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Simulations of Seepage Flows in Dam Subjected to Varying Phretic Levels

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Abstract: New Ede dam embankment is loosed and permeable and results from previous report established the possibility of erosion of fine particles from upstream to downstream of the dam embankment. Seepage problem was also suspected within the dam embankment due to the internal erosion. In this paper, seepage analysis of the earth dam was primarily conducted to evaluate the dam safety against the leakages through the embankment dam. Steady-state analysis, using SEEP2D was employed to investigate the seepage within the dam body at different water levels. As a particular boundary condition for analysis, the water level fluctuation was incorporated to simulate seasonal change and as a result; the various seepage phenomena were quantified such as flow rate, heads, hydraulic gradient, pore water pressure, velocity and seepage quantity. Correlation analysis was carried out to determine coefficients and significant levels; while regression equations were generated, using ANOVA to relate the dependent variable - water level with other seepage parameters (independent variables). The results of the simulated flow net showed ranges of seepage values of 8.1033 x 10-7 - 2.4396 x 10-7 m3/s/ unit width; for water levels at 19.6 m and 11.6 m respectively. At maximum and minimum phreatic levels of 19.6m and 11.6 m and full length of 877 m of dam axis, total seepage value were 7.11 x 10-4 m3/s (42 L/min) and 2.14 x 10-4 m3/s (13 L/min). There was high level of correlation between the seepage parameters ($R > 0.99$) and significant at < 0.05. The seepage quantities flowing through the dam suggested that the dam body was saturated regardless of water level. The result of this study showed that there is possibility of piping, internal erosion and excessive leakage through the dam.

Key words: Correlation Analysis, New Ede earth dam, Regression equations, Seasonal change, Seepage analysis, Steady state, Water level fluctuation

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1. Introduction

Seepage in earth dam is a major concern when considering the life span of the dam and embankment. It is a major minor problem if controlled the effect are minor and not hazardous, but if not it can become a major problem and possibly result in failures. The rate at which water move through the embankment depends on the type of soil, degree of compaction, gradation and the number and size of cracks and voids which the embankment. The study of seepage through earth dams is one of the important analyses in dam design to calculate the quantity of losses from the reservoir, estimating the pore water distribution, locating the position of the free surface/phreatic line, and the value/variation of hydraulic gradient. When a dam is not safe against seepage hence, the need for a control device for seepage. Control device for seepage are cut-off trench, toe drain, vertical or horizontal drain, upstream blanket, rip-rap, clay lining and reservoir basin line with polymeric material. The uses of one of them, any combination of two of them or more are for control of seepage with specifications. Dams are known to occasionally fail due to a combination of following factors: age, decaying infrastructures, engineering design defects due to poor understanding of the subsurface geology, unstable construction materials, construction defects and lack of monitoring or maintenance of the dams [1]. Adequate assessment of geotechnical properties is an important aspects of dam safety investigations [2], [3]. [4] had attempted the application of locally sourced granular filters and drain to model the control of seepage and piping in the fractured foundation of Awba dam, University of Ibadan, Nigeria; while in 2011b, [5] investigated the dam embankment and its foundation for seepage problems, and modeled the dam with the installation of granular filter-drain, as means to controlling anomalous seepage and piping. [6] investigated the seepage within the embankment and foundation of the dam at different water levels to simulate seasonal changes and concluded that the

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embankment and its foundation were saturated regardless of water level.

2. Materials and Methods

New Ede dam is located in Ede North Local Government Area and is situated along Ede-Ofatedo road. The dam was constructed for the production of potable water supply for both domestic and industrial uses in the old Oyo State, and then was also used for generating power supply for the then, western region, osun senatorial district. The dam presently supplies water to sixteen (16) local governments and about 120 villages. The definite seasons in the region are wet and dry seasons. The wet season is between March and October, while dry season is between November and March, which is often accompanied by harmattan. Temperature is highest during February (32oC) and lowest in July and August (27oC).The region lies in the area of ferruginous tropical soil derived mainly from basement complex and old sedimentary rock [7].

2.1. Application of steady- state analysis, correlation analysis and regression equations to investigate seepage at different water levels within embankment dam and its foundation

New Ede dam embankment is loosed and permeable and the results from this report established the erosion of fine particles from the upstream and the deposit of the same at the downstream of the dam embankment. There is seepage problem within the dam embankment due to the internal erosion; which is a factor responsible for dam failure [7]. This study, therefore attempted the application of steady- state analysis, using SEEP2D to investigate the seepage water discharge within the dam embankment at different water levels. As a particular boundary condition for analysis, the water level fluctuation was incorporated to simulate seasonal change and as a result; the various seepage phenomena such as flow rate, heads, hydraulic gradient, pore water pressure, velocity and seepage quantity were quantified. Correlation analysis was carried out to determine coefficients and significant levels; while mathematical equations were developed, using ANOVA to relate the dependent variable, that is water level with other seepage parameters (independent variables).

3. Results and Discussion

3.1. Flow lines and Seepage Rates

The output models were presented in Figures 1- 20. Figures 1- 4 showed the generated output of seepage parameters such as flownet, flowlines, gradient magnitude and velocity vectors, at water level 11.6 m. The generated outputs for water level at 13.6 m were displayed in Figures 5- 8, while the generated seepage outputs at water level 15.6 m were shown in Figures 9- 12. The generated outputs for water level at 17.6 m were displayed in Figures 13- 16, while the generated seepage outputs at water level 19.6 m were shown in Figures 17- 20. The boundary conditions were selected to represent piezometric levels of 11.6 m, 13.6 m, 15.6, 17.6m and 19.6 m equal to the different fluctuating water levels at New Ede dam reservoir, simulating the seasonal changes.

The simulated flownet and flowlines (Figures 1, 5, 9, 13, 17 and 2, 6, 10, 14 and 18 respectively) represented the path of fluid flow through the dam materials and the flows occurred in the direction of decreasing total head. For dam material with isotropic permeability, flow lines are perpendicular to contours of total head. The results of the simulated flow net showed ranges of seepage values of 8.1033 x 10-7 - 2.4396 x 10-7 m3/s/ unit width; for water levels at 19.6 m and 11.6 m respectively. At maximum and minimum phreatic levels of 19.6m and 11.6 m and full length of 877 m of dam axis, total seepage value were 7.11 x 10-4 m3/s (42 L/min) and 2.14 x 10-4 m3/s (13 L/min). The estimated seepage quantities through the dam implied the dam body was saturated regardless of water level. The result of this study showed that there is possibility of piping, internal erosion and excessive leakage through the dam.

[8] had earlier reported a cross- sectional seepage value of 1.02x10-6 m3/s/width and a total seepage value of 6.52x10-5 m3/s (approx. 5633.3 L/day) along the whole length of the same Awba dam axis; indicating a gross loss of water from the fractured foundation of the dam.

From many statistics, the failure of earth dams were mainly due to seepage or piping and it is widely recommended that the monitoring of seepage through an earth dam will control the safety of the dam. Seepage takes place through and under earth dams [9]. [10] proposed element free method for seepage analysis with free surface and the method was applied to steady seepage and transient seepage in uniform earth dams and the application showed satisfactory results. Mohammedet.al (2006) recorded an estimated maximum seepage rates for both Labong and Bukit Merah Dam as 0.52 m3/min and 0.65 m3/min respectively. [11] reported that in a clay core dam, the total seepage registered at maximum reservoir level is 42 l/sec, while the total seepage registered at maximum reservoir level in asphaltic core dam and asphaltic lining dam are 26 and 0.55 l/s respectively.

3.2. Flow Velocity Vectors

The velocity vector models were presented in Figures 4, 8, 12, 16 and 20. The velocities were between the ranges of 1.27 x10-7 cm/sand 1.63 x10-6 cm/s. This was relatively, a slow soil water movement within the embankment. The Figures showed the flow of the seepage water within the embankment, towards the dam toe, in the direction of decreasing total heads. The flow vectors displayed the groundwater flow velocity vectors at each node of the mesh.

The flow vectors indicated the direction of groundwater flow, and the relative size of the flow vector indicated the relative velocity of the groundwater flow. High velocity flows through the dam embankment can cause progressive erosion and piping of the embankment or foundation soils, [12]. If this condition continues unchecked, complete dam failure can result. Saturated soil areas on the embankment slopes, the abutment, or the area at the toe of the dam can slide or slough, resulting in embankment failure. Piping and badly saturated areas can result in settlement of the soils in the lower the height of the dam and create a potential for overtopping during storm events.

3.3 Analysis of variance (ANOVA)

Tables 1, 2 and 3 showed the statistical analyses of the data generated from the seepage parameters. The descriptive analysis of reservoir levels against the seepage parameters were displayed in Table 1. Table 2 showed the correlation coefficients between reservoir levels and seepage parameters, while Table 3 displayed the regression equations relating the dependent (reservoir levels) and independent variables (seepage parameters).

There was high level of correlation between the seepage parameters ($R > 0.99$) and significant at < 0.05.The seepage quantities through the dam as estimated showed that the embankment and its foundation were saturated regardless of water level.

Table 1: The descriptive analysis of reservoir levels against the seepage parameters.

	N	Minimum	Maximum	Mean	Std. Deviation	Variance
Reservoir level (m)	5	11.60	19.60	15.6000	3.16228	10.000
Total flow rate (m^3/s)	5	2.43960E-7	8.10330E-7	4.9721400E-7	2.22434523E-7	.000
Total head (m)	5	11.00	18.00	14.5800	2.80036	7.842
Gradient magnitude	5	.30	.49	.3682	.07295	.005
Pressure head (m)	5	10.00	17.00	13.4000	2.70185	7.300
Pore pressure (KN/m^2)	5	30.00	170.00	110.0000	51.47815	2650.000
Velocity magnitude (m/s)	5	1.27000E-7	1.63000E-7	1.4680000E-7	1.4788509E-8	.000
Seepage quantity @ full length (m^3/s)	5	.000039521500	.000131270000	.00008054806000	.000036033202961	.000

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Table 2: showed the correlation coefficients between reservoir levels and seepage parameters

	Reservoir level (m)	Total flow rate (m^3/s)	Total head (m)	Gradient magnitude	Pressure head (m)	Pore pressure (KN/m^2)	Velocity magnitude	Seepage quantity @ full length(m^3/s)
Reservoir level (m)	1							
Total flow rate (m^3/s)	.992	1						
Total head (m)	.999	.988	1					
Gradient magnitude	.913	.953	.898	1				
Pressure head (m)	.995	.993	.993	.933	1			
Pore pressure (KN/m^2)	.154	.227	.121	.467	.180	1		
Velocity magnitude (m/s)	.962	.940	.963	.840	.935	.207	1	
Seepage quantity @ full length (m^3/s)	.992	1.000	.988	.953	.993	.227	.940	1

Table 3: displayed the regression equations relating the dependent (reservoir levels) and independent variables (seepage parameters).

Pairs of parameters	R	Regression Coefficients		Regression equations
		A	b	
1. Seepage Qty vs. Reservoir level	0.992	-9.579×10^{-5}	1.130×10^{-5}	$SQ = 1.130\times10^{-5}$ (RL)- 9.579×10^{-5}
2. Tot. Flow Rate vs. Reservoir level	0.992	-5.913×10^{-7}	6.978×10^{-8}	$TFL = 6.978\times10^{-8}$ (RL) -5.913×10^{-7}
3. Total Head vs. Reservoir level	0.999	0.774	0.885	TH = 0.885 (RL) + 0.774
4. Gradient Mag vs. Reservoir level	0.913	0.04	0.021	GM = 0.021 (RL) + 0.04
5. Pressure Head vs. Reservoir level	0.995	0.14	0.850	PH = 0.850 (RL) + 0.14
6. Velocity Mag vs. Reservoir level	0.962	7.66×10^{-8}	4.5×10^{-9}	$VM = 4.5\times10^{-9}$ (RL) + 7.66×10^{-8}

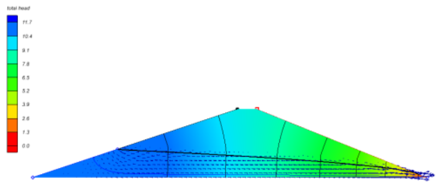

Figure 1: The generated Total Nodal Flow (Flownet) of problem domain @ 11.6 m water level

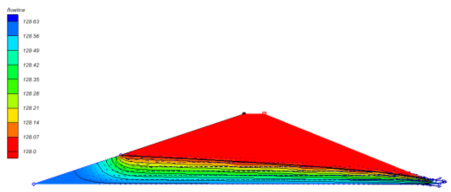

Figure 2: The generated Flowline and direction of Flow of the problem domain @ 11.6 m water level

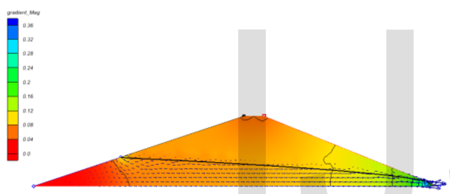

Figure 3: The generated gradient magnitude of problem domain@ 11.6 m water level

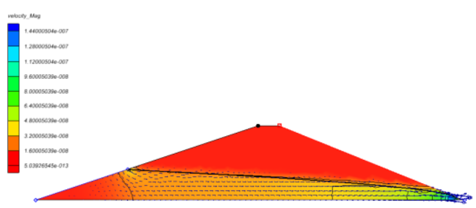

Figure 4: The generated Flow Velocity Vectors of problem domain @ 11.6 m water level

Flow rate @ 11.6m = 2.4396E-07 m3/s/width

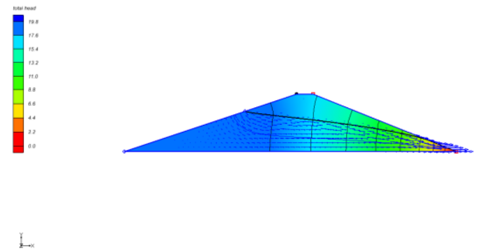

Figure 5: The generated Total Nodal Flow (Flownet) of problem domain @ 13.6 m water level

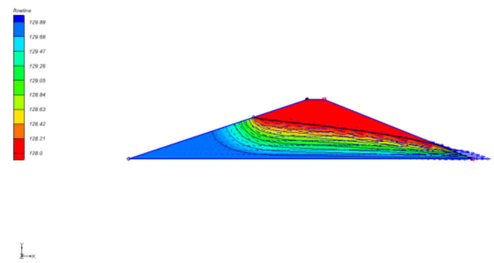

Figure 6: The generated Flowline and direction of Flow of the problem domain @ 13.6 m water level

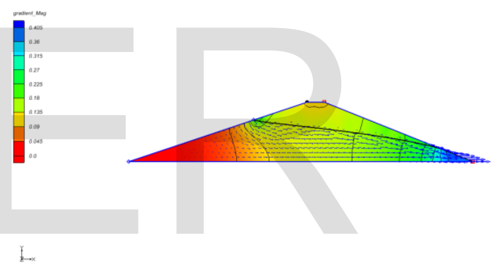

Figure 7: The generated gradient magnitude of problem domain@ 13.6 m water level

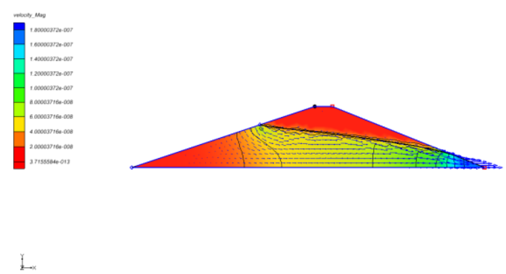

Figure 8: The generated Flow Velocity Vectors of problem domain @ 13.6 m water level

Flow rate @ 13.6m = 7.8091E-07 m3/s/width

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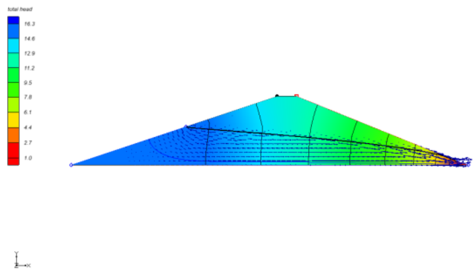

Figure 9: The generated Total Nodal Flow (Flownet) of problem domain @ 15.6 m water level

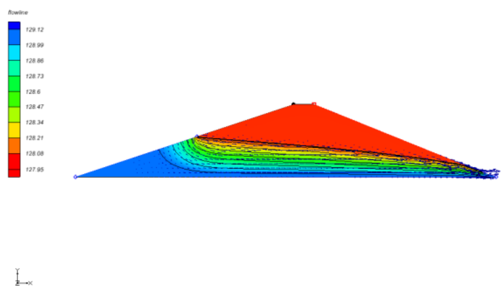

Figure 10: The generated Flowline and direction of Flow of the problem domain @ 15.6 m water level

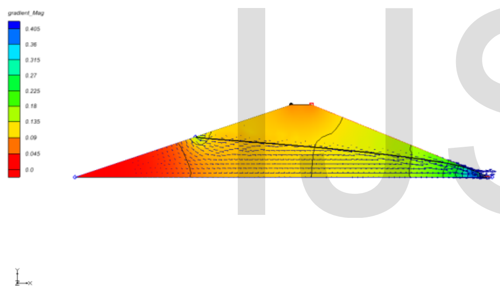

Figure 11: The generated gradient magnitude of problem domain@ 15.6 m water level

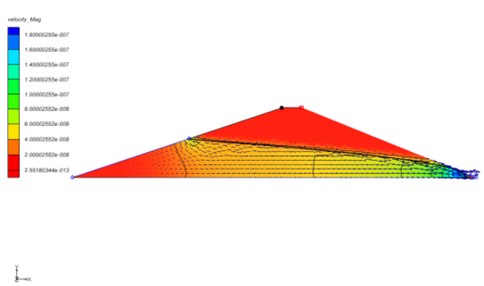

Figure 12: The generated Flow Velocity Vectors of problem domain @ 15.6 m water level

Flow rate @ 15.6m = 4.7535E-07 m3/s/width

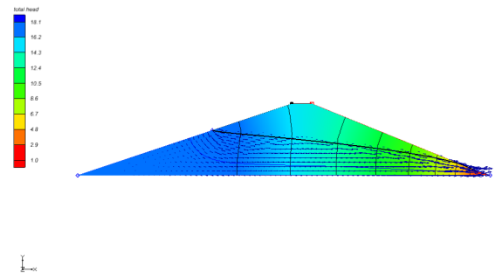

Figure 13: The generated Total Nodal Flow (Flownet) of problem domain @ 17.6 m water level

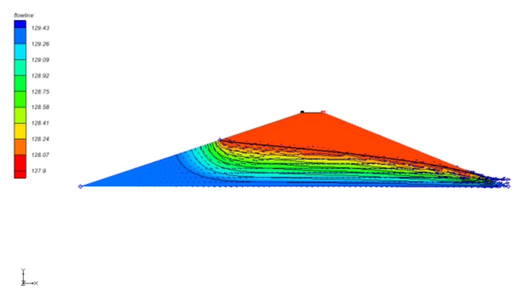

Figure 14: The generated Flowline and direction of Flow of the problem domain @ 17.6 m water level

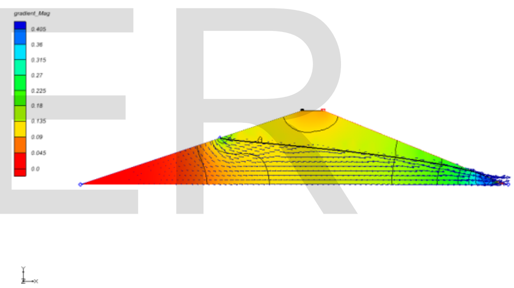

Figure 15: The generated gradient magnitude of problem domain@ 17.6 m water level

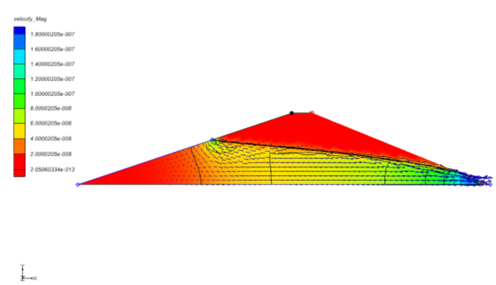

Figure 16: The generated Flow Velocity Vectors of problem domain @ 17.6 m water level

Flow rate @ 17.6m = 6.0961E-07 m3/s/width

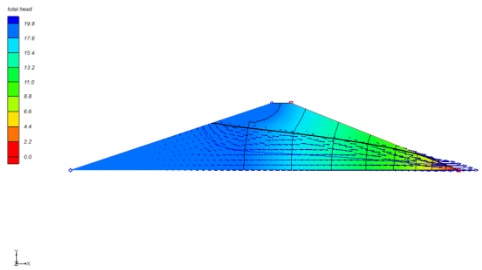

Figure 17: The generated Total Nodal Flow (Flownet) of problem domain @ 19.6 m water level

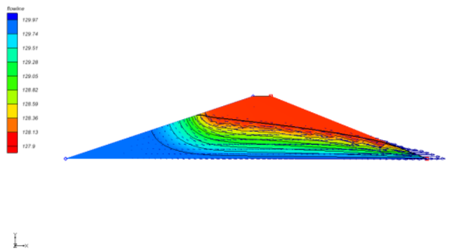

Figure 18: The generated Flowline and direction of Flow of the problem domain @ 19.6 m water level

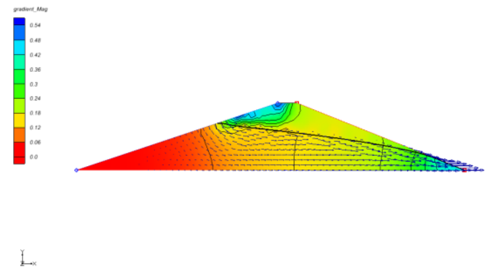

Figure 19: The generated gradient magnitude of problem domain@ 19.6 m water level

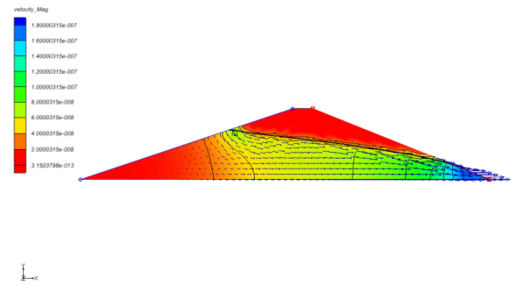

Figure 20: The generated Flow Velocity Vectors of problem domain @ 19.6 m water level

Flow rate @ 19.6m = 8.1033E-07 m3/s/width

4. Conclusions and Recommendations

New Ede dam embankment is loosed and permeable and the results from previous reports established the erosion of fine particles from upstream to downstream of the dam embankment. There was loss of water by seepage through dam toe. Steady- state analysis, using SEEP2D was employed to investigate the seepage within the embankment and foundation of the dam at different water levels to simulate seasonal changes and as a result; the various seepage phenomena were quantified such as flow rate, heads, hydraulic gradient, pore water pressure, velocity and seepage quantity. The seepage quantities through the dam as estimated showed that the embankment and its foundation were saturated regardless of water level. The result of this study showed that there was initial piping and excessive leakage through the dam.

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