Bull. Ind. Soc. Earth. Tech., Paper No.364, Vol.34. No.1, March.1997, pp 27-46.

EVALUATION OF EARTHQUAKE PARAMETERS IN PENINSULAR INDIA AND STRONG MOTION CHARACTERISTICS

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ABSTRACT

The 1967 Koyna and recent 1993 Khillari earthquakes triggered a rethinking on the seismic status of the Peninsular India which hitherto was thought to be a relatively stable land mass. Under such a changed seismotectonic scenario, evaluation of site dependent earthquake design parameters for important projects has become necessary. Earthquake design parameters for several projects have been recommended by the Department of Earthquake Engineering. This involves postulation of causative faults for estimation of Peak Ground Acceleration and proposing design response spectra and ground motion time history. A brief description of parameters adopted for project sites in Peninsular India is given.

Except in Koyna region, no strong motion records are available in Peninsular India. Accelerograms from Koyna which are recorded in the period from 1968 to 1994 have been reanalysed and Attenuation relationship and shape of acceleration response spectra have been derived. The results have been compared with those from Himalayan region and it is seen that Koyna results are on the lower side.

INTRODUCTION

Peninsular India, has till recently been thought as a stable region from seismic view point. The past history of observed or recorded earthquakes has strengthened this impression. The activity in Koyna region, which first surfaced in sixties was thought to be an exception and some have attributed it to reservoir even though the main event in December, 1967 is now accepted as tectonic only. There had been tremors/micro-earthquakes in isolated regions like Bhatsa, Idukki, etc. The relatively strong earthquake that occurred at Khillari in September, 1993 has confounded the scientific community.

The seismic zoning map in IS:1893 of Indian Standards Institution underwent a revision after the main Koyna event. Even then, a very large area in peninsular India is assumed as mild (zone III) or practically non-seismic (zone II & I) and only the region around Koyna was assumed to be moderate (zone IV). Further, the seismic coefficients corresponding to these zone (II & I) were small and earthquake engineering aspects were not considered as important by the engineering community.

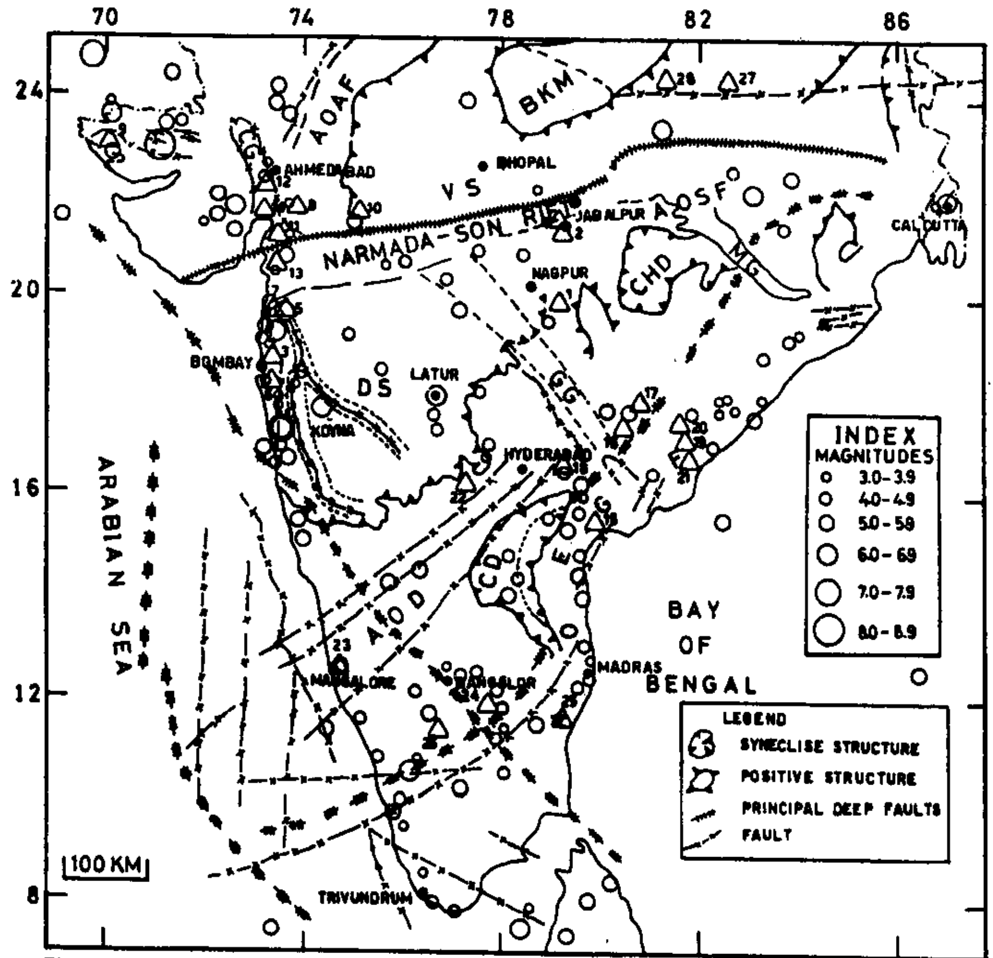

Fig. 1 Tectonic and seismicity map of the Peninsular India. AOEGF - Areas of Eastern Ghat Folding. AOD - Areas of Dharwar. AOAF - Areas of Aravalli Folding. AOSF - Areas of Satpura Folding. BKM - Bundelkhand Massif. DS - Deccan Syneclise. VS - Vindhyan Syneclise. CHD - Chattisgarh Depression. CD - Cuddapah Depression. CG - Cambay Graben. MG - Mahanadi Graben. GG - Godavari Graben. Δ - Numbered project sites as mentioned in text. Compiled from Brahmam, N.K. and Negi, J.G. (1973); Schlumberger (1983) and Rao, B and Rao, P.S. (1984)

However, for important projects, site dependent earthquake design parameters were required to be evaluated. The Department of Earthquake Engineering has recommended design parameters for several projects and the first author was associated with a number of such studies. In the absence of data, such exercise posed problems. Quite often, even if tectonic features (sometimes lineaments) cannot be associated with the past data, they were deemed to be active for the purpose of design. This paper briefly discusses various tectonic features that have been considered as potential and the seismic parameter like Magnitude associated with them. The epicentral distance has been invariably assumed as though the earthquake would occur closest to the site from the postulated tectonic feature. The focal depth ranged from 10 km to 20 km depending on size of Magnitude.

In this region, only at Koyna, strong motion records have been obtained. At Koyna, in the period from 1968 to 1970 records have been obtained on photographic paper installing strong motion instrument model AR-240, and later, records were obtained on photographic film using instrument model RFT-250 from 1975 to 1989 and SMA-1 from 1993 to 1994 respectively. Whereas, in the Himalayan region records have been obtained from instruments model SMA-1 only. Though a large number of events (about 20) have been recorded (from 1968 to 1994) from Koyna region, only a few are significant. Even out of these, the record of main event is controversial and different persons have assigned values which vary (0.4 g to 0.63g). Further, this record was not at ground level but at mid level of abutment. In this paper, attenuation relationship and normalized shape of spectra for Koyna records are discussed and compared with such relationship obtained from the Himalayan region.

SEISMO-TECTONIC SET UP OF PENINSULAR INDIA

The major tectonic features of the Peninsular India are the Narmada-Son fault, Cambay graben, Mahanadi graben, Godavari graben, Kurduwadi and Koyna rift, etc. The earthquake activity of the Peninsular India is relatively sparse with a few moderate earthquakes occurring in the region. On the basis of distribution of earthquake epicenters and tectonic features, some tectonic blocks could be identified. These are the Dharwar, Cuddapah, Deccan Trap and Aravalli. In the Dharwar block, the significant earthquakes are Coimbatore (8 February 1900) and Shimoga (12 May 1975). Ongole(27 March 1967) and Bhadrachalam(13 April 1969) are in the Cuddapah block. Koyna(10 December 1967) and Khillari (30 September 1993) are in the Deccan Trap. In the Aravalli block, which includes Kutch and Bhuj, the significant earthquakes are Kutch (16 June 1819), Paliyad (23 July 1938) and Mount Abu (24 October 1969). Seismotectonic map of the Peninsular India is shown in figure 1.

EARTHQUAKE PARAMETERS POSTULATED FOR SOME SITES IN PENINSULAR INDIA

Though this part of the country is considered as relatively stable, the events at Koyna, Bhadrachalam and Broach in the recent past had meant taking conservative measures. For special structures, it is now necessary to propose site dependent earthquake parameters. A brief description of such postulated values are described. These are the probable causative faults, earthquake parameters, and expected ground motion at the site (Table 1).

MAHARASHTRA REGION

1. **Chandrapur:** Assumed to be in the NW extension of the Godavari Graben. A Magnitude of 6.5 has been assumed, at an epicentral distance of 70 km. The peak ground acceleration (PGA) evaluated from empirical relationship is 0.08g.

2. **Pench:** The Narmada-Son fault zone is the nearest feature. Magnitude 6.0, at an epicentral distance 25 km. PGA-0.12g.

3. **Nagothana:** A Fracture lineament at 5 km from the site. Magnitude 6.5. PGA-0.21g.

4. **Khaperkheda:** A lineament which is the eastern margin of the Deccan Syneclyse passing through the site. Magnitude 6.0. PGA-0.18g.

5. **Vaitarna:** The Ghod lineament at 10 km from the site. Magnitude 6.5. PGA-0.18g.

6. **Raigadh:** The Panvel flexure located at 20 km from the site. Magnitude 6.5. PGA-0.13g.

7. **Tarapur:** The Panvel flexure at 35 km from the site. Magnitude 6.5 and PGA 0.135g. The Agashi Bay lineament at 16 km from the site. Magnitude 6.5 and PGA-0.192g.

GUJARAT REGION

8. **Navagam:** The Piplod fault at 12 km and Jetpur fault at 8 km from the site. Magnitude 6.5. PGA-0.16g.

9. **Kutch:** Earthquake of Magnitude 8.0 occurred at 120 km from the site. Another, Magnitude 6.3 occurred at 150 km. Design MCE assumed as of Magnitude 6.5 at 10 km. PGA-0.20g.

10. **Broach:** The NW-SE trending lineament close to the site. Magnitude 6.5, PGA-0.23g.

11. **Kakrapar:** A E-W trending lineament at 27 km towards south of the site. A NW-SE lineament at 28 km towards NE of the site. A NS trending lineament at 36 km towards east of the site. Another NS trending lineament at 44 km towards west of the site. MCE had magnitude of 6.5 at 24 km from the site. PGA-0.2g.

12. **Baroda:** Lineaments bordering the eastern margin of the Cambay Graben and Northern boundary of the Narmada fault belt. Magnitude 6.5 at 22 km, PGA-0.17g.

13. **Sidhumber:** Surrounded by lineaments in all directions. Magnitude 6.5 at 20 km PGA-0.18g.

14. **Gandhar:** A E-W trending lineament at 10 km from the site. Magnitude 6.5, PGA-0.22g.

ANDHRA PRADESH REGION

15. **Ongole:** The site is 20 km south-east from the Guntur-Kakinada fault. Magnitude 6.0 at 10 km. PGA-0.15g.

16. **Bhadrachalam:** Site is located at the south-east part of the Godavari Graben. Magnitude 6.5 at 15 km, PGA-0.19g.

17. **Khamman:** Located within the Godavari Graben. Magnitude 6.5 with PGA-0.15g.

18. **Nagarjuna:** Located at Northern edge of the Cuddapah depression. Magnitude 5.0 at 10 km, PGA-0.10g.

19. **Jegurupadu:** The Guntur-Kakinada fault at 12 km. Magnitude 6.0. PGA-0.131g.

20. **Polavaram:** The site is 25 km from the bounding fault of the Godavari Graben. Magnitude 6.5. PGA-0.16g.

21. **Kakinada:** Located at 8 km from the Guntur-Kakinada fault. Magnitude 6.0. PGA-0.12g.

KARNATAKA REGION

22. **Raichur:** Lies in the Dharwar folding. Magnitude 5.5 at 10 km. PGA-0.12g.

23. **Mangalore:** A tectonic feature at 75 km from the site. Magnitude 6.0. PGA-0.07g.

TAMIL NADU REGION

24. **Mettur:** Lies in areas of Dharwar folding. Magnitude 6.0 at 15 km. PGA-0.14g.

25. **Neyveli:** A NE-SW trending lineament at 25 km from the site. Magnitude 5.7. PGA-0.11g.

KERALA REGION

26. **Kakkad:** A NW-SE trending deep seated fault at 20 km. Magnitude 6.0. PGA 0.127g.

MADHYA PRADESH REGION

27. **Waidhan:** A lineament separating Bijawar and Granite gneisses in the Satpura folding. Magnitude 6.5, PGA-0.16g.

28. **Bansagar:** Lies 25 km north of the Narmada-Son fault system. Magnitude 6.5, PGA-0.16g.

TABLE 1

S N	SITE	CAUSATIVE LINEAMENT/ FAULT	DISTANCE FROM SITE	EXPECTED PROBABLE MAGNITUDE	ESTIMATED PEAK GROUND ACC. (g)
	MAHARASHTRA				
1.	Chandrapur	Godavari Gravben	70	6.5	0.08
2.	Pench	Narmada-Son Fault	25	6.0	0.12
3.	Nagothana	Fracture Lineament	5	6.5	0.21
4.	Khaperkheda	Eastern Margin of Deccan Syneclyse	<1	6.5	0.21
5.	Vaitarna	Ghod Lineament	10	6.5	0.18
6.	Raigadh	Panvel Flexure	20	6.5	0.13
7.	Tarapur	Agashi Bay Lineament	16	6.5	0.19

	GUJARAT				
8.	Navagam	Jetpur Fault	8	6.5	0.16
9.	Kutch	A Lineament	10	6.5	0.20
10.	Broach	NW-SE Lineament	<1	6.5	0.23
11.	Kakrapar	A Lineament	24	6.5	0.20
12.	Baroda	Eastern margin of Cambay Graben	22	6.5	0.17
13.	Sidhumber	Lineaments	20	6.5	0.18
14.	Gandhar	E-W Lineament	10	6.5	0.22
	ANDHRA PRADESH				
15.	Ongole	Guntur-Kakinada Fault	10	6.0	0.15
16.	Bhadrachalam	Godavari Graben	15	6.5	0.19
17.	Khammam	Godavari Graben	<1	6.5	0.15
18.	Nagarjuna	Cuddapah Depression	10	5.0	0.10
19.	Jegurapada	Guntur-Kakinada Fault	12	6.0	0.13
20.	Polavaram	Godavari Graben	25	6.5	0.16
21.	Kakinada	Guntur-Kakinada Fault	8	6.0	0.12
	KARNATAKA				
22.	Raichur	Dharwar Folding	10	5.5	0.12
23.	Mangalor	A Lineament	75	6.0	0.07
	TAMILNADU				
24.	Mettur	Dharwar Folding	15	6.0	0.14
25.	Neyveli	NE-SW Lineament	25	5.7	0.11
	KERALA				
26.	Kakkad	NW-SE Fault	20	6.0	0.13
	MADHYA PRADESH				
27.	Waidhan	A Lineament		6.5	0.16
28.	Bansagar	Narmada-Son Fault	25	6.5	0.16

For postulation of earthquake design parameters for various sites in Peninsular India, expected magnitudes range from 5.5 to 6.5 and estimated ground motion range from 0.07 to 0.23. For this purpose detailed studies on the nature of causative lineaments/faults around the site were carried out. Then it has been considered that an earthquake of a particular magnitude, having intensity on higher side, is expected along a particular lineament/fault. With these informations available, ground motions at various sites have been worked out using published empirical relations. Therefore, postulated ground accelerations are conservative in view of recent seismic activity of the region which hitherto thought to be less active.

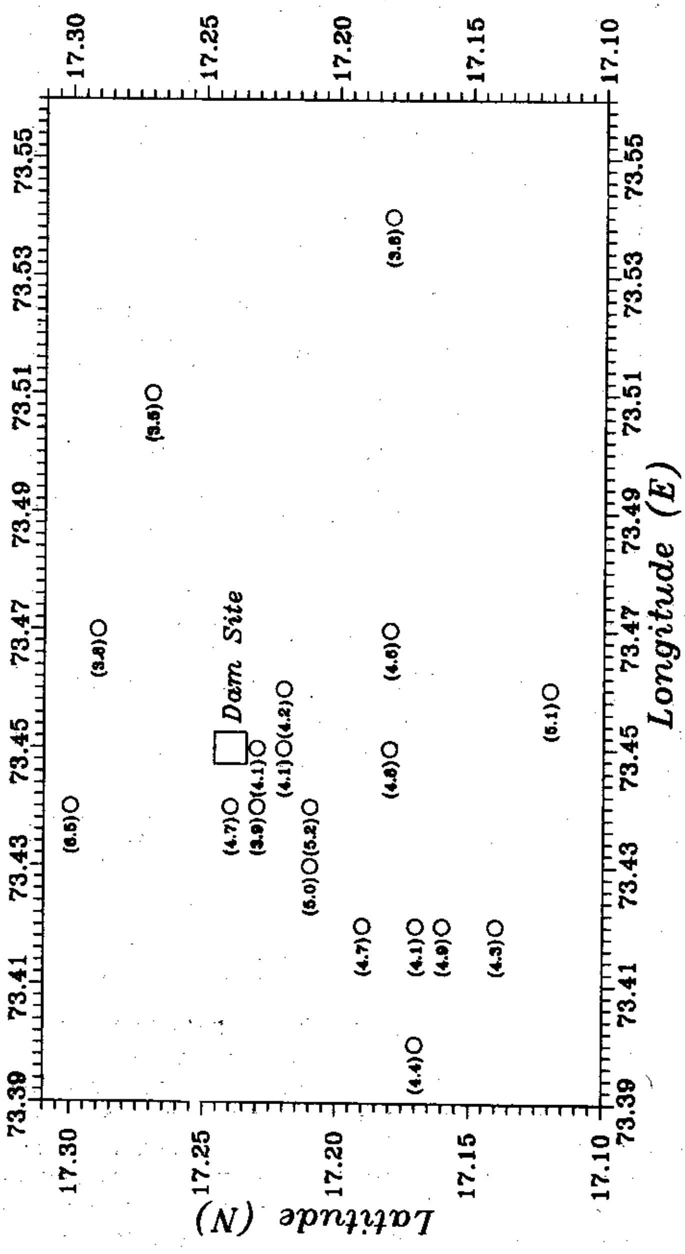

Fig 2 Location of Earthquake Epicentres in Koyna Region. Values within the parenthesis indicate magnitudes.

STRONG MOTION DATA FROM KOYNA DAM INSTRUMENTS

At Koyna dam site, strong motion accelerographs are installed at the following locations;

(a) At the foundation gallery of Monolith 17,
(b) At the foundation gallery of shear zone,
(c) At the downstream observatory,
(d) At the mid gallery of monolith 1A and
(e) At the Top of monolith 17.

The motion at locations (a), (b) and (c) may be deemed to be that as base ground motion. After the main event in December 1967, twelve (12) events have been recorded at the foundation gallery of M-17, eight (8) events at the foundation gallery of shear zone and seven (7) events at the down stream observatory. The magnitude of these events varied from 3.5 to 5.2. After October 1968, the largest event recorded was in February 1994. The reported epicenter of a majority of the events lie in an area bounded by the latitudes 17.12 and 17.30^{0}N and longitudes 73.40 and 73.54^{0}E (Figure 2). There is a very wide scatter in recorded acceleration level with respect to the Magnitude, even though the distance between epicenter and recording station is nearly the same in these events.

ATTENUATION RELATION

For obtaining the attenuation relationship, a data base is needed for several earthquakes, recorded at varying distances. In Koyna, the recording distance for most of the events is nearly the same and variation is only with respect to the Magnitude. The analysis indicate that those events above Magnitude 4.9 could give meaningful results. An attenuation relation was fitted to the recorded data with the help of an equation in the following form as proposed by McGuire, 1978.

Y = c1*exp(c2*M)/(R**c3)

where, Y is the acceleration in m/s^2, M is the Magnitude and R is the hypocentral distance in km. The coefficients c1, c2 and c3 so evaluated for the horizontal direction are: c1 = 7.57, c2 = 1.74 and c3 = 4.21, and in case of vertical ground motion the coefficients are c1 = 5.37, c2 = 1.33 and c3 = 3.31. Estimation of coefficients of the empirical relation has been carried out by linear multiple regression with independent variables. Data consists observed acceleration, hypocentral distance and magnitude. In this case, data used comprised different earthquakes recorded by three different instrument model which are AR-240, RFT-250 and SMA-1. Figures 3a and 3b show a comparison of the above with that of McGuire's attenuation relationship for 1A mid gallery and foundation gallery sites respectively. It has been observed that the

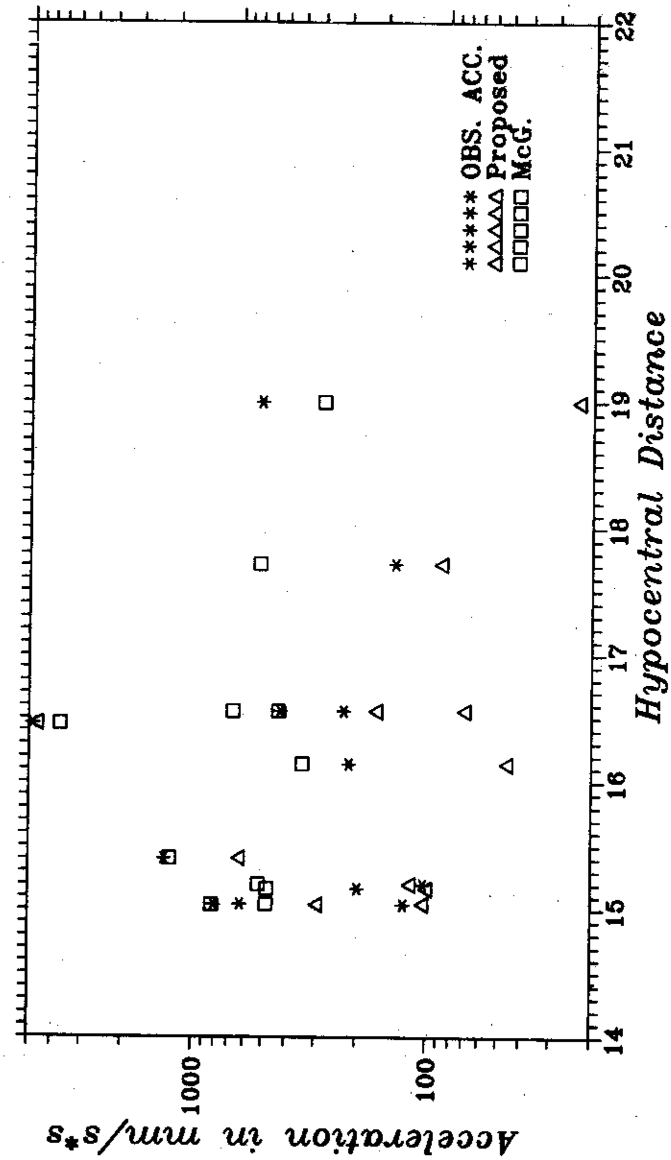

Fig 3a Plot of Observed (max. of horiz. acc.) and Estimated Peak ground acceleration in KOYNA region for 1A mid gallery sites

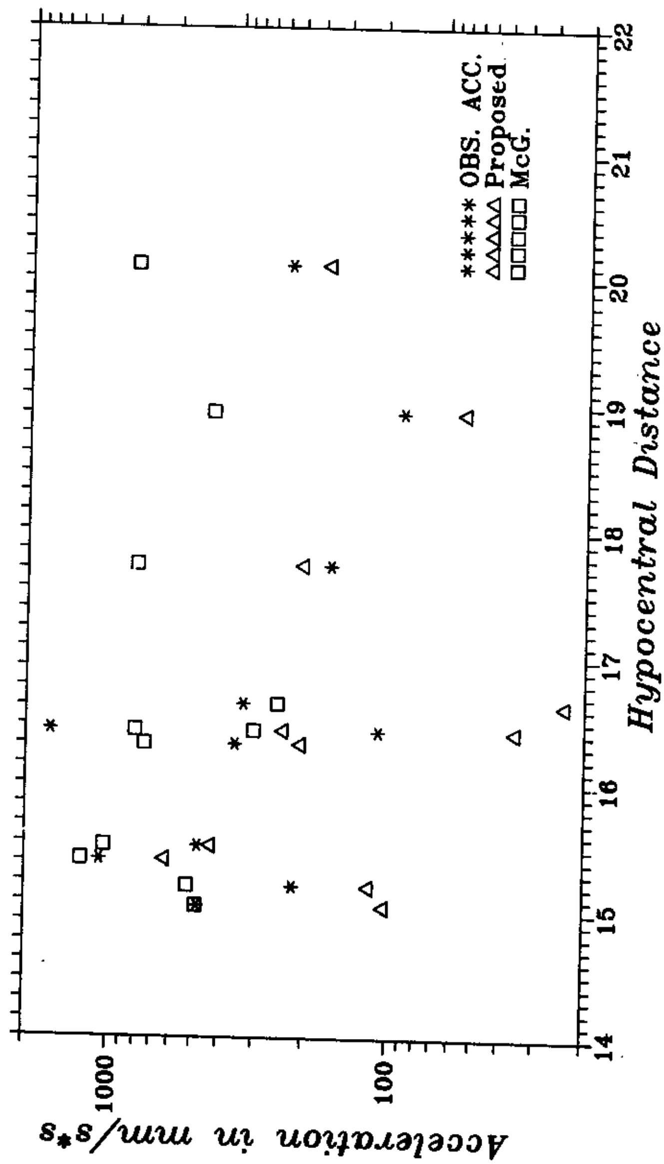

Fig 3b Plot of Observed (max. of horiz. acc.) and Estimated Peak ground acceleration in KOYNA region for foundation gallery

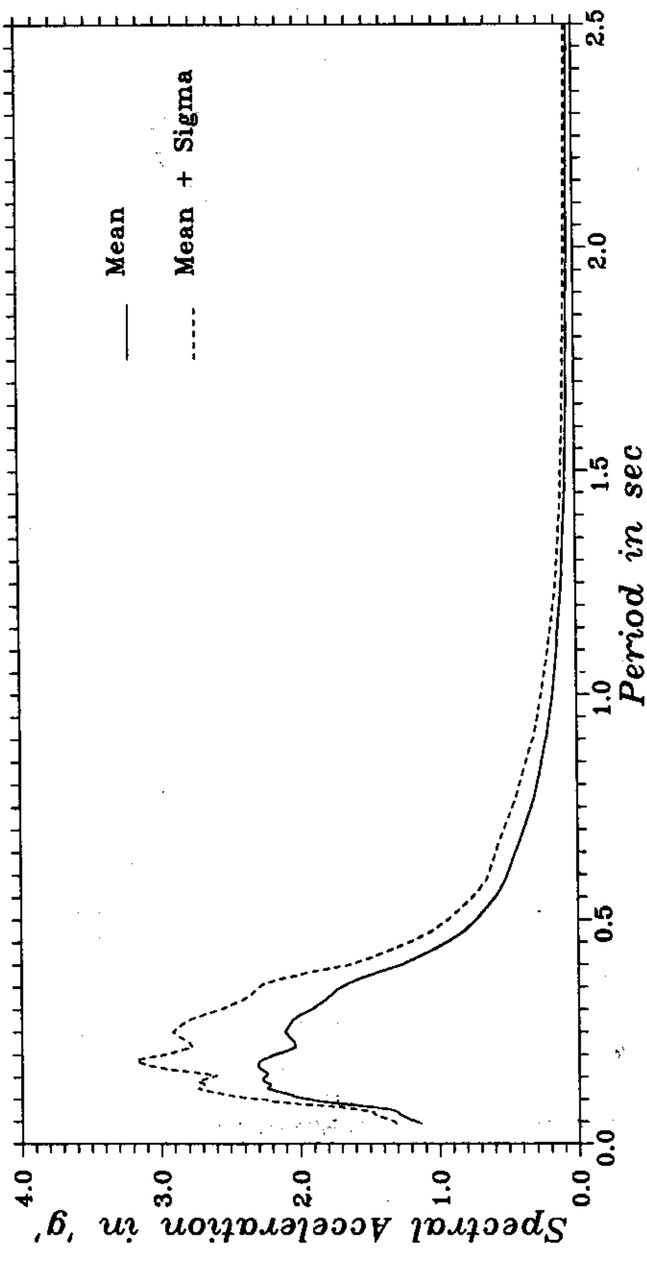

Fig 4 Normalised Horizontal Acceleration Spectra for Koyna earthquakes considering records greater than 0.04g at 5 percent damping.

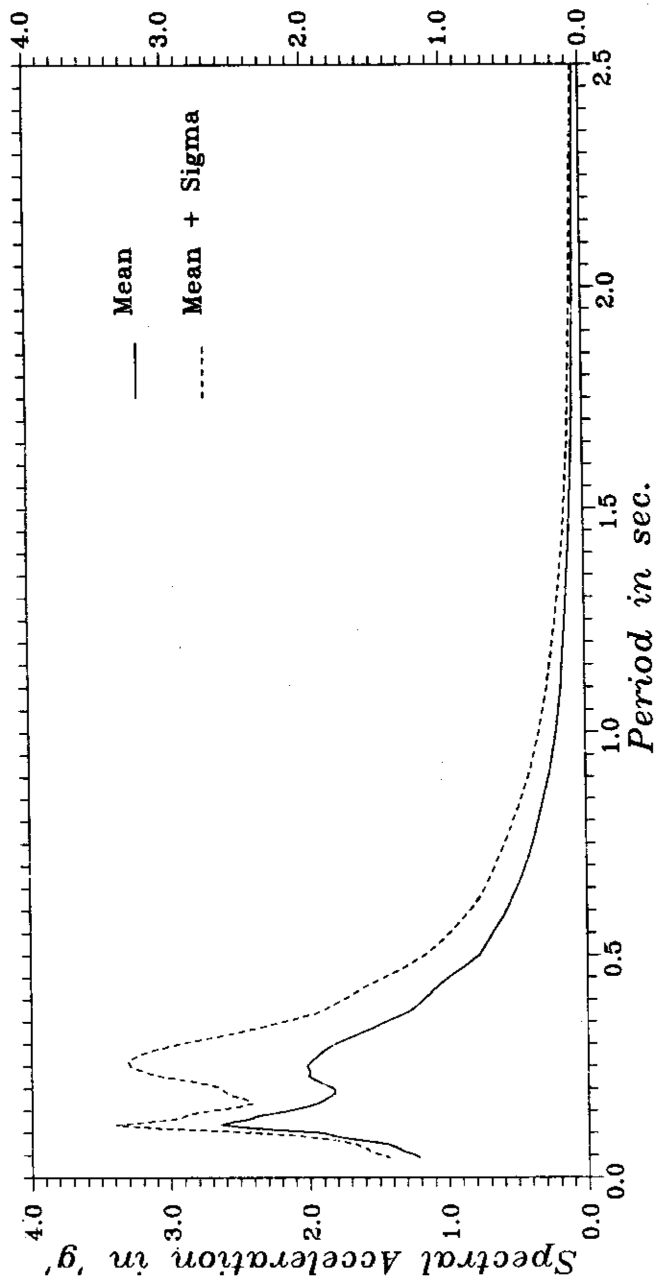

Fig 5 Normalised Vertical Acceleration Spectra for Koyna earthquakes considering records greater than 0.02*g* at 5 percent damping.

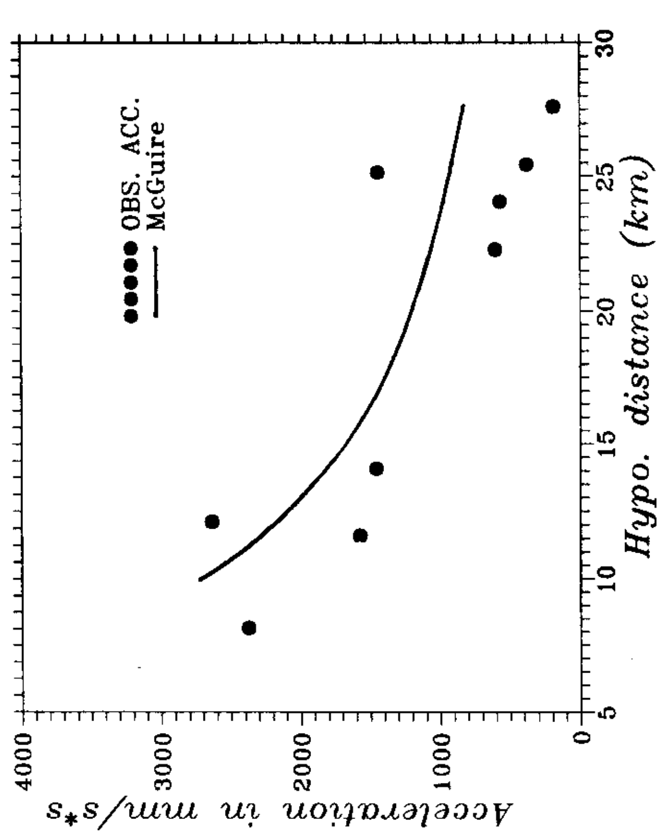

Fig 6 Plot of Observed Peak Ground Acceleration and Comparison with McGuire's relationship. Dharmsala (H.P.) Earthquake, APR 26, 1986

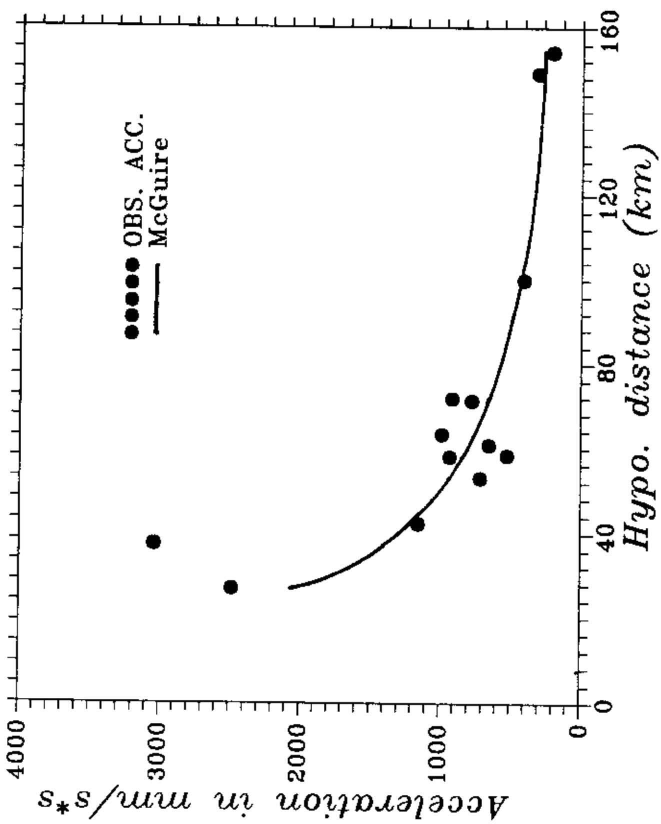

Fig 7 Plot of Observed Peak Ground Acceleration and Comparison with McGuire's relationship Uttarkashi Earthquake, OCT 20, 1991

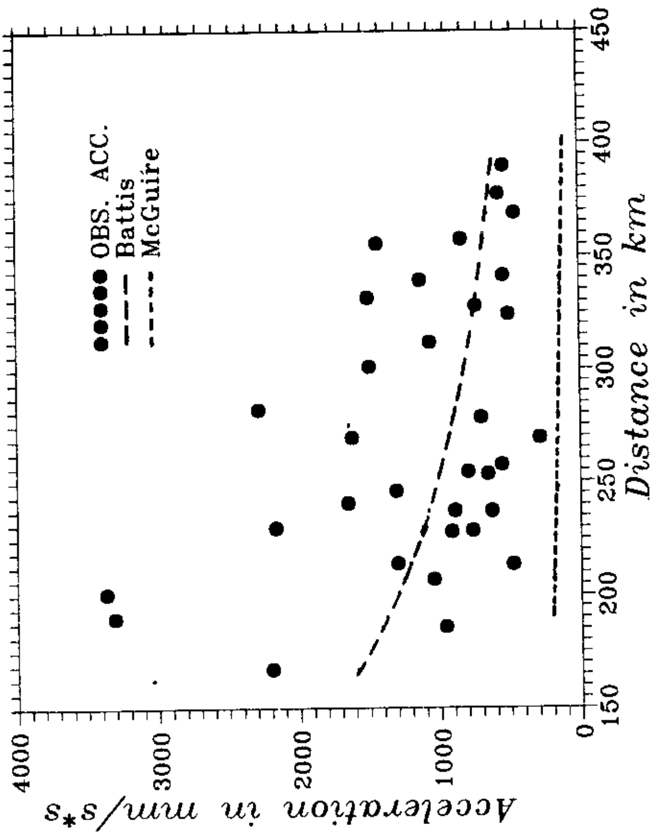

Fig 8 Plot of Observed Peak Ground Acceleration and Comparison with Battis's & McGuire's relationship. Northeast India Earthquake, AUG 6, 1988
McGuire and Battis relation have been shown as an extrapolation.

McGuire's give higher values than the proposed by authors for Koyna region (more near upper bound).

SHAPE OF SPECTRA

For all the events, response acceleration spectra have been worked out for 5% damping. These values were normalized to unit gravity by dividing all ordinates with its respective peak ground acceleration (PGA). Mean and standard deviation have been statistically analyzed for these normalized data. In case of horizontal component of ground motion, events with peak ground acceleration-horizontal (PGA-h) less than 0.04 g and in case of vertical component of ground motion, events with peak ground acceleration-vertical (PGA-v) less than 0.02 g have been ignored (Figures 4 and 5). The shape of mean and mean+sigma for the reduced subset as that used for obtaining attenuation relation is nearly the same and hence the shape is not influenced by the small magnitude events.

In case of horizontal component of ground motion maximum value of mean is 2.30 g at 0.174 Sec. and mean+sigma is 3.17 g at 0.190 Sec. (Figure 4). In case of vertical component of ground motion maximum values of mean and mean+sigma are 2.64 g and 3.39 g respectively, at 0.118 Sec. (Figure 5).

COMPARISON OF STRONG MOTION CHARACTERISTICS IN KOYNA AND HIMALAYAN REGION

ATTENUATION RELATIONS

For the Dharamsala and Uttarkashi events, it was shown (Chandrasekaran and Das, 1990; Chandrasekaran and Das, 1992 and Chandrasekaran, 1994) that the McGuire's (1978) attenuation relationship gives a reasonable prediction (Figures 6 and 7). Figure 8 shows that in Northeast India, McGuire's values are an underestimation (Chandrasekaran and Das, 1994 and Chandrasekaran 1994) but, Battis (1981) gives a resonable prediction. Whereas, figures 3a and b show that in the Koyna region McGuire's emperical relation predicts higher acceleration values. Thus, the values of acceleration are largest in N.E. India and smallest in Koyna.

SHAPE OF SPECTRA

As far as shapes of spectra are concerned, the comparisons for 5% Mean Spectra is as follows:

Koyna region gives smallest values in entire period range (Figures 9 a and b). In the period range between 0.15 to 0.3 sec., both the regions in Himalayas give similar values. In the very short period region below 0.15 sec., the N.E. region

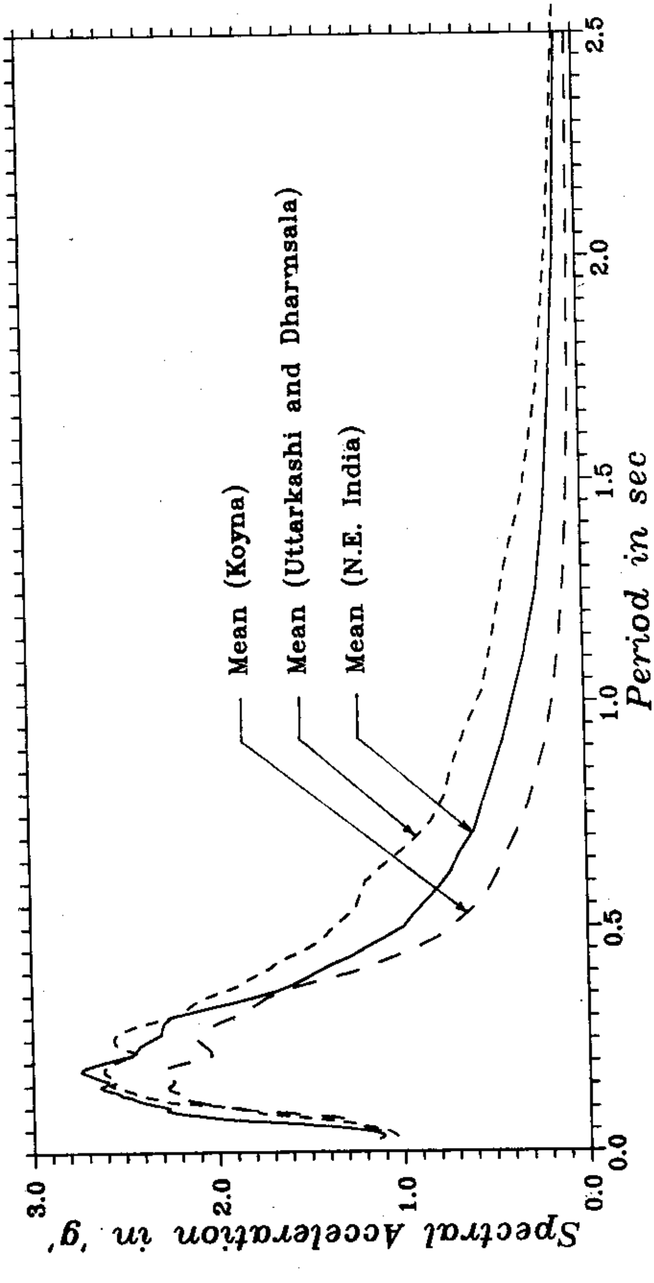

Fig 9A Comparison of Mean Shape of Spectra for N.E. India, Uttarkashi, Dharmsala and Koyna region earthquakes at 5 percent Damping

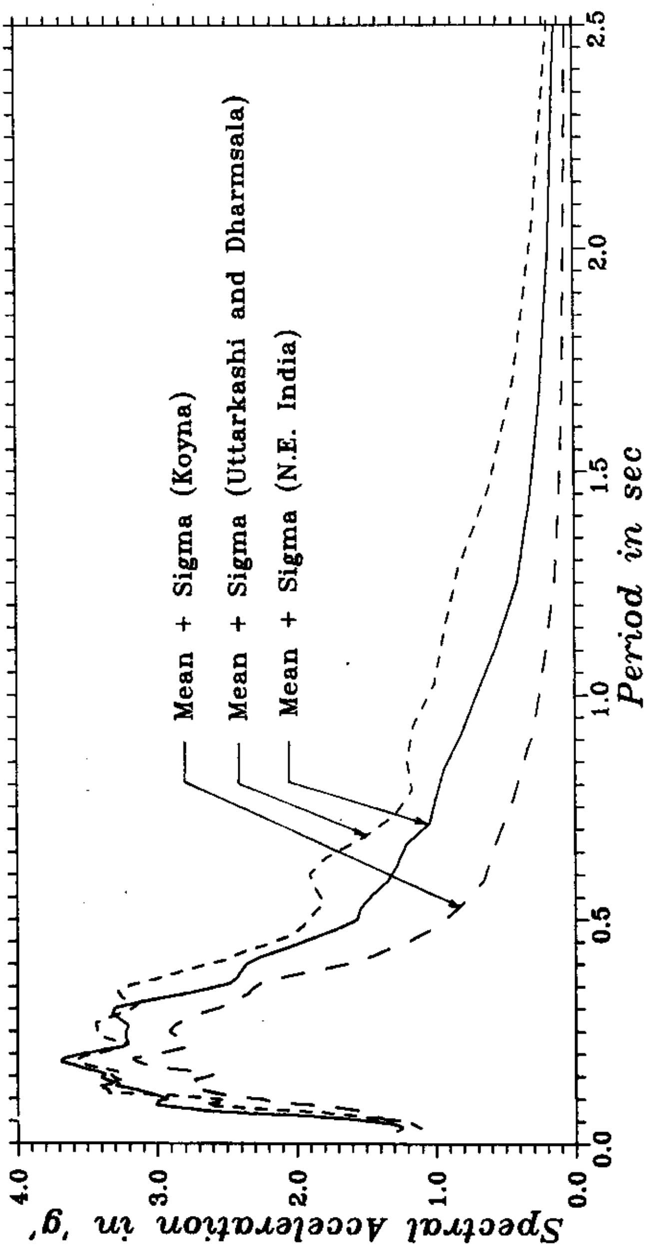

Fig 9B Comparison of Mean + Standard Deviation Shape of Spectra for N.E. India, Uttarkashi, Dharmsala and Koyna region Earthquakes at 5 percent Damping

has highest value and beyond 0.3 sec., the H.P. and U.P. region give highest values.

ACKNOWLEDGEMENTS

Thanks are due to Chief Engineer, KHEP, Pune for making available the Strong motion accelerograms of Koyna region. Several unpublished reports of the Department of Earthquake Engineering, University of Roorkee, dealing with the evaluation of site dependent earthquake parameters in Peninsular India have been briefly referred to in this study.

REFERENCES

1. ***Battis, J.*** (1981) *Regional modification of acceleration functions.* Bull. Seis. Soc. Am., 71, 1309-1321.

2. ***Brahmam, N.K. and Negi, J.G.*** (1973) *Rift valleys beneath Deccan traps (India).* Geophysical Research Bulletin, 11, 207-237.

3. ***Chandrasekaran, A.R. and Das, J.D.*** (1990) *Strong motion arrays in India and characteristics of recent recorded events.* Bull. Indian Soc. Earthquake Tech., 27, 1-66.

4. ***Chandrasekaran, A.R. and Das, J.D.*** (1992) *Analysis of Strong motion accelerograms of Uttarkashi earthquake of 20 October, 1991.* Bull. Indian Soc. Earthquake Tech., 29, 35-55.

5. ***Chandrasekaran, A.R.and Das, J.D.*** (1994) *Analysis of Strong motion accelerograms of North-east India earthquake of 6 August, 1988.* J. Institute of Engineeers. 75, 1-11.

6. ***Chandrasekaran, A.R.*** (1994) *Evaluation of design earthquake parameters for a site and utilization of strong motion data.* Current Science, 67, 353-357.

7. ***McGuire, R.K.*** (1978) *Seismic ground motion parameter relations.* J. Geotech. Engg. Div., ASCE, 104, 481-490.

8. ***Rao, B. and Rao, P.S.*** (1984) *Historical seismicity of peninsular India.* Bull. Seis. Soc. Am., 74, 2519-2533.

9. ***Schlumberger*** (1983) Well Evaluation Conference