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Numerical Analysis of Seepage in Earth-Fill Dams

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Abstract

In an earth-fill dam, the effect of seepage has been studied by applying a finite element method using the SEEP2D program. This is in order to determine the quantity of seepage through the dam. The total head measurements, core permeability, and anisotropy ratio (kx/ky) (Case study: Khassa Chai Dam, Iraq) are taken as the main parameters. The effect of the different water heads of the reservoir were tested on the seepage. The results showed that any increase in the water heads caused an increase in seepage quantity. Also, it was found that the seepage rate decreases by about 8.7%, 13.2%, and 15.3% at levels of water 454, 471, and 485 m.a.s.l, respectively by changing the core permeability from 10^{-6} m/s to 10^{-7} m/s. It has been concluded that the clay core plays a significant role in decreasing the seepage quantity and existing gradient. The results of testing the effect of anisotropy ratio on seepage showed that an increase in (kx/ky) ratio leads to an increase in seepage quantity. Output variables and input variables have been linked by the ANN model that governs seepage quantity through zoned earth dams and existed gradients. The results showed that both models present a good estimation for the determination of coefficient R^2: 0.9003, 0.933.

Keywords: Seepage; SEEP2D; Finite Element; Earth Dams; Water Level; Artificial Neural Network.

1. Introduction

An earth-fill dam, which is viewed as a dike dam, is assembled primarily of compacted earth neither homogeneous nor zoned and contains in excess of 50% earth-fill. The materials are typically unearthed or quarried from close by locales, ideally from inside the water storage area. In the event that the rest of the materials are comprised of coarse particles, there will be a degree in fineness from the centre to the coarse external materials. As a result of the materials situated in the assemblage of the dam, drainage occurs through the dam's body. Leakage can happen under the dam establishment as well. In this examination, leakage through the dam's body was researched. Drainage in the Khassa Chai Dam utilizing the SEEP2D program to demonstrate the impacts of leakage under various water conditions has been investigated. Obaid (2002) presented a finite element procedure for determining the time dependent locations of the free surface, seepage heads, and pore pressures within the dam body. The seepage analysis was based on the Galerkin method involving saturated and unsaturated zones in which the original mesh remains invariant during unsteady flow and iterations [1]. Subuh (2002) presented a mathematical model and applied it for analysing two-dimensional (2D), steady-state seepage through stratified and isotropic earth dams. A numerical solution using finite elements method (Galerkin method) was employed to predict the piezometric head distribution, pore water pressure, seepage quantity, and the location of the free surface profile [2].

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Al-Labban (2007) obtained flow governing equations for earth dams using the finite element method. To model the dam and its foundation, eight node isoperimetric elements were used while mapped infinite elements were used to model the problems of boundaries. The Geo-Slope program was used in the analysis as a sub-program in the SEEP/W program. The program was verified by analysing three problems which were solved by the flow net [3]. AL-Jairry (2010) used Civil FEM/ANSYS software for predicting steady-state, two-dimensional water seepage for an earth dam consisting of two soil zones settled down on an impervious base. Seepage quantity and seepage surface length produced at downstream was assessed. Both of the previous parameters were investigated in contrast to the permeability coefficient ratio change of both soil zones, and based on the results of the solution, it was instituted that seepage quantity and downstream velocity both are very sensitive to any change in the permeability ratio of the two soil zones forming the dam [4]. Rakhshandehroo et al. (2011) simulated an earth dam where a finite element method was used. Pore water pressure in the embankment was studied after its construction as well as the first and second impoundments. The general pattern in checked pore water pressure was good, as modelled by the transient analysis. The simulation results demonstrated that the six-month time period between impoundments was long enough for the pore water pressure to achieve equilibrium throughout the core, except where considerable starting construction induced pore water pressure [5].

Fattah et al. (2018) applied the finite element method using a computer program (Geo-Slope) through its sub-program named SEEP/W to analyse seepage through the Al-Adhaim dam. The total length of the zoned embankment for the dam is 3.1 km. The program SEEP/W was used to analyse the actual design of the dam. The study results revealed that an increase in rate of flow and existing gradient because of the water level rising in the reservoir were approximately equal. It also found that the effect of all filters can be summarized by decreasing the exit gradients by about 10% [6]. Fattah et al. (2014) applied the finite element method by using the Geo-Slope program which used the SEEP/W sub-program in the analysis. The authors also used the Al-Adhaim dam as a case study. The authors performed numerous analyses for studying control of seepage by studying the effects of numerous parameters including the presence of impervious core and permeability of shell material. It was concluded that the clay core attendance has an imperative effect on decreasing exit gradient that may increase the core absence by about 300% [7].

Karampoor and Riazi (2015) used the SEEP/W program to determine the flow rate before embankment construction instead of experimenter models that require more time and cost for analysis of the leakage. The authors investigated the core in the leakage from non-homogeneous embankments by changing of the core permeability, and the results demonstrated that flow rate increased with an increase in the upstream head and decreased with a decrease in flow rate at the downstream head. The authors established that the flow rate had been reduced to 93.72% corresponding to the core permeability of (10-6) to 109, and the seepage flow rate had been increased to 92.28% [8]. Megan (2002) designed and constructed two laboratory-scale embankments to study the influence of a pervious zone on the measured self-potential response to steady state seepage flow. The embankments were constructed of pure quartz silica sand (Ottawa sand) graded according to ASTM C33-93 and compacted in layers at approximately 5% moisture content within a Plexiglas tank [9]. Noori and Ismaeel (2011) practiced the finite element method using the SEEP2D program to compute the line of free surface leakage, amount of leakage through the dam, measurements of total head, the pore water pressure distribution and effect of anisotropy material score of the Duhok zoned embankment [10]. Zhang and Chen (2001) utilized the general commercial software ABAQUS to analyse seepage flow passing through a nonhomogeneous earth dam with porous foundation and toe drain [11]. Duncan and Stephen (2014) analysed slope stability, which is the analysis of an asymmetric zoned earth dam resting on a layer of soil foundation with ponded water at a height of 23.1 m on the left side. The lift and right face of the dam is constructed using shell material [12].

All of the previous works applied the finite element method using different computer programs to relate seepage in dams with one or more coefficient. In this study, a SEEP/W program has been used in order to evaluate the amount of seepage inside zoned earth dams and the exit gradient. Also, an Artificial Neural Network (ANN) model with the help of the MATLAB program was used to illustrate the relative significance of each input variable of earth dams like Khassa Chai Dam on the target outputs.

2. Materials and Methods

2.1. Description of Case Study

The Khassa Chai Dam is a multipurpose dam. Figure 1 presents a cross section of the dam. The dam's right side coordinates are E 452041, N 3934306 and its left side coordinates are E 452441, N 3933254. Table 1 displays the most important laboratory testing properties of the different materials comprising Khassa Chai Dam. The dam was constructed on the Khasa-Chai River which is the seasonal branch of Zaghaitun River. This in turn flows into the Al-Adhaim dam reservoir about (10 km) northeast of Kirkuk near Kuchuk village, as shown in Figures 2(A and B). The 58 m height and 2.36 km length zoned earthen dam with silt clay core was constructed, as the lake was developed and used as a reservoir with active storage and dead storage of 80 and 5.15 Mm^3, respectively. The dam contains many instruments for monitoring and inspecting to ensure that it is in safe condition during the operation periods. These instruments are responsible for observing the settlement, movement and increase in the pore water pressure inside the dam body.

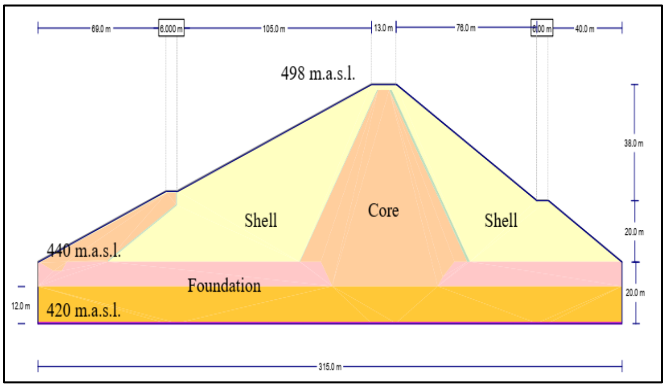
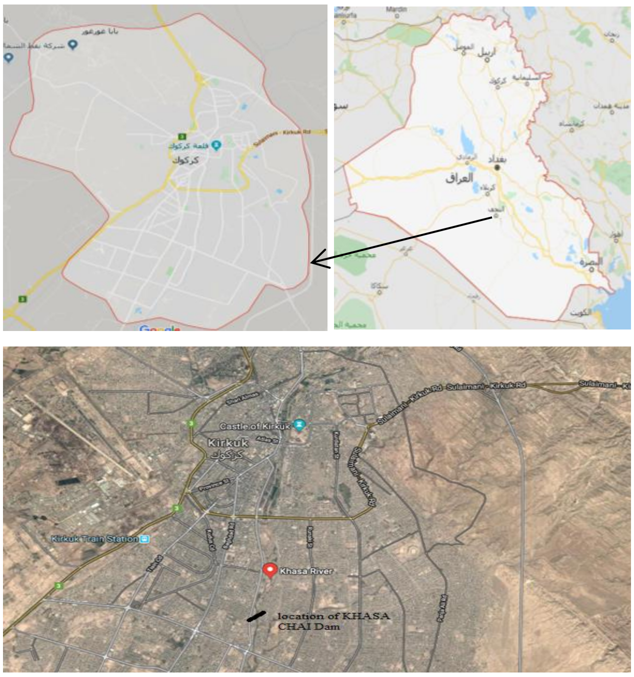


Figure 1. Cross Section of Khassa Chai Dam by Programs

Table 1. Data from Field works

Type of Experiments	Results	Type of Specifications
Sieve Analysis	Coefficient of curvature Cc=2.35	ASTM D-421
	Coefficient of uniformity Cu =50	
Compaction	Max. Dry density = 2.2 (gm/cm^3)	ASTM D-4254
	Optimum moisture content=6%	
Permeability	At (20 ºC) = 1×10^{-7} (m/s)	ASTM D-2434
Specific gravity	At (20 ºC) = 2.69	ASTM C-127
Sieve Analysis	Soil with 76% clay	ASTM D-421
	Soil with 24 % silt	
Compaction	Max. Dry density = 1.8 (gm/cm^3)	ASTM D-4254
	Optimum moisture content=18.8%	
Liquid limit	49%	ASTM D-4318
Plastic limit	34%	ASTM D-4318



(A)

(B)

Figure 2. (A) General location of study area; (B) Exact location of Khasa chai dam [13]

2.2. Finite Element

A seepage analysis of zoned earthen dams is the more sensitive method of analysis, as the great mass of the dam has a complex design structure and is sensitive to water conditions and load conditions. The results of seepage analysis are taken to be the boundary conditions in overall stability analysis. Figure 3 showed that finite element mesh has been used in the analysis. Three node triangle elements are used to describe the domains. The mesh contains 1,854 elements and 876 nodes. Many complex engineering problems used several numerical methods to find an accurate solution. One of these methods is the Finite Elements Method (FEM). Out of all the numerical methods, the finite elements method appears to be the most powerful and efficient tool to solve a wide variety of practical problems [14]. Muhammad (1991) utilized the finite elements method to study seepage through earth dams [15]. Abo (2001) utilized FEM to determine free surface position, drainage amount, pore water pressure dispersion, all out head estimations, and the materials anisotropy of the Al-Adheem zoned earthen dam [16]. Thieu et al. (2001) utilized the two measurements and three measurement limited components strategy for displaying the drainage in a soaked/unsaturated soil arrangement of earth dams under consistent state and transient leakage conditions [17]. Bardet and Tobita (2002) utilized a limited distinction strategy for the arrangement of unconfined drainage with an obscure free surface [18].

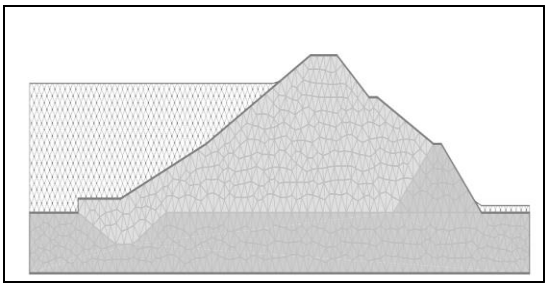


Figure 3. Finite element mesh for nonhomogeneous earth dam by the SEEP2D program

2.3. Research Methodology

The flow chart of the input data is shown in Figure 4. This diagram describes the main features of the input data as well as the model of seepage stability by using the SEEP/W program. The partial differential equation governed the flow at a steady state condition, which is 2D flow through anisotropic. Homogeneous porous media is represented herein by Laplace equation:

$$\frac{\partial}{\partial x}\left(K_x \frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \frac{\partial H}{\partial y}\right) = 0 \tag{1}$$

Where; K_x and K_y: permeability coefficients in (x, y) directions, respectively; H: total water head equals to p/γ+zw; p: pore water pressure; w: water unit weight, and; z: elevation head meter above sea level (m. a. s. l.).

According to USACE (1993), there are four boundary conditions used in unconfined seepage problems [19]:

1. *Impervious boundary*

$$\frac{\partial H}{\partial n} = 0 \tag{2}$$

Where; n: represents the vertical direction of the boundary.

2. *Reservoir boundaries which are known as entrances and exits, also called submerged permeable boundaries, are presented here as:*

$$H = h_1 \tag{3}$$

$$H = h_2 \tag{4}$$

Where; h_1 and h_2 are water heads at entrance and exit, respectively.

3. *Surface of seepage:*

$$H = y \tag{5}$$

4. *Line of seepage:*

$$H = y \tag{6}$$

MODEL is the pre-processing program applied by:

- Entering and editing the model boundaries, loads, material properties, groundwater conditions, and saving the input file.
- MODEL, COMPUTE, and INTERPRET will each run as standalone programs. They also interact with each other.
- The permeability (hydraulic conductivity) characteristics of each material are defined with the Define Hydraulic Properties option to find the effect of water level on the phreatic surface, total head, pressure head, and hydraulic gradient distribution. It may define a saturated permeability for each material.

- In addition, various models are available for defining the unsaturated permeability or probably creating a user-defined permeability function.

The upstream boundaries are designated as:

A. Upstream reservoir level with total head H (m) which represents the height of the water in the reservoir.

B. The downstream boundary conditions were designated as:

1. Potential seepage face located on the downstream face. The point of the toe drain with constant pressure head is equal to (0 m).
2. The analysis was carried out by considering the water in the reservoir to be at maximum water level 485 and minimum water level 454 m.a.s.l. The results from the basic analysis were taken at the point of the toe drain.

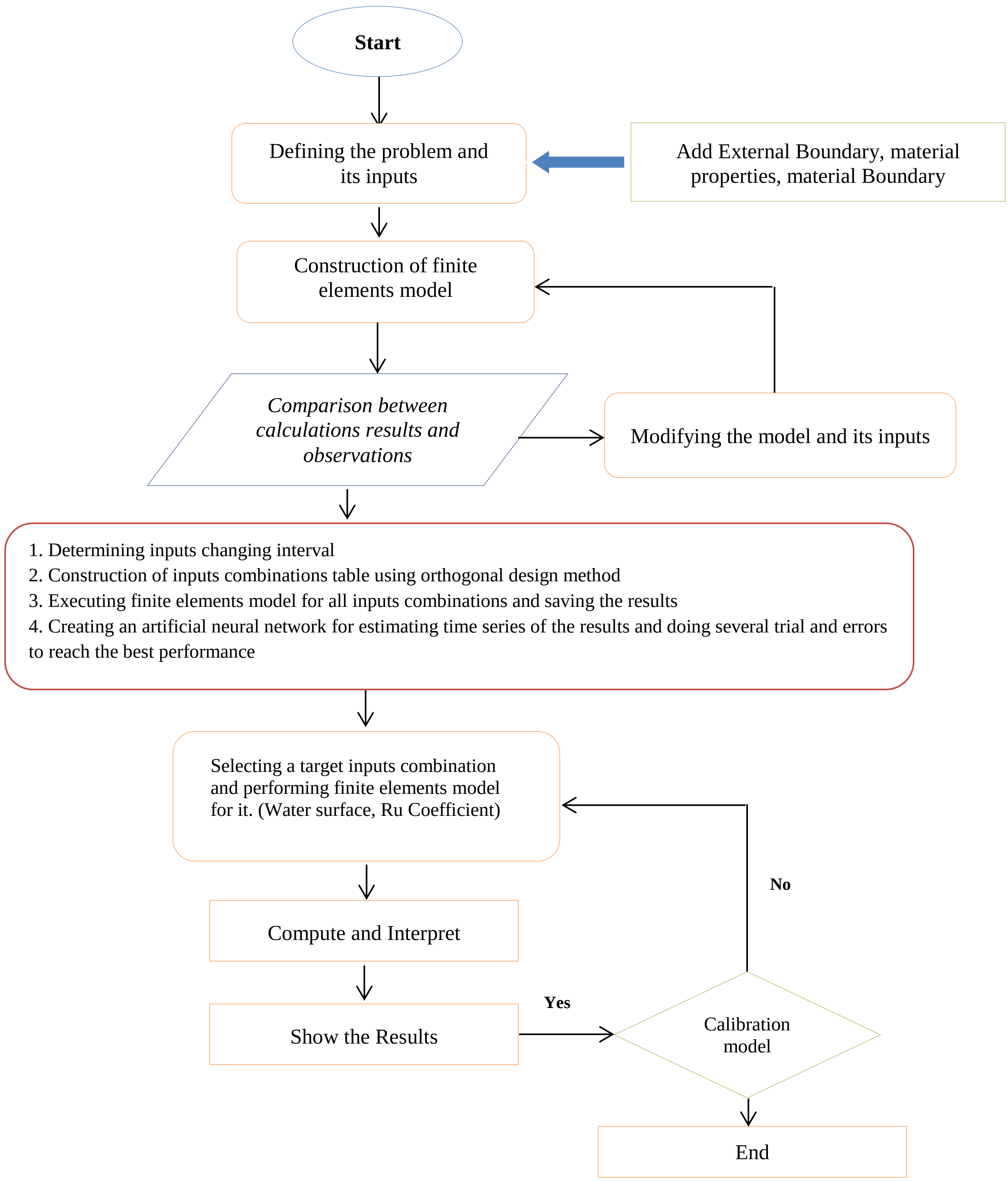


Figure 4. Flow Chart of the modelling by SEEP/W program for seepage analysis

2.4. Artificial Neural Networks

Artificial Neural Networks are numerical displaying, actualizing, and processing frameworks that are particularly useful in the field of expecting and anticipating information in complex settings [20-25]. It is outstanding that the fake neural system can be imagined as a nonlinear discovery model. ANNs have been recently utilized for the arrangement of numerous hydrologic, pressure-driven, and water asset issues from precipitation and overflow [26] to silt transport [27] to scattering. Many of the previous studies investigated seepage under the foundation of dams [28-29]. However in the embankment dams, seepage of phreatic line is formed in the body of the dams. An earth-fill dam's body avoids water flow from the dam's back to downstream.

A MATLAB 6 neural network toolbox was used. Reservoir water levels of the dam, core permeability, and anisotropy ratio (kx/ky) were input variables and the seepage of the body of the dam was the target output in the first model. In the second model, the reservoir water levels of the dam, core permeability, and anisotropy ratio (kx/ky) were input variables and the exit gradient was the target output. The Artificial Neural Networks model has 3 layers: input, hidden, and output layer. The input layer has three neurons while the output layer has one neuron in each model.

3. Results and Discussion

Seepage through Khassa Chai dam was analysed using SEEP2D under the effect of different parameters as follows:

3.1. Effect of Different Heads of Reservoir

To study the effects of water level in a zoned earth dam, different analyses were made considering different elevations of water. Figure 4 shows the relationship between quantities of seepage at different water heads. It is observed that the flow rate is decreased about 61.3% when water height is decreased from 485 to 454 m.a.s.l. Figure 5 shows the relationship between the reservoir's water head and exit gradient. It is noticed that the exit gradient decreased by about 63% when the height of water decreased from 485 to 454 m.a.s.l.

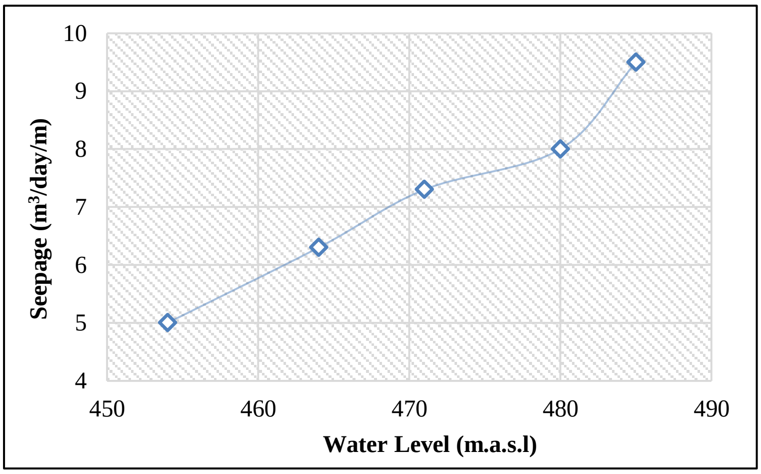


Figure 4. Effect of different water levels of reservoir on the quantity of seepage

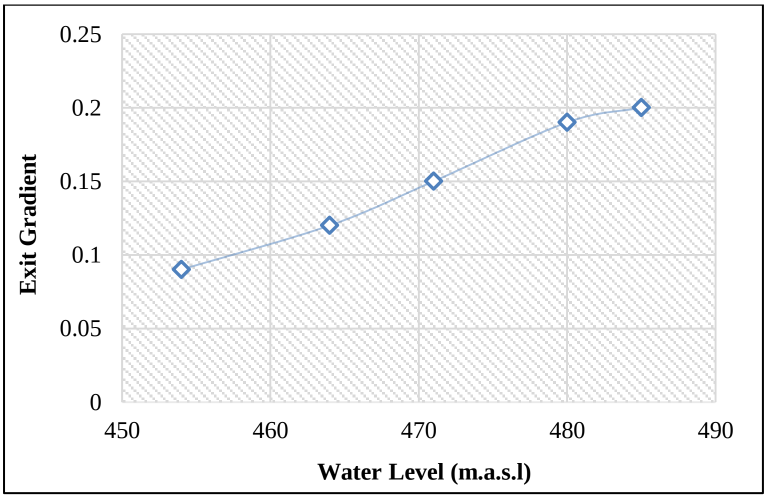


Figure 5. Effect of different values of water levels of reservoir on the exit gradient

The results agreed with Abbas (2015), Soleimanbeigi and Jafarzadeh (2005), Dahl (2004), Hammah et al. (2010) and Tomislav and Travaš (2013) studies [30-34], which indicated that flow rate and exit gradient are decreased with the decreases in the water height. The finite element software (SEEP/W) was used to analyse the seepage through and under homogeneous earth dams. The program was applied to find the seepage quantity through the dam and measurements of total head. The results of the software program showed that the body of the dam and its foundation was safe for the effect of seepage through the dam and its foundation.

3.2. Effect of Core Permeability

To study the effect of changing the core permeability, different analyses were made for different values of core permeability from a maximum value (10-6 m/s) to a minimum value (10-10 m/s) for silty clay material (Azad Koliji, 2013) [35] and for different levels of water. Figure 6 represented the effect of different values of the core permeability on the quantity of seepage. By changing the core permeability from 10-6 m/s to 10-7 m/s, it was observed that the value of the quantity of seepage decreased by about 8.7%, 13.2%, and 15.3% at levels of water 454, 471, and 485 m.a.s.l, respectively. Figure 7 showed the effect of different values in the core permeability on the exit gradient. By changing the core permeability from 10-6 m/s to 10-7 m/s, it was observed that the value of the exit gradient decreased by about 41.7%, 36.5%, and 32% at an elevation of water of 454, 471, and 485 m.a.s.l, respectively.

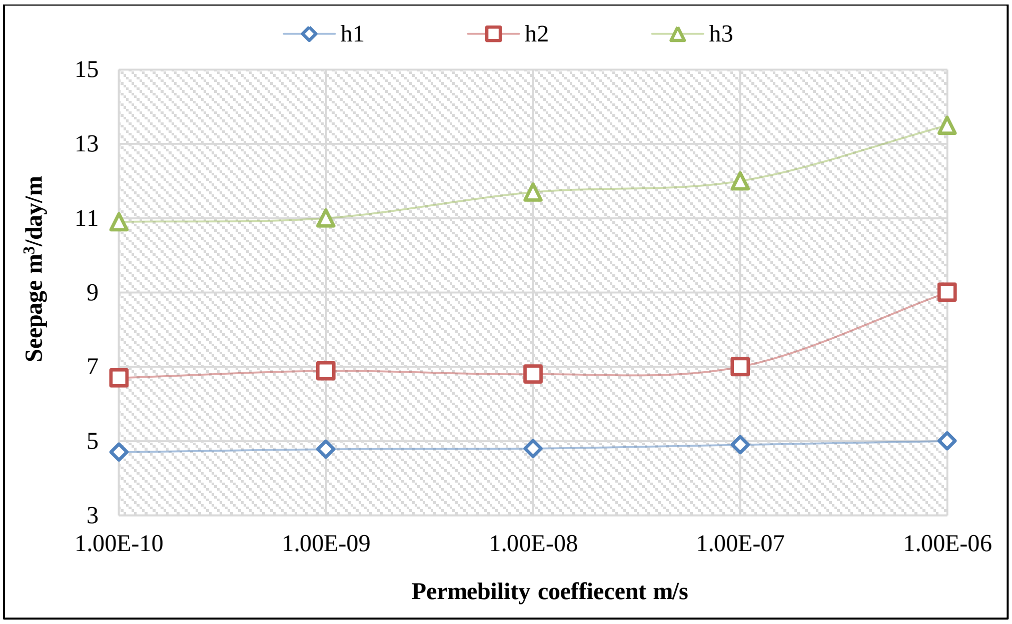


Figure 6. Effect of different values of core permeability on the quantity of seepage

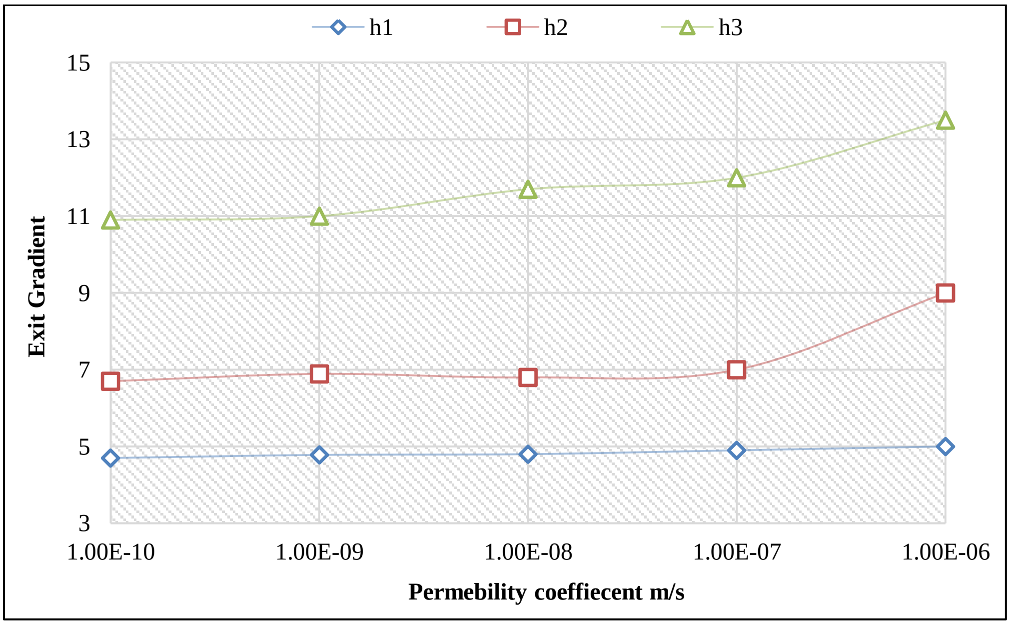


Figure 7. Effect of different values of core permeability on exit gradient

Figures 8 to11 showed some colourful images from the output of the Seep-2D program. Figures 8 and 9 showed a computed contour map of hydraulic gradient distribution for maximum water level 485 m.a.s.l, with core permeability of 1×10^{-6} m/s and 1×10^{-7} m/s, respectively. Figures 10 and 11 showed a computed contour map of pressure head distribution for the same maximum water level with core permeability of 1×10^{-6} m/s and 1×10^{-7} m/s, respectively.

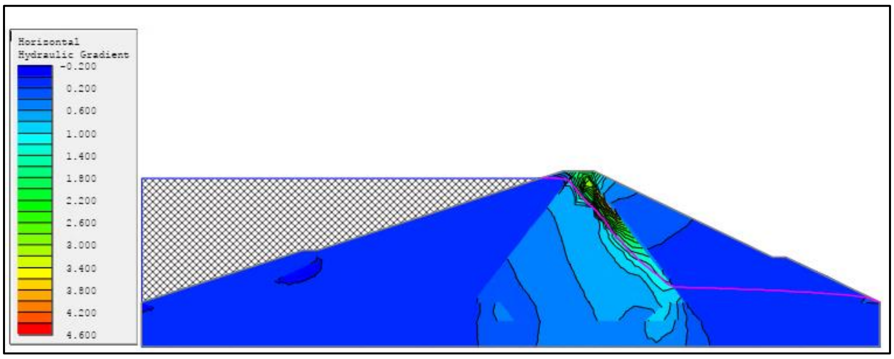


Figure 8. Computed contour map of hydraulic gradient distribution for maximum water level and the core permeability of (1×10^{-6} m/s)

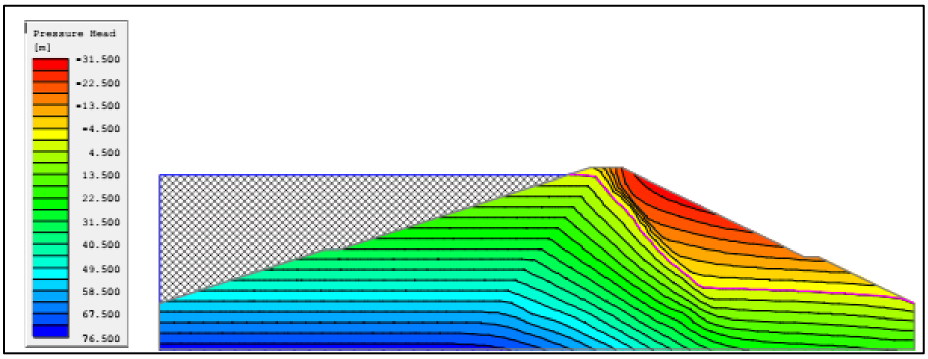


Figure 9. Computed contour map of pressure head distribution for maximum water level and the core permeability of (1×10^{-6} m/s)

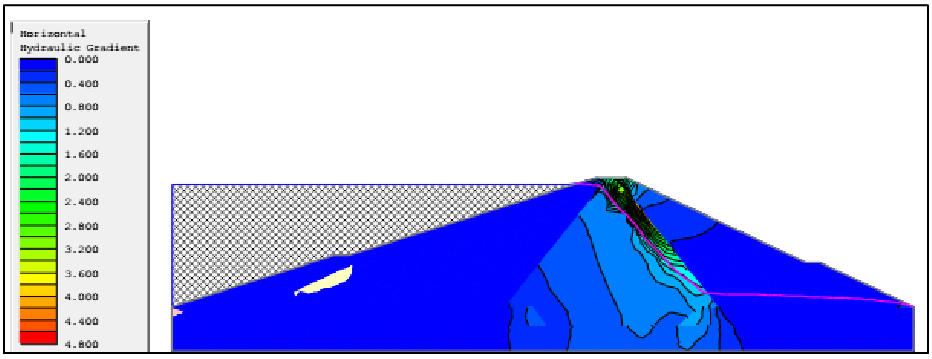


Figure 10. Computed contour map of hydraulic gradient distribution for maximum water level and the core permeability of (1×10^{-7} m/s).

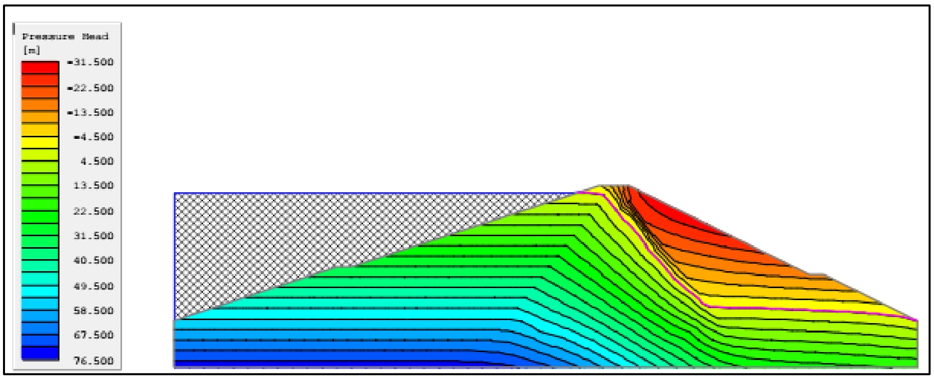


Figure 11. Computed contour map of pressure head distribution for maximum water level and the core permeability of (1×10^{-7} m/s)

The minimum value of the core permeability 1×10^{-10} gave the best acceptable amounts of seepage when the reservoir was used for long-term storage, and the medium value of the core permeability 1×10^{-6} gave the most acceptable amounts of seepage when the reservoir was used for flood control. It was concluded that seepage quantity and exit gradient are decreasing effectively with the occurrence of clay core, which agreed with the results obtained by Al-Jairry (2010) indicating that the construction of second zone Z of the dam at the downstream side with lower permeability than zone one (less than 0.0003 m/min) was recommended and reflected greater stability in seepage control through the body of the dam [4, 36].

3.3. Effect of the Anisotropy Ratio (K_x/K_y)

Usually, the coefficient of permeability for nonhomogeneous earthen dams is minimum in the vertical direction Ky and maximum in the horizontal direction Kx. Thus, to study the effect on the body of the dam, the coefficient of permeability (Kx/Ky) ratio should be varied for this aim. The coefficient of permeability (Kx/Ky) ratio was taken as 0.5, 1.5, 5, and 10 at different water levels (454, 471, and 485 m.a.s.l). Figure 12 showed the effect of different values of Kx/Ky ratio on the quantity of seepage. When Kx/Ky ratio increased from 1 to 10, the results indicated that the quantity of seepage also increased by about 41.8%, 48.2%, and 67.9% at an elevation of water 454, 471, and 485 m.a.s.l., respectively. Figure 13 showed the effect of different values of Kx/Ky ratio on the exit gradient. When the Kx/Ky ratio increased from 1 to 10, the exit gradient increased by about 32%, 38.6%, and 51.2% at an elevation of water 454, 471, and 485 m.a.s.l., respectively.

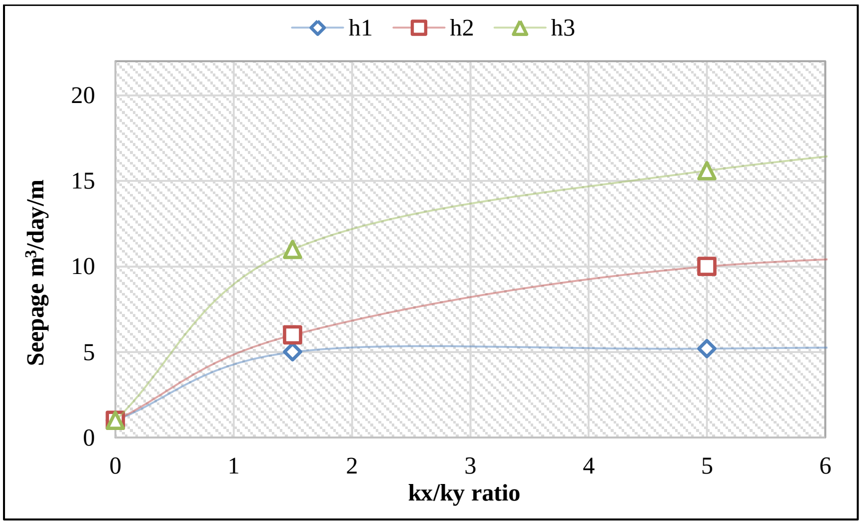


Figure 12. Effect of Kx/Ky ratio on the quantity of seepage

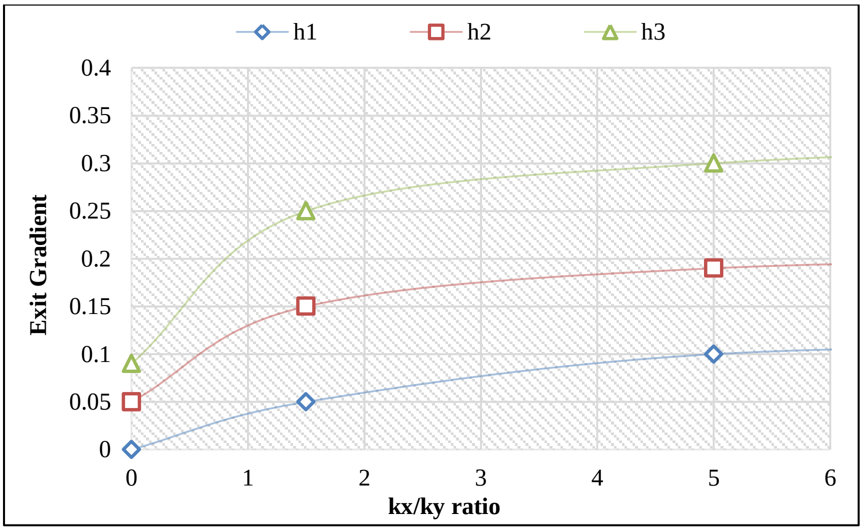


Figure 13. Effect of different values of Kx/Ky ratio on the exit gradient.

From Figures 12 and 13, it appears that the changing ratio of Kx/Ky had an effect on both seepage quantity and exit gradient. When this ratio increased, the exit gradient decreased and seepage quantity increased. The results agreed with those of Noori and Ismaeel (2011) which indicated that the coefficient of permeability ratio has an important effect on location of the free surface line [10]. It is noticed that the free surface line increased and decreased with fluctuations in the ratio. Also, seepage quantity is increased as Kx/Ky ratio increased, therefore, losing water through the dam increased.

3.4. Model Application

The Artificial Neural Networks model was obtained by using the MATLAB 6 neural network toolbox. A previous program is utilized with about 70% of an observed database of 207 cases, which were analysed using the SEEP/W model. The ANN model relates the output variables with the input variables (water level in reservoir, core permeability, and anisotropy ratio) that govern seepage quantity and exit gradient through zoned earthen dams. ANN model permits the determination of the quantity of concealed layers, the most extreme and least number of units permitted to be indicated in the shrouded layer.

The programmed engineering was chosen to process the best number of units in the concealed layer. Programmed engineering determination utilizes the default initiation capacities for the covered up and yield layers. The underlying qualities for the learning rate and the force factor were likewise permitted. The program allows choosing the technique for dividing the dynamic dataset into preparing, testing, and holdout (approval) tests. The preparation test involves the information records used to prepare the neural system; some level of cases in the dataset should be allocated to the preparation test so as to get a model. The initial test is an autonomous arrangement of information records used to follow mistakes during preparation so as to anticipate overtraining. The holdout test is another autonomous arrangement of information records used to survey the last neural system; the blunder for the holdout test gives a "genuine" gauge of the prescient capacity of the model on the grounds that the holdout cases were not used to construct the model. Table 2 demonstrated the rates of the information subsets divisions.

Table 2. Percentages of data subsets divisions

		First Model		Second Model	
		N	Percent	N	Percent
Sample	Training	145	70.0%	25	73.0%
	Testing	40	19.3%	5	15.3%
	Holdout	22	10.6%	4	11.7%
Valid		207	100.0%	34	100.0%
Excluded		0		0	
Total		**207**		**34**	

In order to check the models' validity for all the estimated cases tested in this study, Figure 14 showed the ANN model architecture for seepage of earth-fill dams. A comparison between the estimated values of (q) obtained by ANN and the observed values obtained by SEEP/W was shown in Figure 15 for first model with the activation function of hidden layer being hyperbolic tangent, while the output layer was with one hidden layer (four neuroses). For the second model, Figure 16 showed the ANN model architecture for the exit gradient of earth-fill dams. A comparison between estimated values of exit gradient determined by ANN and observed values determined by SEEP/W was shown in Figure 17, with the activation function of the hidden layer being hyperbolic tangent while the output layer had one hidden layer (four neuroses). It is clear that the model gave a good estimation for all models, and was considered as a strong correlation if ($r \geq 0.8$), which was the case between the two sets of variables.

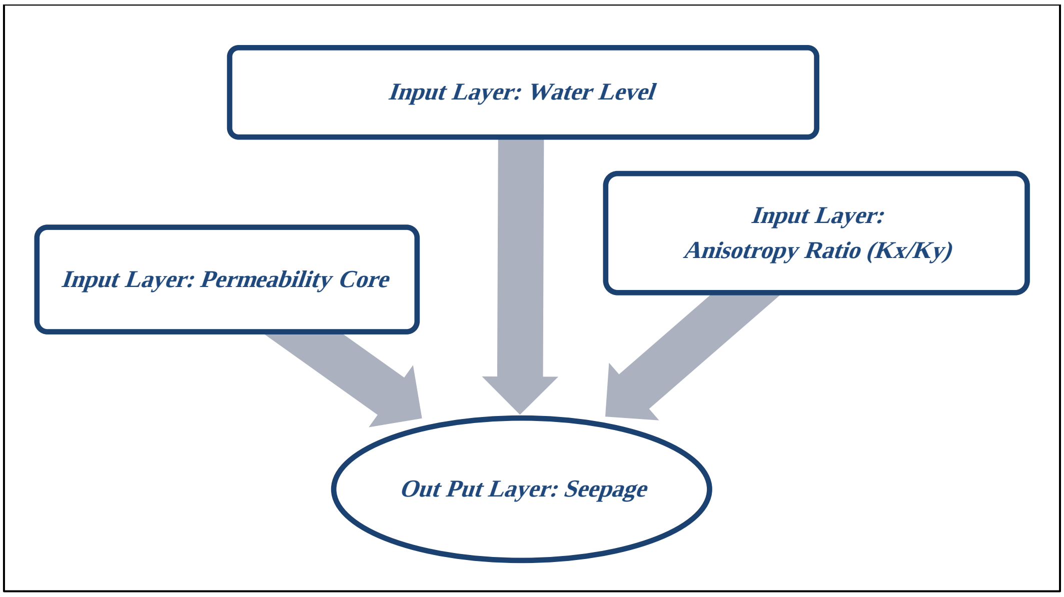


Figure 14. The ANN Model Architecture for seepage of earth-fill dam

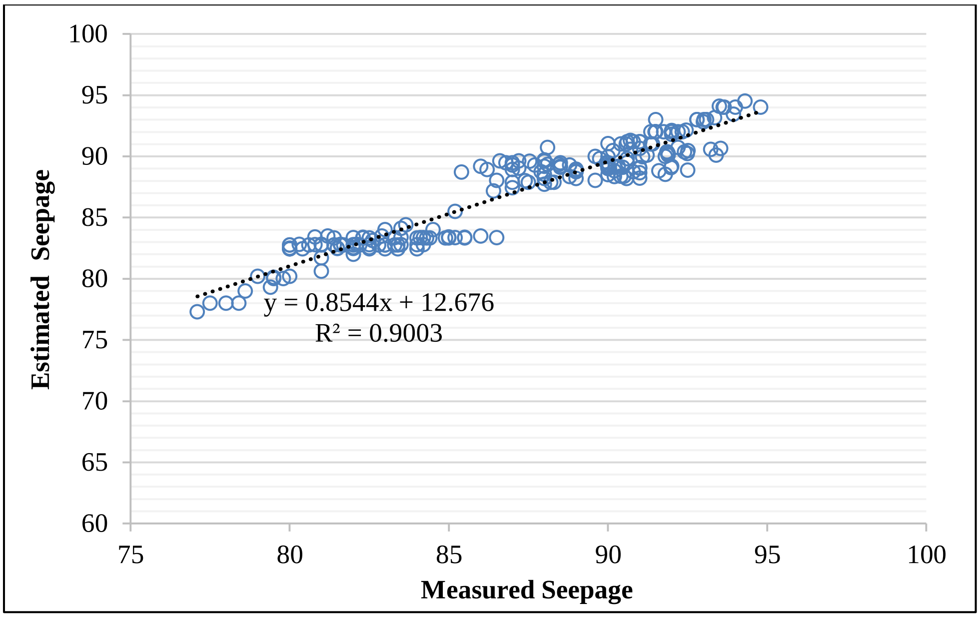


Figure 15. Estimated values of (q) calculated by ANN against observed values determined by SEEP/W

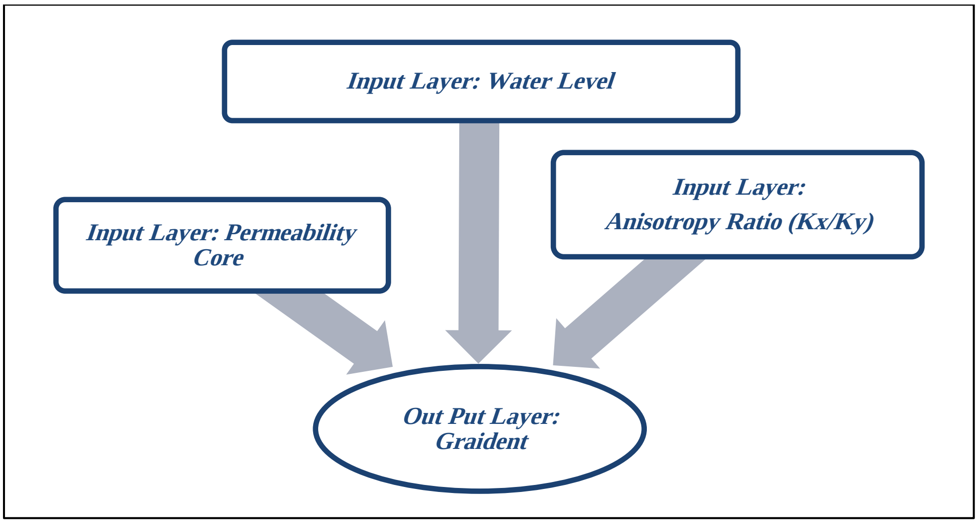


Figure 16. The ANN Model Architecture for exit gradient

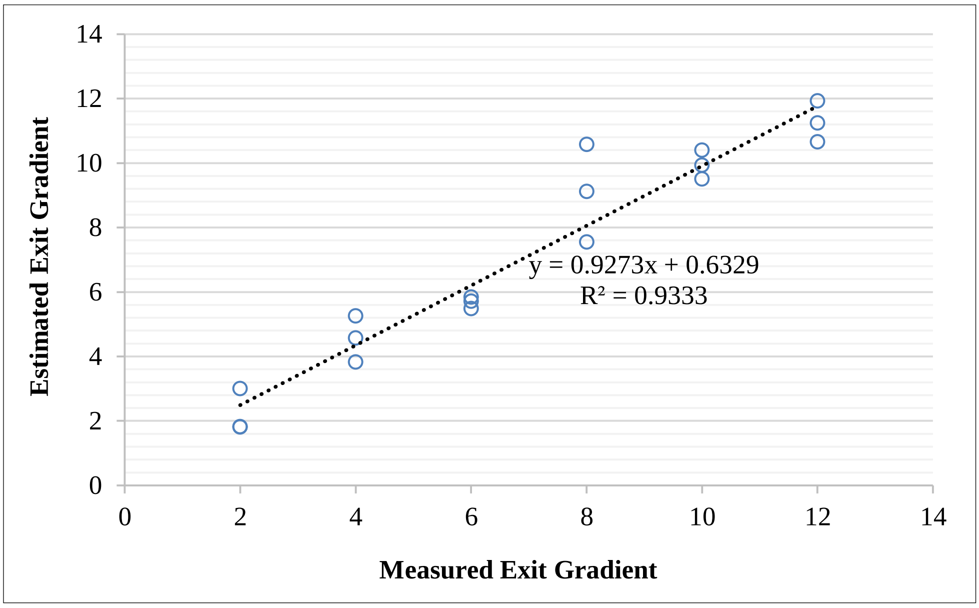


Figure 17. Estimated values of (exit gradient) obtained by ANN and observed values determined by SEEP/W

4. Conclusions

The following conclusions can be summarized:

- Seepage quantity through zoned earthen dams decreased by about 61.3% when the height of water decreased from 485 m.a.s.l to 454 m.a.s.l. Also, the exit gradient decreased by about 63% when the height of water decreased from 485 m.a.s.l to 454 m.a.s.l.
- There was a decrease in the values of the quantity of seepage by about 8.7%, 13.2%, and 15.3% at levels of water of 454, 471, and 485 m.a.s.l, respectively, and a decrease in the values of the exit gradient by about 41.7%, 36.5% and 32% at elevations of water of 454, 471, and 485 m.a.s.l, respectively.
- The quantity of seepage increased by about 41.8%, 48.2%, and 67.9% at elevations of water of 454, 471, and 485 m.a.s.l, respectively. Also, when the Kx/Ky ratio increased from 1 to 10, the exit gradient increased by about 32%, 38.6%, and 51.2% at elevations of water of 454, 471, and 485 m.a.s.l, respectively.
- ANN method showed that output variables with input variables (water level in reservoir, core permeability, and anisotropy ratio) predicted the quantity of seepage and exit gradient through the zoned earth dam. The two models gave a good estimation with determination coefficient R^2 of (0.9003, 0.933).

5. Conflicts of Interest

The authors declare no conflict of interest.

6. References

[1] Obaid, I. H., "Stability of Zoned Earth Dam Coupled with Unsteady Drawdown", M.Sc. Dissertation, Department of Civil Engineering, University of Babylon, Iraq, 2002.

[2] Subuh, M. A., "Finite element solution for unconfined seepage problem with references to Al-Qadisiya Dam", M.Sc. Dissertation, Department of Civil Engineering, University of Babylon, Iraq, 2002.

[3] Al-Labban S.N., "Seepage Analysis of Earth Dams by Finite Element", M.Sc. The College of Engineering of University of Kufa, Iraq, 2007.

[4] Al-Jairry, Hayder Hassan "2D-flow analysis through zoned earth dam using finite element approach." Engineering and Technology Journal 28, no. 21 (2010): 6315-6324.

[5] Rakhshandehroo, GR, M Vaghefi, and ARH Zadeh. "Three Dimensional Seepage Analyses in Mollasadra Dam after Its Impoundments." Journal of Applied Sciences and Environmental Management 15, no. 2 (August 2, 2011). doi:10.4314/jasem.v15i2.68494.

[6] Fattah, Mohammed, Mahmood Ahmed, and Nawar Ali. "Effect of Hydraulic Conductivity of Unsaturated Soil on the Earth Dam Performance." Edited by T.S. Al-Attar, M.A. Al-Neami, and W.S. AbdulSahib. MATEC Web of Conferences 162 (2018): 01008. doi:10.1051/matecconf/201816201008.

[7] Fattah, Mohammed Y., Salama NY Al-Labban, and Firas A. Salman. "Seepage Analysis of a Zoned Earth Dam by Finite Elements." International Journal of Civil Engineering and Technology (IJCIET) 5, no. 8 (2014): 128-139.

[8] Karampoor, Fatemeh, and Roozbeh Riazi. "Investigation the effect of clay core in seepage from non-homogenous earth dams using SEEP/W Model." Journal of scientific research and development 2, no. 5 (2015): 280-285.

[9] Megan, R. S., "Response of the Self-Potential Method to Changing Seepage Conditions in Embankment Dams", M.AS. Dissertation, Department of Civil Engineering, University of British Columbia, MR Sheffer, 2002.

[10] S. Ismaeel, Khaleel, and Dr. Bahzad M. A. Noori. "Evaluation of Seepage and Stability of Duhok Dam." AL-Rafdain Engineering Journal (AREJ) 19, no. 1 (February 28, 2011): 42–58. doi:10.33899/rengj.2011.27885.

[11] Zhang, Jianhong, Qianjun Xu, and Zuyu Chen. "Seepage Analysis Based on the Unified Unsaturated Soil Theory." Mechanics Research Communications 28, no. 1 (January 2001): 107–112. doi:10.1016/s0093-6413(01)00151-3.

[12] Duncan, J. M. and Stephen, G. W., "Soil Strength and Slope Stability" John Wily and Sons, Hoboken, New Jersey, Second Edition, (2014). ISBN: 978-1-11865165-0.

[13] Directorate General of Dams and Reservoirs, "Khassa Chai Dam Project- Geological Report" Ministry of water Resources, (2006).

[14] Saunders, H. "Book Reviews : THE FINITE ELEMENT METHOD IN ENGINEERING S.S. Rao Pergamon Press, Elmsford, NY 1982, 625 Pages." The Shock and Vibration Digest 16, no. 5 (May 1, 1984): 24–25. doi:10.1177/058310248401600507.

[15] Muhammad, J. R., "Calculating Seepage Through Earth Dams by Finite Element Method", M.Sc. Thesis, College of Engineering, University of Salahaddin, Iraq, (1991).

[16] Abo, A. A., "Calculating Seepage Through Earth Dams by Finite Element Method", M.Sc. Thesis, College of Engineering, University of Baghdad, Iraq, (2001).

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

[18] Bardet, Jean-Pierre, and Tetsuo Tobita. “A Practical Method for Solving Free-Surface Seepage Problems.” Computers and Geotechnics 29, no. 6 (September 2002): 451–475. doi:10.1016/s0266-352x(02)00003-4.

[19] U. S. Army Corps of Engineers (USACE), "Engineering and Design: Seepage Analysis and Control for Dams", EM 1110-2-1901, Washington, U. S. A, ((May 29, 1992). doi.org/10.21236/ada403234

[20] Hamed, Maged M, Mona G Khalafallah, and Ezzat A Hassanien. “Prediction of Wastewater Treatment Plant Performance Using Artificial Neural Networks.” Environmental Modelling & Software 19, no. 10 (October 2004): 919–928. doi:10.1016/j.envsoft.2003.10.005.

[21] Al-Suhaili, Rafa H., Jabbar H. Al-Baidhani, and NassrinJ Al-Mansori. "Hydraulic characteristics of a rectangular weir combined with equal and unequal size three rectangular bottom openings." International Journal of Computational Engineering Research 4, no. 1 (2014): 13-29.

[22] Al-Suhaili, Rafa H., Jabbar H. Al-Baidhani, and NassrinJ Al-Mansori. "Removal Efficiency of Sediment by Self-Cleaning of Combined Rectangular Weir with Three Ectangular Bottom Openings by Using ANN." Journal of University of Babylon 23, no. 2 (2015): 420-433.

[23] Al-Mansori, Nassrin J., Jabbar H. Al-Baidhani, and Rafa H. Al-Suhaili. "Hydraulic Characteristics of Flow Over Rectangular Weir With Three Rectangular Bottom Openings Using ANN." Journal of University of Babylon 22, no. 4 (2014): 951-962.

[24] AL-Mansori, Nesrin. “Using ANN to Model the Biological Removal of Nitrogen Compounds from Al-Musayyib’s Domestic Wastewater Using an SBR System.” Mesopotamia Environmental Journal 4, no. 3 (June 15, 2018): 42–54. doi:10.31759/mej.2018.4.3.0042.

[25] Jabbar H. Al-Baidhani, Nassrin J. Al-Mansori and Dhuha Hamza Ali Al-Khafaji, “Using of Granular Filters with Different Materials of Media for Water Treatment.” Journal of Engineering and Applied Sciences, 13, 10976-10982:(2018). doi: 10.36478/jeasci.2018.10976.10982

[26] Rajurkar, M.P., U.C. Kothyari, and U.C. Chaube. “Modeling of the Daily Rainfall-Runoff Relationship with Artificial Neural Network.” Journal of Hydrology 285, no. 1–4 (January 2004): 96–113. doi:10.1016/j.jhydrol.2003.08.011.

[27] Tayfur, Gokmen. “Artificial Neural Networks for Sheet Sediment Transport.” Hydrological Sciences Journal 47, no. 6 (December 2002): 879–892. doi:10.1080/02626660209492997.

[28] Turkmen, Sedat. “Treatment of the Seepage Problems at the Kalecik Dam (Turkey).” Engineering Geology 68, no. 3–4 (March 2003): 159–169. doi:10.1016/s0013-7952(02)00225-9.

[29] Al-Homoud, Azm S., and Najat Tanash. “Modeling Uncertainty in Stability Analysis for Design of Embankment Dams on Difficult Foundations.” Engineering Geology 71, no. 3–4 (February 2004): 323–342. doi:10.1016/s0013-7952(03)00144-3.

[30] Abbas, Ali Laftah. "Influence of head elevation on the stability of earth fill dam, Fada dam as a case study." Diyala Journal of Engineering Sciences 8, no. 4 (December 2015): 110-120.

[31] Soleimanbeigi, Ali, and Fardin Jafarzadeh. "3D steady state seepage analysis of embankment Dams." Electronic Journal of Geotechnical Engineering (EJGE) 10 (2005).

[32] Karina Dahl, PE, "Seepage in Earth Embankment Dams", Term Project, C1281A (2004).

[33] Hammah, R., Yacoub, T., Corkum, B., and Curran J., "A Comparison of Finite Element Slope Stability Analysis with Conventional Limit Equilibrium Investigation", Proceedings of the 58th Canadian Geotechnical and 6th Joint IAHCNC and CGS Groundwater Specialty Conferences Saskatoon, Saskatchewan, Canada, (2010).

[34] Jelenković, Tomislav, and Vanja Travaš. "Numerical and experimental analysis of seepage beneath a model of a gravity dam." Engineering Review 33, no. 2 (2013): 75-84.

[35] Azad Koliji, "Typical values of soil permeability", Resource of geotechnical information, 2013.

[36] Narimani, Samad, Seyed Morteza Davarpanah, and Javad Sattarvand. “Prediction of Hydro-Mechanical Stability of Dam: Using Calibrated Model from Back Analysis and Monitoring Data.” Civil Engineering Journal 2, no. 8 (August 30, 2016): 398–408. doi:10.28991/cej-2016-00000044.