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AN ATTEMPT TO DETERMINE GROUND ACCELERATION DURING KOYNA EARTHQUAKE OF DEC. 10, 1967

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Koyna earthquake of Dec. 10, 1967 of magnitude of about 7·0 (Richter scale) was recorded by an AR-240 accelerograph in 1A gallery of Koyna dam. Various investigators (4, 6) have computed maximum acceleration response spectra, spectrum intensities etc. for the earthquake, assuming that this accelerogram represents true ground acceleration. However, it is of great interest to know the true ground acceleration during this earthquake, specially when it has been recorded almost in its epicentral region. Such an information would be of immense importance to study the nature of seismic forces for aseismic design of structures in the epicentral region of similar earthquakes.

It is well known from many available accelerograms that, at times, the record may be amplified when the accelerograph is situated at high level in the structure. Such 'structural amplification' may also be expected from response studies of accelerograms, specially, if the structure possesses low natural period of vibration and small critical damping as in case of Koyna dam. The acceleration in the structure S'_A at any time t, is given by (1, 2, 3, 5, 7).

$$S'_A = K.S_A \qquad \ldots(1)$$

where $$S_A = \frac{2\pi}{T}\int_0^t a(\tau)\, e^{-\frac{2\pi}{T}\cdot n(t-\tau)} \,.\, \mathrm{Sin}\, \frac{2\pi}{T}(t-\tau)\, d\tau \qquad \ldots(2)$$

T = undamped natural period of the structure

a (τ) = ground acceleration at time τ

n = fraction of critical damping

k = a function of physical properties of the structure, such as mass, rigidity, dimension, and space co-ordinates.

If the accelerograms of Dec. 10, 1967 represents acceleration in the structure S'_A, the apparent way to obtain ground acceleration a (τ) seems to be to solve Eqs. 1 and 2, for known values of K, T and n for the structure (Koyna dam). For obtaining ground acceleration the solution of equation (2) is as follows :

$$S'_A = K \,.\, \frac{2\pi}{T} \,.\, \frac{\Delta t}{3} \sum_{j=0}^{i} c_j\, a_j\, e^{-\frac{2\pi}{T} n\,(i-j)\,\Delta t}\, \mathrm{Sin}\left[\frac{2\pi}{T}\Delta t\,(i-j)\right] \qquad \ldots(3)$$

in which i are even integers 2, 4, 6, 8 and cj are Simpson's constants 1, 4, 2, 4...2, 4, 2, 4, 1. In case, the interval of digitisation is sufficiently small, the solution can be written as follows :

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$$S'_A=K \cdot \frac{2\pi}{T}\left[a_1 \int_0^{t_1} e^{-\frac{2\pi}{T}n(t_1-\tau)} \sin \frac{2\pi}{T} (t_1-\tau)\, d\tau \right.$$

$$\left. + a_2 \int_{t_1}^{t_2} e^{-\frac{2\pi}{T}(t_1-\tau)} \sin \frac{2\pi}{T} (t_2-\tau)\, d\tau + \ldots\ldots \right] \quad \ldots(4)$$

when the ground accelerations a_1, a_2...... are taken to be constants within the small interval of digitisation, $d\tau$. It has been amply verified by extensive numerical computations at this Central Water and Power Research Station, Poona that the response spectrum values (S_A) obtained from equations (3) and (4), and also assuming the variation of a (τ) to be linear within the small interval $d\tau$, are same.

As an example, the following expression (5) can be written from equation (4) :

$$S'_{A1}=K \frac{2\pi}{T} a_1 \int_0^{t_1} e^{-\frac{2\pi}{T} \cdot n\,(t_1-\tau)} \sin \frac{2\pi}{T} (t_1-\tau)\, d\tau \quad \ldots(5)$$

$$S'_{A2}=K \cdot \frac{2\pi}{T}\left[a_1 \int_0^{t_1} e^{-\frac{2\pi}{T}n\,(t_1-\tau)} \sin \frac{2\pi}{T} (t_1-\tau)\, d\tau \right]$$

$$+ a^2 \int_{t_1}^{t_2} e^{-\frac{2\pi}{T}n\,(t_2-\tau)} \sin \frac{2\pi}{T} (t_2-\tau)\, d\tau \quad \ldots(6)$$

and so on.

From equation (5), the ground acceleration a_1, within time t_1 can be obtained, knowing S'_{A1} and ; ground acceleration a_2 within time (t_1 to t_2) can be obtained from equation (6) knowing S'_{A2} and a_1 already computed from equation (5) and so on. Similar computations of ground acceleration can also be done when variation of ground acceleration within time interval $d\tau$ is assumed to be linear or according to equation (3). The results thus obtained by all the three methods are almost identical.

The simultaneously recorded accelerograms, both on the Koyna dam and foundation, during another Koyna earthquake of Oct. 29, 1968 of magnitude 5·2 (Richter Scale) provided an unique opportunity to verify the efficacy of the above procedure. Ground acceleration $a(\tau)$ computed (vide Fig. 1) from the recorded acceleration in the structure S'_A (vide Fig. 2) using Eqs. 1 and 2 could be compared with the corresponding recorded ground acceleration $a(\tau)$ (vide Fig. 1). Conversely, acceleration in the structure S'_A computed (vide Fig. 2) from the recorded ground acceleration $a(\tau)$ (vide Fig. 1) from Eqs. 1 and 2 could also be compared with the corresponding recorded acceleration in the structure S'_A (vide Fig. 2). The values of the physical parameters of the dam viz. k, n and T used in Eqs. 1 and 2 are 0·75, 10% and 0·08 sec respectively. The natural period T and damping n for the monolith of the dam were estimated by resonance method using a variable frequency vibrator on the dam. In the above analysis, it is assumed that the major part of the energy of the dam is obtained in its fundamental mode.

Figure 1 shows close agreement between recorded ground acceleration $a(\tau)$ and $a(\tau)$ computed from the recorded acceleration in the structure S'_A. Fig. 2 also shows that there is a broad agreement between recorded acceleration S'_A and S'_A computed from recorded ground acceleration $a(\tau)$. It is thus seen that the computed and observed accelerations (ground acceleration $a(\tau)$ and acceleration in the structure S'_A) compare favourably in amplitudes and frequency contents. Thus the above analysis and results of simultaneous accelerograms of Oct. 29, 1968 earthquake lends credence to the method of numerical solution of Eqs. 1 and 2 for estimation of ground acceleration $a(\tau)$ from recorded acceleration in the structure S'_A.

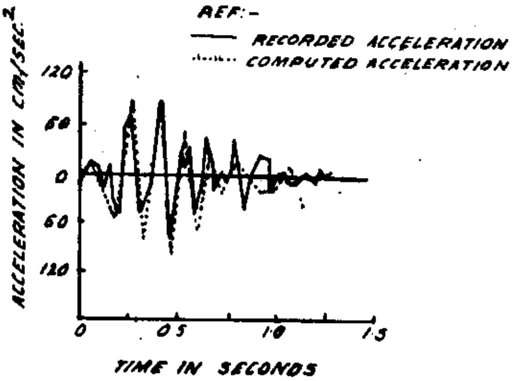

Fig. 1. Shows recorded and computed accelerations, $a(\tau)$, for Oct. 29, 1968 Earthquake.

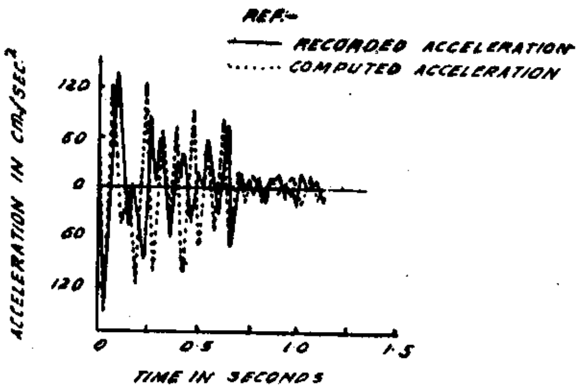

Fig. 2. Shows recorded and computed accelerations in the structure (Koyna Dam) S'_A for Oct. 29, 1968 Earthquake.

Now, applying the above method and using the same values of k, n and T, ground acceleration $a(\tau)$ has been computed from the recorded acceleration in the structure S'_A for Koyna earthquake of Dec. 10, 1967. Fig. 3 gives the recorded acceleration

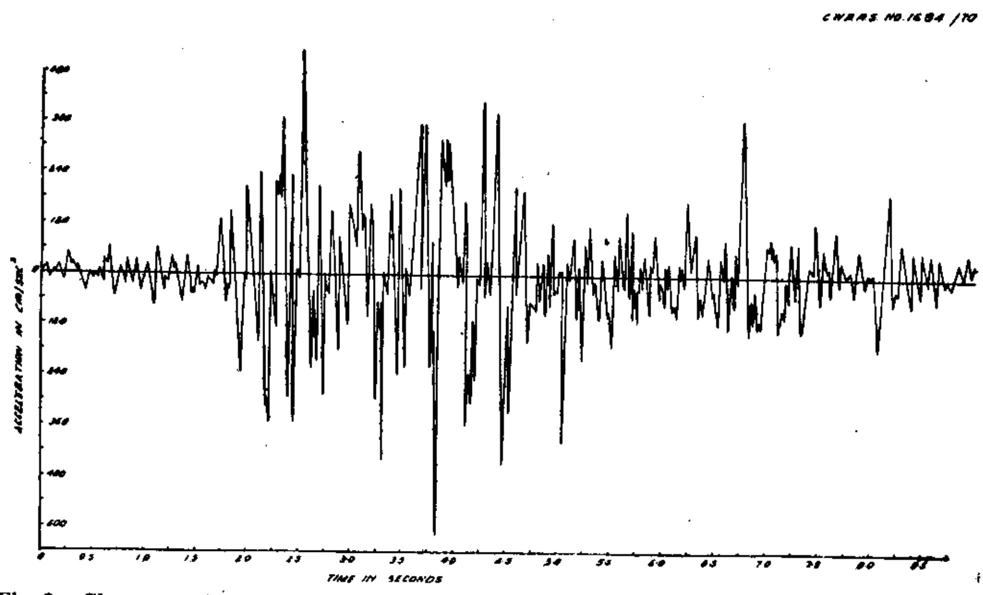

Fig. 3. Shows recorded accelefation in the strueture (Koyna Dam) S'_A for Dec. 10, 1967 Earthquake.

S'_A and Fig. 4 gives computed ground acceleration $a(\tau)$ for this earthquake. It can be broadly inferred from Fig. 3 and 4 that the accelerogram of Dec. 10, 1967 in Fig. 3 has not been unduly influenced by the dam as could have been the case. This conclusion is also broadly corroborated from the fact that an earthquake of magnitude 7·0 should have the order of maximum epicentral ground acceleration as that computed in Fig. 4.

The ground acceleration $a(\tau)$ has been computed in Fig. 4, assuming 10% of critical damping which has been estimated under comparatively small excitation force with a vibrator than that could be available during the large earthquake of Dec. 10, 1967.

It may not be unrealistic to assume that the actual damping in Koyna dam during the earthquake of Dec. 10, 1967 might have been somewhat different than used here —a fact which may influence the solution of Eqs. 1 and 2.

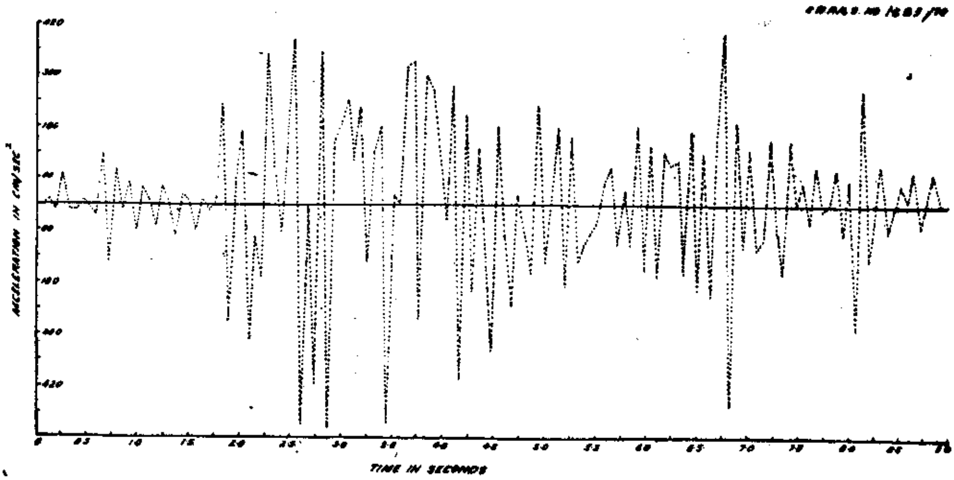

Fig. 4. Shows computed ground acceleration, $a(\tau)$ for Dec. 10, 1967 Earthquake (n=10%)

From the numerical solution of Eqs. 1 and 2, and the results obtained therefrom, it can be broadly concluded that the above procedure can be employed, under certain favourable conditions, to assess the ground acceleration from the corresponding recorded acceleration in the structure.

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REFERENCES

1. Alford, J. L., Housner, G. W., and Martel, R. E., "Spectrum Analyses of Strong Motion Earthquakes", Earthquake Engineering Research Laboratory, California Institute of Technology, Pasadena, California USA, August 1951. (Revised August 1964).

2. Berg, G. V., and Housner, G. W., "Integrated velocity and Displacement of Strong Earthquake Ground Motion", *Bulletin*, Seismological Society of America, Vol. 51, 1961, pp. 175–189.

3. Brady, A. G., "Studies of Response to Earthquake Ground Motion", Earthquake Engineering Research Laboratory, California Institute of Technology, Pasadena, California, U.S.A., 1966.

4. Guha, S. K., Gosavi, P. D., Varma, M. M., Agarwal, S. P., Padale, J. G. and Marwadi, S. C., "Recent Seismic Disturbances in the Shivajisagar Lake Area of the Koyna Hydroelectric Project, Maharashtra, India". Central Water and Power Research Station, Khadakwasla (South), Poona-24, India, Jan., 1970.

5. Housner, G. W., "Behaviour of Structures During Earthquakes", *Journal of the Engineering Mechanics Division*, ASCE, Vol. 85, No. EM 4, Oct., 1959, pp. 109–129.

6. Jai Krishna, Chandrasekaran, A. R., and Saini, S. S., "Analysis of Koyna Accelerogram of December 11, 1967", *Bulletin*, Seismological Society of America, Vol. 59, 1969, pp. 1719–1731.

7. Zeevaert, L., "Strong Ground Motion Recorded During Earthquakes of May, The 11th and 19th, 1962, in Mexico City", *Bulletin* Seismological Society of America, Vol. 54, 1964, pp. 209–231.

APPENDIX–NOTATIONS

$a(\tau)$ = Ground acceleration at time τ.
k = A function of physical properties of the structure, such as mass, rigidity, dimension and space co-ordinates.
n = Fraction of critical damping.
S'_A = Acceleration in the structure.
T = Undamped natural period of the structure.
t = time.