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RESEARCH PAPER

Seepage through earthen dams under different dam geometries and conditions

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A B S T R A C T:

The study presents a method to carry out a new equation for the seepage rate of homogeneous earth fill dam with clay core using various geometry conditions. For this purpose the Slide 6.0 software has been used. The proposed program runs for (85) different geometrical cases of dam body to determine the seepage rate. The aim of the study is to examine the capabilities of slide 6.0 software in computing the rate of seepage and to find the impact of different structure geometry (e.g., upstream horizontal blanket length and thickness and, cutoff depth) on the reduction of the rate of seepage through the proposed earth dam.

Dimensional analysis is conducted using Buckingham π theorem to find the dependent and non-dependent variables. Artificial Neural Network (ANN) model is developed that relates the output variables with the input variables which govern the rate of the seepage through homogenous earth dam with clay core. The results are analyzed using SPSS software.

Three different heights of the dam, three different lengths of the upstream blanket with four different thickness of the blanket and four different cutoff depths with different conditions were used in this study and the results showed that the rate of the seepage decreased as the upstream blanket length, the cutoff depth and the thickness of the blanket are increased. Also, the impact of the upstream blanket length is greater than the cutoff depth and then the thickness of the blanket in decreasing the rate of seepage. While, the rate of the seepage were increased as the top width of the dam were decreased.

The seepage rate obtained by the Slide 6.0 program was compared with its quantity calculated from an empirical equation developed in this study. This relation has a determination coefficient of (R^2 = 0.8842).

KEY WORDS: Seepage; earth dam; Phi theorem; Slide software; Artificial Neural Network (ANN).
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1.INTRODUCTION

The seepage rate can be decreased by using materials with low hydraulic conductivity such as clay, setting cutoffs, and increase the length of the upstream blanket those can cause to increase the seepage path (Fattah et al., 2014). Most of the dam failure is due to seepage through earth dam, for this reason, it should be controlled to eliminate those effects by using sheet pile, upstream horizontal blanket, cutoff trench (Aboelela, 2016).

The seepage of flow through earth dams was studied numerically. Zomorodian and Abodollahzadeh, (2010) used SEEP/W software to investigate the effect of horizontal drains on upstream slope of earth fill dams during rapid drawdown conditions. Olonade et al., (2013) have employed to study seepage through Oba dam using finite element method. Hasani et al., (2013) reported seepage analysis in Ilam earth fill dam that was done using SEEP/W software. Jamel, (2016) used Casagrandi and Dupuits assumptions to estimate seepage through homogeneous earth dam without a filter. Çalamak et al.,(2016) investigated the suitability and the effectiveness of blanket and chimney drains in earth fill dams for various properties of the

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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.
In this study, the Slide 6.0 program was used with the helpful of dimensional analysis method and the statistics software program SPSS, for evaluating seepage rate through homogenous earth dams with clay core for different dam geometries and conditions to find out their impacts on the seepage rate. Artificial Neural Network (ANN) model was used to predict the rate of seepage through earth dams for different geometries and conditions.

2. MATERIALS AND METHODS

In this study, a dimensional analysis using Buckingham π theorem was applied to predict an empirical equation for determining the seepage quantity through the proposed homogenous earth dam with clay core as shown in Figure 1.

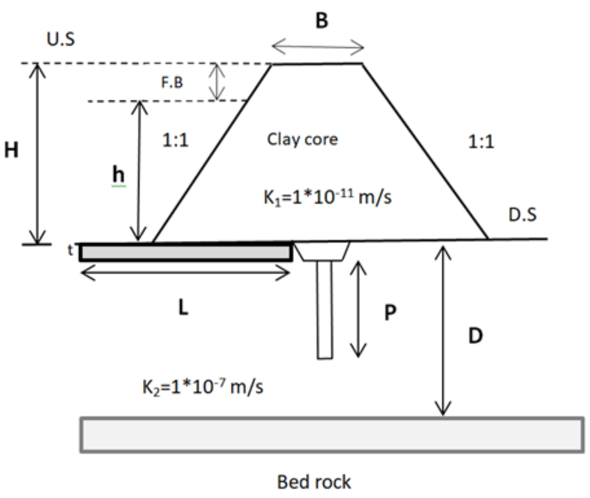

Figure 1: General section of homogenous earth dam with clay core.

The variables that might have an impact on the seepage rate are:
Q: rate of the seepage (L^3/T),
L: upstream length of the blanket (L),
P: cutoff depth (L),
H: dam height (L),
h: reservoir height (L),
t: blanket thickness (L),
B: top width (L), which was taken as a function of the height of the dam.
ρ: density of water (M/L^3), and
g: gravity acceleration(L/T^2).

B=5/3 $H^{0.5}$ ……………………………..... (1)

Q =f (L, P, t, B, h, H, ρ, g)…………..….. (2)

Using π theorem, the following dimensionless terms were carried out from equation (2)

$$\frac{Q}{g^{1/2}H^{5/2}} = f\left(\frac{L}{H}, \frac{P}{H}, \frac{t}{H}, \frac{B}{h}\right) \text{ …………… (3)}$$

An empirical equation of calculating the rate of seepage through earth dam with clay core was obtained using the dimensionless parameters of equation (3) with the SPSS program.

$$Yk = f\left[\sum_{j=1}^{m}\left(Wk_j fh(\sum_{i-1}^{n}(Wj, ixi) + bj)\right) + bk\right] \text{ ……………………………………….. (4)}$$

Where:

Yk: is the output, x: is the input variable, n: is the number of the input layer, and m: is the hidden layer.

The discharge quantities were computed for (85) various geometrical shapes and conditions of the dam, with a slope of 1:1 for both u/s and d/s are considered. Additionally, the hydraulic conductivity of the clay core and the foundation of the dam are considered to be 1x10^11, 1x10^7, and 7.5 x 10^7 m/s, respectively. The depth of the foundation soil (D) was considered to be 60 m.

3. RESULTS AND DISCUSSION

Using three to four different values for each of the dimensionless parameters in equation (3) that have impacts on the rate of the seepage, it concludes that the total runs applied in the Slide 6.0 program were 85 tests. These tests were repeated for three different dam heights (H) (20, 25 and 30 m, respectively). With two conditions first, the upstream blanket length (L) was considered to be constant and secondly, the cutoff depth (P) was considered to be constant.

The tests of each group were carried out with three different lengths of the upstream blanket (L) (0, 5 and 10 m), three different top width (B) as a function of the heights of the dam (7.45, 8.33 and 9.129 m) given in equation (1). Four different cutoff depths (P) (0, 5.10 and 20 m), and four different thickness of the blanket (0, 1, 1.5 and 2 m) were considered for testing of each group.
Figure 2-a, demonstrates a case in the slide 6.0 program, where L=0 m, P=0 m, H=20 m, h=18 m, t=0 m and B =7.45 m. Figure 2-b, illustrates the seepage rate in m^3/s through the Slide.6 program for the same case.

For each run in the Slide 6.0 program, the seepage rate (Q) was obtained and then the dimensionless parameters, given in equation (3), were computed and tabulated in a results table. From these results, the impact of each variable on the seepage rate through homogenous earth dams can be seen as the following:

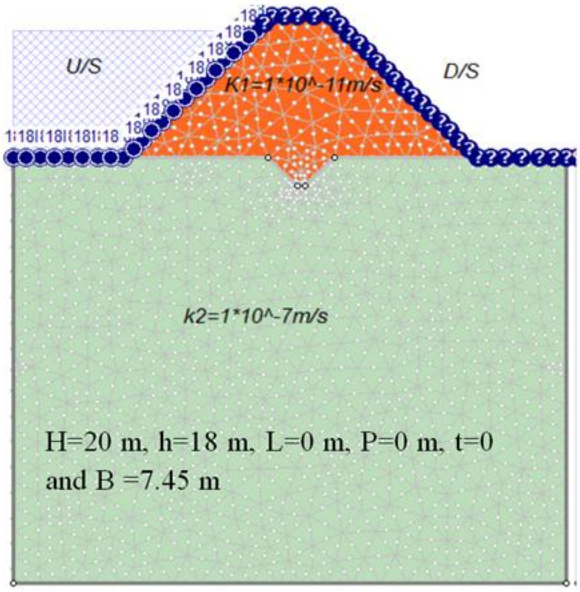

Figure 2-a: The geometrical shape of the earth using Slide program.

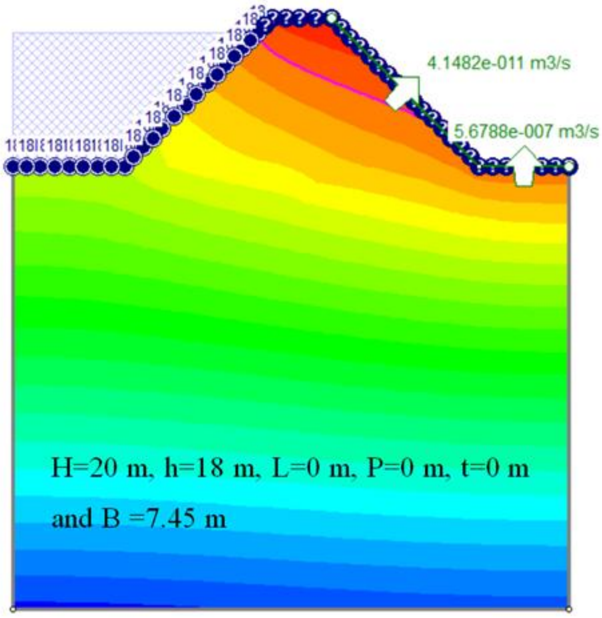

Figure 2-b: Seepage rate of the earth dam through Slide program.

3.1 Impact of the upstream blanket length (L).

Figure 3-a and Figure3-b illustrates the variation of the dimensionless parameter ($Q/g^{1/2}H^{5/2}$) with the dimensionless parameter (L/H) for some testing cases and for the condition where the height of the dam (H) and the cutoff depth (P) are constants and the upstream length of the blanket (L) is variable. From these figures, it can be seen that the rate of the seepage is decreased when the length of the blanket and the cutoff depth are increased if the other affecting parameters are constant. Also, the rates of the seepage increased as the height of the dam (H) are increased. It's worth to mention that all other cases and conditions were given the same results.

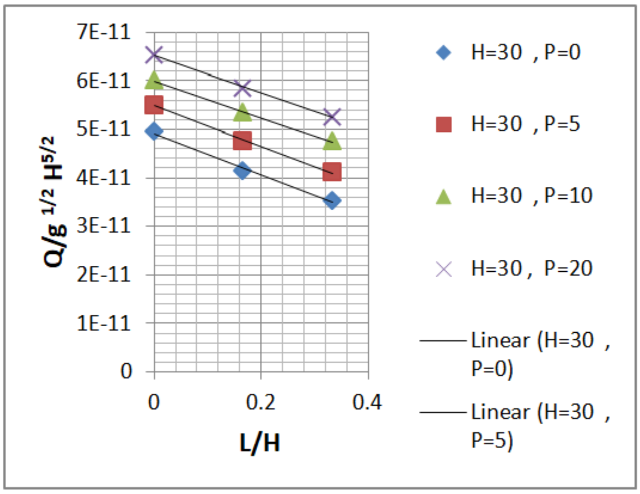

Figure 3-a: Relation of ($Q/g^{1/2} H^{5/2}$) with (L/H) for a constant height (H) of the earth dam.

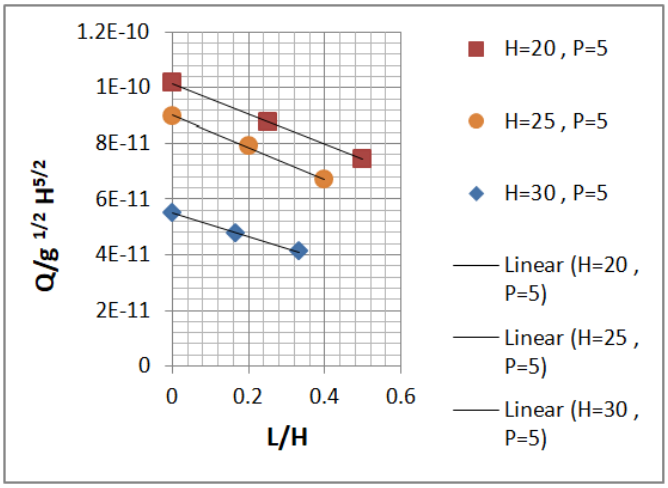

Figure3-b: Relation of ($Q/g^{1/2} H^{5/2}$) with (L/H) for different heights (H) of the earth dam.

3.2 Impact of the cutoff depth (P)

Figure 4-a and Figure 4-b represents the relation between ($Q/g^{1/2}H^{5/2}$) and (P/H) for some testing cases and a condition where the height of the dam (H) and the upstream length of the blanket (L) are constants and the cutoff depth (P) is variable.
From these figures it can be seen that, if the other affecting parameters are constant the rate of seepage will be decreased as the cutoff depths increased. As a comparison between the impacts of the upstream blanket length (L) and the cutoff depth (P). From the steep slopes of the lines in(Figure's 3-a and 3-b), it concludes that the impact of the upstream blanket length is more significant and greater than the impact of the cuttoff depth represented by the flat slopes of the lines in (Figures 4-a and 4-b). It's worth to mention that all other cases and conditions were given the same results.

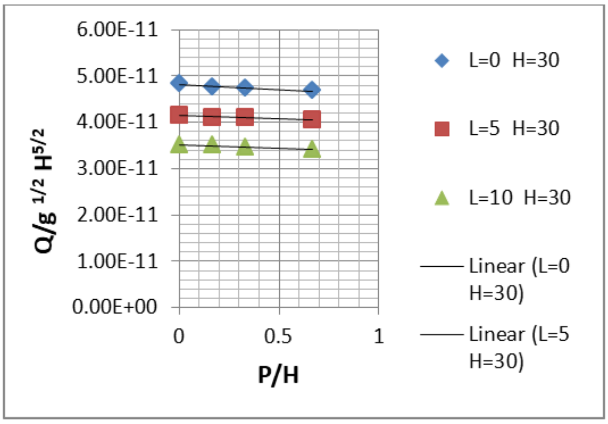

Figure 4-a: Relation of ($Q/g^{1/2} H^{5/2}$) with (P/H) for a constant height (H) of the earth dam.

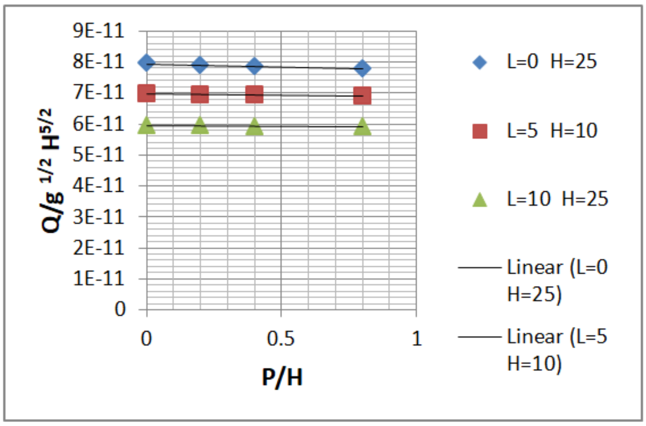

Figure 4-b: Relation of ($Q/g^{1/2} H^{5/2}$) with (P/H) for different heights (H) of the earth dam.

3.3 Impact of thickness of the upstream blanket (t)

Figure 5 shows the relation of the dimensionless parameter ($Q/g^{1/2}H^{5/2}$) with the dimensionless parameter (t/H) for some testing cases and for the conditions where the cutoff depth (P) or the upstream blanket depth (L) were constants. The figure concludes that the rate of the seepage is decreased when the thickness of the blanket (t) is increased if the other affecting parameters are constant. But still, the impact of the blanket thickness (t) is less than the impact of the upstream blanket length as explained in section (3.1) It's worth to mention that all other cases and conditions were given the same results.

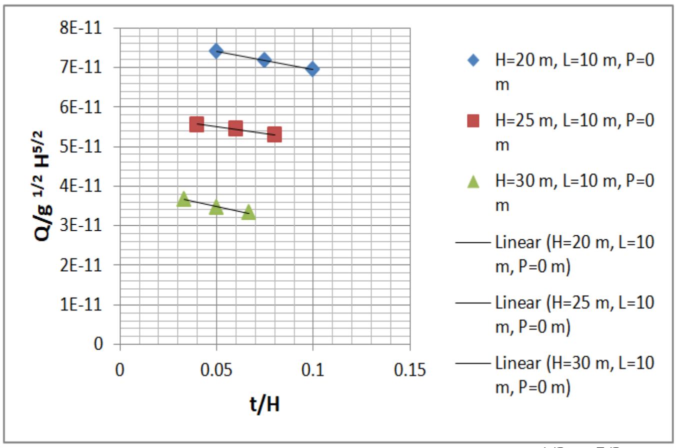

Figure 5: Relation of the parameter ($Q/g^{1/2} H^{5/2}$) with the parameter (t/H).

3.4 Impact of the top width (B).

Figure 6 shows the relation between the dimensionless parameter ($Q/g^{1/2}H^{5/2}$) with the dimensionless parameter (B/h), the figure concludes that the rate of seepage increased as the top width decreasing.

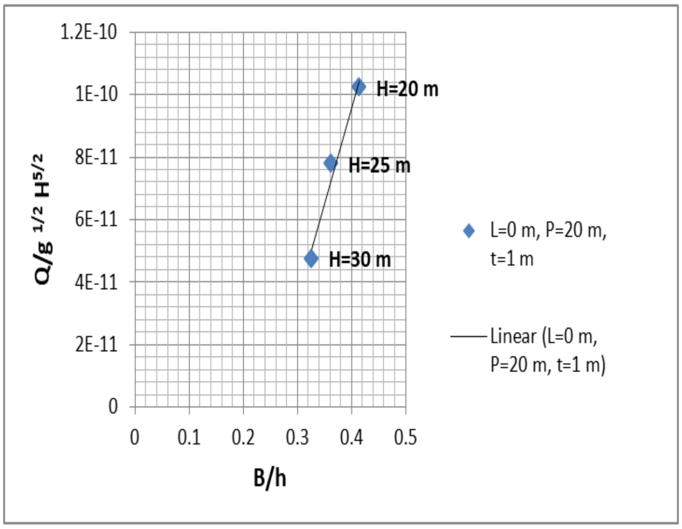

Figure 6: Relation of the parameter ($Q/g^{1/2} H^{5/2}$) with the parameter (B/h).

3.5 Artificial Neural Network (ANN) Model.

An empirical equation of calculating the rate of seepage through earth dam with clay core was obtained using the dimensionless parameters of equation (3) with the SPSS program as given in equation (4).

The database that has been created by using the Slide 6.0 program was employed to create the artificial neural network (ANN), model. The input variables were the most geometrical dimensions of the earth dam that has impacts on the rate of the seepage: as the height of the dam (H), the cutoff depth (P), the upstream blanket length (L), the blanket thickness (t) and the reservoir height (h) and the output variable was the rate of seepage(Q).

The base structure of this model was selected as (9-12-1) which is the most effective selected data set in agreement with results, which means among 85 data sets, 61% was for training and 17% were for testing. By trending the discharge values of both ANN and Slide 6.0 data in excel program SPSS, a new relation is obtained. Figure 7 shows the computed rate of the seepage by ANN and Slide 6.0 program. It is observed that the coefficient of determination (R^2) is about (0.8842), which is considered good.

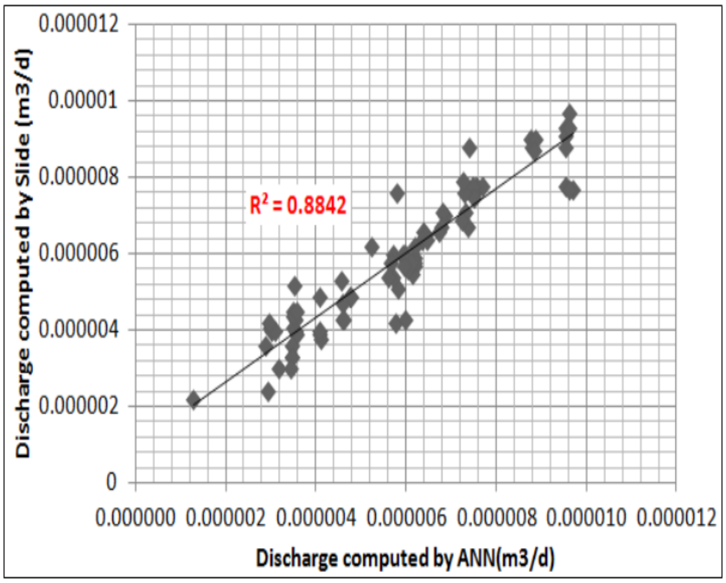

Figure 7: Rate of the seepage computed by ANN and Slide 6.0 program.

4. CONCLUSIONS

In the conducted research, the Slide 6.0 program used to estimate the rate of the seepage of homogeneous earth fill dam with clay core using various geometry conditions. The Slide 6.0 program shows very good performance in estimating the rate of the seepage. The result shows that the seepage quantity through homogenous earth dams decreased with increasing the upstream blanket length (L), the cutoff depth (P) and the thickness of the blanket (t). Also, the result shows that the length of the upstream blanket length (L) is the more affecting geometrical variable on the seepage rate. The seepage rate through the earth dam increased with the decreasing of the top width (B) of the dam. The comparison between the predicted results by (ANN) model and those computed from the Slide 6.0 program for the different geometries and conditions were very good.

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