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Soil porosity and pore size distribution

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Abstract: The characterization of pore space is an essential component of the ground investigation process. Natural or artificial processes in the soil are forming or destroying the soil pores and are causing changes in their size and distribution. Since the soil fluid movement occurs in pore, their size distribution is particularly important in defining some soil characteristics. The research presented in this paper include: analysis of porosity and pore size distribution in natural soils, determination of porosity and pore size distribution curve based on suction, building the suction curve by laboratory experiments and mathematical modeling, results processing, highlighting possible effects of soil processes on the porosity and pore size distribution.
Keywords: porosity, soil, suction, moisture, pore size

1. NATURAL SOIL POROSITY

The porosity of soil as well as pores size distribution, characterizes the part of the soil volume which is not occupied or isolated by solid material [2,5]. Pore space has influence over the soil processes, in the same time being affected by these processes. Among them we can mention: the movement of water, air and other fluids, transport of chemicals and chemical reactions, the lifespan of roots and other bio-organisms.

Currently, the definition of pore space excludes the fluid cavities, which are completely enclosed by solid material and have no connection with pore space.

Thus, a single space is taken into account, determined by the continuous pores of the soil body. In a new concept, pore space represents the routs through which the fluid moves into the soil. These routes are sinuous, variably built and continue.

Pore space is often considered an artificial concept, which allows quantification of its essential nature, as defined above. Although several alternatives could serve as a basis for defining the porosity and pore size in soil science and hydrology, they are expressed by means of the fluids that occupy and move through the pore space [7].

Pore size plays a key role in the various proposed techniques for quantifying soil structure. It also has a major role in the prediction of soil hydraulic properties [6,8].

Soil porosity depends on many factors such as: texture, structure, apparent density (loose or chunky soil conditions), and cementing. This is expressed as a percentage of the total soil volume and is calculated using the formula:

$$PT(\%) = 100\left(1 - \frac{DA}{D}\right) \tag{1}$$

where PT – the total porosity of the soil (%), DA – apparent density (g/cm^3), D - density (g/cm^3).

Total porosity is an indication of the relative volume of soil pores. Coarse-textured soils tend to be less porous than fine-textured soils, although the average size of individual pores is higher in the first one than the second one. In fine-textured soils (clay), porosity is highly variable, as the ground swells, shrinks, aggregates, disperses, compacts or cracks. Total porosity values increase whiles the organic matter content is increasing. They are about 60-70% in organo-mineral soils and can reach over 80% in organic soils (peat).

Another way to express the soil porosity is to report the volume of pores to the volume of soil solid part; it is called the pores index (figure).

$$e = \frac{V_p}{V_s} \tag{2}$$

where: e – pores index, V_p – pore volume (cm^3), V_s – the volume of solid fraction (cm^3).

This index usually varies between 0,3 and 2,0.

Switching from total porosity to pore index can be done using the following equations (3) and (4):

$$e = \frac{PT}{100 - PT} \tag{3}$$

$$PT = \frac{e}{1+e}100 \tag{4}$$

Soil pores are distinguished by their size, a characteristic quite different from soil to soil, having a peculiar importance in defining the characteristics of soil.

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The by size distribution of pores is a result of the settlement status of elementary particles and structural aggregates. Sometimes this is more important than total porosity.

There are basically two types of porosity, macro porosity and micro-porosity, bounded by 50μ pore diameter. The pores larger than 50μ ensure freedom of water circulation and soil aeration; the soil water is retained in the pores with a diameter less than 50μ.

A somewhat more detailed classification includes three types of porosity: draining porosity, consisting of large pores with diameters greater than 10-30μ (30μ diameter characterizes coarse textured soils and 10μ the middle and fine-textured soils) which is occupied by the excess water or air; useful porosity, consisting of medium-sized pores with a diameter between 0.2 and 10-30μ,

where mobile water or air is retained; inactive porosity, consisting of pores having the diameter smaller than 0.2μ, in which water not available to plants is retained, less mobile, which only rarely is lost from soil.

Pore size (r) is given by the average radius of the channel through which fluid flows. Pore size distribution is given by the volume of pores with the same size existing in a representative volume of soil. This can be represented as a function f(r), whose value is proportional to the volume of all pores having the radius within an infinitesimal range centered on r.

2. MATERIALS AND METHODS FOR MEASURING

A common method for measuring total porosity and pore size distribution is to use suction curve S (θ), where S is the soil suction and θ is the volumetric water content [3,4,10,11]. Because large pores are filled or emptied at S close to 8, a soil that has many pores with large diameter will have a water retention curve, which indicates a low water content at high values of suction matrix. Conversely, a soil with many fine pores will retain more water at high values of suction matrix having a water retention curve with more gradual change of slope.

According to capillarity theory the relation between r and S is given by:

$$r = \frac{-2\sigma\cos\alpha}{S} \quad (5)$$

where σ is the surface tension and α is the angle of contact [1,12]. This relationship can transform the S(θ) curve, determined by experimental measurements, to a equivalent curve r(θ). This is actually a cumulative curve of pore size distribution. Water content on a drying curve r(θ) indicates the volume of all pores with diameter less than r. By applying a fundamental theorem of calculus, results that the pore size distribution is given by the derivative:

$$f(r) = \frac{d\theta}{dr} \quad (6)$$

Researches conducted in the laboratory have aimed the characterization of soil porosity and pore size based on data on water retention in soil. Four soil types were studied, for which the suction curves were determined, both on analyses on experimental facility in foto.1 and using the SoilPara program.

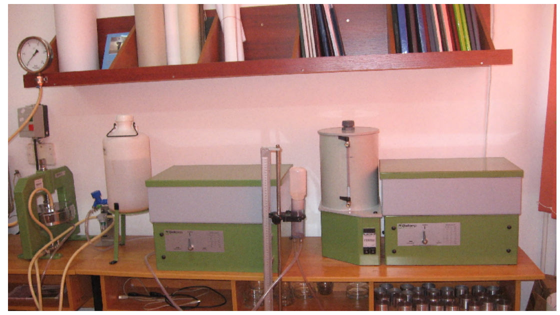


Foto.1 Experimental installation for the determination of the suction curve

The research methodology included the following steps:

A. Soil sampling. Several field trips were done, where soil samples were taken in its natural settlement, using the cylinders [9]. The soil samples were taken from 0-25 cm depth in five repetitions for 4 points.

B. Determination of texture. For each soil sample the content of clay dust and sand was determined.

C. Determination of apparent density. Apparent density was determined as dry soil mass in a given volume of soil.

D. Analysis of soil structure. This consisted of the following determinations: the type of structure, degree of structure and structural stability index.

E. Determination of the theoretical function θ (h), (SoilPara program).

Samples taken from the field were initially analyzed to characterize soils in terms of texture, structure and condition of settlement (Table 1).

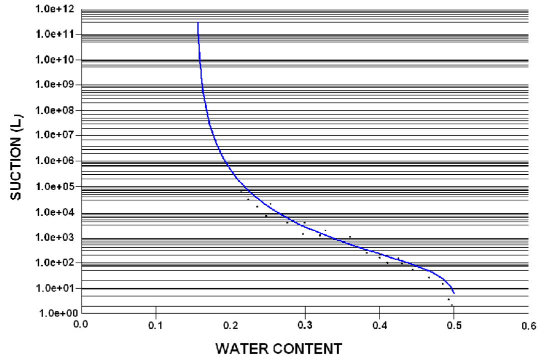
Table 1. The physical characteristics of the analyzed soils

Variant	***Granulometric composition (%)***			***Apparent density (g/cm³)***	***Structure***		
	Clay	Dust	Sand		Type*	Degree of structuring*	Stability Index
V1	9,12	31,75	59,13	1,50	pa	sd	0,29
V2	32,04	38,69	29,27	1,20	gl	bd	0,72
V3	24,56	48,35	27,09	1,39	pa	md	0,35
V4	43,51	13,40	43,09	1,27	pa	md	0,48

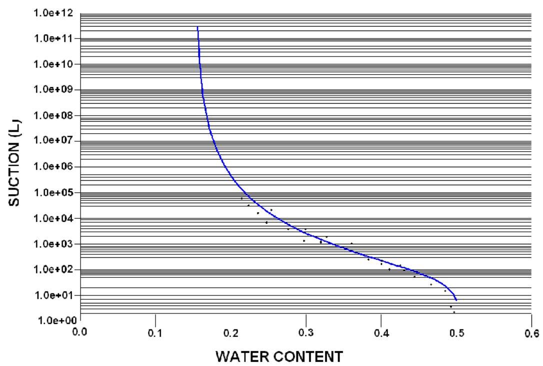
* Classification methodology development after soil studies, 1986, ICPA Bucharest, Romania

3. RESULTS AND DISCUSSION

Suction curves were graphically obtained representing the water content based on pressure values (experimentally determined) and based on the diagrams obtained with the SoilPara program (fig. 1a, b, c and d).



(a)



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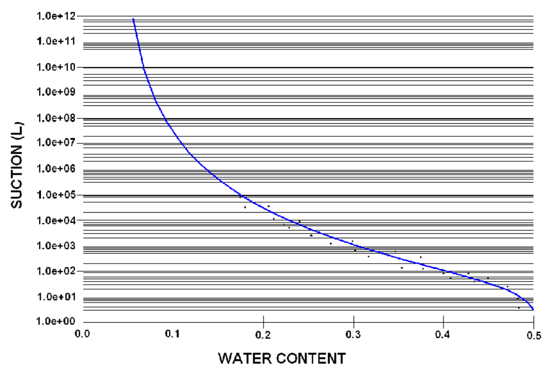
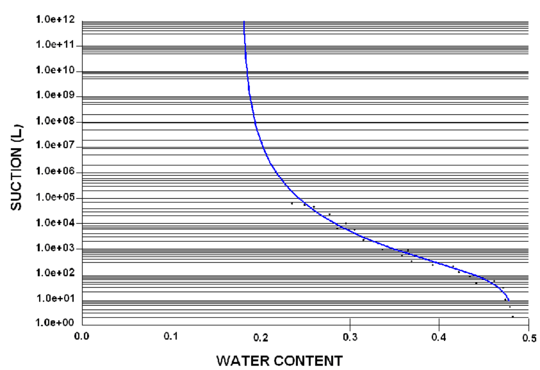


(c)



(d)

Fig.1. Suction curves
a – variant V1, b – variant V2, c – variant V3, d – variant V4

The standard deviation of results (AMPR) obtained by the two methods was calculated with equation 7.

$$AMPR = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\theta_{ei} - \theta_{mi})^2} \quad (7)$$

where: n is the number of pairs of values of moisture, θei şi θmi – experimentally determined humidity values, by modeling respectively.

AMPR values calculated for each variant are as follows: V1-0,01538; V2-0,01612; V3-0,01628; V4-0,01517. As can be seen, they fall between 1.51 and 1.63 percent of moisture, which shows a good correlation of experimental results with those obtained by mathematical modeling.

Applying equation (5) for σ = 72,9·10-3 N/m and α variable, the corresponding diameters were calculated for different values of suction (Table 2). In accordance with equation (5), water will not instantly penetrate the ground having cos α equal to zero or having a negative value (α ≥ 90°).

Under this approach, an impermeable soil has contact angle equal to or greater than 90°. Soils considered permeable will have different water-solid contact angles ranging between 0° and 90°, which will affect the soil-water relations, such as pore size determination based on suction curve.

Based on the suction curves, the percentage of pores having the diameter smaller than that corresponding to the default value of suction calculated for the total volume of soil, was determined (Table 3).

Table 2. Relationship suction-pore radius

Suction (cm CA)	***Pores radius (μ)***			
	α = 0°	α = 30°	α = 45°	α = 60°
10	148.60000	128.70000	105.06000	74.30000
31.62	47.00000	40.70000	33.20000	23.50000
100	14.86000	12.87000	10.50600	7.43000
316.22	4.70000	4.07000	3.32000	2.35000
1000	1.48600	1.28700	1.05060	0.74300
3162.27	0.47000	0.40700	0.33200	0.23500
10000	0.14860	0.12870	0.10506	0.07430
31622.77	0.04700	0.04070	0.03320	0.02350
100000	0.01486	0.01287	0.010506	0.00743

Table 3. Volume of pores with radius less than the radius corresponding to a given suction

Suction (cm CA)	***Pores Volume***			
	V1	V2	V3	V4
10	0.496	0.403	0.485	0.477
31.62	0.456	0.316	0.427	0.451
100	0.435	0.289	0.400	0.433
316.22	0.353	0.189	0.321	0.364
1000	0.334	0.168	0.301	0.345
3162.27	0.274	0.113	0.241	0.294
10000	0.262	0.100	0.227	0.282
31622.77	0.225	0.075	0.183	0.249
100000	0.217	0.068	0.169	0.241

The data in Tables 2 and 3 characterize the pore size and its distribution in the analyzed soils. With the help of this data the r(θ) curve was drawn (Fig. 2).

It also have been determined other characteristics of the porous space: total porosity (TP), micro-porosity and macro-porosity bounded by pore radius r = 25 μ (Table 4).

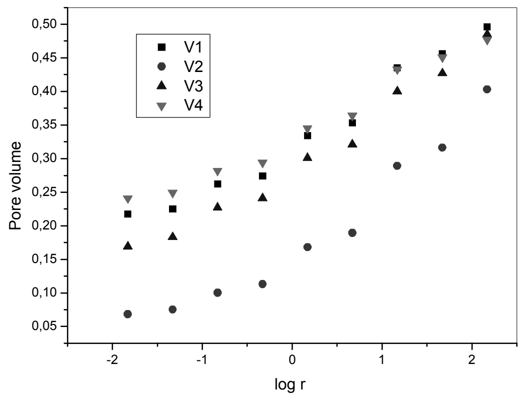


Fig. 2. Soil pore size distribution, (α = 0)

Table 4. Characteristics of the porous space

Variant	*PT (%)*	*Macro-porosity (% of PT)*	*Micro-porosity (% of PT)*
V1	51	12.9	87.1
V2	43	33.2	66.8
V2	50	17.0	83.0
V4	48	8.7	91.3

4. POSSIBLE EFFECTS OF SOIL PROCESSES ON THE PORE SIZE DISTRIBUTION

Natural and artificial processes have as result the creation and destruction of soil pore, leading to changes in size and pore size distribution. Some effects of processes in the soil over pore size distribution are:

a) *The contraction* may be caused by: the formation of new macro-pores; widening of macro-pores; in an aggregate it can cause an increase or decrease of the pores size, if clay particles are expanding.

b) *Inflation* may cause: the decrease of macro-pores size; closing of macro-pores; in an aggregate it can cause an increase or decrease of the pores size, if clay particles are expanding.

c) *Mechanical compaction* can cause: decreased of macro-pores size; closing of macro-pores; reducing the number of pores between aggregates; reducing the fraction of pore space represented by the smaller pores.

d) *Soil tillage* may cause: the destruction of existing macro-pores, destruction of aggregates and thereby reducing the fraction of pore space represented by the smaller pores.

e) *The biological activity* may cause: the creation of new macro-pores, an increased the number of macro-pores as a result of traffic created by ants and mammal burrows, can reduce the size of macro-pores as a result of pressure from the root system development, aggregation growth and porosity development, reducing size or obstruction of pores due to the increasing number of microorganisms.

d) *Chemical activity* may cause: reducing the size or clogged pores due to the formation of precipitates, increasing the pore size due to dissolution of precipitates, increased or decreased cohesion between elementary particles have complex effects on soil structure and pore size.

5. CONCLUSIONS

Pore space characterization is particularly important in the investigation of soil. The liquid, solid, and gaseous constituents of soil pores determines the size and shape, whose characters, in turn exercised profound influence on the nature and behavior of soil.

Determination of pore size and their size distribution, using the suction curve, is a method that can be applied with good results if having a powerful facility to obtain moisture-suction relationship.

Natural and artificial processes induce significant changes on soil porosity. If the soil is subjected to a uniform pressure, it loses macro-porosity and wins micro-porosity. An uneven pressure on soil may cause varying effects over porosity, such as: large pores number decrease, fine pores number increase, closing of pores between aggregates, the complete closure of macro-pores, etc.

The new concept regarding soil porosity, the technique of measuring and the effects on transport phenomena are major objectives in studying the soil.

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