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CHOICE OF GROUND MOTION DATA FOR DESIGN OF STRUCTURES

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INTRODUCTION

For designing structures in seismic zones, two conditions must be examined. For smaller earthquake shocks which are expected frequently, the structure must remain within elastic limit and for the largest size of earthquake expected only once or twice during its life time, the structure could be expected to dissipate energy through its elastic and inelastic deformations. However, for both these conditions one could proceed for design only if an accelerogram of design earthquake shock is available. The instrumental data available for this country is too meagre to meet the varying situations in the seismic zones. However, with the available data for other countries, it is possible to draw certain conclusions which provide useful guidance in deciding about the choice of parameters for design earthquake. The classical average spectrum curves proposed by Housner (5) have been adopted by many countries where seismic instrumentation data is not available. The choice of multiplying factor for the average spectra has, however, been based largely on the experience of the designer. In fact it is very difficult to take into account the wide variations in the geological conditions of the different sites in seismic zones for estimating the multiplying factor. However, it is possible to work out such factors for generally firm ground conditions. One such method to estimate multiplying factor for a site in seismic zone was recently suggested by the author (1). However, in case it is desired to go in for a more detailed investigation of structural response or when it is desired to study inelastic response, the accelerogram of the design earthquake will be required. Obviously such data can never be available before hand and the designer will have to make a choice of accelerogram. The present paper suggests a method to choose an accelerogram for use at a particular site based on the seismotectonic features of the area around the site in question. Description of the method follows.

ACCELEROGRAM PROPERTIES

Before talking about the choice of accelerogram for a place, it may be emphasized here that both acceleration amplitudes as well as frequency contents are equally important characteristics of an accelerogram. It is realized that both these get attenuated with the increasing distance from earthquake epicenter and are greatly affected by the properties of intervening ground. All this would ultimately show up in the response spectra computed from the accelerogram recorded at that site. In fact, the exciting potential of a shock is described by its spectral intensity (SI) which gives a quantitative idea of structural response over a range of structural periods (1,2,5). It is a recognized fact that undamped spectral intensity represents the accelerogram characteristics better than the damped SI values. In the present method of choosing accelerograms, the concept of undamped SI values will be used.

BASIS OF THE PROPOSED METHOD

For the region in question, the designer must estimate the magnitude of the design earthquake and its probable depth of focus. Then, from a study of seismotectonic features of the area, the distance between the possible source of distrurbance and the site under reference must be calculated. It is only after deciding this basic data that an artificial or pseudo accelerogram can be predicted for a site.

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Various methods of assuming artificial earthquakes have been suggested for use in different situations from the data collected in California (6). Such pseudo earthquakes can be developed from recorded earthquakes also (3,4). If the acceleration amplitudes of an accelerogram are toned up or down to take into account their attenuation, and the time base is elongated or contracted to take into account the attenuation of frequencies with distance, an accelerogram can be derived for another site. However, such modification factors have to be determined for each site. In this connection detailed study was carried out by the author to determine the effect of change in time base on the structural response (2,3). In this study the time base of an accelerogram is changed such that the modified time base parameter 'T' is related to the original time parameter 't' as follows:

$$T=\lambda t \qquad \ldots(1)$$

where λ is the time base elongation/contraction factor. It was shown that structure response computed from such modified accelerograms could be similar to those resulting from such recorded accelerogram at another place. For example, Koyna (Dec. 11, 1967) longitudinal component with $\lambda=1.5$ shows response features similar to those of El Centro (May 18, 1940) N-S component. Also, features of the same El Centro accelerogram with $\lambda=0.66$ resemble those of Koyna. The Koyna accelerogram was recorded close to the epicenter at a distance of about 3 miles while El Centro accelerogram was recorded at 30 miles from the epicenter.

The overall effect of such time base modification on the undamped SI values is shown in Fig. 1, in which normalized spectral intensity (i.e. SI divided by peak ground acceleration value) is plotted against λ for the El Centro N-S and Koyna Longitudinal accelerograms mentioned above. It is seen that normalized spectral intensity (SI_n) increases nonlinearly with an increase in λ. From this, one can determine the value of λ for a particular site for which SI_n is known. In an earlier study (1), author has shown that for generally firm ground conditions SI_n can be related with the distance D_x (in miles) of the site from epicenter by a simple relationship as follows:

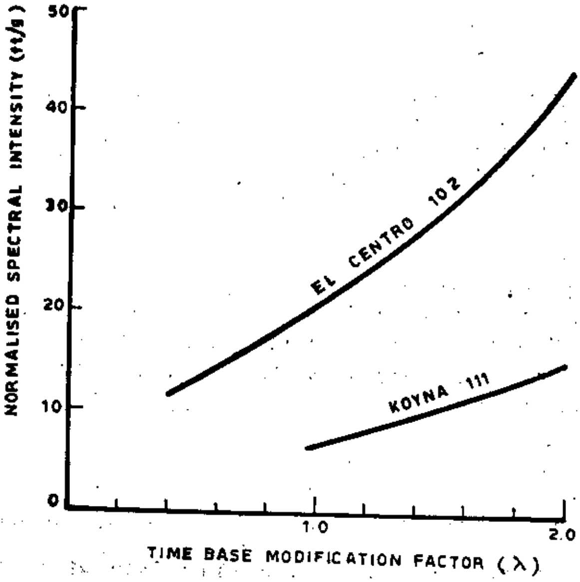

Fig. 1. Variation of Normalised Spectral Intensity with Change in Time Base of Recorded Acclerograms

$$SI_n=0.425\,D_x+5.73 \qquad \ldots(2)$$

Equation (2) has been developed from a statistical study of sixteen strong motion earthquake recorded in California and India. (These alongwith the relevent data are tabulated in Appendix-I). Fig. 2 shows for the actual plot of SI_n versus D_x for these shocks. From eqn. (2), SI_n value can be very easily computed for a site on knowing its distance from possible future epicenter. On knowing SI_n, Fig. 1 may be used to determine the factor λ. This concept alongwith the Magnitude-Distance-Acceleration relationship form the basis of the present method for determining earthquake parameters for a site. The outline of the method is described in the following paragraphs.

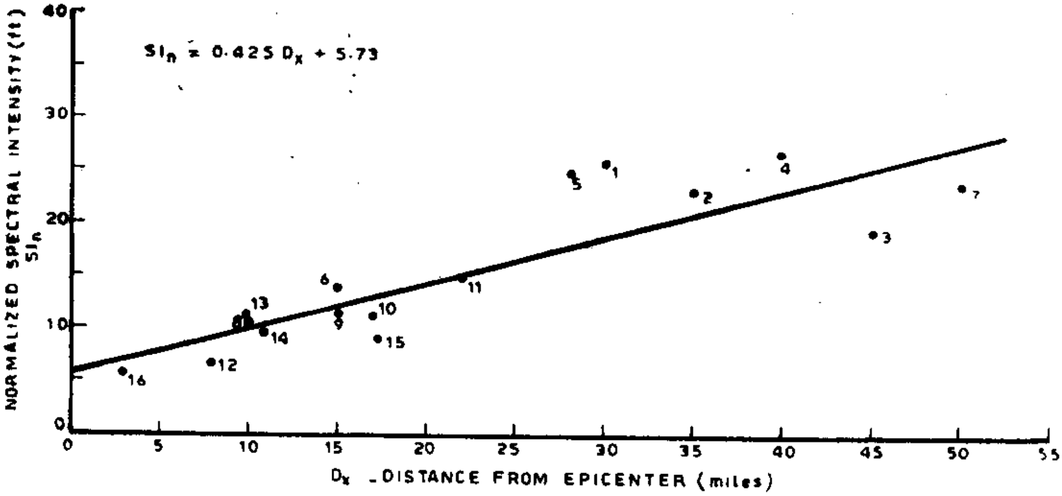

Fig. 2. Variation of Normalized Spectral Intensity with Distance from Epicentre Dots Refer to the Serial Number of Earthquake Shock in Appendix—I

OUTLINE OF THE METHOD

For determining the accelerogram properties at a site, the designer must decide whether El Centro, Koyna or any other from of accelerogram is to be adopted for the site. Once this basic issue is settled, the only parameters remain to be defined are the factor λ and the peak ground acceleration ($\ddot{Y}$) for which the empirical relationship developed by the author (7) can be used. The entire method can therefore be described in following steps:

(i) Based on the seismotectonic features and the seismic history of the area, decide about the magnitude (M) and focal depth (h_f) of the design earthquake and estimate the distance of the site (D_x) from the possible epicenter.

(ii) Work out the peak ground acceleration ($\ddot{Y}$) expected at the site using the following empirical relationship (7):

$$\frac{\ddot{Y}}{g} = \frac{2.925\ \dfrac{10^{(M-5)}}{h_f}}{1+4.5.\dfrac{10^{(M-5)}}{h_f}} \cdot e^{-0.26\,(D_x/h_f)^{3/2}} \qquad \ldots(3)$$

in which g is acceleration due to gravity and D_x and h_f are in miles.

(iii) Using eqn. (2), work out normalised spectral intensity SI_n for the site.

(iv) Using Fig. 1, determine the time base modification factor λ for the desired type of accelerogram.

(v) Modify the acceleration amplitudes and the time axis of the original recorded accelerogram corresponding to $\ddot{Y}$ and λ for use in response computation scheme.

ILLUSTRATIVE EXAMPLE

It is required to determine accelerogram parameters of Koyna or El Centro type shock for a site situated 15 miles from epicenter of a possible earthquake of magnitude 6.2 and focal depth 10 miles.

Step 1. Using eqn. 3, with $D_x=15$, $h_f=10$, and $M=6.2$, the peak ground acceleration works out as 0.354 g.

Step 2. Using eqn. 2, the normalised spectral intensity SI_n works out as 12.20 ft/g.

Step 3. Using Fig. 1, time base modification factor for Koyna accelerogram works out as 1.6 for Koyna type accelerogram and 0.4 for El Centro type accelerogram.

Therefore the accelerogram for the site will have elongated/contracted time base ($\lambda=1.6$ or 0.4) and attenuated acceleration ordinates with peak value of 0.354 g.

CONCLUSIONS

Choice of earthquake accelerogram for a site in seismic region can be made on the basis of seismotectonic data and the seismic history of the area. For a given site an accelerogram can be developed by suitable modifications in the time axis an acceleration ordinates of recorded accelerogram such as for Koyna or El Centro shocks as suggested and illustrated in this paper.

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APPENDIX I—LIST OF STRONG MOTION SHOCKS STUDIED(1)

S. No.	Name of Station and Date of shock	M	D_x (Miles)	h_f (Miles)	Max. recorded accn/g	Average SI (Ft)	SI_n (Ft/g)
1	El Centro May 18, 1940	7.1	30	15	0.33	8.35	25.30
2	El Centro Dec. 30, 1934	6.5	35	15	0.26	5.88	22.60
3	Olympia April 13, 1949	7.1	45	45	0.31	5.82	18.75
4	Taft July 21, 1952	7.7	40	15	0.18	4.69	26.10
5	Vernon May 10, 1933	6.3	28	15	0.19	4.62	24.30
6	Santa Barbara June 30, 1941	5.9	15	19	0.24	3.29	13.70
7	Ferendale Oct. 3, 1941	6.4	50	15	0.13	2.99	23.00
8	Hollister March 9, 1949	5.3	10	15	0.23	2.36	10.50
9	Helena Oct. 31, 1935	6.0	15	25	0.16	1.82	11.38
10	Vernon Oct. 2, 1933	5.3	17	15	0.12	1.32	11.00
11	L. A. Subway Terminal Oct. 2, 1933	5.3	22	15	0.065	0.96	14.75
12	S. F. Golden Gate March 22, 1957	5.3	7.8	7	0.13	0.84	6.46
13	S. F. State Building March 22, 1957	5.3	9.8	7	0.10	1.12	11.20
14	S. F. Alexander Building March 22, 1957	5.3	10.8	7	0.05	0.48	9.60
15	S. F. Oakland March 22. 1957	5.3	17.2	7	0.05	0.38	7.60
16	Koyna Dec. 11, 1967	6.5	3	5	0.63	3.72	5.9