II－7 Modeling Flow of Water through Macroporous Media

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Introduction

A macroporous media is characterized by fast flow. Up to the present there is no detailed study to understand the basic process of flow of water through macroporous media. In this study a new equation is proposed to describe unsaturated flow through macropores. To check the applicability of this new equation laboratory investigations on sand column have been performed on the basis of which a kinematic wave model is developed to simulate unsaturated flow through macroporous media.

Theory

The basic force-balance principle would yield the unsaturated laminar flow discharge Q_p (Beven and Germann, 1981) for a vertical cylindrical macropore (Fig. 1b) which represents the idealization of the real macropore as shown in Fig.1a to be

$$Q_p = \frac{\pi g}{8\nu}\left(R^4 + 3f^4 - 4f^2R^2 + 4f^4 ln\frac{R}{f}\right)\left(\frac{\Delta H}{TL}\right) \tag{1}$$

where *(R-f)* is the width of sheet flow as shown in Fig.1b and $\Delta H/TL$ is the hydraulic head, T is the tortuosity of a single macropoe and is taken to be 1.5 in this study. For unsaturated flow, $\Delta H/L = 1$. Eq.1 expresses Q_p as a function of R and f. Since it is quite difficult to apply Eq.1 for practical use, from Eq.1 we derive a new equation for unsaturated macropore flow as : $K_p = K_s\ S_d^{3.23}$ (2)
where K_p and K_s are the unsaturated and saturated hydraulic conductivity respectively and $S_d = (\pi R^2)/\{\pi (R^2 - f^2)\}$ is the degree of saturation. Eq.2 is very simple and convenient to apply for practical use.

To simulate unsaturated flow through macropores information of the macropore size distribution is needed. In this study we applied saturated water breakthrough curve method of Radulovich et al. (1989) to estimate macropore size distribution of the studied porous media.

Simulation of Unsaturated Macropore Flow

In this study we a propose kinematic (shock) wave model to simulate unsaturated flow through a single macropore. The continuity equation (Eq.3) in combined with the new Eq.2 forms the basis of kinematic wave model.

$$\frac{\partial K_p}{\partial z} + \frac{\partial S_d}{\partial t} = 0 \tag{3}$$

The kinematic wave celerity C_k is : $C_k = K_p / S_d = K_s\ S_d^{3.23-1}$ (4)
And the time of outflow through a single macropore since the onset of input is : $t_{out} = TL / C_k$ (5)

In brief the simulation procedure is to solve for degree of saturation S_d (Eq.2) for a single macropore representative of a certain macropore range where input I would be the unsaturated hydraulic conductivity of that macropore ($I = K_p$). Once the degree of saturation is known, kinematic wave celerity C_k (Eq.4) and hence the time of outflow t_{out} (Eq.5) for that pore can easily be solved. Integration of outflows for macropores of different sizes would give the simulated unsaturated water breakthrough curve.

Comparison of Simulation Result with Experimental Observation

Two types of water breakthrough curve (saturated and unsaturated) experiments were performed on laboratory packed sand column of length 50 cm and diameter 30 cm filled with coarse grained river sand and medium grained sea sand mixed at a ratio of 10:1 by volume.

For saturated water breakthrough curve experiment, water was added manually from the top of the sample maintaining just saturation and free drainage from the bottom of the sample was measured. Fig.2 and 3 show the observed saturated water breakthrough curve and the estimated macropore size distribution respectively. We see that the studied porous media had 19.70% macropores ranging from 78 to 142 μm.

For unsaturated water breakthrough curve experiment, rainfall of constant intensity was applied from the top of sand column using a rainfall simulator. Fig.4 shows the observed and the simulated unsaturated water breakthrough curves for rainfall intensity of $79.37*10^{-6}$ m/sec. Analysis of the observed data showed that 93.58% of the total rainfall contributed flow to the 19.70% (macropores) of the total area and came out very fast as bypassing flow. The rest 6.42% of the total rainfall was stored in the fine pores (micropores). Therefore, input I to a macropore would be 4.75 times the *rainfall intensity*. Comparison of the simulation result with observed data shows that the proposed kinematic wave model in combined with the new equation works quite well. However, there exist small time lag between the observed data and the simulation result.

The physical interpretation of the multiplication factor and the lag time phenomena is that at the beginning of the rainfall, water will be consumed by the micropores and the macropores will remain empty until the surface of the micropores have become saturated when the excess water will enter into the macropores. Thus the flow contributing area of a macropore would be much more larger than the area of the pore itself. This accounts for the multiplication factor in the rainfall intensity to be the input to a macropore. The above interpretation also explains the lag time which is due to the difference between the starting time of rainfall and the actual time of entry into a macropore.

Conclusions

The mechanism of flow of water through unsaturated macropores in laboratory packed sand column is studied. Experimental observations showed that 93.58% of the total rainfall was carried out as bypassing flow by 19.70% macropores. A kinematic wave model for simulating unsaturated macropore flow is proposed and is verified with observed data. It is seen that the proposed model in combined with the newly developed unsaturated macropore flow equation is well capable of predicting the real process of flow.

References

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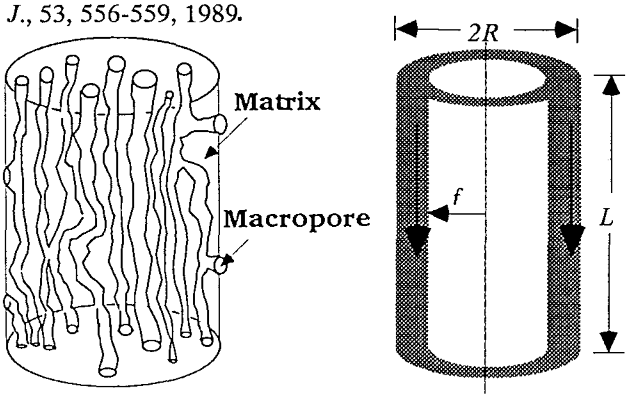
Radulovich, R., Solorzano, E., and Sollins, P.; Soil Macropore Size Distribution ..., *Soil Sci. Soc. Am. J.*, 53, 556-559, 1989.



(a) Real (b) Idealized

Fig.1 Schematic Representation of Macropore(s)

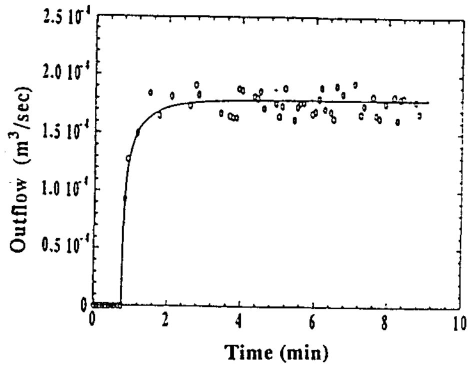


Fig. 2 Saturated Water Breakthrough Curve

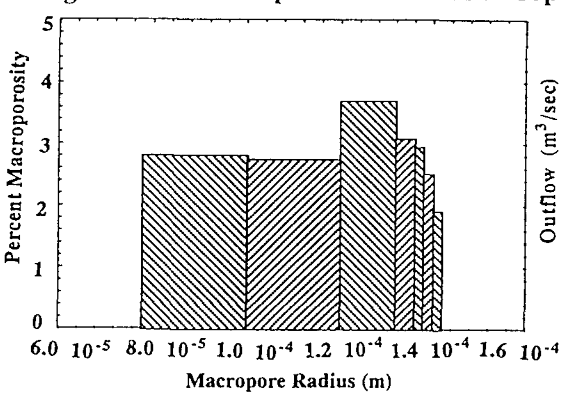


Fig. 3 Macropore Size Distribution

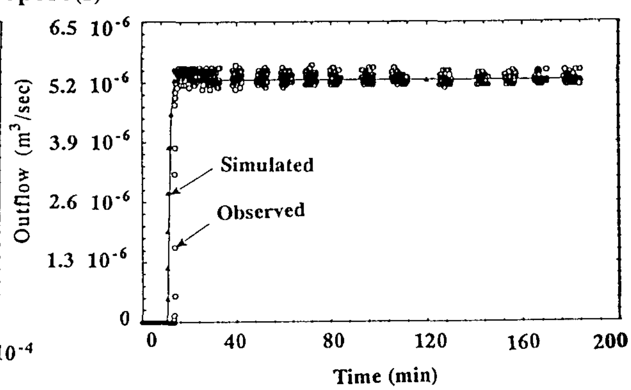


Fig. 4 Unsaturated Water Breakthrough Curves