Gravity Turn-on Deformation Analysis of Zoned Rockfill Dam of Proposed Bagmati Multipurpose Project, Nepal

Zoned rockfill dam, FEM, Gravity turn-on deformation analysis

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1. INTRODUCTION

Nepal has tremendous hydro-potential with an estimated economically feasible power of 42000 MW. Making a good trade-off between run-of-the-river type and reservoir type projects has no option for Nepalese economic development, which is being sought for. From the point of view of inherent stability, high seismic resistance, availability of local construction materials and relatively simple construction technology, zoned rockfill dams are considered more suitable to Nepal. The existing Kulekhani high dam and the proposed high dam of Bagmati Multipurpose Project (BMP) are the typical examples [2]. Narrowly speaking, dynamic analysis refers to the response analysis carried out to determine stress or deformation, considering only the earthquake force. The ultimate objective in carrying out dynamic analysis of a fill dam is to evaluate dam safety based on the calculated values of stress and deformation. The deformation analysis may be of greatest interest in the case of embankment dams for a number of reasons. The most important of all is that the excessive settlements can lead to the loss of freeboard and danger of overtopping which may cause an embankment dam to collapse completely. In the case of fill dams, however, the static initial conditions considerably affect the ultimate stability in earthquake [4]. This paper includes the initial static deformation analysis part of a tiny research on dynamic analysis of zoned rockfill dam, taking BMP as a case.

2. METHODOLOGY

The maximum cross section of the BMP dam designed as per the classical empirical methods was taken for the study. The dam is 117 m high above the lowest foundation. The crest is 10 m wide and about 700 m long. So the ratio of length between canyon walls and height of the maximum cross section, L/H, is about 6. The dam consists of impervious clay core covered by rock, gravel and random fill shells resting on a stiff foundation layer of gravel and sand alluvium deposit down to bedrock. The rock types available nearby are reported to consist mainly of shale and sandstone. The clay is assumed to be of rolled stiff type. Based on this general information available in the report, relevant literatures were surveyed and the material characteristics were assumed [2]. SAP2000 (V10.0.1) software package was used as the numerical tool. The 2-D plane strain assumption was made based on the rationale that the L/H ratio is greater than 5 [1, 5]. The finite element mesh in the model consists of isoparametric quadrilateral and triangular elements. To simulate the lift construction and incorporate the inhomogeneity [3], with the assumption that core is more affected, the core was divided into ten different layers. Two models were adopted; one with rigid foundation (all nodes at the base fully restrained) and other incorporating foundation flexibility (by taking some effective domain of foundation into the model). The boundary conditions for this model were such that all the bottom nodes were restrained in all directions while vertical nodes at either side of foundation were restrained against translation in horizontal direction in addition to the common plane strain restraints. To find the effective part of foundation to be taken in the model, the trial `stress criterion` was used. Fig. 1 shows the rigid foundation model while Fig. 2 shows the flexible foundation model with effective foundation geometry, obtained to be twice the base width on either sides and four times the base width underneath the base. The linear static analysis at the end-of-construction stage was performed. Investigation on the deformations within the core was focused.

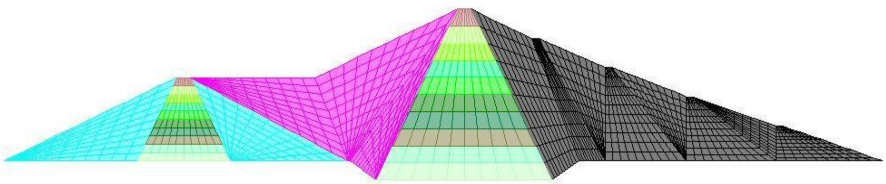

Fig.1: Rigid foundation model

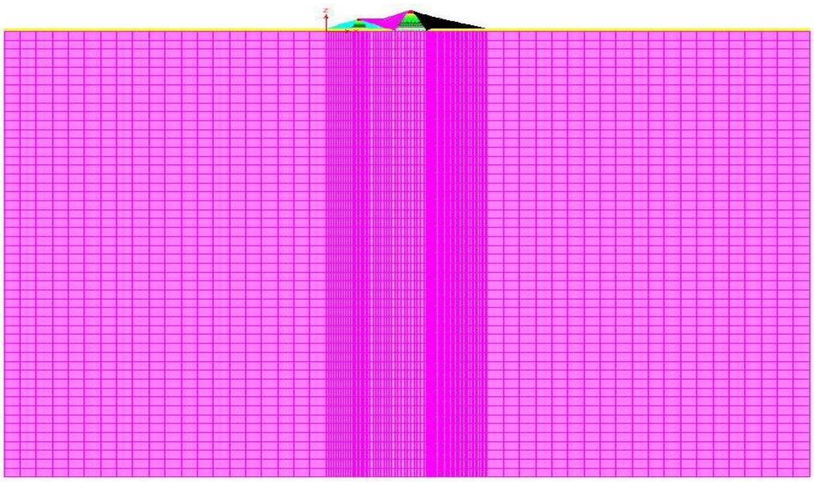

Fig.2: Flexible foundation model

3. RESULTS AND DISCUSSION

In present investigation of BMP dam, the vertical displacement (settlement) profile within the core shows an increasing trend from base towards crest until some depth below the crest where maximum settlement occurs and again decreases for the portion over it. The maximum settlement occurred at the central point of the core at a height of 93.6 m above the base. Fig. 3 and Fig. 4, respectively, show the distribution of vertical displacements (settlements) along a vertical through the core-centre and along a horizontal through maximum settlement point. The profile thus obtained, however, is different from the general perception that the maximum elastic settlement of an embankment under its self weight is at the crest. To verify the results, the FEM models of zoned rockfill dam, prepared on general purpose platform of SAP2000, were verified by carrying out studies on foundation stresses and embankment deformations on simple models of dams. Also, the pattern of the vertical stress contours compared well with the pressure bulbs obtained by the classical theory of soil mechanics. The magnitudes were verified taking a simple finite element plain strain model of a wall compared with line load assumption. Moreover, the parametric studies of elastic constants were made which revealed the negligible effects of them on the vertical foundation stresses, a fact established in the past. Parametric studies on embankment were performed taking a small symmetrical rockfill dam model (equivalent to the upstream coffer dam of the BMP dam) and analyzed for both zoned and homogenous cases. The studies suggested, as generally expected, that for the homogeneous fill dam, under gravity loads without reservoir, the settlement increases from base toward crest; with steep increase at the bottom portion while difference is small toward crest. Investigations with varying material properties also led to that trend. But, the introduction of clay core in the dam gives the same trend as obtained for the BMP dam. It is interesting that the unsymmetrical BMP dam model followed the former trend when assigned hypothetically with homogeneous material properties. For the purposes of analysis, the core of the zoned dam when assigned with some hypothetical material stiffer than the shell also exhibited similar trend with maximum settlement at the crest. Therefore, it is justified that, it is the relative stiffness of the weak core and strong shell of a zoned rockfill dam that results the profile of settlement in the core as obtained in the present research. Fig. 5 and Fig. 6 show the displacement profiles for homogenous and zoned embankments respectively

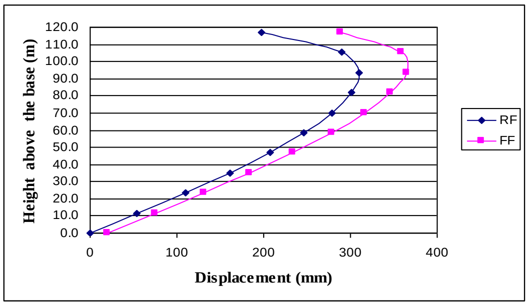

Fig.3: Vertical displacement profile along a vertical through the centre of core

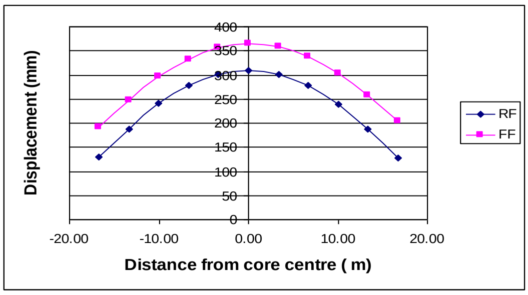

Fig.4: Vertical displacement profile along a horizontal through maximum displacement

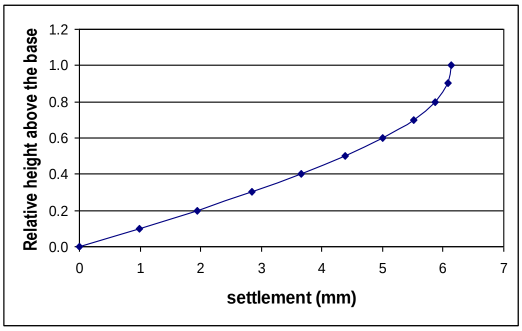

Fig.5: Displacement profile for homogeneous embankment

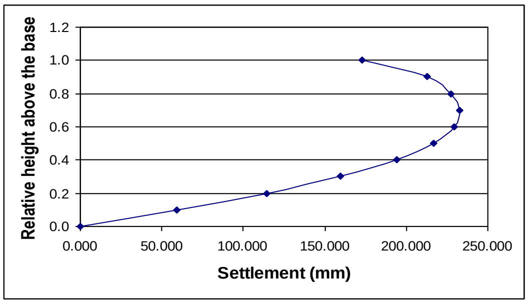

Fig.6: Displacement profile for zoned

4. CONCLUSIONS

To analyze the BMP zoned rockfill dam having irregular geometry and complex distribution of materials, FEM was used. A trial procedure of vertical `stress criterion` under the self weight load of the dam was used to investigate the effective geometry of the foundation. Unlike homogeneous embankments, the maximum settlement is not at the crest for zoned dams; it is maximum at some one-third of height below the crest instead. Under single step gravity turn-on load, the linear elastic analysis reveals that the settlements obtained from rigid foundation assumption are small compared to those with flexibility of foundation considered.

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