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CHARACTERISTICS OF STRONG GROUND MOTION RECORD AS APPLICABLE TO DESIGN FACTORS

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Introduction

A picture of overall influence of a recorded ground motion on structures, around the site of recording it, is obtained through spectral analysis. A comparison of such spectra gives the relative damaging capacity of the earthquakes compared. These spectra have a direct bearing on the design of structures since they contain a relationship between the response of structures based on their dynamic characteristics and the ground motion during a particular earthquake.

Since a structure is designed to resist an earthquake that will occur in future, it is not possible to make an exact analysis, as the precise nature of the future ground motion is not known. The ground motion of a future shock will depend on its magnitude, distance from the epicentre, properties of the medium through which waves travel and the local geology. Under the circumstances, it is considered appropriate to base the analysis and design on past earthquake records duly modified to take into account the differences in the conditions at the site and those at which the past record has been obtained. It is also considered reasonable to assume that the character of future earthquakes will be the same as that of the past ones. Based on the data of four strong motion earthquakes of California, Housner (1) had prepared average response spectra for the purposes of design. Considerable experience and judgment is, however, necessary to make use of these to suit the local conditions.

Jai Krishna (2) has suggested that for the purpose of design, an expected magnitude of design shock may be chosen, taking into account the importance of the structure, its expected iife, probability of occurrence of shocks during this period and the seismicity of the area. Having fixed the magnitude of the design shock, the peak ground acceleration expected at the site may be determined approximately by using magnitude–distance–acceleration relationships (2,3,7). Further, it has been proposed (2) that the shape of the record of the design shock may be assumed to be the same as one of the recorded earthquakes with the acceleration ordinates of the accelerogram changed in the ratio of peaks. This approach enables the designer to use the average spectrum curves proposed by Housner (1).

It is proposed to discuss here the characteristics of the accelerograms with respect to their utility in the manner stated above. Two typical accelerograms, namely Koyna (1967),

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subjectcd to ground motion caused by the earthquake. The equation of motion of such a system is given by :

$$\ddot{x} + 2p\zeta\,\dot{x} + p^2x = -\ddot{y}$$

where 'x' is the displacement of the system relative to base, 'p' the undamped natural frequency of the system and is equal to $2\pi/T$, 'T' the undamped natural period of vibration, 'ζ' the fraction of critical damping and 'y' the ground displacement.

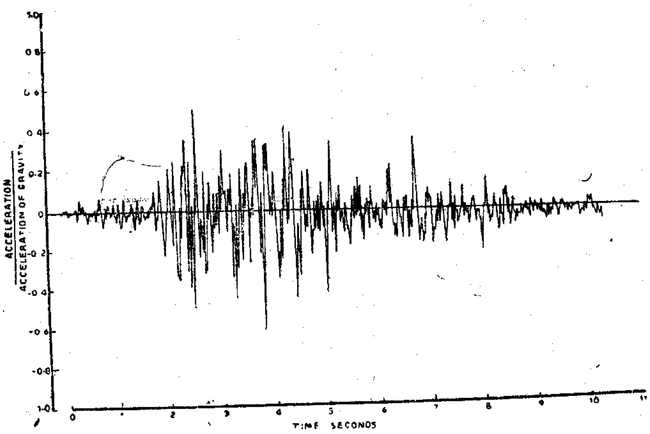

Fig. 1. Koyna accelerogram of Dec. 11, 1967 longitudinal component

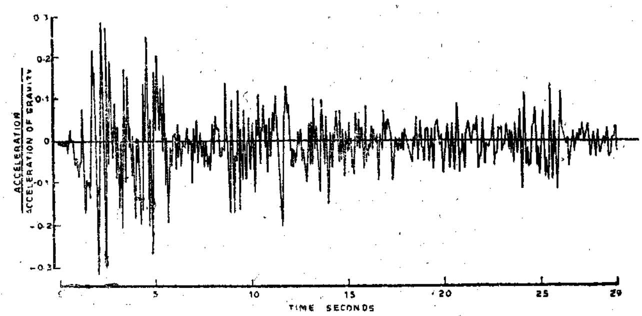

Fig. 2. El centro accelerogram of May 18, 1940 N–S component

Using this notation, the spectral response is given by :

$x_{max} = S_d =$ Spectral displacement

$\dot{x}_{max} = S_v =$ Spectral velocity

$|\ddot{x} + \ddot{y}|\ max = Sa =$ Spectral acceleration

The expressions for the determination of Sd, Sv and Sa are well known (5, 6) and are as given below :

$$S_d = \left[-\frac{1}{p_d}\int_0^t \ddot{y}\ (\tau)\ e^{-p\zeta(t-\tau)}\ \mathrm{Sin}\ p_d\,(t-\tau)\ d\tau \right]_{max} \tag{2}$$

$$S_v = \left[-\int_0^t \ddot{y}\ (\tau)\ e^{-p\zeta(t-\tau)}\ \mathrm{Cos}\ p_d\,(t-\tau)\ d\tau\ + \right.$$

$$\left. + \frac{\zeta}{\sqrt{1-\zeta^2}}\int_0^t \ddot{y}\ (\tau)\ e^{-p\zeta(t-\tau)}\ \mathrm{Sin}\ p_d\,(t-\tau)\ d\tau \right]_{max} \tag{3}$$

$$S_a = \left[\frac{p\,(1-2\zeta^2)}{\sqrt{1-\zeta^2}}\int_0^t \ddot{y}\ (\tau)\ e^{-p\zeta(t-\tau)}\ \mathrm{Sin}\ p_d\,(t-\tau)\ d\tau \right.$$

$$\left. + 2p\zeta \int_0^t \ddot{y}\ (\tau)\ e^{-p\zeta(t-\tau)}\ \mathrm{Cos}\ p_d\,(t-\tau)\ d\tau \right]_{max} \tag{4}$$

where '$\ddot{y}$' is the ground acceleration, 'p_d' the damped natural frequency, 't' the time and 'τ' the time variable of integration.

The peak ground acceleration of Koyna earthquake is approximately twice of that of El Centro earthquake. Had the wave-form ef Koyna accelerogram been of the same pattern as that of El Centro shock, the response due to Koyna shock would have been about twice of that due to El Centro shock. However, the response due to Koyna is much less over a wide range of longer periods and are higher only in a small range of shorter periods upto about 0.4 second period. This shows that the response is not only dependant upon the peak ground aeceleration but also depends on the precise wave-form of the accelerogram. In fact, the response is an integrated effect over the "effective time duration" of strong ground motion and this is clear from equations 2 to 4.

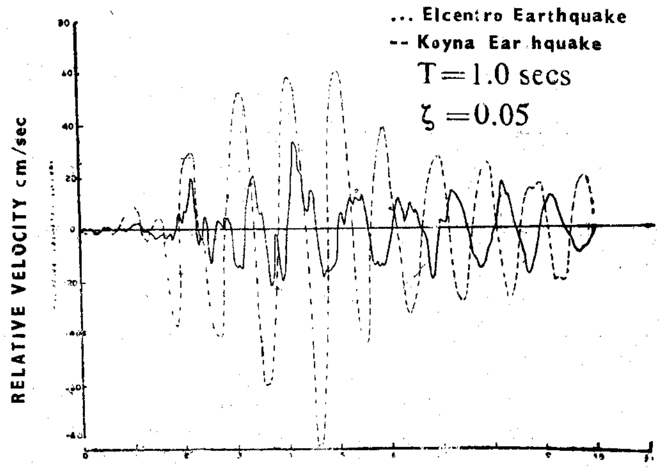

Fig. 6—Relative velocity Versus Time

In ordcr to emphasize the fact that the response does not depend only on the peak ground acceleration, the importance of a peak acceleration was also studied by reducing the peak acceleration of that single peak. The peak ground acceleration of 0.63 g of Koyna earthquake occurred at 3.75 seconds. The acceleration of this single peak was reduced to 0.42 g in one case and 0.21 g in another case. Similarly for the El Centro shock, the peak ground acceleration of 0.33g which occurred at 2.0 seconds was reduced to 0.22 g in one case and 0.11 g in another case. The response of the accelrograms with a change in the acceleration of the single peak were also obtained and are presented in Table 1. Normally, one would expect that if the response depends directly on the peak ground acceleration, the response should decrease as the acceleration of the single peak decreases. However, Table 1 indicates that in few cases, the response is unaffected by the change in the single peak where as the response slightly decreases in some cases and slightly increases in other cases. The change in the response is small and random, and does not show any definite trend. This clearly demonstrates that the response of a system is not directly dependant on the peak ground acceleration but is a cumulative effect over the "effective time duration" of strong ground motion. Thus the peak ground acceleration of an earthquake does not give an indication whether a particular ground motion is more damaging or less. Spectral analysis is necessary to assess the pattern of response spectra and the intensity of an earthquake. Spectral intensity which is defined as the area under the Sv curve between 0.1 and 2.5 second period, is usually used as a measure of the intensity of an earthquake (1).

$$SI\ \zeta = \int_{0.1}^{2.5} Sv\,(\zeta, T)\, dT \qquad (5)$$

Spectrum intensities have been obtained for the two earthquakes and are presented in Table 2.

The importance of the time of the occurrence of spectral velocity relative to the occurrence of peak ground acceleration has also been studied. The time of occurrence of peak response has been obtained for various values of period and damping and these are plotted in figures 7 and 8. The figures indicate that the maximum response generally occurs in the first few seconds of the ground motion. The peak ground acceleration of Koyna earthquake occurred at 3.75 second and that of El Centro earthquake ot 2.0 seconds. Figures 7 and 8 indicate that the time of occurrence of the maximum response has no direct relation with the time of occurrence of peak ground acceleration.

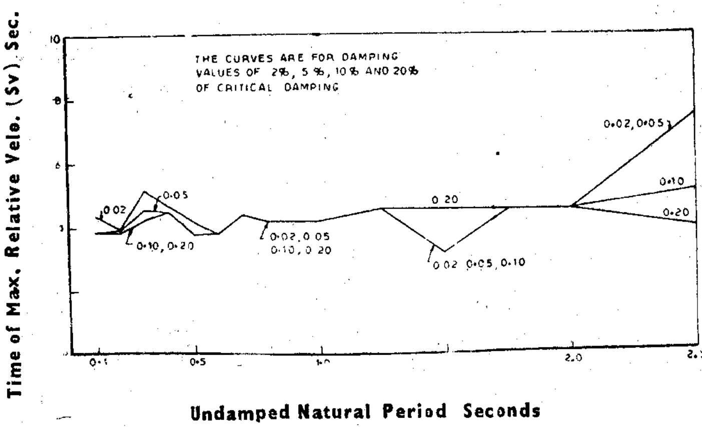

Fig. 7. Time of occurrence of max. response versus undamped period of vibration for Koyna earthquake

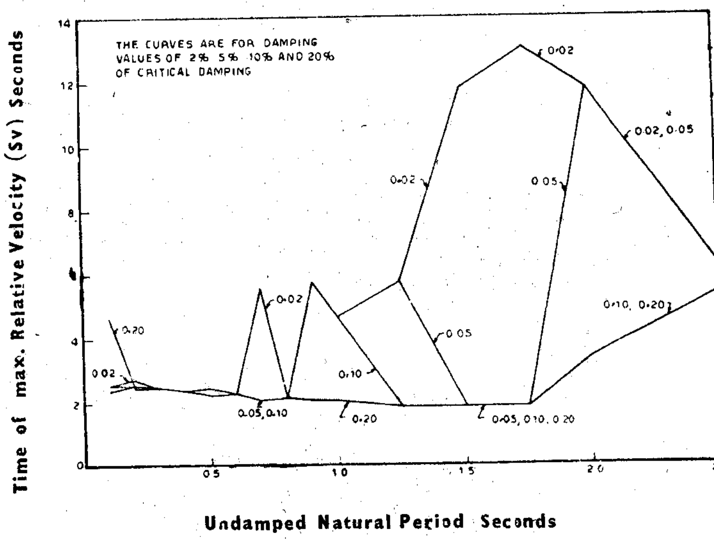

Fig. 8. Time of occurrence of max. response versus undamped period of vibration for El centro earthquake

Jai Krishna (2) had shown that the relationship of magnitude–distance–acceleration is reasonable for most of the earthquakes when the distance of the site is not less than about 20 miles away from the epicentre. This conclusion has been confirmed by its application to Koyna earthquake.

The average spectrum curves proposed by Housner (1) are based on data of four strong motion earthquakes which were recorded at distances more than 30 miles from the epicentre. For earthquakes recorded at short distances from the epicentre as the Koyna earthquake, high frequency components are exhibited in the record with the result that the spectra exhibits a different pattern than the average spectra. Thus, there is a need to define two types of spectra, one for short distances from the epicentre and the other for long distances from the epicentre. Sufficient data, however does not exist to enable drawing a set of standard spectra for epicentral regions.

Conclusions

1. The peak acceleration recorded during an earthquake by itself is no measure of its destruction capacity. The period of the wave form is an important parameter. A large peak at short period is not so destructive as shorter peak at longer period excepting for very short period (<0.4 sec) structures. Damage to structures is a function of the integrated effect of acceleration and period of the wave form.

2. The maximum response of an earthquake does not necessarily occur at the time of the largest peak. It occurs at some moment within the "effective duration" of the earthquake. Thus the duration of the earthquake as a whole has no material influence on the starting of damage of structures. If a structure is not damaged during the "effective duration" of the earthquake, it will not be damaged no matter how long the earthquake lasts.