BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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AN ANALYSIS OF STRONG-MOTION ACCELEROGRAMS FROM YONKI, PAPUA NEW GUINEA

1967-1972

D. DENHAM

DEPARTMENT OF NATIONAL DEVELOPMENT

Minister: The Hon. K.E. Newman, M.P.
Secretary: A.J. Woods

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Director: L.C. Noakes, O.B.E.
Assistant Director, Geophysical Branch: N.G. Chamberlain

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SUMMARY

In the period 1967-1972 an MO2 accelerograph at a soft-rock site at Yonki, in Papua New Guinea, was triggered 22 times, including once by the magnitude 7.0 (MS) Madang earthquake of October 1970, which took place about 165 km from Yonki, where a maximum acceleration of 93 cm/s^2 and velocity of 4.0 cm/s were recorded. The highest ground acceleration (187 cm/s^2) and velocity (10.2 cm/s) were recorded in February 1971 from an earthquake which occurred about 130 km from the recording site.

Least-squares analyses relating maximum ground motion to earthquake magnitude and focal distance gave the best results when ML magnitudes were used. The preferred formulas are:

$$\log Ya = 2.65 + (0.47 \pm 0.20)ML - (1.80 \pm 0.64) \log R$$
$$\log Yv = 0.48 + (0.30 \pm 0.15)ML - (0.87 \pm 0.53) \log R$$

where Ya and Yv are the maximum acceleration and velocity, ML is the Richter magnitude, and R is the distance in km. The standard errors in the regression coefficients are large and preclude the accurate prediction of maximum expected ground motions.

Most of the energy recorded at Yonki was contained in the 2-8 Hz band, and there seemed to be no correlation between the spectral peaks within this range and the magnitude or distance of the earthquakes.

Good correlation was found between Modified Mercalli intensity and the maximum acceleration and velocity. The least-squares formulas for these parameters are:

$$\log Ya = -(0.41 \pm 0.18) + (0.44 \pm 0.04)I$$
$$\log Yv = -(0.72 \pm 0.20) + (0.25 \pm 0.05)I$$

where I is the estimated Modified Mercalli intensity at Yonki.

INTRODUCTION

As a result of an investigation of earthquake engineering problems in Papua New Guinea by Mr R.I. Skinner of the New Zealand Department of Scientific and Industrial Research (Skinner, 1967), two M02 accelerographs were installed at the Upper Ramu damsite to measure the ground response to large local earthquakes. One instrument was situated at a soft-rock site, on about 50 m of recent alluvium. It was installed in October 1967, and by the end of 1972 it had been triggered by 22 earthquakes. Its companion was installed in 1969 on hard rock near the river bed and by the end of 1972 it had not been triggered.

This Report describes the results obtained during the period 1967-1972 and also outlines the methods of analysis used.

METHODS OF ANALYSIS

Figures 1 and 2 illustrate schematically the methods of analysis. Firstly, raw digitized values of acceleration are obtained from the 35-mm accelerograms. The original film is copied, and a transparency (x5) is printed. The enlarged prints are digitized at 0.02-second intervals on a scaling table. Digitized ordinates are obtained from a shaft-position encoding disc fitted to the Y drive of the scaler. The 4096-position encoder allows a resolution of about one-thirteenth of a millimetre, and the net accuracy of the system is about 0.1 mm. At a magnification of x5, 0.1 mm corresponds to an acceleration of about 1 cm/s^2 on a typical M02 trace of a horizontal-component record. The maximum resolution is usually limited by the trace thickness, which can be up to 0.5 mm on the enlarged film.

The output from the scaler is coupled to a paper-tape punch, whose tape was used to produce cards for processing on a CDC 3600 computer. From the card stage the methods of analysis follow those developed by Nigam & Jennings (1969) with the addition of a band-pass filtering procedure to remove the everpresent low-frequency noise caused by film distortion and baseline wobble, and the high-frequency noise caused by digitization chatter. The band-pass filter was designed to cut off at 0.2 and 15 Hz (Peterson & Dobrin, 1966), and standard parabolic baseline correction procedures were applied both before and after filtering. Figure 2 shows schematically the computer reduction processes.

On some of the records the baseline was missing, and the edge of the film was used instead. This procedure usually introduced large low-frequency components to the digitized traces, and without applying low-frequency cut-off filters these records would have been impossible to analyse.

The more important accelerograms were analysed for frequency using standard power-spectral analysis techniques (Blackman & Tukey, 1959).

RESULTS

The Table summarizes the results obtained in the period 1967-1972, and Figure 3 shows the epicentres of the earthquakes that are known to have triggered the accelerograph. Each accelerogram will now be discussed; the isoseismal and intensity maps referred to for the earthquakes in 1967 and 1968 were prepared by Denham (1971, 1974).

14 November 1967

The first earthquake to trigger the accelerograph took place in the Long Island 'nest' at a depth of about 200 km. The accelerograms (Fig. 4), which contain about 15 seconds of usable traces, show ground accelerations and velocities; the power spectra (Fig. 5), obtained from the acceleration traces, show that most of the ground movement is contained in the 2-6 Hz band, with a peak at about 5 Hz.

The earthquake was felt over an area of about 10^5 km^2; an isoseismal map for this earthquake is shown in Figure 6. The map shows that the accelerograph was situated close to the region where the highest shaking was felt, and a Modified Mercalli (MM) intensity of 5 was assigned to the Yonki site.

28 April 1968

Figure 7 shows the accelerograms obtained for this earthquake, and Figure 8 the power spectra of the ground accelerations. The earthquake occurred close to the accelerograph (about 95 km), but it was comparatively small and no felt reports of the event are available. The accelerogram contains only about 7 seconds of useful record, and it is probable that the P wave was too small to trigger the accelerograph. The pattern of the first 2 seconds of the accelerogram suggests that the maximum ground movement was recorded.

The power-spectral curves (Fig. 8) show that the peak ground acceleration occurred at 4.5 Hz and that most of the energy was contained in the 3.5-7Hz band.

11 May 1968

Although this earthquake triggered the accelerograph, the film was fogged when it was removed from the instrument. About 3 cm of unfogged traces are discernible, and the maximum acceleration on this piece of film is about 20 cm/s^2, which sets a lower limit to the ground acceleration.

A map showing felt intensities for this earthquake is shown in Figure 9; an intensity of MM 5 was assigned to the Yonki site.

3 June 1968

Figure 10 shows the accelerograms, and Figure 11 the power spectra of the ground accelerations. The acceleration traces imply that the accelerograph was triggered by the S wave, but it is thought that the peak acceleration was not missed, since the assessed intensity of MM 4 at Yonki corresponds well with the maximum acceleration of 31.9 cm/s^2.

Most of the energy is contained in the 2-7 Hz band, which is a similar result to that obtained for the earthquake of 14 November 1967, which also originated from the Long Island 'nest'. A felt-intensity map is shown in Figure 12.

17 June 1968

The P wave triggered the accelerograph, and the accelerograms in Figure 13 clearly show the arrival of the S wave about 12.5 seconds after the start. The power-spectral plot in Figure 14 shows that most of the energy is contained in the 2-6 Hz band, with peaks at 2.5 and 4.0 Hz. The peak at 2.5 Hz is caused by the first part of the S-wave train, and the larger peak at 4 Hz by the last 11 seconds of it. The felt-intensity map shown in Figure 15; an intensity of MM 5 is estimated for the Yonki site.

16 September 1968

The effects of this earthquake have been described in detail by Denham (1969, 1974). It took place about 40 km off the south coast of West New Britain, broke the SEACOM cable, and caused some damage near Kandrian. At Yonki, which is about 300 km from the epicentre, the felt intensity was assessed as MM 3-4. The accelerograms (Fig. 16) indicate that the accelerograph was triggered by the S wave; their short lengths, however, preclude any worthwhile analysis of the ground motion, and the maximum acceleration of 8.6 cm/s^2 must be regarded as a lower limit. Figure 17 is an isoseismal map for this earthquake.

7 January 1969

Figure 18 shows the ground motions recorded for this earthquake. Only about 16 seconds of useful record was obtained and the maximum acceleration was 14 cm/s^2. No power-spectra calculations were made.

10 March 1969

This was the third earthquake from the Long Island 'nest' that triggered the accelerograph. Nearly 30 seconds of usable record was obtained and the main S-wave phase is evident on the accelerogram (Figure 19) about 13 seconds after the start. Figure 20 shows the power spectra; the maximum accelerations are in the 4-5 Hz range and they correspond to the S-wave arrival. An isoseismal map for this earthquake has not been prepared, but the felt intensity at Yonki was estimated to be MM 5.

8 May 1969

This earthquake triggered the accelerograph, but the film was not developed properly and the accelerogram does not contain any traces showing the ground motion. Consequently the accelerogram was not digitized and no estimate of the maximum recorded acceleration can be made.

The Modified Mercalli intensity at Yonki for this earthquake is not known.

14 June 1969

The accelerogram for this earthquake was recorded on the same piece of film that contained the 8 May 1969 earthquake, and although the accelerograph was triggered the film was not correctly processed. About 2 seconds of the record is missing, and unfortunately it seems that this section would have contained the maximum trace movement.

The accelerogram was not digitized, but an examination of the visible traces suggests that the ground acceleration was at least 30 cm/s^2. No felt reports are available to assess the MM intensity at Yonki during this earthquake.

24 June 1969

The film drive did not work properly during this earthquake. The accelerograph was triggered, but the irregular film speed and absence of time marks preclude a complete analysis of the record. Nevertheless, it was possible to obtain a reliable value for the maximum acceleration (63.1 cm/s^2), and, since a felt intensity value was also obtained at Yonki, the accelerogram was of some use.

13 May 1970

Figure 21 shows the ground motions recorded at Yonki for this earthquake, and Figure 22 shows the spectral analysis. Most of the movement was caused by the S-wave group, which is clearly recorded on the horizontal components of the accelerogram. The power spectra are similar to those obtained for the earthquake on 10 March 1969, with a peak in the 4-5 Hz range.

31 October 1970

The 1970 Madang earthquake was one of the most costly earthquakes to have taken place in New Guinea in recent years, and damage was estimated at about $1.7 million (Everingham, 1975). The maximum reported intensity was at least MM 8, and MM 7 was felt over an area of about 10 000 km^2. At Yonki, about 160 km from the epicentre, the intensity was assessed at MM 5-6, and the accelerograph continued to provide measurable ground movement for about 70 seconds after it was triggered. Figure 23 shows the computed ground motions, and Figure 24 the power spectra.

The horizontal traces on the accelerogram do not exhibit distinct S-wave phases, and the period of maximum ground movement appears to be the result of a gradual increase of energy release. Figure 25 shows the isoseismal map prepared by Everingham (1975).

12 November 1970

This earthquake was the largest aftershock of the main Madang earthquake. The felt intensity at Yonki was estimated to be MM 4, and the ground movements and spectral analysis are shown in Figures 26 and 27 respectively. Although the amplitudes recorded from this earthquake are much smaller than those recorded from the main Madang earthquake, the character of the ground movements from both earthquakes is very similar and the shapes of the power-spectral curves are almost identical. This similarity strongly suggests that the source mechanisms for the two earthquakes were also similar.

12 February 1971

This earthquake produced a felt intensity of about MM 6 at Yonki. The ground movements shown in Figure 28 distinctly show the arrival of the S wave, which produced a maximum ground acceleration of about 190 cm/s^2. This is the highest recorded acceleration at the Yonki site. The peak velocity of 10 cm/s is also the highest value recorded. The results of the power-spectral analysis in Figure 29 show the broad band nature of the shaking and the clear P-wave contribution on the vertical component in the frequency range 5-8 Hz.

13 February 1971

Most of the energy from this earthquake is contained in the S-wave group; this is clearly shown in the accelerograms (Fig. 30). The twin spectral peaks at 2-3 Hz and 4 Hz (Fig. 31) correspond to the low-frequency content in the first part of the S-wave group and the higher frequencies present after 13.5 seconds.

13 March 1971

Figure 32 shows the ground motions from this earthquake: the accelerograph appears to have been triggered by the S wave, and only about 10 seconds of useful record was obtained. No power spectra or velocities were computed, and the maximum acceleration of 15.7 cm/s^2 is regarded as a low estimate.

10 July 1971

The accelerograph was probably triggered by the S wave, and only about 8 seconds of useful record was obtained. The intensity of MM 3 at Yonki corresponds well with the maximum acceleration of about 10 cm/s^2 and is close to the triggering level of the instrument. Figure 33 shows the two horizontal traces recorded at Yonki; the vertical trace was inoperative for this earthquake. No spectral analyses were carried out.

19 July 1971

Only the two horizontal components were recorded for this earthquake; Figure 34 shows the ground motions. The accelerogram was too short to permit spectral analyses, but the clear S-wave arrival on the east-west component 8 seconds after the start suggests that the maximum acceleration was recorded.

25 September 1971

Although this earthquake triggered the accelerograph, the drive mechanism failed and the film remained stationary during the shaking. However, by measuring maximum trace excursions it is estimated that the maximum ground acceleration would have been between 170 and 250 cm/s^2.

18 January 1972

Although most of the film was fogged the ground motions shown in Figure 35 almost certainly correspond to the maximum ground motion, and the value of 31.5 cm/s^2 agrees well with the values obtained from other earthquakes causing a similar level of shaking at Yonki. No spectral analyses were carried out because of the short length of the record.

19 January 1972

This accelerogram was caused either by the earthquake of 18 January at 22 08 13 (an aftershock of the earthquake that occurred on the same day at 21 55 15) or by that of 19 January at 15 00 5.4.

Both earthquakes were of similar magnitude and occurred close to one another, so it is not possible to identify positively which one is recorded on the accelerogram. The earthquake of 19 January has been adopted because its magnitude is slightly higher than that for the earthquake on the previous day. Figure 36 shows the ground motions recorded, and Figure 37 the results of the power-spectral analyses.

DISCUSSION AND CONCLUSIONS

Of the 22 earthquakes, maximum accelerations for 19 (Fig. 38) and maximum velocities for 15 (Fig. 39) were calculated. It is clear that simple analytical formulas cannot predict anything but the order of magnitude of ground motion. The uncertainties in earthquake magnitudes and hypocentral locations, together with variable source effects from different earthquakes, contribute to the large scatter observed.

The standard relation connecting the parameters is:

$$Y = a\, e^{bM} R^{c} \qquad (1)$$

where Y is the maximum acceleration or velocity, M is the earthquake magnitude, R is the distance, e is the base of natural logarithms, and a, b, and c are constants. Least-squares analyses of the data in the Table lead to the following formulas:

$$\log Ya = 2.54 + (0.26 \pm 0.26)MB - (1.10 \pm 0.63) \log R \quad (2)$$
$$\log Ya = 2.65 + (0.47 \pm 0.20)ML - (1.80 \pm 0.65) \log R \quad (3)$$
$$\log Ya = 2.57 + (0.29 \pm 0.16)MS - (1.24 \pm 0.60) \log R \quad (4)$$
$$\log Yv = 0.54 + (0.38 \pm 0.27)MB - (0.55 \pm 0.49) \log R \quad (5)$$
$$\log Yv = 0.48 + (0.30 \pm 0.15)ML - (0.87 \pm 0.53) \log R \quad (6)$$
$$\log Yv = 0.56 + (0.15 \pm 0.14)MS - (0.49 \pm 0.51) \log R \quad (7)$$

where Ya and Yv are in cm/s^2 and cm/s respectively; MB, ML, and MS are the body wave, Richter, and surface wave magnitudes; R is the distance in km; and logarithms are taken to the base 10. The standard errors of the regression coefficients are very large, but the ML magnitudes are preferred because they fit formula (1) the best.

The regression lines for ML = 4, 5, 6, and 7 are superimposed on the plots in Figures 38 and 39, and they indicate how poorly the data fit the empirical formulas.

The results of the spectral analyses exhibit some variability, and there does not appear to be any measurable correlation between the spectral peaks and the locations or magnitudes of the earthquakes concerned. However, on all the accelerograms analysed most of the energy is contained in the 2-8 Hz band, and most have a main spectral peak near 4-5 Hz, which is probably controlled by the site conditions at the accelerograph.

Although good empirical relations between ground motion, magnitude, and distance cannot be obtained from the Yonki results, the dependence of maximum acceleration and velocity on the Modified Mercalli intensity (I) is strong. Figures 40 and 41 show a plot of these parameters, and least-squares fits to the data in the Table give the following results:

$$\log Ya = -(0.41 \pm 0.18) + (0.44 \pm 0.04)I \quad (8)$$

$$\log Yv = -(0.72 \pm 0.20) + (0.25 \pm 0.05)I \quad (9)$$

These relations agree reasonably well with similar empirical formulas derived by other workers. Milne & Davenport (1969) obtained the following relation:

$$\log Ya = I/3 - 0.5 \quad (10)$$

and Newmark & Rosenblueth (1971) proposed

$$\log Yv = 0.3I - 1.14 \quad (11)$$

The agreement between these two formulas (10 and 11) and those derived from the Yonki data (8 and 9) is good.

No attempt has been made to compare formulas 2-7 with other published results because of the considerable scatter observed and the minor differences in the formulation of the results. Some examples to be found in the literature are listed below:

Esteva (1970):

$$a = 123e^{0.8M}(R + 25)^{-2}$$

$$v = 15e^{M}(R + 0.17e^{0.59M})^{-1.7}$$

where a and v are in cm/s^2 and cm/s respectively, M is the magnitude (not defined), and R is in km;

Milne & Davenport (1969):

$$A = \frac{0.69e^{1.64M}}{1.1e^{1.10M} + R^2}$$

where R is in km, M is the magnitude (undefined), and A is expressed as a percentage of the acceleration due to gravity;

Mickey (1971):

$$\log Ya = -0.53 + 0.74\,MB - 1.14 \log R$$

and

$$\log Yv = -2.39 + 0.88\,MB - 1.5 \log R$$

where Ya and Yv are in cm/s^2 and cm/s respectively, MB is the body wave magnitude, and R is the distance in km.

TABLE

EARTHQUAKES WHICH TRIGGERED THE YONKI SOFT-ROCK-SITE ACCELEROGRAPH

(06.24°, 145.98°E, ELEVATION 2 KM)

Date	Time	Lat °S	Long °S	Dep km	Dist km	Magnitudes MB	ML	MS	Max acc cm/s^2	Max vel cm/s^2	MMI	PK-PS HZ
14 NOV. 1967	05 28 37	5.43	147.07	201	253	5.8	6.4	6.0	53.9	2.7	5	5
28 APR. 1968	20 22 05	5.53	146.32	39	97	5.6	5.2	5.6	27.2	1.3	-	4-5
11 MAY 1968	15 33 41	6.41	147.28	76	165	5.5	6.0	5.8	Film fogged		5	
03 JUN. 1968	09 17 46	5.45	146.95	190	237	5.6	6.2	5.9	31.9	2.1	4	4-6
17 JUN. 1968	17 49 44	6.27	146.59	110	131	5.1	6.0	5.3	37.7	2.3	5	3-5
16 SEP. 1968	13 55 36	6.07	148.68	59	305	6.2	6.7	6.3	8.6	-	3-4	
07 JAN. 1969	01 14 14	6.19	146.44	97	112	5.3	5.8*	5.6	14.0	1.9	3-4	
10 MAR. 1969	06 54 18	5.59	147.21	206	279	5.8	6.8	6.4	40.1	2.7	5	4-5
08 MAY 1969	22 37 17	5.57	146.20	76	111	5.1	5.7	5.4	Film u/s			
14 JUN. 1969	09 26 11	5.56	145.52	114	148	5.2	6.1	5.5	Film u/s			
24 JUN. 1969	03 29 17	5.82	146.77	113	152	5.6	6.0	6.0	63.1	-	5	
13 MAY 1970	07 14 01	5.89	146.75	118	152	5.2	5.6	5.4	33.3	1.5	4	4-5
31 OCT. 1970	17 53 09	4.93	145.47	42	162	6.0	7.1	7.0	93.0	4.0	5-6	4-5
12 NOV. 1970	06 07 12	5.05	145.06	15	168	5.9	6.6	6.6	24.6	2.6	4	4-5
12 FEB. 1971	19 06 54	6.25	146.48	113	128	5.7	6.1	6.0	187.3	10.2	6	3-5
13 FEB. 1971	22 09 39	6.02	146.25	101	108	5.4	5.8	5.5	79.3	3.4	5	2-6
13 MAR. 1971	19 12 25	5.72	145.37	118	149	6.3	6.2	6.5	15.7	-	4	4-5
10 JUL. 1971	11 56 26	5.86	144.44	68	189	5.4	5.9	5.5	10.1	1.2	3	
19 JUL. 1971	14 48 42	4.89	144.50	74	234	5.5	6.0	5.7	17.7	2.5	4	
25 SEP. 1971	04 36 14	6.54	146.58	115	138	6.3	6.7	6.9	170.0**	-	5-6	
18 JAN. 1972	21 55 15	4.78	145.04	33	224	5.7	6.6	6.6	31.5	1.3	4	4-5
19 JAN. 1972	15 00 54	4.70	144.97	33	207	5.8	6.4	6.4	20.2	1.3	4	3-5

* DERIVED MAGNITUDE

** ESTIMATED MINIMUM VALUE (SEE TEXT)

PK-PS = PEAK POWER SPECTRAL FREQUENCY

ACKNOWLEDGMENTS

I thank Graeme Small of the Observatory Section, BMR, for assistance with some of the computer programming, and Ian Everingham of the Port Moresby Geophysical Observatory for providing some of the intensity data and for supervising the operation of the Yonki accelerograph in the period 1970-1972.

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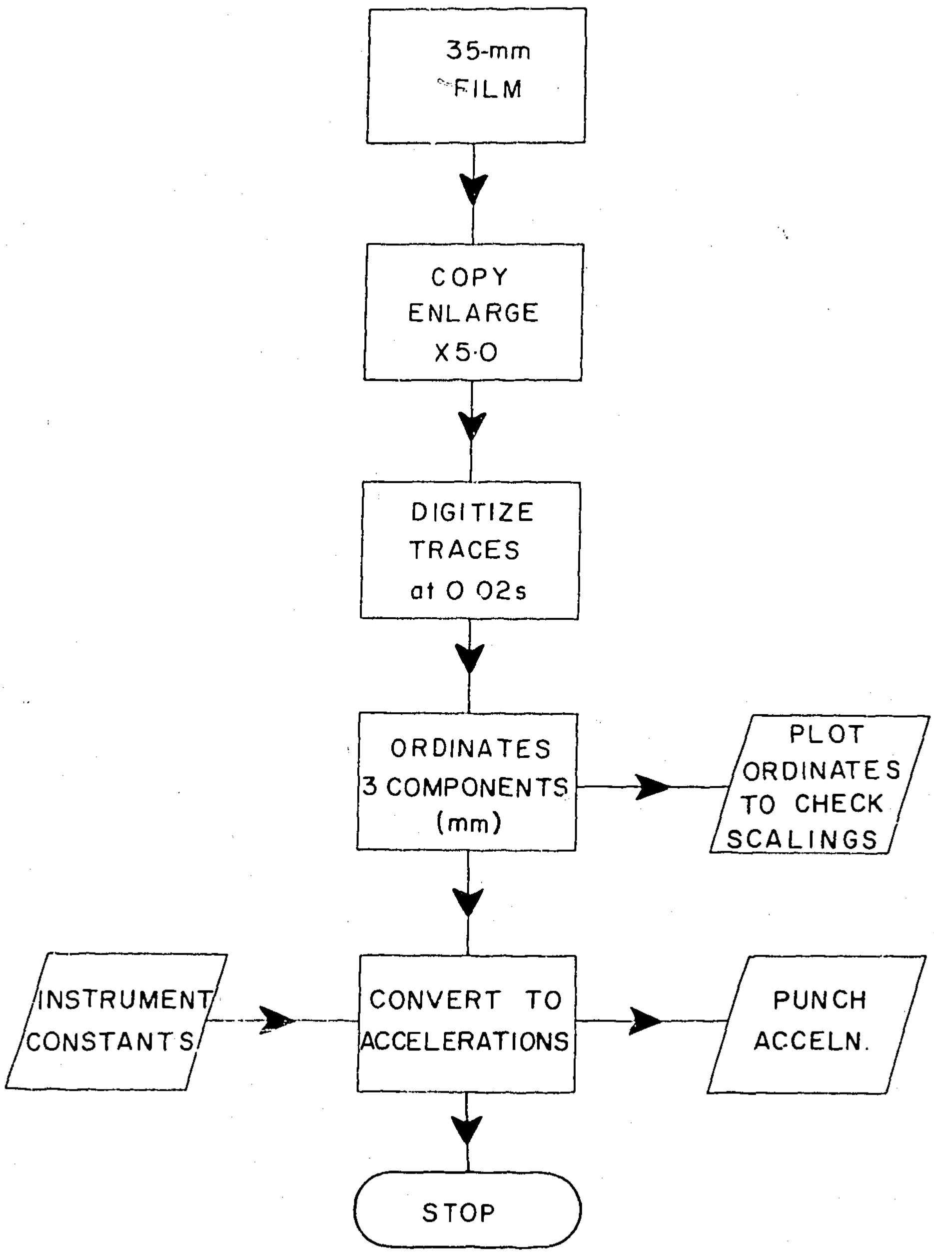

Fig. 1. Flow diagram showing the first steps of the analysis of accelerograms

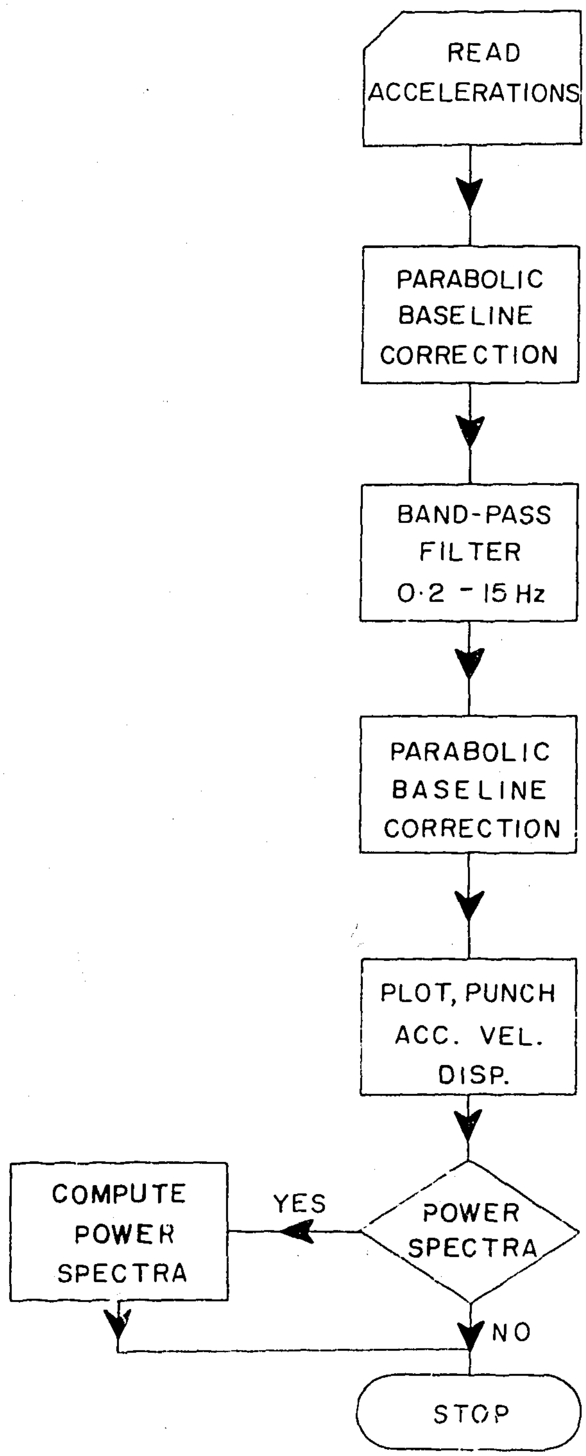

Fig. 2. Flow diagram showing the second steps of the analysis of accelerograms

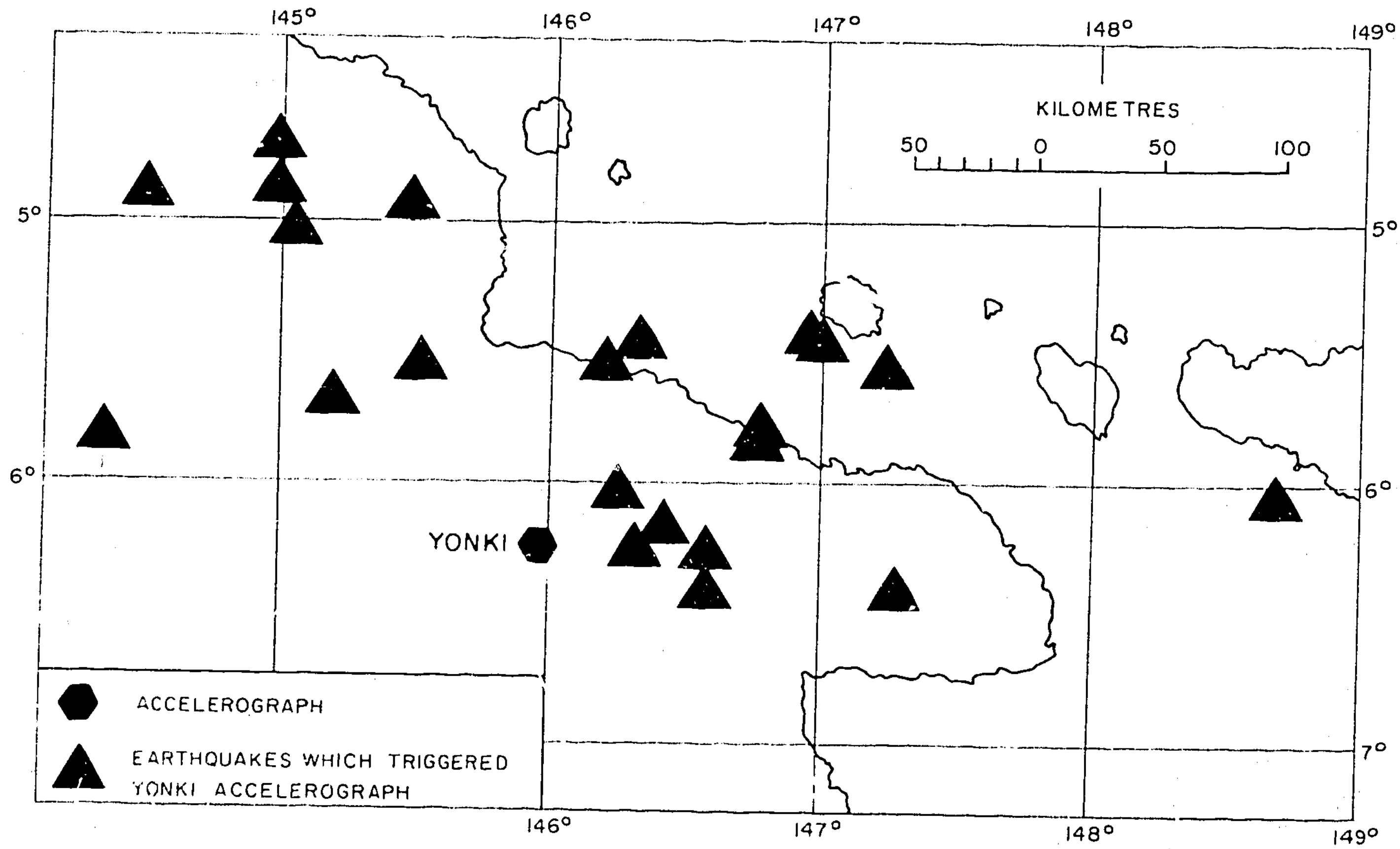

Fig. 3. Epicentres of earthquakes which triggered Yonki accelerograph on soft-rock site

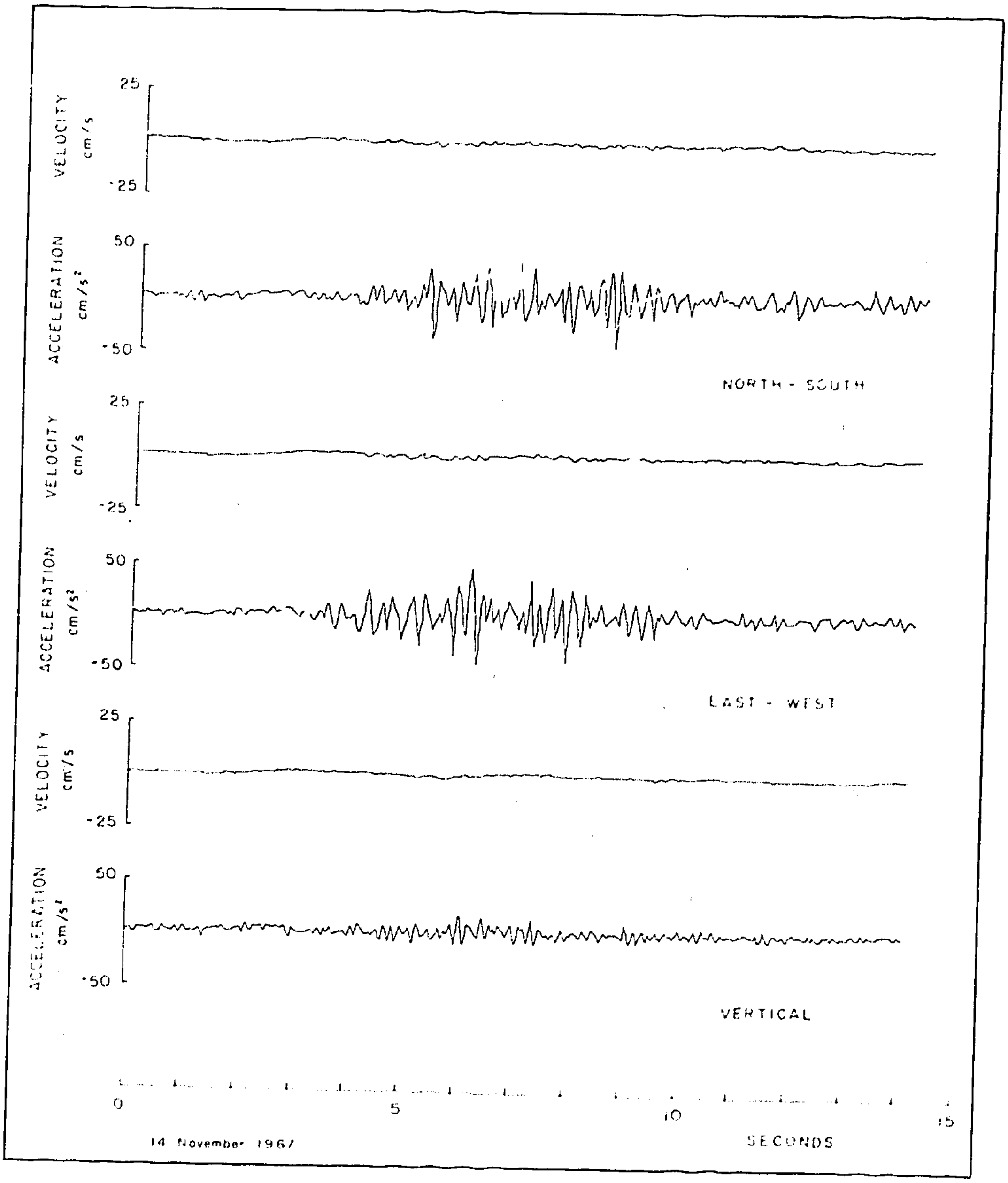

Fig. 4. Ground motions from earthquake of 14 November 1967

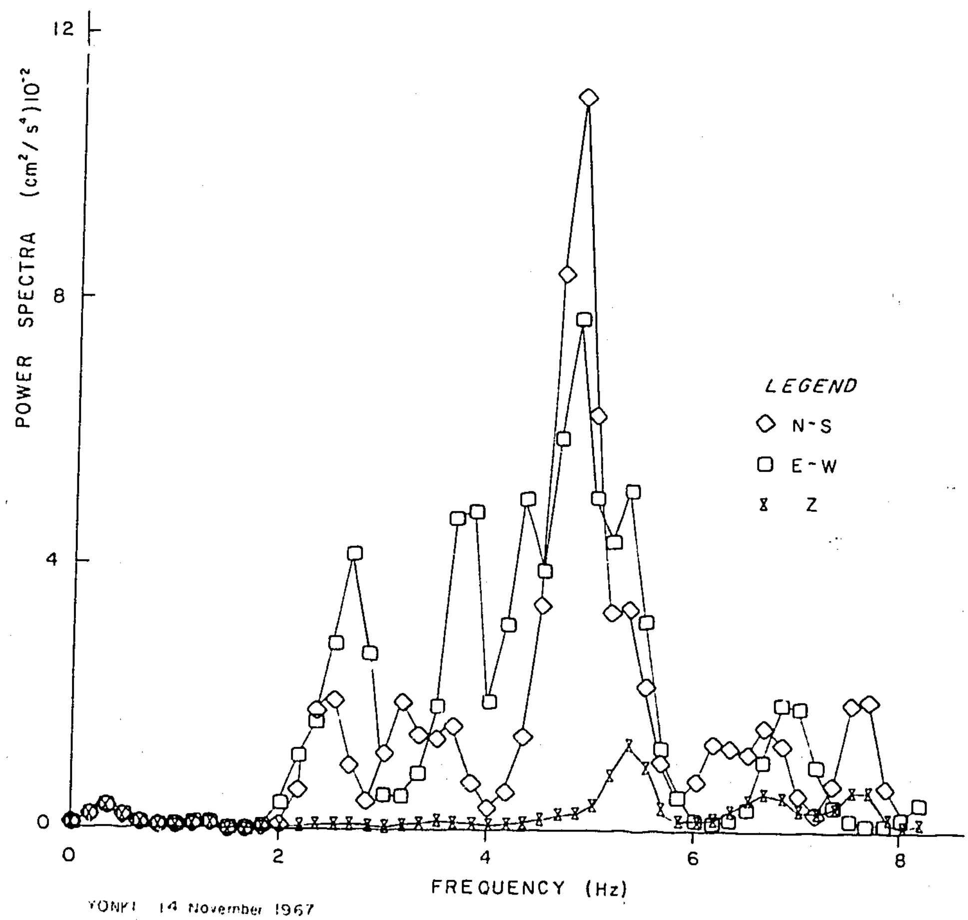

Fig. 5. Power spectra for earthquake of 14 November 1967

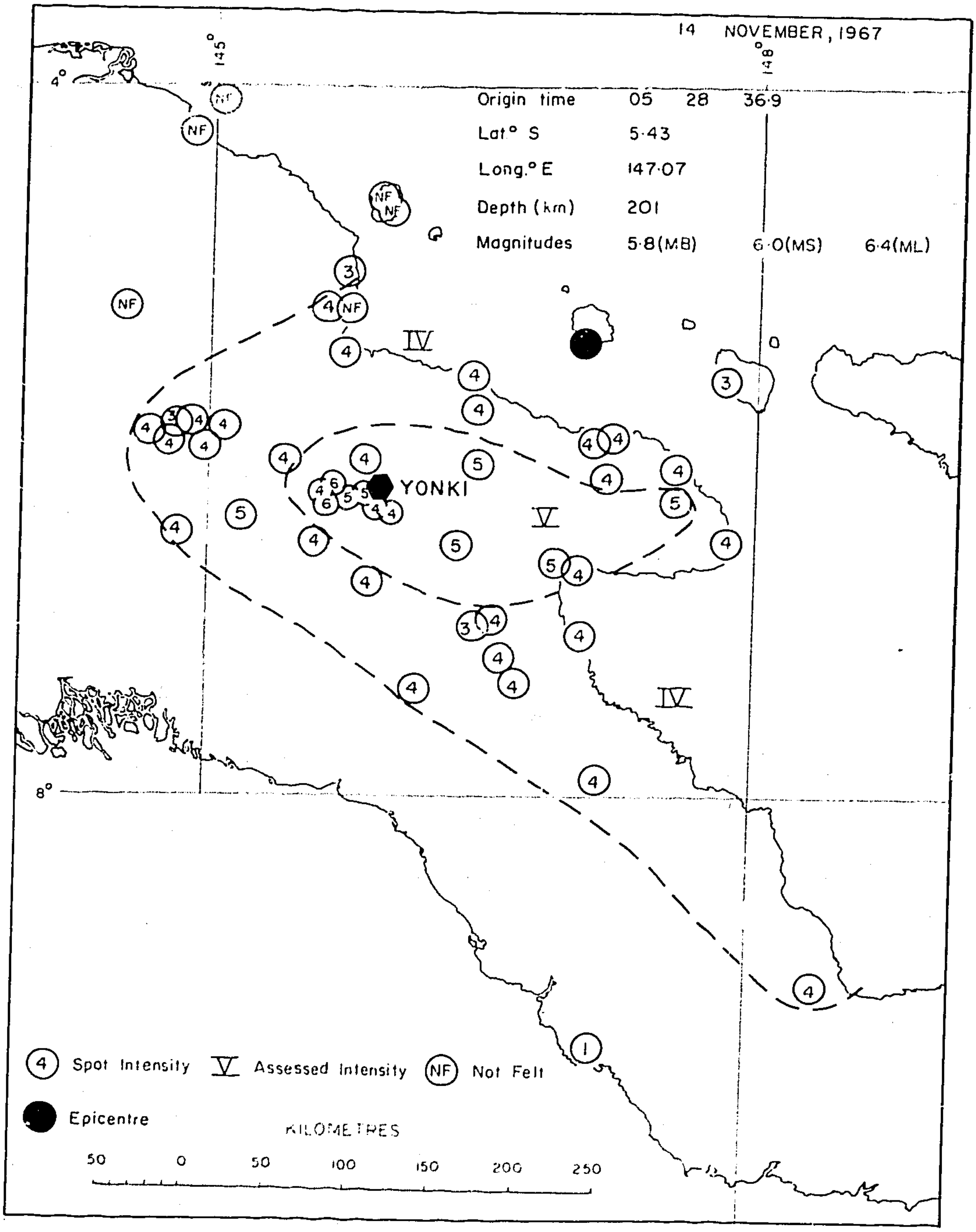

Fig. 6. Felt intensities for earthquake of 14 November 1967

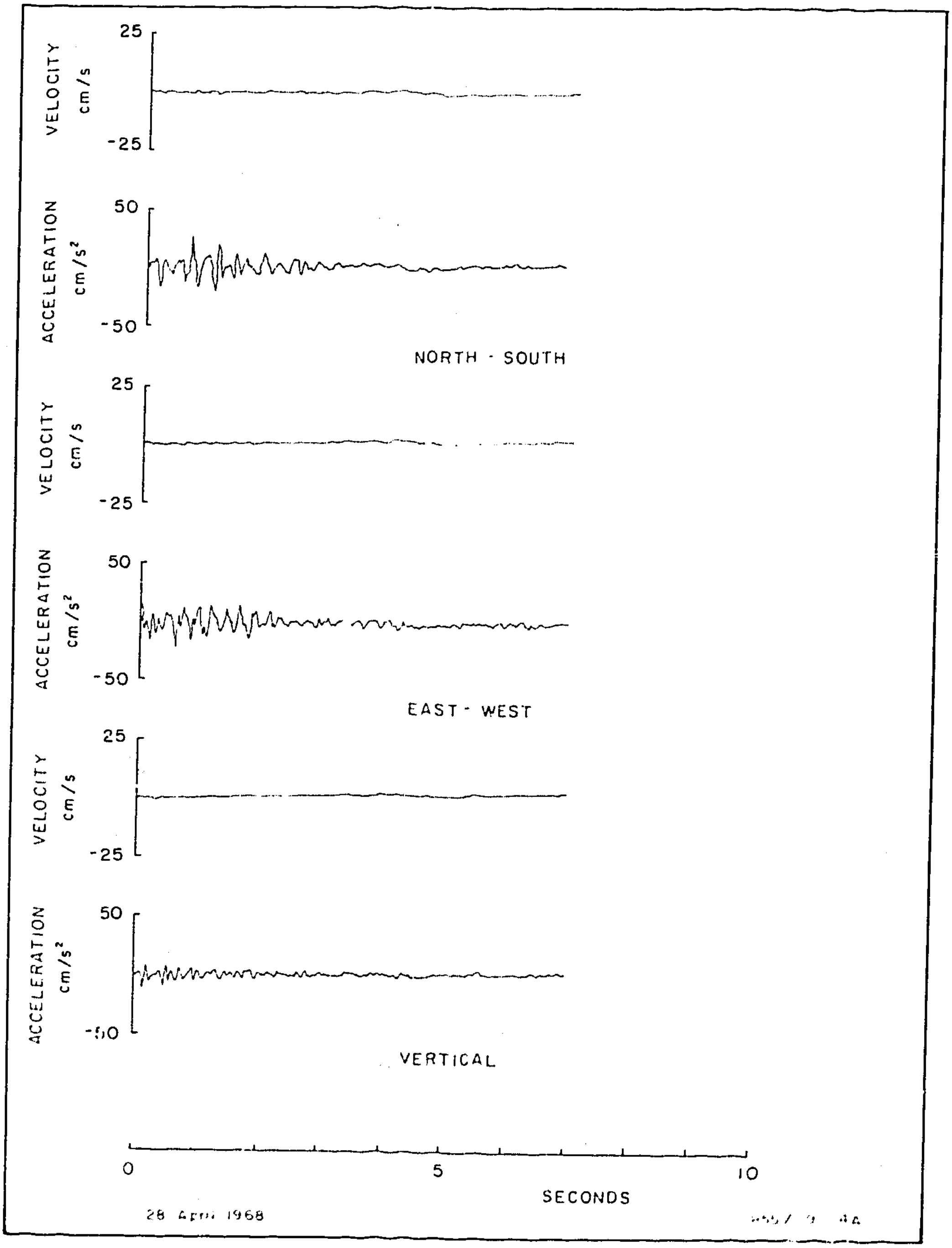

Fig. 7. Ground motions from earthquake of 28 April 1968

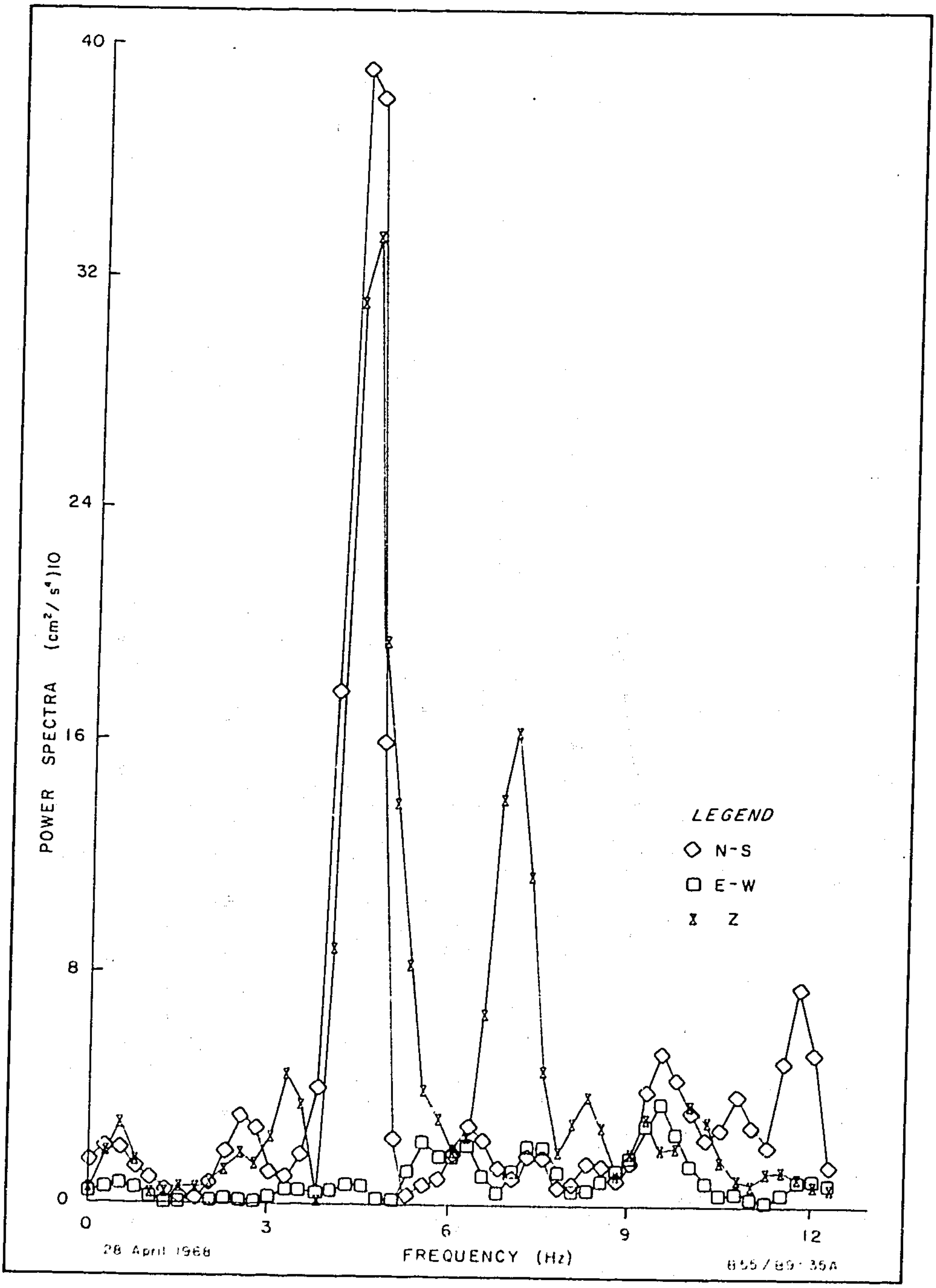

Fig. 8. Power spectra for earthquake of 28 April 1968

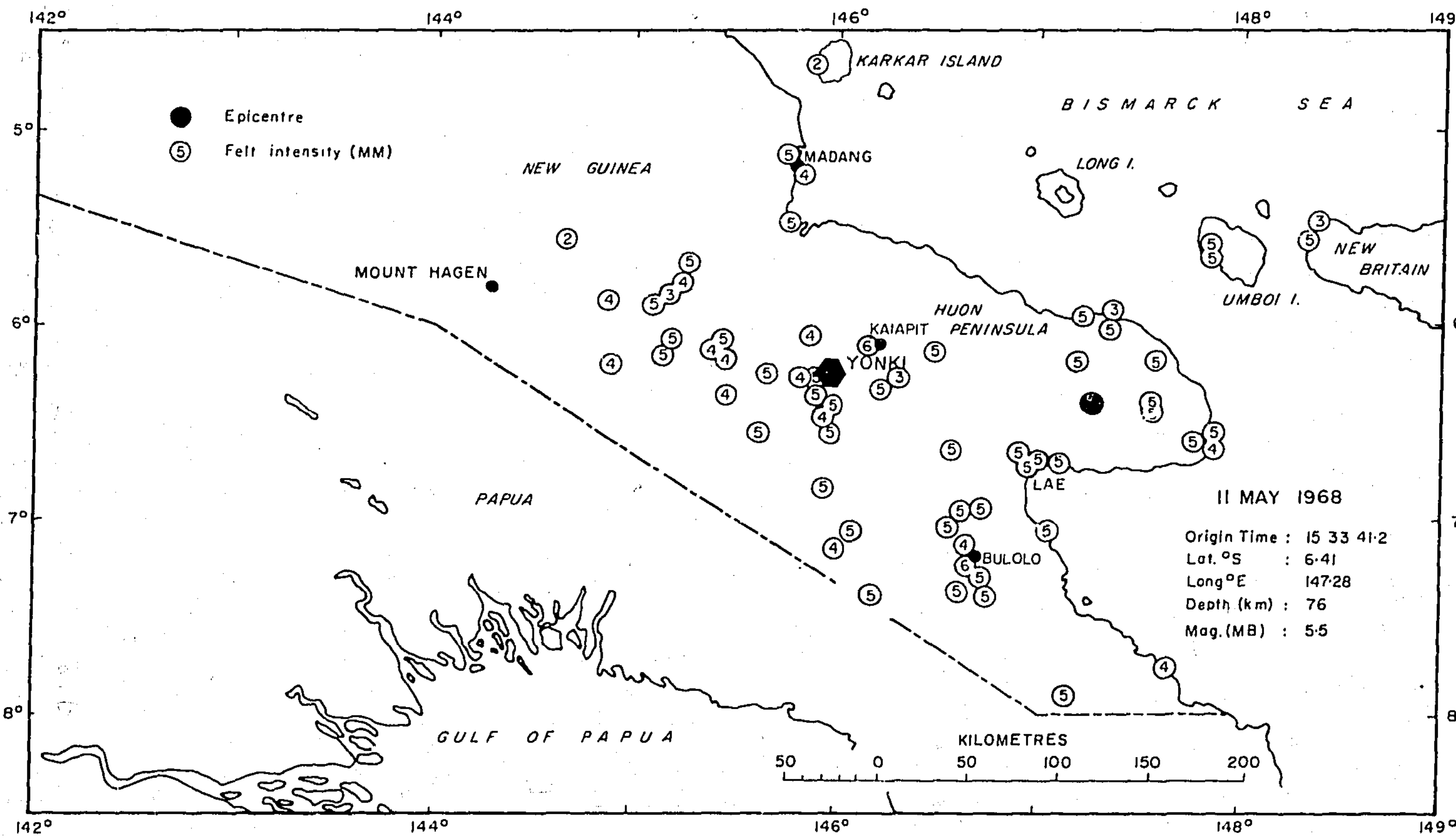

Fig. 9. Felt intensities for earthquake of 11 May 1968

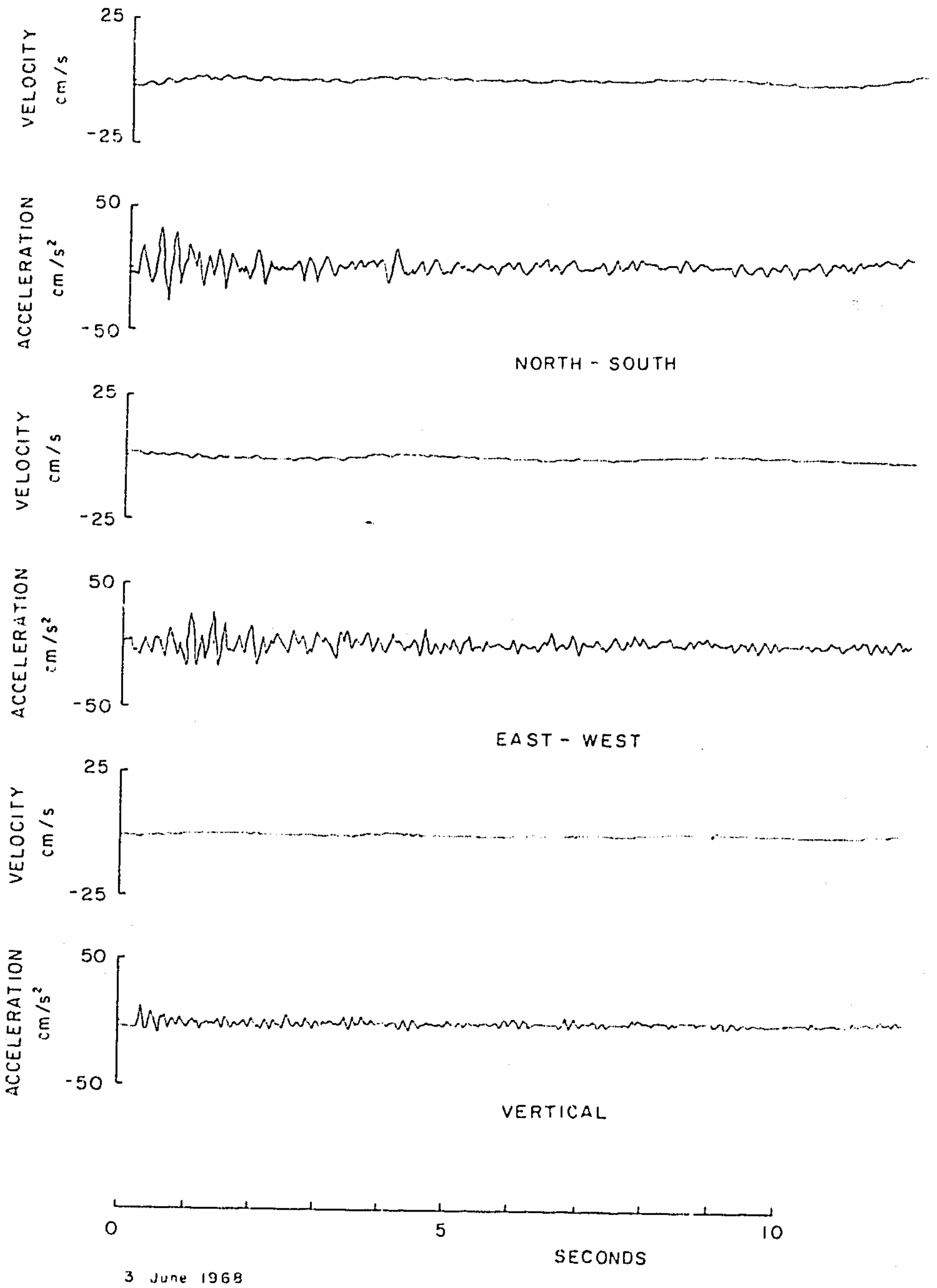

Fig. 10. Ground motions from earthquake of 3 June 1968

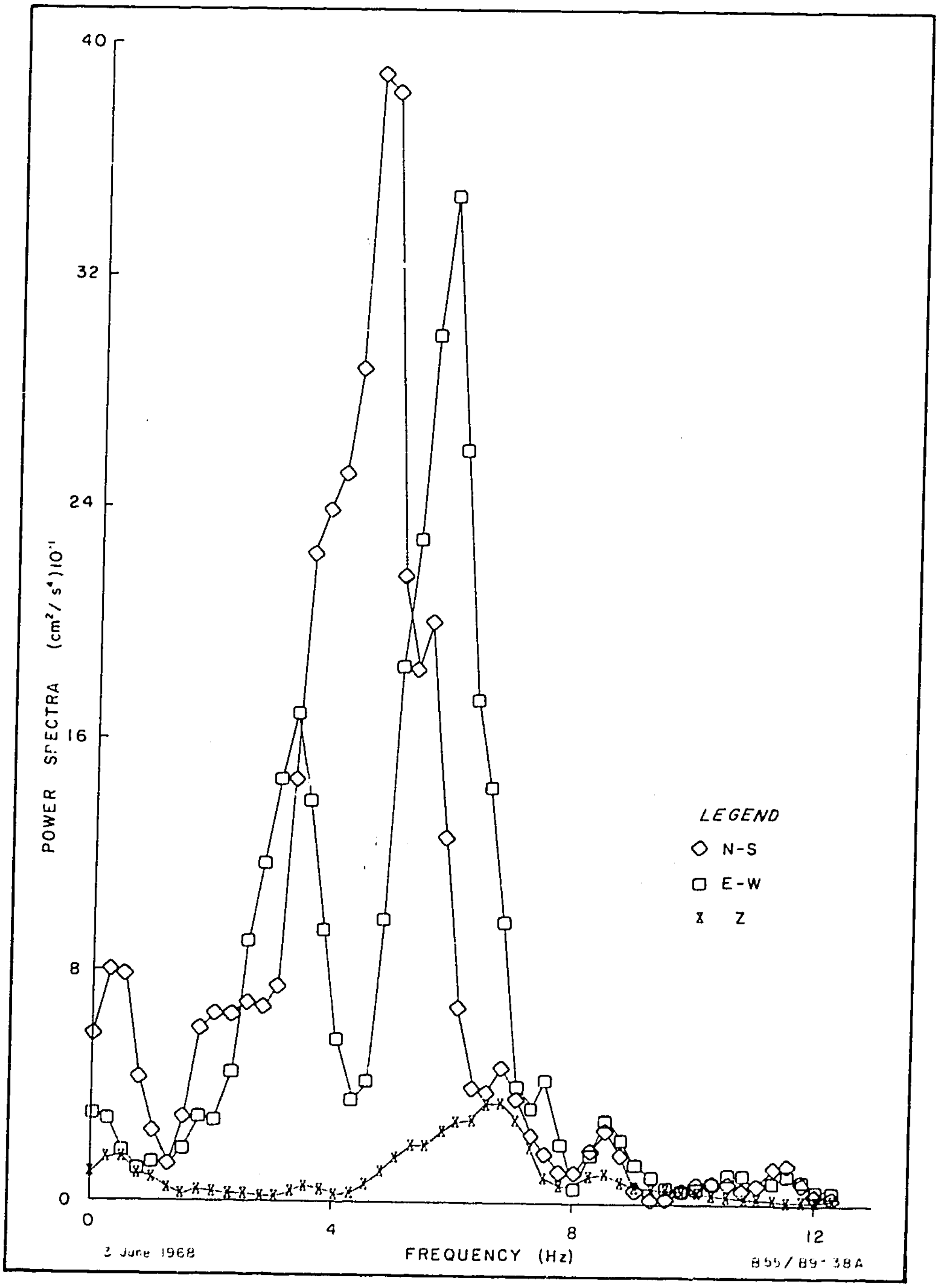

Fig. 11. Power spectra for earthquake of 3 June 1968

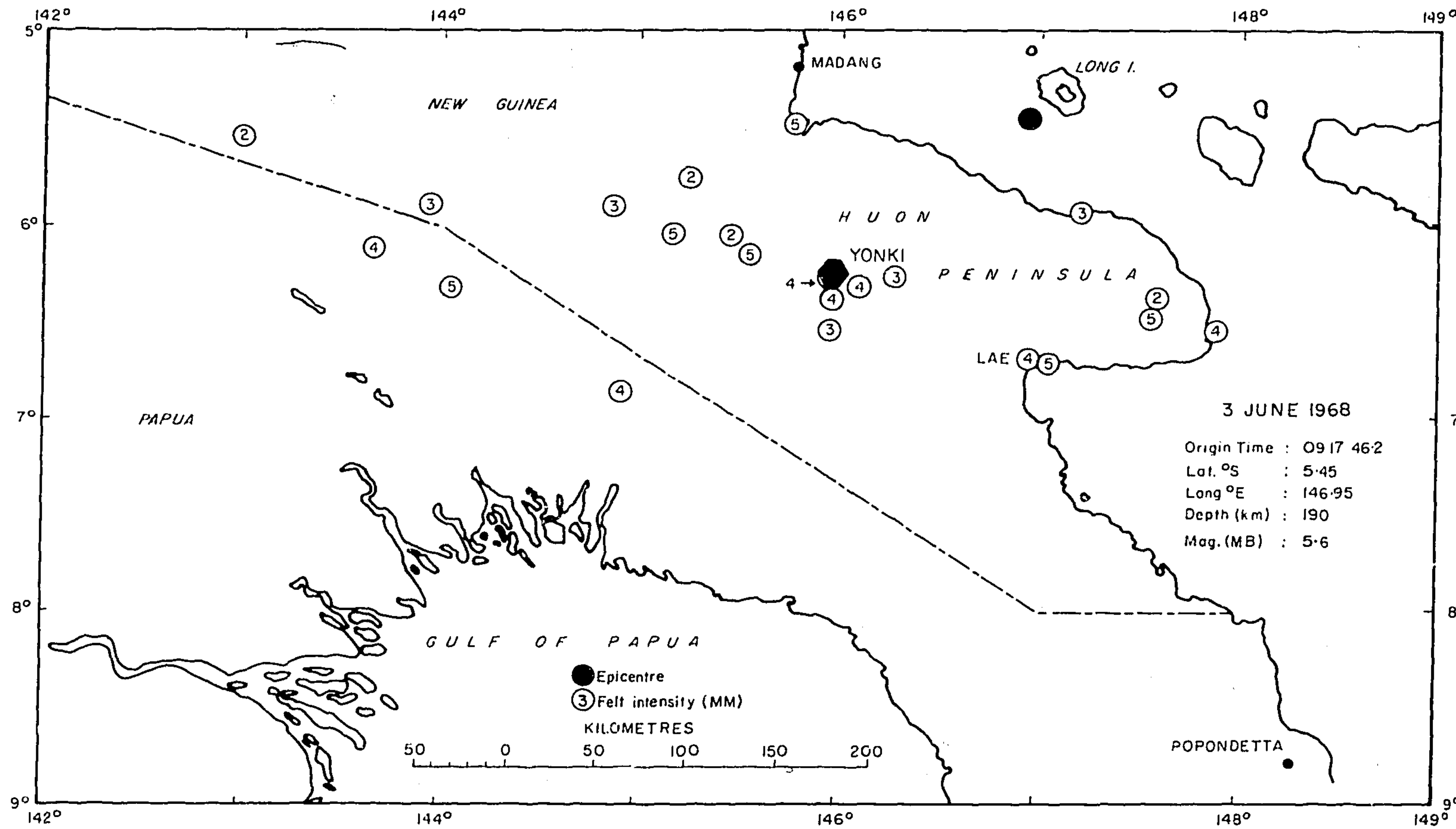

Fig. 12. Felt intensities for earthquake of 3 June 1968

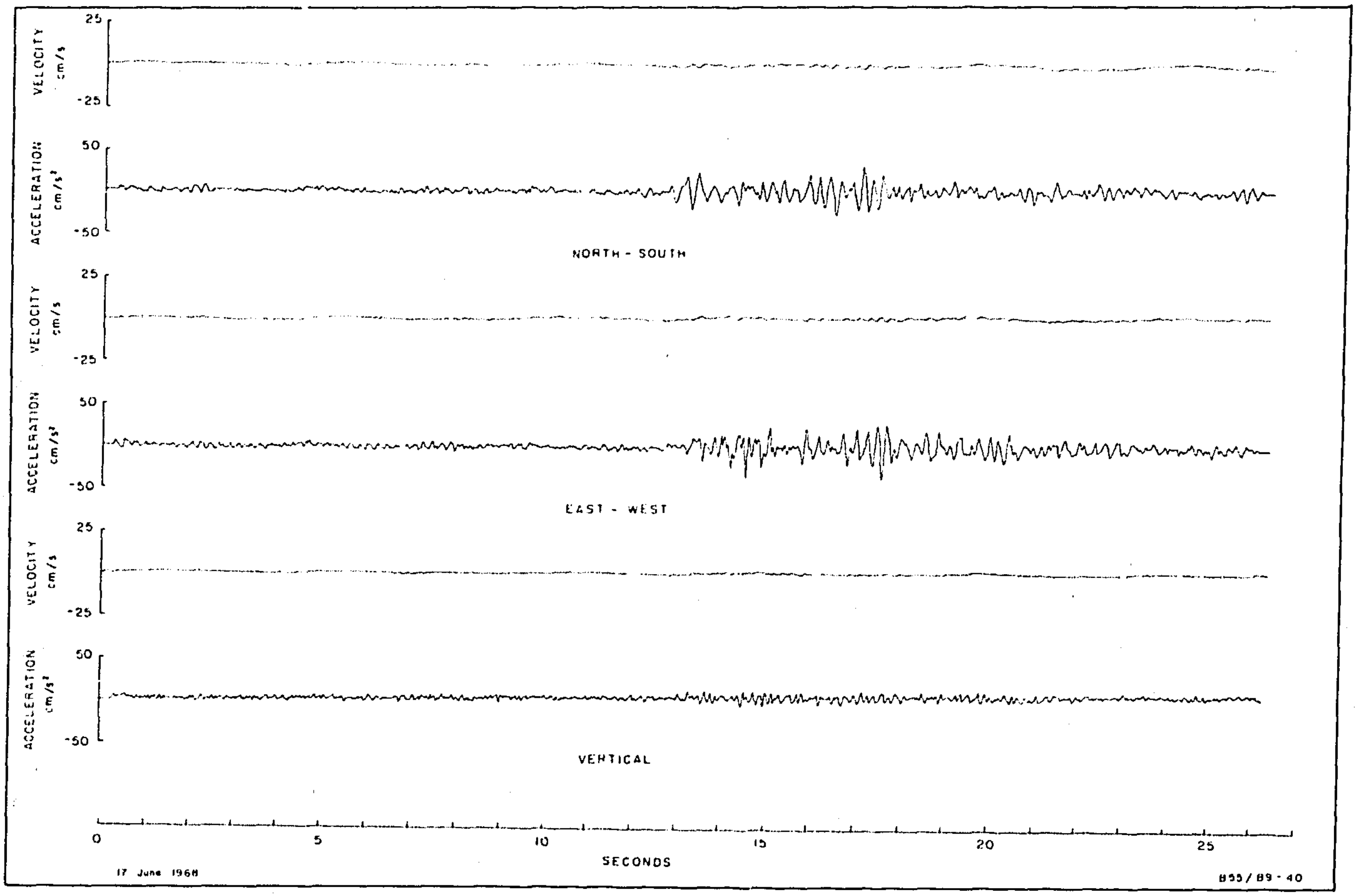

Fig. 13. Ground motions from earthquake of 17 June 1968

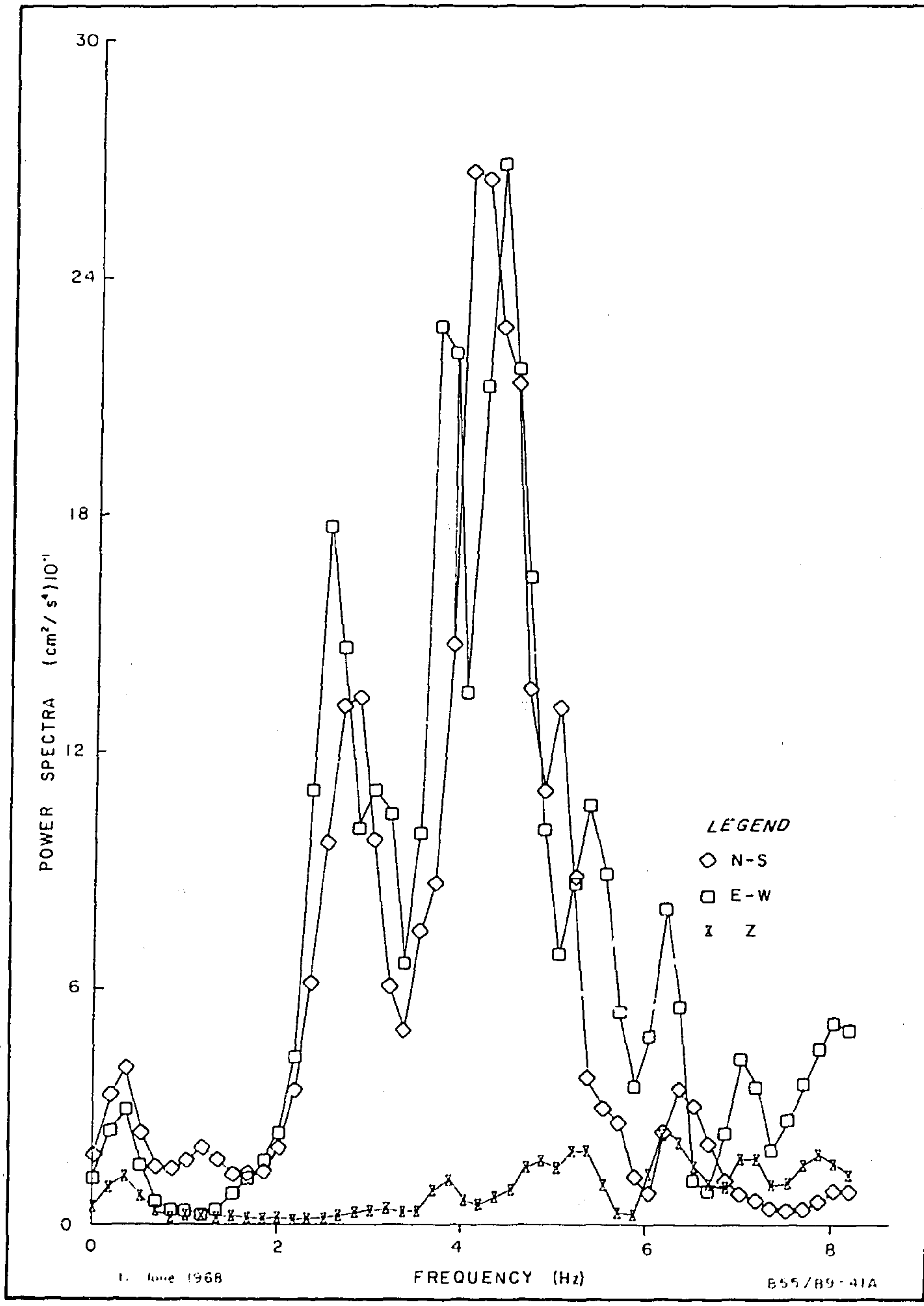

Fig. 14. Power spectra for earthquake of 17 June 1968

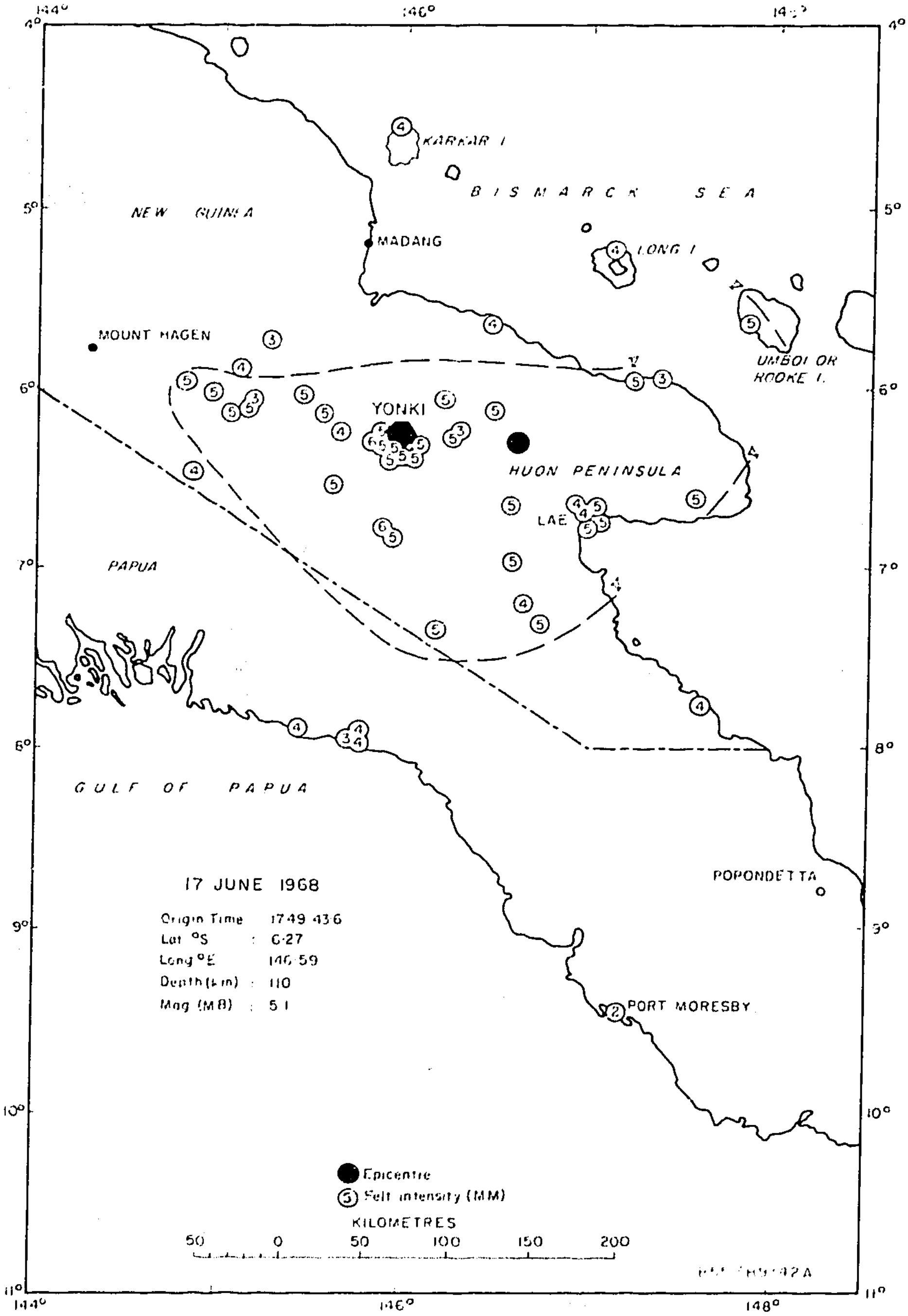

Fig. 15. Felt intensities for earthquake of 17 June 1968

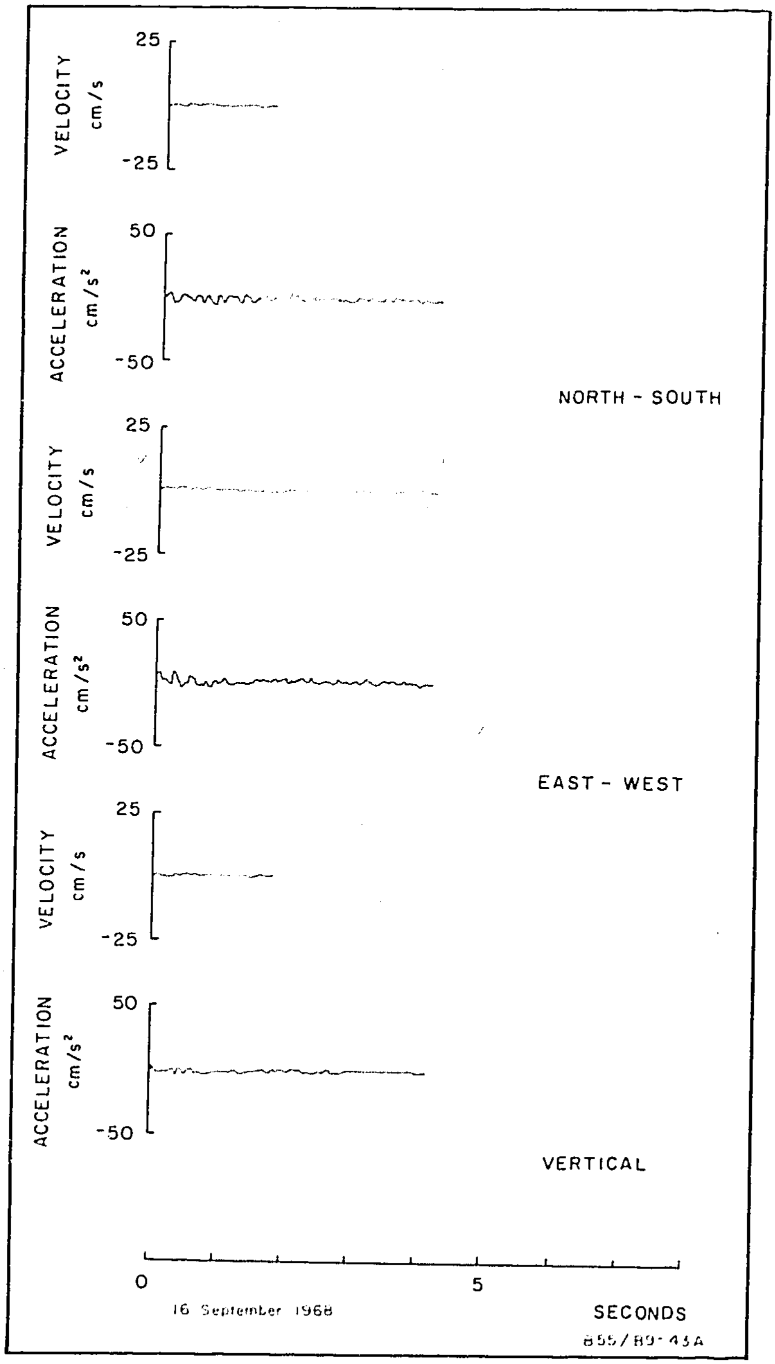

Fig. 16. Ground motions from earthquake of 16 September 1968

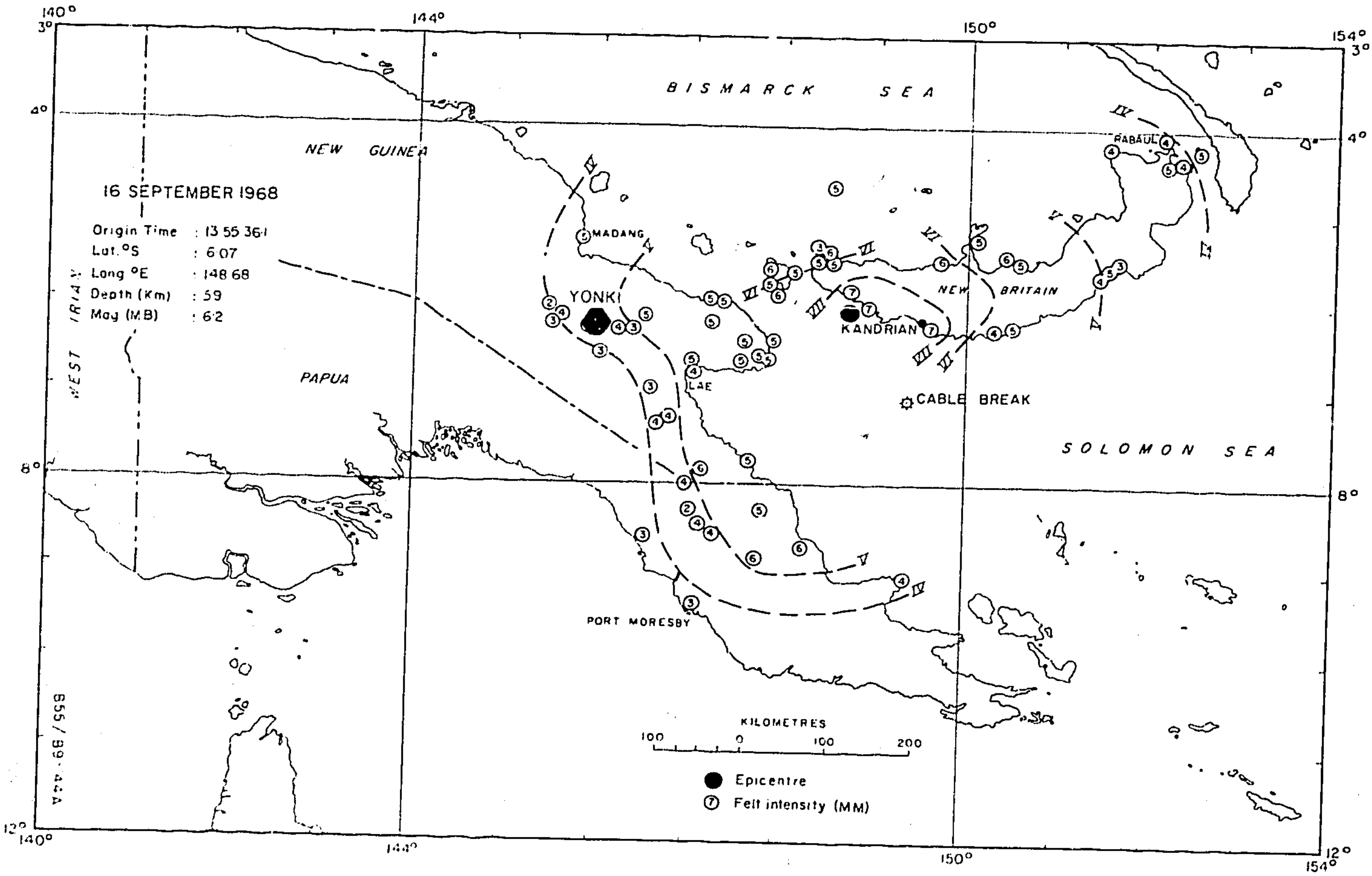

Fig. 17. Isoseismal map for earthquake of 16 September 1968

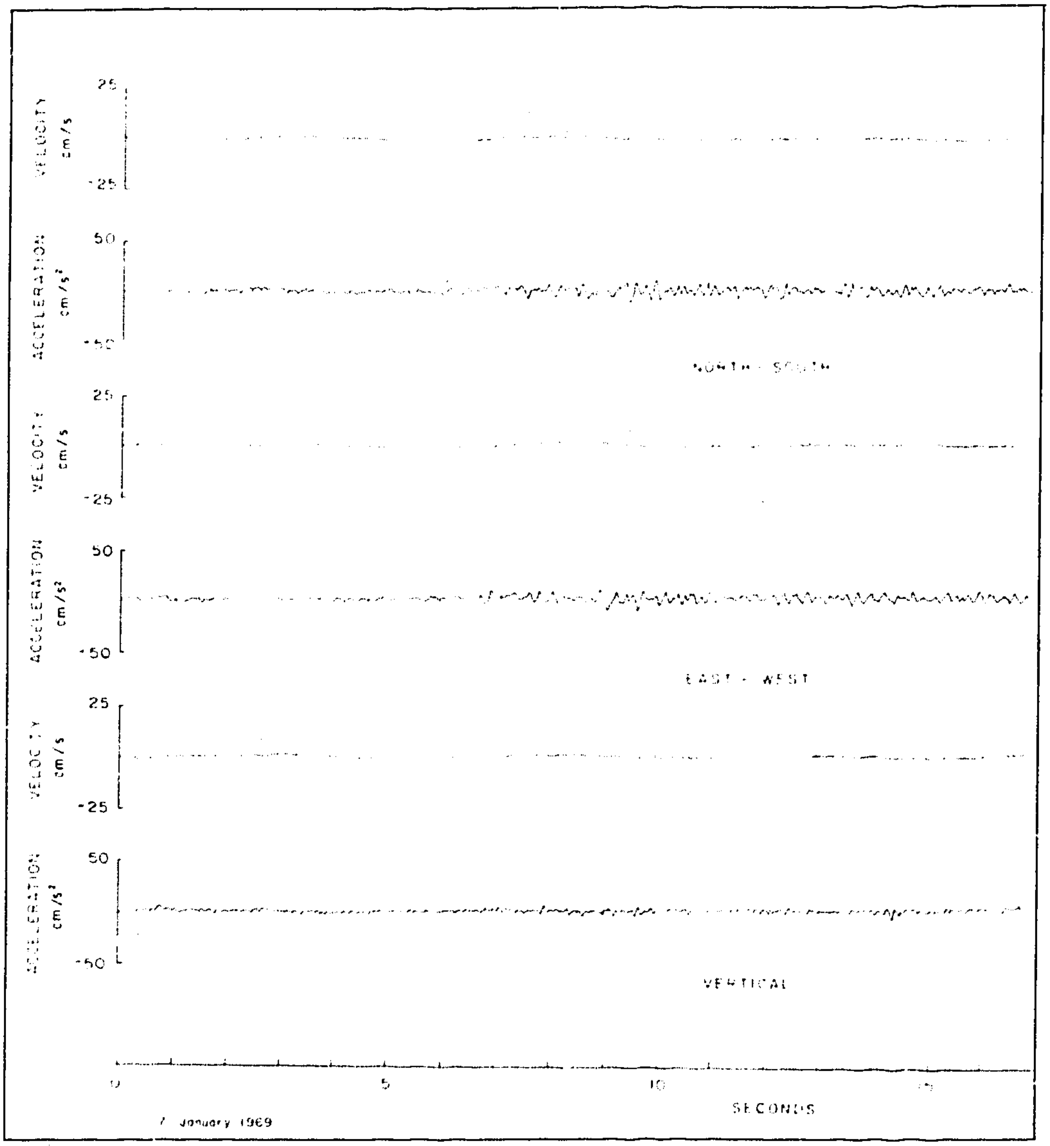

Fig. 18. Ground motions from earthquake of 7 January 1969

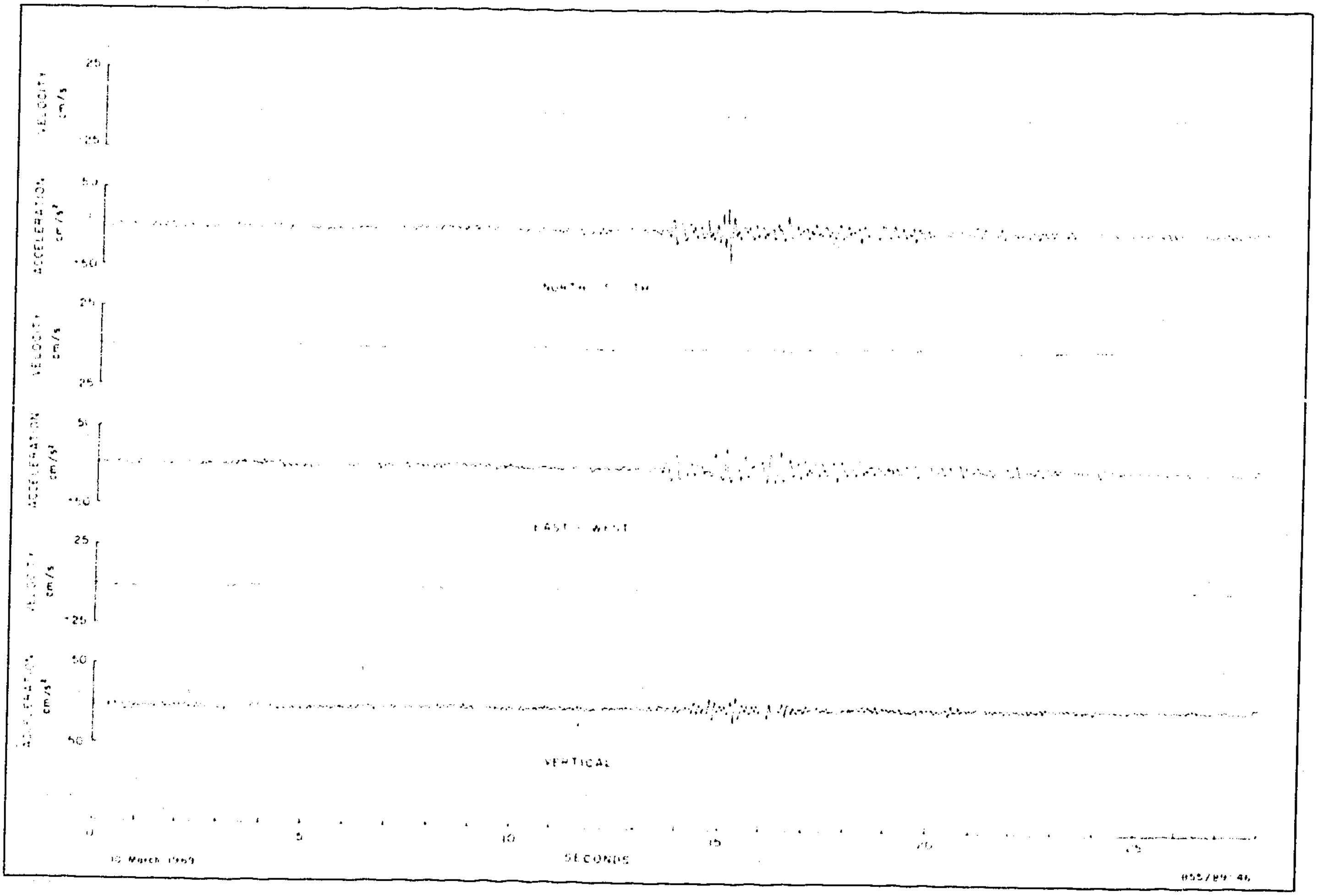

Fig. 19. Ground motions from earthquake of 10 March 1969

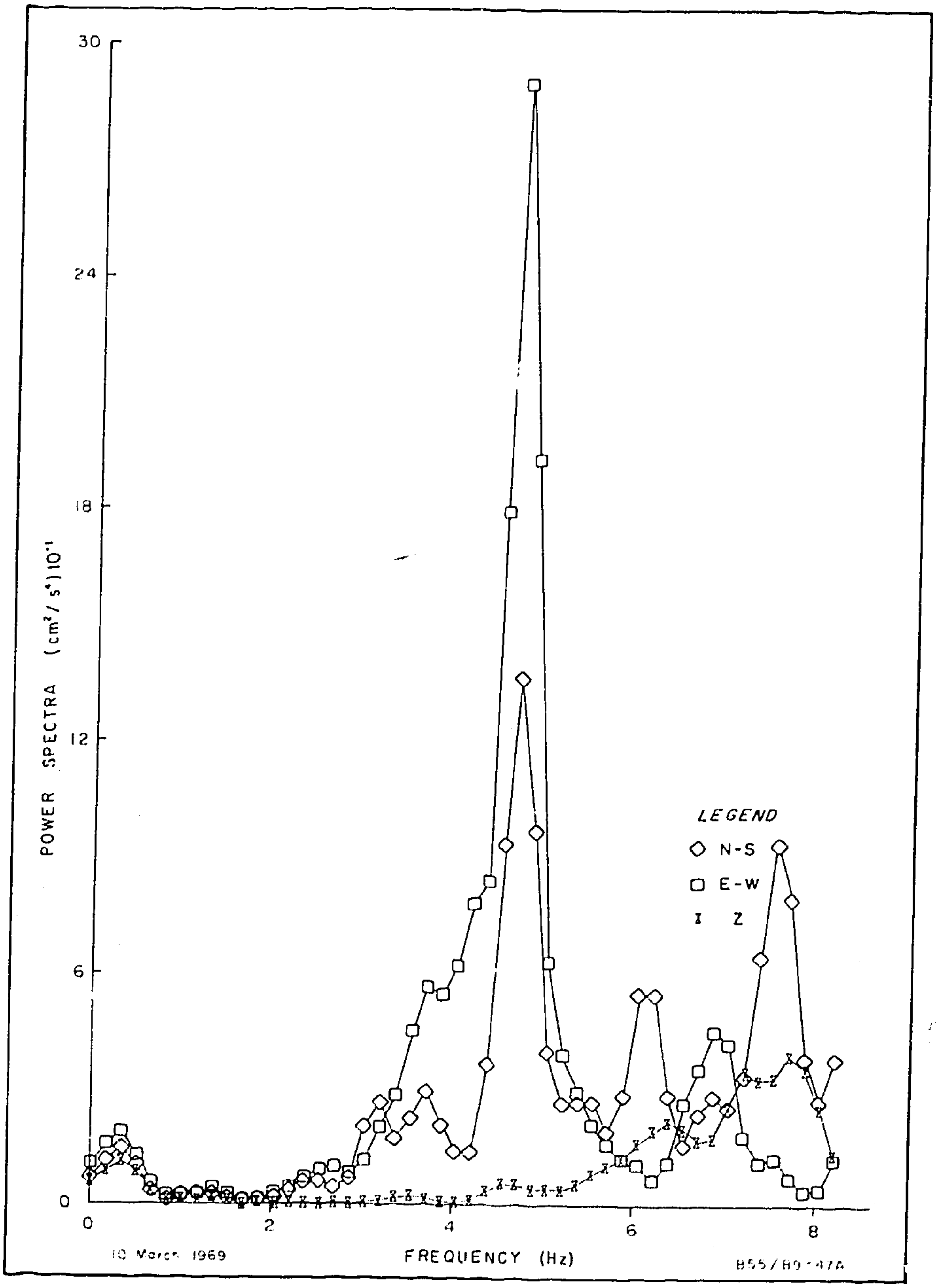

Fig. 20. Power spectra for earthquake of 10 March 1969

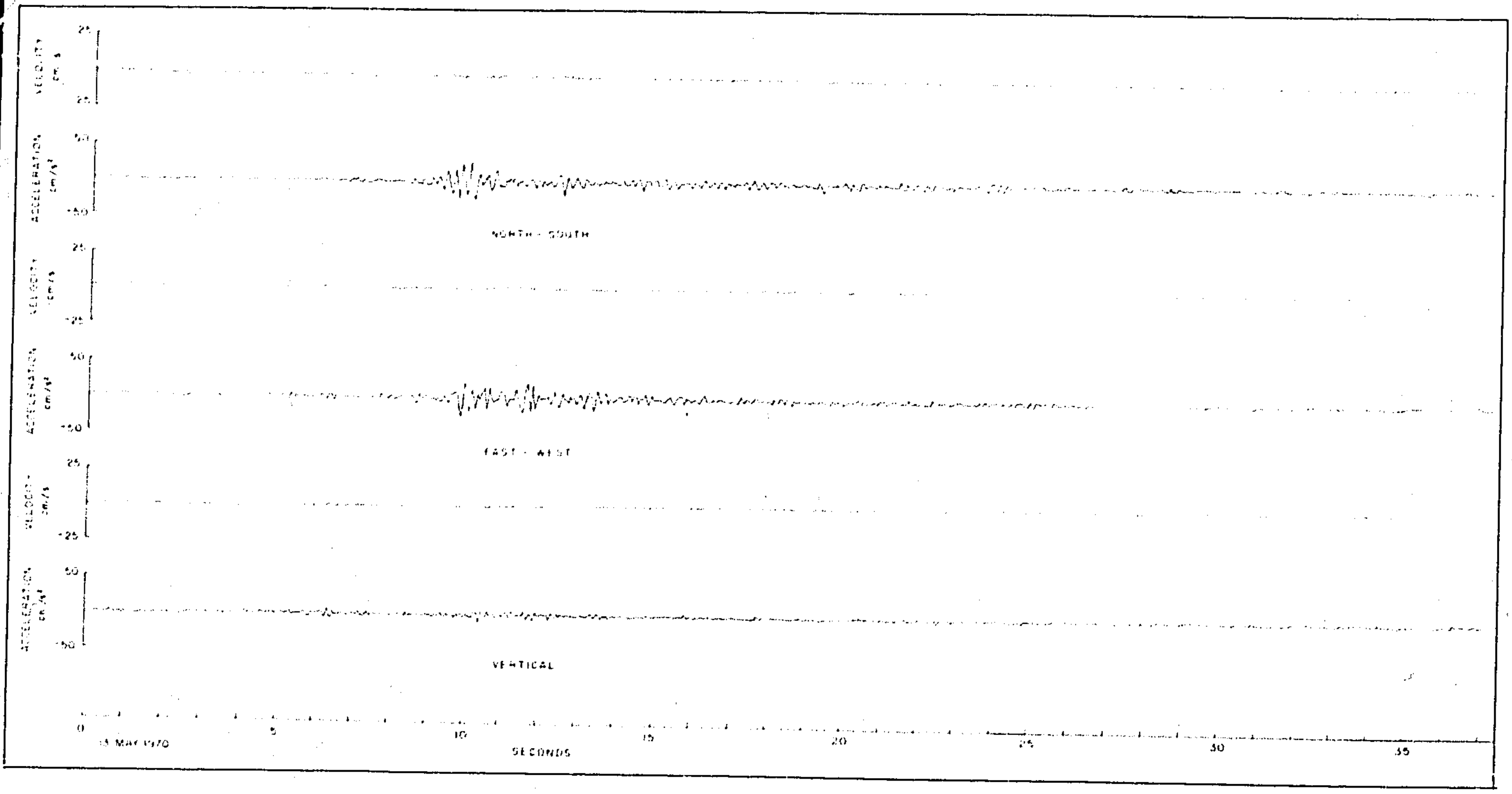

Fig. 21. Ground motions from earthquake of 13 May 1970

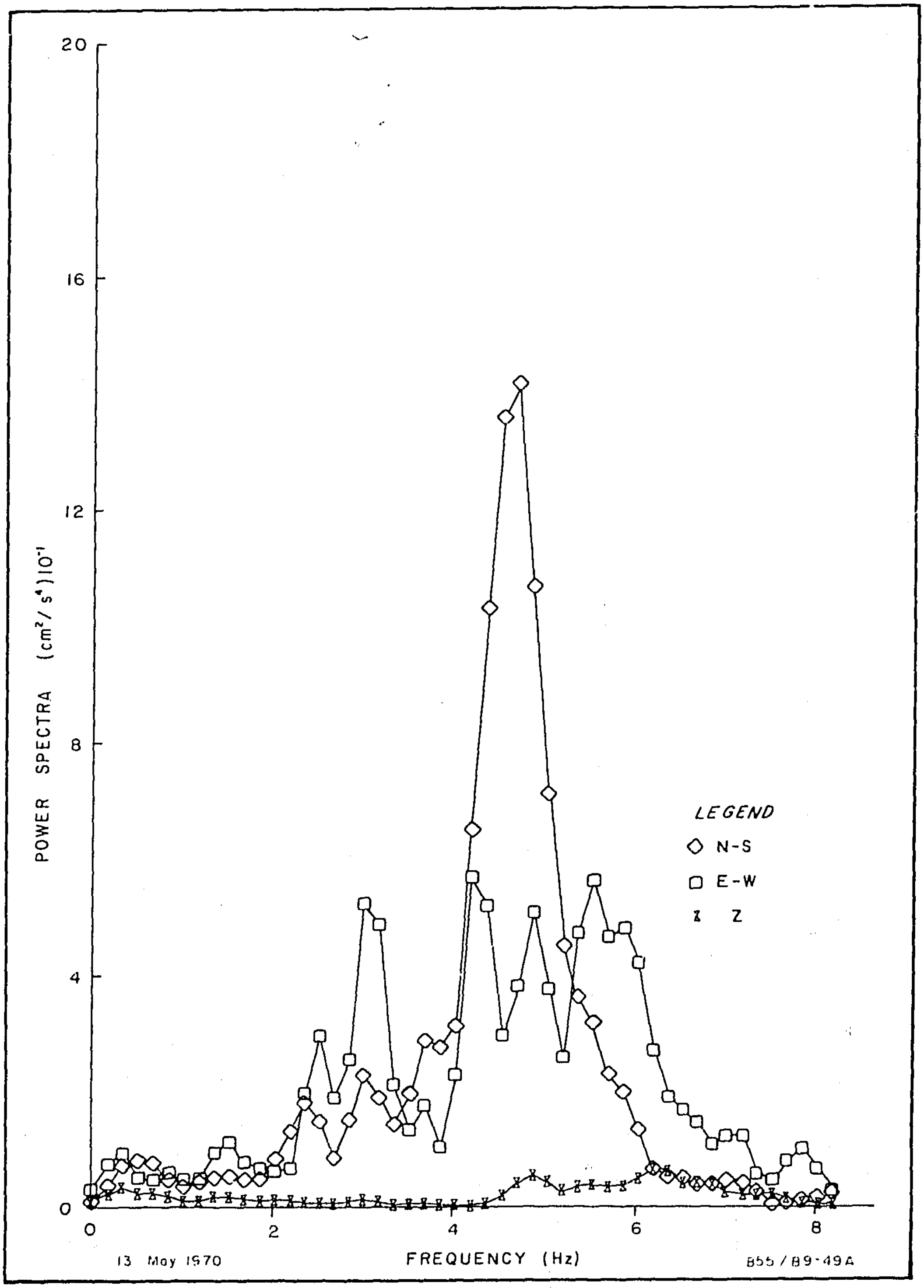

Fig. 22. Power spectra for earthquake of 13 May 1970

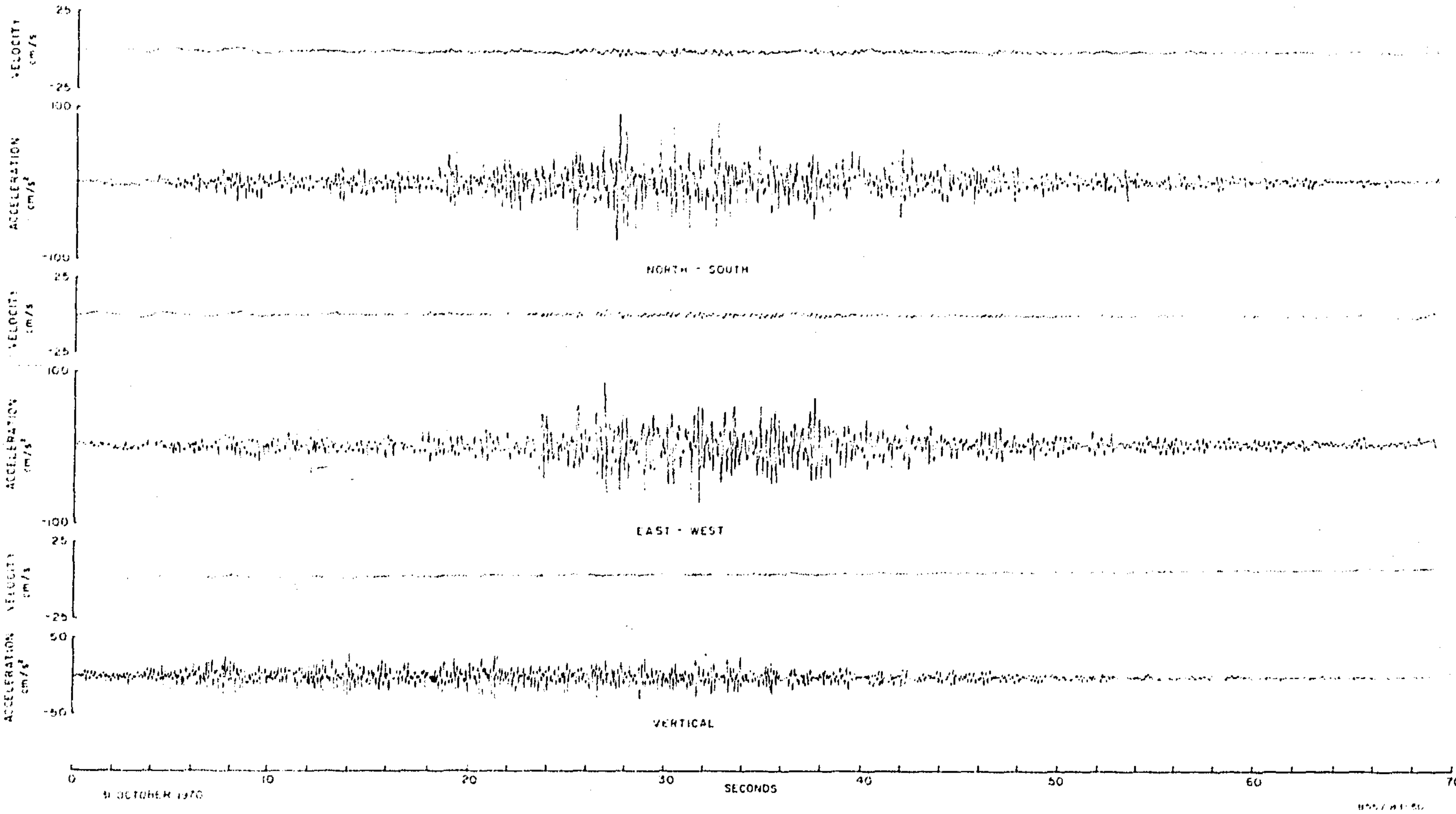

Fig. 23. Ground motions from earthquake of 31 October 1970

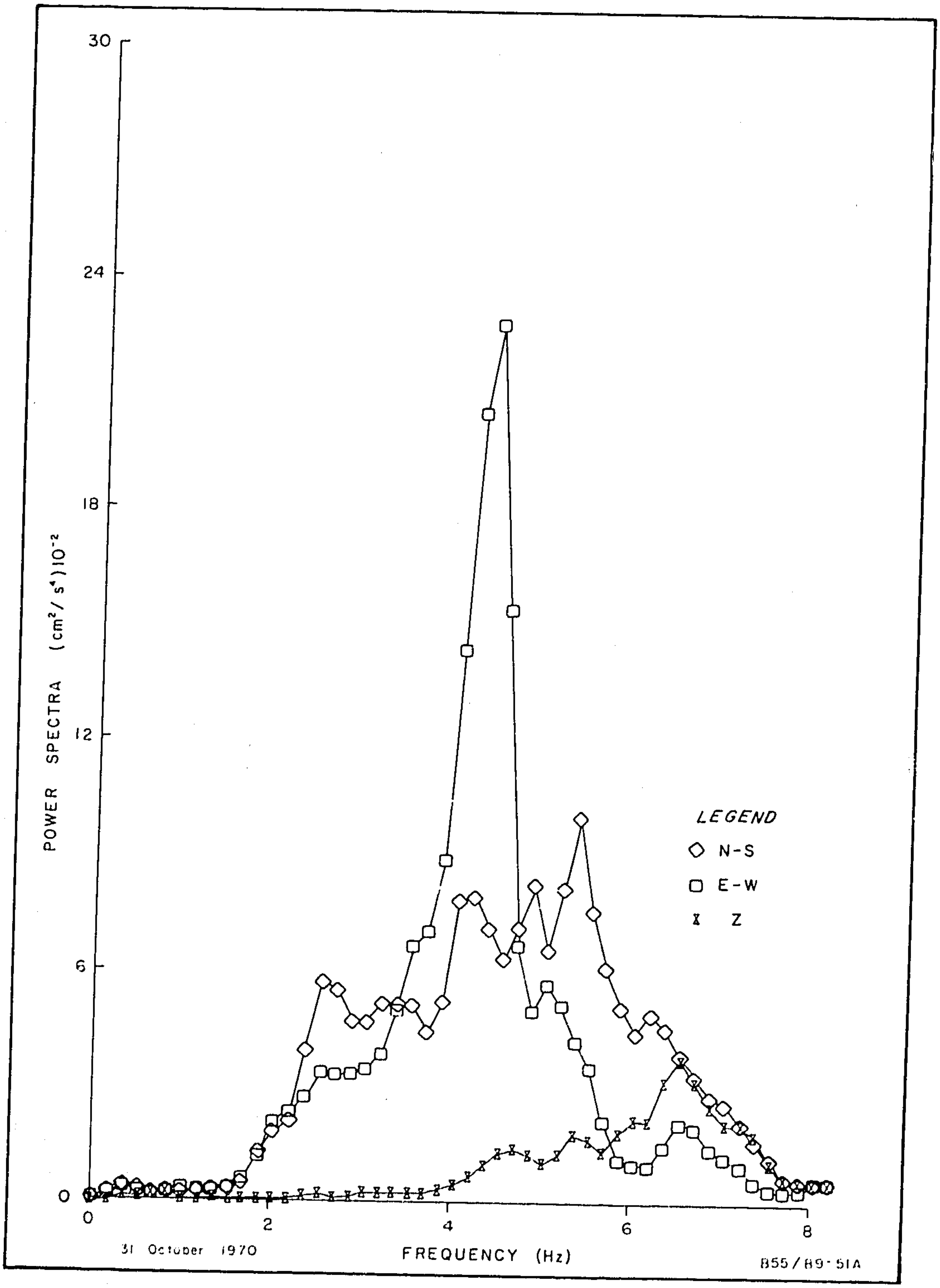

Fig. 24. Power spectra for earthquake of 31 October 1970

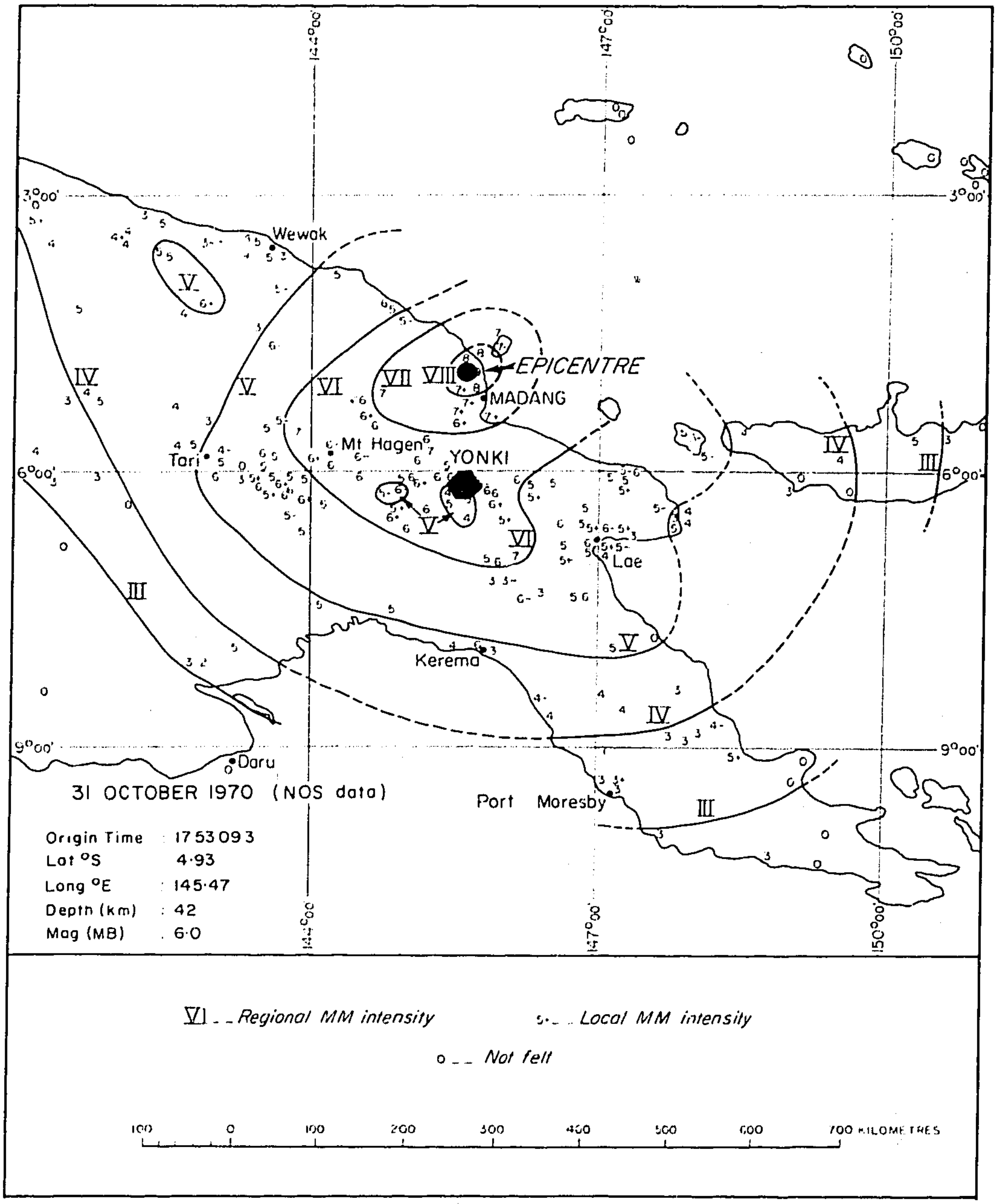

Fig. 25. Isoseismal map for earthquake of 31 October 1970

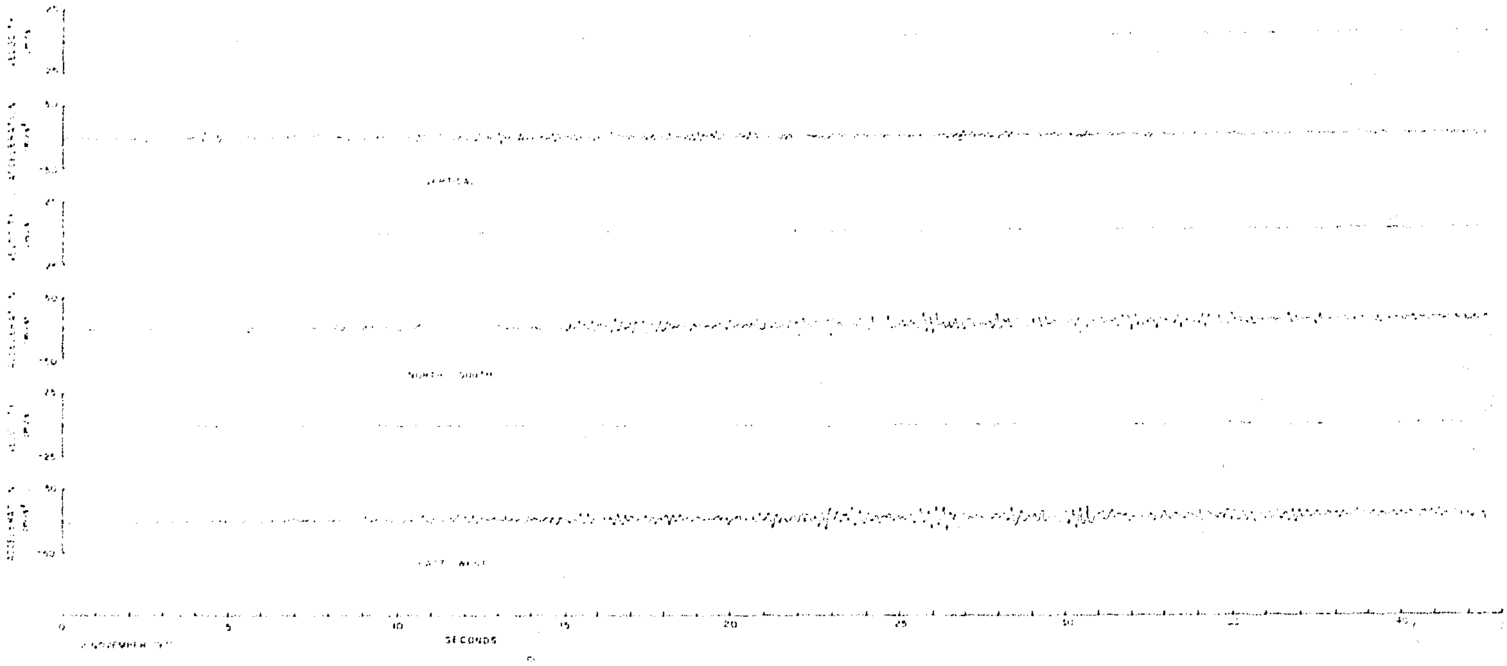

Fig. 26. Ground motions from earthquake of 12 November 1970

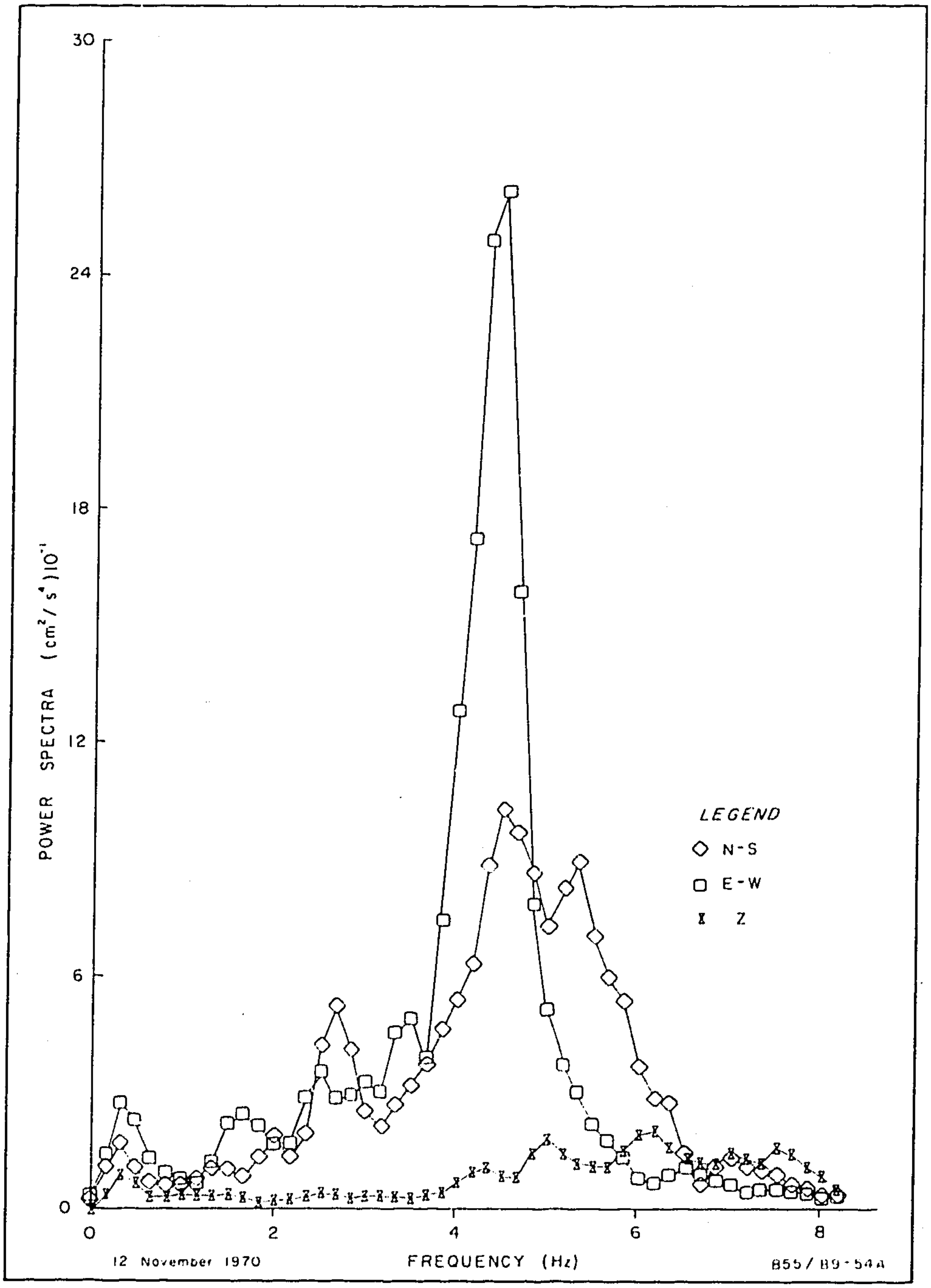

Fig. 27. Power spectra for earthquake of 12 November 1970

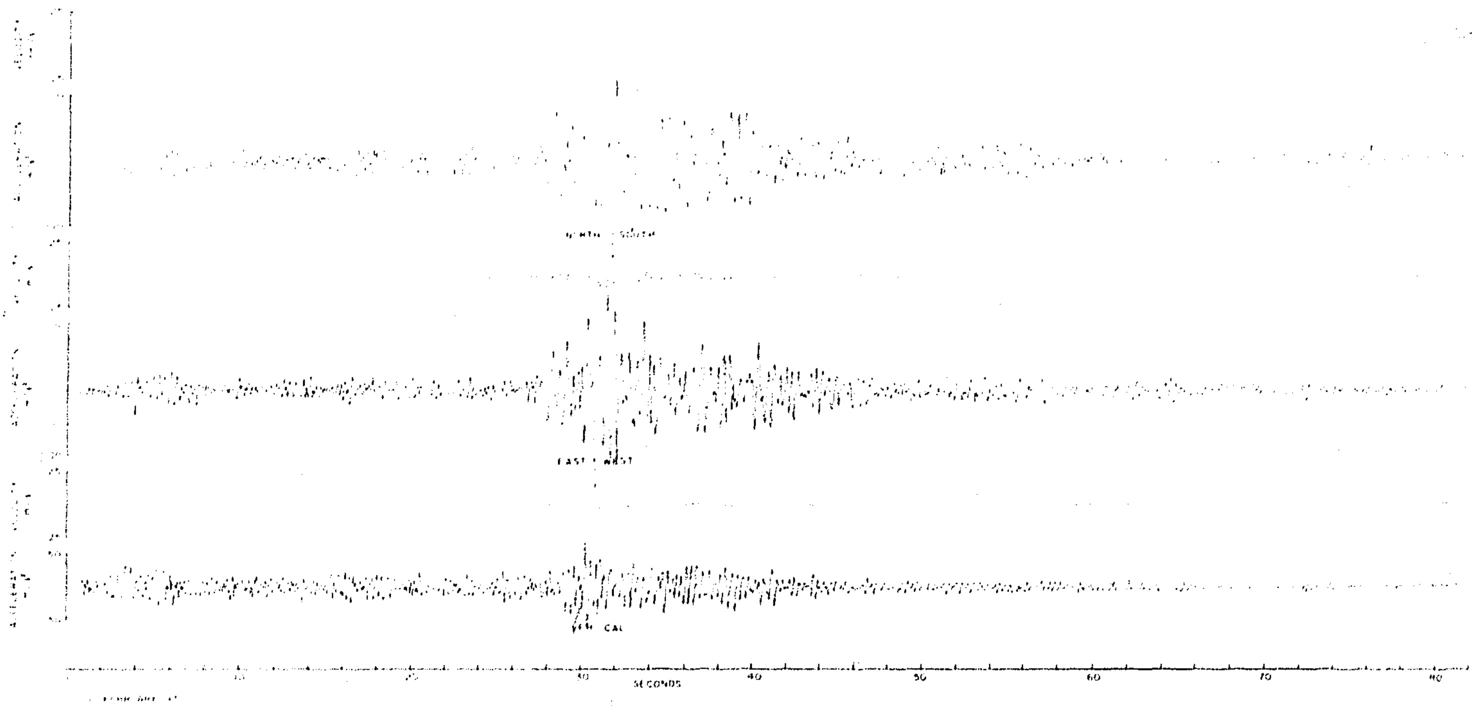

Fig. 28. Ground motions from earthquake of 12 February 1971

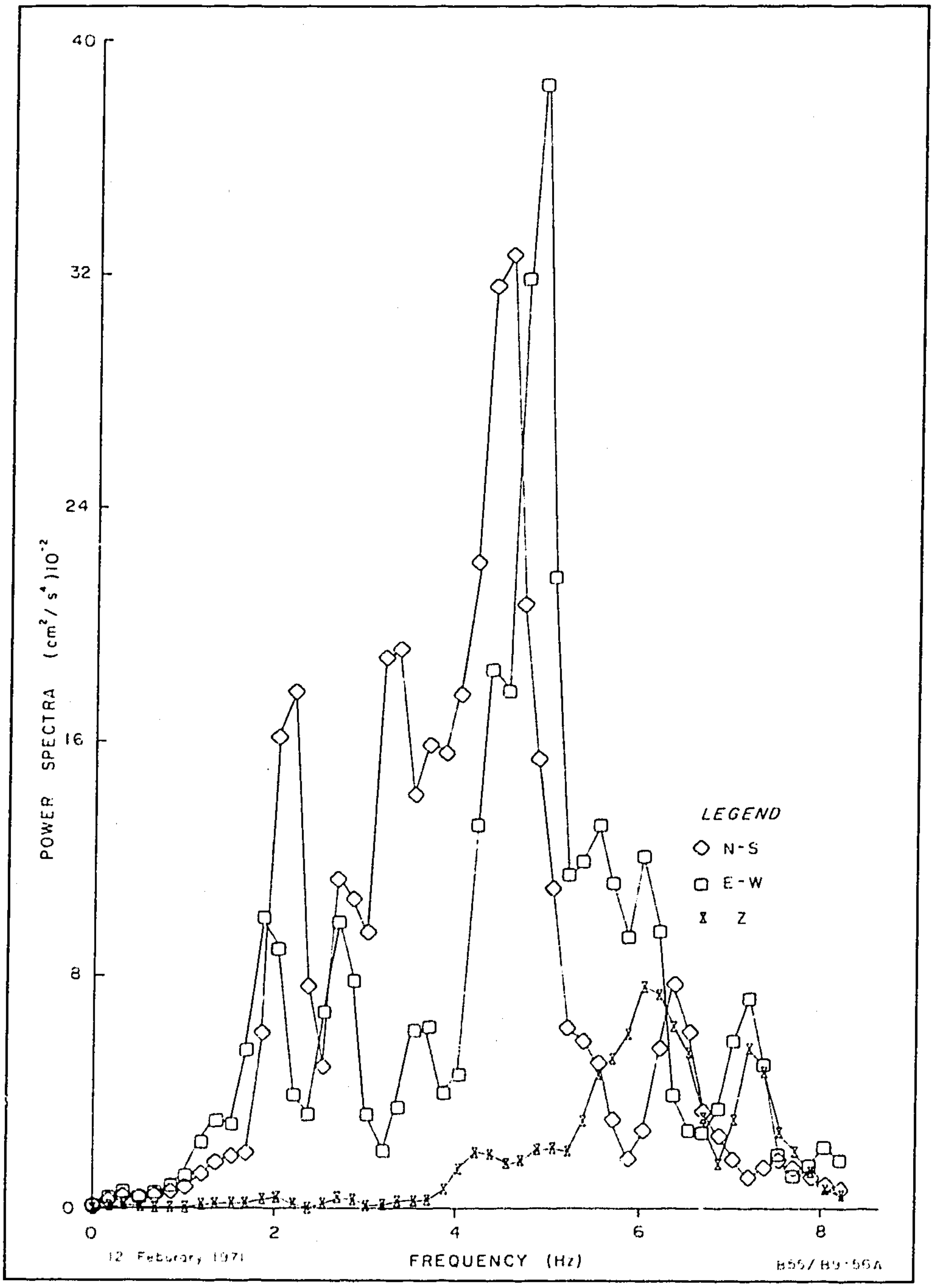

Fig. 29. Power spectra for earthquake of 12 February 1971

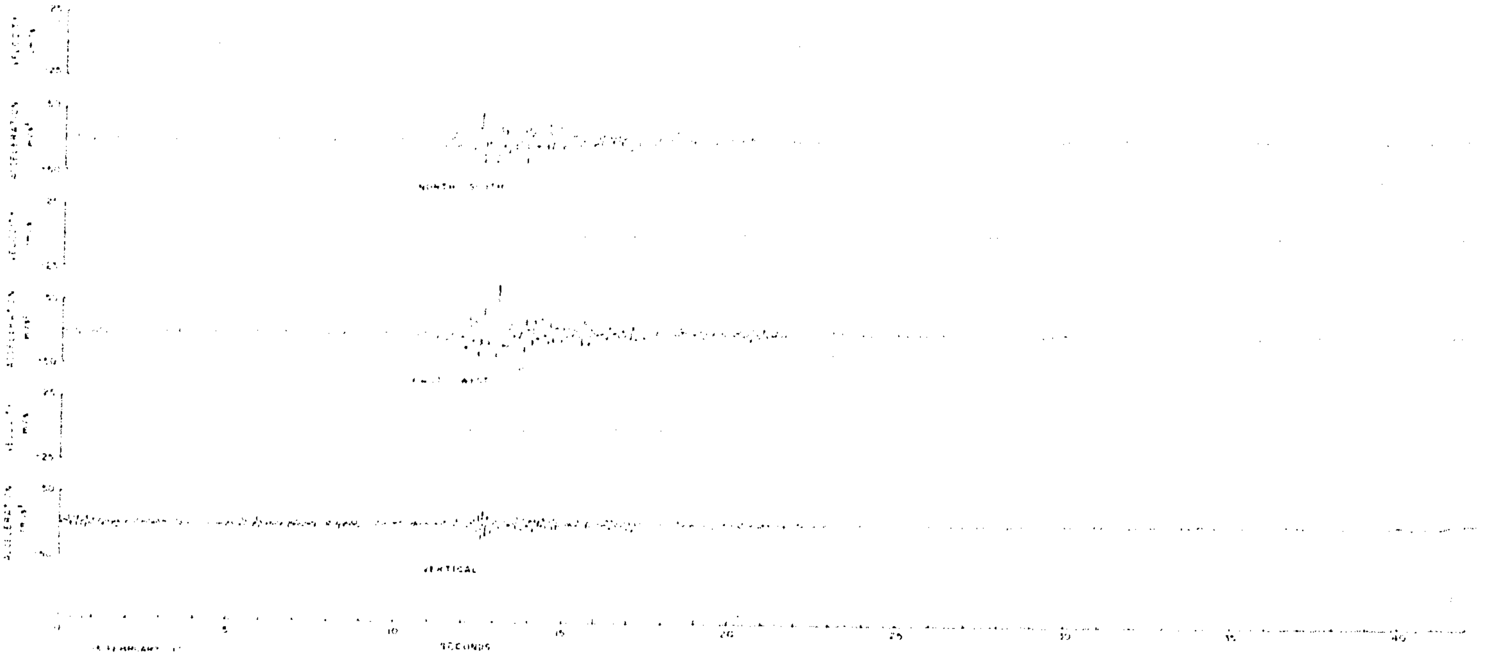

Fig. 30. Ground motions from earthquake of 13 February 1971

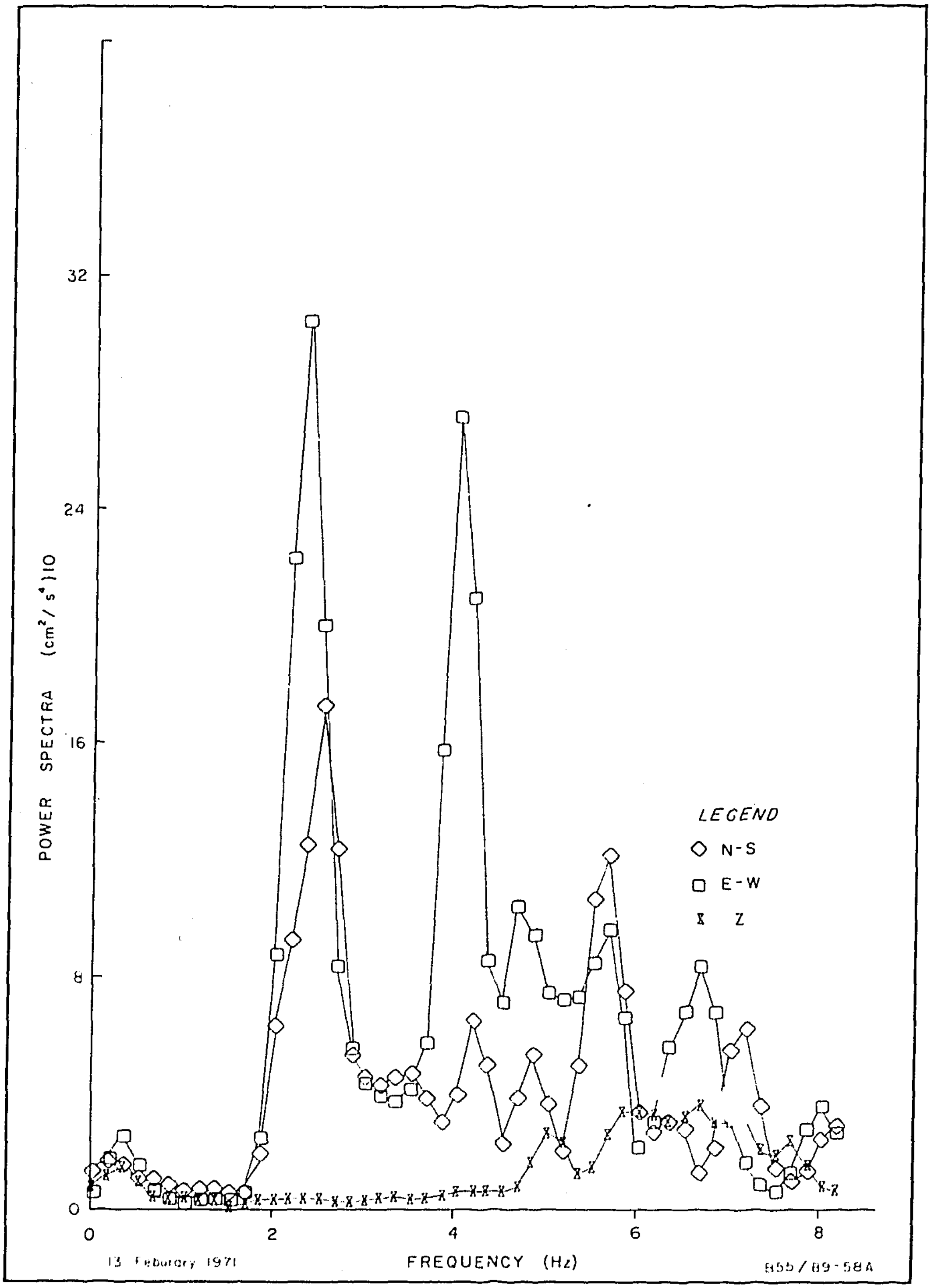

Fig. 31. Power spectra for earthquake of 13 February 1971

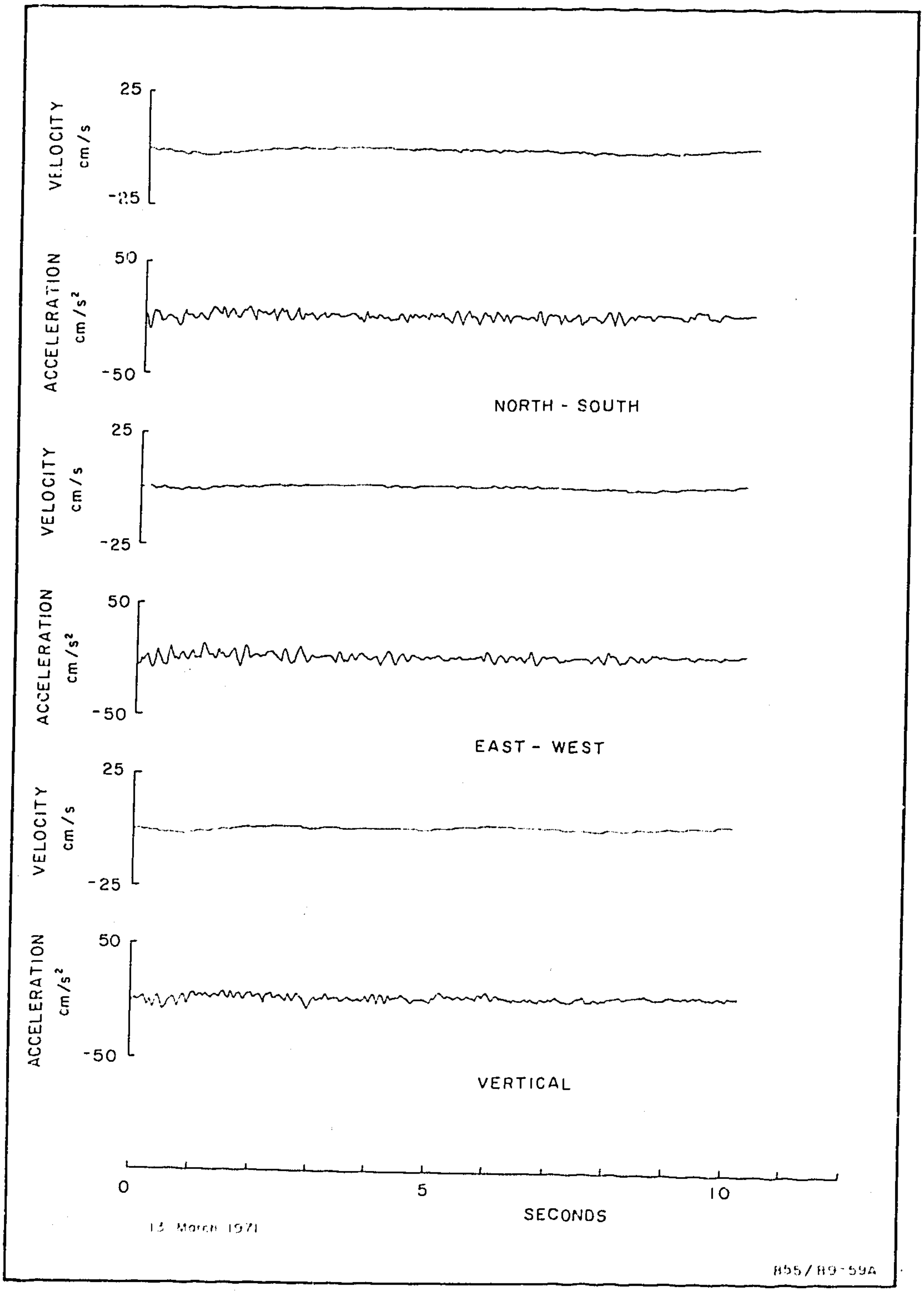

Fig. 32. Ground motions from earthquake of 13 March 1971

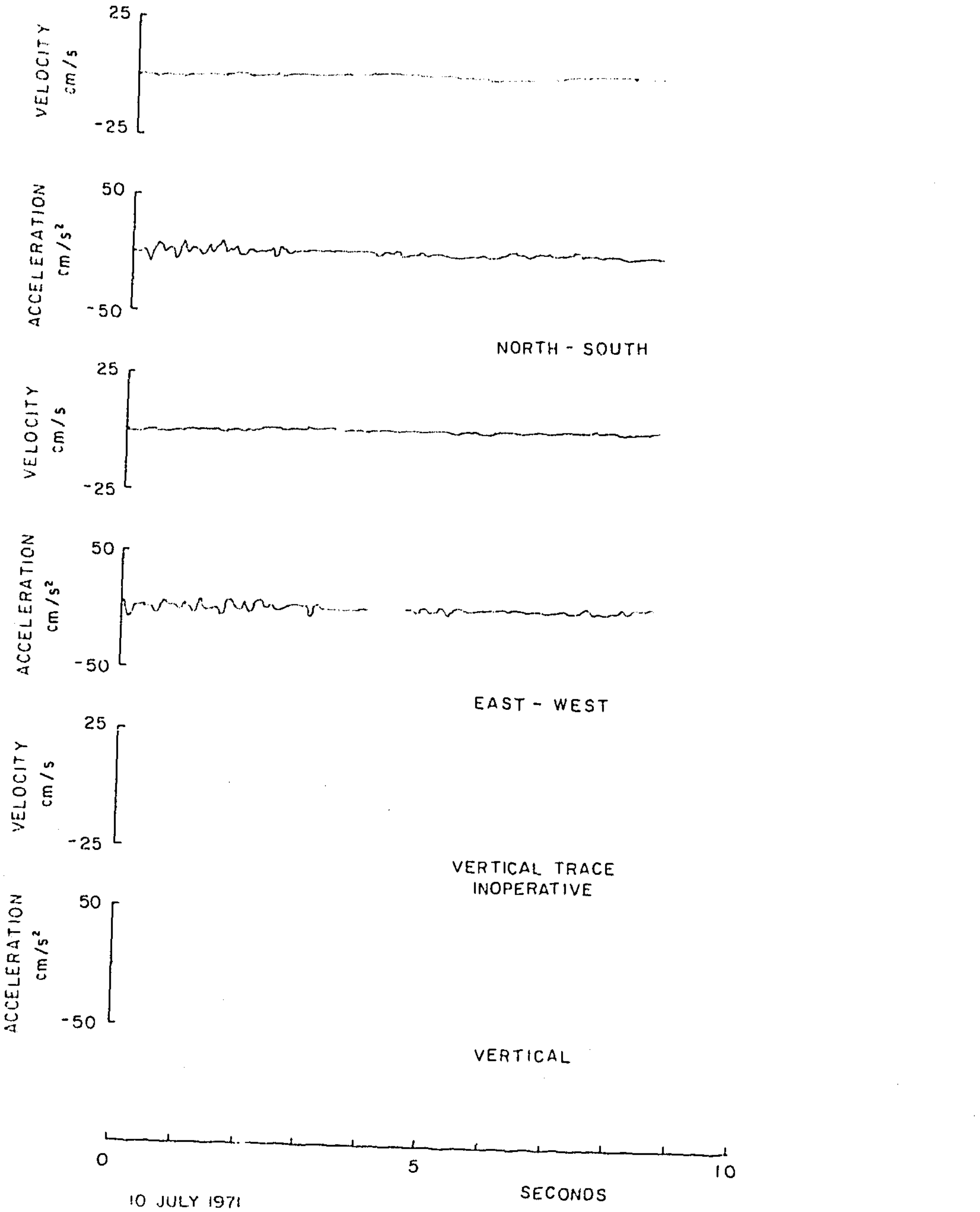

Fig. 33. Ground motions from earthquake of 10 July 1971

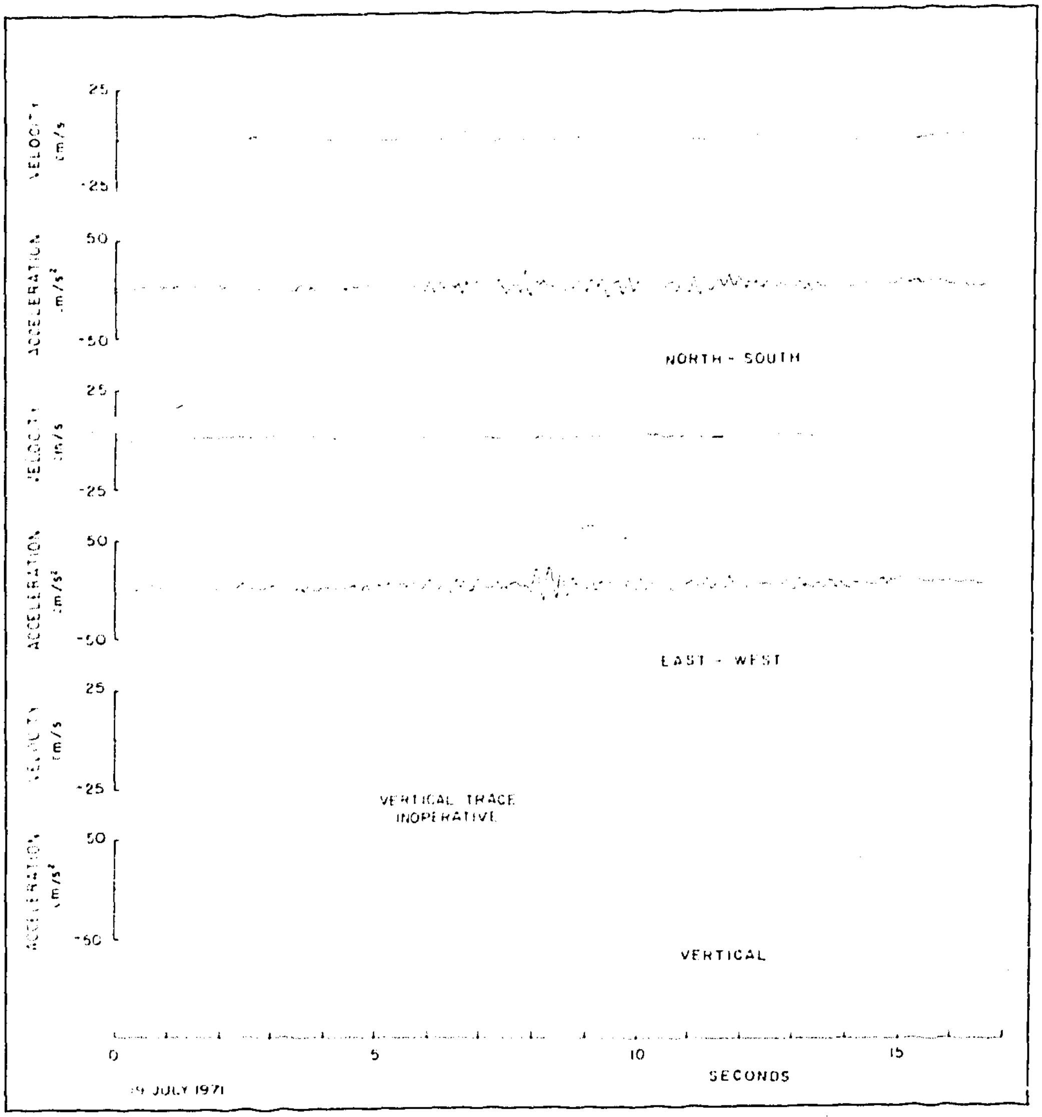

Fig. 34. Ground motions from earthquake of 19 July 1971

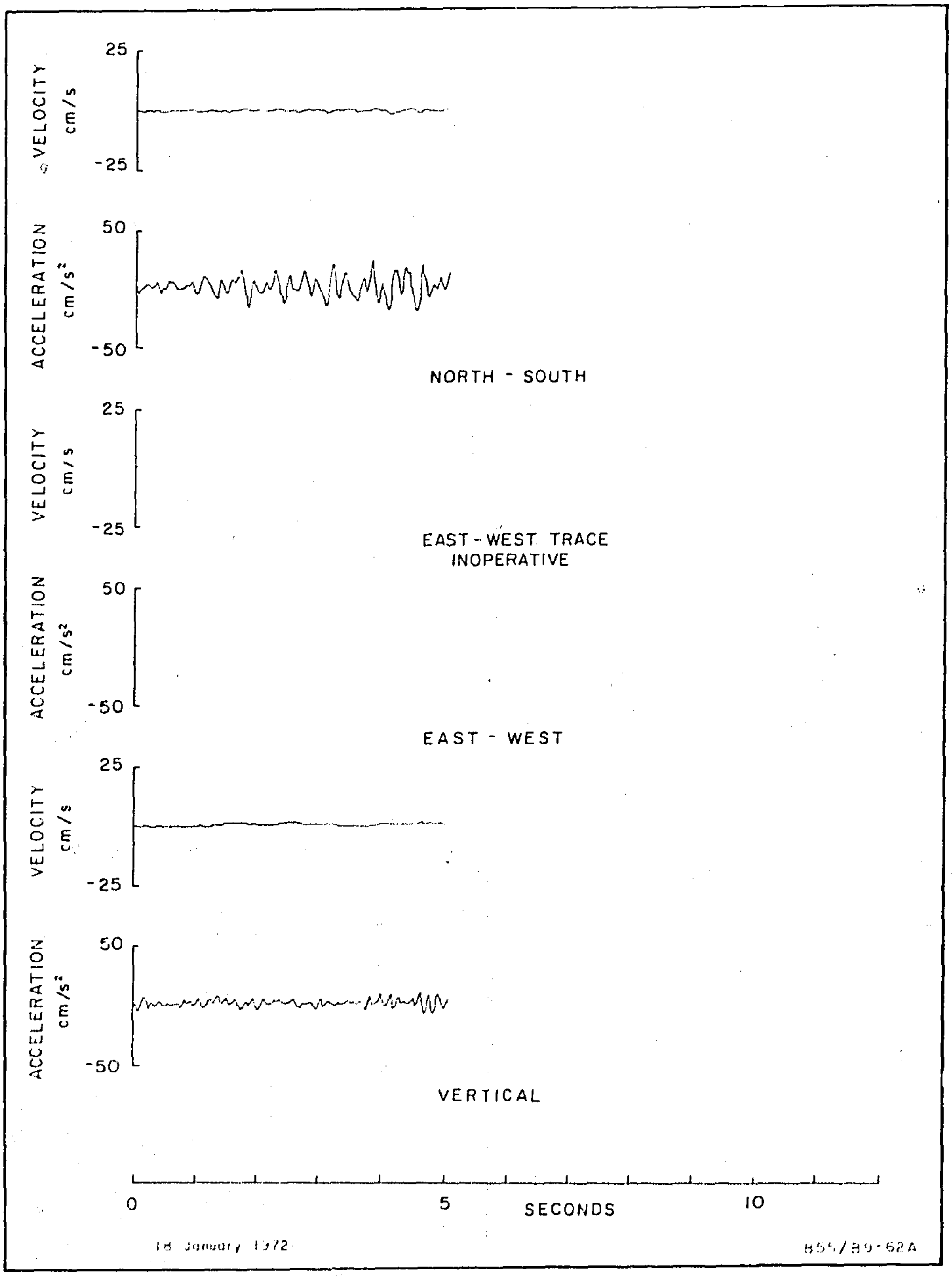

Fig. 35. Ground motions from earthquake of 18 January 1972

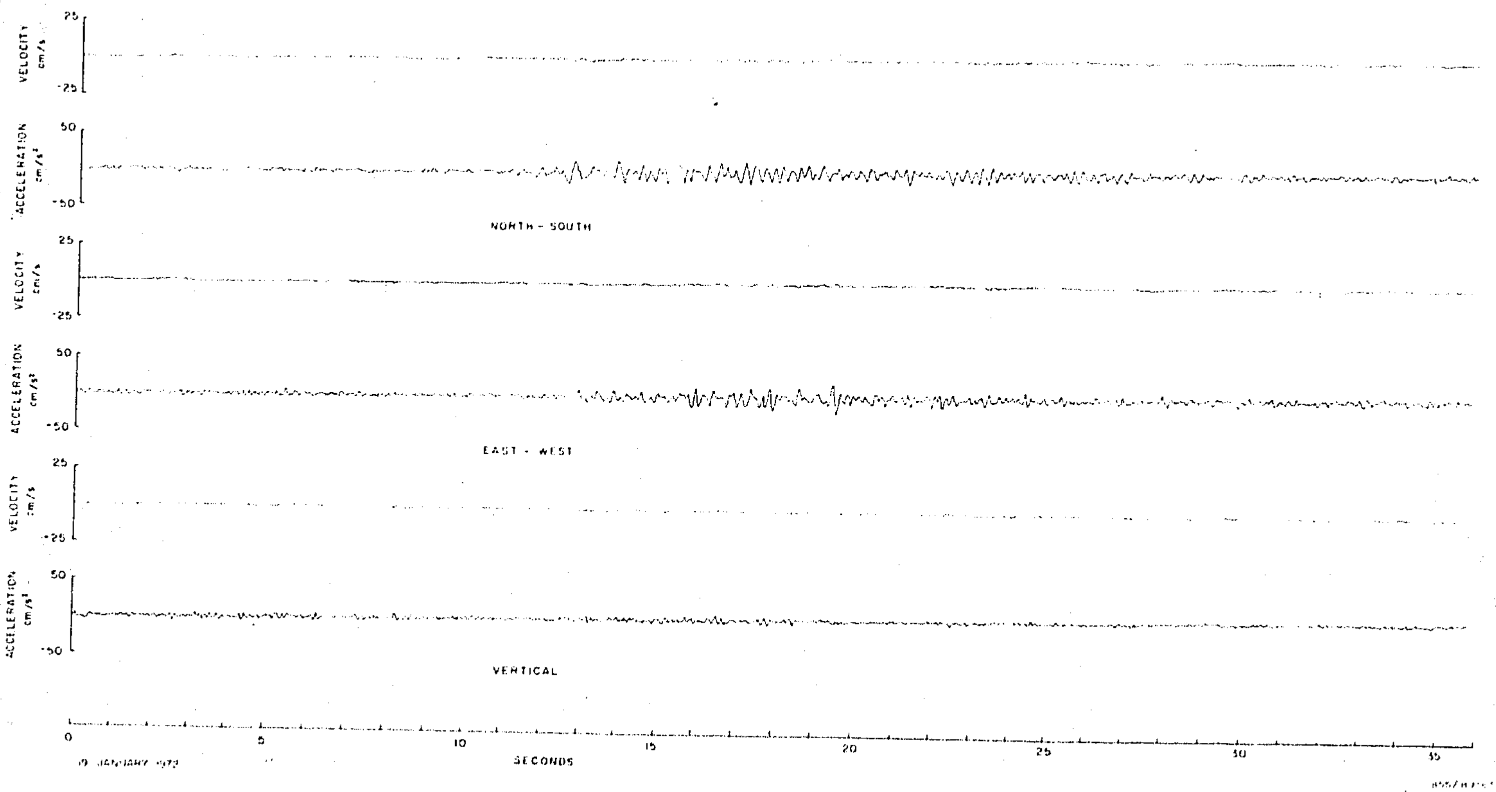

Fig. 36. Ground motions from earthquake of 19 January 1972

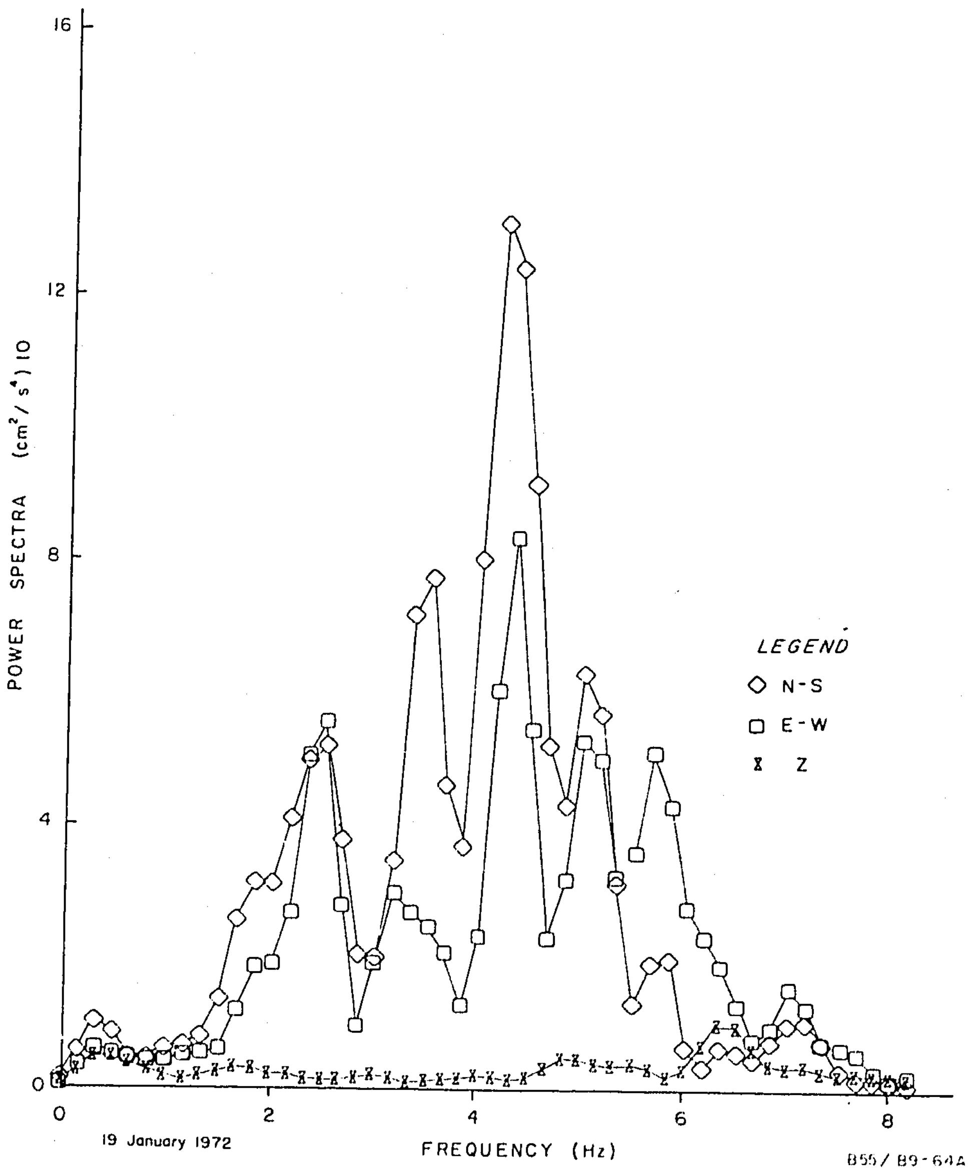

Fig. 37. Power spectra from earthquake of 19 January 1972

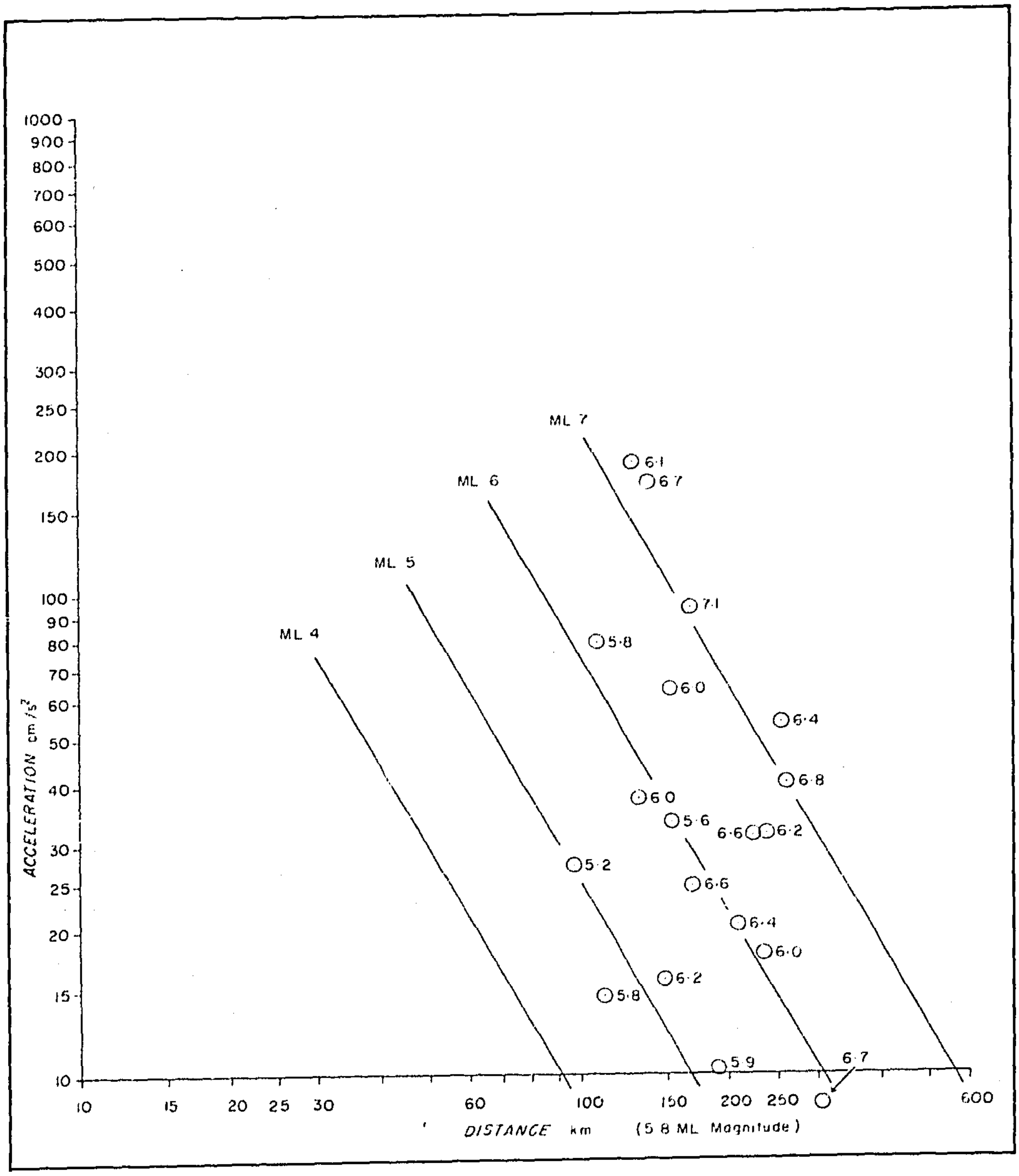

Fig. 38. Maximum accelerations v distance

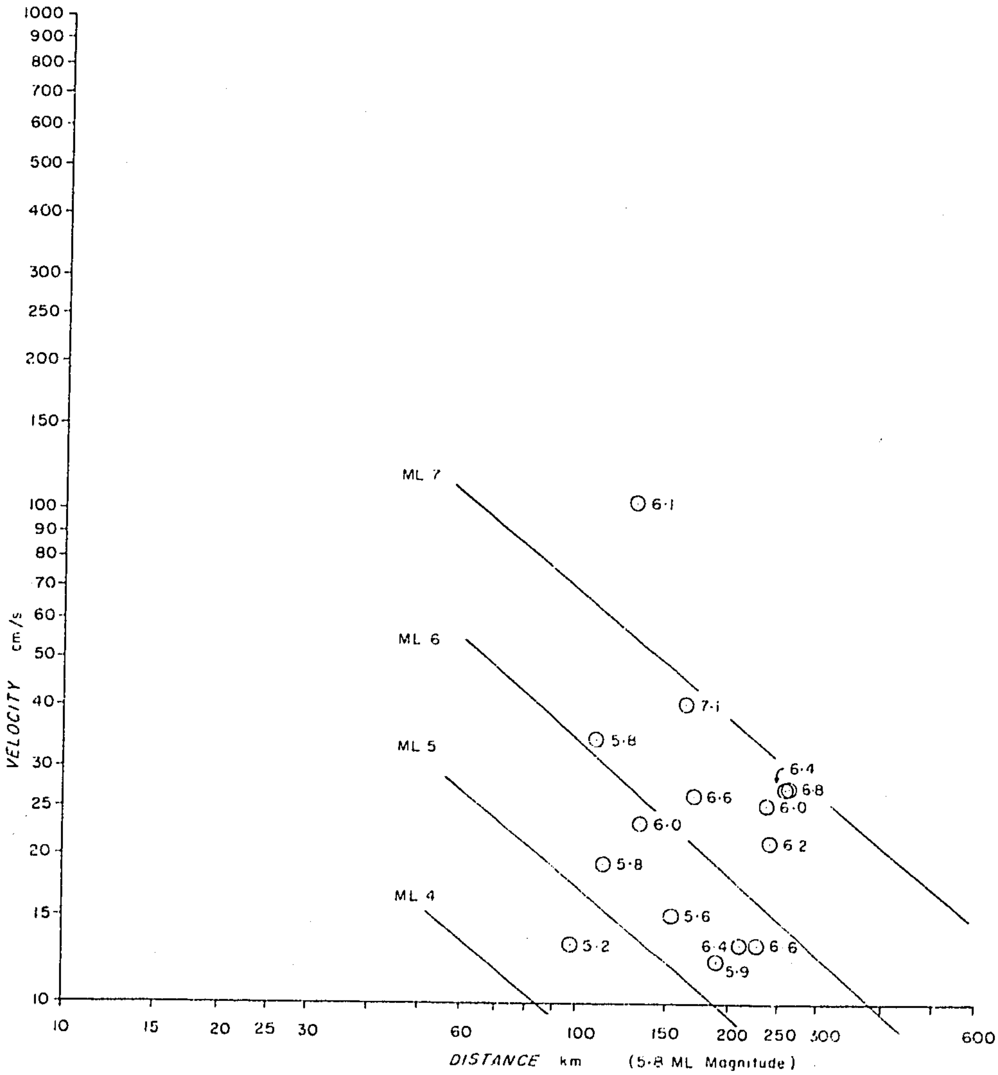

Fig. 39. Maximum velocities v distance

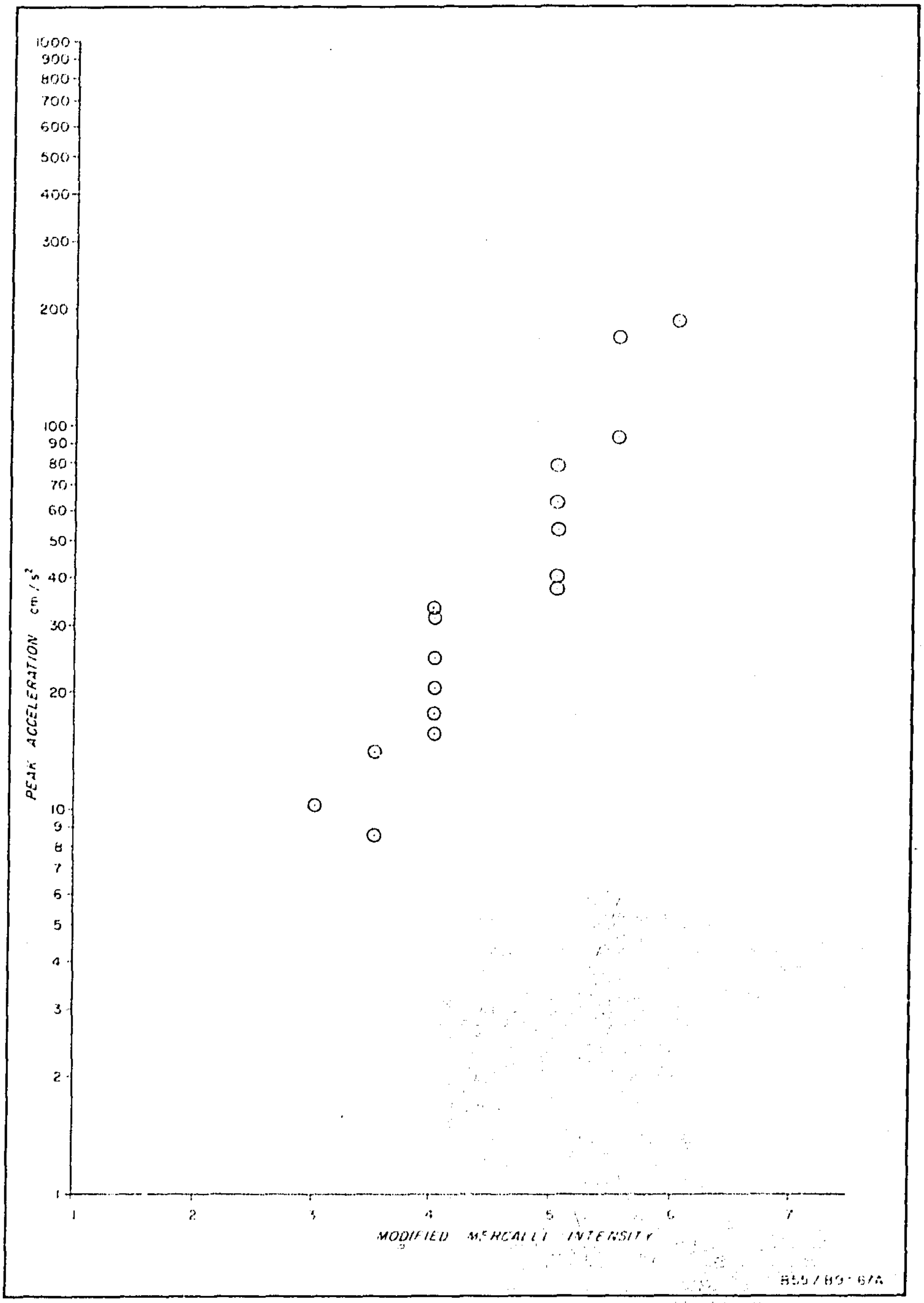

Fig. 40. Maximum accelerations v MM intensity

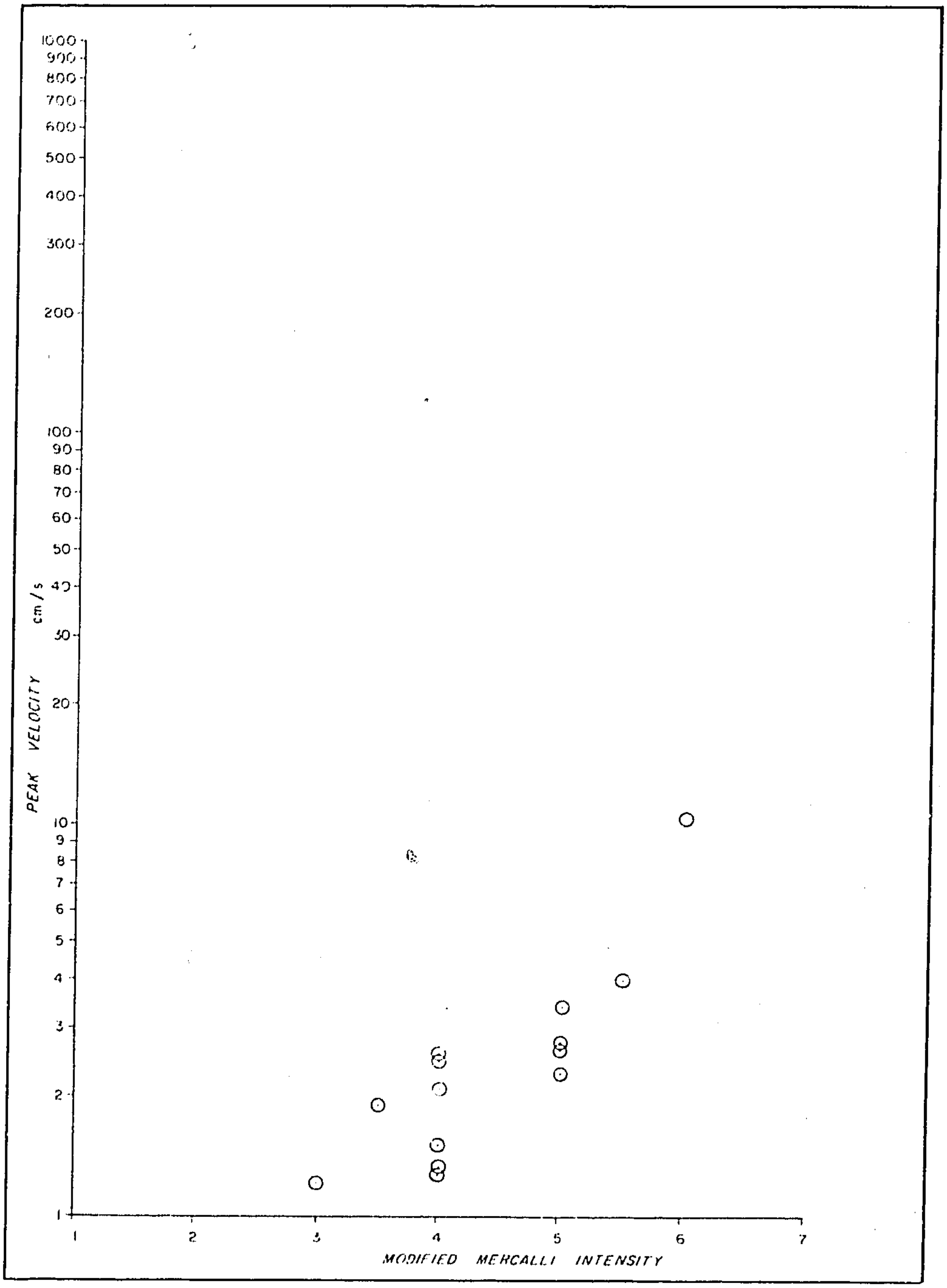

Fig. 41. Maximum velocities v MM Intensity