Seepage through Earth Dam

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Abstract: Seepage through homogeneous and non-homogeneous earth dams includes saturated and un-saturated flow. Unsaturated flow usually is ignored in earth dam but It should be considered in order to compute the position of the water table and seepage face that may develop either on the downstream slope of the homogeneous earth dam or within the filter layer behind the core of a homogeneous earth. Different homogeneous earths with heights of 5, 10, 20, 30, 40, and 50 m have been analyzed numerically with a two-dimensional finite element code. A simplified method is presented to estimate the seepage rate through homogeneous earth dam with vertical drainage and by considering the saturated and unsaturated flow under steady-state conditions.

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1. Introduction

Seepage rate through the homogeneous or zoned earth dam includes saturated and unsaturated flow. Unsaturated flow which is often neglected, but here it is taken into account to obtain the water table and seepage rate through the homogeneous earth dam. When there is no seepage or concentrated flow through some hole, crack, or damaged zone, the total seepage rate through a dam includes seepage through the earth dam itself and seepage through the foundation. Each component can be predicted from the geometry of the water- retaining structure, the foundation materials, and the hydraulic characteristic of the earth dam and foundation. Sometimes the total seepage is measured by experiments and a full-scale test at the end of construction. However there are few methods available for predicting the seepage rate of dikes. In the case of homogeneous dams the following approximate method is frequently used. First, the position of the water table is predicted from the method of Casagrande. It is then assumed that this water table is a flow line. In fact, this is only a crude approximation. The water table is neither a flow line nor an equipotential, but simply a surface where the pore water pressure, u_w, is equal to the atmospheric pressure, p_{atm}, usually taken as the zero value for pressures. The seepage rate is then predicted by either graphical techniques in which the unsaturated flow is neglected or numerical codes that usually do not consider unsaturated flow. Such predictive methods simplify the problem and thus are inaccurate for estimating the flow rate, pore- water pressures, water table position and seepage-face position. This article represents the results of numerical experiment of seepage through the homogeneous earth with horizontal drainage at the toe (which has different shapes) by considering the unsaturated flow. In article seep/w numerical code solves the underground water problems for stable, un-stable, saturated and unsaturated conditions. Problems can be solved in either the vertical or horizontal plane, or for axisymmetric conditions around a vertical axis. In theory the number of nodes is not limited, but in practice most problems are solved with less than 2000 nodes. Seep/W provides a continuous solution between saturated and unsaturated zones. Each material is defined by its two characteristic functions. The function θ(uw) of volumetric water content, θ, versus negative and positive pore-water pressure, u_w, and the function of hydraulic conductivity k(uw) versus pore-water pressure . Where the pore-water pressure, u_w, is equal to the atmospheric pressure, p_{atm}, it is considered zero. Above equations and functions are mostly non-linear for unsaturated conditions. In this investigation the numerical the numerical analyses of the seepage rates through several dikes were done for steady-state conditions. The calculated solution account for saturated and unsaturated seepage conditions through dike. In general a numerical code can sometimes be incomplete or inaccurate within its range of capabilities. This software provides numerical investigation of total seepage, Q, for any dike having the hydraulic conductivity coefficient, K_{sat}, which includes saturated and unsaturated flow. The value of Q depends on K_{sat} and an equivalent section and an equivalent mid gradient. An estimation of an equivalent section can be obtained through the product of height (Δh) and width. We compute Δh/L equation in order to obtain an equivalent average gradient. So it will be a function of $\Delta h^2/L$. According to figure (1) Δh is the upstream water elevation, L is the measured horizontal distance between the nearest vertical drainage point and intersection point of upstream water elevation and upstream surface, Q is the discharge through the earth dam and K is the hydraulic conductivity coefficient of the earth dam.

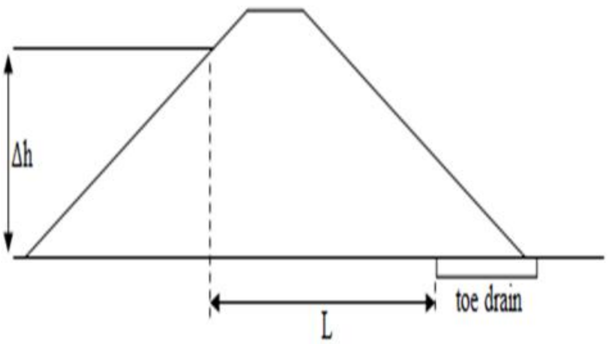

Figure 1, Homogenous earth dam profile

2. Materials and Methods

We have done studies by seep/w software about the saturated and unsaturated flow for the steady- state conditions at the downstream of the horizontal homogeneous earth dam. In this article by seep/w software we have computed seepage discharge through the dam for the two different cases of soil with different hydraulic conductivity coefficient, two slopes of 1/3 and 1/2 and heights of 5, 10, 20, 30, 40, 50 meters. Also we considered three different height of upstream water elevation and two different drainage length at the of these two earth dams. In general there have been 120 cases (Figure 2).

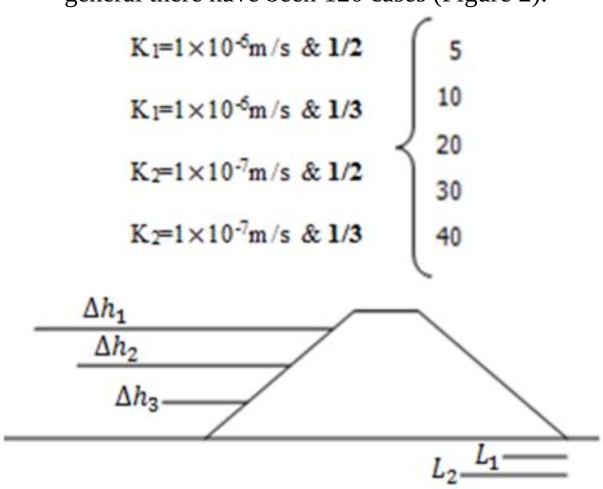

Figure 2, Studied dams parameters

Whereas unsaturated seepage is required for all of these cases so we need the function of hydraulic conductivity pressure. The software itself has the hydraulic conductivity pressure functions and detention coefficient for the 24 soil cases. These functions were obtained by lab experiments. Also these functions can be changed or reformed. Figure 3 represents the hydraulic coefficient functions which have been investigated. By providing the seepage discharge 120 cases by seep/w software and having the k_{sat}, upstream water elevation (Δh), horizontal distance of phreatic surface (L), we compute the Δh^2 /L and Q/K_{sat} for each case. According to the figures 3 and 4 by allocating the X axis to Δh^2/L and Y axis to Q/K_{sat}, the graph for dams with different heights can be gained.

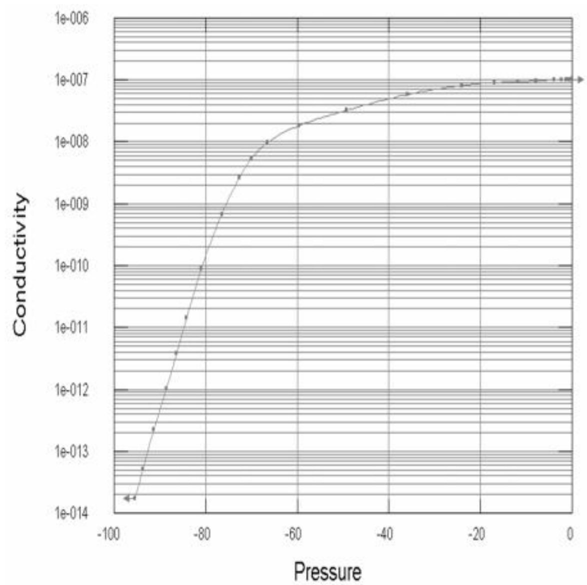

Figure 3, Function of permeability coefficient

3. Discussion and Results

By trending of these points in excel software it is observed that Q/K_{sat}, is a second order function of Δh^2 /L. Because there is not practically a discharge for Δh=0 through the dam, we extend the trending equation from original of coordinate (0,0) point (Figure 5). So by computing the Δh and L, saturated hydraulic conductivity coefficient of dam we can get a suitable estimation of seepage discharge through the earth dam. But regarding the interval high length (Δh^2/L), there is large possibility of error. So we divided the interval into five parts and compute the relating equations for five different intervals of (Δh^2/L). Whereas R^2 is the correlation coefficient and has the value equal to 0.9892 represent the high accuracy of the regression done and also shows the high accuracy of the offered equation.

At least the general equation is as follow:

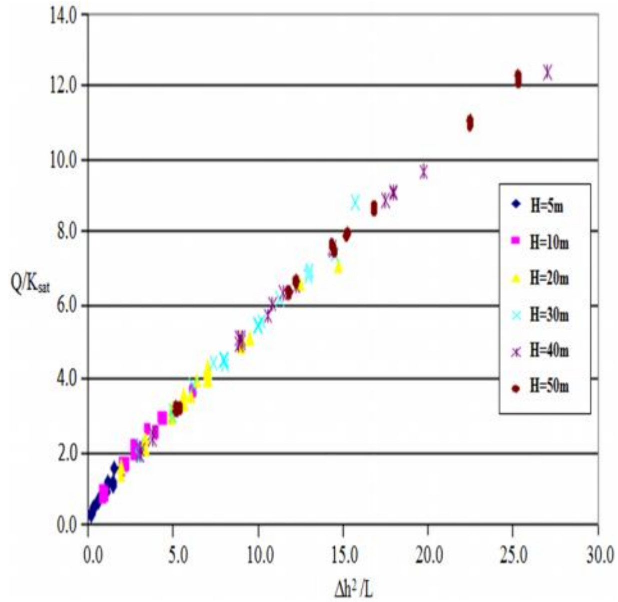

Figure 4, Different dam profiles according to $\Delta h^2/L$ and Q/K_{sat}

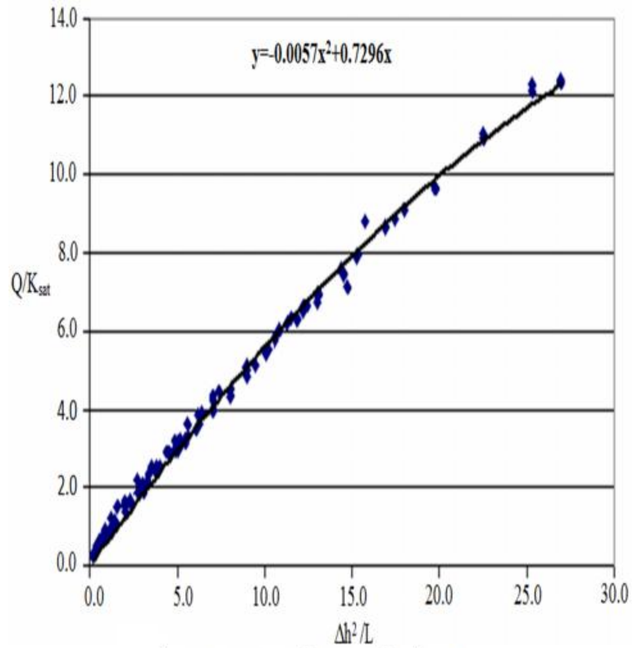

Figure 5, The second order quadratic equation for all of the points

$$\frac{Q}{K_{sat}} = \alpha_1 \left(\frac{\Delta h^2}{L}\right) + \alpha_2 \left(\frac{\Delta h^2}{L}\right)^2 \qquad (1)$$

$\Delta h^2/L$	α_1	α_2
0.2-2	1.1296	-0.2208
2-4	0.8904	-0.0628
4-8	0.6917	-0.0184
8-18	0.6041	-0.0062
18-30	0.5947	-0.0054

Experiments have done to check the reliability of this equation for the different permeability coefficients, different slopes and different drainage length. In the result these equations were accepted. In this article a 2D finite element was used to study conditions of saturated and unsaturated seepage through homogeneous earth dams. Solutions were proposed to solve numerically two difficulties related to the representation of saturated and unsaturated physical flow conditions. Earth dams of different heights (5-50m) were analyzed. When the unsaturated seepage is taken into account, the findings were as follow:

1. Seepage discharge through the earth dam is more than approximate manual computed methods ratio because of the ignoring the unsaturated flow.

2. Seepage water table situation in homogeneous dams is higher than the manual computed method situation.

Numerical codes are the most complete solution for the saturated and unsaturated flow problems. Also it provides complete data about negative or positive pore water pressure. According to the numerical analyses an equation is proposed to estimate the seepage rate through the earth dam as a function dike case, dike geometry and saturated hydraulic conductivity of dike. This equation includes the seepage rate through the earth foundation. Considering research has a limit domain and parameters of the regarding equation were taken from an infinite geometry. Researchers who may use this equation should be aware of its limitation and they should do all of the tests to make guarantee that this equation is reliable for a special project. The superiority of this equation is that it provides a fast estimation of the total seepage through the different earth dams which it may be notified in a practical research. At least it is offered that equations can be obtained to estimate the seepage rate through the homogeneous earth having drainage at the toe and cored earth dams.

4. Conclusion

Chapuis in his studies has divided $\Delta h^2/L$ into two intervals. Whereas the value of $\Delta h^2/L$ was large so there was a possibility of error in equation. But in this article by dividing $\Delta h^2/L$ into 5 intervals and computing different coefficient in the equation it is possible to reduce the possibility of error and find an accurate response. Comparison between the Chapuis equation and equation of this article was done by the real values. It was found out that reduce of interval length leads into obtaining more acceptable results.

The main conclusion of this research can be summarized as following:

- A simple equation is used to estimate the total seepage ratio (saturated-unsaturated).
- The seepage flow rate depends on earth dam permeability coefficient (K), downstream and upstream slopes and the total head (H) parameters.
- Seepage discharge through the earth dam is more than approximate manual computed methods ratio because of the ignoring the un-saturated flow.
- The rate of seepage discharge increase through the earth dam with the increase of downstream slope amplitude angle.

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