A COMPARISON OF GROUND RESPONSE IN THE LOS ANGELES REGION FROM NUCLEAR EXPLOSIONS AND THE 1971 SAN FERNANDO EARTHQUAKE

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Recordings of ground motion generated by nuclear explosions in Nevada were obtained at about 30 sites in Los Angeles for which strong-motion recordings of the 1971 San Fernando Valley earthquake also exist. Local site transfer functions (ratios of Fourier amplitude spectra derived with respect to a single site on a granite outcrop) computed from the data show general characteristics that are also observed in the site transfer functions derived from the strong-motion data. These characteristics are primarily produced by the geologic conditions underlying the site.

INTRODUCTION

Approximately 150 three-component broadband records of nuclear explosions have been obtained in the Los Angeles region to study the geographical variation in ground response. The objective of this research is to establish the predictability of the mean level of ground response as a function of the underlying site geology and to show that the characteristics of ground response, relative to sites on rock, that have been established using nuclear explosions are practically equivalent to relative ground response produced by strong earthquakes. Only a representative portion of these data will be discussed in this paper.

TECHNIQUE

A broadband magnetic-tape-recording seismograph with a flat velocity response in the range 0.05 to 5 s was employed to record Nevada Test Site nuclear explosions in the Los Angeles region (Fig. 1). The recorded time histories were digitized, converted to ground velocity, and used to compute Fourier spectra. Spectral ratios were computed to estimate alluvium site transfer functions by dividing the Fourier spectra at sites underlain by alluvium by Fourier spectra of sites underlain by crystalline rock. The sites at Cal Tech (CIT) and Griffith Observatory (GOC) are the two reference rock sites used in this study. The locations of all the sites occupied are shown in Fig. 2. Additional details and analysis of the assumptions used in this study are presented by Rogers, et al. (1979).

The reproducibility of the nuclear site transfer functions (STF) is shown in Fig. 3, where the mean STF and geometric standard deviation (σ) for five nuclear events are plotted for the transverse component. The pooled σ for all three components at all periods is 1.4.

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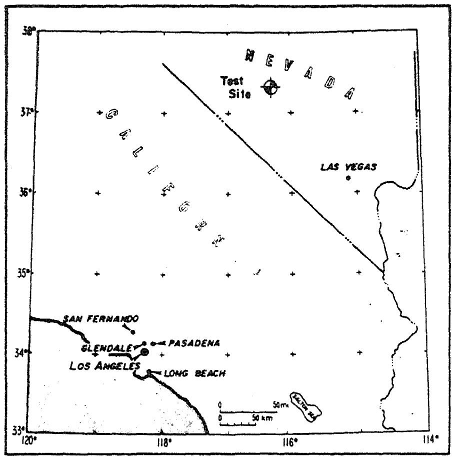

Figure 1.--Map showing the location of the study area.

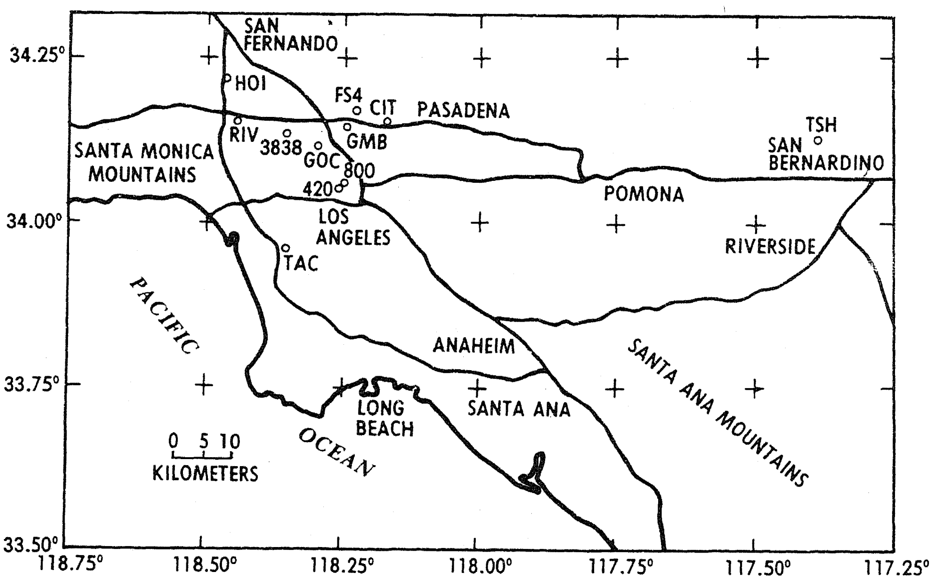

Figure 2.--Map showing the location of stations used in this study.

Portions of the spectra contaminated by noise were not used. For the nuclear explosions, the noise level was determined by computing the spectra of a noise segment preceding the seismic signal. The criterion for using the spectral value in the analyses was that the spectral value at each period must have a signal-to-noise ratio of at least two. The earthquake data were examined for noise contamination by comparing spectral values at periods of interest to the mean spectral level in the period range 0.06-0.09 s. Spectral values at periods of interest were rejected if they were not at least twice this mean level. The blank regions or areas of "drop-out" in the curves of Fig. 3 and following figures are spectral regions contaminated by noise.

THE INFLUENCE OF GEOLOGY ON THE SITE TRANSFER FUNCTION

Fig. 4 shows the time histories of the radial component of ground motion and computed STF for five sites in Los Angeles for nuclear event ICEBERG. The data of this study show that the subsurface geology at the recording sites has a strong influence on ground response. For instance, the sites underlain by alluvium, Glendale Fire Station (FS4), Holiday Inn (HOI), Riverside Drive School (RIV), and Trapp School (TSH), demonstrate amplitudes considerably larger than CIT, a crystalline rock site, and 3838, a sedimentary rock site (<0.6 km thick).

Thin alluvial layers (<100 m) over rock can result in body-wave reverberation having a strong influence on ground motion. This effect is shown at station FS4 which is underlain by less than 15 m of alluvium overlying crystalline rock. Time-history amplitudes at this site are comparable to those of the CIT crystalline rock site, except that at FS4 amplitudes in the body-wave time window are larger. Constructive interference peaks in the spectrum of shear-wave ground motion for a receiver on the surface of a layer over a half-space are known to recur at periods given by

$$T_n = \frac{4H}{(2n-1)\nu_s} \qquad n = 1, 2, \ldots \qquad (1)$$

where H = layer thickness

ν_s = shear velocity.

Although the velocity of the surface layer at FS4 is unknown, if we assume a nominal value of 200 m/s, the calculated fundamental period of constructive interference is 0.3 s. This value is about equal to the period of the fundamental mode observed in Fig. 4, indicating the likelihood of body-wave reverberations at this station. The low LP levels (long-period >0.6 s) at this site are expected because periods greater than 0.6 s correspond to wavelengths greater than 10 times the layer thickness.

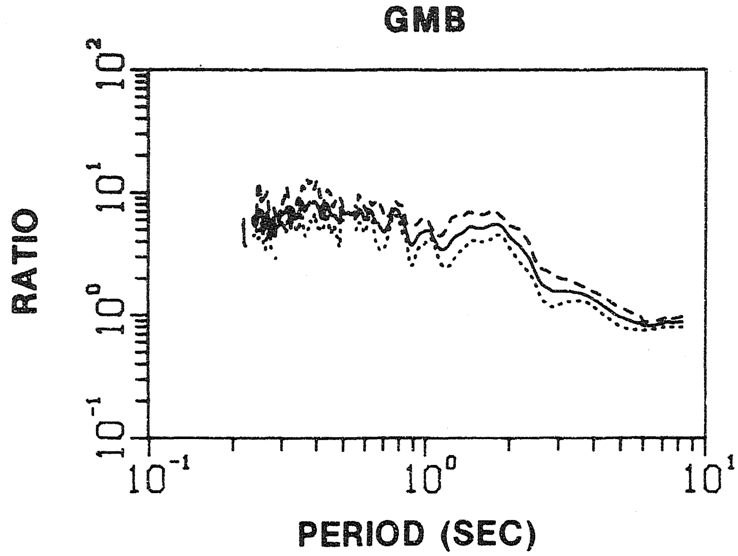

Figure 3.--The mean STF (solid line) relative to CIT and $\pm\sigma$ (dashed and dotted lines, respectively) for five nuclear events at station GMB.

A broadband response that averages 4-6 across most of the spectrum is observed at sites RIV, TSH, and HOI, which are all underlain by intermediate-thickness alluvium (one hundred to several hundred meters). This response is produced by large-amplitude body and surface waves, although surface waves are the predominant feature of the seismogram. Several aspects of the ground response at these sites seem well understood. For instance, the SP response (short-period, <0.6 s) is expected to be high owing to the presence of alluvial layers, because impedance contrasts produced by low-velocity surface layers overlying rock cause reverberation and amplitude increases for waves crossing from high- to low-velocity regions. The high LP response at HOI is believed to be associated with the presence of both alluvial layers (270 m) and a thick sedimentary-rock section (4.2 km). This possibility can be demonstrated by use of Eq. 1, which Hudson and Douglas (1975) have shown to be approximately valid for both body and Rayleigh waves. In the latter case, the period of the fundamental-mode group-velocity minimum for a layer over a half-space occurs in the range 3.6 H/ν_s-4.3 H/ν_s for a variety of velocity and density contrasts. For station HOI, if we assume a mean sedimentary-rock shear velocity of 1.5 km/s, we find that fundamental mode periods as long as 10 s are possible owing to the presence of a thick sedimentary section, and periods of roughly 5 s are possible owing to the presence of the alluvium layer.

The LP response at RIV, which is underlain by 90-120 m of alluvium over crystalline rock, can be similarly explained using Eq. 1. In this case a fundamental period near 2 s is calculated, and the data show a broad peak between 1 and 2 s. TSH is underlain by 200 m of alluvium, consisting of coarse gravel, over crystalline rock. If we assume a shear velocity of 500 m/s as representative of this type of material, the computed fundamental-mode period is about 1.6 s. Again the data indicate a strong peak near this period.

The data of RIV, TSH, and 3838, however, also indicate peaks in the 5-7 s range that are not readily understood. Although path effects occurring at these sites and not at the CIT site could produce the observed effects, it is also possible that the geological models at the sites are not well known. For instance, unknown impedance contrasts may exist within the crystalline rock. TSH, RIV, and 3838 are all sites located near the margin of deep sedimentary basins. It is possible that long-period waves generated within the basin propagate to stations near the margin and create a response at these periods that is not related to the site's underlying geology. Future work will attempt to obtain an improved understanding of this long-period (>5.0 s) behavior.

These data indicate that the qualitative characteristics of the site transfer functions are predictable based on knowledge of the underlying site geology. Quantitative characteristics of the ground response, such as predominant period and mean site response across several period bands, may be predictable in most cases. This predictability, however, can only be established once an adequate sample has been analyzed.

COMPARISON OF SPECTRAL RATIOS DERIVED FROM NUCLEAR EXPLOSIONS AND EARTHQUAKES

Comparisons of STF_{NUC} and STF_{EQ} can be made using the data collected in this study together with the strong-motion data recorded during the 1971 San Fernando earthquake. Here we choose station GOC as the reference rock site because previous studies have found the CIT strong-motion record to be anomalous, possibly because of near-field source effects (Shakal and Toksöz, 1978; Rogers and Hays, 1978). Fig. 5 shows the spectral ratios at four sites where both strong-motion and nuclear recordings were available. Although station CIT was occupied for all the nuclear events used, station GOC was occupied for only two events. Since the stations shown in Fig. 5 were not occupied to record the same nuclear events that station GOC recorded, the ratios shown in Fig. 5 were computed using the following procedure. First, the mean GOC/CIT ratio for two events was computed:

$$R_j^k = \overline{S_{2j}^k / S_{1j}^k}$$

where

S_{1j}^k = spectral estimate of the kth component for station CIT at period j,

S_{2j}^k = spectral estimate of the kth component for station GOC at period j,

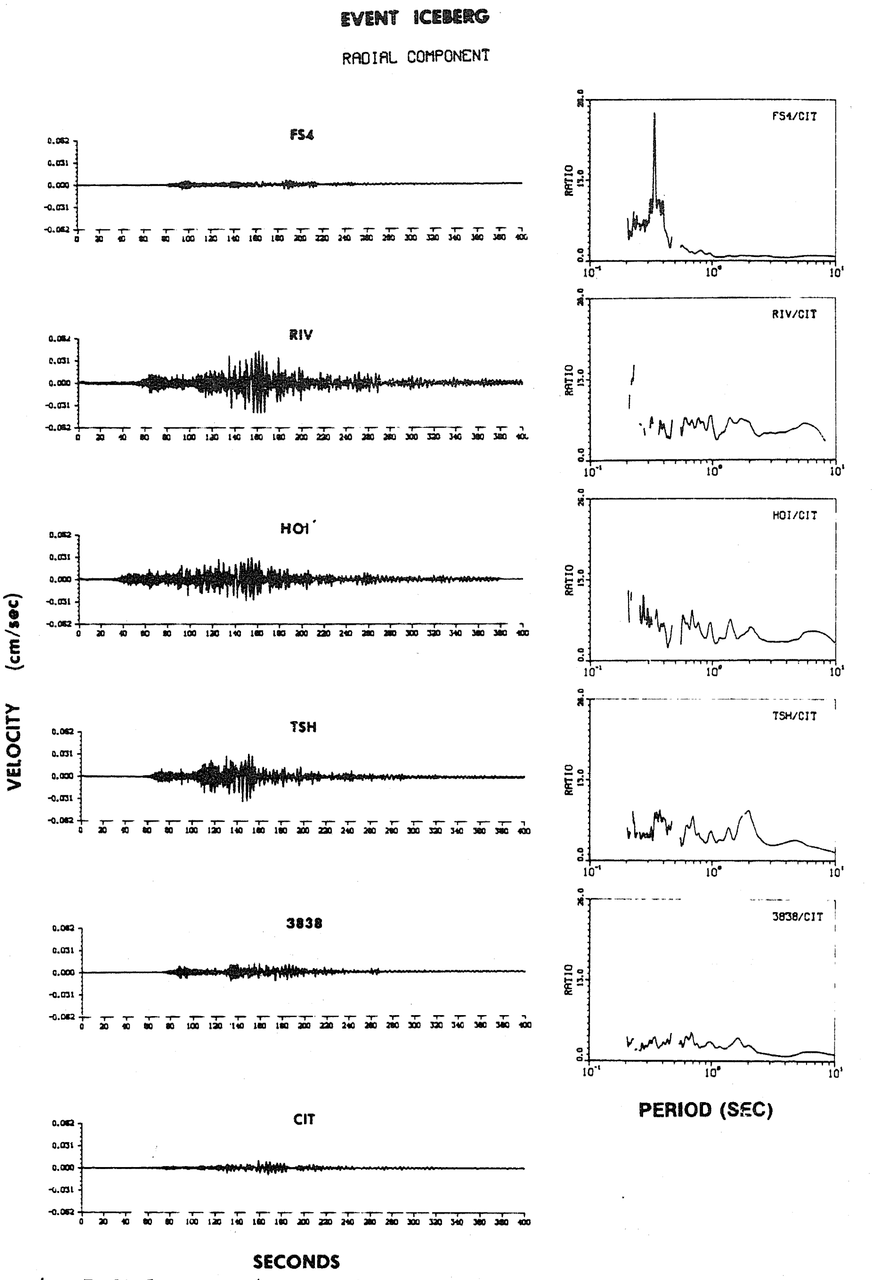

Figure 4.--Radial-component time histories recorded for nuclear event ICEBERG and corresponding site transfer functions relative to station CIT.

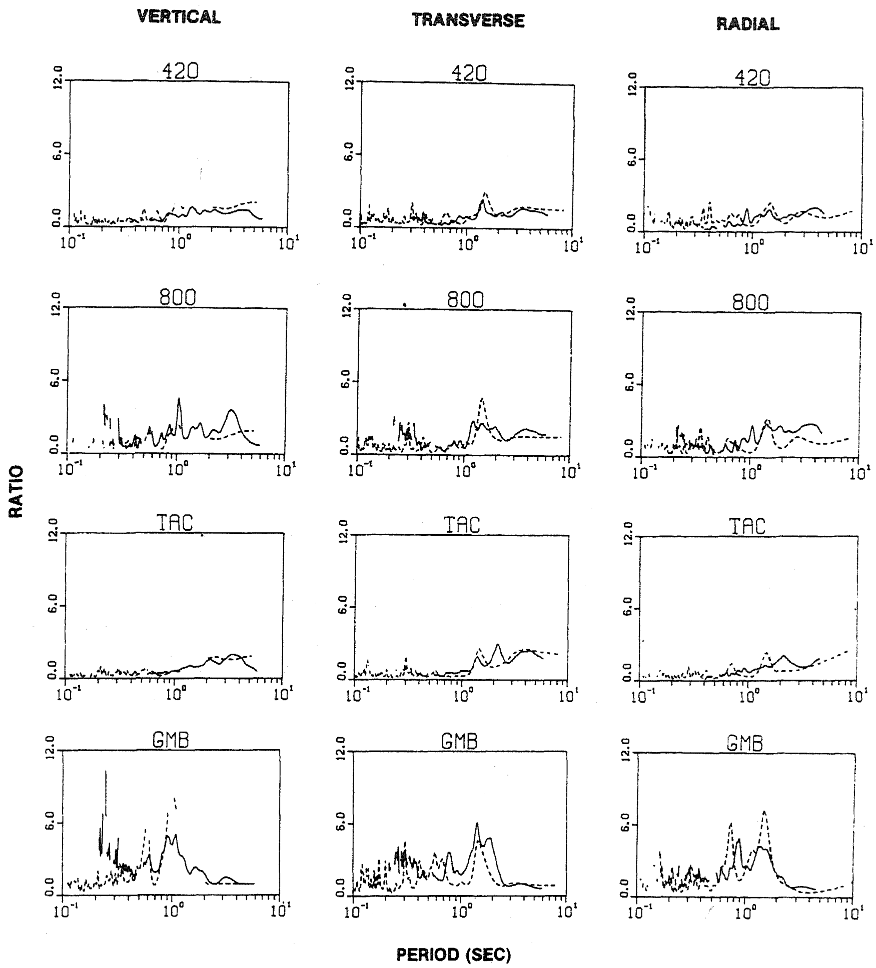

Figure 5.--Spectral ratios relative to station GOC for earthquake and nuclear ground motion at four stations. Nuclear data are shown as solid lines, and earthquake data are shown as dashed lines.

and STA_i/GOC ratios were approximated by

$$R'^k_{ij} = S^k_{ij}/S^k_{2j} \simeq (S^k_{ij}/S^k_{1j})/R^k_j \qquad i = 3, \ldots 6 \text{ (stations 420, 800, TAC, GMB)} \quad k = 1, 2, 3$$

R'^k_{ij} is the quantity plotted in Fig. 5 for the nuclear data. Whereas the shape correlation between the nuclear and strong-motion spectral ratio is variable, the general level of the curves is close. Keeping in mind that the standard derivation of both spectral ratios is a factor of 1.4, it appears that the nuclear ratios are a good approximation of the earthquake ratios at most periods.

It should be emphasized that this method is not being used to estimate the site-specific transfer function because that would require a number of recordings at each site to establish the mean response as a function of period. Instead, the method is intended to be used to estimate the mean level of the STF over several period bands for representative geological settings. From the data of this study and previous work (Rogers, et al. (1979), Rogers and Hays (1978)), the method appears to be adequate in this respect.

CONCLUSION

The preliminary results of this study indicate that spectral characteristics of site response produced by earthquakes are reproduced reasonably well by nuclear explosion-induced ground motions. The predictability of the mean level of site response based on the underlying site geology is not yet established, but the results presented here indicate that in at least some cases good predictions may be possible.

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REFERENCES

Hudson, S. A., and Douglas, A. (1975), Rayleigh wave spectra and group velocity minima, and the resonance of P-waves in layered structures, Geophys. J. R. Astr. Soc. 42, 175-188.

Rogers, A. M., Tinsley, J. C., Hays, W. W., and King, K. W. (1979). Evaluation of the relation between near-surface geologic units and ground response in the vicinity of Long Beach, California, Bull. Seism. Soc. Am. 69, 1603-1622.

Rogers, A. M., and Hays, W. W. (1978), Preliminary evaluation of site transfer functions developed from earthquakes and nuclear explosions, Proc. Second Int. Conf. on Microzonation, vol. II, pp. 753-763.

Shakal, A. F. and Toksöz, M. N. (1978), Analysis of source and medium effects on strong motion observations, Proc. Second Int. Conf. on Microzonation, vol. II, pp. 717-728.