EFFECTS OF SITE ON GROUND MOTION IN THE SAN FERNANDO EARTHQUAKE

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SYNOPSIS

Basement and free field accelerograph stations that recorded the San Fernando, California earthquake of February 9, 1971 were compared with geological and geophysical site data, particularly shear wave velocity profiles. Geophysical surveys were made at 47 accelerograph sites to determine the velocity profiles to about 70 feet in depth.

Both peak particle velocity and Arias instrumental intensity were found to have statistically significant dependence upon the mean shear wave velocity and the rate at which it increased with depth.

INTRODUCTION

A relationship between local site conditions and ground motion has been reported for almost every large magnitude earthquake throughout the world. Measures of the ground motion aspect of this relationship have been until recently limited to the qualitative. However, in the 1971 San Fernando earthquake there were obtained a large number of strong motion accelerograms corresponding with a variety of local site conditions. Various authors have studied the peak indices of these instrumental data, but a clear cut relation between shaking and site conditions has continued to elude recognition.

Attention therefore was transferred to quantitative dynamic representations of the site conditions, with the thought that such a representation might lead to better correlation than the largely static and qualitative representations used in the past, such as surface geology, good vs. bad soil, and depth of alluvium.

One quantitative indicator of the dynamic character of a site is the profile of seismic shear wave velocity as a function of depth down to approximately 70 feet. As will be shown, use of this representation facilitates a statistically significant correlation with certain indices of strong motion in the San Fernando earthquake. This correlation is the focus of this paper (1).

Granted that strong earthquakes generate higher strain level shear velocities than those measured with geophysical seismic techniques, it is nevertheless possible that a correlation could exist. Use of the shear velocity profile would appear to bring in the influences of both body and surface wave responses at a site. Of course, other factors such as source mechanism, directionality and deeper subsurface geology should also be expected to affect any correlation of site conditions with ground motion.

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Shallow refraction surveys (2,3) were made at or near to 47 stations which had recorded the San Fernando earthquake at or near to the ground surface. The accelerograph data were furnished by the U. S. Geological Survey after processing by California Institute of Technology (4).

ANALYSIS

The ground motion parameters used were the peak values of acceleration, velocity and displacement, and the value of Arias Intensity, designated A, V, D and I_a, respectively. Arias intensity is a measure of the area under the power spectral density graph of acceleration (5). The values of A, V and D adopted for analysis were the highest peaks obtained from the corresponding time history plots, considering both horizontal records at the site. The I_a value used was the sum of the intensities in the two horizontal directions.

The parameter of the shear wave velocity profile was obtained from the fact that shear wave propagation velocity, here called β, increases with a power, n of the depth, d:

$$\beta = Kd^n = Kd^{0.37} . \qquad (1)$$

The value of 0.37 for n was found (6) to represent very well the variety of Los Angeles area soils down to 100 feet or so of depth, and was therefore used. This leaves K, a constant, as the site parameter.

Examples of K values are shown in Figure 1. K was obtained for each site by least squares fitting of the results of refraction surveys, using the circled points and the origin, Figure 2. As will be shown, K values correlate rather well with certain ground motion indices for sites on soil, but do not correlate for rock outcrop sites. For rock sites the lithology of the rock may be used instead, but with only rough fitting.

The first result is in Figure 3, showing peak velocity. It was found that the soil sites generally fell into one of two categories: those that experienced higher ground motion tended to have greater K values than sites that experienced lower ground motion. Numerical values of K shown on the figure correspond with the separations of the soil sites into two classifications. It is seen from the figure, as well as from the statistical coefficients in Table 1, that these separations of soil sites are quite pronounced when either V or I_a is the strong motion index.

The rock sites were classified as either sedimentary or basement complex (igneous and metamorphic), according to the surface geology. The correlations are less significant than for the soil sites.

Peak acceleration and displacement did not reveal significant correlations for either soil or rock sites and therefore have been left out of this paper, except that the coefficients are given in Table 1.

Encouraged by certain of these correlations for soils, the computation was made of multiple regressions of peak particle velocity on distance and K value, Figure 4. This was also done for Arias intensity, Figure 5. Table 2 presents the statistical coefficients. These correlations in continuous rather than inequality form may be adaptable for engineering use. Figures 4 and 5 apply for soil sites only. Again it was found that peak acceleration and displacement were only poorly correlated with K.

APPLICATION

As an example of practical use of the results, imagine a site on soil with established K, located at a known distance from an earthquake of magnitude 6.4 (e.g., the 1971 San Fernando Earthquake). Use the multiple regression of Figure 4 to establish the peak particle velocity of ground motion predicted for the site.

Should one wish to have the output in terms of peak acceleration instead of peak velocity, use could be made of the tripartite logarithmic graph with relative ground motion values of A = 1.0g, V = 48 in/sec. and D = 36 in. (7).

Values of K for such an application may be determined from shear wave velocity profiles, using either field or laboratory measurements or a simulation procedure (6).

The quality of the correlations presented would seem to warrant similar studies of future earthquakes that yield large amounts of instrumental data.

ACKNOWLEDGMENT

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BIBLIOGRAPHY

1. Duke, C. M., R. T. Eguchi, K. W. Campbell and A. W. Chow, "Effects of Site on Ground Motion in the San Fernando Earthquake," Report UCLA-ENG, University of California, Los Angeles, 1976.

2. Duke, C. M., J. A. Johnson, Y. Kharraz, K. W. Campbell and N. A. Malpiede, "Subsurface Site Conditions and Geology in the San Fernando Earthquake Area," Report UCLA-ENG-7206, University of California, Los Angeles, 1971.

3. Eguchi, R. T., K. W. Campbell, C. M. Duke, A. W. Chow and J. Paternina, "Shear Velocities and Near-Surface Geologies at Accelerograph Sites that Recorded the San Fernando Earthquake," Report UCLA-ENG-7653, University of California, Los Angeles, 1976.

4. California Institute of Technology, "Strong Motion Earthquake Accelerograms, Digitzied and Plotted Data," Vol. II, 1971-1975.

5. Arias, Arturo, "A Measure of Earthquake Intensity," Proc. Conf. Seismic Design Nuclear Power Plants," Massachusetts Institute of Technology, pp. 438-483, 1970.

6. Campbell, K. W. and C. M. Duke, "Correlations among Seismic Velocity, Depth and Geology in the Los Angeles Area," Report UCLA-ENG-7662, University of California, Los Angeles, 1976.

7. Newmark, N. M. and W. J. Hall, "A Rational Approach to Seismic Design Standards for Structures," Proc. 5th World Conf. on Earthquake Engr., Rome, Italy, 1973.

TABLE 1

STATISTICAL COEFFICIENTS FOR FIGURE 3

Index	K Separation	Correlation Coefficient
Peak Velocity	$K \leq 490$	0.98
	$K > 490$	0.90
Arias Intensity	$K \leq 490$	0.87
	$K > 490$	0.91
Peak Acceleration	$K \leq 450$	0.62
	$K > 450$	0.89
Peak Displacement	$K \leq 475$	0.75
	$K > 475$	0.52

TABLE 2

STATISTICAL COEFFICIENTS FOR FIGURES 4 AND 5

Index	Correlation Coefficient
Peak Velocity	0.90
Arias Intensity	0.86
Peak Acceleration	0.71
Peak Displacement	0.59

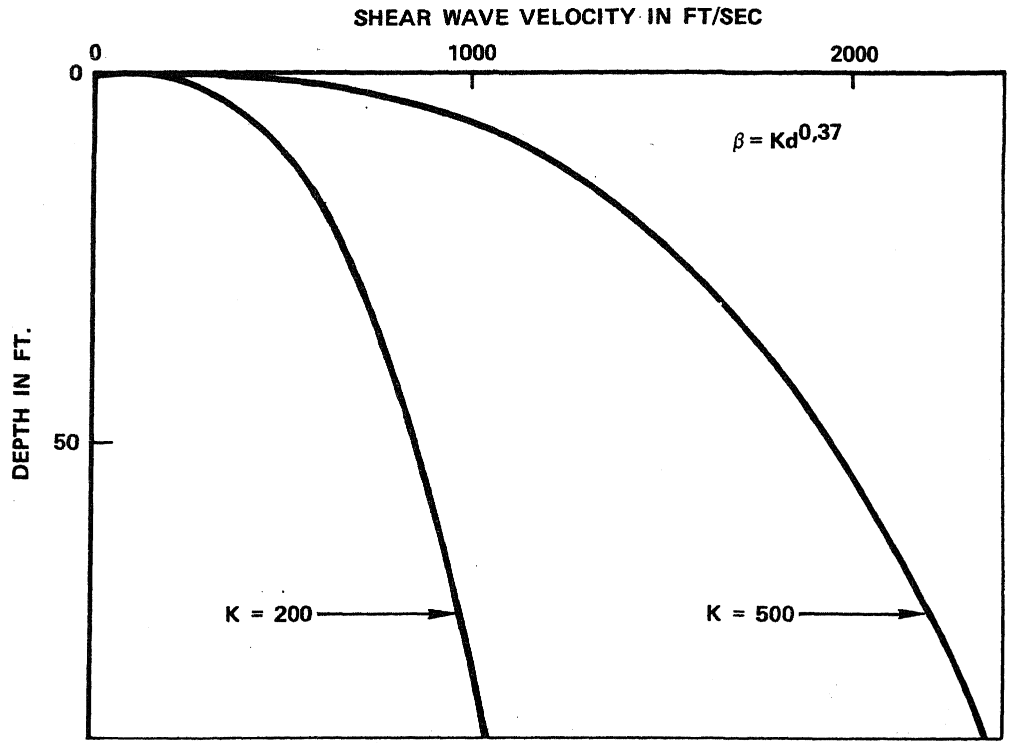


Figure 1. Dependence of Shear Wave Propagation Velocity on Depth and K Value.

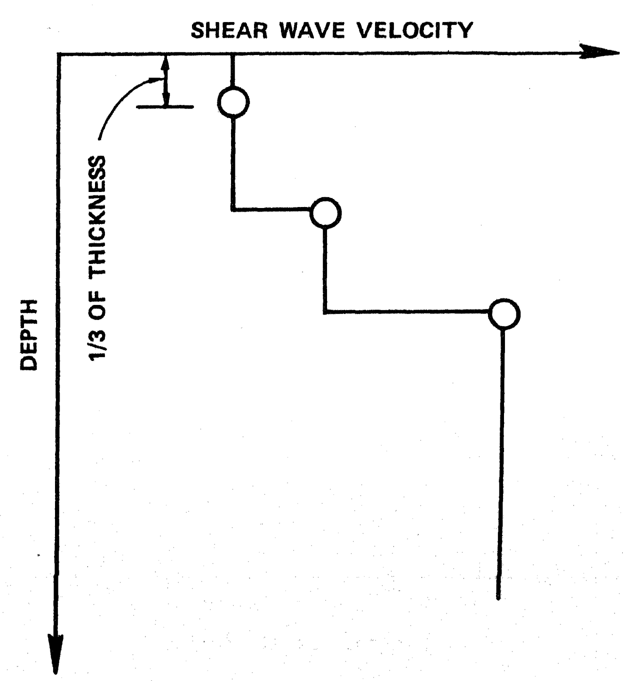


Figure 2. Method of Determining Shear Wave Velocity Profile from Refraction Survey.

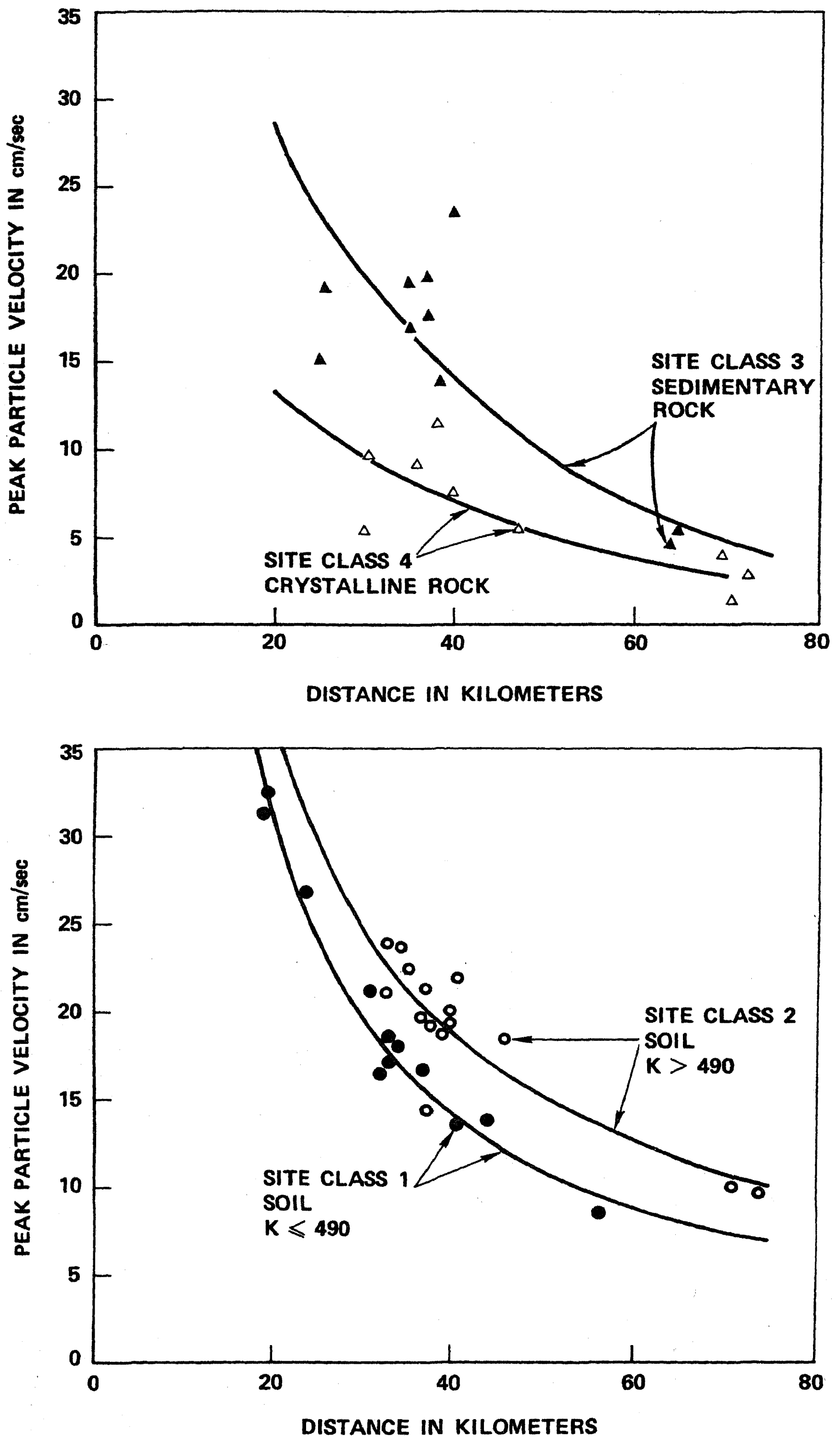


Figure 3. Attenuation of Peak Particle Velocity for Soil and Rock Site Classifications

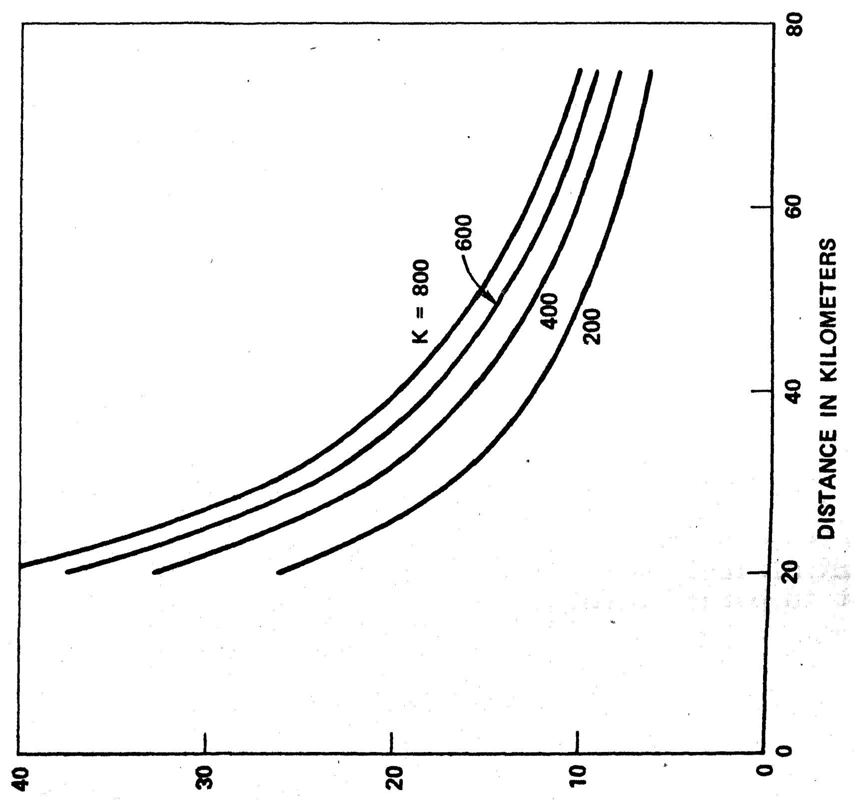


Figure 4. Multiple Regression of V on R and K.

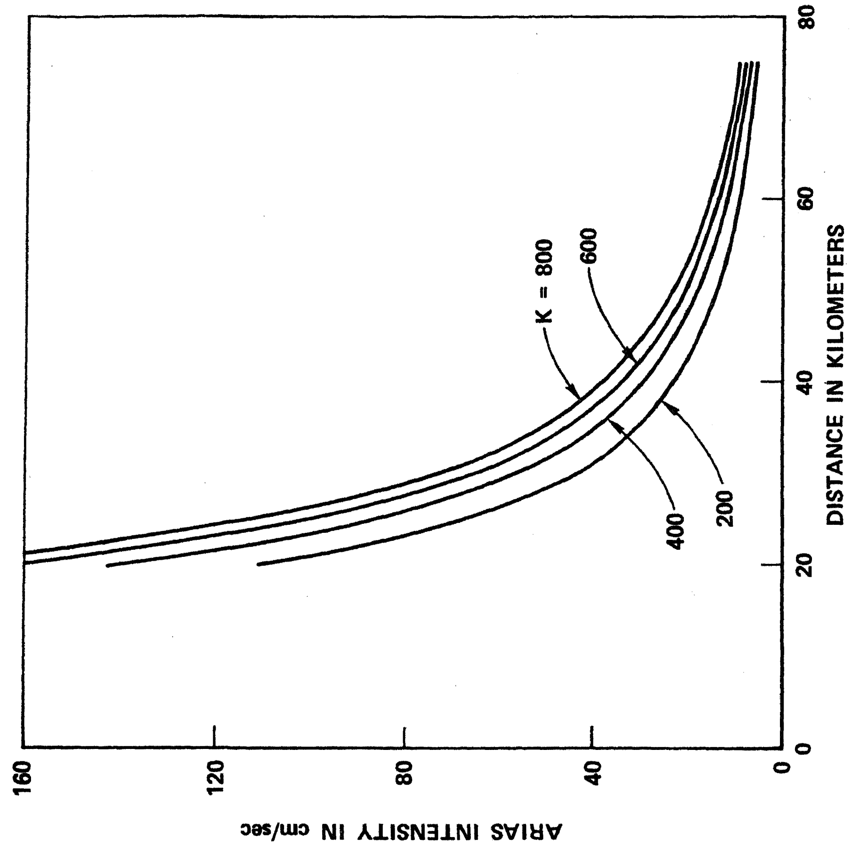


Figure 5. Multiple Regression of I_a on R and K.

DISCUSSION

E. Faccioli (Mexico)

A strong correlation of peak ground velocity with site conditions at least for intermediate and far distances, is suggested by the results of regression analysis on a set of about 160 data from 9 countries of the Circus-Pacific Belt, recently carried out by the discussor. The data, selected from free field strong motion records having peak accelerations higher than 50 gal, were grouped into 4 site categories ranging from competent rock to shoft soil. An expression of the type,

$$V_{max} = a\ 10^{bM}\ (R + 25)^{-c}$$

was employed for the regression analysis, where M = magnitude and R = focal distance. The mean values predicted by the regression equation for M = 6.5 are shown in the figure. Standard deviations of the residuals log error , σ log y range between 0.25 and 0.27.

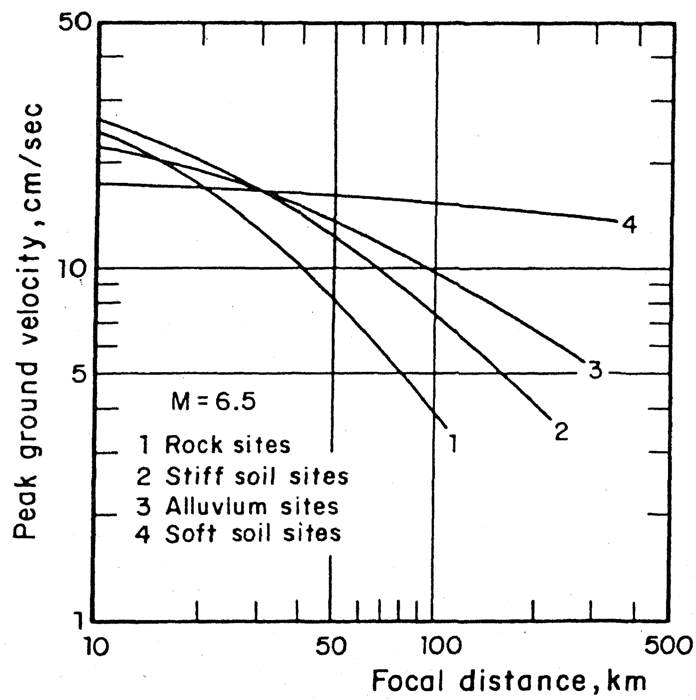
Similar analysis based on western U.S. data only do not exhibit such differences in peak velocity attenuation because of the relatively uniform ground conditions at most strong motion recording stations in this region.

J.B. Berrill (New Zealand)

The discussor would like to support the previous discussor's comment about the importance of rupture propagation. In the 1971 San Fernando, California Earthquake, for example, when the rupture propagated south wards and upwards much more energy was radiated to the south hard rock sites were to the north of the epicentre, unless this focussing of energy to the south is taken into consideration, quite erroneous conclusion, can be drawn about site effects.

Author's Closure

With regard to the question of Mr. Faccioli, we wish to state that the authors are interested to see the regression of distance and site classification on peak ground velocity, as provided by the discussor. Fair agreement was found between this graph and Fig. 3 of the paper, the latter based on San Fernando earthquake data. The differences shown may be due to differences in data used, or due to the definitions of focal distance and site classification. The discussor's use of bayesian technique is to be commended.



Influence of site conditions on the attenuation of expected peak ground velocity with distance