I. GROUND MOTIONS OF OCTOBER 4 AND NOVEMBER 6, 1985, EARTHQUAKES RECORDED BY DENSE SEISMOGRAPH ARRAY

by

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ABSTRACT

On October 4, 1985, an earthquake with the intensity V (JMA), the strongest shock in 56 years, hit Tokyo. The ground motions were successfully recorded at the Chiba Experiment Station of the Institute of Industrial Science, the University of Tokyo. After about one month, earthquake records with slightly smaller maximum acceleration amplitudes of 50-80cm/s/s were also obtained. In this paper, by using these records, the variations of the maximum acceleration amplitudes of the ground motion in a horizontal plane with a dimension of about 300m and the vibration mode of the ground in vertical direction are investigated.

LAYOUT OF ARRAY NETWORK

The layout of the very dense array network, with 36 three-component seismometers, has been already discussed in detail in references 1 and 2. Since February, 1985, the array network, originally covering a region with a maximum dimension of about 120m, was expanded to cover a region of 300m by installing 8 new seismometers at P7, P8, P9 and P0. At present, the array network which includes 44 three-component seismometers is capable of simultaneous recording of 132 components of seismic ground accelerations. A general layout of the on-ground seismometers (one meter from the ground surface) is shown in Figure 1. The vertical positions of the seismometers are given in Table 1.

Figure 2 shows the N values for several representative boreholes. The top 4-5m of the site is covered with the loam with the standard penetration N value being less than 10. The loam layer is underlain by the clayey layer with a depth of 3-4m whose N values are also less than 10. The sand layer underlying the clayey layer generally has N>20-30. This sand layer, although its stiffness generally increases with depth, is interspersed with clay which shows relatively smaller N values. In spite of the slight differences of the locations of the boundaries between different layers from one borehole to another, the overall agreement is good and indicates a relatively simple subsoil structure.

In this paper, the records obtained at the apexes of a triangle with the sides of about 300m (points P5, P8, and P0 in Figure 1) and at the middle points on the three sides (points P7, P9, and C0 in Figure 1) are considered. The notations used in this paper such as 'P510EW' refers to the EW component of ground motion obtained at the depth of 10m in P5 borehole.

EARTHQUAKES AND RECORDS

The characteristics of two earthquakes used in the present study are summarized in Table 2. The epicenter of evevt 1 was located on the border line between Chiba and Ibaraki Prefecture some 30km north of the observation

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station. Evevt 2 occurred in the central part of Chiba Prefecture some 30km south of the observation station. A schematic map of the locations of the recording station and the epicenters of the 2 earthquakes is shown in Figure 3.

The main parts of the accelerograms obtained at different depths at point CO are shown in Figure 4. The maximum acceleration amplitudes are given in Table 3. Displacements at point CO at the depth of -1m were evaluated by double integration of accelerogram records and the loci of the ground particles for two events were also obtained (Figure 5).

Events 1 and 2 continued for about 165s and 80s, respectively. Several strong oscillations were observed during event 1, but essentially only one strong oscillation was observed for event 2 (Figure 4). Referring to Figure 5, it was observed that the dominant ground motions were in EW-direction and NS-direction for events 1 and 2, respectively. In the observation region, the maximum acceleration amplitudes of the ground surface were in the ranges of 60-110cm/s/s and 50-80cm/s/s for events 1 and 2, respectively (Table 3). In terms of the coefficient of variation, the values ranging from 10% to 20% were obtained. However, the coefficients of variation of maximum acceleration amplitudes at the depth of 20m were 5-10%, displaying smaller variation at deeper layers.

VIBRATION MODE OF GROUND

Finite Fourier coefficients of the acceleration records at point CO at the depth of 1m are shown in Figure 6. The frequency characteristics of the NS and EW components seem to be similar for the same event. A dominant peak is observed at about 2.5Hz for event 1 and at 4-5Hz for event 2. However, the two earthquakes apparently show different characteristics in the frequency domain probably due to the different frequency contents of their incident waves. Consequently, the dominant frequencies of the ground cannot be specified exactly, but it can be stated that there are many peaks between 2Hz and 8Hz.

Figure 7 shows the ratios between the finite Fourier coefficients at the depth of 1m and 40m. Although the magnitudes of peak ratios show variation for different events and different components, the frequencies corresponding to peak ratios are common and about 2.5Hz, 5.5Hz, and 8.5Hz for the both events.

The time histories of different frequency components of accelerograms were obtained by band-pass-filtering of the records. The band-pass-filter has a band width of ±10% of the central frequency. The vibration modes of the vertical section of the ground were normarized and are shown in Figure 8 for the EW component of event 1. The ground motion amplitudes at different depths are almost equal at low frequencies. At higher frequencies, however, nodal points begin to appear and their number increases with increase in frequency. The first nodal point appeared at the depth of 40m at the frequency of about 2.5Hz. The nodal position moves upward for higher frequencies. The second node appeared at about 5.7Hz and the third node at about 10Hz. This general trend was commonly found for the records of different directions and different events. It is observed from the values of amplitudes of component waves also shown in Figure 8 that the first two peaks in Figure 7 roughly correspond to the first and second modes of shear beam and that the third peak is associated with the mode in which the relatively soft, superficial layer alone is excited.

It is clear that, for any frequency, the apparent amplification factor becomes large when it is calculated between the particle motions at the surface and at a depth where a nodal point corresponding to that frequency appears. For example, the ratio between the particle motions at the surface and at -20m is expected to show a peak for a frequency of about 4Hz because for this frequency the nodal point appears near -20m (Figure 8). However, since the position of nodal point changes with the frequency, an apparent dominant frequency may change depending on the two points for which the peak response ratios are obtained. Consequently, careful consideration seems to be necessary in estimating the natural frequencies of the ground by the conventional method.

ACKNOWLEDGMENT

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1. Katayama, T., Farjoodi, J., and Sato, N., "Measurement of Seismic Ground Strain by a Dense Seismograph Array", Proceedings of the 8th W.C.E.E., Vol. 11, pp. 207-214, San Francisco, U.S.A., July, 1984.
2. Farjoodi, J., Sato, N., and Katayama, T., "Engineering Properties of Ground Motion Obtained from Dense Seismograph Array Data (Part 1 : Ground Strain)", Bulletin of ERS, University of Tokyo, No.18, March, 1985.

Table 1 Depth of Seismometers

Depth	Borehole														
	C0	C1	C2	C3	C4	P1	P2	P3	P4	P5	P6	P7	P8	P9	P0
-1m	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
-5m	o	o	o	o	o										
-10m	o	o	o	o	o	o	o	o	o	o	o				
-20m	o					o	o	o	o	o	o	o	o	o	o
-40m	o									o					

Table 2 List of Earthquakes

Event No.	Date	Epicenter	Mag.	Focal Depth	Epicentral Distance	I*
1	Oct. 4, 1985	N 35°52', E 140°10'	6.1	78km	28km	4
2	Nov. 6, 1985	N 35°21', E 140°14'	5.0	59km	32km	3

*I : JMA Intensity at Chiba

Table 3 Maximum Acceleration Amplitude (cm/s/s)

Event No.	Depth	Direction	Borehole						Mean Value	COV*
			P5	P7	P8	P9	P0	C0		
1	-1m	NS	69.5	73.1	79.5	86.9	111.0	82.2	83.7	0.16
		EW	81.8	68.7	72.4	62.0	83.6	58.2	71.1	0.13
	-20m	NS	24.3	25.7	23.2	26.1	30.9	27.8	26.3	0.09
		EW	29.2	27.0	25.0	24.1	25.2	26.6	26.2	0.06
2	-1m	NS	48.7	67.8	64.0	68.5	78.0	70.7	66.3	0.13
		EW	48.2	51.0	52.5	44.2	81.0	75.3	58.7	0.24
	-20m	NS	20.0	22.6	21.0	22.0	21.8	23.3	21.8	0.05
		EW	17.7	16.0	13.6	12.9	17.1	17.9	15.9	0.12

*COV : Coefficient of Variation

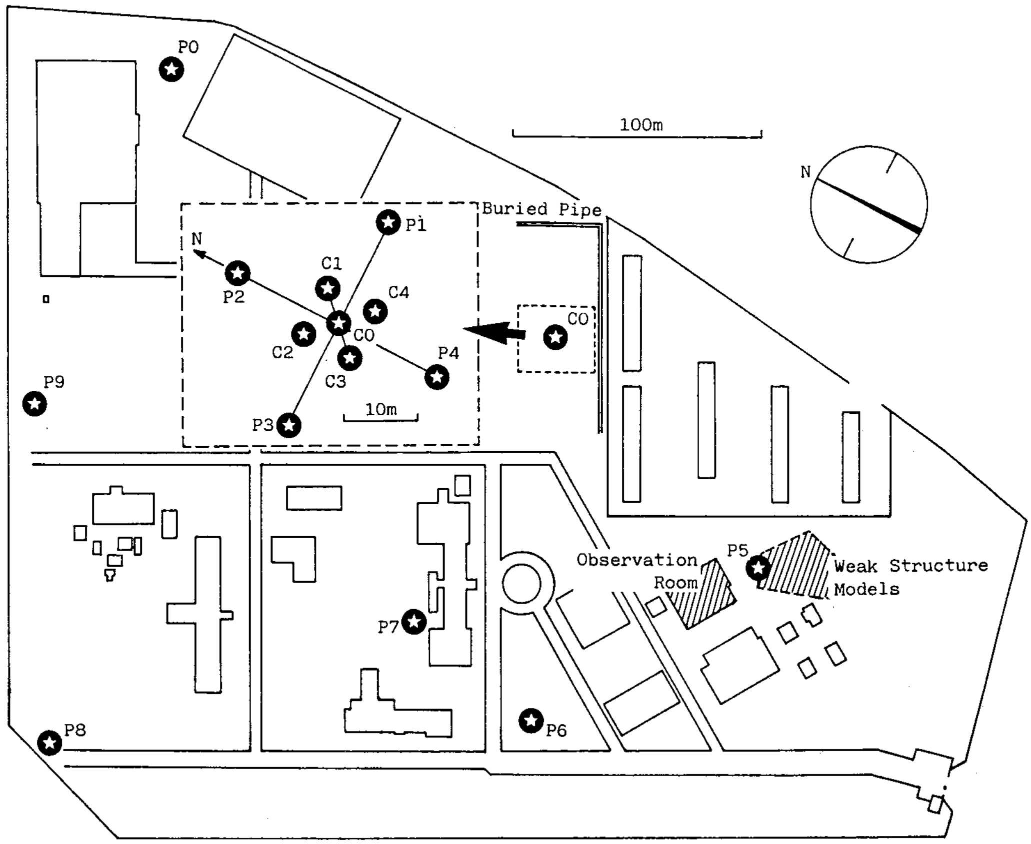

Figure 1 Locations of Boreholes and Observation Room

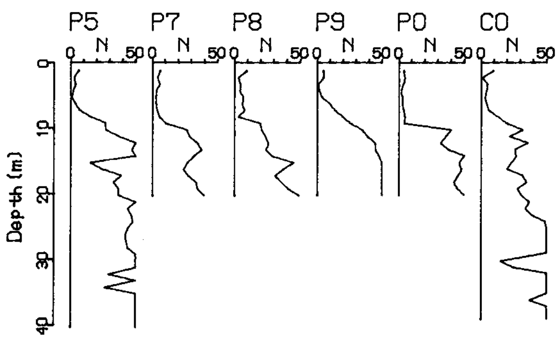

Figure 2 Typical Standard Penetration N Values

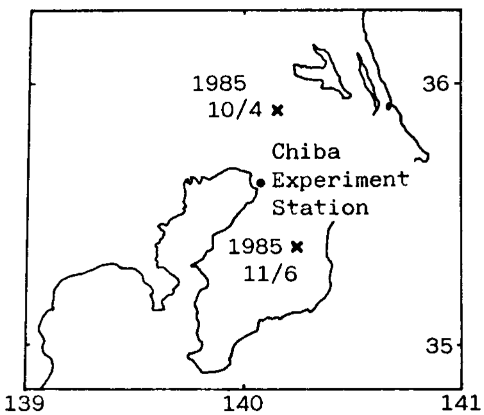

Figure 3 Map of Location of Recording Station and Epicenters of Earthquakes

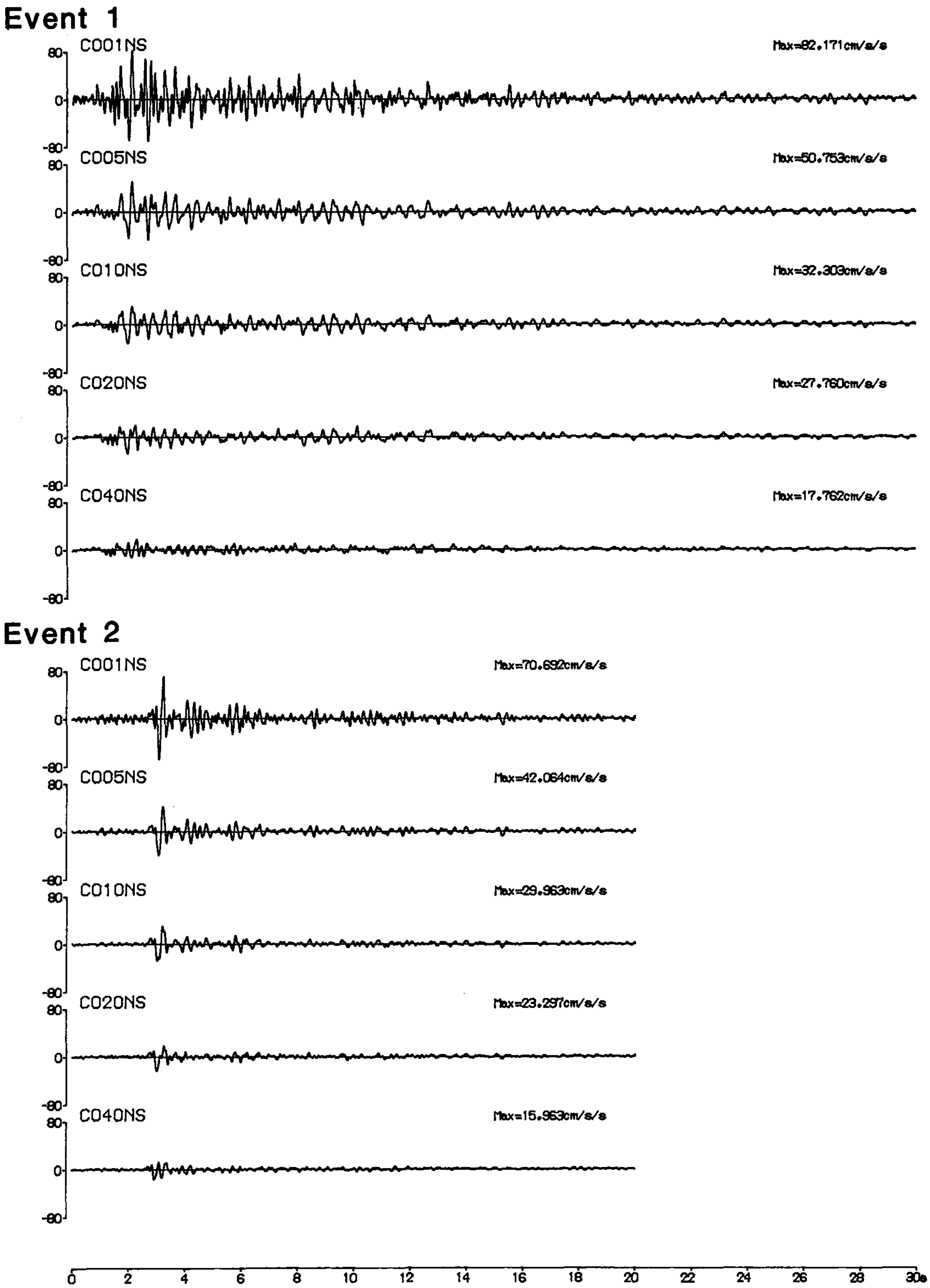

Figure 4 Recorded Accelerograms

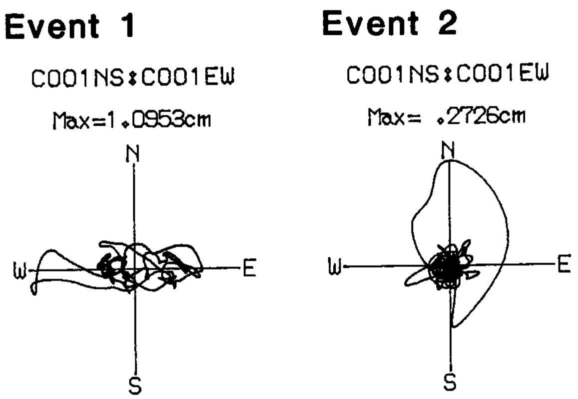

Figure 5 Loci of Displacement in Horizontal Plane

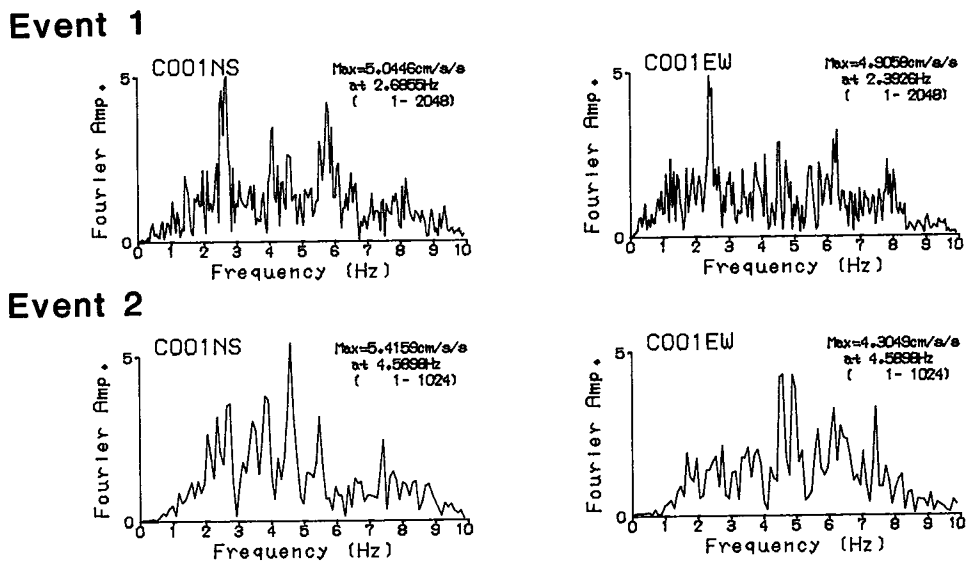

Figure 6 Fourier Amplitudes of Accelerograms on Ground Surface

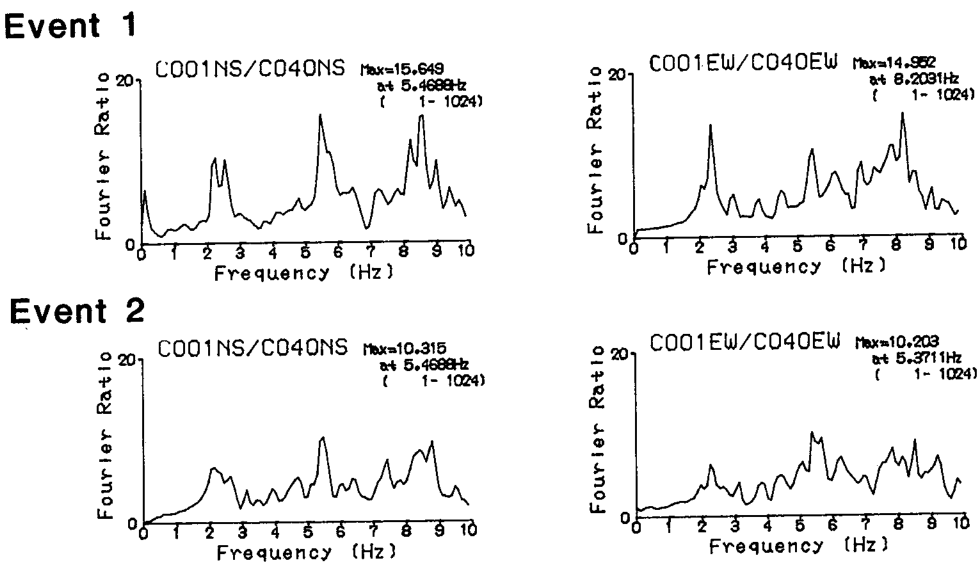

Figure 7 Ratios of Fourier Amplitudes

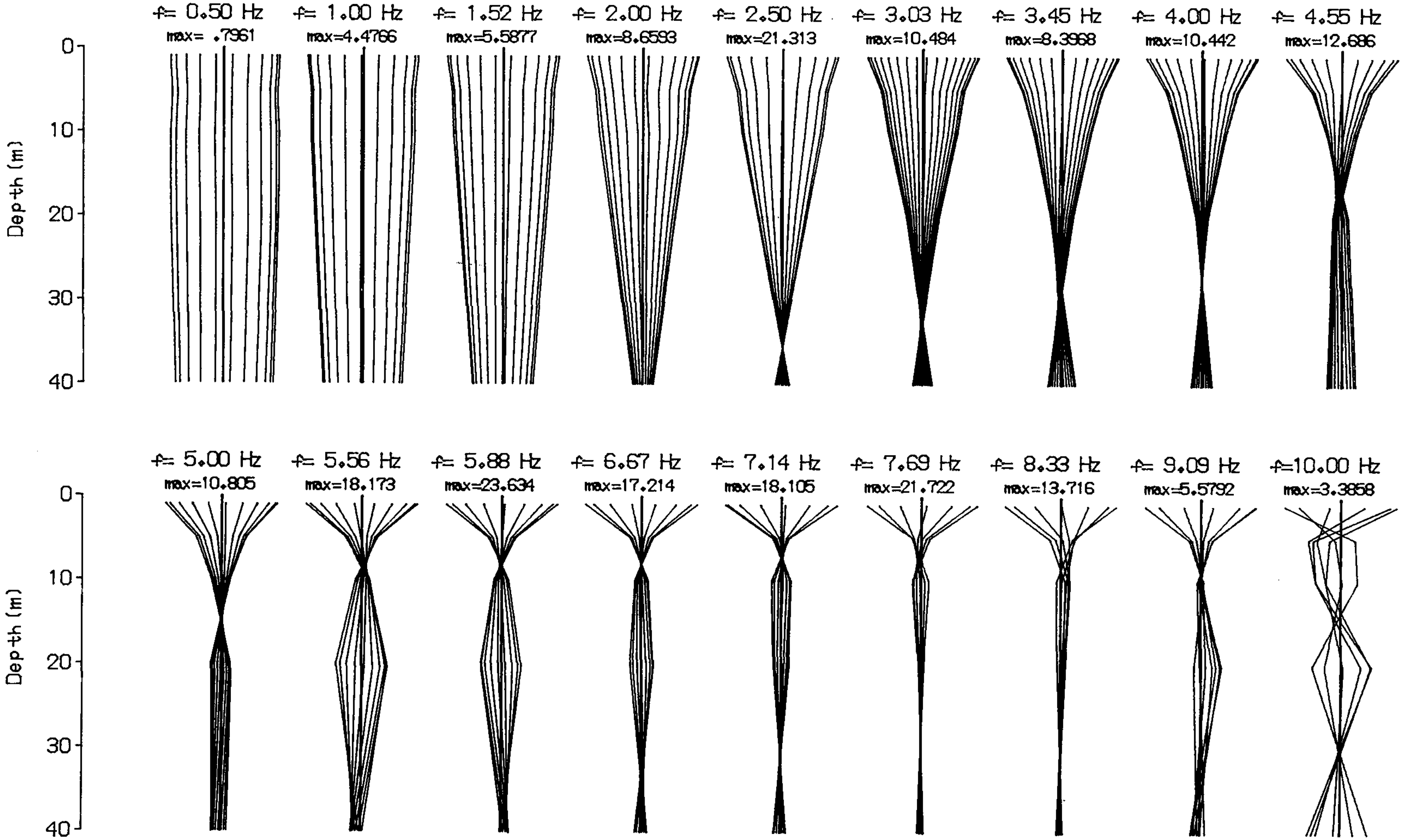

Figure 8 Vibration Mode of Ground (Event 1, EW)