between 1 and 2.272 s (ref. 21). The higher modes will have shorter periods. However, the value of acceleration in this period range adopted for the design of Tehri dam is only 0.22 g. It is thus apparent that the hazard figures adopted for the design of Tehri dam are significantly deficient in the light of results obtained from the present analysis.

Conclusions

This paper presents a method for modelling expected strong ground motion time histories using the composite fault model and synthetic Green's functions. It is shown that this flexible method is quite successful in modelling the Uttarkashi accelerograms and would be useful in estimating accelerograms for future earthquakes. Thus the method can be used to develop detailed and reliable estimates of seismic hazard for a safe design of critical structures in seismic areas.

1. Joyner, W. B. and Boore D. M, Proc. Earthquake Engg. & Soil Dynamics, Park City, Utah, Am. Soc. Civil Engrs., 1988, pp. 43–102.
2. Anderson, J. G., *Rev. Geophys., Seismol. Suppl*, U.S. National Report to the IUGG 1987–1990, pp. 700–720.
3. Aki, K. and Inkura, K., Proc. IV Int Conf. on Seismic Zonation, Earthquake Engg. Res Inst., Oakland, Calif., 1991, vol. 1, pp 61–110.
4. Brune, J N., *J. Geophys. Res.*, 1970, **75**, 4997–5009.
5. Brune, J N., *J. Geophys Res.*, 1971, **76**, 5002
6. Hartzell, S. H., *Geophys. Res. Lett.*, 1978, **5**, 104
7. Hutching, L. J. and Wu, F. T., *J. Geophys. Res.*, 1990, **95**, 1187–1224.
8. Aki, K. and Richards, P. G., *Quantitative Seismology: Theory and Methods*, W. H. Freeman and Co., New York, 1980.
9. Zeng, Y., Anderson, J. G. and Yu, G., A composite source model for computing realistic synthetic strong motions (submitted for publication), 1993.
10. Frankel, A., *J. Geophys. Res.*, 1991, **96**, 6291–6302.
11. Kanamori, H. and Anderson, D. L., *Bull. Seismol. Soc. Am.*, 1975, **65**, 1073–1096.
12. Luco, J. E. and Apsel, R. J, *Bull. Seismol. Soc. Am.*, 1983, **73**, 909–929.
13. Chandrasekaran, A. R. and Das, J. D., *Mem. Geol. Soc. India*, 1992, **23**, 81–122.
14. Yu, G., Khattri, K. N., Anderson, J. G., Brune, J. N and Zeng, Y., (submitted for publication), 1993.
15. Khattri, K N., *Mem. Geol. Soc. India*, 1992, **23**, 45–66.
16. Anooshehpoor, A. and Brune, J N., *Bull Seismol. Soc. Am*, 1989, **79**, 1247–1360.
17. Seeber, L. and Armbruster, J. G., in *Earthquake Prediction: An International Review*, Maurice Ewing Series, 4, Am. Geophys. Union, Washington DC, 1984, pp. 259–277.
18. Khattri, K. N., *Tectonophysics*, 1987, **138**, 79–92.
19. Molnar, P., *J. Him. Geol.*, 1990, **1**, 131.
20 Singh, D. D. and Gupta, H. K., *Bull. Seismol Soc. Am.*, 1984, **70**, 757–773
21. Iyenger, R. N., How Safe is Tehri Dam to Earthquakes, Workshop on 'Seismic Hazard and Large Dams in the Himalaya', Indian National Trust for Art and Cultural Heritage, New Delhi, 15–16 January, 1993.

ACKNOWLEDGEMENTS. KNK is indebted to CSIR and WIHG for support for this research and to Prof A. R. Chandrasekaran, UOR, and the DST for the release of the data.

Evaluation of design earthquake parameters for a site and utilization of strong motion data

A. R. Chandrasekaran
Department of Earthquake Engineering, University of Roorkee, Roorkee 247 667, India

A great majority of structures are designed according to provisions of the Code of Practice in respective countries. The so-called Site Dependent Evaluation of Earthquake Parameters are carried out for some important structural systems. In view of the stringent requirements of safety of nuclear power plants (NPP) very conservative procedures were developed for the prediction of earthquake parameters for design of NPP. Sometimes, the same techniques are sought to be applied for other structures where site-dependent studies are attempted. This paper discusses various aspects of this problem and suggests that prediction of maximum earthquake should not be based on which structure is supposed to be built in that area. One must leave to the judgement of the engineers to tone down the level of design earthquake from the maximum predicted earthquake depending on the methodology of design and acceptable level of damage. This paper also discusses utilization of results obtained from monitoring strong motion earthquakes.

Code provisions of various countries

MOST codes describe the seismicity in terms of seismic coefficient. It has been noted that there is a lot of misconception among scientists and engineers, to confuse seismic coefficient and peak ground acceleration. Seismic coefficient is generally related to response of short period structures (0.1 to 0.2 sec) to earthquakes and hence is larger than ground acceleration.

There are two broad philosophies followed in specifying seismic coefficient. In one, low values of seismic coefficients are specified, like that in Indian standards. However, simultaneously, the permissible increase in stresses due to these occasional loads is also kept small. In the second case, relatively large values are specified and simultaneously large increase in stresses is allowed.

The International Association for Earthquake Engineering (IAEE) brings out every four years a compilation of code of practice dealing with earthquake engineering aspects of various countries[1]. The basic parameter is given in some codes in the form of zero period acceleration (effective peak acceleration) or as seismic coefficient in others. Large values of zero period acceleration are suggested by Algeria (0.35), Colombia (0.30) and Iran (0.35). High values of seismic coefficients are suggested by China (0.32) Bulgaria (0.27), Peru (0.40) and Portugal (0.40). In some countries the seismic coefficient values are low like India (0.08), Philippines (0.12), Turkey (0.10) and Japan (0.15).

Specification of earthquake parameters

In the early years, before the methodology for nuclear power plants (NPP) became well known, recorded time histories or some modifications thereof by altering the amplitude or time scale were specified. For a long time, the waveform of El Centro Earthquake of 18 May 1940 was popularly used in earthquake engineering practice. Later, waveforms of other earthquakes were also used as models. In India, the waveform recorded at Koyna earthquake of 11 December 1967 was extensively used for projects in Western India.

Procedure for NPP

Earthquake engineering research got a lot of impetus due to need for designing safe nuclear power plants. Though there is a lot of conservatism built in the provisions, the methodology proposed had a reasoned scientific basis and hence is sought to be used now for other structures. The earliest standards proposed by USNRC[2,3] were popularly used and formed the basis of some subsequent codes. The International Atomic Energy Agency had subsequently brought out safety series 50-SG-S1 (ref. 4) and 50-SG-S2 (ref. 5). Recently, the Atomic Energy Regulatory Board of India has brought out a code dealing with these matters[6].

In brief, the various steps in a seismic design of NPPs can be summarized as follows:

(i) A region with a radius of 300 km around the site is chosen for detailed study.
(ii) In that region all tectonic features are marked. Modern techniques like Satellite Imagery, etc., are used to elaborate these features in detail.
(iii) Information available for all recorded earthquakes from seismological instruments are plotted. Nowadays, such information can be extracted from databases available with various agencies. Where instrumentation data of earthquakes are not available, isoseismals are used.
(iv) Prediction of seismic parameters from postulated tectonic features or otherwise is made. Magnitude of earthquake is maximized; the hypocentral distance is minimized.
(v) These codes suggest normalized shape of response spectra based on statistical studies of some recorded accelerograms. It is suggested that a more appropriate method could be used in which a set of accelerograms appropriate to the predicted seismic parameters are statistically analysed to propose the normalized shape of spectra.
(vi) To obtain design spectra from the normalized shape of spectra, a multiplying factor is needed. This is to be obtained from some assumed attenuation relation using the predicted seismic parameters. All the codes are silent about the attenuation relationship to be used (except for the AERB Code[6]). Maximum controversy is related to the choice of this factor. The shape of spectra usually corresponds to response acceleration and hence the factor has units of acceleration. Most likely the value of this factor is fixed less than the maximum peak value of acceleration[7,8] associated with recorded accelerograms corresponding to the predicted seismic parameters.

A design spectrum defined in the region of periods 0.1–2.5 s, can match spectra derived from actually recorded waveforms (amplitudes linearly scaled) even when the peak accelerations differ widely. The design spectrum is quite rich in a wide spectrum of frequency range compared to those from real earthquake which have concentration of energy in some selected frequencies. Hence, there is a justification in having a value of this factor, sometimes known as 'effective peak acceleration' much lower than what is recorded in some real events corresponding to predicted seismic parameters[8].
(vii) Quite often for dynamic analysis of systems, specifying response spectra would alone not be sufficient and a time history would be needed. Since the design response spectrum has been obtained from a statistical study of several different accelerograms, no single recorded time history would match such a design spectrum over the entire spectral range. An artificial time history is therefore generated to match the shape of spectra. Naturally, this artificial time history is much more conservative and severe compared to testing the design of a structure during real earthquakes.

Specification for dams

The International Commission on Large Dams (ICOLD) has made recommendations for evaluation of seismic parameters[9]. In India, the Central Water Commission has brought out draft standards[10] more or less based on ICOLD suggestions. These recommendations are on similar lines as those for NPP. However the values specified for magnitude, multiplying factor for shape of spectra and confidence level of spectra could be smaller for dams compared to NPP.

In India, the locations of NPPs are in very mild to moderate seismic regions whereas the real hydro-electric potential is in severely seismic regions. The NPPs are designed for much larger seismic forces than the existing dams in that region. Since the code of practice is different for the two types of structures, and ownership is also resting with separate agencies, there can be conflict of interest.

Other structures

There are no special codes for other structures except the one available for buildings. Whenever a special site-dependent study is made for such structures, procedures similar to that adopted for dams are used.

Provisions of Indian code and suggestions for change

The IS:1893 provides for low values of seismic coefficients[11]. For example, in the most severe zone, the seismic coefficient for ordinary buildings of one or two storeys is 0.08. This corresponds to a zero period acceleration of only 0.036 *g*. It is not mandatory for other structures to make special site-dependent studies and hence whenever it is made, the values obtained are relatively much larger than given in IS code and could cause problems to the management. The author feels that it is better to specify realistic values of zero period acceleration which should be independent of structures to be located. Subsequently, reduction factors could be adopted for design depending on the importance of structure and risks to be taken in the form of permissible damage.

The IS:1893 is under revision. Division of the country into five zones is probably not warranted as we are experiencing seismic activity even in the so-called zones I and II. The revision could call for four zones (mild, moderate, active and severe). The zero period acceleration fraction in these zones could be 0.04, 0.08, 0.16 and 0.32 *g*. The shape of spectra specified in IS:1893 is corresponding to 50% exceedance level. It is now possible to specify mean and standard deviation spectra for two different foundation conditions, namely soil and rock. These could be incorporated in the new revision.

Monitoring of strong motion earthquakes

Collection and analysis of records of three component strong motion accelerograms during earthquakes has proved very useful in earthquake engineering. In India, till recently only the database generated due to earthquakes in Western USA and Japan have been used except for the Koyna accelerogram of 11 December 1967 which has been used in the analysis and retro-fitting of dams in Maharashtra and peninsular India.

The Department of Science and Technology, Government of India, under a priority Himalayan Seismicity Project has funded the installation and maintenance of strong motion arrays in Himalayas. This project is managed by the Department of Earthquake Engineering, University of Roorkee with the author as the principal investigator.

There are three strong motion arrays—in Himachal Pradesh, in the States of Assam and Meghalaya and in the hills of Uttar Pradesh[12]. A fourth one is under installation in Arunachal Pradesh. One event each has been recorded in the HP and UP arrays whereas five events have been recorded in NE India[13]. These have provided valuable information for earthquake engineering practice.

Utilization of results of strong motion database

There are a few accelerograms which can be used for testing the design of structural systems: (i) Accelerograms recorded at Shahpur and Dharmsala in April 1986, (ii) Accelerograms recorded at Diphu and Berlongfer in August 1988, (iii) Accelerogram recorded at Uttarkashi and Bhatwari in October 1991. Particulars of these accelerograms are given in Table 1.

Accelerogram recorded at Shahpur (earthquake of 26 April 1986) is shown in Figure 1.

Normalized shape of spectra for rock and soil sites have been developed from the database generated so far[14]. The mean and standard deviation values of response acceleration spectra (normalized with respect to peak ground acceleration) for soil site and for 5% damping is given in Figure 2. This shape of spectra has been used recently in several projects to develop design spectra.

In Himachal Pradesh and in the Uttaranchal regions of Himalayas, the attenuation relationship proposed by McGuire[15] appears to be reasonable (Figures 3 and 4). The pattern in NE India is quite different. The McGuire relationship considerably underestimates the values actually recorded. The formula of Battis[15] appears to be more appropriate (Figure 5). There is a necessity to study the tectonics in this region to explain why large accelerations have been recorded far away from the epicentre.

In order to develop attenuation relationship for the region, a large number of events has to be recorded. At Saitsama in Meghalaya, five events were recorded. An attenuation relationship of the type was sought to

Table 1. Summary of strong motion data

Location	Component	Derived maximum peak ground acceleration (mm/sec^2)	Derived maximum peak ground velocity (mm/sec)	Derived maximum peak ground displacement (mm)
Dharmsala	L-N 76 W	1722.1	72.97	7.76
	V-VERT	809.4	27.39	4.19
	T-N 14 E	1828.9	94.90	24.79
Shahpur	L-N 75 E	2001.7	59.21	7.26
	V-VERT	643.1	28.04	5.25
	T-N 15 W	2432.0	147.80	10 85
Berlongfer	L-S 76 W	2951.1	217.24	33.40
	V-VERT	1705.8	90.26	13.18
	T-N 14 W	3370.7	228.19	36.30
Diphu	L-N 90 E	2772.5	181.48	23.25
	V-VERT	1764.7	56.12	9.00
	T-S 00 E	3313.7	205.55	22.74
Bhatwari	L-N 85 E	2483.7	178.73	37.54
	V-VERT	2887.8	133.65	23.53
	T-N 05 W	2418.9	297.78	53.23
Uttarkashi	L-N 15 W	2372.7	169.56	21.15
	V-VERT	1926.2	141.56	22.98
	T-N 75 E	3039.9	194.68	19.85

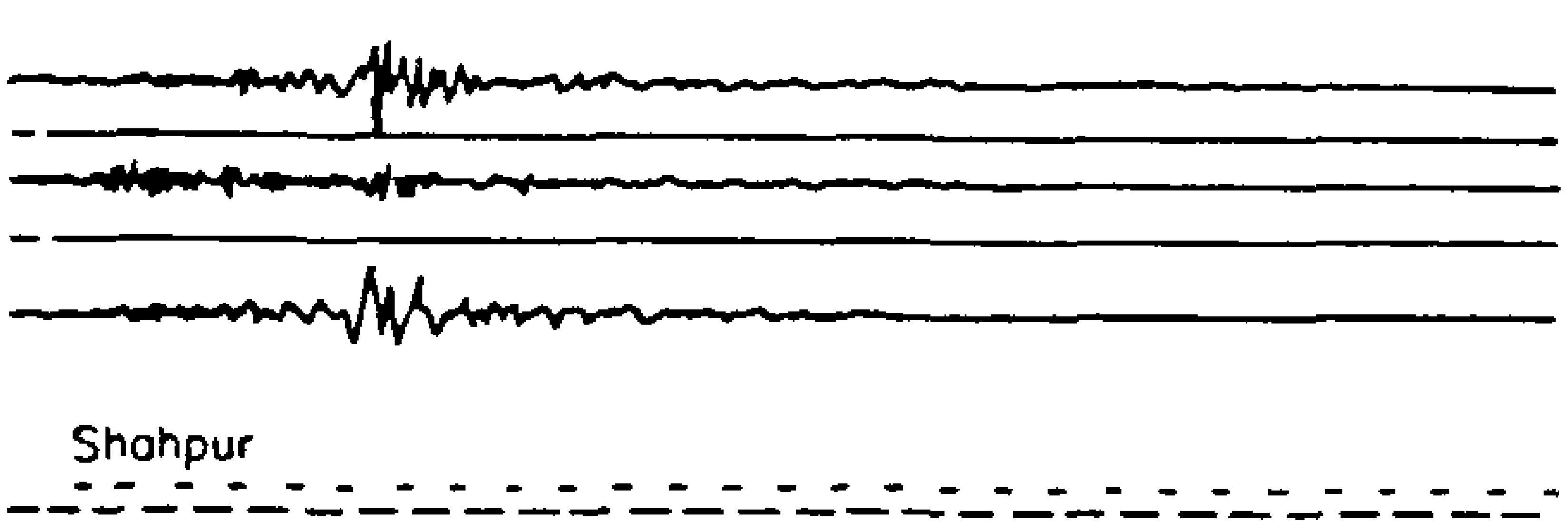

Figure 1. Strong motion accelerogram of 26 April 1986.

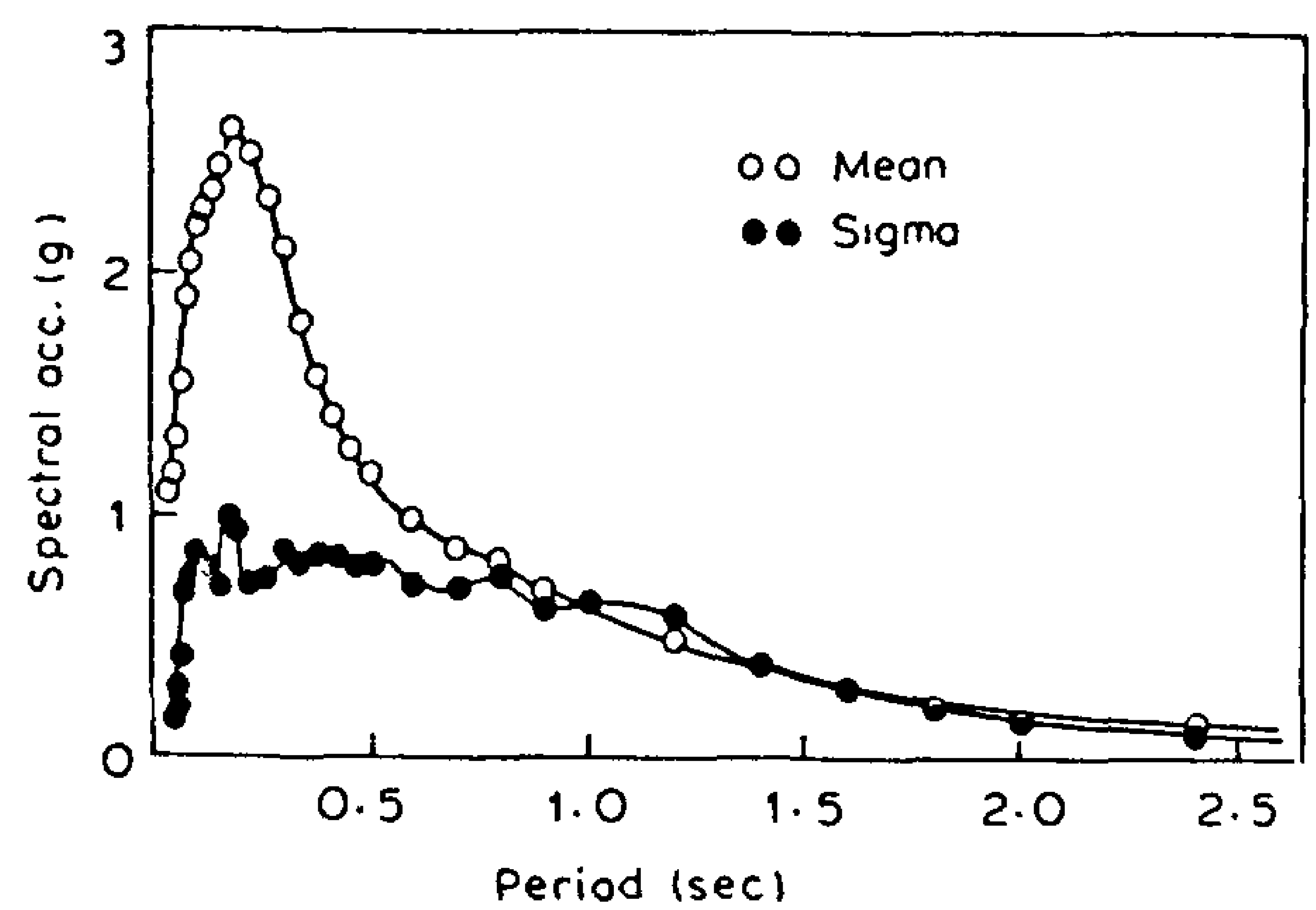

Figure 2. Spectral shape of mean and standard deviation and 5% damping-soil site.

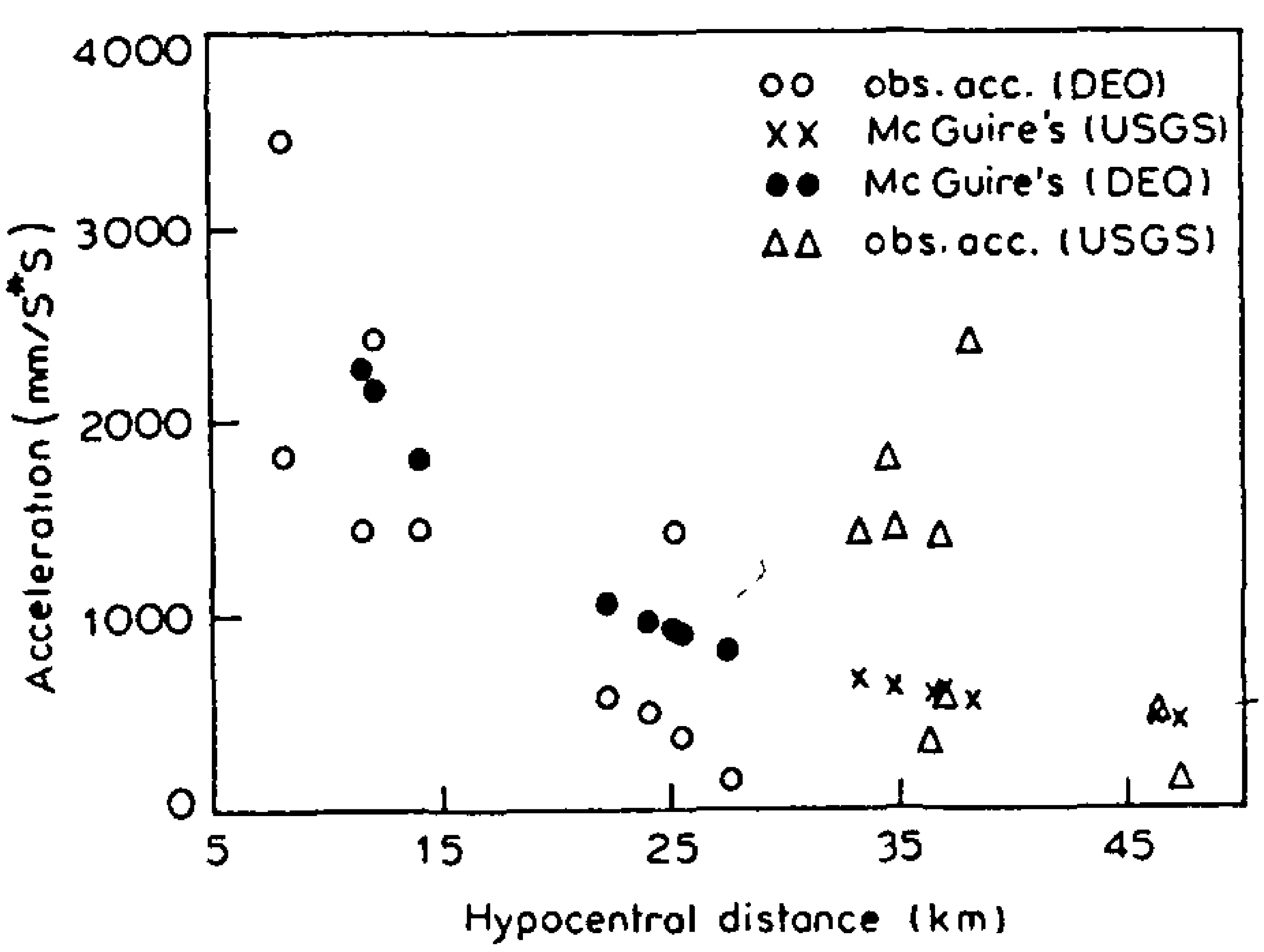

Figure 3. Plot of peak observed acceleration and comparison with McGuire's relationship (event of 26 April 1986).

be fitted.

$$\alpha = a \cdot e^{bM} \cdot R^{-c},$$

where α is the horizontal acceleration in mm/sec^2, M the magnitude, R the hypocentral distance in km, has been fitted.

The values of a, b and c so obtained are

$$a = 50.24 \quad b = 1.26 \quad c = 1.04.$$

It is possible to locate the epicentre of an event

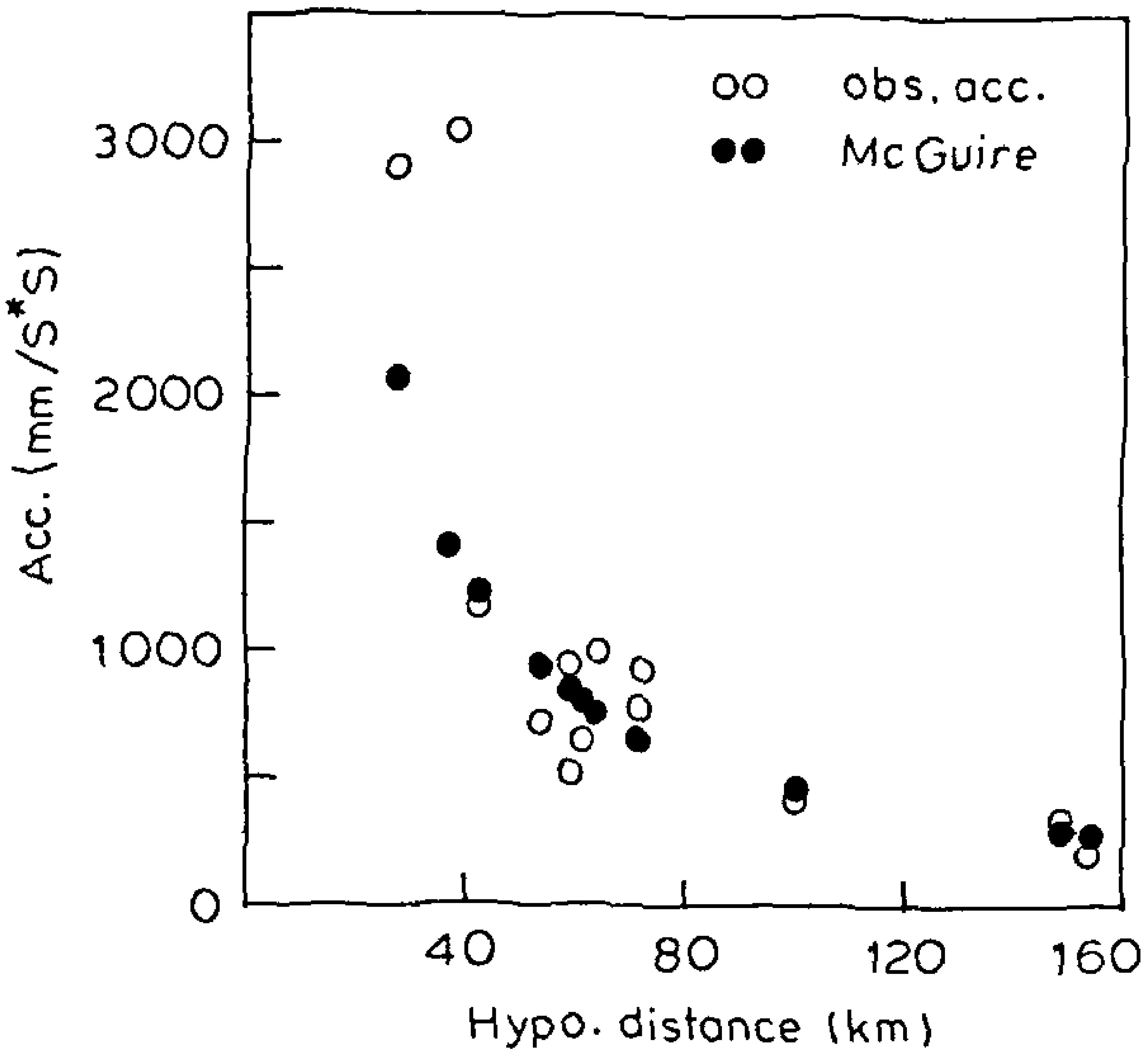

Figure 4. Attenuation w r t USGS epicentre using McGuire empirical formula (Horiz) (Uttarkashi earthquake, 20 October 1991).

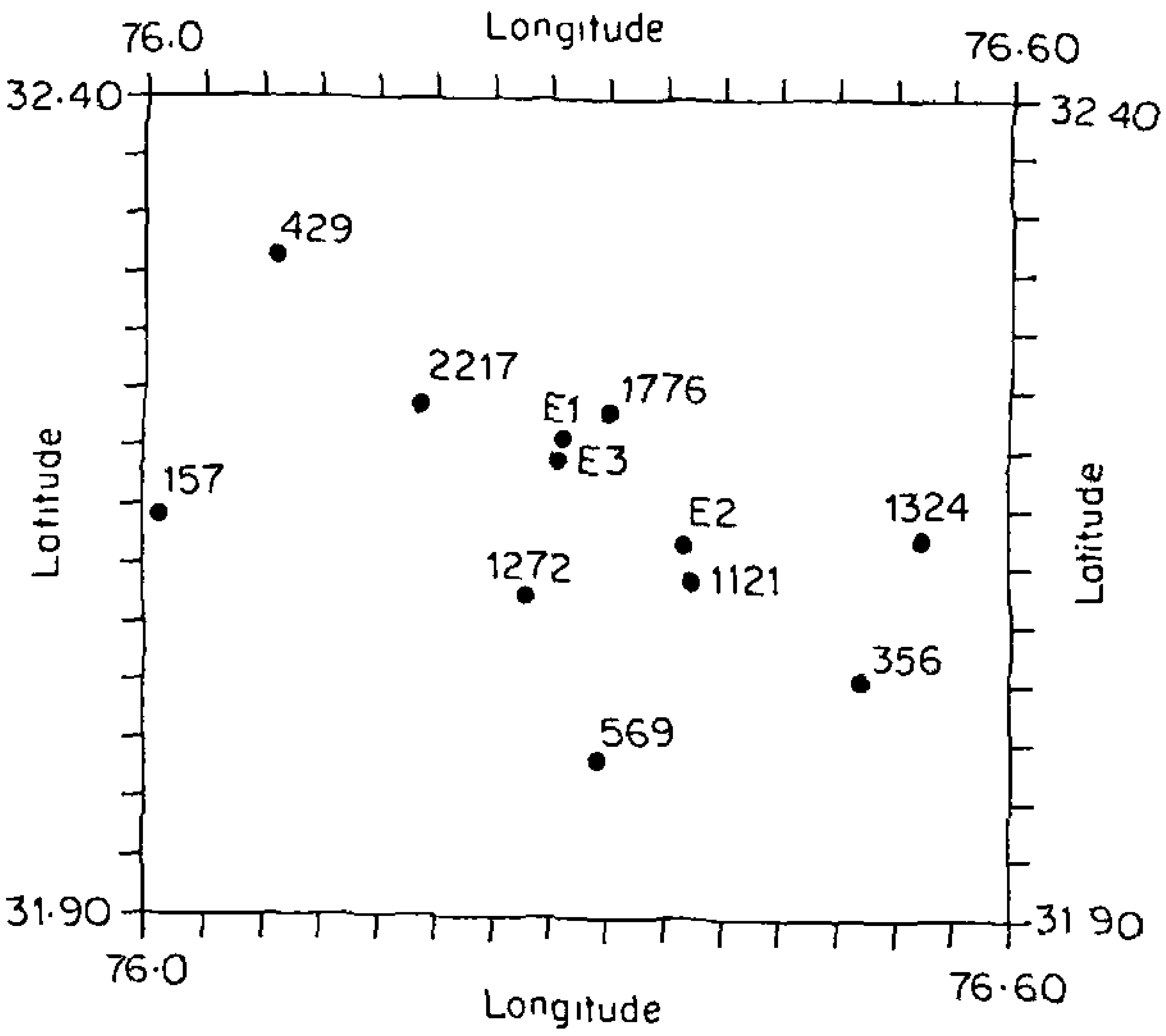

Figure 6. Mean of peak horizontal acceleration (mm/sec^2) recorded in two orthogonal directions and epicentres, 26 April 1986. Epicentre E1 (IMD), E2 (USGS), E3 (DEQ).

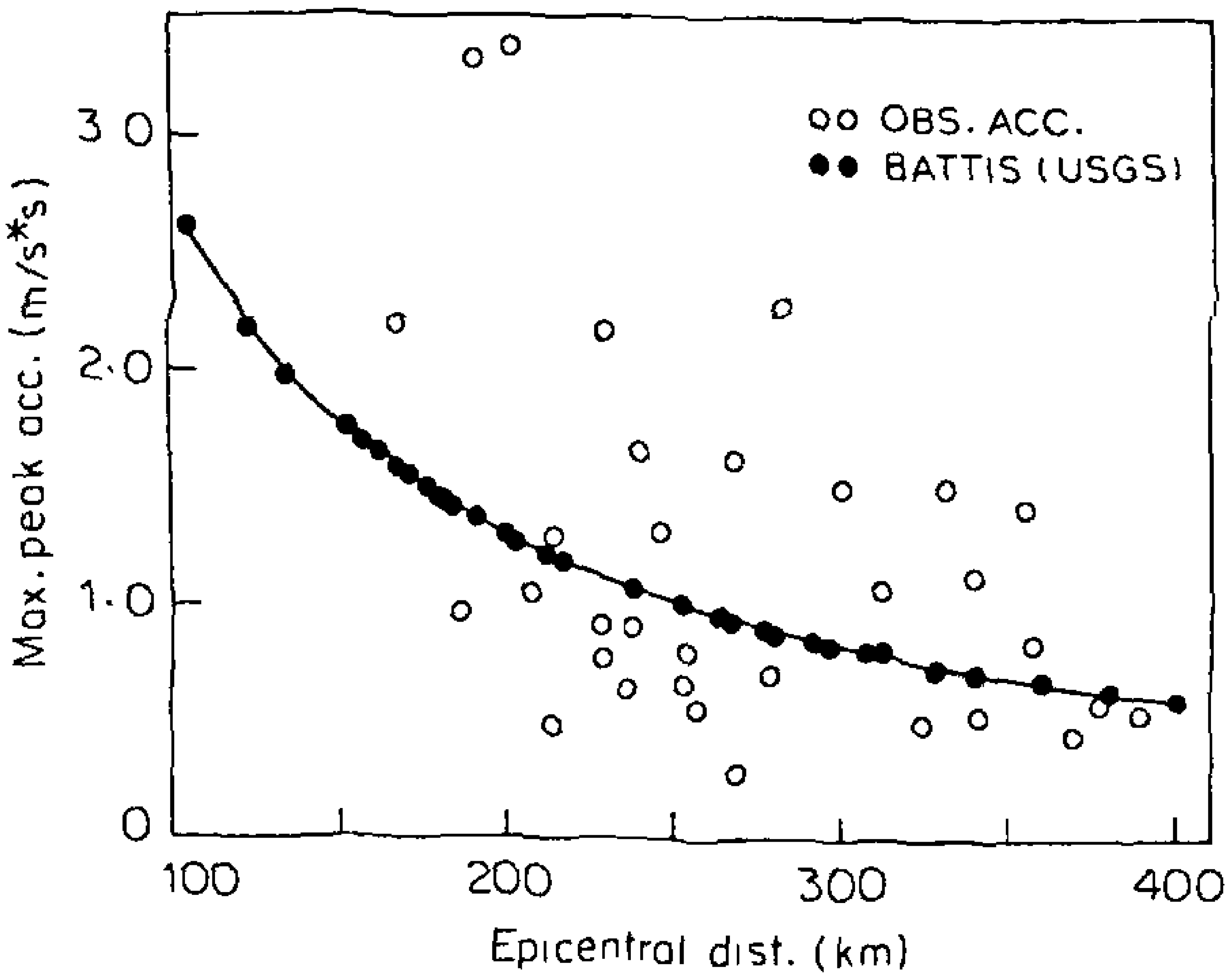

Figure 5. Plot of maximum peak observed acceleration and comparison with Battis formula (6 August 1988).

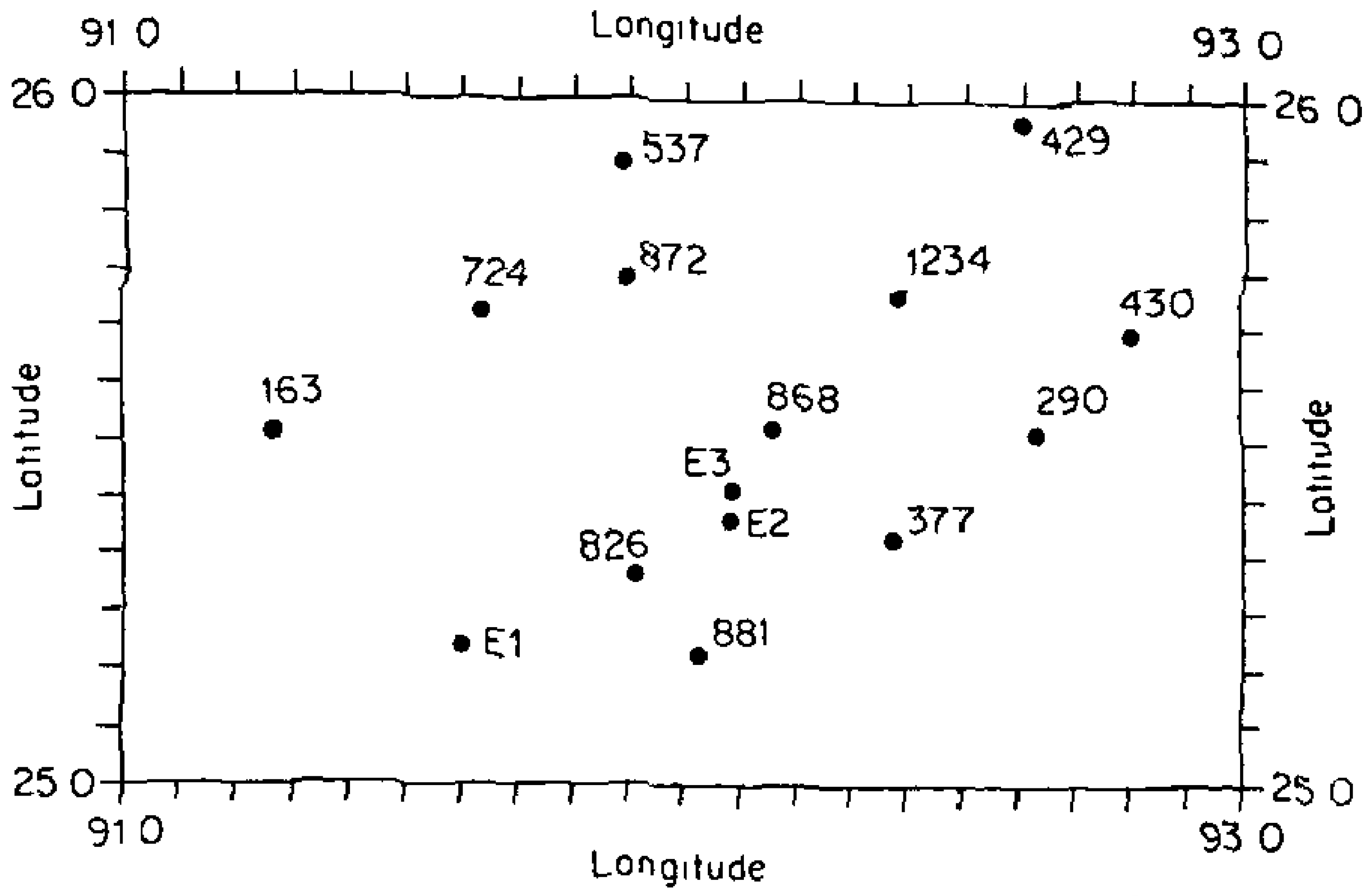

Figure 7. Mean of peak horizontal acceleration (mm/sec^2) recorded in two orthogonal directions and epicentres, 10 September 1986. Epicentre E1 (IMD), E2 (USGS), E3 (DEQ).

accurately from strong motion records as seismographs in near field are usually saturated and epicentres are postulated from distant seismic instruments only. Such an attempt was made for the Dharmsala event of April 1986 and the Shillong region event of September 1986 (Figures 6 and 7). However, for this method to be adopted and accepted, the event should be located within the array and digital accelerographs with pre-event memory should be used in the array. The absolute time should be recorded by Omega timing system or through satellite systems.

There is still a lot of variation in assigning magnitude and epicentral location by various agencies. There is a tendency to use the seismic parameters proposed by USGS (United States Geological Survey) as the star' but the pattern of strong motion values at various locations in an array may indicate otherwise. There are other parameters like effective peak acceleration, predominant frequency, Q values, etc., which can be derived from strong motion data. However, these have not been much used so far in earthquake engineering practice.

Conclusion

As at present, in the short run, it appears that only NE India region would give valuable strong motion data as earthquakes occur there more frequently. At all other regions, a long wait is required to build a meaningful database. Till such time, there is bound to be controversy in the choice of earthquake parameters. Evaluation of earthquake potential of a site should be independent of the structure to be built. The choice of design earthquake parameters should be based on engineering experience gained worldwide.

1. *Earthquake-Resistant Regulation, A World List*, International Association of Earthquake Engineering, Tokyo, 1992.
2. *Seismic and Geologic Siting Criteria for Nuclear Power Plant*, 10 CFR Part 100, USNRC, US Atomic Energy Commission, Washington, DC, 1973.
3. *Design Response Spectra for Seismic Design of Nuclear Power Plants*, Regulatory Guide 1.60, USNRC, US Atomic Energy Commission, Washington, DC, 1973
4. *Earthquake and Associated Topics in Relation to Nuclear Power Plant Siting*, Safety Series No. 50–SG-S1, IAEA, Vienna, 1979.
5. *Seismic Analysis and Testing of Nuclear Power Plant*, Safety Series No. 50–SG-S2, IAEA, Vienna, 1979
6. *Seismic Studies and Design Basis Ground Motion For Nuclear Power Plant Sites*, Guide No. AERB/SG/S-11, Atomic Energy Regulatory Board, India, 1990.
7. Chandrasekaran, A. R., Sixth World Conference on Earthquake Engineering, New Delhi, 1977.
8. Kennedy, R. P. and Short, S. A., SMIRT, K4/1 9, 1984.
9. International Commission on Large Dams Bulletin 72, 1989.
10. *Draft Recommendations for Determination of Seismic Parameters*, Central Water Commission, India, 1990
11. IS·1893–1984, *Indian Standard Criteria for Earthquake-Resistant Design of Structures*, Indian Standard Institution, New Delhi, 1986
12. Chandrasekaran, A. R. and Das, J., 'Strong Motion Arrays in India and Characteristics of Recent Recorded Events', ISET Annual Lecture, 1988, Bulletin, ISET, 1990, vol 27, no. 1.
13. Chandrasekaran, A. R. and Das, J., *Curr. Sci.*, 1990, **62**, 233–250.
14. Chandrasekaran A. R. and Das, J., Fourth International Conference in Seismic Zonation, Stanford, USA, 1991.
15. Campbell, K. W., *Earthquake Spectra*, 1985, vol. 1.

Specifying aseismic design inputs for critical structures

R. D. Sharma

Seismotectonics Group, Nuclear Power Corporation of India Limited, Vikram Sarabhai Bhavan, Anushaktinagar, Bombay 400 094, India

It is possible to design engineering structures, which would withstand the impact of future earthquakes, if this impact is specified in terms of the vibratory ground motion, which the structures are expected to experience during future earthquakes. Such specifications of the vibratory ground motions form the basis of aseismic design. While the procedures for specifying aseismic design inputs for conventional structures which came into existence earlier, were based on an approach of minimizing the losses by preventing collapse, more elaborate procedures are now adopted for aseismic design of structures of critical facilities, e.g. dams and nuclear power plants, where the acceptable limits of damage are much lower. The approach to specifying aseismic design inputs for such structures is discussed in some detail with a view to identifying issues, that need to be addressed from the standpoint of adequacy of design.

State-of-the-art techniques in engineering design have made it possible to design engineering structures to withstand earthquakes. The Bureau of Indian Standards has specified criteria for designing structures to withstand ground vibrations during earthquakes (IS-1893)[1]. Here, the design inputs are specified in terms of a seismic coefficient (or zone factor) and a set of response spectra. The seismic coefficient at any place is equivalent to the maximum peak ground acceleration (PGA), which can be expected on the basis of the maximum earthquake intensity at that place from past earthquakes. The prediction of intensities assumes that earthquakes will follow the observed patterns. Some recent experiences have, however, shown that occurrence of earthquakes stronger than those occurred in a region during historical times, cannot be precluded. The IS-1893 specifications aim at safety of the engineered structures as long as ground motion remains within these levels. If these levels are exceeded, the structures may be damaged, but will not collapse, thereby saving lives and property. Protecting the structures against moderate earthquake intensities and limiting the damage to acceptable limits during the most severe event is, thus, the intent of the IS-1893. It is believed that beyond the levels of these specifications it would be more economical to repair the structures, or even reconstruct them. This works out well for most structures, except for critical ones like dams, nuclear power plants and lifelines, where safety requirements are more stringent. The approaches to aseismic design of such structures were developed during the past twenty five years, particularly in the context of nuclear power plants[2,3]. Salient features of these approaches are discussed here.