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No Tension Approach to Define Failure Phenomena for Rockfill Dam Subjected to Earthquake Loading

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SYNOPSIS: It has been observed that actual behaviour of Rockfill dams during earthquake is much different than that obtained by elastic analysis. No tension approach has thus been developed to overcome the shortfalls of elastic analysis. Using no tension approach redistribution of stresses are obtained which help in defining the failure pattern of the dam subjected to a given seismic acceleration or in other words the failure acceleration is obtained for a given dam subjected to earthquake forces. Various dam models having different upstream and downstream slopes are analysed using finite element technique. The input earthquake motion has been considered as an equivalent static force. Anisotropy of the rockfill material has been considered. The failure acceleration level for various dam models having different upstream and downstream slopes are thus evaluated. The results are compared with those obtained experimentally and show a good agreement.

INTRODUCTION:

Many earth and rockfill dams although of small height have been constructed in past. Because of shooting advancement in the constructional techniques very high dams are being constructed. Since the fill type dams are mainly built of soil and rock, the behaviour of these dams during earthquake becomes essential to be established.

As early as 1933 preliminary studies regarding the behaviour of fill type dams during the earthquake had been carried out. For the last 40 years number of scientists have been working and have contributed to this field. Many scientists have carried out elastic analysis of rockfill dam subjected to earthquake and have arrived at fairly good conclusions. Since very high dams are required to be constructed it becomes mandatory to develop the analysis/design methodology specially when these are subjected to strong earthquake forces.

The present analysis deals with the study of failure phenomena of rockfill dam during earthquake. No tension approach has been developed to overcome the shortfall of elastic analysis. The anisotropy of the fill material has been taken into account in the analysis. The author participated in the experimental study carried out at Institute of Industrial Science, University of Tokyo, Tokyo. Based on the experimental study Okamoto et al (1974) have come out with the results indicating the failure acceleration relationship with regard to the slope of the dam.

METHOD OF ANALYSIS:

Dam model has been idealised as a 2-D section. The input earthquake forces are considered as equivalent static forces. Finite element technique has been used to evaluate the stresses and displacements of the continuum at specified points. 6 dam models have been considered for the analysis. The upstream and downstream slopes have a variation from 1:1.5 to 1:3.0 in different dam models. In the present analysis the empty reservoir condition has been presumed. Therefore the effect of hydro dynamic forces on the dam has not been considered in the analysis. Each of the dam model is divided into finite number of elements. The upstream face of the dam was idealised with a finer mesh distribution whereas a coarser mesh was used for downstream side as this type of idealisation provided better results. The analysis was carried out starting with zero acceleration and then increasing the acceleration upto 0.65 g. in steps. Principal stresses, sheer stresses and the displacements at the nodel points are evaluated.

No Tension Analysis:

It is well known by its physical system that the rockfill dam cannot resist any tension. The elastic analysis indicate presence of tension even at a very low acceleration level. Thus it becomes difficult if not impossible to derive failure phenomena of the rockfill dam using linear elastic approach. In order to have a better feel of the failure phenomena, the elastic analysis is further extended to no tension analysis taking anisotropy of the material into account. Using this approach it is observed that the tension which appears in the continuum at a fairly low acceleration gets redistributed. This, thus indicate that the dam model which was however declared unsafe using linear elastic approach is rather safe because the tensile stress has been redistributed.

To start with, the material is assumed to be perfectly elastic. The stress distribution is obtained for zero acceleration including self-weight of the material. The analysis is carried out for various seismic acceleration values in stages. The existance of tensile stresses at any stage is taken care of by suitable modification of the elastic parameters of the material. The analysis is repeated for the same acceleration using modified elastic constants. This results in redistributed stress levels in the continuum. Again a check is made for the existance of the tension and similar exercise is repeated till the tension disappears or reduced to a very very small value. The dam model is then analysed for the higher acceleration value. If tensile stresses are observed the modification in the elastic parameters is continued and the analysis repeated for the same acceleration. Whole of the analysis undergoes this exercise again and again for every acceleration. It is necessary to point out at this stage that the tension does not exactly converg to zero but all the same this tension converges to the neighbourhood of the zero.

DISCUSSION OF RESULTS:

The analysis is primarily carried out to evaluate stresses and displacements in the continuum and based on this the failure acceleration is determined. Figure (1) indicates an outline of one of the dam models analysed. Figure (2) indicates the changes in tensile stresses in various elements as a result of the modified elastic parameters. It is clear from figure (2) that tensile stresses initially developed approach to the neighbourhood of zero stresses or get converted to compressive stresses. Simply looking at the tension developed in the various elements of the dam model when it is subjected to a specific acceleration, it may not be possible to say whether this would be the failure acceleration or not. Generally it may be rather difficult to estimate the proper value of the acceleration which is supposed to cause failure of the dam. Various parameters were taken to define the failure phenomena. Finally it was observed that for a particular dam model, when subjected to a specific acceleration, the total area under tension can define the failure acceleration of the dam. Figure (3) indicates a graph wherein total tension area has been plotted against various acceleration levels for dams having different upstream and downstream slopes. On close observation it can be seen that for a given dam model there exists a point Cr-1 for a given acceleration. If acceleration is increased to a next higher value the increase in the tension area is not changed appreciably. This point may be called as Cr. When appreciation is further increased to next higher value, point Cr+1, the gradiant of area under tension is seemed to be shooting up. Hence the point Cr. can be taken as central point. The point Cr-1 indicates that slip has started occurring at that particular acceleration and point Cr+1 indicates that complete damage has taken place. Thus acceleration at point Cr. can be treated as failure acceleration of the dam. Figure (4) indicates the difference in results using finer mesh and coarser mesh. It has become obvious that finer mesh on the upstream sight gives better results. Figure (5) gives the relationship of failure acceleration versus upstream slope. Both the experimental and analytical findings have been plotted. The close obseration to this indicates that the analytical results show a fairly good agreement with the experimental results. One more interesting point is seen from the study of figure (5) that the failure acceleration level more or less remains constant after upstream slope value of 1:2.5.

CONCLUSION:

From the analysis of the results the following conclusions can be drawn.

(1) The advantage of no tension analysis over the linear elastic analysis is obvious.

(2) The results obtained by no tension analysis show a fairly good agreement with those obtained experimentally.

(3) Since the tensile stress get redistributed because of consideration of anistropy of the material, merely complete absence of tension is observed for low acceleration values thus certifying that the slip or the failure cannot occur at lower accelerations.

(4) The no tension approach gives a better insight to understand the failure phenomena of the rockfill dam.

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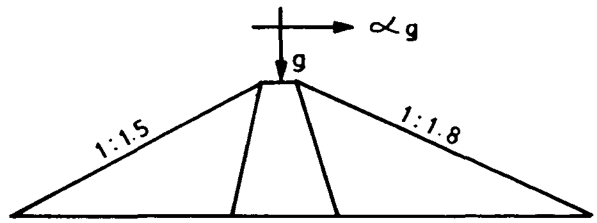

FIG. 1 DAM SUBJECTED TO ACCN. ∝g

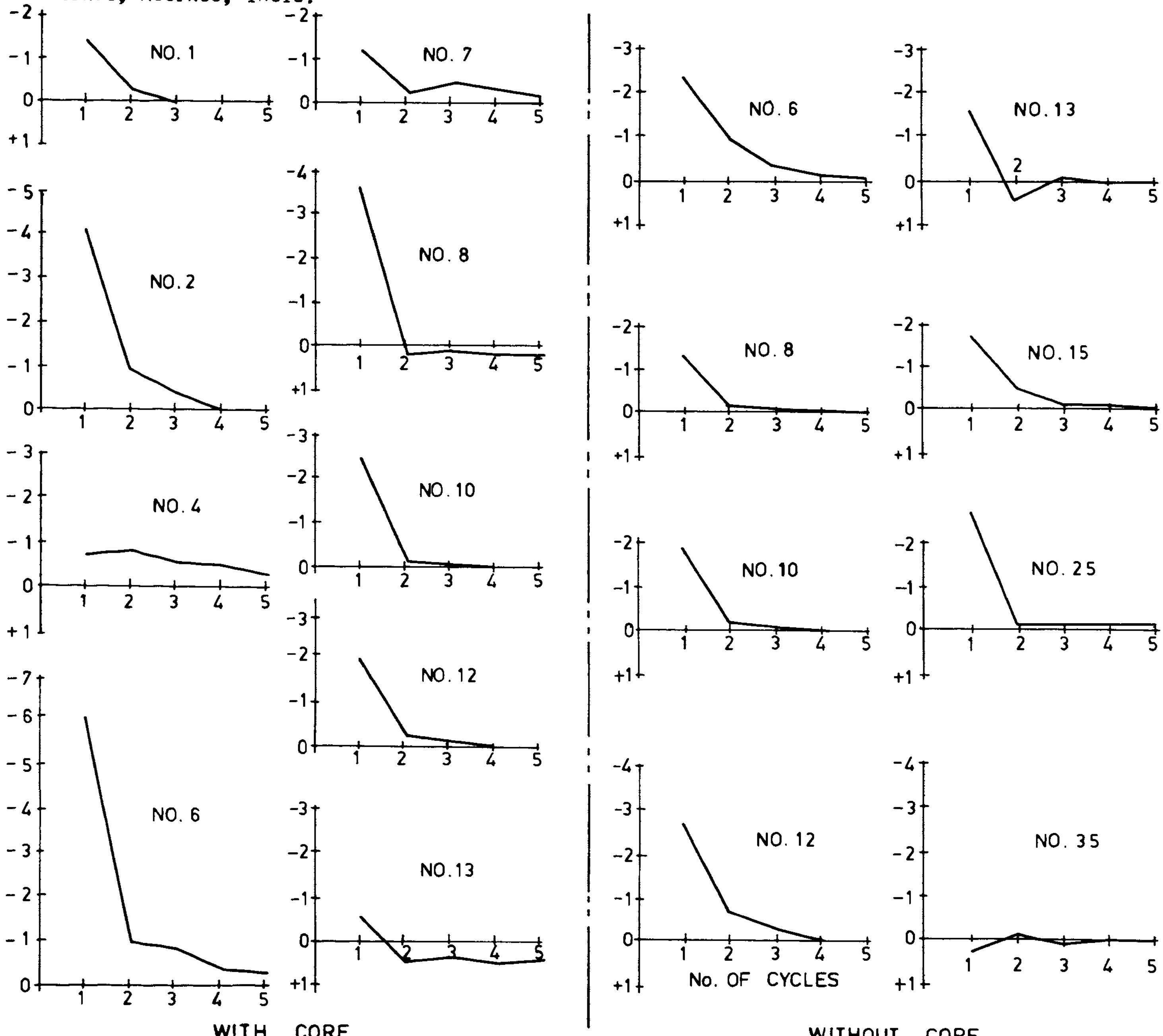

FIG. 2 DAM SUBJECTED TO ACCN. = 0.4g ORDINATE REPRESENTS STRESS (-)REPRESENTS TENSION AND (+) REPRESENTS COMPRESSION.

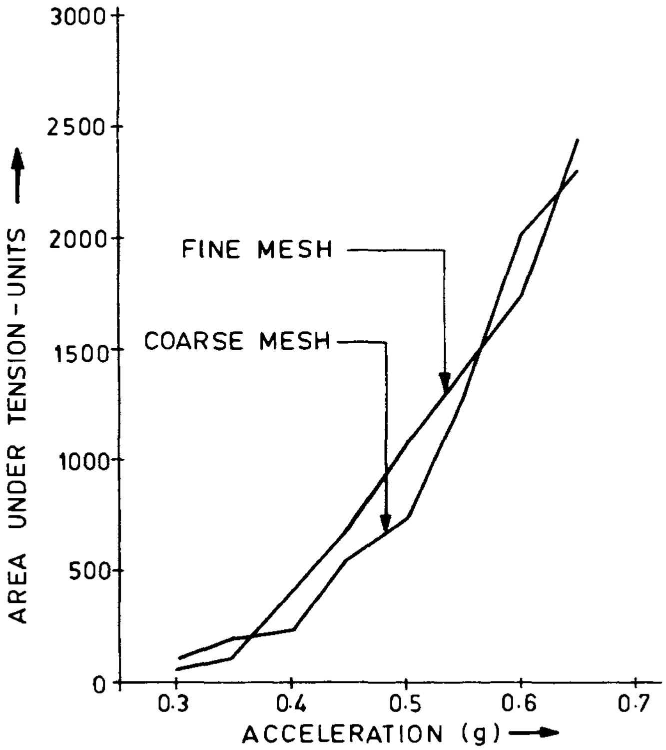

FIG. 3 COMPARISON OF AREA UNDER TENSION FOR FINE MESH AND COARSE MESH DISTRIBUTION.

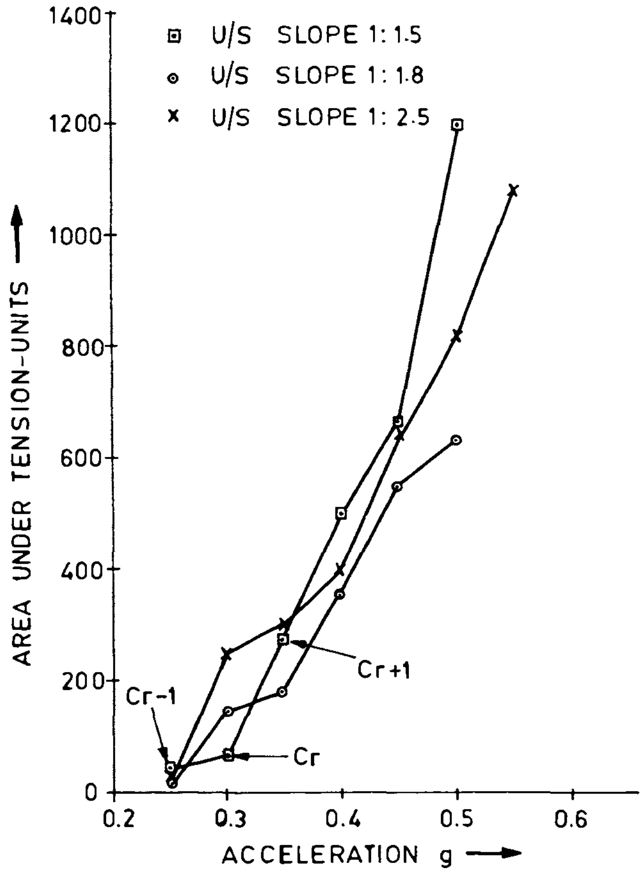

FIG. 4 AREA UNDER TENSION Vs. ACCELERATION.

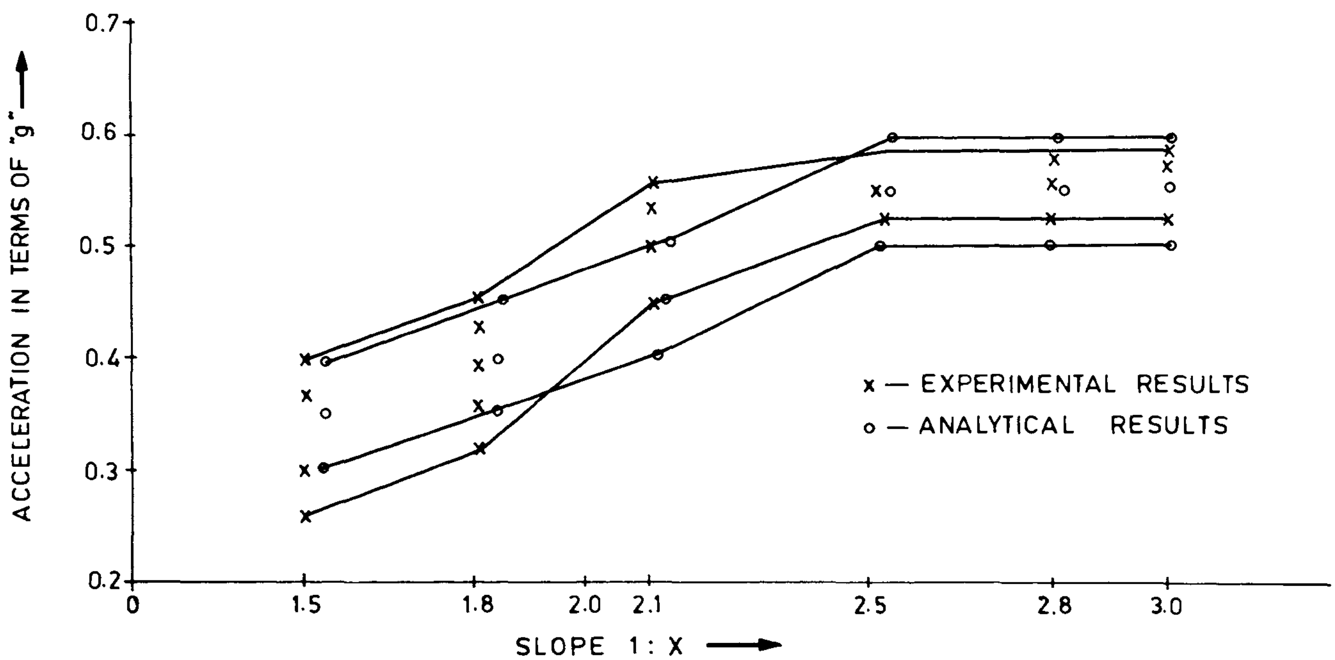

FIG. 5 FAILURE ACCELERATION Vs. U/S SLOPE