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A System for Determination of the Filtration Coefficient of Soil and Rock Structures

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1. Introduction

The determining of the filtering coefficient of soil and rock samples is a fundamental task in solving numerous engineering problems, relevant to water movement through different hydro-technical installations and ground waters regime management. Furthermore, the ground waters together with rainfalls and some other factors determine the humidity of the soil types, which is directly connected with the possibilities for soil ecosystem preservation and growth. For agricultural activities soil humidity has influence on problems connected with the improvement of the fruitfulness of the soil.

The determining of this characteristic in Bulgaria and in the world is based on the existing relevant standards for taking experimental solids – samples and experimental research in the so-called Dasrey’s column, in constant and in variable hydraulic pressure. The measurements connected with determining the volume of the passing liquid ΔV and the time measurement Δt of passing the given volume.

The duration of the experiments is from several days up to several weeks. Obviously, during the experiments it is possible to make some errors, both in volume measurements, and in time measurements, depending on the experience and the precision of the experimentator. It is also possible to make mistakes in volumes determining, as a result of liquid vaporization from the measurement cylinder, especially in prolonged measurements. In finding out the relations, a confusing fact is the operating with two independent parameters – the time Δt and the volume ΔV.

The present state of the art in Information and Communication Technologies gives possibilities for the development of an assessment system for filtering and water physical characteristics of the various types of soils, based on analyzing the parameters of filtration of the passing liquids through them. The subject of the paper is a question of present interest with a view to rational usage and protection of soil fruitfulness and development of biological resources.

2. Actuality of the research

The precise determination of the time (by electronic way it could be done with 1 ms precision) and precise determination of the coefficient of filtration in the soil in laboratory conditions or in nature, hold out opportunities for a more exact study of the filtering processes in the soil and movement of the soil water. It also helps to control these processes with the purpose to provide the best conditions for growing plants and in particular – agricultural cultures, and to obtain the optimal and sustainable agricultural crops production.

The possibilities for data keeping of a large number of experiments allow further comparative analysis and relations determination. The presence of resources allows simultaneous measurements of a large group of diffused devices in natural environment and it is possible to make more conclusions about ground waters distribution, pollution and so on.

In industry intended for monitoring and control of processes and devices, there are various systems based on Programmable Logical Controllers (PLC). The controllers can work in a network, in autonomous and hierarchical systems with an operation station at the upper level. A special characteristic is the large number of inputs/outputs for monitoring and control. The computer-based systems permit communication for large data amounts exchange, which are then processed, stored and visualized in the computer.

Recently, such architectures are used more often in a computer system for environment research and investigation, in particular for water and terrestrial ecosystems resources, including the quality of soils and waters, with the intention of rational usage and bio-resources preservation. In a similar work the research objects are characterized by a large number and different types of observed parameters and that is way it is suitable to use controllers with a large number of different inputs. Another possibility is the usage of a large number of dispersed and autonomous microcontrollers, with a small number of specific inputs, working as sensor nodes in a wireless sensor network. Usually it is necessary to store a large number of cyclic experiments and data preservation in archives, where the use of wireless technologies is important, and in particular – wireless data exchange, especially directly in wild nature or between numerous scattered observing devices. The relationships between the parameters observed and the data processing methods are complex and non-synonymous and this calls for special data processing of large data amounts and application of powerful computers providing enough resources of RAM and hard disks.

3. Methods for determination of the coefficient of filtration

It is known [2, 19] that the filtration rate is not constant for different gradients of pressure ($h = p/r + z$), and different geological breeds (soil, groundwater and rock). According to B u s h-L u c k h e r [2], this connection between k – the coefficient of filtration and the gradient i is shown on Fig. 1.

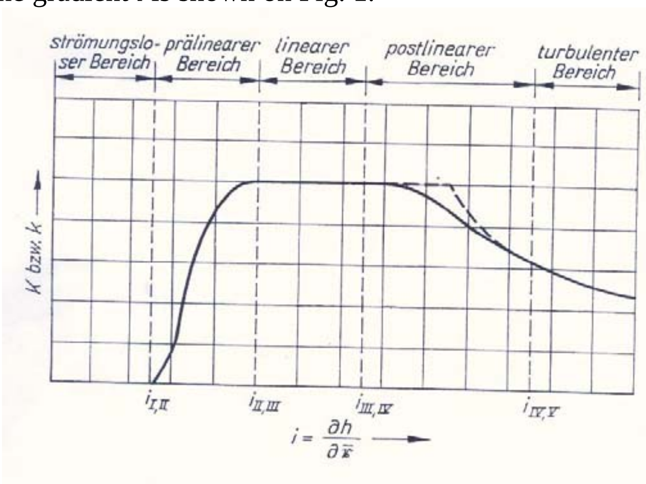

Fig. 1. Connection between the coefficient of filtration and the gradient

Fig. 1 shows that the range of gradients variation is divided into five zones – I field with very low gradients – no movement of water is filtered, i.e., $k = 0$; a prelineary area, in which the initial part of the gradient i starts to increase rapidly the rate of filtration. Then the next area, where the gradient $i > i_{\text{init}}$, the filtration rate remains constant. Next the postlineary area follows, where the ratio of filtration is reduced and this is the area of transition from laminar flow to turbolent regime and finally the area of flow turbolent area is found – with the maximal gradients.

The field of i has separate sub-functions of the size of the channel pore and the coefficient of kinematic viscosity of the mobile phase – the filtered liquid. The prelineary field does not exist in sand and gravel, while there is no postlinear area in clay dust, clay and supesite (sandy clay).

The Bulgarian conditions are known with complex engineering and geological structure of the layers in river valleys, lowland and sediments cone, where the depth alternate layers of different conductivity, i.e., with different coefficients of filtration in sand, gravel, sandy clay, very dense clay, occur. This is confirmed by the development by the Institute of Water Problems of BAS of topics related to the implementation of plan and contract projects [3, 20]. In these studies it was found that the gradients of pressure amended over time ranged from 0.06 to 0.12, i.e., nearly doubled, but they remain far below the limits gradient 1.00, accepted as the basis for determining the rate of filtration. This shows that the gradients (Fig. 1) of filtration rate are not constant, but likely to increase more than twice the alteration range of the gradient i ($i_{\text{init}} < i_k << i = 1$).

This requires a new approach for determining the filtration coefficient as a function of i, $k = k(i(t))$, and its use in solving the filtration problems in determining whether the system of groundwater management in relation to agricultural production or in solving similar problems related to pollution of groundwater (underground) water in farming and industry, and prevent pollution.

One possibility for the determination of the dependence $k = k(i)$ exists in the second modification of the method for determining the rate of filtration in the study of soil and rock monolith (sample) in the drop-down head, described below, followed by a complete automation process.

The main *aim* is the design and development of *automated stand and a computer system for estimation of the filtering characteristics of different types of soils with a view to ecosystems and bio-resources preservation and that will also avoid the inaccuracy and errors previously occurring, as a result of the simultaneous dependence on both factors – time and volume*. The system consists of a specialized sensor, programmable microcontrollers and a base station (a personal computer).

The *aim* is the *development of equipment, allowing possibilities for determination of the coefficient of filtration, based on the measurement only of one parameter: time Δt or volume ΔV of the passing liquid*. The aim is also to minimize the possible errors related to vaporization during the test_measurements. The development of the computer systems makes possible to automate the data obtaining, data processing and storing the results, as well as to give some reports of the results.

The reason of achievement of the aims pointed out is based on analyzing the equitation for coefficient of filtration determination in soils [1, 2]. Fig. 2 presents the experimental equipment for coefficient of filtration determination under constant pressure (Fig. 2a) and under variable pressure (Fig. 2b).

The determination of the coefficient of filtration is realized in the following manner [2].

For the first case (Fig. 2a) the determination of the coefficient of filtration is done by the formula

$$k = \frac{\Delta V\, l}{\Delta t\, A H},$$

where A is the vertical section of the experimental body, across the stream direction, H – active pressure, ΔV – volume of the liquid passing for time Δt.

If, by some means, we fix ΔV = const, it means that all other values for the concrete example of equipment are constant. It remains only to measure the time, and it follows that

(1) $$k = C \frac{l}{\Delta t}.$$

The above formula shows that it is possible only by measuring the time of the constant liquid volume ΔV passing to determine the coefficient of filtration C.

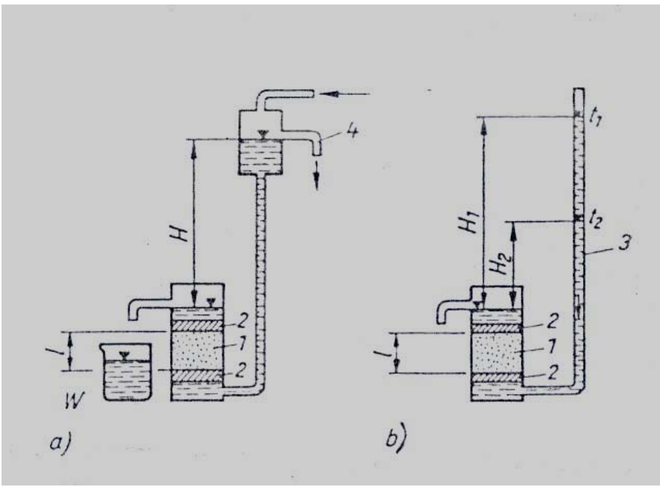

Fig. 2. Equipment for coefficient of filtration determination on soil samples (1 – the soil monolith for investigation; 2 – filtering stab or sandy filter; 3 – pressure pipe; 4 – overflow drain; $H_{1,2}$ – pressure height at the moment $t_{1,2}$; l – height of the soil sample)

In the second case (Fig. 2b), the determination formula for the coefficient of filtration has the following representation:

(2)
$$k = \frac{al}{A\Delta t} \ln \frac{H_1}{H_2},$$

where a is the diameter of the pressure pipe; l, A, H_1 and H_2 are the same as in formula (1).

Following (2) while analyzing all the values, it could be said:

$\frac{al}{A} = C_\varpi$ – a constant of the device,

$\ln \frac{H_1}{H_2} = C_i$ – a constant of the gradient,

where Δt_i is the time interval for the gradient measurement from H_1 to H_2 , or from H_i to H_{i+1}, so that:

$$k = C_\varpi C_i \frac{1}{\Delta t_i} = C_i' \frac{1}{\Delta t_i}.$$

Similar to above, the coefficient of filtration is determined only by the constant C_i' for the given range of alternation on H_i and H_{i+1} in the time range Δt_i .

This analysis shows the possibility for determination of the coefficient of filtration, based only on determination of the time and the possibility for complete automation of the study in k-determination and monitoring, and protocols [3].

Determination of the coefficient of filtration only from exact measurement of the parameter “time” gives possibilities for development of a computer-based system for estimation of the filtering characteristics of the soil types with the following components (Fig. 3).

- a specialized multi-point sensor for consecutive measurement of the liquid level changing, depending on time;

- a programmable controller with extendible periphery for signals obtaining from the multi-point sensor;
- system software and graphic user's interface – an operation system, communication protocol, application software;
- a personal computer, connected to the controller for data acquisition, data processing, monitoring and data keeping;
- special PC based programs, different approaches realized for estimation of the filtrating characteristics of the soils.

The multi-point sensor is a pipe, made of specialized glass, where wire is stretched longitudinally in the middle. In the pipe wall at intervals contacts are attached, stretched outside by the wires. The liquid between the wire and the contact switch on an electric circuit, is connected to the digital input of the controller. With the liquid decreasing, the times for inputs switch off are measured.

Fast and precise (1 ms) *determination of the coefficient of filtration of soil types using such a computer system will provide possibilities to find a solution of the different problems, connected with a regime and movement of the underground water. This will bring new possibilities for research, growth and preservation of the ecosystems, improvement of the soil fruitfulness and bio-recourses.*

A module, supporting four inputs and two outputs and embedded ZigBee modem, is developed in CLMI at BAS (Fig. 3). Such a module is very convenient to use together with an autonomous remote sensor of sensors network, installed on the measurement place. The information is obtained in a module on the place of measurement and then transfered wirelessly to the mobile computer system or to the central computer station in a short range for further data processing, preservation and visualization.

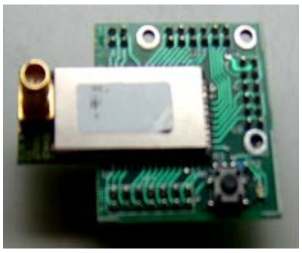

Fig. 3. ZigBee communication and information module

In this case, the stand for investigation of the soil monoliths filtering characteristics could be build, installing a number of small modules, supporting small numbers of inputs directly on the sensor-pipe – as shown on Fig. 4. Such equipment could be easily moved to different places for natural environmental measurements. The collected data (as the time intervals for liquid passing through the soil sample) could be wirelessly transfered to the portable computer or Laptop, located at an appropriate place (for example, in the car near to the measurement place).

By adding a GPS module to the system (the same as we have previously developed), it is possible to receive the exact coordinates of the place, where the soil sample is tested.

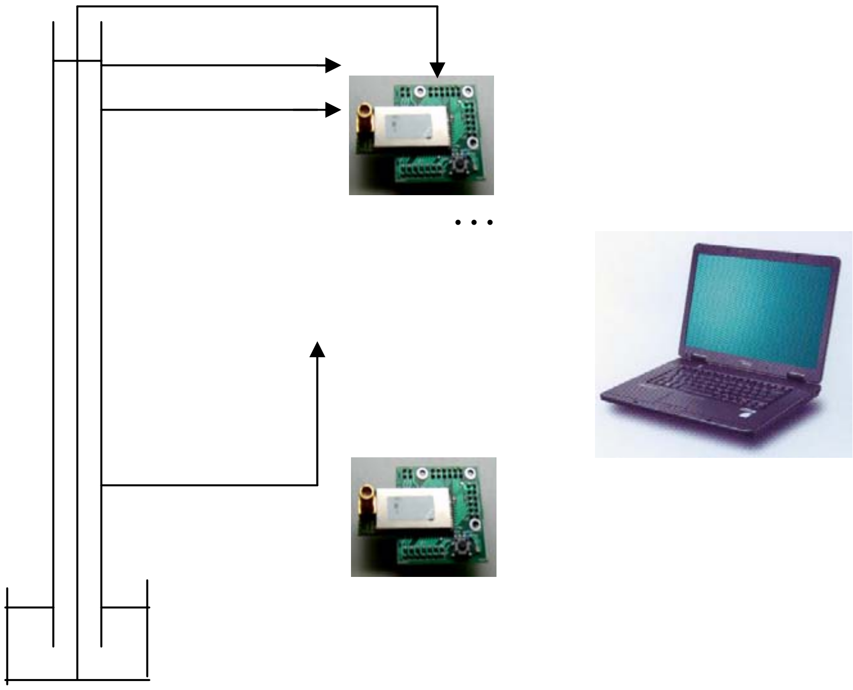

Fig. 4. Measurement equipment (stand) using wireless communication

4. Conclusion

Grounded on the above mentioned, from the experience of the team, consisting of well-trained researchers, the following conclusions could be done:

- the coefficient of filtration is an important characteristic of the quality of soils type and its determining allows the solution of a number of questions regarding engineering problems, eco systems, soil's fruitfulness, bio resources, etc.;
- by using specialized sensors and controllers it is possible to make quick and exact measurement of the time intervals for filtering of different soils type and the measured data are stored and processed in the computer;
- by using appropriate methodology it is possible to determine the coefficient of filtration based on exact measurement only of one parameter – time or volume with minimal errors depending on vaporization, the human factor and measurement duration;
- it would be useful for a wide range of users and applicable in a large number of tasks in the area of environmental investigations to develop a unified system of devices, based on an on-board programmable controller with extendible periphery;

• the additional advantage is the development of base software, such as multi-tasking real time operation system, drivers, communication protocols and so on;

• for a large number of applications, especially in natural environmental data obtaining by mobile devices or scattered intelligent sensors, the distances are not long, that allows wireless protocols implementing, such as Bluetooth, ZigBee, etc.

The general conclusion is that during the development of a computer system for estimation of filtering characteristics of soil types, because of the possibilities given by state of the art in IT, it is possible to automate the measurement, the data and results storing and data processing, as well as the reports and other informational documents. This is a basis for criteria development and methods for estimation of different characteristics of the soil types. This will improve the rational usage and preservation of soil fruitfulness, eco systems and bio recourses growth.

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Система для определения коэффициента фильтрации в почвенных и скальных монолитах

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(Р е з ю м е)

В статье описывается исследование фильтрационных свойств в почвенных и скальных монолитах. Разсматрываются методы измерения фильтрации, специальный сенсор и компьютерную систему для определения коэффициента фильтрации. Предлагается безпроволочная коммуникация типа ZigBee.