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The study was conducted with State financed research funds.

**16. ABSTRACT**
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The study involved a comparison of the density determinations by the backscatter and direct transmission gages which employed both the nuclear source in the rod and the Geiger-Mueller tube in the rod. Density readings were taken for aggregate bases and soils and these readings compared to "true" densities to determine the best mode for density determination of roadway materials. These tests indicated that the gage with the source in the rod consistently gave readings (direct transmission mode) which agreed most closely with calculated densities. Similar tests were also made using metals. Although the densities determined from nuclear readings for metals did not agree as well with the known densities as they did for the roadway materials, the gage with the nuclear source in the rod gave better overall results than those gages having the G-M tube in the rod. Also, in both instances the use of direct transmission mode provided more accurate data than did the use of the backscatter mode.

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C.T.B. (cement treated base), backscatter, direct transmission, Geiger-Mueller pickup tube, nuclear compaction, drop hammer

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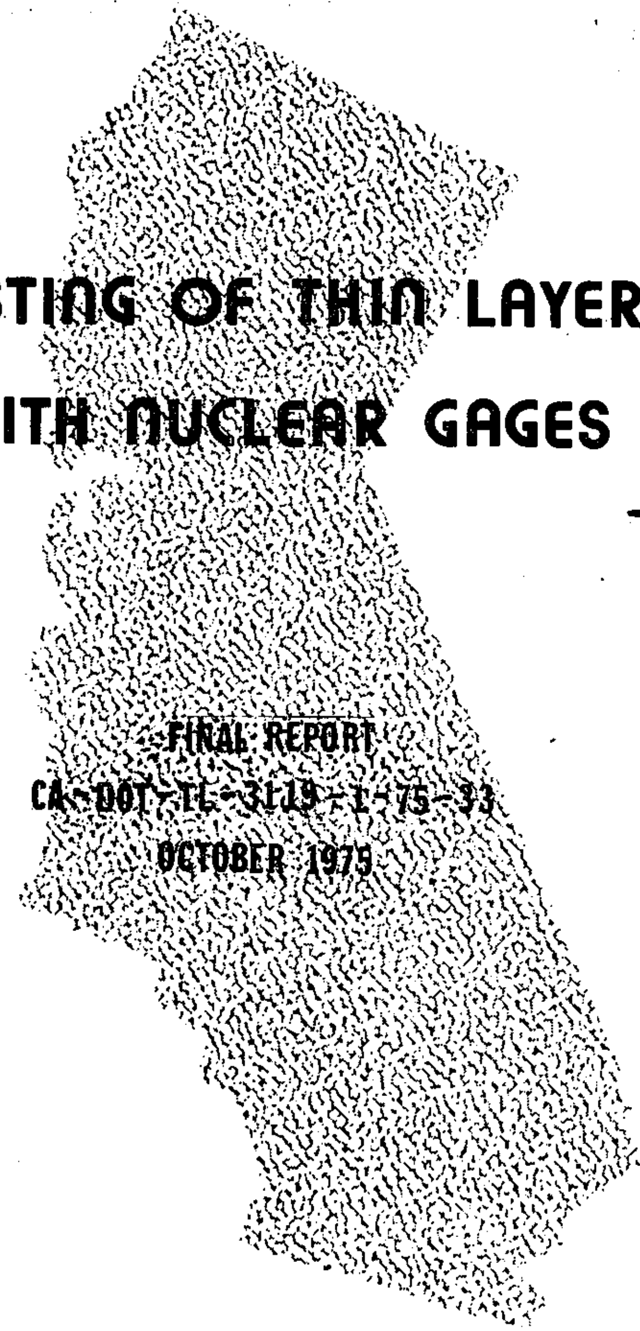
TRANSPORTATION LABORATORY

RESEARCH REPORT



# TESTING OF THIN LAYERS WITH NUCLEAR GAGES

75-33

FINAL REPORT

CA-DOT-TL-3119-1-75-33

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CALIFORNIA DEPARTMENT OF TRANSPORTATION

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION AND RESEARCH
TRANSPORTATION LABORATORY

October 1975

TL No. 643119

Mr. R. J. Datel
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

TESTING OF THIN LAYERS
WITH NUCLEAR GAGES

Study made by . . . . . . . . . . . . . . . . . . . . Pavement Branch

Under the Supervision of . . . . . . . . . . . . . George B. Sherman and John B. Skog

Principal Investigator . . . . . . . . . . . . . Robert E. Smith

Co-Investigators . . . . . . . . . . . . . . . . . Bobby L. Lister, Masayuki M. Hatano, and Karl L. Baumeister

Report prepared by . . . . . . . . . . . . . . . . Karl L. Baumeister and Bobby L. Lister

Very truly yours,

George A. Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

Attachment

ACKNOWLEDGEMENTS

This study was conducted by the Transportation Laboratory to evaluate various types of nuclear gages used to determine the compaction of roadway materials.

The work was planned and supervised by Robert E. Smith. Masayuki M. Hatano, whose familiarity with the gages helped in implementing this work, was consulted during the course of the project. Their contributions to the effort reported herein are sincerely appreciated.


The contents of this report reflect the views of the Transportation Laboratory, which is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California. This report does not constitute a standard, specification, or regulation.

TABLE OF CONTENTS

# INTRODUCTION

Nuclear gages are being used with increasing frequency for determination of density and moisture contents of soils, aggregates, treated bases, and asphalt pavements. Nuclear gages have been used for this purpose in California for several years, gradually replacing the sand volume method. Three types of nuclear gage equipment are used; namely, the "backscatter" method, the "direct transmission" method with the nuclear source at the end of the rod, and the "direct transmission" method with the Geiger-Mueller pick-up tube at the end of the rod.

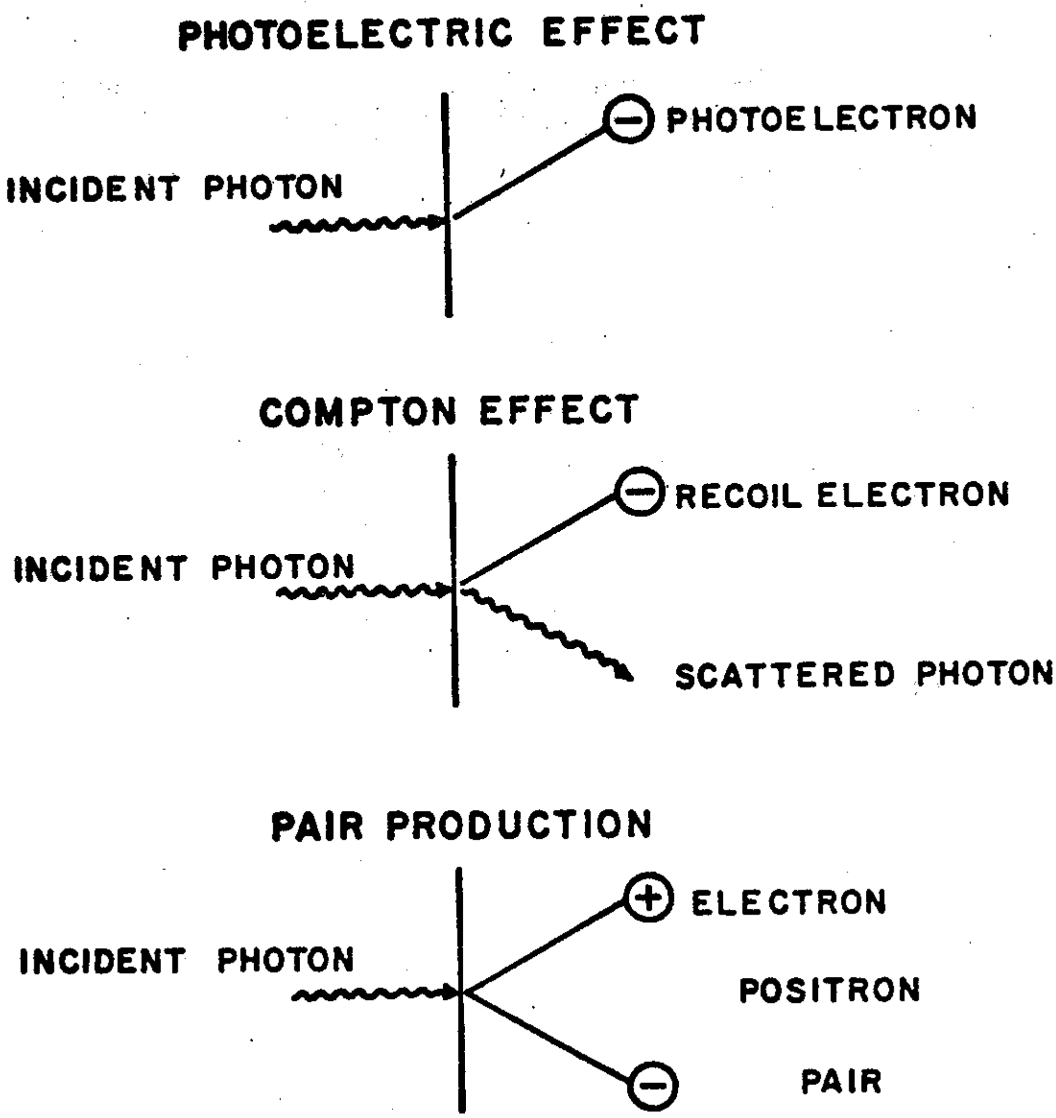
These various types of nuclear gages are used in construction to determine the adequacy of the compaction of subgrades, bases, and asphalt concrete. Since the results of these tests determine whether recompaction or, in the case of stabilized bases, removal is necessary, the need existed to determine the most accurate method of in-situ density measurement. Therefore, this study had as its main objective the comparison of results when testing thin (less than 8") layered systems of roadway materials with differing densities using nuclear gages in the backscatter mode and the direct transmission mode. Thin layers of metal were also tested with these gages for comparison between nuclear density readings and actual densities to determine the accuracy of the nuclear equipment. Two varieties of the direct transmission method were used in this comparison - one with the nuclear source in the end of the rod and the other with the Geiger-Mueller pickup tube in the rod. These comparisons would then be used to choose the most effective density measuring equipment for thin layers such as those found in pavement structural sections.

DENSITY MEASUREMENT USING VARIOUS TYPES OF NUCLEAR GAGES

The ability of any material to absorb or scatter gamma radiation is a function of the density of the material. Gamma photons are absorbed by the material in three principal ways: (1) photoelectric effect, (2) Compton effect, and (3) formation of positron-electron pairs. Diagrams of the three types of gamma photon absorption are presented in Figure 1. The photoelectric effect is most significant for gamma photons of low energy, and for absorbers of high atomic weight. The Compton effect plays a major role when the gamma photons have a medium radiation energy, and when the absorber has a low atomic weight. Pair production is most important for photons of high energy, especially when the absorber is of high atomic weight. In pair production and the photoelectric effect, the initial gamma photon loses all of its energy and ceases to exist, but in the Compton effect the photon loses only part of its energy to the recoil electron.

Sources of gamma photons used in soil density measurement instruments emit photons of lower energy than is required for pair production, and as a soil is not a material of high atomic weight (density), the dominant phenomena in the absorption and scattering of gamma photons for the determination of soil density is the Compton effect. The number of gamma photons passing through soil is measured using a Geiger-Mueller tube or a scintillation crystal. The Geiger-Mueller tube measures all the gamma photons striking it that are capable of penetrating the tube. The scintillation crystal can be used to count photons of all energies, or only those having energies above a given energy level.

Nuclear measurement of soil density can be accomplished using either of two basic modes: 1) the "backscatter" mode which counts only photons that have been scattered by the Compton

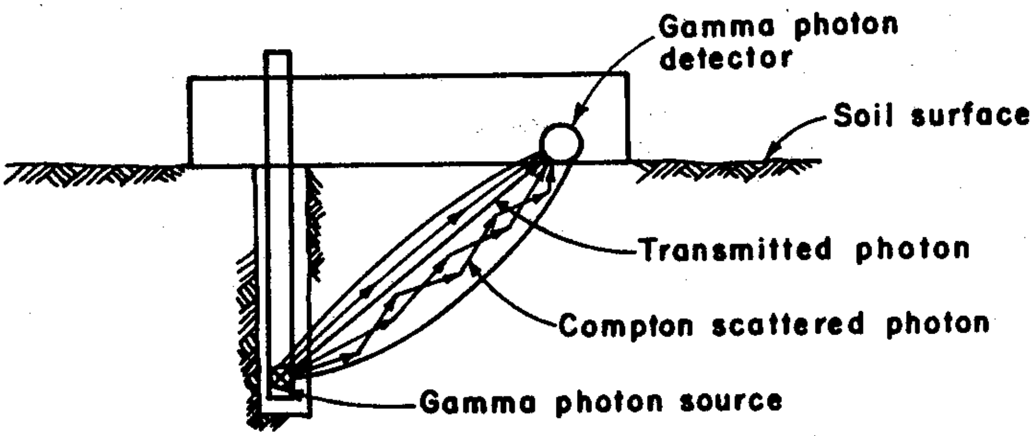



# THREE TYPES OF GAMMA PHOTON ABSORPTION

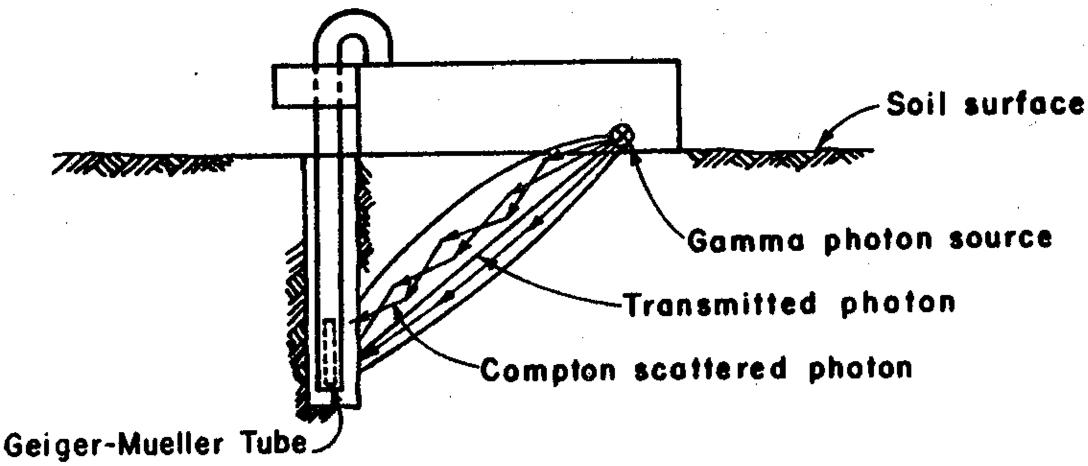
FIGURE 1

effect, and 2) the "direct transmission" mode which counts both photons that have been scattered by the Compton effect and photons that have been transmitted without energy loss. With both modes, low photon counts indicate a high density and high photon counts indicate a low density.

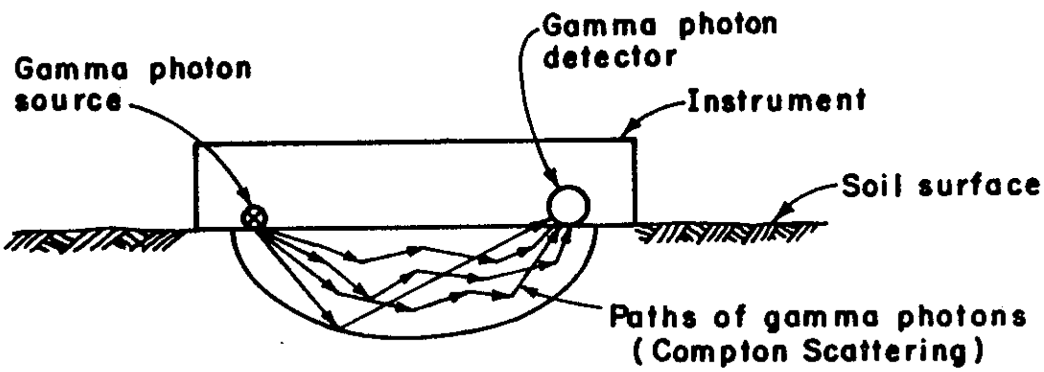
The "direct transmission" mode is available in two varieties. One has the source of nuclear energy in the rod and the other has the Geiger-Mueller tube in the rod. Schematic diagrams of the two types of "direct transmission" and the "backscatter" modes are shown in Figure 2. Before the gages are used to measure densities, their calibration is checked using blocks of known density. This enables the operator to convert the nuclear "counts" to density. Further information regarding nuclear testing is available in references 1 and 2.




**TRANSMISSION**
SOURCE IN THE ROD




**TRANSMISSION**
GEIGER-MUELLER TUBE IN ROD




**BACK SCATTER**

FIGURE 2

## DESCRIPTION OF GAGES TESTED

Three nuclear gages were used for this study, Troxler Model 109-112 with the Geiger-Mueller pickup tube in the rod and two Portaprobes, one with the pickup Geiger-Mueller tube in the rod (#15) and the other with the nuclear source in the rod (#393). All three gages were used for both direct transmission and backscatter readings.

The depth setting on the rods containing the pickup tubes was referenced to the center of the four and one-quarter inch long Geiger-Mueller tube. Thus, at any depth setting on the rod, the G-M tube was influenced by radiation to a depth two and one-eight inches below that depth. The depth setting for the rod with the nuclear source at the tip was essentially the same as the depth being measured.

## GAGE CALIBRATION

Three master standard blocks were constructed of concrete using several varieties of aggregate and three were cut from rock of various densities. The densities of the blocks were 95.7, 101.4, 126.0, 134.4, 167.3 and 173.0 pounds per cubic foot, respectively. They were so constructed that they could be used for calibration for either the direct transmission or backscatter modes.

The gages were calibrated by relating "count ratio" to density for each block for backscatter and for depths between 2 and 8 inches in one-inch increments. The "count ratio" is simply the ratio of the count per minute reading for a particular case to the "standard count", which consists of the count reading for the gage setting on a "standard block" supplied with the gage by the manufacturer. Use of the count ratio for correlation tends to compensate for minor fluctuation in electronic circuitry which would adversely affect the measurements. The calibration data is fed into a computer, a best fit curve calculated, and a table produced (see Table A-1, Appendix). The density corresponding to any particular count ratio is then determined using this table.

# DISCUSSION

## Metal Plates - General

A comparison was made between nuclear density readings and actual densities using metal plates of known uniform density in order to determine which gage and mode gave the most accurate results.

Twelve aluminum and eighteen magnesium plates twenty-four inches long, sixteen inches wide, and one-half inch thick, were fabricated by the Transportation Laboratory's machine shop. These metals were chosen because they were the two most readily available light metals. A hole was drilled in each plate at the same relative location to provide a hole for the nuclear gage rods when testing in the direct transmission mode.

The densities of the plates were determined by weighing a random sample of three aluminum and three magnesium plates in air and then in water. The densities of the aluminum plates and the magnesium plates were 168.5 lb./ft.$^3$ and 108.5 lb./ft.$^3$, respectively, based on these weight and volume measurements.

Readings were taken with the bottom of the gage in contact with the metals and also with a 0.05 inch air gap under the gage to determine whether complete contact was necessary or desirable.

A set of readings for both direct transmission and backscatter modes was taken with all three nuclear gages, in as close to the same position on the plates as possible, with the metal plates arranged in the following manner:

(1) Three inches of magnesium placed upon six inches of aluminum.

(2) Step (1) was repeated with a 0.05 inch air gap placed under the gage at the opposite end from the rod.

(3) Four and one-half inches of magnesium placed upon six inches of aluminum.

(4) Six inches of magnesium placed upon six inches of aluminum.

(5) Step (4) was repeated with a 0.05 inch air gap placed under the gage at the end most distant from the rod.

(6) These five steps were then repeated with aluminum plates over magnesium plates.

A set of readings for each gage consisted of two one-minute counts taken with the probe at each of the depths tested, including the backscatter position.

Standard counts were taken before and after each set of readings with the rod of the nuclear gage in the same position upon the standard block as was used for that set on the metal plates. The count ratio used in developing the tables was the average of any two test counts divided by the average of the standard counts before and after the test readings.

Metal Plates - Test Results

Comparisons of the densities determined using the nuclear gages with the actual densities of the plates at various depths are shown in Figures 3 through 8. The actual composite density for both metals between the surface and the tip of the rod for the Portaprobe No. 393 (or between the surface and the center of G-M tube for Portaprobe No. 15 or the Troxler No. 109-112) was calculated using the following formula:

$$R = \text{Composite density in lb./ft.}^3 = \frac{d}{g}(X-Y) + Y$$

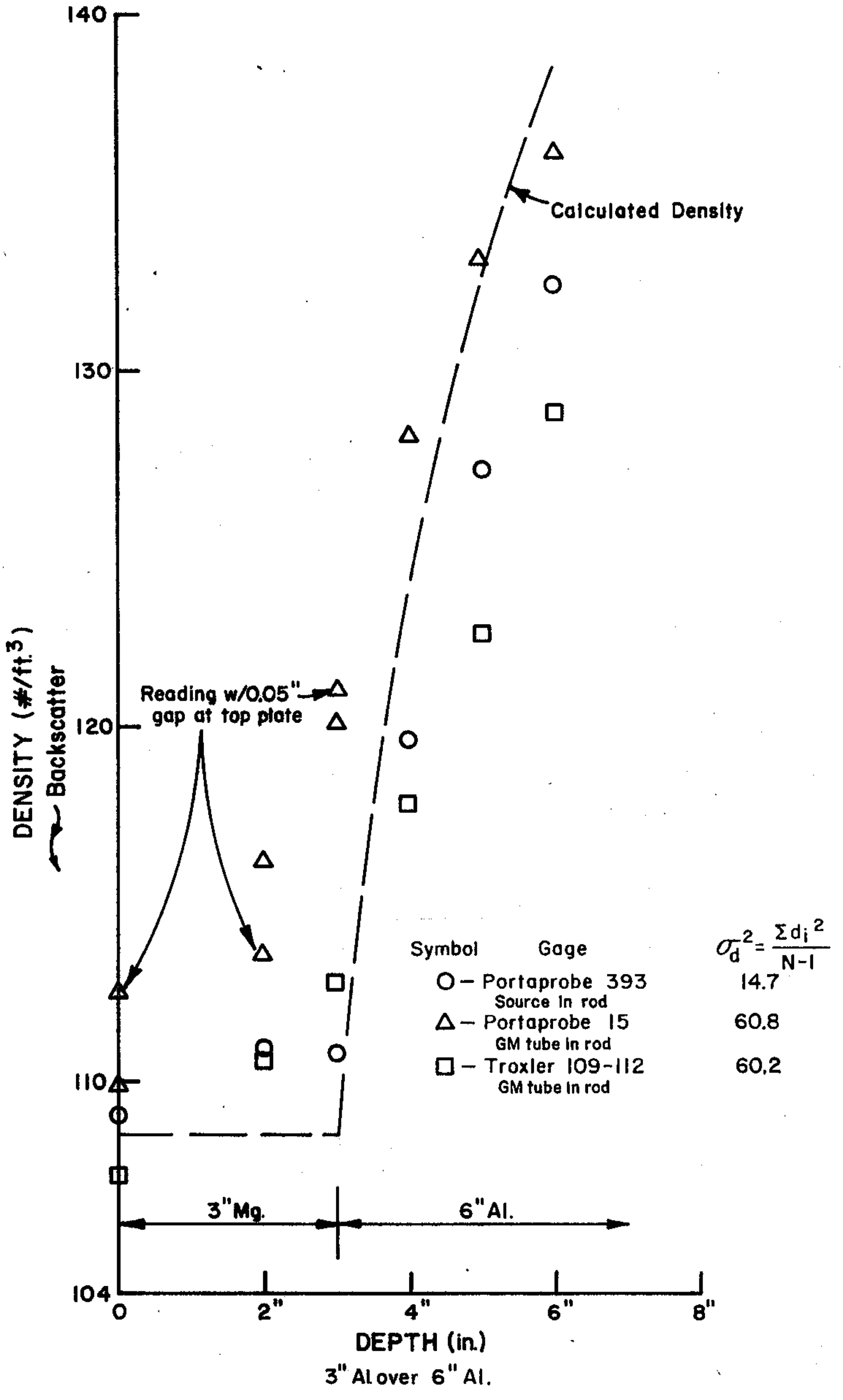
The terms used in the equation were as follows:

- X = density of upper metal in lb./ft.$^3$ (use 108.5 for Mg. and 168.5 for Al.)
- Y = density of lower metal in lb./ft.$^3$ (use 108.5 for Mg. and 168.5 for Al.)
- d = thickness of upper metal
- $z$ = distance from surface to tip of rod in Portaprobe No. 393 or from surface to center G-M tube in Portaprobe No. 15 or Troxler No. 109-112.

The derivation (assuming $z \geq d$) is as follows:

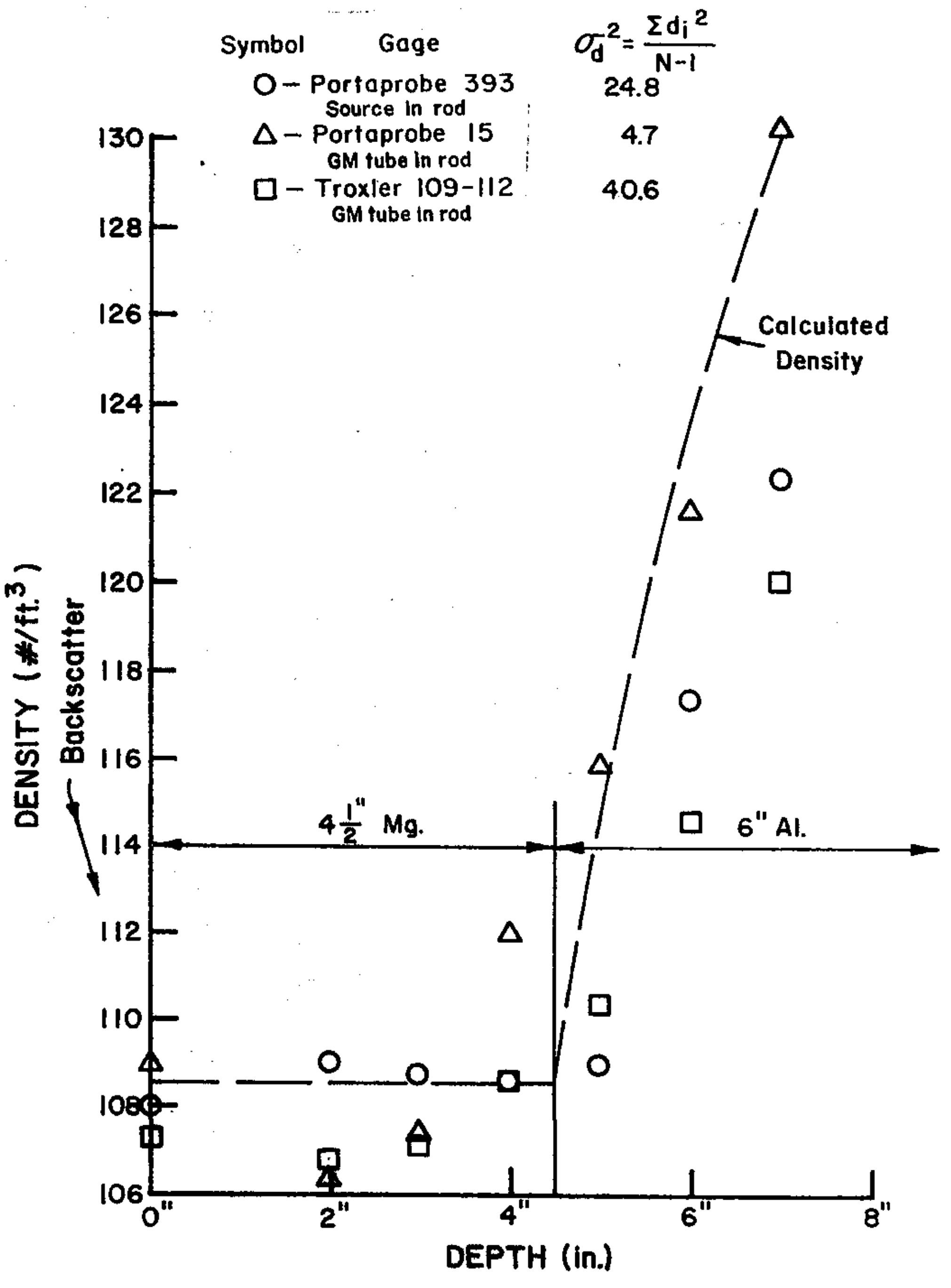
$$R = \frac{d}{z} X + \left(1-\frac{d}{z}\right) Y = \frac{d}{z} (X-Y) + Y$$

The agreement between actual densities and those determined by nuclear gages was generally poor for the aluminum. However, since aluminum is more dense than most subgrade, subbase, and base material, this apparent inaccuracy did not necessarily preclude the successful use of the nuclear equipment for measuring the density of structural section materials. As noted in the discussion of density measurements by nuclear gages, the "Compton effect" is the dominant phenomena when measuring soil density using nuclear gages. In the case of aluminum, which has a relatively high atomic weight, the Compton effect is of less significance, so this may have affected the sensitivity of these gages when testing aluminum. However, in all cases where aluminum was the upper metal, the Portaprobe No. 393 (with the source in the rod) gave better results than the other two. In four out of the six different metal arrangements, the gage with the source in the probe gave the best overall results as indicated by the mean square of the differences between calculated densities and the densities by gage readings as noted in Figures 3 through 8. The two



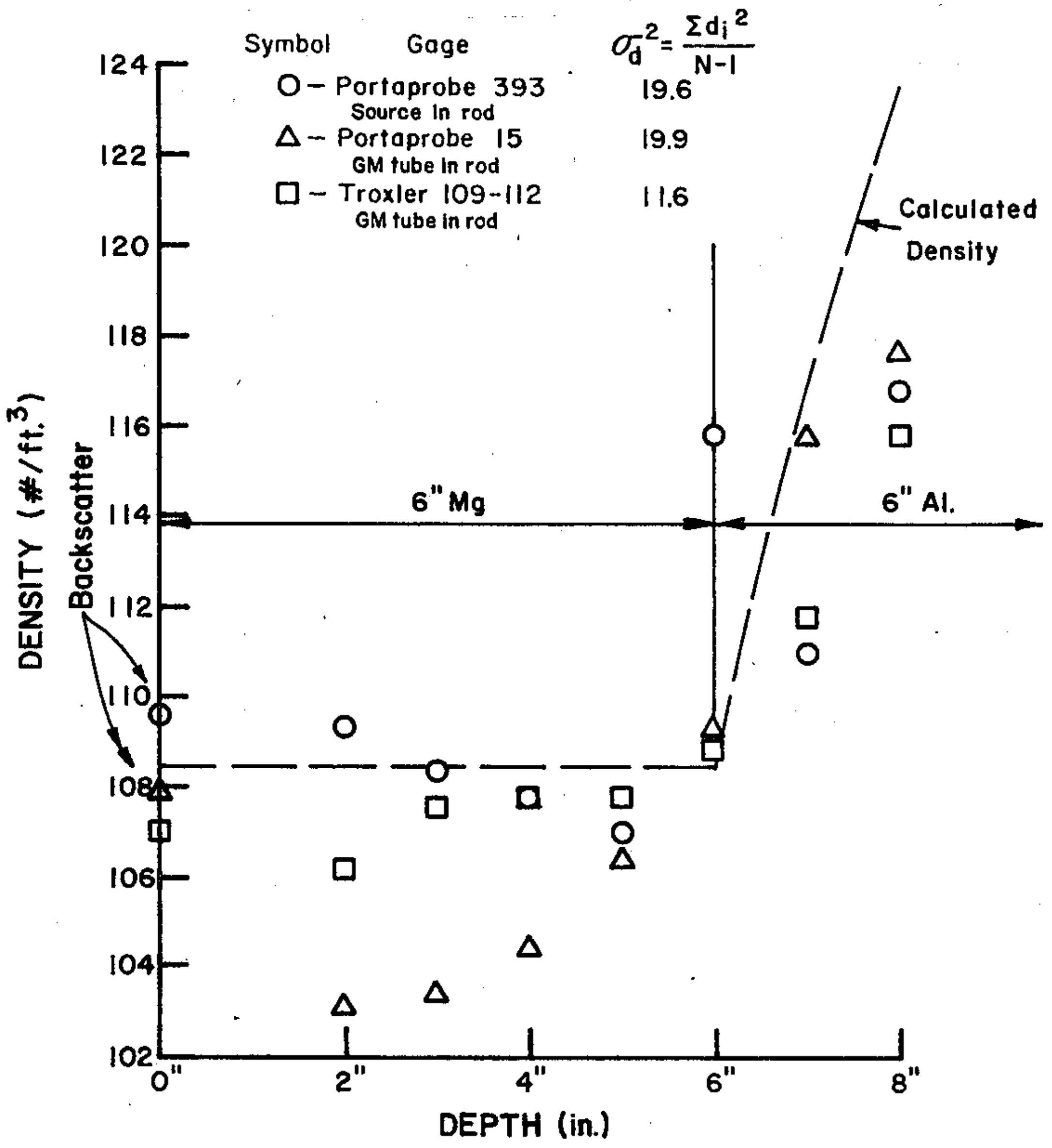
140
130
120
110
104
DENSITY (#/ft.$^3$) Backscatter
Calculated Density
Reading w/0.05" gap at top plate
Symbol Gage
$\sigma_d^2 = \frac{\Sigma d_i^2}{N-1}$
○ – Portaprobe 393 Source in rod 14.7
△ – Portaprobe 15 GM tube in rod 60.8
□ – Troxler 109-112 GM tube in rod 60.2
3" Mg.
6" Al.
0
2"
4"
6"
8"
DEPTH (in.)
3" Al over 6" Al.


Figure 3



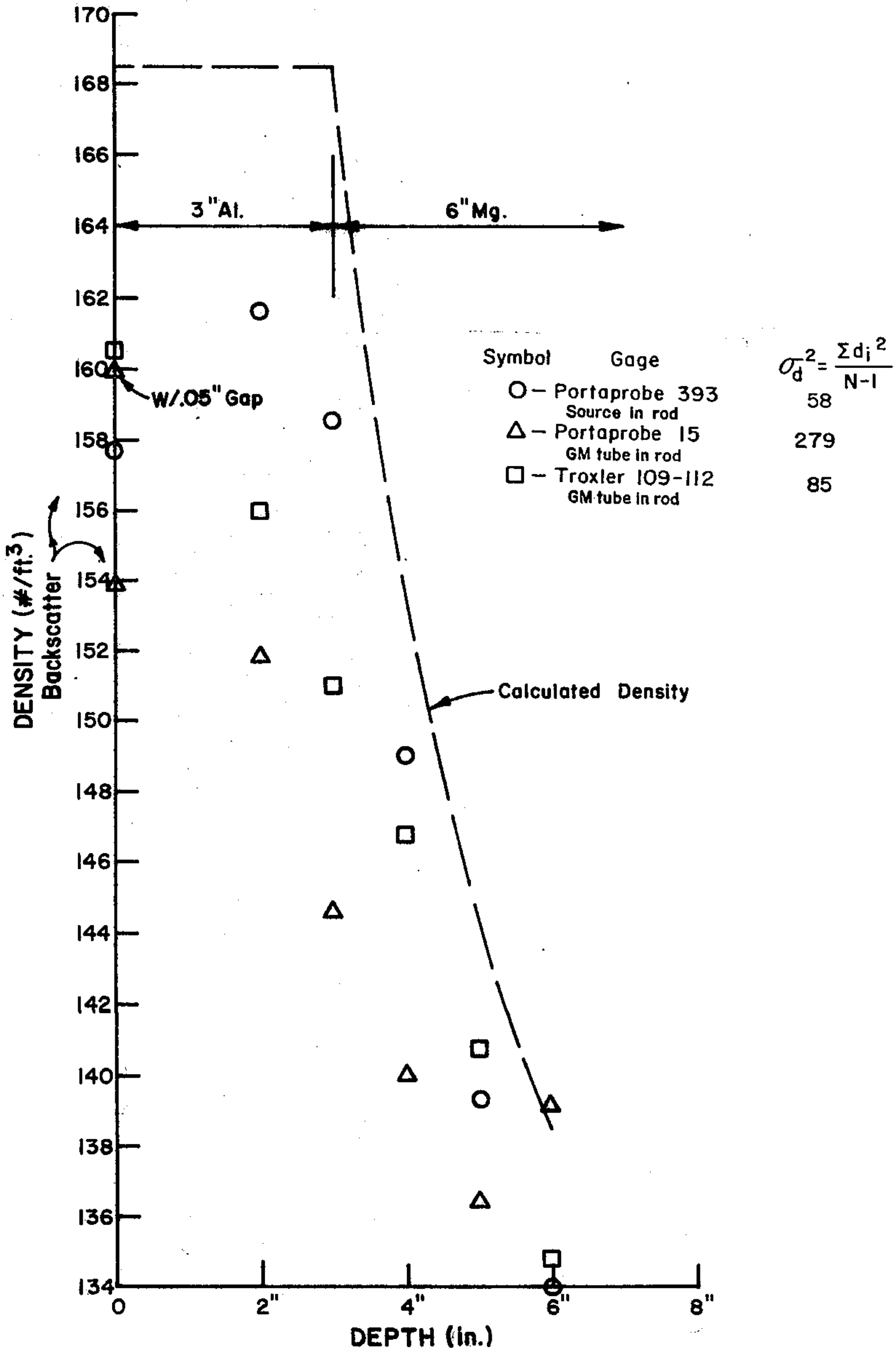
Symbol Gage
$\sigma_d^2 = \frac{\Sigma d_i^2}{N-1}$
O – Portaprobe 393 Source in rod 24.8
Δ – Portaprobe 15 GM tube in rod 4.7
□ – Troxler 109-112 GM tube in rod 40.6
Calculated Density
DENSITY (#/ft.³)
Backscatter
4 1/2" Mg.
6" Al.
130
128
126
124
122
120
118
116
114
112
110
108
106
0"
2"
4"
6"
8"
DEPTH (in.)


**Figure 4**



Symbol
Gage
$\sigma_d^2 = \frac{\Sigma d_i^2}{N-1}$
O – Portaprobe 393
Source in rod
19.6
△ – Portaprobe 15
GM tube in rod
19.9
□ – Troxler 109-112
GM tube in rod
11.6
Calculated
Density
6" Mg
6" Al.
Backscatter
DENSITY (#/ft.$^3$)
DEPTH (in.)
124
122
120
118
116
114
112
110
108
106
104
102
0"
2"
4"
6"
8"


Figure 5




3" Al. over 6" Mg.

Figure 6

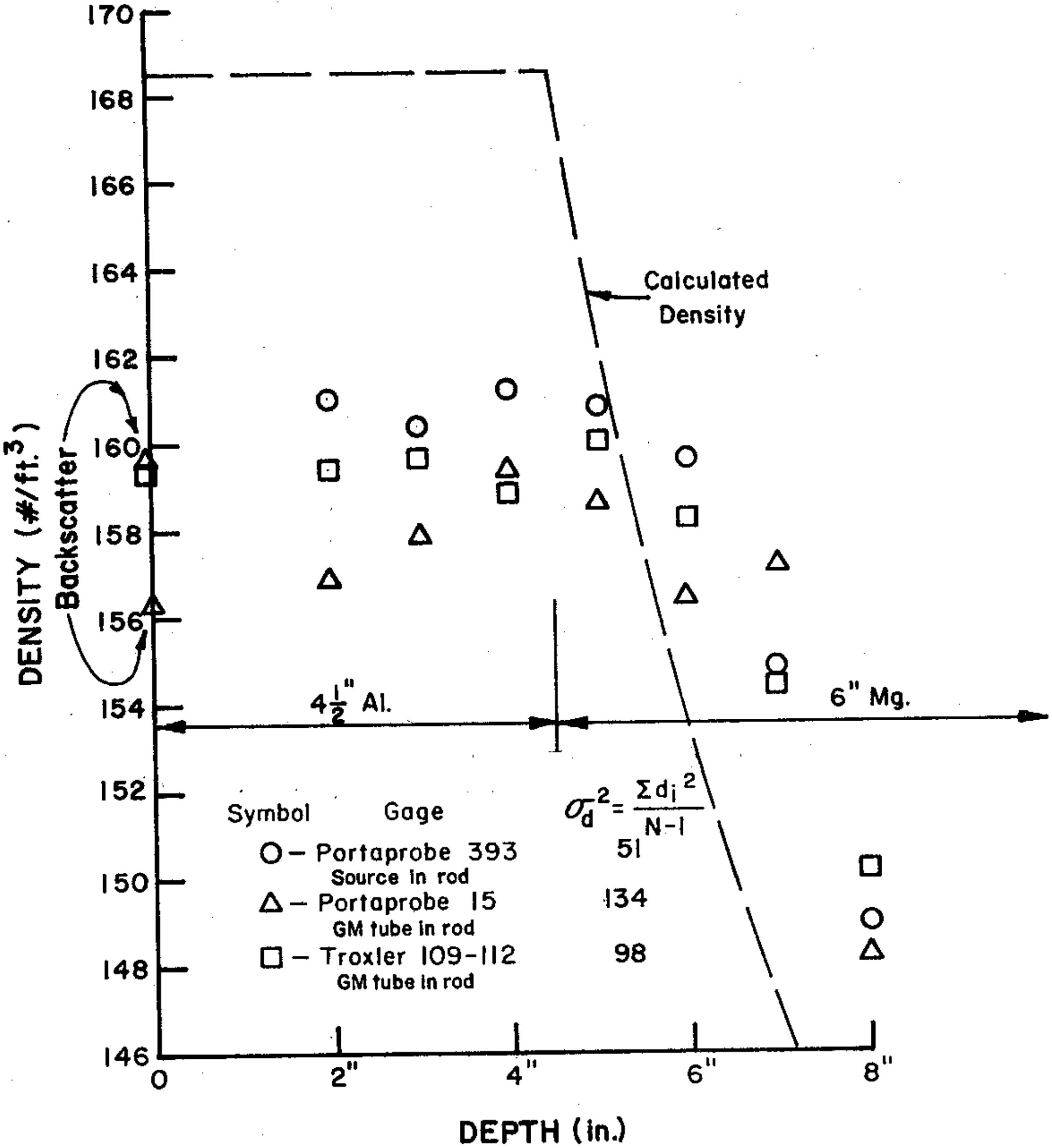

170
168
166
164
162
160
158
156
154
152
150
148
146
DENSITY (#/ft.$^3$)
Backscatter
Calculated Density
4½" Al.
6" Mg.
Symbol Gage
$\sigma_d^2 = \frac{\Sigma d_i^2}{N-1}$
○ – Portaprobe 393 Source in rod 51
△ – Portaprobe 15 GM tube in rod 134
□ – Troxler 109-112 GM tube in rod 98
0
2"
4"
6"
8"
DEPTH (in.)

Figure 7

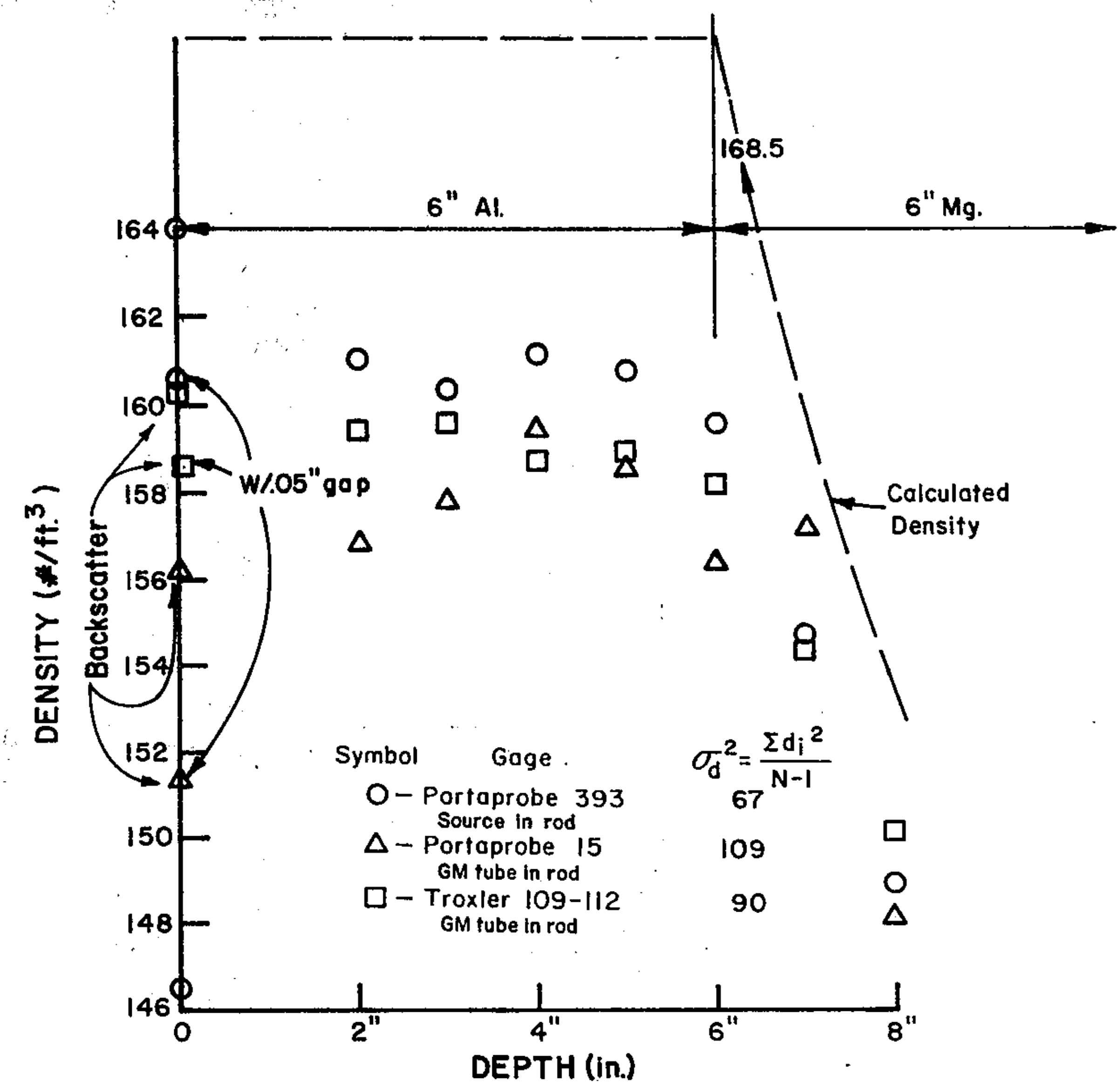

168.5
6" Al.
6" Mg.
164
162
160
158
156
154
152
150
148
146
W/.05" gap
Backscatter
Calculated Density
DENSITY (#/ft.$^3$)
Symbol
Gage
$\sigma_d^2 = \frac{\Sigma d_i^2}{N-1}$
○ – Portaprobe 393
Source in rod
67
△ – Portaprobe 15
GM tube in rod
109
□ – Troxler 109-112
GM tube in rod
90
0
2"
4"
6"
8"
DEPTH (in.)

**Figure 8**

exceptions were due to one exceptionally bad reading of the Portaprobe No. 393 (Figure 5) and an exceptionally good reading of the Portaprobe No. 15 (Figure 4), neither of which were typical. The air gap of 0.05 inch directly beneath the gage did not generally make a difference of more than 1 lb./ft.$^3$ in the nuclear density measurements except in backscatter and therefore these readings were not plotted unless the difference was appreciable. Plots of densities determined by nuclear gages demonstrated that those gages having the G-M tube in the rod tend to be influenced by the density of the material below the center of the G-M tube.

## Roadway Material - General

A 2.25 cubic foot aluminum volumetric mold (with removable sides and bottom) eighteen inches long, eighteen inches wide and twelve inches deep was used as a container for various roadway materials which were compacted for the purpose of taking nuclear density readings and checking them against the true densities of the materials.

Generally, the gage was placed on top of the last layer placed inside the mold but in samples 4 and 5 the mold was inverted after compaction, the bottom plate removed, and the gages placed on these bottom surfaces.

Two drop hammers were used for the compaction of the material in the mold, one weighing ten pounds and the other weighing fifteen pounds. An eighteen inch drop was used for both hammers.

The number of the sample and the type of material used for the various test specimens are given in Table 1. The upper material shown in each case is the one on which the nuclear gage rested.

TABLE 1

| Sample | No. of Layers Compacted | Wt. of Hammer (lbs.) | No. of Coverages of Hammer-Blows per Layer | Approximate Thickness Material | Type of Material |
|---|---|---|---|---|---|
| 1 | 4 | 10 | 3 | 7.7" | Cement Treated Sand |
| | 6 | 10 | 2 | 4.3" | Fine River Silt |
| 2 | 4 | 10 | 2 | 4.2" | Cement Treated Base Aggregate |
| | 6 | 10 | 2 | 7.8" | Fine River Silt |
| 3 | 5 | 10 | 2 | 4.2" | Cement Treated Base Aggregate |
| | 7 | 15 | 2 | 7.8" | Silty Clay |
| 4* | 4 | 10 | 2 | 3.9" | Cement Treated Base Aggregate |
| | 11 | 10 | 2 | 8.1" | Fine River Silt |
| 5* | 4 | 10 | 2 | 3.8" | Cement Treated Base Aggregate |
| | 6 | 10 | 2 | 8.2" | Clean River Sand |
| 6 | 4 | 10 | 2 | 4.4" | Clean River Sand |
| | 8 | 15 | 1 | 7.6" | Cement Treated Base Aggregate |

*These samples were inverted after being compacted, the bottom plate removed and the nuclear gage placed on the inverted sample for testing.

Roadway Material - Test Results

For all the samples, all three gages were used to give density readings for backscatter at the upper surface and direct transmission at rod depths of from 2 to 8 inches. In all the samples, measurements of the distance from the top surface of the material to the top of the form were taken to be used as a basis for determining the true density of the materials knowing the weights of each of the materials placed.

For sample No. 3, which consisted of cohesive silty clay beneath CTB aggregate, it was possible to remove the aggregate after the test and check its "final" volume. These measurements showed that the volume into which the CTB was placed increased 2% during placement and compaction of the CTB. The silty clay layer, being twice as deep, increased 1% in density. Sample No. 3 was the only one where the two materials were easily separable and the final volume of the materials thus easily determined.

In sample No. 1, the river silt density was measured by sand volume after the test as was the CTB aggregate in sample No. 4. The river silt showed an increase in density after compaction of the CTB aggregate above it of 4.8%. When this is compared to the 1% increase for the silty clay of No. 3, it is evident that the volume change of the material in the lower lifts during the compaction of the material in the upper lifts can vary considerably.

In order to compute the true density of the cement treated sand in sample No. 1 and that of the river silt in sample No. 4, the weights of each material and the known density of one material in each sample were used to determine the unknown densities. The density of the CTB aggregate (calculated by sand volume) in the other samples did not vary appreciably whether it was placed at the top or the bottom of the sample. On the basis of the CTB densities and the weights of materials used, the densities of the other materials could be calculated. This information also was used to calculate the average thickness of the materials comprising each sample.

The measured and computed densities are tabulated in Table 2 and presented in Figures 9 through 14. The mean square of the differences between the calculated densities and the densities by gage reading are also noted. These mean squares indicate that the gage with the source in the rod gave consistently better results in all samples. The backscatter readings generally varied depending on which gage was used.

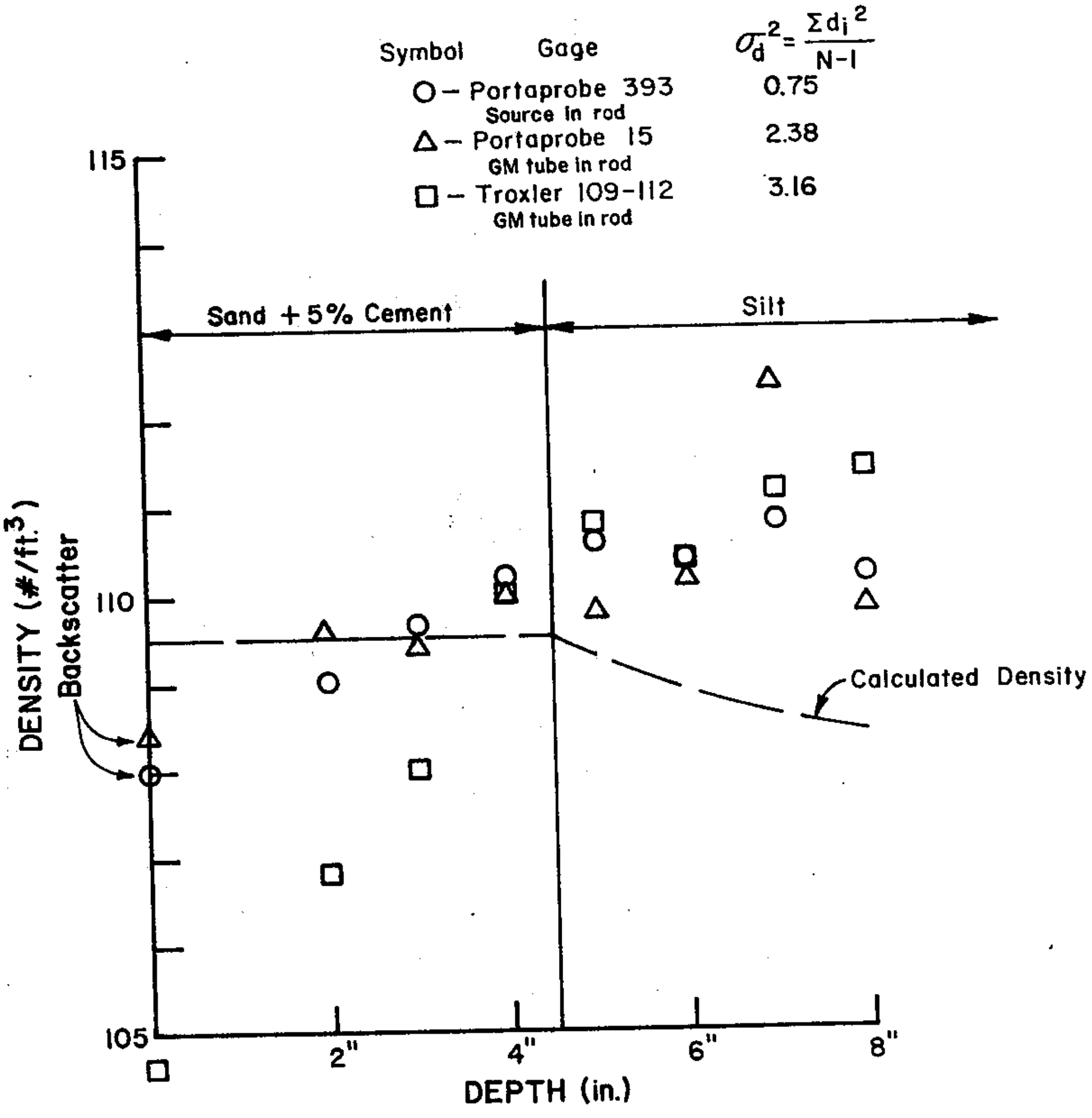
In general, the Portaprobe No. 393 gave results that agreed better with the calculated densities than the Portaprobe No. 15 and the Troxler 109-112 when roadway base material was tested in direct transmission. When the lower material was included in the measurements, there did not seem to be much difference between the densities determined by the three gages except that in measuring the density for the 7 inch depth, the Portaprobe No. 15 always seemed to give anomalous results. The range in backscatter readings was relatively great except when the readings were taken on top of sand. In most cases an average of several readings would give a reasonable answer for the surface material.

Table 2

| Sample No. | Material | Calculated Density (pcf) | Depth Where Density Read or Calculated | Density From Nuclear Measurements: Portaprobe #393 | Portaprobe #15 | Troxler 109-112 | Range Backscatter | $\Sigma di^2/N-1$* Portaprobe #393 | Portaprobe #15 | Troxler 108-112 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Cem. Treated Sand (4.5 inches) over | 109.5 | 3" | 109.5 | 109.5 | 108 | 104.5-108.5 | 0.7 | 2.4 | 3.2 |
| | River Silt (107 pcf) | 108.5 | 0<br>8" | 111 | 109 | 111 | | | | |
| 2 | CTB Aggregate (4.3 inches) over | 140 | 3" | 139.5 | 139 | 137 | 132-135 | 4.3 | 5.0 | 12.1 |
| | River Silt (105 pcf) | 124 | 0<br>8" | 126 | 126 | 127 | | | | |
| 3 | CTB Aggregate (4.2 inches) over | 139.5 | 3" | 137 | 136 | 134.5 | 131-138 | 5.0 | 13.2 | 18.6 |
| | Silty Clay (119.5 pcf) | 130 | 0<br>8" | 130.5 | 130 | 130 | | | | |
| 4 | CTB Aggregate (4.0 inches) over | 140 | 3" | 144.4 | 134 | 135 | 135-148 | 15.9 | 28.4 | 18.3 |
| | River Silt (104 pcf) | 122 | 0<br>8" | 126 | 123 | 124 | | | | |
| 5 | CTB Aggregate (3.8 inches) over | 140 | 3" | 141 | 139 | 137 | 137-146 | 2.9 | 12.8 | 4.6 |
| | Clean Sand (105 pcf) | 121.5 | 0<br>8" | 123 | 124.5 | 123 | | | | |
| 6 | Clean Sand (4.4 inches) over | 104 | 3" | 106 | 104 | 105 | 103-103.5 | 1.8 | 2.8 | 5.0 |
| | CTB Aggregate (140 pcf) | 120 | 0<br>8" | 119 | 118 | 117 | | | | |

*Mean square of differences between calculated densities and densities by gage reading, where di = differences for individual readings and N = number of readings considered, or 7.

## Sample No. 1




$\sigma_d^2 = \frac{\Sigma d_i^2}{N-1}$ where $d_i$ = difference: for each gage reading & N = no. of readings

Figure 9

Sample No.2

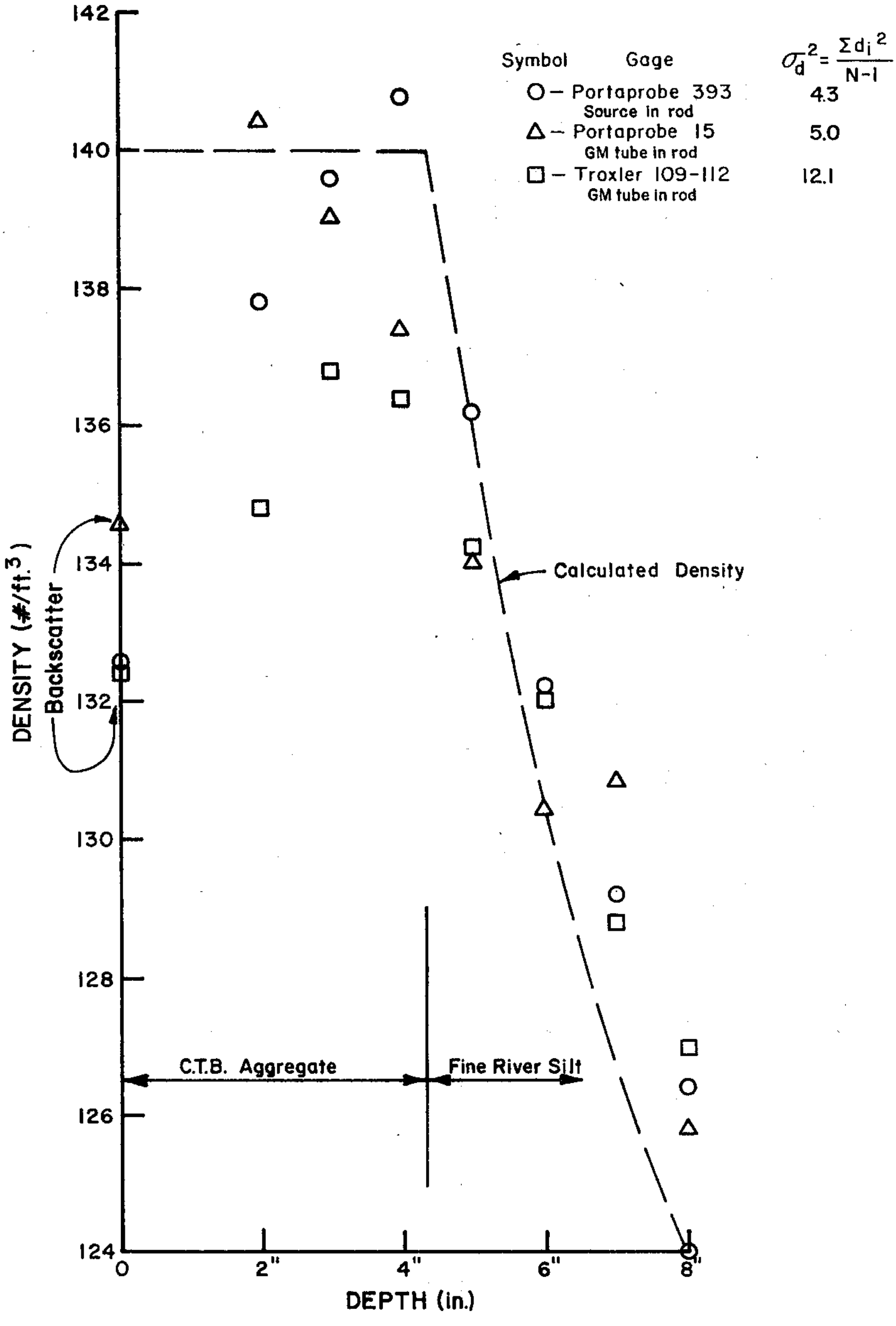



Figure 10

Sample No. 3

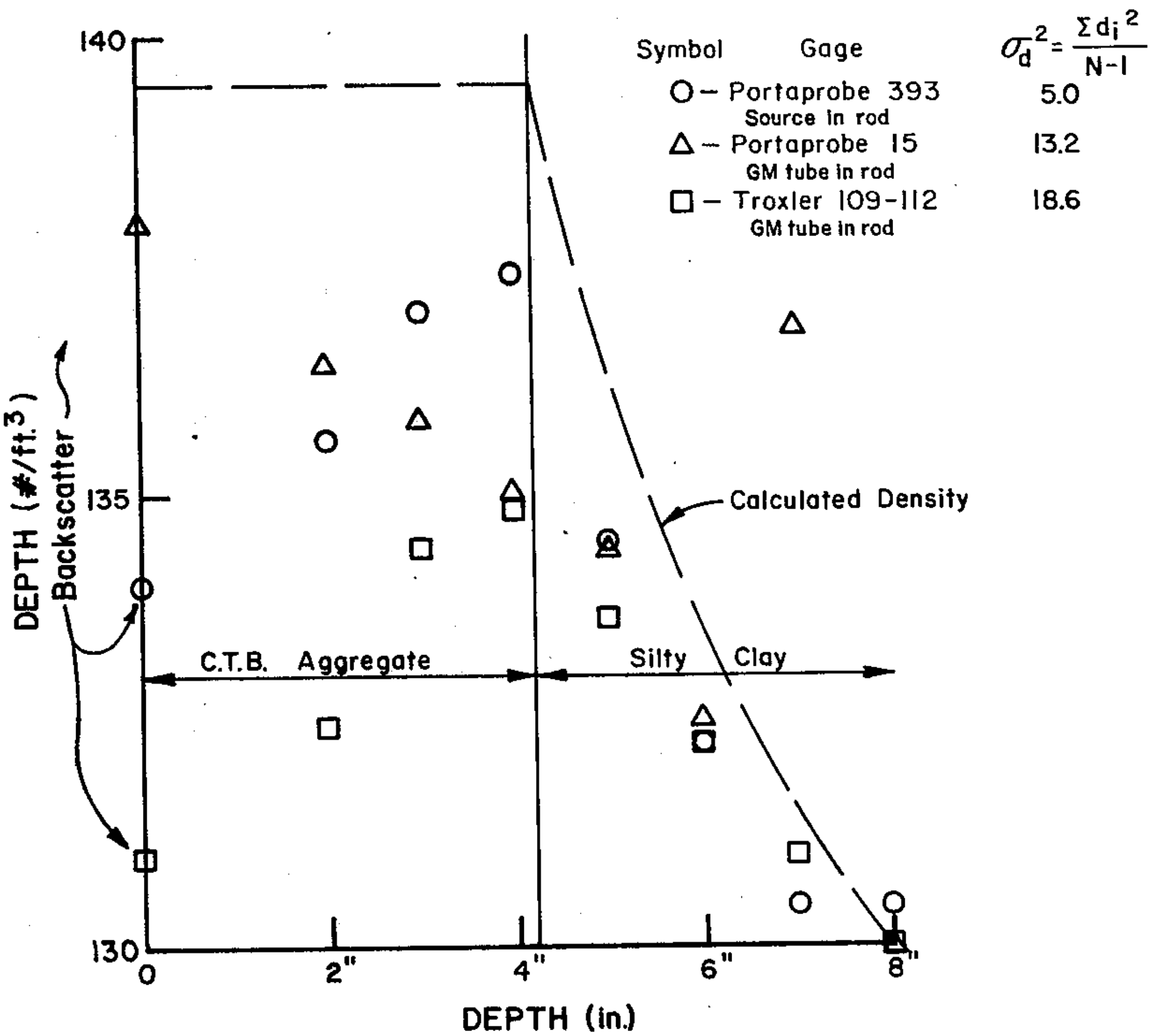
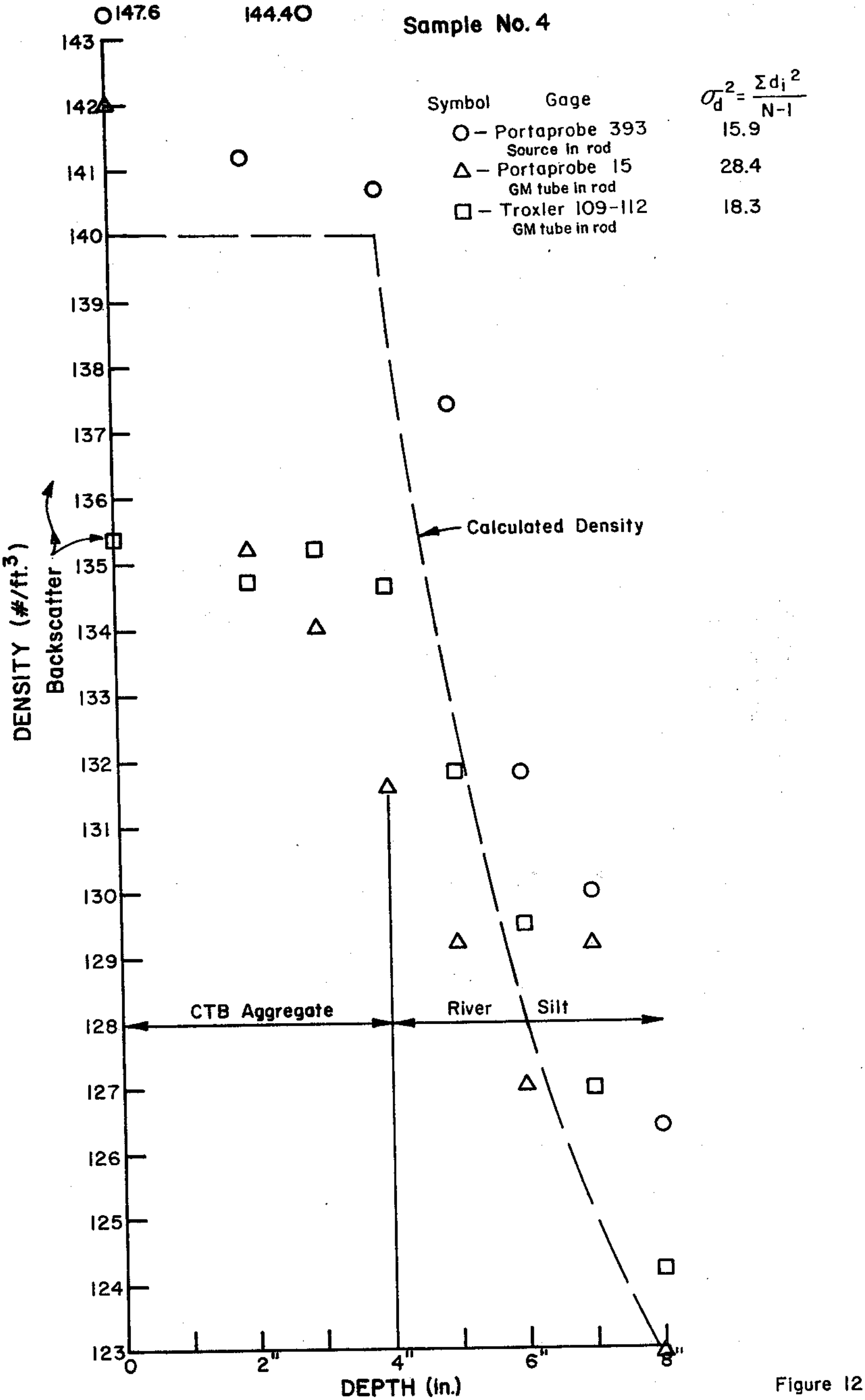
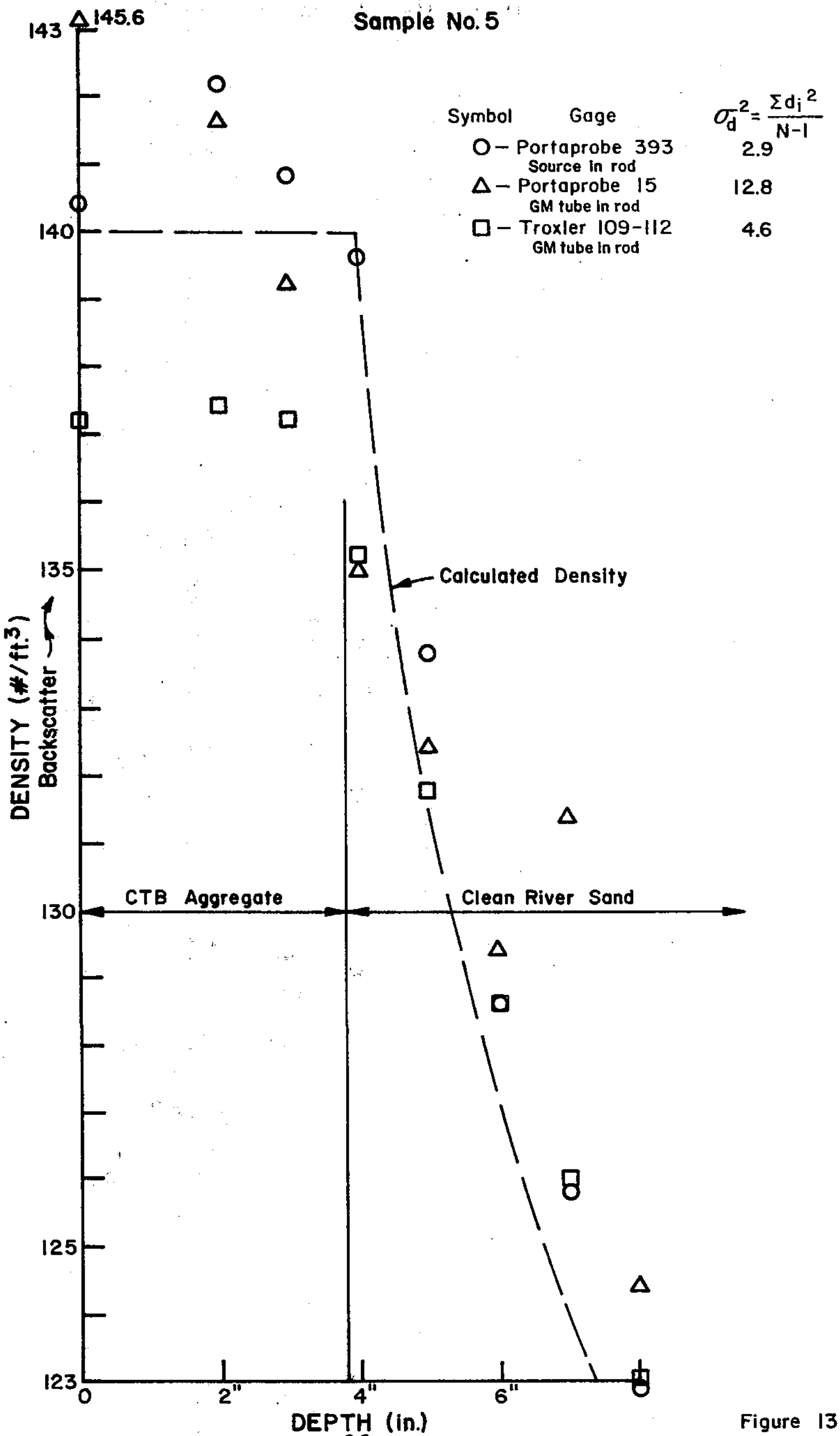



Figure 11



Sample No. 4
147.6
144.4
Symbol
Gage
$\sigma_d^2 = \frac{\Sigma d_i^2}{N-1}$
○ – Portaprobe 393
Source in rod
15.9
△ – Portaprobe 15
GM tube in rod
28.4
□ – Troxler 109-112
GM tube in rod
18.3
Calculated Density
DENSITY (#/ft.$^3$)
Backscatter
CTB Aggregate
River Silt
DEPTH (in.)
0
2"
4"
6"
8"
143
142
141
140
139
138
137
136
135
134
133
132
131
130
129
128
127
126
125
124
123


Figure 12



Sample No. 5
145.6
143
140
135
130
125
123
DENSITY (#/ft.3)
Backscatter
Symbol
Gage
$\sigma_d^2 = \frac{\Sigma d_i^2}{N-1}$
O – Portaprobe 393
Source in rod
2.9
Δ – Portaprobe 15
GM tube in rod
12.8
□ – Troxler 109-112
GM tube in rod
4.6
Calculated Density
CTB Aggregate
Clean River Sand
0
2"
4"
6"
DEPTH (in.)


Figure 13

## Sample No.6

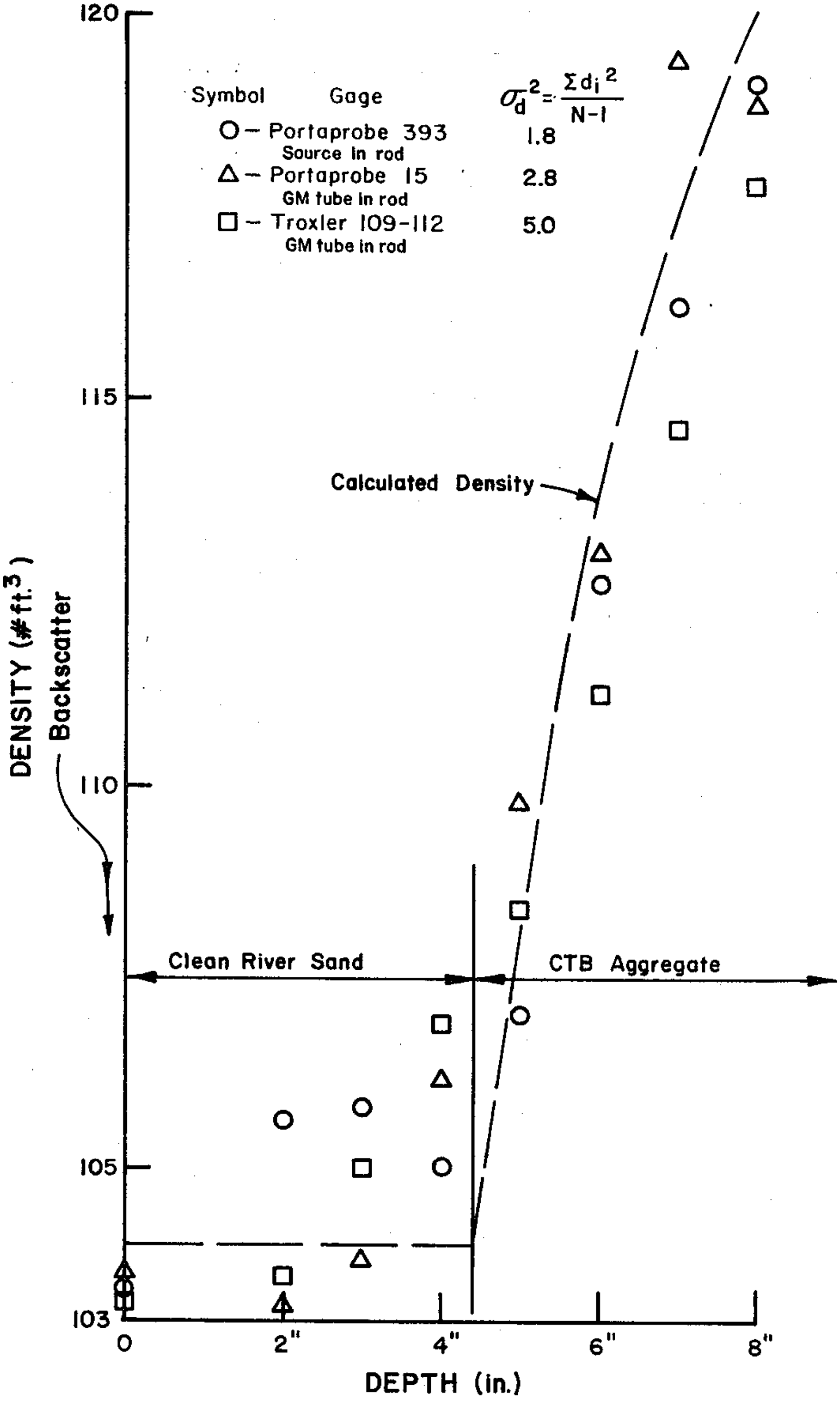



Figure 14

## CONCLUSIONS

In the tests made in this study the direct transmission gage with the nuclear source in the rod (Portaprobe No. 393) gave the best overall results. In general, the individual backscatter readings were less reliable than the direct transmission data as there was generally a fairly wide range of readings at the same location. However, an average of the readings generally gave a reasonable answer.

Since the readings of these nuclear gages are critical to the determination of adequacy of compaction, it is recommended that only gages with the nuclear source in the rod be used for direct transmission testing. The backscatter method was shown to be a less effective method for the determination of density. Therefore, if this mode is used to measure the density of layers thinner than 8 inches, at least 6 readings, none of which vary more than 2 standard deviations from the average, should be used to obtain a representative average to be used to determine density.

## IMPLEMENTATION OF THE TEST RESULTS

The specifications for "Nuclear-Moisture Gage" were revised in September 1973. The changes regarding direct transmission equipment are designated with an asterisk on the specification excerpt in the Appendix. The changes to Test Method No. Calif. 231-E with regard to backscatter tests were made in April 1971 and are denoted with an asterisk on the Test Method excerpt also included in the Appendix.

## REFERENCES


1. Obermuller, John C., and Smith, Travis, "Relative Compaction Study," State of California, Department of Public Works, Division of Highways, Materials and Research Department, March 1971.

2. Forsyth, Raymond A., "Nuclear Gage Standardization Procedure," State of California, Department of Public Works, Division of Highways, Materials and Research Department, November 1972.

3. State of California, Department of Public Works, Division of Highways, Materials Manual I, Test Method No. Calif. 231-E.

4. State of California, Department of Public Works, Division of Highways, Specifications for Nuclear Density-Moisture Gage, September 1973.

SPECIFICATIONS FOR NUCLEAR DENSITY-MOISTURE GAGE

September 1973

I. GENERAL

The portable nuclear density-moisture surface gage shall be suitable for determining density and moisture of soils, aggregates, treated bases, and the density of asphalt pavements. It shall be capable of determining density in two operating modes. These modes shall be direct transmission of gamma radiation, and backscatter of gamma radiation. The gage shall determine moisture by detecting backscattered thermalized neutrons.

The gage shall be a single unit, self-contained and consist of a radioactive source, radiation detectors, power supplies, counting circuits, timing circuits, data display, and related electronic components.

The gage shall be dustproof, moisture proof, shock resistant, and electronically stable. The gage shall operate reliably, accurately, and with negligible drift, in all three operating modes, over an ambient temperature range of 32°F to 145°F and with the probe on, or in, material whose internal and surface temperature will range between 32°F and 300°F.

The radioactive source shall be in the transmission rod and the radiation detector(s) in the case. *

The gage shall weigh not more than forty (40) pounds and have outside dimensions not to exceed seventeen (17) inches in length, ten (10) inches in width and twenty-two (22) inches in height.

All above specified dimensions apply to the gages with any appurtenant lid or cover in place and closed. The dimensions include the carrying handle and any exterior tube positioning brackets with the tubes in place.

All electronic circuitry, radiation detectors and batteries shall be so arranged as to be easily removable from the case without removing, unshielding, or in any way disturbing the source.

All electronic circuitry shall be of solid state, mechanically sound, modular construction. The circuitry shall be mounted on G-10 epoxy glass plug-in circuit boards. The manufacturer shall provide sufficient "burn-in" time for electronic subassemblies to assure himself that premature failure or change in electrical characteristics of a component is only a remote possibility. The length of "burn-in" time shall conform to current instrumentation industry practice and in no case shall be less than fifty (50) hours total.

An exterior service access opening shall be provided in the gage case to permit the use of an external test meter to check the output of the primary voltage supplies while the circuitry is in operation. High voltage adjustment controls to obtain plateau curves for the gamma and neutron detectors shall be adjustable by means of the service access opening. The intent is that the external test meter connection facilities, and the high voltage adjustment controls will be affixed to the electronic circuitry chassis in such a way as to be removable from the case as part of the chassis for bench testing and adjustment, as well as to be reachable through the access opening for field testing and adjustment without removal of the electronic chassis from the case. A dust and moisture proof cover plate to be provided for the service access opening shall be secured in place by means of machine screws rather than sheet metal screws.

Exception to the external test meter connection facilities may be taken, provided the manufacturer supplies a suitable extender board as a part of the gage purchase price. The use of such a board shall be evaluated, on an actual gage, by the purchaser to determine whether or not the exception will be allowed. A bidder may also take exception to the provision of high voltage adjustment controls provided the detectors meet the requirements set forth in Section II of these specifications.

Design of the probe, scaler, and control panel shall reflect consideration of the human operator and the manner in which he functions as the user of the gage.

## II. GAGE SYSTEM

The radioactive source, to be placed in the ground for operation in the direct transmission mode shall be contained in a transmission rod either 5/8 ± 1/64 inch in outside diameter or 3/4 ± 1/64 inch in outside diameter. The tube shall be made of non-corrosive material having a minimum hardness of 60 as rated on the Rockwell B scale. The tube shall be strong enough to resist bending in normal hard usage and the outside surface shall be smooth and true. Permanent markings, referenced to the center of a radioactive source within the rod, shall be provided on the outside surface of the rod (or guide rod) at one (1) inch intervals to denote, from two (2) to eight (8) inches, the depth, below ground, of the transmission readings.

# METHOD OF TEST FOR RELATIVE COMPACTION OF UNTREATED AND TREATED SOILS AND AGGREGATES BY THE AREA CONCEPT UTILIZING NUCLEAR GAGES

## General Scope

This test method provides a procedure for selecting a compacted area of work and for determining the in-place wet density and moisture of untreated and treated soils and aggregates by the use of nuclear methods. Wet density measurements are made in the 8-inch direct transmission mode where the rod is placed into the ground. This mode is used only when measuring wet density of material equal to or greater than 8 inches thick (normally embankment material). The gage is also used for backscatter wet density determinations only when measuring layers less than 8 inches thick (normally structural section material). * The laboratory wet test maximum density shall be determined as specified in Test Method No. Calif. 312 for Class A Cement Treated Base, and as specified in Test Method No. Calif. 216 for untreated materials, Class B Cement Treated Base and lime treated soils and aggregates. On the basis of established acceptance criteria, the relative compaction values are then used to determine the acceptance or rejection of compaction within the designated area. All calculations are based on wet relationships and are made in the metric system.

NOTE: See section 121 of the Materials Manual for Administrative Instructions regarding use of nuclear gages.

This test method is divided into the following parts:

I. Method of field determination of in-place wet density and moisture.

II. Method of applying the area concept and determining percent relative compaction.

## PART I. METHOD OF FIELD DETERMINATION OF IN-PLACE WET DENSITY AND MOISTURE

### A. Apparatus

1. Nuclear gage and standardizing block.

2. Miscellaneous tools such as trowels, scrapers, sieve, etc. for site preparation.

3. Guide plate, 12" x 18" x ¼".

### B. Standardization of the Nuclear Gage for Wet Density and Moisture

1. Place the gage on the standardizing device and take moisture and wet density counts after the gage has been turned on for at least 10 minutes. Actual counts are taken as part of the warmup procedure but not used. After the warmup, perform five or more one-minute counts for moisture and wet density to establish the standard count. Record on Form HMRT-2148 (Figure I). For additional information not covered in this paragraph, follow instructions given in the manufacturer's manual.

2. Average the five or more counts determined in B-1. Discard any counts deviating from the average by over two standard deviations (see note). Average the remaining counts to determine standard count. If two or more counts are discarded, take a second series of five counts, average the five counts and apply the same criteria. This average is to be within ± 1000 counts of the value supplied with the equipment. If it is not, contact the Radiation Administrative Officer who will establish a new standard count or have the gage sent in to be checked and/or repaired.

NOTE: A standard deviation is defined in this test method as $\sigma = \sqrt{n}$; where $\sigma$ is the standard deviation, and n = number of counts indicated on the scaler. This relationship is valid when the number of counts is over 10,000. The standard deviation should be taken as 100 for counts less than 10,000. Table I shows values of $2\sigma$ for various counts.

### C. Site Preparation

1. Preparatory to making a nuclear measurement, remove all loose surface material and obtain a plane surface large enough to seat the probe. Where necessary, in areas compacted by pneumatic-tired or smooth-wheel rollers, remove disturbed surface material. Where sheepsfoot and similar type tamping rollers have been used, remove the loose surface material to a depth of not less than 2 inches below the deepest penetration by the roller. After the surface has been prepared to a flatness and smoothness within ⅛ inch, use a sieve to obtain native fines to smooth off minor depressions, protrusions or slight lack of planeness.

2. Where the 8 inch transmission mode is to be used, make a hole about 12 inches deep with the equipment provided. This hole must be as close as possible to 90 degrees with the plane surface. If the plate is rotated slightly around the pin and the plate does not make contact with the ground or if it appears that the hole is crooked, make a new hole. Site preparation is extremely important to obtaining proper test results.

### D. Field Test for Density Determination

1. Place the nuclear probe on the prepared surface so that the bottom of the probe is firmly seated in contact with the soil. Place the transmission rod over the hole, and then push the rod into the hole to an 8 inch depth. Adjust the gage so that the rod is firmly against the side of the hole that is nearest to the source (detector tube(s)).

2. Obtain a one minute reading. Then rotate the probe 10 to 20 degrees around the rod, adjust the gage so that the rod is firmly against the side of the hole that is nearest to the source (detector tube(s)), and obtain a second one-minute reading. The average of the two readings constitutes one in-place test.

Record the data as shown on Figure I, horizontal lines A, B and C.

3. Determine count ratio by dividing the field count by the standard count (Figure I, horizontal line D).

4. Find the count ratio and corresponding direct transmission wet density (grams/cc) on the table supplied with the gage (Example Table 2). Record the data on Figure I, horizontal line E.

Table 2 also shows densities in pcf for technicians who wish to relate in English units. This information is not to be used for any additional calculations.

5. Where the backscatter density method is used, follow Sections B; C-1; the first sentences of D-1 and D-2; and D-3. Find the count ratio and corresponding backscatter wet density (grams/cc) on the table supplied with the gage (Example Table 3). *

NOTE: Density calibration tables are determined in accordance with Method No. Calif. 911.

### E. Determination of Field Moisture

This test may be needed for Test Method No. Calif. 312 or used for other cases where moistures are desired.

1. Obtain a standard count for moisture as specified in Section B of this Part I.
2. For site preparation, use procedure in Section C-1 of this Part I.
3. Place the gage on the prepared surface and take a one minute gage count.
4. Determine a count ratio by dividing the average field count by the standard count for moisture.
5. Find the count ratio and corresponding moisture (grams/cc) from the table supplied with the gage (Example Table 4).

NOTE: (1) The moisture table may not give comparable results with oven drying. If this correlation is needed, the table must be verified by performing nuclear gage field moisture tests and related to oven dry moistures (see Method No. Calif. 911).

(2) Moisture determinations may be affected by the proximity of vertical obstructions such as structures or soils and aggregates next to the side of the gage. A distance of +10 inches should be clear next to the gage.

(3) Moisture calibration tables are determined in accordance with Method No. Calif. 911.

## PART II. METHOD OF APPLYING THE AREA CONCEPT AND DETERMINING PERCENT RELATIVE COMPACTION

### Scope

This is a statistical procedure where a number of test measurements are taken to evaluate the state of compaction of a selected area.

NOTE: The following procedure outlines calculations not requiring a rock correction. See example on Figure II for rock correction.

### Procedure

### A. Number and Location of Nuclear Tests

1. The area concept will be used with this test. That is, the engineer will determine from a series of density tests whether to accept or reject a designated area. The engineer shall determine the area by inspection, based on uniformity of factors affecting compaction. Insofar as possible, the area designated shall be *generally* homogeneous for both character of material and conditions of production and compaction. Portions of the area which may be observed or suspected to be different than the area as a whole will be excluded from the test. If a relative compaction test is desired for these different portions, they shall be designated as a separate test area or areas and tested separately.

Do not designate test areas which include: (1) materials from separate sources unless such materials were intermixed during placing of the compacted area; (2) materials which were placed and compacted by different types of operations or processes; or (3) material placed during different periods of production or in nonadjoining areas.

2. In order to assure that the material throughout the area is effectively represented by the testing in the direct transmission mode, disperse a *minimum of five or more* individual test sites as impartially as possible at random over the area. The exact location of each in-place wet density test site shall be of a random nature. Determine the wet density of the material by the nuclear tests as described in Part I.

Where the backscatter mode of testing is used, a *minimum of six or more* test sites are required.

3. If the designated test area, described in A-1 above, is of limited size (e.g. structure backfill, short length of shoulders, or other areas less than 1000 square yards) then a *minimum of three or more* tests are required in the direct transmission mode and *four or more* tests are required in the backscatter mode. *

### B. Determination of Wet Test Maximum Density

1. For all treated and untreated soils and aggregates, except Class A Cement Treated Bases, obtain equal representative portions of material from each nuclear test site within the area and thoroughly mix together to form a *composite sample*. Determine the laboratory wet test maximum density (grams per cubic centimeters) in accordance with Test Method No. Calif. 216. Record the data on Figure I, Lines G through I, in the section identified as "IMPACT TEST DATA". The moisture content of the composite sample must be maintained in the same state as when the in-place tests were performed.

For those technicians who wish to relate density in English units, multiply the wet density in grams per cubic centimeters by 62.4.

For Class A Cement Treated Bases, the laboratory wet test maximum density is determined according to Test Method No. Calif. 312. The wet test maximum value in pounds per cubic foot is divided by 62.4 to obtain the laboratory test maximum density in grams per cubic centimeter used for calculating percent relative compaction as outlined in this method.

### C. Correction for Oversize Material

1. A correction is applied to the test in those instances where the original material from which the test specimen samples are obtained, contains more than 10 percent by weight of aggregate retained on the ¾ inch sieve. The data is recorded on Figure II, Lines J through T in the section titled "SAMPLE FOR ROCK CORRECTION".

### D. Percent Relative Compaction

1. Calculate percent relative compaction as follows:

$$\text{Percent relative compaction} = \frac{\text{In-place Wet Density}}{\text{Laboratory Wet Test Maximum Density}} \times 100$$

COUNT RATIO VS DENSITY FOR NUCLEAR GAGE NO. 87015

DIST. 19    10-21-71    STD. CT 19982    4"D/T BY B.LISTER

| BASED ON: | | 95.7 | 101.4 | 126.0 | 134.4 | 167.3 | 173.0 |
|---|---|---|---|---|---|---|---|
| | DENSITY PCF | 95.7 | 101.4 | 126.0 | 134.4 | 167.3 | 173.0 |
| | G/CC | 1.53 | 1.62 | 2.02 | 2.15 | 2.68 | 2.77 |
| | COUNT RATIO | 1.650 | 1.480 | 1.200 | 1.010 | .649 | .586 |

| CR | G/CC | PCF | CR | G/CC | PCF | CR | G/CC | PCF |
|---|---|---|---|---|---|---|---|---|
| 1.916 | 1.28 | 80.0 | 1.765 | 1.41 | 88.0 | 1.622 | 1.54 | 96.0 |
| 1.912 | 1.28 | 80.2 | 1.762 | 1.41 | 88.2 | 1.619 | 1.54 | 96.2 |
| 1.908 | 1.29 | 80.4 | 1.758 | 1.42 | 88.4 | 1.615 | 1.54 | 96.4 |
| 1.904 | 1.29 | 80.6 | 1.754 | 1.42 | 88.6 | 1.612 | 1.55 | 96.6 |
| 1.901 | 1.29 | 80.8 | 1.751 | 1.42 | 88.8 | 1.608 | 1.55 | 96.8 |
| 1.897 | 1.30 | 81.0 | 1.747 | 1.43 | 89.0 | 1.605 | 1.55 | 97.0 |
| 1.893 | 1.30 | 81.2 | 1.743 | 1.43 | 89.2 | 1.601 | 1.56 | 97.2 |
| 1.889 | 1.30 | 81.4 | 1.740 | 1.43 | 89.4 | 1.598 | 1.56 | 97.4 |
| 1.885 | 1.31 | 81.6 | 1.736 | 1.44 | 89.6 | 1.595 | 1.56 | 97.6 |
| 1.881 | 1.31 | 81.8 | 1.732 | 1.44 | 89.8 | 1.591 | 1.57 | 97.8 |
| 1.878 | 1.31 | 82.0 | 1.729 | 1.44 | 90.0 | 1.588 | 1.57 | 98.0 |
| 1.874 | 1.32 | 82.2 | 1.725 | 1.44 | 90.2 | 1.584 | 1.57 | 98.2 |
| 1.870 | 1.32 | 82.4 | 1.722 | 1.45 | 90.4 | 1.581 | 1.58 | 98.4 |
| 1.866 | 1.32 | 82.6 | 1.718 | 1.45 | 90.6 | 1.577 | 1.58 | 98.6 |
| 1.862 | 1.33 | 82.8 | 1.714 | 1.45 | 90.8 | 1.574 | 1.58 | 98.8 |
| 1.859 | 1.33 | 83.0 | 1.711 | 1.46 | 91.0 | 1.571 | 1.59 | 99.0 |
| 1.855 | 1.33 | 83.2 | 1.707 | 1.46 | 91.2 | 1.567 | 1.59 | 99.2 |
| 1.851 | 1.34 | 83.4 | 1.704 | 1.46 | 91.4 | 1.564 | 1.59 | 99.4 |
| 1.847 | 1.34 | 83.6 | 1.700 | 1.47 | 91.6 | 1.560 | 1.60 | 99.6 |
| 1.843 | 1.34 | 83.8 | 1.696 | 1.47 | 91.8 | 1.557 | 1.60 | 99.8 |
| 1.840 | 1.35 | 84.0 | 1.693 | 1.47 | 92.0 | 1.554 | 1.60 | 100.0 |
| 1.836 | 1.35 | 84.2 | 1.689 | 1.48 | 92.2 | 1.550 | 1.60 | 100.2 |
| 1.832 | 1.35 | 84.4 | 1.686 | 1.48 | 92.4 | 1.547 | 1.61 | 100.4 |
| 1.828 | 1.36 | 84.6 | 1.682 | 1.48 | 92.6 | 1.543 | 1.61 | 100.6 |
| 1.825 | 1.36 | 84.8 | 1.679 | 1.49 | 92.8 | 1.540 | 1.61 | 100.8 |
| 1.821 | 1.36 | 85.0 | 1.675 | 1.49 | 93.0 | 1.537 | 1.62 | 101.0 |
| 1.817 | 1.36 | 85.2 | 1.671 | 1.49 | 93.2 | 1.533 | 1.62 | 101.2 |
| 1.813 | 1.37 | 85.4 | 1.668 | 1.50 | 93.4 | 1.530 | 1.62 | 101.4 |
| 1.810 | 1.37 | 85.6 | 1.664 | 1.50 | 93.6 | 1.527 | 1.63 | 101.6 |
| 1.806 | 1.37 | 85.8 | 1.661 | 1.50 | 93.8 | 1.523 | 1.63 | 101.8 |
| 1.802 | 1.38 | 86.0 | 1.657 | 1.51 | 94.0 | 1.520 | 1.63 | 102.0 |
| 1.798 | 1.38 | 86.2 | 1.654 | 1.51 | 94.2 | 1.517 | 1.64 | 102.2 |
| 1.795 | 1.38 | 86.4 | 1.650 | 1.51 | 94.4 | 1.513 | 1.64 | 102.4 |
| 1.791 | 1.39 | 86.6 | 1.647 | 1.52 | 94.6 | 1.510 | 1.64 | 102.6 |
| 1.787 | 1.39 | 86.8 | 1.643 | 1.52 | 94.8 | 1.507 | 1.65 | 102.8 |
| 1.784 | 1.39 | 87.0 | 1.640 | 1.52 | 95.0 | 1.503 | 1.65 | 103.0 |
| 1.780 | 1.40 | 87.2 | 1.636 | 1.52 | 95.2 | 1.500 | 1.65 | 103.2 |
| 1.776 | 1.40 | 87.4 | 1.633 | 1.53 | 95.4 | 1.497 | 1.66 | 103.4 |
| 1.773 | 1.40 | 87.6 | 1.629 | 1.53 | 95.6 | 1.493 | 1.66 | 103.6 |
| 1.769 | 1.41 | 87.8 | 1.626 | 1.53 | 95.8 | 1.490 | 1.66 | 103.8 |