STRONG MOTION ARRAYS IN INDIA AND ANALYSIS OF DATA FROM SHILLONG ARRAY

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ABSTRACT – *There are three Strong Motion Arrays in India, the first in the State of Himachal Pradesh, the second in the North-East (in the State of Assam and Meghalaya), and the third is now being installed in the Himalayan region of Uttar Pradesh. The North-East region is relatively more active seismically and four events recorded by the array resulted in 77 three component accelerograms during the period 1986–88. Significant results based on the analysis of those data are given in this paper.*

INTRODUCTION

Arising out of the recommendations of the 6th World Conference on Earthquake Engineering at New Delhi in 1977, an International Workshop on Strong Motion Measurements was held in Honolulu in 1978, which recommended that dense strong motion arrays be located in active seismic zones of the world in order to get useful information for disaster mitigation. The Department of Science and Technology (DST), Govt. of India, under a programme of Intensification of Research in High Priority Areas is funding three strong motion arrays–in the North-West (in the State of Himachal Pradesh), North-East (partly in the States of Assam and Meghalaya) and Central Himalayas (in the State of Uttar Pradesh)–under the umbrella of Himalayan Seismicity Project. The DST is also planning location of arrays in the Himalayas of Bihar-Nepal. The instrumentation for the strong motion array in Himachal Pradesh was fully funded by National Science Foundation, USA as a part of joint Indo-US collaboration and DST is now funding its maintenance.

As is to be expected, among these regions North-East India is seismically more active and since the installation of the array in 1985–86 five events have been recorded generating 91 three component accelerograms. Only one event was recorded in the Himachal Pradesh array which was recorded by nine stations. The Uttar Pradesh array is under installation and no events have taken place.

The four events recorded in North-East India are September 10, 1986 (Mb = 5·7–IMD), May 18, 1987 (Mb = 5·7–USGS), Feb. 6, 1988 (Mb = 5·8–USGS) and August 6, 1988 (Mb = 6·8–USGS) and January 1990 (Mb = 6·1–USGS). The first four events have been analysed and reports presented to DST and several research publications have been made in progress. Similarly the one event in Himachal Pradesh has also been processed.

This paper highlights the results of investigations concerning epicentral parameters, attenuation relationship, RMS acceleration, predominant frequency, and equivalent ground motion parameters for use with normalized shape of spectra.

Earthquake engineering studies have so far been mainly based on Californian data. The data obtained from the Himalayan Seismicity Project indicates the peculiarity of this region and these features are particularly brought out in this paper. It is expected that the data obtained would be ultimately reflected in the Code of Practices and would be useful for planning projects in the Himalayas.

KANGRA ARRAY – Array Planning and Seismotectonic Setup

For this array, fifty analog strong motion accelerographs (three component SMA-1 make of M S Kinemetrics, USA with provision for absolute time recording using

TCG-I) were made available for installation in the Kangra region, which was the seat of the great 1905 earthquake ($M = 8.4$). There are major multipurpose hydroelectric projects located in the area harnessing major river resources, namely, Ravi, Beas and Satluj. In view of the essentially thrust regime of the region, a two dimensional array was proposed and installed. Figure 1 shows location of array stations, tectonics and seismicity in the array region. The array trends NW to SE having a dimension of about 240 km. The width of the array varies from about 40 to 80 km. In total, an area of about 60 km × 240 km has been covered by this array. The stations are close to each other with interstation spacing of 7 to 21 km.

Most of the stations in this array are located in Lesser Himalayas, ranging in elevation from 470 m to 2700 m. There are numerous faults and thrusts, but among these, two are of prominence and can be traced all along the length of Himalayas. These features are essentially thrust sheets. The tectonic feature separating Tertiaries from Mesozoic is the Main Boundary Thrust (MBT) and Mesozoic from central crystallines is the Main Central Thrust (MCT). Local thrusts and faulting in the region are indicative of neotectonic activities.

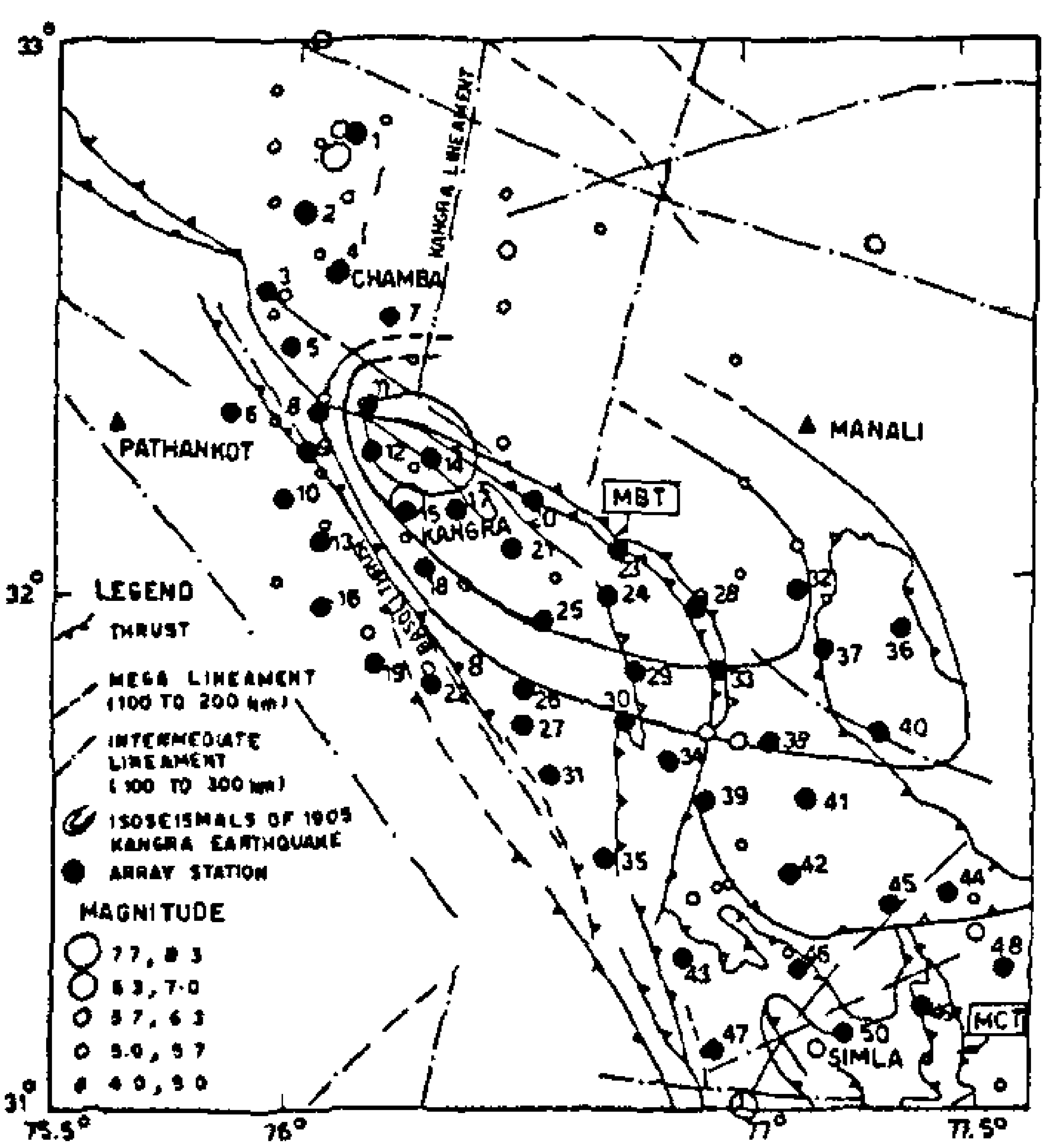


FIGURE 1 Array stations, Tectonic features and Seismicity in the region of Strong Motion Array in Himachal Pradesh (NW India). Compiled from GSI published maps.

SHILLONG ARRAY – Array Planning and Seismotectonic Setup

Northeastern region of India has undergone various stages of tectonic activities and present day seismicity is the testimony of the complex seismotectonic setup. It is desirable to instrument the whole of northeastern region in order to get sufficient earthquake data to have a proper understanding of earthquakes and their effects on structures.

With limited number of instruments available, fortyfive analog strong motion accelerographs have been installed in the region covering parts of Meghalaya and Assam states. A comb-shaped array comprising about 20 instruments has been designed along Dauki fault between latitudes 25° and 26°N with three projected legs. This comb-shaped array merges in the east with a two dimensional array of 25 instruments in the region of NE-SW trending Haflong thrust belt. They are housed mostly in single storeyed buildings of government or semi-government agencies. The interstation spacing in this array is between 20 to 30 km. It is somewhat large due to paucity of instruments and very difficult site conditions. The array has been extended slightly south of 25°N latitude as the region has produced some big earthquakes in the past.

Location of array stations, tectonic and seismicity of the region is shown in figure 2. In order to have a broad generalized picture of seismotectonic set up, some important tectonic features of the whole region are mentioned. Regionally, the northeast India can be classified into four major geotectonic units and these are Arunachal Himalayas, Lohit Himalayas, the Patkai-Naga-Lushai-Arakan-Yoma (Indo-Burma) hill ranges and Shillong plateau-Assam basin. Shillong massif and Mikir hills exposes the basement rocks and are surrounded by the Tertiary formations. The wedge shaped Shillong plateau is a horst which has been block-uplifted since Jurassic times[1]. Its tectonic history marked by the effusion of basalts through fractures and faults in the basement. The plateau had been subjected to a high degree of tectonism as evidenced by intricate folding and flowage in rocks.

Two prominent tectonic features forming the boundary of the Shillong plateau towards west and south are the Dhubri and Dauki faults respectively. The Dauki fault merges with the northeast trending Haflong-Disang thrust towards east. Earlier the Dauki fault was thought to be a strike slip tear fault[2], but the GSI[1] reports indicates it as a vertical normal fault. But recently Molnar[3] suggested thrust type mechanism along the Dauki fault. Hence, the status of Dauki fault is yet to be established.

The Northeast region has experienced some of the biggest earthquakes in the world. Earthquakes of

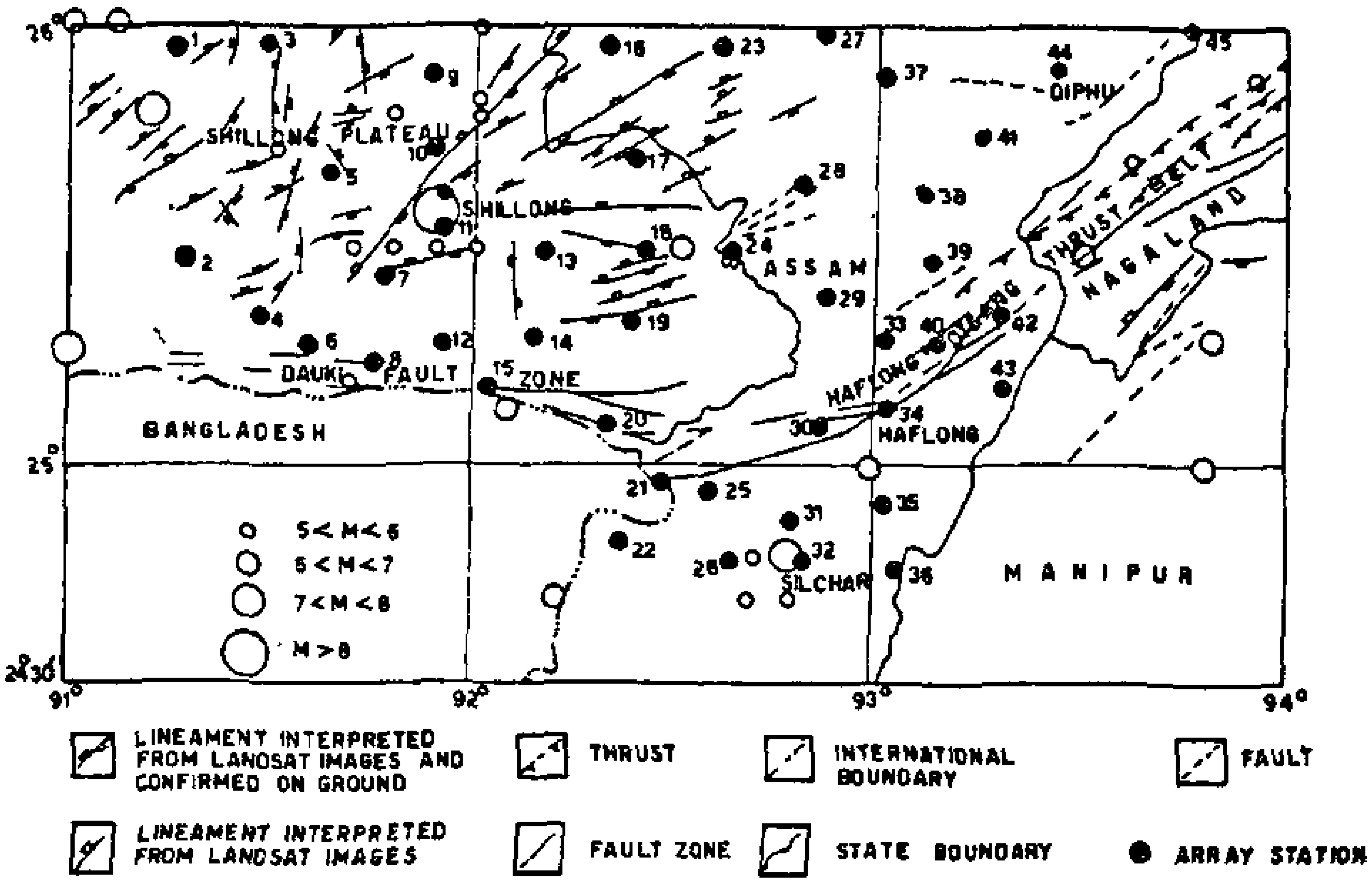


FIGURE 2 Map showing array locations, various tectonic features and seismicity in the Shillong Strong Motion Array region (NE India). Compiled from GSI published maps.

magnitude 8·7 have occurred in the Shillong area in 1897 and in the Mishmi region in 1950.

U.P. ARRAY–Array Planning and Seismotectonic Setup

Physiographically the Uttar Pradesh (U.P.) Himalayan region is represented by high hills and most of the northern part of this Himalayan region is above perpetual snow line and some peaks rises to more than 7500 m high. These areas are inaccessible and in most part of the year remains covered by snow. Himalayan ranges in U.P. represent a wide variety of tectonic features. Broadly the main tectonic features of this region is similar to that of Himachal Himalayas. In this mountainous region many moderate magnitude earthquakes have occured. A few earthquakes having a magnitude of $M > 7$ have occurred, but none of magnitude > 8 have been reported.

Funds for procuring forty analog instruments (SMA–1 make) and three digital (SSA–1 make) accelerographs were made available by DST. Some of the SMA–1's are equipped with Omega time control system which is more accurate and reliable as compared to TCG–1.

A two dimensional array has been proposed to instrument predominantly thrust regions. The tectonic features and the tentative location of stations are shown in figure 3. The array trends northwest to southeast covering a length of about 280 km and it follows the regional strike of the tectonic features and it merges with H.P. array towards NW. The width of the array in the direction transverse to the geological features is about 100 km. In total, an area of about (100 × 280) km has been covered by this array. The interstation spacing varies between 15 to 40 km. Most of the instruments are being installed in one storey buildings.

DESCRIPTION OF THE EVENTS

April 26, 1986 Earthquake in Himachal Pradesh

The magnitude reported by United States Geological Survey (USGS) is 5·5 and by India Meteorological Department (IMD) is 5·7. Figure 4a shows the location of postulated epicenters in which the maximum value of peak acceleration of horizontal components at the various stations are also shown. E1 is the estimate put out by IMD taking array data in addition to that from seismograph stations; E2 that of USGS; E3 from Array records. From acceleration pattern it appears E1 could be the likely epicenter.

Table 1 gives the peak values of acceleration, velocity and displacement at the various stations. The maximum duration of the record is 20 seconds and the maximum values of acceleration, velocity and displacement are 2432 mm/sec^2, 147·80 mm/sec, 24·79 mm in horizontal direction and 809 mm/sec^2, 28·04 mm/sec, 7·53 mm in vertical direction[4].

Figure 5a shows the mean shape of normalized spectra for 5% damping for the 18 horizontal components and 9 vertical components. For comparison, the normalized shape of spectra as recommended

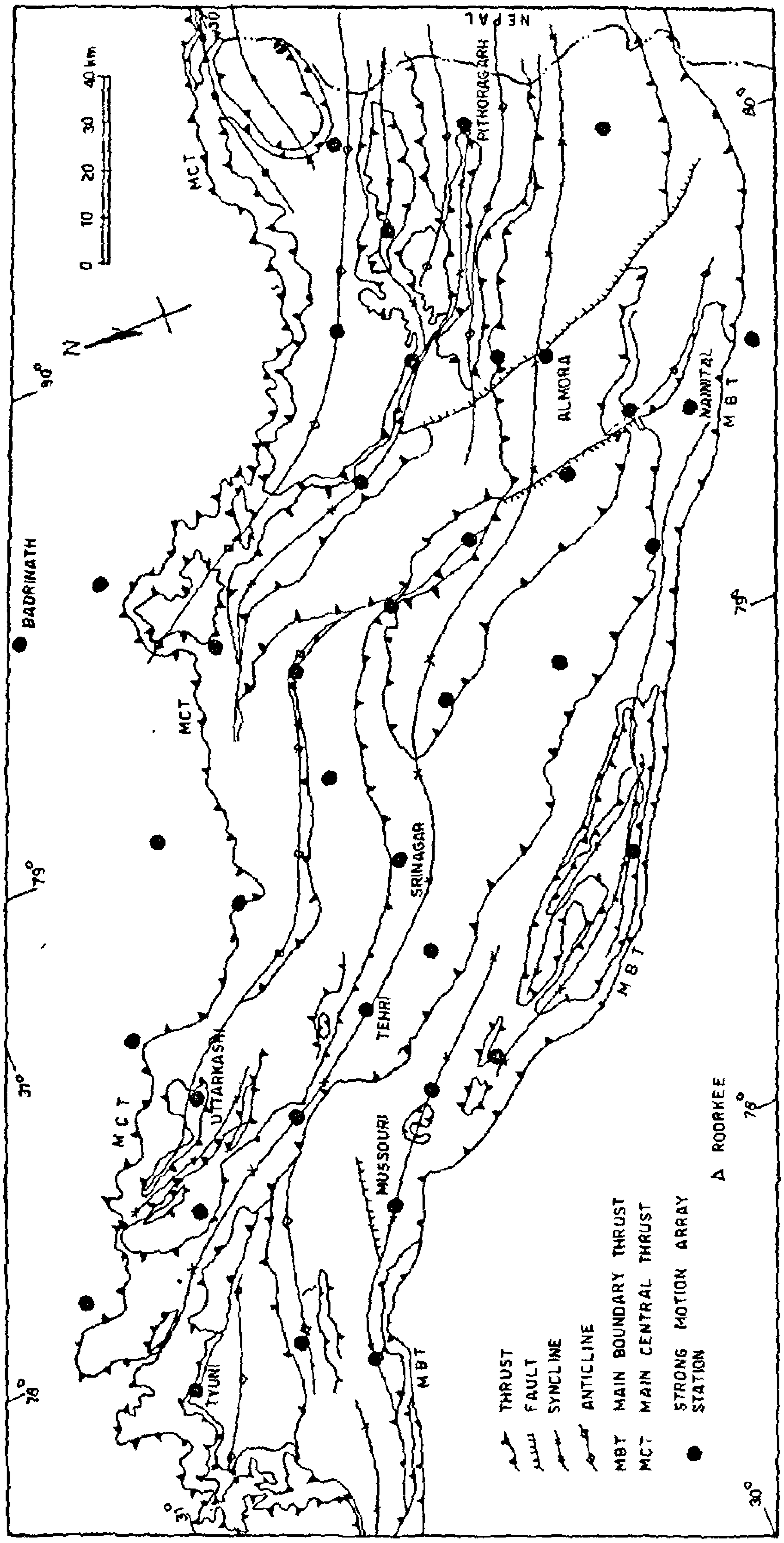


FIGURE 3 Tentative array station locations and tectonic features in Uttar Pradesh Himalayan region. Tectonic features compiled from published maps.

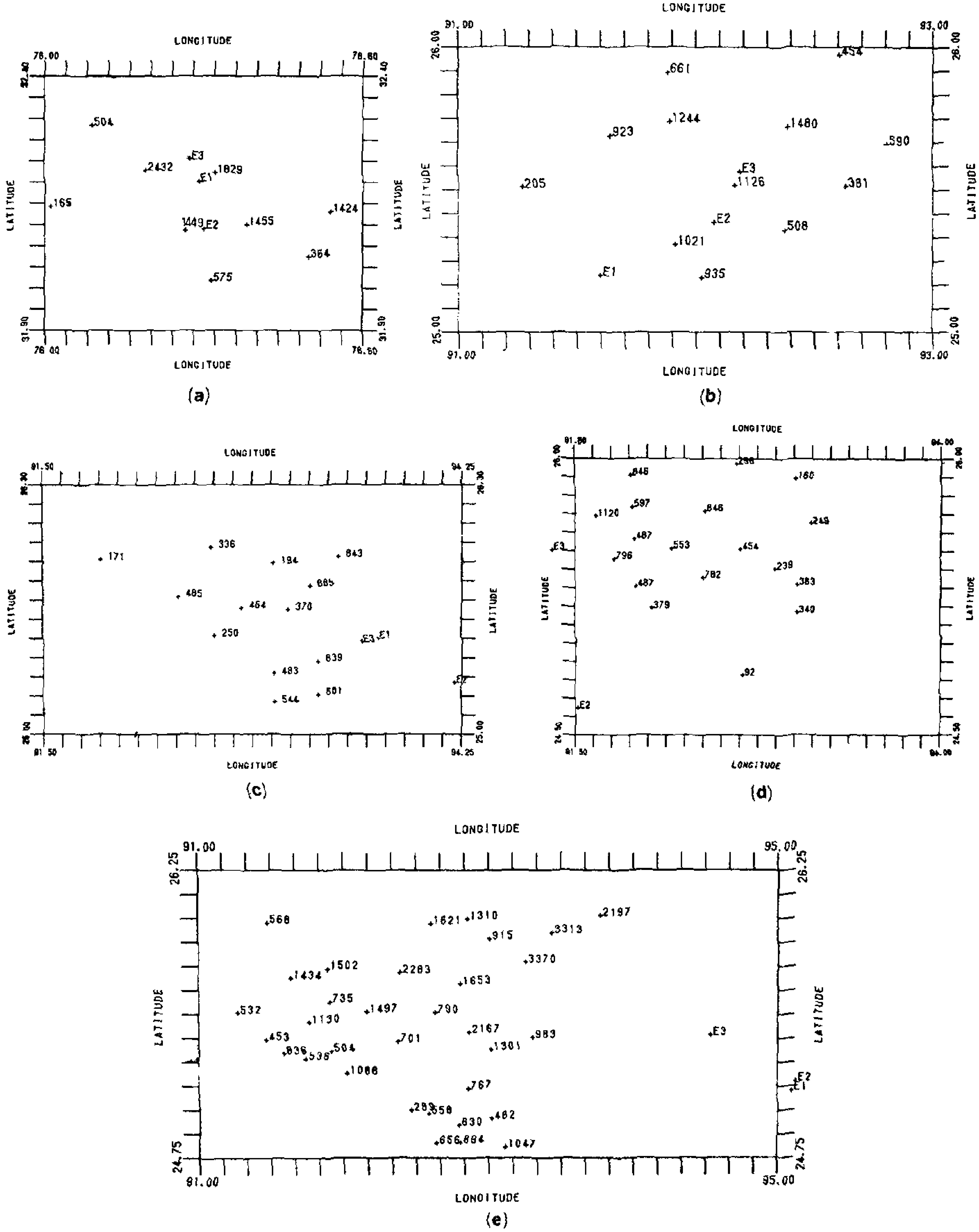


FIGURE 4 a to e Recorded maximum peak horizontal acceleration and postulated epicenters respectively for Earthquakes of April 26, 1986; September 10, 1986; May 18, 1987; February 6, 1988; August 6, 1988.

TABLE 1. Summary of Strong Motion Data.
Dharmsala Earthquake, April 26, 1986, Himachal Pradesh, India.

No.	Location	Component	Derived Maximum Peak Ground Acceleration in CM/SEC/SEC	Derived Maximum Peak Ground Velocity (MM/SEC)	Derived Maximum Peak Ground Displacement (MM)
1	2	3	4	5	6
1.	Bandlakhas	L-S 27 E	142.49	83.13	20.08
		V-VERT	22.07	15.63	6.33
		T-N 63 E	122.36	50.75	5.85
2.	Baroh	L-N 25 W	57.56	36.80	6.55
		V-VERT	22.31	15.07	3.64
		T-N 65 E	56.17	27.62	4.58
3.	Bhawarna	L-N 82 E	36.49	11.70	2.73
		V-VERT	35.36	9.34	21.13
		T-N 08 W	34.72	19.21	4.20
4.	Dharmsala	L-N 76 W	172.21	72.97	7.76
		V-VERT	80.94	27.39	4.19
		T-N 14 E	182.89	94.90	24.79
5.	Jawali	L-S 86 W	14.87	19.20	4.90
		V-VERT	10.81	14.39	7.53
		T-N 04 W	16.55	15.18	9.56
6.	Kangra	L-N 43 W	144.97	50.57	5.23
		V-VERT	70.77	31.93	5.37
		T-N 47 E	109.43	95.75	9.62
7.	Nagrota-Bagwan	L-S 85 W	145.53	94.17	13.09
		V-VERT	49.73	18.19	6.51
		T-N 05 W	78.59	25.40	6.14
8.	Shahpur	L-N 75 E	200.17	59.21	7.26
		V-VERT	64.31	28.04	5.25
		T-N 15 W	243.20	147.80	10.85
9.	Sihunta	L-N 25 W	50.41	26.72	4.71
		V-VERT	38.25	27.73	4.74
		T-N 65 E	35.32	33.88	3.67

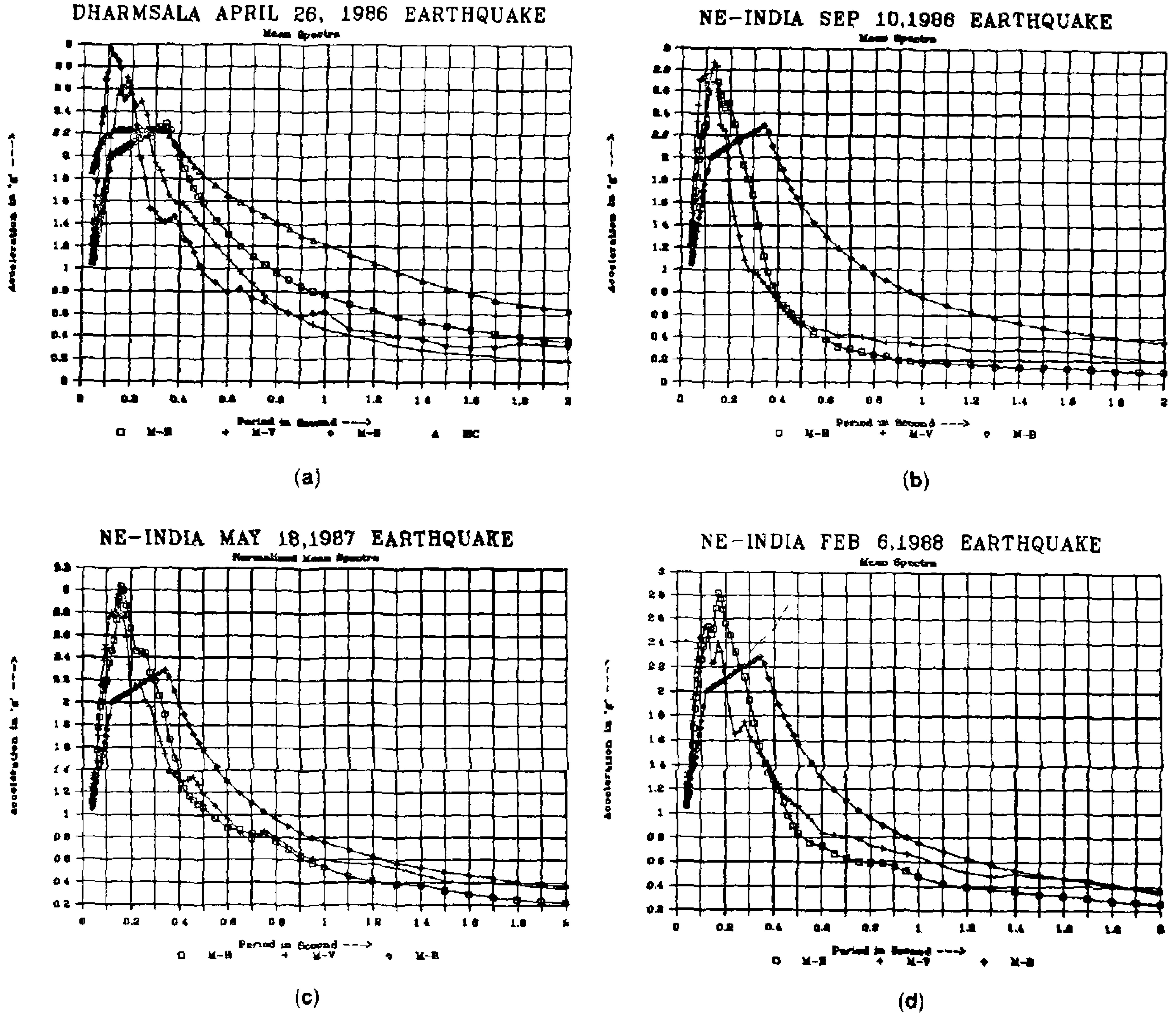
by USNRC[5] (United States Nuclear Regulatory Commission) as well as that given in Indian Standards IS:1893[6] are also shown. In the figure, the notation M–H indicates mean of horizontal components, M–V that of vertical components, M–B that of USNRC Spectra and ISC that of IS Code. It can be seen that in the short period range from 0·04 to 0·25 sec, the values are larger than USNRC and at long periods, the values are considerably lower. The vertical component is smaller than horizontal component at periods greater than 0·9 sec.

September 10, 1986 Earthquake in Meghalaya

USGS assigned a magnitude of 5·2 for this earthquake and IMD a value of 5·7. Location of postulated epicenters and maximum value of peak horizontal accelerations at the various stations are shown in figure 4b. IMD estimate of epicenter for this earthquake is shown as E1; E2 that of USGS; E3 from Array records. From acceleration pattern it appears that E3 could be the likely epicenter.

The derived values of peak acceleration, velocity and displacement at the various stations are given in table 2. The maximum duration of the record is 29 seconds and the maximum values of acceleration, velocity and displacement are 1359 mm/sec^2, 58·73 mm/sec, 9·32 mm in horizontal direction and 607 mm/sec^2, 20·06 mm/sec, 6·83 mm in vertical direction[7].

Figure 5b depicts the mean shape of normalized spectra for 5% damping for the 24 horizontal components and 12 vertical components. The shape of spectra as recommended by USNRC are also shown. It can be seen that in the short period range from 0·04 to 0·24, the values are larger than USNRC and at long



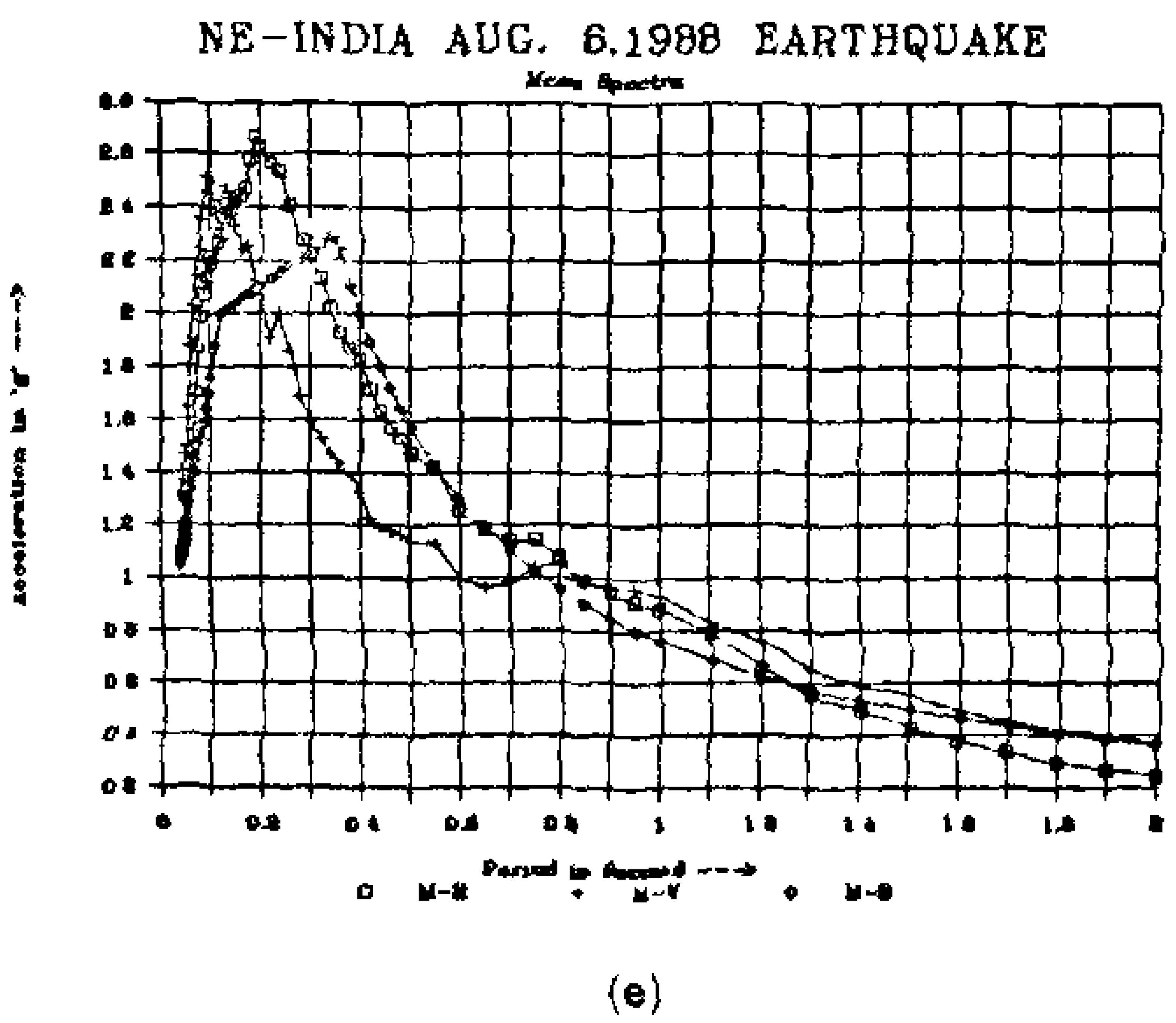


Figure 5 a to e. Mean spectra of horizontal and vertical components and comparison with the USNRC spectra. Abbreviations, M–H: Mean–Horizontal; M–V: Mean–Vertical; M–B: Mean–USNRC.

Table 2. Summary of Strong Motion Data.
NE–India Earthquake Sept. 10, 1986.

No.	Location	Component		Derived Maximum Peak Ground Acceleration in CM/SEC/SEC	Derived Maximum Peak Ground Velocity (MM/SEC)	Derived Maximum Peak Ground Displacement (MM)
1	2	3		4	5	6
1.	Baithalangso	L–S 02	W	44.51	20.58	3.55
		V–VERT		24.58	10.91	4.74
		T–N 88	W	41.25	12.07	2.73
2.	Dauki	L–S 72	E	87.61	32.40	3.00
		V–VERT		31.20	14.14	5.92
		T–S 08	W	88.65	37.33	2.56
3.	Khliehriat	L–S 45	E	30.30	11.30	2.00
		V–Vert		1.45	7.71	1.95
		T–S 45	W	45.01	18.41	3.86
4.	Nongkhlaw	L–N 80	E	53.87	33.09	9.32
		V–VERT		33.55	14.11	6.83
		T–S 10	E	90.96	48.08	5.47
5.	Nongpoh	L–N 40	E	52.87	21.13	4.26
		V–VERT		32.86	11.25	2.64
		T–S 50	E	54.53	11.32	4.59
6.	Nongstoin	L–N 65	E	19.01	10.04	4.90
		V–VERT		8.07	5.95	1.99
		T–S 25	E	13.59	6.48	1.66
7.	Panimur	L–N 65	E	38.35	9.37	2.02
		V–VERT		22.80	5.61	1.40
		T–S 25	E	47.71	21.15	2.65
8.	Pynursla	L–N 59	E	90.95	26.75	3.24
		V–VERT		29.68	9.28	3.80
		T–S 31	E	74.22	20.37	4.55
9.	Saitsama	L–N 85	E	110.87	36.69	4.90
		V–VERT		60.72	20.06	3.22
		T–S 05	E	135.86	58.73	4.92
10.	Ummulong	L–N 87	E	111.42	26.53	2.38
		V–VERT		47.91	14.25	3.21
		T–S 03	E	62.27	12.10	1.56
11.	Umrongso	L–S 27	W	26.73	9.68	1.30
		V–VERT		13.86	7.81	2.26
		T–N 63	W	31.36	11.84	4.41
12.	Umsning	L–N 45	E	99.49	28.72	3.42
		V–VERT		47.82	10.88	3.75
		T–S 45	E	74.89	25.67	3.93

periods, the values are considerably lower. The vertical component is larger than horizontal component beyond period range of 0·5 sec.

May 18, 1987 Earthquake in N.E. India

Magnitude of this earthquake of May 18, 1987 is 5·7 as reported by USGS. The maximum value of peak acceleration of horizontal components at the various stations, which recorded this earthquake and location of postulated epicenter is shown in figure 4c. IMD gave E1 as the epicenter estimated using data from seismological observatories; E2 that of USGS; E3 from Array records.

Table 3 gives the peak values of acceleration, velocity and displacement at the various stations. The maximum duration of the record is 42 seconds and the maximum values of acceleration, velocity and displacement are 843·3 mm/sec^2, 38·07 mm/sec, 11·54 mm in horizontal

TABLE 3. Summary of Strong Motion Data.
NE–India Earthquake May 18, 1987.

No.	Location	Component	Derived Maximum Peak Ground Acceleration in CM/SEC/SEC	Derived Maximum Peak Ground Velocity (MM/SEC)	Derived Maximum Peak Ground Displacement (MM)
1	2	3	4	5	6
1.	Baithalangso	L–S 02 W	33.59	15.53	4.15
		V–VERT	19.12	12.85	3.80
		T–N 88 W	26.26	21.56	8.11
2.	Bamungao	L–N 19 W	19.42	12.22	4.24
		V–VERT	18.60	13.62	3.32
		T–S 71 W	19.37	22.00	6.78
3.	Berlongfer	L–S 76 W	70.56	35.95	5.51
		V–VERT	45.19	19.24	7.47
		T–N 14 W	88.46	36.20	8.95
4.	Bokajan	L–N 34 E	29.33	25.96	9.34
		V–VERT	19.43	13.20	5.25
		T–S 56 E	64.40	34.28	10.31
5.	Diphu	L–N 90 E	84.33	27.69	5.80
		V–VERT	53.00	15.31	6.65
		T–S 00 W	71.93	23.92	11.54
6.	Gunjung	L–N 15 E	41.39	23.04	5.55
		V–VERT	18.26	10.83	3.28
		T–S 75 E	48.40	28.56	5.51
7.	Haflong	L–N 10 W	54.42	36.93	8.35
		V–VERT	14.79	12.15	3.06
		T–S 80 W	34.87	20.61	5.38
8.	Hajadisa	L–S 20 W	76.95	38.07	7.50
		V–VERT	27.73	15.34	3.49
		T–N 70 W	83.86	28.07	5.00
9.	Hatikhali	L–N 40 E	30.49	14.55	5.55
		V–VERT	26.34	18.58	3.64
		T–S 50 E	37.04	17.71	3.48
10.	Laisong	L–S 45 E	41.49	32.35	7.84
		V–VERT	18.85	13.54	6.20
		T–S 45 W	60.07	23.69	9.42
11.	Nongpoh	L–N 40 E	17.08	13.12	4.88
		V–VERT	13.75	9.55	3.13
		T–S 50 E	16.90	12.58	5.93
12.	Panimur	L–N 65 E	39.14	18.00	4.10
		V–VERT	17.25	16.79	5.78
		T–S 25 E	46.43	18.11	2.99
13.	Saitsama	L–N 85 E	36.40	13.92	3.36
		V–VERT	18.53	9.29	4.00
		T–S 05 E	48.53	22.84	8.91
14.	Umrongso	L–S 27 W	20.01	13.79	2.76
		V–VERT	15.95	9.13	2.91
		T–N 63 W	25.02	14.50	5.69

direction and 53·00 mm/sec^2, 19·24 mm/sec, 7·47 mm in vertical direction[8].

Figure 5c shows the mean shape of normalized spectra for the 28 horizontal components and 14 vertical components. For comparison, the shape of spectra as recommended by USNRC are also shown. It can be seen that in the short period range from 0·04 to 0·30 sec, the values are larger than USNRC and at long

TABLE 4 Summary of Strong Motion Data.
NE-India Earthquake Feb. 6, 1988.

No.	Location	Component	Derived Maximum Peak Ground Acceleration in CM/SEC/SEC	Derived Maximum Peak Ground Velocity (MM/SEC)	Derived Maximum Peak Ground Displacement (MM)
1	2	3	4	5	6
1.	Baigao	L-S 28 W	21.43	14.14	3.90
		V-VERT	9.61	11.27	3.26
		T-N 62 W	23.94	20.64	6.90
2.	Baithalangso	L-S 02 W	29.59	13.65	3.81
		V-VERT	13.70	7.44	1.76
		T-N 88 W	21.78	12.26	3.33
3.	Bamungao	L-N 19 W	16.04	5.08	1.30
		V-VERT	9.84	6.23	2.33
		T-S 17 W	13.05	10.35	2.30
4.	Dauki	L-S 72 E	25.99	18.01	2.50
		V-VERT	10.20	8.57	3.41
		T-S 08 W	37.93	18.37	4.41
5.	Gunjung	L-N 15 E	35.70	29.05	6.26
		V-VERT	19.14	12.87	3.30
		T-S 75 E	36.25	24.44	3.87
6.	Haflong	L-N 10 W	33.97	19.42	3.13
		V-VERT	7.88	7.22	1.99
		T-S 80 W	26.82	14.02	3.34
7.	Hatikhali	L-N 40 E	23.18	8.78	3.18
		V-VERT	20.95	7.29	1.98
		T-S 50 E	24.89	9.87	3.84
8.	Katakhal	L-S 89 E	9.20	10 64	3.04
		V-VERT	9.65	9.88	4.00
		T-S 01 W	8.34	7.75	1.60
9.	Khliehriat	L-S 45 E	78.19	47.46	8.45
		V-VERT	28.93	15.91	2.94
		T-S 45 W	64.86	27.87	3.44
10.	Mawphlang	L-S 35 W	79.61	43.85	7.97
		V-VERT	35.27	12.33	4.86
		T-N 55 W	57.68	24.89	10.14
11.	Nongkhlaw	L-N 80 E	105.44	42.94	9.50
		V-VERT	100.76	35.10	11.23
		T-S 10 E	112.09	52.63	11.41
12.	Nongpoh	L-N 40 E	26.90	15.89	4.64
		V-VERT	37.45	10.64	4.02
		T-S 50 E	84.62	26.45	3.75
13.	Pynursla	L-N 59 E	48.75	21.24	4.99
		V-VERT	15.00	9.43	3.63
		T-S 31 E	30.42	11.95	4 93
14.	Saitsama	L-N 85 E	64.58	22.38	4.50
		V-VERT	31.65	9.90	2.37
		T-S 05 E	57.06	32.43	4.37
15.	Shillong	L-N 40 E	46.72	16.06	5.16
		V-VERT	13.41	14.42	5.19
		T-S 50 E	35.13	15.39	7.86

TABLE 4 (continued)

1	2	3	4	5	6
16.	Ummulong	L-N 87 E	55.30	22.48	5.69
		V-VERT	23.74	10.89	4.37
		T-S 03 E	53.73	21.42	6.35
17.	Umrongso	L-S 27 W	45.44	31.43	3.06
		V-VERT	21.68	12.26	2.38
		T-N 63 W	36.11	26.58	6.67
18.	Umsning	L-N 45 E	39.01	16.62	3.14
		V-VERT	17.76	11.95	3.55
		T-S 45 E	59.74	36.73	5.03

periods, the values are lower. The vertical component shows almost the same trend as horizontal component and beyond 0·8 sec. period range it is larger than horizontal.

February 6, 1988 Earthquake in N.E. India

The magnitude reported by USGS is 5·8. Figure 4d shows the location of postulated epicenters in which the maximum value of peak acceleration of horizontal components at the various stations are also shown. Estimate put out by USGS is E2 and E3 from array records. Epicenter estimated by IMD is not shown since, it lies far off.

Table 4 gives the peak values of acceleration, velocity and displacement at the various stations. The maximum duration of the record is 45 seconds and the maximum values of acceleration, velocity and displacement are 1121 mm/sec^2, 52·63 mm/sec, 11·41 mm in horizontal direction and 1008 mm/sec^2, 35·10 mm/sec, 11·23 mm in vertical direction[9].

Figure 5d shows the mean shape of normalized spectra for the 36 horizontal components and 18 vertical components. For comparison, the shape of spectra as recommended by USNRC are also shown. It can be seen that in the short period range from 0·04 to 0·25 sec, the values are larger than USNRC and at long periods, the values are lower. The vertical component shows the same trend as horizontal component, but beyond 0·45 sec period it is larger than horizontal component.

August 6, 1988 Earthquake in N.E. India

This earthquake of August 6, 1988 was very strong and a vast area had been shaken. The magnitude of this earthquake estimated by USGS is 6·8. Figure 4e shows the location of postulated epicenters and maximum peak acceleration of horizontal components at the various stations. IMD suggested the epicenter at E1; E2 that of USGS; E3 from Array records. The acceleration at various stations indicate a non-uniform distribution. It seems, that some of these high accelerations may be due to local geological effect. It needs adequate data supplementation from other local seismograph stations in India and Burma for a better location of epicenter. Moreover, radial effect on epicenter estimation could not be achieved due to data only from one side of the array.

The estimated peak values of acceleration, velocity and displacement at the various stations are given in table 5. The maximum duration of the record is 120 seconds and the maximum values of acceleration, velocity and displacement are 3371 mm/sec^2, 228·19 mm/sec, 36·30 mm in horizontal direction and 1765 mm/sec^2, 90·26 mm/sec, 13·18 mm in vertical direction[10].

Mean shape of normalized mean spectra for the 66 horizontal components and 33 vertical components are depicted in figure 5e. The shape of spectra as recommended by USNRC are also shown. It can be seen that the values are larger than USNRC in 0·04 to 0·3 sec period range. The values for vertical component in case of Mean Spectra becomes larger than that of USNRC beyond period 0·75 sec., but horizontal component first shows larger value than USNRC in 0·6 to 1·25 sec range and then becomes smaller.

ATTENUATION RELATIONSHIP

Several empirical relationship have been proposed to predict peak ground acceleration. These are mainly based on Californian data[11]. Among them, the one proposed by McGuire is popularly used in design. A comparison of McGuire's attenuation relationship for the four events is shown in figure 6a to f. It is seen that McGuire's prediction does not fit the recorded data for all events. From among proposed relationship, those which lie reasonably in the range are (a) April 26, 1986–McGuire; (b) Sept 10, 1986–Hasegawa; (c) May 18, 1987–Hasegawa; (d) Feb. 8, 1988-Hasegawa; (e) Aug. 8, 1988–Battis.

TABLE 5 *Summary of Strong Motion Data.*
NE–India Earthquake Aug. 6, 1988.

No.	Location	Component	Derived Maximum Peak *Ground Acceleration in* CM/SEC/SEC	Derived Maximum Peak *Ground Velocity* (MM/SEC)	Derived Maximum Peak *Ground Displacement* (MM)
1	2	3	4	5	6
1.	Baigao	L–S 28 W	216.82	65.68	10 19
		V–VERT	51.90	20.11	5.85
		T–N 62 W	141.41	63.70	9.80
2.	Baithalangso	L–S 02 W	150.99	75.52	12.36
		V–VERT	80.40	36.12	6.98
		T–N 88 W	162.06	117.05	15.45
3.	Bamungao	L–N 19 W	91.50	64.03	8.96
		V–VERT	64.29	25.06	4.23
		T–S 71 W	68.59	49.80	10.23
4.	Berlongfer	L–S 76 W	295.11	217.24	33.40
		V–VERT	170.58	90.26	13.18
		T–N 14 W	337.07	228.19	36.30
5.	Bokajan	L–N 34 E	147.80	86.75	19.91
		V–VERT	145.00	32.49	9.14
		T–N 56 E	219.78	121.36	20.41
6.	Cherrapunji	L–S 55 E	51.06	21.47	3.57
		V–VERT	23.04	20.45	3.81
		T–S 35 W	53.65	26.78	6.22
7.	Dauki	L–S 72 E	106.60	46.87	7.56
		V–VERT	29.88	20.74	6.52
		T–S 08 W	71.70	44.53	5.78
8.	Diphu	L–N 90 E	277.25	181.48	23.25
		V–VERT	176.47	56.12	9.00
		T–S 00 E	331.37	205.55	22.74
9.	Doloo	L–S 41 E	63.05	58.89	14.40
		V–VERT	37.94	33.83	7.63
		T–S 49 W	60.99	53.49	12.61
10.	Gunjung	L–N 15 E	91.88	44.19	8.74
		V–VERT	60.98	25.56	6.74
		T–S 75 E	130.21	52.05	8.58
11.	Hajadisa	L–S 20 W	90.17	42.73	9.72
		V–VERT	45.27	22.28	5.98
		T–N 70 W	96.27	46.43	8.77
12.	Harengajao	L–S 60 E	63.89	40.99	7.57
		V–VERT	31.47	22.15	6.31
		T–S 30 W	76.68	44.39	8.92
13.	Hojai	L–S 82 W	105.68	51.88	14.06
		V–VERT	59.71	25.25	7.83
		T–N 08 W	131.05	65.61	11.61
14.	Jellalpur	L–N 88 W	28.91	30.40	4.81
		V–VERT	15.33	17.07	4.01
		T–S 02 W	22.66	20.46	5.18
15.	Jhirighat	L-N 47 W	95.71	88.30	11.15
		V–VERT	30.26	30.38	8.21
		T–S 43 W	87.47	70.35	10.05
16.	Kalain	L–S 64 E	55.80	77.76	15.87
		V–VERT	28.12	43.21	10.89
		T–S 26 W	50.25	51.09	15.71

TABLE 5 (continued)

1	2	3	4	5	6
17.	Katakhal	L-S 89 E	65.55	110.74	23.34
		V-VERT	17.60	33.72	10.11
		T-S 01 W	58.28	93.56	25.26
18.	Khliehriat	L-S 45 E	68.78	29.21	4.55
		V-VERT	33.83	16.11	3.44
		T-S 45 W	70.10	31.74	5.42
19.	Koomber	L-S 72 E	48.24	39.04	9.86
		V-VERT	26.30	23.23	5.57
		T-S 18 W	36.02	34.88	7.14
20.	Loharghat	L-N 54 E	56.78	36.58	8.58
		V-VERT	21.78	20.42	5.06
		T-S 36 E	53.42	48.61	9.91
21.	Mawkyrwat	L-N 20 E	45.12	25.18	3.10
		V-VERT	31.57	17.51	4.69
		T-S 70 E	45.33	21.98	4.80
22.	Mawphlang	L-S 35 W	113.14	39.17	6.78
		V-VERT	35.47	12.52	3.85
		T-N 55 W	104.75	38.99	5.34
23.	Mawsynram	L-S 58 W	83.63	33.67	8.29
		V-VERT	35.17	21.45	5.89
		T-N 32 W	63.30	28.61	5.47
24.	Nongkhlaw	L-N 80 E	135.35	64.50	6.02
		V-VERT	81.62	34.17	9.46
		T-S 10 E	143.47	55.66	11.07
25.	Nongstoin	L-N 65 E	53.23	24.09	9.54
		V-VERT	40.84	14.80	6.14
		T-S 25 E	50.67	31.04	11.16
26.	Panimur	L-N 65 E	165.44	55.19	5.29
		V-VERT	71.62	20.85	6.14
		T-S 25 E	122.41	44.38	6.06
27.	Pynursla	L-N 59 E	48.41	42.13	5.92
		V-VERT	35.31	31.55	6.35
		T-S 31 E	50.37	32.24	7.22
28.	Saitsama	L-N 85 E	207.04	87.31	7.83
		V-VERT	96.73	33.77	4.82
		T-S 05 E	228.28	103.63	13.89
29.	Shillong	L-N 40 E	73.50	20.44	3.24
		V-VERT	35.12	9.75	3.31
		T-S 50 E	56.16	17.55	5.86
30.	Silchar	L-N 60 E	63.18	71.52	21.10
		V-VERT	24.76	29.98	8.62
		T-S 30 E	89.38	98.76	21.13
31.	Ummulong	L-N 87 E	98.14	30.76	7.86
		V-VERT	60.80	27.33	11.28
		T-S 03 E	149.76	43.95	12.80
32.	Umrongso	L-S 27 W	76.91	51.06	6.46
		V-VERT	43.67	17.48	4.46
		T-S 63 W	79.04	39.98	7.76
33.	Umsning	L-N 45 E	133.27	41.46	7.88
		V-VERT	69.78	38.31	12.50
		T-S 45 E	150.16	51.94	10.12

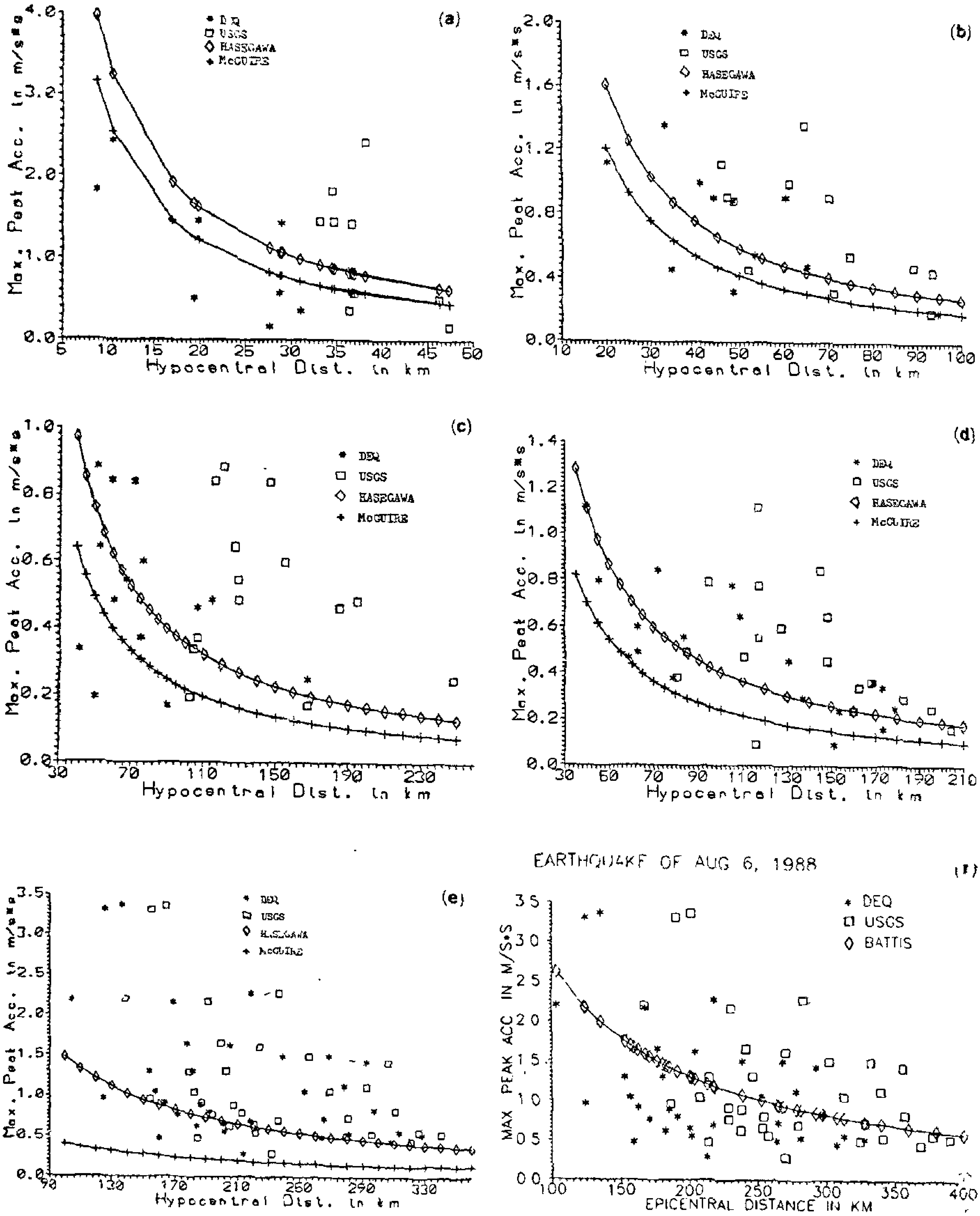


Figure 6 a to f. D^tribution of horizontal acceleration and comparison with McGuire's, Hasegawa's and Battis formula respectively for earthquake of April 26, 1986, September 10, 1986; Mav 18, 1987; February 8, 1988 and August 6, 1988 respectively.

RMS ACCELERATION

Many investigators have pointed out that the maximum peak acceleration is a poor indicator of elastic response spectrum values. The spectral acceleration is primarily influenced by the energy contained within a number of cycle of ground motion and is little influenced by a few spikes of very high acceleration[12].

One approach to define effective peak acceleration is in terms of the rate energy fed into structures. As shown in figure 7, $E(T'_D)$ can serve as a measure of the cumulative energy per unit mass fed into all single degree of freedom oscillator over strong motion duration T'_D. The average rate of energy input, P and root mean square (RMS) acceleration is given by

$$P=\frac{E(T'_D)}{T'_D};\ a_{\rm rms}=\sqrt{P}.$$

The distribution of RMS value for the four events are given in figure 8a and b. The mean value for this region from these four events would be 0.3.

FREQUENCY

One method that has been used is to obtain the number of zero crossings over some time window of the time history of acceleration record. This method is rather crude. A method of obtaining mean frequency has been proposed based on the zero and second moments (λ_0 and λ_2) of the power spectral density function $G(f)$ where $f_m=\sqrt{\lambda_2/\lambda_0}$ and $\lambda_i=\int f^i\,G(f)\,df$.

For the recorded data, Fourier spectra and Power spectral density have been worked out. From this

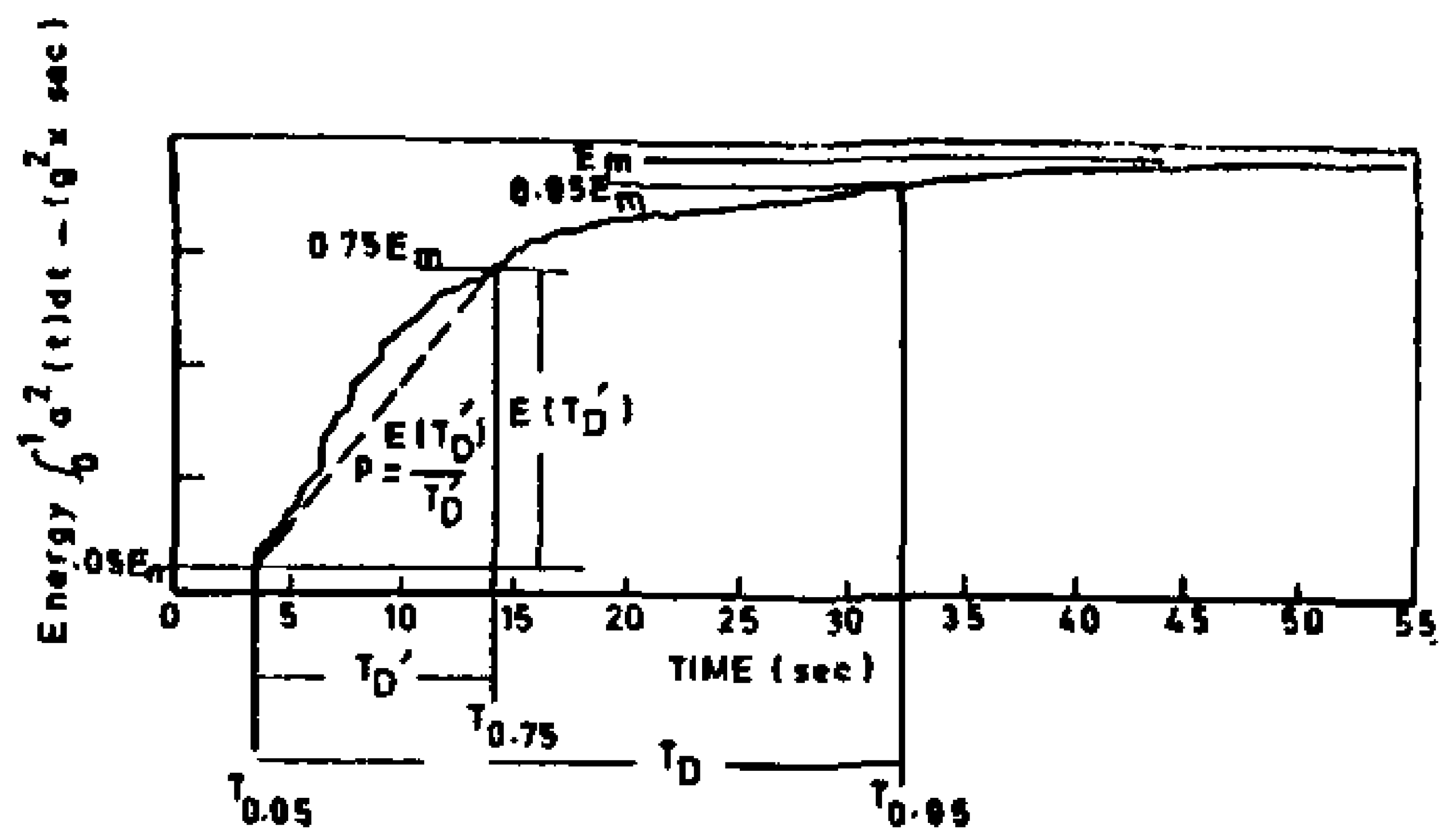


FIGURE 7 Typical variation of cumulative energy with time.

information, the mean frequency of each component of record is obtained and is given in figure 9a and b in the form of discrete plot. The mean and standard deviation of $a_{\rm rms}$ and f_m for the various events are given in table 6.

SHAPE OF SPECTRA FOR SOIL AND ROCK SITE

For engineering design, the shape of spectra is a very important parameter. It is influenced by type of local geological condition in the form of Soil or Rock. The data of 77 acceleration can be classified into 63 in soil sites and 14 in rock sites.

The most popularly used ground motion parameter is peak acceleration for obtaining design spectra as attenuation relations is usually expressed in terms of this parameter. It is now felt that other normalizing parameters can be advantageously used in design. In this paper, three other normalizations Root Mean

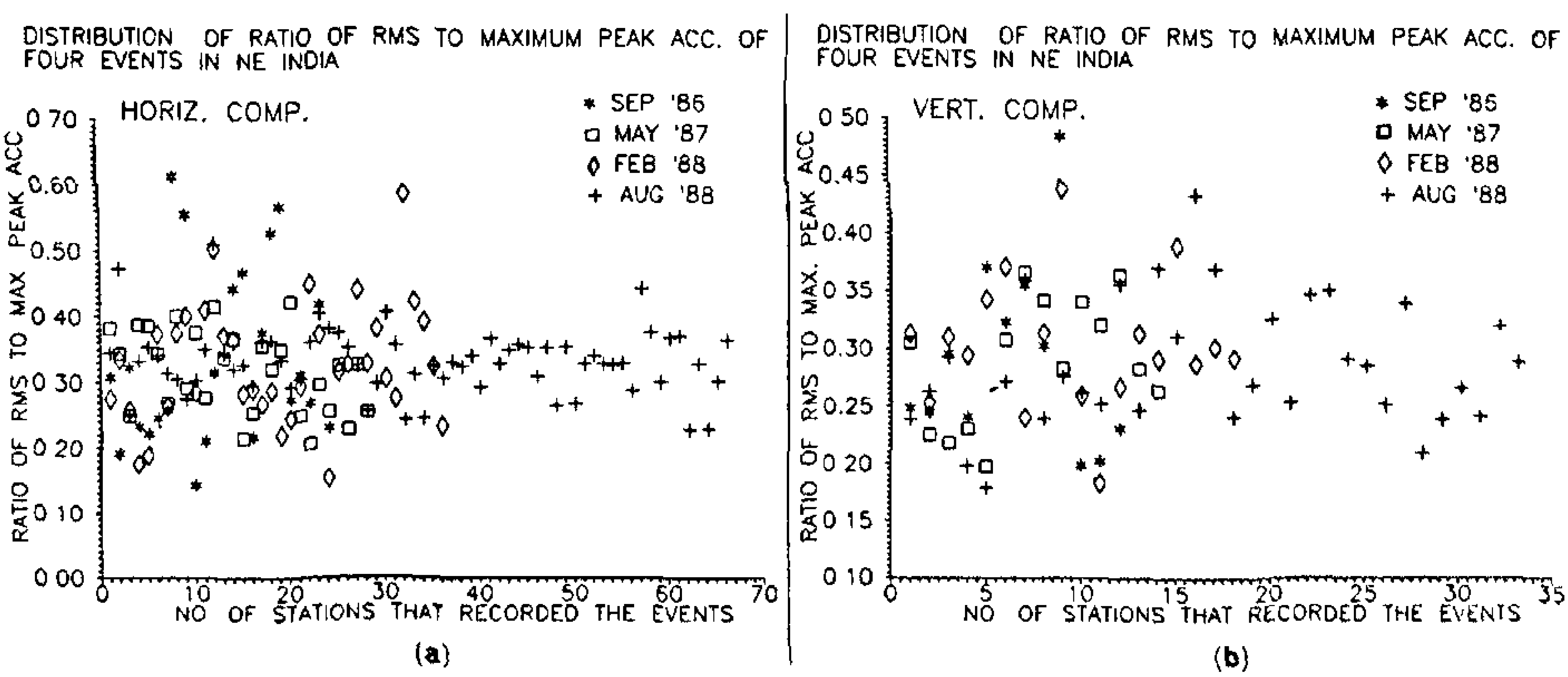
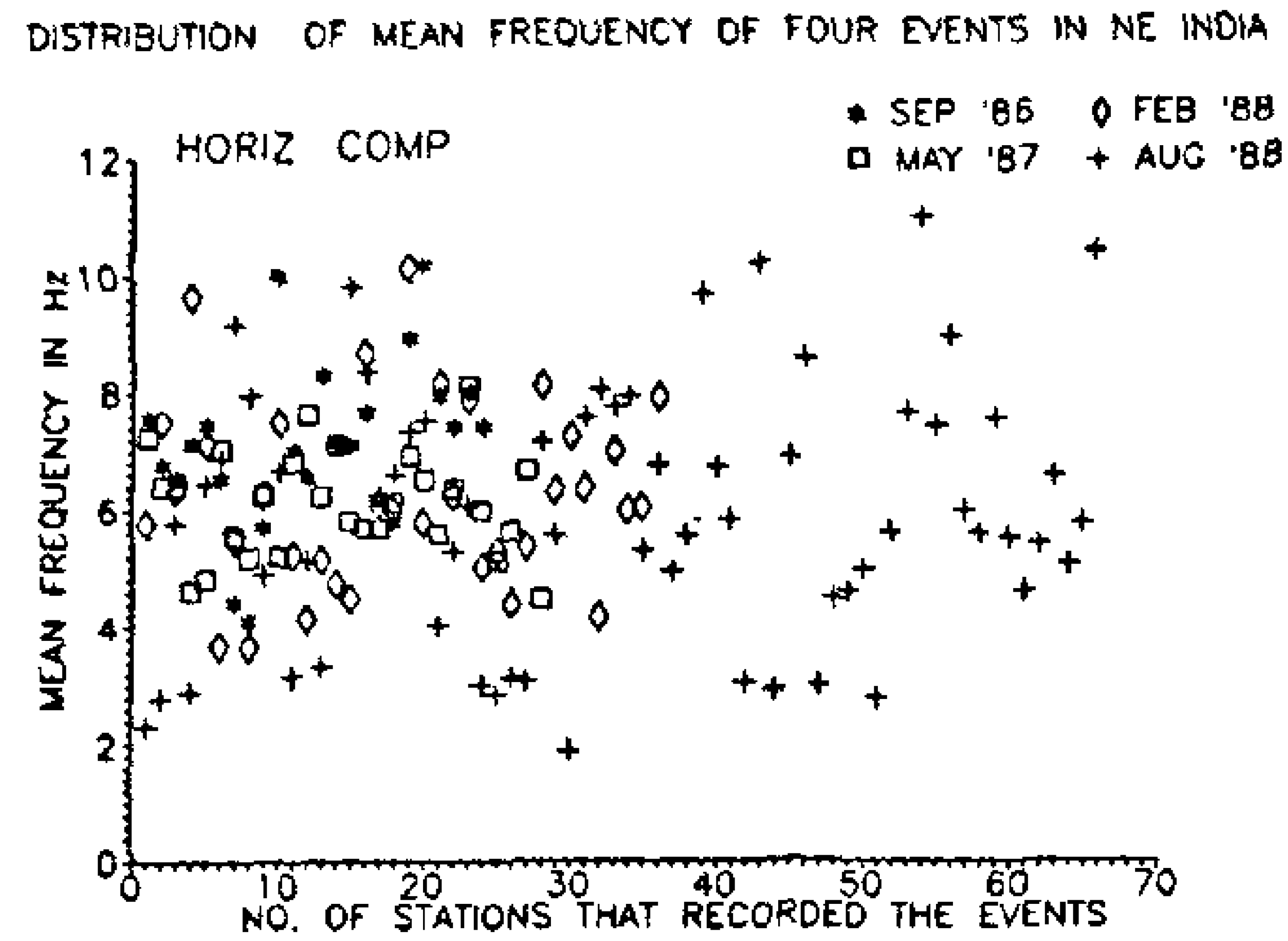
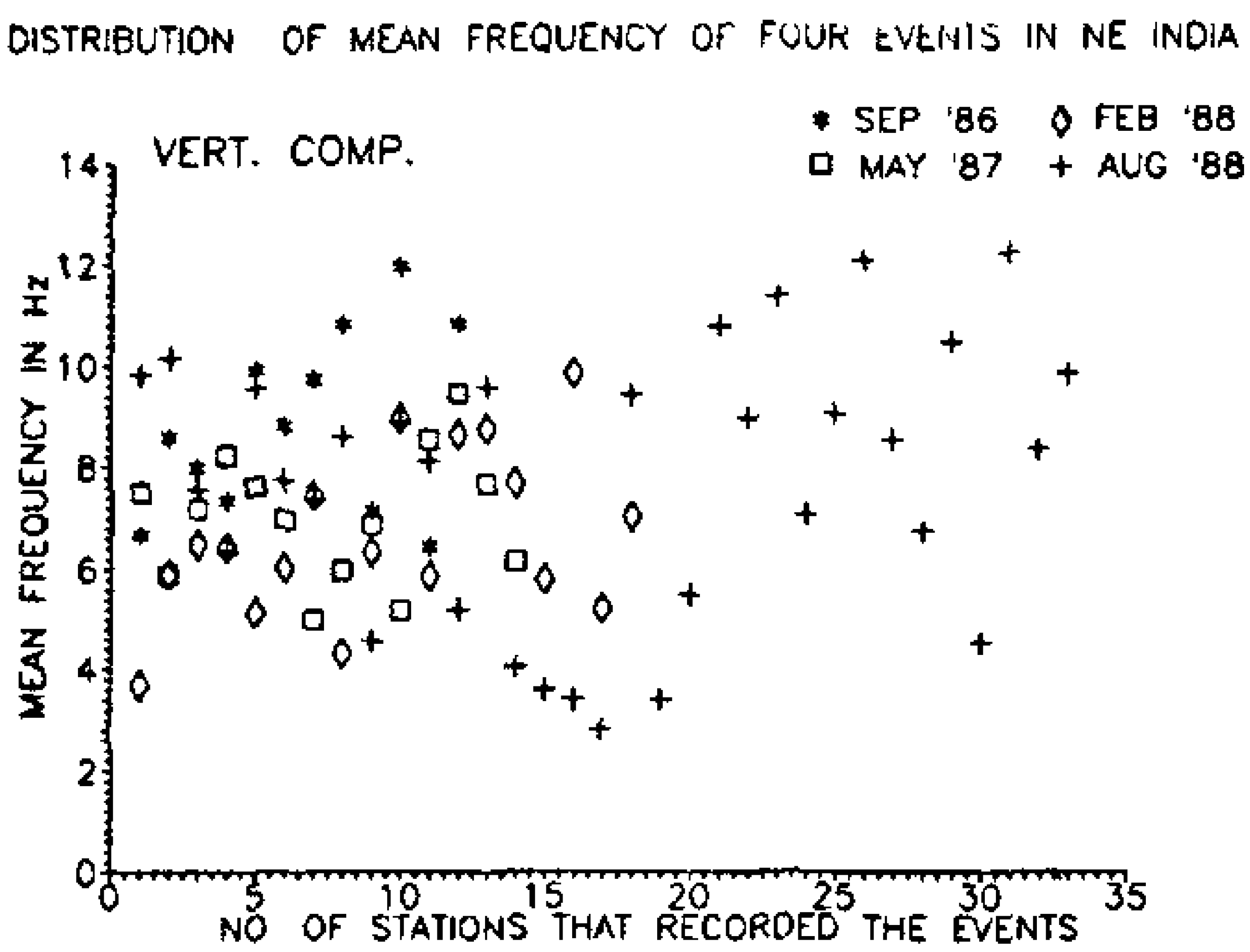


FIGURE 8 a and b. Distribution of ratio of RMS to maximum peak acceleration for horizontal and vertical components respectively for four events in NE India



(a)



(b)

Figure 9 a and **b.** Distribution of mean frequency for horizontal and vertical components respectively for four events in NE India.

Square (RMS), Peak Velocity and Spectral Intensity (SI) have been used. (Spectral Intensity is defined as area under the velocity response versus period of vibration between 0.1 to 2.5 sec. This definition is due to Housner[13]. The spectral values SI are for a damping of 5%). The spectral acceleration value of each record is scaled up/down such that data when normalized corresponds to

- 1 g for peak acceleration
- 100 cm/sec for peak velocity
- 1 g for RMS acceleration and
- 1000 cm for S.I.

After the first stage of normalization of records in terms of these parameters, the area under the normalized spectrum curve have been obtained. For the same area corresponding to 1 g peak acceleration, the corresponding values are given in table 7, and figure 10a to d shows a comparison for different normalization.

Table 6 Mean and standard Deviation of a_{rms} and f_m for Horizontal (H) and Vertical (V) Components

	Ratio of RMS to Max. Peak Acc.					Mean Frequency (in Hz)				
	Apr. 1986	Sep. 1986	May 1987	Feb. 1988	Aug. 1988	Apr. 1986	Sep. 1986	May 1987	Feb. 1988	Aug. 1988
Mean H	0.401	0.336	0.317	0.327	0.331	5.002	7.156	6.110	6.239	5.942
STD H	0.084	0.129	0.062	0.090	0.051	0.922	1.396	0.088	1.562	2.170
Mean V	0.361	0.292	0.289	0.304	0.287	7.054	8.559	7.017	6.638	7.736
Std V	0.041	0.079	0.053	0.056	0.056	1.770	1.318	1.238	1.607	2.616

TABLE 7 Normalizing Factors. Equivalence with respect to Unit Gravity

Case	Normalize factor	Acc. Spectra	Vel. Spectra
	RMS	0.3234	0.3247
SH	PGV	53.79 cm/sec	58.81 cm/sec
	SI	1821.00 cm	2022.00 cm
	RMS	0.2774	0.2799
SV	PGV	48.96 cm/sec	51.37 cm/sec
	SI	1992.00 cm	2085.00 cm
	RMS	0.3145	0.3142
RS	PGV	46.81 cm/sec	47.62 cm/sec
	SI	1491.00 cm	1556.00 cm
	RMS	0.2849	0.2883
RV	PGV	51.29 cm/sec	52.90 cm/sec
	SI	1853.00 cm	1974.00 cm

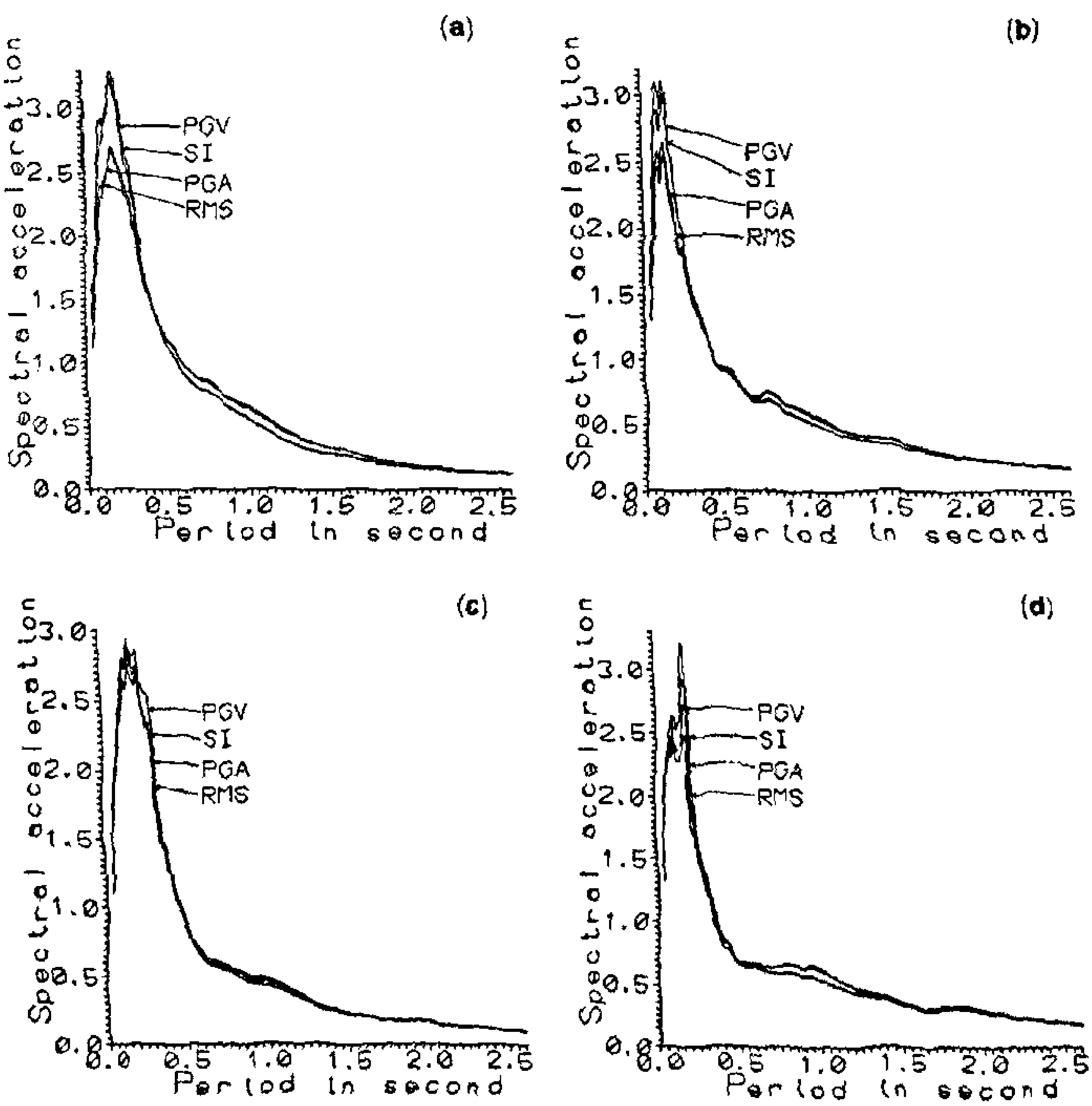


FIGURE 10 a to d. Average acceleration spectra. Soil sites–horizontal and vertical components; Rock sites–horizontal and vertical components.

The spectra shape for peak and RMS acceleration are nearly the same and for peak velocity and SI are also nearly the same but different from above.

CONCLUSIONS

The Shillong array has given valuable data within a short period since installation of the array. The characteristics of the events are quite different from that of Californian data which is currently used in design of structures. This array is likely to produce more data in future leading to better understanding of geological, seismological and engineering aspects.

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