SITE EFFECTS DURING THE SAN FERNANDO, CALIFORNIA, EARTHQUAKE

by

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SYNOPSIS

Fourier amplitude spectra of 71 strong-motion accelerograms are examined in the 0.4 to 16 Hz frequency band for a possible relationship between intensity of ground motion and local geology. No significant difference was found between accelerations recorded on soft sediments, stiffer sediments and sedimentary rock, and basement rock; it is concluded that at sites with these soils, at least, no allowance should be made for local geologic conditions in estimates of future ground motion.

INTRODUCTION

The possible effect of local geologic conditions on the local intensity of motion during an earthquake is a question that has received much discussion[1-6]. Except in a few cases where the site geology is unusually uniform, for example at Mexico City[7], it has not been proven that sites on soft sediments will be shaken more heavily during strong ground motion than sites at similar focal distances on stiffer and more dense soils. While soft and less dense surface soils tend to amplify incoming wave motion, they also have the opposite tendency of dissipating greater amounts of energy than stiffer soils. The analysis of site behaviour is further complicated by the effect of wave interference in two and three dimensions. Material inhomogeneities and irregular surface topography cause complex interference patterns which result in large variations in the amplitude of motion at the ground surface from place to place about a site[8,9]. Full study of the importance and precise nature of site effects has been hampered by the difficulty of obtaining analytical solutions to the related wave propagation problem with damping, transient excitation, and arbitrary boundaries and inhomogeneity included. Numerical solutions are possible under limited conditions; but it is not yet possible to obtain sufficient accuracy at periods of less than a few seconds in a sufficiently large region[10] to determine the importance of local site effects relative to those of the transmission path as a whole. Furthermore, even if computational methods did exist, there is still the practical problem of obtaining sufficient information about the soil properties near a given site for detailed modelling to be practicable.

It is, therefore, of interest to examine strong-motion records for evidence of effects that can be attributed to the local geology, and the large number of accelerograms recorded on a variety of soils during the 1971 San Fernando earthquake provides a suitable set of data for this purpose. Seventy one accelerograms recorded to the south of the epicentre form the basis of this study which looks for systematic differences in the amplitude of acceleration amongst sedimentary sites of different soil stiffnesses, and between sedimentary sites in general and basement rock sites.

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GEOLOGICAL DATA

Trifunac and Brady[11] have compiled a list of descriptions of local geology at a large number of strong-motion accelerograph sites, and have correlated peak ground motion values and Modified Mercalli intensities with geologic type. They have classified local geology into three broad groups: "soft" sites, in the Los Angeles region, usually recent alluvium, as class 0; sites of "intermediate" soil stiffness, usually sedimentary rock, as class 1; and "hard" basement rock sites as class 2. While this is not a fine division, and the classification of any individual site may be in error, average geologic properties should be well-defined over the large number of sites we have, and any correlations that exist between intensity of motion and site geology should be detectable.

ACCELERATION DATA

All 71 strong-motion accelerograms recorded at ground level during the San Fernando earthquake in a sector defined by source-to-station azimuths between 130 degrees and 200 degrees, and with epicentral distances of less than 150 km make up the data set. This range of azimuths was chosen to include almost all of the large concentration of recordings made in the Metropolitan Los Angeles region, while at the same time minimizing the effects of the source radiation pattern and variations in geology of the overall transmission path.

Fourier amplitude spectra of ground acceleration were studied, rather than peak accelerations, so that any frequency dependence in the results could be seen. The amplitude data were computed by the FFT method from 15-second samples of acceleration starting at the S-arrival, and were given one pass of a Hanning filter. Each accelerogram was first transformed into components parallel and transverse to the source-station direction, and the amplitude spectra of both horizontal components were sampled at the frequencies, 0.4, 1, 2, 4, 8 and 16 Hz.

The average Fourier amplitude $\overline{X}(f,r)$ of the San Fernando earthquake accelerograms can be well described in the 0.4 to 16 Hz band by the expression[12]

$$\overline{X}(f,r) = \frac{A(f)}{r} e^{-\frac{\pi f r}{Q\beta}} \qquad (1)$$

where A(f) is a measure of the source strength, r is the hypocentral distance, f is frequency, 1/Q is a specific attenuation constant, and β is the shear wave velocity. Assuming that $\beta = 3.2$ km/sec, then for the set of accelerograms studies here, Q = 330, and A(0.4) through A(16) are equal to 1 050, 1 440, 1 490, 1 440, 1 100 and 370 cm/sec respectively[12].

The strength of each amplitude sample was related to the average amplitude for the set as a whole by an amplification factor k defined as follows:

$$k_{ij} = \frac{X_{ij}}{\overline{X}(f_i, r_j)} \qquad (2)$$

where X_{ij} is a Fourier amplitude sample at frequency f_i from an accelerogram recorded at distance r_j, and $\overline{X}(f_i,r_j)$ is the corresponding average amplitude given by eq. (1).

COMPARATIVE BEHAVIOUR OF THE THREE CLASSES OF SITES

Values of k_{ij} were computed for each amplitude sample and were sorted according to the classification of the soil at the recording site. Statistics of the k-values are listed in Table 1 for each class of sites and sampling frequency.

A comparison of mean values $\bar{k}_0$ from "soft", and $\bar{k}_1$ from "medium" sites shows that on the whole there is very little difference between the accelerations recorded on one class of sedimentary sites and the other. Except at 4 Hz, the difference $(\bar{k}_1-\bar{k}_0)$ between corresponding pairs of average k-values is less than the difference $(\bar{k}_1-\bar{k}_0)$, and it is therefore of little statistical significance. A standard test of statistical significance shows that even the larger difference of 0.22 between $\bar{k}_1$ and $\bar{k}_0$ at 4 Hz does not imply a difference in intensity of shaking between the class 1 sites and the class 0 sites at a 5 percent significance level. It, therefore, appears, that in general the stiffness of the sediment had no appreciable effect on ground motion amplitudes.

The question of whether sedimentary sites in general were shaken more strongly than basement rock sites is more difficult to answer. With only three records from class 2, basement rock, sites in the whole set of 71 accelerograms, the sample is very small and the k-values are generally more scattered than those of the sedimentary sites. Except at 0.4 Hz, the average amplitudes at the three sites in this group are higher than those of the two sedimentary groups; but little can be said about the statistical significance of this observation since, if the hypothesis that the population means of k_1 and k_2 are equal, is tested, the sample values of k_1 and k_2 at 1 and 2 Hz just satisfy a two-sided test at the 5 percent level, but just fail a one-sided test with the alternative hypothesis of $k_2 > k_1$.

Some explanation of the large scatter in the "hard" site data is found when k-values from the individual sites are related to the site topography. The two sites, C041 (Pacoima Dam), and 0198 (Griffith Park Observatory) which have average k's well above the average levels for the whole set of 71 accelerograms are both situated in mountainous terrain. Wong and Jennings[9] have investigated the effect of high topographic relief on the Pacoima Dam record and have concluded that the mountain and canyon topography modified the accelerogram in a complex manner, with constructive interference resulting in amplification of motion at the accelerograph site at some frequencies. In general, topography affects wave components with wavelengths equal to or smaller than the dimensions of the topographic object. Since the Griffiths Park accelerogram was also recorded at the crest of a mountain with a base width of several kilometres, it is probable that it, too, was modified by irregular site topography; this view is reinforced by the high average k of 1.44. On the other hand, G106, the Caltech Seismological Laboratory, which is situated on a low hill without the extremes of relief found at the other sites, recorded much lower amplitudes, particularly in the radial component.

To make better use of the limited data available from hard rock sites, the Seismological Laboratory record was examined in more detail. This record was chosen because of the site's mild relief, and thus its relative freedom from topographic effects.

From Table 2 it is seen that frequency has no obvious influence on the k-value from G106 except at 0.4 Hz, and perhaps at 16 Hz. Values of k were, therefore, computed from all 135 amplitude points of each spectrum in the 1 to 8 Hz frequency band. Their standard deviations, listed in Table 3, show that the k-values are less scattered than those from the sedimentary sites. The lower scatter may occur simply because the values of k in the single-site sample are not influenced by variations in the overall transmission path properties. The mean values of k, also listed in Table 3 and denoted by $\bar{k}_s$, show that in the radial direction the average intensity of shaking was less than the average for the sedimentary sites by about 14 percent. But in the transverse direction, the average intensity of shaking was about 4 percent higher than the average for the sedimentary sites. (No significant difference exists between radial and transverse components recorded on sedimentary sites[12]).

The statistical significance of these observations may be estimated by comparing in turn the two values of $\bar{k}_s$ obtained from G106, with the value of $\bar{k}_1$ = 1.13 found by averaging the $\bar{k}$ values, listed in Table 1, for the class 1 sites over the same range frequency range.

For the radial component of G106, $(\bar{k}_1-\bar{k}_s) = 0.15$, and for the transverse component, $(\bar{k}_1-\bar{k}_s) = -0.08$. Since the standard deviation of $(\bar{k}_1-\bar{k}_s)$, from Table 3, is equal to 0.10, the difference between $\bar{k}$, and $\bar{k}_s$ is not significant at the 5 percent level in either case.

From both the detailed analysis of record G106, and the earlier analyses of the three class 2 records, it is clear that at frequencies of 1 Hz and above basement rock sites were shaken at least as strongly as typical sedimentary sites. These results imply that the current earthquake engineering practice of using lower estimates of future ground motion at hard rock sites than at sedimentary sites is not a conservative one for frequencies of 1 Hz and above, particularly when the site is in an area of high topographic relief.

CONCLUSIONS

1. Soft sedimentary sites in the Los Angeles region did not, as a class, record significantly stronger or weaker accelerations than did stiffer sedimentary rock sites.

2. Basement rock sites were shaken at least as strongly as sedimentary sites when the frequency f was 1 Hz or more. And since the Griffith Park site was shaken more strongly than the Caltech Seismological Laboratory there seems to be a correlation between the height of topographic relief at a basement rock site and the strength of the high-frequency components of acceleration.

3. At the lowest frequency studied, f = 0.4 Hz, sedimentary sites in general were shaken more strongly than basement rock sites. This points to the importance of surface waves at low frequencies.

4. For the purpose of earthquake-resistant design of structures, no distinction should be made between the intensity of ground motion expected on basement rock, sedimentary rock, and coarse-grained alluvium typical of Southern California at frequencies of 1.0 Hz and above, unless it is to estimate stronger shaking at basement rock sites.

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TABLE 1
Statistics of k for sites sorted according to Trifunac and Brady's site soil classification

Frequency (Hz)	Class 0 "soft" soils (550 data)		standard deviation of($\bar{k}_0-\bar{k}_1$)	Class 1 "medium" soils (202 data)		standard deviation of($\bar{k}_1-\bar{k}_2$)	Class 2 "hard" soils (36 data)	
	$\bar{k}_0$	σ_{k_0}	$\sigma(\bar{k}_0-\bar{k}_1)$	$\bar{k}_1$	σ_{k_1}	$\sigma(k_1-k_2)$	$\bar{k}_2$	σ_{k_2}
0.4	1.23	0.87	0.16	1.36	0.99	0.42	0.76	0.45
1	1.15	0.77	0.16	1.15	0.78	0.38	1.88	1.22
2	1.03	0.75	0.15	1.05	0.70	0.39	1.69	1.62
4	0.99	0.65	0.14	1.21	0.80	0.34	1.17	0.51
8	1.10	0.75	0.15	1.10	0.68	0.32	1.16	0.95
16	1.08	0.72	0.14	1.07	0.70	0.35	1.54	1.23
Combined samples	1.10	0.76	0.064	1.16	0.79	0.15	1.37	1.07

TABLE 2
k-values from MOH15 data at basement rock sites

f (Hz)	C041		G106		0198	
	R	T	R	T	R	T
0.4	1.24	1.35	0.21	0.64	0.46	0.64
1	2.23	3.87	0.20	1.42	1.39	2.20
2	0.75	4.55	0.34	0.32	2.16	2.01
4	2.06	0.86	1.26	1.08	0.54	1.21
8	2.62	0.33	0.88	0.38	0.72	2.05
16	0.96	1.24	0.26	0.70	3.39	2.70
Combined samples	1.65	2.03	0.53	0.76	1.44	1.80

TABLE 3
Statistics of k for record G106 computed from all Fo·rier amplitude data in the 1.0 to 8.0 Hz frequency band

	Component	
	Radial	Transverse
$\bar{k}_s$	0.98	1.21
σ_{k_s}	0.48	0.55
$\sigma(\bar{k}_1-\bar{k}_s)$	0.10	0.10

DISCUSSION

J.L. Justo (Spain)

Your conclusions refer to Fourier amplitude spectra, which are related with velocity spectra, but for peak acceleration the discussor have found that there is, in general a relationship between peak acceleration and ground type (Paper 2-203), specially for a given intensity.

Author's Closure

With regard to the question of Mr. Justo, we wish to state that Fourier amplitude spectra were used in this study because they are better-related to structural response than peak acceleration values. At best peak acceleration characterizes only the high frequency components of motion whereas Fourier amplitude gives a more precise measure of the strength of the ground motion over a wide frequency band.

Professor Justo and his colleagues have studied a large number of accelerograms, grouped according to their Intensities, and have concluded that in general there is a relationship between peak acceleration and ground type. The author is not convinced that this conclusion is justified from the data presented in their paper (Table I p 2-208 of the preprints), particularly for the stronger Intensities, because of the large amounts of scatter in the peak acceleration values. For a given Intensity the greatest variation in the average values of $\log_{10} a_{max}$ between soil types is of the same order as the standard error of the estimates, which suggests that the differences may not be significant. Precise statistical significance tests cannot be made from the data presented in Table I since the number of acceleration samples in each group is not given. However, using rough estimates of the numbers of accelerograms available to be included in each group in Table I, the author finds that the statistical significance of the differences between various soil types is probably small at Intensities of VI or more.

Since most of the data used in the author's study were recorded at Intensities of VI or more, there does not appear to be any conflict between his conclusions and Professor Justo's data.