International Journal of Science Academic Research
Vol. 02, Issue 01, pp.814-816, January, 2021
Available online at http://www.scienceijsar.com

ISSN: 2582-6425

Research Article

MODELLING THE EFFECT OF HORIZONTAL SAND BLANKET ON THE STABILITY OF A HETEROGENOUS EARTH DAM AGAINST PIPING FAILURE UNDER STEADY SEEPAGE CONDITION

***Abdul A. Koroma and Simeon S. Turay**

Department of Civil Engineering Fourah Bay College, University of Sierra Leone

Received 18th November 2020; **Accepted** 20th December 2020; **Published online** 29th January 2021

Abstract

GB3 Water storage Earth Dam is a 301m long, 101m wide and 18m high geotechnical structure constructed by Sierra Rutile Mining Company in Sierra Leone. This is a zoned earth filled heterogeneous embankment dam with an upstream slope of 1:3 and downstream slope of 1:2 with a horizontal sand blanket. The reservoir capacity of the dam is 5,386,000m^3. Over the years, piping effect has been the most prevalent cause of failure of most heterogeneous Earth dams. Existing earth dams have suffered a lot from this effect. As a result of this a comprehensive analysis in modelling the effect of horizontal sand blanket on the stability of heterogeneous earth dams against piping failure was carried out. The quantity of water seeping through the dam was estimated using SEEP/W software alongside Slide 7 software which helps in estimating the critical hydraulic gradient used in evaluating the stability nature of the dam against piping. The heterogeneous earth dam was initially modelled without the inclusion of a horizontal sand blanket. The seepage quantity estimated was$0.00511 \times 10^{-6}\, m^3/s$ per metre length of dam with a maximum exit gradient of 0.28. This gives a safety factor against piping failure of 3.1. It was then modelled with the presence of a horizontal sand blanket. In this case, the total seepage quantity was estimated to be $0.141 \times 10^{-6}\, m^3/s$ per metre length of dam with a maximum exit gradient of 0.15. This resulted in a factor of safety against piping failure of 5.8. The results obtained from the study indicate that the inclusion of a sand blanket gradually increases the quantity of water seeping through the dam but there by providing a substantial safety factor against piping failure.

Keywords: DAM, GB3, Blanket.

INTRODUCTION

This paper presents comprehensive findings on the effect of horizontal sand blanket on an embankment dam. Wet areas on the downstream side of Earth Dams and other related structures are not usually natural springs. They are seepage through or under the dam. All dams have some amount of seepage as the impounded water continues to seek paths of least resistance through the dam and its foundation. Seepage becomes very much critical if it is carrying material with it, (a phenomenon referred to as piping) and should be controlled to prevent erosion of the embankment, foundation, or damage to concrete structures. Piping has become one of the common causes of dam failure. It becomes critical under steady state when the seepage flow intersects the downstream slope. Most Earth Dams are designed and constructed with a sand blanket aiming at limiting the movement of fine materials through the dam. Some are constructed without a sand blanket but still serve the purpose, even though the safety nature of the dam against piping will be very much critical. Seepage related problems contribute to about 30% of Earth dam failures and other related structures. As a result of this and in order to evaluate the effect of a horizontal sand blanket in handling piping issues on earth dams, a comprehensive seepage analysis was conducted both with and without the inclusion of a horizontal sand blanket using SEEP/Wand slide 7 softwares. SEEP/W is two dimensional finite element software used in analysing groundwater seepage and excess pore water pressure and dissipation problems within porous soil materials. Its formulation enables analyses ranging from simple saturated steady-state problems to complex saturated/unsaturated time-dependent problems.

Corresponding Author:** ***Abdul A. Koroma
Department of Civil Engineering Fourah Bay College, University of Sierra Leone

Slide 07 is 2 - D finite element software from the Rocscience family used in groundwater seepage analysis for various loading conditions. This software helps in providing the maximum exit gradient used in this study for the two different models.

Objective

Soil materials can be transported by flowing water. This movement can be internal, underground, or beneath the hydraulic structures, especially if there are cavities, cracks in rock, or high exit gradient at the toe of heterogeneous earth dams or other related structures. This has been a critical concern especially towards the stability of the structure. Most embankment dams are constructed with or without a horizontal sand blanket. In either case, seepage and piping issues have been prevalent. The engineering question remains, which case provides substantial safety of the dam against piping? This paper provides an answer to such question. The objective of this study therefore, is to use SEEP/W and Slide 7 softwares in evaluating the effect ofa horizontal sand blanket on heterogeneous Earth Dams in solving seepage and piping related problems.

METHODOLOGY

The study was conducted in two phases. SEP/W and Slide 7 softwares were initially utilized in modelling the heterogeneous earth dam without a horizontal sand blanket. The stability nature of the structure against piping failure was assessed in this case. This was done in order to establish the basis for comparison purposes. A sand blanket was then incorporated and its effect in handling the stability issues of the dam against piping failure was evaluated under steady state seepage condition.

Steady state seepage in an embankment dam without a horizontal sand blanket

Since the need of this research is to effectively evaluate the role of a horizontal sand blanket in handling stability issues of an embankment dam, it is useful to initially analyse the structure without the inclusion of a sand blanket**.** Slide 07 was used in evaluating the maximum critical hydraulic gradient used in assessing the stability of the embankment dam against piping failure. Over the years, some researchers have developed several relationships in order to determine the safety nature of embankment dams against piping failure. These equations are presented below.

$$FS = \frac{i_{critical}}{i_{exit}} \quad \text{.........} (1)$$

$$i_{critical} = \frac{G-1}{1+e} \quad \text{........} (2)$$

$$e = \frac{G\gamma_w}{\gamma_d} - 1 \quad \text{........} (3)$$

$$\gamma_d = \frac{\gamma}{1+w} \quad \text{........} (4)$$

Where $i_{critical}$ and i_{exit} are the critical and maximum exit gradients respectively. The latter is obtained by the use of Slide 07 software. Equations (3) and (4) determine the void ratio and dry unit weight of the soil material. In equation (2),the maximum critical gradient is computed with the results obtained from equations (3) and (4). Equations (1), (2), (3) and (4) were utilised in determining the factor of safety of the embankment dam against piping failure.

The material properties of the various zones of the dam used in both softwares are given in Table 1

Table 1. Properties of the Embankment Soil Material

Material	Unit Weight (KN/m^3)	Cohesion (KN/m^2)	Angle of internal friction (^{o})
Clay	19	40	10
Shell	19	10	35

Steady state seepage in an embankment dam with a horizontal sand blanket

Numerous researchers have performed studies on the application of a sand blanket in embankment dams. There are different types of drainage systems applied to Earth dams. They include Chimney drain, horizontal drain and toe drain. The chimney drain is most times applied at the downstream side of the impermeable clay core in zoned embankment dams and the toe drain and horizontal drain have been widely applied to the downstream side of homogeneous embankment dams. The focus of this study is limited to the use of a horizontal sand blanket which has been widely used in handling seepage and seepage related problems. After modelling the embankment dam as in the above case, a horizontal sand blanket was then incorporated at its toe. SEEP/W software was then applied to the model in estimating the quantity of water seeping through the embankment dam under steady state seepage condition Slide 7 was likewise used in evaluating the maximum critical hydraulic gradient used in assessing the stability of the embankment dam against piping failure. Steady state condition has been considered in both softwares used for this study.

The material properties of the various zones of the dam used in both softwares are presented in Table 2.

Table 2. Properties of the Embankment Soil and Sand Drain Material

Material	Unit Weight (KN/m^3)	Cohesion (KN/m^2)	Angle of internal friction
Clay	19	40	10
Shell	19	10	35
Sand blanket	19	10	35

RESULTS AND DISCUSSION

In this section, the results obtained from the two softwares are presented. Such results are thus used in the equations provided above in order to evaluate the stability of the dam against piping failure. Seepage analysis was carried out to determine the effectiveness of installing a horizontal sand blanket. It was initially performed without the inclusion of a horizontal drainage blanket using SEEP/W software. In such a scenario, the quantity of water expected to seep through the Dam using SEEP/W was obtained to be $0.00511 \times 10^{-6}\, m^3/s$ per metre length of dam with a maximum exit gradient resulting from Slide 07 software of 0.28. This resulted to a factor of safety against piping failure of 3.1, which is considered marginally acceptable.

SEEP/W software results are shown in figure 1 and Slide 07 results are shown in figure 2.

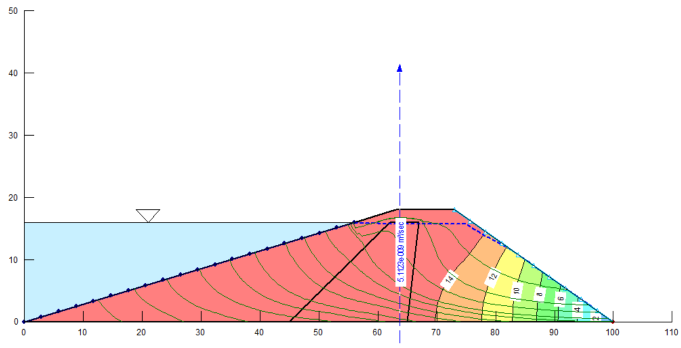

Figure 1.Seepage Quantity without s Sand Blanket using SEEP/W

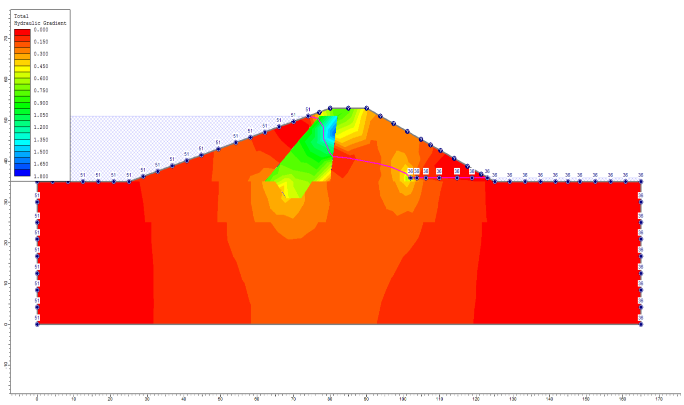

Figure 2. Maximum Exit gradient without a Sand Blanket using Slid 07

Consequently, a horizontal drainage blanket was incorporated. The quantity of water expected to seep through the dam in this case is $0.141 \times 10^{-6}\, m^3/s$ per metre length of dam with a maximum exit gradient of 0.15. This resulted to a factor of safety against piping failure of 5.8.

Results of SEEP/W and Slide 07 Software are shown in figures 3 and 4 respectively.

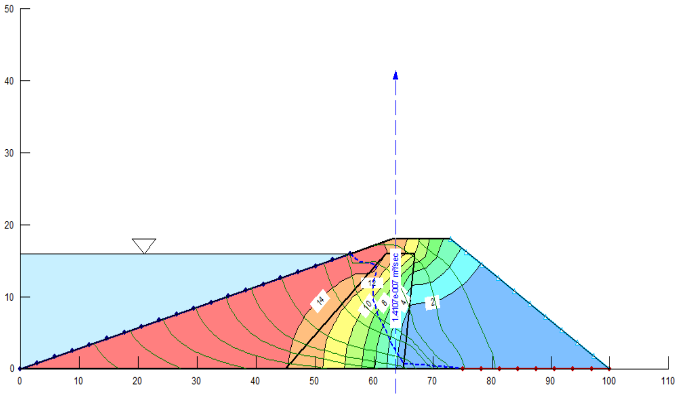

Figure 3. Seepage Quantity with a Sand Blanket using SEEP/W

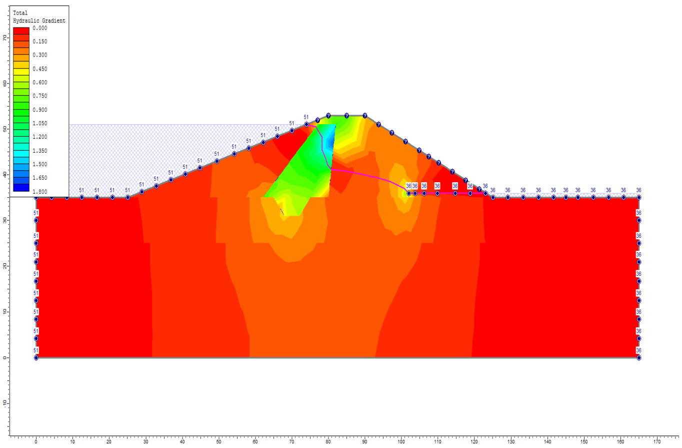

Figure 4. Maximum Exit gradient resulting from the inclusion of a Sand Blanket using Slide07

Based on the results obtained from the two Softwares for the two cases, the following trends were observed and discussed. The quantity of water expected to seep through the dam without incorporating a sand blanket using SEEP/W is$0.00511 \times 10^{-6}\, m^3/s$. That which is expected to seep through the dam when a sand blanket is included rises up to$0.141 \times 10^{-6}\, m^3/s$. This shows a substantial percentage difference of 13.6%. Similarly, the maximum exit gradient obtained in the absence of a sand blanket using Slide 07 software is 0.28.Thishigh exit gradient will induce instability at toe of the dam, such that soil particles can be washed into them and transported away by high velocity seeping water. That which is obtained when a sand blanket is incorporated falls to 0.15. This represents a marginal percentage difference of 13%. It is observed that, the reduction in exit gradient is as a result of the inclusion of the horizontal sand blanket which substantially limits the movement of finer particles within the dam body. This gives a safety factor of 5.8 thereby ensuring greater stability of the dam against piping failure.

Conclusion

In steady state seepage analysis, increase in pore water pressures leads to a decrease in effective stress in the soil. This decrease in effective stress will equally lead to a reduction in the available shear strength of the soil. Water seeping through the dam has the potential of causing internal erosion of the foundation or embankment material. This phenomenon referred to as piping has been investigated under steady state condition both with and without the inclusion of a horizontal sand blanket.

From the study, the following conclusions were made:

That the role of a sand blanket does not necessarily means to limit the amount of water seeping through the earth dam. This is seen by the 13.6% increase in seepage during the inclusion of a horizontal sand blanket. This inclusion of sand blanket basically limits the migration of finer foundation or embankment materials. This will reduce the effect of piping thereby ensuring the safety of the dam against piping failures. The maximum exit gradient in the absence of a sand blanket is 0.28. This represents a substantial steeper slope thereby leading to a greater exit velocity. This large exit gradient will cause the soil on the downstream side of the dam to heave thereby causing the potential for piping failure. With the inclusion of a horizontal sand blanket, the maximum exit gradient drops to 0.15. This is marginally acceptable as such value leads to smaller exit velocity which substantially reduces the flow of finer particles from the dam body. A safety factor against piping failure of 5.8 is achieved. This representsa 2.7 increase in safety from the 3.1 obtained in the absence of a sand blanket. According to the comprehensive studies carried out by Foster et al. (2000)and Fell et al. (2003), internal erosion and piping have been the main causes of failure in embankment dams since they destabilize the downstream slope. Such problem as seen from this current study can be solved by incorporating a well graded sand blanket on the downstream toe of earth dams.The application of the sand blanket has been seen to lower the phreatic line thereby dissipating the excess pore water pressures. It controls any seepage that exits the downstream portion of the dam and prevents erosion of the downstream slope.

REERENCES

Braja M. Das, “Advanced Soil Mechanics”, Third edition, 2007, Taylor & Francis.

Filters for Embankment Dams – Best Practices for Design and Construction by FEMA.

Foster, M., Fell, R. and Spannagle, M., “The Statistics of Embankment Dam Failures and Accidents”, *Can. Geotech. Jr.,* 37, 1000-1024, 2000.

Geotechnical Engineering- Principles and Practices by Donald P. Coduto.

Guidelines for the construction of earth dams – by Dr. Alan Harradine.

Lambe T.W. & R.V. Whitman, “Soil Mechanics”, SI Version, 1979, John Wiley& Sons.

"National Dam Safety Program Research Needs Workshop: Outlet Works" FEMA 539, Federal Emergency Management Agency, August 2006.

Taylor, D.W. Stability of earth slopes. *J. Boston Soc. Civil Eng.,* XXIV (3), 1937, 337-386.

****