PAVEMENT DESIGN AND PERFORMANCE STUDY
PHASE B: DEFLECTION STUDY

Interim Report No. 5

Nuclear Measurement of Subgrade Moisture

by

Dr. N. K. Vaswani
Principal Highway Research Engineer

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

Virginia Highway Research Council
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SUMMARY

The basic consideration in evaluating subgrade moisture conditions under pavements is the selection of a method of determining moisture contents that is sufficiently accurate and can be used with minimal effort, interference with traffic, and recalibrations. In the present study, the electrical resistance method and a nuclear method were tried, and the nuclear method was adopted. The devices and procedures used in both methods are described. Modified methods for eliminating errors in the measurement of moisture by nuclear depth probes were tried and some of these are recommended for use. A method of reducing the standard error of estimate in the use of a nuclear calibration curve for moisture content by utilizing the sieve analysis of a soil is discussed.

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PURPOSE AND SCOPE

The strength of a pavement is greatly influenced by the moisture content of the subgrade. It is therefore essential to determine the changes in the subgrade moisture and the factors contributing to these changes.

In this investigation it was proposed to establish a technique for measuring subgrade moisture under pavements with sufficient accuracy and minimal effort, interference with traffic, and recalibrations.

It was also proposed to determine the details of the method recommended.

METHODS TRIED

The electric resistance and the nuclear methods were considered as two possible alternatives for measuring the subgrade moisture of roads under traffic. The former method has the advantage that it does not interfere with traffic after the moisture cells are installed. With the latter method, there is a slight interference with traffic when measurements are made.

In the electrical resistance method each of the cells must be calibrated before it is embedded in the subgrade and the calibration curve for each cell is different. This is not so with the nuclear method, which therefore is easier to use.

Both the methods were tried in this investigation and are discussed in the following pages.

ELECTRICAL RESISTANCE METHOD

In the electrical resistance method, dielectric type moisture cells (two plates separated by a processed glass binding) are commonly used. In this investigation, dielectric cell No. MCB10A, supplied by Soil Test Incorporated, was employed. This cell, which is approximately 1" x $1\frac{1}{2}$" x 1/8" thick, also encloses a small thermister for temperature measurements. The electric resistance offered by the cell varies with the moisture content around it and each cell must be calibrated independently.

These cells were calibrated in the laboratory by separately embedding each one in a compacted soil obtained from the field site at which it was to be located. The laboratory compacted cells were subjected to one initial wetting and drying cycle and then calibrated through one to three cycles. All cells showed hysteresis with decreasing and increasing moisture content and with the number of cycles, as shown in Figures 1 through 4. This hysteresis would therefore lead to misleading moisture measurements depending on whether the moisture content was decreasing or increasing and on the cycle number.

For the field measurements, the cells were installed in a recently prepared subgrade at two locations. At each location six cells were used, two each at 6", 1'-6" and 2'-6" below the subgrade. The photograph in Figure 5 shows the installation of the cells. The cells were installed at various depths, with the lead wires going beyond the slope. Figure 6 shows the terminal box for the lead wires.

A few days after the subgrade was covered with soil cement, at one location the cells did not provide readings and at another the readings were highly erratic. In the latter case, the thermisters in the cells gave very consistent readings. In spite of the inconsistency in the moisture cell readings the measurements were continued for about two months but to no benefit.

This method of moisture measurement was therefore abandoned and nuclear moisture measurements were undertaken.

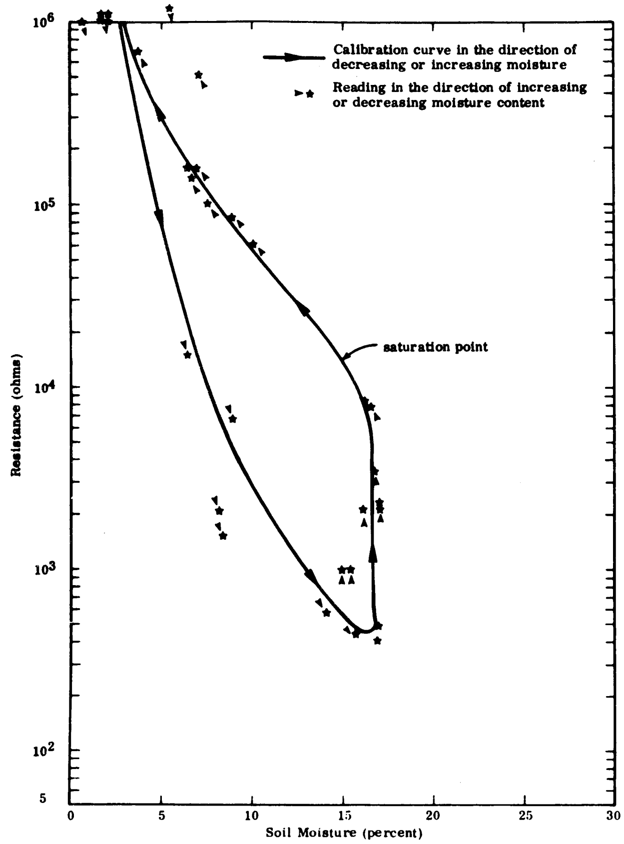


Figure 1. Dielectric moisture cell No. 1 in sandy soil.

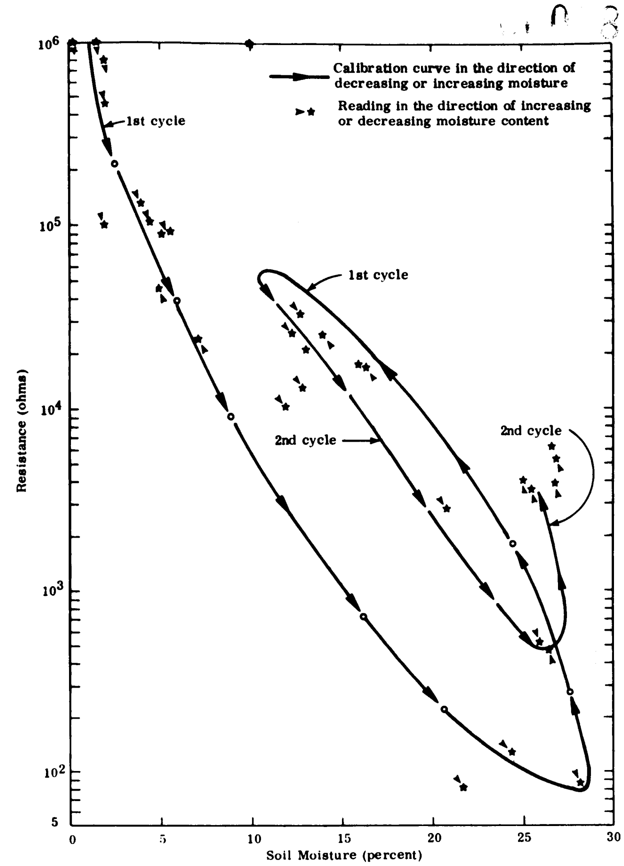


Figure 2. Dielectric moisture cell No. 7 in silty micaceous soil. (Location No. 14)

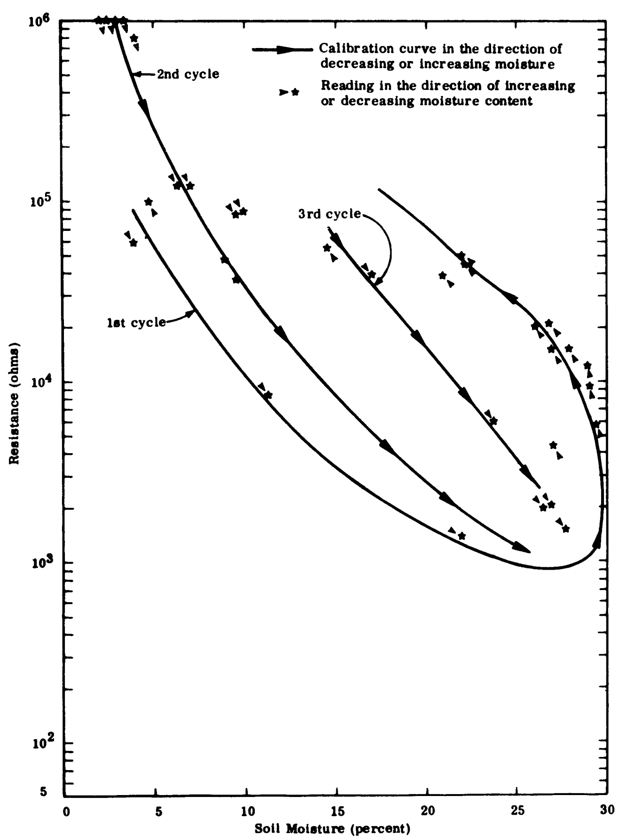


Figure 3. Dielectric moisture cell No. 8 in silty micaceous soil. (Location No. 14)

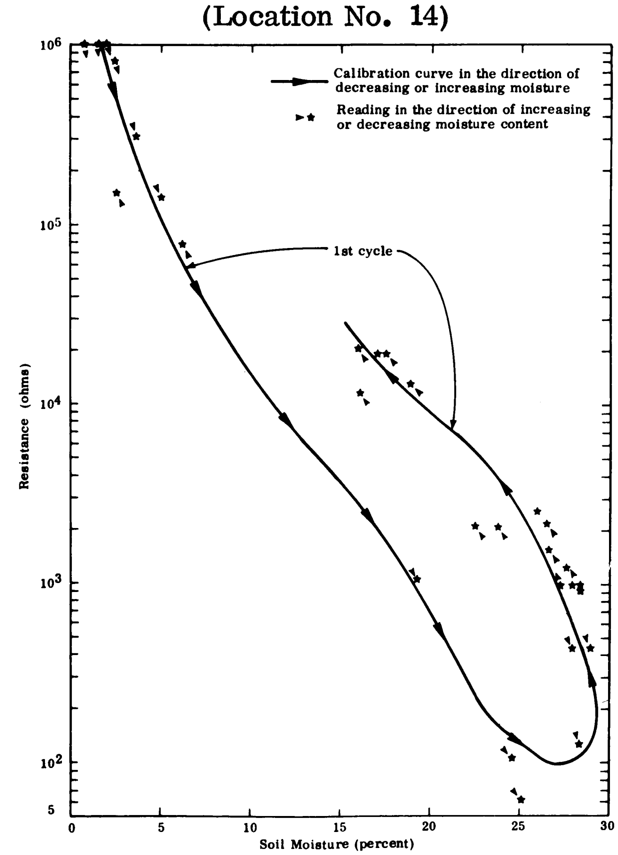


Figure 4. Dielectric moisture cell No. 10 in silty micaceous soil. (Location No. 14)

Figure 5. Lead wires from embedded cells.

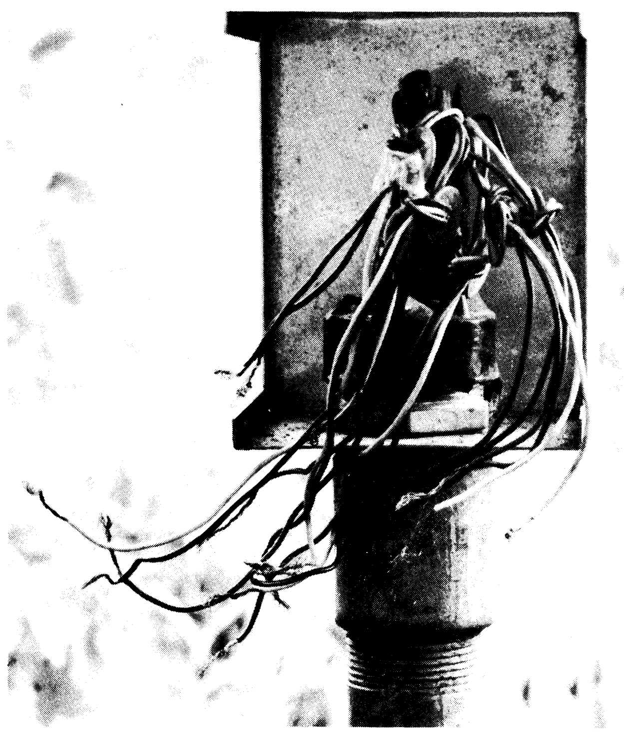


Figure 6. Terminal box with lead wires.

NUCLEAR SUBSURFACE MOISTURE MEASUREMENT

The method and technique of determining nuclear moisture contents under pavements could be divided into three parts as follows: (1) equipment, (2) installation of access tubes, and (3) procedure for calibrating curves. They are described below.

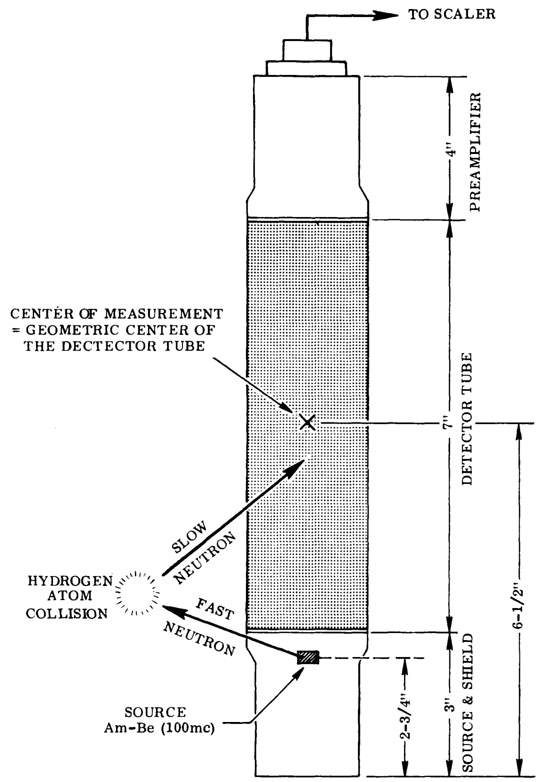
Equipment

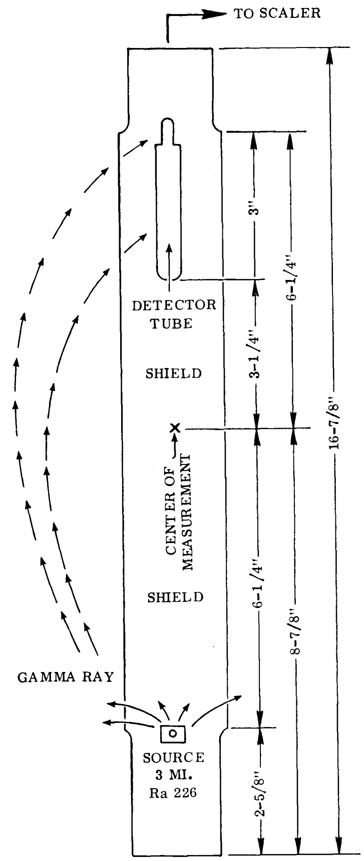
The equipment consists of a nuclear depth density probe and a nuclear depth moisture probe. One scaler is used to determine the readings for both probes. A calibration curve for the density probe is determined to give the wet density of the soil from the readings recorded by the scaler. Similarly, a calibration curve for the moisture probe provides the moisture content of the soil in pcf. Taken together, these values will give the percentage moisture content of the soil. Both nuclear probes are described below.

Nuclear Probes

The Troxler model No. 1255 moisture probe was used for this investigation. It has a nuclear source of 100 mc Americium-Beryllium with a $B^{10}F_3$ detector tube. The nuclear source emits fast neutrons (energy 1,000 to 15 million electron volts) which after colliding with hydrogen atoms undergo a slowing down process. These slow neutrons have an energy less than 0.030 e.v. and are known as thermal neutrons. The $B^{10}F_3$ detector tube detects the thermal neutrons which are counted on the scaler through an amplifier. The probe is shown schematically and pictorially in Figure 7. When inserted through an access tube into the ground the detector tube records the count on the scaler in proportion to the amount of moisture in the soil around its geometric center. The ratio of this count to the standard count (i.e. with the probe in the shield) has a straightline relationship with the moisture content of the soil. The moisture content of the soil is in pcf of the wet soil.

In order to determine the percent moisture, the wet density of the soil has to be determined. For this determination a nuclear density probe that is similar in appearance to the moisture probe is used. The density probe used in this investigation was a Troxler model 504 having a 3 millicurie radium-226 source emitting gamma rays. The probe is shown schematically and pictorially in Figure 8. A ratio of the count with the probe in the aluminum tube to the standard reading with the probe in the shield is correlated with the wet density and a calibration curve drawn.





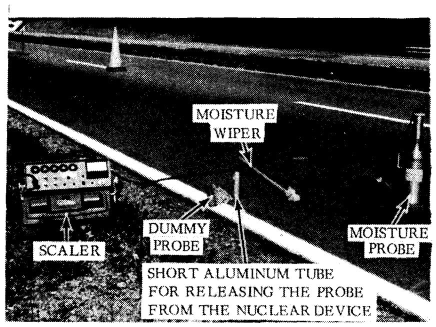


Figure 7. Nuclear depth moisture probe equipment.

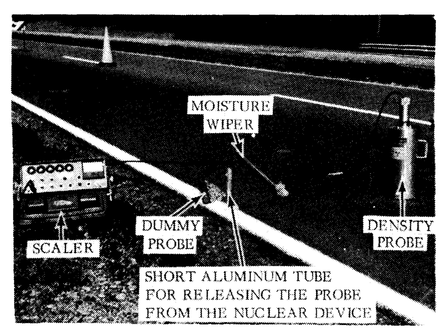


Figure 8. Nuclear depth density probe equipment.

Access Tube

The probe manufacturer recommends that in testing the probe be inserted into the subgrade through a thin-wall aluminum access tube. Aluminum is recommended because of its better nuclear properties (less interference) and its resistance to corrosion. Thin walls are recommended to reduce the effect of the metal through which the neutrons pass.

The probe diameter used in this investigation was 1.865 inches. To provide a minimum possible airgap between the probe and the inside wall, an aluminum access tube of standard class 150 with an inside diameter of 1.9 inches and outside diameter of 2.0 inches was used.

Installation

The installation of the aluminum tube should satisfy the following four requirements.

(1) The earth side walls should fit the outside of the access tube snugly so as to leave no airgaps.

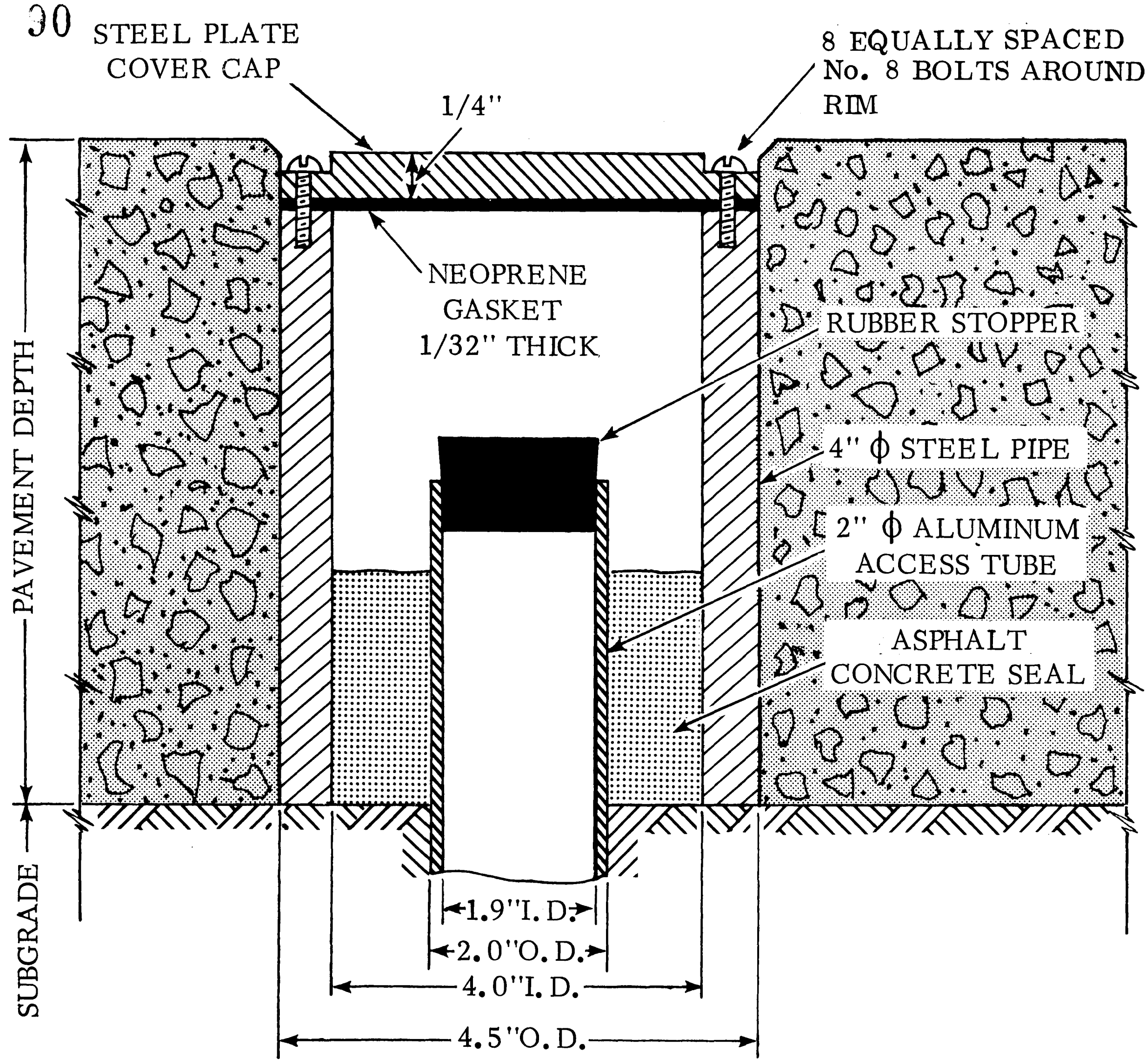
(2) Surface water should not be allowed to enter around the tube.

(3) The tube should be watertight.

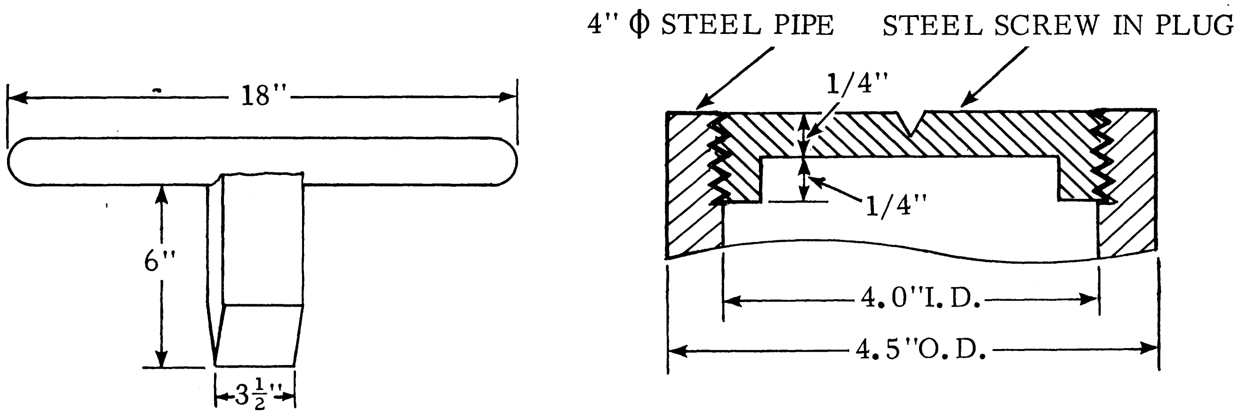
(4) The tube should be straight to allow the passage of a dummy probe.

Heilger and Haliburton[1] have discussed the different methods of installing the tube as suggested by the Highway Research Board and the methods used by the Colorado Department of Highways. Ehler, et al.[2] have used one method of installation and have suggested another method that uses a thin-walled sampler with an outside diameter equal to or slightly smaller than the access tube. The principle of their recommended method was used in this investigation.

In this investigation a split sampler with an outside diameter of 2 inches and a wall thickness of 0.125 inch was used to drill a hole in the ground and at the same time obtain an undisturbed sample. The sampler was driven by core drilling equipment mounted on a 3/4-ton truck. Since the sampler was driven not more than 6 ft. below the subgrade, soils consisting of disintegrated rock or those mixed with small gravel did not cause much of a problem. Sometimes the sampler would hit a large stone and that site had to be abandoned. After the hole was drilled and the split sampler removed, the access tube was pushed into the hole with the help of force obtained from the drilling equipment. A very snug fit between the outside wall of the access tube and the surrounding soil was obtained, which eliminated possible errors in measurement due to an air gap. The method of sealing the access tube is shown in Figure 9.



(a) Screw on cover plate.



(b) Slotted head screw in cover plate plug and driving wrench.

Figure 9. Method of sealing access tube from top of pavement or shoulder.

This method of installing the tube was found to be very satisfactory. The location of the tube is shown in Figure 10.

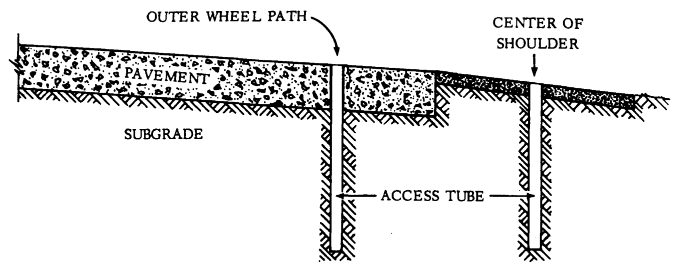


Figure 10. Location of access tubes.

Problems Encountered

A dummy probe having the same diameter as the nuclear probe was inserted into the pipe to verify the evenness of the tube. Sometimes the dummy probe got stuck and slight irregularities were removed by the free fall of the dummy. This practice might have cracked the side wall and allowed water to leak into the pipe.

In this investigation the rubber "o" rings were first tried for sealing the bottom of the pipe. This method is exactly the same as that used by Heilger(1) and Ehler.(2) When tested before installation, the seal was found to be watertight. After installation, some pipes were found to contain water. Another method tried was to weld a circular piece of aluminum 2 inches in diameter to the bottom of the pipe. In a few cases it was found that the water did leak into these pipes, too. Whenever the water leaked into the pipe, it was found that the pipe lay in soil which contained rock. It is guessed that the rock either punctured the pipe or ruptured the weld. The use of rubber "o" rings along with welding the 2-inch disc might prove to be a better solution. This method of capping is simpler and has presented no problems.

During summer, moisture from the air in the pipe would condense on the inside surface. To counter the condensation, a small cloth bag containing a desiccant was hung from the rubber stopper inside the tube. The desiccant did not absorb all the moisture, so this measure was abandoned and the moisture was wiped out with a rag fixed on the end of a rod.

Procedures for Calibrating Curves for Nuclear Density and Moisture Probes

After the access tube was inserted and tested for evenness, separate counts were made with the density and moisture probes on the soil around the top, middle, and bottom of the tube.

The undisturbed soil samples from the split sampler (as discussed previously) were used to determine the density, moisture content and physical and chemical properties of the soil at three levels, i.e., the top, middle and bottom of the hole, by conventional methods in the laboratory. The mercury displacement method was used for measuring the volume of a core piece and thus determining the density of the core samples. The density and the moisture content values of the core samples were used in the preparation of the calibration curves and the physical and chemical property values were used in evaluating the curves.

In addition to the data collected for the soils under the pavements as explained above, moisture data were collected on sites with access tubes installed in uncovered ground and pavement shoulders. The method used here for evaluating the moisture and density of undisturbed samples for each site was the same as for testing the soils under pavements.

The soils at each site, whether under the pavement or in the shoulder or uncovered ground, were evaluated at three levels i.e. 0 to 1 foot, 1 to 2 feet, and 2 to 3 feet. The soils were reevaluated at three months intervals. The three-month interval was adopted to allow for a change in moisture content around the access tube. Whenever such nuclear readings were taken under shoulders or uncovered ground a new hole of the same depth as the access tube was made in the ground at about 2 feet distance from the access tube and soil samples were obtained at the three levels. The moisture contents of the soil samples from this new hole were determined and plotted against the count ratios by the moisture probe measured for the same levels in the access tube. The correlation was made on the assumption that the moisture content and density of the soil around the access tube at any level are the same as the moisture content and density of the soil at the same level but 2 feet away from the access tube.

The holes formed by the soil samples taken for the moisture and density evaluation were filled with similar soil, compacted, and properly sealed to prevent entry of water.

By this means, density and moisture calibration curves were obtained for each site, as further discussed below.

The nuclear density probe count ratios were correlated with the wet density obtained by the conventional methods from the core samples in pcf for each site consisting of (1) test holes in uncovered ground, (2) test holes in the pavement shoulders, or (3) test holes under the pavements. Curves of the count ratios with the nuclear density probe versus wet densities for eleven locations — Nos. 1, 2, 4, 5, 6, 8, 11, 12, 13, 14 and 17 — are shown in Figure 11, along with the calibration curve obtained by a regression analysis of the 37 data points from these sites. The correlation coefficient between the wet density and count ratio is 0.82 and the standard error of estimate is 3.8 pcf. Because of its good correlation, this curve was adopted as a standard calibration curve for this investigation.

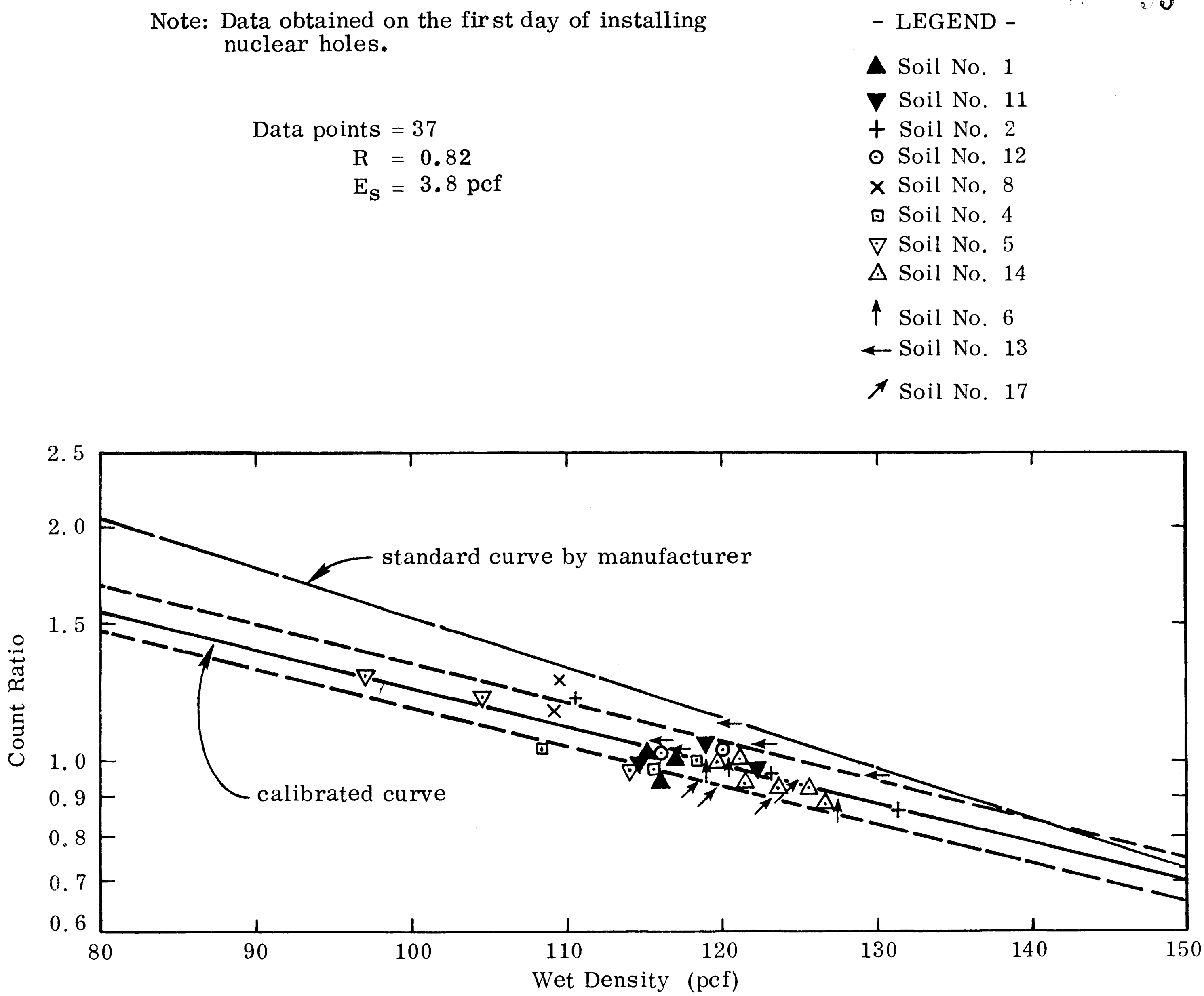


Figure 11. Calibration curve for nuclear depth density probe.

Nuclear moisture probe count ratios (C.R.) were correlated with moisture contents (M.C.) determined by a conventional method in the laboratory for each site consisting of (1) test holes in uncovered ground, or (2) test holes in the pavement shoulders, and (3) test holes under pavements. Curves of count ratios versus moisture contents for eleven locations — numbers 1, 2, 3, 4, 5, 6, 8, 9, 14, 15, and 17 — are shown in Figure 12, where the lines indicate the range of moisture contents measured. Not enough moisture data were available for the remaining site to enable a proper correlation.

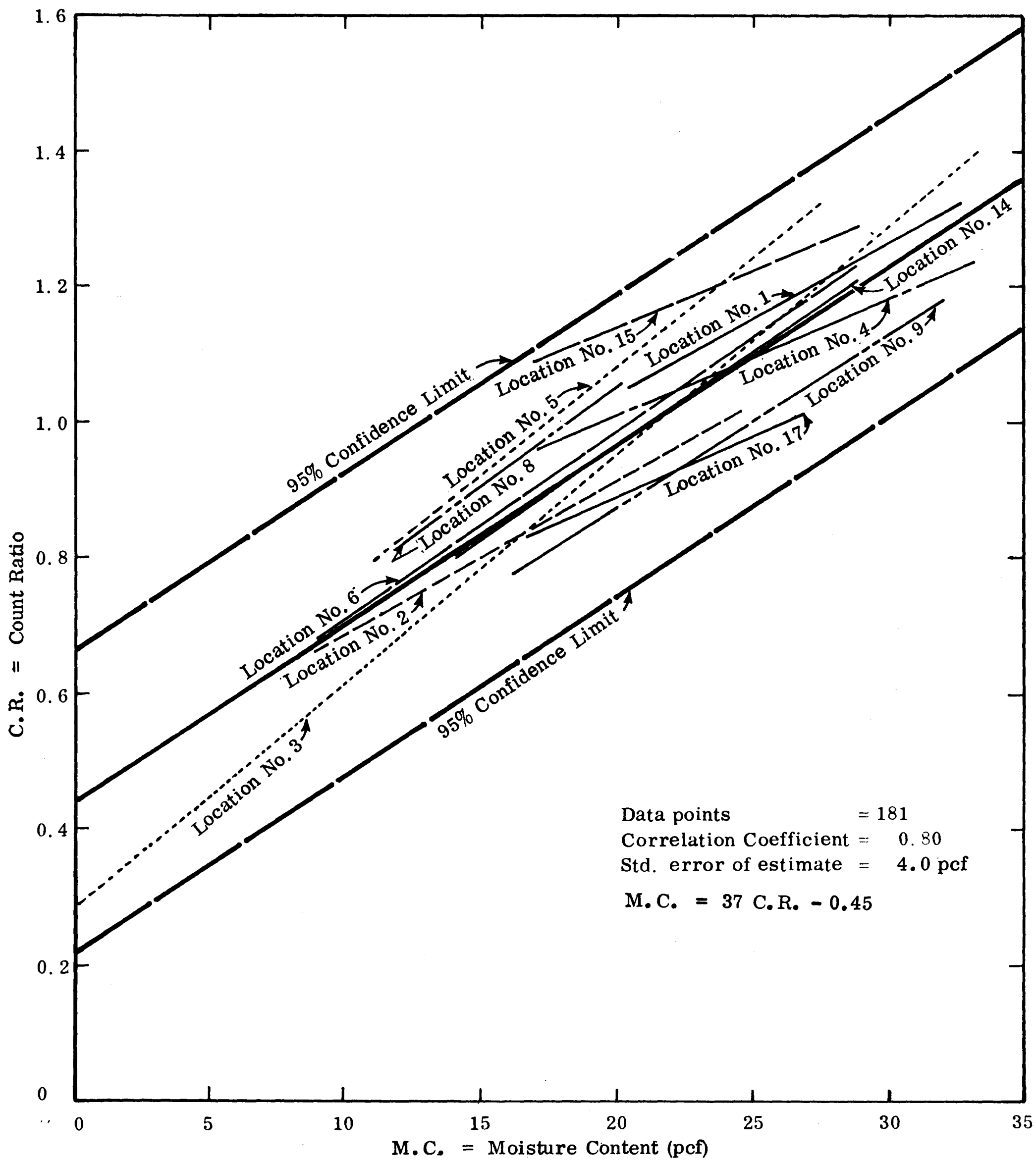


Figure 12. Moisture content (pcf) vs. count ratio for soils tested at site for different locations and their standard curve.

Data for all the sites shown in Figure 12, which amounted to 181 data points, were correlated by a regression method and the following equations were established.

	Moisture content	$= 37$ C.R. $- 16.67$	(1)
		$= 37$ C.R. $- 0.45$	(2)
where	M.C.	= moisture content in pcf, and	
	C.R.	= count ratio by nuclear moisture probe.	

The constant 0.45 is the mean value of the count ratio at zero moisture content.

Equations (1) and (2) have a correlation coefficient of 0.80 and a standard error of estimate of 4.0 pcf. This correlation is shown in Figure 12 by the thick solid line.

THE MOISTURE CURVE

The constant of 0.45 in equation (2) is a hypothetical value probably depending on the adsorbed moisture content, the gauge design, and maybe other unknown variables.

If each soil is taken independently, the standard error of estimate for each would be much less than that obtained by the use of the general curve for all soils. The use of separate curves for each soil would be very difficult in practice because each soil would have to be calibrated separately whenever an investigation with the nuclear moisture probe is made. To make use of the combined data for all soils and also to reduce the standard error of estimate, the following method is recommended.

Before discussing the recommended method it is essential to note that the curve for each soil location in Figure 12 is based on the data collected for a period of about two years and hence each curve almost covers the extreme changes in moisture content and gives the minimum and maximum values that could possibly be obtained for the soil in the field.

As is evident from Figure 12, each soil curve has a different slope and a different intercept value in the linear equation C.R. = a (M.C.) + b, where the slope "a" in the linear equations is modified and equated to that of the general curve for all soils as shown in Figure 13, then the use of the individual curve for each soil within its maximum and minimum values of moisture content (see Figure 13), would give much less error than the use of the general curve for all soils as shown by the thick solid line in Figures 12 and 13.

The use of separate soil curves as shown in Figure 13, even though their slope is known, is impossible unless their intercepts (in these cases count ratios at zero moisture content) could be determined. Research has shown that the nuclear count ratio for moisture content is dependent on the physical and chemical properties of the soil. In the following discussion a method is recommended whereby the nuclear count ratio at zero moisture content for each soil has been correlated with the particle size and density of the soil. The effects of the chemical properties on nuclear measurements for Virginia soils do not seem to be appreciable and hence are not considered. The chemical properties are discussed in the following pages.

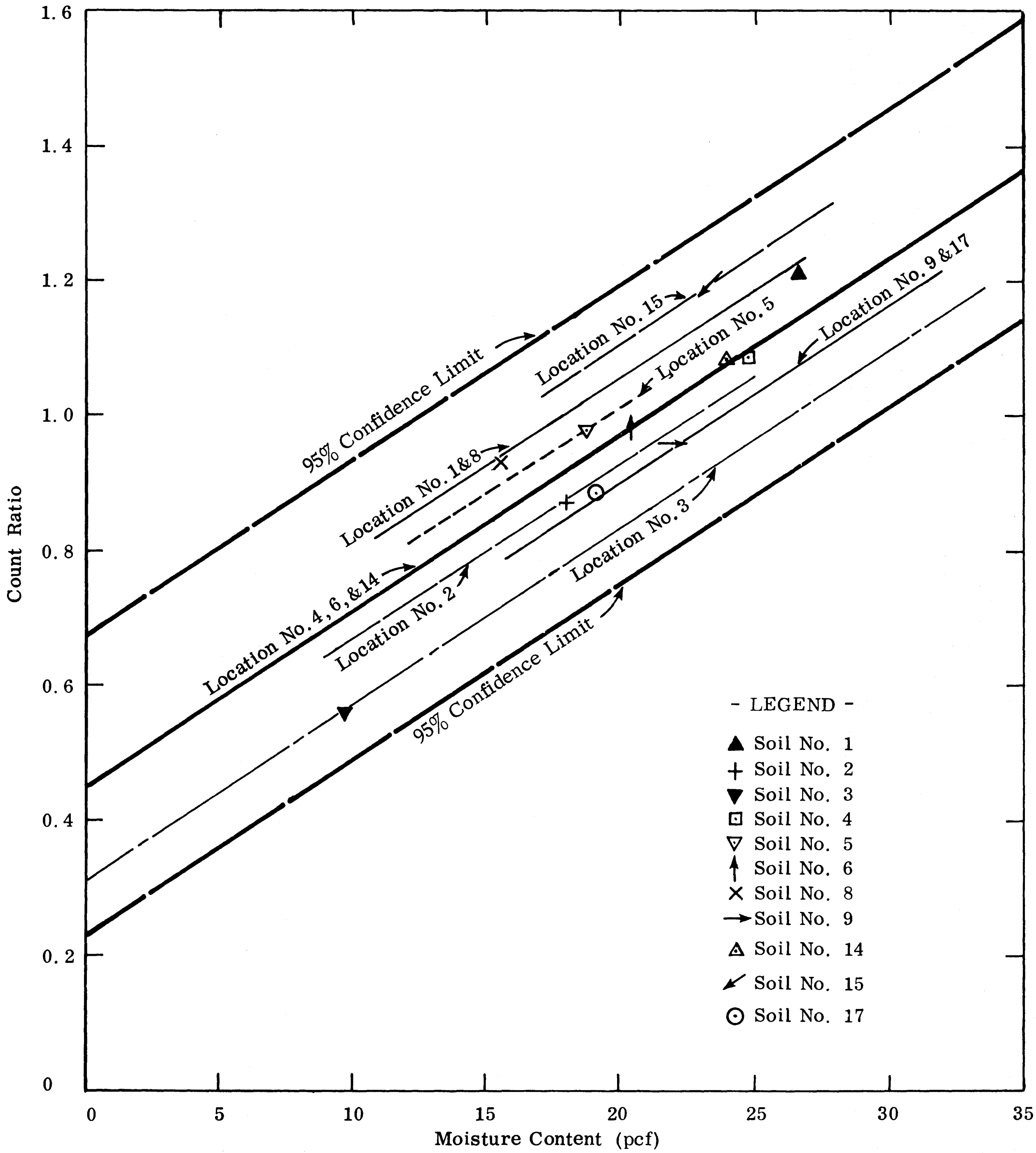


Figure 13. Corrected graphs of moisture content (pcf) vs. count ratio for individual soils.

THE RECOMMENDED METHOD

The intercept, b, of a calibration curve is a hypothetical value that probably depends on gauge design, particle size, adsorbed moisture content, etc. Stepwise multiple regression analysis was carried out for nine soil locations to determine the effect of particle size and dry density on the count ratio at zero moisture content. The model equation used for this analysis is as follows:

$$b = a_0 + a_1 r_d + a_2(\text{C.S.}) + a_3(\text{F.S.}) + a_4(\text{S.}) + a_5(\text{C}) \qquad (3)$$

where b = count ratio at zero moisture content obtained by extrapolation, r_d = maximum dry density or dry density of soil in situ, C.S. = percent coarse sand, i.e., P10 R40, F.S. = percent fine sand, S. = percent silt, C = percent clay, and a_0, a_1, a_2, a_3, a_4, and a_5 are coefficients whose values are to be determined.

The sieve analyses of the soils at the nine locations are given in Table 1. The nine equations based on model equation (3) with the dry density and sieve analysis values are given in Table 2.

The regression analysis of the nine equations gave the values of the coefficients which when plugged in equation (3) give the following equation: The coefficient a_3 for fine sand had zero value.

$$b = 0.5 - 0.00217(r_d) + 0.00596\,(\text{C.S.}) + 0.01030(\text{S.}) - 0.00672(\text{C}) \qquad (4)$$

Hence equations (1) and (4), when combined, could be written as follows:

$$\text{M.C.} = 37\ (\text{C.R.} - b) \qquad (5)$$

Given the dry density and sieve analysis of the soil, the value of b could be obtained by equation (4), the C.R. by the nuclear moisture probe and the moisture content by equation (5).

To verify whether this approach to evaluating the count ratio at zero moisture content could be used for another moisture measuring gauge of different design, nuclear moisture measurement data given by Anday and Hughes[3] were tried in the correlation. Anday and Hughes had carried out laboratory tests on ten soils collected from different regions of Virginia with a nuclear surface moisture measuring gauge which has a different design as compared to the depth moisture measuring gauge used in this investigation.

The plot of count ratio versus moisture content for different soils as given by them has been reproduced in Figure 14 with the suffix A used to differentiate the numbers of their soils from the numbers of soils used in this investigation. The equation of the general calibration curve based on regression analysis as given by them is as follows:

$$\text{M.C.} = 54.97\ (\text{C.R.}) - 17 \qquad (6)$$

TABLE I

PHYSICAL AND CHEMICAL ANALYSES AND ATTERBURG LIMITS OF SOIL

Soil or Location Number	Location	Physical Condition	Physical Analysis: Sieve Analysis - Passing 10	20	40	60	80	100	200	Silt	Clay	Atterburg Lts. L.L.	P.L.	Chemical Analysis: SiO_2	Al_2O_3	Fe_2O_3	K_2O	CaO	TiO_2	MgO	Na_2O	Loss 1000°C
1	Culpeper	Uncovered Gr.	100	98.2	96.7	95.3	94.3	93.6	90.9	40	45	53	38	38.7	--	19.7	0.2	--	--	--	--	10.5
2	Batesville	" "	100	91.7	85.4	--	73.1	67.9	54.8	25	31	0	0	--	--	--	--	--	--	--	--	--
3	Zion Cross Rds.	" "	100	97.1	93.1	87.7	85.7	83.7	76.9	31	41	41	28	64.7	15.9	7.7	1.0	0.1	1.5	0.2	1.3	6.5
4	Skibo Lodge, Ch'ville	" "	100	96.8	95.2	90.0	86.5	82.9	73.0	34	37	54	36	--	--	--	--	--	--	--	--	--
5	Airport - Albemarle	" "	100	96.0	87.6	77.2	71.0	66.3	52.0	29	24	41	35	--	--	--	--	--	--	--	--	--
6	Rt. 631	" "	100	95.8	85.1	77.5	70.3	70.0	61.8	29	33	46	30	59.7	19.6	8.0	2.3	0.1	16.5	0.4	0.4	6.8
7	Engr. Building	" "	100	98.2	96.2	92.4	89.2	86.6	78.8	20	57	58	36	--	--	--	--	--	--	--	--	--
8	Fredericksburg	" "	100	85.2	62.3	61.5	23.2	21.4	00.0	0	0	-	-	79.6	--	2.6	0.5	--	--	--	--	4.2
9	Gordonsville	" "	100	96.0	93.0	89.4	86.6	84.5	77.4	26	41	52	32	58.1	--	11.1	1.4	--	--	--	--	7.7
10	Rt. 708	" "	100	94.8	85.9	--	66.5	60.5	48.2	-	-	-	-	59.7	22.2	6.6	0.8	1.0	1.5	0.3	1.2	7.3
11	Brightwood	" "	--	--	--	--	--	--	--	-	-	-	-	61.3	21.2	12.1	5.2	0.4	0.9	0.2	0.8	5.5
12	Red Hill	" "	--	--	--	--	--	--	--	-	-	-	-	56.7	18.3	10.2	1.5	0.7	2.8	2.9	0.8	6.3
13	31, Williamsburg (Fill)	Pavement	100	97.2	90.9	79.6	71.5	69.9	54.7	23	29	-	-	--	--	--	--	--	--	--	--	--
	(Cut)	"	100	89.0	57.1	57.1	5.6	5.6	0.0	-	-	-	-	--	--	--	--	--	--	--	--	--
14	29 Ch'ville Bypass	Pvt. & Shoulder	100	93.9	88.2	83.4	80.1	78.0	69.8	27	41	53	34	--	--	--	--	--	--	--	--	--
15	Sprouses Corner 15	" "	--	--	--	--	--	--	--	-	-	-	-	--	--	--	--	--	--	--	--	--
16	Madison Bypass (Fill)	" "	100	91.2	83.8	72.8	70.3	66.4	54.1	25	16	31	26	--	--	--	--	--	--	--	--	--
	(Cut)	" "	100	87.0	79.6	73.6	68.2	63.6	42.9	23	13	29	23	--	--	--	--	--	--	--	--	--
17	Massey Corner, (Fill)	" "	100	85.8	73.9	--	60.9	58.2	50.7	-	-	-	-	--	--	--	--	--	--	--	--	--
	Rt. 0211 (Cut)	" "	100	90.0	80.0	--	66.5	63.3	54.3	-	-	-	-	--	--	--	--	--	--	--	--	--
18	Rt. 29, Monroe (Fill)	" "	100	97.3	93.1	85.5	79.5	75.5	63.7	25	37	47	28	--	--	--	--	--	--	--	--	--
	(Cut)	" "	100	94.4	89.5	83.4	77.8	73.6	54.4	36	9	38	33	--	--	--	--	--	--	--	--	--

TABLE 2

EQUATIONS FOR THE NINE LOCATIONS

Location No.	Location	Count ratio at zero M.C.	Equation*
1	Culpeper	0.54	$0.54 = a_0 + 86a_1 + 3.3a_2 + 5.8a_3 + 40a_4 + 45a_5$
2	Batesville	0.40	$0.40 = a_0 + 99a_1 + 14.6a_2 + 30.6a_3\ 25a_4 + 31a_5$
3	Zion Cross Roads	0.31	$0.31 = a_0 + 89a_1 + 6.9a_2 + 16.2a_3 + 31a_4 + 41a_5$
4	Skibo Lodge — Ch'ville	0.44	$0.44 = a_0 + 92a_1 + 4.8a_2 + 22.2a_3 + 34a_4 + 37a_5$
5	Airport — Albemarle	0.50	$0.50 = a_0 + 88a_1 + 12.4a_2 + 35.6a_3 + 29a_4 + 24a_5$
6	Rte. 631	0.44	$0.44 = a_0 + 98a_1 + 14.9a_2 + 23.3a_3 + 29a_4 + 33a_5$
8	Fredericksburg	0.54	$0.54 = a_0 + 100a_1 + 37.7a_2 + 62.3a_3$
9	Gordonsville	0.37	$0.37 = a_0 + 97a_1 + 7.0a_2 + 15.6a_3 + 26a_4 + 41a_5$
14	29 Ch'ville Bypass	0.44	$0.44 = a_0 + 107a_1 + 11.8a_2 + 18.4a_3 + 27a_4 + 41a_5$

* Model Equation — Same as equation (3) above.

This equation, like equation (5), can be rewritten as

$$M.C. = 54.97\ (\text{count ratio} - b) \qquad (7)$$

In Figure 14 (developed by Anday and Hughes) the curves for each soil seem to have the same slope as that of the general curve for all the soils combined. This might be due to chance or be a result of controlled laboratory conditions. The slope of the general curve is 54.97. Hence the slope of each curve is considered to be 54.97.

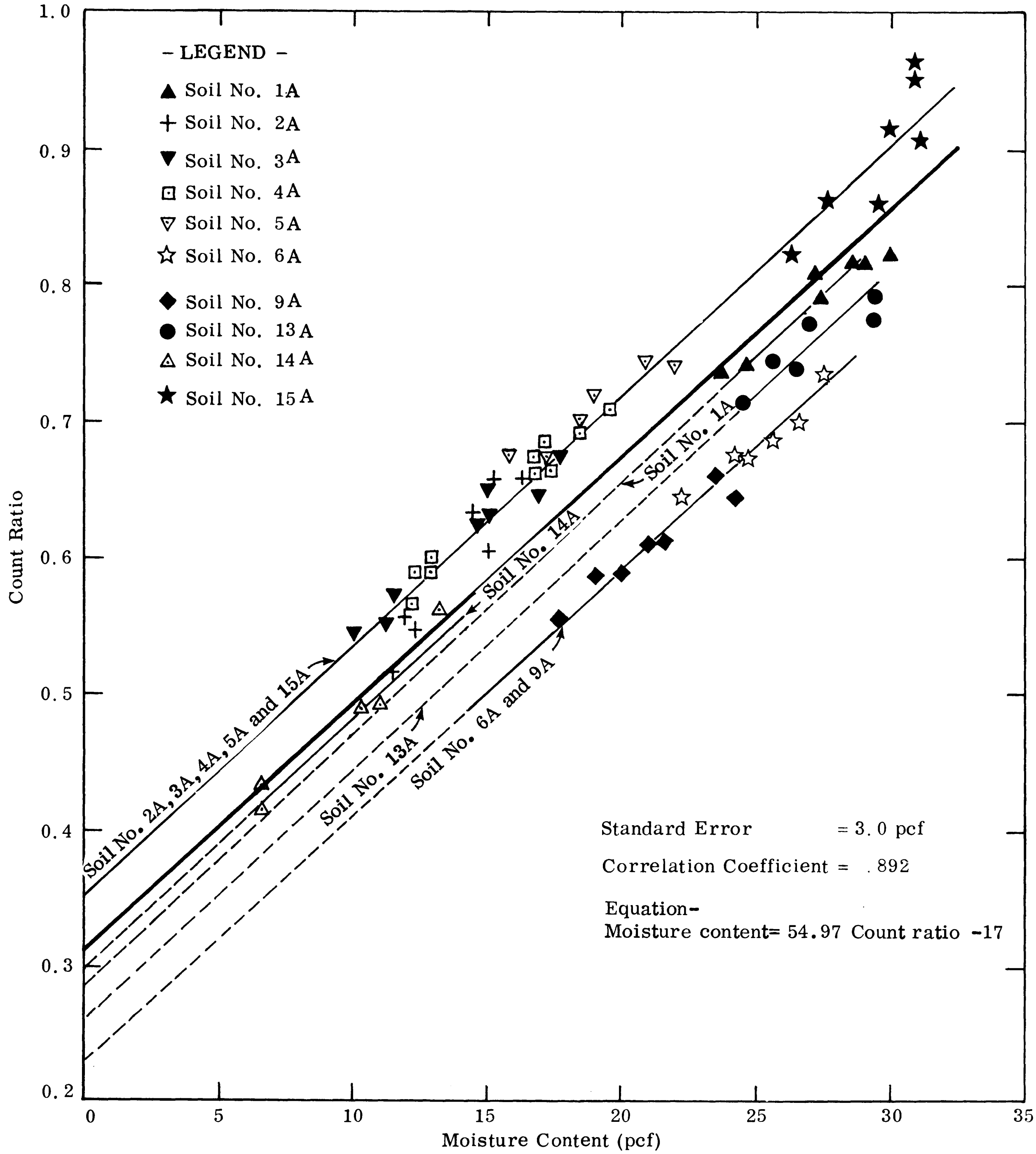


Figure 14. Calibration curve of moisture content vs. count ratio as given by Anday and Hughes. (3)

The intercept value (i.e., count ratio at zero moisture content) of each soil was then equated with the dry density and particle size of the soil, based on model equation (3). The dry densities and particle sizes of these soils are given in Table 3. Equations for each of the ten soils are given in Table 4.

Stepwise multiple regression analysis of these ten equations was carried out and a standard equation with the values of the coefficients for these ten soils was determined. The equation so developed is given below.

$$b = -0.18092 + 0.00118(r_d) + 0.00264(C.S.) + 0.00534(F.S.) + 0.0076(S.) + 0.00631(C) \quad (8)$$

where b = count ratio at zero moisture content for each soil. The values of b obtained from Figure 14, herein termed the actual values, and the values of b from equation (8), herein termed predicted values, are given in Table 5. The percent deviation of the predicted values from the actual values and the percent deviation of the mean of the actual values (i.e., 0.31) from that of the actual values are given separately in Table 5. These two sets of values prove that the predicted values give much less deviation from the actual value than from the mean value. The same was observed for the curves of the soils tested in situ in this investigation. This evidently proves the advantage of using the dry density and the sieve classification in the nuclear moisture measurement method.

The above approach of first determining the slope of the general curve for all soils and then correlating the count ratio at zero moisture content of each soil with the physical properties of the soil for a given moisture nuclear gage will considerably help in establishing a calibration curve with a minimum standard error of estimate.

TABLE 3

PHYSICAL PROPERTIES OF SOILS BY CONVENTIONAL LABORATORY TESTS

Soil No.	Location	Dry Density	Sieve Analysis-Passing			Classification				BPR	OMC
			No. 4	No. 40	No. 200	Percent sand	Percent fine sand	Percent silt	Percent clay		
1A	Piedmont	89.0	93.8	62.0	49.7	21	12	20	29	A-7-5(8)	29.3
2A	Coastal	108.0	100	61.0	6.7	92	54	3	5	A-3	14.1
3A	Coastal	116.0	100	47.1	28.4	70	19	7	23	A-2-7(1)	12.2
4A	Piedmont	115.0	100	55.3	27.4	58	28	14	13	A-2-4	14.0
5A	Piedmont	108.0	100	67.2	45.3	43	22	15	30	A-6-4	17.8
6A	Valley & Ridge	92.0	100	71.0	69.2	5	2	32	35	A-7-6(12)	28.0
9A	Valley & Ridge	102.0	100	72.5	60.3	22	8	29	30	A-4(5)	21.2
13A	Piedmont	89.0	100	83.3	72.9	24	10	48	28	A-7-5(13)	31.8
14A	Piedmont	133.0	100	39.6	20.1	58	20	10	4	A-1-6	7.7
15A	Piedmont	79.0	100	89.5	82.4	14	7	27	49	A-5(12)	39.2

TABLE 4

EQUATIONS FOR THE TEN SOILS TESTED BY ANDAY AND HUGHES[3]

Soil No.	Count Ratio at zero M. C.	Equation
1A	0.28	$0.28 = a_0 + 89a_1 + 38a_2 + 12a_3 + 20a_4 + 29a_5$
2A	0.35	$0.35 = a_0 + 108a_1 + 39a_2 + 53a_3 + 3a_4 + 5a_5$
3A	0.35	$0.35 = a_0 + 116a_1 + 53a_2 + 19a_3 + 7a_4 + 23a_5$
4A	0.35	$0.35 = a_0 + 115a_1 + 46a_2 + 28a_3 + 14a_4 + 13a_5$
5A	0.35	$0.35 = a_0 + 108a_1 + 33a_2 + 22a_3 + 15a_4 + 30a_5$
6A	0.23	$0.23 = a_0 + 92a_1 + 29a_2 + 2a_3 + 32a_4 + 35a_5$
9A	0.23	$0.23 + a_0 + 102a_1 + 27a_2 + 12a_3 + 29a_4 + 30a_5$
13A	0.26	$0.26 = a_0 + 89a_1 + 17a_2 + 10a_3 + 48a_4 + 28a_5$
14A	0.29	$0.29 = a_0 + 133a_1 + 60a_2 + 20a_3 + 10a_4 + 4a_5$
15A	0.35	$0.35 = a_0 + 79a_1 + 12a_2 + 7a_3 + 27a_4 + 49a_5$

TABLE 5

ACTUAL AND PREDICTED VALUES OF COUNT RATIO AT ZERO MOISTURE CONTENT FOR THE LABORATORY TESTED SOILS

Soil No.	Actual Values	Predicted Values	% deviation of predicted value from actual value	% deviation of mean value (i.e. 0.31) from actual value
1	0.28000	0.28684	2.4	10.7
2	0.35000	0.36664	4.7	11.4
3	0.35000	0.34796	0.5	11.4
4	0.35000	0.31862	8.9	11.4
5	0.35000	0.35207	0.5	11.4
6	0.23000	0.26021	13.1	34.8
9	0.23000	0.28637	24.0	34.8
13	0.26000	0.23577	9.3	19.2
14	0.29000	0.27421	5.4	6.9
15	0.35000	0.31132	11.2	11.4

EFFECT OF CHEMICAL COMPOSITION

The effect of chemicals in the soils on the nuclear moisture gauge readings depends mostly upon the following three variables:

(1) The neutron absorption cross section of the element. The higher the neutron absorption of the chemical, the lower the count on the scaler, and the lower the count on the scaler, the lower the count ratio will be. Thus iron and potassium, which have neutron absorption cross sections of 2.5 and 2.07 respectively, are much more effective in lowering the count ratio as compared to silica and alumina, which have absorption cross sections of 0.30 and 0.33 respectively.

(2) The lower the number of average collisions required by each element for thermalization the more effective would be the element to slow down the neutrons. Thus hydrogen, having an average number of collisions for thermalization of 18.2, is much more effective in slowing down the neutron than iron, which has a 514 value. Hydrogen, oxygen, and carbon need low numbers of collisions for thermalization and hence are more effective in increasing the count ratio or less effective in decreasing the count ratio as compared to iron.

(3) The percentage of influencing chemical in the soil.

Among the soils in this investigation, silica, alumina, iron oxide, potassium oxide, and organic materials (loss at 1,000°C) form the most important components which affect the count ratio in relation to moisture content. Silica and alumina have more effect on the count ratio because of their high percentage, while iron and potassium have more effect because of their high neutron absorption cross sections.

Investigations carried out by Anday and Hughes[3] have shown that the trend of these chemicals in interfacing with the detection of thermalized (slow speed) neutrons is not detectable.

The chemical analysis of the soils in Table 1 would show that the total effectiveness of the different chemical components in different proportions would not show much reduction in one soil as compared to another. Therefore, no statistical analysis was conducted to determine the effect of chemical components.

CONCLUSIONS AND RECOMMENDATIONS

The following recommendations are based on the investigations reported here, most of which were carried out in the Piedmont region of Virginia.

1. The nuclear depth probe method of measuring subgrade moisture is more reliable and easier to use than is the electrical resistance method. It does not require pre-calibration and a general calibration curve for a given probe design could be developed for Virginia.

2. The use of a split sampler for a 2-inch diameter access tube gives a snug fit between the outside wall of the access tube and the surrounding soil, and thus eliminates possible errors in measurement due to an air gap. It also gives an undisturbed sample of the subgrade soil which is needed for calibration. The split sampler is therefore recommended for use for underground nuclear measurements.

3. The access tube could be driven in all types of soils through which the split sampler could pass, without becoming bent.

4. This investigation satisfactorily resolved the methods of sealing the access tube from the top and bottom and removing moisture from the access tube before testing.

5. The standard error of estimate in the use of a nuclear calibration curve for moisture content could be reduced by using soil sieve analysis data.

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