Main theoretical preconditions for grounding the cyclic dependence of hydraulic conductivity (*K*) on the mass (*m*) of sand soil fraction

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The investigation results on the dependence of the soil permeability coefficient on soil mass are presented. Such investigations have been performed for the first time in the hydrogeological practice. The soil permeability coefficient has been found to fluctuate cyclically when the soil mass is increasing. The formula for the estimation of the soil permeability coefficient was obtained by the method of cyclic components, using the mass of different fractions of soil granular composition.

Keywords: permeability coefficient, granulometrical, oscillation periods, Kamenski tube, cyclic components

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INTRODUCTION

In order to determine the dependence of soil permeability (*K*) on its mass (*m*) the authors conducted numerous experiments in Kamensky's tube, following a non-stationary scheme of filtration. Within the sand soil mass oscillation range from 250 to 6750 g and the discretion step being 250 g, an obvious cyclic dependence of *K* values on *m* was determined with main mass oscillation periods equalling 9600 and 1440 m. Besides, these values are in good correlation with the fundamental values of force oscillation period calculated by J. N. Sokolov and equal to $F = 0.96 \cdot 10^{-42} \cdot$ N. On the basis of individual and certain literary data a model of cyclic dependence of *K* on *m* of sand fractions was suggested. Fractions 0.5–0.25, 0.25–0.1 and <0.1 mm turned out to be the major regulators of *K* oscillations in dependence on *m*. The overall composition of the masses of fraction from 0.5 mm and coarser shows in this model a linear trend. The coefficient of multiple correlation made $r = 0.965$. On the grounds of experimental material and using the method of cyclic components, a formula for determination of soil permeability from the data on its granulometric composition was derived.

A SHORT HISTORICAL SURVEY OF PREVIOUS INVESTIGATIONS

Already in the 17th century Newton, "as a result of an experiment, the point of which was to measure the dependence of partial reflection of light on the glass thickness", demonstrated the phenomenon called "interference" (Фейман, 1988). "As the glass thickens, the partial reflection of light passes through repeated cycles from 0 to 16% without any signs of extinction. At a further thickenning of the glass the partial reflection of light would increase to 16% and then return to zero. This cycle repeats again and again. Today the have lasers (producing a very clear monochromatic light) which make it possible to observe oscillations after more than 100 mill. repetitions" (Фейман, 1988). We may look upon this experiment from another point of view. Namely, with increasing the glass thickness its mass also increases. We may assert with a certain confidence that the degree of partial reflection of light cyclically depends also on the mass of glass.

At the beginning of the 50s J. Piccardi observed and later proved that the speed of settling down of colloid particles and, correspondingly, the mass of settled ones differs in the time, the other conditions being the same. Making references to Chizhevski, J. Piccardi related the mentioned phenomenon to the electromagnetic solar pulse (Пиккарди, 1965). In the beginning and middle of the 80s A. Achmedov, I. Kerimov and A. Alisade have determined that the level of electromagnetic radiation is in direct dependence on the seismic field and in good correlation with oscillations of the Earth itself (Усейнова, 1986).

Academicians A. Severin, V. Kotov and T. Tsap discovered in 1975 that the Sun pulsates periodically, *i. e*., contracts and expands within the periods of 160 min (9600 s or 2.667 h) (Конюшая, 1988).

A lot of scientific works in many fields of research discuss the cyclic character of various phenomena. Hovewer, few of them contain analysis of the causes of cyclic character. Only in 1993 J. Sokolov (Соколов, 1993) proposed a theory of cyclogenesis. According to this theory, on the grounds of fundamental physical constants (such as Plank's constant, gravitational constant, etc.) by the method of dimensional analysis he calculated the fundamental values of the cycles of length, mass, time and force, which are respectively equal to:

$l = 0.143 \cdot 10^{-33}$ M; $m = 0.157 \cdot 10^{-7}$ kg; $t = 0.485 \cdot 10^{-42}$ s; $F = 0.96 \cdot 10^{-42}$ N (Соколов, 1993).

Solar pulses periodically change the gravitational force on the Earth, *i. e*., they are gravitational. The Earth, in its turn, transforms the solar pulses into its own oscillations. The parameters of these oscillations are determined by geometrical and physical-mechanical properties of the resilient body of the planet. In filtration (permeability) experiments, water flows through pores under the effect of gravitational force. The speed of water flow is regulated by periodical changes of gravitational force. This means that as a result of spheroidal oscillations of the Earth, the mass of the sample being the same, the speeding up of free fall also oscillates (Аки, Ричардс, 1981).

Sandy soil and its granular composition may be considered as a mass of fraction which becomes lighter or heavier with respect to Earth, *i. e*., their weight oscillates within definite cyclic ranges of force, each of which represents an oscillation period of gravity force. As was mentioned, among other fundamental values of cycle J. Sokolov calculated also the fundamental value of oscillation period of force which equals $F = 0.96 \cdot 10^{-42}$ N. If instead of the value of speeding up of free fall ($g = 9.81$ m/s^2) we take the value 10, it becomes clear why the values of oscillation periods of mass tend to divisible or equal to $F = K \cdot 0{,}96 \cdot 10^n$ values, where *K* is the quantum number, *n* is the indicator of the range of the process studied. On the other hand, it is impossible to carry out filtration experiments without taking into consideration the temporal factor, because with changing the mass of sample the time of recorded results also changes. The fundamental value of oscillation period in time, according to J. Sokolov, is equal to $0.485 \cdot 10^{-42}$ s and within $\pm 5 \cdot 10^{-45}$ this value may be considered equal to $0.48 \cdot 10^{-42}$ s. From their individual experience the authors come to a conclusion that in hydrogeological processes the value $0.48 \cdot 10^n$ is closer to the main periods of both mass and temporal oscillations. However, a 45-year long observation of the groundwater level in Lithuania's territory revealed that one of the major periods of oscillation in time equals to 4.85 years. Therefore, in any experiment there remains a problem of distinguishing between the influence of mass oscillation periods and time oscillation periods, as the values $0.48 \cdot 10^{-42}$ s and $0.96 \cdot 10^{-42}$ N are to a certain degree in quantum interelation.

METHODS AND EVALUATION OF THE RESULTS

A quartz tube 105 cm high and 7.14 cm in diameter is filled with marine sand (in portions of 250 g). After adding a new portion of sand the previous one is saturated with water from the bottom in order to eliminate the jammed air. After that the speed of water level fall and its temperature are determined. The soil permeability is calculated according to the commonly accepted formula (Шестаков и др., 1975). In order to ensure uniform conditions, the sand is poured into the tube from the same height and through a narrow tube with a pointed cone-like terminal (the outlet diameter is 3 mm). This allows the sand to pour out at an approximately equal speed and to achieve in the sample (contained in the tube) almost equal initial porosity. Before the experiment the sand is dried at t° = 105 °C. Besides, the experiments are carried out under the conditions of a similar initial gradient of pressure (1.30–1.33). To achieve a similar gradient of pressure at the end of experiment is technically impossible due to the height of the tube. For this reason it ranges from 1.25 to 1.02 (Table 1). The initial pressure in the tube (H) was different for each sand layer and changed from 5.2 to 97.4 cm seeking to obtain the equal pressure.

While adding the next portion of sand (250 g) the level of water in the tube is lowered till the sample surface. Otherwise, the air will penetrate the sample and will not be completely eliminated during the repeated saturation. This was experimentally proved.

Twelve series of described experiments were carried out with the only difference that the time of experiments and average water temperature (ranging from 11.1 to 19.5 °C) varied in every series of experiments, other conditions being the same.

The only common feature of all these experiments was the fact that in the same ranges, at the same pace of adding in mass (from 250 g to 6750 g) the trend of soil permeability dependence on mass revealed three peaks (extremes) with the only difference that in some experiments (depending on time) we could observe shifts of these peaks with respect to the starting point in time, whereas the distance between the extremes was almost similar in all experiments and equalled 1440 g (96 · 15 = 1440).

Table 1. **Experimental data on dependence of soil permeability (*K*) on soil mass (*m*)**
1 Lentelė. **Filtracijos koeficiento (*K*) priklausomybės nuo grunto masės (*m*) eksperimentiniai duomenys**

N°	Soil mass m, g	Thickness of soil layer l, cm	Pressure H, cm	Pressure gradient J	Water temperature T °C	Soil permeability K, m/day
1	250	4	8	2.00	11.4	105
2	500	8	12	1.50	11.6	92
3	750	11.5	15	1.30	11.6	84.5
4	1000	15.2	20	1.30	11.5	78.0
5	1250	19.0	25	1.31	11.5	77.0
6	1500	22.7	30	1.32	11.5	71
7	1750	26.3	35	1.33	11.6	69.5
8	2000	30.0	40	1.33	11.5	70.0
9	2250	33.9	45	1.33	11.6	71.0
10	2500	37.5	50	1.33	11.6	69.0
11	2750	41.2	55	1.33	11.5	67.0
12	3000	45.0	60	1.47	11.8	66.0
13	3250	48.5	65	1.34	11.8	66.0
14	3500	52.4	70	1.33	11.8	67.0
15	3750	56	75	1.34	11.8	68.0
16	4000	60	80	1.33	11.8	66.0
17	4250	63.7	85	1.33	11.8	65.0
18	4500	67.5	90	1.33	11.8	62.0
19	4750	71.1	95	1.34	11.8	62.0
20	5000	74.7	100	1.34	11.8	63.0
21	5250	76.0	100	1.31	11.7	65.0
22	55001	79.5	100	1.25	11.6	64.0
23	5750	83.0	100	1.20	11.7	62.0
24	6000	86.5	100	1.16	11.3	62.0
25	6250	90.2	100	1.10	11.3	63.0
26	6500	93.8	100	1.07	11.3	64.0
27	6750	97.6	102	1.05	11.3	65.0

Applying iteration (selection method) and the method of cyclic components it is possible to find the most important (major) cycles in the approximation of experimental values of *K* depending on the sample mass. The following regression model lies in the basis of the method of cyclic components (Добкевичюс, Кармазинас, 1996):

$$K(m) = K_o + C_n \cdot \cos(w \cdot m \cdot t + \Theta_n) + e_n, \qquad (1)$$

where K_o is the average or the trend value of soil permeability; C_n is the amplitude of *K* oscillations depending on the sample mass (*m*); $w \cdot m$ is used instead of $w \cdot t$ [3] – analogy with time – where *t*, in the primary understanding, is the time of oscillation process of *K*; *w* is the angle frequency in radians on mass unit (not on time unit); Θ is the phase of wave; e_n is the residue (error) of the model; *n* is the number of the cyclic component. The mentioned dependence of *K* on the sample mass (1) can be demonstrated in another form:

$$K(m) = A_n \cdot \sin(2\pi \cdot m/\lambda_n) + B_n \cdot \cos(2\pi \cdot m/\lambda_n) + e_n, \qquad (2)$$

where A_n and B_n are the amplitudes of sinusoidal and cosinusoidal constituents of the cyclic component with the number *n*; λ_n is the period of oscillations (cycle value) of the sample mass.

The process of filtration takes its course under the effect of the force of gravity. Its unit of measure in the SI system is the newton. As was already mentioned, J. Sokolov has calculated the fundamental value of the force cycle which equals F = $= 0.96 \cdot 10^{-43}$ N. Therefore, we can assume that in the *K* dependence (2) $\lambda = m \cdot g = 0.96 \cdot 10^{-43}$ N will be the major fundamental frequency, where *m* is the soil mass, *g* is acceleration of free fall. Of course, there is no such soil mass. However, there exists a multitude of harmonics divisible by many times to the given a value.

Here follows the variant with different divisibles to number $9.6 \cdot 10^{n}$ values of cycles in the approximation $K = f(m)$ calculated by the method of cyclic components (Table 2). For this variant we have concrete values of regression coefficients in the model which, without the constant, has the following expression:

$$K(m) = -7070.51 \cdot \sin(2\pi \cdot m / 192000) + 1008.297 \cdot \cos(2\pi \cdot m / 192000) + 243.065 \cdot \sin(2\pi \cdot m / 19200) - 956.899 \cdot \cos(2\pi \cdot m / 19200) + 123.248 \cdot \sin(2\pi \cdot m / 9600) + 69.494 \cdot \cos(2\pi \cdot m / 9600) - 1.147 \cdot \sin(2\pi \cdot m / 1440) - 0.6997 \cdot \cos(2\pi \cdot m / 1440); \ r^2 = 99.98. \quad (3)$$

Table 2. **Data of dispersion analysis of the model (3) without the constant for λ_n values quantified to the number $9.6 \cdot 10^n$**
2 lentelė. **Dispersinės analizės modelio (3) be konstantos λ_n rezultatai reikšmėms, sukvantintoms skaičiui $9{,}6 \cdot 10^n$**

Depending variable	Sum of squares	Fisher's criterion	Level of significance
$\sin(2\pi \cdot m/192000)$	85661.318	77840.31	0.0000
$\cos(2\pi \cdot m/192000)$	43167.83	39226.54	0.0000
$\sin(2\pi \cdot m/19200)$	554.35	503.74	0.0000
$\cos(2\pi \cdot m/19200)$	272.43	247.55	0.0000
$\sin(2\pi \cdot m/9600)$	138.303	125.68	0.0000
$\cos(2\pi \cdot m/9600)$	6.402	5.82	0.0268
$\sin(2\pi \cdot m/1440)$	15.377	13.97	0.0015
$\cos(2\pi \cdot m/1440)$	5.685	5.17	0.0355
Model 129821.69	$r^2 = 99.984\%$		
Actual 129842			

It must be emphasized that in the aproximation (*i.e.*, in the model (2) $K_o = 0$) the constant was not used. For this reason the actual sum of squares is the sum of squares of experimental values of permeability and not the sum of squares of differences from the arithmetical average as is conventionally understood.

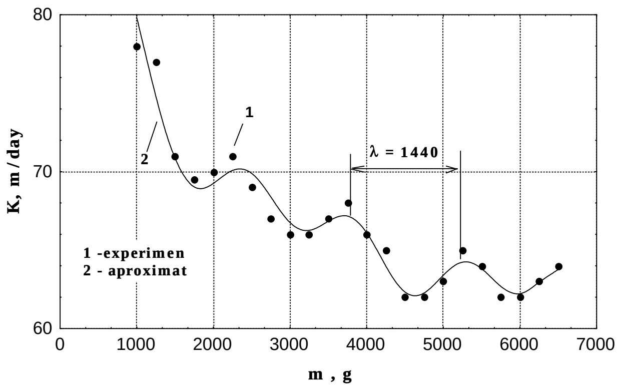

Fig. 1. Dependence of changes in permeability coefficient values upon sand mass and its aproximations by method of cyclic components
1 pav. Filtracijos koeficiento kitimo eiga priklausomai nuo smėlio masės ir jo aproksimacija ciklinėmis komponentėmis

The data aproximated following the model (3) are graphically expressed in Fig. 1.

Here follow the statistical characteristics of experimental data (Table 3).

The dependence of permeability on the soil mass $K = f(m)$ may be interpreted using some major propositions of fractal geometry in the application of the theory and methods of the Norwegian physicist E. Feder. His monograph (Федер, 1991) is a clear and simple account of mathematical properties of fractals and a description how this theory may be applied in hydrodynamics, oceanology, hydrology, investigation of percolation processes, etc. According to a simplified definition of Mandelbrot, the fractal is a structure composed of constituents which, in certain sense, are similar to integer. *E. g.*, the crystal of common salt of cubical syngonia may be taken to pieces which, in their turn, are composed of smaller cubicles, *i. e.*, the form and content is preserved and only the size changes. On the example of the southern coast of Norway it was demonstrated that the more precisely we measure the length of the shoreline (L) the longer it will be; the coefficient of proportionality is in the following way related with the fractal dimension (D_f):

$$L(\delta) = \alpha \cdot \delta^{1-D_f}, \quad (4)$$

where δ is the length of dimension step; *a* is the angle coefficient. In other words, the shoreline may be called fractal with the fractal dimension D_f.

The inconsistency of any measure including the length (as well as the wave length or the values of cycles) may be considered as a function of dimensional character of space where the length or any

Table 3. **Statistical characteristics of experimental data of 26 experiments carried out in Kamensky's tube**
3 Lentelė. **26-ių bandymų, atliktų Kamenskio vamzdelyje, statistikos duomenys**

Statistical characteristics	*K*, m/day	T °C	m, g
Number of experiments	26	26	26
Average	69.96	11.6	3375
Median	66.5	11.6	3375
Mode	62	11.8	3000
Standard deviation (5)	10.16	0.175	1912.13
Standard error	1.993	0.034	375
Minimum	62	11.3	250
Maximum	105	11.8	6500
Scope (R)	43	0.5	6250

other measure undergoes changes (oscillations) moving from one scale to another preserving, however, some coefficient of proportionality.

Fractal properties may be observed also in cyclic processes, with the only difference that in them, according to the theory of cycle (Соколов, 1993), these properties are regulated by fundamental physical constants such as the gravitation constant and Plank's constant. *E. g*., analysing the temporal dynamics of permeability it is possible to carry out measurements every minute, every 10, 100, 1000, etc. minutes. However, following the theory of cycle in the process we may accept the presence of meaningful periods of oscillations divisible by the period of 0.485, 48.5, 485 min, etc., because the fundamental value of time according to the theory of cycle equals $t = 0.485 \cdot 10^{-42}$ s (Соколов, 1993). Thus, the elementary "brick" of the fractal is represented by the fundamental value of the cycle growing internally or externally, *i.e*., increasing or diminishing with a constant tendency by analogy with (4).

In Chapter 7 of his monograph Feder (Федер, 1991) discusses in detail the process of filtration and fractal dimension as a quantitative characteristic of a cluster formed by pores (porous space). It must be emphasized that if the cluster is porous or casual it does not mean that a is fractal. The fractal property is stipulated by the fact that with increasing the size the density of the cluster radius decreases according to the law of graduality. "The fractal dimension of a cluster is a quantitative characteristic of the mode how the cluster flies in the space occupied by it" (Федер, 1991).

The statistical functional dependence $k = f(m)$ may be investigated by the method of rate fixed scope (R/S) or by the method of Cherst (Федер, 1991), where R is the range, and S is the standard devation. In such a case the sequence of the measured values may be characterized by the index H (Herst's index) which is releated to the fractal dimensions as:

$$D_f = 2 - H, \tag{5}$$

where H is determined for temporal successions by the empirical formula

$$R/S = (\tau/2)^H, \tag{6}$$

where τ is the time span, called a delay, whithin which the temporal successiones is analysed. While aproximating the data following this empirical law, Herst would usually obtain overestimated values of H when $H < 0.79$ and underestimated the values of H when $H > 0.72$. At large excerpts ($\tau > 50\ 000$) it is possible to determine more precisely H by the method of least squares from the law $R/S = (a\tau)^H$.

Going back to the data of Table 4, we shall try to apply formula (6) to our experimental data, taking into consideration that each *g* of soil (sand) add casual variations to the real values of *K*, the other conditions being similar. The filtration process in Kamensky's tube represents a percolation cluster with displacment and redistribution of gas phase in the porous space of soil. Therefore, it is interesting to know whether the Hersts index *H* and the calculated by it fractal dimension D_f can be determined experimentally for such a type of clusters.

The data of Table 4 show that in 26 experiments carried out in one tube the scope (difference between the maximal and minimal values) is $R_K = 43$ m/day, standard deviation in variations of permeability values $S_K = 10.16$ m/day and R/S is 43/10.16 = 4.232. For τ we take the scope of soil mass for the whole series of soil samples. It was $R_m = \tau = 6250$ g. It will turn out that $4.232 = (6250/2)^H$ and $H = \ln 4.232 / \ln 3125 = 0.1793$. Having the value of *H* from (5) we shall get $D_f = 2 - H = 2 - 0.1793 = 1.8207$.

Wilkinson and Williamsen (Федер, 1991) carried out an experiment for computing and displacement of air by a liquid from a two-dimensional porous grid composed of squares with side *L* and number of knots $M(L) = AL^{D_{capt}}$, where D_{capt} ranges within 1.82 ± 0.02. This is an indirect statistical proof that in the process of filtration the air is eliminated not from all filtration channels. The rate of filtration may increase only at the expence of displaced air. If all air is displaced (all porous space filled with water), which according to its physical nature may correspond to the dynamic porosity, the displacing cluster will not be fractal and presumably the oscillations of the sun and earth will be less pronounced in Kamensky's tube.

The authors demonstrated that "fractal statistics" may serve as an indirect proof that oscillations of *K* depending on soil mass take place as a result of redistribution of air jammed in the porous space. As regards *K* ascillations in time, the soil mass being the same, their periods are in good correlation with the oscillations of the sun and earth which affect the force of gravity, under the impact of wich filtration takes place. As is commonly known, the greater the mass the stronger the force of gravity. For this reason the redistribution of air in the porous space of soil is regulated (along with all other factors) by the masses of fractions constituting the sand soil.

The approximation of the starting series of digital data by cyclic components follows the strict mathematical rules of search and calculation of these cyclic components. Depending on the choice of the rule of search we may get different values of cycles for which by the method of least squares the amplitude and phase of oscillations is determined. The greater the number of cyclic components in such a model, the closer the values of starting data to the calculated ones. Two main statistical indices serve as the criteria of the quality of the model. They are square of the correlation coefficient (r^2) of multiple regression, which shows in relative units the quantity of dispersion, explained by the model, and the index (D) of residual correlation of the model from the initial series which is called Durbin–Watson statistics. When the values of r^2 are high, the model may be inadequate; when the value of D is somewhat smaller or larger than two, this indicates the presence in the initial series of meaningful cyclic components not taken into account by the model. This means that the value of r^2 of the model may be increased by adding a reccurring variabe (of cyclic component) (Ферстер, Ренц, 1983; Химмельблау, 1973). The rules of search of cyclic components are contained in (Деч, Кноринг, 1985).

Using this method, a model was created of the dependence of K determined under field conditions, on the mass of granular fractions of the layer through which the water was filtrated. The aim of this comparison was to find the value of the cycle (d) from value of fraction mass.

The discussed regularities are obvious from the matrix of correlative interrelation of permeability with different fractions (Table 4). In the first column of the table fractions 0.25–0.1 mm (r = 80) and <0.1 mm (r = 0.7) have the highest values of correlation with permeability. They are followed by fraction 1–0.5 mm (r^2 = 0.17). We can also see that only one fraction, 0.25–0.1 mm, is in direct proportion with permeability, the other ones being in reverse proportion. The matrix also reveals a relationship between the fractions.

The obtained results allow to create a model of permeability dependence on granulometrical composition. Fine-grained particles (<0.1 and 0.25–0.1 mm) play the major role in the formation of the process filtration. They move with the water filling in the gaps between larger particles. Particles <0.1 diminsh the values of permeability, whereas particles 0.25–0.1 increase them. Particles of fraction 5–2 mm reduce the values of permeability only slightly (r = = –0.17). Fraction 0.5–0.25 mm is relativey neutral forming the “framework” of rock (its is found in largest quantites) within which other particles move. The corresponding proportions of all particles in a rock (Table 4) determine the value of permeability. In determining the value of permeability from the values of masses (per cent) of different fractions, the actual data were aproximated by the method of cyclic components. The results obtained lead to a conclusion that the value of permeability depending on the granular composition of rock changes according to the following formula:

$$\ln K = 0.077 \cdot \sin(2\pi \cdot m_1/96) + 0.029 \cdot \cos(2\pi \cdot m_1/96) - 0.273 \cdot \sin(2\pi \cdot m_3/20) + 0.352 \cdot \cos(2\pi \cdot m_3/20) + 18.749 \cdot \sin(2\pi \cdot m_2/1920) - 2463 \cdot \cos(2\pi \cdot m_2/1920) + 0.0435 \cdot (m_4 + m_5 + m_6 + m_7). \quad (7)$$

From top to bottom: coefficients of pair correlations and levels of significance, where m is the average mass (m) of particles of concrete fraction. This

Table 4. **Matrix of pair correlations of soil permeability with fractions of granular composition**
4 lentelė. **Filtracijos koeficiento porinių koreliacijų su granuliometrinės sudėties frakcijomis matrica**

			>5	5–2	2–1
		K	**m_7**	**m_6**	**m_5**
K		1.0000	–0.3545	–0.1715	–0.0837
		0.0000	0.1148	0.4572	0.7184
>5	**m_7**	–0.3545	1.0000	0.2375	–0.1272
		0.1148	0.0000	0.2998	0.5826
5–2	**m_6**	–0.1715	0.2375	1.0000	0.6135
		0.4572	0.2998	0.0000	0.0031
2–1	**m_5**	–0.0837	–0.1272	0.6135	1.0000
		0.7184	0.5826	0.0031	0.0000
1–0.5	**m_4**	–0.3295	0.1949	0.7086	0.7819
		0.1447	0.3973	0.0003	0.0000
0.5–0.25	**m_3**	0.0041	–0.2192	0.3405	0.7975
		0.9858	0.3397	0.1309	0.0000
0.25–0.1	**m_2**	0.8086	–0.5164	–0.3662	–0.2452
		0.0000	0.0165	0.1025	0.2841
<0.1	**m_1**	–0.7057	0.5080	–0.0087	–0.3512
		0.0004	0.0187	0.9702	0.1185

		1–0.5	0.5–0.25	0.25–0.1	<0.1
		m_4	**m_3**	**m_2**	**m_1**
K		–0.3295	0.00	0.8086	–0.7057
		0.1447	0.98	0.0000	0.0004
>5	**m_7**	0.1949	–0.21	–0.5164	0.5080
		0.3973	0.33	0.0165	0.0187
5–2	**m_6**	0.7086	0.34	–0.3662	–0.0087
		0.0003	0.13	0.1025	0.9702
2–1	**m_5**	0.7819	0.79	–0.2452	–0.3512
		0.0000	0.00	0.2841	0.1185
1–0.5	**m_4**	1.0000	0.70	–0.6002	–0.0011
		0.0000	0.00	0.0040	0.9963
0.5–0.25	**m_3**	0.7005	1.00	–0.1150	–0.5377
		0.0004	0.00	0.6198	0.119
0.25–0.1	**m_2**	–0.6002	–0.11	1.0000	–0.7636
		0.0040	0.61	0.0000	0.0001
<0.1	**m_1**	–0.0011	–0.53	–0.7636	1.0000
		0.9963	0.01	0.0001	0.0000

formula may be used for sandy-clayey rocks, the value of permeability of which is >0.1 m/day.

The correlation coefficient of this dependence (*u*)$r = 0.965$, the index of Durbin–Watson $D = 1.5$. The values of permeability calculated by the formula differ from the actual ones by 0–30% (Table 5).

The analysis of the contribution of cyclic components to a dispersion of *K* values is given in Table 6 from which the mass period (*d*) equals 96 g. Other fractions are not significant.

It should be noted that formula (7) was derived using the data on the granular composition of rocks determined in 100 g of mass. If the granular composition was determined from the other amount of rock, the coefficients included in formula (7) were different. Therefore, in order to determine the value of permeability using this formula but having the granular composition calculated for other than 100 g amount of rock, it is necessary to make new calculations for 100 g of mass.

Table 5. **Actual (K_f) and calculated (*K*) values of permeability depending on (6)**
5 lentelė. **Faktinės (K_f) ir apskaičiuotos (*K*) pagal formulę (7) filtracijos koeficiento reikšmės**

K_f	3.4	1.84	0.68	9.6	2.68	0.57	0.47	0.47	3.9	0.35	
K	3.55	2.08	0.57	9.31	2.32	0,76	0.46	0.40	2.99	0.35	
Error, %	4	9	13	3	13	13	2	15	23	0	
K_f	17.9	18.0	2.2	2.4	0.14	4.3	0.28	10.5	0.17	0.28	0.13
K	17.16	16.96	2.58	2.82	0.14	5.6	0.20	10.2	0.20	0.27	0.16
Error, %	4	5	17	17	0	30	28	18	18	4	23

Table 6. **Dispersion analysis of variables included in the dependence (6)**
6 lentelė. **Kintamųjų priklausomybės dispersinės analizės duomenys**

Variable	Sum of squares	Variance, %		Significance level
		Model	Actual	
$\sin(2\pi \cdot m_1/96)$	31.72	69.20	65.06	0.00
$\cos(2\pi \cdot m_1/96)$	2.53			0.00
$\sin(2\pi \cdot m_3/20)$	0.35	8.34	7.84	0.22
$\cos(2\pi \cdot m_3/20)$	3.77			0.00
$\sin(2\pi \cdot m_2/1920)$	5.31	21.83	20.53	0.00
$\cos(2\pi \cdot m_2/1920)$	5.48			0.00
m_7	0.30	0.63	0.59	0.25
Model dispersion	49.50	100%	$r^2 = 94.02$	
Actual dispersion	52.65			

CONCLUSIONS

On the grounds of the presented results we may draw the following conclusions:

1. The most important role in the value of soil permeability of sandy-clayey rock is played by fraction <0.1 mm (~70%). A increase of this fraction in the rock causes a decrease of soil permeability in exponential dependence. About 20% of significance in the value of permeability belongs to fraction 0.25–0.1 mm. Other fractions are of minor importance.

2. By the method cyclic components, using the data of granular composition it is posible to calculate the value of permeability to 0 ÷ 30%.

For determination of soil permeability by the data of granular composition, the empirical formulae of Hasen and other scientists are used. As was tested, in practice the calculations by these formulae of permeability values in some cases differ from the actual ones by 200% and more.

The main fault of these empirical formulae is that they use the percentage of rock fraction, whereas, according to the law of Newton, we should use the value of mass, because it is the gravitation force that determines the motion of water in soil and of soil in water. The gravitation force changes in time. For this reason filtration is also a cyclic process and may be aproximated using the method of cyclic components (Справочник по прикладной статистике, 1990). This is proved by the results obtained by the authors during the experiments carried out in a tube filled with soil. The mass of soil was proportionally increased and saturated with water. Every time soil permeability was determined following G. Kamensky's scheme. The data obtained (Fig. 1, Tables 2, 3) reveal the cyclic process of filtration.

Using the method of cyclic components (Справочник по прикладной статистике, 1990), the values of permeability, determined by the method of pouring into diggings and by data of granular composition of samples taken from these digings where modelled.

With the help of the correlation matrix of interrelation between permeability and different fractions it was determined that the finest rock particles play the most important role in the value of permeability. On the grounds of experimental material and by the method of cyclic components a formula was derived for determination of soil permeability by the data of granular composition.

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FILTRACIJOS KOEFICIENTO PRIKLAUSOMYBĖS NUO SMĖLINGOS UOLIENOS GRANULIOMETRINĖS SUDĖTIES FRAKCIJŲ MASĖS APROKSIMACIJA CIKLINIŲ KOMPONENČIŲ METODU

S a n t r a u k a

Nustatant filtracijos koeficientą pagal granuliometrinės sudėties duomenis yra naudojamos Hazeno ir kitų mokslininkų empirinės formulės. Filtracijos koeficiento vertės, nustatytos lauke įpylimų į šurfus ir laboratorijoje Kamenskio metodu, labai skiriasi nuo apskaičiuotų pagal minėtas formules.

Pagrindinis šių formulių trūkumas yra tas, kad jose yra naudojama granuliometrinės sudėties procentinė išraiška, o pagal Niutono dėsnį reikia naudoti frakcijų mases, kadangi tiek vandens judėjimą uolienoje, tiek ir dalelių judėjimą vandenyje nulemia gravitacinės jėgos, kurios cikliškai keičiasi laike. Taigi filtracijos procesas yra ciklinis ir jį galima aproksimuoti ciklinių komponenčių metodu. Tą patvirtina autorių gauti eksperimento duomenys panaudojant smėliu užpildytą vamzdelį. Nuolat didinant smėlio kiekį, pro jį buvo filtruojamas vanduo, ir kiekvieną kartą buvo nustatomas filtracijos koeficientas pagal. Kamenskio metodą. Gauti duomenys (1 pav., 2, 3 lentelė) rodo ciklinį filtracijos procesą.

Panaudojus ciklinių komponenčių metodą, buvo sumodeliuotos filtracijos koeficiento vertės, nustatytos įpylimų į šurfus metodu pagal uolienos pavyzdžių iš šurfų granuliometrinę sudėtį.

Remiantis filtracijos koeficiento ryšio su atskiromis frakcijomis koreliacine matrica nustatyta, kad didžiausią įtaką filtracijos koeficiento vertei turi pačios mažiausios dalelės.

Eksperimento medžiagos pagrindu panaudojus granuliometrinę uolienos sudėtį ir ciklinių komponenčių metodą gauta formulė filtracijos koeficientui nustatyti.

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АППРОКСИМАЦИЯ ЗАВИСИМОСТИ КОЭФФИЦИЕНТА ФИЛЬТРАЦИИ ОТ МАССЫ ФРАКЦИЙ ГРАНУЛОМЕТРИЧЕСКОГО СОСТАВА ПЕСЧАНОЙ ПОРОДЫ МЕТОДОМ ЦИКЛИЧЕСКИХ КОМПОНЕНТ

Р е з ю м е

При определении коэффициента фильтрации по данным гранулометрического состава используются эмпирические формулы Хазена и других учёных. Как показывает практика, рассчитанные по этим формулам значения коэффициентов фильтрации на 200–800 процентов и более отличаются от реальных, определённых методом налива воды в шурфы в поле и методом Каменского в лаборатории.

Основным недостатком этих эмпирических формул является то, что в них используются проценты фракций породы, а фактически по закону Ньютона здесь нужно использовать массу фракций, так как движение воды в грунте или движение грунта в воде определяют гравитационные силы, циклически изменяющиеся во времени, поэтому и процесс фильтрации является циклическим и его можно аппроксимировать, применяя соответствующий этому процессу метод циклических компонент. Это подтверждают результаты опытов, выполненных авторами в трубе, заполненной грунтом. Постоянно увеличивая массу грунта, через него пропускали воду, и каждый раз по схеме. Каменского определялся коэффициент фильтрации. Полученные данные (рис. 1, табл. 2, 3) показывают циклический процесс фильтрации.

Методом циклических компонент были смоделированы значения коэффициентов фильтрации, определённые методом налива в шурфы, по гранулометрическому составу образцов, взятых из этих шурфов.

С помощью корреляционной матрицы взаимосвязи коэффициента фильтрации с отдельными фракциями установлено, что наибольшее влияние на величину коэффициента фильтрации имеют самые мелкие частицы породы.

На основе экспериментального материала и с применением метода циклических компонент получена формула для определения коэффициента фильтрации по данным гранулометрического состава.