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SHUFFLING OF EARTHQUAKE DATA

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Synopsis

The wave form of records of strong motion accelerograms are highly irregular. In order to determine the influence of this irregularity, acceleration ordinates of recorded data of two accelerograms have been shuffled with respect to time base and spectra as obtained for these modified earthquakes have been compared with those of original ones. Only for higher values of damping, there is no appreciable difference in response. The influence of shuffling has been determined by comparing the spectral intensities of earthquakes.

Introduction

Very few records of strong ground motions have so far been obtained. Among the few, one of the strongest recorded is that of El Centro, May 18, 1940 which had only a peak acceleration of 0.33 g. This earthquake had a magnitude of 7.1 and the record was made at a distance of 30 miles from the epicentre. This record has been used more or less as a standard for most of the investigations in "Structural Dynamics".

Fourier analysis of the recorded accelerograms indicate that these comprise of several frequency components with highly varying amplitudes(1)†. The ground motion depends on a number of factors like the magnitude of the shock, distance from epicentre, the properties of the medium (which are generally hetrogeneous) through which waves travel and the local geology. Therefore, the patterns of ground motion would be varying. In order to determine the influence of this variation, modified earthquakes could be obtained by shuffling recorded earthquake data and then comparing the modified and original ones.

One of the method of comparing earthquakes is to compare their Fourier Spectra. However, in 'Structural Dynamics', an indirect comparison is usually made by obtaining response spectra of earthquakes. Response spectra is of direct interest as it is used for design purposes. Further, it has been shown that response spectra for zero damping is same as Fourier Spectra(1).

For the modified earthquakes as well as original earthquakes, velocity response spectra have been obtained for damping values of 0.05, 0.10 and 0.20. Also, spectral intensities have been obtained from these response spectra. The results indicate that there is appreciable difference in spectral intensities for small values of damping.

The maximum and minimum values of average deviation of spectral intensities of modified earthquakes from that of original earthquakes are 15.8% and 7.9% respectively.

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† Refers to serial number of references given at the end.

Ground Motion Data and Scheme of Shuffling

Two records of earthquake accelerograms that were selected for this study are:

1. El Centro earthquake, May 18, 1940, component N–S.
2. Taft earthquake, July 21, 1952, component N 69 W.

A ground acceleration record is always preferable as it has direct application in response calculations. Digitalized ground acceleration—time data for the two earthquakes selected for this study were available. This data has been obtained by approximating each accelerogram by a series of straight lines. For the purpose of this investigation, the earthquake data corresponding to the first 7.0 seconds of the earthquakes was used. Modified earthquakes were obtained by shuffling the earthquake data with respect to time base in various ways. The original digitalized earthquake data had 120 acceleration-time ordinates. This was divided into ten equal blocks of twelve ordinates each. Only the acceleration ordinates were shuffled in various ways while the time ordinates were kept unchanged. The arrangement of shuffling the blocks (acceleration ordinates only) is indicated in Table 1.

Determination of Response Spectra

Method for evaluation of response spectra are well known[1,2,3] and one of them is briefly summarised below.

For obtaining linear response spectra. the ground motion is applied to the support of a linear single degree of freedom system having a concentrated mass, a linear massless spring and viscous dashpot. The maximum value of the relative displacement of mass with respect to the base is known as the spectral displacement (S_d), the maximum relative velocity of mass with respect to the base is known as the spectral velocity (S_v) and the maximum absolute acceleration of the mass as the spectral acceleration (S_a) These quantities are approximately related to each other by simple expressions[2]. By evaluating the above spectral values for various periods and damping, complete response spectra for an earthquake could be obtained. The equation of motion for a linear single degree of freedom system subjected to ground motion is given by

$$\ddot{z} + 2p\zeta\dot{z} + p^2 z = -\ddot{y} \qquad \ldots \qquad \ldots \qquad \text{(i)}$$

where

z = displacement of mass relative to base.

p = undamped natural frequency of the system

ζ = fraction of critical damping

y = ground displacement

and dots define differentiation w.r.t. time.

Using this notation, we obtain

$$Z_{max} = S_d$$

$$\dot{Z}_{max} = S_v$$

$$|\ddot{z}+\ddot{y}|_{max} = S_a$$

TABLE 1

Scheme of Shuffling

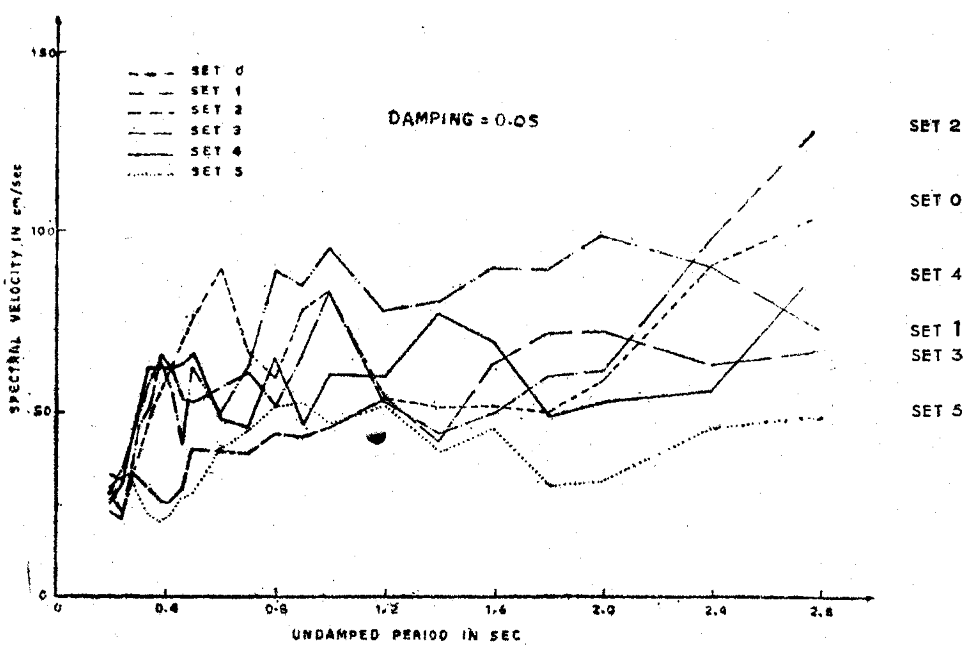
Set No.	Arrangement of Blocks										Remarks
0	I	II	III	IV	V	VI	VII	VIII	IX	X	Original data
1	X	IX	VIII	VII	VI	V	IV	III	II	I	Reversed arrangement of blocks
2	X	IX	VIII	IV	V	VI	VII	I	II	III	Only the first and last three blocks shuffled
3	IV	V	VI	VII	I	II	III	VIII	IX	X	Middle four blocks followed by first three blocks
4	I	III	V	VII	IX	II	IV	VI	VIII	X	Odd block numbers followed by even block numbers
5	II	IV	VI	VIII	X	I	III	V	VII	IX	Even block numbers followed by odd block numbers

The data of these modified earthquakes was obtained on punched cards and this data was subseqently used for determination of spectral response.

The equation of motion (i) has been solved by using fourth order Runge Kutta procedure of numerical integration[3].

Discussion of Results

The response has been obtained for two earthquake excitations namely Elcentro and Taft earthquakes and for various modified earthquakes for specified values of damping and period. Results have been obtained for various periods of vibration varying over a wide range from 0.2 sec. to 2.8 sec. The damping values considered are 5%, 10% and 20% of critical damping. Since the various responses, response spectral displacement S_d, response spectral velocity S_v, and response spectral acceleration S_a, are approximately related with one another by, simple relationships [2], for the purpose of discussion, velocity spectrum values are considered. These have been presented in the form of curves in figures 1 to 6. Spectrum curves for the modified earthquakes have been drawn on the same graph as for the original earthquake for comparison. It is noted that for large values of damping of the order of 0·20, there is no appreciable difference in response. Also for small values of period of vibration, the difference in the response is not significant. However for small damping values, the deviation in the response could be sufficiently significant.

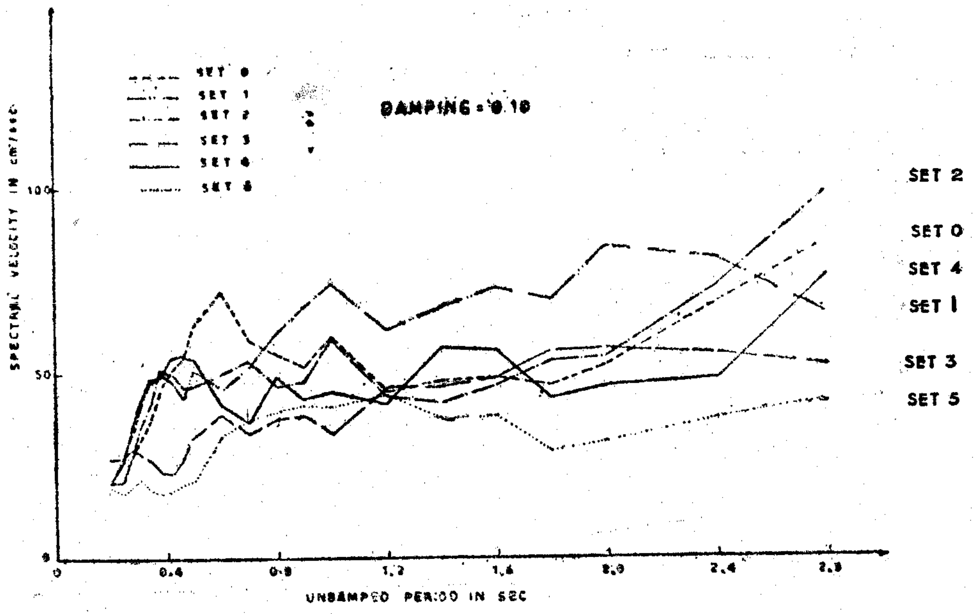


ELCENTRO EARTHQUAKE

Fig. 1

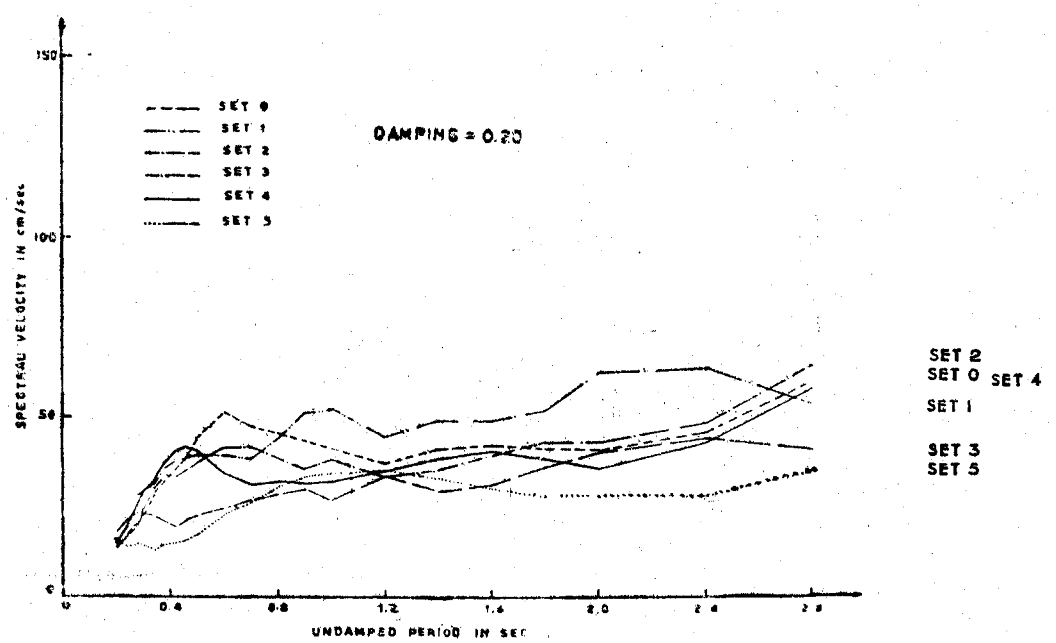
Spectrum Intensities

The maximum response of structures are indicated by the S_v spectrum curves and, hence, the area under one of the curves is a measure of the intenstiy of the earthquake in the sense that it expresses the average response of structures of that amount of damping over the range of periods[4]. The spectrum intensity may be defined to be the area under the S_v curve between 0.2 and 2.8 seconds period.



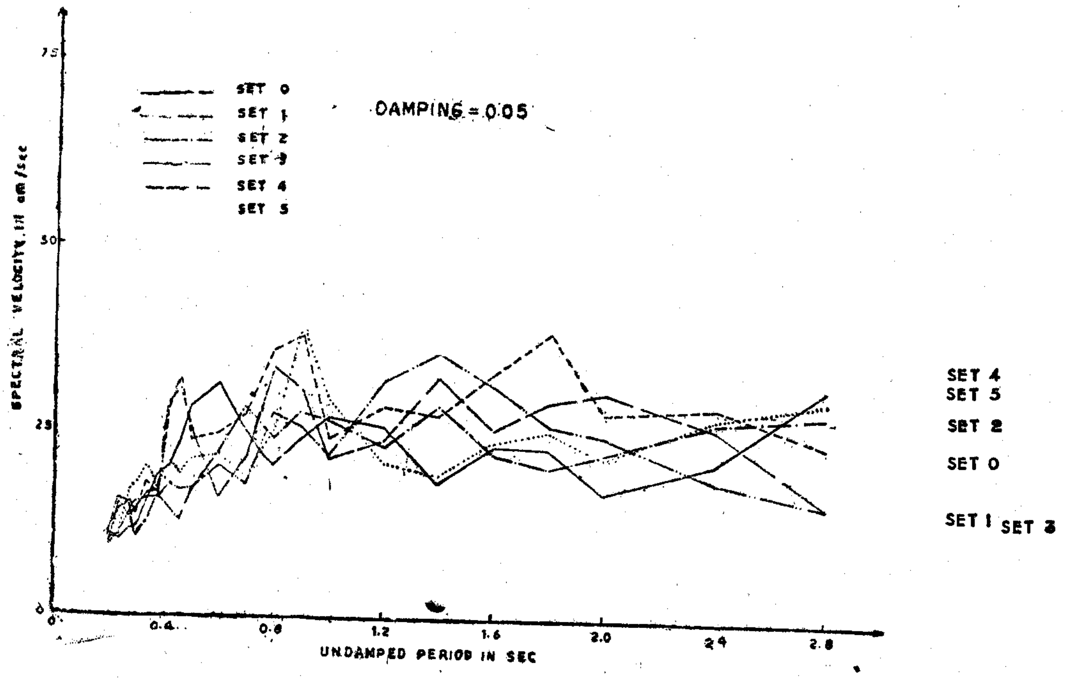
ELCENTRO EARTHQUAKE

Fig. 2



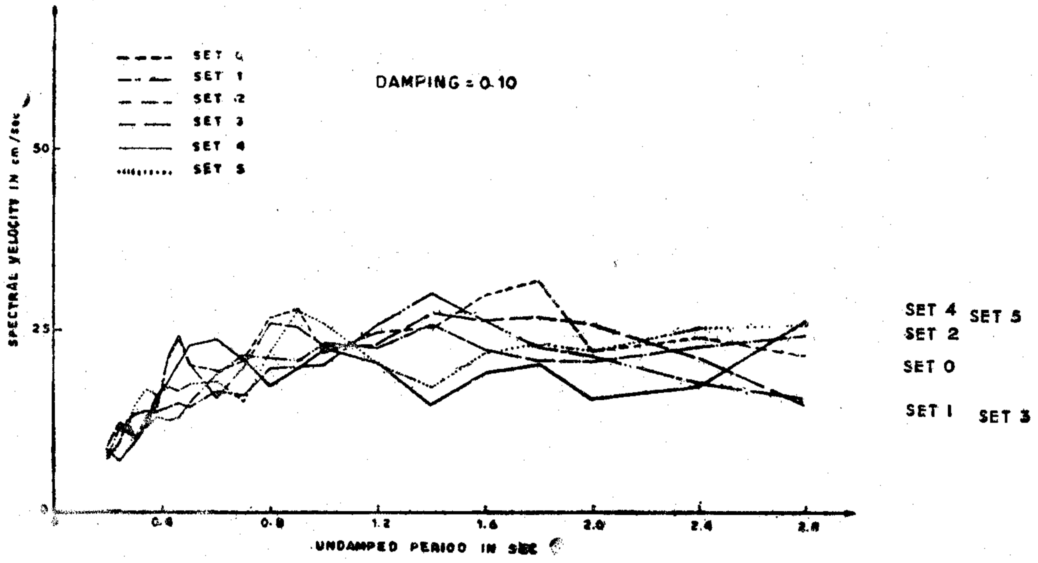
ELCENTRO EARTHQUAKE

Fig. 3



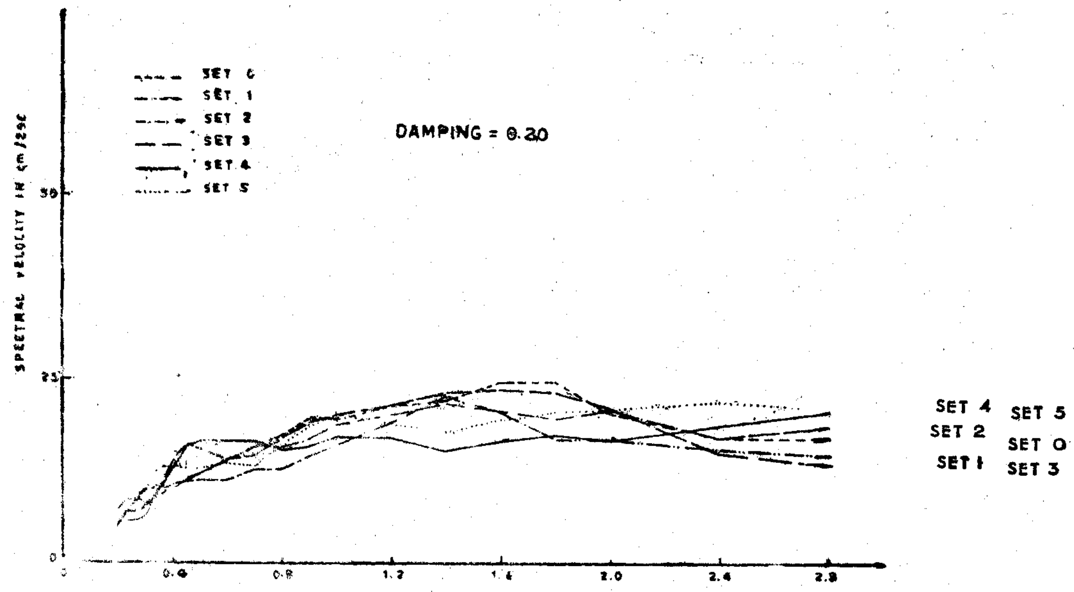
TAFT EARTHQUAKE

Fig. 4



TAFT EARTHQUAKE

Fig. 5



TAFT EARTHQUAKE

Fig. 6

$$SI_{\xi} = \int_{0.2}^{2.8} S_v\ (\xi\,,T)\ \ dT.$$

The spectrum intensities have been obtained for the various cases and are given in Tables 2 and 3.

From the tables, it is seen that the maximum and minimum values of the average deviation of spectral intensities of modified earthquake from that of original ones are respectively 10.2% and 9.8% for El Centro earthquake and 15.8% and 7.9% for Taft earthquake.

A comparison between El Centro and Taft earthquakes could be made by scaling up the acceleration ordinates of Taft such that the peak ground acceleration has the same value as that of El Centro. The spectral intensities of El Centro and scaled up Taft are given in Table 4. It is seen that the deviation is 13.6% for 5% damping, 13.5% for 10% damping and 10.9% for 20% damping.

Keeping El Centro earthquake as a standard it seen that the maximum deviation of spectral intensities are 13.6% and 10.9%. Thus, if this order of error is permitted, the spectral intensities are directly function of peak ground acceleration.

Conclusions

The modified earthquakes obtained by shuffling the data of original earthquakes are also probable earthquakes as ground motion depends on a number of complex factors. For engineering purposes, the best method of evaluating influence of earthquakes is to compare their response spectra. Spectrum intensities represent the integrated effect of response spectra over the frequency range of interest.

The maximum and minimum values of average deviation of spectral intensities of modified earthquakes from that of original ones are respectively 10.2% and 9.8% for El Centro earthquake and 15.8% and 7.9% for Taft earthquake. A comparison has also been made by scaling up the ordinates of Taft earthquake such that peak ground acceleration is same as that of El Centro earthquake. In this case it is found that the deviation in spectral intensity is 13.6% for 5% damping, 13.5% for 10% damping and 10.9% for 20% damping.

This investigation reveals that spectral intensities are more or less directly proportional to peak ground acceleration. Keeping El Centro earthquake as a standard, the maximum and minimum deviations are 13.6% and 10.9% respectively

Acknowledgements

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TABLE 2

Spectrum Intensities for El Centro Earthquake

Set No.	$SI_{0.05}$	Percentage Deviation	$SI_{0.10}$	Percentage Deviation	$SI_{0.20}$	Persentage Deviation
0	5.79	—	4.74	—	3.67	—
1	6.82	17.8	5.67	19.7	4.32	17.7
2	6.07	4.9	4.75	0.2	3.54	−3.5
3	4.86	−19.2	3.80	−19.8	2.87	−21.8
4	5.08	−12.2	4.15	−12.5	3.30	−10.1
5	3.46	−40.5	2.93	−38.2	2.44	−33.5
	Average Deviation = − 9.8%		Average Deviation = − 10.1%		Average Deviation = − 10.2%	

TABLE 3

Spectrum Intensities for Taft Earthquake

Set No:	$SI_{0\cdot05}$	Percentage Deviation	$SI_{0\cdot10}$	Percentage Deviation	$SI_{0\cdot20}$	Percentage Deviation
0	2.43	—	2.00	—	1 60	—
1	2.03	−16.4	1.72	−14.0	1.35	−15.6
2	2.02	−16.8	1.78	−11.5	1.49	− 6.9
3	2.17	−10.7	1.88	− 6.0	1.54	− 3.7
4	1.94	−20.1	1.60	−20.0	1.41	−11.9
5	2.06	−15.2	1 83	− 8.5	1.58	− 1.2
	Average Deviation = − 15.8%		Average Deviation = − 12.0%		Average Deviation = − 7.9%	

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Earthquake	$SI_{0\cdot05}$	Percentage Deviation	$SI_{0\cdot10}$	Percentage Deviation	$SI_{0\cdot20}$	Percentage Deviation
El Centro	5.79	—	4.74	—	3 67	—
Scaled up Taft	5.00	13.6	4.10	13.5	3.27	10.9