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EXTENDED ABSTRACT

Modeling Seepage in Porous Media Using an Unstructured Triangular Finite Volume Algorithm

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Introduction

The explorers consider the study of water flow in saturated and unsaturated soils to determine the seepage, pore pressure, uplift force, and hydraulic gradient in the design of dams. Numerical simulation is a rapid low-cost method for the study of soil water flow, which has recently been increased. Many investigators have described approximate methods, based on Dupuit assumptions, to locate the surface of seepage and seepage discharge for different tailwater positions. In order to reduce the seepage discharge and, consequently, flow energy reduction passing the dam, various actions such as the construction of clay core, trench and grout certain, and clay cover on the reservoir floor have been considered. Despite all the measures taken to prevent the movement of water in the embankment dam, water always penetrates the downstream parts due to the permeability of the materials. Drainage systems are designed to collect and direct seepage of water to downstream areas, keeping the dam's riffle slope dry to decrease the hydroscopic pressure and increase the stability of the embankment dams. Horizontal drains are widely used in homogeneous embankment dams with an average height. In this study, Richards equation was desecrated in two-dimensional and unsteady conditions using an unstructured triangular finite volume algorithm and a computer model developed to simulate seepage in saturated-unsaturated soils. In this model, Van Genuchten equation or other functions can be used to calculate hydraulic conductivity in unsaturated soil for the simulation of flow.

Methodology

In this study, the applied form of the continuity equations and the momentum conservation of flow in porous media are shown in Eqs. (1 – 3) (Richards, 1931). It should be noted that due to the insignificant velocity changes relative to the time and the assumption of the hydrostatic pressure distribution, the momentum equation in porous media is converted into the Darcy law.

$$\frac{\partial \theta}{\partial t} + \nabla . \vec{V} = 0 \tag{1}$$

$$u = -k_x \frac{\partial h}{\partial x} \tag{2}$$

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$$v = -k_y \frac{\partial h}{\partial y} \tag{3}$$

where $\nabla . \vec{V}$ is the gradient of velocity, u and v are the velocity in x and y directions, respectively, θ is the volume of moisture, h is the total potential including gravity and pressure load, and k_x and k_y are the hydraulic conductivity of the soil in x and y directions.

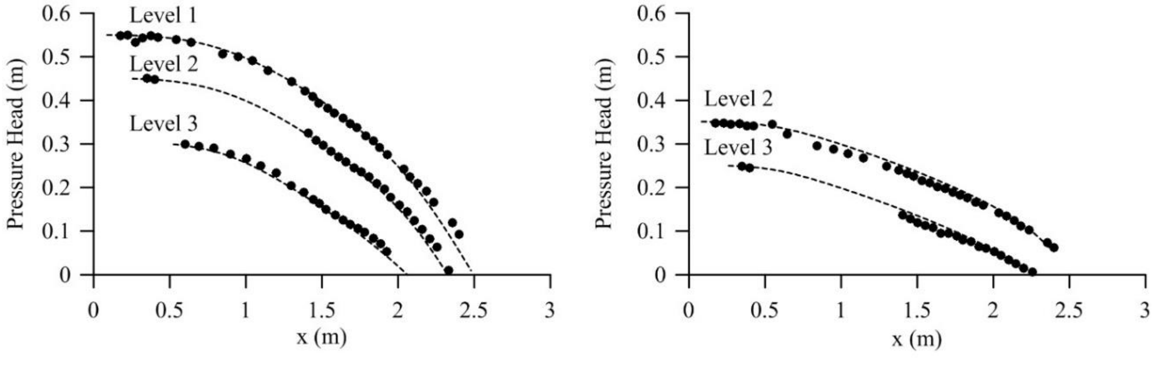
Choosing the meshing type is the first step in dividing the governing equations on the movement of water in the soil. The numerical simulation range can be categorized using regular rectangular meshing or irregular triangular meshing. If the range of irregularity solution is complex, then the irregular triangular meshing is more appropriate to be used. In this study, the computational loops are located at the intersection of the sides of the triangle, and a polygon is produced by the distances between each loop as the control volume. The discrete of the continuity and momentum equations with a combination of explicit and implicit methods is converted to Eq. (4):

$$f(\psi_i^n) A_i \left(h_i^{n+1} - h_i^n\right) = \Delta t \sum_{j=1}^{j=m} \left[\left(\frac{k_r \Delta S_i}{\Delta r_i} \right)_j \left[(1-\phi)\left(h_j^n - h_i^n\right) + \phi\left(h_j^{n+1} - h_i^{n+1}\right) \right] \right] \tag{4}$$

In the above equation, Φ is a weighted variable between zero and one, which expresses the explicit and implicit numerical scheme. If one is chosen, it is the implicit scheme and if zero is chosen, the solution scheme is explicit. The obtained system of equations is solved by the Gauss-Seidel method, and the values of pressure or matrix potential are obtained at the center of each control volume.

Results and Discussion

To verify the numerical model, Ahmadi et al. (2014) and Varjavand et al.'s (2008) experimental data were used. The experimental model in Ahmadi et al. (2014) consisted of a homogeneous embankment dam with a height of 70 cm, a slope of 1 to 1/7 (vertical to horizontal) and a 20 cm crown length. In order to investigate the seepage line and hydroscopic pressure in the dam's body, 80 piezometers were used in three rows at 5, 15 and 30 cm from the bottom. Executing the numerical model, the amount of pressure in different points was calculated and compared with the experimental model. Fig. (1). Shows the upstream values of observational and computational water pressure at different levels for water depths of 40 and 60 cm.



a) 60 cm height of upstream water level b) 40 cm height of upstream water level

Fig. 1- The observational and computational pressure in piezometers for different water levels in the reservoir

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The maximum and average errors in calculating the pressure of piezometers were 3.1% and 1.5% respectively, which is an appropriate precision for the numerical model.

The average error of the numerical model in calculating pressure in confined and unconfined flow were 1.1 and 1.5 percent, respectively, and the average error in calculating seepage in the unconfined flow was 5.6 percent, which is sufficient for the numerical model. One of the most important issues in controlling the stability of earth dams in rapid drawdown conditions is the amount of pore pressure and leakage force. The average error of the numerical model in calculating pore pressure in unsteady condition was 5.6 percent. The pore pressure distribution in the upper part of dams was non-hydrostatic, and the error of the numerical model in the upper part was higher than the bottom sections.

Conclusions

In order to simulate two-dimensional water flow in porous media, a computer model was prepared via control volume method using irregular triangular mesh. The method of dividing the continuity and momentum equations was implicit and explicit, the obtained system of equations was solved by the Gauss-Seidel method, and the values of the pressure or matrix potential were obtained at the center of each control volume. The numerical model developed in this study can calculate the pressure of each loop, the hydraulic gradient, the amount and direction of the flow velocity, the flow discharges, the amount of force each section underwent, and the seepage line in steady and unsteady conditions. The verification results indicate that the average calculation errors in the pressure of the piezometers in confined and unconfined flow are 1.1 and 1.5 percent, respectively, and the average error in calculating seepage in the unconfined flow is 5.6 percent, which is sufficient for the numerical model. Therefore, the numerical model can calculate the seepage pressure and discharge rate with very good accuracy.

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