Paper No. 234, Bull. ISET, Vol. No. 2, June 1984, pp. 62–72

EVALUATION OF RISK FOURIER SPECTRA FOR A SITE IN ASSAM SEISMIC GAP, NORTHEAST INDIA

I. D. GUPTA[1] AND T. V. S. RAMAKRISHNA[1]

ABSTRACT

Risk Fourier Spectra for probabilities of exceedance of .05 and .10 have been calculated for a site in Assam Seismic gap for 100 years return period, using a method which does not make any assumption regarding earthquake recurrence in time and space. Data on past earthquakes and tectonic features have been used to model the seismicity of the seismic gap and the region around it by four different models. Fourier amplitude spectra have been presented for all the four models and specific single earthquake spectra are also depicted for comparison. It is found that a single earthquake assumed to occur at a near distance from the site of interest, gives highly conservative level of risk, whereas the models suggested in this paper provide a more realistic level of risk, because these models take into account the random distribution of earthquakes over a vast area around the site at which risk is estimated.

INTRODUCTION

Major tectonic features in Assam region of Northeast India are seismically very active and have produced several large earthquakes in recent past. Main geotectonic zones of the region are: the zone of Himalayan Boundary Thrusts along which the Indian plate collides with the Eurasian plate; Arakan Yoma tectonic zone (Burmese arc); and the zone comprising of the Shillong Plateau, the Mikir Hills and the Dauki Fault (Fig. 2). Arakan Yoma zone shows pronounced seismic activity all along the Indo-Burma border and many epicentres lie in Shillong Plateau and Dauki Fault zone also. However, a section of Himalayan Boundary Fault between the rupture zones of two great earthquakes of 1897 and 1950 shows no seismic activity. Some of very big projects are proposed to be sited within this seismic gap, which is suspected to be the seat of a future big earthquake (Khattri and Wyss, 1978; Khattri et al., 1983).

Many investigators have analysed the seismic risk for the Assam region including the Assam gap (Kulshershtha and Singh, 1977; Kaila and Rao, 1980; Khattri and Wyss, 1980; Goswami and Sarmah, 1982). These investigations and most of the other studies on seismic risk estimation elsewhere,

---

[1] Earthquake Engineering Research Division, Central Water and Power Research Station, Pune, India.

are primarily based on applying some earthquake recurrence statistics to find out the expected maximum magnitude of the earthquake and its return period (Yegulalp and Kuo, 1974; Lomnitz, 1974; Shrivastava et al., 1976; Knopoff and Kagan, 1977; Rao, 1977; Burton, 1979 etc.). This is then used to find out the peak value of some ground motion parameter (acceleration, velocity or displacement) and its return period. Thus the frequency dependence of ground motion is often overlooked, or a standard spectrum shape (Housner, 1959; Newmark et al., 1973; Seed et al., 1976) is scaled to the required peak value. Hence the probability of exceedance of such a spectrum is different at different wave-frequencies.

This paper describes a method for evaluating Risk Fourier spectrum amplitudes having the same probability of occurrence at all the wave-periods (Anderson and Trifunac, 1977). The method has been applied to get the risk spectra for a site in Assam gap for a return period of 100 years. Four different models, based on the tectonic set up of the region, have been used to describe the seismicity of the area and the risk spectra have been evaluated for all the four models. Single earthquake spectra are also presented for the purpose of comparison.

ASSAM SEISMIC GAP:

Assam region of India is characterized by very high level of seismicity. Some of the biggest earthquakes in the world have occurred in this region. The great Assam earthquake of June 12, 1897 ($M = 8.7$) and the Assam earthquake of August 15, 1950 ($M = 8\ 6$) are two of the greatest earthquakes in the world. However, the epicentral area between these two earthquakes, the so called Assam seismic gap, has been identified as relatively quiet area (Fig. 1). It is almost devoid of earthquakes. Lack of seismic activity in the Assam gap has been also confirmed by recent microearthquakes observations (Khattri et al., 1983). Assam Gap is suspected to be the site of a future great earthquake and the present quiescence in the gap is considered as a preparatory stage for it (Khattri and Wyss, 1978).

Seismotectonic features of the Assam region have been described in several publications (Gansser, 1964; Evans, 1964; Dutta, 1967; Nandy, 1973; Valdiya, 1973; Verma et al. 1977 etc.). Fig. 2 shows important tectonic features of the region. Considering the uncertainties in the location of historical earthquakes, it is seen from Figs. 1 and 2 that the epicentres more or less correlate with the tectonic features. Portion of the main boundary fault lying in the seismic gap is not generating earthquakes and the stress is continuing to accummulate in this area.

THEORY AND METHOD:

Each of the source zones identified in various seismicity models described in next section is divided into small elements. Let $N_i\,(M_j)$ be the expected number of earthquakes with magnitudes in the interval $M_j \pm \delta M$ in the ith element during the period for which risk is to be estimated, and R_i be the distance of this element from the site at which risk spectra are intended to be evaluated. If $p_{ij}\,[FS(T)]$ is the probability of occurrence of Fourier amplitude

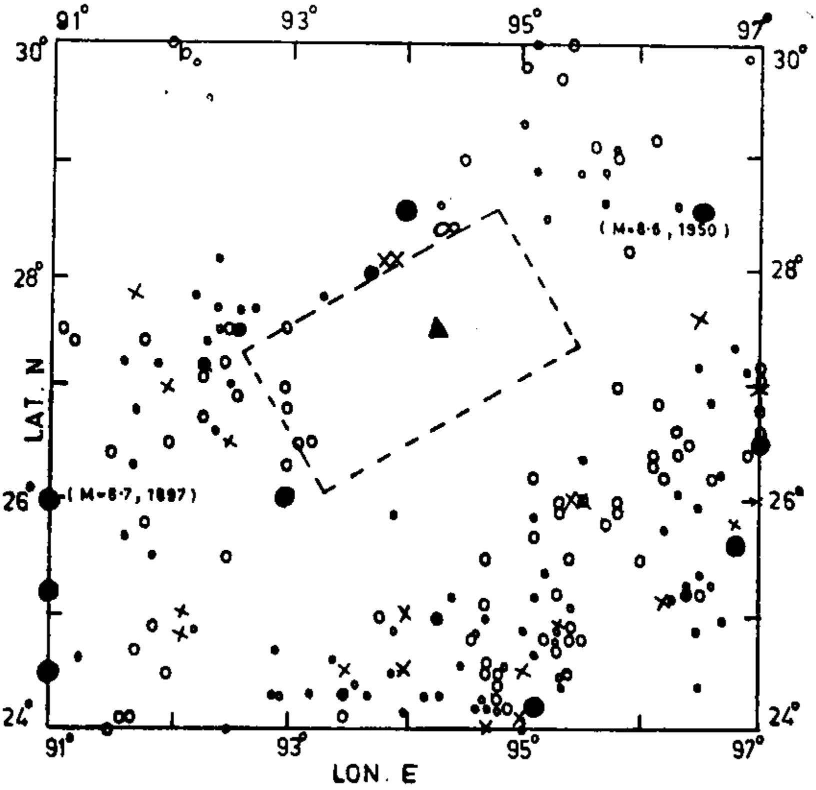


Fig. 1. **Seismicity map of Assam area. Dashed rectangle represents the seismic gap and the site selected for evaluating risk spectra is shown by a solid triangle.**

'$FS(T)$' at the site of interest due to an earthquake of magnitude M_j in the ith source element, then the probability of occurrence of '$FS(T)$' due to all the earthquakes of magnitude M_j in the ith element is given by $N_i\,(M_j).p_{ij}\,[FS(T)]$. Hence the expected number of times the amplitude $FS(T)$ will be exceeded at the site during the period of interest is given by adding the contributions from all the source elements for all the magnitudes

$$N\,[FS(T)] = \sum_i \sum_j N_i\,(M_j)\,p_{ij}\,[FS\,(T)] \qquad \ldots(1)$$

Assuming that $N_i\,(M_j)$ is the mean of a Poissonian distribution, the probability $p\,[FS\,(T)]$ that the Fourier amplitude $FS\,(T)$ will occur at least once during the period of interest is given by (Anderson and Trifunac, 1977)

$$p\,[FS\,(T)] = 1 - \exp\,\{-N\,[FS\,(T)]\} \qquad \ldots(2)$$

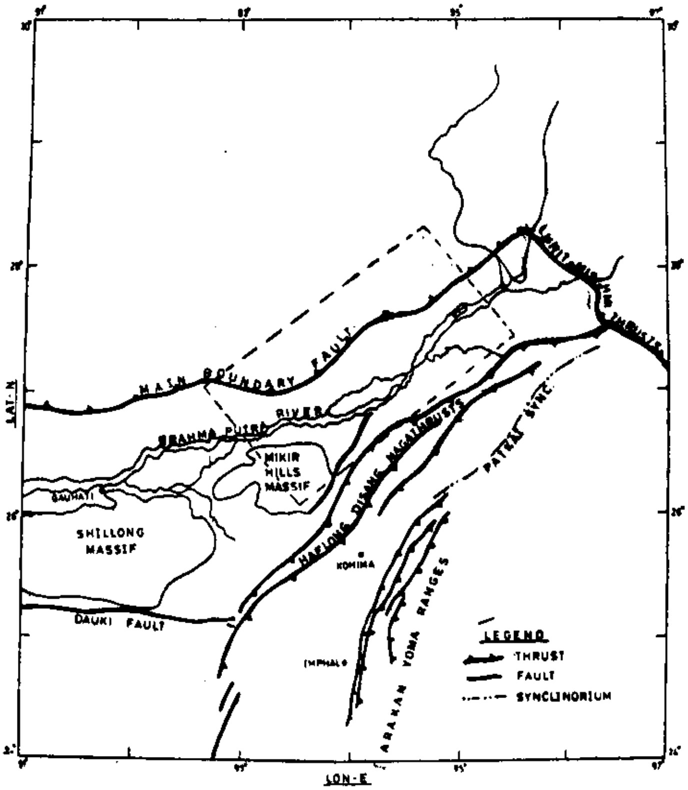


Fig. 2. Map showing important tectonic feactures of Northeast India. Hectangle shows the seismic gap area.

Using this expression, values of Fourier amplitudes $FS(T)$, which have the same probability of occurrence $p\,[FS(T)]$ at all the wave-periods, have been evaluated.

Values of $p_{ij}\,[FS(T)]$ have been obtained from Trifunac's (1976) empirical scaling relations for Fourier spectra, because such relations are not available for Assam region due to lack of recorded strong-motion accelerograms in the region. Probability P_1 that '$FS(T)$' will not be exceeded at the site of interest by an earthquake of magnitude M_j in the ith source element is given by

$$\text{Log}\, FS(T) = \text{Log}\, A_o(R_i) - a(T)P_l - c(T) - d(T)S - e(T)V$$

$$-g(T)R_i + \begin{cases} M_j - b(T)M_1 - f(T)M_1^2; \text{ for } M_j \leqslant M_1 = \dfrac{-b(T)}{2f(T)} \\ M_2 - b(T)M_2 - f(T)M_2^2; \text{ for } M_j \geqslant M_2 = \dfrac{1-b(T)}{2f(T)} \\ M_j - b(T)M_j - f(T)M_j^2; \text{ for } M_1 < M_j \leqslant M_2 \end{cases} \qquad \ldots(3)$$

where $\log A_o(R_l)$ is Richter's attenuation function: $s = 0$ for alluvium, $s = 2$

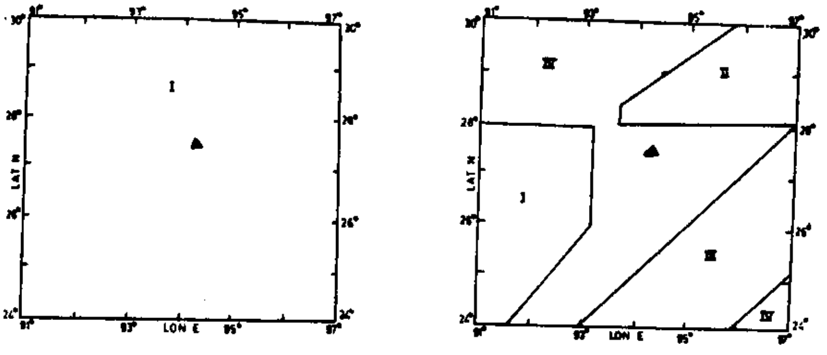
for rock and $s = 1$ for intermediate geological conditions; $v = 0$ for horizontal and $v = 1$ for vertical component; $a(T)$, $b(T)$, ..., $g(T)$ are regression coefficients evaluated by Trifunac for eleven different wave periods using strong motion accelerograms recorded in Western United States. Then the probability $p_{ij}\,[FS(T)]$ is given by

$$p_{ij}\,[FS(T)] = 1 - \frac{1}{\sigma(T)\sqrt{2\pi}}\int_{-\infty}^{P_l} \exp\left[-\frac{1}{2}\left(\frac{\varepsilon-\mu(T)}{\sigma(T)}\right)^2\right] d\varepsilon \qquad ...(4)$$

Values of the parameters $\sigma(T)$ and $\mu(T)$ for various wave-periods are also given by Trifunac (1976).

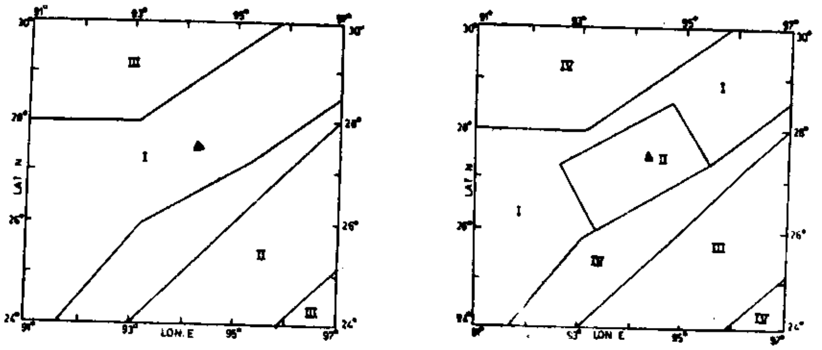
MODELS USED TO DESCRIBE FUTURE SEISMICITY :

Four different models have been suggested to describe the future seismicity of the region around Assam seismic gap. These are depicted in Fig. 3 and Table-1. Different source zones in a model have been identified



MODEL–A
Fig. 3 (a)

MODEL–B
Fig. 3 (b)



MODEL–C
Fig. 3 (c)

MODEL–D
Fig. 3 (d)

Fig. 3. Four models (A, B, C, D) used to describe the future seismicity of the region of Assam seismic gap. Seismicity for various source zones in these models is given in Table-I. Solid triangle shows the site at which risk spectra are evaluated.

TABLE 1: Number of Earthquakes Assigned to Various Source Zones in Different Models Used to Describe the Seismicity of Assam Gap Region.

Model	Source Zones	Magnitude Class								
		4.3–4.7	4.8–5.2	5.3–5.7	5.8–6.2	6.3–6.7	6.8–7.2	7.3–7.7	7.8–8.2	8.3–8.7
A	I	1070	475	200	65	32	14	8	4	2
B	I	340	150	66	19	10	5	3	2	1
	II	234	102	40	16	5	3	2	1	.5
	III	423	188	82	38	17	6	3	1	—
	IV	62	28	12	—	—	—	—	—	—
C	I	710	315	132	44	16	9	7	4	2.5
	II	423	188	82	38	17	6	3	1	—
	III	55	23	10	—	—	—	—	—	—
D	I	515	236	99	33	12	7	5	3	1.5
	II	195	79	33	11	4	2	2	1	1
	III	423	188	82	38	17	6	3	1	—
	IV	55	23	10	—	—	—	—	—	—

on the basis of seismotectonic features of the region, as shown in Fig. 2, and the number of earthquakes of various magnitudes in a source zone have been estimated by assuming that the future seismicity will have the same behaviour as in the past. Occurrence of some big earthquakes has been added in some of the source zones for the long period (100 years) considered to estimate the risk. Number of earthquakes has been also increased in some of the models to account for the occurrence of earthquakes in the gap area.

Model A is based on a very simplifying assumption of uniform spatial distribution of future earthquakes all over the region, including the gap. Expected numbers of earthquakes of various magnitudes for a period of 100 years have been estimated by scaling the number of earthquakes per year for that magnitude range. In order to get the mean number of earthquakes per year for a particular magnitude range, the authors have used the data for the period for which the detectability of that magnitude range appears to be complete. However, the detectibility of magnitudes less than 5.0 is found to be incomplete even for the recent years and it has been compensated by assuming that the annual mean number of earthquakes $n(M)$ with magnitudes in the interval $M \pm \delta M$ satisfy the linear relation

$$\text{Log } n(M) = a - bM \qquad \ldots(5)$$

In Model B, it is assumed that the future earthquakes will continue to occur in the source zones where they had been occurring in the past. Three main source zones in this model are: the region comprising of western part of the Himalayan fault, Dauki fault and Shillong Massif; region of Naga-Patkai belt and Arakan Yoma tectonic zone (Burmese arc); and the northeast corner area of eastern-most part of the boundary fault and the Luhit-Mishmi thrust systems. The gap has been assumed to remain quiescent and the seismicity for the other regions has been scaled for 100 years. Spatial distributions of earthquakes has been assumed to be uniform in each of the source zone.

In model C, Naga-Patkai and Arakan Yoma zone has been kept as it is in Model-B, whereas the other two zones have been connected by assuming that the seismic gap will be closed. The seismicity of this combined area has been scaled to account for the earthquake occurrence in the gap area, but its distribution has been taken uniform over whole of this source zone. Model D, on the other hand, identifies the gap area as a separate source zone. In this case also, the spatial distribution of the seismicity has been assumed uniform for each source zone.

The site for which risk spectra have been evaluated for the seismicity models described above has been chosen arbitrarily, just to illustrate the level of seismic risk in the Assam Seismic gap.

RESULTS AND DISCUSSION

Calculations of risk Fourier amplitude spectra having same probability of exceedance at all the wave-periods have been made for an arbitrary site in the Assam seismic gap and the results are illustrated in Fig. 4. To evaluate the risk spectra, an area of size 6° Lat. × 6° Long. has been considered around the site of interest. Seismicity of this area has been modelled by four different seismicity models and risk spectra have been calculated for horizontal component on rock for two probabilities of exceedance; viz., .05 and .10, for the proposed models. Single earthquake spectra are also

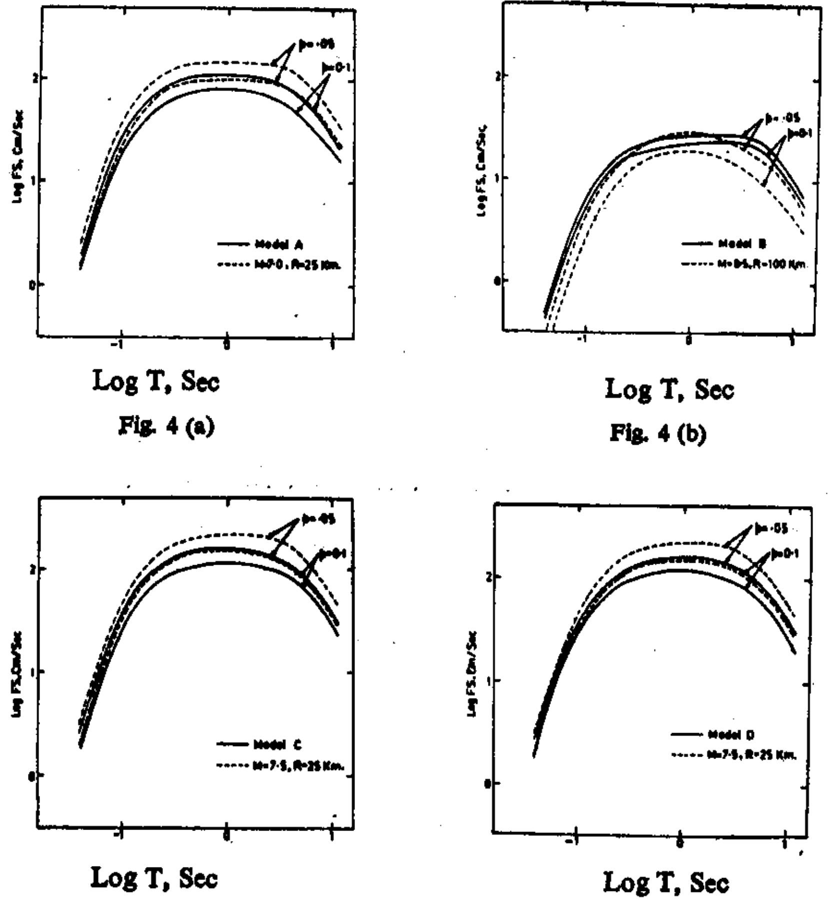


Fig. 4 (a)

Fig. 4 (b)

Fig. 4 (c)

Fig. 4 (d)

Fig. 4. Uniform risk spectra with probabilities of exceedance of 0.05 and 0.10 for the site in Assam gap. Spectra of single earthquakes of the indicated magnitudes and epicentral distances are plotted for comparison. All the spectra are for horizontal component on rock.

presented for comparison. As was expected, risk is highest for model D, but it is not significantly different from the risk estimated by using model C. Model C, however, seems to be more realistic on the ground that whole of the plate boundary zone is considered as a single geodynamic unit and that the possibility of closure of the gap due to rupture produced by an earthquake occurring within as well as outside the gap is taken into account. Model B gives lowest level of risk, because the zone of gap is assumed to produce very low level of seismicity. This model assumes that the cycle of stress building up in the gap will continue in future also. Model A does not give a realistic representation of the seismicity of the region. Such a model may be used for a region, the seismotectonic set up of which is not well known to delineate various seismogenic sources. It is seen that the level of Fourier amplitude spectra for our models are somewhat lower than the spectra of single earthquake which could be expected to occur in the region. This may be attributed to the large area considered which leads to large distances between the source and the site.

The method applied to estimate the risk Fourier spectra for Assam seismic gap uses quite realistic description of the seismicity of the region and is free from using any assumptions regarding earthquake recurrence relations and precise location of future large events. Thus, the results of such studies have better degree of confidence than most of the other investigations.

ACKNOWLEDGEMENTS

The authors are thankful to Shri P. C. Saxena, Director, Central Water and Power Research Station, Pune for his perennial encouragement in carrying out this work and for the permission to publish the paper.

REFERENCES

Anderson, J. G. and M. D. Trifunac (1977). On uniform risk functionals which describe strong earthquake ground motion: Definition, Numerical Estimation, and an application to the Fourier Amplitude of acceleration. Univ. Southern California, Deptt. of Civil Engg. Report No. CE-77-02.

Burton, P. W. (1979). Seismic risk in Southern Europe through India examined using Gumbel's third distribution of extreme values. Geophys. J. R. Astron. Soc., 59, 249-280.

Dutta, T K. (1967). Seismicity of Assam in Relation to Geotectonic Processes—Nature of Instability of the Assam Wedge, Bull. Int. Int. Seis. and Earth. Engg., 4 p. 63.

Evans, P. (1964). The tectonic framework of Assam, J. Geol. Soc., 5 80-96.

Gansser, A. (1964). Geology of the Himalayas, Interscience, London, 289 pp.

Goswami, H.C. and S.K. Sarmah (1982). Probabilistic earthquake expectancy in the Northeast Indian Region, Bull. Seism. Soc. Am., 72, 999-1010.

Housner, G. W. (1959). Behaviour of structures during earthquakes, Jour. Eng. Mechanics Div., Am. Soc. Civil Eng., 85, 109-129.

Kaila, K. L. and N. M. Rao (1980). Expected maximum magnitude, intensity and peak horizontal ground acceleration maps of Himalayan region, Procs. 7th World Conf. Earthq. Engg. Istanbul, Turkey, Vol. 1, 241-244.

Khattri, K. and M. Wyss (1978). Precursory variations of seismicity rate in the Assam area, India, Geology 6, 685-688.

Khattri, K. and M. Wyss (1980). Seismic risk in the Assam Gap, Eastern Himalaya, U. S. Geol. Surv., Open File Report, 80-2011.

Khattri, K., M. Wyss, V. K. Gaur, S. N. Saha and V. K. Bansal (1983). Local seismic activity in the region of the Assam Gap, Northeast India, Bull. Seism. Soc. Am. 73, 359-469.

Knopoff, L. and Y. Kagan (1977). Analysis of the theory of extremes as applied to earthquake problems J. Geophys. Res., 82, 5647-5657.

Kulshreshtha, V. K. and U. N. Singh (1977). Microzonation of the north-eastern part of the Indian subcontinent, Procs. 6th World Conf. Earthq. Engg., India, Vol. 1, 901-902.

Lomnitz, C. (1974). Global Tectonics and Earthquake Risk. Elsevier, Amsterdam, 320 pp.

Nandy, D. R. (1973). Geology and structural lineament of the Luhit Himalaya (Arunachal Pradesh) and adjoining area—A tectonic Interpretation. Seminar on Geodynamics of the Himalayan Region, Hyderabad, 1973, p. 167.

Newmark, N. M., J. A. Blume and K. K. Kapur (1973). Seismic design spectra for nuclear power plants. Jour. of the Power Division, ASCE, 99, No. PO2, 287-303.

Rao, P. V. (1977). Seismic probability diagrams for risk evaluation in the Indian subcontinent Proces. 6th World Conf. Earthq. Engg. India, Vol. 1, 927-928.

Seed, H. B., Ugar and J. Lysmer (1978). Site dependent spectra for earthquake resistant design. Bull. Seism. Soc. Am., 66, 221-244.

Srivastava, V. K., R. K. S. Chouhan and R. Nigam (1976). Largest value theory applied to probability of earthquake occurrence. Bull. Indian Soc. of Earthquake Technology, 13, 19-23.

Trifunac, M. D. (1976). Preliminary empirical model for scaling Fourier amplitude spectra of strong ground motion in terms of earthquake magnitude, source to station distance, and recording site conditions, Bull. Seism. Soc. Am., 66, 1343-1373.

Valdiya, K. S. (1973). Tectonic framework of India: a review and interpretation of recent structural and tectonic studies, Geophys. Res. Bull. **11,** 79-114.

Verma, R. K., M. Mukhopadhyay and B. N. Roy (1977). Seismotectonics of the Himalaya, and the continental plate convergence. Tectonophysics, 42, 319-385.

Yegulalp, T. M. and J. T. Kuo (1974). Statistical prediction of the occurrence of maximum magnitude earthquakes Bull. Seism. Soc. Am, 64, 393-414.