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ANALYSIS AND DESIGN OF EARTH AND ROCKFILL DAMS

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ABSTRACT: Hydropower or water power is a reliable, environment friendly and affordable source of electricity generation. The increased development and expansion of population in India's north eastern region, has created a definite need of hydropower for electricity generation. To meet the current as well as future demands, the available hydropower needs can be harnessed by building dams for storage and management of water for hydropower, and also addition of additional storage at existing dams for the same. As such, this paper concentrates on a case from a proposed dam of a hydro-electric project in the North East region, which has been taken up for analysis and design. The concerned dam is to be built as an earth dam. The dam section has been assumed as per the required criteria and analyzed using GEOSTUDIO software. Analysis is done for the static case. Seepage analysis and stability investigation are very important issues that should be considered for design. Hence, seepage analysis is conducted for the steady state as well as transient states using seep/w program. Stability of the dam has been checked for sliding along the base. Slope stability analysis is also performed for the upstream as well as downstream slopes using slope/w program. The slopes of the dam are considered to be reinforced with layers of geotextile. And thus stability of the dam is attained by using geosynthetics as soil reinforcement.

Keywords: Hydropower, Electricity, Dams, Hydro-electric Project, GEOSTUDIO, Seepage, Seep/w, Slope/w, Geotextile, Geosynthetics

1 INTRODUCTION

Embankment dams have become the most common type of dams, since it is generally built of locally available materials in their natural state with a minimum of processing. The construction of embankment dams is a recent world-wide trend in place of concrete dams. The major distinct features and advantages for the construction of embankment dams are: (i) Rigorous conditions are not required for the dam foundation, (ii) Earth is readily available in most parts of the world close to possible dam sites, (iii) Easy handling of earth and (iv) Lesser cost of construction.

1.1 Purpose

In this study, a case from a proposed dam of a hydro-electric project in the north east region of India, has been taken up for analysis and subsequent design. The concerned dam is to be built as zoned earth dam with an impervious core flanked with outer shells of pervious materials. Seepage analysis and stability investigation are very important issues that should be considered for design of embankment dams. In fact, in any embankment dam, one of the major problems is that of seepage, hence, seepage of the concerned dam is checked. Along with that, slope stability analysis is conducted and stability of the dam against sliding is studied. The entire north east region lies in seismic zone V which makes it vulnerable to earthquakes. As such, along with static analysis, the performance of the dam under pseudo-static earthquake load is also studied.

1.2 Study Area

The proposed dam is to be built on the Umtru river which crosses the Guwahati-Shillong road (NH-40) at Byrnihat, about 26 km from Guwahati. The area lies in the seismic zone V. The concerned dam is to be built as zoned earth dam. Existing soil in the left and right bank of the proposed dam was tested and thus classed as Poorly Graded Sand (SP) and is believed to be fairly suitable as the shell material for a zoned earth dam (Appendix A, IS 8826-1978). For the impermeable core material, borrow areas were identified within 2 km from the site. The borrow area material was classified as clay of intermediate plasticity (CI) and is considered fairly suitable for core material in an earth dam in earthquake zone (Appendix B, IS 8826-1978).

2 ANALYSIS

The analysis is done for the static as well as pseudo-static cases and both steady state and transient conditions are taken into account. SEEP/W and

SLOPE/W programs of GEOSTUDIO software are used for this purpose.

2.1 Introducing Software

GEOSTUDIO is a powerful software for geotechnical engineering, based on finite element analysis and comprising of various useful programs such as SEEP/W, SLOPE/W, QUAKE/W, SIGMA/W etc. for handling a variety of geotechnical problems. Part of the GEOSTUDIO software, SLOPE/W program is a general tool for the stability analysis of earth structures using limit equilibrium method, while SEEP/W is the primary seepage analysis program for analyzing ground water and excess pore pressure dissipation problems in porous media.

2.2 Material Properties

The shell material to be used in the analysis is poorly graded sand having permeability 9.65×10^{-6} m/sec, bulk unit weight of 17.8 kN/m^3 and angle of internal friction of 34^o. The core material is clay of intermediate plasticity having permeability 8.149×10^{-7} m/sec, bulk unit weight of 16.1 kN/m^3, cohesion of 63 kN/m^2 and angle of internal friction of 4^o. Core drilling and packer test conducted at the site reveals the foundation material to be granitic gneiss having permeability of about 1×10^{-11} m/sec. Well graded gravel is used as the material for drain.

2.3 Analysis of Dam Section

Reservoir water height is 20 m. Dam height is assumed to be 25m with a free board of 5m. All calculations are done considering plain strain condition. Initially, an embankment section having side slopes of 0.5H: 1V, as shown in figure 1, is considered. For an assumed top width of 10 m, the base width of the section comes out to be 35 m.

Seepage analysis of the section is conducted to determine important parameters such as the amount of seepage, uplift potential, exit gradients, piping potential etc. Slope stability analysis of upstream and downstream slopes has been carried out. Sliding along the dam base is also checked. In the transient analysis, the reservoir is drawn down for a period of 30 days. In general, a reservoir is not emptied all of a sudden. It is a gradual procedure and generally it takes weeks for the reservoir to be fully drawn down. And under that assumption, in the present work, a draw down period of 30 days has been considered.

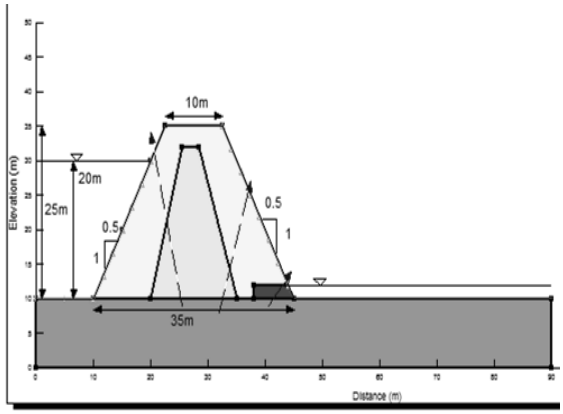

Fig. 1 Dam section having slopes 0.5H:1V

To improve the factor of safety, especially for the pseudo static and transient conditions, one other trial, with top width same as in the previous case, but with comparatively flatter side slopes of 1H:1V, as seen in figure 2, is carried out. The base width in this case increases to 60 m.

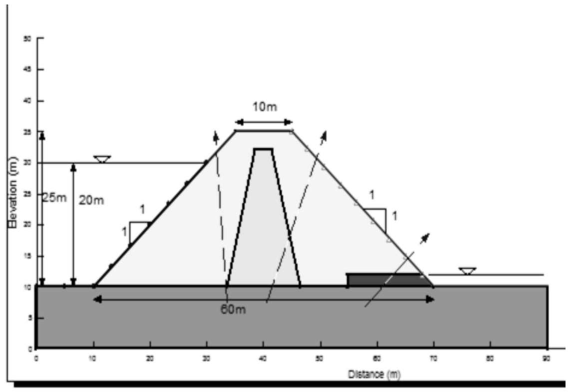

Fig. 2 Dam section having slopes 1H:1V

Though the second trial exhibits adequate factor of safety for all the analyses types namely, steady state seepage, pseudo static as well as transient analysis considering rapid drawdown, volume of earth work is a major concern for a flat side slope of 1H:1V. Considering this, a third trial, with side slopes of 0.5H:1V but reinforced with geosynthetics is carried out again. A steep slope is likely to involve less volume of earthwork and at the same time geosynthetic material placed within the body of the dam in a suitable way is likely to provide the required factor of safety (FOS). The modeled section is shown in figure 3.

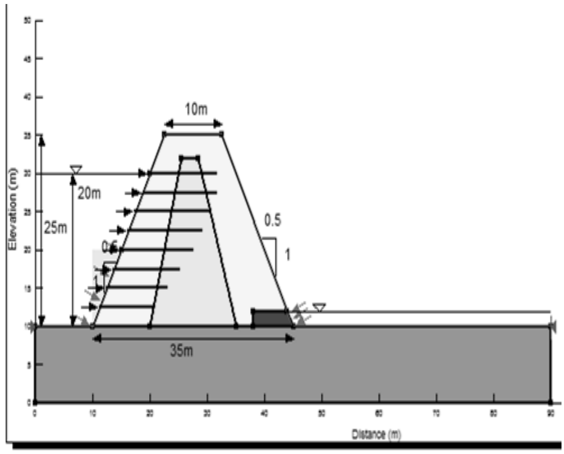

Fig. 3 Dam section having slopes 0.5H:1V reinforced with geosynthetic material

3 RESULTS AND DISCUSSION

Analysis results indicate that amount of seepage through the dam body is not very significant in any of the trials. In case of the section having side slope 0.5H:1V, the amount of seepage is found to be 1.235×10^{-5} m^3/sec while that of the section with slopes 1H:1V is found to be 1.6×10^{-6} m^3/sec.

From the point of view of piping and sliding along the base, the embankment section with slopes 0.5H:1V (with and without reinforcement) as well as the one with slopes 1H:1V, have been found to be safe. The FOS against piping and sliding for section with slopes 0.5H:1V are 4.97 and 2.05 respectively, while those for the section with slopes 1H:1V are calculated as 10.44 and 2.9 respectively.

The results of slope stability analysis for the steady state suggested that the upstream and downstream slopes of the embankment having 0.5H:1V slopes, are safe under the static condition, while under the pseudo-static condition, the upstream slope exhibits a FOS of 1.18, which is much less than the desired value of 1.5. When compared to the static case, the upstream FOS is thus found to decrease by 32%. Dam section with side slopes 1H:1V has been found to be stable under the static as well as pseudo static cases. Although found stable, a reduction of 19% in the FOS is observed in the pseudo-static case.

In the transient case, the results of rapid drawdown analysis shows that the upstream slope of the section 1H:1V is stable with FOS above 1.5 under all stages of drawdown as seen in figure 4.

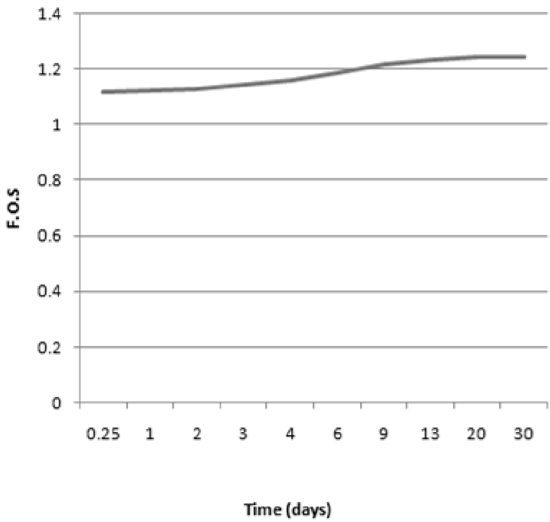

Fig. 4 Factor of safety during all stages of drawdown for the unreinforced section having side slopes 0.5H:1V

However, the upstream slope of the 0.5H:1V section (without reinforcement) is found to be marginally stable which can be seen in figure 5.

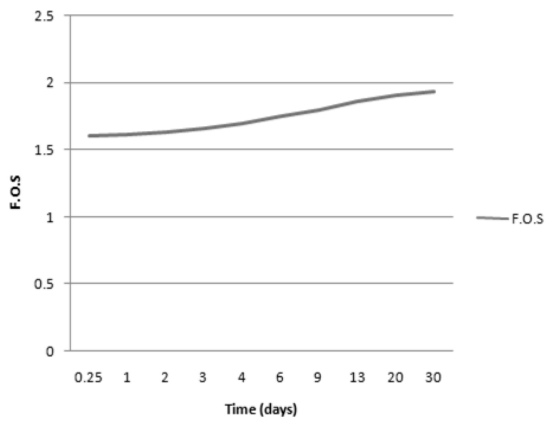

Fig. 5 Factor of safety during all stages of drawdown for the section having side slopes 1H:1V

A significant enhancement in the FOS has been noticed with placement of geosynthetic material having tensile strength of 250 kN at 2.5 m intervals on the upstream face of the dam having side slopes of 0.5H:1V. The FOS for the upstream slope in the pseudo-static case, was found to increase from 1.18 to 1.56 which is higher than the desired value of 1.5. In case of the rapid drawdown condition, FOS during all stages of drawdown increased by around 25% after implementation of reinforcement, which can be seen in figure 6.

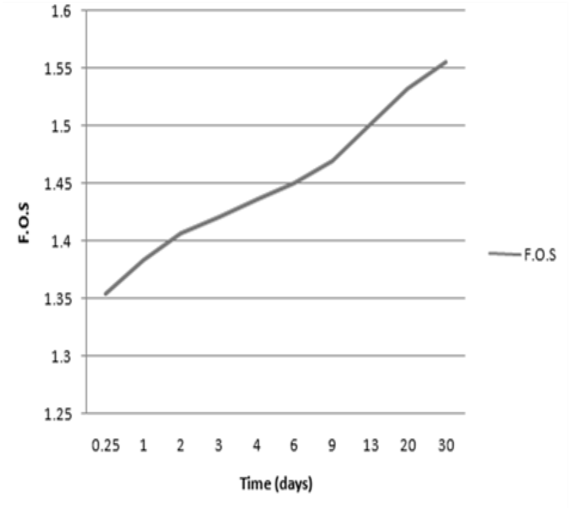

Fig. 6 Factor of safety during all stages of drawdown for the reinforced section having side slopes 0.5H:1V

A calculation of earthwork shows that the volume of earthwork reduces by 55% when 0.5H:1V section is used in comparison to a side slope of 1H:1V.

4 CONCLUSION

Detailed stability analysis has been carried out for a zoned earthfill dam to be built in the north eastern region of India. This study shows that transient analysis is as important as the steady state, especially in the analysis of stability of the upstream slope. It is observed that for a region like the north east which falls under seismic zone V, static analysis may not always ensure the stability of earthen embankments. As such, the study of performance of the dam under pseudo-static earthquake load becomes very necessary. As far as economy is concerned, the volume of earthwork plays an important role. It is seen that a section with flat slopes may satisfy all the stability conditions but may not always involve desired economy. From the current study, the following conclusions can be drawn:

- FOS of the upstream slope of the section having side slopes 0.5H:1V, reduces by 32% when earthquake load is considered, which renders the slope unstable. For the section having side slope 1H:1V, the FOS reduces by 19% in the pseudo-static analysis. However, in this case, the reduced FOS remains higher than the desired value of 1.5 which indicates the slope to be stable even under the earthquake load.
- Stability of the upstream slope of the 0.5H:1V is enhanced with the implementation of soil reinforcement in the form of geosynthetics, with the FOS rising from 1.18 to 1.56.
- In the transient analysis, the upstream slope of the unreinforced section having slopes 0.5H:1V was found to be marginally safe during the rapid drawdown condition. With the introduction of geosynthetics on the upstream slope, the FOS increased by around 25% during all stages of drawdown.
- The section having flat slopes of 1H:1V involved more volume of earthwork compared to the section having 0.5H:1V slopes. The volume of earthwork is calculated to be 55% lesser when 0.5H:1V section is considered, thus leading to economy.
- The reinforced section is found to satisfy all the stability conditions and involves desired economy.

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