American Journal of Engineering Research (AJER)
E-ISSN: 2320-0847 p-ISSN: 2320-0936
Volume-8, Issue-2, pp-95-100
www.ajer.org
Research Paper Open Access

Effect of Cutoff Wall in Seepage Analysis of Dadin Kowa Dam in Gombe State

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ABSTRACT: *Dams are essential elements in any modern society and have great economic values. However, they present potential catastrophic risk of failure which is mostly attributed to seepage. To control seepage, effect of dam cut-off wall at mid sections of the dam having STA 455 was analysed using the Geo-slope SEEP/W 2D finite element method software. The Dam consist of an upstream blanket, 25m deep slurry cut-off wall, which projects into the core and bedrock in the river sand; a grout curtain in under the cut-off wall in the foundation cement and chemical grouting of the river bed and bedrock and a relief well and horizontal drain downstream. Results showed that the annual seepage value at 37m maximum water level of STA 455 was 31.2585 m^3/year with the cutoff wall while 511.4825 m^3/year was recorded without the cutoff wall, the seepage value is far too high compared to the value with the cutoff wall in place. To ensure dam safety and villages at downstream area, it is recommended to use cut-off wall which helps in reducing seepage values. Routine inspections must be carried out by assigned personnel to check against dam break.*

KEYWORDS*: Earth Dam, Seepage, Cutoff-wall, Geo-Slope (SEEP/W), Analysis.*

Date of Submission: 26-01-2019 Date of acceptance: 09-02-2019

I. INTRODUCTION

Throughout history till now there are evidences that mankind has feared and respected the destructive power of water. Especially in the form of heavy rainfall, melted snow, over flooded river banks, tsunamis' wave on open sea, tides and floods. Water is one of the most powerful forces of nature. Hidden in rock crevices and soil pores, it exerts unbelievable force that rip down mountain side, mud slide and destroys engineering works. As a result engineers had long taken importance steps of controlling water on the earth surface and beneath, in pores and cracks of rocks and formations for the benefit of mankind and several engineering project which one of them is the dam. [1]

The building of dams started long time ago. The Sadd-el-kafara Dam, built in Egypt is believed to be the oldest dam in the world. It was built in about 2700 B.C., located on the Nile River about 20 miles south of Cairo. The remains of earth embankment built for diverting water to large community reservoirs can still be found in Sri Lanka and Israel. [2] [3]

Seepage can be defined as the flow of water through homogeneous saturated soil under steady-state conditions. Furthermore, the soil particles, soil structure, and water are assumed incompressible and flow obeys Darcy's law. Also seepage is considered to be all movement of water from the reservoir through the embankment, abutments, and foundation. This includes porous media (inter-granular) flow, flow in fractures, and concentrated flow through "defects" such as cracks, loose lifts, etc.

Most dams have some seepage through or around the embankment as a result of water moving through the soil structure. If the seepage forces are large enough, soil can be eroded from the embankment or foundation. Seepage can also develop behind or beneath concrete spillways or headwalls. The signs of this type of problem could be cracking or heaving. Freezing and thawing will amplify the effects of seepage on concrete structures.

Dadin Kowa dam is selected as the case study for this research work where the climate of Dadin-kowa is characterized by a dry season of six months, alternating with a six months rainy season. The precipitation distribution is mainly triggered by a seasonal shift of the inter-tropical Convergence Zone (ITCZ). The relief of the town ranges between 650 m in the western part to 901 mm in the eastern parts. Dadin-Kowa Dam is a multipurpose dam which impounds a large reservoir of water from Gongola River. It has a storage capacity of 1.77 billion cubic meters. [4]

The maximum flood level is 249 m above sea level (a.s.l), a maximum supply level of 247 m (a.s.l) and minimum supply of 239 m (a.s.l). The surface area of the reservoir is 300 km^2. The 1:10,000 year peak in-flow is 3,160 m^3/sec and the peak outflow is 1,110 m^3/sec. The total catchment area of the Gongola River is approximately 56,000 km^3, 58.5% of which lies upstream of the dam. It also has a gated overflow crest open chute bucket spillway with a maximum design discharge of 1,110 m/sec at reservoir maximum flood level and three (3) radial gates. [5]

The finite element is conceptually a physical rather than a mathematical approximation. The flow region is subdivided into a number of elements and permeability are specified for each element. Boundary conditions are specified in term of heads and flow rates and a system of equations is solved to compute gradients and velocities in each element [6] [7].

Two- and three-dimensional finite element seepage computer programs for both confined and unconfined flow problems have been developed. Steady-state and transient problems can be solved. Darcy's law can be used to describe water flow through soils in both saturated and unsaturated conditions [8] which can be stated as follows:

$$q = - ki \quad \text{--}(1)$$

Where: q = discharge per unit area, i= total head gradient and k = co-efficient of permeability.

The governing partial differential equation for seepage through a heterogeneous, anisotropic, saturated, unsaturated soil can be derived by satisfying conservation of mass for a representative elemental volume. If the assumption is made that the total stress remains constant during a transient process, the differential equation can be written as follows for the three dimensional transient case:

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(k_z \frac{\partial h}{\partial z}\right) = m\gamma\left(\frac{\partial h}{\partial t}\right) \quad \text{--}(2)$$

Where,

K_x, $K_y$and $K_z$are co-efficient of permeability of soil in x, y and z direction, respectively, and m = water storage. [9]

Darcy Law shows the direct proportion relationship between the seepage velocity and the hydraulic gradient and the character of earth will influence it in uniform porous medium. The normal form of Darcy Law is as follows:

$$u = -K\frac{dH}{ds} \quad \text{--}(3)$$

Where: u is the seepage velocity ,K is the permeability coefficient and H is the piezometric head on corresponding point.

This is the summation for pressure head and the location altitude. Because of the linear relation, Darcy Law is adequate to the laminar flow with linear drag force, excepting the turbulence seepage in big pore like rock filled dam, most seepage can be defined as laminar flow, that why the Darcy Law is applied so widely.

Software use in handling seepage has gone a long way in simplifying the analysis of seepage in dam. ANNs have been recently employed for the solution of many hydrologic, hydraulic and water resources problems ranging from rainfall and runoff [10] to sediment transport [11] to dispersion. Depending on the modeling approach, different mathematical models are possible for tackling the same problem [12]. Out of various available numerical techniques, finite difference method (FDM), finite element method (FEM), finite volume method (FVM), boundary element method (BEM) and meshless method have become more popular among scientists and engineers.

Several approaches can be used to transform the physical formulation of the problem to its finite element discrete analogue. If the physical formulation of the problem is known as a differential equation then the most popular method of its finite element formulation is the Galerkin method [13].

GEOSTUDIO software is one of geotechnical program that is based on the finite element and can do analysis such as, stress-strain, seepage, slope stability, dynamic analysis. SEEP/W is a finite element CAD software product for analyzing groundwater seepage and excess pore-water pressure dissipation problems within porous materials such as soil and rock. [14]

The aim of this paper is to investigate and simulate flow, through Dadin Kowa dam using the Geo-slope 2D SEEP/W FEM Software and Dadin Kowa dam in Gombe state, Nigeria as a case study. The results expected are the location of the flow paths within the dam body and foundation, quantity of seepage, flow velocity of water movement and the Pore-water pressure of the dam and to compare the result obtained with a technical report work on the dam.

II. MATERIALS AND METHODS

2.1 Location of Dam:

The dam is located at 37 km from Gombe town and 5 km North of Dadin Kowa village in Yamatu-Deba L.G.A of Gombe state. (Between latitude 10° 19' 19’’N and longitude 11° 28' 54’’E).Dadin kowa dam is a

source of water for the irrigation of Dadin kowa Dam has the potential of irrigating 44,000 hectares of land, comprising of Dadin kowa and Guyuk lots and rural water supply for domestic use.
The dam is an Earth and Rock fill ($1x10^6$ m^3), whose height is 42 meters above deepest foundation. The dam length is 520 meters, width of crest is 8 meters while the width of the base is approximately 230 meters.

2.2 Material data required:

Data used were collected from Upper Benue River Basin Development Authority (UBRBDA) office, based in Dadin Kowa town, Gombe State. The Soil data are the logged ones during construction of dam.

2.2.1 Area Considered for Analysis:

STA 455 was considered for the check on the cutoff wall so as to have a general view of the seepage at those sections, and check the trend of seepage flow. The general details of the dam foundation and sections are shown in plate 1.

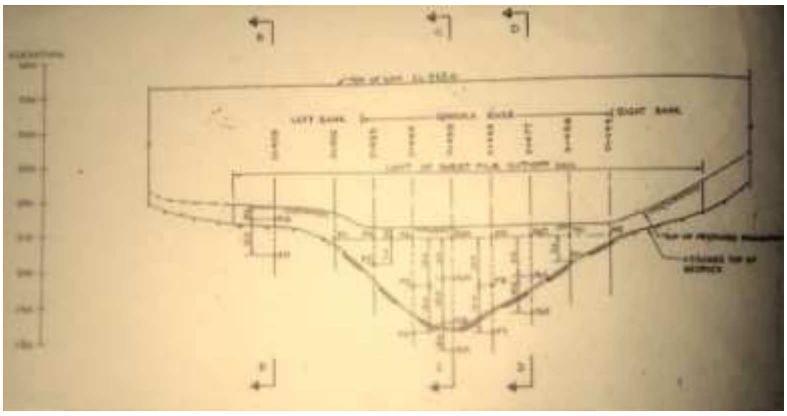

Plate 1. Dam Section Showing details of Dam Foundation. (Source UBRBDA)

2.3 Software for the Analysis

The analysis was carried out using a computer programme SEEP/W (2007), software developed by GEO-SLOPE limited of Alberta, Canada. GEOSTUDIO software is one of geotechnical program that is based on the finite element and can do analysis such as, stress-strain, seepage, slope stability, dynamic analysis. SEEP/W is a finite element CAD software product for analyzing groundwater seepage and excess pore-water pressure dissipation problems within porous materials such as soil and rock.

2.4 Region Property hydraulic conductivity and Cross Section

Regional properties for the selected sections of the Dadin Kowa dam, are presented in Table 1 while that of the Cross section are on Table 2. [15]

Table 1: Region Property

S/N	Region Property	Hydraulic Conductivity
1	Foundation	$1x10^{-5}$ m/s
2	Bedrock	$1x10^{-8}$ m/s
3	Shell	$1x10^{-5}$ m/s
4	Core	$1x10^{-8}$ m/s
5	Filter blanket	$1x10^{-4}$ m/s
6	Cutoff wall	$1x10^{-8}$ m/s

Source: Tectonic Engineering & Consult Ltd, (2011).

Table 2: Typical Cross Section of Dadin Kowa Dam

Dam section	Dimensions (meters)
Dam crest elevation	252
Dam crest width	8
Maximum floor level	249
Maximum reservoir level	247
Minimum reservoir level	239
Upstream slope	2.5:1
Downstream slope	2.2:1
Reservoir volume	1,770 million cubic meters

Source: Tectonic Engineering & Consult Ltd. (2011)

2.5 Mesh Size and Option

A global element size of 3.5 m was adopted and the triangular element mesh pattern used was the triangle because of the geometric nature of the dam.

III. RESULTS

Results from the Figures 1- 6showed that the annual seepage value at 37m maximum water level of STA 455 was 31.2585 m^3/year with the cutoff wall while 511.4825 m^3/year was recorded without the cutoff wall.

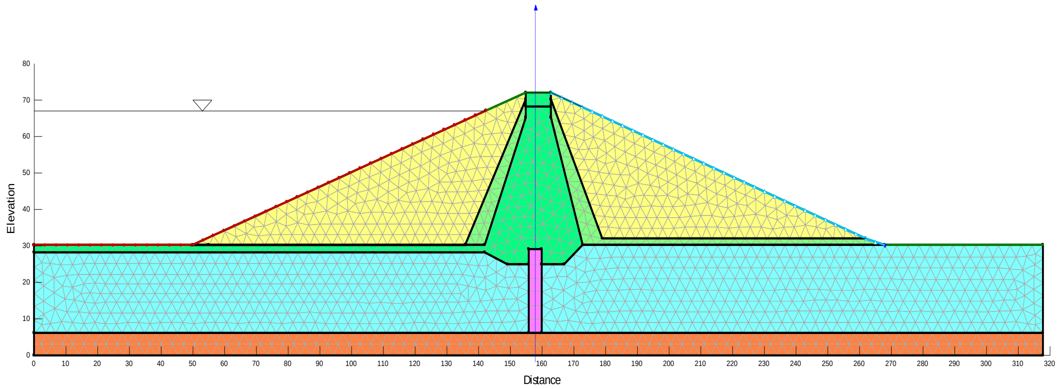

Figure 1. Section 455 Steady-state analysis definition (at maximum pool) 50m upstream and downstream.

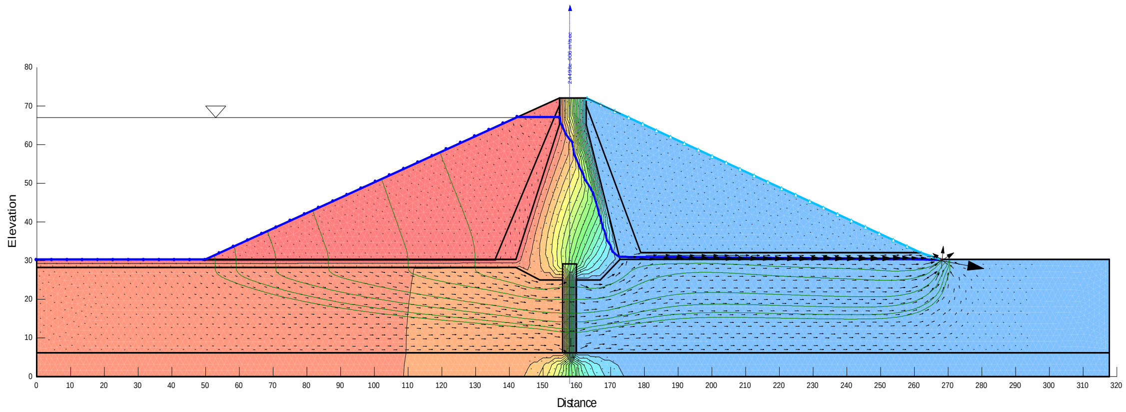

Figure 2. Section 455 Steady-state analysis solution contour (at maximum pool) 50m upstream and downstream.

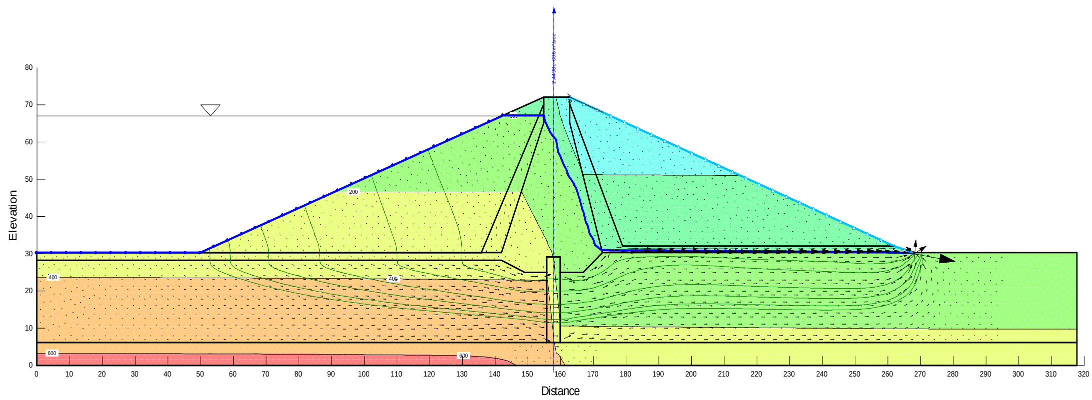

Figure 3. Section 455 Steady-state analysis pore- water pressure (at maximum pool) 50m upstream and downstream.

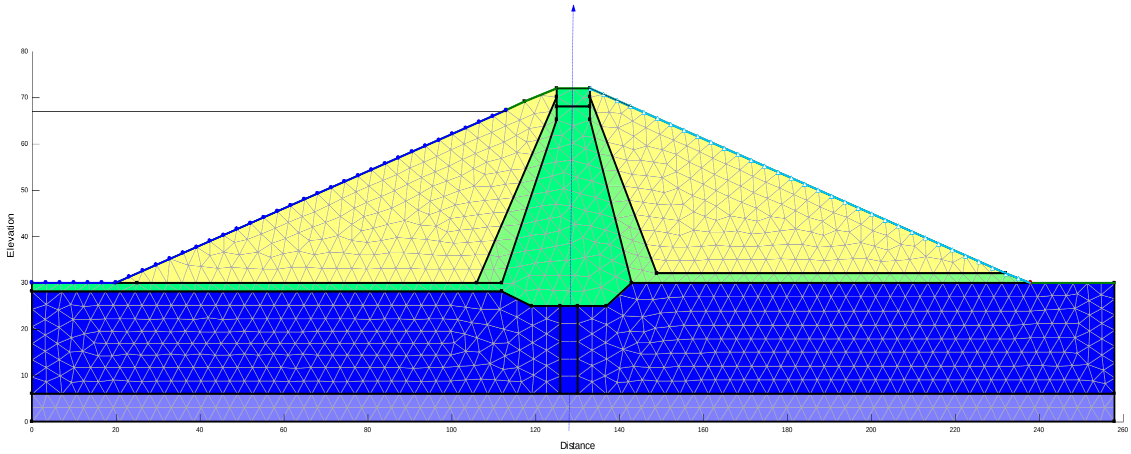

Figure 4. Section 455 Steady-state analysis definition (at maximum pool) 50m upstream and downstream.

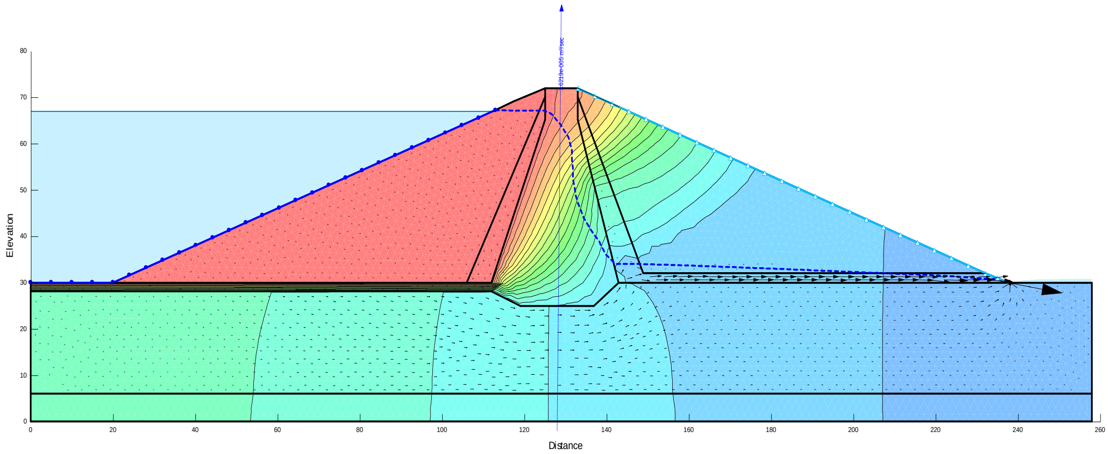

Figure 5. Section 455 Steady-state analysis solution contour (at maximum pool) 50m upstream and downstream.

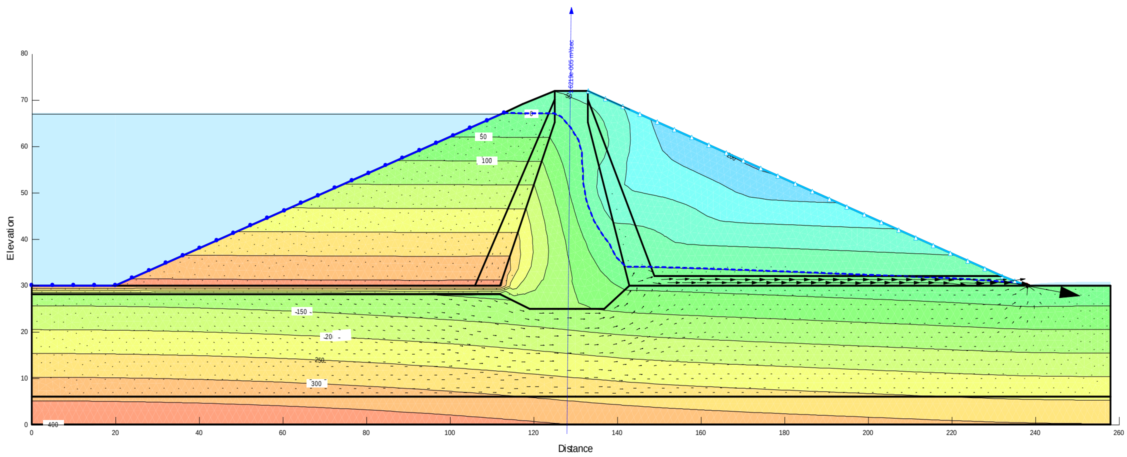

Figure 6. Section 455 Steady-state analysis pore- water pressure (at maximum pool) 50m upstream and downstream.

IV. CONCLUSION

The Dadin Kowa dam was selected as a case study to analysis the seepage using Geo-slope SEEP/W a 2D finite element method based software that can be used to model and determine seepage, provided the hydraulic conductivity and boundary conditions are adequately defined. Analysis were carried out at the maximum pool levels of 37m of the dam at STA 455 [16]

Results showed The seepage value is far too high compared to the value with the cutoff wall in place. Particularly for the maximum section of the dam at 50mm pool level STA 455 values obtained are: 31.2585 m^3/year with the cutoff wall while 511.4825 m^3/year was recorded without the cutoff wall.

To ensure dam safety and villages at downstream area, it is recommended to use cut-off wall which helps in reducing seepage values and ensure stability of the dam, whereby proper monitoring can be checked. Routine inspections must be carried out by assigned personnel to check against dam break.

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J.O. Uloko" Effect of Cutoff Wall in Seepage Analysis of Dadin Kowa Dam in Gombe State" American Journal of Engineering Research (AJER), vol.8, no.02, 2019, pp.95-100