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Embankment Design in Seismic Areas - Indian Practice

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SYNOPSIS A number of river valley projects for the development of water and power resources, particularly in the Northern and North Eastern part of India, lie on the foothills of Himalayas which is seismically active. In the developmental activity of dam building, aseismic design of dam is therefore, recognized and adopted. The paper presents the current Indian practice in the aseismic design of embankment-dams with illustrations from studies carried out on some recent dams.

INTRODUCTION

More than sixty percent of the geographical area of India is prone to eqrthquakes with seismic intensity varying from VI to X on M.M. scale. These areas are mainly contiguous to the Himalayas, along the Southern edge of which a major tectonic boundary fault skirts the Himalayas. For the last 80 years, more than 130 earthquakes with magnitude (Richter) from 5 to 8.6 have been recorded in this region. The Himalayas also constitute the source for the major river systems of the country namely the Indus, Ganges and the Brahamaputra. A number of river valley projects for the development of water and power resources, would therefore lie in this seismically active belt. The importance of aseismic design for dams is therefore well recognized and practised.

PSEUDOSTATIC APPROACH

Pseudostatic approach for the design of embankment dams under seismic conditions is very commonly adopted. In the conventional limit equilibrium analysis, an inertial force is assumed to act statically on the sliding mass in addition to the normal non-seismic forces and the factor of safety against sliding is ensured to be more than unity for safe designs.

The Indian Standards Institution has analysed the seismic status of all parts of India and has codified their recommended Criteria for Earthquake Resistant Design of Structures in IS. 1893-1975, from which the equivalent static coefficient for the aseismic design of dams and other structures in different areas of the country can be determined. The entire country has been divided into 5 zones, corresponding to expected M.M. intensity of V or less, VI, VII, VIII and IX and more respectively. This zoning map is based on the known records of magnitudes and epicentres of earthquakes, modified in the light of tectonics, lithology, and maximum intensities as recorded from damage surveys. For these five zones, seismic zone factors, 0.05, 0.10, 0.25 and 0.40 are specified. The uniform equivalent seismic coefficient in the horizontal direction for the whole dam is determined using the relationship

$$\alpha_h = BIF_o \frac{Sa}{g}, \text{ where } \alpha_h \text{ is horizontal}$$

seismic coefficient, B is coefficient for soil foundation system, I is Importance coefficient (2 for dams), F_o is Seismic zone factor and Sa is average acceleration coefficient read from average acceleration spectrum curve.

The value of equivalent uniform seismic coefficient in the vertical direction is taken equal to half of α_h. The value of the equivalent uniform seismic coefficient with the lowest value of rupture surface at any depth 'y' below top of dam is calculated as :

$$\alpha_y = \left(4.0 - 2.4 \frac{y}{H}\right)\alpha_h$$

It is to be seen that while the approach for selection of a equivalent uniform seismic coefficient has been considerably simplified, the realities of dynamic response of the earth dam is not totally ignored.

ANALYSIS FOR IMPORTANT DAMS IN HIGH SEISMICITY ZONES

It is recognized that pseudostatic approach has its limitations as brought out by Seed (1967). Therefore, in evaluating the performance of major embankments subjected to transient and pulsating forces in high seismic zones, a more rigorous procedure is adopted. The analysis is carried out by shear beam approach to determine the dynamic response of the dam to the applied accelerogram. Deformation analysis for this dynamic response is carried out using

Yield Acceleration approach suggested by Goodman and Seed (1966). In addition, scalar model studies on shake table are also carried out.

Shear Beam Approach

The model adopted considers the dam as a shear beam with its weight lumped at discreet points at suitable height intervals. Only shear modes are considered due to nature of the materials and low ratio of height to base width of the structure. Shear stiffness between two consecutive lumped mass points is obtained by combining the shear stiffness of the various materials constituting the section at that horizontal level. From the response spectra and the model responses, the total response to the earthquake motion is computed by the method of quadratic superposition i.e. total response is equal to the square root of the squares of response from various modes. The response in terms of maximum dynamic shear forces, maximum elastic deflection, and maximum absolute acceleration are worked out. This analysis has been used for a 100m high Salal Rockfill dam (with a moderately slanting core). The design acceleration, and results of shear beam analysis are shown in figures 1 and 2 respectively. For determining the dynamic properties of the materials of the dam, insitu free and forced vibration tests and wave propogation tests were carried out on the dam materials and the values at strainlevels associated with the earthquake were adopted.

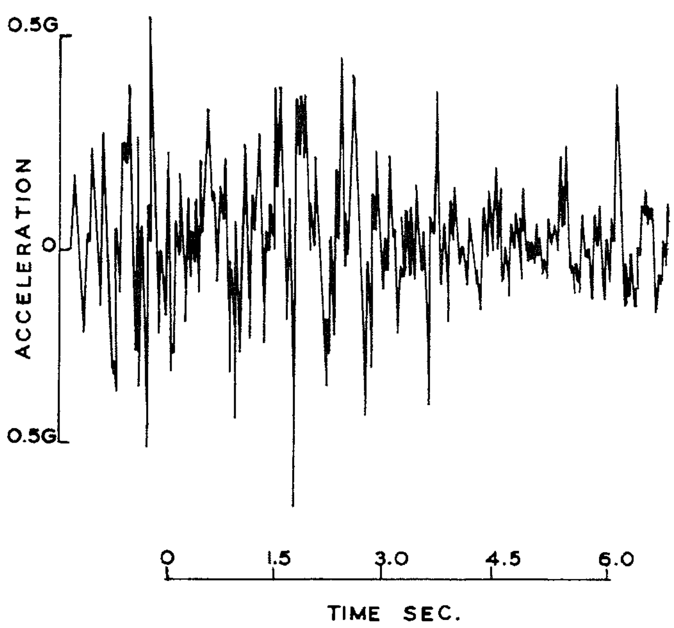

Fig. 1 :- Accelerogram for Salal Dam site.

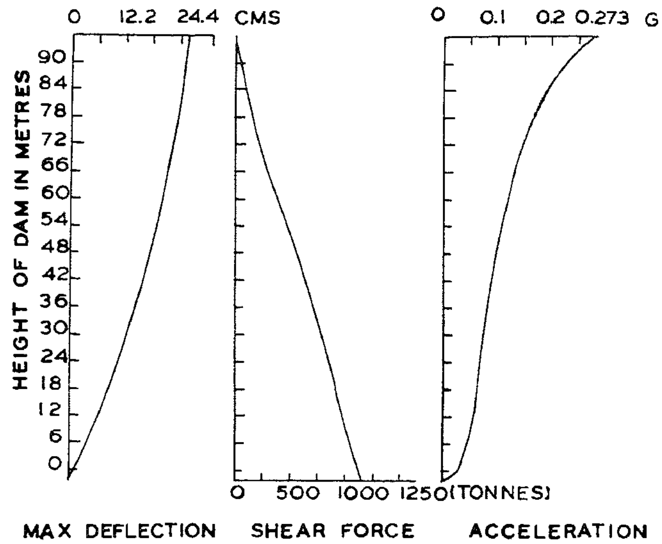

Fig. 2 :- Deflection and Forces, Salal Dam.

Deformation Analysis :

Deformation analysis for the dam is carried out on the assumption that no displacement would occur if the acceleration is less than yield acceleration for the material. For purely frictional materials, the slope-face is itself the most critical surface of least resistance. The sliding mass along the slope is idealized. as a block moving down a plane inclined at an angle θ equal to the slope of the dam face and restrained only by friction. Under horizontal motion, the expression for yield acceleration Ky, for a slope (submerged) with material having effective angle of internal friction ϕ' is given by :

$$Ky = (\gamma b/\gamma s) \tan(\phi' - \theta)$$

where γb and γs are the buyoant and saturated unit weights of the slope material.

For computing the relative displacement, the timewise absolute acceleration response of the dam for a point near the crest is calculated using the expression.

$$ai = yg(t)\left[1.0 - \sum_{r=1}^{n} \gamma_r \phi_{ir}\right] - \sum_{r=1}^{n} 2 p_r \xi_r \phi_{ir} \left(\frac{d\eta_r}{dt}\right) - \sum_{r=1}^{n} p_r^2 \phi_{ir} \eta_r$$

where

γ_r = mode participation factor

r = any particular mode number

n = total number of modes considered

m_i = mass lumped at the ith location

a_i = acceleration response at the location

yg(t) = horizontal ground acceleration at instant 't'

ϕ_{ir} = mode shape displacement at location i in mode r

p_r = natural frequency in radians per sec in mode r

ξ_r = assumed fraction of critical damping in mode r

η_r = normal co-ordinates of the uncoupled equation of motion.

After working out the timewise absolute acceleration response of the dam, intervals at which this acceleration exceeds the yield acceleration are marked. By double integration of the absolute acceleration response curve for the intervals during which the acceleration exceeds the yield acceleration, displacement of the slope can be worked out. This analysis was carried out for the Salal Rockfill dam. Yield acceleration was estimated as 125 cms/sec^2 and the total relative displacement estimated for a point at 1/8th height of dam below the crest worked out to 16.68 cms. Figure 3 shows the timewise absolute acceleration response of the dam.

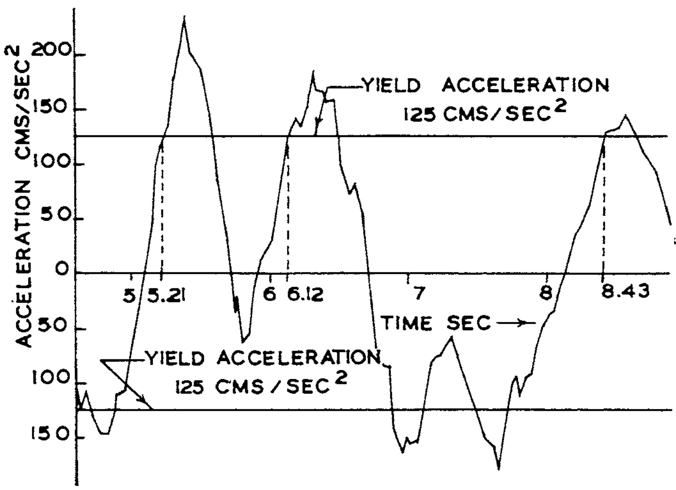

Fig. 3 :- Timewise absolute acceleration response of Salal Dam.

Model Studies :

Laboratory Model Tests on shake table are carried out to give credence to analytical procedures that may be used for determining response of the dam to a given ground motion as well as to get a qualitative idea of the behaviour of the dam. Shake table of the dam size 5.2 X 2.8 X 1.8m is being used which can be excited unidirectionally in the longitudinal direction by the impact of a free-falling pendulam. The weight of the pendulam and its angle of fall are so selected as to satisfy the objective that the simulated ground motion must ensure that within both the elastic and inelastic ranges the effect must be equal or more severe than that of the ground motion at site. In the shake table test, time history of the table acceleration of the simulated earthquake, time history of model response and profile measurement of the dam model after the simulated motion are determined.

LIQUEFACTION STUDIES.

For all projects in earthquake zones, where silty or sandy deposits are met with in foundations, the studies for determining the liquefaction potential of the site are carried out. These studies comprise of laboratory studies on a vibrating table, field studies by blasting tests and analytical evaluation based on Seed and Idriss (1970) simplified procedure for evaluating soil liquefaction potential.

The laboratory studies comprise of de-termining rise in pore pressure in the sand deposit from site placed in a tank mounted on a shake table capable of sinusoidal excitation. Figure 4 presents the results of such studies for Ajmeripura Dam site in Rajasthan (India). The top horizon of 6m depth of foundation consists of loose sand with a relative density of 40%: The sand gets completely liquified at the expected ground motion and is proposed to be removed from the dam foundations.

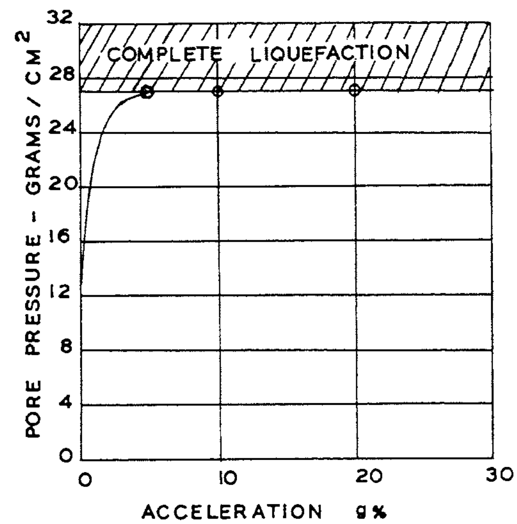

Fig. 4 :- Pore Pressure versus Acceleration, Ajmeripura Dam.

For blasting tests in the field, a charge of gelatine embedded in a hole is blasted and the

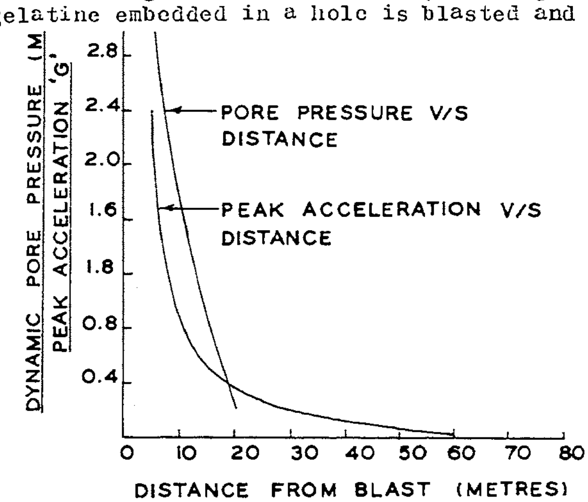

Fig. 5 Pore pressure versus distance, Ajmeripura Dam.

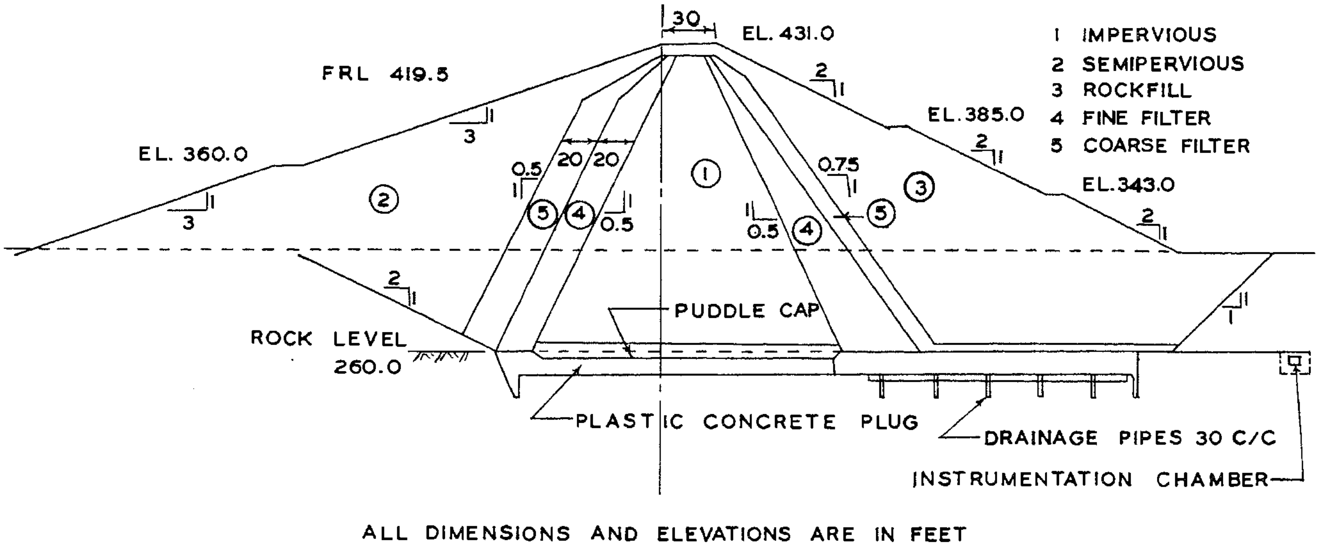

Fig. 6 Section of Sedawgyi Dam.

rise in pore pressure in the piezometres installed in the holes at different depths are measured. Measurement of peak ground accelerations are also made. Figure 5 presents the results for Ajmeripura dam site. It is seen that complete liquefaction takes place under accelerations of the order of 1g. Such studies have also been carried out for a number of other dams namely Tenughat, Obra, Mahanadi etc.

DEFENSIVE DESIGN FEATURES

In addition to the analytic approach, certain defensive design features based on engineering judgement are always incorporated in the design of embankment dams located in high seismicity area. These comprise of additional free board, at 1% of height of dam, over and above the normal free board, a wide crest at the top, avoiding very thin cores, choosing relatively plastic core material, providing liberal filters and large cohesionless graded zones both upstream and downstream of core. Sedawgyi dam in Burma being designed by Central Water Commission, Government of India, presents a typical example in this regard. Sedawgyi dam is 40m high, homogeneous embankment crossed by a normal fault parallel and near to the river. The section was therefore modified from homogeneous to zoned section for a length of 100m across and adjoining the fault. The zoned section has a plastic core of thickness equal to the height of the dam with wide filters on both sides, a rockfill zone on the downstream side and a widened top. In the foundations a 3.5m deep plastic concrete plug with 1m top puddle cap with deep drainage arrangements has been provided to prevent erosion of corebase. Figure 6 shows the section of Sedawgyi dam for fault zone.

CONCLUSIONS :

As major water Resources Development projects are located in the Himalayas in the seismic belt, it is essential that structures are designed to withstand the seismic forces that are likely to be generated during earthquakes. The current design practices adopted in India indicate the importance that is attached to this aspect and are in line with the practices prevalent elsewhere in the world.

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