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A Method for Determining Unsaturated Hydraulic Conductivity of Undisturbed Soil

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Abstract

A new experiment method for determining parameters of soil water movement is put forward, which is that two parameters are determined in the same one experiment. According to the principle of determining undisturbed soil sample parameters, a new device is designed and introduced. Through successive correction of the assumed soil water characteristic curve by iteration method, unsaturated hydraulic conductivity of the undisturbed soil sample is obtained. At the same time, the soil sample is also obtained.

Keywords: Undisturbed soil sample, Soil water characteristic curve, unsaturated conductivity

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INTRODUCTION

Determination of the hydraulic conductivity, commonly used methods can be divided into two categories, direct method and indirect method. The direct method and can be divided into indoor test and field test, Such as the steady infiltration and evaporation method stability, The instantaneous profile method of unsteady flow, Discharge pressure plate or membrane method, The zero flux plane method, The wild instantaneous profile method, etc. Indirect method is using the direct method of parameter calculation of hydraulic conductivity $K(\theta)$ indirectly. Such as CD method, moisture characteristic curve method, etc. CD method is to use and the spread of the degrees $D(\theta)$, and let the water $C(\theta) = d\theta/dh$ concluded from the water characteristic curve. Using $K(\theta) = C(\theta) \cdot D(\theta)$ calculated $K(\theta)$. Water characteristic curve method is to describe the soil water characteristic curve of the power function equation in Burdine or Mualem forecast model of soil hydraulic conductivity, relative to the analysis of the hydraulic conductivity of solution, and then use experimental data fitting moisture characteristic curve obtained by $K(\theta)$. These methods have advantages and disadvantages of each, and some experimental observations is relatively cumbersome, in general, the next test only one parameter is obtained. And this paper puts forward "With fixed parameter method", while for $K(\theta)$, can also be obtained $h \sim \theta$ curve, which is kill two birds with one stone of it.

BASAL PRINCIPLE AND TEST UNITS

This method is proposed according to the basic thought of Wind's (Lei et al. 1988, Shao et al. 1991, Wind 1966, Zhang 1996) dissertation, its theoretical basis is Darcy's Law. Take undisturbed soil with a vertical cylinder, make it saturated, let the water vaporize from top surface, install pressure gauge at the different depth in the soil column, determine the total weight of the soil column and observe the negative pressure meter readings every day. Water flux and hydraulic potential gradient at the different depth could be calculated according to measurement data. In this way, $K(\theta)$ can be calculated by the following formula:

$$q = -K(\theta)\left(\frac{\partial h}{\partial z} - 1\right)$$

In the formula: q is water flux, $\partial h/\partial z$ is negative pressure gradient.

According to the requirement of taking undisturbed soil, using seamless steel pipe with a diameter of 10.5cm, and a height of 25cm. To install 5 depressimeters through the wall, the offset is 5cm, of which both branches is 2.5cm away from the bottom. In order to keep the soil undisturbed, not to destroy it along one direction, depressimeters are arranged heliciformly on the soil column, see **Fig. 1**. Compared with former unit, this unit is smaller, it can test not only the parameters of the disturbed soil, but also undisturbed soil.

This method is simple and useful, and has higher accuracy, and negative pressure and weighing should be

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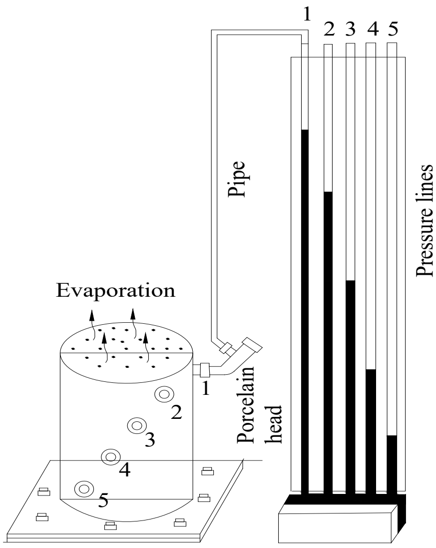

Fig. 1. Schematic diagram showing experimental device

tested once a day. Testing time is 10 days generally to loam. Electronic balance weighing larger is needed in this test.

FIX THE WATER CHARACTERISTIC CURVE WITH ITERATIVE APPROACH

This method seems to be simple, there are many questions. The total water in soil column which is calculates by water characteristic curve h(θ) is inconsistent with that obtained by weighing method. Only in this way can make calculation more accurate. Only main desorption curves (Carrick et al. 2011, Li et al. 2015, Mohammadi et al. 2010, Shen 1993) are fixed in this paper.

The total water content tested by digital electronic balance is quite accurate, the error exists in depressimeters and water characteristic curve. To choose the same performance of porcelain head before test, assuming that: (1) the total water content tested is accurate; (2) negative pressure measured by depressimeters is accurate; (3) moisture content between two points is changing in a linear fashion. On the premise of the basic assumptions correction step is as follow: (1) to offer illusionary water characteristic curve as initial curve; (2) to determine the value moisture content $\theta_{(i,j)c}$ of every point by the result of initial curve; (3) to calculate correction factor $q_j = W_{jr}/W_{jc} (j = 1,2,\cdots n)$, W_{jr} is the measured total water content, W_{jc} is calculated total water content; (4) to calculate moisture content modification value $\theta^1_{(i,j)m} (i = 1,2,\dots,n)$, and to obtain the first fixed water characteristic curve; (5) iterative correction is based on the first correction, and to obtain iterative correction

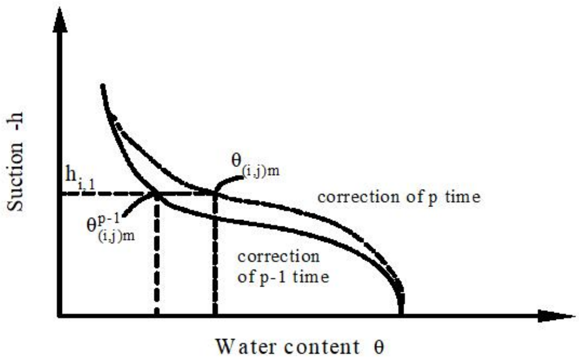

Fig. 2. h(θ) curves of correction

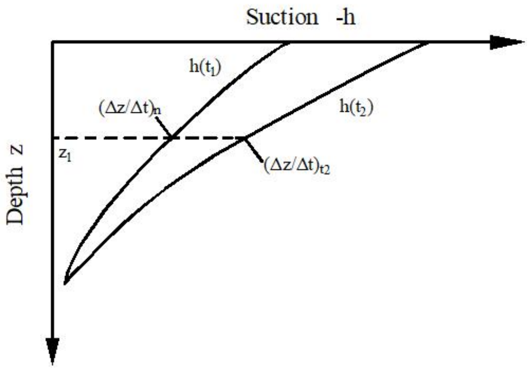

Fig. 3. Tension curves in profile

$\theta^p_{(i,j)m} = \theta^{p-1}_{(i,j)c} \times \theta^{p-1}_j$ and fixed water characteristic curve after P times, $\theta_{(i,j)m}$ is moisture content modification(cm^3/cm^3), $\theta_{(i,j)c}$ is calculation value of moisture content. As negative pressure is measured value, so it is constant, only moisture content is needed to be modified; (6) the convergence criterion (see **Fig. 2**), $Max\left|\theta^p_{(i,j)m} - \theta^{p-1}_{(i,jx)m}\right| < \varepsilon, \varepsilon = 0.01$, it will satisfy the above standards after 4~5 iterations, and the water characteristic curve would be obtained.

THE CALCULATION OF K(θ)

In order to calculate K(θ), water potential gradient should be calculated firstly. Water potential gradient is $\frac{\partial \varphi}{\partial z} = \frac{\partial}{\partial z}(h\text{-}z) = \frac{\partial h}{\partial z}\text{-}1$ (z is positive when it is downwards), when Δz is small, $\frac{\partial \varphi}{\partial z} \approx \frac{\partial h}{\partial z}\text{-}1$, only negative pressure gradient $\frac{\Delta h}{\Delta z}$ is to be calculated. To draw negative pressure curve in profile according to readings (see **Fig. 3**), negative pressure gradient could be obtained at moment of t_1 and t_2 in any section z_1 by drawing method, then the average negative pressure gradient in $\Delta t(t_2\text{-}t_1)$ is:

$$\left(\frac{\Delta h}{\Delta z}\right)_{\Delta t} = \frac{1}{2}\left[\left(\frac{\Delta h}{\Delta z}\right)_{t_1} + \left(\frac{\Delta h}{\Delta z}\right)_{t_2}\right]$$

In the formula: $\left(\frac{\Delta h}{\Delta z}\right)_{t_1} = \frac{h_{i+1}(t_1)-h_{i-1}(t_1)}{2\Delta z}$; $\left(\frac{\Delta h}{\Delta z}\right)_{t_2} = \left(\frac{\Delta h}{\Delta z}\right)_{t_1} = \frac{h_{i+1}(t_2)-h_{i-1}(t_2)}{2\Delta z}$.

To calculate the flux. The water content distribution could be obtained by negative pressure distribution which to get from conversion of h~θ. Water flux at the moment of $(t_2 - t_1)$ in any section z_1 is:

$$q(z_i) = E_0 - \frac{1}{\Delta t}\left[\int_0^{z_i} \theta(t_2)dz - \int_0^{z_i} \theta(t_1)dz\right]$$

In the formula, the evaporativity E_0 on the surface of soil column is measured by weighing. The value in the brackets is calculated from water content distribution at moment of t_1 and t_2. The previous formula shows that the flux in some depth z_i equals to evaporativity minus the loss of moisture in that depth.

Take a series of z sections, and calculate q(z) and $\frac{\Delta h}{\Delta z}$ by previous method, K(θ) could be calculated by the following formula:

$$K(\theta) = -\frac{q(z)}{\frac{\Delta h}{\Delta z} - 1}$$

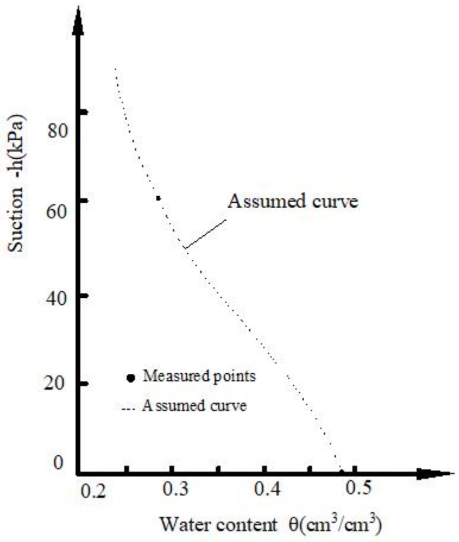

Fig. 4. Assumed curve

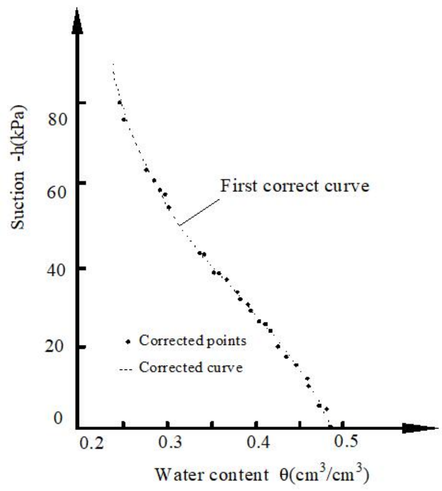

Fig. 5. First corrected curve

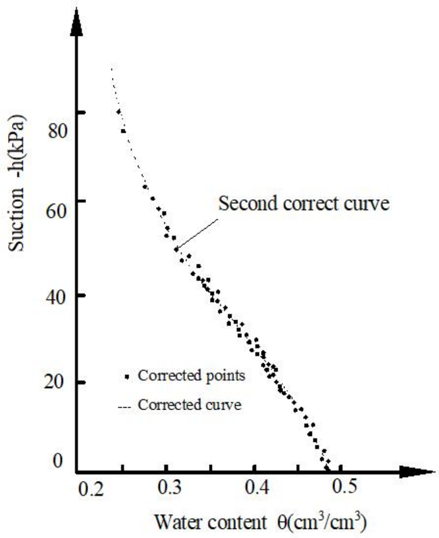

Fig. 6. Second corrected curve

THE PRACTICAL EXAMPLE

The soil sample is medium loam, dry density is $\gamma = 1.38\, g/cm^3$. Remove the soil for 10cm when taking sample and get undisturbed soil. To make the soil saturated before test, to seal the bottom leads to evaporate from top. The test began on May.18th, 1993, ended on May. 28th, totally 10 days. During this period, soil weighing and observation of negative pressure were measured once a day.

The key step is water characteristic curve modification. First to correct according to measured data, after two iterations corrections reach accuracy requirements $\varepsilon < 0.01$. After correction, the distribution of points more and more focus on a smooth curve (see **Figs. 4**, **5**, **6**).

In order to test the reliability of water characteristic curve, The total water in soil column which is calculate by water characteristic curve h(θ) is almost consistent with that obtained by weighing method, The maximum absolute error is 1.14g, relative error is 10-4 order of magnitude.

K(θ) can be gotten from the average pressure gradient calculated from negative pressure curve and

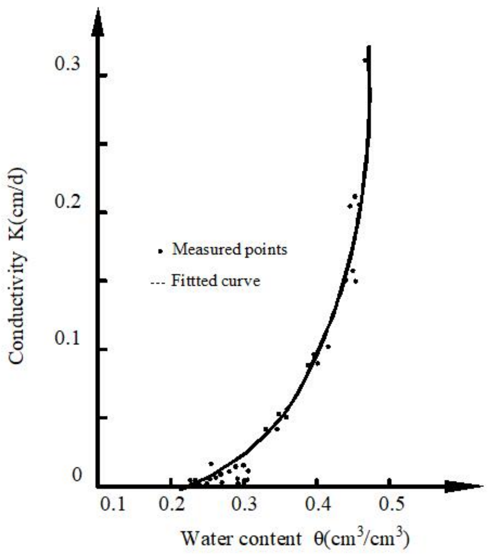

Fig. 7. $K{\sim}\theta$ curve

water flux calculated from profile moisture content curve. Fitting result of K~θ curve see **Fig. 7**. Fitted empirical formula is:

$$K(\theta) = 1.37024 \times 10^{-5} e^{23.13014\theta}$$

In the formula: R=0.8857, n=30.

CONCLUSION

The equipment is improved in this test, in order to keep the soil undisturbed, not to destroy it along one direction, depressimeters are arranged heliciformly on the soil column. To determinate the moisture content and to mark on the figure in the end of the test to make the imaginary curve close to real one faster to accelerate iteration speed. Finally iteration speed has been improved (reaching accuracy requirements after two iterations corrections).

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