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# Seepage Analysis in Embankment Dam under Static Condition Using Numerical Model (Case Study: Legemera Earthen Dam)

Getnet Solomon Temtime [a*], Asalf Shumete Eshete [a], Fikru Fentaw Abera [a]

[a] Department of Hydraulic and Water Resource Engineering, Kombolcha Institute of Technology
Wollo University, Kombolcha, Ethiopia.

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*Corresponding Author: getnetsolomon475@gmail.com

**ABSTRACT**

Seepage constitutes a significant factor in the failure of embankment dams. The analysis of seepage is a crucial consideration in dam safety. To address this concern, a finite element method was employed using the computer program Geo Studio, specifically its sub-program named SEEP/W. This method was utilized to ascertain various aspects, including the surface seepage line, the quantity of seepage through both the dam and its foundation, measurements of seepage velocity, distribution of pore water pressure, total head, pressure head, and exit gradient of a homogeneous earth dam. The study focused on Legemera dam, situated in Borena Woreda of the Amhara region, serving as a representative homogeneous earth dam. The dam, as originally designed, underwent analysis using the SEEP/W 2012 program. Subsequently, multiple analyses were conducted to investigate seepage through Legemera dam under different conditions, namely, normal water level and maximum water level. The findings revealed that during the maximum water level scenario, the quantity of seepage, seepage velocity, and exit gradient were higher compared to the normal water level case. This suggests that as the water level in the upstream area of the dam increases, there is a corresponding increase in the amount of seepage, velocity of seepage, and exit gradient.

Keywords: Embankment dam; seepage analysis; finite element method; Geo Studio; SEEP/W

## 1. INTRODUCTION

All Embankment dams in the world are mainly constructed of earth and rock-fill materials. Embankment dams are generally simple structures which are depending on their self-weight to stop the sliding and overturning. Earth dam failure is attributed to the following: structural failure hydraulic failure, seepage failure, and piping failure through the dam body. The planning and construction of an earth dam is one of the key challenges in the field of geotechnical engineering, due to the unavoidable variation in foundation condition and therefore the properties of the available construction materials. The sensible seepage problems are not easily convertible into the same numerical counterpart due to the heterogeneity of the natural soils and also varying boundary conditions [1]. Seepage through the dam can cause erosion within an embankment in places where a high hydraulic gradient is present. In the case erosion occurred within a dam can be created. These piping take the form of channels, also pipes, which impairs the dam stability [2]. Accurate estimation of seepage amount from the body and foundation in dams are very important for economic and technical considerations. The water escape from the body of the dam body and the foundation of the embankment dams can lead to unacceptable water loss in arid climate and can destabilize effect on earth dam. So seepage control is managing the seepage before a crisis. Controlling of seepage from the embankment dams that are located on foundations with high permeability is one of the important problems for the stability of embankment dams and it is vital for sure and acceptable service in structure maintenance [3]. The seepage control of any embankment dams may be analyzed by various methods of seepage estimation. Seepage through the embankment dams is the main aspects and its control enjoys the main position in designing, construction and maintenance of any dams. Therefore, the hydraulic engineer must be well versed in understanding seepage problems, their solution, and preventive remedial measures in the monitoring of dam important structures. The flow conditions of any porous environment can be investigated by using Numerical methods framed in the form of a software solution [4]. Bahru Mekuria [5] has used the finite element method of seepage analysis and investigation of seepage problems on the left side of Wolkayite dam. And also, the finite element method has been developed to solve the governing equation of flow through the embankment dams. Melat Gebrehiwet [6] compared the results obtained from the finite element method with boundary element method for solving the flow issue in steady state condition. Ksatie Yhdego [7] used the finite element method through a computer program, named SEEP/W to determine the free surface seepage line, the quantity of seepage through the dam, the pore water pressure distribution, the total head measurement, and the effect of an isotopy of the core material of Gomit zoned earth dam. The effect of the ratio of the permeability in Horizontal direction to the vertical direction (Kx/Ky) on seepage was tested and results indicated an increase in seepage quantity as ratio increased. The stability of Gomit zoned Dam was analyzed using slope stability computer program named STABIL2.3. The slope stability analysis result showed that the factor of safety decrease with the increase of Kx=/Ky ratio. The analysis of results of this study showed that Gomit zoned earth dam is safe against the danger of piping and slope sloughing under the present operation levels. The finite element method was utilized by that and his colleagues [8] to solve the governing equation of flow through earth dams. The computer program Geo-Slope was used in the analysis through its sub-program named SEEP/Weight-node isoperimetric elements were used to model the dam and its foundation, while mapped infinite elements were used to model the problem boundaries. The case study adopted was Legemera dam which is a zoned earth fill Dam of 243m length. The dam in its original design was analyzed by adopting the SEEP/W program. After that, several scenarios were conducted to investigate the control of flow in the dam through investigating the effect of different parameters which included the hydraulic conductivity of the shell material and the construction of impervious core at different locations and thicknesses. It was found that the construction of the clay core in the dam provides an important influence on decreasing the exit gradient, which could decrease in order of 300% when there is no core in the dam, the sloping core and the safety factor may be critical when the level of water in the reservoir is at 2456m. The sloping core is the best design for the core for Legemera dam than other choices because it produces the lowest values of rate of flow and low exit gradient. Ali [9] used a finite element software SEEP/W in simulating the seepage flow at Kesem dam, measured seepage values obtained from the Kesem dam Authority were compared with the simulated result of seepage obtained using the SEEP/W software. Based on the findings of this study, the Kesem dam can be considered safe.in this research, seepage through the body and foundation of Legemera dam was analyzed. The finite element method was employed to solve the governing differential equation pertaining to seepage through the body of Legemera dam and its foundation. SEEP/W is the useful tool that uses numerical modeling to solve complex groundwater seepage problems [10]. The SEEP/W software (program) is the sub-program of the Geo-studio (software) computer, which is used for seepage problem analysis and estimation through porous media.

## 2. MATERIALS AND METHODS

### 2.1 Overview of the study zone

The Legemera earthen dam is located in the Welaka sub basin of Abay basin at Borena Woreda, Ethiopia's north-central highlands, and the South Wollo Administration Zone of the Amhara Regional State as shown in Figure 1. It is located approximately 590 kilometers north of Addis Ababa and 185 kilometers southwest of Dessie town. The project location is 100 43' 21" N and 380 43' 47" E. The project site is approximately 5 kilometers from Makenaselam, the capital city of Borena Woreda. It is a one-purpose dam that will irrigate 180 hectares of land. It was designed and built by the Amhara Water, Irrigation, and Energy Bureau and the Amhara Waterworks Contracting Enterprise, respectively.

#### 2.1.1 Topography

The project's topography is composed of 65 percent plain, 25 percent plateau, and the remaining 10 percent mountains. The upper and middle parts of the catchment, on the other hand, are divided by a series of gullies. The upper catchments at the beginning of the stream have hilly and small mountainous landforms. In general, the catchment is characterized by an elongated shape with no significant sub-watersheds. The highest elevation of the Legemera watershed is about 3184 m in its south eastern part. The lowest topography land is at the dam site, which is at an altitude of 2423 m.

#### 2.1.2 Key characteristics of the Legemera earth dam and reservoir

The Legemera dam is an earthen fill embankment dam, consisting of two the permeable zone (shell), one impermeable zone (core), and two filter zones. Figure 2 shows a cross-section of the Legemera dam which is modeled using GeoStudio software.

### 2.2 Collection of data

The first task of this study was gathering important data and information related to the study area. Therefore, this study needs two basic pieces of data that were gathered using several data collection techniques.

Primary data collection:

The primary data collected from the study area was used to cross- check the secondary data. Field observations were especially essential for; visiting the dam site, inspection of the present condition of the dam, interviewing site engineers, hydrogeologists, beneficiaries from the command area and contractors of the dam project.

Secondary data collection:

The geotechnical parameter of the dam, the design document, the geometric parameter of the dam, the foundation material, and dam body material laboratory were collected from Amhara Water, Irrigation, and Energy Bureau (AWIE).

The geological data, project completion report, and dam site map were collected from Amhara Water Works Construction Enterprise (AWWCE). To perform and achieve the objective of this study, the main important data collected and taken from the design document are the profile of the dam, and the material properties of the dam body. The material engineering properties are the vital part of any geotechnical analysis about the slope stability of the dam.

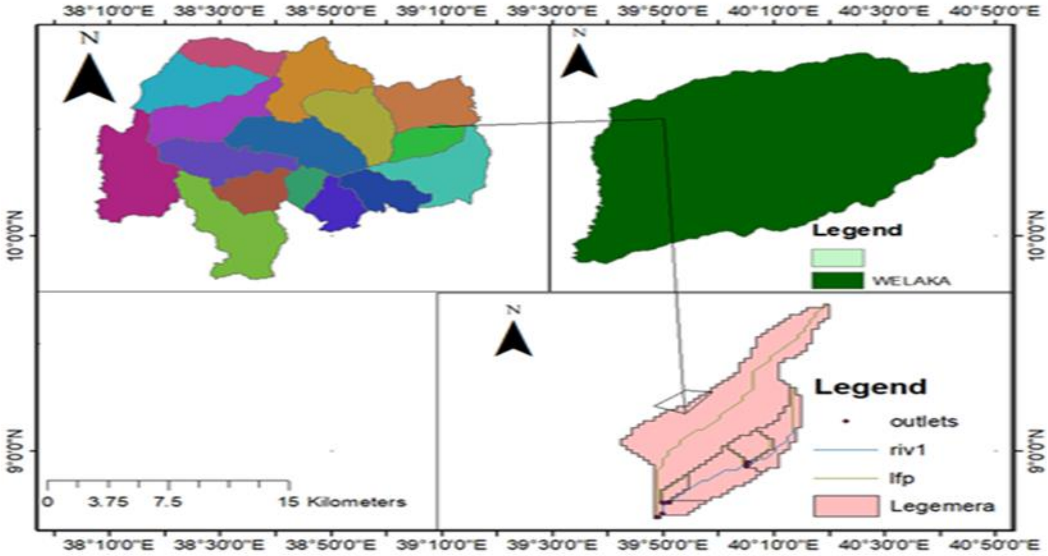

Fig 1. Location of the Study Area

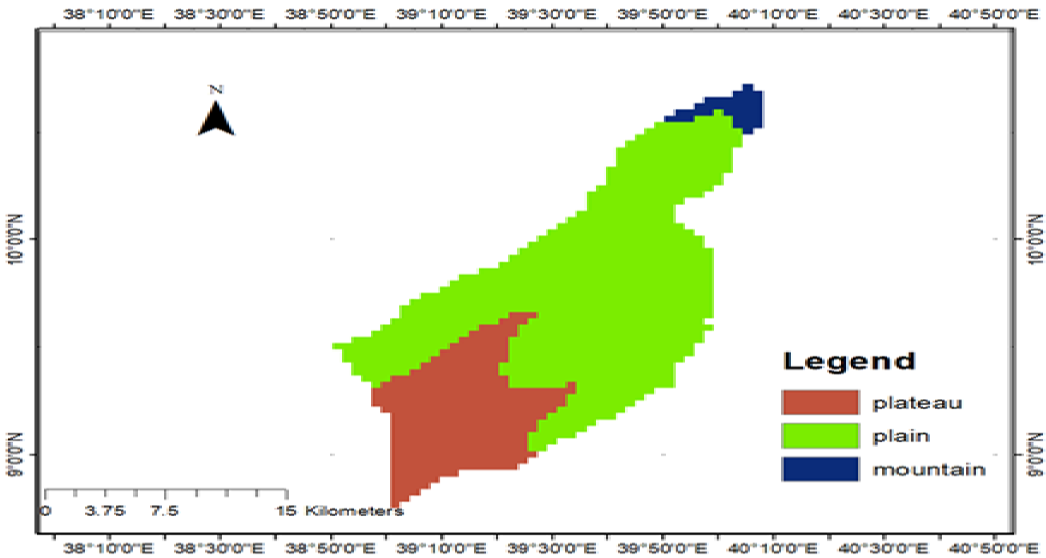

Fig 2. Terrain Characteristics of the Legemera Watershed

Geotechnical summarized data sets used for dam seepage analysis are presented in Table 1.

**2.3 Methods employed**

Various analytical methods for seepage analysis of the Legemera earth dam under static loading conditions were developed in this study. Seepage analysis, as the primary design criterion for seepage calculation, can be evaluated using seep/w. The study area delineation was done using Arc-GIS software. To supplement this research, physical tools/equipment, and materials such as Geographical Position System (GPS), Digital Elevation Model (DEM), Residential documents (such as design, construction, and operational), and Geological and Soil maps, among others, will be used to assess the current performance of the Legemera dam.

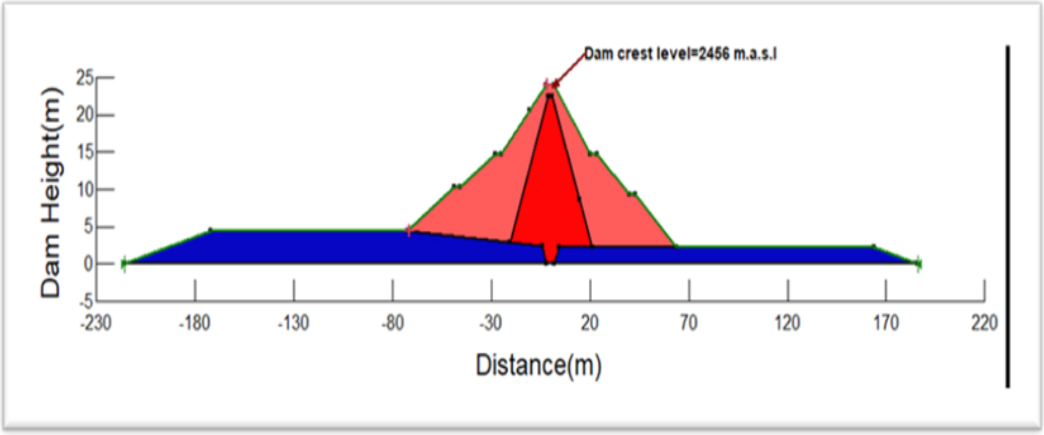


Fig 3. Legemera main dam geometry model

Table 1. Geotechnical summary datasets utilized in the analysis of seepage for the dam

| Material descriptions | ks x10$^5$(m/s) | Liquid limit | Saturated WC(m/m) | Resudal Wc (m/m) | Dia passing (10%) | Dia passing (60%) |
|---|---|---|---|---|---|---|
| Foundation material | 1.06 | 72 | 0.34 | 0.16 | 0.001 | 0.002 |
| Core material | 0.0152 | 80 | 0.41 | 0.07 | 0.001 | 0.003 |
| Shell material | 8.51 | 76.5 | 0.36 | 0.057 | 0.002 | 4 |

**2.4 Selection and configuration of the model**

Nowadays numerous finite element based software are implemented to evaluate the performance of embankment dams, natural engineering slopes, and groundwater flow. In order to achieve the objectives of this study, finite element based GeoStudio-2012 software was employed. This model is selected up on its easiness of its application, ability to solve complicated geometries, loadings, and material properties when compared with other applications. Accordingly, the zipped setup of GeoStudio software was extracted and installed as a full version in an acceptable Windows-10 computer.

**2.5 Model simulation and analysis**

In addition to the GeoStudio software, Arc-GIS 10.5 was used for the delineation of the study area. To perform this study electronic physical equipment and like, global positioning system (GPS), digital elevation model (DEM), photo camera, topographic map of the study area, Microsoft Excel, and Word were used.

Over long periods, Numerical models were used as theory, due to the fast establishment of computer science most of the numerical models like Limit Equilibrium and Finite Element models are used very widely in the world. For this study, the GeoStudio software extension SEEP/W were used carefully and the output of the software was compared with the project documents and standards.

**2.6 Finite element method for the current scenario**

The seepage Analysis of the zoned type of the dam is the more sensitive method of analysis, as the mass of the dam has a complex design structure compared to a homogenous type of the dam and is sensitive to water loading conditions. The Analysis result of seepage is vital for stability analysis of the dam in all condition of the analysis, as shown in Figure 3 and figure 5. The finite element mesh has been used in the analysis of seepage in all loading conditions. The flow chart of this study is shown in the Figure 6 below in detail. This methodological flow diagram mostly describes the important features of the input data as the geo-studio (seep/w) program analysis A finite element model called The Seep/w can simulate water flow through porous media. It's based on is Darcy's Law, which states that water flows through both saturated and unsaturated soils. Determining the scale, units, and sketch the cross-section are the first steps. Once the various material properties of the soil regions have been established, the boundary conditions can be assigned. The volumetric water content data point function is implemented using the sample functions method. In saturated zones, the coefficients of permeability remain constant; however, in unsaturated soil, their values vary based on the matric suction. The upstream side (h=22 m) is designated with the total head boundary condition, the downstream side is assigned the potential seepage boundary condition, and the downstream toe is designated with the zero-pressure boundary condition. Triangles and quads make up the finite element mesh pattern utilized in the numerical models. The control model comprises 1524 elements and 1970 nodes, respectively. Plotting the seepage, flow, and equipotential lines of the total head as well as displaying various hydraulic parameters like pore water pressure, water velocity, and hydraulic gradient are among the seep/w outputs. The total seepage discharge is also calculated. The finite elements method seems to be the most effective and potent tool available for solving a wide range of real-world issues among all numerical techniques [13]. Muhammad (1991) investigated seepage through earth dams using the finite elements method [14]. For the Al-Adheem zoned earthen dam, Abo (2001) used FEM to estimate the materials anisotropy, free surface position, drainage amount, pore water pressure dispersion, and all out head [15]. Trimble et al. (2001) used the three measurement limited components strategy and two measurements strategy to show the drainage in an earth dam's soaked/unsaturated soil arrangement under both steady state and transient leakage conditions [16]. A limited distinction strategy was used by Bardet and Tobita (2002) to arrange unconfined drainage with an obscure free surface [17]. The partial differential equation which is governed by the flow of the study state condition, which is 2D flow through an isotropic homogeneous porous media is presented by the following Laplace equation.

$$\frac{\partial}{\partial x}\left(Kx\frac{\partial H}{\partial x}\right)+\left(Ky\frac{\partial H}{\partial y}\right)+Q=\left(Mw\gamma w\frac{\partial H}{\partial t}\right)$$

Where, Q = the applied boundary flux, Kx, and Ky, = coefficient of permeability of soil in x, and y direction, respectively, t = time, γw= the unit weight of water, H= total head of water and; mw = water storage (the slope of the soil-water characteristic curve). According to USACE (1993), there are mostly four boundary conditions used in unconfined seepage problems [18]. Impervious boundary ∂H/∂n=0 where n is the vertical direction of the boundary Submerged permeable boundary H=h1, H=h2, Where, h1, and h2 are the water head at the entrance and exit.

Surface seepage: H=y, Seepage line = y. The above boundary conditions area is designated as the upstream reservoir level with total head H (m), which represents the height of the water in the reservoir. The downstream boundary condition was designed as: Potential seepage face located in the downstream face where the height is zero. The analysis was carried out by considering the water in the reservoir to be at maximum water levels 2449 and 2456 meters above the sea level.According to USACE (1993), there are mostly four boundary conditions used in unconfined seepage problems [18]. Impervious boundary, where n is the vertical direction of the boundary.

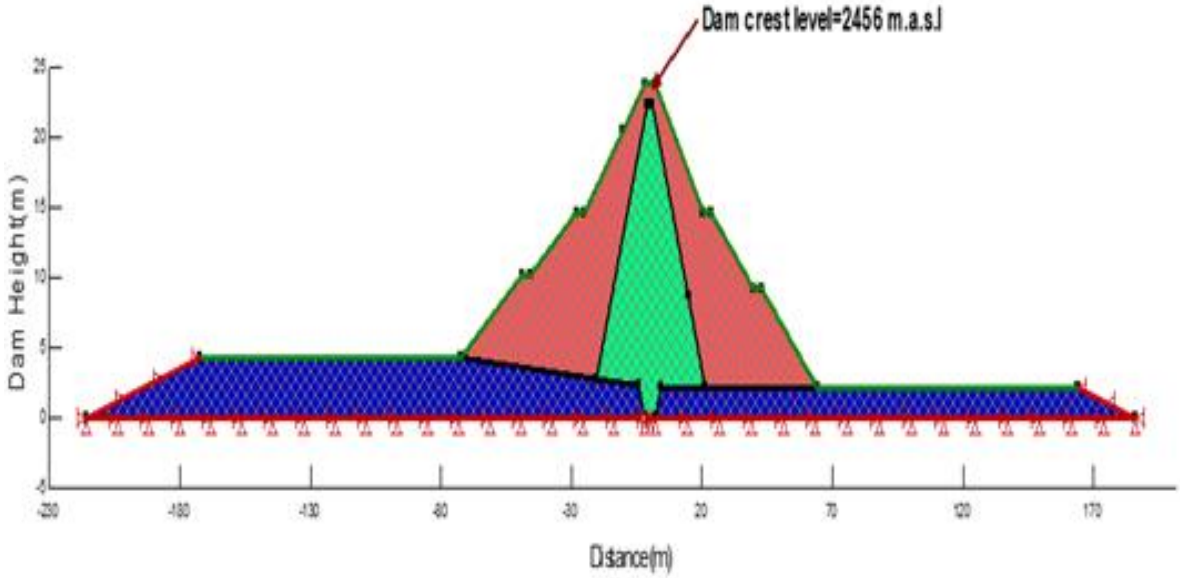


Fig 5. Establishment of finite element mesh for Legemera dam by using seep/w program

**2.6.1 Overall considerations and analytical procedures**

Prior to simulation, the dam was analyzed for steady-state seepage and Full reservoir level conditions, by taking the reservoir water levels at different level taking the demanded hydraulic conductivity values of the embankment and foundation material.

a. Establishment of boundary conditions:

For modelling the seepage analysis using the finite element method SEEP/W boundary conditions are essential. In seepage analysis with SEEP/W, there were two fundamental boundary conditions namely, the head boundary condition and the flux boundary condition. Accordingly, in the seepage simulation of Legemera earthen dam, two different scenarios of head boundary conditions have been used. Computations are carried out for the three important reservoir water levels at an elevation of 2449 m a.m.s.l and full reservoir level scenarios (i.e Elev. =2453.00m a.m.s.l). Because in this reservoir water levels the respective practical seepage measurements were carried out. The water level in the reservoir and downstream face of the dam were taken as a head boundary condition and potential seepage face respectively and finally, the earthen dam was simulated for the steady state condition. After the result of the model, the location of the phreatic line, seepage flux (discharge) and pore water pressure distribution for the above head boundary conditions was determined.

b. Determination of Phreatic Line, Pore water Pressure and Quantity of Seepage:

Phreatic line or seepage line is the line at the upper surface of the seepage flow at which the pressure is atmospheric. For Legemera dam determination of seepage through the dam body, pore water distribution and determination of phreatic line was done using finite elements SEEP/W model. Outcomes of the steady-state and transient seepage analysis were then used to determine the location of phreatic lines, seepage quantity and pore water pressure distribution on the respective reservoir water level. Finally, simulated results obtained from the SEEP/W software for the selected section of the seepage quantity was compared with the actual seepage recorded using Calibrated catch container and Wadding recording methods.

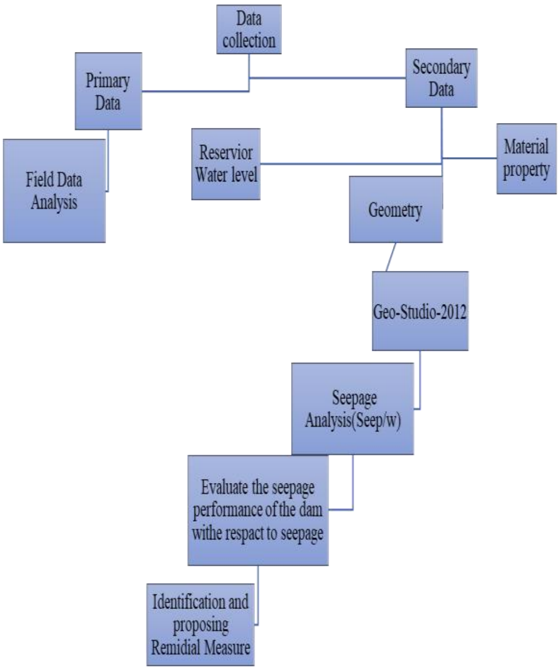


Fig 6. Representation of the research methodology through the flowchart paradigm.

## 3. RESULTS AND DISCUSSION

Analysis of Seepage and Findings: One of the most important parts of embankment dams is the study of discharging flow through construction materials as well as the hydraulic balance of the dam and the amount of water discharging from the foundation and body of the dam [14]. In this study, seepage analysis was carried out based on the two important impoundment conditions. These conditions are full reservoir level at an elevation of 2453.00m and reservoir level at an elevation of 2449m a.m.s.l. Seepage analysis through the dam was performed using the SEEP/W component of GeoStudio 2012 software.

### 3.1 Seepage analysis at an elevation of 2449 meters a.m.s.l

This reservoir level (Elevation of 2449 m) was selected as a scenario due to the semi-constant pool level when the practical seepage quantity measurement was conducted. At this pool level a prolonged storage of reservoir water, water percolating through an earthen dam established as a steady-state condition of seepage. In this condition, the numerical analyses and the computed values of seepage using the Finite Element Models (SEEP/W) are simulated and shown in the following respective Figures 7, 8, 9, 10 and 11. The seepage face is painted as a thick blue line, which flows smoothly across the dam. The vertical lines are the total head isolines. The quantity of seepage flow was computed based on the seepage flux through the dam. A vertical blue line (flux section line) has been drawn through the central part of the clay core and foundation of the dam and the total entire seepage through the dam body and its foundation is unit flux multiplied by the average horizontal length of the dam. The calculated seepage for the embankment was estimated as 3.46x10-5m3/sec/m length of the dam. During this pool level condition, the simulated results obtained from the SEEP/W software of the selected section of the seepage quantity were compared with the actual seepage measured using the Calibrated catch container system, which is generally appropriate for flows less than about 0.003 m3/s [11].

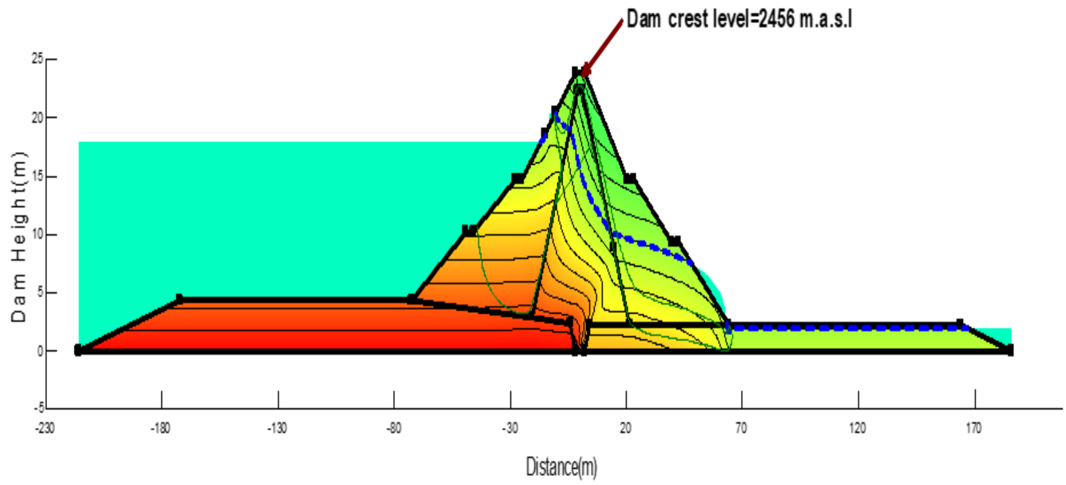


Fig 7. Determination of the phreatic line, flow paths, equipotential lines, and seepage flux within the dam structure and its foundation.

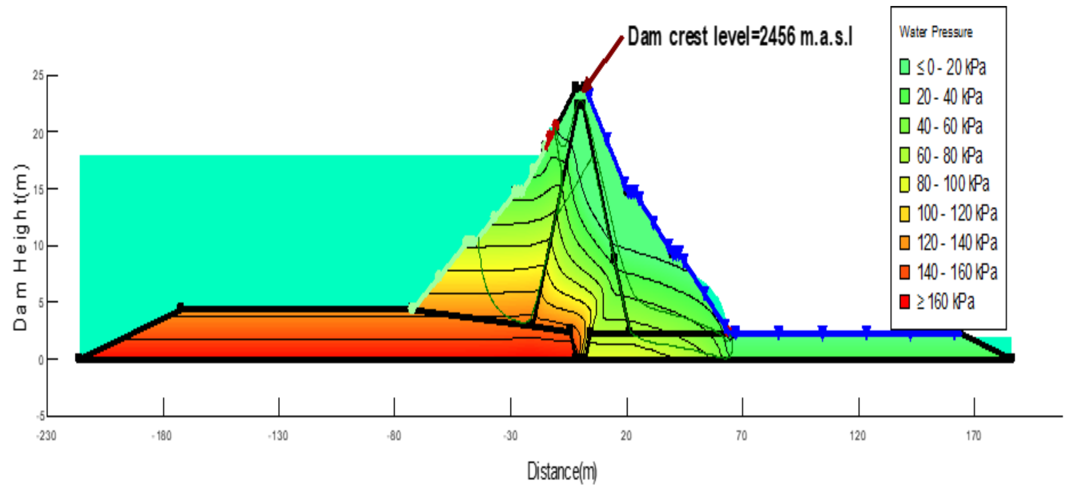


Fig 8. Distribution of pore pressure within the dam structure and its foundation.

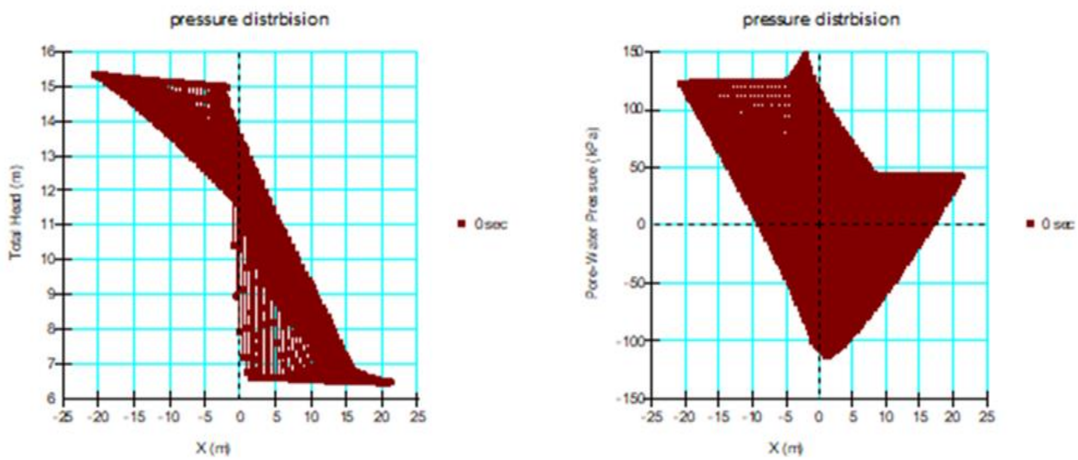


Fig 9. Distribution of pressure, including a) total head and b) pore water pressure, within the dam under the current water level

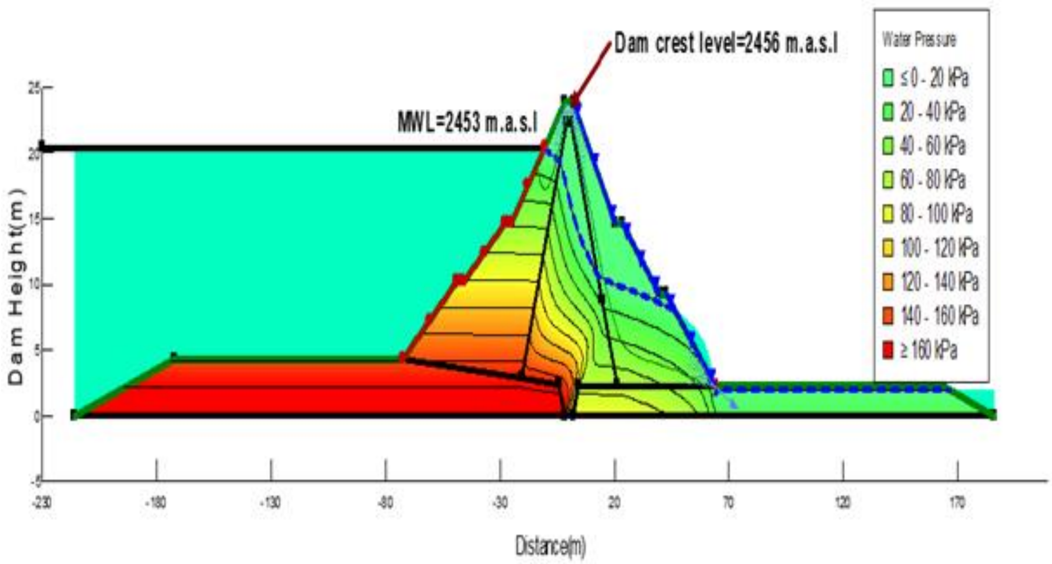


Fig 10. Determination of the phreatic line, flow paths, equipotential lines, and seepage flux within the dam structure and its foundation maximum reservoir level

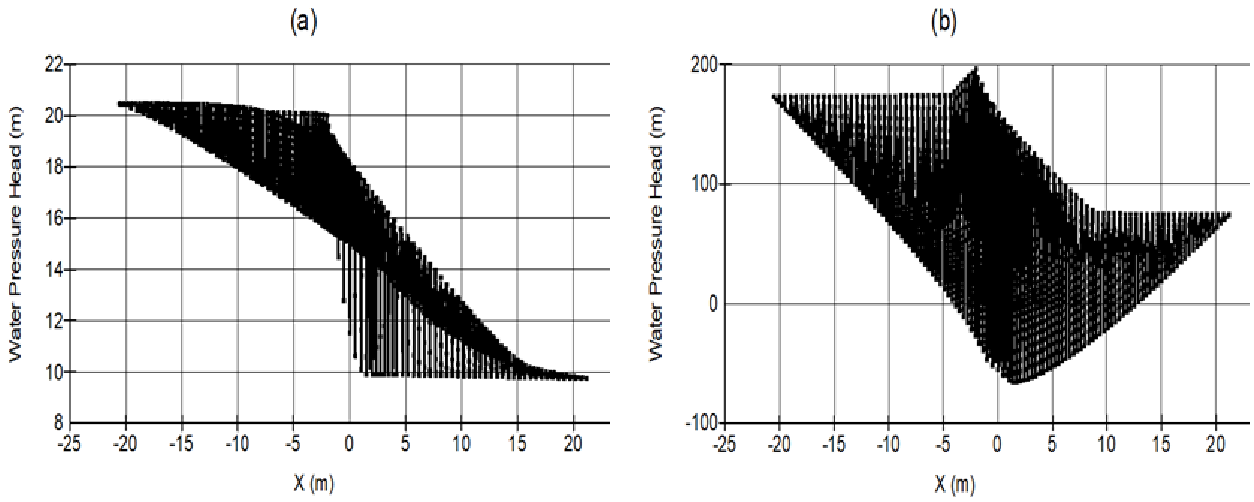


Fig 11. Pressure distribution a) Total Head b) Pore Water pressure in the dam at Maximum water level

Table 2. Summary of the seepage analysis under two significant impoundment conditions across different sections of the dam structure and its foundation.

| S.No | Tasks | Seepage analysis | At elevation 2449 a.m.s.l | At elevation 2453 a.m.s.l |
|---|---|---|---|---|
| 1 | Quantity of Seepage ($m^3/s$) | Numerical analysis method | 0.0113 | 0.01831 |
| | | Practical measurement | 0.0224 | 0.032 |
| 2 | Pore water pressure distribution (kPa) | At bottom of the Dam | 152.01 | 201.04 |
| | | At the water surface elevation of the dam | 0 | 0 |
| 3 | Location of seepage line | | Under the foundation and filter | above the foundation and filter |

The quantity of seepage flow rate through the dam is: Q = q flux (m3/s/m) × Average Length of the dam crest Q= 3.46×10-5 m3/s/m× 260 m = 0.0113 m3/s in this pool level condition, the downstream face of Legemera dam was with a slight sign of leakage sur-faced in the right abutment. And the quantity of seepage through the embankment is accumulated be-low the downstream toe. The recorded actual seepage flow at the down-stream toe of the dam using the calibrated container is 0.0224 m3/s. In this analysis the pore water pressure dis-tribution was also simulated as expected with minimum at the top and maximum at the bottom proportionally with the depth of water increment. It is particularly higher below the reservoir bed. The magnitudes of pore water pressure at an elevation of 2143.8 m and 2104 m a.m.s.l are zero kPa and 377.5 kPa respectively. In the figures of pore water pressure distribution, flow paths and graphs of total pressure heads and pore water pres-sure distributions with their respective values are dis-played centrally as shown Figure 8. In this analysis the pore water pressure distribution was also simulated as expected with minimum at the top and maximum at the bottom proportionally with the depth of water incre-ment. It is particularly higher below the reservoir bed. The magnitudes of pore water pressure at an elevation of 2449 m and 2434.5 m a.m.s.l are zero kPa and 152.01 kPa respectively.

In the figures of pore water pressure distribution, flow paths and graphs of total pressure heads and pore water pressure distributions with their respective values are displayed centrally as shown Figure9.This impound-ment condition (Elevation = 2453.00 m) is the maxi-mum active storage. During the impound-ment, there is fluctuation in the water level of the res-ervoir due to var-ious reasons. This might be the main reasons for sea-sonal inflow variation, high evaporation and sometimes seepage losses.

The numerical analyses of seepage flux, phreatic sur-face, exit gradient was computed using SEEP/W. The computed seepage quantity for the embankment was es-timated as 5.7383*10-5 m3/s per meter length of the dam. At full reservoir level the computed seepage quan-tity exceeded by 0.002197 l/s per meter length over the current water level seepage quantity. Similarly, with the above analysis the pore water pressure distribution was also simulated as expected with minimum at the top and maximum at the bottom proportionally with the depth of water increment. The magnitudes of pore water pres-sure at the surface of the water level and 2434.5.0m a.m.s.l are zero kPa and 201.04 kPa respectively. For the full reservoir level condition (Elevation = 2453.0m) the simulated results from the SEEP/W software, the quan-tity of seepage obtained (flux multiplied by the average crest length of the dam i.e. 319 m) was 0.01831 m3/s. In this research practical seepage measurement was a chal-lenging task because the previously constructed rectan-gular weir structure which is designated for seepage measurement has been damaged due to the underneath scours and collapse.

## 4. CONCLUSION

This study focused on the static condition evaluation of seepage in the Legemera earth dam using GeoStudio 2012 software. The analysis encompassed the en-tire dam structure, including its foundation depth. Seepage analysis was conducted using SEEP/W under two cru-cial impoundment conditions: full reservoir at an eleva-tion of 2453.0 m and water level at an elevation of 2449 meters a.m.s.l. The objectives were to identify the free surface seepage line, determine pore water pressure dis-tribution, and quantify seepage through the dam. The simulation results indicated that, at the current water level of 2449m, the average flow rate of leakage for the entire dam length was 0.0113 m3/s. However, the ob-served seepage at the down-stream toe of the dam was 0.0224 m3/s.

This suggests that the dam is vulnerable to seepage, as the analysis result exceeds the recommended value stated in the embankment dam design manual [12].

## RECOMMENDATIONS

Implementation of Remedial Measures: (i)To address the identified issues, impervious blanketing at the upstream part of the dam should be integrated into the impervious core to seal upstream seepage sources. This method aims to reduce undesirable seepage quantities and pressures beneath the embankment. (ii)Anchoring and stabilizing weak abutments through the use of cut-offs, sealing treatments, and blanketing are crucial to prevent seepage, particularly at the leaky right abutment.

Drainage Filters: (i)The installation of appropriate drainage filters at the downstream toe of the dam is recommended to decrease uplift pressure and minimize weaknesses in the foundation and embankment.

These recommendations are essential to enhance the safety and effectiveness of the Legemera earth dam against seepage-related concerns.

## REFERENCES

[1] S.Athani, Shivakumar, Shivamanth, C.H. Solanki, and G.R. Dodagoudar, "Seepage and stability analyses of earth dam using finite element method", Science Direct, Aquatic Procedia 4, pp.876–883, 2015.

[2] Johan Bäckström and Malin Ljungblad, "Safety evaluation of the zhaoli tailings dam a seepage, deformation and stability analysis with Geostudio", M.Sc., thesis, Uppsala Universitet, China, 2016.

[3] S.Soleymani, A.Akhtarpur."Seepage analysis for shurijeh reservoir dam using finite element method." Geo-Frontiers, ASCE , pp. 3227-3234, 2011.

[4] Arshad, Engr Imran, and M.M.Babar."Comparison of SEEP / W simulations with field observations for seepage analysis through an earthen dam (Case Study:Hub dam-Pakistan)", International Journal of Research (IJR), vol.1, issue 7, pp. 57–70, 2014.

[5] Bahru Mekuria.,"Design and analysis of a high dam under construction material constraint condition (Case study: Wolkayite high dam)", M.Sc., thesis, College of Engineering, Addis Ababa university, 2014.

[6] Melat Gebrhiwot., "Analysis of seepage and slope stability in embankment dam case of Mhtsab Azmat earthen dam Central Tigray, Ethiopia ", M.Sc., thesis, College of Engineering, Addis Ababa science and technology university, 2004.

[7] Ksatie Yhdego,"Evaluation of seepage, slope stability and deformation in embankment dam under static condition (Case Study: Grindeho earthen dam Eastern Tigray, Ethiopia", M.Sc., thesis, College of Engineering, Arbaminch university, 2016.

[8] M.Y.Fattah, S.N.YAl - Labban, F.A.Salman, "Seepage analysis of a zoned earth dam by finite elements", International, Journal of Civil Engineering and Technology, Vol. 5, Issue 8, pp. 128-139, Aug 2014.

[9] Ali Mohamed, "Simulation of seepage flow through the Putrajaya dam using numerical finite - element analysis and SEEP / W model." Red Sea University Journal of Basic and Applied Science Vol. 2 Special Issue 1, March 2017.

[10] GEO-SLOPE International Ltd. Seepage Modeling with SEEP/W, Alberta, Canada, July 2012.

[11] Ministry of Water Resources / Center of Studies and irrigation and drainage Engineering Design/Ethiopia, Addis Ababa, June 2007.

[12] Ministry of Water Resources / Water Sector Development Program / Ethiopia, Addis Ababa, October 2002.

[13] U.S.Army Corps of Engineers, "Seepage analysis and control for dams", Washington, DC, 30, pp. 20314-1000, April 1993.

[14] H.Saunders, "Book reviews : The finite element method in engineering S.S. Rao Pergamon Press,

Elmsford, NY 1982, 625 Pages.” The Shock and Vibration Digest 16, no. 5, pp. 24-25, May 1984.

[15] J.R.Muhammad, "Calculating seepage through earth dams by finite element method", M.Sc. Thesis, College of Engineering, University of Saladdin, Iraq, 2015.

[16] A.A.Abo, "Calculating seepage through earth dams by finite element method", M.Sc. Thesis, College of Engineering, University of Baghdad, Iraq, 2001.

[17] N.T.M.Thieu, M. D. Fredlund, D.G.Fredlund and V.Q. Hung, "Seepage modeling in a saturated/unsaturated soil system", Proceedings of the International Conference on Management of the Land and Water Resources, Hanoi, Vietnam, pp. 20- 22, 2001.

[18] Bardet, Jean-Pierre andTetsuo Tobita. “A practical method for solving free-surface seepage problems”, Computers and Geotechnics, vol. 29, issue 6, pp. 451–475, Sep 2002.

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