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16. ABSTRACT

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From 1959 to 1961, attempts were made by the Materials and Research Department to use the Nuclear-Chicago surface probes on various highway projects. During 1959, a major portion of the time that the equipment was used was spent repairing the nuclear equipment so that only scattered field results were obtained. In 1960 and 1961, the equipment functioned properly and comparative readings with sand volume tests were obtained in field studies. The densities indicated by the nuclear surface probe ranged from zero to fifteen pounds higher than the densities determined by sand volume tests. Limited tests were then run in the laboratory using soil compacted in a large mold. It was found that the densities indicated by the nuclear probe, using the manufacturer's calibration curve, were consistently high. As the manufacturer then claimed that one calibration curve could be used for all soils, this caused considerable concern. During this period, several other items were investigated and are summarized below:

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STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

LABORATORY STUDIES of NUCLEAR SURFACE MOISTURE and DENSITY GAGES

62-02

October 10, 1962

MATERIALS & RESEARCH DEPARTMENT

62-02

State of California
Department of Public Works
Division of Highways
Materials and Research Department

October 10, 1962

Lab Auth. 2331

Mr. F. N. Hveem
Materials and Research Engr.
Division of Highways
Sacramento 19, California

Dear Sir:

Submitted for your consideration is:

REPORT

on

LABORATORY STUDIES

of

NUCLEAR SURFACE MOISTURE

and

DENSITY GAGES

Study made by	Foundation Section
Under general direction of	T. W. Smith
Work supervised by	W. G. Weber
Laboratory work by	J. Campbell
Report prepared by	W. G. Weber

Very truly yours,

T. W. Smith

T. W. Smith
Supv. Highway Engineer

Attach

Introduction

The determination of the moisture and density of soils by the nuclear methods was first reported by Cornell University in 1950. These nuclear probes were for the measurement of subsurface soil moisture and density. From 1954 to 1958, subsurface measurements of soil moisture and density were made by the Materials and Research Department in co-operation with the University of California on several highway projects. By 1958, surface gages were developed for measuring soil moisture and density. During February 1959, a complete set of nuclear probes were ordered from the Nuclear-Chicago Company, the only manufacturers of these nuclear probes at that time.

From 1959 to 1961, attempts were made by the Materials and Research Department to use the Nuclear-Chicago surface probes on various highway projects. During 1959, a major portion of the time that the equipment was used was spent repairing the nuclear equipment so that only scattered field results were obtained. In 1960 and 1961, the equipment functioned properly and comparative readings with sand volume tests were obtained in field studies. The densities indicated by the nuclear surface probe ranged from zero to fifteen pounds higher than the densities determined by sand volume tests. Limited tests were then run in the laboratory using soil compacted in a large mold. It was found that the densities indicated by the nuclear probe, using the manufacturer's calibration curve, were consistently high. As the manufacturer then claimed that one calibration curve could be used for all soils, this caused considerable concern. During this period, several other items were investigated and are summarized below:

1. The temperature range through which the equipment would operate was investigated. The scaler will not operate below 32°F. The equipment operated to temperatures of 140°F without failure.

2. A record was maintained of the standard count and was found to vary as much as 10 percent during a day's run, and 20 percent from day-to-day. Placing a lead shield over the pickup tube increased the stability of the standard count during a day's run to a 2 percent variation. However, as the day-to-day variation was over 10 percent, the ratio method of determining density was used.

3. Little difficulty was encountered in obtaining check reading within 2 percent at any setting of the probe on the soil.

4. Seating of the probe so as to have complete contact between the soil and probe was found to be extremely critical. A standard practice was made of seating the probe on a thin bed of sand.

5. Calibration of the subsurface nuclear probes indicated that the density calibration was shifted about 15 pounds per cubic foot between dry soil and soil at a moisture content of about 100%.

6. Other operational tests were also performed.

A laboratory investigation of the performance of the Nuclear-Chicago surface probes was proposed in a memo to Mr. A. W. Root from W. G. Weber, dated October 18, 1961. This memo covered the use of the surface probes only. The subsurface probes are being used in limited foundation studies. This laboratory study constitutes a portion of the work proposed by the above memo.

During this study, a nuclear probe manufactured by another concern, Hidrodensimeter, was purchased and used in the later phases.

Test Program

The laboratory test program consisted of the following:

I. To obtain calibration curves for various California soils. To combine these calibration curves into one calibration curve. To determine the accuracy of the various calibration curves. To determine if the density calibrations are effected by the moisture content of the soil. To obtain moisture calibration curves on each soil

II. To determine how reproducible the nuclear results are from day-to-day on a standard.

III. To determine the effective volume of the soil being measured by the nuclear probes.

IV. To conduct special studies on performance of equipment. (Plateau curve, uniformity of standard counts, seating, and etc.)

Part I

The calibration curves were obtained by compacting each of eight soils in a steel mold two feet in diameter and one foot in depth. See Figure Nos. 1 and 2 for types of soil used. The soil was compacted in the mold by drop hammers and an electric compaction hammer. The compactions were from 80 to 100 percent of the maximum densities as determined by California Test Method No. 216-D.

The soil sample was air dried when received. A series of tests was run on this air dried sample at two or more densities. Water was then added to the soil to bring the soil moisture content to about one-half the optimum water content, and the soil was then mixed and stored several days in sealed containers. Another series of tests was then performed with the soil at this moisture content at two or more different densities. Water was then added to bring the moisture content of the soil near the optimum and the above procedure repeated. During the latter portion of this study, the soil samples were tested air dry and near optimum moisture content only.

The weight of the soil in the mold was then determined and divided by the volume of the mold, 3.168 cubic feet, to obtain the average density of the soil.

The nuclear density probe was then set on the soil surface and three readings taken that agreed within 250 counts. See photo Nos. 1 and 2 for nuclear equipment used. The probe was rotated 90 degrees and another three readings taken that agreed within 250 counts. The counts were then obtained with the probe rotated 180 and 270 degrees. The four resultant values were averaged and this count used to represent the soil at this density. The above procedure was used with the Nuclear-Chicago and Hidrodensimeter density and moisture probes. See Photos Nos. 3 and 4 of equipment used.

A sand volume test was then performed in the area tested by the nuclear probes. This sand volume test was performed according to California Test Method 216-E. Where the density determined by the sand volume test deviated more than about three pounds per cubic foot from the density determined by the weight and volume of the soil in the total mold, chunk and tube samples were taken. On several occasions up to three sand volume tests were made on the upper one-half foot of the soil in the mold and up to three sand volume tests were made on the lower one-half foot of the soil in the mold. This was to determine the uniformity with which the soil was being compacted in the mold. A typical set of data is shown in Figure No. 4, and a comparison of the sand volume and mold densities is shown in Figure No. 3. As a result of this variation in density between the top and bottom halves of the soil in the mold the standard practice was to run nuclear readings, sand volume and mold densities on both halves and obtain two sets of data each time the mold was filled with soil.

Considerable difficulty was encountered in obtaining agreement between the densities as determined by the mold weight and volume of soil and the sand volume test. This resulted in a side study of the uniformity of the soil compacted in the mold and the accuracy of the sand volume test.

Oven dry moistures were obtained from two or more samples of soil from the mold. The average moisture content of the soil in the mold was then calculated in pounds of water per cubic foot of soil.

The count ratio for the Nuclear-Chicago probes and the counts for the Hidrodensimeter were plotted against the densities and moisture tests. See Figures No. 5 to No. 11. The densities as determined by the weight and volume of soil in the mold and the sand volume test were plotted separately. The equation of the line for the density calibration was calculated for each soil, and then for all soils combined, by the method of least squares. The average error and standard deviations were determined for each calibration.

The theoretical calibration curve for the density determination that has been verified by measurements, is of the following shape: Zero counts in a vacuum with the counts increasing as the density increases to a maximum count at about 60 pounds per cubic foot, as the density increases the counts decrease in a linear manner to a density of about 150 pounds per cubic foot, a further increase in density will result in a small decrease in count. In the region of 80 to 140 pounds per cubic foot, depending upon the geometry of the surface probe, the relation between the density and the counts was assumed linear. All calibration curves are based upon this linear relationship. A linear relationship was also assumed for the moisture count relationship, although theoretically, it has a slight curvature with counts increasing with increase in moisture content.

Part II

To determine the reproducibility of the nuclear readings, two standards were established. One was on the concrete floor in the core shed, and one a block of wood that was sealed so as to prevent loss of moisture. Readings were periodically taken on the surface of these standards throughout the test program. Marks were placed upon the surface of these standards so that the probes were always placed at the same location. Three counts were then obtained that agreed within 2 percent.

Part III

The depth to which the density probes effectively measure the density of the soil was determined in two ways.

A block of wood six inches thick was attached to the bottom of the mold with a thin sheet of iron on top to protect the wood. A series of readings on the wood block was taken. Successive one-inch layers of soil were compacted in the mold and nuclear readings obtained on each layer. The volume and weight of soil in each layer was determined to insure that a uniform density was being obtained. (See Photo No. 5.)

The second method was to construct one to three-inch layers of concrete or soil in boxes 12 by 18 inches in size. The nuclear density probe was suspended in air and a count rate determined. Then each box of soil was placed on a pair of supports and a count rate determined. (See Photo No. 6.)

The data were plotted with the thickness of soil vs. the percent of the total change in count rate. That is the difference in count rate on the wood block (air) and on the soil for each thickness was expressed as a percentage of the difference in count rate on the wood block (air) and the final thickness of soil used. Theoretically, this type of curve will be asymptotic with 100 percent at an infinite volume of soil.

Part IV

Several miscellaneous studies are included in this program. The stability of the pickup tubes was studied by means of standard counts and plateau curves. The general performance of the equipment was evaluated during this testing program.

The affect of the thickness of the sand used for seating of the probes was investigated. A count rate for a spot on the concrete floor was determined. Various thicknesses, 1/8 to 1/2 inch, of sand were placed over this spot. Count rates were determined for each thickness of sand.

Another study was the influence of objects near the probes. Count rates were determined with a clear space at five feet or more around the probes. Various objects were then placed near the probes and count rates determined without moving the probes.

large variations were found between the density in the upper half and lower half of the soil in the mold. The density of the two halves of the mold was then determined for all tests by two methods: (1) the volume of soil in the mold by measurement of its height and weight of soil, (2) sand volume test. These tests indicated that wide variations did occur between the top and bottom halves of the mold. Therefore, two series of readings were obtained each time the soil was compacted in the mold; one on the top half and one on the bottom half.

The density variation in a horizontal plane was also investigated. It was found that the soil in the center of the mold was generally one to two pounds per cubic foot higher than at the sides of the mold. This results in the sand volume tests indicating generally higher densities than the mold densities.

Figure No. 3 shows a comparison of sand volume and mold densities using one-half of the depth of the soil compacted in the mold. These comparisons are mainly on the moist soils as we were unable to obtain sand volume tests on the dry and/or loosely compacted soils. A distribution plot of the differences is included in the lower right-hand corner of Figure No. 3. The sand volume tests tended to indicate slightly higher densities than the mold. The average difference is +0.8 pounds per cubic foot. The standard deviation is 2.0 pounds per cubic foot.

The conclusions from this study were that the density variation within the mold was greater than two pounds per cubic foot from point to point from the average mold density. Using the top or bottom half of the mold, the variation in density within this layer was about two pounds per cubic foot. The indications are that the sand volume test was accurate to one to two pounds per cubic foot.

Calibration curves were determined for each of the two densities, sand volume and mold. Also the equations of the curves were calculated and are shown in Table No. 1. The average and standard deviations are also included in Table No. 1. For comparison, all of the points for different soils were plotted on one plot and a calibration curve obtained. The calibration curves for the different soils were also plotted on one plot for comparison along with the manufacturer's recommended calibration curve. See Figures No. 7, 10 and 11. Due to the variation in standard counts, the Nuclear-Chicago data are plotted using the count ratio. The data for the Hidrodensimeter probe in the full out and full in positions only, are plotted.

The data indicate that the standard deviation where individual calibrations for various soils are used, will be of a magnitude of one to three pounds per cubic foot. As will be discussed later, using one minute readings, the expected standard deviation from random radiation will be of a magnitude of one and one-half pounds per cubic foot. This would indicate that with both the Nuclear-Chicago and Hidrodensimeter equipment, densities could be obtained to two to three pounds per cubic foot accuracy without difficulty, where individual calibrations are obtained for each soil tested.

The Nuclear-Chicago Corporation states that one calibration curve will be within ±3 pounds per cubic foot for all soils. The Hidrodensimeter manufacturers claim that all soils will be within a band of 15 to 20 pounds per cubic foot. An examination of figures Nos. 7, 10, and 11, show that the calibration curve for all soils tested is within a band of 15 to 20 pounds per cubic foot. The standard deviation when using one calibration curve for all soils tested, was about four to five pounds per cubic foot for both instruments.

The distribution of the points using one calibration curve for all soils and a separate calibration for each soil are shown in Figure No. 12. Using the 90 percent criteria, 90 percent of the readings will be within seven pounds per cubic foot when one calibration curve is used for all soils and 90 percent of the readings will be within 3½ pounds per cubic foot when separate calibration curves are used for each soil. The 90 percent criteria for a comparison of the mold and sand volume densities indicated that the results will be in agreement within ±3 pounds per cubic foot 90 percent of the time. To obtain a reasonable accuracy with the density probes, a calibration is required for each soil encountered.

Moisture Calibration

The moisture calibrations are shown on Figure No. 13 for all soils tested. Six of the soils are along one calibration curve and two along a different calibration curve that is parallel to the main calibration curve. A D.T.A. was performed on the soils and Soils No. 4 and 5 were found to be serpentine soils high in hydrous magnesium silicate. The high magnesium content of these two soils is believed to be the cause of the high amount of slow neutrons produced.

The moisture content determinations had an average error of 0.6 pounds of water per cubic foot, and the standard deviation was 0.8 pounds of water per cubic foot. The distribution of the points for the moisture determinations are shown on Figure No. 13. The data indicates that 90 percent of the readings are within one pound of water per cubic foot of the moisture content indicated by the calibration curve. This one pound of water per cubic foot variation will result in a one percent error in moisture at a dry density of 100 pounds per cubic foot and 0.8 percent error in moisture content at a dry density of 125 pounds per cubic foot.

The moisture content of a soil can be accurately determined by means of the surface gage. One calibration curve will generally be accurate for most soils; however, checks must be made to determine that no elements are present that will shift the curve as occurred with Soils No. 4 and 5.

Effect of Moisture on the Density Calibration

The previous work with the subsurface probes indicated that there is a shift in the density calibration curve from a dry soil to a soil at about 100 percent moisture content. It was not known if this effect upon the density readings was significant at lower moisture contents.

A study of the data in this series of tests, does not indicate that a measurable shift in the density calibration curve occurs with a change in moisture content. It is apparent that moisture contents below 20 percent do not affect the density calibration curves within the limits of accuracy of this testing program.

Comparison of Nuclear-Chicago and Hidrodensimeter Density Calibrations

The principal differences in construction of the two probes that would affect the density calibration curves are:

(a) A higher strength source
(b) A source emitting higher energy gamma rays
(c) A device for altering the geometry of the probe

The source strength could be expected to alter the slope and possibly curve the calibration of the probe. The change in count rate per pound per cubic foot in the soil density is a measure of the slope of the calibration. The slope of the Nuclear Chicago calibration is 110, and the Hidrodensimeter is 90 counts per pound per cubic foot change in density. This difference in slope is insignificant. There is some indication that the calibration curve for the Hidrodensimeter and Nuclear-Chicago probes may be slightly curved.

The energy level of the gamma rays will influence the shape of the calibration curve and the effective depth of the soil measured. It does not appear that there is a significant effect upon the shape of the calibration curve by the different energy level gamma rays. The depth of measurement will be discussed later.

The geometry of the source, shielding, pickup should affect the depth of measurement and number of counts recorded. The effective depth of the soil measured will be discussed later. The closer the pickup tube is to the source, the larger the number of counts that will be recorded for the same density soil. The calibration curves in Figure Nos. 10 and 11 indicate the counts were increased by about 50 percent in the in position which will statistically increase the accuracy of the count rates.

The differences in the two probes appear to have minor effect upon the calibration curves. It appears that there is no significant difference in calibrations between the Nuclear-Chicago and Hidrodensimeter surface probes.

Reproducibility of Readings

It was desired to determine how consistent the nuclear readings of a standard were over a period of time. There has been no difficulty in obtaining check count rates in a few hours time, however, the Nuclear-Chicago standard count had been previously observed to vary greatly in a few weeks period of time.

To determine how consistent the readings are, two standards were obtained and reading taken on these standards two or three times a week over a three months period of time. The readings were taken with the probe always in the same position on the standard. The distribution of these readings are shown in Figure No. 14. The range in density or moisture represented by the range in readings is shown on each plot.

The range of readings obtained indicate a difference in density of about 9 pounds per cubic foot. This is a surprisingly large random variation in indicated density. Previous work had indicated that there was a large variation in standard count rates with the Nuclear-Chioago density probe with time. It had been hoped that the use of the count ratio would correct these random variations; however, it does not appear to do so.

A statistical analysis considering random radiation, indicates that the one minute readings used in this study should be constant within about 200 counts, or about two pounds per cubic foot. The standard varied less than one pound per cubic foot in density. The seating of the probes was no problem and should have had no significant effect upon the readings. The remaining six pounds per cubic foot variation in indicated density appears to be caused by elements within the equipment.

The moisture determinations indicate a spread of two to four pounds of water per cubic foot was indicated over the three months' period. The Nuclear-Chicago equipment appears slightly better than the Hidrodensimeter equipment. This range in indicated moisture is about what would be expected from statistical analysis.

To determine the short-time variations, where possible, readings were taken on the compacted soil samples in the late afternoon. The following morning check readings were taken before conducting the sand volume test. These readings all checked within two pounds per cubic foot in density and one pound of water per cubic foot in moisture.

To evaluate the effect of this random variation in apparent density with time, check calibration points on Soils Nos. 1, 3 and 7 were made after obtaining the original calibration curves for these soils. These check calibration points were within about two pounds per cubic foot of the calibration curves obtained two to three months previously. As these check points were within the standard deviation for the calibration curves, it would appear that this random variation in indicated density will not affect the density readings obtained with the nuclear probes.

The significance of this random variation in indicated density of a standard is not clearly understood. There is no significant effect upon the accuracy of the calibration curves obtained. This random variation may well explain the wild readings occasionally obtained and indicates the need for obtaining check readings by rotating the probe.

The Volume of Influence of the Density Readings

The data from the depth of influence readings are shown in Figure No. 15. The percentage of the total change in count rate is plotted against thickness of material. Where the difference in count rate between the wood block and the soil was used, the curves rise rapidly and show a 50 percent change in count rate at one-half to one inch and a 90 percent change in count rate at two to three inches. The one hundred percent count rate change was taken at the greatest thickness of soil tested. Where the difference in count rate between air and soil was used, the Hidrodensimeter and Nuclear-Chicago probes gave slightly different results. The Hidrodensimeter probe indicated a 50 percent count rate change at one-half to one and one-half inches of soil, and a 90 percent count rate change at three to four inches. The Nuclear-Chicago probe indicated a 50 percent count rate change at about two inches and 90 percent count rate change at about three to four inches.

The shape of these curves should theoretically be a rapid rise from zero count rate change at zero thickness of soil in a nearly straight line, to about 60 to 70 percent count rate change at some thickness of soil. The count rate change data should curve and become asymptotic with 100 percent at a large depth. All curves, except the Nuclear-Chicago for the air to soil data, follow this general shape. The Nuclear-Chicago for the air to soil shows a straight line from zero to 95 percent count rate change and then a straight line to 100 percent count rate change. Due to the asymptotic nature of these curves, the effective depth of density measurement has been defined as the depth at 90 percent count rate change.

Theoretically, the effective depth of measurement should be a function of density of the medium being tested. The lower the density, the greater the depth of measurement. While there is a slight tendency for the effective depth of measurement to be larger at lower densities; it does not appear to be a significant factor.

The effective depth measurements were made using the difference in density between a soil and either a wood block or air. The two types of measurements were made because previous experience had indicated that the manufacturers were claiming extremely optimistic depths of measurement. The two methods do not agree on the indicated depths of measurement. The soil to wood block indicates about two to three inches is the effective depth of measurement, and the soil to air indicates three to four inches is the effective depth of measurement. In the previous field comparisons of nuclear and sand volume densities, the sand volume test was made to a depth of 6 to 7 inches. In future field comparisons, the sand volume test will be made to a depth of four inches so as to obtain comparable volumes of soil.

The Hidrodensimeter probe has an arrangement for varying the distance from the source to the pickup tube which is supposed to vary the depth of soil measured. Theoretically, when the pickup tube is close to the source, "in" position, the depth of measurement of the density of the soil will be greater than with the pickup at a greater distance from the source - "out" position. The data obtained in these series of tests indicate that about the same effective depth of measurement was obtained with the pickup tube in the "in" as in the "out" position.

Limited work was done to determine the width and length of the area of influence of the nuclear density probe. The measurements were made by placing a square basaltic stone in a soil having a density of 110± lbs. per cu. ft. The top of the stone was about one inch below the surface of the soil. The zone of influence appears to be irregular-shaped, about eight inches in width at the pickup end and three to four inches in width at the source end. The length of the zone of influence appears to be approximately ten inches. These tests consisted of readings with the Nuclear-Chicago density probe only and with the soil at one density only and with the stone at one depth. These measurements indicate that the zone of influence is in the order of sixty square inches.

The manufacturers state that a depth of four to eight inches and a volume of soil of one-half to one cubic foot is measured with the density probes. Our test data indicate that these figures are not realistic. The actual effective depth of measurement by the nuclear surface probes is three to four inches and the volume one-tenth cubic foot. This reduced depth and volume of soil does not necessarily reduce the usefulness of these probes, however. The volume of soil tested by the sand volume method normally is 0.15 cubic foot which is compatible to the volume tested with the nuclear probes.

Plateau Curves

"Plateau" curves indicate the operation of the pickup tube. The curve is of the following shape: No counts are recorded until a given starting voltage is reached; a further increase in voltage results in a large increase in count until the threshold voltage is reached. An ideal pickup tube then has no change in count as the voltage is increased and this portion is known as the plateau; however, all tubes have a slight increase in count with an increase in voltage. As the voltage is increased past the plateau, the tube goes into continuous discharge. The slope of the plateau expressed in counts per 100 volt change, and the length of the plateau expressed in volts are the important characteristics of a pickup tube.

The Nuclear-Chicago density equipment uses an organic-quench bismuth cathode type pickup tube. When new, the plateau curve has a slope of 500 counts per 100 volts and a length of 150 volts. The slope of the plateau increased with use to 800 counts per 100 volts with a length of 100 volts. The high voltage supply is constant to 10 volts, which can result in a 50 count variation when new and 80 counts after it was used for a period of time. This is believed to be one of the reasons the Nuclear-Chicago standard counts vary. It is understood that the new Nuclear-Chicago density probes use a stainless steel Halogen-quenched type pickup tube.

The Hidrodensimeter uses a stainless steel Halogen-quenched type pickup tube. The plateau has a slope of 100 counts per 100 volts and a length of 200 volts. There has been no change of slope or length of the plateau due to use with this tube.

Standard Counts

The Nuclear-Chicago density standard counts varied from a high of 17,780 to a low of 15,520 counts per minute in the standardizing box provided for this purpose during this study. This wide range of standard counts is believed to be due to the type of pickup tube used, and is the reason that the ratio system is used with the Nuclear-Chicago equipment even though one more step is required in the obtaining of the density. The standard count of the moisture probe varied from 15,560 to 15,370 counts per minute. This is a stable range of counts per minute.

No difficulty was encountered with the Hidrodensimeter probe in obtaining standard counts within 170 counts per minute of the standard count supplied by the manufacturer.

Seating of Probes

The seating of the probes was found to have a major effect on the readings obtained. The problem is to obtain a plane surface upon which to place the probe. An air gap of 1/16-inch was found to increase the counts recorded by about 2000 counts per minute. To overcome the difficulty of obtaining a plane surface on the soil, a thin layer of sand was used to seat the probes.

The Nuclear-Chicago density probe has two raised portions that should be in contact with the soil. The Nuclear-Chicago moisture probe and the Hidrodensimeter probe have plane surfaces that have to be in contact with the soil.

The results of the studies to determine the effect of the thickness of the sand layer upon the readings are shown in Figure No. 16. As the thickness of the sand used in seating the probes was increased, the count rate increased at a rate of about 5 percent per 1/8-inch of sand. The Nuclear-Chicago density probe was least affected by the thickness of the sand seat to a thickness of 1/4-inch. This is believed due to the raised portions of the bottom of the probe with the built-in air gap.

These tests clearly indicate the necessity for having a plane surface to set the probes on. The use of a thin layer of sand to level the surface will result in a small change in reading, however, a thick layer of sand will greatly alter the readings.

The moisture probe readings will also be affected by the thickness of the sand seat.

Objects Near Probe

The effect of objects near the probes upon the count rates were studied. Readings were taken with the probes on a surface, then objects such as steel plates, wooden blocks, concrete slabs, etc., were placed at various distances from the probes and count rates determined. It was found that the objects had to be within one-half foot from the probes before a measurable increase in count rate could be detected.

The manufacturers recommend that no solid material, that will reflect gamma rays, should be within five feet of the probes, which would prevent their use in confined locations, such as structural backfill. These tests indicate that the probes could be used in confined locations where a clear distance of one or more feet is avilable around the probe.

Conclusions

The following conclusions can be made from the work conducted in this report:

1. Using one calibration for each soil will result in 90 percent of the nuclear readings being within about three and one-half pounds per cubic foot; and using one calibration for all soils will result in 90 percent of the nuclear readings being within about seven pounds per cubic foot. The use of a calibration curve for each soil will increase the accuracy of the readings by a factor of about two over using one calibration for all soils.

   Moisture determinations with the nuclear gage can be made with an accuracy of one pound of water per cubic foot. Generally one calibration can be used for most soils, however, a limited testing is necessary to determine that elements are not present that will alter the calibration.

2. The moisture content of the soil did not affect the density calibration curve in the low range, below 20 percent, of moistures used in this study.

3. The effective depth of the density determination is two to four inches and the volume of soil being measured is about one-tenth cubic foot.

4. The stability of the standard count of the Hidrodensimeter is satisfactory while random variations in the Nuclear-Chicago density readings indicate the need for using the ratio system of determining the soil density.

5. The probes may be used in fairly confined locations without loss of accuracy.

6. Great care must be taken in obtaining a plane surface upon which to set the probes. A thin sand layer can be used to aid in leveling the soil surface, but must be kept less than 1/16-inch thick.

Future Work

A field use of this nuclear equipment is now in progress. Periodic readings are being obtained on five current construction projects in District III and District X. Comparative data between the sand volume and nuclear densities are being obtained. Also comparative data between oven dry and nuclear moistures are being obtained.

Along with the comparative tests, studies are being conducted as to the problems that may be encountered in actual field use of the nuclear equipment.

This current field test program will complete the work outlined in the memo to A. W. Root from W. G. Weber, dated October 18, 1961. No further research work is planned at the present time.

Recommendations

In compaction control as now used in the California Division of Highways the necessary result is the relative compaction, which requires knowing the in-place density and the standard maximum density. The standard maximum density requires considerable time to be determined under present California practices and is generally the controlling time element in compaction control. Considering these two portions of compaction control it would appear that the nuclear equipment could be profitably used on soils with the following characteristics:

1. A soil where a calibration curve can be established and maintained.

2. A soil where a standard maximum density can be established and will remain constant.

3. A soil where it is time consuming to obtain sand volume tests.

4. A plane surface for seating the probes is readily obtained.

5. A soil where shallow depth readings would be satisfactory.

One item of work where the above will apply is in the structural section of the roadway. A processed material is used that would enable the determination of 1 and 2 beforehand, and they should remain constant throughout the project. It is generally time consuming to obtain sand volume tests. The contractor usually provides a plane surface during construction operations. A depth of three to four inches would be adequate in this type of construction.

Another item of work where the nuclear probe could be used is in controlling the placing of structural backfill. A uniform material is used that would enable the determination of 1 and 2 beforehand. The confined space would not be objectionable. A rapid determination of the density could be made while compaction operations are being conducted nearby.

In the occasional projects where a uniform soil is used for constructing fills it would appear that the nuclear probes could be used in construction control. It would be necessary to have a soil where items one and two above are valid.

The nuclear equipment can be used to determine the efficiency of compaction equipment. A nuclear reading can be taken at a given spot after each pass of the compaction equipment. Using the counts directly the number of passes where no further compaction occurs can be determined. For these conditions 1 and 2 above are not required. It may be difficult with some compaction equipment to maintain a smooth surface, however, the loose material could be removed for the nuclear test and then returned to the test spot. The nuclear tests may be time consuming; however, this would be of minor concern.

TABLE NO. 1

DENSITY CALIBRATIONS AND ERRORS

Soil No.	USING SAND VOLUME TEST AS STANDARD DENSITY Equation Calibration Curve	Average Error	Standard Deviation	USING MOLD DENSITIES AS STANDARD DENSITY Equation Calibration Curve	Average Error	Standard Deviation
NUCLEAR CHICAGO						
1	R = 1.635 - 0.00857D	2.2	2.6	R = 1.543 - 0.00783D	2.0	2.9
2	R = 1.573 - 0.00758D	1.7	2.1	R = 1.660 - 0.00836D	1.2	1.5
3	R = 1.584 - 0.00780D	1.0	1.3	R = 1.467 - 0.00696D	1.6	1.9
4	R = 1.965 - 0.01151D	2.2	3.0	R = 1.963 - 0.01155D	2.0	2.3
5	R = 1.828 - 0.01009D	3.1	3.7	R = 1.823 - 0.01008D	2.8	3.3
6	R = 1.501 - 0.00751D	1.9	2.3	R = 1.572 - 0.00812D	2.2	2.6
7	R = 1.131 - 0.00467D	2.0	2.3	R = 0.935 - 0.00336D	3.5	4.5
8	R = 1.795 - 0.01003D	1.2	1.5	R = 1.680 - 0.00904D	1.3	3.0
All Soils	R = 1.569 - 0.00786D	3.0	3.8	R = 1.619 - 0.00833D	3.2	4.0
HIDRODENSIMETER - IN POSITION						
4	C = 19740 - 69.52D	2.7	3.4	C = 21850 - 88.05D	1.6	2.0
5	C = 32910 - 163.61D	1.6	1.8	C = 15030 - 22.50D		
6	C = 20000 - 75.59D	2.3	2.8	C = 20690 - 81.37D	2.7	3.2
7	C = 21490 - 82.27D	1.8	2.2	C = 22120 - 88.80D	1.6	2.0
8	C = 25070 - 116.43D	1.8	2.4	C = 23510 - 102.91D	1.8	2.8
All Soils	C = 21940 - 90.00D	3.5	4.3	C = 20780 - 78.91D	4.1	5.0
HIDRODENSIMETER - OUT POSITION						
4	C = 15580 - 66.27D	3.5	4.3	C = 18080 - 88.09D	1.5	2.2
5	C = 21290 - 103.81D	1.1	1.2	C = 8220 - 19.00D		
6	C = 15580 - 68.52D	2.1	2.6	C = 16100 - 73.14D	1.6	2.1
7	C = 21810 - 122.05D	2.8	3.5	C = 22500 - 130.44D	3.1	4.1
8	C = 20360 - 109.45D	1.5	2.1	C = 18900 - 96.92D	2.7	3.9
All Soils	C = 14610 - 57.80D	4.9	6.3	C = 15800 - 68.52D	4.1	5.1

$R = \text{ratio} = \frac{\text{Test Count}}{\text{Standard Count}}$

D = soil density

C = counts per minute

TABLE NO. II

PROPERTIES OF SOILS USED IN NUCLEAR STUDY

Soil No.	Description	Liquid Limit	Plastic Index	Sand Equiv.	Optimum Density	Optimum Moisture	Specific Gravity +4	Specific Gravity -4	Grading-Percentage of Gravel	Sand	Silt	Clay
1	Sacramento Freeway Soil	24	4	12	121	13	--	2.64		41	38	21
2	American River Sand		NP	97	104	16	--	2.71		96	3	1
3	Sacramento Sand and Gravel		NP	22	144	6	2.70	2.75	64	26	6	4
4	Vallejo Base	46	36	21	106	18	--	2.56	56	25	11	8
5	Crushed Rock		NP	80	134	7	2.79	2.80	71	25	3	1
6	Fresno Soil		NP	20	129	10	--	2.69	12	49	31	8
7	San Diego Soil	31	8	25	121	11	--	2.58		75	14	11
8	Eureka Soil	26	11	10	125	12	--	2.65	1	47	22	30

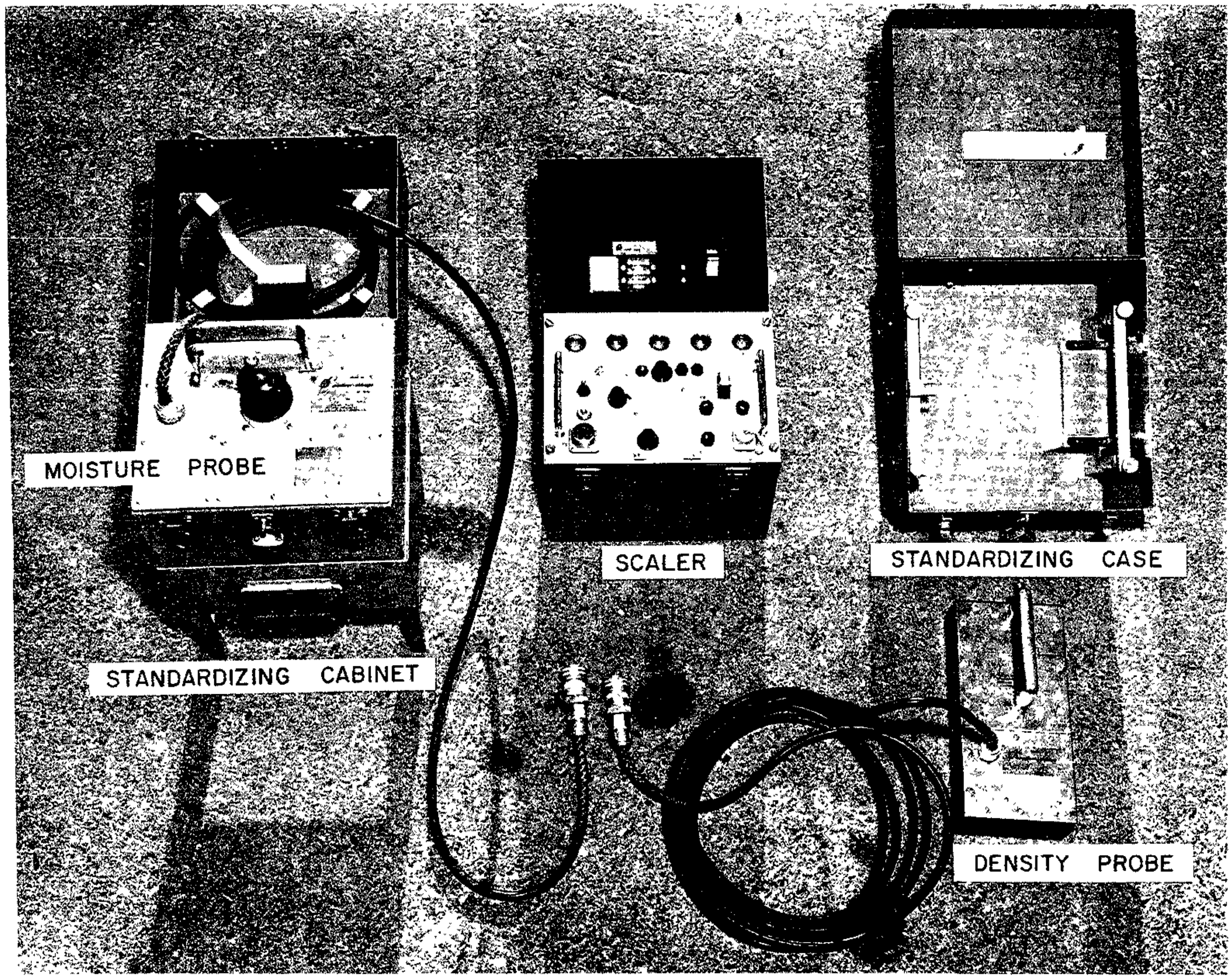


Photo No. 1. Nuclear Chicago equipment.

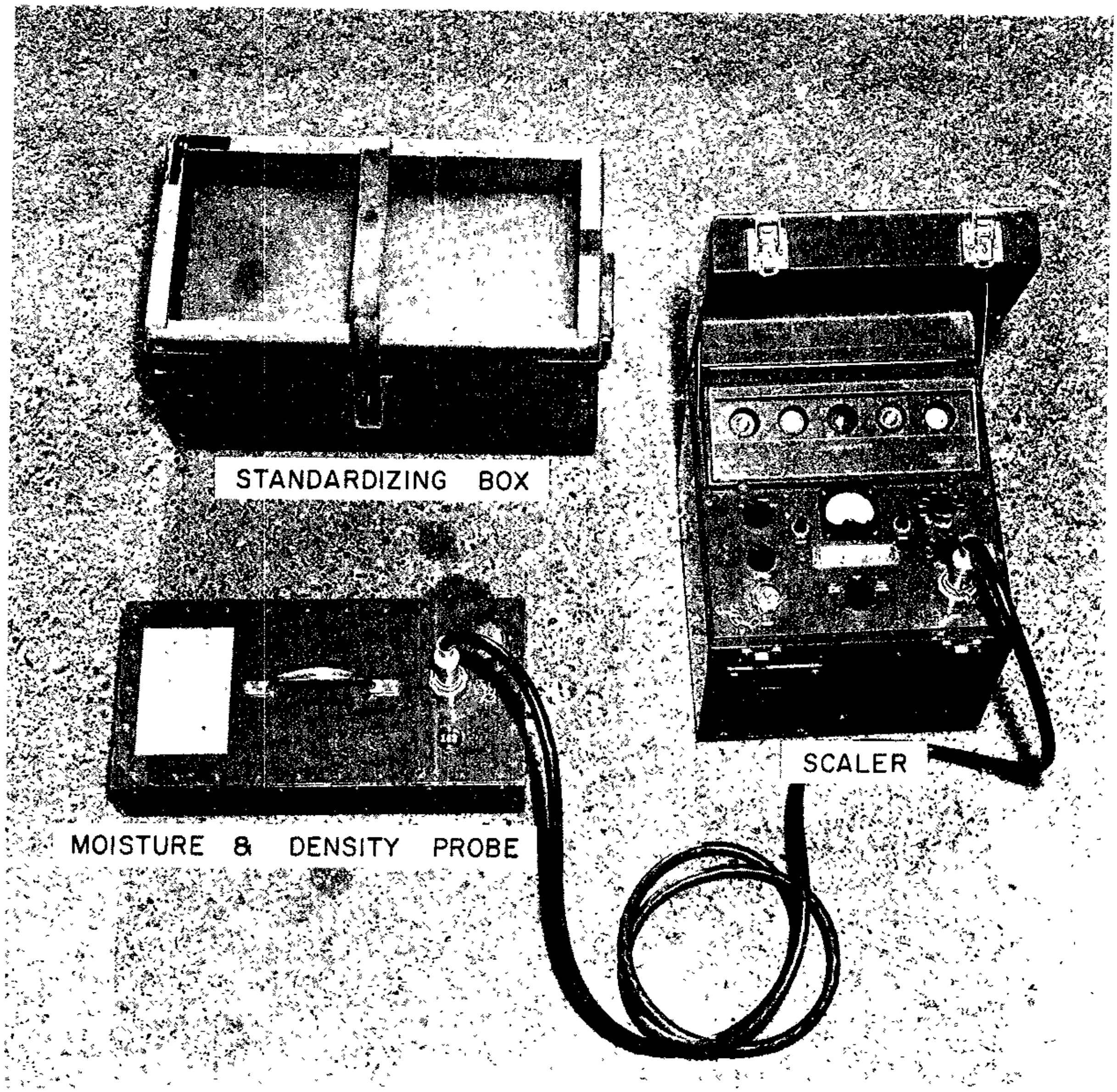


Photo No. 2. Hidrodensimeter equipment.

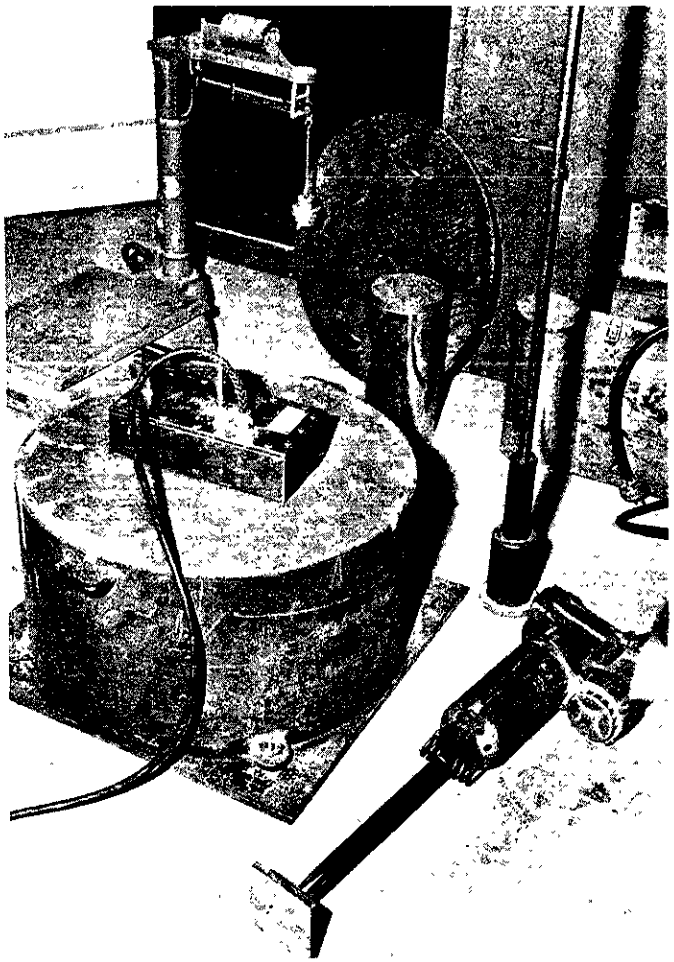


Photo No. 3. Nuclear readings being obtained on top layer of soil in mold.

Photo No. 4. Sand volume test in bottom layer of soil in the mold.

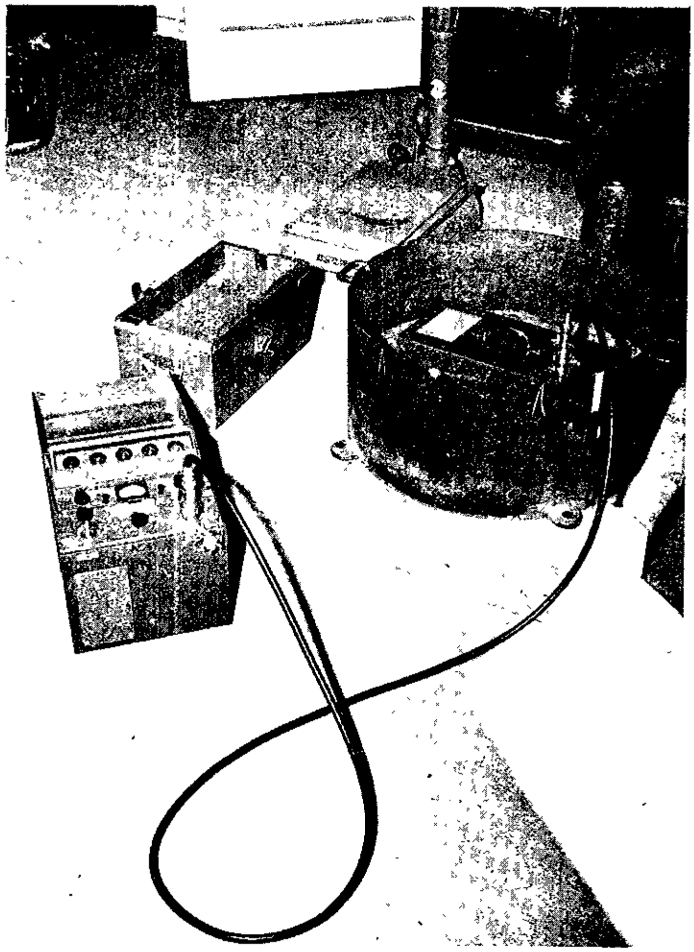


Photo No. 5. Determining the depth of influence of the nuclear probe by placing one inch layers of soil in the mold.

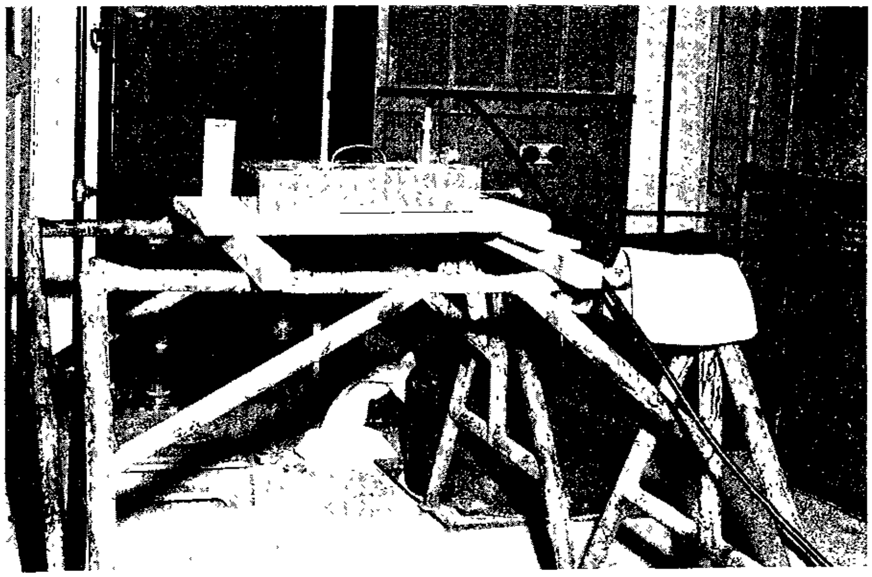


Photo No. 6. Determining the depth of influence of the nuclear probe by means of thin slabs.

GRADING ANALYSIS OF SOILS USED IN NUCLEAR STUDY

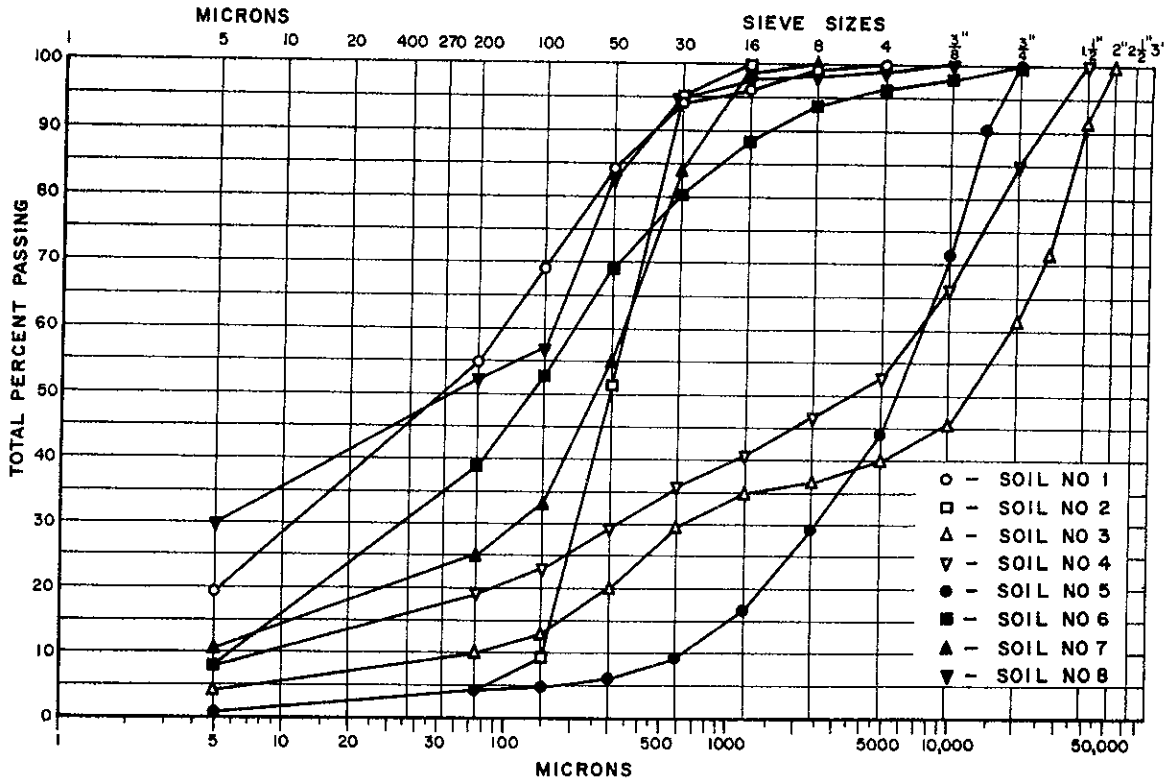


FIGURE 1

COMPACTION CURVES OF SOILS USED IN NUCLEAR STUDY

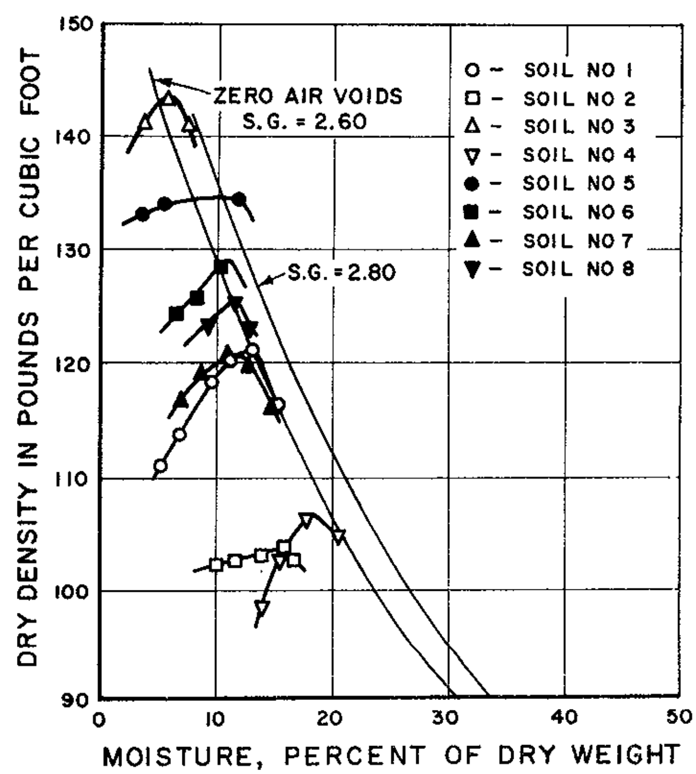


FIGURE 2

MOLD VERSUS SAND VOLUME DENSITIES NUCLEAR STUDIES

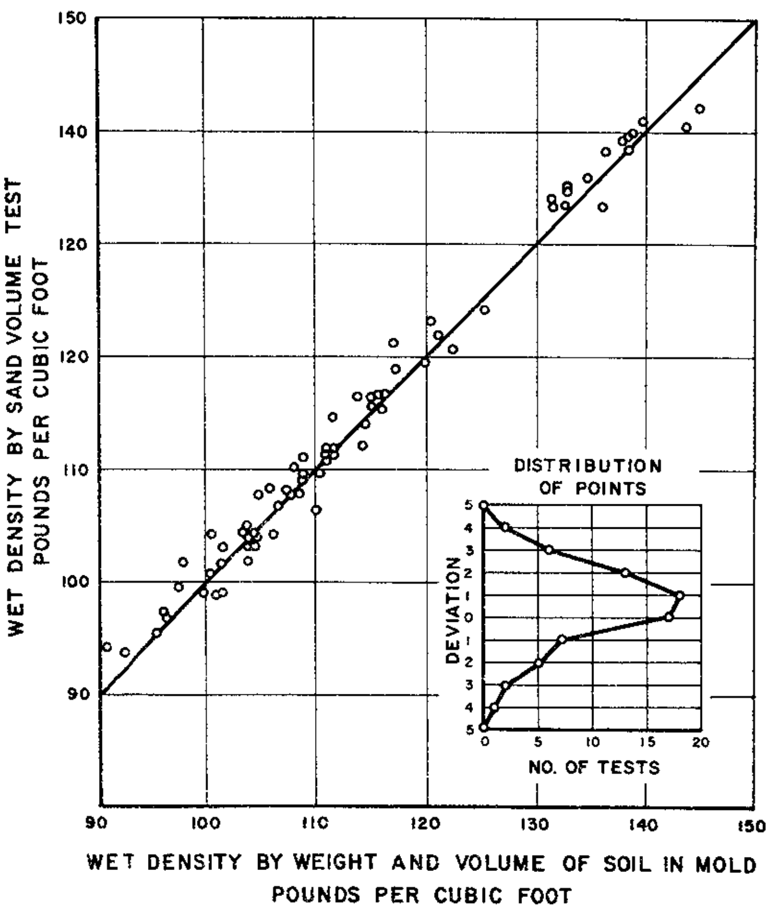
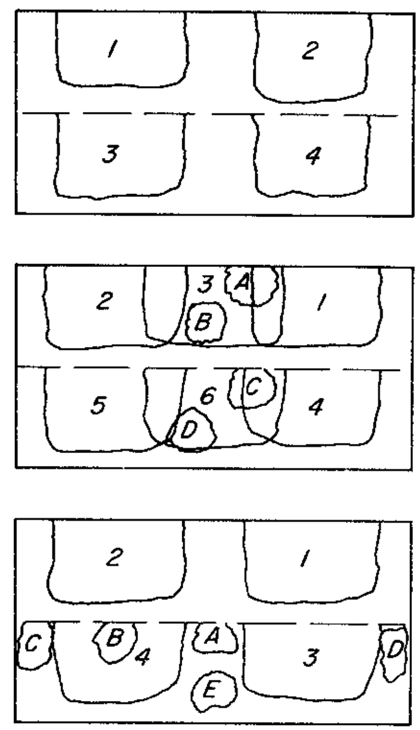


FIGURE 3

TYPICAL DENSITY VARIATIONS IN MOLD USED IN DENSITY CALIBRATIONS



CHUNK SAMPLE DENSITY	SAND VOLUME DENSITY	HALF LAYER MOLD DENSITY	TOTAL MOLD DENSITY
	1-101.3 2-102.2 3-107.9 4-107.6	103.6 107.6	106.5
A-104.5 B-103.8 C-100.3 D-100.9	1-103.6 2-105.7 3-104.0 4-103.3 5- 99.8 6- 99.3	104.7 102.2	104.3
A-116.1 B-115.4 C-114.8 D-116.7 E-115.4	1-116.1 1-116.7 3-116.9 4- N.G.	113.9 119.7	116.5

FIGURE 4

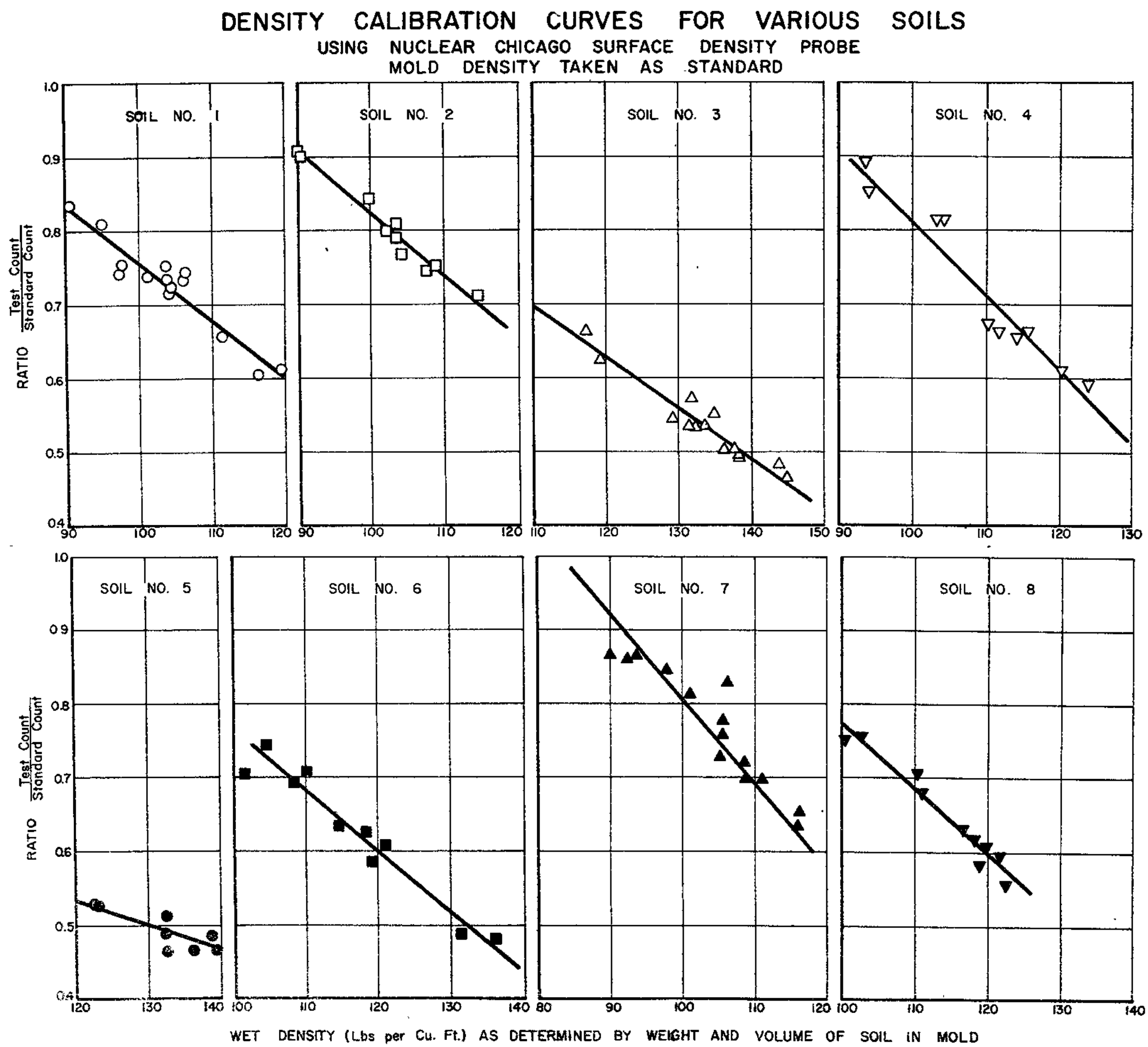

DENSITY CALIBRATION CURVES FOR VARIOUS SOILS
USING NUCLEAR CHICAGO SURFACE DENSITY PROBE
MOLD DENSITY TAKEN AS STANDARD
SOIL NO. 1
SOIL NO. 2
SOIL NO. 3
SOIL NO. 4
SOIL NO. 5
SOIL NO. 6
SOIL NO. 7
SOIL NO. 8
RATIO Test Count / Standard Count
WET DENSITY (Lbs per Cu. Ft.) AS DETERMINED BY WEIGHT AND VOLUME OF SOIL IN MOLD

FIGURE 5

DENSITY CALIBRATION CURVES FOR VARIOUS SOILS

USING NUCLEAR CHICAGO SURFACE DENSITY PROBE
SAND VOLUME DENSITY TAKEN AS STANDARD

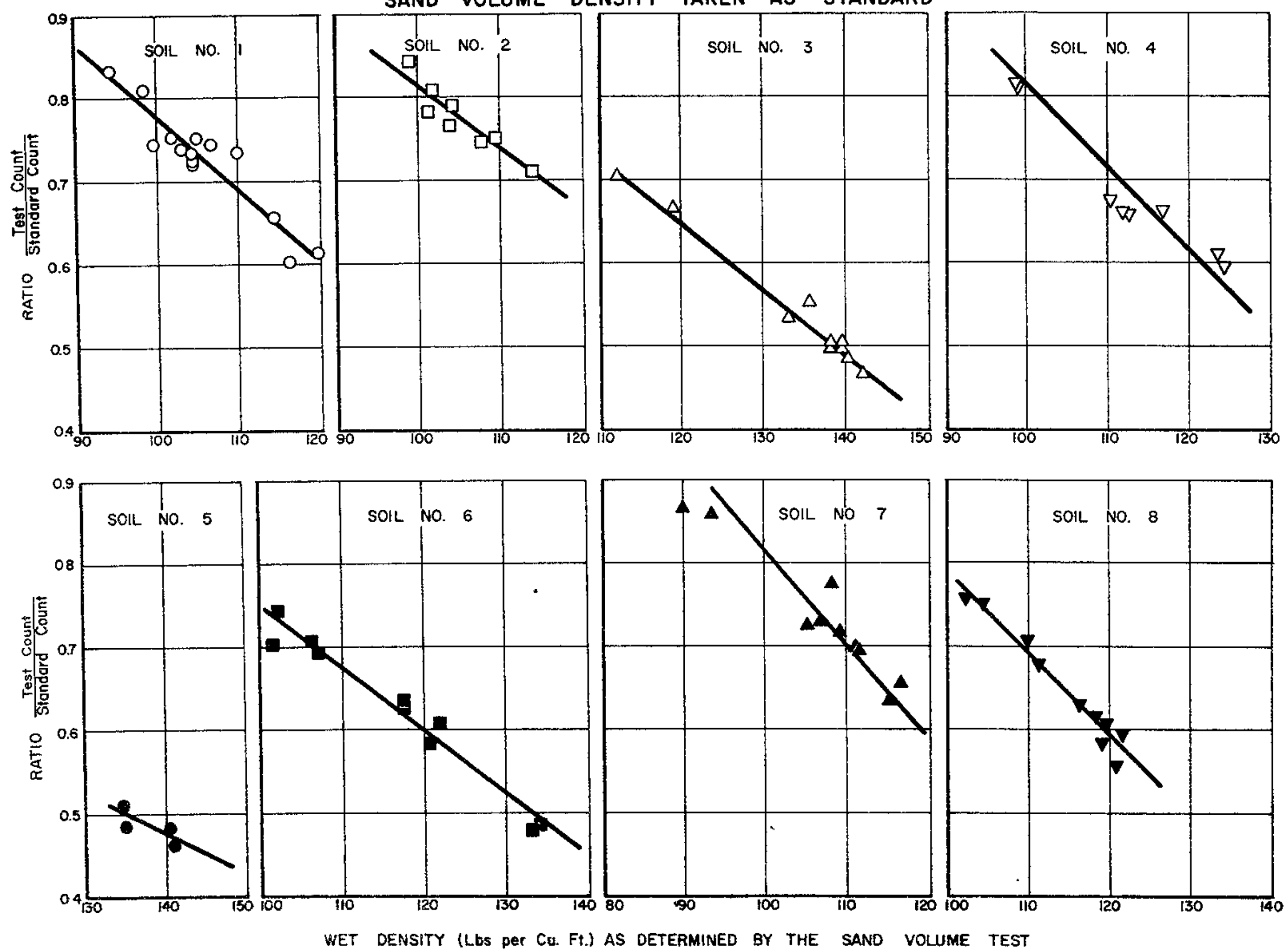


FIGURE 6

DENSITY CALIBRATION CURVES FOR ALL SOILS TESTED

USING NUCLEAR CHICAGO SURFACE DENSITY PROBE

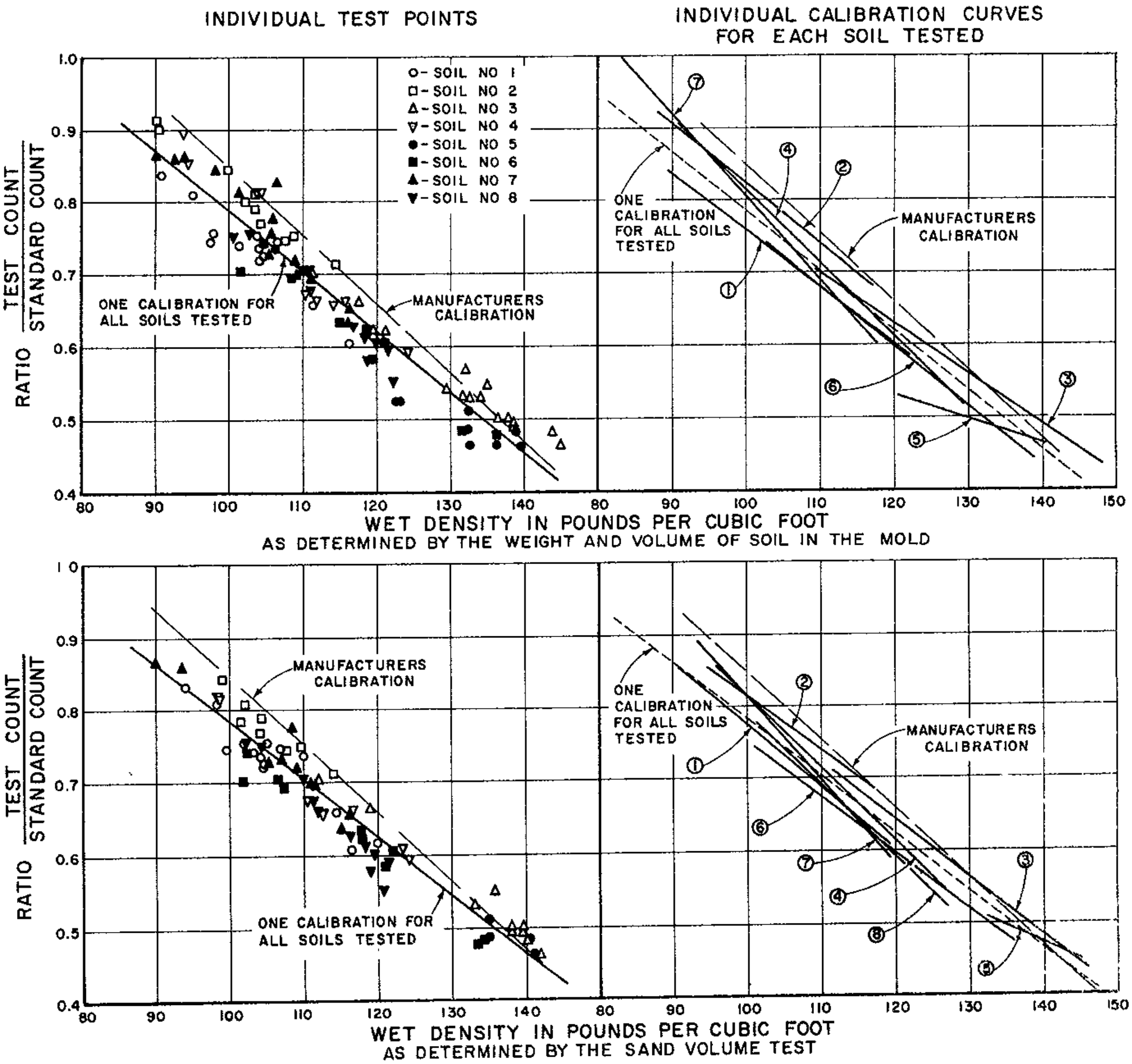


FIGURE 7

DENSITY CALIBRATION CURVES FOR VARIOUS SOILS

USING HIDRODENSIMETER SURFACE DENSITY PROBE
MOLD DENSITY TAKEN AS STANDARD

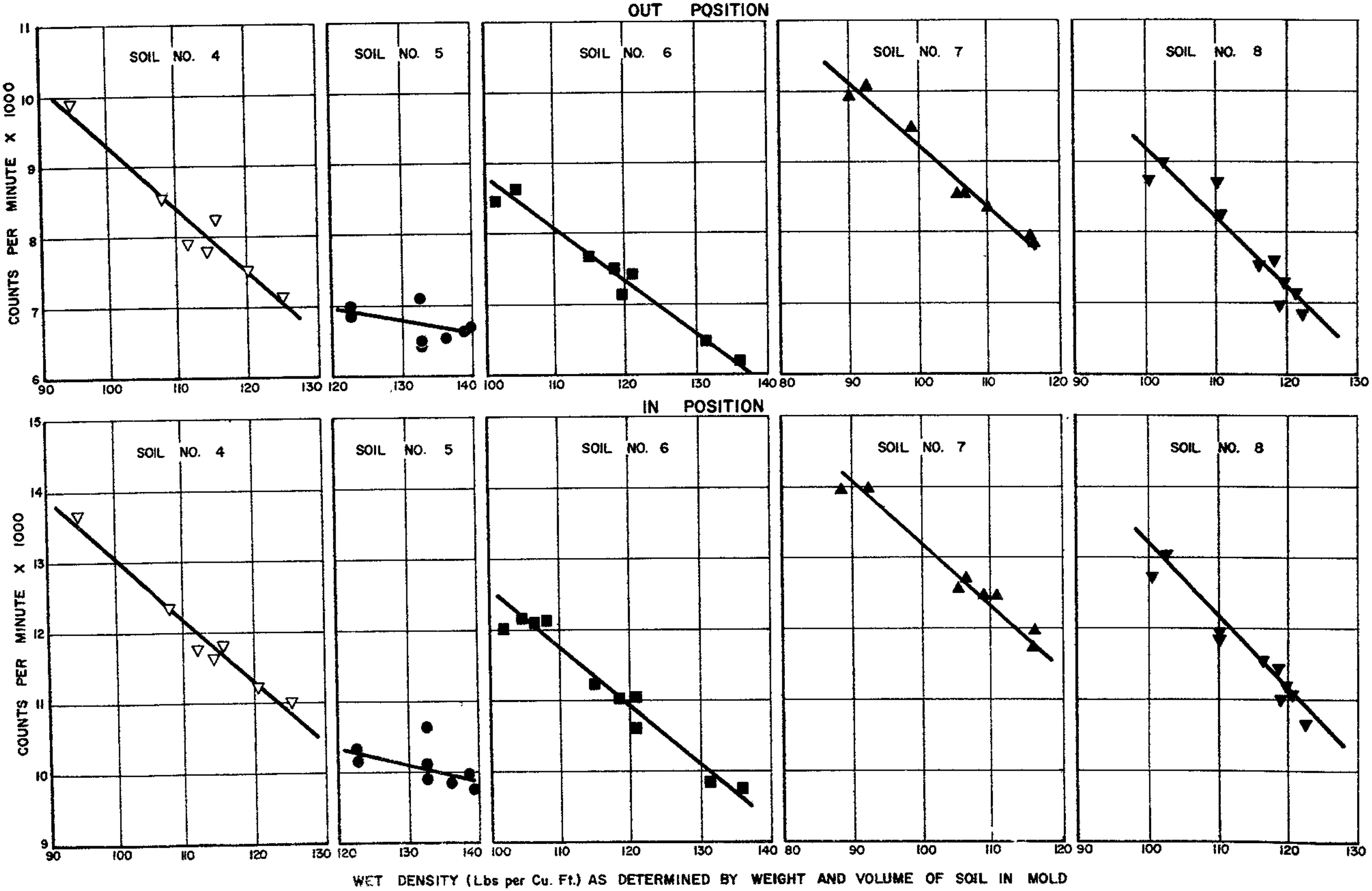


FIGURE 8

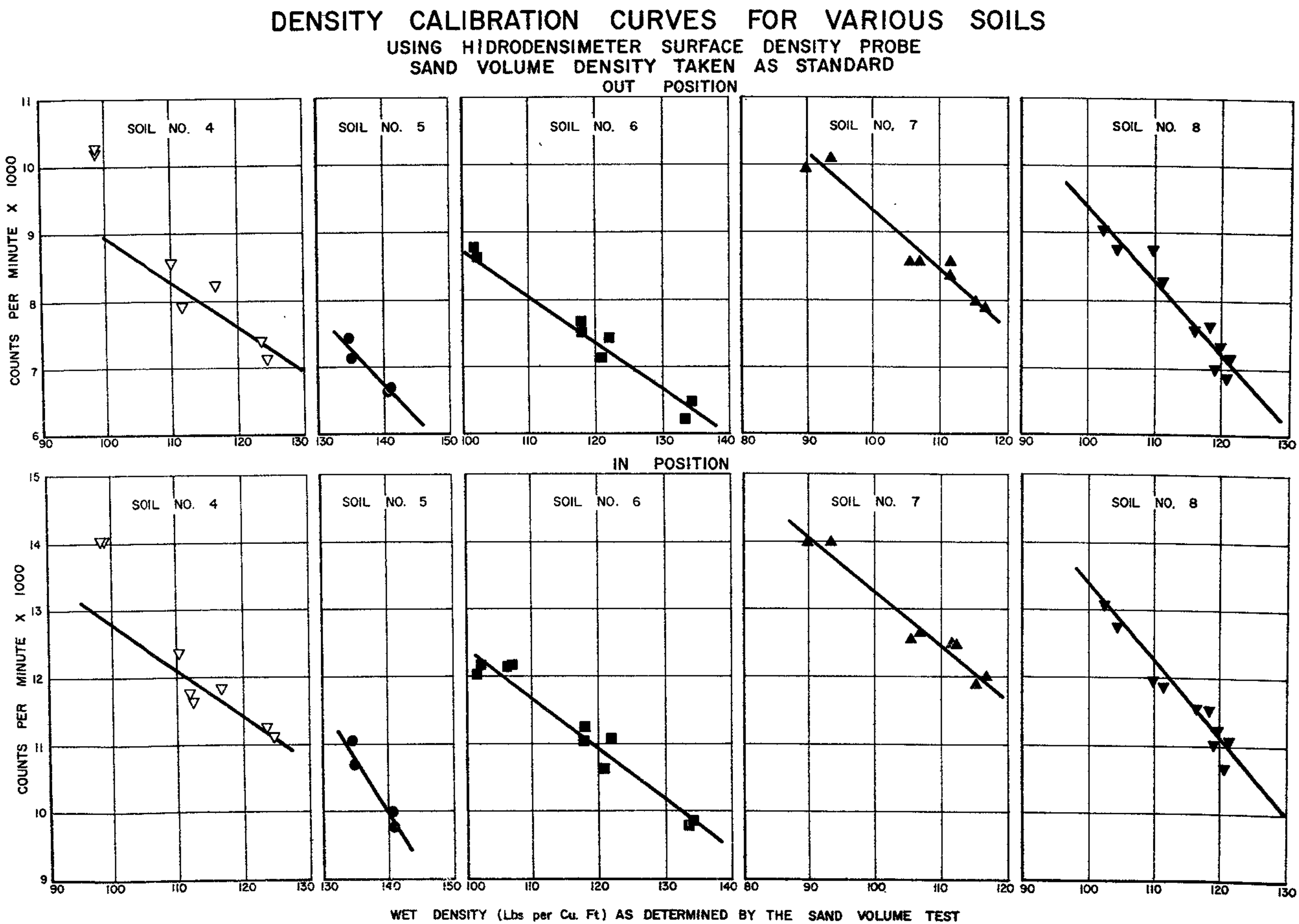

DENSITY CALIBRATION CURVES FOR VARIOUS SOILS
USING HIDRODENSIMETER SURFACE DENSITY PROBE
SAND VOLUME DENSITY TAKEN AS STANDARD
OUT POSITION
IN POSITION
SOIL NO. 4
SOIL NO. 5
SOIL NO. 6
SOIL NO. 7
SOIL NO. 8
COUNTS PER MINUTE X 1000
WET DENSITY (Lbs per Cu. Ft) AS DETERMINED BY THE SAND VOLUME TEST

FIGURE 9

DENSITY CALIBRATION CURVES FOR ALL SOILS TESTED

USING HIDRODENSIMETER SURFACE DENSITY PROBE

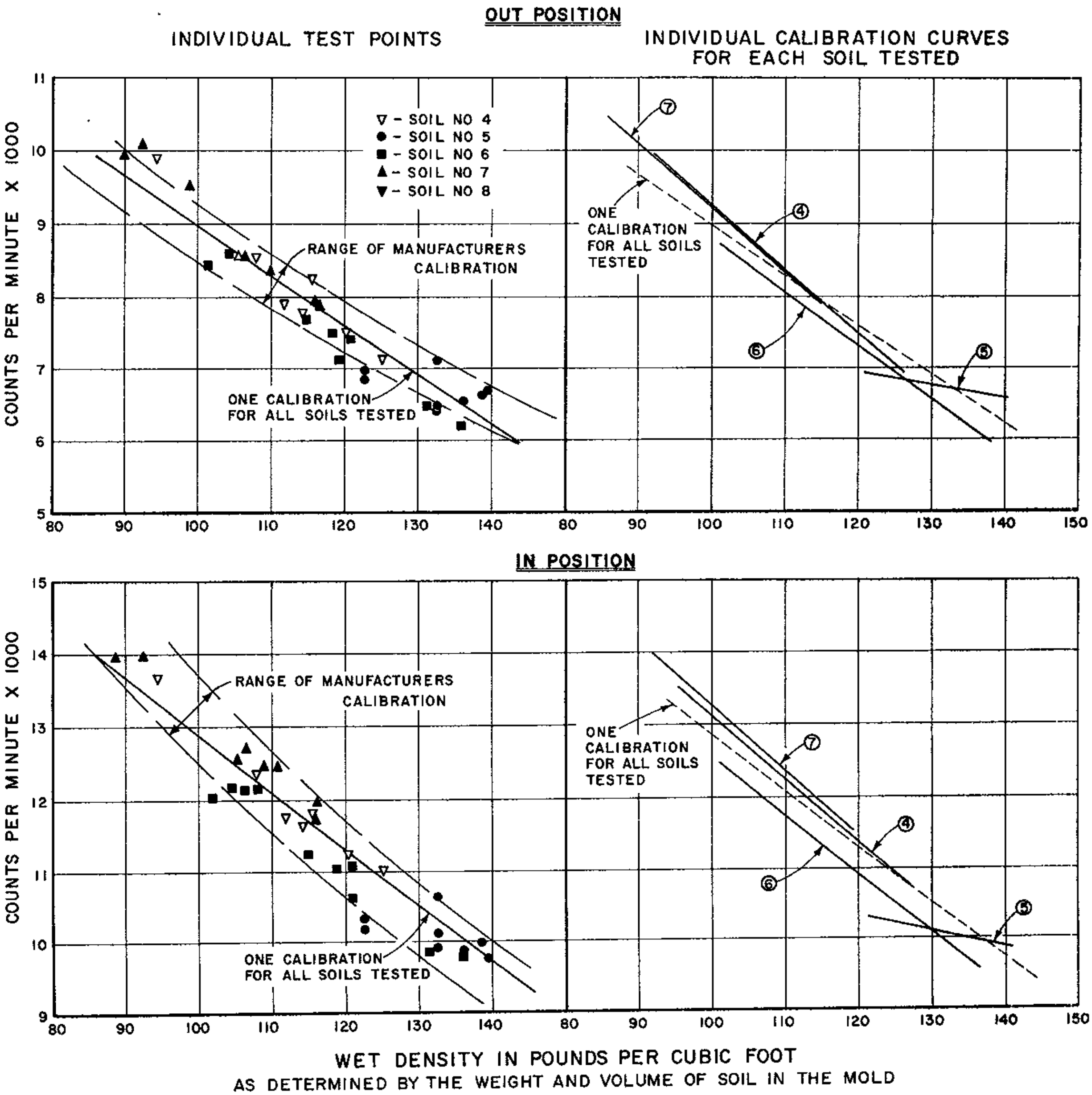


FIGURE 10

DENSITY CALIBRATION CURVES FOR ALL SOILS TESTED

USING HIDRODENSIMETER SURFACE DENSITY PROBE

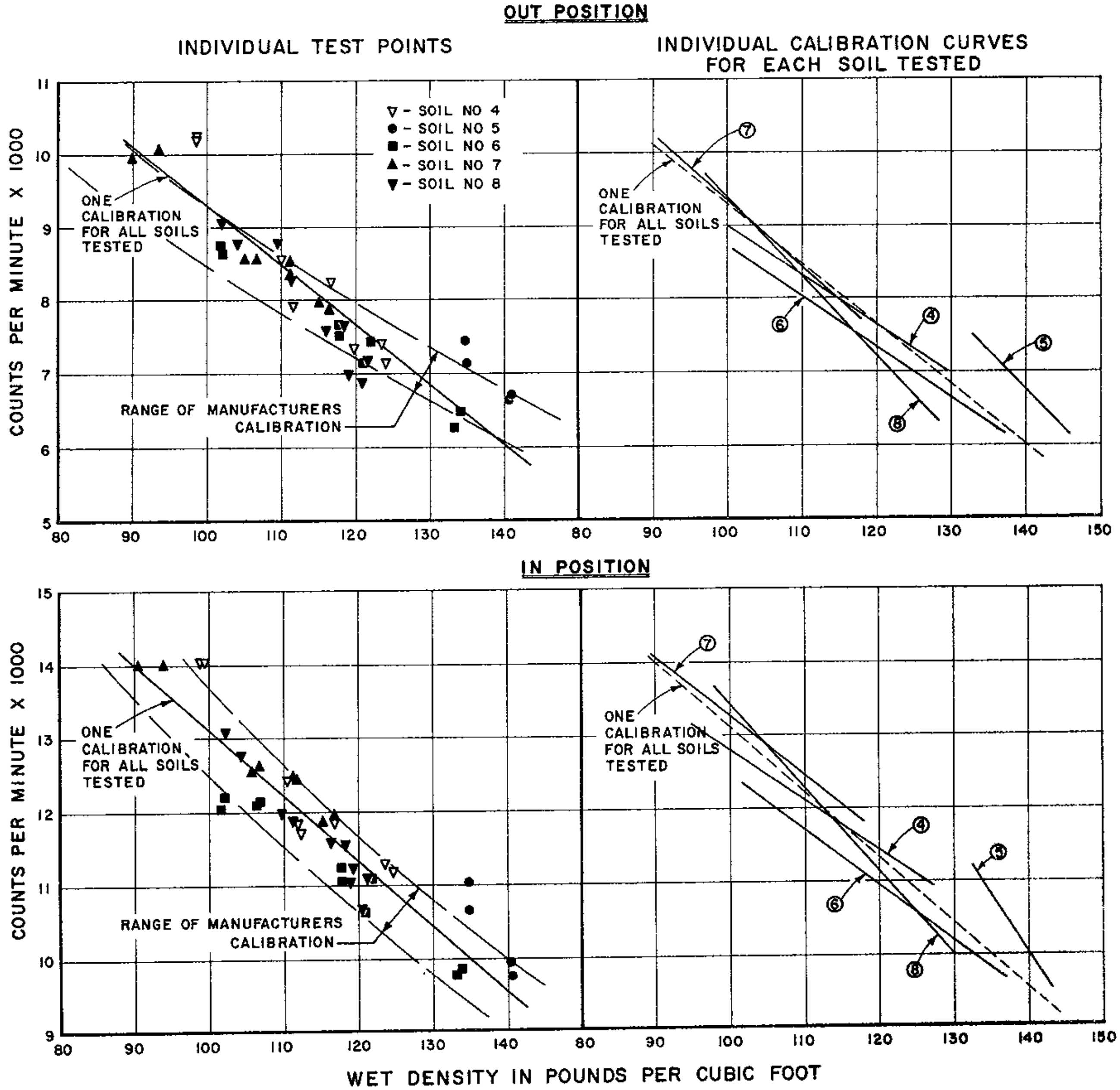
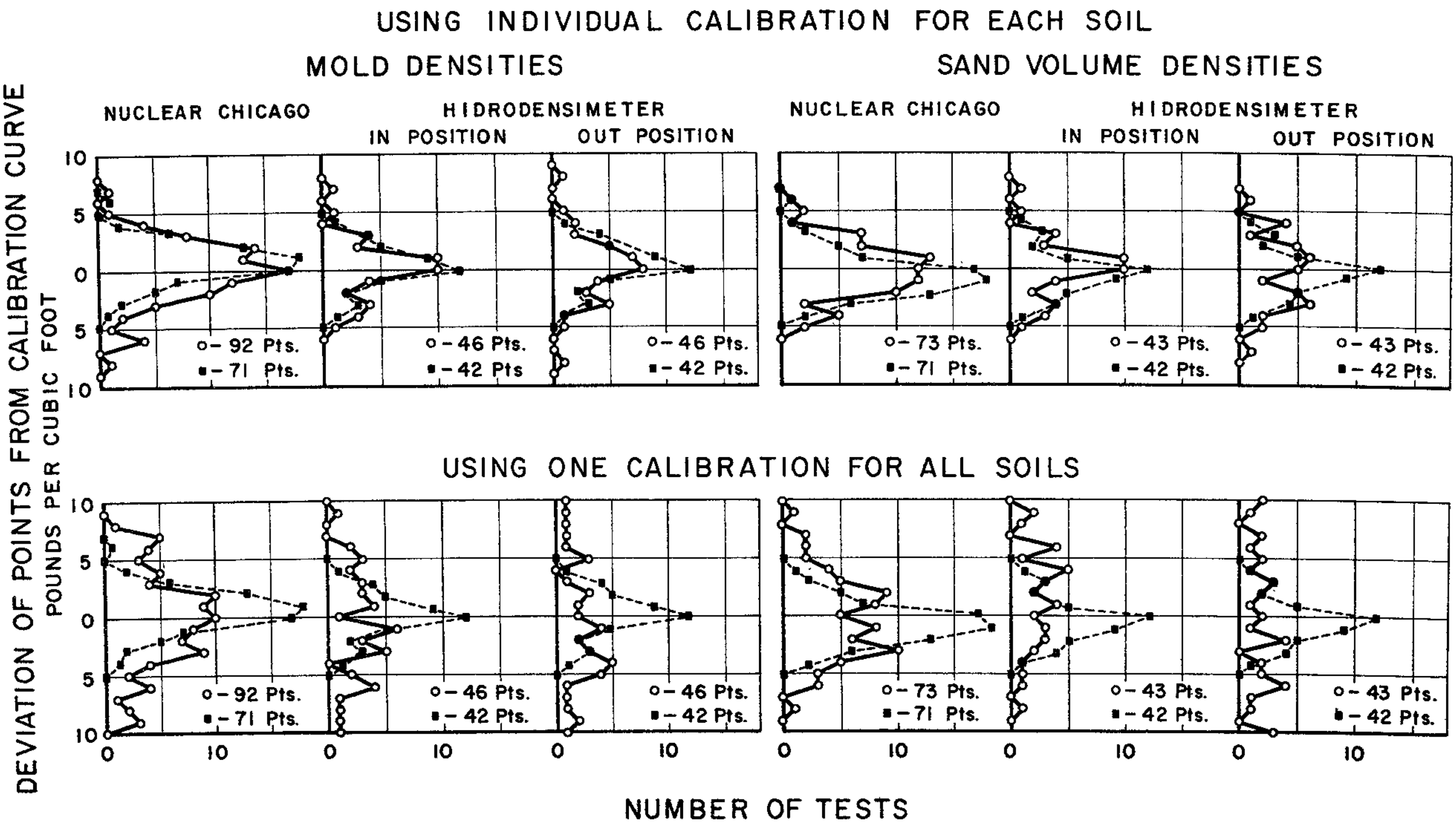


FIGURE 11

DISTRIBUTION OF POINTS IN THE DENSITY STUDIES



Solid line – Deviation in density using nuclear equipment.
Broken line – Deviation between Mold and Sand Volume density.

FIGURE 12

MOISTURE CALIBRATION CURVES

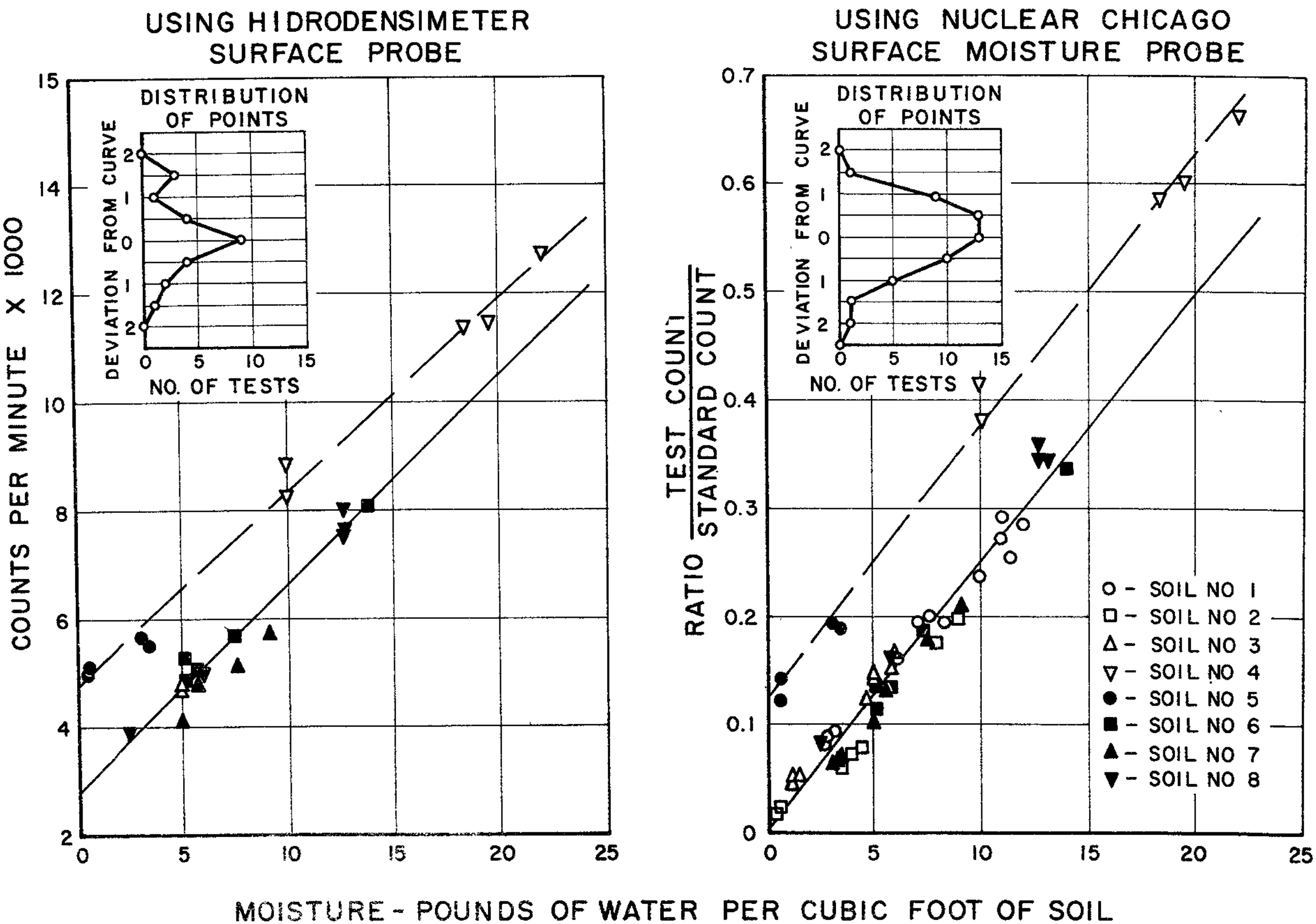
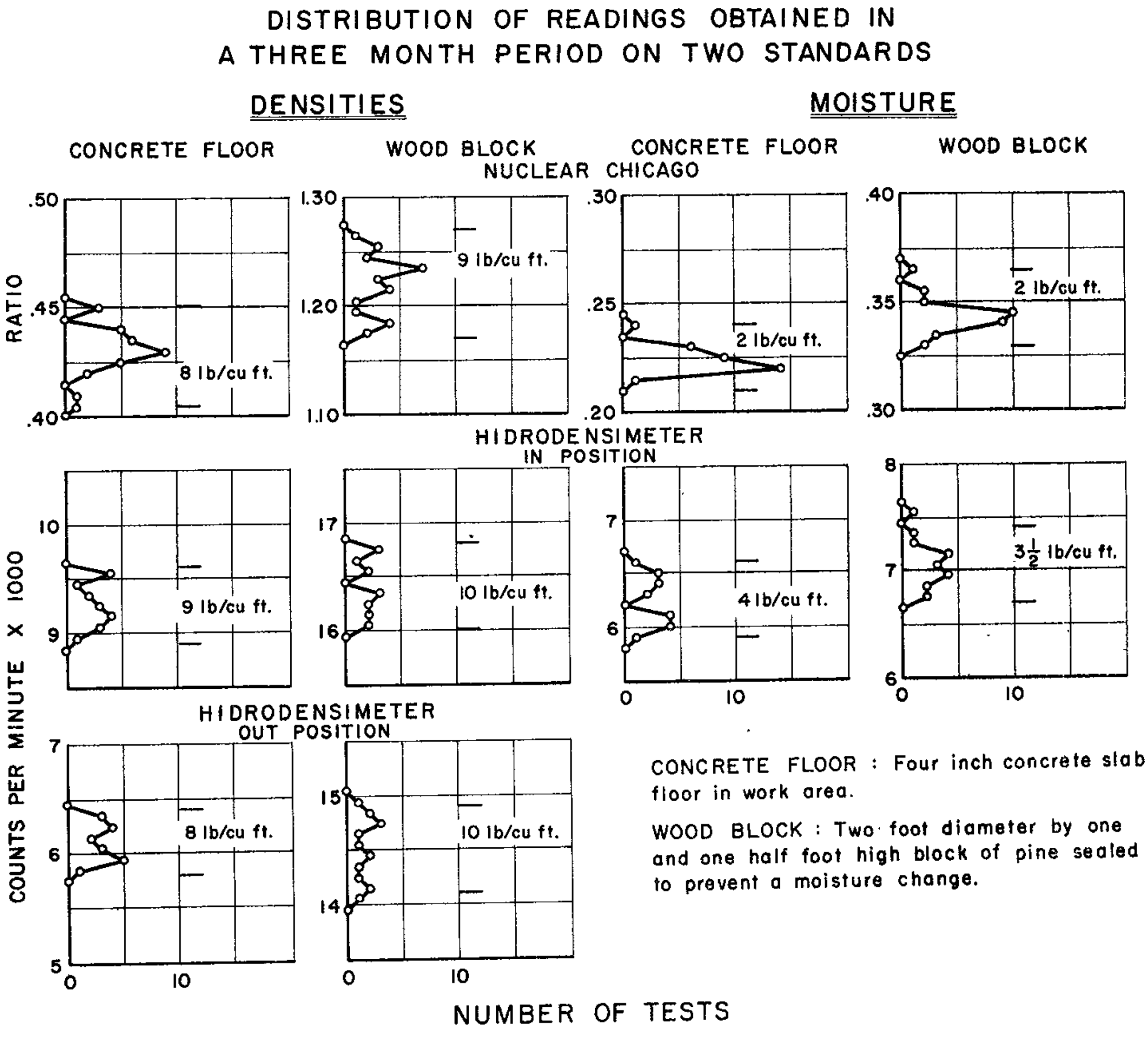


FIGURE 13

REPRODUCIBILITY OF NUCLEAR READINGS



CONCRETE FLOOR : Four inch concrete slab floor in work area.

WOOD BLOCK : Two foot diameter by one and one half foot high block of pine sealed to prevent a moisture change.

FIGURE 14

DEPTH OF INFLUENCE OF NUCLEAR DENSITY PROBES

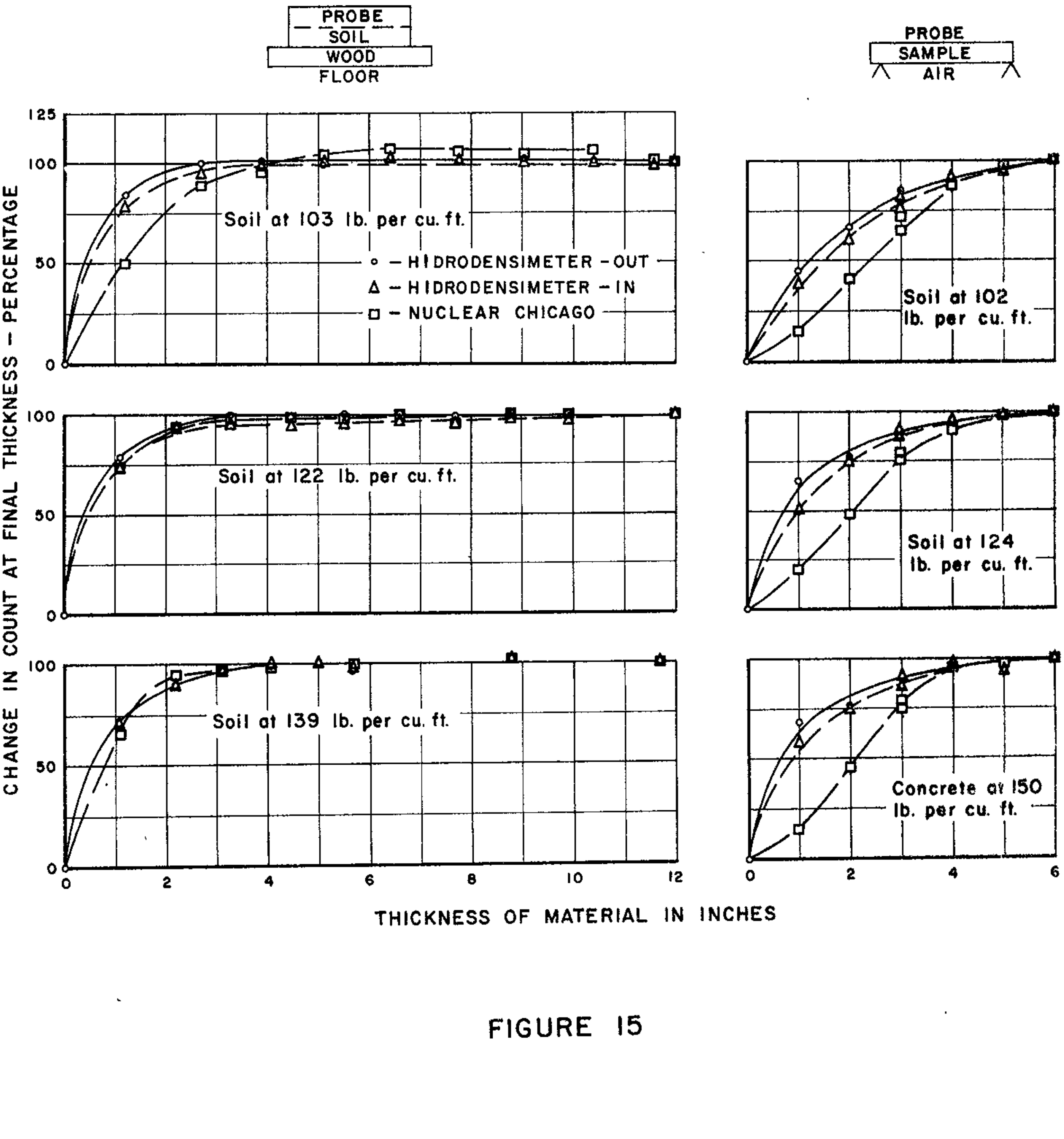


FIGURE 15

EFFECT OF THICKNESS OF SAND SEAT ON NUCLEAR READINGS

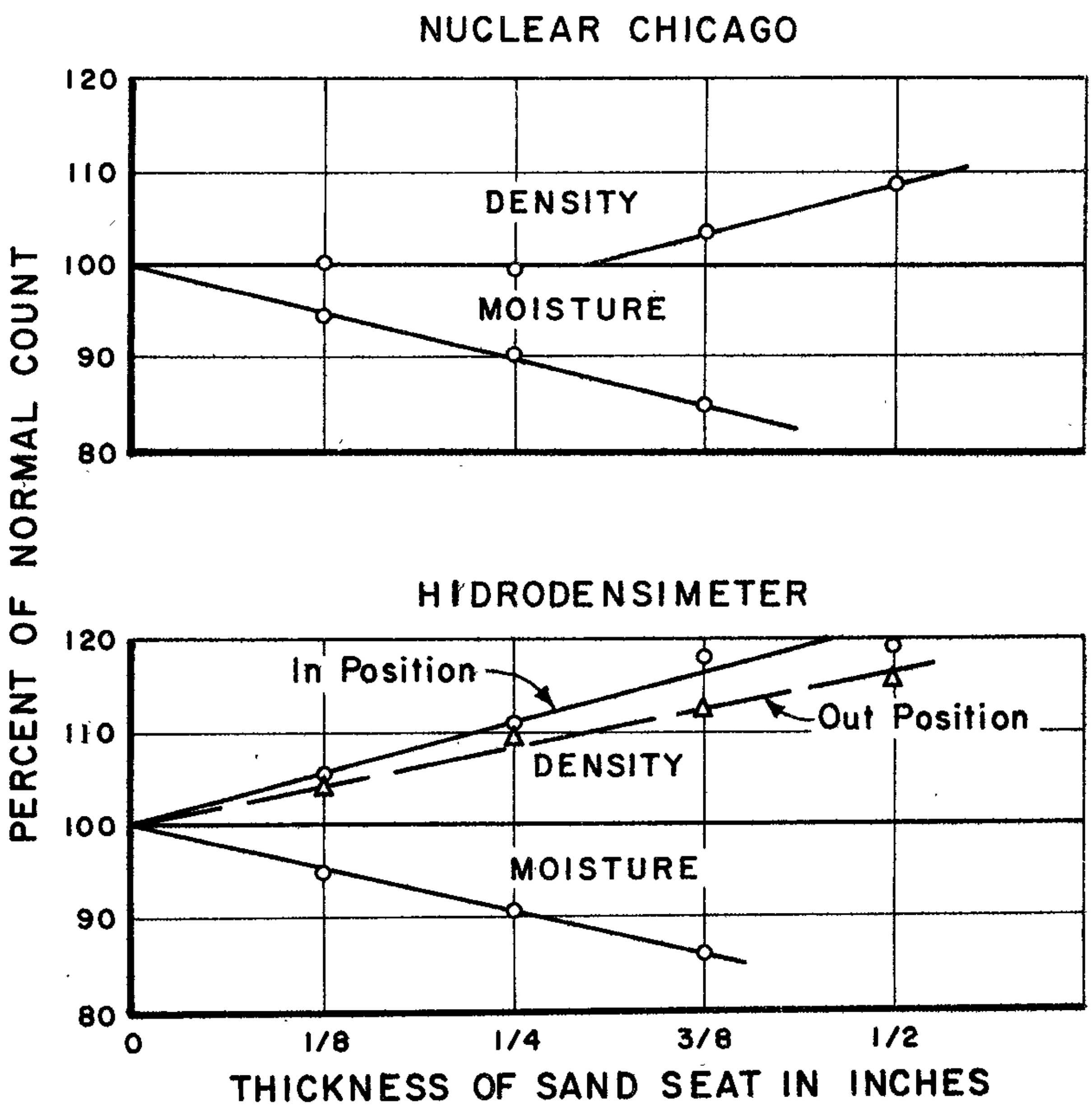


FIGURE 16