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SATURATED HYDRAULIC CONDUCTIVITY MEASUREMENTS OF SOIL SAMPLES AT LABORATORY SCALE

Ružičić Stanko, Flego Anja, Mileusnić Marta, Posavec Kristijan, Durn Goran
University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering, Pierottijeva 6, 10000, Zagreb, CROATIA, e-mail: stanko.ruzicic@rgn.hr, anja.flego@gmail.com, marta.mileusnic@rgn.hr, *kristijan.posavec@rgn.hr, goran.durn@rgn.hr*

Abstract. Saturated hydraulic conductivity (Ks) is one of the most important hydraulic properties affecting water flow in soils/sediments. The objective of this investigation is comparison of different methods for Ks determination. Empirical methods using grain size analysis, ROSETTA pedotransfer function model using grain size analysis and bulk density, as well as falling head test method using permeameter in laboratory conditions were used for determination of Ks in this study. Samples were taken from part of the unsaturated zone profile, located about 800 m from the right bank of the Sava River at the Kosnica water abstraction site. Disturbed samples were collected for grain size analysis, while undisturbed samples were collected for falling head test method. We consider laboratory permeametar method the most reliable among studied methods. However, it is the most time consuming and most expensive method. The choice of method will depend on the time and equipment available, as well as the purpose of investigation.

Keywords: Saturated hydraulic conductivity, unsaturated zone, laboratory scale.

INTRODUCTION

Saturated hydraulic conductivity is a highly valued parameter when dealing with various impact models concerning movement of water in unsaturated zone. The objective of this investigation is comparison of different methods for *Ks* determination. Measurement of *Ks* is an important property whilst investigating e.g. infiltration of water, surface runoff, leaching of pollutants from surface to groundwater, etc. (Bagarello et al., 2006). Many different techniques have been proposed to determine *Ks* value, including field methods, laboratory methods and calculations from empirical formulae (Todd & Mays 2005). Previous laboratory measurements of saturated hydraulic conductivity revealed that it is spatially and seasonably variable given the local heterogeneity of soil (Fodor et al., 2009; 2011). Alternatively, methods of estimating hydraulic conductivity from empirical formulae based on grain-size distribution characteristics have been developed. Numerous investigators have studied this relationship and several formulae have resulted based on experimental work (Beyer, 1966; Shepherd, 1989; Slicther, 1989; Alyamani & Sen 1993). Vukovic and Soro (1992) noted that the applications of different empirical formulae to the same porous medium material can yield different values of hydraulic conductivity, which may differ by a factor of 10 or even 20. This paper represents determination of *Ks* from empirical methods and pedotransfer function model ROSETTA, both using grain size distribution and laboratory measuring using falling head test (FHT). All of these mentioned methods will be explained and compared concerning the quality of data acquired.

MATERIALS AND METHODS

The study area is located near Zagreb, capital city of Croatia, in the second zone of sanitary protection of the water abstraction site Kosnica (45°46' N; 16°05' E). The soil is classified after FAO classification (FAO, 2006) as a Fluvisol (Horizons: A-AC-C-2C/Cl-3Cl-4Cl/Cr-5Cr). In order to determine *Ks*, samples were collected at different depths (0–19 cm, 19–68 cm, 68–110 cm, 110–140 cm, 140-190 cm and 190-215 cm). Disturbed samples were collected for grain size analysis, while undisturbed samples for falling head test method.

Correlation methods (grain size analysis)

In order to derive *Ks* from ROSETTA pedotransfer function model as well as from empirical equations a grain size distribution analysis was conducted in laboratory. Disturbed soil samples (50 g) were taken for grain size distribution analysis. The grain size distribution was determined by wet sieving (2 mm; 1 mm; 0.5 mm; 0.25 mm; 0.2 mm; 0.125 mm; 0.063 mm and 0.032 mm) and sedimentation.

For this study two empirical methods are used.

The first equation used for *Ks* calculation is given by Beyer (1966) as follows:

$$K = \frac{g}{v} \times 6 \times 10^{-4} log \frac{500}{U} d_{10}^{2} \qquad (1)$$

where g is acceleration due to gravity (m/s), v the kinematic viscosity (-), U the coefficient of grain uniformity and is given by $U = (d_{60}/d_{10})$. Where d_{60} and d_{10} are the soil particle diameter (mm) which 60% and 10% of all soil particles are finer.

The second equation used was Slicther's (1989) which is considered to be the most applicable for grain size between 0.01 and 5 mm.

$$K = \frac{g}{v} \times 1 \times 10^{-2} n^{3.287} d_{20}^{2} \qquad (2)$$

where n is porosity that can be derived from the empirical relationship with the coefficient of grain uniformity (U).

Rosetta

Rosetta presents an open-source program which implements pedotransfer functions (PTF) for estimating soil hydraulic parameters (Schaap et al., 2001). In order to calculate *Ks* from Rosetta some basic soil input data is needed such as percentages of sand, silt and clay from grain size analysis and bulk density. Soil bulk density has a particularly significant effect on saturation and hydraulic conductivity as it reflects soil structure and large pore distribution (Saxton & Rawls, 2006).

The hydraulic conductivity *Ks*, can be expressed as follows (Bear 1972):

$$Ks = \frac{k \rho_1 g}{\eta} \qquad (3)$$

where k is intrinsic permeability of soil (m²); ρ_l the density of the fluid (g/cm³); η the coefficient of dynamic viscosity of the fluid (Pa s).

Falling head test

FHT is suitable for fine size material such as silt. Since the grain size analysis for investigated profile showed that the samples mainly consisted of fine sediments FHT seemed appropriate to gain (predicted) large values of hydraulic gradients. For each of the soil horizon, one undisturbed sample (325 cm³) was taken. Sample is set in a stainless steel cell and saturated for at least 24h before the experiment started. After saturation an appropriate hydraulic gradient must be obtained in accordance with sample material. Flow of water through the sample is observed by monitoring the rate of fall of water in the tubes with different diameters (1.5, 3, 4.5 mm). Experiment was performed twice for each sample. The hydraulic conductivity of the sample is calculated with the following equation:

$$k_T = 3.84 \frac{aL}{At} log_{10} \left(\frac{h_1}{h_2}\right) x\, 10^{-5} \qquad (4)$$

where k_T is hydraulic conductivity (m/s); a the area of cross-section of a tube (m²); A the area of cross-section of a sample (m²); L the height of sample in a cell (m); t the time (s); h_1 the height of water in the tube from upper mark to down mark (m); h_2 the height of water in the tube from medium to down mark (m). The Ks value is then calculated separately for the first and second interval and must be corrected for the temperature t (20 °C) by the following equations:

$$K_{20}=RT \times K \qquad (5)$$

$$R_T=2.2902(0.9842^{T})/T^{0.1702} \qquad (6)$$

where K_{20} is corrected hydraulic conductivity for 20 °C (m/s); R_T the ratio between viscosity of water at temperature T during the experiment and viscosity of water at 20 °C temperature; T the average temperature during the experiment (T1+T2)/2) (°C); $T1$ the temperature at the beginning of the experiment (°C); $T2$ the temperature at the end of the experiment (°C).

RESULTS

Investigated soil samples are silt loam except samples from horizons C and 5Cr which are determined as sandy loam (Soil Survey Staff, 1999). Horizons A and AC have almost the same content of clay particles and similar pattern of sand and silt ratio, as well as horizons C and 5Cr which have even more similar grain distribution (Fig. 1). Furthermore similar pattern can be also seen in horizons 2C/Cl and 4Cl/Cr.

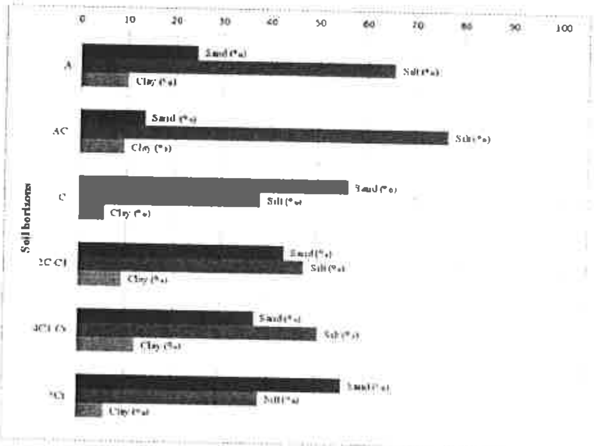

Figure 1: *Soil profile with grain size distribution*

Table 1 shows calculated Ks determined using different methods. Horizons A and AC were determined as silt loam with almost the same content of clay hence the calculated Ks showed similar or same values of Ks. Rosetta model gave higher values of Ks for all horizons compared to other methods. The first horizon has the biggest Ks due to its bulk density. FHT method and Slitcher gave similar values. Horizon 4Cl/Cr has the smallest Ks due to its clay content. Breyer method shows the smallest value for horizon 4Cl/Cr as in Slitcher method.

Table 1. *Saturated hydraulic conductivities calculated from grain-size analysis using correlation and laboratory methods.*

		Ks (m/s)			
Depth (cm)	Soil horizons	Breyer	Slitcher	ROSETTA	FHT
0-19	A	4.15E-07	2.30E-08	1.81E-05	5.23E-08
19-68	AC	6.96E-07	2.30E-08	5.23E-06	5.59E-08
68-110	C	7.23E-06	3.67E-07	7.01E-06	2.14E-07
110-140	2C/Cl	8.20E-07	5.17E-08	4.03E-06	7.43E-08
140-190	4Cl/Cr	6.37E-08	5.74E-09	2.78E-06	1.57E-08
190-215	5Cr	5.41E-06	2.81E-07	5.94E-06	3.85E-07

CONCLUSIONS

Empirical methods using grain size analysis, ROSETTA pedotransfer function model using grain size analysis and bulk density, as well as falling head test method using permeameter in laboratory conditions were used for determination of *Ks* in this study. Rawls et al. (1982) produced a table with average *Ks* based on 11 soil textural USDA classes. An average *Ks* for silt loam is 1.89 x 10^{-6} (m/s) and for sandy loam 7.19 x 10^{-6} (m/s). The *Ks* values derived from ROSETTA model fall into this category. Empirical methods and laboratory methods have slightly higher *Ks* value, but still of the same magnitude. Results showed that the hydraulic conductivities calculated by the Slicther method are for all horizons lower than for the other methods. Beyer method is considered more accurate for well- graded samples such as samples from investigated profile, but it overestimated *Ks* values. Values of *Ks* determined using FHT method gave the best results according to Bowles (1984) classification. In comparison with other methods, FHT is the most demanding method. It needs laboratory apparatus and it is the most time consuming. Other investigated methods need sieves. ROSETTA pedotransfer function model in addition needs equipment for undisturbed samples and more time for preparation of samples. We consider laboratory FHT method the most reliable among studied methods. However, it is the most time consuming and the most expensive method. The choice of method should depend on the time and equipment available, as well as the purpose of investigation.

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REFERENCES

Alyamani M. S. and Sen Z. 1993.Determination of Hydraulic Conductivity from Grain-Size Distribution Curves. *Ground Water* No. 31: 551-555.

Bagarello V., Elrick D.E., Iovino M. and Sgroi A. 2006. A laboratory analysis of falling head infiltration procedures forestimating the hydraulic conductivity of soils. *Geoderma* No. 135: 322–334.

Bear J. 1972. Dynamics of fluids in porous media. New York: Elsevier.

Beyer W. 1966. Hydrogeologische Untersuchungen bei der Ablagerung von Wasserschadstoffen. *Zeitschrift fuer Angewandte Geologie* v 12 No. 11:599-606.

Bowles J.E. 1984. Physical and Geotechnical Properties of Soils. 2nd Edition, New York: McGraw-Hill Book Company.

FAO. 2006. A framework for international classification, correlation and communication World Soil Resources Reports No. 103. FAO, Rome.

Fodor N., Blaskó L., Éri L. and Rajkai, K. 2009. Comparing hydraulic conductivity determination methods on sandy soil. Agrokém. *Talajt* No. 58: 369–380 (In Hungarian).

Fodor N., Sándor R., Orfanus T., Lichner L. and Rajkai, K. 2011. Evaluation method dependency of measured saturated hydraulic conductivity. *Geoderma* No. 165:60–68.

Oosterbaan R.J. and Nijland H.J. 1994. Determining the saturated hydraulic conductivity In: H.P.Ritzema (Ed.), Drainage Principles and Applications. International Institute for Land Reclamation and Improvement (ILRI), Publication 16, second revised edition, Wageningen, The Netherlands, 1-37.

Odong, J. 2007. Evaluation of empirical formulae for determination of hydraulic conductivity based on grain size analysis. *Journal of American Science* No.3: 54-60.

Rawls W. J., Brakensiek D.L. and Saxton K.E. 1982. Estimation of soil water properties. *American Society of Agricultural Engineers* No. 25:1316-1320.

Saxton K. E. and Rawls W. J. 2006. Soil Water Characteristic Estimates by Texture and Organic Matter for Hydrologic Solutions. *Soil Science Society of America Journal* No. 70: 1569-1578.

Schaap M.G., Leij F.J. and Van Genuchten M.T. 2001. ROSETTA: a computer program for estimating soil hydraulic parameters with hierarchical pedotransfer functions. *Journal of Hydrology* No. 251: 163-176.

Shepherd R.G. 1989. Correlations of Permeability and Grain Size. *Groundwater* No. 27(5): 663-638.

Slicther C.S. 1898. Theoretical investigations of the motion of ground waters: United States Geological Survey, 19 th Annual Report, p 295-384.

Soil Survey Staff 1999. Soil Taxonomy. A Basic System of Soil Classification for Making and Interpreting Soil Surveys, 2nded. Washington D.C.: United States Department of Agriculture, Agriculture Handbook No. 436.

Todd D.K., and Mays L.W. 2005.Groundwater Hydrology. New York: John Wiley & Sons.

Vukovic M. and Soro A. 1992. Determination of Hydraulic Conductivity of Porous Media from Grain-Size Composition. Colorado: Water Resources Publications, Littleton.