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2D FEM Analysis of Slippage Phenomenon in Earth and Rockfill Dams

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***Abstract* - Dams are gaining more attention in recent years due to the rise of the environmental awareness and 'renewable energy' and 'sustainability' concepts. Earth embankment dams are preferred over gravity dams for the ease of construction and economical advantage. Despite considerable advances in the field of geotechnical engineering, the occurrence of frequent destructive earthquakes during the past decade and the trend towards construction of structures of unprecedented size and of novel designs has enhanced the importance of earthquake resistant structural design. Rock-fill dam is a type of earth dam where a compacted central clay core is supported from the rock shells by a series of transition zones built of properly graded material. In recent years, rock-fill dams, especially the impervious-faced rock-fill dams (IFRD), are built all around the world using asphalt or concrete as the impervious material in the upstream face of the dam. This paper analyses the slippage phenomenon in the core-shell interface of earth and rock-fill dams with the aid of ANSYS16.2 package. The software was first validated then used to examine the slippage in Tehri Dam, which is located in the seismically active region of Himalayas. A 2D fem analysis is done by modelling the dam as a linear, elastic, non-homogenous material. The slippage phenomenon is modelled using contact element feature of ANSYS. Among the variables, the non-homogeneity of the core and shell material and coefficient of friction is considered in the analysis. On evaluation it is found that core settlement increases where core-shell influence has been considered.**

***Index Terms*—Coefficient of friction, core-shell interface, Earth & Rockfill dam, settlement, slippage.**

I. INTRODUCTION

Tehri Dam is a composite earth & rock fill dam of height 260.5 m consisting of shell, riprap, filter and core constructed on the Bhagirathi river in lesser Himalayas. The crest length is 570m along axis. The cross section of dam is as shown in Fig.1. The crest width is 20 m, flared to 25.0 m at the abutments. It consists of central impervious core and a shell of pervious nature consisting of well graded rock fill. The core of the dam is slightly inclined whereas the dam has an upstream slope of 2.5:1 and downstream slope of 2:1.

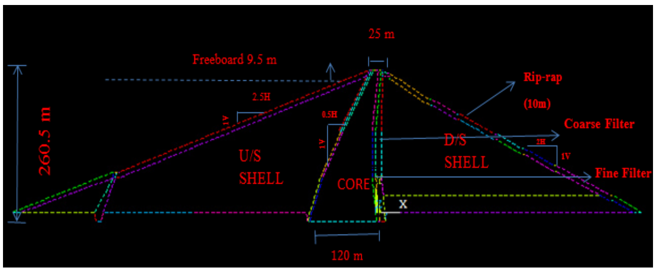

Fig. 1 Cross-section of Dam

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II. SLIPPAGE PHENOMENON

It is observed that the peak strains which remain uniform within each constituent material change abruptly at the core-shell interface. As the core consists of soft clay material the settlements in core are greater than those in shell. In reality occurrence of sliding takes place between shell (rockfill) and core (clay) is likely to occur. The results obtained considering this phenomenon are more accurate as compared to the ones which does not take into consideration the relative movement but treats the whole dam body as a single structure. The contact element feature of ANSYS 16.2 is used to model the interface. The coefficient of friction between dry rockfill and dry clay (D/S section interface) is 0.4 and between wet rockfill and wet clay (U/S section) is 0.2. The coefficient of friction is less in saturated conditions.

III. 2D FEM PLAIN STRAIN MODEL

As the conditions of plain strains are satisfied in 2D fem analysis: The cross-section of the dam was modeled using a commercially available finite element package, ANSYS 16.2 according to ANSYS user's manual. The natural frequencies and mode shapes of the 2D dam model are obtained by modal analysis. The element type used is 'Solid 8 node 183 plane strain' solid elements which is an 8 noded structural shell, suitable for analyzing thin to moderately thick structures. The element has 8 nodes with 6 degrees of freedom at each node. The whole domain is divided into 8 x 8 meshes for all the cases. The boundary condition is given fixed at the bottom of the Dam. This condition closely resembled the field situation. A total number of 1690 elements are considered. Material properties as obtained after testing are given below in Table 1.

Table1. Material Properties

S.No	Property	Shell	Core
1.	Shear Modulus ,G (N/m^2)	5.883e+07	2.942e+07
2.	Modulus of Elasticity E (N/m^2)	1.5e+09	5.29e+08
3.	Poisons ratio	0.35	0.3
4.	Moist Density(N/m^3)	2.402e+04	1.961e+04
5.	Saturated Density(N/m^3)	2.442e+04	2.108e+04
6.	Dry Density(N/m^3)	2.314e+04	1.814e+04

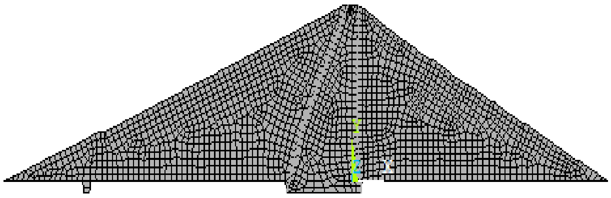

Fig.2 Discretization of 2D model

In static analysis, the submerges unit weight is taken for the U/S shell elements are the water will be seeping in from the end, saturated unit weight for the core and moist density to be considered for the D/S shell elements.

IV. MODELING OF SLIPPAGE

Surface-surface contact has been modeled to simulate the core-shell slippage phenomenon. These contact elements use a "target surface" and a "contact surface" to form a contact pair.

- The target surface is modeled with either TARGE169 (for 2-D) (shell)
- The contact surface is modeled with elements, CONTA172.(core)

Contact surface has been created on both upstream and downstream of core-shell interface. The various types of contact options available are: since the elements are not tied to each other and free to slide over each other standard type of contact is selected.

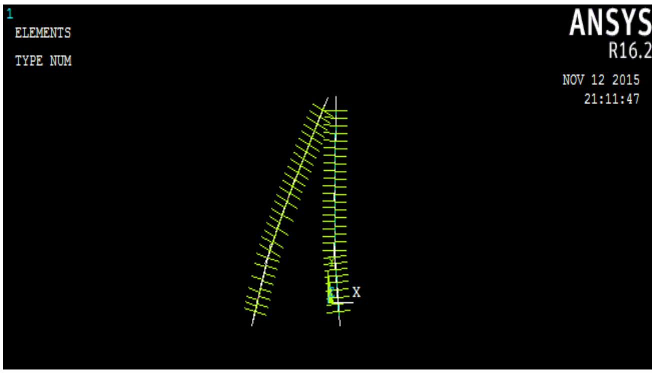

Fig. 3. Contact Elements between core-shell interfaces

V. INITIAL STATIC ANALYSIS

The first step in the analysis is to establish the in situ stress conditions that exist before the earthquake occurs. The two most important soil properties required for the initial static analysis are the:

- Mass Density
- Poisson's Ratio of the materials used

Initial static analysis of the rock-fill dam is carried out due to the self-weight load at the end of the construction. It can be observed that there is a trend of increasing displacement from base towards the crest until some depth below the crest it is observed where maximum settlement has occurred and it again decreased for the portion lying above it. On considering the slippage phenomenon profile pattern of similar nature is observed with higher magnitude.

VI. FREE VIBRATION ANALYSIS

The frequency analysis has been carried out in ANSYS 16.2 using the block lanczos method technique to study the fundamental frequency. The Block Lanczos Method is a very efficient algorithm to perform a modal analysis for large models. It is a fast and robust algorithm and used for most applications as the default solver. The fundamental vibration occurs in lateral translational mode whereas the second mode is vertical translation mode. The translations are pronounced much more near the crest of the dam. The fundamental natural periods of the model in this research have been calculated to be 1.670648 s for model without considering the shell-core interface. Considering a contact element between the shell and core the fundamental natural period increased to 1.8992 s.

VII. SUMMARY

Initial static analysis and modal analysis is being done and results are confirmed with the previous established results done on seismic analysis of Tehri dam. Further a comparative study between the dam modelled with considering the slippage between core-shell interface is done and the results of horizontal and vertical displacement, natural frequency are analyzed with respect to the dam in which core and shell elements are considered to be glued.

<table>
<tr><th colspan="2" rowspan="2">Parameter
(Maximum values)</th><th colspan="2">Contact Elements</th></tr>
<tr><th>Used</th><th>Not used</th></tr>
<tr><td colspan="2">X-Displacement (m)</td><td>2.456</td><td>2.388</td></tr>
<tr><td colspan="2">Y-Displacement (cm)</td><td>6.044</td><td>5.852</td></tr>
<tr><td rowspan="2">Vertical Stress (MPa)</td><td>- Tensile</td><td>0.77</td><td>0.65</td></tr>
<tr><td>-Compressive</td><td>8.05</td><td>8.10</td></tr>
<tr><td rowspan="2">Horizontal Stress (MPa)</td><td>-Tensile</td><td>1.27</td><td>1.38</td></tr>
<tr><td>-Compressive</td><td>3.57</td><td>3.51</td></tr>
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Table 2: Results of Tehri dam

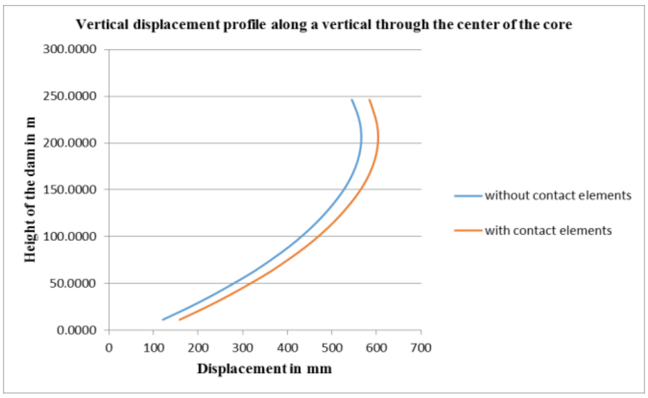

Figure 4: Vertical displacement profile along vertical

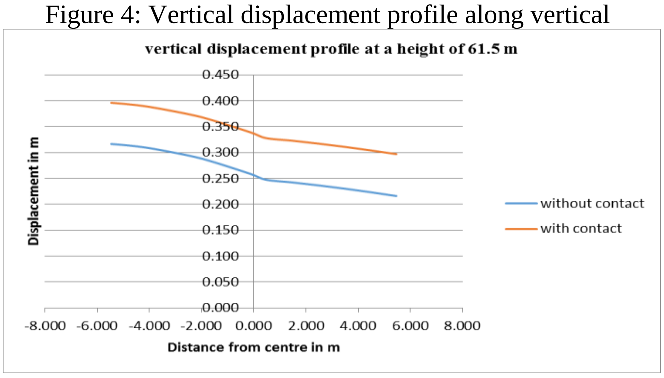

Figure 5: Vertical displacement profile along horizontal

VIII. CONCLUSIONS

1. It is seen that near the crest of the dam, the maximum horizontal and vertical displacement values are more, than in the rest of the dam. This is in agreement with the common knowledge that the top one-third height of the dam vibrates more than other part, and almost all displacement occurs in the top part. The Horizontal and Vertical displacements are within permissible limits as per I.S.:8826-1978 (1% of the embankment height).
2. Under the assumed coefficient friction based on various literature surveys, it is found that the core settlement is considerably affected by the influence of core-shell interface with the increase in excess settlement of about 0.020-0.040 m and also participates in the increase of natural time period.
3. The increase in the crest displacement is of the order of 0.070 m in horizontal direction.
4. Vertical stresses have increased from 0.65 MPa to 0.77 MPa., increase in horizontal stresses is of the order of 0.1MPa.

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Nishtha Saraswat is currently a Master’s student in the Department of Earthquake Engineering of I.I.T Roorkee (India) with bachelor’s in Civil Engineering from Harcourt Butler Technological Institute , Kanpur(India).The Areas of interest are Geotechnical Engineering, Structural Designing ,Soil Dynamics and slope stability analysis. The dissertation topic of final year research is Performance Based Design of Earth and Embankment Dams in Seismic Zone. The research work done in bachelor’s was on the topic Planning and Design of ' Grand Colosseum' cricket stadium in Lucknow involving use of STAAD PRO and AUTOCAD. Manually checking of designs in accordance with Indian Design Codes. The internships undertaken by her were on the topics of Analysis and Design of Large Span Steel Roof Truss as a part of summer training at CSIR-CBRI, Roorkee. Further she also has practical experience of onsite work while working on the project “Constructional Aspects of Modern High Rise Green Building (GAIL Jubilee Tower)”. She also did a summer intern in L & T MHI Boilers Private Limited which involved “Familiarization to Structural Design of Super Critical Boiler Structure”. She has an excellent academic record and has always been top performers in her batch during undergrad and post grad years.