Design of Core of Earthen Dam by Replacement with Geosynthetics

Asif Ali Mohammed, S. Sasanka Mouli, and J. Y. V. Shiva Bhushan

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 [1]. 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 [2]. Hence, proper care has to be taken in the construction of the embankment to control the seepage amount [3].

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. This study introduces geosynthetic clay liners into the core region instead of drains to control seepage. GCL will perform as a water barrier which is

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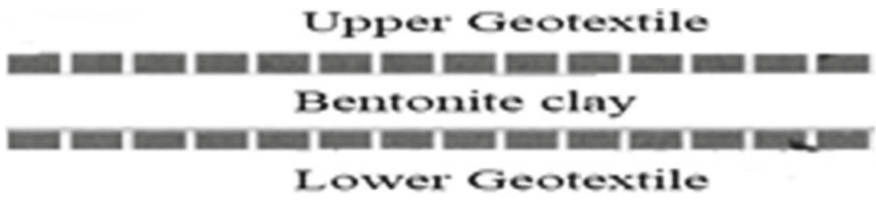

Fig. 1 Geosynthetic Clay Liner

made up of bentonite clay sandwiched with geotextile or geomembrane as shown in Fig. 1 [4]. Aoyama [5] concluded that Geosynthetic Clay Liners can be used in earthen dams in the way it was used in the landfill.

2 Methodology

An earthen 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 [6, 7] was used for the analysis. This software is capable of performing stability analysis of embankment in steady and transient seepage conditions with 2D geometry [8].

The geometrical dimensions are considered from Chahar [9] as shown in Fig. 2. The upstream slope of the dam was considered as 1 Vertical: 3 Horizontal. The downstream slope of the dam was taken as 1 Vertical: 2.5 Horizontal. The depth of water from the base in the reservoir is 30 m. However, the total height of the embankment was 33 m. The slope of the centrally symmetric core was considered

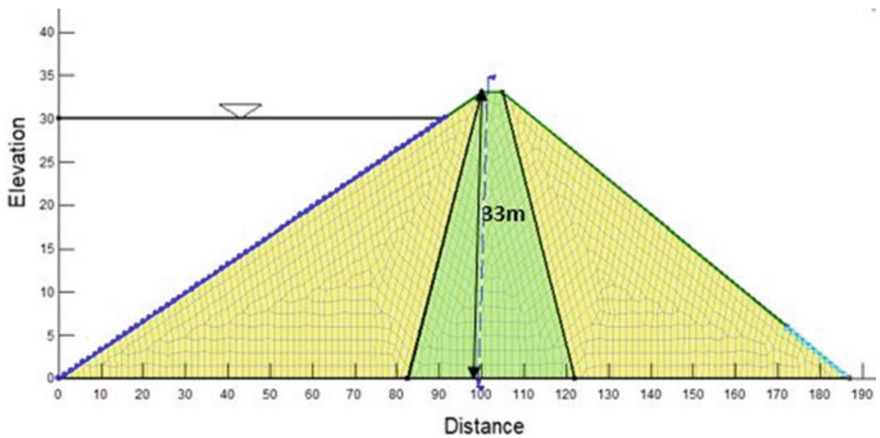

Fig. 2 Sketch of earthen dam

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

1 V:0.5 H. The outer shells of the dam were constructed with homogeneous material (sandy soils) and the core with clayey deposits.

Calamak and Yanmaz [10] described van Genuchten technique used in SEEP/W modeling for saturated/unsaturated conditions 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 [6]. In the modeling of the earthen embankment, medium mesh size was adopted and other boundary conditions were specified. Filter was modeled at the toe of the downstream side. In the steady-state flow condition, the bottom 5 m of the downstream face was considered as a potential seepage face. Geosynthetic Clay Liner was placed at the upstream of the core of the dam. GCL was introduced in the core of the earthen dam, in the form of steps (1 m rise and 0.3 m wide) for the ease of construction. GCL layer was simulated as a single material with 10 mm thickness and hydraulic conductivity as 1e-11 m/s. Later a 3 m clay strip was replaced with outer shell material as shown in Fig. 3.

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 [7]. Slope stability analysis was examined after the steady-state and transient seepage

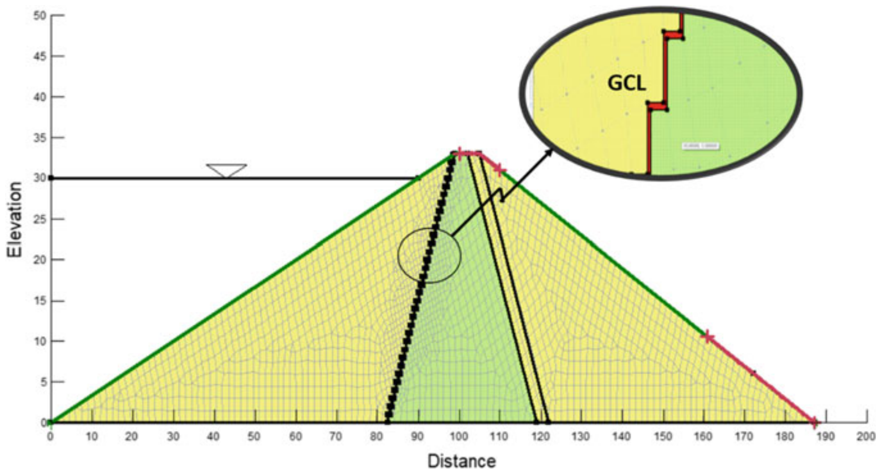

Fig. 3 Inclusion of GCL with reduction of the core area

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

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 (ɸ) listed with values in Table 2.

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. 4, results from the seepage analysis were shown. Contour lines represent the pore pressure in the embankment and the top blue line represents the phreatic line.

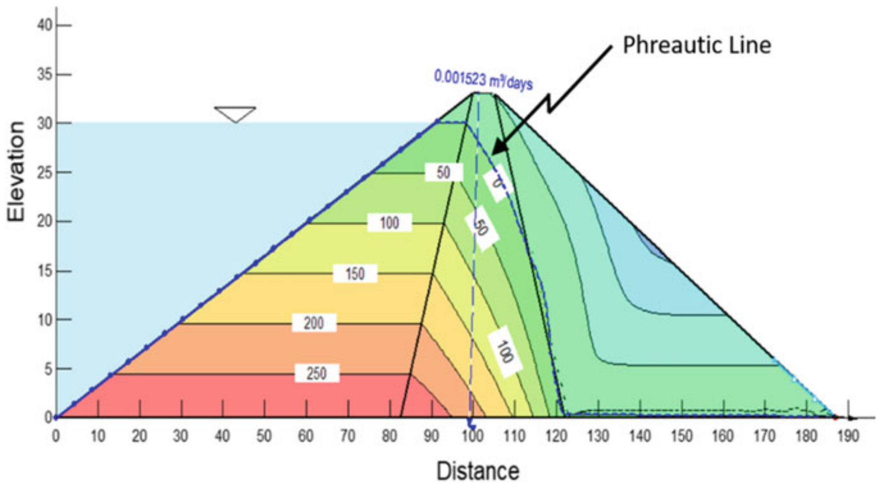

Fig. 4 Steady-state seepage and discharge across the sections of embankment

The discharge flow through the embankment was observed to be 1.52e-3 m^3/day. Pore water pressure was about $\Upsilon_s\ H$ on the upstream side. However, the pore water pressure reduced drastically in the core because the outer shell in the upstream side of the core will dissipate 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. 5).

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. Figure 6 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

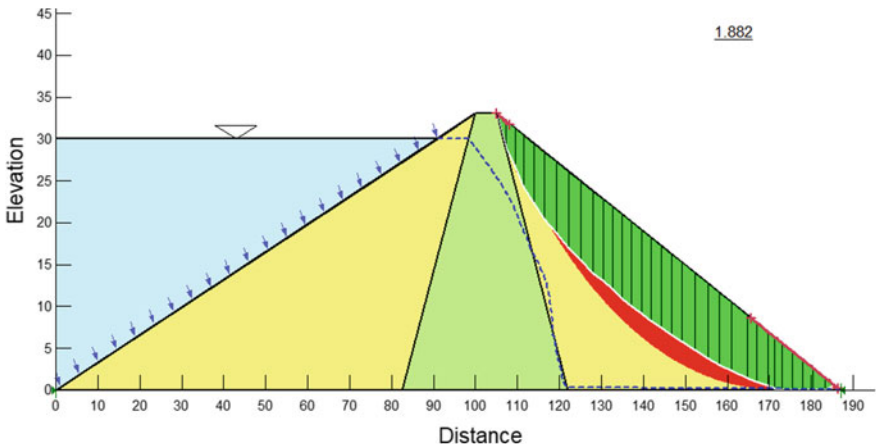

Fig. 5 Critical slip surface of the downstream slope in steady-state seepage analysis

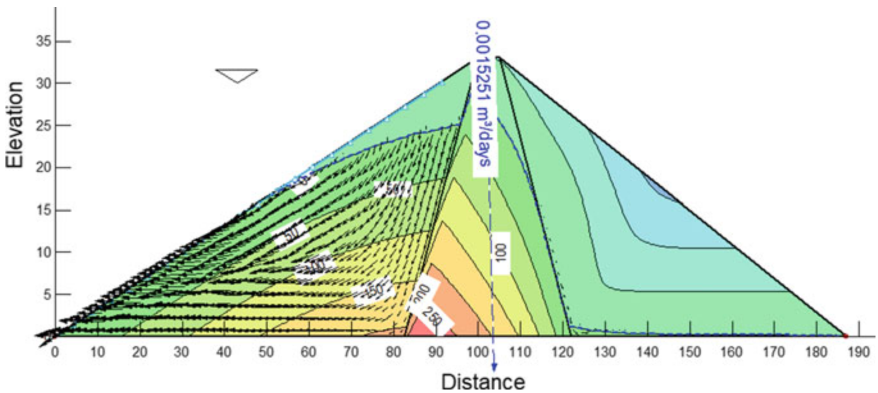

Fig. 6 Pore water pressure contours in transient seepage condition without GCL case

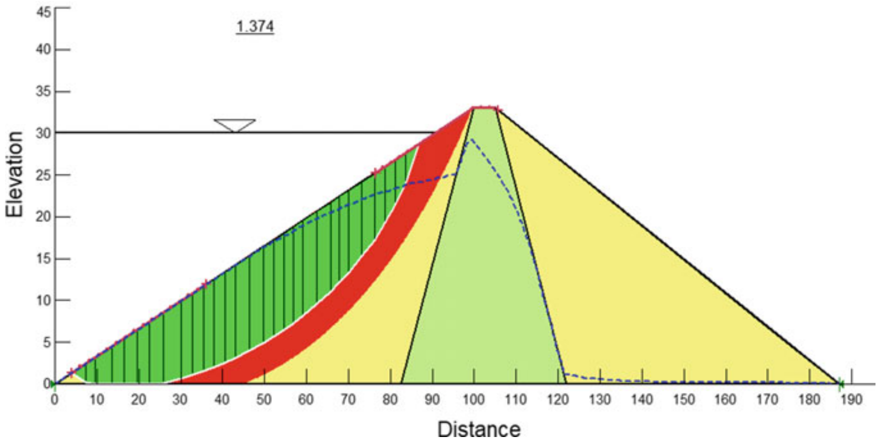

Fig. 7 Critical slip surface of the upstream slope in transient seepage analysis

side slope. The capillary action influences the stability of the upstream side of the embankment, whose factor of safety is 1.374 (Fig. 7).

3.2 Embankment with Inclusion of GCL

Geosynthetic Clay Liner was introduced in the embankment as shown in Fig. 3, which has lower permeability than that of the core material. Figure 8 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-3 m^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. 9, in the steady seepage

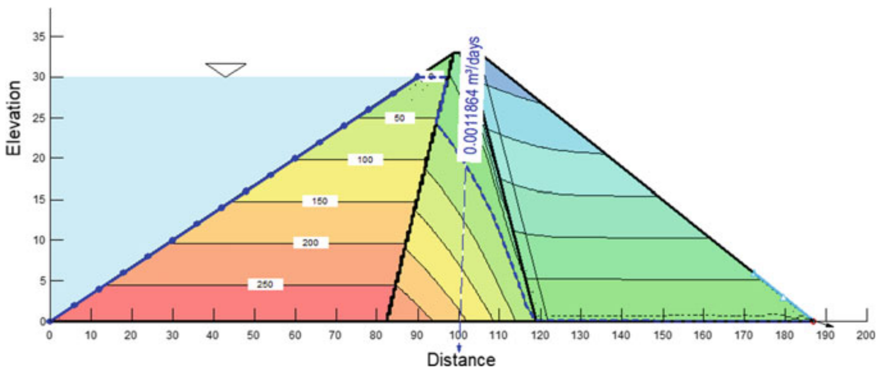

Fig. 8 Steady-state seepage and discharge flow

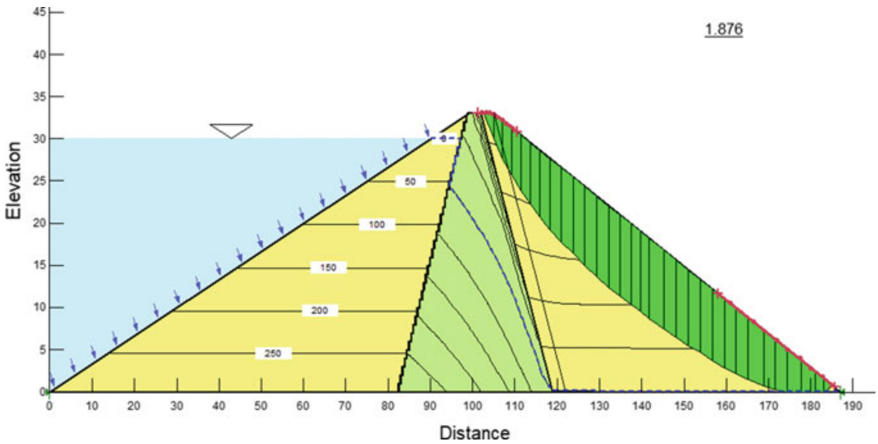

Fig. 9 Critical slip surface in steady seepage analysis

flow condition, the factor of safety of the downstream side slope after the inclusion of GCL was 1.87 which is slightly lower than that of without the inclusion of GCL. However, the reduction was negligible.

Rapid drawdown state of embankment after introducing geosynthetic clay liners and by partially replacing with core lowers the phreatic line as shown in Fig. 10.

Negligible change in the pore water pressures with and without providing the GCL layer. However, the factor of safety of the upstream side of the embankment is 1.58 (Fig. 11).

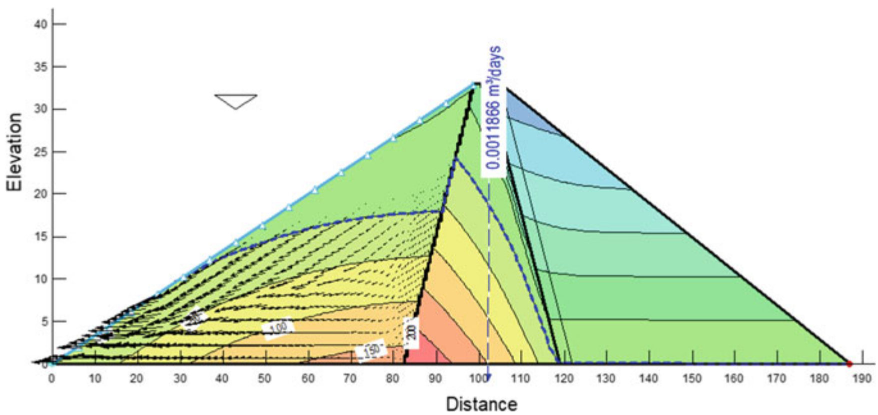

Fig. 10 Transient seepage and discharge flow

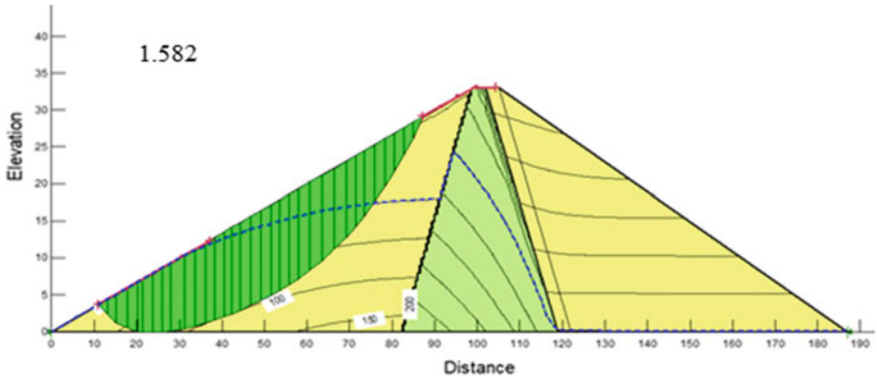

Fig. 11 Critical slip surface for the upstream side in rapid drawdown condition

4 Conclusion

The analysis was carried in both steady seepage and transient conditions. The effect of providing GCL on seepage flow and the 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 was reduced by 22% in both static and transient conditions.
2. Reducing 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. Hence, the GCLs can be used at places where the clay availability is scarce.

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