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EXTENDED ABSTRACT

Assessing the Equivalent Hydraulic Conductivity of Rockfill Dam in Vertical and Horizontal Arrangements

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Introduction

Rockfill dams are considered as detention structures, used to control floods. Due to rocks' size and large pores in between, Darcy's law is invalid in these dams.
Many studies have been conducted to investigate the non-linear flow in homogenous coarse porous media. Wilkins (1955), Ahmed and Sonada (1969), and Stephenson (1979) tried to introduce appropriate coefficients of the non-linear flow equation. Other studies have been also conducted to investigate the flow in heterogeneous rockfill structures, such as Hosseini and Joy (2007), introducing a one-dimensional model for non-linear flow in homogenous and heterogeneous coarse porous media. Realizing the importance of layered rockfill dams and the few conducted studies in this field, flow through layered rockfill dam, and horizontal and vertical arrangement of layers have been modeled in the current study. In this regard, a two-dimensional numerical model solving the governing equations by finite volume method has been developed.

Principles and methodology

In order to investigate the developed model, experimental data were collected.

Experiments

The experiments were carried out in a plexiglass flume, 30cm flume width, 50cm height, and 10m length, in the hydraulic laboratory of Tarbiat Modares University. Different experiments with different layer arrangements were conducted. In each experiment, upstream and downstream depths and discharge flow were measured. The characteristics of the conducted physical models have been shown in tables (1) and (2) for horizontal and vertical arrangements, respectively.

Table 1- Characteristics of the designed horizontal two-layered dam

parameter	Length (m)	Width (m)	Height (m)	Rocks diameter (m)	Ratio of low layer to dam height	Ratio of downstream to Upstream
Range of changes	0.8	0.3	0.2,0.32,0.4	0.02-0.1*	0.33,0.5,0.75،	0.25,0.4,0.6

Table 2- Characteristics of the designed vertical two-layered dam

Parameter	Length (m)	Width (m)	Height (m)	Rocks diameter (m)	Ratio of first layer length to dam length	Ratio of downstream to upstream
Range of changes	0.68,0.76,0.90,1.04,1.32	0.3	0.4	0.02-0.1*	0.1, 0.3, 0.5 0.7, 0.9	0.2, 0.4, 0.6

Numerical Model

In porous media, the continuity equation in the steady-state condition is as follows:

$$\left(\frac{\partial u}{\partial x}.\Delta x\right)\Delta y+\left(\frac{\partial V}{\partial y}.\Delta y\right)\Delta x=0 \quad (1)$$

In which, u and v are flow velocity components in horizontal and vertical directions, respectively. To solve equation (1) using the finite volume method, the equation should be discretized. Considering the abcd control volume (figure (1)), grids N, W, S, E surrounded grid P. Integrating equation (1) using the control volume of the figure (1), replacing flow velocities from non-linear equations, and applying some mathematical manipulations, the two-dimensional flow equation through coarse porous media will be obtained:

$$H_{(i,j)}=\frac{A_E H_{(i+1,j)}+A_W H_{(i-1,j)}+A_S H_{(i,j+1)}+A_N H_{N(i,j-1)}}{A_E+A_W+A_S+A_N} \quad (2)$$

$$A_{E=}\alpha'\,\frac{\Delta y}{\Delta x}\left(\frac{H_{(i,j)}-H_{(i+1,j)}}{\Delta x}\right)^{\beta-1} \quad (3)$$

$$A_{W=}\ \alpha\,\frac{\Delta y}{\Delta x}\left(\frac{H_{(i-1,j)}-H_{(i,j)}}{\Delta x}\right)^{\beta-1'} \quad (4)$$

$$A_{S=}\alpha'\,\frac{\Delta x}{\Delta y}\left(\frac{H_{(i,j)}-H_{(i,j+1)}}{\Delta y}\right)^{\beta-1} \quad (5)$$

$$A_{N=}\alpha'\,\frac{\Delta x}{\Delta y}\left(\frac{H_{(i-1,j)}-H_{(i,j)}}{\Delta y}\right)^{\beta-1} \quad (6)$$

where H is the hydraulic head of each node. Therefore, by applying the boundary conditions and solving the obtained equations for all the domain grid points, the hydraulic head of each grid point will be obtained.

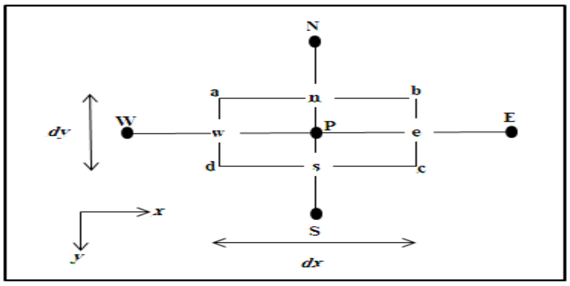

Fig 1- Two-dimensional control volume

Discussion and analysis

Analyzing thehorizontal two-layered dam

In order to analyze the results, the effect of layers' thickness with various hydraulic conductivity and the effect of downstream depth on equivalent hydraulic conductivity are separately investigated.

The effect of layers' thickness with various hydraulic conductivity on an equivalent hydraulic conductivity in a dam with horizontal layers

In order to investigate the effect of layers' thickness with various hydraulic conductivity, the ratio of equivalent hydraulic conductivity to the summation of layers hydraulic conductivity $\left(\frac{\alpha_{eq}}{\alpha_1+\alpha_2}\right)$ has been sketched versus the ratio of lower layer hydraulic conductivity to the upper layer one $\left(\frac{\alpha_1}{\alpha_2}\right)$. What is concluded from the figure is that by increasing $\frac{\alpha_1}{\alpha_2}$, the equivalent hydraulic conductivity is also increased.

The effect of the downstream water level on hydraulic conductivity

In order to investigate the effect of downstream water level on equivalent hydraulic conductivity, $\left(\frac{\alpha_{eq}}{\alpha_1+\alpha_2}\right)$ versus $\frac{\alpha_1}{\alpha_2}$ are sketched for ratios 0.4 and 0.6 of downstream depth to upstream, respectively. Increasing the ratio of lower layer hydraulic conductivity to the upper one increases the equivalent hydraulic conductivity.

Vertical two-layered dam

Also, for the vertical arrangement of layers, same as the horizontal one, for different lengths and different rock sizes in each layer, the passing discharge of each vertical two-layered dam was calculated using the numerical model.

The Effect of layers' length on the equivalent hydraulic conductivity

In order to investigate the effect of layers' length on the equivalent hydraulic conductivity, for $\frac{H_{DW}}{H_{UP}} = 0.2$ and for different ratios of $\left(\frac{L_1}{L_{Total}}\right)$, the value of $\frac{\alpha_{eq}}{\alpha_1+\alpha_2}$ versus $\left(\frac{\alpha_1}{\alpha_2}\right)$ has been illustrated. It has been seen that in a vertically layered dam, unlike the horizontal one, increasing $\frac{\alpha_1}{\alpha_2}$ doesn't always increase $\frac{\alpha_{eq}}{\alpha_1+\alpha_2}$.

The effect of the downstream water level on the hydraulic conductivity

In order to observe the effect of downstream water level on the equivalent hydraulic conductivity in a vertical two-layered dam case, for $\frac{H_{DW}}{H_{UP}} = 0.4$ and $\frac{H_{DW}}{H_{UP}} = 0.6$, and also, for different ratios of $\frac{L_1}{L_2}$, the value of $\frac{\alpha_{eq}}{\alpha_1+\alpha_2}$ versus $\frac{\alpha_1}{\alpha_2}$ has been investigated. It has been seen that lengthening the coarser layer causes the equivalent hydraulic conductivity to increase. Moreover, with increasing the ratio of $\frac{H_{DW}}{H_{UP}}$, the difference of hydraulic conductivity in various ratios of $\frac{L_1}{L_2}$ will be raised.

Conclusion

Horizontal multi-layered and vertical multi-layered dams were investigated in the current study. Given the results of the study, it turned out that in the horizontal two-layered dam, the lower layer plays a bigger role in passing the discharge flow by affecting the equivalent hydraulic conductivity. Increasing the downstream water level also increases hydraulic conductivity in these dams. In case of the vertical two-layered dam, the investigations also show that the order of small and large layers' arrangement doesn't have a significant effect on changing the hydraulic conductivity. The effective factor is the length of each layer.

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