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IN-SITU PERMEABILITY TESTING OF A TOXIC INDUSTRIAL WASTE DEPOSITORY WITH THE PRESSIO-PERMEAMETER

ESSAIS DE PERMÉABILITÉ EN PLACE SUR UN SITE DE DÉCHETS INDUSTRIELS TOXIQUES A L'AIDE D'UN PRESSIO-PERMÉAMÈTRE

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Abstract

According to French official rules, toxic industrial waste (classified in class I) should be stored in impervious medium. The impervious clay layer has to be at least 5 meters thick, with a permeability K lower than 10^{-9} m/s. The regulation does not specify the measurement procedure : in-situ or laboratory, vertical, horizontal or average permeability. Logically, a vertical, in-situ measurement should be considered. However, this type of measurement, when K is very small, can be modified by all sorts of external parameters : duration of saturation, evaporation, temperature, test duration, etc... C.P.G.F., which surveys many sites each year, has constructed a new in-situ, variable head permeameter : the pressio-permeameter developed in collaboration with ÉTUDES PRESSIOMÉTRIQUES LOUIS MENARD. It is based on measurements with different heads, either on the soil surface or at the bottom of an excavation. Various spurious effects are eliminated with an appropriate procedure, using variable heads.

Résumé

La réglementation française exige que le stockage de déchets industriels toxiques se fasse en site étanche (site de classe I). Du point de vue technique, celui-ci doit être constitué par une formation d'argile d'une puissance minimum de 5 mètres et d'une perméabilité K = 10^{-9} m/s, le législateur a omis de préciser dans quelles conditions cette perméabilité devait être mesurée (en laboratoire ?, in situ ?, s'agit-il de la perméabilité verticale, horizontale ou moyenne ?). On peut penser qu'il s'agit de la perméabilité verticale mesurée in-situ, or la mesure d'une valeur aussi faible pose de nombreux problèmes : temps de saturation du terrain, évaporation, température, durée de la mesure, etc... La C.P.G.F. intervenant très souvent pour des études de sites, à mis au point en collaboration avec ÉTUDES PRESSIOMÉTRIQUES LOUIS MENARD un perméamètre à charge variable : le pressioperméamètre permettant de s'affranchir d'un certain nombre de paramètres aléatoies. Son principe est basé sur les mesures de la perméabilité à différentes pressions, celles-ci pouvant se faire aussi bien en surface qu'en fond de fouille creusée à la pelle mécanique.

Introduction

Measurement of very low permeabilities, under 10^{-8} or 10^{-9} m/s, with a conventional, double ring infiltrometer is particularly difficult because certain factors are no longer negligible : evaporation, variations of temperature ane changes in physical properties of clay as a function of saturation. These factors can strongly influence the volume variations which, for this apparatus, are 0.035 cc/hour for K = 10^{-9} m/s, corresponding to a height of $3.5 \cdot 10^{-3}$ mm. It seemed therefore necessary to construct a new type of equipment. The pressio-permeameter is a variable head permeameter, reaching 0.2 MPa (28 psi) which eliminates these factors and allows more correct permeability measurements.

Apparatus description

The conventional Muntz double ring permeameter has been modified :

- Height has been increased
- The base has been equipped with a cutter to help soil anchoring
- Upper closure has been adjusted for maintaining pressure.

The system is anchored in the soil with 4 helicoidal anchors, 75 cm long and 80 mm in diameter, supporting the base plate (fig. 1 and 2). The exits are connected to the measurement section with white, non transparent P.V.C. tubes, to avoid sunshine heat absorption.

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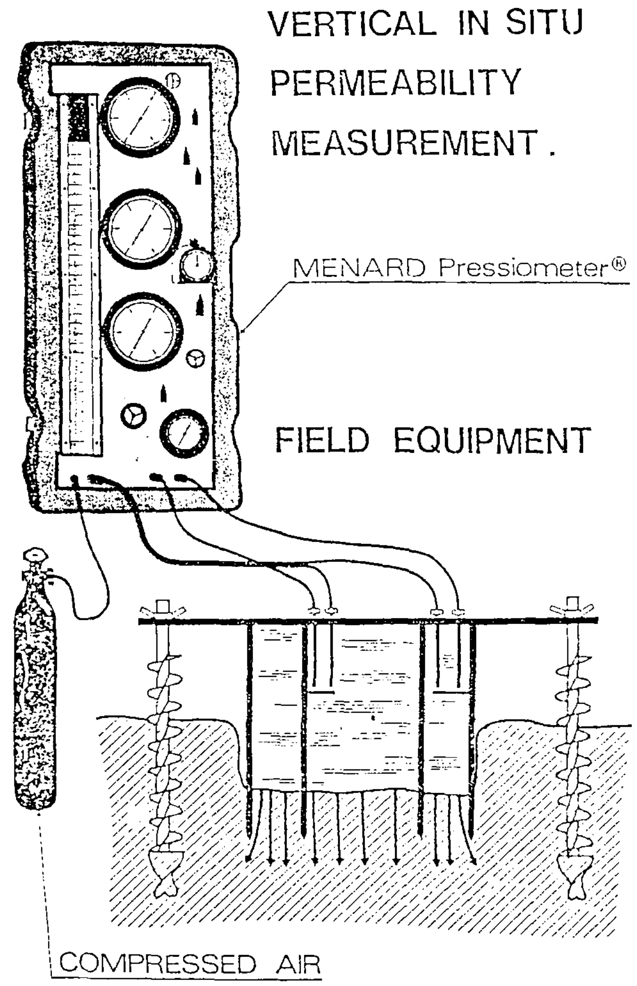

Fig. 1 : Field equipment.

The injection and measurement section is formed by the Pressiometer® itself as shown on figure 2 (Pressiometer is a trademark of Techniques Louis Ménard).

Field tests

For the past year, field tests have been performed on 7 sites :

Essonne : Sparnatian (tertiary) clay
Seine-et-Marne : chert clay (Cretaceous)
Yvelines : Sparnatian (tertiary) clay
Aisne : chert clay (Cretaceous)
Creuse : clay from weathered granite.

20 tests have been made including over 50 measurements at variable pressures (0.01 to 0.2 MPa, i.e. 1.4 to 28 psi). Tests were made either on the soil surface after removal of top soil, or at the bottom of a trench. All tests were repeated at least twice. Measurements are made after a period of saturation, varying from 1 to 5 hours, as a function of soil porosity. Saturation can also be accelerated by injecting water at a pressure slightly higher than the normal test pressure. However, to standardize test procedure, we may select for the future, a systematic saturation period of 4 hours. Saturation at higher pressure will be tested later, in order to check if parasite phenomena occur, such as clay decompression, soil deformation, etc.

Results — Interpretation

Darcy's law defines vertical flow through homogeneous media :

$$Q = - K.S. \frac{\delta H}{\delta H} \text{ or } V = \frac{Q}{S} = - K \frac{\delta H}{\delta Z}$$

Q being flow
K, Darcy's permeability coefficient
V, Darcy's velocity
S, test section
$\frac{\delta H}{\delta Z}$, vertical gradient

In the case of the Muntz infiltrometer, after saturation, it is supposed that $i = \frac{\delta H}{\delta Z} = 1$. In addition to the notion of Darcy's filtration velocity, it is important to take into account the notion of cinetic porosity (nc), particularly for very low permeabilities.

If a measurement made at pressure p is repeated at p after pressure has exceeded p between the 2 measurements, the second one gives a lower "specific flow". This non-reversible character is probably increased by clay decompression. The limit of validity of Darcy's law is related to the limit of application of conventional fluid mechanics. As this is no longer applicable "once

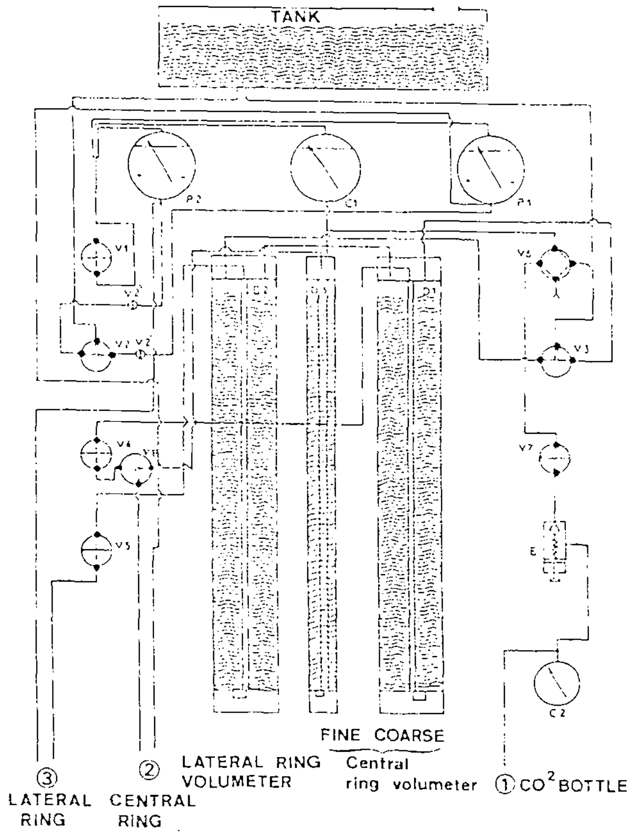

Fig. 2 : Schematic diagram of pressio-permeameter.

the fluid flows through channels so small that the fluid can no longer be considered to be a viscous continuum, and that the molecular structure of matter has to be considered" (Schneebeli, 1966). Unfortunately, practically nothing is presently known of this type of flow.

It is therefore difficult to establish a clear relationship between flow, permeability and pressure, particularly because :

— we do not know Darcy's law's limit of validity for very small K values

— total head Hg + Hp and saturation θ are not well controlled in unsaturated media.

Evaluation of average gradient $\frac{H}{\ell}$ is necessary for calculated (or even estimating) K, particularly when we make H vary from 0.01 MPa to 0.2 MPa, without being able to appreciate ℓ, which is here height of saturated soil.

With the pressio-permeameter, which only intends to measure vertical permeability (with its double rings), it can be seen that V is not a linear function of H (fig. 3). This could be due to a dispersion of water (flow lines) by the soil's horizontal permeability. Relationship is of the type

$$V = f(H^2)$$

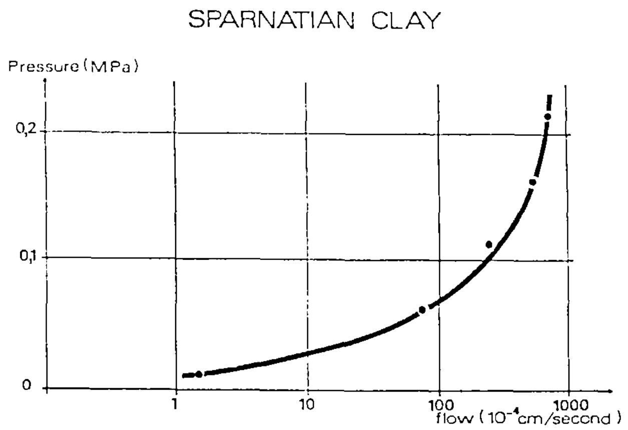

Fig. 3 : Sparnatian clay — Relationship between pressure and flow.

particularly above a pressure of 0.1 MPa (14 psi). All measurements were made after stabilization of flows and pressures, both in the inner and the outer rings, in order to be sure of the quality of each test. Figure 4 shows perfect linearity between total injected volume and time. Non-linearity of relationship between V and H cannot be due to leakage along the edges of the apparatus as anchoring was controlled, nor can it be due to the presence of a shallow saturated zone. In each experiment, no water level was met above a depth of 20 metres.

With our present experiments, we only considered values obtained for pressures less than 0.05 MPa (7 psi). In fact, it should be kept in mind that the

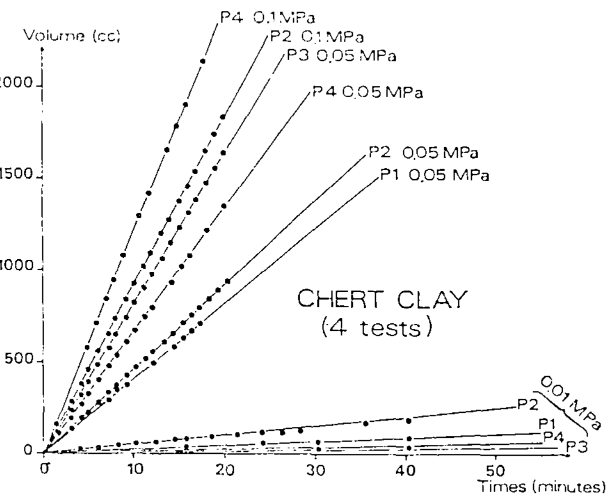

Fig. 4 : Chert clay — Relationship between volume and time.

objective is not the absolute measurment of permeability, but the evaluation of flow which could leak under a certain head. In a class I repository, water head cannot exceed 5 metres. It is therefore not necessary to make measurements for pressures exceeding 0.05 MPa.

When comparing (for various sites) velocities measured at p = 0.001 and p = 0.05 Mpa (0.14 and 7 psi), a linear relationship shows out (fig. 5). Therefore, between these pressures, there is no change in the soil's physical properties, and the same laws are applicable.

Correlation flow — Permeability

As seen above, the theoretical approach is not satisfactory, as ℓ is unknown. The Darcy velocities measured during the 20 tests carried out range from :

$1.8 \cdot 10^{-6}$ m/s (Sparnatian clay)
to $3.0 \cdot 10^{-5}$ m/s (chert clay)
at 0,01 MPa (1.4 psi)

and from $7 \cdot 10^{-5}$ m/s (Sparnatian clay)
to $3.2 \cdot 10^{-4}$ m/s (chert clay)
at 0.05 MPa (7 psi)

If ℓ is comprised between 1 and 100 cm, permeabilities at 0.01 MPa (1.4 psi) could range between :

$1.8 \cdot 10^{-6} < K < 1.8 \cdot 10^{-8}$ m/s (Sparnatian clay)
and $3 \cdot 10^{-5} < K < 3 \cdot 10^{-7}$ m/s (chert clay)

It is therefore clear that a notion of "specific flow" (flow per unit pressure) is more objective, and at the same time more useful than the theoretical notion of permeability itself.

An experimental relationship between flow and permeability could be made by correlating flows and pressures in the range between 0.001 and 0.050 MPa (where this relationship should be linear) by means of detailed tests. When this correlation is extrapolated to p = 0, we attain $\frac{\delta H}{\delta Z} = \frac{H}{\ell} = 1$ and real permeability can be computed.

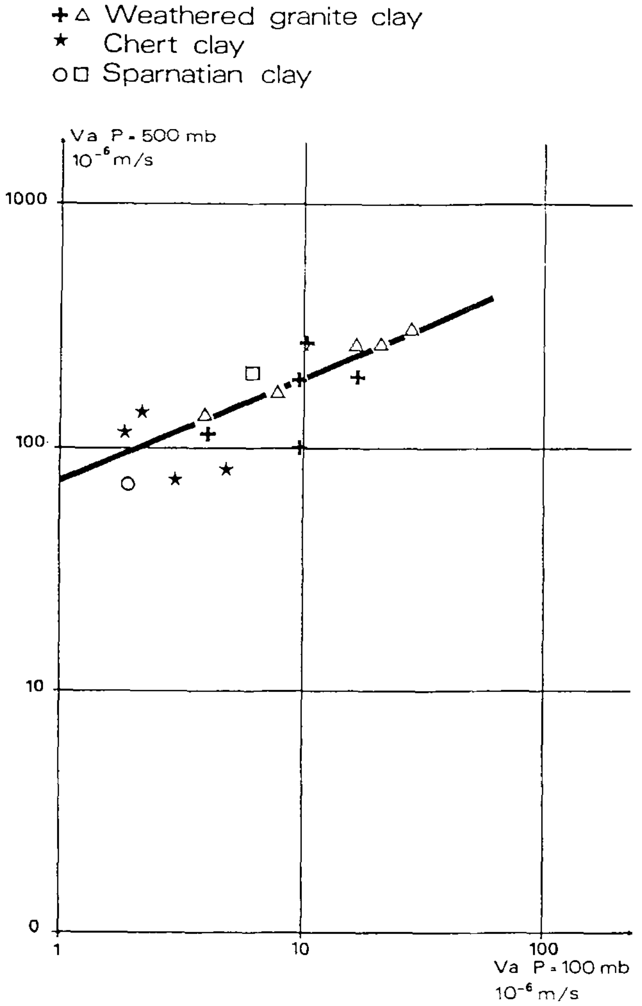

Fig. 5 : Relationship between velocities measured at p = 0,001 and at p = 0,05 MPa.

If this type of relationship is valid for various permeabilities, as suggested by figure 5, then it will be possible to transform specific flows into real permeabilities.

Conclusion

The pressio-permeameter developed by C.P.G.F. for measurement of vertical infiltration is a double ring system operating between 0 and 0.2 MPa (28 psi). It helps to eliminate various spurious phenomena such as evaporation, temperature changes and variation of soil surface by clay swelling during saturation.

The pressio-permeameter can evaluate "specific flow" for a given head. However, the relationship between specific flow and absolute permeability is not yet established, and further research will study :

- Validity of existing laws for very low permeabilities
- Thickness of saturated zone by mathematical modelling and by detailed testing between 0.001 and 0.050 MPa (0.14 and 7 psi).

It should be noted that in 1988, CPGF, as head of a group including 3 other French Public Research Laboratories (Ecole des Mines, INSA, BRGM) was awarded a research grant by the French Government (Ministry of the Environment) to pursue the development of theoretical aspects of pressiopermeameter interpretation.

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