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Flow under retaining structures: a new application of network method.

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Steady state groundwater flow under concrete dams, weirs founded and cofferdams on non-homogeneous, anisotropic and permeable soils, is governed by Laplace equation in terms of the total head (or piezometric level) variable. In these scenarios, water flow and pore pressure changes adjust very rapidly and the steady state conditions are instantaneously performed.

In most cases, analytical complex solution is formed by mathematical series of slow convergence. As an alternative, civil engineers make used of graphical solutions based on the so called flow net construction. The main unknowns of interest reached are the steady state seepage loss, the upthrust on the base of the dam and the maximum exit hydraulic gradient. Standard commercial codes can also be used for the numerical solution.

The present work investigates a model, based on network method and seepage theory, capable of solving these problems with sufficient accuracy and negligible computing time, using a standard circuit simulation code such as Pspice [1]. Network method is a numerical tool widely used for the solution of non-lineal, coupled or uncoupled problems, in many engineering fields such as heat transfer, tribology, corrosion, elastostatic and vibrations [1, 2,3]. For the first time, it is applied in the field of geosciences, particularly to groundwater. The basic problem-scheme is presented in Figure 1.

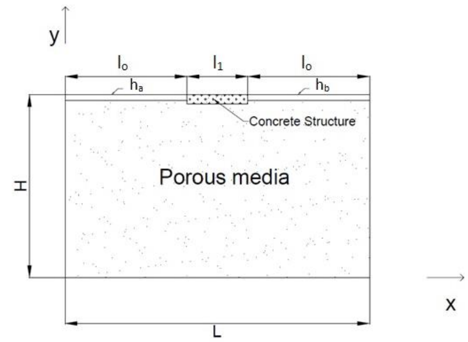


Figure 1. Scheme of the problem

Governing equation and boundary conditions are:

$$k_x \frac{\partial^2 h}{\partial x^2} + k_y \frac{\partial^2 h}{\partial y^2} = 0 \qquad (1)$$

$$y=H, \quad 0<x<l_0 \quad \rightarrow \quad h=h_0 \qquad (2a)$$

$$y=H, \quad l_0 \le x \le l_1 \quad \rightarrow \quad \frac{\partial h}{\partial y} = 0 \qquad (2b)$$

$$y=H, \quad l_0 + l_1 \le x \le L, \quad \rightarrow \quad h=h_0 \qquad (2c)$$

$$x=0, y \quad \text{and} \quad x=L, y \quad \rightarrow \quad \frac{\partial h}{\partial x} = 0 \qquad (2d)$$

$$y=0, x \quad \rightarrow \quad \frac{\partial h}{\partial y} = 0 \qquad (2e)$$

where k_x and k_y are the horizontal and vertical permeability, respectively, and h the piezometric level; h_a and h_b denotes the values of Dirichlet conditions applied to the left and right sides of the dam. The use of the streamfunction variable (ψ), defined as

$$v_x = \frac{\partial \psi}{\partial y} \quad \text{and} \quad v_y = -\frac{\partial \psi}{\partial x} \quad , \tag{3}$$

allows to re-formulated the problem in the form

$$\frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} = 0 \tag{4}$$

$$y=H,\ \ 0<x<l_0 \ \text{ and } \ l_0+l_1 \le x \le L \quad \rightarrow \quad \frac{\partial \psi}{\partial x} = 0 \tag{5a}$$

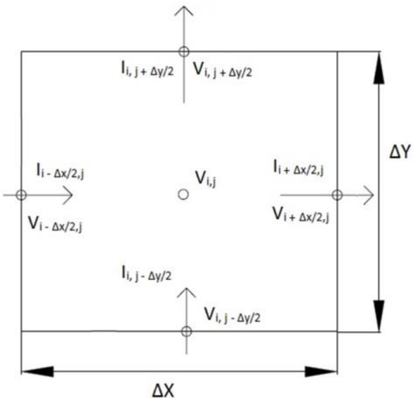
$$y=H,\ \ l_0 \le x \le l_1 \quad \rightarrow \quad \psi = \psi_0 \tag{5b}$$

$$x=0, y, \quad x=L, y \quad \text{and} \quad y=0, x \quad \rightarrow \quad \psi = \psi_1 \tag{5b}$$

The solution of (1) and (2), the scalar function h(x,y), provides the iso-h lines while that of (3) and (4) provides the iso-ψ lines or path lines of water particles.

Network model is based on the electro-hydraulic analogy that set a formal equivalence between piezometric level (in the real process) and electric potential (in the network model) variables. When designing the model for a typical cell or volume element, equation (1) is re-written in finite difference form. Each of equation terms is assumed as an electric current which is balanced with the others at the center of the cell (figure 2). In the network model each cell is formed by four resistors. Coupling successive cells by ideal electric contacts and adding the boundary conditions by simple electric components, the complete model is simulated in the Pspice code. Network model for the ψ variable is developed in the same way, with minor changes in the boundary conditions.

Figure 2. Network model



Two applications of the proposed model are studied to seepage problems: permeable isotropic soil with Dirichlet conditions and anisotropic soil with time-dependent boundary conditions, under concrete dam in both cases.

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