THE MOTU RIVER EARTHQUAKE OF 8 MARCH 1984

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ABSTRACT

The Motu River earthquake of 8 March 1984 (M = 6.4) was the largest event to occur at the Hikurangi Margin of New Zealand since 1973. It originated in the upper part of the subducted Pacific plate at a depth of 73 kilometres, and appears typical of previous larger events in the region. The earthquake was widely felt, and has provided valuable data on the spatial distribution of intensity from intermediate depth events.

The earthquake produced records of strong ground motion at nine sites within 152 kilometres of the epicentre, though the accelerograms of only one site were of sufficient amplitude to permit digitisation. The distribution of recorded peak accelerations correlates reasonably well with the pattern of S-wave radiation expected from a double-couple point source. A strong-motion instrument near the mouth of the Motu River recorded a relatively short-duration, moderate amplitude motion of extremely monochromatic frequency content. It is likely that a site resonance dominates the data at this location, thus severely limiting the usefulness of the accelerograms for earthquake source studies.

INTRODUCTION

The M = 6.4 earthquake which shook the upper reaches of the Motu River on 8 March 1984 was the largest event to occur at the Hikurangi Margin of New Zealand (that is, the North Island [excluding Northland] and the northern South Island) since an M = 7.0 earthquake in 1973. Like the 1973 event, the Motu River earthquake occurred at intermediate depth, and as a consequence it caused only minor damage. Nevertheless, the large magnitude of the earthquake ensured that it was well recorded in both New Zealand and overseas, and as a result it has provided insights into plate subduction and earthquake strong-motion at the Hikurangi Margin.

MAINSHOCK LOCATION AND MECHANISM

Details of the mainshock are summarised in Table 1, and its epicentre is plotted in figure 1. Also shown in figure 1 are approximate isobaths of the upper surface of the subducted Pacific plate, which have been extrapolated from the central North Island where microearthquake surveys have provided good control on the location of this surface (Reyners, 1980). The 1984 event is thus interpreted as having occurred in the upper part of the subducted plate, rather than on the plate interface.

To determine how common such events might be, all earthquakes over magnitude 5.5 that have occurred within 50 kilometres epicentral distance of the Motu River earthquake since 1940 have also been plotted in figure 1. In the past the New Zealand Seismological Observatory has had difficulty determining accurate depths to earthquakes in the 33-100 kilometre depth range in the region of figure 1 since the standard New Zealand crustal model inadequately describes structure there, and seismograph coverage is sparse. Hence hypocentres determined by the International Seismological Centre, using both New Zealand and overseas readings, are shown for the earthquakes of 1965 (M = 6.0) and 1966 (M = 6.0) since these are considered more reliable. The hypocentre of the 1948 event (M = 5.7) has recently been redetermined using current procedures (Eiby, 1982). It is clear from figure 1 that the events of 1948, 1965 and 1966 can also be interpreted as having occurred within the subducted Pacific plate. Like the 1984 event, these earthquakes were also benign from a seismic hazard viewpoint; the maximum felt intensity reported for each was only MM V.

A fault-plane solution for the mainshock based on P-wave first motions at stations worldwide is shown in figure 2. The solution is reasonably well constrained by the data, and is very similar to the best double-couple solution obtained by the United States Geological Survey using a moment tensor inversion (R Needham, pers comm, 1984; see Table 1). In the

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reference plane of the subducted plate, predominantly strike-slip motion is indicated.

The distribution of P-wave first motions in figure 2 is very similar to that of the 1966 earthquake (Harris, 1982; figure 9), suggesting a similar focal mechanism. However, the first motion patterns of both these events are approximately opposite in polarity to the predominant pattern for intermediate depth earthquakes in the subducted plate to the southwest (the group A events of Harris [1982]). Whereas dextral motion is indicated on the nodal plane oriented down the dip of the subducted plate in figure 2, sinistral motion is indicated for a similarly oriented plane in the fault-plane solution for group A events (see Harris, 1982; figure 5). Such a disparity in focal mechanism may be an indicator of lateral segmentation of the subducted plate (Reyners, 1983). What is suggested is that a segment of plate northwest of Hawke's Bay is currently subducting at a faster rate than adjoining segments to the northeast and southwest.

The Motu River earthquake was felt widely throughout the Hikurangi Margin. As can be seen from the isoseismal map (figure 3) intensities reached MM IV as far away as Greymouth and Akaroa, some 700 kilometres from the epicentre. The felt data for this earthquake fill a gap in our knowledge of the spatial distribution of felt intensities for New Zealand earthquakes. No isoseismal maps for earthquakes reliably located at depths between 33 and 82 kilometres were available for a comprehensive study of this distribution by Smith (1978), and as a result likely intensities from such events have been routinely calculated by linearly interpolating intensities calculated for earthquakes of the same magnitude and with the same epicentre, but at focal depths of 40 and 82 kilometres.

The spatial distribution of felt intensity for the Motu River earthquake is intermediate to that of deeper and shallower events. It exhibits the marked ellipticity in isoseismals, with the semi-major axis oriented at approximately 040°, which is characteristic of deeper events (Smith, 1978). Such ellipticity arises because seismic energy is attentuated much less in propagation through the subducted Pacific plate lithosphere than along other paths. On the other hand, there is no marked northwesterly offset of the epicentre from the centre of the isoseismal pattern and extremely rapid fall-off in intensity in a northwesterly direction common for deeper events (for example, Smith, 1978; figure 4). This may be a consequence of the overlying Indian plate and subducted Pacific plate lithospheres being in contact in the vicinity of the hypocentre, in contrast to deeper events to the northwest, which are overlain by an attenuating asthenospheric wedge.

STRONG MOTION DATA

There are 12 strong-motion earthquake recorder sites within 152 kilometres of the epicentre: eight of these sites have three-component (MO-series) accelerographs, while the remaining recorders are of the scratch-plate type, giving measures only of peak ground acceleration. A summary of the peak acceleration responses for all sites is shown in Table 2.

The strongest recorded ground motion (measured in terms of peak acceleration) occurred at Maraenui Primary School, on an ancient alluvial bench near the mouth of the Motu River about 42 kilometres from the epicentre. Here the peak horizontal acceleration was measured as 1.63 m/sec^2 (about 17% of the acceleration of gravity): this is the second-largest strong ground motion recording ever obtained from an MO-series instrument in New Zealand.

It is noteworthy that the strong-motion recorder at Opotiki, only 30 kilometres from the epicentre, recorded a lower peak acceleration than that at Maraenui. When the take-off angles at the source for the S-waves recorded at Opotiki and Maraenui are referred to the focal mechanism of the mainshock (figure 2), it is clear that the S-waves at Opotiki are generated from a point on the focal sphere much closer to the null axis (where S-wave generation is zero) than those at Maraenui. This suggests that for the Motu River earthquake, the distribution of peak acceleration may correlate with the pattern of S-wave radiation. To investigate this, peak accelerations were plotted against an S-wave radiation pattern term, as shown in figure 4. The radiation pattern term represents the theoretical horizontal S-wave radiation from a double-couple point source (for example, Aki and Richards, 1980). The effect of geometrical spreading is included, and attenuation has been approximated assuming a Q of 1000 (cf Haines, 1981) and a predominant S-wave frequency of 5 Hz. Only readings from sites out to Wairoa are included in figure 4, since beyond this distance the vertical, radial and tangential components of S-wave motion at the free surface are no longer linear with respect to one another due to the free surface effect.

Figure 4 indicates a reasonable correlation between measured peak accelerations and theoretically determined horizontal S-wave amplitudes for the Motu River earthquake. The distribution of peak accelerations for this intermediate-depth event is thus quite different to that of shallow earthquakes in California. Hanks and McGuire (1981) find that for these events peak accelerations depend only weakly, if at all, on the S-wave radiation pattern.

Of the three MO-series instruments which triggered during the earthquake, only the Maraenui instrument recorded motion of large enough amplitude to permit digitisation. The strongest portions of the two horizontal components of motion obtained at the Maraenui Primary School are shown in figure 5. For this presentation, the accelerogram records have been band-pass filtered with a pass band extending from 0.50 to 24.5 Hz, and transition bands from 0.25 to 0.50 Hz and 24.5 to 25.0 Hz (see Hodder [1983] for a description of the techniques used).

The larger horizontal component of ground motion is in the direction S50E (130 degrees east of north), with a peak acceleration of 1.51 m/sec². The acceleration record is characterised by a single burst of energy of 4.9 Hz frequency appearing about 10 seconds after the instrument triggered. Although this dominant frequency is of the same order as that obtained from other New Zealand accelerograms, the record has a much more monochromatic frequency content than usual (see Beck et al, [1981]). In the direction N40E (40 degrees east of north), the peak acceleration is 1.08 m/sec², with a less coherent wave pattern of somewhat longer duration than the S50E component.

The acceleration response spectrum for component S50E (see figure 6) shows a greatly amplified response in the period range from 0.18 to 0.24 seconds. The peak spectral amplitude of acceleration for 5% critical damping is 9.77 m/sec² at a natural period of 0.21 seconds: this is the highest spectral acceleration yet recorded on ground in New Zealand, and indicates a strong potential for damage to structures with a natural period within the rather narrow range given above.

Such a high spectral acceleration raises the question of whether some of the acceleration seen at Maraenui may be an instrumental or site effect. To investigate this possibility, Fourier amplitude spectra of acceleration were produced for the S50E and N40E components at Maraenui (see figure 7). Both these spectra are very different from typical earthquake acceleration spectra, which are characterised by a plateau between the source corner frequency f_o and f_{max}, the highest frequency passed by the accelerograph or the earth's attenuation (Hanks and McGuire, 1981). The spectra in figure 7 have a very peaked appearance, precluding identification of either f_o or f_{max}. Such spectra are unlikely to be a consequence of an instrumental effect, since the MO2A transducer has a natural frequency of 30 Hz, whereas the largest spectral amplitudes in figure 7 are in the 3-5 Hz range. It is more likely that the peaks in the spectra reflect resonance effects in the alluvial bench on which the Maraenui accelerograph is situated. Similar resonance effects have been identified at some sites overseas. For example, Seekins and Hanks (1978) identify a site amplification confined to a narrow frequency band around 6 Hz for an accelerograph in California, while Mori and Shimazaki (1984) describe a sand and silt accelerograph site in Japan where a 0.5 to 1 Hz site response dominates the data.

The likely presence of site resonance effects severely limits the usefulness of the Maraenui accelerograms for earthquake source studies. With accelerograph data obtained from rock sites, it is often possible to estimate earthquake moment from either the area under the displacement pulse, or the low frequency asymptote to the displacement amplitude spectrum (see Aki and Richards, 1980). As can be seen in figure 5, the Maraenui accelerograms do not exhibit a clearly identifiable displacement pulse; similarly, the low frequency asymptotes to the displacement amplitude spectra are difficult to define. In addition, the peaked character of the acceleration spectra mentioned previously precludes the determination of earthquake stress drop using the method of Hanks and McGuire (1981).

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TABLE 1 - THE 1984 MOTU RIVER EARTHQUAKE

Origin Time:	8 March 1984 0040 hours 52.6 ± 0.8 seconds
Epicentre:	38.22 ± 0.03°S 177.48 ± 0.05°E
Depth:	73 ± 12 km
Magnitude:	6.4 (M_L) 5.9 (m_b)
Moment:	3.2×10^{18} N.m (US Geological Survey moment tensor determination).
Fault plane solution:	1. Using P-wave first motions from New Zealand and overseas stations Nodal plane 1: Strike = 306°, Dip = 53°, Rake = 146° Nodal plane 2: Strike = 58°, Dip = 63°, Rake = 42°
	2. US Geological Survey moment tensor determination Nodal plane 1: Strike = 317°, Dip = 49°, Rake = 155° Nodal plane 2: Strike = 64°, Dip = 71°, Rake = 44°

TABLE 2 - PEAK ACCELERATIONS RECORDED DURING MOTU RIVER EARTHQUAKE

Recording Site	Instrument	Epicentral Distance (km)	Bearing From Epicentre (°)	Peak Acceleration (m/sec^2)
Opotiki	SP	30	314	0.69
Maraenui	MO2A	42	12	1.63
Matahina Dam Crest	MO2	59	281	0.24
Gisborne Telephone Exchange	SP	68	136	0.96
Tuai Power Station	MO2A	72	204	No record
Tuai Power Station	SP	72	204	0.20
Tolaga Bay	SP	75	103	0.48
Wairoa	MO1	90	183	0.39
Wairoa	SP	90	183	0.32
Te Aroha	MO1	101	50	No record
Rotorua	MO2A	109	280	No record
Iwitahi	MO2A	125	238	No record
Taupo	SP	132	248	0.45
Napier	MO1	152	200	No record
Napier	SP	152	200	0.19

FIGURE CAPTIONS

FIGURE 1 Location of the 1984 Motu River earthquake (star), and previous earthquakes (M 5.5) within 50 kilometre epicentral distance of the event since 1940 (filled circles with date and depth shown). The dashed lines are approximate isobaths of the upper surface of the subducted Pacific plate.

FIGURE 2 Fault plane solution for the Motu River earthquake based on local and overseas P-wave first motions. The diagram is an equal-area projection of the upper focal hemisphere. Solid circles are compressions, open circles dilatations. P and T denote the principal axes of compression and tension respectively, and the dashed curve shows the approximate orientation of the subducted plate in the vicinity of the earthquake.

FIGURE 3 Modified Mercalli intensity distribution for the Motu River earthquake. The epicentre is denoted by a star, and question marks show places where the earthquake was felt but insufficient information was available for assigning an intensity.

FIGURE 4 Peak accelerations produced by the Motu River earthquake plotted against a dimensionless S-wave radiation pattern term which has been corrected for the effects of geometrical spreading and attenuation. Accelerograph legend: GIS - Gisborne; MAR - Maraenui; MAT - Matahina; OPO - Opotiki; TOL - Tolaga Bay; TUA - Tuai; WAI - Wairoa.

FIGURE 5 Strong-motion record at Maraenui, showing time histories of ground acceleration, velocity and displacement.

a) Component S50E (130 degrees east of true north)
b) Component N40E (40 degrees east of true north)

FIGURE 6 Response spectrum of acceleration at Maraenui, component S50E. This represents the peak total acceleration response of single degree of freedom oscillators of given natural vibration period and critical damping ratio.

FIGURE 7 Fourier amplitude spectra of acceleration at Maraenui.

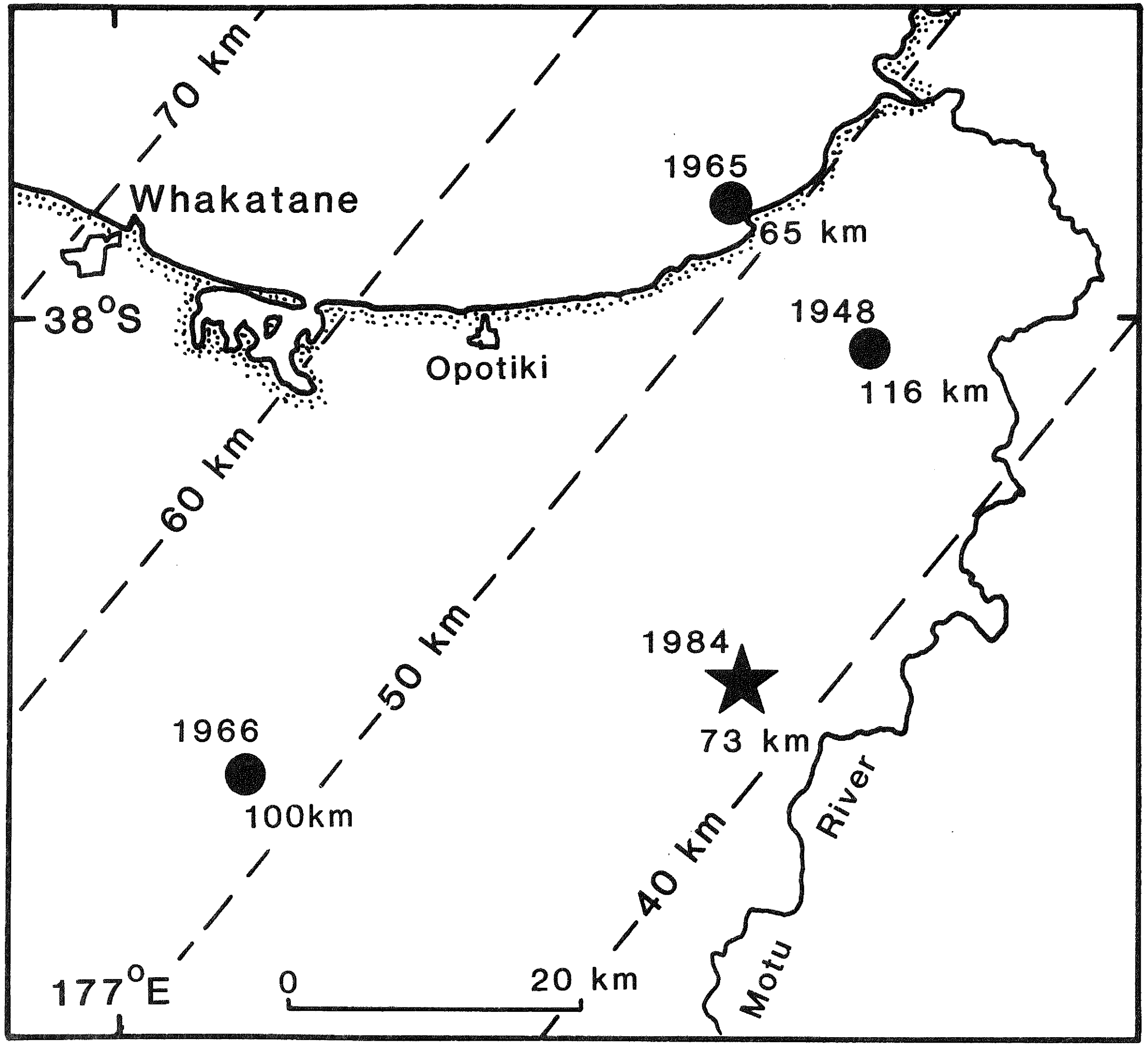

70 km
Whakatane
38°S
60 km
Opotiki
1965
65 km
1948
116 km
50 km
1984
73 km
1966
100km
40 km
Motu River
177°E
0
20 km

Figure 1

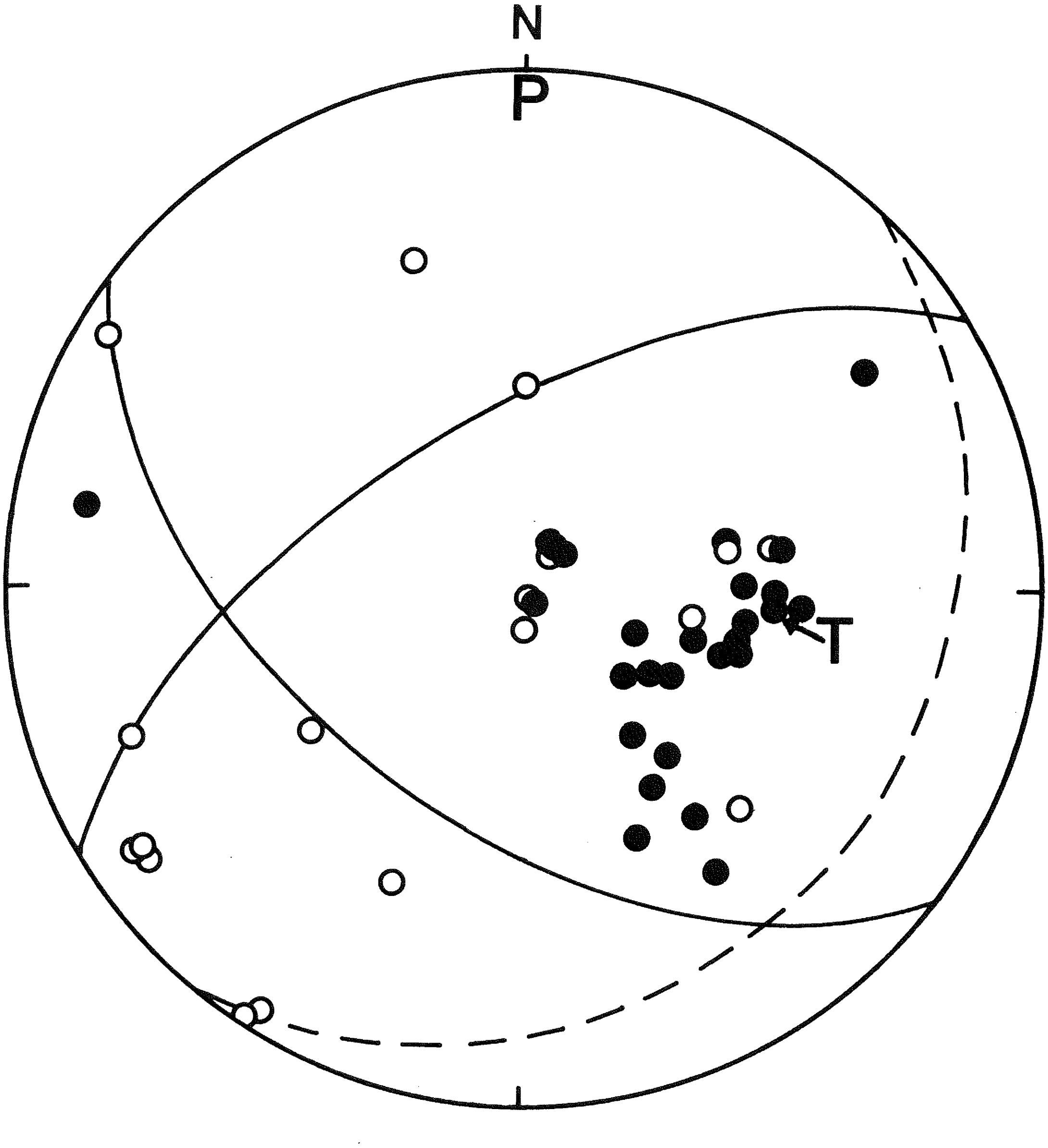


Figure 2

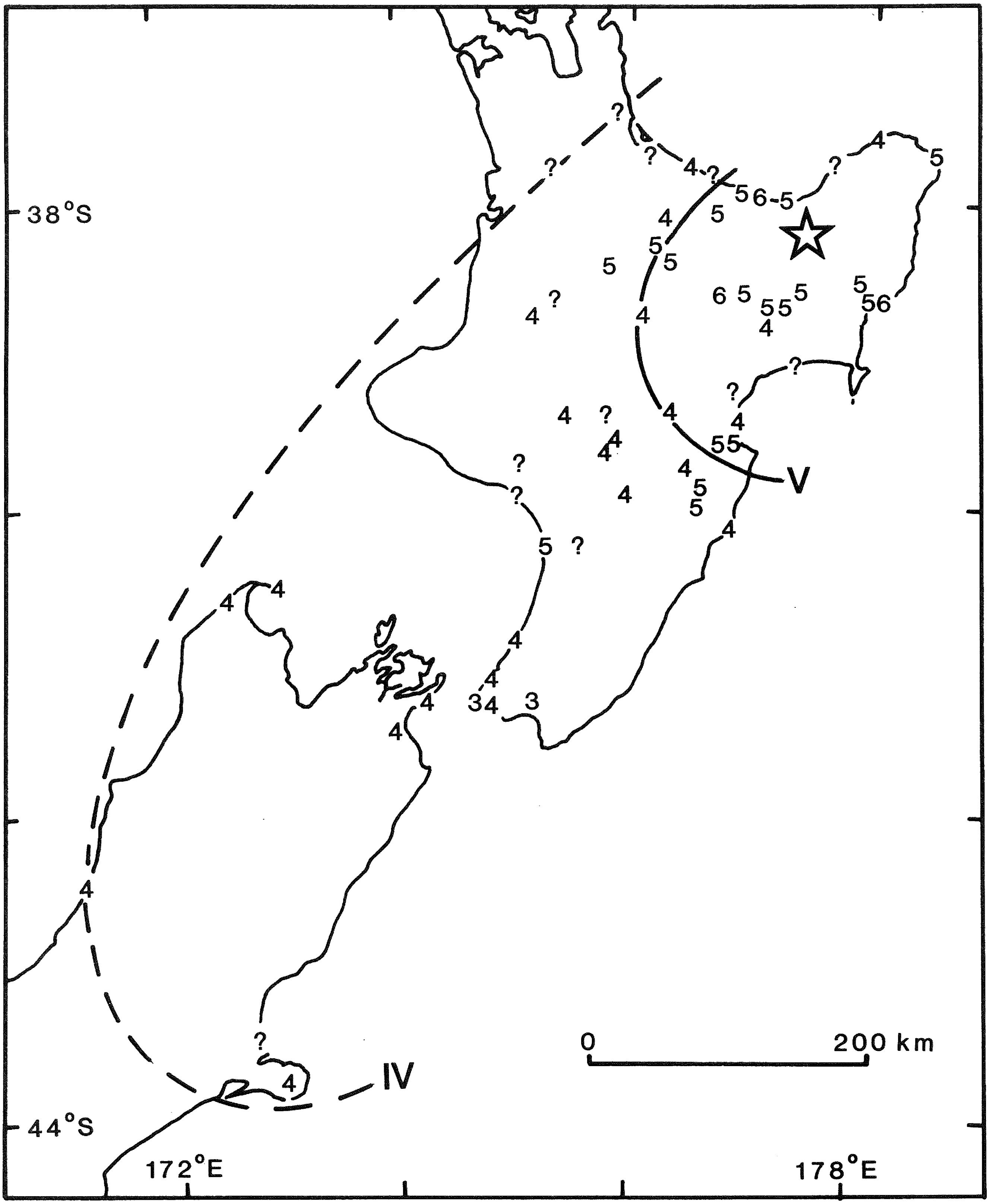


Figure 3

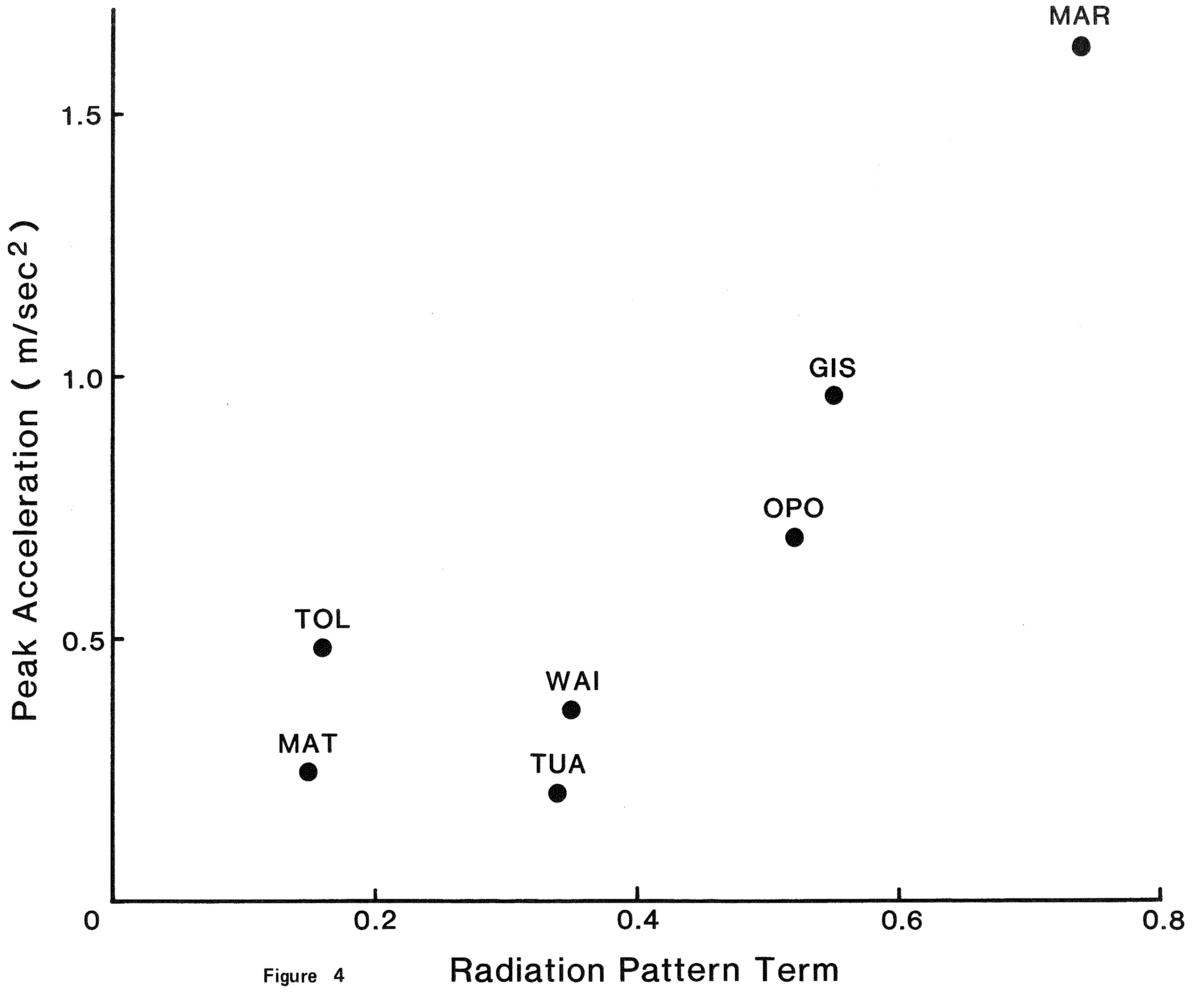
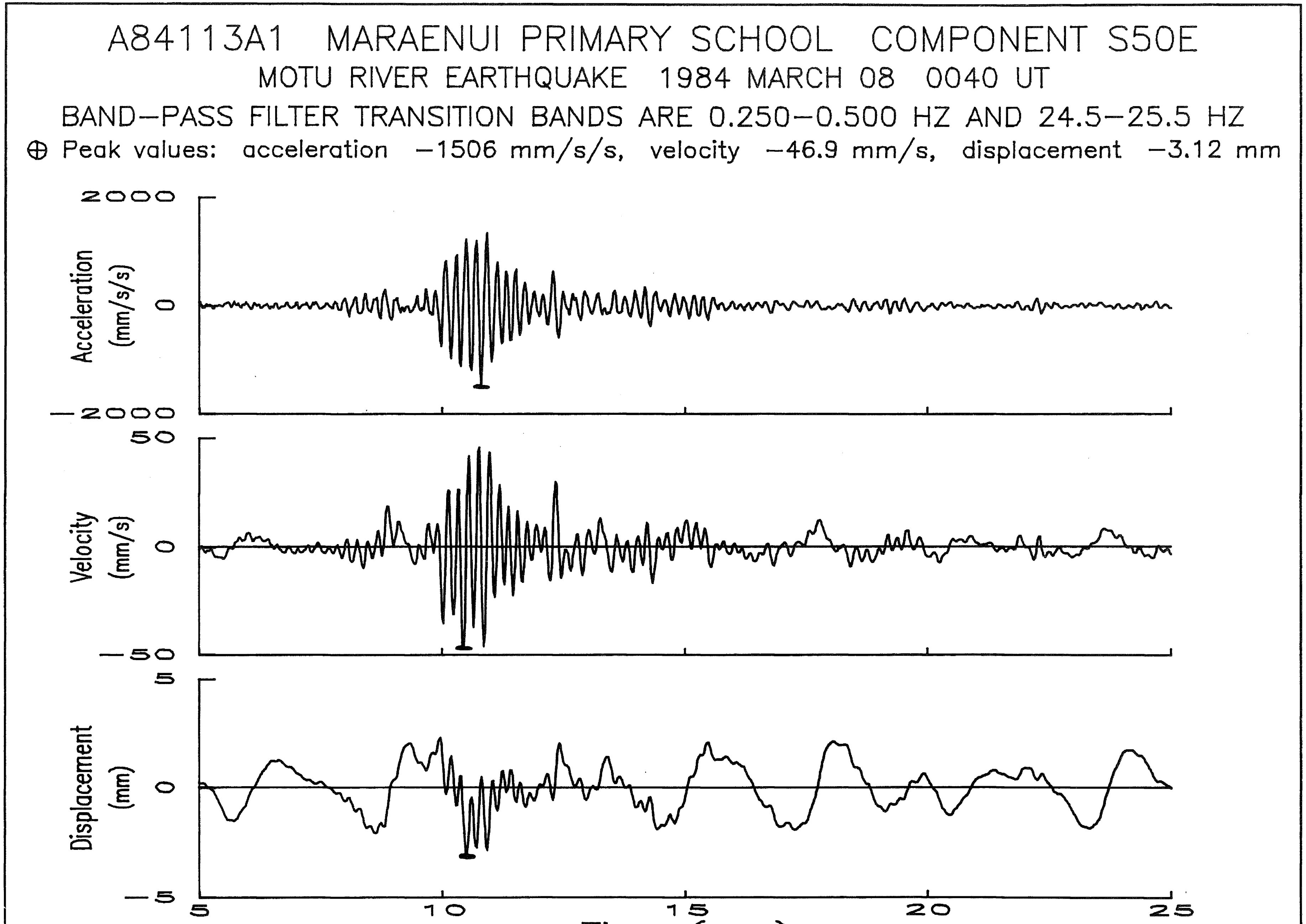

MAR
GIS
OPO
TOL
WAI
MAT
TUA
1.5
1.0
0.5
0
0.2
0.4
0.6
0.8
Peak Acceleration (m/sec2)
Radiation Pattern Term

Figure 4



A84113A1 MARAENUI PRIMARY SCHOOL COMPONENT S50E
MOTU RIVER EARTHQUAKE 1984 MARCH 08 0040 UT
BAND–PASS FILTER TRANSITION BANDS ARE 0.250–0.500 HZ AND 24.5–25.5 HZ
⊕ Peak values: acceleration –1506 mm/s/s, velocity –46.9 mm/s, displacement –3.12 mm
2000
0
–2000
Acceleration (mm/s/s)
50
0
–50
Velocity (mm/s)
5
0
–5
Displacement (mm)
5
10
15
20
25
Time (sec)

Figure 5(a)

A84113A1 MARAENUI PRIMARY SCHOOL COMPONENT N40E

MOTU RIVER EARTHQUAKE 1984 MARCH 08 0040 UT

BAND-PASS FILTER TRANSITION BANDS ARE 0.250-0.500 HZ AND 24.5-25.5 HZ

⊕ Peak values: acceleration 1079 mm/s/s, velocity -41.8 mm/s, displacement 2.31 mm

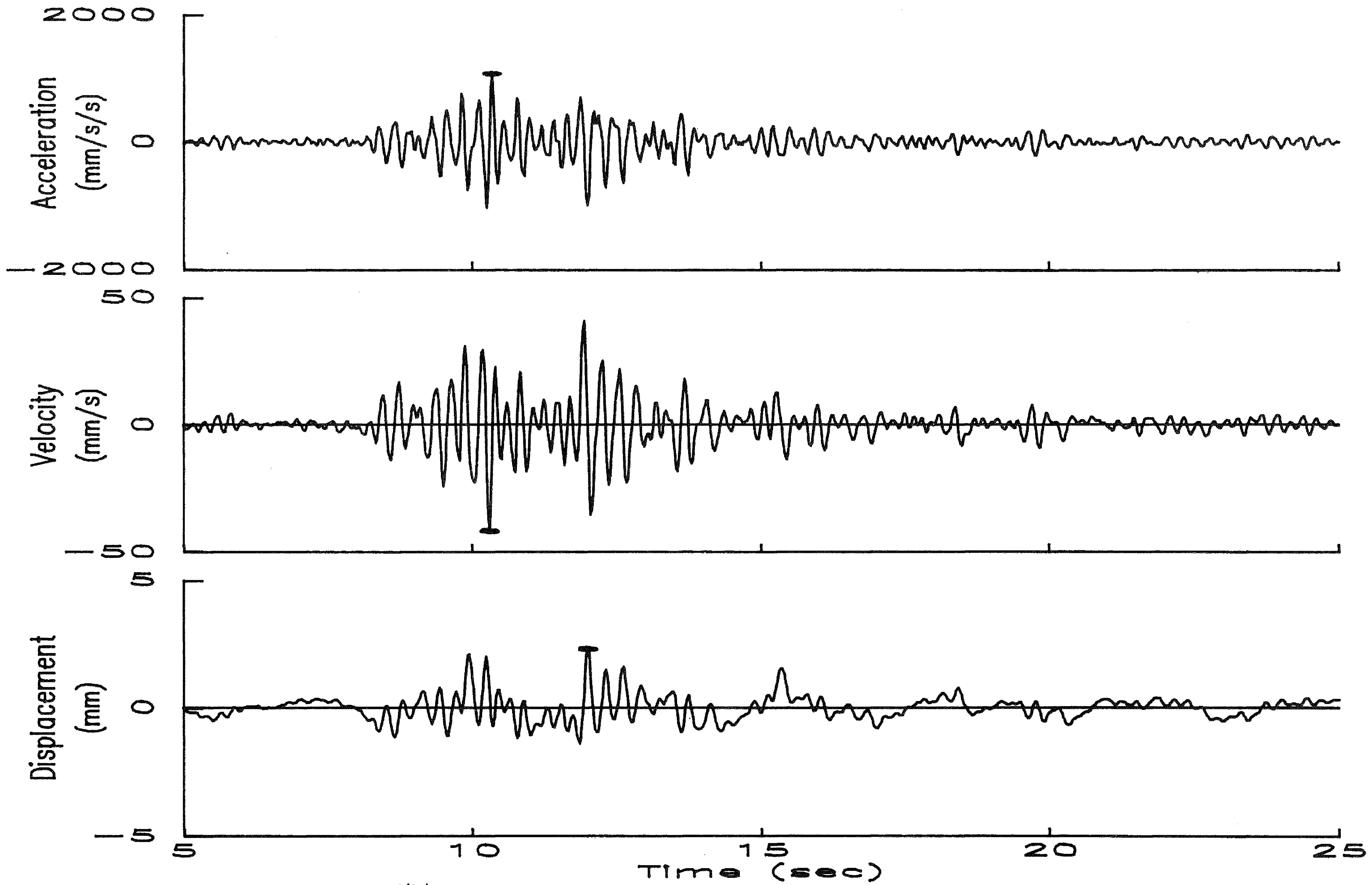
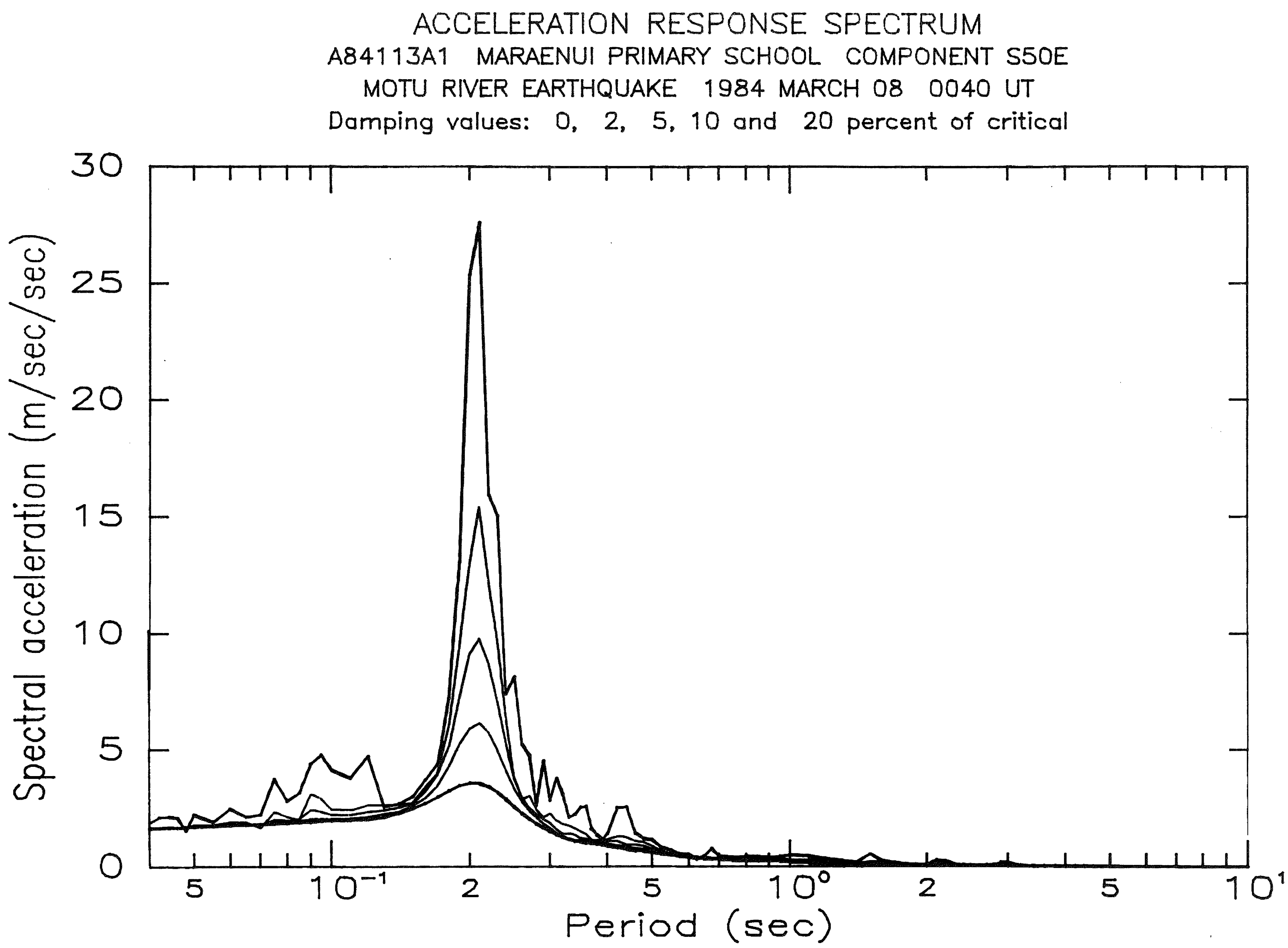


Figure 5(b)



ACCELERATION RESPONSE SPECTRUM
A84113A1 MARAENUI PRIMARY SCHOOL COMPONENT S50E
MOTU RIVER EARTHQUAKE 1984 MARCH 08 0040 UT
Damping values: 0, 2, 5, 10 and 20 percent of critical
Spectral acceleration (m/sec/sec)
30
25
20
15
10
5
0
5
10^{-1}
2
5
10^{0}
2
5
10^{1}
Period (sec)

Figure 6

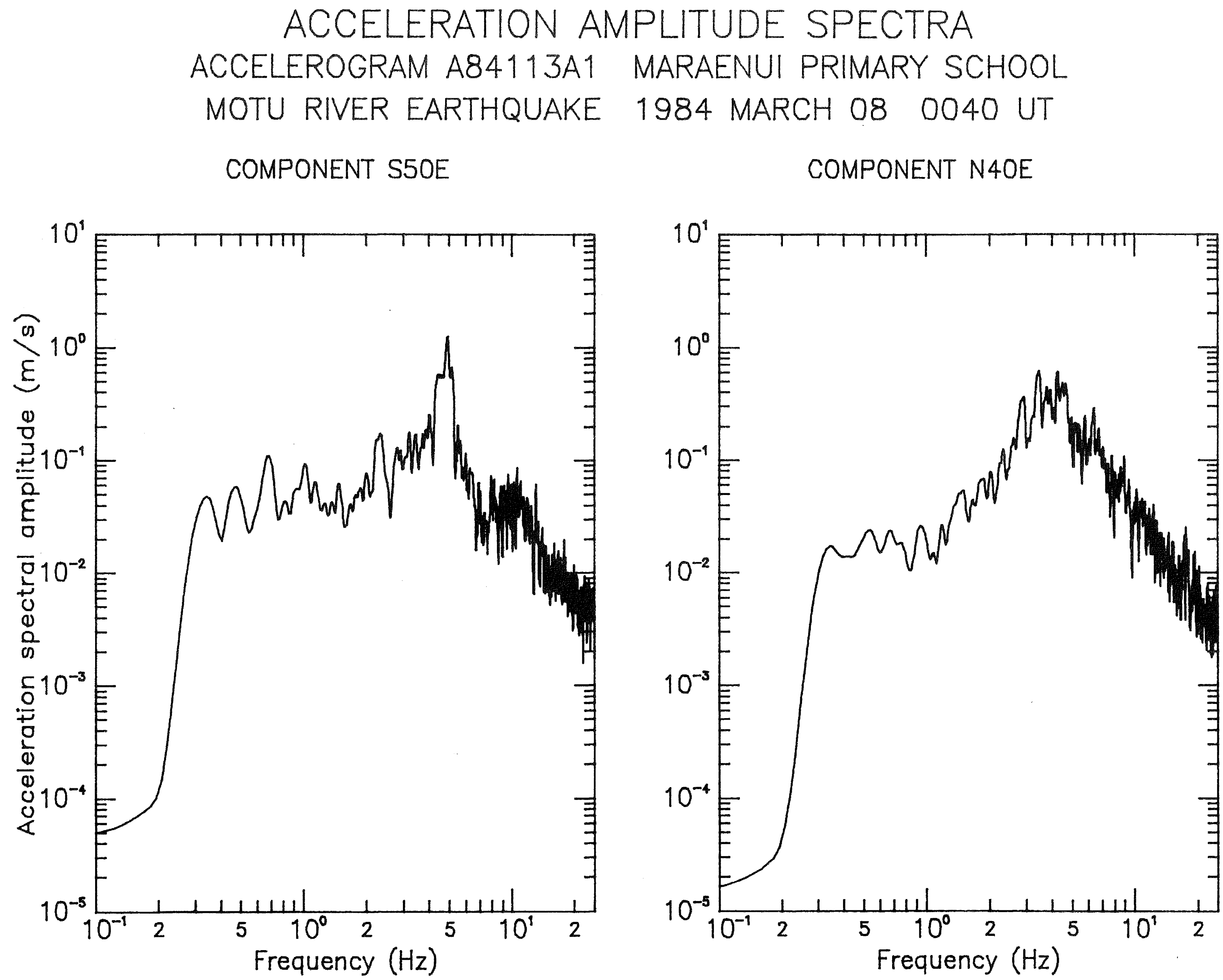

ACCELERATION AMPLITUDE SPECTRA
ACCELEROGRAM A84113A1 MARAENUI PRIMARY SCHOOL
MOTU RIVER EARTHQUAKE 1984 MARCH 08 0040 UT
COMPONENT S50E
COMPONENT N40E
Acceleration spectral amplitude (m/s)
Frequency (Hz)
Frequency (Hz)

Figure 7