

Original Article



Numerical Evaluation of the Mtibwa Sugar Estates Earthfill Dam Safety, in Turiani-Morogoro, Tanzania

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Abstract

Earthfill dams are vital for water supply, irrigation, and flood control, but their safety can be threatened by structural weaknesses and poor maintenance. This study evaluates the safety of the Mtibwa Sugar Estates Earthfill Dam in Turiani, Morogoro Region that supports irrigation and economic development but limited monitoring raise stability concerns, necessitating safety measures to protect livelihoods. The assessment combined field reconnaissance, geotechnical laboratory testing of dam materials, and numerical modeling using GeoStudio 2023.1. Seepage through the embankment was analyzed using SEEP/W, while slope stability was assessed with SLOPE/W. Results showed soil permeability ranging from 2.25×10^{-10} to 1×10^{-2} m/s, cohesion between 0 and 173 kPa, friction angles of 9.28° – 38° , and moisture contents of 10%–30%. These values indicate a clay core with low permeability suitable for seepage control, supported by shell and drain materials that allow adequate drainage. Variations in strength parameters reflect both weak clayey and stronger sandy layers, influencing stability. Seepage discharge was 4.54×10^{-6} m/sec, while slope stability analysis yielded a factor of safety of 1.566, confirming stable slopes. The study recommends improved drainage, monitoring systems, periodic stability assessments, and stronger dam safety management.

Keywords · Earthfill dam; Dam safety; Seepage analysis; Slope stability; GeoStudio; Mtibwa dam,

1 Introduction

A dam is a structure designed to contain, store, or impound water, either permanently or temporarily, for various purposes. Dam safety refers to measures undertaken to minimize the risk of failure and safeguard the structure (MOW, 2020; ICOLD, 2011). These are critical infrastructure that provide benefits such as water supply, irrigation, hydropower, flood control, and recreation (National Research Council, 2012; Chatterje, 1998; Bhattarai, 2016). Designing an

embankment dam is complex because foundation conditions are often uncertain and construction relies on heterogeneous local soils and rock materials, which vary in strength and permeability (Craig, 2004; Fell et al., 2005). Although design and construction practices have improved significantly over time, experience and engineering judgment remain key in their development (Craig, 2004; Agarwal, 2010).

Despite the importance of dam safety management, existing studies in Tanzania predominantly focus on

general administrative frameworks and safety practices, neglecting detailed technical evaluations of geotechnical factors critical to dam stability. For example, (Robert, E.M, 2013) discussed safety management practices across several dams, while overlooked site-specific factors like soil composition, seepage, and slope stability. Unlike larger dams such as Mindu and Nyumba ya Mungu, the Mtibwa Sugar Estates Earthfill Dam has received minimal technical attention despite its critical role in supporting sugarcane irrigation and local livelihoods. The absence of systematic safety evaluations raises concerns about its long-term stability and performance, warranting a detailed investigation into its structural integrity and hydraulic safety. Similar limitations are observed in other regional studies (Mbilyi & Kaduma, 2015; Mbowe, 2018). Previous research emphasizes that soil properties, particularly cohesion and friction angle,

construction and safety challenges (Lucian, 2006 ; Balsubramanian, 2016). Long-term dam performance is also influenced by multiple factors including animal burrowing, erosion, seepage, and slope instability (Chanson, 2015; Fell et al., 2014; Foster et al., 2000). However, there remains insufficient investigation into how these factors interact to influence overall dam safety under varying operational and environmental conditions. Therefore, this study evaluates the safety of the Mtibwa Sugar Estates Earthfill Dam in Morogoro, Tanzania, focusing on technical aspects such as soil characteristics, seepage behavior, and slope stability.

2 Materials and Methods

2.1 Description of the Study Area

Mtibwa Sugar Estates Ltd is a Sugar-producing company located in Turiani, Morogoro Region. The dam site is located on a part of the Dakawa Wami,

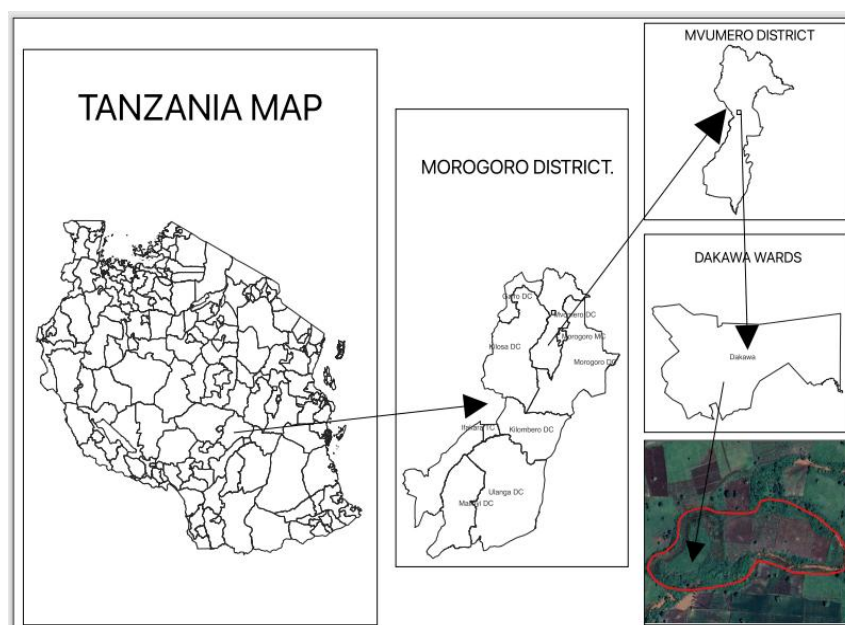


Figure 1: Mtibwa Earthfill dam

strongly affect slope stability, especially under conditions like rapid drawdown (Mkilima, 2022 ; Bidyashwari et al., 2017; Fell et al., 2005). Moreover, the complex geology of Tanzania, marked by variable soil and rock formations, presents additional

Flood Plain ($6^{\circ} 24' 45''\text{S}$, $37^{\circ} 40' 06''\text{E}$). Ground elevations lie between 380m–395m above mean sea level with respective immediate proximities on relatively flat terrain with gentle slope toward the North. Being close to the Equator, Morogoro

experiences a tropical bimodal rainfall pattern. The city has two distinct rainy seasons, 'long' rains, which run from March to May, and 'short' rains, from October to December. The mean annual rainfall ranges between 580mm and 1191mm. The annual average temperature ranges between 23°C and 32°C. The Tanganyika geology map shows that the geology of the dam site originates from Sedimentary and Metamorphic rocks. In 2018, the Company intended to increase its productivity throughout the year by expanding the coverage on the reserved area. The proposed Mtibwa Estates expansion was to be established on approximately 4500ha of virginbush land on Dakawa Wami Ranchi. In that regard, the Mtibwa Sugar Estates Ltd constructed an earth embankment dam capable of storing about 500,000 m³ of water for irrigation purposes. The Dam consists of earth embankment (main embankment and saddle embankment), with spillways. The Dam is zoned consisting of a central core (Clay) of low permeability and earth fill, as shown in Figure 1.

2.2 Reconnaissance Survey (field data collection)

A reconnaissance survey was conducted through site visiting at the dam site to identify the location of the investigation points, geotechnical features and physical ground conditions. Soil samples for geotechnical testing were systematically collected from various key zones of the Mtibwa Sugar Estates earthfill dam to assess the engineering properties relevant to seepage and slope stability analysis. Sampling focused on the following primary zones of the dam structure: -

2.2.1 Clay Core (Central Zone)

Samples were taken along the central longitudinal section of the dam where the impervious core is located. This zone is critical for controlling seepage. Samples were collected at depths ranging from 0.5 meters to 5.0 meters, with intervals of approximately 1.0 meter, depending on the core height and accessibility.

2.2.2 Shell Zone (Upstream and Downstream Shoulders)

The outer shell zones, composed of more pervious materials, were sampled on both the upstream and downstream slopes. Depths varied from 0.5 meters to 3.0 meters, and samples were spaced at 10-meter intervals horizontally to capture lateral variation in material properties.

2.2.3 Foundation Zone (Base of the Dam)

Samples from the foundation beneath the core zone were collected using boreholes to assess seepage potential from underlying layers. Sampling extended down to a depth of up to 6.0 meters below the ground surface, depending on borehole reachability and groundwater conditions.

2.2.4 Drain and Filter Zones (where exposed)

Limited samples were also taken from the toe drain and filter material where accessible, primarily for permeability evaluation.

2.2.5 Laboratory Experiments

Soil samples collected from the dam embankment test pit undergo laboratory testing. Disturbed and undisturbed soil samples from pits were taken, packed in sample bag or waxed and transported to the estate soil laboratory for classification and testing. Soil Classification tests, permeability, shear test were performed in the laboratory.

2.3 Seepage Analysis in Earthdam

Seepage is the movement of water through a dam's body or foundation, primarily influenced by soil permeability. Uncontrolled seepage can lead to internal erosion, piping, or even structural failure. Measures to control seepage include designing a low-permeability core, installing drainage systems, and using filters to prevent soil particle migration (Terzaghi, 1996). Seepage is defined as the flow of water through homogenous saturated soil under steady state condition; the soil particles, the soil structure and water

are assumed to be incompressible and that flow obeys Darcy's law (Delwyn D. Fredlund, 1993)

Modern tools like SEEP/W allow engineers to model seepage patterns and predict potential issues. Continuous monitoring with piezometers helps detect abnormalities, ensuring timely maintenance (Craig, 2004)

The flow of water through soil is one of the fundamental processes in geotechnical and geo-environmental engineering. Flow quantity is a key parameter in quantifying seepage losses from a reservoir or identifying a potential water supply for domestic or industrial use. Pore-pressures associated with groundwater flow are of particular concern in geotechnical engineering. The pore-water pressure, whether positive or negative, is an integral component of the stress state within the soil and consequently has a direct bearing on the shear strength and volume change behavior of soil (Utepov *et al.*, 2022)

In general, all water flow is driven by energy gradients associated with the total head of water as represented by the components of pressure head (or pore water pressure) and elevation. The term seepage often is used to describe flow problems in which the dominant driving energy is gravity, such as a case in which seepage losses occur from a reservoir to a downstream exit point. In other situations, such as consolidation, the primary driving energy may be associated with the creation of excess pore-water pressures as a result of external loading (Utepov *et al.*, 2022)

2.3.1 Seepage Quantification by Finite Element Method

Seepage refers to the flow of water through the body or foundation of an earth dam, primarily governed by the soil's permeability. Uncontrolled seepage may lead to internal erosion, piping, or eventual structural failure. To minimize such risks, dams are constructed with low-permeability cores, drainage filters, and properly designed toe drains (Terzaghi, 1996).

The quantification of seepage in earth dams can be approached through both analytical and numerical methods. The most fundamental analytical method is based on Darcy's Law, which describes the rate of seepage through porous media as:

$$q = k \times i \times A, \quad (1)$$

Where:

q = seepage discharge (m^3/s)

k = coefficient of permeability (m/s)

i = hydraulic gradient

A = cross-sectional area of flow (m^2)

This formula applies to steady-state flow in homogeneous, saturated soils, assuming incompressible fluid and soil particles, and flow that conforms to Darcy's linear law (Fredlund, 1993).

For complex flow patterns and heterogeneous dam structures, numerical methods like the Finite Element Method (FEM) are preferred. Software tools such as SEEP/W simulate seepage by solving governing flow equations over discretized dam geometries. FEM accommodates complex boundaries, variable material properties, and both steady-state and transient flow conditions, providing a more realistic assessment of seepage behavior (Geo-Slope International Ltd, 2013).

FEM: The flow region is divided into discrete grid pattern but not necessarily rectangular, Finite Element Method, divide the flow region into discrete element and provides N equations with N unknown.

Material properties such as permeability are specified for each element and boundary conditions (heads and flow rates are set). A system of equations is solved to compute heads at nodes and flow in the elements. The advantages of finite element methods over other finite methods are:

- i. The complex geometry including sloping layers of material can be easily accommodated

- ii. By varying the size of elements, zones where seepage gradients or velocity are high can be accurately modelled. materials like geotextiles or geomembranes are used to reinforce slopes and prevent erosion. A comprehensive understanding of soil mechanics and slope stability

Table 1: Formula for calculation of the safety factor

Slice No	α_n	$W_n = A \gamma$	$T = W_n \sin \alpha_n$	$N = W_n \cos \alpha_n$
1	α_1			
2	α_2			
N	α_n			
			$\sum T$	$\sum N$

- iii. Pockets of material in a layer can be modelled (Delwyn D. Fredlund, 1993). One of the finite element method computer software is called GEO-SLOPE

2.4 Slope Stability Analysis

Slope stability is a critical aspect of earth dam safety, as it directly affects the dam's ability to withstand various loading conditions, including water pressure, rapid drawdown, and seismic forces. The stability of a dam's slopes is influenced by several factors, including soil type, slope geometry, pore water pressure, and external loads. For instance, soils with high cohesion and friction angles provide better resistance to sliding, while excessive pore water pressure within the soil can reduce shear strength and lead to instability (Bidyashwari *et al.*, 2017). Stability analyses are commonly performed using limit equilibrium methods (LEM) such as Bishop's or Janbu's techniques, which evaluate potential failure surfaces and factors of safety. Advanced software tools like GeoStudio (SLOPE/W) and SLIDE allow engineers to model complex conditions and simulate various failure scenarios. Mitigation strategies for slope instability include reducing the slope gradient, adding berms, and installing drainage systems to lower pore water pressure. In some cases, geosynthetic

principles is vital to ensuring the long-term safety and functionality of earth dams (Craig, 2004). The slope stability of the Mtibwa Sugar Estates earthfill dam was analyzed using Bishop's Simplified Method, a limit equilibrium technique that estimates the factor of safety (FoS) by considering both the forces and moments acting on circular failure surfaces. This method assumes that inter-slice shear forces are negligible, making it suitable for analyzing saturated slopes such as those in embankment dams.

2.4.1 Analysing Finite Elements by the Swedish Slip Circle Method

Swedish slip circle method or Swedish method of slices (for purely cohesive and cohesive-friction soils)

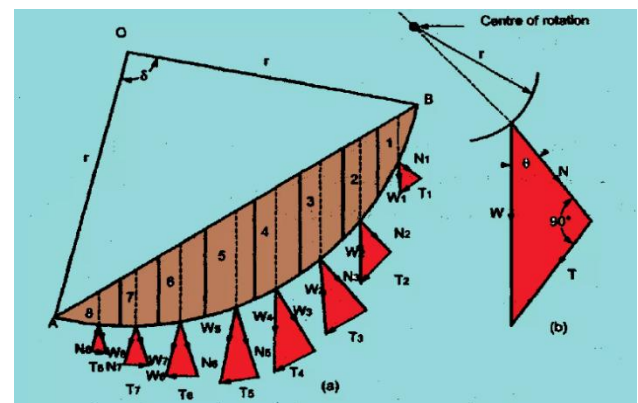


Figure 2: Schematic of a circular slip surface AB showing tangential and normal forces, segment length ΔL , radius r , cohesion C , and internal friction angle Φ

For the entire slip surface AB Figure 2 above, there is Driving moment

$$MD = r \sum T; \text{Resisting moment } M_R = r [c \sum \text{change in } L + \tan \Phi \sum N] \quad (2)$$

Where $\sum T$ = algebraic sum of all tangential components

$\sum N$ = sum of all normal components

$$\sum \text{change in } L = L = 2 \pi r \Delta L / 360 = \text{length AB of slip circle} \quad (3)$$

Hence, factor of safety against sliding is

$$F = M_R / M_D = (CL + \tan \Phi \sum N) / \sum T \quad (4)$$

A number of trial slip circles are chosen and factor of safety of each is computed. The circle giving the minimum factor of safety is the critical slip circle. The sum for T and N is calculation in table form indicated in Table 1

2.4.2 Bishop's Method

Bishop's (1955) took into consideration the forces acting on the sides of the slices, which were neglected

Table 2: Main parameters of the soil properties

Laboratory Test Name	Parameter	Findings
Permeability Test (Falling/Constant Head)	Permeability, K (m/s)	2.25×10^{-10} $- 1 \times 10^{-2}$
Direct Shear Test or Triaxial Test	Cohesion, c' (kPa)	0 – 173
Direct Shear Test or Triaxial Test	Friction angle, Φ ($^\circ$)	9.28 – 38
Oven-Drying Method	Water Content (%)	10 – 30

in the Swedish method

Taking moments about O , the factor of safety (F) is given by the following; -

$$F = \frac{c' l + \tan \Phi \sum N'}{\sum W \sin \alpha} \quad (5)$$

Where W = weight of slice = $\gamma h b$ γ = unit weight of the wedge soil, h = height of the wedge and Normal force on the base N'

$$\text{While } N' = N - ul; \quad (6)$$

Where u = is the pore pressure and l = is the length of the base of slice = $b \sec \alpha$, c' = is the cohesion

2.4.3 Design Factor of Safety

A minimum factor of safety as low as 1.25 is used for highway embankment side slopes. This value of the safety factor should be increased to a minimum of 1.30 to 1.50 for slopes whose failure would cause significant damage such as end slopes beneath bridge abutments, major retaining structures and major roadways such as regional routes, interstates, etc. Failure in embankments made from soils that possess both cohesive and frictional strength components tend to be rotational, the actual slip surface approximating to the arc of a circle. (Geo-Slope International Ltd, 2013).

2.5 GeoStudio Modeling Approach

GeoStudio is an integrated suite of geotechnical

software developed by Geo-Slope International, used for analyzing and modeling a wide range of geotechnical engineering problems. GeoStudio 2023.1, developed by Geo-Slope International, was employed

in this study to conduct numerical analyses of seepage and slope stability within the Mtibwa Sugar Estates earthfill dam. Two modules, SEEP/W and SLOPE/W, were used in an integrated manner to simulate water flow and assess structural safety under different hydraulic conditions. (Geo-Slope International Ltd, 2013).

SEEP/W was applied to evaluate steady-state seepage through the dam body and foundation using

the GeoStudio 2023.1 platform (Geo-Slope International Ltd., 2023). Input parameters included soil hydraulic conductivity (k), soil-water characteristic curves (SWCC), volumetric water content (VWC) at saturated and residual conditions, and relevant boundary conditions such as reservoir levels and drain outlets. Material zones such as the clay core, shell, filters, drains, and foundation were defined based on field and laboratory data.

SLOPE/W was used for slope stability analysis by importing pore-water pressure profiles generated from SEEP/W using GeoStudio 2023.1 (Geo-Slope International Ltd., 2023). Key geotechnical parameters included cohesion (c), angle of internal friction (ϕ), and unit weight (γ), which were derived from laboratory shear tests. The analysis employed the limit equilibrium method of Morgenstern-Price to compute the factor of safety (FoS) under various loading and saturation scenarios.

This combined modelling approach allowed for a realistic evaluation of the dam's structural performance by capturing the interaction between seepage and slope stability mechanisms.

3. Results and Discussion

3.1 Soil Properties

The clay core exhibited low permeability of 2.25×10^{-10} m/s and high water content 25%, supporting its role in minimizing seepage through the embankment. Its cohesion value of 85 kPa and friction angle of 9.28° fall within the expected range for compacted plastic

clays used in core zones, as documented in other dam studies (Lucian, 2006; Shayo et al., 2014).

The tests Permeability Test (Falling/Constant Head), Derived from Density & Specific Gravity Tests, Direct Shear Test or Triaxial Test, Atterberg Limits Test and Compaction/Density Tests. These experiments provide crucial data on the soil properties, are inputs for seepage and slope stability analysis in GeoStudio software as shown in Table 2

Lucian (2006) emphasized that Tanzanian residual and alluvial clays, if well compacted and properly characterized, can provide excellent hydraulic barriers in dam cores. The results obtained from Mtibwa support this assertion, indicating that the core is effective in controlling seepage under normal conditions.

The shell and filter zones, have friction angles of 38° and 35° , respectively, and unit weights ranging from 18.0 to 21.9 kN/m³. This corresponds to well-graded granular soils, which provide the necessary

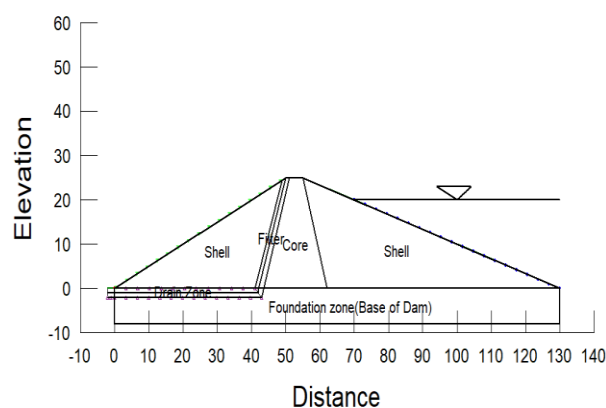


Figure 3: Showing the model setup of the dam

shear resistance and structural support. These values are similar to those reported by Msabi et al. (2019), who examined earthfill dam performance in Central Tanzania and highlighted the importance of using gravelly sand with high friction angles for shell zones to maintain slope stability. On the other hand, the drain

layer, modelled with a high permeability of 1.00×10^{-2} m/s, ensures proper dissipation of pore water, as reported by Makusha and Mutayoba (2017), who recommended that internal drainage layers in embankment dams be constructed with materials having permeability above 10^{-3} m/s for efficient flow

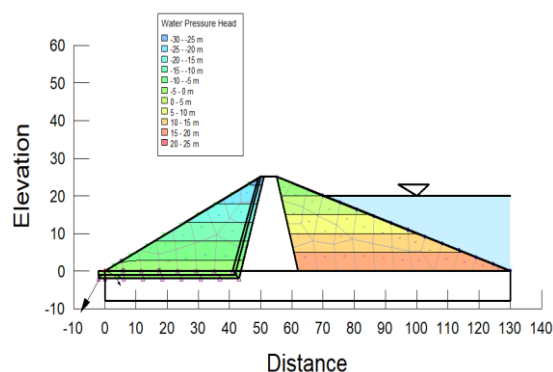


Figure 4: Showing seepage analysis through the dam

control.

Conversely, the presence of high void ratios (0.67 to 1.25) and material variability, particularly within the shell and filter zones, may present localized zones of weakness, especially under rapid drawdown or during prolonged saturation. This observation aligns with findings reported by Chirenje and Mhlongo (2018), that heterogeneous zones in earth dams can create preferential seepage paths, increasing the risk of internal erosion or piping if not carefully monitored.

3.2 Seepage Analysis Through the Dam

The seepage analysis was performed by modeling the dam geometry as a polygon and defining distinct zones for the core, shell, filter, drain, and foundation based on field observations and laboratory data. Each material was assigned properties using the Saturated/Unsaturated material model, incorporating Volumetric Water Content (VWC) and Hydraulic Conductivity (k) functions derived from soil tests.

Boundary conditions were applied by setting the reservoir water level on the upstream face and a drainage boundary at the downstream toe, simulating water flow toward the drainage outlet. A finite element mesh with a global element size of 6 m was generated to ensure numerical accuracy.

The model was executed in SEEP/W using a steady-state seepage analysis, which produced seepage contours, a phreatic line, and flow vectors at reference scale of 1:200 as shown in Figure 3 model set up. Results indicated that the phreatic surface rises close to the dam crest under full reservoir conditions, posing a potential risk of saturation in the downstream zone during prolonged rainfall. Lateral seepage toward the toe was clearly evident, underlining the need for effective drainage to reduce the phreatic level and minimize pore-pressure buildup.

The SEEP/W simulation further revealed that the phreatic surface remains largely confined within the dam body, suggesting generally safe seepage conditions. However, flow vectors showed water infiltration through the upstream face, moving laterally across the embankment with the phreatic line approaching the crest in some sections, as in Figure 4. Although the clay core effectively restricts flow, supported by the low hydraulic conductivity and total head distribution, elevated pore-water pressures near the downstream slope indicate insufficient drainage at the toe. Such conditions increase the risk of localized saturation, which should be addressed through enhanced drainage design. The calculated quantity of seepage was $Q = 4.5392 \times 10^{-6} \text{ m}^3/\text{sec}/\text{m}^2$.

These findings align with Mkilima (2022), who reported that increased saturation significantly reduces the effective cohesive strength of soils, potentially compromising the stability of homogeneous earth dams. The current study extends these observations to zoned earthfill dams, demonstrating that seepage-induced saturation particularly affects the lower downstream shell, where permeability contrasts and inadequate drainage can amplify pore-pressure accumulation.

3.3 Slope Stability for the Dam

The slope stability analysis was performed using SLOPE/W by importing pore-water pressure profiles generated from SEEP/W. Key geotechnical parameters cohesion (c), internal friction angle (ϕ), and unit weight (γ) were assigned based on laboratory shear strength tests.

The analysis applied the limit equilibrium method of Morgenstern-Price to compute the Factor of Safety

The SLOPE/W analysis conducted under steady-state conditions revealed a Factor of Safety (FOS) of 1.5666 for the downstream slope as in Figure 5, which is above the commonly accepted minimum threshold of 1.5 for earthfill dams under normal operation. This indicates that, in its current state, the embankment exhibits adequate stability under normal and flood loading scenarios.

The findings align with those of Mkilima (2022),

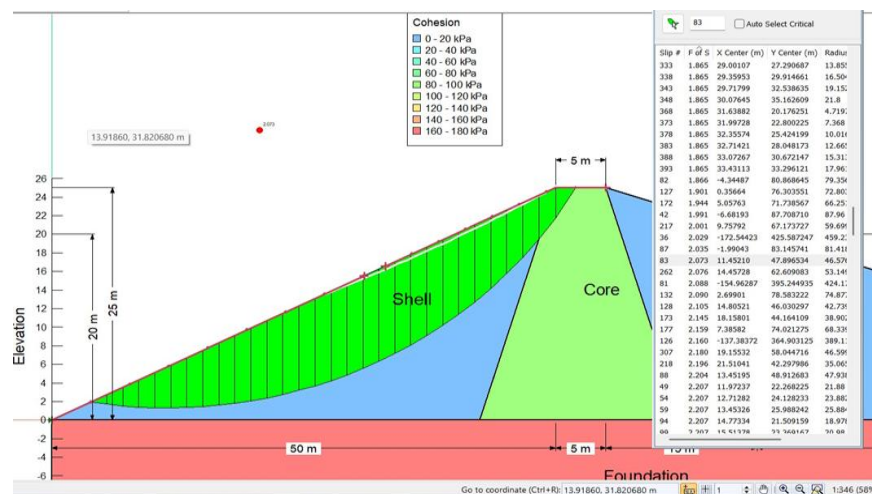


Figure 5: Shows factor of safety (FoS) for Dam's slope

(FoS) under different loading conditions, including normal operation and rapid drawdown scenarios. Computations were executed through the SLOPE/W solver.

Under normal reservoir conditions, the computed FoS was approximately 1.566, which exceeds the commonly accepted threshold of 1.5 for steady-state conditions as recommended by ICOLD standards, indicating that the downstream slope is currently stable under typical loading and flood conditions. However, during simulated prolonged rainfall or rapid drawdown, the FoS decreased below 1.20, suggesting an increased risk of instability due to rising phreatic levels. High pore-water pressures reduce effective stress and shear strength, making the downstream slope more vulnerable during adverse hydraulic or seismic events.

who also reported a significant reduction in slope stability in clay-based earthfill dams subjected to fluctuating water levels. His study emphasized that water-induced changes in effective stress conditions especially in fine-grained soils can critically weaken slope resistance. The current study reinforces this concept and extends it by modeling a zoned embankment, showing that even when high-strength shell materials are used, drainage effectiveness is a key factor in resisting instability during drawdown.

In contrast, Robert (2013) focused on administrative dam safety frameworks without addressing how soil behavior or slope geometry influences structural risk. This study contributes new insight by directly coupling seepage behavior with mechanical strength parameters derived from laboratory tests, enabling a more realistic prediction of

failure potential based on dam geometry, zoning, and pore pressure development.

4. Conclusion and Recommendations

Laboratory tests revealed that the clay core has very low permeability of 2.25×10^{-10} m/s, effectively minimizing internal seepage. However, the shell and foundation materials exhibited comparatively higher permeability, which contributes to lateral seepage toward the downstream face. Cohesion values from 0 to 173 kPa, angles of internal friction ranged from 9.28° to 38° and moisture content ranged from 10% to 30%. SEEP/W analysis showed the phreatic surface rising close to the dam crest, with a seepage rate of 4.5392×10^{-6} m³/sec/m², suggesting potential saturation during prolonged rainfall. Such conditions could reduce soil shear strength and compromise stability. Slope stability analysis using Bishop's method gave a factor of safety of 1.566, slightly above the minimum acceptable threshold of 1.5 under normal conditions, with further reductions anticipated under heavy rainfall or seismic loading. The safety assessment of the Mtibwa Sugar Estates earthfill dam indicates that the structure is generally stable but faces significant risks under adverse conditions.

It is recommended that piezometers and seepage monitoring instruments be installed to track pore water pressures and enable early detection of potential failure. Improvements to the drainage system, such as installing toe drains or relief wells, are recommended to lower the phreatic surface. Regular slope stability assessments, particularly before and after the rainy seasons, are highly recommended.

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Conflict of Interest

The authors declare that there is no conflicts of interest relevant to this study.

Data availability

All relevant data are included in the paper or its supplementary information.

References

- Agarwal, Y.C., 2010. Soil Mechanics and Foundation Engineering. New Delhi: Standard Publishers.
- Balsubramanian, A., 2016. Earth Dam and Earth Structures. Mysore: University of Mysore. Journal of International Academic Research for Multidisciplinary, India.
- Bhattarai, T.N., 2016. Design and Construction of Earth and Rock-fill Dams. Kathmandu: Nepal Engineering Press.
- Bidyashwari, H., et al. (2017). Physical properties of soil and its implication to slope stability of Nungbi Khunou, NH-150, Manipur. International Journal of Geosciences, 8(11), 1332–1343. <https://doi.org/10.4236/ijg.2017.811077>
- Chanson, H., 2015. Hydraulic Structures: A Textbook for Engineers and Scientists. Oxford: Butterworth-Heinemann.
- Chatterje, K., 1998. Water Resources Engineering. New Delhi: Tata McGraw-Hill.
- Craig, R. F. (2004). Craig's soil mechanics (7th ed.). Spon Press. <https://www.scirp.org/reference/referencespapers?referenceid=3031077> (Accessed: 22 March 2025)
- Das, M. B. (2010). Principle of geotechnical engineering (7th ed.). Cengage Learning. <https://www.scirp.org/reference/referencespapers?referenceid=1518594>(Accessed: 10 March 2025)

- Fell, R., MacGregor, P., Stapledon, D., Bell, G. and Foster, M., 2005. *Geotechnical Engineering of Dams*. London: Taylor & Francis.
- Fell, R., Wan, C.F., Cyganiewicz, J. and Foster, M., 2014. *Time for Development of Internal Erosion and Piping in Embankment Dams*. London: Thomas Telford.
- Fredlund, D. D., & Rahardjo, H. (1993). *Soil mechanics for unsaturated soils*. https://www.researchgate.net/publication/37407243_Soil_Mechanics_for_Unsaturated_Soils(Accessed: 22 March 2025)
- Foster, M., Fell, R. and Spannagle, M., 2000. The statistics of embankment dam failures and accidents. *Canadian Geotechnical Journal*, 37(5), pp.1000–1024.
- GEO-SLOPE International Ltd. (2013). *Seepage modeling with SEEP/W: An engineering methodology* (September 2013 ed.). <https://www.scribd.com/document/515698263/Seep-Modeling>(Accessed: 22 March 2025)
- Holtz, R. D. (2011). *An introduction to geotechnical engineering*. https://archive.org/details/introductiontoge0000holt_n5h7_2ed(Accessed: 10 March 2025)
- Hunde, S. (2003). *Investigation of influence of compaction on the stability of earthfill dams of tropical soils* [Master's thesis, Africa Thesis Bank]. <http://thesisbank.jhia.ac.ke/7797/>(Accessed: 10 March 2025)
- ICOLD, 2011. *Dam Safety Guidelines*. Paris: International Commission on Large Dams. Institution of Civil Engineers Lucerne, Switzerland.
- Lucian, C. (2006). *Geotechnical aspects of buildings on expansive soils in Kibaha, Tanzania: Preliminary study*. KTH Architecture and the Built Environment. Royal Institute of Technology Stockholm, Sweden.
- Mbowe, J., 2018. Assessment of dam safety management practices in Tanzania. *Journal of Water Resources and Environmental Engineering*, 10(4), pp.77–85.
- Mbilinyi, B. and Kaduma, S., 2015. Review of dam safety management in Tanzania. *Tanzania Journal of Engineering and Technology*, 34(2), pp.55–64.
- Mkilima, T. (2022). *The impact of soil cohesiveness on earth-fill dam stability under rapid drawdown*. *Engineering*. <https://doi.org/10.20944/preprints202206.0282.v1>
- Ministry of Water [MOW]. (2020). *Dam safety guideline: The United Republic of Tanzania*. Ministry of Water. <https://www.google.com>(Accessed: 10 March 2025)
- Ministry of Water [MOW] DCOM. (2022). *DCOM Volume I Appendix K - Ministry of Water DCOM Manual*. https://design.maji.go.tz/index.php/DCOM_Volume_I_Appendix_K (Accessed: 22 March 2025)
- National Research Council. (2012). *Sustainable water and environmental management in the California Bay-Delta*. The National Academies Press. <https://nap.nationalacademies.org/catalog/13394/sustainable-water-and-environmental-management-in-the-california-bay-delta>(Accessed: 10 March 2025)
- Refaiy, A. R., et al. (2021). Modeling the effect of downstream drain geometry on seepage through earth dams. *Ain Shams Engineering Journal*, 12(3), 2511–2531.
- Robert, E. M. (2013). *Dam safety management of selected earth-fill dams in Tanzania* [Master's thesis, IHE Delft Institute for Water Education]. <https://ihedelftrepository.contentdm.oclc.org/digital/collection/masters1/id/299996/>(Accessed: 10 March 2025)
- Sharma, R. K., & Sharma, T. K. (2002). *Irrigation engineering*. S. Chand Publishing.

<https://www.schandpublishing.com/books/tech-professional/civil-engineering/irrigation-engineering/9788121921282/>(Accessed: 10 March 2025)

Terzaghi, K., Peck, R. B., & Mesri, G. (1996). Soil mechanics in engineering practice (3rd ed.). <http://archive.org/details/soil-mechanics-in-engineering-practice-1996-by-karl-terzaghi-ralph-b.-peck-gholamreza-mesri>(Accessed: 22 March 2025)

Utepov, Y., et al. (2022). The influence of material characteristics on dam stability under rapid drawdown conditions. Archives of Civil Engineering, 539–553. <https://doi.org/10.24425/ace.2022.140184>