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Evaluation of Soil Amplification at Smart1 Array, Taiwan

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SYNOPSIS: In a recent compilation and analysis of nearly 750 accelerograms, we studied six pairs of triaxial accelerograms recorded digitally at two neighboring sites underlain by rock and soil, respectively. The distance between the two sites, both located south of the SMART1 array in northeast Taiwan, is approximately 2 km. The epicentral distances are less than 80 km.

For each component, we computed the ratios of peak and spectral amplitudes recorded at the soil site to that of the rock site, for three peak parameters and 23 spectral ordinates. The mean estimates of the soil amplification for the peak parameters range between 1 and 3.

The spectral variation of soil amplification factor is similar for the two horizontal components. They are relatively flat in the high frequency range, peak in mid-frequency range, and decrease at longer periods. The N-S component has a ratio of about 1.35 at high frequencies, increasing to about 3 between 1 and 2 seconds, then decreasing to around 2.4 at longer periods. The E-W component shows higer ratios, stating at about 2 at high frequencies, increasing as high as 7 near two sec period, and falling off to about 2 at longer periods. For the vertical component the soil-to-rock amplitude-ratio is nearly 1.5 in the high frequency range above 2Hz. This ratio increases to nearly 3 in mid-frequency range, and falls off to about unity for longer periods. While the horizontal ratios peak at about 2 sec, the maximum vertical spectral ratio occurs near 0.8 sec.

INTRODUCTION

The behavior of strong ground-motion in the near-source region of an earthquake is influenced by the properties of the earthquake source, propagation path, and the recording site. In this study, we have attempted to isolate the influence of geology at the recording site by comparing the peak and spectral ground-motion parameters at two adjacent sites, one underlain by rock and the other by alluvial deposits. The measurements are made near the southern edge of the SMART1 array in northeastern Taiwan (sites E1 and E2 in Figure 1), as part of a broader study of the behavior of the strong ground-motion across a dense 2 dimensional array (TENERA, 1990). Of the 12 earthquakes considered in that study, only six had recordings at E1 and E2 stations. Table I gives the list of earthquake sources used in this study.

TABLE I. List of Earthquake Sources Used in this Study

Event	Year	Date	N.Lat. deg	E.Long. deg	Depth km	M	Dist. to E1/E2 km
29	1984	Apr 23	24.79	122.09	8.7	6.0	36.28/37.50
33	1985	Jun 12	24.57	122.19	3.3	6.5	44.40/44.41
36	1985	Sep 20	24.53	122.20	6.1	6.3	45.74/45.56
39	1986	Jan 16	24.76	121.96	10.2	6.5	23.57/25.00
43	1986	Jul 30	24.63	121.79	1.6	6.2	3.70/ 3.34
45	1986	Nov 14	23.99	121.83	13.9	7.8	76.52/74.54

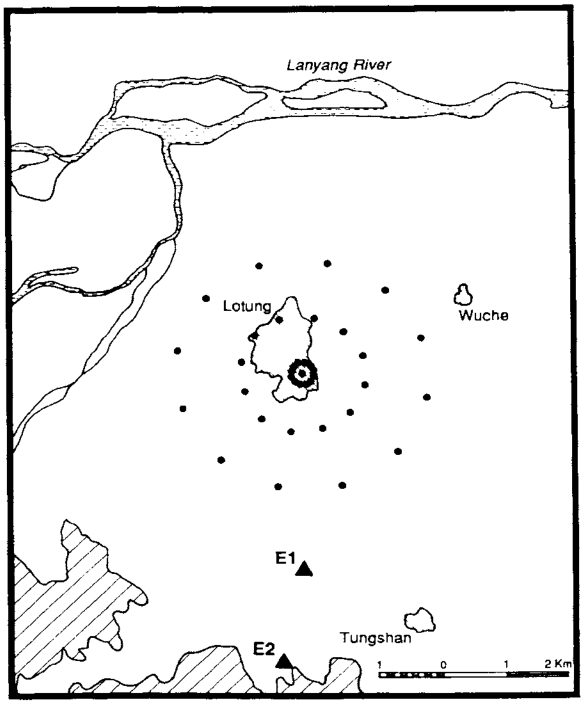

Fig. 1 Position of the recording stations E1 (soil) and E2 (rock) relative to the concentric rings of SMART1 array in northeastern Taiwan

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The array is situated on the Lan-Yang Plain, near the town of Lotung, in northeastern Taiwan. Based on a seismic survey conducted by the Chinese Petroleum Corporation in 1973, the array site is underlain by approximately 450 m of post-Miocene sedimentary section. According to Wen and Yeh (1984), the P-wave velocity is in the range of 3.3 to 4.0 km/sec for the Miocene basement complex, 1.8 to 2.0 km/sec for the overlying Pleistocene sediments, and 1.4 to 1.7 km/sec for the recent alluvium. The thickness of top-soil ranges between 3 and 18 m, with a P-wave velocity of 0.43-0.70 km/sec.

Station E2 is underlain by slate of Miocene age whereas E1 is located nearly 2 km north of E1 on the top of about 150 m of sedimentary materials overlying the basement complex.

DATA PROCESSING METHOD

Ground-motion acceleration time histories are recorded digitally at a rate of 100 samples per second. Data processing, i.e. base-line correction, filtering and integration, are performed using the approach described by Sunder (1981). A trapezoidal band-pass filter with corner frequencies of 0.07, 0.10, 25.0, and 30.6 Hz are used.

For each component of the triaxial accelerograms the ratio of peak parameters, PGA, PGV, and PGD, and spectral amplitudes recorded at the soil site (E1) to that of the rock site (E2) is computed. 23 spectral ordinates in the period range of 0.03 to 10 sec are used.

AMPLIFICATION OF PEAK PARAMETERS

The mean and standard deviation of the amplification factor derived for the peak ground acceleration (PGA), peak ground velocity (PGV), and peak ground displacement (PGD) for the six earthquake studied here, are tabulated in Table II.

TABLE II Soil/rock ratios for peak parameters

Component	PGA	PGV	PGD
E-W	2.07±1.25	2.93±0.80	2.38±0.56
N-S	1.29±0.35	1.72±0.29	2.39±1.54
U-D	1.52±0.07	1.33±0.38	1.16±0.47

Despite large scatter, the results of Table II tend to suggest that the amplification of PGV and PGD, in general, is larger for the horizontal components than for the vertical component. Regardless of the sensor's orientation, however, the estimated mean value derived for soil amplification for the soil geology relative to rock is above unity for all three peak parameters.

SPECTRAL AMPLIFICATION

A comparison of the response spectra for the three components of the motion recorded at sites E1 and E2 during the earthquake of January 16, 1986 (Event 39) is shown in Figure 2.

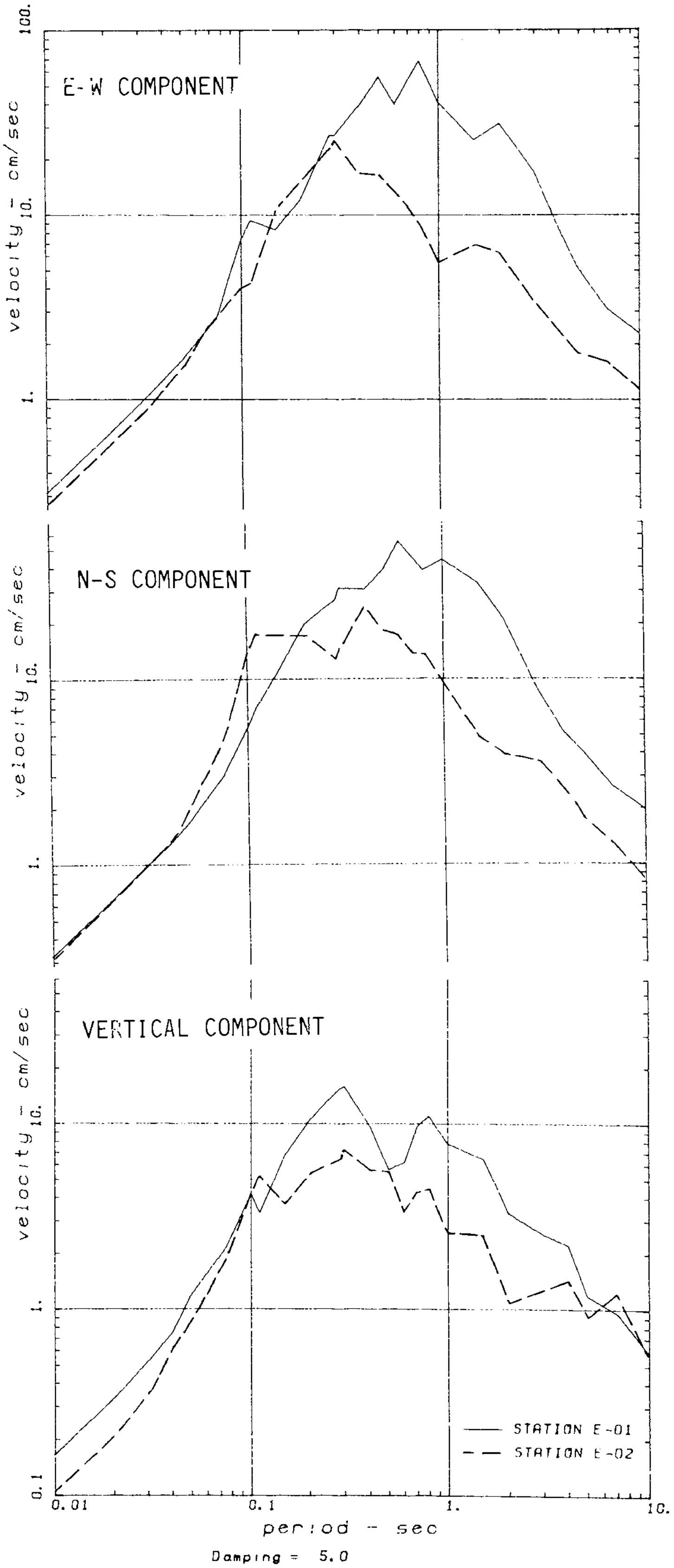

Fig. 2 Response specta of Event 39 at 5% damping

Figures 3 to 5 present the observed spectral ratios for the three components of the motion. The computed ratios for different events are keyed to the inset at 23 periods studied. The solid line in each figure represents the pointwise mean and the dashed lines demarcate the one standard deviation band.

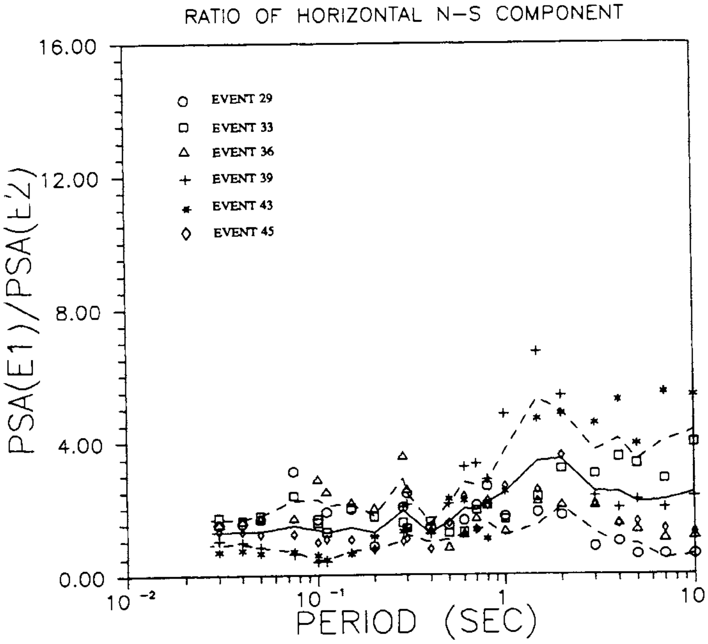

Fig. 3 Observed soil amplification for the N-S component at site E1 relative to the neighboring rock site E2. Solid curve is the computed pointwise mean and the dashed lines show the one standard deviation band.

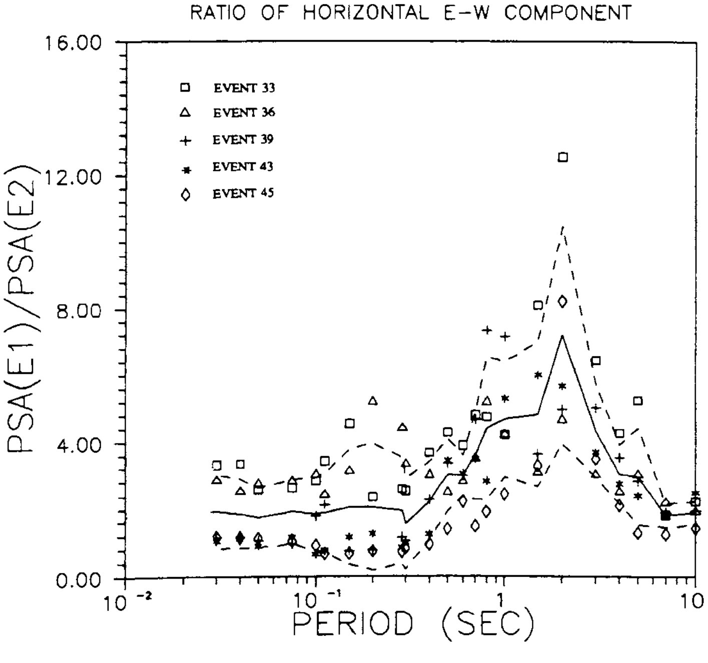

Fig. 4 The same as Figure 3 for the E-W component of motion

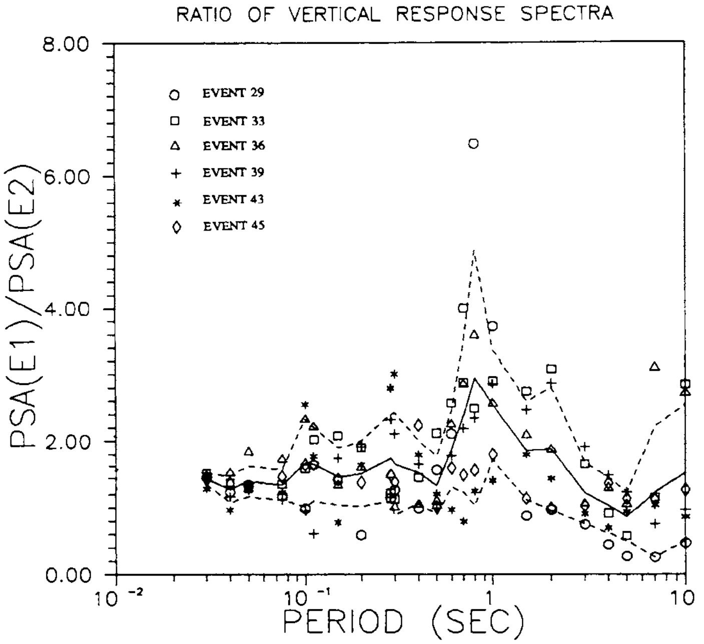

Fig 5 The same as Figure 3 for the vertical component of motion.

The first noticeable feature of Figures 3 to 5 is that the mean spectral amplification is generally above unity indicating that in general the soil site has higher spectral amplitudes than the rock site, even at high frequencies. The shape of the spectral amplification curve is similar for the two horizontal components. They are relatively flat in the high frequency range, increase in the mid-period range and decrease at longer periods. The amplification factor for the north-south component has a mean value of about 1.35 at high frequencies, increases to about three between 1 and 2 sec, and again decreases to nearly 2.4 at longer periods. For the east-west component the spectral ratio shows higher mean values, starting at about 2 at high frequency end of the spectrum increasing as high as 7 near two second period, and falling off again to 2 at longer periods.

For the vertical componentthe amplification factor for soil in the high frequency range above 2Hz is about 1.5. It increases to about 3 in the mid frequency range (0.5-2.0 sec) and falls off to about unity for the longer period ordinates. A study of the down-hole ground-motion records to the north of E1 by Wen and Yeh (1988) also showed that the dominant amplification centered in this frequency range. Note that for the horizontal components, maximum amplification occurs near 2 sec period, whereas for the vertical component it occurs at 0.8 sec.

The spectral amplifications of Figures 3 to 5 are in general agreement with those listed in Table II for peak parameters at representative frequency bands. Thus, for instance, for the east-west component, soil amplification for PGA is comparable with the high frequency spectral amplification (2.1 vs 2.0). The mid-frequency PGV increases to a ratio of 3, though not as high as the one-second spectral ratio of nearly 5. Finally, the low frequency PGD compares well at 2.4 with the long-period spectral ratio varying between 2 and 3.

For the N-S component, again there is a match between the PGA amplification and the high frequency spectral ratio of Figure 3 at around 1.3. As with the E-W component, here again the PGV amplification is not as high as the maximum amplification observed for the PSV near 2 sec. The PGD amplification at 2.4, however, is comparable to the PSV amplification at low frequencies.

The mismatch between the PGV amplification and mid-frequency spectral ratios for vertical is similar to the other two components and may be due to the fact that PGV signal represents a frequency band rather than a single frequency. Within the frequency band representing PGV, the amplification factor varies considerably and, therefore, an integrated effect would be observed.

A noteworthy observation in this study is that the soil amplification for the vertical peak parameters, shows remarkably little variation between the six earthquakes, especially with respect to PGA. While the mean amplification for the vertical PGA is 1.5, the standard deviation is only 0.07.

UNEQUAL AMPLIFICATION OF HORIZONTAL COMPONENTS

As noted in Table II and Figures 3 and 4, the mean amplification values are higher in the east-west direction than are in the north-south direction, for PGA, PGV and the corresponding frequencies of the response spectra. With similar soil column, matched instruments and identical basement depth, the difference may partially be explained in terms of the basement geometry. As shown in Figure 1, E1 is located near the southern edge of the Lan-Yang basin. The station is, therefore, underlain by a 2-D sedimetary wedge, thickening northward. By virtue of being parallel to the basement interface, the E-W component of the particle motion is reflected only as SH. The N-S component on the other hand, impinges on the boundary in the direction of the dip, and would, therefore, partition into SV an P motion upon reflection. Under this scenario, the energy associated with the E-W particle motion would be totally trapped within the wedge, whereas, the N-S particle motion would lose energy to mode conversion upon each reflection (Bard and Bouchon, 1980a, b).

Novaro et al. (1990) have shown that under the prescribed circumstances, the response of the sedimentary wedge would differ substantially from the one-dimensional flat-layer model. In a recent study of soil response during the 1989 Loma Prieta earthquake, Shakal et al. (1990) showed, while resonance frequencies at a specific site may remain unchanged, resonance amplitudes depend on the intesity of shaking, amplification factor being larger for smaller earthquakes. The observed effect was attributed to the nonlinear response of the soil at high amplitudes.

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