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Analysis of frequency dependence of some strong motion parameters for different soil conditions

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ABSTRACT: Recent trends in seismic engineering are aimed at characterizing the ground motion from earthquakes through the whole spectral shape instead of only using peak acceleration values.

Seismic design of structures requires the knowledge of predominant periods of motions in addition to their amplitudes. Since the relationship among these periods and the natural frequency of soil is of utmost importance in attenuation or amplification effects, it is necessary to take into account soil conditions in prediction of ground motion.

In this paper, strong motion records of the San Fernando 1971 earthquake, are used in order to analyze the frequency dependence of some spectral parameters for the frequency range between 0.25 and 10 Hz. The influence of soil, presented through a simple classification, has been studied as well.

Finally, some attenuation laws for different periods are proposed as results of the regression analysis accomplished.

1 INTRODUCTION

In contrast to the more traditional approach, recent trends in strong motion prediction are aimed at estimating the same probability of exceedance of response and Fourier spectra in the whole range of frequencies of engineering interest. This procedure, instead of dealing with the peak ground acceleration at the high frequency asymptote of the spectrum, builds it point by point by using spectral parameters attenuation laws. The result, known as Uniform Hazard Spectrum (U.H.S.), is particularly useful to design structures which cannot be modelled as single degree of freedom systems. A cornerstone in the method is the application of appropriate attenuation relations for every considered frequency. These relations can be inferred through regression analysis of observed strong ground motion data corresponding to either Fourier or response spectral parameters.

On the other hand, it is well known that local site conditions are responsible for important ground motion amplification and attenuation effects. However, the influence of the soil type on different frequencies of movement and the relation between its predominant period and the natural period of soil are not well established.

In accordance with these considerations, a regression analysis of accelerograms of the San Fernando earthquake, has been done. The respective Fourier amplitude spectra, FA, and response spectra in terms of acceleration, SA, and pseudo-velocity, PSV, have been analyzed, to obtain the correspondent attenuation laws. The study has been made for 5 per cent of critical damping and frequencies of 0.25, 0.5, 1, 2, 5 and 10 Hz. Soil conditions have also been considered in the regression to allow us to study the dependence of the soil effect in the motion frequency.

2 STRONG MOTION DATA USED IN THE ANALYSIS

2.1 Selection of recordings

A selection of 76 accelerograms from the San Fernando 1971 earthquake obtained in free field, basement and ground floor stations has been used in the analysis. As the study of the soil influence on the movement contitutes one of the main goals of this analysis, no soil condition has been imposed as a recording selection criterion. For each station, the maximum acceleration of the horizontal components has been taken. All the accelerograms come from the Caltech Data Bank and have been filtered at cut-off frequencies of 0.07 and 25 Hz.

Information concerning epicentral distances and soil conditions has been taken from Hudson (1971) and Trifunac and Brady (1975), respectively. Soil influence has been introduced through the S factor that, according to the Trifunac and Brady (1975) classification, takes values of 0, 1 and 2 for soft, intermediate and rock soils respectively. The model of attenuation has been set forth as a function of hypocentral distance calculated by accepting a focal depth of 8.4 km (Allen et al., 1975). In this way, the data cover a distance range from 11.6 to 139.3 km and the peak ground accelerations vary between 26 and 1148 cm/s^2. The distribution of soil conditions is as follows; 45 stations were located on soft soils, 9 were settled on rock and the remaining 22 were placed on intermediate soils.

The frequencies chosen for the analysis are the same as those taken by Dahle et al. (1990) in their study of attenuation models. This is due to the following fact: the two lowest frequencies, 0.25 and 0.5 Hz, lie within the range in which the response spectrum is usually constant in displacement, while the next two of 1 and 2 Hz correspond to the part of the spectrum constant in velocity and the last two fequencies, 5 and 10 Hz, belong to the range of the constant acceleration response.

Therefore it is possible to obtain a representation of the three branches of the spectrum.

2.2 Distribution of spectral parameters

The first step in the study consists of analyzing the amplitude distributions of FA, SA and PSV. Values observed for these parameters have been represented versus hypocentral distance and class of soil in 3-D diagrams for the different frequencies of the study. As examples of the found distributions, figures 1, 2, 3 and 4 display values of FA and SA for frequencies of 0.5, 1, 5, and 10 Hz, respectively. PSV diagrams have been not included because they present a distribution similar to that of SA with different scale of values. There are several of the most significant features of these data distributions discussed hereafter.

- For a given distance and a fixed soil type, FA and PSV grow when the frequency increases between 0.25 and 1 Hz and diminish when the parameter varies between 1 and 10 Hz. In its turn, the spectral acceleration reaches the maximum value at 5 Hz after increasing gradually from 0.25 Hz. This means that the spectral velocity gets maximum values at lower frequencies than the spectral acceleration, as it can be expected given the frequential composition of PSV.
- For all three kinds of studied spectra, the greatest amplitudes appear at short distances when stations are settled on hard soil or rock. The Figures show a clear increase of the slope when both conditions are met. The strong influence of the acceleration value at Pacoima Dam station (hypocentral distance 11 km) can be clearly noticed in this part of the diagrams.
- Fourier spectrum shows the highest sensitivity to the soil conditions for a frequency of 2 Hz. Figure 2 reveals the appearance of significative peaks at distances shorter than 20 km on hard soil, whereas for intermediate soils these peaks appear between 20 and 75 km and for soft soils between 40 and 135 km. Therefore, a migration of peak values to greater distances due to local effects can be noticed when hard soils are considered instead of softer ones.
- Finally, a very small attenuation of spectral parameters between 12 and 22 km, when intermediate or soft soils are taken, can be pointed out as a common trait for all frecuencies equal or greater than 0.5 Hz. Rock soils present the opposite effect, i.e. a strong attenuation for these distances. The three parameters show a clear decrease for distances varying between 22 and 75 km, when the frequency is higher than 0.5 Hz. The figures corresponding to 0.25 Hz do not show such clear trends due to the lack of linearity of the three types of soil for this frequency.

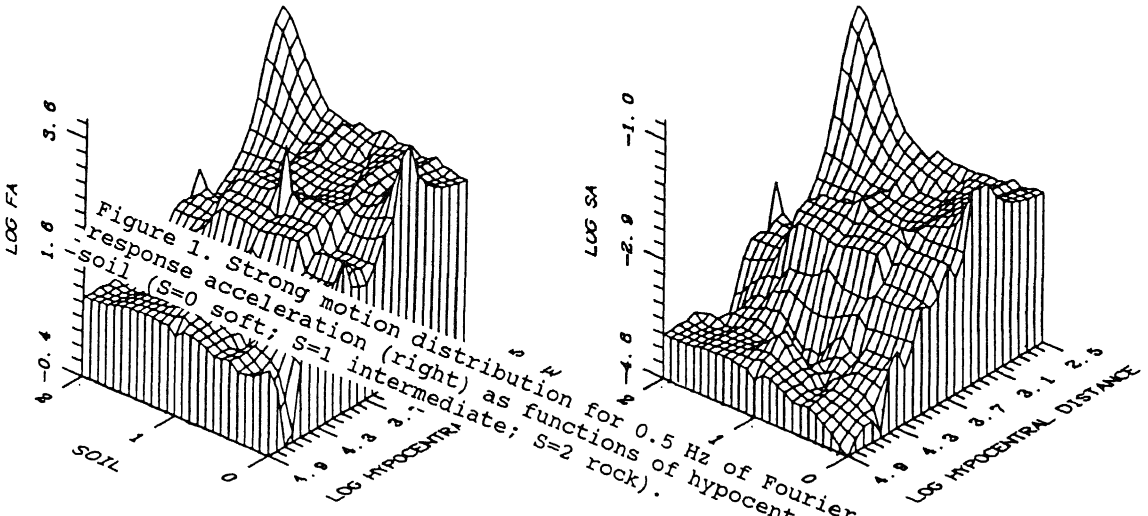

Figure 1. Strong motion distribution for 0.5 Hz of Fourier amplitude (left) and response acceleration (right) as functions of hypocentral distance and class of soil (S=0 soft; S=1 intermediate; S=2 rock).

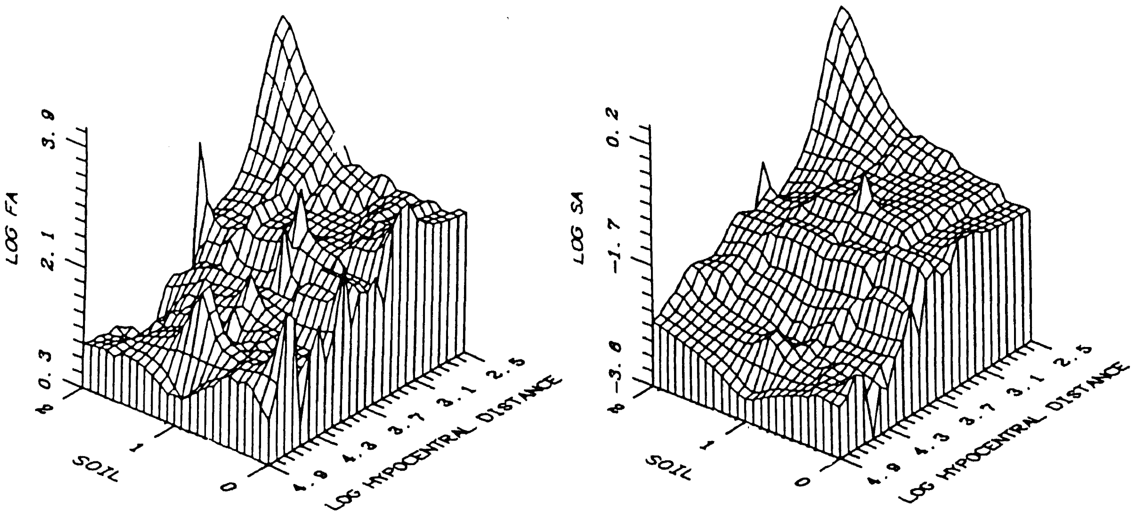

Figure 2. As figure 1 for 1 Hz.

3 CONSIDERATIONS ABOUT SOIL EFFECTS

As it is well known, the soil composition is responsible for local amplification or attenuation effects on the ground motion. These effects depend on the frequency of the motion and may be different for each spectral parameter.

Many authors have noticed the existence of a cross-over period near 0.2 s. Over this period, the amplification on soft soil is greater than that on rock and the relation is reversed for smaller periods (Joyner and Boore, 1982; Kawashima et al., 1986). This fact is an evidence of the frequency dependence on the soil

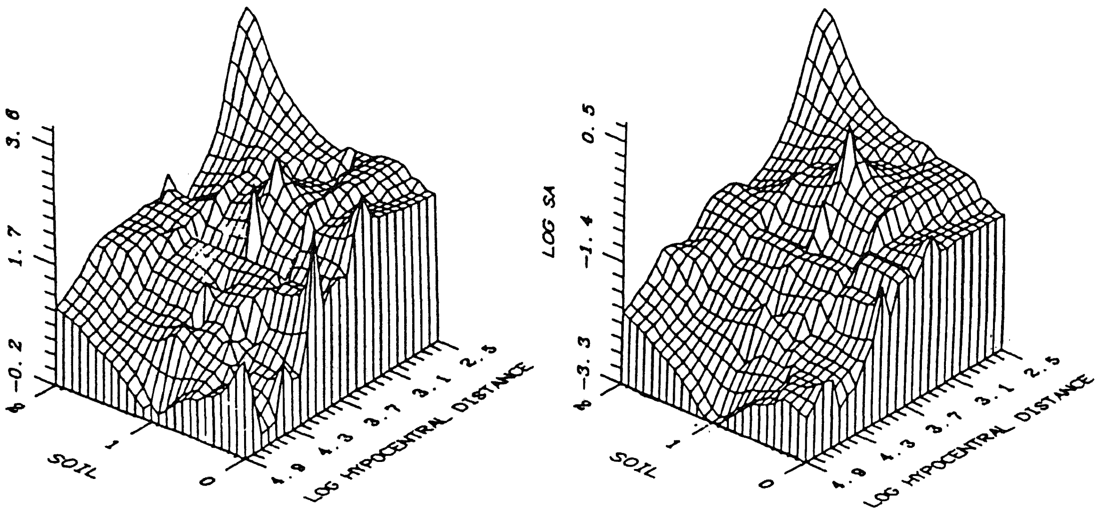

Figure 3. As figure 1 for 5 Hz.

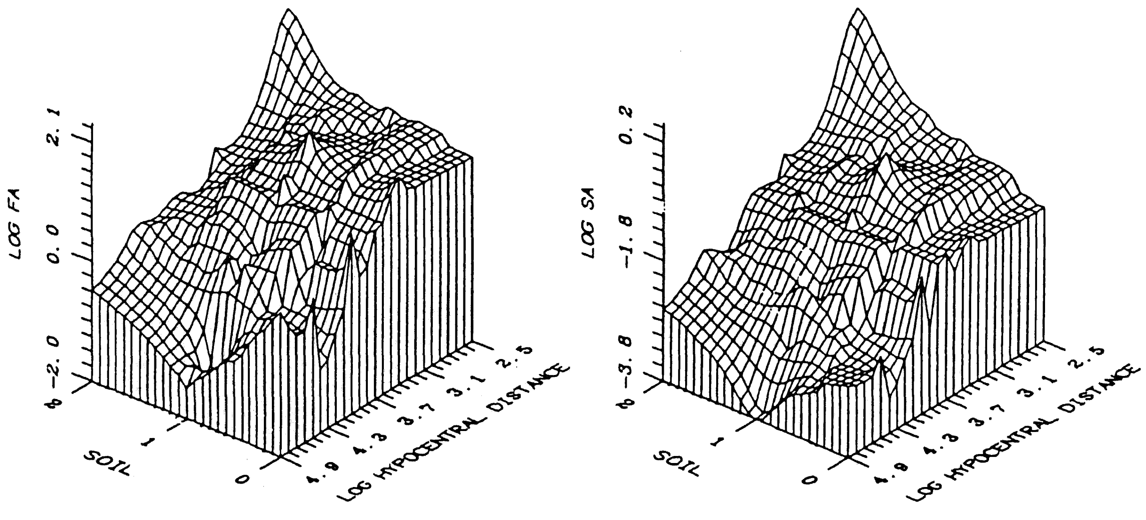

Figure 4. As figure 1 for 10 Hz.

effect in the movement. Therefore, it would be desirable to have the necessary information to quantify the soil effect by introducing its resonance period in the regression analysis. However, as the geotectonic characteristics are not always well known, alternative techniques have been developed. These search for a first estimation of the natural period of soil and its relation with the predominant period of motion. The last purpose consists of quantifying the effect of the three classes of soil on the ground motion (Trifunac, 1990).

4 REGRESSION ANALYSIS

4.1 Attenuation models adopted

The equation representative of the attenuation models adopted has been derived from the expression of the amplitude for an harmonic wave in an infinite elastic half-space:

$$A = \frac{A_0}{R^b} e^{(aM+cR)} \qquad (1)$$

where A is the amplitude of the motion observed at the distance R; M represents the earthquake magnitude; A_0 stands for the amplitude of the motion corresponding to a distance of 1 km from the source, and a, b, c are constants to be determined in the analysis.

Taking logarithms in the previous equation results in:

$$Ln\ A = Ln\ A_0 + aM - b\ Ln\ R + cR \quad (2)$$

where the term b.LnR represents the attenuation by geometrical spreading of the wave front, while c.R means the anelastic attenuation.

Taking into account that, for short distances the geometric attenuation is dominant over the anelastic one and that most of the selected records fall within that distance range, we have introduced a simplification in the analysis. Thus, the dependence on the distance has been taken only through the term b.LnR, which implies an easier way to estimate the coefficients by regression analysis.

On the other hand, the available records correspond to only one earthquake with a magnitude of 6.4 (Allen et al.,1975). As this is a fixed parameter, it cannot be considered as variable in our study. For this reason, the term a.M has been eliminated from the equation and the magnitude influence is included in the independent term. Finally, the representative parameter of the soil effect, S, has been introduced in the expression, to study the influence of soil conditions in the ground motion.

As a result of the previous considerations, the adopted model is represented by the equation:

$$LnA(\omega) = a(\omega) + b(\omega) LnR + c(\omega) S \quad (3)$$

where A indicates the amplitude associated to the frequency ω for the different parameters (FA, SA or PSV).

4.2 Method of calculation and inferred attenuation laws

Attenuation laws have been deduced by fitting data to the expression (3) through a linear regression analysis. Coefficients a(ω),b(ω) and c(ω) have been estimated by using this method under the assumption of normal distribution of residuals with zero mean and constant variance. As it is customary in this kind of analysis, residual means the difference between the observed and estimated values of the considered parameter.

Only attenuation models with quadratic regression coefficient R^2 greater than 0.6, standard errors lower than 15% and high levels of significance evaluated by the t of Student test, have been accepted.

These criteria allow us to conclude that Fourier accelerations do not match the described model that cannot be taken as valid for this parameter. The results are far different for the two other parameters studied, PSV and SA, which show good adjustments for all the frequencies except 0.25 Hz. Table 1 summarizes the coefficients obtained for SA.

Attenuation curves obtained for response spectra, acceleration and pseudo-velocity on rock and soft soil for all the frequencies which yield a good adjustment are displayed in figures 5 and 6. They represent predicted values for the models inferred through the regression analysis starting from the frequency of 0.5 Hz.

In Fig. 5, it can be noticed that the greatest spectral accelerations appear at frequencies of 5 and 10 Hz, whereas the lowest ones are expected for 0.5 Hz, for both rock and soft soils.

One of the differences between the models found for both kinds of soils is the greater amplitude associated to lower frequencies when soft soils are taken. This fact can be explained considering the amplification that this type of soil presents in this range of frequencies. Moreover, as it can be seen in the Fig. 5, greater accelerations can be expected in rock site for 2 Hz than for 1 Hz for all the displayed distances (R<100km). Nevertheless, on soft soil, the curves of both frequencies cross each other at a critical distance of, approximately, 10 km.

In a similar analysis, from spectral velocity curves, it can be observed that the greatest amplitudes

Table 1. Attenuation laws for SA

$\mathrm{LnSA} = a(w) + b(w)\mathrm{LnR} + c(w)S$

w(Hz)	a(w)	b(w)	c(w)
0.5	3.15	-1.61	-0.26
1	4.03	-1.62	-0.12
2	3.43	-1.37	-0.07
5	4.07	-1.46	-0.01
10	4.01	-1.53	0.03

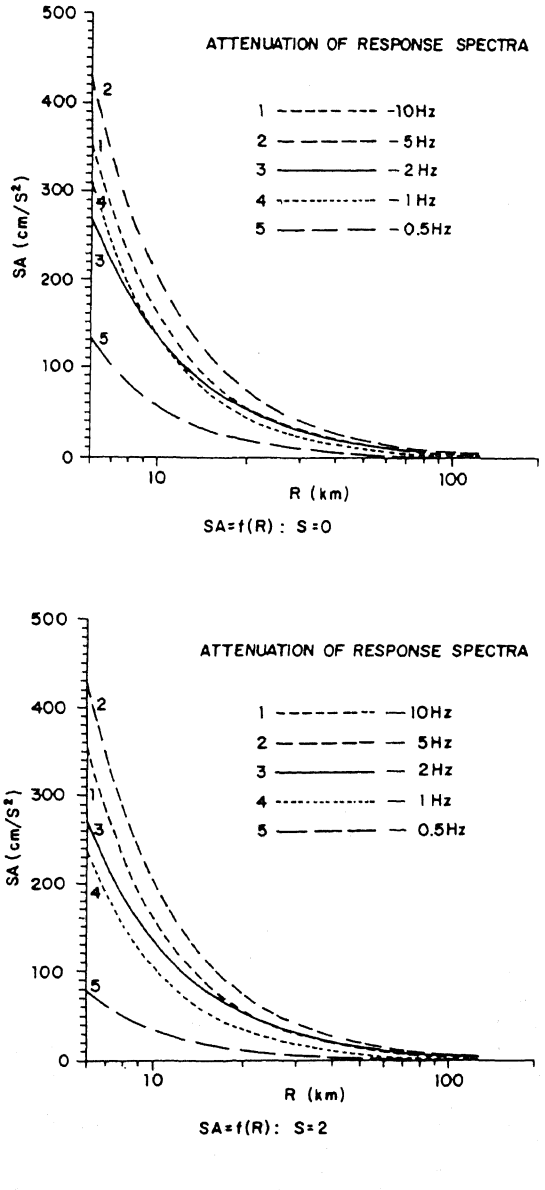

Figure 5. Attenuation laws inferred for spectral acceleration and soft soils (top) or rock (bottom).

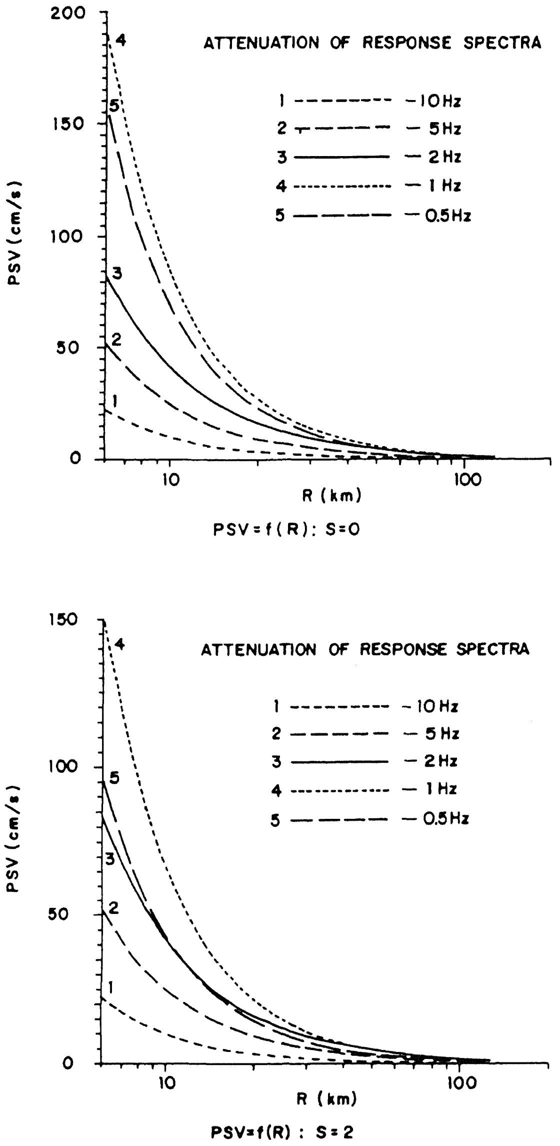

Figure 6. Attenuation laws inferred for Pseudo-velocity and soft soils (top) or rock (bottom).

correspond to 1 Hz. For both kinds of soils, the order of decrease is 0.5, 2, 5 and 10 Hz. Therefore, two ranges of characteristic frequencies for the attenuation of PSV can be considered. Amplitude decrease can be found for frequencies lower than 1 Hz and higher than 2 Hz. The range between these two values shows a more noticeable decay.

The main difference observed between soft soil and rock concerns amplitudes associated to the lowest frequencies (1 and 0.5 Hz) which present values higher than 150 cm/s at the shortest distances for the soft soils. Values obtained on rock are lower than this quantity. This result reveals again the trend of soft soils to amplify lower frequencies for both parameters, acceleration and velocity.

5 DISCUSSION AND CONCLUSION

In the first part of this study, the distributions of observed values concerning Fourier amplitude spectrum, FA, response spectral acceleration, SA, and pseudo-velocity, PSV, versus hypocentral distance and class of soil have been analyzed. As result, highest values for FA and PSV are found for frequency of 1 Hz, while SA reaches maximum amplitude for 5 Hz. A very small attenuation for the three spectral parameters between 12 and 22 km is observed on soft and intermediate soils. The opposite effect, i.e. strong attenuation in that distance range, is found on rock sites.

In the second part, attenuation laws for the spectral parameters have been derived, according to the model described by equation (3). Only laws obtained with good fitting have been taken as valid attenuation models. Thus, we have found that Fourier accelerations for all the frequencies do not match the previous model and the same result is observed for amplitudes of SA and PSV associated with the lowest frequency, 0.25 Hz.

Therefore, only attenuation laws for PSV and SA in the range 0.5-10 Hz are proposed as result of this part of the study. The corresponding curves are presented in the paper, where the differences between the behaviour of both parameters in rock and soft soil for all frequencies in the quoted range may be apreciated. The effect of soil is noted, mainly, by the greater amplitude associated to lower frequencies on soft soils, for both parameters, SA and PSV.

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REFERENCES

Allen, C.R., T.C. Hanks and J.H. Withcomb, 1975,' Seismological studies of the San Fernando earthquake and their tectonic implications in San Fernando, California, Earthquake of 9 February 1971. Bulletin 196, California Division of Mines and Geology, California, 257-262.

Dahle, A., H. Bungum and L.B. Kvanne, 1990, Atenuation models inferred from intraplate earthquake recordings, Earthquake Eng. and Structural Dynamics, 19, 1125-1141.

Hudson, D.E. (Editor), 1971, Strong motion instrumental data on the San Fernando earthquake of February 9, 1971. Earthquake Engineering Research Laboratory, California Institute of Technology and Seismological Field Survey, NOAA, 258 pp.

Joyner, W.B. and D.M. Boore, 1982, Prediction of earthquake response spectra, U.S.G.S. Open File Report 82-977.

Kawashima, K., K. Aizawa and K. Takahashi, 1986, Attenuation of peak ground acceleration, velocity and displacement based on multiple regression analysis of Japanese strong motion records, Earthquake Eng. and Structural Dynamics, 14, 199-215.

Trifunac, M.D., 1990, How model amplification of strong earthquake motions by local and geologic site conditions, Earthquake Eng. and Structural Dynamics, 19, 833-846.

Trifunac, M.D. and A.G. Brady, 1975, On the correlation of seismic intensity scales with the peaks of recorded strong ground motion, Bull. Seism. Soc. Am, 65, 139-162.