GROUND MOTION SPECTRAL CONTENT: THE INFLUENCE OF LOCAL SOIL CONDITIONS AND SITE AZIMUTH

by

Peter Arnold[I] and Erik H. Vanmarcke[II]

SYNOPSIS

The intensity and freqnency of ground motions recorded during the 1971 San Fernando earthquake are studied. The estimated power spectral density (PSD) function is used as the primary tool for studying ground motion characteristics, but comparisons using peak values to parameterize ground motions are also briefly reviewed. Observations are made on the variations in ground motion characteristics, followed by a tentative examination of the possible causes of these variations. In particular, the distance and direction from the source (azimuth) and the characteristics of local soil conditions are identified as factors which appear to exert an important influence on the characteristics of ground motions.

INTRODUCTION

Description of the site ground motion is an important step in the process of designing a structure subject to strong earthquake ground shaking. Both the intensity and frequency content of ground motions are important in the evaluation of structural response. As a part of an overall effort to demonstrate the application of random vibration analysis to evaluate the response of single and multi-degree-of-freedom systems to earthquake excitation, measurements made during the San Fernando, California earthquake of 1971 have been used to study extensively ground motion characteristics. The San Fernando, California earthquake of February 9, 1971, which involved a dominantly thrust-type faulting mechanism, had a Richter magnitude estimated between 6.4 and 6.6. Wide variations in the areal pattern and the distribution of energy between different wave forms attributable to differences in source mechanism, as well as differences in physical and geometrical properties of the fault, can be demonstrated by analytical dislocation models. Recent work by Hanks (1974) suggests that both Rayleigh and Love (surface) waves played an important role in shaping the characteristics and the distribution of ground motions generated by the 1971 San Fernando event. The relative distribution of energy between surface and body waves is likely an important factor in determining the effect of distance, as well as the possible effects of local soil conditions and both surface and subsurface topography, on the intensity and frequency content of ground motions. The approach taken here to study ground motion characteristics is empirical, or observational; it does not pretend to resolve the potential differences between ground motions generated by different fault mechanisms or wave types. In fact, only the San Fernando event is studied and the distribution of body and surface wave energy is not explicitly considered from here on. The intent here is to present observational evidence of wide variations in ground motion characteristics generated by a single earthquake and to suggest causative factors which might be important under more general conditions.

[I] Staff Civil Engineer, Shell Oil Company, Houston, Texas, U.S.A.

[II] Associate Professor, Massachusetts Institute of Technology, Cambridge, Massachusetts, U.S.A.

PEAK GROUND MOTION PARAMETERS

Ground motion records from the San Fernando earthquake have been processed, analyzed, and documented for approximately 100 sites by researchers at the Earthquake Engineering Laboratory of California Institute of Technology (Trifunac et. al., 1972). These data represent motions measured at both rock and soil sites at epicentral distances ranging from less than 10 to more than 150 kilometers. The map shown in Figure 1 gives an overall view of the California coastline near Los Angeles which was affected by the San Fernando earthquake. Studies of the mechanism of this earthquake indicate that the fault strike was approximately north 64 to 72 degrees west and had a dip angle of approximately 50 degrees. In this paper, epicentral distance is used to measure the distance between a site and the source.

It is suggested here that the direction from the source, or the compass heading, at which a site is located, might be an important parameter in determining the intensity and frequency content of ground motions. To study this parameter, sites are identified as falling within a direction, or profile, which is either parallel or perpendicular to the fault strike. These profile directions are indicated in Figure 1. Note that no differentiation is made as to the actual horizontal orientation of recorded motion. Only the azimuth of the site location itself is dealt with here. In addition to profile direction, the local soil conditions at each site have been identified as falling into one of four classifications (as reported by Duke et. al., 1972): Type 1 - Igneous or metamorphic rock; Type 2 - Sedimentary rock; Type 3 - Shallow alluvium; and Type 4 - Deep alluvium (greater than 60 feet).

Peak acceleration is the parameter most commonly used to characterize ground motion intensity. Measured peak accelerations show both a significant degree of scatter and a marked decrease of intensity with increasing distance from the source. A simple statistical analysis indicates that the average peak acceleration at deep alluvium sites in the perpendicular profile direction is approximately 20 to 30 percent greater than at shallow soil and sedimentary rock sites. The data for sites in parallel profile directions are limited and widely scattered. The ratio of peak velocity to peak acceleration (v/a) is sometimes used to characterize the frequency content of motion and to shape design structural response spectra. For a given value of peak acceleration, a motion with a high v/a will cause greater response in longer period structures. Computed v/a ratios for motions measured in the San Fernando earthquake vary between 10 to more than 100. The data show only a slight discernable trend toward higher v/a ratios with increased distance. Despite the wide scatter, however, the data show a clearly significant difference in v/a ratios as a function of the profile direction in which the site is located. The average v/a ratios at sites located in the perpendicular profile direction are significantly higher than at sites in the parallel profile directions. The histograms, or sample frequency distributions, shown in Figure 2 clearly demonstrate this effect of profile direction on frequency content. The implication here is that ground motions in the lower perpendicular profile direction are expected to result in greater response levels for longer period structures than motions with the same overall energy content in the parallel profile directions.

FREQUENCY DOMAIN ANALYSIS

Ground motion records can be represented in the frequency domain by their discrete Fourier transform. The square of the Fourier amplitude spectrum reflects the distribution over frequency of the power in the ground motion and is proportional to the estimated power spectral density (PSD) functions from measured ground motions. The procedure involved the use of Fourier amplitude spectra obtained from horizontal acceleration records by the Earthquake Engineering Research Laboratory at C.I.T. (see Trifunac et. al., 1972). Sites were grouped according to epicentral distance, profile direction and local soil conditions. The resulting groups contained as few as one and as many as seven sites. The ordinates of the PSD function for each group were estimated by averaging the square of the corresponding ordinates of Fourier amplitude spectra for the (2) horizontal motion records from each site included in the group. The total area under the PSD function gives the variance of the motion, and is therefore a measure of its overall intensity. Figure 3 shows a plot of ground motion intensity, measured by the square root of the average of the areas under PSD functions estimated for orthogonal horizontal directions, at each site versus epicentral distance. Sites are differentiated as to local soil type and profile direction. The data in Figure 3 indicate a rapid decrease in ground motion intensity with increasing distance from the source, especially in the short-to-intermediate range. Although at distances beyond approximately 60 kilometers the intensities in parallel (ESE/NW) profile directions are generally lower than those in the lower perpendicular (S/SE) profile direction, the number of data points is relatively small. At distances less than approximately 60 kilometers, no significant difference in intensity levels between the two profile directions is evident. Local soil conditions are only differentiated into two groups: soil (types 3 and 4) and rock (types 1 and 2). Although for the epicentral distance range of approximately 40 kilometers there are several soil sites which have intensities significantly greater than rock sites, there is no clear general amplification trend which can be associated with soil conditions. Estimated PSD functions which have been normalized to have unit area (NPSD) will be used to represent the frequency content of ground motions. Ground motions at some 22 sites where the local soil conditions are relatively well documented have been studied. Attention here will be focused on epicentral distances between approximately 20 and 40 kilometers.

To begin, consider the NPSD functions estimated for two site types (rock and deep cohesionless soil) in both the parallel and lower perpendicular profile directions. Figures 4 and 6 show plots of the smoothed NPSD function estimated for each of four site groups. At the two "SOUTH" sites (lower perpendicular profile) in Figure 6, cohesionless soil extends to a depth of approximately 700 feet. By the simple shear beam analogy one would expect such a site to have a fundamental frequency in the range of 3 to 5 radians per second (periods between approximately 1.25 and 2.0 seconds). It is evident from Figure 4 that a major portion of the power in the motion records obtained at these sites was concentrated in that frequency range. In this paper, the writers will neither support nor criticize the simple one-dimensional theory of soil amplification, which is based on the shear beam analogy. The analogy will be used only to obtain a rough estimate of the dynamic characteristics of such a simple soil profile model. The NPSD function shown in Figure 4 for the "ESE" sites was estimated from 6 records at 3 sites in the Pasadena area, which lies in the parallel profile direction. Cohesionless soil at these sites extends to depths between 350 and 400 feet. The fundamental frequency range of the corresponding simple soil model is between approximately 4 and 8 radians per second (periods between approximately .8 and 1.5 seconds). Unlike the motions for the "SOUTH" sites (perpendicular profile direction), the Pasadena motions do not exhibit a dramatic concentration of energy in the region of the natural frequency of the analogous shear beam. The power is much more evenly distributed over a broad range of frequencies. It is also significant to note that the average intensity of the motions at the perpendicular profile sites is greater than the average intensity of the motions at the parallel profile sites, even if an approximate correction is made for the difference in epicentral distances. This comparison suggests that soil amplification was quite significant for sites in the parallel profile direction, but was not so significant for sites in the parallel profile direction. Although not universal, there are several other motion records in the respective profile directions which exhibit characteristics which are similar to those illustrated in Figure 4.

The smoothed NPSD functions of motions measured at several sites which are classified as rock provide valuable insight into the basic difference between ground motions in the parallel and perpendicular profile directions. Figure 6 represents rock motions at sites in the lower perpendicular and parallel profile directions at epicentral distances between approximately 25 and 40 kilometers. The distribution of power in the lower perpendicular profile is relatively even over a wide frequency range and includes a significant contribution from frequencies below 10 radians per second. In contrast, the rock motions from sites in the parallel profile directions contain larger contributions at higher frequencies, with very little power below 10 radians per second. The average intensity of the rock motions in these two profile directions are approximately the same, but the frequency distributions (or contents) are quite different. The fact that the energy content of the NPSD function for the Pasadena soils (Figure 4) does not exhibit a "predominant period" range like that of the perpendicular profile site group may simply be explained by the fact that the corresponding rock motion contains very little energy in the range of the fundamental frequency of the soil profiles. This distinct difference in the frequency content of motions in the perpendicular and parallel profile directions is consistent with the difference in the ratio of peak velocity to peak acceleration described earlier (see Figure 2). Although there appear to be other factors which also contribute to influence the characteristics of ground motions at other locations around the San Fernando earthquake source, the influence of the direction at which a site is located, relative to the fault strike, which is illustrated by Figure 6, is visible in the motions at many other sites and epicentral distances.

A common practice in studying the effect of local soil conditions on earthquake motions is to define an "amplification ratio", which compares some measure of ground motion intensity at a soil site with the same parameter at a nearby rock outcrop. We shall define an amplification ratio which is given by the ratio of the square root of the ordinates of smoothed PSD functions estimated for soil and rock sites respectively. The average intensity of the PSD function for the soil site was modified using an eyeball average of the data in Figure 3 if the distance between the soil and rock site exceeded approximately 5 kilometers. Two typical amplification ratios computed for sites in both perpendicular and parallel profile directions are shown in Figure 5. In the perpendicular profile direction amplification ratios as high as 6 occur in the frequency range of approximately 2 to 4 radians per second. Although some details are different, amplification ratios computed for several similar deep soil sites in the perpendicular profile direction also suggest that local soil conditions had a significant effect on the intensity and frequency content of ground motions. It is evident that the low frequency components are significantly amplified. The amplification ratio for the parallel site in Figure 5 is typical for motions recorded at sites in the Pasadena area. These plots suggest that local soil conditions could have had an important influence on ground motions at sites in parallel profile directions, even though the effect is not evident in the recorded motions at soil sites. The lack of dominance may simply be due to the absence of energy at low frequencies in the base rock motion in the parallel direction. The characteristics of estimated PSD functions and amplification ratios at other sites in the parallel profile direction are similar to those described here.

CONCLUSIONS

Observations are made on the variations in ground motion characteristics from records measured during the 1971 San Fernando earthquake. The distance and direction from the source (azimuth) and the characteristics of local soil conditions are identified as factors which exert potentially major influence on the characteristics of ground motions. The estimated PSD function graphically illustrates variations in the intensity and frequency content of ground motion which are potentially important to structural response, but which are not always clearly reflected by peak motion parameters. The particular characteristics of intensity and frequency content observed during the San Fernando earthquake will not necessarily be the same as those resulting from future earthquakes in California but the effects of local soil conditions and profile direction may be similarly important in influencing ground motion chatacteristics during future events.

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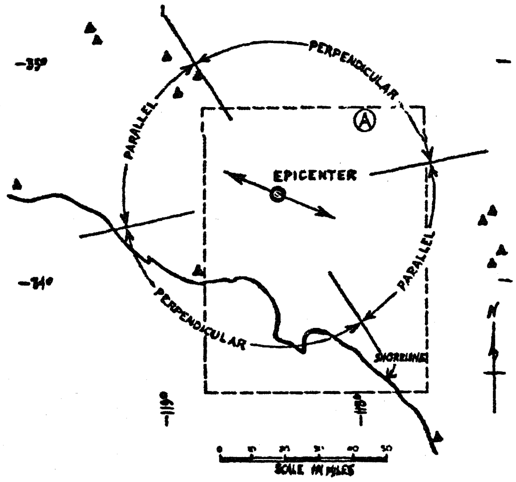

Figure 1

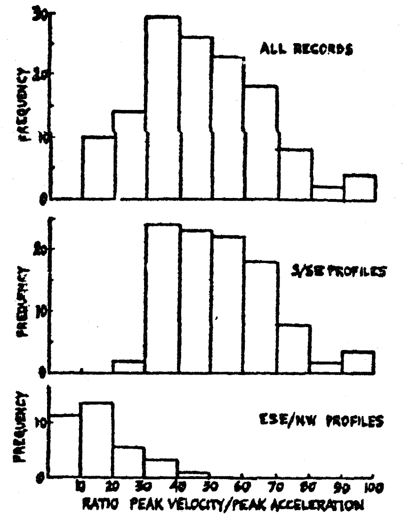

Figure 2

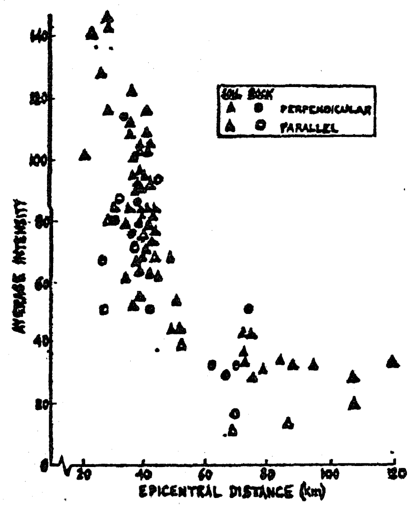

Figure 3

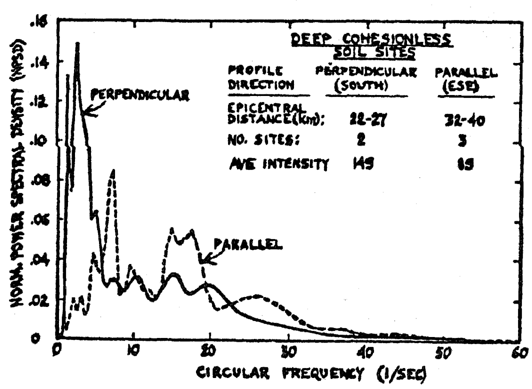

Figure 4

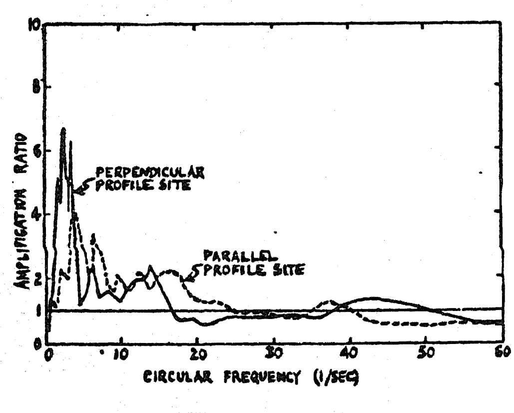

Figure 5

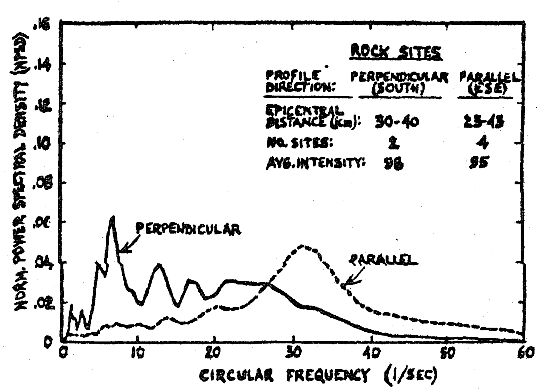

Figure 6

DISCUSSION

P.N. Agrawal (India)

The study of records from single earthquake like this would not permit seeing the effect of variation of source parameters at all whose effects may be important. Thus generalisation of results for use for predicting the future ground motions character may have very restricted applicability.

Author's Closure

Not received.