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# **Seepage Estimation through Earth Dams**

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### ABSTRACT

This paper presents the physical and geometric factors of earth dam such as permeability, upstream and downstream slope of the damto analysis of saturated-unsaturated seepage problem. The seepage rate through homogeneous earth includes saturated and unsaturated flow. The latter is often neglected but should be considered to obtain the positions of the water table and the seepage face that may develop either on the downstream slope of a 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 50m have been analyzed numerically with a two-dimensional finite element code. The cases investigated include the most frequent types of homogeneous earthdesigned to retain municipal or industrial wastewater. Solutions are proposed to solve numerically two difficulties related to the representation of saturated and unsaturated physical flow conditions. One difficulty is treating a downstream seepage face. The other is treating the passage of water from the core into a draining layer. The paper presents simple expressions to predict the total (saturated and unsaturated) seepage flow rate through a homogeneous earth and discusses precautions to be taken. A simplified method to estimate seepage through earth dams under steady-state conditions also presented.

KEY WORDS: Seepage, Earth Dam, Saturated Soil, Unsaturated Soil, Steady-State.

# **1 INTRODUCTION**

Water flow through the dam is one of the basic problems for geotechnical engineers. This paper presents simple expressions to predict the total (saturated and unsaturated) seepage flow rate through a homogeneous embankment and discusses precautions to be taken. The physical and geometric factors of dam such as permeability, upstream and downstream slope of the dam slop (amplitude) are considered. 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 (drawing of flow net) in which the unsaturated flow is neglected (e.g., Cedergren 1997) or numerical codes that usually do not consider unsaturated flow (e.g., MODFLOW). Such predictive methods simplify the problem and thus are inaccurate for estimating the flow rate, pore-water pressures, watertable position, and seepage-face position. In general seepage problem, hill is a consistent environment which has infinite continuous pores. Any type of dams and earths, although were built by drillingmaterials or rarely impermeable artificial materials will experience the seepage. So the seepage is inevitable and to optimize the discharge we should do the exact computation of seepage (compute the seepage exactly). Seepage computation has an effective influence in stability of earth dams and exact estimation of it causes the operation cost reduction. Providing of simple and suitable methodto solve the seepage problems through the earth dams and exact estimation of discharge ratio is the main purpose of this article. It is represented a method to provide this purpose and present a suitable way which can estimate the discharge ratio through the earth dam satisfactorily. The Seep/W (geo-slope 1999)computer software can be used to estimate the seepage. Nomirov researched on the water seepage control through the isotropic-homogenous earth dams and represented a suitable method to solve the seepage problem through the earth dam. Nomirov used the advanced mathematical relations to compute the characteristics of seepage in the isotropic dam profile which has a downstream horizontal drainage. But Nomirov's method has defects and errors which were used in his equations. In this article, Seep/W software is used to analyze the foundation and body seepage. Aubertin et al. (1996) used this software to solve the unsaturated problems of multi-layer covers is infinite aquifer pumping test. This software solves the underground water problems for stable, un-stable, saturated and un-saturated conditions. Chapuis et al. (2002) researched on estimation of seepage discharge ratio through the embankment dams. It can be gained good results by using the Seep/W software. This software not only has the superiority to the graphic method and manual calculation, but also regarding the time we can gain good results. This software has many applications which helps designers in best designing of dams and analyzing the weak or strength points of dams and also designing of the construction which dealing with the seepage problems.

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#### **2Geometry and Hydraulic Parameters**

The following parameters are defined for a homogeneous earth dam and will be used to generalize the results in terms of flow rate per linear meter of dam (Figure 1): $\Delta h$  is the difference in hydraulic head between the reservoir and the downstream toe of the earth dam; and L is the distance measured horizontally between the water in the reservoir and either the downstream toe of the damor the nearest point of the toe drain (either horizontal or triangular). The function of conductivity against to the pressure is shown in Figure 2. The selection of dam dimensions and material is not done independently, but all of them are relating to each other. The ratio of existing materials, slope of the alley, economy, volume of the reservoir and etc are the effective factors in this selection. Also the change domains of some parameters are clear. For example because of the stability problems and difficulties the slopes wouldn't be more than the specified limit, therefore random variable domain is as follow:

*K*: Earth dam permeability coefficient

S: Two slopes (upstream and downstream) of earth dam

H: The total head

 $\Delta h$ : Total head difference

Q: Seepage flow rate through a earth dam

*L*: The distance measured horizontally between the water in the reservoir and either the downstream toe of the dam.



Figure 2. Curve of hydraulic conductivity K.

#### **3 ANALYSES**

In this research for each homogeneous earth dam of hydraulic conductivity  $k_{sat}$ , the numerical analysis provides the total seepage rate, Q, including both saturated and unsaturated flow. After computing the seepage discharge for 120 earth dams by Seep/W software and having the saturated hydraulicconductivity  $(k_{sat})_{A}$  and L,

so we compute the  $\Delta h^2/L$  and  $Q/K_{sat}$  for each case and according to the figures 3 and 4 by allocating the X axis to  $\Delta h^2/L$  and Y axis to  $Q/K_{sat}$ , the graph for dams with different highs can be gained. By trending of these points in excel software it is observed that  $Q/K_{sat}$  is a second order function of  $\Delta h^2/L$ . Because there is not practically a discharge for  $\Delta h=0$  through the dam, we extend the trending equation from original of coordinate (0,0) point.Regarding the different variables, multiple regression method, which a dependant variable value is computed according to some independent variable values, is used. In the condition that  $n=k_y/k_x=1$ , different tests (experiments) is done on the sample case to obtain the best curve covering sample case. So by computing the  $\Delta h$  and L, saturated hydraulic conductivitycoefficient of dam we can get a suitable estimation of seepage discharge through the earth dam. But regarding the interval high length  $(\Delta h^2/L)$ , there is large possibility of error. So we divided the interval into five parts and compute the relating equations.



Figure 4. Homogenous earth dam: results for dams with heights of 5-20 m.



Figure 5. Homogenous earth dam: results for dams with heights of 5 m.

#### **4** General Equation

A compilation of the numerical results indicates that the total seepage flow rate, Q (in m<sup>3</sup>/sec. per linear meter), can be correlated to the geometric ratio  $\Delta h^2/L$  by the following approximate equation:

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

$\Delta h^2/L$	$\alpha_1$	$\alpha_2$
0.2-2	1.1317	-0.2166
2-4	0.8763	-0.0641
4-8	0.6861	-0.0141
8-18	0.5982	-0.0051
18-30	0.5851	-0.0044

**Table 1.**Parameters  $\alpha_i$  for a homogeneous dike as a function of  $\Delta h^2/L$ .

The represented equation is simply a best-fit correlation providing Q=0 for  $\Delta h=0$ . In represented equation, parameters  $\alpha_j$  depend on the range of  $\Delta h^2/L$  values, as indicated in Figures 3, 5, and 5 for earth dam heights up to 5, 10, 20, 30, 40 and 50 m, respectively. The corresponding values of parameters are given in Table 1. Whereas  $R^2$  is the correlation coefficient and has the value equal to 0.9945 represent the high accuracy of the regression done and also shows the high accuracy of the offered equation.

#### **5** Conclusion

In this article a 2D finite element method 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. The numerical results illustrate that the complete solution of a saturated and unsaturated flow problem provides better information relative to positive and negative pore-water pressures. This will also allow a better evaluation of any mechanical problem (deformation analysis, stability analysis). One of these difficulties is how to treat a downstream seepage face. The other difficulty relates to the passage of water from the core into a downstream-sloping drain layer. Earth dams of different heights (5–50m) were analyzed. 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 ratedepends 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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