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ABSTRACT

Earthquake accelerograms recorded on rock sites have been analysed to develop site-specific response spectra for use in aseismic design. Normalized pseudo absolute acceleration spectra for various values of damping, pertinent to nuclear power plant design in particular are presented. Various ground motion parameters, viz. peak displacement, velocity acceleration (including v/a, ad/v^2 and and the ratios of the three orthogonal components) for fifty four accelerograms are examined through statistical analysis to enable a sutaible description of ground motion time histories to be used in structural response analysis. The analysis presented in this paper aims at specifying site specific response spectra for earthquake resistant design of structures and generation of spectrum compatible accelerograms. The salient features of the data set have been discussed.

SPECTRAL SHAPES FOR ACCELEROGRAMS RECORDED AT ROCK SITES

(A.K.GHOSH N.MURALIDHARAN AND R.D.SHARMA)

1_INTRODUCTION

The basic objective of aseismic design is to ensure safety of complex engineering structures, and the people around in the event of a major earthquake at minimum sacrifices towards costs of construction and operation. The maximum credible earthquake (MCE) for a site (the strongest earthquake, which can be expected to occur in the neighborhood of the site, but has a very low probability of occurrence) may be estimated by evaluating the geology and seismotectonics of the region (USNRC,1973; IAEA,1979). The effect of an earthquake of magnitude M may be quantified in terms of the intensity of the earthquake estimated from the damage done in the neighborhood of the site. More precisely, the earthquake effects may be described in terms of the vibratory ground motion response spectra through a set of curves which relate the values of ground motion parameters (acceleration, velocity and displacement) produced at different frequencies.

The response of a structure during an earthquake depends on the size of the earthquake (measured in terms of the magnitude or intensity in the epicentral region, the distance of the center of energy release from the site, the maximum peak ground motion (acceleration, velocity and displacement), the frequency content and duration of the signal, and a complex combination of several other factors related with source dynamics (stress drop, rupture velocity etc.), signal modification characteristics of the propagation path between the earthquake focus and the site and site geology,damping of the structure and its natural frequencies. Further, during vibratory ground motions neither the maximum values of acceleration, velocity and displacement occur simultaneously, nor the order of these occurrences remains the same from one earthquake to another. Quantification of the roles of each of these parameters, separately or in combination is hardly possible, atleast in the very near future, for characterizing earthquake ground motion in a deterministic manner. An alternative approach, which has been adopted to overcome this difficulty, is to combine a large number of ground motion time histories, recorded at similar sites under varying source conditions to specify the earthquake design basis, and associate statistical confidence limits with the specified values. For the earthquake design basis specified in this manner, the variations in the source-site-signal transmission path combinations will be reflected in the average values as well as in the scatter in the derived values of the ground motion parameters for individual events, which will permit estimation of probabilities of exceeding certain specified values of the ground motion parameter in question, thereby allowing the definition of confidence limits. The utility of the design basis defined in this manner will depend on how well the data set has been restricted to represent the source-site conditions in question, while its adequacy will be determined by size of the ensemble events constituting the data base.

2 DERIVATION OF RESPONSE SPECTRA

Earthquake design basis is generally specified in terms of the peak values of the ground motion parameters and spectral shapes of these parameters for different values of damping. Nuclear installations are characterized by rigid structures, and component frequencies in the range 2-10 Hz are typical. For these structures acceleration response spectra dominate the structural behaviour, and hence they should be accurately determined.

The utility of response spectra in aseismic design input was recognized long ago. Since it was first proposed by Housner (1941), efforts to arrive at representative response spectra approaching real situations (determined by the source, site and signal propagation path conditions) have continued (Newmark et al.,1973; Mohraz,1976). Over the number of years, a large data set pertaining to several strong earthquakes and different site conditions has become available,and it is now possible to use site-specific response spectra in aseismic design. Such a step is now not only possible but desirable because the use of standard response spectra is likely to lead to overconservative designs,particularly at frequencies which could be important in design, resulting in avoidable escalation of costs. It has been noted that the standard response spectra are overconservative in certain ranges of frequency, while they are underconservative in some other ranges. If a design has been made with a more conservative spectrum, it stands to reason that the structures will have more inbuilt strength. However, the resulting increase in strength will be at the cost of flexibility, which is also required to be provided in the engineering structures and, in particular, to components like piping. This paper is a step towards specifying site-specific design response spectra for rock sites.

3_EARLIER_WORK

It was in 1959 for the first time when standard response spectra were proposed by G.W.Housner (Housner,1959). These spectra were obtained by averaging normalized pseudo absolute acceleration spectra for eight strong motion records of horizontal components of four earthquakes namely: the El Centro recordings of the Imperial Valley earthquakes of December 12, 1934 (magnitude 6.5) and May 19,1940 (magnitude 7.1), The Taft recording of the July 21, 1952 Kern County earthquake (Magnitude 7.6) and the Olympia recording of the April 13,1949 Puget Sound earthquake (magnitude 7.1). These spectra had been to serve as standard response spectra in aseismic design. Here, three of the four recording stations were located on soil sites. Two comprehensive studies on normalized spectral shapes were carried out in the U.S., one by Blume et al.(1973) and the other by Newmark et al.(1973). The former study was based on 33 horizontal component accelerograms normalized with respect to maximum peak ground acceleration and the latter was based on a set of 28 similar records. Several records were common in both these studies. Selection of records was limited to those with maximum peak ground acceleration greater than or equal to 0.1 g. The resulting spectral shapes of these two studies were in close agreement. Records from both rock and soil sites were analysed together in both these studies and, though there was a preponderance of soil site data, differentiation between the spectral shapes for different site conditions was not attempted.

Site dependence of spectral shapes was first demonstrated by Hayashi et al (1971). Analysis of 61 accelerograms, recorded in Japan, by these authors illustrated the differences in the spectral shapes for (i) very dense sands and gravels, (ii) soils of intermediate characteristics and (iii) very loose soils. However, many of these records had peak accelerations in the low acceleration range of 0.02 to 0.05 g.(It has been pointed out by Seed et al.(1976a) that the maximum peak ground motion at a site is also greatly dependent of the strain levels, so that the observed variations cannot be attributed entirely to the differences in the local site conditions.) Seed et al.(1976b) and Mohraz (1976) have presented the spectral shapes for various geological site conditions, namely: (i) rock, (ii) stiff soil, (iii) deep cohessionless soil and (iv) soft to medium clay and sand. These results clearly show the shift in the spectral peaks and variations in amplification factors with changing site conditions.

The two studies mentioned above present the spectral shapes for the horizontal components of the ground motion only. The former gives spectral shapes for 5% damping while the latter contains those for 2% and 5% damping. Nuclear power plant design needs a wider range of damping values for specifying design response spectra. The present study includes spectral shapes for rock sites for both, horizontal and vertical, components of ground motion. The spectral shapes are presented for damping 0%, 2%, 3%, 5%, 7% and 10% of critical. The damping values considered are typically those encountered in power plant components and strucures (Figs 12-20).

The ratios of the peak values of the two horizontal components of acceleration and the ratio of the peak vertical to the higher peak horizontal acceleration, the v/a and ad/v^2 ratios (where a, v and d are the peak values of the acceleration, velocity and displacement respectively) are also presented in the paper for the purpose of describing the nature of the data set used, and also to serve as design information for fixing the varoius peak ground accelerations, velocity and displacement, once the maximum peak ground acceleration is obtained from a valid correlation (see Esteva and Villaverde, 1974) (Table-2).

4_PRESENT_STUDY

The data set for the present study includes a total of 54 accelerograms, 36 for the horizontal and 18 for the vertical component, from seven earthquakes recorded on rock sites (Table-1) in the western United States. For the Pacoima dam records of the San Fernando earthquake of February 9,1971 (item 8 of Table-1), though they contain the accelerograms of the main shock and six aftershocks, the tabulated accelerations are only for the main shock. The digitized accelerograms were obtained on magnetic tapes from the World Data Centre (WDC) at Boulder, Colorado. In these data, the original accelerograms have been band pass filtered between 0.07 Hz and 25 Hz, and base line corrections have been applied (1) . The geological conditions of the recording sites identified by the name and the station number were verified from published sources, and the corresponding references are also listed in Table-1. It may be seen from this table that both the near field and far field motions of moderately strong earthquakes have been covered here, and the data set is quite comparable (though not identical) with that used by Seed et al (1976b) for rock sites. It is generally presumed that the recorded accelerograms represent free field conditions. In this report spectra of different records have been presented. Though the studies have been carried made for 0%,2%,3%,5%,7% and 10% damping,the detailed event-by-event results of only 0% damping are presented here for brevity (Figs 1 - 18).

5_EVALUATION_OF_RESPONSE_SPECTRA

The response of a single degree of freedom system to a ground acceleration may be written as:

---

(1) The acceleration time-histories given at equal intervals of 0.02 second interval provide correct Fourier spectra upto a frequency of 25 Hz. The effect of base line correction, though less important for the accelerogram itself, is quite significant for velocity and displacement time-histories(see Newmark et al, 1973)

$$\ddot{x}(t) + 2\zeta\omega\,\dot{x}(t) + \omega^2\,x(t) = -\ddot{x}_g(t)\ldots\ldots.(1)$$

Here $\ddot{x}_g(t)$ is the applied ground acceleration, $x(t)$ is the displacement of the single degree of freedom system relative to the ground and dots represent the derivatives with respect to time, ω is the undamped natural frequency and ζ is the damping ratio. The general solution of equation (1) with initial displacement x_0 and initial velocity, v_0 is given by:

$$x(t) = x_1(t) + x_2(t) + x_3(t)\ldots\ldots\ldots.(2)$$

where

$$x_1(t) = x_0 e^{-\zeta\omega t}[\cos\omega' t + \{\zeta/\sqrt{(1-\zeta^2)}\}\sin\omega' t]$$

$$x_2(t) = (v_0/\omega')e^{-\zeta\omega t}\sin\omega' t$$

$$x_3(t) = -(1/\omega')\int \ddot{x}_g(\tau)e^{-\zeta\omega(t-\tau)}\sin\omega'(t-\tau)\,d\tau$$

ω' is the damped natural frequency given by:

$$\omega' = \omega\sqrt{(1-\zeta^2)}$$

The velocity $\dot{x}(t)$ is obtained as

$$\dot{x}(t) = -x_0\omega\, e^{-\zeta\omega t}\sin\omega t + v_0 e^{-\zeta\omega t}[\cos\omega' t - (\zeta/\sqrt{(1-\zeta^2)}\sin\omega t]$$
$$-\int_0^t \ddot{x}_g(\tau)e^{-\zeta\omega(t-\tau)}[\cos\omega'(t-\tau) - (\zeta/\sqrt{1-\zeta^2})\sin\omega'(t-\tau)]d\tau$$

Assuming a linear variation of $\ddot{x}_g$ between two successive digitized values at time t and $t+\Delta t$, where Δt is the sampling interval, the response is calculated recursively. After lengthy algebraic computations the final solution for the relative displacement is obtained as:

$$x(t+\Delta t) = x(t)e^{\zeta\omega'\Delta\tau}[\cos\omega'\Delta t + (\zeta/\sqrt{1-\zeta^2})\sin\omega'\Delta t)]$$
$$+v(t)e^{-\zeta\omega\Delta t}\sin\omega'\Delta t/\omega'$$
$$+\ddot{x}_g(t)/\omega^2 e^{-\zeta\omega\Delta t}(\cos\omega'\Delta t + \zeta\omega/\omega'\sin\omega\Delta t - 1]$$

$$-S(t)/\omega^2-\{S(t)/\Delta t\omega^3\}2\zeta[e^{-\zeta\omega\Delta t}\{\cos\omega'\Delta t+\zeta\omega/\omega'\sin\omega'\Delta t\}-1] \quad \ldots\ldots\ldots\ldots\ldots(5)$$

$$S(t)=\ddot{x}_g(t+\Delta t)-\ddot{x}_g(t) \quad \ldots\ldots\ldots\ldots\ldots(6)$$

Pseudo Absolute Acceleration (PSAA) is given by a(t) where

$$a(t)=\omega^2 x(t) \quad \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

The response spectrum is obtained as a plot of the maximum response of a single-degree of freedom system to the earthquake excitation against its undamped natural frequency, and a set of spectra are obtained for different values of damping. The spectra are normalised with the peak ground acceleration. The normalised PSAA spectral values, S_a (also called dynamic amplification factor, DAF), therefore, may be written as

$$S_a(\omega,\zeta,i)=|\omega^2 x(t)|_{max}/|\ddot{x}_g|_{max} \quad \ldots.(8)$$

Here i refers to the i th record.

After computing the response spectra for all the accelerograms of the horizontal and the vertical motions, the mean (M) and standard deviation (σ) of the spectra at each frequency were obtained to compute the mean and the mean plus sigma (S_{am} and $S_{am+\sigma}$ respectively) spectra.

$$S_{am}(\omega,\zeta)=(1/N)\sum_{i=1}^{N}S_a(\omega,\zeta,i) \quad \ldots\ldots\ldots(9)$$

$$S_{am+\sigma}(\omega,\zeta)=\sqrt{[(1/N-1)\sum_{i=1}^{N}\{S_a(\omega,\zeta,i)-S_{am}(\omega,\zeta)\}^2]} \quad \ldots(10)$$

The envelope spectra (E) are obtained from:

$$E(\omega,\zeta)=[S_a(\omega,\zeta,i)]_{max},\ i=1,2,\ldots.N \quad \ldots(11)$$

For the present study, N=36 for the horizontal component spectra and N=18 for the vertical component spectra.

If the spectral values are assumed to be normally distributed at each frequency, then for the data set considered, the mean and the mean plus sigma spectra would correspond to exceedance probabilities of 50% and 84.1% respectively. Consequently, these are referred to as the 50th and the 84th percentile spectra respectively.

6 SOME OBSERVATIONS ON THE COMPUTED SPECTRA

In general, spectral shape for each accelerogram is different from that of the other However, despite the differences in the basic parameters of t ccelerograms, namely: maximum peak ground acceleration, nce between the earthquake source and the recording site and quake magnitude and other parameters related to the natu f the earthquake source e.g.fault movement, some observat can be made on the ensemble of the spectral shapes.

1) For most acceler s most of the energy is contained within a narrow frequency band, say 0.5 to 5 Hz, while the response spectra have been computed for a frequency range as large as 0.3 to 40 Hz. This is the range which has been considered by earlier workers.

2) The shape of the spectra are dependent on the local site conditions, even for the vertical component records with similar levels of peak ground acceleration, and even the same earthquake. In the case of the horizontal spectra, there is an extra element of orientation of the instrument which produces the variation in the recorded ground motion.

3) The records obtained from the Pacoima dam site, which have been obtained at a distance of about 3 kilometres are somewhat different from other records. These recordings are in the nearfield of the San Fernando earthquake, and it is widely believed that in the near field of an earthquake the peak ground accelerations is poorly correlated with earthquake magnitude. In seven records, one pertaining to

the main shock and the remaining to the six aftershocks, the vertical peak ground acceleration has varied between 0.07g and 0.71g, while the horizontal peak ground acceleration has varied between 0.019g and 1.25g. A comparision between the spectra of different records at this site shows that:

(a)Notwithstanding the differences in the signal-to-noise ratios of these records, the width of the spectrum is strongly correlated with the value of the maximum peak ground acceleration. In general, higher spectral width has been observed for records with higher peak ground acceleration.

(b)The low frequency content of the spectrum increases, as expected, with increasing maximum peak ground acceleration. The maximum dynamic amplification factors do not exhibit any correlation with the maximum peak ground acceleration.

(c)The maximum dynamic amplification factors are not distinctly different for the Pacoima dam recordings than those of accelograms recorded elsewhere.

A synoptic view of the horizontal component spectra is slightly more difficult to take than the vertical component, because the former are dependent on the orientation of the accelerograph. However, some observations as follows,can be made without much difficulty.

1) The spectral shapes of the two mutually orthogonal components are often very different from each other with respect to the relative responses at different frequencies. The differences, the recording site being common between two accelerograms, may be attributed to the source parameters (orientation of the fault and nature of faulting in particular).

2) The maximum DAF is generally large for accelerograms with smaller peak ground accelerations than those with average value of the peak ground acceleration(say,>0.1g), and also appears at a higher frequency for the former. For the two

horizontal components at a site the larger DAF is associated with the component having smaller peak ground acceleration in 10 out of 18 cases.

When we consider the horizontal component having smaller peak gropund acceleration and the associated DAFs for the 18 records at hand, no distinct pattern of the variation of peak DAF with peak ground acceleration can be established. This is true for the DAFs associated with the vertical component as well. Further there is no clear pattern in the normalised spectral peak with respect to distance for the same earthquake.

3) As distance of the recording site from the earthquake source increases, the spectral peak shifts towards the low frequency end of the spectrum. Also, the latter have a comparatively greater spread in the frequency domain.

4) Spectral peaks, well separated in the frequency domain can be located in the spectra of most records. (It may be possible to get confirmation on the natural frequency of the ground arrived at by other techniques.)

In both the horizontal as well as the vertical component spectra, spectral peaks are very sharp, and need a great deal of care in computations to arrive at accurate response spectral shapes. If the responses are not computed at sufficiently close intervals of frequency (or period) erroneous spectral shapes may be inferred from an otherwise correct computing technique. The spectra, in the present study, have been calculated by considering up to 36 points in each frequency decade.

7 DISCUSSION

Securing conservatism in design response spectra is the basic objective behind using spectral shapes derived from a combination of individual response spectra. Newmark et al.(1973) recommended spectral shapes for three different levels of exceedance probability, namely: 50%, 15% and 2%. The data set of the present paper has also been subjected to a similar analysis. An envelope of the actual spectral shapes for all the used accelerograms is also given. The ordinates of the envelope are associated with very low exceedance probability.

In combining response spectral shapes to arrive at design response spectra, the importance of the choice of the data set cannot be overemphasized. However, the decision to include a given accelerogram in the combination cannot be decided simply on some apparent factors. For example, the authors have encountered two extreme situations, where a generalist opinion favours exclusion or inclusion of a particular acceleogram. In one case, a construction site is located in a moderately seismic area, and a design basis event (or a combination of events) has been fixed on the basis of the regional geotectonics. An accelerogram recorded several hundred kilometres from the site is the only record available in the region of moderate seismicity. It is sometimes argued that the accelerogram be included in the data set. In the second case emphasis is laid on excluding some accelerograms, which were recorded in a different environment, the difference not necessarily limited to the tectonic environment only. For instance, in the present case the Pacoima dam recordings are a class in themselves. Analysis of spectral shapes of accelerograms carried out in this paper has demonstrated that in order to achieve the desired degree of conservatism in aseismic design it is necessary that:

A) The requirements of engineering design are quantified purely from the consideration of providing strength to the engineering structures in the existing geotectonic environment. This should be done firstly by determining the frequency range in which extra strength as to be provided, and secondly by examining the possibility of occurrence of the earthquake vibrations giving rise to such frequencies.

B) Acceleration time histories are chosen after analysing their spectral shapes and ensuring their suitability for meeting the desired objective.

C) A suitable procedure to combine the spectral shapes is evolved to ensure that it leads to added conservatism in the desired manner. Use of response spectra derived from a combination of spectral shapes does not always lead to enhancement of conservatism.

Once the data set,on the basis of which the design spectra have to be specified, have been examined with respect to hypocentral and ground motion parameters and recording site conditions, and their spectral shapes analysed, it may be possible to divide the data set into subsets using predecided criteria of classification. Iyengar and Prodhan (1983) have proposed a principal component classification of earthquake data characterised by twelve standardized strong motion parameters. The homogeneity according to a preset criterion of data set can be checked using such an analysis. The subsets may be combined using a M or $M+\sigma$ spectral shape to arrive at a spectral shape characteristic of each subset. The spectral shapes arrived in this manner may then be combined using a different combination procedure, the envelope for example. Such a practice, whereas it will fullfil the objectives behind the inclusion of each subset, will guard against the excessive conservatism which could have resulted from the use of an overall envelope.

8_CONCLUSIONS

1) In view of the established differences in the spectral shapes for sites with different geological conditions, it is desirable that site specific spectra are used in aseismic design. Response spectra for rock sites from 54 accelerograms of earthquakes having magnitudes between 5.4 and 7.6, and recorded at stations in the distance range of 3 to 122 kilometres have been presented for different values of damping (0%,2%,3%,5%,7% and 10% of critical) (Figs 19-20).

2) Choice of the data set for determining site specific response spectra requires attention. Preponderance of accelerograms of events having spectral characteristics significantly different from the stipulated design basis earthquake may change the spectral shapes considerably, at least in certain frequency ranges. Inclusion of such events, though desirable, needs to be controlled very judiciously before specifying the spectra.

3) Inclusion of earthquakes from close proximity of the source, while accentuating the high frequency component of the spectra, reduces the low frequency content.

4) For lower values of damping smoothening of the spectra, if considered desirable, should be carried out carefully.

5) The horizontal and vertical spectral shapes should be independently determined from their respective data samples.

REFERENCES

1) Blume, J.A. and Associates, Engineers(1973). Recommendation for shape of Earthquake Response Spectra, Report WASH-1254, Directorate of Licensing, United States Atomic Energy Commission under contract AT(49-5)3011.

2) Campbell, K.W.(1981). Near Source Attenuation of Peak Ground Horizontal Acceleration, Bull. Seism. Soc. Am. 71, 2039-2070.

3) Esteva, L. and R.Villaverde(1974). Seismic Risk Design Spectra and Structural reliability. World Conf. Earthquake Engineering 5th, Rome, 1973, Proc. V2, pp 2586-2596.

4) Hayashi, S., H.Tsuchida and E.Kurata(1971). Average Response Spectra for Various Subsoil Conditions. Third Joint Meeting, U.S.-Japan Panel on Wind and Seismic Effects.,UJNR,Tokyo,May 10-12, 1971.

5) Housner, G.W.(1941). An Investigation of the Effects of Earthquakes on Buildings, Ph.D. Thesis, California Institute of Technology, Pasedena.

6) Housner, G.W.(1959).Behaviour of Structures during Earthquakes. Proc. ASCE, 85 , October.

7) IAEA(1979).Earthquakes and Associated Topics in Relation to Nuclear Power Plant Siting. 50-SG-S1,IAEA, Vienna.

8) Iyengar, R.N. and K.C.Prodhan(1983). Classification and Rating of Strong Motion Earthquake Records. Earthquake Engineering and Structural Dynamics. II,415-426.

9) Mohraz, B.(1976). A study of Earthquake Response Spectra for Different Geological Conditions, Bull. Seism. Soc. Am., 63 , 915-935.

10) Newmark, N.M. and Consulting Engineering Services(1973). A Study of Vertical and Horizontal Earthquake Spectra. Report WASH-1255 prepared for the Directorate of

Licensing, United States Atomic Energy Commission under contract AT(49-5)2667.

11) Seed,H.B.,C.Ugas and J.Lysmer(1976a). Site Dependent Spectra for Earthquake Resistant design, Bull. Seism. Soc. Am., 66, 221-243.

12) Seed,H.B.,R.Murarka, J.Lysmer and I.M.Idris(1976b). Relationship of Maximum Acceleration, Maximum Velocity, Distance from Source and Local Site Conditions for MOderately Strong Earthquakes. Bull. Seism. Soc. Am. 66, 1323-1342.

13) USAEC (1973). Design Response Spectra for Seismic Design of Nuclear Power plants. Regulatory Guide 1.60 U.S. Atomic Energy Commission, Directorate of Regulatory Standards.

14) USNRC(1973). Seismic and Geologic Siting Citeria for Nuclear Power Plants. Rules and Regulations, Title 10 Chapter 1 Code of Federal Regulations-Energy, Part 100 Appendix-A. U.S.A.

15) World Data Centre(1977).Catalog of seismographs and strong motion records, Report SE-6,Solid Earth Geophysics Division. Environmental Data Service, North Carolina.

TABLE-1

DATA BASE FOR THE PRESENT STUDY

Sl No.	Earthquake	Station Name & No.	Mag.	Source Dist(Km)	Component	Acc (g)	Source †
1	Kern county 21/07/52	Taft, CAL 1095 §	7.6	56.0	N21E S69E	.156 .179	Seed et al (1976 a)
2	SanFrancisco 22/03/57	Golden Gate 1077 §	5.25	11.0	N10E S80E	.083 .105	Seed et al (1976 a)
3	Helena Mnt 31/10/35	Federal Bldg Helena, 323 §	6.0	8.0	S00W S90W	.146 .145	Seed et al (1976 a)
4	WheelerRidge 12/01/1954	Taft, CAL 1095	6.0	51.0	N21E S69E	.064 .067	Seed et al (1976 a)
5	Parkfield 27/06/66	Temblor, CAL 1097 §	5.6	7.0	N65W S25W	.269 .347	Seed et al (1976 a)
6	Parkfield 27/06/66	San Luis 1083	5.6	63.6	N36W S54W	.018 .013	Joyner&Boore (1981)
7	Borrego Mtn 08/04/68	SCE Plant § 280	6.5	122.0	N33E N57W	.041 .046	Seed et al (1976 a)
8	San Fernando 09/02/71	Pacoima Dam 279	6.6	3.2 *	S16E S74W	1.250 1.240	Campbell (1981)
9	San Fernando 09/02/71	Castiac Old 110	6.6	22.8 *	N21E N69W	.390 .320	Campbell (1981)
10	San Fernando 09/02/71	LA Water & Power, 137	6.6	24.1 *	N50W S40W	.200 .140	Campbell (1981)
11	San Fernando 09/02/71	LA2011 Zonal 190	6.6	25.5 *	S62E S28W	.080 .070	Campbell (1981)
12	San Fernando 09/02/71	Pmp Pt, Pear- blossom 269	6.6	35.5 *	N00E N90W	.150 .100	Campbell (1981)

§ Records considered by Seed et al (1976 a), ref Table -3.
* Distance from Causative Fault
† Source for verifying Geological Conditions

TABLE - 2

GROUND MOTION PARAMETERS FOR ROCKSITES

	v/a (sec)		ad/v^2		r_h	r_{vh}
	horizontal	vertical	horizontal	vertical		
M	0·0875	0·0923	5·4781	8·5319	0·8260	0·5000
$M + \sigma$	0·1305	0·1499	8·1819	14·2590	0·9230	0·7200

d, v, a : PEAK DISPLACEMENT VELOCITY AND ACCELERATION OF GROUND MOTION

r_h : RATIO OF THE SMALLER TO LARGER PEAK HORIZONTAL ACCELERATION

r_{vh} : RATIO OF THE PEAK VERTICAL TO LARGER PEAK HORIZONTAL ACCELERATION

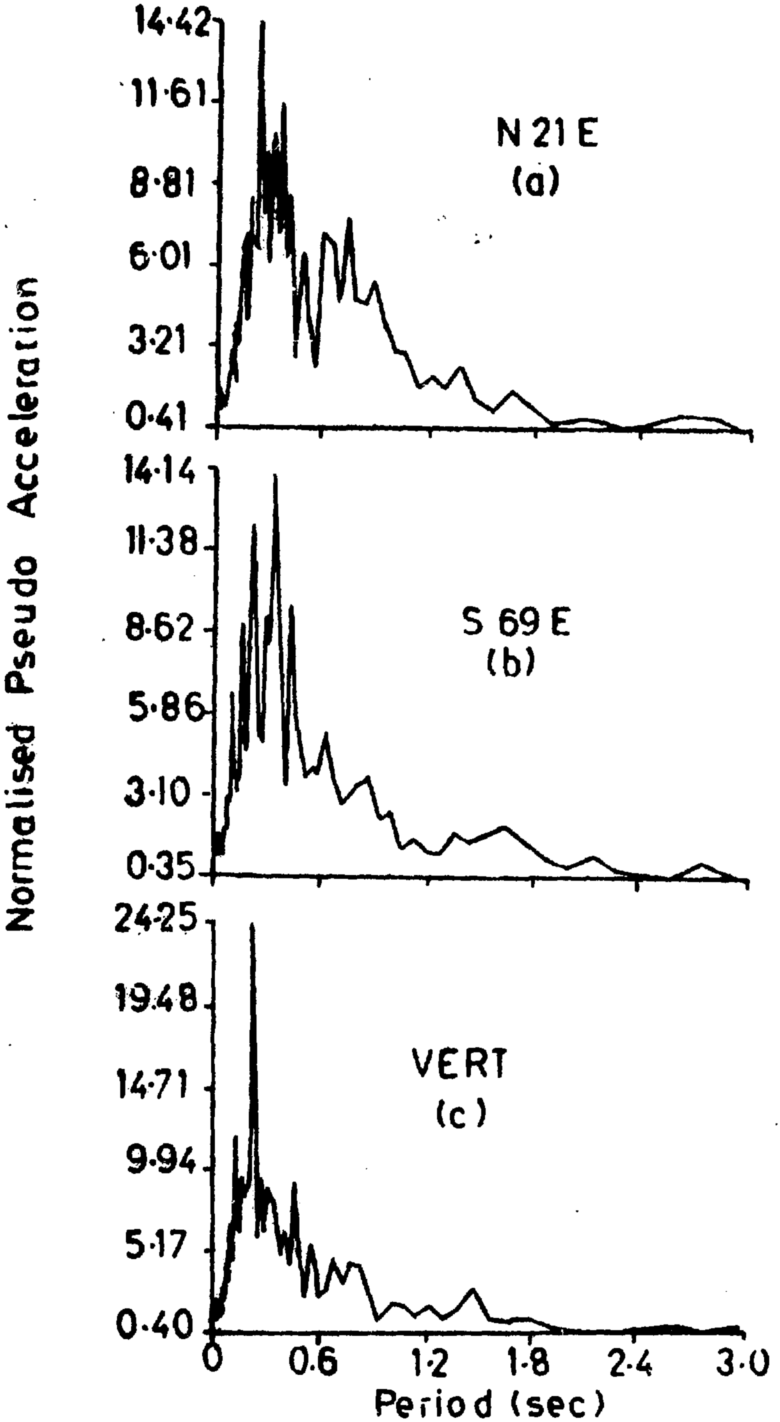


FIG.1: NORMALISED SPECTRA OF KERN COUNTY EARTHQUAKE OF 21-07-1952 RECORDED AT TAFT; M = 7·6 ; R=56 Km ; PEAK ACCELERATION (a) 0·156g, (b) 0·179g, (c) 0·105g

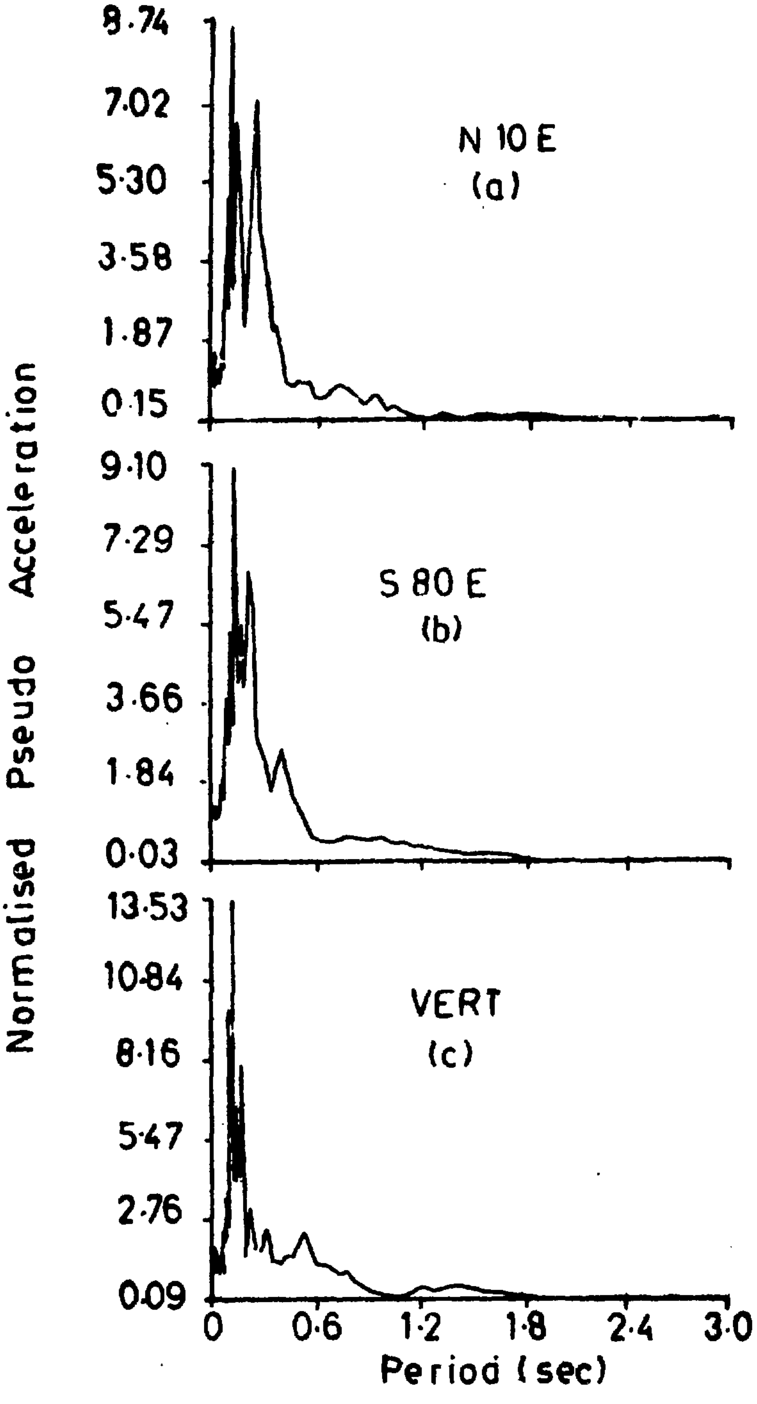
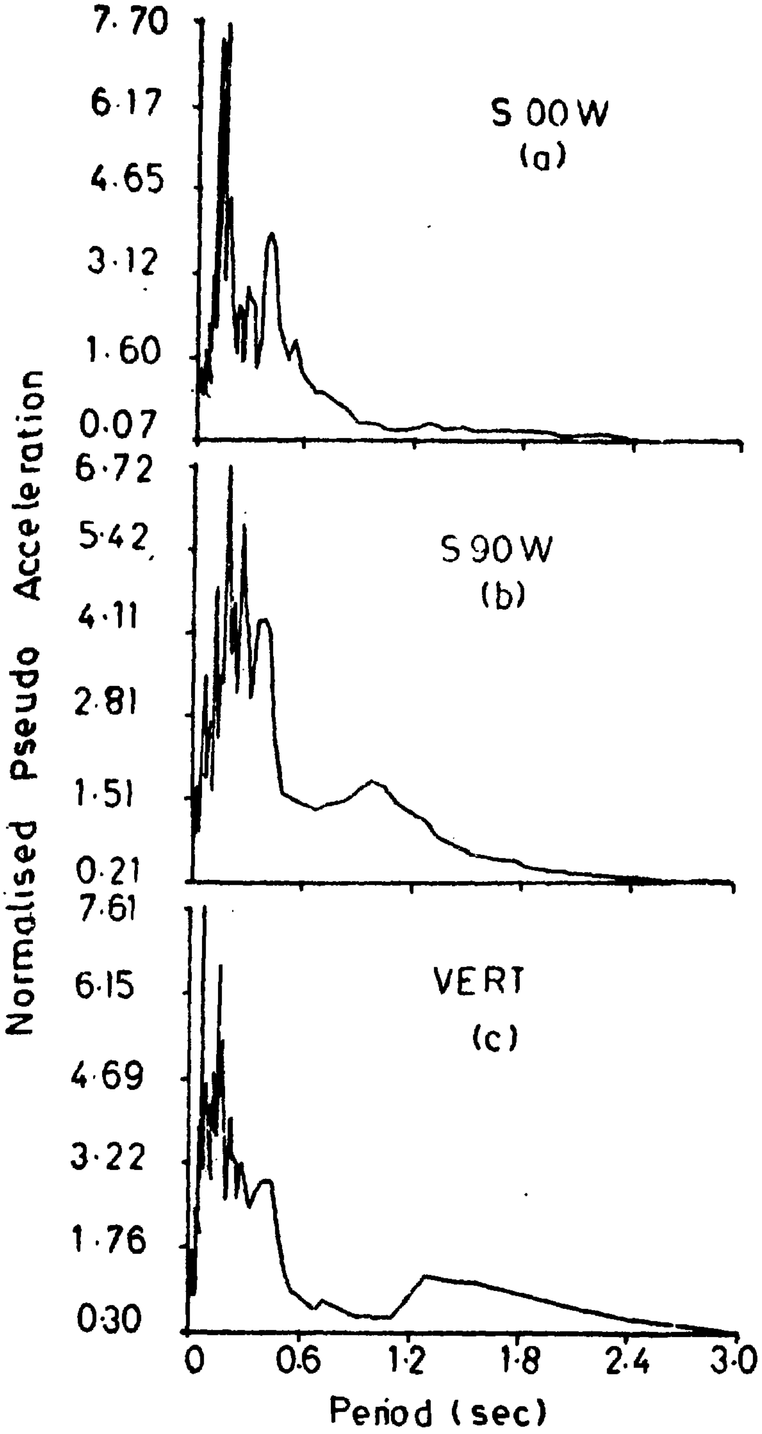


FIG. 2: NORMALISED SPECTRA OF SANFRANCISCO EARTHQUAKE OF 22-03-1957 RECORDED AT GOLDEN GATE PARK; M=5.25; R=11km; PEAK ACCELERATION (a) 0.083g (b) 0.105g, (c) 0.038 g



FIG·3: NORMALISED SPECTRA OF HELENA MONTANA EARTHQUAKE OF 31-10-1935 RECORDED AT FEDERAL BUILDING; M=6·0 R=8 km; PEAK ACCELERATION: (a) 0·146g; (b) 0·145g; (c) 0·089g

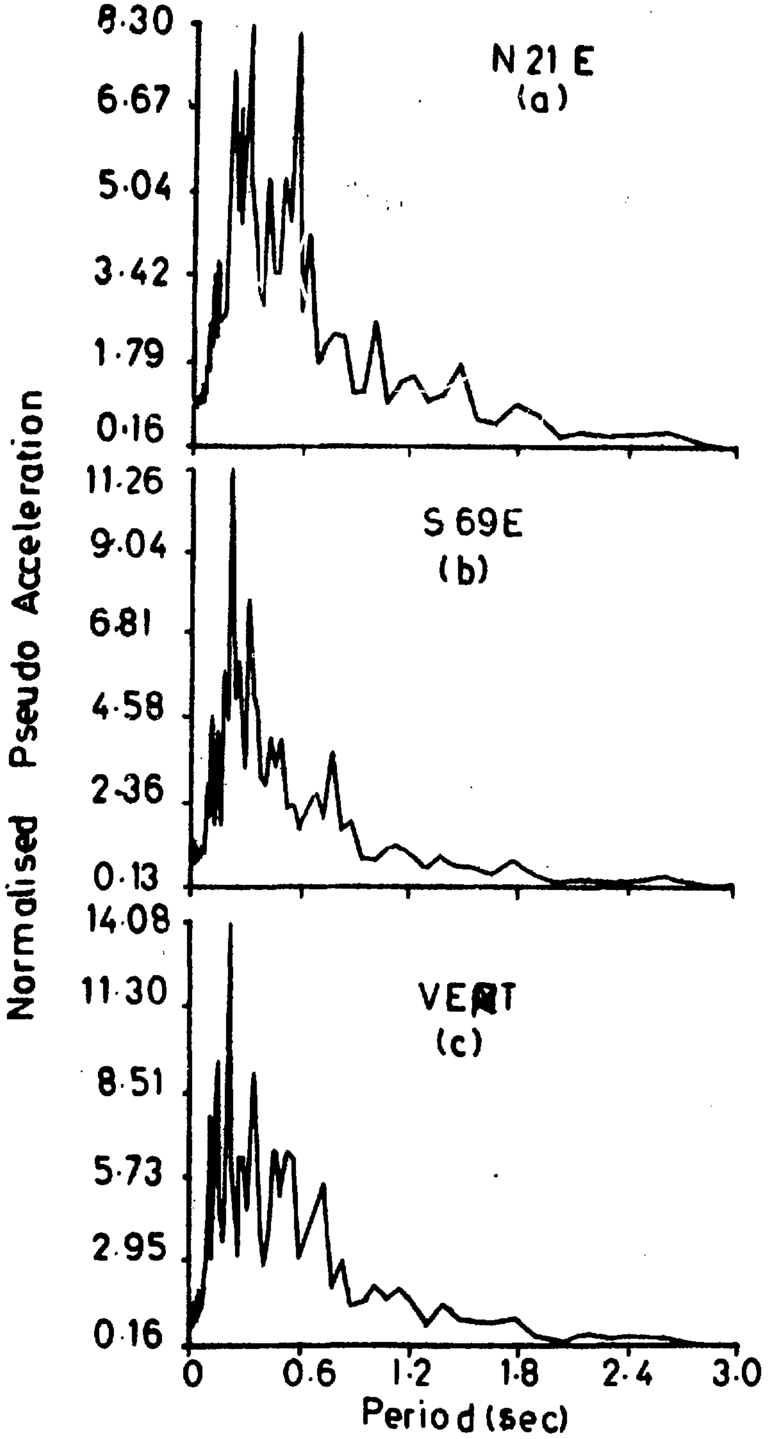


FIG. 4: NORMALISED SPECTRA OF WHEELER RIDGE EARTHQUAKE OF 12-01-1954 RECORDED AT TAFT; M = 6; R = 51 km; PEAK ACCELERATION: (a) 0·064g, (b) 0·067g; (c) 0·036g

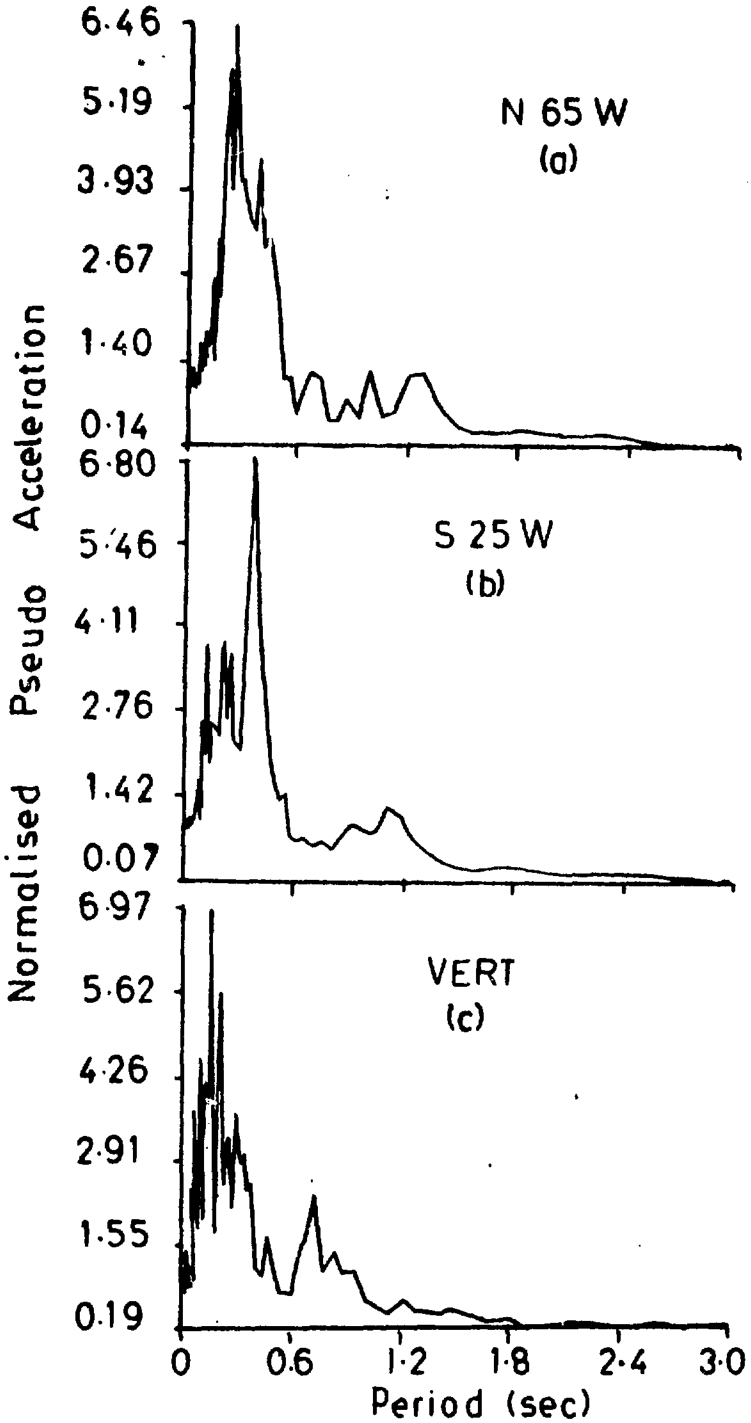
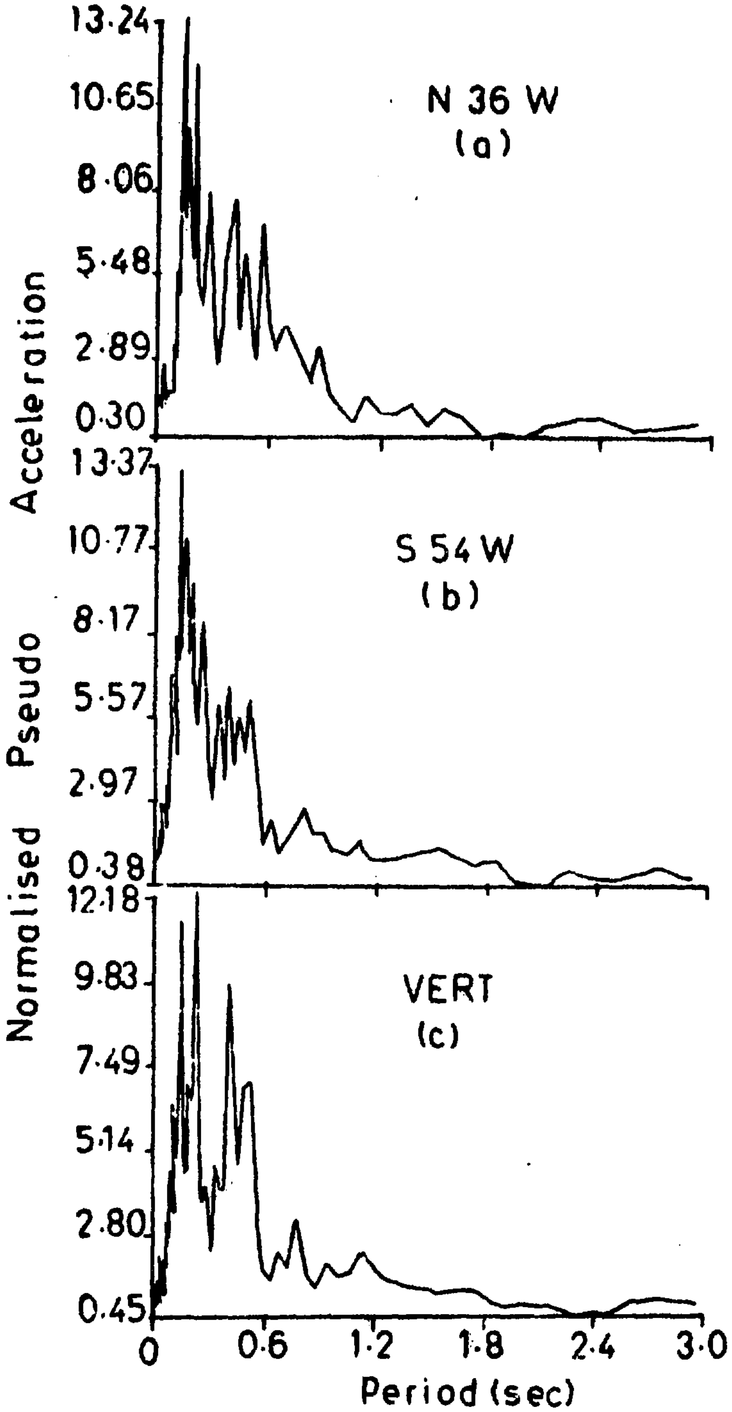


FIG.5: NORMALISED SPECTRA OF PARK FIELD EARTHQUAKE OF 27-06-1966 RECORDED AT TEMBLOR; M = 5.6; R = 7 km; PEAK ACCELERATION (a) 0·269g; (b) 0·347g; (c) 0·132g



FIG·6: NORMALISED SPECTRA OF PARK FIELD EARTHQUAKE OF 27-06-1966 RECORDED AT SAN LUIS Rec. Cent.; M=5·6; R=63·6km; PEAK ACCELERATION: (a) 0·018g; (b) 0·013g. (c) 0·006g.

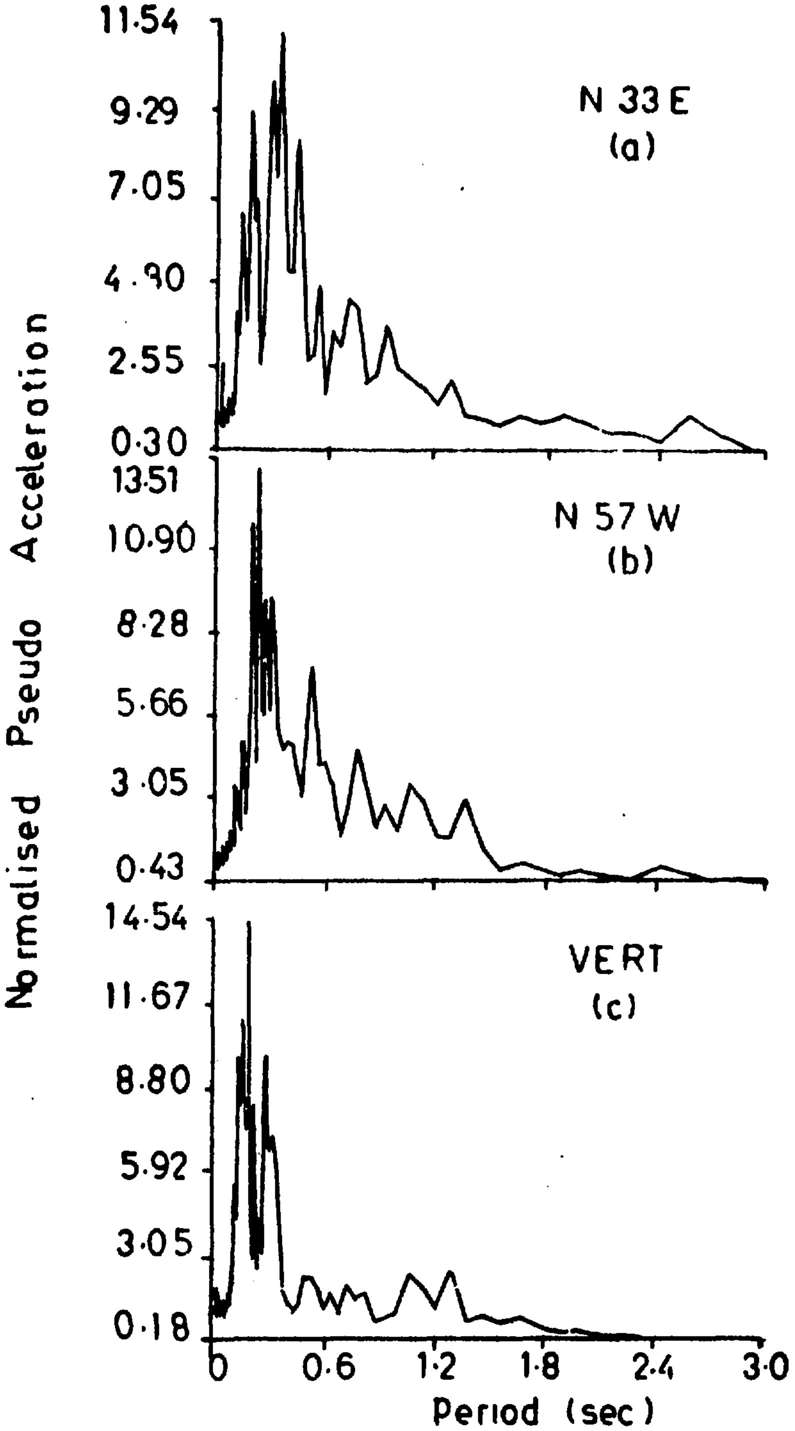


FIG. 7: NORMALISED SPECTRA OF BORREGO MOUNTAIN EARTHQUAKE OF 08-04-1968 RECORDED AT SCEPP: M=6.5; R=122 km; PEAK ACCELERATION: (a) 0.041g, (b) 0.046g, (c) 0.055g

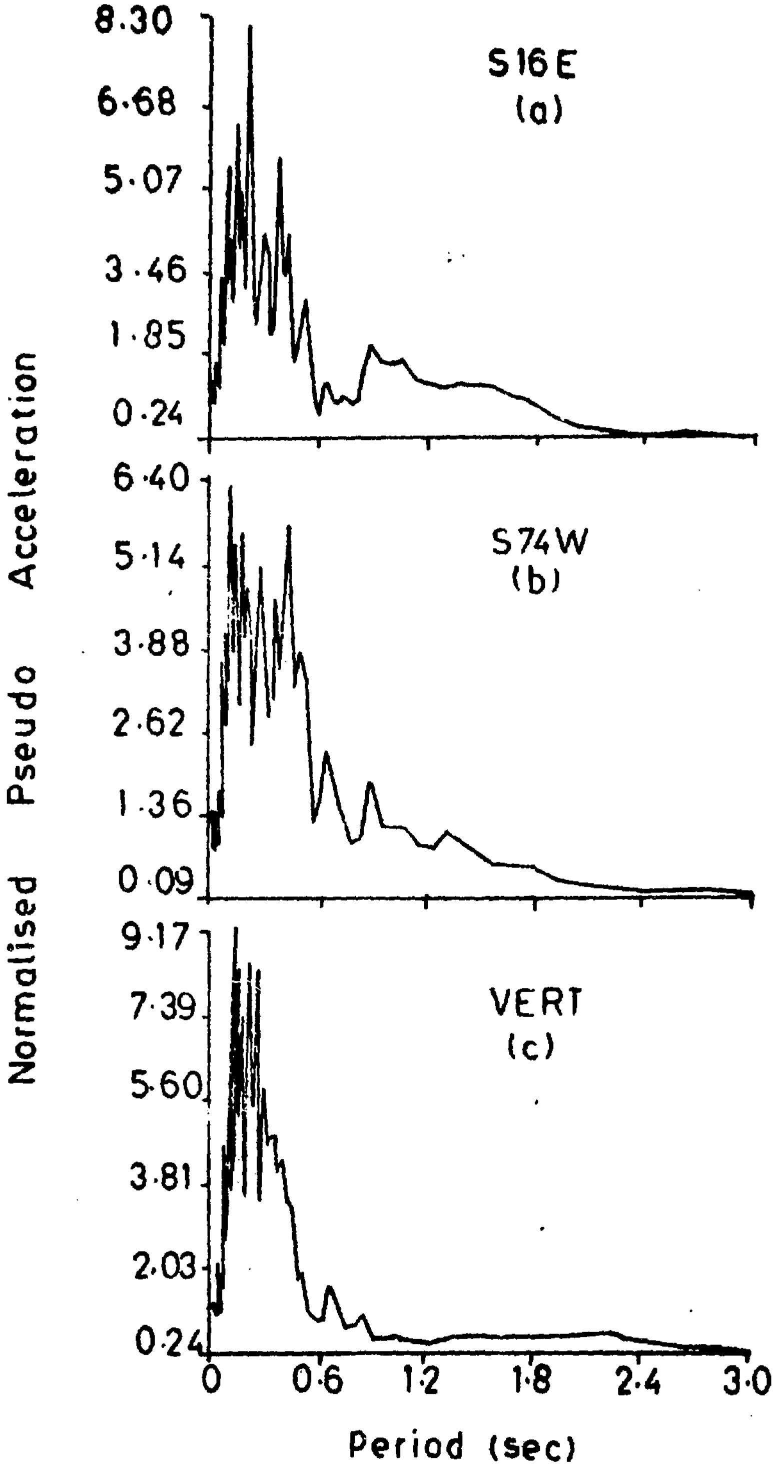


FIG.8: NORMALISED SPECTRA OF SAN FERNANDO EARTHQUAKE OF 09-02-1971 RECORDED AT PACOIMA DAM, M = 6.6, R = 3.2km; PEAK ACCELERATION: (a) 1.25g, (b) 1.24g, (c) 0.709g (MAIN SHOCK).

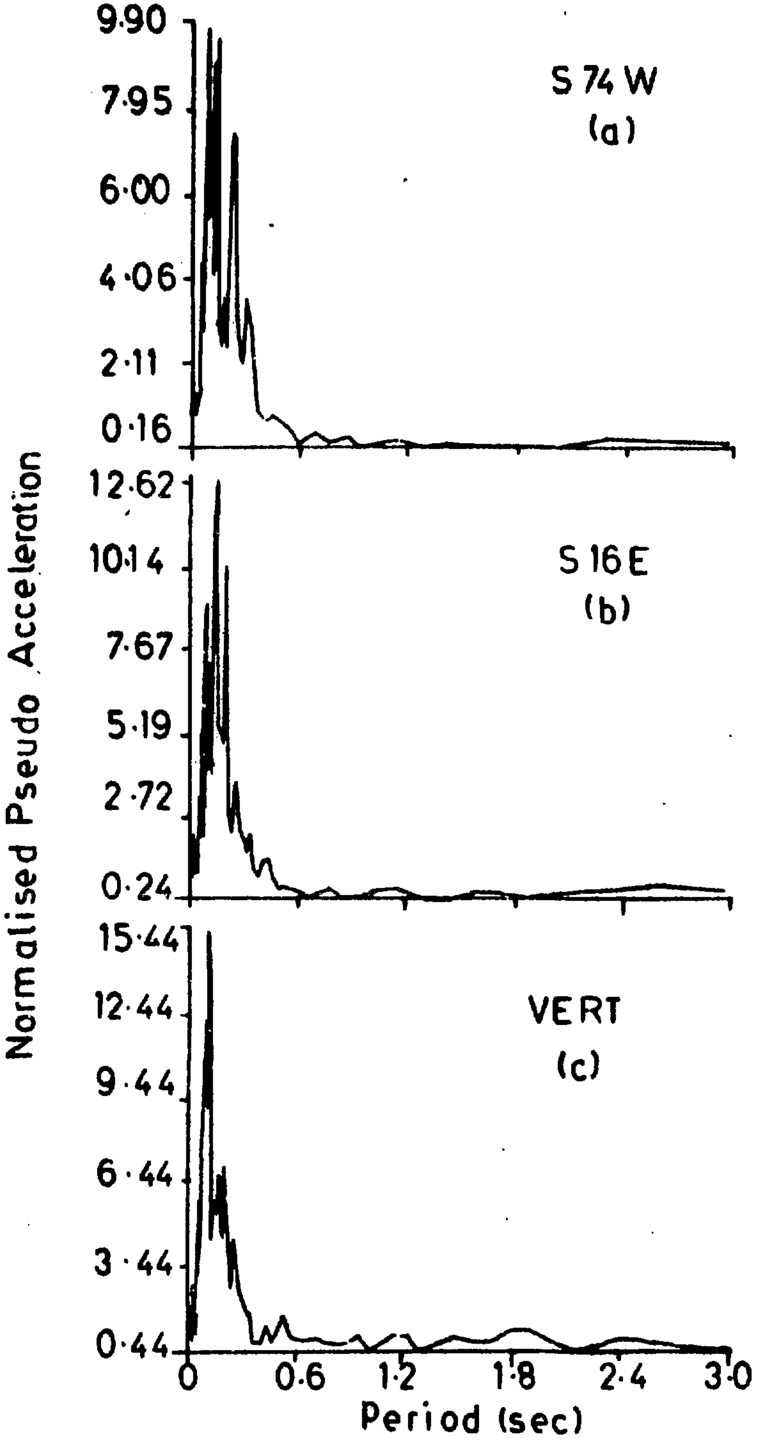


FIG 9: NORMALISED SPECTRA OF SAN FERNANDO EARTHQUAKE OF 09-02-1971 RECORDED AT PACOIMA DAM; M=2.4, R=3.2km PEAK ACCELERATION: (a) 0.021g, (b) 0.028g, (c) 0.008g (FIRST AFTERSHOCK)

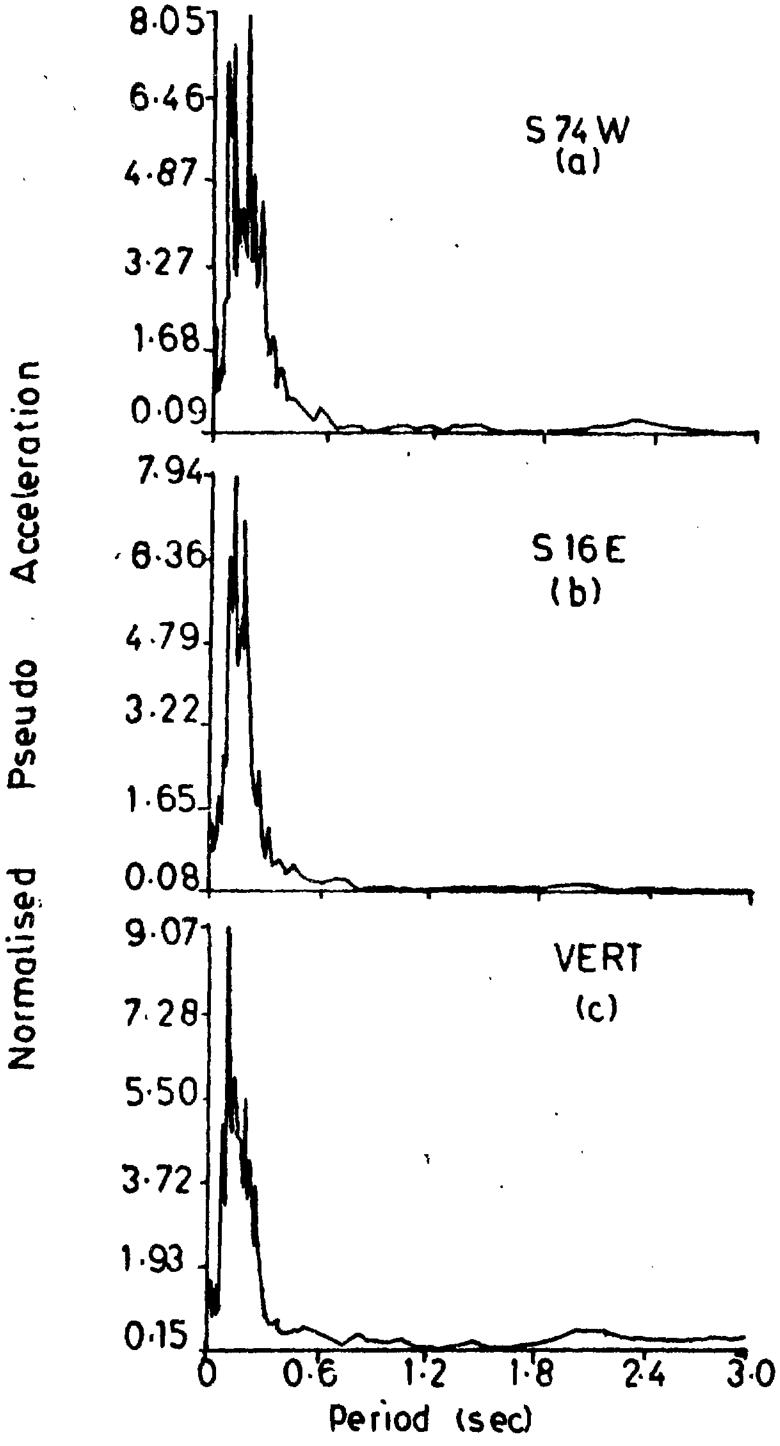


FIG.10: NORMALISED SPECTRA OF SAN FERNANDO EARTHQUAKE OF 09_02_1971 RECORDED AT PACOIMA DAM M = 3·1, R = 3·2 km ; PEAK ACCELERATION · (a) 0.046 g, (b) 0.052 g, (c) 0.021 g (SECOND AFTERSHOCK)

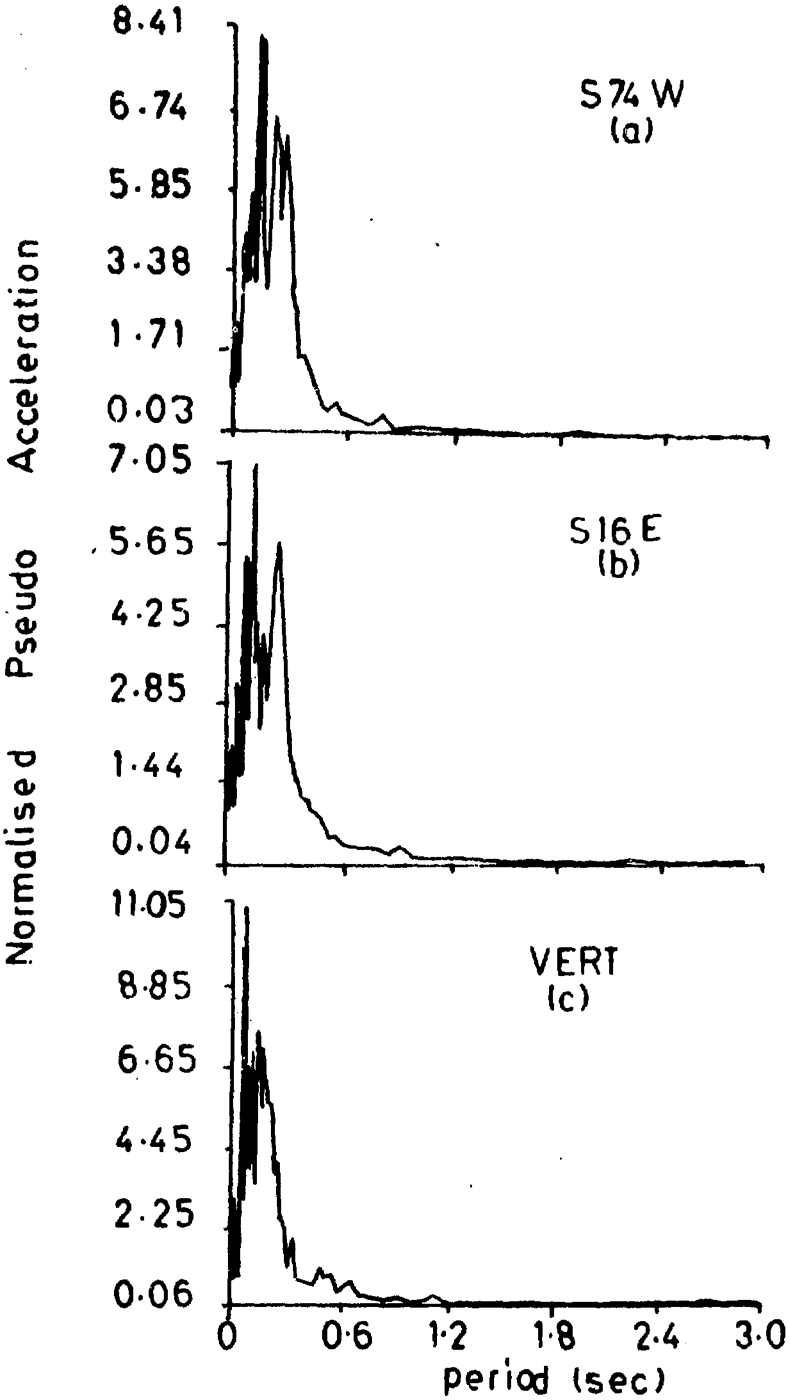


FIG.11: NORMALISED SPECTRA OF SAN FERNANDO EARTHQUAKE OF 09-02-1971 RECORDED AT PACOIMA DAM; M = 4.0 . R = 3·2 km, PEAK ACCELERATION:(a) 0·112g, (b) 0·115g, (c) 0·041g (THIRD AFTERSHOCK)

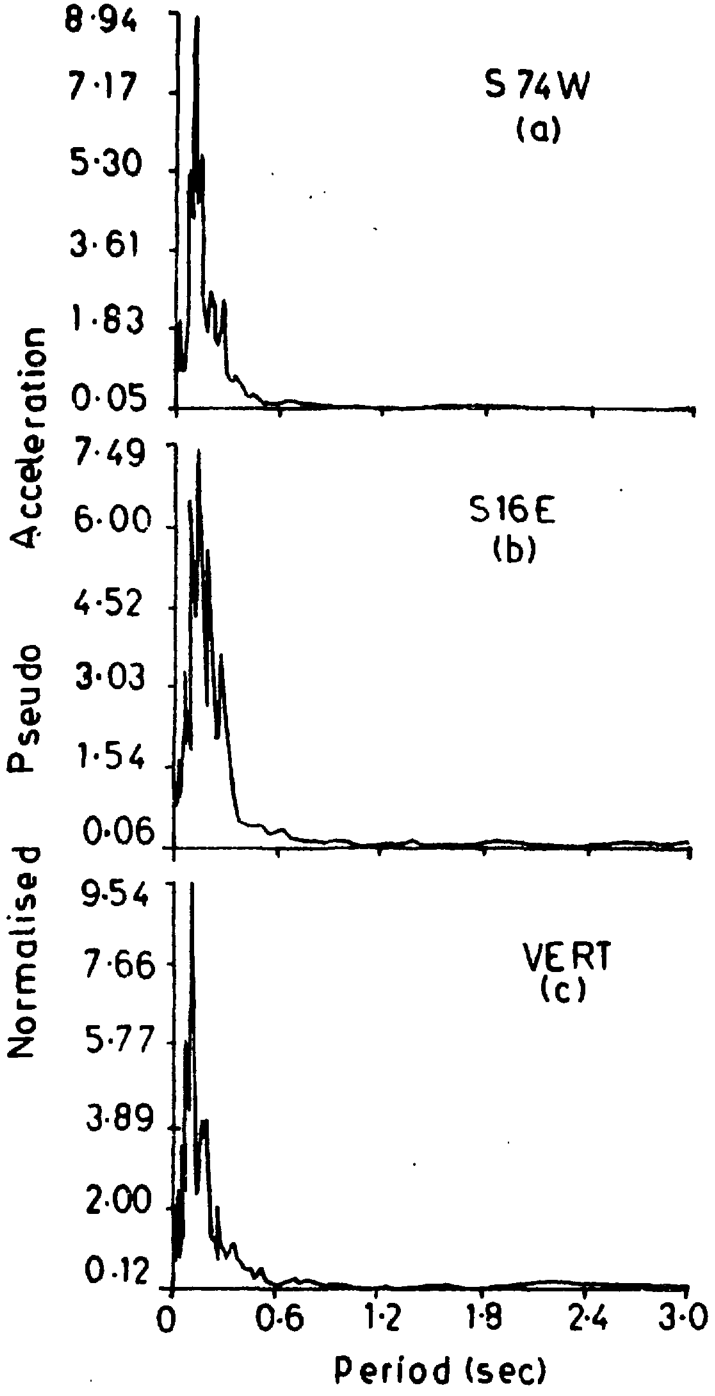
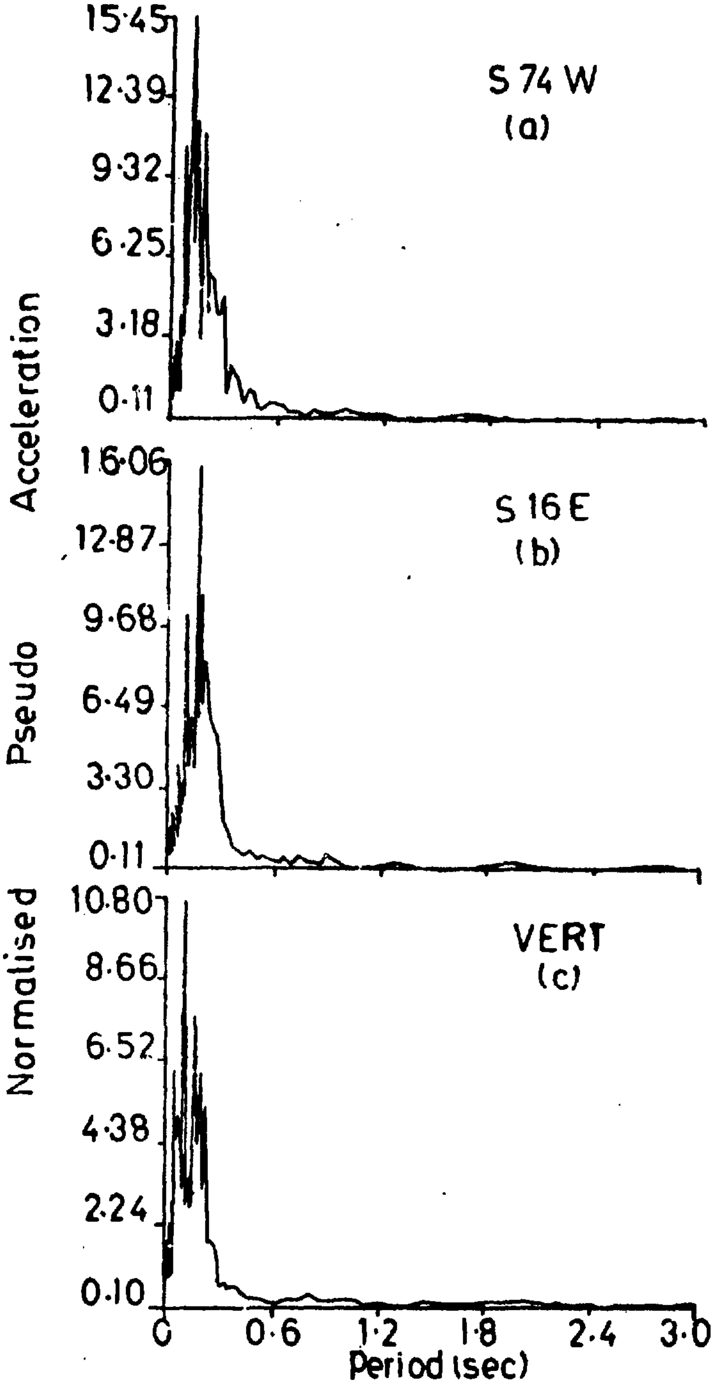


FIG. 12 : NORMALISED SPECTRA OF SAN FERNANDO EARTHQUAKE OF 09-02-1971 RECORDED AT PACOIMA DAM, M = 3 ; R = 3·2 km ; PEAK ACCELERATION : (a) 0.032g , (b) 0·048g , (c) 0.015g (FOURTH AFTERSHOCK)



FIG·13: NORMALISED SPECTRA OF SAN FERNANDO EARTHQUAKE OF 09-02-1971 RECORDED AT PACOIMA DAM; M=2·5, R=3·2 km; PEAK ACCELERATION (a) 0·024g (b) 0·031g (c) 0·025g (FIFTH AFTERSHOCK

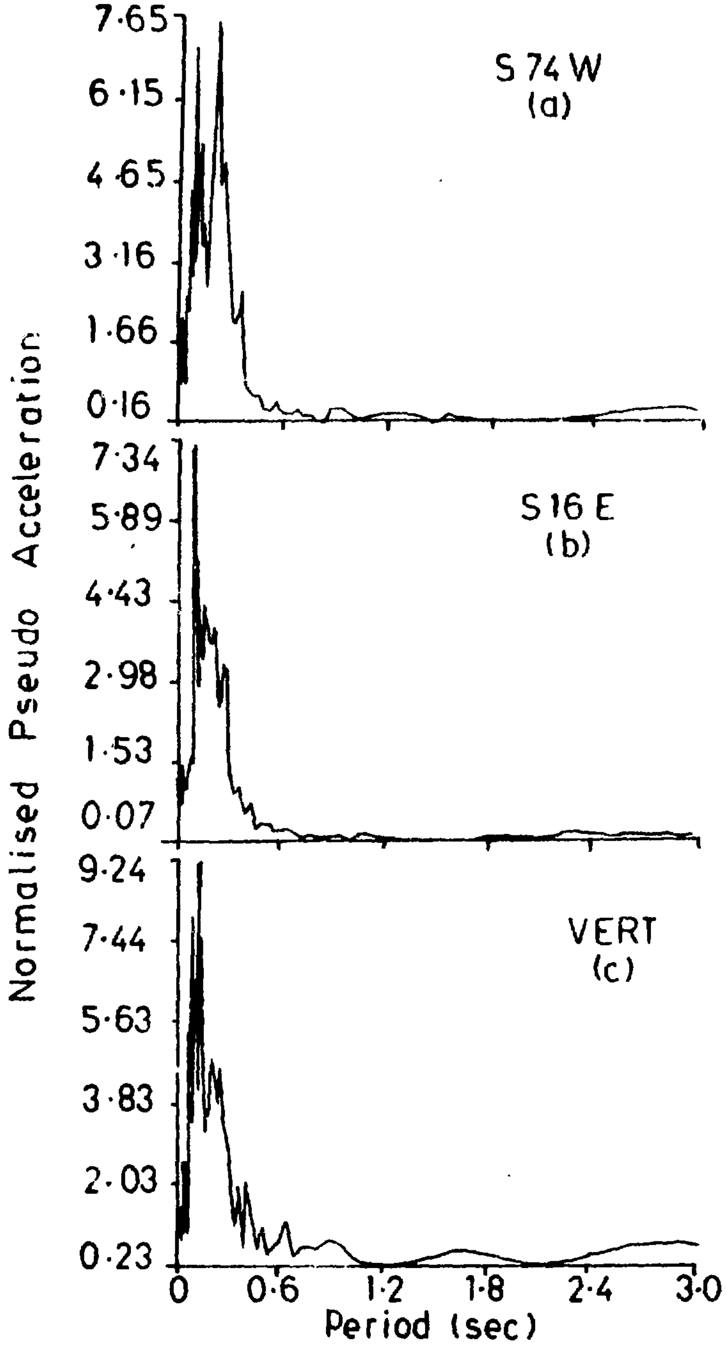


FIG.14 · NORMALISED SPECTRA OF SAN FERNANDO EARTHQUAKE OF 09-02-1971 RECORDED AT PACOIMA DAM; M=24,R=3 2km; PEAK ACCELERATION: (a) 0.019g ; (b) 0.028g ; (c) 0.007g (SIX AFTERSHOCK)

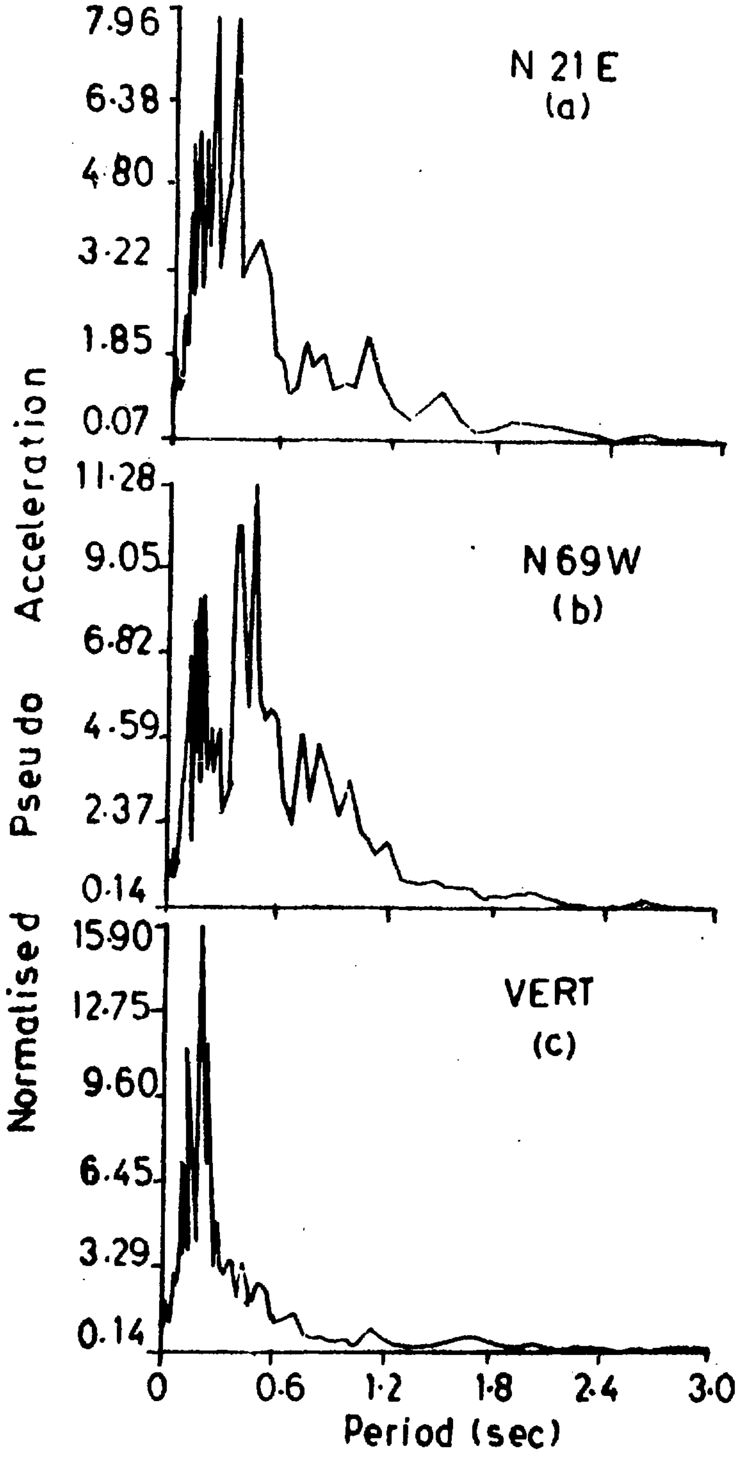
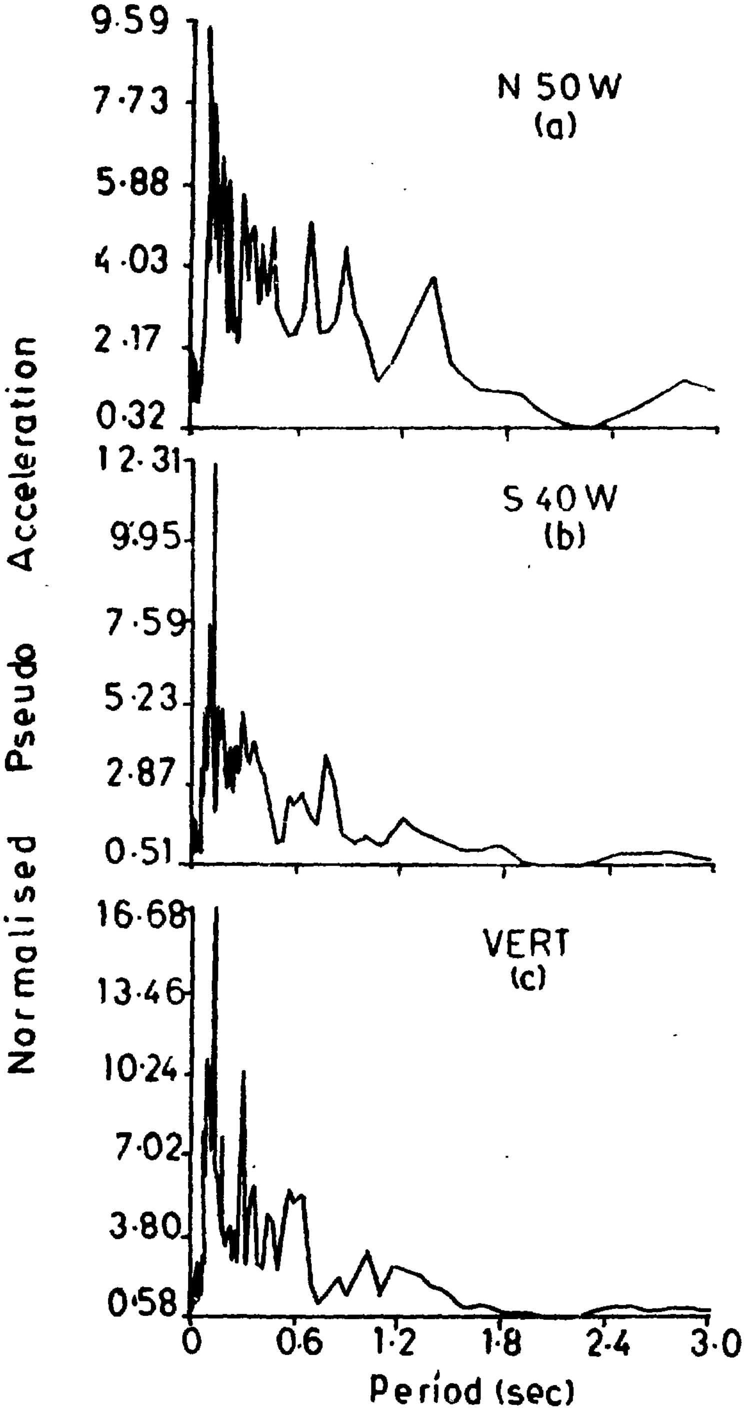


FIG. 15: NORMALISED SPECTRA OF SAN FERNANDO EARTHQUAKE OF 09-02-1971 RECORDED AT CASTIAC ; M = 6.6 , R = 22.8km ; PEAK ACCELERATION: (a) 0.39g , (b) 0.32g, (c) 0.156g



FIG·16 : NORMALISED SPECTRA OF SAN FERNANDO EARTHQUAKE OF 09-02-1971 RECORDED AT LA WATER POWER ; M = 6·6, R = 24·1km PEAK ACCELERATION:(a) 0·20g,(b) 0·14g,(c) 0·068g

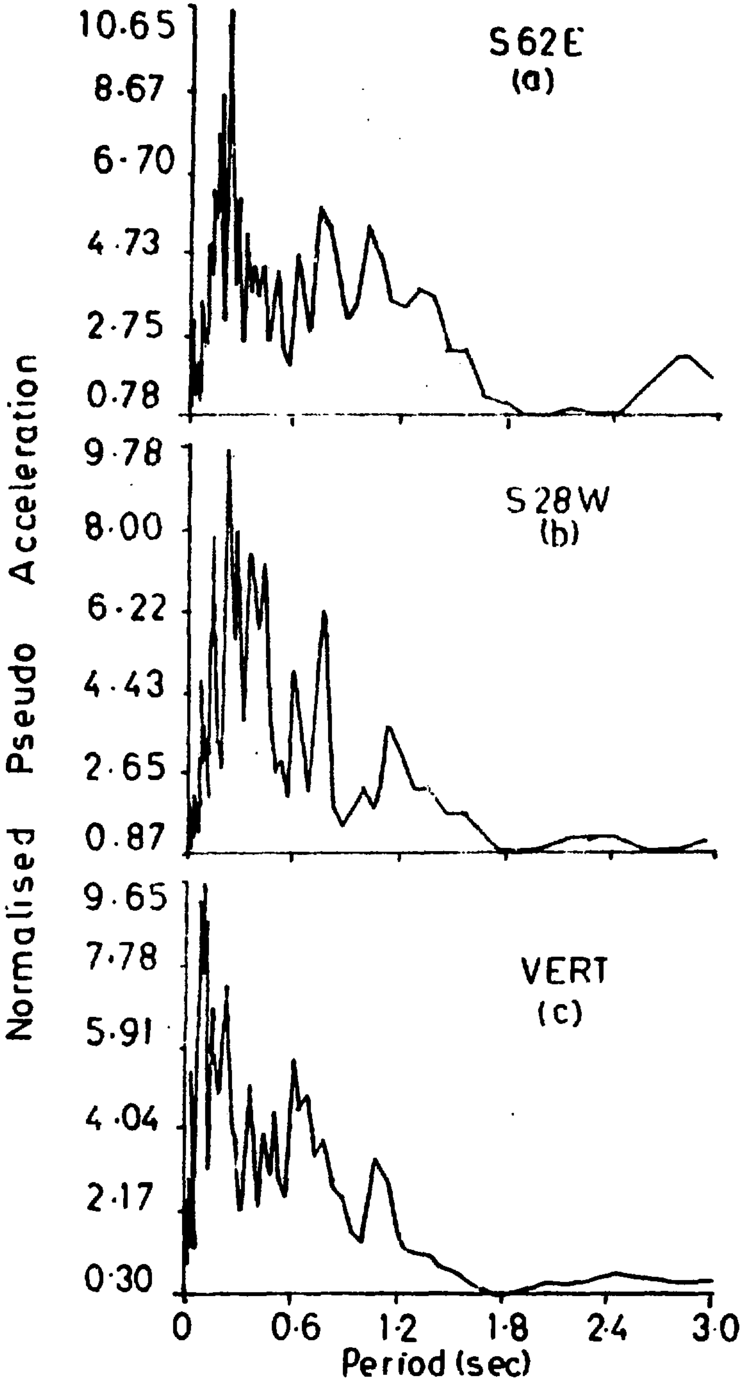
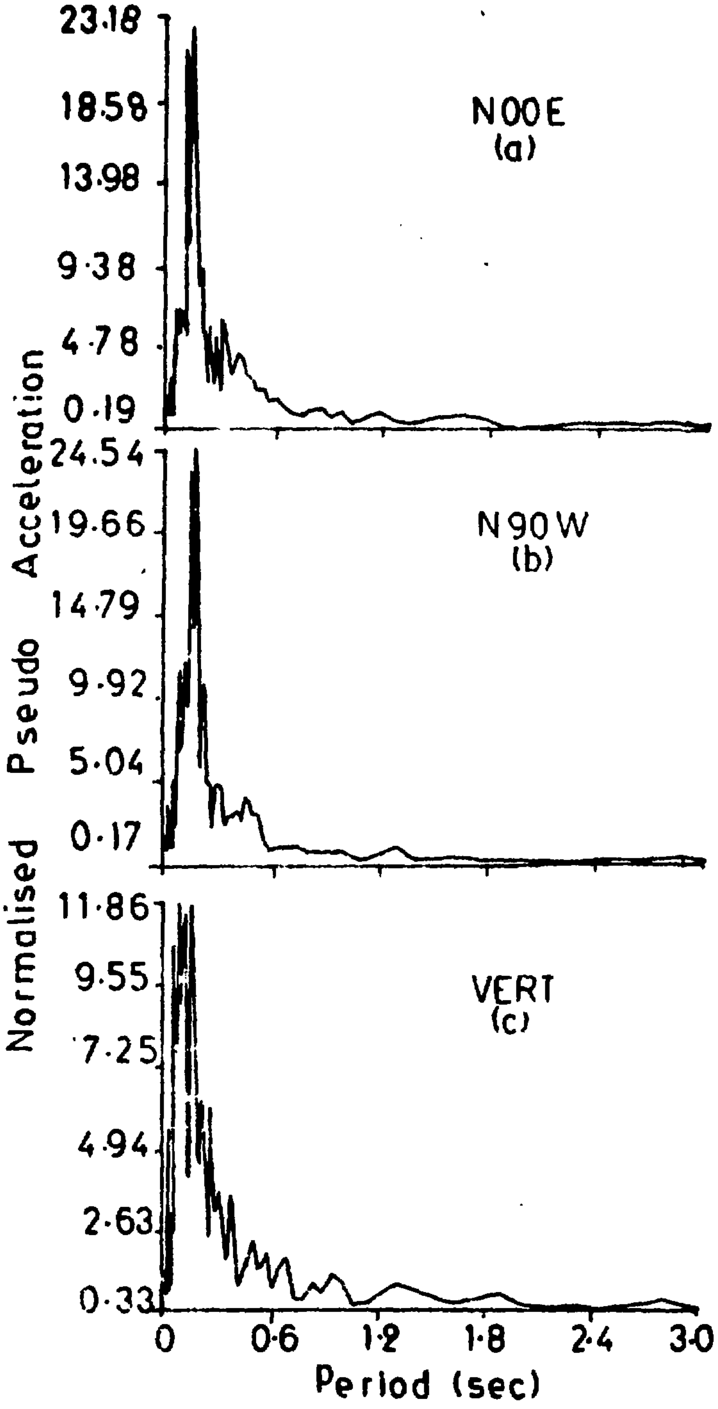


FIG.17: NORMALISED SPECTRA OF SANFERNANDO EARTHQUAKE OF 09-02-1971 RECORDED AT LA 2011 ZONAL, M=6.6 R=25.5km; PEAK ACCELERATION: (a) 0.08 g (b) 0.07g (c) 0.050g



FIG·18: NORMALISED SPECTRA OF SAN FERNANDO EARTHQUAKE OF 09-02-1971 RECORDED AT Pmp.Pt. PEAR BLOSSOM; M=6·6, R=35·5km.; PEAK ACCELERATION: (a) 0·150g, (b) 0·10g, (c) 0·050g

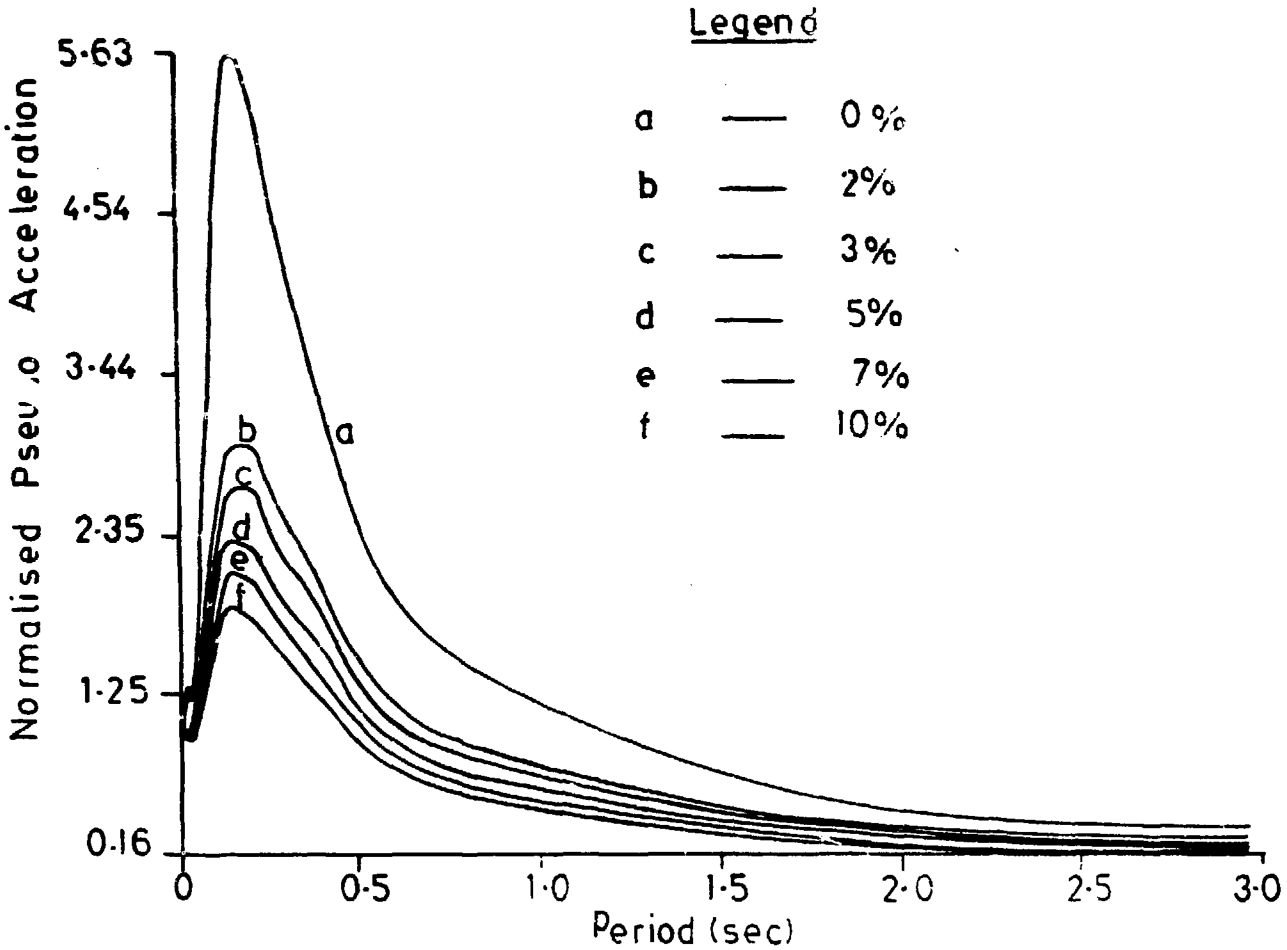


FIG. 19: MEAN HORIZONTAL RESPONSE SPECTRA FOR ROCKSITES — SMOOTHENING BY THREE POINT MOVING AVERAGE

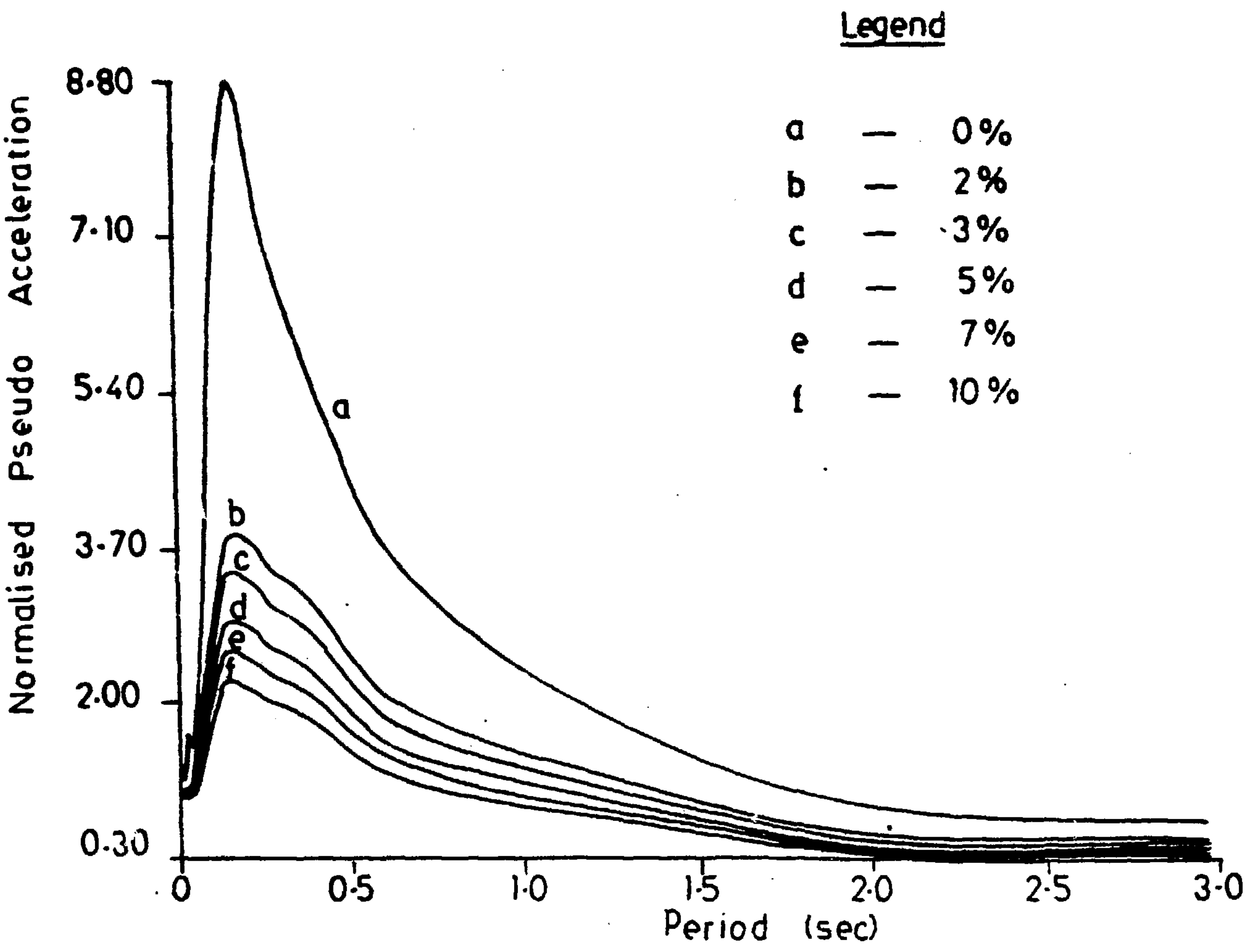


FIG-20: M+T HORIZONTAL RESPONSE SPECTRA FOR ROCK SITES – SMOOTHENING BY THREE POINT MOVING AVERAGE