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Bedrock motion characteristics during the 1989 Loma Prieta earthquake in the northwest area from the epicenter

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ABSTRACT: Bedrock motion characteristics were examined using strong ground motion records at rock and stiff shallow soil sites during the 1989 Loma Prieta earthquake. The results are (1) The attenuation of peak horizontal accelerations had a regional difference which was analyzed considering both fault dimensions and the rupture process. (2) The orientation of the principal axes of strong motion had a specific direction in the northwest area from the epicenter which indicates the propagation of a specific wave.

1 INTRODUCTION

This report intends to discuss two specific features of strong ground motions recorded at rock and stiff shallow soil sites during the 1989 Loma Prieta earthquake especially focusing the records compiled for the area in the northwest sector from the epicenter including the San Francisco Bay Region.

The first issue is the regionally different attenuation of peak horizontal accelerations depending on distance from the epicenter. The attenuation in the northwest area is somewhat lower than in the other regions even when the effect of amplification caused by soft soil deposits was excluded.

The second issue is the direction of ground motion. The principal axes of strong ground motions seems to have a fixed orientation, perpendicular to the direction of the fault line, and indicates the propagation of a specific wave.

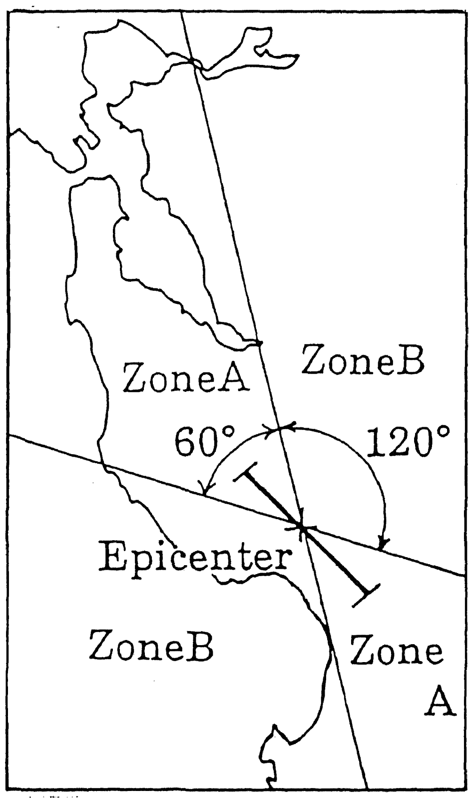

Figure 1. Zoning

2 REGIONAL DIFFERENCES IN ATTENUATION

2.1 Attenuation

The regional difference in peak horizontal accelerations depending on distance was examined here. The data for peak horizontal accelerations consisted of 44 records at rock and stiff shallow soil sites, which were compiled by the California Division of Mines and Geology(CDMG) and the U.S. Geological Survey(USGS). For the peak values the larger of the two horizontal components as originally recorded was used

At first, peak horizontal acceleration data were divided into two groups, one of which consisted of records from the sites in the sector area (called Zone A) with an inner angle of 60° and a central direction parallel to the fault line and another of which consisted of those in the sector area (called Zone B) with an inner angle of 120° and a central direction perpendicular to the fault line as shown in Figure 1.

Figure 2 shows a plot of recorded peak horizontal accelerations vs. epicentral distanceΔ. 31 data represented by solid circles are from Zone A and 13 data represented by empty circles from Zone B. For comparision, a mean attenuation relationship proposed by Kawashima et al.(1983) is superimposed on the plot. It is immediately apparant that peak horizontal accelerations in Zone A attenuated less rapidly than those in Zone B at distances of 40 to 100 km.

Equations 1 and 2 show the mean attenuation relationships of peak horizontal accelerations g which were evaluated using two data sets which belong to Zone A and Zone B, respectively.

$$\log A_A = 0.39 - 0.72\log\Delta \text{ in Zone A} \quad \text{------------} \quad (1)$$

$$\log A_B = 0.93 - 1.12\log\Delta \text{ in Zone B} \quad \text{------------} \quad (2)$$

Next, for the purpose of taking the extent of a fault rupture zone into account, we recompiled peak horizontal acceleration data as a function of distance d from the recording site to the nearest point of surface projection of the fault rupture as shown in Figure 3. Superimposed on this is a mean attenuation relationship proposed by Joyner and Boore(1981). Figure 4 shows the regional distribution of the data. Employing distance d decreases the difference between the two data sets better than utilization of distance Δ.

But recorded peak horizontal accelerations at distances of 40 to 100km in Zone A greatly exceeded the values predicted by this type of attenuation relationship.

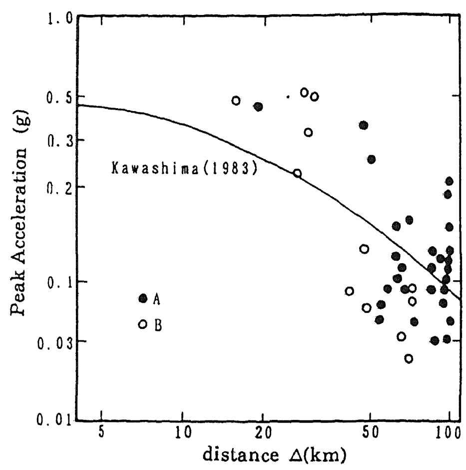

Figure 2. Recorded peak horizontal acceleration vs. distance Δ from the epicenter

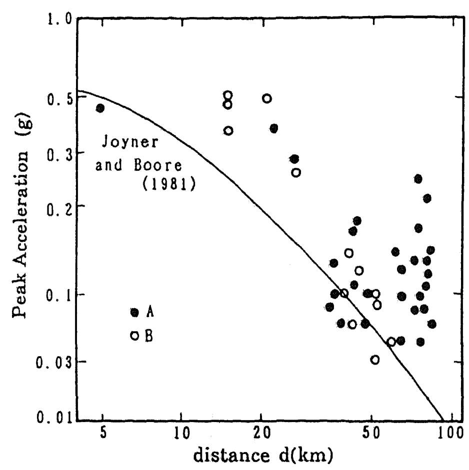

Figure 3. Recorded peak horizontal acceleration vs. distance d from the fault rupture surface

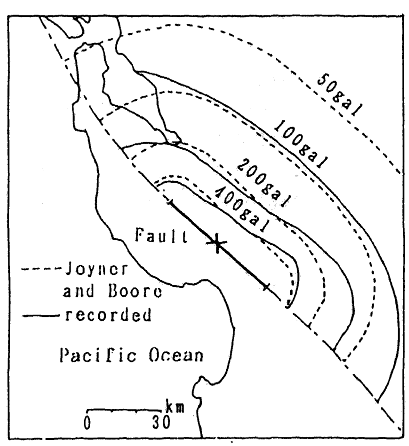

Figure 4. Recorded peak horizontal acceleration compared with the attenuation relati-onship by Joyner and Boore (1981) in plain distribution

2.2 Analysis by a source model

Next, it was attempted to explain the regional difference in attenuation using a source model proposed by Haskell (1964) which can simulate the shear wave generation that is caused by the rupture process of faulting and the sonic wave effect(*sometimes called vaguely* understanding Doppler's effect) by varying a dynamic source parameter V/C.

V and C are, respectively, fault rupture velocity and shear velocity in the Earth's crust. In the source model used, it was assumed that the fault length was L = 50km which was long enough to fault width W, a rupture occurred in the center of the rupture fault line and propagated to the right and left fault ends (bilateral rupture process), and S-wave radiation was used. Figure 5 shows the distribution of amplitude. Ovals by dotted lines represent the distribution of amplitude analyzed using the source model by varing a source model parameter V/C. The exact length of long axis of the ovals represents the amplitude of far-field displacement in the parallel direction to the fault line, the short one represents it in the perpendicular direction to the fault line. Amplitude is at the frequency of 1 Hz which is consistent with the general predominant frequency in acceleration spectra of recorded accelerograms.

An oval by a solid line represents distribution of peak horizontal acceleration at a distance of 100km using Equations 1 and 2. The meanings of the long and short axes are the same as those mentioned above.From this figure it is clear that the analytical distribution of amplitude conforms best to the one observed at V/C = 0.7, which is consistent with the average V/C reported by Geller (1976). From this result it appears that the fault rupture process is one of the factors which caused the predicted peak horizontal accelerations using a mean attenuation relationship at rock and stiff shallow soil sites in the San Francisco Bay Region to be exceeded as shown in Figure 3 and 4.

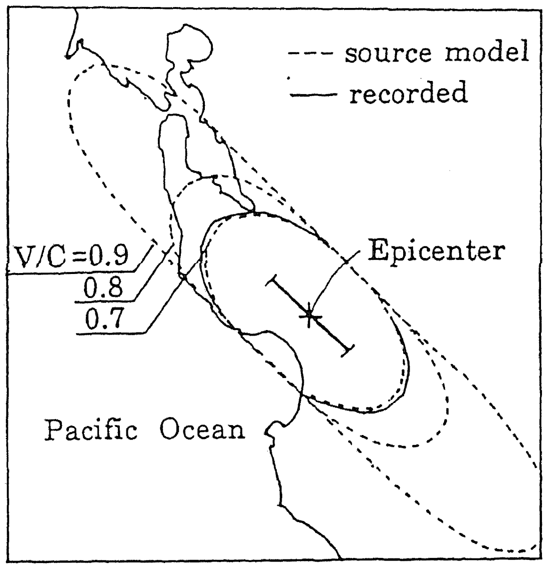

Figure 5. Distribution of amplitude as analyzed by a source model by varying the source parameter V/C

3 CHARACTERISTICS OF STRONG GROUND MOTIONS

3.1 Orientation of the principal axes

For the purpose of obtaining overview of strong ground motion characteristics, the orientation of the principal axes which were defined as those which yielded maximum values for the covariances (i.e. mean power or RMS) of recorded accelerogram amplitude[6] was examined. The data which consisted of 27 horizontal accelerograms pairs recorded at rock and stiff shallow soil sites were analyzed. As shown in Figure 6, examination of real accelerograms reveals that the principal axes of ground motions in the sector area towards the San Francisco Bay Region point generally in a direction perpendicular to the fault line. This indicates the propagation of a specific wave towards the San Francisco Bay Region. This kind of aspect does not appear in the other area.

3.2 Evolutionary power spectra

Next, the nonstationary characteristics of strong ground motions were examined. The evolutionary power spectra of accelerogram records from the Lexington dam and the S.F. Presidio were calculated using the method of Sugito and Goto(1984). The results are shown in Figure 7 (a) and (b).

From this figure, it is apparant that most of the power spectra intensity appears to concentrate around 1 Hz, and in the same frequency range, slight dispersion of phase velocity seems to appear.

3.3 Phase velocity from accelerogram records

Accelerograms recorded at four recording stations on rock for which trigger times were known were used for analysis. Table 1 shows the data of these recording stations.

Phase velocity between each recording stations was determined from accelerogram records using the method proposed by Toki (1975). The component analyzed here is in a direction perpendicular to the epicenter and the range of frequency is from 0.5Hz to 2Hz. Figure 8 shows dispersion curves which were detected.

As shown in Figure 8 (a), in the area nearest to the epicenter between LX and UP, dispersion of phase velocity hardly appeared. As the mean phase velocity was about 5 km/sec and that value is consistent with the shear velocity in Earth's crust, it seems that body wave propagated in this area.

In Figure 8 (b), slight dispersion of phase velocity appeared. Phase velocity around 1 Hz decays and its mean value was about 2km/sec. In Figure 8 (c), the appearance of the dispersion of phase velocity was not clear but the phase velocity around 1Hz was about 2-3km/sec. Its value was the same as the one in the area between UP and PR as shown in Figure 8 (b). In the same range of frequency, this phase velocity fits the theoretical dispersion curve well for first-mode Love wave as reported by Sugito(1990). From these results, it can be seen that the wave propagated toward the San Francisco Bay Region included Love wave.

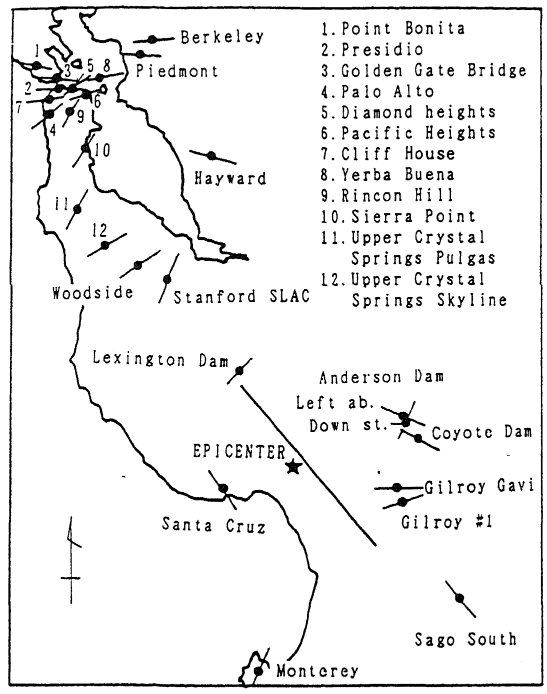

Figure 6. Distribution of the principal axes

4 CONCLUSIONS

For the strong ground motions recorded at rock and stiff shallow soil sites,

(1) Peak horizontal accelerations in the sector area in a direction parallel to the fault line attenuated with distance less rapidly than those in another sector.

(2) Considering the effects of both the fault dimensions and the sonic wave phenomena, regional difference of attenuation and regional distribution of peak horizontal accelerations were analyzed well. The source model parameter V/C = 0.7 which was generally used in past studies was also applicable to this analysis.

(3) The orientation of the principal axes of the strong ground motions recorded in the sector area towards the San Francisco Bay region was nearly perpendicular to the fault line.

(4) Predominant frequencies of acceleration spectra for the strong ground motions mentioned above were around 1Hz. In this frequency range, slight dispersion of phase velocity appeared at a distance far from the epicenter, with phase velocity of about 2-3km/sec.

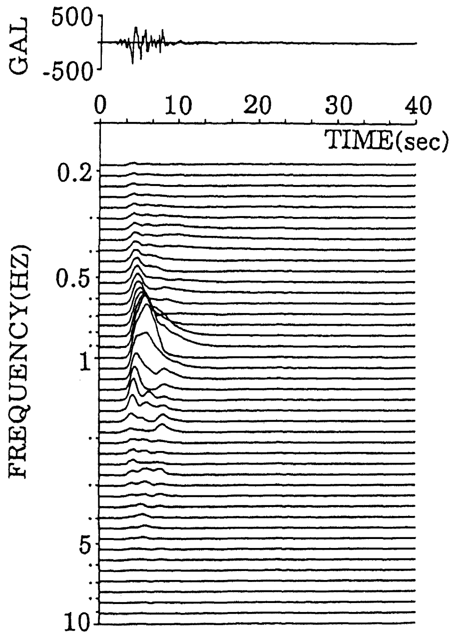

Figure 7(a). Evolutionary spectra of EW component recorded at the Lexington dam

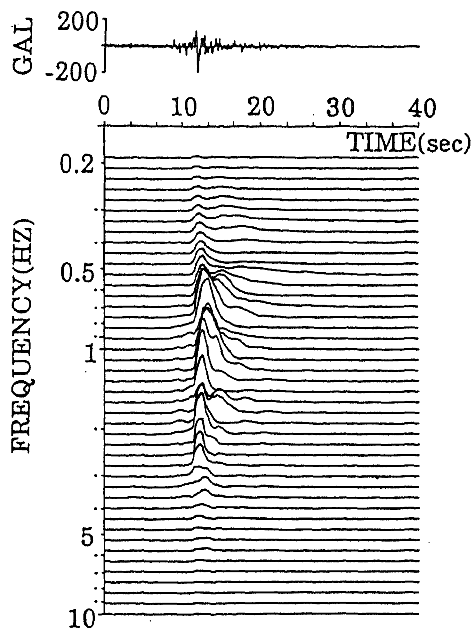

Figure 7(b). Evolutionary spectra of EW component recorded at the S.F. Presidio

Table 1. Data of recording stations

Recording sitations	Geology	DistanceΔ (km)
LX--Lexington dam	slate and sandstone	20
UP--Upper crystal springs	sandstone	69
PR--S.F. Presidio	serpentine	105
PO--Point Bonita	sandstone	112

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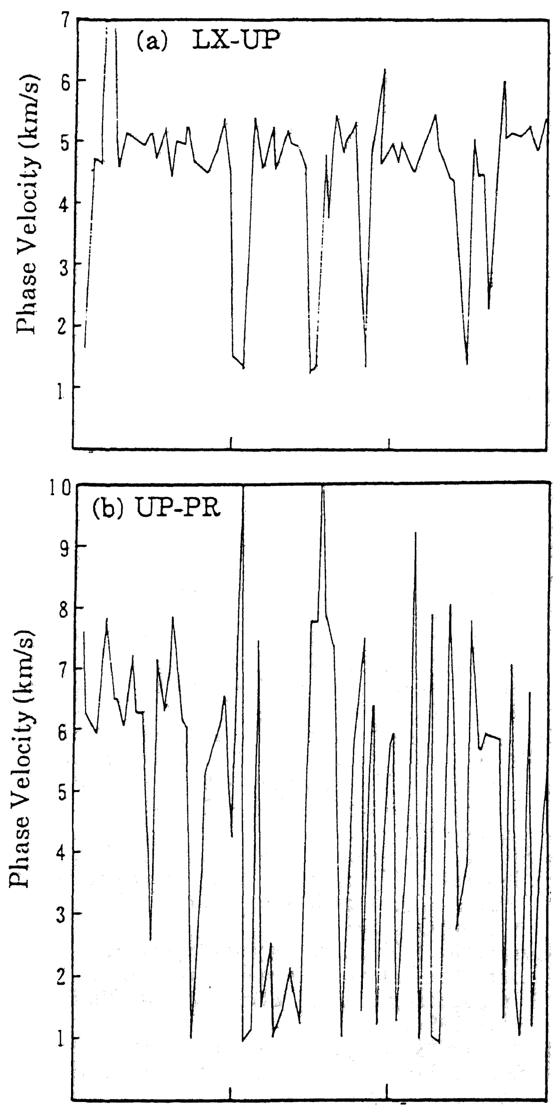

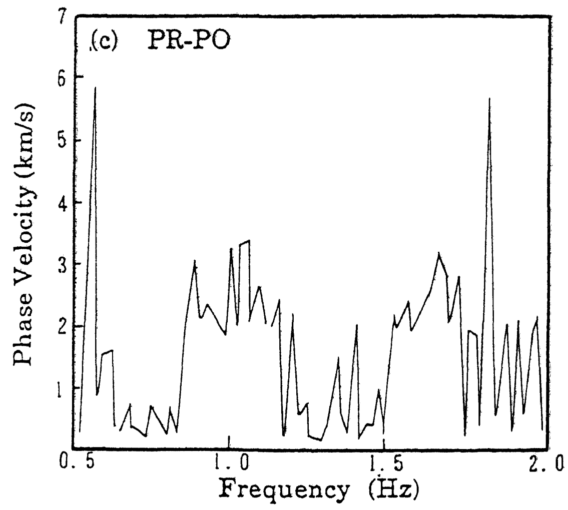

Figure 8. Dispersion curves from analysis of recorded accelerograms