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RESEARCH PAPER

Estimating Seepage Quantity through Homogenous Earth-Fill Dam with Horizontal Drainage Using Different Methods

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A B S T R A C T

Seepage is the main cause of failure of earthen dams; to prevent this failure, excessive seepage problems should be controlled. In this study, lowest seepage quantity through homogenous earth dam with horizontal filter by different methods was estimated. SEEP/W code in (GeoStudio software 2012) and (Slide software 6.025) was used to investigate 972 models with various upstream and downstream face slopes, horizontal filter lengths, free boards, top widths, dam heights and permeability coefficients.

Results showed that, comparing the seepage rates obtained from Slide and GeoStudio softwares has average differences of ratio of seepage discharge to permeability coefficient and filter length (q/kL) was less than 2%. Furthermore, nonlinear empirical equation was developed using (SPSS 22) program. The comparison of seepage quantity measured by SEEP/W and Slide versus its quantity calculated from empirical equations gave a coefficient of determination (R^2 = 0.815, 0.788) respectively.

Multilinear perceptron (MLP) was used as suitable type of artificial neural network (ANN) with a base structure (5-4-1) in which 75% of data sets were for training and 17.2% were for testing. The quantity of seepage predicted by ANN compared with obtained seepage rates from SEEP/W and Slide has (R^2=0.923, 0.942) respectively.

Finally, the average percent of errors of empirical equation, Slide Program and ANN was 15.814%, 8.519% and 1.060% respectively. This means that, seepage quantities obtained from ANN was more accurate than other methods may be due to different ways of analysis.

KEY WORDS: Homogenous dam; Seepage quantity; Horizontal filter; SEEP/W; Slide software.
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1. INTRODUCTION

Earth dams are important structures used as artificial reservoirs consists from impervious compacted layers of soils for its core and permeable materials on their upstream and downstream faces to be safe against sliding and overturning forces. Seepage is the quantity of water through an earth dam starts from upstream of the reservoir level to the downstream toe of the dam. The upper surface of this stream of percolating water is known as the phreatic surface.

For the purpose of controlling this phenomenon in the dam, different types of filters should be designed. The Laplace equation which governs water seepage cannot be solved analytically, except for cases with very simple and special boundary conditions. In the literature reviews, the numerical example that proposed equations is simple to use; hence the designers may find these equations as an additional check to their design by the conventional flow net method (Chahar, 2004). While, a series of tests and different drain sizes including different filter thicknesses and lengths were applied to a physical model of an embankment dam to check the stability in steady and transient seepage conditions using a number of piezometers and pressure sensors (Malekpour *et*

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al., 2012). Seepage and Stability of earth dam were analyzed Using Ansys and GeoStudio Softwares, the significant difference of two programs is related to safety factor deducted that Ansys answer is more acceptable (Kamanbedast and Delvari, 2012).

The other investigation performed the numerical simulation to find the effect of horizontal drain length and cutoff wall on seepage and uplift pressure in heterogeneous earth dam (Mansuri and Salmasi, 2013). The case study on "Hub" earthen dam located on (Karachi city-Pakistan) also investigated. SEEP/W simulation compared with field observations for seepage analysis. Calibration of the material properties is made on the basis of minimization of error while comparing observed hydraulic heads with the simulated ones (Arshad and Babar, 2014). Alnealy and Alghazali (2015) analyzed of seepage under hydraulic structures using Slide program. Single and multi- layers soils and its effect on structures with inclined cut-off were studied.

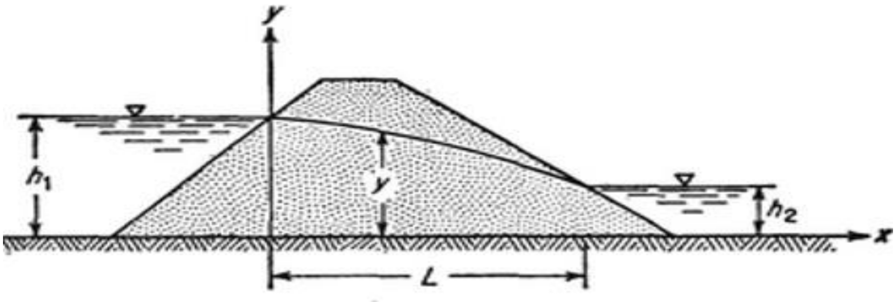
Casagrandi and Dupuits assumptions were analyzed to estimate seepage through homogeneous earth dam without filter (Jamel, 2016). Çalamak *et al.* (2016) investigated the suitability and the effectiveness of blanket and chimney drains in earth fill dams for various properties of the drainage system. (Irzooki, 2016) was used SEEP/W code to run on homogenous earth dam models with horizontal toe drain, a new equation was found for computing the quantity of seepage. (Omofunmi *et al.*, 2017) reviewed on effects and control of seepage through earth-fill dams. San Luis dam used to evaluate the unsaturated and transient seepage analysis in which pore-water pressures at failure and progression of the phreatic surface through the fine-grained core for drawdown stability analyses (Stark *et al.*, 2017).

The goal of this research is to examine the capabilities of different software's that estimate the lowest quantities of seepage to verify the accurate and optimum one.

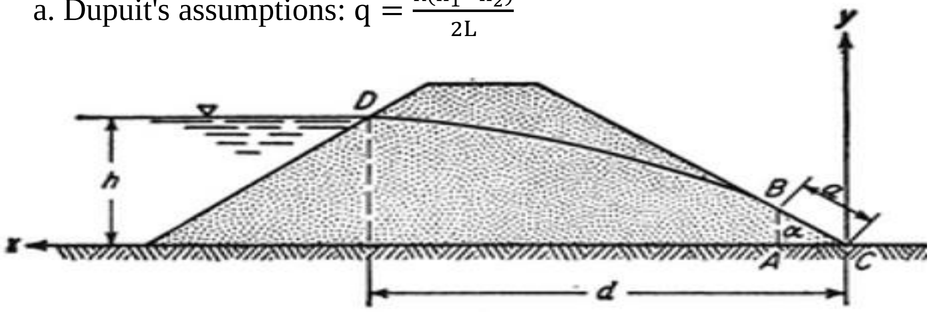
2. THORETICAL CONSIDERATION

As clearly explained by Harr (1962), there were many different assumptions for determining the seepage quantity as explained below:

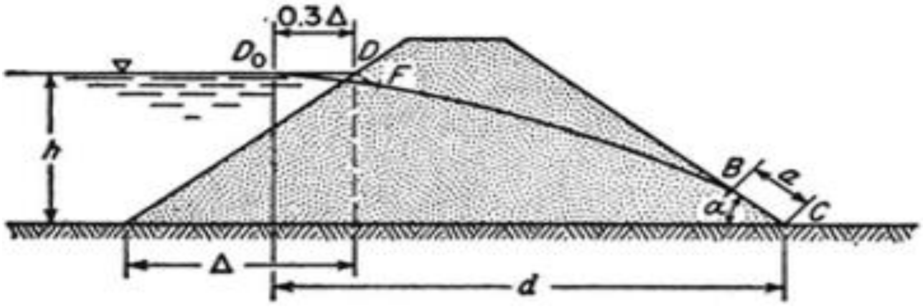
- **Dupuit's Assumptions**: Both discharge quantity and free surface are independent of the slopes of the dam. The discharge (per unit width) through any vertical section of the dam for the condition of tail water at potential seepage face are shown in Figure (1-a).
- **Schaffernak & Van Iterson**: The first approximate method that accounts for the development of the surface of seepage considering an earth dam on an impervious base shown in Figure (1-b) with no tail water.
- **L. Casagrande's**: Recommended that point D_o shown in Figure (1-c) instead of point D be taken as the starting point of the line of seepage (D_o is 0.3Δ from point D at the upstream reservoir surface). The actual entrance condition is then obtained by sketching in the arc DF normal to the upstream slope and tangent to the parabolic free surface.
- **Pavlovsky's Solution:** Considered the dam divided into three zones as shown in figure (1-d). The upper section (I) bounded by the upstream slope and y-axis, the central section (II) by the y-axis and a vertical line through the discharge point of the free surface and the lower section (III) by the latter vertical line and the downstream slope. The streamline in zone (I) are known to be curvilinear (dotted curves *cd*); however, Pavlovsky assumed that they may be replaced by horizontal streamline of almost equivalent length (*ed)* then assuming purely horizontal flow in zone (I).



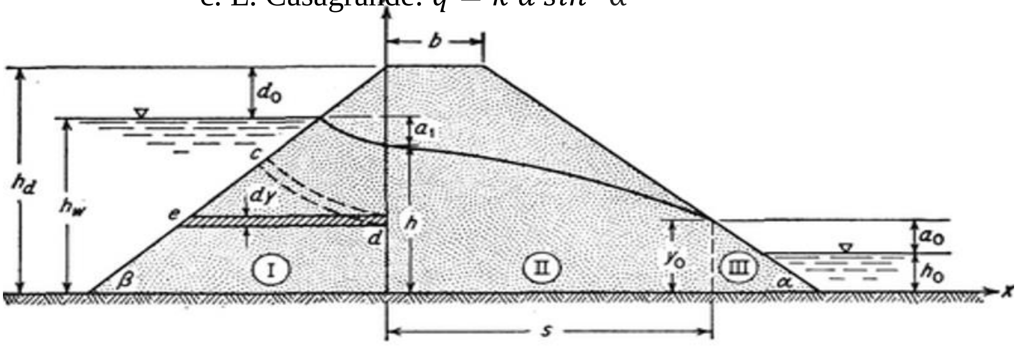
a. Dupuit's assumptions: $q = \frac{k(h_1^2 - h_2^2)}{2L}$



b. Schaffernak & Van Iterson: $q = k\ a\ \sin(\alpha)\ \tan(\alpha)$



c. L. Casagrande: $q = k\ a\ sin^2\ \alpha$



d. Pavlovsky's Solution: $dq = k \frac{a_1}{\cot ß\ (h_d - y)} dy$

Figure 1. Assumptions of seepage quantity through earth dam (Harr, 1962).

2.1 Dimensional Analysis

Dimensional analysis is an important tool to investigate the relationship between different variable's and categorize to convert them into a smaller number of dimensionless parameters to identify any phenomenon. In the present study, the Buckingham's π- theorem was used for evaluation of the manner in which the variables controlled the seepage quantity through a homogenous earth dam. The expected factors that affecting on the seepage quantity for a general section of homogenous earth dam with horizontal drainage blanket as sketched in Figure (2), was defined in Equation (1):

$$q = f\,(H, k, L, b, F_B, \rho, \tan\theta, \tan\alpha,) \;........\; (1)$$

The basic variables are (L, q and ρ) taken as repeated variables in all π-terms, and each of other variables are presented in each π-terms. After performing the dimensional analysis, new expression was found as shown in Equation (2):

$$q = kL\;\; f\left(\tan\theta, \tan\alpha, \frac{F_B}{H}, \frac{b}{L}\right) \;.............\; (2)$$

In which the obtained dimensionless parameters from the above equation can be defined as: (θ) is the slope of the upsteam face of the dam, (α) is the slope of the downsteam face of the dam, (F_B/H) is the dimensionless ratio of the dam freeboard to its height, (b/L) is the proportion of top width of the dam to the span of the horizontal blanket filter and (q/kL) ratio related to the permeability coeffeicient of the soil with seepage quantity and the length of horizontal blanket filter.

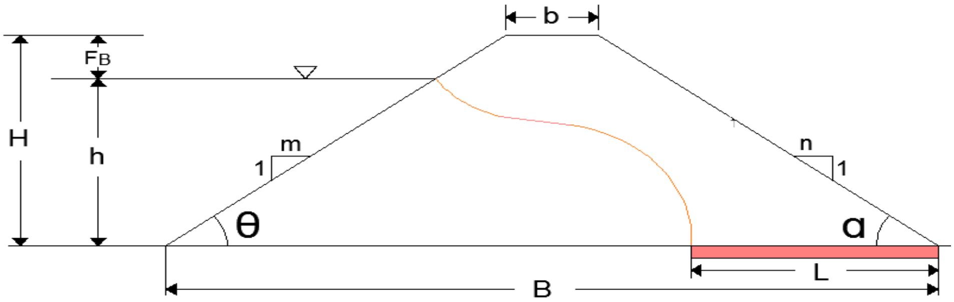


Figure 2. Overall sector of homogenous earth dam.

3. METHODOLOGY OF THE STUDY

Methodology of this study was conducted on the total of 972 homogenous earth dam models. These models includes the summation of 486 runs that done by GeoStudio (SEEP/W code) and also 486 runs done by (Slide) software taking into consideration the same models for each test in both software. Different geometries of homogenous dam were created and the material for dam body and filter modeled with hydraulic conductivity data point function. The details of selected variables are shown in Table (1), in which it consists of two different upstream and downstream slopes of the dam and three different values for each: dam height, filter length, permeability coefficient, free board and top width.

As explained in Figure (3), the upstream boundary blue nodes are designated as head boundaries with total head equal to the water level in the reservoir. The downstream toe is assigned a total head of 0.0 m (H = elevation). The downstream slope is assigned a potential seepage face type of boundary condition. Also the Slide software can be automatically utilized by the seepage analysis engine because it has the capability to carry out a finite element groundwater seepage analysis for steady state or transient conditions.

Table (1). Conducted dam section variables for both GeoStudio & Slide programs.

D/S & U/S slope (α, θ)	Variables	1	2	3
α_1= 2:1 θ_1=2.5:1	H: Dam Height (m)	14	16	18
	b: Top Width (m)	4	6	7
α_2= 2.5:1 θ_2=3:1	L: Filter Length (m)	10	20	25
	F_B: Free Board (m)	1	1.5	2
	k: Permeability Coefficient (m/s)	$1*10^{-4}$	$1*10^{-5}$	$1*10^{-6}$

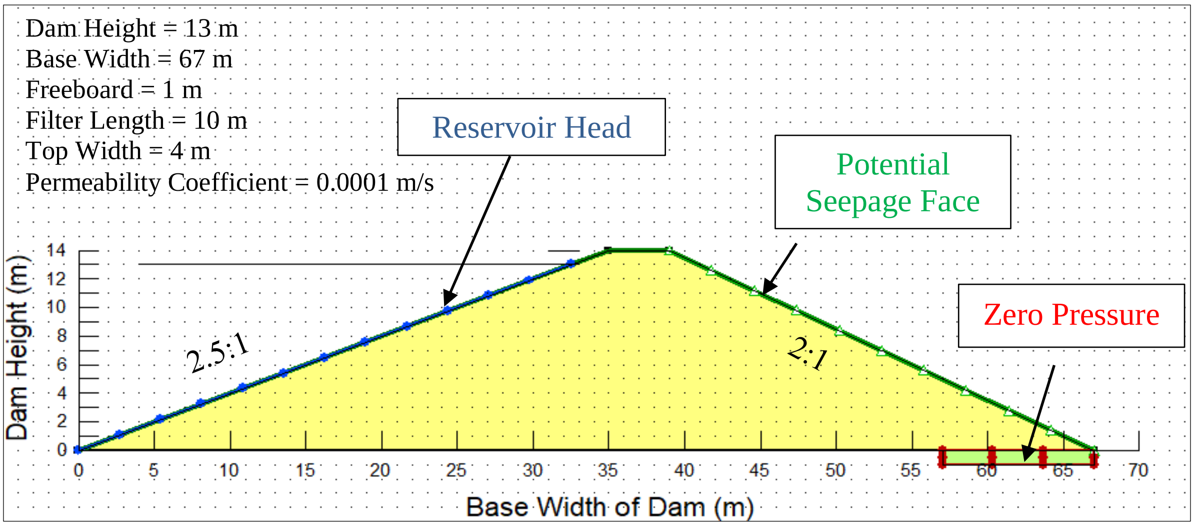


Figure 3. Location of the boundary conditions of homogenous earth dam.

4. RESULTS AND DISCUSSION

The main sections of this study deal with the effect of dimensionless parameters in regards of homogenous dam on the seepage quantity of the dam itself. Results of each part were concluded separately in the following configurations:

4.1 Mesh Size Dependence

In order to test mesh dependence on the amount of seepage discharge, four types of meshes as quads and triangles, triangles only, rectangular grid of quads and triangular grid of quads was investigated. The result of each method on the first run is shown in Table (2). The differences in seepage quantities was a small fractions but quads and triangles grid type was selected in all runs because of the lowest seepage quantity.

Table (2). Seepage quantification using different grid types.

Grid Type	No. of Elements	No. of Nodes	Seepage discharge (m^3/s)
Quads and triangles	500	559	$3.726*10^{-6}$
Triangles only	495	299	$3.782*10^{-6}$
Rectangular grid of quads	497	545	$3.844*10^{-6}$
Triangular grid of quads / triangles	468	512	$3.799*10^{-6}$

4.2 Effect of the Thickness of Filter

In this study the thickness of filter was investigated and compared with the dam section assuming filter thickness as zero. For this purpose two tests were done, first test was on the dam section having one grid thickness of the horizontal filter. The results of seepage quantity for 13m reservoir head was ($3.7243*10^{-4}$ m^3/s) as shown in Figure (4-a); whereas the second test of dam section with no filter thickness gave as ($3.7375*10^{-4}$ m^3/s) as a seepage quantity inside the dam body as shown in Figure (4-b).The difference between seepage quantities of both runs was ($1.32*10^{-6}$ m^3/s) which can be ignored.

4.3 Effect of the Dimensionless Parameters on Seepage Quantity

In this section, the effect of dimensionless parameters that computed from SPSS was clearly investigated. Figure (5) and Figure (6) demonstrate the relationship between the dimensionless parameter (q/kL) versus upstream and downstream slopes respectively. Results showed that the quantity of seepage obtained from Slide software was smaller than that of SEEP/W for the same effecting variables on the dam. In which the average difference of (q/kL) between both software was 1.696%. Also, both figures explained that seepage quantity increases as the upstream and downstream face slopes were increased.

Figure (7) shows the relationship between (q/kL) and (F_B/H) for Slide and SEEP/W software's. The effect of the freeboard on the seepage quantity was investigated in which seepage quantity decrease with increasing the height of freeboard when a height of dam not more than 18m.

Figure (8) demonstrates the relation between (q/kL) and (b/L). For the range of (b/L = 0.2 to 0.6) the seepage quantity decreases with increasing the top width of the dam. While, it increased with increasing length of horizontal toe drain.

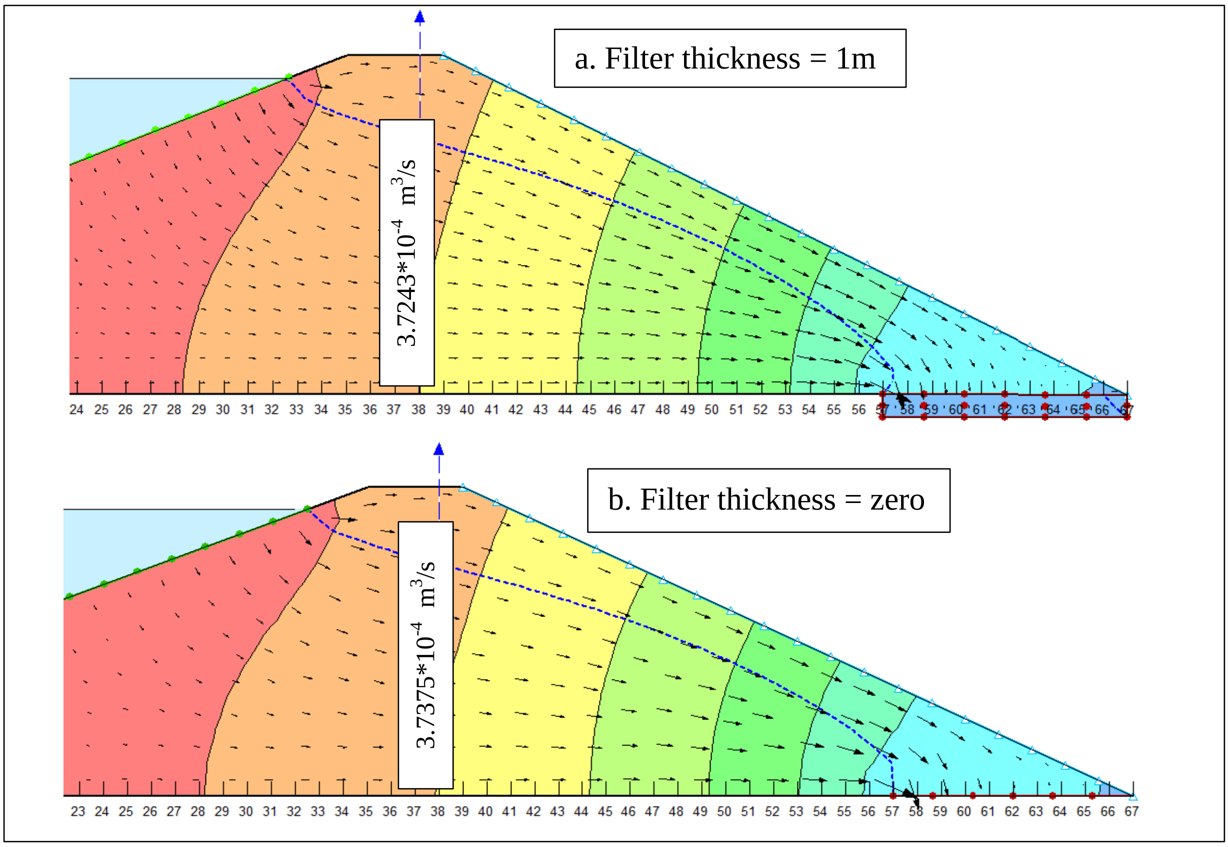


Figure 4. SEEP/W runs to explain the effect of filter thickness.

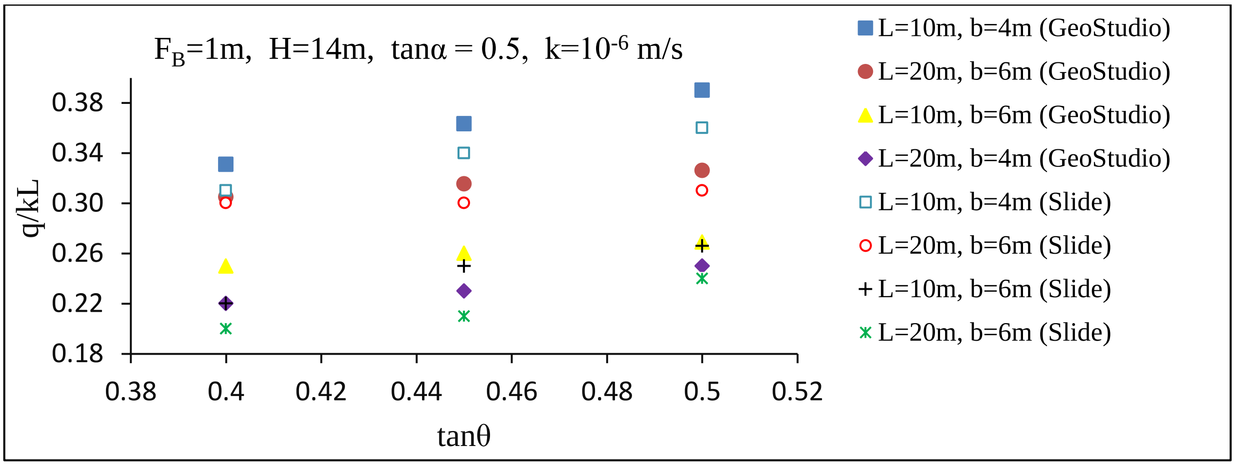


Figure 5. Relationship between (q/kL) and (tanθ).

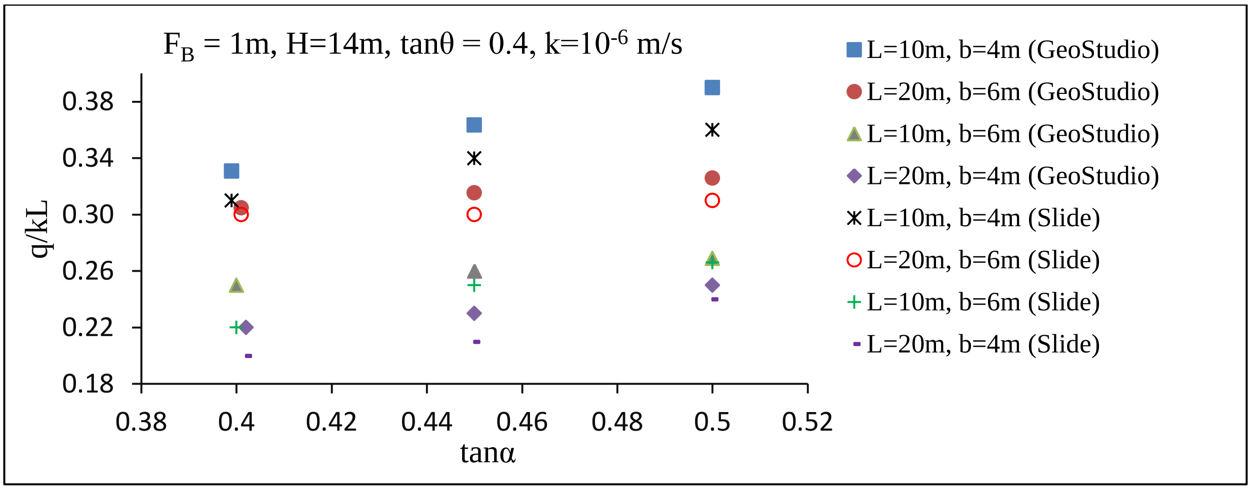


Figure 6. Relationship between (q/kL) and (tanα).

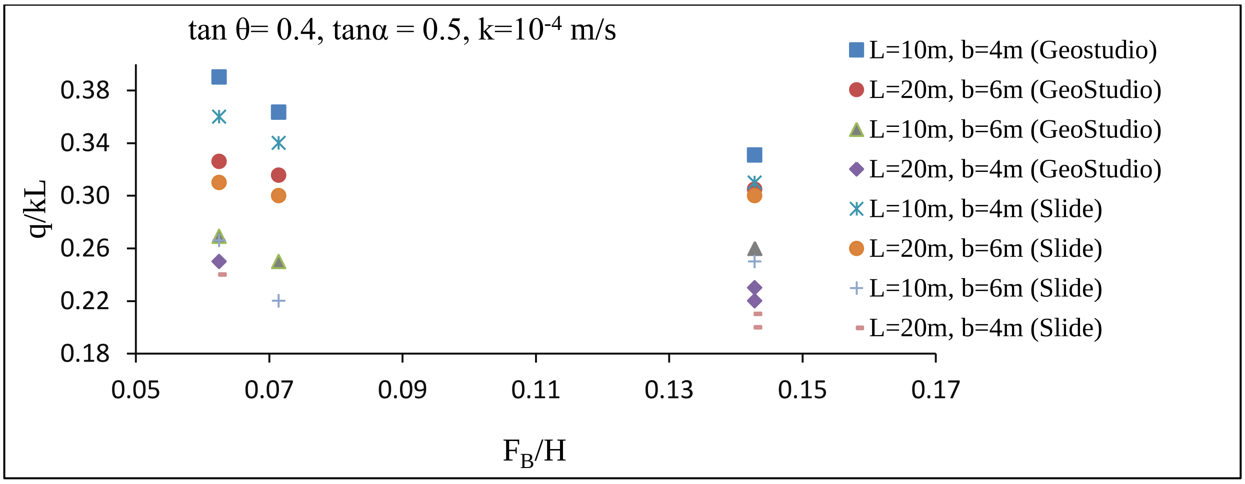


Figure 7. Relationship between (q/kL) and (F_B/H).

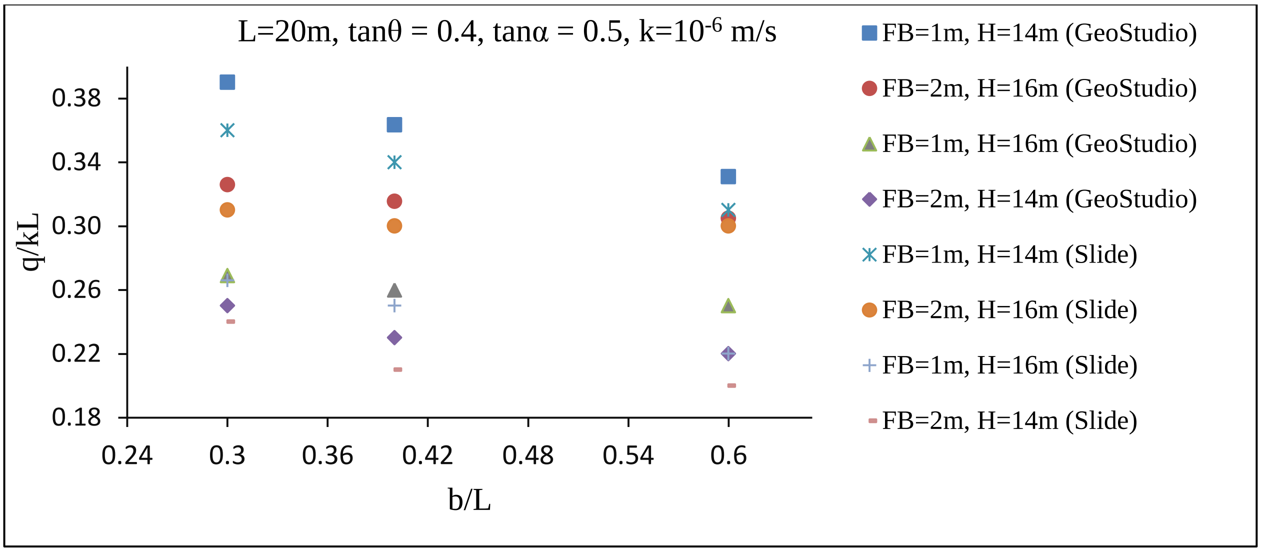


Figure 8. Relationship between (q/kL) and (b/L).

4.4 Empirical Equation for Determining the Seepage Quantity

In this section, the SPSS statistical software was used for predicting empirical general relationships. This relations was represented the relating independent pi-terms which significantly affect the seepage quantity per unit width. For this purpose the seepage quantities that obtained from SEEP/W and Slide software were examined in SPSS based on the dimensional analysis pi-terms. Two new expressions were obtained as Equation (3) based on GeoStudio results and equation (4) based on seepage quantities obtained from Slide software.

$$q = \frac{(\tan\theta)^{3.652}\ \ (\tan\alpha)^{3.573}\ \ (kL)^{0.4}}{(\frac{F_B}{H})^{0.231}\ \ (\frac{b}{L})^{0.226}} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

$$q = \frac{(\tan\theta)^{3.804}\ \ (\tan\alpha)^{3.734}\ \ (kL)^{0.381}}{(\frac{F_B}{H})^{0.272}\ \ (\frac{b}{L})^{0.218}} \quad \ldots\ldots\ldots\ldots\ldots (4)$$

The empirical equation in regards of calculated values of seepage discharge should be compared with the measured seepage discharges. For the purpose of predict a best relation, non-linear regression equations were founded. Figure (9) shows the seepage quantities obtained from GeoStudio and Slide program was compared with its quantities calculated from Equations (3 and 4) respectively. Best fitting intercept line was selected to show a better regression depends on high determination coefficient (R^2). Eventually, results explained that the seepage rates from SEEP/W code versus Equation (3) gave higher determination coefficient (R^2=0.815), whereas it was (R^2=0.788) in comparison between seepage rates from Slide software versus Equation (4).

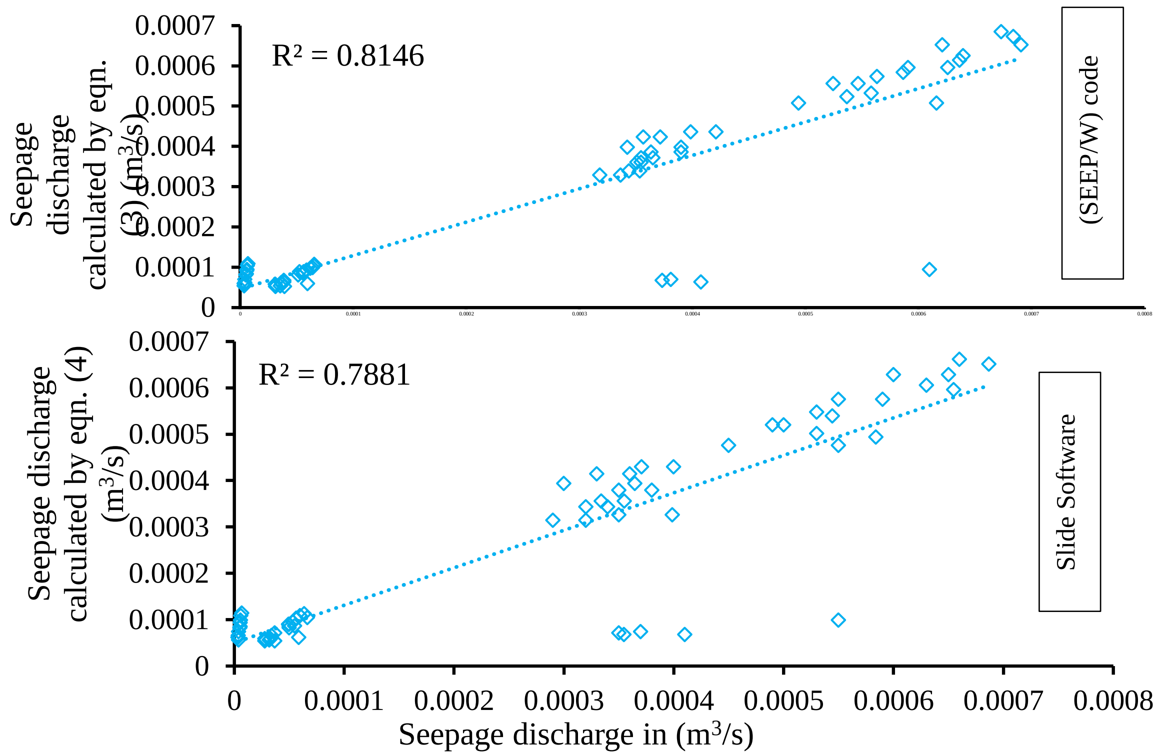


Figure 9. Comparisons of seepage rates found from GeoStudio and Slide with calculated seepage rates from empirical equations.

4.5 Artificial Neural Network (ANN)

ANN is a nonlinear mathematical model that can simulate arbitrarily complex nonlinear processes that relate the inputs and outputs of any system. In many complex mathematical problems that lead to solving complex nonlinear equations, Multilayer Perceptron (MLP) and radial basis function (RBF) networks are common types of ANN that are widely used in water resources engineering (Parsaie and Haghiabi, 2018). In this investigation, the MLP model was used to define of appropriate functions, weights and bias that should be considered. For this purpose the seepage quantity through homogenous earthen dam sections were collected. The datasets were divided in to two groups as training and testing, 75% was for training and 17.2% was for testing with 7.8% for validation (holdout). An ANN may have different values of input, hidden and output layers. Therefore the base structure of this investigation was (5-4-1) this means that: five inputs, four hidden layers and one output. Figure (10) shows that the accuracy of the ANN models for calculating the seepage discharge through homogenous earth dam. The quantity of seepage predicted by ANN was compared with the seepage quantity from SEEP/W and Slide software, the determination coefficients for these relations was R^2= 0.923 and R^2= 0.942 respectively. This means that slide software gave accurate results than that of SEEP/W code.

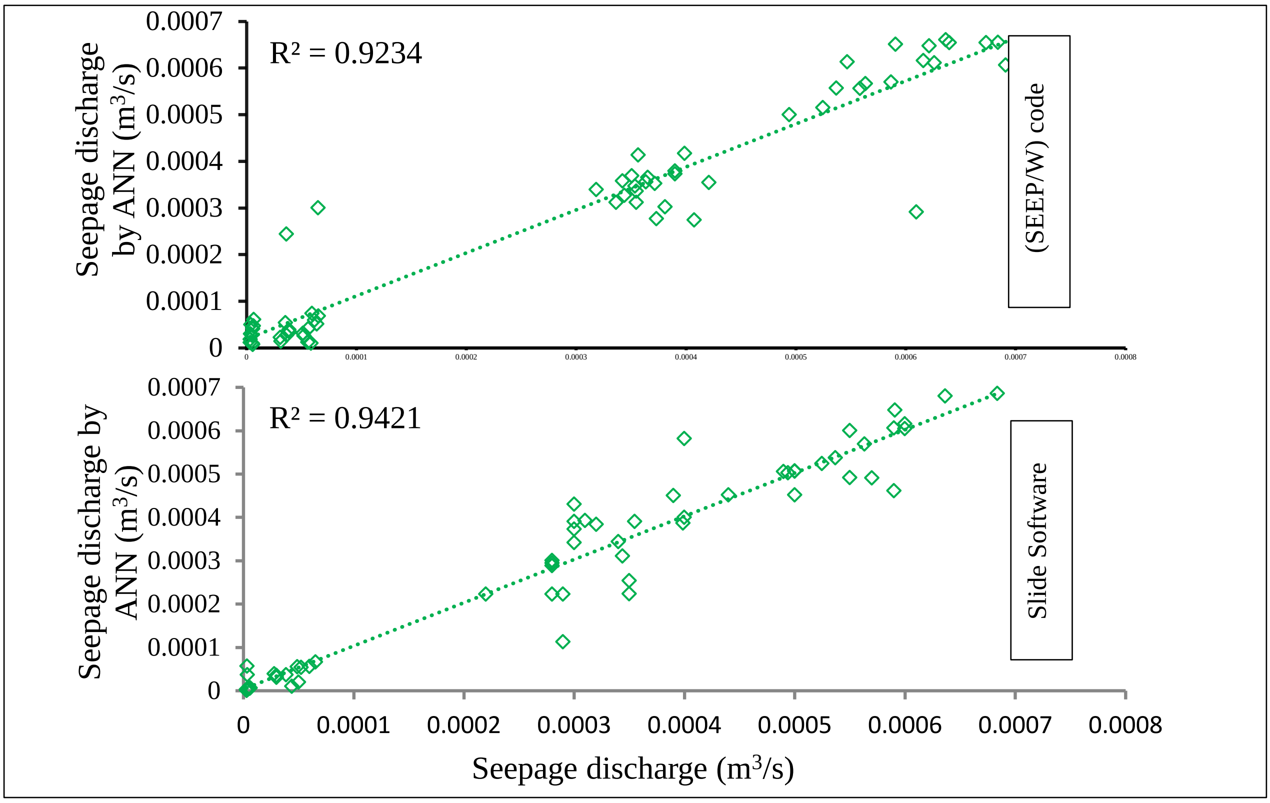


Figure 10. Comparisons of seepage rates found from GeoStudio and Slide with calculated seepage rates from ANN.

4.6 Comparison of Seepage Quantity by Different Methods

Figure (11) shows the comparison between seepage discharges obtained from different methods. It seems that among 64 runs of each method, the seepage quantities were divided as group points based on the same dimensions of the dam, reservoir level and permeability coefficient. There are small fractions in differences between them. In which; seepage quantities that obtained from SEEP/W code was much greater than the amount that obtained from slide software for the condition of ignoring tail water at the potential seepage face and approximated phreatic line of the homogenous dam.

For more details on the differences in seepage rates, the average percent of errors in each method based on the seepage quantities obtained from SEEP/W code was shown in Table (3). This table demonstrates that SEEP/W seepage quantities compared with its quantity obtained from ANN and Slide software has the average percent errors about 1.060% and 8.519% respectively. On the other hand, SEEP/W quantities compared with its quantity obtained from Equation (3) of this investigation, it has 15.814% average errors in seepage rates.

Eventually, the maximum seepage quantity obtained from ANN was ($6.856*10^{-4}$ m^3/s) which is less seepage rates than the quantities measured by other methods taking into consideration of the same affecting dimensionless parameters.

Table (3). Different % errors of seepage quantity with comparing to SEEP/W.

Seepage quantities obtained from:	Empirical Equation (eqn. 3)	Slide Program	Artificial Neural Network
Average Errors:	15.814 %	8.519 %	1.060 %

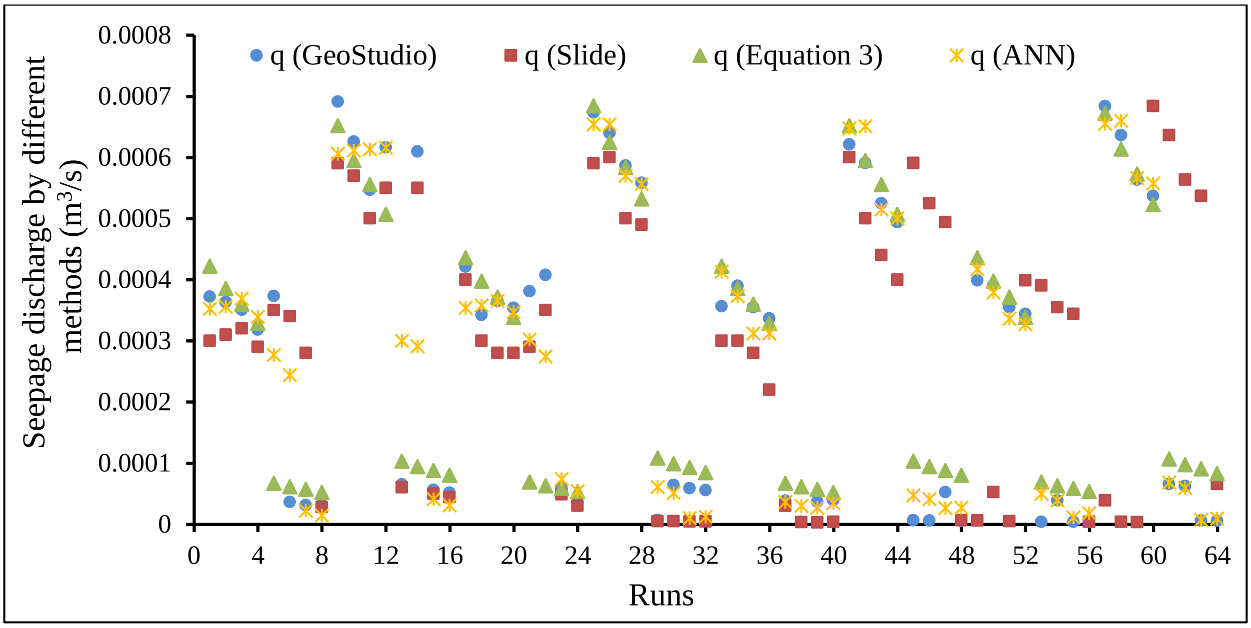


Figure 11. Comparison of seepage quantities by different methods.

5. CONCLUSIONS

The key messages of this study are the following:

1. The slight increasing in quantity of seepage was observed with increasing the upstream and downstream slopes of the earth dam.
2. The quantities of seepage increases with increasing horizontal toe drain and decreasing top width of the earth dam.
3. The seepage quantity obtained from GeoStudio software was greater than its quantity attained from Slide software. In which, the average difference of dimensionless parameter (q/kL) between Slide software and SEEP/W code was 1.696 %.
4. The seepage rates measured by Slide software was compared with its quantity achieved by ANN. This relation gave a higher determination coefficient (R^2 = 0.942) than nonlinear empirical equations found from SPSS.
5. SEEP/W seepages compared with its quantity obtained from ANN and Slide software has the average percent of errors less than 1.5 % and 9 % respectively.

6. REFERENCES

Arshad E.I. and Babar M.M. (2014), 'Comparison of SEEP/W Simulations with Field Observations for Seepage Analysis through an Earthen Dam (Case Study: Hub Dam- Pakistan)', International Journal of Research, Vol. 1, Issue 7, pp. 57-70.

An example: 'Seepage through a Dam Embankment', GEO-SLOPE International Ltd, Calgary, Alberta, Canada.

Alnealy H.K.T. and Alghazali N.O.S. (2015), 'Analysis of Seepage Under Hydraulic Structures Using Slide Program', American Journal of Civil Engineering. Vol. 3, Issue 4, pp. 116-124.

Chahar B.R. (2004), 'Determination of Length of a Horizontal Drain in Homogeneous Earth Dams', Journal of Irrigation and Drainage Engineering, Vol. 130, Issue 6, pp. 530-536.

Çalamak M., Bingöl A. N. and Yanmaz A. M. (2016), 'Effect of Drainage Properties on Seepage Behavior of Earth-Fill Dams', Conference: 12th International Congress on Advances in Civil Engineering, Istanbul, Turkey.

Harr M.E. (1962), 'Ground water and seepage-book', school of civil engineering, purdue university, McGraw Hill, New York 91-37779.

Irzooki R.H.(2016), 'Computation of Seepage through Homogenous Earth Dams with Horizontal Toe Drain', Engineering and Technology Journal, Vol. 34, Issue 3 part (A), pp. 430-440.

Jamel A.A. (2016), 'Analysis and Estimation of Seepage through Homogeneous Earth Dam without Filter', Diyala Journal of Engineering Sciences, Vol. 9, No. 2, pp. 38-49.

Kamanbedast A. and Delvari A. (2012), 'Analysis of Earth Dam: Seepage and Stability Using Ansys and

GeoStudio Software', World Applied Sciences Journal, Vol. 17, No. 9, pp.1087-1094.

Malekpour A., Farsadizadeh D., Dalir A. H. and Sadrekarimi J. (2012), 'Effect of horizontal drain size on the stability of an embankment dam in steady and transient seepage conditions', Turkish Journal of Engineering and Environmental Sciences, Vol. 36, No. 2, pp.139-152.

Mansuri B., Salmasi F. (2013), 'Effect of Horizontal Drain Length and Cutoff Wall on Seepage and Uplift Pressure in Heterogeneous Earth Dam with Numerical Simulation', Journal of Civil Engineering and Urbanism, Vol. 3, No. 3, pp.114-121.

Omofunmi O. E., Kolo J. G., Oladipo A. S., Diabana P. D., and Ojo A. S. (2017), 'A Review on Effects and Control of Seepage through Earth-fill Dam' Journal of Applied Science and Technology, Vol. 22, No. 5, pp.1-11.

Parsaie A. and Haghiabi A.H. (2018), 'Prediction of side weir discharge coefficient by radial basis function neural network', MedCrave Online Journal of *Civil Engineering*, Vol. 4, issue 2.

Stark T.D., Jafari N.H., Zhindon J.S.L. and Baghdady A. (2017), 'Unsaturated and Transient Seepage Analysis of San Luis Dam', Journal of Geotechnical and Geoenvironmental Engineering, Vo.143, Issue. 2.