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SEISMIC COEFFICIENTS FOR EARTHQUAKES RECORDED NEAR EPICENTRE

BY

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INTRODUCTION

Strong motion earthquakes exhibit high frequency components in acceleration records near epicentre. Recently, near epicentre motions have been recorded in Koyna valley, India and San Fernando valley, U S A. There is a school of thought that some reservoirs of river valley projects cause earthquakes. If so, the structures in the river valleys would be subjected to earthquakes having high frequency components.

This paper deals with elastic as well as inelastic spectral characteristics of three of the strong recent earthquakes in Koyna valley. For each earthquake, all the three components, namely, longitudinal, transverse and vertical are taken up for analysis. Thus, in all nine components are analysed. The inelastic behaviour considered is of elasto-plastic type. Seismic coefficients have been obtained considering elastic behaviour of structures and these can be used for design purposes. However, under strong ground motions, the structures could undergo deformations which extend in the post-elastic range. To cater for the inelastic action, a reduction factor technique has been used which can be used to obtain the seismic coefficients under inelastic conditions. Single degree of freedom systems have been considered which form the basic element for the analysis of more complex systems. The study indicates that special care has to be exercised in the design of short period structures located near epicentres of earthquakes.

EQUATIONS OF MOTION AND SPECIFICATION OF PROBLEMS

The maximum response expressed in terms of either relative displacement or relative velocity or absolute acceleration of single degree of freedom systems are termed as spectra and these quantities are a useful measure of evaluating behaviour of structures during earthquakes. The equation of motion of a single degree of freedom nonlinear system subjected to ground motion can be written as (1) :

$$m\ddot{x}+c\dot{x}+Q(x)=-m\ddot{y}(t) \qquad \ldots(1)$$

where m is the mass of the system, c the coefficient of viscous damping, $Q(x)$ the functional relation between restoring force and displacement, x the displacement of the mass relative to base, $\ddot{y}$ the ground acceleration and dots define differentiation with respect to time. For inleastic systems, the restoring force characteristics have been taken to be elasto-plastic. For elastic stystems, the restoring force can be written as:

$$Q(x)=k\,x \qquad \ldots(2)$$

where k is the spring constant of the system in the elastic range. Divide Eq. 1 throughout by $mp^2 x_y$,

$$\frac{\ddot{x}}{p^2 x_y}+\frac{c}{m}\frac{\dot{x}}{p^2 x_y}+\frac{1}{mp^2 x_y}Q(x)=-\frac{1}{p^2 x_y}\ddot{y}(t) \qquad \ldots(3)$$

$$\frac{\ddot{x}}{p^2 x_y}+2\beta\frac{\dot{x}}{px_y}+\frac{Q}{Q_y}\left(\frac{x}{x_y}\right)=-\frac{1}{q_y}\ddot{y}(t) \qquad \ldots(4)$$

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where $p=\sqrt{k/m}$ is the undamped natural frequency, β the fraction of critical damping. x_y the yield displacement, Q_y the yield force, q_y the yield force per unit mass and known as yield level of the system.

Equation 4 is the dimensionless form of the equation of motion where $\frac{x}{x_y}$ is the ratio of the relative deflection of the system to its yield deflection and its maximum value is termed as ductility. The solution of equation 4 has been obtained using corrector-predictor methods for various values of natural periods of vibration, damping and yield levels of the systems. For a system having a particular period and damping, a plot of ductility versus yield levels is drawn. From this plot, it is possible to find yield levels corresponding to specified values of ductility. To simplify the design of structures considering inelastic behaviour, a reduction factor technique has been used. Reduction factor is defined as the ratio of elastic spectral acceleration to the yield levels of the nonlinear system corresponding to any particular value of the ductility. Knowing these reduction factors, it is possible to find forces in a non-linear system by carrying out only linear analysis because the reduction factor represents the scale by which the amplitudes of the earthquake data be toned down so that a linear analysis with the modified data indicates a seismic lateral load coefficient which corresponds to that of yield point of the nonlinear system.

The three components each of the three earthquakes in Koyna valley namely, Dec. 11, 1967, Oct. 29, 1968 and Sept. 13, 1967 were considered for analysis. The pertinent data of the earthquakes are given in table 1 and the digitized data are available in references 2 and 3. For purposes of comparison the NS Component of May 18, 1940. Elcentro earthquake has also been considered.

TABLE I
PERTINENT DATA OF KOYNA EARTHQUAKES

S. No.	Event	Component	Peak Ground Acceleration	Zero Axis Width in Seconds	Average No. of Zero crossings Per Second	Index No.
1	December 11, 1967	Longitudinal	0.630 g	0.05	24	111
		Transverse	0.490 g	0.05	21	112
		Vertical	0.340 g	0.05	23	113
2	October 29, 1968	Longitudinal	0.096 g	0.05	28	114
		Transverse	0.068 g	0.05	26	115
		Vertical	0.084 g	0.05	31	116
3	September 13, 1967	Longitudinal	0.234 g	0.06	36	117
		Transverse	0.096 g	0.04	35	118
		Vertical	0.080 g	0.07	39	119

DISCUSSION OF RESULTS

Figs. 1, 2 and 3 show the seismic coefficients for the three earthquakes considering elastic behaviour of structures for natural periods varying from 0.1 to 2.5 seconds and for damping equal to 5% of critical damping. The figures show that short period structures are subjected to very high earthquake forces if elastic behaviour is assumed.

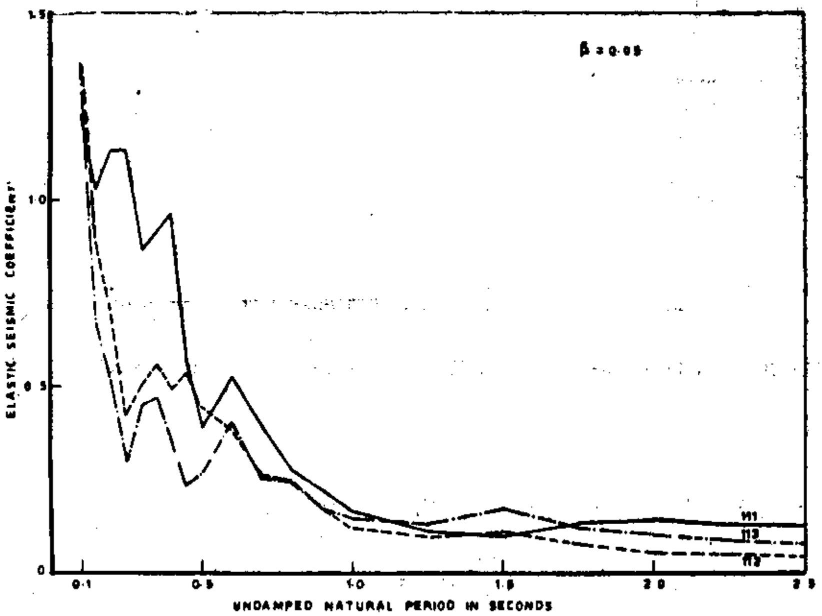

Fig. 1. Elastic Seismic Coefficients Due to Koyna Earthquake of December 11, 1967

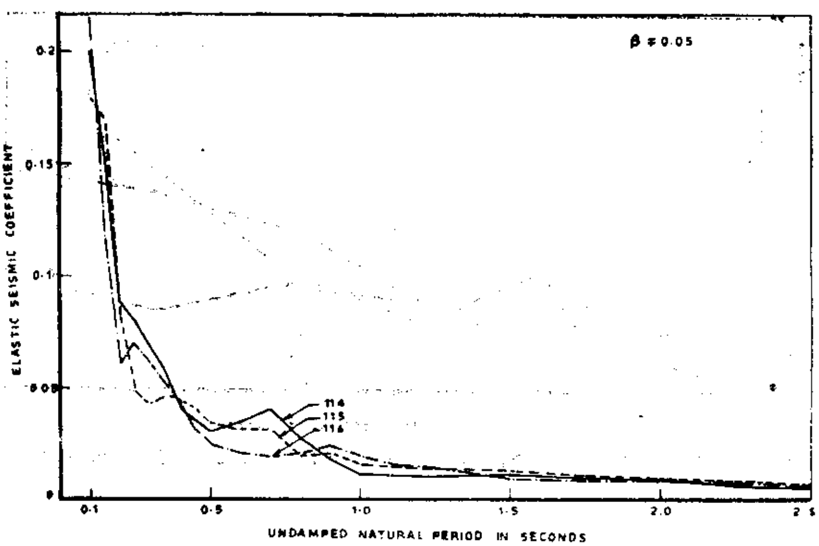

Fig. 2. Elastic seismic coefficients Due to Koyna Earthquake of October 29, 1968

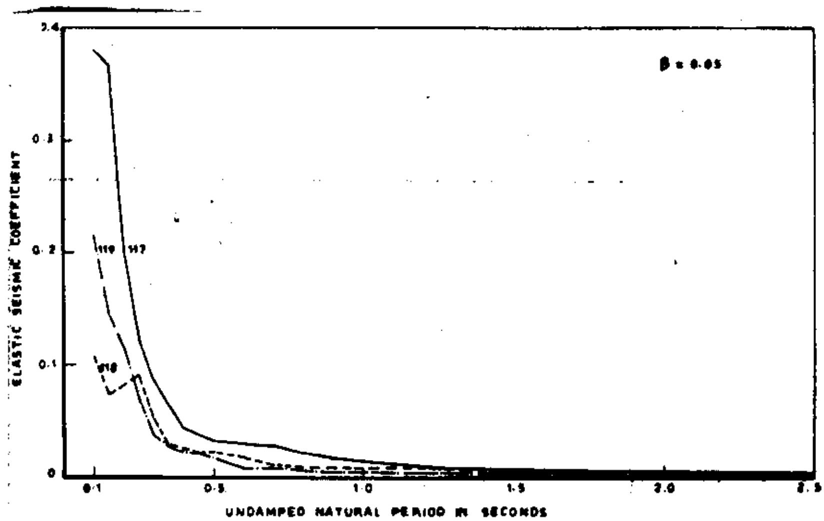

Fig. 3. Elastic seismic Coefficients Due to Koyna Earthquake of September 13, 1967

Figs. 4, 5 and 6 show respectively, the displacement, velocity and acceleration under inelastic conditions as a function of period for systems having 5% critical damping and 10% gravity as yield level. Probably, at shorter periods, the system would have higher yield level (4) and the damping would also be higher. It can be seen that displacements and velocities increase whereas accelerations decrease with increase in period. The trend in inelastic case is similar to that of elastic case (2) except that acceleration spectra is somewhat more flatter in inelastic case.

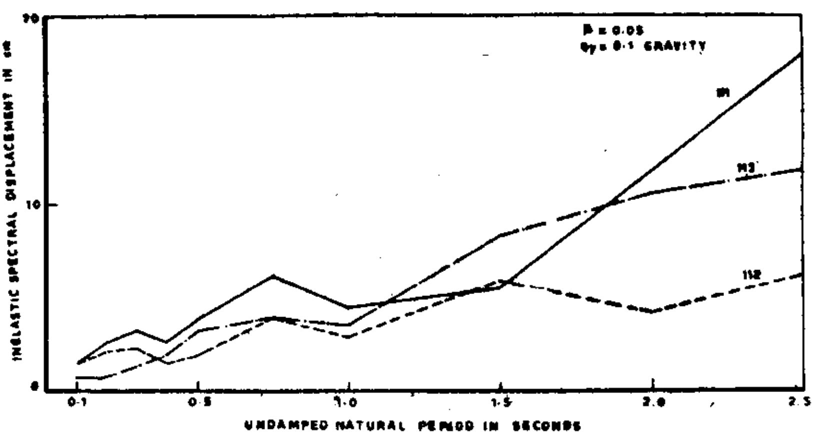

Fig. 4. Inelastic Displacement Spectra Due to Koyna Earthquake of December 11, 1967

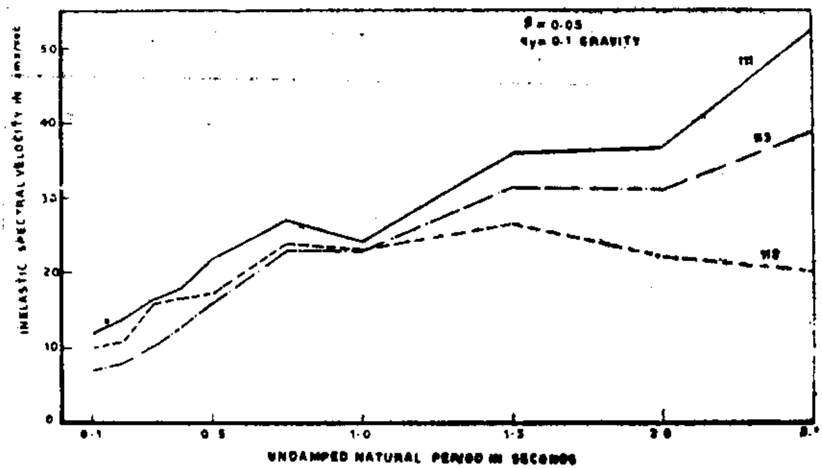

Fig. 5. Inelastic velocity spectra Due to Koyna Earthquake of December 11, 1967

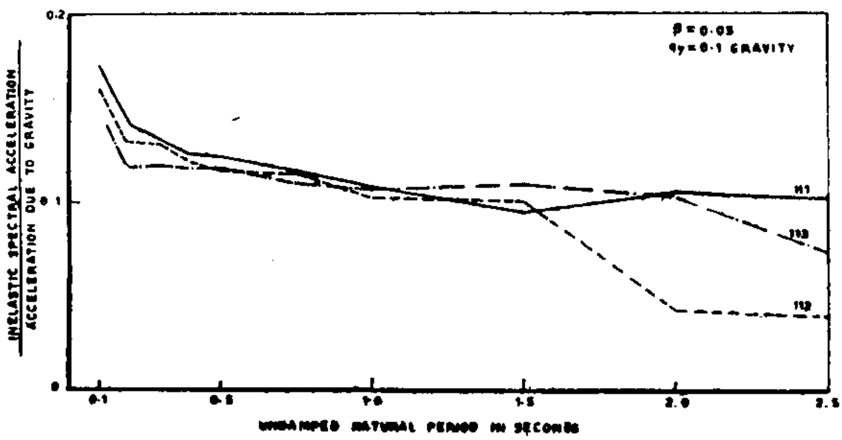

Fig. 6. Inelastic Acceleration spectra Due to Koyna Earthquake of December 11, 1967

Fig. 7 shows the ratio of inelastic to elastic displacements for one yield level. It is seen that for long periods, say, above 0.4 sec., the ratio is nearly unity. In other words, for systems having periods much longer than that of ground period, the inelastic deformations are nearly the same as the elastic deformations. For shorter period structures and for low yield levels, the inelastic deformations can be very high.

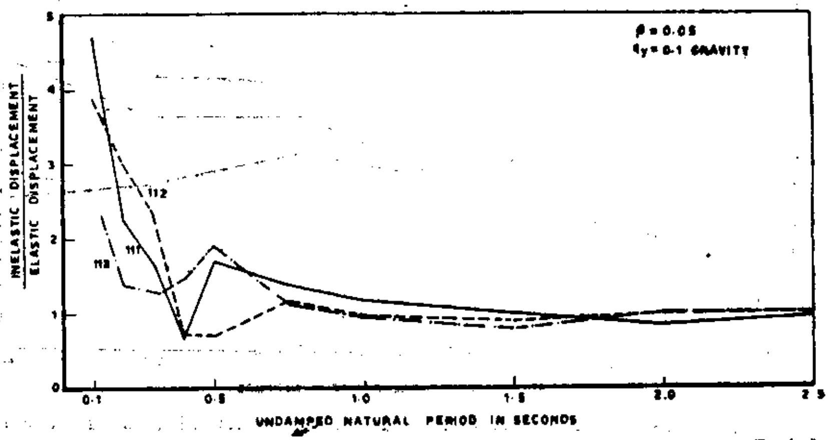

Fig. 7. Ratio of Inelastic and Elastic Displacements VS Undamped natural Period of Vibration Due to Koyna Earthquake of December 11, 1967

Fig. 8 shows relationship between yield level and deformation for particular values of periods. For short periods particularly, deformations increase very rapidly with decrease in yield level.

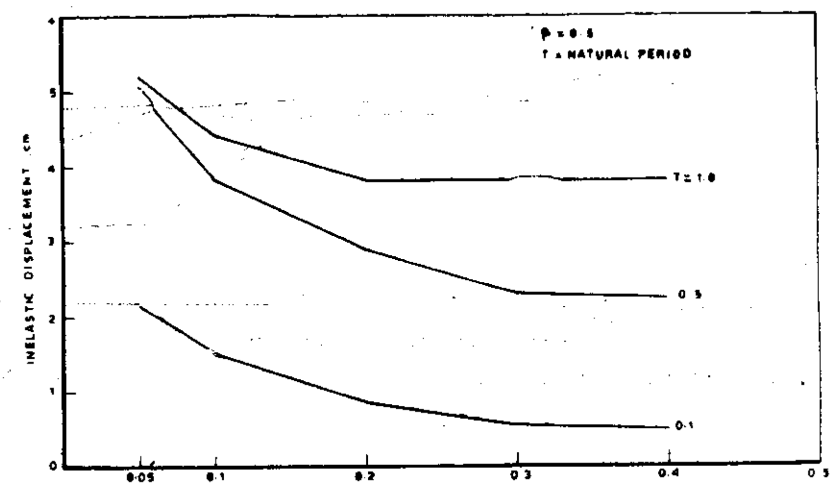

Fig. 8. Inelastic Displacement VS yield level Due to Longitudinal component of Koyna Earthquake of December 11, 1967

Figs. 9 and 10 show respectively the ratio of velocities and acceleration between inelastic and elastic conditions. For short periods the velocities and acceleration are much smaller whereas for longer periods the ratio is very nearly unity. Since the displacement ratio is almost unity for longer periods, the system behaves as a linear one for periods much longer than the periods exhibited in ground acceleration records.

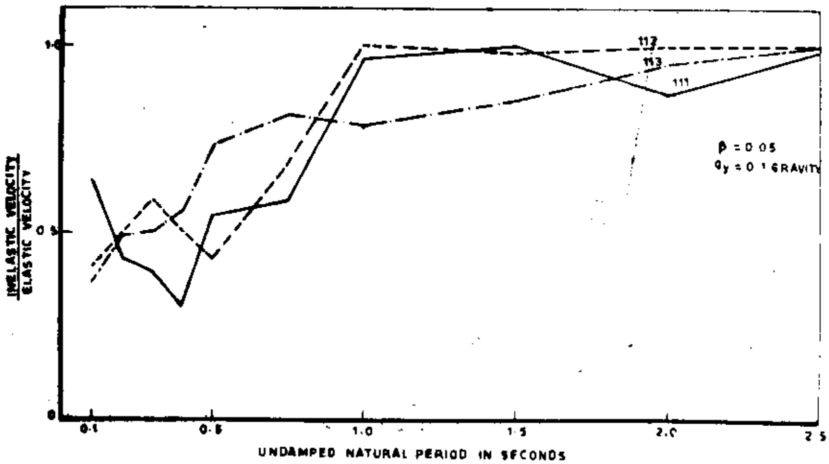

Fig. 9. Ratio of Inelastic and Elastic Velocites versus Undamped Natural Period of Vibration Due to Koyna Earthquake of December 11, 1967

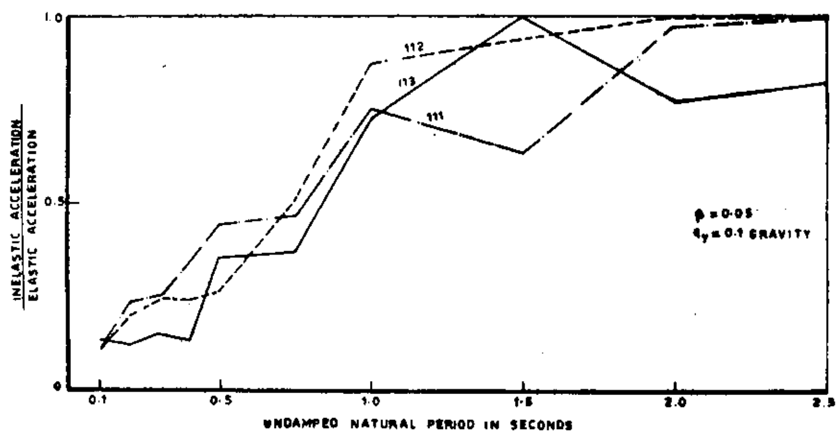

Fig. 10. Ratio of Inelastic and Elastic Accelerations versus Undamped natural Period of Vibration Due to Koyna Earthquake of December 11, 1967

Fig. 11 shows a plot of reduction factor versus period for different ductility ratios. The pattern of the curves are similar and reduction factors increase with increase in ductility.

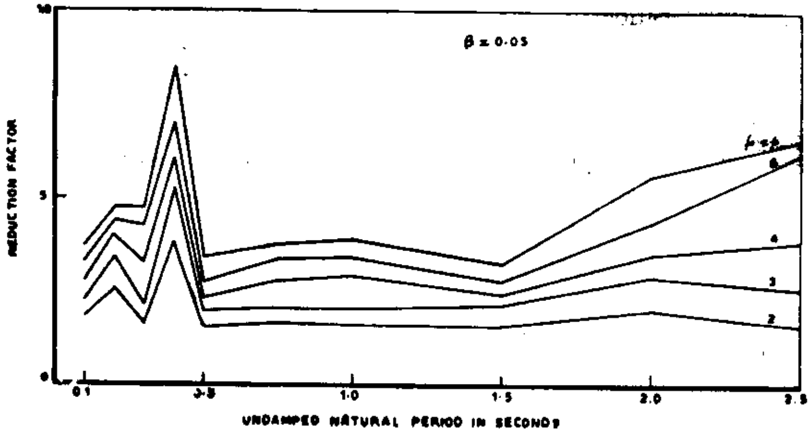

Fig. 11. Reduction Factors Due to Koyna Earthquake of December 11, 1967 Longitudinal component

Fig. 12 shows the variation of ductility factor as a function of period for different earthquakes. Between the three components of an earthquake (say either between index number 111, 112 and 113 or 114, 115 and 116 or 117, 118 and 119) the variation with respect to period is small. The December 11, 1967 earthquake gives lesser reduction factors compared to Oct. 29, 1968 quake. Further, it is also seen that El centro earthquake gives higher reduction factors. Since, these curves are based on a non-dimensional solution of the equation of motion, one might infer that the variation in reduction factors may be due mainly to waveform of ground motion.

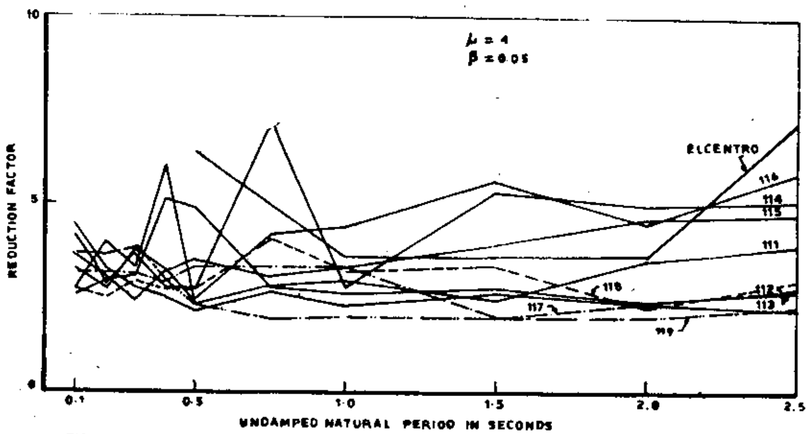

Fig. 12. Reduction Factors Due to Koyna and Elcentro Earthquakes

Fig. 13 gives relationship between yield level expressed as a function of peak ground acceleration versus natural period for various earthquakes and corresponding to one ductility. It can be observed, that if ductility is a criterion for design then the yield levels are rather very high for short period systems. It can therefore be concluded that special care has to be exercised in the design of short period structures as unless the yield levels (seismic coefficients) are high, the deformations would be large.

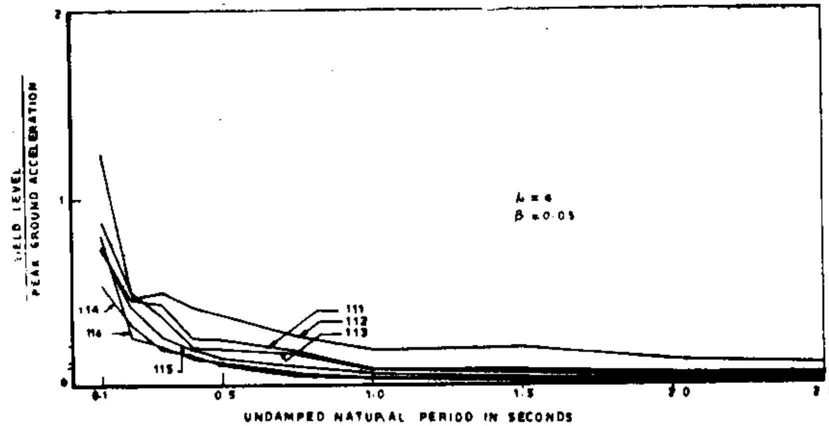

Fig. 13. Ratio of Yield level and Peak ground Acceleration versus Undamped natural Pe iod of Vibration Due to Koyna Earthquakes

CONCLUSIONS

Earthquakes recorded near epicentres have predominantly short period components of the order of 0.15 second or less. The inelastic response of long period structures (greater than, say, 0.4 sec.) subjected to these types of earthquakes is very nearly the same as the elastic response. For short period structures, however, the inelastic response is much different than that of elastic response. In order to obtain reasonable ductility values in short period range, the yield levels must be high. Since yield levels, determine the so called seismic coefficients, the short period structures must be designed for large values of coefficients and the concept of reduction factor cannot be loosely applied for short period structures located near epicentre.

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