THE NUCLEAR METHOD OF SOIL-MOISTURE DETERMINATION AT DEPTH

by

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Research Report Number 89-4

Soil Properties as Related to
Load Transfer Characteristics of Drilled Shafts

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The opinions, findings, and conclusions
expressed in this publication are those
of the authors and not necessarily those
of the Bureau of Public Roads.

PREFACE

This is the fourth in a series of reports from Research Project 3-5-65-89 of the Cooperative Highway Research Program, and describes the use of nuclear equipment for measuring the variations of moisture content at the drilled shaft test sites.

A number of people on the staff of the Center for Highway Research contributed to the investigations made in this report. Technical contributions were made by Harold H. Dalrymple, James N. Anagnos, V. N. Vijayvergiya, W. R. Hudson, J. Crozier Brown, and John W. Chuang. Preparation and editing of the manuscript were done by Beth Davis, Joyce Yonker, Eddie B. Hudepohl, and Arthur Frakes.

The Texas Highway Department Project Contact Representatives Messrs. Horace Hoy and H. D. Butler and District No. 14 personnel have been most helpful and cooperative in the development of this work. Our thanks to them as well as the U. S. Bureau of Public Roads who jointly sponsored the research program.

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Report No. 89-1, "Field Testing of Drilled Shafts to Develop Design Methods,"
by Lymon C. Reese and W. Ronald Hudson, describes the overall approach to
the design of drilled shafts based on a series of field and laboratory
investigations.

Report No. 89-2, "Instrumentation for Measurements of Lateral Earth Pressure
in Drilled Shafts," by Lymon C. Reese, J. Crozier Brown, and H. H. Dalrymple,
describes the development and evaluation of pressure gages to measure lateral-
earth pressures on the drilled shaft.

Report No. 89-3, "Studies of Shearing Resistance Between Cement Mortar and
Soil," by John W. Chuang and Lymon C. Reese, describes the overall approach
to the design of drilled shafts based on field and laboratory investigations.

Report No. 89-4, "The Nuclear Method of Soil-Moisture Determination at
Depth," by Clarence J. Ehlers, Lymon C. Reese, and James N. Anagnos, describes
the use of nuclear equipment for measuring the variations of moisture content
at the drilled shaft test sites.

Report No. 89-5, "Load Distribution for a Drilled Shaft in Clay Shale," by
Vasant N. Vijayvergiya, W. Ronald Hudson, and Lymon C. Reese, describes the
development of instrumentation capable of measuring axial load distribution
along a drilled shaft, the development, with the aid of full-scale load
testing, of a technique of analysis of observed data, and the correlation of
observed data with the Texas Highway Department cone penetration test.

ABSTRACT

This report contains the results of an investigation conducted for the primary purpose of studying the capabilities, limitations, and problems associated with the nuclear method of moisture determination at depth.

Nuclear equipment manufactured by Troxler Electronic Laboratories, Inc., was used to measure moisture changes at depth at three different test sites. Moisture contents were obtained using the manufacturer's calibration curve, with the accuracy of the manufacturer's curve being checked in the field by comparing nuclear and gravimetric results. The effect of air gap, the reproducibility of a neutron count, and time and temperature effects were also investigated.

The major problem associated with the nuclear method during the investigation was concerned with access-tube installation; a possible solution of the problem in soil containing gravel is discussed.

Results showed that the nuclear method of soil-moisture determination was fast and efficient. The accuracy of the nuclear method was found to be satisfactory when compared to gravimetric results, and recalibration of the nuclear equipment was not necessary. The nuclear method is recommended for studies concerned with the measurement of soil-moisture changes at depth.

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CHAPTER 1. INTRODUCTION

The usefulness and economic life of most structures depend upon the strength of the underlying soil which supports the load transmitted to it by the foundation of the structure. Since the strength of the soil is influenced by the amount of water which the soil contains, a reliable method for the determination of the water content of the soil mass in place would be of valuable assistance in the analysis of soil strength.

PROBLEM

The Center for Highway Research at The University of Texas at Austin is engaged in a project, sponsored by the Texas Highway Department, which is concerned with the load testing of drilled shafts for the purpose of evaluating their design criteria. Since a change in moisture content influences the strength of the soil and, thus, the load carrying capacity of a drilled shaft, soil-moisture changes or the movement of moisture in soil surrounding drilled shafts is of interest.

Limitations of moisture measuring devices have made it difficult to study the movement of moisture in soils, especially in unsaturated soils. The need for long-time, continual, nondestructive observations of the moisture content at depth of the same soil throughout its seasonal cyclic changes is important, if a satisfactory study of values and trends in soil moisture is to be conducted. The information obtained about the in situ moisture content of the soil would enable the engineer to identify subsurface characteristics as they are affected by weather or other conditions. Such measurements are of significant value in site selection and evaluation for construction of bridges (most of which are supported by drilled shafts in Texas), buildings, and dams, and of the stability of cliffs and embankments as related to highway construction. Thus, there exists within the civil engineering field a need for a moisture measuring device which will enable the engineer and contractor alike to determine the in situ moisture content at depth in a manner which is fast, efficient, and accurate.

METHODS OF MEASURING SOIL MOISTURE AT DEPTH

Gravimetric

Today, there are a number of devices and procedures used for the purpose of determining the moisture content of soil at depth. Perhaps the oldest and most widely used procedure is the gravimetric method, which involves collecting a soil sample, weighing the sample before and after drying, and calculating its moisture content at the time of sampling. This type of an investigation, although simple, is expensive and also lacks continuity, especially over critical periods of rapid rise and fall of the ground water table, since continuous readings with depth at the same point cannot be made. Although there are disadvantages to the gravimetric procedure, it is the most satisfactory method for most problems requiring one-time moisture-content data (Ref 1).

Electrical Resistance

The electrical-resistance method of soil moisture measurement operates on the principle that resistance to the passage of an electrical current between two electrodes or electrical-resistance blocks buried in the soil will depend upon the moisture content of the soil. Nylon, Fiberglas fabric, or plaster of Paris surrounding the electrodes permits uniform contact with soil moisture; and the porous texture of the blocks allows them to readily absorb moisture or give it up, so that the moisture content of the block tends to stay in equilibrium with the moisture content of the soil. Changes in the moisture content cause changes in electrical resistance which is measured by a meter at the surface. The electrical resistance is converted to moisture-content values by means of a calibration chart.

The accuracy claimed by the developers of soil-moisture blocks is at best 1 percent by weight. The method is generally considered most dependable in the low-moisture-content range, below field capacity.

The term "field capacity" is defined as the amount of water remaining in a well-drained soil when the velocity of downward flow into unsaturated soil has become small (usually after one or two days). Field capacity is not a constant, equilibrium value, but is a point on the drainage curve where drainage has become very slow. The measurement of field capacity is accomplished by thoroughly wetting a soil area, covering it to prevent evaporation, and measuring the water content after 24 or 48 hours (Ref 2).

Disadvantages of the electrical-resistance method are: (1) At higher moisture contents, between field capacity and saturation, the change in resistance per unit change in moisture content is small, thus reducing the sensitivity of the units. (2) The soil must be disturbed during installation. (3) The depths of installation are limited (Ref 1).

Heat-Diffusion

The heat-diffusion method of moisture measurement is based upon the principle that the heat conductivity of a soil varies with its moisture content. The temperature rise caused by an electrically activated heat source installed in the soil is measured by a sensitive temperature measuring device and is correlated with moisture content. Wet soil will conduct heat rapidly away from the heat source in the cell and will thus have a smaller temperature rise than dry soil.

Disadvantages of the heat-diffusion method are as follows: (1) The heat-diffusion cells are sensitive to minor variations in construction. (2) The method is unsatisfactory when used in soils at moisture contents above field capacity. (3) Consistent correlation between soil-moisture and cell measurements cannot be obtained under different soil conditions. (4) Cells cannot be easily installed at depths of more than 5 feet or in undisturbed soil (Ref 1).

Tensiometer

The tensiometer method of moisture determination at depth utilizes a tensiometer which consists of a porous point or cup (usually ceramic) connected through a tube to a pressure measuring device. The system is filled with water, and the water in the point or cup comes into equilibrium with the moisture in the surrounding soil. Water flows out of the point as the soil dries and creates greater tension or back into the point as the soil becomes wetter and has less tension. These changes in pressure or tension are indicated on a Bourdon-tube vacuum gage or a mercury manometer. The relation between moisture tension and moisture content is found in the laboratory from a moisture-tension curve constructed by means of a pressure-membrane or porous plate apparatus, or by collecting soil samples in the

area surrounding a tensiometer installation and relating the moisture content of the samples to the tensiometer reading obtained concurrently.

Disadvantages of the tensiometer method are as follows: (1) At higher tensions found in drier soils, tensiometers become inoperative because air enters the system through the porous point, but they are useful for a range in moisture content from slightly below field capacity to saturation. (2) Tensiometers are affected by temperature such that temperature gradients between the porous point of the tensiometer and the soil may cause variations in the tension readings. (3) Tensiometers exhibit considerable hysteresis effect and tend to give a higher soil-moisture tension during soil drying than during soil-wetting. (4) Time lags of half an hour to many hours in indicating changes in tension caused by changes in moisture content have been produced (Ref 1).

The tensiometer is probably the easiest to install and the most rapidly read of all soil-moisture measuring equipment, but is not suitable for installation at depths greater than about 20 feet.

Nuclear

A development contract for the study of the application of neutrons and gamma-ray techniques to soil moisture and density measurements was obtained by Cornell University from the Civil Aeronautics Administration shortly after World War II. The reports of the successful application of these new methods by Belcher, Cuykendall, and Sack (Ref 3) of the Cornell group were followed by many others, which clearly established the feasibility of the nuclear method of soil-moisture analysis and the advantages over other analytical methods.

The neutron method for measuring soil moisture evolved through a need in many types of studies to follow moisture changes in the soil without resorting to destructive sampling. The neutron method satisfies this need by providing a fixed location where moisture-measurement readings with depth may be made whenever desired and needed. The fixed location, created by the insertion of an access tube in the ground, causes no substantial disturbance to the strata involved and may be left in place over long periods of time without disturbing the drainage or other characteristics of the surrounding terrain (Ref 4). If there is any difference in reading through time at a

location, it is attributed to soil-moisture change and not to possible soil variations as could be evidenced in gravimetric sampling where the locations change with each sampling.

Studies have shown that the moisture readings are relatively independent of soil type; therefore, the need for only one calibration curve is an advantage. Other advantages include the fact that the moisture reading obtained represents an average over a large sample of about 0.5 cubic feet (Ref 5) and is a measure of all the phase states (solid, liquid, or vapor) of water.

The disadvantages associated with the neutron method are: (1) The initial cost of the equipment is relatively high. (2) The necessity for access holes and tubing to position the probe within the soil may present problems depending upon the type of soil encountered. (3) Calibration is quite difficult with some uncertainty in its generality as applied to diverse materials. (4) Precision is reduced at a high moisture content (Ref 5).

The neutron method is being used in a wide variety of both research and routine applications, such as highway and airstrip soft spots, foundations migration due to climatic conditions, improper backfills, and embankments. Research groups at universities are using the nuclear probe to learn more about the nature of the various types of terrain, to identify subsurface characteristics as they are affected by weather or other conditions, and to evaluate engineering methods and practices. Since the location and movement of ground water are also of primary importance to those engaged in the fields of agriculture and forestry, the neutron method is being widely used and ac-accepted. Petroleum engineers have applied neutron scattering measurements in the location of strata likely to contain hydrogenous material. In the Netherlands the neutron method is currently employed to measure the rate of water penetration and erosion in earth dikes (Ref 4). The knowledge acquired from research and engineering studies using the nuclear method should be especially useful to civil engineers.

SCOPE OF THE INVESTIGATION

Since there is a need to measure changes in moisture content of the soil surrounding a drilled shaft during the test period, one particular phase of the project sponsored by the Texas Highway Department is concerned with the nuclear determination of changes in moisture content at depth. Before

the nuclear method was selected for use on the project, an investigation was conducted for the primary purpose of investigating the capabilities, limitations, and problems associated with the nuclear method. This report contains the results of this investigation, a review of the theory of neutron moisture determination, and information on the installation of access tubing and testing procedures.

CHAPTER 2. THEORY OF NEUTRON MOISTURE MEASUREMENT

DESCRIPTION OF EQUIPMENT

The nuclear equipment used for this investigation was manufactured by Troxler Electronic Laboratories, Inc., of Raleigh, North Carolina, and consisted of the Troxler Model 200B battery powered, transistorized, portable scaler, and the Model 104 depth moisture probe. The portable scaler, shown in Fig 1(a), is a five-decade glow-tube readout with a built-in combination voltmeter and ratemeter. The depth moisture probe, backscatter type, consists of the following components (see Fig 2): (1) preamplifier, (2) BF_3 detector tube, and (3) 3 mc $Ra^{226}Be$ source. The probe is stored or housed in a combination shield and standard shown in Fig 1(b).

The shield and standard, constructed internally of a heavy metal, provides radiological safety during the transportation and storage of the moisture probe and reduces the hazard of careless handling of the radioactive source. It is designed to be placed on top of the access tube so that the probe may be lowered into the access tube to the desired depth. When testing is completed, the probe is drawn into the shield; therefore, the need for anyone coming in direct contact with the radioactive source is eliminated. In addition to serving as a shield, the shield and standard provides a constant reference standard or a water equivalent for the moisture probe by virtue of the hydrogen content of its plastic outer surface or mass.

OPERATIONAL THEORY FOR DEPTH MOISTURE PROBE

The depth moisture probe spontaneously emits fast or fission neutrons (energy of 10^6 to 10^7 electron volts) by means of a radium-beryllium source into the soil, which are then slowed down or sustain energy losses as a result of elastic collisions with hydrogen nuclei. After roughly 18 hydrogen-atom collisions, the fast neutrons are reduced to slow neutrons with energies of about 0.025 electron volts. A small quantity of the slowed neutrons are
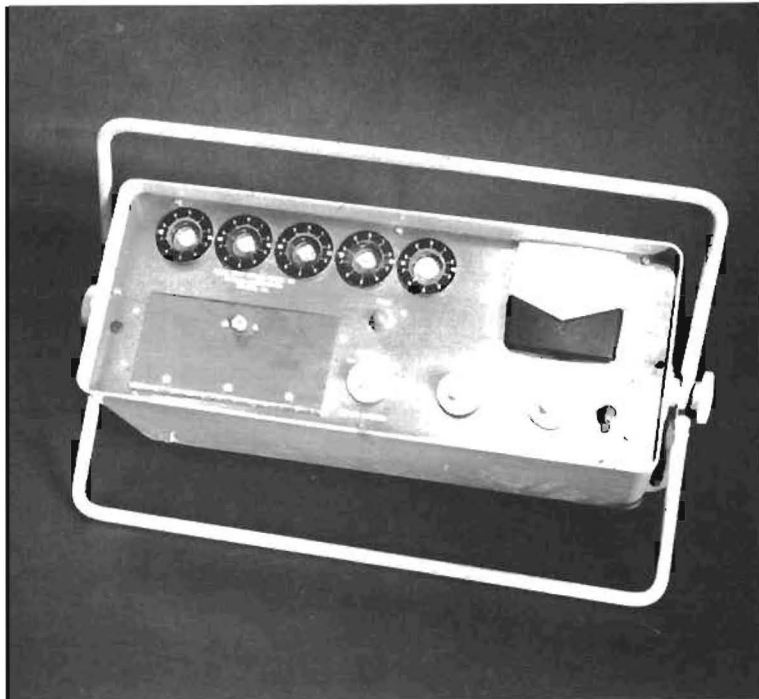
(a) Scaler.

(b) Standard and shield.

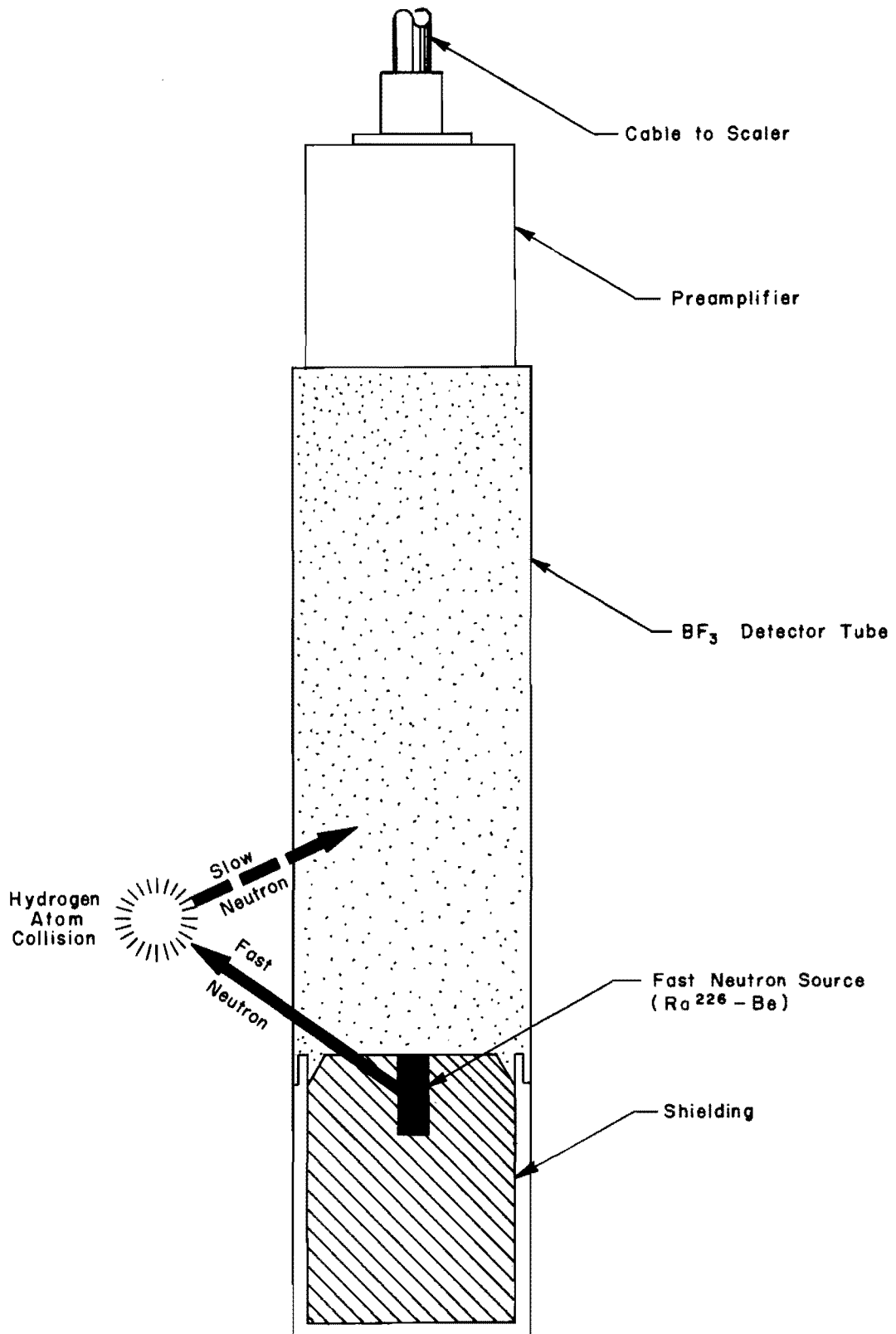Fig 1. Neutron moisture measuring equipment.

Fig 2. Depth moisture probe.

backscattered towards the counter or detector region as shown in Fig 2 and are detected. The number of slow neutrons detected is proportional to the concentration of the hydrogen nuclei or water contained in the soil; and with proper calibration of the moisture probe, the moisture content of the soil may be obtained.

The detector that is sensitive to slow neutrons and not to fast neutrons contains boron trifluoride gas, BF_3, and after absorbing a neutron, a boron 10 atom emits an alpha particle and an excited atom of lithium 7. Both of these recoil particles are highly ionized, and a large pulse is produced. The pulses or signals produced by the BF_3 detector are then amplified by the preamplifier, driven through a cable to the scaler, and recorded on the five-decade glow-tubes for a fixed interval of time.

THEORY OF FAST AND SLOW NEUTRONS

In practical terms, four types of radiation must be considered by the user of radioactive materials: gamma, alpha, beta, and neutron. Gamma radiation is a penetrating form of electromagnetic radiation with an energy of several million electron volts, mev, and indistinguishable from X-rays except that gamma energies are ordinarily higher. Alpha particles, ionized helium atoms, have high energies (4 - 8 mev), but their range in matter is very short, and a sheet of paper or even a few centimeters of air will completely stop an alpha particle. Thus, a sealed source normally presents no great danger. Beta particles, either positive or negative electrons, have ranges in air of up to several meters and adequate protection can be provided by a 1/2-inch solid shield of lucite which will stop beta particles of energies up to 1 mev.

Origin of Fast Neutrons

Neutrons, the form of radiation utilized by the depth moisture probe, are uncharged particles which are highly penetrating and interact with different materials in different ways. A typical source of neutrons is radium-beryllium which emits the radium gamma rays, alpha particles, and beta particles. The atoms of the beryllium are bombarded by the alpha particles, and the result is the ejection of a fast neutron from the nucleus which has a mass approximately equal to that of a hydrogen atom, has an average kinetic energy of 4 - 5 mev,

and is electrically neutral. Of all this radiation, only the neutrons and gamma rays penetrate the source capsule.

Interaction of Neutrons with Soil

If a point source (or a source of small but finite dimensions) of fast neutrons is placed within a medium such as soil, the neutrons travel radially outward from the source until they collide with atoms of the surrounding material and become absorbed by the nuclei of these atoms, or are elastically or inelastically scattered. For the elements contained in soils, the probability of collision for elastic scattering is predominant. In a mass of soil, a fast neutron is slowed or moderated, primarily by a series of elastic collisions, until its kinetic energy approaches the average kinetic energy of the moderating atoms as determined by the ambient temperature. When a neutron has the same energy as the surrounding atoms, it is called a slow or thermal neutron, which has no definite velocity direction with respect to the source and thus moves in a random fashion throughout the medium (Ref 6).

Hydrogen is more effective in slowing fast neutrons than any other element because its microscopic cross section or effective target area for elastic scattering is large, and its mass is about the same as that of the neutron. Therefore, in a head-on collision with a stationary hydrogen atom, a neutron may transfer all its energy and momentum to the hydrogen nucleus and thus becomes a slow or thermal neutron.

Ping-pong balls and bowling balls may be used to illustrate the collision of neutrons with other atoms. Neutrons and hydrogen atoms that have approximately the same mass may be represented by ping-pong balls, and an average atom may be represented by a bowling ball. If a ping-pong ball (neutron) is thrown with force against a bowling ball (average atom), the ping-pong ball rebounds at a high speed and affects the massive bowling ball little, if any. When a ping-pong ball (neutron) is thrown against another ping-pong ball (hydrogen atom), the second ball is set in motion while the first rebounds with a greatly reduced velocity and becomes a slow neutron (Ref 7).

Capture or Absorption of Neutrons

Neutrons, which are slowed down or scattered principally by colliding with nuclei of the light elements such as hydrogen, may also be captured or absorbed by the nuclei of other elements. For moisture measurements by the neutron method, it is undesirable that neutrons undergo capture, because captured neutrons are prevented from functioning as desired.

Different elements and even different isotopes of the same element differ very greatly in their ability to capture neutrons. The probability of capture is expressed as capture cross section, and this cross-sectional area is measured in barns where a barn is 10^{-24} square centimeters. For instance, boron 10 has a capture-cross-section of 3,800 barns for slow neutrons and boron 11 has a capture cross section of less than 0.05 barn (Ref 8).

Of the strong neutron absorbers, only boron, lithium, chlorine, and perhaps cadmium need to be taken into consideration in normal soil research. Moist soils consist mostly of oxygen, silicon, and hydrogen and have an absorption cross section of roughly a few tenths of a barn on the average. When the effective contribution of cadmium, chlorine, lithium, and boron approaches 0.01 barn, the nuclear moisture technique must be recalibrated for the specific circumstances (Ref 5).

SOURCES OF HYDROGEN IN SOIL

Most of the hydrogen found in the soil is contained in the soil water. A small amount of hydrogen is found chemically combined in the mineral fraction, and should be constant regardless of whether the soil is wet or dry (Ref 9). It is also a fact that scattering and slowing of neutrons is practically independent of whether or not the hydrogen is bound chemically; but in a few instances, field results did not agree with the calibration curve due to the presence of chemically bound water, which was measured by the nuclear equipment but was not released by heating samples to 110° C in the routine oven-drying operation (Ref 10). In particular, the scattering and slowing of neutrons is independent of whether water is in the vapor, liquid, or solid state.

Other than soil water itself, organic matter is the most important source of hydrogen in soil. The hydrogen content of humus is about 5 percent of its weight. As the amount of hydrogen in water is about 11 percent of its weight,

the amount of hydrogen in soil organic matter may be an appreciable part of the total hydrogen. Soils containing much organic matter also contain large amounts of water (Ref 9), and, therefore, the hydrogen content of the humus is usually small in comparison to the hydrogen content of the soil water, and it will have a negligible effect on the scattering and slowing of neutrons.

PRACTICAL CONSIDERATIONS

Zone of Measurement

In principle, the zone of measurement of a neutron probe is infinite; in practice, it is rather sharply limited to an effective space zone of measurement within which occur about 90-95 percent of all the neutron interactions that become registered as the moisture measurement (Ref 5). For the depth moisture probe, the zone of measurement or sphere of influence is assumed to be nearly spherical in shape, and the size depends on the nature of the source and the moisture content of the soil but not on the strength of the source (Ref 11).

Approximate formulas and procedures exist for determining the effective radius of the sphere of influence, such as the one worked out by C. H. M. Van Bavel (Ref 11) which states that

$$R = 5.9 \left(\frac{100}{\text{Vol. } \% \text{ H}_2\text{O}} \right)^{1/3} \tag{1}$$

where R is the radius in inches of the sphere of influence. By using the above formula, the calculated zone diameter is 12 inches for pure water, 16 inches for 40 percent moisture by volume, and 25 inches for 10 percent moisture. The formula loses its meaning below 3 percent. Other authors find the zone of influence for pure water to range from 4 - 12 inches and for ordinary soils to range from 7 - 16 inches in diameter.

The distribution of thermal neutrons from a point source of fast neutrons indicates that as the moisture content of the soil decreases, the density of the thermalized neutrons within the vicinity of measurement is reduced, and the sphere of influence becomes tenuous with an ill-defined radius at low moisture content. This reduction in the density of thermalized neutrons as the moisture content decreases occurs because the path length traveled by a fast neutron

before interacting with a hydrogen nucleus increases as the moisture content decreases. Also, scattering by hydrogen is always in the forward hemisphere. This forward scattering lessens the effectiveness of hydrogen as a thermalizing medium, because it increases the average distance that neutrons migrate from their point of origin before being completely slowed down. Therefore, under field conditions the effective volume of measurement may be extremely large (Ref 12).

When moisture measurement readings are taken near the surface of the ground (usually within 1-1½ feet of the ground surface), erroneous results are usually obtained because the sphere of influence in its entirety is not located within the soil. A soil-air interface exists that allows a portion of the slow neutrons to escape from the soil without detection. The depth at which this error no longer tends to exist is dependent on the radius of the sphere of influence, since it is a function of the moisture content.

Center of Measurement

A moisture probe has an effective center of response to the stimulus of slow neutrons. This center of response or measurement has been shown to be undoubtedly affected by the moisture content and the position of the detector with respect to the source. For maximum sensitivity it has been shown, theoretically, that the neutron source should be as near the detector tube as possible (Ref 9); therefore, the source is usually placed beneath or at the center of the detector tube. It has also been experimentally verified that the sensitivity is doubled by placing the source in the midplane of the sensitive volume of the detector tube (Ref 13), and if the source is placed at the center of the BF_3 tube, the midpoint of the source is used as the location of the exact depth of measurement or center of measurement.

Irrespective of the location of the source, the most sensitive point of the BF_3 detector tube in a heterogeneous medium can only be approximated; and as an approximation, the geometric center of the active volume of the BF_3 detector tube is usually used. For this particular investigation the center of measurement was determined as shown in Fig 3 (Ref 5). R is determined from Eq 1.

Since the BF_3 tube tends to integrate the volume of measurement due to its length, the exact point of measurement may not be critical for the purpose of
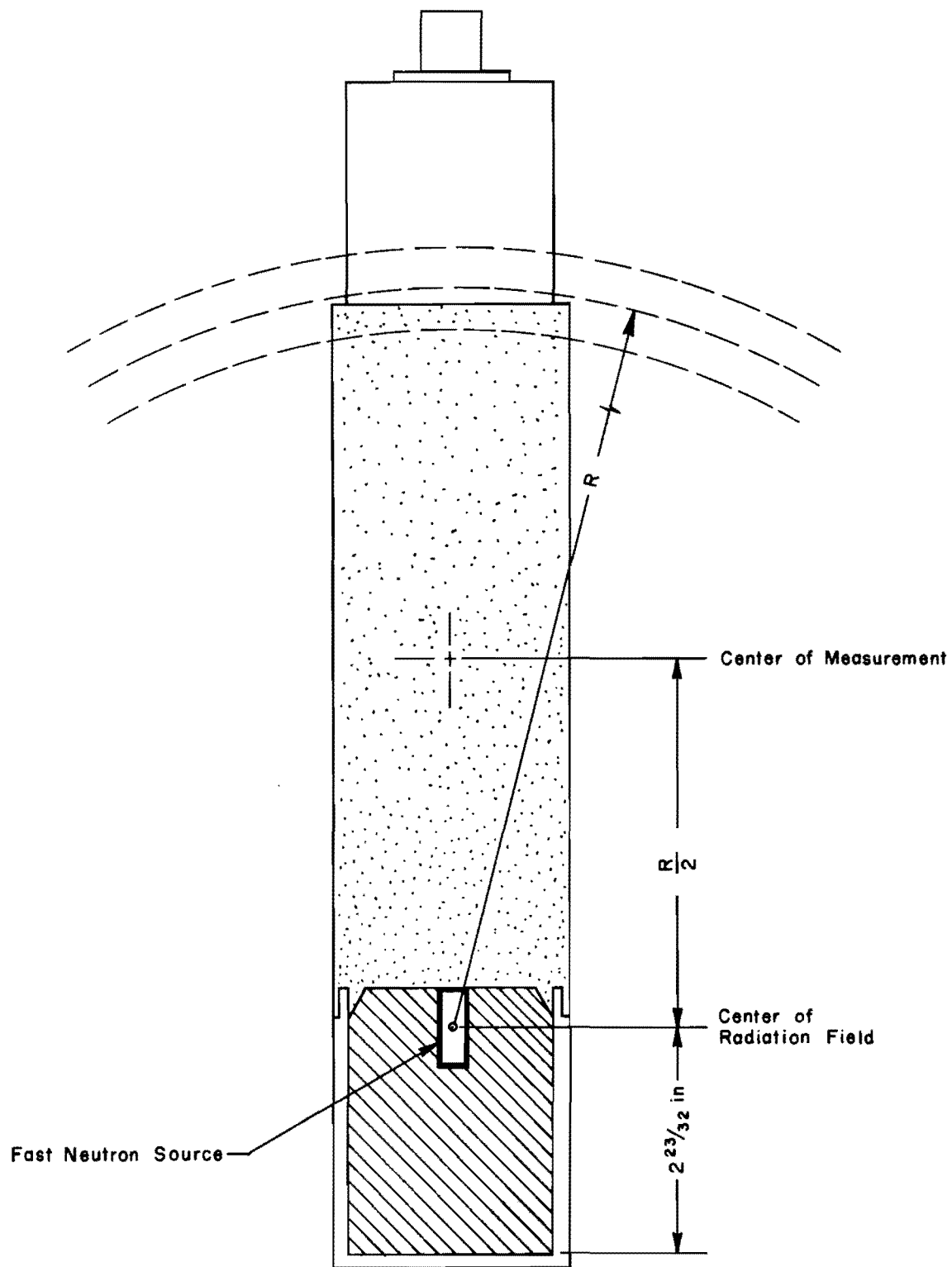
Fig 3. Determination of center of measurement.

defining the depth of measurement; but the inability to define its position will undoubtedly serve to increase the variability of field measurements taken at a point. Although variability will exist because of the inability to define accurately the center of measurement, it will not be as great as that of other methods since a much larger sample is being considered and the error tends to be averaged out.

CHAPTER 3.   INSTALLATION OF ACCESS TUBING

The nuclear method of moisture determination at depth in soil requires the installation of an access tube into which the moisture probe is lowered to the desired depth. In many cases, the use of the nuclear method is limited or handicapped by problems associated with the installation of access tubing, and of all the problems associated with the nuclear method, this one is probably the most critical and requires the most consideration.

DESCRIPTION OF ACCESS TUBING

The type of access tubing recommended by the manufacturer of the moisture probe and used in connection with this investigation was standard Class 150 aluminum irrigation tubing of 2.000 inches (outer diameter) and 1.900 inches (inner diameter), which allowed the insertion of the moisture probe with a diameter of 1.865 inches. Aluminum is used because of its better nuclear properties and its resistance to corrosion. Aluminum gives approximately the same readings as those obtained in an unlined hole (Ref 14), and is also relatively inexpensive and very easy to handle.

The types of materials that can be used for access tubes are limited. Steel, brass, and stainless steel are reasonably satisfactory but necessitate a different calibration curve than that used for aluminum tubing. Steel has one advantage over aluminum in that it can be driven into the soil with less damage if the method of installation requires the access tube to be driven. Studies have shown that the slow neutron count is lower per unit of time with steel tubes than with aluminum, but this effect can be taken into account with calibration.

Plastic tubing has also been used, but the neutron count per unit of time was observed to be at least 15 percent less when compared with the neutron count obtained using aluminum access tubing (Ref 14). If both types gave the same results, the plastic would be preferred because of better thermal properties and less corrosive action in many soils. If it is specially calibrated and if the water content is not too low, say under 10 percent, plastic tubing would be satisfactory (Ref 5).

REVIEW OF METHODS OF INSTALLATION

Several methods and procedures for access-tube installation have been tried and are being used, but most of them have limitations and problems associated with them. Replies to letters of inquiry sent by the School of Civil Engineering at Oklahoma State University to the highway research departments of the fifty states, the District of Columbia, Puerto Rico, and various other governmental agencies, showed that field installation of access tubing appeared to be a major problem among the few agencies that had experience with nuclear instruments (Ref 15).

In response to the letter of inquiry, the Highway Research Board suggested four techniques for access-tube installation and listed the problems associated with each method (Ref 15).

    (1)   Drill a hole and insert the access tube. Voids around the tube pose difficulties in obtaining accurate readings from nuclear probes.

    (2)   Drill with a small auger inside the access tube as the tube is inserted into the soil. The auger scars the inner surface of the tube and hinders the passing of the probe through the tube.

    (3)   Force closed tubing to a desired depth. This is impossible with thin-walled tubing except in very soft material, and this procedure increases the soil density.

    (4)   Force open-end tubing 3-4 feet, allowing material to enter the bottom of the tube. This results in less soil densification than that which would occur in technique (3) above, and allows measurement to approximately two-thirds the depth of the inserted tube. The main disadvantage to this method is the limited depth of insertion, 4-5 feet, and measurement, 3 feet.

The Colorado Department of Highways has used two methods of installation (Ref 15).

    (1)   For shallow depths, a steel tube may be sharpened and driven into the soil with a sledge hammer and appropriate driving collar. The soil within the tube is removed from the top with a ship auger having an outside diameter slightly smaller than the inside diameter of the tubing. Although this method provides an excellent contact between soil and tube, it has been successful only in soils containing no rocks, and depths have been limited to 4 feet because of sidewall friction.

    (2)   For deeper holes, a ship auger with an outer diameter of 0.10 inch larger than the outer diameter of the tubing may be used to hand auger the material. The tubing is then slipped into the hole and in time, the soil settles around the tube for good metal-to-soil

contact. In harder materials, a drill rig, utilizing air, can be used to a depth of 22 feet.

Another method of installation which has proven to be quite satisfactory involves the use of a thin-walled sampler with a diameter equal to or slightly smaller than the diameter of the access tube. Continuous undisturbed soil samples are taken to the desired depth, and the bore hole formed by sampling permits the insertion of the access tube. The water content and density of each sample can be subsequently determined in the laboratory. The application of this method is not possible when the soil is too stiff or rocky for continuous sampling.

The seven methods of installation listed above may be considered to be the basic methods of installation that apply to field installation of access tubing. Methods may exist that are modifications of these methods or procedures, but their importance is relatively insignificant and will not be discussed.

METHODS OF INSTALLATION ASSOCIATED WITH THIS REPORT

After studying the feasibility of all the different methods of installation and making a survey of the equipment available in comparison to the type of equipment required for the different methods, it was decided that the access tubes required for this investigation could be installed by means of augering to the desired depth with a hand auger, and then inserting the access tube into the hole. With the use of a hand auger there would be limitations to the depth of installation, but great depths (10 - 20 feet) were not of primary importance in this investigation.

A hole approximately 2-1/8 inches in diameter was produced to the desired depth or to the maximum depth attainable by the hand auger, and the access tube was inserted in the hole. The void which existed between the 2.000-inch (OD) access tube and the hole was filled with dry sand. The effects of this void and the filling of the void with sand were studied and will be discussed later.

The bottom end of the access tube was sealed with an aluminum plug or disk and a rubber O-ring (see Fig 4) before it was placed in the hole. A groove was machined in the disk to receive the O-ring, which assured a
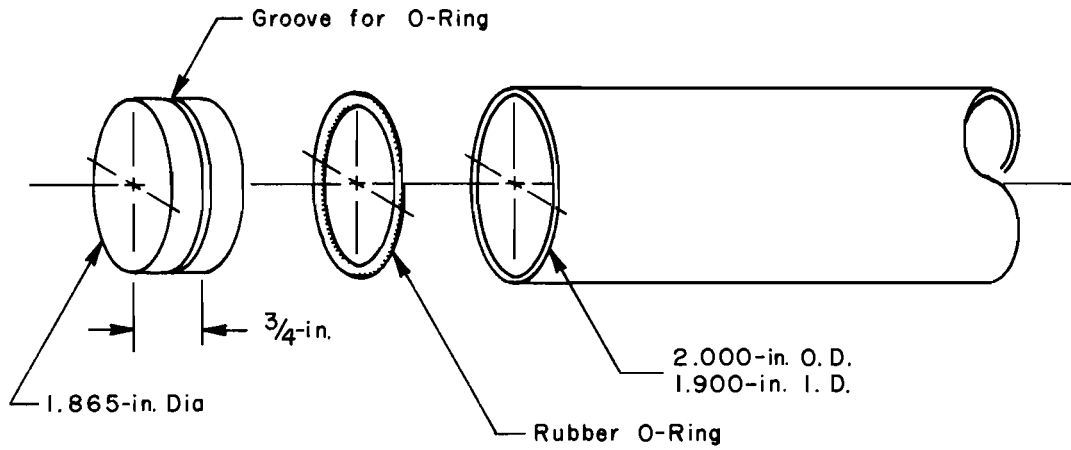
Groove for O-Ring

3/4-in.

1.865-in. Dia

2.000-in. O. D.
1.900-in. I. D.

Rubber O-Ring

Fig 4. Procedure for sealing access tube.

End Cap

3/4-in.

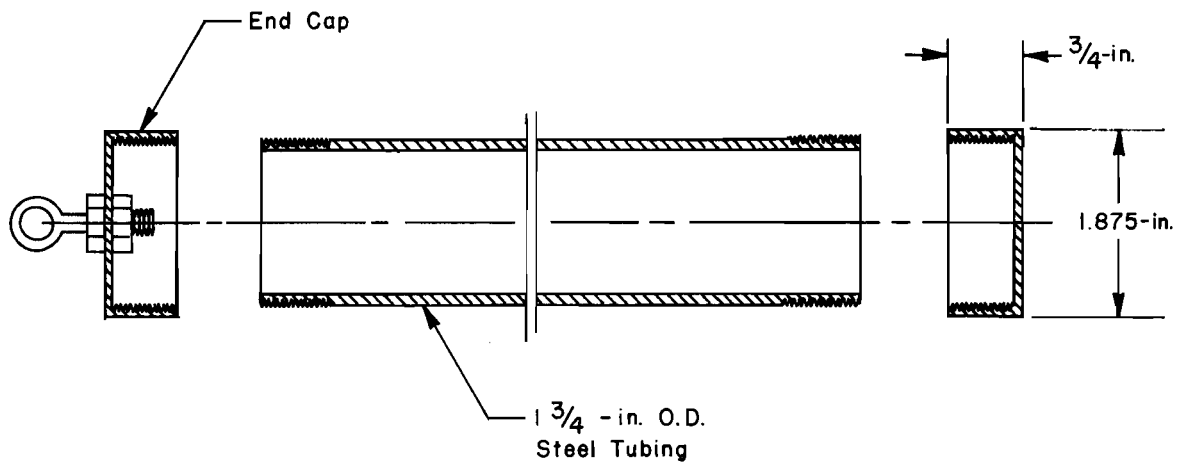1.875-in.

1 3/4 -in. O.D.
Steel Tubing

Fig 5. Dummy probe.

leak-proof seal. After the plug was installed, the sealed end was coated with liquid metal as an additional precaution against leaks.

After the installation of the tube, but before the initial reading was taken, a dummy probe was lowered into the access tube for the purpose of revealing any damage to the tube that would prevent the passage of the nuclear probe. The dummy probe shown in Fig 5 consisted of a 1-foot length of 1-3/4-inch diameter steel tubing with a 1.875-inch diameter cap screwed on each end.

To assure that no moisture could enter the access tube through the top opening when the tube was not in use, a rubber stopper was placed in the opening and a can was placed over the stopper and the end of the tube. Moisture contained in the air inside the access tube was removed or held to a minimum by the placement of a small bag of desiccant inside the tube. To prevent the entry of surface water, the void which existed between the tube and the hole was sealed with clay (asphalt may also be used) at the ground surface; and the ground surrounding the tube was sloped to prevent the ponding of water around the tube. A completed installation is shown in Fig 6.

Rubber
Stopper

Can

Clay or
Asphalt
Seal

3 or More
Inches

Bag of
Desiccant

Access
Tube

Sand-Filled
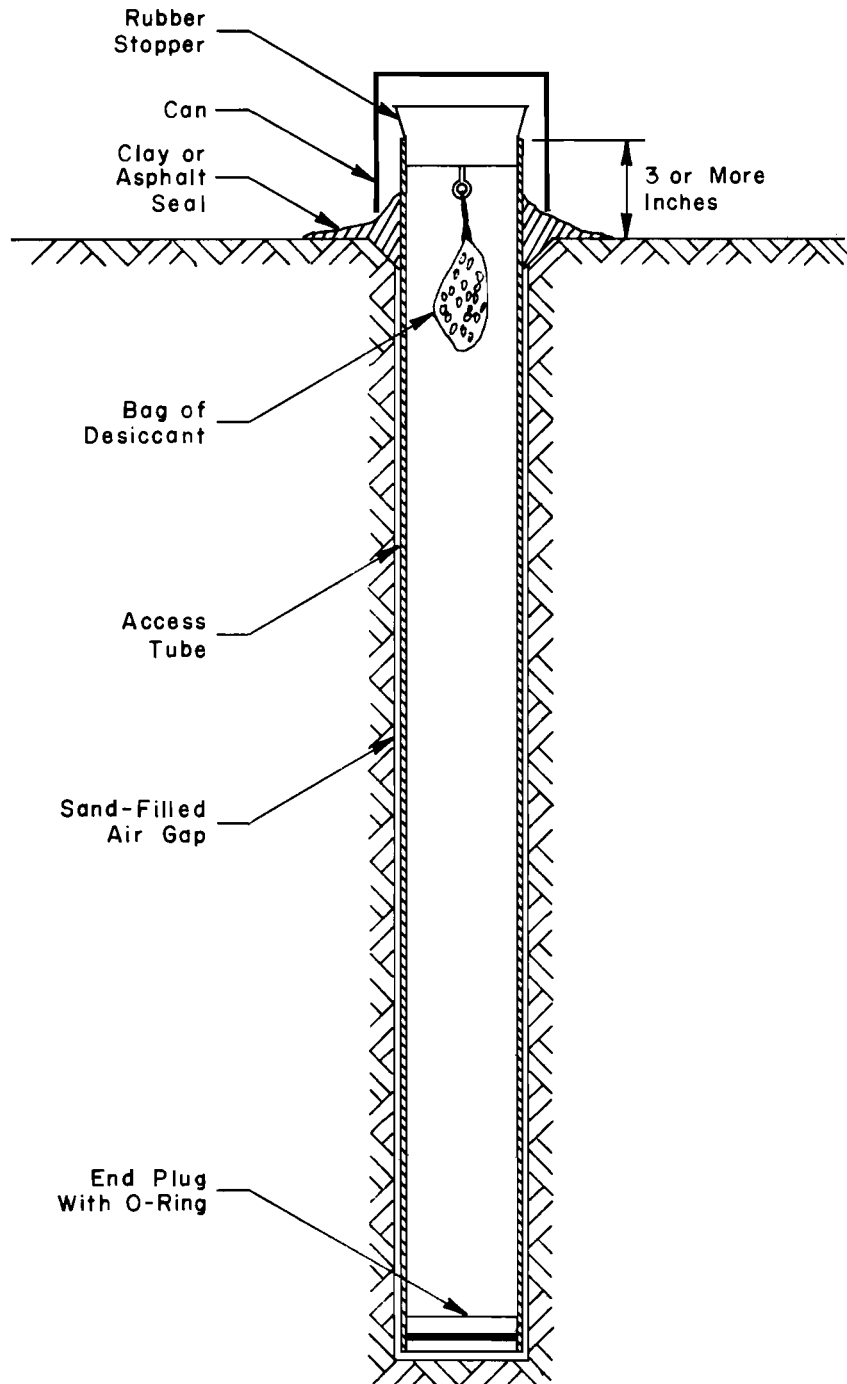Air Gap

End Plug
With O-Ring

Fig 6. Completed access tube installation.

CHAPTER 4.   CALIBRATION AND OPERATION OF NUCLEAR EQUIPMENT

CALIBRATION

The proper calibration of the neutron measuring equipment is an important requirement for the successful application of the nuclear method to the problem of soil-moisture determination. Differences of opinion exist as to whether the moisture unit should be calibrated in the laboratory using a calibration standard or calibrated in the field and as to whether a calibration curve is required for each test site.

Certain factors should be considered in gathering data for a calibration curve. If one is interested in evaluating only the method, controlled laboratory studies would be the best approach. If one is interested in using the method to determine soil moisture in the field, then a field calibration should be made (Ref 14).

Calibration of the neutron apparatus in tanks of homogeneous soil in the laboratory may result in a calibration curve which is not suitable for the determination of soil moisture in a field profile. Soil moisture in the laboratory standard may not represent the soil-moisture status within a field profile. Also, the variation of moisture within the soil profile and associated problems of core or bulk sampling reduce the desirability of a field calibration. Therefore, to advocate either a laboratory or a field calibration for the neutron count rate as related to soil-moisture content requires an understanding of the magnitude of error which may occur and which can be tolerated within the medium being sampled (Ref 12).

Standards prepared in the laboratory for the purpose of calibration are usually prepared in 55-gallon drums with an access tube installed in the center of the drum. The standard can be constructed from many different materials that include aggregate, alum, sand, clay, or the soil which is to be encountered in the field installation. By preparing several standards with various moisture contents and known densities and by obtaining a slow neutron count in each standard, a calibration curve of count ratio versus moisture content can be prepared. Count ratio is the ratio of the slow neutron count obtained

with the probe positioned in the soil standard to the slow neutron count
obtained with the probe positioned in the shield and standard.

Some of the problems which must be considered when calibrating a mois-
ture probe in the laboratory are as follows (Ref 5):

(1) The physical size of the calibration standard must be adequate.

(2) The soil used as a calibration standard must be uniform in its
    properties, and the moisture must be uniformly distributed
    throughout the standard. Careful mixing is required and precau-
    tions must be taken against subsequent changes in moisture content.
    If the soil is heterogeneous or if it contains a moisture gradient,
    the resulting calibration curve may not be applicable to soil and
    moisture conditions in the field.

(3) The samples taken for moisture determination must be representa-
    tive and must be protected from changes in water content before
    analysis.

Since there are problems associated with the calibration of the moisture
probe in the laboratory and doubts about the validity of a laboratory calibra-
tion curve when used under field conditions, calibration of the moisture probe
was not attempted in the laboratory for this investigation. The time that
would have been spent on calibration in the laboratory was spent checking,
under field conditions, the accuracy of the calibration curve supplied by
the manufacturer. The accuracy of the calibration curve was determined by
comparing the results obtained by the nuclear method with the results obtained
by the gravimetric method.

The manufacturer uses secondary standards (cadmium chloride) in preparing
his calibration curves. These standards are calibrated using homogeneous
soils of known moisture contents (Ref 5). The calibration results used in
the preparation of the manufacturer's calibration curve are obtained from
the particular combination of probe, reference standard, and the investi-
gator's access tubing.

The calibration curve supplied by the manufacturer (Fig 7) is linear
between 0 and 35 percent moisture by volume, but there is no information
about the shape of the curve for volume percent moisture greater than
35 percent. A linear extension with the same slope as the existing curve
was assumed in this investigation, whenever soil was encountered with a
volume percent moisture greater than 35. This linear extension may intro-
duce additional errors to the neutron method, since other authors (Refs 6
and 15) have shown that there is a decrease in the slope of the count rate
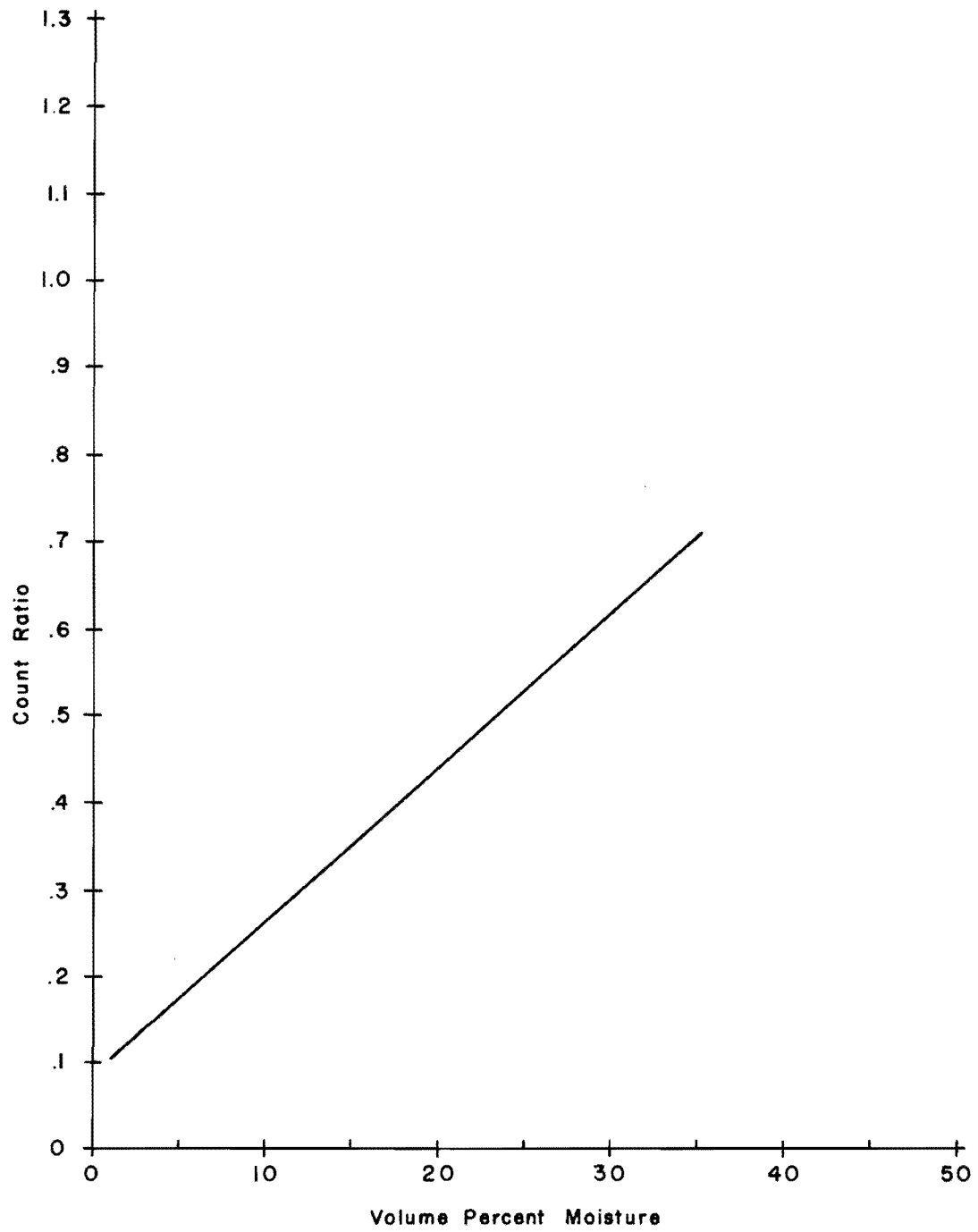
Fig 7. Manufacturer's moisture calibration curve.

versus moisture curve at high moisture content (greater than 30 or 35 percent); and with this decrease in slope, there is a deduction in the precision. The reasons for the leveling off of the count rate at high moisture content are not definitely known, but the absorption of slow neutrons by hydrogen atoms may partially account for the leveling off. Because the number of hydrogen atoms increases with increasing moisture content, absorption may begin to counteract the increase in slow neutron density due to increased scattering (Ref 6).

There are some investigators who have shown that the manufacturer's calibration curve is invalid, and that the moisture probe must be recalibrated in the laboratory using soil standards prepared from soils that will be encountered or calibrated in the field itself. LeFevre (Ref 16), using the Troxler moisture probe, showed that there was a definite difference between the manufacturer's calibration curve and one obtained in the laboratory (see Fig 8). The laboratory standards were prepared from water, limestone, Permian clay, river gravel, and expanded shale.

Since actual calibration of the probe in the laboratory or the field was not attempted, the probe was calibrated at each test site with respect to the dry density of soil at each depth interval. The moisture content at each depth interval was determined from the soil samples taken at the time the bore hole for the access tube was produced. The volume percent moisture was determined from the initial nuclear readings. The dry density of the soil was then calculated from the moisture content and volume percent moisture. By calculating the dry density in this manner, any uncertainties, such as neutron absorbers, and any soil peculiarities that tend to remain constant with time would be allowed for and taken into account. It is realized that if the manufacturer's calibration curve is invalid, calibration by means of the dry density is also invalid. The inability to obtain undisturbed samples for the purpose of determining the density of soil was the primary reason for using the dry density of the soil for the calibration of each test site.

Once the problem of calibration has been solved, the question arises of whether the calibration curve obtained is valid for all types of soil. Results from a number of investigations concerned with this question support the one-calibration-curve concept. "Except when strong neutron absorbers (such as cadmium, chlorine, boron, lithium) are substantially present, it
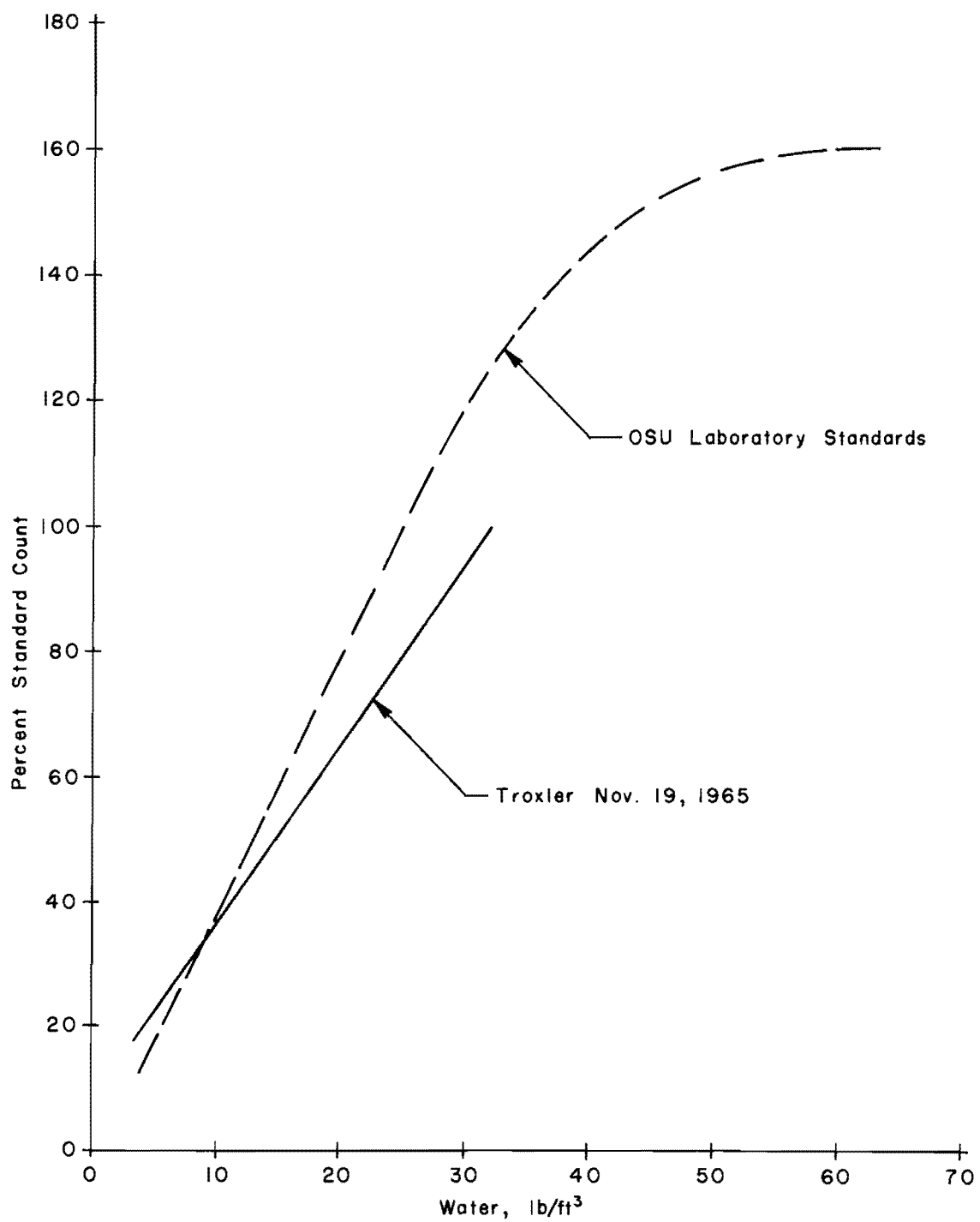
Fig 8. Moisture calibration curves - OSU and manufacturer's standards.

is claimed by practically all authors that one calibration curve is applicable to virtually all soils" (Ref 5).

OPERATION

Moisture Count

The moisture probe is almost always introduced into the soil with the aid of an access tube and with the shield and standard positioned on top of the access tube as shown in Fig 9. With the shield and standard in this position, the safety cam-locks in the shield automatically recess, clearing the way for the entry of the probe into the access tube. By loosening the cable clamp, the probe may be lowered to the desired depth.

After lowering the probe to the desired depth, the scaler is put into operation and a moisture count (a count of the number of slow neutrons detected per minute) is obtained. Readings are taken at regular intervals of depth (usually 6 inches or 1 foot) from the top to the bottom of the hole. For this particular investigation, two readings of one-minute duration were taken at each depth interval as the probe was lowered from the top to the bottom of the tube, and at the same depth intervals as the probe was being brought to the top from the bottom of the access tube.

The average of the moisture measurement counts at each depth is divided by the standard reference count and the count ratio is thus obtained. Once the count ratio is obtained, the percent moisture by volume is easily obtained from the calibration curve and if desired, percent moisture by volume can be converted to percent moisture by weight if the density of the soil is known.

Standard Reference Count

It is customary to calibrate a moisture probe in terms of count ratio and to express a given instrumental reading or moisture measurement as the count ratio and not as the absolute count rate. The standard reference count is required for the determination of the count ratio and is obtained with the moisture probe positioned inside the standard as shown in Fig 10. The standard reference count serves to correct for time and temperature drifts that occur in the electronic circuitry.

There is no recommended or established rule for the number of standard counts that should be taken during a test period. During this investigation,

Cable Clamp

Standard
And Shield

Lead
Shielding

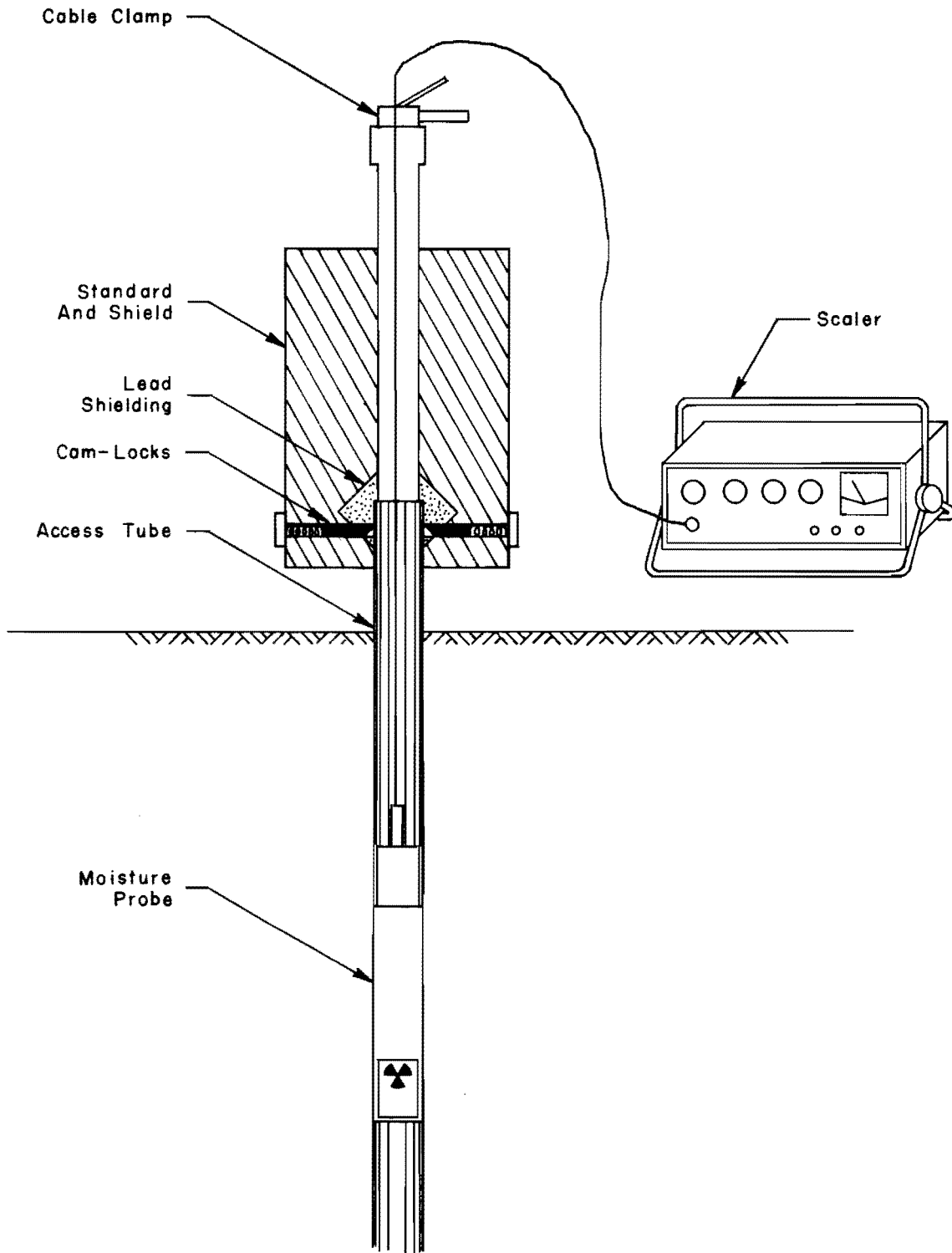Cam-Locks

Access Tube

Scaler

Moisture
Probe

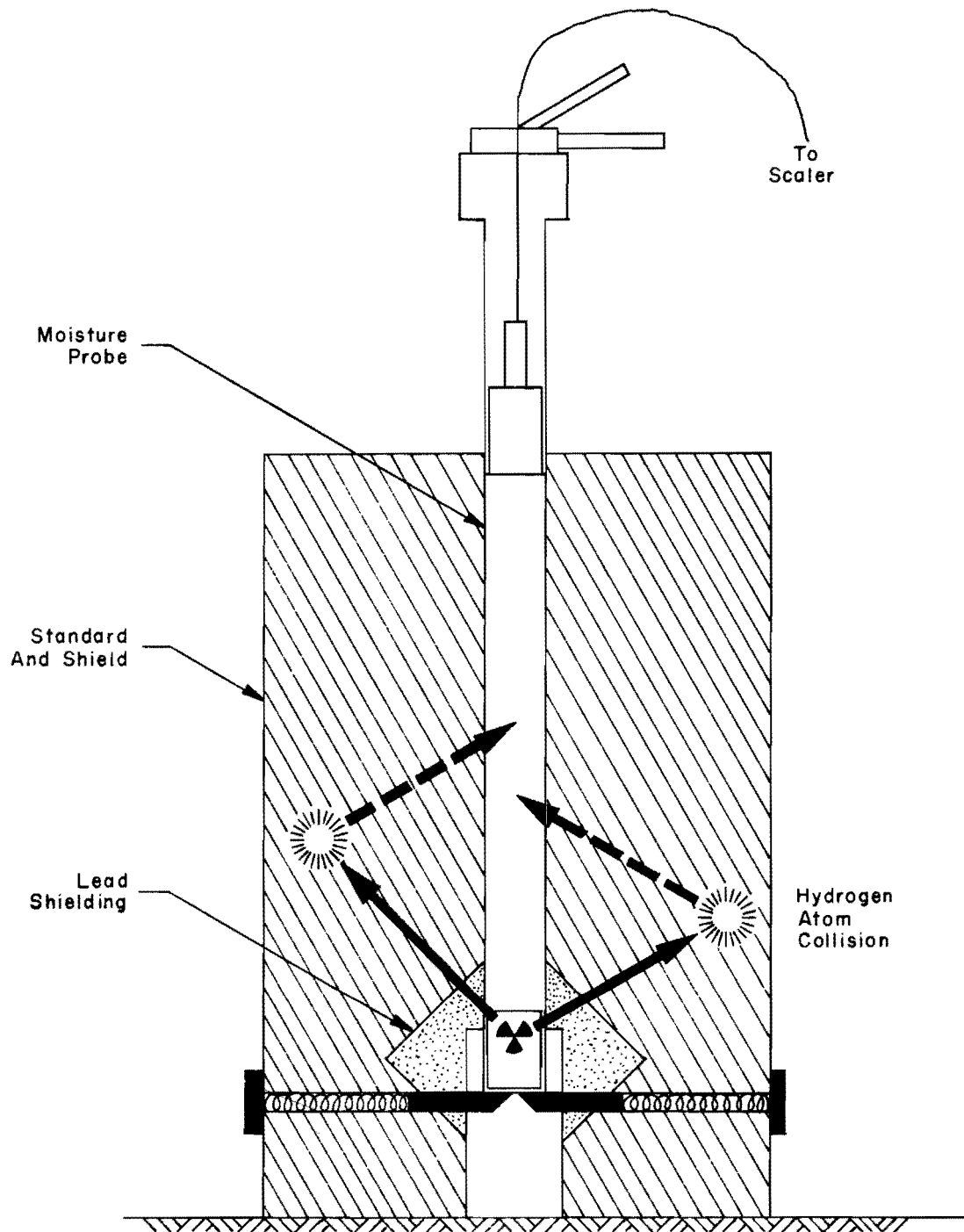Fig 9. Position of probe for moisture count.

Fig 10. Position of probe during standard reference count.

five standard reference counts were taken at the beginning and end of a test period. Typical moisture and standard reference counts are shown in Table 1.

Background Count

A neutron moisture probe will always detect a small background count due to such things as stray neutrons and gamma and beta radiation, all of which provide a few counts. The fast neutron source also produces a few slow neutrons in its spectrum of energies. These different sources of background count are not always constant with respect to time and location.

The background count is usually between 20 and 100 counts per minute; and when compared to a typical reading of 5,000 - 15,000, it is relatively small and can be ignored. If a large background count is present, it should be reflected in an increased standard count which tends to remain relatively constant. If a large background count is detected, there is no way to allow or correct for it.

To obtain or check the background count, the probe is positioned 3 feet away from appreciable amounts of material containing hydrogen (Ref 5). This is usually accomplished by simply suspending the probe in air, away from other bodies, and operating the scaler in the same manner that a standard or moisture count is obtained.

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TABLE 1.   TYPICAL MOISTURE AND STANDARD REFERENCE COUNTS

Location: Austin Country Club

Date: April 28, 1967

Standard Reference Count:	Start	Finish
	14245	14176
	14109	14216
	14151	14096
	14062	14302
	14189	14157

Moisture Count:

Depth (Feet)	Readings Down	Up	Time per Reading (Minutes)
0.50	13708	13646	2
1.00	12163	12074	2
1.50	10481	10504	2
2.00	9447	9430	2
2.50	8688	8976	2
3.00	9662	9670	2
3.50	11870	11931	2
4.00	12961	13212	2
4.50	14617	14637	2
5.00	14906	14643	2
5.50	14491	14624	2
6.00	14330	14635	2
6.50	14327	14243	2
7.00	13624	13803	2
7.50	12381	12334	2
8.00	10928	10931	2
8.50	10656	10571	2
9.00	11335	11496	2

CHAPTER 5.   TESTING PROGRAM

The testing associated with this investigation was performed in both the field and laboratory.   The following test sites were associated with field testing:

(1)   Montopolis,

(2)   Austin Country Club, and

(3)   San Antonio.

The Montopolis and Austin Country Club sites were used for the primary purpose of evaluating the nuclear method.   At the San Antonio test site, an access tube was installed near a drilled shaft for the purpose of measuring moisture changes with depth.

MONTOPOLIS

The Montopolis test site, located in the city of Austin, required the installation of an access tube in a preconsolidated clay.   The clay, preconsolidated by desiccation, was dark gray and contained some calcareous material. The average unconfined compressive strength was 5.0 tons per square foot, and the clay was classified as CH according to the unified system.   Moisture content at the time of installation, Atterberg limits, and a boring log are shown in Fig 11.

Installation and testing at the Montopolis test site was performed in the following manner:

(1)   The access tube was installed by means of a hand auger, in the manner previously described in Chapter 3, to a depth of 4 feet on March 2, 1967.

(2)   Moisture samples were taken at 6-inch intervals as the hole for the access tube was produced.

(3)   Initial nuclear moisture counts were taken at the same depth intervals, and the volume-percent moisture at the time of installation was obtained from the manufacturer's calibration curve.
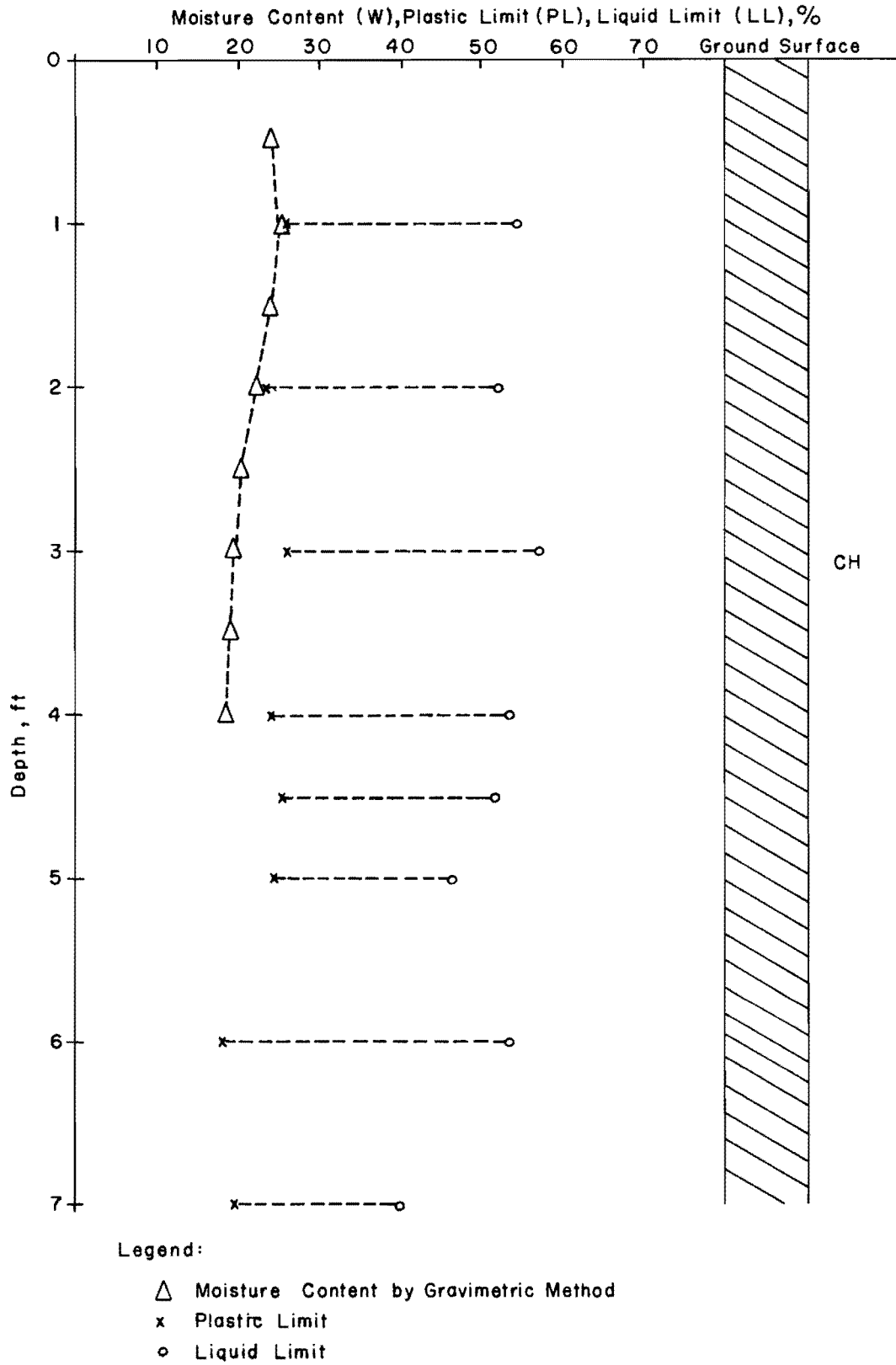
33

Fig 11. Atterberg limits and moisture content versus depth
and a boring log for the Montopolis test site.

(4) The moisture content, determined from the samples, and the volume percent moisture were used to calculate the dry weight of the solids per cubic foot or the dry density of the soil. Since the density of the soil was determined in this manner, the moisture content at the time of installation was equal to the moisture content of the soil samples taken at the time of installation.

(5) Additional moisture counts were taken on March 8, March 23, and April 18, 1967. Volume-percent moisture was calculated from the moisture count and used in conjunction with the dry weight of the solids (calculated above) to calculate the percent moisture by weight.

(6) On April 18, 1967, soil samples were taken at a distance of 4 inches from the access tube. The gravimetric results obtained were compared with the nuclear results. The test site was abandoned after the April 18, 1967, testing.

AUSTIN COUNTRY CLUB

The soil associated with the Austin Country Club site was mainly a lean clay. The top 8 feet were classified as CL according to the unified system, and the next 2 feet were ML followed by a foot of CL-ML and then returning to CL. The average shear strength was about 1 ton per square foot (Ref 17), and the moisture content at the time of installation was below the plastic limit. Moisture content, Atterberg limits (Ref 17), and a boring log are shown in Fig 12.

Installation and testing at the Austin Country Club were very similar to that incorporated at the Montopolis test site. The particulars are as follows:

(1) The access tube was installed by means of a hand auger, in the manner previously described in Chapter 3, to a depth of 10 feet on March 28, 1967. Moisture samples were taken at 6-inch intervals.

(2) Initial moisture counts were taken before and after the void between the soil, and the access tube was filled with dry sand. A comparison of the moisture counts would show the effect of the presence of dry sand in the void. The effect of the presence of the dry sand was not studied at the Montopolis test site.

(3) The dry density of the soil was calculated in the same manner as the Montopolis test site.

(4) Additional moisture counts were taken and the moisture content determined on April 11, April 28, May 26, June 17, June 28, and July 27, 1967. The area surrounding the access tube was flooded after the June 17, 1967, reading until June 28, 1967.

(5) Soil samples were taken on April 28, June 17, June 28, and July 27, 1967, and the gravimetric results were compared with the nuclear.
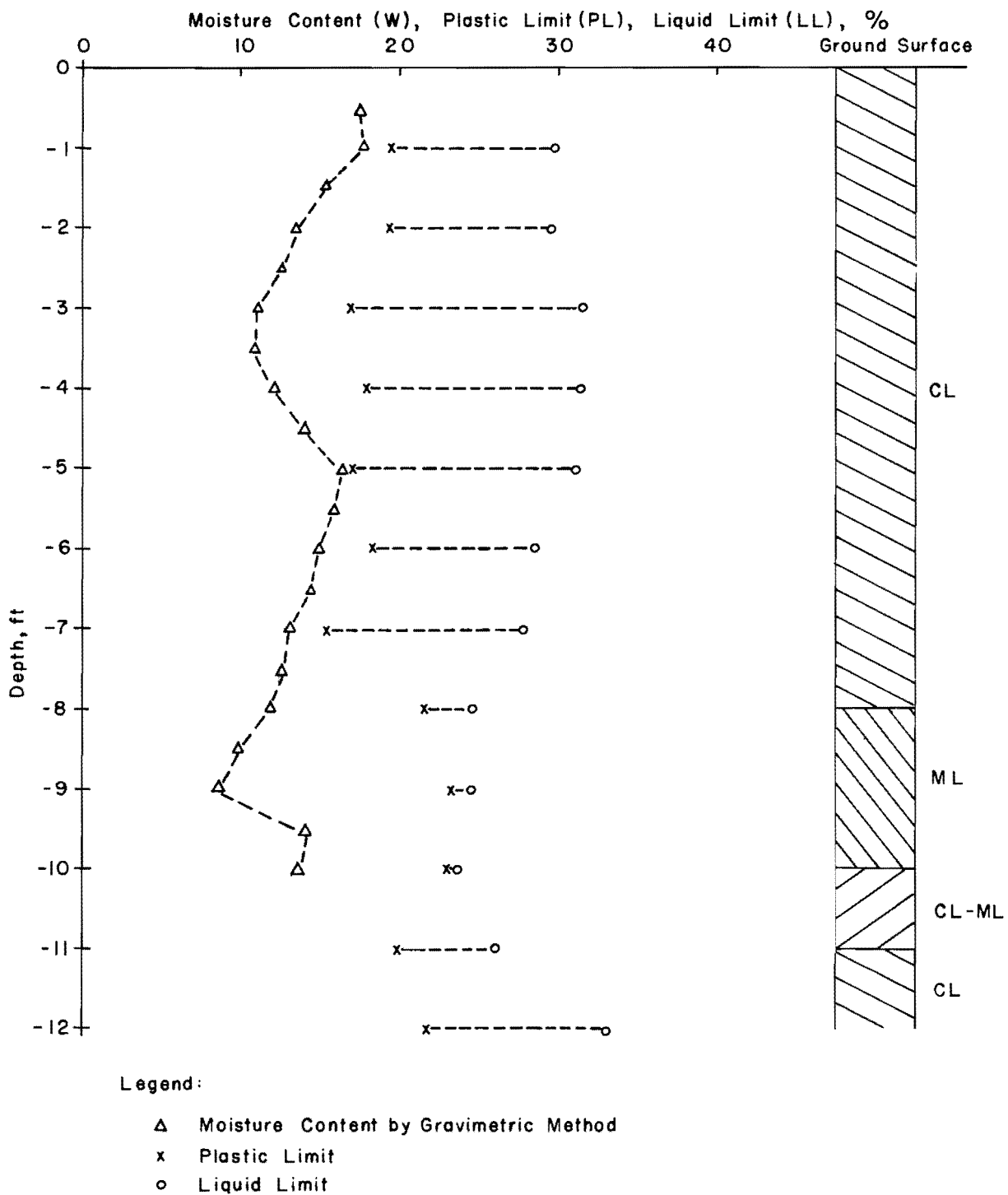
Fig 12. Atterberg limits and moisture content versus depth and
a boring log for the Austin Country Club test site.

(6) The effect of an air gap between the access tube and the soil was studied on May 18, 1967. A hole was augered to a depth of 5 feet at a distance of 10 feet from the access tube, and an access tube was inserted in the hole. An air gap of 1/16 inch existed but was not filled with dry sand as usual. A moisture count was taken at 6-inch intervals. The air gap was increased to approximately 1/8 inch and 3/16 inch with larger augers, and moisture counts were taken at the same depth intervals for each increase in air gap. When the readings were completed, the air gap (3/16 inch) was filled with dry sand; and a moisture count was obtained to see what effect the dry sand had on the moisture count.

(7) The reproducibility of a moisture count at a particular depth was checked on June 8 and June 28, 1967. Ten one-minute readings were taken at each interval of depth, and the coefficient of variation for the 10 readings was computed. The coefficient of variation was used as a measure of the reproducibility of a moisture count and was computed by dividing the mean of the 10 readings by the standard deviation of the 10 readings.

SAN ANTONIO

The first access-tube installation near a drilled shaft occurred at the San Antonio test site. The presence of gravel made the installation of the access tube very difficult and required the adoption of a new method of installation. The top 10 feet of soil at the site was a black or a dark gray, stiff clay with gravel. The unconfined compressive strength was about 2 tons per square foot. The second layer was a yellow clay, 8 feet thick with layers of silt. Its unconfined compressive strength was from 3 - 8 tons per square foot.

The presence of gravel required the access tube to be installed in a manner which is different from the method described in Chapter 3. The method of access-tube installation and the testing program are as follows:

(1) An 8-inch diameter core barrel sampler was used to produce a bore hole to the desired depth of 16 feet on June 22, 1967. The hole was 12 feet from the drilled shaft.

(2) The soil for each 1-foot interval was sampled to determine the moisture content at the time of removal. The soil was then wrapped in plastic sheeting to prevent excessive loss of moisture.

(3) The access tube was centered in the 8-inch diameter hole, and the soil that had been removed at each foot interval was replaced at the same foot interval. The soil was replaced in 2-inch lifts that were compacted by means of a four-square-inch foot located on the end of a rod of the proper length.

(4) Moisture samples were taken at 1-foot intervals at the time the soil was replaced. These moisture contents were assumed to be the same as

moisture content of the soil located within the zone of influence
at the time the initial nuclear moisture readings were taken.

(5) A 3-foot section of seamless steel tubing with a diameter of 1.865
inches (diameter of the probe) was placed inside the access tube and
positioned at the depth where the soil was being compacted to pre-
vent damage to the access tube during the replacement of the soil.

(6) Nuclear readings were taken on June 30 and August 10, 1967, and the
results are shown in Chapter 6.

LABORATORY

Laboratory studies related to this investigation were concerned with the
precision of measurement or the reproducibility of a slow neutron count and the
effect of time and temperature on the precision of measurement. The reproduci-
bility of the standard reference count was determined from 100 standard
reference counts of one-minute duration. The mean, the standard deviation, and
the coefficient of variation were computed for the 100 readings.

To study the effect of temperature on the reproducibility of a moisture
count, 100 standard reference counts were taken at 40° F, 75° F, and 110° F;
and the mean, the standard deviation, and the coefficient of variation for
each set of 100 readings were computed and compared. To determine whether
time had an effect on the reproducibility of a moisture count, each set of 100
readings taken at the above mentioned temperatures was analyzed in sets of 10
readings which represented 10 minutes of actual counting time. The mean,
standard deviation, and coefficient of variation for the first 10 readings or
10 minutes, the second 10 readings or 10 minutes, etc., were calculated. A
plot of the average standard count and coefficient of variation for each set
of 10 readings versus its respective set was made.

CHAPTER 6. TEST RESULTS AND DISCUSSION

MOISTURE CHANGES WITH TIME UNDER NORMAL AND ACCELERATED CONDITIONS

The ability to follow moisture changes in soil at depth without
resorting to destructive sampling is an advantage of the nuclear method.
Test results obtained at all three test sites showed that the investigator
is capable of following moisture changes at depth with a nuclear moisture
probe, in a manner which is fast and efficient and requires no sampling of
the soil being investigated.

Represented in Fig 13 are the results obtained at the Montopolis test
site. The study at the Montopolis test site was relatively short, only
about 1-1/2 months; but even in this short period, the moisture probe was
able to detect noticeable moisture changes at depth. The depth of instal-
lation was too shallow and the length of study too short to show any sea-
sonal cyclic changes.

The Austin Country Club test results, shown in Fig 14, represent a
2-1/2-month study under normal conditions and a short study under accelerated
conditions. Since the depth of installation of the access tube was 10 feet,
determination of the depth of soil below the surface which was affected by
day-to-day weather conditions was possible; but the study was too short to
show any seasonal cyclic changes. Six feet was the maximum depth to which
noticeable changes in moisture occurred, with the greatest variation occurring
in the top 1-1/2 - 2 feet of soil.

The plot of moisture content versus depth shown in Fig 14 for the Austin
Country Club test site on June 28, 1967, represents the detection of moisture
changes under accelerated conditions, which resulted from the flooding of the
area surrounding the access tube. The plot of moisture content for June 17,
1967, represents the moisture conditions before flooding.

The San Antonio test results, shown in Fig 15, show an increase in
moisture content at every depth with time. This increase in moisture may
be related to the disturbance of the soil during installation which causes

39
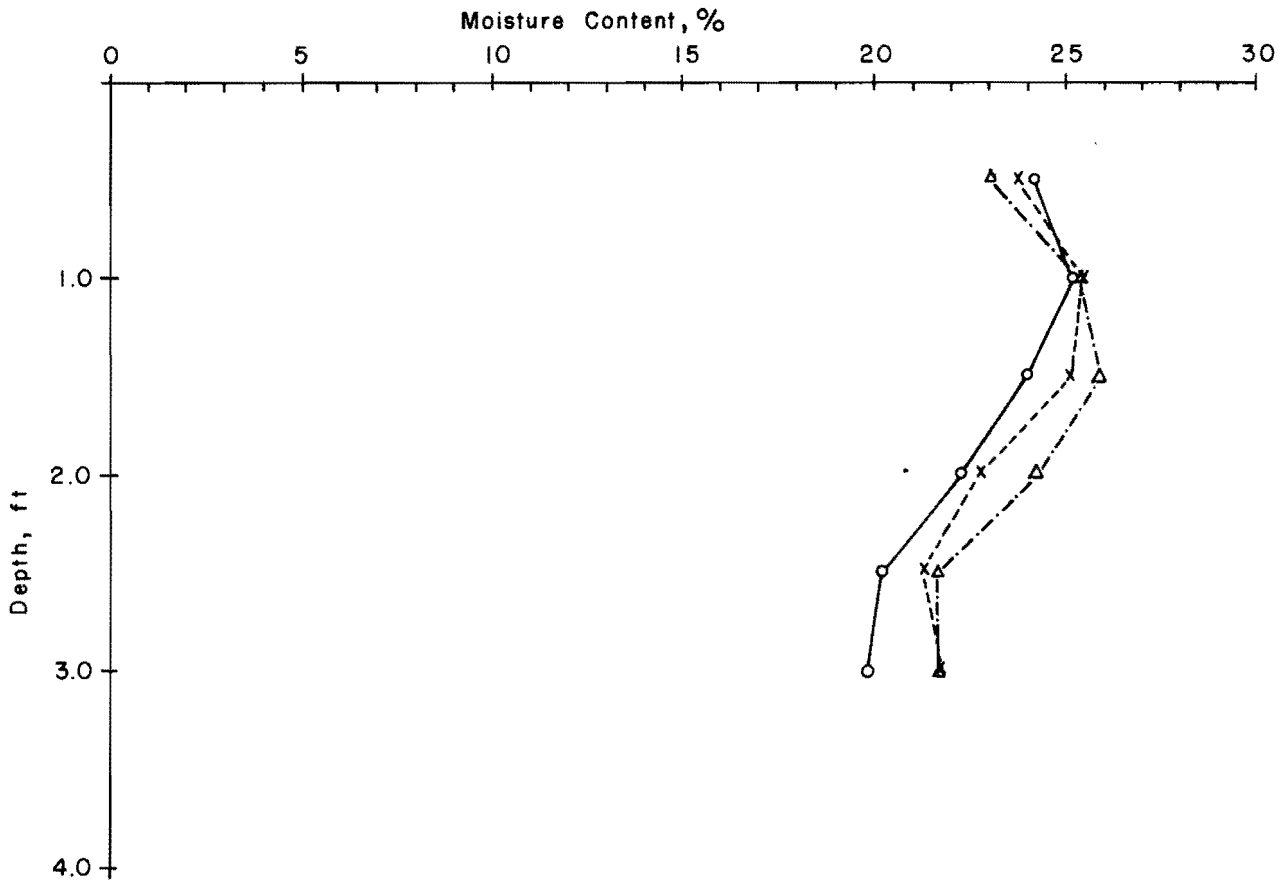
Fig 13. Moisture content determined by the nuclear method
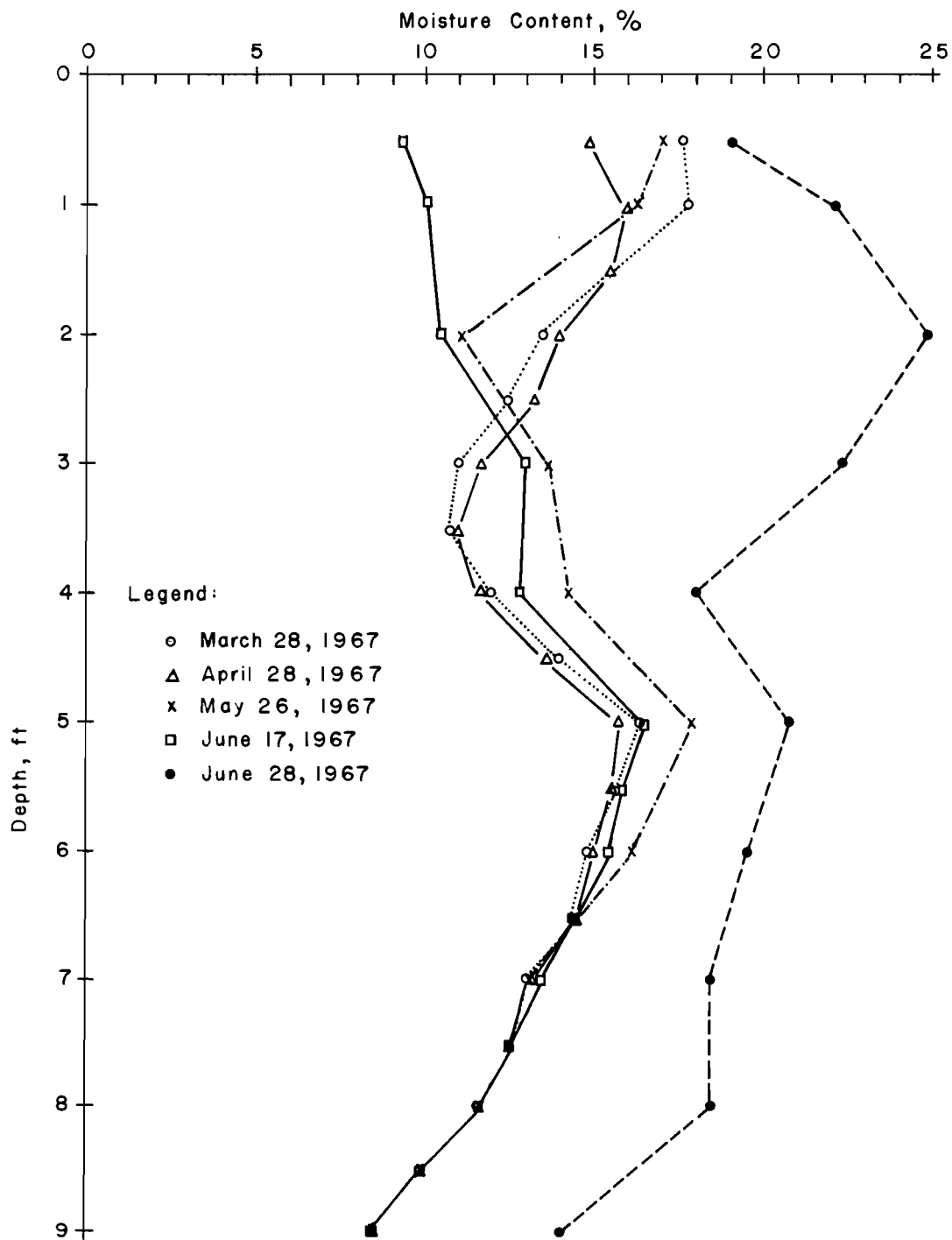versus depth for the Montopolis test site.

Fig 14. Moisture content determined by the nuclear method
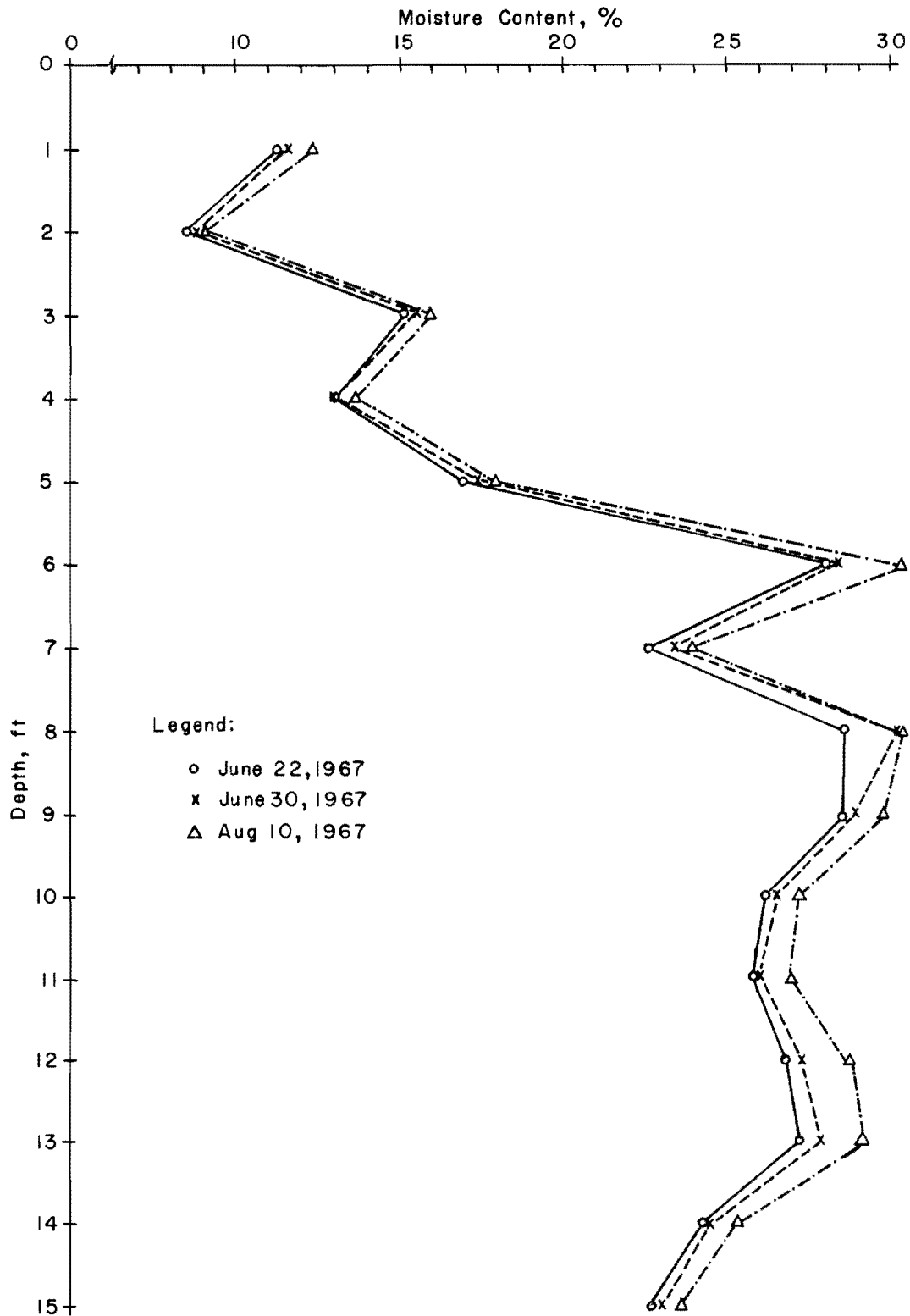versus depth for the Austin Country Club test site.

Fig 15. Moisture content determined by the nuclear method
versus depth for the San Antonio test site.

a possible decrease in the soil-water potential. This decrease in soil-water potential will be discussed in a later portion of this chapter.

ACCURACY OF MEASUREMENT

The accuracy of the nuclear method of moisture determination was determined entirely under field conditions using the calibration curve supplied by the manufacturer of the moisture probe. The values obtained with the probe were compared with values obtained by the gravimetric method, and conclusions concerning the accuracy of the nuclear method will be based on this comparison.

One comparison of nuclear and gravimetric values was made for the Montopolis test site and is shown in Fig 16. The variation in moisture content between the nuclear and gravimetric method was found to be 2 percent or less by weight. Soil samples required for the gravimetric method were obtained by means of a hand auger at a distance of 4 inches from the center of the access tube. The purpose for sampling so close to the access tube was to eliminate most of the variation that exists with field sampling and to obtain a representative sample of the soil that influenced the moisture count. Since the samples were taken so close to the access tube, a void was introduced within the sphere of influence. If the soil removed during sampling was not replaced or if the disturbed soil was replaced, error would be introduced into future moisture counts; therefore, the installation was abandoned.

Several checks of the accuracy of the nuclear method were performed at the Austin Country Club site. The plots of moisture content versus depth for the gravimetric and nuclear methods for April 28, 1967, are shown in Fig 17. The gravimetric results shown were determined from soil samples obtained from one location 2 feet from the access tube. A comparison of the results shows a variation in moisture content of about 0-2 percent by weight.

A comparison of the nuclear and gravimetric results, shown in Fig 18, obtained on June 17, 1967, before the Austin Country Club test site was flooded, shows an increased variation between the two methods which ranges from 0-4 percent moisture by weight. Soil samples were taken at two different locations, one 2 feet from the access tube and the other 4 feet, and the gravimetric results shown in Fig 18 are an average of the two.
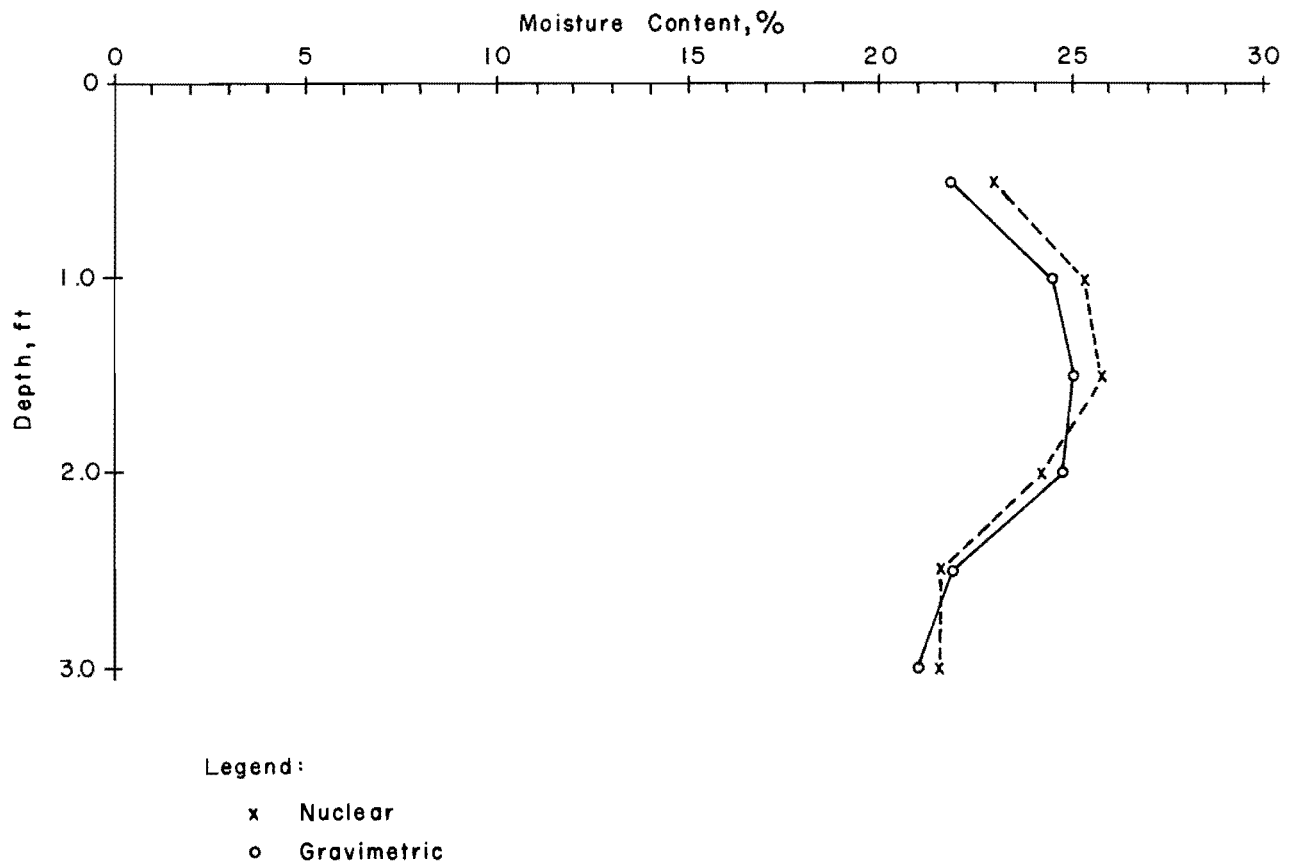
Fig 16. Comparison of moisture content versus depth for the nuclear and gravimetric methods at the Montopolis test site on April 18, 1967.
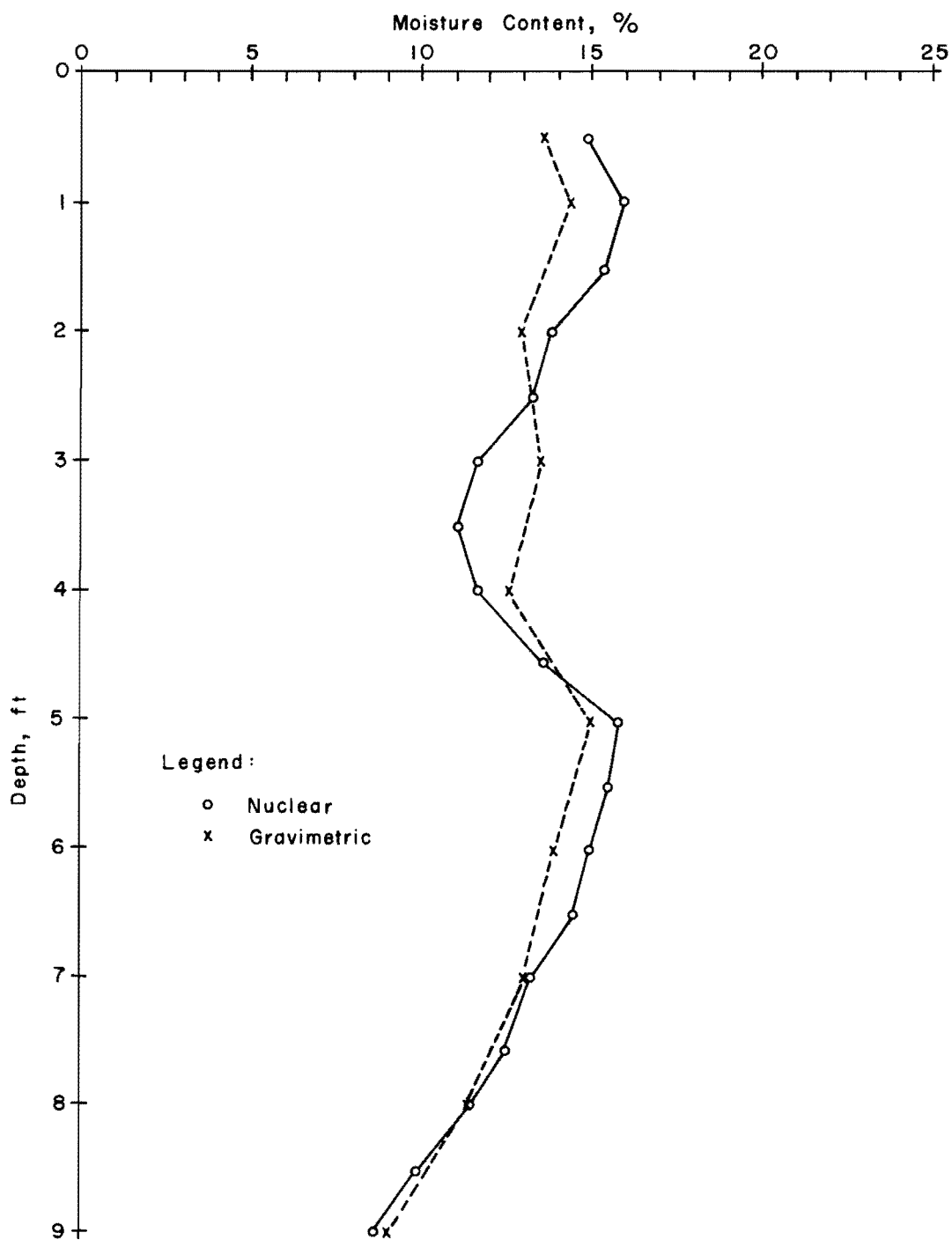
Fig 17. Comparison of moisture content versus depth for the nuclear and
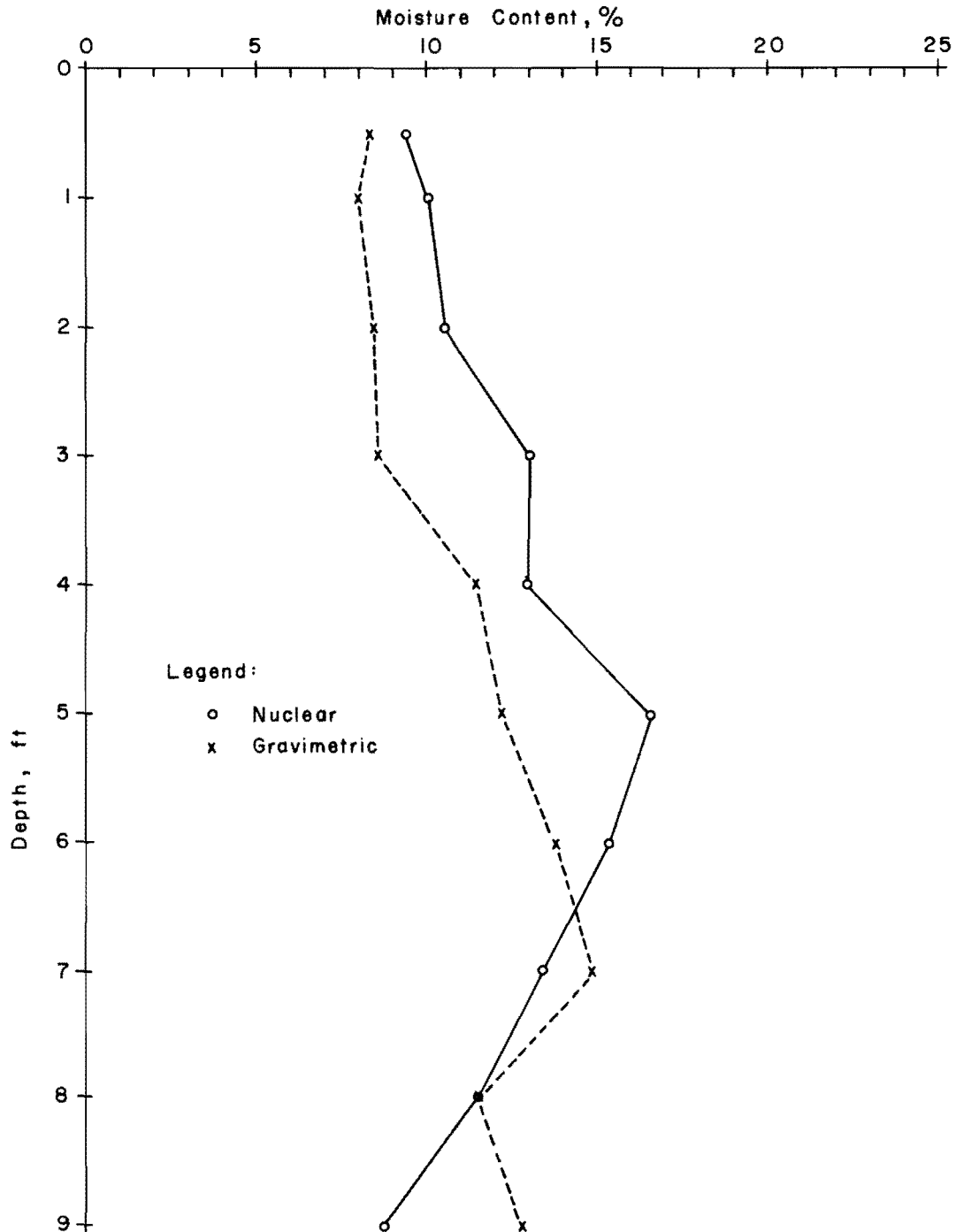gravimetric methods at the Austin Country Club on April 28, 1968.

Fig 18. Comparison of moisture content versus depth for the nuclear and
gravimetric methods at the Austin Country Club on June 17, 1967.

After the area surrounding the access tube at the Austin Country Club had been flooded, soil samples were taken at two locations 2 feet from the access tube, averaged, and compared to the nuclear results. The results are shown in Fig 19. There was a large, unexplainable variation in the two methods in the first 3 feet, but good agreement was obtained at the remaining depths.

A final check of the accuracy of the nuclear method at the Austin Country Club was performed on July 27, 1967. The results are shown in Fig 20. Soil samples for the gravimetric method were taken 4 inches from the access tube. There is good agreement between the nuclear and gravimetric results and a maximum variation of ± 2 percent moisture by weight.

The accuracy of the nuclear method is based on the assumption that the gravimetric method is correct, but the correctness of the gravimetric method is questionable because of variations that occur among samples taken at the same depth and separated by relatively short distances of only 2-3 feet. Such variations among samples taken during this investigation are shown in Figs 21 and 22, and Taylor (Ref 18) has shown that the coefficient of variation for field sampling of moisture plots cannot be reduced much below 10 percent.

There is also error associated with the gravimetric method since the samples are usually small in comparison to the amount of soil which is taken into account by the nuclear method, and there exist possibilities of the sample losing moisture before weighing and possibilities of error occurring during weighing. Therefore, it is difficult to evaluate the accuracy of the nuclear method if the gravimetric method contains such variations and errors.

PRECISION OF MEASUREMENT

The precision of measurement or the reproducibility of a neutron count at a fixed position with a constant moisture content was determined in the laboratory and in the field. The precision of measurement determined in the laboratory was a test of the reproducibility of the standard reference count which represents approximately 50 percent moisture by volume. One hundred standard reference counts of one-minute duration had a mean of 14,210 CPM (counts per minute) and a standard deviation of 112 CPM which
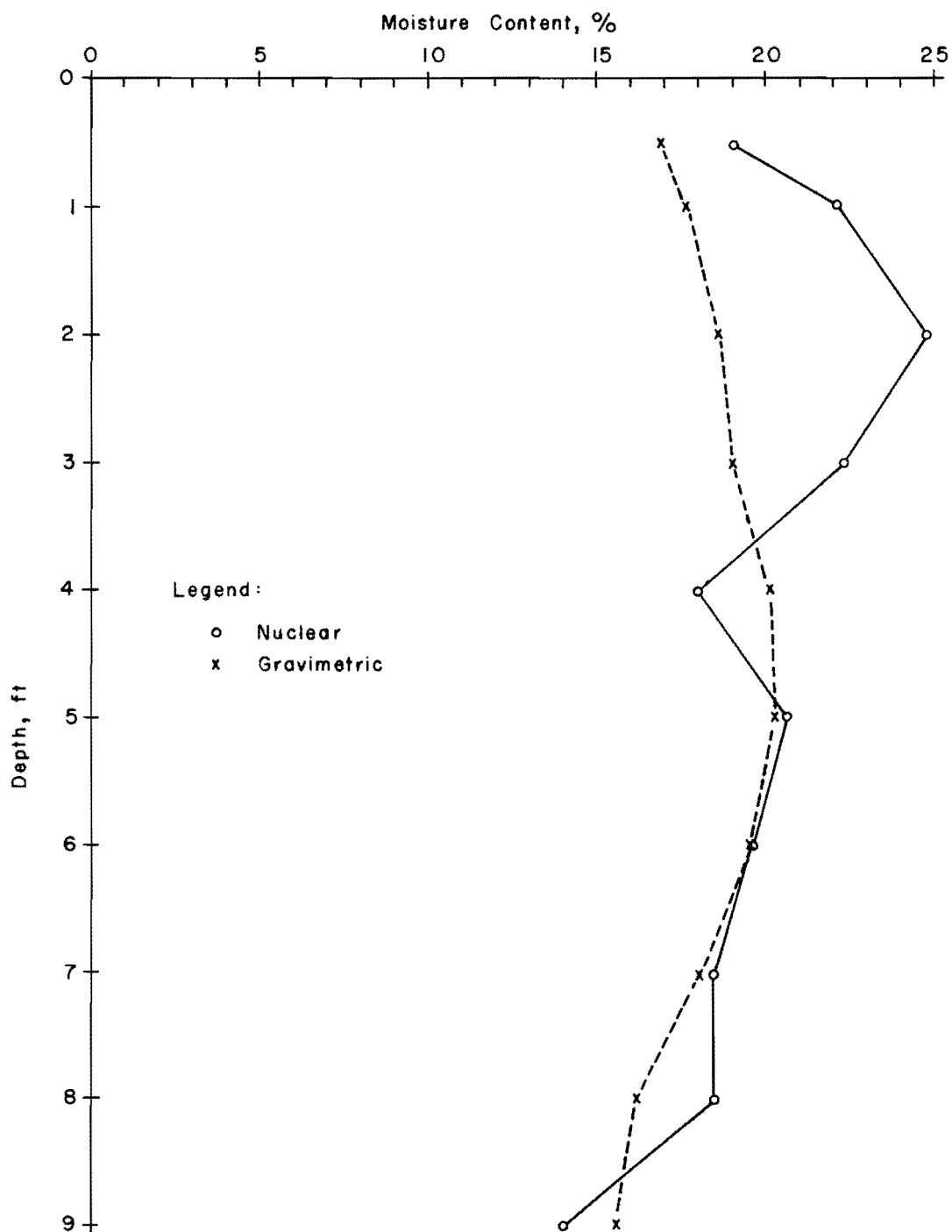
48

Fig 19. Comparison of moisture content versus depth for the nuclear and gravimetric methods at the Austin Country Club on June 28, 1967.
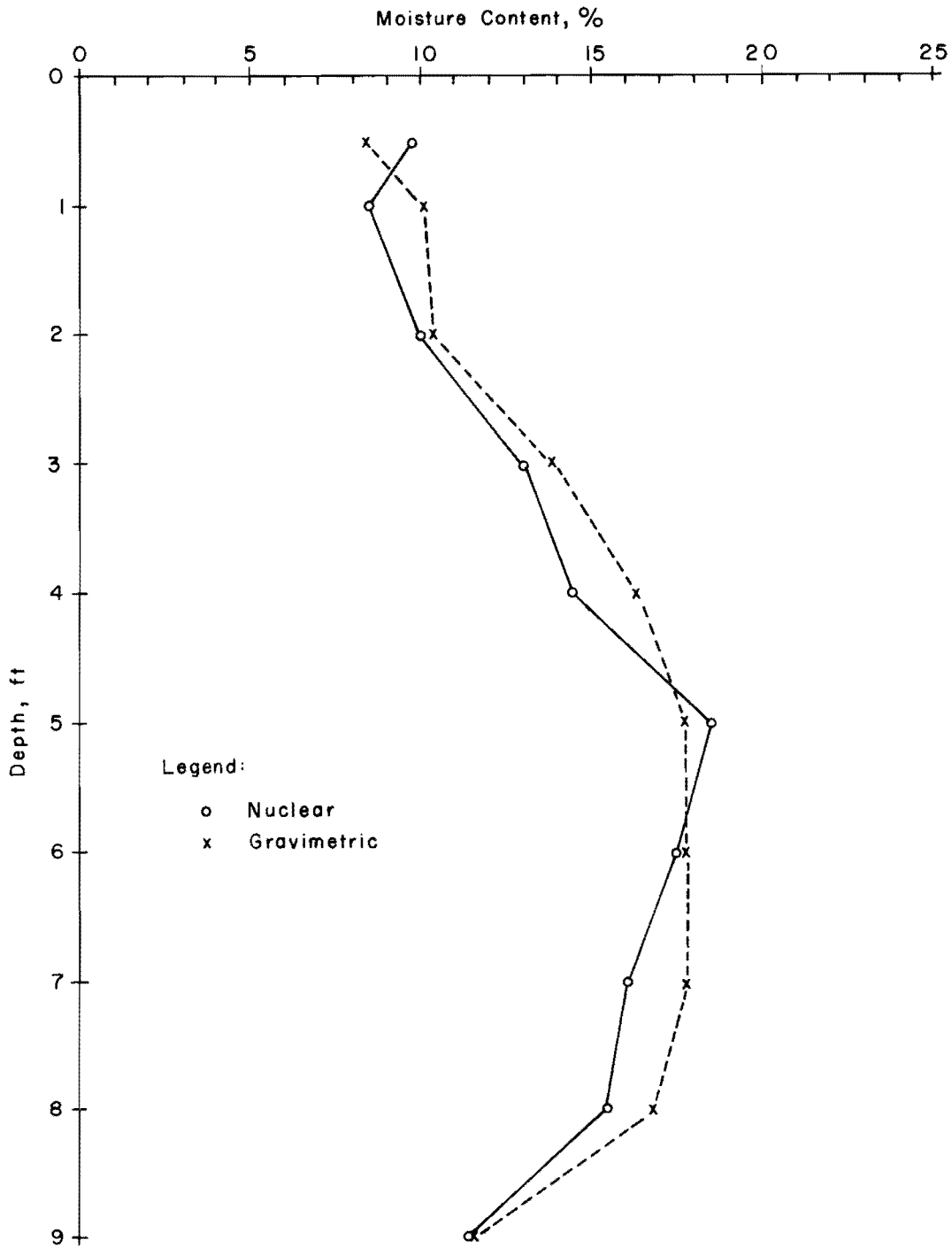
Fig 20. Comparison of moisture content versus depth for the nuclear and
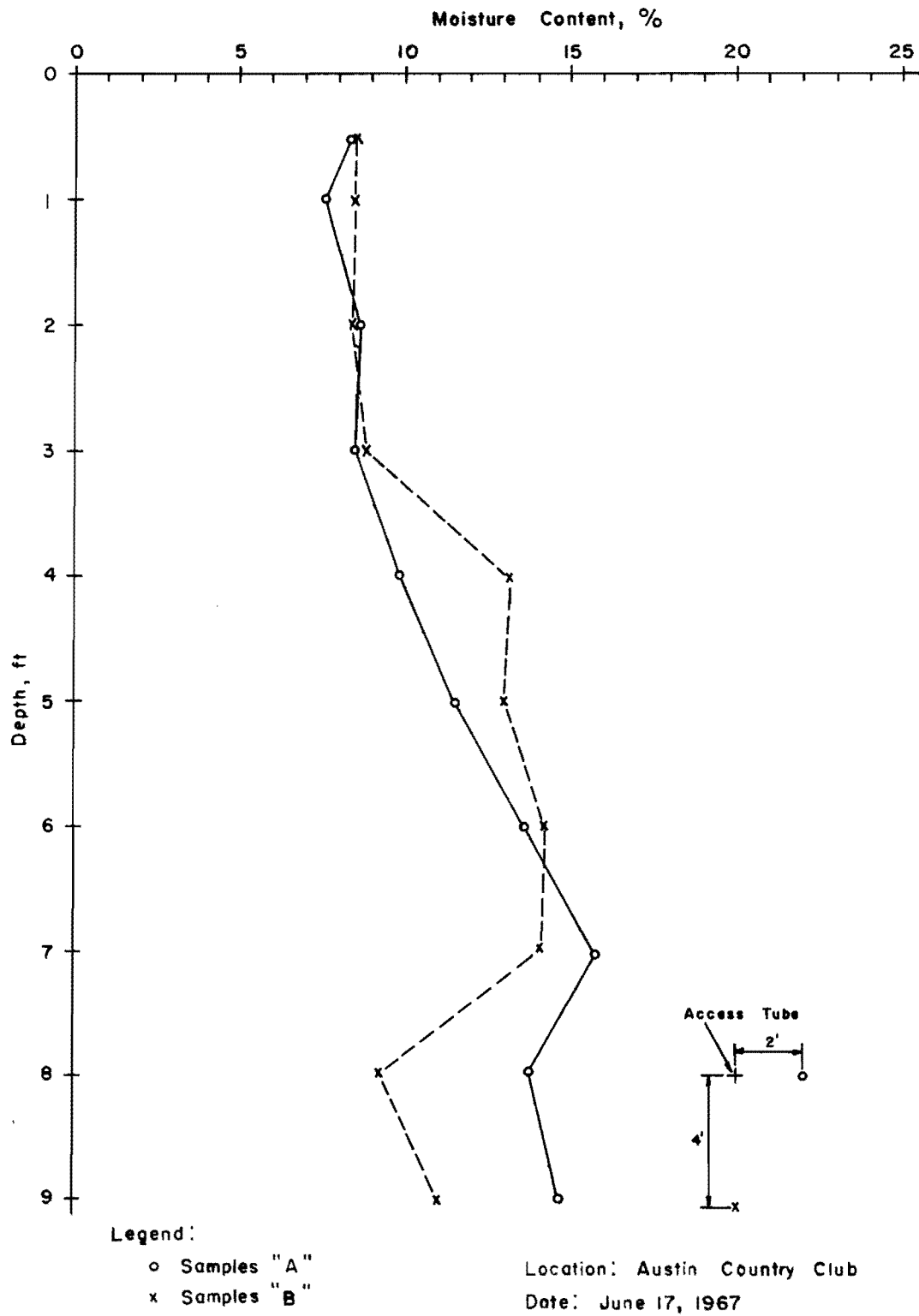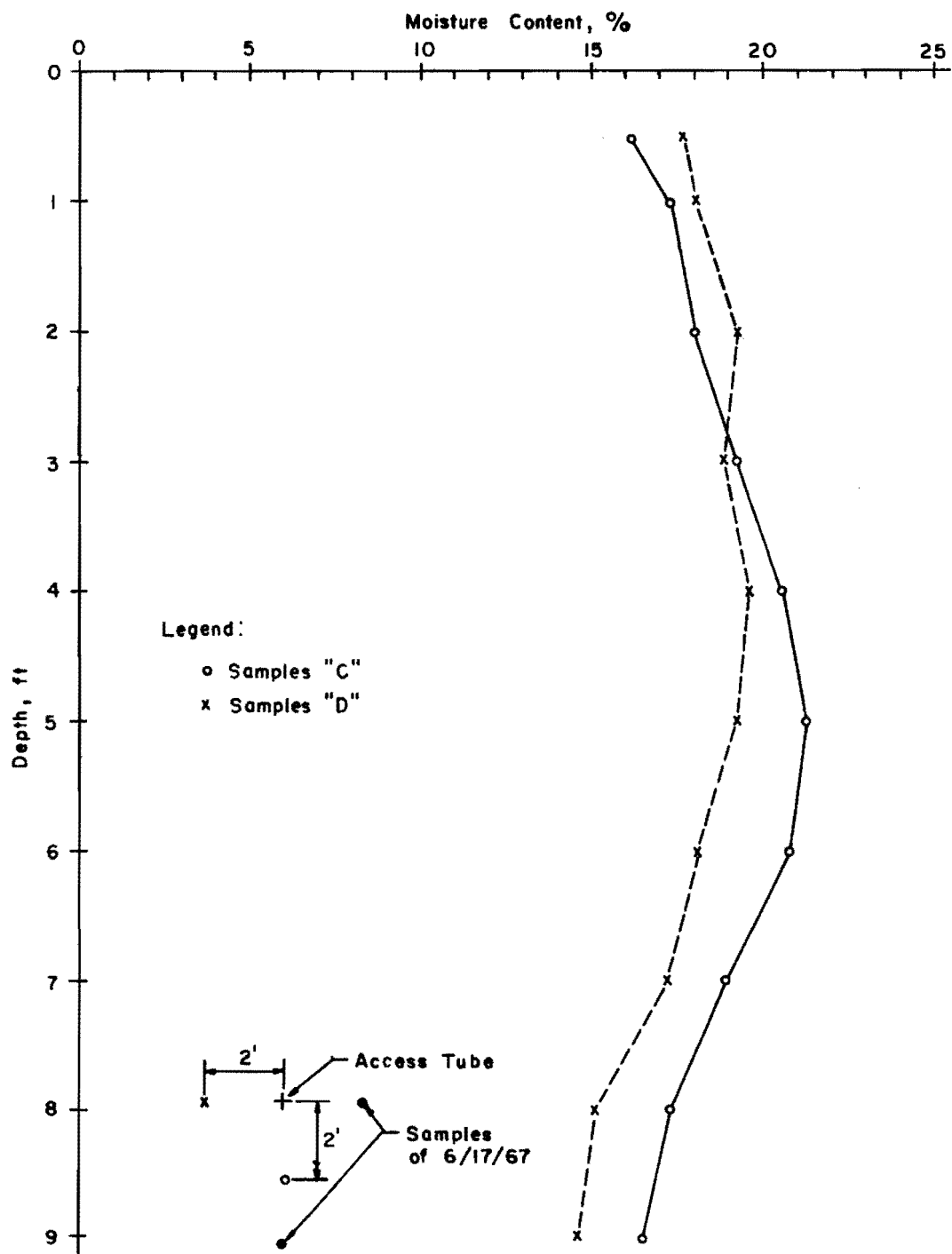gravimetric methods at the Austin Country Club on July 27, 1967.

Fig 21. Comparison of gravimetric results.

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Fig 22. Comparison of gravimetric results.

is 0.79 percent of the mean. This ratio of standard deviation to the mean is referred to as such in the remainder of this report.

To check the precision of measurement under field conditions, the moisture probe was lowered to a certain depth in the field installation, and ten one-minute readings were taken. It was assumed that there was no change in moisture content during the time required to obtain the ten readings. The coefficient of variation with respect to depth for two different test periods is shown in Fig 23. The maximum coefficient of variation was found to be 1.5 percent, the minimum was 0.6 percent, and the average was 1.0 percent.

Since there was a considerable difference in the moisture content of the soil with respect to depth for the two test periods (Fig 24) and no distinguishable difference in the two curves (Fig 23), it was concluded that the coefficient of variation of the moisture readings was relatively independent of moisture content in the range of 15-50 percent by volume, and also independent of depth, since there was neither an increase nor a decrease in the coefficient of variation with depth.

TIME AND TEMPERATURE EFFECTS

It was realized that time and temperature effects are not a serious problem with the nuclear method since they are eliminated or corrected by the standard count, but it was of interest to see if time and temperature had any effect on the reproducibility of a moisture count. This part of the investigation would give clues as to how often standard counts would be required when testing in the field. If the reproducibility of the standard reference count was independent of time and temperature, then one set of standard counts would be sufficient for a testing period.

To study the effect of temperature, 100 standard reference counts were taken in a constant temperature room at temperatures of 40°, 75°, and 110° F. It was felt that the temperature during field testing would most likely lie in the range of 40° - 110° F. The manufacturer stated that the nuclear equipment was reliable in the -10° to 140° F range.

For the tests at 40° and 110° F, the equipment was placed inside the constant temperature rooms after having been stored at 75° F, and counting was begun immediately. The usual warm-up time of 3-5 minutes was allowed, and counts were recorded thereafter.
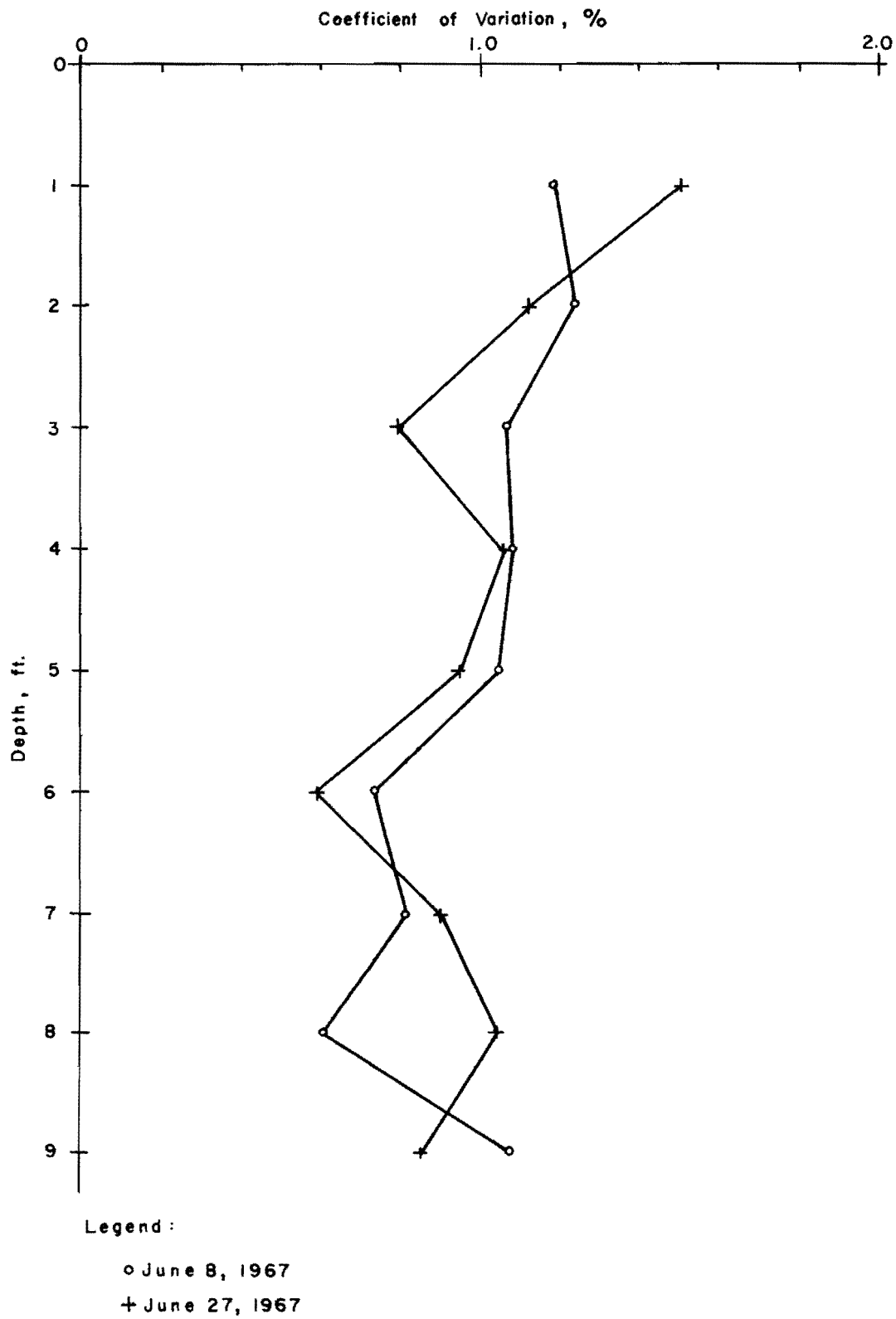
Fig 23. Coefficient of variation versus depth for June 8
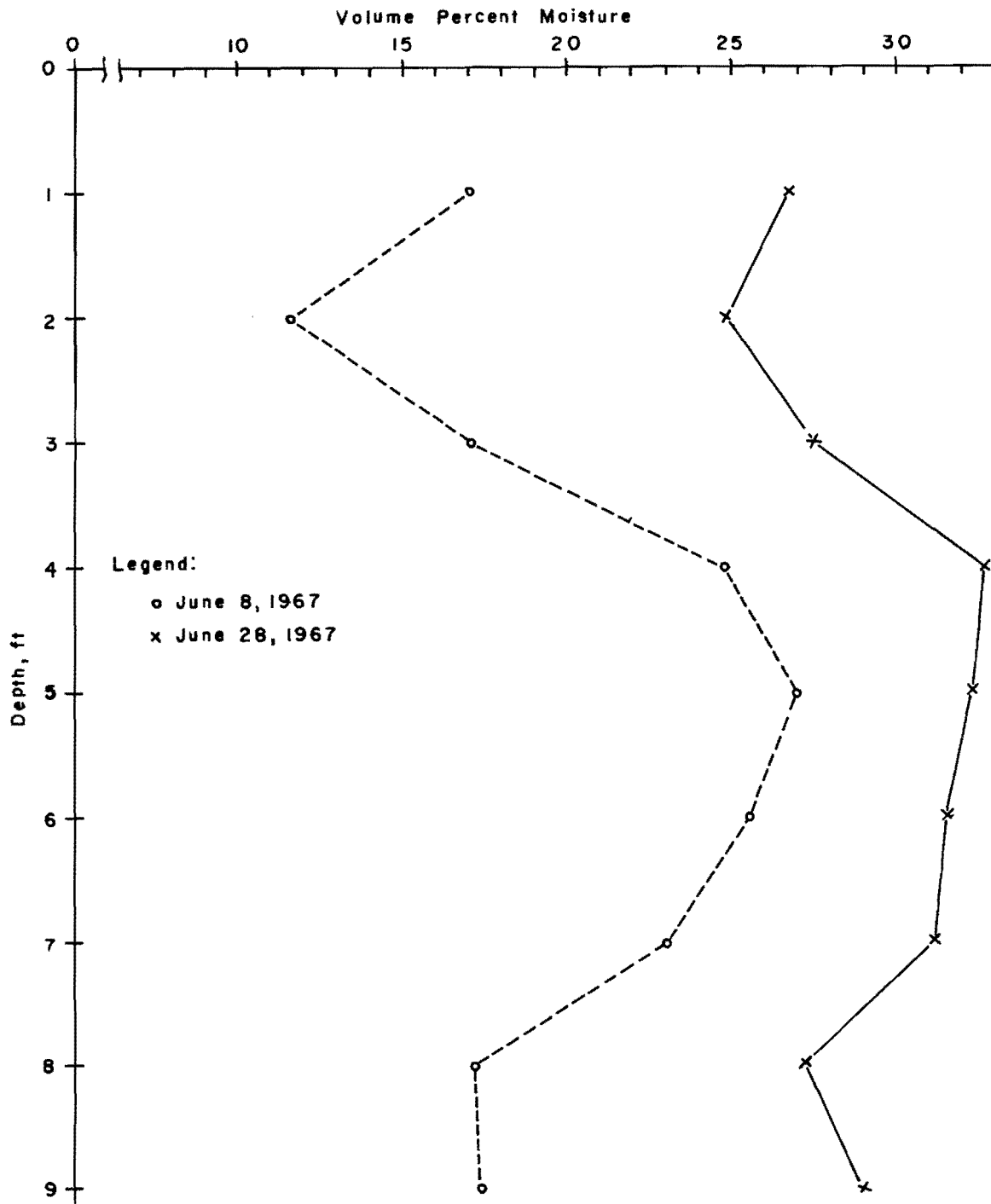and June 28, 1967, at the Austin Country Club.

Fig 24. Volume percent moisture versus depth for June 8
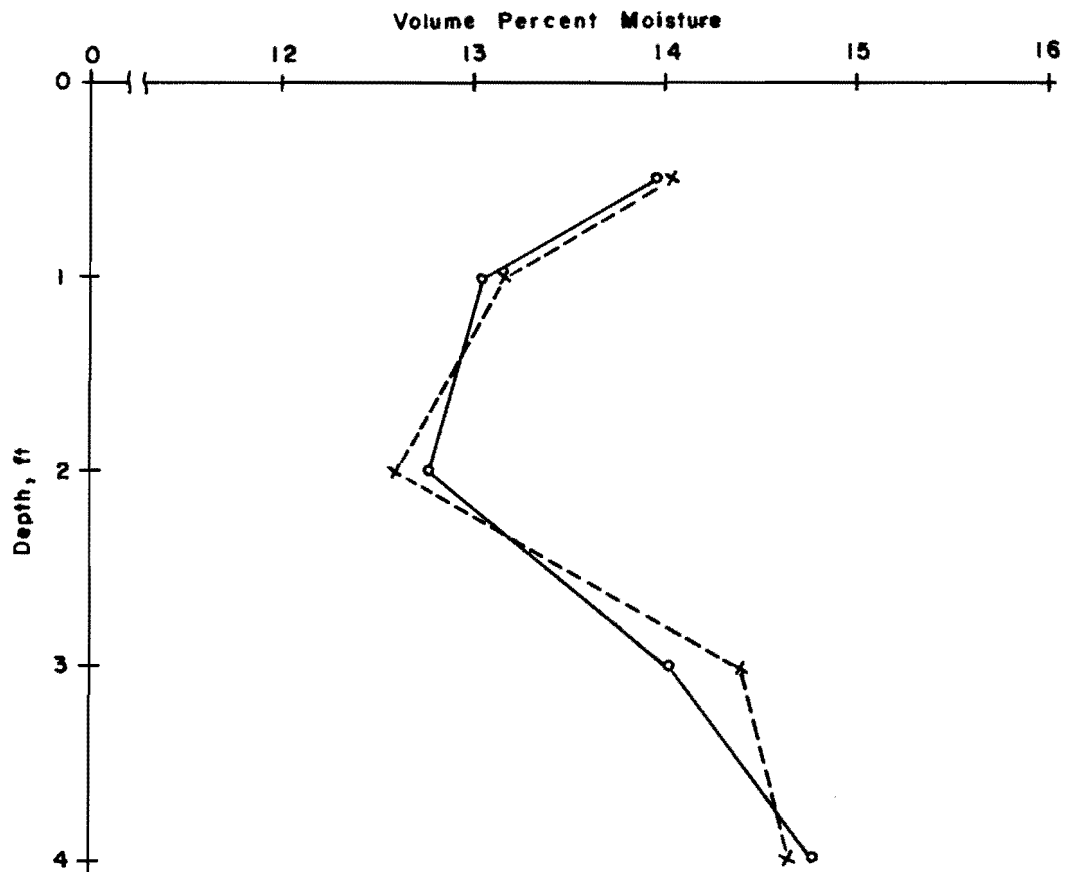and June 28, 1967, at the Austin Country Club.

For 100 standard counts at 110° F, the average count was 14,202 with a standard deviation of 112 CPM and a coefficient of variation of 0.79 percent. At 75° F the average standard count was 14,210 with a standard deviation of 112 and a coefficient of variation of 0.79 percent. The low temperature of 40° F produced an average standard count of 14,289 CPM with a standard deviation of 112 CPM and a coefficient of variation equal to 0.79 percent. Reproducibility of the mean value at different temperatures was very good, and the mean values of the standard count are in good agreement with the manufacturer's suggested standard count of 14,185 CPM.

To determine whether the standard count was affected by time, the 100 readings which were taken at each temperature were analyzed in sets of 10 which represented 10 minutes of actual counting time. The mean and coefficient of variation for the first 10 readings or 10 minutes, the second 10 readings or 10 minutes, the third 10 readings or 10 minutes, etc., were calculated. A plot of the average standard count and coefficient of variation for each set of 10 readings versus its respective set is shown in Figs 25 and 26, respectively. The average standard count and coefficient of variation of the individual sets of 10 readings are scattered randomly about the mean and coefficient of variation for the total of 100 readings.

EFFECT OF AIR GAP

The presence of an appreciable air gap either between the probe and the access tube or between the access tube and the soil can lead to error and, therefore, must be kept at a minimum. The gap clearance which is equal to one-half the difference in the diameter of the probe and the inside diameter of the access tube, or one-half the difference in the diameter of the access hole and the outside diameter of the access tube should be held to less than 0.15 inch, preferably about 0.03 inch (Ref 5).

The use of the hand auger for the purpose of installing the access tube resulted in an air-gap clearance of about 1/8 or 0.125 inch. As mentioned before, this air gap was filled with a dry sand which had a moisture content of 0.05 percent by weight as determined from oven drying. Readings were taken before and after the air gap was filled with sand at the time of installation of the access tube. The results are shown in Figs 27 and 28 for two different installations in the same type of soil.

Fig 25. Effect of time and temperature on the average standard reference count for a set of 10 standard reference counts.

57

Fig 26. Effect of time and temperature on the coefficient of
variation of a set of 10 standard reference counts.

58

Fig 27. Comparison of volume percent moisture versus depth for an air
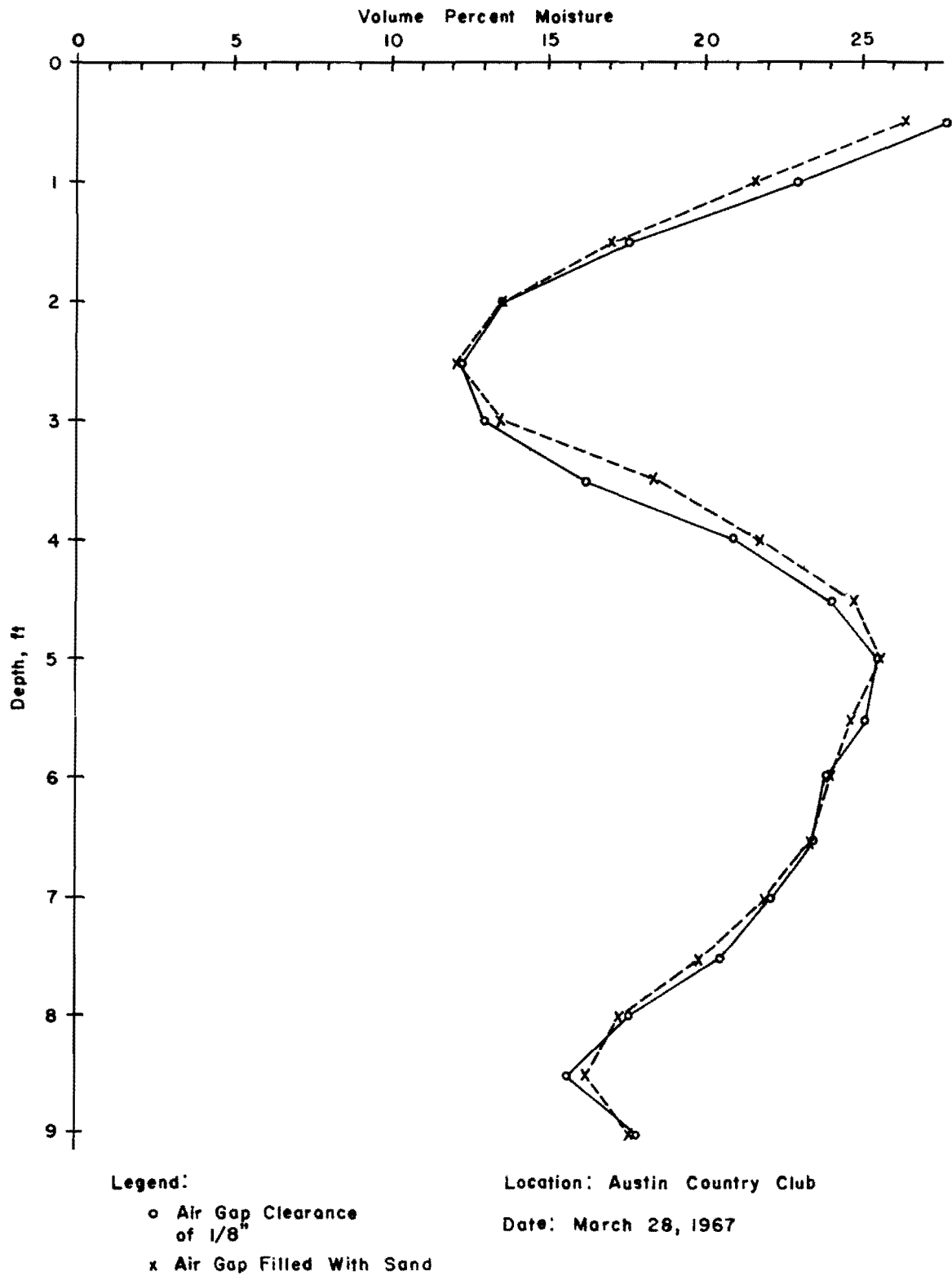gap clearance of 3/16 inch and an air gap filled with dry sand.

Fig 28. Comparison of volume percent moisture versus depth for an air
gap clearance of 1/8 inch and an air gap filled with dry sand.

The volume percent moisture obtained when the void was filled with sand was not always larger than the volume percent moisture obtained when the sand was absent from the void. No definite conclusion can be reached as to whether the dry sand contributed to the neutron count; but if there is any contribution, it is very small. Another investigation (Ref 9) conducted using oven-dry loam showed that the counting rate for air was 8.6 ± 0.2 CPM and 9.0 ± 0.3 CPM for the loam.

At the time of installation the sand was in a dry state, but with time the moisture content of the sand will come into equilibrium with the surrounding soil. The initial readings at the time of installation will be in error, since the dry sand is located within the sphere of influence and is averaged in with the undisturbed soil of a certain moisture content also located within the sphere of influence. Thus, the moisture reading is lowered below that which would have been obtained if the void did not exist or was occupied by the surrounding undisturbed soil. The amount of sand located in the air gap is small in comparison to the total volume of the sphere of influence; therefore, the error introduced by the presence of the dry sand is small.

To study the effect of various sizes of air gaps on the neutron readings, a hole was augered that resulted in an air gap of 1/16 or 0.0625 inch, and moisture readings were taken at different depths. The air gap was increased to 1/8 or 0.125 inch and 3/16 or 0.1875 inch with a larger hand auger, and readings were taken for each increase. The results are shown in Fig 29.

For this particular range of volume percent moisture (13 - 15 percent), the decrease in volume percent moisture was about 0.4 percent for each 1/16-inch increase in air gap. At lower moisture contents, the decrease in volume percent moisture would be less due to the increase in size of the sphere of influence; at higher moisture contents, the decrease would be greater because of the increase in size of the sphere of influence.

PROBLEMS RELATED TO ACCESS-TUBE INSTALLATION

As stated by many authors, the primary problem associated with the nuclear method is concerned with the installation of the access tube and this particular investigation was no exception. The use of a hand auger was found to have many limitations, and for stiff soils or rocky soils its application was not possible. It is felt that if the nuclear method is to be of any
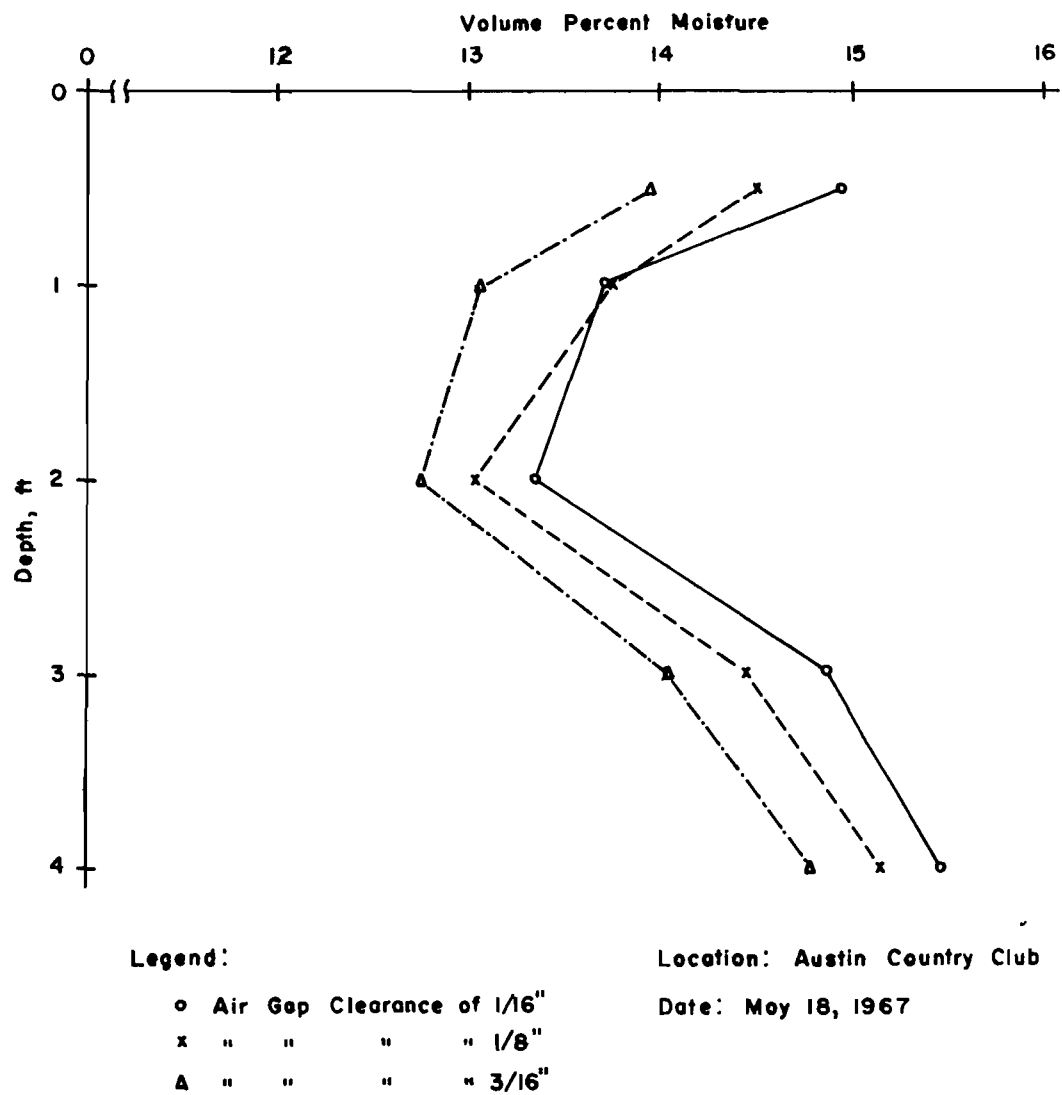
Fig 29. Plot of volume percent moisture versus depth for an
air gap of 1/16 inch, 1/8 inch, and 3/16 inch.

value to the investigator and utilized to the fullest extent, installation methods or devices must be developed that will be effective in any soil type.

A problem of access-tube installation did occur at the San Antonio test site due to the presence of gravel, requiring the adoption of the method of installation described in Chapter 5. There are questions concerning this type of installation since the soil must be disturbed. The primary question of whether the density of the disturbed soil was returned to the density of the surrounding undisturbed soil is difficult to answer, but it was probably not since there was no means of controlling the compaction of the soil. The density of the soil after replacement was most likely less than the undisturbed in most cases since most of the soil was a stiff clay, and extra voids were introduced upon replacement of the soil in the form of chunks. The voids could not be removed by tamping or compaction.

Since the soil surrounding the tube was disturbed, the soil water potential or soil suction was probably changed. For a clay (the predominant soil at the installation) which has been consolidated or weathered (undergone many cycles of wetting and drying), a disturbance of the soil breaks up the particle arrangement and exposes the full surface of the particle for water retention and, hence, decreases the soil-water potential (Ref 2). Water will flow from a point of higher potential to one of lower potential; therefore, soil water will flow from the surrounding undisturbed soil of a higher potential to the disturbed soil of a lower potential surrounding the tube and increase its moisture content above that of the undisturbed soil. Due to this increase in moisture content, the moisture readings obtained will be higher than the true moisture content of the soil at a distance from the access tube.

The question of whether heterogeneous material such as gravel or rock has any effect on the moisture readings needs also to be answered. Several tests (Ref 7) were run with glacial drift in a 55-gallon drum in which rocks of well-defined size and shape were placed at known positions near the access tube. The results showed that though some fluctuations were observed, the indicated moisture content was still within 1.25 pounds (1 percent dry weight) of the average. Since the nuclear method gives an average of the moisture content over moderately large volumes, it can be expected that the influence of inhomogeneities such as rocks is small.

After about two months, moisture samples will be taken near the tube to check the accuracy of the nuclear readings. This check has not yet been performed and, therefore, is not presented in this report. This method of installation was presented as a possible solution to the problem of access-tube installation in soil containing a large amount of gravel.

To increase the versatility and depth of installation (except in rocky soil), a 2-inch diameter continuous flight auger in 3-foot sections has been purchased. The proper power supply and means of operation are now under investigation. This particular kind of auger has been used by Oklahoma State University (Ref 15) with good success, and it should eliminate most of the problems associated with future access-tube installations.

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

This investigation was conducted for the purpose of evaluating the nuclear method and related equipment and studying the problems associated with the nuclear method. The results were favorable and resulted in the acceptance of the nuclear method as a means of determining the moisture content in soil at depth.

The following conclusions and recommendations are made on the basis of the results and observations of this investigation.

CONCLUSIONS

(1) Continual nondestructive observations of the moisture content at depth can be made satisfactorily and with ease.

(2) The accuracy of the nuclear method when compared to the gravimetric method is satisfactory. The variation between the moisture contents determined by the two methods was 2 percent or less by weight in most cases and never greater than 4 percent.

(3) The degree of accuracy obtained using the manufacturer's calibration curve is acceptable, and the nuclear equipment does not require recalibration.

(4) The calibration curve seems to be independent of soil type on the basis of moisture measurements in two different soils.

(5) The reproducibility of a nuclear moisture count is very good with a coefficient of variation of about 1 percent.

(6) The reproducibility or precision of measurement is independent of moisture content in the range of 15-50 percent moisture by volume, and time and temperature (40° - 110° F) also have no effect on the precision of measurement.

(7) The error introduced by the presence of an air-gap clearance of 1/8 inch has no noticeable effect on the accuracy of the results, and the placement of dry sand in the air gap presents no problems and acts satisfactorily as a filler. There is a definite decrease in neutron count with an increasing air gap; therefore, the air-gap clearance must be held to a minimum.

(8) The hand auger is a satisfactory means of producing a hole for the insertion of the access tube when soil conditions allow, but its use is limited.

(9) The use of the moisture content determined by sampling at the time of installation and the volume percent moisture obtained from the nuclear readings is a satisfactory means of determining the moisture of the soil surrounding the access tube, when a density probe is not available or the application of another method of density determination is not possible.

(10) The portable nuclear equipment is very reliable, simple to operate, and requires very little, if any, maintenance.

RECOMMENDATIONS

(1) The method of installation of the access tube must be investigated further. The adaptation of the proper power supply to the continuous flight auger should provide a solution to the problem.

(2) The method of access-tube installation in rocky soil described in this report should be investigated further with emphasis being placed on density control, change in soil-water potential, and the effect of the presence of rocks. A method which does not require a disturbance of the soil also needs to be investigated.

(3) Precautions should be taken to seal properly the air gap at the ground surface, if a material such as sand is used to fill the air gap which might exist between the soil and the access tube. This thin layer of sand can act as a medium for transferring surface water or moisture down the tube, and migration of the moisture into the surrounding soil will occur, and, thus, increase the moisture readings above what they should be.

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