Determination of Moisture Content in Porous Materials by means of the Relative Humidity inside a Cavity

Détermination de la Teneur en Eau des Matériaux Poreux par la Mesure de l'Humidité Relative d'une Cavité

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Summary

This paper sums up the present state of research in progress at the L.N.E.C. for the *in situ* measurement of the moisture content of soils and concretes chiefly for roads, foundations and dams based on the following principle: the relative humidity inside a cavity in a porous material is a function of the moisture content in the neighbourhood of the cavity; thus, measuring the relative humidity in the cavity, the corresponding moisture content in the porous material can be obtained if the relation between relative humidity and moisture content of that material has been previously determined in the laboratory.

A vibrating wire hygrometric cell, at present being studied, is described. It is based on the humidity-induced variations of length of certain hygroscopic materials. Calibration results so far obtained are presented.

Sommaire

Cette communication expose sommairement les résultats actuels d'une recherche en cours au L.N.E.C. pour la détermination *in situ* de la teneur en eau des sols et bétons, surtout pour les routes, fondations et barrages. Le procédé est basé sur le principe suivant: l'humidité relative dans une cavité d'un matériau poreux est une fonction de la teneur en eau dans le voisinage de la cavité; ainsi, en mesurant l'humidité relative dans la cavité on peut obtenir la teneur en eau du matériau poreux si l'on a déterminé préalablement au laboratoire le rapport de l'humidité relative à la teneur en eau du matériau.

On décrit une cellule hygrométrique à corde vibrante, actuellement à l'étude, basée sur la variation de longueur de certains matériaux hygroscopiques avec l'humidité. On présente les résultats des étallonages, déjà obtenus.

Introduction

The continuous measurement of the soil moisture *in situ*, without disturbance, is of great importance in civil engineering. The same problem arises in connection with concrete and reinforced concrete structures where moisture behaviour plays a very important role. In order to interpret the deformations observed in concrete and reinforced concrete structures, and especially to determine the stresses induced in them, the possibility of measuring the moisture in the point under observation is of the utmost interest.

The moisture measurement at inaccessible points raises difficulties of various kinds, the most important being the need for the measuring apparatus to remain adjusted for years after having been put in place and the need for readings at a distance from the point under observation.

Various techniques have been developed for the continuous measurement of moisture in soils: field tensiometers, electrical resistance methods, electrical capacitance methods and thermal conductivity methods.

Tensiometers cannot be applied at inaccessible points or in measurements lasting for years, they are excluded when these conditions are required. Of the other three methods, the one deserving the most attention is based on the variation of electrical resistance of porous materials as a function of their moisture content (BOUYOUCOS and MICK, 1946; CRONEY, COLEMAN and CURRER, 1951).

BOUYOUCOS (1949) applied this method using plaster of Paris or nylon units that were put in contact with the soil and absorbed its moisture, thus undergoing a variation of resistance.

However, although the ionic concentration of soil water has no influence on the absorption properties of the plaster or the nylon, this factor modifies the resistance of these materials. The aging of these units is another factor of considerable importance.

The 'téléhumètre' developed by Brasey, which has been used in concrete, is also based on the same principle (HUGGENBERGER, 1950).

The direct contact of the measuring apparatus with the soil (or concrete) has disadvantages such as: change of the contact conditions due to volumetric variations; changes of resistance due to variations of the ionic concentration of absorbed water, inducing measuring errors; chemical instability of the hygroscopic substances used, which is increased by absorption of chemically impure water together with attacking of electrodes, bringing about aging and impairing the reliability of indications given by the apparatus.

To overcome these disadvantages a way was sought in which this contact could be prevented and one method, dealt with in the present paper, consists essentially in measuring the moisture content by means of the relative humidity determined with a tele-hygrometer in cavities left inside the structures. This is being studied at the Laboratório Nacional de Engenharia Civil.

Basis of the Humidity Method

A given porous material (soil or concrete) placed at a certain temperature in an environment with a certain relative humidity (H) reaches a moisture content of equilibrium (W), a function of its characteristics and of the relative humidity of the air. Thus for each porous material a function exists of the type

$$W = f(H) \quad \ldots . \ (1)$$

Conversely, if a cavity is made in a porous material with a given moisture content, the relative humidity in this cavity is a function of the moisture content of the material

$$H = f_1(W) \quad \ldots . \ (2)$$

In Fig. 1, 5 suction curves obtained by the method of the vacuum desiccator for Lisbon soils (CRONEY, COLEMAN and BRIDGE, 1952; NASCIMENTO, 1954) are presented. The magnitudes plotted are relative humidity–moisture content.

Fig. 2 shows the results of direct measurements of relative humidity on the same soils by means of an earth-hygrometer placed inside: the soils had different moisture contents (determined by the usual method of oven-drying at 105–110° C.). The arrangement used is schematically shown in Fig. 3.

Thus, relationship 2 being known for a given soil, it is possible to determine its moisture content from the value of the

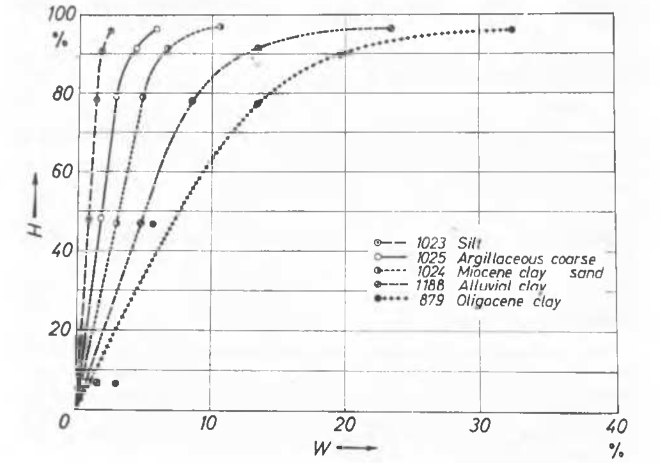

Fig. 1 Vapour pressure curves of 5 Lisbon soils
Courbes de succion de 5 sols de Lisbonne

relative humidity in a cavity inside it. It is then possible, after testing the soil in the laboratory, to determine its moisture content in the field by the measurement of the relative humidity obtained by a hygrometer placed in a cavity at the point under observation.

Usual Procedures for the Measurement of Relative Humidity

The determination of the relative humidity of the air in a cavity raises the problem of obtaining a hygrometer with

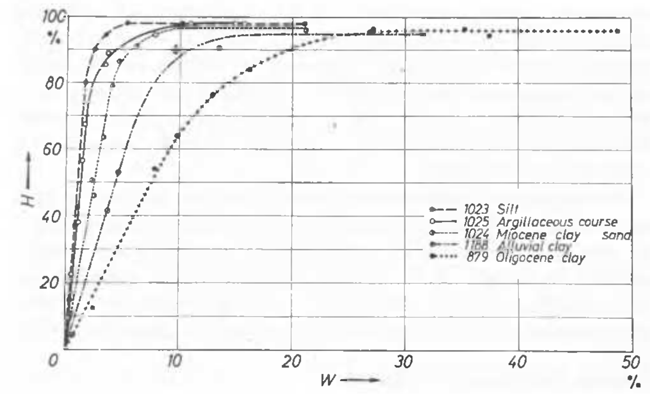

Fig. 2 Relation between the relative humidity ($H\%$) determined with an earth-hygrometer and the moisture content ($W\%$) of 5 Lisbon soils
Relation entre l'humidité relative ($H\%$) determinée par un geo-hygromètre et la teneur en eau ($W\%$) de 5 sols de Lisbonne

characteristics suitable to the conditions in which it will operate.

If, for laboratory measurements, high sensitivity and quick response are more important than long term reliability (since calibration is possible whenever necessary) the case is not the same for observations *in situ*. What is required in this case is, above all, that the hygrometer readings remain accurate for long periods.

It is also important to have remote reading, so that one can place the hygrometer in a cavity in the material, prepared during construction, and to read from outside the values of relative humidity, after the structure is complete.

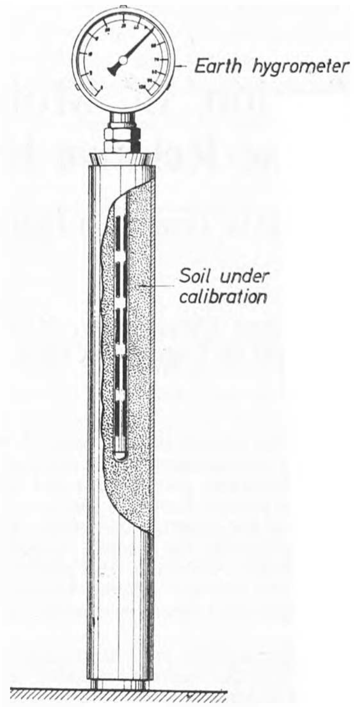

Fig. 3 Arrangement for direct measurement of relative humidity of a soil by an earth hygrometer
Dispositif utilisé dans la détermination des courbes de la Fig. 2

Hair hygrometers, of the earth-hygrometer type (Fig. 3), or the sample hygrometer, can be used in laboratory tests. In the latter type the soil is placed inside a small box that is in

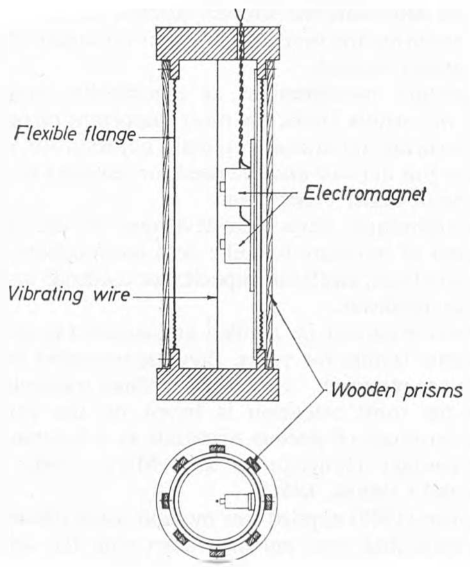

Fig. 4 Schematic drawing of the vibration wire hygrometric cell (in study)
Schéma de la cellule hygrométrique à corde vibrante (en étude)

communication with the hair, exerting influence on the surrounding atmosphere.

Hair hygrometers with tele-transmitter are available, such as the 'Pernix' hygrometers that render possible remote reading. Hygrometers of this type have the disadvantage of getting out of adjustment with time, needing periodic calibrations.

Another tele-hygrometer is the 'Electric Hygrometer Sensing Elements Aminco-Dunmore' with a high sensitivity and quick response. It is useful only for short-term measurements and not for permanent installations (Dunmore, 1938; Gause and Tucker, 1940).

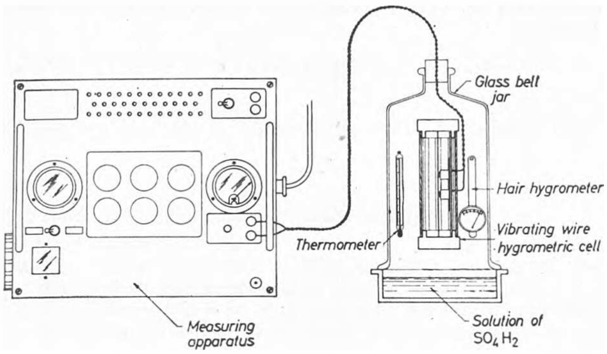

Fig. 5 Schematic drawing of the arrangement used in the calibration of the vibrating wire hygrometric cell

Schéma du dispositif utilisé dans l'étalonnage de la cellule hygrométrique à corde vibrante

None of these hygrometers is suitable for the measurement of relative humidity in inaccessible cavities, where they should remain adjusted for long periods.

Tele-hygrometer being Developed at the Laboratório Nacional de Engenharia Civil

A hygrometer of another type is now being studied at the L.N.E.C. It is based on the principle of humidity-induced variations of length experienced by some hygroscopic materials and on the measurement of these variations by means of vibrating wire strain gauges. This type of strain meter was chosen on account of being the most reliable for long-term observations and additionally for its high sensitivity.

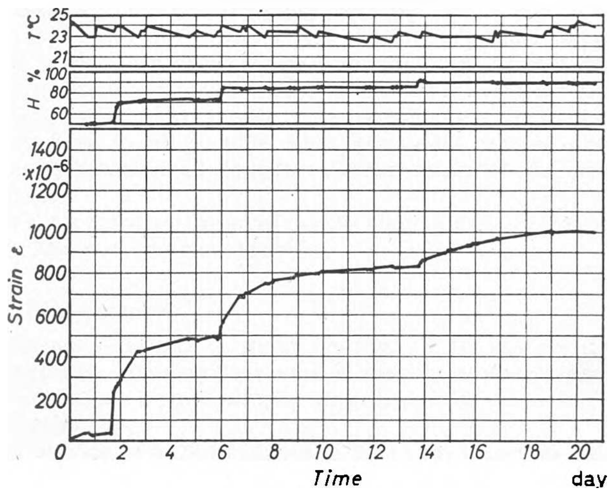

Fig. 6 Results of the calibration test. Strain (ε), relative humidity (H%) and temperature (t° C.) as a function of time (days)

Resultats de l'essai d'étalonnage. Déformation (ε), humidité relative (H%) et température (t C.°) en fonction du temps (jours)

The wire strains are influenced only by the strains of the hygroscopic materials, and hence by the humidity.

The effect of humidity in these materials should be reversible and they should, if possible, present a quick response, a minimum of hysteresis, be little influenced by temperature and stable in time. Various substances were studied for this purpose, ranging from inorganic materials to plastics and wood, but so far wood (namely hard wood, such as oak), cut lengthwise, seems the most adequate. It is a material very sensitive to air moisture variations, with a small hysteresis, and has great durability that can be increased by prior treatment. The quickness of response depends on the thickness and the surface exposed.

The hygrometric cell consists essentially of a vibrating wire that can be excited by an electromagnet. The length of the wire varies with the length of rectangular-base wooden prisms (lengthwise cut oak) placed around it. A flexible flange prevents the contact of the wire or the electromagnet with the surrounding atmosphere (Fig. 4).

Changes in the relative humidity of the air in contact with the cell induce variations of length in the wood and consequently variations of tension in the wire.

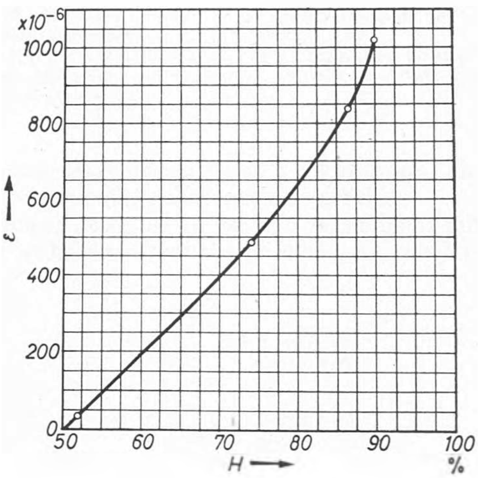

Fig. 7 Calibration curve of the vibrating wire hygrometric cell (relative humidity (H%)–strain (ε))

Courbe d'étalonnage de le cellule hygrométrique à corde vibrante (humidité relative (H%)–déformations (ε))

Strains are measured with the apparatus usually employed to take readings in acoustical strain gauges.

The calibration represented in Figs. 6 and 7 was carried out in atmospheres where the relative humidity was kept constant by means of H_2SO_4 solutions with an adequate density (Fig. 5).

As can be seen in Fig. 7 the law of variation of strain (ε) as a function of the relative humidity (H) is not linear for the values of humidity used; the rate of increase of ε increases as H increases. By means of the vibrating wire hygrometric cell it seems possible to measure variations of relative humidity of the order of a few tenths per cent.

The cell was deemed stabilized when the daily readings began to oscillate about a certain value. This stabilization was obtained in periods ranging from four to eight days (Fig. 6).

When it is desired to reduce the stabilization time the thickness of the wooden prisms will be reduced. Calibration curves, for each material and for each application, should take hysteresis into account. It is thus necessary to make the calibration in successive cycles of desiccation and wetting. This and other factors, such as the influence of temperature and the creep of the materials of the cell, are being allowed for in the research now in progress.

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