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16. ABSTRACT

The use of radioactive materials for measuring soil moisture and density has received much attention in recent years. Many papers have been presented indicating a great future for this nondestructive type of testing. The California Division of Highways has been interested in this process for many years and in 1954 started applying nuclear methods to the study of moisture and density changes in subsurface soils. In recent years the Division has been doing experimental work with the surface units for measuring soil moisture and density.

A brief explanation of the principles underlying these measurements of soil moisture and density is desirable for those not familiar with this method. The density of a soil is measured by means of the Compton effect. A radioactive source emitting gamma rays is used. As the gamma ray penetrates the material being tested it collides with the electrons in the outer orbit of atoms and rebounds at a slightly lower energy level. The returning reflected rays are registered by a detector. Each scattering increases the probability that the gamma ray will be absorbed before it reaches the detector. The combined effect is that the more dense the soil the fewer will be the number of rays returning to the detector tube. By placing a pickup tube in the system, with the pickup tube lead-shielded against direct radiation from the source, the gamma rays reaching the detector tube can be counted. Thus the counts received by the pickup tube will be inversely proportional to the electron density of the material being tested, and the density of the media being tested. Unfortunately the rebound of the gamma rays, or Compton effect, is affected by the chemical composition of the elements of the material being tested. The gamma ray absorption is also a function of the chemistry of the material being tested.

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STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
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NUCLEAR DEVICES FOR DETERMINATION OF MOISTURE AND DENSITY

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Nuclear Devices for Determination of Moisture and Density

By

William G. Weber, Jr.*

The use of radioactive materials for measuring soil moisture and density has received much attention in recent years. Many papers have been presented indicating a great future for this nondestructive type of testing. The California Division of Highways has been interested in this process for many years and in 1954 started applying nuclear methods to the study of moisture and density changes in subsurface soils. In recent years the Division has been doing experimental work with the surface units for measuring soil moisture and density.

A brief explanation of the principles underlying these measurements of soil moisture and density is desirable for those not familiar with this method. The density of a soil is measured by means of the Compton effect. A radioactive source emitting gamma rays is used. As the gamma ray penetrates the material being tested it collides with the electrons in the outer orbit of atoms and rebounds at a slightly lower energy level. The returning reflected rays are registered by a detector. Each scattering increases the probability that the

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gamma ray will be absorbed before it reaches the detector. The combined effect is that the more dense the soil the fewer will be the number of rays returning to the detector tube. By placing a pickup tube in the system, with the pickup tube lead-shielded against direct radiation from the source, the gamma rays reaching the detector tube can be counted. Thus the counts received by the pickup tube will be inversely proportional to the electron density of the material being tested, and the density of the media being tested. Unfortunately the rebound of the gamma rays, or Compton effect, is affected by the chemical composition of the elements of the material being tested. The gamma ray absorption is also a function of the chemistry of the material being tested.

The moisture is measured by the moderation of high energy neutrons. A high energy neutron source is placed at the surface of the material being tested. When the neutron collides with the nucleus of a heavy atom it rebounds with little loss of energy, but when it collides with the nucleus of a hydrogen atom, (the same weight as a neutron) it loses about half of its energy. By placing a pickup tube near the material being tested that measures only low energy neutrons, a count proportional to the hydrogen content of the material is obtained. To determine the moisture content of a media it is assumed that the hydrogen content is proportional to the water content.

The Materials and Research Department of California Division of Highways has been evaluating the use of nuclear surface gages in compaction control. A portion of this study consisted of a laboratory investigation of the practicability of using the surface units in construction control. Eight soils from various areas throughout California were obtained. These soils ranged from silty clays to sand and gravel soils used in fill construction and base courses. Each of the soils was compacted into a mold one foot in depth and two feet in diameter. The moisture content and density were varied so as to obtain a range of moistures and densities for each soil. Nuclear moisture and density determinations were made on the surface of the soil and a sand volume test and oven dry moisture test was run on the sample each time the mold was filled with soil. Two types of commercial nuclear gages were used in this study. Sufficient points were thus obtained to permit the calculation of a calibration curve for each soil.

A comparison of the densities as determined by the sand volume tests and the weight and volume of soil in the mold was made. It was found that the sand volume density had a standard deviation of two pounds per cubic foot when compared with the overall mold density.

Calibration curves were then obtained by the method of least squares for each soil assuming that the calibrations are straight lines. The calibration curves for one of the commercial nuclear density gages is shown in Figure No. 1. All of the densities obtained in this series of tests were then combined and a calibration curve for all soils tested was calculated. The combined density calibration curve is shown in Figure No. 2. The same procedure was used for the moisture tests and are shown in Figure No. 3.

When one calibration curve was used for the densities obtained in this study the individual tests fell in a band of 15 to 20 pounds per cubic foot, which is a fairly broad range. 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 (still a fairly broad deviation) and 90 percent of the readings will be within 3½ pounds per cubic foot (a more tollerable spread) when separate calibrations 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 ± three pounds per cubic foot 90 per cent of the time. It seems evident that if we are to obtain a reasonable degree of accuracy with the nuclear density probes, an individual calibration is required for each soil encountered.

The calibration curve for the moisture probes were along two lines, soil No. 4 and 5 along one calibration and all other soils along another calibration. Soils No. 4 and 5 were found to be serpentine soils high in hydrous magnesium silicate which is believed to have caused this shift in the calibration.

The density and moisture data both indicate the desirability of obtaining calibration curves for each soil encountered in construction.

Our investigations have included studies of numerous factors. The effective volume of soil being measured by the nuclear density probe was one of those investigated. It was found that the top inch of the soil accounts for about 75 percent of the gamma rays counted by the pickup tube, and the upper four inches about 95 percent of the counts recorded. The effective volume of the soil being measured was about one tenth of a cubic foot using the 95 percent criteria.

A field investigation was then undertaken in ten projects currently under construction. Comparative sand volume and nuclear tests were obtained. The results of the density tests are shown in Figure No. 4 and the moisture tests in Figure No. 5.

The field nuclear density tests were in a range of over 20 pounds per cubic foot when compared with the sand volume test where one calibration curve was used for all soils. The standard deviation was about 7 pounds per cubic foot and the 90 percent confidence limits were about 10 pounds per cubic foot. This is a very broad deviation when compared to the deviation of the sand volume test, our present control test.

The soils tested on each project were then grouped according to the visual descriptions and calibration curves obtained for each soil using the field test data. When separate calibrations were used for each soil the standard deviation was about 4 pounds per cubic foot and the 90 percent confidence limits were 7 pounds per cubic foot. This approaches a usable accuracy for control of compaction.

The nuclear moisture tests showed an average deviation of two pounds of water per cubic foot from the conventional tests. This is a larger deviation than occurred in the laboratory test program, however, it is smaller than the deviation due to the density tests.

In compaction control it is the practice of the California Division of Highways to establish the optimum moisture for each field sand volume test to determine the percent relative compaction. The determination of the optimum density is the time consuming portion of the compaction control. Thus, the time savings in using the nuclear probes for field densities would be minor unless a standard optimum compaction could be used.

Considering the two values necessary for determining the relative compaction of a soil, the field density and optimum density, it appears that the nuclear surface probes could be profitably used on soils having the following characteristics:

1. A soil sufficiently uniform so that 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 conventional field tests.
4. A soil where shallow depth readings would be satisfactory.
5. A plane surface for seating the probes is readily obtained.

The limitations of the nuclear surface gages impose restrictions upon the use of this equipment. It cannot be used indiscriminately on all projects without checking the calibration curve of the soil encountered. In the field study it was found that on about one-third of the projects a single calibration curve could be applied to all the soil being placed, and on the remainder of the projects two or more calibrations were required. These calibration curves frequently varied by 10 to 15 pounds per cubic foot.

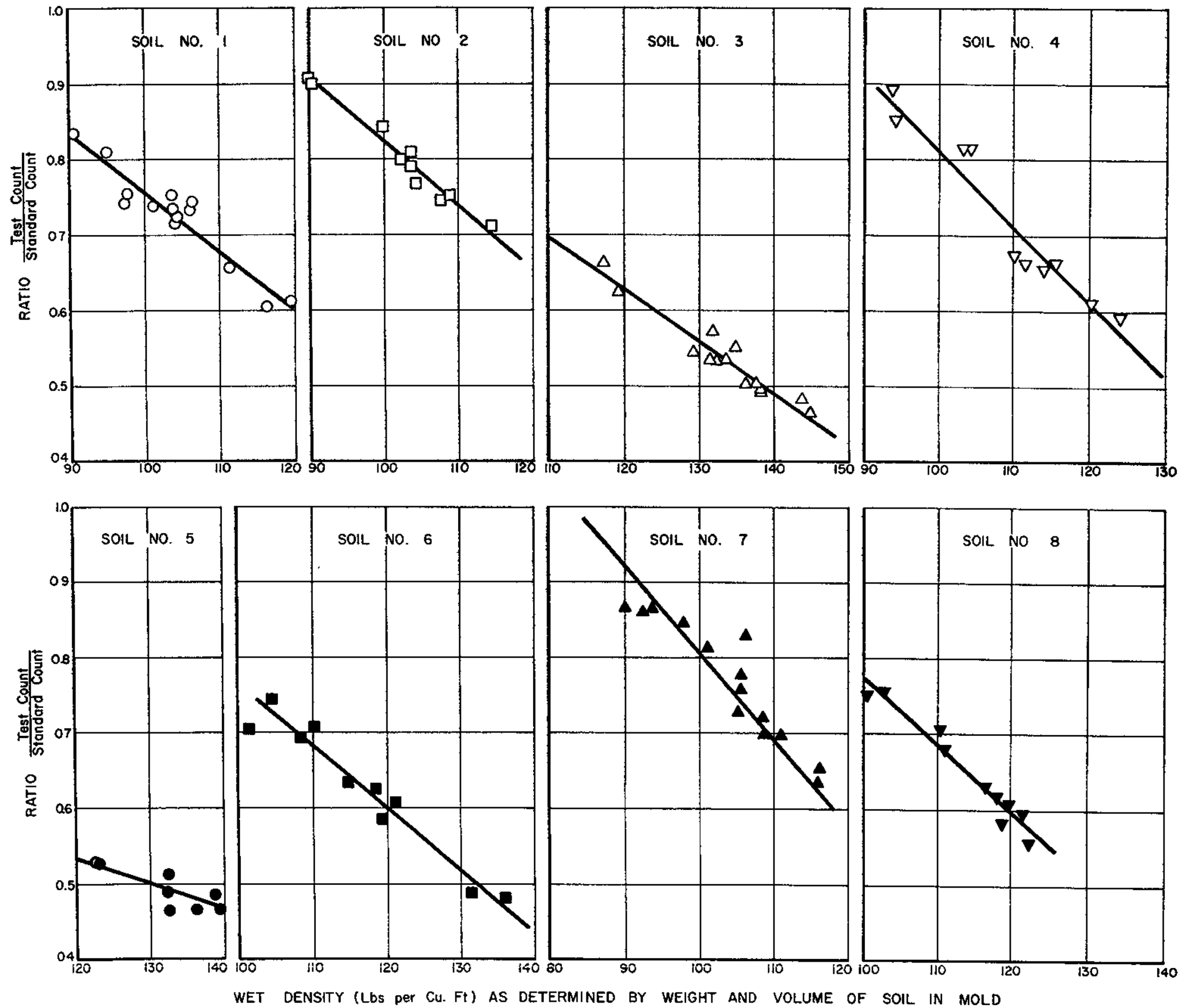
There are uses that can be made of the surface nuclear gages at the present time. For example, where a uniform soil is encountered such that the calibration and the optimum density will remain uniform the surface gages can be used to advantage. A specialized use would be in roller compaction studies. The counts could be plotted against the passes of the roller. Where the counts no longer show a decrease with passes of the roller the highest density possible for the soil conditions has been obtained with this roller. The nondestructive nature of this type of testing enables the same soil mass to be repeatedly tested.

In conclusion there are limited uses that can be made with the nuclear surface gages at the present time. However, these gages should not be used to control and evaluate the quality of contract work without a full understanding of the scope and limitations of the presently available nuclear-density equipment.

FIGURE 1

DENSITY CALIBRATION CURVES FOR VARIOUS SOILS

USING INSTRUMENT "A" SURFACE DENSITY PROBE
MOLD DENSITY TAKEN AS STANDARD



DENSITY CALIBRATION CURVES FOR ALL SOILS TESTED

USING INSTRUMENT "A" SURFACE DENSITY PROBE

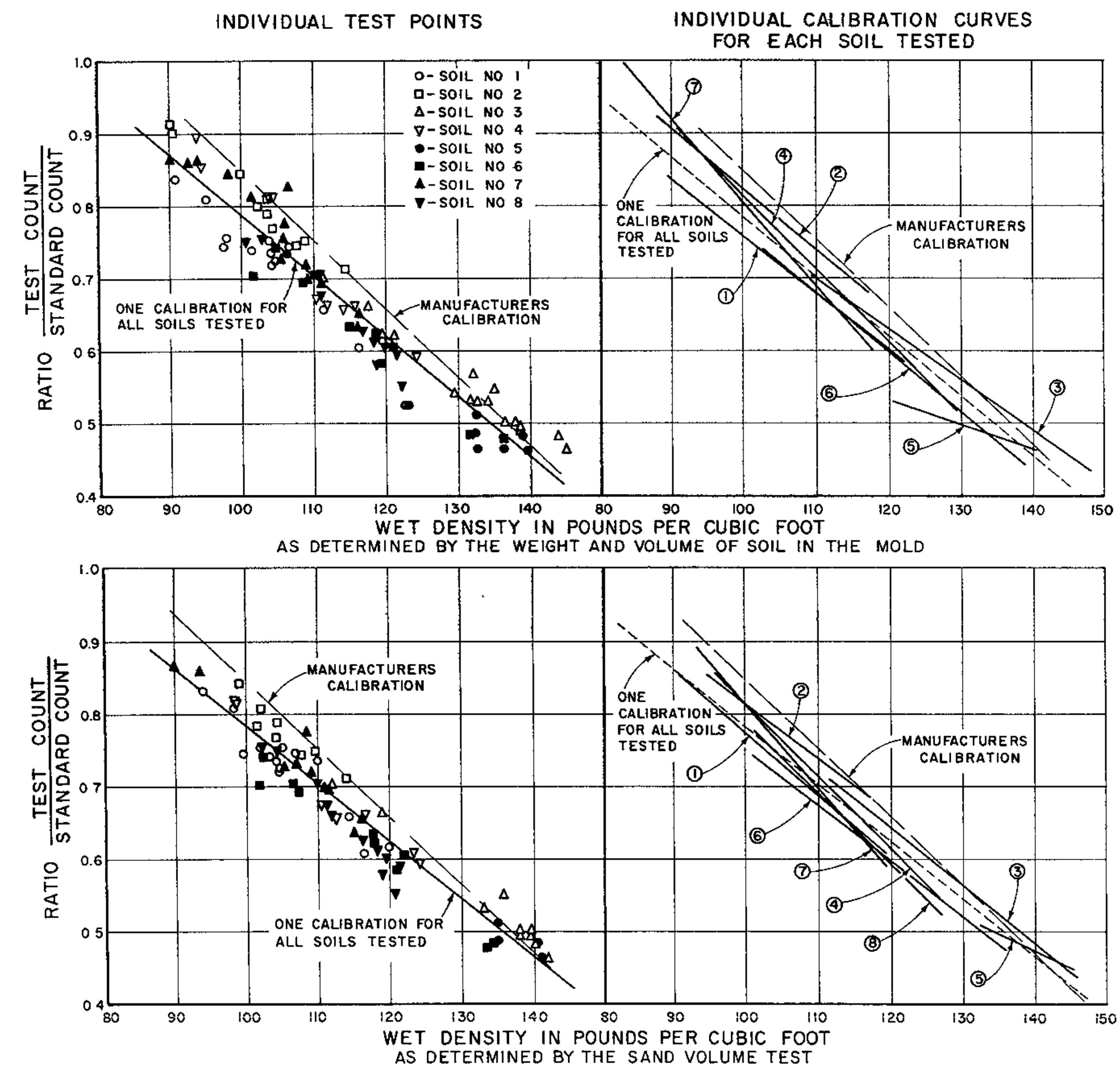


FIGURE 2

FIGURE 3

MOISTURE CALIBRATION CURVES

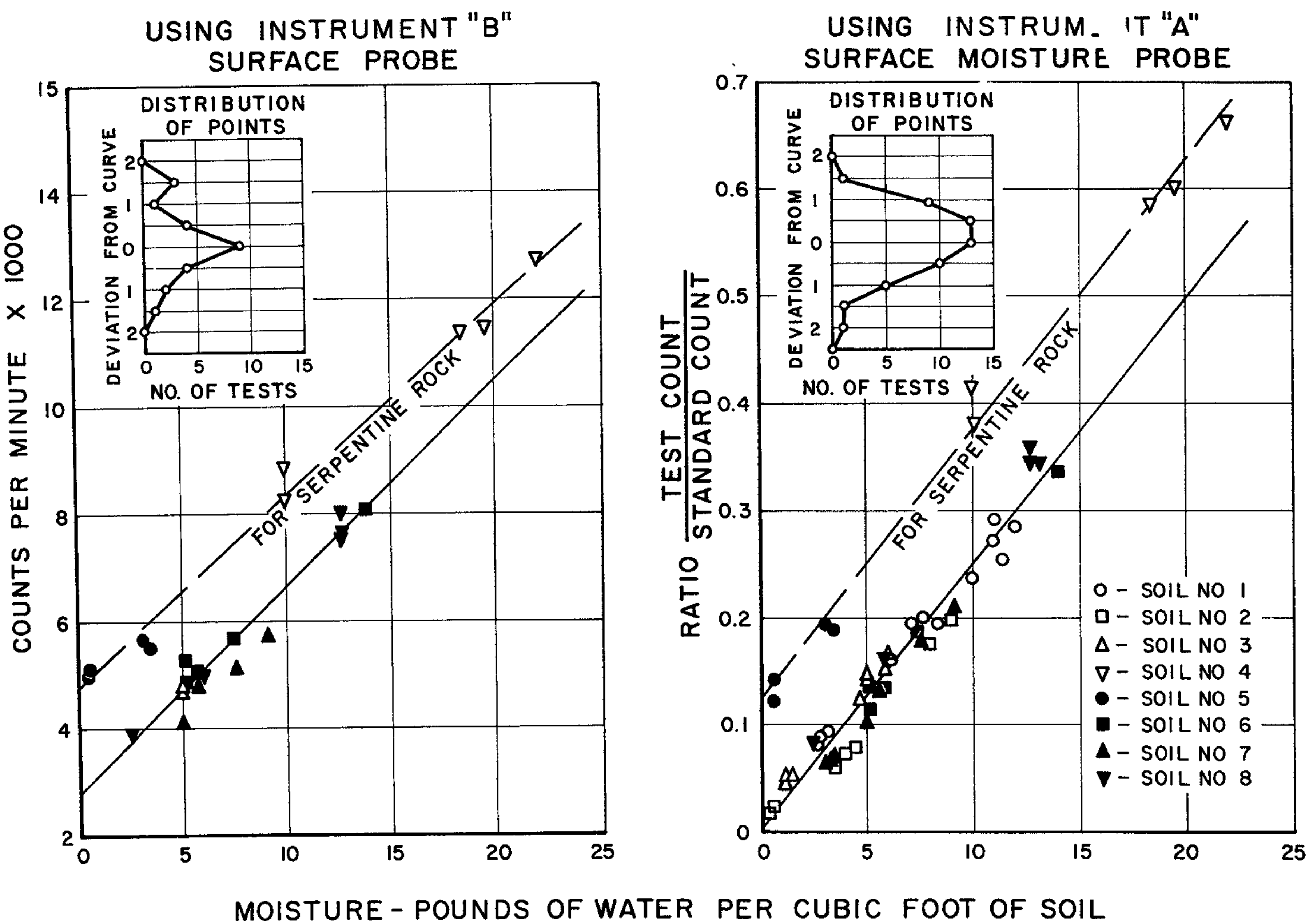
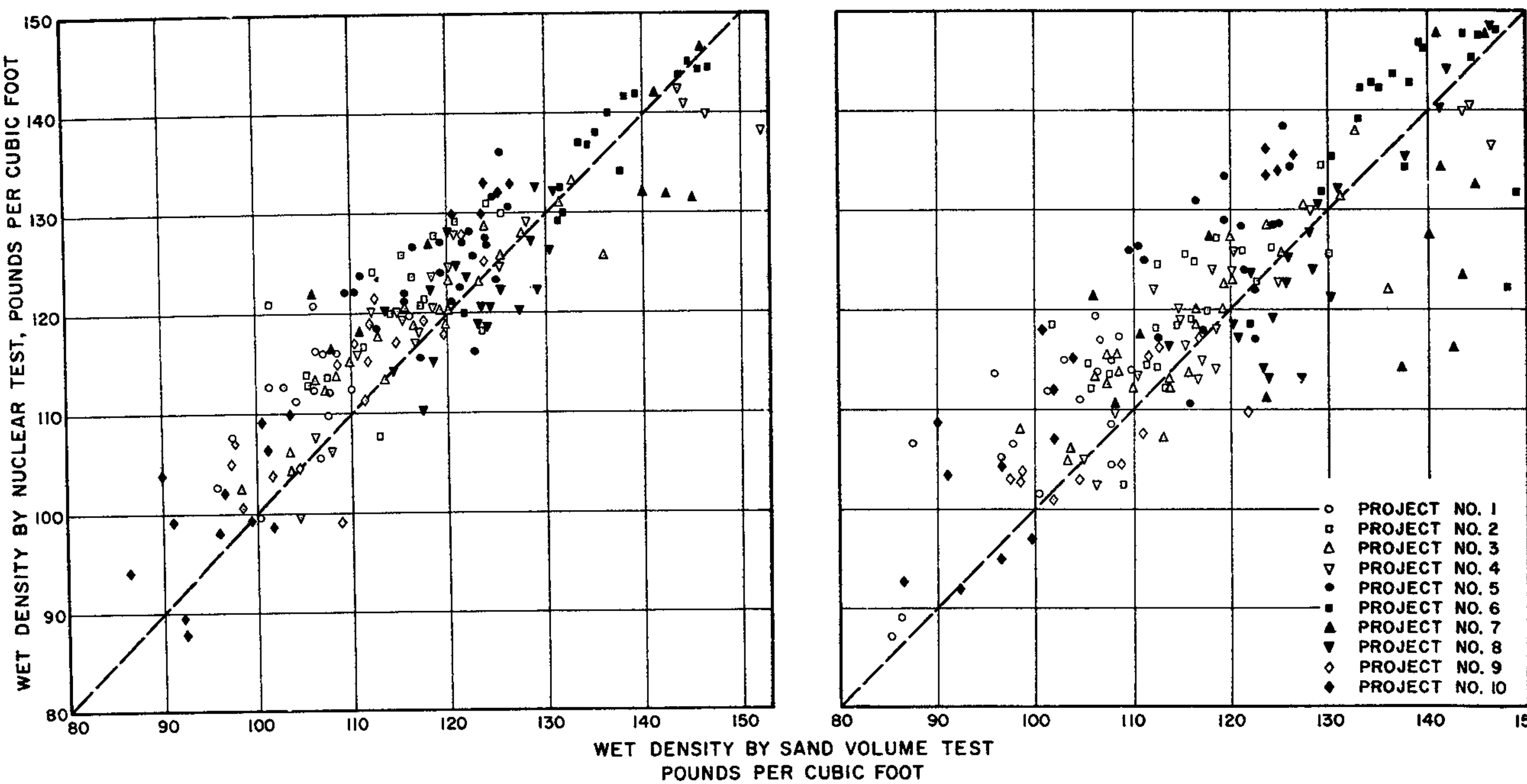


FIGURE 4

COMPARATIVE SAND-VOLUME & NUCLEAR DENSITY TESTS
FIELD SURFACE NUCLEAR STUDIES
DISTRICTS III & X
USING ONE CALIBRATION CURVE FOR ALL SOILS

INSTRUMENT "A" INSTRUMENT "B"



COMPARATIVE OVEN DRY & NUCLEAR MOISTURE TESTS
FIELD SURFACE NUCLEAR STUDIES
DISTRICTS III & X

USING ONE CALIBRATION CURVE FOR ALL SOILS

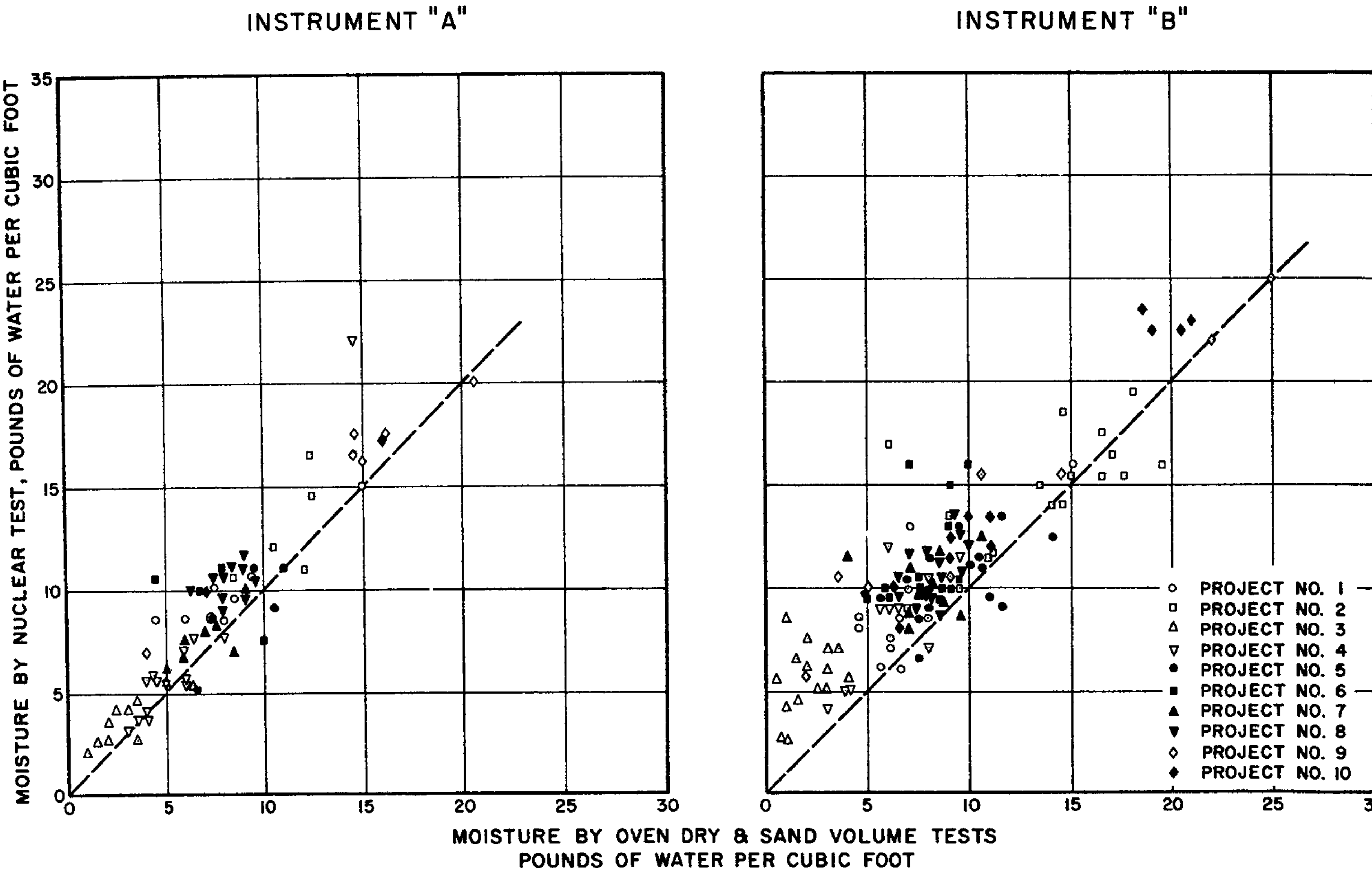


FIGURE 5