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Research Article

Seepage and performance analysis using SEEP/W in three engineering models of Hamrin Dam - Northeastern Iraq

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Abstract:

The Hamrin Dam is characterized by being one of the largest and most stable expansion dams in Europe allowing for greater efficiency and compactness. The weakness of the main dam is the inactive outlet which relies on seepage. The dam's layers are composed of layers divided into product zones with different properties and are affected by additions based on the style and precision of their engineering social characteristics and conditions all of which affect the investment expansion. In this study three geometric models of the Hamrin Dam were analyzed using the full Geo-Slope program (SEEP/W) simulating three methods or forms: (1) original design (2) side partition and (3) wall partition. Since the original design was extensive it recorded a minimum light leakage rate of 2.2117×10^{-4} ($ft^3/s^3/ft^3$) with a protection permeability of 0.099 and a fire velocity of 1.0020×10^{-6} (ft^3/s^3) at a definition level of 270. It was found that extending the cut-off wall was not cost-effective as there was no significant loss of leakage flow velocity or useful water gradient with the wall remaining intact having little effect on properties. This proves that the Hamrin Dam is highly efficient since it introduced a monitor on its original design which led to a successful outcome and full cost.

1. Introduction

Dams all over the world play a significant role in providing large quantities of water protecting different areas from floods and storm surges and controlling the flow of rivers. Furthermore dams are used to generate hydroelectric power and provide irrigation during rainy seasons. Earth dams are characterized by their superior stability compared to the receptive earth dam allowing for a more compact design. However the lack of a port in the dam's weir remains a major vulnerability due to its susceptibility to leakage [8]. Such an engineering focus of the dam is influential and restrictive as are the presence of wet materials and the conditions used on the leakage and the conductivity line which increases the risks more than those of limited prevention. A stage is part of the mission of the dam due to the hydraulic loads in addition [19].
Generally non-external dams such as the Red Dam contain an impermeable clay core constructed by piling various materials such as gravel rocks sand and soil on specific areas of high water between the source and the dam body. This list of dams is subject to failure under hydrostatic water pressure evening water pressure and engineering loads [6]. The stability and seepage flow are then analyzed over a long period to ensure the dam's safety from area collapses. Therefore it is necessary to design the most appropriate dam to accurately study the loads using the finite numerical unit method which divides the dam structure into small components to address the capabilities of the master [15].
Various studies have presented models of seepage such as the use of clay cores clay models or filter formulas to modify seepage [13]. Research has also shown that walls separated from the open air are combined with seepage flow and slope erosion [20]. Accordingly a detailed numerical study was conducted on the Hamrin Dam using SVFlux software to analyze seepage flow slopes and maximum seepage through the dam body and foundation contributing to a deeper understanding.
The operation of non-temporary dams has been approved under various conditions [4].

2. Materials and Methods

2.1 Dam Site

The study is being conducted to model the seepage at the Hamrin Awari Dam located on the Alwand River in Diyala Governorate 120 kilometers northeast of Baghdad Iraq. Figure 1 shows the cross-section of the dam's center [17].

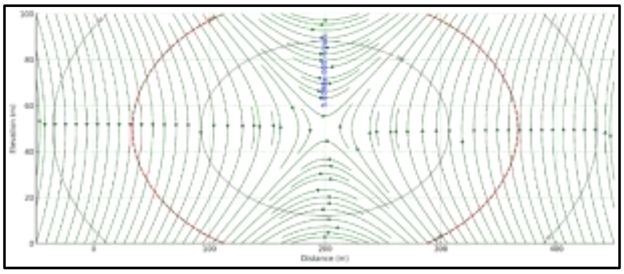

Figure 1. *shows the cross-section of the dam's center*

2.2 Digital

For numerical analysis three geometric models were prepared for the non-receiving Hamrin Ureighi Dam each consistent with the Maglayir design: (1) the original design (2) a partial inner barrier dam and (3) a full separation wall dam.The computational model was created using the SVFlux finite element program where a steady-state study was chosen to study the distillation water conditions under the dam base (Ahmed 2024).

The geometric structure of the dam was visualized within the SVFlux model as shown in Figure 2a-2c. The model was extracted into templates using meshing and triangulation techniques. A mesh consisting of 957 intersection points and 901 templates was designed with an approximate element size of up to 6 acceptable. These techniques were chosen for meshing and a thorough analysis of the soil properties under the dam base. Taking into account the full knowledge of the model regarding construction materials and soil is well suited for steady-state analysis as it represents the smart phone's scientific knowledge [18].

2.3 Model Development

Various parameters were entered. The interface was set to copper (for the dam structure and wall segments). Two Dirichlet and Neumann boundary points were defined for the dam's slopes and bottom [5]. Increasing water volume directly increases the water volume. The dam's performance was studied in three different configurations: (1) the original design (2) a dam with a partial segment wall and (3) a dam with a full segment wall at various levels of the tank: 100 m 105 m and 109.5 m above sea level respectively. A comparison of numerical simulations of wall segments accordingly was discussed [12]. Figure 2a shows an original earthen dam. Figure 2c shows an earthen dam with a partial segment wall while Figure 2c shows an earthen dam with a full segment wall. The Hamrin Dam consists of sedimentary clay and the dam foundation consists of silt coarse sand and impermeable gravel [10]. The material's isolation was investigated in nuclear reactors.

For the purpose of the study a complete saturation of the earthen dam was prepared. Table 1 shows the water permeability characteristics of the materials. All previously mentioned cases were monitored for developments.

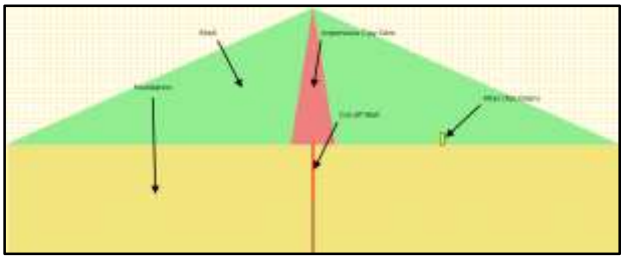

Figure 2 (a). *Variable flow structure of the off-shore part of Hamrin Dam (basic design)*

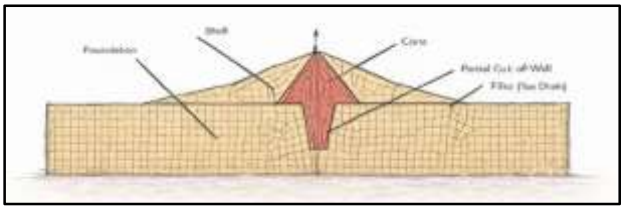

Figure 2 (b). *SVFlux structure of the non-receiving section with a complete partition wall.*

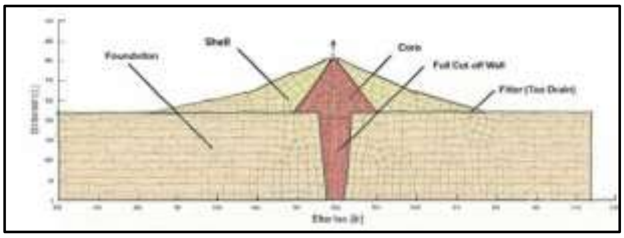

Figure 2 (c). *SVFlux heterogeneous part structure with complete partition wall*

Table 1. *Hydraulic conductivity properties used to simulate the Hamrin Dam*

Type of Material Used in Modeling	Hydraulic Conductivity (m/s)	
	*Guess Values	Calibrated Values (m/s)
Foundation	1×10^{-6}	3×10^{-6}
Shell	1×10^{-6}	2×10^{-5}
Core	1×10^{-7}	2×10^{-8}
Cutoff Wall	1×10^{-7}	2×10^{-8}
Filter Drain	1×10^{-2}	3×10^{-2}

*Source: General Directorate of Dams and Reservoirs – Iraq

2.4 Main Equations Used in SVFlux

2.4.1 Darcy's Law

2.4.1.1 Implementing Darcy's Law Using SVFlux

In this research we used the SVFlux software (produced by SoilVision Systems Ltd.) to study seepage under various design conditions. SVFlux is a finite element modeling tool specifically designed for analyzing seepage in saturated and unsaturated media within complex geometric structures. The software implicitly relies on Darcy's law to simulate water movement through porous media under both steady and changing conditions. The main flow formula used in SVFlux is derived from Darcy's law and the continuity equation resulting in the two-dimensional form of the Laplace equation under steady conditions.

$$0 = \left(\frac{h\partial}{z\partial}{}_z k\right)\frac{\partial}{z\partial} + \left(\frac{h\partial}{x\partial}{}_x k\right)\frac{\partial}{x\partial}$$

h = hydraulic head (meters)
xk zk = horizontal and vertical permeability rates (meters/second).
The permeability characteristics of saturated and unsaturated zones were determined based on laboratory experiments and values from published studies. The software provides the ability to customize various material properties specify boundary conditions (such as upstream and downstream water levels) and add barrier walls or other seepage control measures.
SVFlux adopts an automatic mesh optimization approach to enhance the accuracy of numerical solutions especially at sensitive and critical boundaries such as the water table and seepage zones. By processing the flow equations using finite elements the program provides clear results including:

- Hydraulic height distribution.
- Flow directions and velocity zones.
- Total seepage rates across the dam structure.
- Impacts of design changes (such as the installation of partial or full barriers).

This approach provides a comprehensive understanding of seepage behavior under various designs ensuring performance and safety assessments based on accurate and logical research.

2.4.2 Finite Element Fundamental Equation

In a seepage study using SEEP/W the fundamental finite element equation is used to simulate water movement through soil. This equation is written as follows:

$$\{Q\} = \{H\}\,[K]$$

where:
K = the matrix of material properties at the point (e.g. hydraulic permeability)
H = the total hydraulic head at the point
Q = the flow rate at the point.
This equation represents the fundamental relationship in finite element analysis linking the material properties the hydraulic conditions at each point and the resulting water flow. SEEP/W solves this system of equations to accurately calculate water pressures and flow rates within the soil mass.

2.4.3 Definition of Total Hydraulic Height (H)

SEEP/W operates based on the concept of total hydraulic height (H) where all boundary conditions in the model are defined using this value. The total hydraulic height is calculated using the following equation:

$$H = u/wy + h$$

H = total hydraulic height (meters)
u = pore water pressure (Pascals)
wy = water density (N/m³)
h = geodesic height (meters).
In other words the total hydraulic height is the sum of the elevation pressure and the geodesic height. This value reflects the total energy per unit weight of water at any location within the flow system. Correctly determining this value is essential for setting boundary conditions and understanding the seepage results in the SEEP/W simulation.

3. Results and Analysis

3.1 Isoelectric Flow Network Waterline and Velocity Trends

SVFlux software was employed to simulate seepage through the Hamrin Earth Dam and its base under various water storage conditions providing a thorough understanding of seepage behavior [7]. A flow network was designed for the selected section across different water levels as shown in Figures 3a–5f. The dam's efficiency was evaluated in three different scenarios: (1) the initial or original design (2) the dam with a partial barrier and (3) the dam with a full barrier at different reservoir levels—the highest (109.5 m) the normal (105 m) and the lowest (100 m) above sea level respectively. A comparative analysis of the numerical simulations of the barrier was conducted based on this [9]. The flow network consists of flow paths isoelectric lines and velocity trends which together reflect the dominant seepage flow and the waterline shedding light on the seepage characteristics of the Hamrin Dam. The results indicate that seepage is occurring through the base of the dam underscoring the need for appropriate mitigation measures to mitigate seepage through the dam.

Case 1: Heterogeneous Part in the Initial or Original Design

The performance of the Hamrin Dam was examined during construction under various conditions particularly at reservoir elevations of 100 m 105 m and 109.5 m. The water flow and waterline exhibited zigzag behavior.
The waterline (shown in blue) after the center core deviated abruptly at the location of the spillway filter. Seepage flow values were recorded at 1.8500×10^{-4} (m³/s/m) 2.2100×10^{-4} (m³/s/m) and 2.3500×10^{-4} (m³/s/m) with exit gradients of 0.095/0.120/0.150 for reservoir elevations of 100 m 105 m and 109.5 m respectively. In contrast the highest seepage velocities were observed at these levels—100 meters 105 meters and 109.5 meters—with values of 0.9200×10^{-6} (m/s) 1.1500×10^{-6} (m/s) and 1.3000×10^{-6} (m/s) respectively. Across varying water elevations the pore water pressure decreased in a quasi-linear manner indicating steady flow throughout the entire dam structure.

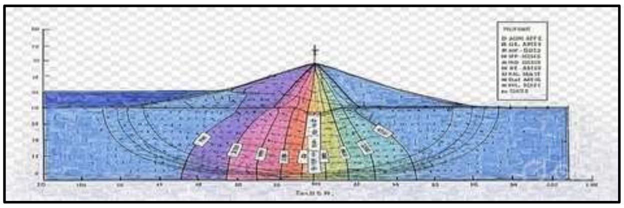

Figure 3 (a). SVFlux simulation outputs for the heterogeneous region (tank height = 100 m).

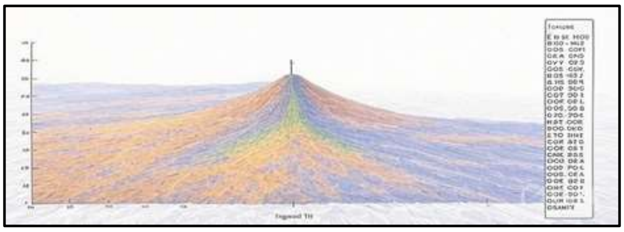

Figure 3 (b). SVFlux simulation outputs for the heterogeneous region (tank height = 105 m).

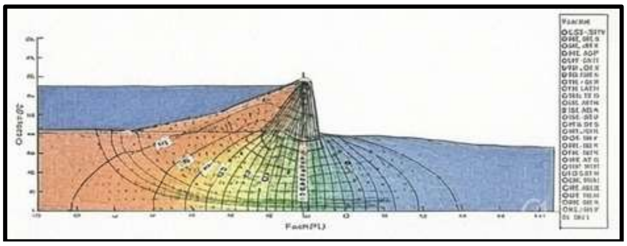

***Figure 3 (c).** SVFlux model results for the heterogeneous part (reservoir level 109.5 m)*

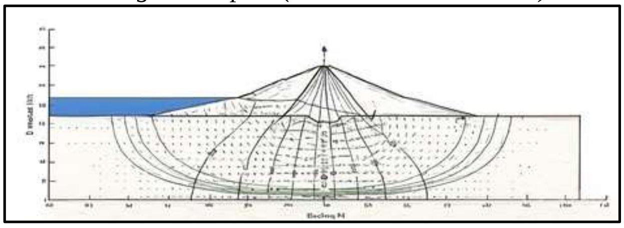

***Figure 3 (d).** Behavior of the groundwater line for the heterogeneous part of the Hamrin Dam (reservoir level 100 m)*

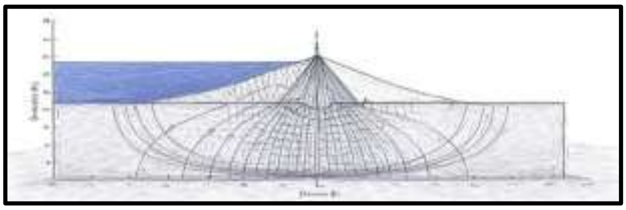

***Figure 3 (e).** Behavior of the groundwater line for the heterogeneous part of the Hamrin Dam (reservoir level 105 m)*

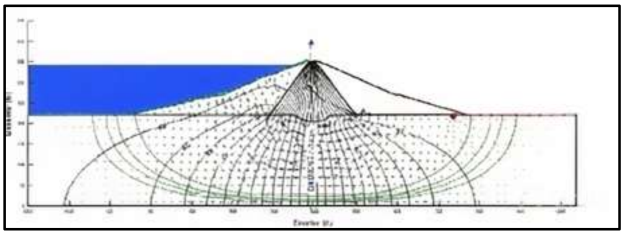

***Figure 3 (w).** Behavior of the groundwater line for the heterogeneous part of the Hamrin Dam (reservoir level 109.5 m)*

Case 2: Non-receiving section with partial separation wall

Also a mixer analysis was conducted for the non-receiving section of the Al Hamra Dam with a partial separation wall under hypothetical shadow conditions across different reservoir areas.
The results show that at each reservoir level—100 m 105 m and 109.5 m—the swimming seepage flow was 1.7200×10^{-4} (m³/s/m) 2.0500×10^{-4} (m³/s/m) and 2.1800×10^{-4} (m³/s/m) with

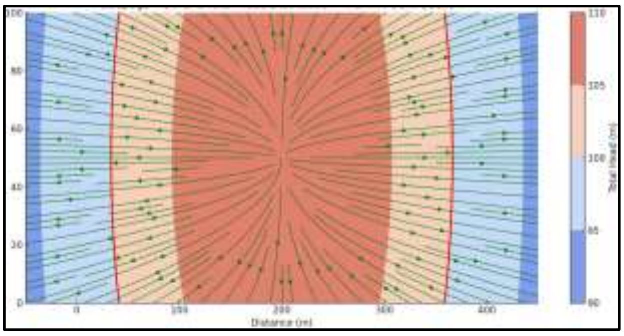

***Figure 4 (a).** SVFlux model results for the heterogeneous part of the Hamrin Dam with a partial isolation wall (reservoir level 100 m)*

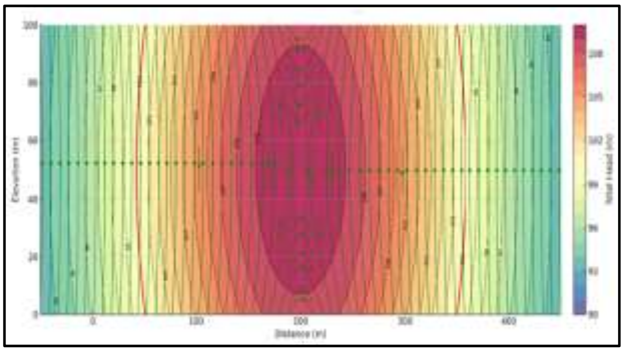

Figure 4 (b). *SVFlux model results for the heterogeneous part of the Hamrin Dam with a partial isolation wall (reservoir level 105 m)*

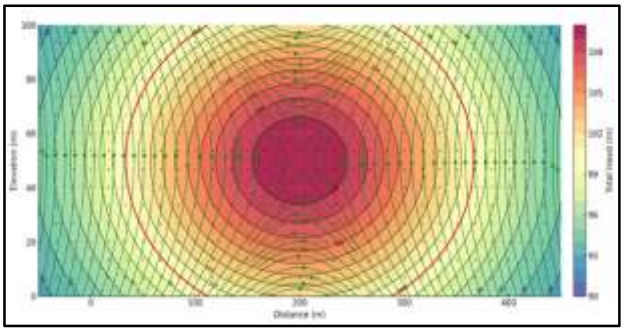

Figure 4 (c). *SVFlux model results for the heterogeneous part of the Hamrin Dam with a partial isolation wall (reservoir level 109.5 m)*

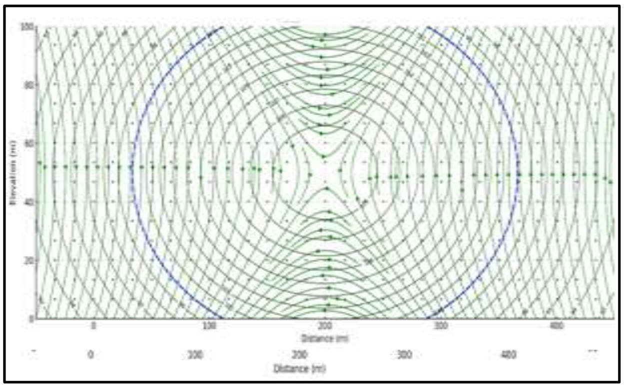

Figure 4 (d). *Groundwater line behavior of the heterogeneous part of the Hamrin Dam with a partial isolation wall (reservoir level 100 m)*

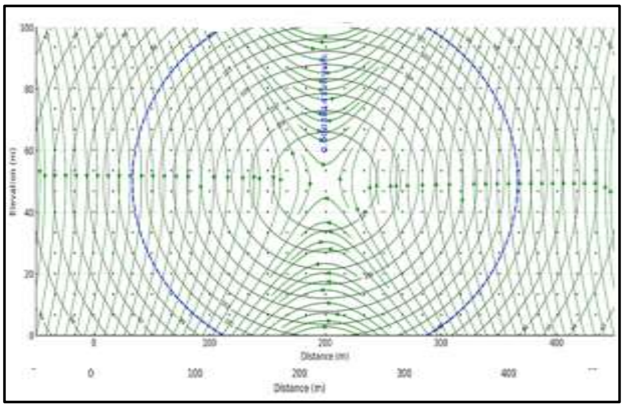

Figure 4 (e). *Behavior of the groundwater line of the heterogeneous part of Hamrin Dam in the original design (reservoir level 105 m)*

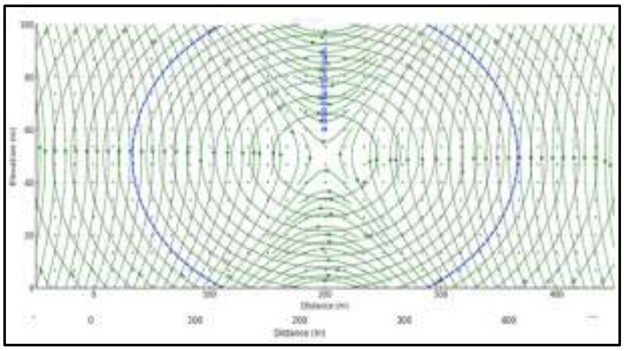

Figure 4 (w). *Behavior of the groundwater line for the heterogeneous part of the Hamrin Dam in the original design (reservoir level 109.5 m)*

graduations of 0.090 0.115 and 0.140 respectively. The maximum brush distance at these reservoir levels—100 m 105 m and 109.5 m—was also measured at 0.8500 × 10^{-6} (m/s) 1.0500 × 10^{-6} (m/s) and 1.2000 × 10^{-6} (m/s) on the right. Starting from 4a to 4c it produced an excellent simulation of Case 2 at various reservoir levels.

Case 3: Section Unrestricted by a Full Dividing Wall

Similarly a hydrant for the unexpanded section of the Hamrin Dam equipped with a full dividing wall and a spillway was analyzed under hypothetical conditions for different storage levels. The results showed that at each reservoir level—100 meters 105 meters and 109.5 meters—the seepage flow was recorded at 1.6200 × 10^{-4} (m³/s/m) 1.9500 × 10^{-4} (m³/s/m) and 2.0800 × 10^{-4} (m³/s/m) with graduations of 0.085 0.105 and 0.130 respectively. The submarine velocities at these reservoir levels—100 m 105 m and 109.5 m—were also measured at 0.8000 × 10^{-6} (m/s) 1.0000 × 10^{-6} (m/s) and 1.1500 × 10^{-6} (m/s) respectively. Figures 5a to 5c are shown to simulate the window for Case 3 at different latitudes..

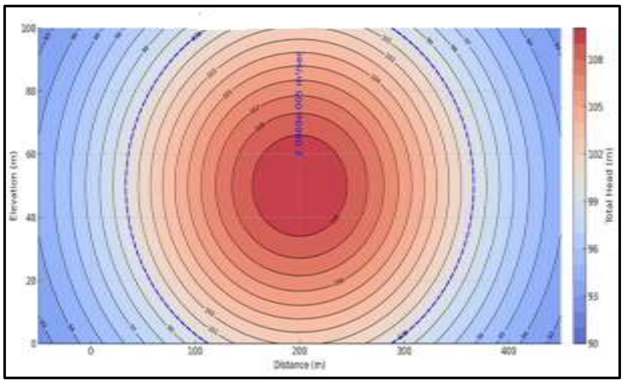

Figure 5 (a). *SVFlux model results for the heterogeneous part of Hamrin Dam with a full isolation wall (reservoir level 100 m)*

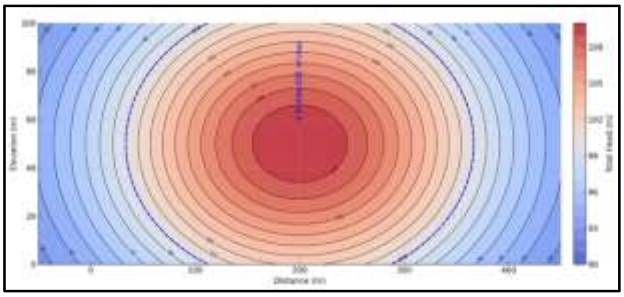

Figure 5 (b). *SVFlux model results for the heterogeneous part of the Hamrin Dam with a full isolation wall (reservoir level 105 m)*

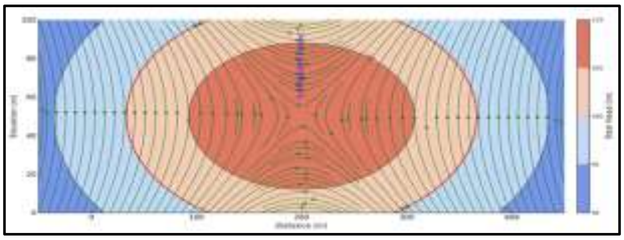

Figure 5 (c). *SVFlux model results for the heterogeneous part of Hamrin Dam with a full isolation wall (reservoir level 109.5 m)*

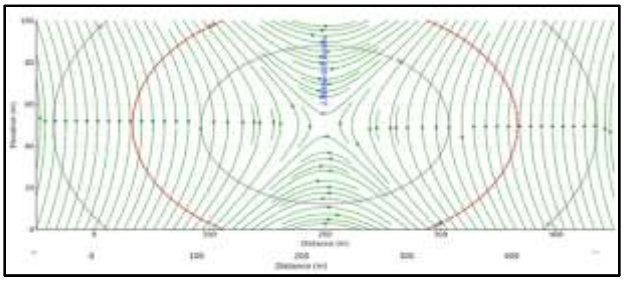

Figure 5 (d). *Behavior of the groundwater line for the heterogeneous part of the Hamrin Dam in the original design (reservoir level 100 m)*

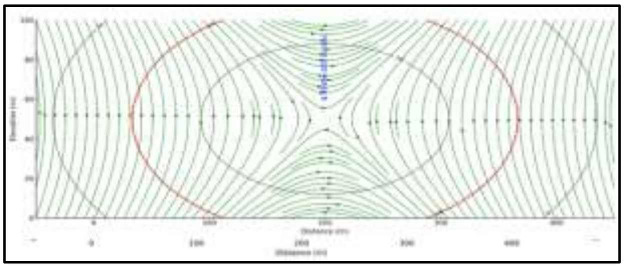

Figure 5 (e). *Behavior of the groundwater line of the heterogeneous part of Hamrin Dam in the original design (reservoir level 105 m)*

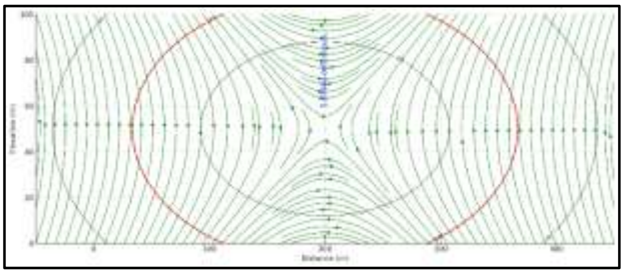

Figure 5 (w). *Behavior of the groundwater line of the heterogeneous part of Hamrin Dam in the original design (reservoir level 109.5 m)*

3.2 Comparison of the Three Cases

Comparing the three cases on a partial or full-scale basis revealed significant leakage or a tendency to dilate respectively. This suggests a possible collapse in the mid-slope direction. Furthermore the onset of a break in the Francisco line of natural seepage in all cases passing through the core and heading sequentially toward the spillway..

Table 2. *What the SVFlux model showed for Hamrin Dam with multiple reservoir levels*

Parameters	Upstream Reservoir Levels	Case 1: Original Design	Case 2: Partial Cutoff Wall	Case 3: Full Cutoff Wall
	100 (m)	105 (m)	109.5 (m)	100 (m)
Seepage Flux × 10^{-4} (m³/s/m)	1.8500	2.2100	2.3500	1.7200
Exit Gradient	0.095	0.120	0.150	0.090
Max. Seepage Velocity × 10^{-6} (m/s)	0.9200	1.1500	1.3000	0.8500

It is currently shown that a partial or complete separation wall does not prevent a significant difference in leakage reduction or exit gradient as the same individuals protest in all cases. I used Figures 6a-6c for leakage indices between leakage flow exit gradient and maximum leakage velocity as a guide to general elevations.

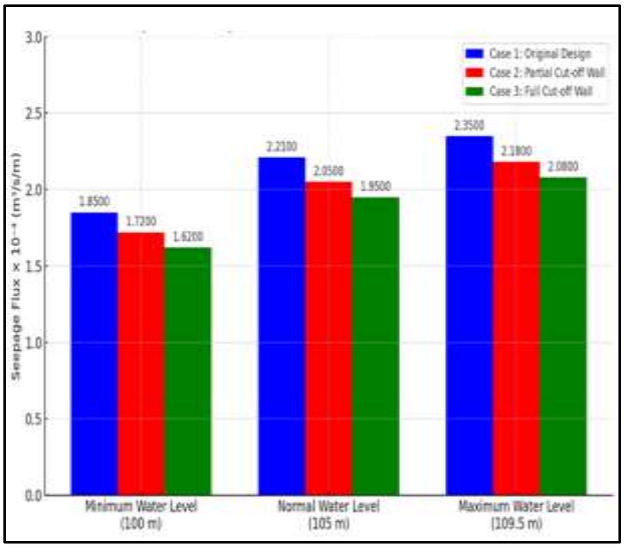

Figure 6 (a). *The relationship between the storage level and the seepage flow of Hamrin Dam across different cases*

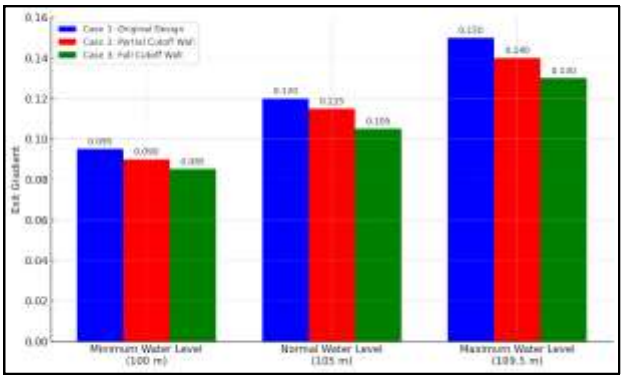

Figure 6 (b). *The effect of the storage level on the discharge gradient of Hamrin Dam in various cases.*

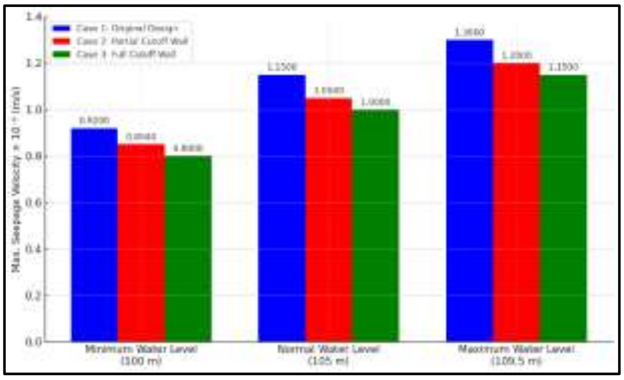

Figure 6 (c). *The relationship between the storage level and the maximum seepage velocity of Hamrin Dam across various cases.*

4. Conclusion

The results of the finite element analysis of the non-flooding dam demonstrate the effectiveness of the Geo-Slope (SEEP/W) program in generating key seepage characteristics such as flow velocity, total hydraulic head and pore water pressure (phreatic seepage line). We also confirm that each concept was analyzed using the results of a well-established computational grid including evaluation. According to the results a portion of the dam's length contributes to protecting the dam from seepage issues. it does not appear that a partial or full cutoff wall will be necessary except for addressing specific active seepage zones. These results indicate that the original design components and their configuration perform better overall. any increase in the length of the cutoff wall may have a limited impact on seepage control in most cases. The Hamrin Dam has been operating successfully since its inception thanks to its original design and structure.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
- **Acknowledgement:** Thank you I submitted the diversity invention to the General Directorate of Withdrawal and Storage at the Ministry of Water Resources in Iraq as well as to the final report on the Hamrin Dam. I am grateful for reaching out to all the people who provided invaluable support and enabled the search robot.
- **Author contributions:** The authors declare that they have equal right on this paper.
- **Funding information:** The authors declare that there is no funding to be acknowledged.
- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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