[TH-06] STABILITY OF EARTHEN EMBANKMENT WITH CLAY CORE UNDER TIDAL FLUCTUATION

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ABSTRACT: Seepage through and below earth dam plays an important role in determining the stability of earthen embankment. Stability analysis during rapid drawdown is an important aspect in earthen embankment. Reducing pore water pressure through improved drainage could possibly ensure longer life of embankments. Introduction of filters, drains, clay blankets, clay core and flatter side slopes are the potential remedial measures to avoid the failure of embankment, due to seepage. Out of these provision of an embankment core is an economic solution. The embankment core is usually installed at the centre of the embankment, has significance in controlling the seepage through embankment body. In the present investigation stability analysis of an embankment using clay core under tidal fluctuation has been studied. The current study has been done by seepage and stability analysis of a typical section of an embankment with base width of 17m and side slope 2(H):1(V) made of homogeneous soil, under rapid drawdown condition. The study has been done by finite element method using SEEP/W software varying thickness of thin clay core of embankment. Pore pressure variations, Flownet and Phreatic surface have been obtained for the numerical models by SEEP/W software. In this study the pore pressure development of the embankment, by a mixed clay core of different thicknesses, is investigated and evaluated. The stability of the slope during water level drawdown conditions has also been analyzed, considering the variation of pore water pressures calculated from the transient seepage analysis. It has been observed that, factor of safety against slope failure, decreases when river side slope of the embankment is subjected to drawdown condition. The paper brings out the effect of variation on thickness of thin clay core on improvement of stability of earthen embankments through numerical modeling.

Keywords: Stability, Pore pressure variations, Flow net, phreatic surface, Finite element method, SEEP/W

1 INTRODUCTION

When a totally or partially submerged slope experiences a decrease of the external water level, the slope may collapse by the increased seepage forces. Failures in slopes or earth dams induced by the water drawdown have been reported and investigated by Morgenstern (1963), Pauls et al. (1999), and Dai et al. (2004). Gao et al (2014) invented a slope stability chart for 3D slope subjected to drawdown condition. Reducing pore water pressure through improved drainage could possibly ensure longer life of embankments using clay core. In thin core embankment, core or impervious soil zone is flanked on either side by a zone of rock fill. Tidal induced water-level fluctuations have been specifically studied for a long time. Drawdown of an external water level is important in the stability analysis. During a transient process if the total stresses remain constant, the differential equation governing three dimensional transient case through a porous medium when the controlling parameters change with respect to has been can be written as,

$$\frac{\partial}{\partial x}\left(k_x\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_x\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(k_x\frac{\partial h}{\partial z}\right)=m_\gamma\frac{\partial h}{\partial t} \quad (1)$$

Where h = total available head under which unsteady seepage occurs; x, y= two mutually perpendicular directions i.e. Horizontal and vertical direction respectively; k_x, k_y= permeability in horizontal and vertical directions respectively; $\boldsymbol{m_\gamma}$=storage co-efficient. With this in view an attempt has been made in the present study to analyze stability of an embankment using with and with out clay core. With this in view, an attempt to analyze the stability of an embankment has been made in the present study. The present analysis has been done for an embankment of 5m height with side slope of 2(H):1(V) on seaside and 1.5(H):1(V) on countryside. A 1m wide earth filled berm has been considered at 3m from the bottom with varying clay core thickness. Pore pressure, flow net, and phreatic surface have been obtained by numerical models in numerical analysis. The stability of the slope during water level drawdown conditions is also analyzed incorporating the pore water pressures calculated from the seepage analysis.

2 ANALYTICAL MODEL

The model dam studied is presented with its dimension and the relevant soil parameters are also indicated in figure. 1. Table 1 and Table 2 represents the typical clay core geometry and properties.

Table 1 Geometry of clay core

Core crest width	2m
Slope of core (x_1)	0.4(H):1(V)
Slope of core (x_2)	0.6(H):1(V)

Table 2 Properties of clay core

Bulk Density	19.0 kN/m^3
Cohesion	43.0 kN/m^2
Friction	15°
Coefficient of Permeability	1×10^{-10} m/sec

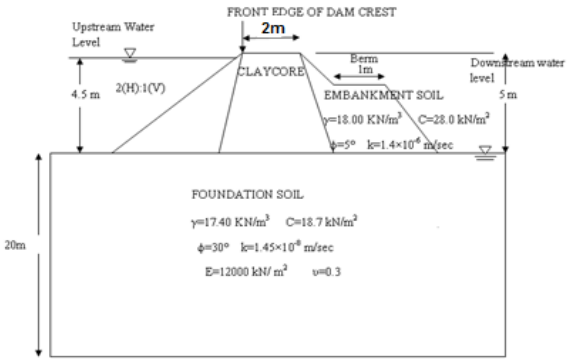


Fig. 1: Schematic diagram of dam with details

3. NUMERICAL MODELING USING GEO STUDIO

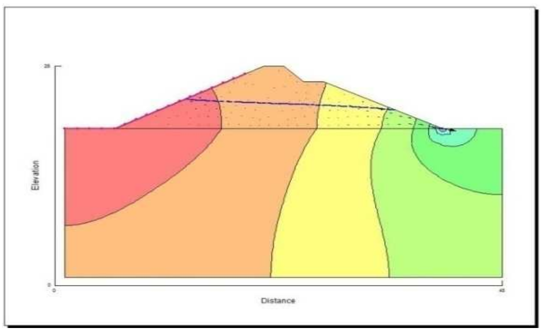
Seepage and Slope stability analyses have been carried out using Geo-Studio (GEO-SLOPE International 2012) software packages considering uncoupled transient seepage. The soil is modeled by the linear elastic perfectly-plastic Mohr-Coulomb (M-C). In this numerical model, at the upstream face of embankment Spline data point function have been applied. At the downstream end of the embankment in this numerical model, potential seepage face boundary condition has been applied. Limit equilibrium method is adopted for the present methods using uncoupled transient seepage analyses to evaluate the stability of slopes affected by change of hydraulic boundary conditions. In finite element calculation, the model has been discretized into smaller finite numbers of 1084 no of quadratic elements.

4. RESULT AND DISCUSSION

The seepage analysis in the present study has been carried out for the earthen dam with clay core. Results obtained from SEEP/W with and with out clay core, at the rate of 0.85 m/hour in draw down condition for time (t)= 0, 216 Sec, 535 Sec, 1004 Sec, 1696 Sec, 2715 Sec, 4218 Sec, 6433 Sec, 9697 Sec, 14509 Sec, 18109 Sec and 21600 Sec respectively. The results of the parametric studies are discussed below.

4.1Flownet and Phreatic Surface

Figure 2 shows the flow net diagram obtained from SEEP/W without clay core, at the rate of 0.85 m/hour for time (t) = 9697 sec in drawdown condition. Figure 3, Figure 4 shows the flow net diagram obtained from SEEP/W with clay core, at the rate of 0.85 m/hour for time (t)= 9697 Sec, 14509 Sec respectively. Figure 5 show the iso-line of phreatic surface for drawdown rate of 0.85 m/hour at time (t)= 0.0 Sec to 21600 Sec respectively obtained from SEEP/W. Phreatic surface shifts in downward direction slowly with drawdown of water level. In all the cases the nature of phreatic surface is in tangent direction to the water level and its proceeds towards downstream side. From Figure 3 to Figure 5 it is clearly observed that the phreatic surface passes through the clay core zone which decreases the exit gradient and therefore increases the factor of safety. From figure 5, in all the cases, phreatic surface



maintains continuity from the upstream to downstream side of the interface with the increment of time.

Fig. 2 Earthen dam flow net for drawdown rate= 0.85 m /hour and t= 9697 Sec

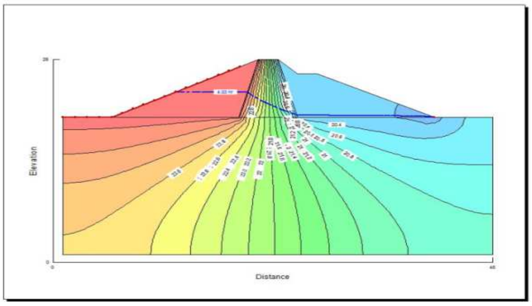


Fig. 3 Earthen dam flow net with clay core for draw down rate =0.85 m /hour and t= 9697Sec

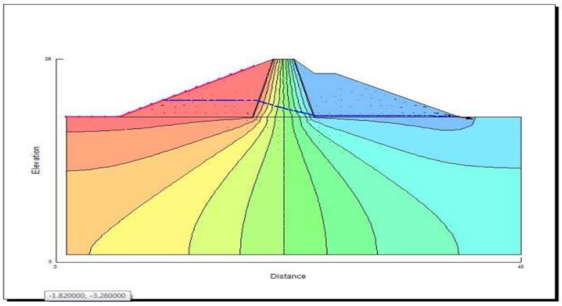


Fig. 4 Earthen dam flow net with clay core for draw down rate =0.85 m /hour and t= 9697Sec

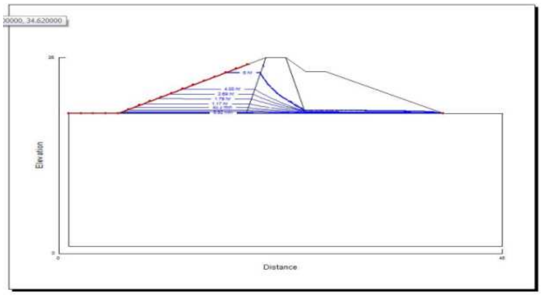


Fig. 5 Iso-line of Phreatic Surface of Earthen dam with clay core for draw down rate= 0.85 m /hour for (t)= 0 sec to 21600 sec.

4.2 PORE PRESSURE VARIATION WITH TIME

The pore water pressure variation for t=9697 hrs with and without clay core represented in Figure 6 and 7. Figure 8 represent the pore water pressure variation with clay core 5m below the base of dam for time = 0 sec to 21600 sec. It is observed that in case of the embankment with clay core pore pressure is reduced at the downstream side in single tidal cycle development.

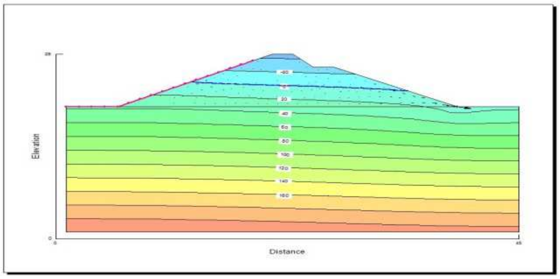


Fig. 6 Pore water pressure variation of Earthen dam with out clay core for drawdown rate= 0.85 m /hour for time (t) =9697 Sec

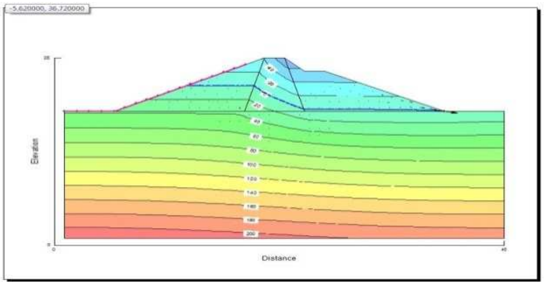


Fig. 7 Earthen dam with clay core for drawdown rate= 0.85 m/hour for time (t) =9697 Sec

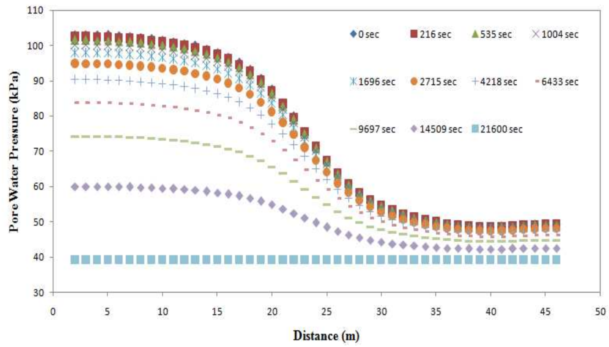


Fig. 8 Pore water pressure variation of earthen dam with clay core for drawdown rate= 0.85 m /hour for time (t) = 0 Sec to 21600 Sec (5m below the embankment)

4.3VARIATION OF FACTOR OF SAFETY WITH TIME

Slope Stability analysis has been carried out during the entire tidal cycle using SLOPE/W. The Limit equilibrium method was followed for the uncoupled analysis, with each slice analyzed by the Spencer method. A typical Slip surfaces, F.O.S and Safety map during Draw-down of a single tidal cycle has been shown in Figure 9. A total of 176 trial slip surfaces were taken and the minimum Factor of Safety was recorded. It is observed from Fig. 10 that with the use of clay core in embankment factor of safety increases up to 17% in transient seepage analysis than embankment without clay core in both drawdown conditions. It has been seen that the Factor of Safety (F.O.S) decreases from t = 6 hrs to t = 12 hrs, for a single tidal cycle. It is observed from Fig. 11 that approximately factor of safety increases up to 28 % due to increment of slope of core material. For a slope under slow drawdown or drawdown with a constant drop in water levels, the factor of safety decreases to the minimum and then increases slightly. The reason for this phenomenon may be due to the balance achieved between the rate of internal pore-water pressure and the external water pressure on the submerged boundary.

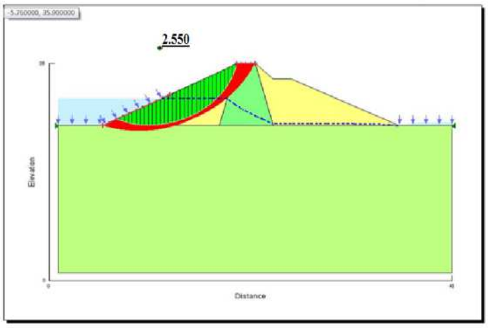


Fig. 9 Factor of safety of earthen dam with clay core for drawdown rate= 0.85 m /hour for time (t) = 14509 sec during a Single Tidal Cycle

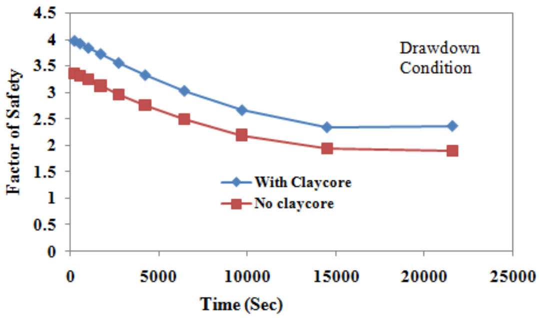


Fig. 10 Plot of Factor of safety of earthen dam with and with out clay core against Time during a Single Tidal Cycle

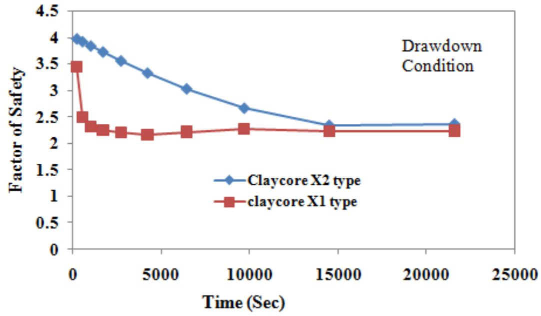


Fig. 11 Plot of Factor of safety of earthen dam for different clay core sizes against Time during a Single Tidal Cycle

5 CONCLUSIONS

The following conclusions may be drawn from the present study,

1. Clay core within embankment effectively change the position of phreatic surface
2. Development of pore pressure within the embankment and its foundation effectively reduces by using clay core under drawdown condition.
3. With use of clay core factor of safety increases upto 17% in transient seepage analysis than embankment without clay core in tidal cycle.
4. Factor of safety increases up to 28 % due to increment of size of core upto 25%.

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