Comparison of 2/3-g Housner Reanalysis Spectrum with Multiple Regression Analyses of Spectral Values San Onofre Nuclear Generating Station

June 1982

TABLE OF CONTENTS

TABLE OF CONTENTS
(cont'd)

1.0 BACKGROUND AND SUMMARY

1.0 BACKGROUND AND SUMMARY

1.1 Introduction

This report summarizes the results of various ground motion studies completed for the SONGS site by Woodward-Clyde Consultants (WCC) beginning with the June 1979 WCC report entitled, "Report of the Evaluation of Maximum Earthquake and Site Ground Motion Parameters Associated with the Offshore Zone of Deformation San Onofre Nuclear Generating Station," and extending to the latest WCC update on ground motion parameters for the site reported herein. The various updates have been required to accommodate new significant data gathered subsequent to the data available for the June 1979 report. These updates have been documented in several reports including: (1) response to NRC Questions 361.54, 361.55 and 361.62 in the SONGS Units 2 and 3 FSAR; (2) the 22 February 1982 WCC report entitled," Instrumental Response Spectra for the San Onofre site," included as Appendix B to the 23 February 1982 SCE report entitled," Analysis of 2/3g Housner Reanalysis Design Spectrum for San Onofre Nuclear Generating Station"; and (3) the 12 April 1982 WCC report entitled, "Development of Instrumental Response Spectra for the San Onofre Site." The results of the studies documented in the aforementioned reports are summarized and compared with the results of analyses completed subsequent to the 12 April 1982 report.

1.2 Summary

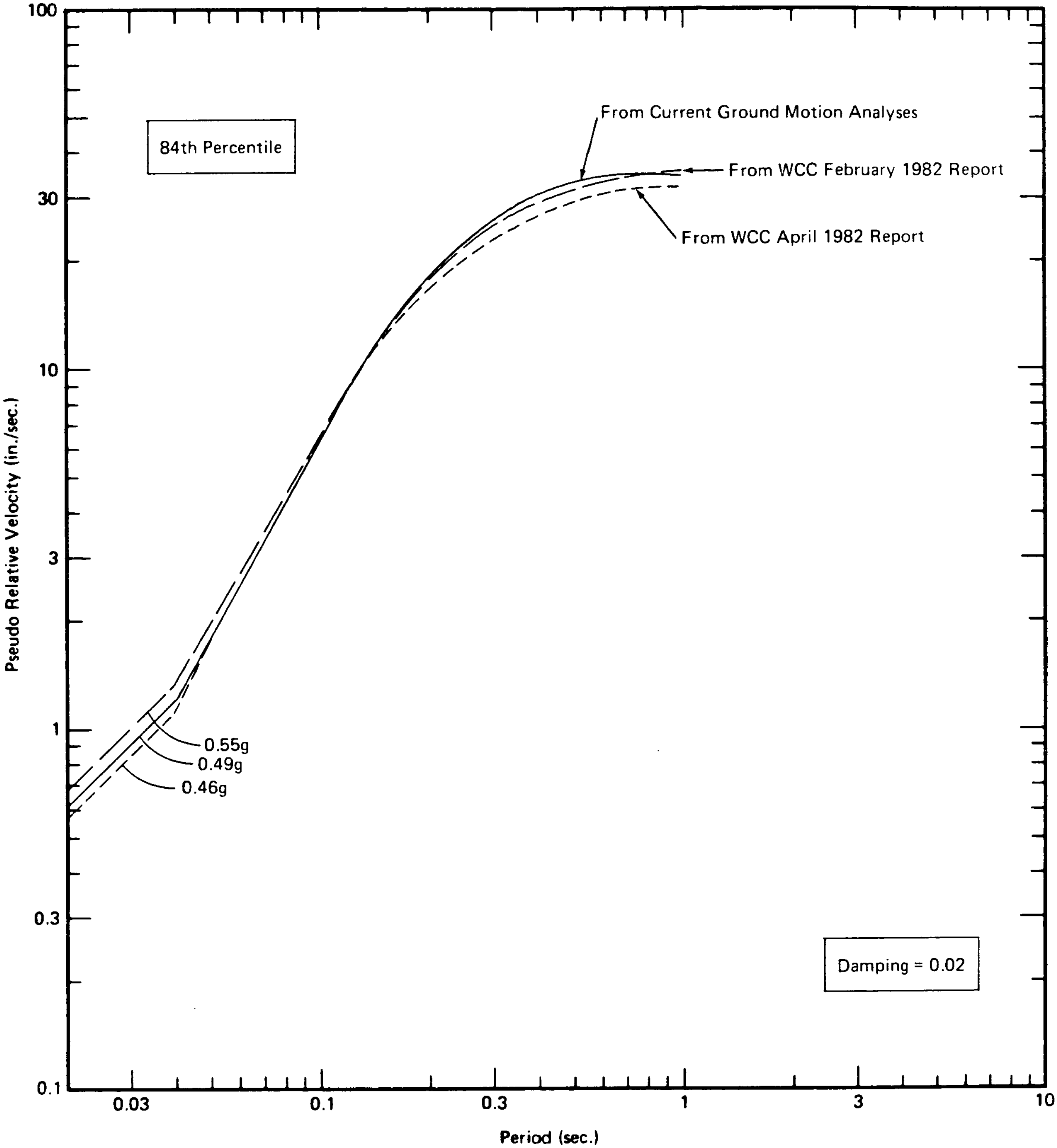
In brief, the results of the June 1979 report were shown to be very conservative based on the analysis of data from the 1979 Imperial Valley (IV79) earthquake and the results were modified based on the use of closest distance to the fault in lieu of the significant distance definition used in the June 1979 report. The revisions made in the 22 February 1982 report were based on judgements made from a comparison of an instrumental spectrum developed from a revised interpretation of the SONGS data base (developed in the June 1979 report and the responses to NRC Questions 361.54 and 361.62) and on the IV79 instrumental spectrum developed in the response to NRC Question 361.55. Consideration was also given to peak ground acceleration from Campbell (1981) and Idriss et al. (1982) at a closest distance from the fault of 8 km. The ground motion analysis documented in the 12 April 1982 report was specifically addressed to the magnitude range of interest (i.e. magnitude 6½ to 7) and considered the modification of the IV79 instrumental spectrum at a closest distance of 8 km from the causative fault. This modification was accomplished by interpolating a transfer function between deep soil and rock spectra for the SONGS site conditions primarily on the basis of the 1971 San Fernando (SF71) earthquake data. The current ground motion analyses follow the same general format as that documented in the 12 April 1982 report; however, they make use of a much larger data set (a total of 1,053 peak ground acceleration data points and 292 spectral velocity data sets of 68 periods each) extending the magnitude range to also include data from earthquakes with magnitudes as low as M3. The data set from this wider magnitude range (i.e. magnitude 3 to 7) provided the basis for conducting multiple regression analyses to develop relationships for spectral ordinates as a function of magnitude, distance and site conditions. The resulting relationships were used to provide an estimate of the 84th percentile instrumental response spectrum for the SONGS site for M_s 7 at a distance of 8 km.

The results of a comparison of spectra for magnitude 7 at 8 km developed from all three of these studies to the 2/3g Housner reanalysis spectrum are summarized on Figures 1-1 and 1-2. It should be noted that the spectra developed from these analyses are considered an improvement on the original spectra presented in the June 1979 report because they incorporate the observed trends as well as the specific data from earthquakes occurring after the data base for the June 1979 report was fixed. Also, as can be noted from the results summarized in Figures 1-1 and 1-2, all of the WCC updated analyses completed to date show about the same results with regard to the 2/3g Housner reanalysis spectrum, namely that the instrumental spectra exceed the design form of the 2/3g Housner reanalysis spectrum over a period range of about 0.06 to 0.25 seconds 10 to 15% for 2% damping. In the period range 0 to 1 seconds, the design form of the Housner reanalysis spectrum falls within the 73rd and 98th percentile instrumental response spectra for the San Onofre site. The shaded zone in the lower portion of Figure 1-2 shows a more appropriate comparison, i.e. comparison of the SONGS instrumental spectrum with the instrumental form of the Housner reanalysis spectrum. (The instrumental form of the reanalysis spectrum was derived from the 23 February 1982 report and incorporates the effects of soil-structure interaction and ductility.) Figure 1-2 shows that the SONGS instrumental spectrum at 2% damping is only 35 to 70 percent of the instrumental form of the reanalysis spectrum. This report is restricted to 2 percent damping because inspection of the effects of damping shows the spectra for damping values higher than 2 percent to be less critical than 2 percent spectra with respect to maximum exceedance of the Housner reanalysis spectrum.

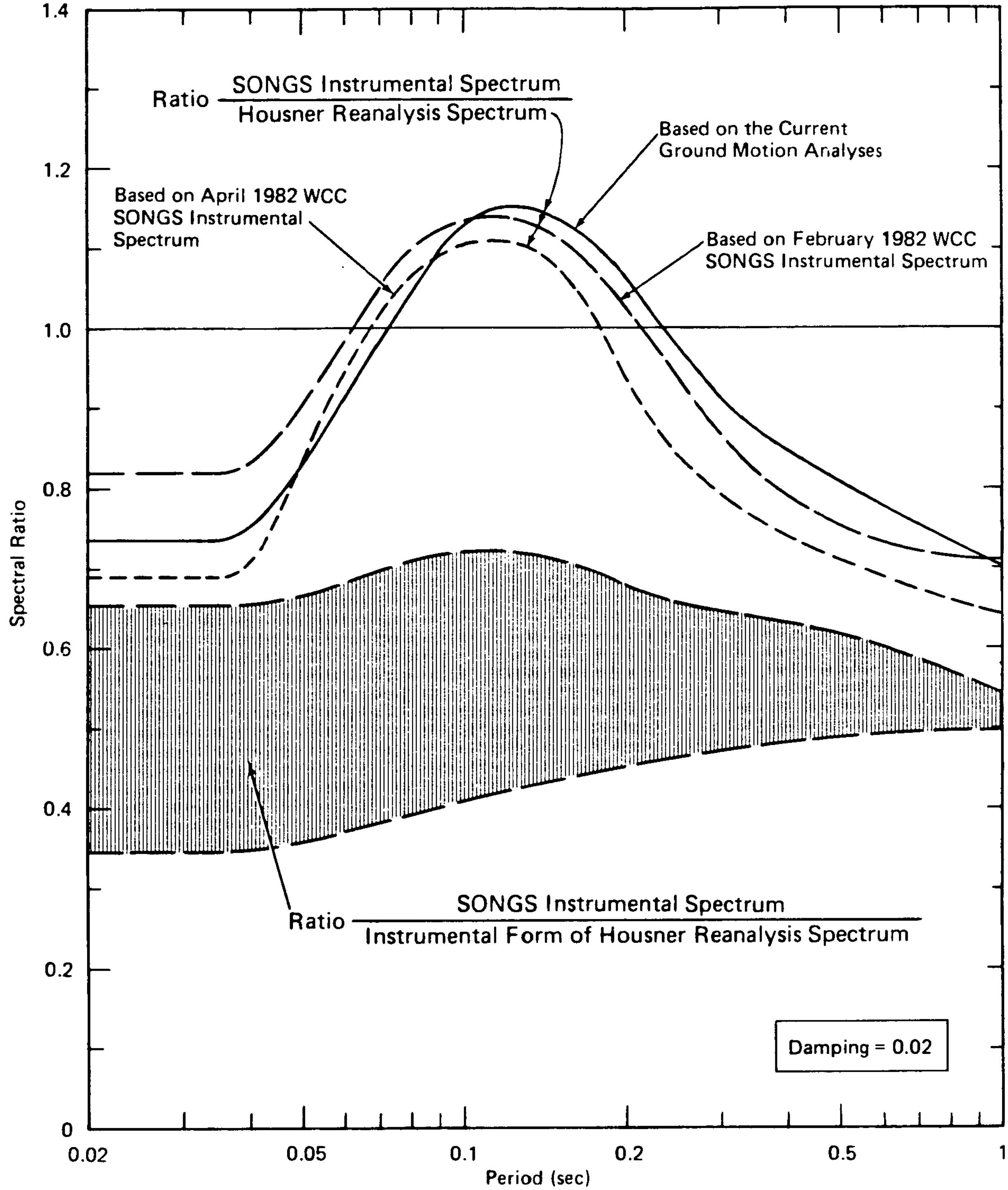
1.3 Organization of Report

The results of the ground motion analysis completed subsequent to the 12 April 1982 report are summarized in Sections 2.0 and 3.0. Specifically, Section 2.0 presents the development of SONGS specific instrumental median spectrum at a distance of 8 km. Section 3.0 presents the results of the dispersion analyses completed and develops the 84th percentile spectrum from the median spectrum developed in Section 2.0. A recap of the results of all WCC update analyses and a comparison of these results are presented in Section 4.0. Basic data and analysis results upon which discussions in Sections 2.0 through 4.0 are based are presented in Appendices A through D as follows:

Appendix A	Basis for the Current Ground Motion Analyses
Appendix B	SONGS Site Response Relative to Deep Soil and Rock for Interpolating Ground Motions
Appendix C	Effects of Site Conditions on Recorded Ground Motions during the IV79 Earthquake
Appendix D	Sensitivity of Ground Motion Estimates to the Magnitude of the IV79 Earthquake



Project No. 414821	SONGS Unit 1 Spectra	Comparison of Instrumental Response Spectra Developed by WCC for the SONGS Site	Figure 1-1
Woodward-Clyde Consultants			



Project No. 414821	SONGS Unit 1 Spectra	Ratio of SONGS 84th Percentile Instrumental Spectra to Reanalysis Spectra for 2% Damping	Figure 1-2
Woodward-Clyde Consultants			

2.0 DEVELOPMENT OF SONGS-SPECIFIC MEDIAN INSTRUMENTAL RESPONSE SPECTRUM FOR M_s 7 AT 8 KILOMETERS

2.0 DEVELOPMENT OF SONGS-SPECIFIC MEDIAN INSTRUMENTAL RESPONSE SPECTRUM FOR M_s 7 AT 8 KILOMETERS

2.1 Basic Approach

The general approach in developing SONGS-specific median instrumental response spectrum is illustrated in Table 2-1. The main components of this approach are:

a. Selection of a data base of Volume I peak horizontal accelerations for rock and deep soil sites.

b. Selection of a data base of 2% damped response spectra (each spectrum defined by spectral velocities at 68 periods in the range 0.04 to 10 seconds) for rock and deep soil sites.

c. Multiple-Regression analyses of peak horizontal acceleration (a) for rock and deep soil data sets to develop median attenuation relationships for PGA.

d. Multiple-Regression analyses of normalized response spectra (S_v/a) for rock and soil data sets to develop median attenuation relationships for S_v/a.

e. Development of median attenuation relationships for S_v (for rock and deep soil) through synthesis of the multiple-regression analysis results from items c and d.

f. Development of median response spectra for rock and deep soil sites for M7 and R = 8 km based on the results of item e.

g. Developing median response spectra for SONGS by interpolating between rock and deep soil spectra from item e.

Detailed description of the approach, the selected data base, analysis procedure and the general analysis results are given in Appendix A. Use of the general analysis results to develop SONGS specific response spectra is described in the following subsections. The development of the 84th percentile values from the median is covered in Step 3 in Table 2-1 and is discussed in Section 3.

2.2 Instrumental Response Spectra for Deep Soil and Rock for M_s 7 at R = 8 km

Median attenuation relationships for deep soil and rock were developed for response spectral ordinates using the approach described in Section 2.1. Using the median attenuation relationships for S_v, median response spectra for deep soil and rock were readily developed for the magnitude and distance of interest (i.e. M_s 7 and R = 8 km). The median response spectra, thus determined for deep soil and rock and applicable to M_s 7 at R = 8 km are presented in Figure 2-1. The ratio of the median spectrum for rock to the median spectrum for deep soil is shown in Figure 2-2.

2.3 SONGS-Specific Median Instrumental Response Spectrum for M_s 7 at R = 8 km

The development of SONGS-specific median instrumental spectrum are conducted in three steps as described below.

Step 1 involved developing a relationship between spectral ordinates applicable to SONGS site conditions and spectral ordinates applicable to deep soil conditions. This relationship was developed using the rock to deep soil relationship shown in Figure 2-2 as a basis and interpolating to the

SONGS site conditions. The interpolation was based on the SONGS site response relative to deep soil and rock as described in Appendix B. The estimated range of SONGS to deep soil spectral ratio is shown in Figure 2-2.

Step 2 involved developing median base response spectrum for deep soil and applicable to earthquake source conditions postulated for SONGS (i.e. strike-slip). The approach followed was identical to the one described in Section 2.2. The data base was the same as the deep soil data base, except that all San Fernando 1971* data were excluded while retaining all the IV79* data. This was done because it was felt that the base spectrum should reflect the same strike-slip source conditions as are appropriate for SONGS for data near the magnitude of interest. The resulting median response spectrum is shown in Figure 2-3. This spectrum is the most applicable for the SONGS source conditions and is therefore used as the base spectrum. Inclusion of the San Fernando data in the base spectrum would have slightly reduced the spectral values in the period range below 0.12 seconds and slightly increased the spectral values above a period of 0.12 seconds as is reflected by comparison of deep soil spectra in Figures 2-1 and 2-3 and inferred from the February 1982 WCC report.

Step 3 involved developing SONGS-specific median spectrum by adjusting the median base spectrum to SONGS site conditions using the relationship shown in Figure 2-2 and described in Appendix B. Because the site modification factors from Figure 2-2 range within only a few percent at each record, the average of the range was used. The SONGS specific spectrum obtained by scaling the base spectrum in Figure 2-3 by the average site modification relationship is shown in Figure 2-4.

---

* San Fernando 1971 earthquake is a thrust event, whereas IV79 earthquake is a predominantly strike-slip event.

TABLE 2–1
SUMMARY OF PROCEDURE TO DEVELOP 84th PERCENTILE SONGS SPECTRUM

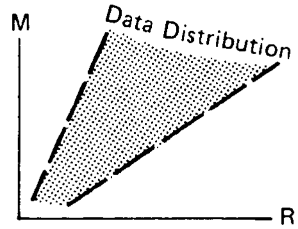
STEP 1: DATA BASE

PGA 1053 data points (Volume 1)

S_v 292

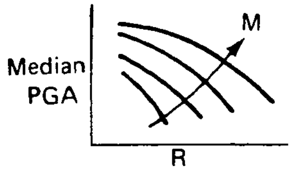
Magnitude Range M3 to M7

Distance Range ~0 to 100 km



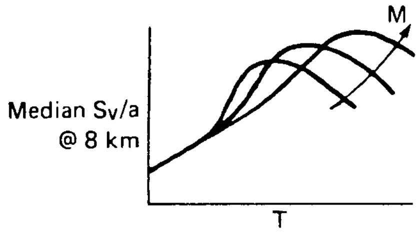
STEP 2: MULTIPLE REGRESSION OF SPECTRAL VALUES (MEDIAN)

a. Volume - 1 PGA = a



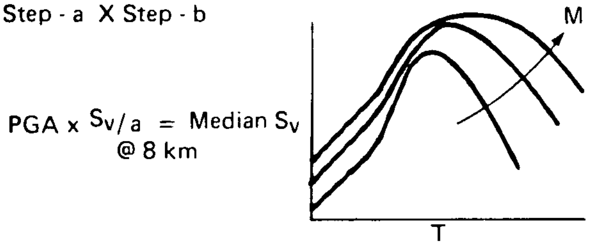
for rock and soil separately

b. S_v/a analysis



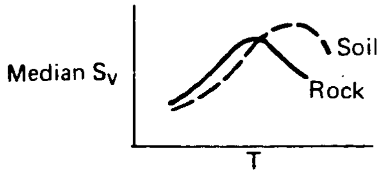
for rock and soil separately

c. S_v Step - a X Step - b



for rock and soil separately

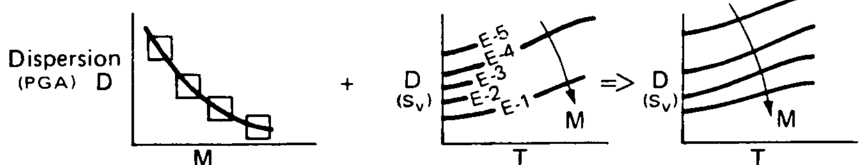
d. S_v Rock and S_v Soil @ 8 km from Step c



e. Interpolate between rock and soil spectra from Step d to obtain SONGS specific Spectrum

STEP 3: DEVELOP S_v vs T 84th PERCENTILE SPECTRUM

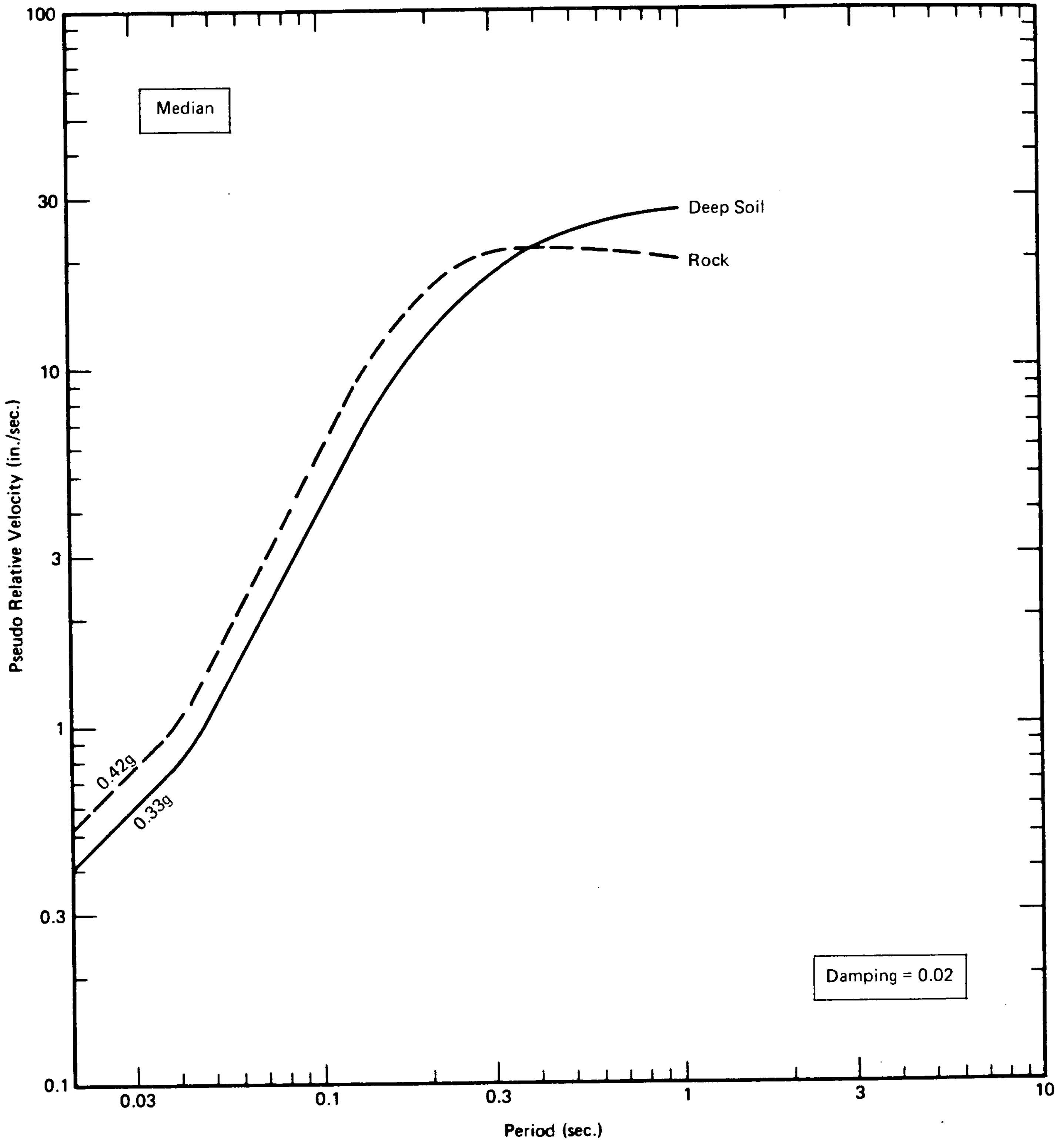
a. and b. Data Trends for PGA and Spectral values for step a. and b., respectively, Various Earthquakes



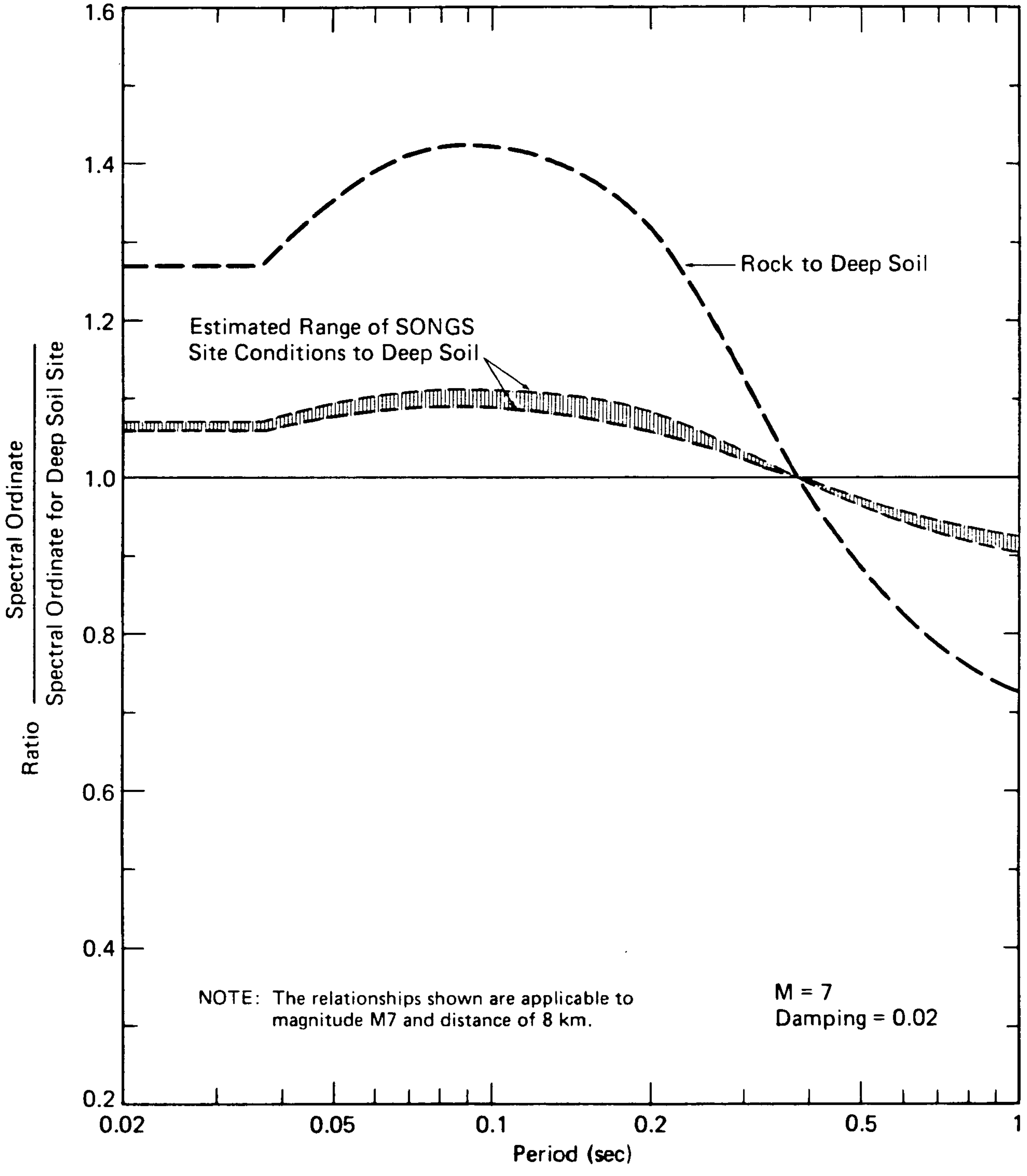
Note: Complete data for earthquakes E-1 and E-4, but limited for E-2,-3, and 5

c. Develop Final Dispersion vs T for Various Magnitude Plots by combining a. and b. as shown above

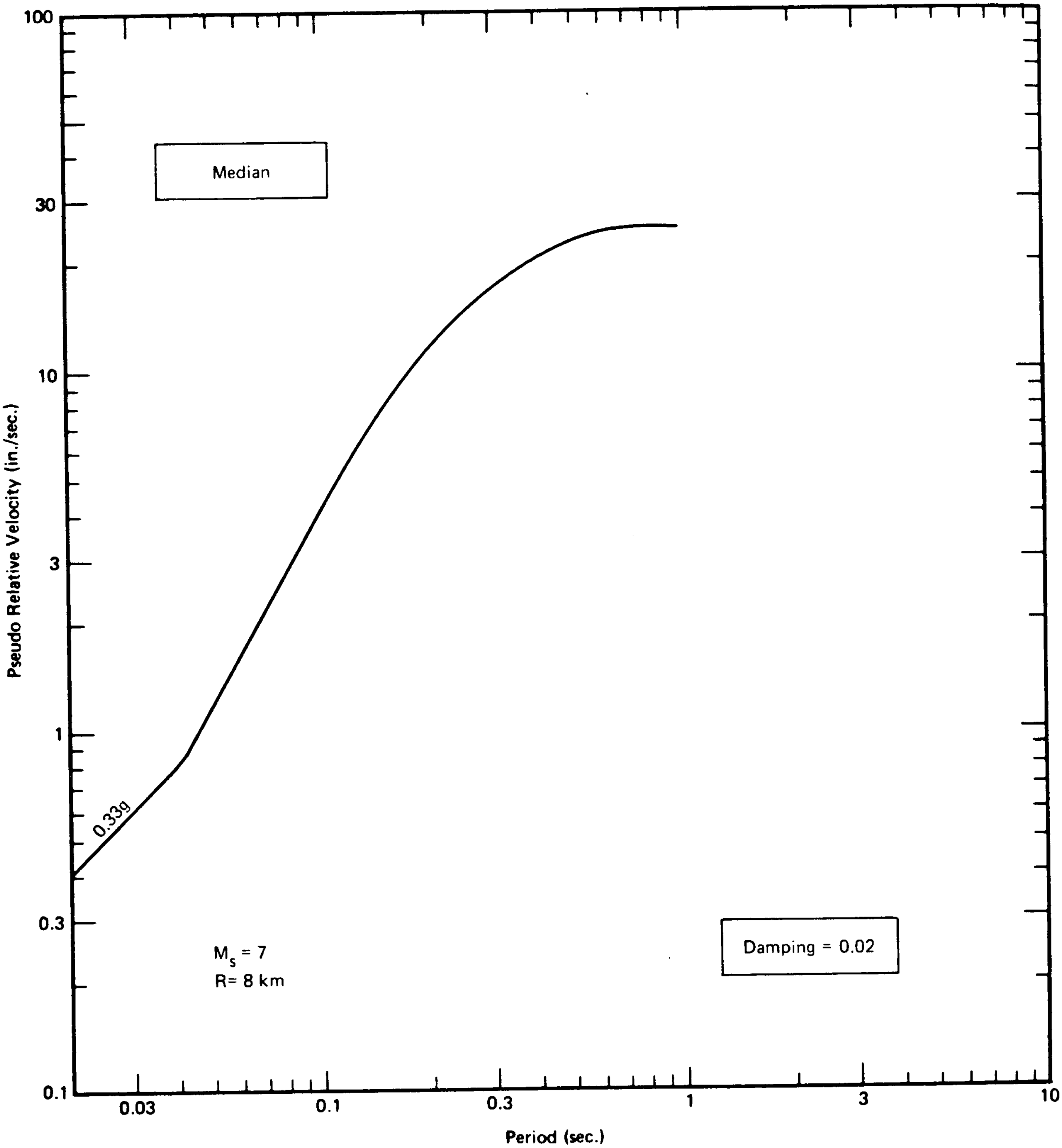
d. Develop 84th Percentile Spectrum by multiplying Median SONGS Spectrum from Step 2e by Appropriate Dispersion –T Curve from Step 3c



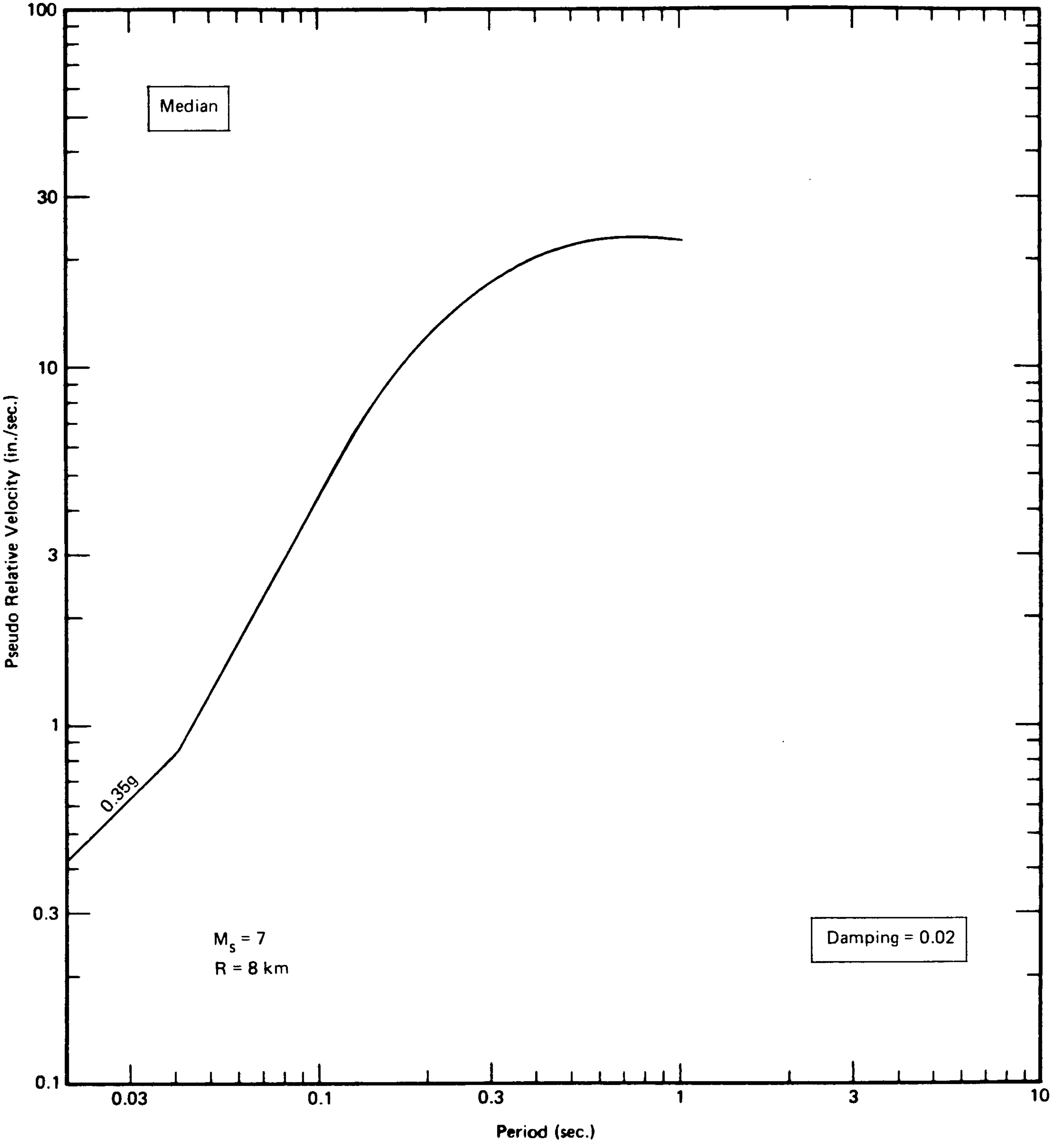
Project No. 414821	SONGS Unit 1 Spectra	Comparison of Median Response Spectra for Deep Soil and Rock for M 7 at R = 8 km	Figure 2-1
Woodward-Clyde Consultants			



Project No. 414821	SONGS Unit 1 Spectra	Relationships Between SONGS and Deep Soil Conditions	Figure 2-2
Woodward-Clyde Consultants			



Project No. 414821	SONGS Unit 1 Spectra	Median Response Spectrum for Deep Soil and Applicable to Earthquake Source Conditions Postulated for SONGS	Figure 2-3
Woodward-Clyde Consultants			



Project No. 41482I	SONGS Unit 1 Spectra	Median Instrumental Response Spectrum for the SONGS Site from the Current Ground Motion Analyses	Figure 2-4
Woodward-Clyde Consultants			

3.0 DEVELOPMENT OF SONGS-SPECIFIC 84th PERCENTILE INSTRUMENTAL RESPONSE SPECTRUM FOR M_s 7 AT 8 KILOMETERS

3.0 DEVELOPMENT OF SONGS-SPECIFIC 84th PERCENTILE INSTRUMENTAL RESPONSE SPECTRUM FOR M_s 7 AT 8 KILOMETERS

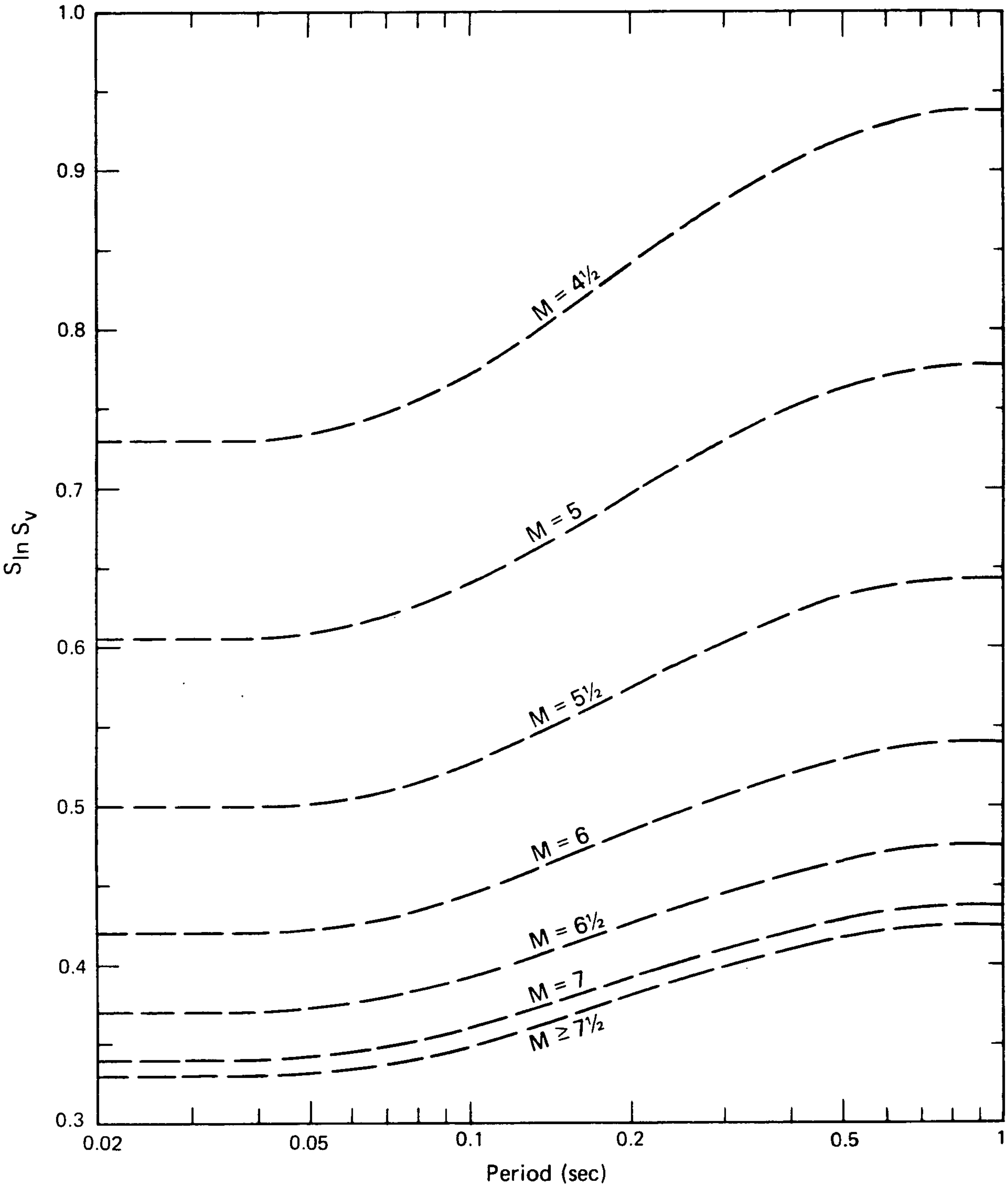
3.1 Basic Approach

The basic approach used to develop the 84th percentile response spectrum from the median response spectrum for the SONGS site follows the concepts indicated in Step 3 of Table 2-1. Specifically, it allows for the use of variable dispersion as a function of period and magnitude which cannot be directly obtained from the multiple regression analysis. As described in Appendix A and as shown by the results presented below, the dispersion in empirical data typically decreases with increasing magnitude. Therefore, for the wide range of magnitudes used in the current analysis (i.e. M3 to M7), the use of constant dispersion with magnitude would lead to under-predicting 84th percentile values at the low magnitudes and over-predicting the 84th percentile values at the high magnitudes. These trends of dispersion have been observed previously by other investigators. For example, Donovan and Bornstein (1978) provide dispersion values as a function of acceleration level (varying from 0.3 for accelerations greater than 0.3g to 0.43 for an acceleration of 0.05g). Also, Idriss et al. (1982) give dispersion values for horizontal acceleration in the near-source region ranging from about 0.3 (for magnitude 7.5) to about 0.7 (for magnitude 4.5).

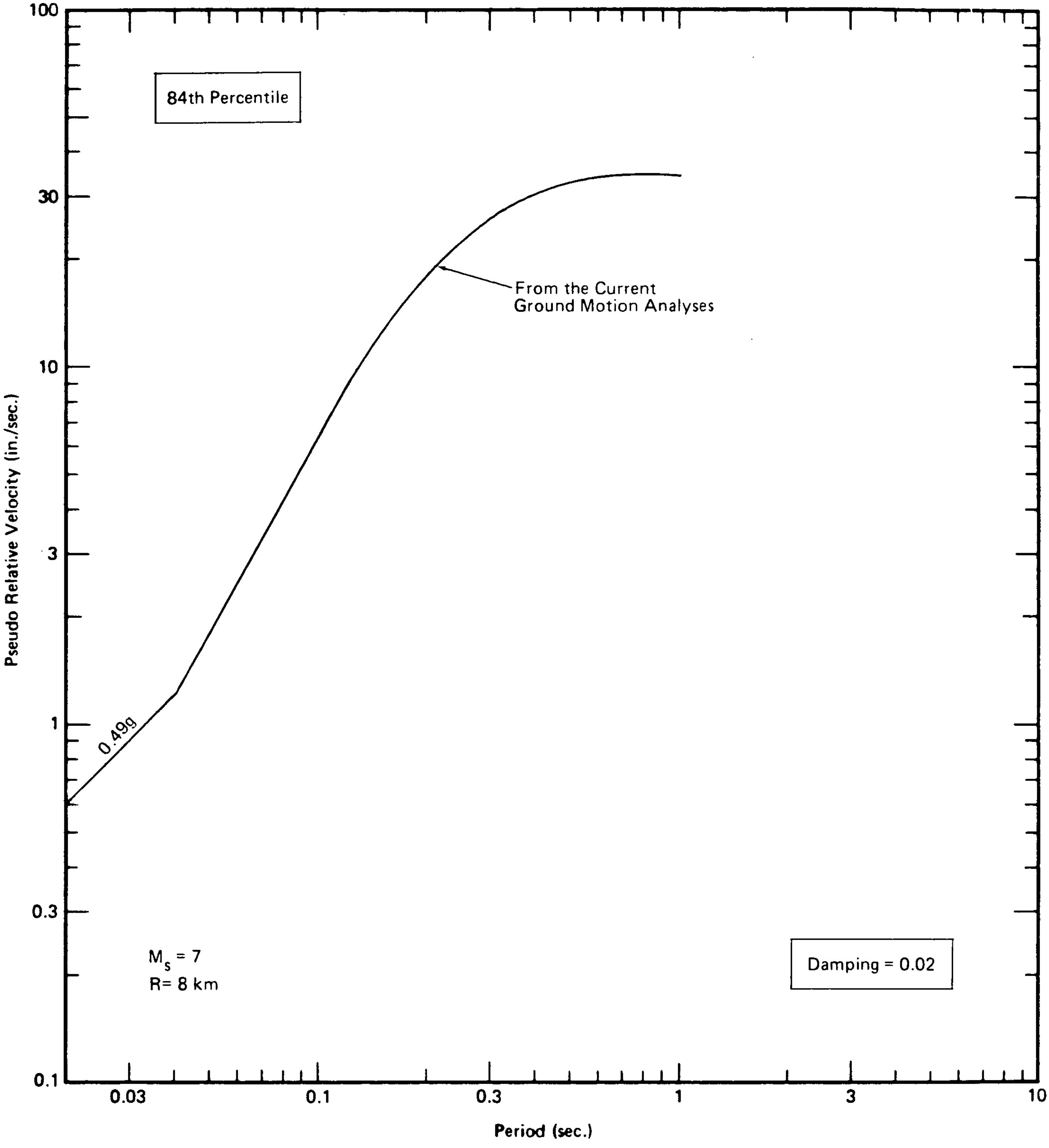
3.2 Dispersion of Data for Individual Earthquakes and Narrow Magnitude Bands to Develop the 84th Percentile SONGS Spectrum

Dispersion relationships as a function of magnitude and period were developed in three steps as indicated in Table 2-1 (Steps 3a, 3b and 3c). The first step, 3a, involved calculation of the standard error of estimate, $S_{\ln a}$, for individual earthquakes or narrow magnitude bands for peak acceleration, PGA. The second step, 3b, involved calculation of $S_{\ln S_v}$ for individual earthquakes or narrow magnitude bands for S_v to develop relative dispersion trends with period. The third step, 3c, consisted of developing dispersion as a function of magnitude and period by linearly scaling the relative dispersion trends with period from the second step to the PGA dispersions from the first step. This analysis results in the family of curves $S_{\ln S_v}$ versus period parametricized on magnitude shown in Figure 3-1.

To develop the 84th percentile spectrum for any given magnitude, the median spectral ordinates would be multiplied by the exponential $S_{\ln S_v}$ from Figure 3-1 for the appropriate periods as provided for in Step 3d of Table 2-1. The SONGS 84th percentile spectrum shown on Figure 3-2 was then calculated using the exponential of the M7 curve from Figure 3-1 times the median spectra from Figure 2-4 [i.e. at each period T, S_v (84th percentile) = S_v (median) x exp ($S_{\ln S_v}$)].



Project No. 414821	SONGS Unit 1 Spectra	Variation of Dispersion as a Function of Magnitude and Period	Figure 3-1
Woodward-Clyde Consultants			



Project No. 414821	SONGS Unit 1 Spectra	84th Percentile Instrumental Response Spectrum for the SONGS Site from the Current Ground Motion Analyses	Figure 3-2
Woodward-Clyde Consultants			

4.0 DISCUSSION AND COMPARISON OF GROUND MOTION ANALYSES

4.0 DISCUSSION AND COMPARISON OF GROUND MOTION ANALYSES

4.1 June 1979 WCC Report and Responses to NRC Questions

The June 1979 WCC report developed an instrumental response spectrum for the SONGS site for a M_s 6½ earthquake. In response to the subsequent NRC question 361.54, this spectrum was extended to M_s 7 using relationships available in the literature for ratios of 84th percentile peak acceleration between M_s 7 and M_s 6½ and observed trends in data to develop similar ratios for spectral velocities. The resulting instrumental spectra for M_s 6½ and M_s 7 are presented in Figure 4-1. These spectra were derived using the distance to energy center as a basis for the treatment of ground motion data in the regression analysis. Subsequently, a significant number of high quality ground motion accelerograms have become available, most notably those from the IV79 earthquake. Based on detailed analyses completed on IV79 data as reported in the response to NRC question 361.55, it was found that data treatment using the closest distance definition provided the best data fit. In response to NRC question 361.62, the SONGS data base from the June 1979 report was treated using the closest distance definition and Figure 4-2 was developed for peak acceleration indicating the June 1979 instrumental results were very conservative.

4.2 February 22, 1982 Report, "Instrumental Response Spectra for the San Onofre Site"

The 22 February 1982 WCC report was contained as Appendix B of the 23 February 1982 report entitled, "Analysis of 2/3g Housner Reanalysis Design Spectrum for San Onofre Nuclear Generating Station." Basically, this report reanalyzed the June 1979 SONGS data set using the closest distance definition and combined the resulting 84th percentile spectrum with the 84th percentile IV79 spectrum at a closest distance of 8 km and with the 84th percentile peak acceleration values from Campbell (1981) and

Idriss et al. (1982) to interpret an 84th percentile spectrum for the SONGS site as summarized on Figure 4-3.

4.3 April 12, 1982 Report, "Development of Instrumental Response Spectra for the San Onofre Site"

The basic logic which the 12 April 1982 report followed is summarized on Figure 4-4. Step A of Figure 4-4 shows the development of a base spectrum from the 1979 Imperial Valley earthquake (IV79) for scaling to develop a spectrum which is site-specific to SONGS. This earthquake was chosen because it is the most completely instrumented earthquake in the magnitude and distance range of interest, and most of the seismograph stations were located on sites with the same general deep soil subsurface conditions. Step B-1 provided for development of ratios between spectral velocities of rock to deep soil sites versus spectral period, developed from the IV79 and the 1971 San Fernando earthquake (SF71). The SF71 data represent the most extensive set of data for deep soil and rock conditions from a single source motion. The ratios of rock to deep soil spectral velocities were analyzed for distances of 8 and 20 to 30 km. Similar ratios were developed between the two horizontal recordings from a rock site during IV79 and the several deep soil recordings available in the distance range 20 to 30 km as discussed in Appendix C. These ratios were used to extrapolate the spectral ratio versus period relationships for rock to deep soil applicable to the IV79 earthquake at a distance of 8 km. Step B-2 provided for multiple regression of a larger data base from several earthquakes for peak ground acceleration and peak ground velocity as a general validation of the spectral ratio relationships with period. By combining the results of Steps B-1 and B-2 and using the differences in response between the SONGS site, the deep soil sites in the Imperial Valley and rock sites, a spectral velocity versus period relationship for the SONGS site, relative to the IV79 deep soil conditions, was developed in Step C. Next, Step D used this spectral velocity ratio to modify the base spectrum for IV79 at 8 km from Step A and to obtain a spectrum applicable to SONGS site conditions at 8 km. Finally, Step E compared the SONGS instrumental spectrum to the 2/3g Housner spectrum. The resulting 84th percentile spectrum at 2% damping developed in Step D is presented on Figure 4-5.

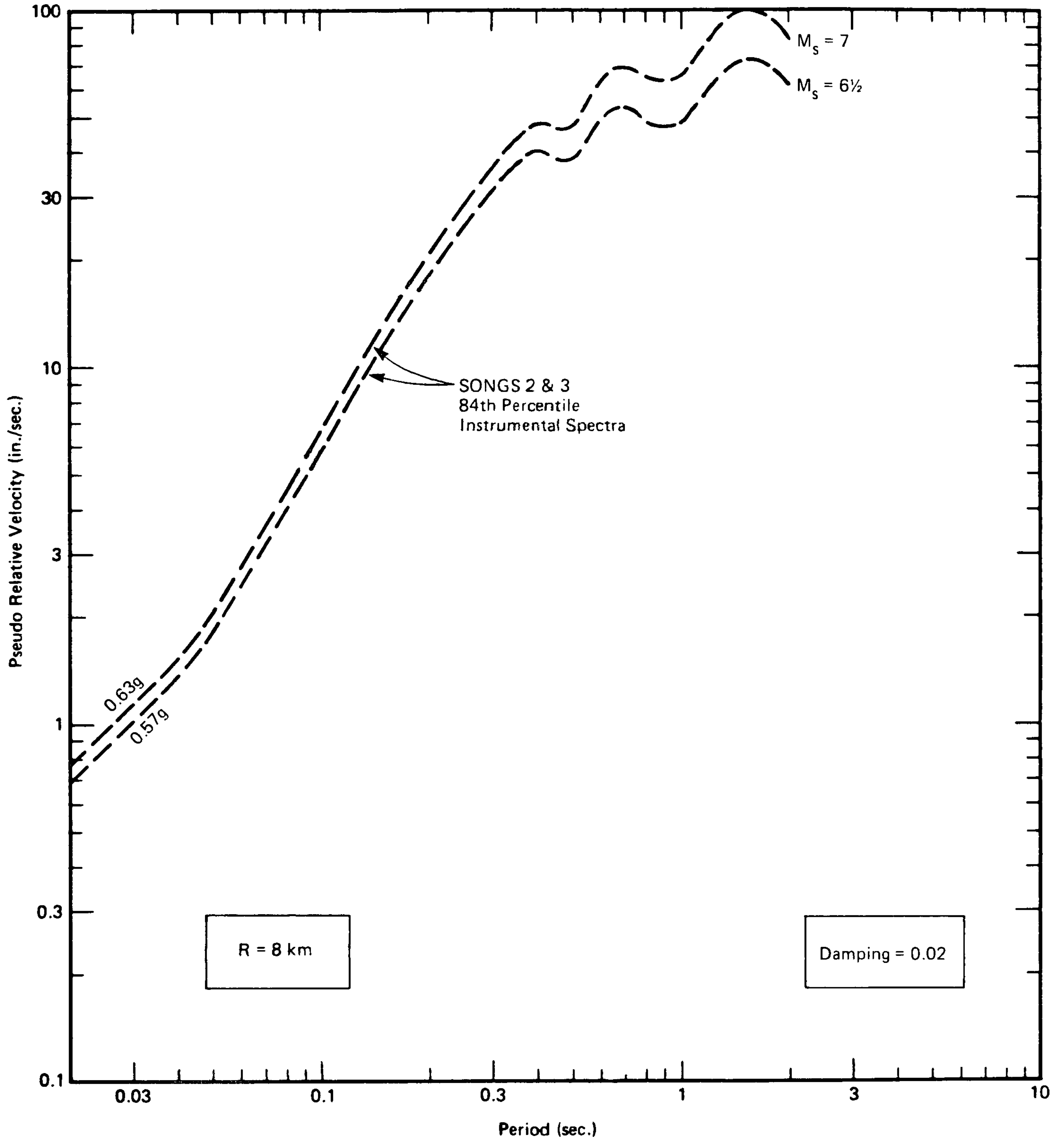
Subsequent to the 12 April 1982 report, more formalized analyses of the SONGS site stiffness relative to deep soil and rock and of the effects of site conditions, and recorded ground motions during the IV79 earthquake have been completed and are summarized in Appendices B and C, respectively. The results of Appendix B indicate that the selected site modification factor between SONGS site conditions and deep soil are conservative based on relative SONGS site response considerations. Appendix C shows that the effects of site conditions on IV79 ground motion values cannot be directly determined due to lack of data from rock sites, but that the general trends developed from the 1971 San Fernando earthquake are appropriate. From Appendix C, the deep soil modification factors used in the 12 April 1982 report may have been a few percent low in the high frequency range (<0.25 seconds) and a few percent high in the low frequency range (>0.25 seconds). The conservative modification factor effect on the analysis (Appendix B) would tend to compensate for the low modification factor (Appendix C) for periods less than 0.25 seconds indicating the spectrum on Figure 4-5 is a good approximation of ground motions. For periods greater than 0.25 seconds, however, the spectrum on Figure 4-5 could be considered high in reviewing the data used.

4.4 Results of Current Ground Motion Analyses

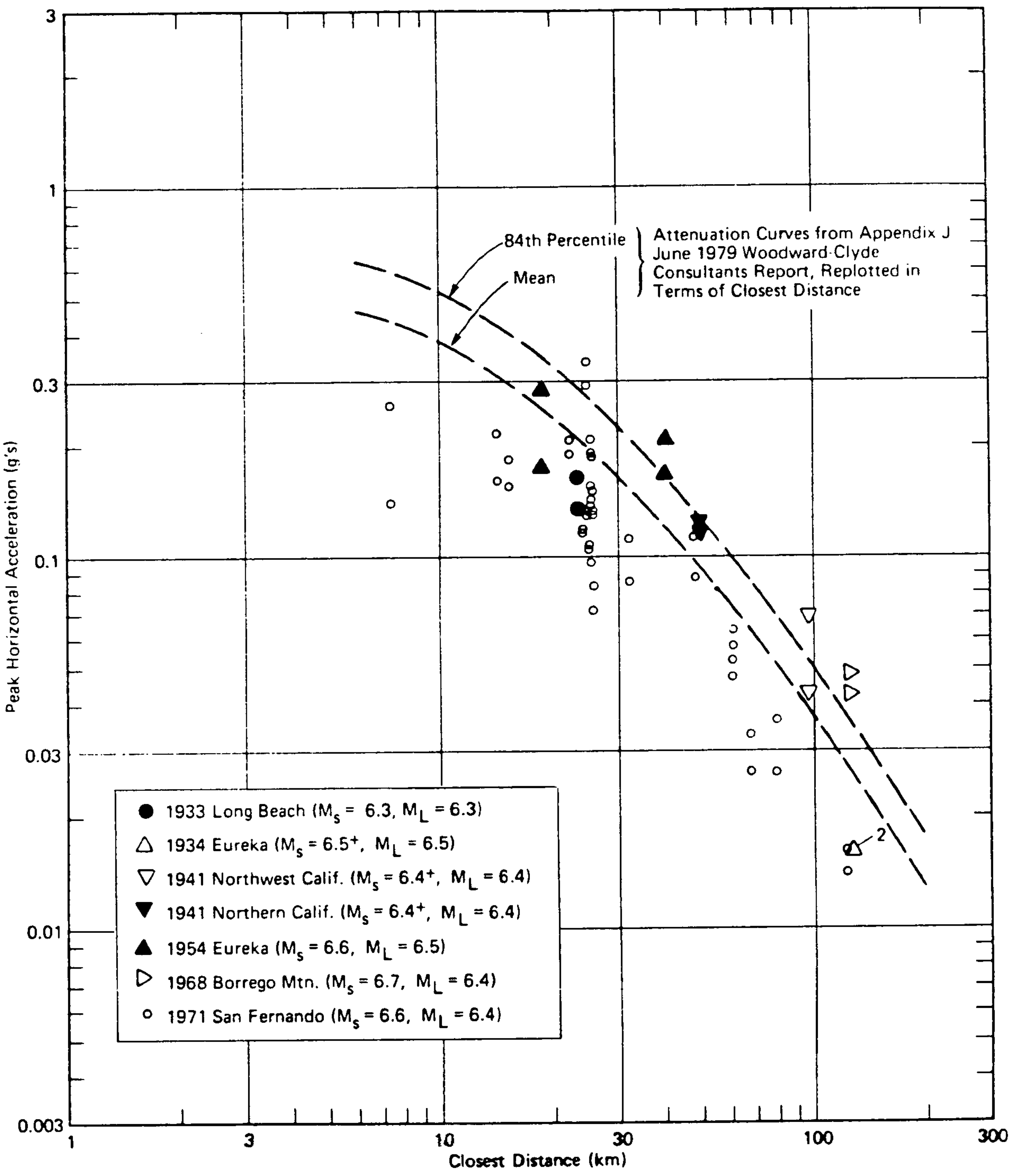
The current ground motion analyses are discussed in Sections 2 and 3 of this report. Section 2 presents the results based on a multiple regression of a large number of ground motion data points (1,053 peak ground acceleration data points and 292 spectral velocity data sets of 68 periods each) to develop the median spectrum for the SONGS site. Because, as shown in Section 3.0, the dispersion of data varies with magnitude and period, the 84th percentile spectrum was calculated from the median spectrum developed from the multiple regression analysis in Section 2.0 using the relationship presented in Section 3.0. The resulting 84th percentile spectrum is presented in Figure 4-6. The sensitivity of the results to the magnitude of the IV79 earthquake is assessed in Appendix D. For example, if the magnitude of the IV79 earthquake is assumed to be M_s 6½ rather than the published value of M_s 6.9, the 84th percentile response spectra for M_s 7 appropriate to SONGS would be slightly higher as indicated in Appendix D.

4.5 Comparison of Instrumental Response Spectra Developed by WCC for the SONGS Site

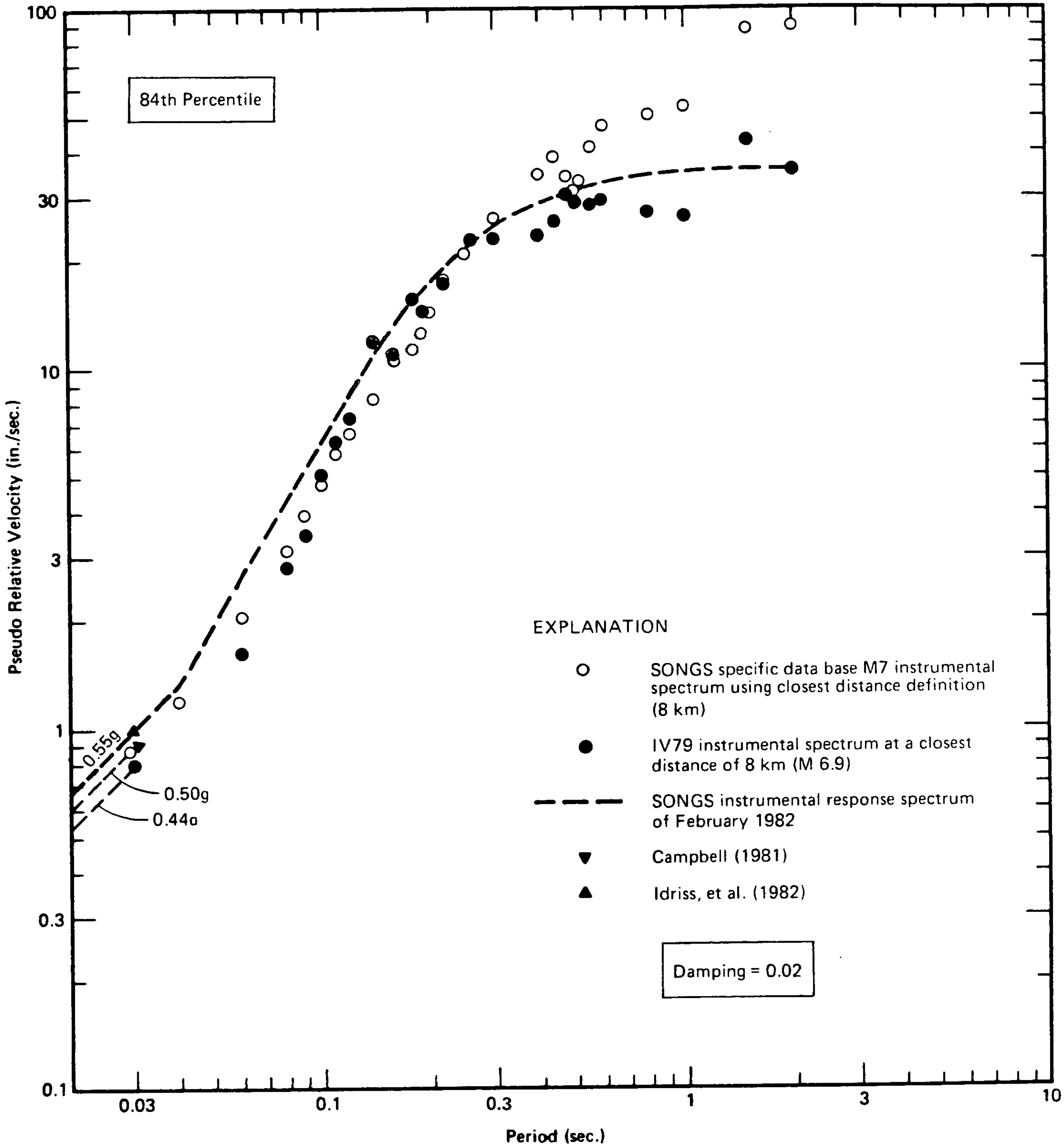
The response spectra developed in the 22 February 1982 report, the 12 April 1982 report, and Sections 2 and 3 of this report all represent an improvement on the results presented in the June 1979 report. This improvement primarily stems from the use of observed trends as well as specific ground motion data from recent earthquakes occurring subsequent to the June 1979 report. As indicated in Figure 4-2, the high-frequency end (as represented by the PGA) of the June 1979 spectrum at M_s 6½ is very conservative with respect to the data base from which it was developed when the more appropriate "closest distance" is used in data treatment. Based on this observation and the response to NRC question 361.55 where the June 1979 spectrum was shown to be conservative with respect to a corresponding spectrum from the IV79 earthquake, it is concluded that the June 1979 SONGS spectrum is very conservative. More realistic estimates of 84th percentile spectra were therefore developed as presented in Figures 4-3, 4-5 and 4-6. For comparison purposes, these spectra have been summarized in Figure 4-7 which shows very little difference between them. Figure 4-8 shows a comparison of these spectra when normalized to the 2/3g Housner re analysis spectrum at 2% damping. As can be noted from Figure 4-8, the maximum exceedance of the Housner spectrum ranges between about 10 and 15% over period range of 0.06 to 0.25 seconds. Specifically, maximum exceedances are 13 percent at 0.11 seconds from the 22 February 1982 report, 11 percent at 0.12 seconds from the 12 April 1982 report, and 15 percent at 0.13 seconds from the current study.



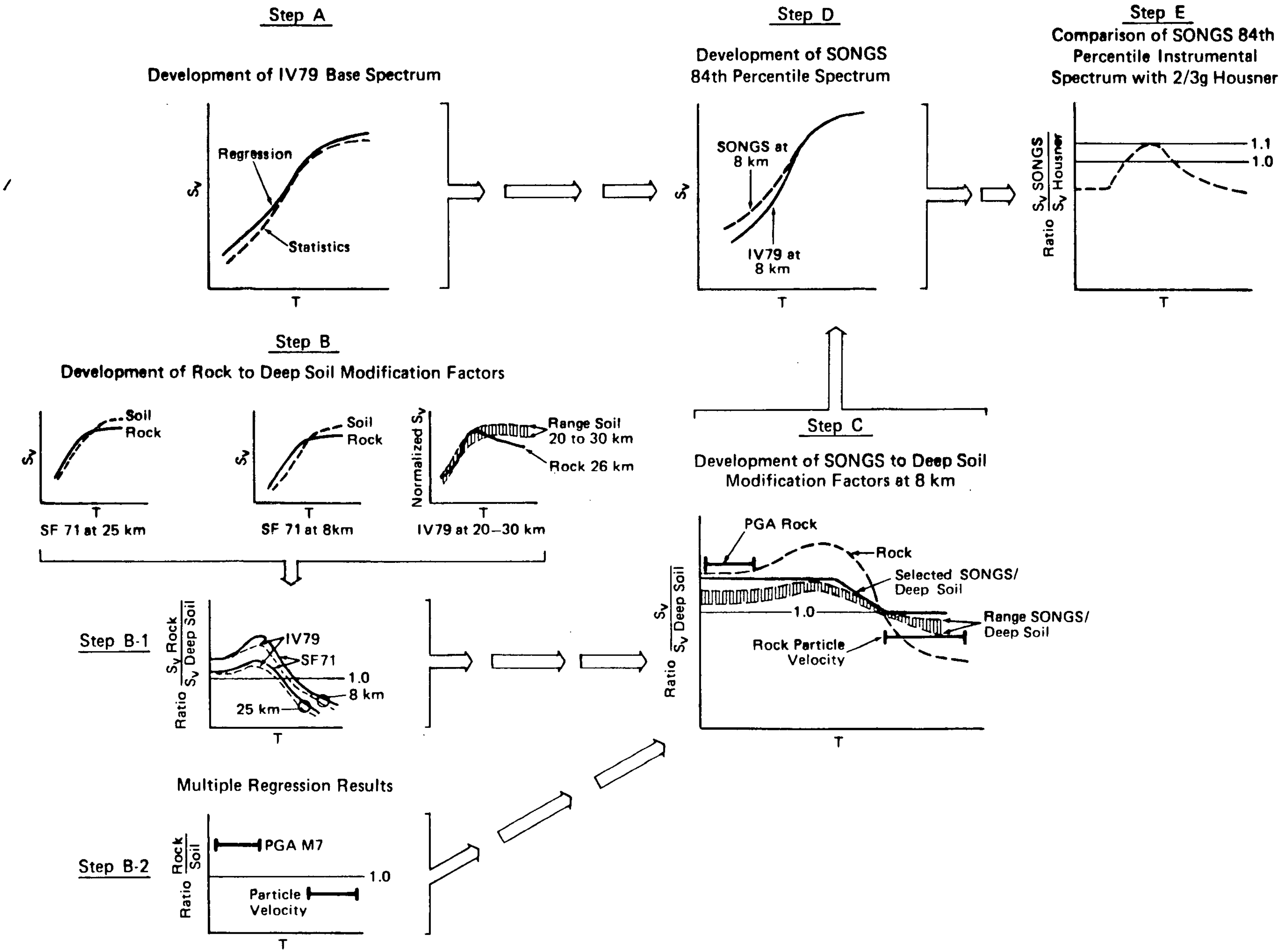
Project No. 414821	SONGS Unit 1 Spectra	Instrumental Response Spectra for the SONGS Site Based on WCC June 79 Report and Response to NRC Question 361.54	Figure 4-1
Woodward-Clyde Consultants			



Project No. 414821	SONGS Unit 1 Spectra	SONGS Appendix J Data Set and Regression Results Plotted in Terms of Closest Distance	Figure 4-2
Woodward-Clyde Consultants			



Project No. 414821	SONGS Unit 1 Spectra	Basis for the Development of the February 1982 WCC Instrumental Response Spectrum for the SONGS Site	Figure 4-3
Woodward-Clyde Consultants			



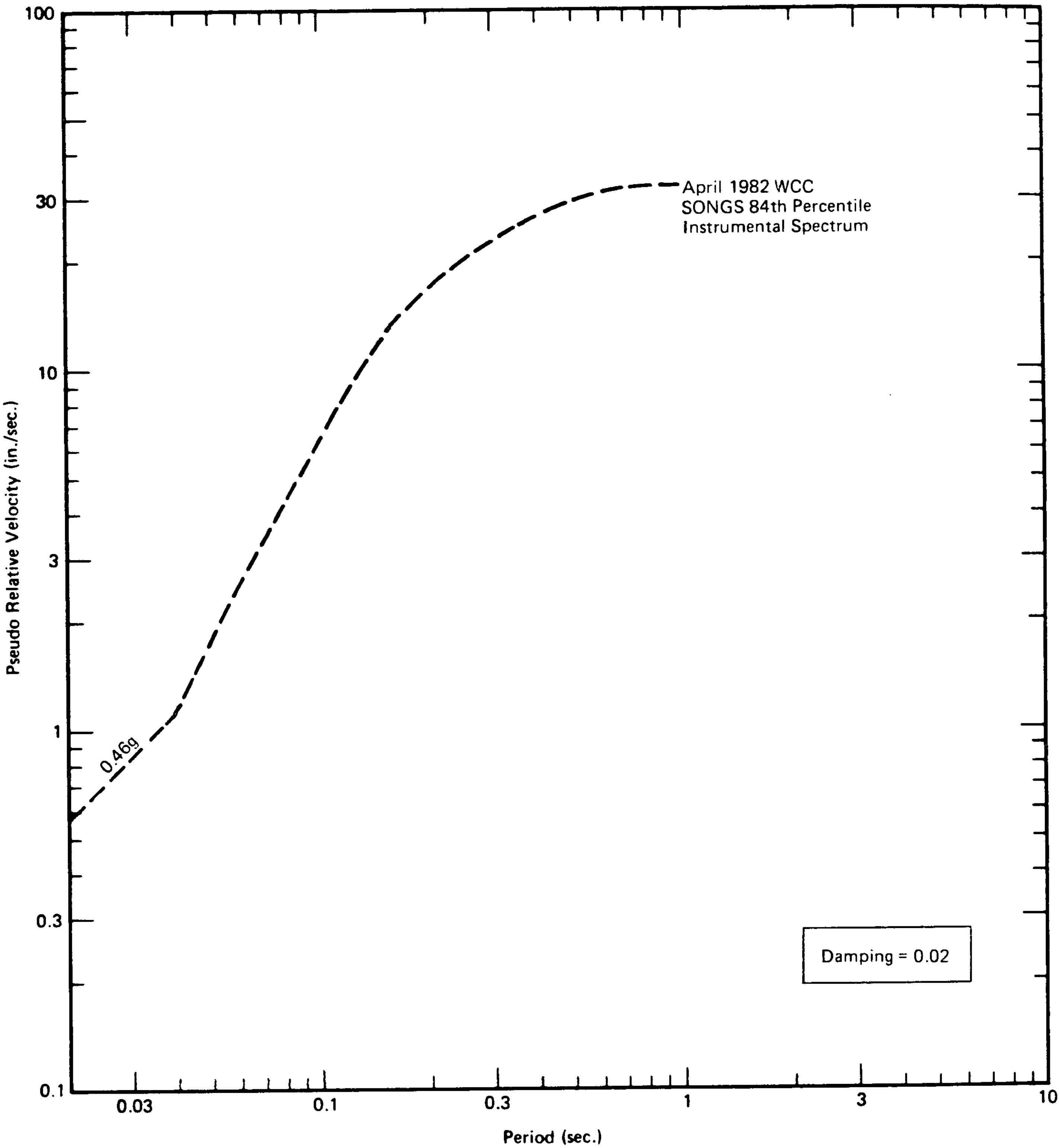
Woodward-Clyde Consultants

Project No. 41482I

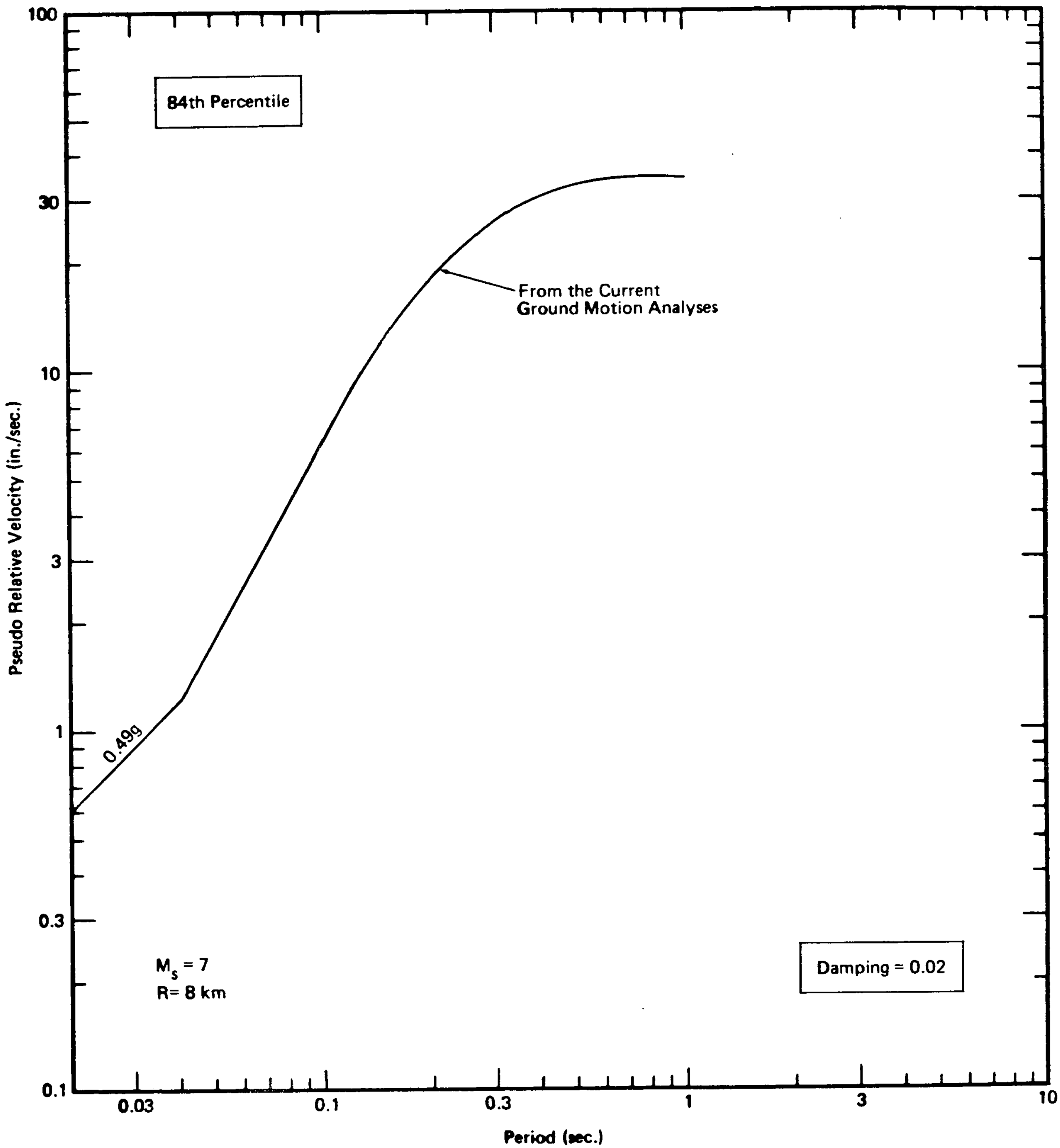
SONGS Unit 1 Spectra

Basis for the Development of April 1982 WCC Instrumental Response Spectrum for the SONGS Site

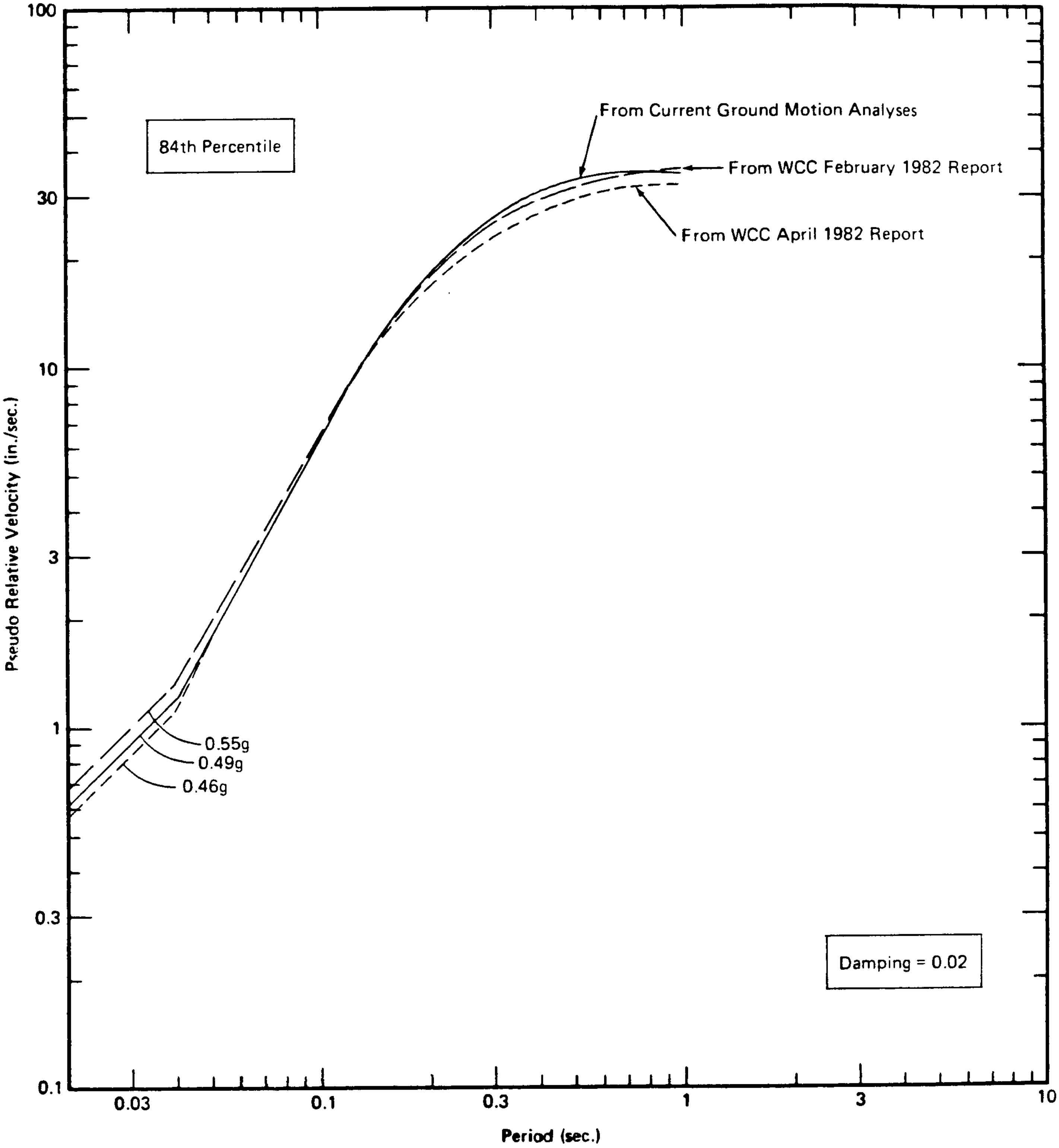
Figure 4-4



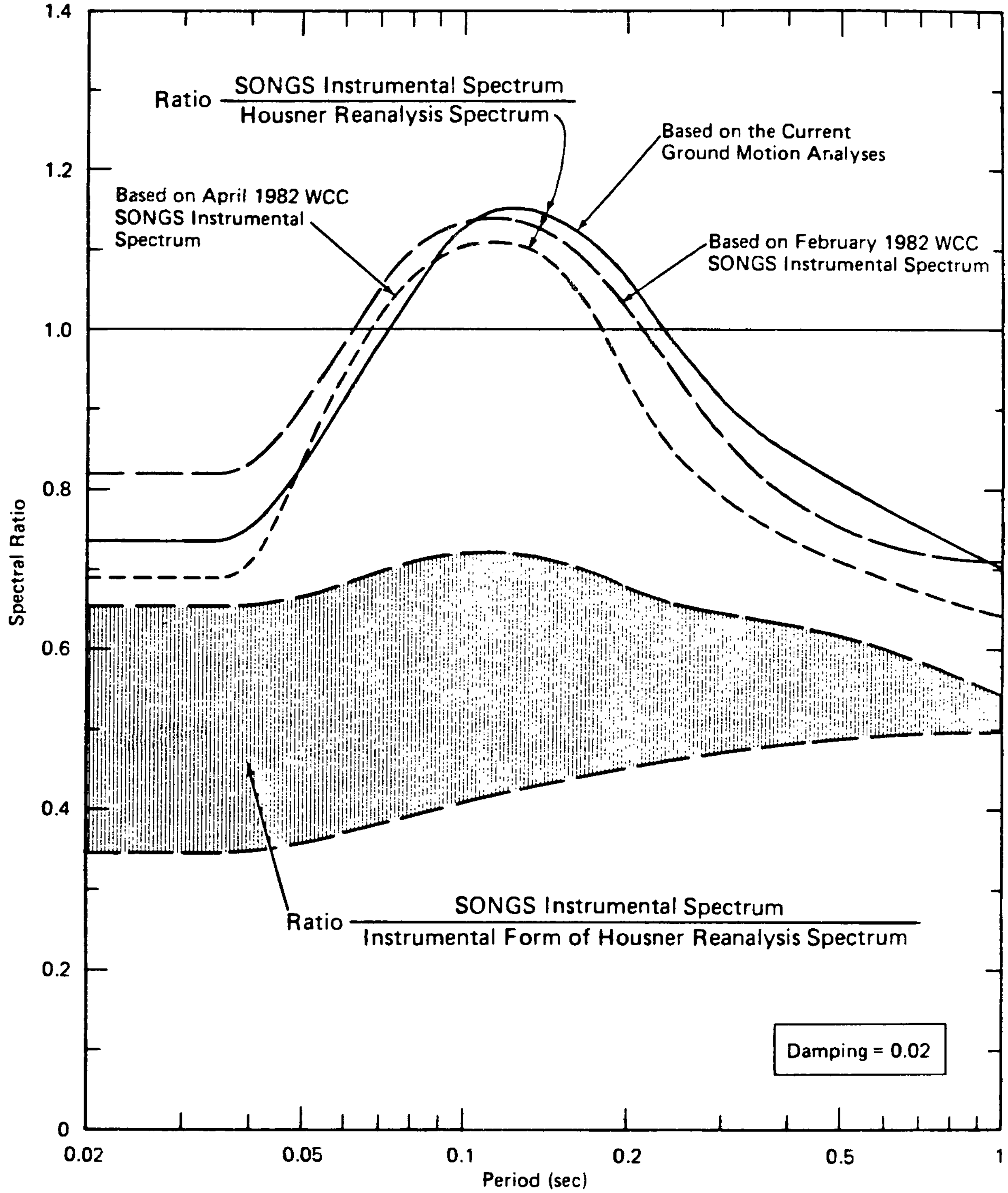
Project No. 414821	SONGS Unit 1 Spectra	April 1982 WCC SONGS 84th Percentile Instrumental Spectrum	Figure 4-5
Woodward-Clyde Consultants			



Project No. 414821	SONGS Unit 1 Spectra	84th Percentile Instrumental Response Spectrum for the SONGS Site from the Current Ground Motion Analyses	Figure 4-6
Woodward-Clyde Consultants			



Project No. 414821	SONGS Unit 1 Spectra	Comparison of Instrumental Response Spectra Developed by WCC for the SONGS Site	Figure 4-7
Woodward-Clyde Consultants			



Project No. 414821	SONGS Unit 1 Spectra	Ratio of SONGS 84th Percentile Instrumental Spectra to Reanalysis Spectra for 2% Damping	Figure 4-8
Woodward-Clyde Consultants			

REFERENCES

REFERENCES

Campbell, K. W. (1981), "Near-Source Attenuation of Peak Horizontal Acceleration," Bulletin of the Seismological Society of America, Vol. 71, No. 6, December.

Donovan, N. C. and Bornstein, A. E. (1978), "Uncertainties in Seismic Risk Procedure," Journal of the Geotechnical Engineering Division, ASCE, Vol. 104, No. GT7, July, pp. 869-887.

Idriss, I. M. (1978), "Characteristics of Earthquake Ground Motions," State-of-the-art paper; Proceedings of the Specialty Conference on Earthquake Engineering and Soil Dynamics, Geotechnical Engineering Division of the American Society of Civil Engineers, Pasadena, California, June 19-21, Vol. III, pp. 1151-1263.

Idriss, I. M., Sadigh, K. and Power, M. S. (1982), "Earthquake Ground Accelerations and Velocities at Close Distance to the Source," Paper presented at the April, 1982 meeting of the Seismological Society of America.

Joyner, W. B. and Boore, D. M. (1981), "Peak Horizontal Acceleration and Velocity from Strong-Motion Records Including Records from the 1979 Imperial Valley, California Earthquake," Bulletin of the Seismological Society of America, Vol. 71, No. 6, pp. 2011-2038.

Seed, H. B. and Idriss, I. M. (1982), "Soil Behavior During Earthquakes," Earthquake Engineering Research Institute, Berkeley, California (monograph to be published as Volume III of a series titled: Engineering Monographs on Earthquake Criteria, Structural Design and Strong Motion Records).

APPENDIX A

BASIS FOR THE CURRENT GROUND MOTION ANALYSES

APPENDIX A

BASIS FOR THE CURRENT GROUND MOTION ANALYSES

A.1 Background and Basic Approach

The objective of the current ground motion analyses was to develop an 84th percentile instrumental response spectrum to characterize ground motion for the SONGS site resulting from an M_s 7 earthquake at a closest distance of 8 km.

The analyses conducted in 1979 (June 1979 WCC report) developed an instrumental response spectrum for the SONGS site for an M_s 6½ earthquake. This spectrum was then extended to M_s 7 using scaling relationships for peak acceleration and spectral ordinates (response to NRC Question 351.54). To accommodate new significant data gathered subsequent to the data available for the June 1979 report, additional studies were conducted and the results reported in the February 1982 and April 1982 WCC reports.

In the analyses summarized above, the data base was intentionally limited to earthquakes in the magnitude range M_s 6½ to 7, namely close to the maximum magnitude of M_s 7 postulated for SONGS design criteria. Also to the extent possible, preference was given to recordings obtained within the distance range of interest and from recording stations with subsurface soil conditions similar to the SONGS site.

For example, the ground motion analyses documented in the 12 April 1982 report specifically addressed the magnitude range of interest (i.e. magnitude 6½ to 7) and considered the modifications of the IV79 instrumental spectrum at a closest distance of 8 km from the causative fault. This modification was accomplished by interpolating a transfer function between deep soil and rock spectra for the SONGS site conditions primarily on the basis of the 1971 San Fernando (SF71) earthquake data.

The purpose of the current ground motion analyses was to provide an estimate of the response spectrum applicable to the SONGS site on the basis of multiple regression analyses of a much larger data base covering a much wider magnitude range than utilized in the previous studies.

It should be emphasized that, with regard to predictions beyond the magnitude and distance range of the majority of the data, multiple regression analysis results could be extremely sensitive to the analysis procedure, regression model and constraints on regression parameters. Furthermore, development of regression relationships for response spectral ordinates by means of multiple regression analysis entails additional considerations compared to development of regression relationships for PGA. This is mainly due to: (1) much smaller number of available digitized and processed accelerograms compared to available PGA values; and (2) less experience of the profession with response spectra than with PGA and therefore lack of well-tested and well-constrained regression models for spectral ordinates.

Finally, the multiple regression analyses cannot directly give how the magnitude of the dispersion changes for various subsets of the data.

The approach for the current ground motion analyses entails a number of steps to eliminate or reduce the potential shortcomings and limitations discussed above in connection with multiple regression analyses to develop attenuation relationships for response spectral ordinates. The significant features of the current ground motion analyses are summarized below.

Development of Median Attenuation Relationships - Median attenuation relationships for spectral velocity, S_v, were developed separately for deep soil and rock because of empirically-observed and physically-inferred differences in peak acceleration and relative frequency content of ground motions.

The median attenuation relationships for S_v were developed by a three-step process: Step 1 involved development of attenuation relationships for PGA, Step 2 involved development of attenuation relationships for normalized spectra, S_v/a, and Step 3 involved development of attenuation relationships for absolute spectra, S_v, through the synthesis of results of Steps 1 and 2. This three-step process was found preferable to the one-step multiple regression analysis of S_v for primarily two reasons: (1) this approach allows and facilitates distinguishing the intrinsic trends of ground motion frequency content (S_v) through examination of the relative frequency content (S_v/a); thus the selection of the regression model and development of constraints for regression parameters could be more readily accomplished and tested; and (2) this approach allows one to utilize all available acceleration data (i.e. a much larger data base than available data base for S_v) to enhance and stabilize results for spectral ordinates.

Selection of the regression model and development of constraints for regression parameters were based on: (i) examination and analysis of data from individual earthquakes, (ii) analysis of data from limited magnitude and distance bands, and (iii) consideration of theoretical and physical concepts regarding generation of seismic waves and their transmission through earth materials.

Development of Relationships for Dispersion - One of the limitations of least-squares regression analysis is that the variation of dispersion as a function of magnitude cannot be directly obtained from the multiple regression analysis results. In the current ground motion analyses, dispersion relationships for spectral ordinates were developed as a function of magnitude and period by conducting multiple regression analyses of several subsets of the data.

Specifically, dispersion relationships as a function of magnitude and period were developed in three steps. The first step involved calculation of the standard error of estimate, $S_{\ln a}$, for individual earthquakes or narrow magnitude bands for PGA. The second step involved calculation of $S_{\ln S_v}$ for individual earthquakes or narrow magnitude bands for S_v to develop relative dispersion trends with period. The third step consisted of developing dispersion as a function of magnitude and period by linearly scaling the relative dispersion trends with period from the second step to the PGA dispersions from the first step.

A.2 Data Base

Peak ground acceleration and spectral velocity data were selected from earthquakes tabulated on Table A-1 for the magnitude range approximately M 3 to M 7½. Specific data selection criteria which excluded data from several earthquakes (including all data from a few earthquakes - those without asterisks in Table A-1) in Table A-1 are summarized as follows:

a. exclude data from structures with deep basement;

b. include only those data which are well located and for which the distance is well documented;

c. include only those data from shallow crustal earthquakes typical of California; and

d. include only those data for deep soil and rock excluding shallow soil over rock or very soft soil sites.

Based on the analysis format (Table 2-1), the data were separated by site classification to fall under two general classifications: deep soil sites and rock sites. For peak acceleration, applying the selection criteria to the recordings from earthquakes shown in Table A-1 yielded 1,053 Volume I PGA values of which 892 were from deep soil sites and 161 were from rock sites. The data set for response spectra are subsets of the deep soil and rock PGA data set and are comprised of the digitized and processed accelerograms. The spectral data subsets represent approximately one-third of the main PGA data set. Specifically, the spectral subset is comprised of 292 spectra (224 for soil and 68 for rock) defined by 68 periods between 0.04 and 10 seconds at 2% damping.

The distribution of data for each earthquake as a function of distance for rock and soil are summarized in Tables A-2 through A-5. Specifically, Tables A-2 and A-3 show the number of PGA data points, in various distance ranges, for soil and rock sites, respectively. Similarly, Tables A-4 and A-5 show the number of spectra in various distance ranges from soil and rock sites, respectively. The overall distribution of PGA data as a function of magnitude and distance is summarized for soil sites as follows:

	NO. OF DATA POINTS MAGNITUDE RANGE			
R (km)	2.8 - 3.9	4.0 - 4.9	5.0 - 5.9	6.0 - 6.9
0 - 10	170	150	27	55
10 - 25	56	112	87	42
25 - 50	4	4	55	34
50 - 100	0	0	29	22
>100	0	0	5	40

and for rock sites:

NO. OF DATA POINTS
MAGNITUDE RANGE

R (km)	2.8 - 3.9	4.0 - 4.9	5.0 - 5.9	6.0 - 6.9
0 - 10	10	30	10	8
10 - 25	0	6	15	22
25 - 50	0	2	26	6
50 - 100	0	0	15	8
>100	0	0	1	2

Similarly, the overall distribution of spectral data as a function of magnitude and distance is summarized for soil sites as follows:

NO. OF SPECTRA
MAGNITUDE RANGE

R (km)	2.8 - 3.9	4.0 - 4.9	5.0 - 5.9	6.0 - 6.9
0 - 10	32	62	13	37
10 - 25	0	0	10	34
25 - 50	0	0	4	18
50 - 100	0	0	0	6
>100	0	0	0	8

and for rock sites:

NO. OF SPECTRA
MAGNITUDE RANGE

R (km)	2.8 - 3.9	4.0 - 4.9	5.0 - 5.9	6.0 - 6.9
0 - 10	0	20	8	8
10 - 25	0	0	2	12
25 - 50	0	0	0	8
50 - 100	0	0	0	8
>100	0	0	0	2

The various distributions of data presented above for PGA for soil sites, PGA for rock sites, spectra for soil sites and spectra for rock sites are plotted as points of M vs. R on Figures A-1 and A-2. In general, these graphs show that the PGA data sets are more complete than for spectra

(Figure A-1 vs. Figure A-2), and that the soil data sets are more complete than the rock data sets (Figure A-1 for PGA and Figure A-2 for S_v). For these reasons, spectra shapes S_v/a were analyzed and augmented by the more extensive PGA data base. Also, the analysis of rock data required careful extrapolation of the regression into close distances taking into account the relative trends of soil and rock data with distance and acknowledgement of physical principles.

A.3 Attenuation Relationships for Peak Ground Acceleration

The soil and rock PGA data sets described in Section A.2 were analyzed by multiple regression using the following relationship:

$$\ln a = b_1 + b_2 M + b_3 \ln [R + C(M)]$$

Constraints on parameter b_3 (far field slope) and C (distance normalizing parameter) were developed based on: (i) examination and analysis of data from individual earthquakes, (ii) analysis of data from limited magnitude and distance bands, and (iii) consideration of theoretical and physical concepts regarding generation of seismic waves and their transmission through earth materials.

These multiple regression analyses resulted in the development of median attenuation curves of PGA as a function of distance for M 5 to 7 as shown in Figure A-3 for deep soil sites and Figure A-4 for rock sites. By cross plotting PGA values for deep soil site from Figure A-3 versus PGA values for rock from Figure A-4, the range of values shown in Figure A-5 was developed. As can be noted from Figure A-5, this range of value is in good agreement with the curve developed by Seed and Idriss (1982) for deep soil sites.

A.4 Attenuation Relationships for Response Spectra

The soil and rock spectra data sets described in Section A.2 were normalized by their corresponding PGA values and analyzed period by period by multiple regression using the following relationship:

$$\ln S_v/a = b_1' + b_2' (8.5 - M)^n + b_3' \ln [R + C(M)]$$

Use of the term $b_2' (8.5 - M)^n$ instead of the more common b_2M term in the above equation was found to better represent the effect of magnitude on the normalized spectral ordinates. It also provides for saturation of normalized spectral ordinates at a magnitude of 8.5.

Parameters b_3' and C were constrained for each period considered in much the same manner as for PGA. The results of the S_v/a analyses were then augmented by the PGA results to develop attenuation relationships for S_v having the following form:

$$\ln S_v = b_1'' + b_2M + b_2' (8.5 - M)^n + b_3'' \ln [R + C(M)]$$

The attenuation relationship developed for PGA in Figures A-3 and A-4, together with the spectral ordinate attenuation relationship described above, were used to develop the spectral shapes and absolute response spectra for a distance of 8 km appropriate to the SONGS site. The results for soil and rock for S_v/a (spectral shapes) for M 5 to 7 are presented in Figures A-6 and A-7, respectively. The corresponding median response spectra for soil and rock are presented in Figures A-8 and A-9, respectively. For comparison purposes, Figure A-10 shows the spectra for M_s 7 at 8 km for soil and rock. As indicated in Figure A-10, the rock spectrum is higher than the soil spectrum in the period range below about

0.35 seconds and lower than the soil spectrum for periods longer than about 0.35 seconds.

The spectral ratios resulting from the multiple regression analyses for M 7 data divided by M 6½ data are plotted as a function of period on Figure A-11. It is noted that these values are in good agreement to those used to extrapolate the M 6½ spectrum from the June 1979 WCC report to M 7 instrumental spectrum in the response to question 361.54.

A.5 Development of Relationships for Dispersion

Empirically derived attenuation relationships for earthquake ground motion parameters are typically expressed in the following form:

$$y = f\,(\text{magnitude, distance, site conditions}) \cdot \varepsilon$$

in which y is the parameter of interest (e.g. acceleration, velocity, ..., etc.) and ε is an error term and represents the measure of the dispersion of the data and the expected values (50th percentile or median) determined from the function. Most, if not all, attenuation relationships are derived on the basis that y is lognormally distributed and the error term, ε, is given by S_{ln} such that the 84th percentile of the parameter y is given by the expected (or median) value times exp (S_{ln}).

The early work for deriving such attenuation relationships (e.g. Esteva and Rosenblueth, 1964; Esteva, 1970) included a sparse amount of data. The resulting error term was fairly large, with exp (S_{ln}) equal to 2 or greater.

Following the availability of recordings from the 1971 San Fernando earthquake (which significantly increased the size of the data base), several investigators derived revised attenuation relationships. These derivations can be divided into two categories: (1) derivations based on the entire data set, i.e. multiple regression analyses for all magnitudes and distances and no isolation of site effects; or (2) derivations based on subsets in terms of a narrow magnitude range and/or for one comparable site condition. Equations based on approach (2) typically resulted in significant reduction in S_{ln}.

Typical examples of the equations derived using approach (1) include those given by Esteva and Villaverde (1973), Trifunac (1976), McGuire (1978) and more recently, Campbell (1981) and Joyner and Boore (1981). The values of S_{ln} calculated by these investigators range from approximately 0.6 to 0.7 for acceleration, with the corresponding values of exp (S_{ln}) ranging from approximately 1.8 to 2.

Typical examples of the equations derived using approach (2) includes those given by Duke et al. (1976), Seed et al. (1976), Sadigh et al. (1978), Boore et al. (1978) and Idriss (1978). The values of S_{ln} calculated by these investigators using data from earthquakes with magnitude 6.5± range from approximately 0.3 to 0.45 for acceleration, with the corresponding values of exp (S_{ln}) ranging from approximately 1.35 to 1.55.

The 1979 Imperial Valley earthquake and its aftershocks, together with data from the 1971 San Fernando earthquake, the 1975 Oroville earthquake and aftershocks, the 1979 Coyote Lake earthquake and the 1980 Mammoth Lakes earthquake and aftershocks, provide the following values for dispersion.

Event	Magnitude	S_{lna}	exp(S)
1971 San Fernando	6.6	0.30 to 0.40	1.35 to 1.5
1975 Oroville Aftershocks	4.1 to 4.6	0.65 to 0.75	1.9 to 2.1
1979 Imperial Valley	6.9	0.3 to 0.33	1.35 to 1.4
1979 Imperial Valley Aftershocks	4.9 to 5.4	0.5 to 0.65	1.65 to 1.9
1979 Coyote Lake	5.6	0.45 to 0.55	1.55 to 1.7
1980 Mammoth Lake Aftershocks	4 to 4.9	0.7 to 0.8	2 to 2.2

The results from these earthquakes show a very definite trend that the dispersion decreases significantly as the magnitude of the event increases. Accordingly, for M_s = 7, the dispersion as expressed by exp(s) can be reasonably established as 1.35 to 1.4.

The multiple regression analyses described in the foregoing subsections tend to minimize the differences between predicted and observed ground motion parameters. The analysis results provide the model parameters which give the best fit to observed data and the average dispersion about the "best" estimate of the model. For the current analysis, the average dispersion calculated as a function of period is shown in Figure A-12. The regression analysis can not, however, directly give how the magnitude of dispersion changes for various subsets of the data. For example, the foregoing discussion indicated a dependence of dispersion on magnitude as summarized in Figure A-13. This cannot be incorporated into the multiple regression analysis; so that considering the trends shown in Figure A-13, use of the average dispersion shown in Figure A-12 would yield over-prediction of the 84th percentile ground motion parameters for high magnitude earthquakes and under-prediction of the 84th percentile ground motion parameters for low magnitude earthquakes. For this reason, the dispersion relationships shown in Figure A-14 were developed based on the smooth curve shown in Figure A-13 for PGA and on the trends of dispersion with period from individual well recorded earthquakes.

TABLE A-1 - LIST OF EARTHQUAKE EVENTS USED IN SONGS1 ATTENUATION STUDY

EARTHQUAKE NAME	DATE	ML	MS
Long Beach, CA	03/01/33	6.3	6.3*
Helena, MT	10/31/35	5.6	6.0*
Imperial Valley, CA	05/19/40	6.4	7.1
Kern County, CA	07/21/52	7.2	7.7
Port Hueneme	03/18/57	4.7*	
Southern Calif.	07/15/65	4.0*	4.0
Koyna, India	12/10/65	6.0	6.5*
Parkfield, CA	06/27/66	5.6	6.4*
Borrego Mtn., CA	04/08/68	6.4	6.7*
Lytle Creek	09/12/70	5.4*	
San Fernando, CA	02/09/71	6.4	6.6*
Lake Isabella, CA	03/08/71	4.1*	
Bear Valley, CA	09/04/72	4.7*	4.3
Managua, Nicaragua	12/23/72	6.1	6.2*
Point Mugu	02/21/73	6.0*	5.2
Hollister, CA	11/28/74	5.2	4.5*
Oroville, CA (Mainshock)	08/11/75	5.7	5.6*
Aftershock R	08/02/75	5.1*	
Aftershock S	08/02/75	5.2	4.7*
Aftershock A	08/03/75	4.6*	
Aftershock B	08/03/75	4.1*	
Aftershock D	08/05/75	3.3*	
Aftershock F	08/06/75	4.7*	
Aftershock J	08/06/75	3.6*	
Aftershock K	08/08/75	4.9*	
Aftershock N	08/11/75	4.3*	
Aftershock O	08/11/75	3.6*	

TABLE A-1 - LIST OF EARTHQUAKE EVENTS USED IN SONGS1 ATTENUATION STUDY (cont'd)

EARTHQUAKE NAME	DATE	ML	MS
Oroville, CA (cont'd)			
Aftershock P	08/16/75	4.0*	
Aftershock Q	08/16/75	2.8*	
Aftershock T	09/26/75	4.0*	
Aftershock U	09/27/75	4.6*	
Gazli, USSR	05/17/76	6.5	7.0 (7.3)
Santa Barbara, CA	08/13/78	5.1	5.6*
Tabas, Iran	09/16/78	7.5	7.7
Coyote Lake, CA	08/06/79	5.7	5.6*
Imperial Valley, CA	10/15/79	6.6	6.9*
Aftershock (A01)	10/15/79	3.4*	
Aftershock (A02)	10/15/79	3.8*	
Aftershock (A03)	10/15/79	5.2*	
Aftershock (A04)	10/15/79	3.4*	
Aftershock (A05)	10/15/79	4.0*	
Aftershock (A06)	10/15/79	3.5*	
Aftershock (A07)	10/15/79	4.2*	
Aftershock (A08)	10/15/79	3.0*	
Aftershock (A09)	10/15/79	3.0*	
Aftershock (A10)	10/15/79	4.2*	
Aftershock (A11)	10/15/79	3.7*	
Aftershock (A12)	10/15/79	3.2*	
Aftershock (A13)	10/15/79	4.6*	
Aftershock (A14)	10/15/79	3.6*	
Aftershock (A15)	10/15/79	4.3*	
Aftershock (A16)	10/15/79	4.0*	
Aftershock (A17)	10/15/79	3.0*	
Aftershock (A18)	10/15/79	3.2*	
Aftershock (A19)	10/15/79	3.2*	
Aftershock (A20)	10/15/79	3.7*	
Aftershock (A21)	10/15/79	4.5*	
Aftershock (A22)	10/15/79	4.5*	
Aftershock (A23)	10/15/79	3.4*	
Aftershock (A24)	10/15/79	3.3*	
Aftershock (A25)	10/15/79	5.1*	
Aftershock (A26)	10/15/79	4.0*	

TABLE A-1 - LIST OF EARTHQUAKE EVENTS USED IN SONGS1 ATTENUATION STUDY (cont'd)

EARTHQUAKE NAME	DATE	ML	MS
Imperial Valley, CA (cont'd)			
Aftershock (A27)	10/15/79	4.1*	
Aftershock (A28)	10/15/79	3.6*	
Aftershock (A29)	10/15/79	5.1*	
Aftershock (A30)	10/15/79	4.6*	
Aftershock (A31)	10/15/79	5.7*	
Aftershock (A32)	10/16/79	4.2*	
Aftershock (A33)	10/16/79	3.6*	
Aftershock (A34)	10/16/79	4.0*	
Aftershock (A35)	10/16/79	4.8*	
Aftershock (A36)	10/16/79	4.0*	
Aftershock (A37)	10/16/79	3.7*	
Aftershock (A38)	10/16/79	4.9*	
Aftershock (A39)	10/17/79	3.1*	
Aftershock (A40)	10/17/79	3.2*	
Aftershock (A41)	10/17/79	3.3*	
Aftershock (A42)	10/17/79	3.4*	
Aftershock (A43)	10/17/79	4.1*	
Aftershock (A44)	10/17/79	4.5*	
Aftershock (A45)	10/17/79	3.2*	
Aftershock (A46)	10/17/79	3.0*	
Aftershock (A47)	10/18/79	3.3*	
Aftershock (A48)	10/18/79	3.2*	
Aftershock (A49)	10/20/79	3.3*	
Aftershock (A50)	10/21/79	3.3*	
Aftershock (A51)	10/21/79	4.6*	
Mammoth Lakes			
Shock A	05/25/80	6.1*	6.1
Shock B	05/25/80	6.0*	
Shock C	05/25/80	6.1*	5.8
Shock D	05/27/80	6.2*	6.0
Aftershock	05/25/80	5.7*	5.3
Aftershocks	05/27/80 to 06/13/80	3.0 to 4.9	

TABLE A-1 - LIST OF EARTHQUAKE EVENTS USED IN SONGS1 ATTENUATION STUDY (cont'd)

EARTHQUAKE NAME	DATE	ML	MS
Livermore (Shock A)	12/04/80	5.9	5.9*
Livermore (Shock B)	12/06/80	5.2	5.0*

Notes: (1) Earthquake magnitude chosen for current analyses is indicated by the asterisk; as a general rule, the magnitude chosen is M_S for earthquakes with magnitudes greater than about 5.5 and M_L for earthquakes with magnitude less than about 5.5.

(2) Total number of recordings used in the analyses is 892 for soil sites and 161 for rock sites (excluding Tabas, Gazli, IV40 and Kern County).

TABLE A-2 - NUMBER OF VOLUME 1 PGA DATA POINTS FOR SOIL SITES

EARTHQUAKE	MAGNITUDE	R (km) 0 - 10	10 - 25	25 - 50	50 - 100	>100	TOTAL
SF71	6.6	2	16	20	12	26	76
IV79	6.9	38	18	8	10	6	80
IV79A*	3.0 - 3.8	40	32	4	0	0	76
IV79B	4.0 - 4.9	28	50	2	0	0	80
IV79C	5.1 - 5.7	10	60	16	0	0	86
Livermore A	5.9	0	6	10	4	0	24
Livermore B	5.0	2	8	10	4	0	24
Oroville A	2.8	2	1	0	0	0	3
Oroville B	3.6	14	3	0	0	0	17
Oroville C	4.0 - 4.9	84	28	0	0	0	112
Oroville D	5.1	0	4	0	0	0	4
Coyote Lake	5.6	6	7	17	13	3	46
Mammoth Lakes	6.0 - 6.2	8	4	6	0	0	18
Mammoth A	3.0 - 3.5	60	4	0	0	0	64
Mammoth B	3.7 - 3.9	54	16	0	0	0	70
Mammoth C	4.0 - 4.4	16	22	2	0	0	40
Mammoth D	4.6 - 4.9	14	10	0	0	0	24
Santa Barbara	5.6	7	0	0	0	0	7
Parkfield	6.4	5	2	0	0	0	7
Lytle Creek	5.4	0	2	2	8	2	14
Bear Valley	4.7	6	0	0	0	0	6
Port Hueneme	4.7	2	0	0	0	0	2
So. Calif.	4.0	0	2	0	0	0	2
Borrego Mtn.	6.7	0	0	0	0	8	8
Managua	6.2	2	0	0	0	0	2
Point Mugu	6.0	0	2	0	0	0	2
Mammoth E	5.7	2	0	0	0	0	2

Notes: (1) Letters after each earthquake apply to aftershocks.
(2) Total number of soil sites in Vol. 1 = 894.
(3) R is the closest distance to rupture surface; for small earthquakes, R is the epicentral distance.

TABLE A-3 - NUMBER OF VOLUME 1 PGA DATA POINTS FOR ROCK SITES

		R (km)					
EARTHQUAKE	MAGNITUDE	0 - 10	10 - 25	25 - 50	50 - 100	>100	TOTAL
SF71	6.6	2	12	4	8	2	28
IV79	6.9	0	0	2	0	0	2
IV79A*	4.5	0	0	2	0	0	2
IV79B	5.7	0	0	2	0	0	2
Livermore A	5.9	0	2	8	6	0	16
Livermore B	5.0	2	0	10	2	0	14
Coyote Lake	5.6	6	1	2	7	1	17
Mammoth Lakes	6.0 - 6.2	0	10	0	0	0	10
Santa Barbara	5.6	0	8	0	0	0	8
Lytle Creek	5.4	0	4	4	0	0	8
Oroville A	2.8	6	0	0	0	0	6
Oroville B	3.6	4	0	0	0	0	4
Oroville C	4.0 - 4.9	26	6	0	0	0	32
Helena	6.0	2	0	0	0	0	2
Koyna	6.5	2	0	0	0	0	2
Parkfield	6.4	2	0	0	0	0	2
Oroville (Mainshock)	5.6	2	0	0	0	0	2
Lake Isabella	4.1	2	0	0	0	0	2
Hollister	4.5	2	0	0	0	0	2

Notes: (1) Letters after each earthquake apply to aftershocks.
(2) Total number of rock sites in Vol. 1 = 161.
(3) R is the closest distance to rupture surface; for small earthquakes, R is the epicentral distance.

TABLE A-4 - NUMBER OF RESPONSE SPECTRA FOR SOIL SITES

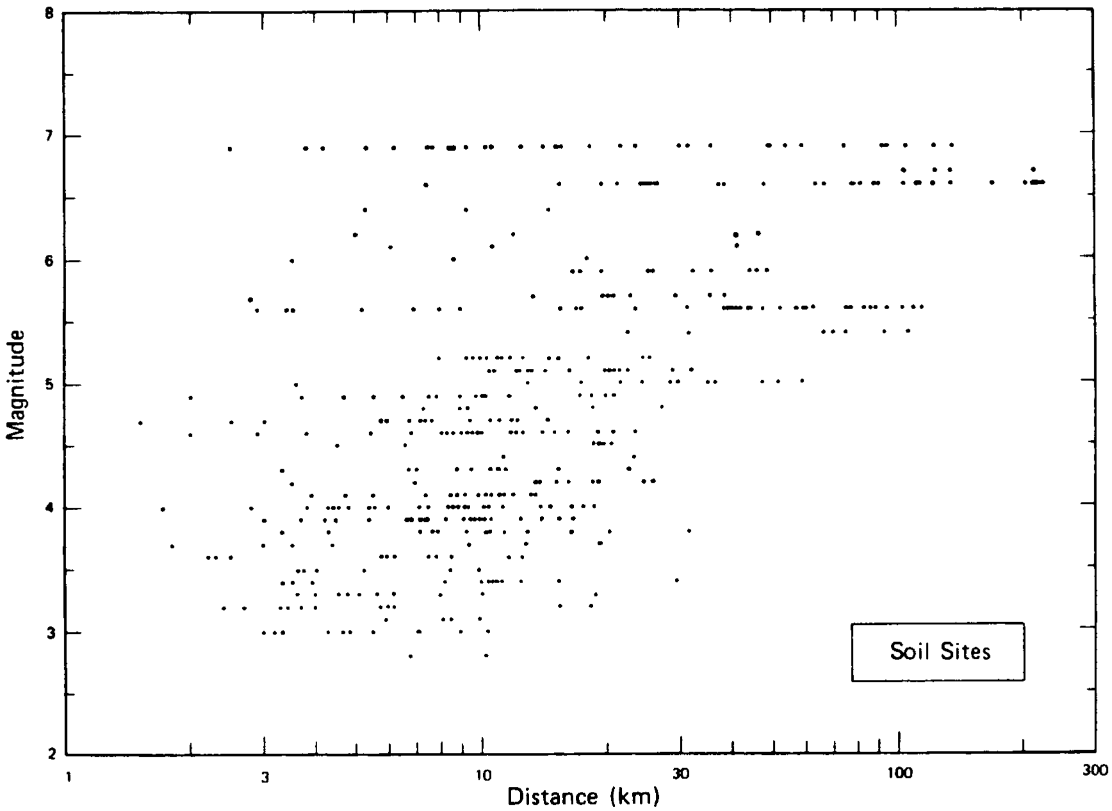
		R (km)					
EARTHQUAKE	MAGNITUDE	0 - 10	10 - 25	25 - 50	50 - 100	>100	TOTAL
IV79	6.9	24	16	4	0	0	44
SF71	6.6	2	14	12	6	8	42
Coyote Lake	5.6	6	6	0	0	0	12
Mammoth Lakes	6.0 - 6.2	6	2	2	0	0	10
Santa Barbara	5.6	7	2	0	0	0	9
Parkfield	6.4	5	2	0	0	0	7
Lytle Creek	5.4	0	2	2	0	0	4
Livermore A	5.9	0	0	2	0	0	2
Oroville A	4.0 - 4.3	24	0	0	0	0	24
Oroville B	4.6	8	0	0	0	0	8
Oroville C	4.9	4	0	0	0	0	4
Mammoth A	3.8 - 3.9	32	0	0	0	0	32
Mammoth B	4.0 - 4.1	12	0	0	0	0	12
Mammoth C	4.8 - 4.9	14	0	0	0	0	14

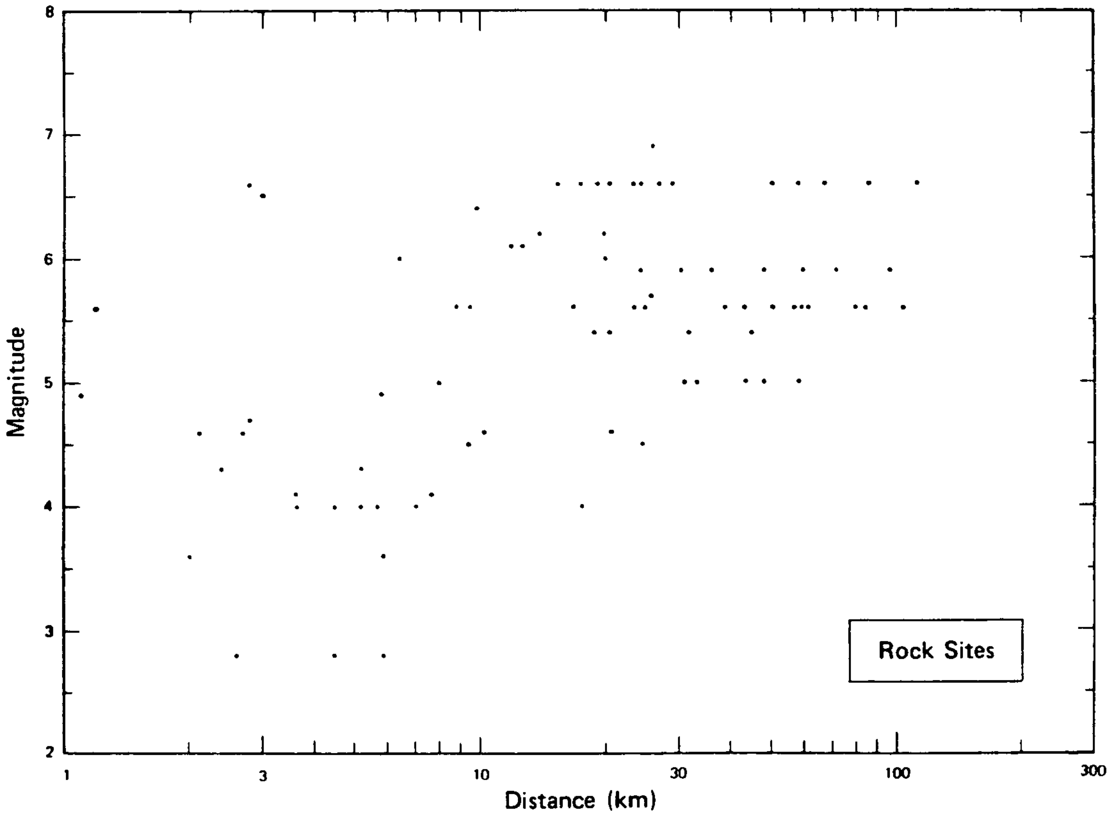
Note: Total number of soil spectra = 224.

TABLE A-5 - NUMBER OF RESPONSE SPECTRA FOR ROCK SITES

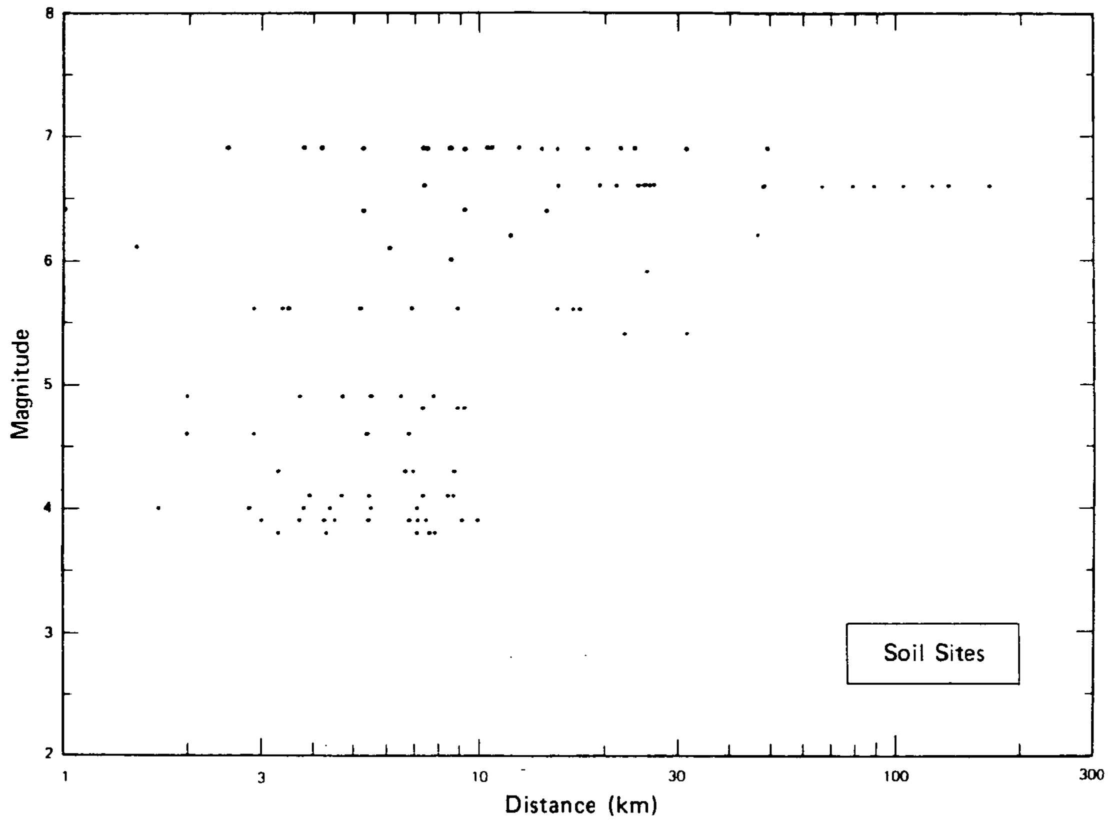
		R (km)					
EARTHQUAKE	MAGNITUDE	0 - 10	10 - 25	25 - 50	50 - 100	>100	TOTAL
IV79	6.9	0	0	2	0	0	2
SF71	6.6	2	12	4	8	2	28
Coyote Lake	5.6	6	0	0	0	0	6
Parkfield	6.4	2	0	0	0	0	2
Lytle Creek	5.4	0	2	0	0	0	2
Oroville A	4.0 - 4.3	12	0	0	0	0	12
Oroville B	4.6	4	0	0	0	0	4
Oroville C	4.9	4	0	0	0	0	4
Oroville (Mainshock)	5.6	2	0	0	0	0	2
Helena	6.0	2	0	0	0	0	2
Long Beach	6.3	0	0	2	0	0	2
Koyna	6.5	2	0	0	0	0	2

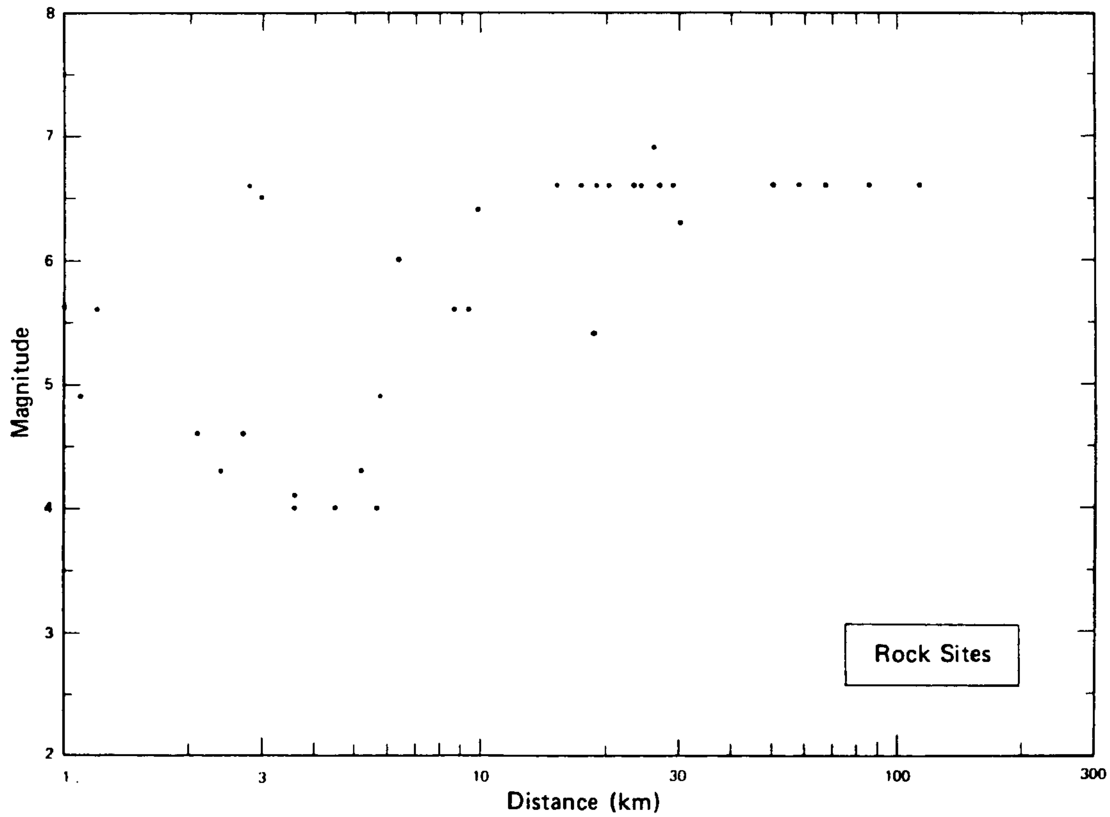
Note: Total number of rock spectra = 68.



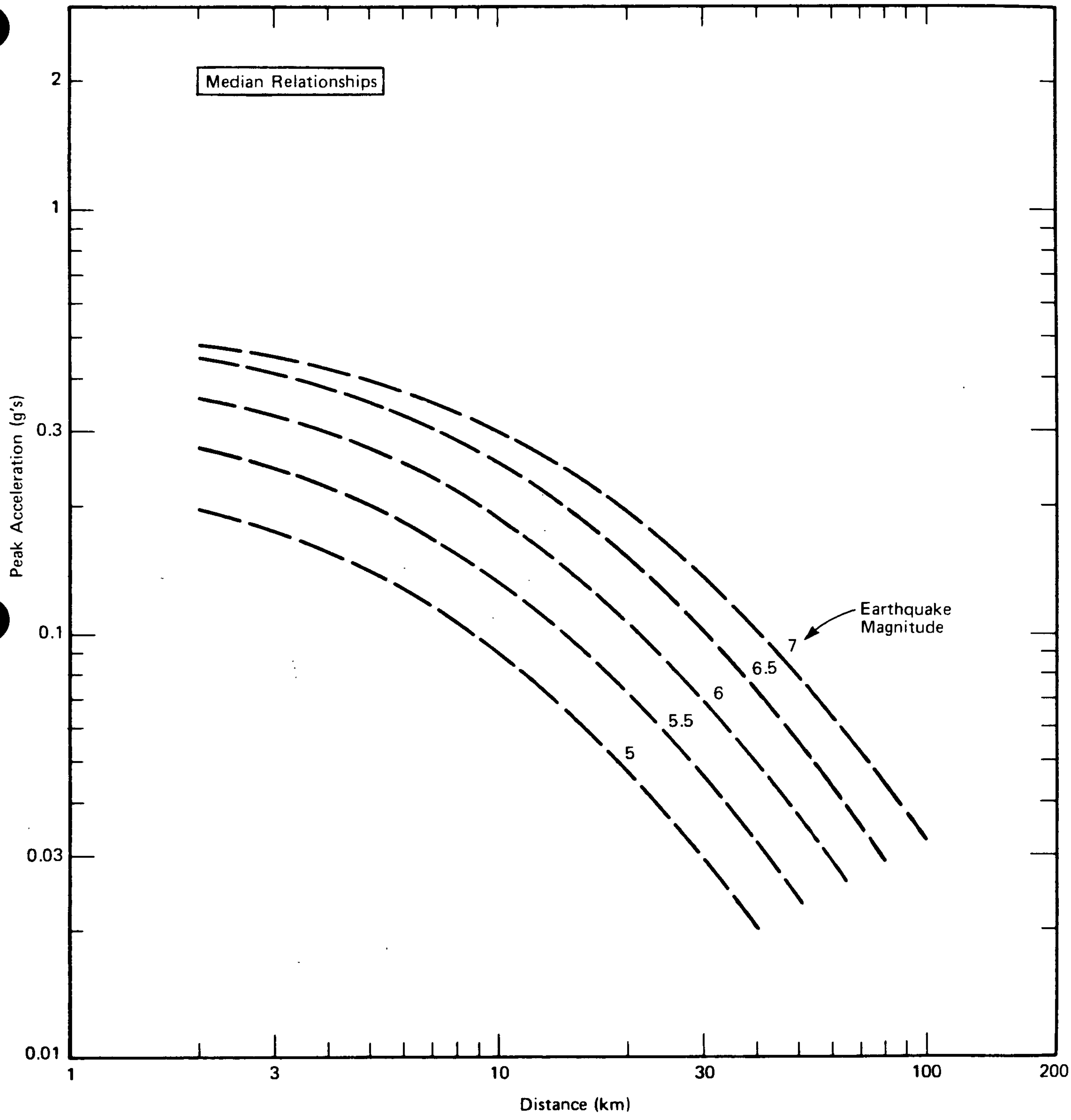


Project No. 414821	SONGS Unit 1 Spectra	Distribution of PGA Data	Figure A-1
Woodward-Clyde Consultants			

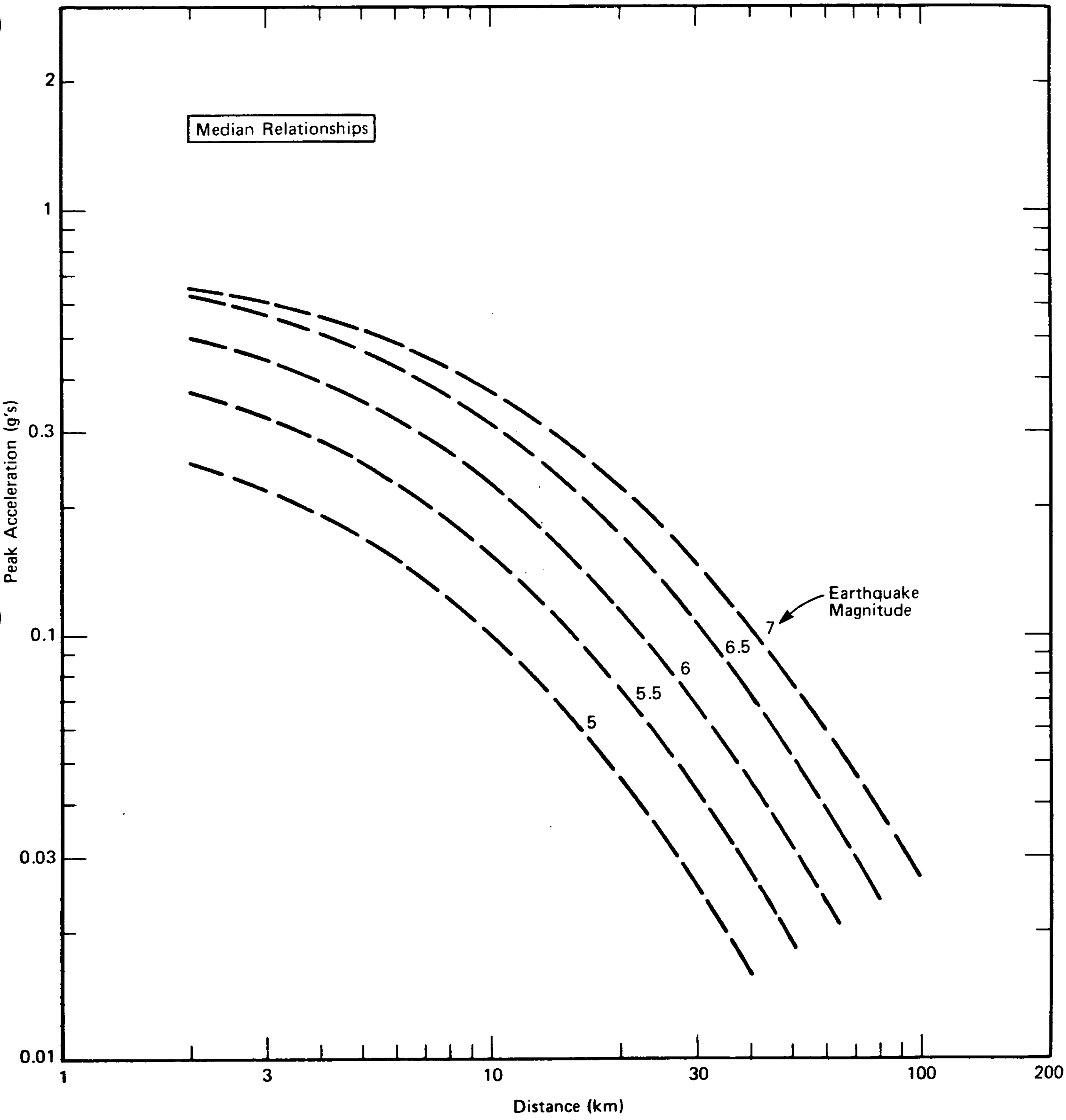




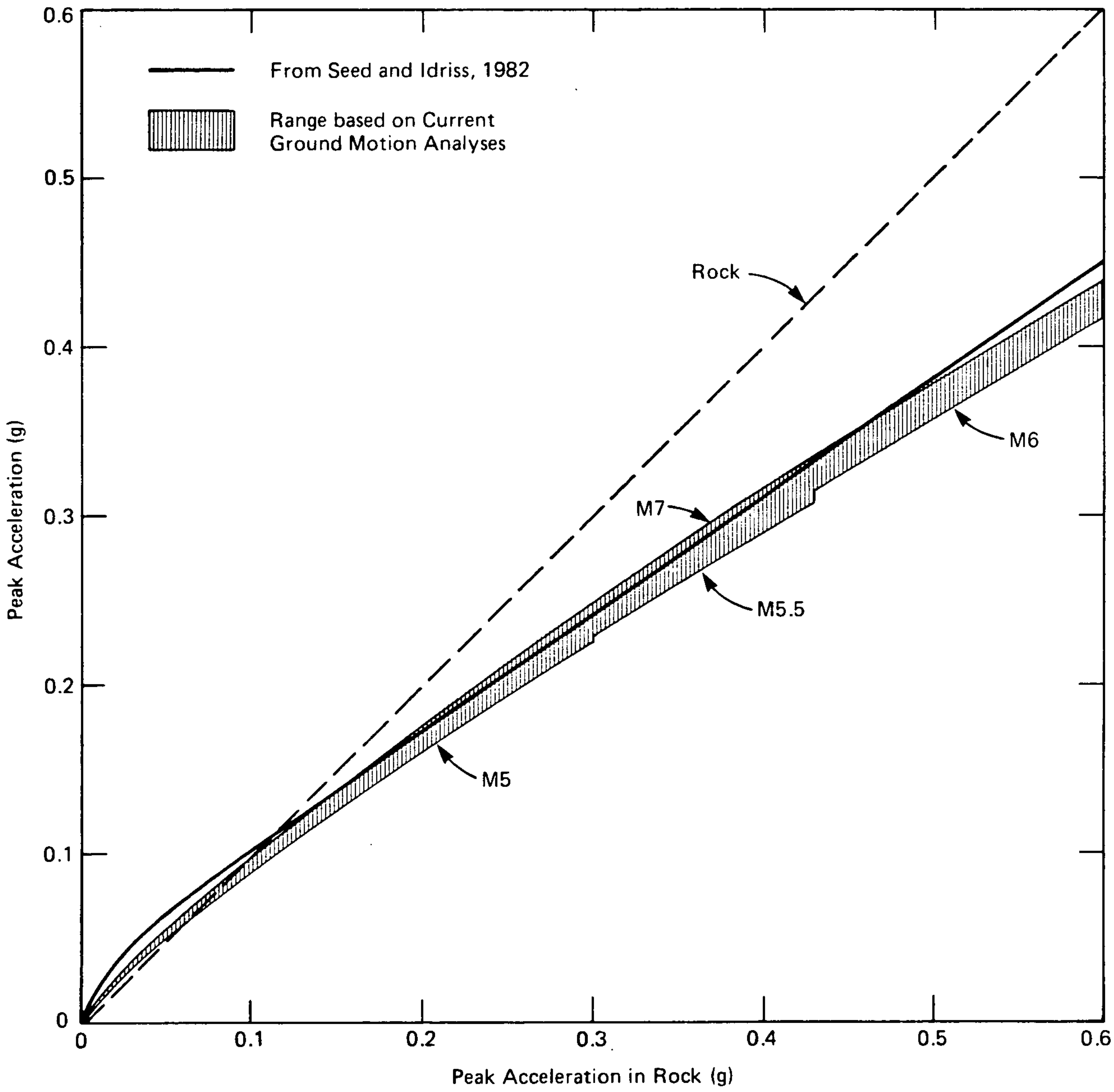
Project No. 414821	SONGS Unit 1 Spectra	Distribution of Response Spectra Data	Figure A-2
Woodward-Clyde Consultants			



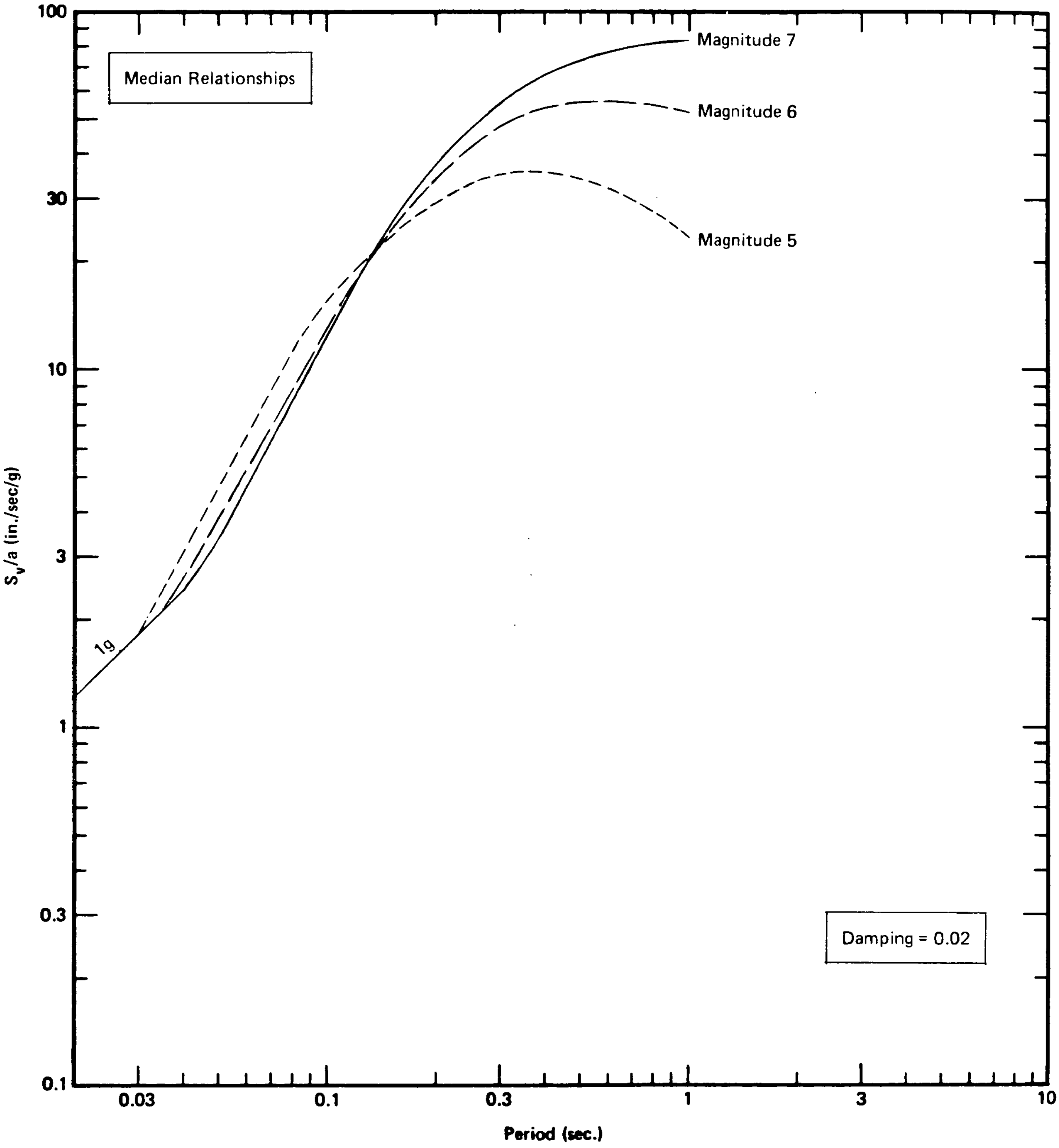
Project No. 414821	SONGS Unit 1 Spectra	Attenuation of Peak Ground Acceleration with Distance for Deep Soil Sites	Figure A-3
Woodward-Clyde Consultants			



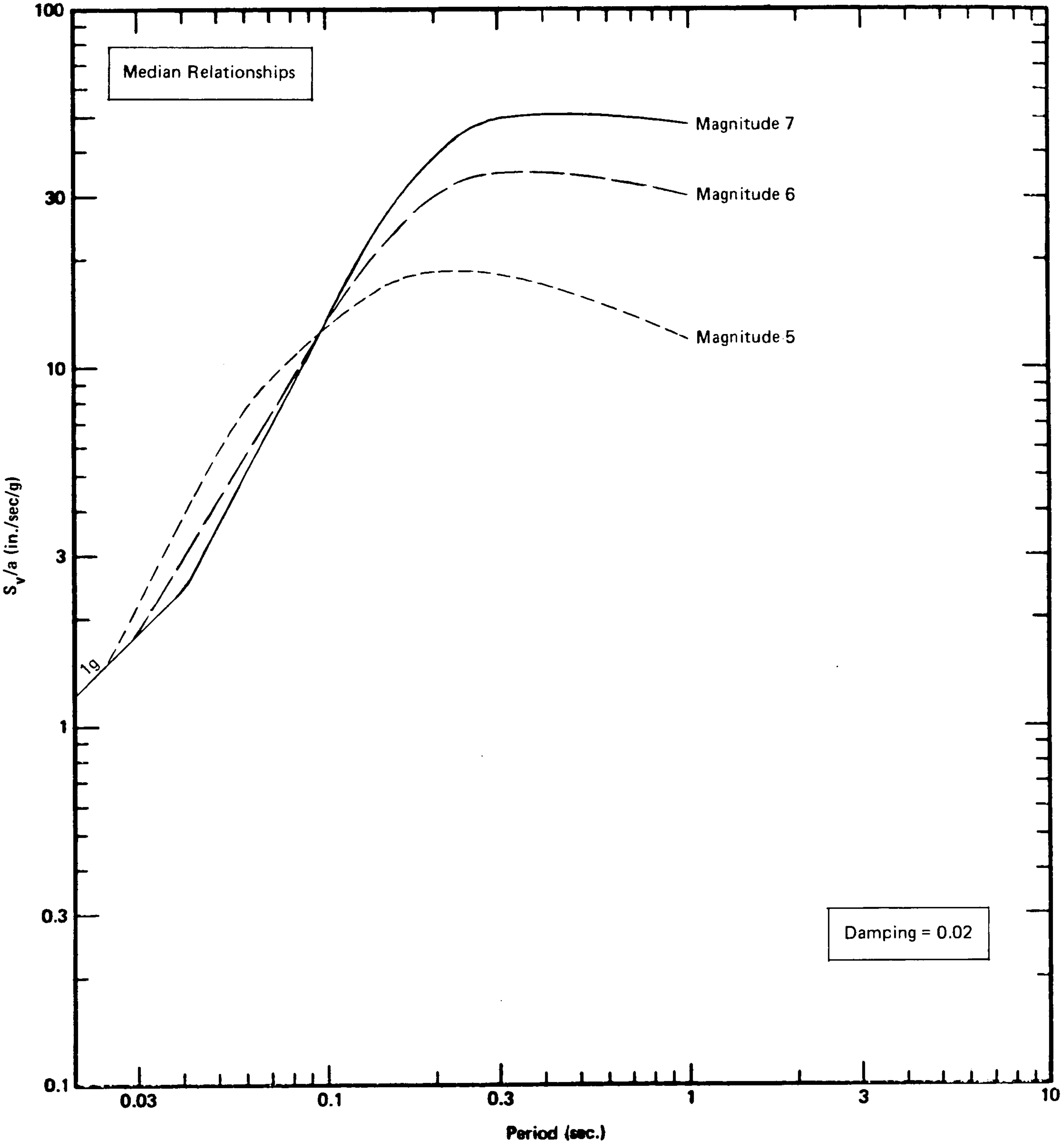
Project No. 414821	SONGS Unit 1 Spectra	Attenuation of Peak Ground Acceleration with Distance for Rock Sites	Figure A-4
Woodward-Clyde Consultants			



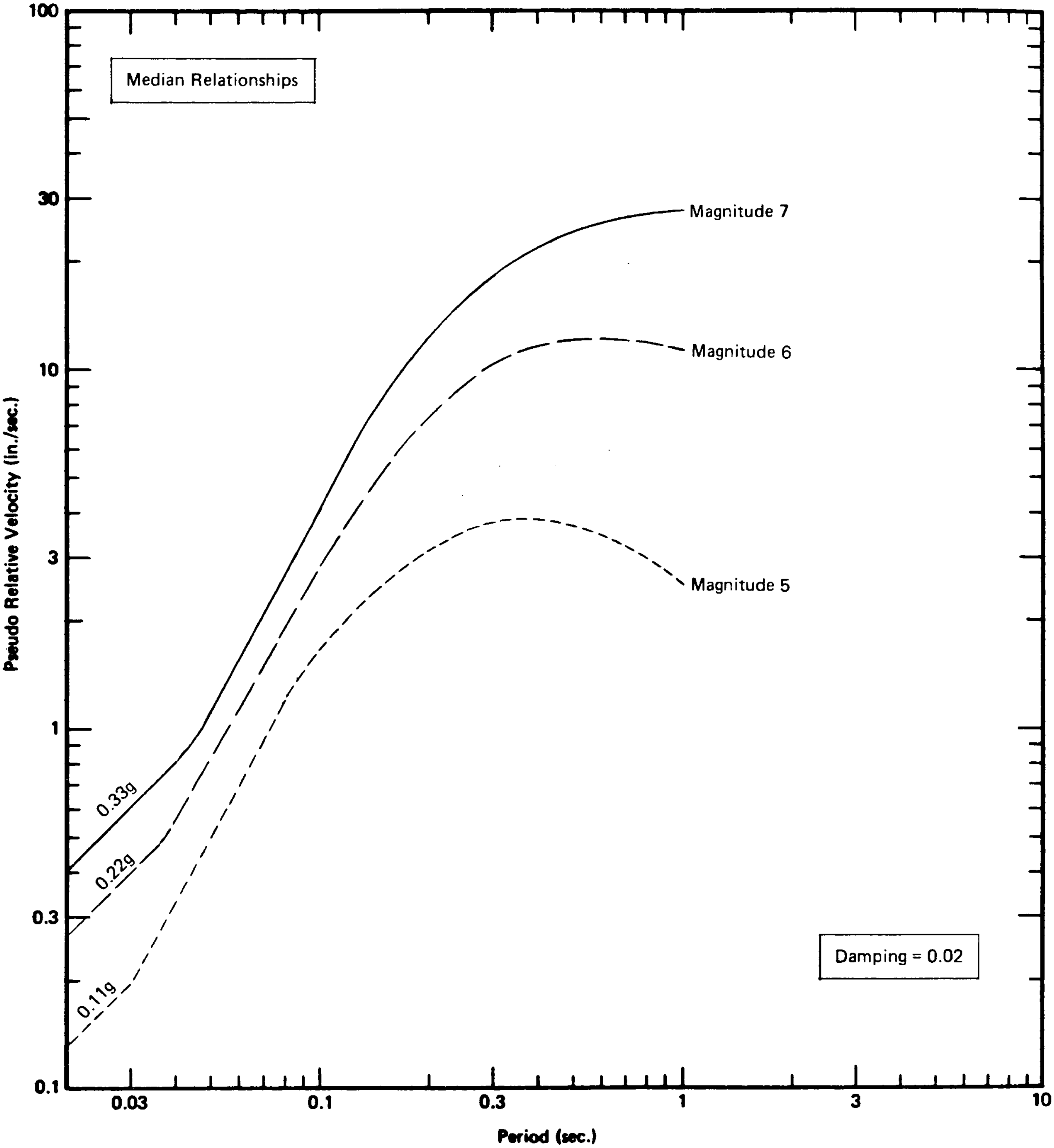
Project No. 414821	SONGS Unit 1 Spectra	Relationships between Peak Acceleration on Rock and Deep Cohesionless Soil	Figure A-5
Woodward-Clyde Consultants			



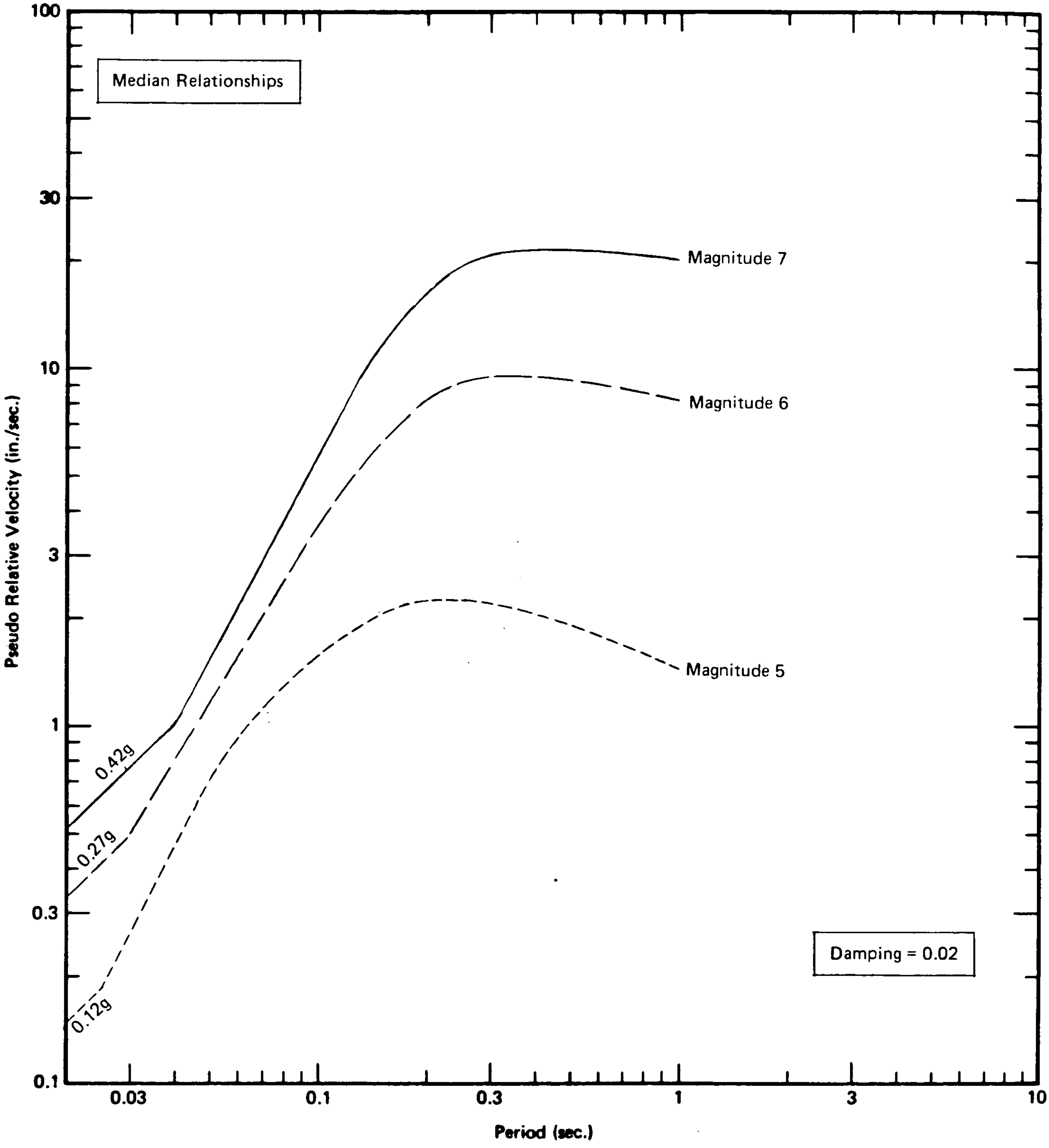
Project No. 41482I	SONGS Unit 1 Spectra	Summary of S_V/a versus T for M 5, 6, and 7 for Soil Sites at R = 8 km	Figure A-6
Woodward-Clyde Consultants			



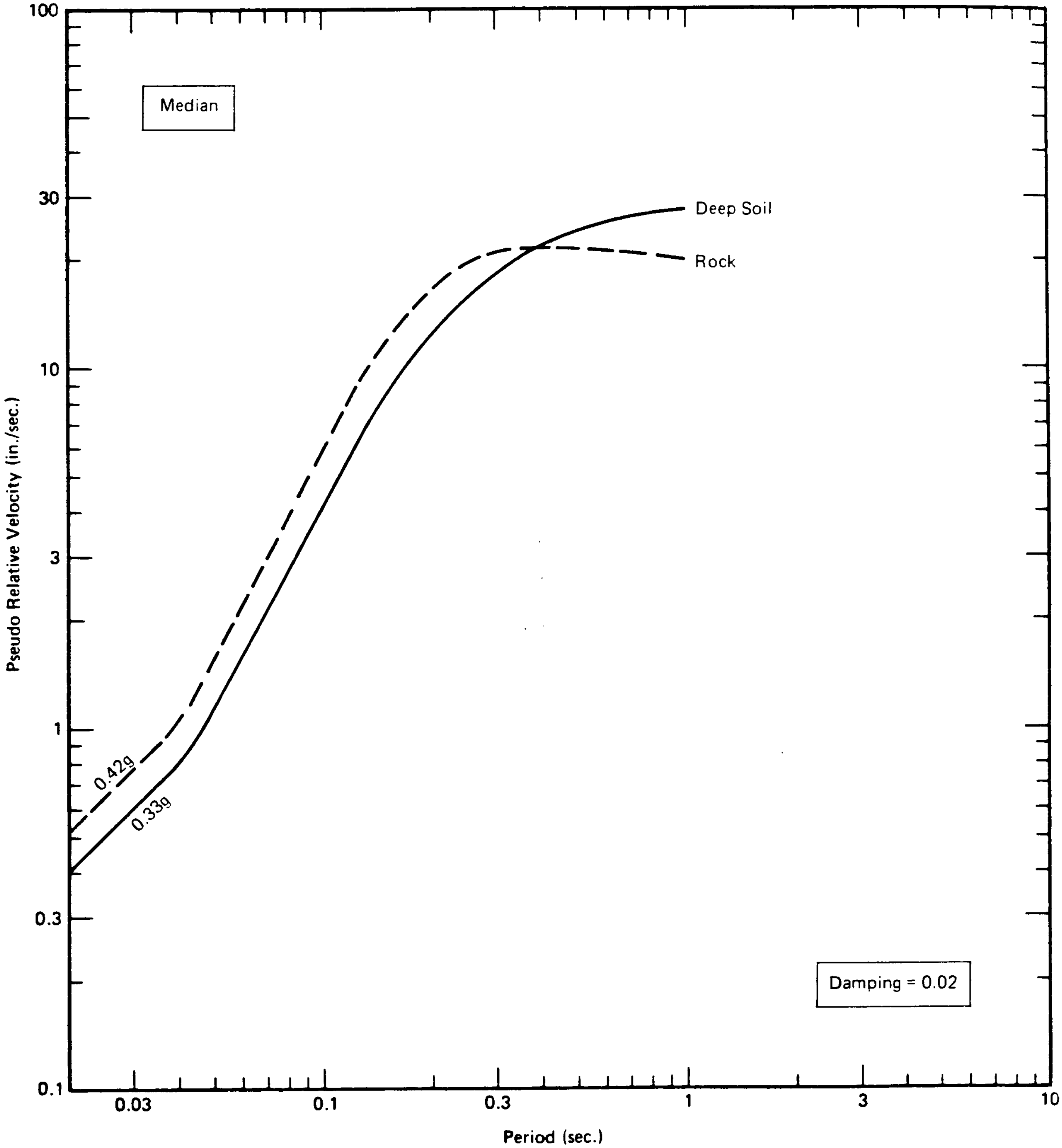
Project No. 414821	SONGS Unit 1 Spectra	Summary of S_V/a versus T for M 5, 6, and 7 for Rock Sites at R = 8 km	Figure A-7
Woodward-Clyde Consultants			



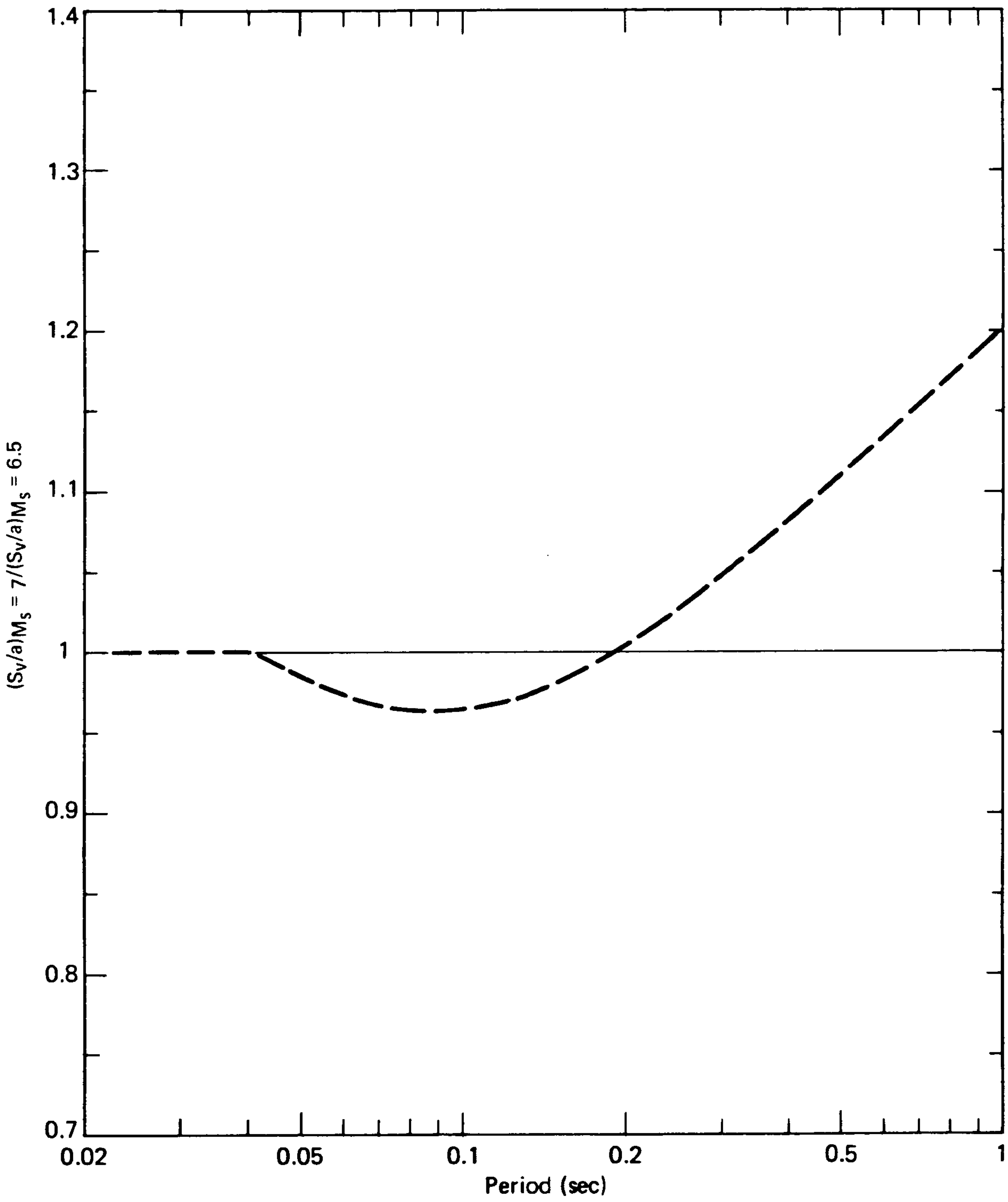
Project No. 414821	SONGS Unit 1 Spectra	Summary of Response Spectra for M 5, 6 and 7 for Soil Sites at R = 8 km	Figure A-8
Woodward-Clyde Consultants			



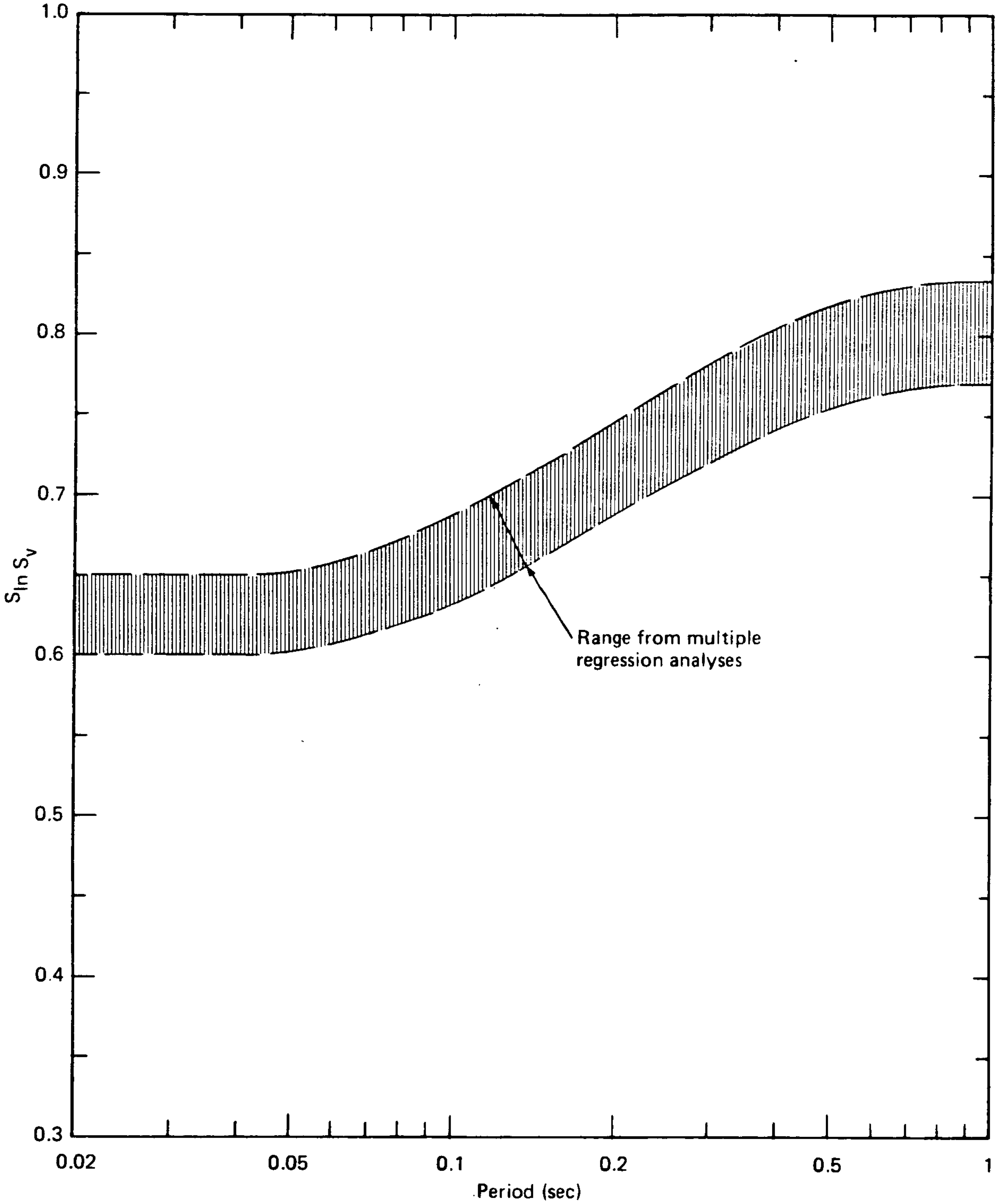
Project No. 414821	SONGS Unit 1 Spectra	Summary of Response Spectra for M 5, 6 and 7 for Rock Sites at R = 8 km	Figure A-9
Woodward-Clyde Consultants			



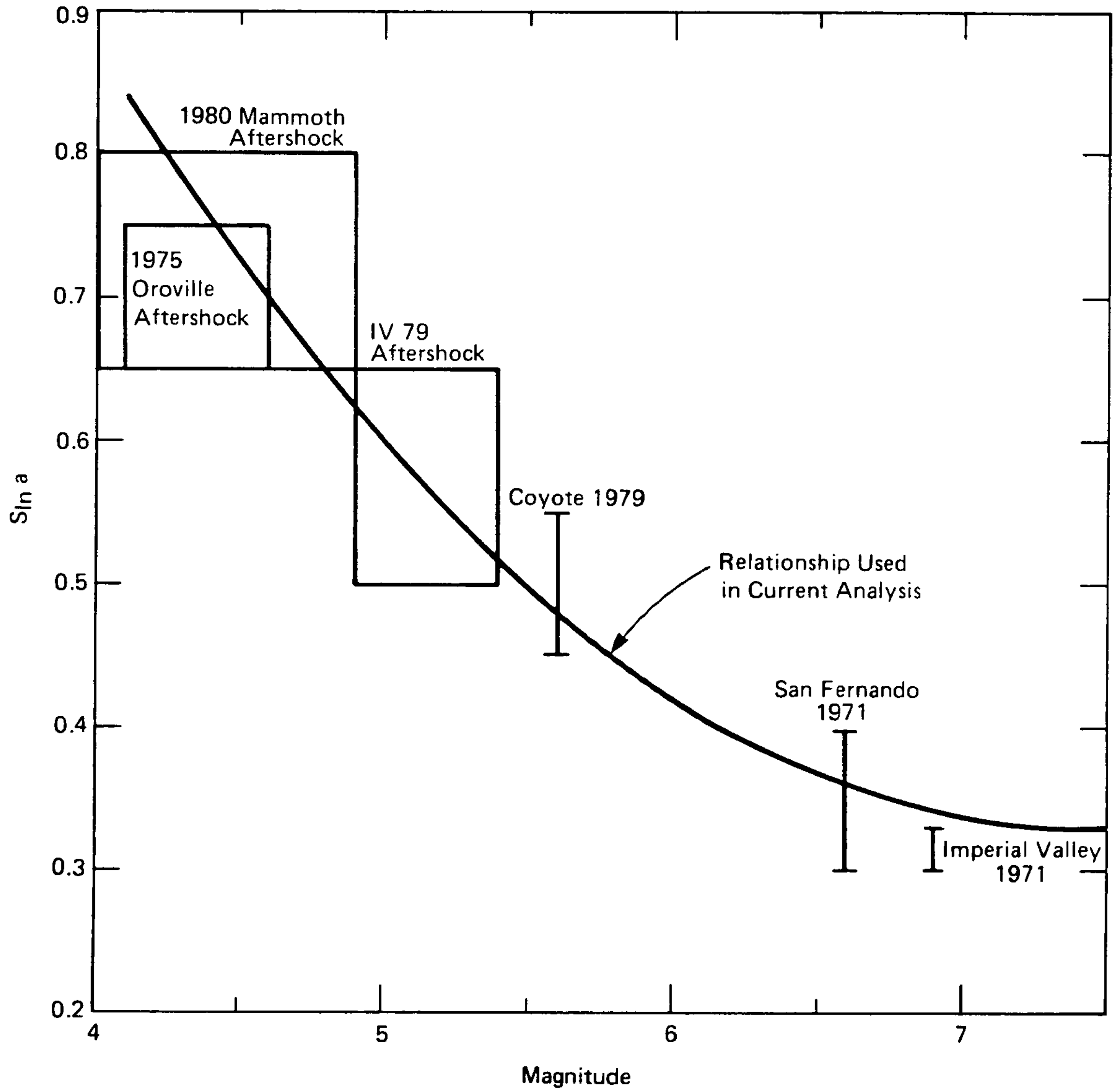
Project No. 414821	SONGS Unit 1 Spectra	Comparison of Median Response Spectra for Deep Soil and Rock for M 7 at R = 8 km	Figure A-10
Woodward-Clyde Consultants			



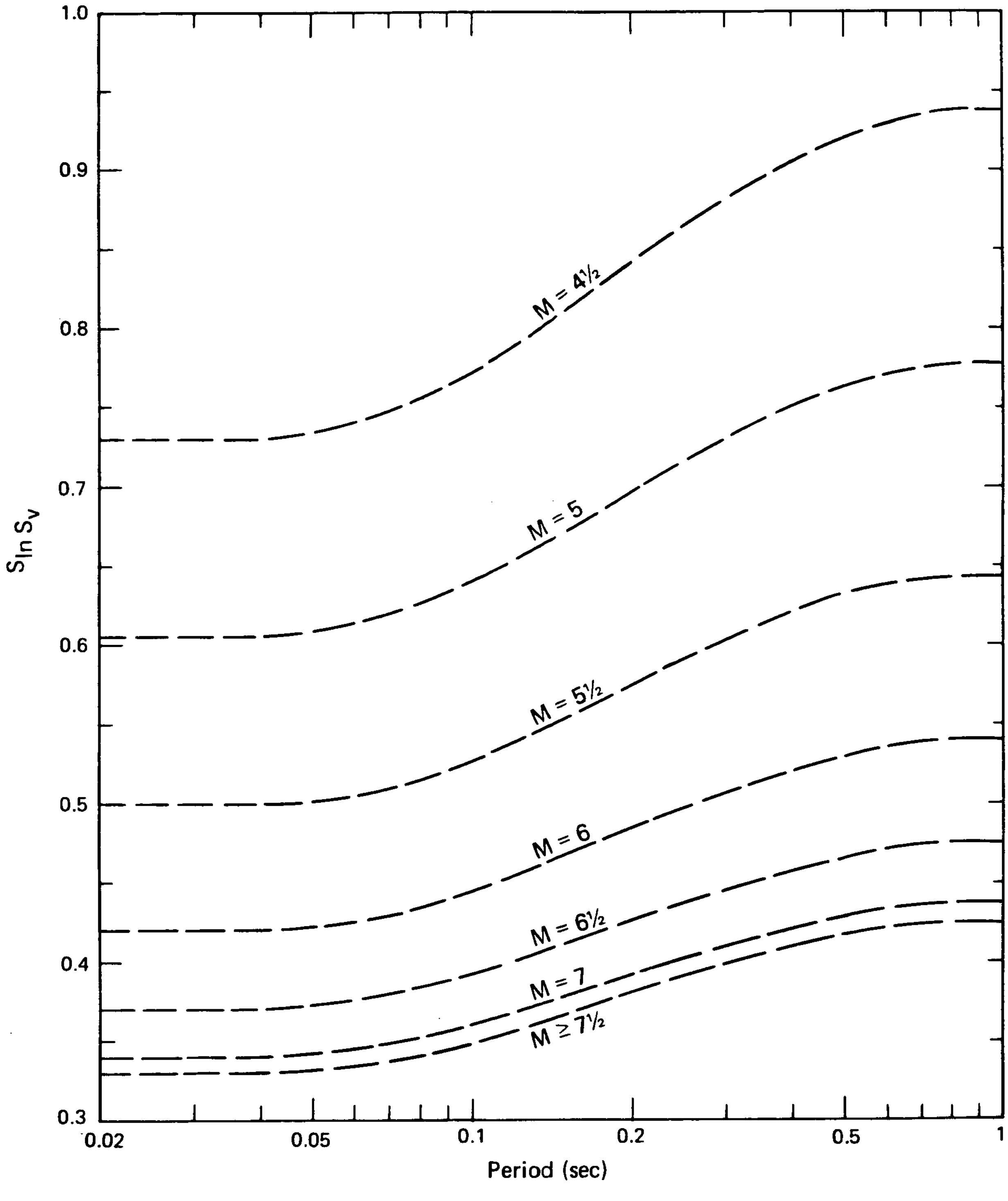
Project No. 414821	SONGS Unit 1 Spectra	Spectral Ratio of M7 Spectral Ordinate Divided by M6.5 Spectral Ordinate	Figure A-11
Woodward-Clyde Consultants			



Project No. 414821	SONGS Unit 1 Spectra	Variation of Dispersion as a Function of Period from Multiple-Regression Analyses of S_v	Figure A-12
Woodward-Clyde Consultants			



Project No. 41482I	SONGS Unit 1 Spectra	Variation of Dispersion for PGA as a Function of Magnitude	Figure A-13
Woodward-Clyde Consultants			



Project No. 414821	SONGS Unit 1 Spectra	Variation of Dispersion as a Function of Magnitude and Period	Figure A-14
Woodward-Clyde Consultants			

APPENDIX B

SONGS SITE RESPONSE RELATIVE TO DEEP SOIL AND ROCK FOR INTERPOLATING GROUND MOTIONS

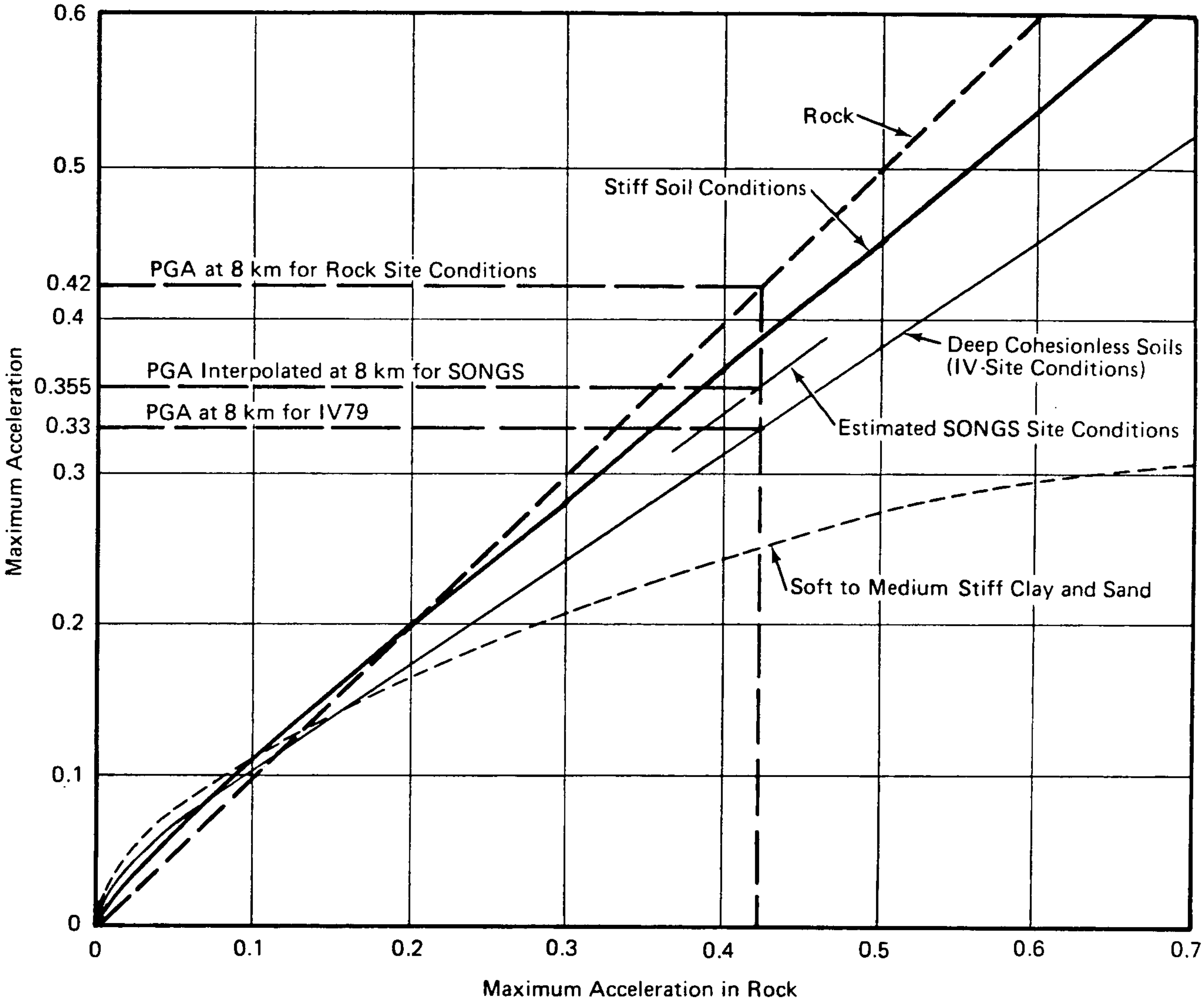
APPENDIX B

SONGS SITE RESPONSE RELATIVE TO DEEP SOIL AND ROCK FOR INTERPOLATING GROUND MOTIONS

The seismic response of the SONGS site relative to deep soil (characterizing the Imperial Valley) and rock was evaluated based on interpolation between curves relating peak acceleration for stiff soil conditions and deep cohesionless soil conditions to accelerations in rock as developed from Seed and Idriss (1982). Specifically, the results of WCC analyses described in Section 2 of this report show a median PGA of 0.42g at 8 km for rock site conditions and a median PGA of 0.33g at 8 km for deep cohesionless soil site conditions. These values are plotted on the maximum acceleration graph, Figure B-1, depicting relative PGA values for various site conditions. As shown in Figure B-1, the estimated corresponding PGA at the SONGS site has been interpreted, as a matter of physical principle, to be about mideway between deep cohesionless soils and stiff soil conditions. This interpretation is based on two considerations: 1) stiff soil sites in Figure B-1 are characterized by 150 to 200 ft of stiff soil over rock while SONGS is characterized by almost 1,000 ft of stiff soil over rock; and 2) SONGS site conditions while deep are judged more stiff than those characterizing Imperial Valley deep soil sites having the same basic response as the deep cohesionless soils shown in Figure B-1. From this interpretation, a median PGA for SONGS site conditions at 8 km is interpreted in Figure B-1 to be 0.355g. By comparing this value to the 0.33g PGA for IV79 and 0.42g for rock sites at 8 km, it is noted that SONGS is closer to deep soil than rock in relative response, yielding a PGA response that lies within the lower third of the range between IV79 deep soil sites and rock (specifically 28 percent [(0.355 - 0.33)/0.42 - 0.33) x 100]).

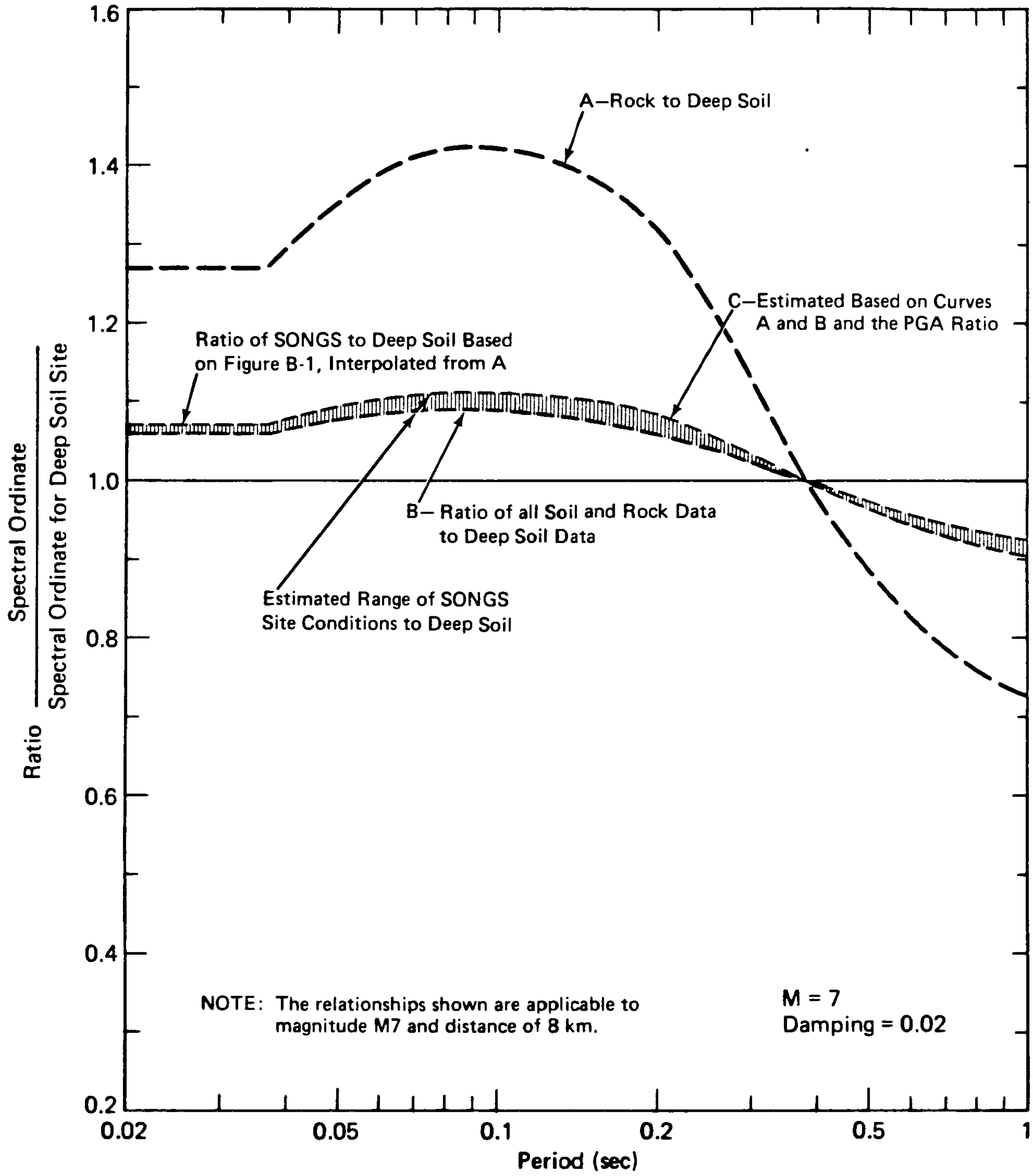
To develop the relative response of SONGS to deep soil for other periods, a multiple regression analysis of all rock and soil sites data was completed and compared to the results developed for deep soil in Section 2 of the report. This procedure was followed because about three quarter of the data are from deep soil sites and about one quarter of the data are from rock sites, a proportion appropriate for SONGS site conditions considering the comparison of SONGS site condition relative to rock and deep soil sites discussed above and shown in Figure B-1. The results of ratios of spectral ordinates versus period developed for all rock and soil data to deep soil data (curve B) and rock data alone to deep soil data (curve A), are shown in Figure B-2. Also, the ratio of SONGS to deep soil based on the Figure 2-1 interpolation for PGA has been extended over a period range from the PGA up to 1.0 seconds (curve C) in Figure B-2 by interpolating between curves A and B. It is judged that the spectral ratios for SONGS to deep soil conditions can be characterized by the shaded range between curves B and C shown in Figure B-2.

As indicated in Figure B-2, the SONGS site response varies from about 25 to 30 percent of soft rock site response above the IV79 deep soil site response; this estimate is in good agreement with the estimated range of 20 to 40 percent shown in Figure B-3 (Figure 16 of the 12 April 1982 report). As shown in Figure B-3, the selected site condition modification factors between SONGS site condition and deep soil for the 12 April 1982 study enveloped or exceeded the upper bound of the estimated range and were therefore very conservative.

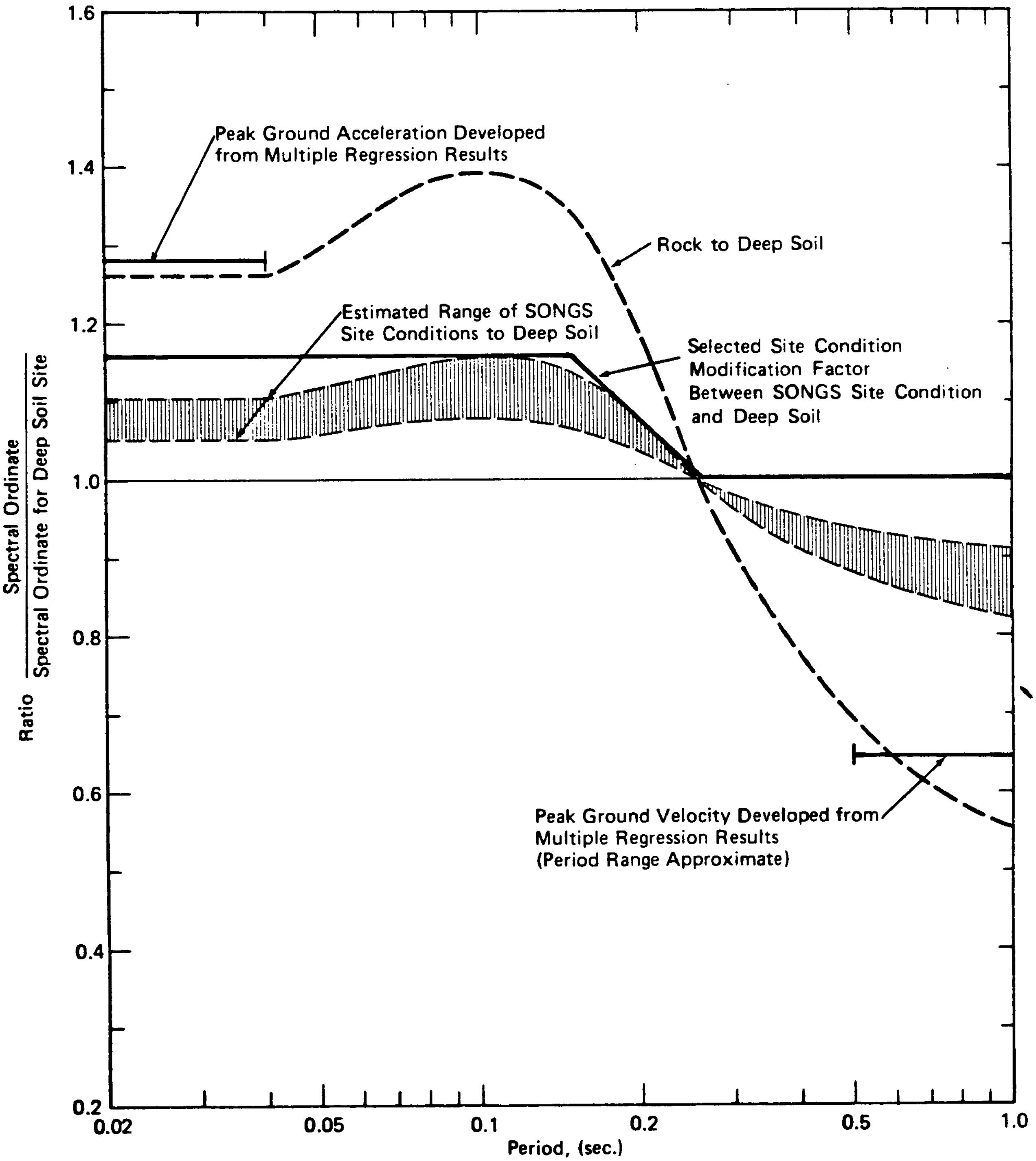


NOTE: Base Figure after Seed and Idriss, 1982

Project No. 414821	SONGS Unit 1 Spectra	Approximate Relationships Between Maximum Accelerations on Rock and Other Local Site Conditions Including SONGS	Figure B-1
Woodward-Clyde Consultants			



Project No. 414821	SONGS Unit 1 Spectra	Relationships Between SONGS and Deep Soil Conditions	Figure B-2
Woodward-Clyde Consultants			



NOTE: The relationships shown are applicable to a distance of 8 km.

SOURCE: WCC April 12, 1982 Report

Project No. 414821	SONGS Unit 1 Spectra	Relationships Between SONGS and Deep Soil Conditions	Figure B-3
Woodward-Clyde Consultants			

APPENDIX C

EFFECTS OF SITE CONDITIONS ON RECORDED GROUND MOTIONS DURING THE IV79 EARTHQUAKE

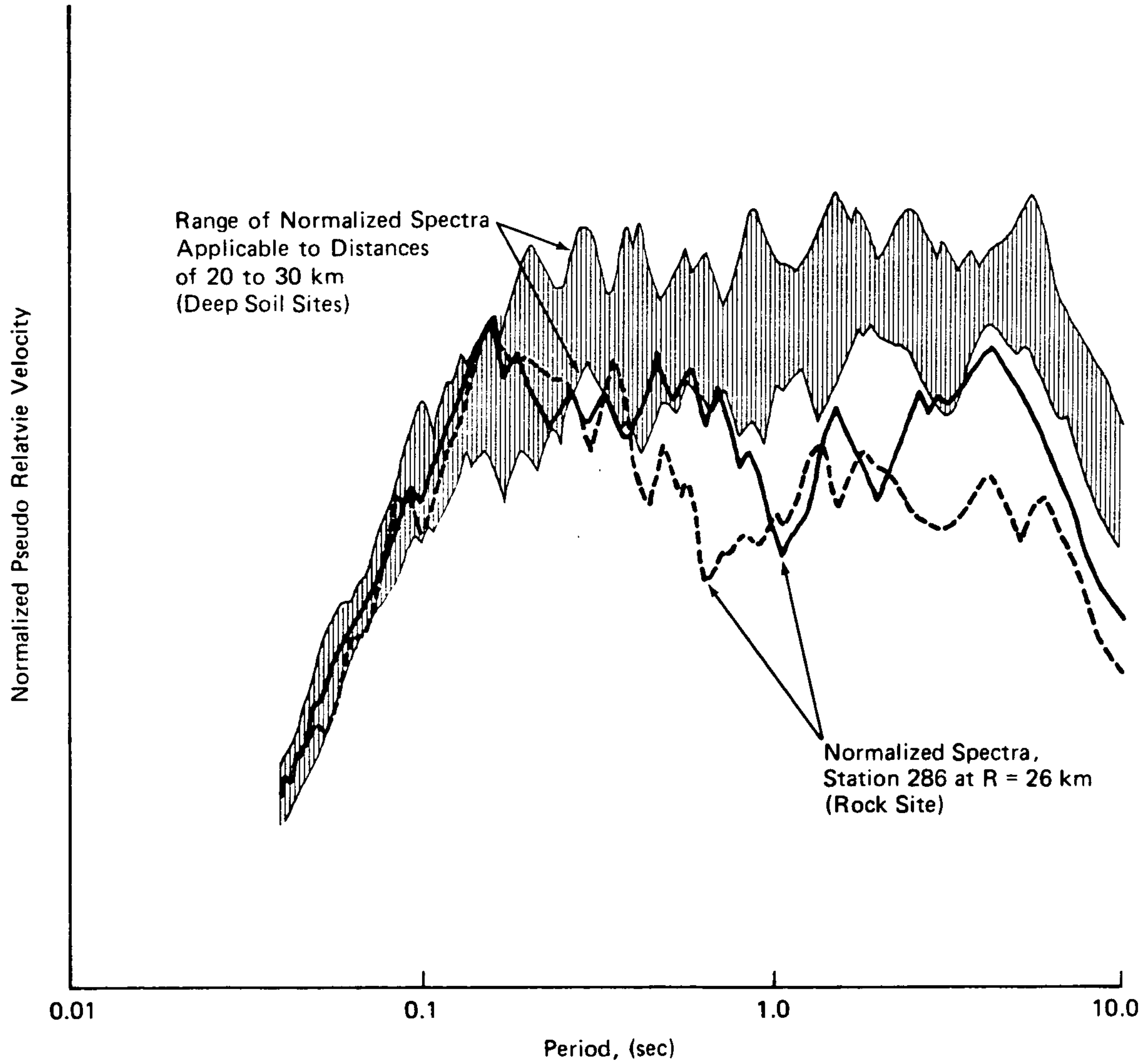
APPENDIX C

EFFECTS OF SITE CONDITIONS ON RECORDED GROUND MOTIONS DURING THE IV79 EARTHQUAKE

During the IV79 earthquake, only one set of accelerograms was recorded at a rock site within 50 km of the causative fault, while many accelerograms were recorded on deep soil sites within 50 km of the causative fault. This set of rock accelerograms was recorded at USGS Station 286 on Superstition Mountain about 26 km from the causative fault. In the 12 April 82 WCC report, these accelerograms together with the envelope of accelerograms from soil sites in the same general distance range were roughly normalized as shown in Figure C-1 and a smooth estimate of the ratio of rock to deep soil site spectral velocities was made as shown in Figure C-2 for the distance range of 20 to 30 km to the causative fault. These spectra were normalized because only two rock records are not enough to develop an appropriate median spectrum and therefore only a general trend can be developed for spectral shape. The spectra shown on Figure C-1 illustrate a similar trend of spectral ratios as shown for the San Fernando earthquake data at 25 km on Figure C-2. The smooth averaging interpreted the IV79 trend to be slightly lower than the San Fernando trends as shown in Figure C-2.

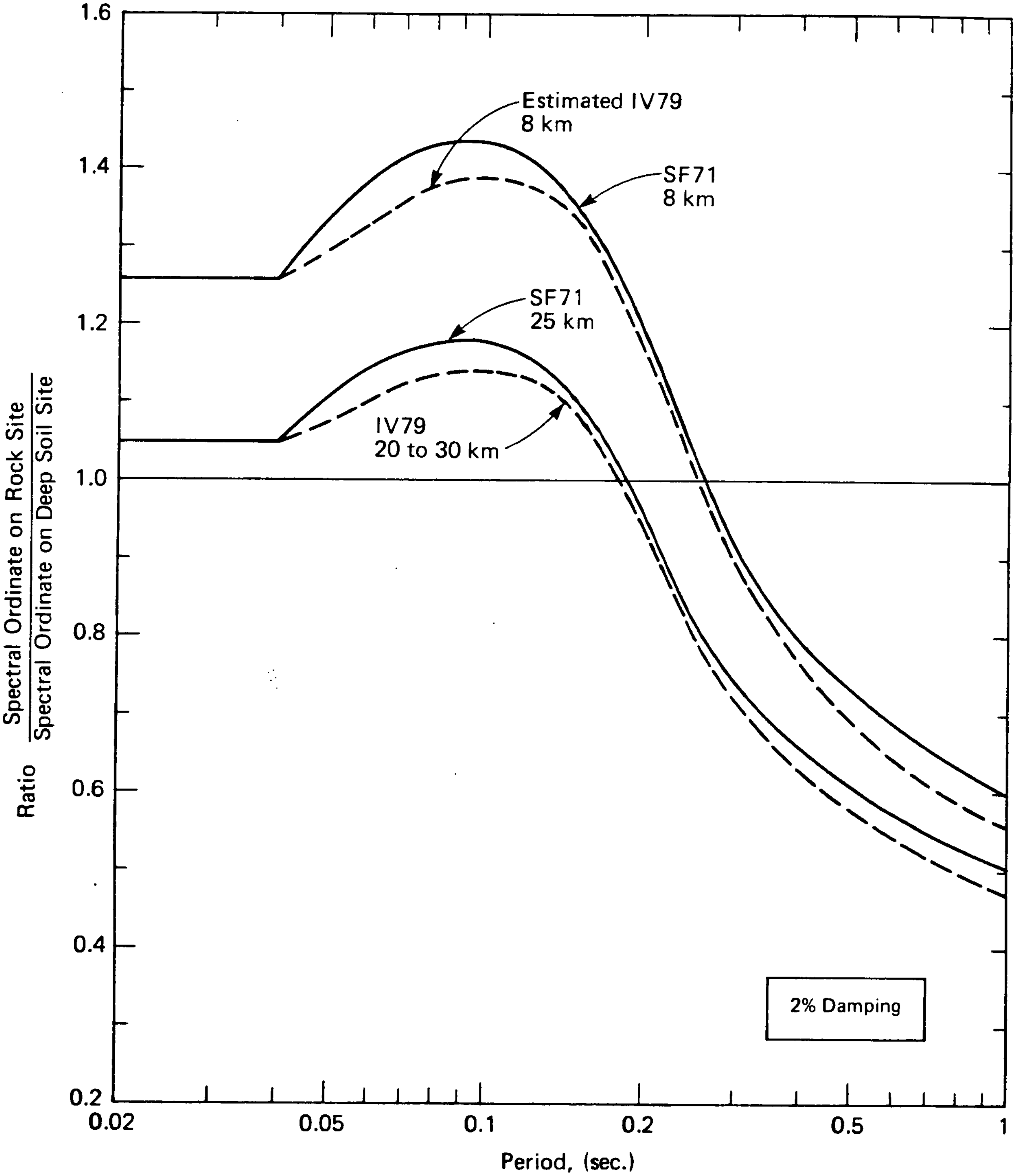
Subsequent to the 12 April 1982 report, a more formal statistical analysis of the IV79 rock and soil data has been completed as shown on Figure C-3. The median spectra shown on Figure C-3 characterize the rock and soil sites, with the soil site spectrum being relatively smooth, thus allowing for the construction of a hand-smoothed median curve for soil sites. Because of the large peaks and valleys that characterize the median of the two rock site accelerograms, such smoothing is difficult to do. To evaluate the consistency of the interpreted spectral ratios for IV79 shown on Figure C-2, these spectral ratios were multiplied by the smoothed median spectrum for soil sites to obtain the smoothed median spectrum for rock sites shown on Figure C-3. As can be seen in Figure C-3, the smooth median spectrum for rock site lies within the range of the peaks and valleys of the median rock spectrum for Station 286. Specifically, it falls near the upper bound of the range in periods greater than about 0.2 seconds and near the lower bound of the range for periods less than about 0.2 seconds. In general, there is some degree of consistency of the data shown on Figure C-3 with the data trends on Figure C-2 for the 20 to 30 km distance range, with good correlation for the ratio "cross-over" (ratio of 1.0) at a period of about 0.2 seconds and some indication that for periods less than 0.2 seconds the curves on Figure C-2 are lower than what the correlation of soil data to data from Station 286 show. Similarly, for periods greater than 0.2 seconds the curves on Figure C-2 are higher than what the correlation of soil data to data from Station 286 show. The primary basis consistent with the above observation is the SF71 data analysis results. This has been further substantiated based on the multiple regression results for rock and soil as described in Section 2 and shown in Figure C-4.

For completeness, the absolute response spectra for two rock accelerograms and eight deep soil site accelerograms in the distance range of about 20 to 30 km are presented in Figure C-5. For ease of comparison, only the lower and upper envelopes of the eight deep soil site spectra are shown in this figure. Interpretation of these results to develop specific data trends is not possible due to very limited rock data. That is, the rock recording may represent 84th percentile or higher values rather than a mean as suggested by the differences between rock and soil spectra shown in Figure C-5 and by the multiple regression results presented in Appendix A.



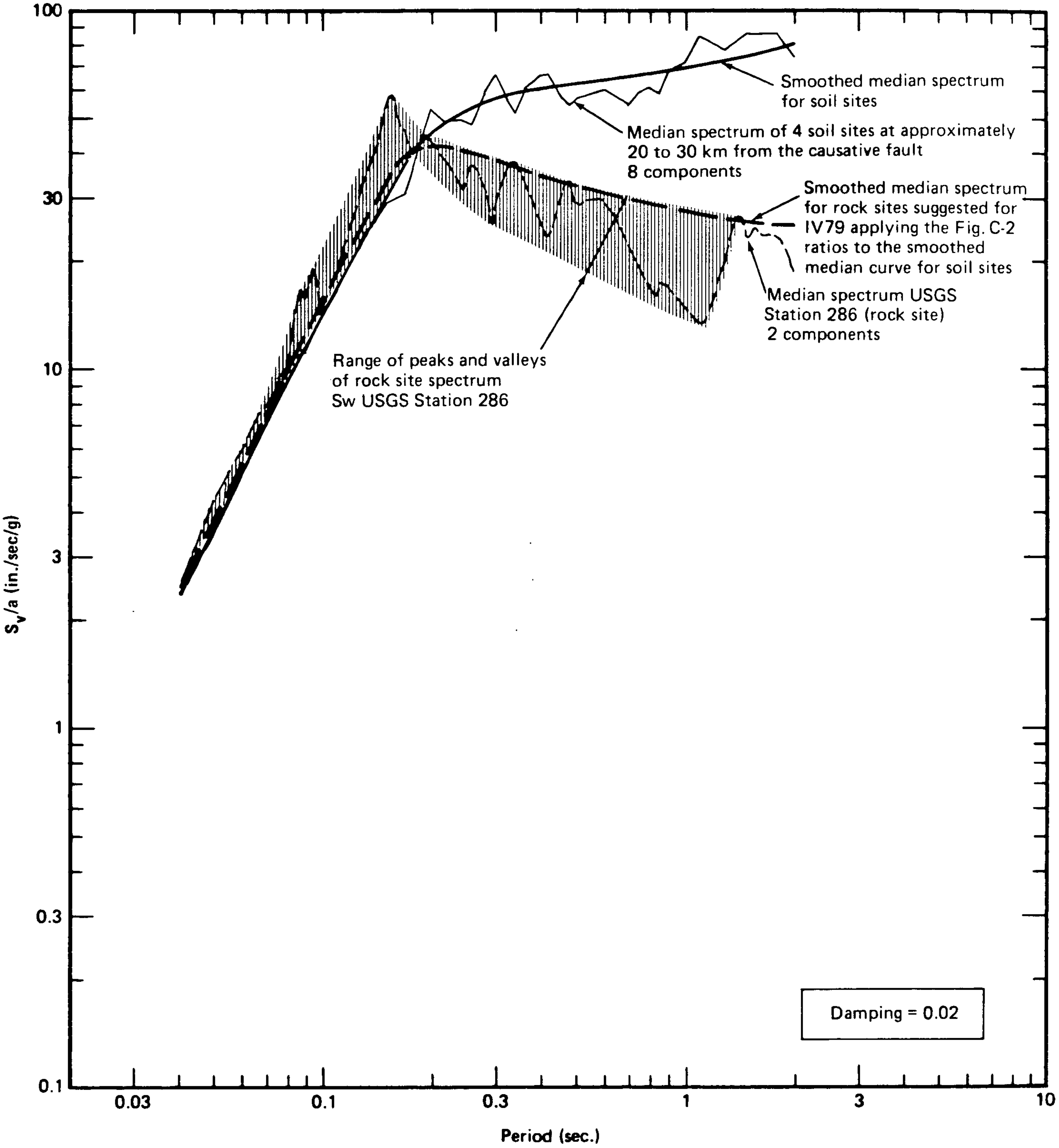
Source: WCC April 12, 1982 Report

Project No. 414821	SONGS Unit 1 Spectra	Comparison of Normalized Response Spectra for Rock and Deep Soil Sites at R = 20 to 30 km 2% Damping	Figure C-1
Woodward-Clyde Consultants			

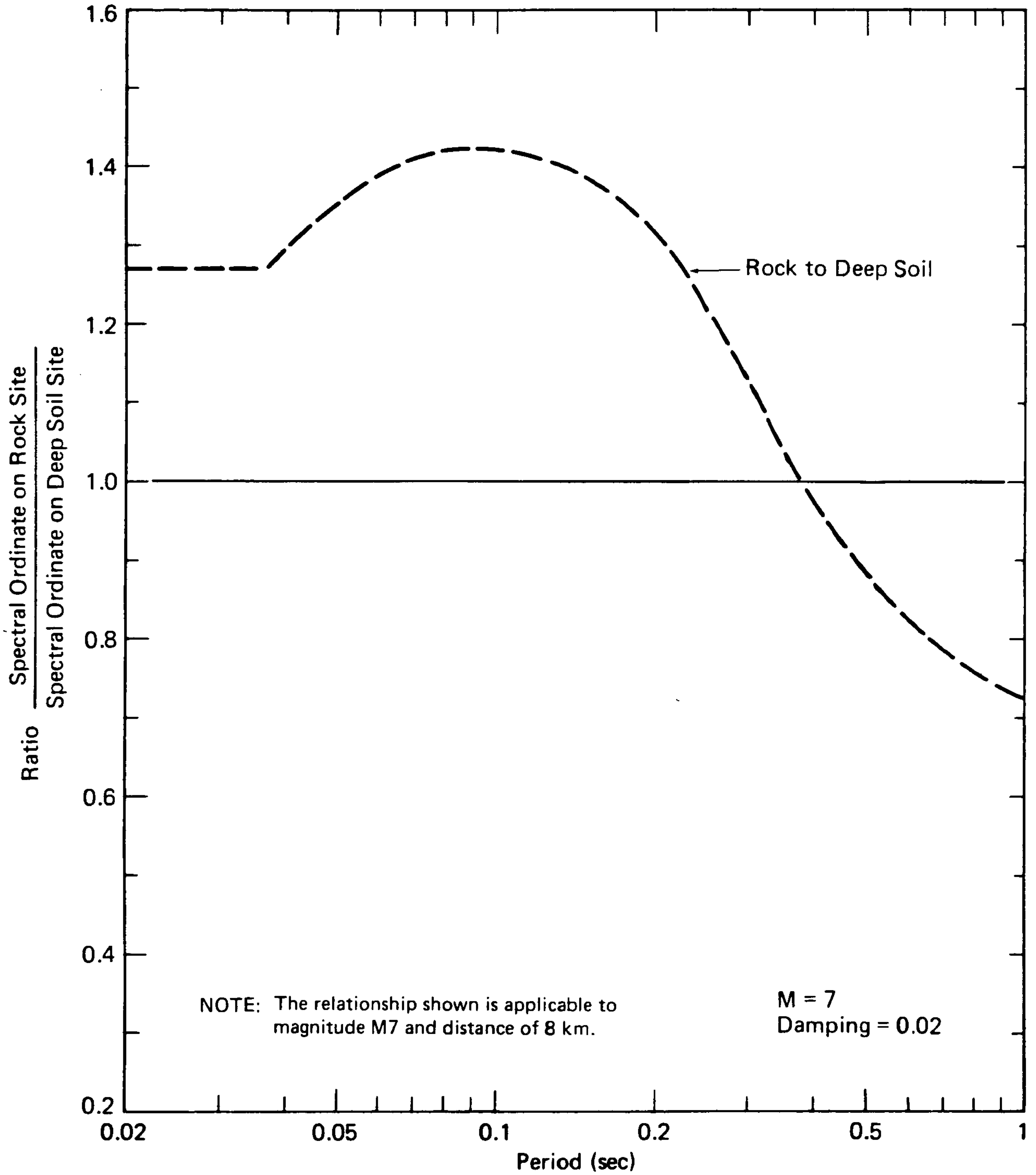


Source: WCC April 12, 1982 Report

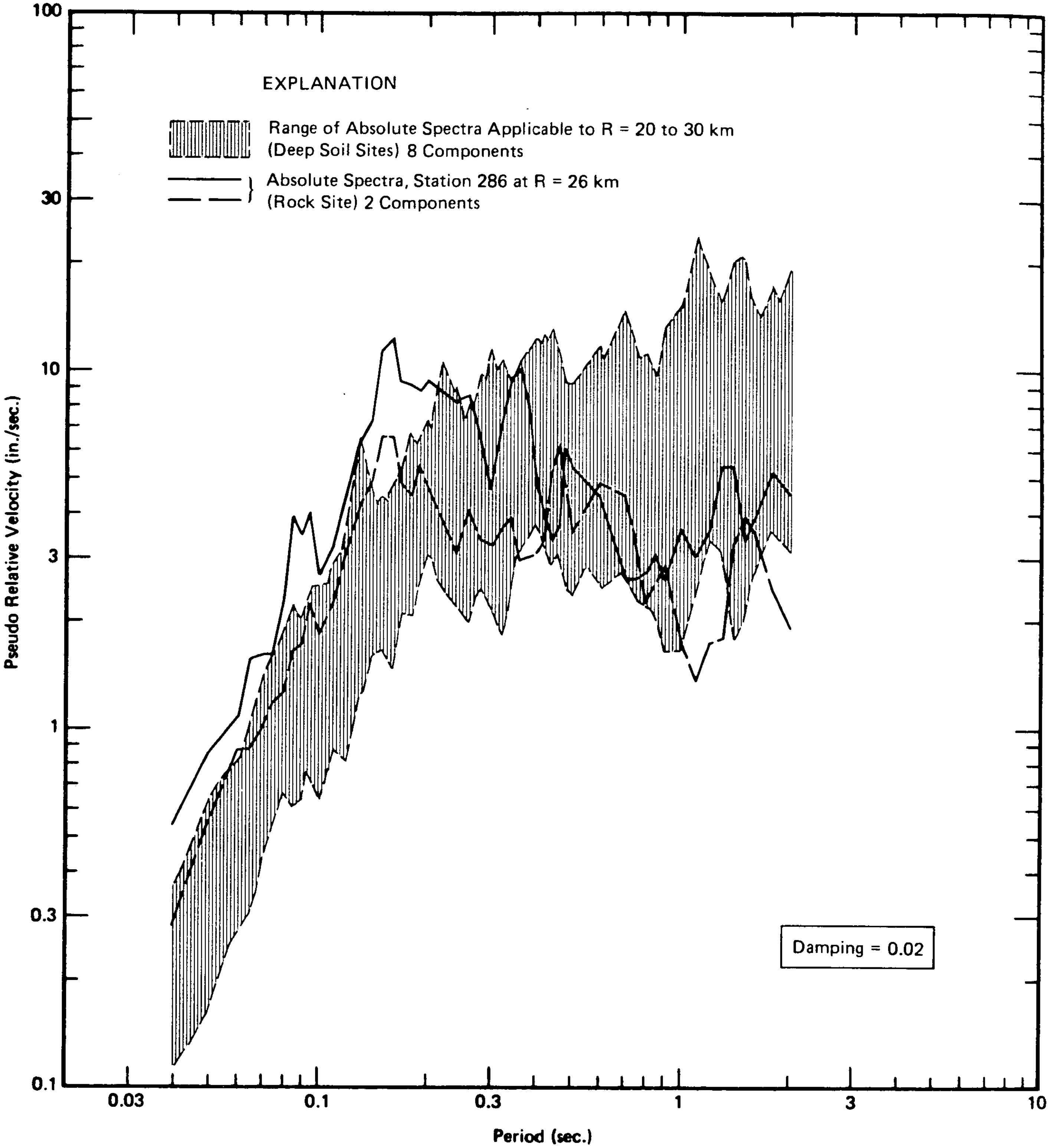
Project No. 414821	SONGS Unit 1 Spectra	Relationship Between Rock and Deep Soil Spectra for SF71 and IV79	Figure C-2
Woodward-Clyde Consultants			



Project No. 414821	SONGS Unit 1 Spectra	Median S_V/a Versus Period for IV79, R = 20 to 30 km Rock and Soil Sites	Figure C-3
Woodward-Clyde Consultants			



Project No. 414821	SONGS Unit 1 Spectra	Relationship Between Rock and Deep Soil Spectra Developed from Multiple-Regression Results	Figure C-4
Woodward-Clyde Consultants			



Project No. 414821	SONGS Unit 1 Spectra	Comparison of the Response Spectra for Rock and Soil Sites for Recordings obtained at R = 20 to 30 km during IV79	Figure C-5
Woodward-Clyde Consultants			

APPENDIX D

SENSITIVITY OF GROUND MOTION ESTIMATES TO THE MAGNITUDE OF THE IV79 EARTHQUAKE

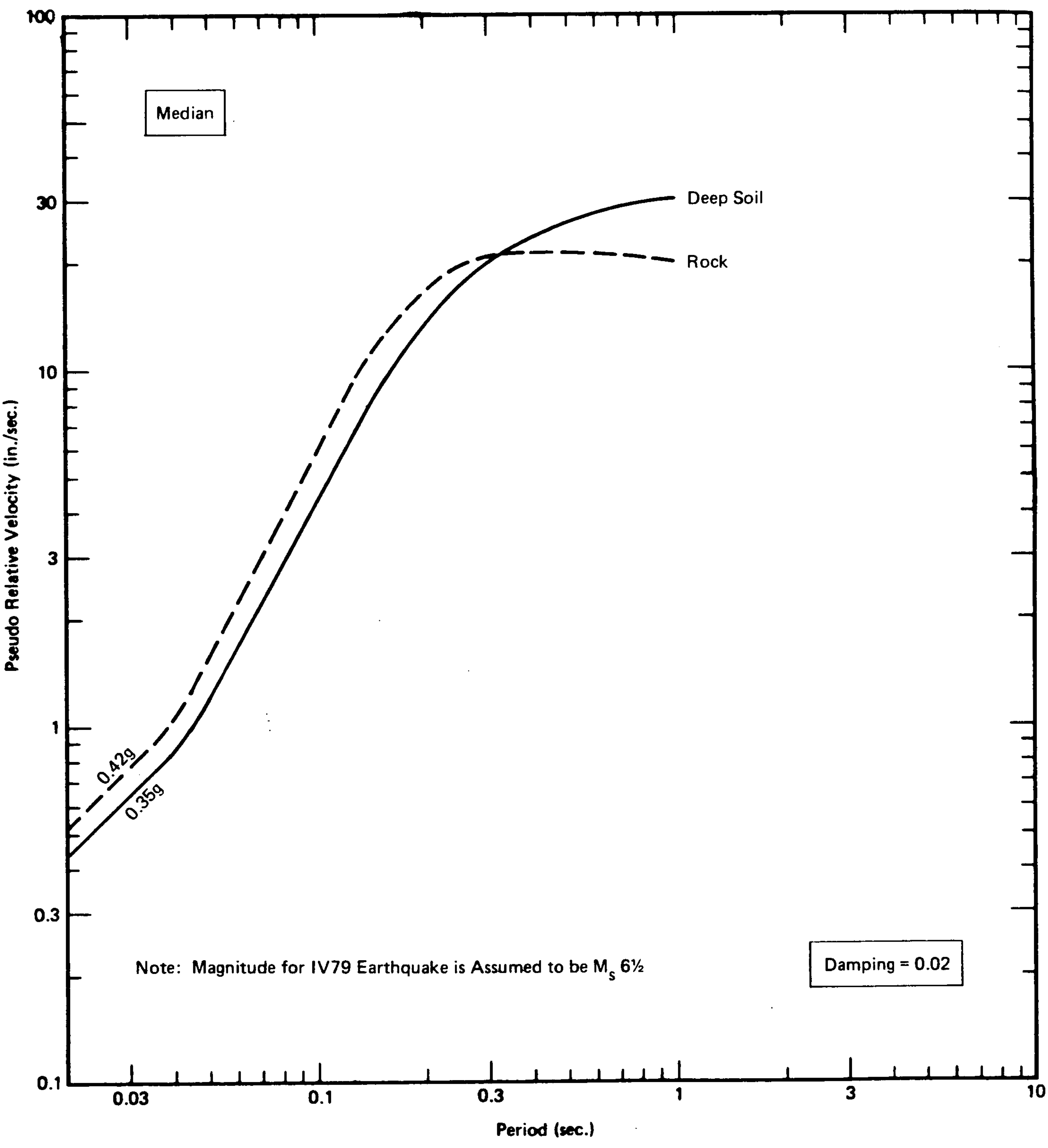
APPENDIX D

SENSITIVITY OF GROUND MOTION ESTIMATES TO THE MAGNITUDE OF THE IV79 EARTHQUAKE

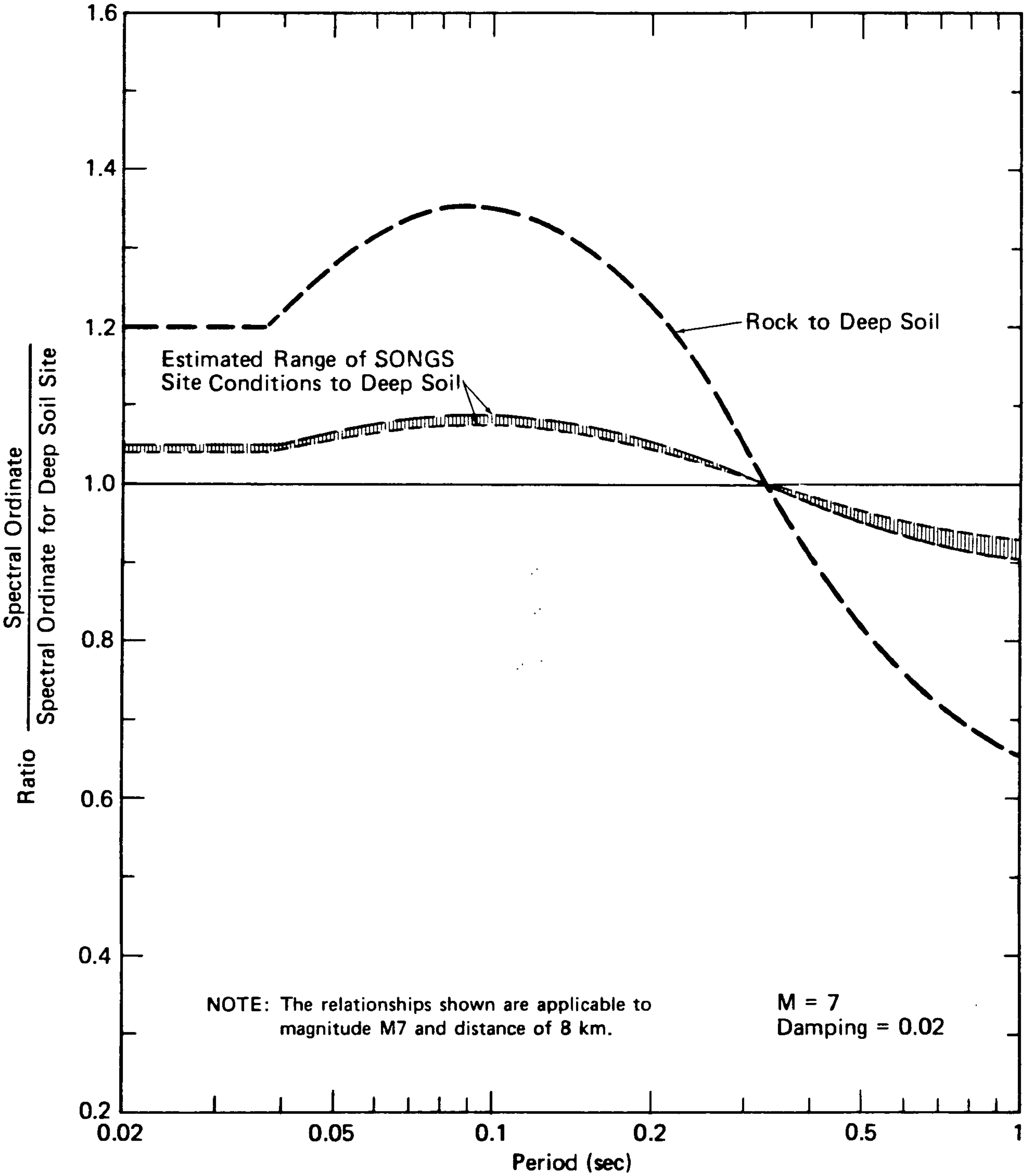
The surface wave magnitude has been established for the IV79 earthquake at M_s 6.9 (NEIS). In order to evaluate the sensitivity of the ground motion analysis results to the assigned magnitude of the IV79 earthquake, the ground motion analyses described in Section 2.0 were repeated using an M_s 6½ for the IV79 earthquake. These results are discussed below.

The results of the median rock and deep soil spectra at a closest distance of 8 km developed in a similar way as in Section 2.0, but assuming IV79 to be M_s 6½, are presented in Figure D-1. Similarly, the ratio of rock to deep soil versus period is shown in Figure D-2 with the interpolated range of values appropriate to SONGS based on evaluations similar to those described in Appendix B. The median base spectrum postulated for SONGS source conditions has also been developed on the same basis as described in Section 2.0 but using IV79 as an M_s 6½ as shown in Figure D-3. By applying the average spectral ratios of SONGS to deep soil from Figure D-2 to the base spectrum on Figure D-3, the median spectrum appropriate to SONGS assuming IV79 as M_s 6½ are calculated as shown in Figure D-4. The dispersion relationships as a function of period for M7 developed in Section 3.0 were applied to the spectra in Figure D-4 to develop 84th percentile spectra appropriate to SONGS assuming IV79 as M_s 6½ to calculate the spectra presented in Figure D-5. The SONGS 84th percentile instrumental spectrum shown in Figure D-5 was normalized to the Housner 2/3g reanalysis spectrum to develop the comparison shown in Figure D-6. In comparing Figure D-6 to Figure 4-8 which uses the published IV79 M_s of 6.9, it can be noted that using IV79 as M_s 6½ leads to a maximum exceedance of the design form of the Housner reanalysis spectrum of about

20% or a maximum of about 5% above that using M_s 6.9 for IV79. The dashed zone in the lower part of Figure D-6 which shows the SONGS instrumental spectrum at 2% damping is only about 40 to 75% of the instrumental form of the Housner reanalysis spectrum (as derived from the 23 February 1982 report).

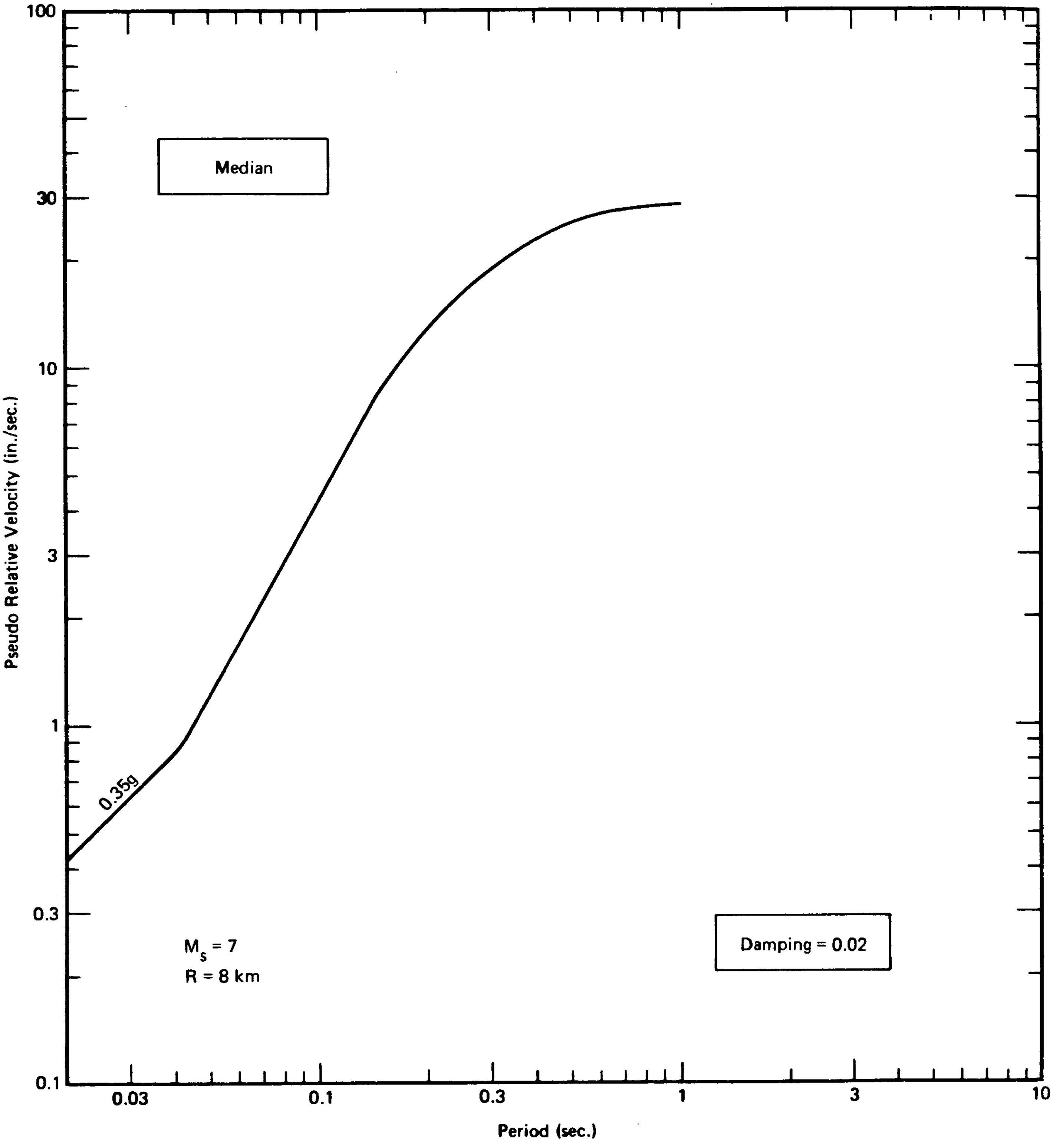


Project No. 414821	SONGS Unit 1 Spectra	Comparison of Median Response Spectra for Deep Soil and Rock for M 7 at R = 8 km	Figure D-1
Woodward-Clyde Consultants			



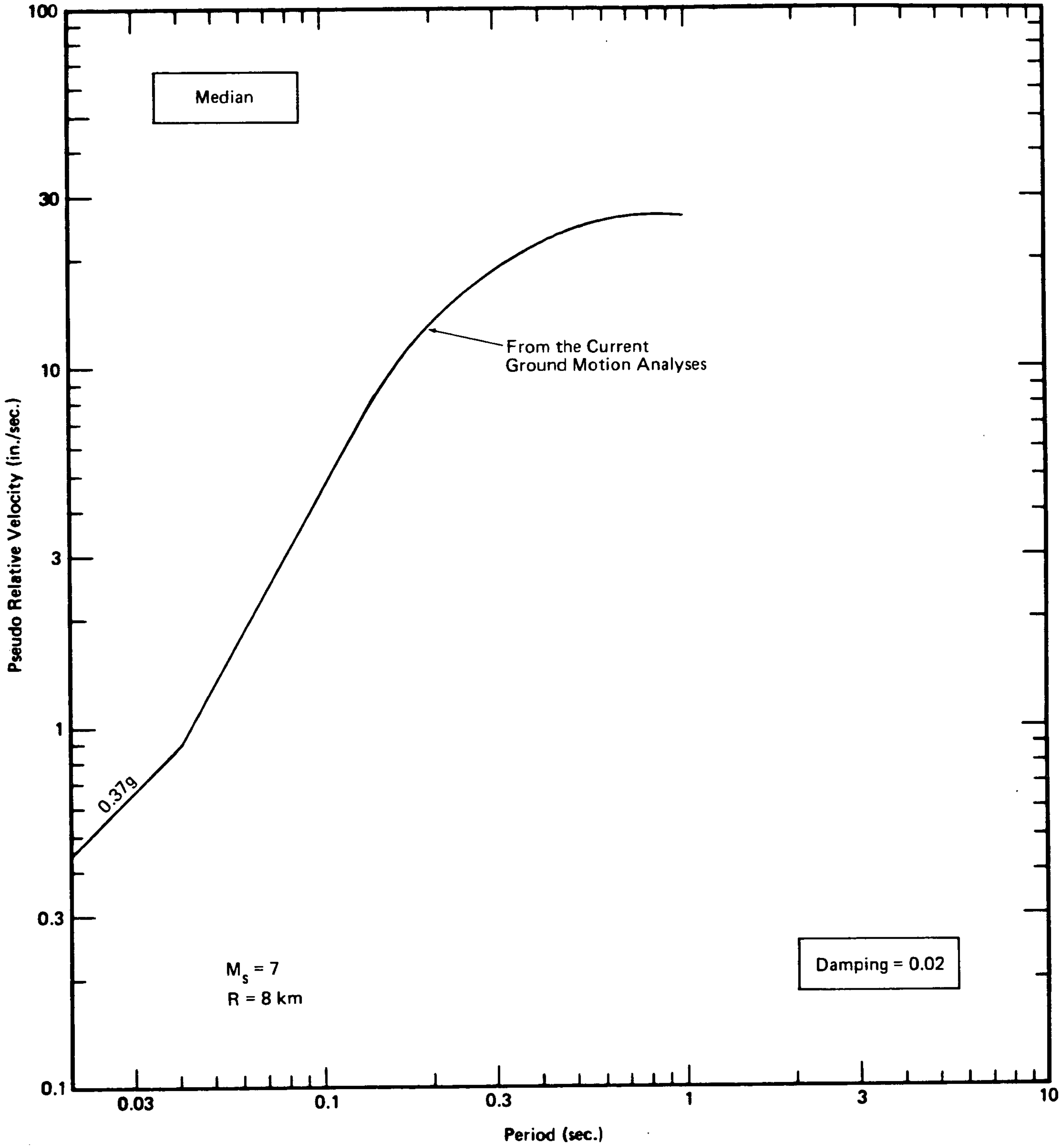
Note: Magnitude for IV79 Earthquake is Assumed to be M_s 6½

Project No. 414821	SONGS Unit 1 Spectra	Relationship Between SONGS and Deep Soil Conditions	Figure D-2
Woodward-Clyde Consultants			



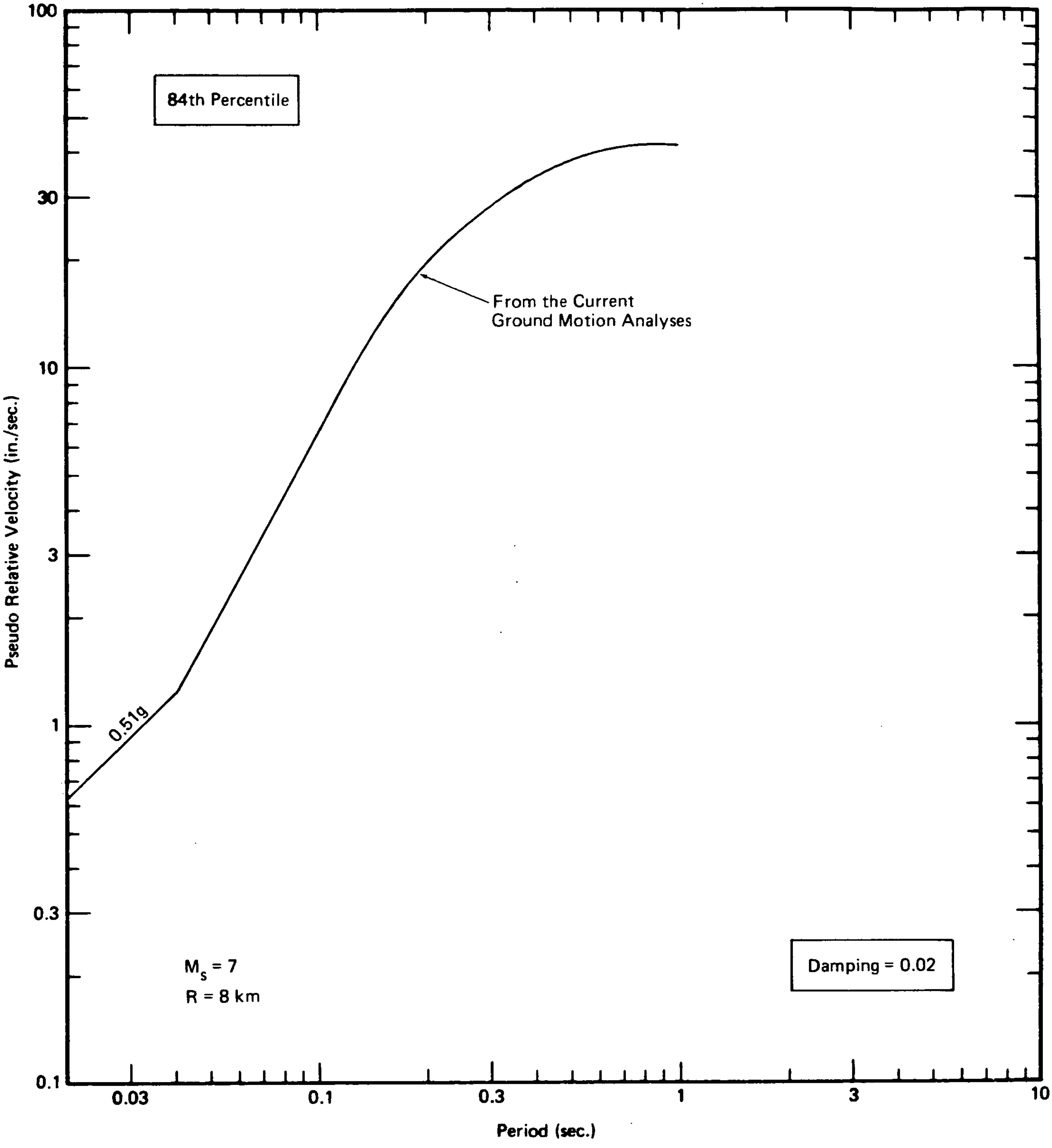
Note: Magnitude for IV79 Earthquake is Assumed to be M_s 6½

Project No. 414821	SONGS Unit 1 Spectra	Median Response Spectrum for Deep Soil and Appicable to Earthquake Source Conditions Postulated for SONGS	Figure D-3
Woodward-Clyde Consultants			



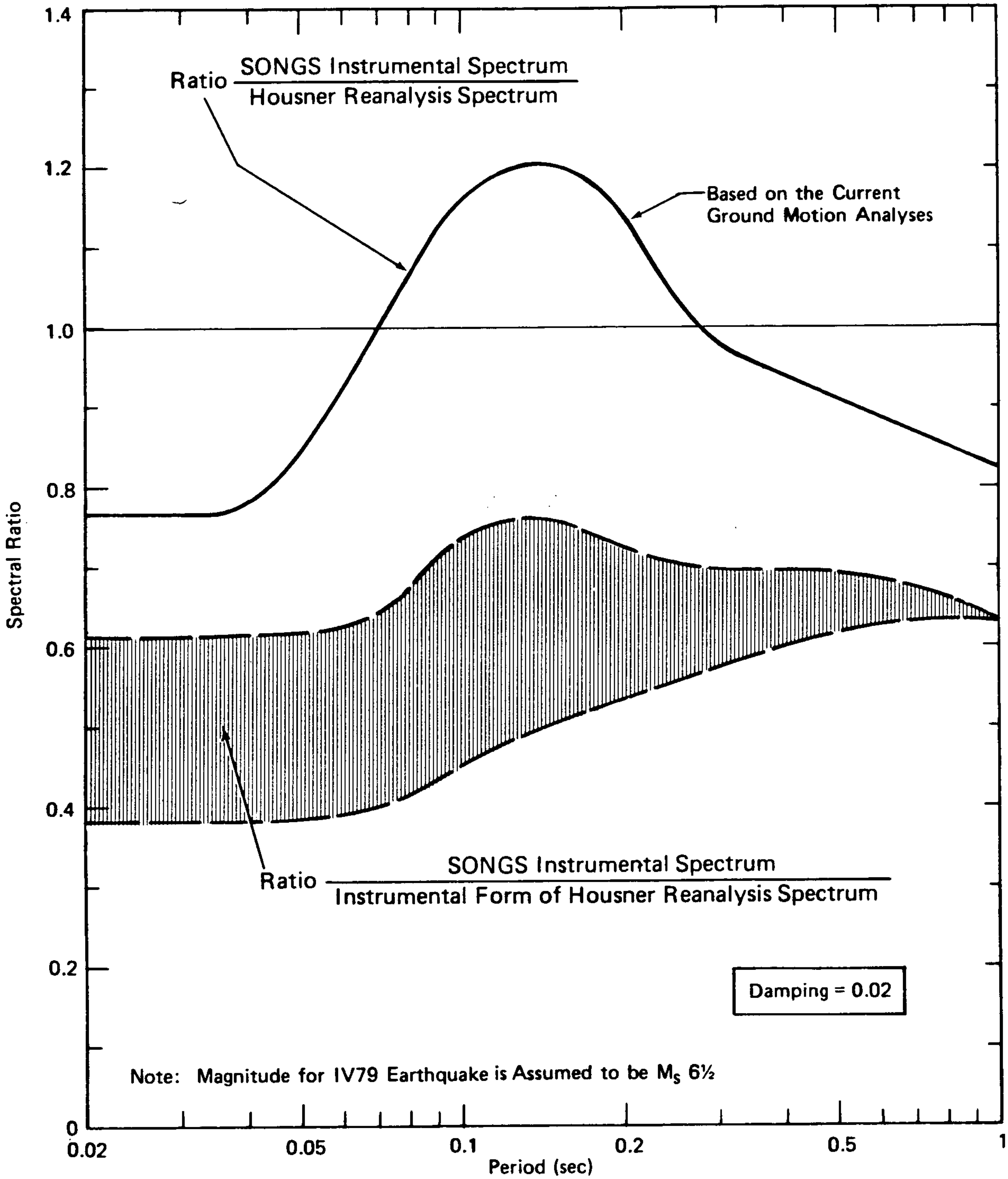
Note: Magnitude for IV79 Earthquake is Assumed to be M_s 6½

Project No. 414821	SONGS Unit 1 Spectra	Median Instrumental Response Spectrum for the SONGS Site from the Current Ground Motion Analyses	Figure D-4
Woodward-Clyde Consultants			



Note: Magnitude for IV79 Earthquake is Assumed to be M_s 6½

Project No. 414821	SONGS Unit 1 Spectra	84th Percentile Instrumental Response Spectrum for the SONGS Site from the Current Ground Motion Analyses	Figure D-5
Woodward-Clyde Consultants			



Project No. 414821	SONGS Unit 1 Spectra	Ratio of SONGS 84th Percentile Instrumental Spectra to Reanalysis Spectra for 2% Damping	Figure D-6
Woodward-Clyde Consultants			