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EFFECT OF OVER-BURDEN SOIL ON GROUND MOTION SPECTRA

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INTRODUCTION

Most of the earthquake codes divide their countries into a few regions and allot basic seismic coefficients to those regions. These basic coefficients are in some cases multiplied by an ad-hoc factor based on the type of soil at site. The depth of soil cover over bed rock generally does not figure in any of these ad-hoc provisions. There have been very little attempts at microzoning of regions.

For small regions like that of a city, it may be reasonable to assume the motion at bed rock to remain more or less similar during an earthquake but the ground motion at various location depends on the depth of over burden soil and its properties. Such phenomenon has been observed during actual earthquakes[1].

In this study, the overburden soil has been represented as a linear single degree of freedom filter having periods in the range of 0.25 to 0.40 second and a damping of 20% of critical. This range of periods may be construed either to correspond to the fundamental period of a soil layer of depth 50 m and shear wave velocity in the range of 500–800 m/sec or to a soil layer having a shear wave velocity of 650 m/sec and depth in the range of 45–65 m. The damping of 20% is a reasonable value for the fundamental mode of vibration of soil layer.

At bedrock four different earthquake motions were assumed. They have the same waveform as four recorded earthquakes but their acceleration amplitudes were normalised such that the Housner's spectral intensity[2] for all the records is same. Corresponding to four periods of filter and four motions at bed rock, sixteen ground motions were generated and response spectra evaluated. Average of these spectra were also obtained. It is concluded that peak of the acceleration spectra occurs nearly in the region of the period of the soil layer. The ratio of maximum acceleration spectra to the maximum ground acceleration, that is, magnification factor generally increases as the period of the soil layer increases. The soil layer filters out high frequency components of bed rock motion.

BED ROCK MOTION

For this study, it was assumed that the region is close to the epicentre of a medium size earthquake. The waveforms chosen were (a) Koyna Dec. 11, 1967, Longitudinal[3] (b) Koyna Dec. 11, 1967 Transverse[3] (c) San Fernando, Feb. 9, 1971, Pacoima Dam Transverse S–74N[4] (d) San Fernando, Pacoima Dam Longitudinal S 16 E[4].

There are several methods used for normalising earthquake motion so that various waveforms may have similar intensity. The following three quantities were calculated for the four records.

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(1) Housner's Spectral Intensity,

$$I_1=\int_{0.1}^{2.5} Sv.\, dT \tag{1}$$

where Sv is the maximum response spectrum velocity and T the time period. The damping has been taken as 5% of critical.

(2) Peak ground velocity,

$$I_2=\left|\int_0^{\tau} \ddot{y}(t)\, dt\right|_{max.} \tag{2}$$

where $\ddot{y}(t)$ is the ground acceleration at any time t

and (3) Root mean square value of ground acceleration

$$I_3=\left|\left(\frac{1}{N}\sum_{i=1}^{N} a_i^2\right)^{1/2}\right|_{maxm} \tag{3}$$

where a_i is the acceleration ordinate and N is the number of such ordinates. These values are tabulated in Table 1.

TABLE I. INTENSITY

Earthquake	I_1 cm	Ratio*	I_2 cm/sec	Ratio*	I_3 cm/sec^2	Ratio*
Koyna Transverse	60.6	1	20.9	1	0.0165	1
Koyna Longitudinal	98.2	1.62	24.65	1.18	0.0176	1.07
San Fernando Trans.	273.0	4.5	71.59	3.43	0.058	3.52
San Fernando Long.	348.0	5.74	111.5	5.33	0.065	3.94

* Ratio of intensity to the intensity of Koyna transverse earthquake.

Comparing other motions with respect to Koyna Transverse, it is seen that intensity I_1 gives maximum values for the ratio and intensity I_3 the minimum.

In the present study, the acceleration amplitudes of all the records are scaled such that the Housner's spectral intensity I_1 is 100 cm.

GROUND MOTION

The overburden soil acts as a filter and modifies the bed rock motion. The absolute acceleration $\overset{\circ\circ}{x}$, at ground level are obtained from

$$-\ddot{x}=\frac{4\pi}{T_s}\zeta_s(\mathring{x}-\mathring{y})+\frac{4\pi^2}{T_s^2}(x-y)$$

where T_s is the period and ζ_s the percentage of critical damping of the soil layer. y is the bed rock motion.

Sixteen ground motions have been generated corresponding to four bed rock motions and four periods of soil layer. Figures 1 (a)—1 (c) show four such ground acceleration versus time records corresponding to modified Koyna Longitudinal at bed rock and soil layer periods of 0.25, 0.30, 0.35 and 0.40 sec and damping ζ_s of 0.20.

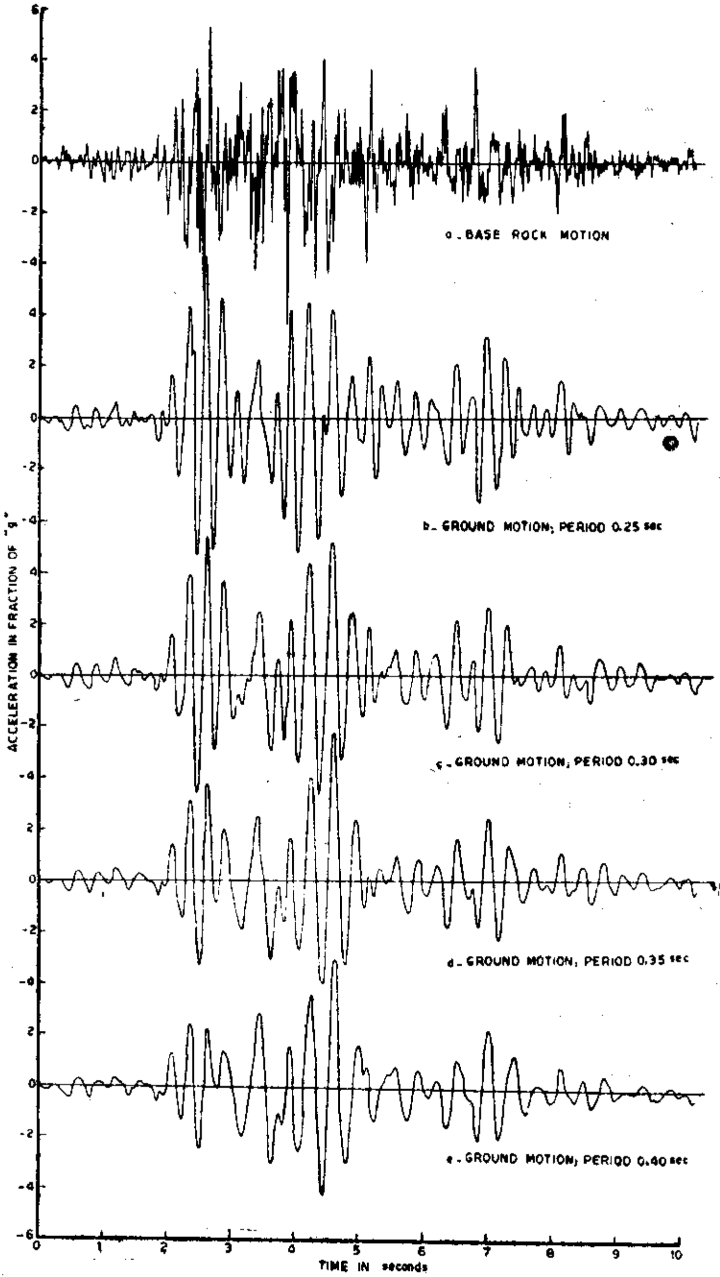

FIGURE - 1

The pertinent data like peak accelerations and number of zero crossings are shown in Tables 2 and 3.

TABLE 2. MAXIMUM ACCELERATION

Earthquake Type	Bed Rock acceleration	Ground motion Period 0.25 sec		Ground motion Period 0·30 sec		Ground motion Period 0.35 sec		Ground motion Period 0.40 sec	
		max^m acc^n	Ratio[1]	max^m acc^n	Ratio[1]	max^m acc^n	Ratio[1]	max^m acc^n	Ratio[1]
Koyna transvese	0.807	0.50	0.62	0.497	0.615	0.540	0.67	0.531	0.65
Koyna Longitudinal	0.645	0.645	1.0	0.555	0.86	0.585	0.905	0.50	0.79
San Fernando Transverse	0.274	0.426	1.55	0.419	1.53	0.422	1.54	0.421	1.53
San Fernando Longitudinal	0.296	0.349	1.27	0.291	1.06	0.342	1.25	0.315	1.28

1 Ratio of peak ground acceleration to the base rock acceleration.

TABLE 3. NUMBER OF ZERO CROSSINGS

Earthquake Type	Bed rock motion	Ground motion period 0.25 sec	Ground motion period 0.3 sec	Ground motion period 0.35 sec	Ground motion period 0.40 sec
Koyna Trans.	17	8.0	7.0	5	3.5
Koyna Long.	17.5	8.5	8.0	7	5.5
San Fernando Trans.	17.0	8.5	7.0	6	4.5
San Fernando Long.	18.0	7.0	6.5	5	3.0

For the same bed rock motion, the peak ground motion is very nearly the same for different periods of soil layer. It may be concluded that the depth of soil layer has no significant effect on the peak ground acceleration. Even though bed rock motions were normalised, the ratio of peak of ground motion acceleration to that of bed rock are different in each case. This indicates the importance of type of motion. In case of Koyna earthquake this amplification is less than unity whereas in San Fernando earthquake it is greater than unity.

The number of zero crossings decrease with an increase of period of soil layer as would be expected due to the filter action. The ratio of maximum spectral acceleration to the maximum ground motion is tabulated in Table 4. It could be seen that as the period of the soil layer increases this ratio also increases.

TABLE 4. RATIO OF MAXIMUM SPECTRAL ACCELERATION TO THE MAXIMUM GROUND ACCELERATION

	Period of soil layer 0.25 sec	Period of soil layer 0.30 sec	Period of soil layer 0.35 sec	Period of soil layer 0.40 sec
Koyna Trans.	3.24	3.14	3.74	4.14
Koyna Long.	3.10	4.00	3.93	4.30
San Fernando Trans.	3.66	3.81	4.27	4.50
San Fernando Long.	3.66	4.95	5.55	5.7

SPECTRA OF GROUND MOTION

Corresponding to 5% damping, acceleration spectrum values for different soil layer period have been obtained for the various derived ground motions and plotted in figures 2(a)–2(d).

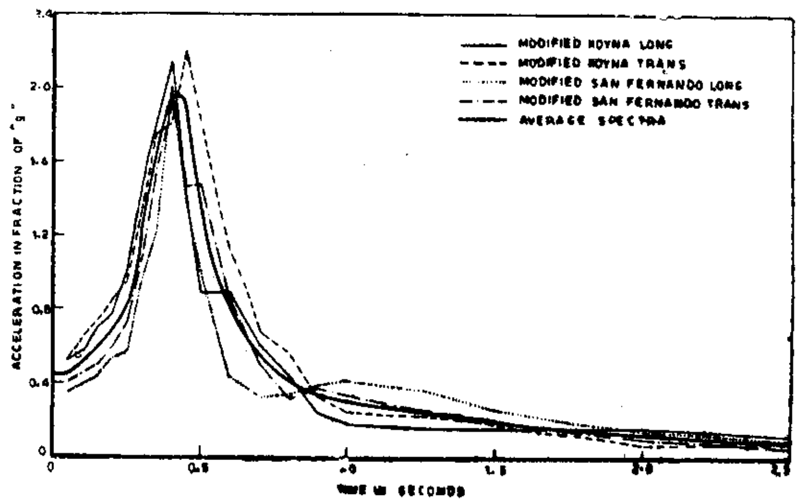

Fig. 2 (a)—Acceleration spectra for soil layer period 0.40 sec.

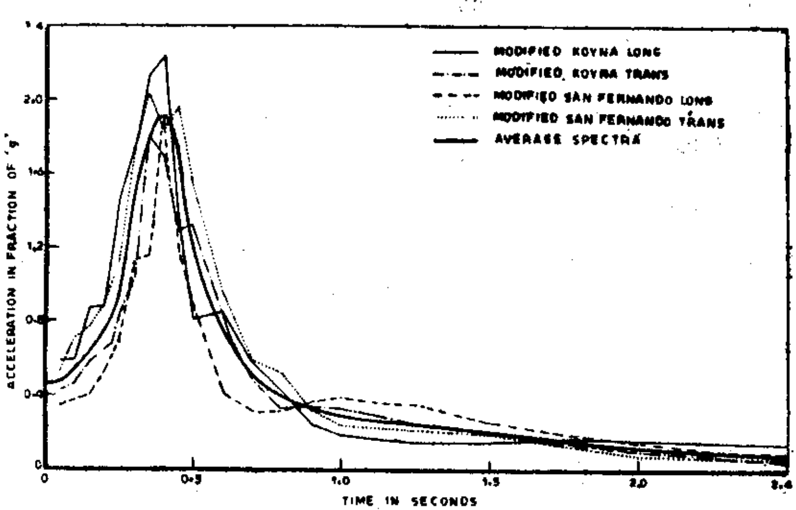

Fig. 2 (b)—Acceleration spectra for soil layer period 0.35 Sec.

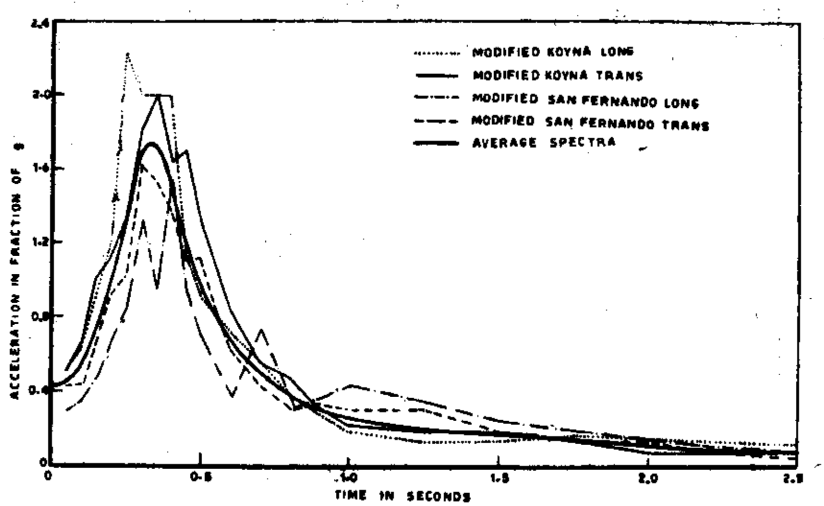

Fig. 2 (c)—Acceleration spectra for soil layer period 0.30 Sec.

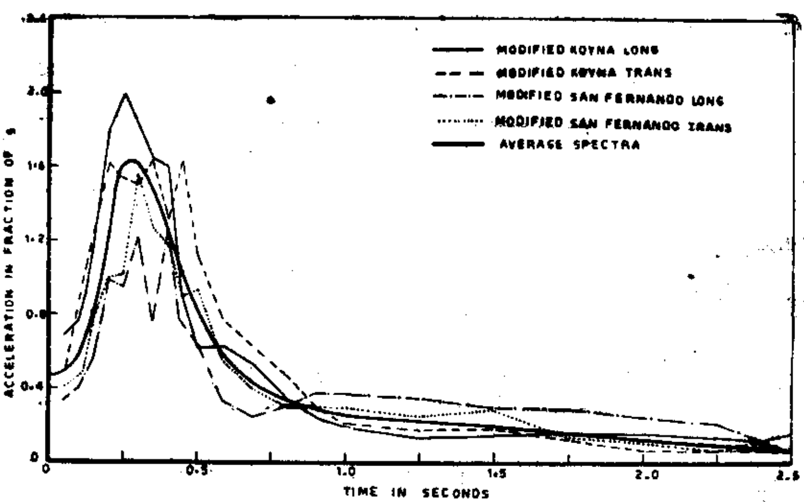

Fig. 2 (d)—Acceleration spectra for soil layer period 0.25 Sec.

It could be seen that the peak of the acceleration spectra nearly correspond to the period of the soil layer as shown in Fig. 3.

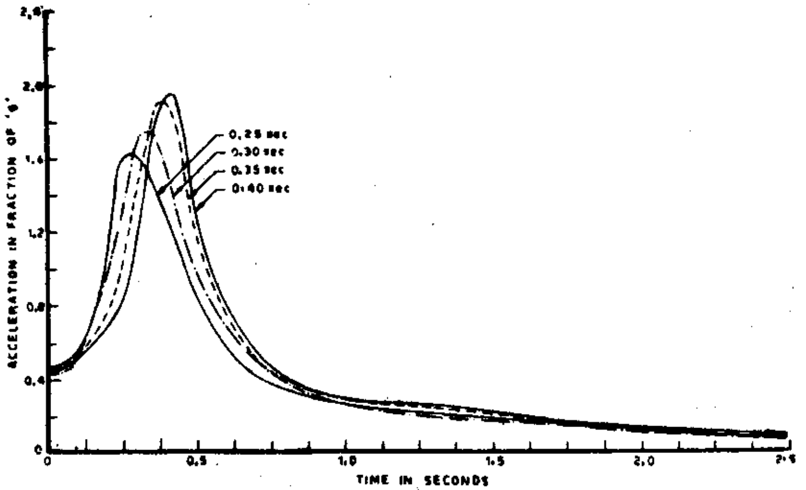

Fig. 3—Average Acceleration spectra corresponding to various filter periods.

A comparison of spectral intensities of ground motion as compared to spectral intensity of bed rock motion could be made from table 5. The spectral intensity generally increases as the period of the soil layer increases.

TABLE 5. SPECTRAL INTENSITY OF GROUND MOTION WITH RESPECT TO BED ROCK MOTION

	Koyna Trans.	Koyna Long.	San Fernando Trans.	San Fernando Long.
Modified bed rock motion	1.00	1.00	1.00	1.00
Mod. Ground Motion Period 0.25 sec	1.28	1.38	1.17	1.24
Mod. Ground Motion Period 0.30 sec	1.36	1.51	1.25	1.27
Mod. Ground Motion Period 0.35 sec	1.44	1.54	1.32	1.32
Mod. Ground Motion Period 0.40 sec	1.51	1.47	1 37	1.37

CONCLUSIONS

The overburden soil over bed-rock very much influences the motion at ground level. The important parameters are soil characteristics and its depth. The soil layer acts as a filter and the number of zero crossings in the ground motion records are generally fewer than that at bed-rock. The spectral intensity of ground motion increases with the period of soil layer. For the range of filter periods considered, the ratio of peak ground acceleration to peak bed rock acceleration remains very nearly the same. However, this ratio is different for the various waveforms assumed at bed-rock. The peak of the acceleration spectrum curve very nearly corresponds to the period of soil layer.

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