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A Cone Permeameter for determining hydraulic conductivity in unsaturated soils

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ABSTRACT: The cone permeameter test is a generally accepted field test by geotechnical engineers for determination of infiltration characteristic of unsaturated soils (Kodešovā *et al*., 1998). In this study, cone permeameter test is conducted for estimating soil moisture characteristic and hydraulic conductivity curves from in-situ measurement. Results show that the saturated hydraulic conductivity is well estimated and the soil moisture characteristic curve lies between the wetting and drying curves obtained from other standard laboratory methods.

1 INTRODUCTION

Recently, a record rainfall has caused a large number of riverbank failures in Japan. In a structure like a riverbank the seepage condition are constantly changing. So there are complicated moisture behavior on the boundary between saturated region and unsaturated region. Consequently, definition of the hydraulic properties of unsaturated soils is increasingly necessary for geotechnical applications. Knowledge of the soil-moisture characteristic and hydraulic conductivity curves, θ and K, is particularly important for accurate numerical modeling of variably saturated flow (Mualem and Dagan, 1978). These soil properties can be determined in the laboratory, but in-situ measurements are often preferred. The definition of the hydraulic properties of unsaturated soils is increasingly necessary for geotechnical applications.

2 METHODS

A Cone permeameter device was modified for in-situ hydraulic testing which can be used easier than a prototype test. A Cone permeameter method is used to obtain data of hydraulic conductivity in-situ in unsaturated soils that can be analyzed using inverse program after measuring the pressure heads and volume of water content. Additionally, it would be possible to cut down waste of time and easily to use.

A Cone Permeameter device was made of stainless-pipe, with a shapened cone tip.

For the test, it is necessary to dig the hole in-situ soils and then, install the probe into the hole. This device is able to pour water into the in-situ soils through a porous element 1 mm in diameter at the cone tip. Above the porous element, there are two tension rings that can measure in-situ pressure heads. Pressure heads and Cumulative water flow that are measured with the Cone permeameter are recorded to a data logger through the control unit.

The Cone permeameter is 30 mm in diameter, and length is 118.5cm. The capacity of the water tank is 10 ℓ that it is possible to carry by one person. A more detail of this method of Cone permeameter device set-up, as shown in Photo 1.

Photo1. Cone permeameter device set-up

The cumulative water flow and pressure heads at the two locations are recorded with time. Two porous rings serving as tensiometers are located 5 and 9cm above the screened section. After the Cone permeameter is install in the soil, a constant head is applied to the screen using a microprocessor-controlled solenoid valve assembly.

The obtained data is able to get unsaturated infiltration characteristics using an inverse solution based on finite element method.

3 THEORY

3.1 *Numerical solution of unsaturated hydraulic conductivity*

Van Genuchten (1980) made an attempt to find an analysis formula for unsaturated hydraulic conductivity based on Mualem and Dagan (1978), as follows.

$$k(\phi) = k_s;\ S_e^{1/2}\left\{\int_0^{S_e}\frac{dS_e}{\psi}\Big/\int_0^{1}\frac{dS_e}{\psi}\right\} \qquad (1)$$

In equation 1, there are factors for; unsaturated hydraulic conductivity : $k(\varphi)$, saturated hydraulic conductivity : k_s , pressure heads : ϕ , and the effective of saturation : S_e are defined in (2).

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \quad (0 \leq S_e \leq 1) \qquad (2)$$

Where θ_s refer to maximum water content; θ_r refer to minimum water content. Equation 2 is a simple integral equation, having a characteristic that it can easily calculate unsaturated hydraulic conductivity by defining a continuous function for an estimated moisture characteristic curve. Van Genuchten (1980) proposed equation 3 for an estimated equation of moisture characteristic curve that can be used in equation 2 to get the equation for leading unsaturated hydraulic conductivity and water content ratio. They refer to equations 3, 4, 5, and 6.

$$S_e = \left\{1 + |\alpha\psi|^n\right\}^{-m} \qquad (\alpha > 0) \qquad (3)$$

$$m = 1 - \frac{1}{n} \qquad (0 < m < 1,\ \ n > 1) \qquad (4)$$

$$k(\theta) = k_s;\ S_e^{1/2}\left\{1 - \left(1 - S_e^{1/m}\right)^m\right\}^2 \qquad (5)$$

$$C(\theta) = \alpha(n-1)(\theta_s - \theta_r)\cdot S_e^{1/m}\left(1 - S_e^{1/m}\right)^m \qquad (6)$$

4 RESULTS

4.1 *Cumulative water flow*

We compare the measurement results with the estimated results. Figure 1 and Figure 2 refer to time-dependent change of cumulative water flow which are sand and loam. These estimated data are obtained using the Van Genuchten numerical model (1980). Measured and simulated cumulative flow data which is sand and loam in time from the inverse solutions is plotted in Figures.1 and-2.

In case of sand, the predicted cumulative flow data fit the measurement data so good. In case of loam, the predicted and observed data doesn't approach at the end of measurement time.

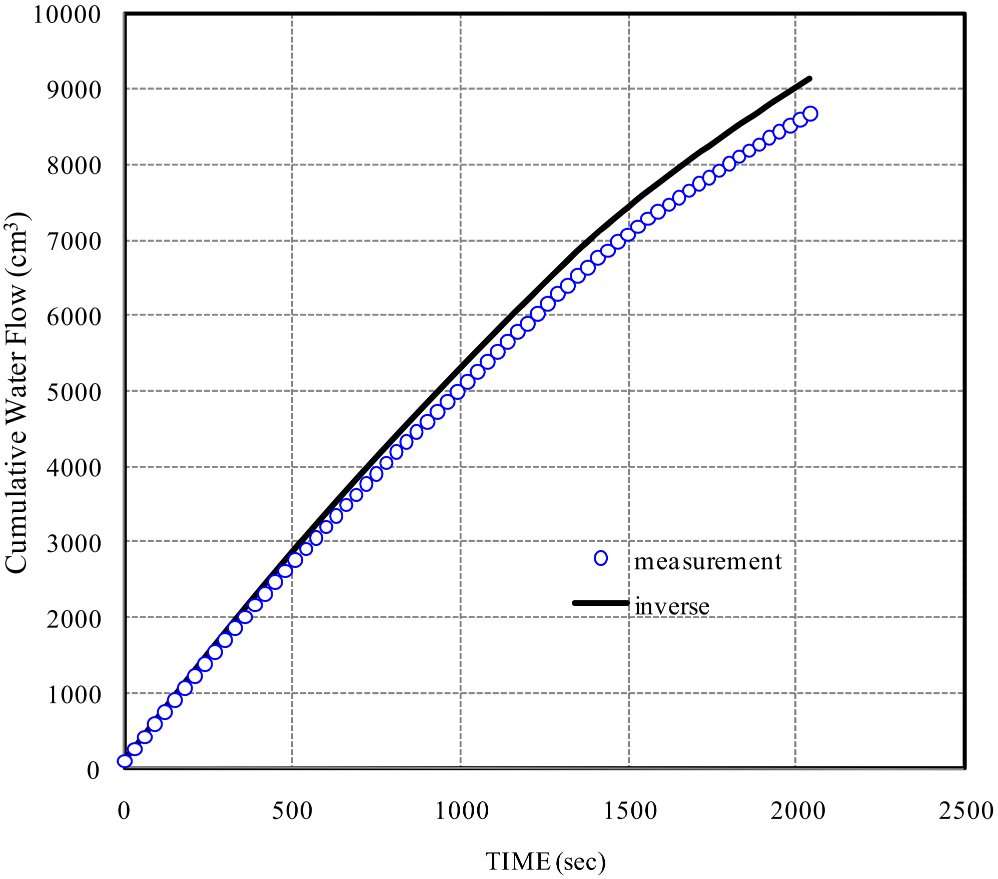

Figure 1. Comparison the measurement result with the predicted results that Cumulative water flow of sand

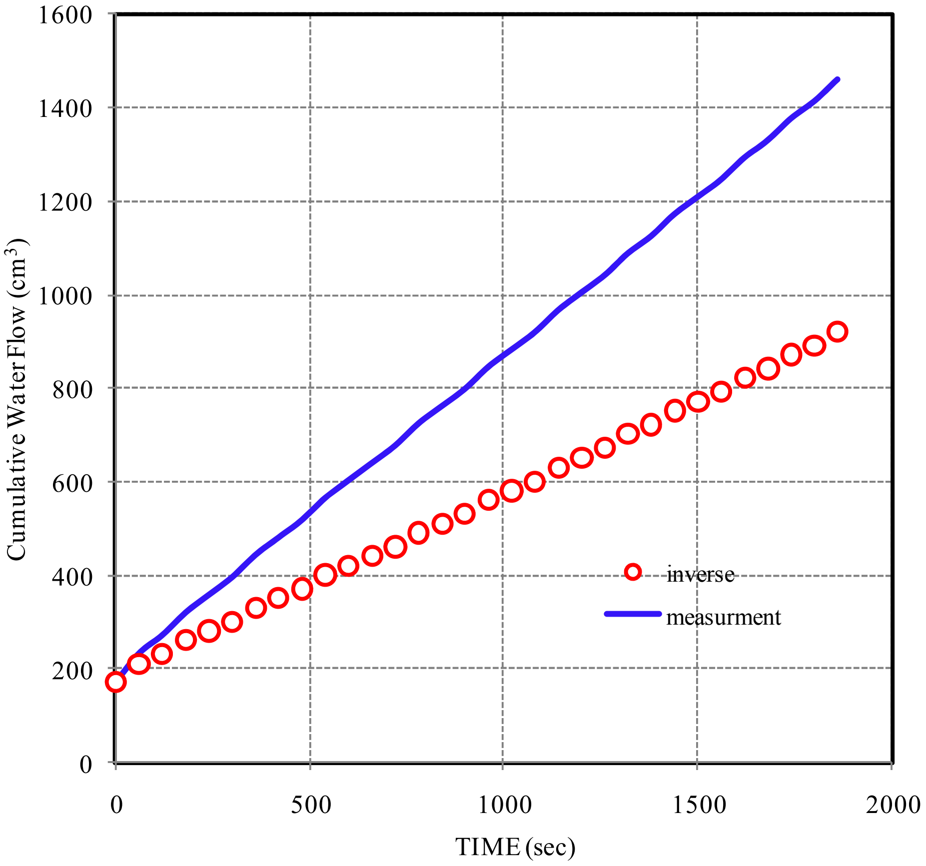

Figure 2. Comparison the measurement result with the predicted results that Cumulative water flow of loam

4.2 *Pressure head*

Figures 3 and 4 show the comparison between the measurement results with the estimated results of pressure head. In case of sand, the predicted data both of upper and lower pressure head tracked closely to measurement data. On the other hand, in case of loam, the measurement pressure head at the lower tensiometer showed higher suction at the beginning of measurement. However, predicted pressure head and measurement pressure head run through closer.

When we measured at the in-situ ground that is loam, the measured pressure head shows considerable variation. The cause could be attributed to difference of density along the Cone permeameter device and in-situ ground. Therefore, the case of in-situ measurement could be different between the predicted results and the measurement results.

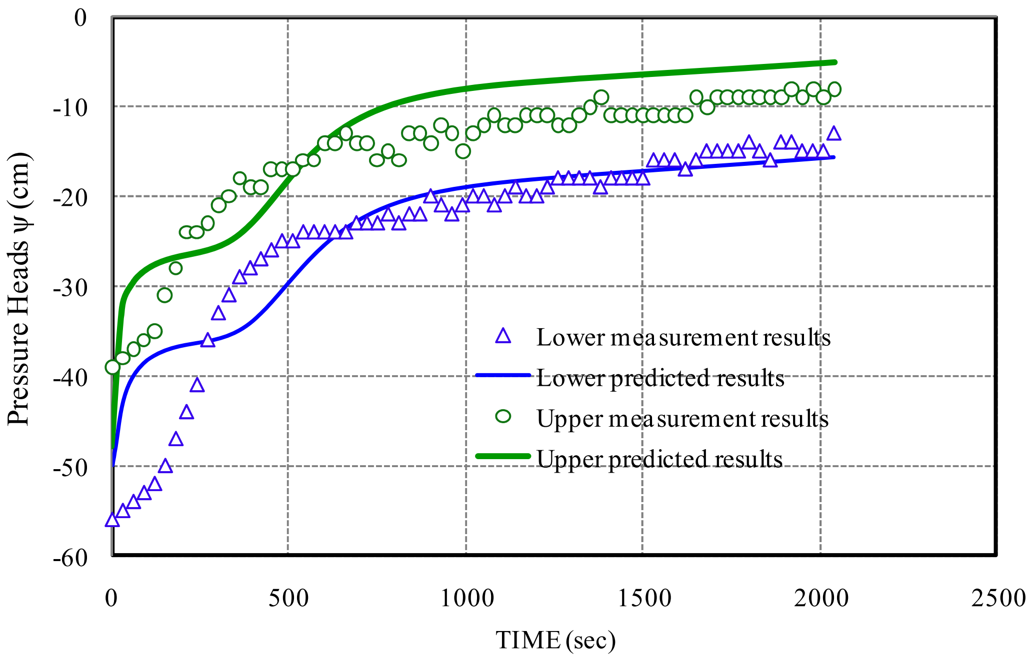

Figure 3. Comparison the measurement result with the predicted results that pressure head of sand

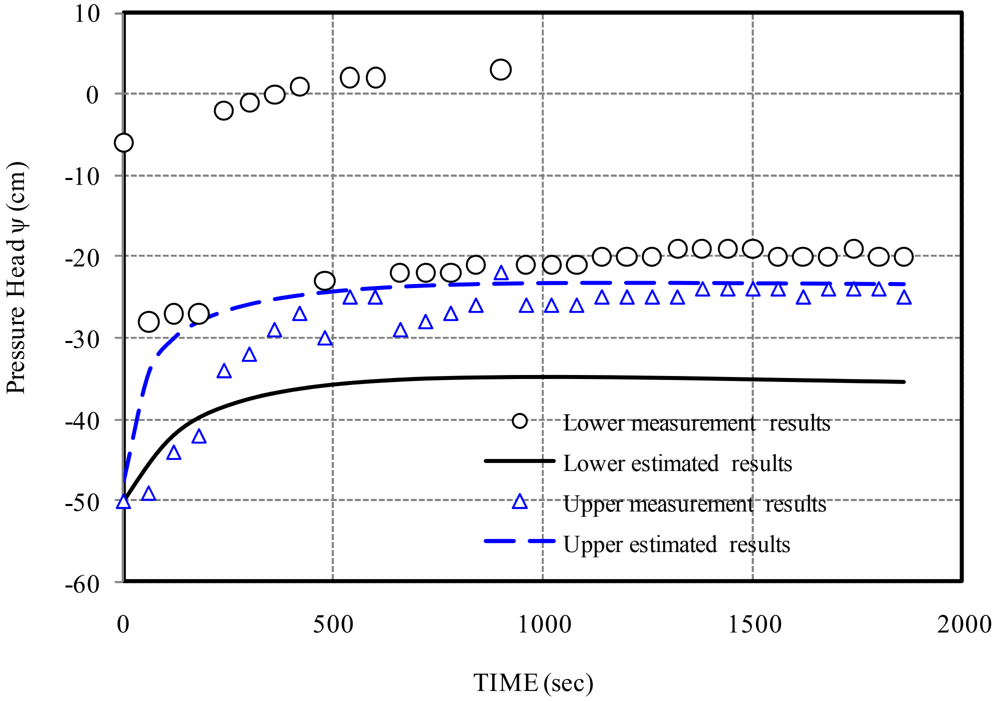

Figure 4. Comparison the measurement result with the predicted results that pressure head of loam

4.3 *Moisture Characteristic curve*

The in-situ soil moisture characteristic and relative hydraulic conductivity measurements are presented in Figure 5. For visual valuation, two representative curves are showed that the cone permeameter test can be obtained reliable data. The reason why these curves can be trusted is possible to see characteristic of each soil sample.

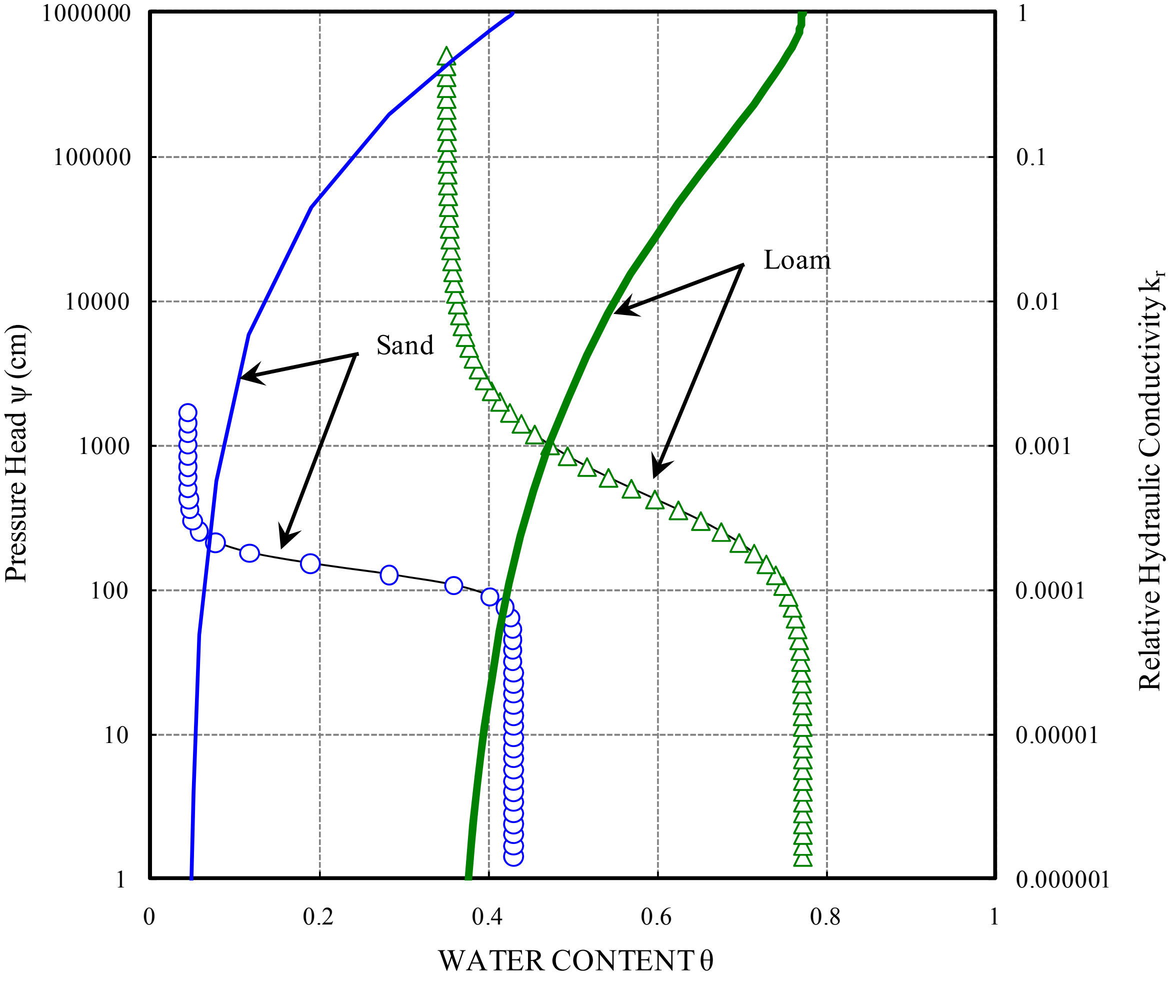

Figure 5. Comparison of two types Soil moisture characteristic curve and hydraulic conductivity curve that are sand and loam

5 CONCLUSIONS

Although Japan is known for its narrow and small area, there are many rivers. For that reason, when the riverbanks have failed, it was necessary to repeatedly build up the riverbanks. Therefore, the geological materials of the riverbanks have become a heterogeneity material year by year. In order to comprehend the infiltration condition of heterogeneity layer, we have been produced the test device imagined from the thesis (Kodešovā *et. al.* 1998) that can make the time shortened and get the specify data that is achieved to a large extent. This device was proposed by Kodešovā *et. al.* (1998), it is predictably-effective as engineering equivalent.

The proposed device consists of two porous ceramic rings and cone measuring as pressure heads and cumulative water flow. We evaluate the device is closely to our experimentally device from a case of inverse solution data. As a matter of fact, we implemented the measurement and calculation in many times, especially pressure head it has been hard to fit the predicted data and measurement data. Though we have made all kinds of efforts, there are not reliable results. Moreover, this device consists of two ceramic ring but there is a problem of strength performance, So we will have to keep pursuing improvement of our Cone permeameter device.

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