PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

# Task 3:
# Characterization of Site Response General Site Categories

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## ABSTRACT

Seismic site response and the amplification of ground motions are significantly affected by the combined effect of the dynamic stiffness of the soil and the depth of the soil. Current design practice, however, either uses an oversimplified approach to soil classification (e.g., "soil" vs. "rock"), or ignores the effect of depth by accounting only for the average shear wave velocity over the upper 100 feet of a site profile (e.g., 1997 UBC). The significant quantity of ground motion data recorded in the 1994 Northridge and 1989 Loma Prieta, California, earthquakes provides an opportunity to assess and improve empirically based predictions of seismic site response.

This report presents a geotechnically based site classification system that includes a measure of the dynamic stiffness of the site and a measure of the depth of the deposit as primary parameters. The measurement of a site’s shear wave velocity profile is not essential for the proposed classification system. This site classification system is used to analyze the ground motion data from the Northridge and Loma Prieta earthquakes. Period-dependent and intensity-dependent spectral amplification factors for site conditions are presented.

The proposed classification system results in a reduction in standard deviation when compared with a simpler "rock vs. soil" classification system. Moreover, results show that sites previously grouped as "rock" can be subdivided as rock sites and weathered, soft rock/shallow stiff soil sites resulting in an improved site categorization system for defining site-dependent ground motions. The standard deviations resulting from the proposed classification system are comparable with the standard deviations obtained using a more elaborate (and costly) average shear wave velocity classification system.

## CONTENTS

## INTRODUCTION

The effect of local site conditions on the amplification of ground motions has long been recognized (e.g., Seed and Idriss 1982). Recent earthquakes, such as the 1985 Mexico City, 1989 Loma Prieta, 1994 Northridge, and 1995 Kobe earthquakes have resulted in significant damage associated with amplification effects due to local geologic conditions (e.g., Seed et al 1987, Chang et al. 1996). While potentially other factors lead to damage (such as topographic and basin effects, liquefaction, ground failure, or structural deficiencies), these events emphasize the need to characterize the potential effect of local soil deposits on the amplification of ground motions.

Extensive studies of seismic site response have been performed over the last thirty years. Recently, Borcherdt (1994) developed intensity-dependent, short and long period amplification factors based on the average shear wave velocity measured over the upper 100 feet of a site. Concurrently, Seed et al. (1991) developed a geotechnical site classification system based on shear wave velocity, depth to bedrock, and general geotechnical descriptions of the soil deposits at a site. Seed et al. (1991) then developed intensity-dependent site amplification factors to modify the baseline "rock" peak ground acceleration (PGA) to account for site effects. With this site PGA value and a site-dependent normalized acceleration response spectra, a site-dependent design spectra can be developed. Work by these researchers along with work by Dobry (Dobry et al. 1994) has been incorporated into the 1997 Uniform Building Code (UBC) based primarily on the site classification system and amplification factors developed by Borcherdt (1994). A shear wave velocity based classification system, however, has two important limitations:

(a) it requires a relatively extensive field investigation, and (b) it overlooks the potential importance of depth to bedrock as a factor in site response. Recent work completed at the University of California at Berkeley based on results from the Northridge and Loma Prieta earthquakes reflects the importance of introducing a measure of depth in a site classification system (Chang and Bray 1995, Chang et al. 1997). Moreover, the Borcherdt (1994) site amplification factors are based primarily on observations from the 1989 Loma Prieta Earthquake, which shows significant nonlinear site response effects; whereas, observations from the 1994 Northridge Earthquake indicate that site amplification factors should not decrease as significantly with increasing ground motion intensity. Hence, the current code site factors may be unconservative, and this should be re-evaluated using the extensive Northridge ground motion database.

A probabilistic seismic hazard assessment requires not only an estimation of the median expected levels of ground motion intensity, but also the standard error associated with such a median estimation. Current ground motion attenuation relationships provide this information (e.g., Abrahamson and Silva 1997, Campbell 1997, Sadigh et al. 1997, Boore et al. 1997). However, most current attenuation relationships have a simplified classification scheme for site conditions in which all sites are divided into two or three broad classifications, e.g., rock/shallow soils, deep stiff soils, and soft soils. A notable exception is the attenuation relationship by Boore et al. (1997). In this relationship, the factor that accounts for site response (site factor) is a continuous function of the average shear wave velocity measured over the upper 100 feet of a site. However, Boore et al. (1997) ignore the effects of ground motion intensity on the site factor, which contradicts measured observations of nonlinear site response (e.g., Trifunac and Todorovska 1996). Conversely, studies involving a more elaborate site classification scheme encompassing stiffness, depth, and intensity of motion, currently lack an appropriate estimate of the statistical uncertainty involved (e.g., Seed et al. 1991).

The significant quantity of ground motion data recorded in the 1994 Northridge and 1989 Loma Prieta earthquakes provides an opportunity to assess and to improve empirically based predictions of seismic site response. The objective of this work is to develop site amplification factors that are both intensity-dependent and frequency-dependent. The site amplification factors will be estimated based on a new proposed site classification system that includes soil stiffness and soil depth as key parameters. The uncertainty levels resulting from the proposed classification system will be compared with those resulting from a simplified "rock vs. soil" classification system and the more elaborate code-based system which uses average shear wave velocity measured over the upper 100 feet of a site.

## METHODOLOGY

The following three steps constitute the methodology used in the development of the proposed empirically based site-dependent amplification factors:

(1) A site classification scheme was developed with the objective of encompassing the factors that have the greatest influence on seismic site response. The proposed scheme utilizes only general geological and geotechnical information, including depth to bedrock or to a significant impedance contrast. More elaborate measurements, such as average shear wave velocity ($\overline{V}_s$), are utilized only as a

guideline and are not essential to the classification system. The classification scheme will be described in detail in the next section.

(2) Two major recent earthquakes, the Loma Prieta Earthquake of October 17, 1989, and the Northridge Earthquake of January 17, 1994, were considered in this study. The strong motion sites that recorded these earthquakes were classified according to the site classification scheme developed in this study. Distance-dependent attenuation relationships for 5% damped elastic acceleration response spectra were developed for each earthquake and for each site condition. For simplicity, hereinafter, any reference to response spectral values will imply linear elastic acceleration response spectra at 5% damping.

(3) These attenuation relationships were utilized to develop site-dependent amplification factors with respect to the baseline site condition, Site Class B, "California Rock." The site-dependent amplification factors are a function of both spectral period and intensity of motion. Amplification factors estimated for the Northridge and Loma Prieta earthquakes were combined to develop recommendations that can be generalized to other events.

## SITE CLASSIFICATION

*Classification Scheme*

The amplification of ground motions at a nearly level site is significantly affected by the natural period of the site ($T_n = 4H/V_s$; where $T_n$ = natural period, H = soil depth, and $V_s$ = shear wave velocity; i.e., both dynamic stiffness and depth are important). Other important seismic site response factors are the impedance ratio between surficial and underlying deposits, the material damping of the surficial deposits, and how these seismic site response characteristics vary as a function of the intensity of the ground motion, as well as other factors. To account partially for these factors, a site classification system should include a measure of the dynamic stiffness of the site and a measure of the depth of the deposit. Although earlier codes made use of natural period as a means to classify site conditions (e.g., 1976 UBC), recent codes such as the 1997 UBC disregard the depth of the soil deposit and use mean shear wave velocity over the upper 100 feet as the primary parameter for site classification.

Both analytical studies and observation of previous earthquakes indicate that depth is indeed an important parameter affecting seismic site response. Figure 1 shows a measure of building damage as a function of site depth in the Caracas Earthquake of 1967. Damage is concentrated in buildings whose natural period matches the natural period of the soil deposit (Seed and Alonso 1974). To illustrate the effect of soil profile depth on surface ground motions, a synthetic motion for an earthquake of moment magnitude 8.0 ($M_w$ = 8.0) on the San Andreas Fault in the San Francisco Bay was used as an input outcropping rock motion for a soil profile with varying thickness. The input rock motion was modified to match the Abrahamson and Silva (1997) attenuation relationship for an earthquake of moment magnitude 7.5 ($M_w$ = 7.5) at a distance of 30 km. The soil profile represents a generic stiff clay site. The upper 100 feet of the profile was kept constant, while the depth of the profile was varied between 100 feet and 500 feet (Figure 2a). A one-dimensional wave propagation analysis was performed using the equivalent-linear program SHAKE91 (Idriss and Sun 1992). Figure 2b shows the resulting surface linear elastic acceleration response spectra, and Figure 2c shows the corresponding spectral amplification factors. Observe that an increase in depth shifts the fundamental period, where amplification is most significant, toward higher values. This results in significantly different surface motions as a function of the depth to bedrock. An increase in depth also results in a longer travel path for the waves through the soil deposit. This accentuates the effect of soil material damping, resulting in greater attenuation of high frequency motion. However, the significantly higher response at longer periods for deep soil deposits is an important expected result that should be accommodated in a seismic site response evaluation.

The same input motion was applied to the four profiles illustrated in Figure 3a. The depth to bedrock for the four profiles is kept constant at 100 feet. The four different profiles correspond to a dense sand, a stiff clay, a loose sand, and a soft clay profile. The shear modulus reduction curves proposed by Iwasaki et al. (1976) were used for the dense and loose sand, along with the damping curves for sand proposed by Seed and Idriss (1970). The Vucetic and Dobry (1991) shear modulus reduction and damping curves for clays with PI = 30 were used for the stiff clays, whereas for the soft clays the shear modulus reduction and damping curves for Holocene Bay Mud proposed by Sun et al. (1988) were used. Figure 3b illustrates the resulting spectral amplification factors. Observe that the effect of different average dynamic shear wave velocities over the upper 100 feet is similar to the effect of changing the depth to bedrock, as observed in Figure 2; that is, the peak spectral amplification factor shifts toward higher periods. Hence, case records and analytical studies support a site classification scheme that captures both the important influences of soil stiffness and soil depth on seismic site response and resulting damage.

Seismic site response is also a function of the intensity of motion due to the nonlinear stress-strain response of soils. The effect of nonlinearity is largely a function of soil type (e.g., Vucetic and Dobry 1991). Factors such as cementation and geologic age may also affect the nonlinear behavior of soils. The effect of soil nonlinearity is two-fold: (a) the site period shifts toward longer values, as illustrated in the previous example, and (b) material damping levels in the soils at a site increase. The increased damping levels result in lower spectral amplifications for all periods. The effect of damping, however, is more pronounced for high frequency motion. Hence, PGA is more significantly affected by soil damping. The consequences of the shift toward longer site periods depend on the soil type and the input motion. For some sites, the site period may be shifted toward periods containing high-energy input motion, resulting in large spectral amplification factors with an associated increase in PGA. Conversely, the site period may be shifted to periods where the energy of the input motion is low, resulting in large spectral amplification at long periods associated with a decrease of amplification for short periods. This may result in lower levels of PGA, and possibly even in attenuation of PGA.

The site classification system proposed herein is an attempt to encompass the factors affecting seismic site response while minimizing the amount of data required for site characterization. The site classification system is based on two main parameters and two secondary ones. The primary parameters are:

(1) Type of deposit, i.e., hard rock, competent rock, weathered rock, stiff soil, soft soil, and potentially liquefiable sand. These general divisions introduce a measure of stiffness (i.e., average shear wave velocity) to the classification system. However, a generic description of a site is sufficient for classification, without the need for measuring shear wave velocity over the upper 100 feet.

(2) Depth to bedrock or to a significant impedance contrast.

The secondary parameters are depositional age and soil type. The former divides soil sites into Holocene or Pleistocene groups, the latter into primarily cohesive or cohesionless soils. These subdivisions are introduced to capture the anticipated different nonlinear responses of these soils. Table 1 summarizes the site classification scheme.

*Site Classification*

The list of sites with the corresponding site classification based on the proposed classification system is given in Appendix A (Tables A-1 and A-2). The sites are also classified according to the 1997 UBC and the Seed et al. (1991) systems (Tables A-3 and A-4 in Appendix A). The references used for the classification of each site are also included in Appendix A. Due to the lack of consistent information for all the sites, the subdivision of Site D into a very deep site sub-category ($D_3$) was omitted. Additionally, sufficient information was not available to categorize sites by a precise depth to bedrock parameter, so that a regression analysis could not be performed using this parameter as a continuous variable.

The references listed in Appendix A were complemented with site visits for some of the sites where information was incomplete. A list of the visited sites is given in Appendix B. Note that an important source of information, particularly for sites belonging to the University of Southern California, was the database of Vucetic and Doroudian (1995). The shear wave velocity values presented in this database have recently been challenged (e.g., Wills 1998, Boore and Brown 1998). In light of these observations, the shear wave velocities for these sites were used, whenever possible, only as a secondary reference. For those sites where the only data available was those in the Vucetic-Doroudian database, these shear wave velocity data were used incorporating the comments made by Boore and Brown (1998).

## GROUND MOTION DATA

Ground motion data from two recent earthquakes, the 1989 Loma Prieta Earthquake and the 1994 Northridge Earthquake, were used in this study. The ground motion recordings were obtained from a database provided by Dr. Walter Silva from Pacific Engineering and Analysis (personal comm. 1998). The database consists of computed elastic spectral acceleration values at 5% damping.

The ground motion database provided by Dr. Walter Silva was complemented with four additional motions for the Northridge Earthquake and eleven motions for the Loma Prieta Earthquake. The baseline corrected motions were obtained from the Internet from sites supported by the institutions in charge of the instruments (see Appendix A). A total of 149 and 70 recorded "free-field" ground motions were used from the 1994 Northridge and 1989 Loma Prieta earthquakes, respectively.

The ground motion recordings used in the study are listed in Appendix A. The number of recordings is a function of spectral period, because of the acceptable filtering parameters used in the processing of the data. The response spectral values are only used if the frequency is greater than 1.25 times the high-pass-corner frequency and less than 1/1.25 times the low pass-corner frequency (Abrahamson and Silva 1997). The distribution of recorded motions with distance as a function of site type for spectral periods between 0.055 seconds and 1.0 seconds is given in Figure 4 for each earthquake. The number of recordings as a function of period is given in Figure 5 for each earthquake.

## STATISTICAL ANALYSIS

### *General*

The ground motion sites were divided into the major categories indicated in the site classification scheme (Table 1). A regression analysis was performed to develop event and site specific attenuation relationships for acceleration response spectral values (5% damping) at selected periods. A basic form of an attenuation relationship was selected for this study, that is,

$$\ln[Sa] = a + b \ln(R + c) + \varepsilon \quad (1)$$

where ln[Sa] is the natural logarithm of the spectral acceleration at a specified period, T, R is the closest distance to the rupture zone (Sadigh et al. 1993), $\varepsilon$ is an error term, and a, b, and c are regression coefficients. Equation (1) is used for various spectral periods, thus the regression coefficients a, b, and c, and the error term $\varepsilon$ are functions of period. This functional form was previously used by Idriss (1994) and Somerville (personal comm.). Note that this functional form does not capture the effects of directivity (Somerville et al. 1997) and the hanging-wall effect (Abrahamson and Somerville 1996). Forward directivity effects result in larger response spectral values at periods larger than one second for near-fault sites and for the component of motion perpendicular to the fault orientation. Directivity effects, however, are not as pronounced when the geometric mean of the ground motion is used, and become secondary for sites located at more than 20 km from the rupture zone (Somerville et al. 1997). Similarly, the hanging-wall effect increases the motion of sites located directly above the rupture zone. For the 1994 Northridge Earthquake, which is primarily reverse slip, forward directivity effects are more pronounced for nearby footwall sites, thus balancing the hanging wall effect for periods longer than one second (Abrahamson and Somerville 1996). A list of sites located over the hanging-wall and the footwall for the Northridge Earthquake is provided in Table 2. Directivity and hanging-wall effects introduce a systematic bias for the affected near-fault sites. This bias, however, generally affects all sites regardless of their type, thus the effect on amplification factors should not be significant.

The regression coefficients were estimated by means of a maximum likelihood estimate (Meyer 1970). The error term $\varepsilon$ in Equation (1) is assumed to be normally distributed with mean zero and standard deviation $\sigma$. With this assumption, maximum likelihood estimates are equivalent to ordinary least squares estimates (Meyer 1970). The natural logarithm of the likelihood function is thus given by:

$$\sum_{i=1}^{N} \ln\left(\frac{1}{\sigma}\exp\left(-0.5\left(\frac{\ln(Sa_i)_{est} - \ln(Sa_i)_{meas}}{\sigma}\right)^2\right)\right) \qquad (2)$$

where $\sigma$ is the standard deviation, $\ln(Sa_i)_{meas}$ is the natural logarithm of the measured spectral acceleration and $\ln(Sa_i)_{est}$ is the mean value given by Equation (1). Similar to Equation (1), Equation (2) is applied at each spectral period. The values of the coefficients "a", "b", and "c" from Equation (1) and the standard deviation ($\sigma$) result from the minimization of the negative of the natural logarithm of the likelihood function (Equation 2). The regression analysis was performed using the software JMP (SAS Institute, Inc. 1995). This analysis was performed separately for each earthquake and for selected periods. In the following sections, the details of each analysis for the two events are described.

*Northridge Earthquake*

The data distribution by site type is shown in Figure 4. Initially, a separation between sites $C_1$, $C_2$ and $C_3$ (weathered/soft rock, shallow stiff soil, and intermediate depth stiff soil, respectively) was assumed, but no significant differences were observed in the resulting attenuation relationships. Consequently, the subdivision of Site C was ignored in the preliminary analysis. Similarly, differences for deep soil sites based on age and soil type (i.e., Holocene or Pleistocene and primarily cohesive or cohesionless) were also not considered in the preliminary analysis.

The response of potentially liquefiable sand deposits (Site F) is mainly a function of whether or not liquefaction is triggered or partially triggered (i.e., significant pore pressure generation develops) at the site. Triggering of liquefaction is a function of the intensity and duration of ground motion, the relative density of the soil, the permeability of the soil, the fines content of the soil, as well as other factors. If liquefaction is triggered or nearly triggered, ground motion is a function of a number of parameters, including rate of excess pore pressure generation, dissipation of pore pressure, reduction of effective stress, shear modulus degradation, duration of motion, as well as other factors. The analysis of these sites is beyond the scope of this project; thus, ground motion sites that are classified as Site F will be excluded from the analysis.

Most of the ground motion sites are concentrated between 20 and 70 km of the zone of energy release (Figure 4). Accordingly, the resulting attenuation relationships are judged to be appropriate for sites located within this distance range from an active fault. Of all the sites located closer than 20 km from the rupture plane, most sites are C and D sites, and only one Site B (California rock) is located within 20 km.

Equation (1) is defined for all distance values only if the coefficient "c" is non-negative. Accordingly, this coefficient was assumed to be non-negative for all periods. Moreover, initial analyses yielded a large standard deviation for the coefficient "c", implying that changes in this coefficient did not result in an increase of the overall standard deviation in Equation (1). In the interest of obtaining reasonable relations between different site conditions, the coefficient "c" was held constant across site conditions. This is consistent with a number of previous studies (e.g., Somerville, personal comm.; Abrahamson and Silva 1997).

Preliminary results yielded spectral accelerations at long periods larger at rock sites (Site B) than at soil sites (Sites C and D) for distances greater than 70 km, a result that contradicts both previous analyses (Abrahamson and Silva 1997, Borcherdt 1994) and theoretical considerations (Dobry et al. 1997). This result is thought to be primarily a consequence of the poor sampling for Site B across all distances. Data for Site B are concentrated within a distance range of 20 to 40 km (See Figure 4), thus there is limited data to constrain adequately all of the coefficients in Equation (1). The approach taken was to assume that the coefficient "a" is equal for both B and C sites.

In summary, the regression analysis for the Northridge Earthquake proceeded in three steps:

(1) The value of "c" was determined using the whole data set (Sites B, C and D). The values of the coefficient "c" obtained in this manner for different spectral periods were fitted to a piece-wise linear function.

(2) Using the values obtained in step 1 for the coefficient "c", the coefficient "a" for site types B and C was obtained using the data for these two site types.

(3) Finally, the remaining coefficients were determined using the data set for each site type separately.

*Loma Prieta Earthquake*

The distribution of data by site type was given in Figure 4. Due to the limited quantity of data, the distinction between $C_1$, $C_2$, and $C_3$ sites (i.e., weathered/soft rock, shallow stiff soil, and intermediate depth soil, respectively) and the difference in age or soil type (i.e., Holocene or Pleistocene and primarily cohesive or cohesionless sites) were not considered in the preliminary stage of the analysis. Similar to the Northridge Earthquake, potentially liquefiable sand and peat deposits (Site F) were excluded from the analysis. Separate regression analyses were performed for sites B, C, D, and E. Most of the data are concentrated within a distance range of 10 km to 90 km from the zone of energy release. Moreover, there are only two sites located within 10 km of the fault rupture plane, implying that the resulting attenuation relationships are poorly constrained for close distances to the zone of energy release. Consequently, the results presented in this report will not reflect the localized effects of near-fault ground motions on seismic site response. Numerical simulations will be required to provide insight into the near-fault seismic response of soil sites, and this is the objective of another ongoing research project by the authors.

Only three rock sites (Site B) are located within 20 km of the zone of energy release. This poor sampling implies that the attenuation relationship is not well constrained for short distances. This is especially important since Site B is taken as the baseline site for developing amplification factors. The low number of soft clay sites (7 sites) and the poor distribution with distance (see Figure 4) results in a poorly constrained attenuation relationship for this site class. Previous studies (e.g., Seed et al. 1991) complemented this lack of empirical data with numerical simulations. Since the objective of this work was the development of empirically based amplification factors, soft clay sites were excluded from the analysis.

As previously indicated for the analysis of the Northridge data, the coefficient "c" in Equation (1) was constrained to be non-negative. Unconstrained regression analysis yielded a negative value of "c" for all periods. Consequently, the coefficient "c" was set to 1 for all periods. As a result of the better sampling in the Loma Prieta data set, there was no need to constrain the parameter "a" in the analysis.

*Results*

The coefficients "a", "b", and "c" found for each earthquake were smoothed by a convolution with a triangular function with a window-width of three. The convolution was repeated until no further improvement was obtained. The smoothed coefficients are illustrated in Figures 6 and 7 and listed in Table 3. A comparison between the resulting smoothed and non-smoothed spectra is shown in Figure 8. The resulting attenuation relationships are illustrated in Figures 9 and 10 for selected distances. Spectral acceleration values as a function distance for selected periods are shown in Figures 11 and 12.

## EVALUATION OF RESULTS

### *General*

The attenuation relationships obtained using the classification system introduced in this work are compared with results from a simplified "Rock vs. Soil" classification system, as well as with a more elaborate code-based classification system (1997 UBC). Residuals for sites C and D were evaluated to judge whether a further subdivision is justified.

### *Comparison With a "Soil vs. Rock" Classification System*

Most current attenuation relationships use a broad and general site classification, dividing sites in either rock/shallow soil or deep stiff soil, in addition to deep soft clay sites (e.g., Abrahamson and Silva 1997). This classification is also often applied in design practice (Abrahamson, personal comm.). Results from this study, however, show that this classification is an oversimplification, and further division into additional categories is warranted.

As a basis for comparison, the earthquake specific attenuation model developed by Somerville and Abrahamson (Somerville, personal comm.) will be compared with the model developed in this study. The Somerville and Abrahamson model will be denoted as S&A. This model divides sites into rock/shallow soil (rock) and deep stiff soils (soil). Deep soft clay sites are excluded. Figure 13 shows a comparison of the results at a distance of 20 km. Note that the spectra for soil sites in S&A generally match the spectra for Site D (deep stiff soils). However, the spectra for rock sites in S&A generally match the spectra for Site C (shallow and intermediate depth soils and weathered/soft rock). This result reflects the fact that for the joint database of rock and shallow soil sites, 83% of the sites are shallow soil or weathered rock sites, and only 17% of these sites actually belong to the Site B classification (competent rock sites). Note that the spectrum for Site B falls significantly below that for Site C (approximately 30% lower on average).

A significant difference in response spectra was observed between the proposed site categories (see Figures 9 and 10). Again, Site B (California rock) data plot significantly below that for Site C (weathered rock/shallow stiff soil), which illustrates that a further subdivision from the 'rock' vs. 'soil' classification is warranted. More significant, however, is the reduction of uncertainty that results from the proposed classification system. Table 4 compares the standard deviations from the S&A relationships with those from the relationships proposed in this report. The decrease in the standard deviation for Site B compared with S&A rock sites is between 30% and 40%. A similar reduction is observed for soil sites (S&A Soil vs. Site D). Standard deviations for Site C, however, remain high and are only marginally lower than standard deviations for rock in the S&A model. A reduction in the uncertainty bands for sites B and D reflects the more selective grouping criteria applied in this study.

*Comparison With a Code-Based Site Classification System*

The data set for both earthquakes was also divided according to the 1997 UBC (i.e., using the average shear wave velocity measured over the upper 100 feet of the site). The UBC classification system is presented in Table 4 in Appendix A. Differences in the classification of ground motion sites using both systems are shown in Table 5. For simplicity, sites classified according to the system presented in this work (Table 1) will simply be denoted by Site X, while sites classified according to the UBC system will be denoted UBC X. Note that in the Northridge database, there is a significant number of C sites that correspond to either UBC B or UBC D sites. The former are weathered rock sites lying on top of harder, intact rock (such as Lake Hughes #9), and the latter are either shallow soil or weathered rock sites with depth to bedrock ranging from 80 to 200 feet. There are also five D sites in Northridge and one in Loma Prieta that classify as UBC C sites. These sites correspond to stiff clay or sand deposits with shear wave velocities only slightly larger than the boundary values determined by the UBC classification system (such as Sepulveda VA Hospital). This overlap results in different attenuation relationships depending on the classification system. Because shear wave velocity measurements were not taken at all ground motion stations used in this study, the classification of sites according to the scheme presented in this work probably is more accurate than the classification of sites according to their average shear wave velocity value. The same finding carries over to the results of the regression analyses.

Table 6 compares the standard deviations at selected periods resulting from the regression analysis using both classification systems. For the Loma Prieta Earthquake, standard deviations for both classification systems are comparable. This is expected because there is little overlap between classification systems for the Loma Prieta database (Table 5). For the Northridge Earthquake, standard deviations vary slightly from one classification system to the other. Standard deviations for Site B are slightly lower for the proposed classification system. For Sites C and D, standard deviations are equal for a period of 0.3 seconds, but vary slightly at a period of one second. With the exception of Site D at a period of one second, the differences of the standard deviations resulting from both classification systems are within the ranges of the estimates. Given that the spectral amplification factors change significantly with depth at a period close to one second (Figure 2), the exclusion of sites shallower than 60 m from Site D in the proposed classification system result in a reduction of the scatter in the data.

*Subdivision of Site C*

For the Northridge Earthquake, the standard deviations of Site C at long periods are larger than those of Sites B and D. This observation motivated a closer examination of the results for Site C. Figure 14 shows the residuals for Site C for the Northridge Earthquake, along with the mean value of the residuals. Each site is identified by its corresponding UBC classification. Note that well-defined trends are observed for periods larger than 0.1 seconds. UBC D sites plot significantly above the median while UBC C sites plot below the median, illustrating that a further subdivision for Site C according to shear wave velocity may be warranted. Similarly, these results demonstrate that whereas for deep stiff soil sites and rock sites the additional expense of a shear wave velocity characterization may not be justified, for intermediate depth soil sites characterization using average shear wave velocity may reduce the uncertainty in the prediction of ground motions.

A subdivision of Site C as indicated in Table 1 was also studied. Residuals for Site C are plotted in Figure 15a for the Northridge Earthquake. Observe that no specific trends for sites $C_1$, $C_2$, and $C_3$ are observed, as opposed to the trend observed when C sites were divided according to an average shear wave velocity-based classification system. This observation implies that for shallow and intermediate depth soils, the average shear wave velocity may be the discriminating additional factor.

*Subdivision of Site D*

A further subdivision for deep soil sites (Site D) according to age and soil type is also studied. As shown in the classification system (Table 1), Site D is subdivided as either Holocene or Pleistocene, or as primarily clayey or sandy. Figure 16a shows the residuals for sites D for the Northridge Earthquake. Mean residuals consistently greater than zero are observed for clay sites at all periods. These mean residuals are considered important, however, not overly significant when compared with the standard deviation for the entire distribution of around 0.4. This trend is magnified when only Pleistocene sites (D2) are considered. However, since the number of such sites is low, further studies are needed to confirm this trend. No apparent trend based solely on the age of the deposit is observed. The same trends are observed in the Loma Prieta Earthquake (Figure 16b), but the small number of sites precludes any definite finding in this regard.

In general, it appears that greater amplification can occur at clay sites, especially if Pleistocene, and this is consistent with the concept that higher plasticity soils have higher threshold strains and hence exhibit less shear modulus reduction and less material damping at intermediate levels of ground motion. However, until additional ground motion and site classification data are obtained, the limited number of sites and records, and the level of scatter associated with Site D, precludes further subdivision at this time.

*Effect of Depth to Basin*

In an effort to assess the ability of a depth to basement rock term to capture seismic site effects, sites within the Los Angeles basin were investigated. The depth to basement bedrock was obtained from a map by Conrey (1967), and is defined as the depth to the top of Pliocene bedrock. All of the selected sites are classified as Site D, with the exception of the USC 54 site (LA Centinela), which is a $C_3$ site. Residuals for periods of one and two seconds as a function of depth to bedrock are plotted in Figure 17 for sites located in the Los Angeles basin. No trend is observed for sites shallower than 6000 feet, but residuals are higher than zero for sites deeper than 6000 feet. Positive residuals may be due to basin effects rather than to local site amplification.

*Amplification Factors*

The attenuation relationships developed hereinbefore are event-specific relations that cannot be generalized to other events. To extend the applicability of the results presented in this work, amplification factors with respect to a baseline site condition were obtained. By agreement with other PEER researchers, the baseline site condition was taken to be rock (Site B). However, since current "rock" attenuation relationships reflect mostly site condition C, factors with respect to Site C will also be presented. The amplification factors are obtained by dividing Equation (1) for the two site conditions. The resulting relationship can be written as

$$\ln\left(F_{C/B}\right) = a_{C/B} + b_{C/B}\ln(R + c) \tag{3}$$

where $F_{C/B}$ is the spectral acceleration amplification factor for Site C with respect to Site B, R is the closest distance to the rupture plane, and $a_{C/B}$ and $b_{C/B}$ are coefficients defined by:

$$a_{C/B} = a(\text{Site C}) - a(\text{Site B}) \tag{4a}$$

$$b_{C/B} = b(\text{Site C}) - b(\text{Site B}) \tag{4b}$$

The regression coefficient "c" was assumed to be independent of site conditions and therefore no site-dependent ratio is necessary for this coefficient. These two coefficients were smoothed for all periods. The smoothed coefficients are listed in Appendix C. The resulting amplification factors are shown in Figure 18 for each earthquake. For the Loma Prieta Earthquake, a reduction in spectral amplification factors for increasing levels of base rock motion is observed for periods shorter than one second. This trend is consistent with nonlinear soil behavior. At periods greater than one second, spectral amplification values do not necessarily decrease with increasing levels of base rock motion, as soil response nonlinearity would also tend to increase the response at larger periods as the site softened. Other issues may have affected the data in this period range, such as basin effects and surface waves. In addition, rather than a reflection of soil response, these observations may be a result of the significant scatter of the data at long periods. Moreover, for high values of PGA, the attenuation relationships are not well constrained due to the lack of near-fault data for the Loma Prieta Earthquake.

Amplification factors from the Northridge Earthquake do not show the same degree of nonlinearity, as do the results from Loma Prieta. Because the current UBC is based mainly on observational data from the Loma Prieta Earthquake (e.g., Borcherdt 1994), amplification factors presented in the UBC may be misleadingly unconservative.

*Recommended Factors*

The spectral amplification factors from each earthquake were combined to develop a set of recommended amplification factors. The factors were combined at equal PGA values. Note that since the attenuation relationships are different for each earthquake, the relationship between PGA and distance is not unique for both earthquakes. Two different weighting schemes were utilized. One weighting scheme gives equal weight to each earthquake, while the other gives a weight inversely proportional to the variance of the sample mean. The equations and coefficients used to determine the amplification factors are given in Appendix C. The resulting amplification factors are shown in Figures 19 and 20, and are given in Tables 7 and 8. The standard deviations for each site condition were averaged using the same weighting schemes, and are also presented in Tables 7 and 8.

For long periods ($T > 1.0$ s) the difference in amplification factors between earthquakes is significantly smaller than the difference in amplification factors between site type. For shorter periods, however, differences between earthquakes are comparable to differences due to site type.

Amplification factors with respect to Site B (Figures 19a and 20a) show a significant degree of nonlinearity. On the other hand, spectral amplification factors from Site D to Site C are nearly linear, mainly because of the linearity observed in the Northridge data (Figure 18b). This effect is increased when weighting factors inversely proportional to sample variance are applied (Figure 20b) as a result of the larger number of Site C and Site D data points in the Northridge Earthquake (see Figure 21 for the weights for each earthquake).

A comparison of Figures 20a and 20b illustrates the dramatic difference in spectral amplification factors that results from taking either rock (Site B) or weathered-soft rock/shallow stiff soil (Site C) as the baseline site condition. Current practice takes an intermediate site condition as reference. The large differences in behavior between these site conditions illustrated in this work serve to highlight the need to define a unique baseline site condition.

For the sake of comparison with current code provisions, the spectral amplification factors were averaged over a range of periods to obtain short-period and mid-period amplification factors. The period range for the short-period amplification factor ($F_a$) is 0.1 to 0.5 seconds, and the period range for the mid-period amplification factor ($F_v$) is 0.4 to 2.0 seconds (Borcherdt 1994). The mean factors were averaged from a double logarithmic plot of amplification factors versus period. The values of the code factors (UBC 1997) and the factors obtained in this work are given in Table 9, and are presented graphically in Figure 22.

The short-period amplification factors ($F_a$) obtained in this work are larger than the code values. This is due in large part to the larger levels of motion observed in the Northridge earthquake, which was not included in the studies that led to the adoption of the 1997 UBC factors. Additionally, the site classification scheme adopted for the 1997 UBC differs from that proposed in this study, so that some sites are classified differently (see "Comparison with a code-based site classification system," pp. 18-19 and Table 5). The difference, however, is less than 20%, which is well within the statistical uncertainty in our results. The intermediate-period amplification factors obtained in this work are also within 20% of the code values. The factors presented herein, however, show a lesser degree of nonlinearity than the code factors. This, again, is a result of the inclusion of the Northridge data set.

## SUMMARY

### *Conclusions*

The strong ground motion data from the Loma Prieta and Northridge earthquakes were analyzed and used to evaluate a proposed new site classification system to account for site amplification. The proposed classification system is based on a general geotechnical characterization of the site including depth to bedrock. Two important conclusions were reached:

(1) The proposed classification system results in a reduction in standard deviation when compared with a simpler "rock vs. soil" classification system. Moreover, results show that sites previously grouped as "rock" can be subdivided as rock sites and weathered soft rock/shallow stiff soil sites resulting in an improved site categorization system for defining site-dependent ground motions.

(2) The standard deviations resulting from the proposed classification system are comparable with the standard deviations obtained using a more burdensome average shear wave velocity classification system. This illustrates that depth of the soil deposit is an important parameter for the estimation of seismic site response.

(3) Current attenuation relationships use as the baseline site condition a generic “rock” class that groups soft rock/shallow stiff soil and competent rock sites (California rock). The results shown in this paper indicate a significant

difference in behavior between these two site classes. This, in turn, highlights the need to review the database to redefine the baseline site condition.

*Products*

The project deliverables are in the form of a database and a seismic site-amplification model. The data are given as site classifications of strong motion stations affected by the Northridge and Loma Prieta earthquakes in the Los Angeles and San Francisco Bay areas, respectively. The seismic site-amplification model is given in the form of intensity-dependent, period-dependent spectral acceleration amplification factors for sites B, C, and D with respect to either a baseline Site B (PEER 1998) or C (i.e., "rock" classification for most attenuation relationships, e.g., Abrahamson and Silva 1997). The intensity-dependent, period-dependent spectral acceleration amplification factors can be obtained using the formulas given in Appendix C.

*Recommendations*

Based on the results of this analysis of the Loma Prieta and Northridge earthquake ground motion databases, it is judged that the site-dependent, period-dependent amplification factors given in Tables 7 and 8 and in equation form in Appendix C, can be used in general probability seismic hazard assessments. However, caution should be exercised when using these factors, because they are obtained from a data set containing only two earthquakes. Hence, intra-event scatter could be assessed for these two earthquakes, but inter-event scatter could not be evaluated satisfactorily based on only two earthquake events. Moreover, due to the scarcity of the data, results are not well defined at high acceleration levels. Amplification factors are given with respect to site condition B (rock) and Site C (i.e., "rock" classification for most attenuation relationships, e.g., Abrahamson and Silva 1997). Current attenuation relationships (i.e., Abrahamson and Silva 1997) and probabilistic maps use an intermediate baseline site condition of B-C. Due to the relative scarcity of data of B sites relative to C sites, their “rock” sites are more closely analogous to Site C. This should be taken into consideration when applying the recommended amplification factors to current attenuation relationship and probabilistic map values.

The results of this study strongly support the development of an attenuation relationship based on the proposed site classification scheme. With this new relationship, spectral acceleration values for a site could be estimated directly without the use of amplification factors. A better estimate of the uncertainty involved in ground motion estimation could be made with this direct approach, rather than the approach applied herein that required ratios of spectral ordinates.

*Recommendations for Future Research*

While the work in this report has increased the understanding of seismic site response, it also identified a number of issues that warrant further investigation:

(1) Inclusion of additional earthquakes to the database of ground motions used in this study.

(2) Development of new attenuation relationships that use the geotechnical site categories presented in this report.

(3) Evaluation of near-fault site effects with nonlinear coupled response analyses.

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# TABLES

Table 1. Geotechnical Site Categories.

| Site | Categories |
|---|---|
| A | Hard Rock |
| B | Rock |
| C | Weathered/Soft Rock or Shallow Stiff Soil |
| D | Deep Stiff Soil |
| E | Soft Clay |
| F | Special, e.g., Liquefiable Sand |

| Site | Description | Site Period | Comments |
|---|---|---|---|
| **A** | Hard Rock | ≤ 0.1 s | Hard, strong, intact rock; $V_s \geq 5000$ fps |
| **B** | Rock | ≤ 0.2 s | Most "unweathered" California rock cases; $V_s \geq 2500$ fps or < 20 ft. of soil. |
| **C-1** | Weathered/Soft Rock | ≤ 0.4 s | $V_s \approx 1200$ fps increasing to > 2000 fps, weathered zone > 20 ft. and < 100 ft. |
| **-2** | Shallow Stiff Soil | ≤ 0.5 s | Soil depth > 20 ft. and < 100 ft. |
| **-3** | Intermediate Depth Stiff Soil | ≤ 0.8 s | Soil depth > 100 ft. and < 200 ft. |
| **D-1** | Deep Stiff Holocene Soil, either **S** (Sand) or **C** (Clay) | ≤ 1.4 s | Soil depth > 200 ft. and < 700 ft. Sand has low fines content (< 15%) or non-plastic fines (PI < 5). Clay has high fines content (> 15%) and plastic fines (PI > 5). |
| **-2** | Deep Stiff Pleistocene Soil, **S** (Sand) or **C** (Clay) | ≤ 1.4 s | Soil depth > 200 ft. and < 700 ft. See $D_1$ for S or C sub-categorization. |
| **-3** | Very Deep Stiff Soil | ≤ 2 s | Soil depth > 700 ft. |
| **E-1** | Medium Depth Soft Clay | ≤ 0.7 s | Thickness of soft clay layer 10 ft. to 40 ft. |
| **-2** | Deep Soft Clay Layer | ≤ 1.4 s | Thickness of soft clay layer > 40 ft. |
| **F** | Special, e.g., Potentially Liquefiable Sand or Peat | ≈ 1 s | Holocene loose sand with high water table ($z_w \leq 20$ft.) or organic peats. |

Table 2. Sites located on the footwall (FW) and hanging-wall (HW) in the Northridge Earthquake (adapted from Abrahamson and Somerville 1996)

| Organization | Station # | Location | Classification |
|---|---|---|---|
| CDMG | 24047 | FW | B |
| CDMG | 24207 | FW | B |
| CDMG | 24279 | FW | C3 |
| CDMG | 24469 | FW | B |
| CDMG | 24514 | FW | D1C |
| CDMG | 24575 | FW | C2 |
| CDMG | 24607 | FW | C1 |
| USC | 90057 | FW | D1S |
| USGS | 127 | FW | C1 |
| CDMG | 24396 | HW | C1 |
| DWP | 75 | HW | D1S |
| DWP | 77 | HW | C2 |
| USC | 90003 | HW | D1C |
| USC | 90049 | HW | C2 |
| USC | 90053 | HW | C3 |
| USC | 90055 | HW | C2 |
| USGS | 637 | HW | D2C |
| USGS | 655 | HW | F |
| USGS | 5080 | HW | B |
| USGS | 5081 | HW | C2 |
| USGS | 5108 | HW | C1 |

Table 3a. Regression coefficients and Standard Error for spectral acceleration values at 5% damping for the Northridge Earthquake.

| | B Sites | | | | C Sites | | | | D Sites | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T | a | b | c | σ | a | b | c | σ | a | b | c | σ |
| PGA | 2.3718 | -1.2753 | 6.3883 | 0.3209 | 2.3718 | -1.1538 | 6.3883 | 0.4686 | 2.6916 | -1.2161 | 6.3883 | 0.3559 |
| 0.055 | 3.5192 | -1.4829 | 10.2486 | 0.4343 | 3.5192 | -1.3869 | 10.2486 | 0.4661 | 3.5126 | -1.3703 | 10.2486 | 0.3560 |
| 0.06 | 3.7423 | -1.5138 | 11.8103 | 0.4343 | 3.7423 | -1.4266 | 11.8103 | 0.4655 | 3.7970 | -1.4257 | 11.8103 | 0.3654 |
| 0.07 | 4.3982 | -1.6291 | 14.5768 | 0.4310 | 4.3982 | -1.5480 | 14.5768 | 0.4636 | 4.4475 | -1.5472 | 14.5768 | 0.3705 |
| 0.08 | 4.8097 | -1.7006 | 16.9734 | 0.4180 | 4.8097 | -1.6152 | 16.9734 | 0.4619 | 4.9774 | -1.6422 | 16.9734 | 0.3754 |
| 0.09 | 4.9993 | -1.7175 | 18.0000 | 0.3935 | 4.9993 | -1.6366 | 18.0000 | 0.4617 | 5.2637 | -1.6826 | 18.0000 | 0.3779 |
| 0.1 | 4.9768 | -1.6855 | 18.0000 | 0.3615 | 4.9768 | -1.6089 | 18.0000 | 0.4642 | 5.3000 | -1.6679 | 18.0000 | 0.3774 |
| 0.11 | 4.9365 | -1.6614 | 18.0000 | 0.3457 | 4.9365 | -1.5844 | 18.0000 | 0.4667 | 5.2529 | -1.6439 | 18.0000 | 0.3766 |
| 0.12 | 4.8748 | -1.6330 | 18.0000 | 0.3322 | 4.8748 | -1.5530 | 18.0000 | 0.4703 | 5.1563 | -1.6072 | 18.0000 | 0.3759 |
| 0.13 | 4.7753 | -1.5991 | 18.0000 | 0.3226 | 4.7753 | -1.5140 | 18.0000 | 0.4750 | 5.0044 | -1.5586 | 18.0000 | 0.3758 |
| 0.14 | 4.6161 | -1.5564 | 17.3303 | 0.3179 | 4.6161 | -1.4646 | 17.3303 | 0.4808 | 4.7947 | -1.4991 | 17.3303 | 0.3766 |
| 0.15 | 4.3937 | -1.5041 | 16.0757 | 0.3182 | 4.3937 | -1.4037 | 16.0757 | 0.4877 | 4.5454 | -1.4330 | 16.0757 | 0.3786 |
| 0.16 | 4.1376 | -1.4471 | 14.9021 | 0.3232 | 4.1376 | -1.3364 | 14.9021 | 0.4952 | 4.2958 | -1.3685 | 14.9021 | 0.3820 |
| 0.17 | 3.8807 | -1.3907 | 13.7997 | 0.3315 | 3.8807 | -1.2694 | 13.7997 | 0.5030 | 4.0778 | -1.3133 | 13.7997 | 0.3865 |
| 0.18 | 3.7555 | -1.3635 | 12.7603 | 0.3368 | 3.7555 | -1.2373 | 12.7603 | 0.5069 | 3.9820 | -1.2900 | 12.7603 | 0.3893 |
| 0.19 | 3.6370 | -1.3378 | 11.7771 | 0.3418 | 3.6370 | -1.2069 | 11.7771 | 0.5105 | 3.8913 | -1.2680 | 11.7771 | 0.3918 |
| 0.2 | 3.4048 | -1.2891 | 10.8444 | 0.3531 | 3.4048 | -1.1508 | 10.8444 | 0.5174 | 3.7044 | -1.2249 | 10.8444 | 0.3974 |
| 0.22 | 3.1681 | -1.2413 | 9.1112 | 0.3646 | 3.1681 | -1.0982 | 9.1112 | 0.5234 | 3.4809 | -1.1745 | 9.1112 | 0.4026 |
| 0.24 | 2.9146 | -1.1904 | 7.5290 | 0.3759 | 2.9146 | -1.0449 | 7.5290 | 0.5285 | 3.2196 | -1.1160 | 7.5290 | 0.4071 |
| 0.26 | 2.7904 | -1.1657 | 6.6312 | 0.3818 | 2.7904 | -1.0198 | 6.6312 | 0.5308 | 3.0913 | -1.0874 | 6.6312 | 0.4089 |
| 0.28 | 2.6754 | -1.1429 | 5.8000 | 0.3872 | 2.6754 | -0.9965 | 5.8000 | 0.5330 | 2.9725 | -1.0610 | 5.8000 | 0.4106 |
| 0.3 | 2.5178 | -1.1149 | 4.9000 | 0.3983 | 2.5178 | -0.9682 | 4.9000 | 0.5372 | 2.8087 | -1.0250 | 4.9000 | 0.4129 |
| 0.32 | 2.4644 | -1.1117 | 4.4939 | 0.4087 | 2.4644 | -0.9657 | 4.4939 | 0.5415 | 2.7420 | -1.0110 | 4.4939 | 0.4141 |
| 0.34 | 2.4645 | -1.1197 | 4.4254 | 0.4176 | 2.4645 | -0.9768 | 4.4254 | 0.5463 | 2.7212 | -1.0067 | 4.4254 | 0.4145 |
| 0.36 | 2.4594 | -1.1242 | 4.3606 | 0.4242 | 2.4594 | -0.9870 | 4.3606 | 0.5515 | 2.6916 | -0.9999 | 4.3606 | 0.4142 |
| 0.4 | 2.4375 | -1.1239 | 4.2415 | 0.4276 | 2.4375 | -0.9935 | 4.2415 | 0.5570 | 2.6466 | -0.9915 | 4.2415 | 0.4133 |
| 0.44 | 2.4279 | -1.1279 | 4.1337 | 0.4277 | 2.4279 | -1.0049 | 4.1337 | 0.5627 | 2.6269 | -0.9946 | 4.1337 | 0.4119 |
| 0.5 | 2.4692 | -1.1545 | 3.9890 | 0.4198 | 2.4692 | -1.0526 | 3.9890 | 0.5739 | 2.7651 | -1.0629 | 3.9890 | 0.4066 |
| 0.55 | 2.4447 | -1.1582 | 3.8812 | 0.4140 | 2.4447 | -1.0682 | 3.8812 | 0.5792 | 2.8613 | -1.1091 | 3.8812 | 0.4023 |
| 0.6 | 2.3687 | -1.1540 | 3.7828 | 0.4090 | 2.3687 | -1.0710 | 3.7828 | 0.5843 | 2.9263 | -1.1469 | 3.7828 | 0.3968 |
| 0.667 | 2.2699 | -1.1513 | 3.6630 | 0.4060 | 2.2699 | -1.0675 | 3.6630 | 0.5892 | 2.9650 | -1.1752 | 3.6630 | 0.3901 |
| 0.7 | 2.1804 | -1.1550 | 3.6084 | 0.4059 | 2.1804 | -1.0660 | 3.6084 | 0.5937 | 2.9956 | -1.1995 | 3.6084 | 0.3826 |
| 0.75 | 2.1276 | -1.1664 | 3.5303 | 0.4090 | 2.1276 | -1.0746 | 3.5303 | 0.5977 | 3.0096 | -1.2199 | 3.5303 | 0.3750 |
| 0.8 | 2.1239 | -1.1848 | 3.4573 | 0.4151 | 2.1239 | -1.0966 | 3.4573 | 0.6009 | 2.9754 | -1.2294 | 3.4573 | 0.3680 |
| 0.85 | 2.1516 | -1.2064 | 3.3887 | 0.4235 | 2.1516 | -1.1267 | 3.3887 | 0.6030 | 2.8866 | -1.2261 | 3.3887 | 0.3621 |
| 0.9 | 2.1703 | -1.2244 | 3.4413 | 0.4332 | 2.1703 | -1.1539 | 3.4413 | 0.6041 | 2.7784 | -1.2185 | 3.4413 | 0.3579 |
| 0.95 | 2.1451 | -1.2353 | 3.2629 | 0.4435 | 2.1451 | -1.1701 | 3.2629 | 0.6041 | 2.6965 | -1.2187 | 3.2629 | 0.3556 |
| 1.0 | 2.0734 | -1.2443 | 3.2048 | 0.4538 | 2.0734 | -1.1775 | 3.2048 | 0.6033 | 2.6601 | -1.2333 | 3.2048 | 0.3551 |
| 1.1 | 1.9888 | -1.2635 | 3.0970 | 0.4637 | 1.9888 | -1.1873 | 3.0970 | 0.6017 | 2.6461 | -1.2583 | 3.0970 | 0.3563 |
| 1.2 | 1.9252 | -1.2983 | 2.9986 | 0.4726 | 1.9252 | -1.2071 | 2.9986 | 0.5995 | 2.6099 | -1.2804 | 2.9986 | 0.3587 |
| 1.3 | 1.8811 | -1.3390 | 2.9080 | 0.4799 | 1.8811 | -1.2317 | 2.9080 | 0.5962 | 2.5295 | -1.2884 | 2.9080 | 0.3618 |
| 1.4 | 1.8327 | -1.3706 | 2.8242 | 0.4799 | 1.8327 | -1.2510 | 2.8242 | 0.5909 | 2.4272 | -1.2846 | 2.8242 | 0.3649 |
| 1.5 | 1.7582 | -1.3853 | 2.7461 | 0.4799 | 1.7582 | -1.2588 | 2.7461 | 0.5850 | 2.3331 | -1.2785 | 2.7461 | 0.3664 |
| 1.7 | 1.5420 | -1.3800 | 2.6045 | 0.4799 | 1.5420 | -1.2565 | 2.6045 | 0.5800 | 2.1862 | -1.2817 | 2.6045 | 0.3811 |
| 2.0 | 1.3896 | -1.3970 | 2.4206 | 0.4799 | 1.3896 | -1.2933 | 2.4206 | 0.5700 | 2.0500 | -1.3154 | 2.4206 | 0.4130 |
| 2.2 | 1.2440 | -1.3983 | 2.3128 | 0.4799 | 1.2440 | -1.3004 | 2.3128 | 0.5600 | 1.8906 | -1.3182 | 2.3128 | 0.4244 |
| 2.6 | 0.9829 | -1.3739 | 2.1238 | 0.4799 | 0.9829 | -1.2719 | 2.1238 | 0.5400 | 1.6293 | -1.2941 | 2.1238 | 0.4145 |
| 3.0 | 0.6859 | -1.3338 | 2.0000 | 0.4799 | 0.6859 | -1.2207 | 2.0000 | 0.5200 | 1.3413 | -1.2536 | 2.0000 | 0.3877 |

Table 3b. Regression coefficients and Standard Error for spectral acceleration values at 5% damping for the Loma Prieta Earthquake.

| | B Sites | | | | C Sites | | | | D Sites | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T** | **a** | **b** | **c** | **σ** | **a** | **b** | **c** | **σ** | **a** | **b** | **c** | **σ** |
| PGA | 0.7219 | -0.7954 | 1.0000 | 0.4713 | 0.8212 | -0.7502 | 1.0000 | 0.3111 | 0.5716 | -0.6032 | 1.0000 | 0.3896 |
| 0.055 | 1.6308 | -0.9794 | 1.0000 | 0.4566 | 1.4230 | -0.8769 | 1.0000 | 0.3708 | 1.3201 | -0.7767 | 1.0000 | 0.4334 |
| 0.06 | 1.8207 | -1.0119 | 1.0000 | 0.4561 | 1.4804 | -0.8841 | 1.0000 | 0.3747 | 1.2568 | -0.7489 | 1.0000 | 0.4338 |
| 0.07 | 1.9001 | -1.0181 | 1.0000 | 0.4554 | 1.4819 | -0.8734 | 1.0000 | 0.3798 | 1.2413 | -0.7315 | 1.0000 | 0.4340 |
| 0.08 | 2.0559 | -1.0383 | 1.0000 | 0.4538 | 1.5348 | -0.8701 | 1.0000 | 0.3886 | 1.3041 | -0.7271 | 1.0000 | 0.4331 |
| 0.09 | 2.1619 | -1.0489 | 1.0000 | 0.4518 | 1.5875 | -0.8642 | 1.0000 | 0.3973 | 1.4037 | -0.7300 | 1.0000 | 0.4303 |
| 0.1 | 2.2305 | -1.0551 | 1.0000 | 0.4500 | 1.6419 | -0.8595 | 1.0000 | 0.4027 | 1.5122 | -0.7400 | 1.0000 | 0.4269 |
| 0.11 | 2.2946 | -1.0607 | 1.0000 | 0.4481 | 1.7031 | -0.8527 | 1.0000 | 0.4074 | 1.6341 | -0.7524 | 1.0000 | 0.4220 |
| 0.12 | 2.3215 | -1.0625 | 1.0000 | 0.4472 | 1.7361 | -0.8492 | 1.0000 | 0.4091 | 1.6890 | -0.7575 | 1.0000 | 0.4187 |
| 0.13 | 2.3462 | -1.0642 | 1.0000 | 0.4464 | 1.7665 | -0.8461 | 1.0000 | 0.4108 | 1.7395 | -0.7622 | 1.0000 | 0.4157 |
| 0.14 | 2.3659 | -1.0613 | 1.0000 | 0.4451 | 1.8339 | -0.8450 | 1.0000 | 0.4124 | 1.7916 | -0.7621 | 1.0000 | 0.4084 |
| 0.15 | 2.3410 | -1.0484 | 1.0000 | 0.4448 | 1.9079 | -0.8523 | 1.0000 | 0.4120 | 1.7724 | -0.7458 | 1.0000 | 0.4004 |
| 0.16 | 2.2804 | -1.0268 | 1.0000 | 0.4460 | 1.9696 | -0.8621 | 1.0000 | 0.4095 | 1.7156 | -0.7191 | 1.0000 | 0.3924 |
| 0.17 | 2.2370 | -1.0125 | 1.0000 | 0.4476 | 1.9792 | -0.8631 | 1.0000 | 0.4071 | 1.6926 | -0.7066 | 1.0000 | 0.3888 |
| 0.18 | 2.1960 | -0.9991 | 1.0000 | 0.4491 | 1.9882 | -0.8640 | 1.0000 | 0.4049 | 1.6710 | -0.6949 | 1.0000 | 0.3853 |
| 0.19 | 2.0939 | -0.9675 | 1.0000 | 0.4545 | 1.9513 | -0.8531 | 1.0000 | 0.3989 | 1.6405 | -0.6754 | 1.0000 | 0.3797 |
| 0.2 | 1.9861 | -0.9352 | 1.0000 | 0.4626 | 1.8633 | -0.8291 | 1.0000 | 0.3923 | 1.5961 | -0.6551 | 1.0000 | 0.3761 |
| 0.22 | 1.8879 | -0.9051 | 1.0000 | 0.4731 | 1.7414 | -0.7944 | 1.0000 | 0.3861 | 1.5361 | -0.6348 | 1.0000 | 0.3748 |
| 0.24 | 1.8523 | -0.8933 | 1.0000 | 0.4797 | 1.6772 | -0.7749 | 1.0000 | 0.3837 | 1.5154 | -0.6295 | 1.0000 | 0.3754 |
| 0.26 | 1.8196 | -0.8825 | 1.0000 | 0.4858 | 1.6182 | -0.7570 | 1.0000 | 0.3815 | 1.4963 | -0.6245 | 1.0000 | 0.3759 |
| 0.28 | 1.8136 | -0.8775 | 1.0000 | 0.5001 | 1.5268 | -0.7272 | 1.0000 | 0.3796 | 1.5140 | -0.6328 | 1.0000 | 0.3796 |
| 0.3 | 1.8860 | -0.8959 | 1.0000 | 0.5149 | 1.4800 | -0.7104 | 1.0000 | 0.3812 | 1.5933 | -0.6598 | 1.0000 | 0.3859 |
| 0.32 | 1.9446 | -0.9120 | 1.0000 | 0.5223 | 1.4703 | -0.7068 | 1.0000 | 0.3841 | 1.6498 | -0.6788 | 1.0000 | 0.3906 |
| 0.34 | 1.9996 | -0.9271 | 1.0000 | 0.5292 | 1.4613 | -0.7033 | 1.0000 | 0.3868 | 1.7028 | -0.6968 | 1.0000 | 0.3950 |
| 0.36 | 2.0373 | -0.9373 | 1.0000 | 0.5358 | 1.4510 | -0.7011 | 1.0000 | 0.3916 | 1.7453 | -0.7128 | 1.0000 | 0.4012 |
| 0.4 | 2.0412 | -0.9393 | 1.0000 | 0.5524 | 1.3972 | -0.6925 | 1.0000 | 0.4092 | 1.7829 | -0.7364 | 1.0000 | 0.4219 |
| 0.44 | 1.8966 | -0.9057 | 1.0000 | 0.5600 | 1.3081 | -0.6785 | 1.0000 | 0.4251 | 1.6708 | -0.7148 | 1.0000 | 0.4396 |
| 0.5 | 1.5766 | -0.8357 | 1.0000 | 0.5658 | 1.0905 | -0.6402 | 1.0000 | 0.4486 | 1.3791 | -0.6481 | 1.0000 | 0.4659 |
| 0.55 | 1.3683 | -0.7909 | 1.0000 | 0.5678 | 0.9405 | -0.6134 | 1.0000 | 0.4616 | 1.1859 | -0.6031 | 1.0000 | 0.4808 |
| 0.6 | 1.2193 | -0.7593 | 1.0000 | 0.5685 | 0.8299 | -0.5944 | 1.0000 | 0.4699 | 1.0459 | -0.5707 | 1.0000 | 0.4906 |
| 0.667 | 1.0380 | -0.7209 | 1.0000 | 0.5694 | 0.6953 | -0.5713 | 1.0000 | 0.4799 | 0.8757 | -0.5314 | 1.0000 | 0.5025 |
| 0.7 | 0.9158 | -0.6959 | 1.0000 | 0.5700 | 0.5954 | -0.5543 | 1.0000 | 0.4867 | 0.7392 | -0.4998 | 1.0000 | 0.5112 |
| 0.75 | 0.7412 | -0.6602 | 1.0000 | 0.5708 | 0.4527 | -0.5302 | 1.0000 | 0.4965 | 0.5444 | -0.4547 | 1.0000 | 0.5235 |
| 0.8 | 0.6212 | -0.6371 | 1.0000 | 0.5719 | 0.3418 | -0.5106 | 1.0000 | 0.5038 | 0.3623 | -0.4116 | 1.0000 | 0.5335 |
| 0.85 | 0.5083 | -0.6155 | 1.0000 | 0.5728 | 0.2376 | -0.4923 | 1.0000 | 0.5106 | 0.1913 | -0.3712 | 1.0000 | 0.5428 |
| 0.9 | 0.2964 | -0.5761 | 1.0000 | 0.5760 | 0.0693 | -0.4630 | 1.0000 | 0.5215 | -0.1385 | -0.2932 | 1.0000 | 0.5598 |
| 0.95 | 0.0614 | -0.5335 | 1.0000 | 0.5803 | -0.0415 | -0.4494 | 1.0000 | 0.5296 | -0.3583 | -0.2461 | 1.0000 | 0.5739 |
| 1.0 | -0.1915 | -0.4913 | 1.0000 | 0.5854 | -0.0967 | -0.4555 | 1.0000 | 0.5354 | -0.4193 | -0.2456 | 1.0000 | 0.5852 |
| 1.1 | -0.4301 | -0.4563 | 1.0000 | 0.5904 | -0.1041 | -0.4806 | 1.0000 | 0.5401 | -0.3485 | -0.2856 | 1.0000 | 0.5936 |
| 1.2 | -0.6336 | -0.4304 | 1.0000 | 0.5941 | -0.0738 | -0.5215 | 1.0000 | 0.5450 | -0.2165 | -0.3463 | 1.0000 | 0.5996 |
| 1.3 | -0.8156 | -0.4103 | 1.0000 | 0.5953 | -0.0320 | -0.5691 | 1.0000 | 0.5511 | -0.0920 | -0.4091 | 1.0000 | 0.6035 |
| 1.4 | -1.0118 | -0.3912 | 1.0000 | 0.5931 | -0.0357 | -0.6071 | 1.0000 | 0.5593 | -0.0276 | -0.4612 | 1.0000 | 0.6063 |
| 1.5 | -1.2503 | -0.3703 | 1.0000 | 0.5874 | -0.1493 | -0.6191 | 1.0000 | 0.5697 | -0.0722 | -0.4911 | 1.0000 | 0.6087 |
| 1.7 | -1.5259 | -0.3501 | 1.0000 | 0.5785 | -0.3975 | -0.6017 | 1.0000 | 0.5819 | -0.2535 | -0.4925 | 1.0000 | 0.6117 |
| 2.0 | -1.7950 | -0.3397 | 1.0000 | 0.5674 | -0.7453 | -0.5663 | 1.0000 | 0.5950 | -0.5395 | -0.4756 | 1.0000 | 0.6160 |
| 2.2 | -1.9108 | -0.3426 | 1.0000 | 0.5611 | -0.9419 | -0.5467 | 1.0000 | 0.6018 | -0.7079 | -0.4662 | 1.0000 | 0.6187 |
| 2.6 | -2.0796 | -0.3504 | 1.0000 | 0.5508 | -1.2418 | -0.5188 | 1.0000 | 0.6119 | -0.9767 | -0.4513 | 1.0000 | 0.6233 |
| 3.0 | -2.1924 | -0.3596 | 1.0000 | 0.5428 | -1.4567 | -0.5011 | 1.0000 | 0.6189 | -1.1824 | -0.4400 | 1.0000 | 0.6268 |
| 3.4 | -2.3459 | -0.3686 | 1.0000 | 0.5302 | -1.7104 | -0.4873 | 1.0000 | 0.6263 | -1.5020 | -0.4122 | 1.0000 | 0.6310 |
| 4.0 | -2.4736 | -0.3683 | 1.0000 | 0.5170 | -1.8745 | -0.4834 | 1.0000 | 0.6284 | -1.7876 | -0.3769 | 1.0000 | 0.6319 |

Table 4. Standard deviations for the Northridge Earthquake compared with standard deviations from Somerville and Abrahamson (Somerville, personal comm.). Values of the standard deviation of the sample standard deviation are given in parenthesis.

| Period | This Study Site B | This Study Site C | This Study Site D | Somerville & Abrahamson: Rock | Somerville & Abrahamson: Soil |
|---|---|---|---|---|---|
| PGA | .32 (.07) | .47 (.04) | .36 (.03) | .53 | .48 |
| 0.3 | .40 (.08) | .54 (.05) | .41 (.04) | .60 | .51 |
| 1 | .45 (.11) | .60 (.05) | .36 (.03) | .62 | .48 |
| 2 | .48 (.12) | .57 (.05) | .41 (.04) | .57 | .60 |

Table 5. Subdivision of sites classified according to the presented classification system by means of the 1997 UBC shear wave velocity-based classification system.

**Northridge**

| Site Classification (from this work) | $\overline{V}_s$ based Classification | Number of sites |
|---|---|---|
| B | UBC B | 11 |
| | UBC C | 0 |
| C | UBC B | 9 |
| | UBC C | 41 |
| | UBC D | 20 |
| D | UBC C | 5 |
| | UBC D | 54 |

**Loma Prieta**

| Site Classification (from this work) | $\overline{V}_s$ based Classification | Number of sites |
|---|---|---|
| B | UBC B | 13 |
| | UBC C | 5 |
| C | UBC B | 1 |
| | UBC C | 21 |
| | UBC D | 4 |
| D | UBC C | 1 |
| | UBC D | 18 |

Table 6. Comparison of standard errors at selected periods for an analysis based on the classification system presented herein and an analysis based on the 1997 UBC average shear wave velocity-based classification system. Values in parenthesis are standard deviations of the estimate of the standard error.

| | **Northridge** | | | | **Loma Prieta** | | | |
|---|---|---|---|---|---|---|---|---|
| | **T = 0.3 s** | | **T = 1.0 s** | | **T = 0.3 s** | | **T = 1.0 s** | |
| Site | This Study | UBC | This Study | UBC | This Study | UBC | This Study | UBC |
| B | .40(.08) | .46(.07) | .45(.11) | .52(.09) | .51(.10) | .52(.10) | .58(.11) | .61(.11) |
| C | .54(.05) | .54(.06) | .60(.05) | .54(.06) | .38(.05) | .36(.05) | .53(.08) | .52(.07) |
| D | .41(.04) | .42(.03) | .36(.03) | .41(.03) | .39(.07) | .39(.06) | .59(.11) | .64(.10) |

Table 7a. Spectral acceleration amplification factors with respect to Site B and standard deviations for corresponding soil type. Geometric mean of the Loma Prieta and Northridge earthquakes.

| | Site C | | | | | Site D | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **T** | **PGA = 0.1 g** | **PGA = 0.2 g** | **PGA = 0.3 g** | **PGA = 0.4 g** | σ | **PGA = 0.1 g** | **PGA = 0.2 g** | **PGA = 0.3 g** | **PGA = 0.4 g** | σ |
| PGA | 1.43 | 1.35 | 1.31 | 1.28 | 0.39 | 1.75 | 1.58 | 1.49 | 1.43 | 0.37 |
| 0.055 | 1.30 | 1.20 | 1.14 | 1.11 | 0.42 | 1.57 | 1.37 | 1.27 | 1.20 | 0.39 |
| 0.06 | 1.30 | 1.20 | 1.14 | 1.11 | 0.42 | 1.57 | 1.37 | 1.27 | 1.20 | 0.40 |
| 0.07 | 1.30 | 1.20 | 1.14 | 1.11 | 0.42 | 1.57 | 1.37 | 1.27 | 1.20 | 0.40 |
| 0.08 | 1.30 | 1.20 | 1.14 | 1.10 | 0.43 | 1.57 | 1.37 | 1.27 | 1.20 | 0.40 |
| 0.09 | 1.31 | 1.20 | 1.14 | 1.10 | 0.43 | 1.58 | 1.38 | 1.28 | 1.21 | 0.40 |
| 0.1 | 1.32 | 1.21 | 1.15 | 1.11 | 0.43 | 1.59 | 1.39 | 1.29 | 1.21 | 0.40 |
| 0.11 | 1.33 | 1.22 | 1.16 | 1.11 | 0.44 | 1.61 | 1.40 | 1.29 | 1.22 | 0.40 |
| 0.12 | 1.35 | 1.23 | 1.16 | 1.12 | 0.44 | 1.62 | 1.41 | 1.30 | 1.23 | 0.40 |
| 0.13 | 1.36 | 1.24 | 1.17 | 1.13 | 0.44 | 1.63 | 1.42 | 1.31 | 1.24 | 0.40 |
| 0.14 | 1.38 | 1.25 | 1.19 | 1.14 | 0.45 | 1.65 | 1.44 | 1.33 | 1.26 | 0.39 |
| 0.15 | 1.39 | 1.27 | 1.20 | 1.15 | 0.45 | 1.68 | 1.46 | 1.35 | 1.27 | 0.39 |
| 0.16 | 1.41 | 1.28 | 1.21 | 1.16 | 0.45 | 1.70 | 1.48 | 1.37 | 1.29 | 0.39 |
| 0.17 | 1.42 | 1.29 | 1.22 | 1.17 | 0.46 | 1.72 | 1.50 | 1.38 | 1.30 | 0.39 |
| 0.18 | 1.43 | 1.29 | 1.22 | 1.17 | 0.46 | 1.73 | 1.50 | 1.39 | 1.31 | 0.39 |
| 0.19 | 1.44 | 1.30 | 1.23 | 1.18 | 0.45 | 1.74 | 1.52 | 1.40 | 1.32 | 0.39 |
| 0.2 | 1.45 | 1.31 | 1.23 | 1.18 | 0.45 | 1.76 | 1.54 | 1.42 | 1.34 | 0.39 |
| 0.22 | 1.46 | 1.31 | 1.23 | 1.18 | 0.45 | 1.78 | 1.55 | 1.44 | 1.36 | 0.39 |
| 0.24 | 1.46 | 1.31 | 1.23 | 1.17 | 0.46 | 1.79 | 1.56 | 1.44 | 1.36 | 0.39 |
| 0.26 | 1.46 | 1.31 | 1.23 | 1.17 | 0.46 | 1.80 | 1.57 | 1.45 | 1.37 | 0.39 |
| 0.28 | 1.46 | 1.30 | 1.22 | 1.16 | 0.46 | 1.80 | 1.57 | 1.46 | 1.38 | 0.40 |
| 0.3 | 1.46 | 1.30 | 1.21 | 1.15 | 0.46 | 1.81 | 1.58 | 1.47 | 1.39 | 0.40 |
| 0.32 | 1.45 | 1.29 | 1.21 | 1.15 | 0.46 | 1.82 | 1.59 | 1.48 | 1.39 | 0.40 |
| 0.34 | 1.44 | 1.29 | 1.20 | 1.14 | 0.47 | 1.83 | 1.60 | 1.49 | 1.40 | 0.40 |
| 0.36 | 1.44 | 1.28 | 1.20 | 1.14 | 0.47 | 1.83 | 1.61 | 1.50 | 1.42 | 0.41 |
| 0.4 | 1.42 | 1.27 | 1.19 | 1.13 | 0.48 | 1.83 | 1.62 | 1.51 | 1.43 | 0.42 |
| 0.44 | 1.41 | 1.26 | 1.18 | 1.13 | 0.49 | 1.84 | 1.63 | 1.52 | 1.45 | 0.43 |
| 0.5 | 1.38 | 1.25 | 1.18 | 1.13 | 0.51 | 1.85 | 1.66 | 1.55 | 1.48 | 0.44 |
| 0.55 | 1.36 | 1.24 | 1.17 | 1.13 | 0.52 | 1.85 | 1.67 | 1.57 | 1.50 | 0.44 |
| 0.6 | 1.35 | 1.24 | 1.17 | 1.13 | 0.53 | 1.86 | 1.68 | 1.59 | 1.52 | 0.44 |
| 0.667 | 1.34 | 1.23 | 1.17 | 1.13 | 0.53 | 1.87 | 1.70 | 1.60 | 1.54 | 0.45 |
| 0.7 | 1.33 | 1.23 | 1.17 | 1.13 | 0.54 | 1.88 | 1.71 | 1.62 | 1.56 | 0.45 |
| 0.75 | 1.32 | 1.23 | 1.18 | 1.14 | 0.55 | 1.89 | 1.73 | 1.64 | 1.58 | 0.45 |
| 0.8 | 1.32 | 1.23 | 1.18 | 1.14 | 0.55 | 1.91 | 1.75 | 1.67 | 1.61 | 0.45 |
| 0.85 | 1.31 | 1.23 | 1.19 | 1.15 | 0.56 | 1.92 | 1.77 | 1.69 | 1.63 | 0.45 |
| 0.9 | 1.31 | 1.24 | 1.20 | 1.18 | 0.56 | 1.95 | 1.81 | 1.73 | 1.67 | 0.46 |
| 0.95 | 1.31 | 1.26 | 1.22 | 1.20 | 0.57 | 1.98 | 1.85 | 1.78 | 1.72 | 0.46 |
| 1.0 | 1.31 | 1.27 | 1.25 | 1.23 | 0.57 | 2.02 | 1.89 | 1.83 | 1.78 | 0.47 |
| 1.1 | 1.31 | 1.29 | 1.27 | 1.26 | 0.57 | 2.05 | 1.94 | 1.88 | 1.84 | 0.47 |
| 1.2 | 1.31 | 1.30 | 1.29 | 1.29 | 0.57 | 2.09 | 1.99 | 1.94 | 1.90 | 0.48 |
| 1.3 | 1.32 | 1.32 | 1.32 | 1.32 | 0.57 | 2.12 | 2.04 | 2.00 | 1.96 | 0.48 |
| 1.4 | 1.32 | 1.33 | 1.34 | 1.34 | 0.58 | 2.15 | 2.09 | 2.05 | 2.02 | 0.49 |
| 1.5 | 1.32 | 1.35 | 1.36 | 1.36 | 0.58 | 2.18 | 2.13 | 2.10 | 2.08 | 0.49 |
| 1.7 | 1.33 | 1.36 | 1.37 | 1.38 | 0.58 | 2.22 | 2.18 | 2.16 | 2.14 | 0.50 |
| 2.0 | 1.33 | 1.37 | 1.38 | 1.39 | 0.58 | 2.25 | 2.22 | 2.20 | 2.18 | 0.51 |
| 2.2 | 1.33 | 1.37 | 1.39 | 1.40 | 0.58 | 2.26 | 2.24 | 2.22 | 2.20 | 0.52 |
| 2.6 | 1.33 | 1.37 | 1.39 | 1.40 | 0.58 | 2.27 | 2.25 | 2.23 | 2.22 | 0.52 |
| 3.0 | 1.33 | 1.37 | 1.39 | 1.40 | 0.57 | 2.27 | 2.25 | 2.24 | 2.23 | 0.51 |

Table 7b. Spectral acceleration amplification factors with respect to Site B and standard deviations for corresponding soil type. Variance weighted geometric mean of the Loma Prieta and Northridge earthquakes.

| | Site C | | | | | Site D | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **T** | **PGA = 0.1 g** | **PGA = 0.2 g** | **PGA = 0.3 g** | **PGA = 0.4 g** | **σ** | **PGA = 0.1 g** | **PGA = 0.2 g** | **PGA = 0.3 g** | **PGA = 0.4 g** | **σ** |
| PGA | 1.45 | 1.37 | 1.33 | 1.30 | 0.37 | 1.74 | 1.60 | 1.53 | 1.48 | 0.36 |
| 0.055 | 1.29 | 1.19 | 1.13 | 1.09 | 0.42 | 1.56 | 1.38 | 1.28 | 1.22 | 0.37 |
| 0.06 | 1.29 | 1.19 | 1.13 | 1.09 | 0.42 | 1.56 | 1.38 | 1.28 | 1.22 | 0.38 |
| 0.07 | 1.29 | 1.19 | 1.13 | 1.10 | 0.43 | 1.56 | 1.38 | 1.28 | 1.22 | 0.38 |
| 0.08 | 1.30 | 1.19 | 1.14 | 1.10 | 0.43 | 1.57 | 1.38 | 1.29 | 1.23 | 0.38 |
| 0.09 | 1.31 | 1.20 | 1.15 | 1.11 | 0.44 | 1.57 | 1.39 | 1.30 | 1.24 | 0.39 |
| 0.1 | 1.33 | 1.22 | 1.17 | 1.13 | 0.44 | 1.58 | 1.41 | 1.32 | 1.26 | 0.39 |
| 0.11 | 1.35 | 1.24 | 1.18 | 1.14 | 0.44 | 1.59 | 1.42 | 1.34 | 1.28 | 0.38 |
| 0.12 | 1.36 | 1.25 | 1.19 | 1.16 | 0.45 | 1.60 | 1.44 | 1.35 | 1.29 | 0.38 |
| 0.13 | 1.38 | 1.27 | 1.21 | 1.17 | 0.45 | 1.61 | 1.45 | 1.36 | 1.31 | 0.38 |
| 0.14 | 1.40 | 1.28 | 1.22 | 1.18 | 0.45 | 1.63 | 1.47 | 1.38 | 1.32 | 0.38 |
| 0.15 | 1.41 | 1.30 | 1.23 | 1.19 | 0.46 | 1.66 | 1.49 | 1.40 | 1.34 | 0.38 |
| 0.16 | 1.43 | 1.31 | 1.24 | 1.20 | 0.46 | 1.68 | 1.50 | 1.41 | 1.35 | 0.38 |
| 0.17 | 1.44 | 1.31 | 1.25 | 1.20 | 0.46 | 1.70 | 1.52 | 1.42 | 1.36 | 0.39 |
| 0.18 | 1.45 | 1.32 | 1.25 | 1.20 | 0.46 | 1.72 | 1.53 | 1.43 | 1.36 | 0.39 |
| 0.19 | 1.45 | 1.32 | 1.25 | 1.21 | 0.46 | 1.73 | 1.54 | 1.44 | 1.37 | 0.39 |
| 0.2 | 1.46 | 1.33 | 1.25 | 1.21 | 0.45 | 1.75 | 1.56 | 1.45 | 1.39 | 0.39 |
| 0.22 | 1.47 | 1.33 | 1.25 | 1.20 | 0.45 | 1.77 | 1.57 | 1.47 | 1.40 | 0.39 |
| 0.24 | 1.47 | 1.32 | 1.24 | 1.19 | 0.45 | 1.79 | 1.58 | 1.47 | 1.40 | 0.40 |
| 0.26 | 1.47 | 1.32 | 1.24 | 1.18 | 0.45 | 1.79 | 1.59 | 1.48 | 1.41 | 0.40 |
| 0.28 | 1.47 | 1.32 | 1.23 | 1.18 | 0.45 | 1.80 | 1.60 | 1.49 | 1.41 | 0.40 |
| 0.3 | 1.46 | 1.31 | 1.23 | 1.17 | 0.45 | 1.81 | 1.61 | 1.50 | 1.42 | 0.41 |
| 0.32 | 1.46 | 1.30 | 1.22 | 1.16 | 0.45 | 1.82 | 1.62 | 1.51 | 1.43 | 0.41 |
| 0.34 | 1.45 | 1.30 | 1.21 | 1.16 | 0.46 | 1.83 | 1.63 | 1.52 | 1.44 | 0.41 |
| 0.36 | 1.44 | 1.29 | 1.21 | 1.15 | 0.46 | 1.84 | 1.64 | 1.53 | 1.45 | 0.41 |
| 0.4 | 1.43 | 1.28 | 1.20 | 1.15 | 0.48 | 1.84 | 1.65 | 1.55 | 1.48 | 0.42 |
| 0.44 | 1.42 | 1.28 | 1.20 | 1.15 | 0.49 | 1.85 | 1.67 | 1.57 | 1.50 | 0.42 |
| 0.5 | 1.39 | 1.26 | 1.20 | 1.15 | 0.51 | 1.86 | 1.70 | 1.61 | 1.55 | 0.42 |
| 0.55 | 1.38 | 1.26 | 1.20 | 1.15 | 0.53 | 1.87 | 1.72 | 1.63 | 1.57 | 0.41 |
| 0.6 | 1.36 | 1.25 | 1.19 | 1.15 | 0.53 | 1.87 | 1.73 | 1.65 | 1.60 | 0.41 |
| 0.667 | 1.35 | 1.25 | 1.19 | 1.15 | 0.54 | 1.88 | 1.75 | 1.68 | 1.63 | 0.40 |
| 0.7 | 1.34 | 1.25 | 1.19 | 1.15 | 0.55 | 1.89 | 1.77 | 1.70 | 1.65 | 0.40 |
| 0.75 | 1.33 | 1.24 | 1.19 | 1.16 | 0.56 | 1.91 | 1.79 | 1.72 | 1.68 | 0.39 |
| 0.8 | 1.33 | 1.24 | 1.20 | 1.16 | 0.56 | 1.92 | 1.81 | 1.75 | 1.70 | 0.38 |
| 0.85 | 1.32 | 1.24 | 1.20 | 1.17 | 0.57 | 1.94 | 1.83 | 1.77 | 1.72 | 0.38 |
| 0.9 | 1.32 | 1.25 | 1.22 | 1.19 | 0.57 | 1.97 | 1.86 | 1.80 | 1.76 | 0.37 |
| 0.95 | 1.32 | 1.26 | 1.23 | 1.21 | 0.58 | 2.00 | 1.90 | 1.84 | 1.80 | 0.37 |
| 1.0 | 1.32 | 1.28 | 1.25 | 1.24 | 0.58 | 2.04 | 1.94 | 1.89 | 1.85 | 0.37 |
| 1.1 | 1.32 | 1.29 | 1.28 | 1.26 | 0.58 | 2.08 | 1.99 | 1.94 | 1.90 | 0.37 |
| 1.2 | 1.32 | 1.31 | 1.30 | 1.29 | 0.58 | 2.12 | 2.03 | 1.99 | 1.95 | 0.37 |
| 1.3 | 1.33 | 1.32 | 1.32 | 1.32 | 0.58 | 2.15 | 2.08 | 2.04 | 2.01 | 0.37 |
| 1.4 | 1.33 | 1.34 | 1.34 | 1.34 | 0.58 | 2.19 | 2.13 | 2.09 | 2.06 | 0.38 |
| 1.5 | 1.33 | 1.35 | 1.36 | 1.36 | 0.58 | 2.23 | 2.17 | 2.14 | 2.11 | 0.38 |
| 1.7 | 1.34 | 1.36 | 1.37 | 1.38 | 0.58 | 2.28 | 2.23 | 2.19 | 2.17 | 0.39 |
| 2.0 | 1.35 | 1.37 | 1.38 | 1.39 | 0.58 | 2.31 | 2.27 | 2.24 | 2.21 | 0.43 |
| 2.2 | 1.35 | 1.37 | 1.39 | 1.39 | 0.57 | 2.32 | 2.28 | 2.25 | 2.23 | 0.44 |
| 2.6 | 1.35 | 1.37 | 1.39 | 1.40 | 0.56 | 2.33 | 2.29 | 2.26 | 2.24 | 0.43 |
| 3.0 | 1.34 | 1.37 | 1.39 | 1.41 | 0.54 | 2.32 | 2.29 | 2.27 | 2.25 | 0.41 |

Table 8a. Spectral acceleration amplification factors with respect to Site C and standard deviations for corresponding soil type. Geometric mean of the Loma Prieta and Northridge earthquakes.

| | Site B | | | | | Site D | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **T** | **PGA = 0.1 g** | **PGA = 0.2 g** | **PGA = 0.3 g** | **PGA = 0.4 g** | **σ** | **PGA = 0.1 g** | **PGA = 0.2 g** | **PGA = 0.3 g** | **PGA = 0.4 g** | **σ** |
| PGA | 0.68 | 0.72 | 0.74 | 0.76 | 0.40 | 1.24 | 1.18 | 1.15 | 1.12 | 0.37 |
| 0.055 | 0.74 | 0.81 | 0.85 | 0.88 | 0.45 | 1.23 | 1.16 | 1.13 | 1.10 | 0.39 |
| 0.06 | 0.74 | 0.81 | 0.85 | 0.88 | 0.45 | 1.23 | 1.16 | 1.13 | 1.10 | 0.40 |
| 0.07 | 0.74 | 0.81 | 0.85 | 0.88 | 0.44 | 1.23 | 1.16 | 1.13 | 1.10 | 0.40 |
| 0.08 | 0.74 | 0.81 | 0.85 | 0.88 | 0.44 | 1.23 | 1.16 | 1.13 | 1.10 | 0.40 |
| 0.09 | 0.73 | 0.80 | 0.85 | 0.88 | 0.42 | 1.23 | 1.17 | 1.13 | 1.11 | 0.40 |
| 0.1 | 0.72 | 0.80 | 0.84 | 0.88 | 0.41 | 1.22 | 1.17 | 1.13 | 1.11 | 0.40 |
| 0.11 | 0.72 | 0.79 | 0.84 | 0.87 | 0.40 | 1.22 | 1.17 | 1.13 | 1.11 | 0.40 |
| 0.12 | 0.71 | 0.78 | 0.83 | 0.86 | 0.39 | 1.22 | 1.17 | 1.13 | 1.11 | 0.40 |
| 0.13 | 0.70 | 0.78 | 0.82 | 0.86 | 0.38 | 1.22 | 1.17 | 1.13 | 1.11 | 0.40 |
| 0.14 | 0.69 | 0.77 | 0.81 | 0.85 | 0.38 | 1.22 | 1.17 | 1.13 | 1.11 | 0.39 |
| 0.15 | 0.68 | 0.76 | 0.80 | 0.84 | 0.38 | 1.22 | 1.17 | 1.14 | 1.11 | 0.39 |
| 0.16 | 0.68 | 0.75 | 0.80 | 0.83 | 0.38 | 1.22 | 1.17 | 1.14 | 1.12 | 0.39 |
| 0.17 | 0.67 | 0.74 | 0.79 | 0.82 | 0.39 | 1.22 | 1.17 | 1.14 | 1.12 | 0.39 |
| 0.18 | 0.66 | 0.74 | 0.79 | 0.82 | 0.39 | 1.22 | 1.18 | 1.15 | 1.13 | 0.39 |
| 0.19 | 0.66 | 0.74 | 0.78 | 0.82 | 0.40 | 1.23 | 1.18 | 1.15 | 1.13 | 0.39 |
| 0.2 | 0.65 | 0.73 | 0.78 | 0.81 | 0.41 | 1.23 | 1.18 | 1.16 | 1.14 | 0.39 |
| 0.22 | 0.65 | 0.73 | 0.78 | 0.81 | 0.42 | 1.23 | 1.19 | 1.17 | 1.16 | 0.39 |
| 0.24 | 0.65 | 0.73 | 0.78 | 0.82 | 0.43 | 1.24 | 1.20 | 1.18 | 1.17 | 0.39 |
| 0.26 | 0.65 | 0.73 | 0.78 | 0.82 | 0.43 | 1.24 | 1.21 | 1.19 | 1.17 | 0.39 |
| 0.28 | 0.65 | 0.73 | 0.78 | 0.82 | 0.44 | 1.24 | 1.21 | 1.20 | 1.19 | 0.40 |
| 0.3 | 0.65 | 0.73 | 0.78 | 0.83 | 0.46 | 1.25 | 1.22 | 1.21 | 1.20 | 0.40 |
| 0.32 | 0.65 | 0.73 | 0.79 | 0.83 | 0.47 | 1.26 | 1.24 | 1.22 | 1.21 | 0.40 |
| 0.34 | 0.65 | 0.74 | 0.79 | 0.83 | 0.47 | 1.27 | 1.25 | 1.24 | 1.23 | 0.40 |
| 0.36 | 0.66 | 0.74 | 0.80 | 0.84 | 0.48 | 1.28 | 1.26 | 1.25 | 1.24 | 0.41 |
| 0.4 | 0.67 | 0.75 | 0.80 | 0.84 | 0.49 | 1.29 | 1.28 | 1.27 | 1.26 | 0.42 |
| 0.44 | 0.67 | 0.75 | 0.81 | 0.84 | 0.49 | 1.31 | 1.29 | 1.28 | 1.28 | 0.43 |
| 0.5 | 0.69 | 0.77 | 0.81 | 0.85 | 0.49 | 1.34 | 1.33 | 1.32 | 1.31 | 0.44 |
| 0.55 | 0.70 | 0.77 | 0.82 | 0.85 | 0.49 | 1.36 | 1.34 | 1.33 | 1.33 | 0.44 |
| 0.6 | 0.71 | 0.78 | 0.82 | 0.85 | 0.49 | 1.38 | 1.36 | 1.35 | 1.34 | 0.44 |
| 0.667 | 0.71 | 0.78 | 0.82 | 0.85 | 0.49 | 1.39 | 1.37 | 1.36 | 1.36 | 0.45 |
| 0.7 | 0.72 | 0.78 | 0.82 | 0.85 | 0.49 | 1.41 | 1.39 | 1.38 | 1.37 | 0.45 |
| 0.75 | 0.73 | 0.79 | 0.82 | 0.85 | 0.49 | 1.43 | 1.41 | 1.39 | 1.39 | 0.45 |
| 0.8 | 0.73 | 0.79 | 0.82 | 0.85 | 0.49 | 1.45 | 1.42 | 1.41 | 1.40 | 0.45 |
| 0.85 | 0.74 | 0.79 | 0.82 | 0.84 | 0.50 | 1.47 | 1.44 | 1.42 | 1.41 | 0.45 |
| 0.9 | 0.74 | 0.78 | 0.81 | 0.83 | 0.50 | 1.50 | 1.46 | 1.44 | 1.42 | 0.46 |
| 0.95 | 0.75 | 0.78 | 0.80 | 0.81 | 0.51 | 1.53 | 1.48 | 1.45 | 1.43 | 0.46 |
| 1.0 | 0.75 | 0.77 | 0.79 | 0.80 | 0.52 | 1.55 | 1.50 | 1.47 | 1.45 | 0.47 |
| 1.1 | 0.75 | 0.77 | 0.77 | 0.78 | 0.53 | 1.58 | 1.52 | 1.49 | 1.46 | 0.47 |
| 1.2 | 0.75 | 0.76 | 0.76 | 0.76 | 0.53 | 1.61 | 1.54 | 1.51 | 1.48 | 0.48 |
| 1.3 | 0.76 | 0.75 | 0.75 | 0.75 | 0.54 | 1.63 | 1.56 | 1.52 | 1.50 | 0.48 |
| 1.4 | 0.76 | 0.75 | 0.74 | 0.74 | 0.54 | 1.65 | 1.58 | 1.54 | 1.52 | 0.49 |
| 1.5 | 0.76 | 0.74 | 0.73 | 0.73 | 0.53 | 1.67 | 1.60 | 1.56 | 1.53 | 0.49 |
| 1.7 | 0.75 | 0.73 | 0.72 | 0.72 | 0.53 | 1.70 | 1.63 | 1.59 | 1.56 | 0.50 |
| 2.0 | 0.75 | 0.73 | 0.72 | 0.71 | 0.52 | 1.72 | 1.65 | 1.61 | 1.58 | 0.51 |
| 2.2 | 0.75 | 0.73 | 0.72 | 0.71 | 0.52 | 1.72 | 1.65 | 1.61 | 1.59 | 0.52 |
| 2.6 | 0.75 | 0.73 | 0.72 | 0.71 | 0.52 | 1.73 | 1.66 | 1.62 | 1.59 | 0.52 |
| 3.0 | 0.76 | 0.73 | 0.72 | 0.71 | 0.51 | 1.73 | 1.66 | 1.63 | 1.60 | 0.51 |

Table 8b. Spectral acceleration amplification factors with respect to Site C and standard deviations for corresponding soil type. Variance weighted geometric mean of the Loma Prieta and Northridge earthquakes.

| | **Site B** | | | | | **Site D** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **T** | **PGA = 0.1 g** | **PGA = 0.2 g** | **PGA = 0.3 g** | **PGA = 0.4 g** | **σ** | **PGA = 0.1 g** | **PGA = 0.2 g** | **PGA = 0.3 g** | **PGA = 0.4 g** | **σ** |
| PGA | 0.67 | 0.71 | 0.73 | 0.75 | 0.36 | 1.17 | 1.15 | 1.14 | 1.14 | 0.36 |
| 0.055 | 0.74 | 0.81 | 0.86 | 0.89 | 0.45 | 1.14 | 1.12 | 1.10 | 1.09 | 0.37 |
| 0.06 | 0.74 | 0.81 | 0.86 | 0.89 | 0.45 | 1.14 | 1.12 | 1.10 | 1.09 | 0.38 |
| 0.07 | 0.74 | 0.81 | 0.86 | 0.89 | 0.44 | 1.14 | 1.12 | 1.10 | 1.09 | 0.38 |
| 0.08 | 0.74 | 0.81 | 0.85 | 0.89 | 0.44 | 1.14 | 1.12 | 1.11 | 1.10 | 0.38 |
| 0.09 | 0.73 | 0.80 | 0.85 | 0.88 | 0.42 | 1.14 | 1.12 | 1.11 | 1.10 | 0.39 |
| 0.1 | 0.72 | 0.79 | 0.83 | 0.86 | 0.40 | 1.14 | 1.12 | 1.11 | 1.10 | 0.39 |
| 0.11 | 0.71 | 0.78 | 0.82 | 0.85 | 0.39 | 1.13 | 1.12 | 1.11 | 1.10 | 0.38 |
| 0.12 | 0.70 | 0.77 | 0.81 | 0.84 | 0.37 | 1.13 | 1.12 | 1.11 | 1.10 | 0.38 |
| 0.13 | 0.70 | 0.76 | 0.80 | 0.83 | 0.36 | 1.13 | 1.12 | 1.11 | 1.10 | 0.38 |
| 0.14 | 0.69 | 0.75 | 0.79 | 0.82 | 0.36 | 1.13 | 1.12 | 1.11 | 1.10 | 0.38 |
| 0.15 | 0.68 | 0.74 | 0.79 | 0.81 | 0.36 | 1.13 | 1.12 | 1.11 | 1.10 | 0.38 |
| 0.16 | 0.67 | 0.74 | 0.78 | 0.81 | 0.36 | 1.14 | 1.12 | 1.11 | 1.10 | 0.38 |
| 0.17 | 0.66 | 0.73 | 0.77 | 0.81 | 0.37 | 1.14 | 1.13 | 1.12 | 1.11 | 0.39 |
| 0.18 | 0.66 | 0.73 | 0.77 | 0.81 | 0.38 | 1.15 | 1.13 | 1.12 | 1.11 | 0.39 |
| 0.19 | 0.66 | 0.73 | 0.77 | 0.80 | 0.38 | 1.15 | 1.14 | 1.13 | 1.12 | 0.39 |
| 0.2 | 0.65 | 0.72 | 0.77 | 0.80 | 0.39 | 1.16 | 1.15 | 1.14 | 1.13 | 0.39 |
| 0.22 | 0.65 | 0.72 | 0.77 | 0.80 | 0.41 | 1.17 | 1.16 | 1.15 | 1.14 | 0.39 |
| 0.24 | 0.65 | 0.72 | 0.77 | 0.81 | 0.42 | 1.18 | 1.17 | 1.16 | 1.16 | 0.40 |
| 0.26 | 0.65 | 0.72 | 0.77 | 0.81 | 0.42 | 1.19 | 1.18 | 1.17 | 1.16 | 0.40 |
| 0.28 | 0.65 | 0.72 | 0.78 | 0.81 | 0.43 | 1.19 | 1.18 | 1.18 | 1.18 | 0.40 |
| 0.3 | 0.65 | 0.73 | 0.78 | 0.82 | 0.44 | 1.20 | 1.20 | 1.19 | 1.19 | 0.41 |
| 0.32 | 0.65 | 0.73 | 0.78 | 0.82 | 0.45 | 1.21 | 1.21 | 1.21 | 1.21 | 0.41 |
| 0.34 | 0.65 | 0.73 | 0.79 | 0.83 | 0.46 | 1.23 | 1.22 | 1.22 | 1.22 | 0.41 |
| 0.36 | 0.66 | 0.74 | 0.79 | 0.83 | 0.47 | 1.24 | 1.24 | 1.24 | 1.24 | 0.41 |
| 0.4 | 0.66 | 0.74 | 0.79 | 0.83 | 0.48 | 1.25 | 1.26 | 1.26 | 1.26 | 0.42 |
| 0.44 | 0.67 | 0.75 | 0.80 | 0.84 | 0.48 | 1.27 | 1.28 | 1.28 | 1.28 | 0.42 |
| 0.5 | 0.69 | 0.76 | 0.80 | 0.84 | 0.47 | 1.30 | 1.31 | 1.32 | 1.33 | 0.42 |
| 0.55 | 0.69 | 0.76 | 0.81 | 0.84 | 0.47 | 1.32 | 1.34 | 1.34 | 1.35 | 0.41 |
| 0.6 | 0.70 | 0.77 | 0.81 | 0.84 | 0.46 | 1.34 | 1.36 | 1.37 | 1.38 | 0.41 |
| 0.667 | 0.71 | 0.77 | 0.81 | 0.84 | 0.46 | 1.36 | 1.38 | 1.39 | 1.40 | 0.40 |
| 0.7 | 0.72 | 0.78 | 0.81 | 0.84 | 0.46 | 1.37 | 1.40 | 1.41 | 1.42 | 0.40 |
| 0.75 | 0.72 | 0.78 | 0.81 | 0.84 | 0.46 | 1.39 | 1.42 | 1.43 | 1.45 | 0.39 |
| 0.8 | 0.73 | 0.78 | 0.81 | 0.84 | 0.47 | 1.41 | 1.44 | 1.45 | 1.47 | 0.38 |
| 0.85 | 0.73 | 0.78 | 0.81 | 0.83 | 0.48 | 1.43 | 1.45 | 1.47 | 1.48 | 0.38 |
| 0.9 | 0.74 | 0.78 | 0.80 | 0.82 | 0.49 | 1.45 | 1.48 | 1.49 | 1.50 | 0.37 |
| 0.95 | 0.74 | 0.77 | 0.79 | 0.81 | 0.50 | 1.48 | 1.50 | 1.51 | 1.52 | 0.37 |
| 1.0 | 0.74 | 0.77 | 0.78 | 0.80 | 0.51 | 1.50 | 1.52 | 1.53 | 1.54 | 0.37 |
| 1.1 | 0.75 | 0.76 | 0.77 | 0.78 | 0.51 | 1.53 | 1.54 | 1.55 | 1.56 | 0.37 |
| 1.2 | 0.75 | 0.76 | 0.76 | 0.77 | 0.52 | 1.55 | 1.56 | 1.57 | 1.58 | 0.37 |
| 1.3 | 0.75 | 0.75 | 0.75 | 0.75 | 0.53 | 1.58 | 1.59 | 1.59 | 1.60 | 0.37 |
| 1.4 | 0.75 | 0.74 | 0.74 | 0.74 | 0.53 | 1.60 | 1.61 | 1.61 | 1.62 | 0.38 |
| 1.5 | 0.75 | 0.74 | 0.73 | 0.73 | 0.53 | 1.63 | 1.63 | 1.63 | 1.64 | 0.38 |
| 1.7 | 0.74 | 0.73 | 0.72 | 0.72 | 0.52 | 1.67 | 1.66 | 1.66 | 1.67 | 0.39 |
| 2.0 | 0.74 | 0.73 | 0.72 | 0.72 | 0.52 | 1.70 | 1.69 | 1.69 | 1.69 | 0.43 |
| 2.2 | 0.74 | 0.73 | 0.72 | 0.71 | 0.52 | 1.71 | 1.70 | 1.70 | 1.70 | 0.44 |
| 2.6 | 0.74 | 0.73 | 0.72 | 0.71 | 0.51 | 1.71 | 1.71 | 1.71 | 1.71 | 0.43 |
| 3.0 | 0.75 | 0.73 | 0.72 | 0.71 | 0.51 | 1.72 | 1.71 | 1.70 | 1.70 | 0.41 |

Table 9a. Short-period ($F_a$) and mid-period ($F_v$) spectral amplification factors from the 1997 Uniform Building Code.

| $F_a$ | PGA =.08 g | PGA =.15 g | PGA = .2 g | PGA = .3 g | PGA = .4 g |
|---|---|---|---|---|---|
| B | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| C | 1.2 | 1.2 | 1.2 | 1.1 | 1.0 |
| D | 1.6 | 1.5 | 1.4 | 1.2 | 1.1 |

| $F_v$ | PGA =.08 g | PGA =.15 g | PGA = .2 g | PGA = .3 g | PGA = .4 g |
|---|---|---|---|---|---|
| B | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| C | 1.7 | 1.7 | 1.6 | 1.5 | 1.4 |
| D | 2.4 | 2.1 | 2.0 | 1.8 | 1.6 |

Table 9b. Average spectral amplification periods over the short-period range (0.1 s – 0.5 s) and the mid-period range (0.4 s – 2.0 s), denoted by $F_a$ and $F_v$, respectively.

| $F_a$ | PGA =.08 g | PGA =.15 g | PGA = .2 g | PGA = .3 g | PGA = .4 g |
|---|---|---|---|---|---|
| B | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| C | 1.5 | 1.3 | 1.3 | 1.2 | 1.2 |
| D | 1.8 | 1.6 | 1.6 | 1.5 | 1.4 |

| $F_v$ | PGA =.08 g | PGA =.15 g | PGA = .2 g | PGA = .3 g | PGA = .4 g |
|---|---|---|---|---|---|
| B | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| C | 1.4 | 1.3 | 1.3 | 1.3 | 1.2 |
| D | 2.1 | 2.0 | 1.9 | 1.8 | 1.8 |

# FIGURES

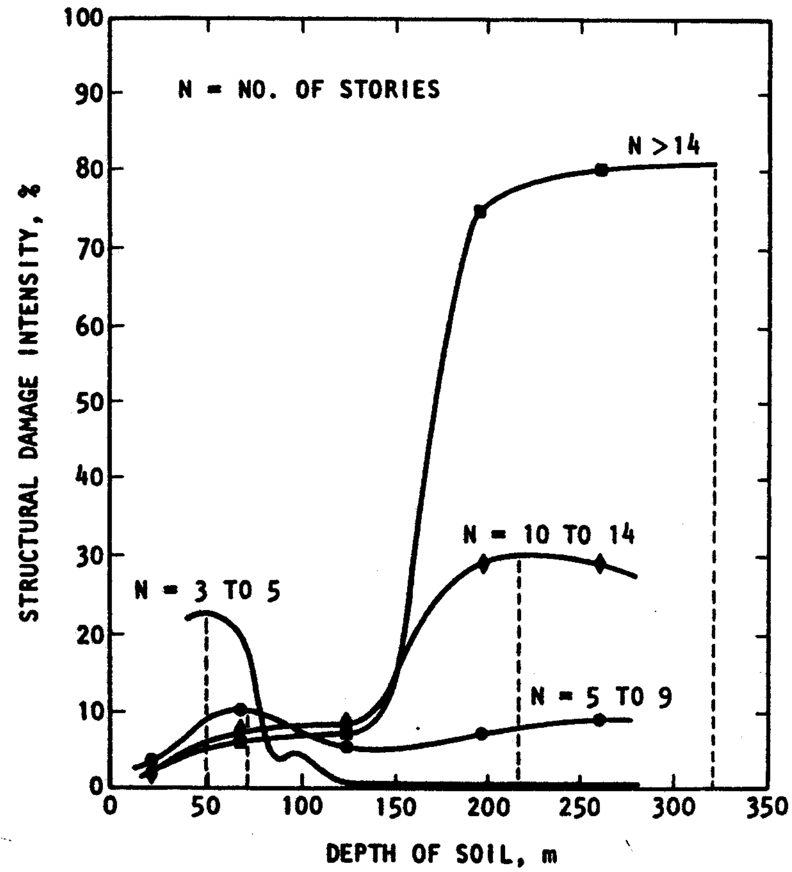



Figure 1. Relationship between structural damage intensity and soil depth in the Caracas earthquake of 1967 (From Seed and Alonso 1974)

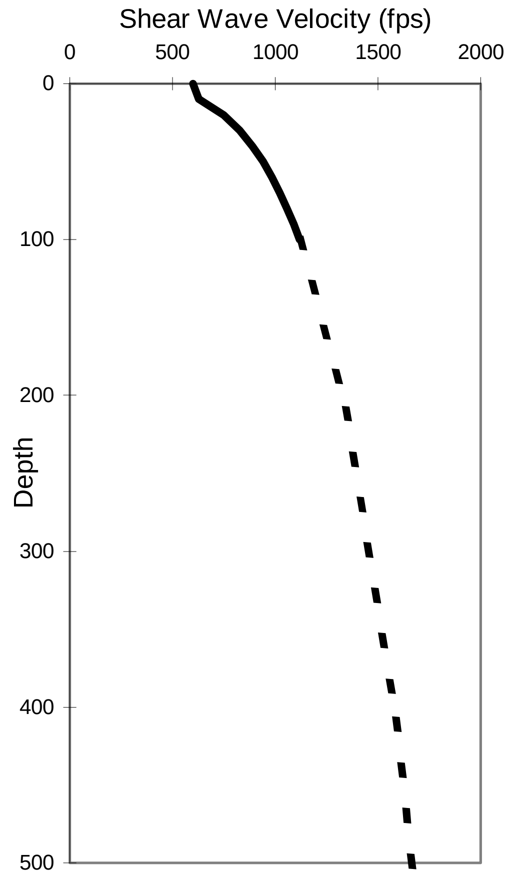



Figure 2a. Shear wave velocity versus depth for a generic stiff clay deposit. Shear wave velocity of underlying bedrock is 4000 fps.

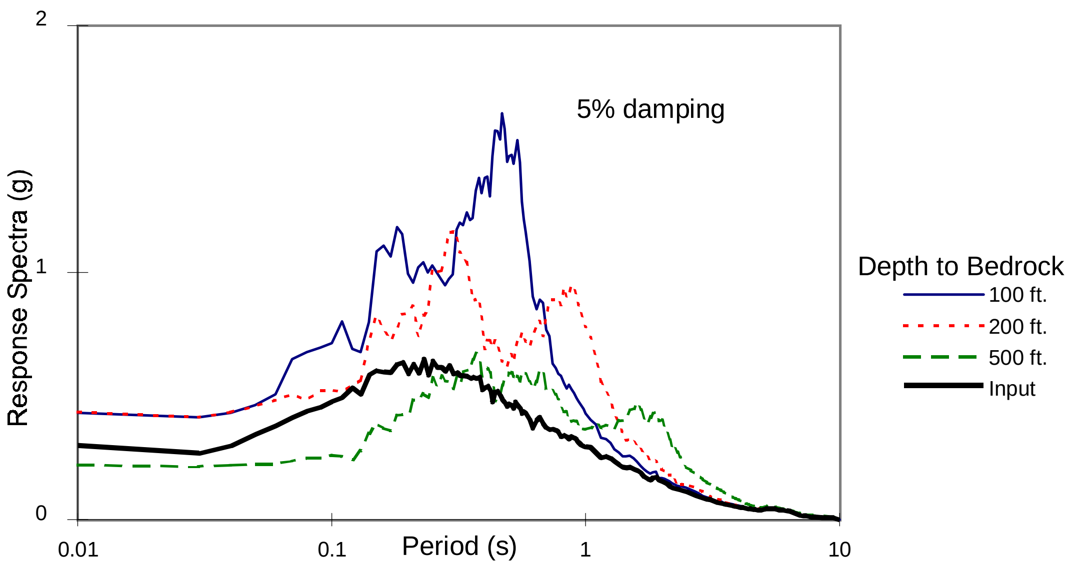



Figure 2b. Spectral accelerations for the stiff soil deposit shown in Figure 2a, with PGA = 0.3 g for a M = 8.0 earthquake.

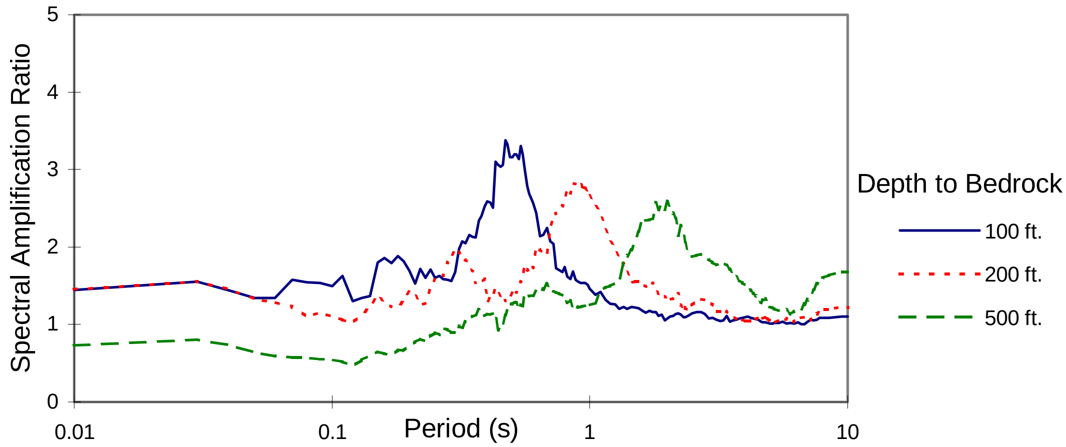



Figure 2c. Spectral acceleration amplification ratio for the stiff soil deposit shown in Figure 2a with PGA = 0.3 g for a M = 8.0 earthquake.

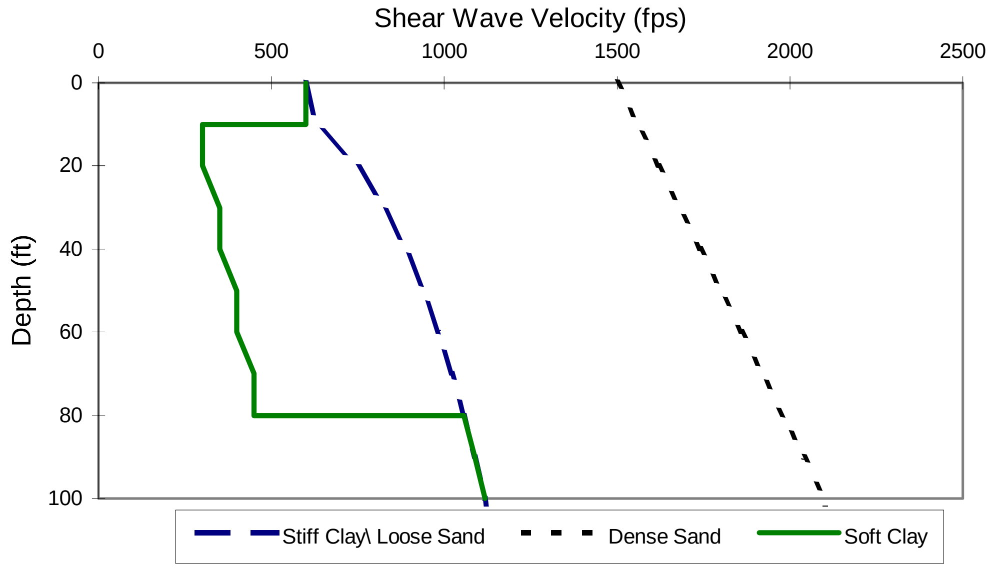



Figure 3a. Shear wave velocity profiles for generic sites. Shear wave velocity of underlying bedrock is 4000 fps.

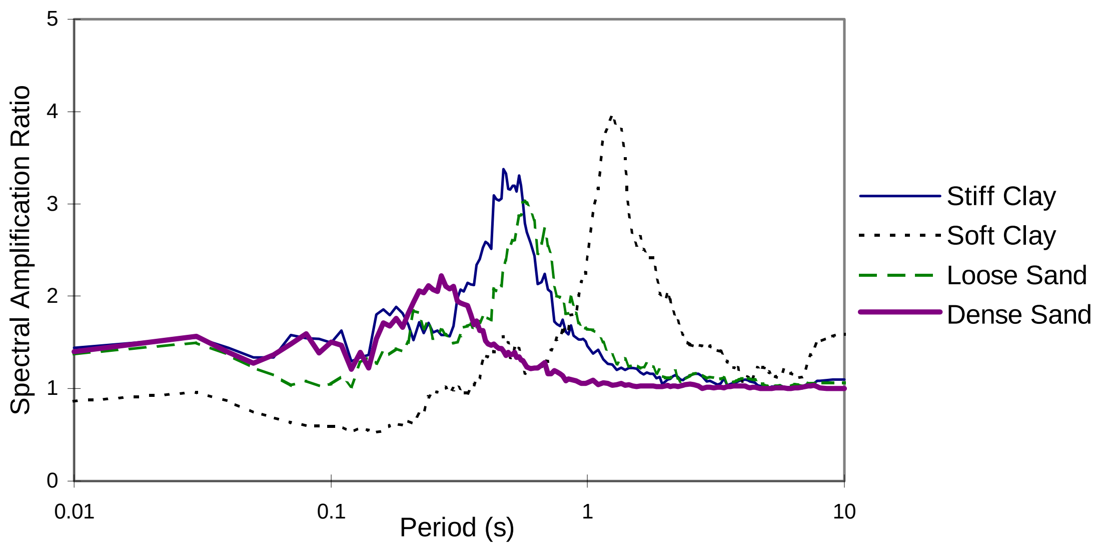



Figure 3b. Spectral acceleration amplification ratio for the soil profiles shown in Figure 3b, with PGA = 0.3 g for a M = 8.0 earthquake.

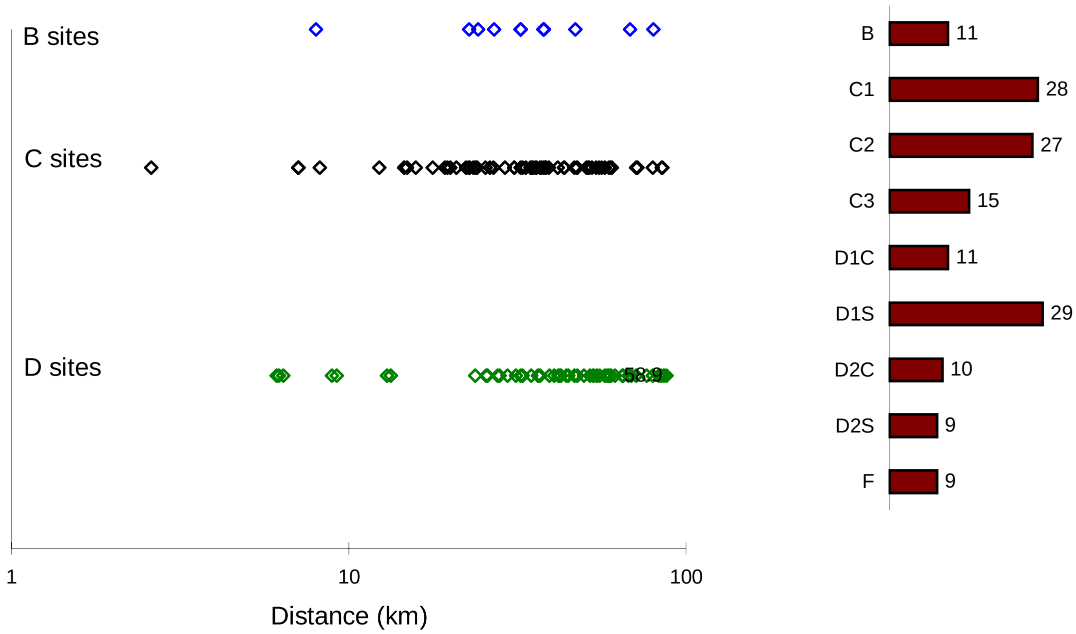



Figure 4a. Distribution of data by site type for the Northridge Earthquake.

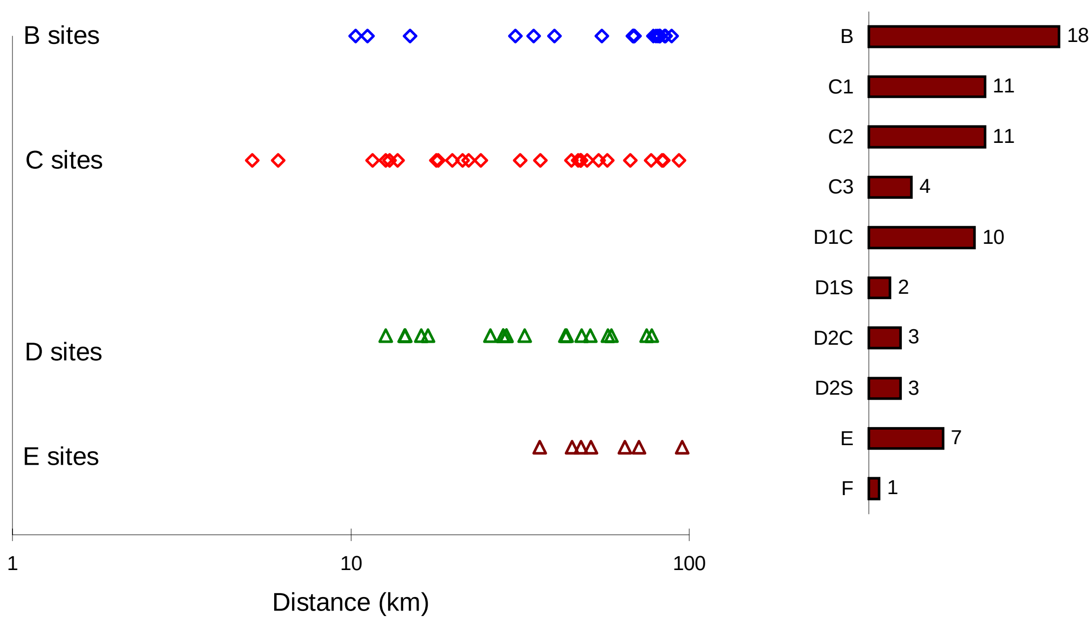



Figure 4b. Distribution of data by site type for the Loma Prieta Earthquake.

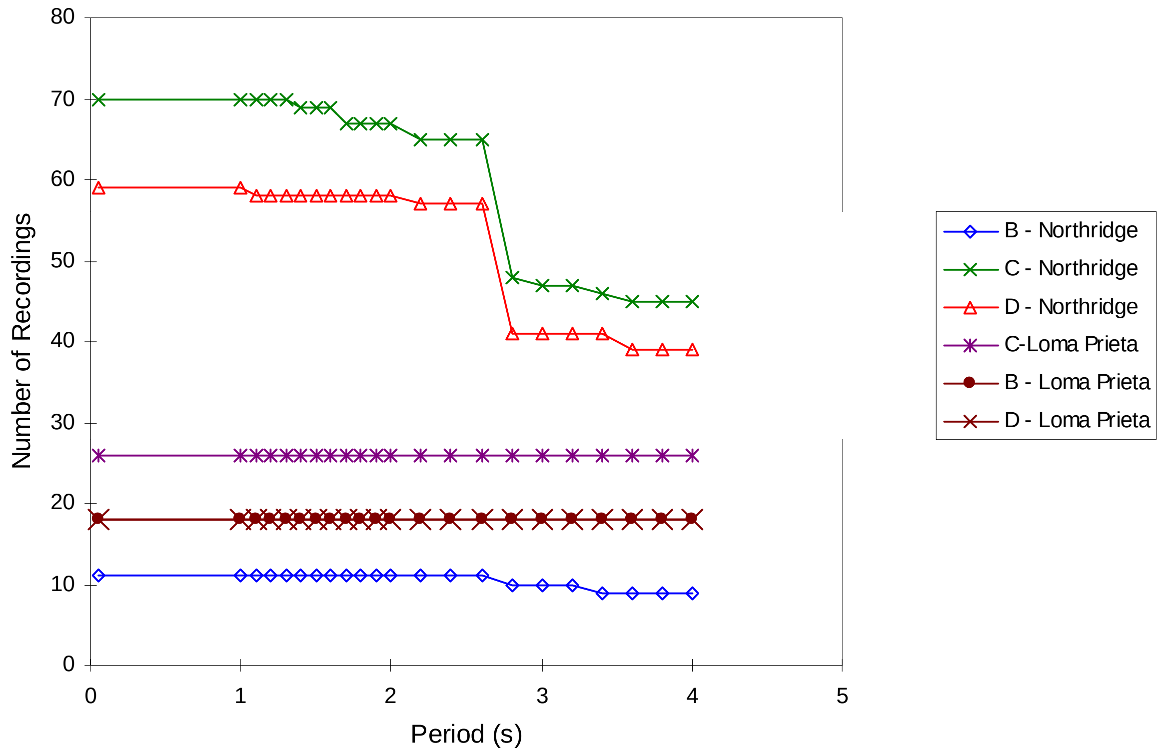



Figure 5. Number of recordings as a function of period.

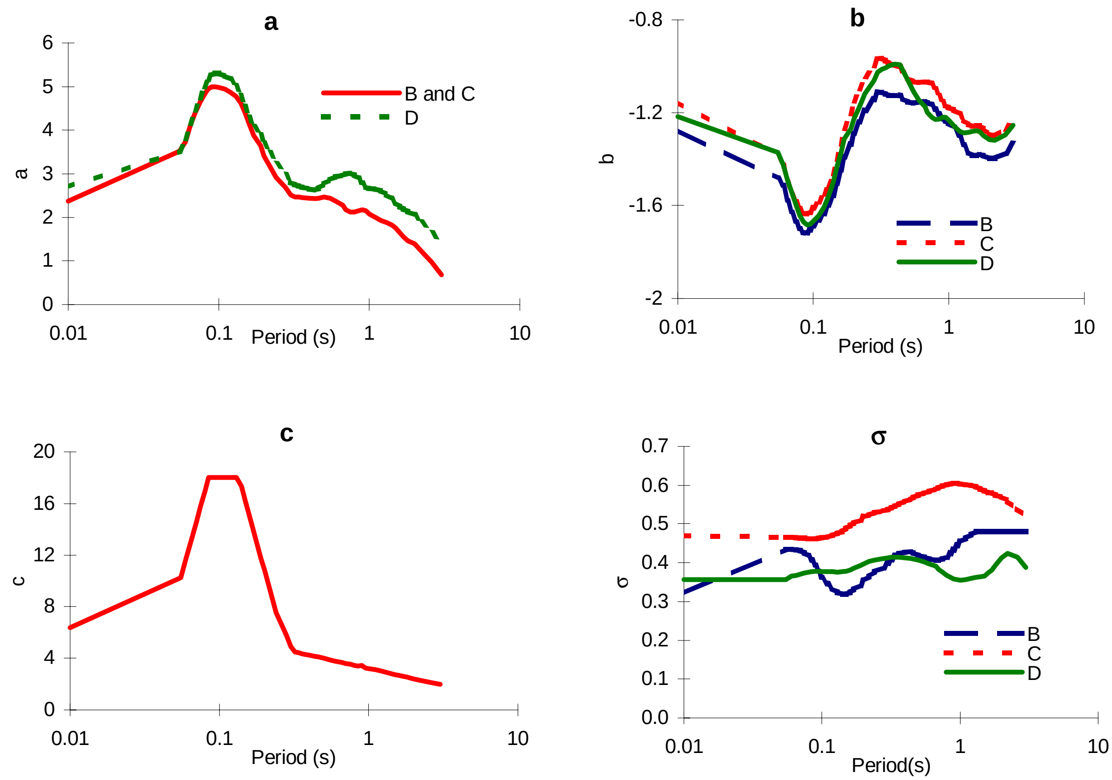



Figure 6. Regression coefficients for the Northridge Earthquake.

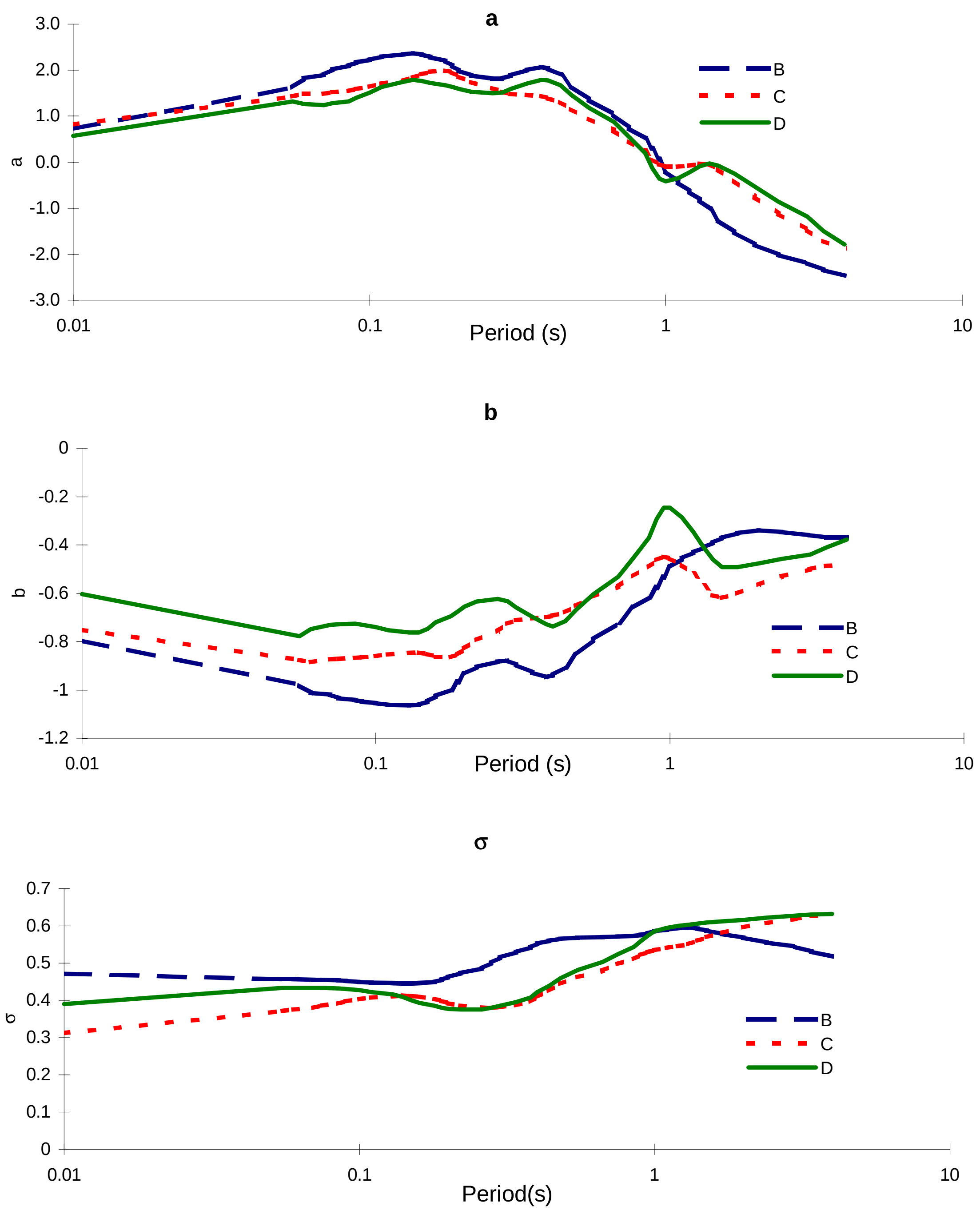



Figure 7. Regression coefficients for the Loma Prieta Earthquake. The coefficient "c" is equal to 1.0 for all periods.

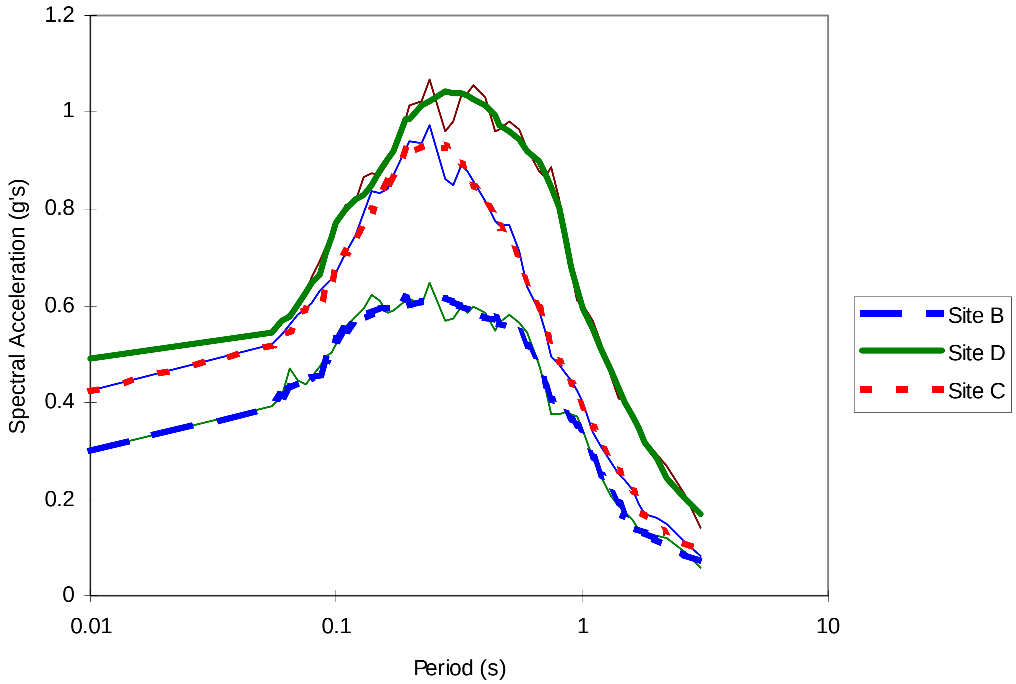



Figure 8. Comparison of response spectra before smoothing and after smoothing regression coefficients. Corresponds to the Northridge Earthquake at R = 10 km.

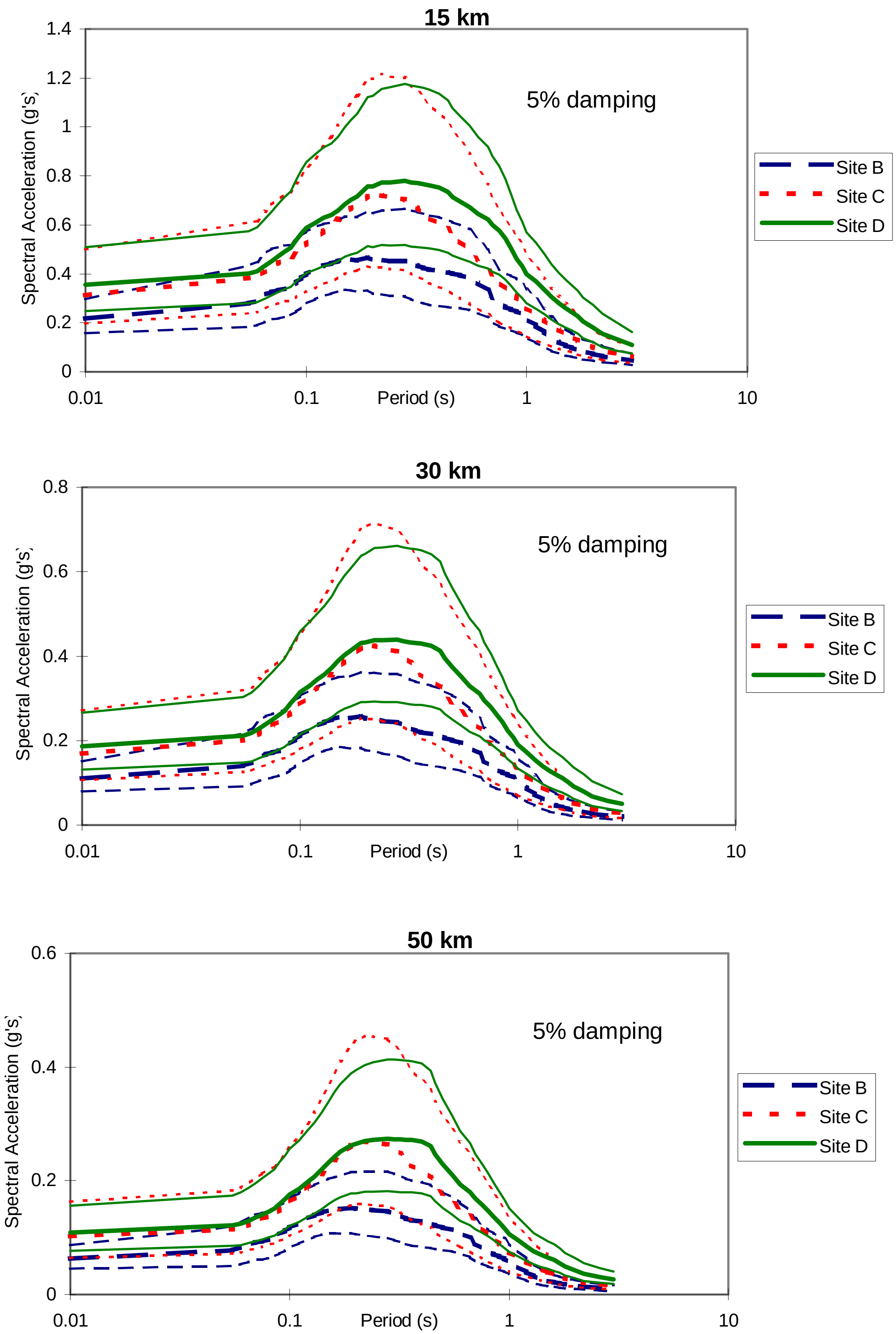



Figure 9. Response spectra for the Northridge Earthquake. Thick lines represent median values, thin lines represent ± one standard deviation.

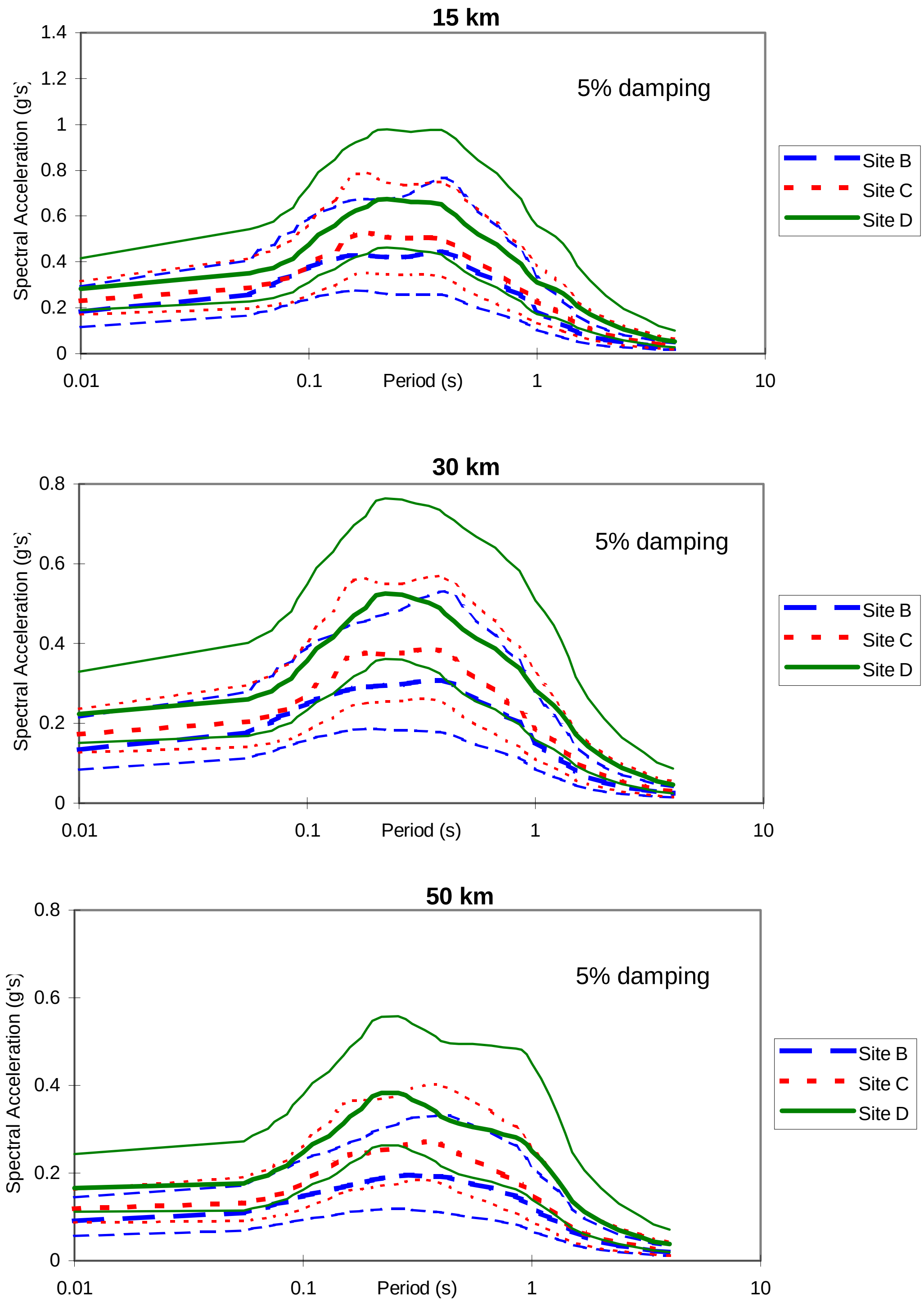



Figure 10. Response spectra for the Loma Prieta Earthquake. Thick lines represent median values, thin lines represent ± one standard deviation.

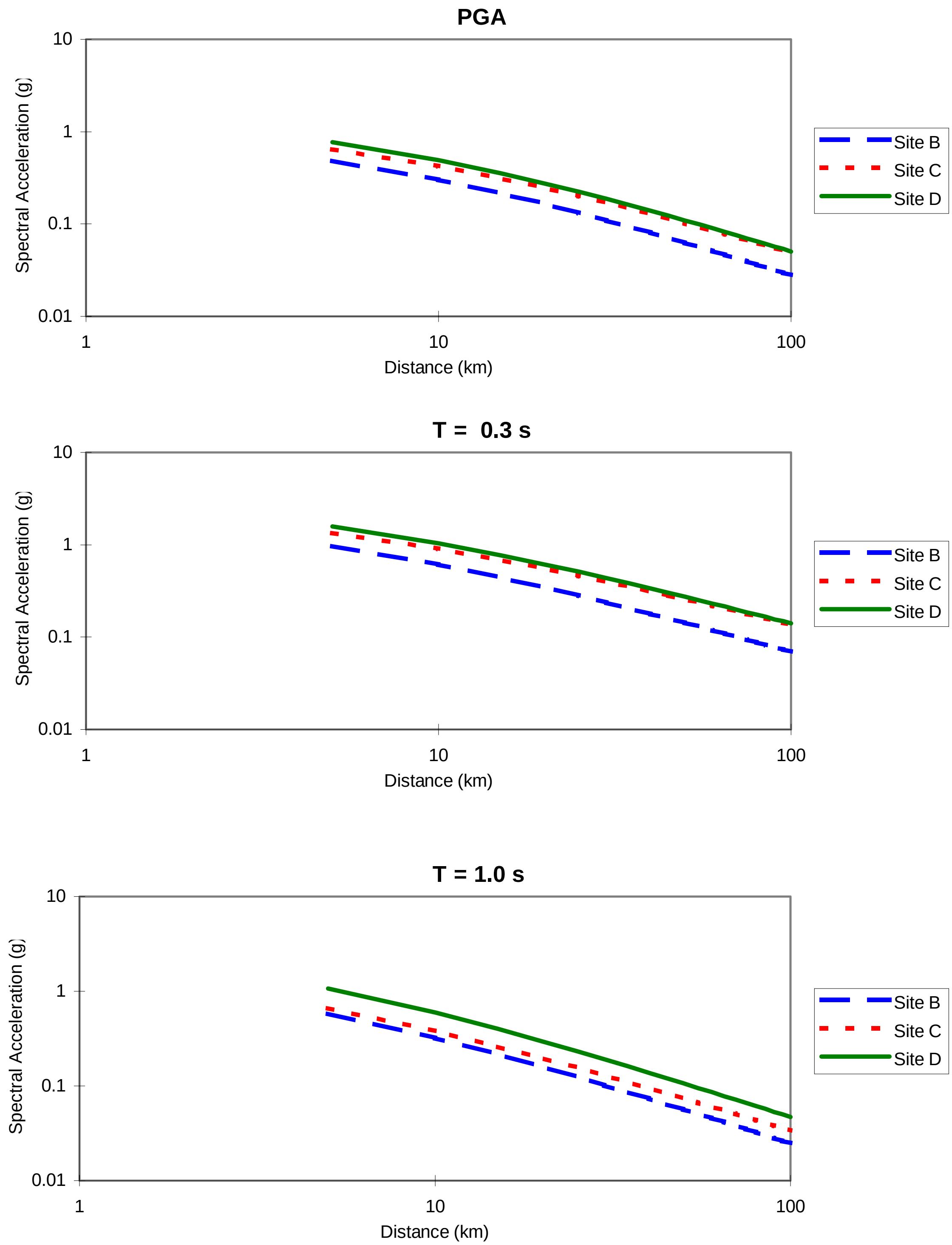



Figure 11. Median spectral values vs. distance for the Northridge Earthquake.

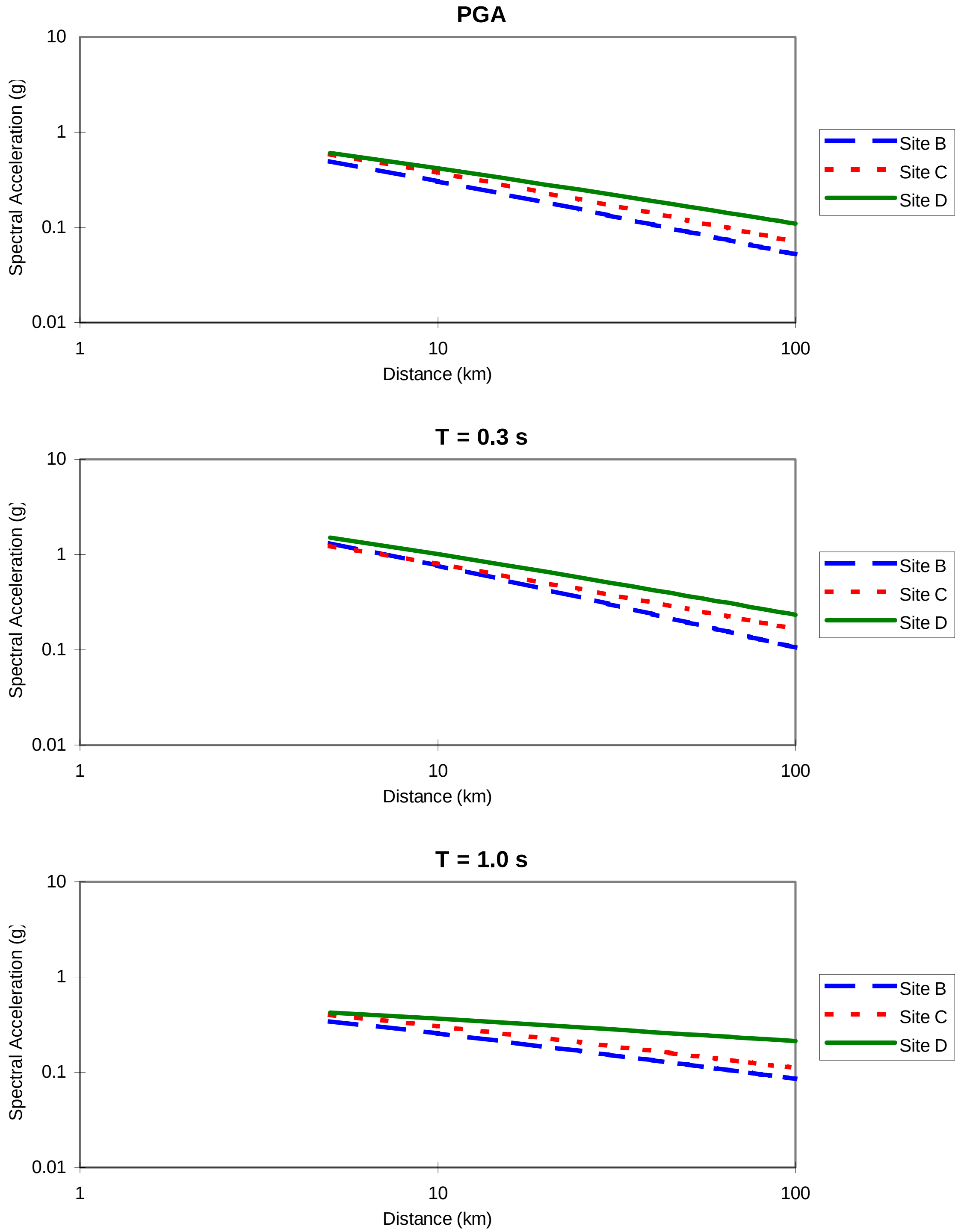



Figure 12.  Median spectral values vs. distance for the Loma Prieta Earthquake.

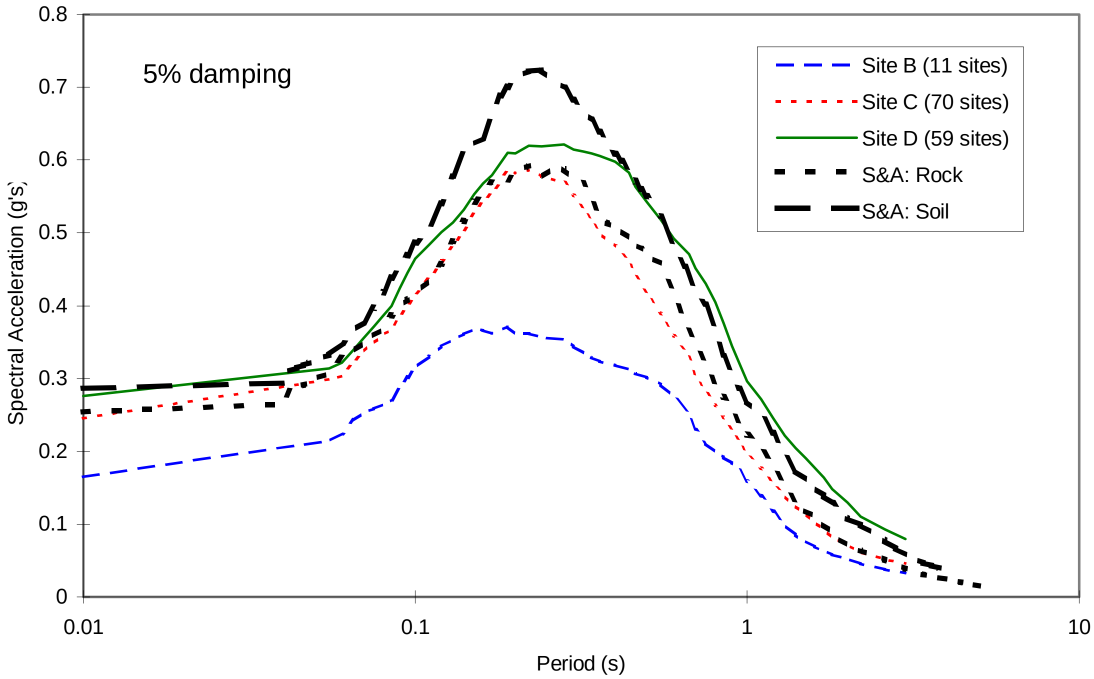
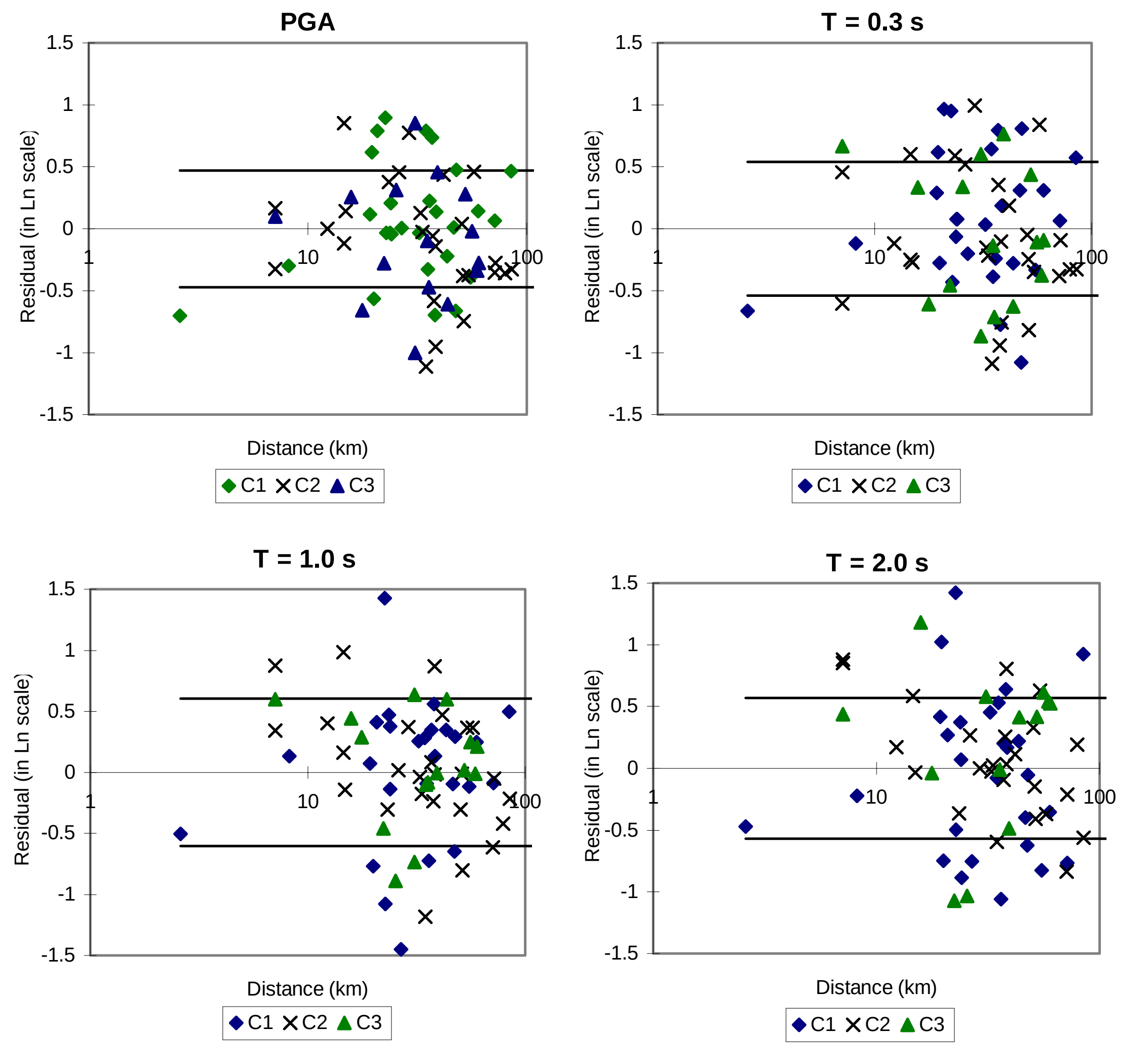
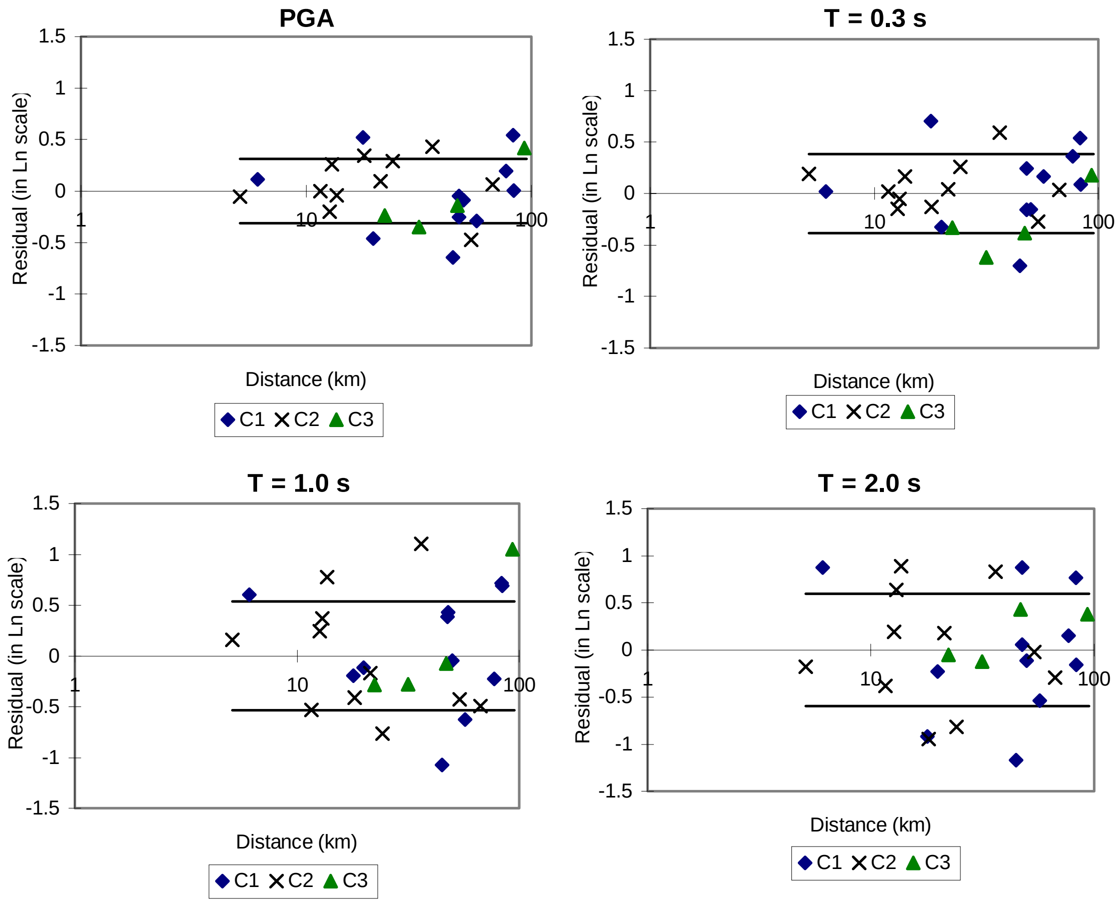



Figure 13. Comparison of results with an earthquake specific attenuation relationship by Somerville and Abrahamson (1998). Response spectra at 5% damping for the Northridge Earthquake at R = 20 km.



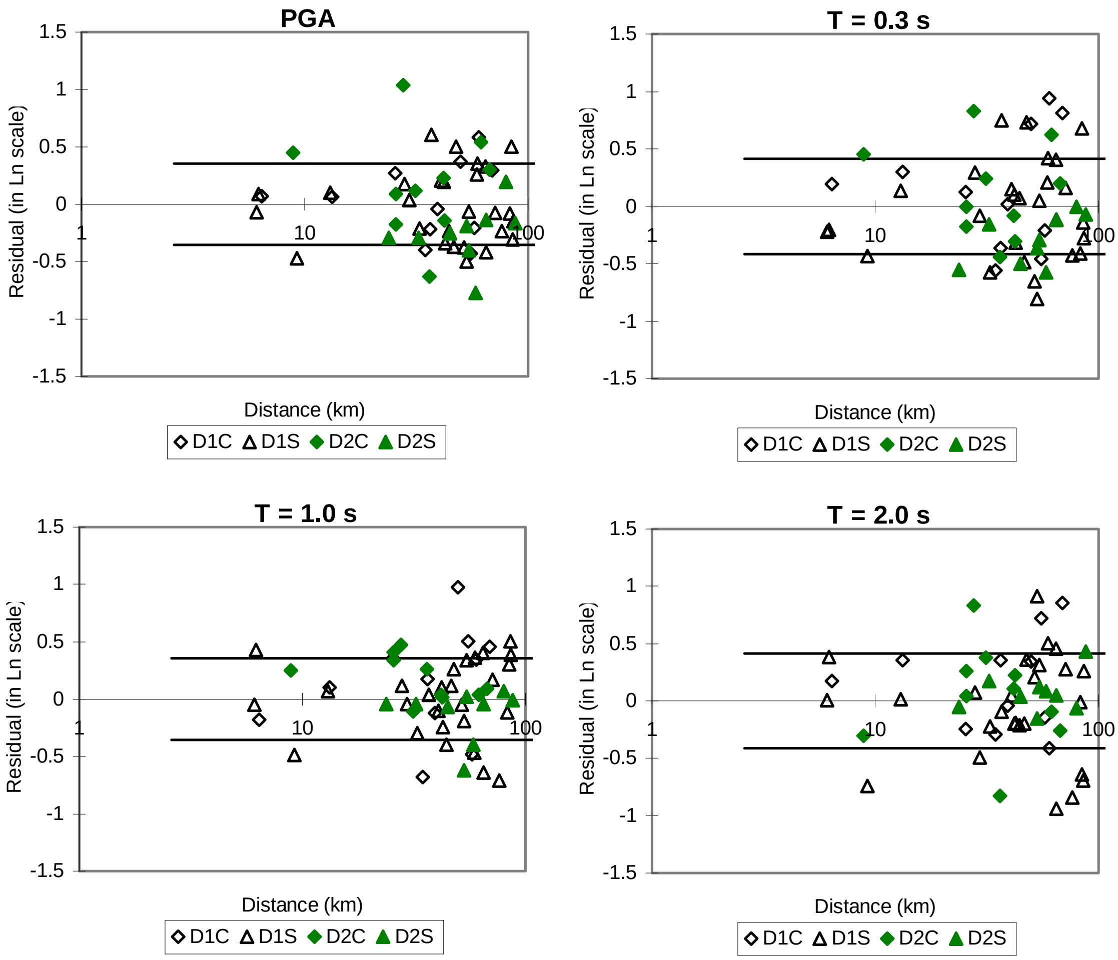

| | PGA | T=0.3 | T=1 | T=3 |
|---|---|---|---|---|
| C1 | 0.08 | 0.08 | 0.10 | 0.01 |
| C2 | -0.08 | -0.10 | 0.01 | 0.05 |
| C3 | -0.10 | -0.06 | 0.05 | 0.16 |

Figure 15a. Residuals for Site C, Northridge Earthquake. Table gives mean of residuals for each subgroup.



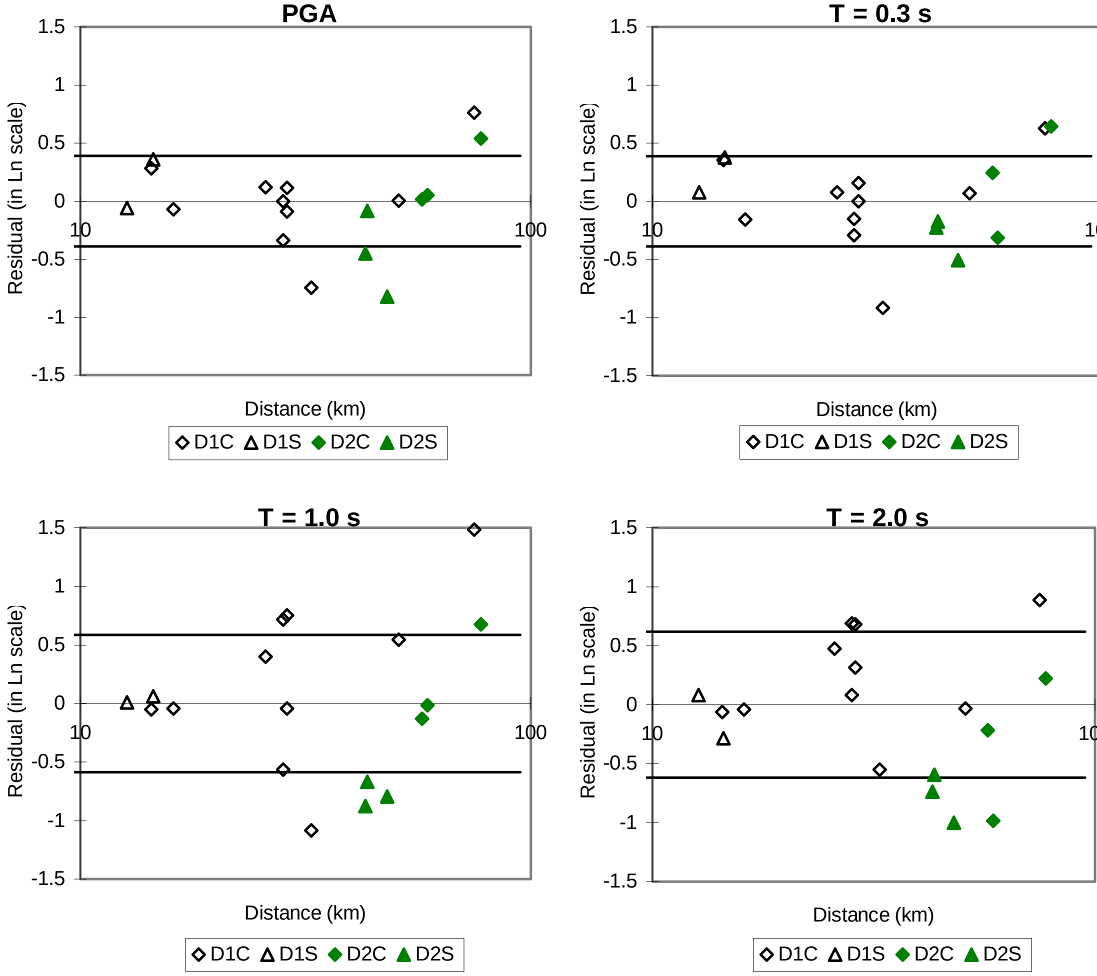

| | PGA | T=0.3 | T=1 | T=3 |
|---|---|---|---|---|
| C1 | -0.04 | 0.07 | 0.05 | -0.04 |
| C2 | 0.07 | 0.06 | -0.01 | 0.01 |
| C3 | -0.08 | -0.29 | 0.10 | 0.16 |

Figure 15b. Residuals for Site C, Loma Prieta Earthquake. Table gives mean of residuals for each subgroup.



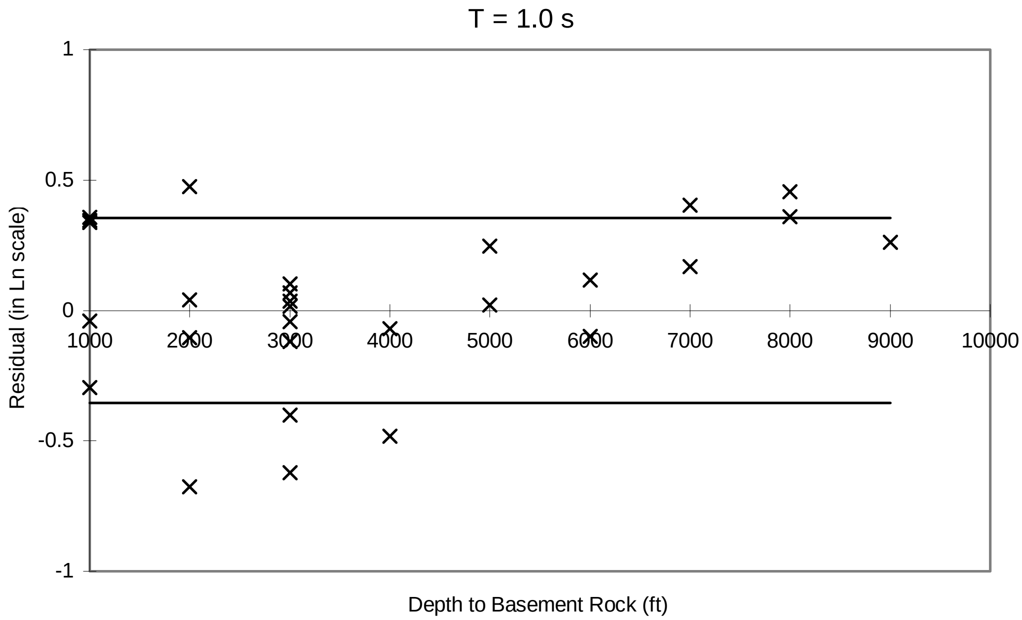

| | PGA | T=0.3 | T=1 | T=3 |
|---|---|---|---|---|
| D1C | 0.03 | 0.14 | 0.13 | 0.15 |
| D1S | 0.00 | -0.02 | 0.01 | -0.07 |
| D2C | 0.18 | 0.13 | 0.18 | 0.04 |
| D2S | -0.26 | -0.29 | -0.13 | 0.07 |
| D1 | 0.01 | 0.02 | 0.04 | -0.01 |
| D2 | -0.03 | -0.07 | 0.04 | 0.05 |
| DC | 0.10 | 0.14 | 0.16 | 0.10 |
| DS | -0.06 | -0.09 | -0.02 | -0.04 |

Figure 16a. Residuals for Site D, Northridge Earthquake. Table gives mean of residuals for each subgroup.




| | PGA | T=0.3 | T=1 | T=3 |
|---|---|---|---|---|
| D1C | 0.00 | -0.02 | 0.21 | 0.24 |
| D1S | 0.15 | 0.23 | 0.04 | -0.10 |
| D2C | 0.20 | 0.19 | 0.18 | -0.32 |
| D2S | -0.46 | -0.30 | -0.78 | -0.78 |
| D1 | 0.03 | 0.02 | 0.18 | 0.19 |
| D2 | -0.13 | -0.05 | -0.30 | -0.55 |
| DC | 0.05 | 0.03 | 0.20 | 0.11 |
| DS | -0.21 | -0.09 | -0.45 | -0.51 |

Figure 16b. Residuals for Site D, Loma Prieta Earthquake. Table gives mean of residuals for each subgroup.



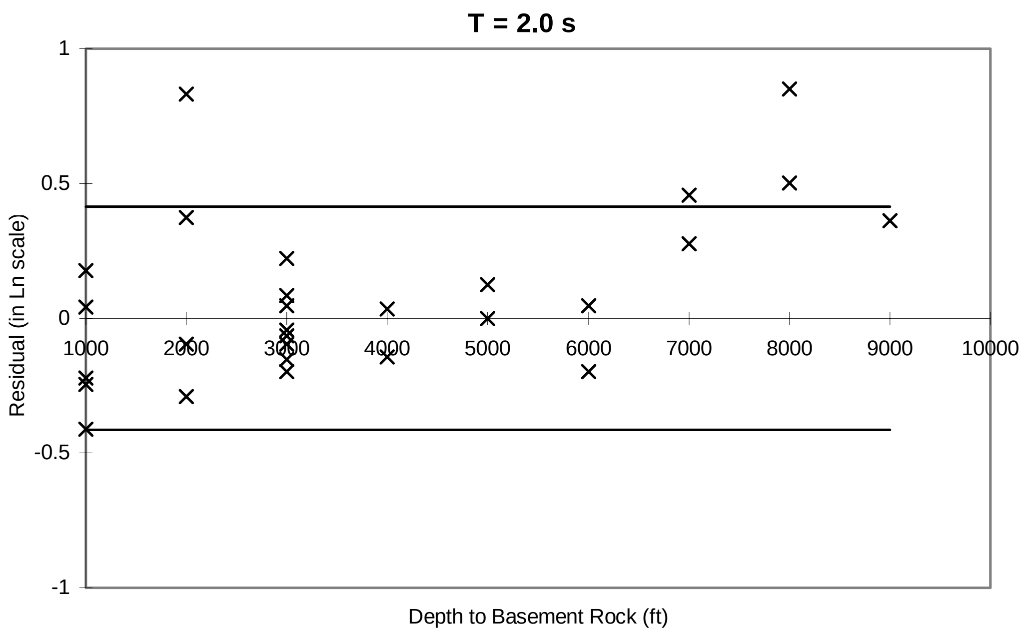




Figure 17. Residuals for D sites within the Los Angeles Basin plotted as a function of depth to basement rock.

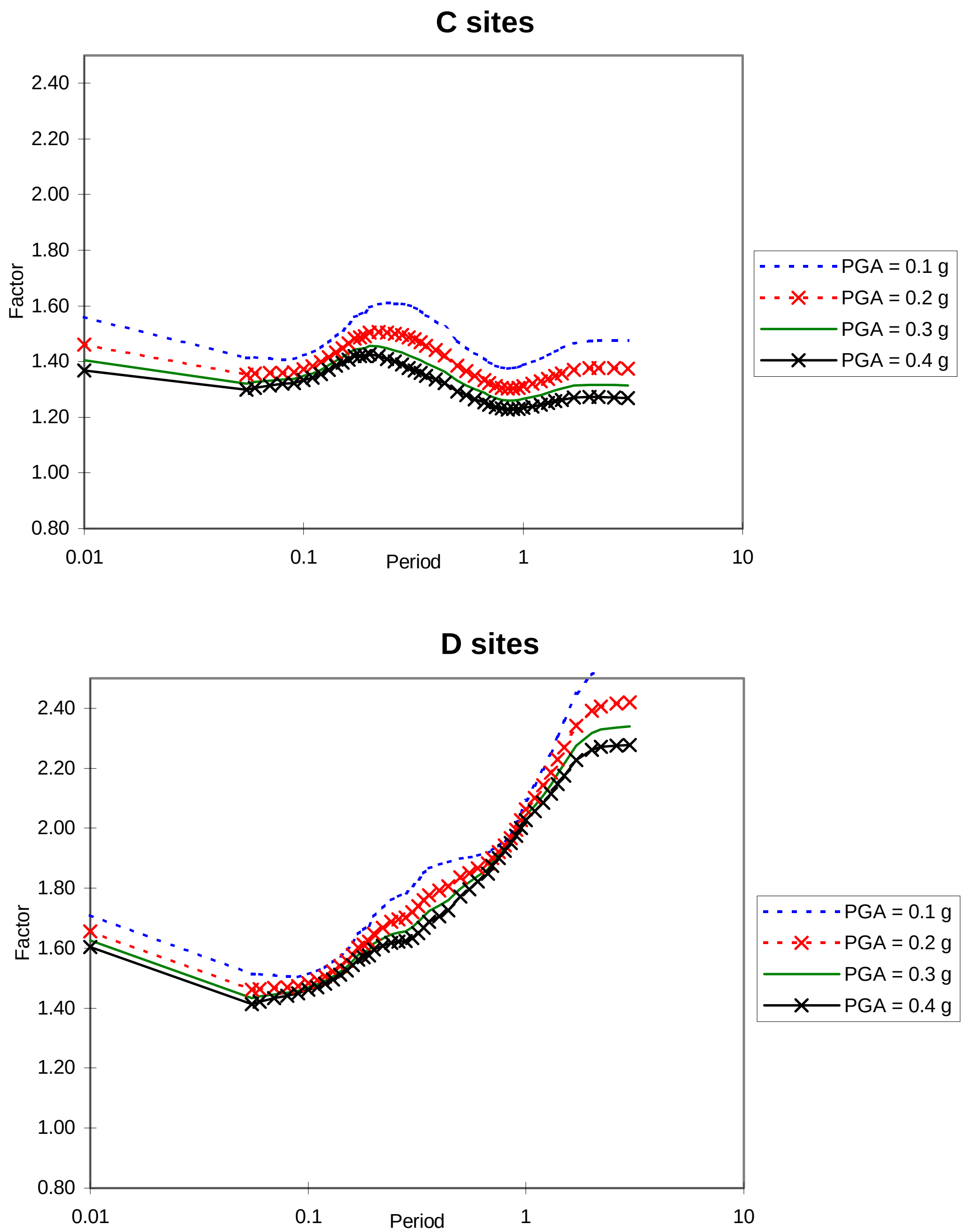



Figure 18a. Amplification factors with respect to Site B for the Northridge Earthquake.

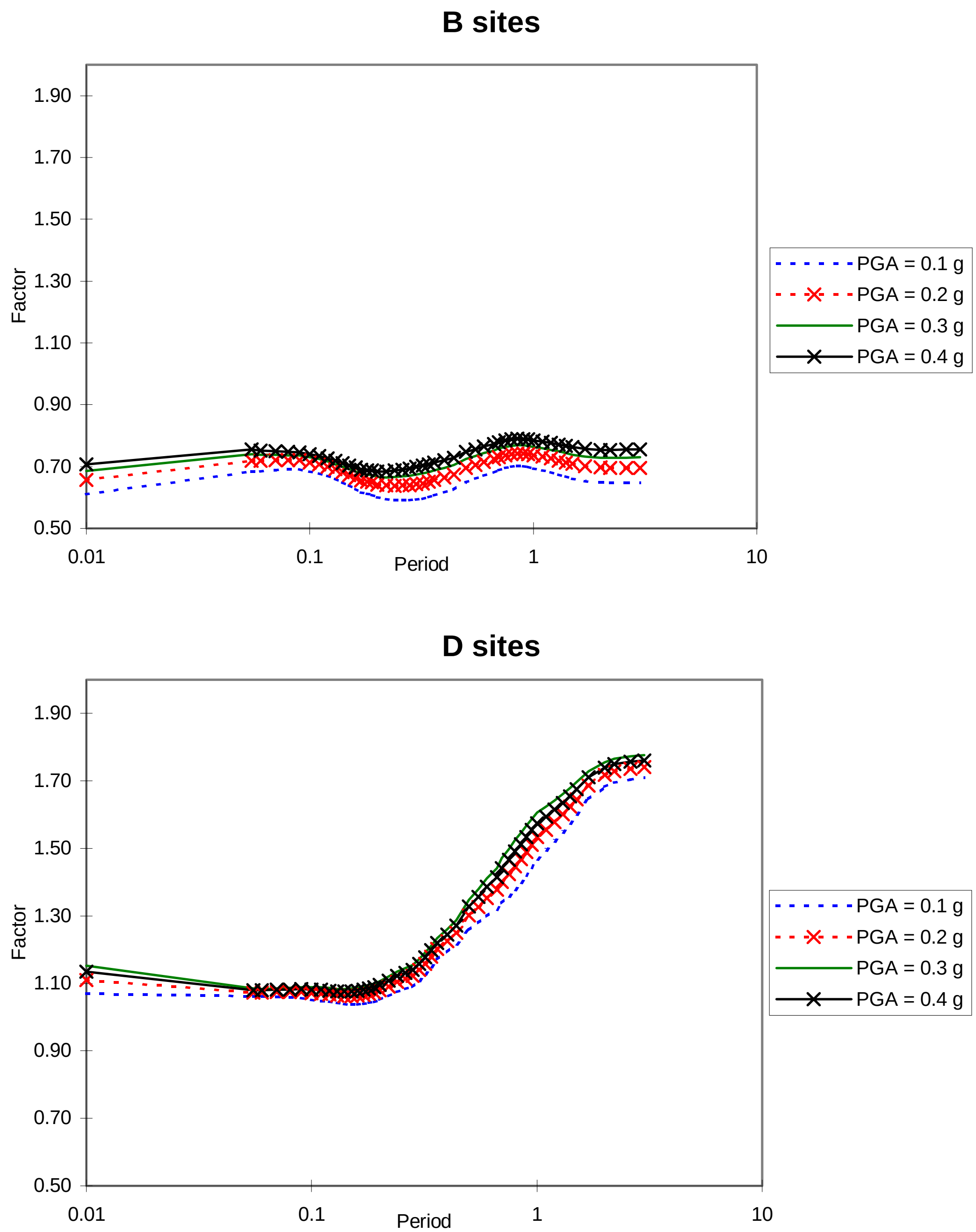



Figure 18b. Amplification factors with respect to Site C for the Northridge Earthquake.

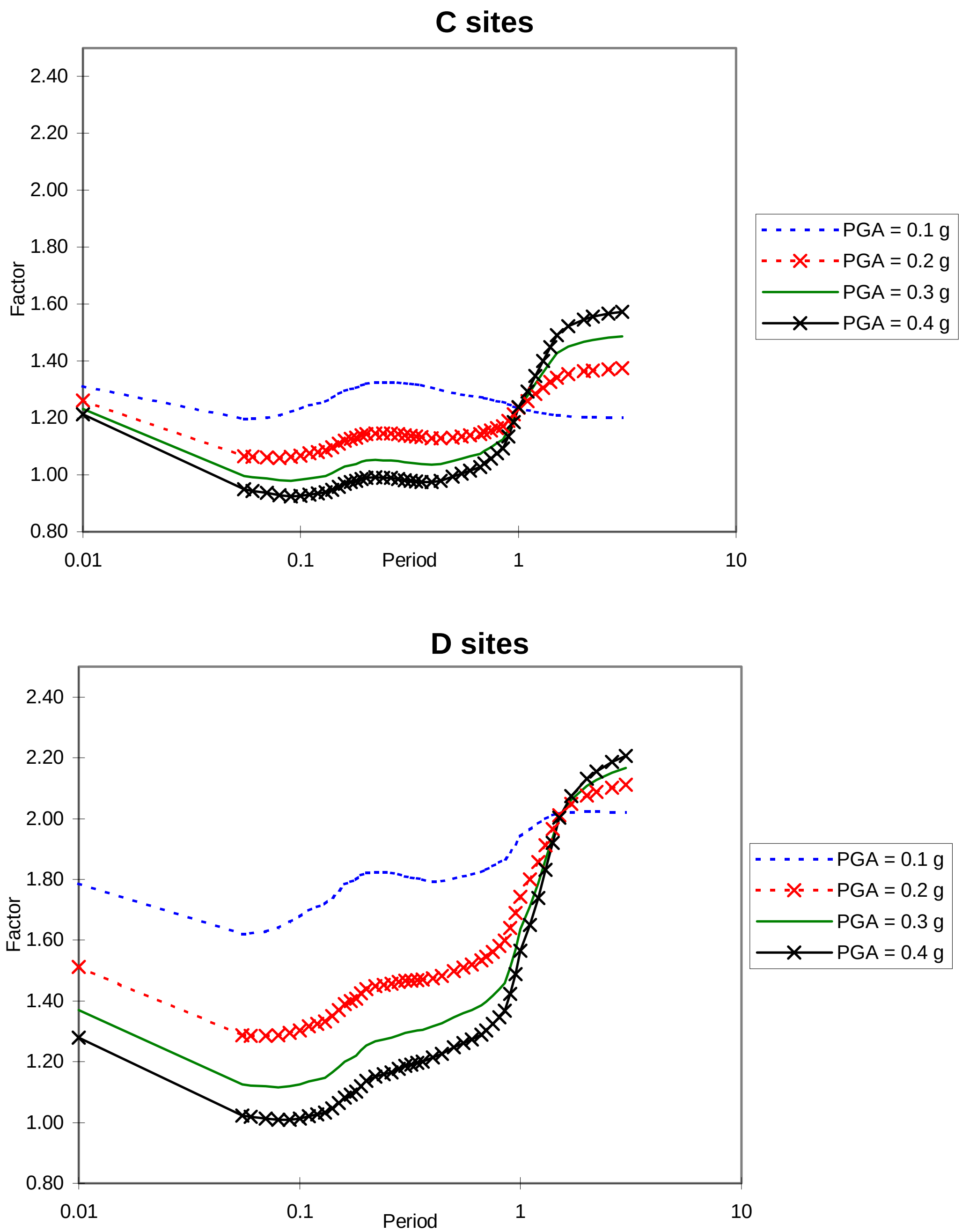



Figure 18c. Amplification factors with respect to Site B for the Loma Prieta Earthquake.

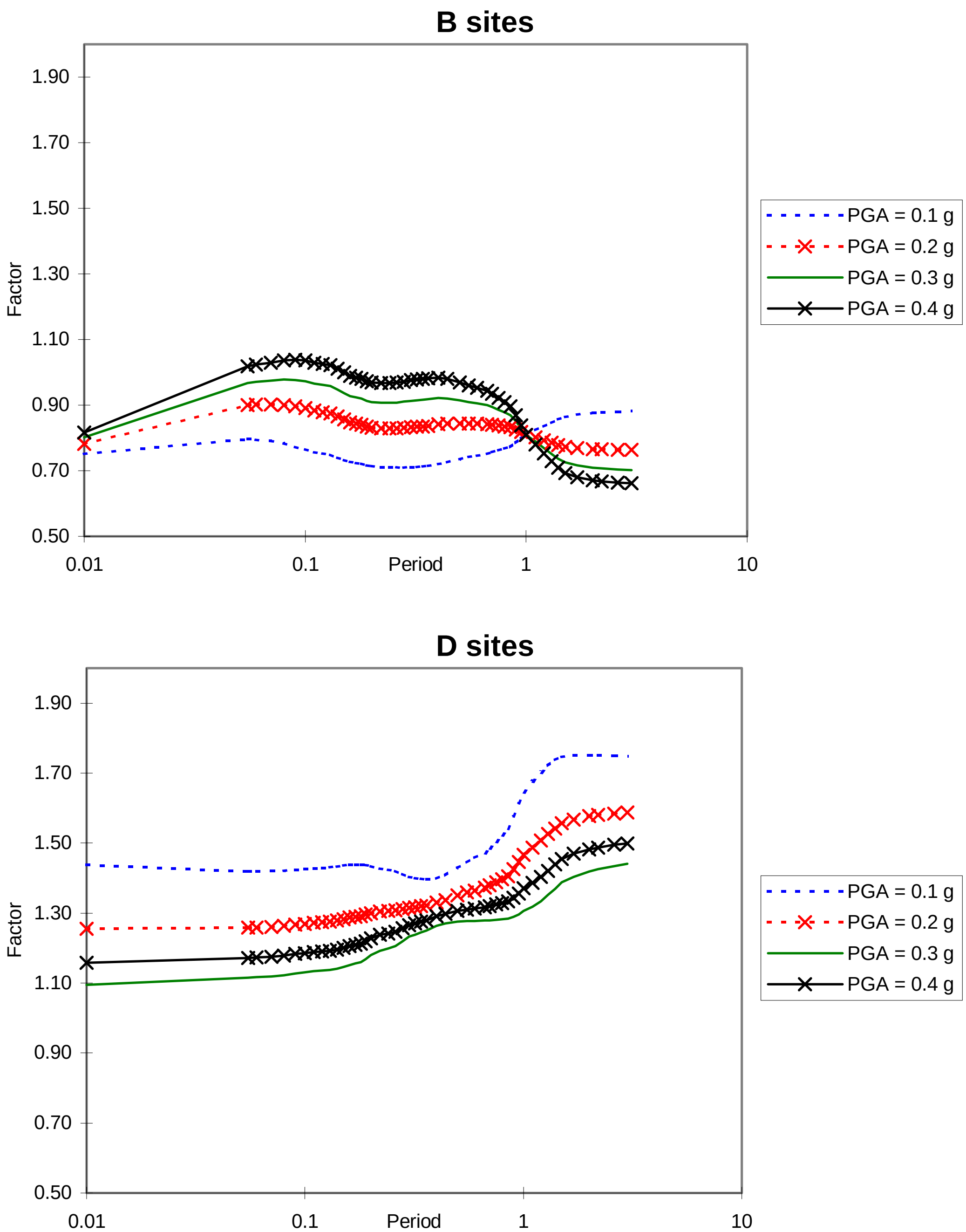
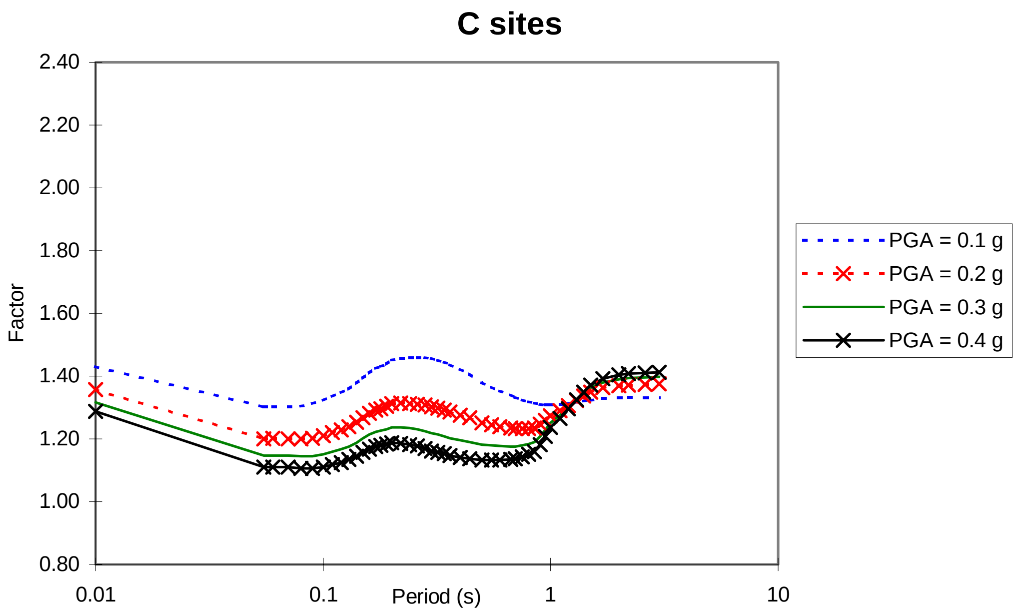



Figure 18d. Amplification factors with respect to Site C for the Loma Prieta Earthquake.



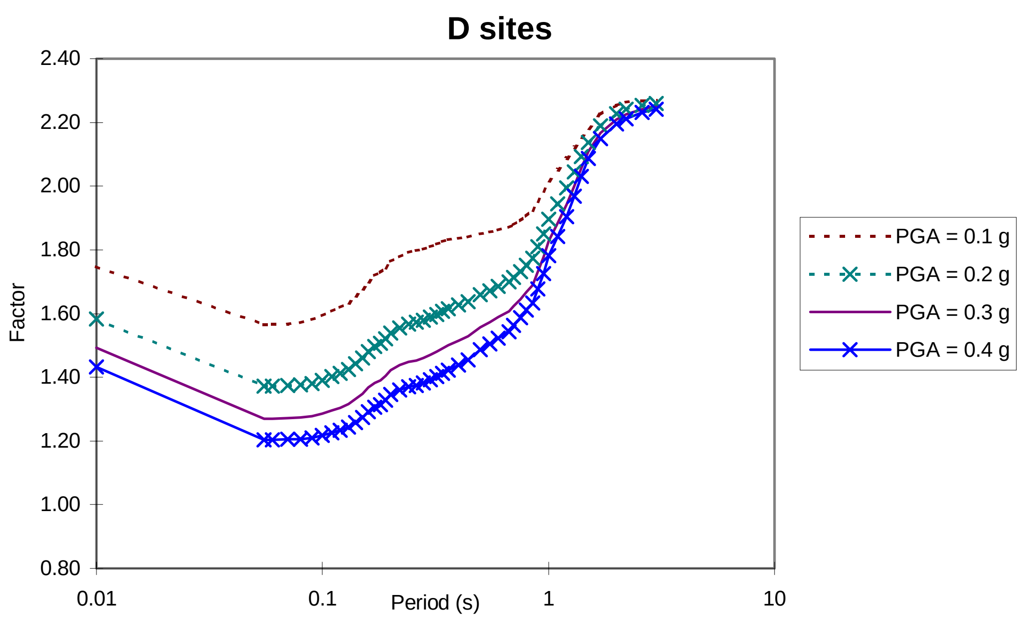
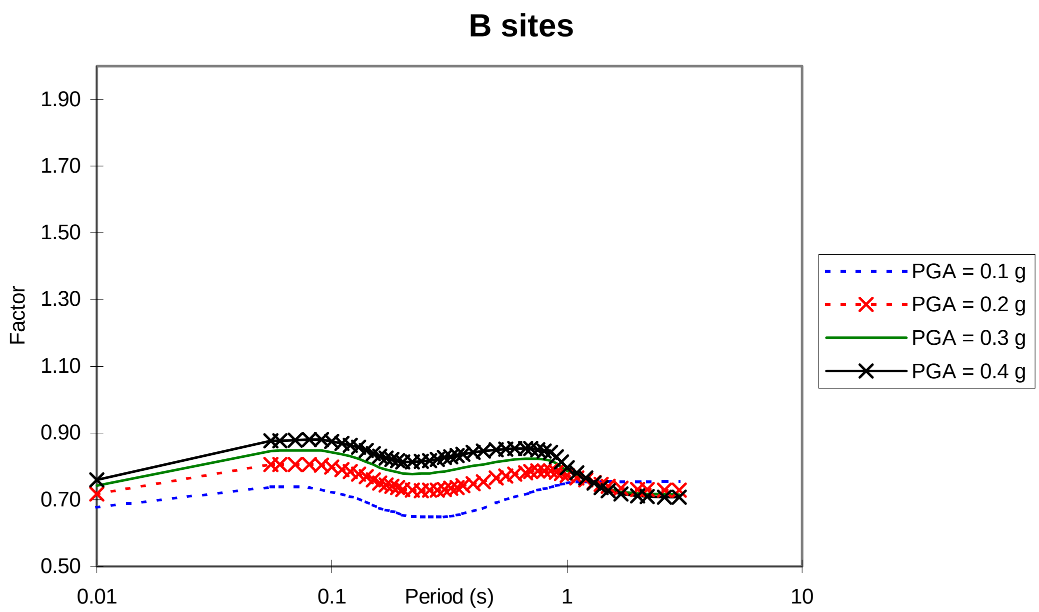




Figure 19a. Amplification factors with respect to Site B. Geometric mean of the Northridge and Loma Prieta Earthquakes.



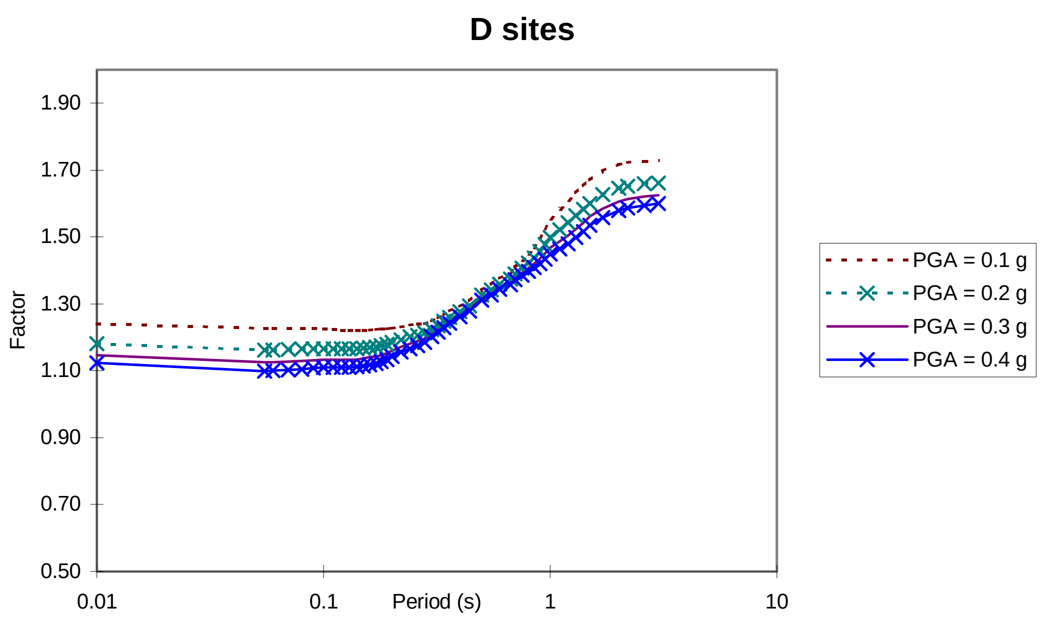




Figure 19b. Amplification factors with respect to Site C. Geometric mean of the Northridge and Loma Prieta Earthquakes.

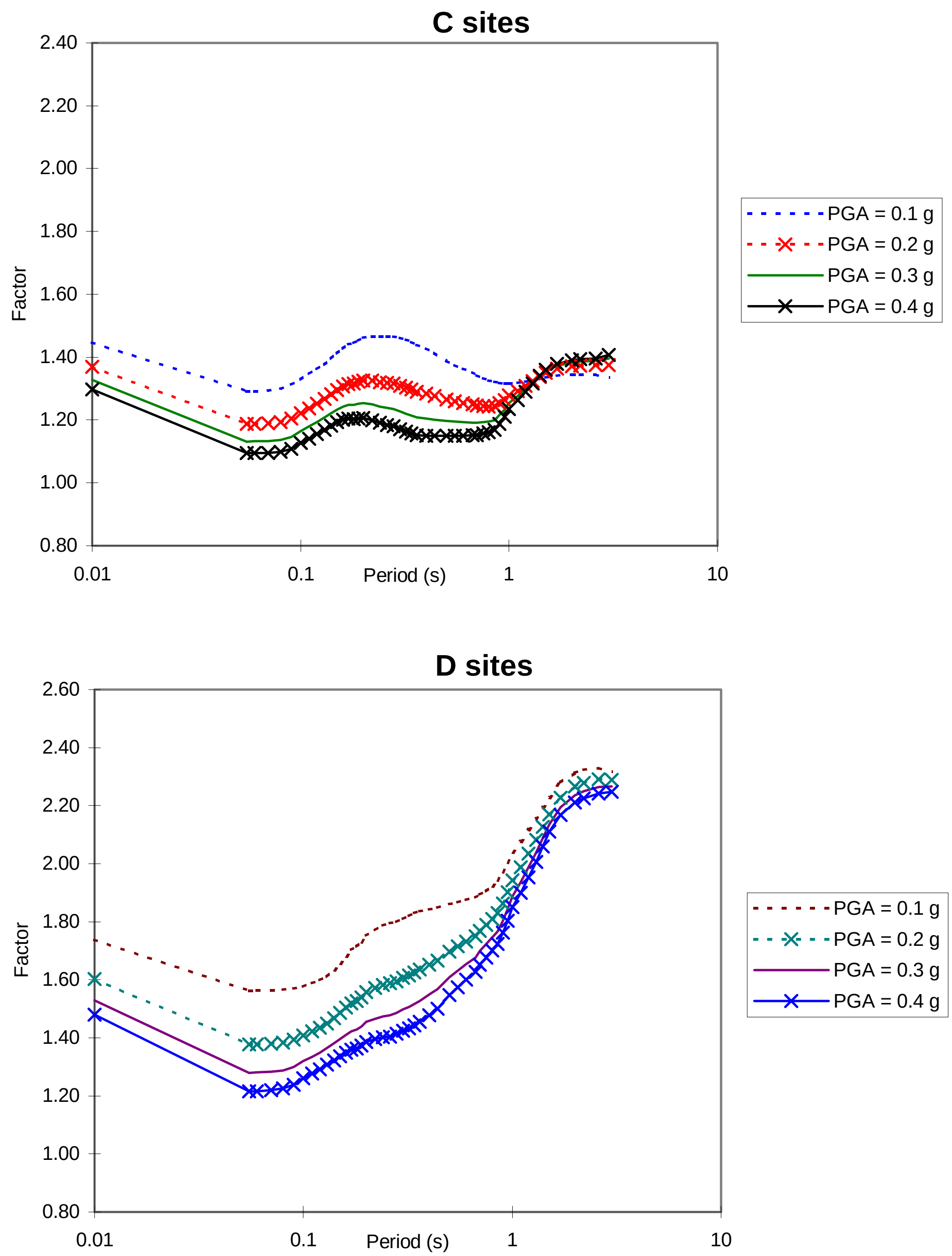



Figure 20a. Amplification factors with respect to Site B. Weighted mean of the Northridge and Loma Prieta Earthquakes.

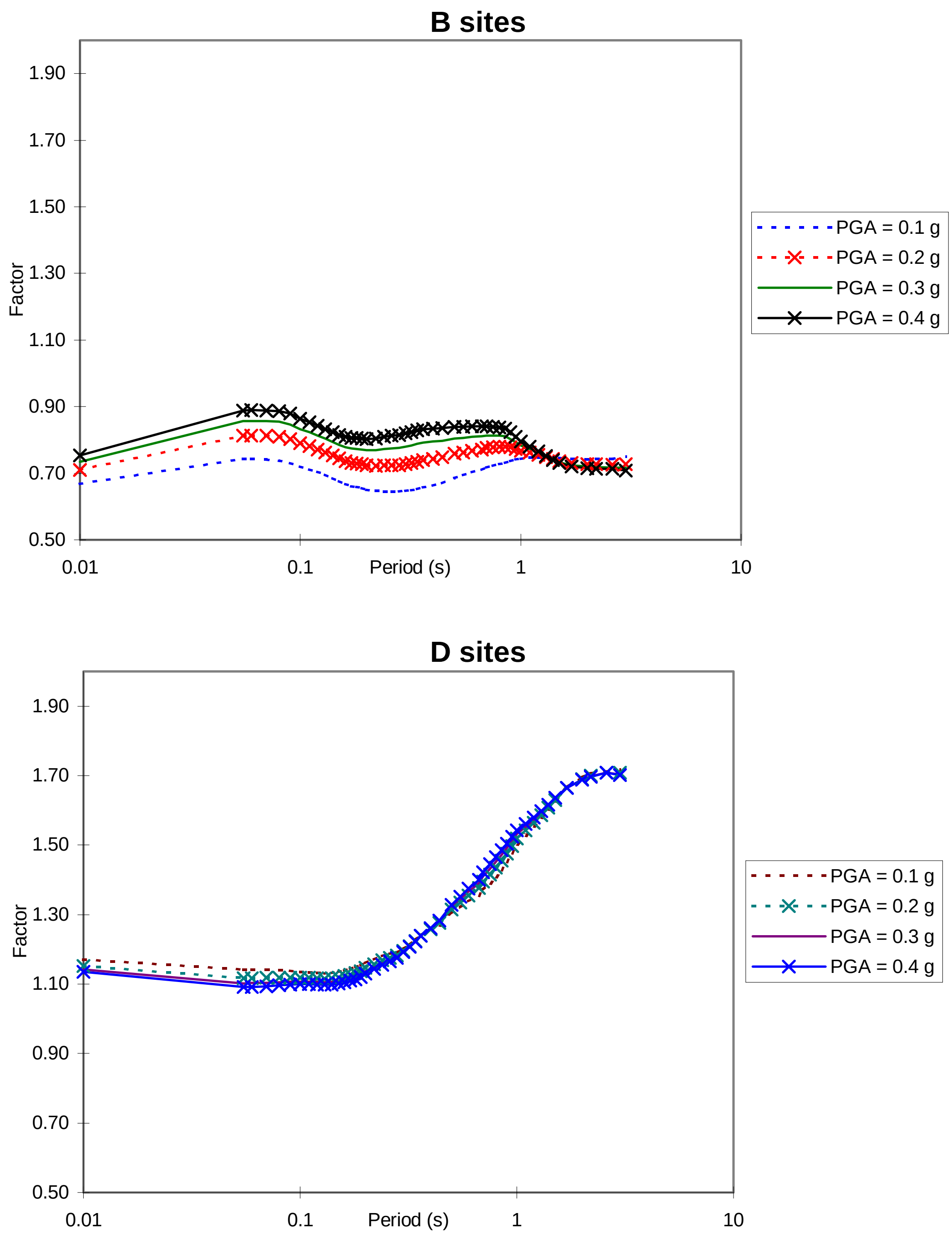



Figure 20b. Amplification factors with respect to Site C. Weighted mean of the Northridge and Loma Prieta Earthquakes.

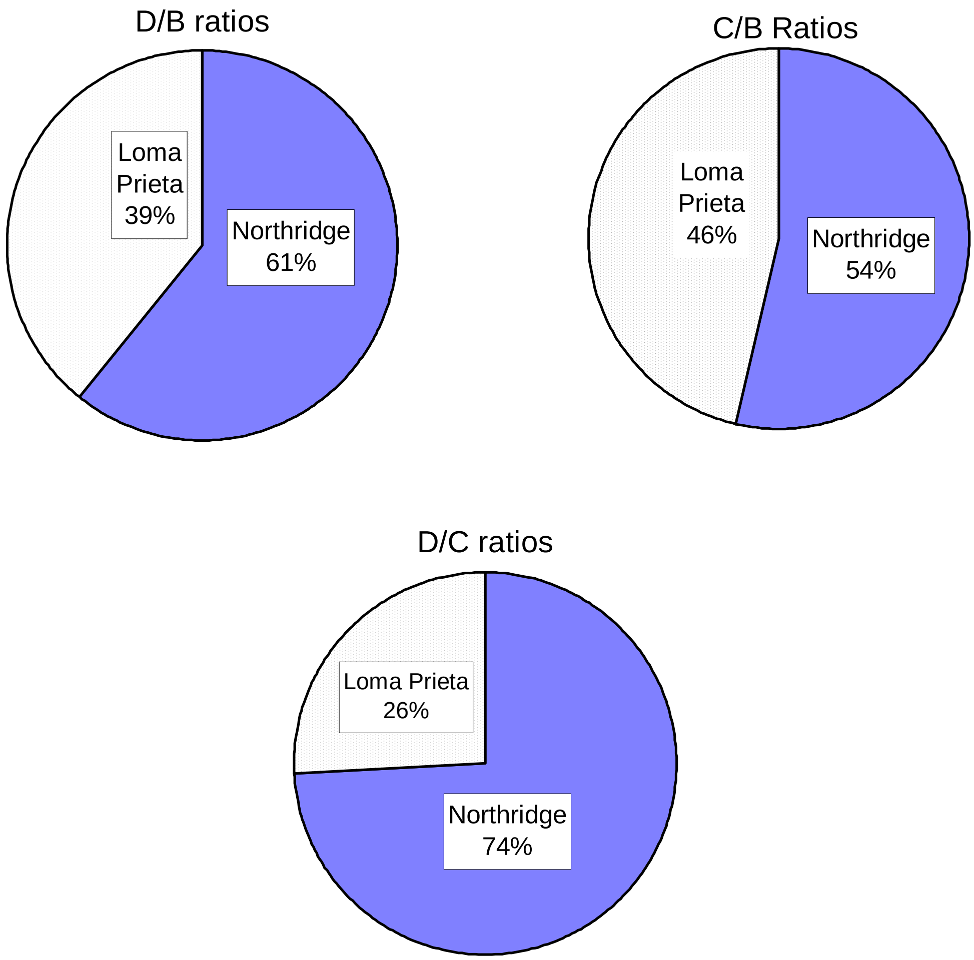
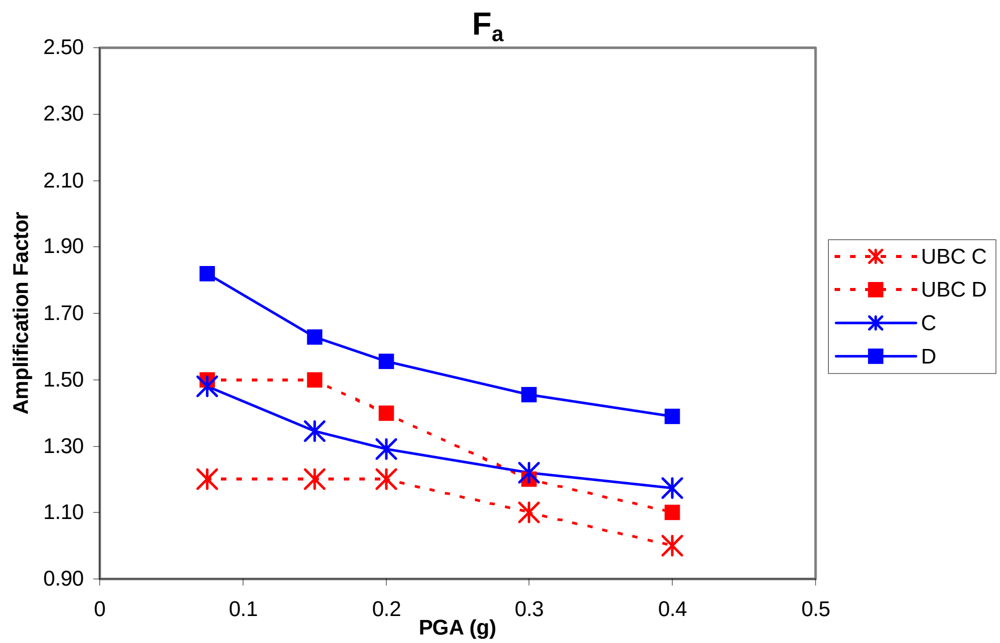



Figure 21. Earthquake weighting scheme used for calculating spectral amplification factors. Shown here is an average of the weights used for all periods. Weights are inversely proportional to the sample variance.



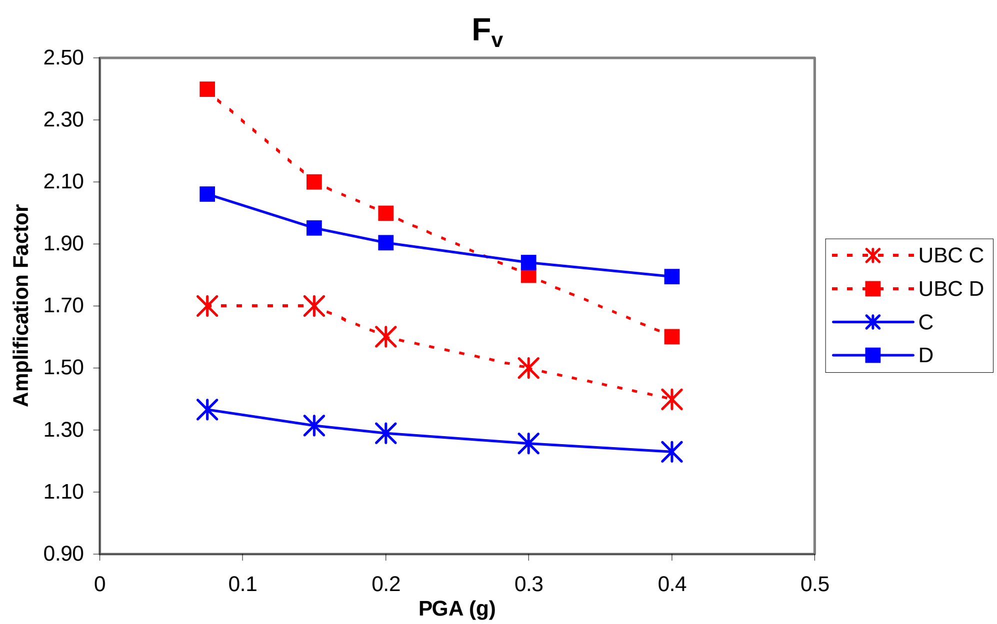




Figure 22. Short-period ($F_a$) and intermediate-period ($F_v$) spectral amplification factors. Dotted lines are code values (UBC 1997), and continuous lines are values obtained in this report.

# APPENDIX A

List of Ground Motion Sites with Corresponding Site Classification

Table A-1. Ground motion stations showing site classification, Northridge Earthquake.

| **Station Name** | **Agency** | **Sta. #** | **Surface Geology** | **Seed & Dickenson** (Table A-4) | **UBC 97** (Table A-3) | **This Study** (Table 1) | **Quality** | **Depth[1] (m)** | **IR[2]** | **Conrey's depth[3] (ft)** | **Source [5]** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alhambra - Fremont School | CDMG | 24461 | Holocene | B1? | C | **C3?** | Fair | >9 | | 0? | SCEC |
| Anacapa Island # | CDMG | 25169 | Miocene | AB2? | D? | **C2?** | Poor | - | - | - | Geol. |
| Anaheim - W Ball Rd | USC | 90088 | Holocene | C3? | D | **D1S?** | Fair | >23.5 | - | 7000 | SCEC |
| Anaverde Valley - City R # | CDMG | 24576 | Holocene | AB2? | C? | **C?2** | Poor | - | - | - | Geol. |
| Antelope Buttes # | CDMG | 24310 | Jurassic-Cretaceous | AB1 | B | **C?1** | Poor | - | - | - | Geol. ,T. |
| Arcadia - Arcadia Av | USC | 90099 | Holocene | C3? | D | **D?1S?** | Fair | >40 | - | - | SCEC |
| Arcadia - Campus Dr. | USC | 90093 | Holocene | C3? | D | **D?1S?** | Fair | 19 | 1.8 | - | SCEC |
| Arleta - Nordhoff Fire Sta # | CDMG | 24087 | Holocene | C3 | D | **D1S** | Good | >150 | - | - | SCEC,ROSRINE |
| Baldwin Park - N. Holly Ave | USC | 90069 | Holocene | AB2 | C | **C2** | Good | 21.5 | 5.5 | - | SCEC |
| Bell Gardens - Jaboneria | USC | 90094 | Holocene | C3 | D | **D1S?** | Fair | >29 | - | 6000 | SCEC |
| Beverly Hills - 12520 Mulhol | USC | 90014 | Miocene | AB1 | C | **C1** | Fair | 22(w?) | 3.3 | - | SCEC |
| Beverly Hills - 14145 Mulhol | USC | 90013 | Miocene | AB? | D | **C1** | Fair | 24(w?) | 4.0 | - | SCEC |
| Big Tujunga, Angeles Nat F | USC | 90061 | Mesozoic | AB2 | C | **C1** | Fair | 21.5(w) | 3.3 | - | SCEC |
| Brea - S. Flower Ave. | USC | 90087 | Pleistocene | B2? C2? | D? | **D?2C** | Fair | >35 | - | - | SCEC |
| Brentwood V.A. Hospital | USGS | 638 | Pleistocene | C2? | D? | **D?2S?** | Poor | >30? | - | - | SCEC, Geol. |

Table A-1. (Cont.)

| Station Name | Agency | Sta. # | Surface Geology | Seed & Dickenson (Table A-4) | UBC 97 (Table A-3) | This Study (Table 1) | Quality | Depth[1] (m) | IR[2] | Conrey's depth[3] (ft) | Source [5] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Buena Park - La Palma | USC | 90086 | Holocene | C3? | D | **D1S (F?)** | Poor | >30 | - | 7000 | SCEC |
| Burbank - Howard Rd. | USC | 90059 | Cretaceous + | A1 | B | **C?1** | Good | 6 - 9 (w) | 3.0 | - | SCEC |
| Camarillo | CDMG | 25282 | Holocene | C2 | D | **D1C?** | Fair | >30 | - | - | SCEC |
| Canoga Park - Topanga Can | USC | 90053 | Holocene | C2 | D | **C3** | Good | 50 (to soft rock) | 2.2 | - | SCEC, G.e.a. |
| Canyon Country - W Lost Cany | USC | 90057 | Holocene | B1? C3? AB1? | D? | **D?1S** | Poor | >24 | - | - | SCEC |
| Carson - Catskill Ave | USC | 90040 | Pleistocene | C3 | D | **D2S** | Fair | >22 | - | 3000 | SCEC |
| Carson - Water St. | USC | 90081 | Holocene | F | F | **F** | Fair | 220 | 4.0 | 3000 | SCEC,ROSRINE |
| Castaic - Old Ridge Route # | CDMG | 24278 | Miocene | AB2 | C | **C?1** | Fair | 8 (w) | - | - | USGS, D.e.a., CSMIP |
| Compton - Castlegate St | USC | 90078 | Holocene | F | F | **F** | Poor | - | - | 5000 | SCEC |
| Covina - S. Grand Ave. | USC | 90068 | Pleistocene | B | D | **C3** | Fair | 25.5 | 3.0 | - | SCEC |
| Covina - W. Badillo | USC | 90070 | Holocene | B | D | **C3** | Fair | 23 | 2.2 | - | SCEC |
| Downey - Birchdale | USC | 90079 | Holocene | C3 | D | **D1S** | Good | 120 | 3.0 | 6000 | SCEC |
| Downey - Co Maint Bldg # | CDMG | 14368 | Holocene | B1? C2? C3? | D | **D1S?** | Fair | >120? | - | 9000 | SCEC, CSMIP, G. |
| Duarte - Mel Canyon Rd. | USC | 90067 | Holocene? | AB2 (F?) | C (F?) | **C2?** | Good | 17 | 8.0 | - | SCEC |
| El Monte - Fairview Av | USC | 90066 | Holocene | F | F | **F** | Fair | 31 | 2.8 | - | SCEC |
| Elizabeth Lake # | CDMG | 24575 | Holocene | AB2? | D? C? | **C?2** | Poor | - | - | - | Geol. |

Table A-1. (Cont.)

| Station Name | Agency | Sta. # | Surface Geology | Seed & Dickenson (Table A-4) | UBC 97 (Table A-3) | This Study (Table 1) | Quality | Depth[1] (m) | IR[2] | Conrey's depth[3] (ft) | Source [5] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Featherly Park - Pk Maint Bldg # | CDMG | 13122 | Holocene | B1? C3? | D? | **D?1S?** | Poor | - | - | - | G. |
| Garden Grove - Santa Rita | USC | 90085 | Holocene | C2 | D | **D?1C** | Fair | >30 | - | 8000 | SCEC |
| Glendale - Las Palmas | USC | 90063 | Pleistocene | AB2 | D | **C3??** | Fair | 33 | 2.6 | - | SCEC |
| Glendora - N. Oakbank | USC | 90065 | Holocene | B | C | **C3?** | Fair | 41 | 2.0 | - | SCEC |
| Hacienda Hts - Colima Rd | USC | 90073 | Holocene | B2 | D | **C3??** | Fair | 34? | 2.0 | - | SCEC |
| Hemet - Ryan Airfield # | CDMG | 13660 | Holocene | C2? C3? | D? | **D1C?** | Poor | - | - | - | Geol. |
| Hollywood - Willoughby Ave | USC | 90018 | Holocene | C2 | D | **D2C** | Good | 100 | - | 1000 | SCEC |
| Huntington Bch - Waikiki | USC | 90083 | Holocene | C2 | D | **D1C?** | Check | - | - | 4000 | Geol. |
| Huntington Beach - Lake St # | CDMG | 13197 | Holocene-Pleistocene | C2? | D? | **D2S?** | Poor | - | - | 3000 | G. |
| Inglewood - Union Oil # | CDMG | 14196 | Pleistocene | C3 | D? | **D2S?** | Poor | - | - | 4000 | G. |
| Jensen Filter Plant # | USGS | 655 | Holocene | F | F | **F** | Good | >93 | - | - | G.e.a., Stew. |
| LA - 116th St School # | CDMG | 14403 | Pleistocene | C2 | C? | **D2C** | Poor | 152 | - | - | SCEC, D&L,G |
| LA - Baldwin Hills # | CDMG | 24157 | Pleistocene | C2 | D | **D2C?** | Good | >85 | - | 2000 | SCEC,G, D&L,ROSRINE |
| LA - Centinela St | USC | 90054 | Pleistocene | AB2 | D | **C3** | Fair | 22 | 3.6 | 5000 | SCEC |
| LA - Century City CC North # | CDMG | 24389 | Pleistocene | C2 | D? | **D2C?** | Fair | >120 | 2.6 | - | S&W,G |
| LA - Chalon Rd | USC | 90015 | Jurassic? | AB1 | C | **C1** | Good | 15 (w) | >2.0 | - | SCEC |

Table A-1. (Cont.)

| Station Name | Agency | Sta. # | Surface Geology | Seed & Dickenson (Table A-4) | UBC 97 (Table A-3) | This Study (Table 1) | Quality | Depth[1] (m) | IR[2] | Conrey's depth[3] (ft) | Source [5] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LA - City Terrace # | CDMG | 24592 | Pliocene | AB1? A1? | B? C? | **C?1** | Fair | <10? | - | 0 | CSMIP, SCEC,S&S |
| LA - Cypress Ave | USC | 90033 | Holocene | AB2 | C | **C2** | Fair | 21 | 3.5 | - | SCEC |
| LA - E Vernon Ave | USC | 90025 | Holocene | C2?C3? | D | **D1C?** | Fair | >30 | - | 3000 | SCEC |
| LA - Fletcher Dr | USC | 90034 | Holocene | C3?B1? | D | **D?1S** | Fair | - | - | - | SCEC |
| LA - Hollywood Stor FF # | CDMG | 24303 | Holocene | C2 | D | **D1C** | Good | 103.6 | 2.8 | 1000 | USGS, Chang |
| LA - N Faring Rd | USC | 90016 | Jurassic? | AB1 | D | **C1** | Good | 20 (w) | | | |
| LA - N Westmoreland | USC | 90021 | Holocene | AB2 | C | **C2** | Good | 22 | 3.8 | - | SCEC |
| LA - N. Figueroa St. | USC | 90032 | Holocene | AB2 | C | **C2** | Fair | 24 | 2.0 | - | SCEC |
| LA - Obregon Park # | CDMG | 24400 | Holocene | F? | F? | **F?** | Poor | - | | <1000 | Geol., SCEC |
| LA - Pico & Sentous # | CDMG | 24612 | Holocene | B1? | D | **D1S** | Fair | 120 | - | <1000 | SCEC, D&L |
| LA - S Grand Ave | USC | 90022 | Holocene | C3 | D | **D?1S** | Good | >24.5? | - | 3000 | SCEC |
| LA - S. Vermont Ave | USC | 90096 | Holocene | C2 | D | **D1C** | Good | >150 | - | 2000 | SCEC, S&S |
| LA - Saturn St | USC | 90091 | Holocene | F | F | **F** | Good | - | - | 2000 | SCEC |
| LA - Temple & Hope # | CDMG | 24611 | Miocene | AB1 | D? | **C1** | Good | 64 (w) | 2.4 | 0 | CSMIP, D&L,S&S |
| LA - UCLA Grounds | CDMG | 24688 | Pleistocene | AB2 | C | **C2** | Good | 20 (w) | 2.0 | - | S&S |
| LA - Univ. Hospital # | CDMG | 24605 | Miocene | AB1 | D? | **C1** | Good | 20? | - | - | S&S |

Table A-1. (Cont.)

| Station Name | Agency | Sta. # | Surface Geology | Seed & Dickenson (Table A-4) | UBC 97 (Table A-3) | This Study (Table 1) | Quality | Depth[1] (m) | IR[2] | Conrey's depth[3] (ft) | Source [5] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LA - W 15th St | USC | 90020 | Pleistocene | C3 | D | **D2S** | Fair | - | - | 1000 | SCEC |
| LA - Wonderland Ave | USC | 90017 | Cretaceous | A1 | B | **B** | Good | 4 (w) | 2.7 | - | SCEC |
| La Crescenta - New York | USC | 90060 | Pleistocene | AB2 | D | **C3** | Good | 30 | 2.0 | - | SCEC |
| LA Dam | USGS | 0 | Pliocene | AB1 | C | **C1** | Good | 0 | - | - | G.e.a. |
| La Habra - Briarcliff | USC | 90074 | Pleistocene | C2?C3? | D | **D2C?** | Fair | - | - | 2000 | SCEC |
| La Puente - 504 Rimgrove Ave | USC | 90072 | Holocene | B | D | **D?1S?** | Fair | - | - | - | SCEC |
| Lake Hughes #1 # | CDMG | 24271 | Holocene | C2 | C | **D2C** | Good | 260 | - | - | G., USGS, S&W |
| Lake Hughes #12A # | CDMG | 24607 | Paleocene | A1 | C | **C?1** | Good | 10 | 5 | - | USGS, S&W, G. |
| Lake Hughes #4 - Camp Mend # | CDMG | 24469 | Mesozoic | A1 | B | **B** | Good | 5 (w) | - | - | G., S&W |
| Lake Hughes #4B - Camp Mend # | CDMG | 24523 | Mesozoic | A2 | B | **B** | Good | 6 (w) | - | - | G., S&W |
| Lake Hughes #9 # | USGS | 127 | Precambrian | A1 | B | **C?1** | Good | 8 (w) | - | - | USGS, S&W, G. |
| Lakewood - Del Amo Blvd | USC | 90084 | Holocene | C3? | D | **D1S?** | Fair | >25 | - | 8000 | SCEC |
| Lancaster - Fox Airfield Grnds | CDMG | 24475 | Holocene | C3 | D | **D1S** | Good | - | - | - | S&S |
| Lawndale - Osage Ave | USC | 90045 | Pleistocene | C2? | D | **D2C?** | Poor | - | - | 3--- | SCEC |
| LB - City Hall # | CDMG | 14560 | Pleistocene | C3 | D? | **D2S?** | Fair | - | - | 3000 | SCEC, Geol. |
| LB - Rancho Los Cerritos # | CDMG | 14242 | Pleistocene | C3? | D? | **D2S?** | Poor | - | - | 5000 | SCEC |

Table A-1. (Cont.)

| **Station Name** | **Agency** | **Sta. #** | **Surface Geology** | **Seed & Dickenson** (Table A-4) | **UBC 97** (Table A-3) | **This Study** (Table 1) | **Quality** | **Depth[1] (m)** | **IR[2]** | **Conrey's depth[3] (ft)** | **Source [5]** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Leona Valley #1 # | CDMG | 24305 | Pleistocene | A1? | B? | **B** | Fair | - | - | - | Geol., CSMIP |
| Leona Valley #2 # | CDMG | 24306 | Holocene | AB2? | C? | **C2??** | Poor | - | - | - | Geol. |
| Leona Valley #3 # | CDMG | 24307 | Holocene? | A1? | B? | **B?** | Poor | - | - | - | CSMIP |
| Leona Valley #4 # | CDMG | 24308 | Pleistocene | AB2? | C? | **C1?** | Poor | - | - | - | CSMIP, Geol. |
| Leona Valley #5 - Ritter # | CDMG | 24055 | Holocene | AB2? | C? | **C2?** | Poor | - | - | - | Geol. |
| Leona Valley #6 # | CDMG | 24309 | Holocene | AB2? | C? | **C?1** | Poor | - | - | - | Geol. |
| Littlerock - Brainard Can # | CDMG | 23595 | Mesozoic | A1? | B? | **B?** | Poor | - | - | - | Geol., CSMIP |
| Malibu - Point Dume Sch # | CDMG | 24396 | Pleis? Miocene? | AB1? | C? | **C1?** | Poor | - | - | - | Geol., SCEC |
| Manhattan Beach - Manhattan | USC | 90046 | Holocene | C3? | D | **D1S** | Fair | >22 | - | 3000 | Geol. |
| Mojave - Hwys 14 & 58 # | CDMG | 34093 | | | D? | **D?1?S?** | Poor | | | | |
| Mojave - Oak Creek Canyon # | CDMG | 34237 | | | D? | **D?1?S?** | Poor | | | | |
| Montebello - Bluff Rd. | USC | 90011 | Holocene | F | F | **F** | Good | >21.5 | - | 1000? | SCEC |
| Moorpark - Fire Sta # | CDMG | 24283 | Holocene | C3-2? | C?D? | **D1S** | Poor | 150 | - | - | Geol. |
| Mt Baldy - Elementary Sch # | CDMG | 23572 | Holo. near Cret. | AB?A? | B?C? | **C?1** | Fair | - | - | - | Geol., CSMIP |
| Mt Wilson - CIT Seis Sta # | CDMG | 24399 | Mesozoic | AB2 | B | **C1** | Fair | 23 (w) | 11.5 | - | Geol., CSMIP, D&L,G.,S&S |
| N. Hollywood - Coldwater Can | USC | 90009 | Holocene | AB2 | C | **C2** | Good | 17 | 4.0 | - | SCEC |

Table A-1. (Cont.)

| **Station Name** | **Agency** | **Sta. #** | **Surface Geology** | **Seed & Dickenson** (Table A-4) | **UBC 97** (Table A-3) | **This Study** (Table 1) | **Quality** | **Depth[1] (m)** | **IR[2]** | **Conrey's depth[3] (ft)** | **Source [5]** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Neenach - Sacatara Ck # | CDMG | 24586 | Holocene | C? | C? | **D1S?** | Poor | | | | |
| Newhall - Fire Sta # | CDMG | 24279 | Holocene | B1 | D | **C3** | Good | 55 | 2.8 | - | ROSRINE |
| Newhall - W. Pico Canyon Rd. | USC | 90056 | Holocene | AB2? | D? | **C2?** | Check | - | - | - | Geol. |
| Newport Bch - Irvine Ave. F.S. # | CDMG | 13160 | Pleistocene | B1? | C?D? | **D?2S?** | Poor | - | - | - | Geol. |
| Newport Bch - Newp & Coast # | CDMG | 13610 | Miocene | AB1 | C? | **C1** | Fair | - | - | - | Geol., CSMIP,S&S |
| Northridge - 17645 Saticoy St | USC | 90003 | Holocene | C3 | D | **D1C** | Good | 81 | 2.5 | - | SCEC |
| Pacific Palisades - Sunset Blvd | USC | 90049 | Holocene | AB2 | D | **C2** | Good | 21 | 4.3 | - | SCEC |
| Pacoima Dam (downstr) # | CDMG | 24207 | Mesozoic | A1 | B? | **B** | Fair | 0 | 3 | - | CSMIP, Geol. |
| Pacoima Dam (upper left) # | CDMG | 24207 | Mesozoic | A1 | B | **B** | Fair | 0 | 3 | - | D.e.a., G. |
| Pacoima Kagel Canyon # | CDMG | 24088 | Miocene | AB1 | C | **C1** | Good | 20 (w) | 2 | - | G., ROSRINE |
| Palmdale - Hwy 14 & Palmdale # | CDMG | 24521 | Holocene-Pleistocene | B1? | C | **C3?** | Fair | >30,<60 ? | High? | - | S&S, SCEC |
| Pardee - SCE | | 0 | | | | | | | | | |
| Pasadena - N Sierra Madre | USC | 90095 | Holocene - Pleistocene | AB2 | D | **C3?** | Good | 34 | 2.0 | | SCEC |
| Phelan - Wilson Ranch # | CDMG | 23597 | Holocene | C2?C3? | D? | **D1S?** | Poor | - | - | - | Geol. |
| Playa Del Rey - Saran | USC | 90047 | Holocene | F | F | **F** | Fair | - | - | 3000 | SCEC |
| Point Mugu - Laguna Peak # | CDMG | 25148 | Miocene | AB1? | C? | **C?1** | Poor | - | - | - | Geol. |

Table A-1. (Cont.)

| Station Name | Agency | Sta. # | Surface Geology | Seed & Dickenson (Table A-4) | UBC 97 (Table A-3) | This Study (Table 1) | Quality | Depth[1] (m) | IR[2] | Conrey's depth[3] (ft) | Source [5] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Port Hueneme - Naval Lab. # | CDMG | 24281 | Holocene | C3 | D | **D1S** | Fair | >30 | - | - | Geol., SCEC |
| Rancho Cucamonga - Deer Can # | CDMG | 23598 | Mesozoic | A1? | B? | **B?** | Poor | - | - | - | Geol., CSMIP |
| Rancho Palos Verdes - Hawth # | CDMG | 14404 | Miocene | A1? | B? | **C1** | Fair | - | - | 0 | Geol. |
| Rancho Palos Verdes - Luconia | USC | 90044 | Miocene | AB1 | D | **C1?** | Poor | 10.5 | 2.0 | - | Geol. ,SCEC |
| Rinaldi Receiving Sta # | DWP | 77 | Holocene (thin) | AB2 | C | **C2** | Fair | 40-Pico 250 | 2.0 3.0 | - | G.e.a. |
| Riverside - Airport # | CDMG | 13123 | Pleistocene | AB2? | C | **C2** | Poor | - | - | - | Geol. |
| Rolling Hills Est-Rancho Vista | CDMG | 14405 | Pliocene | AB1? | C? | **C1** | Poor | - | - | - | Geol. |
| Rosamond - Airport # | CDMG | 24092 | Holocene | B? | D? | **D?1S?** | Poor | - | - | - | Geol. |
| San Bernardino - CSUSB Gr # | CDMG | 23672 | Holocene | B1?C3? | D? | **D?1S?** | Poor | - | - | - | Geol. ,S&S |
| San Bernardino - E & Hosp # | CDMG | 23542 | Holocene | C3? | D | **D?1S** | Poor | - | - | - | CSMIP, SCEC |
| San Gabriel - E. Grand Ave. | USC | 90019 | Holocene | A1 | C | **C?2** | Good | 6.5 | >10 | 0 | SCEC |
| San Jacinto - CDF Fire Sta # | CDMG | 12673 | Holocene | C2?C3? | D? | **D1C?** | Poor | - | - | - | Geol. |
| San Marino, SW Academy # | CDMG | 24401 | Holocene | C3? | C?D? | **C3??** | Poor | >30 | - | - | D&L,USGS, D&L,G |
| San Pedro - Palos Verdes # | CDMG | 14159 | Miocene | AB1? | C? | **C?1** | Poor | - | - | 0 | Geol. |
| Sandberg - Bald Mtn # | CDMG | 24644 | Mesozoic | AB1? | B?C? | **C?1** | Poor | - | - | - | Geol. |
| Santa Barbara - UCSB Goleta # | CDMG | 25091 | Holocene | AB1 | C? | **C1** | Good | >5 | - | - | SCEC |

Table A-1. (Cont.)

| Station Name | Agency | Sta. # | Surface Geology | Seed & Dickenson (Table A-4) | UBC 97 (Table A-3) | This Study (Table 1) | Quality | Depth[1] (m) | IR[2] | Conrey's depth[3] (ft) | Source [5] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Santa Fe Spr - E. Joslin | USC | 90077 | Holocene | C? | D | **C3??** | Check | 25.5 | 3.0 | - | SCEC |
| Santa Monica City Hall # | CDMG | 24538 | Pleistocene | B1 | D | **D2C** | Good | 183+ | 6.0 | 2000 | Chang, SCEC |
| Santa Susana Ground # | USGS | 5108 | Cretaceous | A1?AB1? | B?C? | **C1** | Fair | 2 | - | - | S&S |
| Seal Beach - Office Bldg # | CDMG | 14578 | Pleistocene | C3? | D? | **D2S** | Fair | - | - | 3000 | Geol., S&S |
| Sepulveda VA # | USGS | 637 | Pleistocene | C2 | C | **D2C** | Good | >76 | 1.8 | - | G.e.a. |
| Simi Valley - Katherine Rd | USC | 90055 | Holocene | A1 | C | **C2** | Good | 12.5 | 4.0 | - | G.e.a. |
| Stone Canyon # | MWD | 78 | | | | | | | | | |
| Sun Valley - Roscoe Blvd | USC | 90006 | Holocene | AB2 | C | **C2** | Fair | - | - | - | SCEC |
| Sunland - Mt Gleason Ave | USC | 90058 | Holocene | AB2 | C | **C3** | Good | 24.5 | 2.7 | - | SCEC |
| Sylmar - Converter Sta # | DWP | 74 | Holocene | C3 | D | **D1S** | Fair | >92 | 2.9 | - | G.e.a. |
| Sylmar - Converter Sta East # | DWP | 75 | Holocene | C3? | D? | **D1S?** | Poor | - | - | - | G.e.a. |
| Sylmar - Olive View Med FF # | CDMG | 24514 | Holocene | C2 | C | **D1C?** | Good | 79 | 2.5 | - | G.e.a. |
| Tarzana, Cedar Hill # | CDMG | 24436 | Pliocene | AB2 | D | **C2?** | Fair | - | - | - | Geol., CSMIP, ROSRINE |
| Terminal Island - S Seaside | USC | 90082 | Holocene | C2 | D | **D1C** | Fair | > 17 | - | 1000 | SCEC |
| Topanga - Fire Sta # | USGS | 5081 | Holo. near Mioc. | AB? | C? | **C2?** | Poor | - | - | - | Geol. |
| Tustin - E. Sycamore | USC | 90089 | Holocene | F | F | **F** | Fair | - | - | 1000 | SCEC |

Table A-1. (Cont.)

| Station Name | Agency | Sta. # | Surface Geology | Seed & Dickenson (Table A-4) | UBC 97 (Table A-3) | This Study (Table 1) | Quality | Depth(1) (m) | IR(2) | Conrey's depth(3) (ft) | Source (5) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Vasquez Rocks Park # | CDMG | 24047 | Pleistocene | A?AB? | C?B? | **B?** | Poor | - | - | - | Geol., CSMIP |
| Ventura - Harbor & California | CDMG | 25340 | Holocene | C2 | D | **D1C** | Fair | >24 | - | - | S&S |
| Villa Park - Serrano Ave | USC | 90090 | Pleistocene (Shallow) | A1 | C | **C?2** | Good | 7 | - | - | SCEC |
| West Covina - S. Orange Ave | USC | 90071 | Holocene | AB2 | D | **C2** | Good | 16 | - | - | SCEC |
| Whittier - S. Alta Dr | USC | 90075 | Pleistocene | A1 | C | **C2** | Good | 7 | - | - | SCEC |
| Wrightwood - Jackson Flat # | CDMG | 23590 | Mesozoic | A1? | B? | **B?** | Poor | - | - | - | Geol. |
| Wrightwood - Nielson Ranch # | CDMG | 23573 | Holocene | AB2? | C?D? | **C2??** | Poor | - | - | - | Geol. |
| Wrightwood - Swarthout # | CDMG | 23574 | Holocene | AB2? | C?D? | **C2??** | Poor | - | - | - | Geol. |
| Malibu Canyon, Monte Nido Fire (4) | USGS | 5080 | Miocene | A?AB? | B? | **B?** | Poor | - | - | - | Geol. |
| Point Mugu - Naval Air Station (4) | CDMG | 25147 | Holocene | C? | D? | **D1C?** | Poor | - | - | - | Geol. |
| Malibu, W. Pacific Coast Hwy. (4) | USC | 90051 | Pleistocene | AB2 | C | **C2** | Good | 14 | 4.0 | - | SCEC |
| Rancho Cucamonga - L&J (4) | CDMG | 23497 | Holocene | C3 | D | **D1S** | Good | 210 | - | - | S&S, G. |

(1) Depth to bedrock obtained from boring log. If nothing is specified it refers to depth of soil cover over weathered rock.
(2) Estimated Impedance Ratio.
(3) Depth to base of Pliocene deposits (Conrey 1967).
(4) Ground motion sites added to the Walter Silva Database.
(5) Abbreviated source for geotechnical and geological data. Corresponds to the following references:
Chang - Chang et. al. (1997).
CSMIP - CSMIP (1992).

Table A-1. (Cont.)

D.e.a. - Duke et al. (1971).
D&L - Duke and Leeds (1962).
G - Geomatrix Consultants (1993).
G e.a. - Gibbs et al. (1996).
Geol. - Local geological maps (CDMG and Dibblee).
ROSRINE - Internet Site (ROSRINE 1998).
S&S - Stewart and Stewart (1997).
S&W - Shannon and Wilson (1980).
SCEC - Vucetic and Dourodian (1995).
Stew - Stewart et. al. (1994)
T. - Trifunac and Todorovska (1996).
USGS - Fumal, Gibbs, and Roth (1981, 1982, and 1984).

Table A-2. Ground motion stations showing site classification, Loma Prieta Earthquake.

| Station Name | Agency | Sta. # | Surface Geology | Seed & Dickenson (Table A-4) | UBC 97 (Table A-3) | This Study (Table 1) | Quality | Depth[1] (m) | IR[2] | Source[4] |
|---|---|---|---|---|---|---|---|---|---|---|
| Agnews State Hospital | CDMG | 57066 | Holocene | C2 | D | **D1C** | Good | 300? | - | T&S,G |
| Alameda NAS | Navy | | Holocene | C4-D1-E2 | E | **E1** | Good | 141 | - | T&S |
| Anderson Dam (Downstream) | USGS | 1652 | Pleistocene | B1? | C | **C3?** | Good | > 50 ? | - | G, 94-552 |
| APEEL 10 - Skyline | CDMG | 58373 | Eocene | AB1 | C | **C1** | Good | 17(w) | 1.7 | 79-1619,G |
| APEEL 2 - Redwood City | USGS | 1002 | Holocene | C4-D1-E2 | E | **E1** | Good | 84.7 | 8.6 | 93-376,G,79-1619 |
| APEEL 2E Hayward Muir School | CDMG | 58393 | Pleistocene | C2 | D | **D2C** | Good | 152 | - | 79-1619 |
| APEEL 3E Hayward CSUH | CDMG | 58219 | Pliocene | AB2 | C | **C?1?** | Good | 12 | 3.6 | 79-1619,T&S |
| APEEL 7 - Pulgas | CDMG | 58378 | Eocene | AB1 | C | **C1** | Good | 16 (w) | 1.3 | G |
| APEEL 9 - Crystal Spring Residence | USGS | 1161 | Pleistocene | B1 | C | **C3??** | Good | >30 | 1.3 | 79-1619,G |
| Bear Valley Sta 10, Webb Residence[3] | USGS | 1479 | Holocene - Pleistocene | B2 | D | **C2** | Good | 21 | 1.8 | 94-552 |
| Bear Valley Sta 12, Williams[3] | USGS | 1481 | Holocene | C3 | D | **D1C** | Good | >60 | | 94-552 |
| Bear Valley Sta 5, Callens Ranch[3] | USGS | 1474 | Holocene | B2 | C | **C2** | Good | 30 | 2.6 | 94-552 |
| Bear Valley Sta. 7, Pinnacles[3] | USGS | PNM | Miocene (Rhyolite) | A1 | B | **B** | Fair | | | 91-311 |
| Belmont - Envirotech | CDMG | 58262 | Franciscan | AB1 | C | **C1** | Good | 13(w) | 1.2 | T&S,G |
| Berkeley LBL | CDMG | 58471 | Cretaceous | AB1 | C | **C1** | Fair | shallow soil ? | 1.3 | |
| BRAN | UCSC | 13 | | AB1? | B? | **B?** | Poor | | | |

Table A-2. (Cont.)

| Station Name | Agency | Sta. # | Surface Geology | Seed & Dickenson (Table A-4) | UBC 97 (Table A-3) | This Study (Table 1) | Quality | Depth[1] (m) | IR[2] | Source[4] |
|---|---|---|---|---|---|---|---|---|---|---|
| Capitola | CDMG | 47125 | Holocene | B1 | D | **C2??** | Check | >183? ,16? | 2.6 | T&S |
| Corralitos | CDMG | 57007 | Holocene | AB2 | C | **C1** | Good | 5 (soft),32(Hard) | 1.8 | G |
| Coyote Lake Dam (Downst) | CDMG | 57504 | Holocene | AB2 | C | **C3?** | Fair | <50? | 1.5? | G |
| Foster City - 355 Menhaden | USGS | 1515 | Holocene | C4-D1-E2 | E | **E1** | Good | 115 | High | G |
| Foster City -Redwood Shores[3] | CDMG | 58375 | Holocene | C4-D1-E2 | E | **E2** | Good | 188 | | 93-376 |
| Fremont - Emerson Court | USGS | 1686 | Pleistocene | B1?C3? | D | **D??2S** | Good | >46 | - | 94-222, G |
| Fremont - Mission San Jose | CDMG | 57064 | Pleistocene | B1 | D | **D??2S** | Fair | 5? 78? | - | G |
| Gilroy - Gavilan Coll. | CDMG | 47006 | Pleistocene | AB2 | C | **C2** | Good | 13 | 6 | S&W, G |
| Gilroy - Historic Bldg. | CDMG | 57476 | Holocene | AB2 | C | **C2??** | Poor | - | - | G |
| Gilroy Array #1 | CDMG | 47379 | Franciscan | A1 | B | **B** | Good | 1 | 2.85 | G |
| Gilroy Array #2 | CDMG | 47380 | Holocene | C2 | D | **D1C** | Good | 165 | - | G,92-387,T&S |
| Gilroy Array #3 | CDMG | 47381 | Holocene | C2 | D | **D1C** | Good | >60, 480? | - | 92-387,T&S,G |
| Gilroy Array #4 | CDMG | 57382 | Holocene | C2 | D | **D1C** | Good | >30, 800? | - | G |
| Gilroy Array #6 | CDMG | 57383 | Eocene-Paleocene | AB1 | C | **C1** | Good | 1 | - | G |
| Gilroy Array #7 | CDMG | 57425 | Pleistocene | AB2 | D | **C2** | Good | 17m | 3.5 | G, 92-376 |
| Golden Gate Bridge | USGS | 1678 | Franciscan | AB1 | C? | **C?1** | Poor | 5? | 1.3 | |
| Halls Valley | CDMG | 57191 | Holocene | AB2 | D | **C2??** | Fair | 17 Soft, 43 Hard | 5.2 | T&S,G |
| Hayward - BART Sta | CDMG | 58498 | Pleistocene | B2? | D? | **D??2C** | Poor | - | - | Stewart |

Table A-2. (Cont.)

| Station Name | Agency | Sta. # | Surface Geology | Seed & Dickenson (Table A-4) | UBC 97 (Table A-3) | This Study (Table 1) | Quality | Depth[1] (m) | IR[2] | Source[4] |
|---|---|---|---|---|---|---|---|---|---|---|
| Hayward City Hall, ground site[3] | USGS | 1129 | Pliocene (Rhyolite) | A1 | C | **B** | Good | 10 | | 94-222 |
| Hollister - SAGO Vault | USGS | 1032 | Mesozoic | A1 | B | **B** | Fair | 0 | 2.5 | G |
| Hollister - South & Pine | CDMG | 47524 | Holocene | C2 | D | **D1C?** | Fair | > 105? | | G |
| Hollister City Hall | USGS | 1028 | Holocene | C2? | D | **D1C** | Good | >105 | | 79-1619,G |
| Hollister Diff. Array | USGS | 1656 | Holocene | C2? | D | **D1C?** | Good | >106 | | 79-1619,G |
| Larkspur Ferry Terminal[3] | USGS | 1590 | Holocene | C4-D1-E2 | E | **E2** | Good | 27.5 | 5 | 94-222 |
| LGPC | UCSC | 16 | | AB1 | C? | **C?1** | Poor | | | |
| Monterey City Hall | CDMG | 47377 | Mesozoic | AB1 | C | **C1?** | Good | 6s, >8(w) | - | T&S |
| Oakland - Title & Trust | CDMG | 58224 | Pleistocene | C2 | D | **D2C** | Good | 137 | - | 93-376,T&S |
| Oakland Outer Harbor [3] | CDMG | 58472 | Holocene | C2 | D | **D1C** | Good | 150 | 3.8 | Chang |
| Palo Alto - 1900 Embarc. | CDMG | 58264 | Holocene | C4-D1-E2 | E | **E1** | Good | >55 | - | 93-376 |
| Palo Alto - SLAC Lab | USGS | 1601 | Pleistocene | AB2 | C | **C2** | Good | 12 | - | 94-222 |
| Piedmont Jr High | CDMG | 58338 | Franciscan | A1 | B | **B** | Good | 4 | 9 | T&S |
| Point Bonita | CDMG | 58043 | Cretaceous | A1 | B | **B** | Good | 2 (w) | 2 | T&S |
| Richmond City Hall | CDMG | 58505 | Pliocene-Pleist. | C2 | D | **C3??** | Good | 58 | 2.5 | T&S |
| SAGO South - Surface | CDMG | 47189 | Mesozoic | A1 | B | **B** | Good | 4.5(w) | 2.5 | T&S |
| Salinas - John & Work | CDMG | 47179 | Holocene | B?C? | D | **D?1C?** | Poor | - | - | G |
| San Francisco, 1295 Shafter, Fire Station[3] | USGS | 1675 | Franciscan | A1 | B | **B** | Fair | 7 | | 91-311 |

Table A-2. (Cont.)

| **Station Name** | **Agency** | **Sta. #** | **Surface Geology** | **Seed & Dickenson** (Table A-4) | **UBC 97** (Table A-3) | **This Study** (Table 1) | **Quality** | **Depth**[1] **(m)** | **IR**[2] | **Source**[4] |
|---|---|---|---|---|---|---|---|---|---|---|
| San Jose - Sta. Teresa Hills[3] | CDMG | 57563 | ? | A1 | B? | **B?** | Poor | | | G. |
| Saratoga - Aloha Ave | CDMG | 58065 | Pliocene | AB1? | C | **C2?** | Poor | - | - | G |
| Saratoga - W Valley Coll | CDMG | 58235 | Pleistocene | AB2? | C | **C2?** | Poor | 4-10? | - | G |
| SF - Cliff House | CDMG | 58132 | Franciscan | A1?AB1? | C?B? | **B?** | Poor | 0? | - | |
| SF - Diamond Heights | CDMG | 58130 | Franciscan | AB1 | C | **C1** | Good | 4 s, 11 (w) | 4.7 | T&S |
| SF - Pacific Heights | CDMG | 58131 | Cretaceous | A1 | B | **B** | Good | 6-9(w) | 1.5 | T&S |
| SF - Presidio | CDMG | 58222 | Franciscan ? | AB1 | C | **C1** | Good | 17.5 | 1.9 | 93-376 |
| SF - Rincon Hill | CDMG | 58151 | Franciscan | A1?AB1? | C? | **B?** | Poor | 5 (w) | | T&S (may be wrong boring) |
| SF - Telegraph Hill | CDMG | 58133 | Franciscan | A1?AB1? | C? | **B?** | Fair | 6? | - | T&S |
| SF Intern. Airport | CDMG | 58223 | Holocene | C4-D1-E2 | E | **E1** | Good | 134 | - | T&S,G,92-287 |
| So. San Francisco, Sierra Pt. | CDMG | 58539 | Franciscan | A1 | B | **B** | Good | 4-5(w) | 1.3 | T&S |
| Sunnyvale - Colton Ave. | USGS | 1695 | Holocene | C2 | D | **D1C?** | Good | >60 | - | 94-222,G |
| Sunol Fire St (Calaveras Array)[3] | USGS | SNF | Pleistocene | B1 | C | **D?2S** | Good | 35(>48) | 2 | 94-552 |
| Treasure Island | CDMG | 58117 | Holocene | F | F | **F** | Check | 88 | - | 92-287 |
| UCSC | UCSC | 15 | | AB2 | C? | **C2?** | Poor | | | |
| UCSC Lick Observatory | CDMG | 58135 | Paleozoic | AB2 | C | **C1** | Fair | >13 (w) | - | T&S |
| Woodside | CDMG | 58127 | Eocene | AB2 | C | **B** | Good | 6 | 1.6 | 93-376 |
| Yerba Buena Island | CDMG | 58163 | Franciscan | A1 | B | **C1** | Good | 0? | 2.5 | 92-287 |

Table A-2. (Cont.)

(1) Depth to bedrock obtained from boring log. If no modifier is specified next to the depth value it refers to depth of soil cover over weathered rock. If (w) is indicated, indicates depth of weathering (depth of weathered rock to slightly weathered or unweathered rock)

(2) Estimated Impedance Ratio.

(3) Ground motion sites added to the Walter Silva Database.

(4) Unless specifically omitted, information for all sites was also obtained from Fumal (1991). All other abbreviated source for geological data correspond to the following references:

79-1619 (Silverstein 1979).
92-287 - (Gibbs et al. 1992).
93-376 - (Gibbs et al. 1993).
94-222 - (Gibbs et al. 1994).
94-552 - (Gibbs and Fumal (1993).
Chang - Chang and Bray (1995).
D&L - Duke and Leeds (1962).
G - Geomatrix Consultants (1993).
Geol. - Local geological maps (CDMG).
S&S - Stewart and Stewart (1997).
S&W - Shannon and Wilson (1980).
Stewart - Stewart, J. P. (personal comm.)
T&S - Thiel and Schneider (1993).

Table A-3. Site categories in the 1997 UBC. $\overline{V}_s$ is the average shear wave velocity measured over the upper 100 feet.

| | |
|---|---|
| $S_A$ | Hard rock with measured shear wave velocity, $\overline{V}_s$ > 5000 ft/s. |
| $S_B$ | Rock with 2500 ft/s < $\overline{V}_s$ ≤ 5000 ft/s |
| $S_C$ | Very dense soil and soft rock with 1200 ft/s < $\overline{V}_s$ ≤ 2500 ft/s or with either $\overline{N}$ > 50 or $\bar{s}_u$ ≥ 2000 psf., where $\overline{N}$ is the average Standard Penetration blowcount over the upper 100 ft, and $\bar{s}_u$ is the average undrained shear strength over the upper 100 feet. |
| $S_D$ | Stiff soil with 600 ft/s ≤ $\overline{V}_s$ ≤ 1200 ft/s or with 15 ≤ $\overline{N}$ ≤ 50 or 1000 psf ≤ $\bar{s}_u$ ≤ 2000 psf. |
| $S_E$ | A soil profile with $\overline{V}_s$ < 600 ft/s or any profile with more than 10 ft. of soft clay defined as soil with PI > 20, $w_{mc}$ ≥ 40 percent and $s_u$ < 500 psf. |
| $S_F$ | Soils requiring site-specific evaluation.<br>1. Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils.<br>2. Peats and/or highly organic clays (H > 10 ft of peat and/or highly organic clay where H = thickness of soil.<br>3. Very high plasticity clays (H > 25 ft with PI > 75).<br>4. Very thick soft/medium stiff clays (H > 120 ft). |

Table A4. Seed et al. (1991) site classification system (from Dickenson 1994).

| Site Class | Site Condition | General Description | Site Characteristics[1,2] |
|---|---|---|---|
| ($A_o$) | $A_o$ | Very Hard Rock. | $V_s$ (avg.) > 5,000 ft/sec in top 50 ft. |
| A | $A_1$ | Competent rock with little or no soil and/or weathered rock veneer. | 2,500 ft/sec ≤ $V_s$ (rock) ≤ 5,000 ft/sec, and $H_{soil + weathered\ rock}$ < 40 ft with $V_s$ > 800 ft/sec (in all but the top few feet[3]). |
| AB | $AB_1$ | Soft, fractured and/or weathered rock. | For both $AB_1$ and $AB_2$: 40 ft ≤ $H_{soil + weathered\ rock}$ ≤ 150 ft, and $V_s$ ≥ 800 ft/sec (in all but the top few feet[3]). |
| | $AB_2$ | Stiff, very shallow soil over rock and/or weathered rock. | |
| B | $B_1$ | Deep, primarily cohesionless[4] soils. ($H_{soil}$ ≤ 300 ft.) | No "Soft Clay" (See Note 5), and $H_{cohesive\ soil} < 0.2\ H_{cohesionless\ soil}$. |
| | $B_2$ | Medium depth, stiff cohesive soils and/or mix of cohesionless with stiff cohesive soils; no "Soft Clay." | $H_{all\ soils}$≤ 200 ft., and $V_s$(cohesive soils) > 500 ft/sec. (See Note 5). |
| | $C_1$ | Medium depth, stiff cohesive soils and/or mix of cohesionless with stiff cohesive soils; thin layer(s) of "Soft Clay." | Same as $B_2$ above, except $0 < H_{soft\ clay} \leq 10$ ft. (See Note 5) |
| | $C_2$ | Deep, stiff cohesive soils and/or mix of cohesionless with stiff cohesive soils; no "Soft Clay." | $H_{soil}$ > 200 ft, and $V_s$ (cohesive soils) > 500 ft/sec. |
| | $C_3$ | Very deep, primarily cohesionless soils. | Same as $B_1$ above, except $H_{soil}$ > 300 ft. |
| | $C_4$ | Soft, cohesive soil at small to moderate levels of shaking. | 10 ft. ≤ $H_{soft\ clay}$ ≤ 100 ft, and $A_{max,rock} \leq 0.25$ g |
| D | $D_1$ | Soft, cohesive soil at medium to strong levels of shaking. | 10 ft. ≤ $H_{soft\ clay}$ ≤ 100 ft, and 0.25 g ≤ $A_{max,rock}$ ≤ 0.45 g, or [0.25 g ≤ $A_{max,rock}$ ≤ 0.45 g and M ≤ 7.25] |
| (E)[4] | $E_1$ | Very deep, soft cohesive soil. | $H_{soft\ clay}$ ≥ 100 ft. (See Note 5) |
| | $E_2$ | Soft, cohesive soil and very strong shaking | $H_{soft\ clay}$ ≥ 10 ft., and either: $A_{max,rock}$ ≥ 0.55 g, or $A_{max,rock}$ ≥ 0.45 g and M > 7.25 |
| | $E_3$ | Very high plasticity clays | $H_{clay}$ > 30 ft with PI > 75% and $V_s$ < 800 ft/sec. |
| (F)[7] | $F_1$ | Highly organic and/or peaty soils. | H > 20 ft. of peat and/or highly organic soils |
| | $F_2$ | Sites likely to suffer ground failure due either to significant soil liquefaction of other potential modes of ground instability. | Liquefaction and/or other types of ground failure analysis required. |

(See next page for "notes")

Notes for Table A-4.

1. H = total (vertical) depth of soils of the type or types referred to.

2. $V_s$ = seismic shear wave velocity (ft/sec) at small shear strains (shear strain ≈ $10^{-4}$ %).

3. If surface soils are cohesionless, $V_s$ may be less than 800 ft/sec in top 10 feet.

4. "Cohesionless soils" = soils with less than 30% "fines" by dry weigth;
   "Cohesive soils" = soils with more than 30% "fines" by dry weight, and 15% ≤ PI (fines) ≤ 90%. Soils with more than 30% fines, and PI (fines) < 15% are considered "silty" soils herein, and these should be (conservatively) treated as "cohesive" soils for site clasification purposes in this Table. (Evaluation of approximate $V_s$ for these "silty" soils should be based either on penetration resistance or direct field $V_s$ measurement; see Note 8 below).

5. "Soft Clay" is defined herein as cohesive soil with: (a) Fines content ≥ 30%, (b) PI (fines) ≥ 20%, and (c) $V_s$ ≤ 500 ft/sec.

6. Site-specific geotechnical investigations and dynamic site response analyses are strongly recommended for these conditions. Variability of response characteristics within this class (E) of sites tends to be more highly variable than for classes $A_o$ through D, and the very approximate response projections herein should be applied conservatively in the absence of (strongly recommended) site-specific studies.

7. Site-specific geotechnical investigations and dynamic site response analyses are recquired for these conditions. Potentially significant ground failure must be mitigated, and/or it must be demonstrated that the proposed structure/facility can be engineered to satisfactorily withstand such ground failure.

8. The following approaches are recommended for evaluation of $V_s$:

   (a) For all site conditions, direct (in-situ) measurement of $V_s$ is recommended.
   (b) In lieu of direct measurement, the following empirical approaches can be used:

      (i) For sandy cohesionless soils: either SPT-based or CPT-based empirical correlations may be used.
      (ii) For clayey soils: empirical correlations based on undrained shear strength and/or some combination of one or more of the following can be used (void ratio, water content, plasticity index, etc.) Such correlations tend to be somewhat approximate, and should be interpreted accordingly.
      (iii) Silty soils of low plasticity (PI ≤ 15%) should be treated as "largely cohesionless" soils here; SPT-based or CPT-based empirical correlations may be used (ideally with some "fines" correction relative to "clean sand" correlations.) Silty soils of medium to high plasticity should be treated more like "clayey" soils as in (iii) above.
      (iv) "Other" soil types (e.g. gravelly soils, rockfill, peaty and organic soils, etc.) require considerable judgement, and must be evaluated on an individual basis; no simplified "guidance" can appropriately be offered herein.

# APPENDIX B

Site Visits to Selected Ground Motion Sites

## CONTENTS OF APPENDIX B

## CDMG 24461- Alhambra - Fremont School

**Date:** June 2, 1998
**Time:** 2:00 p.m.
**Instrument:** Could not access to school.

**Description:** The school is located in a flat area north of the Los Angeles basin. Some hills are seen in the SW and NE (about 200 m to the SW and 300 m to the NE) that correspond to units of Miocene Shale in geological maps (Dibblee).

## USC 99 - Arcadia - 855 Arcadia Av.

**Date:** June 3, 1998
**Time:** 3:00 p.m.
**Instrument:** The instrument is located in private property. Could not access it nor locate it.
**Description:** Building is located in a very flat region. Closest relief are the beginning of the San Gabriel Mountains about 1 mile north.

## USC 93- Arcadia - Campus Dr.

**Date:** June 3, 1998
**Time:** 3:30 p.m.
**Instrument:** Inside the school, but not located.

**Description:** The school is located in a very flat region. Closest relief are some hills to the north (about 1 mile, the beginning of the San Gabriel Mountains). The site is far enough from any topographic feature that, from observation alone, it would be assumed that it has thick sedimentary deposits. The C2 classification may be reviewed.

## USC 14 - Beverly Hills - 12520 Mulholland

**Date:** June 3, 1998
**Time:** 11:00 p.m..
**Instrument:** Located in the equipment room of Fire Station #108, about 50 m from the southern end of an esplanade along a cliff on Mulholland Dr.

**Description:** The building is located next to Mulholland Dr., along a cliff in the Santa Monica Mountains. There are canyons on both sides of the fire station, which is build on an esplanade facing lower ranges of the Sta. Monica Mountains in the south side. On the east and west side the slopes are relatively steep (~ 45º). There is some exposed rock in the south of the station, a well-cemented, medium-size grained sandstone (about 100 m. south of the station, in the slope of the south side of the station). There is a rock cut on the north side of Mulholland Dr. showing what could be basalt as indicated in the Dibblee map. A cut in the parking lot (a small 1 $m^3$ manhole opening) shows what could be shale in the south edge of the cut, and sandstone in the north side. Probably is unit Tt in Dibblee.

From this we can infer that the site is in between Tt and Ttls (see Dibblee map for Beverly Hills Quadrangle).

Geological Units mentioned:

**Tt** Middle Topanga formation—mostly interbedded gray to tan semi-friable sandstone and gray micaceous claystone, locally includes lenses of pebbly sandstone and pebble-cobble conglomerate

**Ttls** Lower Topanga formation—mostly tan, semi-friable to hard arkosic sandstone; locally includes gray micaceous shale.

**Recommended Classification from Site Visit:** C1

## USC 13 - Fire Station # 99, 14145 Mulholland

**Date:** June 3, 1998
**Time:** 10:00 a.m.
**Instrument:** At the time of the visit, the instrument was not installed because of work being done in the floor of the building. Normally the instrument is located underneath a stairwell in the office (2 story building).

**Description:** The fire station is located on Mulholland Drive, which is placed along a ridge on the Santa Monica Mountains. To the north, you can overlook the San Fernando Valley, and the Sta. Monica Mountains continue to the south. The location is surrounded by vegetation and heavy brush. There are some recent landslides west of the station, about 1 mile away (on some steep cliffs). Exposed surface beneath the fire station looks like soil, likely residual soil.

An outcrop on 13030 Mulholland, shows highly jointed, yellow-brown, poorly cemented sandstone. Major joint sets dips north (about 70º). In the same road cut there is also a medium to coarse grained sandstone, bedded. Sedimentation plains dip ≈ 70º N, crumbles easily with hand pressure. Another exposure further west shows a deeper soil horizon, also outcrop of sandstone, less weathered and more cemented than the previous one.

**Recommended Classification from Site Visit:** C1

## USC 57: Canyon country – W. Lost Canyon

**Date:** June 2, 1998
**Time:** 2:00 p.m.
**Instrument:** Bolted to concrete floor on a one floor building (Main office, closet next to the lounge)
**Description:** The instrument is located in a valley next to the Santa Clara River.

## USC 65 - Glendora - N. Oakbank

**Date:** June 3, 1998
**Time:** 4:00 p.m.
**Instrument:** Could not access the church. The instrument is located in a church in N. Oakbank.

**Description:**

Very close to the foothills of the San Gabriel Mountains. Site is located in the point where the slope starts to increase, probably in the edge of recent alluvial fans. No inferences can be made with respect to the soil depth.

## USC 34 - LA Fletcher Dr.

**Date:** June 3, 1998
**Time:** 1:00 p.m.
**Instrument:** Located inside the fire station (LA Fire Station 52). Could not access instrument in site visit, building was closed.

**Description:** The site is located in a very broad valley, possibly a deep site.

## CDMG 24271 - Lake Hughes #1 - Fire Station #78

**Date:** June 2, 1998
**Time:** 10:00 a.m.
**Instrument:** Located in the fire station building (1 story garage), bolted on concrete.

**Description:** On edge of hills overlooking the rift valley formed by the San Andreas fault, in the north side of the fault. The fire station is located in the mouth of a small canyon; this may explain why the soil cover is so thick in this station.

## Leona Valley sites (1-6)

CDMG 24305
CDMG 24306
CDMG 24307
CDMG 24308
CDMG 24055
CDMG 24309

**Date:** June 2, 1998
**Time:** 12:00 noon
**Instrument:** All of the instruments located directly on soil. All but #5 have metal instrument shelters with an antenna. #5 has an older instrument shelter.

**Description:**

#1 Located in a large hill in the middle of a (cherry?) orchard. There is a rock outcrop next to the stations (moderately weathered crystalline rock). According to the geologic map, the rock is likely to be Pelona Schist. From this observation, I would classify the site as B.
# 2 Located in a small, broad valley, low relief. To the north there is a hill where #3 is located at about 50 m., to the south is the hill where #1 is located. The bottom of the hill is at about 100 m. from the station. There is a small creek next to the station, exposes about 1 m of gravel and clay. It is impossible to infer the depth of soil from just a cursory observation, but given proximity of hills and older deposits, I would classify this site as C2 or C3.
#3 Located on the top of a hill with moderate slope (slope angle ≈ 20º). Definitely not metamorphic bedrock as indicated in CSMIP. Most likely a C1 site, probably a B site.
#4 Located on the slope of a small hill (about 5 -10 m. high). On the hill there is highly weathered sedimentary rock exposed; crumbles with slight pressure from the hand. You can find quartz pebbles around the station. Inferring from rock behind the instrument, the site is on highly weathered sedimentary rock, likely a C1 site.
#5 On a flat region near a small hill with mild slope. This site is located near a hill, but closer to the larger valley where the SAF is located. This site may be a C2 or a C3 site.
#6 Located on a hill on the north side of the road (N2). The road has been recently moved to allow for the construction of a spillway in the creek running parallel to the San Andreas fault (SAF) (Amargosa creek). The station is located apparently to the north of the main trace of the SAF. to the north of the station there is a small valley and on the other side of the valley there are larger mountains dividing the rift valley from the Antelope valley. Soil around the station is gravelly, angular. A canyon on a creek about 300 m. east of the station exposes sedimentary rock. Due to this observation and the geologic map, I would classify this as a C1 site.

## CDMG 24396 - Malibu, Point Dume School

**Date:** June 4, 1998
**Time:** 10:00 a.m.
**Instrument:** Located in the Point Dume community center office (copy room)

**Description:** Instrument located at the foot of a mild sloping hill (~70 m. from the base of the hill). A shallow soil cover may exist, probably formed from materials transported from the hill. According to the map, the site is in Tertiary Marine deposits.
I would classify the site C1 because in general the tertiary deposits in this zone are weathered. Note that USC 51 is close by and on the same formation; however it is on a hill at a very different elevation than this site.

## CDMG 14404 - Rancho Palos Verdes - Hawthorne Blvd.

**Date:** June 3, 1998
**Time:** 6:30 p.m.
**Instrument:** Located in a small maintenance building (1 story). It could not be accessed. The site, formerly a Loyola Marymount University building, now belongs to the Salvation Army.

**Description:**
Very weathered sandstone, light tan (looks the same formation as for CDMG 14159 Site). Building located against a hill on what appears to be a cut section.

## USC 44 - Rancho Palos Verdes - 30511 Lucania Dr.

**Date:** June 3, 1998
**Time:** 8:00 p.m.
**Instrument:** Located in Mira Catalina School.

**Description:** Site located in the side of a hill facing south. No rock exposures where found close to the site, but the geology is likely to be similar to the CDMG 14159 Site.

## CDMG 14405 - Rolling Hills Estates - Rancho Vista School

**Date:** June 3, 1998
**Time:** 7:00 p.m.
**Instrument:** Located in Rancho Vista School, the school was closed at the time of the visit and access to the exact location of the instrument was not possible.

**Description:** Site is on an esplanade in a hillside facing towards the LA Valley (N).

## CDMG 14159 - San Pedro - Palos Verdes

**Date:** June 3, 1998
**Time:** 6:00 p.m.
**Instrument:** Located in a fire station on 25th Street in front of Whites Park. The instruments in a deposit in the east side of the building (1 story building). The instrument is not the same one that recorded the Northridge earthquake, the previous one was located in the other side of the wall from its current location.

**Description:** The fire station is located in top of a hill overlooking the ocean (at least 80 m from the top of the slope). In Whites Park, south of the site there are some impressive rock exposures:

Sandstone, varies in grain size and color across the exposure, weathered to very weathered at spots. The cut in the slope where rock is exposed is about 40 - 50 m. high. If station were located here, it would be a C1 site, but probably bordering on a B site. Given that the cut has been exposed, weathering in the cut may be due to its exposure, and may not reflect true depth of weathering; therefore the site may also be a B site.

Small slide W of the station (about 500 m) on the side of the road that goes down to Whites Park exposes sandstone, horizontal bedding, lightly tan, fine grained, very weathered. Also layers of hard shale, dark tan, very weathered.

**Recommended Classification from Site Visit:** C?1

## CDMG 24644 - Sandberg - Bald Mountain

**Date:** June 2, 1998
**Time:** 8:00 a.m.
Instrument: Instrument Shelter, placed on ground surface.

**Description:** Site located on the top of a mountain. Low vegetation cover. The surrounding peaks all are dome-shaped; no abrupt peaks are seen. A recently scraped road next to the instrument exposes soil (clay?) with considerable amount of coarse sand-size particles of granitic origin; some larger (1in. - 2 in.) granitic pebbles also found. No outcrops of intact rock visible in the near vicinity.

A small slide (10 m. wide) caused by road work about 0.5 miles east of the station shows what seems to be residual soil at least 3 m deep. Grain size of mother rock (granite, pink) increases downward. Some highly weathered granite blocks seen also at about 1m. deep.

**Recommended Classification from Site Visit:** C1

## USC 77 - Santa Fe Spring - 11500 E. Joslin

**Date:** June 3, 1998
**Time:** 5:00 p.m.
**Instrument:** Located in Lake View School

**Description:** The site was visited because it had the particularity that it was the only C2 site in the LA basin, however, nothing particular in the topography surrounding the site was noticed. From the site visit alone, it is recommended to change the classification to a D site, given that the C2 classification is inferred only from the SCEC shear wave velocity database (see Boore and Brown 1998).

## USGS 5081

**Date:** June 3, 1998
**Time:** 2:00 p.m.
**Instrument:** Instrument located in the NW side of the station, in a small wash room (1 story building) in a fire station. (FS is in the intersection of Topanga Canyon Rd. with Fernwood-Pacific Dr.)

**Description:**

Station located in the wall of a steep canyon (W side of canyon). There is a landslide in the road in front of the station on Topanga Canyon Rd. A driller on the site indicated to me that they found superficial colluvium over sandstone (soft, not well cemented). Strangely, they found a 10 ft. layer of river sand interbedded with the Sandstone.

**Recommended Classification from Site Visit:** C2, although it may be also C1. Station is likely located in landslide deposits.

## CDMG 24047 - Vasquez Rock Park

**Date:** June 2, 1998
**Time:** 3:00 p.m.
**Instrument:** Not located

**Description:** The instrument could not be exactly located due to the high vegetation. The site where the instrument should be located is near a creek bed just north of Vasquez Rock Park.

## USC 51 - Malibu - St. Adams Episcopal Church

**Date:** June 3, 1998
**Time:** 11:00 a.m.
**Instrument:** Located in a small deposit adjacent to the men's room in the church.

**Description:**
Instrument is located in a hill on the N side of Hwy. 1. The hill has relatively steep graded slopes. The instrument is about 30 m from the edge of the slope.

# APPENDIX C

Equations to Obtain Combined Spectral Acceleration Ratios for the Northridge and Loma Prieta Earthquakes

**Formula for Spectral Amplification Factors from Site j to Site i**

The amplification factors from Site j to Site i ($F_{i/j}$) for a given reference peak ground acceleration ($PGA_{ref}$) and a given spectral period are given by the following formula:

$$\ln\left(F_{i/j}\right) = w_{i/j,N}\left[a_{i/j,N} + b_{i/j,N}\ln\left(R_N + c_N\right)\right] + w_{i/j,L}\left[a_{i/j,L} + b_{i/j,L}\ln\left(R_L + c_L\right)\right] \qquad \text{(C1)}$$

where the subscripts N and L denote coefficients for the Northridge and Loma Prieta Earthquakes respectively, $a_{i/j}$ and $b_{i/j}$ are given by Equation 4 (rewritten here for convenience), and are listed in Table C1;

$$a_{i/j} = a(\text{Site i}) - a(\text{Site j}) \qquad \text{(4a)}$$

$$b_{i/j} = b(\text{Site i}) - b(\text{Site j}) \qquad \text{(4b)}$$

a, b, and c are period-dependent coefficients given in Table 3 (rewritten as Table C4 for convenience) for each earthquake; R is the distance corresponding to the reference PGA ($PGA_{ref}$), and is given by:

$$R = e^{\left(\frac{\ln(PGA_{ref}) - a}{b}\right)} - c \qquad \text{(C2)}$$

where a, b, and c are the coefficients given in Table 3 (Table C4) corresponding to the peak ground acceleration (PGA) and $w_{i/j}$ are weights for each earthquakes. If a simple geometric mean of both earthquakes is used, the weights are equal to 0.5 for each earthquake. If the variance-weighted geometric mean is used, the weights are obtained by:

$$w_{i/j,N} = \frac{\left(VAR_{i/j,N}\right)^{-1}}{\left(VAR_{i/j,N}\right)^{-1} + \left(VAR_{i/j,L}\right)^{-1}} \qquad \text{(C3)}$$

for the Northridge Earthquake and:

$$w_{i/j,L} = \frac{\left(VAR_{i/j,L}\right)^{-1}}{\left(VAR_{i/j,N}\right)^{-1} + \left(VAR_{i/j,L}\right)^{-1}} \qquad \text{(C4a)}$$

for the Loma Prieta Earthquake. The variance of the sample mean, $VAR_{i/j}$, is obtained for each earthquake using the following formula:

$$VAR_{i/j} = \frac{\sigma_i^{\ 2}}{N_i} + \frac{\sigma_j^{\ 2}}{N_j} \qquad \text{(C4b)}$$

where $\sigma$ and N are the standard deviation and number of sites corresponding to each site condition, spectral period, and earthquake. The standard deviations are given in Table 3

(Table C4) and the number of sites is a function of period and is given in Table C2. The resulting weights for the variance weighted scheme ($w_{i/j}$) are given in Table C3.

## Standard Deviations

The standard deviations associated with each site condition are obtained using a similar weighting scheme as the amplification factors. For Site i, the standard deviations are given by:

$$\sigma_i^2 = \left(w'_{i,N}\right)\left(\sigma_{i,N}^2\right) + \left(w'_{i,L}\right)\left(\sigma_{i,L}^2\right) \tag{C5}$$

where $\sigma_i$ is the standard deviation and $w'_i$ the weight for site condition i for each earthquake. The weights $w'_i$ are equal to 0.5 if a simple geometric mean of both earthquakes is used. If the variance-weighted geometric mean is used, the weights are obtained by:

$$w_{i,N} = \frac{\left(VAR_{VAR(i),N}\right)^{-1}}{\left(VAR_{VAR(i),N}\right)^{-1} + \left(VAR_{VAR(i),L}\right)^{-1}} \tag{C6a}$$

for the Northridge Earthquake and:

$$w_{i/j,L} = \frac{\left(VAR_{VAR(i),L}\right)^{-1}}{\left(VAR_{VAR(i),N}\right)^{-1} + \left(VAR_{VAR(i),L}\right)^{-1}} \tag{C6b}$$

for the Loma Prieta Earthquake. The variance of the sample variance, $VAR_{VAR(i)}$ is estimated for each earthquake by:

$$VAR_{VAR(i)} = \frac{2(N_i - 1)}{N_i^2} \sigma_i^4 \qquad \text{(C7)}$$

where σ and N are the standard deviation and number of sites corresponding to each site condition, spectral period, and earthquake. The resulting weights, $w'_i$, are given in Table C5.

Table C1. Coefficients for determining spectral amplification ratios (Equation C1).

| | Northridge | | | | | | Loma Prieta | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T** | $a_{c/b}$ | $b_{c/b}$ | $a_{d/b}$ | $b_{d/b}$ | $a_{d/c}$ | $b_{d/c}$ | $a_{c/b}$ | $b_{c/b}$ | $a_{d/b}$ | $b_{d/b}$ | $a_{d/c}$ | $b_{d/c}$ |
| PGA | 0.0000 | 0.1215 | 0.3198 | 0.0592 | 0.3198 | -0.0623 | 0.0993 | 0.0452 | -0.1503 | 0.1922 | -0.2496 | 0.1470 |
| 0.055 | 0.0000 | 0.0922 | 0.1404 | 0.0728 | 0.1404 | -0.0195 | -0.3276 | 0.1334 | -0.5213 | 0.2640 | -0.1937 | 0.1306 |
| 0.06 | 0.0000 | 0.0914 | 0.1449 | 0.0709 | 0.1449 | -0.0205 | -0.3414 | 0.1374 | -0.5322 | 0.2673 | -0.1907 | 0.1299 |
| 0.07 | 0.0000 | 0.0893 | 0.1597 | 0.0653 | 0.1597 | -0.0240 | -0.3589 | 0.1426 | -0.5456 | 0.2717 | -0.1867 | 0.1290 |
| 0.08 | 0.0000 | 0.0875 | 0.1801 | 0.0585 | 0.1801 | -0.0290 | -0.3859 | 0.1515 | -0.5655 | 0.2790 | -0.1796 | 0.1275 |
| 0.09 | 0.0000 | 0.0873 | 0.2017 | 0.0527 | 0.2017 | -0.0346 | -0.4068 | 0.1595 | -0.5793 | 0.2856 | -0.1724 | 0.1261 |
| 0.1 | 0.0000 | 0.0896 | 0.2193 | 0.0497 | 0.2193 | -0.0398 | -0.4141 | 0.1637 | -0.5821 | 0.2891 | -0.1680 | 0.1254 |
| 0.11 | 0.0000 | 0.0917 | 0.2257 | 0.0497 | 0.2257 | -0.0421 | -0.4150 | 0.1665 | -0.5788 | 0.2913 | -0.1638 | 0.1248 |
| 0.12 | 0.0000 | 0.0946 | 0.2306 | 0.0507 | 0.2306 | -0.0440 | -0.4124 | 0.1673 | -0.5740 | 0.2918 | -0.1616 | 0.1245 |
| 0.13 | 0.0000 | 0.0982 | 0.2343 | 0.0525 | 0.2343 | -0.0456 | -0.4100 | 0.1680 | -0.5695 | 0.2922 | -0.1595 | 0.1242 |
| 0.14 | 0.0000 | 0.1022 | 0.2373 | 0.0552 | 0.2373 | -0.0470 | -0.4002 | 0.1682 | -0.5545 | 0.2917 | -0.1543 | 0.1235 |
| 0.15 | 0.0000 | 0.1066 | 0.2401 | 0.0584 | 0.2401 | -0.0482 | -0.3874 | 0.1676 | -0.5346 | 0.2898 | -0.1472 | 0.1222 |
| 0.16 | 0.0000 | 0.1112 | 0.2430 | 0.0621 | 0.2430 | -0.0491 | -0.3740 | 0.1665 | -0.5110 | 0.2866 | -0.1370 | 0.1201 |
| 0.17 | 0.0000 | 0.1158 | 0.2463 | 0.0661 | 0.2463 | -0.0497 | -0.3679 | 0.1659 | -0.4975 | 0.2843 | -0.1297 | 0.1184 |
| 0.18 | 0.0000 | 0.1179 | 0.2482 | 0.0682 | 0.2482 | -0.0498 | -0.3621 | 0.1654 | -0.4848 | 0.2822 | -0.1227 | 0.1168 |
| 0.19 | 0.0000 | 0.1200 | 0.2501 | 0.0701 | 0.2501 | -0.0498 | -0.3537 | 0.1648 | -0.4572 | 0.2768 | -0.1035 | 0.1119 |
| 0.2 | 0.0000 | 0.1237 | 0.2544 | 0.0742 | 0.2544 | -0.0496 | -0.3500 | 0.1650 | -0.4293 | 0.2705 | -0.0793 | 0.1055 |
| 0.22 | 0.0000 | 0.1267 | 0.2593 | 0.0780 | 0.2593 | -0.0487 | -0.3512 | 0.1661 | -0.4018 | 0.2637 | -0.0506 | 0.0976 |
| 0.24 | 0.0000 | 0.1288 | 0.2649 | 0.0815 | 0.2649 | -0.0474 | -0.3541 | 0.1671 | -0.3881 | 0.2600 | -0.0340 | 0.0929 |
| 0.26 | 0.0000 | 0.1294 | 0.2683 | 0.0829 | 0.2683 | -0.0465 | -0.3568 | 0.1679 | -0.3755 | 0.2566 | -0.0187 | 0.0887 |
| 0.28 | 0.0000 | 0.1300 | 0.2714 | 0.0843 | 0.2714 | -0.0457 | -0.3650 | 0.1700 | -0.3508 | 0.2494 | 0.0142 | 0.0793 |
| 0.3 | 0.0000 | 0.1301 | 0.2796 | 0.0862 | 0.2796 | -0.0438 | -0.3736 | 0.1719 | -0.3279 | 0.2423 | 0.0457 | 0.0704 |
| 0.32 | 0.0000 | 0.1291 | 0.2901 | 0.0869 | 0.2901 | -0.0422 | -0.3769 | 0.1723 | -0.3170 | 0.2389 | 0.0599 | 0.0665 |
| 0.34 | 0.0000 | 0.1272 | 0.3039 | 0.0861 | 0.3039 | -0.0410 | -0.3799 | 0.1728 | -0.3067 | 0.2357 | 0.0732 | 0.0629 |
| 0.36 | 0.0000 | 0.1244 | 0.3218 | 0.0836 | 0.3218 | -0.0408 | -0.3804 | 0.1724 | -0.2964 | 0.2325 | 0.0840 | 0.0601 |
| 0.4 | 0.0000 | 0.1209 | 0.3444 | 0.0792 | 0.3444 | -0.0417 | -0.3737 | 0.1688 | -0.2669 | 0.2238 | 0.1068 | 0.0550 |
| 0.44 | 0.0000 | 0.1169 | 0.3718 | 0.0730 | 0.3718 | -0.0439 | -0.3561 | 0.1626 | -0.2461 | 0.2183 | 0.1101 | 0.0557 |
| 0.5 | 0.0000 | 0.1081 | 0.4385 | 0.0562 | 0.4385 | -0.0519 | -0.3135 | 0.1491 | -0.2137 | 0.2110 | 0.0998 | 0.0619 |
| 0.55 | 0.0000 | 0.1038 | 0.4753 | 0.0467 | 0.4753 | -0.0571 | -0.2834 | 0.1399 | -0.1935 | 0.2067 | 0.0899 | 0.0668 |
| 0.6 | 0.0000 | 0.0998 | 0.5120 | 0.0373 | 0.5120 | -0.0625 | -0.2578 | 0.1324 | -0.1770 | 0.2034 | 0.0808 | 0.0710 |
| 0.667 | 0.0000 | 0.0962 | 0.5466 | 0.0288 | 0.5466 | -0.0674 | -0.2267 | 0.1232 | -0.1571 | 0.1994 | 0.0697 | 0.0762 |
| 0.7 | 0.0000 | 0.0933 | 0.5774 | 0.0217 | 0.5774 | -0.0715 | -0.1980 | 0.1149 | -0.1380 | 0.1955 | 0.0599 | 0.0806 |
| 0.75 | 0.0000 | 0.0910 | 0.6030 | 0.0167 | 0.6030 | -0.0743 | -0.1569 | 0.1030 | -0.1109 | 0.1900 | 0.0461 | 0.0870 |
| 0.8 | 0.0000 | 0.0895 | 0.6227 | 0.0139 | 0.6227 | -0.0756 | -0.1148 | 0.0910 | -0.0811 | 0.1839 | 0.0338 | 0.0928 |
| 0.85 | 0.0000 | 0.0888 | 0.6365 | 0.0135 | 0.6365 | -0.0753 | -0.0753 | 0.0798 | -0.0531 | 0.1781 | 0.0222 | 0.0983 |
| 0.9 | 0.0000 | 0.0889 | 0.6448 | 0.0154 | 0.6448 | -0.0735 | 0.0161 | 0.0540 | 0.0173 | 0.1630 | 0.0011 | 0.1090 |
| 0.95 | 0.0000 | 0.0898 | 0.6486 | 0.0195 | 0.6486 | -0.0704 | 0.1146 | 0.0266 | 0.0999 | 0.1448 | -0.0146 | 0.1182 |
| 1.0 | 0.0000 | 0.0914 | 0.6491 | 0.0251 | 0.6491 | -0.0663 | 0.2165 | -0.0017 | 0.1932 | 0.1237 | -0.0233 | 0.1253 |
| 1.1 | 0.0000 | 0.0936 | 0.6475 | 0.0320 | 0.6475 | -0.0616 | 0.3180 | -0.0297 | 0.2941 | 0.1002 | -0.0239 | 0.1298 |
| 1.2 | 0.0000 | 0.0961 | 0.6449 | 0.0395 | 0.6449 | -0.0565 | 0.4150 | -0.0564 | 0.3984 | 0.0753 | -0.0167 | 0.1317 |
| 1.3 | 0.0000 | 0.0987 | 0.6423 | 0.0472 | 0.6423 | -0.0515 | 0.5039 | -0.0809 | 0.5014 | 0.0503 | -0.0025 | 0.1311 |
| 1.4 | 0.0000 | 0.1013 | 0.6402 | 0.0547 | 0.6402 | -0.0466 | 0.5815 | -0.1022 | 0.5984 | 0.0263 | 0.0169 | 0.1285 |
| 1.5 | 0.0000 | 0.1036 | 0.6389 | 0.0614 | 0.6389 | -0.0422 | 0.6458 | -0.1199 | 0.6853 | 0.0044 | 0.0395 | 0.1243 |
| 1.7 | 0.0000 | 0.1072 | 0.6389 | 0.0721 | 0.6389 | -0.0350 | 0.6961 | -0.1338 | 0.7592 | -0.0145 | 0.0631 | 0.1193 |
| 2.0 | 0.0000 | 0.1090 | 0.6411 | 0.0787 | 0.6411 | -0.0302 | 0.7329 | -0.1441 | 0.8187 | -0.0301 | 0.0859 | 0.1140 |
| 2.2 | 0.0000 | 0.1094 | 0.6424 | 0.0806 | 0.6424 | -0.0287 | 0.7459 | -0.1477 | 0.8423 | -0.0363 | 0.0964 | 0.1114 |
| 2.6 | 0.0000 | 0.1096 | 0.6434 | 0.0818 | 0.6434 | -0.0277 | 0.7634 | -0.1526 | 0.8753 | -0.0451 | 0.1119 | 0.1075 |
| 3.0 | 0.0000 | 0.1096 | 0.6441 | 0.0825 | 0.6441 | -0.0272 | 0.7733 | -0.1554 | 0.8958 | -0.0506 | 0.1224 | 0.1048 |

Table C2. Number of sites for each earthquake as a function of site condition and spectral period. The number of sites for periods lower than one second is equal to the number of sites for peak ground acceleration.

| | **Northridge** | | | **Loma Prieta** | | |
|---|---|---|---|---|---|---|
| **T** | **B** | **C** | **D** | **B** | **C** | **D** |
| PGA | 11 | 70 | 59 | 18 | 26 | 18 |
| 1.0 | 11 | 70 | 59 | 18 | 26 | 18 |
| 1.1 | 11 | 70 | 58 | 18 | 26 | 18 |
| 1.2 | 11 | 70 | 58 | 18 | 26 | 18 |
| 1.3 | 11 | 70 | 58 | 18 | 26 | 18 |
| 1.4 | 11 | 69 | 58 | 18 | 26 | 18 |
| 1.5 | 11 | 69 | 58 | 18 | 26 | 18 |
| 1.6 | 11 | 69 | 58 | 18 | 26 | 18 |
| 1.7 | 11 | 67 | 58 | 18 | 26 | 18 |
| 1.8 | 11 | 67 | 58 | 18 | 26 | 18 |
| 1.9 | 11 | 67 | 58 | 18 | 26 | 18 |
| 2.0 | 11 | 67 | 58 | 18 | 26 | 18 |
| 2.2 | 11 | 65 | 57 | 18 | 26 | 18 |
| 2.4 | 11 | 65 | 57 | 18 | 26 | 18 |
| 2.6 | 11 | 65 | 57 | 18 | 26 | 18 |
| 2.8 | 10 | 48 | 41 | 18 | 26 | 18 |
| 3.0 | 10 | 47 | 41 | 18 | 26 | 18 |

Table C3. Weights used to combine spectral amplification ratios for the Northridge and Loma Prieta Earthquakes. Weights are inversely proportional to the variance of the sample mean.

| | Northridge | | | Loma Prieta | | |
|---|---|---|---|---|---|---|
| **T** | **b/c** | **b/d** | **c/d** | **b/c** | **b/d** | **c/d** |
| PGA | 0.56 | 0.64 | 0.70 | 0.44 | 0.36 | 0.30 |
| 0.055 | 0.45 | 0.53 | 0.75 | 0.55 | 0.47 | 0.25 |
| 0.06 | 0.46 | 0.53 | 0.75 | 0.54 | 0.47 | 0.25 |
| 0.07 | 0.46 | 0.53 | 0.75 | 0.54 | 0.47 | 0.25 |
| 0.08 | 0.48 | 0.54 | 0.75 | 0.52 | 0.46 | 0.25 |
| 0.09 | 0.50 | 0.57 | 0.75 | 0.50 | 0.43 | 0.25 |
| 0.1 | 0.54 | 0.60 | 0.75 | 0.46 | 0.40 | 0.25 |
| 0.11 | 0.56 | 0.61 | 0.75 | 0.44 | 0.39 | 0.25 |
| 0.12 | 0.57 | 0.63 | 0.74 | 0.43 | 0.37 | 0.26 |
| 0.13 | 0.58 | 0.64 | 0.74 | 0.42 | 0.36 | 0.26 |
| 0.14 | 0.58 | 0.64 | 0.73 | 0.42 | 0.36 | 0.27 |
| 0.15 | 0.58 | 0.63 | 0.73 | 0.42 | 0.37 | 0.27 |
| 0.16 | 0.57 | 0.62 | 0.72 | 0.43 | 0.38 | 0.28 |
| 0.17 | 0.56 | 0.61 | 0.71 | 0.44 | 0.39 | 0.29 |
| 0.18 | 0.56 | 0.60 | 0.70 | 0.44 | 0.40 | 0.30 |
| 0.19 | 0.55 | 0.60 | 0.69 | 0.45 | 0.40 | 0.31 |
| 0.2 | 0.54 | 0.58 | 0.68 | 0.46 | 0.42 | 0.32 |
| 0.22 | 0.53 | 0.58 | 0.67 | 0.47 | 0.42 | 0.33 |
| 0.24 | 0.52 | 0.57 | 0.66 | 0.48 | 0.43 | 0.34 |
| 0.26 | 0.52 | 0.57 | 0.66 | 0.48 | 0.43 | 0.34 |
| 0.28 | 0.52 | 0.57 | 0.66 | 0.48 | 0.43 | 0.34 |
| 0.3 | 0.52 | 0.57 | 0.66 | 0.48 | 0.43 | 0.34 |
| 0.32 | 0.52 | 0.57 | 0.67 | 0.48 | 0.43 | 0.33 |
| 0.34 | 0.51 | 0.56 | 0.67 | 0.49 | 0.44 | 0.33 |
| 0.36 | 0.51 | 0.56 | 0.67 | 0.49 | 0.44 | 0.33 |
| 0.4 | 0.53 | 0.58 | 0.69 | 0.47 | 0.42 | 0.31 |
| 0.44 | 0.54 | 0.59 | 0.71 | 0.46 | 0.41 | 0.29 |
| 0.5 | 0.55 | 0.61 | 0.73 | 0.45 | 0.39 | 0.27 |
| 0.55 | 0.56 | 0.63 | 0.74 | 0.44 | 0.37 | 0.26 |
| 0.6 | 0.57 | 0.64 | 0.74 | 0.43 | 0.36 | 0.26 |
| 0.667 | 0.57 | 0.65 | 0.75 | 0.43 | 0.35 | 0.25 |
| 0.7 | 0.58 | 0.65 | 0.76 | 0.42 | 0.35 | 0.24 |
| 0.75 | 0.58 | 0.65 | 0.77 | 0.42 | 0.35 | 0.23 |
| 0.8 | 0.57 | 0.65 | 0.77 | 0.43 | 0.35 | 0.23 |
| 0.85 | 0.57 | 0.65 | 0.78 | 0.43 | 0.35 | 0.22 |
| 0.9 | 0.56 | 0.65 | 0.79 | 0.44 | 0.35 | 0.21 |
| 0.95 | 0.56 | 0.65 | 0.80 | 0.44 | 0.35 | 0.20 |
| 1.0 | 0.56 | 0.65 | 0.80 | 0.44 | 0.35 | 0.20 |
| 1.1 | 0.55 | 0.64 | 0.81 | 0.45 | 0.36 | 0.19 |
| 1.2 | 0.55 | 0.64 | 0.81 | 0.45 | 0.36 | 0.19 |
| 1.3 | 0.55 | 0.63 | 0.81 | 0.45 | 0.37 | 0.19 |
| 1.4 | 0.55 | 0.63 | 0.82 | 0.45 | 0.37 | 0.18 |
| 1.5 | 0.55 | 0.63 | 0.82 | 0.45 | 0.37 | 0.18 |
| 1.7 | 0.55 | 0.63 | 0.82 | 0.45 | 0.37 | 0.18 |
| 2.0 | 0.55 | 0.62 | 0.82 | 0.45 | 0.38 | 0.18 |
| 2.2 | 0.55 | 0.62 | 0.82 | 0.45 | 0.38 | 0.18 |
| 2.6 | 0.55 | 0.62 | 0.83 | 0.45 | 0.38 | 0.17 |
| 3.0 | 0.52 | 0.59 | 0.80 | 0.48 | 0.41 | 0.20 |

Table C4a. Regression coefficients and Standard Error for spectral acceleration values at 5% damping for the Northridge Earthquake.

| | B Sites | | | | C Sites | | | | D Sites | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T | a | b | c | σ | a | b | c | σ | a | b | c | σ |
| PGA | 2.3718 | -1.2753 | 6.3883 | 0.3209 | 2.3718 | -1.1538 | 6.3883 | 0.4686 | 2.6916 | -1.2161 | 6.3883 | 0.3559 |
| 0.055 | 3.5192 | -1.4829 | 10.2486 | 0.4343 | 3.5192 | -1.3869 | 10.2486 | 0.4661 | 3.5126 | -1.3703 | 10.2486 | 0.3560 |
| 0.06 | 3.7423 | -1.5138 | 11.8103 | 0.4343 | 3.7423 | -1.4266 | 11.8103 | 0.4655 | 3.7970 | -1.4257 | 11.8103 | 0.3654 |
| 0.07 | 4.3982 | -1.6291 | 14.5768 | 0.4310 | 4.3982 | -1.5480 | 14.5768 | 0.4636 | 4.4475 | -1.5472 | 14.5768 | 0.3705 |
| 0.08 | 4.8097 | -1.7006 | 16.9734 | 0.4180 | 4.8097 | -1.6152 | 16.9734 | 0.4619 | 4.9774 | -1.6422 | 16.9734 | 0.3754 |
| 0.09 | 4.9993 | -1.7175 | 18.0000 | 0.3935 | 4.9993 | -1.6366 | 18.0000 | 0.4617 | 5.2637 | -1.6826 | 18.0000 | 0.3779 |
| 0.1 | 4.9768 | -1.6855 | 18.0000 | 0.3615 | 4.9768 | -1.6089 | 18.0000 | 0.4642 | 5.3000 | -1.6679 | 18.0000 | 0.3774 |
| 0.11 | 4.9365 | -1.6614 | 18.0000 | 0.3457 | 4.9365 | -1.5844 | 18.0000 | 0.4667 | 5.2529 | -1.6439 | 18.0000 | 0.3766 |
| 0.12 | 4.8748 | -1.6330 | 18.0000 | 0.3322 | 4.8748 | -1.5530 | 18.0000 | 0.4703 | 5.1563 | -1.6072 | 18.0000 | 0.3759 |
| 0.13 | 4.7753 | -1.5991 | 18.0000 | 0.3226 | 4.7753 | -1.5140 | 18.0000 | 0.4750 | 5.0044 | -1.5586 | 18.0000 | 0.3758 |
| 0.14 | 4.6161 | -1.5564 | 17.3303 | 0.3179 | 4.6161 | -1.4646 | 17.3303 | 0.4808 | 4.7947 | -1.4991 | 17.3303 | 0.3766 |
| 0.15 | 4.3937 | -1.5041 | 16.0757 | 0.3182 | 4.3937 | -1.4037 | 16.0757 | 0.4877 | 4.5454 | -1.4330 | 16.0757 | 0.3786 |
| 0.16 | 4.1376 | -1.4471 | 14.9021 | 0.3232 | 4.1376 | -1.3364 | 14.9021 | 0.4952 | 4.2958 | -1.3685 | 14.9021 | 0.3820 |
| 0.17 | 3.8807 | -1.3907 | 13.7997 | 0.3315 | 3.8807 | -1.2694 | 13.7997 | 0.5030 | 4.0778 | -1.3133 | 13.7997 | 0.3865 |
| 0.18 | 3.7555 | -1.3635 | 12.7603 | 0.3368 | 3.7555 | -1.2373 | 12.7603 | 0.5069 | 3.9820 | -1.2900 | 12.7603 | 0.3893 |
| 0.19 | 3.6370 | -1.3378 | 11.7771 | 0.3418 | 3.6370 | -1.2069 | 11.7771 | 0.5105 | 3.8913 | -1.2680 | 11.7771 | 0.3918 |
| 0.2 | 3.4048 | -1.2891 | 10.8444 | 0.3531 | 3.4048 | -1.1508 | 10.8444 | 0.5174 | 3.7044 | -1.2249 | 10.8444 | 0.3974 |
| 0.22 | 3.1681 | -1.2413 | 9.1112 | 0.3646 | 3.1681 | -1.0982 | 9.1112 | 0.5234 | 3.4809 | -1.1745 | 9.1112 | 0.4026 |
| 0.24 | 2.9146 | -1.1904 | 7.5290 | 0.3759 | 2.9146 | -1.0449 | 7.5290 | 0.5285 | 3.2196 | -1.1160 | 7.5290 | 0.4071 |
| 0.26 | 2.7904 | -1.1657 | 6.6312 | 0.3818 | 2.7904 | -1.0198 | 6.6312 | 0.5308 | 3.0913 | -1.0874 | 6.6312 | 0.4089 |
| 0.28 | 2.6754 | -1.1429 | 5.8000 | 0.3872 | 2.6754 | -0.9965 | 5.8000 | 0.5330 | 2.9725 | -1.0610 | 5.8000 | 0.4106 |
| 0.3 | 2.5178 | -1.1149 | 4.9000 | 0.3983 | 2.5178 | -0.9682 | 4.9000 | 0.5372 | 2.8087 | -1.0250 | 4.9000 | 0.4129 |
| 0.32 | 2.4644 | -1.1117 | 4.4939 | 0.4087 | 2.4644 | -0.9657 | 4.4939 | 0.5415 | 2.7420 | -1.0110 | 4.4939 | 0.4141 |
| 0.34 | 2.4645 | -1.1197 | 4.4254 | 0.4176 | 2.4645 | -0.9768 | 4.4254 | 0.5463 | 2.7212 | -1.0067 | 4.4254 | 0.4145 |
| 0.36 | 2.4594 | -1.1242 | 4.3606 | 0.4242 | 2.4594 | -0.9870 | 4.3606 | 0.5515 | 2.6916 | -0.9999 | 4.3606 | 0.4142 |
| 0.4 | 2.4375 | -1.1239 | 4.2415 | 0.4276 | 2.4375 | -0.9935 | 4.2415 | 0.5570 | 2.6466 | -0.9915 | 4.2415 | 0.4133 |
| 0.44 | 2.4279 | -1.1279 | 4.1337 | 0.4277 | 2.4279 | -1.0049 | 4.1337 | 0.5627 | 2.6269 | -0.9946 | 4.1337 | 0.4119 |
| 0.5 | 2.4692 | -1.1545 | 3.9890 | 0.4198 | 2.4692 | -1.0526 | 3.9890 | 0.5739 | 2.7651 | -1.0629 | 3.9890 | 0.4066 |
| 0.55 | 2.4447 | -1.1582 | 3.8812 | 0.4140 | 2.4447 | -1.0682 | 3.8812 | 0.5792 | 2.8613 | -1.1091 | 3.8812 | 0.4023 |
| 0.6 | 2.3687 | -1.1540 | 3.7828 | 0.4090 | 2.3687 | -1.0710 | 3.7828 | 0.5843 | 2.9263 | -1.1469 | 3.7828 | 0.3968 |
| 0.667 | 2.2699 | -1.1513 | 3.6630 | 0.4060 | 2.2699 | -1.0675 | 3.6630 | 0.5892 | 2.9650 | -1.1752 | 3.6630 | 0.3901 |
| 0.7 | 2.1804 | -1.1550 | 3.6084 | 0.4059 | 2.1804 | -1.0660 | 3.6084 | 0.5937 | 2.9956 | -1.1995 | 3.6084 | 0.3826 |
| 0.75 | 2.1276 | -1.1664 | 3.5303 | 0.4090 | 2.1276 | -1.0746 | 3.5303 | 0.5977 | 3.0096 | -1.2199 | 3.5303 | 0.3750 |
| 0.8 | 2.1239 | -1.1848 | 3.4573 | 0.4151 | 2.1239 | -1.0966 | 3.4573 | 0.6009 | 2.9754 | -1.2294 | 3.4573 | 0.3680 |
| 0.85 | 2.1516 | -1.2064 | 3.3887 | 0.4235 | 2.1516 | -1.1267 | 3.3887 | 0.6030 | 2.8866 | -1.2261 | 3.3887 | 0.3621 |
| 0.9 | 2.1703 | -1.2244 | 3.4413 | 0.4332 | 2.1703 | -1.1539 | 3.4413 | 0.6041 | 2.7784 | -1.2185 | 3.4413 | 0.3579 |
| 0.95 | 2.1451 | -1.2353 | 3.2629 | 0.4435 | 2.1451 | -1.1701 | 3.2629 | 0.6041 | 2.6965 | -1.2187 | 3.2629 | 0.3556 |
| 1.0 | 2.0734 | -1.2443 | 3.2048 | 0.4538 | 2.0734 | -1.1775 | 3.2048 | 0.6033 | 2.6601 | -1.2333 | 3.2048 | 0.3551 |
| 1.1 | 1.9888 | -1.2635 | 3.0970 | 0.4637 | 1.9888 | -1.1873 | 3.0970 | 0.6017 | 2.6461 | -1.2583 | 3.0970 | 0.3563 |
| 1.2 | 1.9252 | -1.2983 | 2.9986 | 0.4726 | 1.9252 | -1.2071 | 2.9986 | 0.5995 | 2.6099 | -1.2804 | 2.9986 | 0.3587 |
| 1.3 | 1.8811 | -1.3390 | 2.9080 | 0.4799 | 1.8811 | -1.2317 | 2.9080 | 0.5962 | 2.5295 | -1.2884 | 2.9080 | 0.3618 |
| 1.4 | 1.8327 | -1.3706 | 2.8242 | 0.4799 | 1.8327 | -1.2510 | 2.8242 | 0.5909 | 2.4272 | -1.2846 | 2.8242 | 0.3649 |
| 1.5 | 1.7582 | -1.3853 | 2.7461 | 0.4799 | 1.7582 | -1.2588 | 2.7461 | 0.5850 | 2.3331 | -1.2785 | 2.7461 | 0.3664 |
| 1.7 | 1.5420 | -1.3800 | 2.6045 | 0.4799 | 1.5420 | -1.2565 | 2.6045 | 0.5800 | 2.1862 | -1.2817 | 2.6045 | 0.3811 |
| 2.0 | 1.3896 | -1.3970 | 2.4206 | 0.4799 | 1.3896 | -1.2933 | 2.4206 | 0.5700 | 2.0500 | -1.3154 | 2.4206 | 0.4130 |
| 2.2 | 1.2440 | -1.3983 | 2.3128 | 0.4799 | 1.2440 | -1.3004 | 2.3128 | 0.5600 | 1.8906 | -1.3182 | 2.3128 | 0.4244 |
| 2.6 | 0.9829 | -1.3739 | 2.1238 | 0.4799 | 0.9829 | -1.2719 | 2.1238 | 0.5400 | 1.6293 | -1.2941 | 2.1238 | 0.4145 |
| 3.0 | 0.6859 | -1.3338 | 2.0000 | 0.4799 | 0.6859 | -1.2207 | 2.0000 | 0.5200 | 1.3413 | -1.2536 | 2.0000 | 0.3877 |

Table C4b. Regression coefficients and Standard Error for spectral acceleration values at 5% damping for the Loma Prieta Earthquake.

| | **B Sites** | | | | **C Sites** | | | | **D Sites** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T** | **a** | **b** | **c** | **σ** | **a** | **b** | **c** | **σ** | **a** | **b** | **c** | **σ** |
| PGA | 0.7219 | -0.7954 | 1.0000 | 0.4713 | 0.8212 | -0.7502 | 1.0000 | 0.3111 | 0.5716 | -0.6032 | 1.0000 | 0.3896 |
| 0.055 | 1.6308 | -0.9794 | 1.0000 | 0.4566 | 1.4230 | -0.8769 | 1.0000 | 0.3708 | 1.3201 | -0.7767 | 1.0000 | 0.4334 |
| 0.06 | 1.8207 | -1.0119 | 1.0000 | 0.4561 | 1.4804 | -0.8841 | 1.0000 | 0.3747 | 1.2568 | -0.7489 | 1.0000 | 0.4338 |
| 0.07 | 1.9001 | -1.0181 | 1.0000 | 0.4554 | 1.4819 | -0.8734 | 1.0000 | 0.3798 | 1.2413 | -0.7315 | 1.0000 | 0.4340 |
| 0.08 | 2.0559 | -1.0383 | 1.0000 | 0.4538 | 1.5348 | -0.8701 | 1.0000 | 0.3886 | 1.3041 | -0.7271 | 1.0000 | 0.4331 |
| 0.09 | 2.1619 | -1.0489 | 1.0000 | 0.4518 | 1.5875 | -0.8642 | 1.0000 | 0.3973 | 1.4037 | -0.7300 | 1.0000 | 0.4303 |
| 0.1 | 2.2305 | -1.0551 | 1.0000 | 0.4500 | 1.6419 | -0.8595 | 1.0000 | 0.4027 | 1.5122 | -0.7400 | 1.0000 | 0.4269 |
| 0.11 | 2.2946 | -1.0607 | 1.0000 | 0.4481 | 1.7031 | -0.8527 | 1.0000 | 0.4074 | 1.6341 | -0.7524 | 1.0000 | 0.4220 |
| 0.12 | 2.3215 | -1.0625 | 1.0000 | 0.4472 | 1.7361 | -0.8492 | 1.0000 | 0.4091 | 1.6890 | -0.7575 | 1.0000 | 0.4187 |
| 0.13 | 2.3462 | -1.0642 | 1.0000 | 0.4464 | 1.7665 | -0.8461 | 1.0000 | 0.4108 | 1.7395 | -0.7622 | 1.0000 | 0.4157 |
| 0.14 | 2.3659 | -1.0613 | 1.0000 | 0.4451 | 1.8339 | -0.8450 | 1.0000 | 0.4124 | 1.7916 | -0.7621 | 1.0000 | 0.4084 |
| 0.15 | 2.3410 | -1.0484 | 1.0000 | 0.4448 | 1.9079 | -0.8523 | 1.0000 | 0.4120 | 1.7724 | -0.7458 | 1.0000 | 0.4004 |
| 0.16 | 2.2804 | -1.0268 | 1.0000 | 0.4460 | 1.9696 | -0.8621 | 1.0000 | 0.4095 | 1.7156 | -0.7191 | 1.0000 | 0.3924 |
| 0.17 | 2.2370 | -1.0125 | 1.0000 | 0.4476 | 1.9792 | -0.8631 | 1.0000 | 0.4071 | 1.6926 | -0.7066 | 1.0000 | 0.3888 |
| 0.18 | 2.1960 | -0.9991 | 1.0000 | 0.4491 | 1.9882 | -0.8640 | 1.0000 | 0.4049 | 1.6710 | -0.6949 | 1.0000 | 0.3853 |
| 0.19 | 2.0939 | -0.9675 | 1.0000 | 0.4545 | 1.9513 | -0.8531 | 1.0000 | 0.3989 | 1.6405 | -0.6754 | 1.0000 | 0.3797 |
| 0.2 | 1.9861 | -0.9352 | 1.0000 | 0.4626 | 1.8633 | -0.8291 | 1.0000 | 0.3923 | 1.5961 | -0.6551 | 1.0000 | 0.3761 |
| 0.22 | 1.8879 | -0.9051 | 1.0000 | 0.4731 | 1.7414 | -0.7944 | 1.0000 | 0.3861 | 1.5361 | -0.6348 | 1.0000 | 0.3748 |
| 0.24 | 1.8523 | -0.8933 | 1.0000 | 0.4797 | 1.6772 | -0.7749 | 1.0000 | 0.3837 | 1.5154 | -0.6295 | 1.0000 | 0.3754 |
| 0.26 | 1.8196 | -0.8825 | 1.0000 | 0.4858 | 1.6182 | -0.7570 | 1.0000 | 0.3815 | 1.4963 | -0.6245 | 1.0000 | 0.3759 |
| 0.28 | 1.8136 | -0.8775 | 1.0000 | 0.5001 | 1.5268 | -0.7272 | 1.0000 | 0.3796 | 1.5140 | -0.6328 | 1.0000 | 0.3796 |
| 0.3 | 1.8860 | -0.8959 | 1.0000 | 0.5149 | 1.4800 | -0.7104 | 1.0000 | 0.3812 | 1.5933 | -0.6598 | 1.0000 | 0.3859 |
| 0.32 | 1.9446 | -0.9120 | 1.0000 | 0.5223 | 1.4703 | -0.7068 | 1.0000 | 0.3841 | 1.6498 | -0.6788 | 1.0000 | 0.3906 |
| 0.34 | 1.9996 | -0.9271 | 1.0000 | 0.5292 | 1.4613 | -0.7033 | 1.0000 | 0.3868 | 1.7028 | -0.6968 | 1.0000 | 0.3950 |
| 0.36 | 2.0373 | -0.9373 | 1.0000 | 0.5358 | 1.4510 | -0.7011 | 1.0000 | 0.3916 | 1.7453 | -0.7128 | 1.0000 | 0.4012 |
| 0.4 | 2.0412 | -0.9393 | 1.0000 | 0.5524 | 1.3972 | -0.6925 | 1.0000 | 0.4092 | 1.7829 | -0.7364 | 1.0000 | 0.4219 |
| 0.44 | 1.8966 | -0.9057 | 1.0000 | 0.5600 | 1.3081 | -0.6785 | 1.0000 | 0.4251 | 1.6708 | -0.7148 | 1.0000 | 0.4396 |
| 0.5 | 1.5766 | -0.8357 | 1.0000 | 0.5658 | 1.0905 | -0.6402 | 1.0000 | 0.4486 | 1.3791 | -0.6481 | 1.0000 | 0.4659 |
| 0.55 | 1.3683 | -0.7909 | 1.0000 | 0.5678 | 0.9405 | -0.6134 | 1.0000 | 0.4616 | 1.1859 | -0.6031 | 1.0000 | 0.4808 |
| 0.6 | 1.2193 | -0.7593 | 1.0000 | 0.5685 | 0.8299 | -0.5944 | 1.0000 | 0.4699 | 1.0459 | -0.5707 | 1.0000 | 0.4906 |
| 0.667 | 1.0380 | -0.7209 | 1.0000 | 0.5694 | 0.6953 | -0.5713 | 1.0000 | 0.4799 | 0.8757 | -0.5314 | 1.0000 | 0.5025 |
| 0.7 | 0.9158 | -0.6959 | 1.0000 | 0.5700 | 0.5954 | -0.5543 | 1.0000 | 0.4867 | 0.7392 | -0.4998 | 1.0000 | 0.5112 |
| 0.75 | 0.7412 | -0.6602 | 1.0000 | 0.5708 | 0.4527 | -0.5302 | 1.0000 | 0.4965 | 0.5444 | -0.4547 | 1.0000 | 0.5235 |
| 0.8 | 0.6212 | -0.6371 | 1.0000 | 0.5719 | 0.3418 | -0.5106 | 1.0000 | 0.5038 | 0.3623 | -0.4116 | 1.0000 | 0.5335 |
| 0.85 | 0.5083 | -0.6155 | 1.0000 | 0.5728 | 0.2376 | -0.4923 | 1.0000 | 0.5106 | 0.1913 | -0.3712 | 1.0000 | 0.5428 |
| 0.9 | 0.2964 | -0.5761 | 1.0000 | 0.5760 | 0.0693 | -0.4630 | 1.0000 | 0.5215 | -0.1385 | -0.2932 | 1.0000 | 0.5598 |
| 0.95 | 0.0614 | -0.5335 | 1.0000 | 0.5803 | -0.0415 | -0.4494 | 1.0000 | 0.5296 | -0.3583 | -0.2461 | 1.0000 | 0.5739 |
| 1.0 | -0.1915 | -0.4913 | 1.0000 | 0.5854 | -0.0967 | -0.4555 | 1.0000 | 0.5354 | -0.4193 | -0.2456 | 1.0000 | 0.5852 |
| 1.1 | -0.4301 | -0.4563 | 1.0000 | 0.5904 | -0.1041 | -0.4806 | 1.0000 | 0.5401 | -0.3485 | -0.2856 | 1.0000 | 0.5936 |
| 1.2 | -0.6336 | -0.4304 | 1.0000 | 0.5941 | -0.0738 | -0.5215 | 1.0000 | 0.5450 | -0.2165 | -0.3463 | 1.0000 | 0.5996 |
| 1.3 | -0.8156 | -0.4103 | 1.0000 | 0.5953 | -0.0320 | -0.5691 | 1.0000 | 0.5511 | -0.0920 | -0.4091 | 1.0000 | 0.6035 |
| 1.4 | -1.0118 | -0.3912 | 1.0000 | 0.5931 | -0.0357 | -0.6071 | 1.0000 | 0.5593 | -0.0276 | -0.4612 | 1.0000 | 0.6063 |
| 1.5 | -1.2503 | -0.3703 | 1.0000 | 0.5874 | -0.1493 | -0.6191 | 1.0000 | 0.5697 | -0.0722 | -0.4911 | 1.0000 | 0.6087 |
| 1.7 | -1.5259 | -0.3501 | 1.0000 | 0.5785 | -0.3975 | -0.6017 | 1.0000 | 0.5819 | -0.2535 | -0.4925 | 1.0000 | 0.6117 |
| 2.0 | -1.7950 | -0.3397 | 1.0000 | 0.5674 | -0.7453 | -0.5663 | 1.0000 | 0.5950 | -0.5395 | -0.4756 | 1.0000 | 0.6160 |
| 2.2 | -1.9108 | -0.3426 | 1.0000 | 0.5611 | -0.9419 | -0.5467 | 1.0000 | 0.6018 | -0.7079 | -0.4662 | 1.0000 | 0.6187 |
| 2.6 | -2.0796 | -0.3504 | 1.0000 | 0.5508 | -1.2418 | -0.5188 | 1.0000 | 0.6119 | -0.9767 | -0.4513 | 1.0000 | 0.6233 |
| 3.0 | -2.1924 | -0.3596 | 1.0000 | 0.5428 | -1.4567 | -0.5011 | 1.0000 | 0.6189 | -1.1824 | -0.4400 | 1.0000 | 0.6268 |
| 3.4 | -2.3459 | -0.3686 | 1.0000 | 0.5302 | -1.7104 | -0.4873 | 1.0000 | 0.6263 | -1.5020 | -0.4122 | 1.0000 | 0.6310 |
| 4.0 | -2.4736 | -0.3683 | 1.0000 | 0.5170 | -1.8745 | -0.4834 | 1.0000 | 0.6284 | -1.7876 | -0.3769 | 1.0000 | 0.6319 |

Table C5. Weights used to combine standard deviations for the Northridge and Loma Prieta Earthquakes. Weights are inversely proportional to the variance of the sample variance.

| | Northridge | | | Loma Prieta | | |
|---|---|---|---|---|---|---|
| **T** | **B** | **C** | **D** | **B** | **C** | **D** |
| PGA | 0.75 | 0.34 | 0.82 | 0.25 | 0.66 | 0.18 |
| 0.055 | 0.44 | 0.51 | 0.87 | 0.56 | 0.49 | 0.13 |
| 0.06 | 0.44 | 0.52 | 0.86 | 0.56 | 0.48 | 0.14 |
| 0.07 | 0.44 | 0.54 | 0.86 | 0.56 | 0.46 | 0.14 |
| 0.08 | 0.47 | 0.57 | 0.85 | 0.53 | 0.43 | 0.15 |
| 0.09 | 0.52 | 0.59 | 0.84 | 0.48 | 0.41 | 0.16 |
| 0.1 | 0.60 | 0.60 | 0.84 | 0.40 | 0.40 | 0.16 |
| 0.11 | 0.64 | 0.60 | 0.83 | 0.36 | 0.40 | 0.17 |
| 0.12 | 0.68 | 0.60 | 0.83 | 0.32 | 0.40 | 0.17 |
| 0.13 | 0.70 | 0.59 | 0.83 | 0.30 | 0.41 | 0.17 |
| 0.14 | 0.71 | 0.59 | 0.81 | 0.29 | 0.41 | 0.19 |
| 0.15 | 0.71 | 0.57 | 0.80 | 0.29 | 0.43 | 0.20 |
| 0.16 | 0.70 | 0.55 | 0.78 | 0.30 | 0.45 | 0.22 |
| 0.17 | 0.68 | 0.53 | 0.76 | 0.32 | 0.47 | 0.24 |
| 0.18 | 0.67 | 0.52 | 0.75 | 0.33 | 0.48 | 0.25 |
| 0.19 | 0.66 | 0.49 | 0.74 | 0.34 | 0.51 | 0.26 |
| 0.2 | 0.65 | 0.46 | 0.72 | 0.35 | 0.54 | 0.28 |
| 0.22 | 0.64 | 0.44 | 0.70 | 0.36 | 0.56 | 0.30 |
| 0.24 | 0.63 | 0.42 | 0.69 | 0.37 | 0.58 | 0.31 |
| 0.26 | 0.62 | 0.41 | 0.69 | 0.38 | 0.59 | 0.31 |
| 0.28 | 0.64 | 0.40 | 0.70 | 0.36 | 0.60 | 0.30 |
| 0.3 | 0.64 | 0.40 | 0.71 | 0.36 | 0.60 | 0.29 |
| 0.32 | 0.63 | 0.40 | 0.71 | 0.37 | 0.60 | 0.29 |
| 0.34 | 0.62 | 0.40 | 0.72 | 0.38 | 0.60 | 0.28 |
| 0.36 | 0.62 | 0.40 | 0.73 | 0.38 | 0.60 | 0.27 |
| 0.4 | 0.64 | 0.43 | 0.77 | 0.36 | 0.57 | 0.23 |
| 0.44 | 0.65 | 0.46 | 0.80 | 0.35 | 0.54 | 0.20 |
| 0.5 | 0.68 | 0.50 | 0.84 | 0.32 | 0.50 | 0.16 |
| 0.55 | 0.69 | 0.51 | 0.87 | 0.31 | 0.49 | 0.13 |
| 0.6 | 0.70 | 0.52 | 0.88 | 0.30 | 0.48 | 0.12 |
| 0.667 | 0.71 | 0.54 | 0.90 | 0.29 | 0.46 | 0.10 |
| 0.7 | 0.71 | 0.54 | 0.91 | 0.29 | 0.46 | 0.09 |
| 0.75 | 0.71 | 0.56 | 0.92 | 0.29 | 0.44 | 0.08 |
| 0.8 | 0.70 | 0.56 | 0.93 | 0.30 | 0.44 | 0.07 |
| 0.85 | 0.68 | 0.57 | 0.94 | 0.32 | 0.43 | 0.06 |
| 0.9 | 0.66 | 0.59 | 0.95 | 0.34 | 0.41 | 0.05 |
| 0.95 | 0.65 | 0.61 | 0.96 | 0.35 | 0.39 | 0.04 |
| 1.0 | 0.64 | 0.62 | 0.96 | 0.36 | 0.38 | 0.04 |
| 1.1 | 0.63 | 0.63 | 0.96 | 0.37 | 0.37 | 0.04 |
| 1.2 | 0.61 | 0.64 | 0.96 | 0.39 | 0.36 | 0.04 |
| 1.3 | 0.60 | 0.66 | 0.96 | 0.40 | 0.34 | 0.04 |
| 1.4 | 0.60 | 0.68 | 0.96 | 0.40 | 0.32 | 0.04 |
| 1.5 | 0.59 | 0.70 | 0.96 | 0.41 | 0.30 | 0.04 |
| 1.7 | 0.57 | 0.72 | 0.95 | 0.43 | 0.28 | 0.05 |
| 2.0 | 0.55 | 0.75 | 0.94 | 0.45 | 0.25 | 0.06 |
| 2.2 | 0.54 | 0.77 | 0.93 | 0.46 | 0.23 | 0.07 |
| 2.6 | 0.52 | 0.80 | 0.94 | 0.48 | 0.20 | 0.06 |
| 3.0 | 0.49 | 0.78 | 0.94 | 0.51 | 0.22 | 0.06 |

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