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U.S. DEPARTMENT OF ENERGY
OFFICE OF RIVER PROTECTION POSITION

CONCERNING

ASSUMED PROBABILITY OF TECTONIC ACTIVITY, AND ADEQUACY OF GROUND MOTION ATTENUATION MODEL USED IN THE DESIGN OF THE WASTE TREATMENT PLANT

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ASSUMED PROBABILITY OF TECTONIC ACTIVITY, AND ADEQUACY OF GROUND MOTION ATTENUATION MODEL USED IN THE DESIGN OF THE WASTE TREATMENT PLANT

1.0 PURPOSE

This position paper provides the Office of River Protection's (ORP) technical position concerning the probability of tectonic activity of the anticlines and associated faults for the Yakima Folds, and the appropriate spectral amplification to be associated with the attenuation relationship used in the ground motion attenuation model for the Waste Treatment Plant (WTP).

2.0 BACKGROUND

The River Protection Project WTP selected DOE-STD-1020-94 as the seismic standard for the facility in 1997, using the contractually required standards-based integrated safety management selection process. The U.S. Department of Energy (DOE), Office of Safety Regulation (OSR) approved this selection in 1997.

In order to perform the facility design, the previous contractor, BNFL Inc., selected the most limiting site-specific peak ground acceleration (.26 g horizontal, .18 g vertical) associated with the 2,000-year recurrence interval, along with the corresponding site-specific seismic response spectra. (A 2,000 year recurrence interval was selected because the facility is Performance Category 3 using DOE-STD-1020, having significant radiological hazard (Hazard Category 2), but less than a nuclear reactor).

These acceleration values, and associated spectra, originated in the seismic hazard report for the Hanford Site (Geomatrix 1996). This report refined the seismic hazard model for the region that was begun in 1981 for the Washington Public Power Supply System's reactor sites, and that was subsequently updated to accommodate the latest seismic considerations in 1989 and 1993-1996. The acceleration and spectra were accepted for the DOE Hanford Site in 1997 by the DOE Richland Operations Office (RL). The determination was extensively peer reviewed, revalidated by the previous privatized contractor, BNFL Inc., and independently reviewed by OSR contractors from the U. S. Corps of Engineers and Lawrence Livermore National Laboratories (LLNL) in 1999. It is also consistent with the latest recommendations of the USGS (National Earthquake Hazard Reduction Project, or NEHRP). Subsequently, the current contractor, Bechtel National, Inc. (BNI), adopted the same criteria in 2001, after a due diligence review.

The Defense Nuclear Facilities Safety Board (DNFSB) staff questioned the assumptions used in the seismic design, in informal discussion on March 21-22, 2002. Initially, the focus of these was the adequacy of the geotechnical survey of the site performed by Shannon-Wilson (all of these issues have subsequently been resolved by providing additional information), related to the seismic design basis. Follow-up discussions were held on April 18, 2002. On May 22-23, 2002, the DNFSB further explored these and other issues with DOE and BNI, in combination with a site visit by Vice Chairman Eggenberger. The seismic concerns of the DNFSB that are the subject of this position paper were discussed in some detail at a June 5, 2002, meeting held in

San Francisco, California. Since that meeting, further discussions with the DNFSB staff, and between BNI and DOE have occurred, and additional information has been provided on June 28, 2002, and July 8, 2002.

3.0 POSITION

a. The probability of tectonic activity table in Geomatrix (1996, Table 3-1) is appropriate for use by the ORP for the WTP located on the Hanford Site, when used as input to the probabilistic seismic hazard analysis currently required by the Safety Requirements Document Safety Criterion 4.1-3 (which endorses DOE STD 1020).

b. The design ground response spectra developed in Geomatrix (1996) are adequate and the use of California soil attenuation models is appropriate for application to the Hanford Site.

4.0 ANALYSIS

4.1 Probability of Tectonic Activity

The Probability of Activity Table (Table 3-1) in Geomatrix (1996) was developed in a multi-step process. That table is reproduced here as Table 1. An expert team (Attachment 3) of geologists, geophysicist, and seismologists, with Pacific Northwest and Hanford site-specific knowledge, collectively assembled the geologic and seismologic data used. Most of the members of this team had at least two decades of experience in the area and have the greatest knowledge of the area. This group continues to actively study the tectonics of the area.

Once the data were assembled, an expert team (Attachment 3) of probabilistic hazard practicians worked with the technical team to determine the relative probabilities of activity to ensure that they were appropriately selected. The team of geologists, geophysicist, and seismologists also assembled the most current fault recurrence rates and worked with the probabilistic hazards team to ensure that the fault recurrence rates were appropriately selected. The Geomatrix report was then subjected to a formal and informal peer review by members of the geotechnical community (Attachment 3). The comments were resolved and the final report was issued.

It is important to distinguish differences between the probability of activity for a given source and the subsequent assignment of “fault” slip rates to these sources. As a general result of the lack of late Quaternary deformation for most of these “fault” sources, slip rates relied on the pre-Quaternary history of deformation. The principal record of rate of growth of the Yakima folds comes from the Miocene, specifically 16-8 Ma. Studies have shown that the growth of the Yakima folds was greatest during the Miocene. Deformation of the late Miocene to Pliocene Ringold Formation sediments is recorded also in the folds but evidence for Quaternary and Holocene deformation, and thus slips rates, is sparse to absent (except for example, Toppenish Ridge). As a result, slip rates for the faults are based upon Miocene growth rates for the Yakima folds that have been extrapolated to the present, which we believe is the best estimate that can be made for slip rates on these sources.

In contrast, the assessment of probability of activity is strongly influenced by evidence (or lack thereof) of late Quaternary deformation, with lower reliance on the pre-Quaternary history of deformation. Thus, there should not be expected a strong correlation between the probability of activity and the rates of slip assigned to “fault” sources.

Since the release of the report, the US Geological Survey’s (USGS) seismic hazard assessment’s 2500-year ground motion study was completed and was found to compare favorably with this study (see Figure 1). The USGS is currently revising that original hazards study and is incorporating many of the faults and slip rates used in the Geomatrix report in their current update of the US hazards maps. The local experts are involved in that process and are contributing site information to those maps.

In addition, the Probability of Activity values are consistent with a new generation of models for the development of the Yakima Fold belt. Since the original work done for developing the Hanford seismic hazard model, new models have been presented in the literature. These new models (Mege 2001, and Mege and Ernst 2001, and papers cited therein) have related the Columbia River basalt and the Yakima fold belt to hot spot/mantle plume dynamics. The Probability of Activity values are consistent with these newer tectonic models.

Tectonic studies of the Columbia Basin have continued since the release of the Geomatrix report. Most recently, S. Reidel (Pacific Norwest National Laboratory (PNNL)), A. Rohay (PNNL), K. Fecht (Bechtel Hanford, Inc.) and N. Campbell have continued studies in an attempt to find evidence of Quaternary and Holocene faulting in the Yakima Fold Belt. Under a National Earthquakes Hazards Reduction Program grant from the US Geological Survey, they have been studying the Rattlesnake Mountain fault zone, the largest seismic source for the Hanford Site. For the first year of a proposed two year study, they examined the Rattlesnake Mountain fault zone at five locations using ground penetrating radar and auguring techniques. The results of that first phase of that study found no evidence for Quaternary or Holocene faulting.

Table 2, discussed below, has been prepared to further support the DOE position that the results of the process presented in Geomatrix (1996, Table 3-1, and reproduced here as Table 1) process are still valid. Table 2 uses the probability of activity attributes (factors) from Geomatrix (1996**,** see section 3.2.2.1) as column headings and evaluates each of these for each of the “fault” sources used in the probabilistic seismic hazard analysis. Even though developed in the mid-1990’s, these attributes (factors) are consistent with later guidance provided in the Senior Seismic Hazard Analysis Committee report “Recommendation for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts,” (NUREG/CR-6372, see section 4.3.1). The probability of activity values from the Geomatrix report (1996, Table 3-1 and reproduced here in Table 1) are shown in the left column of Table 2 as “Scores,” directly under the item: (Table 3.1 - number).

Table 2 quantifies the relative activity among the structures/faults, based largely on the evidence for recent movement. The categories and rankings used to derive the values in Geomatrix (1996, Table 3-1) were added to this table. These rankings reflect DOE's current thought and best recollection of the rankings that were used in 1996. The total possible number of points or score for any structure is 1.0. The first column is the source. The Geomatrix Table 3-1 probability of activity value is listed there for each source and a score based on the next six columns. The next four columns deal with evidence for Quaternary and Recent deformation or activity. These columns are considered equally important. They are ranked equally and are given values of 0.2 each. The last two columns are considered less important because they are the Pre-Quaternary History, which is based on long-term growth rates (as slip rates), and orientation with respect to the current stress field. They are ranked equally and given a possible value of 0.1 each. The total of all probabilities of activity for each structure is reported in column 1 (Structure) as the "score". The scores for all source structures are similar and a uniform value of 0.25 was applied except for the Hog Ranch anticline (0.1), the Saddle Mountains (0.5) and Toppenish Ridge (1.0).

4.2 Adequacy of Ground Motion Attenuation Model

The following paragraphs present a summary of the results obtained to address the issue of relative site amplification between California deep soil site profiles and Hanford profiles associated with the 200 East area. The uncertainty in the relative site response parameter is considered minor as compared to the relatively large variability associated with the attenuation models. In addition, other conservatisms incorporated into the design basis spectra are equal or greater than uncertainties involved with the relative amplification parameter.

4.2.1 Sensitivity to Profile Variability

Previous sensitivity analyses have been performed to quantify the relative site response effect comparing the surface response of the Hanford site profile(s) to that of the California deep soil site(s) representative of the California soil attenuation models used in the development of the design surface ground response spectrum (Geomatrix 1996). The conclusions presented in Geomatrix 1996 indicated that the relative response was on average unity over the frequency range of typical interest, allowing use of the California soil attentuation models for the Hanford site. The DNFSB staff observed that the relative spectral amplifications (Figure A-22 of Geomatrix 1996) were frequency dependent and were greater than unity in some of the frequency ranges of interest. The fundamental issue is the adequacy of the set of attenuation models used to complete the probabilistic seismic hazard analysis and whether these models inherently include site amplification compatible with that expected at the Hanford site. This is somewhat different than coupling site response with an attenuation model developed for a site condition different than that appropriate for a given facility (an example would be a probabilistic seismic hazard analysis completed for rock site conditions and soil site response being added for application at site specific soil sites).

To address this concern, several additional calculations (Carlson, 7/10/02) were performed to more completely assess the relative site response between California deep soil and Hanford profiles. In this process, site randomization approaches were used for California deep soil and Hanford profiles to develop estimates of the relative amplification factor as a function of frequency. This process is in agreement with current approaches to assessing site response (RG 1.165, NUREG/CR-6728). This process was also selected as being more current when compared to the approaches available and presented in Geomatrix (1996). Attachment 2 describes the process in detail.

In performing these calculations, however, an assessment of uncertainty in profile properties (in particular layer shear wave velocity) is needed to allow for assessment of relative surface responses. Since site-specific data for Hanford is too sparse to compute a detailed assessment of uncertainty, two bounding sets of sigma[1] were used to determine sensitivity of the relative amplification to this parameter set. One set of sigmas selected is based on California soil recording site data and a second set from site-wide measurements from the Savannah River Site (SRS). The first data set possesses relatively large values of sigma, indicating the large variation in profiles associated with the California recording stations (Figure A-7 of Geomatrix 1996). The second set uses relatively small values of sigma associated with the generally uniform soil conditions encountered at SRS. A typical plot of the mean shear wave velocity profile and +/- one-sigma values from SRS is shown in Figure 4. The soils at SRS, extending to a depth of around 1,000 feet, are typically silty sands and clays and velocity profiles are relatively consistent across the site.

As described in Geomatrix 1996, the soils at Hanford consist generally of sandy alluvium and loess at and near the ground surface, underlain by Hanford sand and gravel flood deposits. The Hanford soils consist of poorly graded gravels and fine to coarse-grained sands, with small amounts of embedded silt and clay components. These soils are generally uncemented. Below the Hanford sands and gravels are soils of the Ringold formation which are described as consisting of an upper unit of silts and sands, a middle unit of muddy, locally cemented gravels and a lower unit of silt and clay. The conglomerates consist of pebble to cobble sizes embedded within a fine to coarse sand matrix. Based on information available at other sites, cementation is variable but usually present to some degree. Although the shear wave velocity data available in the 200 areas do not extend into the Ringold, compression velocity measurements indicate the presence of high velocity intrusions at depths of 200 to 400 feet below grade.

Below the Ringold lie the basalts of the Columbia River Basalt Group. Velocity profiles through the basalts were estimated from various well velocity and stratigraphic data available from the site. A sample of a model profile (P1 profile) is shown in Figure 5, in which the basalts and interbeds (below 500 feet) are shown. Other profiles were developed in the 1996 development of the seismic hazard (Figure 6) that incorporated a number of different high velocity layers through the Hanford and Ringold formations to assess the potential of these interbeds on site response. The comparison of the P1 profile for Hanford with that of SRS shown in Figure 5 indicates potentially much higher profile variability for the Hanford site, especially when considering the variability in depth of these various layers. It is concluded that sigma in velocity for Hanford, although possibly not as great as that associated with the California deep soil recording profiles, is most likely higher than that associated with the tight data set associated with SRS.

To determine sensitivity of the relative amplification ratio, Hanford to California deep soil, to the sigma profiles, three sets of randomized convolution calculations were performed. The first set used the values of sigma associated with the California deep soil profile, a second set using the SRS sigma profile and a third set using an intermediate sigma profile (average of California deep soil and SRS) for the Hanford P1 profile. A plot of these sigma profiles is shown in Figure 7. The results from these calculations are presented in Figure 8 together with the data originally presented in Geomatrix 1996.

[1] "Sigma," as used here, means the standard deviation of the log of the shear wave velocity for any one soil layer.

If the relatively large values of sigma associated with the California deep soil data set are used, the relative amplifications are uniformly less than unity across the entire frequency range of interest. If the small values of sigma associated with the SRS data set are used, the relative amplifications are also less than unity, except in the frequency range from 4 Hz to 9 Hz. The exceedances are generally small with the maximum exceedance being approximately 15% at about 5 Hz. If the intermediate range of sigma values is used, exceedances occur in the narrow frequency range from 4 Hz to 5 Hz with the maximum exceedance being only 3%. These exceedances are less than those originally contained in Geomatrix 1996. The conclusion of this sensitivity study is that the relative amplification is less than unity over almost the entire frequency range of interest, with only small exceedance over a very small frequency range. These exceedances are insignificant when compared to the other uncertainties typically included in the assessment of the design basis hazard.

4.2.2 Degradation Models for Gravelly Hanford Soils

In the convolution calculations performed for the Hanford site profiles, the soil degradation model used to account for nonlinear effects in the site column responses made use of the degradation models determined by Shannon & Wilson (1994). These degradation curves are similar to the EPRI93 model (Figure A-12 of Geomatrix 1996) and are similar to the upper range of the original Seed-Idriss sand degradation model. Recent summary work for gravels by Rollins, et al (ASCE Geotechnical Journal, 1998) indicates that the degradation model associated with gravelly soils is much more nonlinear than the EPRI curves, that is, shear modulus degradation occurs at much lower strain levels than for typical sand data. The coarser the grain sizes the greater the degradation in shear wave velocity with strain. The effect of this nonlinearity would be to decrease the site amplifications for the Hanford soils, further lowering the relative amplification effects.

4.2.3 Other Conservatisms Included in Ground Motion Definitions

In addition to the conservatism included in the relative amplification between Hanford and California deep soil, a number of other conservatisms have been incorporated into the development of the design response spectra. First is the fact that the design surface spectrum is based on the envelope of the ground spectra developed from both the 200 West and East areas. As noted in Figure 9, the 5% damped design ground response spectrum for 200W exceeds the 200E spectrum by about 8% at 5 Hz, the peak of the spectrum.

Secondly, the generation of the H1 and H2 time histories that envelope the design ground spectrum at 5% damping (Figures 10 and 11) both exceed the target at the peak of the spectrum by about 5%. These time histories define the input into the SASSI response analyses and define the input from which load resultants are determined.

4.2.4 Conclusion

Based on the material presented and the conservatisms discussed above, it is concluded that the use of the set of soil attenuation models by Geomatrix (1996) remains appropriate for the WTP site, and these models inherently include soil site amplification consistent with that expected at the WTP.

5.0 REFERENCES

BNFL Inc. (1999), "Validation of the Geomatrix Hanford Seismic Hazard Report for Use on the TWRS-P Project." Prepared for Tank Waste Remediation System Privatization Project, Revision 0 (draft), dated February 18, 1999.

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Rollis, K., et. al. (1998), "Shear Modules and Dumping Relationships for Gravels," ASCE, Journal of Geotechnical and Geoenviornmental Engineering, Vol. 124, No. 5.

Attachment 1. Assessment of Impact of Assumptions Regarding Probability of Tectonic Activity

NOTE: Information requested and previously submitted to cognizant DNFSB staff.

A request was made by the Defense Nuclear Facilities Safety Board staff to perform probabilistic seismic hazard curve sensitivity studies using alternative probability of activity values for the "fault" seismic sources. Table 3 below includes three sets of probabilities of activity for the Yakima Fold seismic sources: the original values used in Geomatrix (1996) and two sets of values used for the sensitivity studies that were proposed by the DNFSB staff.

Figure 2 indicates the change in the composite Yakima Folds hazard curve by comparing the original hazard curve with those using the two sets of modified probabilities of activity. The readily available hazard curves for three spectral ordinates – PGA, 0.3 sec, and 2.0 sec – are indicated.

Figure 3 is similar to Figure 2, except the total hazard curves are presented.

Table 4 uses the hazard curves presented in Figure 2 to derive the 2,000-year spectral ordinate values considering the three sets of probabilities of activity for the Yakima Fold seismic sources. Percentage changes of the spectral ordinate values considering each of the two sets of modified probabilities of activity relative to use of the original probabilities are indicated in this table. The table and figures show that as the probability of activity is increased the mean probabilistic seismic hazard curve also increases, approximately linearly (in annual frequency space) to the proportion increase in the probability of activity.

While these sensitivity studies have been completed, the discussion in Section 4.1 above related to how the probability of activity values were originally developed continues to be valid. DOE's position is that the probability of activity values in the modified sets are inappropriate for use in the probabilistic seismic hazard analysis for the WTP.

Attachment 2. Updated Relative Site Response Study for Hanford

NOTE: Information requested and previously submitted to cognizant DNFSB staff.

This attachment provides an updated relative site response analysis comparing the response of the Hanford profiles to that of California soil sites representative of empirical California soil attenuation models. This updated analysis incorporates randomization of the California and Hanford profiles. The analysis steps agreed upon in informal discussions with cognizant DNFSB staff are numbered below.

1. Develop 30 Randomized Profiles Representative of California Rock Sites

The shallow velocity profile representative of California rock recording sites developed by Silva et al. (1998) was used in this analysis. Randomized profiles were used instead of actual profiles because measured velocities are not available for all of the recording sites. The use of randomized versus measures profiles should not have a significant effect on the results because the objective is to remove the average crustal amplification from the rock records. Figure 12 compares this profile to that used in Appendix A of Geomatrix (1996). Thirty randomized profiles were generated to a depth of 350 feet using the median velocity profile shown on Figure 12 and the covariance model developed by Silva et al. (1998) for rock sites. Figure 13 compares the median and standard deviation velocities for the simulated profiles to the target values. Below 350 feet, the Northern and Southern California crustal models shown on Figure A-11 of Geomatrix (1996) were used to define the rock shear wave velocity to a depth of 3 kilometers.

2. Select Appropriate California Rock Recordings.

The updated relative response analysis was performed using the 8 crustal earthquake recordings listed in Table A-2 of Geomatrix (1996). For this analysis, both horizontal components were used. Figure 14 shows the 5%-damped response spectra for the 16 components.

3. Perform Deconvolution Analyses

For each of the 30 California rock profiles developed in Step 1, the 16 rock recordings were deconvolved to a depth of 3 km. The analyses were conducted assuming that the rock behaves as a linear material. The damping in the upper 2 kilometers of the rock was computed using the procedure described in Appendix A of Geomatrix (1996) and was set to produce a value of κ of 0.04 seconds. The upper 100 meters of the Northern and Southern California crustal models were replaced by a layer with the average shear wave velocity for the rock velocity profile shown on Figure 12. The resulting damping values are given in the following table.

Damping Ratios in Rock for Deconvolution

Depth Range (km)	Average Shear Wave Velocity (km/sec)	Q_S	Damping Ratio (%)
Northern California Crust			
0 – 0.1	0.84	9.8	5.11
0.1 – 0.5	1.95	22.7	2.20
0.5 – 1.0	2.48	28.9	1.73
1.0 – 2.0	2.77	32.3	1.55
Southern California Crust			
0-0.1	0.84	15.0	3.33
0.1-0.4	1.53	27.4	1.83
0.4-1.0	1.67	29.9	1.67
1.0-1.5	1.96	35.1	1.43
1.5-2.0	2.31	41.3	1.21

The motions at 3-kilometer depth were obtained as outcrop motions for input into the relative site response analyses. As a result, 240 Northern California and 240 Southern California base motions were produced.

4. Develop 30 Randomized Profiles Representative of California Soil Sites

The velocity profile representative of California soil recording sites developed by Silva et al. (1998) was used in this analysis. Figure 15 compares this profile to the soil profiles used in Appendix A of Geomatrix (1996). Thirty randomized profiles were developed using the median profile. Because the empirical ground motion data were recorded at sites with varying depth to rock, the depth to rock in the profile randomization was modeled as a uniform distribution between 100 and 1000 feet. Once rock is reached for each soil randomization, the profile below is replaced by the appropriate rock model from Step 1, 15 soil profiles with the Northern California rock profile and 15 soil profiles with the Southern California rock profile. Figure 16 compares the median and standard deviation velocities for the simulated profiles to the target values for California soil sites.

5. Develop 30 Randomized Profiles Representative of Hanford

Figure A-3 of Geomatrix (1996) shows three shear wave velocity profiles considered to be representative of the Hanford Site. Thirty randomized profiles were developed for each of these median velocity profiles using the same California soil site velocity correlation model used in Step 4. Figures 17, 18, and 19 compare the median and standard deviation velocities for the simulated profiles to the target values for the three Hanford profiles. These profiles were placed on top of the shear wave velocity profile for the basalt sequence shown on Figure A-6 of Geomatrix (1996).

As an additional sensitivity analysis, randomized profiles were developed for the three Hanford velocity profiles using the Savannah River Site (SRS) generic velocity correlation model. Figure 20 compares the median and standard deviation velocities for the simulated profiles to the target values for profile P1. Similar results were obtained for profiles P2 and P3.

6. Compute the Response of the California Soil Sites

The 30 randomized California soil and rock profiles from Step 4 were used to compute the surface motions using as input the deconvolved rock motions from Step 3. The 15 Northern California soil and rock profiles were paired with the 240 Northern California base motions and the 15 Southern California soil and rock profiles were paired with the 240 Southern California base motions. The EPRI (1993) shear modulus reduction and damping curves shown on Figure A-12 of Geomatrix (1996) were used for the Northern California soil sites. As recommended in Silva et al. (1998), a reduced set of these curves was used for the Southern California soil sites.

7. Compute the Response of the Hanford Sites

The 30 randomized Hanford soil and rock profiles from Step 5 for the alternative velocity profiles and correlation models shown of Figures 17 through 21 were used to compute the surface motions using as input the deconvolved rock motions from Step 3. Results were computed using both the 240 Northern California base motions and the 240 Southern California base motions. The site-specific 200 East Area shear modulus reduction and damping curves (Shannon and Wilson, 1994) shown on Figure A-12 of Geomatrix (1996) were used for the analysis. The damping in the upper portion of the basalt was set to 2% consistent with Geomatrix (1996). As a sensitivity test, one set of analyses was performed using the modulus reduction and damping relationships developed by EPRI (1993).

8. Compute Spectra Ratios

The relative response between California soil sites and Hanford sites was evaluated by computing the ratio of the response spectra for the surface motions at the two sites computed using the same input base motion. Thus, 480 response spectra ratios were obtained for each Hanford profile case. The spectral ratios were computed for frequencies between 0.2 and 50 Hz (periods of 0.02 to 5 seconds). The original deconvolved motions from Step 3included all frequencies up to 50 Hz. As a result, there was often extensive amplification of the very high frequency motions, producing large peak acceleration values in the outcrop base motions. The deconvolution analysis performed assumes that all of the surface rock motions are a result of vertically propagating shear waves. However, Silva (1986) found that some of the higher frequency surface motions consist of higher mode surface waves. He recommended that surface motions be filtered to remove frequencies higher than about 15 Hz before deconvolution to reduce the potential for overestimation of the motions at depth. This problem was addressed in the convolution analysis by restricting the input motion to frequencies below 15 Hz for the purpose of computing strain-compatible shear modulus and damping values. As a final step, the unfiltered base motion was used to compute the surface motion in order to examine the results at higher frequencies. The resulting surface motions exhibited some amplification at high frequencies (> 25 Hz) which may be an artifact of not filtering the rock motions before deconvolution.

9. Results

Figure 21 shows the statistics of the ratio for the Hanford P1 profile response divided by the California soil site response. Shown are the median (mean log), mean, and 84th-percentile (lognormal assumption) spectral ratios.

Figure 22 compares the median spectral ratio for the three Hanford profiles. All three profiles produce similar median spectral ratios.

Figure 23 shows the effect of using the EPRI soil modulus and damping curves versus the soil modulus reduction and damping curves for the 200 East Area. In general, use of the EPRI curves produces slightly higher response for the Hanford P1 profile.

Figure 24 shows the effect of using the SRS type velocity correlation model versus the California soil site velocity correlation model. The median spectral ratio curves shown on this figure represent the combined statistics for all three Hanford velocity profiles. The use of reduced variability for the Hanford randomized profiles (the SRS correlation model) produces sharper peaks in the relative response. Also shown for comparison on Figure 25 is the average spectral ratio curve from Figure A-22, part (b) of Geomatrix (1996).

10. Conclusions

The updated relative response results indicate that the response of the Hanford soil and basalt profile is generally less than that for California soil sites. The use of a velocity correlation model with lower variability developed for a specific location (e.g. the Savannah River Site) produces some sharper peaks in the relative response, but these peaks are lower that the average relative response curve developed in Appendix A of Geomatrix (1996). The maximum relative response from this updated analysis is about 1.15 and occurs over a narrow frequency range.

Additional References not in Geomatrix (1996)

Silva, W., 1986, Soil response to earthquake ground motion: Report prepared for the Electric Power Research Institute, Research Project RP2556-07, and September.

Silva, W.C., Abrahamson, N., Toro, G., and Costantino, C., 1998, Description and validation of the stochastic ground motion model: Report submitted to Brookhaven National Laboratory, Associated Universities, Inc., New York.

Attachment 3. List of Developers and Reviewers of the Seismic Design Basis for the WTP Discussed in this Paper

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Table 1. Probability of Activity for Yakima Fold

Probability of Activity for Yakima Fold Sources (from Geomatrix 1996, Table 3-1)	
Fold	**Original**
Umtanum-Gable Mountain	0.25
Saddle Mountains	0.50
RAW	0.25
Frenchman Hills	0.25
Rattlesnake Hills	0.25
Yakima Ridge	0.25
Toppenish Ridge	1.00
Manastash Ridge	0.25
Hog Ranch	0.10
Horse Heaven Hills	0.25

Table 2. Assessment of Probability of Activity

Assessment of Probability of Activity						
Structure (Activity, Table 3-1)	Association with Historic Seismicity	Evidence for late Quaternary fault displacement	Geomorphie evidence for geologically recent deformation	Association with neighboring structures showing evidence for Quaternary deformation	Pre-Quaternary history of deformation	Orientation relative to present stress field
Value (total – 1.0)	0.2	**0.2**	**0.2**	**0.2**	**0.1**	**0.1**
Toppenish Ridge **(Table 3.1 - 1.0)** **Score = 1.00**	**Yes**, Native American legends **0.2**	**Yes,** Campbell NEHRP study **0.2**	**Yes**. Many mapped fault scarps. **0.2**	**Yes**. Simco Volcanic field and bulge in Horse Heaven Hills **0.2**	**Yes**, based on long-term growth rates. **0.1**	**Yes** **0.1**
Hog Ranch-Naneum Ridge Anticline **(Table 3.1 - 0.10)** **Score = 0.10**	No **0**	No **0**	No **0**	No **0**	**Yes**, based on long-term growth rates **0.1**	No **0**
Frenchman Hills **Table 3.1 – 0.25)** **Score = 0.20**	No **0**	No (Pliocene to early Pleistocene) (Geomatrix 1990) **0**	No **0**	No **0**	**Yes**, based on long-term growth rates **0.1**	**Yes** **0.1**
Saddle Mountains **(Table 3.1 = 0.50)** **Score = 0.40**	No (Saddle Mts EQ swarm north of structure) **0**	**Yes**, Normal fault in graben. (not as extensive as reported. **0.2**	No. Evidence proposed is not tectonic. **0**	No **0**	**Yes**, based on long-term growth rates **0.1**	**Yes** **0.1**
Manastash Ridge, (continuation of SM) **(Table 3.1 - 0.25)** **Score = 0.20**	No **0**	No **0**	No **0**	No **0**	**Yes**, based on long-term growth rates **0.1**	**Yes** **0.1**
Umtanum Ridge-Gable Mt. **(Table 3.1 - 0.25)** **Score = 0.25**	No **0**	**Yes** – Central fault – small tear fault (tectonic ?) **0.05**	No **0**	No **0**	**Yes**, based on long-term growth rates **0.1**	**Yes** **0.1**
Yakima Ridge **(Table 3.1 - 0.25)** **Score = 0.25**	No **0**	No **0**	No **0**	No **0**	**Yes**, based on long-term growth rates **0.1**	**Yes** **0.1**
Rattlesnake Mt **(Table 3.1 - 0.25)** **Score = 0.20**	No **0**	No **0**	No **0**	No **0**	**Yes**, based on long-term growth rates **0.1**	**Yes** **0.1**
Rattles-Wallula **(Table 3.1 - 0.25)** **Score = 0.25**	No **0**	**Possibly** (Finley Quarry >200Ka **0.05**	No **0**	No **0**	**Yes**, based on long-term growth rates **0.1**	**Yes** **0.1**
Horse Heaven Hills-NW **(Table 3.1 -0.25)** **Score = 0.20**	No **0**	No **0**	No **0**	No **0**	**Yes**, based on long-term growth rates **0.1**	**Yes** **0.1**
Horse Heaven Hills NE **(Table 3.1 - 0.25)** **Score = 0.20**	No **0**	No **0**	No **0**	No **0**	**Yes**, based on long-term growth rates **0.1**	**Yes** **0.1**

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Table 3. Assignment of Probability of Activity for the Yakima Folds.

Table 3. Assignment of Probability of Activity for the Yakima Folds Seismic Sources

Fold	Probability of Activity Original	Modified Set #1	Modified Set #2
Umtanum-Gable Mtn.	0.25	0.75	0.50
Saddle Mtns.	0.50	0.75	0.50
RAW	0.25	0.50	0.50
Frenchman Hills	0.25	0.50	0.50
Rattlesnake Hills	0.25	0.75	0.50
Yakima Ridge	0.25	0.50	0.50
Toppenish Ridge	1.00	1.00	1.00
Manastash Ridge	0.25	0.50	0.50
Hog Ranch	0.10	0.50	0.10
Horse Heaven Hills	0.25	0.50	0.50

Table 4. Changes to Uniform Hazard Spectra.

Table 4. Changes to Uniform Hazard Spectra from Modification of the Probabilities of Activity

Freq. (Hz)	Period (s)	Hazard Level	Original PGA/Sa (g)	Modified Set #1 PGA/Sa (g) [% Change]	Modified Set #2 PGA/Sa (g) [% Change]
33.00	0.03	5.0E-04	0.236[2]	0.310 [31]	0.278 [18]
3.33	0.30	5.0E-04	0.500[2]	0.662 [32]	0.591 [18]
0.50	2.00	5.0E-04	0.127[2]	0.142 [11]	0.135 [6]

Variation from values given in Table 5-1 of Geomatrix (1996) due to arithmetic rounding and differences in the way Geomatrix and Bechtel performed interpolation – see Section 6 of BNFL Inc. (1999

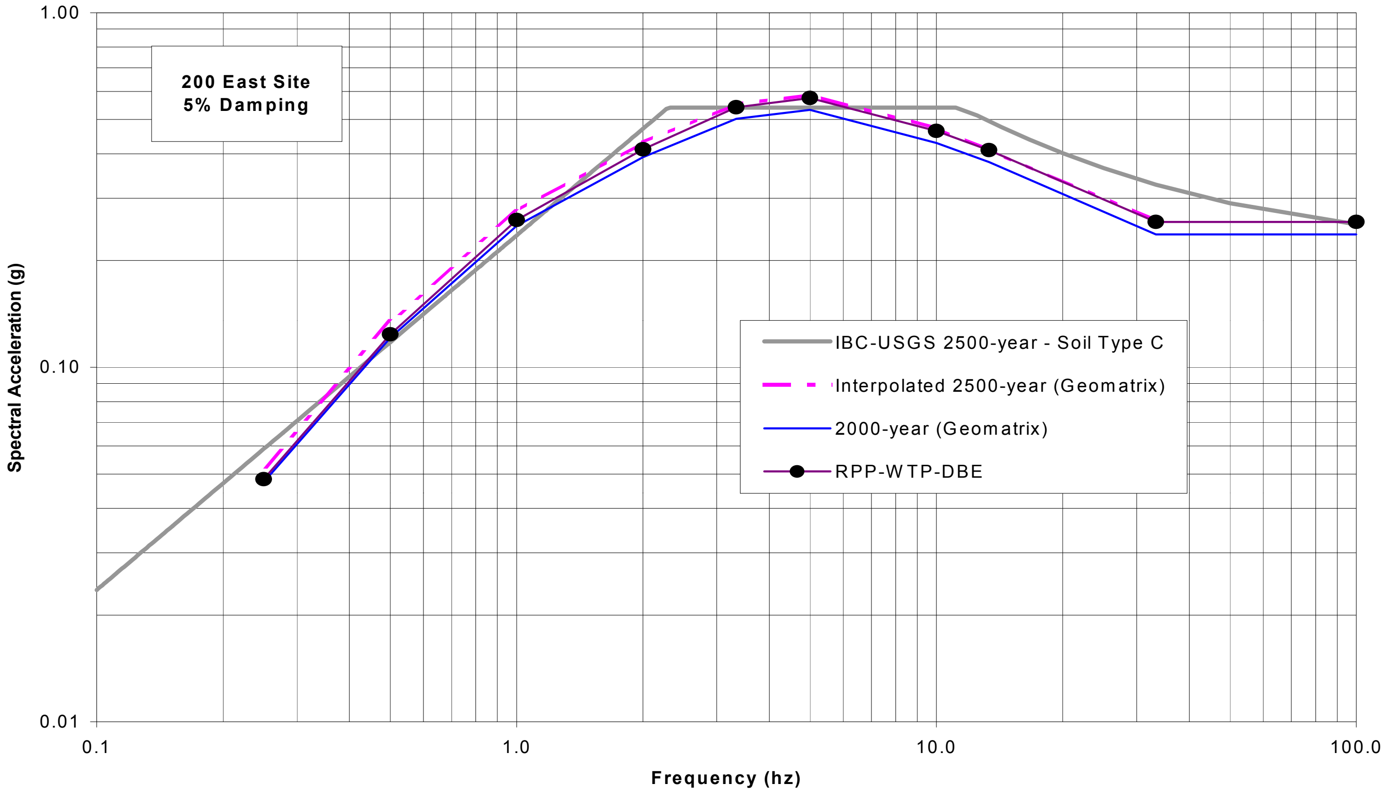

Figure 1. Comparison of Geomatrix 2000- and 2500-year Motions for 200-East Area with DBE and IBC/USGS.

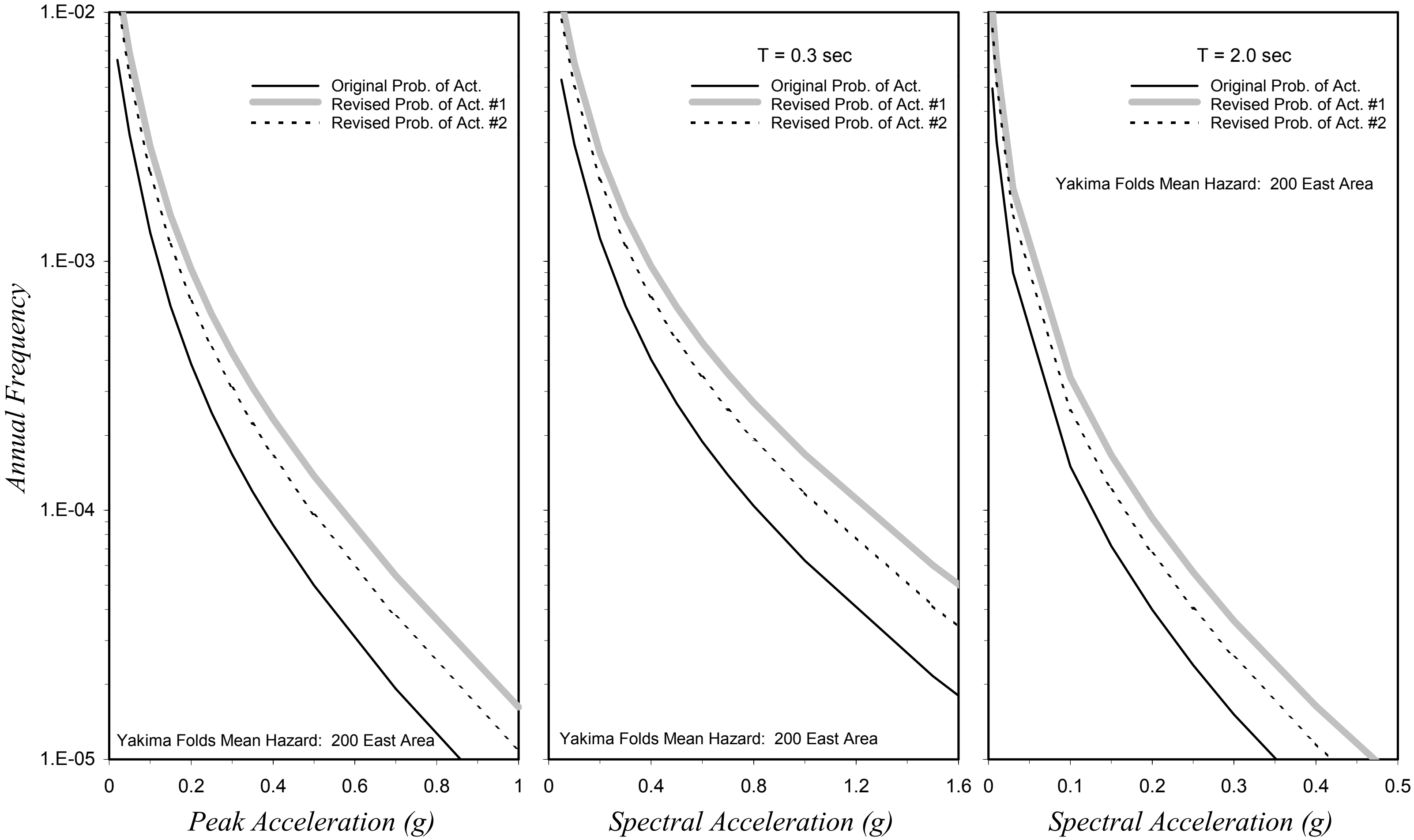

Figure 2. Comparison of mean hazard curves from the Yakima Folds at the 200 East Area for original and modified sets of probabilities of activity.

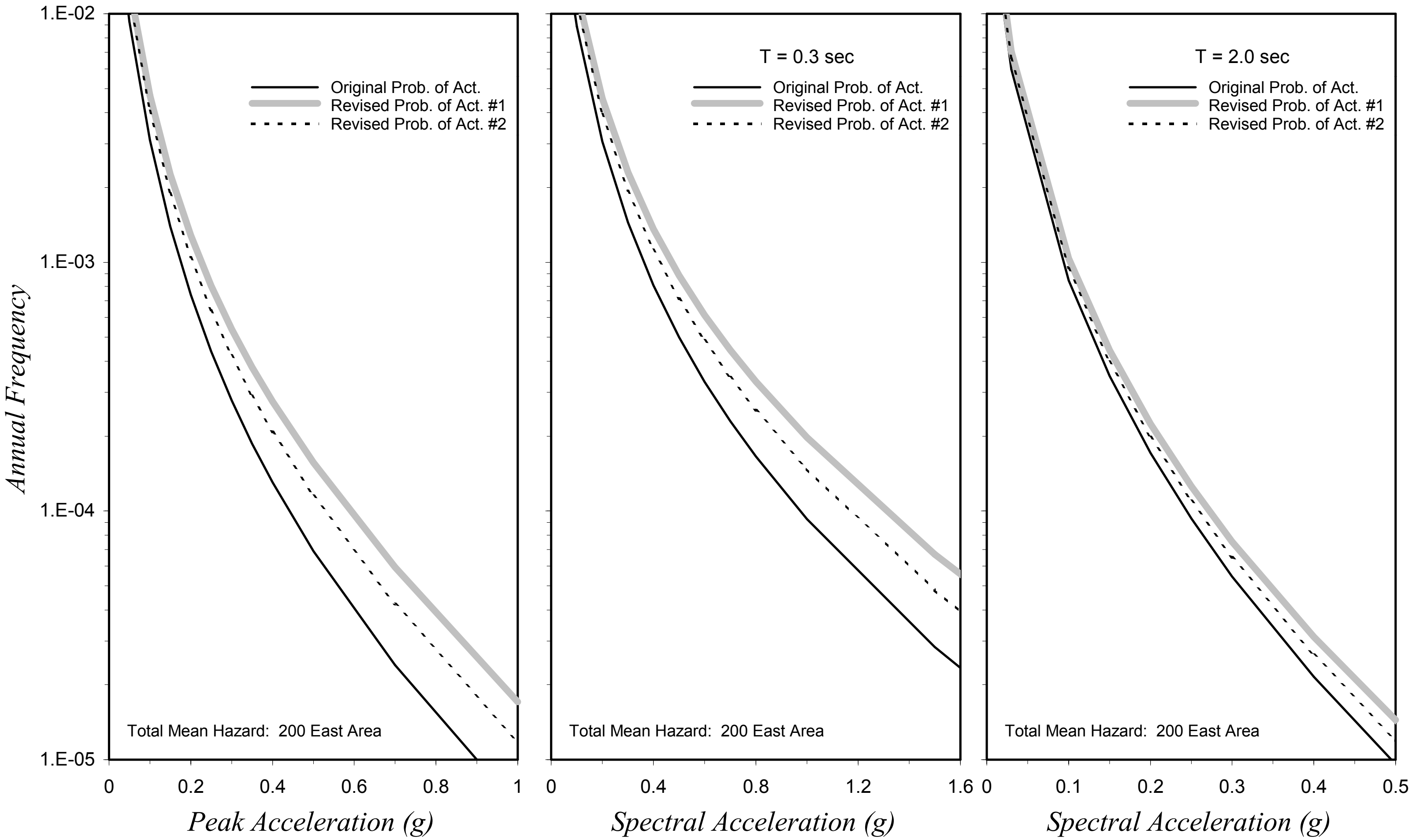

Figure 3. Comparison of Total Mean Hazard Curves at the 200 East Area for Original and Modified Sets of Probabilities of Activity.

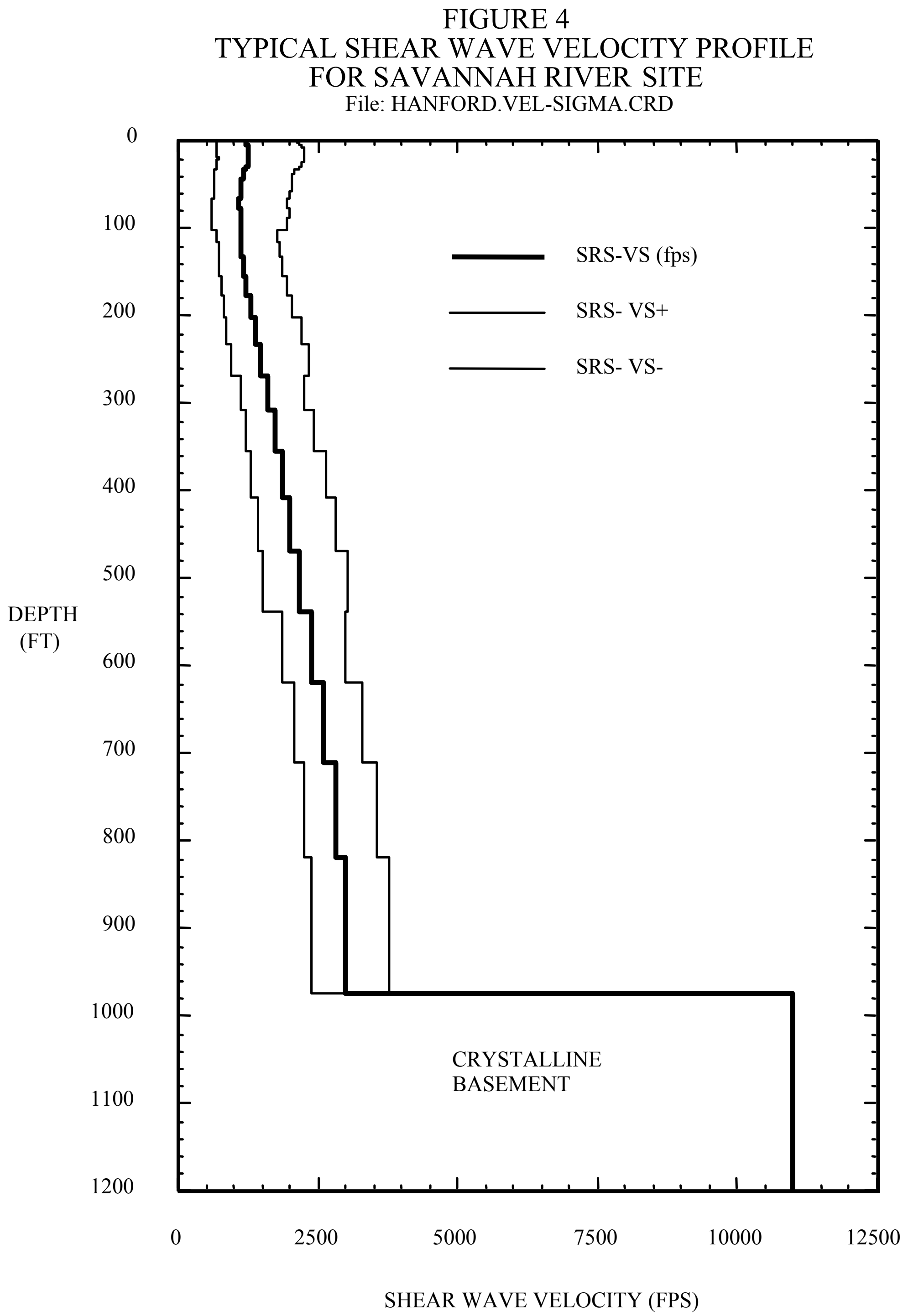

Figure 4. Typical Shear Wave Velocity Profile.

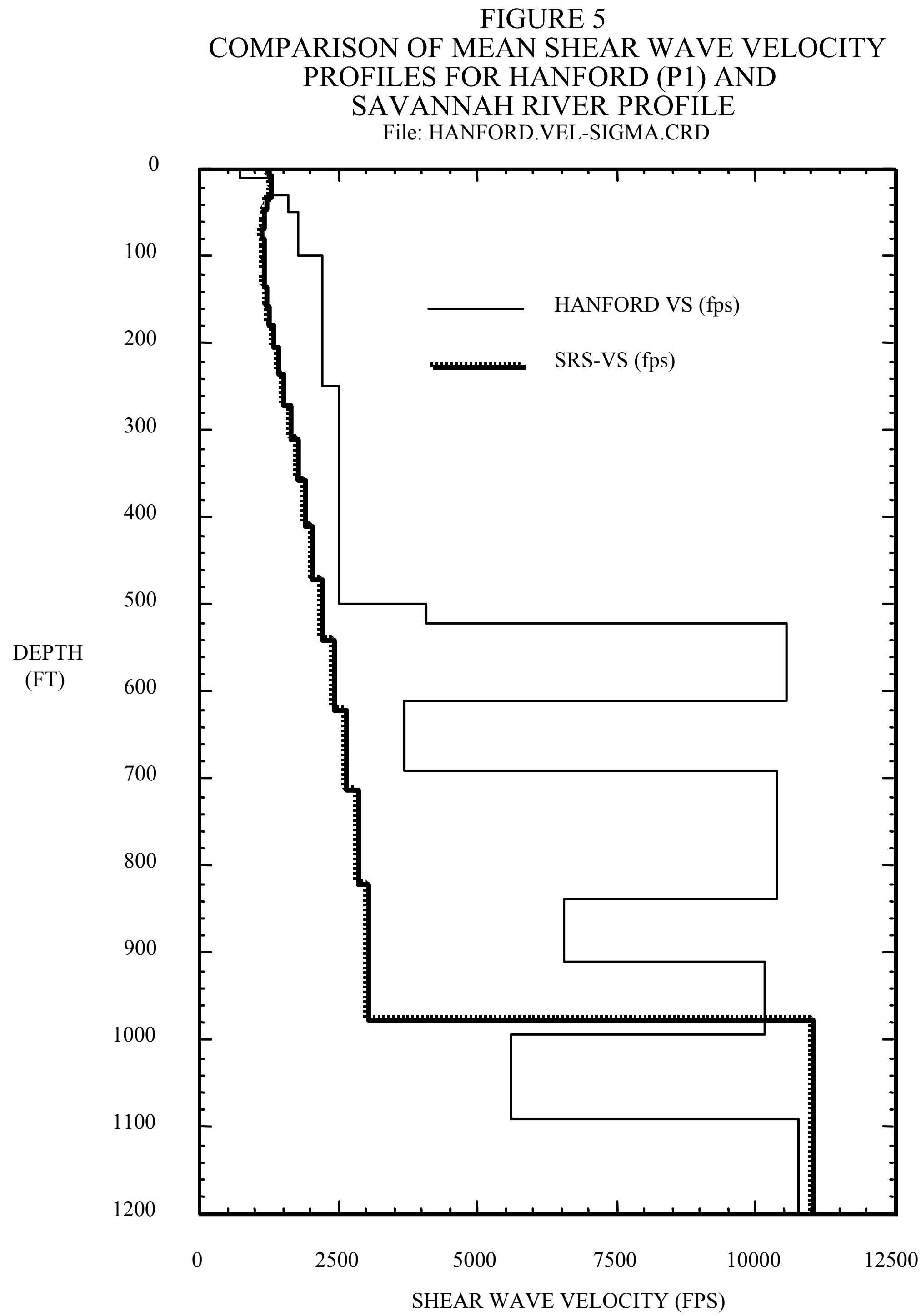

Figure 5. Comparison of Mean Shear Wave Velocity Profiles.

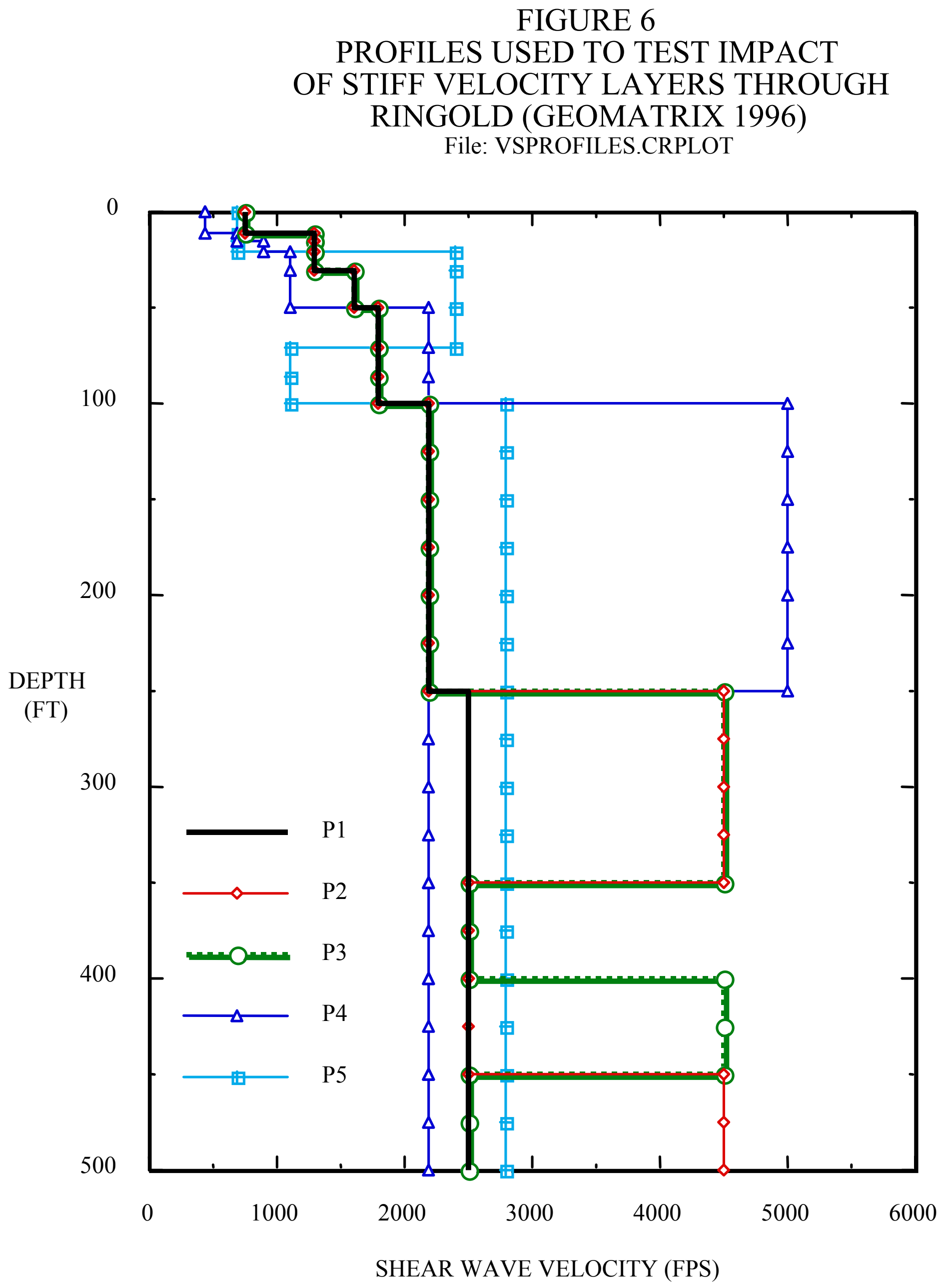

Figure 6. Profiles Used to Test Impact of Stiff Velocity Layers.

FIGURE 7
COMPARISON OF SIGMA FOR
CALIFORNIA DEEP SOIL and SRS PROFILES
File: HANFORD.VEL-SIGMA.CRD

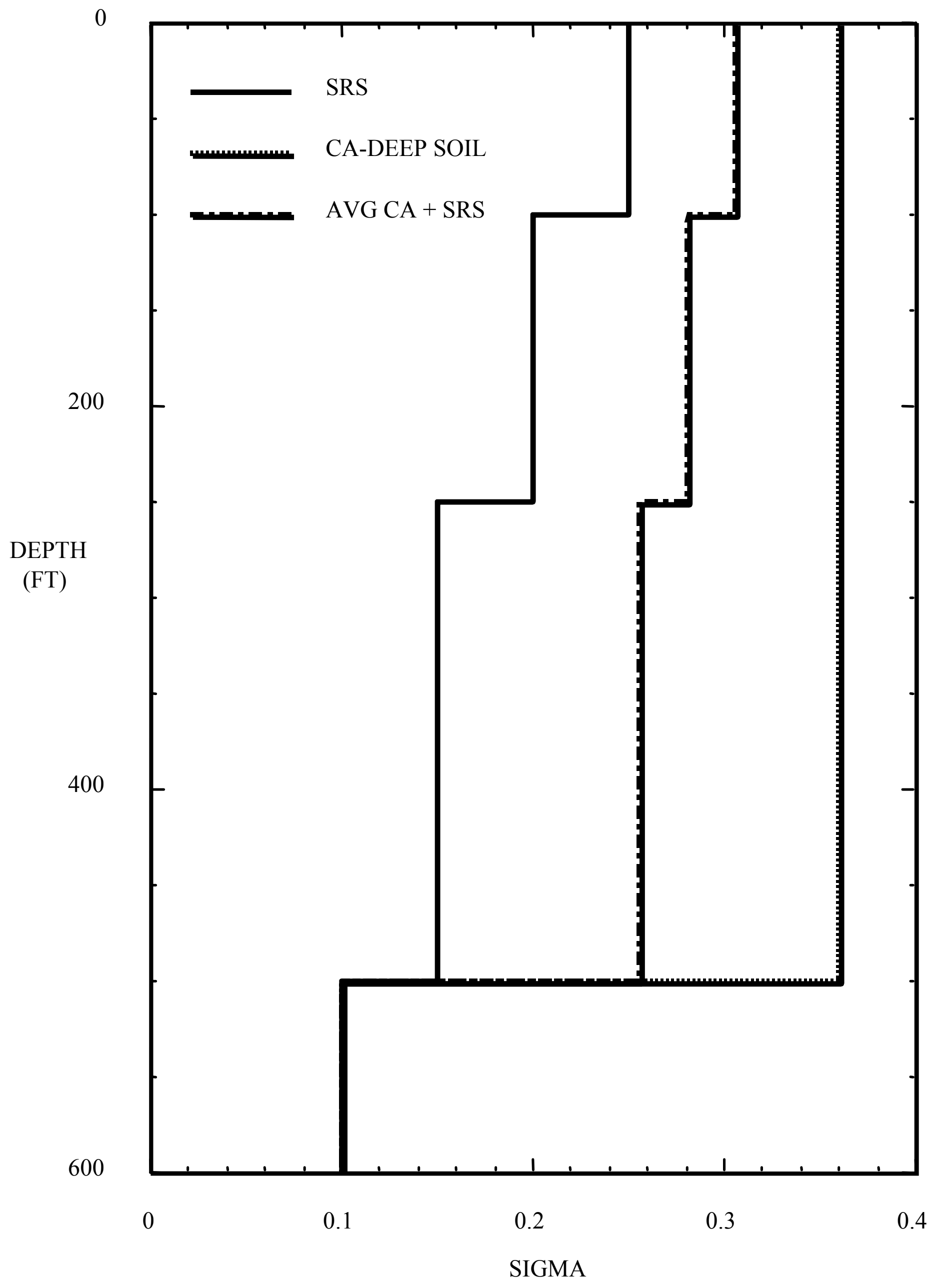

Figure 7. Comparison of Sigma for California Deep Soil and SRS Profiles.

FIGURE 8
INFLUENCE OFASSUMED SIGMA PROFILE
ON COMPUTED SPECTRAL RATIOS
(HANFORD/CALIFORNIA DEEP SOIL)
File: specratio2.crdata

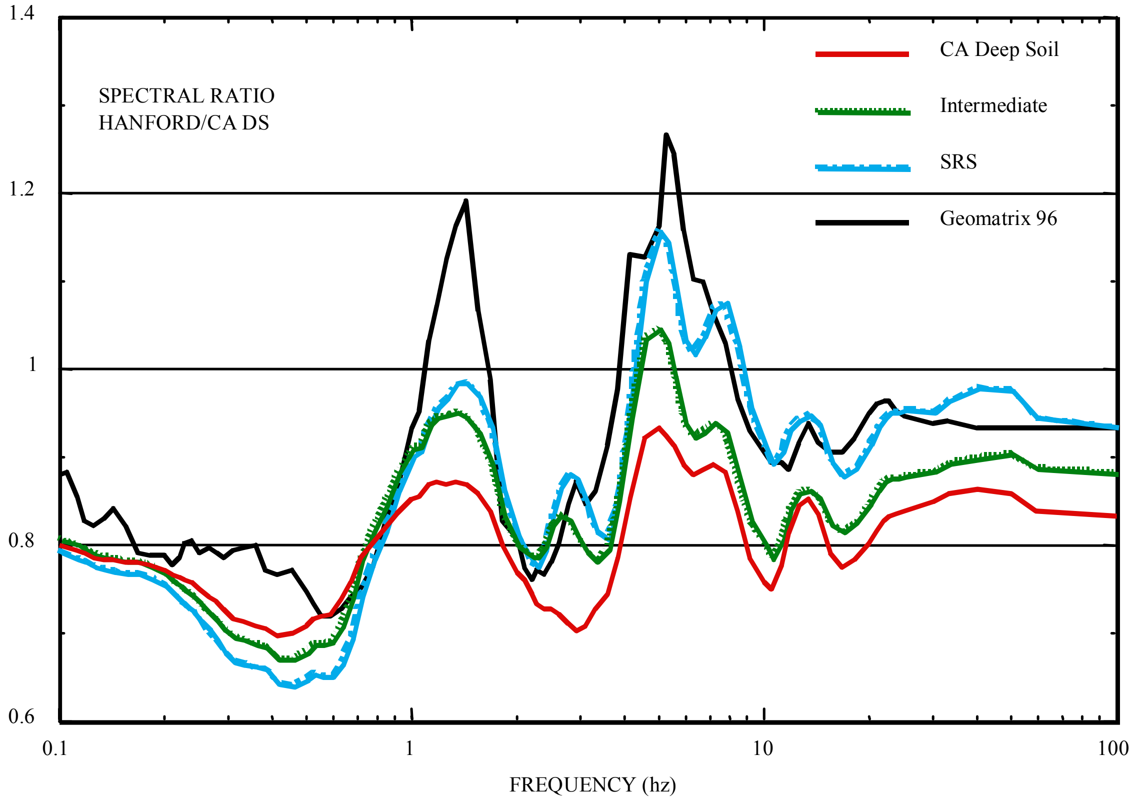

Figure 8. Influence of Assumed Sigma Profile.

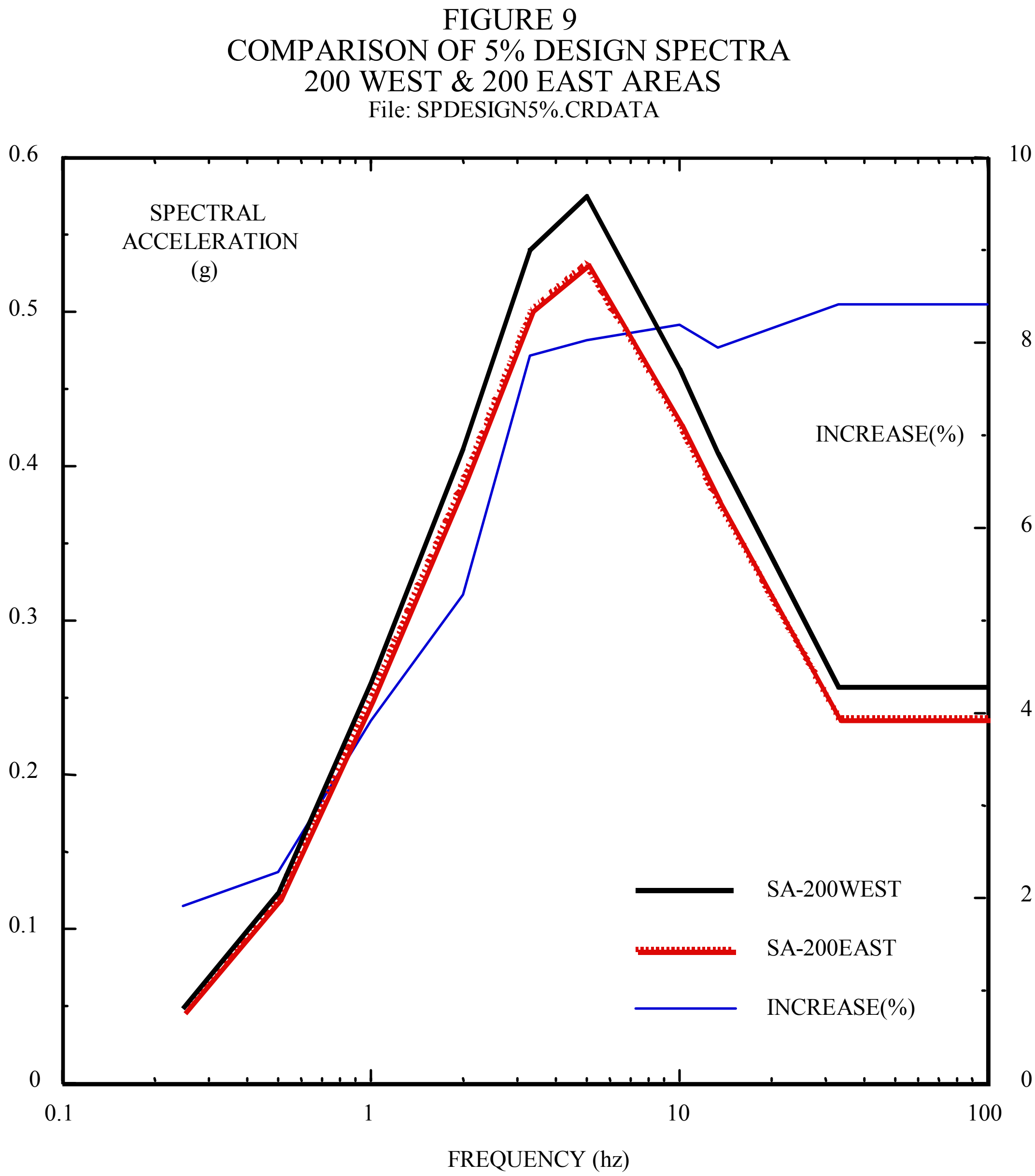

Figure 9. Comparison of 5% Design Spectra.

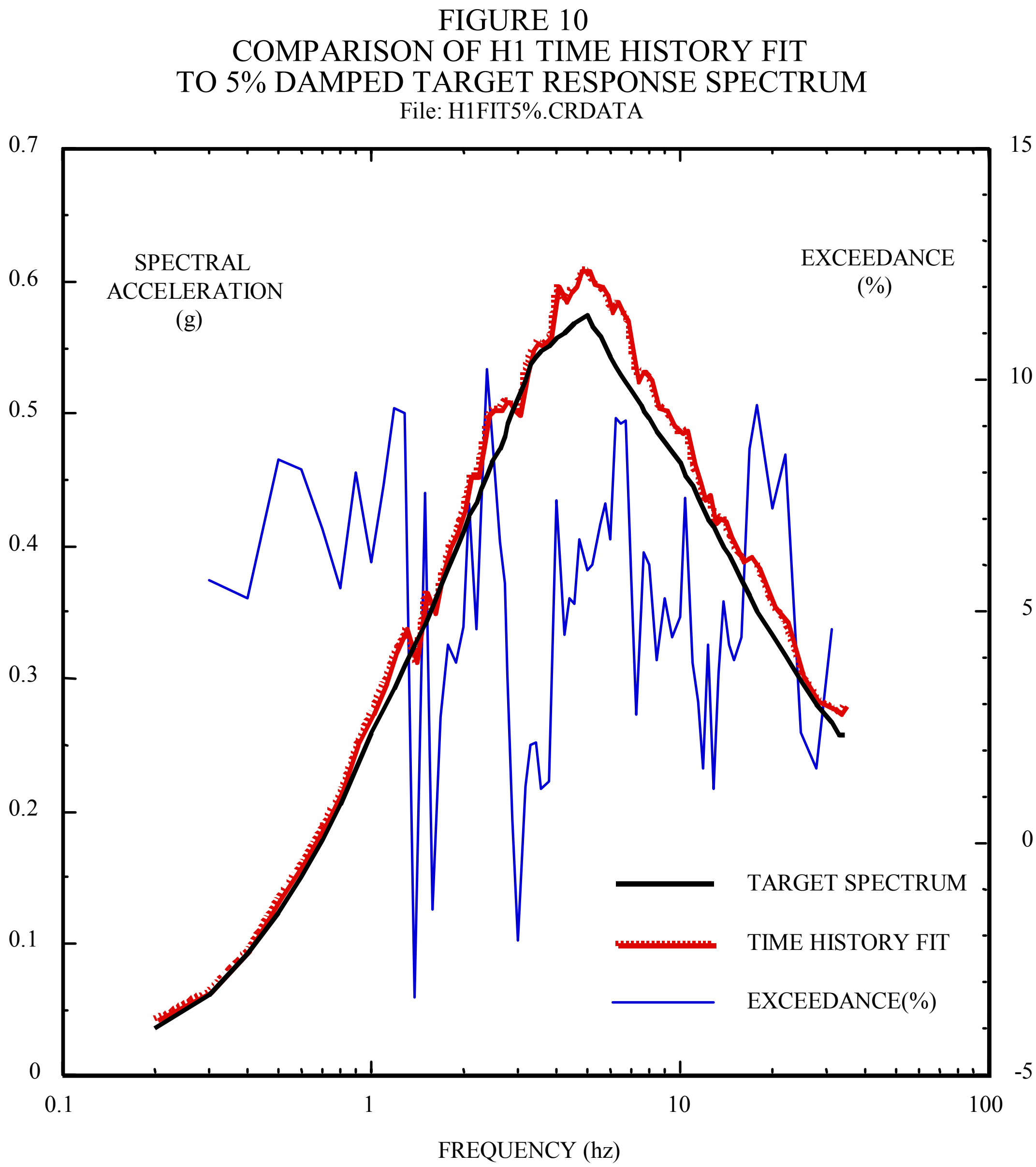

Figure 10. Comparison of H1 Time History Fit.

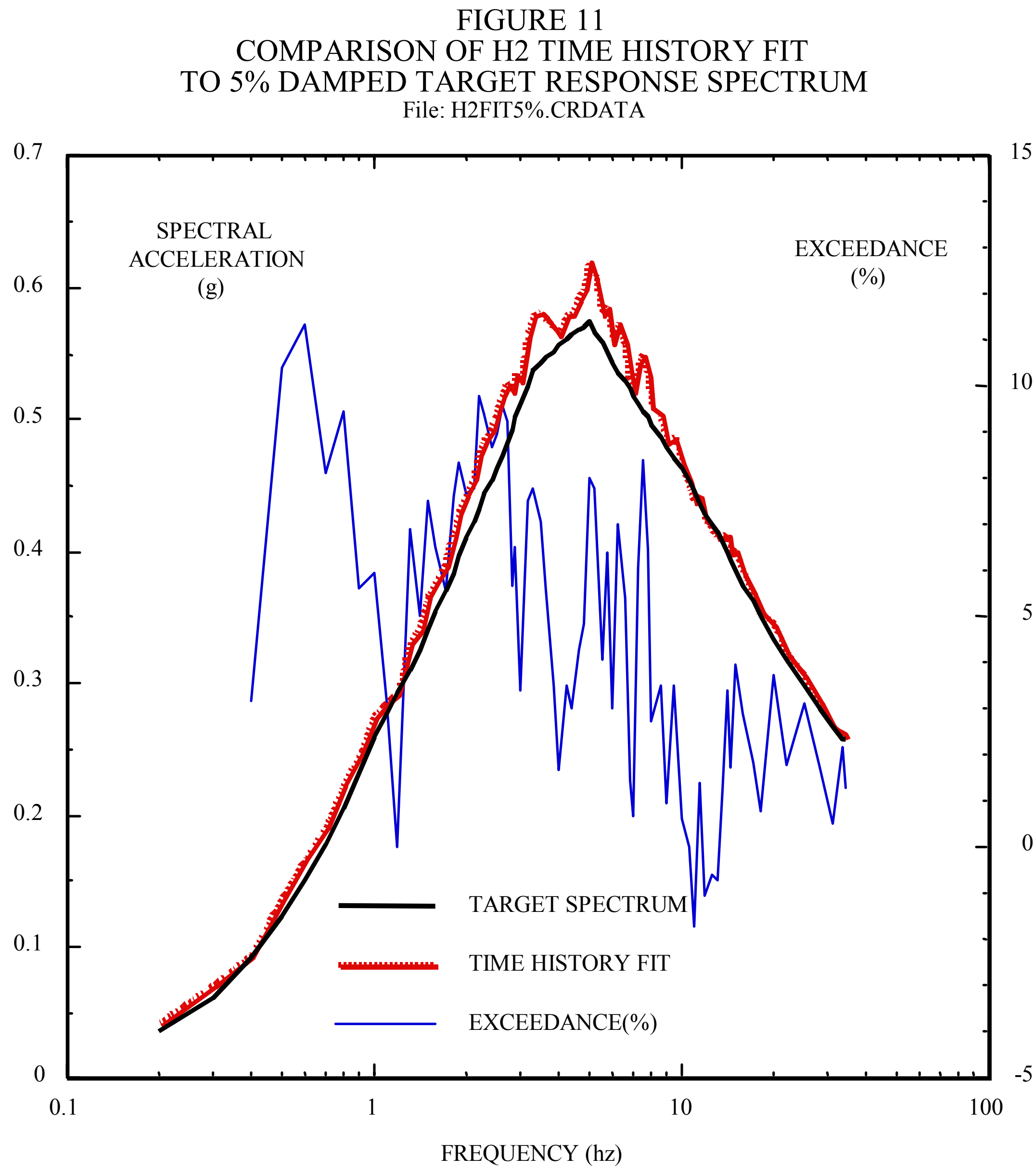

Figure 11. Comparison of H2 Time History Fit.

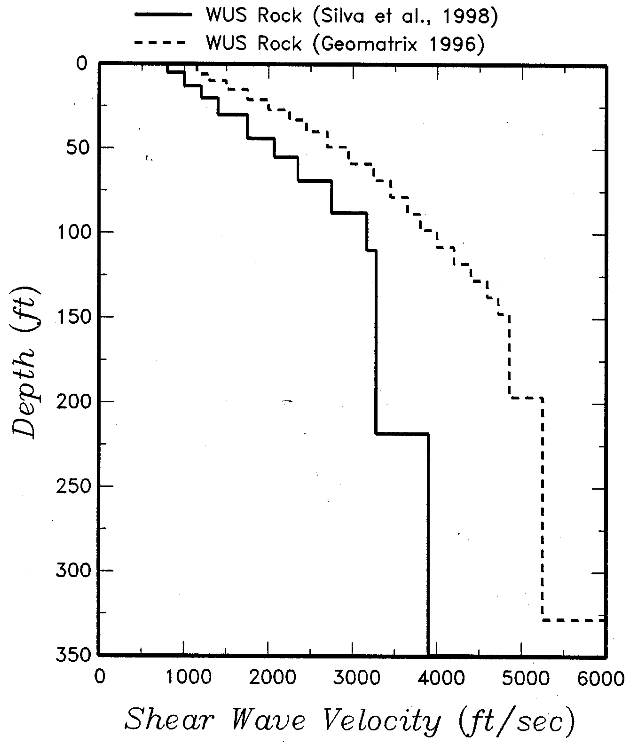

Figure 12. Velocity Profiles for California Rock Sites.

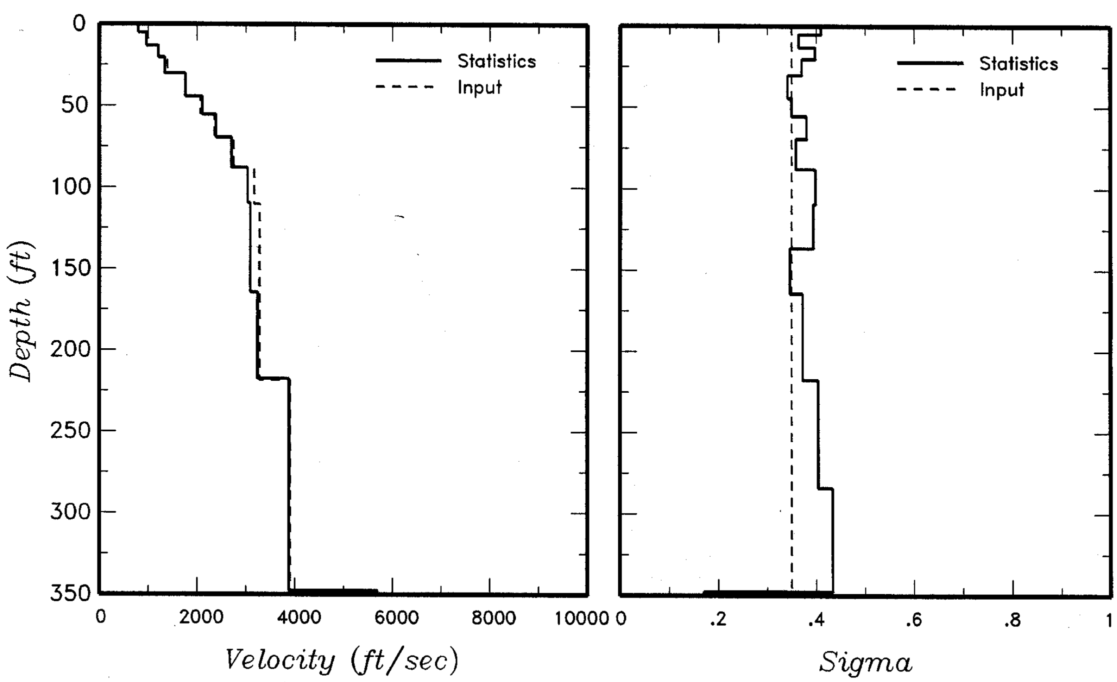

Figure 13. Comparison of Statistics of Randomized California Rock Velocity Profiles to Target Values.

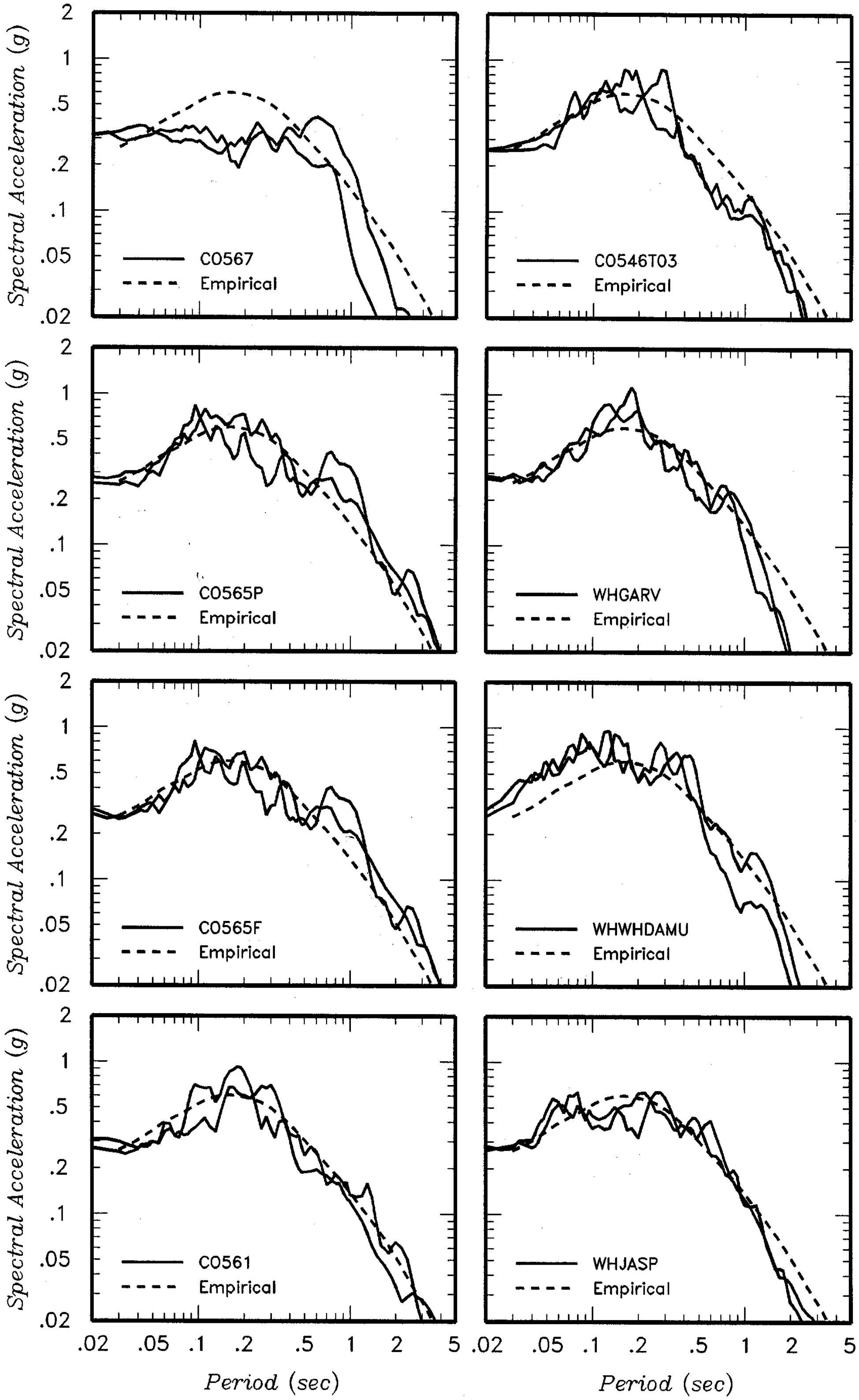

Figure 14. Response Spectra for Selected Rock Site Recordings.

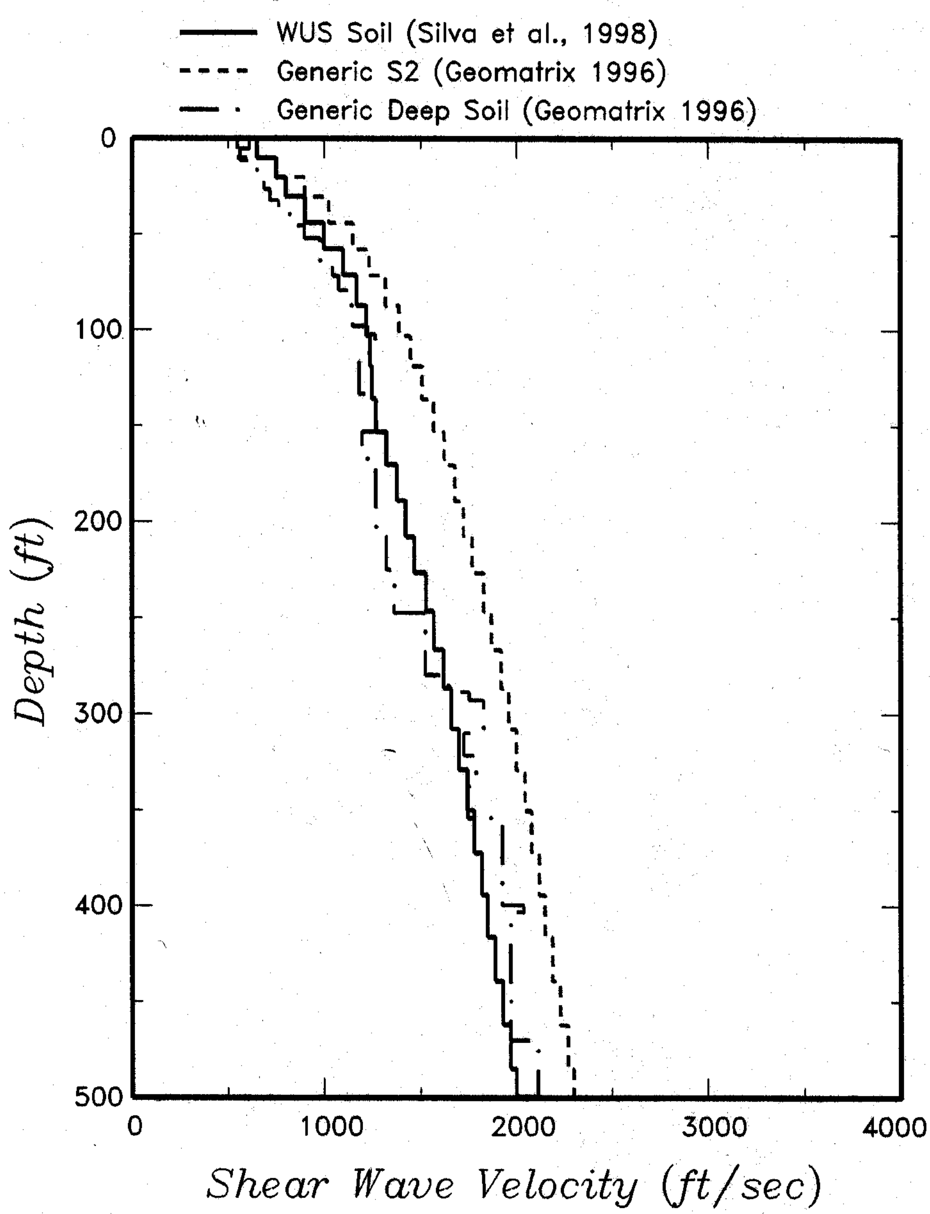

Figure 15. Velocity Profiles for California Soil Sites.

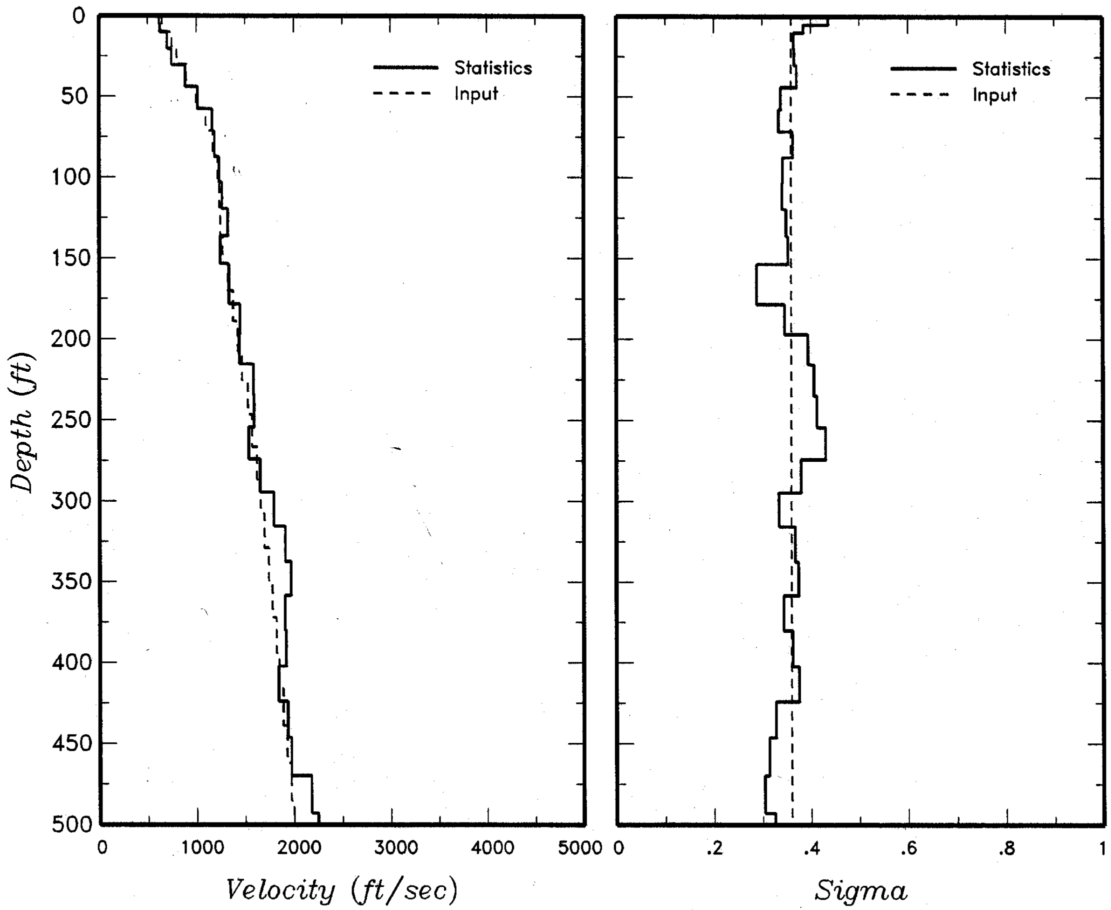

Figure 16. Comparison of Statistics of Randomized California Soil Velocity Profiles to Target Values.

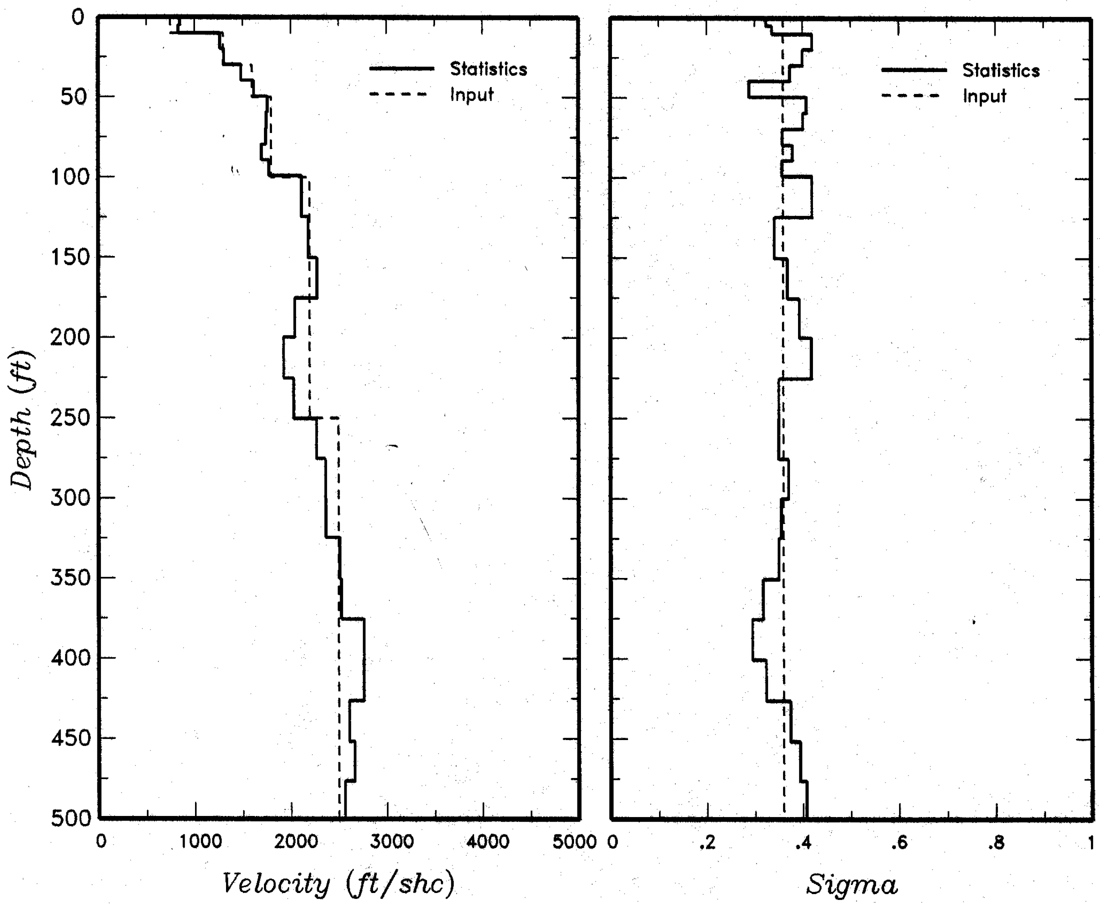

Figure 17. Comparison of Statistics of Randomized Hanford P1 Soil Velocity Profiles to Target Values for the California Soil Velocity Correlation Model.

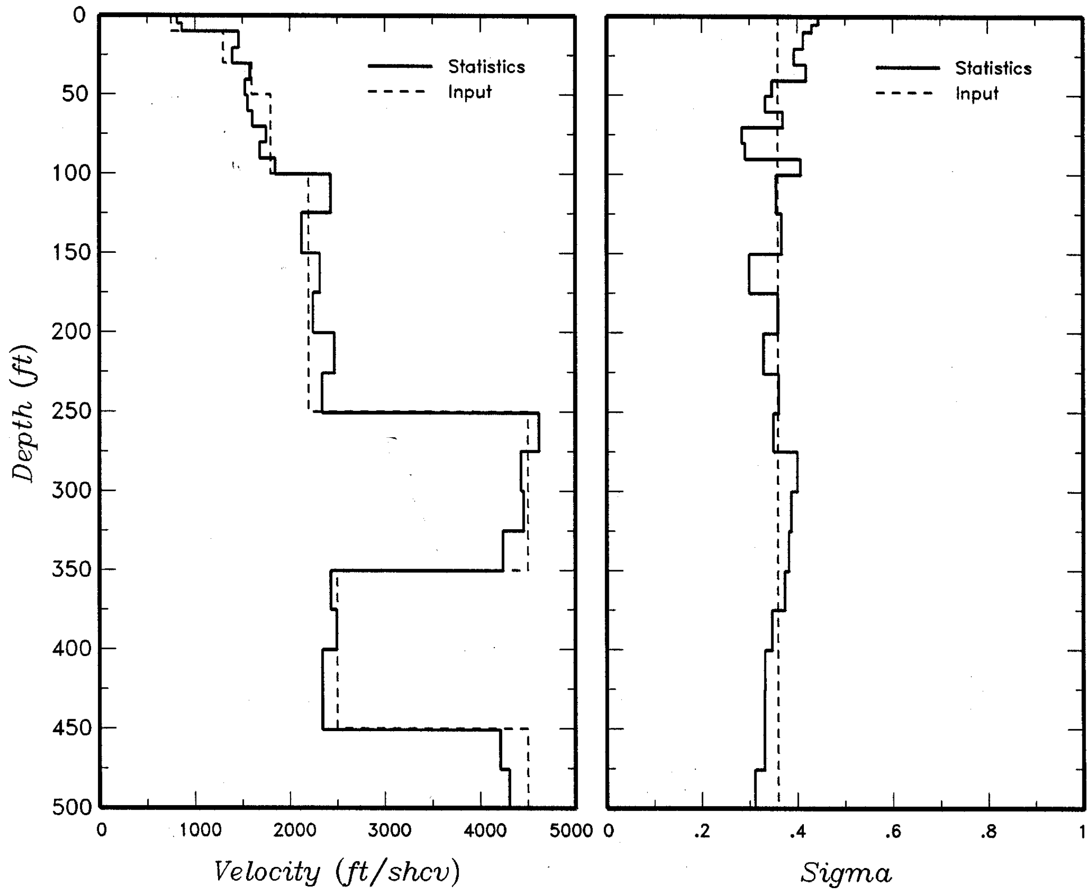

Figure 18. Comparison of Statistics of Randomized Hanford P2 Soil Velocity Profiles to Target Values for the California Soil Velocity Correlation Model.

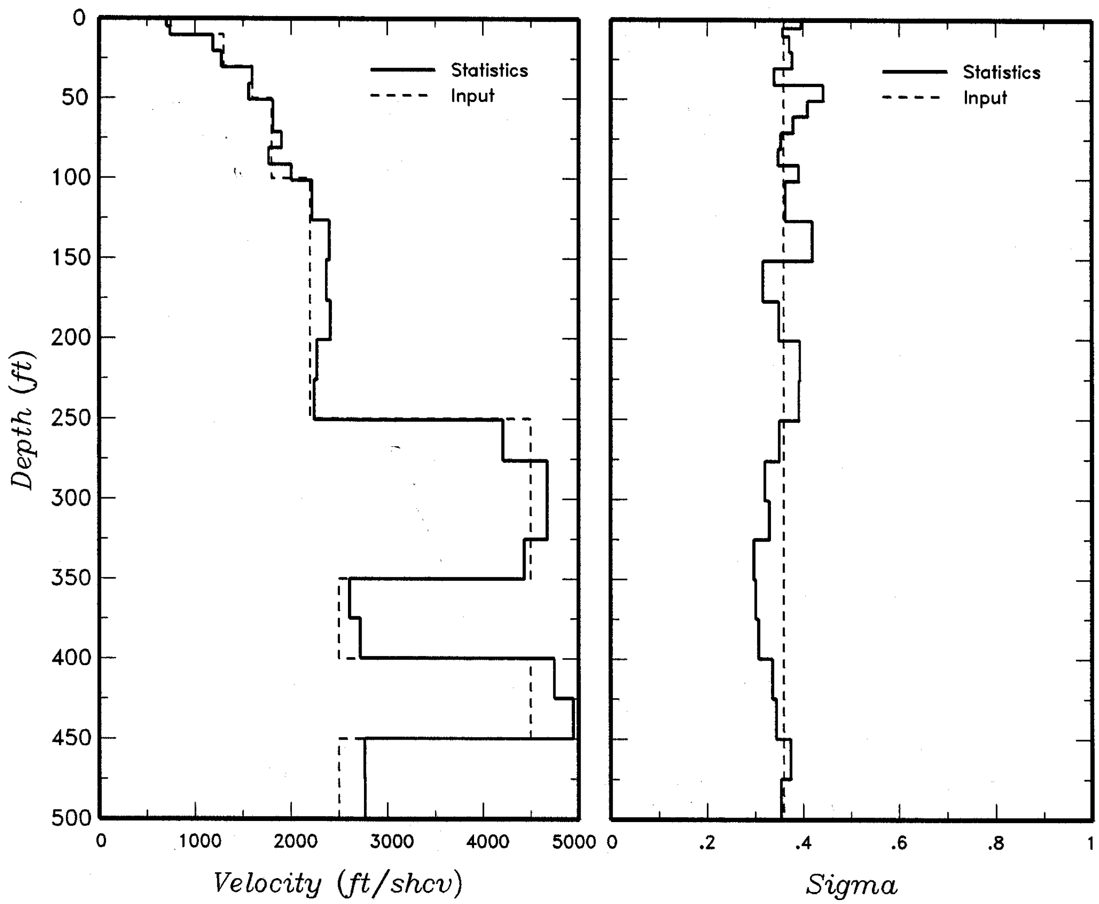

Figure 19. Comparison of Statistics of Randomized Hanford P3 Soil Velocity Profiles to Target Values for the California Soil Velocity Correlation Model.

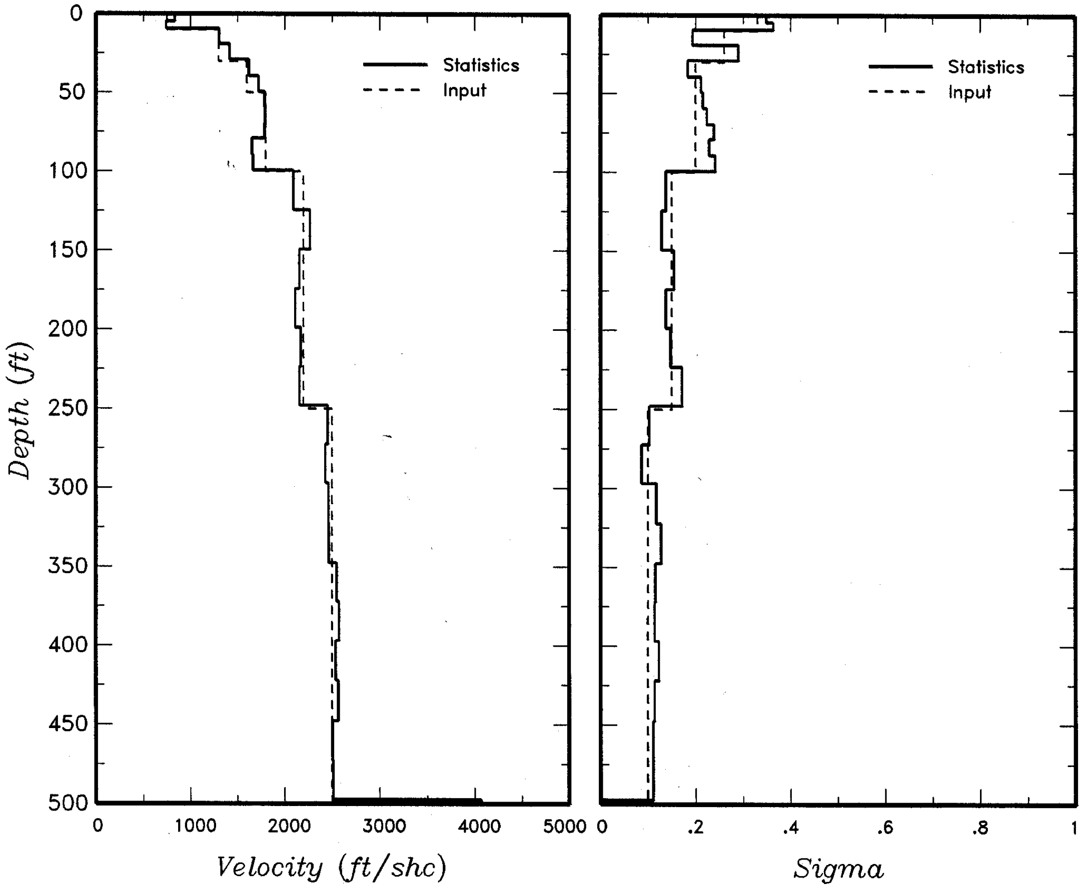

Figure 20. Comparison of statistics of randomized Hanford P1 soil velocity profiles to target values for the SRS generic velocity correlation model.

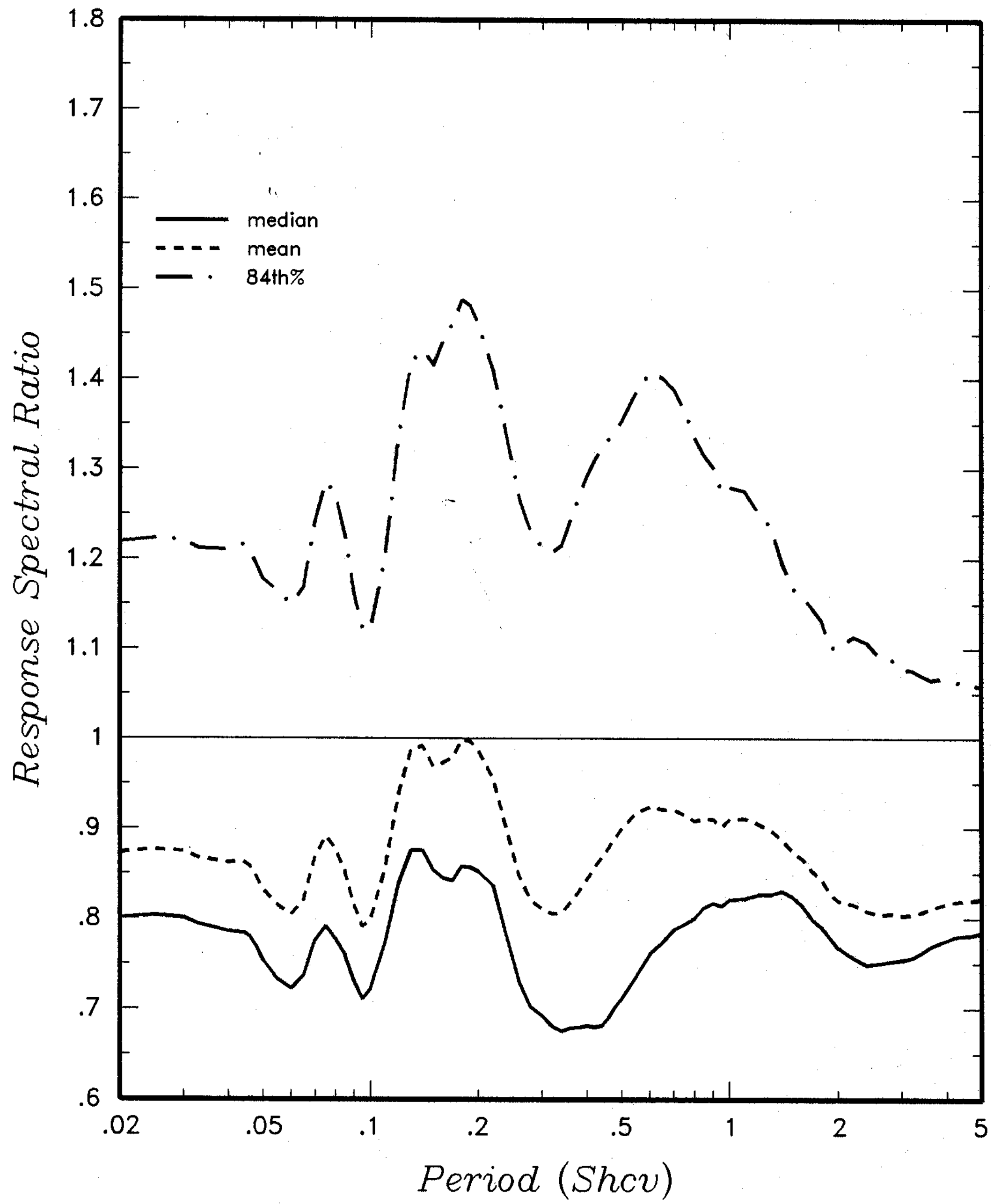

Figure 21. Statistics of Spectra Ratios for Hanford P1 Profile (California soil velocity correlation model, 200 East Area soil curves) Divided by California Deep Soil.

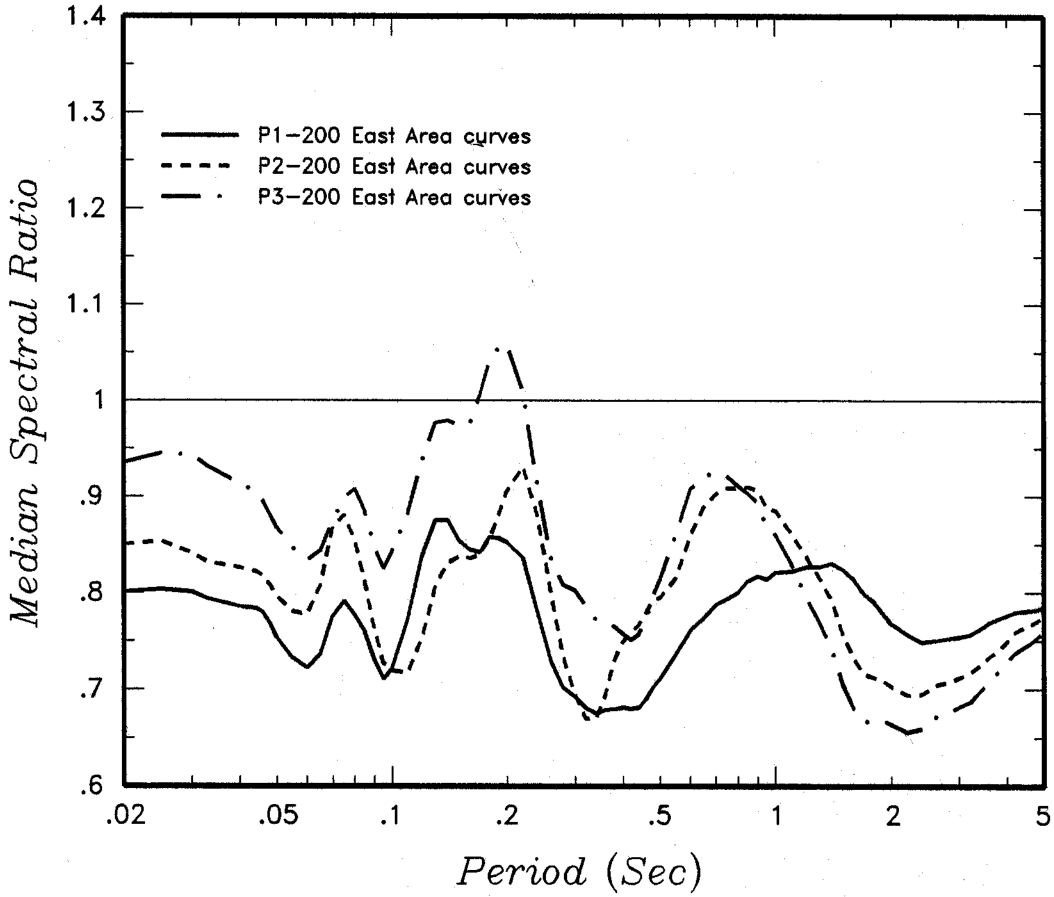

Figure 22. Median Spectra Ratios for the Three Hanford Profiles (California soil velocity correlation model).

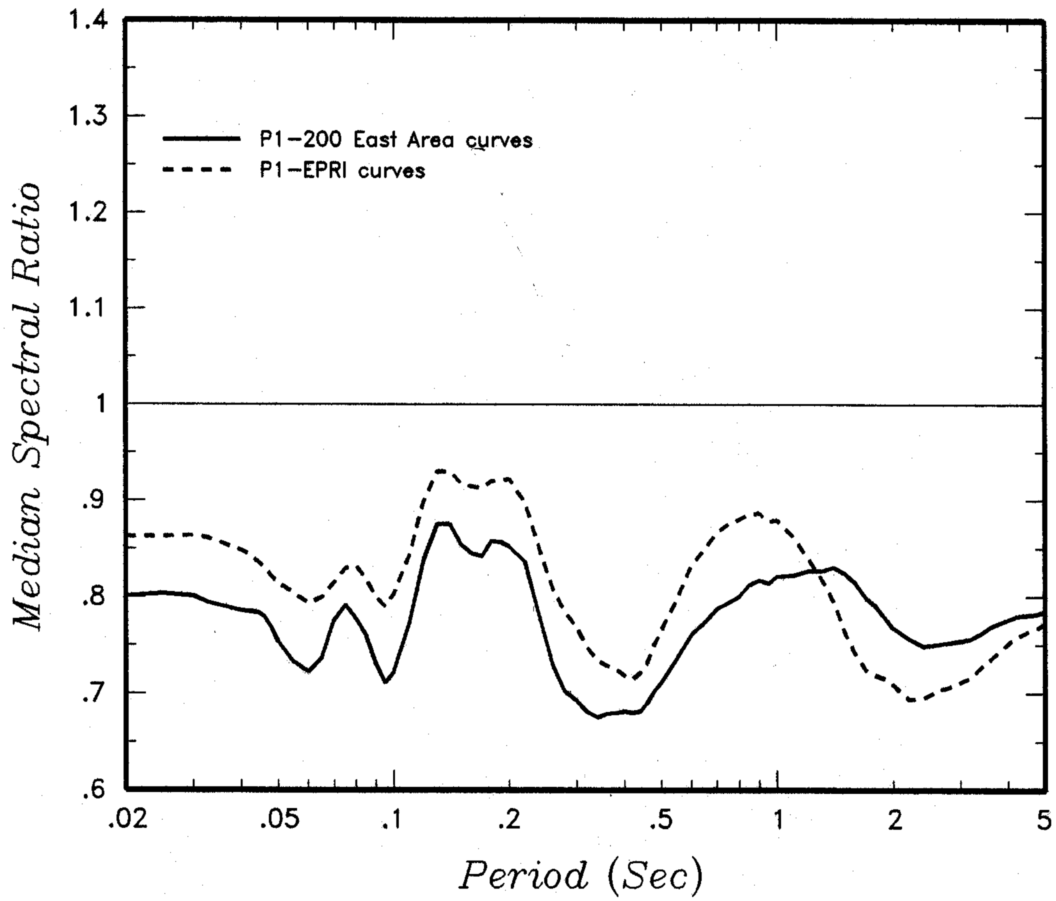

Figure 23. Median Spectra Ratios for the Hanford P1 Profile (California soil velocity correlation model)

NOTE: Showing the effect of using the EPRI soil curves versus the Shannon and Wilson (1994) 200 East Area Curves.

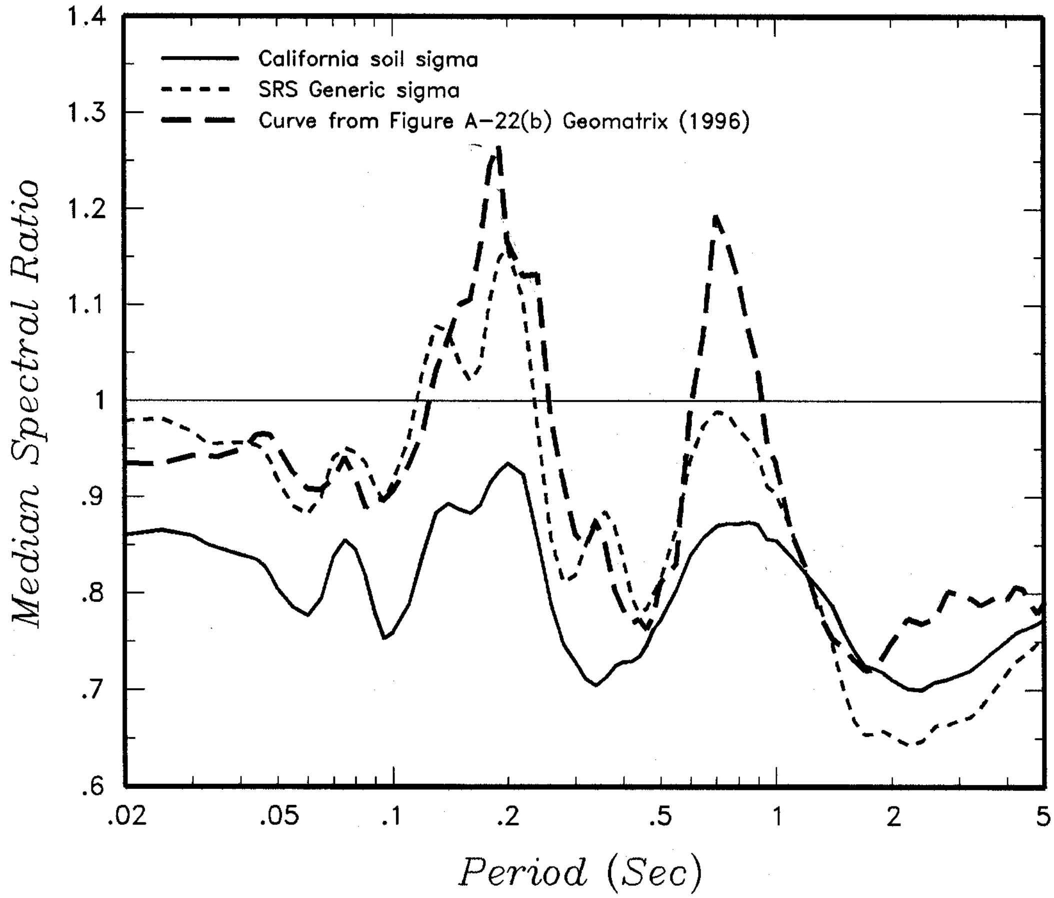

Figure 24. Median Spectra Ratios for the Combined Results of Hanford Profiles P1, P2, and P3 (200 East Area soil curves)

NOTE: Showing the effect of using the SRS generic correlation model versus using the California soil site correlation model. Also show is the average spectra ratio curve from Figure A-22 (b) of Geomatrix (1996)