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ANALYSIS AND ESTIMATION OF SEEPAGE THROUGH HOMOGENOUS EARTH DAM WITHOUT FILTER

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ABSTRACT: - This investigation concerns to study the quantity of seepage through homogenous earth dam without filter resting on impervious base using computer program SEEP/W (which is a sub-program of Geo-Studio).

Using SEEP/W experiments carries out with three different downstream slopes of the dam, three different upstream slopes, three variable downstream head, three different upstream head, three different height of earth dam and three different top width of earth dam. For each run the quantity of seepage have determined. Dimensional analysis was used with helping of the theoretical results to develop an empirical equation in order to determine the quantity of seepage through homogenous earth dam without filter resting on impervious base. Also, Verify the SEEP/W results with an artificial neural network (ANN), and compare with analytical methods. Results show that when compare the suggest equation with artificial neural network (ANN) less than 3% error with SEEP/W results less than 2% error, Dupuit's solution has more than 20% error and Casagrande's solution has more than 15% error.
Keywords: *Discharge, SEEP/W, Homogenous Earth Dam, ANN, Dimensional analysis, Casagrande solution, Dupuit solution*

Nomenclature

q = Discharge (L^3/T)
b = Top width of earth dam (L).
H = Height of earth dam (L).
h_1 = Upstream reservoir head (L).
h_2 = Downstream reservoir head (L).
k = Hydraulic conductivity of dam soil (L/T).
F_B = Upstream free board of earth dam (L).
F_D=Downstream free board of earth dam (L).
α = Angel of downstream slope.
θ = Angel of upstream slope.

1- INTRODUCTION

Dams have individually unique structures. Irrespective of size and type they demonstrate great complexity in their load response and in their interactive relationship with site hydrology and geology. Due to indeterminate dams' nature of many major design inputs, dam engineering has not a stylized and formal science. As practiced, it has a highly specialist activity which draws upon many scientific disciplines and balances them with a large element of engineering judgment; dam engineering has thus a uniquely for challenging and stimulating field of endeavor. Seepage has very important, as seepage affects the stability of dam. Because of its importance, which the determination of the seepage through an earth dam has received a great deal of attention.

Earth dams have always associated with seepage as they seep water in it. The water has looked for paths of least resistance through the earth dam and its foundation [1]. Several investigators have suggested various methods to determine the quantity of seepage through earth dam without filter, Dupuit (1863) had used the Darcy's Law to calculate the discharge rate passing for each vertical profile of the dam by assumed that the hydraulic gradient has equal to the slope of the free surface according to Equation (1) [2].(see Figure 1)

$$q = k\left(\frac{h_1^2 - h_2^2}{2L}\right) \quad (1)$$

Casagrande (1937) assume equations have (2) and (3) to calculate quantity of seepage through the body of a homogenous earth dam have placed on an impervious foundation, for case with zero downstream head and by made a correction for the entrance condition at the upstream face by suggested the parabolic free surface to start at a point $(\Delta 0.3)$ upstream, where (Δ) is equal to base width of the upstream triangular part [3] (Figure 2).

$$q = kl sin^2\alpha (2)$$

$$l = \sqrt{d^2 + h_1^2} - \sqrt{d^2 - h_1^2 cot^2}\alpha \ (3)$$

Schaffernak (1917) had developed approximate method to calculate the seepage through a homogeneous earth dam with zero downstream head by suggested that the phreatic surface has intersected the downstream slope at a distance (l) from the impervious base as show in Figure (3). Equations (4) and (5) [4].

$$l = \frac{d}{cos\alpha} - \sqrt{\frac{d^2}{cos^2\alpha} - \frac{h_1^2}{sin^2\alpha}} (4)$$

$$q = -k.l.sin\alpha.tan\alpha \ (5)$$

Also, the finite element method has developed to solve the governing equations of flow through earth dams. Al-Damluji et al. (2004) compared the results obtained from finite elements method with the boundary elements methods for solving the flow issue in steady state conditions [5]. Baghalian et al. (2012) analysis and estimation of seepage discharge in dams have based on piezometric head data values of seepage discharge of dam [6]. Javad et al. (2012) has developed a novel non-boundary-fitted mesh capable of solving the unconfined seepage problem in domains with arbitrary geometry and continuously varied permeability in earth dam [7]. Hillo (1993) Dunbar et al. (1999) has used finite element method for seepage flow below hydraulic structures on anisotropic soil foundation [8]-[9]. Khsaf (1998) has used finite element method to analyze seepage through pervious soil foundation underneath hydraulic structures provided with flow control devices [10]. Irzooki (1998) has used finite element method for analysis and investigation of seepage problems on the left side of Al-Qadisiya dam [11]. Olonade et al. (2013), have employed to study seepage through Oba Dam Using Finite Element Method [12].

Artificial Neural Networks (ANN) have one of the artificial intelligence related technologies and have many properties investigated seepage in the dam's body. The (ANN) have software methods that have constructed from one or several layers with several processing elements (neurons) in each layer. The processing elements are highly connected with each other within or outside the layers with weights. The (ANN) have widely used in several applications. They are capable of modeling complex and highly nonlinear relationships where analytical solutions are difficult to obtain. Deniz (2006), has estimated by artificial neural networks seepage path in dam's body for Jeziorsko nonhomogeneous earthfill dam in Poland [13]. Gokmen et al. (2005), have studied unsteady and non-uniform flow through a non-homogeneous and anisotropic saturated and unsaturated porous body of an earth dam by finite element method and artificial neural network models for Jeziorsko Earth

Dam in Poland, results have shown that the ANN model done as good as and in some cases better than the FEM model [14].

The SEEP/W has a finite element software product that can be used to model the movement and pore-water pressure distribution within porous materials such as soil and rock. It has comprehensive formulation made. It has possible to analyze both simple and highly complex seepage problems. The SEEP/W has application in the analysis and design for geotechnical, civil, hydrogeological, and mining engineering projects [15]. Nasim (2007), has studied the seepage analysis of earth dams by using SEEP/W software. Then an attempt has made to study the control of seepage in the dam through studying the effect of several parameters including the permeability of the shell material, the presence of impervious core and its location and thickness, the presence of vertical and horizontal filters, and the presence of cutoff wall and impervious upstream blanket [16]. Singh (2008), has studied seepage characteristics for a modified homogeneous isotropic earth dam with filter on impervious base under steady state condition by applying Software ANSYS/ SEEP-W/ PLAXIS to evaluate seepage characteristics and design of dam with different antiseepage elements [17]. Khattab (2009), has studied Mousl dam stability by simulate Seepage through dam using SEEP/W for three period rapid drawdown of water level (30, 21, 8 day) with the associated saturated-unsaturated transient seepage [18]. Farzin et al. (2013), have compared SEEP/W software simulation results with Schaffernak and Casagrande’s analytical solutions, Results have shown that numerical solution to give more seepage rate than the two other solutions [19].

The present paper has studied the characteristic of seepage through homogenous earth dam then predicted an empirical equation in order to determine the quantity of seepage through homogenous earth dam without filter resting on impervious base, by application of dimensional analysis to the setup experiment of the SEEP/W results, and using software program SPSS-19 statistics, this equation has provided information on the amount of drainage within the body of the dam in addition to help us choose a suitable filter length corresponding to the amount of leakage in the dam body. Also the continuity of seepage from the SEEP/W model has verified using artificial neural networks (ANN), then compare with analytical formulas for Dupuit's and Casagrande’s solutions.

2- PROCEDURE OF EXPERIMENTAL SETUP

For the purpose of running SEEP/W model tests, has used three different values for each variable, which have three different upstream slopes (3:1, 2.5:1 and 2:1), three different downstream slopes (2.5:1, 2.25:1 and 2:1), three different top width of dam (b) (4, 5, 6)m, three different upstream freeboard (F_B) (1, 1.5, 2)m, three different downstream freeboard (F_D) (11, 12, 13)m, three different height of dam (H) (14, 15, 16)m and different permeability (k). Depended on the above seven variables, the overall runs were carried out in this study are (729) runs. For each run determine the amount the seepage through the homogenous earth dam without filter resting on impervious base.

3- SEEP/W VERIFICATION

In this research, data has collected from an artificial neural network (ANN) for the same cases of the SEEP/W. The ANN model has (3) layered: input layer, hidden layer, and output layer. The input layer had (7) neurons and the output layer had one neuron. However, number of hidden layers and number of neurons in hidden layers can set. After trials with several ANN architectures have made a Multilayer Perceptron (MLP), ANN model with one hidden layers has used due to its accurate results compared to others. The input variables for (ANN) model earth dam were constant permeability and variable top width of the earth dam, height of the earth dam, and free board on the upstream and downstream sides of the earth dam, upstream and downstream slope, while the discharge through dam have the target outputs in the artificial neural network model. A tangent hyperbolic (tanh) transfer function has used for the internal layers with four processing elements hidden. A linear bias transfer function has used for the output layer. The training and testing data has randomly chosen as 70% to use as training data and 30% as testing data. The trained ANN model has tested using 234 randomly selected data sets as test data, and ANN predicted discharge have then compared with the values of discharge calculated using the SEEP/W, the comparison has shown good agreement between the (ANN) and the SEEP/W results, see figure (4).

4- DIMENSIONAL ANALYSIS

Dimensional analysis has proved to be a generally valid method to recognize the information structure in the relationships between physical quantities in a precise and clear way. It has startd from the fact that in quantitative natural science the descriptive quantities, it have dimensions and can be correspondingly divided into basic quantities and derived quantities [20].

A dimensional analysis has applied in order to develop an empirical equation to determine the seepage through homogenous earth dam without filter resting on impervious base.

As show in figure (5) the possible variables that can be effect on the quantity of seepage through homogenous earth dam are:

$$q = f\,(\tan\theta,\ \tan\alpha,\ K,\ H,\ F_B,\ F_D,\ b) \qquad (6)$$

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

$$\frac{q}{KF_D} = f\left(\tan\theta, \tan\alpha, \frac{H}{F_D}, \frac{F_B}{F_D}, \frac{b}{F_D}\right) \qquad (7)$$

5- RESULTS AND DISCUSSION

a. Relations Between the Variables

For using the SEEP/W data, the following relations between the variables have shown in the left side of the equation (6) with each one of the variable in the right side of this equation have obtained.

(See the figure 6) has shown the relationship between the top width of earth dam (b) with the discharge through earth dam (Q) for some models of homogenous earth dam with boundary conditions of constant upstream slope, height of dam and upstream free board, with three different downstream slope, top width of dam and free board downstream. From this figure it can be shown that the discharge decrease with increasing the top width of dam, the discharge increases with decreasing the downstream slope. Also, the figure has shown that the discharge increases with decreasing the downstream free board.

(See figure 7) has shown the relationship between the top width of earth dam with the discharge through earth dam (Q) for some models of homogenous earth dam resting on impervious base with boundary conditions of constant downstream slope, upstream free board dam, height of dam . With three different downstream slope, top width of dam and free board downstream. From this figure it can be shown the discharge decrease with increasing the top width of dam. Also, the show the low effect of changing upstream slope on the quantity of seepage through earth dam body.

(See the figure 8) has shown the relationship between the height of earth (H) and the discharge through earth dam (Q) for some models of homogenous earth dam with boundary conditions of constant upstream slope, downstream slope, top width of dam and upstream free board, with three different high of dam and downstream free board. From this figure it can be shown the discharge increase with increasing the height of dam Also, the figure has shown that discharge increases with decreasing downstream free board.

(See the figure 9) has shown the relationship between the upstream free board (F_B) and the discharge through earth dam (Q) for some models of homogenous earth dam with boundary conditions of constant upstream slope, downstream slope, height of dam and top width of dam, with three different upstream free board and downstream free board. From this figure, it can be shown that the discharge increases with decreasing the upstream free board. Also, the figure has shown that the discharge increases with decreasing the downstream free board.

b. Equation For Computing The Discharge Through Homogenous Earth Dam Without Filter

By substituting approximately two thirds of the SEEP/W results of the dimensionless terms in software program SPSS-19 Statistics, it will get the following equation which use to determine the quantity of seepage through homogenous earth dam without filter resting on impervious base at any geometry shape of homogenous earth dams with correlation coefficient R^2=0.974.

$$q = \frac{0.117 \times K \times F_D \times (tan\theta)^{0.039} \times (tan\alpha)^{0.681} \times \left(\frac{H}{F_D}\right)^{2.072}}{\left(\frac{F_B}{F_D}\right)^{0.194} \times \left(\frac{b}{F_D}\right)^{0.068}} \quad (8)$$

(See the figure 10) has shown the comparison between the remaining one third results of the unit discharge through homogenous earth dam without filter have measured by the SEEP/W and those that which calculated from the equation (8) using the same characteristics and geometry boundary conditions. The figure above has shown good agreement between the calculated unit discharge from the equation (8) and measuring from the SEEP/W model.

c. Comparison Discharge With Other Method

Figure (11) compare the results have from the suggest equation (8), the SEEP/W results, Multilayer Perceptron (MLP) in (ANN) and the results have obtained from the equations recommended by previous researchers Dupuit and Casagrande.

The figure above has shown good agreement between SEEP/W, equation (8) and ANN results. Also, the figure has shown that analytical solutions for Dupuit's and Casagrande's solutions gives different seepage rate than the other methods due to the approximate solution for drawing the phreatic surface in both analytical methods which effect on the quantity of seepage through the earth dam, and the neglect of the downstream reservoir head in Casagrande's solution. Results have shown that numerical Dupuit's solution gives more seepage rate in most cases than the other solutions.

By compare between the calculated discharge from the suggest equation (8) and measuring from other methods in most cases, Dupuit's solution has more than 20% error and Casagrande 's solution has more than 15% error, the artificial neural network (ANN) has less than 3% and SEEP/W results has less than 2%.

6- CONCLUSION

In the current research, the SEEP/W model has used to simulate the seepage flow through homogenous earth dam without filter resting on impervious base. From the results it can be conclude the following:

The discharge has decreased with increasing the top width of dam. Also, the discharge has increased with decreasing the downstream slope, decreasing the downstream free board, increasing the high of dam and decreasing the upstream free board. Also, it can be shown the low effect of changing upstream slope on the quantity seepage.

For using dimensional analysis theorem with the help of the SEEEP/W results, an empirical equation has developed for determine the quantity of seepage through homogenous earth dam without filter resting on impervious base.

When compare the suggest equation with artificial neural network (ANN) less than 3% error and with SEEP/W results less than 2% error. Dupuit's solution has more than 20% error and Casagrande's solution has more than 15% error duo to the approximate solution for the phreatic surface in the analytical theorem. Also, the absence of water in the downstream dam for Casagrande solution will increase the quantity of seepage error. Dupuit's solution gives more seepage rate in most cases than the other solutions.

REFERENCES

[1] Abhilasha P. S. and Antony Balan T. G., (2014)," Numerical Analysis of Seepage in Embankment Dams", IOSR Journal of Mechanical and Civil Engineering, PP 13-23.

[2] Das Braja M, (2007). "Advanced soil mechanics", Third edition, published in the Taylor & Francis e-Library.

[3] Farzin Salmasi1 and Fatemeh Jafari, (2013), "Validity of Schaffernak and Casagrande's analytical solutions for seepage through a homogeneous earth dam", International Journal of Pure Scientific Researches, Vol., 1 (1), 5-11.

[4] Harr, M. E., (1962), "Groundwater and Seepage", McGraw-Hill Book Company, New York.

[5] Al – Damluji, O. A., Fattah, M. Y., and Al-Adthami, R. A., (2004), "Solution of Two-Dimensional Steady-State Flow Field Problems by the Boundary Element Method", Journal of Engineering and Technology, No. 12, Vol. 23, p.p. 750-766.

[6] S. Baghalian, F. Nazari and S.S.Malihi, (2012), "Analysis And Estimation Of Seepage Discharge In Dams", International Journal of Engineering & Applied Sciences, *Vol.4, Issue 3, 49-56.*

[7] Mohammad Javad, Kazemzadeh-Parsi, and Farhang Daneshmand, (2012), "Unconfined seepage analysis in earth dams using smoothed fixed grid finite element method", International Journal for Numerical and Analytical Methods in Geomechanics, 36:780-797.

[8] Hillo, A. N., (1993), "Finite Elements for Seepage below Hydraulic Structure on Anisotropic Soil Foundation". M.Sc. Thesis, College of Engineering, University of Basrah, Iraq.

[9] Dunbar, S. W., and Sheahan, T. C., (1999), "Seepage Control Remediation at Hodges Village Dam", Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Vol. 125, No. 3, p.p. 198-206, March.

[10] Khsaf, S. I., (1998), "Numerical Analysis of Seepage Problems with Flow Control Devices underneath Hydraulic Structures". Ph.D. Thesis, Dept. of Building and Construction Eng., College of Engineering, University of Technology, Iraq.

[11] Irzooki, R. H., (1998), "Investigation and Analysis of Seepage Problems on the Left Side of Al-Qadisiya Dam". Ph.D. Thesis, Dept. of Building and Construction Eng., College of Engineering, University of Technology, Iraq.

[12] Kolawole Adisa Olonade and Oluwole Akinyele Agbede, (2013), "A Study of Seepage through Oba Dam Using Finite Element Method", Civil and Environmental Research, Vol. 3, No 3

[13] Deniz Ersayin, (2006), "Studying Seepage in A Body of Earth-Fill Dam By (Artificial Neural Networks) Anns", M.Sc. Thesis, College of Engineering, University of Izmir, Turky.

[14] Gokmen Tayfur, Dorota Swiatek and Wita, (2005), "Case Study: Finite Element Method and Artificial Neural Network Models for Flow through Jeziorsko Earthfill Dam in Poland", Journal of Hydraulic Engineering, Vol. 131, No. 6, pp. 431-440.

[15] An Engineering Methodology, (2007), "Seepage Modeling with SEEP/W", GEO-SLOPE International Ltd.

[16] Nasim S., (2007), "Seepage Analysis of Earth Dams by Finite Elements", M.Sc. Thesis, Collage of Engineering, University of Kufa, Iraq.

[17] Singh, A. K., (2008), "Analysis of Flow in a Horizontal Toe Filter", International Association for Computer Methods and Advances in Geomechanics (IACMAG), pp. 2449-2455.

[18] Khattab, Suhail. A.A. (2009), "Stability Analysis of Mousl Dam under Saturated and Unsaturated Soil Conditions", Al-Rafidain Engineering Journal, Vol. 18, No.1.

[19] Farzin Salmasi and Fatemeh Jafari, (2013), "Validity of Schaffernak and Casagrande's analytical solutions for seepage through a homogeneous earth dam", International Journal of Pure Scientific Researches. Vol., 1 (1), 5-11.

[20] Durst, F., (2008), "Fluid Mechanics", German.

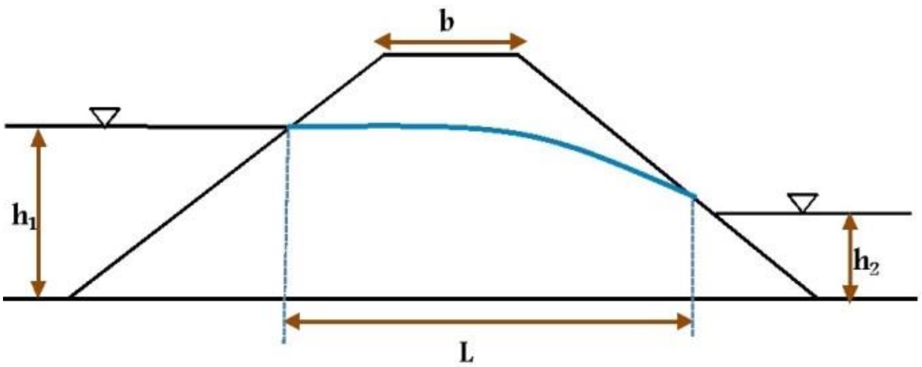

Fig. 1. Dupuit's solution for flow through an earth dam

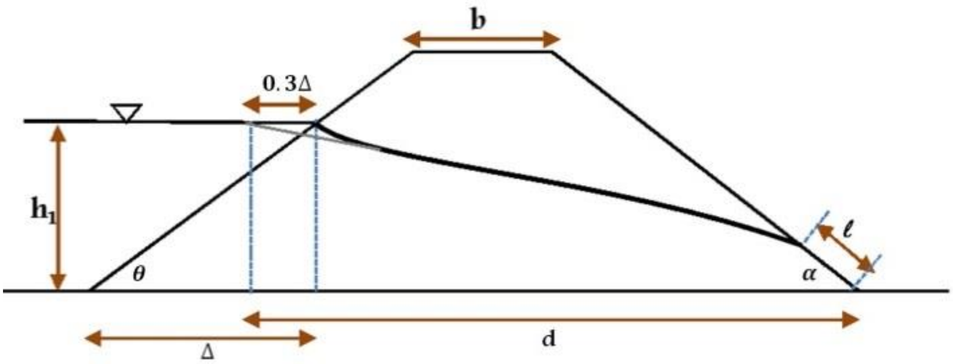

Fig. 2. Casagrande's solution for flow through an earth dam

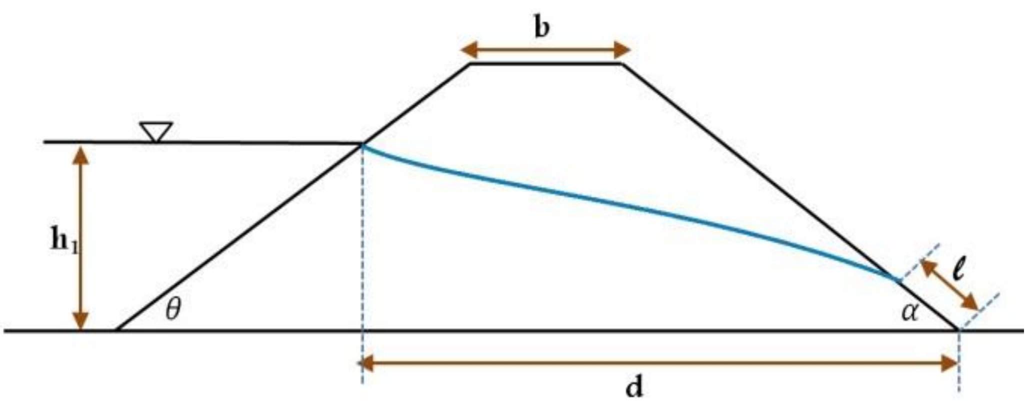

Fig. 3. Schaffernak's solution for flow through an earth dam

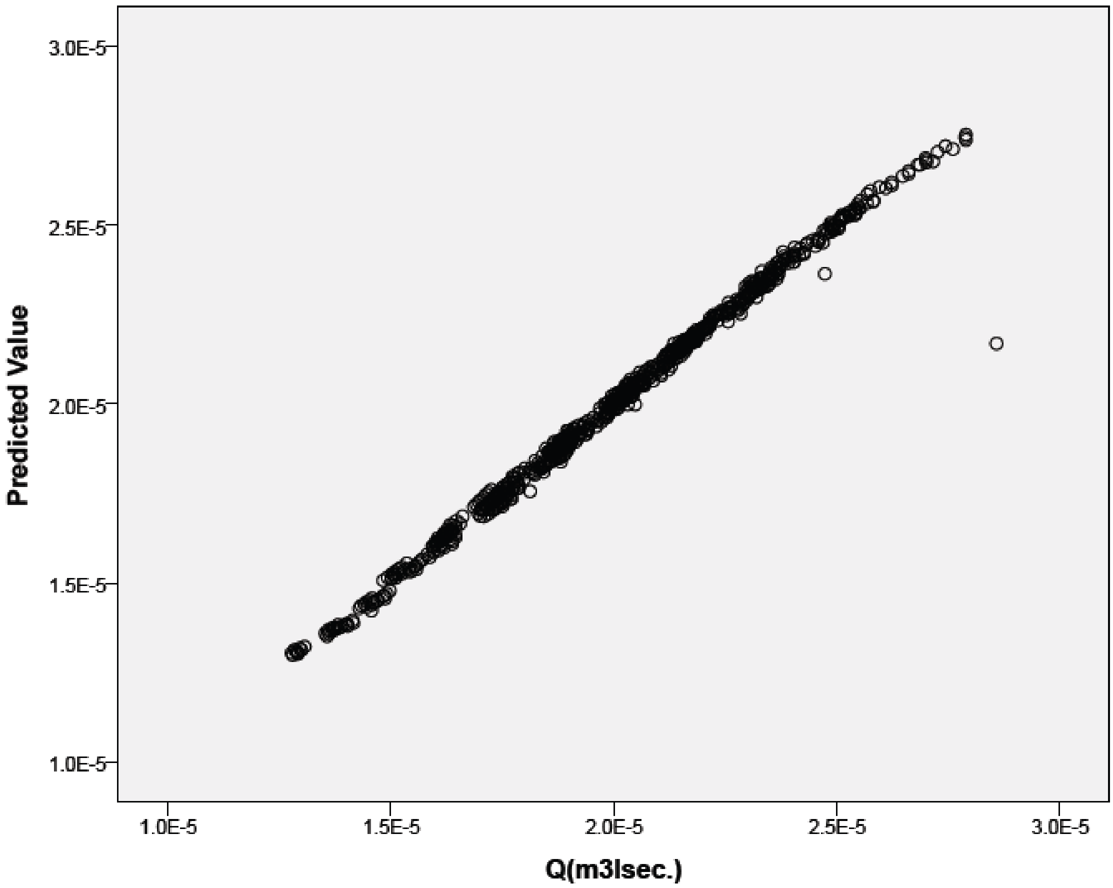

Fig. 4. Comparison between the SEEP/W discharge and predicted seepage by ANN (artificial neural network)

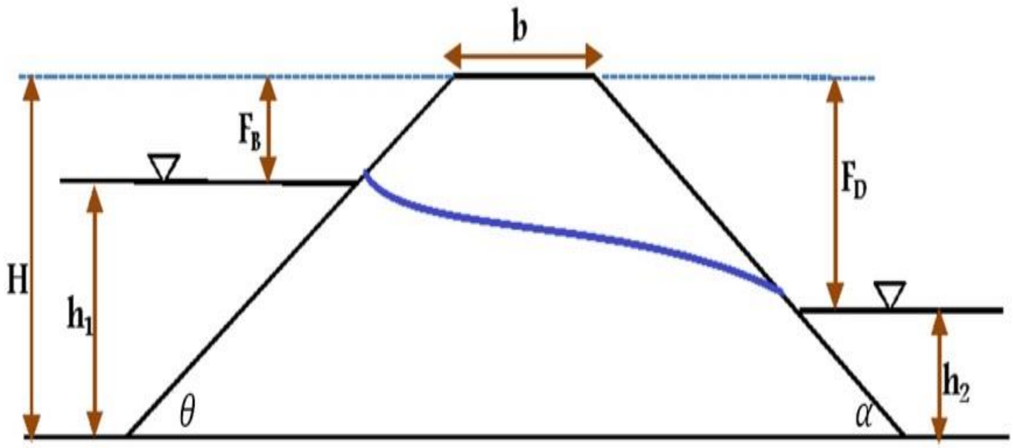

Fig. 5. The general section of homogenous earth dam without filter

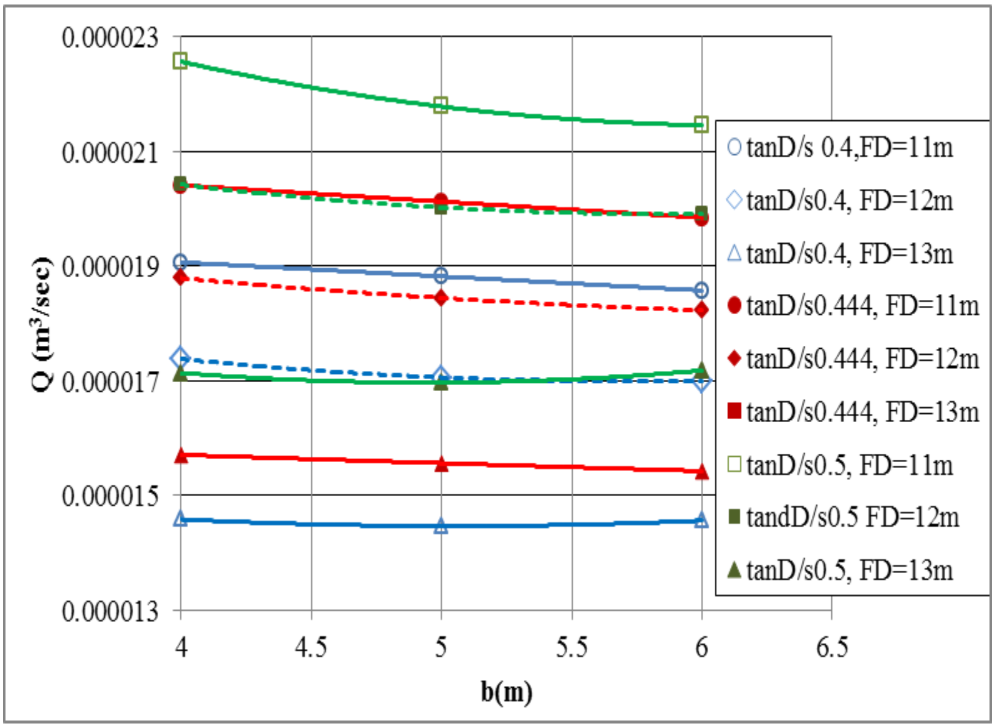

Fig.6. Relationship between (b) and (Q) of earth dam with upstream slope 1:3, F_B=1m, H=14m

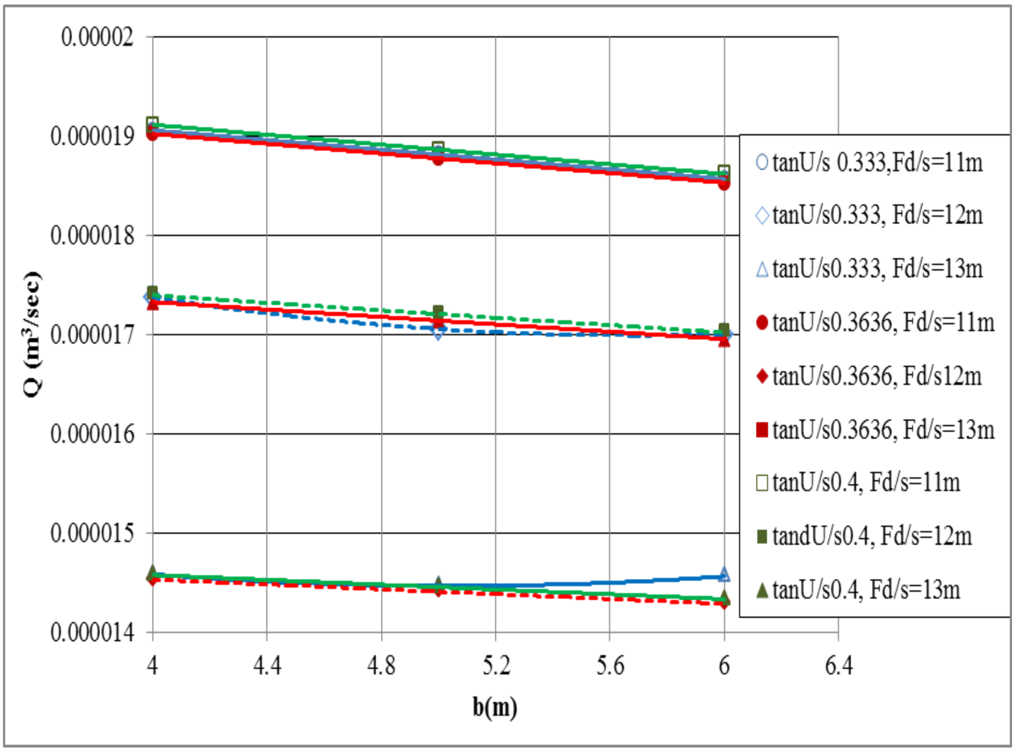

Fig.7. Relationship between (b) and (Q) of earth dam with Downstream slope 1:2.5, F_B=1m, H=14m

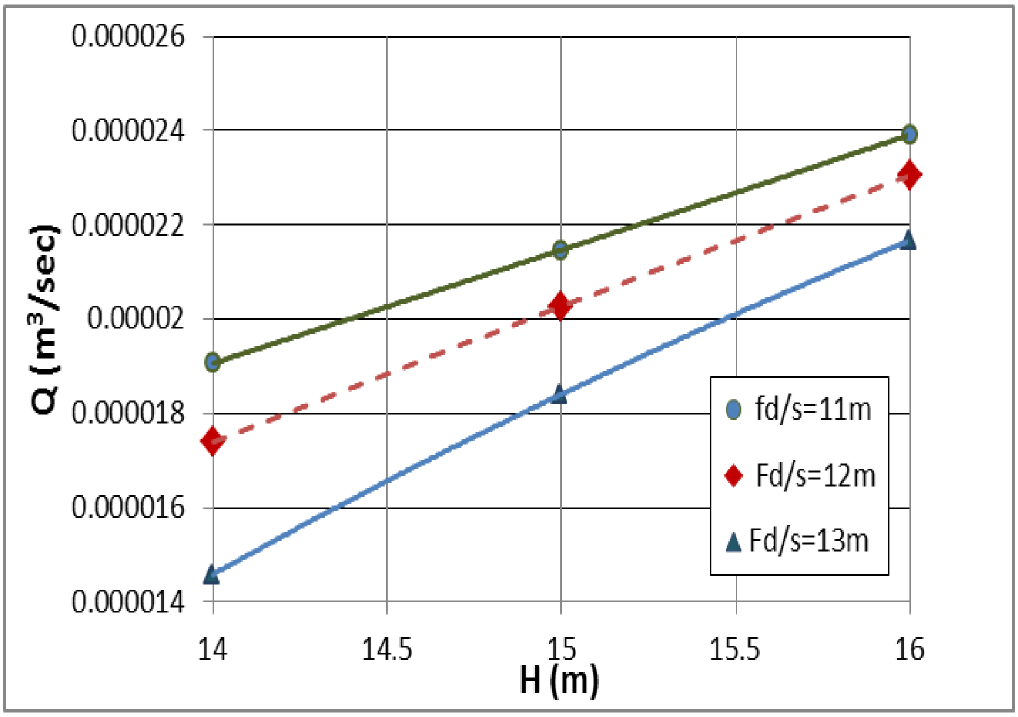

Fig.8. Relationship between (H) and (Q) of earth dam with upstream slope 1:3, downstream slope 1:2.5, F_B=1m, b=4m

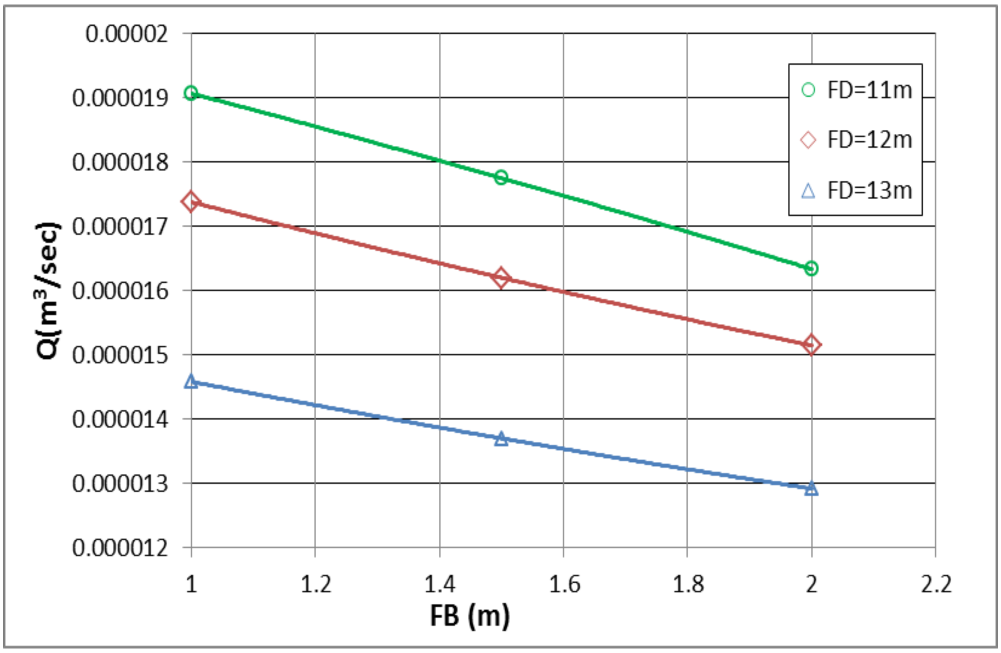

Fig.9. Relationship between (F_B) and (Q) of earth dam with upstream slope 1:3, downstream slope 1:2.5, F_B=1m, H=14m

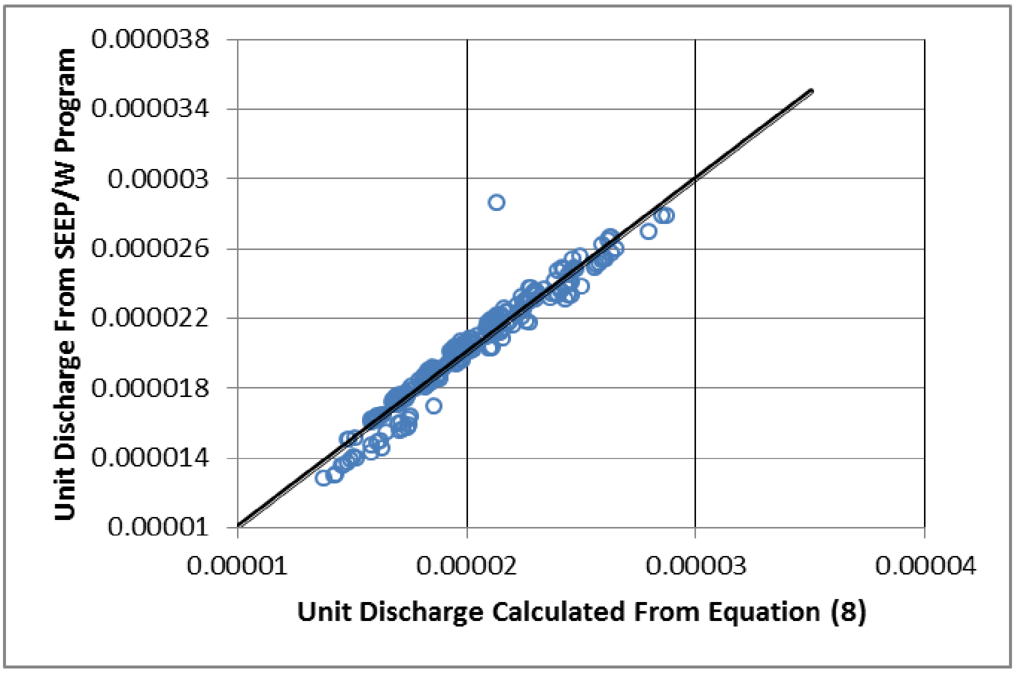

Fig. 10. Comparison between the calculated discharge from the equation and measuring from SEEP/W model

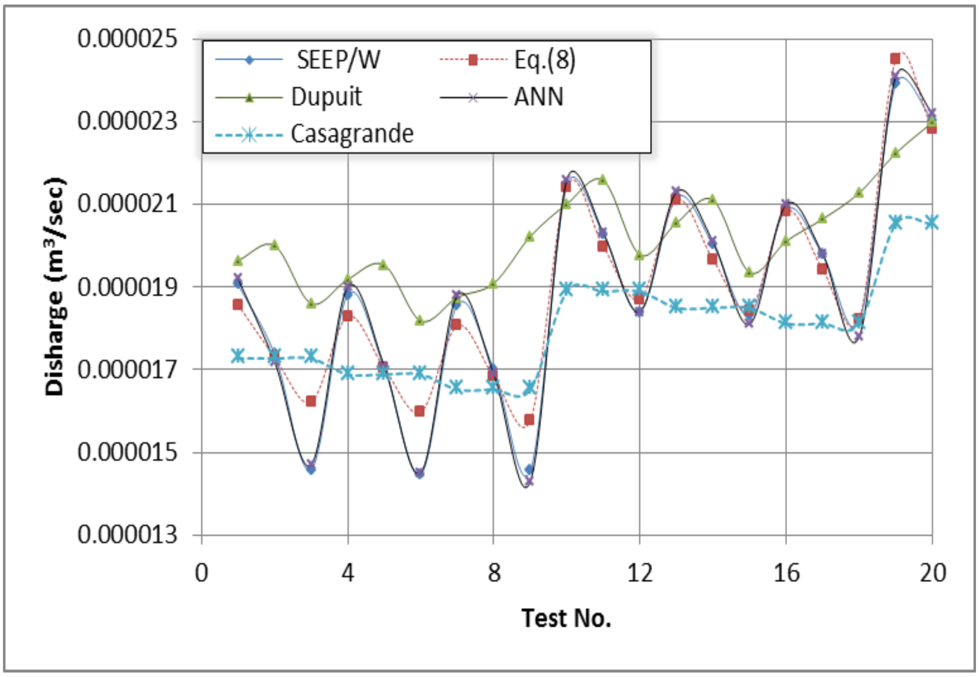

Fig. 11. Comparison between the calculated discharges for twenty test with different method.

تحليل وتقدير التسرب خلال السدود الترابية المتجانسة بدون مرشحات

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الخلاصة

أهتمت هذه الدراسة بكميه التسرب خلال السدود الترابية المتجانسة غير الحاويه على مرشح وذات ارضيات غير نفاذة باستعمال برنامج (SEEP/W) (وهو البرنامج الفرعي للبرنامج الحاسوبي (Geo–Studio)).
نفذت التجارب باستعمال برنامج SEEP/W لثلاث ميول مختلفة لمؤخر السد (Downstream Slopes) مع ثلاث ميول مختلفة لمقدم السد (Upstream Slopes) وثلاث ارتفاعات مختلفة لمقدار شحنة المقدم (Upstream Head) وثلاث ارتفاعات مختلفة لمقدار شحنة المؤخر (Downstream Head) وثلاث ارتفاعات مختلفة للسد (Height of Dam) وثلاث قيم مختلفة لعرض السد العلوي (Top Width). لكل تجربه تم قياس كمية التسرب خلال السد، بعدها تم اجراء التحليل بعدي (Dimensional Analysis) بالاعتماد على نتائج التجارب للحصول على معادلة رياضية لإيجاد كميه التصريف خلال جسم السد الترابي غير الحاوي على مرشح وذي ارضيه غير نفاذة. كذلك قد تم التحقق من نتائج (SEEP/W) باستخدام الشبكة العصبية الصناعية (ANN)، كما وتم مقارنه النتائج التي تم الحصول عليها مع الاساليب التحليلية، حيث اظهرت نتيجة هذه المقارنة مع الشبكة العصبية الصناعية نسبه خطا اقل من 3% ونسبه خطا اقل من 2% مع نتائج برنامج (SEEP/W) ونسبه خطا اكبر من 20% عند المقارنة مع طريقة (Dupuit) ونسبه خطأ اكبر من 30% عند المقارنة مع طريقة (Casagrande).

الكلمات الدالة: التسرب، السد الترابي المتجانس، التحليل البعدي، الشبكة العصبية الصناعية ANN، SEEP/W، Dupuit Casagrande.