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A SHORT NOTE ON INFLUENCE OF LOCAL SOIL ON GROUND MOTIONS AND ON RESPONSE SPECTRUM DURING EARTHQUAKES

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INTRODUCTION

In recent years number of studies have been made and data collected regarding the influence of local soil on ground motions and on response spectrum (Housner, 1959) during earthquakes. Probably, the first qualitative study showing the influence of local soil on the intensity of ground motion and the damage to structures was made by wood (1908) during an earthquake. Kanai et al. (1954, 1959) showed that ground accelerations on poor soil were amplified to a large extent in comparison to the ground motions on adjacent rock exposures. Neumann (1954), Cherry (1969), Ohsaki (1969), Apostel Poceski (1969), Seed (1969), seed and Idriss (1969) and Chandrasekaran and Nandakumaran (1971) had showed that ground motions and, in turn, the damage to structures during earthquake were influenced to a great extent by the local soil conditions. Recently, Agarwal et al. (1972) had studied the influence of the soil on damage to structures during Koyna (1967), Kothagudem (1969) and Broach (1970) earthquakes. Fig. 1 shows the damage occurred during the Koyna (1967) earthquake at different sites.

In order to take into account the effect of local soil condition on the design seismic coefficient it is essential to know the parameters influencing the ground motion quantitatively. On the basis of macroseismic observations Medvedev (1965) had suggested an expression for intensity increment (S) in seismic scale (MM) on soil and it can be expressed as,

$$S = 1.67 \log \frac{V_0 \rho_0}{V_n \rho_n} + e^{-0.04d^2} \qquad \ldots(1)$$

where,

d = depth of ground water in metres

V_n, V_0 = velocity of seismic waves in the local soil and in granite (km/sec)

ρ_n, ρ_0 = density of local soil and of granite (g/cm^3) Madvedev (1965) had also suggested a formula for assessing the seismic intensity increment(s) of a place Y with reference to a place X and it can be expressed as,

$$S = 3 \log \frac{Ay}{Ax} + 6 \log \frac{Tx}{Ty} \qquad \ldots(2)$$

where, Ax and Tx are means of amplitude and period of short microseism (microtremor) at a place X and Ay and Ty are the same at place Y. Kanai et al., (1966) from semi-empirical approach had obtained the following expression for amplification factor G (T):

$$G(T) = 1 + \frac{1}{\sqrt{\left[\frac{1+\alpha}{1-\alpha}\left\{1 - \left(\frac{T}{TG}\right)^2\right\}\right]^2 + \left\{\frac{0.3}{\sqrt{TG}} \cdot \frac{T}{TG}\right\}^2}} \qquad \ldots(3)$$

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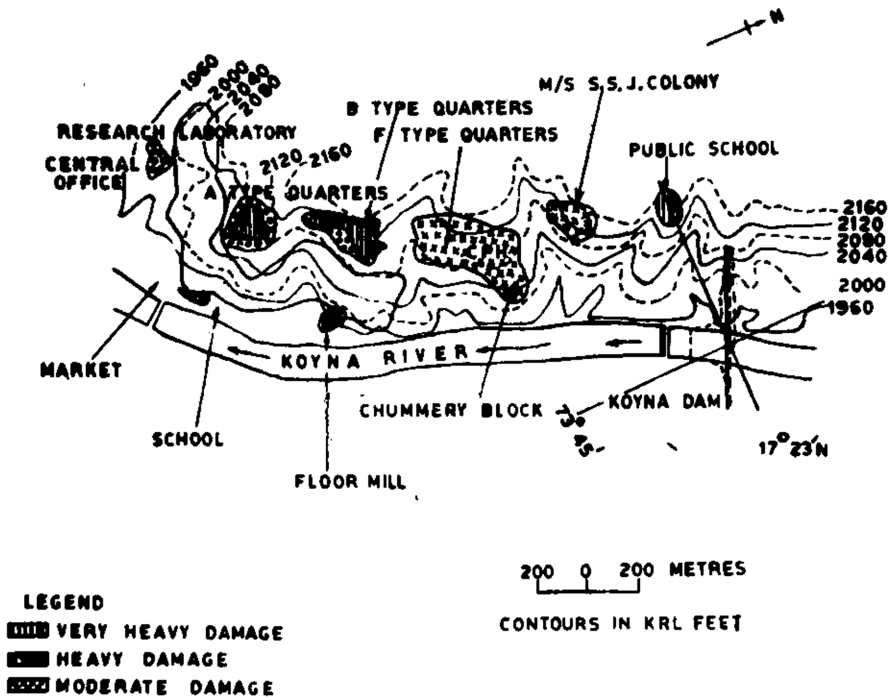


Fig. 1. Koyna-nagar staff colony plan showing damage to residential quarters during Dec. 10, 1967 Koyna earthquake

where,

T = earthwave period

TG = predominant period of the ground

α = impedance ratio of surface layer to lower medium Thus, the soil amplification factor G(T) or intensity increment (S) can be obtained from the above equations, provided, the value of predominant ground period (microtremor) and other variables as mentioned in the equations are known. The predominant period of the site can be estimated by any of the following methods as explained by Agarwal et al. (1972).

(i) MICROTREMOR (Kanai, 1961)

(ii) SHALLOW UNDERGROUND EXPLOSIONS (Yoshikawa et al., 1967 and Agarwal et al., 1972)

(iii) FORCED VIBRATIONS (Guha and Rao, 1959; Yoshikawa et al., 1967 and Apostel Poceski, 1969)

Medvedev (1965) and Kanai (1966) in their approach had probably assumed that the behaviour of local soil would be same when sujected to different levels of vibratory forces which is not borne out by the field observations. From the observations near a dam site during earthquakes of varying magnitudes, Okamoto et al., (1966) showed that the amplification factor depended to a large extent on the magnitude of the earthquakes. As such, the behaviour of soils during microtremers may not give the correct representation of its performance when subjected to strong earthquakes. Due to this lacuna, there is still a great need to obtain the strong motion records under different soil condi-

TABLE I

DETAILS OF ACCELEROGRAPHS, PERIOD OF OPERATION AND FOUNDATION AT DIFFERENT OBSERVATORIES OF KOYNA SEISMOLOGICAL NET

Accelerogaph Station	Latitude	Longitude	Height of Pedestal top above M.S.L (METERS)	Foundation	Accelerograph Type	Period of operation
Koyna dam (Shear zone gallery) K_2	17°23′.85N	73°45′.00E	595	Hard basalt	AR–240 RFT–250	29–3–66 to 22–9–71 24.9.71 onwards
Koyna dam (1A gallery K_1)	17°23′.85N	73°45′.00E	644	Concrete monolith founded on basalt	AR–240 RFT–250	29–3–66 to 22–9–71 24.9.71 onwards
Koyna dam (Top of monolith 17)	17°23′.85N	73°45′.00E	665	Concrete monolith founded on basalt	RFT–250	28–6–72 onwards
Koynanagar K_5	17°23′.85N	100Meters downstream of Koyna dam on right bank	644	Weathered basalt underlain by hard basalt	AR–240 RFT–250	10–9–68 to 22–9–71 24.9.71 onwards
Pophali (Power House)	17°26′N	73°41′E	168	Massive basalt	RFT–250	17.9.71 onwards
Pophali (Inter Adit Point)	17°26′N	73°41′E	365	Massive basalt	RFT–250	17.9.71 onwards
Alore	17°29′N	73°39′E	85	Thick soil layer underlain by weathered basalt and hard basalt successively	RFT–250	27.10.71 onwards
Govalkot	17°32′50N	73°29′43E	—	Hard basalt	AR–240	16.9.71 onwards
Satara	17°40′37N	74°00′00E	650	Hard basalt	AR–240	23.1.72 onwards
Mahabaleshwar	17°55′36N	73°39′55E	1430	Thick Hard lateritic soil under-lain by basalt	AR–240	24.1.72 onwards

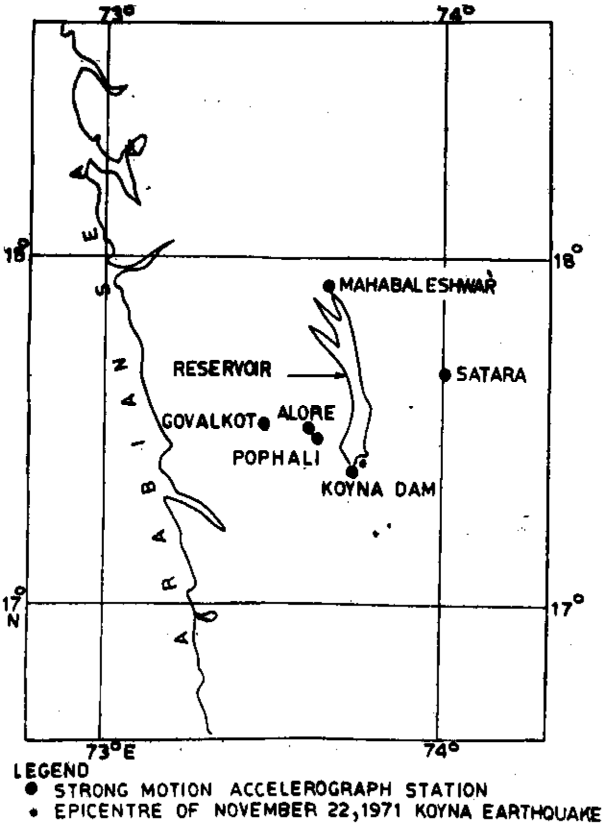
tions during earthquakes which would help in understanding the influence of local soil on the ground motions and on response spectrum during strong earthquakes.

ACCELEROGRAMS FROM KOYNA RESERVOIR SEISMOLOGICAL NET

Soon after impounding the Koyna dam (73°45′E, 17°23′.85N) reservoir in 1962 reports of experience of small earthquakes near the dam site became prevalent. In order to study the seismic activity at Koyna, seismological observatories around the reservoir were established. In addition to the seismographs for recording low magnitude earthquakes, AR—240 type of strong motion accelerographs were also installed in the observatories situated in the Galleries 1A and at shear zone of the Koyna dam. These accelerographs recorded the main shock of December 10, 1967 as well as many other aftershocks. The results of the analyses of the accelerograms as reported by Guha et al. (1970) would be of immense importance for the design of structures, specially, to be located in the epicentral region. Subsequently, in addition to the above accelerographs, additional accelerographs were installed in the observatories at Koynanagar, Pophali, Alore, Govalkot, Satara and Mahabaleshwar. Table I gives the details of the accelerographs, period of operation and soil conditions at different observatories. It can be seen from the Table I that the soil conditions at different observatories are quite different. As such, the accelerograms obtained from these observatories for a particular earthquake would be of great help in studying the influence of local soil on ground motions and on response spectrum. Fig. 2 shows the location of strong motion accelerograph stations.

On November 22, 1971, an earthquake of magnitude 4.2 (Richter Scale) occurred in the Koyna region and was recorded by the accelerographs at Koynanagar, Koyna dam (shear zone gallery) and Alore stations. Fig. 2 also shows the location of epicentre of the November 22, 1971 earthquake. The accelerograms as obtained at the stations at Alore, Koynanagar and at Koyna dam (shear zone gallery) are shown in Fig. 3. It is interesting to note that though the Pophali accelerograph stations were nearer to the epicentre in comparison to the Alore accelerograph station, no accelerogram was obtained at Pophali accelerograph stations, indicating that the accelerations were less than 10 cm/sec^2 at Pophali stations (minimum acceleration required for actuating the accelerograph had been set at 10 cm/sec^2). Low accelerations at Pophali accelerograph stations might have been due to the fact that they are founded on massive basalt and are at about 500 metres below the Koynanagar stations. The influence of depth in reducing the ground motions had been earlier also shown by Agarwal et al. (1972). Further, the accelerograph at Alore Station recorded unduly large accelerations and the duration of accelerogram was also quite long in comparison to the accelerograms at other stations. Very large accelerations at Alore Station and comparatively higher accelerations at Koynanagar Station, respectively in comparison to that the Koyna dam (shear zone gallery) station could be explained, probably, in terms of the amplification of ground motions due the soil conditions at different stations. The maximum accelerations recorded during the above earthquake at Koyna dam (shear zone gallery), Koynanagar and Alore were 10, 22 and 77 cm/sec^2 respectively. The ratio of ground accelerations and in turn the amplification factors for Koynanagar and Alore Stations with respect to the Koyna dam (shear zone gallery) station works out to be 2.2 and 7.7 respectively. Seed and Idriss (1969) from the study of amplification effects during San Francisco 1957, Mexico 1962 and Alaska 1964 earthquakes had obtained amplification factors in the range of 1 to 4. Kanai (1961) had obtained amplification factors of the order of 5 to 6 due to the influence of low velocity surface layers. Similar values were found by Hisada et al. (1965) during Japanese earthquake of March 27, 1963. The values of amplification factor as obtained here are of similar order.

It is well-known that maximum ground accelerations at the structure do not alone determine the damage to the structure. Damage to a structure also depends on the



← **Fig. 2. Shows the strong motion accelerograph stations around the Koyna reservoir, Maharashtra and the epicentre of November 22, 1971 Koyna earthquake**

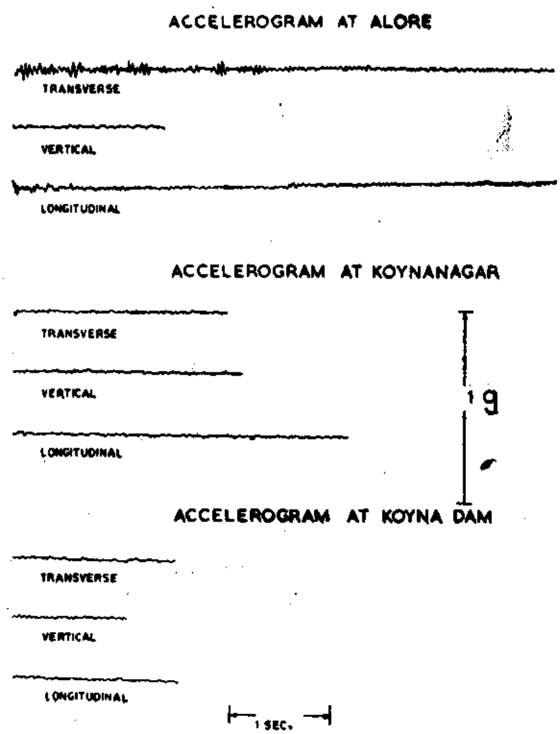


Fig. 3. Accelerograms (RFT-250) obtained at Alore, Koynanagar and at Koynadam (shear zone gallery) showing the effect of different foundations →

frequency characteristics of the ground motions and its duration. Response spectrum as suggested by Housener (1959) probably gives the best combined influence of the amplitude of ground accelerations, their frequency contents and to some extent the duration of ground shaking on the structure. Further, since the stress produced (Sa) in the medium is directly proportional to the particle velocity as shown by following relation (4), the maximum velocity response spectra (SV_{max}) is expected to give better idea about the damaging effect of the ground motion than the maximum acceleration response spectra:

$$Sa = \rho V \frac{dx}{dt} \qquad \ldots(4)$$

where

ρ = density of the medium

V = wave velocity in the medium

$\frac{dx}{dt}$ = particle velocity

An estimate of the maximum dynamic stress in the structure (S_{max}) in general can also be made from the following expression :

$$S_{max} = K \rho V SV_{max} \qquad \ldots(5)$$

where,

K = dimensionless parameter containing mode shape factor and dimension of the structure

With this end in view maximum velocity response spectra were plotted for the accelerograms obtained from the different stations during November, 22, 1971 earthquake for three components and are show in Figs. 4, 5, and 6. Table II shows the ratio of maximum velocity response spectra values (SV_{max}) as obtained for three components for different values of damping from the analyses of above mentioned three accelerograms. It can be seen that the maximum value of the ratio of maximum velocity response spectra values (SV_{max}) is about 4 only. This indicates that through the amplification factor in terms of recorded ground accelerations may be large, the maximum velocity response spectra may not be amplified to that extent which probably decides the damage to any structure. As such, in order to incorporate the influence of local soil on the seismic design coefficient, maximum velocity response spectra values should be considered for evaluation of amplification factor.

CONCLUSIONS

Local soil conditions influence to a great extent the characteristics of ground motions in terms of amplitude, frequency and consquently the response spectra during earthquakes. During the Koyna earthquake of November 22, 1971 the ground accelerations were amplified at Alore site by about 7.7 times compared to that at the Koyna dam (shear zone gallery) site. However, the amplification factor in the above case in terms of maximum velocity response spectra values was about 4 only and this should be preferred while estimating the design seismic coefficient for structures.

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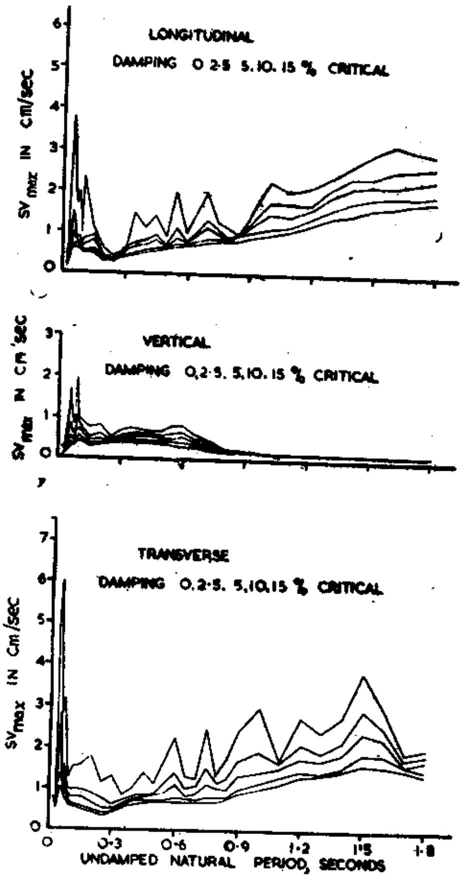

Fig. 4. Velocity response spectra for Koyna earthquake of Nov. 22, 1971 (accelerogram from Alore station)

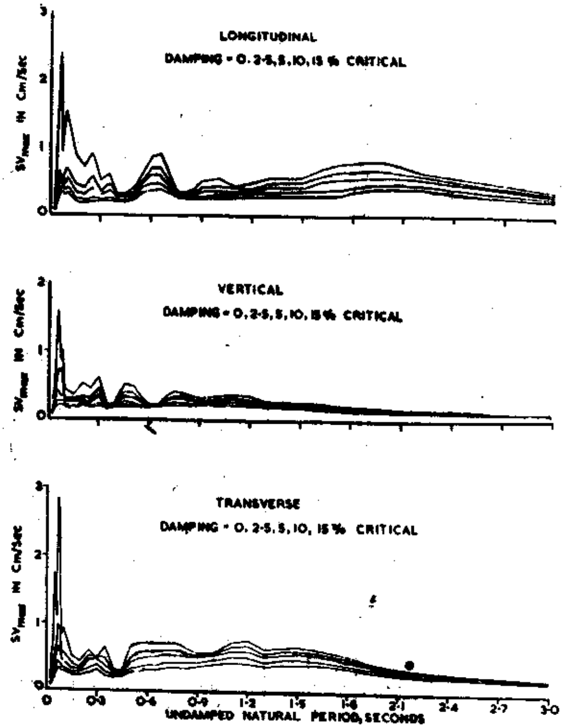

Fig. 5. Velocity response spectra for Koyna earthquake of Nov. 22, 1971 (accelerogram from Koynanagar station)

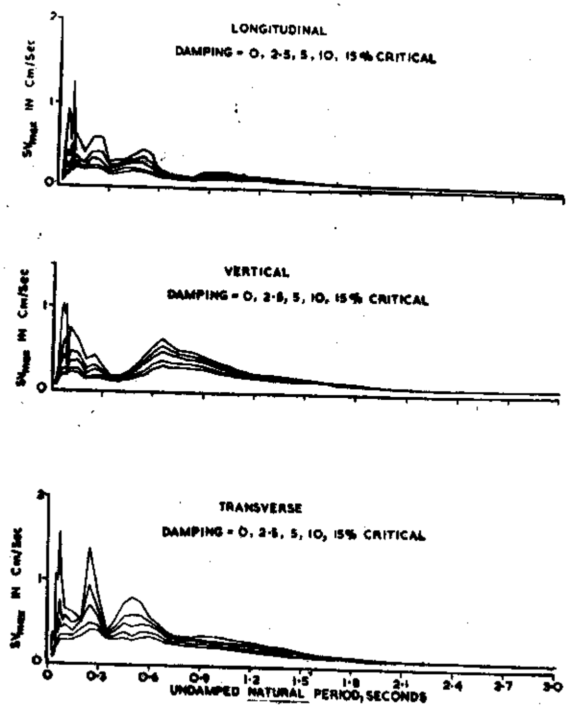

Fig. 6. Velocity response spectra for Koyna earthquake of Nov. 22, 1971 (accelerogram from Koyna dam shear-zone gallery station) →

TABLE II

RATIO OF MAXIMUM VELOCITY RESPONSE SPECTRA VALUES FOR ACCELEROGRAMS FROM DIFFERENT OBSERVATORIES OF KOYNA SEISMOLOGICAL NET

Ratio of Maximum velocity response spectra values for (SV_{max}) for the accelerograms at																	
Koynanagar and Koyna dam for component									Alora and Koyna dam for component								
Longitudinal for damping ratio			Vertical for damping ratio			Transverse for damping ratio			Longitudinal for damping ratio			Vertical for damping ratio			Transverse for daming ratio		
2.5%	5%	10%	2.5%	5%	10%	2.5%	5%	10%	2.5%	5%	10%	2.5%	5%	10%	2.5%	5%	10%
1.28	1.61	1.64	1.01	1.00	1.00	1.28	1.00	1.00	2.96	2.97	3.80	1.60	1.69	2.00	3.68	2.91	2.83

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APPENDIX I—NOTATIONS

Ax = amplitude of short period microseism (microtremor) at a place x
Ay = amplitude of short period microseism (microtremor) at a place y
d = depth of ground water
$G(T)$ = amplification factor
K = dimensionless parameter containing mode shape factor and dimensions of the structure
S = intensity increment
Sa = stress produced in the medium
SV_{max} = maximum velocity response spectrum value
S_{max} = maximum dynamic stress in the structure
T = earthwave period
T_G = predominant period of the ground
Tx = period of short period microseism (microtremor) at a place x
Ty = period of short period microseism (microtremor) at a place y
V = wave velocity in the medium
V_n, V_0 = Velocity of seismic waves in the local soil and in granite
x, y = reference places
ρ = density of the medium
ρ_n, ρ_0 = density of local soil and of granite
α = impedance ratio of surface layer to lower medium
$\frac{dx}{dt}$ = particle velocity