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GENERATION OF EARTHQUAKE FOR DIFFERENT GROUND CHARACTERISTICS

A Dissertation
submitted in partial fulfilment
of the requirements for the Degree
of
MASTER OF ENGINEERING
in
EARTHQUAKE ENGINEERING
WITH SPECIALIZATION IN STRUCTURAL DYNAMICS

By
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CERTIFICATE

Certified that the thesis entitled "GENERATION OF EARTHQUAKE FOR DIFFERENT GROUND CHARACTERISTICS" which is being submitted by Sri DILIP KUMAR PAUL in partial fulfilment for the award of the degree of Master of Engineering in Earthquake Engineering with specialization in STRUCTURAL DYNAMICS, of the University of Roorkee, Roorkee, is a record of student's own work carried out by him under our supervision and guidance. The matter embodied in this thesis has not been submitted for the award of any other degree or diploma.

This is further to certify that he has worked for a period of 5 months from May, 1971 to Sept., 1971 for preparing this thesis for Master of Engineering Degree at the University.

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SYNOPSIS

This investigation primarily deals with the effect of soil characteristics on the ground motion. A large number of earthquake accelerograms with varying soil characteristics have been generated on digital computer and corresponding ground acceleration spectra were studied.

A nonstationary process is used to simulate the bed rock acceleration. The bed rock acceleration is then filtered through the soil deposit to get the ground acceleration. The filter parameters depend upon the characteristics of the soil deposit. Statistical characteristics of the ground acceleration have been studied with respect to the base rock acceleration.

It is observed that rate of zero crossings of the ground motion decreases as the period of the soil layer is increased. Predominant period also increases with the increase of period of soil deposit. The maximum ground acceleration varies with the fundamental period of the soil deposit. The maximum ground acceleration shows a regular decrease, as the damping of the soil layer is increased.

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CHAPTER - I

INTRODUCTION

Recorded earthquake accelerograms are often used for designing important structures even though these might not have completely suitable properties at another site. For example, the El-centro, 1940, and Taft, 1952, accelerograms have been used all over the world even though its special character is not really applicable everywhere. The statistical fluctuations in intensity, duration and frequency content in the past recorded strong motions need to define adequately. In absence of these informations, it is difficult to estimate the ground motion and consequently the design of structures. In such cases it becomes necessary to use the probabilistic methods that provide the solution within some reliability. Large number of recorded earthquakes on similar condition (i.e. epicentral distance, soil condition, intensity etc.) are needed for probabilistic design. Unfortunately the number of recorded strong-motion earthquakes are very few. In some seismic regions, not even a single record is available. This has motivated simulations of ensemble of ground motion on the basis of available earthquake records. Similar process could be adjusted to reflect the local geology which affects the ground motion.

If detailed seismic history of the region is available, it is possible to predict for a given location, the number and size of earthquakes expected in future during the service life of the structure. If the location of the active fault relative to the site is known, magnitude information can be related to other ground parameters such as duration, peak acceleration etc.(67) These in turn could be incorporated in the simulation of ground acceleration.

To perform a probabilistic analysis of the behaviour of structures to withstand strong motion earthquake, different investigators have designed stochastic model to generate artificial ground acceleration similar to those of real earthquakes. The stochastic models of earthquakes could be classified in two main groups, namely, stationary models and nonstationary models.

The models are constructed by incorporating the statistical properties of recorded ground motion, the most significant of which are the duration, intensity, peak acceleration, envelope function and the frequency content.

The stationary models could be represented by the white noise. This model was proposed by Housner (33) and have been used by several other investigators (14, 35, 54). White noise may be taken as a reasonable representation of ground acceleration at the bed rock (35). The effect of the soil deposit may then be incorporated by filtering the bed rock acceleration.

Stationary models are not adequate for modelling the tail of the large earthquakes (1, 43). Non-stationarity in earthquakes enters primarily through the envelope function. Records of different earthquakes are all different in detail but have the features in common i.e., the motion is highly oscillatory about zero central line and non-periodic. At the start of the accelerogram, the amplitude builds up rapidly to its maximum, then remains almost constant over a certain period, this is followed by gradually decaying tail upto the end of the record. Nonstationary models could be constructed by using envelope function.

Engineers have not yet been able to agree on a way of incorporating site effects in design. The various effects of the site conditions, should be represented in the records. In recent years, procedures have been developed for analysing and predicting the ground motion caused by an earthquake at different sites, taking into account the characteristics of the soil deposit underlying the site, magnitude and epicentral distance (31, 67, 68, 74, 75). The method involves in assessing the base rock motion at the site due to an earthquake establishing the properties of the overlying soil layers and computing the response at the ground surface, using a lumped mass analysis.

Chapter II briefly reviews previous work in simulation of earthquake records. Chapter III deals with the generation process of artificial ground acceleration. In this dissertation, normally distributed random numbers with mean zero and variance unity have been generated by a method suggested by J. N. Franklin of the California Institute of Technology (23). A computer programme has been made to generate random numbers on a digital computer IBM 1620 as given in Appendix 'C'. White noise is obtained by spacing these numbers at uniform interval and joining them by straight lines. The accuracy of white noise depends upon the spacing of the random numbers. Five different bed rock acceleration have been obtained by multiplying the white noise with the envelope function. This envelope function, describes the manner in which the intensity of the desired nonstationary process varies with time. By filtering the bed rock acceleration through the soil deposits having different soil characteristics, ground accelerations have been generated on a digital computer IBM 7044.

It is assumed that the soil deposit acts as a single degree of freedom system. The frequency and damping of soil deposit changes from site to site and both of these are assumed to vary over a wide range. Finally the effect of soil characteristics on the ground motion have been discussed. Chapter IV discusses the effect of change in period and damping of soil layer on the ground motion spectra. Average acceleration spectras have been drawn for 5 per cent damping and from these conclusions are made thereafter. Finally, the conclusions obtained from this investigation are summarised in Chapter V.

CHAPTER - II

HISTORICAL REVIEW

Simulation of earthquake motions is done mostly by digital computer. All these methods have a common trend, to match the average pseudo velocity spectra of the generated process to that of real earthquake.

Housner (33) used random pulses of the same magnitude and later sinusoidals, arriving randomly in time. Stochastic characteristic of the process is estimated by matching the expected spectrum to that of real earthquake.

Thomson (72) formed a ground acceleration process as a series of random velocity pulses and showed that this process is almost white noise when the duration of pulse is short as compared to the natural period of typical structures.

Bogdanoff and Goldberg (27, 28) represented earthquake type motion by superimposition of waves with nonstationary amplitudes.

Bycroft (13) used an analog simulation of white noise to represent ground acceleration during an earthquake. Power spectral density has been estimated by matching the spectral response of a single degree of freedom system to Housner's average spectra (33).

The next refinement to the use of white noise is the use of a filtered white noise, or a stationary process with a prescribed power spectral density function. This kind of power spectral density function is strongly supported by the work of Kanai and his associates (45, 46). How ground layer of different properties affected incoming waves have been investigated and then arrived to an amplification factor as a function of the frequency content of the waves.

Tajimi (71) suggests that for firm ground the damping and period could be taken equal to 0.6 and 0.4 second respectively. These values change due to local soil conditions.

Housner and Jennings (35) used a digital computer to generate a white noise process that was later passed through a second order linear filter. It has been shown that the key central portion of the strong motion acceleration can be modelled by sections of stationary Ganssian process with power spectral density derived from average undamped velocity spectra.

Arias and Petit Laurent (3) studied the process generated at the ground surface by a train of shear waves passing through a soil layer which have been produced by a white noise process at bed rock. It has been found that this process could be simulated using a dashpot in series with a spring to represent the soil layer.

Lin (52) showed that if a white noise is passed through a linear filter, the output process shows a stationary trend, thus, implying that this simulation cannot be used to model the decay observed towards the end of real earthquake records, It has been suggested that the filtered shot noise with a variance intensity function that has a similar shape to that of the expected output process, could be used.

Amin and Ang (1) using the above suggestion used filtered shot noise. Variance intensity function with an initial steep rise, then a constant value during the strong part of the motion and finally exponential decay towards the end has been selected. The computed variance function of the filtered process resulted very similar to the selected variance shape.

Shinozuka and Sato (69) formulated a general form to simulate a Ganssian nonstationary random process. It has been suggested that either a filter shot noise or a filtered white noise multiplied by a deterministic shaping function after filtering could be used as nonstationary process. In both cases it has been tried to represent general earthquake characteristics with the nonstationary features. It has been showed that under certain condition the simulated process is equivalent to a filtered poisson process thus providing a more physical interpretation to simulation.

Patrico Ruiz and Joseph Penzien (56) proposed a method of investigation using a nonstationary random process obtained from filtering a shot noise through a second order linear filter. Both the filter and the shot noise are selected so that, on the average, simulated accelerograms generated with this model will simulate the most relevant features of strong motion earthquakes recorded on firm soil at moderate epicentral distance. A Ganssian nonstationary shot noise has been used to represent the acceleration at bed rock during an earthquake. The soil above the bed rock is replaced by a dashpot and a spring of known value.

The filtering parameter and variance intensity function of the shot noise are estimated using the available earthquake records. Ground acceleratics of the overlying soil layer and computing the response at the ground surface using a lumped mass analysis procedure. A method of analysis which incorporates strain dependent soil characteristics obtained from the laboratory tests, appears to provide adequate means for assessing the seismic response of soil deposit. Wiggins (74) made a study of over one hundred strong motion records in investigating the effect of soil conditions on the intensity of ground shaking. Strong motion instrument records at a number of locations developed at different sites in the same general area but underlain by different site conditions.

Duke and Associates (22) - Dynamic model of sub-surface conditions has been developed and Fourier spectra method has been used for isolating the effect of site conditions. A modification of earthquake motion at the base of structure due to soil structure interaction is also given.

tion has been generated by filtering the bed rock acceleration through the second order linear filter.

Iyengar and Iyengar (40) The ground acceleration is represented by nonstationary process. Fourier Series is used to represent stationary process and variance function is determined by past record earthquakes. An expression is also found out for variance function. The strength of oscillation or violence is exhibited by the number of zero crossings and extremes.

Housner, Jennings and Tsai (43) simulated various type of earthquakes with different characteristics. Nonstationary process has been obtained by multiplying a filtered white noise by a shaping function. The shaping function has been selected depending upon duration and magnitude, according to the type of earthquake that is to be simulated. Finally, the process is passed through a filter to determine the low frequency content of the process according to observed records.

Seed and Idriss (67, 68) - Ground motion at several sites are evaluated using recently developed techniques which involve assessing the base rock motion at the site due to an earthquake establishing the properties of the overlying soil layer and computing the response at the ground surface using a lumped mass analysis procedure. A method of analysis which incorporates strain dependent soil characteristics obtained from the laboratory tests, appears to provide adequate means for assessing the seismic response of soil deposit. Wiggins (74) made a study of over one hundred strong motion records in investigating the effect of soil conditions on the intensity of ground shaking. Strong motion instrument records at a number of locations developed at different sites in the same general area but underlain by different site conditions.

Duke and Associates (22) - Dynamic model of sub-surface conditions has been developed and Fourier spectra method has been used for isolating the effect of site conditions. A modification of earthquake motion at the base of structure due to soil structure interaction is also given.

CHAPTER - III

GENERATION OF ARTIFICIAL ACCELEROGRAMS

White noise modified by nonstationary function is used for generation of pseudo accelerograms.

3.1 GENERATION OF WHITE NOISE

Several investigators (35, 42) have modelled earthquakes accelerograms by white noise. White noise is a mathematical idealization of a stationary random process in which all the frequencies contribute with equal intensity to the mean square value of the process, such a process is characterised by a constant frequency range. A white noise that has a flat power spectral density over the range of frequencies of interest is constructed as follows (23).

A sequence of independent random numbers x_1, x_2, x_3, ... with uniform distribution in the interval (0, 1) could be obtained by computing the fractional part from the expression

$$x_n = \theta^n \quad , \quad n = 1, 2, 3, \ldots\ldots$$

where θ is some trancendental number greater than unity i.e. $\theta > 1$. The fractional part of the above expression is computed as accurately as possible. Fractional part means the part beyond the decimal. One of the value of θ may be taken equal to π. Uniformly distributed random numbers are calculated upto eight decimal places as accurately as possible. While calculating these numbers corresponding to higher powers of θ, the term θ^n becomes very large and also further calculations become very combersome, so some simplification is done which causes small error in calculating the fractional part due to the overflow of integer part. Thus fairly accurate random numbers of uniform distribution could be calculated.

Given the sequence x_n of independent samples from the uniformly distributed on $0 < x < 1$, a new sequence of independent random numbers w_n with a Ganssian distribution having zero mean and unit variance is obtained using the following transformation (23)

$$W_{2n-1} = (-2 \log x_{2n-1})^{1/2} \operatorname{Cos} 2\pi\, x_{2n} \;;\; n=1, 2, 3, \ldots \quad (1)$$

$$W_{2n} = (-2 \log x_{2n-1})^{1/2} \operatorname{Sin} 2\pi\, x_{2n} \;;\; n=1, 2, 3, \ldots \quad (2)$$

These random numbers have been generated on digital computer and are listod in Appendix 'C', together with the computer programme. By spacing these numbers at equal interval of time and then joining them by straight lines, an ensemble of these random wave forms W(t) could be obtained. This wave form approximates white noise, the degree of approximation being dependent on the time spacing Δt and the fundamental frequency of soil deposit. As Δt approaches zero, this wave form approaches white noise. The power spectral density function of the wave form for small value of $\omega\Delta t$ has the form

$$S(\omega) = \frac{\sigma_n^2}{\pi}\left(1 - \frac{(\omega\Delta t)^2}{6}\right) \quad \ldots \quad \ldots \quad (3)$$

where σ_n^2 is the variance of the white numbers. This power spectral density is approximately constant over a certain range but falls to zero as ω tends to infinity. Thus the frequency, ω, and the time spacing, Δt, is so chosen that power spectral density remains constant over the range of interest. Power spectral density is constant within less than three per cent error for $\omega\Delta t < 0.42$ and within less than 25 per cent error for $\omega\Delta t < 1.25$. It is evident that as the frequency is increased keeping the time spacing constant the error increases. In the present investigation the time spacing is kept constant and frequency is changed over a wide range. The values of time spacing and the frequency are decided such that errors are within reasonable range. P. C. Jennings, and Penzien and Ruiz have taken spacing time Δt equal to 0.025 and 0.03 second respectively. In the present investigation Δt is taken equal to 0.04 second. Frequency is assumed to vary from 63 to 10.5 radians per second corresponding to periods 0.1 and 0.6 second. For periods 0.2 to 0.6 second the error is within 25 per cent whereas for period 0.1 second the spacing time is reduced so that the error remains within reasonable limit.

3.2 BED ROCK ACCELERATION

Jennings (41) has shown that the central portion of strong motion earthquake accelerogram can be modelled by the stationary process $N(t)$. Further it has been shown that the response spectra resembled closely with corresponding results for real earthquake motions. The frequency content of the process should be so selected that the average spectra of the real and artificial earthquake match closely.

White noise when multiplied by nonstationary function represent earthquake like motion (1, 3, 35, 52, 69). Similar type of motion is taken for bed rock acceleration due to an earthquake. The nonstationary function or envelope function describes the manner in which the intensity of desired earthquake type motion varies with time. For selecting the envelope function it is necessary to determine the time history of motions in the rock like base material. By studying the characteristics of the base rock motions, it is possible to develop a reasonable assessment of the time history of the motion by either generating a synthetic earthquake motion with the desired characteristics (1, 35, 42, 43, 49) or by modifying an earthquake record.

The envelope function, ENV(t), specify how the intensity of acceleration varies with time, from an initial build up of intensity to the final decay to a negligible value. The envelope function, ENV(t), is chosen for 20 seconds duration of the type shown in fig. 1.

where

OA, $ENV(t) = t^2/16$

AB, $= 1.0$

BC, $= EXP(-0.268(t-8))$

Consider a stationary random process W(t) which can be taken to be normally distributed with mean zero and variance unity. The nonstationary process is obtained

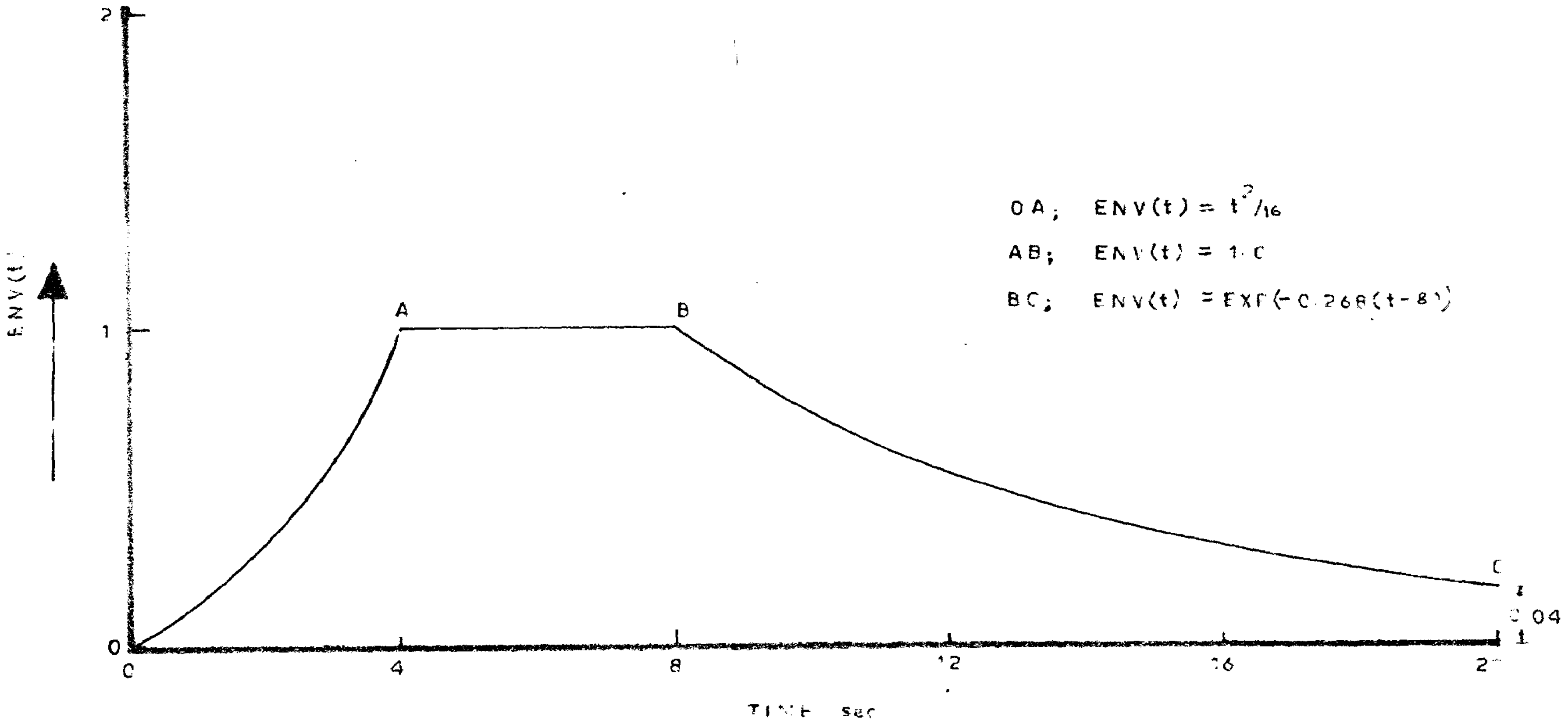


FIG. 1 _ENVELOPE FUNCTION

by multiplying the white noise, W(t), with envelope function, ENV(t), i.e.

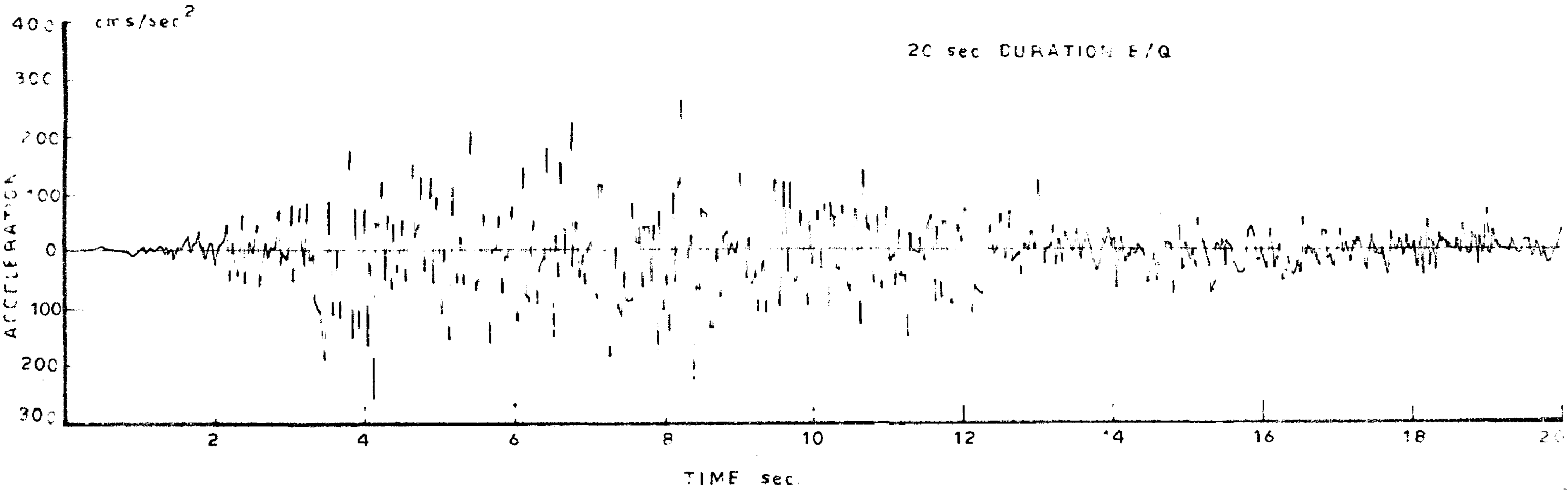
$$a_b(t) = ENV(t).W(t) \quad \ldots \quad \ldots \quad (4)$$

where $a_b(t)$ is bed rock acceleration

The properties of $a_b(t)$ will also be normally distributed with zero mean and variance $ENV^2(t)$. The frequency content of nonstationary process will depend upon the white noise. Five different base rock motion are taken, to study the statistical properties of the pseudo accelerogram. Figure 2 shows a sample of bed rock acceleration. These bed rock motions have been developed for the same duration and envelope function. The number of zero crossings, maximum acceleration and time period to the maximum acceleration of each record have been tabulated as below :

Table 1 - Table showing the number of zero crossings, Maximum acceleration and time period to the maximum acceleration of the bed rock accelerations.

Sample Number	Number of zero crossings	Maximum acceleration cms/Sec^2	Time - to maximum acceleration in sec.
1	12.5	250.0	8.2
2	11.5	220.0	9.6
3	12.0	270.0	9.0
4	14.0	220.0	8.0
5	13.0	260.0	9.0



SAMPLE NO. 1

FIG. 2 _ BED ROCK ACCELERATION

From the table it may be inferred that these bed rock acceleration represent the similar characteristics.

3.3 GROUND ACCELERATION

Ground motion developed during an earthquake may be attributed due to upward propagation of shear waves from the underlying rock formation. The dynamic characteristic of soil layer could be defined by a filter. The filter characteristics are defined by equivalent spring constant and equivalent damping constant as presented in Appendix 'B'. Therefore ground motion during an earthquake could be treated as the response of the soil deposit equivalent to single degree of freedom system whose support is excited by bed rock acceleration, $a_b(t)$.

The ground acceleration $a_g(t)$ is obtained as the absolute acceleration of the mass, which could be obtained by the differential equation

$$\ddot{Z} + 2\varrho w\dot{Z} + w^2 Z = -a_b(t) \quad \ldots \quad \ldots \quad (5)$$

where Z is the relative displacement of bed rock and the ground surface. w and ϱ are the equivalent frequency and damping of soil deposit. The relative displacement is given by the expression

$$Z(t) = -\frac{1}{w_d}\int_0^t a_b(\tau)\, e^{-w\varrho(t-\tau)}\, \mathrm{Sin}\, w_d(t-\tau)\, d\tau \quad \ldots \ (6)$$

where

$$w_d = w\sqrt{1-\rho^2}$$

Two differentiation of equation (6) gives the absolute acceleration of the ground

$$\ddot{Z} + a_b(t) = w\frac{1-2\rho^2}{\sqrt{1-\rho^2}}\int_0^t a_b(\tau)e^{-w\rho(t-\tau)}\operatorname{Sin} w_d(t-\tau)d\tau$$

$$+ 2w\rho\int_0^t a_b(\tau)e^{-w\rho(t-\tau)}\operatorname{Cos} w_d(t-\tau)d\tau \quad \ldots (7)$$

The artificial earthquake acceleration could be calculated from the expression

$$a_g(t) = \ddot{Z} + a_b(t) = -(2\rho w\dot{Z} + w^2 Z)$$

The initial condition of Z and $\dot{Z}$ are taken equal to zero. The solution of equation (6) could be obtained by using step by step procedure with piece-wise linear, taking the interval of 0.01 second.

Tajimi (71) has suggested that damping factor, $\rho = 0.6$ and period of the soil layer, T = 0.4 Sec., based on past earthquake records for the firm soil strata. To study the effect of various type of soil conditions on the ground motion, the damping factor is assumed to vary from 0.1 to 0.6 and the period of the soil deposit vary from 0.1 second to 0.6 second, to cover the wide

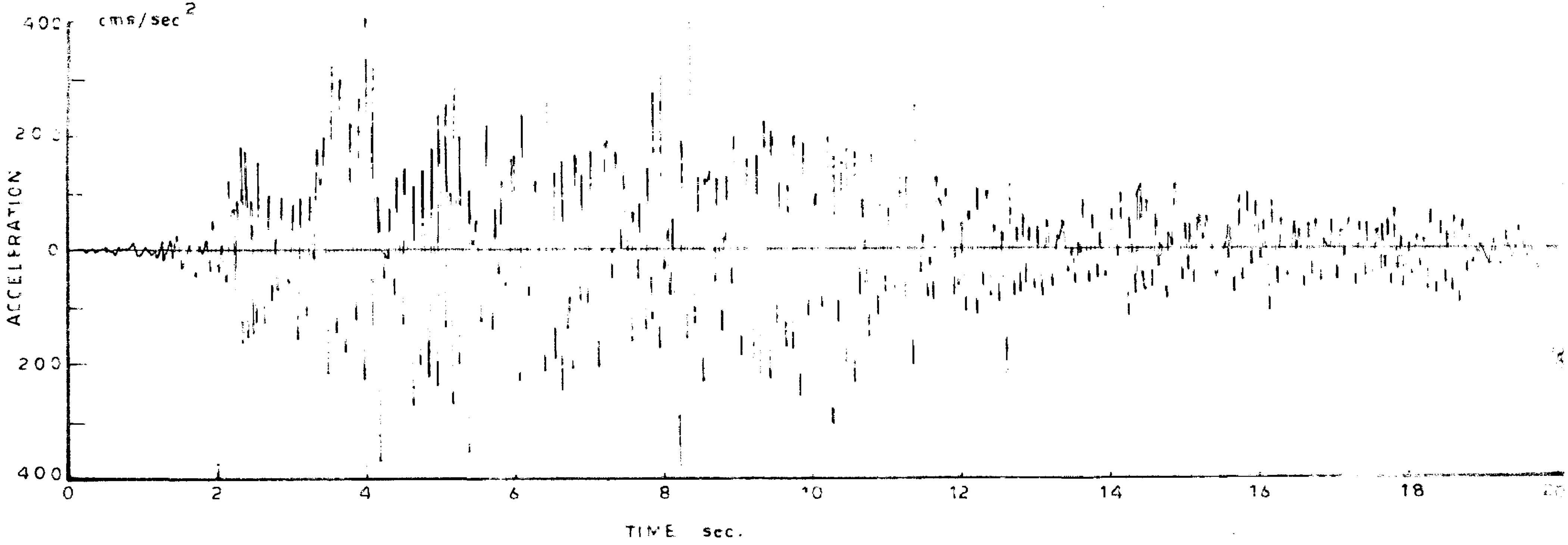


FIG. 3 _ARTIFICAL GROUND ACCELERATION

SAMPLE _1

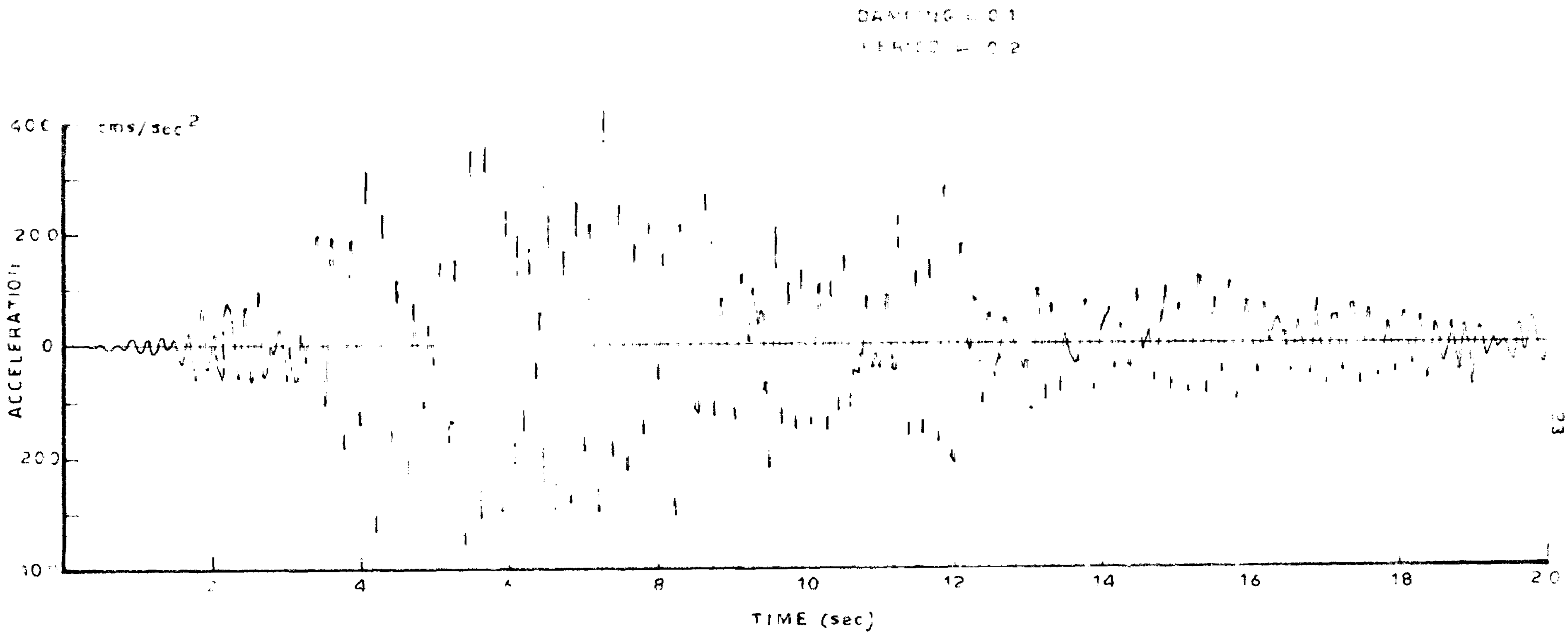


FIG. 4 – ARTIFICIAL GROUND MOTION

SAMPLE – 1

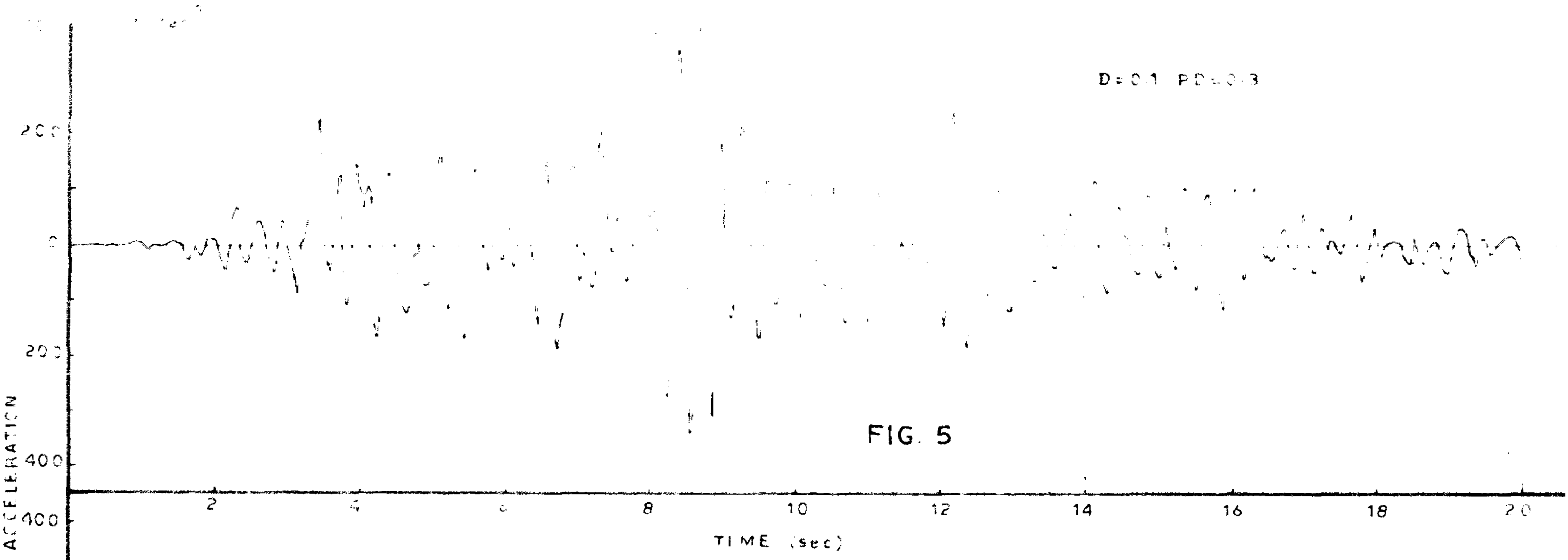


FIG. 5

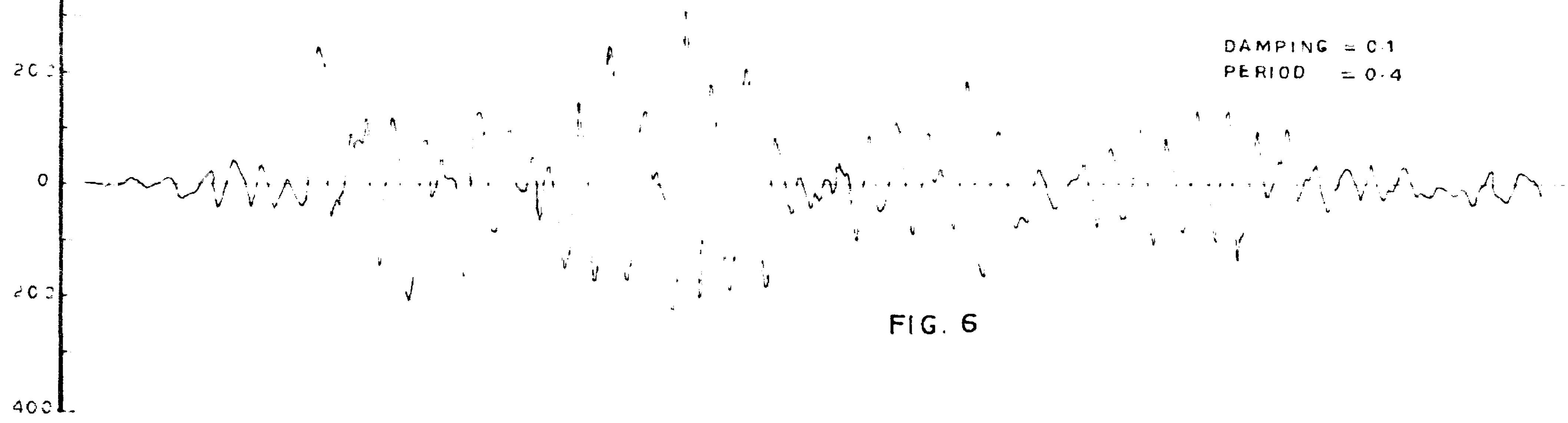


FIG. 6

ARTIFICIAL GROUND MOTION

SAMPLE_1

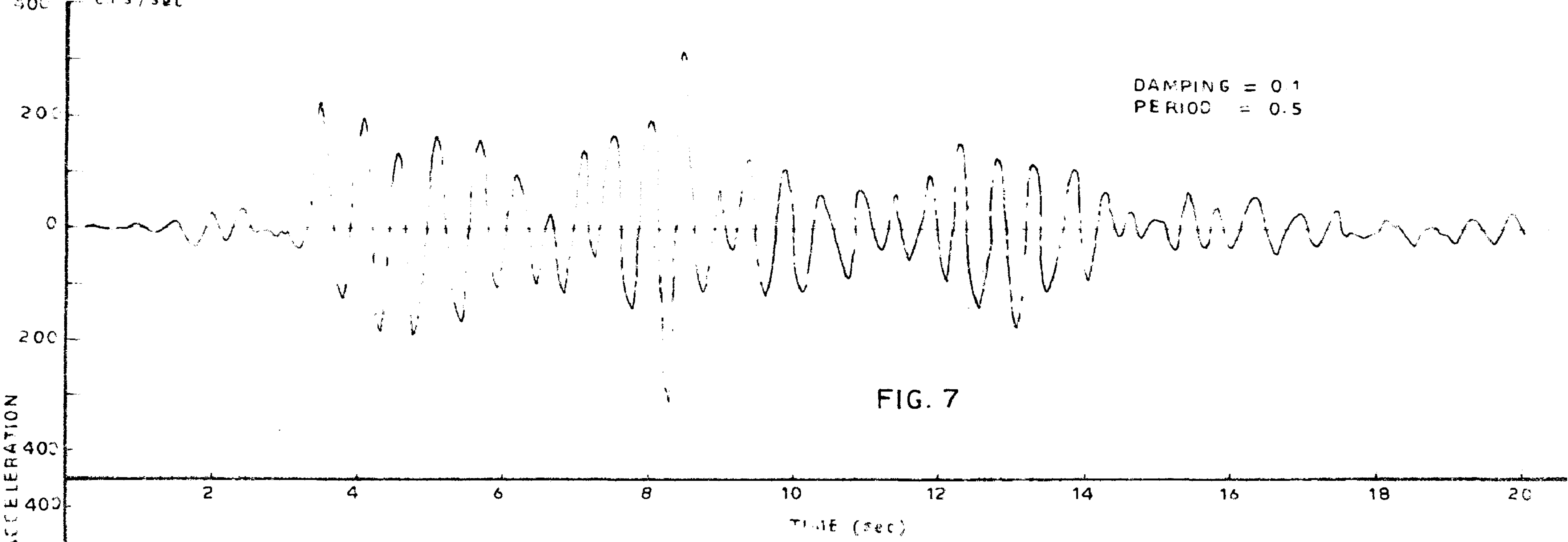


FIG. 7

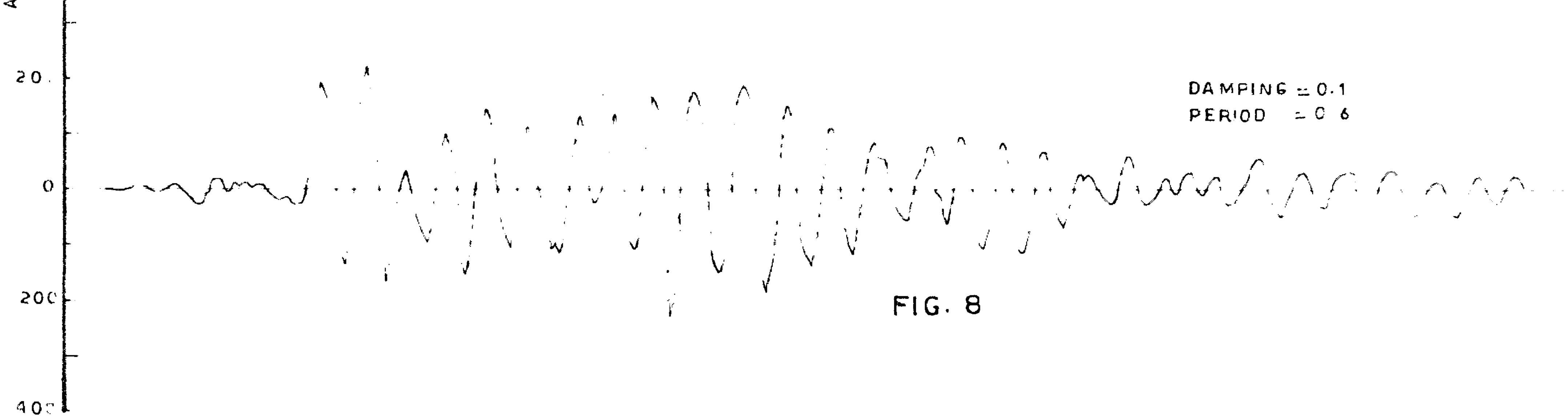


FIG. 8

ARTIFICIAL GROUND MOTION

SAMPLE-1

range. Large number of earthquake ground motions have been generated on a digital computer IBM 7044 using a computer programme (16), for various damping factor and period of the soil deposit. A few artificial accelerograms are shown in figures 3-8.

3.4 DISCUSSION

It has been observed that as the period of the soil deposit is increased the rate of zero crossings of artificial accelerogram show a definite decrease, except for 0.1 second period where it shows high rate of zero crossings than the rate of zero crossings at the bed rock acceleration as could be seen in Table II.

Table II - Table showing the variation of number of zero crossings with damping and period of soil deposit.

damping / Period	0.1	0.2	0.3	0.4	0.5	0.6
0.1	15.0	12.0	11.0	12.5	12.1	13.1
0.2	9.0	8.8	7.75	9.5	8.0	10.5
0.3	5.5	6.75	6.25	6.0	6.0	7.5
0.4	4.2	5.75	4.75	4.75	6.0	5.0
0.5	3.25	4.0	3.75	4.75	3.75	3.5
0.6	3.0	2.75	3.25	4.75	3.75	3.75

From actual earthquake record it could be seen that as the softness of soil increases the number of zero crossings reduce. Therefore it may be concluded that as the softness of soil deposit increases, the period of the soil deposit goes on increasing as evident from the table above.

Period of the soil deposit less than 0.3 second show very high rate of zero crossings and period greater than 0.4 second show slow rate of zero crossings. It may be recommended that periods greater than 0.4 second may be attributed to soft soil and period less than 0.3 second for hard soil strata or rock like material. It can also be observed that for the same period, as the damping is increased there is no appreciable change in the rate of zero crossings, or in other words damping has insignificant effect on the number of zero crossings.

CHAPTER - IV

RESPONSE SPECTRA OF ARTIFICIAL ACCELEROGRAMS

4.- RESPONSE SPECTRA

Response spectra has been used as a check for artificial accelerogram with the real earthquake records. Spectral response represents the response of single degree of freedom systems, having different periods and damping, to strong ground motion. The response may be evaluated either as the maximum value of relative displacement or as maximum relative velocity or as maximum absolute acceleration of mass. The determination of spectral response involves an evaluation of maximum value of an integral for a series of values of period and damping. The integral is given by equation (6) in Chapter III. Response spectra for all the five bed rock acceleration has been calculated for 5 per cent damping and 20 different periods. Then acceleration average spectra has been calculated as shown in figure 9. The time to the maximum acceleration occurs at 0.05 second.

The response spectra for ground motion has been calculated for 20 different periods. These spectras have been calculated for three different dampings, i.e. 2, 5, and 10 per cent of critical damping. A few spectrum is shown in figures 10-14. These spectras are then normalised by making the area equal under the curve for only 5 per cent damping. Then average spectras have been drawn and are shown in figures 15 through 17. To show the accuracy of average spectra, the normalised spectra of various earthquakes are also drawn alongwith the average spectra. It could be observed that the deviation is not very much significant.

4.2 DISCUSSION

The variation of maximum acceleration developed for different fundamental period of the soil layer for the same damping is shown in figure 18. It is apparent that the maximum acceleration induced varies with the fundamental period of the soil deposit. For the same period of the soil deposit, the maximum acceleration shows a definite decrease with the increase of damping which is evident from the table III. The variation of maximum acceleration with damping is also shown in figure 19.

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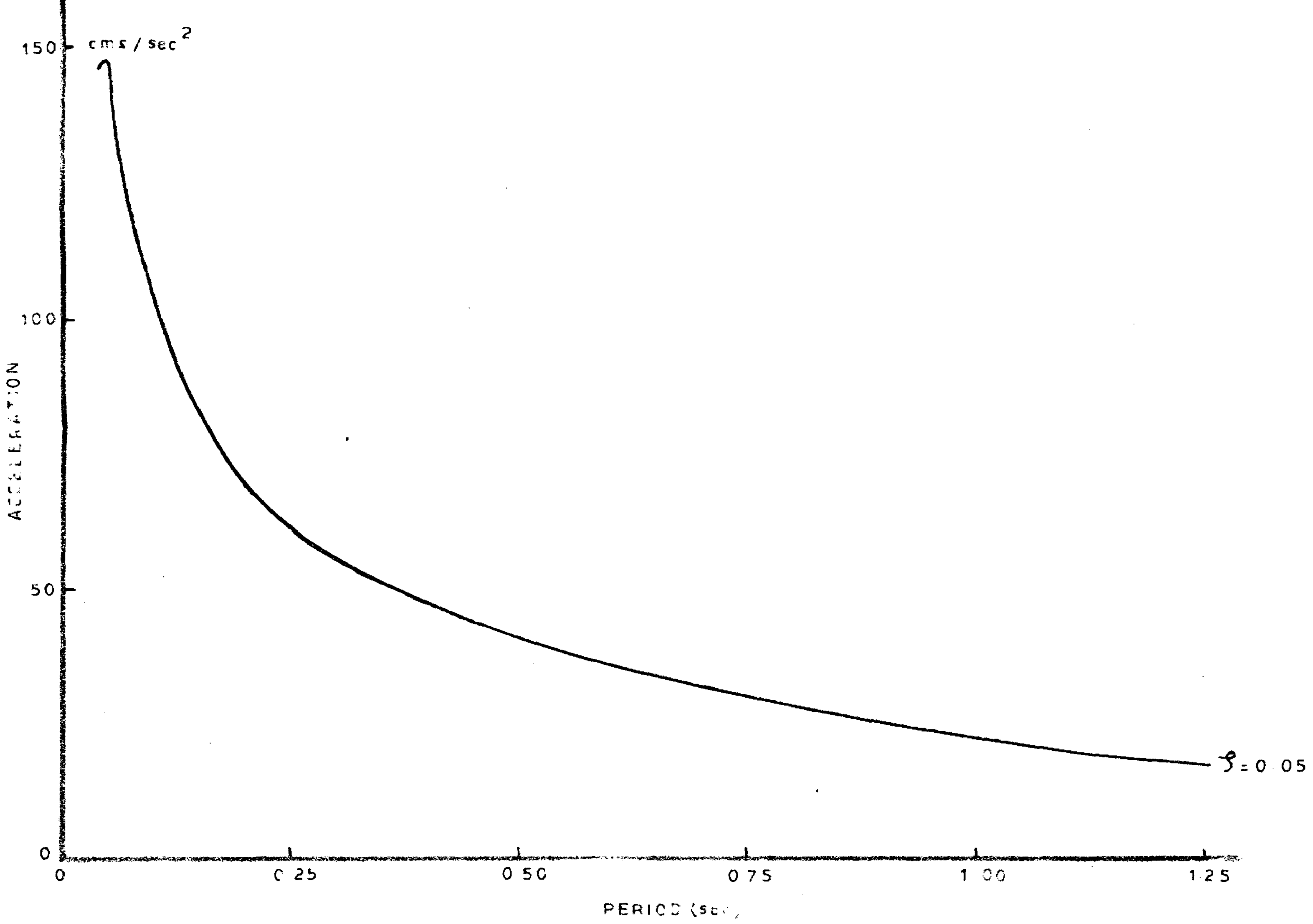

FIG. 9 _ BED ROCK ACCELERATION, SMOOTH AVERAGE SPECTRA

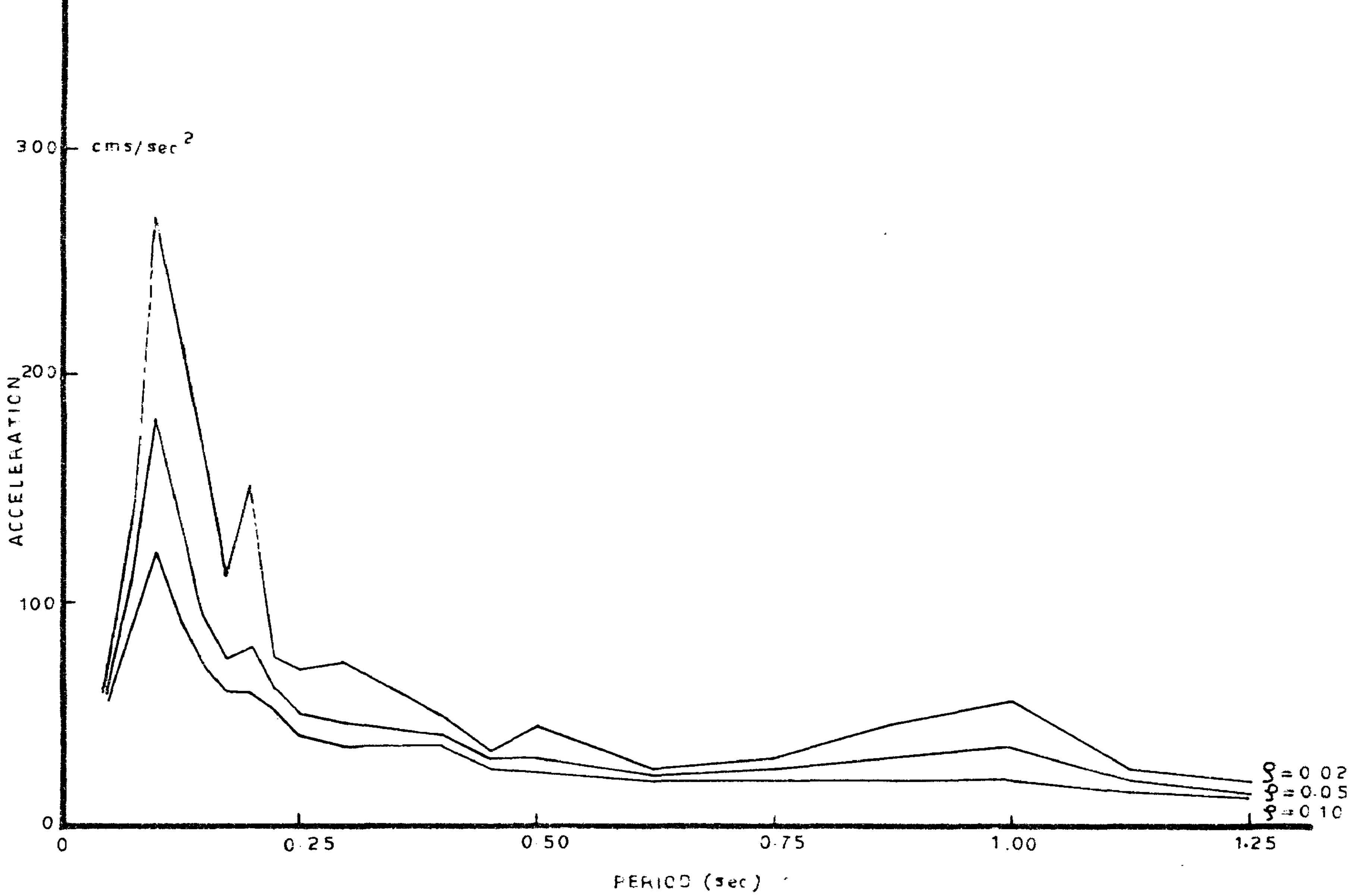

FIG.10 _ACCELERATION SPECTRUM FOR DAMPING 0.1 AND PERIOD 0.1 OF SOIL DEPOSIT SAMPLE _ 4

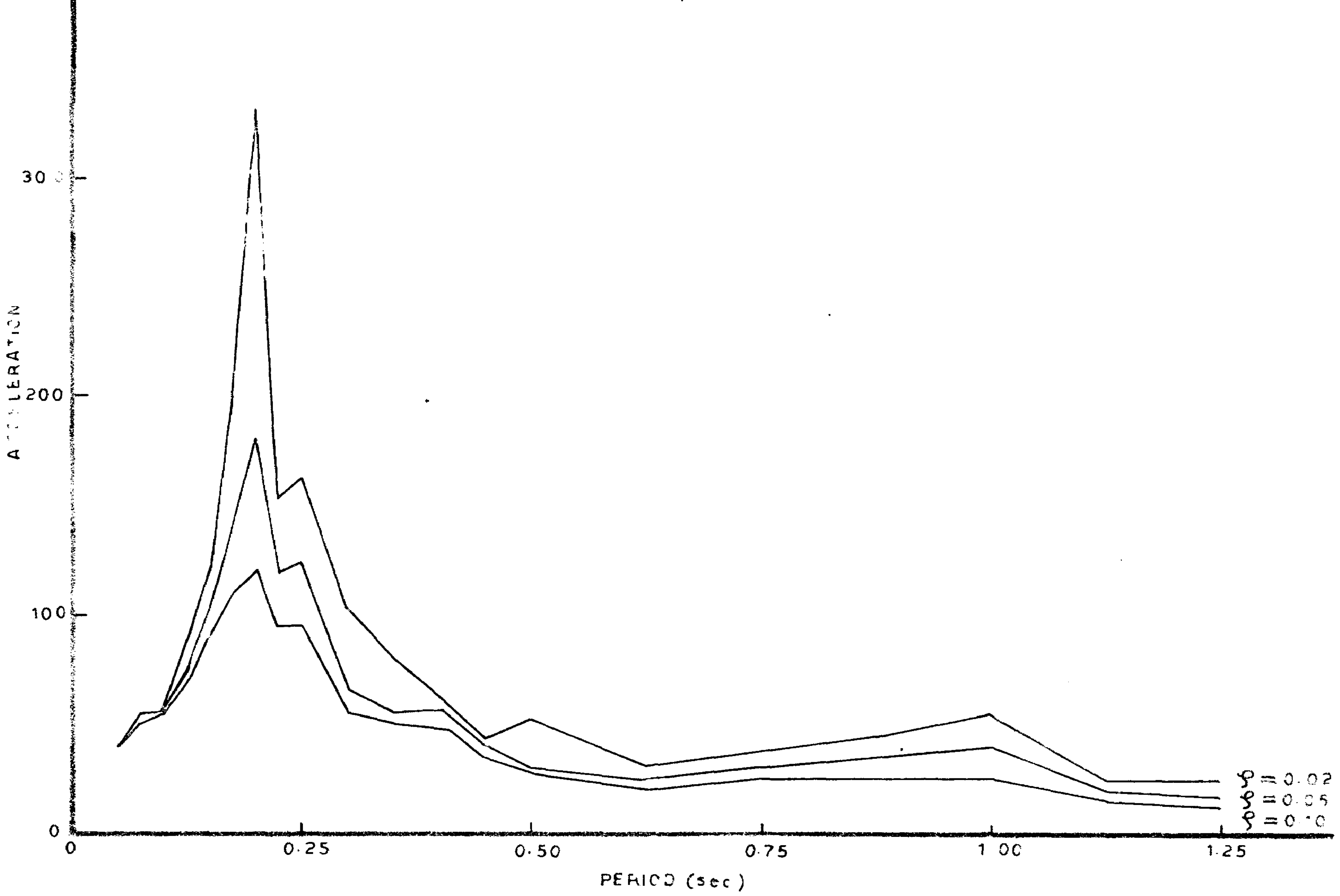

FIG. 11 _ ACCELERATION SPECTRUM FOR DAMPING 0·1 AND PERIOD 0·2 OF SOIL LAYER SAMPLE – 4

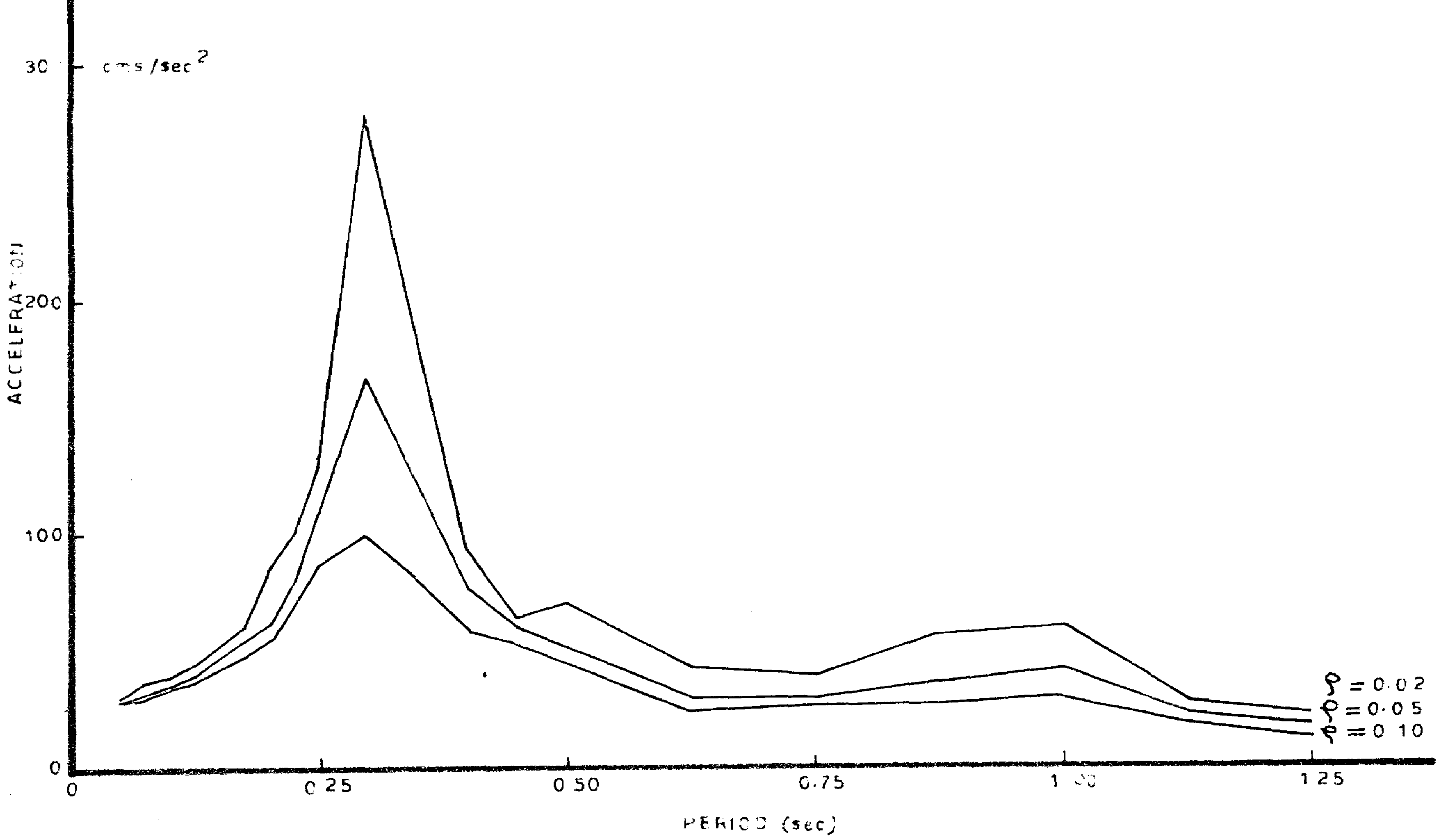

FIG.12 _ ACCELERATION SPECTRUM FOR DAMPING 0.1 AND PERIOD 0.3 OF SOIL LAYER

SAMPLE - 4

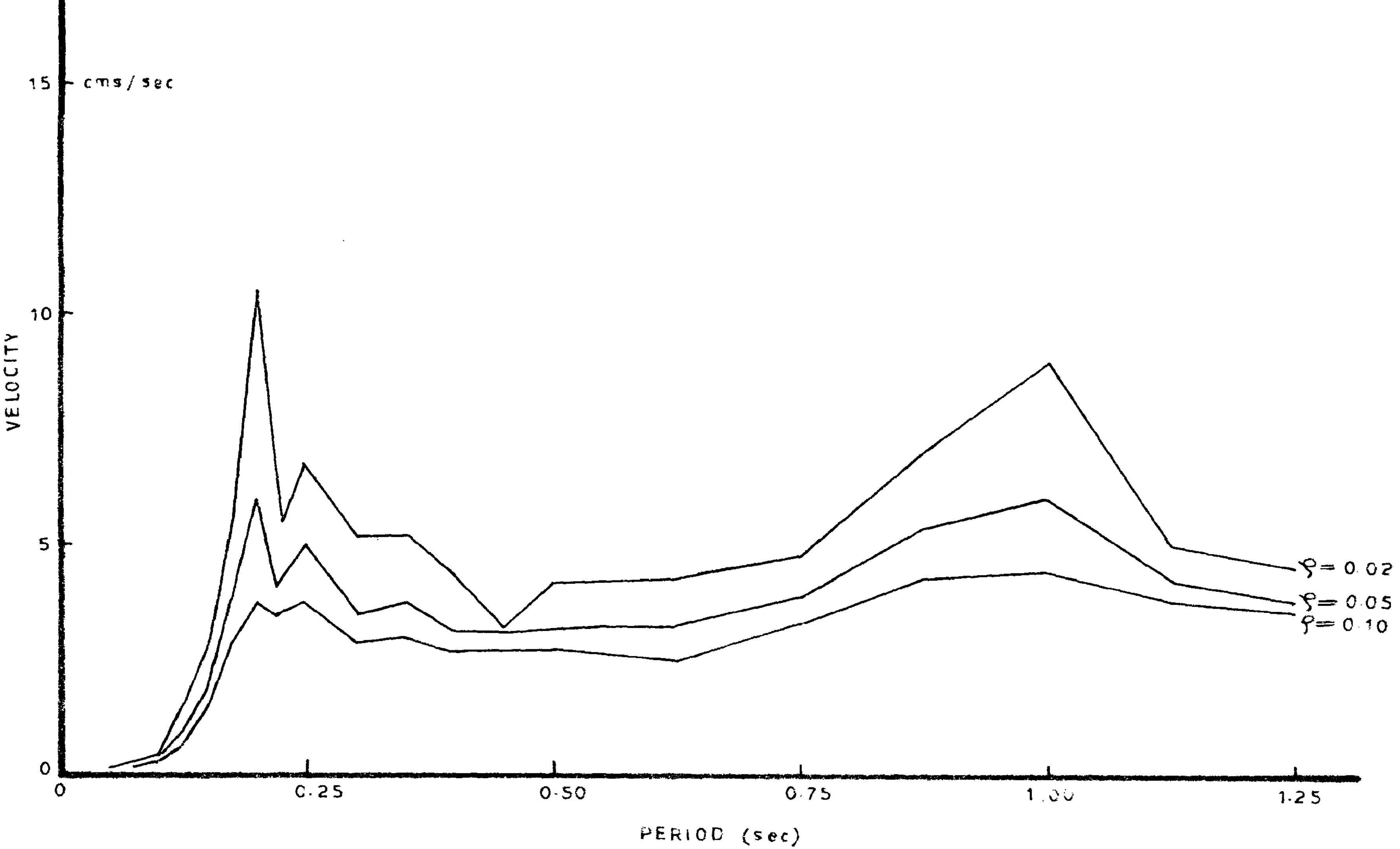

FIG.13 _VELOCITY SPECTRUM FOR DAMPING 0.1 AND PERIOD 0.2 OF SOIL LAYER

SAMPLE - 4

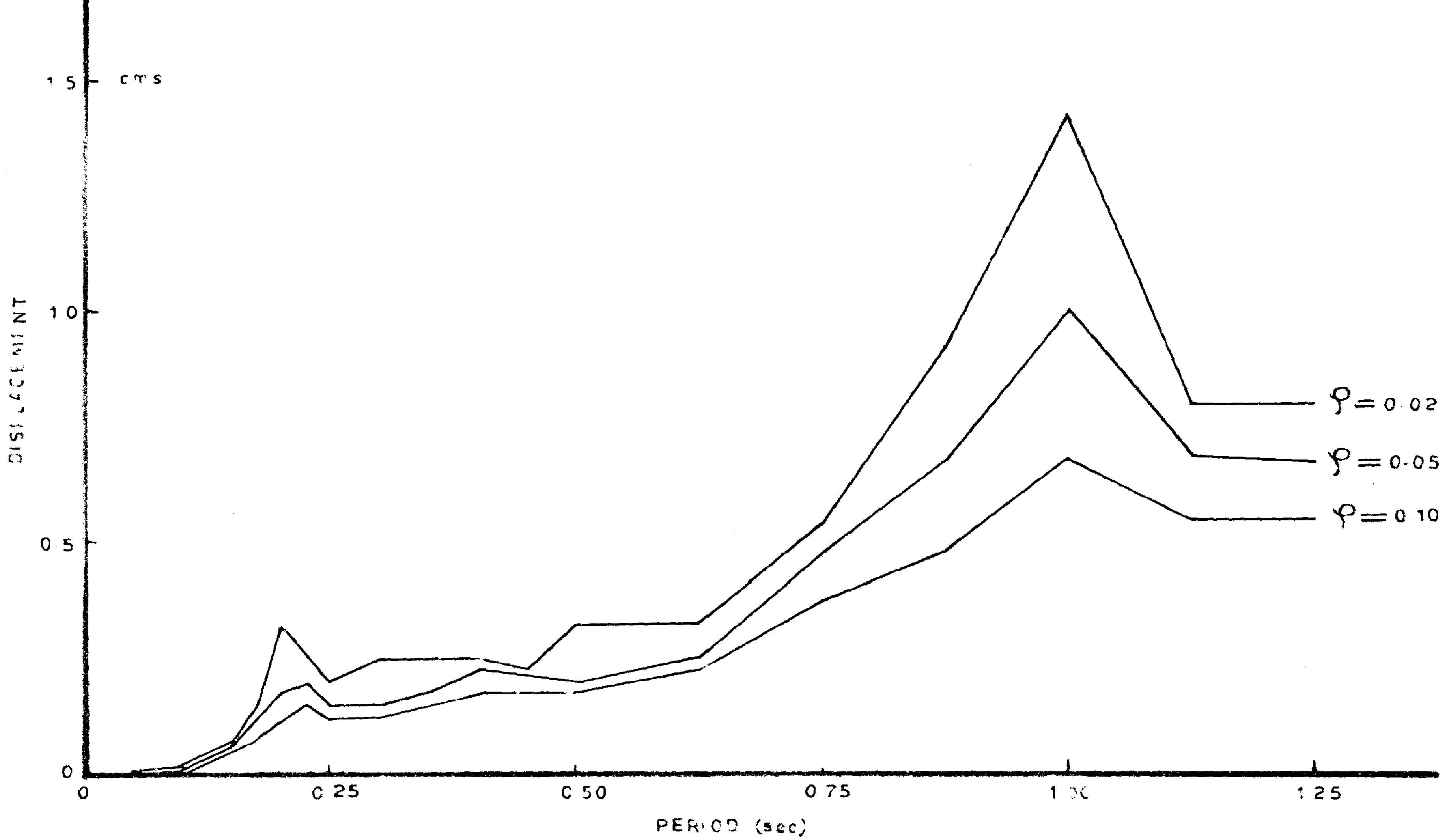

FIG. 14 _DISPLACEMENT SPECTRUM FOR DAMPING 0.1 AND PERIOD 0.2 OF SOIL LAYER

SAMPLE_4

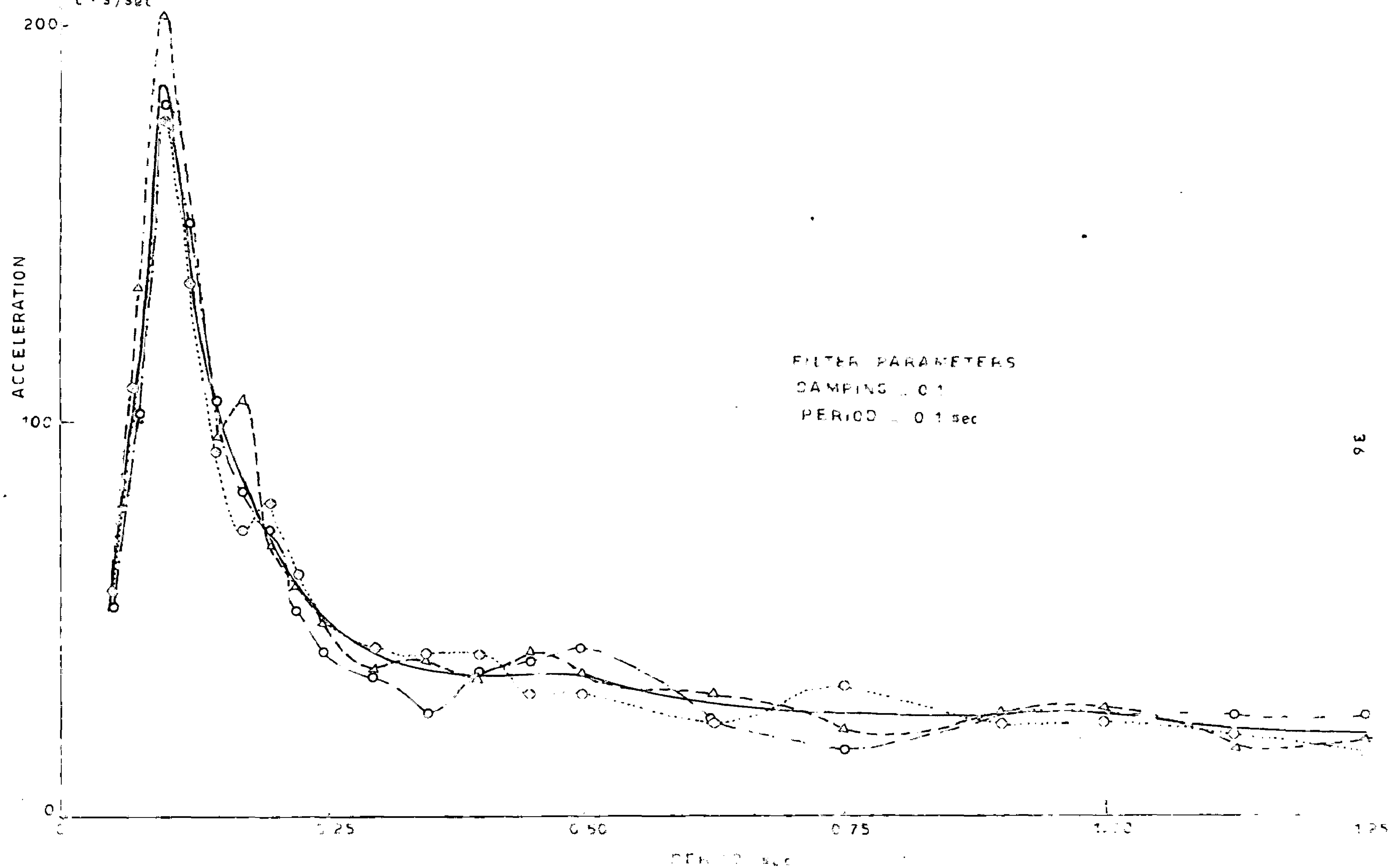

FIG.15 _ AVERAGE ACCELERATION SPECTRA OF GROUND MOTION AND NORMALISED SPECTRA

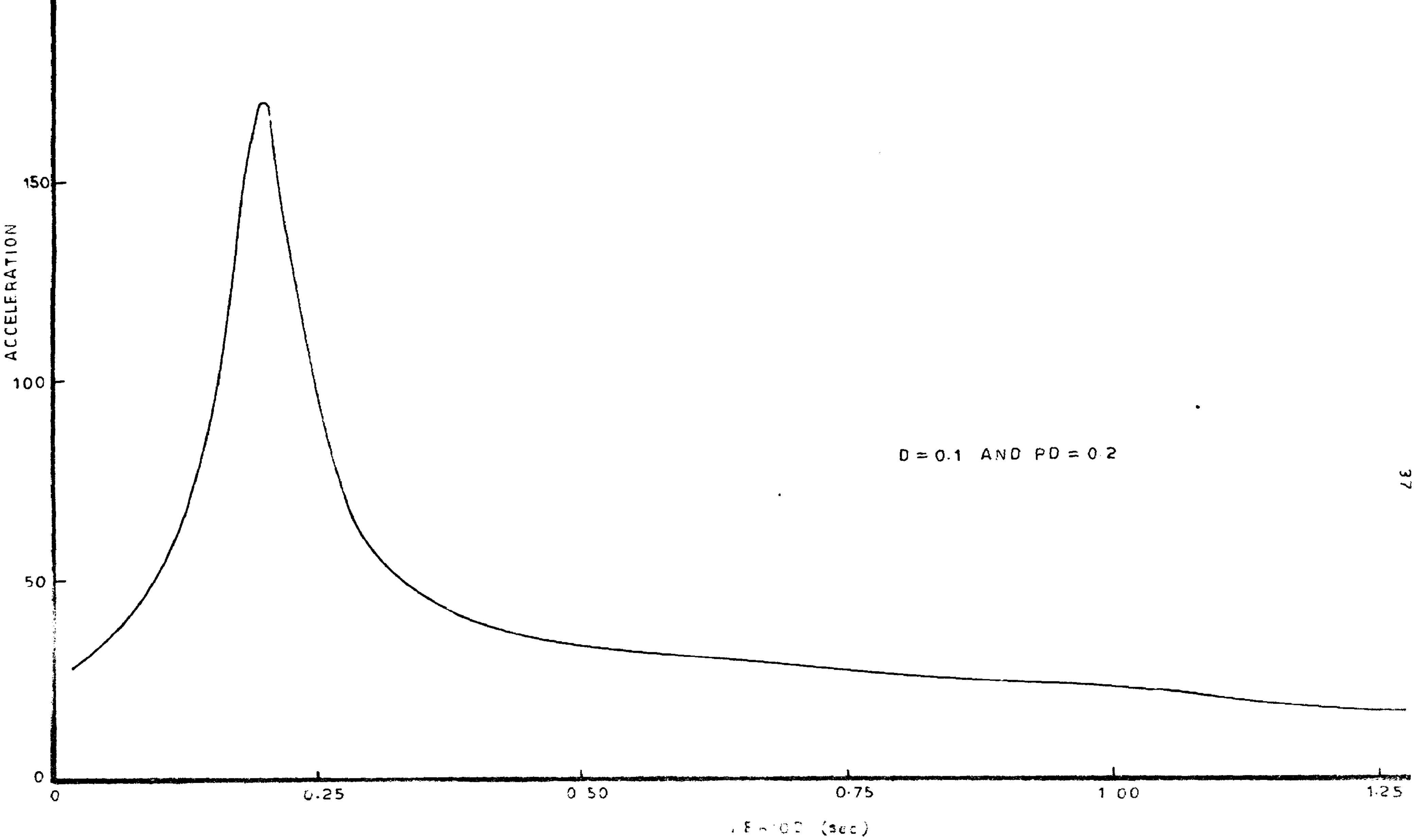

FIG.16 _ AVERAGE ACCELERATION SPECTRA

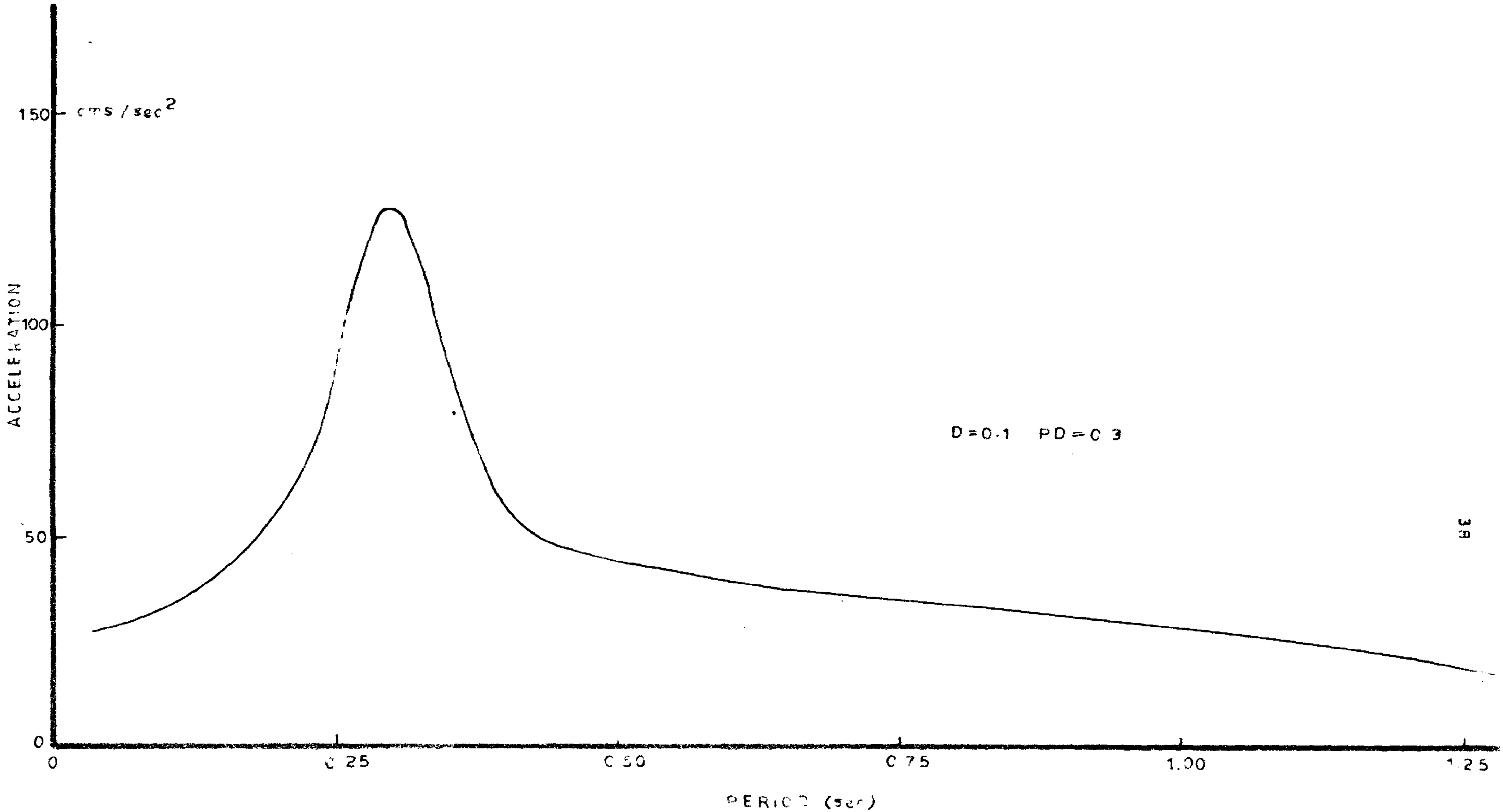

FIG.17_ AVERAGE SPECTRA

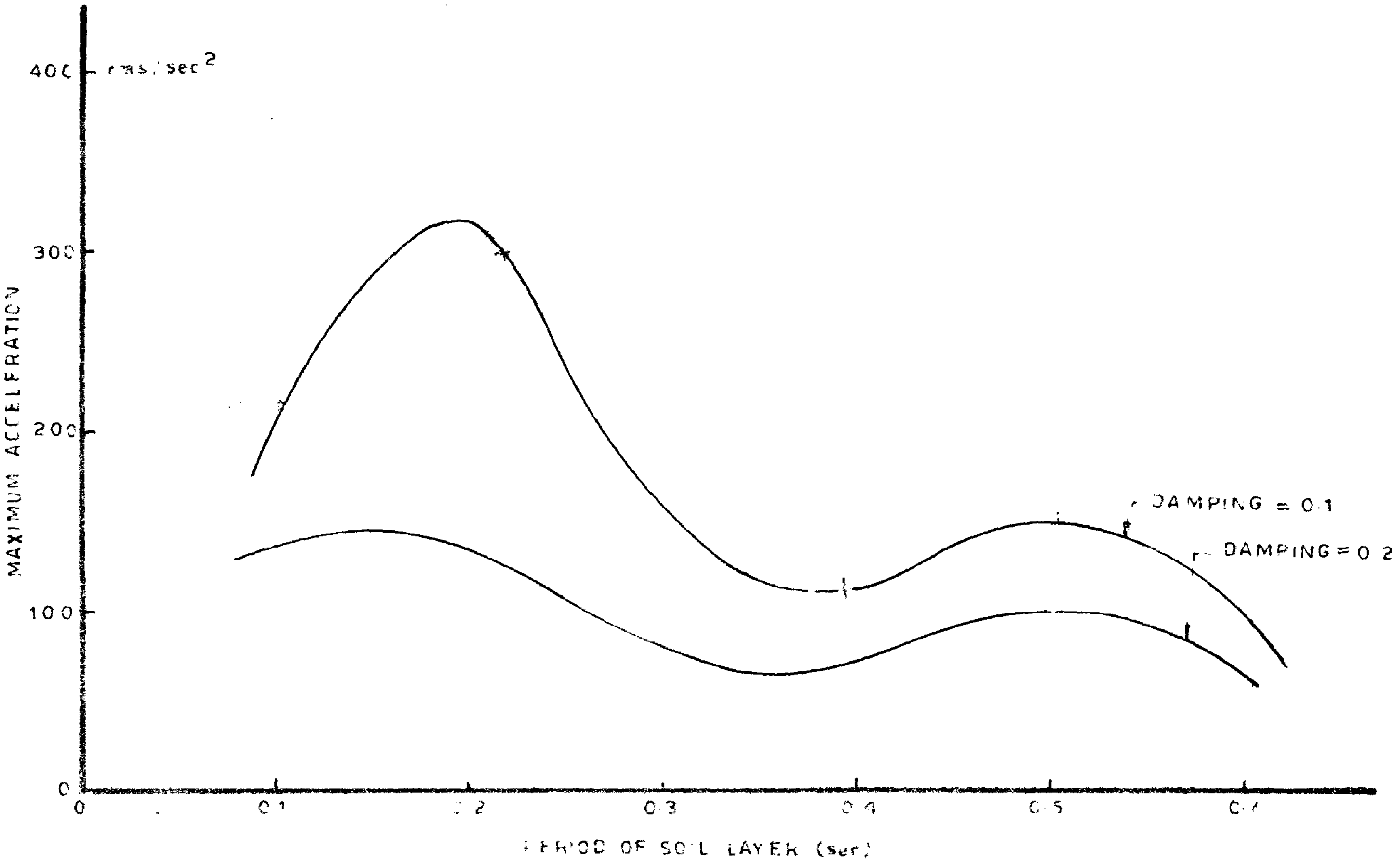

FIG.18 _ SHOWING VARIATION OF MAXIMUM ACCELERATION WITH FUNDAMENTAL PERIOD

SAMPLE_ 4

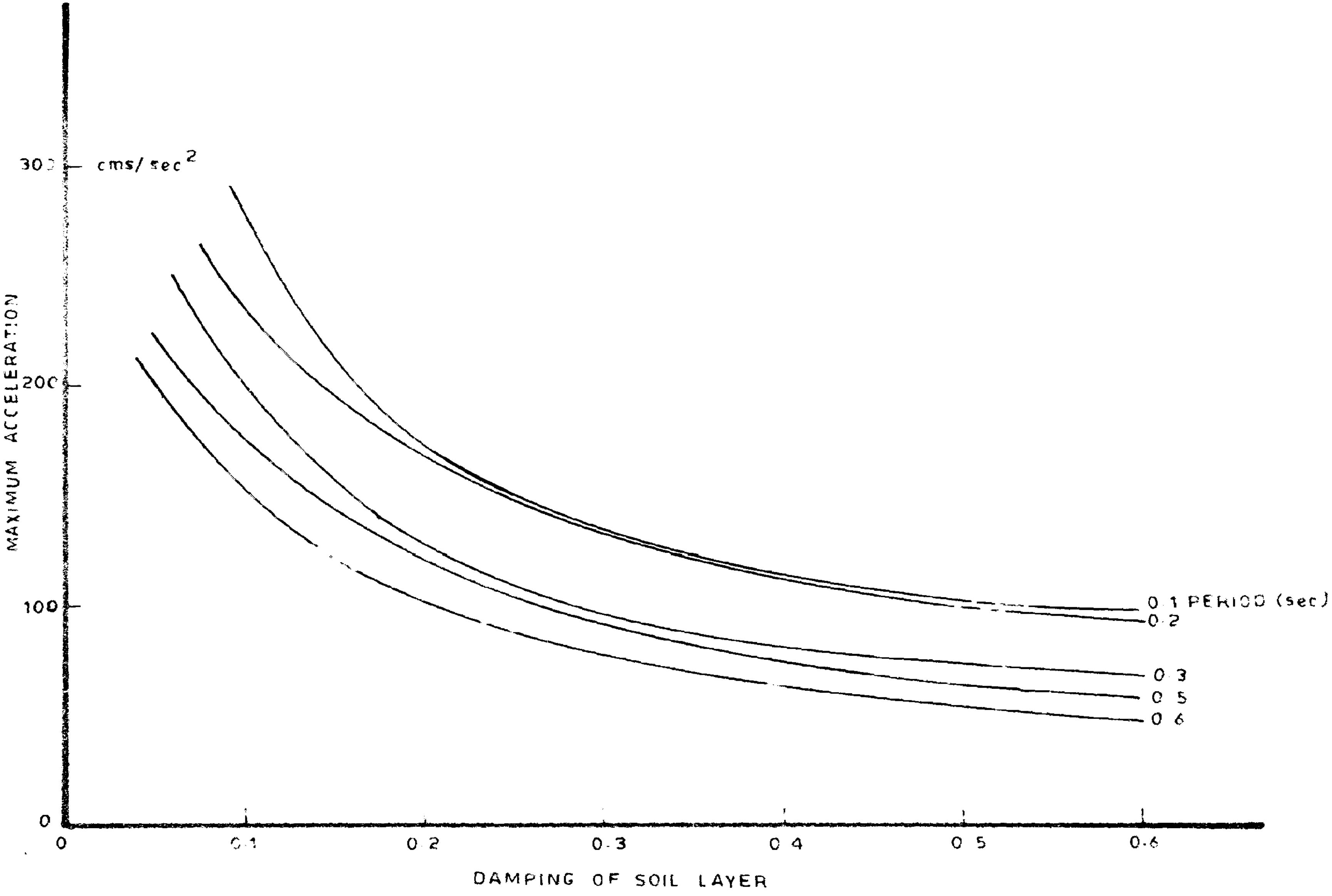

FIG.19 – FOR SAMPLE 4
VARIATION OF MAX. ACC. WITH DAMPING OF SOIL LAYER

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Peak

Table III - Table shows the variation of maximum acceleration with damping and period

Damping / Period	Maximum acceleration in fraction of g					
	0.1	0.2	0.3	0.4	0.5	0.6
0.1	0.1908	0.1322	0.1063	0.0916	0.0810	0.0782
0.2	0.22032	0.13529	0.1031	0.0883	0.07948	0.07460
0.3	0.15976	0.10206	0.0777	0.06628	0.05951	0.05483
0.4	0.1451	0.09223	0.0716	0.06070	0.05180	0.0439
0.5	0.1407	0.09678	0.0727	0.0632	0.0537	0.0472
0.6	0.12417	0.05414	0.05327	0.05163	0.04494	0.03817

The response spectra changes in reasonable consistent fashion depending upon the softness or hardness of the soil. For the soft deposit of soils, the peak ordinates of the acceleration response spectra tend to occur at a rather higher value of the fundamental period. Therefore, the structures of long period resting on soft soil deposit will be severely affected and those resting on hard soil strata will be less affected.

As the period of the soil layer is increased, the time period to the maximum acceleration is also increased as could be seen in the figures 10-14. This may be due to the fact that the frequency characteristics of the ground motions and thus the form of the response spectra is profoundly influenced by the nature of the soil conditions underlying the site.

Velocity and displacement response spectra for only one accelerogram have been shown in figures 13-14, which look like actual earthquake spectras. It has been observed that time period to the maximum velocity also increases as the period of the soil deposit increases. The maximum velocity also changes as the periods of the soil layer change.

CHAPTER - V

CONCLUSIONS

In the present analysis the effect of soil characteristics on the ground motion during an earthquake and corresponding forms of response spectra have been studied. Soil characteristics of a deposit have great influence on the response spectra of the ground motion. This response spectra is used to determine seismic force on a structure, hence the design of a structure is very much affected by the type of soil deposit. Therefore in designing a structure aseismically the soil characteristic of the underlying soil should be taken into consideration.

To study the effect of various type of soil conditions on the ground motion various combination of damping coefficient and period of the soil layer have been studied and following conclusions are made.

Period of the soil layer is an important parameter, as the period of the soil layer increases, there is a definite decrease in the frequency of the motion.

Soil layer period greater than 0.4 second show slow rate of zero crossings which may be attributed to soft soil and period less than 0.3 second show high rate of zero crossings. Hence, period less than 0.3 second could be recommended for hard soil strata.

Damping has insignificant effect on the number of zero crossings or frequency of motion.

The maximum acceleration induced varies with the fundamental period of the soil deposit.

The maximum acceleration decreases as the damping of the soil layer is increased, period of the soil deposit remaining the same.

As the softness of soil deposit increases the period of the soil layer is also increased. It may be inferred that long period structures resting on soft soil deposit would be affected most while on hard strata the long period structures would be less affected.

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APPENDIX - 'A'

BASIC CONCEPT OF GROUND MOTION GENERATION PROCESS

Here, the basic concept that will be useful for an understanding of the generation, of artificial earthquake are briefly summarised :-

A.1 Random Process

A function $x(t)$ such that for each value of $t = t_1$ behaves like a random variable $X_1 = X(t_1)$, the ensemble of all possible form of $x(t)$ is a member of the process. The existing records of actual earthquakes can be considered to be members of random process. Random process is described by its mean or statistical averages (expectation) and covarience functions.

$E\{x(t)\}$, denotes the expected mean value of $x(t)$ and $R(t_1, t_2) = E\{x(t_1)\ x(t_2)\}$ denotes covarience function describes the interrelationship between $x(t_1)$ and $x(t_2)$. If $x(t_1)$ and $x(t_2)$ are independent then

$$R(t_1, t_2) = 0$$

The stationary characteristics of the random process $x(t)$ are reflected in that, the covarience function is not a function of both time t_1, and t_2 but only of their difference

$$= t_2 - t_1$$

A.2 White Noise

White noise is a mathematical idealization of a stationary random process in which all the frequencies contribute with equal intensity to the mean square value of the process. Such a process is characterized by a constant power spectral density S_0, over the entire frequency range.

A white noise process can also be interpreted as superposition of random pulses arriving randomly in time according to homogeneous poissons process. If the time interval between pulses tends to zero, the white noise tends to Ganssian Procéss.

A.3 Shot Noise

The nonstationary counterpart of the white noise is called shot noise. The physical interpretation of the shot noise process is as a superposition of random pulses arriving randomly in time according to a non-homogeneous poisson process. This characteristic allows the inclusion of an initial build up and a decay towards the end in the intensity of the arriving pulses. The shot noise process can be described mathematically as the product of a white noise and a deterministic function of time.

A.4 Stochastic Model

A Ganssian nonstationary shot noise is used to represent the acceleration at bed rock during an earthquake. This stochastic process is completely characterised by the variance intensity factor.

A.5 SECOND ORDER LINEAR FILTER

The second order linear filter is used to represent a damped single degree of freedom system formed by a mass supported on a spring and dashpot in parallel. The acceleration at the bed rock is used as the acceleration of the support and the absolute acceleration of the mass simulates the acceleration of the ground surface, the behaviour of the mechanical model is completely defined by the parameters ξ and w.

A.6 Power spectral density

It gives the distribution of the power of the signal or a noise with respect to frequency. It is represented by a curve; area under which gives the total power.

If x(t) represents a complex wave form. Let x(t) be represented by Fourier series

$$x(t) = \sum_{n=-\infty}^{\infty} a_n e^{inw_0 t} \quad ; \quad w_0 = \frac{2\pi}{T}$$

where w_0 is frequency and n is a counter. T is the time period and

$$a_n = \frac{1}{T} \int_0^T x(t) e^{-inw_0 t} dt$$

Parseval's theorem states that the average energy in the signal is equal to the sum of the average energies in each frequency component i.e.

$$\sum_{n=-\infty}^{\infty} |a_n|^2 = \frac{1}{T} \int_0^T x^2(t) dt$$

The time average of energy i.e. power is equal to a sum of terms, each term associated with one frequency in the Fourier series expansion. Each term, in fact, can be interpreted as the time average of the energy of one particular component frequency. Thus we define power spectral density

$$S(w) = \sum_{n=-\infty}^{\infty} |a_n|^2 \delta(w - w_0)$$

S(w) consists of a series of impulses at the component frequencies of x(t), each impulse having a strength equal to the power in that component frequency, and clearly is a measure of the distribution of the power in x(t).

APPENDIX - B

ESTIMATION OF SITE PARAMETERS

As such site parameters, intensity, epicentral distance, duration and magnitude are not easy to assess accurately for a locality. Even then a rough estimate could be made by the past history of that locality or by using emperical formulas based on past earthquake records.

The maximum value of the ground acceleration will be used to define the intensity of the process. Faults are detected by micro waves. Nearest active fault will cause severe earthquake. Seismological and geological investigation fix the fault which will cause earthquake in near future. From the past history of the region expected magnitude of earthquake could be estimated. Then the expected maximum acceleration as a fraction of gravity could be related to the magnitude, M, and the epicentral distance in miles, D, of real earthquakes, using an emperical relation given by Rosenblueth

$$a_{max} = 0.8\ e^{0.8\ M/D2}$$

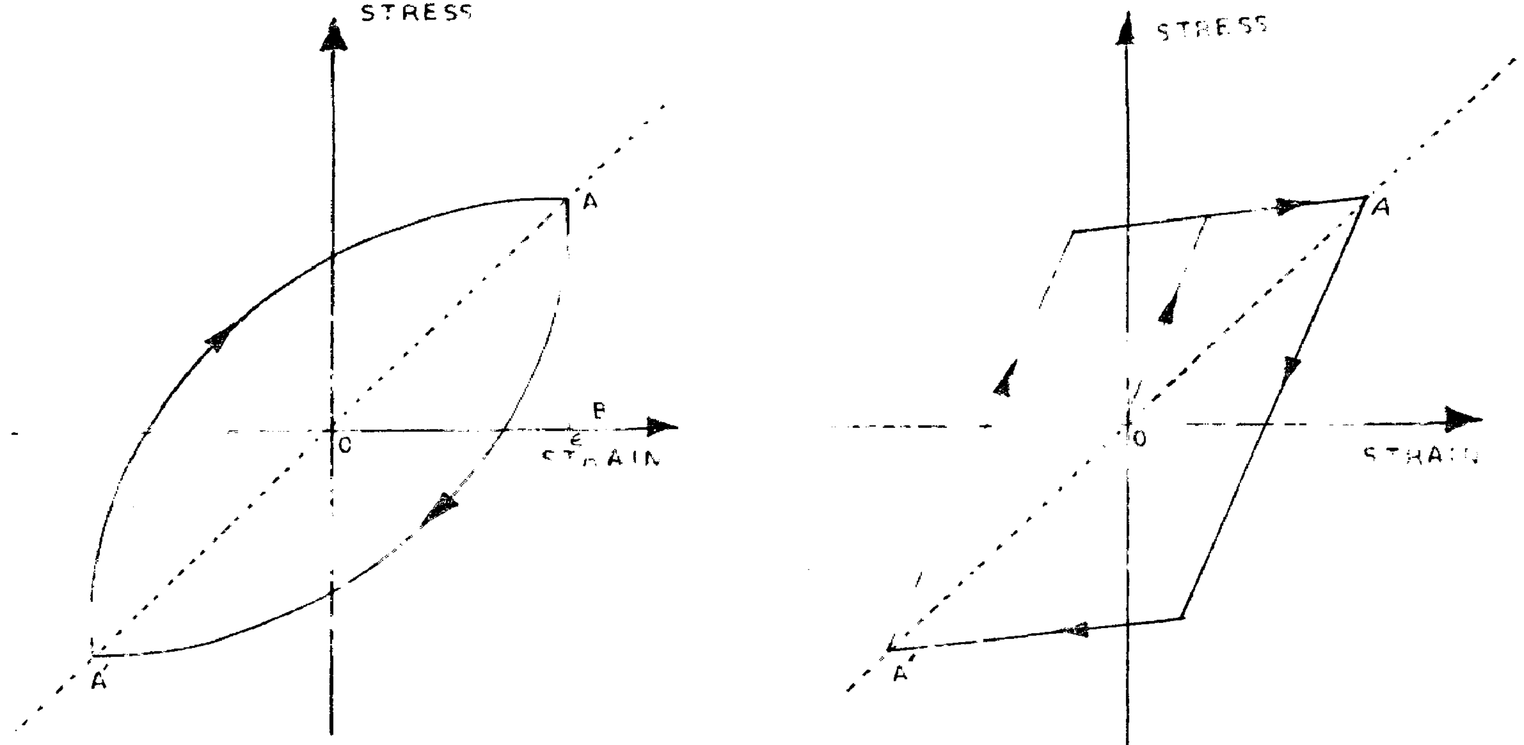
The duration of the ground acceleration process could be estimated from the empirical expression

$$S = 0.48 D + 0.02 e^{0.74 M}$$

where S is the expected duration of the records in seconds. Having estimated the magnitude, duration and maximum acceleration, the envelope function as given by Amin and Ang (1) can be fixed.

SOIL CHARACTERISTICS

Small earthquake and microtremors could be used for evaluating the site characteristics. Response of soil deposits to the base excitations is determined by the effective shear moduli and damping characteristic of soil deposit. Stress strain behaviour of soil is quite different for small and large earthquake motions. Hence, the shear moduli and damping factor very much depend upon the amplitude of induced strains. Therefore prediction of strong motion earthquake based on small earthquake or microtremors will not be true representation. The nonlinear stress-strain relationship is approximated to equivalent bilinear stress-strain system as shown:



a_STRESS STRAIN CURVE

b_BILINEAR IDEALIZATION

FIG.20_ STRESS STRAIN RELATIONSHIP

Equivalent damping and equivalent shear moduli are chosen to correspond to the average strain developed. Equivalent shear modulus, G, would be determined by the slope of the line OA and equivalent damping factor by the expression (Jacobson 1930)

$$\rho = \frac{\text{Area of hyteresis loop AA'}}{4\pi \times \text{Area of OAB}}$$

The equivalent stiffness of the soil layer is determined by

$$G = K(\sigma_0)^{1/3}$$

where σ_0 = effective over burden pressure. From the known stiffness and mass, frequency, w, could be determined. Hysteritic stress-strain relationship for different strain amplitudes may be determined by means of cyclic simple shear test or cyclic triaxial compression tests.

APPENDIX-C

TABLE OF NORMALLY DISTRIBUTED RANDOM NUMBERS

C.1 PROGRAMME-GENERATION OF WHITE NOISE

```
C***************************************************
C  C          RANDOM NUMBER GENERATION OF UNIT VARIANCE
C***************************************************
                 DESCRIPTION OF VARIOUS TERMS
C                     **********             **********
C       IN PUT DATA
C       A=3.    B=0.141592654     C=1.        D=0.0
C
C       OUT PUT DATA
C       SB(I)=UNIFORMALLY DISTRIBUTED RANDOM NUMBER OF UNIT VARIANCE
C      W2N,W2N1=WHITE NUMBERS  TO BE GENERATED
C****************************************************
*0810
      DIMENSION SB(2)
      READ10, I
      READ20,A,B,C,D
   10 FORMAT(I6)
   20 FORMAT(4F10.8)
      PH=3.141592654
      DIVI=10000000.
   14 DO75J=1,2
      X1=A*D+B*C
      NX1=X1
      ANX1=NX1
      ANX2=(X1-ANX1)
      DB=(D*D)+ANX2
      IDB=DB
      AIDB=IDB
      SB(J)=(DB-AIDB)
      SA=(A*C+ANX1+AIDB)/DIVI
      ISA=SA
      BISA=ISA
      SA=(SA-BISA)*DIVI
      C=SA
   75 D=SB(J)
      Y1=-2.*LOGF(SB(1))
      Y2=2.*PH*SB(2)
      W2N1=SQRTF(Y1)*COSF(Y2)
      W2N=SQRTF(Y1)*SINF(Y2)
      PUNCH30,I,W2N1,W2N,(SB(J),J=1,2)
   30 FORMAT(I5,4F15.10)
      I=I+2
      GO TO 14
      END
***************************************************
```

C.2 TABLE OF RANDOM NUMBERS

```
-2.6791 1.7218-2.1504 1.7978-1.5374 -.3010 2.0694  .5948 1.9063 2.4908
  .1234-1.9767 1.0478  .5082 -.8172 -.5659 1.0441-1.5135-1.2984 -.7710
 -.6242 -.3861 -.7122  .5603  .1409 1.4308 -.6054-1.4929  .1485-1.9169
-1.2777  .3351-2.3326  .1584 -.9918  .0858  .5192 -.6025-2.1976 -.8512
  .5987-3.0059  .7946  .5092 -.3777 -.7117  .4585 -.2375 -.7220 1.9250
 1.0621  .5705  .5089-1.0409-1.0523  .3717  .8507-2.1911  .8414-1.9041
 -.8224 -.5117-2.0819  .7972 1.8249 1.4877 -.0233-1.4779  .0328  .4435
  .3869 -.3467-1.0572 -.7701  .7133  .4979 -.1577 -.7709 -.5805  .4259
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