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EVALUATION OF DESIGN SEISMIC COEFFICIENT

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INTRODUCTION

Aseismic design of structures has been a subject of great interest for engineers and seismologists in recent times as more and more instrumental and observational data duing the earthquakes are becoming available in different parts of the world. Normally, the seismic forces are determined from the seismic regionalisation maps based on studies of seismic intensities, ground accelerations etc. during past earthquakes. However, the effects of local geology, depth of the structure below the ground surface (for underground structures) and dynamic characteristics of the structure on the seismic forces thus estimated should also be incorporated in order to obtain the suitable value of design seismic coefficient. Attempts have been made here to discuss a suitable approach to estimate the same in the light of above factors with a few illustrative examples.

LOCAL GEOLOGY

It is well known (7, 8, 18, 19, 22, 23, 24, 27, 28, 29, 31, 32) that the ground motions during earthquakes are influenced to a great extent by the soil conditions. Studies were carried out for assessing the effect of the type of ground on the damage produced to the structures during Koyna (1967), Kothagudem (1969) and Broach (1970) earthquakes. Figs. 1, 2, 3 and 4 show the damage occurred during these earthquakes. It is seen from these figures that the degree of damage varies with the type of ground. Fig. 2 shows that very heavy, heavy and moderate damage to structures has taken place whose foundations rested on deep, moderately deep and thin soil cover underlain by hard strata in case of Koyna earthquake. In case of Kothagudem earthquake, heavy damage along the bank of the river such as at Parnshala etc. were observed which could be attributed to thick cover of alluvial deposits. The effect of two types of foundation rocks (Sedimentaries and Crystallines) on damage to structures is also evident from Fig. 3 for this earthquake. Fig. 4 shows that very heavy damage to structures (resisdential buildings) had occured along the river bank where the soil was moist and slumpy while only moderate damage had occurred to the structures resting on comparatively compact soil during Broach earthquake. Similar studies were also made in Japan (22,23), U.S.A. (10,30) and U.S.S.R. (27) for some of the past earthquakes. Medvedev (27) had suggested seismic intensity increments for the basic catagories of ground from macroseismic data in U.S.S.R. and the same are given in Table I.

AMPLIFICATION FACTOR

The influence of type of ground on ground motions during earthquakes has also been studied here from the analysis of seismograms (Benioff Seismograph, vertical) obtained at Satara (Lat. 17° 40'. 87 N ; Long. 74°0'.00 E), Mahabaleshwar (Lat. 17°55'.36 N, Long. 73°39'.55 E), Ratnagiri (Lat. 16°59'. 44 N; Long. 73°17'.63 E) and Govalkot (Lat.17°32'.50 N; Long. 73°29'.43 E) for several earthquakes in the Koyna region. These observatories are founded on different types of ground which are in close proximity and almost

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* Central Water and Power Research Station, Poona.

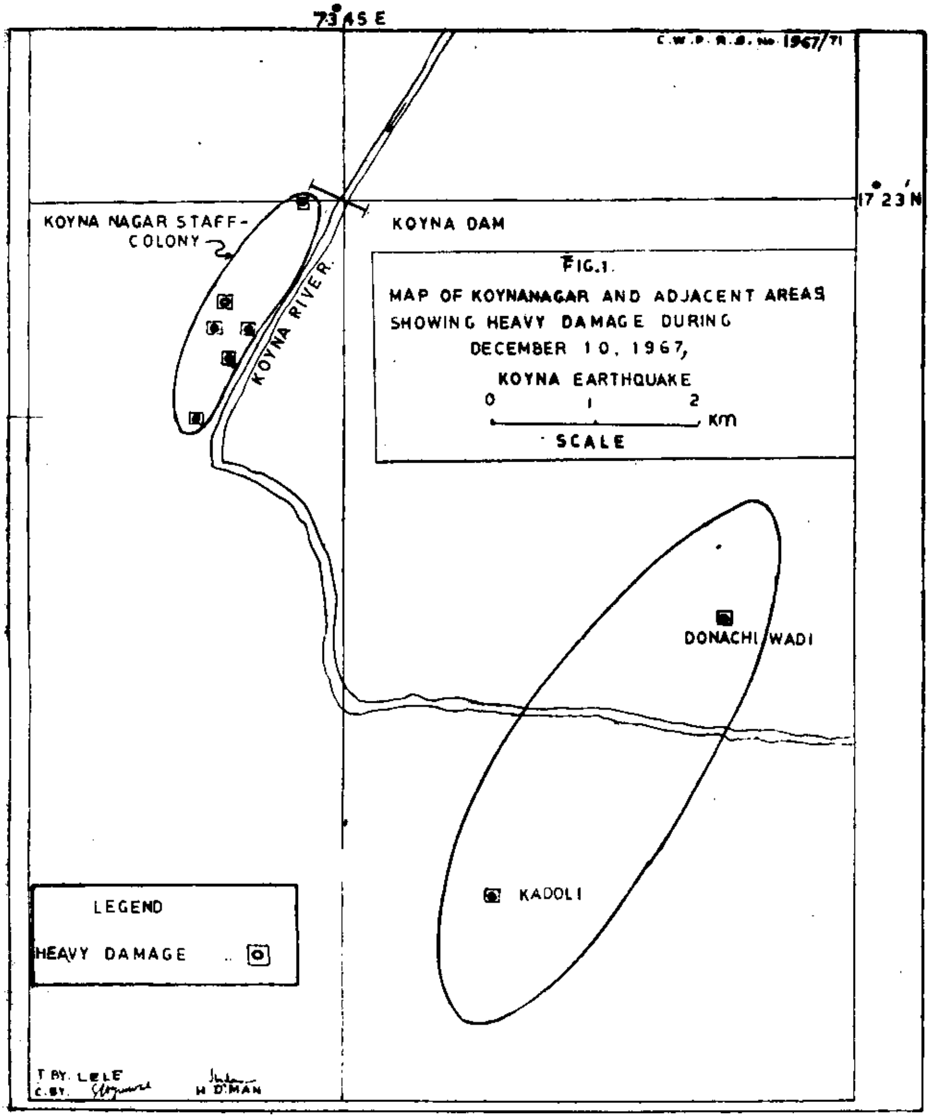

Fig. 1. Map of Koynanagar and Adjacent Areas Showing Heavy Damage During December 10, 1967

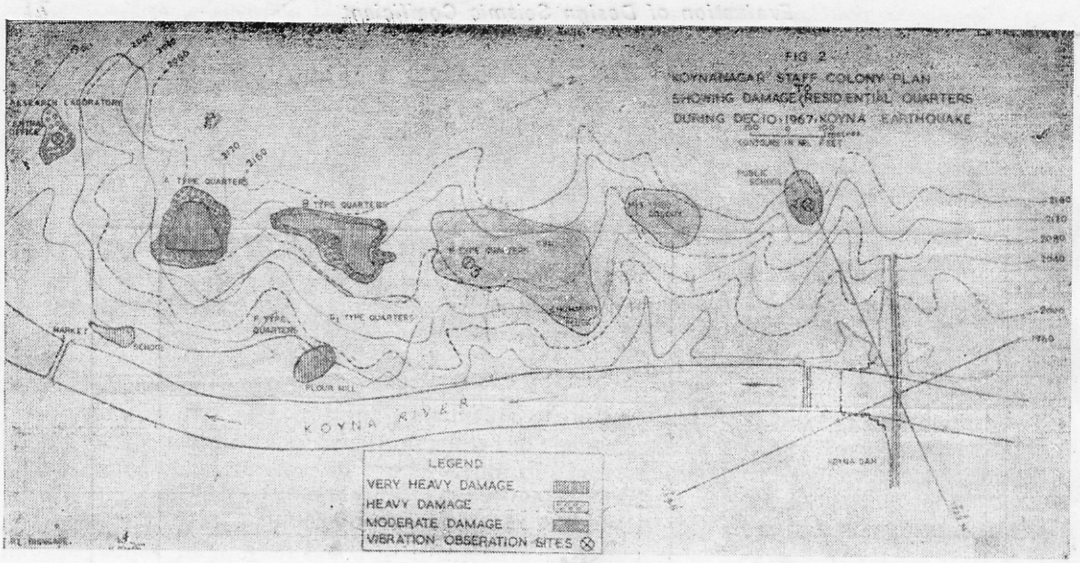

FIG 2
KOYNANAGAR STAFF COLONY PLAN SHOWING DAMAGE TO RESIDENTIAL QUARTERS DURING DEC 10, 1967 KOYNA EARTHQUAKE

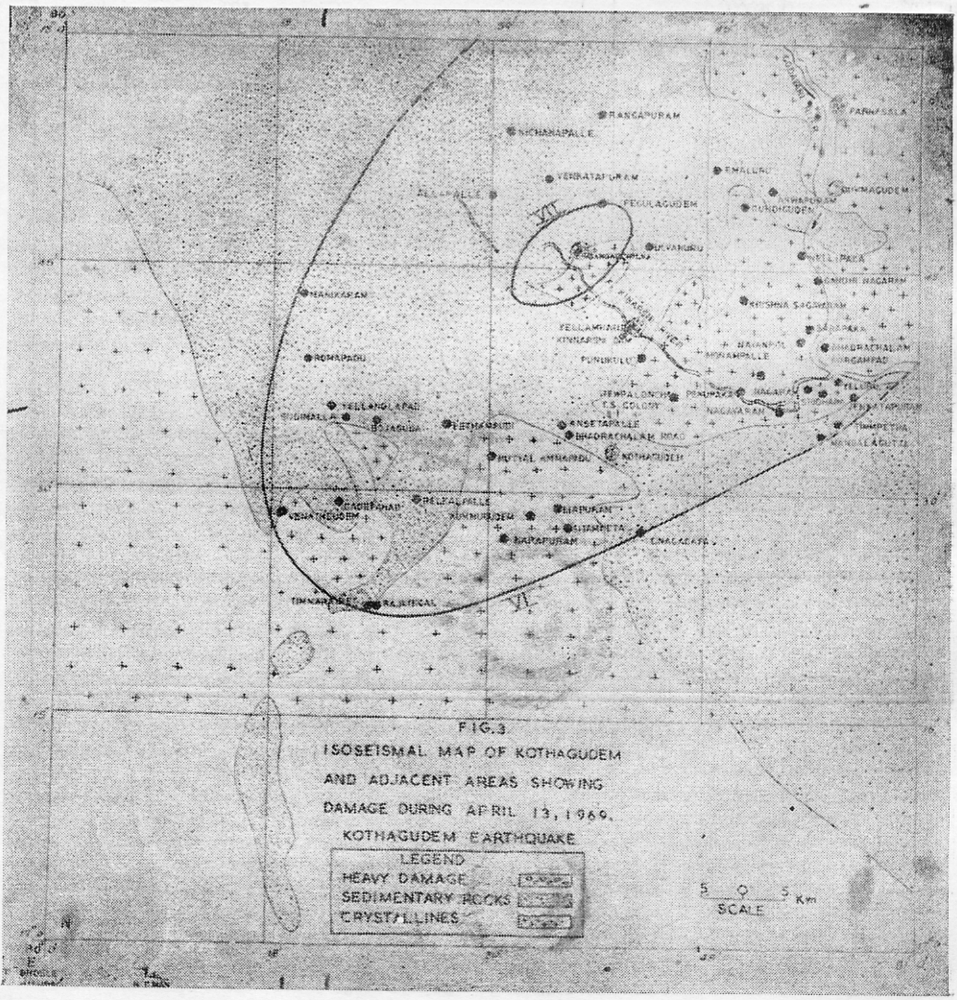

FIG.3
ISOSEISMAL MAP OF KOTHAGUDEM AND ADJACENT AREAS SHOWING DAMAGE DURING APRIL 13, 1969, KOTHAGUDEM EARTHQUAKE

TABLE I
CLASSIFICATION OF SOIL FOUNDATION, ASSOCIATED PREDOMINANT PERIOD OF VIBRATION AND AMPLIFICATION FACTOR

Type of ground	Type of ground according to Kanai (22)	Microtremor period (sec.) according to Kanai (22)	Type of ground according to Medvedev (27)	Seismic intensity increment according to Medvedev (27)	Type of ground as classified for underground explosion data	Amplification factor obtained from Benioff Seismograms	Predominant frequency in cps (period in sec) as obtained from underground explosion records
A	—	—	Granite	0	Compact rock such as basalt, granite etc.	1	Above 50 (0.02 sec)
B	—	—	Limestones & sandstones etc.	0—1	Weathered rock and sedimentary formations etc.	1—2	50—10 (0.02—0.10)
C	*Kind I	0.2—0.6	Moderately firm ground	1	Hard soil, hard sandy gravel bed etc.	2	10—3 (0.10—0.33)
D	Kind II	0.6—1.1	Sandy ground	1—2	Sandy gravel, compact clay and soil etc.	2—3	3—1 (0.33—1.0)
E	Kind III	1.1—1.4	Clayey ground	1—2	Thick alluvium underlain by somewhat harder strata	3	—
F	Kind IV	1.4—1.6	Loose soil	2—3	Deep and loose alluvium, clay, made-up soil etc.	3 and above	—

*Kind I : Rock, hard sandy gravel etc. classified as tertiary or older strata over a considerable area around the structure.

Kind II : Sandy gravel, hard clay, loam etc. classified as diluvial, or gravelly alluvium, about 5 metres or more in thickness over a considerable area around the structure.

Kind III : Alluvium 5 metres or more in thickness which can be distinguished from the ground of Kind II by bluff formation.

Kind IV : Alluvium consisting of soft delta deposits top soil mud or the like of which depth is about 30 metres or more.

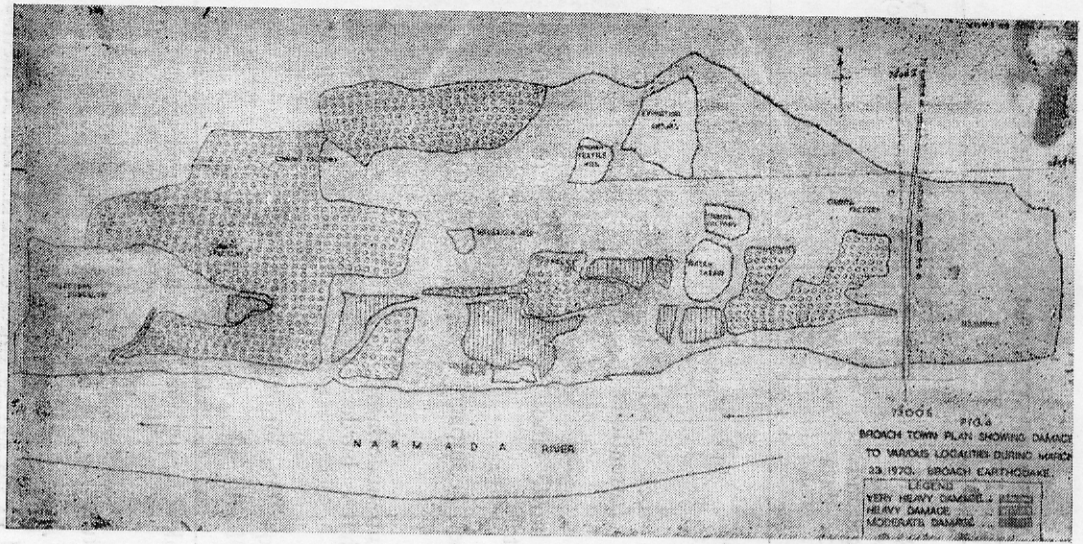

FIG. 4
BROACH TOWN PLAN SHOWING DAMAGE TO VARIOUS LOCALITIES DURING MARC
23, 1970. BROACH EARTHQUAKE.

equidistant from the epicentres of the earthquakes. Table II gives the amplitudes of the seismic waves and their ratios (amplification factor—ratio of seismic wave amplitude at the station to that at a station situated on hard ground like Satara) obtained from the seismograms recorded simultaneously at different observatories. Figs 5(a), 5(b) and 5(c) show seismograms obtained from three of the above mentioned observatories for a particular earthquake (Jan. 30, 1971 vide Table II) This Table shows that the amplification factors for Mahabaleshwar, Ratnagiri and Govalkot are about 1.4, 2.8 and 2.8 respectively. Further, the amplification factors for ground motions as estimated from these studies for different types of ground are given in Table I.

Similar amplification factors for the different types of ground can also be assessed from underground explosion studies. From extensive explosion data (14), the following type of statistical relationship has been obtained for vibration intensity on different types of ground :

$$A = KQ^{m}R^{-n} \quad \ldots\ldots\ldots(1)$$

where,

A = Vibration intensity
K, m & n = Constants
Q = Amount of charge
R = Distance between the explosion and station of observation.

In the above relationship the factor K depends primarily on geology of the site. It is thus possible to estimate the amplification factors with respect to hard rock (type A) from the ratios $\frac{K_B}{K_A}$, $\frac{K_C}{K_A}$ etc. where K_A, K_B and K_C are values of the constant K in Eq. (1) for different types of ground A, B, C etc. (vide Table I) respectively. Actual field measurements (14) suggest that values of $\frac{K_B}{K_A}$, $\frac{K_C}{K_A}$ etc. range between 5 and 10, which

TABLE II

MAXIMUM AMPLITUDES OF SEISMIC WAVES RECORDED SIMULTANEOUSLY AT VARIOUS OBSERVATORIES BY BENIOFF SEISMOGRAPHS DURING SOME OF THE EARTHQUAKES IN KOYNA REGION

Date	Arrival times of seismic waves at Koynanagar (G.M.T.)	Relative maximum amplitude of seismic waves at				Amplification factor			
		Satara (Compact rock, basalt)	Mahabaleshwar (thick hard lateritic soil underlain by basalt)	Ratnagiri (thick alluvial soil layer underlain by basalt)	Govalkot (Thick alluvial soil layer underlain by basalt)	Satara	Mahabaleshwar	Ratnagiri	Govalkot
1	2	3	4	5	6	7	8	9	10
4.5.70	01:13:20.0	51.0	28.1	—	52.6	1	0.5	—	1.0
14.5.70	16:15:40.2	3.6	—	—	4.8	1	—	—	1.3
5.10.70	11:46:0 .0	1.4	—	5.0	4.8	1	—	3.5	3.3
21.12.70	09:24:32.2	4.2	—	—	11.5	1	—	—	2.7
26.1.71	13:37:30.7	6.4	6.0	15.0	19.2	1	0.9	2.3	3.1
30.1.71	14:34:54.3	3.6	7.0	9.0	12.4	1	1.9	2.5	3.4
31.1.71	12:55:53.9	4.0	—	—	11.5	1	—	—	2.9
4.2.71	00:12:06.2	6.4	7.0	—	9.6	1	1.1	—	1.5
18.3.71	16:21:36.2	6.0	—	—	14.3	1	—	—	2.4
20.4.71	22:52:38.8	2.7	7.0	—	20.1	1	2.6	—	7.4
24.4.71	22:56:12.5	10.0	12.3	—	16.3	1	1.2	—	1.6
	Mean value of amplification factor :					1	1.4	2.8	2.8

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* Amplification factor at a station is the ratio of seismic wave amplitude at the station to that at a station situated on hard ground like Satara.

FIG. 5 (a)

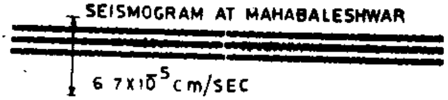

FIG 5 (b)

FIG 5 (c)

SEISMOGRAMS (BENIOFF, VERTICAL) OBTAINED AT SATRRA, MAHABLESHWAR AND AT GOVALKOT SHOWING THE EFFECT OF DIFFERENT FOUNDATIONS

are somewhat higher than the amplification factors obtained from earthquake data. Thus. both earthquake and explosion data confirm accentuation of seismic intensity on loose soils. The above studies show that the total ground conditions considerably influenced the damage to structures during the three earthquakes.

PREDOMINANT PERIOD

According to Kanai (22, 23) the ground can be classified in different kinds depending upon the predominant period (microtremor) of the site. The predominant period of the site can be estimated by any of the following methods :

(i) MICROTREMOR STUDIES

Extensive microtremor studies were made by Kanai (22, 23) for different kinds of ground in Japan and the same has been classified in four groups depending on its predominant period as shown in fig. 6.

Fig. 7 shows four representative records of microtremors as obtained by Kanai at four kinds of ground.

(ii) SHALLOW EXPLOSION METHOD

The average value of period of seismic waves recorded with the help of suitable seismographs during shallow underground explosions can also be used to estimate the predominant period of the site. Fig. 7 also shows four seismic records obtained during underground explosions at four different sites. The order of the charges and the obser-

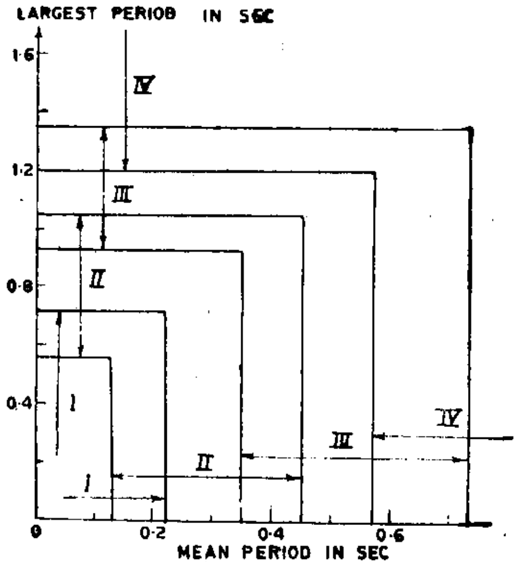

Fig. 6. Showing the Classification of the Ground by Microtremor Measurement

vational distances for the underground explosions for all the sites was similar. The predominant periods of the ground obtained by microtremor studies in Japan and underground explosions mentioned here are given in Table I. It can be seen from this Table that the predominant periods of the C and D types of ground obtained by two different methods are similar. Unfortunately, microtremor data are not available for A and B types of ground, and underground explosion records are not available for E and F types of ground. However, it can be said from Table I that the predominant periods estimated from underground explosions can also be used as an index to classify the types of ground.

(iii) FORCED VIBRATION

The frequency response curve obtained by exciting thin surface layers at any site into forced vibrations with the help of suitable vibrator can be used to assess the predominant period of the site. Such studies were carried out at Koynanagar after the Koyna earthquake of Dec. 10, 1967 to co-relate the damage to structures with the type of ground at their foundation sites. Use of an electrodynamic vibrator capable of producing maximum thrust of about 140 lbs was made for vibrating the surface layers at various sites. The forced vibrations were picked up by electrodynamic pick-ups and were recorded by an oscillograph. The frequency response curves thus obtained at three sites (Fig.2) are given in Fig.8(a), 8(b) and 8(c) and the results are given in Table III. It can be observed from Table III that the predominant frequency of the site increases as the ground becomes harder and the extent of damage decreases with increase in predominant frequency of the ground. Similar results were obtained by Kanai in Japan from the microtremor studies (22, 23).

It can thus be reasonably anticipated from above studies that the predominant period of a site estimated by any of the three methods is of similar order, i.e. any of these methods can be suitably used to study the influence of type of ground on ground motions. Table I gives the classification ground which could possibly be made on the basis of predominant

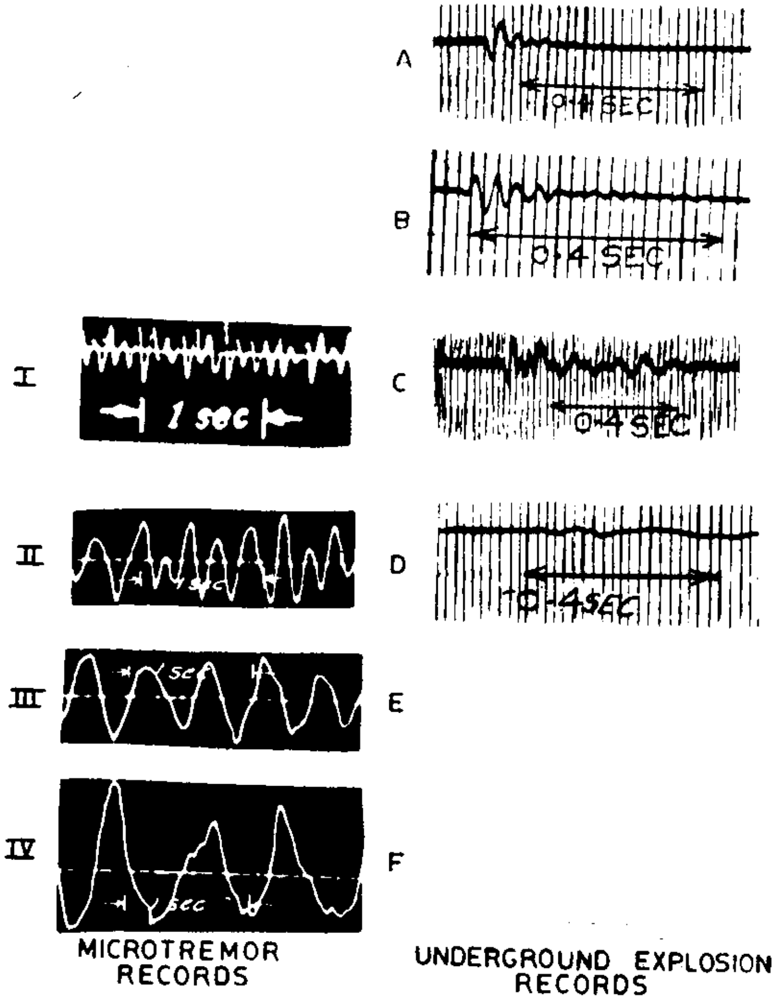

Fig. 7. Showing the Representative Microtremor and Underground Explosion Records

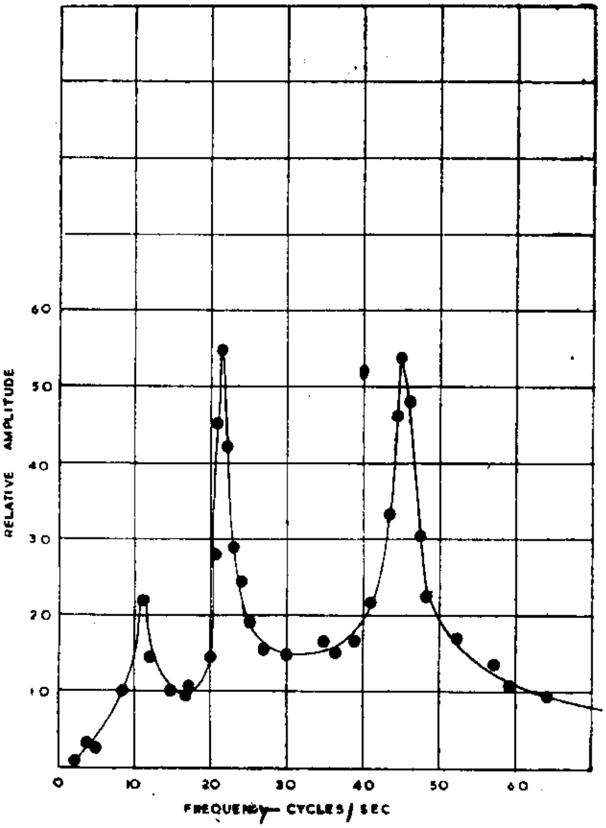

Fig. 8 (a) Shows the Frequency Response Curve at Site 1

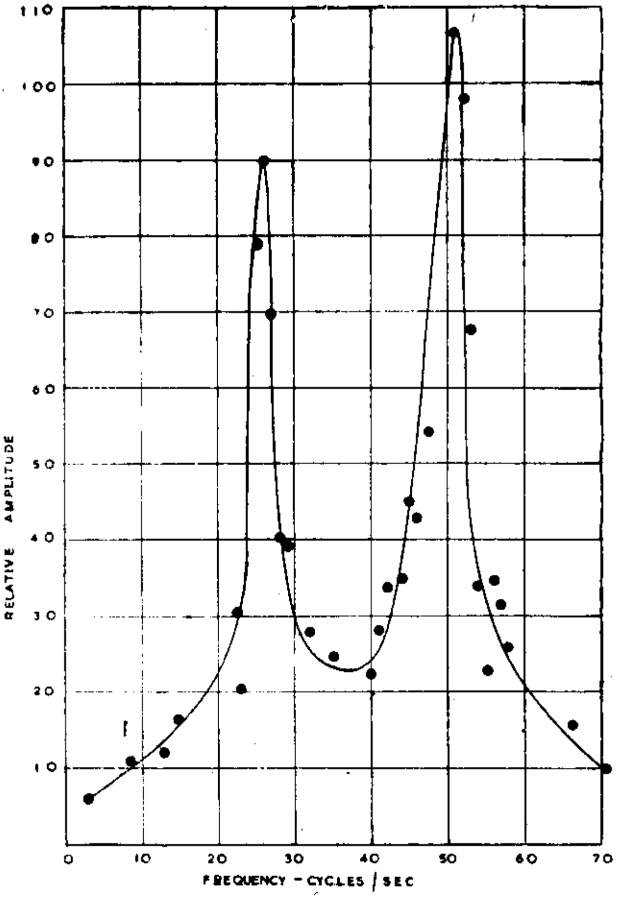

Fig. 8 (b) Shows the Frequency Response Curve at Site 2

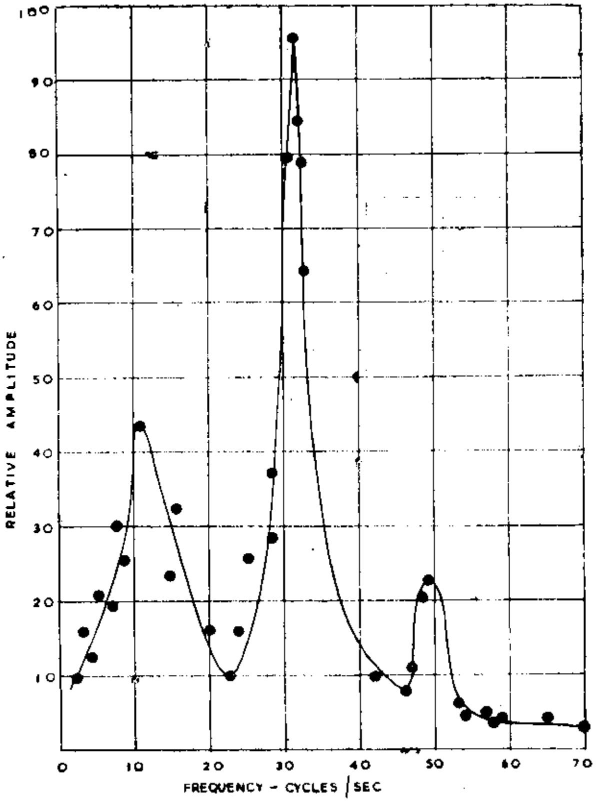

Fig. 8 (c) Shows the Frequency Response Curve at Site 3

TABLE III

RESULTS OF VIBRATION STUDIES AND EARTHQUAKE DAMAGE AT KOYNANAGAR DURING DECEMER 10, 1967 EARTHQUAKE.

Site No.	Frequency response curve vide Fig. No.	Predominant* frequency in cps	Type of ground	Damage
1.	8 (a)	22	Compact soil cover underlain by hard strata	Very heavy
2.	8 (b)	26	Compact soil cover underlain by hard strata	Heavy
3.	8 (c)	32	Thin compact soil cover . underlain by hard strata	Moderate

* Predominant frequency is the frequency at which the response is maximum during forced vibration.

periods, seismic intensity increments and amplification factors of ground motions. This classification can be reasonably utilised to assess the ground accelerations during earthquakes taking into account the influence of the type of ground.

The predominant period of the site can also be obtained by treating the problem as propagation of progressive waves in the layered earth. Perhaps, the predominant period could also be obtained through surface wave dispersion analysis corresponding to the lowest value of the group velocity. In case of simple stratification i.e. soft thin layer underlain by high elastic layer, the predominant period is approximately given by $4H/V_1$ where H=thickness of the surface layer, V_1=velocity of shear waves in the surface layer. Extensive measurements of microtremors confirm the validity of this simple relationship (22, 23).

The predominant period T_G of the ground, estimated by any of the above methods, can be reasonably utilised to estimate the maximum acceleratoion (a_{max}) of earthquake motions at the ground by the following equation (23) :

$$a_{max}=\frac{1}{T}\times 10^{0.61\,M-P\log x+W}\left[1+\frac{1}{\sqrt{\left[\frac{1+\alpha}{1-\alpha}\left\{1-\frac{T}{T_G}\right\}\right]^2+\left(\frac{0.3}{\sqrt{T_G}}\cdot\frac{T}{T_G}\right)^2}}\right] \qquad \ldots(2)$$

where,

T = earth wave period

M = magnitude of the earthquake in Richter Scale

$P = 1.66+\frac{3.60}{x}$

$W = 0.167-\frac{1.83}{x}$

x = hypocentral distance

α = impedance ratio of surface layer to lower medium.

UNDERGROUND STRUCTURE

The effect of the depth on the intensity of seismic forces for underground structures can be assessed from analysis of surface waves (3, 6) or multiple reflection of elastic waves in a superficial layer (20, 21). These methods have been briefly described in Appendix I and utilised for estimating the probable seismic forces at the underground Power House at Pophali (Koyna Hydroelectric Project, Maharashtra). The results show that the seismic intensity at the underground Power House at Pophali would be about half of that at surface. It can be broadly said from these studies that the seismic forces for underground structures situated at a depth of about a wavelength or more below the ground surface are about half of that at the surface, and approximately equal for structures situated at depths within a wavelength.

DYNAMIC CHARACTERISTICS OF THE STRUCTURES

The above studies show that the influence of local geological conditions and depth below the grond surface for underground structures can be incorporated for estimating the seismic forces from the seismic regionalisation map (11, 35). It is the normal practice to reduce the ground accelerations thus estimated to about half to one-fourth to obtain the value of design seismic coefficient for usual structures. The design seismic coefficient can be more realistically obtained from the response spectrum analysis (utilising the dynamic characteristics of the structure) of suitable accelerogram corresponding to the seismic intensities (ground accelerations) as estimated from the regionalisation map (11, 35) and subsequently correcting the same for effects of local geology and depth of the structure below the ground surface. However, there are very few accelerograms available in the world like those of El Centro (1940), Taft (1952,) San Francisco (1957), Koyna (1967) and San Fernando (1971), etc. which could be used for design purposes (2, 4, 5, 13, 33, 34, 36). Housner (17) has suggested average response spectrum curves based on the spectrum analysis of limited number of earthquakes in the past which could be utilised by designers. Fortunately, now large number of accelerograms have been recorded in the epicentral region of Koyna earthquakes of magnitudes upto 7.0 which would be of immense importance for aseismic design of structures specially those situated close to epicentres. The details and analysis for these accelerograms can be found elsewhere (1,9,12,13,15,16, 25). The average spectra computed for Koyna earthquakes (having recorded maximum accelerations more than 2.5% g) of magnitudes between 4.0 and 4.9, and 5.0 and 5.7 are given in Figs. 9(a) and 9(b). These average acceleration response curves can be conveniently utilised for aseismic design of structures if their natural periods and damping coefficients are known. The natural periods and damping coefficients for the structures can be estimated by forced vibration tests as reported for a few dams earlier (26). It may be mentioned here that the average response curves obtained for Koyna region are somewhat similar to those of Housner (17) except that the response accelerations are large for low periods and diminish rapidly at higher periods in case of Koyna earthquakes. This may be mainly due to the fact that these earthquakes have been recorded in their epicentral region. Response curves of similar nature

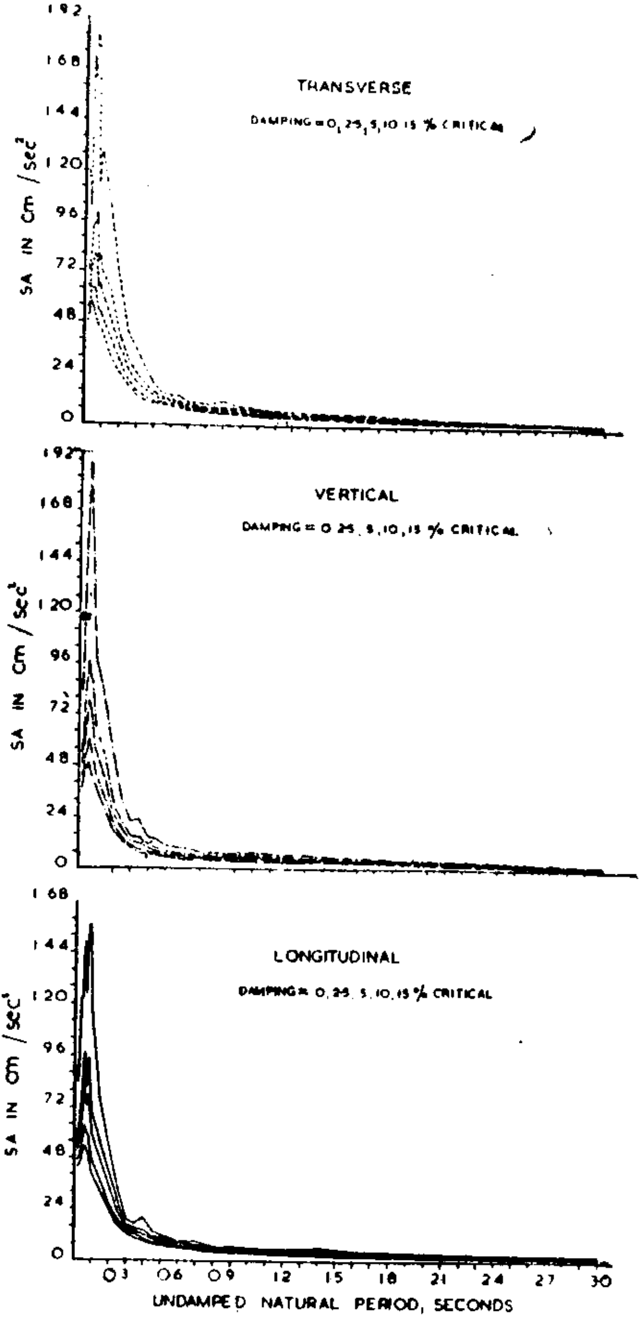

Fig. 9 a Average Acceleration Response Spectra for Koyna Earthquakes of Magnitudes Between 4.0 and 4.9

have also been obtained for a recent earthquake of San Fernando recorded almost in its epicentral region (33, 34).

In the light of above discussions, engineering seismological studies were made to estimate the design seismic coefficient for Pandoh dam in Himachal Pradesh (Appendix II) and a value of 0.15 g has been recommended. Table IV gives the design seismic coefficients adopted for some of the dams in India. It can be observed from this Table that the design seismic coefficients of about 0.25 g, 0.15 g and 0.10 g or less have been adopted in India for structures like dams situated in very active, active and less active seismic zones respectively. Also, a survey of design seismic coefficients in different countries such as in Japan, U.S.A. and Canada, etc. shows that the values of about 0.15 g, 0.10 g and 0.10 g to 0.05 g are used for similar structures situated in very active, active and less active seismic zones respectively. Thus, in view of the above prevalent practice for a seismic design of structures like dams all over the world the value of 0.15 g recommended for Pandoh dam is consistent with the seismicity of the area.

ACKNOWLEDGEMENTS

The writers record with great appreciation the encouragement received from the Director and Joint Director of the Central Water and Power Research Station, Poona, during the preparation of this paper.

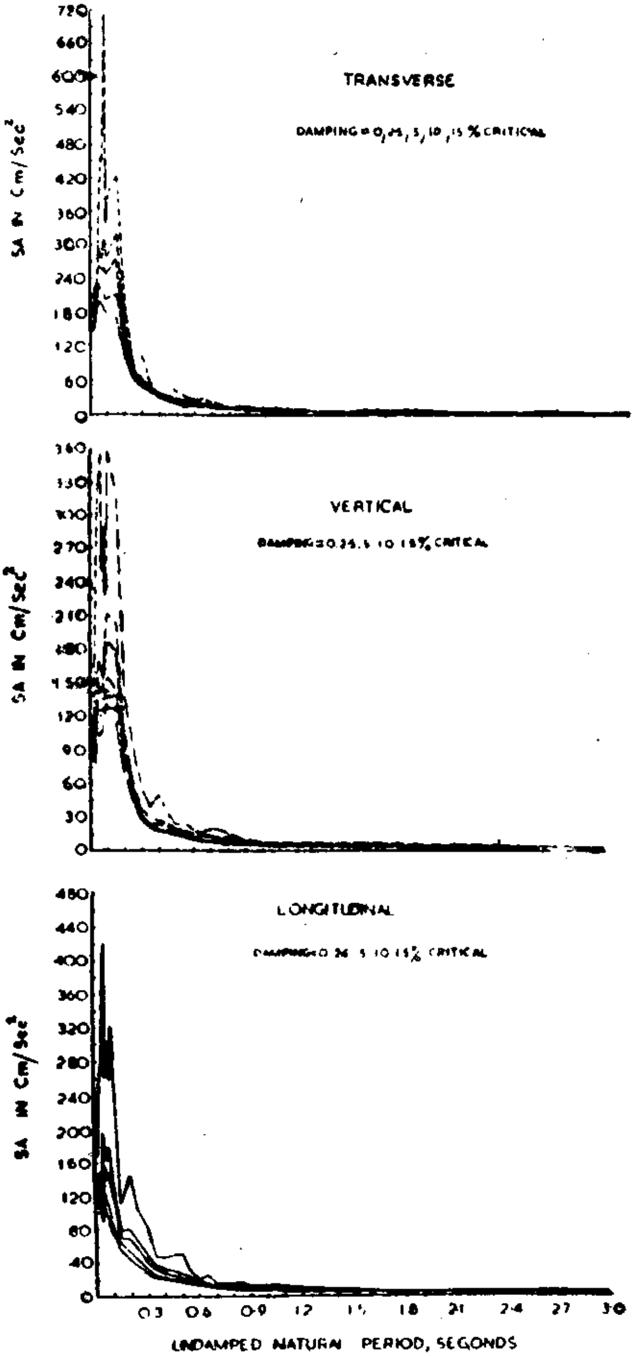

Fig. 9 b Average Acceleration Response Spectra for Koyna Earthquakes of Magnitudes Between 5.0 and 5.7

TABLE IV
DESIGN SEISMIC COEFFICIENTS ACTUALLY USED FOR SOME DAMS IN INDIA

Name of the dam	State	Type of dam	Height (metres)	General geology of foundation	Design seismic coefficient	Remarks
1	2	3	4	5	6	7
Umiam Barapani	Assam	Concrete, gravity	78.0	Gneisses and Schists	0.25g	
Jaldhaka	West Bengal	Concrete, barrage		Gneisses (Damuda series)	0.15g (horizontal) 0.10g (vertical)	
Bhakra	Himachal Pradesh	Concrete, gravity	226.0	Sandstone	0.15g (horizontal) 0.10g (vertical)	
Idikki	Kerala	Non-overflow double curvature arch, concrete	170.7	Charnokites (Granite)	0.10g	
Cherutheni	Kerala	Concrete, gravity	135.6	Gneisses and Schists	0.05g	
Koyna	Maharashtra	Rubble concrete, gravity	85.3	Basalt	0.05g*	
Rana Pratap Sagar	Rajasthan	Masonry, gravity	54.0	Sandstone	Nil	
Sholayar	Kerala	Masonry, gravity	65.9	Granite	0.05g	
Kulamavu	Kerala	Masonry, gravity	71.6	Gneisses	0.05g	
Pandoh	Himachal Pradesh	Rock-fill, gravity	60.9	Quartzites, slates and Phyllites	0.15g	
Pong	Punjab	Earth core cum gravel, gravity	115.8	Sandstone	0.15g	

1	2	3	4	5	6	7
Ram Ganga	Uttar Pradesh	Composite earth and boulder fill, Masonry, gravity	125.6	Sandstone	0.12g	
Ukai	Gujrat	Composite earth masonry, gravity	68.5	Basalt	0.05g**	
Tenughat	Bihar	Composite earth, concrete, gravity	50 6	Gneisses and Schists for spillway structure, predominantly, sandy formation for earth dam portion.	0.10g	
Tawa	Madhya Pradesh	Composite earth, masonry, gravity	57.9	Sandstone	0.05g	Designed for 0.05 g and checked for 0.07 g
Balimela	Orissa	Composite earth, masonry, gravity	70.1	Gneisses and Schists	0.05g	

* Strengthened after Koyna earthquake of December 10, 1967 for 0.15 g.

** Strengthened after Broach earthquake of March 23, 1970 for 0.15 g.

The above seismic coefficients have been supplied by the Design Directorates of Central Water and Power Commission, New Delhi and the respective Project Authorities.

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APPENDIX—I

EFFECT OF DEPTH ON SEISMIC FORCES

It is well-known that seismic forces decrease with increase in depth, but the exact rate of decrease of these seismic forces with respect to depth is a complex function of various parameters such as seismic spectrum, physical properties of the ground and the number of superficial layers in ground. Basic principle involving the computation of this decrease in seismic forces with depth consists of estimation of decrease in surface wave amplitude with respect to depth from analysis of surface waves (3, 6) or from multiple reflection theory (20, 21). The variation of amplitude of siesmic surface waves (U), with depth for non-dispersive uniform medium can be estimated from the following equation :

$$U = a\left[\exp\left(0.85\frac{2\pi d}{V_2 T}\right) - 0.58\exp\left(0.39\frac{2\pi d}{V_2 T}\right)\right] \qquad \ldots(3)$$

By utilising the following values of various parameters for the Pophali power House (Maharashtra) in the above equation, the amplitude of seismic waves at the Pophali underground Power House has been estimated at about half of the amplitude at surface :

a = constant
d = depth below the surface ($\simeq$244 metres)
T = earth wave period (0.1 sec)
V_2 = shear wave velocity in the medium (2.14 km/sec)

In Kanai's method of multiple reflection of elastic waves in single superficial layer, the ratio of the amplitudes at the free surface (U) and that of the incident waves (U_O) is given by :

$$\left|\frac{U}{U_O}\right| = \frac{2}{\sqrt{\phi_1^2 + \phi_2^2}} \qquad \ldots(4)$$

where,

$$\phi_1 = \cos E \cos hF + \alpha(L \cos E \sin hF - S \sin E \cos hF)$$

$$\phi_2 = \sin E \sin hF + \alpha(L \sin E \cos hF + S \cos E \sin hF)$$

$$E = \frac{\pi T_G}{2T} I \cos (J)$$

$$F = \frac{\pi T_G}{2T} I \sin (J)$$

$$L = I \left\{ \cos (J) + \frac{Z}{T} \sin (J) \right\}$$

$$S = I \left\{ \frac{Z}{T} \cos (J) - \sin J \right\}$$

$$\alpha = \frac{V_1 \rho_1}{V_2 \rho_2}, \; T_G = \frac{4H}{V_1}$$

$$I = \left\{ 1 + \left(\frac{Z}{T} \right)^2 \right\}^{-1/4}$$

$$J = \frac{1}{2} \tan^{-1} \left(\frac{Z}{T} \right)$$

$$Z = \frac{2\pi \xi_1}{\mu_1}$$

Following values of various parameters involved in the above computations had been assumed for assessing the ratio of amplitude of seismic waves at the free surface to the amplitude at the underground Power House and comes out to be about 1.8.

Velocity of the shear waves	(V_1)	=	0.61 km/sec	(Overburden, surfacel ayer)
Density	(P_1)	=	2.2 gm/cc	
Viscous coefficient	(ξ_1)	=	5×10^6 C.G.S. Units	
Velocity of the shear waves	(V_2)	=	2.14 km/sec	(underground layer, compact rock)
Density	(P_2)	=	2.8 gm/cc	
Earthwave period	(T)	=	0.1 sec	
Predominant period of the ground	(T_G)	=	0.05 sec	

It is interesting to observe that the seismic amplitudes at the Pophali Power House were about half of those at surface obtained from the analysis of surface waves (Eq. 3) as well as from principles of multiple reflection (Eq. 4).

The results obtained in the present analysis are also corroborated from the following facts.

(i) During Dec. 10, 1967 Koyna earthquake, the observed seismic intensity at the surface above the power house (isoseismal map) was VII($\sim$70 cm/sec²) and at the underground Power House was more than V ($\sim$30 cm/sec²) in M.M Scale. The ratio of accelerations corresponding to these intensity scales is about 2.3 while the calculated value is 1.8.

(ii) The amplitudes of seismic waves for several earthquakes recorded simultaneously by Wood Anderson Seismographs installed at Koyna and Pophali underground Power House are given in Table V. It is seen from this Table that the average amplitude of seismic waves at Pophali Power House is about half of that at Koyna. Figs. 10(a) and 10(b) show the typical records obtained simultaneously from Wood Anderson Seismographs installed at Koyna and underground Power House at Pophali for an earthquake (April 14, 1971 —vide Table V).

TABLE V

MAXIMUM AMPLITUDE OF SEISMIC WAVES RECORDED SIMULTANEOUSLY AT KOYNANAGAR AND POPHALI UNDERGROUND POWER HOUSE BY WOOD ANDERSON SEISMOGRAPHS (HORIZONTAL COMPONENT) DURING SOME OF THE EARTHQUAKES IN KOYNA REGION

Date	Time (G.M.T.) of arrival of seismic waves at Koynanagar	Maximum amplitude of seismic waves in the sismogram at Koynanagar A_1 (m. m.)	Maximum amplitude of seismic waves in the seismogram at Pophali A_2 (m. m.)	Magnitude of the earthquake in Richtes scale	Ratio $\frac{A_2}{A_1} \times 100$
1	2	3	4	5	6
5.4.68	20:33:24.0	1.0	0.7	1.9	70
8.4.68	13:33:36.4	2.5	0.7	2.2	28
11.4.68	16:05:40.0	1.5	1.0	2.4	67
15.4.68	21:07:34.6	0.9	0.7	2.2	73
16.4.68	10:49:44.6	1.0	0.7	2.2	70
1.5.68	07:46:22.4	5.0	2.1	3.5	42
1.5.68	15:44:49.5	2.0	0.8	2.3	40
8.5.68	13:03:12.4	2.4	1.7	3.0	70
24.5.68	20:55:11.0	2.0	0.9	3.2	45
30.5.68	05:35:11.1	2.7	0.8	2.3	30
31.5.68	18:02:10.6	2.3	0.8	2.4	35
9.9.70	22:56:05.2	1.5	0.9	2.3	60
9.9.70	22:57:15.7	2.1	1.0	3.3	48
21.9.70	03:02:00.0	31.0	9.5	3.8	31
27.9.70	00:19:00.0	1.4	0.7	2.3	50
8.11.70	07:29:00.0	4.0	1.7	3.1	42
12.11.70	07:09:00.0	1.2	0.7	2.1	58
14.4.71	16:37:45.8	6.5	2.0	3.5	30

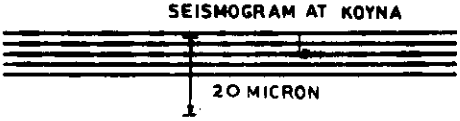

FIG 10 (a)

FIG 10(b)

SEISMOGRAMS (WOOD ANDERSON) OBTAINED AT KOYNA AND AT POPHALI (UNDERGROUND) SHOWING THE DECREASE IN AMPLITUDE WITH DEPTH

APPENDIX—II

ESTIMATION OF DESIGN SEISMIC COEFFICIENT FOR PANDOH DAM

A rock fill type of dam of height of about 61 metres with inclined impervious clay core was proposed under Beas Sutlej link project at Pandoh (Himachal Pradesh). The dam site is situated in active seismic region at a distance of about 90 km from the site of the Kangra earthquake of 1905. The actual procedure of estimating the siesmic design coefficient for Pandoh dam consisted of assessing the predominant period (T_G) of the site by underground explosion experiments. Seven explosions were made at depths ranging from 25 to 50 metres and the charges (60% gelatine) being between 25 and 75 kg. The seismic waves thus produced were recorded with the help of Sprengnether Seismographs and Philips electrodynamic pick-ups with a continuous recording oscillograph. The seismograms thus obtained normally showed the earlier body wave arrivals followed by dispersive surface waves and finally by slow codas. The explosion codas normally consist of few waves and die down quickly as such the dispersion curves cannot be plotted and used for obtaining the period corresponding to maximum group velocity. However, as is well known the explosion surface waves might exist only when their period is near the minimum of group wave velocity which corresponds to maximum energy in the spectra, the average values of period of surface waves from these explosions could be reasonably regarded to give the predominant period of the site. From all the seismograms obtained at the Pandoh dam site a histogram had been plotted and the period corresponding to the maximum frequency of occurrence in explosion surface waves was reasonably taken to be the predominant period of the site which was found to be about 0.08 sec.

Utilising the above obtained value of T_G the maximum ground acceleration was estimated from Eq. (2) for a Kangra type earthquake with $M=8$, $x=90$ km and the value of $\alpha=0.38$. The value of maximum ground acceleration thus computed was about 880 cm/

sec^2. As per the prevalent practice, mentioned eartlier, one-fourth value of this a_{max} could be taken as the seismic design coefficient which is about 0.22 g. Alternatively, the seismic design coefficient could be estimated more reasonably by utilising the Housner's average acceleration spectra (17). The average acceleration spectra was converted to that due to Kangra type earthquake for epicentral distance equal to 90 km by multiplying the ordinate of the average acceleration spectra by 0.6. This multiplication facter had been obtained by computation from Eq. (2) and by comparison with that of Taft earthquake of July 21, 1952. The value of acceleration response thus obtained for the dam at Pandoh with its probable natural period of 0.35 sec. and damping coefficient of 7% was estimated at 0.1g However, the average value (o.15g) of the seismic design coefficient as estimated by above two methods has been recommended as the seismic design coefficient for the Pandoh dam.

APPENDIX—III

NOTATION

The following symbols are used in the paper :

A = Vibration intensity
a = Constant
a_{max} = Maximum acceleration of earthquake motions at the ground
d = Depth below the surface.
E, F = Algebraic constants
H = Thickness of the surface layer
I, J = Algebraic constants
K, K_A, K_B, K_C = Constants
L = Algebraic constant
M = Magnitude of the earthquake in Richter scale
m, n, P = Constants
Q = Amount of charge
R = Distance between the explosion and station of observation
S = Algebraic constant
T = Earthwave period
T_G = Predominant period of the ground
U = Amplitude at the free surface
U_0 = Amplitude of the incident wave
V_1 = Velocity of the shear waves in the surface layer
V_2 = Velocity of the shear waves in the underground layer
W = Constant
x = Hypocentral distance
Z = Algebriac constant
α = Impedence ratio of surface layer to lower medium,
μ_1 = Rigidity of the surface layer
ξ_1 = Viscous coefficient of the surface layer.