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Applicability of Relative Effective Porosity Model to Tracer Tests

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<Abstract>

An attempt has been made in this study to evaluate an applicability of Relative Effective Porosity Model (REPM) as a method for estimating saturated hydraulic conductivity (K_s) for homogeneous coarse, medium, and fine sands. The saturated hydraulic conductivities obtained from REPM are converted into average linear velocities using Darcy's Law and compared with the results from experimental tracer tests for homogeneous coarse, medium, and fine sand layer. Two types of tracer tests analyses, analytical solution using CXTFIT and moment methods, are performed to obtain reasonable linear velocity range for each layer. For the coarse and medium sands, the converted average linear velocity from REPM is in the velocity range obtained from tracer tests. However, small difference between the results from REPM and tracer tests is found for the fine sands. These results show that REPM gives reasonable estimates of saturated hydraulic conductivity.

KEY WORD : Relative Effective Porosity Model, Tracer tests, Saturated hydraulic conductivity

1. Introduction

It is necessary to obtain appropriate hydraulic parameters, such as saturated hydraulic conductivity and effective porosity, to simulate groundwater movement in both saturated and unsaturated conditions. The methods for estimating saturated hydraulic conductivity (K_s) from soil properties have been developed by many researchers (Ahuja et al., 1993; Brutsaert, 1967; Ritchie, 1999). However, measuring the saturated hydraulic conductivity of soil from the methods is somewhat time consuming, expensive, and encounters a lot of uncertainties (Suleiman, 2001). A method reported by Suleiman and Rawls (2001), which relates Ks to total porosity (P) and field capacity (FC, the soil water content after free drainage is negligible) has an advantage of needing just two parameters, which are easy to obtain.

Objective of this work is to evaluate an applicability of Relative Effective Porosity Model (REPM) as a method for estimating saturated hydraulic conductivity.

2. Method and Materials

2.1 Relative Effective Porosity Model

In order to estimate Ks using Suleiman and Ritchie (2001) method the relative porosity is needed, which can be obtained from both of total porosity and field capacity. Total porosity (P) is calculated from bulk density (B_d, the mass of dry soil per unit bulk volume) and particle density (P_d) as

$$P = 1 - B_d / P_d \tag{1}$$

where P_d can be assumed to be 2.65 g/㎤. The relationship between saturated hydraulic conductivity and relative effective porosity can be written as,

$$K_s = 75 \times \phi_{er}^2 \ (cm/day) \tag{2}$$

where Φ_{er} is the relative effective porosity, which can be related as

$$\phi_{er} = \theta_e / FC = (P - FC)/FC \ (cm/day) \tag{3}$$

and FC is the field capacity and θ_e is the effective porosity defined as the total porosity minus field capacity. From the Equation (3), to estimate the relative porosity of a soil is to measure its bulk density and FC.

2.2 Estimation of Saturated Hydraulic Conductivity

Three columns were prepared to measure the water content of coarse, medium, and fine sands. The column consisted of a 330 mm long acrylic cylinder, with internal diameter of 5 mm. Each cylinder was filled with air-dried coarse, medium, and fine sand and the middle particle diameter was 0.75 mm, 0.375 mm, and 0.188 mm, respectively.

The measured bulk densities of coarse, medium, and fine sands were 1.354 mg/㎤, 1.526 mg/㎤, and 1.774 mg/㎤, respectively. Those estimated bulk densities can be generally considered as moderate, when compared with values for the general bulk densities of sand soils, which range from 1.2 gm/cm^3 for very loose soils to as high as 1.8 gm/cm^3 for very tight fine sandy loam soils (Brady, 2002).

A Time Domain Reflectometry (TDR, Model TRIME-FM3, IMKO, German) was used to measure the soil moisture content. The total porosity for each column was obtained by measuring the moisture content when the material was saturated and the field capacity was measured after draining for a week.

Figure 1 shows that as the particle size increases, the changes in soil water content are much significant during the first day of the observation. The volumetric water content of coarse, medium, and fine sand after seven days of drainage is 0.049, 0.058, and 0.185, respectively. Each measured value can be considered as a field capacity of each material because the drainage becomes practically negligible. The field capacity values for the coarse and medium sand are reasonable however the value for the fine sand somewhat higher than expected. The difference may be resulted from much compaction of fine sand.

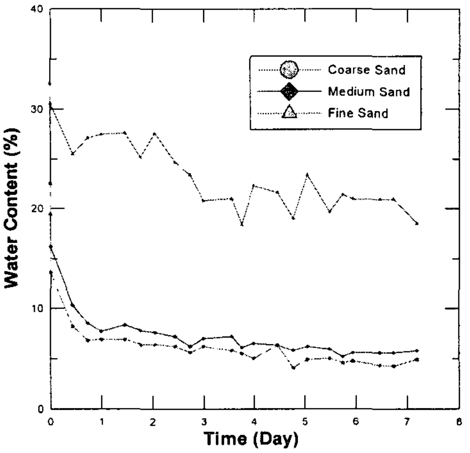

Figure 1. Changes in water content

2.3 Bench-Scale Tracer Tests

In order to evaluate the values determined from REPM, tracer tests were performed under various experimental conditions, such as injection type, volume, and rate. The Experimental setting consisted of three homogeneous coarse, medium, and fine sand layers (15cm thick). Clayey layers, 2 cm thick, were embedded within two sand layers to prevent the interaction between adjacent layers (Figure 2).

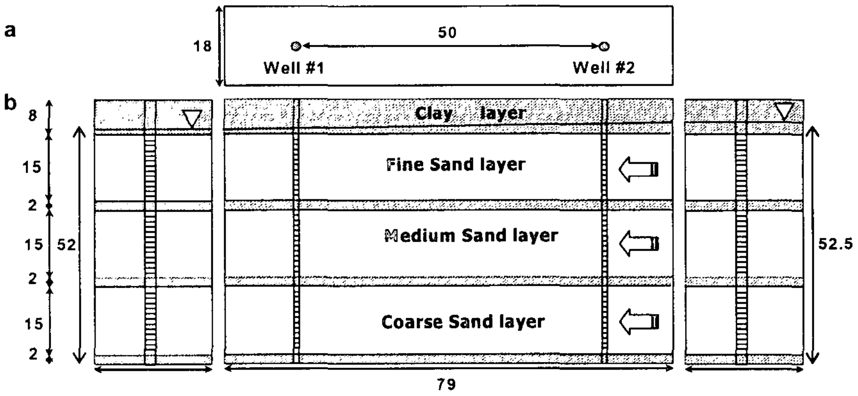

Figure 2. Setup of tank experiment (a) Plan view. (b) Cross section (units in ㎝)

A series of tracer tests using potassium bromide as a conservative tracer were conducted under various injection types and volumes to obtain reasonable linear hydraulic parameters, especially linear velocities, of the porous medium. The injection volumes were 500, 300, 200, and 100 ml, and injection types were constant and step inputs.

The breakthrough curves from the tracer tests were evaluated with an analytical solution and moment methods. For the simulation of analytical solution CXTFIT code was used to estimate transport parameters. For moment analysis Yu et al. [1999] reported a method for step inputs and Wolff et. al., [1979] presented for pulse input as

$$M_1 = \tau = \frac{\int_0^1 tdC_1}{\int_0^1 dC_1} = \int_0^1 tdC_1 \tag{4}$$

and the second central moment is

$$\mu_2 = \frac{m_2}{m_0} = \int_0^\infty (t - M_1)^2 dC_1 \tag{5}$$

Using moment method, linear velocity and dispersion coefficient of the Convection Dispersion Equation can be calculated as

$$v = \frac{z}{M_1} \text{ (for } \textit{step input}\text{)} \quad ; \quad = \frac{z}{M_1 - t_0/2} \text{ (for } \textit{pulse input}\text{)} \tag{6}$$

$$D = \frac{\mu_2 v^3}{2z} \text{ (for } \textit{step input}\text{)} \quad ; \quad = (\mu_1 - \frac{t_0}{12})\frac{v^3}{2z} \text{ (for } \textit{pulse input}\text{)} \tag{7}$$

where t_0 is the time used for a pulse input.

3. Results and Discussion

The calculated linear velocity from analytical solution and moment methods for coarse, medium, and fine sand layer ranges $5.04\times10^{-2} \sim 6.36\times10^{-2}$, $3.48\times10^{-2} \sim 4.11\times10^{-2}$, and $6.76\times10^{-3} \sim 7.51\times10^{-3}$ cm/min, respectively.

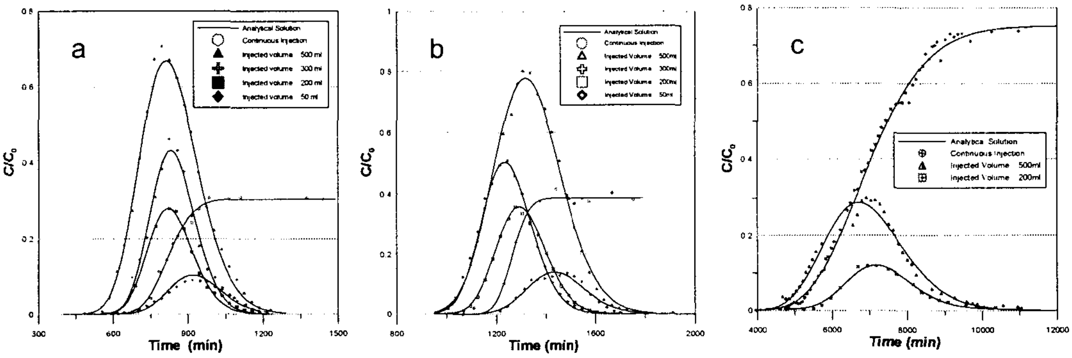

Figure 3. Breakthrough curves analysis obtained from coarse;(a), medium;(b), and fined;(c), sand layers

The saturated hydraulic conductivity of coarse, medium, and fine sand obtained from REPM is 4.197㎝/min, 2.107㎝/min, and 0.0323㎝/min, respectively. With this saturated hydraulic conductivity the linear velocity can be converted into linear velocity by using Darcy's Law. The estimated linear velocity of coarse, medium, and fine sand layer is 6.04×10^{-2} cm/min, 3.64×10^{-2} cm/min, and 1.4×10^{-3} cm/min, respectively. The comparison between the results from tracer test and REPM shows that the linear velocity for coarse and medium sand is in the same range however for fine sand the obtained linear velocity from REPM is somewhat lower than that of. tracer tests. This may be resulted from too much compaction of fine sand. These results show that REPM gives reasonable estimates of saturated hydraulic conductivity.

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