Visakhapatnam Chapter

Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam

Design of Core of Earthen Dam by Replacement with Geosynthetics

Asif Ali Mohammed[1], S. Sasanka Mouli[2] and J. Y. V. Shiva Bhushan[3]

[1]Post graduate student, asifalimuhammed37@gmail.com
[2]Assistant Professor, sasankamouli_s@vnrvjiet.in
[3]Assistant Professor, jyvshivabhushan@gmail.com
VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, 500090, India.

Abstract. Earthen dams are embankments constructed from easily available soil in the vicinity of the construction site. The main components of an earthen dam are outer shells and inner core. The core is provided in the center of the dam to reduce the seepage through the embankment. The core materials of earth dams are usually selected based on available burrow areas and mainly from low-permeable geomaterials (mostly clay). Many times, it may be difficult to find a suitable clay for the core in the locality of the embankment. In the present study, the effect of the introduction of Geosynthetic Clay Liner (GCL) in the core of the embankment is analyzed. A 33m high embankment was considered and analyzed for seepage and slope stability analysis. In the present study, a geosynthetic clay liner is introduced in the core in order to reduce the thickness of the clay core. Seepage flow analysis through the embankment is studied with and without a Geosynthetic Clay Liner. Steady and sudden drawdown conditions are also considered in the study. It is observed that the usage of Geosynthetic Clay Liner results in the reduction of seepage flow through the embankment by 22 percent. Even the core material has been reduced by 13 %.

Keywords: Geo-Studio; Geosynthetic Clay Liner; Static and rapid drawdown conditions.

1 Introduction

Earthen dams are constructed with easily available soil in the surrounding area. The main components of the embankment consist of an outer shell, inner core, and drainage layer. Seepage is one of the prominent concerns in earthen dams since they are constructed by porous soil. Many embankments were failed due to seepage problems[6]. The major role of the inner core is to control the seepage through the embankment. Hence the core material is chosen in such a way that it has low permeability. However, the availability of compatible clay in the vicinity of the embankment construction site might be difficult and may incur so much transportation cost to transfer the clay to the site. In various conditions, the volume of core might be increased to a large extent in order to control seepage through the earthen dam. The stability of slopes may be critical if the pore water pressures in the dams increase beyond the permissible limits[9]. Hence proper care has to be taken in the construction of embankment to control the seepage amount [4].

Nowadays geosynthetics have many applications in the construction field. Over the past few decades, these have been widely used as they serve various functions in Embankment dams. Some of them are drainage, filtration, reinforcement, water barrier, and surficial erosion control. The main aim of using geosynthetics in dams is to prevent excessive leakage and minimize the material cost of the core section of the earthen dam. In this study, introducing geosynthetic clay liners into the core region instead of drains to control seepage. GCL will perform as a water barrier which is made up of bentonite clay sandwiched with geotextile or geomembrane as shown in Fig.1[10]. Aoyama [1] concluded that Geosynthetic Clay Liners can be used in earthen dams in the way it was used in the landfill.

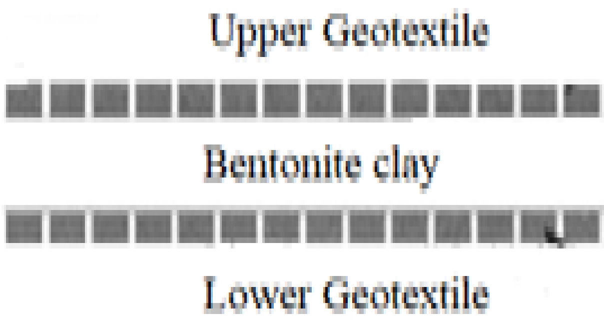

Fig. 1. Geosynthetic Clay Liner

2 Methodology

An earthen embankment dam was considered and the seepage and slope stability analysis was carried out with and without the geosynthetic Clay Liners. In the present study, limit equilibrium software-GeoStudio 2012 [7, 8]was used for the analysis. This software is capable of performing stability analysis of embankment in steady and transient seepage conditions with 2D geometry [2].

The geometrical dimensions are considered from Chahar[5] as shown in Fig.2. The upstream slope of the dam was considered as 1Vertical: 3 Horizontal. The downstream slope of the dam was taken as 1Vertical: 2.5 Horizontal. The depth of water from the base in the reservoir is 30m. However, the total height of the embankment was 33m. The slope of the centrally symmetric core was considered 1V: 0.5 H. The outer shells of the dam were constructed with homogeneous material (sandy soils) and the core with clayey deposits.

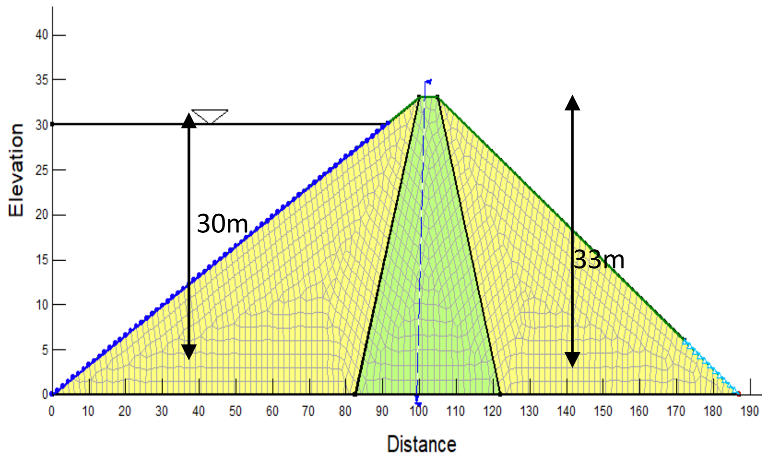

Fig.2. Sketch of Earthen dam

Calamak and Yanmaz [3] described van Genuchten technique used in SEEP/W modeling for saturated/unsaturated condition of soil material. The parameters required for van Genuchten technique are mentioned in Table 1. where k is hydraulic conductivity, θ_s is saturated water content and θ_r residual water content. Seepage analysis of the embankment for both steady state and sudden drawdown (transient state) conditions were analyzed using SEEP/W [7]. In the modelling of earthen embankment, medium mesh size was adopted and other boundary conditions were specified. Filter was modelling at the toe of the downstream side. In the steady state flow condition, the bottom 5m of the downstream face was considered as potential seepage face. Geosynthetic Clay Liner was placed at the upstream of the core of the dam. The GCL was introduced in the step manner in order to simulate field condition. GCL layer was simulated as a single material with 10cm thickness and hydraulic conductivity as 1e-11 m/s. Later a 3m clay strip was replaced with outer shell material as shown in Fig. 4.

Table.1 Parameter used in Seep/w analysis

Material	k (m/s)	θ_s (cm^3/cm^3)	θ_r (cm^3/cm^3)
Sandy clay	$1*10^{-5}$	0.4300	0.1090
Clay Core	$1*10^{-9}$	0.4750	0.0900
GCL	$1*10^{-11}$	0.500	0.0700

After the seepage analysis, the updated pore water pressures were used for the slope stability for both the upstream and downstream slopes using SLOPE/ W [8]. Slope stability analysis was examined after the steady-state and transient seepage analysis. The Morgenstern-Price method was adopted for the slope stability analysis. The entry-exit method was adopted for the calculation. The properties used for analysis are unit weight (ϒ), cohesion (*c*), and angle of shearing strength (ϕ) listed with values in Table 2.

Table 2. Soil properties for slope stability analysis

Material	ϒ (kN/m^3)	ϕ (degrees)	*c* (kPa)
Sandy Clay	19	34	10
Clay Core	17	26	100
GCL	15	20	120

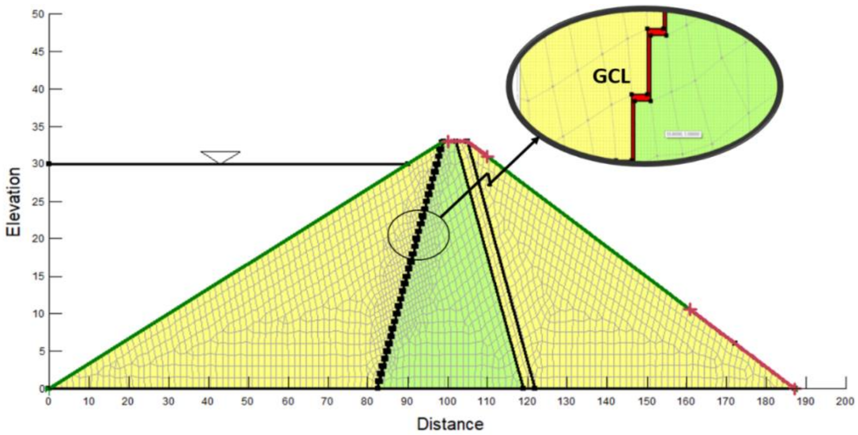

Fig. 3. Inclusion of GCL with reduction of the core area

3 Results

The seepage analysis was performed and discharge quantity was found through SEEP/W. Slope stability analysis was done in continuation of it through SLOPE/W and the factor of safety was found.

3.1 Embankment without the inclusion of GCL

In Fig. 5, results from the seepage analysis were shown. Contour lines represent the pore pressure in the embankment and the top blue line representsthe phreatic line. The discharge flow through the embankment was observed to be 1.52e-3m^3/day. Pore water pressures were about $\Upsilon_s H$on the upstream side. However, the pore water pressures reduced drastically in the corebecauseouter shell in the upstream side of the core will dissipates water from low permeable zone. It is found that the critical slip surface of the downstream side of embankment in case of steady seepage flow gives a factor of safety of 1.9 which is safe for the stability of earthen dams (Fig. 6).

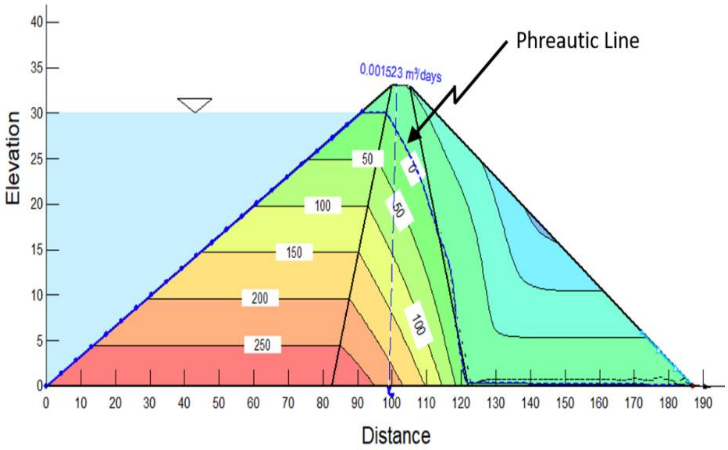

Fig. 4. Steady-state seepage and discharge across the sections of embankment

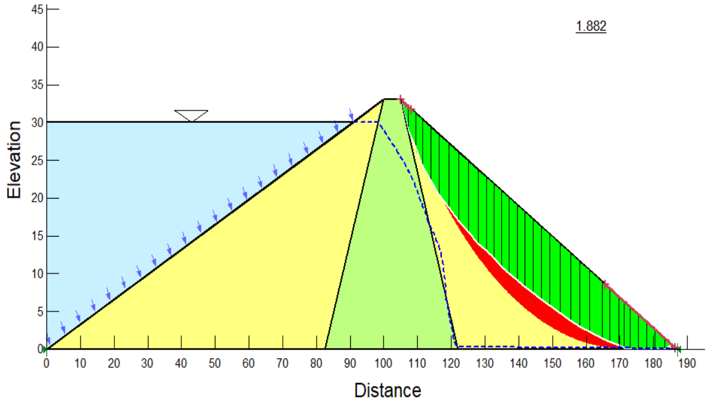

Fig.5. Critical slip surface of the downstream slope in steady-state seepage analysis

A rapid drawdown condition was also considered for the analysis. It was assumed that the water level in the reservoir was emptied suddenly to zero level in 5 days. In this condition, the soil in the upstream slope experiences undrained loading. Fig.7 shows the pore water pressure contours in the transient condition. It can be observed that water seepage is observed from the upstream side. In this condition, upstream side slope stability is critical as the pore water pressures are high in the upstream side slope. The capillary action influencedin the factor of safety of the upstream side of the embankment, which is 1.374 (Fig. 8).

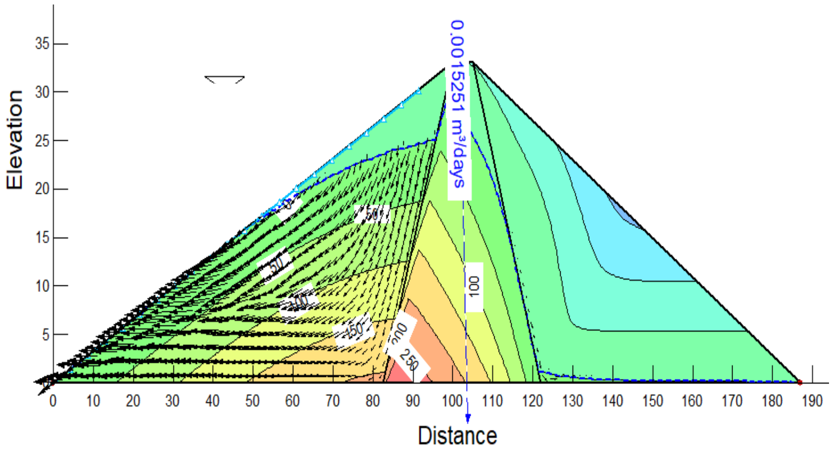

Fig.6. Pore water pressure contours in transient seepage condition in without GCLcase

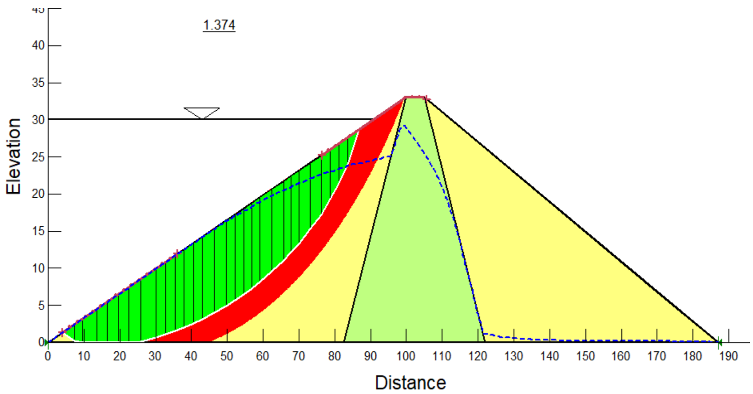

Fig.7. Critical slip surface of the upstream slope in transient seepage analysis

3.2 Embankment with inclusion of GCL

Geosynthetic Clay Liner was introduced in the embankment as shown in Fig. 4 which has lower permeability than that of the core material. Figure 9 shows the steady seepage flow in the embankment with GCL. In this case, the clay core section was reduced by 15% (by volume). The discharge rate was observed to be 1.19e-3m^3/day through the cross-section of the embankment. The discharge rate was observed to be reduced by about 22% from the case without GCL. In Fig. 10, the factor of safety of the downstream side of the embankment with steady seepage flow after the inclusion of GCL was 1.87 which is slightly lower than the factor of safety without inclusion. However, the reduction was negligible.

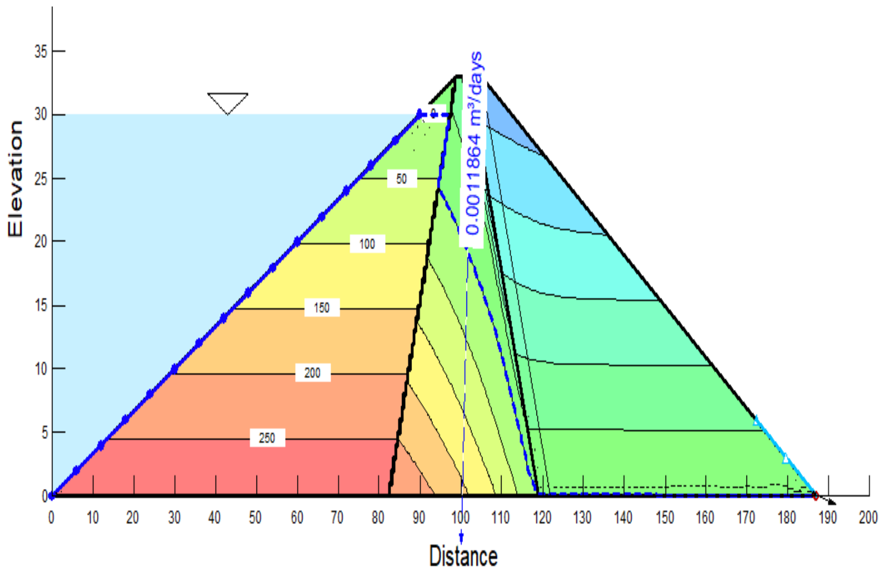

Fig.8. Steady-state seepage and discharge flow

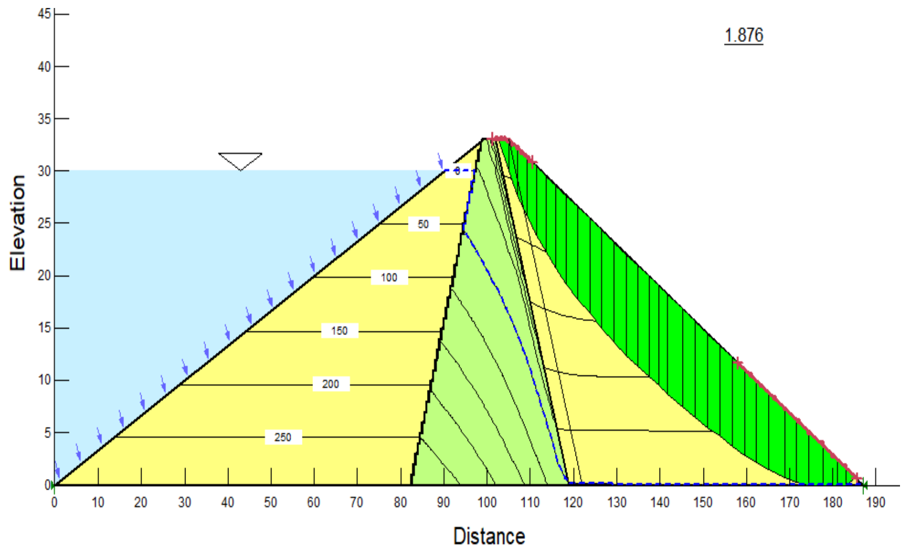

Fig.9. Critical slip surface in steady seepage analysis

Rapid drawdown state of embankment after introducing geosynthetic clay liners and by partially replacing with core lowers the phreatic line as shown in Fig.11.

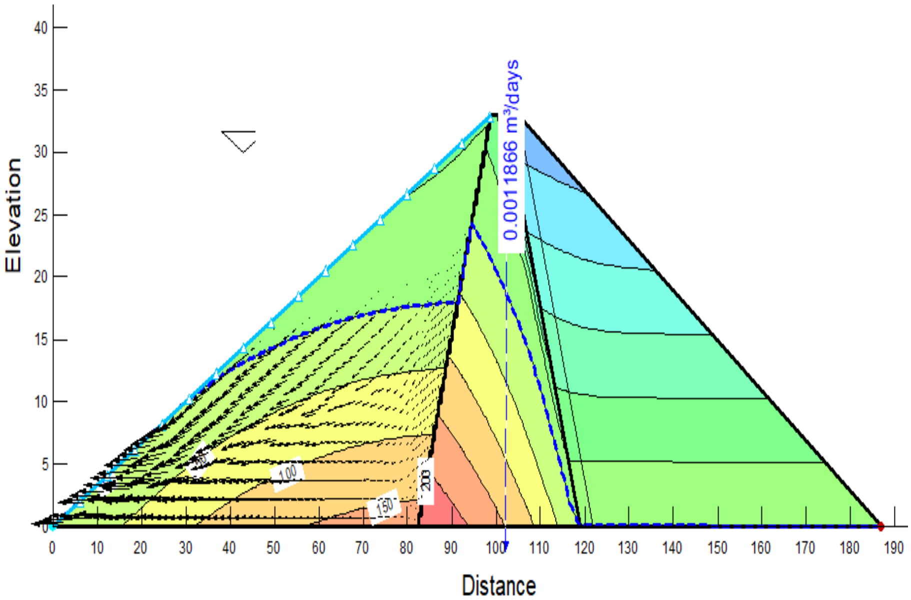

Fig.10. Transient seepage and discharge flow

Negligible change in the pore water pressures with and without providing the GCL layer. However, the factor of safety of the upstream side of embankment is 1.58 (Fig.12).

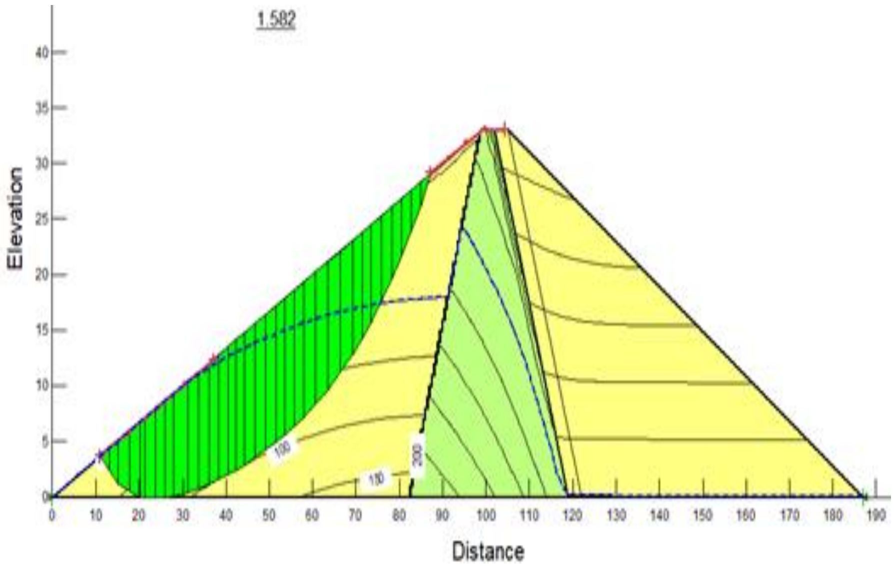

Fig. 11. Critical slip surface for the upstream sidein rapid drawdown condition

4 Conclusions

The analysis was carried in both steady seepage and transient conditions. The effect of providing GCL on seepage flow and factor of safety was well understood. The following conclusions were drawn from the study:

1. With the inclusion of GCL, discharge quantity through the embankment dam reduced by 22% in both static and transient conditions.

2. Reducing of clay core size by including Geosynthetic Clay Liners does not alter the upstream and downstream stability in both transient and steady seepage state of the embankment. Hencethe GCLs can be used at places where clay availability is scarce

References

1. Aoyama M (2011) Rehabilitation of Irrigation Ponds using Bentonite Sheets. Water L Envi Eng 79.
2. Calamak M, Melih Yanmaz A, Kentel E (2017) Probabilistic Evaluation of the Effects of Uncertainty in Transient Seepage Parameters. J Geotech Geoenvironmental Eng 143:06017009. https://doi.org/10.1061/(asce)gt.1943-5606.0001739
3. Calamak M, Yanmaz AM (2017) Uncertainty Quantification of Transient Unsaturated Seepage through Embankment Dams. Int J Geomech 17:04016125. https://doi.org/10.1061/(asce)gm.1943-5622.0000823
4. Calamak M, Yilmaz AN, Yanmaz AM (2018) Performance Evaluation of Internal Drains of Earthen Dams. J Perform Constr Facil 32:04018085. https://doi.org/10.1061/(asce)cf.1943-5509.0001232
5. Chahar BR (2004) Determination of Length of a Horizontal Drain in Homogeneous Earth Dams. J Irrig Drain Eng 130:530–536. https://doi.org/10.1061/(asce)0733-9437(2004)130:6(530)
6. Foster M, Fell R, Spannagle M (2000) The statistics of embankment dam failures and accidents. Can Geotech J 37:1000–1024. https://doi.org/10.1139/t00-030
7. Geo-slope International (2012) Seepage modeling with SEEP/W. Calgary, Canada
8. Geo-slope International (2012) Stability Analysis with SLOPE/W. Calgary, Canada
9. Singh B, R.S V (1995) Engineering for embankment dams. A.A._Balkema_Publishers
10. Shukla S kumar, Yin J-H (2006) Fundamentals of Geosynthetic Engineering. Taylor and Francis Ltd.