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# CONSIDERATIONS ON METHODS USED FOR DETERMINATION THE HYDRAULIC CONDUCTIVITY OF SOIL

BY

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**Abstract.** Research influence of hydraulic conductivity plays a very important role in water and various substances transport, marking a great extent in all areas, we highlight just a few of them such as hydrological, pedological, geotehinic etc.. The content of this article was strictly reserved for studying the methods and technologies used in the determination and measuring of the hydraulic conductivity of unsaturated and saturated soils. For this purpose in the last decades there have been developed and improved a wide range of technologies with applicability both in field and laboratory, which ultimately proved their usefulness in predicting and analyzing the physical properties that are considered very important when modeling the water transport and various substances in the unsaturated and saturated zones.

**Keywords:** methods; determininination; hydraulic conductivity.

## 1. Introduction

Soil is a porous medium which comprises a very complicated system of canals and variables pathways , soil pores that allow the movement of fluids through them. This definition leads to the conclusion that the movement of water and chemical compounds in soil implies the existence of two environments: solid medium (soil matrix) and a water stream moves through

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soil pores. During water percolation into the soil the permeability is change. So, based on dry soil permeability is high at the beginning and then decreases rapidly until the soil is saturated with water. From that moment amount of water that penetrates the soil becomes constant. If saturated water penetration into the soil is carried out by filtration, and if unsaturated soil infiltration.

In saturated soil, water circulation is in compliance with Darcy's law:

$$V = K \times I, \tag{1}$$

where: *V* is the average filtration speed, [cm/s]; *K* – the hydraulic conductivity or the coefficient of filtration, [cm/s]; *I* – the hydraulic gradient or the pressure gradient (dimensionless).

For unsaturated soils, Richards, based on Darcy's law, has established the following relationship:

$$V = K(\theta) \times I, \tag{2}$$

where: *V* is the average filtration speed, [cm/s]; $K(\theta)$ – the hydraulic conductivity depending on the moisture, [cm/s]; *I* – the hydraulic gradient or the suction gradient (dimensionless).

## 2. Comparative Analysis on Methods for Determining Hydraulic Conductivity

In recent times, scientists have been concerned about the continued development of technologies that facilitate the analysis as thorough and at the same time providing more concrete data in terms of water transport and loaded different substances or compounds chemical. Determination of hydraulic conductivity can be achieved by:

a) the empirical methods for estimating;

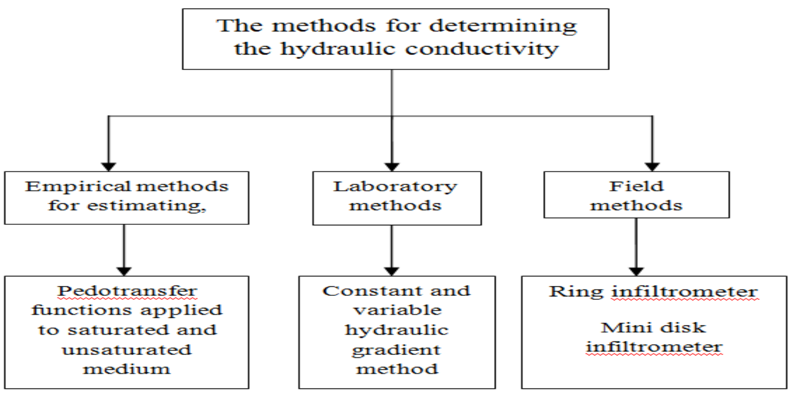


Fig.1 – Methods for determining soil hydraulic conductivity.

b) the experimental laboratory methods;
c) the experimental methods *in situ*.
A general classification of these methods is shown in Fig. 1.

## 2.1. Empirical Methods Used for Estimating Hydraulic Conductivity of the Soil

### 2.1.1. *Pedotransfer Functions Applied for Estimating Unsaturated Hydraulic Conductivity*

Empirical methods involves the use of a correlation of hydraulic conductivity of the ground with some property such as pore size, their distribution, soil texture. One of the most common analytical functions for estimating unsaturated hydraulic conductivity ($K(d)$) is represented by the model of van Genuchten (1980), with pore size Mualem model (1976):

$$\theta = K_s S_e^{0.5}\left[1-\left(1-S_e^{n/(n-1)}\right)^{(1-1/n)}\right]^2. \tag{3}$$

Also $S_e$, is:

$$S_e = \frac{\theta(\psi)-\theta_r}{\theta_s-\theta_r}, \tag{4}$$

where: $\theta(\psi)$ is the measured volumetric water content, [cm$^3$.cm$^{-3}$], at suction $\psi$, [cm-water]; $\theta_r$ and $\theta_s$ – residual and saturated water content; $n$ – the shape factor; $K_s$ – saturated hydraulic conductivity.

### 2.1.2. *Pedotransfer Functions Applied for Estimating Saturated Hydraulic Conductivity*

Pedotransfer functions have become a very important topic for research in soil science and environmental engineering. Pedotransfer functions used to estimate saturated hydraulic conductivity $K_s$ were developed using textural class, geometric mean size, organic carbon content, bulk density and porosity effective as variables used to predict saturated hydraulic conductivity pedotransfer. Here are the following functions applied for estimating $K_s$. All of these features give $K_s$ m/s$^{-1.}$.

Wösten *et al.* (1997), have reported the following function to determine $K_s$:

$$K_s = 1.15741 \times 10 - 7\exp(x), \tag{5}$$

where: $x$ for sandy soil is:

$$x = 9.5 - 1.471(\mathrm{BD}^2) - 0.688(\mathrm{Om}) + 0.0369(\mathrm{Om}^2) - 0.332\ln(\mathrm{CS}), \tag{6}$$

and $x$ for clay soil is:

$$x = 43.1 + 64.8(BD) - 22.21(BD^2) + 7.02(Om) - 0.1562(Om^2) + \\ + 0.985\ln(Om) - 0.01332(Clay)(Om)4.71(BD)(Om), \quad (7)$$

where: BD is the density, [g/cm$^3$]; Clay – the percentage of clay; CS – the percent of the amount of clay and powders; OM – the percentage of organic matter .

Another pedotransfer function used for this purpose was reported by Cosby (1984), this in turn was derived using sand and clay content and presented as follows:

$$K_s = 7.05556 \times 10 - 6 \times (10 - 0.6/0.0126(Sand) - 0.0064(Clay), \quad (8)$$

where: Clay and Sand are the percentages of clay and sand.

From the same category of relations applied to estimate saturated hydraulic conductivity, is part and pedotransfer function suggested by Saxton *et al.* (1986), recounted in the following shape

$$K_s = 2.778 \times 10 \sim 7\exp(x), \quad (9)$$

where:

$$x = 12.012 - 7.55 \times 10^{-2}(Sand) + (-3.895 + 3.671 \times 10^{-2}(Sand) - \\ - 0.1103(Clay) + 8.7546 \times 10^{-4}(Clay^{2)})/\theta_s, \quad (10)$$

where: Clay and Sand are percentages of clay and sand; $\theta_s$ – the saturated water content.

### 2.2. Laboratory Methods Adopted for Determining the Permeability of Soil

Determination of hydraulic conductivity is realized in laboratories according to some methodologies reported in STAS 1913/6-76, STAS1913/8-82, by:

a) the constant-head method with or without suction;

b) the falling head method.

#### 2.2.1. *The Constant-Head Method with or Without Suction*

Determination of hydraulic conductivity of the soil is evidenced by a stream crossing under a constant hydraulic gradient through undisturbed soil sample or wrap the desired shoving in a time $t$ (Stanciu & Lungu, 2006).

The components of the device used to measure the permeability of the soil are shown in Fig 2.

The device used for this purpose usually is composed of the:

a) cylindrical soil sample (1) of length $L$ and area $A$;

b) reservoir (2) with constant level, that maintaining unchanged the share piezometric level $h$;

c) contact tube (3);

d) porous-plates (4);

e) surcharge (5) as the volume of water discharged who percolated soil sample;

f) graduated cylinder (6) used for collecting the surcharge discharged in a period of time $T$.

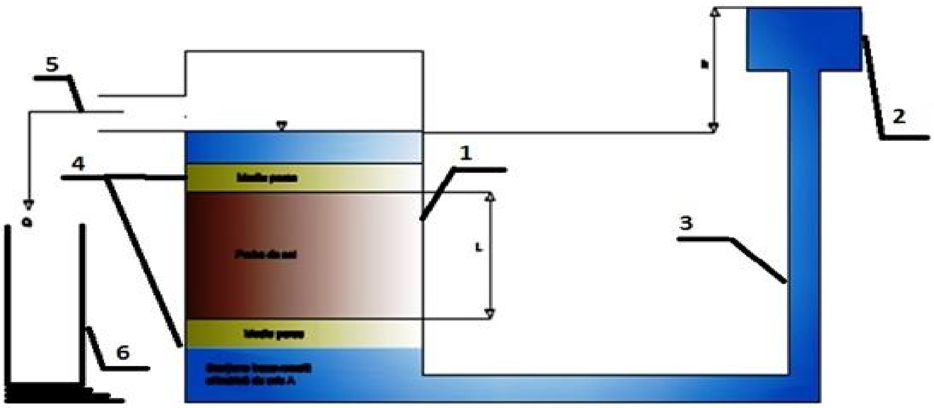


Fig. 2 – The principle of constant-head method: 1 – cylindrical soil sample; 2 – reservoir; 3 – contact tube; 4 – poroase- plates; 5 – surcharge; 6 – graduated cylinder.

Determination of hydraulic conductivity of the soil is achieved by applying the following steps (Lungu *et al*., 2013):

a) connect the permeametry cell at constant level water tank (2);

b) it allows the penetration of water from the a constant level tank;

c) take measurements to check if water entered into filtration mode (saturated sample). Saturation of the sample (1) can last from a few minutes to tens of hours sands where clay;

d) after the entry into of filtration procedure is measure water volume $V$ (5) collected in the cylinder (6) in time $T$ measured by the timer;

e) determine the difference in the piezometric level $h$ in cm;

f) determine the the water temperature in the cylinder.

The determination will be repeated at least three times at different hydraulic gradients.

Hydraulic conductivity $K$ on vertical direction of the water flow is calculated from the relationship:

$$K = \frac{V \times L}{T \times A \times h}, \quad (10)$$

where: $V$ is the volume of water collected; $L$ – length of the soil sample; $T$ – time for the collection volume of water (the excess); $A$ – cross-sectional area of the sample.

### 2.2.2. *The Falling Head Method*

Determination of hydraulic conductivity of the soil is evidenced by a stream crossing under a variable hydraulic gradient through undisturbed soil sample or wrap the desired shoving in a time *t* (Stanciu & Lungu, 2006).

The components of the device used to measure the permeability of the soil are shown in Fig. 3.

The device used for this purpose usually is composed of the:

a) cylindrical soil sample (1) of length *L* and area *A*;

b) graduated contact tube (2);

c) poroase- plates (3);

d) surcharge (4) as the volume of water discharged who percolated soil sample;

e) graduated cylinder (5) used for collecting the surcharge discharged in a period of time *T*.

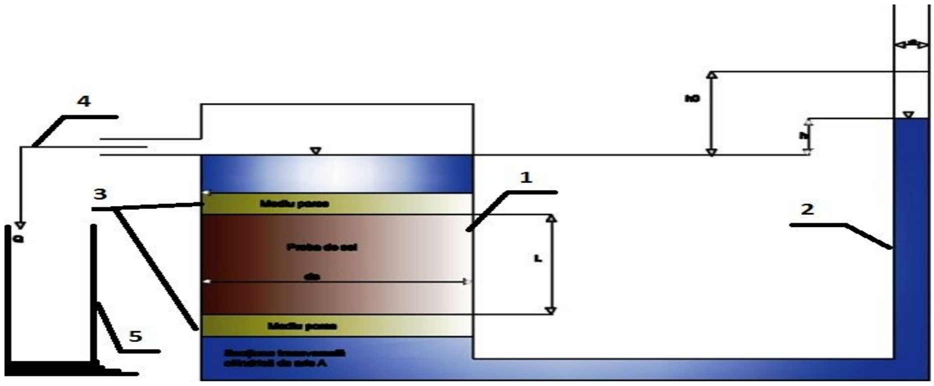


Fig. 3 – The principle of falling head method: 1 – Cylindrical soil sample; 2 – graduated contact tube; 3 – poroase-plates; 4 – surcharge; 6 – graduated cylinder.

Determination of hydraulic conductivity of the soil is achieved by applying the following steps (Lungu *et al*., 2013):

a) connect the permeametry cell at graduated contact tube (2);

b) determination is started when the fluid entering in sample from graduated contact tube;

c) measure necessary time $T$ as takes the water from the graduated tube to descend at a rate of piezometric level $h_1$ to level $h_2$;

d) determine the the water temperature in the cylinder;

e) the determination will be repeated at least three times at different hydraulic gradients $h_1$ and $h_2$.

Hydraulic conductivity $K$ on vertical direction of the water flow is calculated from the relationship:

$$K = \frac{a \times L}{T \times A} \ln\left(\frac{h_1}{h_2}\right), \quad (11)$$

where: $a$ is the cross-section of graduated tube; $L$ – length of the soil sample; $T$ – time for the collection volume of water (the excess); $A$ – cross-sectional area of the sample; $h_1$ and $h_2$ – height of water column after a time $T$.

Advantages attributed to methods for determining hydraulic conductivity in the laboratory are gleaned in large numbers, we can enumerate just a few of them:

a) low operating costs;

b) soil permeability values are obtained in a relatively good time;

c) applicability on all types of soils (cohesive and non-cohesive);

d) does not require the use of sophisticated devices.

But like other methods applied, this in their turn presents a disadvantage: the possibility of errors that can be characterized by an eventual decrease in conductivity with increasing hydraulic gradient recorded which could indicate a turbulent flow.

### 2.2.3. *Measuring the Hydraulic Conductivity of the Soil by Applying the Methods in situ*

#### *2.2.3.1. Ring infiltrometer*

**Ring infiltrometers** are relatively simple devices, consisting mainly from a tank (provided with a graduated scale), a metallic ring (single or double) partially into the ground, and a stop valve. The principle of this method is relatively simple if it complies with its application after the following steps.

The principle of this method is simple if it complies the following steps:

i) select the location where you want application of this method represented by the undisturbed soil and enter the infiltrometer in soil;

ii) after the introduction quickly pour some water to the piezometric default and start the timer;

iii) water is added in a constant mode while the piezometric level previously set is maintaining;

iv) the same time must be registered with attention the total volume of water added;

v) after approximately 2,…,3 minutes the timer is stoped;

vi) after stopping the timer, records the total volume of water added into infiltrometer throughout the determination.

It is recommended to repeat the experiment on all soil types, and preferably on the undisturbed (compacted) taking into account the conditions for the site's land.

For the calculation rate of infiltration obtained by determination must be made following steps:

1º Calculate the depth of infiltration (*H*), by dividing the volume of water (*V*) to the surface (*A*) assigned to the base infiltrometer

$$H = \frac{V}{A}. \tag{12}$$

Convert elapsed time during the determination of the minutes in seconds

2º Calculate the infiltration rate by dividing the depth of infiltration (*H*) to the time elapsed (*t*), for example:

$$I = \frac{H}{t}. \tag{13}$$

Observation:The volume of water used in the determination is measured in milliliters: 1 ml = 1 $cm^3$.

The advantages:

a) the time for obtaining dates is small;

b) doesn t requireest sophisticated technical support;

c) low costs for maintenance.

The disadvantages:

a) relatively high costs imposed by carrying out the data acquisition;

b) the obtained data should be recorded at small time intervals (1 to 5 min).

### *2.2.3.2 Mini disk infiltrometer*

Such a small size infiltrometer is ideal for in-situ measurements of soil hydraulic properties, being easily handled and transported. It can be used in hydrological studies, soil, and in training students in specific laboratory works. The main body is made of a polycarbonate tube, to which is attached a disc semi-permeable sintered stainless steel (Catalogul produselor…, 2010). Cylinder is divided into two chambers in which water will be introduced.

Superior enclosure controls the suction rate of the infiltrometer. Lower enclosure is graded and contains water that will be infiltrate into the soil. Infiltrometer is placed on the surface, ensuring good contact with, and it should be noted that the water level in the cylinder at every 30 s.

For the calculation of hydraulic conductivity, observed data are entered, parameters related to soil type (ex. Van Genuchten parameters, Table 1) and the rate of suction (adjusted inside the top of the cylinder) spreadsheet file found on the CD that came with infiltrometer.

**Table 1**
*Van Genuchten Parameters and the Values of a for Mini Disk Infiltrometer*

| Texture | *a* | *n*(*h*) | *A* | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0.145 | 2.68 | –0.5 | –1 | –2 | –3 | –4 | –5 | –6 |
| Sand | 0.124 | 2.28 | 2.9 | 2.5 | 1.8 | 3 | 0.9 | 0.7 | 0.5 |
| Loamy sand | 0.075 | 1.89 | 3.0 | 2.8 | 2.5 | 2.2 | 1.9 | 1.6 | 1.4 |
| Sandy loam | 0.036 | 1.56 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.1 | 4.1 |
| Loam | 0.016 | 1.37 | 5.6 | 5.8 | 6.4 | 7.0 | 7.7 | 8.4 | 9.2 |
| Sill | 0.020 | 1.41 | 8.1 | 8.3 | 8.9 | 9.5 | 10.1 | 10.8 | 11.5 |
| Silt loam | 0.059 | 1.48 | 7.2 | 7.5 | 8.1 | 8.7 | 9.4 | 10.1 | 10.9 |
| Sandy clay loam | 0.019 | 1.31 | 3.3 | 3.6 | 4.3 | 5.2 | 6.3 | 7.6 | 9.1 |
| Clay loam | 0.010 | 1.23 | 6.0 | 6.2 | 6.8 | 7.4 | 8.0 | 8.7 | 9.5 |
| Silty clay loam | 0.027 | 1.23 | 8.1 | 8.3 | 8.7 | 9.1 | 9.6 | 10.1 | 10.6 |
| Sandy clay | 0.005 | 1.09 | 3.4 | 3.6 | 4.2 | 4.8 | 5.5 | 6.3 | 7.2 |
| Silty caly | 0.008 | 1.09 | 6.2 | 6.3 | 6.5 | 6.7 | 6.9 | 7.1 | 7.3 |
| Caly | 0.145 | 2.68 | 4.1 | 4.2 | 4.4 | 4.6 | 4.8 | 5.1 | 5.3 |

The advantages:

a) minimizing the allocated time for data acquisition;

b) doesn t requireest sophisticated technical support;

c) low costs for maintenance.

The disadvantages: the obtained dates should be recorded at small time intervals (1 to 5 min).

## 3. Conclusions

The main objective of this work was characterized by a brief presentation as of the principal method for analyzing hydraulic conductivity using: estimation methods, laboratory methods and measuring devices used in the field. For the estimation of soil permeability have developed pedotransfer functions which have demonstrated the usefulness but also showed some disadvantages attributable to these methods, represented by any uncertainty, some underestimating others overestimating hydraulic conductivity in recent studies conducted by scientists.

For the hydraulic conductivity measurement, in recent years, is frequently used laboratory methods witch have provided good results in comparison with the in situ herein and with reference to the accuracy of data obtained. Making a comparative analysis the methods employed to determine soil permeability can emphasize some advantages and disadvantages.

When one of disadvantages of laboratory methods would be the occurrence of any damage caused by handling and transport of samples to the laboratory and the advantage of these methods is the high control environment in which they occur in situ measurements compared to those who do not have this advantage this constituid a great disadvantage, and that present advantages highlight the possibility of making determinations on undisturbed soils - natural state.

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CONSIDERAȚII PRIVIND METODELE UTILIZATE PENTRU DETERMINAREA CONDUCTIVITĂȚII HIDRAULICE ALE SOLULUI

(Rezumat)

Cercetarea influenței conductivității hidraulice joacă un rol foarte important în transportul apei şi a diferitelor substanțe, marcând într-o mare măsură toate domeniile, subliniem doar câteva dintre ele, cum ar fi hidrologic, pedologic, geotehinic etc..

Conținutul acestui articol a fost strict rezervat pentru studierea metodelor şi tehnologiilor utilizate în determinarea şi măsurarea conductivității hidraulice a solurilor nesaturate şi saturate.

În acest scop, în ultimele decenii s-au dezvoltat şi perfecționat o gamă largă de tehnologii cu aplicabilitate atât în teren cât şi în laborator, care s-au dovedit în cele din urmă utilitatea în estimarea şi analizarea proprietăților fizice care sunt considerate foarte importante, în modelarea transportului de apă şi a diverselor substanțe în zonele nesaturate şi saturate.