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SHORT NOTES

SITE EFFECTS ON SEISMOGRAMS OF LOCAL EARTHQUAKES IN THE KALAMATA REGION, SOUTHERN GREECE

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In an attempt to investigate both seismic attenuation and site effects in relation to the aftershock activity of the 13 September 1986 ($M_S = 6.2$) earthquake which devastated the city of Kalamata, the Geophysics Department of Athens University installed a short-period five-station network in the epicentral area. Structural damage surveys related to this earthquake are not included here, since detailed information has been documented by Anagnostopoulos *et al.* (1987).

The present work aims to contribute to the knowledge of the site effects when the same earthquake was locally recorded at stations characterized by different geological conditions. The general geological setting of the area along with the five observation stations equipped with 1-Hz vertical geophones is shown in Figure 1. Both primary and shear wave velocity measurements were performed in these sites and the obtained results, together with a description of the geology of each site, are presented in Table 1.

Eleven events representative in location and best signal-to-noise ratio are used, and their epicenters are plotted in Figure 1. We determined the involved experimental error by placing all of the seismometers within 5 m of one another and recording several earthquakes in order to compare the resulting spectra (following the procedure of Tucker *et al.*, 1984). From this test, we concluded that the involved uncertainty in the evaluated spectral ratio is about 0.2 log units for frequencies up to 20 Hz. For calculating amplitude spectra, the first 4 to 8 sec of the S waves were used. The time sequence was tapered by a 10 per cent cosine window, and the spectra were calculated using a Fast Fourier transform. The instrumental response was carefully checked, and the corresponding corrections were applied by frequency-domain deconvolution.

Recent attenuation measurements in the area employing coda wave analysis (Tselentis *et al.*, 1987) and explosion seismic techniques (Tselentis *et al.*, 1988b) showed that the attenuation character of the area cannot be described by adopting a single attenuation low. This is a result of the complex geological and tectonic character of the region.

Since the attenuation factor Q plays an important role in the correction of the seismic spectra, the following procedure was followed

1. The earthquakes were separated into three groups, considering their location and the geological character of their epicentral area.
2. For each group, a representative event was chosen, and starting with an initial value of Q, a final estimate was made for the whole ray path in such a way that the corrected spectra become nearly flat out to a frequency of about 20 Hz.

The attenuation correction, together with the correction for geometrical spread-

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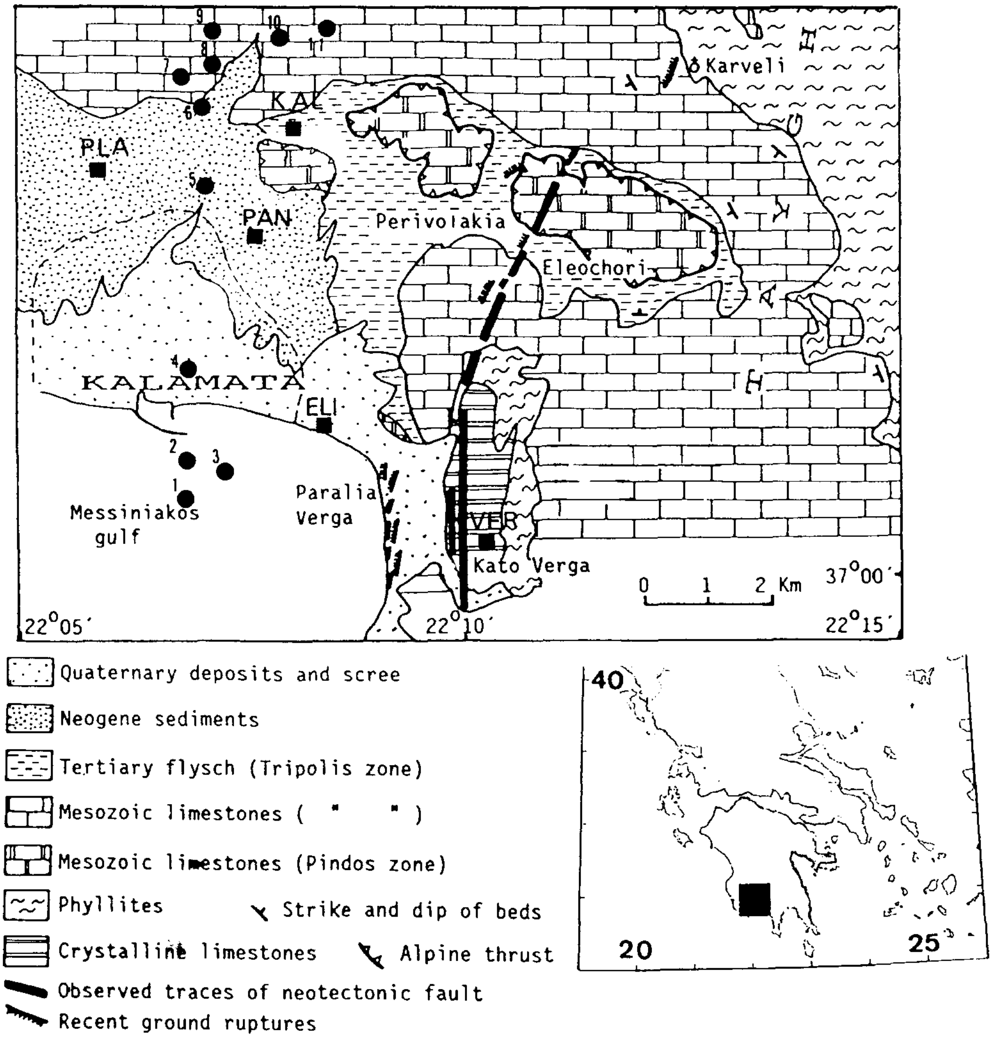

FIG. 1. Geological features of the Kalamata district. Circles denote earthquakes used for site investigations, while squares indicate the station location (modified from Papazachos *et al.*, 1988.)

TABLE 1

GEOLOGY AND SITE VELOCITIES OF THE RECORDING SITES

Station	Site Description	V_p (m/sec)	V_s (m/sec)
VER	Limestone bedrock	4100	1150*
ELI	Alluvium over marine sediments	350	180
PAN	Approximately 130 m of marine sediments of Neogene-Pliocene age (clays)	2100	620
PLA	Approximately 25 m of alluvium of Pliocene age with interbedded clays and sands	550	310
KAL	Approximately 150 m of flysch	2900	—

* Value adopted from a near site (Tselentis *et al.*, 1988a).

TABLE 2

Q VALUES FOR THE RAY PATHS CONSIDERED AND INFORMATION ABOUT EARTHQUAKES USED

Group	Event [Magnitude Depth (km)]			Station				
				ELI Q	VER Q	KAL Q	PLA Q	PAN Q
I	1	2.1	4.1	250	300	250	250	250
	2*	1.9	3.2					
	3	1.9	4.6					
	4	2.3	5.2					
II	5*	1.7	3.1	350	200	300	300	300
	6	2.2	4.8					
III	7	2.0	3.6	250	250	200	200	250
	8	1.9	1.8					
	9*	2.1	3.2					
	10	1.8	1.9					
	11	2.2	3.6					

* Representative ray path for Q estimation.

ing, was obtained in the frequency domain by utilizing the following operator (Görich and Müler, 1987)

$$QG = (1/V_s t) \exp[-\pi f(t/Q) - i2\pi f(t/Q) \ln(f/f_\eta)]$$

where t is the travel time, V_s is the shear-wave velocity (2.5 km/sec), f_η is the Nyquist frequency (50 Hz), and Q is the obtained best estimates (tabulated in Table 2). The obtained spectra ratio were smoothed by convolving with a 2-Hz bandwidth triangular window function.

Figure 2a shows a sample of the Fourier amplitude spectral ratio plots (up to 10 Hz) for three of the events used at each one of the stations with respect to station VER, which is characterized as a "rock site," while Figure 2b summarizes the different amplification effects of the station sites of the band analyzed by averaging the results for all 11 earthquakes used. Judging from these results, we see that in almost all of the cases considerable amplification is observed.

The greatest amplification ratio is encountered at sites PLA and PAN, which are located on soft alluvial formations. Site PAN shows peak amplitudes at about 3 Hz while site PLA shows a rather monotonic decrease of amplification with increasing frequency. Station KAL, which is located on shale, shows intermediate amplification.

Despite the thick (>200 m) sedimentary cover of site ELI, the obtained amplification values are the lowest from all of the cases examined. It is also interesting to note that the largest peaks of the horizontal components of motion, both for the main event and a $M = 5.2$ aftershock, recorded by a nearby installed accelerograph, occur all at the same period of 0.32 sec ($\simeq$3 Hz) (Theofanopoulos *et al.,* 1988). The observed relatively lower amplification ratios at site ELI are in agreement with the fact that there was a rapid decrease of the damage toward this area.

As a final note, it must be pointed out that, although the city does not extend over a large area, the observed distribution of damage for the same type of construction was quite nonuniform. This suggests significant variations in the ground motion, which is attributed to possible differences in local soil conditions.

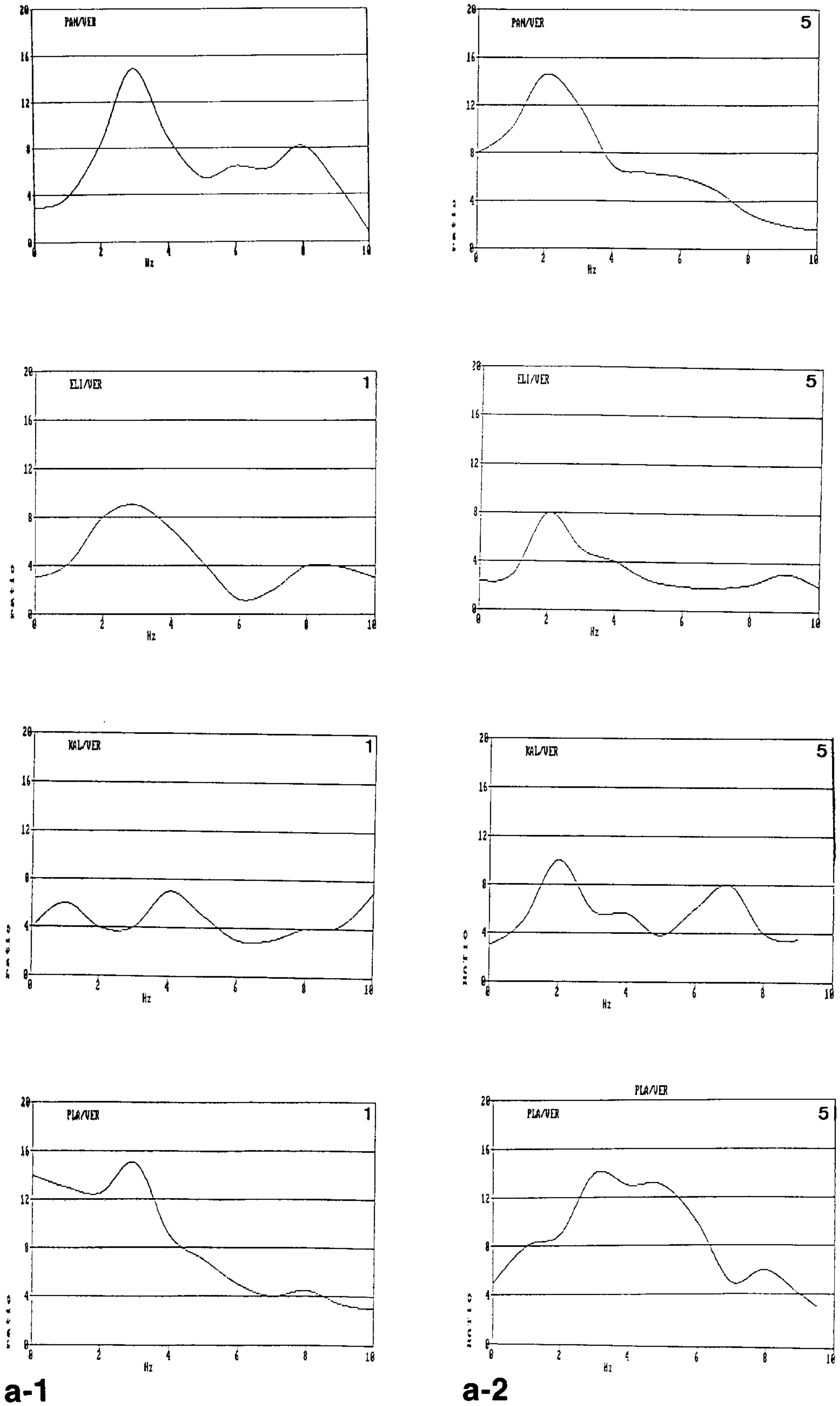

FIG. 2. (a) Amplification ratios. *Numbers inside diagrams* denote corresponding earthquakes. (b) Average amplifications for all 11 events used.

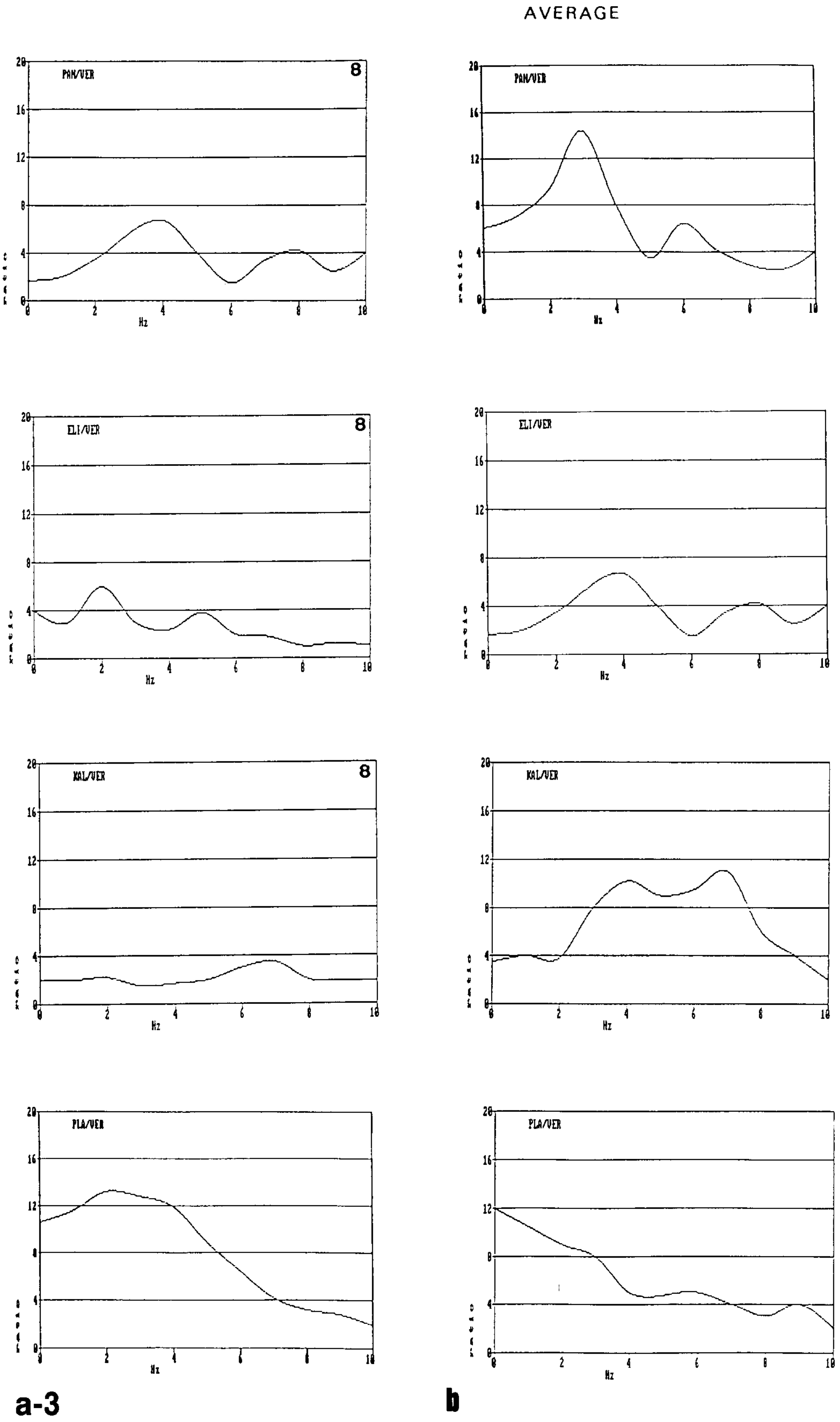

FIG. 2. Continued

The results of the present analysis confirm that the site dependence may play an important role in the amplitude of ground motion.

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