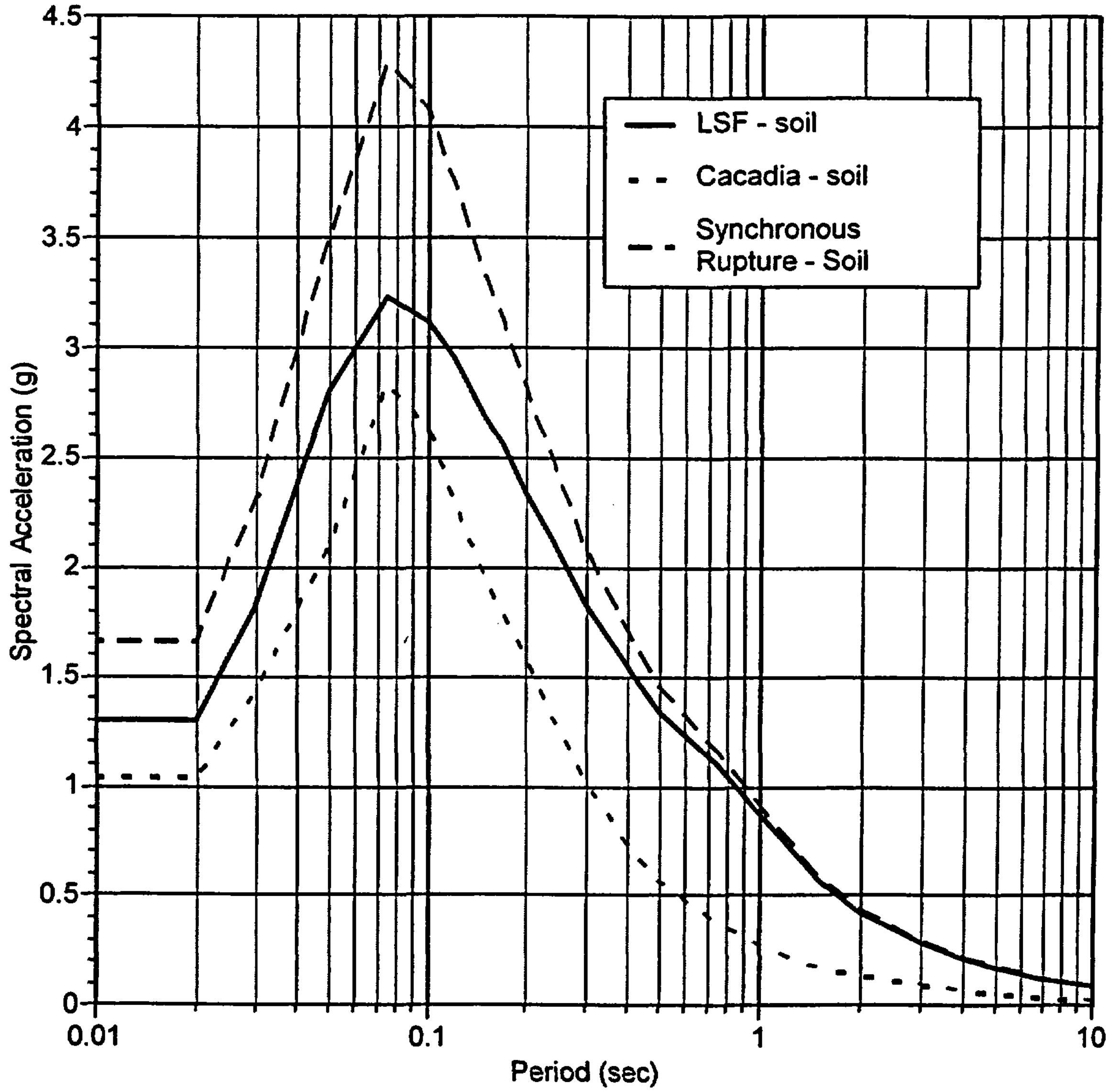

Figure 12. Vertical component spectra for the individual subsources and for synchronous rupture.

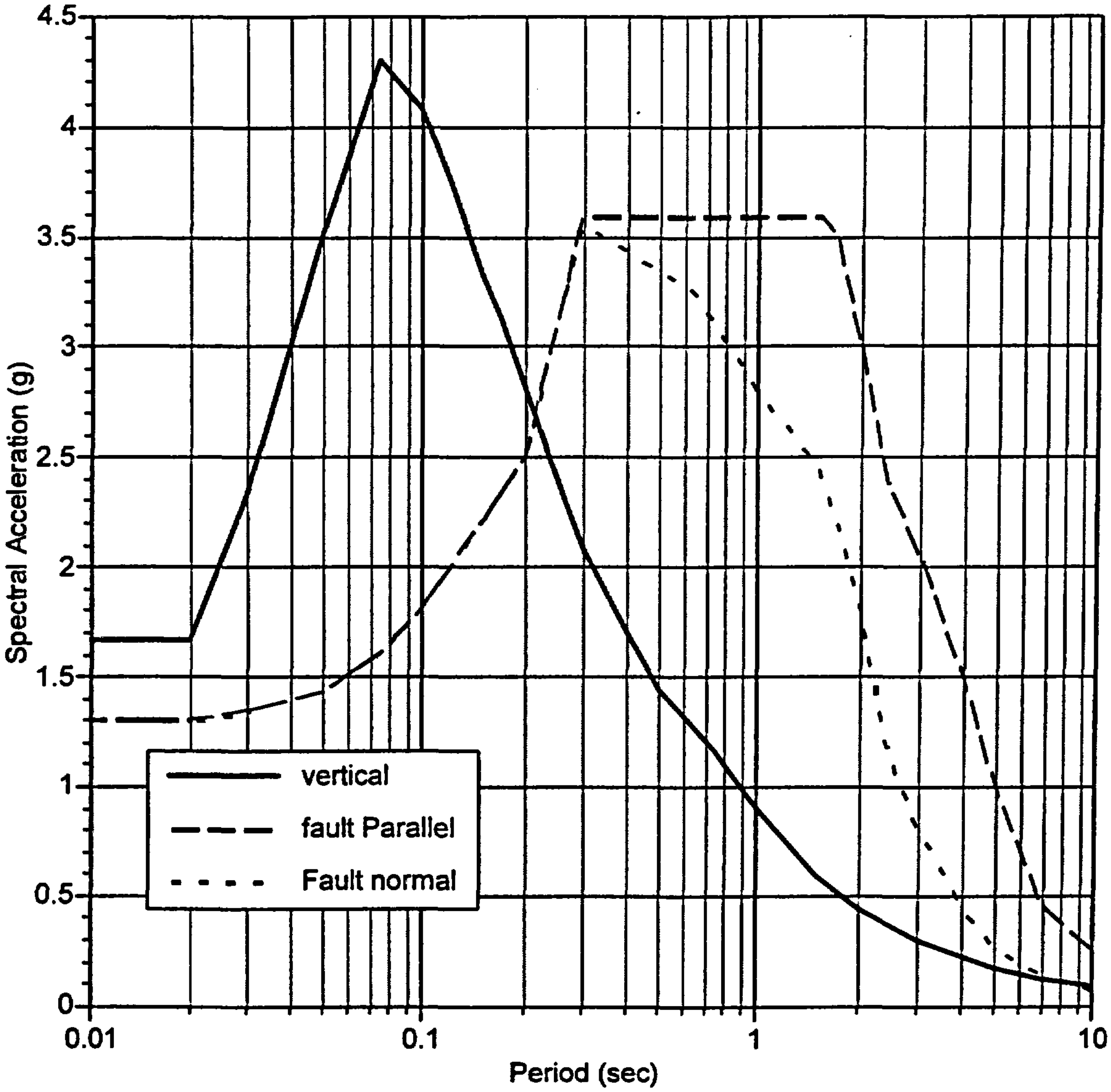

Figure 13. Comparison of the 5% damped soil spectra for the vertical, fault normal, and fault parallel components.

7.3 Spectra for Damping values other than 5%.

7.3.1 Step 1: Damping Scale Factors for the Horizontal Component

The natural logarithm of the scale factors for scaling the 5% damped horizontal to damping values of 2%, 3%, and 7% are computed using eq. (5-32) with coefficients from Tables 5-10a, 5-10b, and 5-10c. A magnitude of 8.0 is used (assumption 3-15). The resulting values are listed in columns #1, #2, and #3 of Table 7-28.

The arithmetic values of the scale factors are computed using eq. (5-33) with the values in Table 7-28, columns #1, #2, and #3 as the inputs. The resulting scale factors are listed in columns #1, #2, and #4 of Table 7-29.

For spectral periods of 1.7 and 2.4 seconds, the values are estimated by interpolation using eq. (5-20).

For spectral periods greater than 5.0 seconds, the damping ratio is held constant at the value for T=5 seconds (assumption 3-14).

7.3.2 Step 2: Damping Scale Factors for 4% damping

The coefficients for the Abrahamson and Silva (1996) damping scale factors for the horizontal component (Tables 5-10a, b, and c) are not given for 4% damping. Using assumption 3.13, the scale factor for 4% damping (Table 7-29, column #3) is computed by taking the square root of the scale factor at 3% damping (Table 7-29 column #2).

7.3.3 Step 3: Damping Scale Factors for the Vertical Component

The natural logarithm of the scale factors for scaling the 5% damped horizontal to damping values of 2%, 3%, and 7% are computed using eq. (5-32) with coefficients from Tables 5-11a, 5-11b, and 5-11c. A magnitude of 8.0 is used (assumption 3-15). The resulting values are listed in columns #1, #2, and #3 of Table 7-30.

The arithmetic values of the scale factors are computed using eq. (5-33) with the values in Table 7-30, columns #1, #2, and #3 as the inputs. The resulting scale factors are listed in columns #1, #2, and #4 of Table 7-31.

For spectral periods of 1.7 and 2.4 seconds, the values are estimated by interpolation using eq. (5-20).

For spectral periods greater than 5.0 seconds, the damping ratio is held constant at the value for T=5 seconds (assumption 3-14).

7.3.4 Step 4: Damping Scale Factors for 4% damping

The coefficients for the Abrahamson and Silva (1996) damping scale factors for the vertical component (Tables 5-11a, b, and c) are not given for 4% damping. Using assumption 3.13, the scale factor for 4% damping (Table 7-31, column #3) is computed by taking the square root of the scale factor at 3% damping (Table 7.31 column #2).

7.3.5 Step 5: Fault Normal Spectra for 2%, 4%, and 7% Damping

The fault normal spectral values at 2%, 4%, and 7% damping are computed using eq. (5-34) with the damping scale factors from Table 7-29 and the 5% damped fault normal spectrum (Table 7-19). The resulting fault normal spectral values are listed in Table 7-32.

7.3.6 Step 6: Fault Parallel Spectra for 2%, 4%, and 7% Damping

The fault parallel spectral values at 2%, 4%, and 7% damping are computed using eq. (5-34) with the damping scale factors from Table 7-29 and the 5% damped fault parallel spectrum (Table 7-19). The resulting fault normal spectral values are listed in Table 7-33.

7.3.6 Step 7: Vertical Spectra for 2%, 4%, and 7% Damping

The vertical spectral values at 2%, 4%, and 7% damping are computed using eq. (5-34) with the damping scale factors from Table 7-31 and the 5% damped fault parallel spectrum (Table 7-27, column #3). The resulting fault normal spectral values are listed in Table 7-34.

Table 7-28. Natural logarithm of the damping scaling factor for the horizontal component (relative to 5% damping)

	#1	#2	#3
Period (sec)	LN(2.0%/5%)	LN(3.0%/5%)	LN(7.0%/5%)
0.000	0.0000	0.0000	0.0000
0.020	0.0000	0.0000	0.0000
0.030	0.0462	0.0273	-0.0205
0.050	0.1094	0.0648	-0.0486
0.075	0.1580	0.0936	-0.0701
0.100	0.1922	0.1138	-0.0853
0.150	0.2284	0.1353	-0.1014
0.200	0.2379	0.1409	-0.1056
0.300	0.2379	0.1409	-0.1056
0.400	0.2379	0.1409	-0.1056
0.640	0.2379	0.1409	-0.1056
0.750	0.2379	0.1409	-0.1056
1.000	0.2394	0.1419	-0.1063
1.500	0.2380	0.1410	-0.1056
2.000	0.2339	0.1384	-0.1037
3.000	0.2236	0.1324	-0.0991
4.000	0.2127	0.1258	-0.0945
5.000	0.2022	0.1198	-0.0897

Table 7-29. Damping scaling factor for the horizontal component (relative to 5% damping)

	#1	#2	#3	#4
Period (sec)	2.0%/5%	3.0%/5%	4%/5%*	7.0%/5%
0.000	1.000	1.000	1.000	1.000
0.020	1.000	1.000	1.000	1.000
0.030	1.047	1.028	1.014	0.980
0.050	1.116	1.067	1.033	0.953
0.075	1.171	1.098	1.048	0.932
0.100	1.212	1.121	1.059	0.918
0.150	1.257	1.145	1.070	0.904
0.200	1.269	1.151	1.073	0.900
0.300	1.269	1.151	1.073	0.900
0.400	1.269	1.151	1.073	0.900
0.640	1.269	1.151	1.073	0.900
0.750	1.269	1.151	1.073	0.900
1.000	1.271	1.153	1.074	0.899
1.500	1.269	1.152	1.073	0.900
1.700	1.267**	1.151**	1.073**	0.900**
2.000	1.264	1.149	1.072	0.901
2.400	1.258**	1.146**	1.071**	0.903**
3.000	1.251	1.142	1.069	0.905
4.000	1.238	1.134	1.065	0.910
5.000	1.225	1.128	1.062	0.914
7.000	1.225	1.128	1.062	0.914
10.000	1.225	1.128	1.062	0.914

* The 4%/5% damping ratios are estimated as the sqrt(3%/5%) values.

** Interpolated using eq. 5-20

Table 7-30. Natural Logarithm of damping scaling factor for the vertical component (relative to 5% damping)

	#1	#2	#3
Period (sec)	LN(2.0%/5%)	LN(3.0%/5%)	LN(7.0%/5%)
0.000	0.0000	0.0000	0.0000
0.020	0.0000	0.0000	0.0000
0.030	0.1232	0.0725	-0.0528
0.050	0.2072	0.1220	-0.0888
0.075	0.2488	0.1464	-0.1067
0.100	0.2818	0.1658	-0.1208
0.120	0.2890	0.1701	-0.1239
0.150	0.2932	0.1726	-0.1257
0.170	0.2910	0.1713	-0.1247
0.200	0.2839	0.1671	-0.1217
0.240	0.2776	0.1634	-0.1190
0.300	0.2727	0.1605	-0.1169
0.400	0.2727	0.1605	-0.1169
0.500	0.2727	0.1605	-0.1169
0.750	0.2727	0.1605	-0.1169
1.000	0.2742	0.1614	-0.1176
1.500	0.2717	0.1599	-0.1165
2.000	0.2663	0.1567	-0.1142
3.000	0.2527	0.1487	-0.1083
4.000	0.2386	0.1405	-0.1023
5.000	0.2254	0.1326	-0.0965

Table 7-31. Damping scaling factor for the vertical component (relative to 5% damping)

	#1	#2	#3	#4
Period (sec)	2.0%/5%	3.0%/5%	4%/5%*	7.0%/5%
0.000	1.000	1.000	1.000	1.000
0.020	1.000	1.000	1.000	1.000
0.030	1.131	1.075	1.037	0.949
0.050	1.230	1.130	1.063	0.915
0.075	1.282	1.158	1.076	0.899
0.100	1.326	1.180	1.086	0.886
0.120	1.335	1.185	1.089	0.883
0.150	1.341	1.188	1.090	0.882
0.170	1.338	1.187	1.089	0.883
0.200	1.328	1.182	1.087	0.885
0.240	1.320	1.178	1.085	0.888
0.300	1.314	1.174	1.084	0.890
0.400	1.314	1.174	1.084	0.890
0.500	1.314	1.174	1.084	0.890
0.750	1.314	1.174	1.084	0.890
1.000	1.315	1.175	1.084	0.889
1.500	1.312	1.173	1.083	0.890
2.000	1.305	1.170	1.082	0.892
3.000	1.287	1.160	1.077	0.897
4.000	1.269	1.151	1.073	0.903
5.000	1.253	1.142	1.069	0.908
7.000	1.253	1.142	1.069	0.908
10.000	1.253	1.142	1.069	0.908

* The 4%/5% damping ratios are estimated as the sqrt(3%/5%) values.

The horizontal component scale factors for damping values of 2%, 4%, and 7% from Table 7-29 are listed in columns #2, #3, and #4 of Table 7-32. These values are multiplied by the fault normal spectrum at 5% damping (column #1 in Table 7-32) to computed the fault normal spectra for 2%, 4%, and 7% damping (columns #5, #6, and #7 in Table 7-32).

Table 7-32. Spectral values for the damping values of 2%, 4%, and 7% for the fault normal component.

	#1	#2	#3	#4	#5	#6	#7
Period (sec)	Fault Normal 5% damp Sa(g) (from Table 7-19)	2.0%/5% scale factor (from Table 7-29)	4.0%/5% scale factor (from Table 7-29)	7.0%/5% scale factor (from Table 7-29)	Fault Normal 2% damp Sa(g)	Fault Normal 4% damp Sa(g)	Fault Normal 7% damp Sa(g)
0.000	1.316	1.000	1.000	1.000	1.316	1.316	1.316
0.020	1.316	1.000	1.000	1.000	1.316	1.316	1.316
0.030	1.351	1.047	1.014	0.980	1.415	1.370	1.324
0.050	1.441	1.116	1.033	0.953	1.608	1.489	1.373
0.075	1.612	1.171	1.048	0.932	1.888	1.689	1.502
0.100	1.821	1.212	1.059	0.918	2.207	1.928	1.672
0.150	2.224	1.257	1.070	0.904	2.796	2.380	2.010
0.200	2.515	1.269	1.073	0.900	3.192	2.699	2.264
0.300	3.600	1.269	1.073	0.900	4.568	3.863	3.240
0.640	3.600	1.269	1.073	0.900	4.568	3.863	3.240
0.750	3.600	1.269	1.073	0.900	4.568	3.863	3.240
1.000	3.600	1.271	1.074	0.899	4.576	3.866	3.236
1.500	3.600	1.269	1.073	0.900	4.568	3.863	3.240
1.700	3.502	1.267	1.073	0.900	4.434	3.754	3.152
2.000	3.000	1.264	1.072	0.901	3.792	3.216	2.703
2.400	2.400	1.258	1.071	0.903	3.020	2.570	2.167
3.000	2.050	1.251	1.069	0.905	2.565	2.191	1.855
4.000	1.500	1.238	1.065	0.910	1.857	1.598	1.365
5.000	1.000	1.225	1.062	0.914	1.225	1.062	0.914
7.000	0.460	1.225	1.062	0.914	0.564	0.489	0.420
10.000	0.255	1.225	1.062	0.914	0.312	0.271	0.233

The horizontal component scale factors for damping values of 2%, 4%, and 7% from Table 7-29 are listed in columns #2, #3, and #4 of Table 7-33. These values are multiplied by the fault parallel spectrum at 5% damping (column #1 in Table 7-33) to computed the fault parallel spectra for 2%, 4%, and 7% damping (columns #5, #6, and #7 in Table 7-33).

Table 7-33. Spectral values for the damping values of 2%, 4%, and 7% for the fault parallel component.

	#1	#2	#3	#4	#5	#6	#7
Period (sec)	Fault Parallel 5% damp Sa(g) (from Table 7-19)	2.0%/5% scale factor (from Table 7-29)	4.0%/5% scale factor (from Table 7-29)	7.0%/5% scale factor (from Table 7-29)	Fault Parallel 2% damp Sa(g)	Fault Parallel 4% damp Sa(g)	Fault Parallel 7% damp Sa(g)
0.000	1.316	1.000	1.000	1.000	1.316	1.316	1.316
0.020	1.316	1.000	1.000	1.000	1.316	1.316	1.316
0.030	1.351	1.047	1.014	0.980	1.415	1.370	1.324
0.050	1.441	1.116	1.033	0.953	1.608	1.489	1.373
0.075	1.612	1.171	1.048	0.932	1.888	1.689	1.502
0.100	1.821	1.212	1.059	0.918	2.207	1.928	1.672
0.150	2.224	1.257	1.070	0.904	2.796	2.380	2.010
0.200	2.515	1.269	1.073	0.900	3.192	2.699	2.264
0.300	3.587	1.269	1.073	0.900	4.552	3.849	3.228
0.640	3.242	1.269	1.073	0.900	4.114	3.479	2.918
0.750	3.100	1.269	1.073	0.900	3.934	3.326	2.790
1.000	2.800	1.271	1.074	0.899	3.559	3.007	2.517
1.500	2.460	1.269	1.073	0.900	3.122	2.640	2.214
1.700	2.199	1.267	1.073	0.90	2.784	2.357	1.979
2.000	1.800	1.264	1.072	0.901	2.275	1.930	1.622
2.400	1.200	1.258	1.071	0.903	1.510	1.285	1.083
3.000	0.800	1.251	1.069	0.905	1.001	0.855	0.724
4.000	0.450	1.238	1.065	0.910	0.557	0.479	0.410
5.000	0.270	1.225	1.062	0.914	0.331	0.287	0.247
7.000	0.130	1.225	1.062	0.914	0.159	0.138	0.119
10.000	0.069	1.225	1.062	0.914	0.084	0.073	0.063

The vertical component scale factors for damping values of 2%, 4%, and 7% from Table 7-31 are listed in columns #2, #3, and #4 of Table 7-34. These values are multiplied by the vertical spectrum at 5% damping (column #1 in Table 7-34) to computed the vertical spectra for 2%, 4%, and 7% damping (columns #5, #6, and #7 in Table 7-34).

Table 7-34. Spectral values for the damping values of 2%, 4%, and 7% for the vertical component.

	#1	#2	#3	#4	#5	#6	#7
Period (sec)	Vertical 5% damp Sa(g) (from Table 7-27)	2.0%/5% scale factor (from Table 7-31)	4.0%/5% scale factor (from Table 7-31)	7.0%/5% scale factor (from Table 7-31)	Vertical 2% damp Sa(g)	Vertical 4% damp Sa(g)	Vertical 7% damp Sa(g)
0.000	1.673	1.000	1.000	1.000	1.673	1.673	1.673
0.020	1.673	1.000	1.000	1.000	1.673	1.673	1.673
0.030	2.329	1.131	1.037	0.949	2.634	2.415	2.209
0.050	3.503	1.230	1.063	0.915	4.309	3.724	3.205
0.075	4.299	1.282	1.076	0.899	5.513	4.625	3.864
0.100	4.076	1.326	1.086	0.886	5.403	4.428	3.612
0.120	3.753	1.335	1.089	0.883	5.011	4.086	3.316
0.150	3.328	1.341	1.090	0.882	4.462	3.628	2.935
0.170	3.127	1.338	1.089	0.883	4.183	3.407	2.760
0.200	2.828	1.328	1.087	0.885	3.756	3.074	2.504
0.240	2.489	1.320	1.085	0.888	3.285	2.701	2.210
0.300	2.095	1.314	1.084	0.890	2.752	2.270	1.864
0.400	1.714	1.314	1.084	0.890	2.251	1.857	1.525
0.500	1.452	1.314	1.084	0.890	1.907	1.573	1.292
0.750	1.162	1.314	1.084	0.890	1.526	1.259	1.034
1.000	0.909	1.315	1.084	0.889	1.196	0.985	0.808
1.500	0.589	1.312	1.083	0.890	0.773	0.638	0.524
2.000	0.443	1.305	1.082	0.892	0.578	0.479	0.395
3.000	0.299	1.287	1.077	0.897	0.385	0.322	0.268
4.000	0.223	1.269	1.073	0.903	0.283	0.239	0.201
5.000	0.177	1.253	1.069	0.908	0.222	0.189	0.161
7.000	0.125	1.253	1.069	0.908	0.157	0.134	0.114
10.000	0.087	1.253	1.069	0.908	0.109	0.093	0.079

The response spectra at damping values of 2%, 4%, 5%, and 7% are plotted for the fault normal, fault parallel, and vertical components in Figures 14, 15, and 16, respectively.

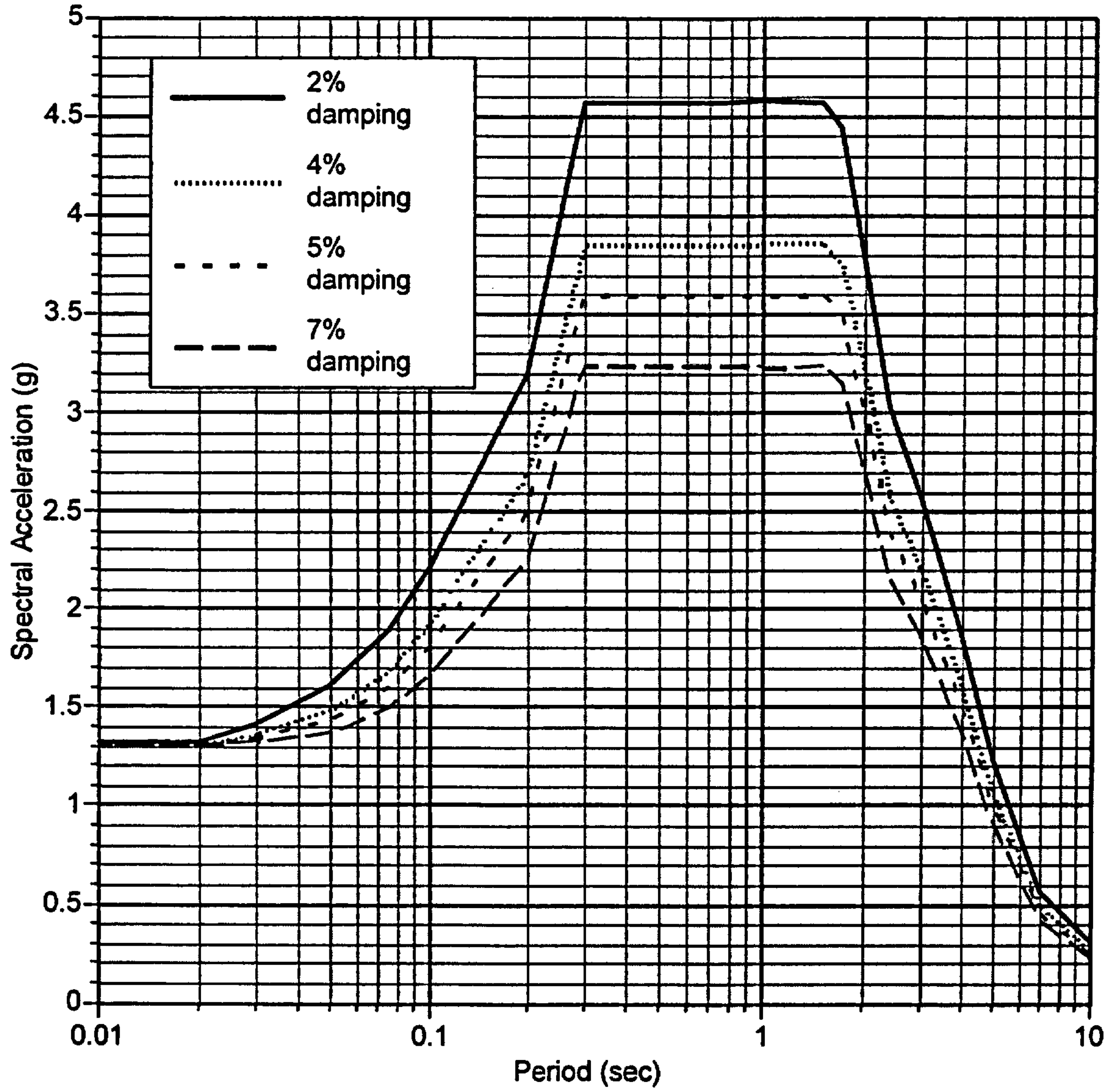

Figure 14. Fault normal design spectrum for damping values of 2%, 4%, 5%, and 7%. (Table 7-32)

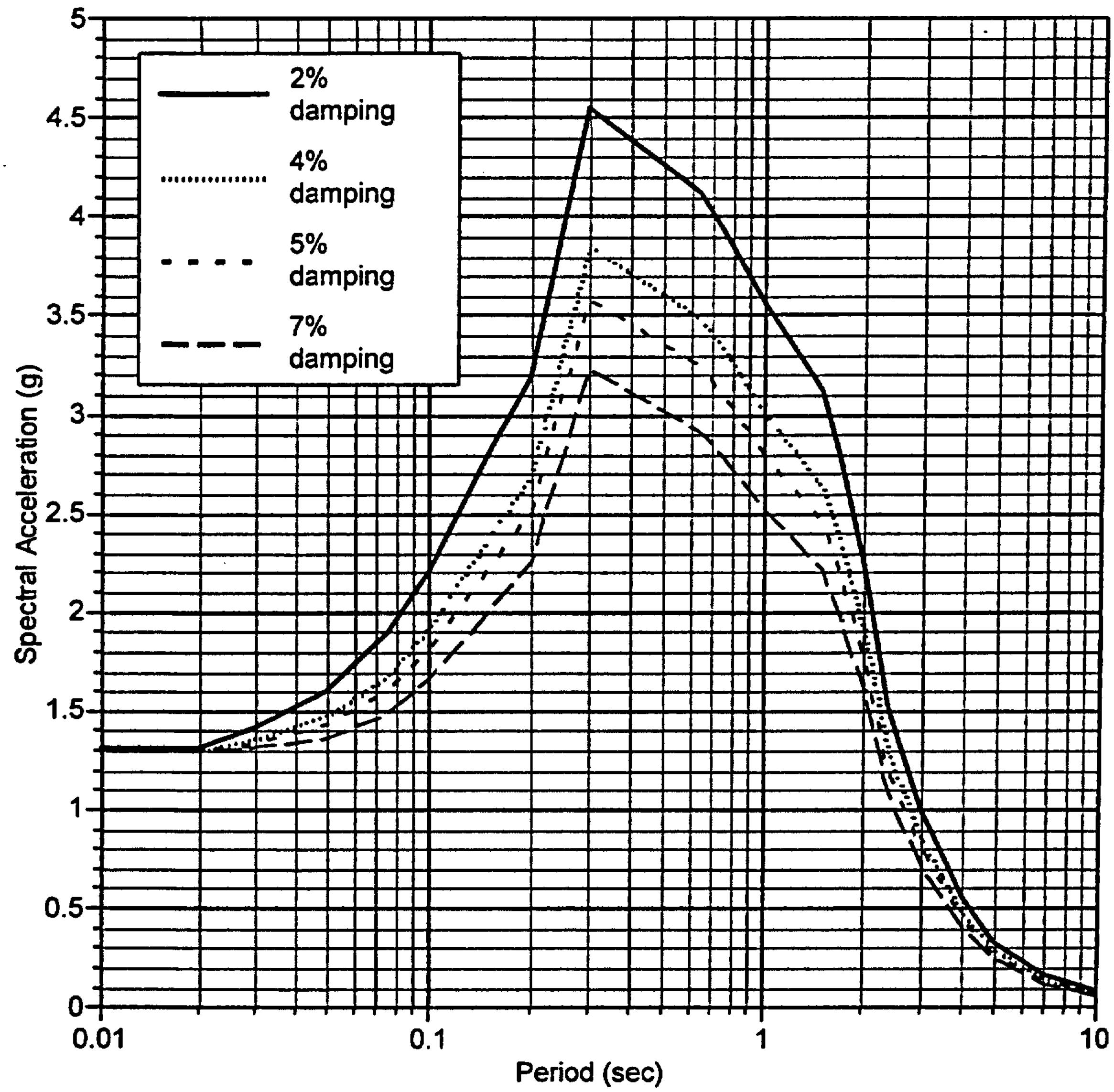

Figure 15. Fault parallel design spectrum for damping values of 2%, 4%, 5%, and 7%. (Table 7-33)

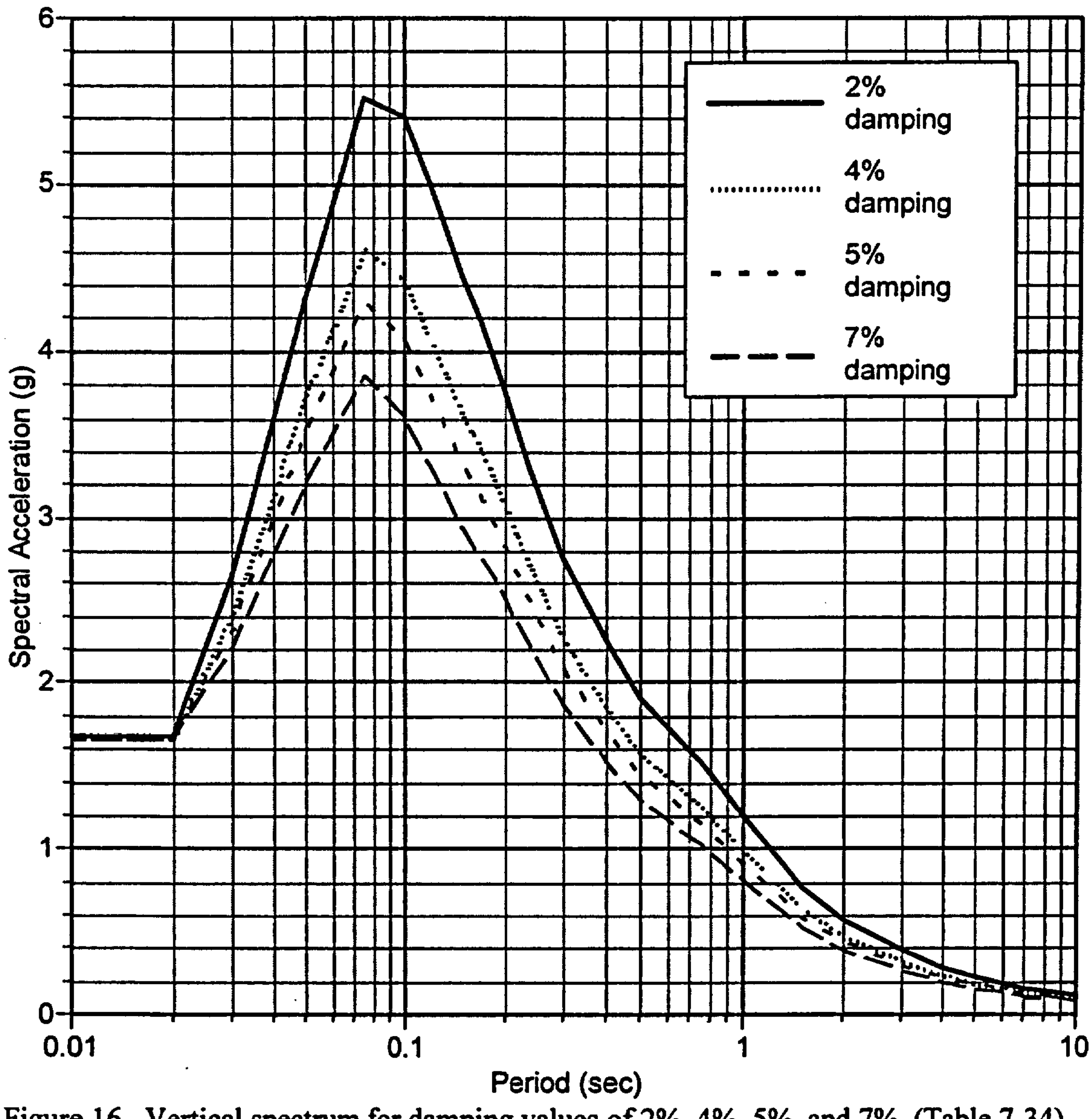

Figure 16. Vertical spectrum for damping values of 2%, 4%, 5%, and 7%. (Table 7-34)

8 RESULTS

The horizontal and vertical deterministic design response for the MCE at 2%, 4%, 5%, and 7% damping are listed in Tables 8-1, 8-2, and 8-3 for the fault normal, fault parallel, and vertical components, respectively.

Table 8-1. 84th percentile MCE design spectra for the Fault Normal Component (from Table 7-32)

Period (sec)	2% damping	4% damping	5% damping	7% damping
0.000	1.316	1.316	1.316	1.316
0.020	1.316	1.316	1.316	1.316
0.030	1.415	1.370	1.351	1.324
0.050	1.608	1.489	1.441	1.373
0.075	1.888	1.689	1.612	1.502
0.100	2.207	1.928	1.821	1.672
0.150	2.796	2.380	2.224	2.010
0.200	3.192	2.699	2.515	2.264
0.300	4.568	3.863	3.600	3.240
0.640	4.568	3.863	3.600	3.240
0.750	4.568	3.863	3.600	3.240
1.000	4.576	3.866	3.600	3.236
1.500	4.568	3.863	3.600	3.240
1.700	4.434	3.754	3.502	3.152
2.000	3.792	3.216	3.000	2.703
2.400	3.020	2.570	2.400	2.167
3.000	2.565	2.191	2.050	1.855
4.000	1.857	1.598	1.500	1.365
5.000	1.225	1.062	1.000	0.914
7.000	0.564	0.489	0.460	0.420
10.000	0.312	0.271	0.255	0.233

Table 8-2. 84th percentile MCE design spectra for the Fault Parallel Component (from Table 7-33)

Period (sec)	2% damping	4% damping	5% damping	7% damping
0.000	1.316	1.316	1.316	1.316
0.020	1.316	1.316	1.316	1.316
0.030	1.415	1.370	1.351	1.324
0.050	1.608	1.489	1.441	1.373
0.075	1.888	1.689	1.612	1.502
0.100	2.207	1.928	1.821	1.672
0.150	2.796	2.380	2.224	2.010
0.200	3.192	2.699	2.515	2.264
0.300	4.552	3.849	3.587	3.228
0.640	4.114	3.479	3.242	2.918
0.750	3.934	3.326	3.100	2.790
1.000	3.559	3.007	2.800	2.517
1.500	3.122	2.640	2.460	2.214
1.700	2.784	2.357	2.199	1.979
2.000	2.275	1.930	1.800	1.622
2.400	1.510	1.285	1.200	1.083
3.000	1.001	0.855	0.800	0.724
4.000	0.557	0.479	0.450	0.410
5.000	0.331	0.287	0.270	0.247
7.000	0.159	0.138	0.130	0.119
10.000	0.085	0.073	0.069	0.063

Table 8-3. 84th percentile MCE design spectra for the Vertical Component (From Table 7-34)

Period (sec)	2% damping	4% damping	5% damping	7% damping
0.000	1.673	1.673	1.673	1.673
0.020	1.673	1.673	1.673	1.673
0.030	2.634	2.415	2.329	2.209
0.050	4.309	3.724	3.503	3.205
0.075	5.513	4.625	4.299	3.864
0.100	5.403	4.428	4.076	3.612
0.120	5.011	4.086	3.753	3.316
0.150	4.462	3.628	3.328	2.935
0.170	4.183	3.407	3.127	2.760
0.200	3.756	3.074	2.828	2.504
0.240	3.285	2.701	2.489	2.210
0.300	2.752	2.270	2.095	1.864
0.400	2.251	1.857	1.714	1.525
0.500	1.907	1.573	1.452	1.292
0.750	1.526	1.259	1.162	1.034
1.000	1.196	0.985	0.909	0.808
1.500	0.773	0.638	0.589	0.524
2.000	0.578	0.479	0.443	0.395
3.000	0.385	0.322	0.299	0.268
4.000	0.283	0.239	0.223	0.201
5.000	0.222	0.189	0.177	0.161
7.000	0.157	0.134	0.125	0.114
10.000	0.109	0.093	0.087	0.079

9. CONCLUSIONS

The response spectral values given in section 8 represent the surface design response spectra for the HBIP, consistent with the specification in the Work Plan.

Limitations: Since the design spectra are based on an envelope of the response of three soil profiles and the empirical spectral shape (from Northridge), there is no single defined soil velocity model that is consistent with this spectrum. Subsequent engineering analysis should not associate a single soil profile to these design spectra. Doing so could result in unrealistic ground motion estimates at depth.

10. REFERENCES

Abrahamson, N. A. and W. J. Silva (1996). Empirical Ground Motion Models, Appendix A in Silva et al (1997).

Abrahamson, N. A. and W. J. Silva (1997). Empirical response spectral attenuation relations for shallow crustal earthquakes, Seism. Res. Let., vol. 68, 94-127.

Boore D. M., W. Joyner, and T. Fumal (1997). Equations for estimating horizontal response spectra and peak acceleration from western North America earthquakes: a summary of recent work, Seism. Res. Let., 68, pp128-153.

Campbell (1997). Empirical near-source attenuation relationships for horizontal and vertical components of peak ground acceleration, peak ground velocity, and pseudo absolute accelerations response spectra, Seism. Res. Let., 68, 154-179.

Hudson, D. E. (1979) reading and interpreting strong motion accelerograms, Earthquake Engineering Research Institute, Monograph.

Idriss, I. M. (1995). An overview of earthquake ground motions pertinent to seismic zonation, Proc. Fifth International Conference on Seismic Zonation, vol. III, 2111-2126.

Idriss, I. M. (1994). Updated standard error terms, Memo to Phalkun Tan, April 17, 1994.

Idirss, I. M. (1992). Empirical procedures for estimating earthquake ground motions, Proc. SEAOC conference, October 15, 1992.

Idriss. I. M. (1991). Selection of earthquake ground motions at rock sites, report prepared for the Structures Division, Building and Fire Research Laboratory, National Institute of Standard and Technology, Department of Civil Engineering, University of California, Davis.

Sadigh K., C.Y. Chang, N. A. Abrahamson, S. . Chiou, and M. S. Power., (1993). Specification of long period ground motions: updated attenuation relationships for rock site conditions, Proc. ATC 17-1, Volume 1, 59-70.

Sadigh, K., C. Y. Chang, J.A. Egan, F. Makdisi, and R. R. Youngs (1997). Attenuation relationships for shallow crustal earthquakes based on California strong motion data, Seism. Res. Let. 568, 180-189.

Silva, W.J., N. Abrahamson, G. Toro, C. Costantino (1997). "Description and validation of the stochastic ground motion model." Draft Report to Brookhaven National Laboratory, Associated Universities, Inc. Upton, New York.

Somerville, P. G., N. F. Smith, R. G. Graves, N. A. Abrahamson (1997). Modification of empirical strong ground motion attenuation relations to include the amplitude and duration effects of rupture directivity, Seism. Res. Let., vol. 68, 199-222.

Youngs, R. R., S. J. Chiou, W. J. Silva, and J.R. Humphrey (1997). Strong ground motion attenuation relationships for subduction zone earthquakes, Seism. Res. Let., 68, 58-73.

10. ENCLOSURES AND ATTACHMENTS

Attachment 1: Abrahamson and Silva (1997) attenuation relations for horizontal and vertical response spectral values.

Attachment 2: Sadigh et al. (1997) attenuation relations for the horizontal response spectral values

Attachment 3: Sadigh et al (1993) attenuation relations for the vertical response spectral values

Attachment 4: Idriss (1995) attenuation relation for peak acceleration

Attachment 5: Idriss (1992) Attenuation relations for horizontal response spectral values.

Attachment 6: Idriss (1994) updated standard error terms

Attachment 7: Somerville et al (1997) Scale factors for directivity effects

Attachment 9: Abrahamson and Silva (1996) scale factors for response spectra at various damping values