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Explosion Codas and Design Seismic Coefficient

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SYNOPSIS In view of construction of structures in seismic zones like high dams, nuclear power plants etc., evaluation of 'site dependent design seismic coefficient' has been of paramount importance. It is thus necessary to assess correctly 'amplification factor' of ground motion due to surface geology during earthquakes. This ground amplification factor depends on 'predominant period' of site in addition to other factors according to Kanai and others. Though microtremors have been utilised for estimation of predominant period of site, it has been shown that explosion generated codas could also be used to obtain ground amplification factor useful for estimation of probabilistic site dependent design seismic coefficient from response spectra of probable maximum earthquake magnitude estimated from seismic environment and assumed life of the structure.

INTRODUCTION

There has been ample corroboration from earthquake damage surveys that soft soil specially of particular thickness induces greater damage to superstructures due to enhanced ground motion. Anomalous damage distribution generally observed in earthquakes could be largely attributed to the above soil properties. Hence there has been greater need of exploring in-situ soil properties for quantifying the resultant ground motion for assessment of dynamic design of superstructures. Thus earthquake damage observations and associated soil properties are significant data base for quantitative assessment of soil-foundation interaction and consequently 'site dependent design seismic spectra'.

METHODOLOGY AND OBSERVATIONS

In order to quantify the effects of soil character on the ground motion due to earthquake (magnitude M), amplification factor (K) has been introduced in expressions for ground motions. Some of the wellknown forms for ground velocity (V) are : $Ke^{bM} R^{-c}$ and $Ke^{bM} (R + R_o)^{-c}$. In the above expressions, the influences of the soil is designated by the factor K. Value of K is smaller for compact formations but larger for loose or madeup soil. This formulation could to some extent explain the effects of soil on ground motion and consequently earthquake damage. Similar observations on ground motion have been confirmed in case of shallow underground explosions. Normally, following type of expression has been evolved for ground velocity (V) due to shallow underground explosions of charge Q :

$$V = K.Q^m R^{-n} \qquad \ldots (1)$$

where R is distance of observation from explosion or earthquake and b,c,R_o,m and n are statistical coefficients. Variation in ground motion due to soil character is largely dependent on the constant K and to very small extent on m,n,b and c. For specific geology, the following expression in basalt rock has been obtained :

$$V = 550\ Q^{0.65}\ R^{-1.0} \quad \text{(mm/sec)} \qquad \ldots (2)$$

where Q is expressed in kg and R in metres. Thus there is great parallelism between the expressions for ground motion and soil amplification factor K due to earthquake and underground explosion.

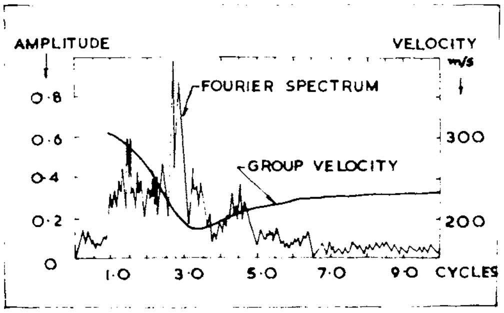

Fig.1 Fourier spectrum and Rayleigh wave dispersion curve (vide Omote et al, 1973)

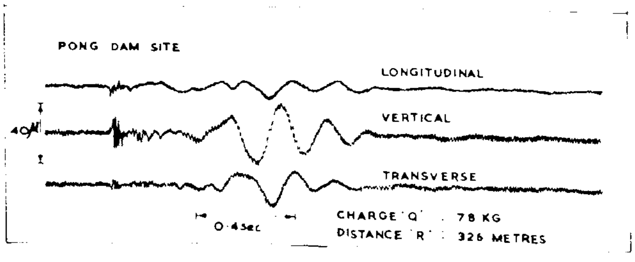

Fig.2 A record of blast showing codas consisting of Rayleigh and Love waves

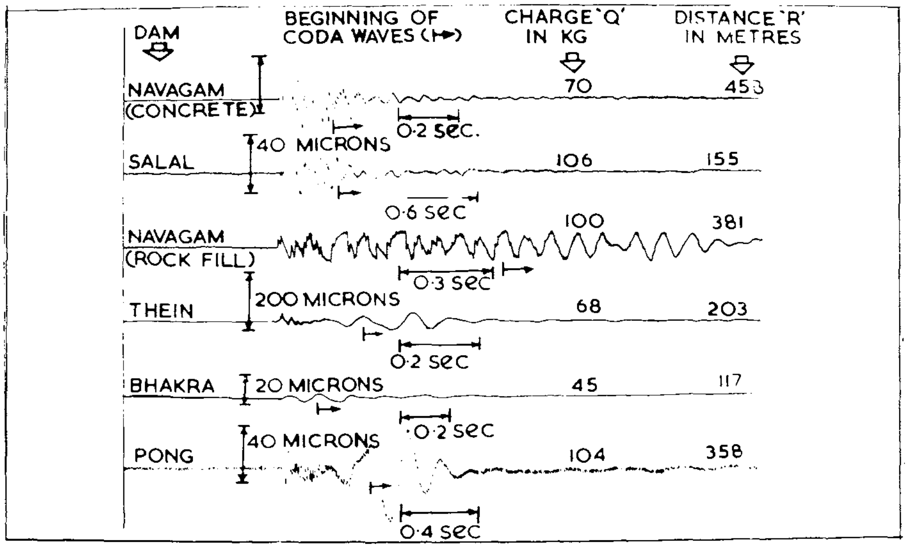

Fig.3 Blast induced Rayleigh waves (codas) recorded at various dam sites in India (Vertical Component)

Though the above formulation could substantially explain the enhanced ground motion on loose soil compared to compact ground, earthquake damage surveys bring out wide disparity in damages on superficially similar soils. Japanese seismologists and earthquake engineers have developed efficient method of exploring this anomalous variation in the ground motion through microtremor observations (T_G:predominant period of ground). Microtremors at a particular site depend primarily on elastic properties and thickness of the upper layer. They consider microtremors to consist of body waves generated through the process of multiple reflections. Kanai et al (1966), through extensive observations, had quantified earthquake ground motion depending on predominant period. In contrast to Kanai's observations, many researchers correlate microtremor (predominant period) to minimum group velocity of surface waves. Fig.1 shows correspondence between Fourier amplitude of microtremor with minimum group velocity (Omote et al, 1973). From numerous observations of maximum ground acceleration (a_{max}) during earthquakes at various sites and corresponding microtremors (predominant period), Kanai et al(1966) have obtained the following expression

$$a_{max} = \frac{G(T)}{T_G} \cdot 10^{(0.61M - P\ \log R + W)} \qquad \ldots (3)$$

where $P = 1.66 + 3.6/R$
$W = 0.167 - 1.83/R$
and

$$G(T) = 1 + \left[\left[\frac{1+K}{1-K}\left\{1 - \left(\frac{T}{T_G}\right)^2\right\}\right]^2 + \left(\frac{0.3}{\sqrt{T_G}} \cdot \frac{T}{T_G}\right)^2\right]^{-1/2}$$

where K is the square root of the ratio of the acoustic impedances of layers. Thus, the amplification factor G(T) which depends on T_G (predominant period of site) amongst other factors is a resonance type expression, and hence G(T) would have maximum value at certain earth wave period (T). Thus G(T) explains broadly the anomalous character of earthquake damage which is maximum for particular earth wave period. Extensive earthquake damage survey and associated microtremor observations in Japan have corroborated broadly these observations. However microtremor observations (predominant period) have not been so far universally accepted as a criterion representing vibrational characteristics of the ground. There have been therefore efforts to obtain site dependent design spectra at selected representative sites such as : (1) soft to medium clay and sand (2) deep cohesionless soil (3) stiff soil and (4) rock specially in California(Seed et al,1974; Kiremidjian and Shah,1977) and in Japan (Hayashi et al,1971). These site dependent spectra could serve general purposes and do not incorporate vibrational characteristics of specific sites. The need thus was felt to develop methodology, wherein amplification factor G(T) could be evaluated for specific sites through evaluation of T_G by alternate method.

It has been long observed that earthquake codas have to some extent site dependent characteristics. From extensive observations of explosion coda in diverse surface geological conditions, it is also found that codas are normally of higher frequency on rocky formations and of lower frequency on loose soils. These observations were extended to various surface geology and depths of explosion etc.. Explosion coda being

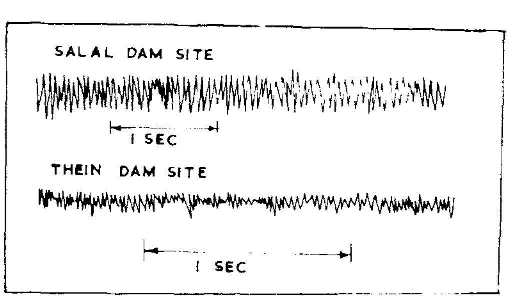

Fig.4 Microtremor records

Table I : Details of Dam Sites and Structures

Dam/Structure	Location		Type of Dam/ Structure	Height of dam (m)	Geology of foundation
	Lat. N	Long. E			
Navagam(Concrete) I	21°50'	73°45'	Concrete gravity	137	Basalt
Salal	33°13'	74°54'	Rockfill gravity	112	Dolomites
Tansa	19°30'	73°15'	Masonry gravity	40	Basalt
Vaitarna	19°35'	73°17'	Concrete gravity	67	Basalt
Navagam(Rockfill) II	21°52'	73°45'	Rockfill gravity	50	Basalt
Pandoh	31°36'	77°03'	Rockfill gravity	69.9	Quartzites, slates and phyllites
Thein	32°26'	75°44'	Earthcore gravel shell gravity	134	Sandstones, claystones and siltstones
Shanan Extension Stage I	31°54'	76°40'	-	-	Phyllites, schists and gneisses
Thal Fertilizer Complex	18°42'	72°52'	RCC / Steel	-	Basalt
Bhakra	31°20'	76°30'	Concrete Gravity	225	Sandstones
Pong	32°	76°	Earthcore-cum-gravel gravity	115.8	Sandstones

Table II : Dynamic Characteristics of Sites and Structures and Design Seismic Coefficients

Dam/Structure	Predominant period of site T_G (sec)	Natural period of structure T_n (sec)	Square root of impedance ratio K	Amplification factor $G_2(T)$	Maximum acceleration(Kanai) a_{max} (cm/sec^2)	Site dependent design seismic coefficient (cm/sec^2)
Navagam(Concrete) I	0.06	0.19	0.25	1.81	329	110
Salal	0.06	0.60	0.38	1.81	470	230
Tansa	0.067	0.10	0.25	1.37	280	80
Vaitarna	0.067	0.10	0.25	1.37	280	80
Navagam(Rockfill) II	0.08	0.40	0.25	1.93	262	100
Pandoh	0.08	0.35	0.38	1.94	690	220
Thein	0.10	1.00	0.35	2.05	600	125
Shanan Extension Stage I	0.10	0.60	0.35	2.05	480	230
Thal Fertilizer Complex	0.10	-	0.25	2.05	280	100
Bhakra	0.11	0.30	0.38	1.60	444	220
Pong	0.15	0.50	0.35	2.30	460	250

normally of higher frequency could thus be efficient tool to discriminate surface geological characters in the form of prevalent codas. It has been often observed that predominant coda periods associated with explosions correspond to surface wave group velocity minimum. These conditions favourable for generation of codas or surface waves could be treated as a process of resonant excitation of the upper layer. This method though rather complicated, has been utilised to excite few important dam sites of diverse geological and seismic environment for estimation of predominant period T_G and subsequently G(T) and finally 'site dependent design seismic coefficient' for important structures. The method has been specially developed to obtain T_G for high dam sites in India over the last one decade or so. At each dam site about a dozen explosions at specified depths and charges are exploded to excite codas of sufficient strength. The depths of explosions are normally greater than one-fourth of Coda wave length, and amount of charge was determined following equation (1) and sensitivity of recording system while recording was done beyond some wave lengths of the codas. Normally explosion depths are between 40 and 80 m, and charges range between 50 and 200 kg. Explosion Codas thus broadly represent free vibration of surface layers. The high dam sites explored are Bhakra, Pandoh, Thein, Navagam I and II and Salal (Tables I and II). In a few cases, both explosion and microtremor observations were done. Periods of both codas and microtremors are found to be similar at few sites. Thus both explosion codas and microtremors could be effectively used as both are dispersed surface waves (Figs.1 and 2).

RESULTS

Thus the explosion codas are similar to microtremors (predominant period), and both are equivalent to period corresponding to minimum group velocity of surface waves. It is, therefore, natural to utilise explosion codas for assessment of amplification factor G(T) for obtaining probabilistic site dependent design seismic coefficient (Guha and Padale, 1979)

$$\alpha = \frac{I.S_A.N}{D} \qquad \ldots (4)$$

where I = importance factor, S_A = maximum acceleration response spectra of probable maximum earthquake magnitude M_d corresponding to life period (L_o), natural frequency and damping of structure, D = ductility factor and N = ratio of $G_2(T)$ for the site of structure/dam to $G_1(T)$ that of the accelerogram recording station. Probable maximum earthquake magnitude (M_d) is statistically obtained from Gutenberg-Richter equation log N = a-bM. $G_2(T)$ is obtained from T_G value at the site of the dam from explosion codas, while $G_1(T)$ is obtained from assumed microtremor (predominant period) in absence of explosion data for obvious reasons. Numerous microtremor measurements in Japan at various geological situations provide the proper microtremor period for site of the accelerograms (M_d) recording station. Sample records of explosion generated waves and codas at various dam sites are shown in Fig.3 alongwith microtremor records from couple of dam sites -Fig.4. Response spectra corresponding to M_d is chosen from recorded accelerogram data world over. Tables I and II show various parameters of the dams alongwith T_G obtained from explosion codas and the deduced probabilistic site dependent design seismic coefficient (α).

CONCLUSION

Thus, explosions of 50 to 200 kg at depths over quarter wavelength of the codas could set up resonant or predominant vibrations in the upper layers. Periods of these codas are similar to period of microtremor and correspond to period at minimum group velocity. Following Kanai et al (1966) amplification factor could be found out for any geological surface layer from these explosion codas and the same is used for obtaining probabilistic site dependent design seismic coefficient of structures without any assumption.

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