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Direct and indirect measurements of porosity on a real heterogeneous confined aquifer

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Abstract

The porosity plays a very important role among the parameters characterizing a porous media. The measurement of this parameter can be performed directly in laboratory, on undisturbed soil samples, or indirectly on field, relating the porosity with other parameters easier to measure, such as hydraulic conductivity, electric resistivity, velocity of seismic waves,…(Archie, 1942; Biot, 1956). In this study direct and indirect porosity measurements, performed on the confined aquifer of Montalto Uffugo test field (Department of Soil Conservation - Calabria University – Italy), have been considered. The indirect measurement of porosity has been carried out by hydraulic conductivity measurements. The porosity values measured in direct and indirect manner have been compared on a graph, to verify a substantial difference between the values measured by the considered two methods, that is at different scales.

1. Introduction

Porosity represents the soil macroscopic property of including voids within the solid framework; so therefore it describes the capacity of a soil to store and to release water. The total porosity (n), expressed in percentage, is defined as the ratio between the volume of voids (V_v) and the total volume (V):

$$n = \frac{V_v}{V} \cdot 100 \qquad (1)$$

Referring to the hydraulic flow in the porous media, it is common to talk about the so called effective porosity (n_e), which considers only the interconnected voids (V_{vi}), the microscopic channels and spaces mutually connected and communicating, that really take part into the flow:

$$n_e = \frac{V_{vi}}{V} \cdot 100 \qquad (2)$$

Porosity is the parameter that mostly characterizes a porous medium, giving an estimation of its two constituting phases (void and solid). It is of fundamental importance also for the characterization of the hydraulic flow within the porous media, that, nevertheless, also strongly depends on other factors, such as the shape of the particles forming the medium, their characteristic dimensions, the tortuosity,… Referring to these last factors, porosity can be classified in different ways, the most important of which is undoubtedly the one based on the pore dimension (d).

The International Union of Pure and Applied Chemistry (IUPAC) divides pores into three categories (Fig.1):
Micropores (d<2 nm) (are the pores contained in the inner structure of a single particle; the cause of the water retention.
Mesopores (2 nm<d<50 nm) are constituted by the inner voids and channels of a single particle or grain, mostly linked to the particle surface.
Macropores (d>50 nm) are the biggest pores constituted by the space between the single, in which there can be no water retention. Both air and water flow freely.
Consequently the mobile phase is mainly made of spaces among the grains (intergranular pores). The contribute of the inner porosity of the particles is often negligible, specially the part related to the macroporosity.

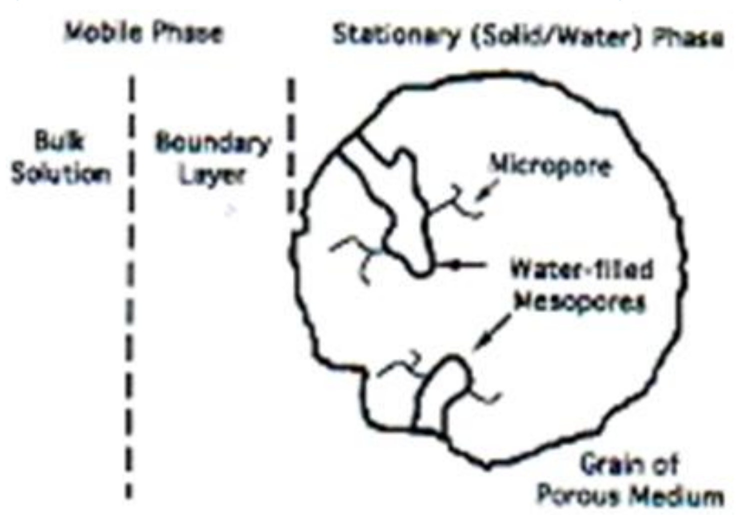

Fig.1: Conceptual model of a porous medium (Cunningham et al., 1997).

2. Measurements and methods

Once the fundamental role played by the porosity in the porous media was ascertained, it is clear the importance of the measurement of this parameter, that can be obtained both by direct methods in laboratory (resaturation, porosimeter, optical measurement) and indirect methods, usually on field by measuring physical properties that can be related to it somehow (as a function of the grain size distribution or of the electric conductivity, the sound speed,…).
As for the direct measurement of the porosity, in the present study the resaturation method was adopted, that allows to estimate both total and effective porosity.
As for the indirect measurements of the porosity the method of the grain size distribution was used, relating the porosity to the hydraulic conductivity to the porous medium (k) by the laws given by Kozeny-Carman (Kozeny, 1927; Carman, 1937) and Slitcher (Odong, 2007), whose expressions are as follows:

$$k = \frac{g}{\nu} \cdot 8.3 \cdot 10^{-3} \left[\frac{n_e}{(1-n_e)^2} \right] \cdot d_{10}^2 \qquad (3)$$

$$k = \frac{g}{\nu} \cdot 1 \cdot 10^{-2} \cdot n_e^{3.287} \cdot d_{10}^2 \qquad (4)$$

where g is the acceleration due to gravity, ν is the kinematic viscosity and d_{10} is the grain diameter (mm) for which 10% of the sample is finer than.
To do so, the hydraulic conductivity of the medium on field was measured by slug tests and aquifer tests. At the same time, to make the values of n measured on field comparable with those measured in laboratory, k was estimated also in laboratory, by means of flow cells, on the same undisturbed soil samples of the aquifer subjected to the porosity measurements.

3. The investigation area

The investigation was carried out on the aquifer of Montalto Uffugo (Italy) test field.
The examined area has the geological characteristics of a recently formed valley, with slightly consolidated and easily broken-up conglomeratic and sandy alluvial deposits. In correspondence with the test field a sand and conglomerate formation of relatively limited thickness can be identified, with a variable percentage of loam. Fig.2 shows the planimetrical layout of the wells and the stratigraphic scheme of the test field, which points out the interposition of a clay bed between a consistent sand bank and a covering layer of alluvial deposits.

4. Results

Tab.1 shows the number of k and n_e values measured by direct and indirect methods, in laboratory and on field respectively.

	Direct laboratory measurements	Indirect field measurements	
	Flow cells	Slug tests	Aquifer tests
Data number ($k - n_e$) for each set	18	9	12

Tab.1: Number of values (k and ne) for each set of direct and indirect measurements.

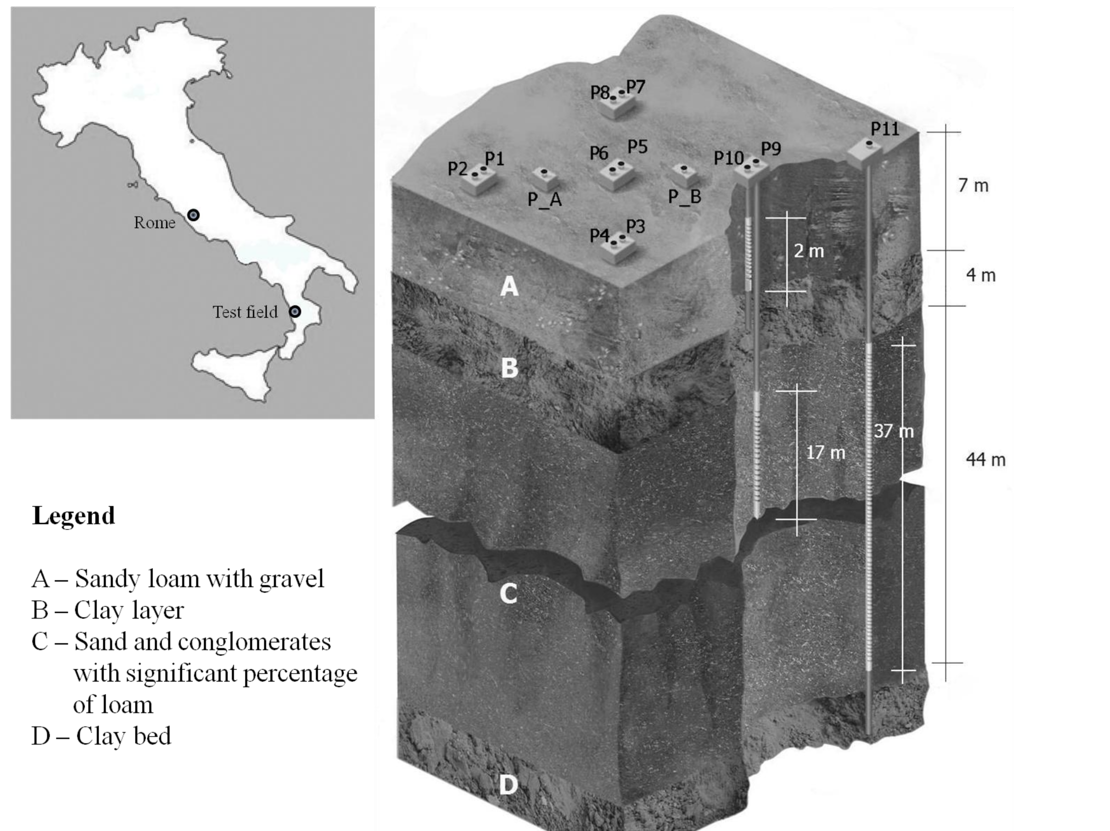

Fig.2: Schematization of the test field.

The graph in Fig.3 shows the relationship between hydraulic conductivity and effective porosity considering dyads of values obtained both in laboratory (directly) and on field (indirectly), by means of the grain size distribution. The indirect measurements of n_e were obtained both by the Kozeny-Carman law and by Slitcher law, not being possible to find out from the experimental laboratory data which one is better fitting.

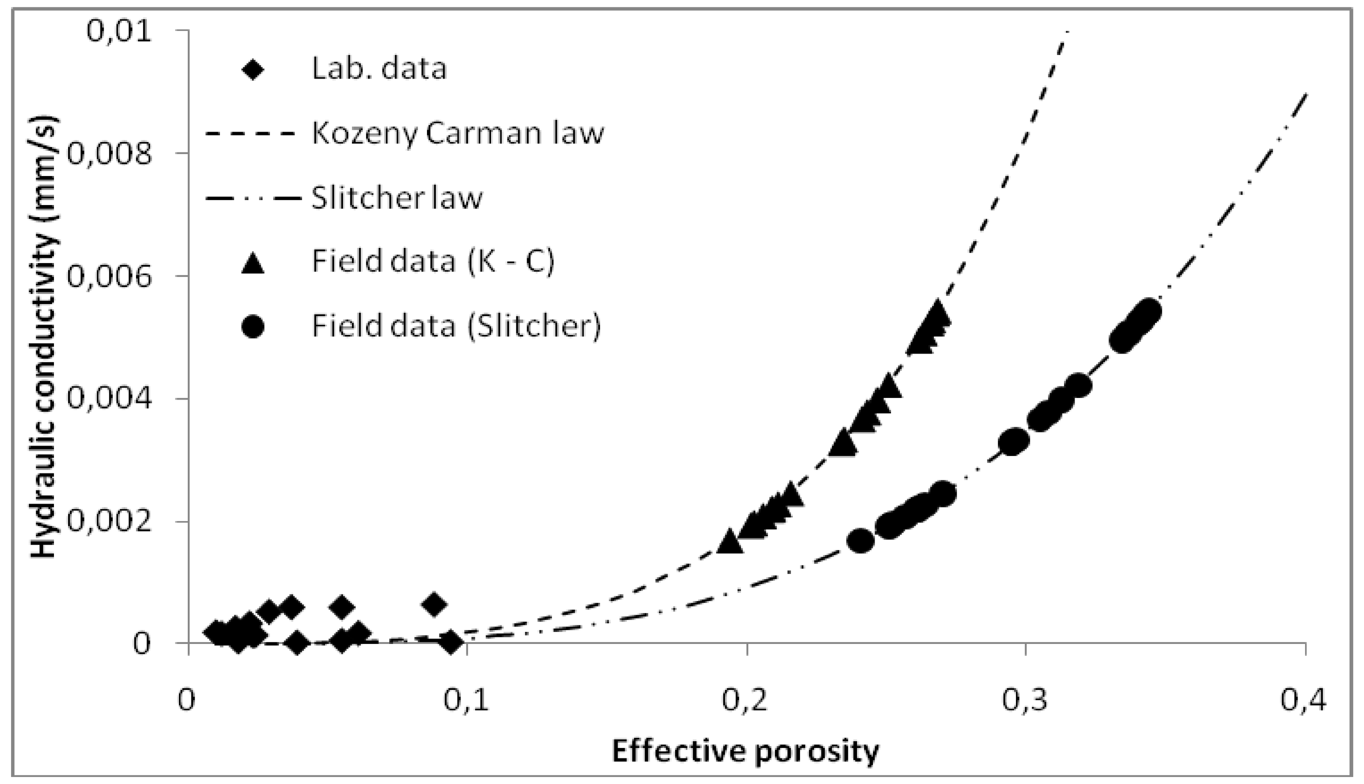

Fig.3: Direct and indirect measurements of n_e in relation to k.

The uncertainty that remains between the n_e values indirectly measured by one method or the other is basically the one existing between Kozeny-Carman and Slitcher relationships. Nevertheless it is necessary to remind that the first one is undoubtedly known as the best reliable, while the second one gives underestimated k values, which means highly overestimated n_e values.

5. References

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