

DEVELOPMENT OF A PLASTER-NYLON
MOISTURE BLOCK FOR SOIL
ENGINEERING USE

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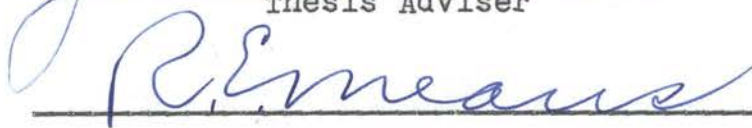
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PREFACE

Plaster of Paris moisture blocks have been used in agriculture as a control method for irrigation for many years, but because of calibration difficulties and limited ranges, they have not been used for soil engineering moisture determinations.

The purpose of this study is to present a modification of these blocks which will increase their range, and further, to offer an accurate method of calibrating such blocks. Suggested engineering applications of moisture blocks are also included.

Indebtedness is acknowledged to Professor J. V. Parcher for his guidance and encouragement throughout the research and preparation of this paper. Further thanks are extended to Professor R. E. Means, Professor J. V. Parcher, Mr. D. W. Erby and Mr. G. F. Hauck for their work and planning on the proposed "Pier Swelling Tests". These tests will provide a practical application for the moisture blocks developed in this paper. The author would also like to thank Mr. W. R. Bain for the use of his many agricultural references, and Mr. C. P. Bickford for supplying the author with certain articles of agricultural equipment and for his demonstration of special equipment dealing with soil moisture blocks.

A great debt of gratitude is expressed to the United States Air Force and the Air Force Institute of Technology, which have made my advanced studies possible.

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CHAPTER I

INTRODUCTION

The Three-Phase Soil System

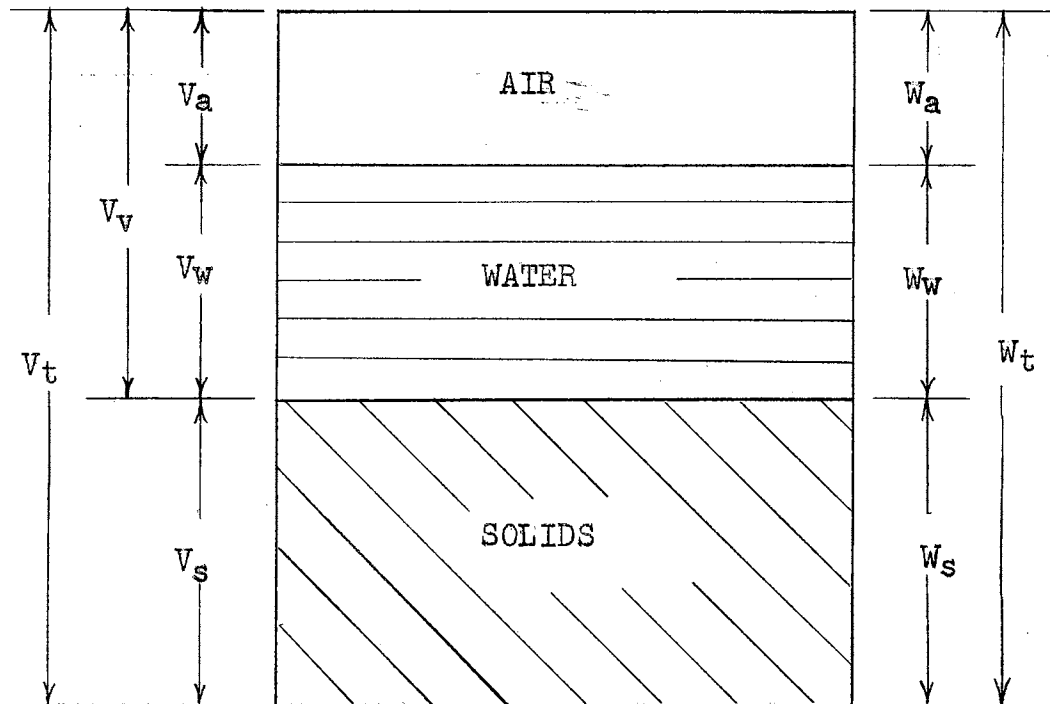
Soil as it exists in nature may be considered a three-phase system, consisting of solids, water, and air. The latter two are often unrecognizable as such and might more accurately be called liquids and gases. There is an infinite number of combinations of these phases and an interrelationship of each with the other. Together they make up and determine the physical properties of soils. Figure 1 shows a diagrammatical representation of the three-phase soil system.

The solids in this three-phase system are formed from the mechanical and chemical weathering of rock. They vary in size from small colloidal particles to large pieces of gravel. These solids have definite physical properties which depend on their shape, size, structure, and parent material. But perhaps the most important consideration is that the colloidal-sized solids behave as a group of nuclei with a definite charge--normally negative. (1).* Therefore, these particles behave essentially as colloidal anions (attracted to a

*Numbers in parentheses refer to bibliography at end of text.

THE THREE PHASE SOIL SYSTEM

Fig. No. 1.



WHERE: Volume

V_t = total volume

V_a = volume air

V_s = volume solids

V_v = volume voids

V_w = volume water

Weight

W_t = total weight

W_w = weight water

W_a = weight air

W_s = weight solids

positive electrode), and they have cations (attracted to a negative electrode) absorbed around their surface. The surface of the particle and the absorbed cations form an electrical system called the Helmholtz double layer. (2). This double layer, the liquids associated with it, and the activity of the parent material, determine the cohesive strength of colloidal soils, namely, clays.

The gas phase in the soil system usually consists of atmospheric air; however, chemical reactions in the soil may produce a variety of different gases. Electrical reactions also take place in the soil between different minerals and these may produce gases. In general these gases are not of importance to the soil engineer, except where large pockets of gas occur under pressure, and in cases of a soil whose voids are filled with explosive or harmful gases.

The water with which we are concerned in the three-phase soil system is, of course, not pure; in fact, it has been contaminated to such a degree that it might better be called an electrolytic fluid or liquid. An electrolytic fluid may be defined as a fluid which is either an acid, base, or salt, and which contains both negative and positive ions. In a cohesionless soil this liquid occupies the voids to varying degrees, and although it affects the physical properties of the soil, this liquid maintains its own identity and usually has a viscosity approaching that of water. In soils consisting of colloidal particles (i.e., cohesive soils), the electrolytic liquid next to the particle is tightly attached

to the particle and is sometimes called "solid liquid". As the distance increases from the particle, the liquid is less firmly attached, until at some distance--depending on the material making up the particle and the concentration of the electrolyte--there is free liquid...

Importance of Soil Moisture

Soil moisture, or the liquid phase of the soil system, is perhaps the most important single consideration in dealing with the physical properties of all soils under different conditions. A knowledge of the amount and type of soil moisture then becomes a tool for the soil engineer, with which he can predict the behavior of soils used in structural foundations, earthworks, and highway or airfield construction. A few of the soil moisture considerations dealing with various soils are discussed here.

Fine-grained cohesionless materials in a loose condition and saturated are prone to flow slides when subjected to rapid or shock loads. In this case the grain-to-grain contact is slight and the angle of internal friction cannot be developed, the water attempts to take the load, and the material flows. If the material is less than saturated, some of its shear strength could be developed, but this hinges on moisture control and drainage.

The settlement of foundations on sand depends to a large degree on the confining pressure of the sand above, adjacent to, and below the foundation. This confining pressure is

roughly proportional to the effective pressure on the sand at various depths. If the water table rises from below the foundation to the surface, the effective pressure will be reduced by approximately one-half. If the sand is at a low relative density this conceivably could double the anticipated settlement. (3). Here again water plays an important part.

Loess is an aeolian soil of predominantly a single particle size. This soil is normally cemented by calcium carbonate and clay. Such soils are usually unsaturated and have high void ratios. In the dry state they are often able to support loads of several tons per square foot; however, when these soils become saturated, because of a rising water table or ponding of run-off, their cementing bonds are dissolved and great settlements can occur. Moisture control here is of primary importance.

Silts normally have little cohesive strength; however, at certain moisture contents capillary tensions cause such soils to behave as if they possessed cohesive strength. Small increases in moisture content above this point relieve the capillary tensions, and the apparent cohesion is lost. Thus, for silts as for most other soils, water content is a predominant factor in determining its physical properties.

When a saturated clay soil is subjected to load, the load is initially carried by the water. This water is gradually squeezed out of the clay and the load is transferred to the soil structure. This process is known as consolidation. Laboratory consolidation tests give data from which

the rate of settlement and the total settlement can be estimated. These estimates depend, among other factors, on the effective pressures at various depths in the clay. If the water table is lowered in the clay the resulting effective pressures are increased, resulting in additional settlement of the surface. It can be seen that foundation settlement on clays will vary with the position of the water table. Hence, the water squeezed out during consolidation depends partly on the position of the water table which may vary considerably through the years. The problem of increased effective pressures due to lowering of the water table is applicable to all soils. Rapid drawdown of water behind an earthen dam, causing increased effective pressures, will often cause a dam to fail.

The shear strength of clays is made up of two parts, one which is due to friction, and the other due to cohesion. This may be expressed by the Coulomb equation:

$$s = c + p \tan \phi$$

where:

s = shear strength

c = cohesion

p = normal stress on considered plane

ϕ = angle of internal friction

Cohesion, as mentioned earlier, is dependent on the activity of the clay mineral, the concentration of the electrolytic fluid, the properties of the double layer, and the quantity of this fluid normally referred to as "free water".

Hence, if all other things remain equal, the strength of clay can vary only as the water content changes--the higher the water content the less the strength and vice versa.

In the Southwestern United States, building on the so-called expansive clays presents another problem. These clays are heavily over-consolidated and are desiccated. Bearing capacity is seldom a consideration. However, if these soils become saturated due to capillary rise or external sources of water, they are capable of exerting tremendous swelling pressures, which in turn can ruin or seriously damage foundations and buildings. The control of moisture in these soils after buildings have been erected is of primary consideration to all engineers building and designing in the area.

Many types of earth construction such as dams, retaining walls, highways and airfields require compaction to give the soil the desired shear strength, permeability and settlement characteristics. Although compaction is not completely understood, it is known that water plays an important part, and that for a given compactive effort there is a certain water content which will give the maximum dry density. This water content is called the "optimum moisture" content. It is normally determined by the Proctor compaction test in the laboratory, and from these tests water control is set up in the field.

The properties of soils at different moisture contents have been used as a basis of an entire soil classification system. This classification system is based on the Atterberg

limits. The moisture content at which a drying soil ceases to act as a liquid is called the "liquid limit"; the moisture content at which a soil ceases to act as a plastic is called the "plastic limit"; and the moisture content at which shrinkage ceases is called the "shrinkage limit". The range in which a soil is plastic, or the liquid limit minus the plastic limit, is called the "plastic index". To assist in utilizing the Atterberg limits as a classification system, Dr. Arthur Casagrande developed a plasticity chart in which the plasticity index of a soil is plotted against its liquid limit. So, not only does water play an important part in determining the physical properties of soils, but soils are often classified according to the moisture content at which certain properties are evident. Figure 2. shows a basic plasticity chart.

Standard Determination of Soil Moisture

The moisture content of a soil is normally defined as the ratio of the weight of the water to the weight of the solids in a given quantity of soil. This is generally expressed as a percentage of the oven-dry weight of the soil, when it has been dried to a constant weight at 105° C. The standard method of determining soil moisture is simple and accurate. It consists of the following: the soil sample is placed in a seamless covered tin whose tare is known. The sample and the tin are weighed to the desired accuracy; and the sample is then uncovered and placed in an oven at 105°C.

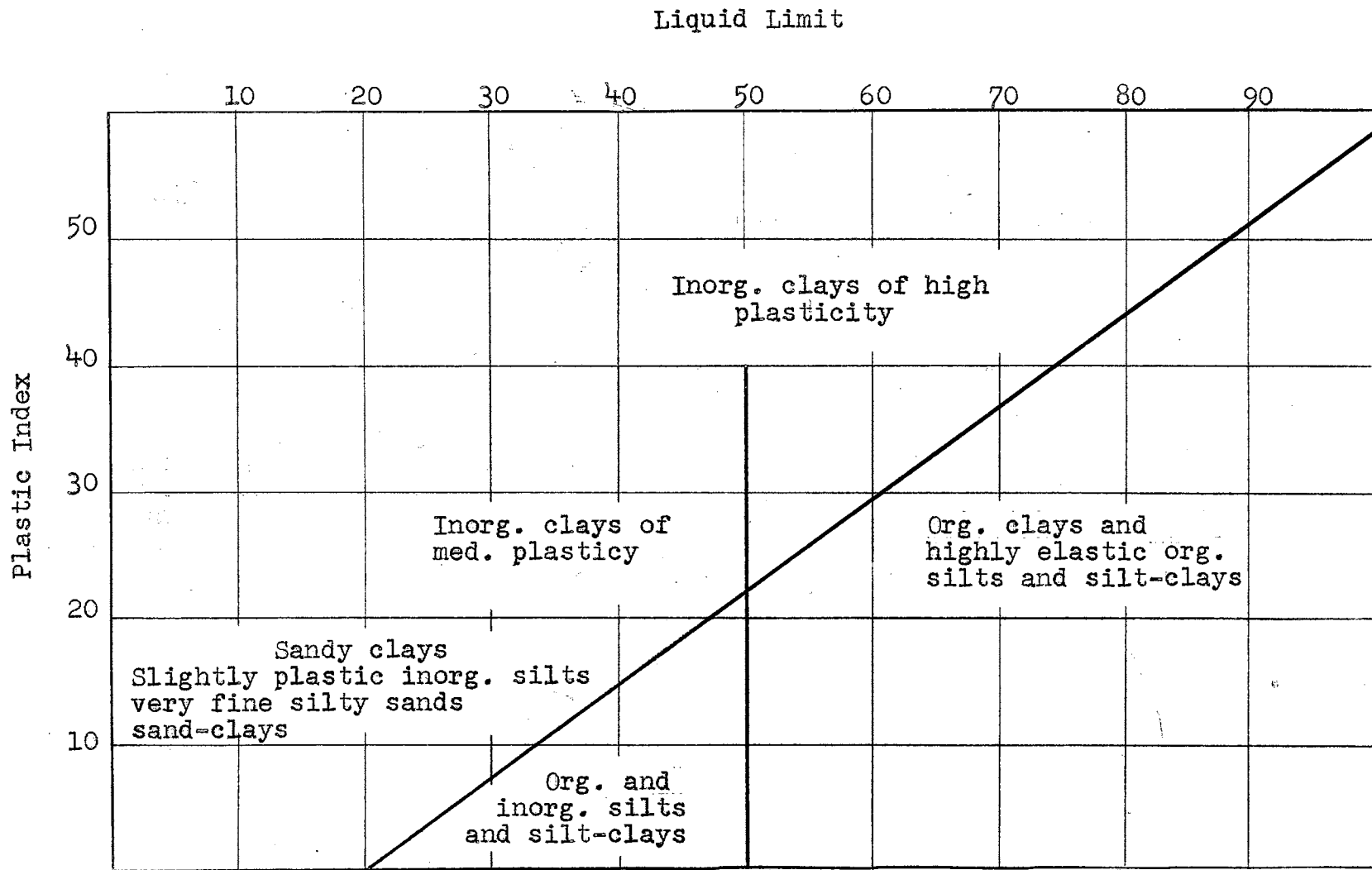


Fig. No. 2.

PLASTICITY CHART

(After A. Casagrande)

and dried until a constant weight is obtained, (12-24 hours). After cooling in a desiccator, the dry sample and tin are weighed and the moisture content is obtained from the following:

$$w\% = \frac{\text{wet weight} - \text{dry weight}}{\text{dry weight} - \text{tare weight}} \times 100$$

See Appendix A for apparatus and expanded procedure.

Although this method is simple and accurate, it is time consuming and physical samples have to be taken from the soil for weighing and drying. If soil moisture contents are desired under foundations, roadways or airfields, sample-taking is difficult--if not impossible--and the drying time required by the standard method can make the difference between taking corrective action or suffering the consequences of increasing or decreasing moisture content. When time is important and physical samples can be taken, rapid moisture determinations can be made by reagent type moisture tests and high heat ovens, but the accuracy of such tests does not approach that of the standard method.

CHAPTER II

REVIEW OF THE LITERATURE

Definition of Terms

Since most of the electrical processes for determining soil properties have been developed in the field of soil physics and used primarily in agriculture, a brief discussion and definitions of agricultural terms will be given before proceeding further. Although the Atterberg limits and moisture percentages are used to some extent in agricultural work, most of the soil-moisture contents are expressed in terms of "atmospheres of tension". The following three terms are perhaps the most important ones used in discussing soil moisture in the agricultural field.

Field Capacity: Veihmeyer and Hendrickson, in 1931, defined the field capacity as, "The amount of water held in the soil after the excess gravitational water has drained away and after the rate of downward movement of water has materially decreased". (4). This value would vary widely in different types of soils, but will be less than one atmosphere of tension, say--about 1/3 of an atmosphere with a moisture content somewhere between 8% and 22%. (5).

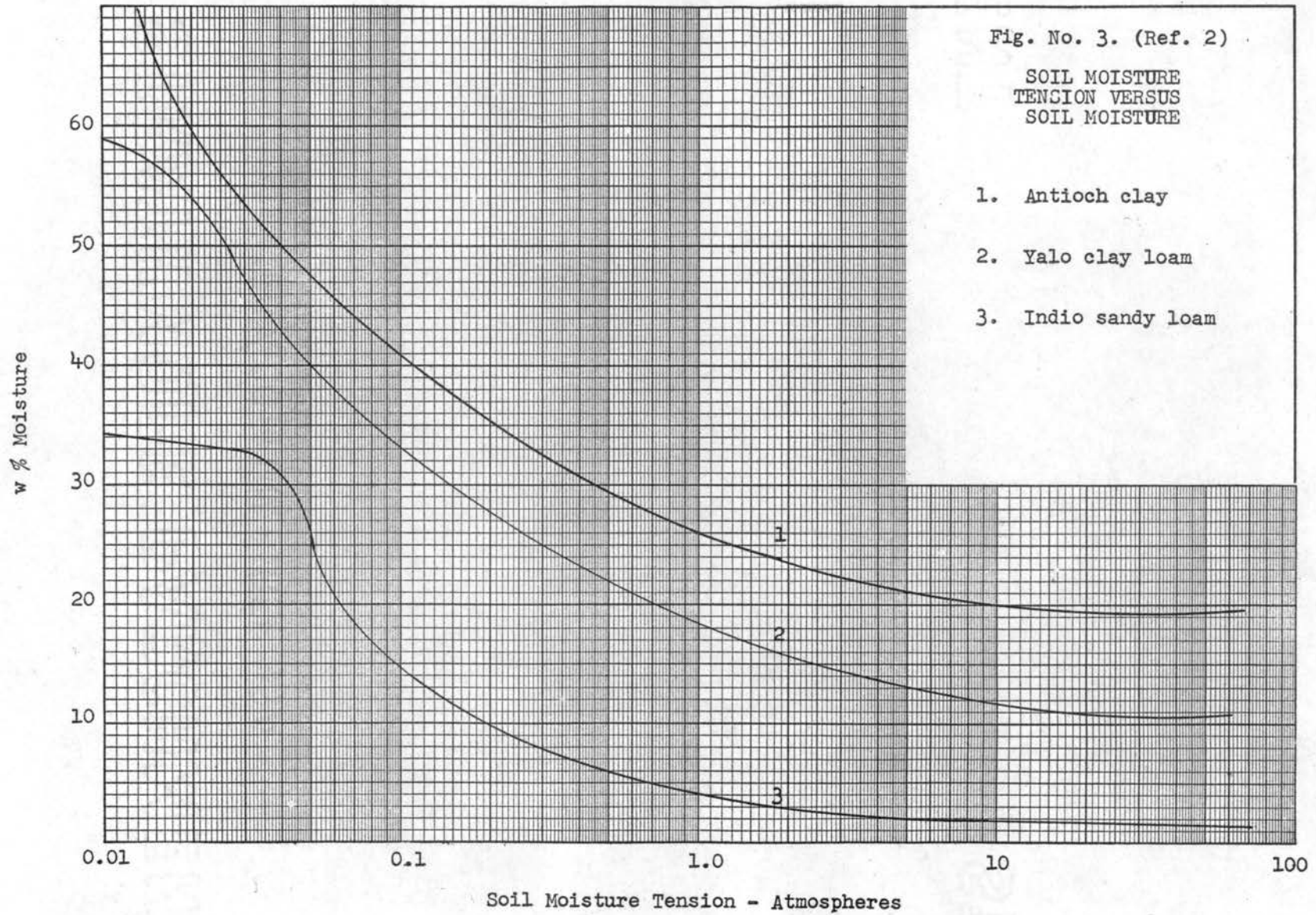
Moisture Equivalent: This was originally introduced by Briggs and McLane, in 1907, as a method of determining the field capacity. It is obtained by centrifuging a saturated soil in a perforated cup at a speed equivalent to a force 1000 times that of gravity. This was considered to remove most of the water that is held in the larger pores, and it has been found to be a close approximation to the field capacity of fine-textured soils. (6).

Wilting Point: This refers to the soil moisture content at which soil cannot supply water to a plant at a sufficient rate to maintain turgor, and the plant permanently wilts. The moisture tension at which this occurs is about 15 atmospheres, and the moisture percentage varies from 1% to 8% for most soils. (7). Figure 3. shows the soil moisture percentages plotted against atmospheres of tension for several selected soils.

The above definitions should provide the engineer with a frame of reference to help him better understand data in the agricultural field dealing with soil moisture.

Resistance and Conductance Method of Determining Soil Moisture

In 1898, Whitney, Gardner, and Briggs proposed an electrical resistance and conductance method of determining soil moisture in the field. Electrodes were placed in the soil and conductance was measured and interpreted on the basis that any change in conductance was brought about by varying amounts of water between electrodes. It was soon observed,



however, that small changes in the salt content of the soil solution affected the conductance more than the amount of water that was present. As a result of the latter, this means of determining soil moisture has never proved satisfactory in the agricultural field. (8).

Another major drawback to this system is irregular electrode contact which would greatly affect the results. A variation of this method is to put a potential between the electrodes and determine moisture content based on current flow, but here again the results are affected by salt content and irregular electrode contact.

It should be pointed out here that conductance is expressed in mhos and is the reciprocal of ohms, that is:

$$\text{mho} = \frac{1}{\text{ohm}} .$$

They are both actually measurements of resistance. Results in terms of mhos are often more convenient and are better adapted to graphical presentations of data.

Although the resistance or conductance method of determining soil moisture has never been too successful, it has proved so sensitive to salts that it is now, in a modified form, the accepted method for determining soil salinity. (9).

The Dielectric or Capacitance Method of Determining Soil Moisture

In 1939, J. E. Fletcher (10), developed a dielectric method for determining soil moisture. A special condenser is placed in the soil and allowed to reach equilibrium with

the soil water. Readings are taken with a capacitance bridge. These readings are affected by the amount of moisture, the colloidal content, and the salt concentration. Salt concentrations in excess of 0.1 gm. per 100 cc. give constant readings at the same moisture content. This salt error is usually not significant, especially in arid soils. Once the relationship between moisture content and the dielectric values has been determined, a buried condenser gives readings which may be correlated with soil moisture.

A. B. Anderson (11), in 1943, using the electrical capacitance method of determining soil moisture on the Yalo series of California soils, found that the shape of the curve showing the relation of electrical capacitance to soil moisture content, from the wilting point to beyond the field capacity, did not change appreciably with the soil texture. This means that for these soils, one calibration curve could be used for the entire series.

Electrical Soil-Moisture Determination by the Use of Moisture Blocks

In 1940, G. J. Bouyoucos (12), of the Michigan Agricultural Experiment Station, introduced a moisture unit that employed a block of plaster of Paris. The block consists of two electrodes made of straight wire, or 20-mesh stainless steel screen, cast in plaster of Paris. The latter provides an absorbent material for contact with the soil.

When buried in soil, the plaster of Paris becomes essentially a part of the soil and responds to changes in soil-

moisture content. As the moisture content fluctuates, it causes the amount of gypsum in solution in the block to vary, which in turn determines the resistance of the block. The resistance then is an indirect measure of soil moisture when the block is calibrated for the particular soil.

Other materials such as nylon and fiberglass have been used as absorbent materials to enclose electrodes. The nylon unit, also developed by Bouyoucos (13), consists of two pieces of stainless steel screen which serve as electrodes. They are separated and wrapped by three single pieces of nylon fabric. Wire leads are silver-soldered to each electrode, and the parts are enclosed in a perforated stainless steel case.

E. A. Coleman and T. M. Hendrix (14), of the California Forest and Range Experiment Station, developed a fiberglass unit which is similar to the nylon unit. The moisture sensitive element is made from two monel-screen electrodes separated by two thicknesses of fiberglass cloth. Three additional wrappings of the same cloth are made around the electrodes. This moisture sensitive sandwich is then enclosed in a monel metal case with perforations in each side. A thermistor may be placed in the unit if temperature readings are desired.

Fiberglass and nylon units provide greater sensitivity in the higher ranges of soil moisture than the plaster units. However, an objection in their design and use is that soil contact is not always constant, and hence results are sometimes not reproducible. (15). Figure 4. shows a photograph of various types of moisture blocks.

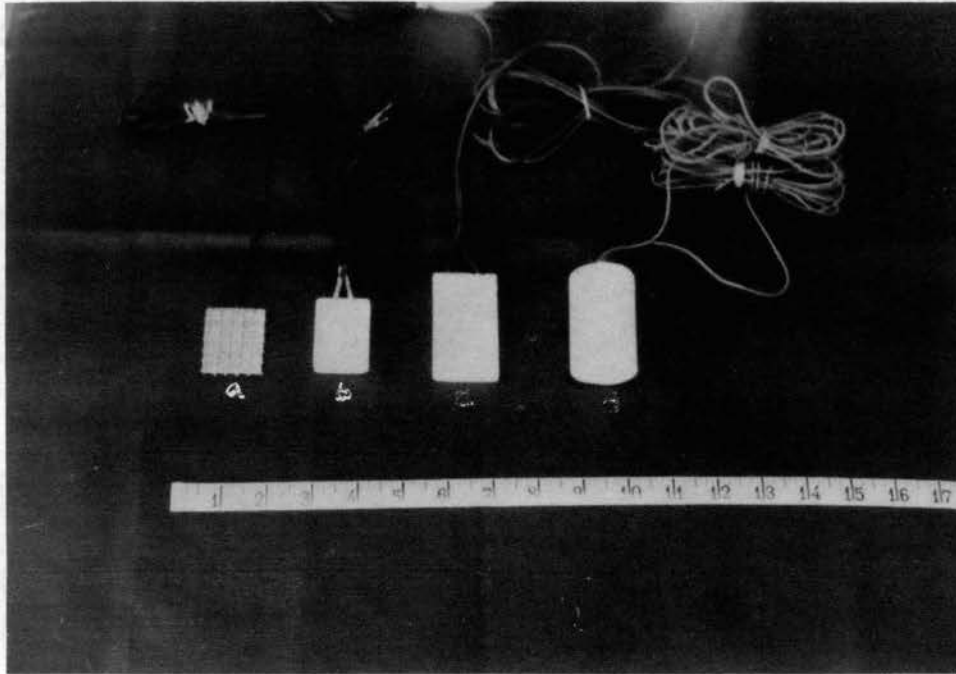


Figure 4. Various Types of Moisture Blocks.
a, Bouyoucos Nylon Block
b, Bouyoucos Plaster of Paris Block
c, Standard Plaster of Paris Block
d, Plaster-Nylon Block

Laboratory and field experience has shown that electrical moisture blocks--if properly calibrated--provide moisture information which is reproducible; however, each type of block has a use or condition for which it is best suited. Plaster of Paris blocks are more sensitive in the drier ranges at the vicinity of the wilting point, while nylon and fiberglass units are more sensitive in the wetter ranges above the field capacity. All of these units are adversely affected by soluble salts in the pore water; however, the plaster unit is the least affected. The plaster unit itself contains a saturated solution of calcium sulphate when wet. A salt concentration less than the amount in the block has only a slight effect on the resistance of the unit. This critical salt value is about 2000 parts per million. (16).

Temperature, of course, affects the resistance readings of all units, but the magnitude of the resistance change is small in relation to other sources of variations. The largest variations among individual blocks are random variations in the manufacture of the blocks and drift from calibration. The random variation can be minimized by selecting units whose resistances do not differ by more than 50 ohms after being immersed in water. Drift results from excessive wetting and drying cycles. Compensating for this is difficult. (17).

Various apparatus have been designed for taking readings from moisture units. Perhaps the most popular is the Bouyoucos Bridge designed by Dr. Bouyoucos. This instrument is essentially a Wheatstone bridge with 54 volts A.C. across the

bridge. This bridge is rugged and accurate and uses a headset to detect the balance null. Other types of bridges may be used, such as the newer cathode ray null-indicator type. (18).

A moisture meter developed by Dr. E. A. Colman (19), has proved very successful. This meter is actually a battery-powered A.C. ohm meter and is especially applicable for use with the fiberglass moisture unit. Alternating current is employed in all such measuring devices to prevent polarization of the soil moisture or the solution in the blocks.

Electro-Thermal Moisture Determination

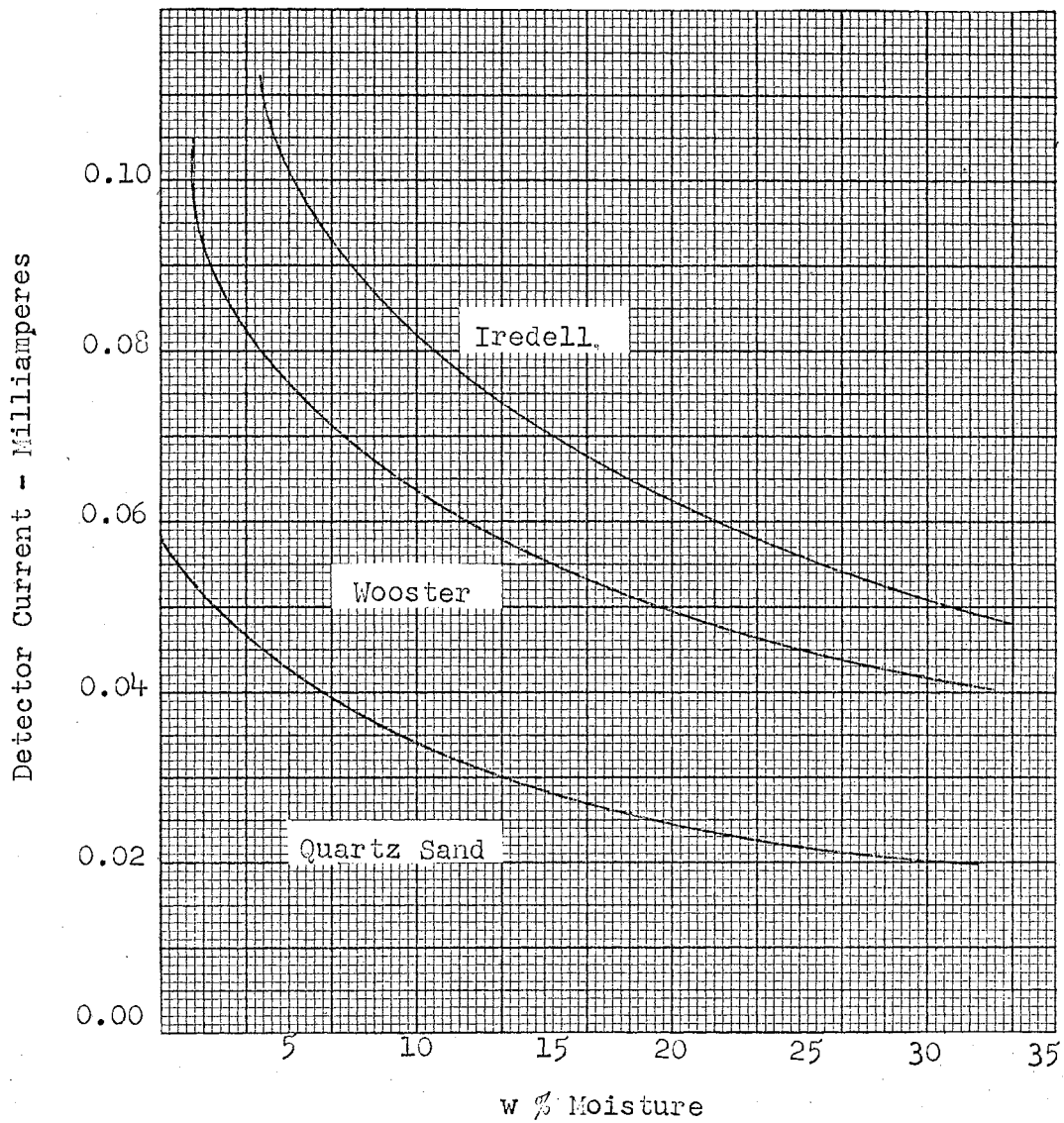
Operation of the thermal unit is based on the principle that heat conductivity of water in the soil is much greater than that of the soil itself. Thus, when a constant current is passed through a heating element for a given period, the amount of heat that is conducted away from the unit depends on the amount of water present in the soil. Since heat conductivity is high in moist soil, the element remains cool and has a relatively low resistance. As the soil dries, heat conductivity of the soil-water system becomes less, and the subsequent rise in temperature of the element causes a corresponding increase in resistance. This relationship between resistance and soil-water provides an indirect measurement of soil moisture. (20).

An electro-thermal unit consists of a piece of glass tubing around which is wound copper-enameled wire having a

resistance of 7 ohms at 0° C. This unit is placed in the ground and connected through a Wheatstone bridge arrangement with a microammeter. Starting with a balanced bridge, a current of 0.4 amperes is passed through the bridge for one minute, at which time the current going through the microammeter is read. The magnitude of the current going through the microammeter reflects the rise in temperature and increase in resistance of the element in the soil. (21). Figure 5. gives the thermal moisture curves for several soils.

Researchers with the Civil Aeronautics Administration in Indianapolis (now the Federal Aviation Agency), have devoted considerable effort to development of a workable unit of this type, which will be applicable for engineering use. More than fifty moisture cells of various designs have been tested and evaluated. Some of the units had limited applications, but none was entirely satisfactory over the range of moisture contents encountered in both civil engineering and agricultural use. The major problem has been the easily damaged copper-enameled wire. The need is for a suitable porous material in which to imbed the resistance unit to prevent damage of the wires and still to give accurate results. (22).

Fig. No. 5. (Ref. 2.)

THE RELATION OF HEAT CONDUCTIVITY
TO SOIL MOISTURE CONTENT

Note: High detector current signifies low heat conductivity.

CHAPTER III

APPARATUS AND PROCEDURE

General

At the beginning of this research it was hoped that direct soil resistance readings could be correlated with soil moisture content to a degree of accuracy acceptable for soil engineering work. However, such resistance readings for soil samples at varying water contents proved difficult to obtain and they were not readily reproducible. As a result the author turned to an indirect method of soil moisture determination based on the resistance of a buried block in direct contact with the soil. The limited ranges and sensitivities of existing blocks of this type used in the agricultural field led to the development by the author of a plaster-nylon block.

Special Equipment

In the early stages of this research, moisture tests were conducted on soil samples in pint Mason jars. The tests were along the lines proposed by Whitney and Gardner in 1898, (23), that is, based on the assumption that soil resistance or conductance is a function of the soil moisture. For these

measurements a 1,000 ohms/volt multimeter, model number 536 from the Electronic Instrument Company (EICO), 30-00 Northern Blvd., Long Island City 1, New York, was used. This meter was obtained in kit form and built by the author. Appendix B lists the specifications for this meter.

In the later stages of testing soil samples and calibrating various types of moisture blocks, the need for a more accurate and versatile measuring device was felt. Serious thought was given to the Bouyoucos Bridge; however, this instrument uses a headset to obtain the balance null, and at best is rather cumbersome and awkward to use. It was decided to use a newer cathode ray null-indicator type bridge similar to that used by Dr. Leo Casagrande (24), for measuring resistance and conductance of soil samples. This type of meter is also approved by L. A. Richards (25), for soil conductance tests; however, in selecting this bridge unit, one was sought that closely followed the basic construction of the Bouyoucos Bridge. The latter uses 54 volts A.C. across the bridge, and it was felt that the selection should have this same voltage if the results should ever be correlated against the Bouyoucos Bridge in future research. For this reason the Resistance Capacitance Bridge and R-C-L Comparitor, number 950 B, manufactured by the Electronic Instrument Company, was chosen. This instrument was also secured in kit form and constructed by the author. Appendix C gives the specifications for this bridge. Figure 6. shows both pieces of special equipment.

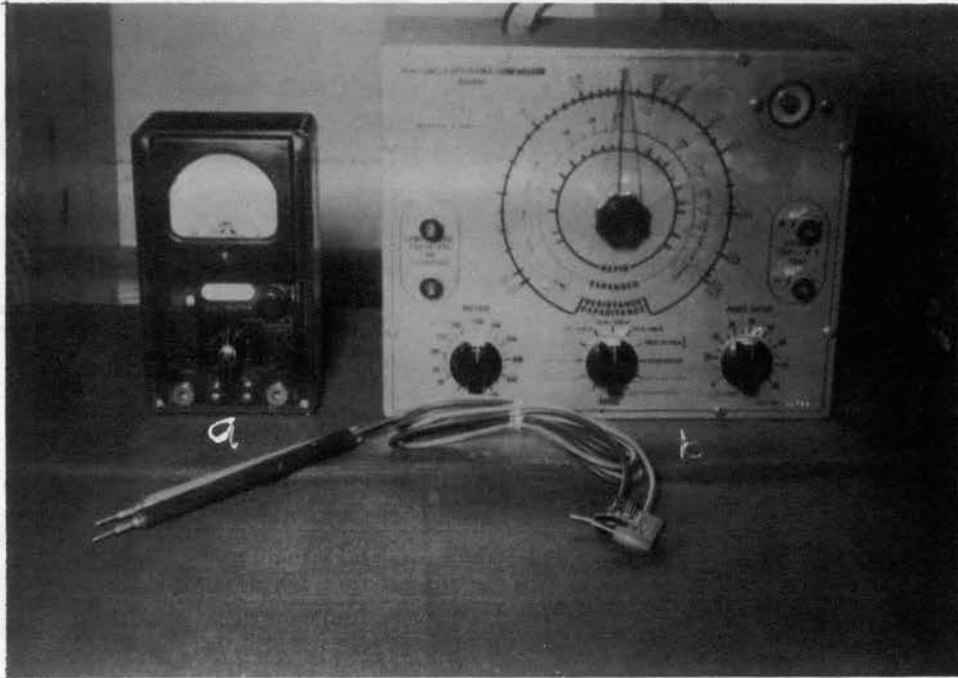


Figure 6. Special Equipment.
a, EICO 1,000 ohms/volt V-O-M #536
b, EICO Resistance and Capacitance
Bridge #950B

All other items of equipment used in these tests were normal soil laboratory equipment, such as an analytical balance weight-measuring device, desiccator, drying oven, liquid limit device, sieves, etc. Such items should not require explanation here, but will be mentioned as they are used in various tests.

Direct Current Resistance Test

Soil samples were prepared at various moisture contents starting with oven-dried specimens and going through the entire moisture range to the liquid state. These samples were placed in sealed pint jars for one week so that moisture distribution would be uniform. Samples were prepared from red Permian clay having a plastic limit (PL) of 19.4 and a liquid limit (LL) of 37.6. Additional samples were prepared from a coarse river-run sand, which passes through the No. 4 standard sieve and is retained on the No. 10 sieve.

At the time of testing the tops were removed from the sample jars and the test leads of the EICO #536 were inserted in the sample. The resistance in ohms was recorded. The spacing of probes on the leads was held constant at 1 centimeter. For the denser materials, heavy hand-pressures on the leads were required to obtain reasonable readings. These readings were not always reproducible and the results are in question. After each reading was obtained, moisture samples were taken and soil moisture content was determined by standard means. (Appendix A). These moisture readings were

plotted on an arithmetic scale against ohm readings on a logarithmic scale, and are recorded in figure 14, Chapter IV.

Alternating-Current Resistance Bridge Test

In this test the procedures were exactly the same as in the previously described direct-current ohmmeter test, except that the EICO #950 B alternating-current resistance bridge was used as the measuring device. Here again difficulty was experienced in obtaining reasonably reproducible results. These results were plotted in the same manner as for the previous tests and can be found in figure 15., Chapter IV. Since results were questionable, only the red permian clay was tested in this manner.

Block Design and Construction

The standard Bouyoucos plaster block (Fig. No. 4.), is constructed of electrodes imbedded in plaster of Paris. It is rectangular in shape, measuring $2\frac{1}{2}$ " by $1\frac{7}{16}$ " by $\frac{1}{2}$ ". The resistance of this block gives acceptable soil moisture data in the lower ranges of soil moisture. This will, of course, vary with the type of soil, and for the red Permian clay it is between $w = 2\%$ and $w = 12\%$. The Bouyoucos nylon block, also rectangular in shape, measuring $1\frac{5}{8}$ " by $1\frac{7}{16}$ " by $\frac{1}{8}$ ", (Fig. No. 4.), gives good soil moisture data in the higher ranges above $w = 12\%$ for the red permian clay.

The shape and range of neither of these blocks make it readily adaptable to engineering use. Since most soil

investigation equipment: drills, augers, etc., produce round holes, a cylindrical shape was selected for the author's plaster block. In order to increase the sensitivity of this block so that one unit could be used throughout the entire moisture range, a smaller, cylindrical, nylon element with two electrodes was imbedded in the basic block. In this manner it was hoped to take advantage of the plaster of Paris's moisture susceptibility in the drier ranges and nylon's properties in the wetter ranges.

The nylon material used in the Bouyoucos block is a thick, heavy material of over 2000 denier, having 48 heavy multi-fibered threads per inch. To gain more sensitivity, a fine 50 denier material with 100 threads to the inch was selected for use in constructing the blocks described here. This material was cut in two-inch strips 46 inches long, folded in half lengthwise, and pressed with a low-heat electric iron, producing a double thickness strip, one inch wide and 46 inches long. Into the fold at one end of this strip was placed a one square inch piece of number 18 copper screen wire to which was soldered a ten foot length of 18 gauge plastic-covered copper wire. Rosin core solder was used instead of acid core solder which might have affected the resistance of the block. The strip was then wound around a one inch length of 3/16 inch glass rod. As the strip was wound, care was taken to keep the nylon material neat and even. When the winding was completed, a second wire screen electrode and lead was inserted in the fold of the last inch of

the nylon strip. This winding operation produced a small cylindrical shaped bundle 1 inch high and 11/16 inches in diameter. The entire bundle was then wrapped and secured with a 4 foot length of size A nylon thread. The one inch length of glass rod was left intact in the center of this cylinder. (Figure No. 7 shows the nylon core construction.)

In preparing the plaster of Paris for molding, the water-plaster ratio is extremely critical. Low water-plaster ratios produce dense, high strength plaster. (26). This plaster has low moisture absorption properties and even in the early stages of mixing, it is too thick to pour into molds. On the other hand, high water-plaster ratios produce low strength plaster with large voids. Neither of these conditions is desirable for construction of the moisture blocks.

Figure 8. shows the effect of water-plaster ratios on plaster strength. (27). After experimenting with various ratios, one of 0.75 was selected for use. This ratio provides 1600 psi plaster and can be poured up to several minutes after mixing. It is important that all blocks of a series have the same water-plaster ratio so that their density and moisture absorption properties will be nearly the same after hydration.

The weights for the mixing were determined on a triple beam balance to two decimal places (the second place being estimated), and mixing was performed by sprinkling the plaster of Paris into the predetermined amount of water, stirring with a plastic spoon and tapping the container to remove air. (28).

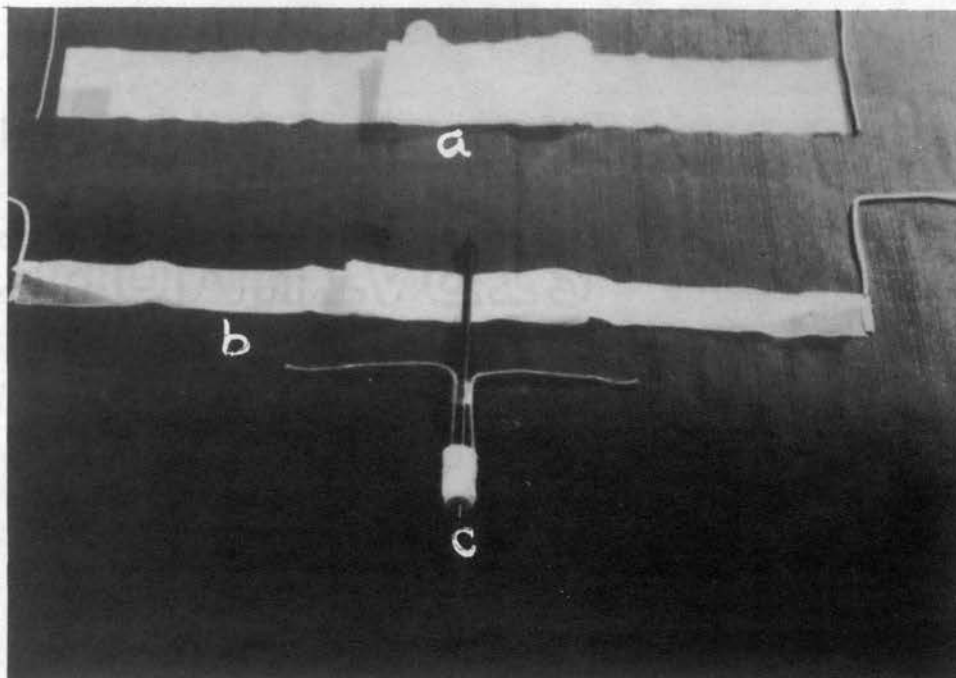


Figure 7. Nylon Core Construction.
a, Core materials
b, Assembled materials prior to winding
c, Completed core

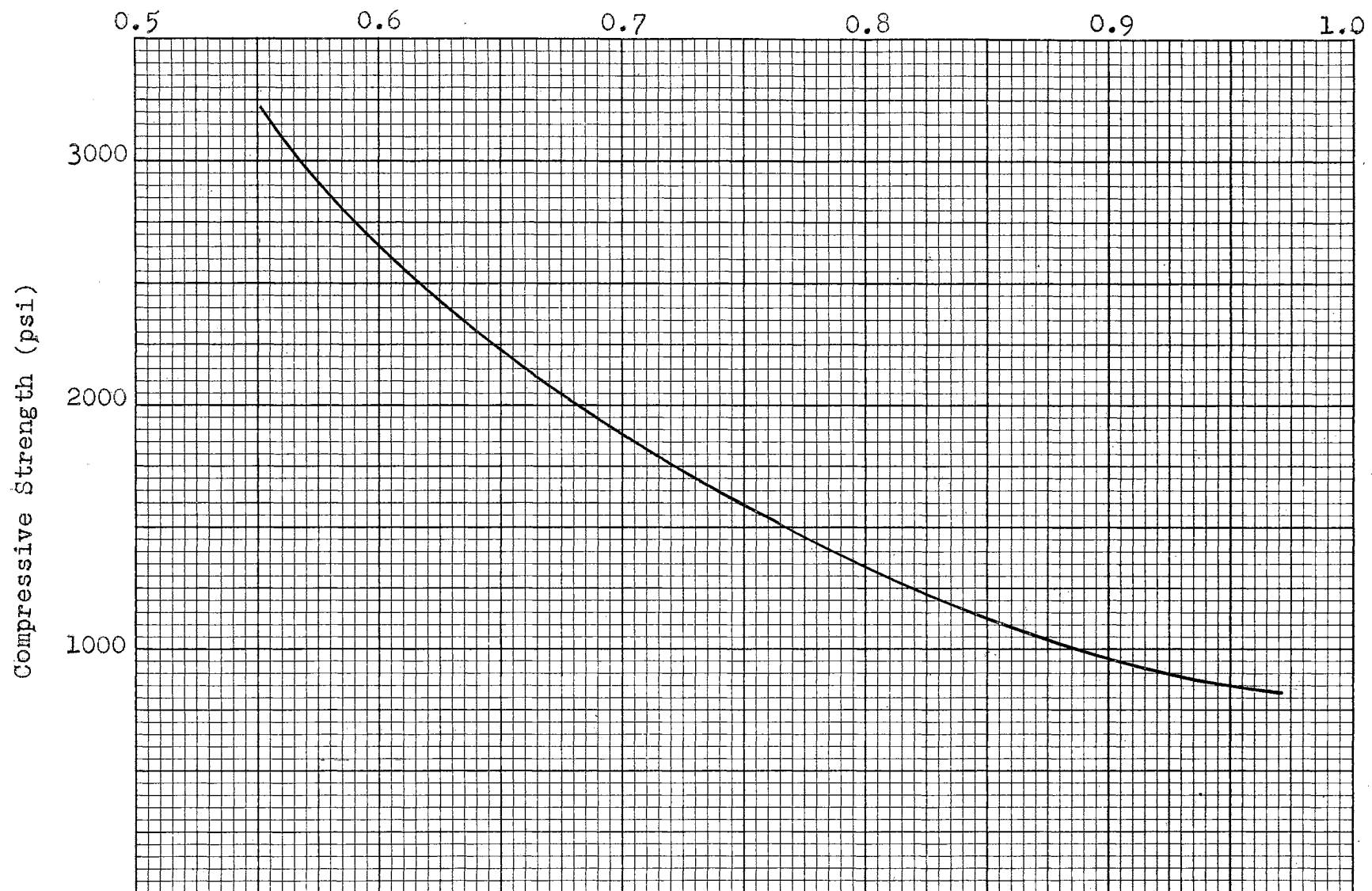


Fig. No. 8. (Ref. 27.) EFFECT OF WATER-PLASTER RATIO ON PLASTER STRENGTH

During the mixing the nylon cylinder was worked in the plaster to remove excess air from the nylon and electrodes.

The mold used was a commercial stick-deodorant container. (Fig. No. 9.). The nylon core was positioned in the horizontal and vertical center of the mold. It was held in place by varying the tension on the electrode leads. Approximately two minutes after the plaster was added to the water, the mixture was poured into the mold. The side of the mold was tapped continuously to remove trapped air. Plaster of Paris attains its initial set in about five minutes and expands as it hardens. It is believed that this expansion in the essentially rigid mold improved the bond of plaster and nylon, and provided a uniform pressure within the nylon itself. However, since the mold could yield very little without fracturing, the cylinder had to be extruded from the mold before complete hydration could take place. With the aid of a length of 1 1/4 inch dowel rod, this was done 15 minutes after the mold was poured. Figure 9. shows the mold, extruding apparatus, and a plaster cylinder partially extruded from the mold. The plaster cylinders were then dried on a board at room temperature for two days. The final cylindrical block produced was 2 5/16 inches high with a diameter of 1 1/2 inches.

Variable Humidity Test

In this test an attempt was made to evaluate the reaction of a plaster-nylon moisture block suspended in air at different

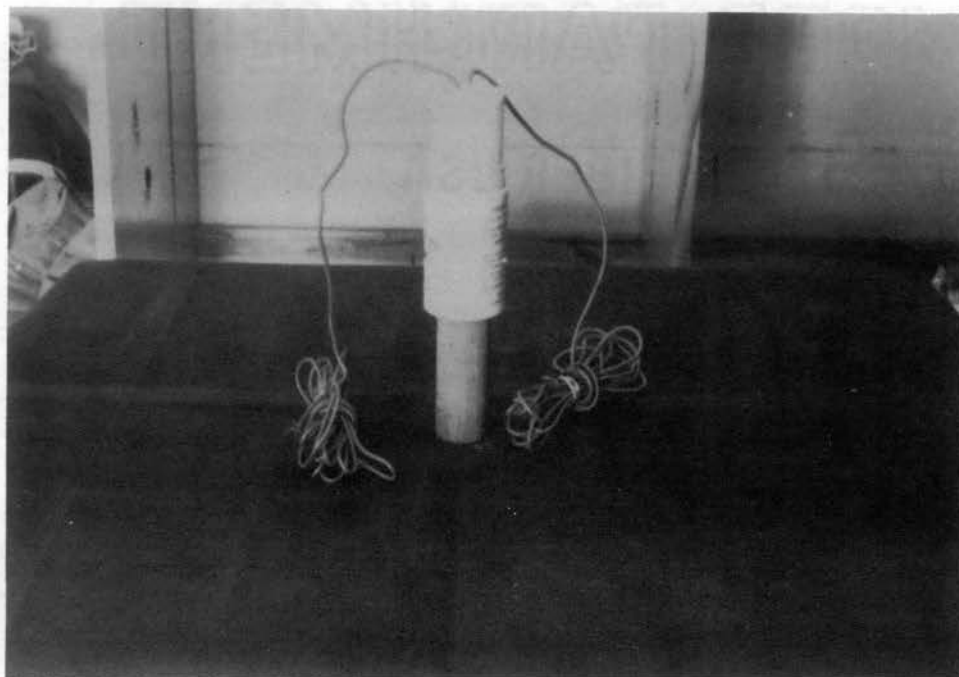


Figure 9. Extrusion of a Plaster-Nylon Block from the mold.

absolute humidities. It was hoped that the block would be sensitive enough to react to changes in humidity in a cavity in the soil, and in turn that this humidity could be correlated with soil moisture.

Absolute humidity may be defined as the weight of water vapor contained in a unit volume of air. In this test the moisture block was suspended in free air in a sealed jar. The jar was filled to 5 cm. depth with water (Fig. No. 10.). The absolute humidity was increased by raising the saturated vapor pressure of the water with heat from a Bunsen burner. Varying amounts of vacuum were also applied to the air space above the water. As the absolute humidity rose in the air space surrounding the block, the resistance of the block decreased, but these decreases were only slight; and severe temperature and pressure changes were required to bring them about. The influence of temperature and pressure changes on the absorptive capacity of the block itself was not investigated. Since such changes do not exist in nature, and because the natural humidity variations are small compared to the variations imposed in the laboratory, this test was abandoned. However, with precise and very sensitive humidity-measuring equipment, some correlation of humidity with soil moisture might be possible.

Block Calibration

All units such as electrodes, capacitance units, and moisture blocks are affected by the physical make-up of the

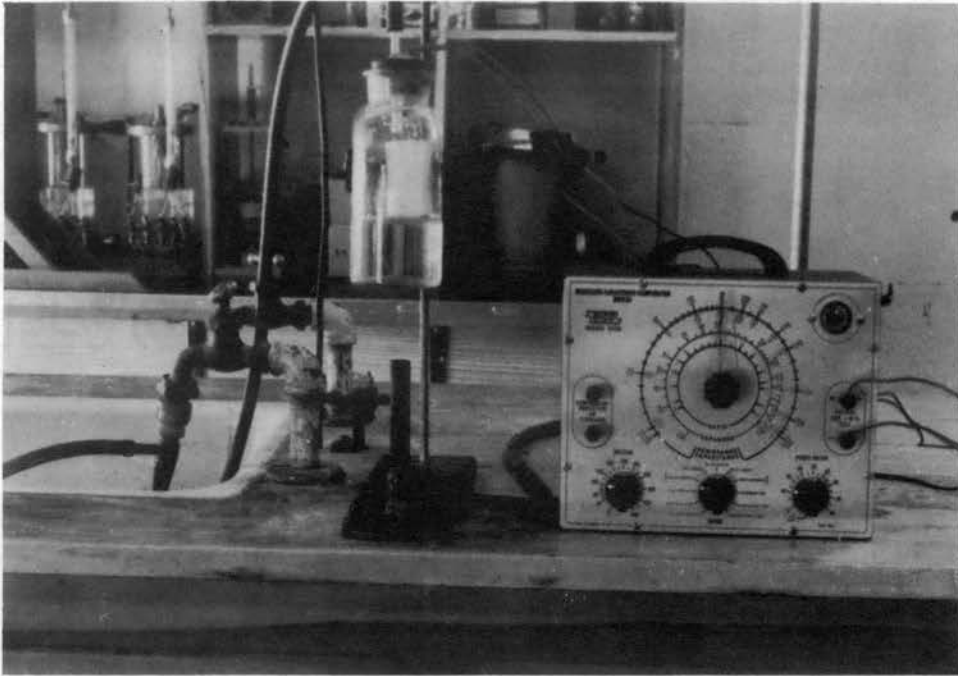


Figure 10. Variable Humidity Test.

liquid phase of the soil system. For this reason, such units must be calibrated for the particular soil in which they are to be used. Normally such units are calibrated in a "humid room," in groups of twenty to thirty after reaching constant resistance in large, open, metal pans filled with a particular soil.

In the calibration procedure utilized in this investigation the blocks were calibrated individually in a sealed container. (Fig. No. 11.). It was felt that in this manner evaporation or drying out of the samples was prevented; and by leaving the block in the sample for many days, complete equilibrium was reached. In the open pan method of calibration, assuming equilibrium exists between the partial vapor pressure in the humid room and the saturated vapor pressure of the water in the sample, there are still irregular areas of moisture content. The latter is the result of the moisture units themselves having an affinity for water and drawing the soil moisture to them. In addition to this, the initial assumption of equilibrium may not be true, causing evaporation of the soil moisture or addition to the soil of more moisture.

Initial calibration was begun on an oven dried sample. The same previously prepared samples of red Permian clay were used. The block was imbedded in the sample and each insulated-wire electrode-lead was carried through a separate hole in the lid of the container. The holes were then sealed with modeling clay and the leads carried to the resistance terminals of

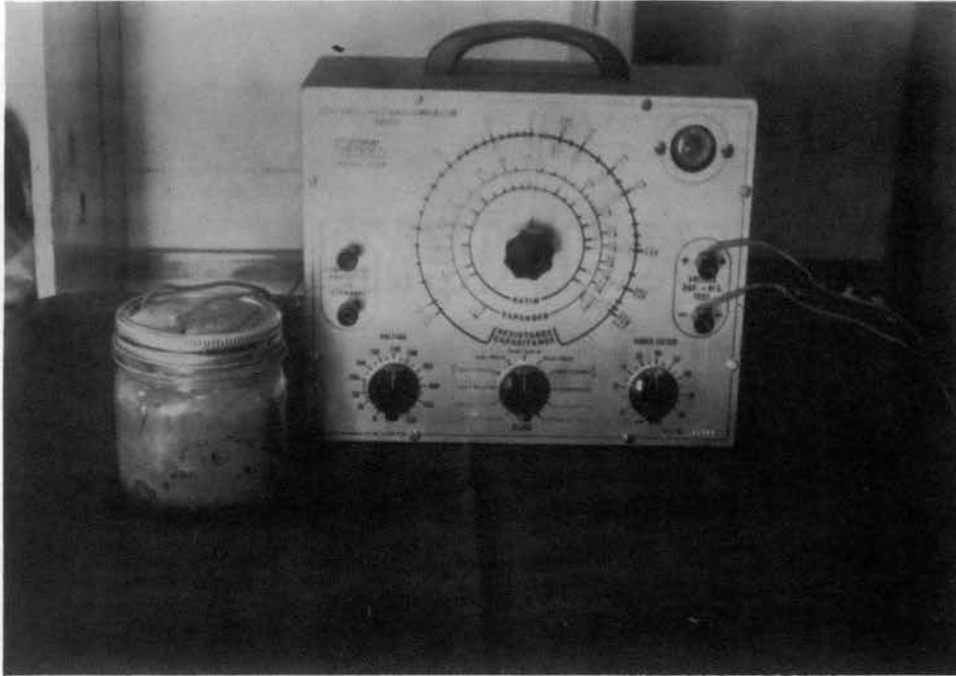


Figure 11. Plaster-Nylon Block Calibration.

the EICO #950B Bridge. (Fig. No. 10.). The initial reading was above the limits of the equipment (500 megohms) and no balance null could be obtained. Readings were taken at 24 hour intervals for the next three days, but readings were still above 500 megohms. This indicated that the resistance of the block for zero moisture content is infinitely great, and that the calibration curve for the block is asymptotic to the line of zero moisture content.

On the third day the block was placed in a new sample of moist clay and readings were taken at 24 hour intervals. Equilibrium was obtained (no change over 24 hour period) on the eighth day. The balance null (widest "V" on the cathode ray tube) was at 15 million ohms. A moisture sample was taken and the moisture content determined by standard methods (Appendix A.) as 3.81%. This procedure was repeated using samples with increased moisture contents, until at $w = 72\%$ the block had the same resistance as if immersed in tap water. This was considered to be the upper limit of the calibration for the red Permian clay. Table I, shows the samples by number and gives the time to reach equilibrium, the resistance readings, and the determined water content. The resistance readings from this calibration were plotted on a logarithmic scale against moisture content on an arithmetic scale, and are shown in Chapter IV, figure 16.

A similar calibration was performed on a plain plaster block--that is, without a nylon core--and the resulting curve is also shown in Chapter IV, figure 16. With the latter, a

TABLE I

PLASTER-NYLON BLOCK CALIBRATION DATA

SAMPLE #	TIME FOR EQUILIBRIUM Days	RESISTANCE ohms	WATER CONTENT %
1	8	15,000,000	4.82
2	6	675,000	5.51
3	5	16,600	8.53
4	4	3,700	13.61
5	4	1,400	19.52
6	3	890	25.44
7	3	480	35.64
8	3	175	53.80
9	2	115	60.10
10	2	60	72.01

comparison can be made between the two types of blocks and the use of the nylon core can be evaluated.

In conjunction with the block calibration, the effects of drift and temperature were investigated. Drift is the result of changes in resistance due to repeated wetting and drying cycles. Actually the block goes "off" calibration. To obtain data from which to evaluate drift, a block was immersed in tap water for 24 hours. (Fig. No. 12.). A resistance reading was taken at the end of this period. The block was then air dried for 48 hours and the cycle repeated. Ten cycles were performed and the effect of drift may be seen in Chapter IV, figure 18.

To determine the effect of temperature changes on block readings, a block was imbedded and allowed to reach equilibrium in a sealed sample of soil of known water content and temperature. The electrode leads and a centigrade thermometer were taken out through holes in the lid of the sample jar. These holes were sealed with modeling clay and the entire assembly was placed in a laboratory refrigerator. (Fig. No. 13.). As the temperature of the sample and block decreased, resistance readings were taken. Data from this test and values for " α ", the temperature coefficient of resistance, are shown in Chapter IV, table II. If R_1 is taken as the resistance of the block at the reference temperature, the resistance at a second temperature, R_2 , is given by $R_2 = R_1 (1 + \alpha t)$, where "t" is the number of degrees above or below the reference temperature.

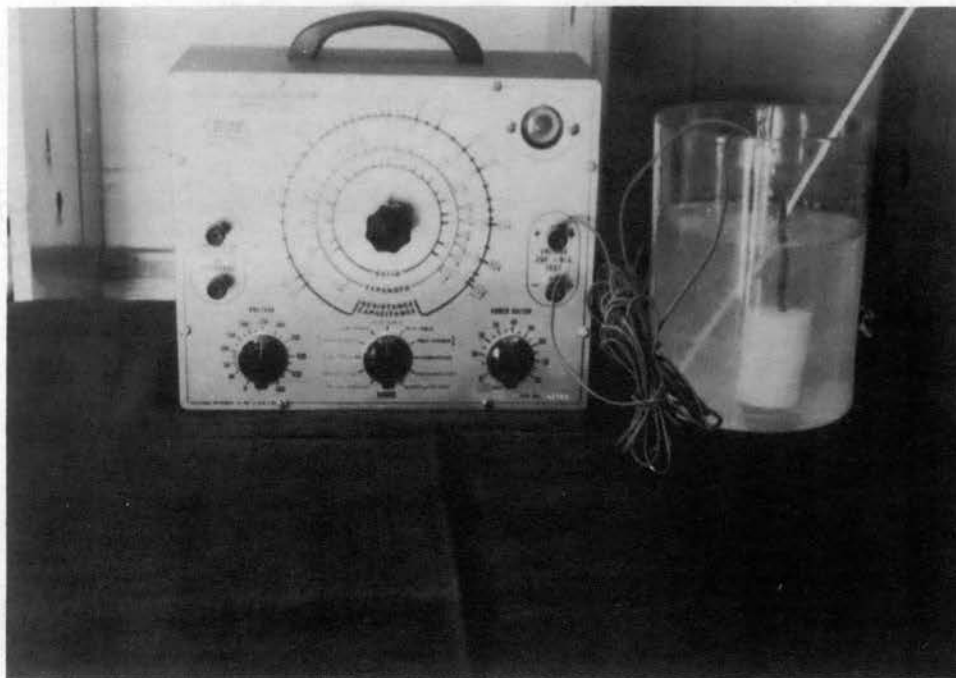


Figure 12. Plaster-Nylon Block Drift Evaluation.

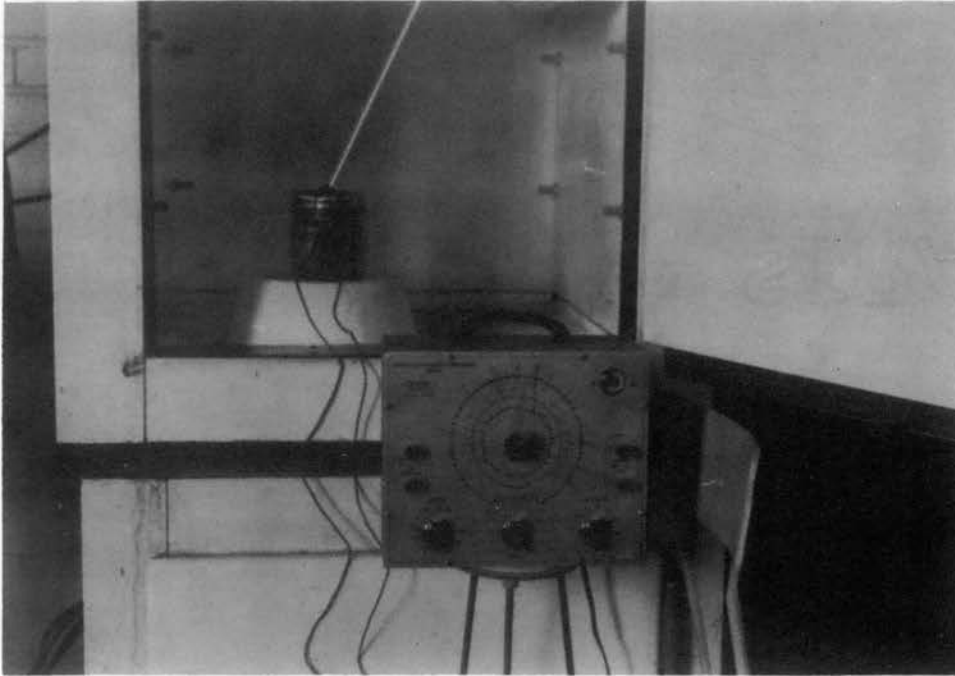


Figure 13. Plaster-Nylon Block Temperature Evaluation.

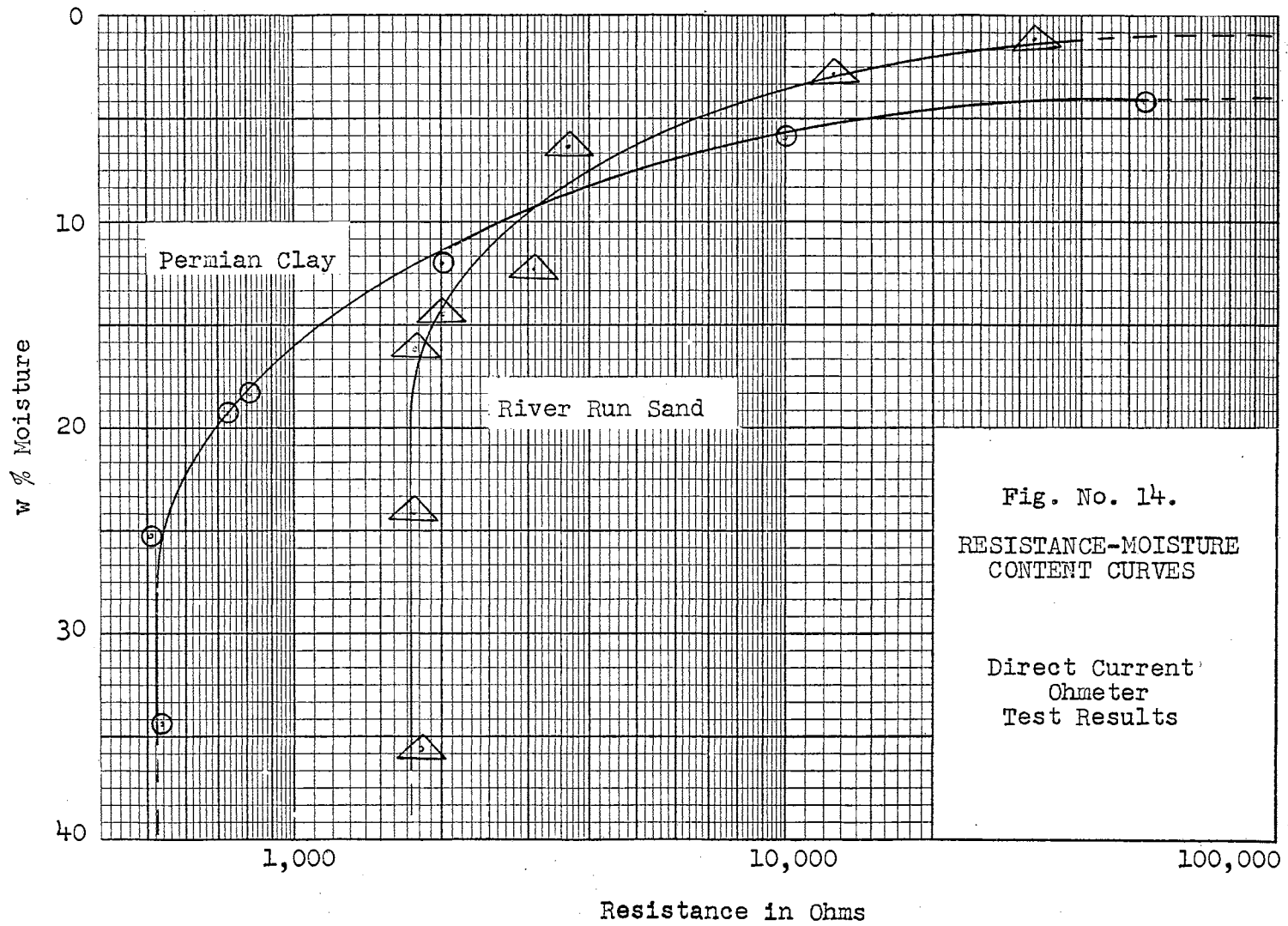
CHAPTER IV

RESULTS AND DISCUSSION

Direct Current Resistance Test

The results of the direct current ohmmeter test, for both the Permian clay and coarse river-run sand, are shown in figure 14. Both curves are asymptotic to the line of zero moisture content. That is, the resistance of the soil samples for a one cm. electrode spacing is infinitely great. The curves for both types of soil are relatively flat to approximately $w = 6\%$ moisture content. This indicates that small sections of resistance data in this range might better be represented on an arithmetic scale for greater accuracy. However, the logarithmic scale is necessary to present the entire curve from the low to the high moisture contents.

It should be noted that as moisture content increases, both curves reach a vertical tangent. Beyond a certain point, additional moisture does not decrease the resistance reading. This point was at a higher moisture content, or lower resistance reading, for the clay than for the sand. As a result of the shape of the curves, a moisture determination can be made only in a limited range. This is between $w = 6\%$ and $w = 20\%$ for the sand, and $w = 6\%$ and $w = 15\%$ for the clay.



A great deal of difficulty was encountered in taking the resistance readings for this test. Although varying salt content was not a problem, irregular electrode contact pressure caused readings to vary greatly. Efforts to overcome this difficulty, with the use of constant weighted electrodes, were to no avail. Also, because the measuring device itself was powered by direct current, errors due to polarization were introduced.

When the electrodes were initially placed in the soil, a minimum reading was shown on the meter; however, this reading did not hold. It rapidly rose to a much higher value. Even when the electrodes were weighted to give near constant contact pressure the readings rose, although more slowly. In securing data for these curves, the initial low or minimum reading for each sample was used. Even these were not always reproducible.

It is felt that the data from this test has served to reaffirm the findings of Whitney, Gardner and Briggs (29); and that such methods of measuring soil moisture can serve to make only rough estimates of moisture contents, and even then, only within a limited range.

Alternating Current Resistance Bridge Test

The results of the alternating-current resistance bridge test are shown in figure 15. This test was performed only on the clay samples. The characteristics of the resultant curve are the same as for the direct current resistance test,

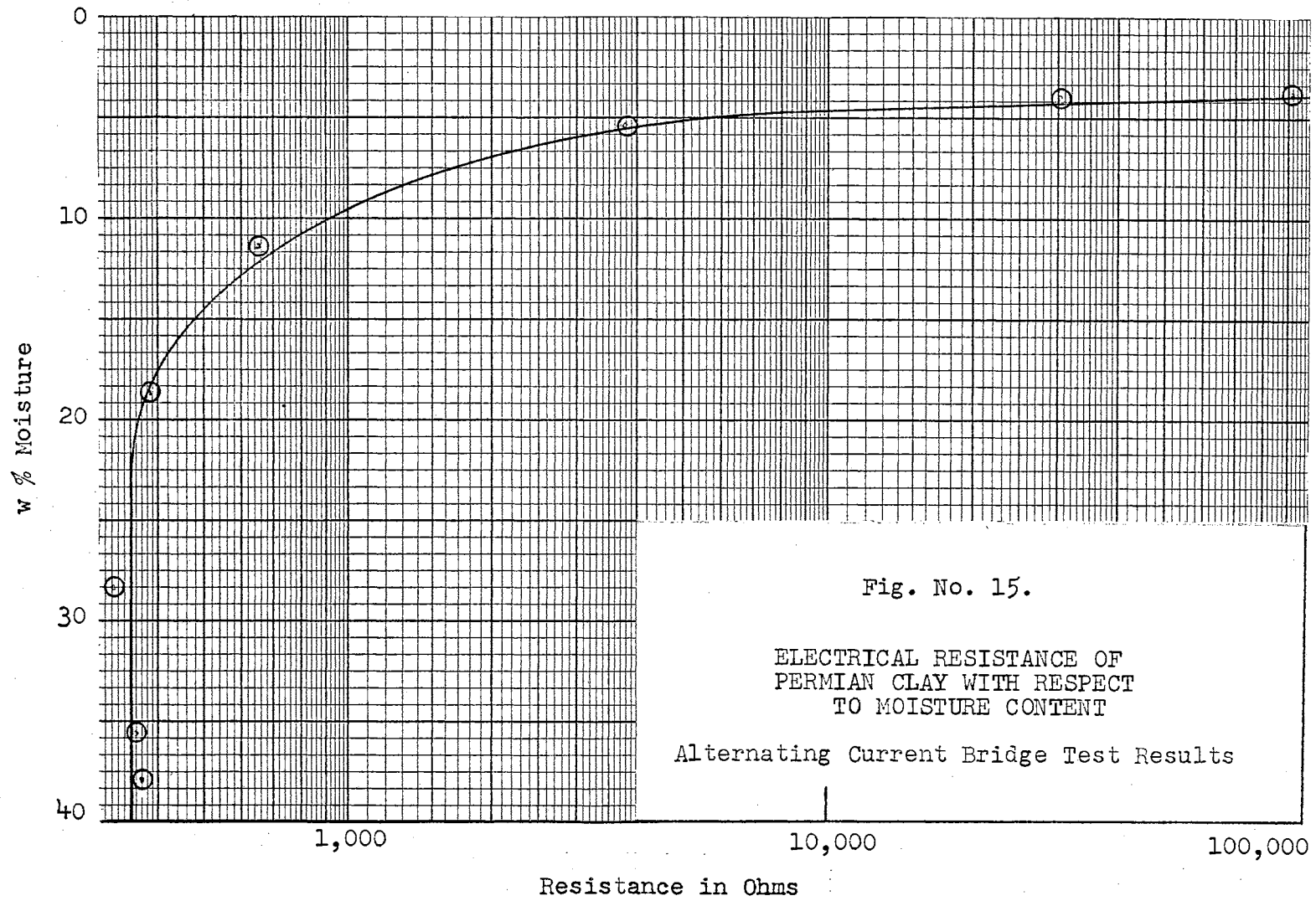


Fig. No. 15.

ELECTRICAL RESISTANCE OF
 PERMIAN CLAY WITH RESPECT
 TO MOISTURE CONTENT

Alternating Current Bridge Test Results

that is: having a flat portion in the lower moisture range between $w=5\%$ and $w=0\%$, and a vertical tangent at approximately $w=20\%$.

With alternating-current resistance measuring devices, such as the EICO #950B, the polarization error is nil; this accounts for the difference between the two curves. The difference is more apparent in the lower resistance readings.

Varying electrode contact pressure was still a problem in this test, and it was difficult to obtain reproducible data. It is believed that soil moisture estimates made from resistance readings would be more nearly correct if made with alternating current measuring equipment.

The length of the curve, or the moisture range over which a rough estimate might be made, is somewhat larger for the alternating current test. With the use of the A-48¹ soil cup offered by Soiltest (30) to minimize errors due to irregular electrode contact pressure, this method might have a good, practical application.

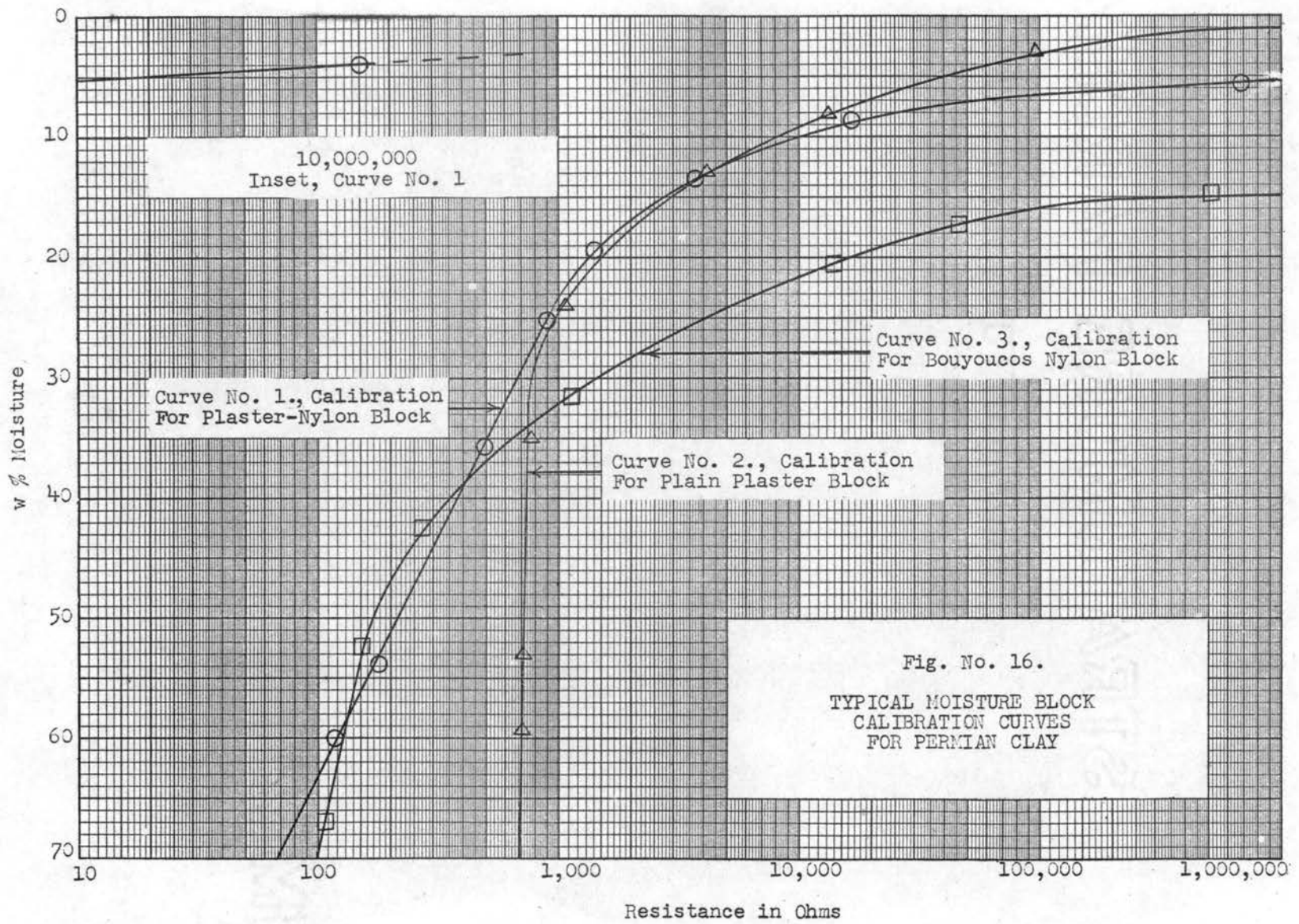
Variable Humidity Test

There was no effort made to record data from this test as it was run purely for the purpose of determining the need for a full-scale, carefully controlled test. Figure 10., Chapter III, shows the apparatus and arrangements for this test. Indications were that a nylon-plaster block lacks the sensitivity to react to humidity changes normally found in a cavity within a soil mass. During the test, the block did

react by giving lower resistance readings as the humidity was increased; but the pressures and temperature differences required to bring this about were so large, compared with those which occur in nature, that testing along these lines was discontinued. This does not mean that there is not some humidity-measuring device which is sensitive enough for such work. Further research along these lines might well prove worthwhile. For example, an extremely thin-walled plaster cylinder might be sensitive enough to give such information.

Block Calibration

The use of a moisture-sensing device or block was resorted to because of the difficulties and inaccuracies encountered in correlating direct resistance readings with soil moisture. The design of such a block, employing both plaster of Paris and nylon, has been covered in Chapter III. The results of the calibration of one of these blocks with the Permian clay is shown in figure 16. as curve No. 1. The calibration curve for a plain plaster block (without a nylon core) is shown as curve No. 2. The calibration curve for a nylon block is shown as curve No. 3. These curves follow the same general shape as the straight resistance reading curves; however, by comparing the three curves, the advantages and disadvantages of the nylon core can be seen. Because of the nylon core, curve No. 1., for the plaster-nylon block, is flatter in the lower ranges of moisture content than curve No. 2., for the plain plaster block, and gives a higher resistance reading



for the same soil moisture content. With the EICO 950B resistance bridge, this is a disadvantage because of lower accuracy at high resistance readings.

At the $w = 13\%$ point, curves No. 1. and No. 2. cross; from this point on, the nylon core gives an increasingly advantageous effect, permitting the curve to give usable moisture data to a value of $w = 70\%$. On the other hand, curve No. 2 starts to approach a vertical tangent at $w = 25\%$, and beyond $w = 30\%$ additional soil moisture makes no appreciable difference in the curve.

Curve No. 3. for the nylon block is very flat in the lower ranges of moisture content and provides no usable data until the curve breaks at about $w = 20\%$. From this point, the nylon block supplies suitable moisture data, primarily in the higher ranges. Although the plaster block and the nylon block provide usable data in the lower and higher ranges, respectively, the plaster-nylon cylindrical block provides moisture data over a wide range, from $w = 5\%$ to $w = 70\%$.

There was no difficulty in obtaining the readings for the block calibrations. The readings held steady and the balance null (widest "V" on the cathode ray tube) was easily detected. The readings were reproducible, and the equipment and blocks functioned satisfactorily.

The disadvantage caused by the nylon core in the lower moisture ranges could be minimized by the use of measurement equipment which offers greater accuracy in the higher

resistance ranges, such as the A-40 conductivity bridge offered by Soiltest. (31). Also small sections of the curve in this area can be displayed to a straight arithmetic scale for greater accuracy.

It should be noted that curve No. 2 (plain plaster block) gives a greater range over which soil moisture content may be determined than either of the straight resistance methods--its vertical tangent being $w = 30\%$. However, a still larger usable range is given by curve No. 1 for the plaster-nylon block: $w = 5\%$ to $w = 70\%$.

The accuracy of these blocks in determining soil moisture was checked by re-establishing a calibrated block in various soil samples at different water contents. Below $w = 10\%$, accuracy was within $\Delta w = 1\%$. At the approximate liquid limit of the clay, $w = 35\%$, the error was within $\Delta w = 3\%$. The error at $w = 60\%$ was within $\Delta w = 5\%$ and this appeared to be the maximum error with respect to "w". This is shown in Figure 17.

The laboratory accuracy of these blocks may be considerably different than that encountered when the blocks are left in the ground for months or years. Agricultural writings (Chapter II) indicate that repeated wetting and drying cycles cause a drift from calibration. This is hard to compensate for, and may in part be due to deterioration of the plaster or leaching of soluble gypsum.

An investigation of this deterioration was made by subjecting a block to ten cycles of wetting and drying in the

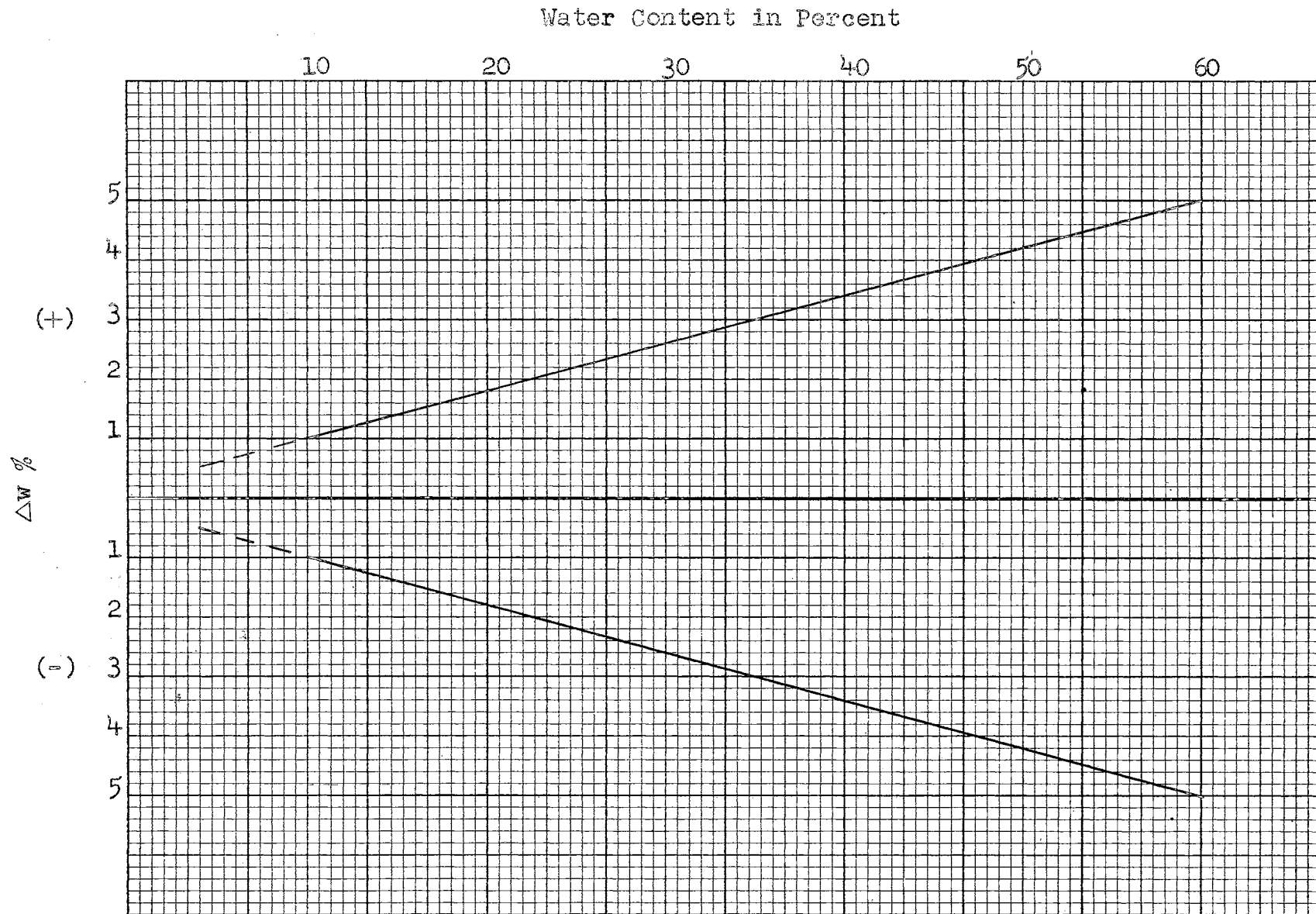


Fig. No. 17. MAXIMUM PROBABLE ERROR IN MOISTURE CONTENT PLOTTED AS A FUNCTION OF MOISTURE CONTENT FOR A PLASTER-NYLON BLOCK

laboratory. The block was immersed in tap water for 24 hours and air-dried for 48 hours, then re-immersed, etc. At the end of this test, the surface of the plaster was rough, the edges had become rounded, and the surface and bottom of the container in which the block was immersed was covered with fine white particles of plaster. However, no appreciable change in the size of the block was noticed. Readings taken at the end of each 24 hour immersion period indicate that drift was occurring. The readings went higher after each cycle, showing a decrease in the available gypsum which could go into solution in the block. The leaching-out of gypsum from the block was substantiated by the fact that the resistance of the immersion water decreased. The immersion resistance readings of the block are plotted against wetting cycles in figure 18. It was found that this drift practically ceased at the completion of the fifth immersion cycle. Because of this, it is suggested that blocks which are to be used in the higher soil moisture ranges be subjected to five immersion cycles before calibration and placing.

Control of block deterioration may be effected by impregnation with resins such as phenol or urea formaldehyde. (32). These resins increase the strength and durability of the plaster but change the absorption qualities of the block. Phenol, the most frequently used resin for improving the strength and durability of plaster of Paris, can not be used in this case, because it is one of the few substances in which nylon is soluble. (33). An alternative would be to

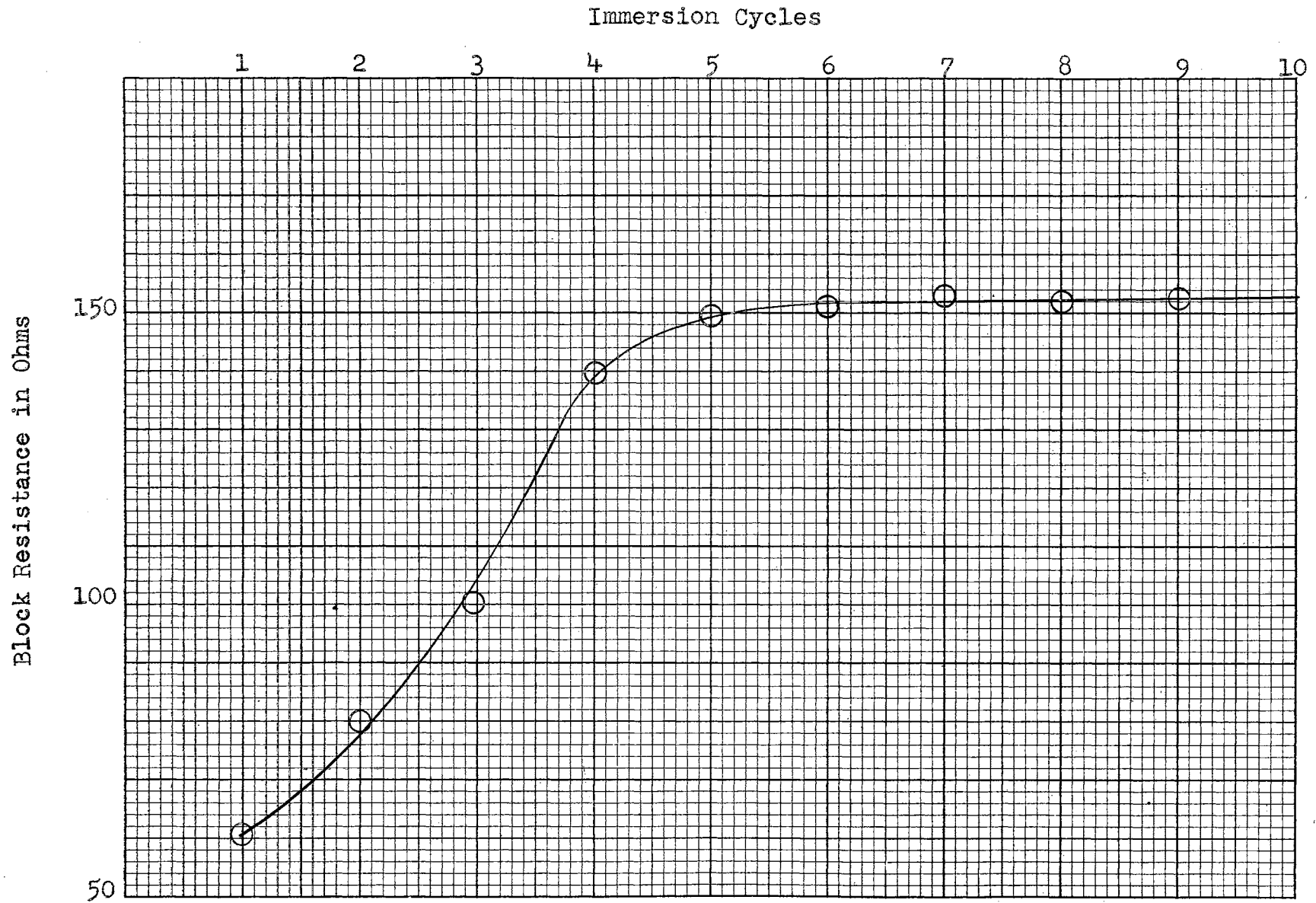


Fig. No. 18

PLASTER-NYLON BLOCK DRIFT EVALUATION CURVE

use acetic acid as an additive in the mixing of the plaster to retard setting time. This would allow pouring and molding the plaster at lower water contents, with a consequent increase of its strength. Here again, though, the acid would affect the resistance of the block. Although many additives have merit, all would produce a different calibration curve for the block concerned.

Temperature is another factor which affects the resistance of a moisture block. In agricultural use the temperature effect is considered negligible. For engineering use of a plaster-nylon block, temperature must be considered if a reasonable degree of accuracy is to be obtained. Investigation revealed that the change in resistance of a block in the lower moisture ranges, due to temperature changes, was very small, not being measurable with the author's equipment. However, as the moisture content of the sample increased, the amount of gypsum in solution in the block increased rapidly and temperature had an increasingly greater effect. This effect becomes constant at a point approximately equal to the liquid limit for the Permian clay. This means that a temperature coefficient of resistance, " α ", may be calculated for the resistance of the block, at or near the liquid limit of the clay, and applied to the resistance values at and above this point. Below the liquid limit there is little or no change when the correction is applied.

" α ", the temperature coefficient of resistance, physically represents the increase or decrease of resistance of a

one ohm resistance, when subjected to a temperature change of one degree from a reference temperature. (34). In this case, the block's resistance was found to increase as the temperature was lowered, and to decrease as the temperature was raised. The test data and resulting value of " α " are given in Table II.

TABLE II

PLASTER-NYLON BLOCK TEMPERATURE
CORRECTION DATA

	<u>Temperature</u> °C	<u>Resistance</u> ohms	<u>Water Content</u> %	$\frac{\infty}{\text{per } ^\circ\text{C.}}$
Test # 1				
	18.6	600	25.1	ref. temp.
	10.2	620	25.1	0.00396
Test # 2				
	18.2	210	35.2	ref. temp.
	9.0	270	35.2	0.0311
Test # 3				
	18.5	90	60.4	ref. temp.
	9.4	120	60.4	0.0366

CHAPTER V

SUMMARY AND CONCLUSIONS

Significance of Results

For a rough approximation of soil moisture in a limited range ($w = 6\%$ to $w = 20\%$ for Permian clay), direct current resistance readings may be employed. These readings are affected by polarization, irregular electrode contact pressures and areas, varying chemical make-up of the soil moisture, and the properties of the soil particles themselves. Such readings are not readily reproducible and accuracy is poor.

A better approximation of soil moisture in the same limited range may be made based on alternating current resistance readings. With alternating current the readings are not affected by polarization; however, the adverse effects due to varying electrode pressures and properties of the soil system are still present. These readings are also difficult to reproduce, but their accuracy is somewhat better than direct current resistance readings.

The short-comings of moisture determination based on resistance readings led to the design of the plaster-nylon moisture block. The plaster serves as the absorbent medium

and provides contact with the soil. Plaster provides good sensitivity to moisture variations in the lower ranges. To secure good moisture sensitivity in the higher ranges, a nylon core was added. A central electrode was placed in the center of the nylon and another on the exterior of the nylon adjacent to the plaster. A cylindrical shape was selected for the block because of its adaptability for installation in borings made during soil exploration.

To check the sensitivity of the block it was subjected to air at different absolute humidities. Some small response was shown to large humidity changes, but not enough to warrant use of the block in a soil cavity as a method of determining soil moisture. As a result, it was decided that direct contact of the block with the soil would be used to obtain resistance readings, which in turn would be correlated with soil moisture.

Block calibration was accomplished by taking resistance readings from a block at equilibrium within a sealed soil sample. This resistance reading was taken as the resistance of the block at the moisture content of the sample, as determined by the standard method. (Appendix A). From these resistance readings and moisture contents a calibration curve was drawn. The accuracy of the blocks was evaluated by re-establishing them in soil samples at various moisture contents, and comparing the moisture content indicated by the resistance of the block to those determined by the standard method. The deviations varied from $\Delta w = 1\%$ in the lower ranges to $\Delta w = 3\%$

near the liquid limit (37.6% for the clay used), and reached a maximum of $\Delta w = 5\%$ at $w = 60\%$.

The effect of drift from calibration, caused by repeated wetting and drying cycles, was investigated by subjecting a block to repeated cycles of immersion in water followed by air drying. Resistance readings were taken at the end of each cycle. These resistance readings increased substantially during the first five cycles, indicating that five immersion cycles should be accomplished prior to placing, when a block is to be used in soils with high moisture contents.

The affect of temperature on block readings was investigated by placing a sealed sample and block in a laboratory refrigerator and taking resistance readings at various temperatures.

The temperature of the soil sample was found to affect greatly the resistance of the block above a moisture content approximately equal to the liquid limit of the sample ($w = 37.6\%$). A temperature correction was determined for the applicable range and should be applied if ground or sample temperatures vary above or below calibration temperature.

It may be concluded that a nylon-plaster moisture block will give rapid, reasonably accurate, soil moisture data within a wide range of soil moistures; and further, that once a block has been placed, this data is continually available. It should be understood, however, that the block or blocks should first be calibrated for the soil in which they are to

be placed, and that a temperature correction--if applicable--should be made.

Suggested Applications

Building on expansive desiccated clays in the Southwest, and in particular, Oklahoma, presents an unusual problem. Because these clays are heavily over-consolidated, bearing capacity is seldom a problem. On the other hand, swelling of these clays presents a heaving problem. The building foundation itself cuts off evaporation, and normal capillary rise ultimately saturates the clay underneath the foundation. The resultant swelling may often cause major damage to the building.

It has been suggested in recent years that this damage can be reduced by placing a layer of gravel several inches thick below the sole of the foundation. It is theorized that the swelling of the clay will be into the voids of the gravel, and that the heaving of the foundation will be minimized. However, research by Mr. Hsu-Hwa Yie (35.) in his Master's Report indicates, among other things, that the intrusion of clay into cohesionless materials depends on the water content of the clay in the area where intrusion is taking place. In other words, once the size and depth of the gravel has been determined, the gravel placed, and the foundation laid, the only factor which could conceivably be varied for the needed control would be the water content of the clay. A possible method of achieving such water control would be through the

use of a system of plaster-nylon moisture blocks placed in the clay beneath the gravel layer.

During the 1959-1960 school year, tests at Oklahoma State University will be conducted to evaluate the swelling forces of the Permian clay against cast-in-place concrete flared or bell-bottom piers. (36.). These tests will be conducted on full-size piers placed at a depth of approximately 12 feet. Three piers are to be used; one flared and in contact with clay, another flared and in contact with a low shear strength styrofoam, the third not flared and in contact with the clay. On the two flared piers an area between the bell and the stem will be occupied by a box arrangement, through which will pass the reinforcing bar or bars joining the bell to the stem. SR-4 strain gauges placed on the steel bar, or bars, will be used to measure the heaving forces. The amount of heaving on the pier without the flare will be measured with a level.

Plaster-nylon moisture blocks will be placed in 2 inch auger holes adjacent to the piers at depths of 12, 8 and 4 feet. The entire area around the piers will be covered with a plastic tarpaulin. This will simulate the bottom of a building. It is hoped this will cut off evaporation, thus allowing capillary rise to saturate the clay in the former evaporation zone. The readings from the plaster-nylon blocks will be used to chart rates of capillary rise, and also to relate heaving forces with water content.

It is possible that the area surrounding the piers will be flooded instead of covered over with plastic. If this should be the case, the moisture blocks would provide data concerning the advancement of water downward, as well as the rate of capillary rise upward. The resulting upheaval pressures would still be correlated with water content.

In highway and airfield work there are often many problems caused by the subgrade becoming saturated. These problems could be anticipated, and in many cases prevented, if moisture data was available from within the subgrade. A moisture unit such as the nylon-plaster moisture block could provide such data.

The settlement and upheaval of buildings and foundations is dependent upon many factors, two important ones being the position of the water table and the moisture content of the soil. Properly employed moisture blocks beneath a building could provide continuous soil moisture data. This would allow engineers to anticipate building or foundation movement and to take corrective steps if possible.

Many disastrous earth slides have been attributed to increasing soil moisture content. With the use of a moisture block the moisture content of a critical area could be continually monitored. As the danger point was approached, people could be evacuated, if required, and steps taken to prevent further additions of moisture.

In the manufacture of concrete the water content of the aggregates used must be taken into consideration in preparing

the mix. Moisture blocks could provide this moisture information for many of the fine aggregates used--sand--for example.

Actually, the possible uses of a plaster-nylon moisture block in the civil engineering field are many and varied; however, their use should be carefully considered with respect to the accuracy required, the moisture range in which data is required, and the accessibility of the location from which a moisture content is desired.

Problem Areas for Future Research

In the development of the plaster-nylon moisture block many problems were encountered both in the construction of the block and in the selection of materials. These problems will be mentioned here together with suggestions for possible improvement.

The nylon core, used in the block to gain moisture sensitivity in the higher ranges, caused higher readings in the lower moisture ranges. This was a decided disadvantage. The need is for a material or method which will give the required sensitivity in the higher moisture ranges without causing increased readings in the lower moisture ranges. This might be obtained by separate electrodes for each sensing element--that is--a four wire system.

The affect of the water-plaster ratio on block absorption properties and durability should be determined. Indications are that a block placed in the soil for an extended

period, and subjected to many wetting and drying cycles, might deteriorate excessively. Plaster additives might prevent this deterioration and should be evaluated with respect to the core materials used. Additives to retard plaster setting time should also be investigated.

Molding the block was rather difficult, and various molds should be tried in an effort to provide for controlled expansion as hydration progresses.

The material used in electrode construction should be evaluated to determine whether or not it is chemically affected by the gypsum in solution in the block. It is believed that stainless steel and silver solder might be superior to copper and lead-tin solder.

Finally, the use of various types of absorbent materials should be investigated. Materials such as Portland cement concrete, fiber glass, chemically treated styrofoam or plain Portland cement might have moisture susceptible qualities superior to those of plaster of Paris.

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APPENDIX A

STANDARD METHOD OF DETERMINING PERCENT MOISTURE (1)

Apparatus:

1. Aluminum moisture boxes of suitable size, watch glasses with clamps, or seamless tin boxes for weighing.
2. Weighing device of desired accuracy, such as triple beam balance or analytical balance.
3. Constant-temperature oven capable of maintaining a temperature of $110^{\circ}\text{C} \pm 5^{\circ}$.
4. Desiccator.

Procedure:

The weight of the sample container shall be weighed to the desired accuracy and recorded as T.W. (tare weight). A representative sample of the soil to be tested shall be placed in the moisture container and immediately covered. The container with the wet sample shall be weighed to the required accuracy and recorded as W.W. (wet weight): the weight of container plus soil plus moisture.

Remove the lid from the box and place the sample in the oven. If soil adheres to the lid it shall also be placed in the oven; however, if the lid is clean it may be placed beside the oven.

The soil shall be dried to constant weight at $110^{\circ}\text{C} \pm 5^{\circ}$. The time required for drying will depend upon the size of the sample and the shape of the drying box. It may be determined by drying for an estimated required time, cooling in the desiccator, and weighing. Replace the sample in the oven for an additional period of one hour, then cool and reweigh. Repeat this process until two successive weighings give the same weight within the required accuracy, showing that no additional moisture was lost during the final drying period.

Samples weighing less than 50 gm. will usually reach constant weight in less than 12 hours, while those weighing less than 200 gm. will usually reach constant weight in less than 24 hours.

Immediately upon removing the sample from the oven it shall be placed in the desiccator to cool. After the sample has reached room temperature, it shall be removed from the desiccator and the container immediately covered and weighed; this weight is recorded as D.W. (dry weight): the weight of the container plus dry soil.

The percent moisture, w , with respect to the oven-dry weight, may then be determined by the following relationship:

$$\text{percent moisture } (w) = \frac{WW - DW}{DW} \times 100$$

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APPENDIX B

SPECIFICATIONS FOR EICO #536 V.O.M. (1)

AC/DC Voltage Ranges: 0-1, 5, 10, 50, 100, 500, 5000 volts.

AC/DC Sensitivity 1000 ohms/volt.

AC/DC Current Ranges: 0-1 ma, 10 ma, 0.1 amp, 1 amp.

Ohm Ranges . . . 0-5000 ohms, 100 K ohms, 1 meg ohm

DB Ranges: -20- + 69 in 6 ranges.

Meter: 3" size 400 ua movement

Size: 6 1/2" high, 3 3/4 wide, 2 3/4 deep

Weight 2 lb.

(1) Specifications supplied by Electronic Instrument Co.,
Inc., 33-00 Northern Blvd., Longs Island City 1,
New York.

APPENDIX C

SPECIFICATIONS FOR EICO RESISTANCE
CAPACITANCE BRIDGE # 950B (1)

Capacity: 4 ranges 10 mmf to 5000 mf
Resistance: 4 ranges 0.5 ohms to 500 megohms
Comparator: 1 range ratio from 0.05 59 20 (400 to 1)
DC polarizing voltage . . . 0 to 500 volts DC (Continuously
variable)
Tube Complement 1-1629, 1-6x5
Power Requirements 105-125 volts AC 50/60 cps
Overall Dimensions 8" high, 10" wide, 4 3/4 deep.
Weight 8 lbs.

(1) Specifications supplied by Electronic Instrument Co.,
Inc., 33-00 Northern Blvd., Long Island City 1,
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VITA

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