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ASSESSMENT OF NON-RECOVERABLE DEFORMATIONS IN TEHRI DAM DUE TO EARTHQUAKE

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SUMMARY

Tehri Dam Project, envisaging construction of a 260.5 m high earth and rockfill dam, is under construction in U.P. State of India. The project lies in active seismic region in which a number of earthquakes have occured. The dam is to be placed in a very narrow valley. The site response spectra and accelerogram, evaluated on the basis of seismotectonic studies, are available. Attempt has been made to assess the non-recoverable deformations in the dam slopes and identify the potential sliding wedges during earthquake. Due to narrowness of the valley rigid body behaviour of the dam has been assumed. The rock mass contained in the sliding wedge is expected to show rigid plastic behaviour.

INTRODUCTION

The Tehri Project is an irrigation-power project of the State of Uttar Pradesh in India, envisaging construction of: (1) A 260.5m high rockfill dam across the Bhagirathi river to store 2,880,000 acre-ft of water; (2) underground power house, having installed capacity of 2000-2200 MW; and (3) spillway for design discharge capacity of 11,700m^3/s. The four diversion tunnels of 11.00 m diam each have already been constructed. The layout of project works is given in Fig. 1. The dam is to be placed at the site such that its foundation will be highly jointed and sheared phyllitic rocks and its abutment contact slopes be steep (Ref. 1,2). The area is also seismicically active.

An earthquake can affect a rockfill dam in a number of ways (Ref.3) and one of these is to cause slope slides. Newmark in 1965 (Ref. 4) for the first time gave an approach based an determination of yield acceleration, with rigid plastic behaviour of sliding soil mass, to assess non-recoverable displacements for an earth dam. Seed and Sultan (Ref.5) and Sultan and Seed (Ref.6) demonstrated applicability of this approach for determining displacements of a dry cohesionless soil slope. The outer shells of earth and rockfill dams are generally of cohesionless material. The upstream shell is mostly submerged in water and downstream shell is dry. It is considered that the approach based on yield acceleration can be applied to assess the non-recoverable displacements and the configuration of potential sliding wedges of the slopes. For Tehri dam, because of narrowness of the valley, the dam is expected to respond as a rigid body and therefore applicability of the approach becomes very simple. However, incase, it is considered to evaluate the actual effect of valley confinement , the problem becomes very complex and would require three dimensional analyses for response time history of the dam at different heights. There can also be an approximate analysis, as indicated in this paper, to consider amplification of the ground motion, without confining effect, based or one on two dimensional analysis.

EARTHQUAKE PARAMETERS

Based on the seismotectonic set up of the region, analyses have been carried out (Ref. 7) to suggest levels of earthquakes for design of structures and equipments. Two levels of ground motion resulting from earthquakes, designated as Maximum Credible Earthquake (MCE) and Design Basis Earthquake (DBE), for design of the dam and appartenent structures have been recommended. MCE is the most sever earthquake that may occur once in the life time of the structure. Under its effect the structure may undergo distress in the form of cracks in case of concrete or change of profile in case of rockfill dam (which could be repaired). However, various structures and equipments should be able to servive under this condition without complete collapse. Under DBE the rockfill dam may be designed to have a factor of safety of nearly unity due to combined horizontal and vertical earthquake. An effective peak ground acceleration of 0.25 g is recommended for evaluation of a response spectra and compatible time history of ground motion for dynamic analysis of the dam corresponding to MCE. The recommended smoothened response spectra for the purpose of design corresponding to DBE for the project site is given in Fig. 2. The spectral accelerations for design under MCE canditions, be obtained by multiplying the DBE spectral values by a factor of 2.0. It has also been recommended that no further enhancement of design spectral acceleraltions will be necessary on account of Importance Factor given in the Indian Standard (Ref. 8). An artificial accelerogram generated to match the shape of the spectra with damping 10 percent and normalised to 1.0g is given in Fig. 3 corresponding to MCE. The peak ordinate of the artificial accelerogram may be taken as 0.25g. It is likely that an actual accelerogram of a future earthquake recorded at the site may have few strong peaks larger than 0.25g. However, the artificially generated accelerogram would be more intense as various frequency components of ground motion are well represented as compared to an actual record which may have gaps.

THE DAM

The sections of the dam and valley are shown in Fig. 4(a) & (b). All the fill materials are to be obtained from the river terraces. The core consists of a mixture of clay, silt, sand, gravels and boulders upto 150 mm size. The upstream and downstream shells consist of clean gravels and boulders. On either side of the core and just adjecent to it, a layer of fine to medium sand has been provided which enables provision of subsequent well designed filter layers. The upstream and downstream slopes (H:V) are 2.5:1 and 2:1 respectively. The core has upstream slope of O.5:1 and downstream slope (sloping towards upstream) of 0.2:1. The fill material properties are as given below.

Fill Material	Unit weight t/m^3			Friction Angle	Cohesion
	Dry	Moist.	Sat.	Degrees	t/m^2
1. In Shell	1.9	2.0	2.2	38	0.1
2. In Core	1.7	1.8	2.15	27	1.5

The dynamic soil parameters of fill and foundation of the dam have also been evaluated (Ref.9 and 10).

DEFORMATION ANALYSIS

Flow slides occur in the cohesionless material slopes when subjected to ground shaking. Due to interlocking effect of the particles, which may be named as apparent cohesion, the slide may occur at some depth rather than at surface. The slide would occur (assuming rigid plastic behaviour) when the inertia force brings down the safety factor below unity. The acceleration corresponding to this inertia force (yield acceleration) has been workedout for the dam slopes considering various configurations of the potential sliding wedges (Ref. 6). As the valley is very narrow, it has been assumed that the inertia force does not vary along the height of the dam. The yield acceleration values for upstream slope for reservoir full condition and for downstream slope dry condition are found to be 0.1654g and 0.2115g respectively. The corresponding configuration of upstream and downstream sliding wedges is shown in Fig.5.

The artificial accelerogram generated for the site is given in Fig. 3 . The peak acceleration ordinate of the accelerogram, corresponding to MCE has been recommended as 0.25g which is more than the yield acceleration levels of upstream and downstream slopes, indicating the occurrence of non-recoverable displacements of the slopes. Assuming the rigid body behaviour of the dam in the narrow canyon, these displacements have been obtained by integrating twoice the accelerogram above yield acceleration level. As the accelerogram is not symmetrical about the time axis, calculations for displacements have been done by marking yield acceleration levels for upstream and downstream slope on both sides of this and choosing the greater of the two displacements. The non-recoverable (plastic) displacements thus obtained for upstream and downstream slopes are 48.25 cm and 17.37cm respectively.

I.S. CODE APPROACH

IS: 1893-1984 (Ref. 8) suggests to consider the spectra as shown Fig. 6 for 10% damping for priliminary design of earth and rockfill dams. The time period of Tehri Dam works out to be 1.9 sec. and corresponding to this, the design horizontal seismic coefficient (   ) as per the code is 0.04. The code considers the amplification of ground motion with the height and, accordingly, the value of equivalent uniform seismic coefficient (   ), for checking slope failure with the lowest point of the rupture surface at any depth 'y' below top of the dam, is recommended as

$$= (2.5 - 1.5\ Y/H)$$

where, H is the height of the dam above foundation level. This shows that even at the crest the acceleration would be less than the yield acceleration workedout earlier (considering constant value of the inertia force). However, in case the spectra developed for the site, as a shown in Fig. 2 , is used, the value of   is 0.105 indicating non-recoverable deformations in upper half of the dam.

REMEDIAL MEASURES

The depth of potential sliding wedge in upstream slope, as shown in Fig. 5 is 15m. Therefore, it is proposed to provide a layer of quarried rocks (angle of internal friction 45^{o} or so) of thickness 20m on the two faces of the dam.

CONCLUSION

The assessment of non-recoverable deformations due to earthquake can be done in a simple way for small dams and for dams situated in narrow canyon where rigid body behaviour of the dam may be a reasonable assumption. In other cases also, some approximate estimation can be done by evaluating acceleration time history response at the heights where displacements would occur.

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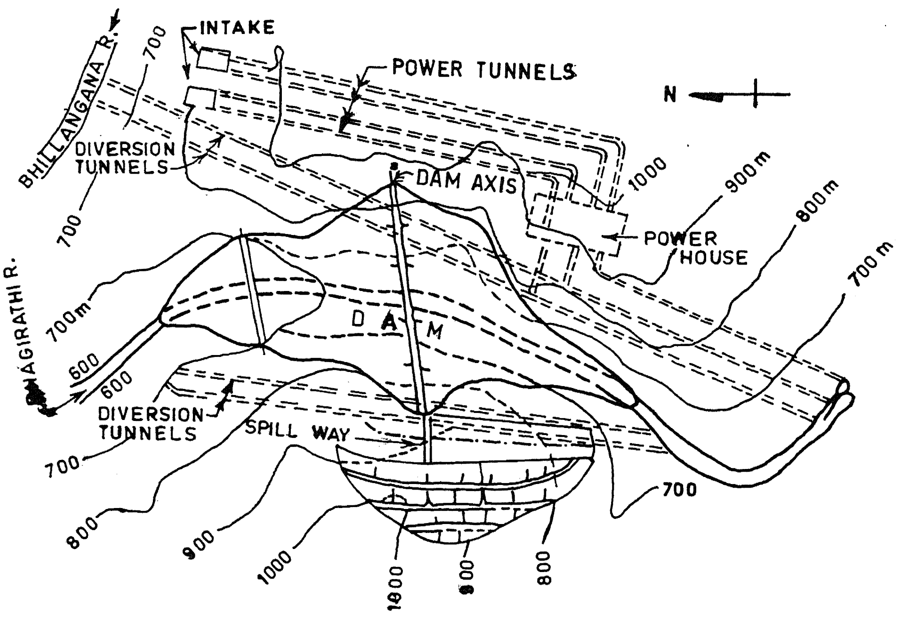

FIG.1 _ GENERAL LAYOUT OF THE PROJECT WORKS

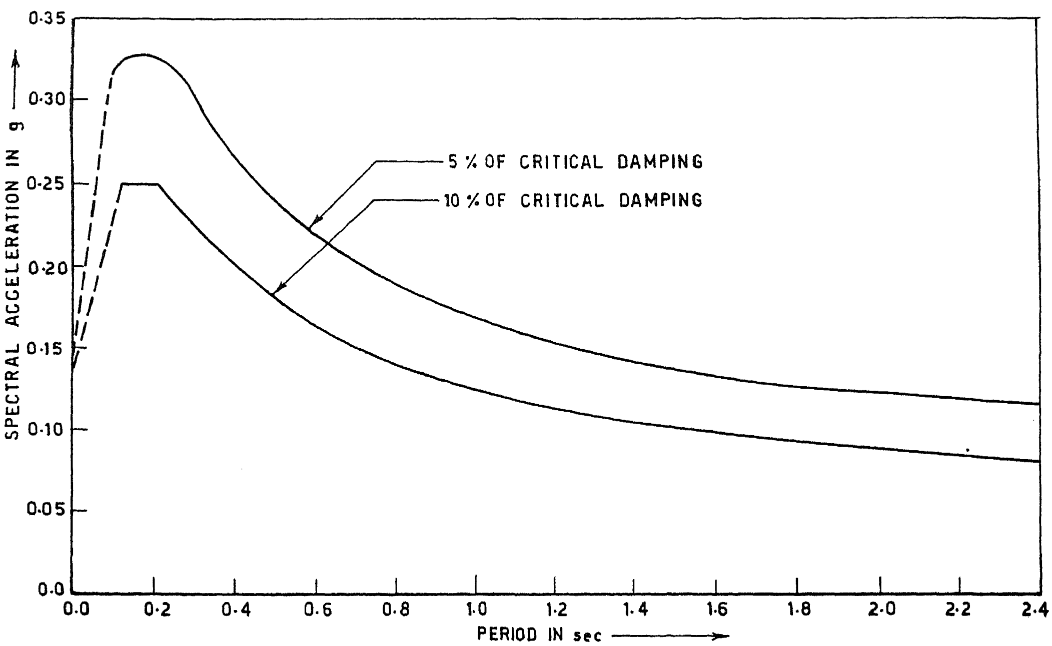

FIG. 2 _ RECOMMEDED SMOOTHENED DESIGN SPECTRA CORRESPONDING TO DBE FOR TEHRI DAM SITE

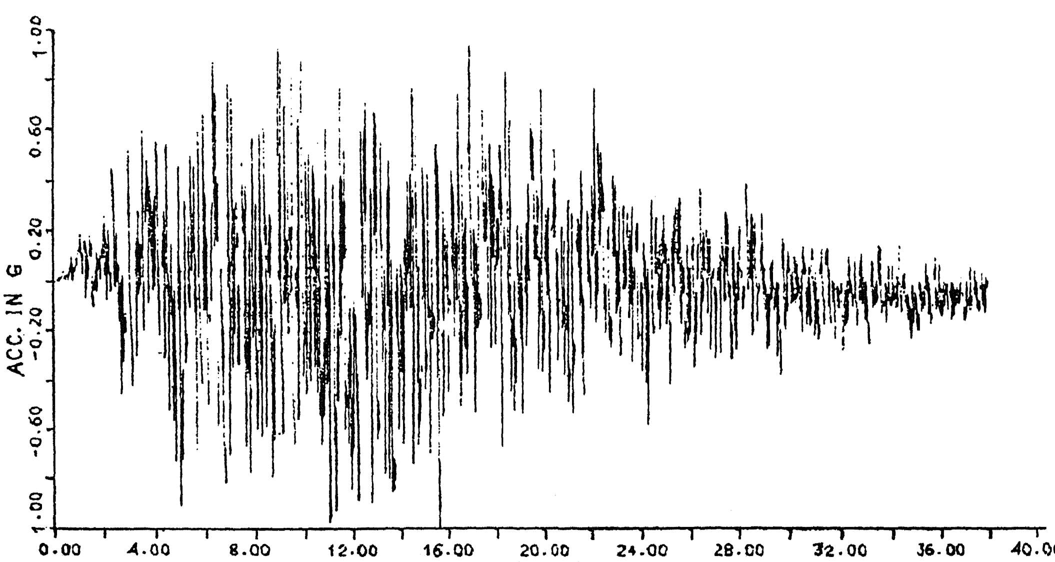

FIG. 3 - ARTIFICIAL EARTHQUAKE FOR TEHRI SITE. NORMALIZED TO G.

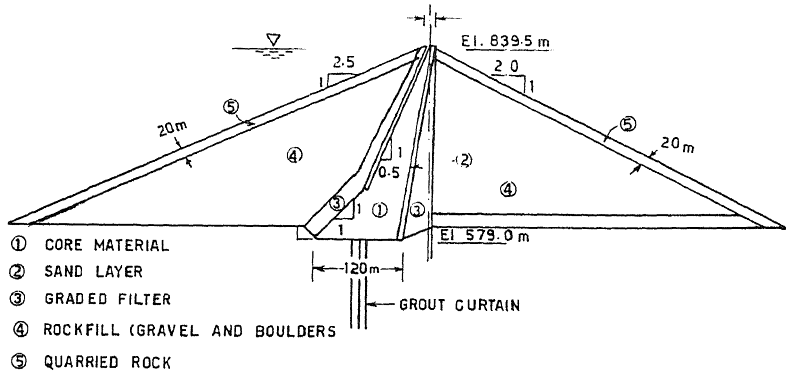

FIG. 4a _ DAM SECTION

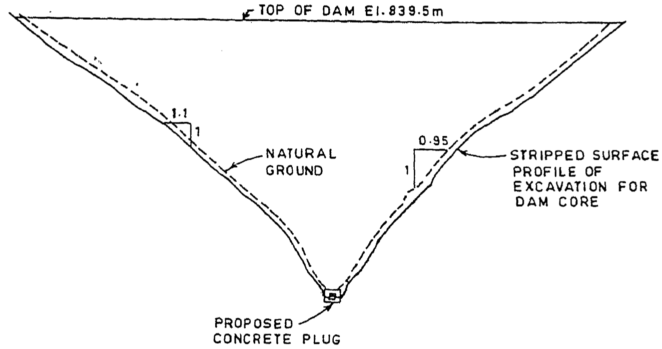

FIG. 4b _ VALLEY SECTION

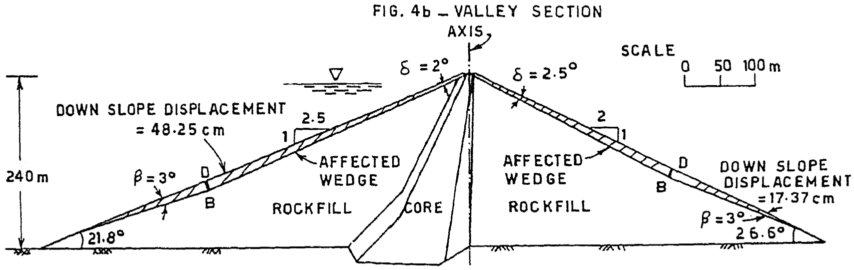

FIG. 5 _ POTENTIAL SLIDING WEDGES OF DAM

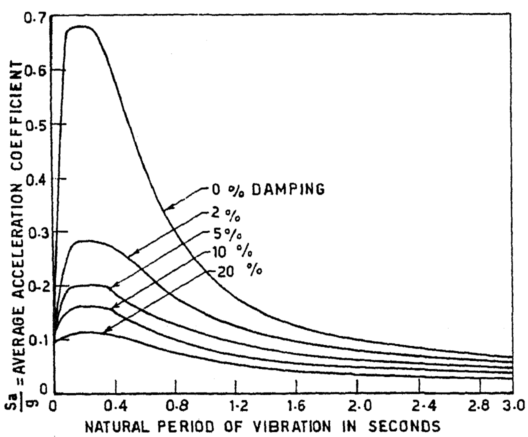

FIG. 6 _ AVERAGE ACCELERATION SPECTRA
(I S CODE)