

INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING



This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:

<https://www.issmge.org/publications/online-library>

This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.

Some considerations about the control of the laminar flow in the percolation through porous media

Quelques considérations sur le contrôle de l'écoulement laminaire dans les milieux poreux

L.R.CAVICCHIA, Professor, M.Sc., FEL, University of Campinas (UNICAMP), Consultant, Brazil

T.L.PEIXOTO JR., Professor, Dr, EESCUSP, University of São Paulo (USP); FEL, University of Campinas (UNICAMP); Paulista Institute of Engineering (IEEP - Objetivo), Consultant, Brazil

SYNOPSIS: The concept of Reynolds Number has been widely used for the control of the flow condition on sandy soils permeability tests.

The use of the Reynolds Number for this purpose, however, can lead to considerable errors and absurd conclusions, mainly due to the existent difficulties in the definition of the numbered values of the involved parameters (Reynolds Number itself, percolating velocity and diameter of tube).

This work makes a critical analysis of such a usage of the Reynolds Number, and introduces a suggestion of procedures for the strict control of flow permanency on the laminar state, in the sandy soils permeability tests, without the use of Reynolds Number.

1 INTRODUCTION

This work was based on Cavicchia's experimental researches (1986), whose main purpose was to establish statistically determined equations leading to the determining of permeability coefficients of sandy materials, through indirect methods starting from the concept of void size distribution curve for granular materials developed by Silveira (1964).

To that effect, permeability tests were done upon samples of several kinds of sand, which constituted soil samples molded in loose and dense states, and for which the approximate void size distribution curves were determined in those two states of compactness.

For the execution of the permeability test over the molded soil sample in the compact state, the water flow could be oriented downwards because there was not the danger of making the compactness of the soil sample become modified by the percolation of the water.

However, for the execution of the permeability test over the molded soil sample in the loose state, there was the hazard of having the water flow itself compacting the sample, thus influencing the value of the permeability to be reached. Therefore, the waterflow was next oriented upwards, which gave origin to the possibility of the appearance of the hydraulic rupture phenomenon. As it may be aggravated by the existence of turbulence in the waterflow, it was confirmed that the flow should be definitely laminar.

Thus, for the elaboration of Cavicchia's publication (1986), that gave origin to this work, the permanency of the flow in the laminar state should be strictly controlled, mainly on account of two imperative reasons:

1. the Darcy's equations are valid only for the laminar flow.
2. the turbulence could modify the compactness state of the molded soil samples in the loose state.

Therefore, it was established the evidence of a necessity to use a process that supported effectively a strict control of permanency of the waterflow in the laminar state, during the permeability tests to be executed.

2 PURPOSE

The purpose of this work is to analyze critically the processes commonly used for the checking up the laminar motion validity limit, on the percolation of water through porous media, based in the Reynolds Number. The work also presents a suggestion of diretrizes of procedures for the strict control of permanency of the flow in the laminar state, without using the Reynolds Number.

The critical analysis presented (herewith) has as its base, the difficulties observed in the execution of the experimental researches necessary for the preparation of Cavicchia's work (1986).

3 FLOW CONDITIONS

Starting with Osborne Reynolds, in 1883, and based in experiments in smooth wall tubes of small diameters, the rules of laminar and turbulent flow were well-established.

Since then, illustrated graphics of the kind "i x v" (as shown in Fig. 1) show the existence of three distinct regions corresponding to the laminar, indefinite and turbulent states of flow.

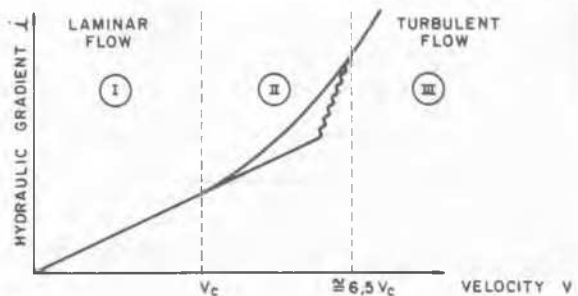


Figure 1. Laminar and turbulent flows. Critical velocity.

On his experiments, Reynolds concluded that the critical velocity is inversely proportional to the diameter of the tube, expliciting the obtained results in the following equation:

$$N = \frac{v_c \cdot d}{\nu} \leq 2.000 \quad (1)$$

where: v_c - critical velocity, superior limit for flow in laminar condition
 d - diameter of the tube
 ν - kinematic viscosity of the fluid

This expression is known as "Reynolds Number" for the critical velocity and it has been usually used for the control of permanency in the permeability tests within the laminar condition.

4 FLOW THROUGH THE SOILS

In the general case of soils, the flow analysis has been done from a macroscope point of view, being the phenomenon quantified through the average results extracted from the sample as a whole, regardless of what happens in its interior.

For this usually developed analysis, it is used the experimentally established law demonstrated by Henry Darcy in 1856, valid for the flow in the laminar condition, expressed by

$$q = k \cdot i \cdot A \quad (2)$$

or

$$v = k \cdot i \quad (3)$$

where: q - rate of flow
 k - coefficient of permeability
 i - hydraulic gradient
 A - total cross-sectional area of soil sample
 v - velocity of the fluid

When a sample of soil is submitted to the permeability water test, it is considered that the water reaches the soil sample through the permeameter with an approximating velocity v_a , and percolates through the soil sample with a percolating velocity v_p .

In Fig. 2, the values that interact with the phenomenon are indicated, as well as the differentiation between the approximating and the percolating velocity in the permeability test.

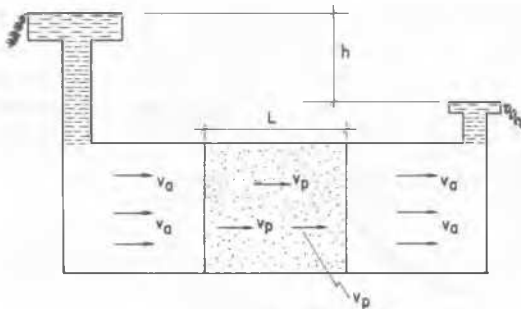


Figure 2. Permeability test. Approximation and percolation velocities.

The relation between the two velocities is usually expressed by

$$v_a = f(n, v_p) \quad (4)$$

where n is the porosity of the sample.

The velocity in the interior of the sample, as it was calculated, shows that the percolating phenomenon through the soils has been faced as if the spaces filled by the solids and voids existed, independently of one another, each one occupying an area well defined in the permeameter.

Then, it is important to notice that the velocity v_p , as it was calculated, does not represent the real velocity of the flow in the interior of the sample. The channels formed by the voids of the soils can be so irregular and tortuous, of a transversal section so variable and of such great complexity in their interconnections and subdivisions, and of a rugosity so heterogeneous along its length, that an analysis of flow through their voids becomes practically impossible. Moreover, due mainly to the heterogeneity of the ways and to the non-acquainted of the real distance made by the flow in the interior of the sample, its real velocity remains unknown.

5 TURBULENCE

The turbulence is generated by the appearance of shear stresses in the interior of the flow in percolation.

In Fig. 3, the parameters that influence in the appearance of turbulence, for a circular tube of radius r are thus represented.

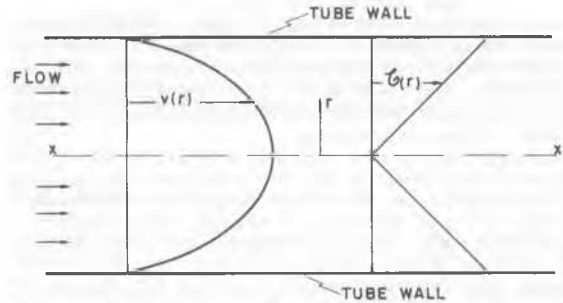


Figure 3. Velocity distribution and shearing stresses in a circular tube of small diameter.

From equation

$$\tau = n \frac{dv}{dr} \quad (5)$$

where: τ - shearing stresses
 n - dynamic viscosity of the fluid
 $\frac{dv}{dr}$ - variation of the velocity with the radius of the tube

it can be noted that the shearing stresses increase as the velocity increases. When these shearing stresses exceed determined values, variable from flow to flow, the turbulence shows up in the tube, and the permeability value decreases. At the same time, the flow in movement starts applying some kind of force on the walls of the tube, in direction to its own movement. In the case of percolation through sandy soils, the walls of the channels are formed by the sand grains. Thus, as the turbulence comes up, the

soil grains are urged to the flow movement.

6 CONTROL OF THE FLOW CONDITION

Usually, as it is shown by the vast bibliography and technical literature available, the flow state through the sandy soils has been controlled by the Reynolds Number ($N = \frac{v_c \cdot d}{\nu}$), usable, in the first instance, to smooth tube of small diameters, assuming that the sand can be divided in solid and void parts, independent from one another, and directing the calculus as if they would be the expression of the truth.

However, the control of the flow condition through the Reynolds Number is made impossible for a series of reasons:

1. Initially, the great difficulty for the choice of a numbered value for the Reynolds Number adequate for the water percolation through sandy soils. The Reynold's experiments established $N < 2.000$ for smooth tubes of small diameters. Taylor (1966) mentions $N < 1$ for soils; Numerov and Aravim (1965) recommend N varying from 4 to 6; Burmister asserts that Darcy's law is valid, for sandy soils, with hydraulic gradient from 0,2 to 0,5; Scheidegger (1960) and Harr (1962) recommend $N < 1$ for sandy soils.

Thus, according to the recommendation of values so differently among themselves, it is concluded that forcibly the subject needs to be further researched experimentally.

2. The certainty that the flow velocity in the interior of the sample, calculated as it is usually done through the equation ($v_a = nv_p$), does not express the real velocity of the percolation test, thus liable to lead to errors and absurd conclusions.

3. The difficulty for choosing a characteristic diameter, among the several ones formed by the sand grains in the interior of the sample, that may be representative for the phenomenon.

It has been usually chosen the D_{10} (effective sample diameter) for the calculations.

More recently, with the introduction of the theories of void size distribution curves, several diameters of formed voids are available. Even so, there are not theoretical or experimental bases, yet for the adoption of a value from the curve of voids, for the calculation of the Reynolds Number of a flow.

4. The certainty that the channels, formed by the soil grains inside the samples, must be seen as rugous, with variable rugosity, and not smooth, over which Reynolds executed his experiments and for which his conclusions are valid.

Therefore, the insistence in using the Reynolds Number concept, for the control of permanency of the waterflow in the laminar condition, in case of water percolation by the samples of sandy soils, can lead to absurd results and erroneous conclusions.

Such being the case, procedures based on the theoretical concepts of Fluid Mechanics were used, for the control of the flow condition over the permeability tests.

The equipment used had as a main characteristic the possibility of easy and quick variation of the hydraulic charges applied on the soil samples, in the same permeability test.

It has been built as seen in the graphic presented in Fig. 4

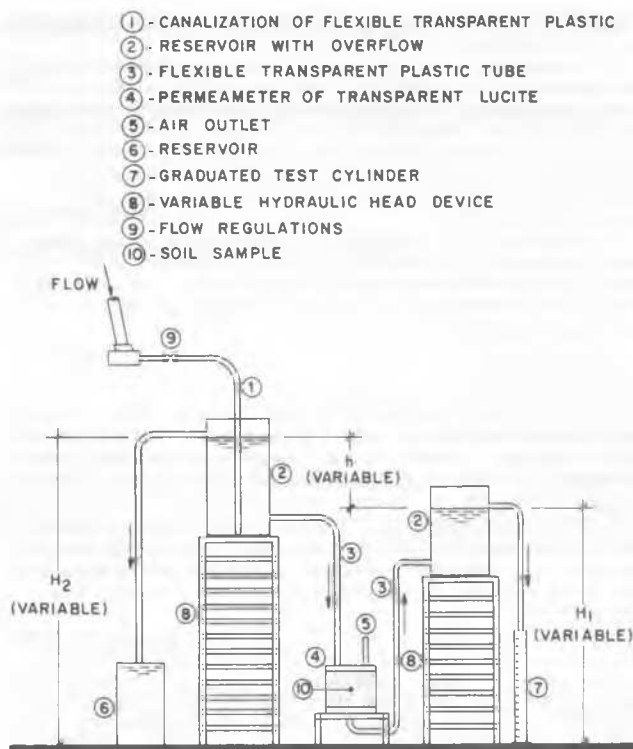


Figure 4. Variable hydraulic head equipment.

The equipment allows the execution of a same permeability test, with several and different hydraulic charges (and consequently different hydraulic gradients), with quickness and facility.

The process for the control of the flow permeability in the laminar condition was constituted of the following steps:

1. The hydraulic charge, for the sands studied in the research, could not exceed certain values, variable from sample to sample, under the risk of having the flow changed to a turbulent state and as a consequence introducing undesirable variance to the phenomenon.

2. For each test, at least three different hydraulic gradients should be taken.

3. For each different hydraulic gradient i , the numbered value of the velocity v may be calculated through the equation $v = \frac{q}{A}$, being the rate of flow q measured in the graduated cylinder (7) (Fig. 4).

4. For each test, a minimum number of three points (v, i) plotted on a graphic ($i \times v$), should be placed on a straight line passing by the origin, which is how the points of Region I, Fig. 1 must be placed (laminar condition).

5. If such condition would not be checked for the three first points measured, the hydraulic charge should be decreased, additional tests should be executed with smaller hydraulic gradients, and more points (v, i) should be plotted on the graphic ($i \times v$).

6. The permeability test was considered as satisfactory, and concluded, only when it is

possible to see that, at least three points (v , i) are aligned on a graphic ($i \times v$).

7. Besides, an additional second checking may be executed to confirm the results, relative to the fact that the permeability takes a constant value in the laminar state. Thus, in the part in which the three points (v , i) were aligned, the permeability may be calculated and it may be observed whether its value was constant and equalled to v/i .

8. Furthermore, a third checking can be done: any permeability value, placed outside the straight part passing by the origin, is smaller than the constant value calculated in the straight line.

7 CONCLUSIONS

The elaboration of this research has allowed that several conclusions, relative to the permeability test with sandy materials, could be drawn.

1. The permeability tests should always have their permanency in the laminar condition subjected to a rigid control, because the permeability values are different in different flow conditions.

2. The turbulence control by the Reynolds Number, for the case of water percolation through sandy soils, does not lead to satisfactory results, since there is much difficulty upon the choice of the numbered values of parameters involved in the calculations.

3. For the general case of sandy soils, the considerations made for smooth tubes of small diameters are, at least, debatable hypothesis.

4. The turbulence control can be made through a graphic ($i \times v$); for the assurance of the permanency of the flow in the laminar condition, at least three points (v , i) must be placed on a straight line that passes by the origin.

5. The numbered value of the permeability, measured as previously referred in the laminar condition, is constant for all points (v , i) aligned on a straight line passing by the origin; this is the permeability value in the laminar state, and it is always larger than their values measured in different conditions of the turbulent flow.

REFERENCES

- ASTM (1955). Symposium on permeability of soils. Special Technical Publication nº 163. Philadelphia. USA.
- Badillo, E.J. & Rodriguez, A.R. (1969). Mecânica de suelos - Tomo I - México.
- Cavicchia, L.R. (1986) - Análise crítica da permeabilidade nos materiais granulares em função da distribuição de vazios. M.Sc. Thesis, FEAGRI - UNICAMP - Brasil.
- Harr, M.E. (1962). Groundwater and seepage. McGraw-Hill Book Company. New York. USA.
- Numerov, S.N. & Aravin, V.I. (1965). Theory of fluid flow in underformable porous media. Israel Program of Scientific Translaction.
- Peixoto Jr., Thales de L. (1973). Análise da permeabilidade de materiais granulares em função de sua distribuição de vazios. Ph.D. Thesis. EESCUSP - São Carlos - Brasil.
- Scheidegger, A.E. (1960). The physics of flow through porous media. The Macmillan Company. New York. USA.

- Silveira, A. (1964). Algumas considerações sobre filtros de proteção - Uma análise do carreamento. Ph.D. Thesis. EESCUSP - São Carlos - Brasil.
- Taylor, D.W. (1966). Fundamentals of soil mechanics. John Wiley & Sons, Inc. New York, USA.