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Mathematical Methods and Computer Modeling to Predict the Formation of the Fill Grounds in Urban Environment

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***Abstract* – A method for predicting fill grounds used in landscaping of urban infrastructures is proposed. One of the measures to solve this problem is land remediation. New techniques of reducing economic costs are required. A program of a mathematical model has been developed with this objective. The mentioned program bases on the main hydrophysical characteristics of soils. The algorithm for calculating a computer model uses the properties of chernozem and light gray forest bleached soil. The calculation model is based on the Voronin regression equations. The model presented in the method is characterized by visualization, clarity and ease of use. The analysis of the main hydrophysical characteristics obtained due to this method enables to make a conclusion. Water retention curves characterize the pore space which water saturation depends on. This can be used in the design of fill grounds with the desired characteristics.**

Keywords – soil; modeling; grain-size distribution; porosity; main hydrophysical characteristic; analysis.

I. INTRODUCTION

At present, urban landscaping is becoming increasingly important, more and more parks and squares are appearing. Soils of such structures located in industrial areas are of great value.

However, they are still imperfect regards to agro-environmental assessment. It should be taken into account that natural soil formation processes must take place even on artificially created soil grounds. In order to create high quality plantations bringing not only aesthetic satisfaction but also largely participating in the processes of purifying air from pollution caused by industrial enterprises, a complete assessment of the soil for these plantations is necessary [4].

And, consequently, it is necessary to create soil with specified properties.

It is vital to determine the particle size distribution, porosity, density, permeability and other physical indicators of soil to make it the basis of a park design [10]. These indicators can be determined under the conditions of an undisturbed structure, although this will take a long time. However, it is rather problematic to determine these indicators in case of composition violation. We propose to determine these indicators through the main hydrophysical characteristic of soils and the grain-size distribution, which does not cause any problem in case of fill grounds.

Currently, any justification of projects and calculations for projects in urban infrastructure is impossible without the use of computers and computer programs [9]. At the same time, it should be remembered that it is necessary to take into account all factors of a preliminary study of territories in mathematical modeling [5].

Since complex models require a large set of parameters and characteristics for describing the soil in detail and are expensive as well, we propose to consider one of the possible ways of modeling for the basic hydrophysical characteristics of the soil. Such a model requires fewer parameters and is easy to use.

In addition to the problem of creating structures necessary for urban greening I would like to note a reduction in natural ecosystems and an increase in the area of disturbed land. One of the measures to solve this problem is land remediation. Typically, a remediation process is carried out by technical or biological methods. The technical stage includes planning, formation of slopes, removal, transportation and application of soil to the land being remediated. The biological stage involves implementation of agrotechnical and ameliorative measures that are aimed at improving agrophysical, agrochemical, biochemical, and other soil properties.

When applying the technology of creating a fertile soil layer, the optimal water-holding capacity, porosity and volume

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weight, the absence of swimming and cracking of the soil mixture should be taken into account. It should be noted as well that the set out plants will be under the influence of local soil conditions. Therefore, additional soil mixture components which will provide optimal conditions for plant growth must be selected in accordance with the grain-size distribution of a local soil.

Earth mulching is one of the common ways to improve the soil. It implies that humic layers of soil or soils of different thickness suitable for growing plants are applied to the surface of the dumps. Some specialists believe that this layer should be 0.5–1.0 m, while according to others it should be 1.5–2.0 m thick. The earth mulching phase is very expensive as it is difficult to find such amount of fertile soil. Experiments show that a soil layer of 35–40 cm is often sufficient. However, the cost of land will be significant even with such a thin layer. It should be remembered that it is required to create a water-proof in order to prevent toxic substances from entering the fertile layer and to provide shielding of soils by clay rocks.

We propose to consider one of the ways to simulate the fill ground on the main hydrophysical characteristics of the soil. The main hydrophysical characteristic of soils is one of the most informative functions widely used in both scientific soil physics research and practical problems solving [8]. This method can be used with due account for the selection of a specific range of crops.

II. Subjects and Methods

It is convenient to use various process models with the objective to reduce the computation time and the complexity of various processes. Modern science enables to put mathematical models of various types of complexity in practice [8-10]. There are complex improved models enabling detailed descriptions of processes. However, the creation of such a model requires a detailed set of parameters and characteristics of the soil. In addition, an expensive specialist is required for the calculations.

Simple models apply fewer parameters. Therefore, there will be fewer equations taken for calculations. In addition, they will be easier to use.

We are considering one of the ways to simulate the fill ground with regards to soils main hydrophysical characteristics. The leached chernozem became the object of study devoted to creating a model. The basic physical properties being the grain-size distribution, density and porosity of chernozem were determined. The obtained data were used to create an algorithm for a computer model and for the computational method for determining the basic hydrophysical characteristics of soil. The advantage of this method is the use of information conventional for domestic soil scientists [3] and soil properties, which are determined relatively easily. It is based on the concept developed by Voronin. According to them each soil-hydrological constant on the water-holding curve corresponds to a moisture pressure determined by one of the equations [3]:

porosity $\varepsilon \Rightarrow P=0$;

yielding point $W_{YP} \Rightarrow pF=2.17$;

minimum water capacity $W_{WC} \Rightarrow pF=2.17+ W_{WC}$;

maximum molecular capacity $W_{MMC} \Rightarrow pF=2.17+3\cdot W_{MMC}$;

maximum hygroscopicity $W_{MG} \Rightarrow pF=4.45$.

Thus, the task of restoring the basic hydrophysical characteristics of soil is reduced to the calculation of soil-hydrological constants on the basis of the soil grain-size distribution. The application of extensive experimental material enables to conclude that the soil grain-size distribution values are related to the density ρ, soil porosity ε and the content of the particle size fractions ω, regression equations:

$$\varepsilon=0.805-0.183\omega_1+0.285\omega_2+0.057\omega_5-0.266\rho$$

$$W_{YP}=0.082+1.163\omega_2-0.287\omega_3-0.107\omega_6+0.312\varepsilon$$

$$W_{WC}=0.15+0.085\omega_1+0.514\omega_2+0.142\omega_4-0.145\omega_6$$

$$W_{MMC}=0.053+0.941\omega_2-0.139\omega_3-0.031\omega_6+0.165\varepsilon$$

$$W_{MG}=-0.009+0.198\omega_1-0.059\omega_2+0.04\omega_4+0.078\omega_5$$

where $\omega_1, \omega_2 \ldots \omega_6$ is soil grading fraction from organic silt to coarse sand according to N.A. Khachinsky classification [7].

The content of organic carbon in the presented calculation equations is not taken into account and the soil profile is not differentiated by depth. But this disadvantage is compensated by regarding the values of soil density and porosity, which are largely dependent on the genetic features of the soil.

III. Results

Comparison of the outcomes of laboratory tests and their virtual computer equivalents enable to choose the design model of the soil and determine its parameters. There are many mixtures of both organic and inert materials. The mixture may contain sand, gravel, sawdust, peat, plexiglass. At this stage our research did not aim to find such substances that could be used to create artificial soil. We consider the process of creating a soil of a known grain-size distribution from particles which are of different mechanical strength and have different ability to retain moisture in the process of forming different layers. Such modeling is possible if the hydrophysical characteristics of various soils are known. Lab work has proved it. It should be noted that the software was created without taking into account soil mineralization and its thermal properties [6].

In our work, we have created an algorithm and a simplified model for calculating and building the main hydrophysical characteristics of the soil, which would clearly enable to observe and model the flow of the studied processes [1].

The developed program is designed to calculate the grain-size distribution of the soil basing on the soil-hydrological constants. The program builds experimental and model plots at the input points, combines these plots at a user-specified point (Fig. 1) and finds an error in humidity W (%) (Fig. 2) and pressure pF for this point.

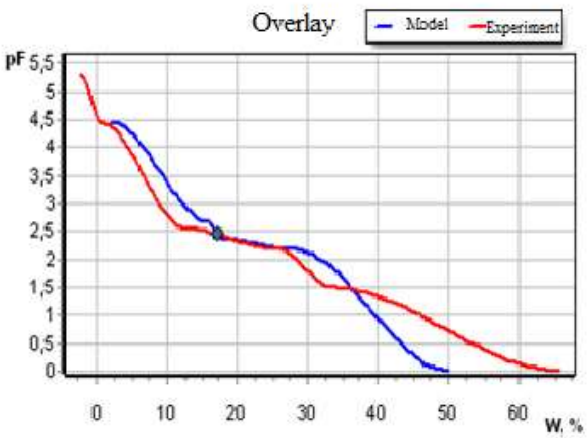

Fig. 1. Combination of the graphs of the water holding capacity curve function

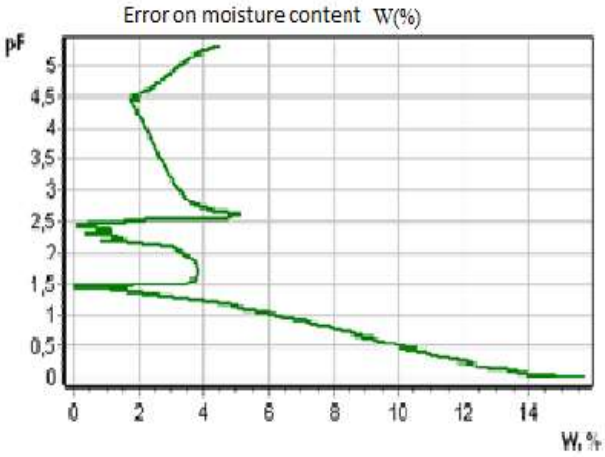

Fig. 2. Error in calculating moisture for the graphs of the water holding capacity curve function

The presented model solves the problem of finding moisture values for given fractions of soil grain-size distribution (from organic silt to coarse sand) (Fig. 3) and the inverse problem of finding the values of fractions for given humidity (Fig. 4). It is possible to save the current settings on each of the program windows. This enables to return to the original calculations as well as to compare and select the optimal properties necessary for the design. The labor intensity decreases and the calculations visibility increases in this case.

Single-type curves were obtained when comparing the result gained with the application of a software package with the laboratory studies, [2]. Therefore, the basic hydrophysical characteristics of light gray forest bleached soils were built using the program, [11] (Fig. 5).

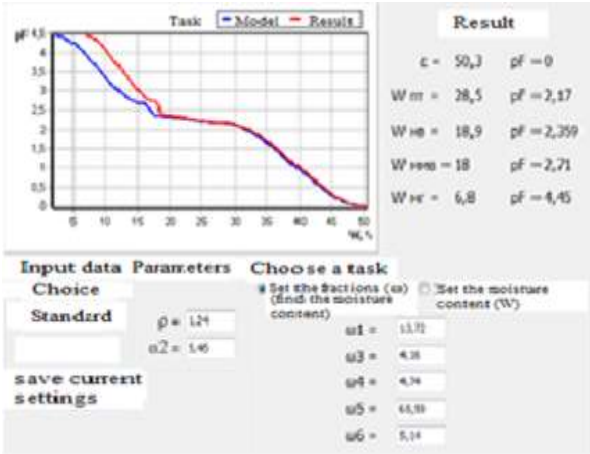

Fig. 3. Moisture values determination

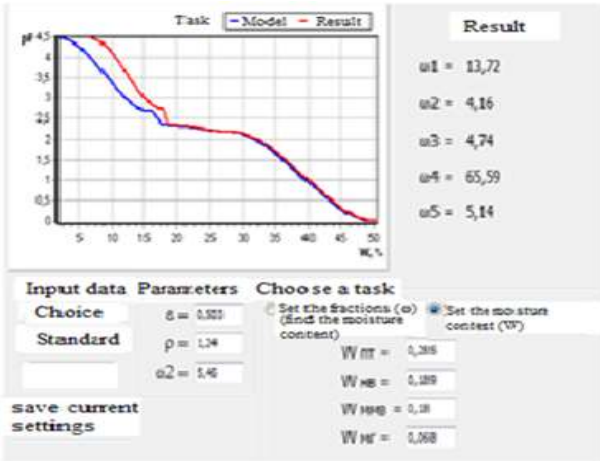

Fig. 4. Determination of grain-size distribution fractions values

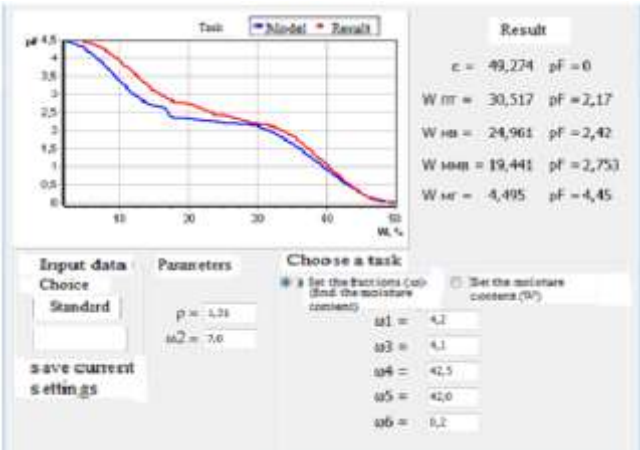

Fig. 5. Combination of the graphs of the curve function of water holding capacity (basic hydrophysical characteristics) for the model of chernozem and light gray forest bleached soils

The obtained graphs assist in calculating the thickness of active soil layer suitable for planting flowers, growing fruit crops and laying the landscape. Specific planting crops require

certain conditions: 1) the need of this culture for water; 2) the amount of moisture that may be contained in the active layer; 3) the lower permissible limit of moisture content in the soil; 4) daily water consumption in phases of cultural development. The optimal values of irrigation rate take into account the favorable degree of soil moisture for plant growth and development [6].

$$H = \frac{M}{\rho_b \cdot (W_{FMC} - W_{0.7FMC})}$$

where H is active soil layer, m;

M is irrigation rate, m^3/ha;

ρ_b is density of active soil layer, t/m^3;

W_{FMC} is optimum moisture content of the active layer of the soil, almost equal to or slightly less than field moisture capacity;

$W_{0.7FMC}$ is moisture of the active layer before watering.

The remediation process requires improvement and study. New techniques are needed to reduce economic costs. To achieve this objective, it is possible to try using pedotransfer functions that enable to solve the problem of designing fill ground by setting the grain-size distribution with the specified properties of the working layer. Visualization of this method is provided by the main hydrophysical characteristics. It is necessary to carry out a comparison of laboratory, calculation and software methods in order to avoid the wrong choice of the calculation model. This will help to compare the simulated conditions to the real ones and to choose the optimal calculated model.

IV. CONCLUSION

The analysis of the received basic hydrophysical characteristics of chernozem and light gray forest bleached soils showed that the proposed program can be used in constructing the curve of water retention of various soils. The curves demonstrating the basic hydrophysical characteristics retain their shape but have offsets along the moisture axis and depend on the properties of the studied soils. The studied graphs make [12] it possible to follow the dynamics of soil shrinkage, determine the fluidity of the soil and characterize the pore space, which water saturation depends on, at a known humidity.

Thus, it is currently possible to design fill grounds that meet the requirements of target uses. This task is well implemented under the conditions of a certain optimal ratio of coarse and fine sand, fine dust, small silt particles. At the same time, the working layer is given the required grain-size distribution using pedotransfer functions.

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