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PG&E Letter DCL-15-154

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D.C. 20555-0001

10 CFR 50.54(f)

Docket No. 50-275, OL-DPR-80
Docket No. 50-323, OL-DPR-82
Diablo Canyon Units 1 and 2
Response to NRC Request for Additional Information dated October 1, 2015, and November 13, 2015, Regarding Recommendation 2.1 of the Near-Term Task Force Seismic Hazard and Screening Report

References:

1. PG&E Letter DCL-15-035, "Response to NRC Request for Information Pursuant to 10 CFR 50.54(f) Regarding the Seismic Aspects of Recommendation 2.1 of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident: Seismic Hazard and Screening Report," dated March 11, 2015 (ADAMS Accession No. ML15071A046)
2. NRC Letter, "Diablo Canyon Power Plant, Unit Nos. 1 and 2 - Request for Additional Information Associated with Near-Term Task Force Recommendation 2.1, Seismic Reevaluations (TAC Nos. MF5275 and MF5276)," dated October 1, 2015 (ADAMS Accession No. ML15267A774)
3. NRC, "Information Request Related to Diablo Canyon Regulatory Audit of Reevaluated Seismic Hazard," E-Mail from N. DiFrancesco (NRC) to P. Soenen (PG&E), dated November 13, 2015 (ADAMS Accession No. ML15323A200)
4. NRC Letter, "Diablo Canyon Power Plant, Unit Nos. 1 and 2 - Request for Additional Information Associated with Near-Term Task Force Recommendation 2.1, Seismic Reevaluations (TAC Nos. MF5275 and MF5276)," dated June 29, 2015 (ADAMS Accession No. ML15153A033)
5. PG&E Letter DCL-15-095, "Response to NRC Request for Additional Information Regarding Recommendation 2.1 of the Near-Term Task Force Seismic Hazard and Screening Report," dated August 12, 2015 (ADAMS Accession No. ML15224B575)

Dear Commissioners and Staff:

On March 11, 2015, Pacific Gas and Electric Company (PG&E) submitted PG&E Letter DCL-15-035, "Response to NRC Request for Information Pursuant to 10 CFR 50.54(f) Regarding the Seismic Aspects of Recommendation 2.1 of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident: Seismic Hazard and Screening Report," (Reference 1).

On October 1, 2015, and November 13, 2015, the NRC Staff requested additional information to complete the review of PG&E's response (References 2 and 3). These information requests were subsequently discussed by the NRC Staff and PG&E representatives during an audit held in Bethesda, MD on December 3, 2015, which included clarifications of the information requests. PG&E's responses to the Staff's questions, including the clarifications identified during the December 3, 2015 audit, are included in the Enclosure to this letter.

The updated ground motion characterization information, described in the Enclosure to this letter, supersedes that previously submitted to the NRC on March 11, 2015, (Reference 1) and updates the information provided by PG&E in response to the NRC Staff's June 29, 2015, request for additional information (Reference 4) in PG&E Letter No. DCL-15-095 (Reference 5). This information represents the final seismic hazards and ground motion response spectrum for Diablo Canyon Power Plant, which will be used as input to the screening evaluation in response to the NRC's Request for Information Pursuant to 10 CFR 50.54(f) Regarding the Seismic Aspects of Recommendation 2.1 of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident. The conclusions from the screening evaluation remain the same as in Reference 1.

PG&E makes no new or revised regulatory commitments (as defined by NEI 99-04) in this letter.

If you have any questions, or require additional information, please contact Mr. L. Jearl Strickland at (805) 595-6476.

I have been delegated the authority of Edward D. Halpin, Senior Vice President – Power Generation and Chief Nuclear Officer, during his absence. I declare under penalty of perjury that the foregoing is true and correct.

Executed on December 21, 2015.

Sincerely,

L. Jearl Strickland, P.E.
Director, Technical Services

mjrm/50465913-99/4557
Enclosure:
cc: Diablo Distribution
cc/enc: Marc L. Dapas, NRC Region IV Administrator
Nicholas J. DiFrancesco, NRR/JLD Senior Project Manager
Siva P. Lingam, NRR Project Manager
Gonzalo L. Perez, Branch Chief, California Department of Public Health
John P. Reynoso, NRC Acting Senior Resident Inspector

Response to NRC Request for Additional Information dated October 1, 2015 and November 13, 2015 Regarding DCPP Seismic Hazard and Screening Report

NRC Request dated October 1, 2015

Review of Site Response Evaluation

By letter dated August 12, 2015, Pacific Gas and Electric Company (the licensee) sent a response to the U. S. Nuclear Regulatory Commission's (NRC's) June 29, 2015, request for additional information (RAI) for Diablo Canyon Power Plant, Unit Nos. 1 and 2 (DCPP, Diablo Canyon), which provides an estimate of the site amplification using the analytical site response modeling approach. As shown in Figure 1 of the RAI response, which compares the DCPP site term as developed from the observed ground motion or empirical approach with the site term from the analytical approach (i.e., SPID[3] methodology), there are notable differences in the site term from the two approaches particularly in the 1-3 Hertz, as well as the higher frequency ranges. The licensee attributes these differences to the analytical modeling approach using (1) a shallow velocity model that does not capture the effects of the site-specific deep velocity profile and (2) a broad range of site kappa values that far exceed the range of observed values for the site.

Commenting on the second factor, the RAI response states on page 4,

> *The broad uncertainty range for kappa is included in the response to the questions to be consistent with the SPID methodology, but, based on the high frequency content of the observed ground motions at DCPP, we consider this low kappa value to be not applicable to DCPP.*

The NRC staff notes that the guidance in Appendix B of the SPID was developed to systematically capture the uncertainty in the properties of the near-surface materials in the site-amplification functions and the subsequent control point seismic hazard curves using a probabilistic methodology. Broad uncertainty ranges for the subsurface material properties are necessary for sites for which the level of detail and scope of geological and geotechnical investigations are limited; however, the DCPP site has abundant subsurface data that can be used to constrain the range of uncertainty for these properties.

a) *Please provide an updated analytical site response analysis which reflects the uncertainties in the material properties specific to the Diablo Canyon site, with*

[3] The NRC endorsement of the industry issued SPID Guidance "Screening, Prioritization and Implementation Details (SPID) for Resolution of Fukushima Near-Term Task Force Recommendation 2.1'. Appendix B - contains an approach to develop site-specific amplification factors (Agencywide Document Access and Management System (ADAMS) Accession No. ML12333A170).

respect to the shear-wave velocity profiles, low-strain damping or kappa, and capturing the potential differences in the site terms as developed from both the empirical and analytical approaches.

The RAI response cites an updated 3-D velocity model (Reference 3[4]) for development of the base case shear wave velocity profiles. The NRC staff review of the 3-D velocity model provided in Reference 3 indicates that the near-surface shear wave velocities beneath seismic station ESTA27 are higher than previous estimates used to develop the empirical site term for the March 11, 2015, Seismic Hazard and Screening Report (SHSR)

b) Please update the SHRS to reflect the empirical site response analysis that incorporates the higher near-surface shear wave velocities for station ESTA27, shown in Reference 3. In addition, provide updated control point seismic hazard curves, uniform hazard response spectra, and ground motion response spectrum that incorporate any changes to the DCPP site term. Also, please provide any updates and refinements to the empirical site response approach in an Appendix to the revised SHSR.

<u>NRC Request dated November 13, 2015</u>

In follow-up to the Regulatory Audit conducted on Sept 11, 2015 (Agencywide Documents Access and Management System [ADAMS] No. ML152448099) NRC staff identified technical information needs and issued a request for additional information dated October 1, 2015 (ADAMS No. ML15267A774) to support reviewing the Diablo Canyon Power Plant's reevaluated seismic hazard. In response to the technical information requests, PG&E made available electronic records for review on the PG&E electronic reading room. In review of those records, the NRC staff has identified the following additional information needs to support understanding of the site response approach:

<u>VS-kappa adjustment factors</u>

- *Clarify the source(s) of the host-region VS30 760 m/sec profile(s) and provide the profile(s) in tabular format*
- *Provide the target VS profiles (lower, middle, upper) in tabular format*
- *Provide the quarter wavelength (QWL) or square-root impedance (SRI) linear site amplification factors (or explain applicable approach) for the host VS30 760 m/sec profile(s) compared to the QWL amplification factors for the target VS profiles*
- *Provide the magnitudes and distances used to compute the response spectra compatible [Fourier Amplitude Spectrum] FAS using Inverse Random Vibration Theory (or explain applicable approach)*

[4] Fugro (2015). Updated of the Three-Dimensional Velocity Model for the DCPP Foundation Area, May 2015.

- *Provide the host kappa values and target site kappa values*
- *Provide the target reference baserock kappa values where $kappa_{baserock}$ = $kappa_{site}$ - $kappa_{profile}$ and indicate the depth for the reference baserock horizon*
- *Provide the final VS-kappa factors used to modify the [Southwest United States] SWUS median [Ground Motion Model] GMMs*

Analytical Site Response Approach

- *Provide in a table: layer description, thickness, density, and VS values for the lower, middle and upper base case VS profiles as well as the scale factor used to develop the lower and upper profiles*
- *Provide the shear modulus and damping ratio curves and the depth ranges over which each curve is implemented*
- *Provide the site kappa values for each of the three profiles*
- *Provide the number of randomizations, and the correlation model used to randomize the VS about each of the three base case profiles*
- *Indicate whether the damping ratios are constrained to a maximum of 15 percent*
- *Provide the magnitudes and distances of the earthquakes used for the input VS-kappa corrected spectra and indicate the location where these spectra are input into the site response analysis*
- *Provide a description of the approach used to develop the site amplification factors, including the incorporation of both the aleatory and epistemic uncertainty.*
- *Indicate whether the amplification factors are constrained to not fall below 0.5*
- *Provide a description of the approach used to develop the control point hazard curves, including how the aleatory uncertainty in the amplification factor is incorporated into the hazard integral*

Empirical Site Response Approach

- *Provide a description of any deviations from the approach used to develop the empirical site term as described in Sections 2.3.5 and 2.3.6 of the March 15, 2015 Seismic Hazard Screening Report [SHSR] submittal*
- *Provide the VS30 values used for [seismic station] ESTA27 and ESTA28*

Final Ground Motion Response Spectra (GMRS)

- *Provide the bases for developing control point hazard curves that combine the results of both the analytical and empirical site response approaches, including the weighting for the two approaches*

Pacific Gas and Electric Company (PG&E) Response

In order to provide a comprehensive response to the above information requests, Pacific Gas & Electric Company (PG&E) has prepared a technical discussion describing the updated site response evaluation for the Diablo Canyon Power Plant (DCPP). This updates the information previously provided in Section 2.3, "Site Response Evaluation," and Section 2.4, "Control Point Response Spectra," of the March 11, 2015, DCPP Seismic Hazards and Screening Report (Reference 3). The conclusions described in Section 4.0, "Screening Evaluation," Section 5.0, "Interim Evaluation," and Section 6.0, "Conclusions," of Reference 3 remain unchanged.

1. INTRODUCTION

The specific questions from the November 13, 2015, request for additional information (RAI) are listed in Table 1-1 along with the section of this document in which the response to the question is provided. Note that the responses to questions from the October 1, 2015, RAI are implicitly addressed in this enclosure.

Table 1-1 - November 13, 2015, RAI Questions and Response Sections

Question	Response Section
VS-kappa Adjustment Factors	
Clarify the source(s) of the host-region VS30 760 m/sec profile(s) and provide the profile(s) in tabular format.	**2.1**
Provide the target VS profiles (lower, middle, upper) in tabular format.	**2.2**
Provide the quarter wavelength (QWL) or square-root impedance (SRI) linear site amplification factors (or explain applicable approach) for the host VS30 760 m/sec profile(s) compared to the QWL amplification factors for the target VS profiles.	**2.3**
Provide the magnitudes and distances used to compute the response spectra compatible [Fourier Amplitude Spectrum] FAS using Inverse Random Vibration Theory (or explain applicable approach).	**2.4**
Provide the host kappa values and target site kappa values	**2.4**
Provide the target reference baserock kappa values where $kappa_{baserock} = kappa_{site} - kappa_{profile}$ and indicate the depth for the reference baserock horizon.	**2.5**
Provide the final VS-kappa factors used to modify the [Southwest United States] SWUS median [Ground Motion Model] GMMs.	**2.6**
Analytical Site Response Approach	
Provide in a table: layer description, thickness, density, and VS values for the lower, middle, and upper base case VS profiles, as well as the scale factor used to develop the lower and upper profiles.	**2.2, App A**
Provide the shear modulus and damping ratio curves and the depth ranges over which each curve is implemented.	**3.2**
Provide the site kappa values for each of the three profiles.	**2.4**

Table 1-1 - November 13, 2015, RAI Questions and Response Sections (continued)

Question	Response Section
Analytical Site Response Approach (continued)	
Provide the number of randomizations, and the correlation model used to randomize the VS about each of the three base case profiles.	**3.3**
Indicate whether the damping ratios are constrained to a maximum of 15 percent.	**3.2**
Provide the magnitudes and distances of the earthquakes used for the input VS-kappa corrected spectra and indicate the location where these spectra are input into the site response analysis.	**2.4, 3.1**
Provide a description of the approach used to develop the site amplification factors, including the incorporation of both the aleatory and epistemic uncertainty.	**3.1**
Indicate whether the amplification factors are constrained to not fall below 0.5.	**3.2**
Provide a description of the approach used to develop the control point hazard curves, including how the aleatory uncertainty in the amplification factor is incorporated into the hazard integral.	**5.2**
Empirical Site Response Approach	
Provide a description of any deviations from the approach used to develop the empirical site term as described in Sections 2.3.5 and 2.3.6 of the March 15, 2015, Seismic Hazard and Screening Report [SHSR].	**4.2**
Provide the VS30 values used for [seismic station] ESTA27 and ESTA28	**4.1**
Final Ground Motion Response Spectra (GMRS)	
Provide the bases for developing control point hazard curves that combine the results of both the analytical and empirical site response approaches, including the weighting for the two approaches.	**5.2**

2. VS-KAPPA ADJUSTMENT FACTORS

The hazard calculation was conducted for a reference rock site condition corresponding to a time-averaged shear-wave velocity in the top 30 meters (VS30)=760 meters per second (m/s) for a site with a shear-wave velocity (VS) profile representative of the data used to derive the ground motion prediction equations (GMPEs) used in the Southwestern U.S. (SWUS) study by GeoPentech, "Southwestern United States Ground Motion Characterization SSHAC Level 3" (Reference 6).

To adjust the results for the reference rock condition to the site conditions for the control point, the differences between the VS profiles and kappa values for the reference rock condition (called the host profile and host kappa) and the control point (called the target profile and target kappa) are evaluated.

2.1 Reference VS Profile for California for VS30=760 m/s

The host profile for the SWUS GMPEs is taken as the generic California profile for VS30=760 m/s developed by Pacific Engineering and Analysis, and described in Kamai et al, "Nonlinear Horizontal Site Response for the NGA-West2 Project" (Reference 7).

The layer thicknesses, shear-wave velocities, and densities for the host profile are listed in Table A-1 in Appendix A.

2.2 Control Point Definition and VS Profiles

The control point is defined as a hypothetical location with VS profiles representative of the range of site conditions over the power-block and turbine building footprint at elevation 85 feet. This region is shown in Figure 2-1. To define the velocity profile for the control point, the three-dimensional (3-D) velocity model described in the May 2015 version[5] of the Fugro Report, "Update for the Three-Dimensional Velocity Model for the Diablo Canyon Power Plant (DCPP) Foundation Area," (Reference 4) was used. The range of one-dimensional (1-D) profiles extracted from the 3-D model are shown in Figure 2-2 for the top 125 meters (m). The central profile is developed based on the geometric mean VS profile, which approximates the median profile. The standard deviation of the natural logarithm of the VS is depth dependent with a maximum value of 0.21 at a depth of 10 m. The lower and upper profiles shown in Figure 2-2 are based on plus and minus (±)1.6 standard deviations above and below the median VS. A minimum range of 10 percent was applied (affects the lower part of profile in Figure 2-2). Because the distribution of the velocities is not normal, the ±1.6 standard deviation range are near the bounds the 1-D profiles from the best 3-D model. The Fugro Report for the 3-D model (Reference 4) gives an additional uncertainty of about 0.15 natural log (LN) units due to different tomographic inversions. This additional

[5] The 3-D velocity model was updated in November 2015 (Reference 12). The May 2015 and November 2015 velocity models are compared in Appendix A.

uncertainty was not included in the range shown in Figure 2-2, but when the broad range of upper and lower profiles shown in Figure 2-2 are combined with the profile randomization, the resulting profiles used in the site response will capture the range of alternative 3-D models due to different inversions.

To compute the upper and lower bound shallow velocity profiles, the central profile is scaled by factors shown in Figure 2-4 representing ±1.6 standard deviations of the LN (VS) values or a factor of 1.1, whichever is larger. This standard deviation did not include the additional epistemic uncertainty due to the tomographic inversion uncertainty.

The Fugro Report, 1-D Vp Profile below the DCPP Area (Reference 5) provides an estimate of the VS in the depth range of 125 m to 3000 m. Below that depth, the profiles were extended to a depth of 8 kilometer (km) based on the reference profiles for the NGA-West2 data set provided in Pacific Engineering and Analysis (PEA) Report, "Development of Amplification Factors for the Diablo Canyon Nuclear Power Plant: Site-Wide Profiles," (Reference 8). Figure 2-3 compares the VS profiles for the Host region with the VS profiles for the central, upper, and lower target VS models for the full 8 km depth range. The layer thicknesses, shear-wave velocities, and densities for each of the three profiles are listed in Table A-2 in Appendix A.v The scale factor used to develop the lower and upper profiles are shown in Figure 2-4a and 2-4b, for the shallow and full profiles, respectively. The scale factors are listed in Table A-3 in Appendix A.

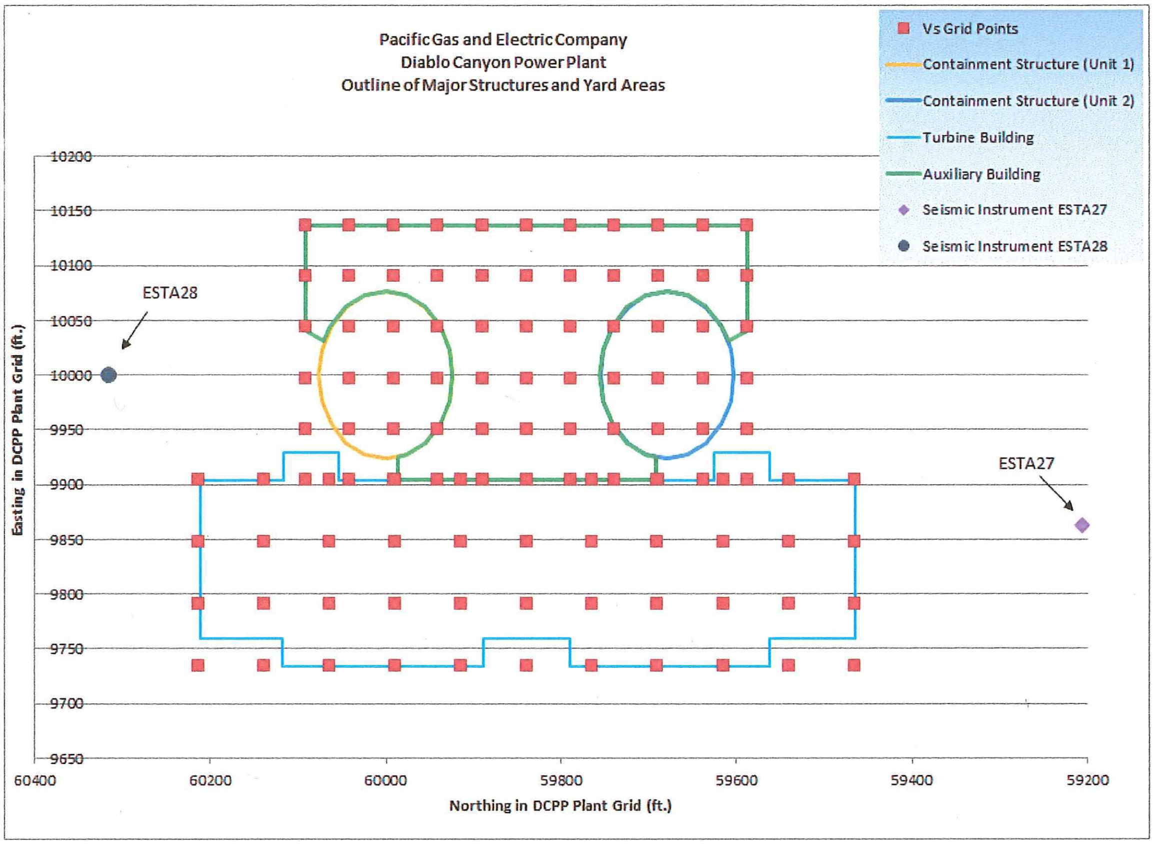

Figure 2-1 - Locations of 1-D Profiles used to Define the Power-Block and Turbine Building Region

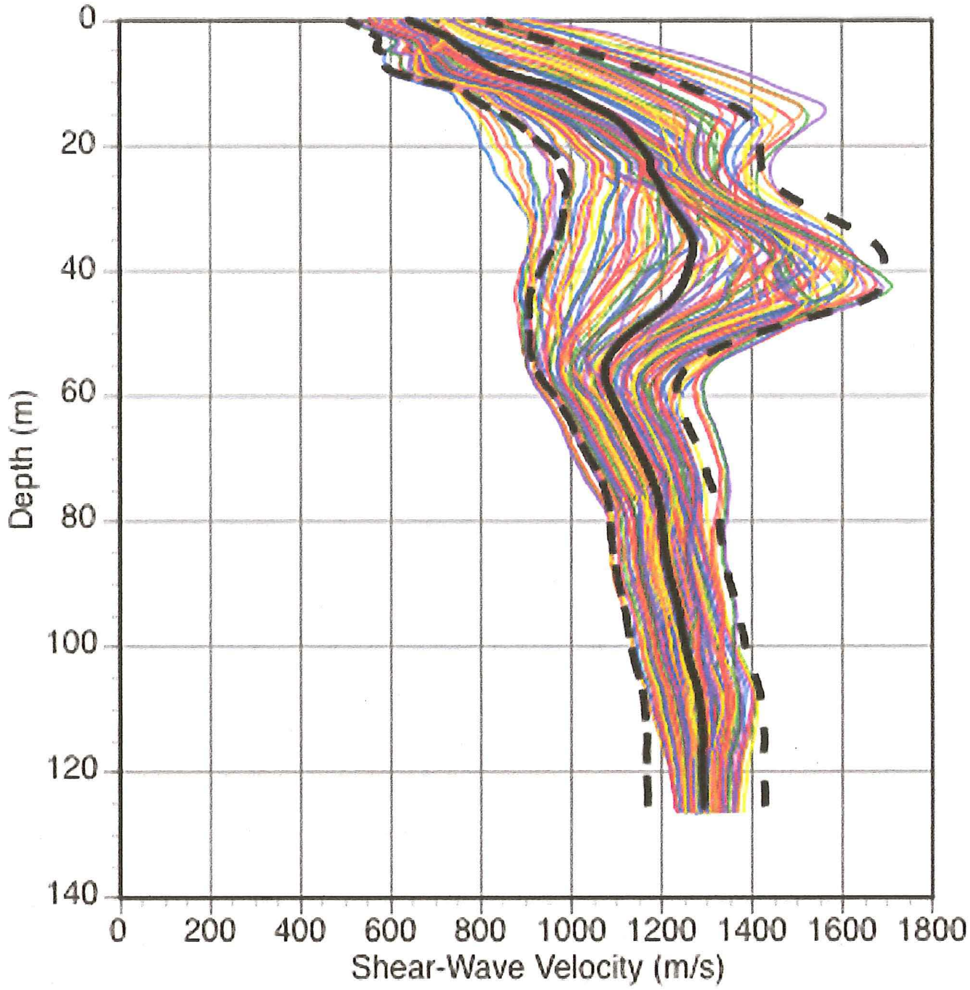

Figure 2-2 - Range of VS Profiles Under the Power-Block and Turbine Building Region in the Top 125 m
(The heavy black curves show the central, upper, and lower profiles)
(From PG&E Calculation No. GEO.DCPP.15.02 (Reference 9))

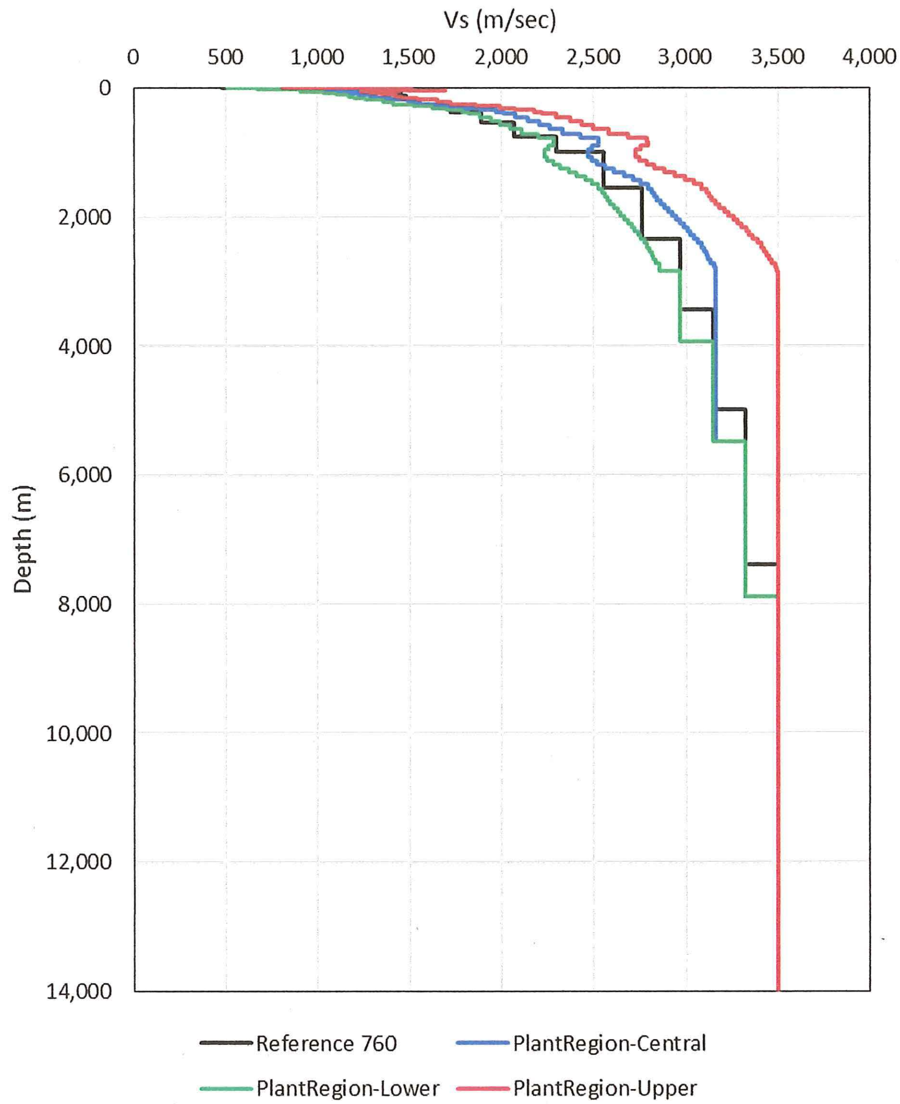

Figure 2-3 - Comparison of the Host VS Profile (labeled Reference 760) and the Central, Upper, and Lower Profiles for the Target
(From Reference 8)

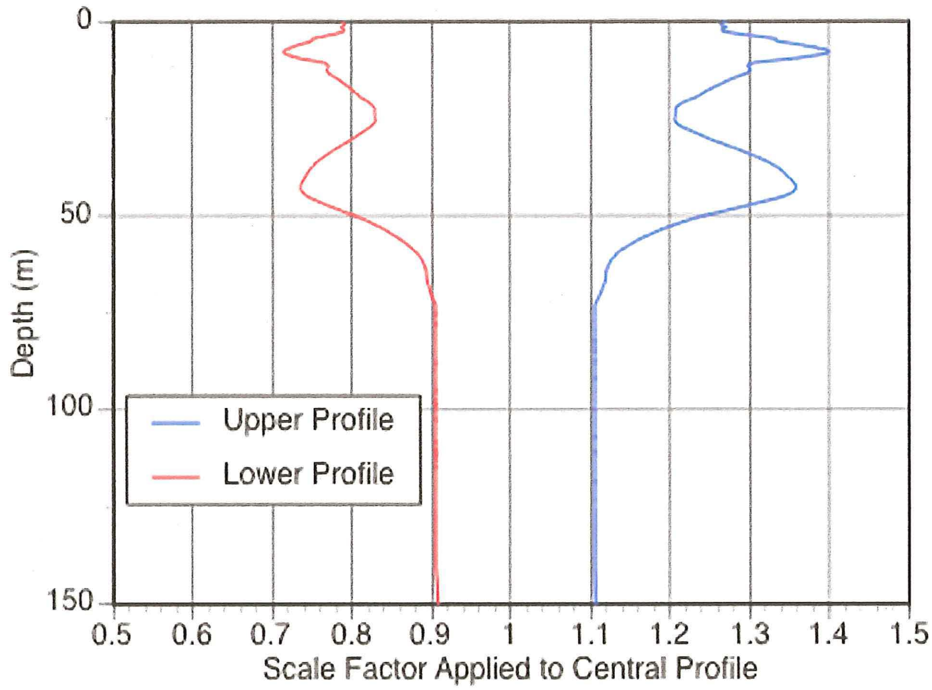

Figure 2-4a - Scale Factors used to Develop the Upper and Lower VS Profiles for the top 150 m
(From Table A-3)

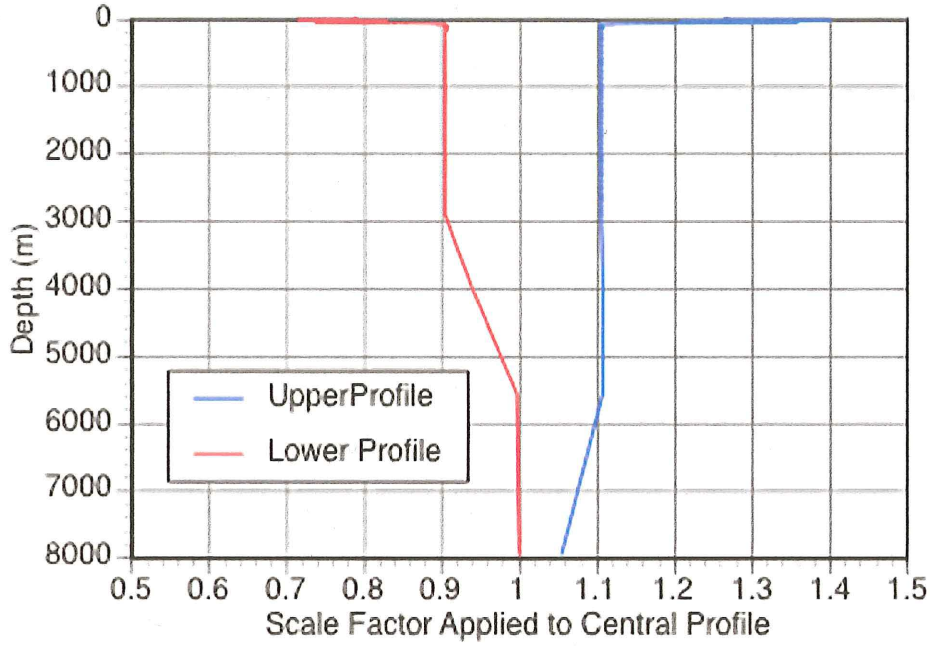

Figure 2-4b - Scale Factors used to Develop the Upper and Lower VS Profiles for the Full Depth Range
(From Table A-3)

2.3 Quarter-Wavelength Amplification

The quarter-wavelength (QWL) method can be used to estimate the effect of the differences in the linear amplification between the host and target VS profiles. The QWL crustal amplification is usually given in terms of the scaling on the Fourier amplitude spectra, not the response spectra.

The QWL crustal amplification factors for the three alternative profiles for the control point and the host profile are compared in Figure 2-5. The host profile amplification is similar to the central target profile amplification for frequencies less than 2.5 Hertz (Hz). At frequencies above 5 Hz, the host profile amplification is similar to the lower target profile amplification.

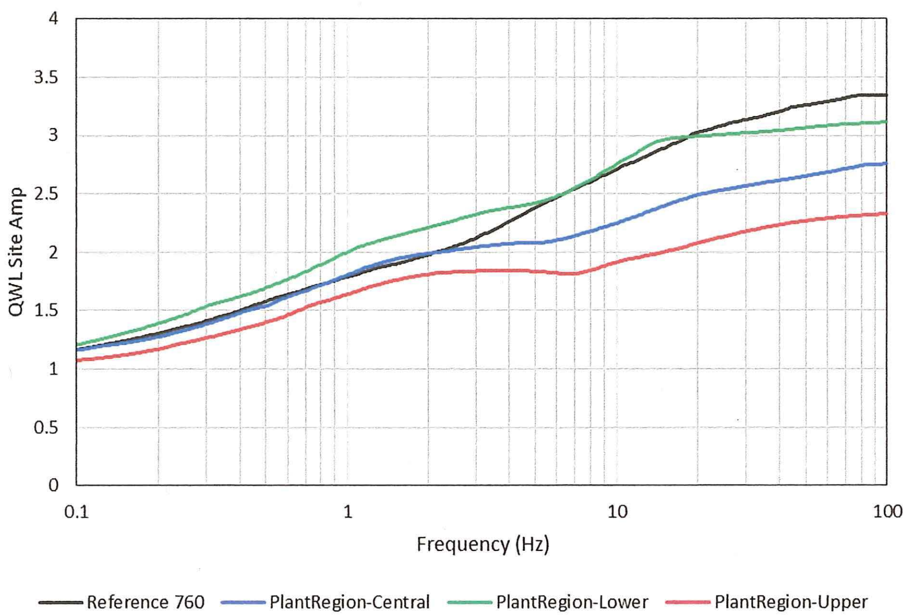

Figure 2-5 - Quarter Wave-Length Crustal Amplification Factors (Fourier Amplitude Spectra Amplification) for the Host VS profile and the Central, Upper, and Lower Target VS Profiles
(From GEO.DCPP.15.03 (Reference 10))

2.4 Target Kappa at Surface

The host kappa value was estimated for the both the SWUS DCPP ground motion model and the NGA-West2 GMPEs. The Inverse Random Vibration Theory (IRVT) method was used for both SWUS and NGA-West2 GMPEs. The broadband inversion method was applied only to the NGA-West2 GMPEs.

The broadband inversion of the response spectral shapes was conducted by PEA using the point-source spectrum with kappa being one of the parameters in the point-source model. The broadband inversion fit the spectral shape up to frequencies of 20 Hz. From the broadband inversion, the best estimate of kappa for the NGA-West2 models is 0.03 seconds (sec).

An alternative approach is to use IRVT to estimate the Fourier Amplitude Spectrum (FAS) from the response spectral values and then estimate the kappa from the slope of the estimated FAS. The IRVT approach was applied to the NGA-West2 GMPEs and to the SWUS weighted ground motion model. The IRVT evaluation used M6 at rupture distances of 5, 10, and 20 km. The resulting kappa values from the IRVT method are listed in Table 2-1.

Table 2-1 - Kappa Values Based on IRVT Method
(From Reference 10)

	ASK14	BSSA14	CB14	CY14	SWUS
Best	0.0405	0.0419	0.0294	0.0356	0.0341
High	0.0438	0.0430	0.0312	0.0369	0.0366
Low	0.0361	0.0409	0.0266	0.0335	0.0309

Based on evaluations of the kappa from the San Simeon and Parkfield earthquakes at DCPP, the target kappa is constrained to a range of 0.03 to 0.05 sec. The resulting alternative kappa values are 0.03, 0.040, and 0.050 sec with weights of 0.2, 0.6, and 0.2 representing the 5 to 95 percent range of the kappa values.

2.5 Host and Target Kappa at Baserock and in the Profiles

The kappa at the surface ($kappa_{site}$) is the sum of the kappa at the baserock ($kappa_{baserock}$) and the kappa due to the low strain damping as modeled in the shallow layers ($kappa_{profile}$).

The $kappa_{baserock}$ is the value of kappa input into the point source model. For this application, the baserock is at a depth of 8 km. The low strain damping is only modeled in the top 500 feet of the profile. For layers between 500 feet and 8 km, there is no damping in the layers.

The $kappa_{baserock}$, $kappa_{profile}$, and $kappa_{site}$ values for the three target profiles are listed in Table 2-2. For depths greater than 152.4 m, there is no damping in the layers and nonlinearity is not applied.

Table 2-2. Kappa Values
(from Reference 8)

Base-case Name	Profile Name	Kappa_profile (sec.) Surface to 500 feet (152.4 m) depth	Kappa_baserock (sec.) 500 feet (152.4 m) to 8.0 km depth	Kappa_site (sec.) at Surface
Lower	M1P1K1	0.005	0.035	0.040
	M1P1K2	0.005	0.045	0.050
	M1P1K3	0.005	0.025	0.030
	M2P1K1	0.011	0.029	0.040
	M2P1K2	0.011	0.039	0.050
	M2P1K3	0.011	0.019	0.030
	M3P1K1	0.002	0.038	0.040
	M3P1K2	0.002	0.048	0.050
	M3P1K3	0.002	0.028	0.030
Central	M1P1K1	0.004	0.036	0.040
	M1P1K2	0.004	0.046	0.050
	M1P1K3	0.004	0.026	0.030
	M2P1K1	0.009	0.031	0.040
	M2P1K2	0.009	0.041	0.050
	M2P1K3	0.009	0.021	0.030
	M3P1K1	0.002	0.038	0.040
	M3P1K2	0.002	0.048	0.050
	M3P1K3	0.002	0.028	0.030
Upper	M1P1K1	0.003	0.037	0.040
	M1P1K2	0.003	0.047	0.050
	M1P1K3	0.003	0.027	0.030
	M2P1K1	0.008	0.032	0.040
	M2P1K2	0.008	0.042	0.050
	M2P1K3	0.008	0.022	0.030
	M3P1K1	0.002	0.038	0.040
	M3P1K2	0.002	0.048	0.050
	M3P1K3	0.002	0.028	0.030

2.6 Final VS-Kappa Factors

In some applications, the VS-kappa correction is first made to develop the site rock motion from the reference rock condition. In a second step, the site response is conducted relative to the adjusted rock motion.

For DCPP, the VS-kappa correction and the site response are done in a single step. The VS-kappa correction is integrated into the site response, but it can be separated out in the linear range. The amplification at low rock ground-motion values provides the VS-kappa correction. A reference rock peak ground acceleration (PGA) value of 0.1 times the acceleration of gravity (g) is used for the linear range.

The VS-kappa factors are computed for both the broadband analytical method and the IRVT method. The resulting VS-kappa factors are shown in Figure 2-6 for the nine combinations of target kappa (kappa_site) and target VS profile. The VS-kappa scaling is similar for the two approaches with the broad-band approach showing slightly less scaling at high frequencies even though the kappa is smaller for the broadband approach.

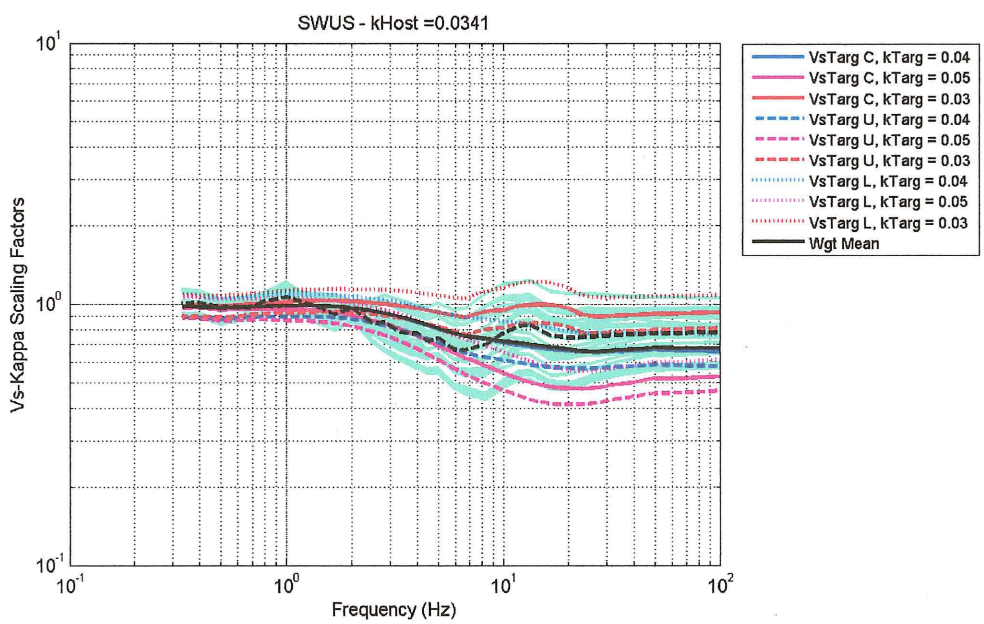

Figure 2-6 - VS-Kappa Factors from the Best Kappa from IRVT (colored curves) and from Analytical Modeling (cyan curves). The mean for the analytical model is given by dashed black line. The mean for the IRVT method is shown by the solid black line. (From Reference 10)

3. ANALYTICAL SITE RESPONSE APPROACH

3.1 Site Response Approach

The site response approach does not provide amplification relative to the baserock site condition. Instead, the amplification is computed relative to the SWUS reference rock condition with VS30=760 m/s.

The amplification is computed using ratios of the surface response spectra for the DCPP profile relative to the surface response spectra for the SWUS reference rock condition profile (Reference 8). For each profile, the surface response spectrum is computed using the point-source stochastic model. A magnitude 7 earthquake at a depth of 8 km is used for the input motion. A range of point source distances is used leading to a range of input motion levels. For each distance, the surface spectrum is computed for the velocity profile corresponding the SWUS reference rock site condition (called the host profile). Using the same distances, the surface spectrum is then computed for each of the alternative DCPP velocity profiles, kappa values, and nonlinear material properties (called the target profile). The amplification is defined as the ratio of surface spectrum for the DCPP site condition to the surface spectrum for the SWUS reference rock site condition and provides the combined effect of the linear VS-kappa correction and nonlinear site effects. By using the ratio of the two surface spectra, this approach avoids the need for deconvolution. This process is illustrated in Figure 3-1.

The logic tree for the analytical site response is shown in Figure 3-2. The alternative profiles were described in Section 2.2. The kappa values were described in Section 2.4. The nonlinear properties are described in Section 3.2 below.

3.2 Nonlinear Material Properties

The material models (damping and modulus reduction) are modeled using three models: linear (M1); nonlinear rock (M2) per Electric Power Research Institute (EPRI) Report, "Guidelines for Determining Design Basis Ground Motions," (Reference 2); and nonlinear Peninsula Range (M3) per Silva et al's, "Description and Validation of the Stochastic Ground Motion Model," (Reference 11). For the linear model, the small strain damping is from the Peninsula Range model; however, the results are not sensitive to the selected small strain damping because additional small strain damping is added to the deeper part of the profile so that the total kappa matches the specified kappa value (Reference 8). The modulus and damping curves for the two nonlinear models are shown below in Figures 3-3 and 3-4. The nonlinear model is applied to the layers at depths up to 500 feet (152 meters). For layers at depths below 500 feet, a linear model is used.

For the EPRI nonlinear model, there are 5 depth ranges from 0 to 500 feet as shown in Figure 3-3. For the Peninsula Range model, there are 2 depth ranges from 0 to

500 feet as shown in Figure 3-4. The numerical values for the 2 nonlinear models are listed in Table 3-1.

Laboratory testing of the soft-rock material at DCPP was conducted in 1977 and 1978 (Reference 15). The strain dependence of the G/Gmax measurements and the damping are shown in Figures 3-5 and 3-6. These laboratory measurements can be compared with the three material models used in the analytical modeling. The range of the G/Gmax measurements are consistent with the range of the three models, with most of the data near the linear range. The lower end of the lab data is consistent with the EPRI model. Therefore, the linear and nonlinear approaches are given equal weight, and the two nonlinear models are also given equal weight. The logic tree weights are 0.5 for the linear model (M1) and 0.25 each for the two nonlinear models (M2 and M3).

To avoid excessive nonlinear effects, the damping values in the site response calculation are limited to be less than 15 percent.

The amplification depends on the linear amplification and the non-linear effects. The concept of limiting the amplification to be greater than or equal to 0.5 is intended to avoid large nonlinear effects that may not be reliable. Therefore, for the soil hazard calculation, the nonlinear part of the amplification is limited to be greater than or equal to 0.5, but the total amplification is not limited. For example, if the nonlinear amplification is 0.6 and the linear amplification is 0.7, then the net amplification is 0.42 (i.e. 0.6 x 0.7). This is allowed because the nonlinear amplification by itself is 0.6, which is above 0.5.

The maximum strains at the 1E-4 and 1E-5 hazard levels for the two nonlinear models are given in the PEA report (Reference 8).

3.3 Profile Randomization

For each of the three base profiles, 30 randomized profiles are developed based on the EPRI "footprint" model because the 3-D VS model provides local constraints on the VS profile. Because there is a gradient in the VS profile and there is not a clear depth to rock parameter, the depth to rock is not randomized. Only the VS values are randomized.

3.4 Example Results

Examples of the results from the analytical approach for three ground motion levels are shown in Figures 3-7, 3-8, and 3-9. Figure 3-7 shows the amplification for a PGA of 0.2 g on the SWUS reference rock condition and reflects the linear site amplification (SA). Figures 3-8 and 3-9 show the amplification for a SWUS reference rock PGA values of 1.07 g and 1.91 g which are close to the 1E-4 and 1E-5 hazard levels for the SWUS reference rock condition (Table B-1).

Table 3-1. Modulus Reduction and Damping Curves*

PR GENERIC SAND MODULUS REDUCTION CURVE; 0 - 50 FEET.									
1.0	1.0	1.0	0.97	0.87	0.68	0.43	0.22	0.09	0.05
PR GENERIC SAND DAMPING CURVE; 0 - 50 FEET.									
1.0	1.0	1.2	1.64	2.8	5.49	10.2	15.0	15.0	15.0
PR GENERIC SAND MODULUS REDUCTION CURVE; 51 - 500 FEET.									
1.0	1.0	1.0	0.99	0.95	0.852	0.65	0.41	0.20	0.10
PR GENERIC SAND DAMPING CURVE; 51 - 500 FEET.									
0.6	0.6	0.6	0.81	1.2	2.5	5.3	10.27	15.0	15.0
EPRI GENERIC ROCK MODULUS REDUCTION CURVE; 0 - 20 FEET.									
1.0	1.0	0.9716	0.8614	0.6294	0.383	0.1747	0.0714	0.0238	0.0084
EPRI GENERIC ROCK DAMPING CURVE; 0 - 20 FEET.									
3.263	3.39	4.017	5.58	9.191	14.397	15.0	15.0	15.0	15.0
EPRI GENERIC ROCK MODULUS REDUCTION CURVE; 20 - 50 FEET.									
1.0	1.0	0.9801	0.8844	0.6653	0.4177	0.1967	0.0821	0.0277	0.0098
EPRI GENERIC ROCK DAMPING CURVE; 20- 50 FEET.									
3.245	3.339	3.869	5.25	8.55	13.532	15.0	15.0	15.0	15.0
EPRI GENERIC ROCK MODULUS REDUCTION CURVE; 50 - 120 FEET.									
1.0	1.0	0.9898	0.9121	0.7118	0.4655	0.229	0.0984	0.0338	0.012
EPRI GENERIC ROCK DAMPING CURVE; 50- 120 FEET.									
3.225	3.282	3.701	4.865	7.773	12.429	15.0	15.0	15.0	15.0
EPRI GENERIC ROCK MODULUS REDUCTION CURVE; 120 - 250 FEET.									
1.0	1.0	0.9997	0.9417	0.7667	0.5264	0.2735	0.1224	0.0431	0.0154
EPRI GENERIC ROCK DAMPING CURVE; 120 - 250 FEET.									
3.206	3.227	3.534	4.463	6.926	11.14	15.0	15.0	15.0	15.0
EPRI GENERIC ROCK MODULUS REDUCTION CURVE; 250 - 500 FEET.									
1.0	1.0	1.0	0.9668	0.8324	0.6119	0.3454	0.1649	0.0608	0.0222
EPRI GENERIC ROCK DAMPING CURVE; 250 - 500 FEET.									
3.186	3.167	3.348	3.995	5.881	9.398	15.0	15.0	15.0	15.0

* The ten strain levels are (percent):
1.E-4.0, 1.E-3.5, 1.E-3.0, 1.E-2.5, 1.E-2.0, 1.E-1.5, 1.E-1.0, 1.E-0.5, 1.E-0.0, 1.E+0.5.

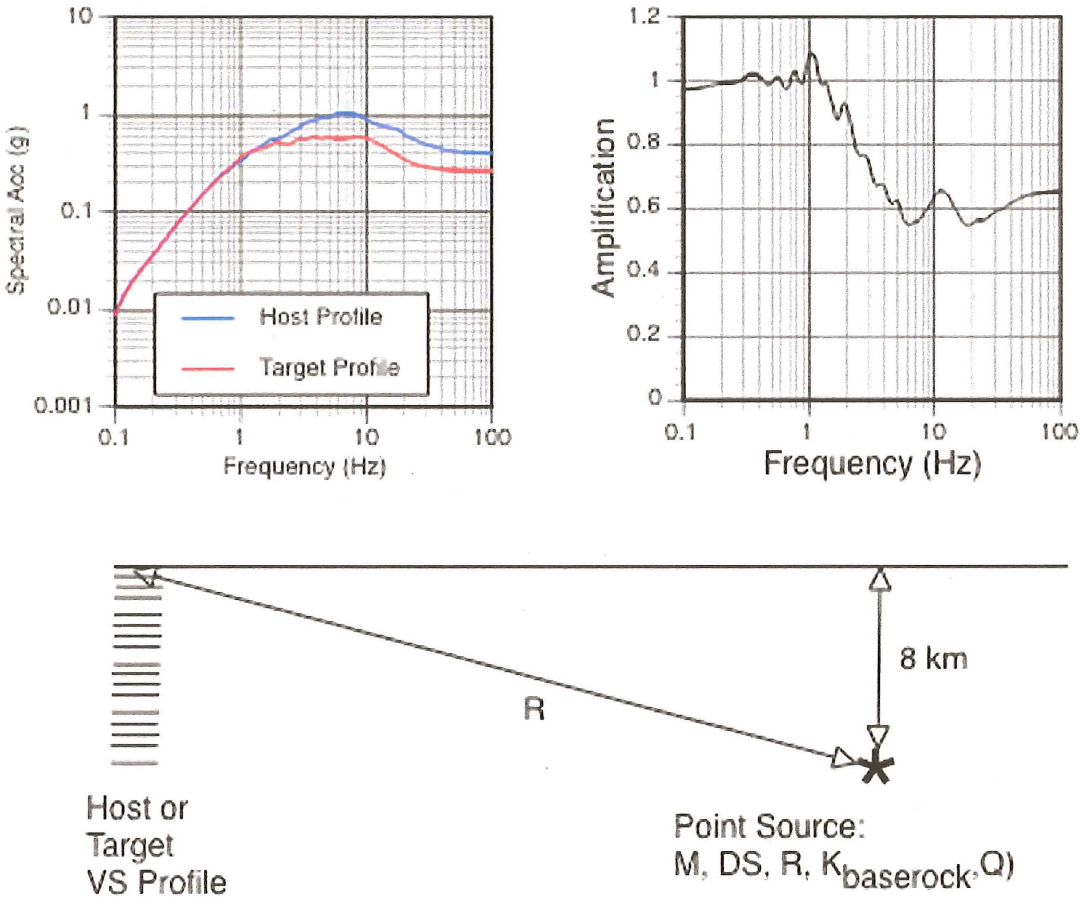

Figure 3-1 - Cartoon of the Analytical Site Response

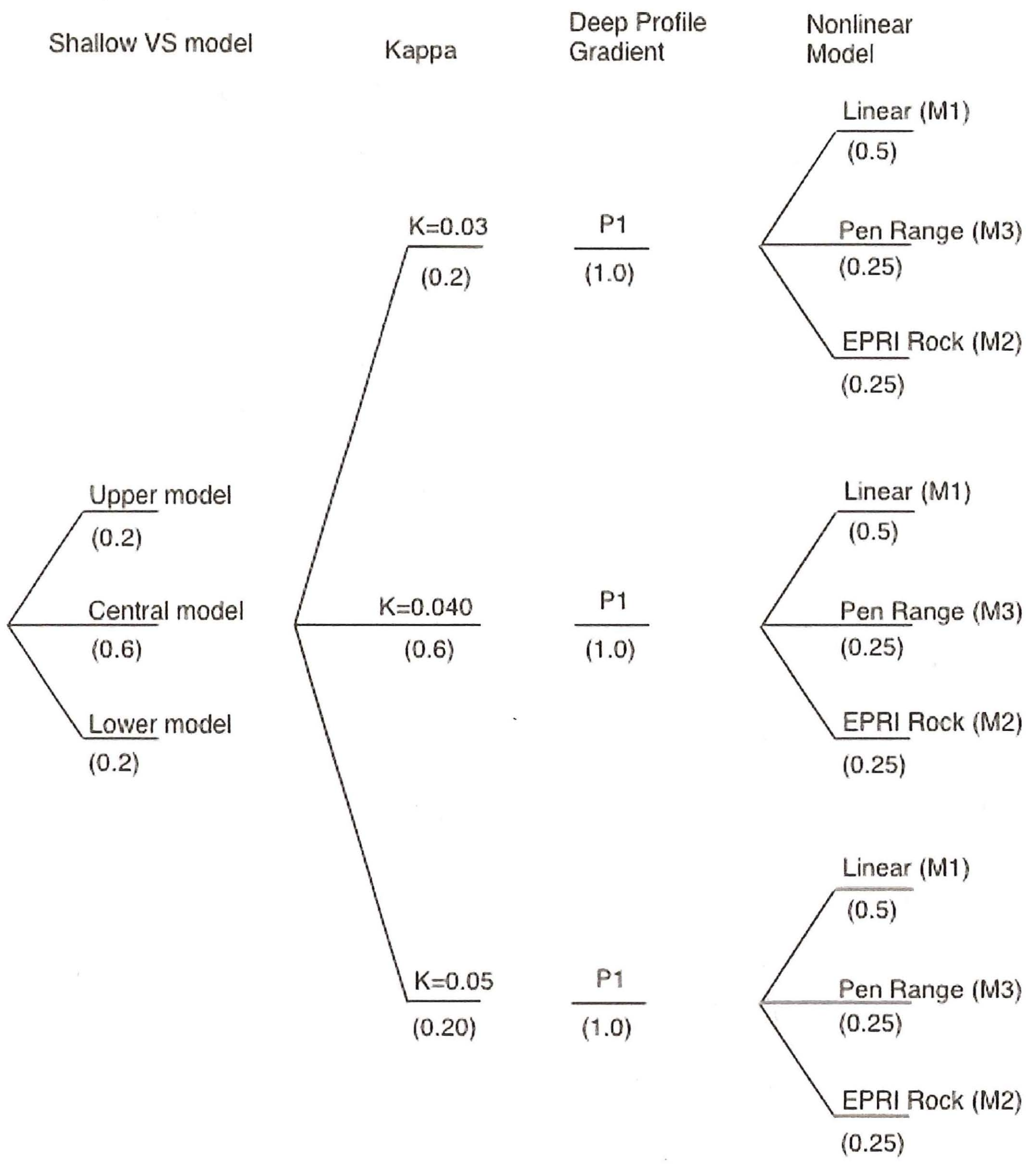

Figure 3-2 - Logic Tree for Inputs to Analytical Site Response

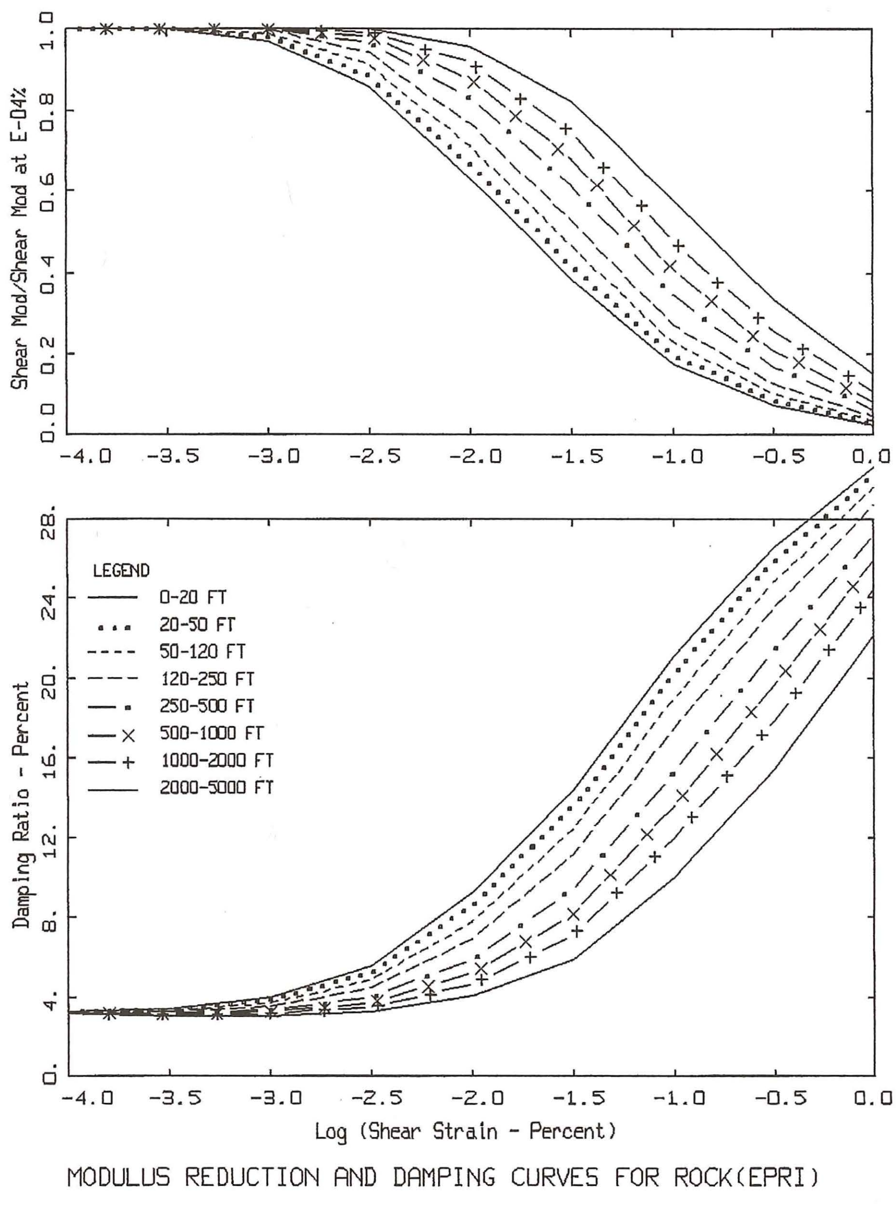

Figure 3-3 - Modulus and Damping curves for the EPRI Rock Model (M2)
(From Reference 8)

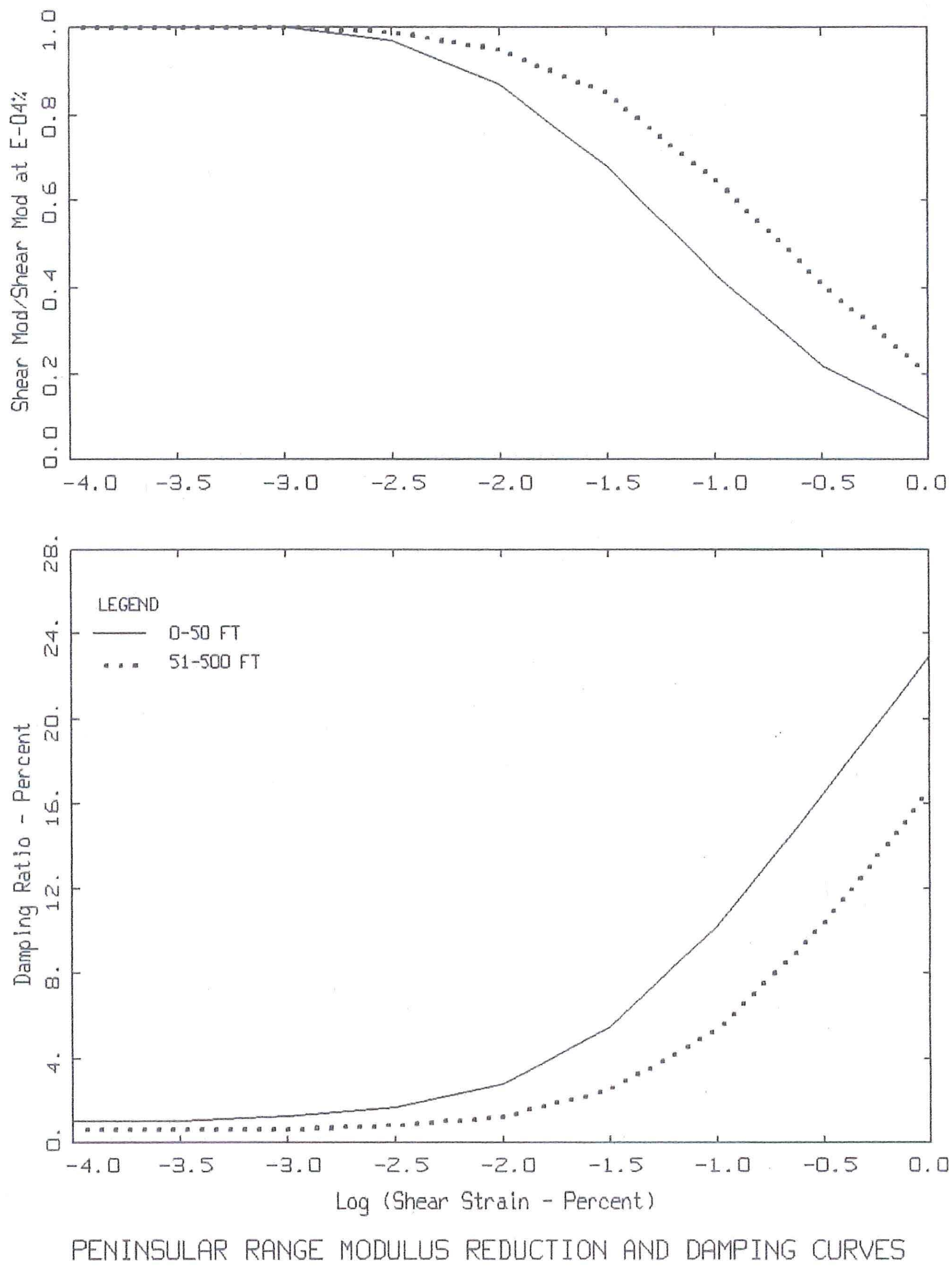

Figure 3-4 - Modulus and Damping Curves for the Pen Range Model (M3)
(From Reference 8)

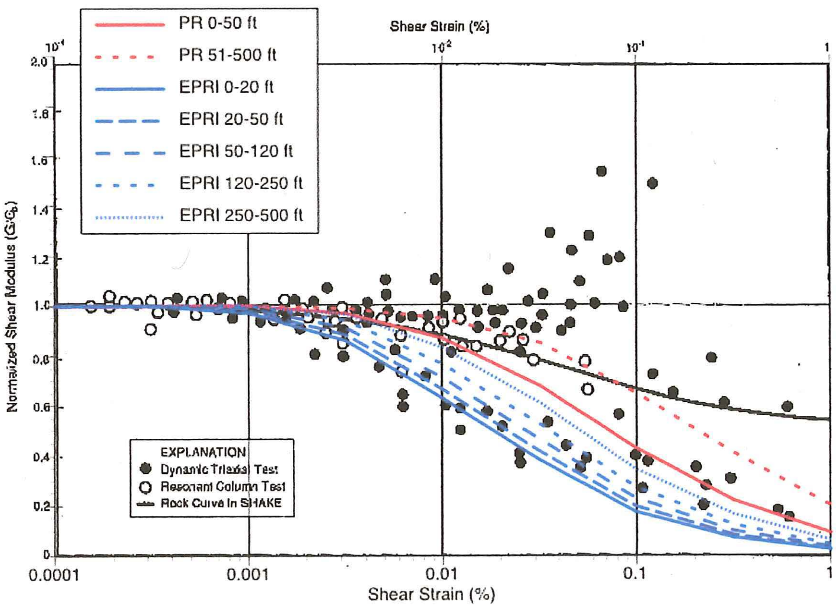

Figure 3-5 - 1978 Lab Testing for DCPP Rock for G/Gmax

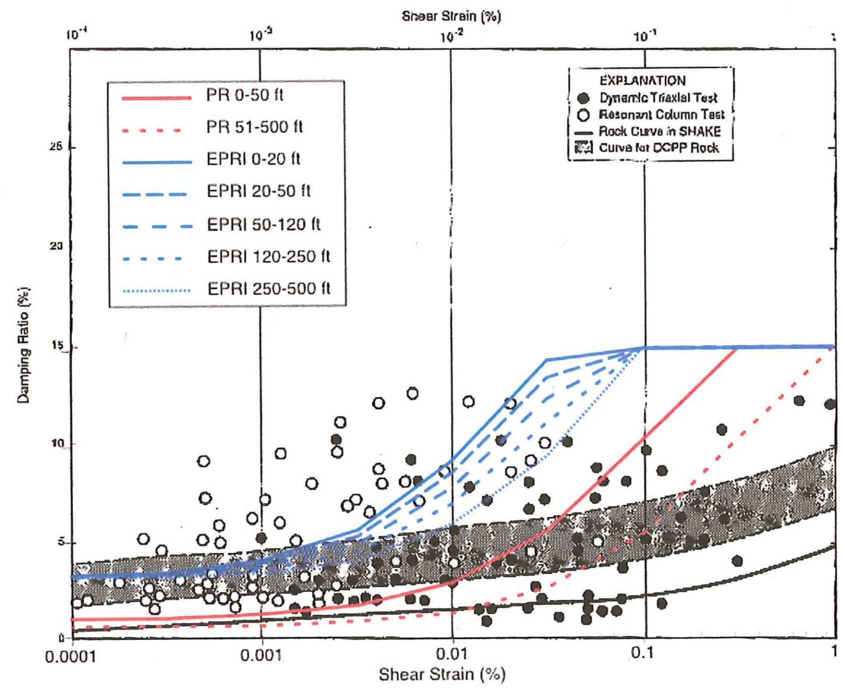

Figure 3-6 - 1978 Lab Testing for Nonlinear Damping for DCPP Rock

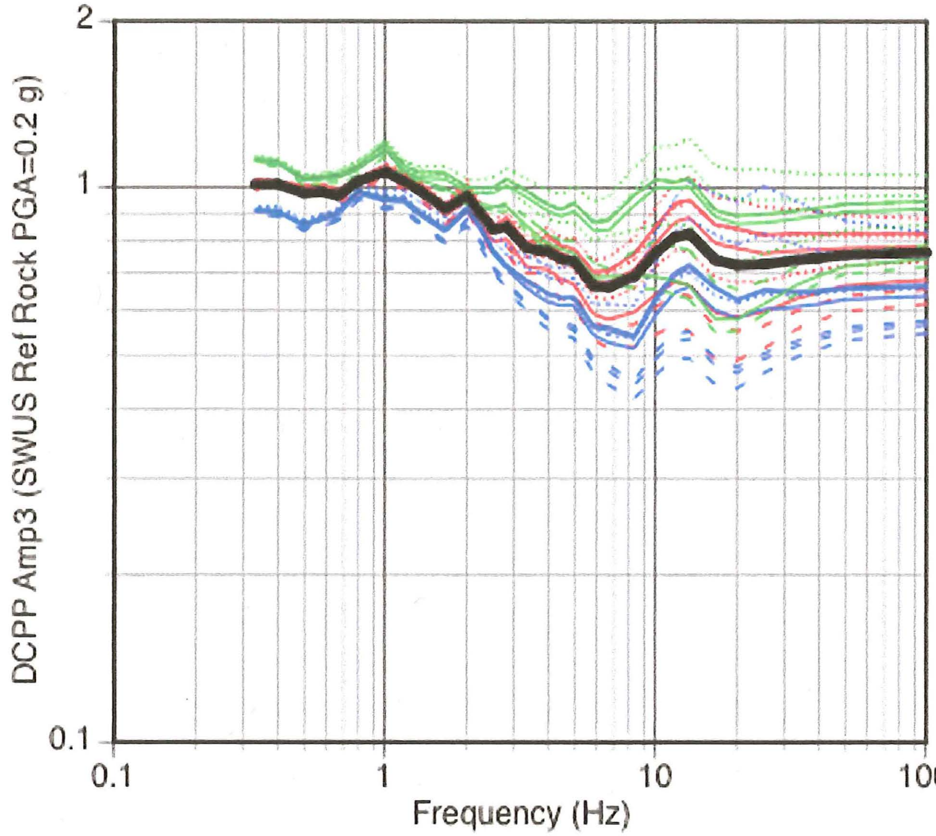

Figure 3-7 - Analytical Site Terms for a SWUS Reference Rock (760 m/s) PGA of 0.2 g

(The green curves are for the lower VS profile; red curves are for the central VS profile; and the blue curves are for the upper VS profile. The short dashed lines are for the target kappa of 0.03 sec, the long dashed lines are for the target kappa of 0.05 sec, and the solid lines are for the target kappa of 0.04 sec. The black line is the mean.) (From Reference 9)

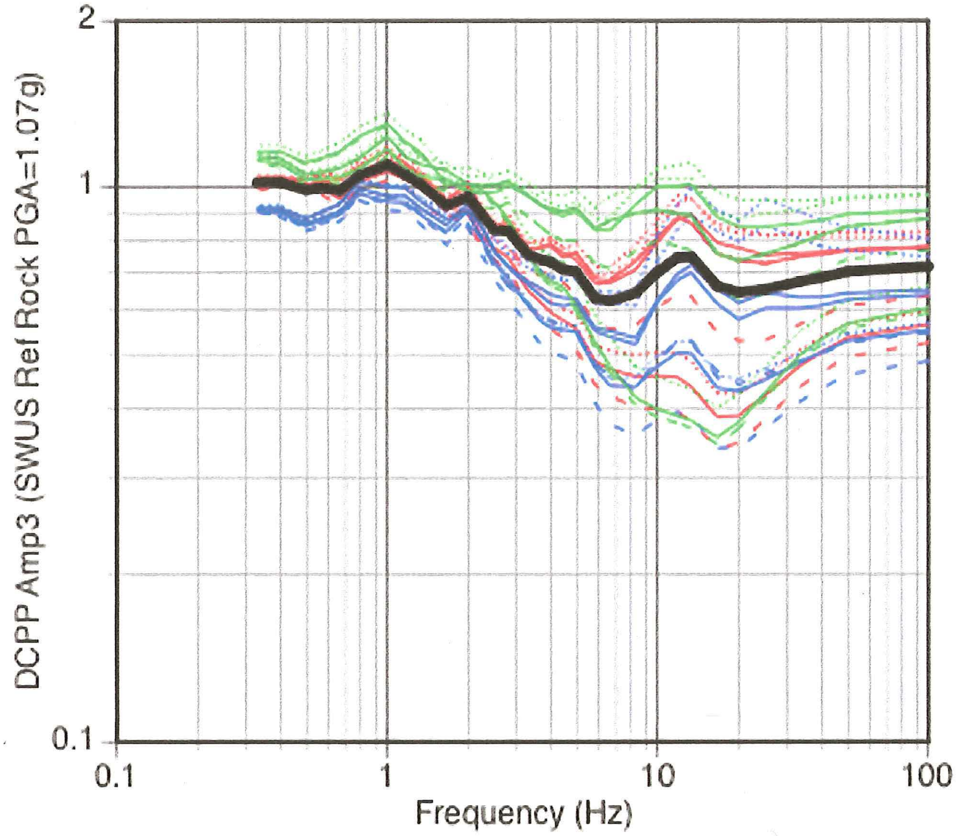

Figure 3-8 - Analytical site terms for a SWUS reference rock (760 m/s) PGA of 1.07 g

(The green curves are for the lower VS profile; red curves are for the central VS profile; and the blue curves are for the upper VS profile. The short dashed lines are for the target kappa of 0.03 sec, the long dashed lines are for the target kappa of 0.05 sec, and the solid lines are for the target kappa of 0.04 sec. The black line is the mean.)
(From Reference 9)

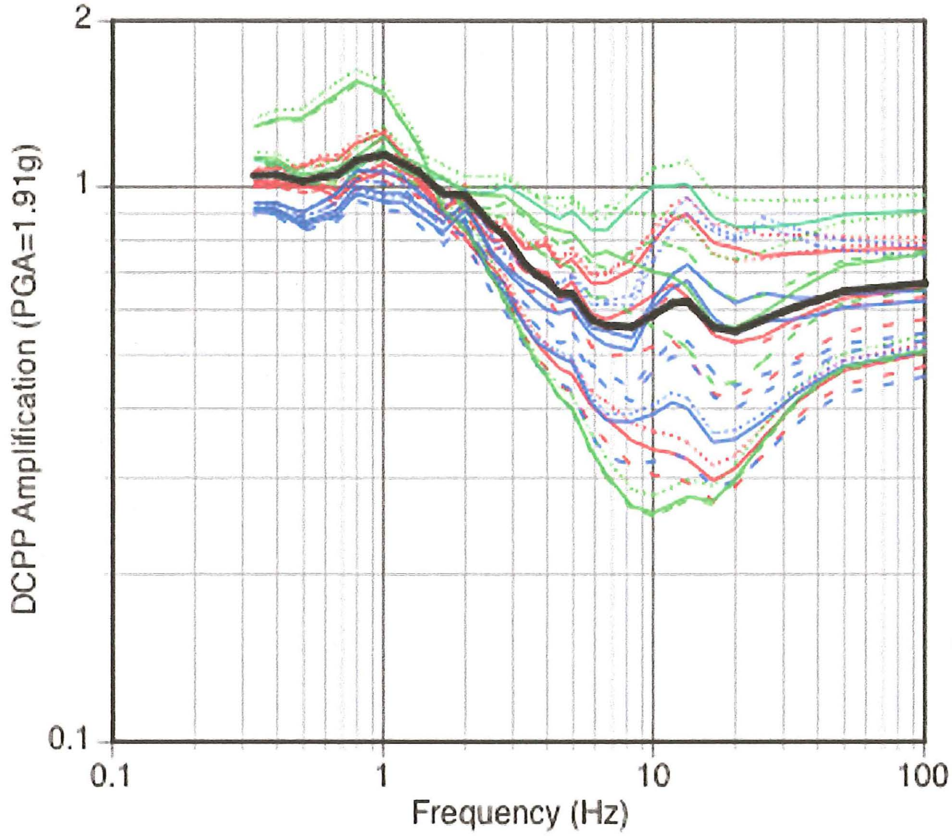

Figure 3-9 - Analytical site terms for a SWUS reference rock (760 m/s) PGA of 1.91 g, corresponding to the 1E-5 hazard level.

(The green curves are for the lower VS profile; red curves are for the central VS profile; and the blue curves are for the upper VS profile. The short dashed lines are for the target kappa of 0.03 sec, the long dashed lines are for the target kappa of 0.05 sec, and the solid lines are for the target kappa of 0.04 sec. The black line is the mean.) (From Reference 9)

4. EMPIRICAL SITE RESPONSE APPROACH

4.1 Residuals for ESTA27 and ESTA28

Station ESTA27 recorded both the 2003 San Simeon and the 2004 Parkfield earthquakes. Station ESTA28 only recorded the 2004 Parkfield earthquake. The event-path corrected residuals are listed in Table 4-1. Following the methodology used in the DCPP Seismic Hazard and Screening Report (Reference 3), they are adjusted to account for the expected differences in the average SA due to the differences between the VS30 for the control point and the VS30 for the two free-field sites.

The VS30 values for central models for ESTA27, ESTA28, and the control point are listed in Table 4-2. The VS30 adjustment factors, based on the NGA-W2 GMPEs are listed in Table 4-3.

The standard error of the DCPP site term, $\delta S\hat{2}S(f)$, has three parts:

(1) There is the standard error (SE) due to the number of observations at DCPP. PG&E use the phi0 from Lin et al (2011), "Repeatable Source, Site, and Path Effects on the Standard Deviation for Empirical Ground-Motion Prediction Models," (Reference 13) as the estimate of the aleatory variability of the DCPP event-corrected residuals. This part of the SE is phi0 / sqrt(N). Although there are 3 recordings, the data at ESTA27 and ESTA28 for the Parkfield earthquake are correlated. So, N=2 is used as a conservative assumption.

(2) The second part is the SE of the estimate of the event-path term, SP_j, terms. For each event, this is the SE of the mean (sigma/sqrt(n)) for each earthquake.

(3) The third part is SE of the VS30 adjustment (correcting the ESTA27 and ESTA28 residuals to the control point). The standard deviation of the VS30 at ESTA27 and ESTA28 is about 0.18 LN units and the standard deviation of the VS30 for the control point is about 0.23 LN units.

These three sources of uncertainty are uncorrelated and can be combined by simple propagation of errors:

$$SE\left(\delta S\hat{2}S\right) = \sqrt{\frac{1}{4}VAR\left(SP_1\right) + \frac{1}{4}VAR\left(SP_2\right) + \frac{1}{2}\phi_0^2 + \sigma_{VS30\_adjust}^2}$$

The components of the SE are shown in Figure 4-1 and are listed in Table 4-4. The total SEs are smoothed.

Using the standard deviations listed in Table 4-4, the VS values for the central profiles are scaled up and down by exp(1.6 SE). The resulting lower and upper profiles are listed in Table 4-5.

4.2 Changes from the Approach used in the DCPP Seismic Hazard and Screening Report

There were three changes to the approach to empirical site terms used in the SHSR:

1) The control point was changed from the location of ESTA28 at elevation 85 feet to being a hypothetical location that represents the center and range of profiles under the power-block and the turbine building.

2) The epistemic uncertainty in the site was computed using the approach described in Section 4.1, rather than the simplified approach used in the SHSR based on the phiS2S from global data.

3) All three recordings at DCPP from the San Simeon and Parkfield earthquakes were used rather than just using the ESTA27 recording from San Simeon (adjusted to ESTA28) and the ESTA28 recording from Parkfield. All three are considered applicable to the average for the power-block and turbine building region.

Table 4-1 - Event-Path Corrected Residuals(from Reference 9)

Period (sec)	Parkfield ESTA28	San Simeon ESTA27	Parkfield ESTA27
0.01	-0.296	-0.242	-0.028
0.02	-0.310	-0.259	-0.046
0.03	-0.330	-0.315	-0.140
0.05	-0.508	-0.427	-0.248
0.075	-0.537	-0.382	-0.310
0.1	-0.726	-0.399	-0.480
0.15	-0.476	-0.315	-0.357
0.2	-0.628	-0.076	-0.283
0.25	-0.419	0.117	-0.285
0.3	-0.283	0.100	0.036
0.4	0.292	0.216	0.677
0.5	0.483	0.156	0.798
0.75	0.188	0.517	0.450
1	-0.231	0.560	0.071
1.5	-0.331	0.098	-0.064
2	-0.191	0.917	-0.049

Table 4-2 - VS30 for Free-Field Sites and Hypothetical Control Point
(From Reference 9)

Location	VS30 (m/s)
ESTA27	856
ESTA28	777
Control Point (Power-Block and Turbine Building)	968

Table 4-3 - Linear VS30 Scaling from the Free-Field Sites to the Control Point
(The scaling is computed using four NGA-West2 models for a M6.5 vertical strike-slip earthquake at a rupture distance of 50 km.)
(From Reference 9)

Period (sec.)	PSA (g) for VS30=856 (m/s)	PSA (g) for VS30=777 (m/s)	PSA (g) for VS30=968 (m/s)	VS30 Scale Factor for 968/856	VS30 Scale Factor for 968/777
0.01	0.043	0.045	0.042	0.965	0.922
0.02	0.044	0.046	0.042	0.957	0.916
0.03	0.048	0.050	0.046	0.952	0.916
0.05	0.061	0.063	0.058	0.961	0.932
0.075	0.076	0.079	0.073	0.960	0.930
0.1	0.086	0.089	0.081	0.950	0.914
0.15	0.094	0.100	0.088	0.933	0.885
0.2	0.092	0.098	0.085	0.920	0.862
0.25	0.085	0.091	0.077	0.910	0.845
0.3	0.077	0.083	0.069	0.903	0.833
0.4	0.063	0.069	0.057	0.895	0.821
0.5	0.053	0.058	0.047	0.890	0.812
0.75	0.035	0.039	0.031	0.885	0.804
1	0.025	0.028	0.022	0.882	0.798
1.5	0.015	0.017	0.013	0.879	0.793
2	0.010	0.012	0.009	0.890	0.805
3	0.006	0.007	0.006	0.919	0.844
4	0.004	0.004	0.004	0.939	0.868
5	0.003	0.003	0.003	0.943	0.889
7.5	0.002	0.002	0.001	0.949	0.904
10	0.001	0.001	0.001	0.956	0.916

Table 4-4 - Components of the Standard Error of DCPP Site Terms
(From Reference 9)

Period (sec)	STD Dev of VS30 Adjustment (LN units)	phi0 (Reference 13) (LN units)	SE of event –path term (LN Units)	Total SE of DCPP Site Term (LN Units)	Smoothed Total SE of DCPP Site Term (LN units)	1.6*Smoothed Total SE (LN units)
0.01	0.088	0.230	0.112	0.216	0.22	0.352
0.02	0.090	0.232	0.113	0.219	0.22	0.352
0.03	0.080	0.234	0.112	0.215	0.22	0.352
0.05	0.065	0.236	0.115	0.213	0.22	0.352
0.075	0.067	0.238	0.120	0.217	0.22	0.352
0.1	0.082	0.238	0.135	0.231	0.23	0.368
0.15	0.112	0.241	0.162	0.260	0.26	0.416
0.2	0.136	0.244	0.138	0.259	0.26	0.416
0.25	0.155	0.247	0.115	0.260	0.26	0.416
0.3	0.168	0.249	0.109	0.267	0.27	0.432
0.4	0.182	0.267	0.089	0.277	0.28	0.448
0.5	0.192	0.282	0.097	0.293	0.29	0.464
0.75	0.198	0.288	0.113	0.306	0.31	0.496
1	0.202	0.294	0.128	0.317	0.32	0.512
1.5	0.199	0.294	0.151	0.325	0.33	0.528
2	0.189	0.293	0.175	0.331	0.33	0.528

Table 4-5 - DCPP Empirical Site Term with Epistemic Uncertainty
(From Reference 9)

Period (sec)	Frequency (Hz)	Mean (LN units)	Upper Range (LN units)	Lower Range (LN units)
0.01	100	-0.254	0.098	-0.606
0.02	50	-0.278	0.074	-0.630
0.03	33.3	-0.338	0.014	-0.690
0.05	20	-0.454	-0.102	-0.806
0.075	13.3	-0.456	-0.104	-0.808
0.1	10	-0.566	-0.198	-0.934
0.15	6.67	-0.455	-0.039	-0.871
0.2	5	-0.373	0.043	-0.789
0.25	4	-0.240	0.176	-0.656
0.3	3.33	-0.144	0.288	-0.576
0.4	2.5	0.207	0.655	-0.241
0.5	2	0.247	0.711	-0.217
0.75	1.33	0.260	0.756	-0.236
1	1	0.077	0.589	-0.435
1.5	0.667	0.000	0.560	-0.560
2	0.5	0.000	0.560	-0.560
3	0.333	0.000	0.560	-0.560
4	0.25	0.000	0.560	-0.560
5	0.2	0.000	0.560	-0.560
7.5	0.133	0.000	0.560	-0.560
10	0.1	0.000	0.560	-0.560

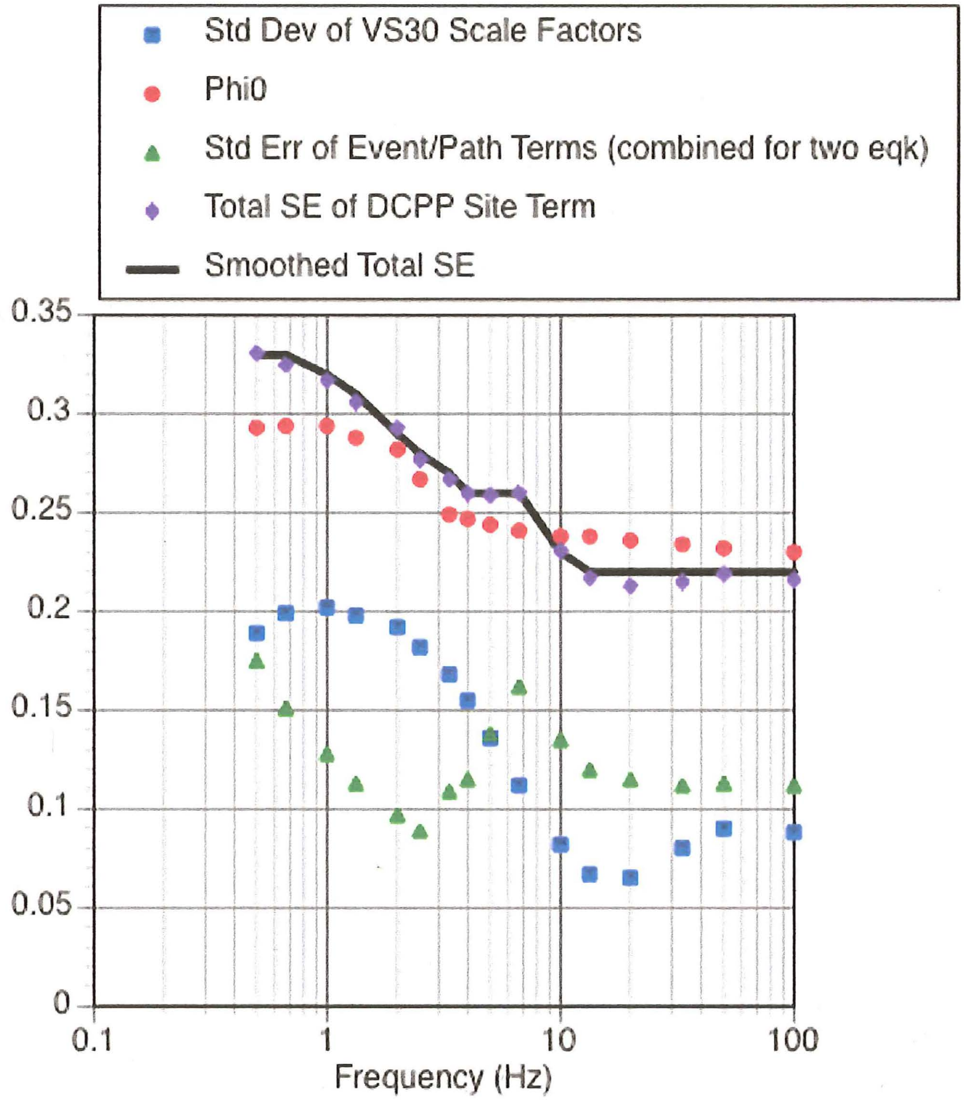

Figure 4-1 - Empirical Site Term for DCPP Relative to SWUS Reference Rock
(From Reference 9)

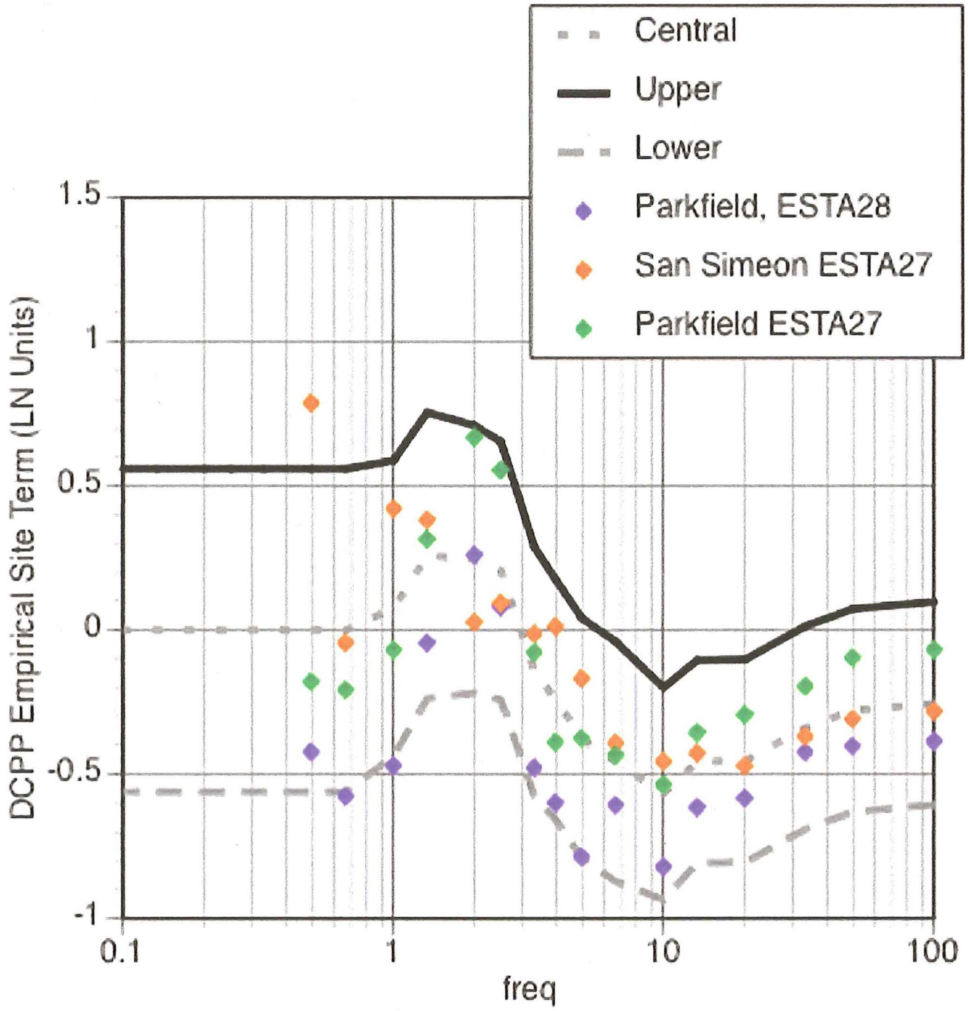

Figure 4-2 - Empirical Site Term for DCPP Relative to SWUS Reference Rock
(From Reference 9)