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D.R. Howe

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**16. ABSTRACT**

In the investigation of the nuclear gage for the density and moisture determination of soils, there are many phases of its application which need to be explored. Foremost are the problems involved in the practical use of the instrument in the control of compaction during highway construction. While previous studies (1), (2) have indicated several serious technical and operational difficulties with nuclear devices, more recent investigations (3) are demonstrating that the major deficiencies are gradually being overcome by the industry and the engineering profession. As a consequence it is felt that the experimental application of the equipment on actual construction projects is now feasible.

With this in mind, the decision was made to select a number of construction projects within an hour's driving time from Sacramento and operate, with a nuclear device, out of Headquarters laboratory. One density and moisture gage was utilize by a Materials and Research Department operator for this purpose. A total of five projects were selected and these are described in Table I.

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

August 18, 1965

Lab Auth 426028

Mr. J. C. Womack
State Highway Engineer
Division of Highways
Sacramento, California

Dear Sir:

Submitted for your con

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THE FIELD USE OF A

ON SEV

CONCURRENT CONSTRU

in

DISTRICTS 03 A 10

65-23

Study made by .................. Foundation Section
Under general direction of .... Travis Smith
Work supervised by............. W. G. Weber, Jr.
Report prepared by ............ D. R. Howe

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

Attach
cc:LRGillis:JFJorgensen
ACEstep:JObermuller
GEbenhack
WLWarren:ELMiller
DMYoung:DRHislop
JGMeyer:EFGregory
WFFleharty:MDEngrahm
RGElliott

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## ACKNOWLEDGMENTS

This work was performed on various projects in District 03 and 10 that were under construction in the Sacramento area. These projects were under the general supervision of the construction engineers of both districts and under the direct supervision of the Resident Engineers. The Resident Engineers contributed both personnel for performing tests and time in evaluating the use of the nuclear gage on their project. Considerable credit for the success of this project is due to the efforts of the Resident Engineers and other construction personnel on the various projects.

This project was financed by State of California, Division of Highways research funds under work order authorization No. 64-19U51H1. The field testing with the nuclear gage was conducted by Mr. C. R. Sundquist and Mr. E. A. Satow.

# The Field Use of a Nuclear Soil Gage on Several Concurrent Construction Projects in Districts 03 & 10

## INTRODUCTION

In the investigation of the nuclear gage for the density and moisture determination of soils, there are many phases of its application which need to be explored. Foremost are the problems involved in the practical use of the instrument in the control of compaction during highway construction. While previous studies (1), (2) have indicated several serious technical and operational difficulties with nuclear devices, more recent investigations (3) are demonstrating that the major deficiencies are gradually being overcome by the industry and the engineering profession. As a consequence it is felt that the experimental application of the equipment on actual construction projects is now feasible.

With this in mind, the decision was made to select a number of construction projects within an hour's driving time from Sacramento and operate, with a nuclear device, out of Headquarters laboratory. One density and moisture gage was utilized by a Materials and Research Department operator for this purpose. A total of five projects were selected and these are described in Table I.

TABLE I

| Road | Contract | Location | Miles from HQs Lab. |
|---|---|---|---|
| 03-Sac,Ed-50 | 074024 | El Dorado Hills | 25 East |
| 03-Sac-99,80 | 039904 | 29th & 30th St., Sacto. | 3 West |
| 10-Sol-80 | 056634 | Milk Farm | 25 West |
| 10-Sol-80 | 056664 | Nut Tree | 35 West |
| 10-Sol-21,680 | 049004 | Benicia to Cordelia | 50 West |

One of the primary purposes of this study was to examine the practicality of covering various projects at the same time from a central laboratory. The arrangement of using a central location for construction control testing on several projects has been the practice of Districts 04, 07 and 11 for a number of years.

Another important object of the study was to determine if the so-called "multiple testing" concept would be feasible for control testing. The idea involves the determination of a relative compaction value, from a group of random nuclear tests to represent the degree of compaction of an area.

It is the purpose of this report to examine the potential problems associated with the use of a nuclear gage in field construction and analyze the test data obtained from the operation of the device.

The field operations for this study were undertaken in the months of July through September in 1964.

## CONCLUSIONS AND RECOMMENDATIONS

1. It is practical to operate with nuclear gages out of a central laboratory and provide compaction control testing services for several projects which are under concurrent construction where the recommendations listed in 2 below are followed.

2. The following recommendations are made where testing services are provided from a central laboratory with backscatter type nuclear gages:

   (a) Each project, including the small ones, should have an exclusively assigned gage.

   (b) There should be two gages calibrated to each project. One of the gages may be a "backup" instrument for several projects.

   (c) There must be the same number of trained personnel and backup operators as is required for the performance of the Sand Volume Test.

   (d) Vehicles used to transport nuclear gages must be in first-class mechanical condition.

3. Calibration testing must be undertaken on each soil type encountered on each project.

4. Calibration testing should be undertaken before actual compaction operations are started, whenever possible.

5. The performance of a number of nuclear density tests (multiple testing), within an area of roadway having one soil type and using the average relative compaction determined from these tests for construction control, appears feasible and should be explored further.

6. The site for obtaining impact compaction test samples, when undertaking "multiple testing," should be selected as the location of the nuclear test nearest to the average density of all nuclear tests for the area being tested.

## METHOD OF OPERATION

The nuclear soil density and moisture gage, used throughout this study is a modified hidrodensimeter, Model HDM-1, utilizing 5 millicuries of Radium-Berlyium. This device is a surface type of instrument which measures the Compton backscatter effect from radiation acting upon the soil.

For the purposes of the testing program, arrangements were made with the resident engineers on the various projects to inform Headquarters Laboratory when routine field density tests were expected to be performed. Upon being informed, an operator would drive to the job with the nuclear equipment to undertake concurrent testing with the "Sand Volume" test operations (Test Method No. Calif. 216-F, Part I). In order to improve efficiency, it also became the practice of the operator when attending a particular job, to communicate in the field with the other projects in the program and perform additional testing as opportunity and time permitted.

Normally the sites for the routine density and moisture tests were selected by the district inspector. Once a particular location was established, the ground surface would be carefully prepared by scraping and smoothing for good seating of the probe. Two nuclear count readings for density were then taken for timed periods of one minute. On the second reading the probe was rotated 90°. If these readings checked each other within the square root of the average value (one standard deviation) then the average was used as the count for that test. If they did not check satisfactorily then the gage was rotated 180° and 270° from the original position with additional readings being taken. All values, that fell within one standard deviation, were then averaged together for the test count.

Standard counts for the apparatus were also determined at the beginning and end of nuclear operations for the day, on each project tested. This was accomplished by averaging several readings taken with the probe resting on a standard plastic and paraffin block provided with the instrument. The primary reason for determining the standard counts is to check the daily functioning of the electronic equipment, which might influence the test counts.

When the calibration was being undertaken on the various projects to relate the test counts to density, a sand volume test would be performed at the same location on the ground where the nuclear device had been placed. The test hole made in this operation ranged from 4 to 5 inches in depth, rather than the usual 8± inches. This was done in order to conform more nearly to the effective backscatter depth of the nuclear gage* and

*Previous studies (1), (3) indicate that about 90% of the backscatter is developed in the upper 3 inches of the soil.

provide a more realistic basis for correlation between the two tests.

After suitable calibration curves had been established, for the various soil types, a limited number of trials involving multiple nuclear testing were undertaken to examine the feasibility of this type of operation for construction control. In this instance a recently compacted area of roadbed, or structural backfill having a similar soil type throughout, would be selected. Nuclear tests for density and moisture were then performed at a number of sites picked at random within the area. At the same time a location for obtaining samples for the Impact Compaction test (Test Method No. 216-F, Part II) and the performance of a sand volume test, would be selected within the area of the nuclear test by district project personnel. The maximum density determined from the Impact Test was then used to calculate the relative compaction for both the sand volume test and the nuclear tests.

## ANALYSIS OF DATA

Calibration:

Figures 1 through 6 illustrate the density calibration data obtained on each of the five projects. These scatter diagrams are plotted on the basis of counts per minute versus density as determined from the sand volume test. Assuming linear correlation between these two variables, a straight regression line was calculated* by the method of least squares for each set of data representing a project and soil type. Also determined were the standard deviations (Sx) of the respective data from these regression lines in terms of density. The Sx values determined as shown in Table II.

*Calculations were performed using program No. ST-05 arranged for an IBM 704 computor.

TABLE II

| Project | No. of Tests | Standard Deviation Sx |
|---|---|---|
| El Dorado Hills | 21 | 7 pcf |
| 29th & 30th St., Sacto. | 20 | 6 " |
| Milk Farm, AS | 3 | 2 " |
| Milk Farm, CTB | 3 | 5 " |
| Nut Tree | 6 | 5 " |
| Benicia to Cordelia (Normal Embankment Mtl.) | 12 | 5 " |
| Benicia to Cordelia (Tuff Material) | 18 | 10 " |

It is noted that the standard deviations given in Table II above, ranged from 5 to 10 pcf. This is somewhat greater than the range of about 4 to 7 pcf encountered in the previous laboratory work (3). There appears to be several reasons for this.

First of all there was a rather broad shift downward in the standard counts (approx. 600 counts per minute) during the first three weeks of gage operation (see Fig. 7). This is usually indicative that some change was taking place in the electronic circuitry of the device. During this period the gage stopped functioning entirely and an investigation revealed two broken connections in the scaler. After repair of the connections and cleaning of the circuit boards, the standard count leveled off with minor fluctuations ranging, on the average, about 300 counts (which is considered normal). Since all soils test data was included in the calculations for standard deviation, the gage malfunction was a significant factor in the apparent dispersion of results.

Another factor which should be considered, when comparing laboratory and field data, is the different conditions under which the tests are performed. The laboratory experiments are normally very carefully controlled and executed with the influence upon the results of such things as specimen fabrication, specimen surface condition, ambient temperature, etc., minimized. On the other hand, under field conditions, the control of these factors is very limited at best. Therefore, a somewhat greater dispersion of test data may be expected in construction testing.

In general, the relative degree of precision of the data (reflected by the standard deviation, Sx), between the various projects, appears to be dependent, in some degree, upon the uniformity and character of the soil being tested. Excluding the Nut Tree and Milk Farm projects, because of limited testing, the best correlation was achieved on the normal embankment material from the Benicia to Cordelia project with an Sx of 5.

The soil tested was a fairly homogeneous imported borrow composed of a clayey silt and sand. By coincidence the soil showing the poorest correlation is also found on the same project. This is the "tuff" material which indicates an Sx of 10. While this soil is classified as a Tuffaceous material, it comes from an excavation containing varying amounts of silty sand similar to the "normal embankment" material. The El Dorado Hills project represents another soil condition of a different character. The Sx of 7 was obtained on a rocky material which affected the results in two ways. First the rocky, uneven ground surface made good seating conditions for the probe almost impossible to attain. Secondly, the random occurrence of large rock particles under the source or pickup or both resulted in some variation in results.

One of the most significant findings in this calibration study is the evidence that each project and each soil type has its own distinct calibration relationship. This is illustrated in Figure 8 where all the regression lines are plotted on one chart. The most recent laboratory study (3) indicated that it is possible to develop one calibration curve to represent most soils. It appears, however, that when field testing is undertaken there are still variations in slope and position with different soils. This again appears to be, at least partially, a reflection of the basic difference between laboratory and field operating conditions.

On the whole the moisture determinations made in the study were not very satisfactory. Figure 9 illustrates the data obtained from all projects and demonstrates a wide scattering of points which are not resolved by separation into individual projects. A thorough examination of the device indicated an unusual temperature sensitivity but did not reveal the source of the difficulty. As a consequence the nuclear testing for moisture was discontinued before the program was completed.

Multiple Testing:

Unfortunately calibration was started, on most of the projects, after construction compaction was well underway. As a consequence compaction was nearing completion by the time suitable calibration curves were obtained, which could be used for multiple testing. This seriously limited the number of multiple test trials which could be performed. In the future it would be advisable to start calibration before construction begins whenever possible. Regular calibration checks should be made, after construction starts, in order to detect changes in soil type which might be occurring. Multiple testing should continue concurrently with any necessary calibration work.

Multiple testing was conducted on three projects which are identified in Table III along with a summarization of the test data obtained. This data is also illustrated graphically in Figures 10 through 12.

It is noted from Table III and the figures that the <u>average</u> relative compaction values from the nuclear tests on both the 29th and 30th St. and Milk Farm projects are very close to those attained with the sand volume test. It can also be seen, however, that there are some instances where individual relative compaction values, from nuclear tests, fell below acceptable limits*. In the case of the 29th and 30th St. project, 2 out of 3 tests were low in the "embankment" group and 2 out of 4 were low in the "structural backfill" series.

From a statistical standpoint it is rational to expect an occasional "low" value, where a large quantity of material is being tested (e.g. several hundred or thousand feet of roadbed) even though the overall average is at an acceptable level. In construction compaction, even though the compactive effort is assumed to be uniform throughout a given area, variations in soil moisture content, segregation of aggregates, etc., in localized "spots" will often indicate low density if a randomly selected test happens to be taken at that location. The statistical variation in the test itself can also affect the outcome in marginal cases.

On the other hand, it is also possible to have a series of "low" values in combination with a minority of extremely high tests which results in an acceptable average. This apparently happened in the embankment tests on the 29th and 30th St. project (see Figure 11a) where relative compactions of 87 and 88% in combination with a 97% resulted in an acceptable average of 91%. In random testing it is possible to "hit" an occasional dense spot in an area which may be generally low in density.

It is, therefore, felt that further study should be undertaken to develop a criteria based upon a minimum number of acceptable individual tests to be used in combination with the average in "passing" or "failing" an area.

While random selection of test sites is an essential feature in maintaining the statistical credibility of multiple testing, some control should be exercised on the spacing of test locations. Referring to the El Dorado Hills project (see Figure 10b) it is noted that of the five tests on about a 1000 feet of structural backfill, one pair of tests were within 7 feet of each other and another pair were only 5 feet apart. This practice could seriously bias the average of an area, from a practical viewpoint, even though it was accomplished through random selection.

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*Specification limits are 90% for embankment and 95% for structural backfill.

In the testing program for this study, the sites for obtaining the impact compaction samples, were arbitrarily selected by the project inspectors without reference to density values obtained from the nuclear tests. As a result there were several instances where samples were taken at locations demonstrating somewhat higher or lower nuclear densities than the average for the group. (See Figures 10a and b). While these densities are primarily presumed to reflect the degree of compaction obtained, it is possible that they might also be influenced, to some degree, by a minor change in the character of the soil, even though the area is assumed to contain the same soil type. It is, therefore, felt that obtaining soil samples for the impact test at the site where the nuclear density determination was closest to the average density for the group would be most representative in terms of relative compaction.

## DISCUSSION OF GAGE OPERATION

In general, the practical operation of the nuclear gage from Headquarters laboratory, to the various projects, proceeded satisfactorily. However, during the progress of the field testing, some aspects of the operation were revealed which can serve as guidelines for future work. The following discussion will endeavor to cover the various operating problems encountered.

One of the factors which caused considerable difficulty involved the coordination of testing between projects. It is noted from Table I that the extreme distance between projects is about 75 miles (between El Dorado Hills and Benicia to Cordelia) and the minimum distance about 10 miles. When two widely spaced projects were ready for testing in the same period, driving time became a serious detriment to the efficiency of the operation. There were several instances where the operator arrived on the job and found the contractor working on the next lift after the district had approved compaction on the basis of sand volume tests. In these cases, waiting for the nuclear tests would have constituted delay of the contractor's operations. The use of backup equipment and testing personnel would minimize this situation.

There were two instances of failure of the nuclear device during the progress of field testing. In one case a nuclear gage shutdown was the result of the broken connections mentioned earlier. In the other instance, the moisture phase apparently developed an abnormal sensitivity to temperature. While the reasons for these breakdowns are not known, it is felt that the probability of equipment failure is somewhat increased in a "central laboratory" type operation due to the continual vehicle transport of the gage over considerable distances. This further substantiates the need for backup nuclear devices.

From the standpoint of coordinating the testing between projects, the condition of the vehicle used for transportation becomes an item which should be considered. In this study there were two cases of mechanical difficulties, one was a leaking radiator and the other a defective tire. The vehicle used in field operations to transport nuclear devices should be in first-class mechanical condition.

In summarizing this study, it is felt that much insight has been gained into the application of nuclear gages to construction control. The program gave many construction people, both engineers and contractors in Districts 03 and 10, an opportunity to observe nuclear gages in operation. While there are field calibration problems evidenced by this study, it appears, from other work currently being undertaken by the Materials and Research Department, that the difficulties may soon be overcome by improved backscatter or transmission type gages.

# REFERENCES

(1) "Laboratory Studies of Nuclear Surface Moisture and Density Gages." A Materials and Research Department Report, October 10, 1962.

(2) "Report on Field Studies During 1962 of Nuclear Surface Moisture and Density Gages." A Materials and Research Department Report, July 24, 1963.

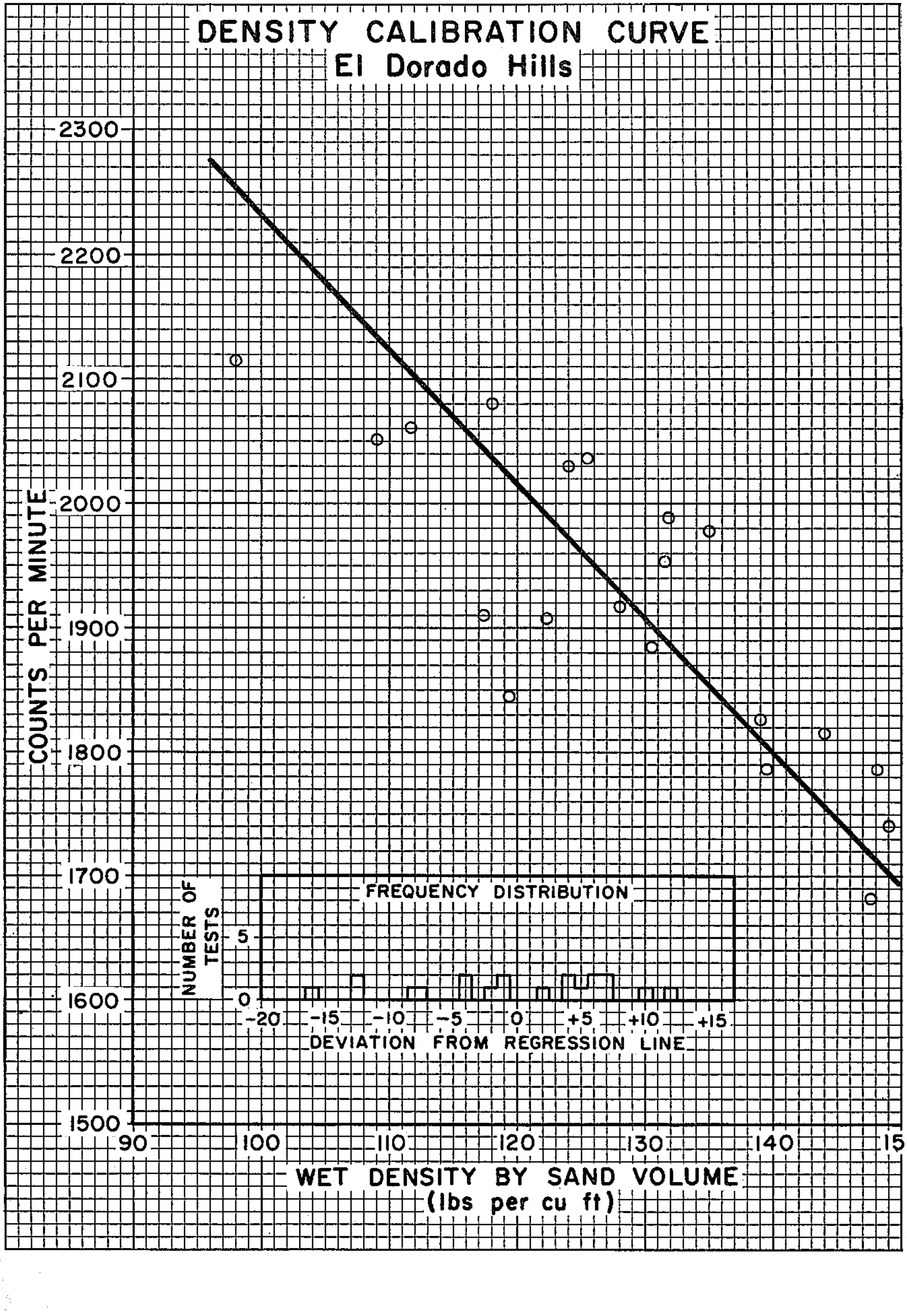
(3) "A Basic Study of the Nuclear Determination of Moisture and Density." A Materials and Research Department Report, August 1965.

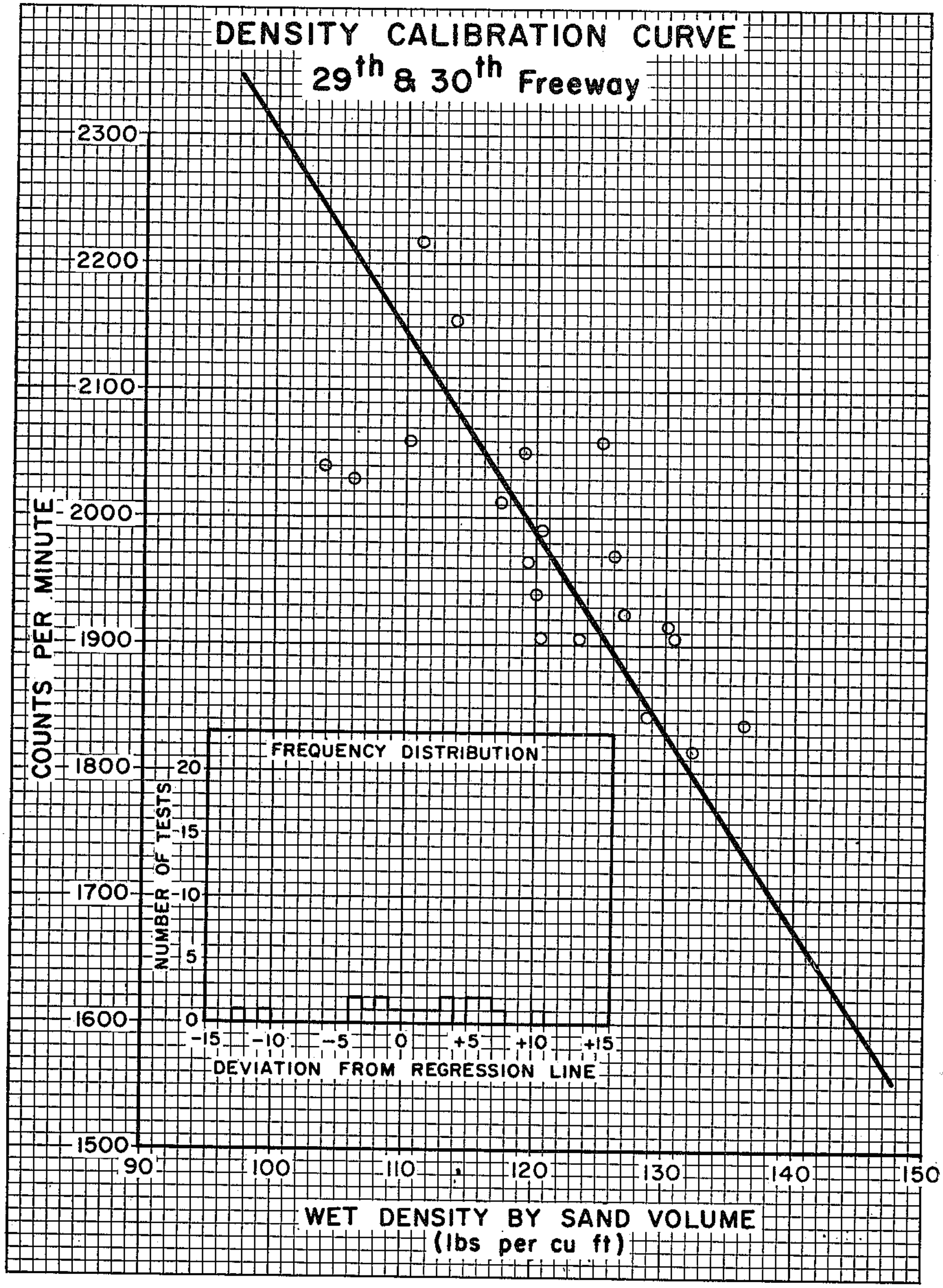
## TABLE III

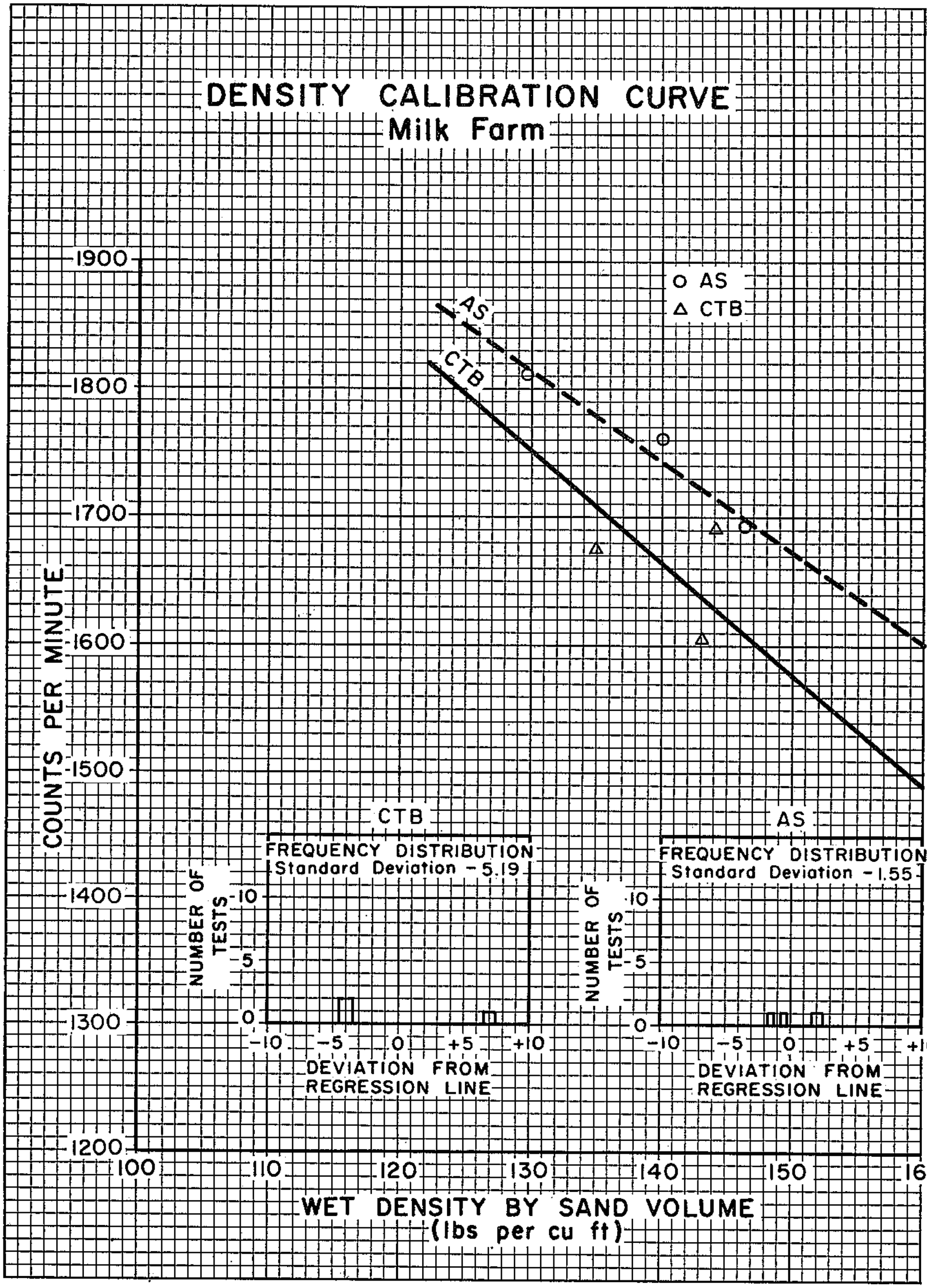
## SUMMARY OF MULTIPLE TESTING OPERATIONS

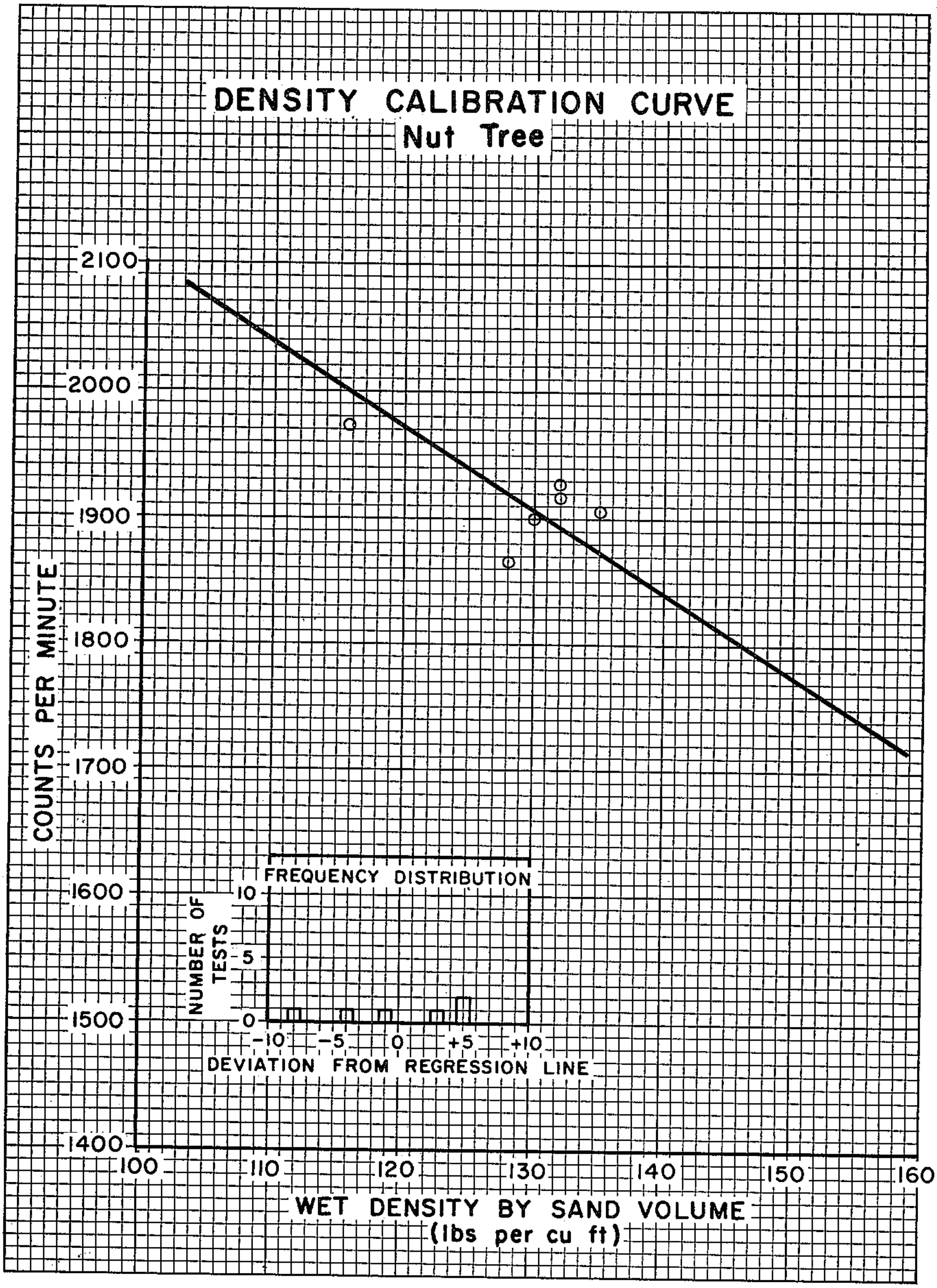
| Project | Date | Area Length | Area Width | Type Mtl. | Impact Test Density (wet) | Multiple Nuclear Test Item | Test #1 | Test #2 | Test #3 | Test #4 | Test #5 | Test #6 | Av. | Sand Volume Test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29th & 30th St., Sacto. | 8-3-64 | 150' | 24' | Emb. | 132.4 | Den | 128.8 | 116.6 | 115.0 | - | - | - | 122.2 | 120.5 |
| | | | | | | R.C. | 97 | 88 | 87 | | | | 91 | 91 |
| | | | | | | Sta. | 6+85 | 6+40 | 5+60 | | | | - | 6+40 |
| | 8-11-64 | 200' | 5' | Struct. B.Fill | 124.4 | Den | 101.8 | 117.3 | 119.5 | 110.0 | - | - | 112.1 | 113.6 |
| | | | | | | R.C. | 82 | 95 | 96 | 88 | | | 90 | 91 |
| | | | | | | Sta. | 884+55 | 885+00 | 885+60 | 886+40 | | | - | 885+00 |
| El Dorado Hills | 8-26-64 | 500' | 24' | Emb. | 130.9 | Den | 133.8 | 132.0 | 136.2 | - | - | - | 134.0 | 122.2 |
| | | | | | | R.C. | 102 | 101 | 104 | | | | 103 | 93 |
| | | | | | | Sta. | 16+05 | 18+20 | 25+75 | | | | - | 18+20 |
| | 9- 3-64 | 1000' | 5' | Struct. B.Fill | 150.3 | Den | 160.2 | 157.4 | 153.7 | 158.5 | 159.8 | 154.5 | 157.2 | 147.2 |
| | | | | | | R.C. | 107 | 105 | 102 | 106 | 106 | 103 | 105 | 98 |
| | | | | | | Sta. | 76+00 | 76+07 | 70+45 | 78+35 | 78+40 | 80+30 | - | 80+38 |
| Milk Farm | 8- 6-64 | 2100' | 12' | A.S. | 142.3 | Den | 137.0 | 139.5 | 140.3 | 136.8 | 128.0 | - | 136.3 | 140.0 |
| | | | | | | R.C. | 96 | 98 | 98 | 96 | 90 | | 96 | 98.0 |
| | | | | | | Sta. | 306+30 | 302+35 | 295+30 | 308+25 | 312+60 | | | 306+30 |
| | 8-12-64 | 400' | 12 | CTB | 134.3* | Den | 136.3* | 132.2* | 134.4* | - | - | - | 134.4* | 133.2* |
| | | | | | | R.C. | 102 | 98 | 100 | | | | 100 | 99 |
| | | | | | | Sta. | 318+00 | 321+50 | 318+85 | | | | - | 318+00 |

*Dry Density


DENSITY CALIBRATION CURVE
El Dorado Hills
COUNTS PER MINUTE
2300
2200
2100
2000
1900
1800
1700
1600
1500
90
100
110
120
130
140
150
WET DENSITY BY SAND VOLUME
(lbs per cu ft)
FREQUENCY DISTRIBUTION
NUMBER OF TESTS
5
0
-20
-15
-10
-5
0
+5
+10
+15
DEVIATION FROM REGRESSION LINE


DENSITY CALIBRATION CURVE
29th & 30th Freeway
COUNTS PER MINUTE
2300
2200
2100
2000
1900
1800
1700
1600
1500
FREQUENCY DISTRIBUTION
NUMBER OF TESTS
20
15
10
5
0
-15
-10
-5
0
+5
+10
+15
DEVIATION FROM REGRESSION LINE
90
100
110
120
130
140
150
WET DENSITY BY SAND VOLUME
(lbs per cu ft)


DENSITY CALIBRATION CURVE
Milk Farm
o AS
Δ CTB
AS
CTB
COUNTS PER MINUTE
1900
1800
1700
1600
1500
1400
1300
1200
100
110
120
130
140
150
160
WET DENSITY BY SAND VOLUME
(lbs per cu ft)
CTB
FREQUENCY DISTRIBUTION
Standard Deviation - 5.19
NUMBER OF TESTS
10
5
0
-10
-5
0
+5
+10
DEVIATION FROM REGRESSION LINE
AS
FREQUENCY DISTRIBUTION
Standard Deviation - 1.55
NUMBER OF TESTS
10
5
0
-10
-5
0
+5
+10
DEVIATION FROM REGRESSION LINE


DENSITY CALIBRATION CURVE
Nut Tree
COUNTS PER MINUTE
2100
2000
1900
1800
1700
1600
1500
1400
100
110
120
130
140
150
160
WET DENSITY BY SAND VOLUME
(lbs per cu ft)
FREQUENCY DISTRIBUTION
NUMBER OF TESTS
10
5
0
-10
-5
0
+5
+10
DEVIATION FROM REGRESSION LINE

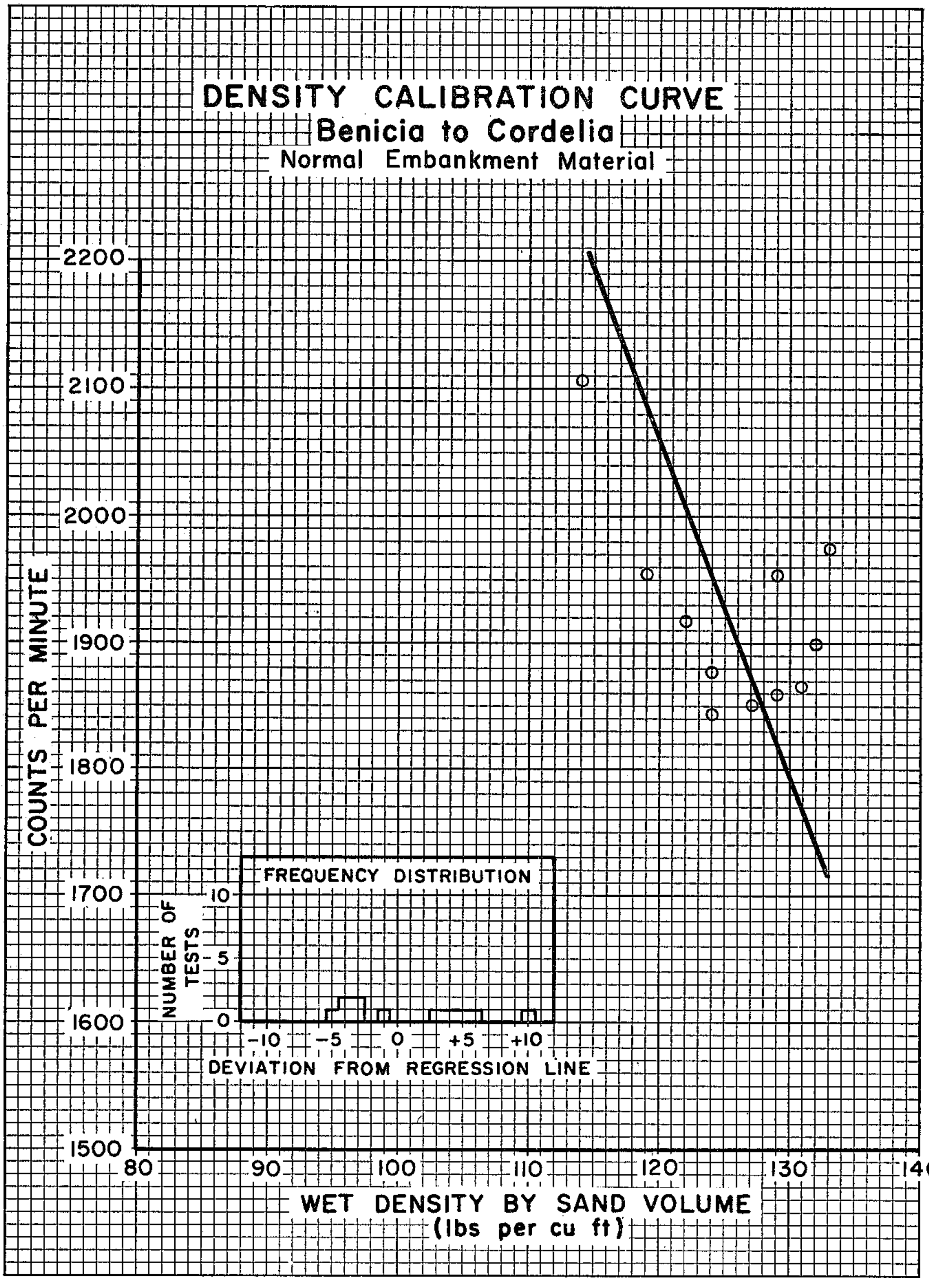
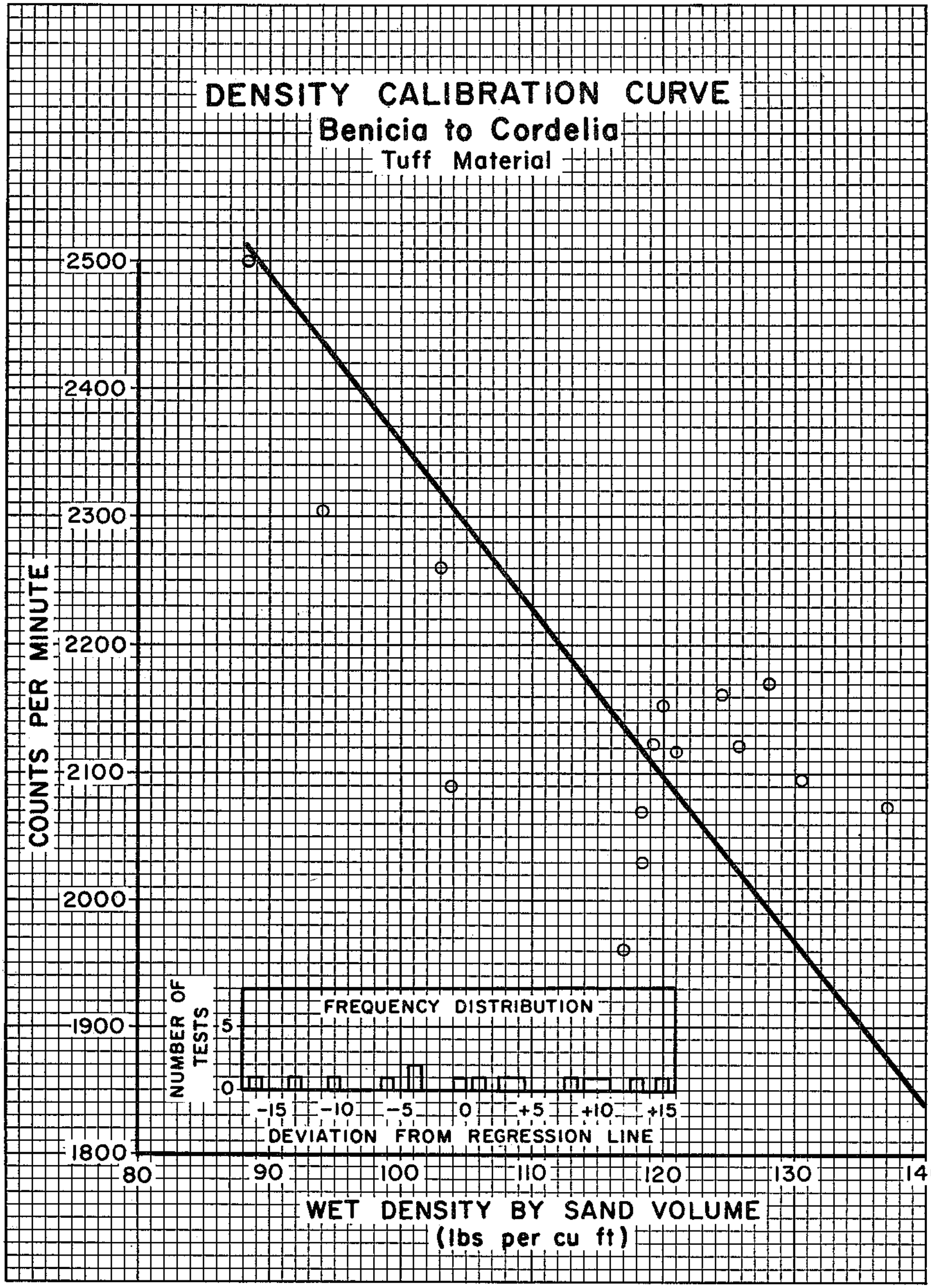

DENSITY CALIBRATION CURVE
Benicia to Cordelia
Normal Embankment Material
COUNTS PER MINUTE
2200
2100
2000
1900
1800
1700
1600
1500
80
90
100
110
120
130
140
WET DENSITY BY SAND VOLUME
(lbs per cu ft)
FREQUENCY DISTRIBUTION
NUMBER OF TESTS
10
5
0
-10
-5
0
+5
+10
DEVIATION FROM REGRESSION LINE

FIGURE 6



DENSITY CALIBRATION CURVE
Benicia to Cordelia
Tuff Material
COUNTS PER MINUTE
2500
2400
2300
2200
2100
2000
1900
1800
80
90
100
110
120
130
140
WET DENSITY BY SAND VOLUME
(lbs per cu ft)
FREQUENCY DISTRIBUTION
NUMBER OF TESTS
5
0
-15
-10
-5
0
+5
+10
+15
DEVIATION FROM REGRESSION LINE

FIGURE 7

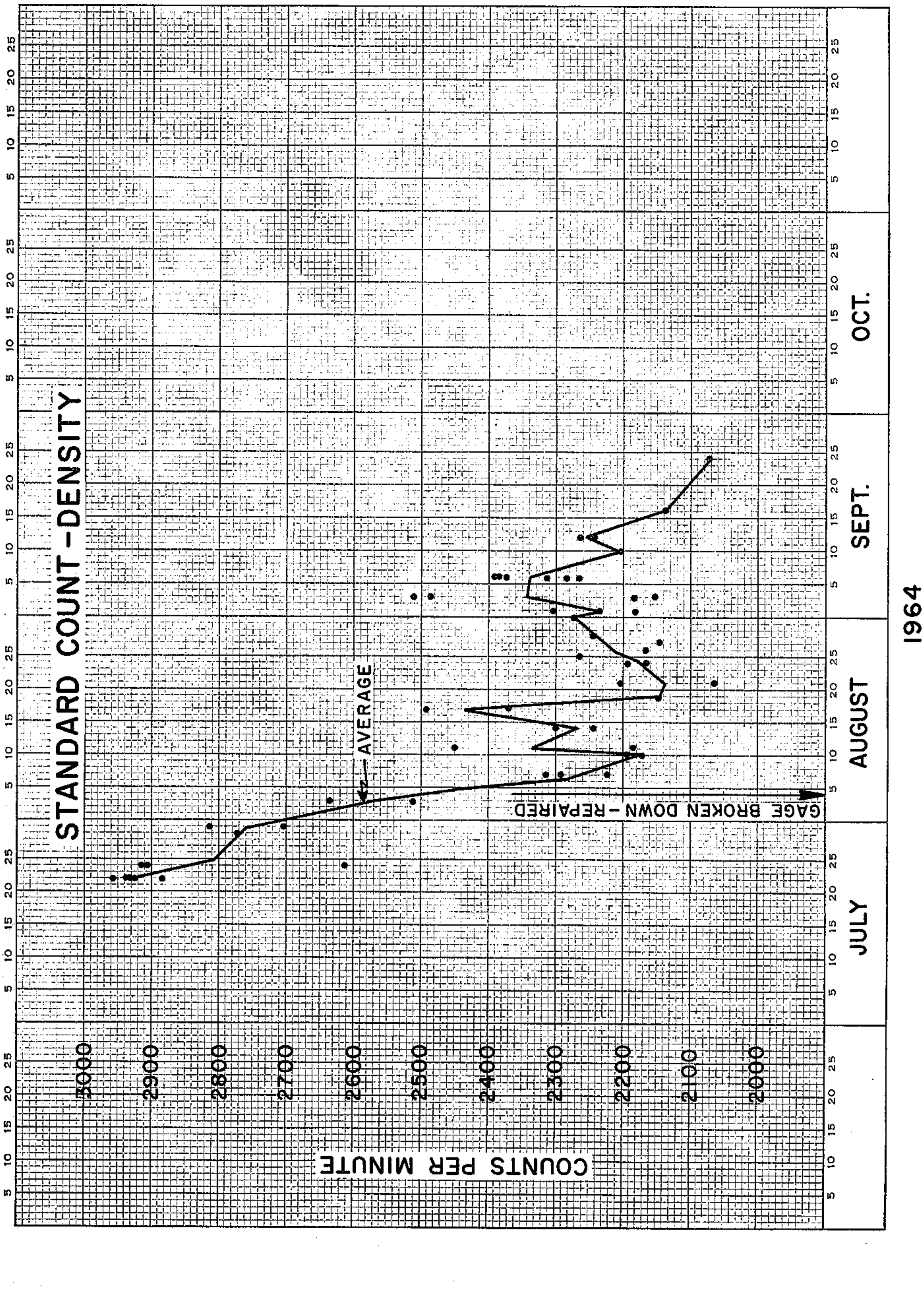

STANDARD COUNT-DENSITY
AVERAGE
GAGE BROKEN DOWN - REPAIRED
COUNTS PER MINUTE
3000
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
JULY
AUGUST
SEPT.
OCT.
1964

FIGURE 9

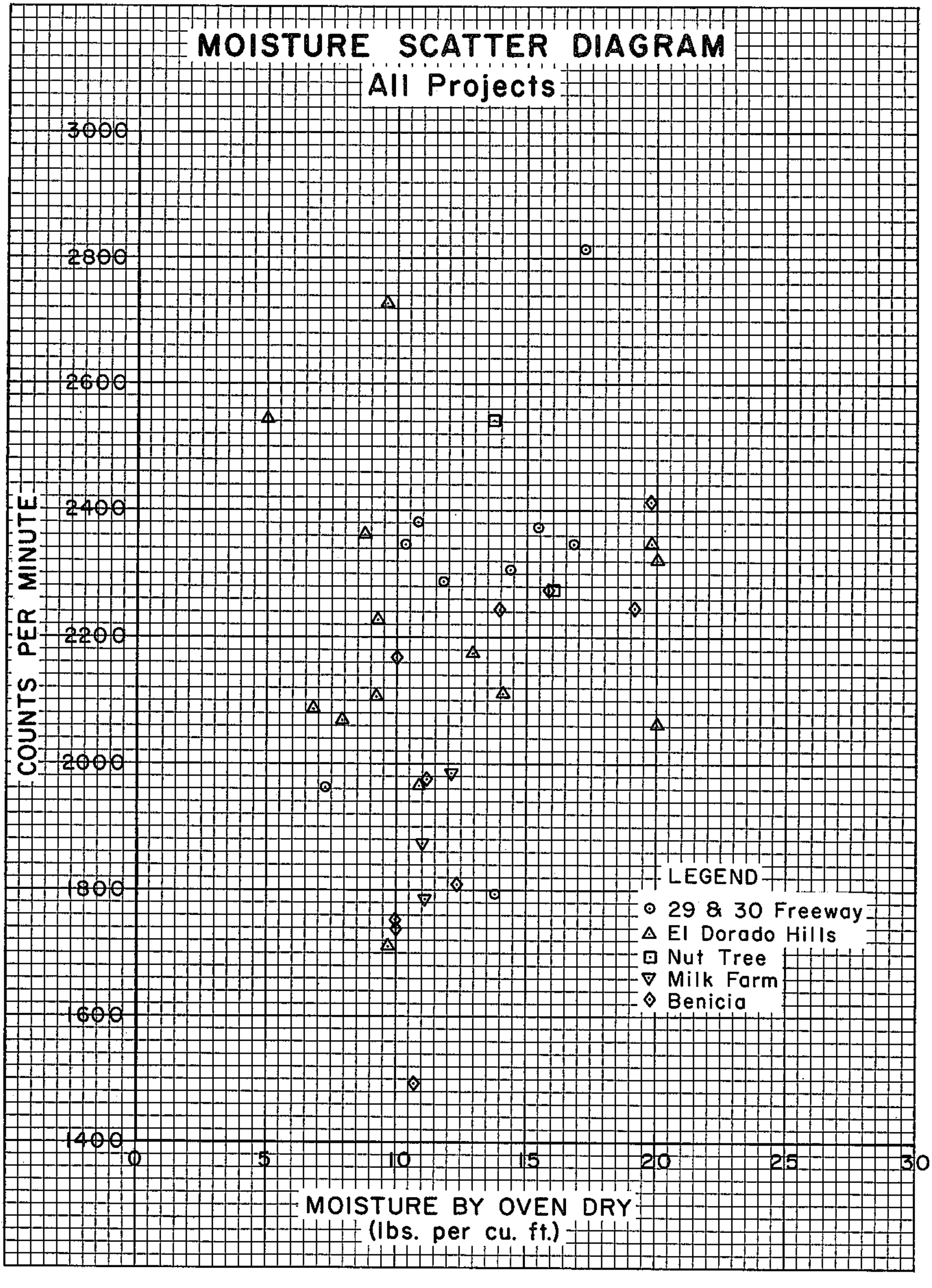
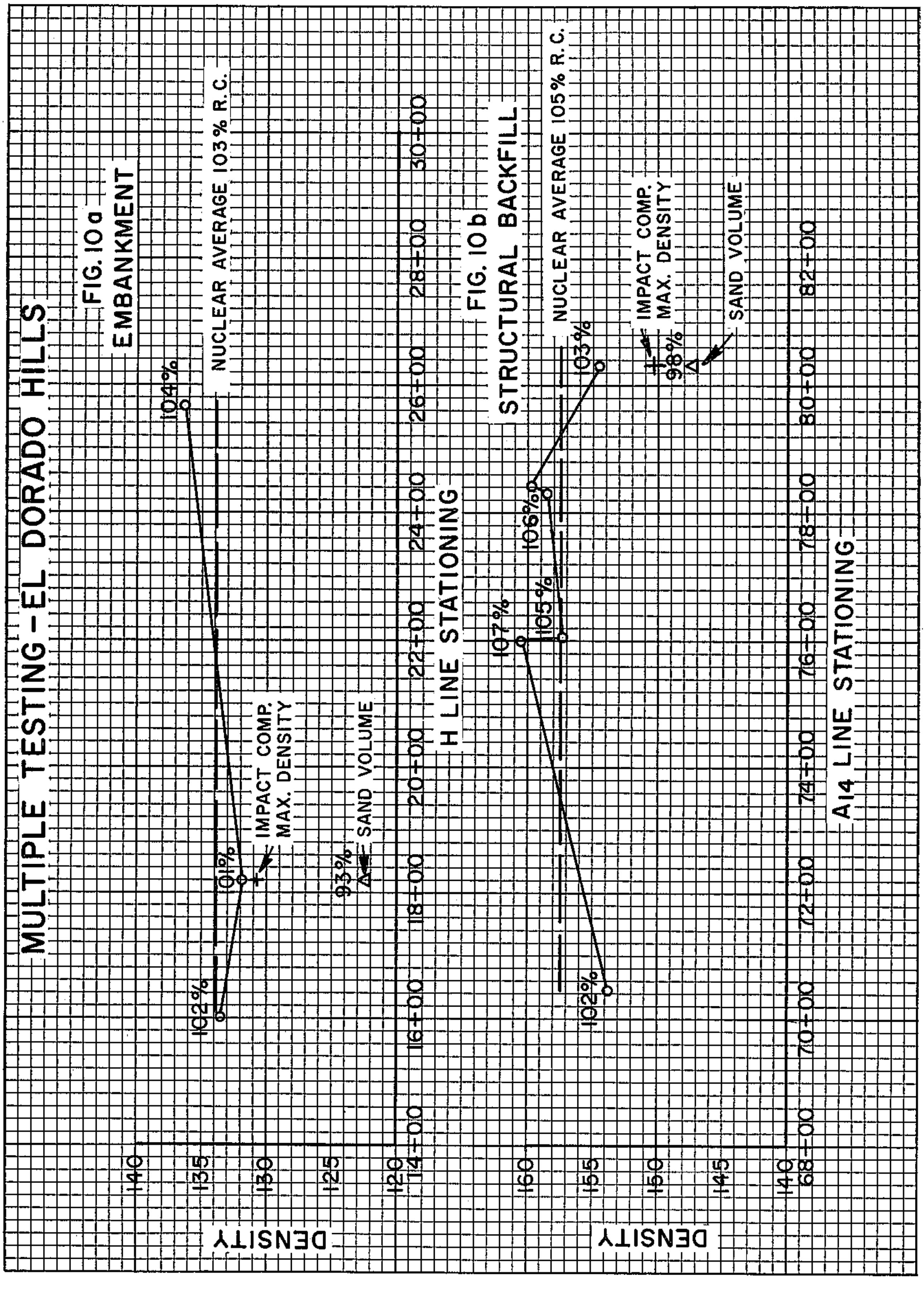

MOISTURE SCATTER DIAGRAM
All Projects
COUNTS PER MINUTE
3000
2800
2600
2400
2200
2000
1800
1600
1400
0
5
10
15
20
25
30
MOISTURE BY OVEN DRY
(lbs. per cu. ft.)
LEGEND
29 & 30 Freeway
El Dorado Hills
Nut Tree
Milk Farm
Benicia

FIGURE 10


MULTIPLE TESTING - EL DORADO HILLS
FIG. 10 a
EMBANKMENT
NUCLEAR AVERAGE 103% R.C.
104%
102%
101%
IMPACT COMP. MAX. DENSITY
93%
SAND VOLUME
DENSITY
140
135
130
125
120
14-00
16-00
18-00
20-00
22-00
24-00
26-00
28-00
30-00
H LINE STATIONING
FIG. 10 b
STRUCTURAL BACKFILL
NUCLEAR AVERAGE 105% R.C.
103%
106%
105%
107%
102%
IMPACT COMP. MAX. DENSITY
98%
SAND VOLUME
DENSITY
160
155
150
145
140
68-00
70-00
72-00
74-00
76-00
78-00
80-00
82-00
A14 LINE STATIONING

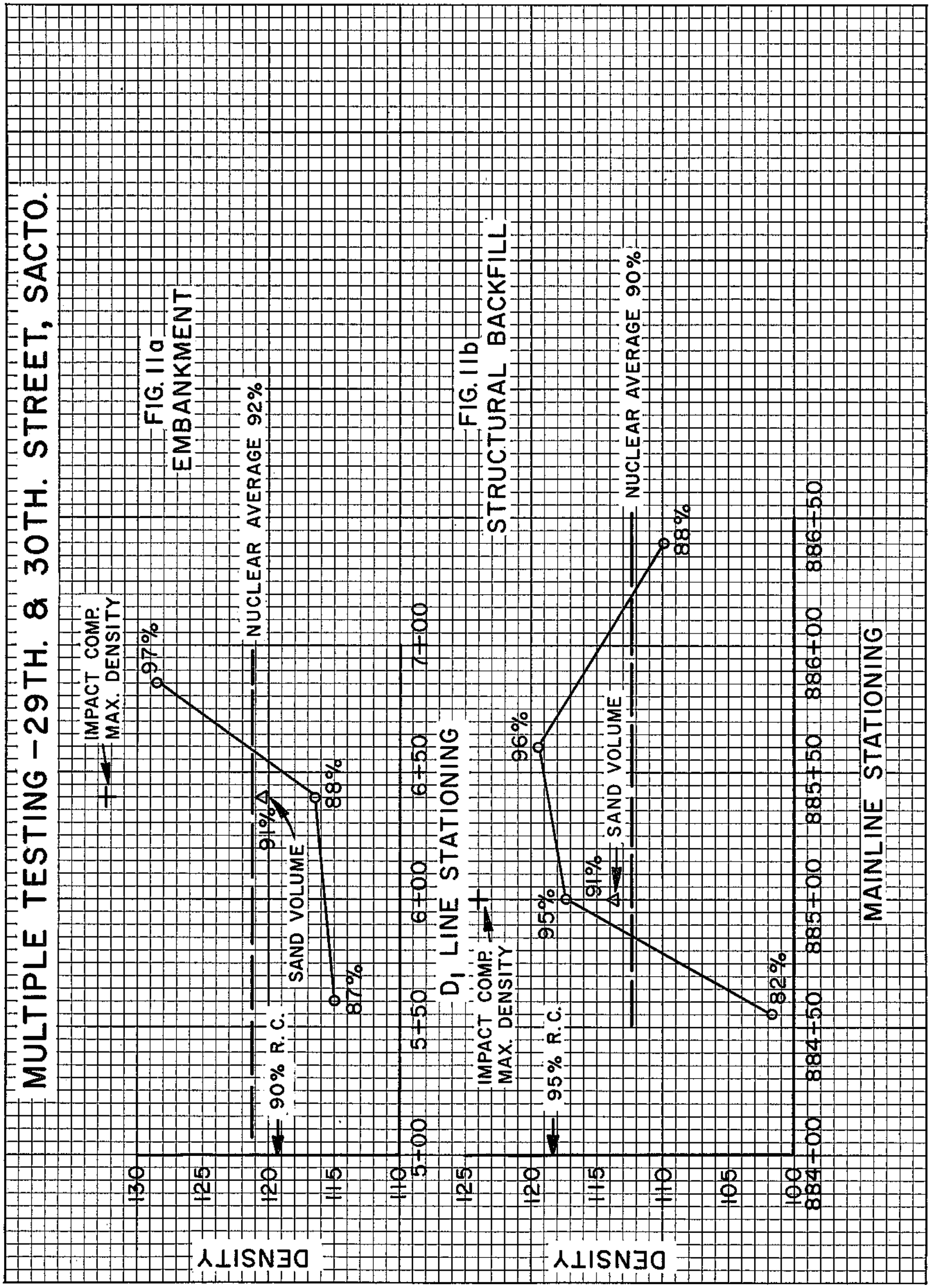
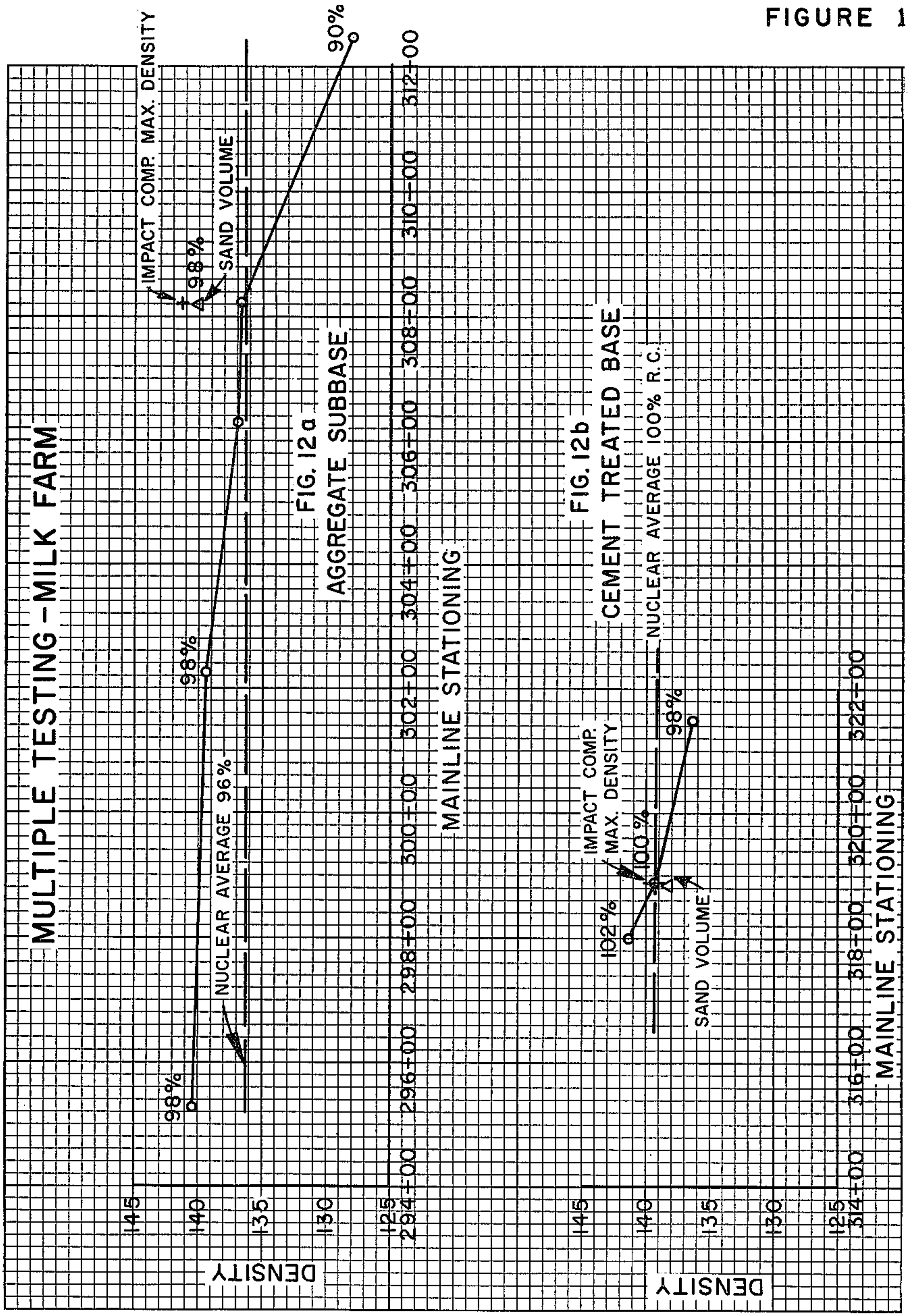

MULTIPLE TESTING - 29TH. & 30TH. STREET, SACTO.
FIG. 11a
EMBANKMENT
IMPACT COMP.
MAX. DENSITY
97%
88%
87%
91%
SAND VOLUME
NUCLEAR AVERAGE 92%
90% R.C.
DENSITY
130
125
120
115
110
5+00
5+50
6+00
6+50
7+00
D1 LINE STATIONING
FIG. 11b
STRUCTURAL BACKFILL
IMPACT COMP.
MAX. DENSITY
96%
95%
91%
82%
88%
SAND VOLUME
NUCLEAR AVERAGE 90%
95% R.C.
DENSITY
125
120
115
110
105
100
884+00
884+50
885+00
885+50
886+00
886+50
MAINLINE STATIONING

FIGURE 12


MULTIPLE TESTING - MILK FARM
FIG. 12a
AGGREGATE SUBBASE
FIG. 12b
CEMENT TREATED BASE
IMPACT COMP. MAX. DENSITY
SAND VOLUME
NUCLEAR AVERAGE 96%
NUCLEAR AVERAGE 100% R.C.
IMPACT COMP.
MAX. DENSITY
98%
90%
100%
102%
MAINLINE STATIONING
DENSITY
145
140
135
130
125
294+00
296+00
298+00
300+00
302+00
304+00
306+00
308+00
310+00
312+00
314+00
316+00
318+00
320+00
322+00