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ESTIMATION OF UNSATURATED HYDRAULIC CONDUCTIVITY USING EMPIRICAL MODELS

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Abstract Hydraulic Conductivity, the most important property that governs water flow in the soil. Groundwater recharge and contaminant transport mainly depend on the hydraulic properties of soil. Unsaturated hydraulic conductivity (K) were determined both internal drainage method (Hillel et al., 1972) and using selected closed form models. The study was undertaken for the estimation of K using different empirical models. The field-measured values of K were compared with estimated values by four popular closed-form models namely, Brooks-Corey (1966), Campbel (1974), Bresler et al. (1978) and Van Genuchten (1980). Selection of the best model was done based on statistical analysis and graphical interpretation. A comparison of estimated values with the measured hydraulic conductivity shows that Van Genuchten model gives the values close to the field values (Dey, 2000). So, Van Genuchten (1980) model can be used as most suitable for estimation of unsaturated hydraulic conductivity.

Keywords: Unsaturated Hydraulic Conductivity, Flux, Empirical Model.

INTRODUCTION

Knowledge of the hydraulic conductivity (K), either as a function of volumetric water content (θ) or soil water pressure head (h), is essential for the solution of the general transport equation for water flow. Application of the water flow equation to field situations usually require that K(θ) or K(h) is determined in situ. Mathematical models of hydrologic and agricultural systems require knowledge of the relationship of soil unsaturated hydraulic conductivity to volumetric soil moisture content or soil matric potential. Hence, a sustained research effort towards the parameterization of unsaturated hydraulic conductivity has resulted in the development of several laboratory, field and empirical methods. Laboratory techniques for determining unsaturated hydraulic conductivity involve setting up either steady or transient flow systems in which field extracted soil samples are tested. However, it is now recognized that laboratory tests cannot fully duplicate field conditions. Among field methods, the internal drainage test has been accepted as a standard in-situ procedure, notwithstanding certain inherent limitations (Hillel et al., 1972).

It is very difficult to measure unsaturated hydraulic conductivity, but it is so important that literature on the quantification of it is very exhaustive. Many methods have been reported, but there is no single method, which is best suited to all circumstances. This has led to the development of theoretical methods for estimation of unsaturated hydraulic conductivity from basic properties or the soil moisture characteristic (SMC). In particular, closed-form equations for unsaturated hydraulic conductivity (Brooks and Corey, 1966; Campbel, 1974; Bresler et al., 1978; Van Genuchten, 1980;) in terms of certain descriptive parameters of the SMC have become extremely popular because of their simple forms. A few works on the hydraulic properties of unsaturated soil in Bangladesh were performed. The study of saturated-unsaturated subsurface flow modeling by Bhuiyan (1995) has discussed the difficulties which arise due to non-availability of the relevant parameters. Joshua and Rahman (1983a, b) studied the physical properties of soil of the Teesta river floodplain, the Ganges floodplain and the Barind Tract. The present study has been taken to determine the unsaturated hydraulic conductivity for the selected soil by field methods and using empirical equations and selection of the best model for the estimation of K.

METHODS

Field Experiment

The experiments were conducted at the Bangladesh University of Engineering and Technology (BUET) campus. The experiment was carried out during March 10 to April 4, 1999. The soil samples were collected for the determination of saturated hydraulic conductivity (K_s) and particle size analysis in the laboratory. The soil is silty clay loam (SiCL) in BUET campus. Saturated

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hydraulic conductivity (K_s) for SiCL soil was determined by constant head method. Saturated moisture content (θ_s) was measured by Time Domain Teflectometry (TDR) when field was fully saturated.

A plot of 3 m×3 m was leveled and bounded with 0.3 m high wooden dikes. Four tensiometers of lengths 30 cm, four of 45 cm and four 60 cm were installed in experimental site.

Unsaturated hydraulic conductivity was measured by using internal drainage method. Each experimental plot was ponded for several days until the tensiometer readings were stabilized. The excess surface water was drained out and the time was recorded as zero. The plot was covered with thick black plastic to prevent evaporation. A column of soil between 30 to 45cm was considered for the calculation of hydraulic gradient and flux of water. The flow rate per unit cross-sectional area of the column was determined from the change in moisture content. The average moisture content of the soil column at the beginning and end of each time step was determined using TDR. Wave-guides of the TDR were inserted into the soil upto the depths of tensiometers in order to determine moisture contents for different soil water suctions. Both TDR and tensiometer readings were taken at six- hour interval during the first two days, twelve- hour interval during the third and fourth days, every day for the next seven days and finally at an interval of two days for the rest of the test period. Unsaturated hydraulic conductivity (K)

$$K=\frac{\frac{dw}{dt}}{\frac{dH}{dz}} \qquad 1$$

was determined as:

$$dw/dt = L d\theta/dt \qquad 2$$

where, L = length of the column (15 cm)
$d\theta$ = (θ_1- θ_2)
dt = (t_2-t_1)
θ_1 = moisture content at time t_1
θ_2 = moisture content at time t_2
dH/dz = hydraulic gradient

Fluxes of water from the soil column were determined from change in moisture content.

ESTIMATION OF MODELS PARAMETERS

The following empirical equations were used for the estimation of unsaturated hydrulic conductivity.Parameters of four closed form models were estimated based on field retention data. The procedures of parameter estimation are explained in following sections. Residual moisture content (θ_r) corresponding to soil moisture suction of 15000cm of H_2O and air entry matric potential (h_e) were needed for the estimation of unsaturated hydraulic conductivity using empirical equations. Parameters values of θ_r and h_e were derived from field experiment conducted by Joshua and Rahman (1983). Soil water capacity (S_p) was estimated from slope of the soil-moisture characteristics curve corresponding to the average value of θ_s and θ_r.

Bresler et al. Model (1978)

Bresler et al. (1978) suggested a procedure that provides a quick estimate of the unsaturated hydraulic conductivity as a function of moisture content or soil moisture suction. The unsaturated hydraulic conductivity was determined from the following expression:

$$K(\theta)=K_s[(\theta-\theta_r)/(\theta_s-\theta_r)]^{7/2} \qquad 3$$

Where θ is volumetric moisture content. The value of K_s and θ_r was taken 60.00 mm per day 0.23 respectively.

Brooks-Corey Model (1966)

Brooks and Corey (1966) presented a very popular model for the determination of unsaturated hydraulic conductivity of porous media. He determined unsaturated hydraulic conductivity from the following relations

where τ is a parameter. S_w is expressed as:

The value of τ differs from soil to soil. The value of τ was estimated from the following relation,

$$S_p=1.151\tau \qquad 6$$

The value of S_p was found equals to 0.77.

$$K(S_w)=K_s(S_w)^{3+2/\tau} \qquad 4$$

Campbel Model (1974)

$$S_w=\frac{\theta-\theta_r}{\theta_s-\theta_r} \qquad 5$$

$$K=K_s\left(\frac{\theta}{\theta_s}\right)^{2b+3} \qquad 7$$

The unsaturated hydraulic conductivity can be calculated from the following relation:

where b is an empirically determined constant. Parameter value of b was calculated from regression analysis of log (θ/θs) on log (h/he). The value of b and he were used 5.57 and 15.0 respectively.

Van Genuchten Model (1980)

Van Genuchten (1980) obtained the following closed-form expression for unsaturated hydraulic conductivity, K:

$$K(S_w)=K_s(S_w)^{\rho}\left[1-\left(1-S_w^{1/m_1}\right)^{m_1}\right]^2 \qquad 8$$

where ρ is a pore interaction factor, assumed by Van Genuchten to be equal to 0.5 and m_1 is the model parameter derived from the following relation:

$$m_1 = 1-0.5775/S_p + 0.1/S_p^2 + .025/S_p^3 \qquad 9$$

The value of S_p (slope of the soil moisture characteristic curve) was estimated corresponding to average value of θ_s and θ_r.

RESULTS AND DISCUSSION

Unsaturated hydraulic conductivity (K) of the SiCL soil was determined by internal drainage method and the value ranged from about 25.0 to 0.04 mm per day corresponding to moisture content of 48 to 35 percent (Dey, 2000). The results are comparable to those of Joshua and Rahman (1983). Selection of the best model was done based on statistical analysis and graphical interpretation. The correlation coefficient through the origin of measured value versus model estimated value varied from 0.96 to 0.98. The highest value (0.98) was found for Van Genuchten model and lowest value (0.96) was found for campbel model. Similarly, standard error of estimate (SEE) of the model value varied from 1.5 to 4.8. Van Genuchten model gave least value of SEE (1.5) among the four selected models. The SEE of Brooks-Corey model was found abnormally high. Among the four selected models, it is seen that the Van Genuchten model gives the values close to the field values (Fig. 1). All other equations overestimated the unsaturated hydraulic conductivity and the largest deviation was observed for Brooks-Corey model.

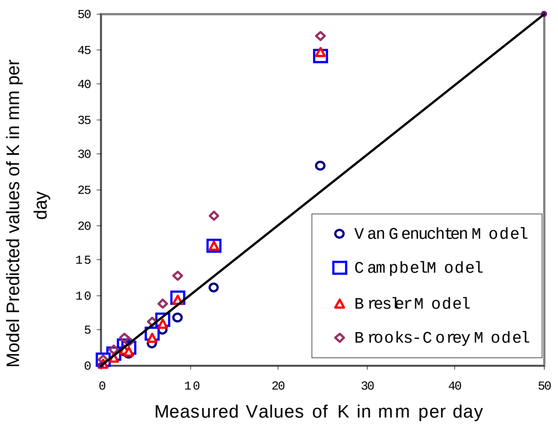

Fig.1 Relation Between Measured Values and Models Estimated values of Unsaturated Hydraulic Conductivity (K)

CONCLUSIONS

Unsaturated hydraulic conductivity (K) of the SiCL soil ranged from about 25.0 to 0.04 mm per day corresponding to moisture content of 48 to 35 percent. Van Genuchten model was found to match well with the measured values whereas the campbel, Bresler et al. and BC models did not show best performance for K estimation. Among the four models the Van Genuchten model was found to superior. So, Van Genuchten (1980) model can be used as most suitable for estimation of unsaturated hydraulic conductivity.

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