SOIL MOISTURE AND MOISTURE MOVEMENTS

METHODS FOR MEASURING THE MOISTURE CONTENT OF SOILS UNDER FIELD CONDITIONS

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Up to about a decade or so ago there were no suitable methods for measuring the moisture content of soils under field conditions, in spite of the fact that the need for such methods has always been very great in such fields as agronomy, irrigation, drainage, hydrology, and highway engineering. The standard method in general use was the gravemetric method of sampling and oven drying. In the last several years, however, a very intensive effort has been made to discover and develop appropriate and reliable soil-moisture determining methods for field use. As a result of this research, several methods have been evolved. The most important of these methods are:

1. The plaster-of-paris-block electrical resistance method of Bouyoucos and Mick (5) and the nylon electrical-resistance method of Bouyoucos (7);
2. The fiberglas electrical-resistance method of Colman (12);
3. The electrothermal conductance methods of Shaw and Baver, (49) and of Johnstone (25);
4. The electrocapacitance method of Fletcher (17), and of Anderson and Edelfsen (4);
5. The tensiometer method of Richards (34, 35) and others; and
6. The sorption-plug gravemetric method of Davis and Slater (14).

These various methods have been studied and compared by numerous investigators. None has been found to be perfect. The general consensus if that the plaster-of-paris-block electrical resistance method is the most satisfactory, particularly for agronomic purposes. This view finds general confirmation in the statement by Kelly and others (27), that the plaster-of-paris-block method "is the most practical instrument available at the present time for measuring moisture changes at tensions above one atmosphere in soils not containing large amounts of salts."

Of the six methods of soil moisture determination mentioned, this paper will confine its further discussion to those first mentioned: plaster-of-paris and nylon electrical-resistance elements.

Plaster-of-Paris Electrical-Resistance Method

The plaster-of-paris-blockmethod had its inception in 1939. It was the first time that the principle of electrical resistance was utilized successfully in measuring soil moisture content. This was accomplished by imbedding electrodes inside a plaster-of-paris block and establishing a constant environment around the electrodes, thereby minimizing or eliminating the effects of soil factors, such as texture, structure, degree of compaction, salt content, and electrical lines of force. Previous investigators (19, 32, 55) who had tried to employ electrical resistance to measure soil moisture failed because they used bare electrodes. Such bare-electrode units have been found completely unsuccessful for soil moisture determination (6).

The plaster-of-paris block (Fig. 1) is made of a special type of plaster of paris using a definite ratio of powder to water. Inside the block are imbedded two electrodes attached to wire leads. When this block is placed in the soil it acts as though it had become part of the soil. It absorbs moisture from the soil, and gives it up to the soil very readily, so that its moisture content is in constant equilibrium with the moisture content of the soil. The electrical resistance of the block varies with its moisture content and that, in turn, varies with the moisture content of the soil in which it is buried. Thus, by calibration, the moisture content of the soil is determined by measuring the electrical resistance of the block.

The calibration curve and a typical performance curve yielded by this method are shown in Figure 2. The calibration curve shows the effective relationship between percentage of moisture in the soil and electrical resistance of the block. The curve is similar to that resulting when moisture tension is plotted against moisture percent, gradual at first and then steep in its rise, i. e. , hyperbolic.

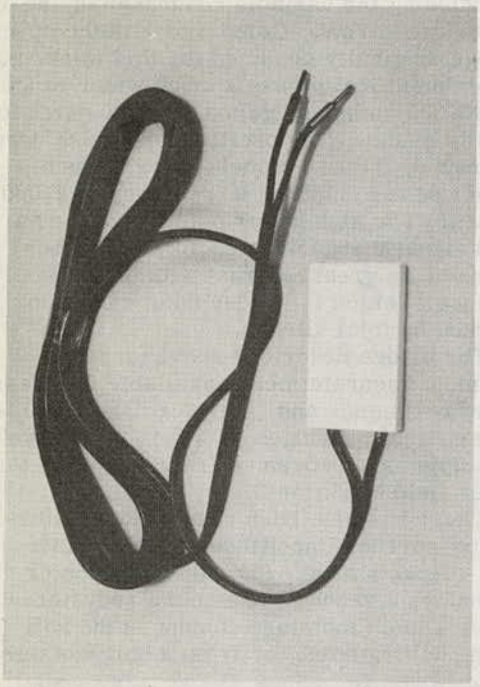

Figure 1. The Plaster of Paris Block.

This method does not measure the total moisture content of the soil but does measure that portion which is available to the plants. This portion ranges from field capacity to the wilting point, or from a soil moisture tension of less than 1 atmosphere to above 15 atmospheres. The method becomes extremely sensitive to moisture changes at the drier region but very insensitive above field capacity. On the other hand, all well-drained soils tend to not hold water above field capacity. Figure 3 shows the actual performance of the method under field conditions. It reveals the daily electrical resistance of the plaster-of-paris blocks as the moisture content of the field soil fluctuates due to evaporation, water absorption by the plants, rainfall, etc.

Resistance-Measuring Instruments

The electrical resistance of the plaster-of-paris blocks is best measured by a moisture bridge specially developed for this purpose and based upon the Wheatstone bridge principle (Fig. 4). This instrument, as now manufactured, combines rugged, compact construction with a high degree of sensitivity. It is a completely self-contained unit designed to measure resistances in circuits containing appreciable capacitance, such as is encountered in installations where the units may be connected by up to 200 ft. of commercial multiple-strand, rubber-coated copper wires. The instrument will operate at temperatures considerably below freezing. Ordinary bridges do not generally have sufficient range for this work.

Headphones, making use of the sound characteristics of the necessary oscillating current, are the most useful type of null indicator. In conjunction with the present circuit design a great contrast in tone volume, which rapidly fades to a minimum level within an extremely narrow range, contributes to the ease of adjusting the instrument. For prolonged operation sponge-rubber cushions over the phones have been found to be helpful by reducing the interference of extraneous sounds, adding to the comfort of the operator.

To avoid the influence of capacitance factors present in field circuits, a large condenser has been included which assists greatly in obtaining a good null balance within the bridge. The instrument is powered by dry-cell batteries feeding through a 2,000-cycle electronic oscillator. The extremely wide range of sensitivity is obtained by inserting two series of standardized resistances in opposite arms of the bridge; the proper combination is selected by means of multiplier switches, and the final null point is obtained by adjusting a logarithmic potentiometric rheostat filled with a 6-inch graduated dial in a matter of seconds. Null points are reduced to the width of not more than two turns of the rheostat coil, which permits finer adjustment than can be conveniently interpolated from the graduations.

Compared with the general purpose conductivity bridges standard in most research

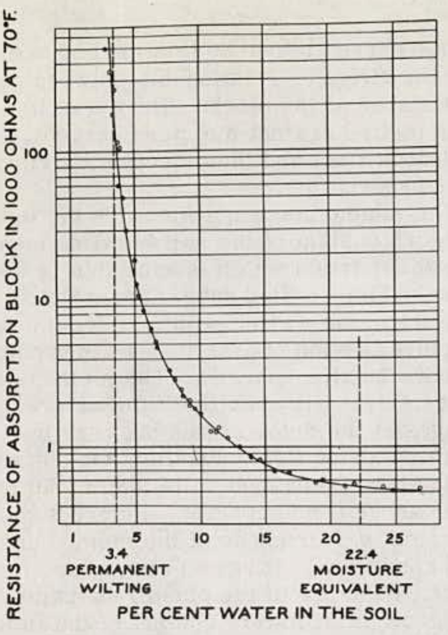

Figure 2. Typical Performance and Calibration Curve of the Paris Block Method.

laboratories, this special bridge has several advantages: It is self-contained and portable, the power unit is rugged enough to withstand shocks encountered in field work, and a sharp null point is obtainable as a result of including the variable condenser in one of the bridge arms. Compared with the special bridge originally designed for this work, the newer modification has a much wider range: 5,000,000 ohms as against 100,000 ohms for the old model. The oscillator has also been improved, the new model having a much higher power output at a frequency of 2,000 cycles. The high power output produces a loud signal that facilitates adjustment because of its great contrast with the null balance, which is, under most conditions, marked by total silence.

The bridge described above furnishes the most accurate means available for measuring resistance and, therefore, soil moisture content. Bridges with the "magic eye" principle have proven entirely unsatisfactory under field conditions.

There has also been developed an alternating-current-impedance meter (8) as a direct-reading meter to be used with the plaster-of-paris block (Fig. 5). This meter is portable, is powered by dry batteries, and employs a vacuum tube and a rectifier. It is calibrated to read directly in percentage of available moisture content in the soil (Fig. 6), having a range from field capacity to the wilting point, or from a soil moisture tension of less than 1 to more than 15 atmospheres. The percentage refers to and is based upon the original total amount of available moisture in each soil. This meter is accurate with wire leads on the plaster-of-paris block up to about 10 ft. in length; beyond this length the meter readings become inaccurate due to capacitance effects introduced by the leads.

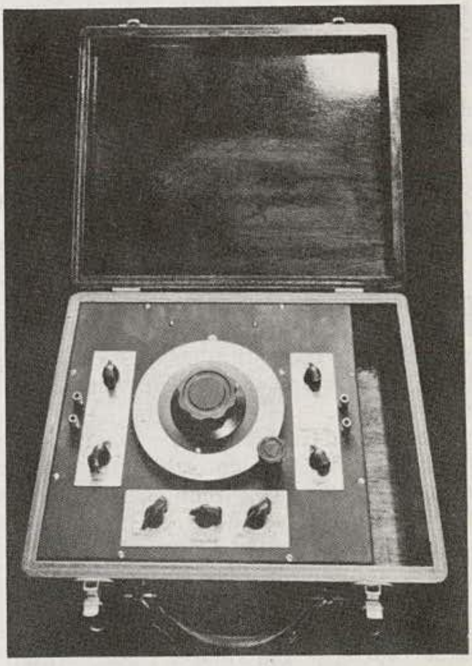

Figure 3. The Special Soil Moisture Wheatstone Bridge

Advantages of the Plaster-of-Paris Method

1. The plaster-of-paris block possesses the most favorable combination of pore-size distribution and buffer action of any material thus far investigated. Its pore-size distribution is such as to enable the block to measure moisture from less than 1 to more than 15 atmospheres of soil moisture tension. At the same time, the solubility factor of 2200-2400 ppm. of the gypsum is of sufficient magnitude to act as a buffer and minimize interference from variations in salt content in different soils but not such a high magnitude as to reduce the resistance sensitivity of the block to moisture changes.

2. It has been found that at any given electrical resistance different soils hold water with approximately the same force, or the soil moisture potential is approximately the same for all soils. This being the case, the percentage of water existing between field capacity and the wilting point can be directly determined in all soils without calibrating the method for each individual soil (Fig. 6). For example, when the block resistance

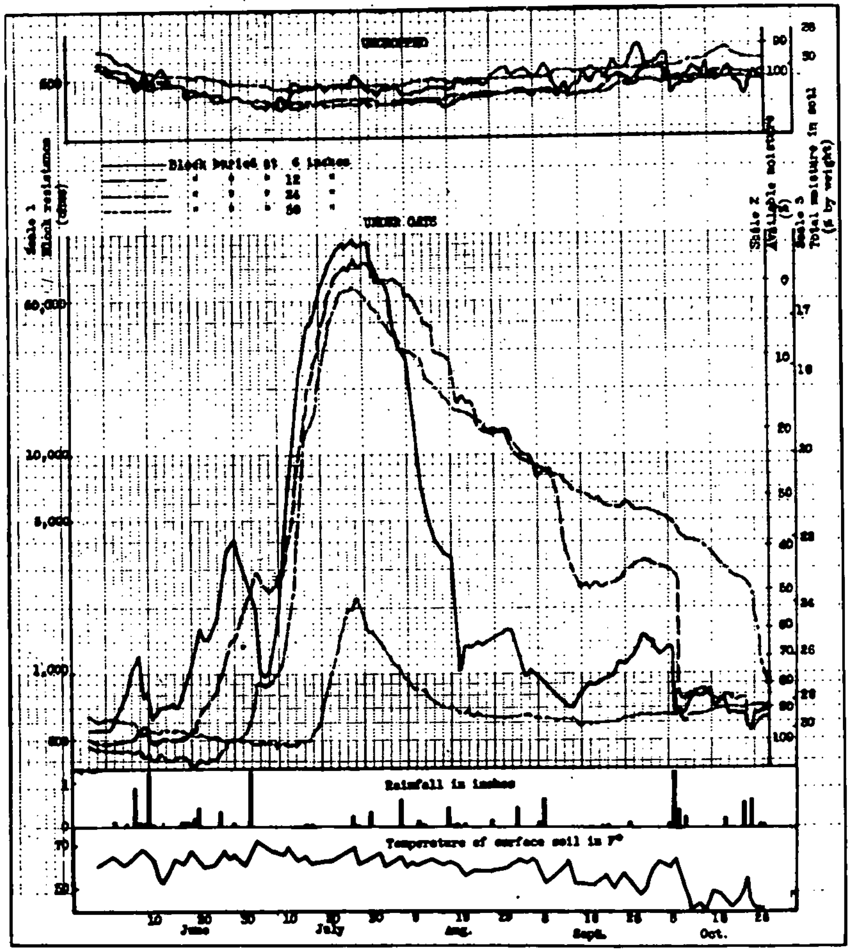

Figure 4. Daily Electrical Resistance of Brookston Clay Loam at Different Depths, Uncropped and Under Oats and Relative Amount of Available Water at Any Given Resistance Reading and Total Soil Moisture Content at Six Inches.

registers 2,800 ohms, the soil contains 50 percent of the total amount that existed between field capacity and the wilting point. The ability of the method to make this direct measurement in all soils without calibration is of high importance and can be of great value to the agronomist as well as to the highway engineer.

3. The plaster-of-paris blocks are very dependable in their performance. When mechanically sound, they always tell a true story.

4. The blocks lend themselves for successful use with long-wire leads up to 200 ft., or even longer.

5. The method is inexpensive.

Disadvantages of the Plaster-of-Paris Method

1. On well-drained soils the plaster-of-paris blocks have lasted for as long as 7 years. However, in constant wet conditions, the blocks do not last for more than 1 or 2 years, especially if submerged in the ground-water table for any considerable length of time. This is perhaps the greatest weakness of the plaster-of-paris blocks.

2. The blocks are not sensitive to changes in moisture content from saturation to field capacity. However, as previously stated, well-drained soils usually do not hold water above field capacity for any length of time.

3. Although the plaster-of-paris blocks possess a buffer action of considerable magnitude, their readings are affected by excessively high salt content of the soil. Experiments seem to indicate that a salt concentration of above 5,000 ppm. may affect the resistance readings. The electrical resistance of the blocks under concrete pavements may be influenced by the excessive salt content of the concrete if placed in intimate contact or too close to the concrete slab. Therefore, blocks should be at least 5 in. below a concrete slab.

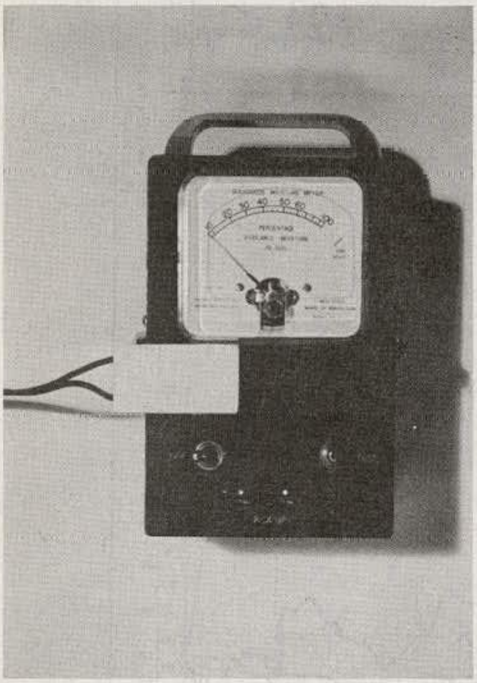

Figure 5. Alternating Current Impedance Moisture Meter.

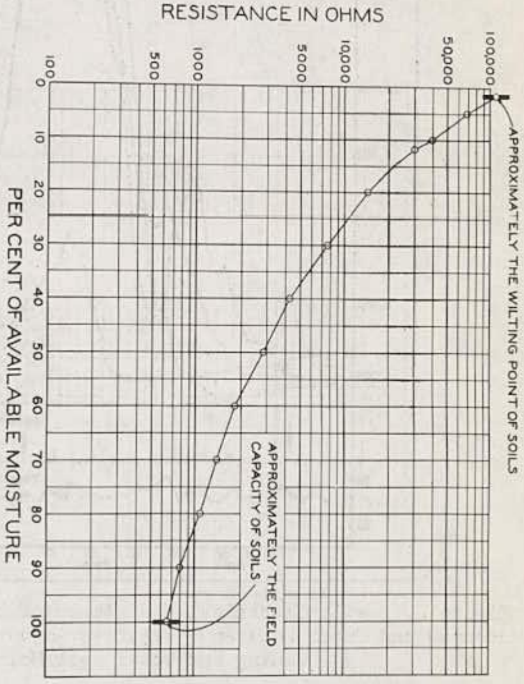

Figure 6. Percent Available Water in Soil.

The Nylon Electrical-Resistance Method

An intensive and extensive research has been conducted to develop a moisture measuring unit superior to the plaster-of-paris block, especially in respect to durability and range of moisture determination. This research had in mind the hydrologist and the highway engineer, who are especially interested in measuring the entire range of soil moisture content. The materials examined have been numerous, including fire-processed clay, cement and concrete mixtures, cement and plaster-of-paris mixtures, hydrocal, and hydrostones, rubber foam, asbestos, fiberglas, nylon, etc. Of all the materials examined, the nylon fabric proved to be the most satisfactory, and was found, in some ways, to be superior to plaster of paris.

Principle of the Nylon Unit

The moisture-measuring unit composed of nylon fabric was made on the same principle as the plaster-of-paris block, insofar as the electrodes are imbedded in the block in a constant environment. The nylon unit, as finally perfected and embodying the principle of the plaster-of-paris block, is shown in Figure 6. It consists of two pieces of fine stainless steel, acting as electrodes, to which are soldered wire leads. The soldered joints are covered with a long-lasting coating. The electrodes are separated or wrapped by three single pieces of nylon fabric. The whole assemblage is then placed in a perforated stainless steel case and subjected to a uniform and controlled high pressure. While the center of the unit is held under constant high pressure, the edges of the unit are mechanically united to hold the enclosed assemblage permanently in intimate contact. The enveloping case has 0.2-in. square holes, 1/4-in. center straight, and is 64 percent open. The holes cover the entire surface of the case, thus affording the absorbent extensive exposure to the soil.

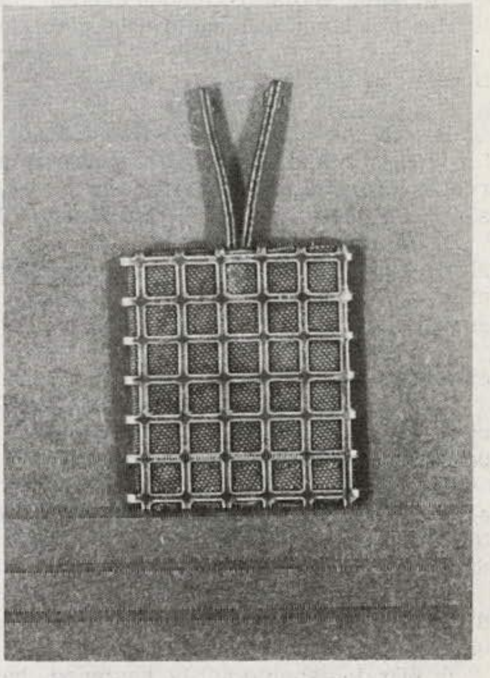

Figure 7. The Nylon Electrical Resistance Unit.

Like the plaster-of-paris block, the nylon unit absorbs moisture from the soil and gives it up to the soil very readily. When the nylon unit is buried in the soil, its moisture content tends to achieve and maintain equilibrium with that of the soil. The electrical resistance of the unit varies with its moisture content and is an index of moisture in the soil.

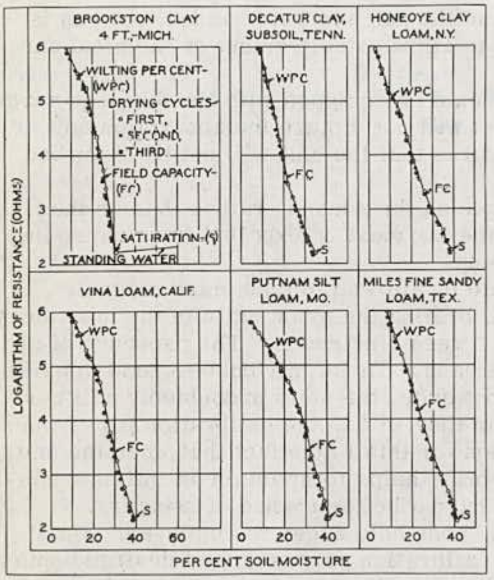

Figure 8. Typical Performance and Calibration Curves of the Nylon Unit.

Like the plaster-of-paris blocks, the nylon units provide a continuous measure of field-moisture variation. The units may be imbedded in the soil at the desired depth and left there permanently. Soil moisture is determined by measuring the electrical resistance of the unit. Resistances are then translated into moisture percentages by means of previously determined calibration curves. Figure 7 shows typical performance and calibration curves of the nylon unit.

The construction of the nylon units is somewhat difficult and complicated. The pressure applied to bring the electrodes and the nylon fabric into intimate contact must be of a controlled magnitude. If too much pressure is applied, the fabric is liable to be crushed or cut and electrical short circuits encouraged. If the pressure is not sufficient, the contact between electrodes and fabric will be poor, and the unit will give an unstable performance. The earliest nylon units manufactured proved defective in these respects. The technique presently in use has been greatly improved, and has eliminated these defects. The units are now standardized and give surprisingly similar readings at similar moisture levels.

An interesting feature of these nylon units is the outer metal case, which acts as a shield and almost entirely eliminates electrical lines of force. The nylon unit has virtually no lag in its response to changes of soil moisture. Two factors are responsible for this: the extreme thinness of the unit and the extremely low water-holding power of the nylon fabric.

The same moisture bridge used in connection with the plaster-of-paris block (Fig. 3) is also employed to measure the electrical resistance of the nylon units.

Directions For Use

For the most accurate determination of soil moisture, nylon units must be calibrated for each soil and temperature corrections applied to each measurement. Although directions for calibration will be found with the original publication (7), it is here emphasized that the following points must be closely observed:

1. An excess of water must be added to the soil when the units are calibrated in a shallow pan. Not only must the sample be saturated, but there must be a thin film of excess water on top. This precaution insures intimate contact between soil and absorbent surfaces.
2. Air trapped underneath the unit must be expelled by gentle pressure on the unit and by tapping the pan.
3. After the unit has been properly settled in the pan and water added, the pan is covered and allowed to stand for 5 to 10 hours to allow establishment of chemical and physical equilibriums.
4. For calibration purposes, nylon units should be equipped with flexible lead wires so that handling after equilibrium is established will not disturb the absorption unit or the sample. Clamping the leads to the pan assures that the unit will not be disturbed during subsequent manipulation.
5. Calibration measurements should be made on the second, rather than on the first, drying cycle. After every wetting, however, the air must be expelled from under the unit and the pan contents settled by gentle tapping.
6. Drying should not be hastened, but should be allowed to take place naturally.

Probably the greatest source of error in calibrating the nylon units in the laboratory is the tendency of air bubbles to adhere to the screen electrodes. The presence of air bubbles causes the electrical resistance to increase. These air bubbles tend to exist of their own accord. Under field conditions, however, the units undoubtedly will perform accurately and yield smoother curves than they will in the calibration pans, where only 40 gm. of soil is used. The obvious reason for this is the fact that when the units are buried in the ground the weight of the soil mass helps to maintain an intimate contact between soil and unit, and the air bubbles have a better chance of escaping.

When units are installed in the field, a 4-in. post-hole auger is employed. Small samples of various horizons are set aside for calibration purposes. At desired depths the bottom of the hole is tamped flat, and a unit, placed horizontally, is well firmed within the material of that particular horizon. It is advisable to place some loose soil on top of the tamped bottom before setting the unit. This will insure better contact and act as a cushion at the bottom. Then a small amount of soil is placed on the top of the unit and firmly tamped. This procedure is employed for every unit buried in the same hole. In order to make certain that the nylon fabric in the unit makes an intimate contact with the soil, it is advisable to press moist soil into the perforations of the outer metal case. This soil should be from the horizon at which the units are placed.

Advantages of the Nylon Method

1. The fabric used in the nylon unit is very durable and will last a long time in the

soil, a minimum of more than 5 years, even in very wet conditions.

2. The unit has an extraordinarily wide range, capable of measuring the moisture content of soils from saturation to almost air dryness.

3. It is highly responsive and sensitive to changes in moisture content, especially at the higher levels of water content where a sensitive method is most needed.

4. It lends itself easily and conveniently to calibration.

5. Although nylon has no buffer action, it is less sensitive to variations of salt content in the soil than such materials as fiberglas, where there is a definite chemical reaction or ion exchange.

6. Because of its high sensitivity, any physical changes in the soil which tend to alter the soil moisture relationship will be reflected by the unit. For example, a soil in normal condition at field capacity appears well drained; yet, when it is tapped and its macrosize pores are destroyed, free water appears at the surface and the soil appears saturated. The nylon method indicates this condition very readily.

7. The outer metal case of the unit acts as a shield and almost entirely eliminates electrical lines of force.

8. Although the nylon method is rather new and has not been tested as long and as widely as the plaster-of-paris method, and consequently no very definite claims can be made for it at present, nevertheless, from all evidence thus far obtained it is indicated that the method, when properly used, is a good, reliable, highly-sensitive method for measuring soil moisture content from saturation to almost air dryness.

Disadvantages of the Nylon Method

1. The nylon is an inert fabric and has no buffer action. The unit, therefore, is sensitive to salt content. However, this lack of buffering action may not be a serious handicap since each soil is calibrated and the calibration takes into account the physical and chemical characteristics and salt content. In placing units under concrete pavements, it is advisable to place the units at least 3 in. below the concrete slab so the salts from the concrete will have the minimum effect upon the units.

2. In calibrating the unit in the soil pan there is a tendency for air bubbles to adhere to the screen electrodes and to the nylon fabric at the saturation range and prevent an exact duplication of results. However, with care these air bubbles can be made to exit. Furthermore, when the units are buried in the ground, the weight of the soil mass helps to maintain an intimate contact between soil and unit and prevents the formation of air bubbles.

3. The wrapping of fabric around the screen electrodes makes the contact artificial and imperfect. However, by using only one thickness of wrapping the contacts are greatly improved.

4. The outer metal case of the fabric unit tends to interfere with a perfect contact between soil and unit. This interference may be especially serious at the bottom of the unit as it is placed upon the soil. This interference, however, can be almost entirely eliminated by placing the unit upon loose soil and pressing it down, and also by pressing moist soil into the perforations of the metal case.

5. The method must be calibrated for each individual soil. However, there is a possibility of developing a technique similar to that used in the plaster-of-paris method whereby the method may not need such individual calibrations.

Conclusion

The plaster-of-paris and nylon electrical-resistance methods have been found to be the most satisfactory means now available for measuring soil moisture content under field conditions. Neither one is perfect, but if properly used they will give very valuable results. These methods give a much more representative picture of actual soil moisture conditions than can be obtained by sampling procedures. A comparable measurement cannot, in fact, be obtained by sampling because of the difficulty in procuring constant, representative samples where soils are heterogeneous and not uniform in texture. For highway engineers interested in determining total water content over a wide range and by a more or less permanent method, the nylon is definitely superior to the plaster-of-paris method. On the other hand, the plaster-of-paris method has the distinct advantage of possessing considerable buffer action, and can measure the range of moisture content from less than 1 atmosphere to more than 15 atmospheres tension in practically all soils without calibrating the method for each individual soil. The nylon unit, however, possess great promise, especially in view of the recent improvements it has undergone. These improvements include (a) a standardized technique of manufacturing it; and (b) the use of stainless steel in place of the monel electrodes and case. This latter change is of vital importance because stainless steel does not corrode in the soil, while monel metal corrodes badly in many soils, and the corrosion products tend to destroy the insulating property of the nylon fabric.

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THE MEASUREMENT OF SOIL MOISTURE AND TEMPERATURE BY HEAT DIFFUSION TYPE MOISTURE CELL

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Synopsis

Procedure and materials employed in the development of soil moisture-temperature measuring equipment are described. The various stages of development are outlined briefly. Results obtained with the several types of cells investigated are presented.

The performance characteristics of the cell in its present state of development have been investigated through the medium of laboratory-calibration test and soil-moisture determinations. The performance of the present cell is unsatisfactory when in soil at moisture content above 15 percent by dry weight and is quite variable unless positive contact with ambient soil is initially established and maintained during readings. Future improvement in design to increase operating efficiency and simplify fabrication is briefly outlined.

The significance of soil moisture as a medium for altering or modifying the structural value of foundation and paving subgrade soils is well recognized. The influence of temperature gradient on the migration of moisture vertically and laterally in the soil is generally less well understood. Facilities for observing and measuring both temperature and moisture content in existing subgrade soils under paving concurrently with weather observations are urgently needed. Such factual information obtained and compiled for various soil types over an extensive period of time and related to climatic environment, types of paving, and other pertinent physical features would be extremely useful in determining the range of moisture content to be expected. Determination of soil bearing value, shear strength and other structural properties required for rational design could thus be predicated upon definitely observed moisture content. As the