Amount of Heat Transferred (Cont'd)

Ceroc #27

t	Run 1 ΔR	ΔR5	ΔR15	Run 2 ΔR	ΔR15	ΔR15	Run 3 ΔR	ΔR15	ΔR15
0									
5	1.60			1.80			2.20		
		2.00			1.90			2.00	
10	3.60			3.70			4.20		
		1.50			1.50			1.40	
15	5.10			5.20			5.60		
		1.10 (			1.18 (			1.00 (	
20	6.20		(2.60	6.38	(	2.48	6.60	(	2.38
		1.10 (			.76 (			.80 (	
25	7.10			7.14			7.40		
		.60 (			.54(			.58 (	
30	7.70			7.68			7.98		
			1.26			1.32			1.12
45	8.96			9.00			9.10		
			.64			.74			.70
60	9.70			9.74			9.80		

THE MEASUREMENT OF SOIL MOISTURE AND DENSITY BY NEUTRON AND GAMMA-RAY SCATTERING

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Over a span of approximately 50 years the records and literature on the subject of soils contain descriptions of various apparatus developed for determining soil moisture. The lack of knowledge in the field of soil moisture can be attributed to a lack of adequate means of measurement rather than a lack of interest. Because of the limitations of moisture measuring devices little is known, in a definite sense, of the movement of moisture in soils. This is particularly true in unsaturated soils. The movement of moisture through soil by percolation, by capillary action, and by vapor transfer is little known except by analogy and inference. When in the frozen state, the soil conditions defy study.

An essential to the satisfactory study of values and trends in soil moisture is the need for continuing observations of the same soil throughout its seasonal cyclic changes. Destructive sampling with an auger introduces many uncertainties in most soil formations because of their heterogeneous nature. 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. To date, the problem of installing measuring devices without materially altering the adjacent soil conditions has been met with but limited success.

Most of these early instrument methods have been related to the variations in electrical resistance offered by soils in varying degrees of saturation. In general, these have presented overwhelming difficulties, particularly in the calibration of the equipment at its installation site. A number of improvements over the direct measurement method have been developed. These, in general, substitute for the direct (electrode) contact with the soil, blocks of material that absorb and give up moisture in a way related to the changes in the moisture of the surrounding soil. The electrodes embedded in these blocks are used to measure the resistance of the material in the block and the variations in the moisture content. This arrangement simplifies the calibration of the installation and also insures uniform contact between the electrodes and the measured media.

The ever-present need for information on soil moisture characteristics has been enlarged by the need for more accurate information in subgrade soil moisture as a means of providing better design information for pavements. With the recent availability of radioactive materials, the problem of determining soil moisture was reviewed in the light of the ability of some of these materials to react indirectly, although with great sensitivity, to moisture. The interest of the Civil Aeronautics Administration and staff members of the Engineering College of Cornell University combined to study the possibilities of using nuclear materials to measure soil moisture contents. In principle, the neutron method of counting hydrogen nuclei seemed to hold considerable promise. Among the favorable characteristics was the fact that the neutrons would detect the presence of water regardless of state so that whether the water was in a form of liquid, vapor, or solid, meant that it would be possible to make observations at any time of the year.

Secondly, it appeared that there would be equal sensitivity over the entire range of moisture, and third, that it does not depend upon the installation of electrodes at various depths in the soil column. The neutrons that have the ability to count the hydrogen nuclei contained in water particles readily penetrate stainless steel and aluminum metals so that the simplicity of the installation seemed a desirable attribute. The fact that the measurements could be made by lowering a small unit into a water-tight stainless-steel tube indicated that a low-cost installation could be made, especially with reference to the infinite variation in the number of levels at which moisture determinations could be made. It also largely removed the question of selecting a representative site since the tubes could be installed and withdrawn almost at will and in great numbers, if necessary. Finally, measurements can be made in short-time intervals of the order of one-quarter hour or less, thus recording relatively rapid changes in moisture content.

One of the requisites of a soil-moisture-measuring device is that it be adaptable in all types of soil, ranging from clays through silts, sands and gravels, as well as in stratified and heterogeneous deposits, such as glacial drift containing material sizes ranging from clay to boulders. The problem of inhomogeneities is not confined to that of grain sizes but it also includes variations in density of the soil, the presence of organic matter, such as vegetation and inorganic salts of magnesium, potassiu, and other metals. The latter is particularly important in the dry areas west of the Mississippi River. The organic materials are often associated with low, level ground, that is, at the same time, topographically favorable to engineering installations. The alkali soils of the west, containing the inorganic salts, are also concentrated in those areas that are predominantly level.

Destructive sampling has introduced one of the chief uncertainties into field studies. The use of an auger of 2-in. diameter may well change the drainage properties of the surrounding soil throughout a 2-ft. radius of influence. Further sampling at a later date must avoid this influence. In doing so, variations in the soil may introduce significant errors. This problem becomes magnified many times when sampling beneath pavements.

Representative sites for sampling are important. When an auger boring is made or a resistance unit installed, it is desirable to know what application these observations will have beyond the immediate site. In many instances, particularly in auger sampling, ignorance of surrounding subsurface inequalities gives false values to the data obtained.

Under some conditions it is impossible to obtain satisfactory moisture samples by the auger method. Where water can drain freely down the test hole from seepage planes, these difficulties will occur. It has also been virtually impossible to obtain samples for studies of water in the form of vapor or ice in soil.

The ideal condition for making soil moisture studies exists when non-destructive testing can be used, when moisture in the soil itself can be measured, and when the soil is undisturbed and free from unnatural influences.

The advantages of the nuclear method closely parallel the ideal described. The simple tube, placed vertically in the soil column, introduces a minimum of change in environment. Since the tube is placed in a drilled hole of slightly smaller diameter, the intimate contact between the outer tube wall and soil eliminates any unnatural tendency for vertical drainage downward along the tube wall. The tube provides access to the soil at any practical depth to which it is driven and an unlimited opportunity for making measurements of the same soil at any period of the year. Inexpensive to install, it can be withdrawn or abandoned without appreciable loss of time or investment.

On the basis of the need for a solution to the problem and the promise inherent in the nuclear method, an exploratory and development contract was arranged between the Civil Aeronautics Administration, Airport Development Division, and the College of Engineering at Cornell University. As the work under this contract progressed, many useful applications of the laws governing radioactivity could be seen. Of these, one of the most important was the relationship between the extent of gamma-ray penetration in soil and its in-place density. The relationship between soil moisture and density and its importance in soils engineering encouraged an investigation of this unknown quantity.

Physical Basis of the Neutron Method

The physical phenomena that form the basis of the new method for the determination of moisture content and density of soils are the scattering of neutrons or gamma rays and the loss in their energy during this process . It is well known that the interaction between neutrons and other materials is, with the exception of a few specific substances, very weak. These neutrons, therefore, can travel for a long time before they are destroyed. However, during their lifetime they collide with the nuclei of the material through which they travel and are scattered in all directions. At the same time, in each collision or scattering process they lose some of their energy. The scattering is particularly strong and the loss of energy marked if the neutrons collide with hydrogen atoms. Fast neutrons differentiate between hydrogen nuclei and most other kinds because they are much alike in mass. Neutrons may be compared to ping-pong balls. When thrown with force against a bowling ball (average atom) the ping-pong ball rebounds at high speed without much affecting the massive bowling ball. But when thrown against another ping-pong ball (hydrogen atom) the second ball is set in motion while the first rebounds with a greatly reduced velocity, thus becoming a "slow" neutron. Therefore, if we have a source of fast neutrons, and if these neutrons travel away from the source, they will be scattered by the material surrounding the source and a great number will return to the source or to its immediate vicinity. Those neutrons which have been scattered by hydrogen atoms will have lost most of their energy and return as slow neutrons. The more hydrogen atoms present, the more slow neutrons will return to the vicinity of the source. Thus, in counting the number of slow neutrons at or near to the source, one obtains a measure of the number of hydrogen atoms present. It is also a fact that this scattering and slowing down process is practically independent of whether or not the hydrogen is bound chemically. In particular, it is independent of whether water, which contains two hydrogen atoms per molecule, is in the vapor, liquid, or solid state.

Such a device for measuring the moisture content consists, then, of a source of fast neutrons, e. g. , a mixture of radium and beryllium or polonium and beryllium, a detector for slow neutrons, rigidly placed near the source, e. g. , a silver or rhodium foil or a boron counter; and an electronic device for counting and, if desired, recording the number of slow neutrons reaching the detector per second. Such an assembly of source and detector can be lowered into a small diameter (1-in.) metal tube placed in the soil and can be connected by a cable to the counting mechanism, which is placed above the soil surface.

To measure density of soil the scattering properties of gamma rays can be used. If gamma rays emitted by a source, e. g. , radium, pass through a material, these rays are scattered as a consequence of their interaction with the atoms of the material. The stronger the scattering, the greater the number of electrons are contained in an atom. The number of electrons is proportional to the density of the substance; a heavy substance scatters more than a light one. Here again, the method is to measure the gamma rays scattered back from the material to the vicinity of the source. In the case of gamma-ray scattering, the theory of the effect has not been as well studied and the phenomenon is very complex.

This apparatus for the determination of the density, then, consists of a gamma-ray source, e. g. , a weak radium preparation; and a detector for gamma rays, e. g. , a Geiger counter mounted at a well-defined distance from the source, and shielded from the source by lead in order to prevent direct gamma rays from the source reaching the detector. This assembly is mounted so that it can be lowered in a metal tube connected by a cable to an electronic-count-rate meter.

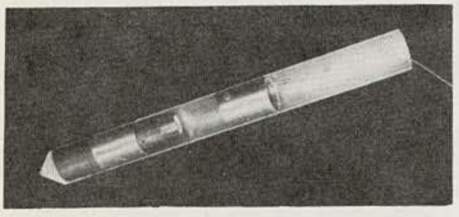

Figure 1. Photograph of Assembly Used in Moisture Determinations. The center foil holder has been partially pulled out so as to make visible the neutron source and its support.

Since the theoretical consideration of scattering of neutrons and of gamma rays under these conditions presents a difficult problem, counting rates cannot yet be calculated in advance for a specific arrangement. Therefore, it is necessary to obtain a calibration curve to relate the readings with the actual moisture content or with the density.

The laboratory experiments and the field tests have been made with the simple arrangements described above. Where this method is given special application in the field or laboratory, adjustments in instrumentation would be necessary. Since the art of detecting and measuring neutrons, gamma rays, etc. , is advancing rapidly, developments in this field will be of help in the consturction of future instruments. The results obtained with the equipment, as developed so far (May 1950) are sufficiently significant to permit a judgment of the usefulness, minimum accuracy, and the possibilities of this new method.

Figure 2. Photograph of Assembly Used in Density Determinations.

Experimental Laboratory Procedure

A program of laboratory experiments was set up to determine if the number of low energy neutrons scattered back from the soil mass surrounding the neutron source could effectively be used as a measure of soil moisture.

Studies were made in soil masses of various sizes in order to correlate the laboratory measurements, involving limited volumes, with field observations where an infinite soil mass prevails. Studies with glacial drift were made on samples built up in 55-gallon drums so that stones of various sizes could be placed at a series of known locations.

The moisture content of the soil mass was determined by taking several, usually four, samples from different positions in a drum and then weighing and drying them in the standard manner. The density of the soil was determined from the net weight of the filled drum and its volume.

A measure of the number of slow neutrons was obtained by placing one or more small

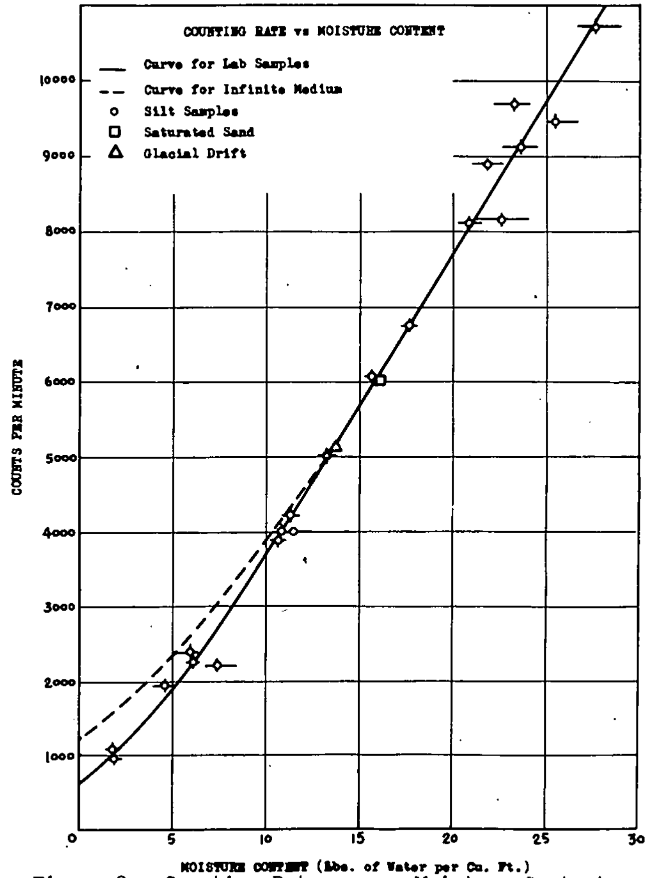

Figure 3. Counting Rate versus Moisture Content.

cylinders (7/8-in. diameter by 1-by 0.003-in. wall) of rhodium-metal foil (subsequently changed to silver, resulting in a decreased time of measurement and less cost) within the soil mass and subsequently measuring the degree of radioactivity induced in the foil by its selective capture of slow neutrons. This method is simple, dependable, and requires a minimum of expensive equipment.

An assembly consisting of a neutron source and suitable holders for the foils was inserted into the aluminum tube and lowered to the desired position. After the foil detector had reached "radioactive equilibrium" the foils in its holder were rapidly withdrawn and slipped over a Geiger counter mounted inside a lead shield provided to reduce background counts. 1/ The degree of activity of the foil, proportioned to the slow neutron intensity at the place where the foil had been exposed, was determined from the rate at which beta rays from the foil cause the counter to count. The counting rate, in counts per minute, properly corrected for background counts, was then plotted for successive experiments as a function of the soil moisture and a calibration curve for the soil was thus obtained.

In order to obtain precise results, the time interval between removal of the detector foil from the proximity of the source and the time at which counting of the foil activity is started must be determined by stop-watch technique, and be held constant to about $\pm$ 1/2 second.

The special equipment employed was a neutron source, a Thyrode 1B85 Geiger counter

1/ Extraneous radiation from contamination; cosmic rays, etc., cause a certain number of residual counts.

manufactured by the Victoreen Instrument Corporation, a Model No. 161 pulse amplifier and scaler manufactured by the Nuclear Instrument and Chemical Corporation, and an ordinary telephone message register.

A polonium-beryllium mixture, having very weak gamma-ray emission, was used as a neutron source. For these tests it was possible to locate it adjacent to the neutron source. Then the Geiger counter continuously recorded the beta activity built up in the foil under the impact of slow neutrons and thus a continuous automatic reading can be taken. A polonium-beryllium mixture decays to one-half its initial strength in about four months.

Since radioactive processes are random processes, the experimental precision is determined by the total number of counts. In fact, if N is the number of counts taken during a given experiment, $\sqrt{N}$ is the mean error attached to this measurement, and, therefore, $\sqrt{N}/N$ is the percentage error. In most experiments approximately 16,000 counts were taken for maximum moisture (saturation) with the percentage error of the order of 1 percent and accordingly higher for fewer counts (lower moisture). It is doubtful whether the overall precision was as good as 1 percent because the stability of the counter tube and other equipment was probably not better than 2 percent.

Since there is always the possibility of changes in sensitivity of the counter tube, or of the amplifier system, it is essential to check the arrangement from time to time. For the moisture measuring device this is achieved by inserting the assembly in a water-tight tube rigidly centered in an ordinary pail filled with water. At regular intervals a check was made by inserting the assembly into this block. During the ordinary lifetime of the counter tube the results obtained with the standard were always the same within the statistical error.

The assembly for the measurement of density consisted of a 4-millicurie radium source and a Geiger counter of the type described above. The assembly was lowered into the tube penetrating the soil mass, and the counting rate determined at the desired position in the soil by the same counter, scaler, and register. In order to calibrate the system, a very weak source of gamma rays was placed in a rigorously reproducible position with respect to the Geiger counter.

Figure 1 shows the assembly used in the moisture determination; the tube has been cut away to show the arrangement of the neutron source on its support, the lower foil holder, and the center foil holder, partially pulled out to make the source visible. Figure 2 shows the assembly for density measurements; the conically terminated lead cylinder between the source and counter tube can clearly be seen.

Results of Laboratory Tests

Moisture Content - In the diagrams shown, the length of the vertical line indicates the probable statistical error of the readings while the horizontal lines indicate the range of the moisture determinations obtained by the standard method.

(1) Sensitivity, Accuracy, Reproducibility - From Figure 3, which shows the results of a great number of measurements with silt taken over an extended period of time, it is clear that the sensitivity of the method is more than adequate. It can be seen that these points lie on a smooth curve within the error of the moisture determination and that the statistical precision of the counting rate is higher than the precision of the ordinary moisture determination.

Since this method measures moisture content in lb. of water per cu. ft. of volume, the comparison of these results with the moisture content expressed in percentage of dry weight requires that the density of the material be known. Under normal conditions, when the density remains constant, the density factor can be eliminated by taking one moisture observation and then converting the calibration curve into counting rate versus moisture in percentage of dry weight.

(2) The effect, if any, of the type of soil on the shape of the curve (Fig. 3) has not yet been thoroughly explored. However, Figure 3 includes results obtained with sand and glacial drift to show that the influence of the type of soil is negligible.

(3) Since this method is based on a scattering process and since this scattering

takes place over some reasonable volume, the results given by this method will represent an average moisture content over a more or less extended volume. It is important to investigate the order of magnitude of the effective volume. For low moisture contents the volume over which an average is taken is greater than that for higher moisture contents. Experiments in drums of different sizes have shown that for a moisture content higher than 13 lb. water per cu. ft. any increase of size beyond a 17-in. diameter does not increase the number of counts, but for low moisture contents the number of counts increases slightly if a bigger drum is used. In order to compare laboratory results directly with field tests in which the soil-medium is infinitely extended, a correction to the curve, Figure 3, must be applied. Though the laboratory measurements are not quite precise for this purpose, a corrected calibration curve can be drawn and is seen in Figure 3 as a broken line. This, then, would be the calibration curve that holds for field tests. The calibration curve and the correction for the extended soil-medium will change with changes in the geometric arrangement of source and detector, and the

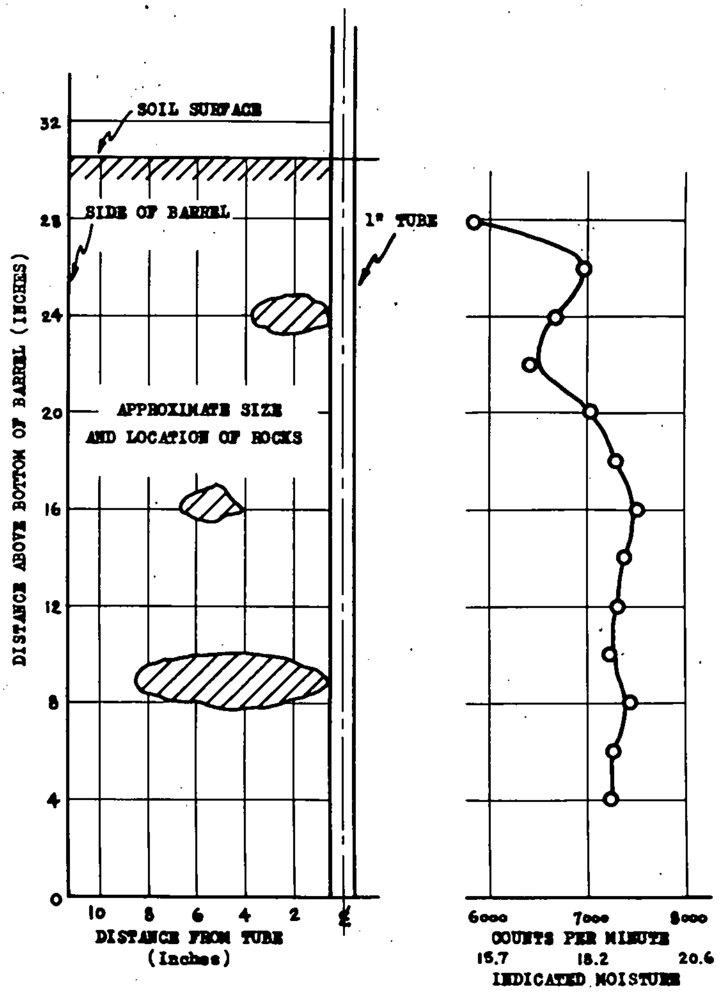

Figure 4. Cross Section and Moisture Curve Showing Influence of Rocks in Glacial Drift Soil.

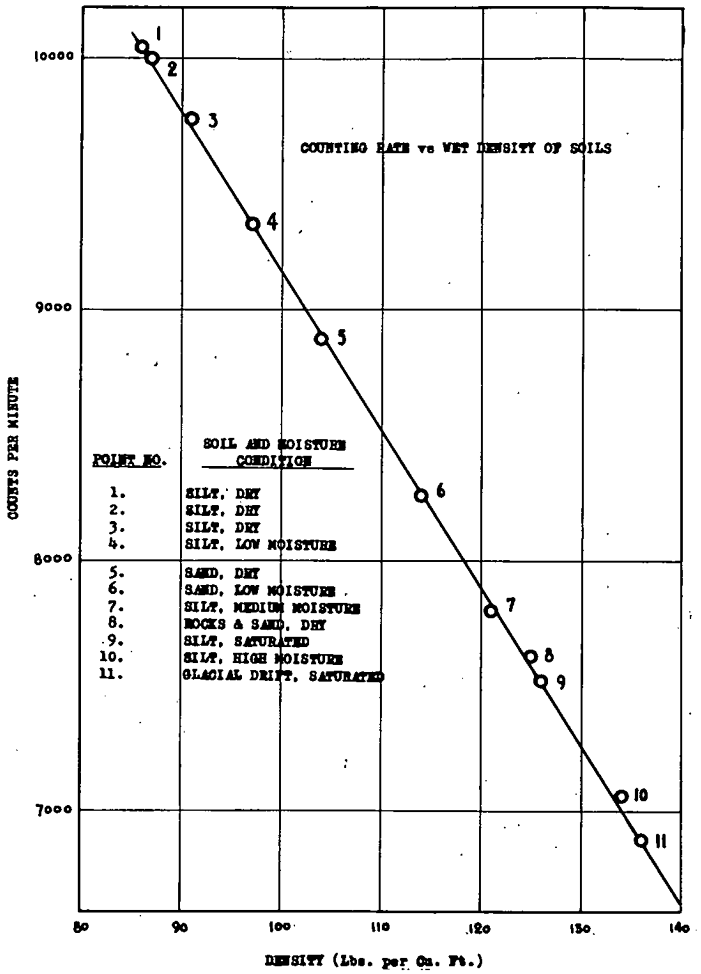

Figure 5. Counting Rate versus Wet Density of Soils.

wall thickness and material of the tube. The curve given in the figure is obtained with the detector foil centered around the source and with an aluminum tube of 1/32-in. wall thickness.

(4) A further point of importance is the influence of inhomogeneities; rocks, for example. Several curves 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 tube. Figure 4 shows the variations of the counting rate as the measuring device was moved up or down. The location and size of the rocks is also indicated. Since this method gives an average of moisture content over moderately large volumes, it can be expected that the influence of inhomogeneities is small; in fact, it can be seen from Figure 4 that, though some fluctuations are present, the indicated moisture is still within 1.25 lb. (1 percent dry weight) of the average.

(5) It can be expected that in certain parts of the country a considerable amount of salt will be present in the soil. Chlorine, one of the main constituents of the inorganic salts which may be present, shows a strong interaction with neutrons; it "captures" them, and thus reduces the number of neutrons that can reach the detector. If chlorine is present the use of the normal calibration curve (Fig. 3) will result in an incorrect (low) moisture determination. The effect of the salt is relatively small and since the amount added in these experiments is much higher than can be reasonably expected in the field, it can be assumed that the presence of salts will not influence appreciably the

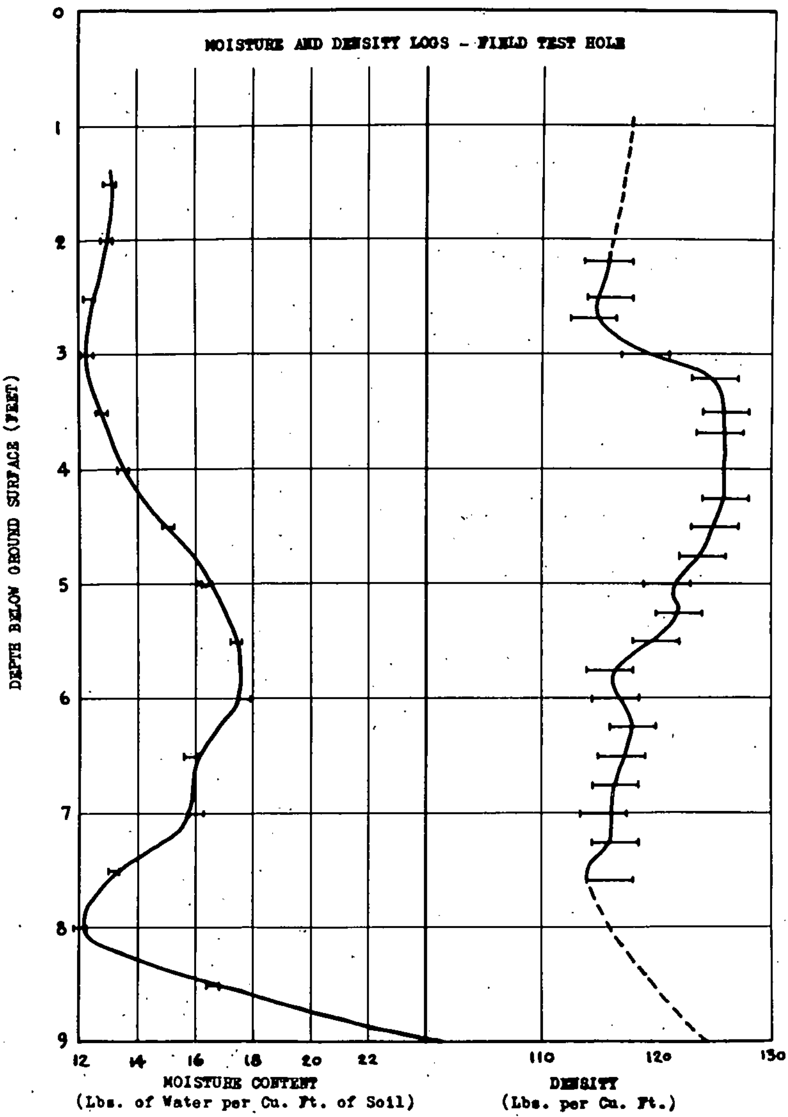

Figure 6. Moisture and Density Logs - Field Test Hole.

precision of the measurements. If more salt is present than in saline soils, a new calibration curve should be made.

(6) Another factor that may alter the calibration curve is the presence of organic matter in the soil. Organic matter contains hydrogen (in the form of hydrocarbons, for instance) and since the new method cannot distinguish between hydrogen in water or in any other chemical compound, an excessively-high counting rate may be observed. Measurements of a sample of a high ground-water soil with a highly developed organic top soil containing about 75 percent moisture gave a reading that fell on the calibration curve, thus showing that the influence of organic matter, to the extent present in this soil sample, at least, was negligible.

(7) Some preliminary experiments were made with the objective of investigating the ability of this method to differentiate between different moisture contents occurring in relatively thin horizontal strata. By means of a particular arrangement of source and detector, it was possible to measure accurately the moisture content of a layer of 4 to

6 in. , independently of the moisture content of adjacent layers, provided the measured layer was not too dry. There are a number of other possibilities, such as shielding arrangements, and variations in the geometry of the assembly that may still further improve the usefulness of this method for the study of thin layers.

Density

Figure 5 shows the counting rate as a function of density observed with various types of soils of various moisture content. The fact that the counting rate decreases as the density increases is consistent with the simple theory of gamma-ray scattering. This figure shows that the sensitivity of this method is very great. The results are reproducible within the statistical error.

Again, this method measures the density as an average over an extended volume. Experimentation with drums of various sizes and with one arrangement of source and Geiger counter shows that for soil weights greater than 85 lb. per cu. ft. this region is less than 18 in. in diameter. However, the experiments indicate that the phenomena are much more complex in the case of gamma-ray scattering than obtains for neutron scattering ; accordingly, some details have still to be clarified, although as a whole, the method seems to be practical.

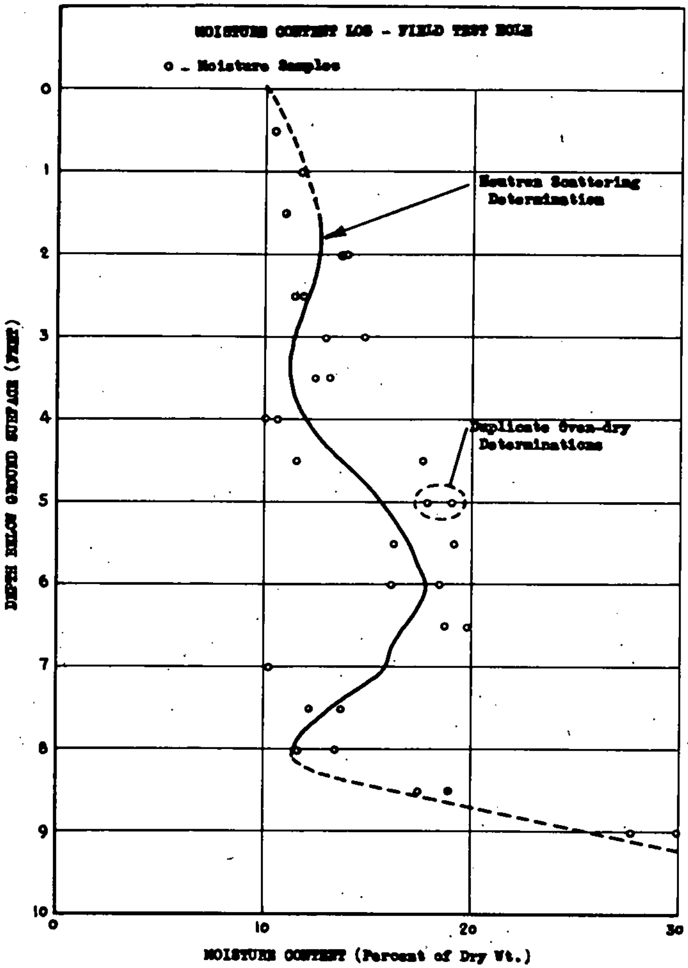

Figure 7. Moisture Content Log - Field Test Hole.

Field Tests

Two sets of tests were made to check the performance of the new device under field conditions. In the first test the manually-operated laboratory equipment was used to explore the profile of a soil to 9 ft. below the surface. In the second test, exploring a soil-layer 4 ft. thick, automatic equipment especially designed for this purpose was used, and the counts were telemetered from the field station to the laboratory where the results were automatically recorded.

Tests with Manually-Operated Laboratory Equipment

For this test a place was selected approximately 100 ft. from the building where the laboratory tests were performed. Excavation at the site subsequent to the measurements showed that the soil consisted of a 4-ft. layer of gravelly loam underlain by medium sand with occasional minor strata of sandy clay approximately 1 in. thick, which turned at about 8 ft. into clean sand down to the water table at 9 to 9.5 ft. A 9-ft. stainless steel tubing, 1-in. inner diameter, 1.25-in. outside diameter 2/, was provided on one end with a solid point. A hole was drilled with an auger down to approximately 6 ft. The steel pipe was inserted into this hole and then driven down for the remaining 3 ft. In the drilling, the auger struck rocks in the upper horizon resulting in a loose fit between the outside of the steel pipe and the soil. This space was filled with sand as well as possible. While drilling the hole, soil samples were taken at regular intervals for weighing and drying. For the moisture determination the assembly used in the laboratory test was lowered into the hole and observations were made at different predetermined positions. In the most complete run, measurements were taken every 6 in. After each exposure of 1/2 hr. the foil was withdrawn and quickly carried to the counting device in the laboratory. Care was taken that always exactly the same time (60 seconds) elapsed between the withdrawal of the foil and the beginning of the counting. For the density measurements the count-rate meter was placed near the hole and the density-measuring assembly (Fig. 2) directly connected by a coaxial cable, so that readings were taken on the spot. Several runs were taken on different days.

The observations expressed in counts per minute were transformed by means of the laboratory calibration curves into values of moisture content in lb. water per cu. ft. of soil and into soil density in lb. per cu. ft. These results, plotted as a function of the distance below the surface, are shown in Figure 6 for measurements made on one particular day. Other runs, made within one or two days during which there was little probability for a change in moisture, gave practially identical results.

In order to judge the reliability of this method, it was necessary to compare the results with moisture and density determinations made by standard methods. For this purpose, a hole, 4 ft. by 3 ft. by 9 ft., was excavated. As the hole was excavated, one or two samples of approximately 75 grams were taken every 6 in. for the moisture determination. In order to determine the density, a steel tube, 8 in. long and 3 in. in inner diameter, was pressed to its full length into the undisturbed wall, at a given depth, and then carefully taken out without disturbing the soil contained in the tube. The weight of the soil withdrawn, divided by the volume of the tube, was taken as the soil density in that region. The unit weights thus obtained at four different depths were, in general, lower than those obtained with the new device, the maximum difference being 10 lb. per cu. ft. This is ascribed to the fact that the volume used in the direct method is too small for obtaining a good average, particularly in the locations where stones are present.

The moisture content, expressed in terms of lb. of water per unit weight in Figure 6 has been transformed into units of moisture content expressed as a percentage of dry weight by means of the density values taken from the density curve of Figure 6. This more conventional curve is shown in Figure 7 where the smooth curve represents values determined by the neutron device; the symbols represent moisture as given by

2/ Tubes of different wall thicknesses may yield different calibration curves.

the standard technique. This figure demonstrated that, within the spread of values obtained by sampling, good agreement is obtained. It is not clear whether the "smooth" aspect of the curve from the nuclear device, as compared to the variation of the standard measurements, is due to inherent difficulties of the drying and weighing method, or it is a result of the fact that the nuclear device reads an average moisture over a radius of perhaps 6 in.

Radiation Hazard

Government regulations for the handling and shipping of polonium-beryllium sources do not require any special safety measures. The gamma-ray source used in the density measurements was much too weak a source to require special handling. Nevertheless, the personnel on this project were warned not to carry either of these sources unshielded in the pocket or otherwise in close contact with the body.

Summary and Critical Evaluation of Laboratory and Field Tests

Moisture Determination - The neutron-scattering method proves to be a reliable method for determining, without disturbing the soil mass, the moisture content. The precision ± 1 lb. water per cu. ft. or better, corresponding to about ± one percent moisture content.

The method lends itself to practical measurements in the field without giving rise to any essential difficulties.

The results obtained are averages over a radius of approximately from 6 in. for high to 15 in. for low moisture contents, a fact that should be kept in mind in analyzing the readings obtained by this device.

The method permits exploration of the profile by simple movement of the measuring device inside a tube.

Different soils seem to have the same calibration curve although this fact has still to be thoroughly established. The calibration curve obtained by laboratory experiments can be used for measurements in the field.

Inhomogeneities, such as ordinary rocks in glacial drift, do not introduce serious disturbances.

Addition of salts or humus in quantities encountered under normal conditions will not alter the calibration curve.

With the present equipment variations of moisture occurring within a time interval as short as 1/2 hour can be detected.

By using a polonium-beryllium source, readings can be continuously and automatically recorded and telemetered from the test site to a central station.

Density Determination

The gamma-ray scattering method proves to be a reliable method for determining density without disturbing the soil mass, at least if care is taken that the placing of the tube does not disturb the soil mass near the tube. This sensitivity to soil disturbances near the tube can be minimized by changing the geometric arrangement of the source-detector assembly.

The precision, at present, is ± 2 lb. per cu. ft.

The readings represent averages over a radius of less than 9 in.

The method lends itself to the continuous exploration of profiles by moving the measuring device inside a tube penetrating the soil. The readings may be telemetered and automatically recorded.

The calibration curve is independent of the type of soil.

Small inhomogeneities, such as rocks, do not seriously disturb measurements, provided they do not occur in the immediate proximity of the tube. There is hope that this shortening can be overcome.

Summarizing, it can be said that both methods have proven themselves in laboratory and field tests and promise to become satisfactory and very useful tools for the measurement and continuous recordings of moisture content and density of soils.

Field and Laboratory Applications

The progress in research leading to improvements, refinements and special applications is rapid. In two months' time major alterations have been made to produce a greater accuracy and a reduced time of measurement. In that same period the problem of radiation hazard has been virtually eliminated by the use of the polonium-beryllium as a source rather than radium.

These improvements and experimental application to various problems has shown that the existing apparatus is suitable for locating seepage zones as they are found in landslides, dams and in drainage investigations. Special adaptations have shown that moisture control in concrete aggregates can be exercised in batching plants and the density obtained by compaction quickly determined in the course of the work.

WATER IN HIGHWAY SUBGRADES AND FOUNDATIONS

F. N. Hveem, Materials and Research Engineer, California Division of Highways

The structural integrity and endurance of almost every engineering work is jeopardized by the action of water. The permanence of relatively perishable materials, if protected from moisture, is illustrated by the ancient buildings, manuscripts, fabrics, and even cereal grains preserved for thousands of years in Egypt, which of course, is noted for the dryness of its climate. The rapid deterioration of all things in a warm, humid climate points the contrast.

In its simplest form then, one of the major problems confronting the civil engineer is the necessity for guarding against or combating the deleterious effects arising from the action of water upon the materials of construction. Everyone is aware of the more spectacular attacks of water, such as the destructive wave action along the shores of oceans and lakes and the washing out of bridge piers or damage to embankments by rivers during flood. The necessity for providing waterproof roofs and protective coatings on most buildings and structures is common knowledge. Engineers have also recognized that water has an adverse effect upon the ability of soils to serve as foundations for dams, buildings, and even pavements for highways and air fields.

A great deal has been written on the subject of bearing or supporting power of soils, and it may be significant to note that this particular field of engineering is generally classed under the heading of "soils mechanics." When a mixture of sand and gravel is mixed with a liquid such as asphalt for the purpose of producing a pavement, such mixtures are invariably referred to as bituminous mixtures or asphaltic pavements, even though the amount of asphalt present commonly does not exceed 5 or 6 percent by weight of the total mass. When considering the properties of soils or granular base materials, however, engineers rarely mention that they are dealing with a water-soil combination even though the water content commonly ranges between 5 and 30 percent of the weight of soil.

Narrowing our attention to the special problems surrounding the construction of adequate bases and foundations for pavements, we are forced to conclude that the fundamental relationships depend almost entirely upon the effects of water upon the particular soils in place. The long history of pavement failures due to foundation troubles and inadequate soil support casts no particular credit upon the engineering profession, and when such failures continue to reoccur, it is evident that there is a lack of understanding and probably insufficient knowledge of the mechanism by which water is introduced into the soil and of its effects when present. The fact that water is responsible for most of the troubles has, of course, not been entirely overlooked, because texts on highway engineering have stressed the importance of drainage, and for a great many years it has been the practice to provide drainage structures, road-