Computation of Seepage through Homogenous Earth Dams with Horizontal Toe Drain

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ABSTRACT

This investigation concerns to find a new equation for computing the quantity of seepage through homogenous earth dam with horizontal toe drain. For this purpose the computer program SEEP/W (which is a sub-program of Geo-Studio) was used. The SEEP/W runs were carried out with three different downstream slopes of the dam, three different upstream slopes, three variable horizontal toe drain lengths, three different free boards, three different top widths and three different heights of the dam. For each run the quantity of seepage was determined. The results show that the seepage discharge increased with increasing upstream slope, downstream slope, upstream reservoir water depth and length of horizontal toe drain. Also, the results show that the seepage discharges decreased with increasing the top width of the dam and the height of the free board. Using SEEP/W results with helping a dimensional analysis theory, a new easy and reliable empirical equation for computing seepage discharge through homogenous earth dams with horizontal toe drain was developed. The analysis of the results by Artificial Neural Network (ANN) shows that the length of horizontal toe drain (L) is the more geometrical variable effect on the seepage discharge, while the upstream slope (tanθ) of the earth dam has a little effect.

Keywords: Homogenous earth dams, Seepage quantity, SEEP/W, Artificial Neural Network, Dimensional Analysis

حساب التسرب خلال السدود الترابية المتجانسة التي لها منظومة تصريف افقية

الخلاصة

الدراسة الحالية تطرقت الى ايجاد معادلة جديدة لحساب كمية التسرب خلال السدود الترابية المتجانسة التي لها منظومة تصريف أفقية عند النهاية السفلى لميل مؤخر السد. لهذا الغرض تم استخدام البرنامج الحاسوبي (SEEP/W) الذي هو برنامج فرعي للبرنامج (Geo-Studio). برنامج العمل في هذا البحث تم بتشغيل برنامج (SEEP/W) باستخدام ثلاث حالات مختلفة لميل مؤخر السد وثلاث حالات مختلفة لميل المقدم وثلاثة اطوال مختلفة لمنظومة الصرف الأفقية وثلاثة أعماق مختلفة لفضلة العمق وثلاثة ابعاد مختلفة لعرض قمة السد وكذلك ثلاثة ارتفاعات مختلفة للسد. لكل تجربة تم اجراؤها تم حساب كمية التسرب خلال جسم السد. بينت النتائج ان كمية التسرب تزداد مع زيادة زاوية ميل المقدم والمؤخر وزيادة عمق الماء في خزان المقدم وكذلك زيادة طول منظومة الصرف الأفقية. كذلك بينت النتائج ان كمية التسرب تقل مع زيادة عرض قمة السد وكذلك زيادة ارتفاع فضلة العمق. باستخدام نتائج البرنامج (SEEP/W) وبتطبيق نظرية التحليل البعدي تم الحصول على معادلة وضعية جديدة وبسيطة من حيث التطبيق لايجاد كمية التسرب خلال السدود الترابية المتجانسة التي لها منظومة صرف افقية. تم تحليل النتائج المستحصلة باستخدام نظرية الشبكات العصبية الاصطناعية (ANN)، وقد أظهرت نتائج

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التحليل أن طول منظومة الصرف الأفقية هي أكثر المتغيرات الهندسية تأثيرا على كمية التسرب وأن ميل المقدم هو أقل العوامل تأثيرا على كمية التسرب.

INTRODUCTION

Seepage within and under the embankment must be controlled to prevent concealed internal erosion and migration of fine materials, or external erosion and sloughing. With the homogeneous embankment of dam, the buildup of excess pore pressures within the embankment and seepage has been a problem, especially for a reservoir having high, or rapidly fluctuating water levels for long periods; or for a dam having impervious foundation. If seepage is excessive, this can lead to instability and eventual failure of all or part of the downstream face [1]. Seepage through an earth dam is the continuous movement of water from the upstream face toward its downstream face. The top seepage line of percolating water is known as the phreatic surface. In order to allow adequate embankment and to eliminate seepage problems in the downstream areas of an embankment on impervious foundation, the phreatic surface should be kept within the dam by providing a horizontal drainage filter. The amount of water seeping through and under an earth dam, together with the location of the phreatic surface, can be estimated by considering the flow through porous media. The Laplace equation which governs water seepage cannot be solved analytically, except for cases with very simple and special boundary conditions. Therefore, researchers have invoked to empirical, graphical and recently numerical methods. Several methods have been developed to solve exactly or approximately Laplace's equation for various cases of seepage. One of the most widely used methods, the flow net, can be adapted to many of the under seepage and through-seepage problems found in dams and other projects involving hydraulic structures. The seepage of flow through earth dams was studied analytically by a number of researchers [2,3,4]. Numerical models are used to make acceptable approximations for the Laplace equation in complex flow conditions. The methods of numerical solution, such as finite element [5,6,7,8,9,10,11], finite difference [12], finite volume [13] and boundary element [14], were used to analyze the phenomenon of seepage through earth dams.

Casagrande derived a graphical method to determine the coordinates of the phreatic surface and to estimate the seepage quantity through homogenous earth dam with horizontal drain.

There are some different models were used experimentally to simulate the flow of water in porous media. These models provide a good sense for what is occurring during seepage and allow a physical estimate for the reaction of the flow system to changes in head, design geometry, and other assumptions. The most used models for representing the seepage phenomenon in porous media are sand models, viscous flow models and electrical analogs [3]. Irzooki[15], developed a hybrid solution (velocity hodograph- viscous flow analog) in order to determine the slope of the inflection point of the free surface for flow through an earth dam with horizontal under drain. Also, Irzooki and Jamel [16], studied the characteristics of phreatic line of seepage through homogenous earth dam with and without horizontal filter using viscous flow analog, which also named Hele-Shaw model. Finally, Kokaneh *et al.* [17], developed a method using artificial neural network for the prediction of seepage discharge through earth dam.

In this paper a SEEP/W program was used, with the helpful of dimensional analysis method and the statistics software program SPSS-19, in order to develop a simple empirical equation for evaluating seepage quantity through homogenous earth dams with horizontal toe drain. Also, in this research, the Artificial Neural Network (ANN) model was used to show the relative importance of each input variable of earth dam geometry on the seepage quantity through this type of dams.

SEEP/W Program

SEEP/W (which is a sub-program of Geo-Studio) is a finite element software product for analyzing groundwater seepage and excess pore-water pressure dissipation problems within porous materials such as soil and rock. Its comprehensive formulation allows you to consider analyses ranging from simple, saturated steady-state problems to sophisticated, saturated and unsaturated time-dependent problems. SEEP/W can be applied to the analysis and design of geotechnical, civil, hydrogeological, and mining engineering projects [18]. Many previous works studied different seepage problems by using SEEP/W program [8,19,20,21,22,23].

Dimentional Analysis

Dimensional analysis proves to be a generally valid method to recognize the information structure in the relationships between physical quantities in a precise and clear way. It starts from the fact that in quantitative natural science the descriptive quantities, it has dimensions and can be divided correspondingly into basic quantities and derived quantities [24].

In this research, a dimensional analysis was applied to predict an empirical equation for determining the seepage quantity through homogenous earth dams with horizontal drain, as shown in Figure (1). From this figure, the possible variables affecting on the quantity of seepage per unit width (q) are:

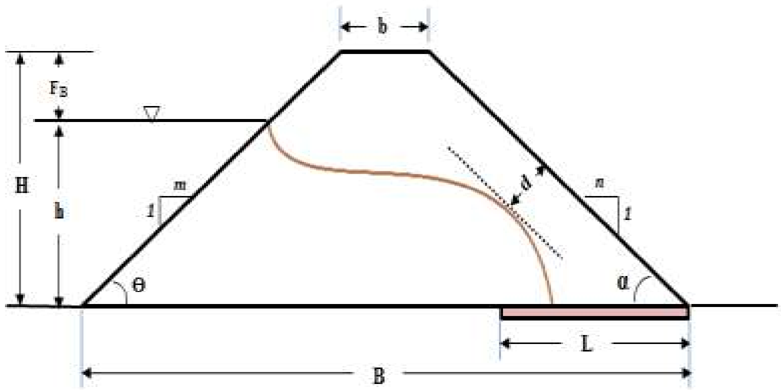

Figure (1): General section of homogenous earth dam with horizontal toe drain

θ = angle of upstream face with the horizontal
α = angle of downstream face with the horizontal
K = permeability of dam soil (m/sec)
H = Height of the dam (m)
F_B = Free board (m)
L = length of horizontal toe drain (m)
b = top width of the dam (m)
Therefore:

$$q = f(\tan\theta, \tan\alpha, K, H, F_B, L, b) \quad \ldots(1)$$

Using π theorem, the following dimensionless terms may be obtained from the above equation.

$$\frac{q}{LK} = f(\tan\theta, \tan\alpha, \frac{H}{L}, \frac{F_B}{L}, \frac{b}{L}) \quad \ldots(2)$$

Procedure of Running Seep/W Program

Using three different values for each of the above seven effecting variables on the quantity of seepage, it concludes that the total runs were applied in SEEP/W program are 2187 tests. These tests were divided into three groups (A, B and C) for D/S slope 1:2, 1:2.25 and 1:2.5

respectively. The tests of each group were carried out with three different U/S slope (1:2.5, 1:2.75 and 1:3), three different dam heights (H) (14, 15 and 16m), three different top widths (b) (4, 5 and 6m), three different lengths of horizontal toe drain (L) (10, 15 and 20m), three different free board (F_B) (1, 1.5 and 2m) and three different permeability (k) (0.0001, 0,00001 and 0.000001 m/sec).

Results and Discussion

For each run in SEEP/W program the seepage quantity (q) was observed and then the dimensionless parameters, shown in Equation 2, were computed and tabulated in a results table. From these results, the effect of each variable on seepage quantity through homogenous earth dams can be seen as the following:

Effect of upstream slope (tanθ)

Figure (2) represents the relation between the dimensionless parameter (q/kL) and upstream slope of the homogenous earth dam (tanθ) for some testing cases. From this figure it can be seen that if the downstream slope (tanα), height of the dam (H), free board (F_B) and permeability (k) are constant, a little increasing in the quantity of seepage (q), not more than 1%, occurs with increasing the upstream slope from 1:3 to 1:2.5 for all cases. Also, this figure concludes that for the same values of upstream and downstream slopes (tanθ & tanα), height of the dam (H), free board (F_B) and top width (b), the quantity of seepage increases with increasing the horizontal toe drain (L). Moreover, this figure shows that the seepage discharge decreases with increasing the top width when the remaining variables are constant.

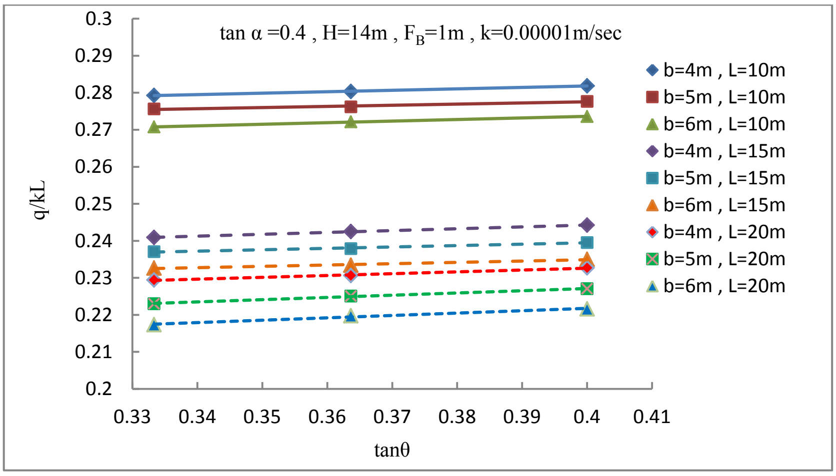

Figure (2): Relation of the dimensionless parameter (q/kL) with the upstream slope (tanθ) for homogenous earth dams

Effect of downstream slope (tanα)

Figure (3) shows the relation between the dimensionless parameter (q/kL) and downstream slope of the homogenous earth dam (tanα) for some testing cases. From this figure its appear that if the upstream slope (tanθ), height of the dam (H), free board (F_B), length of horizontal toe drain (L) and permeability (k) are constants, the quantity of seepage (q) increases with increasing the downstream slope. Where, the average percent of increasing of seepage quantity equal to 30%, for all testing cases, occurs with increasing the downstream slope from 1:2.5 to 1:2.25. The same percent of increasing of seepage quantity occurs when the downstream slope increased from 1:2.25 to 1:2. Also, this figure shows the same trend that shown in Figure (2), where the seepage discharge increases with increasing the length of horizontal toe drain and decreasing the top width when the other affecting variables are constant.

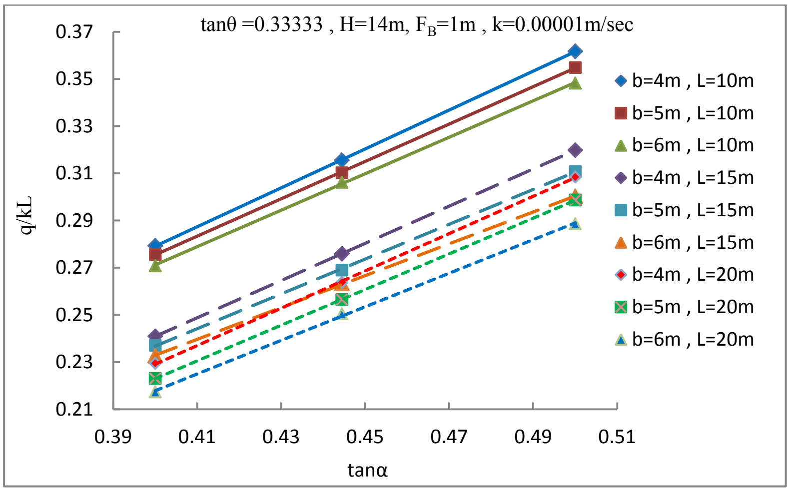

Figure (3): Relation of the dimensionless parameter (q/kL) with the downstream slope (tanα) for homogenous earth dams

Effect of the dam height (H)

The relation between the dimensionless parameter (q/kL) and the ratio of the dam height to the horizontal drain length (H/L) is shown in Figure (4). This relation concludes that the seepage through earth dam increased with increasing the dam height if the other affecting parameters are constant. It's worth to mention, the relation (difference) between the dam height and the free board (F_B) means height of the water surface (h) in the upstream reservoir.

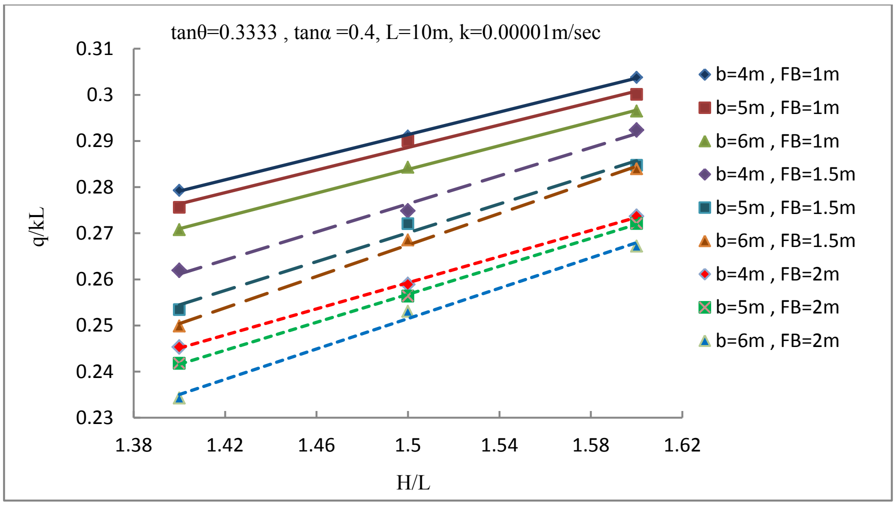

Figure (4): Relation of the dimensionless parameter (q/kL) with (H/L) ratio for homogenous earth dams

Effect of free board height (F_B)

The free board is a vertical distance between the top level of the dam and reservoir water level. Therefore, increasing the free board, when dam height is constant, exactly leads to decrease the upstream water depth, which causes decreasing in the seepage quantity. Figure (5) shows the above fact, where the seepage discharge decreases with increasing the free board height.

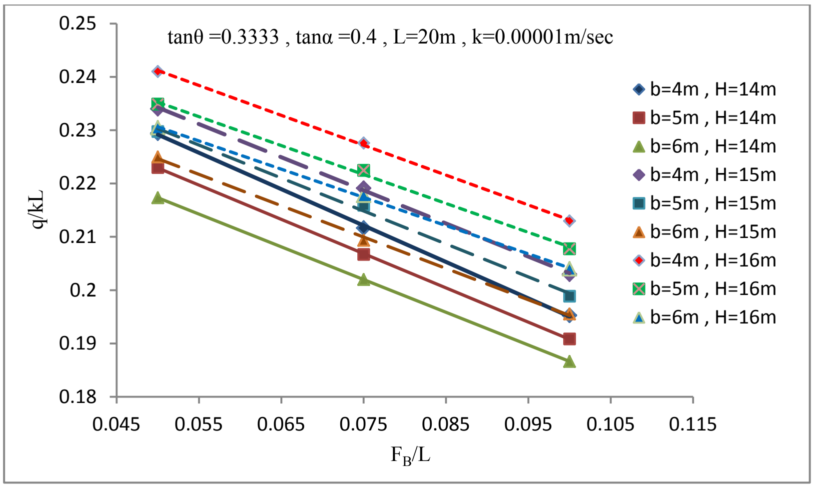

Figure (5): Relation of the dimensionless parameter (q/kL) with (F_B/L) ratio for homogenous earth dams

Effect of top width (b)

Figure (6) shows the relation between the dimensionless parameter (q/kL) and the ratio of the top width to the drain length (b/L). This figure concludes the same result that shown in Figures 2, 3, 4 and 5, where the seepage discharge decreases with increasing the top width of the dam when all other parameters are constant.

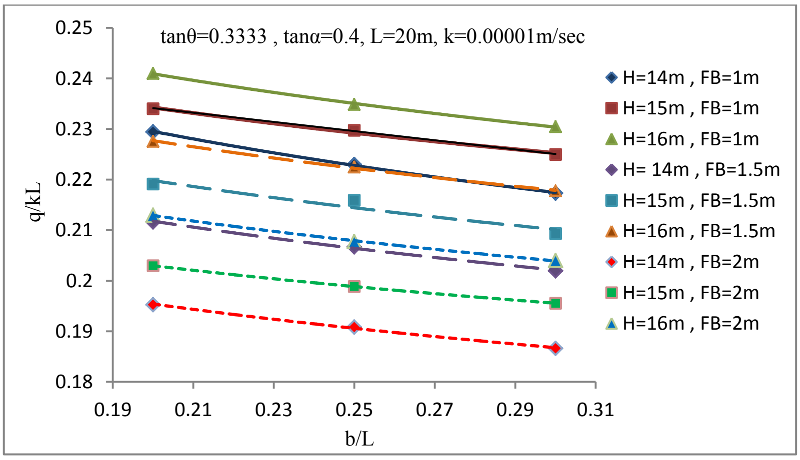

Figure (6): Relation of the dimensionless parameter (q/kL) with (b/L) ratio for homogenous earth dams

Statistical Analysis Results

In order to develop an empirical equation that can be used to measure the quantity of seepage through homogenous earth dams with horizontal toe drain, a statistical analysis was carried out using the resulted data of the dimensionless parameters of Equation 2 with SPSS.19 program. Firstly, the data were arranged descending and then approximately two thirds of these data were used in the program. The developed equation for computing the quantity of seepage through homogenous earth dam with horizontal drain is expressed as the following, with coefficient of determination R^2 equal to 0.98:

$$q = \frac{0.45K(L)^{0.681}(\tan\theta)^{0.101}(\tan\alpha)^{1.167}(H)^{0.589}}{(F_B)^{0.176}(b)^{0.094}} \quad (3)$$

Verification of Empirical Equation

Figure (7) shows the relation between the remaining one-third results of the unit discharge through homogenous earth dam were observed from SEEP/W program and those that which calculated from the Equation 3 using the same characteristics and geometry boundary conditions. From this figure, it can be seen a very good agreement between the results of program and equation.

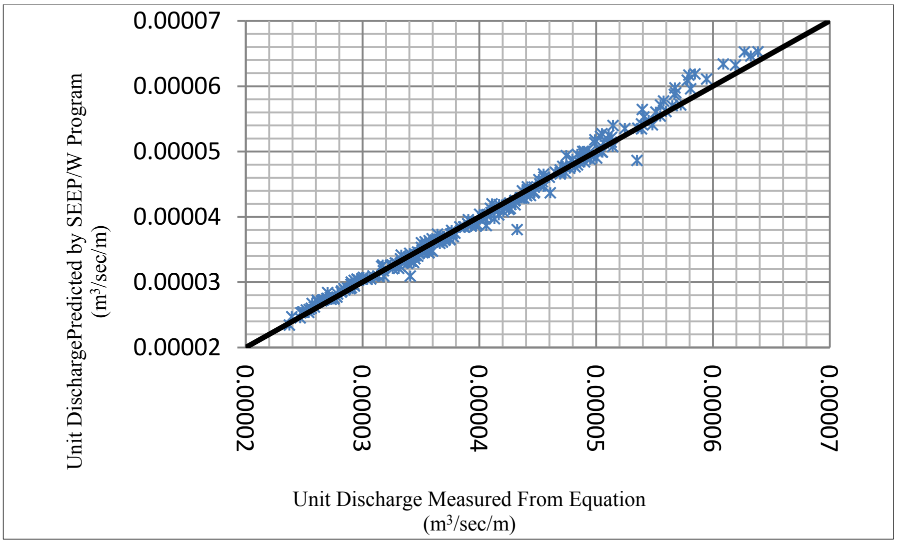

Figure (7): Relation between the observed unit discharge by SEEP/W program and calculated from empirical equation

Also, for verification of the correctness and accuracy of the above empirical equation, it was applied on a number of homogenous earth dams have geometries outside the scope of the dimensions that were used in the derivation of this equation, as mentioned above in section of procedure of running of SEEP/W program. The results of calculated seepage discharge from this equation show a very slight difference when comparing these results with the observed results by SEEP/W program, as shown in Table (1). The above results conclude that the derivative empirical equation has very good confidence; also it is very easy, when applying this equation for calculating the seepage discharge through homogenous earth dam with horizontal toe drain.

Table(1) Results of observed seepage discharge by SEEP/W and calculated from empirical equation

U/s Slope	tanθ	D/S Slope	tanα	H (m)	F_B (m)	b (m)	L (m)	K (m/sec)	Seepage discharge m^3/sec/m		Difference %
									SEEP/W	Equation	
1:3.5	0.286	1:2.5	0.40	10	1.5	3.0	12	1×10^{-5}	2.32×10^{-5}	2.41×10^{-5}	+3.9
1:3.5	0.286	1:2.5	0.40	13	2.0	4.0	15	1×10^{-5}	2.90×10^{-5}	3.03×10^{-5}	+4.5
1:3.5	0.286	1:2.5	0.40	17	2.5	6.0	23	1×10^{-5}	4.28×10^{-5}	4.39×10^{-5}	+2.6
1:2.75	0.364	1:2.3	0.435	11	1.3	3.5	14	1×10^{-5}	3.28×10^{-5}	3.23×10^{-5}	-1.5
1:2.75	0.364	1:2.25	0.444	9	1.0	3.0	12	1×10^{-5}	2.90×10^{-5}	2.82×10^{-5}	-2.8
1:2.75	0.364	1:2.4	0.417	13	2.0	4.0	15	1×10^{-5}	3.17×10^{-5}	3.26×10^{-5}	+2.8
1:2.6	0.385	1:2	0.50	8	1.0	2.5	10	1×10^{-5}	2.77×10^{-5}	2.73×10^{-5}	-1.6
1:2.6	0.385	1:2.1	0.476	10	1.5	3.0	11	1×10^{-5}	2.81×10^{-5}	2.87×10^{-5}	+2.1

1:2.6	0.385	1:2.25	0.444	12	2.0	4.0	13	1×10^{-5}	2.94×10^{-5}	3.05×10^{-5}	+3.9

Artificial Neural Network (ANN) Model

The data base built in the previous section using SEEP/W software was utilized to create artificial neural network (ANN) model that relates the output variables with the input variables that governs the quantity of seepage through homogenous earth dam with horizontal drain. ANN is a layered network of artificial neurons. The neurons or nodes are generally arranged in parallel to form layers. The first layer, which receives the inputs, is called input layer and the last layer is the output layer. The rest are hidden layers whose number depends on the problem to be solved. The input layer is the layer which takes the input values. All nodes of the input layer form the input of the neural network. The output layer is the layer in which all the nodes send the output values to the user's external environment [25]. The hidden layers are the processing center of the network system. The weights are adjusted in an iterative manner to achieve the expected output values. The number of nodes in the input and output layers is fixed according to the number of dependent and independent variables in the training data, while the selection of an optimal number of neurons in the hidden layer is small, the network may not learn the process correctly. On the other hand, if the number is too high, the training will take a long time and the over fitting of the training data may produce [26].

In order to obtain the ANN model, the SPSS 19 was used. This software was utilized using about 70% of the observed data base of (729) cases were analyzed by SEEP/W model. The input variables are the geometrical dimensions such as U/S slope (tanθ), D/S slope (tanα), Height (H), free board (F_B), length of horizontal drain (L) and top width (b) with using constant permeability of dam material (k). The output variable is the rate of seepage quantity per unit width (q) through an earth dam. The ANN model relates the output variables with the input variables that govern the quantity of seepage through homogenous earth dam with horizontal toe drain. The ANN model allows the selection of the number of hidden layers, the maximum and minimum number of units allowed to be specified in the hidden layer. The automatic architecture was selected to compute the best number of units in the hidden layer. Automatic architecture selection uses the default activation functions for the hidden and output layers. The initial value for the learning rate and the momentum factor were also allowed to be specified.

The software allows selecting the method of partitioning the active dataset into training, testing, and holdout (validation) samples. The training sample comprises the data records used to train the neural network; some percentage of cases in the dataset must be assigned to the training sample in order to obtain a model. The testing sample is an independent set of data records used to track errors during training in order to prevent overtraining. The holdout sample is another independent set of data records used to assess the final neural network; the error for the holdout sample gives an "honest" estimate of the predictive ability of the model because the holdout cases were not used to build the model. Table (2), shows the data subsets division percent.

Table (2): Data subsets division percent

Item		N	%
Sample	Training	306	62.2
	Testing	135	27.4
	Holdout	51	10.4
Valid		492	100.0
Excluded		0	
Total		492	

The comparison between predicted values of (q) by ANN and observed values by SEEP/W is shown in Figure (8). The relative importance for each input variables is shown in Table (3). It can be seen that the length of horizontal toe drain (L) has importance ratio 46.7%, that means it is the more affecting geometrical variable on seepage quantity through homogenous earth dams, while the upstream slope (tanθ) of the earth dam has a little importance ratio which is 1.7%.

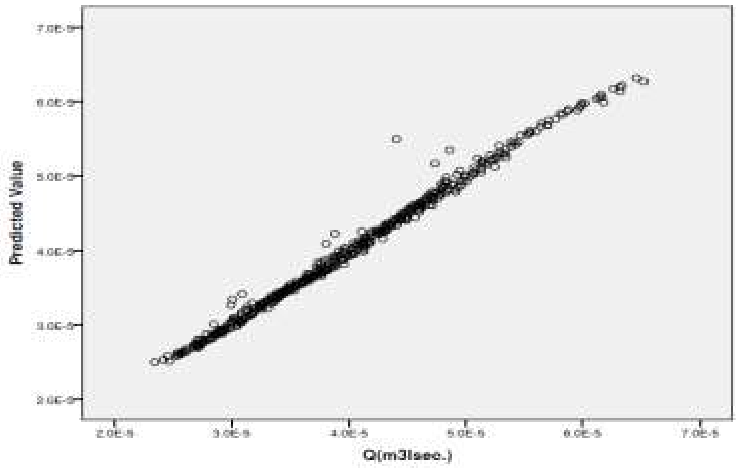

Figure (8): Comparison between predicted unit discharge by ANN and observed from SEEP/W

Table (3): Percent of importance for geometries of homogenous earth dams with horizontal toe drain

Geometrical Variables	Importance (%)	Normalized Importance (%)
U/S slope (tanθ)	1.7	3.7
D/S slope (tanα)	26.9	57.6
Dam height (H)	7.0	15.1
Free board (F_B)	13.4	28.7
Drain length (L)	46.7	100
Top width (b)	4.2	8.9

CONCLUSIONS

In the present research, the characteristics of seepage through homogenous earth dams with horizontal toe drain were studied using results which obtained from running the SEEP/W program on different geometries of dams. Based on the results and analysis, the following conclusions can be summarized:

1- The seepage quantity through homogenous earth dams increased with increasing the upstream and downstream slopes. However, the influence of varying the downstream slope on seepage flow is more than that for upstream slope. Also, the seepage quantity increased with increasing the height of upstream water depth and the length of horizontal toe drain.

2- The seepage through earth dams decreased with increasing the top width and the free board when the other geometrical variables of the dam are constant.

3- ANN method shows that the length of horizontal toe drain (L) is the more affecting geometrical variable on the seepage discharge, where the percent of importance of this parameter is 46.7%, while the upstream slope (tanθ) of the earth dam has a little effect with percent of importance 1.7%. The percent of importance of the downstream slope, height of the dam, top width and free board is 26.9%, 7.0%, 4,2% and 13.4% respectively.

4- A simple and straight forward reliable empirical equation was developed for directly computing the seepage quantity through homogenous earth dam with horizontal toe drain. For verification of the correctness and accuracy of this empirical equation, the results for different geometries of earth dams which computed from this equation were compared with the predicted results from SEEP/W program. This comparison shows a very good agreement.

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