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DEVELOPMENT OF UNIFORM HAZARD RESPONSE SPECTRA FROM ACCELEROGRAMS RECORDED ON ROCK SITES

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ABSTRACT

Traditionally, the seismic design basis ground motion has been specified by response spectral shapes and the peak ground acceleration(PGA). The mean recurrence interval (MRI) is evaluated for PGA only. The present work has developed response spectra having the same MRI at all frequencies. This report extends the work of Cornell (on PGA) to consider an aerial source model and a general form of the spectral acceleration at various frequencies. The latter has been derived from a number of strong motion earthquake recorded on rock sites. Sensitivity of the results to the changes in various parameters has also been presented. These results will help to determine the seismic hazard at a given site and the associated uncertainties.

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1. INTRODUCTION

The safety of a nuclear power plant (NPP) depends upon a number of factors - intrinsic and external to the plant. The safety of the plant or, alternatively, the risk associated with it depends, among others, on seismic ground motion.

The objective of aseismic design of power plant components and structures is to ensure safety of the plant and the people around in the event of an earthquake. The structural response to the ground motion is conveniently expressed by pseudo absolute acceleration response spectra(RS) for various values of damping and these spectra are useful inputs for design and analysis of components and structures.

The response of a structure to an earthquake depends on its magnitude, the distance of the site from the centre of energy release, the frequency content and duration of the signal, attenuation characteristics of the transmission path, earthquake source dynamics and the properties of the structure in question. Obviously, safety against a set of postulated events originating at various locations, as dictated by the local geological and tectonic features, can be ensured only by considering a large number of records having earthquake parameters in the range of interest. For better compatibility, these data should be drawn from sites having similar geological conditions (rock/soil). The response spectra of the individual records can be statistically combined. The mean and the standard deviation of spectral values (at all frequencies) will then reflect the variations in the source-transmission path-site characteristics and help in evaluating the probabilities of exceedence of the specified spectral values. It has been the practice to normalise the response spectra of the individual accelerograms with respect to the corresponding peak ground acceleration (PGA) before the statistical combination. The design basis ground motion is generally specified by normalised response spectra (also knownn as response spectral shapes or the dynamic amplifications factors, DAFs) for various values of damping and a PGA together with a ground motion time-history. The PGA is evaluated by empirical relations involving earthquake magnitude and the distance between the source and the site.

Design basis normalised response spectra based on a number of recorded time-histories have been evolved since the first standard response spectra were proposed by Housner(1959) on the basis of eight strong motion records of four earthquakes. The studies by Blume et al. (1973) based on 33 accelerograms and Newmark et al. (1973) based on 28 accelerograms eventually led to the development of the spectral shapes recommended by USAEC(1973). These studies, however, considered only horizontal accelerograms and did not differentiate between the spectral shapes on the basis of site conditions (rock/soil).

Subsequent studies by Hyashi et al. (1971), Seed et al. (1976a) and Mohraz (1976) demonstrated the site dependence of spectral shapes. The published results are for horizontal response spectra for 5% and 2% damping. It has been observed that the standard site-independent response spectra are unconsevative in certain frequency ranges e.g., in the high frequency range for rock sites and in the low frequency range for soil sites(IAEA,1979).

Spectral shapes for rock and soil sites were presented by Ghosh et al. (1986, 1987,1998). The Indian Atomic Energy Board in its regulatory guide (AERB, 1990) has recommended some site-specific spectral shapes.

Several correlations are available for defining the peak ground acceleration (a) for horizontal motion - each developed from a particular data set, and therefore, best suited for interpolation within a particular range of parameters. A measure of the dispersion of the results from the basic data can be had from the standard errors associated with these correlations [Campbell, 1985]. It should be recognised that the standard error as reported by each author is with respect to the data set used by the individual author. However, the relative merit of a particular correlation has to be judged by determining the standard errors of a number of correlations for a common data set. Two widely used forms for PGA are:

$$a = b_1 \exp(b_2 M) (R+D)^{-b_3} \qquad (1)$$

$$a = b_1 10^{b_2 M} (R+D)^{-b_3} \qquad (2)$$

where M is the magnitude, R is the distance and D is a correction term to account for 'zero distance'. For any application, an equation has to be chosen that is best suited to a given source-site combination and the range of parameters under consideration.

Ghosh et al.(1998a,b) lists some well known correlations for predicting PGA.

The predicted value by a correlation generally corresponds to the mean value of PGA. A mean-plus-sigma level PGA can be obtained by adding the standard error to the mean value. For nuclear power plants (NPPs) the response spectrum (RS) is generally obtained by multiplying the mean-plus-sigma spectral shape (DAF) by the PGA obtained by a suitable correlation . Fig. 1 shows a typical response spectrum of this type(Ghosh et al.(1998a)). For comparison, a spectrum obtained by multiplying the mean value of the DAF with mean-plus-sigma level PGA is also shown in Fig. 1.

The various uncertainties and randomness associated with the occurrence of earthquakes and the consequences of their effects on the NPP components and structures call for a probabilistic seismic risk assessment (PSRA).

The PSRA comprises the evaluation of the following parameters considering variations due to their randomness and uncertainties (Kennedy et al.(1984)).

1) Seismic hazard at the site
2) Response of plant systems and structures
3) Component fragilities
4) The effect of various accident sequences

The seismic hazard at a given site is generally quantified in terms of the probability of exceedence of the design level PGA(Cornell(1968)) and the probability of exceedence of the specified ground motion response spectral shapes(USAEC(1973), Seed et al.(1976), Ghosh et al.(1986,1987,1998a)).

The approach which has traditionally been adopted in aseismic design of structures is basically deterministic in nature. The probability of exceedence in relation to the spectral shape is with respect to the database from which it has been derived and is not related with the temporal or spatial distribution of earthquakes. The probability of exceedence of the PGA is, however, evaluated considering the temporal distribution of earthquakes.

While unconservative response spectra are not desirable, overconservatism in the design basis response spectra leads to avoidable escalation of costs on one hand and reduction of the flexibility of components on the other. The choice of the data set to arrive at the design response spectra thus plays a pivotal role in engineering design.Over the years, a large data set pertaining to several strong earthquakes and different site conditions have become available, and it is now possible to use site-specific response spectra in aseismic design. It is also possible to have a suitable data set for various combinations of source and site conditions.

The present work aims to develop uniform hazard response spectra i.e. response spectra having the same mean recurrence interval(MRI), or equivalently, the same probability of exceedence in a specified span of time at all frequencies. An aerial earthquake source model has been used.The present paper extends the work of Cornell(1968) to consider an aerial source model and a more general form of the correlation for spectral acceleration. It is further recognised that the predicted seismic hazard can vary with various parameters involved. Numerical results have been presented to show this variability. These results will help to determine the seismic hazard at a given site and the associated uncertainties.

2. THEORY

Cornell(1968) has presented a model for evaluating the MRI or the probability of exceedence, P of a specified value of PGA. Ghosh et al.(1998b) considering aerial source distribution extended the method for more generalised forms for the correlation for PGA. In this report the same methodology is applied to determine the MRI and P of the spectral acceleration at various frequencies of a given response spectrum. Alternatively, a response spectrum can be generated with a specified MRI or P at any frequency. A uniform hazard RS is one where the MRI or P is the same at all frequencies. To have analytical results it is therefore necessary to develop an attenuation relation for the RS.

2.1 ATTENUATION RELATION FOR SPECTRAL ACCELERATION

Scaling of the standard response spectral shape by the peak value of the ground motion parameter implicitly assumes that the spectral shape is either independent of the intensity of ground motion or, at any rate, conservative enough to accommodate possible variations in earthquake magnitude and distance from the source. Except in case when the standard response spectral shape is an envelope of the spectral shapes of the individual accelerograms, the conservatism cannot be guaranteed. The present regulatory documents(USNRC(1997a,b)) requires the ground motion to be presented as the unnormalised response spectrum itself without scaling it to PGA. Ghosh(1987a) and Ghosh et al.(1998a) had earlier presented scaling laws for the response spectral shapes. In this work attenuation relation is developed for the unnormalised response spectrum.

The response spectral value (S) can be written as,

$$S = S(M, R, \zeta,.T) \tag{3}$$

where ζ is the value of damping and T is the period for which the response spectrum is being evaluated. For any value of damping the response spectral acceleration at each period is assumed to be of the same form as given by equation (1) i.e.

$$S = b_1 \exp(b_2 M) (R+D)^{-b}{}_3 \tag{4}$$

McGuire(1977) has used a form similar to equation (2). As has been shown by Ghosh et al.(1998b) equations (1) and (2) are equivalent.

2.2 SEISMIC HAZARD ANALYSIS

The seismic hazard analysis presented by Cornell(1968) considers (i) point source model, (ii) line source model and (iii) aerial source model for earthquake occurrence. The severity of ground motion has been considered in terms of (i) felt intensity of the earthquake at site and (ii) peak ground acceleration. The peak ground acceleration (a_p) has been assumed to be of the form

$$a_p = b_1 \exp(b_2 M) R^{-b_3} \tag{5}$$

where b_1, b_2 and b_3 are constants, M is the earthquake magnitude and R is the hypocentral distance.

It has been observed(Campbell(1985)) that PGA predicted by relations of the type given by equation (5) does not agree very well with observations particularly for smaller values of R and a distance correction term (D) has been considered by many workers.

It is assumed that earthquakes are equally likely to occur anywhere in a circular area of radius l around the site and there is no earthquake occurring in a circular area of radius Δ around the site. The earthquakes are assumed to occur at a depth d. A circular area of radius l around the site is considered for evaluation of seismic hazard.

The spectral acceleration (S) is given by equation (4).

The constants b_1, b_2 *and* b_3 at each frequency are derived from the response spectra of the recorded strong motion time histories.

The annual rate of occurrence of earthquakes of magnitude greater than or equal to M is given by the Richter equation (Richter(1958))

$$\log_{10} N = a - bM \tag{6}$$

The constants a and b are derived from the earthquake records of the region under consideration.

From the probability density function for the spatial distribution of earthquakes and equation (4) and (6), the probability of exceedence of a certain specified value of S at any frequency can be evaluated by considering earthquake occurring anywhere within the area under consideration.

The temporal distribution of earthquakes is assumed to follow a Poisson distribution. Thus it is possible to predict the probability of exceeding (P/S >S_P) a certain specified level of the spectral acceleration at any frequency in a given time span or, alternatively, to evaluate the mean recurrence interval, T_y of the specified spectral acceleration. The methodology of evaluating (P/S >S_P) and T_y is described in detail by Ghosh et al.(1998b) which also brings out the relation between these two quantities.

The seismic hazard at a site is quantified by the probability (P/S >S_P) and T_y and the uncertainties in these quantities due to variations in the correlations for spectral acceleration and uncertainties in the seismic source and occurrence models i.e. a and b, depth of focus d.

3. PRESENT STUDY

The present study uses 144 horizontal acceleration records from rock sites. The range of magnitude is generally from 4.1 to 8.1 and there are few records of magnitude 2.4 to 4. The distance from the causative fault varied generally about from about 6km to 125 km with some events outside this range.

The salient features of the accelerograms are given in Table-1. The digitised accelerograms were obtained on magnetic tapes from the World Data Center (1985). In these data, the original accelerograms have been band-pass filtered between 0.07 Hz and 25 Hz and base line corrections have been made (Newmark 1973). Analysis has been carried out with the recorded accelerograms representing the free-field conditions. The geological conditions of the recording sites, identified by the name and number of the recording station, are verified from published sources.

It has been observed that the response spectra of the two horizontal components recorded at the same location are often significantly different. This may be attributed to the orientation of the instrument with respect to the fault. To ensure conservatism, the attenuation for spectral acceleration (equation(3)) at any frequency was developed by selecting only the higher of the two horizontal spectral values of the records at a particular site. The attenuation relations thus developed were used for the subsequent seismic hazard analysis.

4. NUMERICAL RESULTS

The 5% damping response spectrum for each accelerogram was calculated at 90 equispaced points on a logarithmic scale in the range of period of 0.01 to 2.97 sec. The constants b_1,b_2 and b_3 in equation (4) have been obtained through a least square fit of the various spectra. Apart from this, the mean and the mean+sigma values of the dynamic amplification factors (DAF) were also evaluated.

The base values of the various parameters considered for the seismic hazard analysis are given in Table-2. The `a' and `b' values are typical for certain areas in peninsular India.

In the subsequent figures 2-11 the values of l,Δ, a and b are the base values given in Table-2.

Fig.2 presents the response spectra for various chosen values of MRI, T_y varying from 10 to 10^8 years. As stated before, for any spectrum in this set the T_y value is constant at all values of period. Expectedly , higher the value of T_y, higher the spectral acceleration, the difference being not very significant for periods beyond 2 Sec. As per the prevalent practice, the ground motion for a NPP site is generally deterministically obtained and the MRI for PGA value only is calculated by a probabilistic method. Usually, the value of T_y for PGA is required to be of the order of few hundred years for the operating basis earthquake (OBE or S_1) and few tens of thousand years for the safe shutdown earthquake (SSE or S_2) (IAEA (1979)). These values of T_y are adequately covered in the range of T_y considered in this study.

Figure 3 presents the response spectra for various chosen values of P, the probability of exceedence in 50 years, ranging from 10^{-1} to 10^{-6}. Quite naturally, the spectral acceleration at any frequency is higher as the probability of exceedence reduces. Here also the difference in the spectral values is not very significant for periods beyond 2 Sec.

As mentioned before, the design basis response spectra are presently generated by multipying the DAF with a specified value of PGA. The MRI or the value of P of such spectra are generally not computed. However, since ZPA = PGA and the MRI and P for PGA are evaluated the same are known at zero period.

Figures 4 to 7 present the response spectra obtained with the mean and mean-plus-sigma DAF and a fixed value of PGA of 0.2g and the associated values of MRI and P. The mean-plus-sigma DAF is generally used for design of critical facilities like a NPP. The mean DAF is used for design of various conventional structures(Blume et al. (1973)). From these figures it is seen that MRI and P vary by about two orders of magnitude over the range of period considered. Generally speaking, the MRI is lower and the corresponding P is higher around the spectral peak.

Figures 8 and 9 present the response spectrum obtained by multiplying the mean DAF with the mean-plus-sigma PGA (mean PGA taken as 0.2g) together with the corresponding values of MRI and T_y. This spectrum generally lies above those shown in Figs.4-7. Thus it has a higher value of T_y and a lower value of P.

The new USNRC's SRP/regulatory Guide (USNRC(1997a)) recommends development of unnormalised response spectra.

Figures 10 and 11 present the unnormalised mean and mean-plus-sign response spectra scaled to a PGA of 0.2g and the associated values of P. The PGA for this set has been kept the same as that in the previous set (i.e. Figs. 4 to 7) to facilitate comparison. From these figures it is observed that the unnormalised mean and mean-plus-sigma response spectra normalised to the same PGA are not significantly different and hence the associated values of P are also practically the same.

Figures 12 to 16 show the sensitivity of the uniform hazard spectra to variations in Δ, l, a and b; While one parameter is changed all the other parameters are kept at their base values given in Table-2. The value of T_y is 10^6 years in these figures except in Figure 14 where it is $2.5\text{x}10^5$ years. As the radius of the no earthquake zone, Δ increases the value of the spectral acceleration for a fixed MRI reduces. Similarly, for a fixed MRI, the spectral acceleration reduces with l, the radius of the zone containing the earthquake sources. As, l increases, the results tend to become assymptotic. The effect of the long period motion for distant earthquakes is quite apparent from figures 13 and 14 for period in the range 0.5s - 2s. The differences are more pronounced for smaller values of T_y which is consistent with the fact that distant earthquakes produce smaller accelerations which have smaller values of MRI. The variations with a and b also substantiate this reasoning.

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TABLE-1

DATA BASE FOR CURRENT STUDY (Rock-Sites)

Sr. No	Earthquake / Date	Station Name/No.	Magnitude	Source Distance (km.)	Component	Acc. cm/sec^2
1.	Kern County 21/07/1952	Taft CAL 1095.	7.6	56.0	N21E S69E VERT	153.036 175.599 103.005
2.	San Francisco 22/07/1957	Golden Gate 1077	5.25	11.0	N10E S80E VERT	81.423 103.005 37.278
3.	Helena Mont. 31/10/1935	Federal Bldg Helena, 323.	6.0	8.0	S00W S90W VERT	143.226 142.245 87.309
4.	Wheeler Ridge 12/01/1954	Taft CAL. 1095	6.0	51.0	N21E S69E VERT	62.784 65.727 35.316
5.	Parkfield 27/06/1966	Temblor, CAL. 1097	5.6	7.0	N65W S25W VERT	263.889 340.407 129.492
6.	Parkfield 27/06/1966	San Luis 1083	5.6	63.6	N36W S54W VERT	17.658 12.753 5.886
7.	Borrego Mtn 08/04/1968.	SCE Plant 280	6.5	122.0	N33E N57W VERT	40.221 45.126 53.955
8	San Fernando 09/02/1971	Pacoima Dam 279	6.6	3.2	S16E S74W VERT	1226.250 1216.440 695.529
9.	San Fernando 09/02/1971	Pacoima Dam 279	2.4	3.2	S16E S74W VERT	20.601 26.487 7.848
10	San Fernando 09/02/1971	Pacoima Dam 279	3.1	3.2	S16E S74W VERT	51.012 45.126 20.601
11.	San Fernando 09/02/1971	Pacoima Dam 279	4.0	3.2	S16E S74W VERT	112.815 109.872 40.221
12.	San Fernando 09/02/1971	Pacoima Dam 279	3.0	3.2	S16E S74W VERT	31.392 47.088 14.715
13.	San Fernando 09/02/1971	Pacoima Dam 279	2.5	3.2	S16E S74W VERT	30.411 23.544 23.544
14.	San Fernando 09/02/1971	Pacoima Dam 279	2.4	3.2	S16E S74W VERT	27.468 18.639 6.867
15.	San Fernando 9/02/1971	Castiac Old 110	6.6	22.8	N21E N69W VERT	382.590 313.920 153.036
16.	San Fernando 09/02/1971	LA Water & power, 137	6.6	24.1	N50W S40W VERT	196.200 137.340 66.708
17.	San Fernando 09/02/1971	LA 2011 Zonal 190	6.6	25.5	S62E S28W VERT	78.480 68.670 49.050

Sr. No	Earthquake / Date	Station Name/No.	Magnitude	Source Distance (km.)	Component	Acc. cm/sec^2
18.	San Fernando 09/02/197	Pmp.Pt, Pearblossom 269	6.6	35.5	N00E N90W VERT	147.150 98.100 47.088
19.	San Fernando 09/2/19 71	Caltech Seis mological Lab., Psadena CAL./266-	6.6	35.0	S00W S90W , VERT	87.5 188.6 83.5
20.	San Fernando 09/2/1971	Lake Hughes Array Stn LA, CAl./126	6.6	28.0	S69E S21W VERT	168.2.4 143.5 150.7
21.	San Fernando 09/2/1971	Lake Hughes Array Stn.9,, LA, CAL./127	6.6	28.0	N69W N21E VERT	109.4 119.2 71.4
22.	San Fernando 09/2/1971	Lake Hughes, Array Stn.1, LA, CAL./128	6.6	20.0	N21E N69W VERT	346.2 277.9 105.3
23.	San Fernando 09/2/1971	3838 Lankersh im Blvd. Base ment, LA CAL./220	6.6	29.0	N00E S90W VERT	164.2 147.6 69.7
24.	San Fernando 09/2/1971	NPP, San Onofore CAL./ 280	6.6	139.0	N33E N57W VERT	11.9 15.9 10.2
25.	San Fernando 09/2/1971	Griffith Park, Observatory Moon Room, LA CAL./141	6.6	33.0	S00W S90W, VERT	176.9 167.4 120.3
26.	San Fernando 09/2/1971	Fairmont Reservoir, CAL./121	6.6	34.0	N56E N34W VERT	64.7 97.1 32.9
27.	San Fernando 09/2/1971	1215, Gallery Hoover Dam, CAL./292	6.6	378.0	S45E S45W VERT	0.7 1.2 0.9
28.	San Fernando 09/2/1971	Puddingston Resservoir, San Dumas CAL./247	6.6	64.0	N55E N35W VERT	69.7 53.2 37.8
29	Michoacan 19/09/1985	Caleta De Campo Mexico City	8.1	27.0	N00E N90E VERT	138.5 137.8 69.8
30.	Michoacan 19/09/1985	Caleta De Campo Mexico City	8.1	27.0	N00E N90E VERT	36.1 44.3 22.1
31.	Michoacan 19/09/1985	La Villita Mexico City	8.1	40.0	N00E N90E VERT	121.0 85.9 51.0
32.	Michoacan 19/09/1985	La Union Mexico City	8.1	80.0	N90E VERT	135.3 120.9
33.	Michoacan 19/09/1985	Aero Puerto Mexico City	8.1	131.0	S00E N90W VERT	101.3 161.8
34.	Michoacan 19/09/1985	Papanoa Mexico City	8.1	185.0	S00E N90W VERT	119.0 107.3 81.6
35.	Michoacan 19/09/1985	El Suchil Mexico City	8.1	227.0	S00E N90W VERT	103.1 81.5 38.7
36.	Michoacan 19/09/1985	Atoyac Mexico City	8.1	248.0	N00E N90E VERT	42.4 40.9 61.0

Sr. No	Earthquake / Date	Station Name/No.	Magnitude	Source Distance (km.)	Component	Acc. cm/sec^2
37.	Michoacan 19/09/1985	Coyuca Mexico City	8.1	291.0	S00E N90W VERT	40.0 33.4 18.5
38.	Michoacan 19/09/1985	La Venta Mexico City	8.1	321.0	N00E N90E VERT	15.3 20.1 16.7
39.	Michoacan 19/09/1985	Cerro De Piedra Mexico City	8.1	346.0	S00E N90W VERT	19.4 14.2 12.4
40.	Michoacan 19/09/1985	Las Mesas Mexico City	8.1	352.0	N00E N90E VERT	20.8 14.2 12.5
41	Michoacan 19/09/1985	Ocotito Mexico City	8.1	337.0	S00E N90E VERT	48.6 20.8 20.8
42.	Michoacan 19/09/1985	Teacalco Mexico City	8.1	328.0	N00E N90E VERT	32.0 23.6 27.1
43.	Michoacan 21/09/1985	Aero Puerto Mexico City	7.6	30.0	S00E N90W VERT	161.7 129.2 88.4
44.	Michoacan 21/09/1985	Papanoa Mexico City	7.6	83.0	S00E N90W VERT	223.0 222.0 151.2
45.	Michoacan 21/09/1985	El Suchil Mexico City	7.6	125.0	S00E N90W VERT	87.0 42.9 41.9
46.	Michoacan 21/09/1985	Coyuca Mexico City	7.6	188.0	S00E N90W VERT	41.9 46.1 25.1
47	Michoacan 21/09/1985	Cerro De Piedra Mexico City	7.6	243.0	S00E N90W VERT	10.8 10.2 8.7
48	Michoacan 21/09/1985	Teacalco Mexico City	7.6	249.0	N00E N90E VERT	28.2 22.2 19.8
49.	Hollister Earthquake 28/11/1974	Gilroy Array #1, Gavilan College Tower	5.2	22.0	S67W S23E VERT	134.7 29.3 94.1
50	Cape Mendocino Eq 12/01/1975	Cape Mendocino Petrolia	4.5	23.0	S60E. N30E VERT	92.1 72.4 27.2
51.	Cape Mendocino Eq. 07/05/1975	Shelter Cove Stn. 1	4.2	76.0	N70W S20W VERT	50.0 54.9 30.5
52	Humboldt County Eq 07/06/1975.	Cape Mendocino Petrolia	5.3	31.0	S60E N30E VERT	198.7 103.0 37.7
53.	Humboldt County Eq 07/06/1975.	Shelter Cove Stn. 1	5.3	62.0	N70W S20W VERT	26.3 30.0 0.0
54.	Isabella Dam Earthquake 08/03/71	Isabella Dam Aux. Abutment,	4.1	7.0	N14E N76W VERT	46.6 106.0 22.8
55.	Oroville Eq. 01/08/1975	Oroville Dam Crest	5.7	13.0	N46E N44W	115.4 83.3

Sr. No	Earthquake / Date	Station Name/No.	Magnitude	Source Distance (km.)	Component	Acc. cm/sec^2
					VERT	130.6
56.	Oroville Eq. 01/08/1975	Oroville Seismograph Stn -	5.7	13.0	N53W. N37E VERT	82.5 90.6 112.8
57.	Coyote Lake 06/08/1979	Gilroy Array #1, Gavilan College Tower	5.8	16.0	320 230 VERT	111.0 84.0 58.0
58.	Coyote Lake 06/08/1979	Gilroy Array #6, San Ysidro	5.8	10.0	320 230 VERT	315.0 409.0 1147.0
59	Coyote Lake 06/08/1979	Coyote Creek Abutment San Martin	5.8	1.0	250 160 VERT	245.0 138.0 101.0
60.	Michoacan 19/09/1985	Inst De, Mexico City Ingunieria Unam	8.1	375.0	S00E N90W VERT	25.5 33.5 21.6
61.	Michoacan 19/09/1985	Inst De, Mexico City Unam Ingunieria	8.1	375.0	N00E N90W VERT	31.7 31.8 21.9
62.	Michoacan 19/09/1985	Mesa Mexico City Vibradora CU	8.1	375.0	S00E N90W VERT	137.4 38.8 19.8
63.	Mount Diablo 24/1/1980	Delle Valle Dam Crest	5.8	24.0	246 156 VERT	227.2 125.3 107.5
64.	Mount Diablo 24/1/1980	Delle Valle Dam Toe	5.8	24.0	246 156 VERT	249.9 126.7 74.8
65.	Mount Diablo 27/1/1980	Delle Valle Dam Crest	5.4	15.0	246 156 VERT	64.7 37.2 33.7
66.	Mount Diablo 27/1/1980	Delle Valle Dam Toe	5.4	15.0	246 156 VERT	43.7 37.9 26.4
67.	Nahanni AS 23/12/1985	Iverson Northwest Territories	6.9	7.0	10 280 VERT	1080.5 1319.1 2322.4
68.	Nahanni AS 23/12/1985	Iverson Northwest Territories	5.4	7.0	10 280 VERT	224.1 87.7 110.1
69.	Nahanni AS 09/11/1985	Slide Mountain	4.8	6.0	330 240 VERT	374.3 451.0 249.1
70.	Nahanni AS 23/12/1985	Slide Mountain	6.9	6.0	330 240	382.4 534.4
71.	Nahanni AS 23/12/1985	Battlement Creek, Northw est Territories	6.9	21.0	360 270 VERT	190.2 182.4 178.0
72.	Nahanni AS 25/12/1985	Battlement Creek, Northw est Territories	5.7	18.0	360 70 VERT	103.4 87.4 72.9

☐

TABLE-2

VALUES OF VARIOUS PARAMETERS USED IN THE ANALYSIS

Parameter	M_0	d (km)	Δ (km)	l (km)	a	b
Base Value	4.75	15.0	0.0	300.0	3.10	1.05
Minimum Value	1.0	15.0	0.0	50.0	2.90	0.85
Maximum Value	4.75	15.0	50.0	300.0	3.40	1.25

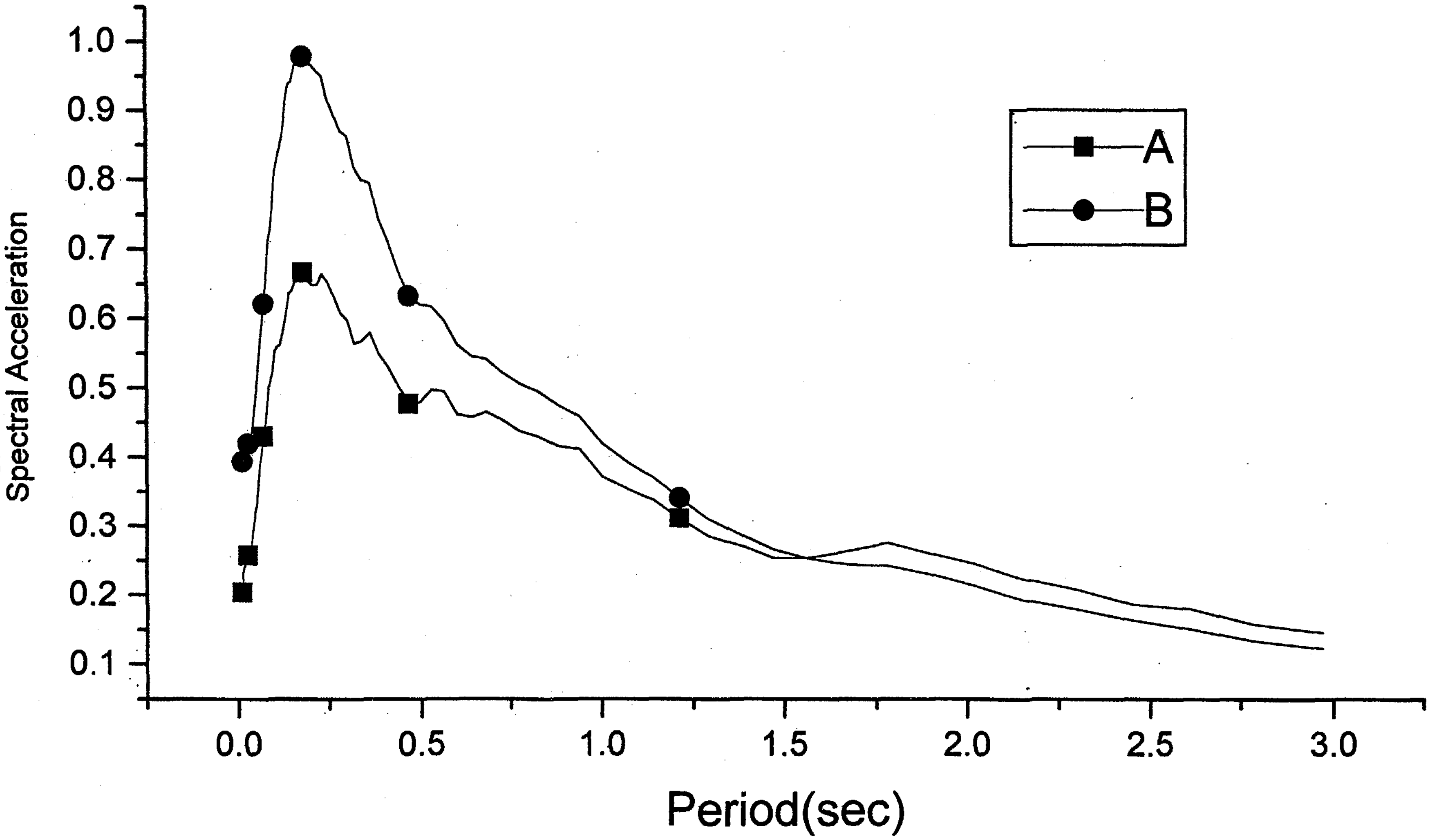

Fig. 1: Comparison of 5% Damping Response Spectra;
(A) (Mean+Sigma)DAF*(Mean)PGA;
(B)(Mean)DAF*(Mean+Sigma)PGA;Mean PGA=0.2g

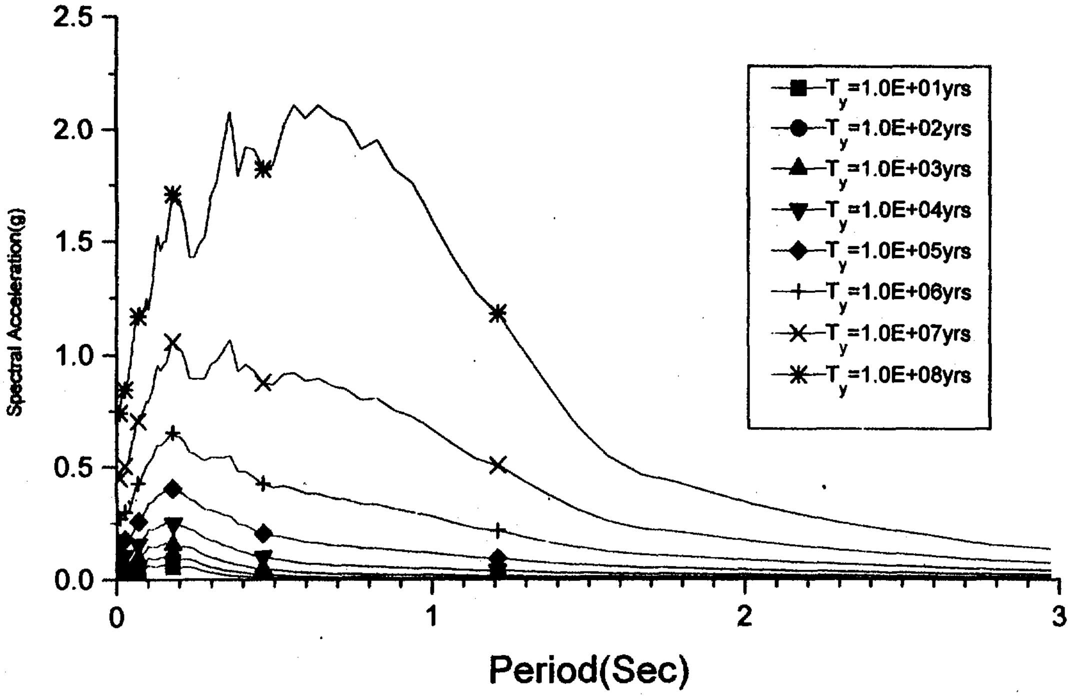

Fig. 2: Response Spectra for Various Values of Mean Recurrence Interval, T_y; Rock Sites; Horizontal Motion; 5% Damping.

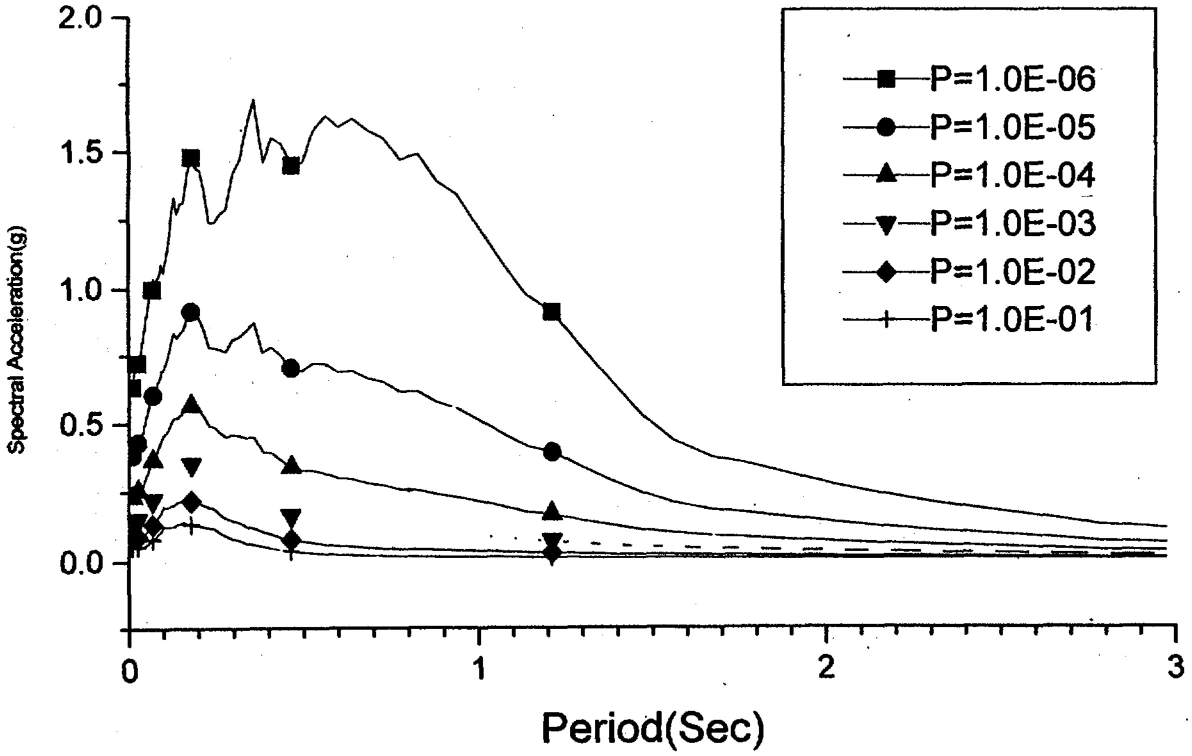

Fig. 3: 5% Damping Response Spectra for Various Values of P, Probability of Exceedence in 50 yrs.

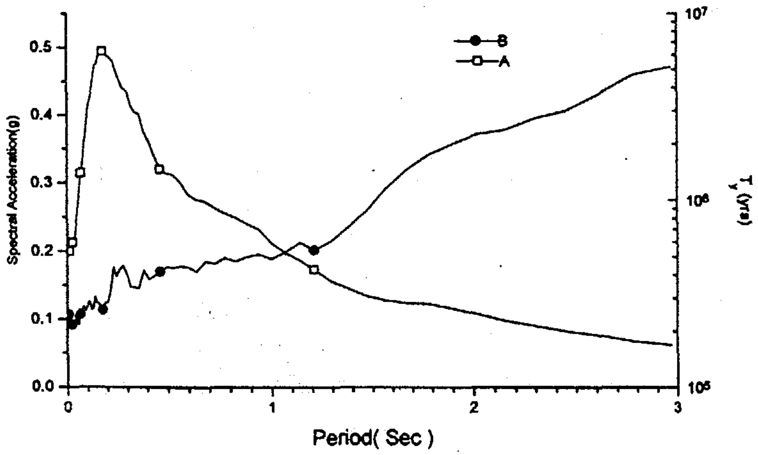

Fig. 4: (A)Response Spectrum:(Mean)DAF * PGA; PGA=0.2g;
(B) Mean Recurrence Interval, T_y

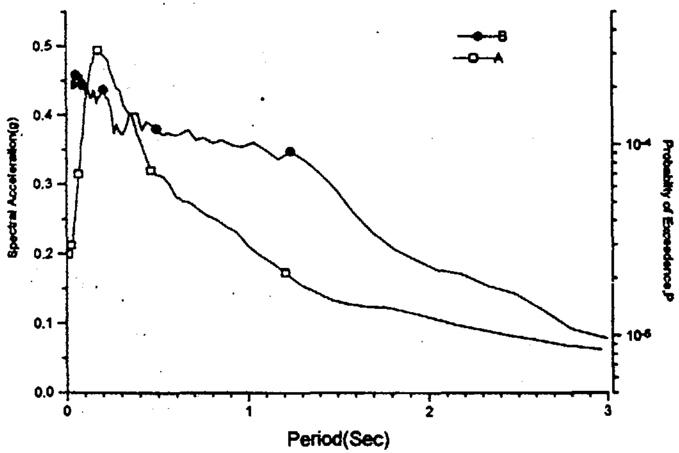

Fig. 5: (A)Response Spectra- (Mean)DAF*PGA; PGA=0.2g
(B) Probability of Exceedence in 50 years,P

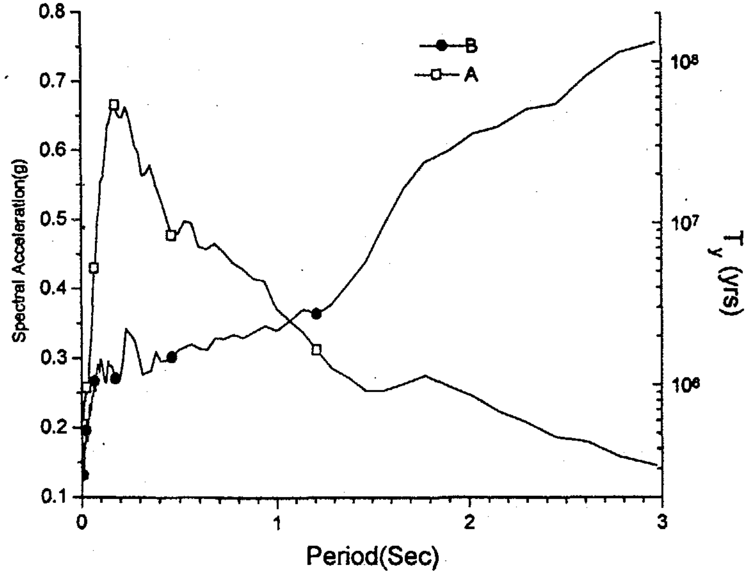

Fig. 6: (A)Response Spectrum- (Mean+Sigma)DAF*PGA;PGA=0.2g
(B)Mean Recurrence Interval, T_y

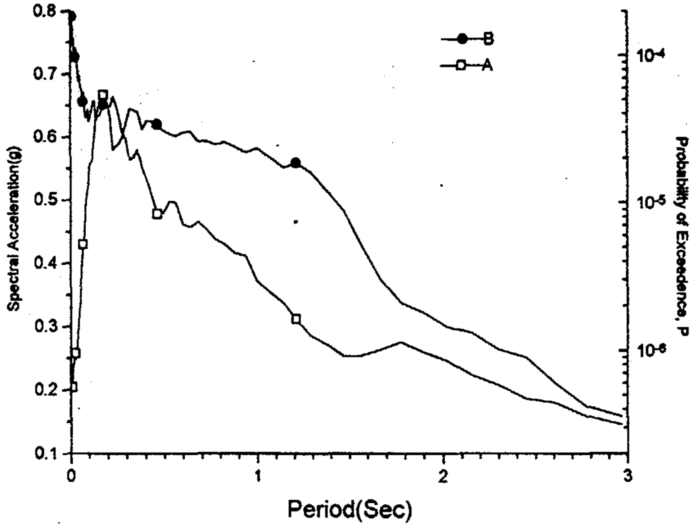

Fig.7 :(A) Response Spectrum- (Mean+Sigma)DAF*PGA;PGA=0.2g
(B) Probability of Exceedence,P

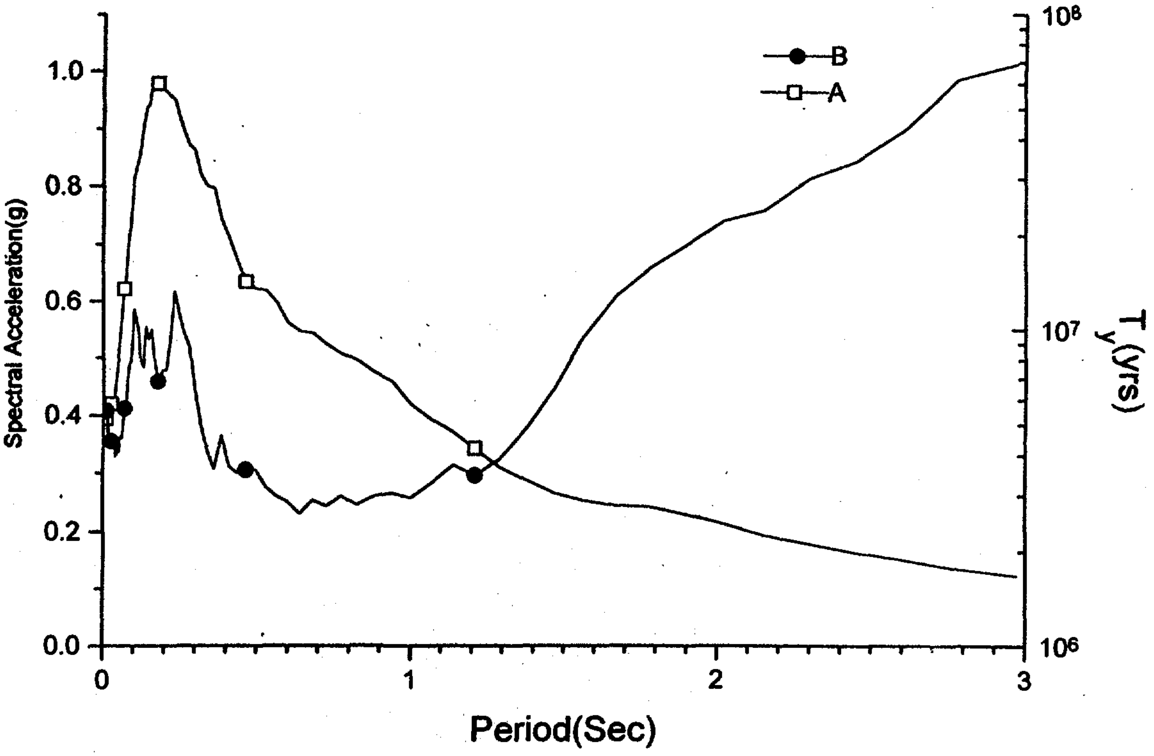

Fig. 8: (A) Response Spectrum-(Mean)DAF*(M+Sigma)PGA; Mean PGA=0.2g; (B) Mean Recurrence Interval, T_y

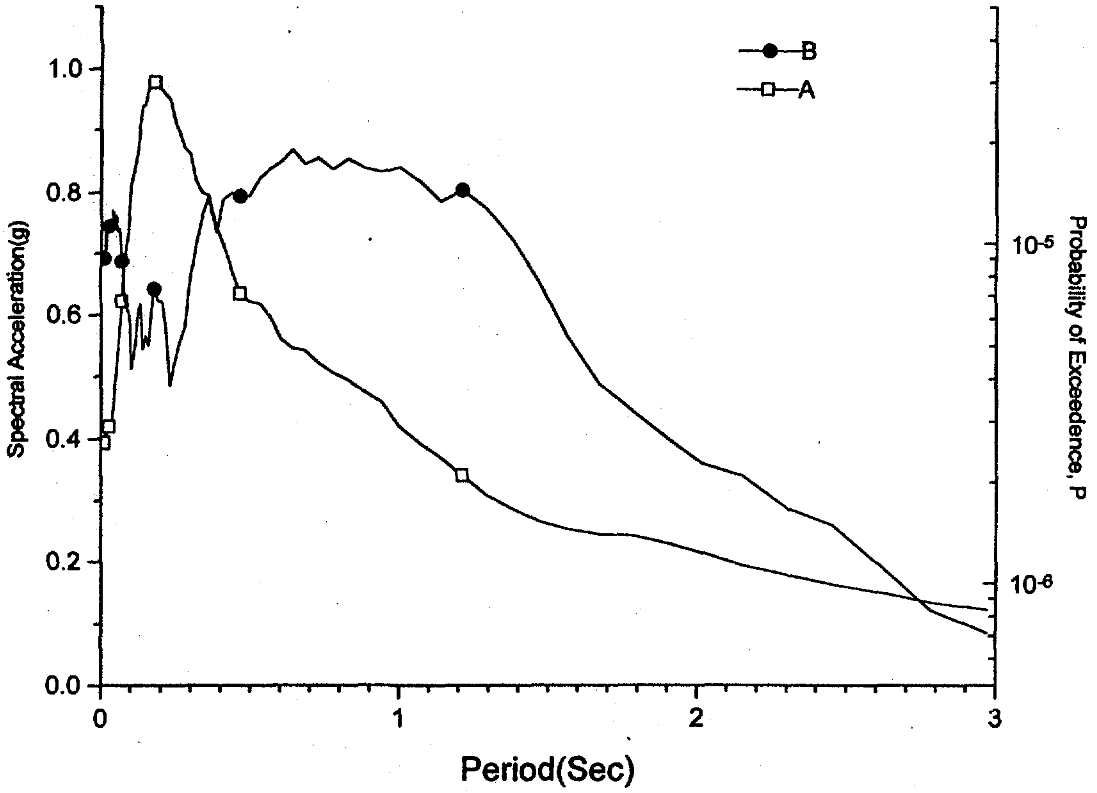

Fig. 9: (A) Response Spectrum - (Mean)DAF*(M+Sigma)PGA; Mean PGA=0.2g; (B) Probability of Exceedence in 50 yrs., P.

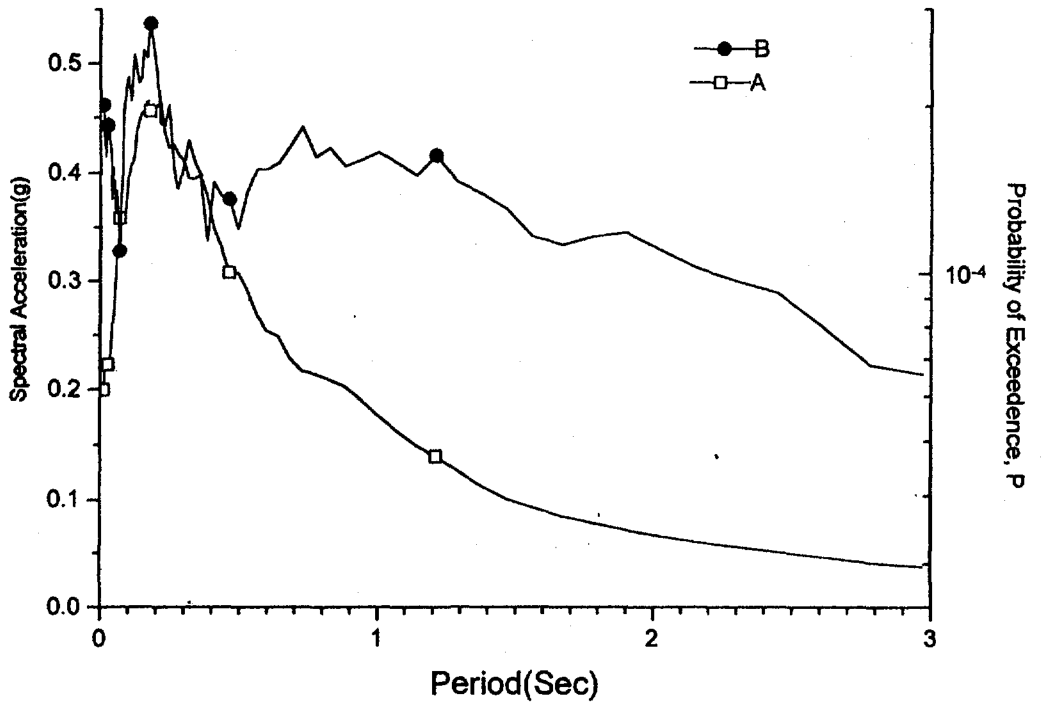

Fig. 10: (A) (Mean) Unnormalised Spectrum- ZPA Scaled to 0.2g;
(B) Probability of Exceedence in 50 yrs., P

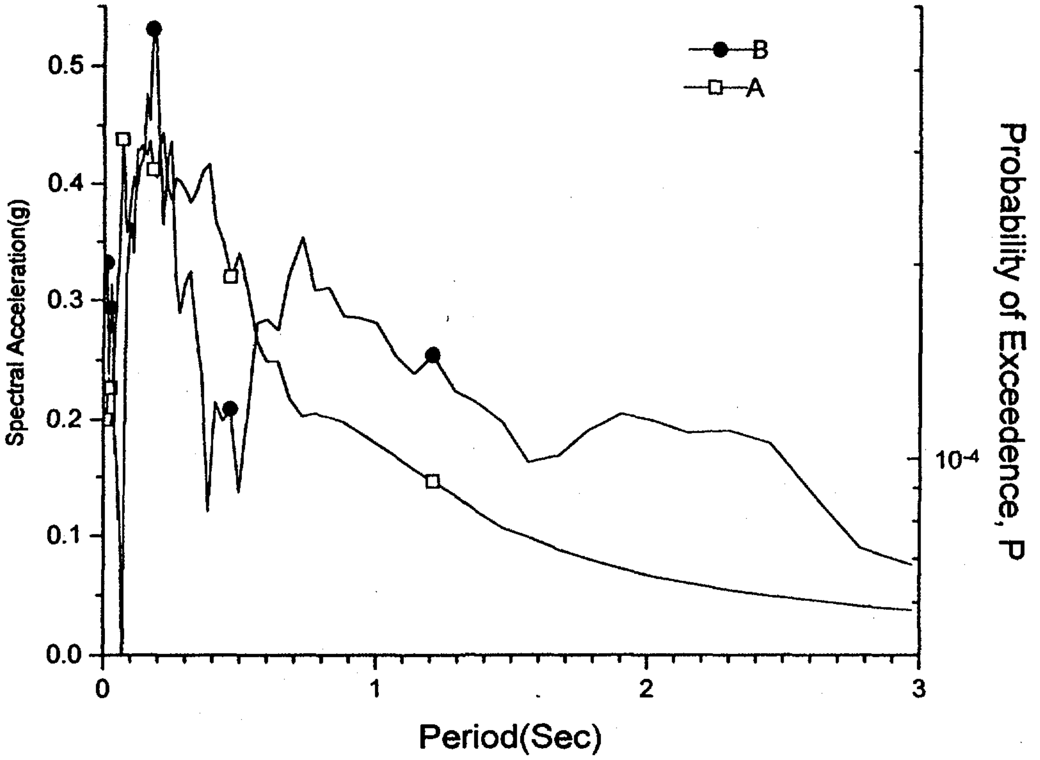

Fig. 11: (A)Unnormalised (Mean+Sigma) Response Specrum with ZPA Scaled to 0.2g
(B) Probability of Exceedence in 50 yrs., P

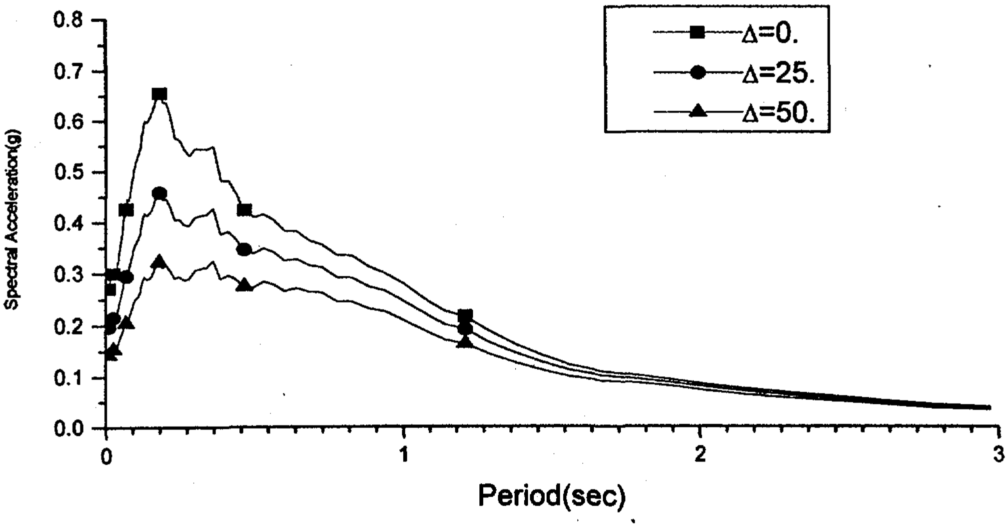

Fig. 12: Response Spectra for Various Values of Δ ; T_y = 1.0e+06yrs.

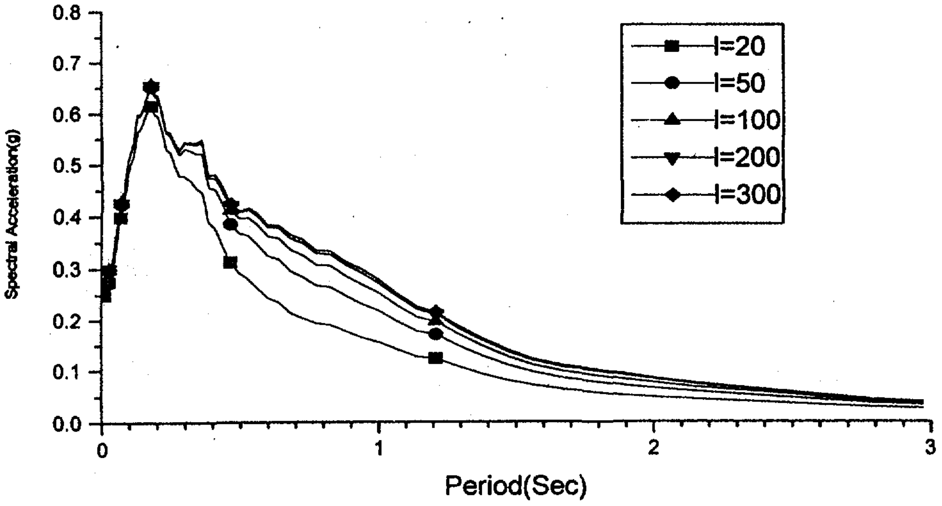

Fig. 13: Response Spectra for Various Values of I; T_y = 1.0E+06yrs.

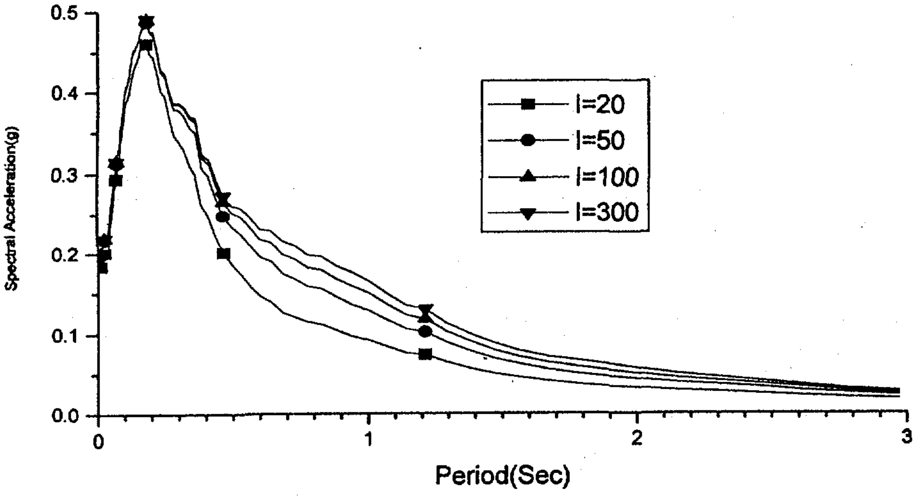

Fig. 14: Response Spectra for Various Values of I; T_y = 2.5E+05 yrs.

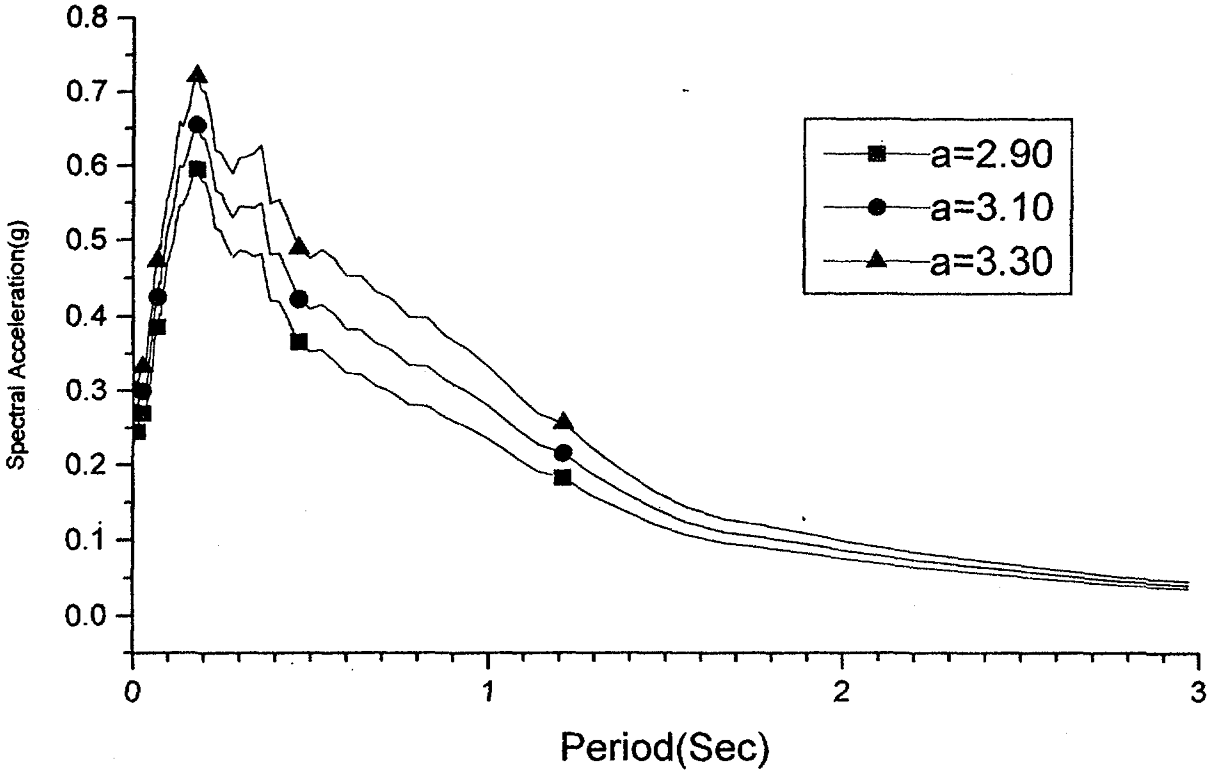

Fig. 15: Response Spectra for Various Values of a; T_y = 1.0E+06 yrs.

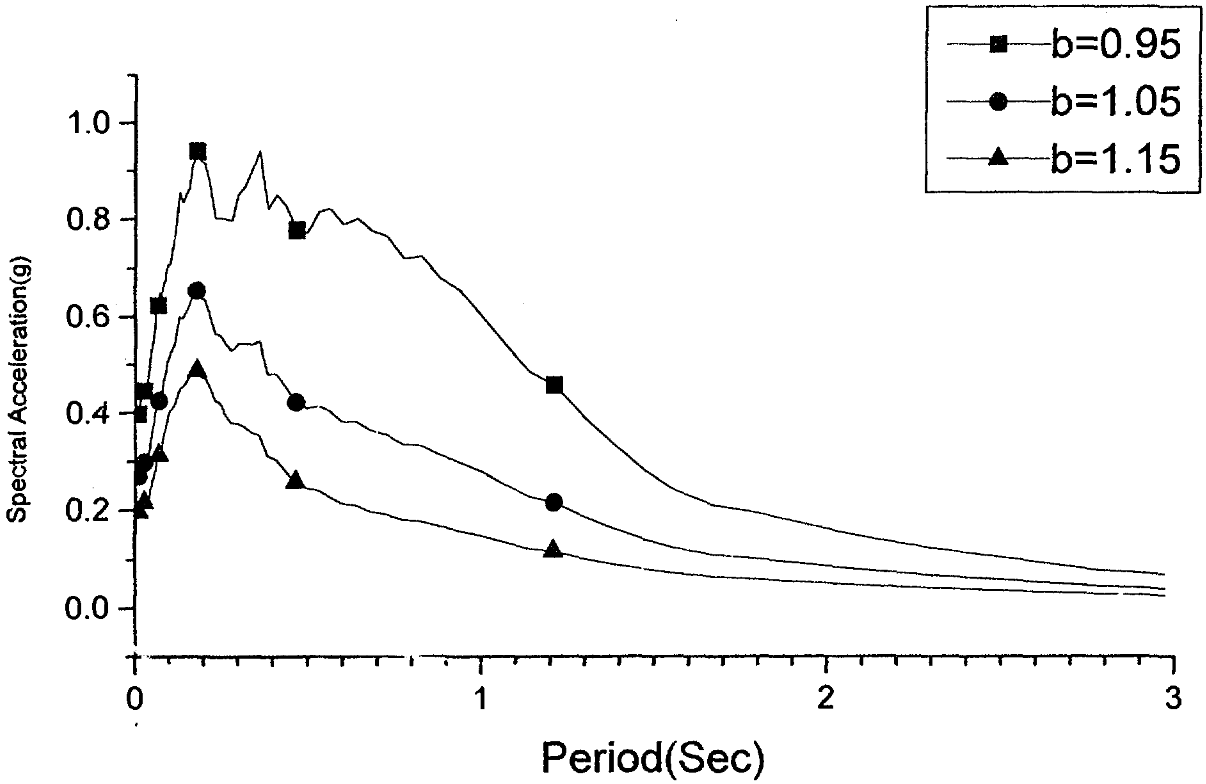

Fig. 16: Response Spectra for Various Values of b; T_y = 1.0E+06 yrs.

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