

Determining the anisotropy of the hydraulic conductivity on sand samples

A szivárgási tényező anizotrópiájának meghatározása homokmintákon

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Abstract – One of the most important properties of porous media is the so-called hydraulic conductivity. Hydraulic conductivity determinations are important for resolving hydrogeological problems, management and protection of groundwater resources, soil mechanics, geotechnics and environmental geology projects. In fact the hydraulic conductivity is a site specific parameter, which horizontal, vertical changes and directional dependence could have an affect significantly on the prediction of hydrodynamic, geotechnical or transport models.

This paper present a comparison of hydraulic conductivity K values of unconsolidated fluvial sand samples collected at two sandpits near Nagykereki in the Berettyó–Körös region. The aim was to investigate whether anisotropy or with other words, directional dependence of hydraulic conductivity may occur or not. The K values were determined using laboratory permeameter as well as were calculated using empirical formulas of Beyer, Hazen and Zamarin. Undisturbed samples were taken from five directions: vertical, horizontal parallel and horizontal perpendicular to flow, and parallel and vertical to stratification and the hydraulic conductivity measurement was carried out using Eijkelkamp laboratory permeameter. After the measurement the undisturbed sand samples were dried and a mixed. With these new samples the measurement was repeated.

For this study site it was found that definite hydraulic conductivity anisotropy cannot be observed, however small scale effects of stratification were detected. Hydraulic calculation methods based on grain-size distribution data cannot be applied to demonstrate anisotropy. The hydraulic calculations using Hazen and Beyer methods yielded almost the same values that were measured in laboratory on the samples with mixed stratification. Despite the fact that with the Zamarin calculation we got much smaller values they can be compared to the values of the natural stratification.

Összeoglalás – Porózus víztartó rétegek egyik leggyakrabban vizsgált tulajdonsága az úgynevezett szivárgási tényező. A szivárgási tényező minél pontosabb meghatározása hidrogeológiai, vízgazdálkodási, vízbázis védelmi problémákon túl a talajmechanikai, geotechnikai és környezetföldtani projektek esetében is kiemelt fontossággal bír. A szivárgási tényező olyan helyspecifikus paraméter, amely horizontális, vertikális eltérései, irányfüggősége jelentős mértékben hatással lehet hidrogeológia, geotechnikai, vagy szennyeződésterjedési modellek előrejelzésére.

Jelen cikkben a Berettyó–Körös-vidék területén található Nagykereki melletti két homokbányából gyűjtött konszolidálatlan folyóvízi homokmintákon végzett laboratóriumi szivárgási tényező mérések és Beyer, Hazen, valamint Zamarin-féle szivárgási tényező számítások eredményeit mutatjuk be. Konkrétan arra keresünk választ, hogy a vizsgálati területen szivárgási tényező irányfüggősége, vagy más néven anizotrópiája kimutatható-e. Ennek érdekében zavartalan mintákat gyűjtöttük függőleges, folyási iránnyal párhuzamos, arra merőleges, valamint rétegzésre merőleges és azzal párhuzamos irányok szerint. A szivárgási tényező mérését laboratóriumi Eijkelkamp gyártmányú permeabiméteren végeztük. A mérést követően a zavartalan mintákat kiszáritottuk, majd a homok eredeti rétegzést megbontva, keverten visszatettük a hengerbe és a laboratóriumi mérést újból elvégeztük.

A vizsgálati területen határozott szivárgási tényező anizotrópia nem volt kimutatható, azonban a rétegzettség kis mértékben befolyásolta az értékeket. A szemeloszlás adatokon alapul szivárgási tényező számítási módszerek az anizotrópia kimutatására nem alkalmasak. A Hazen és Beyer módszerekkel számított szivárgási tényező adatok jó egyezést mutattak a laboratóriumban átkevert mintákon mért értékekkel. Ezzel ellentétben Zamarin módszerrel számolva lényegesen kisebb értékeket kaptunk az eredeti, természetes rétegzésen mért eredményekhez képest.

Keywords – hydraulic conductivity, anisotropy, grain size distribution, Beyer, Hazen, Zamarin methods

Tárgyszavak – szivárgásitényező, anizotrópia, szemcse eloszlás, Beyer, Hazen, Zamarin módszerek

Introduction

All the waters on the surface are in connection with the groundwaters, creating a very changeable and vulnerable system that can be easily damaged by human activity. Preserving the water quality nowadays there are more and more researches dealing with the mining, utilization, and contamination of the ground water.

It is essential to know all the properties of the groundwater and bearing media. This knowledge helps us to plan all the facilities are in connection with the water, and also the research of the soil mechanics.

One of the most important properties of the porous media, which determines the flow of fluids is the hydraulic conductivity. In fact the hydraulic conductivity is a combined property of the medium and fluid, some of which the grain-size distribution, the grain fabric, orientation, porosity, fluid viscosity and the amount of

insoluble gases in the pore are the most important (VERVOORT & CATTLE 2003). These properties mentioned above show spatial heterogeneity within a sedimentary deposit resulting directional dependency or anisotropy. The phenomenon of anisotropy is very typical of stratified sedimentary system. These kind of sedimentary systems form in marine, fluvial or aeolian environments mainly.

In Hungary the significant part of the Great Hungarian Plain (GHP) is covered by young, stratified, coarse-grained (gravel and sand) fluvial deposits with high permeability. The diverse stratification, random occurrence of divergent dips, trough-type cross-beddings, erosional surfaces, channel or scour and fill structures, bioturbation and erosional marks are main features of sand deposited in fluvial environment.

In this paper we provide information about the hydraulic conductivity anisotropy of fluvial sand deposits situated near Nagykereki.

Geographical and geological frame

To study the hydraulic conductivity anisotropy of fluvial sand deposits a sampling area was chosen near the village of Nagykereki in the Berettyó–Körös region, which is located in the eastern part of the GHP. The examined samples were collected from a sandpit near the village, which is situated 45 km far from Debrecen to southward direction. In this mining claim the fluvial sand is mined in two site, the so called Nagykereki I. and the Nagykereki II. During the field work both of the sites were sampled.

Quaternary is the final episode in the geological evolution. It begins when the filling up of the Pannonian Lake is ended (RÓNAI 1985). Quaternary can be divided into two parts: the older and longer Pleistocene and the younger Holocene. Approximately 90 % of the surface of Hungary is covered by Quaternary sediments (JÁMBOR 1998). Their thickness is only a few meters in mountain areas, 3–30 m in hilly territory and can reach couple hundred meters in the basin (Fig. 1).

The material of the Quaternary sediments derived from four main sources (BÉRCZY & JÁMBOR 1998). The largest part of the sediment was transported and deposited by rivers and streams. The second large part of the sediments is aeolian by its origin. Finally Quaternary sediments formed in karst areas due to the dissolution limestone and precipitation of calcium carbonate (travertine, limnic lime), while volcanic pyroclastics also deposited in a minor amount. The Quaternary sediments were not divided into formations; their classification is based on genetic viewpoints (GYALOG 1996).

The Pannonian Basin was a periglacial area during the Pleistocene. The significant portion of the Quaternary sediments was deposited in that time, while certain parts of the Pannonian Basin sank. Due to the tectonic movements

and the sediment transport of the rivers fluvio-lacustrine, alluvial deposits and fan complex were formed.

In the Middle Pleistocene the sediment transport of the rivers decreased and semi-aquitards and aquitards were formed due to the high clay content. In the Upper Pleistocene aquifers with high permeability were formed again, thank to the increased stream gradient. These aquifers are close to the surface and more sensible to contamination. The Pleistocene fluvial layers are covered by or connected with loess deposits, however Upper Pleistocene-Holocene aeolian sand also covered significant areas (Fig. 2).

At present the surface is built up by a few meters thick Holocene alluvial deposits (sand, aleurit), however the Pleistocene formations also occur in patches.

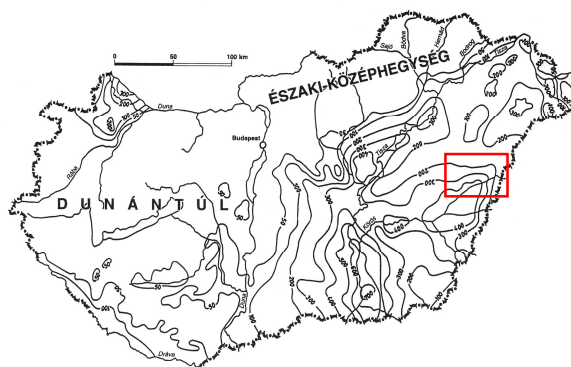


Figure 1 Thickness of quaternary sediments, the sampling area is signed with a rectangle (RÓNAI & FRANYÓ, 1989 in BORSY, 1992)

1. ábra: A kvarter üledékek vastagsági térképe, piros színnel jelölve a mintaterület (RÓNAI & FRANYÓ, 1989 in BORSY, 1992)

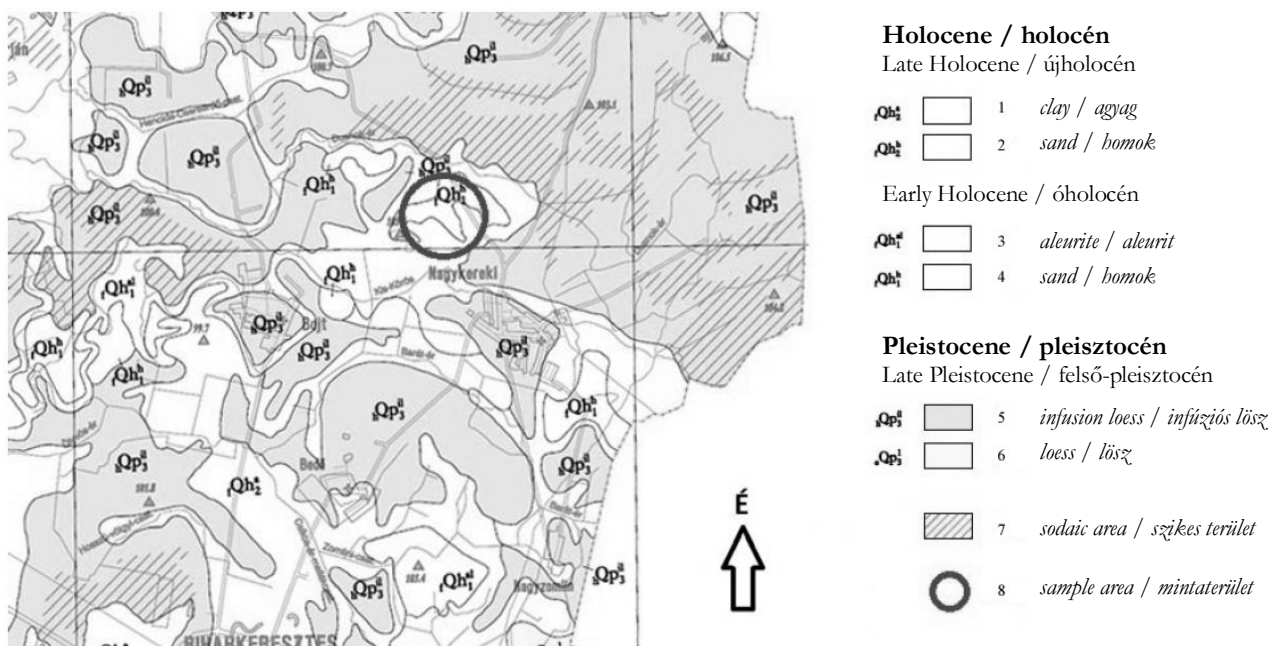


Figure 2: The Quaternary sediments on the sampling site (according to GYALOG 2005)

2. ábra: A negyedidőszaki üledékek a vizsgált területen (GYALOG 2005)

Research methods and theoretical background

Determining the hydraulic conductivity of sand or any other soil can be done with correlation methods or with hydraulic methods (RITZEMA 1994). Hydraulic methods can be divided to laboratory methods and *in situ* (field) methods. The hydraulic laboratory methods are based on applying the Darcy's Law.

The Darcy's Law describe the flow of a fluid through a porous media, but it is valid for the laminar flowing of fluids. In nature not only laminar, but turbulent fluid flow also may occur, however in our case according to KOVÁCS (1972) only laminar flow appears, because in porous media the flow is really slow despite that the pores make a curvy medium.

If the flow is three dimensional the following formula of the Darcy's Law is used:

$$\vec{q} = -K \cdot \text{grad}h$$

where q : specific discharge [m/s]
 $\text{grad}h$: hydraulic head gradient vector [-]
 K : hydraulic conductivity [m/s]

Based on Darcy's experiments in the water discharge through a homogenous porous sample:

$$Q = K \cdot A \cdot \frac{(h_1 - h_2)}{L}$$

where Q : water discharge [m³/s]
 K : hydraulic conductivity [m/s]
 A : sample cross-section [m²]
 h_1-h_2 : hydraulic head difference [m]
 L : sample length [m]

Correlation methods for determining the hydraulic conductivity are based on the relationships between K-value and soil properties such as texture, pore-size and grain-size distribution of the soils (RITZEMA 1994).

There are several formulas to calculate the hydraulic conductivity. Most of them use grain-size distribution as the main part of the formulas, but in this way anisotropy cannot be calculated.

To calculate the hydraulic conductivity from the grain-size distribution the following three different calculation methods were used:

Beyer's formula (BEYER 1967):

$$K = \frac{g}{\nu} \left[(6 \cdot 10^{-4}) \log \frac{500}{\frac{d_{60}}{d_{10}}} \right] \cdot d_{10}^2$$

where K : hydraulic conductivity [cm/s]
 g : acceleration of gravity [9.81 m/s]
 ν : kinematic coefficient of viscosity at water temperature of 30 °C [m²/s]
 d_{60} : diameter of grains in the 60th percentile [mm]
 d_{10} : diameter of grains in the 10th percentile [mm]

Hazen's formula (HAZEN 1892, 1911):

$$K = 116 \cdot d_e^2$$

where K : hydraulic conductivity [cm/s]
 d_e : Hazen's effective grain size, relative to which 10% of the sample is finer [cm]

Zamarin's modified formula (ZAMARIN 1954):

$$K = 3500 \cdot \frac{n^3}{1-n} \cdot (1.275 - 1.5n)^2 \cdot d_z^2$$

where K : hydraulic conductivity [m/day]
 n : porosity [-]
 d_z : effective grain size according to Zamarin [mm]

$$\frac{1}{d_z} = \sum_i A_i \cdot \Delta G_i$$

where ΔG_i : i-th fraction weight in part of the total weight [-]
 A_i : value of the weight function by Zamarin belonging to the i-th fraction [-]

The anisotropy is a term used to denote preferential directions in materials. If the value of hydraulic conductivity is dependent directionally at a point within a soil layer, which means anisotropic, then this dependence can expressed graphically by an ellipsoid (Fig. 3).

The beds in a sediment are not horizontal in many cases, which result complex spatial pattern in the hydraulic conductivity (MARTON 2009). If the grain fabric is not oriented parallel to the bedding, then the effective hydraulic conductivity ellipsoid is a combined result of K-values associated to grain fabric and lamination (BERG & VRIES 2003).

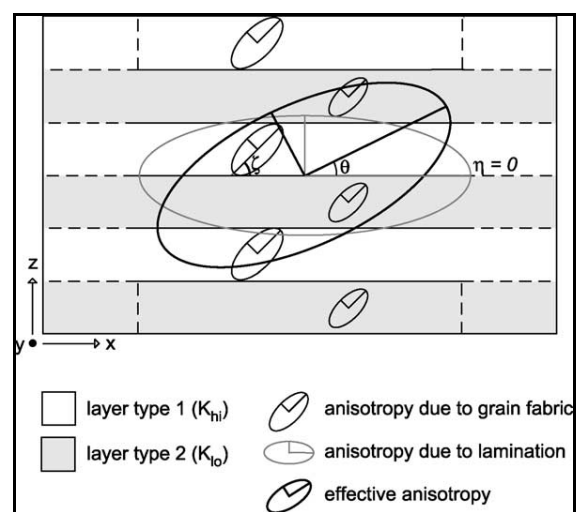


Figure 3: Formation of anisotropy in stratified system (BERG & VRIES 2003)

3. ábra: Anizotrópia kialakulása rétegzett rendszerben (BERG & VRIES 2003)

Fieldwork and sampling

As the aim of this study was to investigate the anisotropy of the hydraulic conductivity, undisturbed oriented samples were required for the laboratory measurements. Oriented core samples were taken from the two sandpits during the year of 2012. Samples were taken from five directions: vertical, horizontal parallel and horizontal perpendicular to flow, and parallel and vertical to stratification (Fig. 4). In the case of horizontal stratification only three direction were sampled (one vertical and two horizontal perpendicular to each other).

From each direction three samples were collected. Five sampling sites were made and all together 56 samples were collected.

The undisturbed core sample were collected into stainless steel Eijkelkamp cylinders (length 5 cm, diameter 5.1 cm). The cylinders were sealed with plastic caps. These core samples were used to determine the grain-size distribution after the hydraulic conductivity measuring (BUDAY et al. 2012).

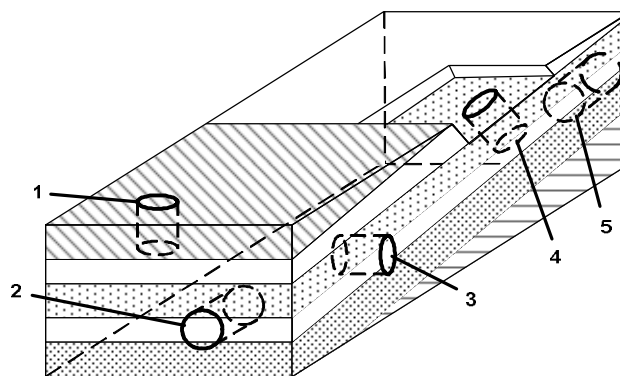


Figure 4: Sketch of the oriented undisturbed sampling. 1 - vertical, 2 - parallel to flow, 3 - perpendicular to flow, 4 - perpendicular to stratification, 5 - parallel to stratification sampling

4. ábra: Orientált zavartalan mintavételezés elvi ábrája.
1 - függőleges, 2 - áramlással párhuzamos, 3 - áramlásra merőleges, 4 - rétegzésre merőleges, 5 - rétegzéssel párhuzamos mintavétel



Figure 5: Oriented undisturbed samples

5. ábra: Orientált zavartalan minták

Bioturbation may occur in certain part of the sand deposit. The bioturbation usually modify the primary, original orientation of the grains, thus may affect to the K value. If we avoid to get samples from bioturbation, than the results cannot be regarded representative for the sand layer, however if a sample contains bioturbation, then the homogeneity of the set of the samples is not resolved.

Laboratory measurements

Hydraulic conductivity measurement

All the analysis were carried out in the laboratory of the Department of Mineralogy and Geology, University of Debrecen. The hydraulic conductivity was determined by

laboratory permeameter on constant pressure. The main point of this method is to make a constant water pressure difference between the two endpoints of the sample, while the volume of the water flowing through in a given time is measured (KLUTE & DIRKSEN 1986). For the measurements an Eijkelkamp type permeameter was used (Fig. 6). The samples were saturated upwards by the following method: a small piece of hydrophilic gauze were placed on the bottom end of the samples, then they were place in water in a porcelain dish for saturation.

After the determination of the hydraulic conductivity of the sand samples with natural stratification, the samples were dried and a mixed. With these new samples the measurement was repeated (BUDAY et al. 2012).

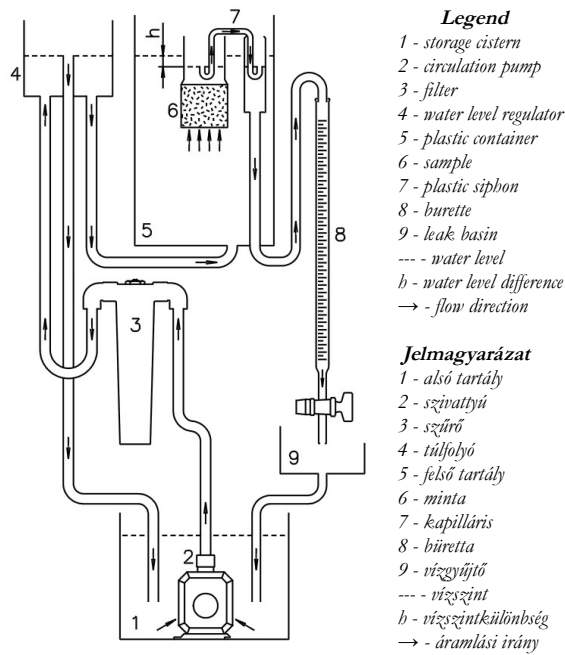


Figure 6: Sketch of Eijkelkamp type permeameter (www.eijkelkamp.com)

6. ábra: Eijkelkamp típusú permeabiméter elvi ábrája (www.eijkelkamp.com)

Through the processing of results the following standardized abbreviation were used.

- 1.1nk sample ID
- f vertical
- v horizontal
- vm horizontal and perpendicular to forming flow direction
- vp horizontal and parallel with forming flow direction
- rm perpendicular to stratification
- rp parallel with stratification

Darcy's Law was used to calculate the K-value:

$$K = \frac{l}{h \cdot F} \cdot \frac{\Delta V}{\Delta t}$$

- where K : hydraulic conductivity [m/s]
- l : length of the sample [m]
- h : water level difference [m]
- ΔV : volume of water flowing through the sample [m³]
- F : cross-section of the sample [m²]
- Δt : time used for flow through water volume ΔV [s]

Porosity and matrix density

After the determination of hydraulic conductivity of the sand samples with natural and mixed artificial stratification the porosity and matrix density were calculated. Proceed to the permeameter measurement the masses of the saturated samples with the stainless steel cylinders and the gauzes were measured.

After that the masses of the dried sand samples plus the masses of the steel cylinders and the wet gauzes also were measured. On the basis of the obtained data the porosity and the matrix density of the soil samples can be calculated.

Calculation of porosity:

$$n = \frac{m_{water}}{A \cdot l \cdot \rho}$$

- where n : porosity [-]
- m_{water} : mass of the water [g]
- A : cross-section of the sample [cm²]
- l : sample length [cm]
- ρ : water density [g/cm³]

Calculation of matrix density:

$$\rho_m = \frac{m_d}{A \cdot l - \frac{m_{water}}{\rho}}$$

- where ρ_m : matrix density [-]
- m_d : mass of dried sample [g]
- A : cross-section of sample [cm²]
- l : sample length [cm]
- m_{water} : mass of the water [g]
- ρ : water density [g/cm³]

After determining the hydraulic conductivity, porosity and matrix density, the grain-size distribution of the samples were measured by sieve analysis and hydrometer analysis methods (KÉZDY 1964).

Before sieving the samples were dried at 105 °C temperature for 2 to 3 hours. Next the dry mass of samples were determined accurately using laboratory balance. 100–200 g specimen were taken in porcelain dishes from every sample, were soaked in ionized water and were mixed in a blender for 10 minutes. The sediment slurry was washed through 0.08 and 0.063 mm sized sieves. The proportion of soil passing through was collected in a porcelain dish and was transferred into an empty, 1000 cm³ sedimentary cylinder. The soil retained on the sieves was transferred in a porcelain dish and was dried out at 105 °C.

Set of sieves with 5.0, 4.0, 3.15, 2.5, 2.0, 1.6, 1.25, 1.0, 0.8, 0.63, 0.5, 0.4, 0.315, 0.25, 0.2, 0.16, 0.125, 0.1, 0.08, 0.063 mm opening sizes were prepared and a pan was placed under it to collect the portion of soil passing through. The sieve stack was placed in a CISA mechanical shaker and was shaken for 10–12 minutes. The mass of soil retained on each sieve and the pan at last were measured by using laboratory balance. The material accumulated in the pan was transferred into its sedimentary cylinder. 1cm³ of dispersing agent (waterglass) was added into the sedimentary cylinder and was filled with ionized water to the mark. The slurry was shaken well and a Pappfalvi hydrometer was used to measure the suspension's density. Hydrometer readings were taken after elapsed time of 0.5, 1, 2, 5, 45 minutes and 2, 6, 24 and 48 hours.

Table 1: Measured calculated K-values, porosity and matrix density of the samples
 1: táblázat: A minták mért és számított szivárgási tényező, porozitás és matrixsűrűség értékei

		measured hydraulic conductivity (cm/s)						calculated hydraulic conductivity (cm/s)			porosity		matrix density		
		natural stratification			mixed			Beyer	Hazen	Zamarin	(-)		(g/cm ³)		
		k	mean	deviation	k	mean	deviation				átlag	natural	mixed	natural	mixed
1.1nk vm	1	6.00E-02			7.72E-02			4.50E-02	4.31E-02	1.18E-02	3.33E-02	0.50	0.49	2.87	2.64
	2	1.88E-02			2.33E-02			3.50E-02	4.13E-02	6.24E-03	2.75E-02	0.48	0.57	3.01	3.44
	3	2.49E-02			3.90E-02			4.20E-02	4.81E-02	4.70E-03	3.16E-02	0.47	0.47	2.77	2.68
			3.46E-02	2.22E-02		4.65E-02	2.77E-02								
1.1nk vp	1	1.92E-02			2.92E-02			4.50E-02	4.93E-02	5.68E-03	3.33E-02	0.49	0.45	3.03	2.67
	2	7.44E-02			5.58E-02			4.50E-02	4.83E-02	1.46E-02	3.59E-02	0.55	0.47	2.62	2.56
	3		4.68E-02	3.90E-02		4.25E-02	1.88E-02								
1.1nk f	1	4.45E-02			4.40E-02			3.50E-02	4.04E-02	1.37E-07	2.51E-02	0.43	0.52	2.44	2.93
	2	5.41E-02			4.10E-02			4.50E-02	4.74E-02	4.19E-03	3.22E-02	0.43	0.47	2.41	2.72
	3	5.41E-02			2.64E-02			3.50E-02	3.69E-02	1.50E-03	2.45E-02	0.43	0.49	2.33	2.82
			5.09E-02	5.57E-03		3.71E-02	9.40E-03								
1.1nk rp	1	5.74E-02			4.12E-02			4.50E-02	4.28E-02	1.36E-02	3.38E-02	0.44	0.49	2.35	2.81
	2	9.46E-03			2.25E-02			2.00E-02	2.23E-02	1.25E-04	1.41E-02	0.47	0.44	2.82	2.56
	3	2.83E-02			2.32E-02			2.70E-02	2.94E-02	3.81E-04	1.89E-02	0.43	0.45	2.27	2.52
			3.17E-02	2.41E-02		2.90E-02	1.06E-02								
1.1nk rm	1	2.06E-02			1.73E-02			2.00E-02	2.14E-02	1.30E-04	1.38E-02	0.50	0.48	2.78	2.72
	2	3.75E-02			1.61E-02			2.80E-02	3.13E-02	1.63E-03	2.03E-02	0.49	0.47	2.72	2.79
	3	2.11E-02			2.48E-02			2.80E-02	3.19E-02	5.43E-03	2.18E-02	0.48	0.50	2.53	2.66
			2.64E-02	9.58E-03		1.94E-02	4.70E-03								
1.2nk f	1	2.62E-02			1.48E-02			2.30E-02	2.62E-02	1.46E-02	2.13E-02	0.39	0.42	2.36	2.73
	2	1.30E-02			1.14E-02			1.70E-02	2.04E-02	1.07E-03	1.28E-02	0.41	0.41	2.45	2.61
	3	7.41E-03			1.83E-02			1.80E-02	1.89E-02	4.47E-03	1.38E-02	0.40	0.48	2.46	2.99
			1.55E-02	9.64E-03		1.48E-02	3.47E-03								
1.2nk v	1	7.68E-02			4.43E-02			3.30E-02	4.07E-02	9.01E-03	2.76E-02	0.42	0.45	2.47	2.74
	2	3.58E-02			3.16E-02			3.30E-02	4.02E-02	1.77E-03	2.50E-02	0.38	0.37	2.34	2.47
	3	3.85E-02			2.44E-02			2.50E-02	3.04E-02	2.69E-04	1.86E-02	0.40	0.41	2.36	2.58
			5.03E-02	2.29E-02		3.44E-02	8.47E-03								
2.1nk vm	1	4.36E-02			3.42E-02			3.60E-02	3.39E-02	5.88E-03	2.53E-02	0.46	0.50	2.39	2.77
	2	4.43E-02			1.91E-02			3.50E-02	4.12E-02	1.06E-03	2.57E-02	0.48	0.49	2.51	2.85
	3	5.36E-02			4.64E-02			3.50E-02	3.60E-02	8.46E-03	2.65E-02	0.49	0.49	2.50	2.81
			4.72E-02	5.63E-03		3.32E-02	1.36E-02								
2.1nk vp	1	4.64E-02			5.62E-02			3.50E-02	3.70E-02	3.97E-04	2.41E-02	0.50	0.50	2.56	2.80
	2	5.69E-02			4.12E-02			3.50E-02	3.59E-02	3.32E-03	2.48E-02	0.49	0.50	2.60	2.85
	3	3.62E-02			4.96E-02			4.20E-02	4.38E-02	2.37E-03	2.94E-02	0.51	0.48	2.78	2.79
			4.65E-02	1.04E-02		4.90E-02	7.51E-03								
2.1nk f	1	4.31E-02			3.43E-02			2.80E-02	3.01E-02	1.03E-04	1.94E-02	0.48	0.49	2.68	2.87
	2	3.22E-02			3.04E-02			n.d.	n.d.	n.d.	n.d.	0.47	0.48	2.58	2.76
	3	2.85E-02			2.52E-02			n.d.	n.d.	n.d.	n.d.	0.46	0.47	2.58	2.75
			3.46E-02	7.56E-03		3.00E-02	4.59E-03								
2.1nk rp	1	3.46E-02			5.44E-02			4.50E-02	4.89E-02	9.69E-03	3.45E-02	0.51	0.54	2.63	3.06
	2	4.87E-02			3.93E-02			4.50E-02	4.52E-02	2.22E-03	3.08E-02	0.50	0.50	2.75	2.92
	3	5.85E-02			4.03E-02			3.60E-02	3.78E-02	4.98E-03	2.63E-02	0.51	0.50	2.84	2.98
			4.73E-02	1.20E-02		4.47E-02	8.43E-03								
2.1nk rm	1	3.24E-02			5.49E-02			5.10E-02	5.52E-02	5.09E-03	3.71E-02	0.50	0.48	2.59	2.72
	2	5.40E-02			4.94E-02			4.50E-02	4.96E-02	8.45E-03	3.43E-02	0.50	0.51	2.62	2.92
	3	5.10E-02			4.97E-02			4.50E-02	4.65E-02	1.82E-03	3.11E-02	0.49	0.50	2.70	2.94
			4.58E-02	1.17E-02		5.13E-02	3.09E-03								
2.2nk vm	1	4.62E-02			2.52E-02			2.70E-02	3.23E-02	1.08E-03	2.01E-02	0.48	0.47	2.67	2.81
	2	5.80E-02			3.34E-02			2.70E-02	3.14E-02	1.10E-03	1.98E-02	0.52	0.47	2.82	2.66
	3	4.33E-02			2.47E-02			2.50E-02	2.46E-02	1.04E-03	1.69E-02	0.50	0.47	2.79	2.78
			4.92E-02	7.78E-03		2.78E-02	4.86E-03								
2.2nk vp	1	3.86E-02			2.15E-02			1.20E-02	1.47E-02	5.76E-04	9.08E-03	0.48	0.46	2.52	2.71
	2	2.97E-02			2.12E-02			1.60E-02	1.65E-02	8.68E-04	1.11E-02	0.57	0.53	2.83	2.99
	3	4.04E-02			1.92E-02			1.60E-02	1.54E-02	1.04E-03	1.08E-02	0.52	0.45	2.70	2.60
			3.63E-02	5.72E-03		2.07E-02	1.24E-03								
2.2nk f	1	3.44E-02			2.15E-02			1.80E-02	1.87E-02	1.84E-03	1.29E-02	0.46	0.46	2.61	2.77
	2	4.83E-02			2.04E-02			2.40E-02	2.78E-02	2.06E-03	1.80E-02	0.48	0.47	2.75	2.87
	3	2.16E-02			2.61E-02			1.90E-02	1.95E-02	1.70E-03	1.34E-02	0.48	0.49	2.75	2.91
			3.48E-02	1.34E-02		2.26E-02	3.02E-03								
2.2nk rp	1	5.11E-02			2.32E-02			1.80E-02	1.92E-02	1.99E-04	1.25E-02	0.49	0.46	2.59	2.68
	2	4.42E-02			2.53E-02			2.10E-02	2.41E-02	8.34E-04	1.53E-02	0.49	0.49	2.65	2.81
	3	4.71E-02			2.98E-02			2.00E-02	2.25E-02	9.01E-04	1.45E-02	0.47	0.47	2.64	2.79
			4.75E-02	3.48E-03		2.61E-02	3.41E-03								
2.2nk rm	1	2.59E-02			3.44E-02			3.50E-02	3.63E-02	2.27E-03	2.45E-02	0.48	0.46	2.76	2.76
	2	2.79E-02			3.47E-02			3.50E-02	3.47E-02	2.40E-03	2.40E-02	0.46	0.45	2.46	2.63
	3	2.83E-02			3.94E-02			3.50E-02	3.54E-02	2.20E-03	2.42E-02	0.46	0.47	4.38	2.68
			2.74E-02	1.28E-03		3.62E-02	2.84E-03								
2.3nk f	1	3.59E-02			2.06E-02			3.50E-02	3.68E-02	8.58E-04	2.42E-02	0.36	0.48	2.28	2.80
	2	5.15E-02			1.10E-02			3.50E-02	3.80E-02	7.87E-04	2.46E-02	0.59	0.43	2.98	2.42
	3	4.77E-02			2.15E-02			4.50E-02	4.50E-02	1.03E-03	3.03E-02	0.49	0.45	2.67	2.57
			4.50E-02	8.10E-03		1.77E-02	5.85E-03								
2.3nk v	1	7.60E-02			2.12E-02			4.50E-02	4.83E-02	1.21E-03	3.15E-02	0.50	0.48	2.67	2.69
	2	8.87E-02			5.60E-02			5.40E-02	5.18E-02	1.14E-03	3.57E-02	0.50	0.47	2.61	2.64
	3	7.49E-02			3.91E-02			3.50E-02	3.96E-02	9.20E-04	2.52E-02	0.51	0.48	2.67	2.73
			7.99E-02	7.66E-03		3.87E-02	1.74E-02								

Results

Hydraulic conductivity

By applying permeameter measurements for a sample we defined two different hydraulic conductivity K-values, one for the natural stratification and one for the mixed, without stratification.

The results suggest that within a series of measurements the samples with the mixed stratification have more similar values than the samples with the natural stratification.

Samples perpendicular to the stratification showed the lowest hydraulic conductivity in the most cases, while the highest values occurred when the samples were parallel with the stratification. The results are shown in *Table 1*.

Porosity and matrix density

According to the results of the samples collected from the different directions it can be stated that samples with natural and mixed, artificial stratification have almost the same porosity and matrix density values (*Table 1*). These results are very important, because they indicate that significant grain loss did not occur while the man-made samples were produced.

Grain-size distribution

Cumulative curves of grain-size distribution were plotted (*Fig. 7*). The curves of the samples taken from the same direction show little differences, however, comparing the different directions also small changes can be observed.

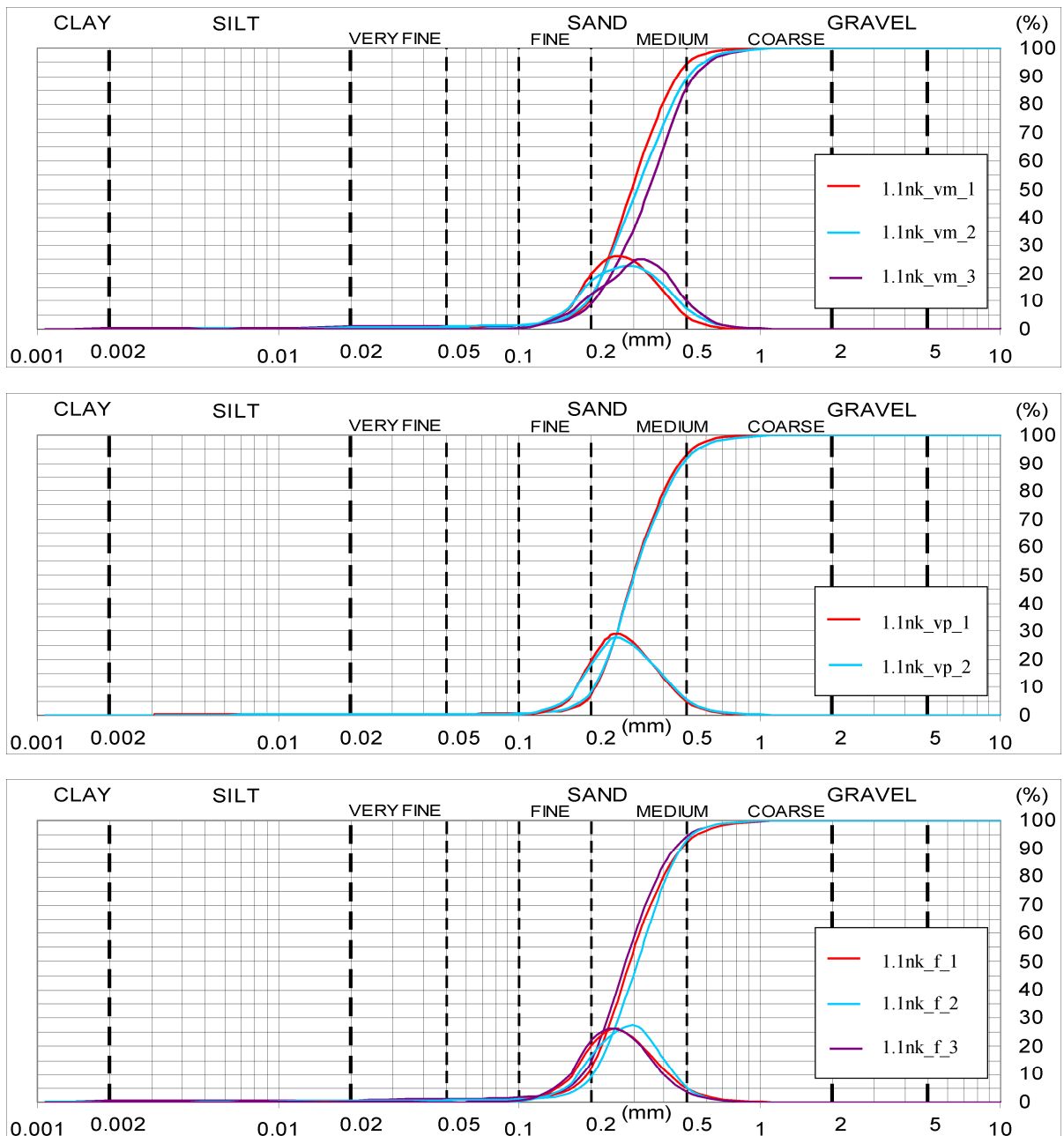


Figure 7: Cumulative curves of the grain-size distribution of the samples

7. ábra: A minták szemeloszlásának kumulatív görbéi

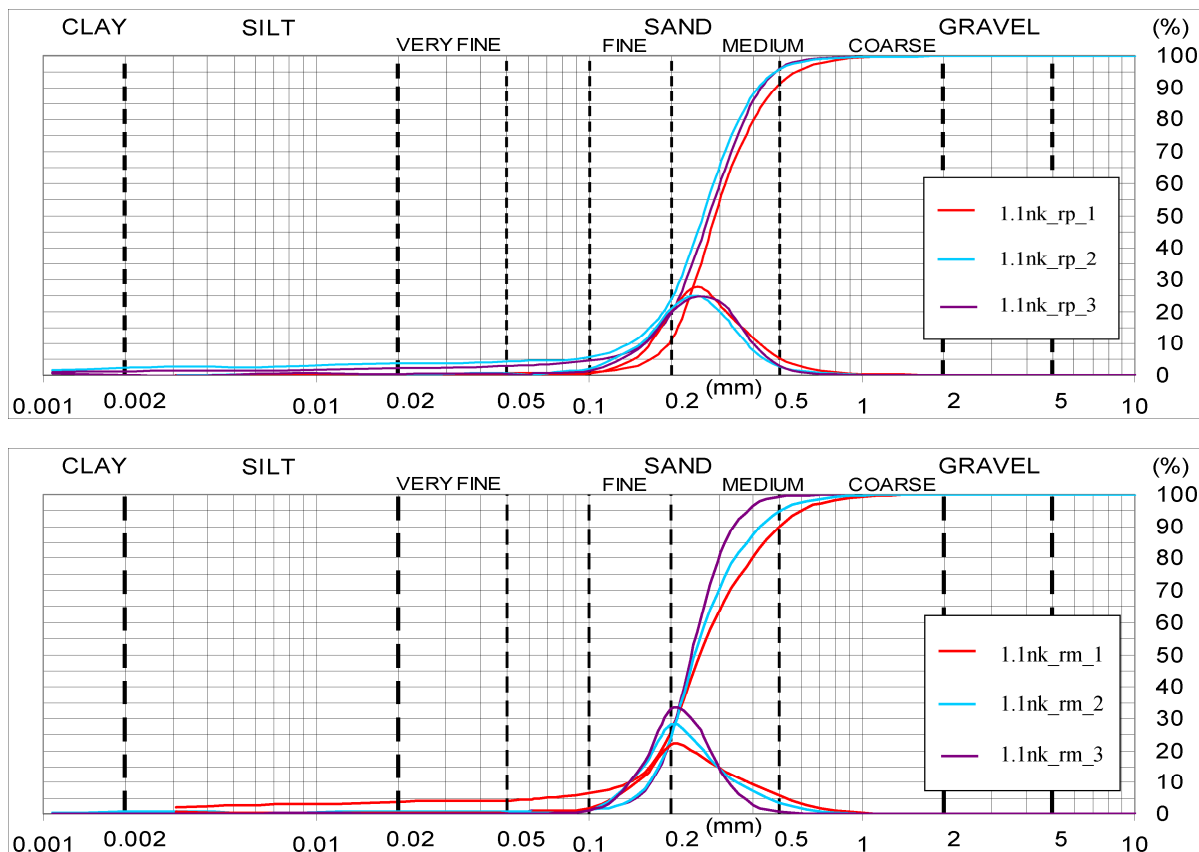


Figure 7: Cumulative curves of the grain-size distribution of the samples (cont.)

7. ábra: A minták szemeloszlásának kumulatív görbéi (folyt.)

Discussion

The grain-size distribution results show that the average size of the particles are between 0.1 and 1.0 mm, which means the samples contained medium sand mainly (Fig. 7). Coarse-sand and fine gravel rarely appeared, and there was only one case, when a gravel bigger than 1 cm were found. The ration of the clay fraction in the samples was very low (below 5–6 %).

Five different hydraulic conductivity values were determined for a sample. Two from the natural and mix stratification with laboratory measurements, and three others from grain size distribution.

Our results suggest that the strongest correlation occurred between the hydraulic conductivity measured on natural stratification and the hydraulic conductivity calculated by the Beyer’s method (coefficient of determination R^2 : 0.4618) (Fig. 9).

The measured hydraulic conductivity values of samples with natural stratification are little bit greater, than the measured values of mixed ones in the most cases. Only 15 cases yielded greater K-value for the mixed samples, however, 5 samples from the 15 cases were originally perpendicular to the stratification, where this phenomenon is very common. These results suggest that the stratification has an effect on the hydraulic conductivity, however, this effect results only small difference in the K-value (within one order of magnitude).

Results of the laboratory measurements suggest that definite anisotropy in the hydraulic conductivity does not occur (Fig. 8). It means despite the well-preserved stratification there is no significant (at least greater than one order of magnitude) difference between K-values measured in different orientation.

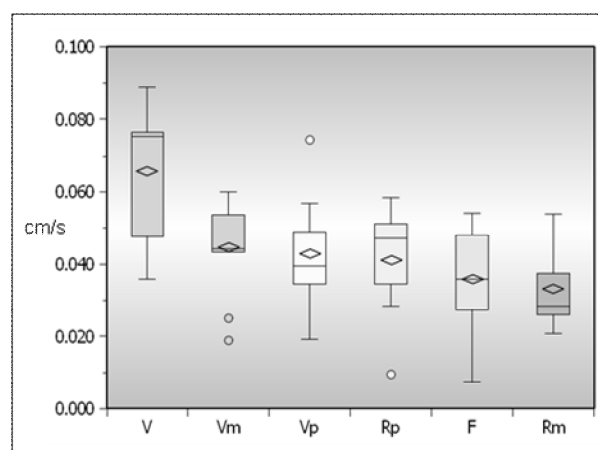


Figure 8: Hydraulic conductivity values in boxplot diagram with minimum, maximum, outliers and arithmetic mean values by direction

8. ábra: Szívárgási tényező értékek boxplot diagramja a minimum, maximum, kieső és számtani átlag értékekkel (rombusz) irányonként

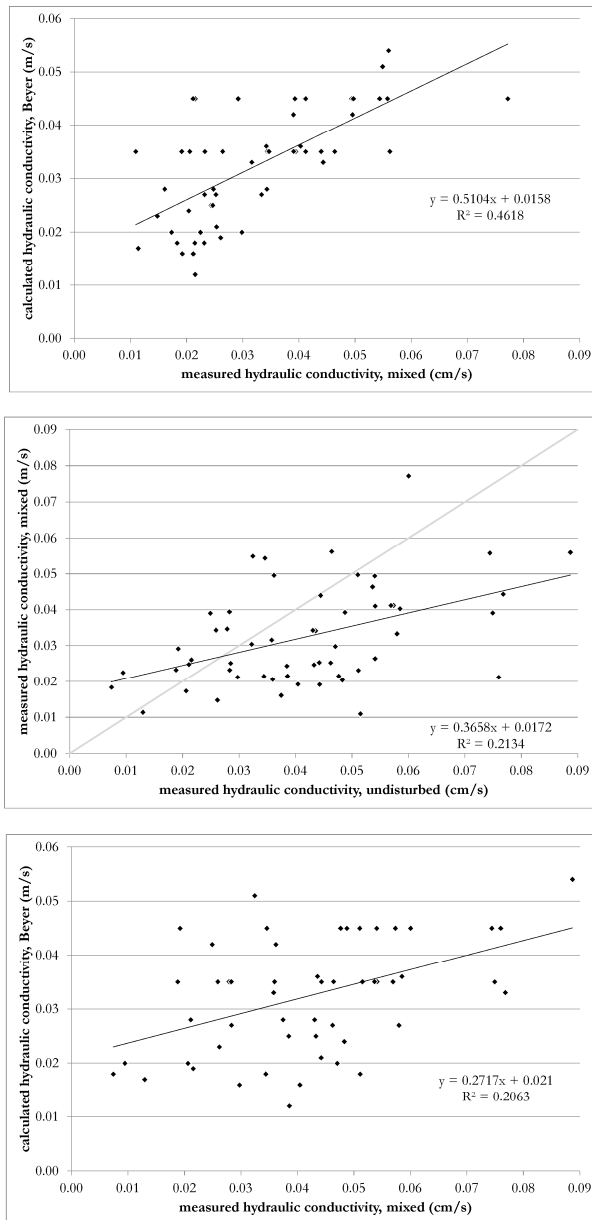


Figure 8: Plots of measured (natural and mixed) and calculated hydraulic conductivity values

8. ábra: Eredeti rétegzésen és kevert mintákon mért illetve számított szivárgási tényező értékek diagramja

Empiric formulas of Beyer, Hazen and Zamarin were used to define the hydraulic conductivity from the grain-size distribution. These formulas do not take account of the inner stratification or grain fabric of the samples. That is why we got approximately the same values within one series of measurement, which means these methods useless to demonstrate anisotropy of hydraulic conductivity.

Two of the methods – the Beyer and the Hazen – yielded very similar results, while the Zamarin method gave values smaller with one order of magnitude. The Zamarin formula counts with the clay content of the samples as well, which can modify significantly the values of hydraulic conductivity.

Conclusion

The aim of this paper was to provide information about the hydraulic conductivity anisotropy of fluvial sand deposits situated near Nagykereki.

During the comprehensive fieldwork undisturbed soil samples were taken from the fluvial sand deposit of Nagykereki pit mine. The grain-size distribution, hydraulic conductivity, porosity and matrix density were measured in laboratory using sieve series, hydrometer, permeameter, laboratory drying oven and balance.

The porosity, the matrix density, the grain-size distribution and the hydraulic conductivity of natural undisturbed samples and samples with mixed, artificial stratification were determined.

From the data of the grain size distribution the hydraulic conductivity values were calculated by three different methods.

Our results suggest that definite hydraulic conductivity anisotropy cannot be observed on the well sorted medium sand samples with natural stratification. It means that a sediment layer with natural stratification does not have to show well-determined hydraulic conductivity anisotropy, however, small-scale effects are undeniable. The calculations made by the Hazen and Beyer methods yielded almost the same K values that were measured in laboratory on the samples with mixed stratification. Despite the fact that with the Zamarin calculation we got much smaller values they can be compared to the values of the natural stratification.

It is seen that during the field and laboratory works there are several points to make mistakes that is why it is hard to determine properly the hydraulic conductivity anisotropy in a sorted sedimentary system. These difficulties and errors can be corrected by taking large number of samples. In a poorly sorted sedimentary system hydraulic conductivity anisotropy could be determine more easily.

The examination of aquifers' hydraulic conductivity is extremely important, not just because of the environment protection and hydrogeological exploration, but because of the field of energy too.

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