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A Comparison Of Guelph Permeameter And Double Ring Infiltrometer Methods For Estimating The Saturated Hydraulic Conductivity In Sandy Soils

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Abstract
Saturated hydraulic conductivity (Ks) is a key parameter of modeling water flow in soils. Even though several methods of measuring Ks exist, there is no standard methodology to measure this parameter. In this paper, we compare two most common Ks measurement technics, namely Guelph Permeametr (GP) and Double Ring Infiltrometer (DRI), to measure Ks in sandy soils. The geometric mean values for Ks measured using these methods were $4.297 \times 10^{-6} \frac{m}{s}$ and $5.625 \times 10^{-6} \frac{m}{s}$ for GP and DRI methods, respectively. From the engineering perspective, both tested methods provided similar mean values and they were not statistically different.
Keywords: *Guelph Permeameter, Double Ring Infiltrometer, Infiltration Rate, Hydraulic Conductivity.*

1. Introduction

Soil hydraulic conductivity can refer to both saturated and unsaturated hydraulic conductivity parameters. The ability of a soil to conduct water under saturated conditions is called the saturated hydraulic conductivity (Ks) which is the key soil parameter for modeling the water movement and transport processes of solutes through the soil profile (Kuráž, 1996). Unsaturated hydraulic conductivity of the soil is the other important parameter in water movement design in unsaturated conditions which requires specific test method to measure such as disk infiltrometer (Fatehnia et al., 2014).

Because of the high temporal and spatial variabilities, it is not easy to measure Ks (Mallants et al., 1997; Warrick and Nielsen, 1980) and different methods result in various values of Ks. Because of that, comparison of different methods can give us better understanding of the various Ks measurement procedures. The appropriate selection of a method is dependent on soil properties, the purpose of the research, resources available, time requirements, and the required accuracy of the data (Reynolds et al., 2000).

Mohanty et al. (1994) compared GP, a velocity permeameter, a disk permeameter and a double tube method in glacial till soil (23% clay, 42% sand in depth of 15 cm). GP yielded lower values than the other methods. Gupta et al. (1993) compared a DRI, a GP and a rain simulator in the uppermost layer of sandy-loam soil (9% clay, 64% sand). The estimated means were statistically the same for GP and for the DRI method.

In our study, two well-known methods of Ks measurement, DRI and GP, were compared. These methods measure the saturated hydraulic conductivity of the soils.

Double Ring Infiltrometer (DRI) shown in Fig. 1 is widely used for field measurements of infiltration rate. The steady infiltration rate can be used for an estimate of the saturated hydraulic conductivity (Fatehnia et al., 2016). When a single ring infiltrometer is used, infiltration occurs in both the horizontal (lateral) and vertical directions. In DRI method, an outer ring is used to avoid lateral flow. The flow geometry depend on the depth of flooding inside the infiltrometer, the initial soil water content, the depth of the rings insertion, the area of the rings, and the soil properties (Fatehnia, 2015). The main advantages of the DRI method are that the device is simple and robust, inexpensive, relatively easy to operate, provides accurate measurements of the field Ks, has been in use for a long time and is widely accepted by scientists. The main disadvantages are difficulties with inserting the rings in stony soils, and disturbance of a porous system during the rings insertion process (Reynolds, 2008b).

Guelph permeameter (GP) shown in Fig. 2 is a modified Mariotte bottle device. This method is designed for measuring Ks in boreholes (Kuráž, 1996). GP was constructed to measure Ks in initially unsaturated field conditions by maintaining a constant water level value inside the hole. Ks is calculated using a steady state rate of the water recharge from a small cylindrical hole to the surrounding soil. Therefore, three-dimensional flow is measured using this method. The sampled volume of soil is about 0.4 times the depth of the water in the auger hole (Dorsey et al., 1990). Three measurement methods of single-head, two-head, and multiple-head analysis are suggested for the measurement procedure and evaluation of the data (Elrick et al., 1989). The single-head approach was selected in this analysis.

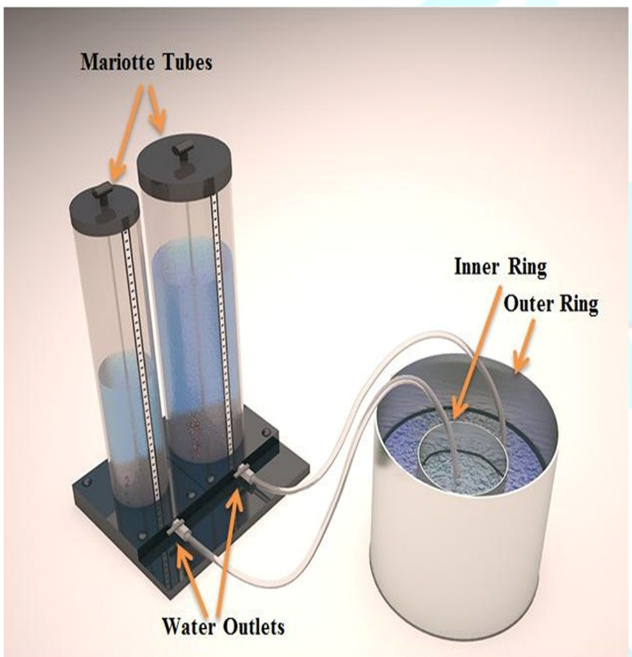

Fig. 1 Double ring infiltrometer test set-up (Fatehnia, 2015).

The main advantages of GP are the easiness of operating the test, rapid measurement time, and low water requirement. While, the main disadvantages are difficulties of drilling in non-cohesive soils (sands, coarse sands, gravelly materials) and the instability of the well.

The main purpose of this research is to compare the two well-established methods of GP and DRI. Estimated Ks values obtained using each of the applied methods in this study are widely used as input for hydrological and hydropedological models, and for numerous engineering applications.

2. Material and methods

2.1 Study area

The test site for all the experiments had a gently sloping surface (4-6°). Soil classification of the material was determined based on ASTM D 422-02. The soil was classified as Poorly Graded Sand (SP) based on Unified and A-3 based on AASHTO soil classification systems.

Fig. 2 Guelph permeameter test set-up (Fatehnia, 2015).

2.2 Field procedure

The spatial distribution of the test locations was randomly selected on site. The important parameter which influenced the location of the measurement place on the site was the mutual distance of the experiments. The minimum separation of the experiments was defined as 1.5 m to prevent any interaction between the infiltration experiments.

Double ring infiltrometer:

DRI test as described by ASTM D3385 consists of an open inner and outer cylinders which should be manually inserted into the ground and be partially filled with a constant head of water. Standard rings with 30 cm inner and 60 cm outer ring diameters were used for measurements. The infiltration rate was determined by measuring the volume of liquid added to the inner ring to maintain the liquid level constant.

The Ks value can be measured from the steady state infiltration rate (I). Some other test and soil parameters are also affecting the infiltration rate and hence, are important in measuring Ks (Reynolds et al., 2002). To measure Ks values of the experiments, the equation suggested by Fatehnia (2015) (Eq. (1)) was used:

$$\begin{cases} I/K_s = 1 + 1.10451 \times B^{0.53} & For\ \lambda < 15\ cm \\ I/K_s = 1 + 0.7243 \times B^{0.5174} & For\ \lambda \geq 15\ cm \end{cases}$$

$$B = \frac{H \times \lambda}{(S+1) \times d_i \times D} \qquad (1)$$

Where (S) is effective saturation, (λ) is macroscopic capillary length, (H) is head of ponding in the ring, (d_i) is inner ring diameter, and (D) is ring insertion depth.

Guelph permeameter:

A GP, a Mariotte bottle device constructed from two clear Plexiglas tubes, was used to obtain an estimation of the Ks values. The experiments were performed in 20 cm deep boreholes. The depth of the constant water level (H_W) inside the borehole was maintained at 17 cm. The radius of the well (r_W) was 3 cm. Extended single head analysis (Eq. (2)) was performed according to Reynolds (2008a) to estimate the Ks value from the quasi-steady rate of the fall in the water level in the reservoir (I_g):

$$K_S = \frac{wf \times I_g \times A_g}{2 \times \pi \times H_W{}^2 + wf \times \pi \times r_W{}^2 \times 2 \times \pi \frac{H_W}{S}} \qquad (2)$$

where (A_g) is the cross sectional area of the GP water reservoir, (S) is the sorptive number and (*wf*) is the dimensionless well shape factor. The calculation of *wf* (Eq. (3)) for s = 0.12 cm^{-1} was made according to Zhang et al. (1998).

$$W_f = \left(\frac{\frac{H_W}{r_W}}{2.074 + 0.093 \times \frac{H_W}{r_W}} \right)^{0.754} \qquad (3)$$

2.3 Analysis of the measured data

The measured Ks value data of the two methods was evaluated as two different datasets. The comparison of the methods was based on the range of the measured values, maximum, minimum, median, mean and coefficient of variation.

3. Statistical comparisons of the measured datasets

A total of 12 measurements using GP and 15 measurements using DRI were conducted. A statistical description of the results is given in Table 1.

The measurement time until a quasi-steady state was reached varied from 25 to 55 min using the GP method. To make the measurement using the DRI method, it was also necessary to obtain a quasi-steady infiltration rate, which took between 1 and 2 h. The average water consumption for the DRI method (including water for flooding the soil surface) was 5 times higher than the water consumption for the GP method (including water for flooding the borehole). It is important to minimize the water requirements for measurements conducted in locations with complex water accessibility.

Table 1: Statistical description of the Guelph permeameter (GP) and Double Ring Infiltrometer (DRI).

Parameters	***units***	***GP***	***DRI***
Geometric mean	$[m.s^{-1}] \times 10^{-6}$	6.297	5.625
Arithmetic mean	$[m.s^{-1}] \times 10^{-6}$	8.912	6.072
Standard deviation	$[m.s^{-1}] \times 10^{-6}$	9.233	6.164
Median	$[m.s^{-1}] \times 10^{-6}$	12.591	8.912
Minimum	$[m.s^{-1}] \times 10^{-6}$	0.316	0.631
Maximum	$[m.s^{-1}] \times 10^{-6}$	79.123	40.642
Coefficient of variation	%	121	98
Range*		2.50	1.80
No. of experiments		12	15

* Parameters of decadic log-transformed datasets.

Table 1 and the box plots depicted in Fig. 3 show that the means, the medians, the ranges of measured values, and the coefficients of variation vary depending on the applied method. The two methods yielded a non-significant difference in the means.

One potential limitation of GP is that the sorptive number (the parameter of the soil texture and structure for the calculation of Ks) may be estimated with insufficient accuracy (McKenzie and Cresswell, 2008). In order to decrease sensitivity to the sorptive number (S), Reynolds (2008a) recommended that for extended single head analysis, the water level in the borehole be maintained as large as possible. The categories for selection of S according to Elrick et al. (1989) are broad enough and even if a mistake is made during selecting S, this will introduce an error into the Ks estimation often less than 25% (Reynolds et al., 1992).

Slightly higher mean values and the highest three values were measured using GP (Figure 3, and Table 1). These highest values could cause the highest measured range and coefficient of variation. The higher values, means and median could be explained by the influence of horizontal infiltration in comparison with DRI.

The DRI method yielded the lowest measured range and the lowest coefficient of variation which can be explained by reduced amount of horizontal infiltration caused by the outer ring around the inner ring. On the other side, the double ring inserted through the surface layer to the deeper layer represents the Ks value of the less permeable deeper layer. Since different flow directions were measured, the isotropy of Ks in the measured subsurface layer may explain the similarity of the means.

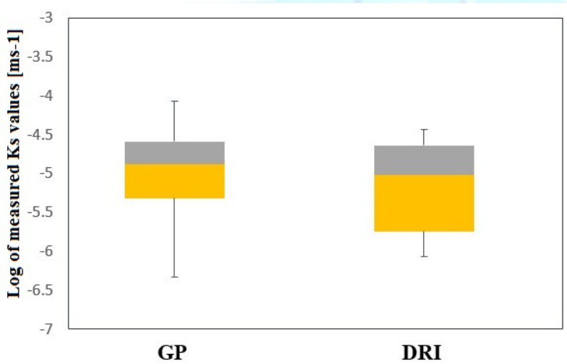

Fig. 3 Box plots (sample minimum, first quartile, median, third quartile, maximum) of the decadic log-transferred ks values measured using a Guelph permeameter (GP) and Souble ring infiltrometer (DRI).

4. Conclusions

Ks is one of the most difficult soil properties to measure, and the main problem in comparison of Ks measurement methods is that no independent standard has been established. Comparison of different methods is the main source of information for selecting proper method in specific conditions and soil properties. DRI and GP methods compared in this research yielded very similar central values. Non-significantly higher mean values and a few distinctly higher values were measured using the GP method. These values were also partially responsible for the highest coefficient of variation and could be explained by the influence of horizontal infiltration rate compared to DRI. Practical experience shows that the DRI method required a 4–6 times greater volume of water than the GP method. The total measurement time using DRI was approximately twice higher than for GP. Although methods based on different flow geometries and sample sizes have been compared, the methods led to similar values. Measuring Ks predominantly in sandy soils without distinct anisotropy could explain this similarity. For most practical purposes, the ranges of the mean values $6-9 \times 10^{-6}\, ms^{-1}$ obtained by the two methods tested here seem to represent the examined layer in the site. In the case of need for high precision for specific purpose, another independent experimental check should be used. The results of this research can help to decide which methods to use for Ks measurement in the analyzed soil by considering different test limitations and expectations.

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