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The Seepage Behavior of Rockfill Dam Due to Change of Reservoir Conditions

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ABSTRACT

The governing differential equations about the seepage were resolved using the standard numerical. The research location was on the Darbandikhan dam, which is about 230 kilometres northeast of the governorate of Baghdad in the district of Sulaymaniyah on the Diyala River. The Geo-Studio program and its subprogram SEEP/W were used to examine the total water head through the dam and water flux, and exit gradient through the numerical model that represents the dam body to show how seepage affects the dam's stability. To run the dam numerical model, three upstream reservoir water levels at a Minimum water level of 434 m, Normal water level of 472 m, and flood water level of 485 m were selected to represent the model boundary conditions. Maximum total water head through the dam was found when the water level in the reservoir was 485 m while the maximum water flux through the dam was found when the water level in the reservoir was 472 m. It was found the dam safety was ensured for all tested reservoir water levels.

Keywords: Seepage, Exit gradient, Geo-studio, Pore water pressure, Rockfill dam.

1. INTRODUCTION

Due to the water they retained, earth dams were always associated with seepage. Water finds its way through the dam and its base by following routes with less resistance. Seepage and piping are serious problems that affect dam safety and they should be continuously monitored. Earthfill dams are simple structures made of compacted material that can resist twisting and sliding caused by weight **(Jansen, 1988).** Zoned earthen dams are homogeneous earth dams that have an inclined or central impermeable center. These dams have an interior core that is impermeable, providing water resistance on both sides of the core. The purpose of zoning is to use the most cost-effective combination of materials to ensure sufficient strength, seepage control, and resistance against cracking. Introducing impermeable zones or drainages allows for better control of the drainage and reduces the

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amount of water in the earthen dams **(Singh and Varshney, 1995).** A dam made of earth can become damaged by erosion or piping caused by excessive moisture**. (Khattab, 2010)** studied the failure of earth dams caused by the impact of seismic load. Earthfill dams are the most common type of dams because they can be built using natural materials that are easily available. Moreover, they can be constructed on weak foundations and are usually more suitable for their location and topography compared to other types of dams **(Chugh, 2011).** **(Fattah et al., 2012**) looked at how joining characteristics in clay soil were affected by changes in the permeability coefficient during the joining process. The study used the finite element approach and two programs called SIGMA/W and SEEP/W. Through these, they could quantify that effect by using three samples from each of these algorithms, which implicitly adopted the link between pressure and permeability. It was determined that because of the decline in the void ratio and the gradual release of the pressure of the porous water, the influence of permeability could be seen more clearly after 400 days of shedding loads. Considering that increased adhesion causes a change in permeability with time. **(Fattah et al., 2013)** used the finite element approach, they performed an analytical analysis on a strip foundation with a width of 1 m that was constructed on both fully and partially saturated soil. The approach presupposed obtaining an H-modulus function from the soil's moisture characteristics curve. The investigation employed the SEEP/W tool to simulate the pore water pressure and soil structure. The study demonstrated that the load-bearing capacity of the surface foundation is increased over the load-bearing capacity of the same soil in the event of total saturation when the groundwater level is lowered to different depths and degrees of saturation. Due to the soil's ability to absorb water, there is a negative pore water pressure. **(Soleimani and Adel, 2014)** studied the stability of Nian Dam embankment. **(Abbas, 2014)** studied the ability of stability embankment by using 2D FEM. **(Arshed and Babar, 2014; Sotoodehnia et al., 2014)** studied reducing the volume of exchange using the SEEP/W program.

(Kirra et al., 2015) used the finite element Geo Studio tool to construct the Mandali dam and assess its stability and seepage. The dam is 1326 m long and a height of 14 m. The analysis of this study includes three upstream reservoir conditions, namely empty, constant, and flood reservoir conditions. The results revealed that Mandali Dam is safe under these operation conditions. **(Nia et al., 2015)** SEEP/W software was used to simulate the water flux effects in the Meydanak Dam's body and foundation. Numerical simulation was utilized to analyze semi-saturated soil sampling. An analysis was performed using the experimental data to compare with the model predictions. Based on comparing the results, it was found that the difference of 3.9 % was acceptable. **(Irzooki, 2016)** simulate three different cases of the water flux effect in an embankment dam by using the Geo-Studio program. The dam geometry was varied in terms of the embankment slopes, height, length of drainage, and freeboard. The simulation revealed that the water flux rate is directly increase with the dam geometry and reservoir water level. Conversely, it is inversely related to the top width and height of the freeboard**. (Jamel, 2016)** determined the extent of the effect of seepage and piping on the dam downstream. **(Wu et al., 2016)** estimated numerically the water flux rate through a non-homogenous dam.

(Jamel, 2017) used a simulation model to study the effects of water flux rate on uplift pressure and Exit gradient. **(Ameen et al., 2018)** aimed to improve the safety of dams by studying the effect of vibrations resulting from the operation of the electric power plant on the dam body. The physical properties were determined using numerical simulation by ANSYS. **(Li et al., 2018: Ameen, 2018)** studied the vibration effect of a turbine operation on the body of Haditha dam by using ANSYS program. **(Cheng et al., 2018)** studied the water flux and slope safety of a rockfill dam using machine learning. The program's results were based on the dam's field data and were conducted for flood and half-full conditions. The study showed that having a core in the dam is crucial to prevent leaks and enhance stability. **(Asmaa, 2018)** studied the behavior of water flux through earth dams. (**Mishal and Khayyun , 2018)** studied numerically the variation of water flux and safety of AL-Adhaim dam in Iraq.

(Khanna et al., 2019) studied the water flux in homogenous and nonhomogeneous rockfill dams The permeability of the core material and core penetration on the dam safety had been studied too. **(Jassam and Abdulrazzaq, 2019)** assessed the water flux effect through homogeneous dams and its influence on increasing downstream water levels. For saturated soil, they found that the relationship between seepage and water height upstream was not linear. The amount of seepage increased as the water height upstream increased, but for heterogeneous dams, the relationship was linear. **(Bredy and Jandora, 2020)** studied the effect of water flux through the dam body by using standard numerical Plexis 3D to determine the factor of safety for the body of dam and foundation.

(Al-Nedawi and Al-Hadidi, 2020: Ameen et al., 2020) simulated the water flux rates and total water head numerically through Hemrim dam, Iraq. **(Bredy and Jandora, 2020)** used Plaxis-3D to determine the impact of dam height on a safety factor of Karolinka dam body and foundation. **(Jassam and Abdulrazzaq, 2020)** used numerical simulation using the Geo-Studio program in the SEEP/W branch to study the effect of seepage through the Al-Wand Dam in the presence of a clay core and the case of the absence of a clay core. **(Al-Salakh and Albusoda, 2020)** studied the phenomenon of liquefaction, which leads to failure in the existing facilities and the occurrence of a large decline in the foundations of these facilities, especially the shallow ones. For this purpose, laboratory experiments were conducted using shaking tables representing shallow foundations established on saturated and weak sandy soils. Texture, where several levels of applied acceleration were used (0.05 g, 0.1 g, and 0.2 g) to represent and study the soil behavior during vibrations and their impact on existing foundations. To reduce the liquefaction resulting from the accumulation of pore water pressure, the soil was treated to reduce the effect of the vibratory load. Statistical analysis found that practical experiments are close and appropriate and can be adopted as approved formulas in similar cases. **(Khalaf et al., 2020)** explained the effect of seepage and water movement through saturated and unsaturated soil using the SEEP/W program.

(Al-Hadidi and Hashim, 2021) studied seepage under or inside the Kongele dam as a case study to show the behavior of seepage under different U/S and D/S water levels. **(Ameen et al., 2021)** carried out a study on the dynamic analysis 3D FEM for rock dam by using ANSYS program. **(Alzamily and Abed, 2022)** conducted multiple tests to measure the permeability of alluvial and sandy soils by adding different substances. They developed a laboratory model to suggest an alternative soil for the clay soil used in the dam's core. They constructed a digital model of the dam using Geo Studio software, SEEP/W branch and represented it empirically with the selected soil model. They added 10% cement kiln dust (CKD) and 5% cement as additives, based on Hamrin and Haditha dams, and found that the sandy soil model of class C has a permeability similar to the clay soil. The results showed a high correlation between the two scenarios.

This study aims to reduce seepage through the dam body using the SEEP/W program. This study, in addition to studying the effect of the earthquake on the dam, represents the requirements for evaluating of liquefaction phenomena of the Darbandikhan Dam, which will be evaluated in a later study.

2. METHODOLOGY

2.1 Darbandikhan Dam and Reservoir Study Area

The Darbandikhan dam shown in **Fig. 1** is a rockfill dam situated on the Diyala-Sirwan River, approximately 65 kilometers southeast of Sulaimaniyah Governorate and 230 kilometers northeast of Baghdad, Iraq. Its coordinates are latitude 35.1128° N and longitude 45.7053° E. The height of the dam is 128 meters, its length is 445 meters, and its width is 17 meters. It is located at an elevation of 495 meters.

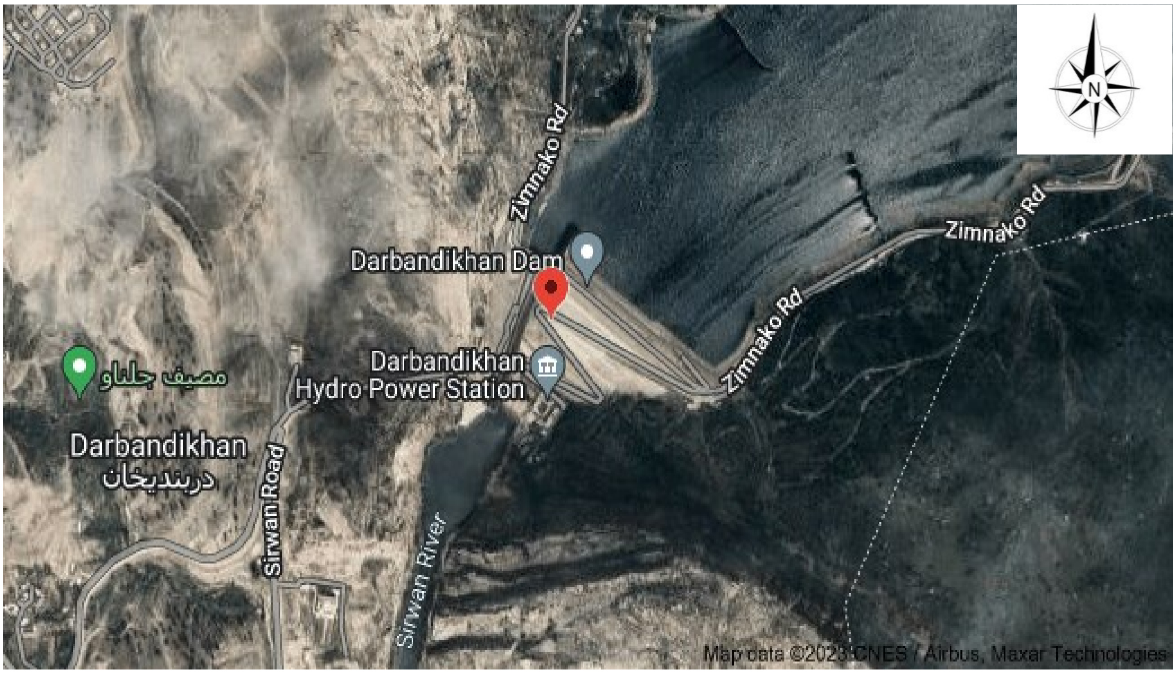

Figure 1. Location of Darbandikhan rockfill Dam, (Scale 1:200 m) **(Google Earth)**.

The construction of the Darbandikhan reservoir began in 1956 and was completed in 1961. At normal reservoir level (El. 485.00 m), the reservoir was designed to hold a total capacity of 3 km^3, which includes 0.5 km^3 of dead storage and 2.5 km^2 of active storage. It is found that after 57 years of operation, the sediment volume is less than the design storage by 2.5 km^3. The upstream reservoir is managed by three 15 m x 15 m tainter gates on an ogee spillway with gates located at the dam embankment's right abutment. The powerhouse near the dam's toe feeds three massive turbines through two outlet conduits with diameters of 6 m and 9 m. There is a concrete inlet tower between the canal and the dam embankment. (see **Fig. 2**) **(Yousif et al., 2019).** The intake tower houses have three 4.75 m x 9.5 m vertical lift gates, with one gate feeding a conduit with a diameter of 6m and the other servicing a 9 m diameter.

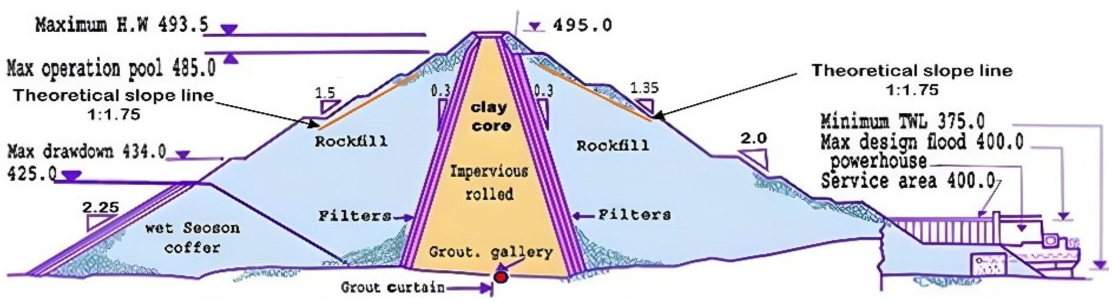

Figure 2. Darbandikhan Dam Directorate **(Yousif et al., 2019)**.

2.2 Finite Element Method Simulations

Geo-Studio software was used to create a two-dimensional model of Darbandikhan dam based on numerical simulation. This model was developed to evaluate the effect of water flow on the dam body. In addition, an elastic linear model and an equivalent linear model were built using Geo-Studio software. Additionally, the 2015 SEEP/W User's Guide Manuals were consulted to provide condensed explanations of various operating systems. **Fig. 3** displays the full-scale model of the Darbandikhan rockfill dam, which measures 535 m by 660 m.

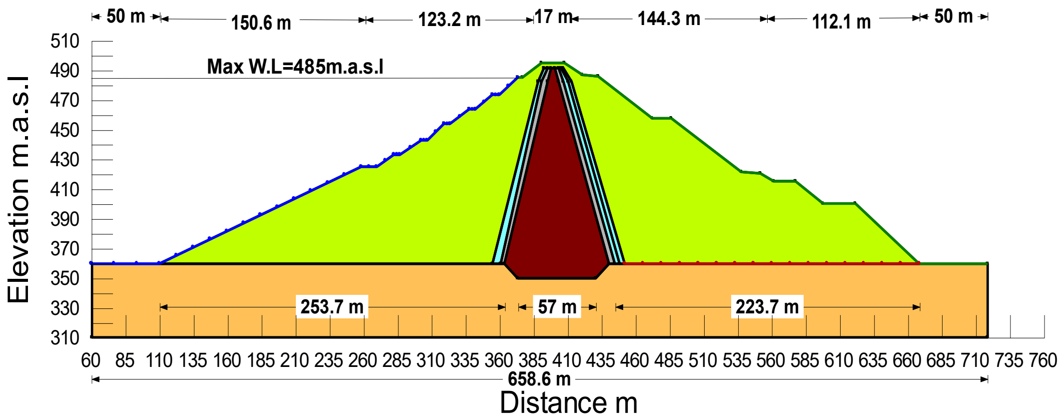

Figure 3. 2D Darbandikhan rockfill dam Model **(Ministry of Water Resources, local measurements)**.

2.3 Governing Equations

The covering differential equations of stability and water flux in the dam's body and base were solved using the numerical simulation. Following **(Arshad and Babar, 2014)**:

$$\frac{\partial}{\partial x}\left(k_x \times \frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \times \frac{\partial H}{\partial y}\right) + Q = \frac{\partial \theta}{\partial t} \quad (1)$$

where: θ is the volumetric water content $= \frac{V_{water}}{Vt_{otal}}$, H is the total head (m); K_x is the hydraulic conductivity in a horizontal direction (m/s), K_y is the hydraulic conductivity in a vertical direction (m/s), Q is the water flux (m^3 /s), t is the time domain (T).

Equation is a time variable that explains the difference between the stream that enters the volume and exits an important volume at a moment comparable to the adjustment in the water substance of volumetric in a certain time. If the out-transition volume equals the deluge volume, the condition will satisfy the consistent state requirements, and the condition's proper hand will change to zero.

$$\frac{\partial}{\partial x}\left(k_x \times \frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \times \frac{\partial H}{\partial y}\right) + Q = 0 \tag{2}$$

2.4 Modeling Program Description

The SEEP/W software, developed by Geo-Slope International, is a CAD-style application that uses finite element method (FEM) to analyze seepage and groundwater issues in permeable soil mediums. The software is designed to dissipate excess pore pressure within porous materials such as soil and rock and is limited to analyzing groundwater seepage and leakage problems. The governing equation for the SEEP/W system is the partial differential equation (PDE). The program analyzes a range of assessments, from straightforward saturated steady-state issues to complex saturated/unsaturated time-dependent programs. According to **(Al-Nedawi and Al-Hadidi, 2020)**, the software was used to analyze the Darbandikhan Dam model in two phases:

A- A suitable mesh with 17953 and 17715 nodes of the 2 m-sized quadrilateral element type was chosen by utilizing several trails. The FEM mesh at this point comprises four distinct types of elements of varying sizes, including triangular, square, rectangular, and trapezoidal shapes **Fig. 4**. By positioning nodal points, some components effectively divide the field. To replicate the Darbandikhan dam model, this mesh was utilized.

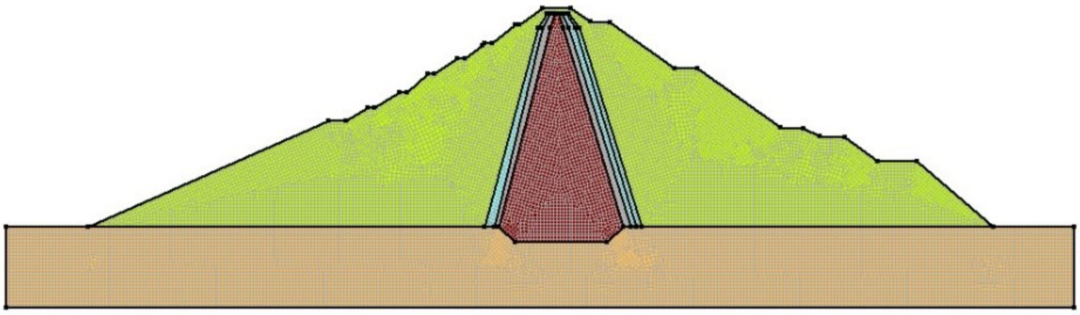

Figure 4. FEM mesh details.

To confirm the correctness of the model running the dam model, the model was calibrated, and the results were compared with the information provided and the thorough reports that used horizontal linear instructions, the calibration was according to the previous study **(Al-Nedawi and Al-Hadidi, 2020).**

B- Boundary Conditions of the model: The model runs with three different upstream reservoir water levels, as follows:

I. Maximum upstream reservoir water level (485 m).
II. Normal water level (472 m).
III. Minimum upstream reservoir water level (434 m).

2.5 Physical Properties of Dam Body Materials

Table 1 describes the physical properties of the main parts of Darbinikhan Dam, which must be defined in the program for each part to evaluate seepage in parts of the dam.

Table1. Physical properties of soil (ministry of water resources, gotten from local measurements)

Location	γ (kN/m³)	Cohesion (kPa)	Permeability (m/sec)	Poisson Ratio	angle of repose θ	Modulus of Elasticity (MN/m²)
Clay core	20	60	2.7×10^{-11}	0.45	24	30
Filter 1	21	0	1.69×10^{-5}	0.31	35	35
Filter 2	21	0	1.69×10^{-4}	0.31	35	35
Rockfill	21.0	14	1.2×10^{-5}	0.30	38	20
Foundation	22	600	1.10×10^{-7}	0.33	35	300

The material characteristics of the Darbandikhan rockfill dam section, comprised of five zones and depicted in **Fig. 5**, were compared with model hydraulic heads. The hydraulic conductivity of the materials was optimized for the region selected for the various types of materials utilized in **Table 1** using SEEP/W programming. The dam consisted of different zones such as filters with graded materials, chimney drain, hardcore and dam shells.

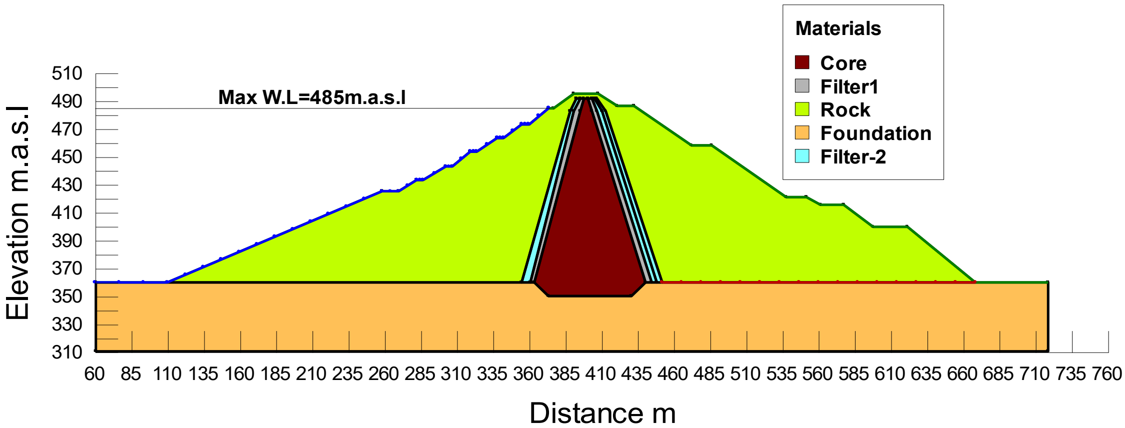

Figure 5. Darbandikhan rockfill dam components **(Ministry of water resources, gotten from local measurements).**

2.6 Flow Net with Current and Equipotential Lines, Phreatic Line

To gather intrusive information about the establishment of Darbandikhan and its various lake-level conditions, the SEEP/W software is utilized. The product flow net was then applied to the chosen region at different heights, as seen in **Figs. 6 to 8.**

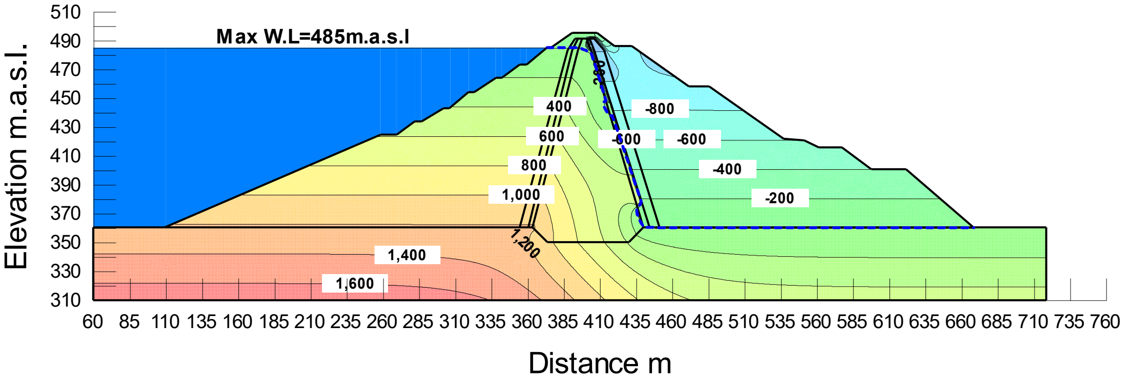

Figure 6. Flow net for section (lake level is 485 m.a.s.l).

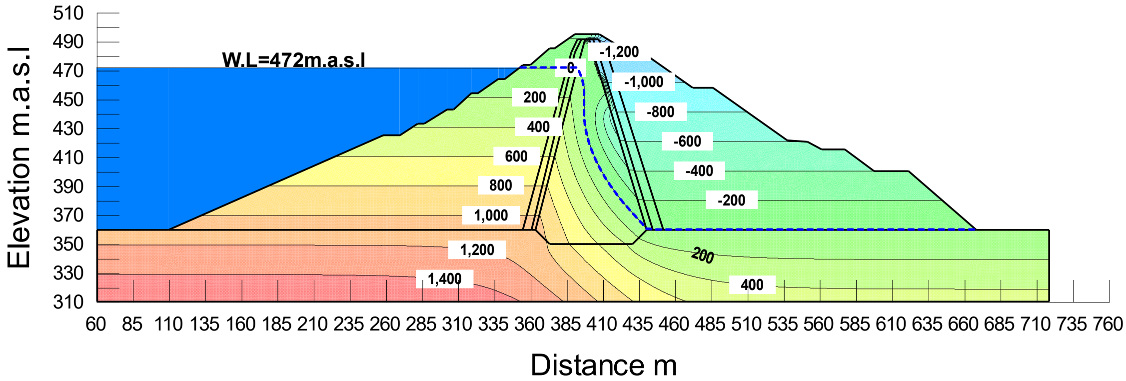

Figure 7. Flow net for section (lake level is 472m.a.s.l).

The flow net represented by a flow lines, equipotential lines, and speed. It also shows vectors indicating the predominant land stream or seepage and the phreatic line that represents the Darbandikhan dam's seepage behavior. The equipotential and stream lines at reservoir water levels of 485 m, 472 m, and 434 m are analyzed. It can be inferred that they are typical of one another, which supports the leakage hypothesis.

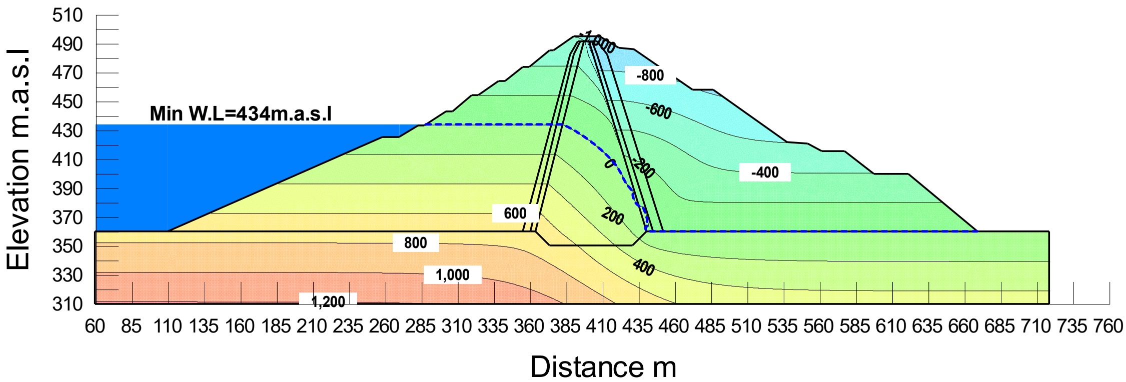

Figure 8. Flow net for section (lake level is 434 m.a.s.l).

2.7 Pore Pressure, Exit Gradient, and Water Flux.

Table 2, records the water flux, exit gradient, and pore pressure for different reservoir water levels in the selected slice.

Table 2. Computed pore pressure, water flux, and exit gradient for different reservoir water levels in Darbandikhan rockfill dam

Parameter	Upstream Water Levels		
	Minimum W.L. (434 m.a.s.l)	Average W.L. (472 m.a.s.l)	Maximum W.L. (485 m.a.s.l)
pore pressure (kPa)	-800	1400	1600
Exit gradient (mm/m)	1.743936	2.080386	2.335535
seepage flux (m^3/s)	1.2271E-09	4.9911E-09	2.3292E-08

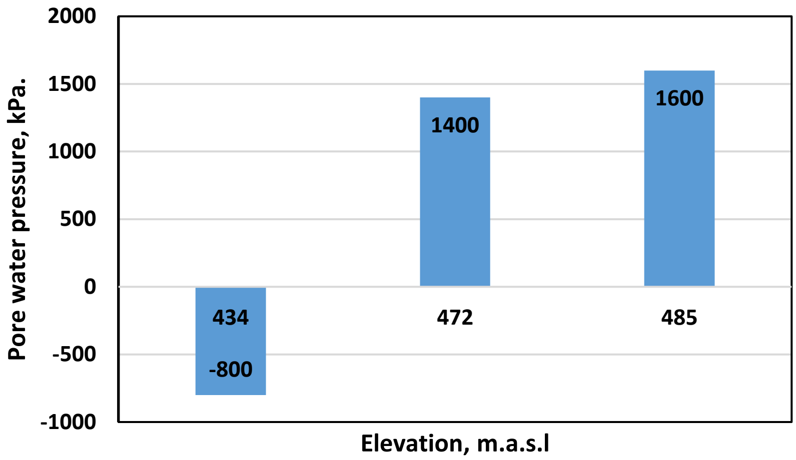

Figure. 9. Pore pressure vs elevation (head of water).

Fig. 10 shows the graphics connection for the exit gradient. Right now, first increases in the estimation of the exit gradient with the increment reservoir level until it reaches the normal elevation (472 m); after that exit gradient keeps increasing rises until it reaches the ultimate extreme worth (0.0023) at the greatest rise (485 m) as appeared in **Table 2,** for the selected area, according to the studies of **Goel and Pillai 2010** and **Norouzi et al. 2020**, the value of critical Exit Gradient should not be greater than 1.0. Otherwise, the SEEP / W analysis shows that the seepage flux reaches its minimum value at the minimum water level (434 m), i.e. in the case of the normal level of the same section which was selected, as the maximum seepage flux value (2.3292E-08 m^3/s) in this case, the behavior of the phreatic line differs, and its work is different in the two cases in which the level is 434 m and 485 m, as shown in **Figs. 6** and **8. Fig. 11** illustrates a graphics relation for seepage flux as a function of elevations.

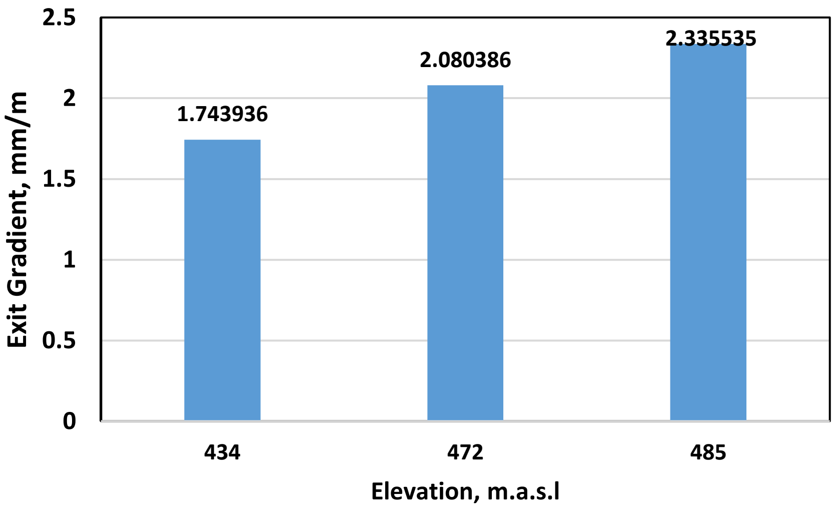

Figure 10. Exit gradient vs elevation (head of water).

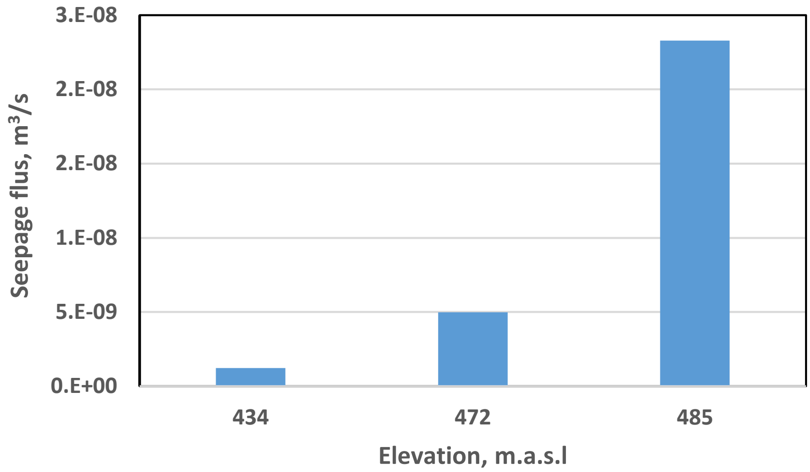

Figure 11. Water flux vs elevation (head of water).

5. CONCLUSIONS

In this study, the Geo-Slope software with SEEP/W was used to calculate seepage in Darbandikhan rockfill Dam. The results of the study showed the following conclusions

1. The exit gradient increases with the increase in the upstream reservoir water level. followed by a slight increase to a maximum value of 2.335 mm/m at the maximum reservoir elevation.
2. The seepage flux values are proportional to the upstream reservoir water level. At an elevation of 434 m.a.s.l, the minimum value is 1.227×10^{-9}. As the elevation increases to bond level 472 m.a.s.l, the value increases significantly to 2.33×10^{-8}. at the maximum reservoir level of 485 m.a.s.l.
3. The pore water pressure varies from -800 kPa to 1600 kPa. There is a slight increase from the minimum to reach maximum value at the maximum reservoir elevation.
4. Darbandikhan Dam is considered safe from seepage in all upstream reservoir conditions.

The following suggestions can be made to prevent or reduce the risk of water flux through the body of the dam:

1. Increasing the amount riprap at the U/S side of the dam.
2. Making grout for the U/S shell.

Credit Authorship Contribution Statement

Omar Abbas Mohammed: Writing – original draft, Validation, Software, Methodology.
Ameen Mohammed Salih Ameen: Writing – review & editing, Methodology.

Declaration of Competing 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.

REFERENCES

Abbas, J. M., 2014. Slope stability analysis using numerical method, *Journal of Applied Sciences*, 14, pp. 846-859. https://doi.org/10.3923/jas.2014.846.859

Al-Hadidi, M.T., and Hashim, S.H., 2021. Finite element analysis of seepage for Kongele earth dam using Geo-Studio software. *Journal of Physics: Conference Series,* 1895(1), P. 012003. *IOP Publishing*. https://doi.org/10.1088/1742-6596/1895/1/012003

Al-Nedawi, N.M., and Al-Hadidi, M.T., 2020. Finite element analysis of seepage for Hemrin earth dam using Geo-Studio software. *Diyala Journal of Engineering Sciences*, 13(3), pp. 66-76. https://doi.org/10.24237/djes.2020.13307

Al-Salakh, A.M., and Albusoda, B.S., 2020. Experimental and theoretical determination of settlement of shallow footing on liquefiable soil. *Journal of Engineering*, *26*(9), pp. 155-64. https://doi.org/10.31026/j.eng.2020.09.10

Alzamily, Z.N., and Abed, B.S., 2022. Comparison of seepage trough zoned earth dam using improved light-textured soils. *Journal of Engineering*, *28*(3), pp. 32-45. https://doi.org/10.31026/j.eng.2022.03.03

Ameen, A.M.S., Al-Sulttani, A.O., and Al-Bakri, B.A., 2021. Evaluating the effects of reservoir level and foundation depth on the dynamic behaviour of a rockfill dam using three-dimensional finite elements modelling. *IOP Conference Series: Earth and Environmental Science,* 779(1), P. 012044. IOP Publishing. https://doi.org/10.1088/1755-1315/779/1/012044/meta

Ameen, A.M.S., Ibrahim, Z., Othman, F., Al-Ansari, N., and Yaseen, Z.M., 2018. Minimizing the principle stresses of powerhoused Rock-Fill dams using control turbine running units: Application of finite element method. *Water*, *10*(9), P. 1138. https://doi.org/10.3390/w10091138

Arshad, I., and Babar, M.M., 2014. Finite element analysis of seepage through an earthen dam by using geo-slope (SEEP/W) software. *International Journal of Research*, *1*(8), pp. 612-619.

Ameen Mohammed Salih Ameen, 2018. Dynamic behaviour and hydraulic performance of reaction turbines in embankment dams, (PhD thesis), University of Malaya (Malaysia)

Asmaa A.J., 2018. Investigation and estimation of seepage discharge through homogenous earth dam with core by using SEEP/W Model and artificial neural network**.** *Diyala Journal of Engineering Sciences*, 11(3), pp. 54-61. https://doi.org/10.24237/djes.2018.11309

Bredy, S., and Jandora, J., 2020. Effect of Dam Height on The Stability of earth dam (case study: Karolinka dam). *Journal of Engineering*, 26(3), pp. 117–126. https://doi.org/10.31026/j.eng.2020.03.10

Cheng X, Li Q, Zhou Z, Luo Z, Liu M, Liu L., 2018. Research on a seepage monitoring model of a high core rockfill dam based on machine learning. *Sensors*. 21,18(9), P. 2749. https://doi.org/10.3390/s18092749

Chugh A., 2011. Embankment dams general design standards. *In chapter 1, the U.S. Department of the Interior Bureau of Reclamation.*

Fattah, M.Y., Ahmed, S., and Al-Hadidi, M.T., 2012. Effect of change in the coefficient of permeability on consolidation characteristics of clays. *Journal of Engineering*, *18*(1), pp. 20-37. https://doi.org/10.31026/j.eng.2012.01.02

Fattah, M.Y., Ahmed, M.D., and Mohammed, H.A., 2013. Behavior of partially saturated cohesive soil under strip footing. *Journal of Engineering*, *19*(3), pp. 298-311. https://doi.org/10.31026/j.eng.2013.03.02

Goel, A., and Pillai, N.N., 2010. Variation of exit gradient downstream of weirs on permeable foundations. *Pacific J. Sci. Tech*, *11*(1), pp. 28-36.

Irzooki, R.H., 2016. Computation of seepage through homogenous earth dams with horizontal toe drain. *Engineering and Technology Journal*, 34(3 part), pp. 430-440. https://doi.org/10.30684/etj.34.3A.1

Jamel, A.A.J., 2016. Effect of intermediate sheet piles in non-homogenous soil on seepage properties under hydraulic structure using SEEP/W program. *Tikrit Journal of Engineering Sciences*, *23*(3), pp. 79-90. https://doi.org/10.25130/tjes.23.3.09

Jamel, A.A.J., 2017. Effect of two sheet piles in double soil layers on seepage properties under hydraulic structure using SEEP/W program. *Al-Nahrain Journal for Engineering Sciences*, *20*(1), pp. 194-205.

Jansen, R.B., 1988. Advanced dam engineering for design, construction, and rehabilitation. *Springer Science and Business Media.*

Jassam, M.G., Abdulrazzaq, S.S., and Khalaf, W.D., 2020. Seepage characteristics analysis through homogeneous earth dams using theoretical model of SEEP/W program. *Journal of Criical Reviews*, *7*, pp. 5984-5996.

Jassam, M.G., and Abdulrazzaq, S.S., 2019. Theoretical analysis of seepage through homogeneous and non-homogeneous saturated-unsaturated soil. *Journal of Engineering*, 25(5), pp. 52-67. https://doi.org/10.31026/j.eng.2019.05.04

Jassam, M.G., and Abdulrazzaqb, S.S., 2020. Analysis of seepage through Al-Wand dam by using SEEP/W model. *Anbar Journal of Engineering Sciences*, *8*(2), pp. 33-37. https://doi.org/10.37649/aengs.2020.171284

Khanna R, Datta M, Ramana GV, 2019. Influence of core thickness on stability of downstream slope of earth and rockfill dams under end-of-construction and steady-state-seepage: a comparison. *International Journal of Geotechnical Engineering*, 13(1), pp. 25-31. https://doi.org/10.1080/19386362.2017.1318230

Khattab, A., 2010. Stability analysis of Mosul dam under saturated and unsaturated soil conditions. *Al-Rafidain Engineering Journal (AREJ)*, *18*(1), pp. 13-27. https://doi.org/10.33899/rengj.2010.27983

Kirra, M. S., Shahien, M., Elshemy, M., and Zeidan, B. A., 2015. Seepage and slope stability analysis of Mandali earth dam, Iraq: A case study. *In International Conference on Advances in Structural and Geotechnical Engineering* (ICASGE'15).[6–9 April 2015 Hurghada, Egypt].

Li, J., Ameen, A.M.S., Mohammad, T.A., Al-Ansari, N., and Yaseen, Z.M., 2018. A systematic operation program of a hydropower plant based on minimizing the principal stress: Haditha Dam case study. *Water*, *10*(9), p.1270. https://doi.org/10.3390/w10091270

Mishal, U.R., and Khayyun, T., 2018. Stability analysis of an earth dam using GEO-SLOPE model under different soil conditions. *Engineering and Technology Journal*, 36 (5), pp. 523-532. https://doi.org/10.30684/etj.36.5A.8

Nia, Ruhollah P., Ali S., and Hossein Sedghi, 2015. Investigating and analyzing leakage phenomenon in the earth dam by using SEEP / W numerical model case study: Down Meydank Dam. *Journal UMP Social Sciences and Technology Management*. 3(3), 1. https://doi.org/10.24237/djes.2018.11309

Norouzi, R., Salmasi, F., and Arvanaghi, H., 2020. Uplift pressure and hydraulic gradient in Sabalan Dam. *Applied Water Science* , 10, 111. pp. 1-12. https://doi.org/10.1007/s13201-020-01195-2

Salih Ameen, A.M., Ibrahim, Z., Othman, F. and Mundher Yaseen, Z., 2020. Water flow stabilization using submerged weir for draft-tube reaction hydraulic turbine. *Scientia Iranica*, *27*(1), pp.159-176. https://doi.org/10.24200/sci.2018.50038.1476

Singh, B., and Varshney, R.S., 1995. Engineering for embankment dams. *A.A. Balkema*. 745, 745.

Soleimani, S., and Adel, A., 2014. Evaluation of static stability of earth dams using geo-studio software. *International Journal of Engineering,* Facicule 3, (IRAN), pp. 265-268.

Sotoodehnia, A., Razi, F., and Daneshkar Arasteh, P., 2014. Using SEEP/W numerical model to simulate drain installation depth effects on drain water salinity improvement. *Iranian Journal of Irrigation & Drainage*, *8*(1), pp. 187-196.

Wu, Y., Zhang, B., Yu, Y., and Zhang, Z., 2016. Consolidation analysis of Nuozhadu high earth-rockfill dam based on the coupling of seepage and stress-deformation physical state. *International Journal of Geomechanics*, 1,16(3). Https://doi.org/10.1061/(ASCE)GM.1943-5622.0000555

Yousif, O.S., Zaidn, K., Alshkane, Y., Khani, A., and Hama, S., 2019, May. Performance of Darbandikhan Dam during a major earthquake on November 12, 2017. In *Proceedings of the EWG2019, 3rd Meeting of Dams and Earthquakes, An International Symposium, Lisbon, Portugal* (pp. 6-8).

سلوك التسرب لسد املائي ركامي نتيجة تغير حاله الخزان

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الخلاصة

استخدمت طريقة العناصر المحددة لحل المعادلات التفاضلية المتعلقة بالتسرب.لغرض دراسة ضغط الماء المسامي، انحدار المخرج والتصريف باستخدام برنامج Geo-Studio وبرنامجة الفرعي Seep/W يقع السد على نهر (سيروان – ديالى) ضمن محافظة السليمانية قضاء دربندخان، على بعد 230 كم شمال محافظة بغداد. لتشغيل النموذج العددي للسد تم اختيار ثلاثة مستويات لمياه الخزان عند مقدمة السد وهي اقل منسوب للخزان 434 متر فوق مستوى سطح البحر، المنسوب الطبيعي 472 متر فوق مستوى سطح البحر واعلى منسوب تشغيلي عند منسوب 485 متر فوق مستوى سطح البحر والتي تمثل شروط حدود النموذج. اظهرت النتائج اعلى ضغط مسامي و اعلى انحدار للمخرج عند اعلى منسوب تشغيلي 485 متر فوق مستوى سطح البحر، بينما اعلى معدل تصريف خلال السد عند المنسوب الطبيعي 472 متر فوق مستوى سطح البحر. نتائج الدراسة اظهرت ان السد مؤمن لجميع حالات الخزان التي اجريت عليها الدراسة.

الكلمات المفتاحية: التسرب، انحدار المخرج، جيو–ستوديو، ضغط الماء المسامي، سد املائي ركامي.