# 4.3-DESIGN SPECTRA

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## SYNOPSIS

In aseismic design of systems based on elastic theory, 'Response Spectra' is extensively used. There is a large volume of literature on this topic but this paper would confine its attention to the following aspects of the problem: (i) Shape of the spectra, (ii) The scaling factor for normalising the spectra and (iii) Choice of time history ground motion to suit a design spectra. Given earthquake parameters for a site in the form of peak ground acceleration, peak ground velocity, etc., and its soil characteristics it would would be possible to predict a design spectra. However, at present, there is a great uncertainty with regard to evaluation of these earthquake parameters.

## INTRODUCTION

Housner (1) was the first to propose a smoothened average design spectra derived from actual response spectra of recorded earthquakes. The normalisation was done with respect to spectral intensity (that is, area under spectral velocity - period curve). Blume, et. al. (2) publicized the idea that the spectra may be plotted in a tri-partite log-log plot and the spectra tends at the two extremes to ground displacement and ground acceleration. Several authors have now proposed design spectra. Some (3,4) have classified according to confidence level, some have classified according to type of soil, like rock (4,5,6) and alluvium (4,5,6,7). The normalisation has been mostly done with respect to peak ground acceleration (3) but a few has been with respect to peak ground velocity (4,8), spectral intensity (1), nondimensional parameter $ad/v^2$(4,7), etc. Codes of practices of various countries also give design spectra either directly or indirectly in the form of a coefficient varying with respect to period. Some aspects of design spectra like the shape of spectra and normalising factors are discussed in this paper.

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## SHAPE OF SPECTRA

The shape of spectra as given in various codes of practice and those obtained by normalising with respect to peak ground motions are discussed below.

a) Codes of Practices: For the purpose of this discussion, the information contained in Earthquake Resistant Regulations (9) has been analysed except in the case of Indian Code where the latest revision has been included. Fig. 1a to 1c shows the shape of variation of seismic coefficient as a function of period of systems. These graphs are in one sense design acceleration spectra. All the graphs are normalised such that the maximum value is unity. Except in the case of French code and one case of Mexican code, in all cases the spectra has a constant value between zero period and a period '$T_o$' which varies between countries. The value of $T_o$ varies between 0.2 sec to 0.6 sec except in the case of Japanese code and in one case of Mexican code. Since the codes mostly apply to buildings, the assumption of flat response in the short period range is not critical. However, in order to be realistic the codes could represent the portion between zero second and 0.1 second by a straight line joining the maximum value at 0.1 sec to a value of about one-third the maximum at zero second. The rate of decay beyond $T_o$ sec. generally is inversely proportional to period upto a cut-off period '$T_c$' beyond which it is assumed to be constant. The decrease in values of design acceleration spectra between $T_o$ and $T_c$ nearly corresponds to constant response velocity in this period range. Beyond the cut-off period, the value remains constant in order to provide certain minimum forces to be considered in design. In the Japanese code, the value of $T_o$ is rather too large. The shape of spectra in the Mexican code for zones of high compressibility is a unique one which might have been dictated by special conditions there.

b) Rocky or Hard Soil: Fig. 2 shows typical 5% damping average acceleration spectra for rocky soil. The peaks lie in the range of 0.15 to 0.30 sec. The magnification of peak response with respect to zero period value varies between two to three. The response decreases rapidly with respect to period and the value at 3.0 sec period may be about one-eighth of the peak. A comparison of these with the smoothened spectra obtained for one particular site, Koyna, (10) indicate that for Koyna, peak of the spectra lie in a shorter period range and it decays much faster than that given in Fig. 2.

c) Alluvial Soil: Fig. 3 shows typical 5% damping average acceleration spectra for alluvial soil. The peaks have a greater spread as compared to rocky soil and lie in the range of 0.2 to 0.6 sec. The magnification varies between 2.2 to 2.8 with an average value of 2.5. The response reduces to about one-fifth of the peak at 3.0 sec period. Compared to that for rock, magnification is small, band spread at peak is large and the decay rate is slow in the case of alluvium.

The above conclusions for 5% damping average spectra curve can also be extended for other dampings and for spectra corresponding to higher 'confidence levels'.

## NORMALISATION FACTORS

For comparing spectra of different records, invariably peak ground acceleration has been used as a normalising factor. In a few cases (4,8), peak ground velocity has been used as a factor. Other factors sometimes used are spectral intensity(1), nondimensional factor $ad/v^2$ (4), where a, v and d are respectively peak ground acceleration, velocity and displacement. Since displacement values obtained from records vary considerably depending upon the method of base line correction, the normalisation using $ad/v^2$ may be discarded. The spectral intensity is a derived quantity unlike that of acceleration and velocity which are basic. Not much work is reported connecting spectral intensity with earthquake parameters.

Spectra obtained for alluvial sites based on 50 records is analysed in this paper. Figs. 4 and 5 show respectively envelope of maxima, mean, and minima of absolute acceleration and relative velocity spectra. In Fig. 4, the dashed lines are obtained by multiplying the spectral acceleration in 'g' by 145 and dividing by peak ground velocity in cm/sec. Similarly, in Fig.5, the dashed lines are obtained by dividing the spectral velocity for an earthquake( expressed in cm/sec) by 145 times the peak ground acceleration expressed as a fraction of acceleration due to gravity. This factor 145 is chosen such that the two mean spectra are very close to each other. This would imply that one "g" peak ground acceleration corresponds to 145 cm/sec peak ground velocity. The corresponding relation suggested by Newmark (4) is 122 cm/sec for one "g".

In Fig. 4, the ordinates of the chain dotted line are obtained by multiplying those of the mean velocity of Fig. 5 by (145/981) x ($2\pi$/T). Similarly, in Fig. 5 the chain dotted line is obtained from mean acceleration of Fig. 4 by using a factor of (981/145 x T/$2\pi$). It is an interesting coincidence that the two graphs representing mean spectra are close to each other. This would imply that for this sample both the normalisation criteria give similar results.

The mean response velocity is flat above a period of one second and has a magnification of two times the ground velocity. The mean response acceleration has a peak 2.5 times that of ground acceleration.

It, therefore, appears that both type of normalisations could be used to obtain shape of spectra. However, the preference of the author is to use ground velocity as a scaling factor to obtain design spectra due to reasons set forth in the next section.

## CHOICE OF TIME-HISTORY TO SUIT A DESIGN SPECTRA

Quite often it is necessary to have time-history accelerograms for vibration analysis of systems and if a design spectra is specified for a site, the accelerogram will have to match it. In general, spectra of recorded accelerograms will not closely hug the design spectra and will match only in certain period range. New accelerograms can be generated by modifying the amplitude and time scales of the entire portion of the record or some selected parts of it. Accelerograms can also be evaluated artificially (11).

Koyna Dam (Dec. 11,1967) and Pacoima Dam (Feb. 9,1971) accelerograms are unsuitable for matching a design spectra as these have pronounced few large peaks of accelerations. It is known that peak values are alone not important but 'pulse areas' may signify the intensity of a motion (12).

El Centro (May 18, 1940) motion has been most extensively used by earthquake engineers. This accelerogram has a number of peaks of comparable magnitude as compared to the maximum peak. Author carried out a study of selective modification of the amplitudes of this accelerogram. No peak was allowed to have a value more than 0.25 g (the original record had a peak value of 0.34 g) but all peaks of the original record above a threshold acceleration were raised to this cut-off value of 0.25 g. Fig. 6 shows the results of two threshold values of 0.15 g and 0.20 g and these are compared with the original spectra. It clearly shows that even with reduced peak acceleration, the intensity of the original motion can be achieved or even exceeded. The maximum peak ground velocity was very little affected due to these modifications of acceleration peaks. Fig. 7 shows a similar study for an artificial accelero. gram (with a zero period acceleration of 0.3 g) generated to closely hug a 5% design spectra according to the procedure given in ref. 11. In this case, the cut-off acceleration was 0.25 g and the two threshold accelerations were 0.15 g and 0.20 g. Once again, it is seen that by this process a design spectra could be achieved by ground motions of different peak accelerations. Such a study for Koyna dam and Pacoima dam motions indicated that peak accelerations could be reduced even by 50% without affecting the spectra.

The influence of selective modification of the time scale of a portion of record was also studied. Fig. 8 shows such a study for El Centro motion. It is seen that the spectra in the long period range is magnified by this process.

There is a wide variety of empirical formulae available for predicting peak ground acceleration, peak ground velocity etc., given earthquake data like magnitude, distance and focal depth corresponding to a site. However, it is seen that for a particular earthquake data, the scatter in the values obtained for peak acceleration, peak velocity, etc., is very large. The choice of these peak values pose problems and depends on the judgement of the designer. If a shape of spectra is specified, then there is a tendency to choose smaller values of the peak values of the scaling factors so that design does not become too costly. For example, if we consider earthquake data for a site having a magnitude of 6.5, epicentral distance of 30 kms and focal depth of 15 kms, the peak ground acceleration may vary from 0.06 g to 0.33 g. However, one is more likely to use an average value of, say, 0.20 g as a scaling factor to obtain design spectra from a given normalised shape of spectra. The peak velocity, representing the integrated effect of an accelerogram is not much influenced by a few stray high peaks of acceleration of the record. Hence, peak velocity may be preferred as a scaling factor.

## CONCLUSIONS

The shape of spectra for different confidence levels could be reasonably predicted for a site based on its soil characteristics. The various codes could now incorporate such spectra. The spectra could be normalised with respect to either peak ground acceleration or peak ground velocity. Given a set of earthquake data for a site in the form of magnitude, distance from epicentre and focal depth, the various empirical formulae now available give a wide scatter of values for peak ground motion. In particular, if peak ground acceleration is taken as a scaling factor to obtain design spectra, it is very unlikely that a designer would choose the maximum from among the empirical values as it is now well established that few large peaks of acceleration do not influence the intensity of spectra. The selection of the scaling factor depends on the judgement of the designer.

## ACKNOWLEDGEMENT

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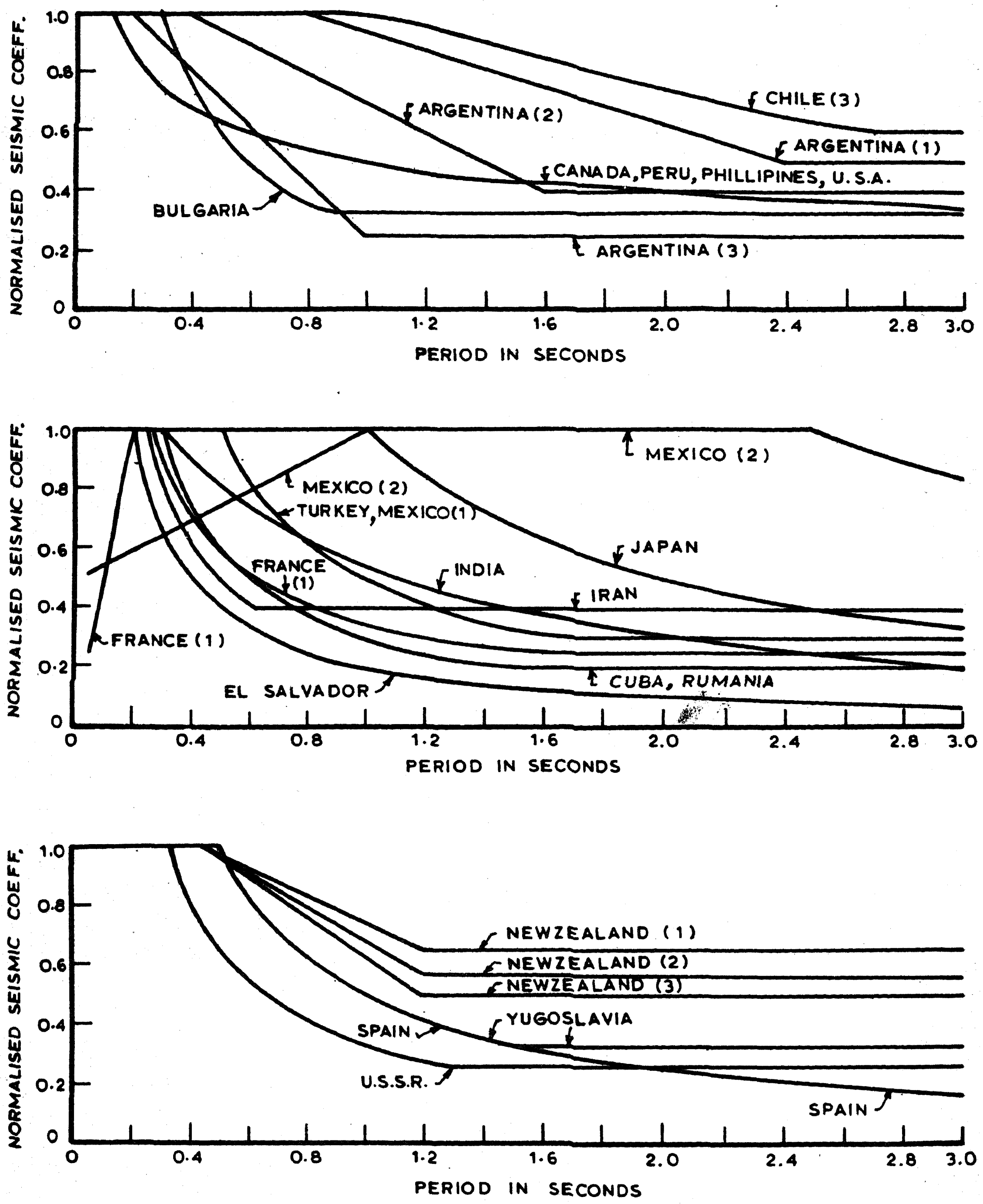

FIG. 1 _ SHAPE OF SPECTRA IN VARIOUS CODES (DATA OBTAINED FROM REF. 1)

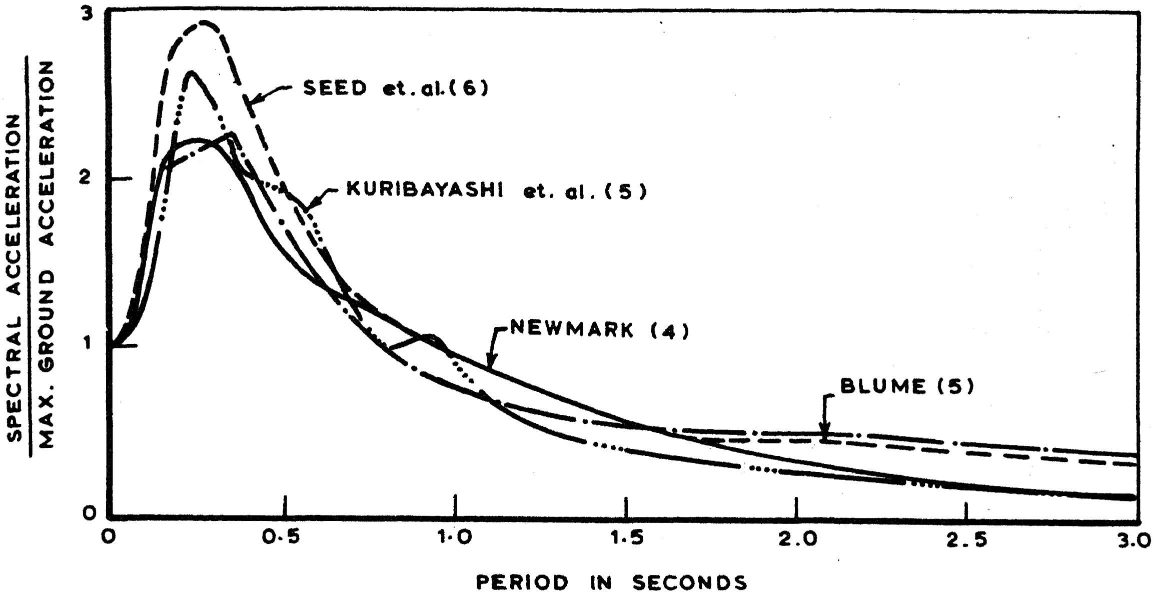

FIG. 2 _ AVERAGE ACCELERATION SPECTRA FOR ROCK SITES (5 % DAMPING)

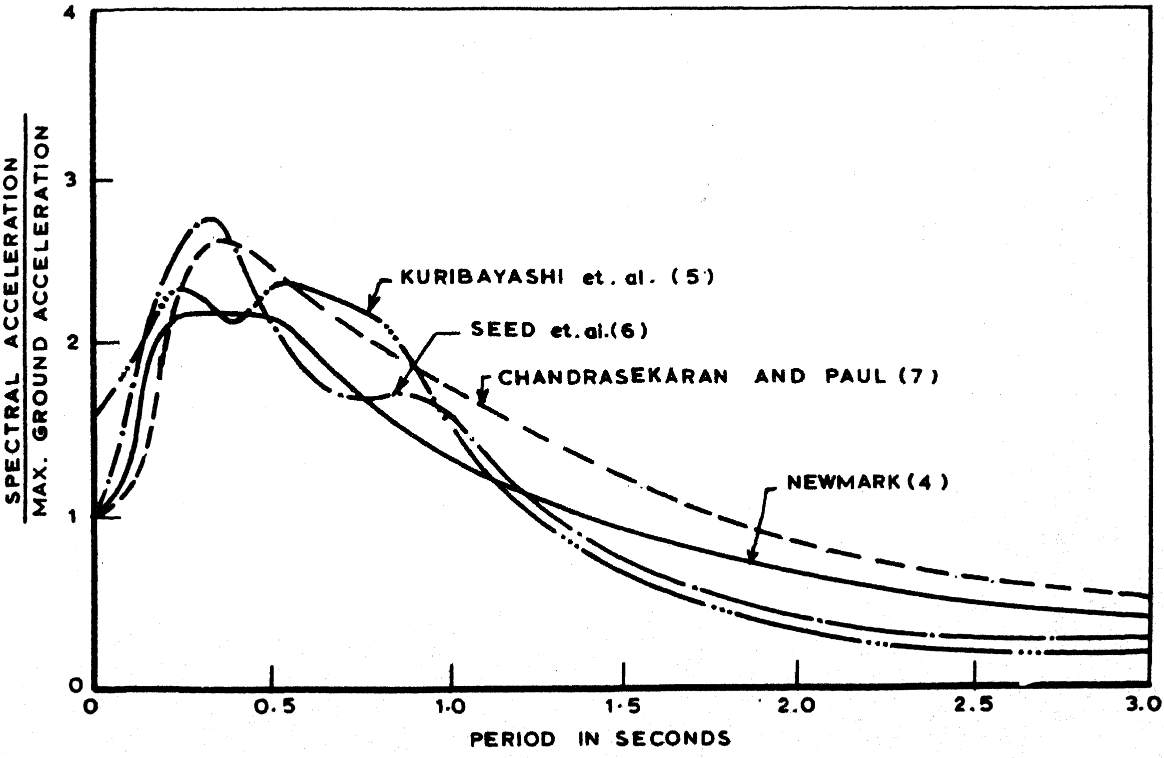

FIG. 3 _ AVERAGE ACCELERATION SPECTRA FOR ALLUVIAL SOILS (5 % DAMPING)

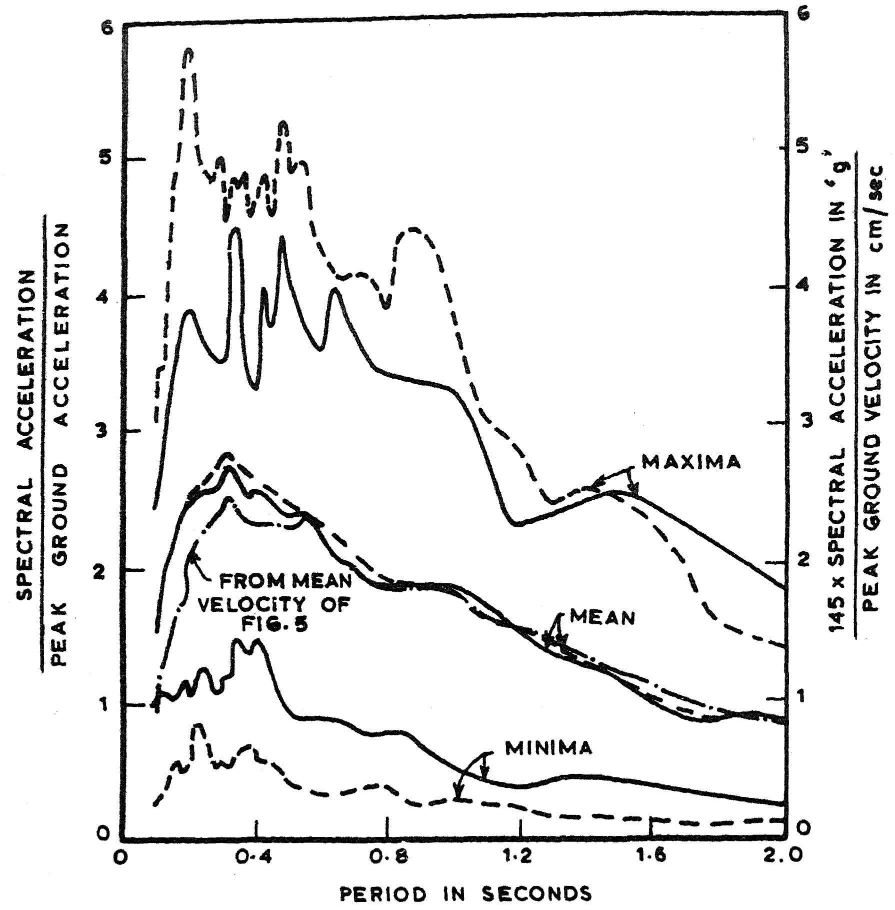

FIG. 4 _ ACCELERATION SPECTRA FOR ALLUVIAL SOILS

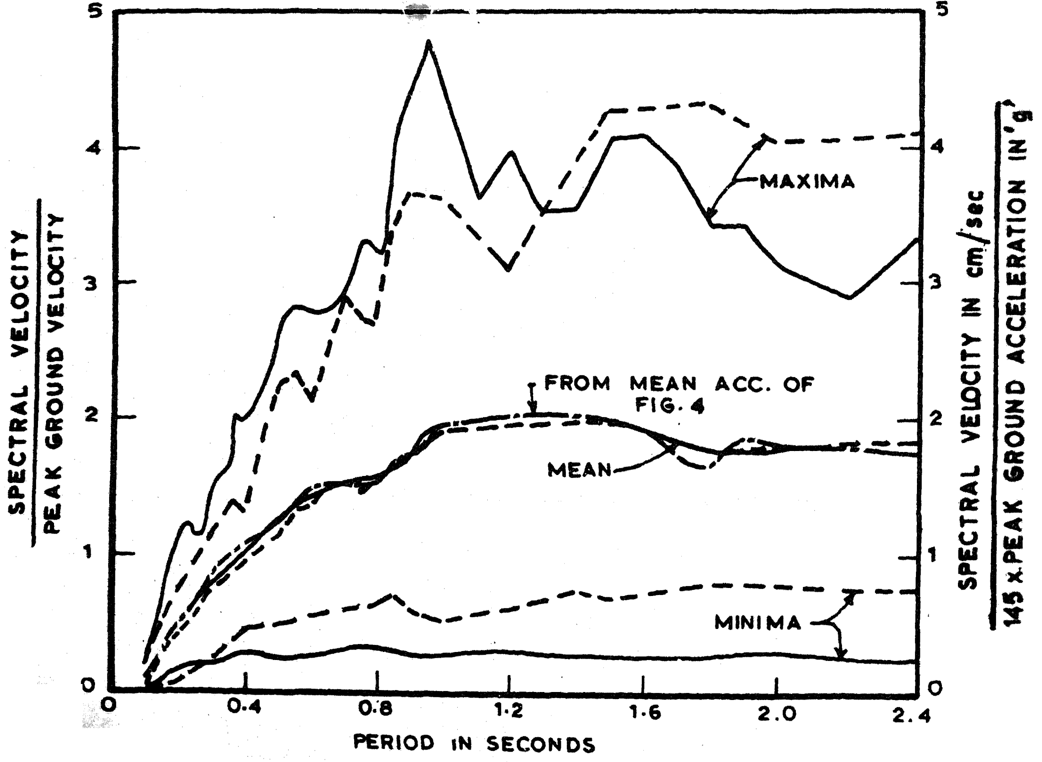

FIG. 5 _ VELOCITY SPECTRA FOR ALLUVIAL SOILS

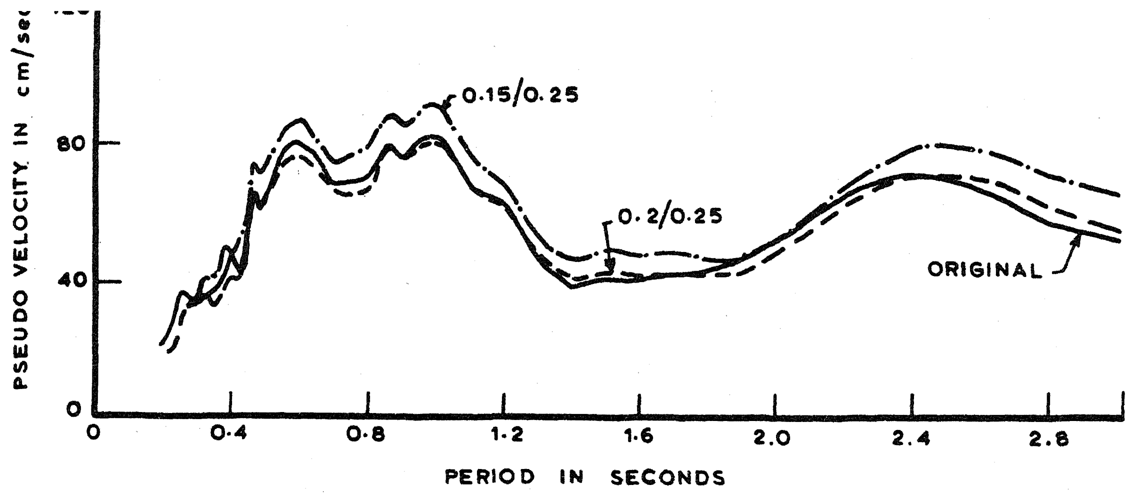

FIG. 6 _ VELOCITY SPECTRA OF ELCENTRO EARTHQUAKE WITH SELECTIVE MODIFICATION OF ACCELERATION PEAKS

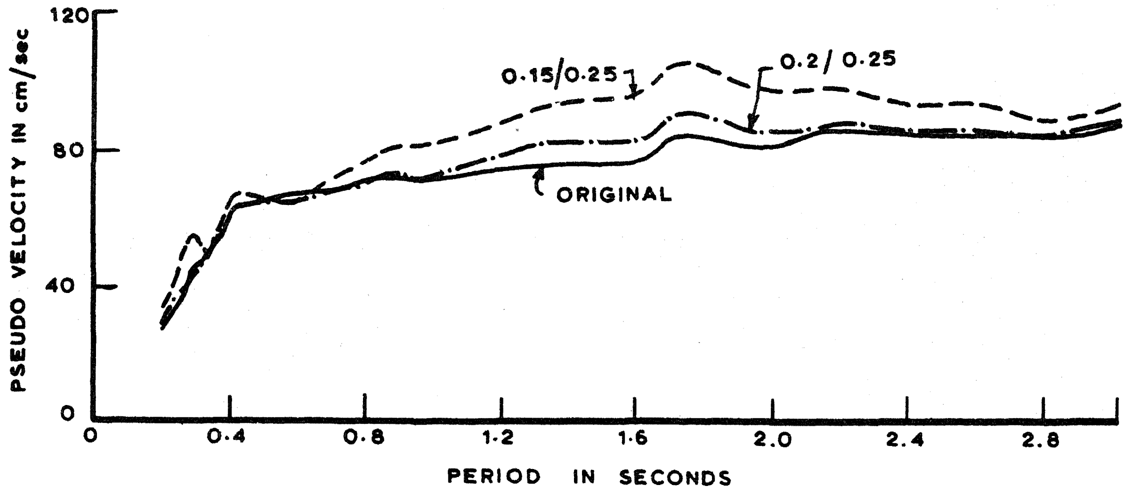

FIG. 7 _ VELOCITY SPECTRA OF AN ARTIFICIAL EARTHQUAKE WITH SELECTIVE MODIFICATION OF ACCELERATION PEAKS

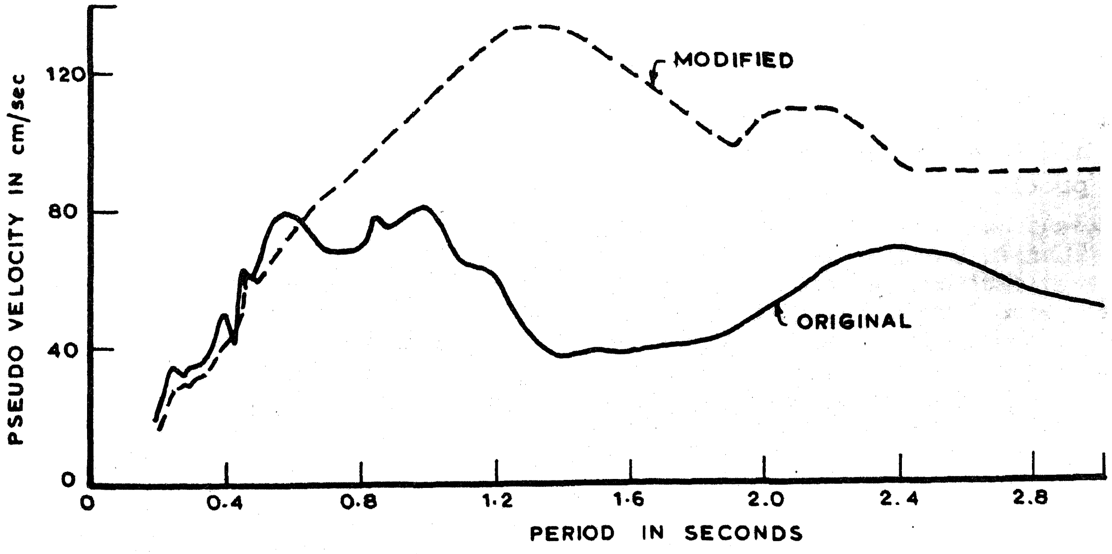

FIG. 8 _ VELOCITY SPECTRA OF ELCENTRO EARTHQUAKE WITH SELECTIVE MODIFICATION OF TIME SCALE

## DISCUSSIONS

### J.L. Justo (Spain)

I agree with Professor Chandrasekaran in that the flat response assumed in most codes for the short period range is not justified. Even more, the period that gives the maximum response should depend upon ground type and distance of the fault.

### R. Grossmayer (Austria)

You have mentioned in your paper the problem of constructing a time history that matches a given response spectrum. In my opinion this and many other problems in design (secondary systems, modal interaction) could be handled easier if we start our design procedure with a design power spectral density instead of a response spectrum. What is your opinion about this ?

### Ricardo Duarte (Portugal)

I have the following comment to make on the discussion by Dr. Grossmayer.

The problem with response spectra and power spectral density is not which shall comes first or is more fundamental, but to what extent we could use both to have a better understanding of ground motion.

### Author's Closure

Dr. Grossmayer's question has been answered by Dr. Duarte. I would like to add here that, all over the world, response spectrum in some form or other is specified for design and therefore we should study the problems associated in adopting a particular design spectrum for major projects. I have highlighted some of the important aspects connected with this problem.