Technical Report Documentation Page

1. REPORT No.
632697-2, HPR -1(2), F-04-03

2. GOVERNMENT ACCESSION No.

3. RECIPIENT'S CATALOG No.

4. TITLE AND SUBTITLE
Evaluation of the Nuclear Compaction Test Method, District 05

5. REPORT DATE
February 1967

6. PERFORMING ORGANIZATION

7. AUTHOR(S)
Howe, D.R. and Bobby Lister

8. PERFORMING ORGANIZATION REPORT No.
632697-2, HPR -1(2), F-04-03

9. PERFORMING ORGANIZATION NAME AND ADDRESS
State of California
Department of Public Works
Division of Highways
Materials and Research Department

10. WORK UNIT No.

11. CONTRACT OR GRANT No.

13. TYPE OF REPORT & PERIOD COVERED

12. SPONSORING AGENCY NAME AND ADDRESS

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Introduction

The Materials and Research Department of the Division of Highways is currently undertaking an extensive research program to evaluate the application of a modified statistical test method, using nuclear soil gages, to contract compaction control. The basic goal of this study is to determine the feasibility of using this test method in California highway construction. The decision as to the extent that nuclear testing and the statistical approach will be utilized in construction control of embankments will rest on the outcome of this research project.

This data report is the second of eleven, from the projects in ten of our eleven highway districts involved in this study. The project is located on Route 180 in San Benito County between south of Hollister and Tres Penos, approximately 3.6 miles in length. The location map, shown in Figure 1, illustrates the general layout of the project. Two lanes were constructed with asphaltic concrete surface on aggregate base over aggregate subbase.

It is the purpose of this report to examine the application of the test method to specification control, on this project, and analyze the data obtained from the field operation of the nuclear equipment. Conclusions and recommendations will not be made until a final report is prepared combining information obtained from all of the projects.

17. KEYWORDS

18. No. OF PAGES:
48

19. DRI WEBSITE LINK
http://www.dot.ca.gov/hq/research/researchreports/1966-1967/67-07.pdf

20. FILE NAME
67-07.pdf


80

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

February 1, 1967

Lab Auth 632697-2
HPR -1(2), F-04-03

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

Dear Sir:

Submitted for your consideration is:

INTERIM REPORT #2

on

EVALUATION OF THE NUCLEAR COMPACTION

TEST METHOD

District 05

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

Very truly yours,

George B Sherman
for JOHN L. BEATON
Materials and Research Engineer

Attach
cc: LR Gillis
AC Estep
JF Jorgensen
RJ Datel
CG Beer
Research Files
FA Avilla

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Acknowledgments

The construction contract where this study was conducted was under the general supervision of the District 05 Construction Engineer and under the direct supervision of the Resident Engineer. Considerable credit is given to the test operator for his efforts in the successful application of the nuclear gages. Supervision of the nuclear test method and operational liaison was undertaken by the Materials and Research Department.

This Materials and Research Department research study was financed with Bureau of Public Roads 1½ percent research funds under authorization HPR 1(2) F-04-03.

Supplemental Statement

Reference is made to the letter from Mr. D. J. Steele, Division Engineer for the Bureau of Public Roads, dated December 7, 1966, concerning interim report #1. In this letter Mr. Steele stated that for the Bureau's purposes "it would not be necessary to present formal interim reports" on each project in the other nine districts.

The original purpose in preparing these interim reports was (1) provide engineers, in this department and in the districts, with information and data in an "approved and organized" form for their use before the final report is published, and (2) "spread" the routine compilation and analysis of a huge quantity of data over a broad base of time so that effort can be concentrated on the basic aims of the study at the final report stage.

For these reasons it is felt that the continued preparation of these interim reports, as the individual projects are completed, is very desirable. In the future it is proposed to provide only a brief discussion pertinent to the individual project and include tables and plots of the data accumulated.

This report on the District 05 project is patterned after the previous interim report #1 on District 03. Since the final draft was completed, at the time Mr. Steele's correspondence was received, it was decided to proceed with reproduction without spending additional time to condense the report.

Introduction

The Materials and Research Department of the Division of Highways is currently undertaking an extensive research program to evaluate the application of a modified statistical test method, using nuclear soil gages, to contract compaction control. The basic goal of this study is to determine the feasibility of using this test method in California highway construction. The decision as to the extent that nuclear testing and the statistical approach will be utilized in construction control of embankments will rest on the outcome of this research project.

This data report is the second of eleven, from the projects in ten of our eleven highway districts involved in this study. The project is located on Route 180 in San Benito County between south of Hollister and Tres Penos, approximately 3.6 miles in length. The location map, shown in Figure 1, illustrates the general layout of the project. Two lanes were constructed with asphaltic concrete surface on aggregate base over aggregate subbase.

It is the purpose of this report to examine the application of the test method to specification control, on this project, and analyze the data obtained from the field operation of the nuclear equipment. Conclusions and recommendations will not be made until a final report is prepared combining information obtained from all of the projects.

Method of Operation

In order to establish the new test method as the method of compaction control, on this contract, it was necessary to write a specification which resulted in the following statement being placed in section 5-1.02 of the contract special provisions:

> "Relative compaction will be determined by nuclear Test Method No. Calif. T-231. Copies of this experimental test method may be obtained at the Materials and Research Department, Division of Highways, Sacramento, California, and will be furnished on request."

The experimental nuclear Test Method No. Calif. T-231-B is shown in Appendix A.

The district assistant construction engineer and the project testing technician were given a one-week course of instruction in Sacramento. The course included the basic concepts of nuclear physics, health safety, application of the test method and operation of nuclear equipment.

A Nuclear Chicago Model 5901 d/M combination moisture and density backscatter type gage was used on this project (see Fig. 2). This device has a 4.5 mc Radium Beryllium source. The density is measured by the Compton effect of radiation acting upon the soil and the moisture content is measured by the neutron moderation by soil water.

In the initial phases of the project, the nuclear testing involved the undertaking of both density and moisture calibrations on the soils encountered, in accordance with Test Method No. Calif. 231-B (see Appendix A). Five separate density calibration curves were established for the different types of material on this project (see Figure 3, 4, and 5). The moisture calibration did not change due to the different soil types (see Figure 6), therefore, one curve was used throughout the contract.

Calibration and subsequent control testing was accomplished, in this study, by relating "count ratios" to densities obtained by the sand volume method and moistures obtained by the oven-dry method, respectively. A "count ratio" is calculated for each nuclear soils test by dividing the test count by the standard count.* This ratio then becomes the test value which is correlated with density and moisture in the calibration and multiple testing operations. The use of count ratios, instead of test counts tends to compensate for change variation in the daily functioning of the electronic circuitry, source, etc., which might influence the test values determined for density and moisture. The area concept was used in measuring the earthwork compaction (see Appendix A). The general practice on this project was to select at random six test sites with the same material type covering an area not exceeding a thousand foot length of roadbed without use of sections. An in-place nuclear density and moisture test was performed at each site within the area. The "dry weight density method" was used on all soils encountered on this project for calculating relative compaction.

In the early stages of construction a sample of soil was obtained for the Impact Compaction test from the site of the nuclear test nearest to the average nuclear density value within the area being tested. The maximum density thus obtained would then be used to compute the relative compactions from the individual nuclear tests within this area. After considerable impact data had been accumulated, the average maximum density for the particular soil type under nuclear test was used to calculate relative compaction values.

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*See Part B of Test Method T-231-B for procedure for determining standard counts.

Illustrated in Figure 7 is the frequency distribution of the dry density impact tests of all the different materials plotted from the data in Table I. An indication of the differences in the physical characteristics of the materials may be seen from these results.

Analysis of Data

Calibration

To determine if one calibration curve would be valid for all soil types encountered on this project, several correlation tests were performed on each soil type (see Part C of Appendix A). Two distinct soil types were obtained from the same borrow site, a silty clay and a silty clay with gravel. A separate calibration curve was used for each. A separate calibration curve was used for the structure backfill, base material, and subbase material, making a total of five separate calibration curves. A direct comparison of these curves may be made in Figure 3. The density calibration curves were constructed assuming a linear correlation between nuclear count ratio and soil density from the data in Table II.

The straight lines were drawn through the plotted data at locations calculated by method of least squares and were used for construction control. The precision of the calibration data, calculated in terms of the standard deviation from the calculated "best fit" line, is illustrated in Table III for each of the soil types.

The moisture calibration data shown in Figure 6 were plotted as "oven dry" moisture content (in lbs. of water per cubic foot) versus nuclear count ratio. Assuming linear correlation between these two variables, a straight line was drawn through the plotted data at calculated "best fit," and was used for field moisture determination. This calibration curve was plotted from the data in Table IV. The standard deviation of the data from the calculated "best fit" line is 1 lb. per cu. ft. One moisture calibration curve sufficed for all soils on this project.

The "dry weight basis" was used to calculate the relative compaction for the entire project. A nuclear moisture content (lbs. of water per cubic foot of soil) was obtained at each test site to establish the dry in-place density.

Construction Control Testing

The relative compaction (RC) data are shown in Table V and VI for embankment and structure backfill (including AB and AS), respectively. The tables are arranged to display the test values at the individual sites as well as the averages for the various areas tested. Those areas which do not meet the relative compaction specification requirements for the particular material tested are underlined to indicate that they are "failing" or unacceptable areas.

Frequency distribution (histogram) charts of relative compaction values are shown in Figures 8 and 9. They were constructed from the data in Tables V and VI, respectively for individual test sites. Tests from passing areas are shown as solid bars while the values from failing areas are indicated by dashed lines. Figures 10 and 11 are similar plots of area averages.

It is noted from Figure 8 that the individual tests from the passing embankment areas (solid bars only) range from a low of 77% RC to a high of 105% RC. The average for this distribution is 94 and the standard deviation is 4.

While the majority of the individual tests from the passing areas were at or above the minimum 90% RC specification for the embankment, it can also be seen in Figure 8 that there is a small group of substandard RC values scattered through these areas. These tests represent about 16 percent of the total tests from the passing areas.

Seventy-three percent of all the relative compaction tests were taken on structure backfill, O.G., A.B., and A.S. The trend shows a pattern similar to the embankment as illustrated in Figure 9. The passing areas indicate a range of 87 percent to 111 percent RC, an average of 98 percent, and a standard deviation of 4. There are about 12 percent of the individual tests from the passing areas which fall below the minimum specification of 95 percent RC.

It should be noted, in the above statistical analysis, that the tests from the failing areas (shown as dashed bars in Figures 8 and 9) were <u>not</u> included in the calculations. The primary reason is that the failing areas were reworked by the contractor and retested until the area averages met the specification limit. As a consequence the failing values no longer relate to the finished product and the acceptable retest values are included with the original tests for the passing areas. The purpose of showing the failing area tests, in the figures, was merely to provide an impression of the proportion and distribution of these tests encountered during construction operations.

The distribution charts for the area averages of both type of material are shown in Figures 10 and 11. It is to be expected, in these charts, that the passing area will only extend from the relative compaction specification limit upward, since the failed areas are normally reworked and retested until they too become passing areas. However, it should be pointed out that this does not present an entirely true representation of the probable final state of compaction. Besides the statistical effect of increasing the probabilities of obtaining passing samples through retesting, as demonstrated by Jorgensen and Watkins(1), the limitations of sampling tends to result in a distorted impression of the true "universe" conditions. The normal or bell shaped curves, superimposed on the respective charts, indicate the most probable distribution for all possible test areas (universe distribution) for each material. It can be seen that a portion of each distribution curve extends somewhat below 90% and 95% RC, indicating that some material may still be below the specification limit. The relative compaction data is plotted in Figures 12 and 13 for only those areas which do not meet the minimum specification requirements. Individual test points and area averages are plotted against relative compaction in the ordinate. In the abscissa the areas are grouped in proportion of passing to failing tests with the "passing" ratio diminishing from left to right (e.g. 50%:50%; 40%:60%; 33%:67%; 25%:75%; etc.). Within the groups, the areas are generally arranged to show increasingly unsatisfactory test values to the right.

For embankment (Figure 12) it can be seen that only one group has 33% failing tests with an average of 89% R.C. When the proportion of failing tests increase to 67% and all failing, the test averages drop off quite rapidly. A similar situation exists in the case of structure backfill, O.G., AB, and AS (Figure 13) where it is noted that there are no failing areas tested on the project having less than 50% of the tests failing and that the area averages decrease as the number of failing tests increase. Table VII combines the results of Figures 12 and 13. This data indicates that in 79% of all the test areas whose averages failed, 2/3 of the individual tests were also below the minimum RC requirement. Table VII also shows that 17% of all the test areas failed by the 2/3 requirement but had averages above the minimum specification. This indicates that both of these requirements must be satisfied for compaction control.

The fact that areas failing by virtue of sub-specification averages normally contain a perponderance of failing tests provides further evidence to support the contention that areas containing more than 33% or 1/3 failing tests should automatically be classed as failed areas, even though the area average occasionally meets the specification requirement.

Discussion of Test Operations

The nuclear compaction procedures used on this project and the problems encountered were very similar to those described in interim report #1(2). These problems are discussed in the following paragraphs.

Only one nuclear operator was trained for this project and this presented a problem to the operator as well as to the project. In one instance the operator became ill and was not on the job for one entire day which delayed the nuclear compaction tests. It is recommended that at least two nuclear gage operators be trained for each project.

Site preparation was a problem especially in the rocky embankment material. Scraping of the ground surface caused the rocks to "pop out" leaving small voids which had to be filled with natural fines. As the job progressed, the nuclear operator developed techniques which tended to minimize these difficulties.

Testing the structure backfill around pipes, with the nuclear gage, presented somewhat of a problem. When the tests were taken too close to the pipe, erroneous readings were obtained. This made it impossible to take a valid test between the trench wall and the pipe.

The nuclear gage was out of service only 3.6% of the total working days due to malfunctions (see Table VIII). These malfunctions were repaired immediately by the gage manufacturer service department.

The health-safety aspects of nuclear testing did not present any difficulties on this project. There was no apprehension indicated at any time by either the State employees, the contractor, or the general public. The operator was equipped with a film badge and a dosimeter to monitor exposure. The average weekly dosage received by the operator did not exceed 4.2 milliroentgens equivalent man (mrem). The highest dosage received by the test operator in any one week was 16. This is well below a 50 mrem per week limit normally observed by this department or the 100 mrem maximum allowable specified by the California State Department of Public Health.

The transportation of the nuclear gage to the test areas imposed no problem. The gage was transported in the rear of a pick-up type vehicle. A special locked container was constructed and fastened to the vehicle to protect the nuclear gage from theft, wet weather, and excessive jarring (see Figure 2).

"The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads."

References

(1) "Compaction-Myth or Fact?" by J. Frank Jorgensen and Robert O. Watkins, presented at the 44th Annual WASHO Conference, June 16, 1965.

(2) "Evaluation of the Nuclear Compaction Test Method District 03," a Materials and Research Department Report, California Division of Highways, September 1966.

TABLE I

Impact Compaction Maximum Densities

Date	Wet Dens.	Dry Dens.	% Moist.	Type of Material
9-2-65	130.0	119.3	9.1	Silty clay (OG)
9-7-65	135.0	121.0	11.6	Clay Emb.
9-10-65	131.4	118.8	10.7	Silty clay Emb.
9-16-65	136.0	120.3	13.1	Clay & shale Emb.
9-22-65	139.2	125.5	11.1	Silty clay Emb.
10-1-65	133.2	117.3	13.5	Clay & Shale (Emb.)
10-7-65	134.5	120.9	11.0	Clay & Shale (Emb.)
10-20-65	138.0	131.7	4.9	Sand & gravel (Str. Bkf)
10-21-65	121.1	119.0	1.8	Sand (Str. Bkf.)
10-22-65	135.6	128.1	5.9	Clay & gravel Emb.
10-25-65	124.5	122.5	1.7	Sand (Str. Bkf.)
10-30-65	142.0	131.3	8.1	Clay & gravel
11-5-65	137.2	122.1	12.5	Clay & gravel
11-12-65	130.5	119.4	9.4	Clay (O.G.)
1-27-66	136.8	120.7	13.5	Clay (Emb.)
1-28-66	149.5	138.6	7.9	Cl. 4 Agg. Subbase
2-26-66	144.0	131.4	9.4	Cl. 4 Agg. Subbase
2-26-66	146.2	134.7	8.6	Cl. 4 Agg. Subbase
3-10-66	151.8	140.6	8.1	Cl. 2 Agg. Base
3-11-66	154.2	143.6	7.3	Cl. 2 Agg. Base
3-18-66	150.2	140.0	7.5	Agg. Subbase

TABLE II

Calibration Data

Count Ratio versus Sand Volume in lbs. per ft.^{3}

NUCLEAR CHICAGO 99

Silty Clay

Count Ratio	In-Place Density (lbs. per cu. ft.) Sand Volume
1.66	105.0
1.64	95.0
1.75	92.0
1.39	122.3
1.39	120.0
1.44	113.0
1.64	101.0
1.47	110.0
1.49	107.5
1.56	107.0
1.32	133.0
1.43	124.0
1.37	132.0
1.37	122.0
1.42	118.0
1.43	115.0
1.36	130.0
1.40	118.4
1.29	132.0
1.50	111.0
1.42	130.0
1.34	127.0

Clay and Gravel

c/r	Density
1.48	128.0
1.39	133.0
1.35	125.0
1.43	120.0
1.39	121.0
1.44	125.0
1.40	125.0
1.41	127.0
1.45	121.0
1.41	120.0
1.40	120.0
1.42	129.0
1.39	125.0
1.38	123.0
1.60	105.0
1.61	105.0
1.53	114.0

Table II - Contd.)

Structure Backfill

c/r	Density
1.37	130.0
1.49	126.0
1.47	127.0
1.51	118.0
1.45	129.0
1.58	107.0
1.48	119.0
1.50	110.0
1.43	133.0
1.43	122.0
1.46	126.0

Aggregate Subbase

c/r	Density
1.33	136.0
1.37	138.5
1.39	137.8
1.34	136.0
1.39	140.0
1.37	134.7
1.40	132.0
1.44	120.0
1.47	119.0
1.46	109.0
1.42	121.0
1.41	134.0
1.37	137.0
1.25	139.0
1.32	138.0
1.28	139.0
1.30	148.0
1.21	153.0
1.25	142.0

Aggregate Base

c/r	Density
1.23	148.0
1.23	149.0
1.27	145.0
1.37	132.0
1.41	125.0
1.40	127.0
1.28	142.0

TABLE III

Standard Deviation of Density Calibration Tests

Soil Type	No. of Tests	Standard Deviation (pcf) Calculated Regression Line
Silty Clay (Emb) & O.G.	22	5
Clay & Gravel (Emb)	17	5
Structure Backfill	11	5
Aggregate Subbase	19	5
Aggregate Base	7	1

TABLE IV

Count Ratio Versus Moisture in lbs. per ft.^{3}

NUCLEAR CHICAGO 99

Count Ratio	In-Place Moisture (lbs. per cu. ft.)
.269	10.4
.81	1.0
.336	13.3
.298	11.0
.230	9.0
.092	5.0
.295	10.0
.207	7.5
.241	9.0
.362	15.7
.308	9.4
.417	14.4
.240	9.0
.267	9.0
.425	18.5
.268	8.0
.358	13.0
.249	8.0
.246	7.0
.238	7.0
.310	12.0
.239	9.0
.216	8.0

90% R.C. Required

TABLE V

SUMMARY OF RELATIVE COMPACTION DATA

Rte. 180-SBt

Cont. # 021214

Date	Test No.	#1	#2	#3	#4	#5	#6	Avg.	Accept	Reject	Remarks
		Relative Compaction, %									
9-8-65	1	81	82	80	79	88	80	82		X	
9-13-65	2	96	93	94				94	X		
9-14-65	3	84	87	89	82	79	82	84		X	
"	4	94	92	97				94	X		
9-15-65	5	92	98	94	97	92	93	94	X		
9-20-65	6	95	97	100	101	93	91	96	X		Retest of Test #1
"	7	98	97	85				93	X		
9-22-65	8	95	96	92				94	X		
9-27-65	9	83	93	99	94	93	85	91	X		
9-30-65	10	93	88	93	89	87	88	89		X	
"	11	93	88	94	93	88	90	91	X		
"	12	96	96	98	89	96	94	95	X		Retest of Test #10
10-1-65	13	99	92	94	89	90	94	93	X		
10-4-65	14	89	85	100	95	97	94	93	X		
"	15	98	90	87	88	90	85	90		X	
10-5-65	16	93	93	91	99	93	97	94	X		Retest of Test #15
"	17	93	93	92	88	83	91	90	X		
10-7-65	18	99	97	88	95	92	91	94	X		
"	19	98	94	88	88	91	94	92	X		
10-15-65	20	101	93	101	100	95	94	97	X		
"	21	96	88	93	91	95	91	92	X		
10-19-65	22	88	95	94	92	86	83	89		X	
10-20-65	23	99	99	105	105	98	102	101	X		Retest of Test #22
10-22-65	24	94	95	92	88	88	92	91	X		
10-28-65	25	94	87	84	90	89		89		X	
10-28-65	26	99	90	89	93	77	91	90	X		Contractor rerolled low area
10-30-65	27	101	97	97	98	97	88	96	X		
"	28	86	81	74				80		X	
11-4-65	36	92	88	84				88		X	
11-5-65	37	91	78	81				83		X	
11-6-65	39	97	90	94	87	95	92	93	X		
11-6-65	40	95	94	95				95	X		Retest of Test #37
"	41	96	96	90	90	93	92	93	X		
11-9-65	42	91	90	87				89		X	
3-19-66	61	92	94	88				91	X		

95% R.C. Required

TABLE VI

SUMMARY OF RELATIVE COMPACTION DATA

Rte. 180-SBt

Cont. 021214

Date	Test No.	#1	#2	#3	#4	#5	#6	Avg.	Accept	Reject	Remarks
		Relative Compaction, %									
11-1-65	29	101	102	95	100	94	87	96	X		Subgrade
"	30	95	96	97	99	95	97	97	X		"
11-3-65	32	102	97	97				99	X		"
11-4-65	33	95	98	101	98	98	97	98	X		"
11-4-65	34	98	102	102	98	102	98	100	X		"
"	35	88	91	93				91		X	"
11-5-65	38	99	103	97	102	96	96	99	X		"
11-10-65	43	87	96	97	101	89	98	95	X		"
"	44	97	98	90	93	100	93	95		X	"
11-11-65	45	101	94	92	96	90		94		X	"
"	46	99	102	96	87	91	92	94		X	"
"	47	100	98	100				99	X		"
"	48	98	100	98	96	102	102	99	X		"
1-27-66	49	92	89	92				91		X	"
"	50	90	91	89				90		X	"
"	51	93	84	88				88		X	"
2-16-66	52	98	97	92	98	100	94	97	X		"(Retest of Test #49)
2-17-66	53	97	97	93	96	95	100	96	X		"(Retest of Test #50)
2-19-66	54	88	96	100	91	96	101	95	X		"
"	55	99	94	92				95		X	"
2-23-66	56	93	100	102				98	X		"
"	57	92	98	97				96	X		"
3-15-66	58	92	92	102	90			94		X	"
"	59	98	102	100	99	98	98	99	X		"
3-16-66	60	100	94	99	97	102	91	97	X		

95% R.C. Required

TABLE VI-contd.

SUMMARY OF RELATIVE COMPACTION DATA

Rte. 180-SBt — Cont. 021214

Date	Test No.	Relative Compaction, % #1	#2	#3	#4	#5	#6	Avg.	Accept	Reject	Remarks
3-25-66	62	94	102	100	97	100	98	98	X		Subgrade
"	63	103	100	96	97	89	97	97	X		"
3-26-66	64	88	82	85				85		X	"
"	65	92	101	97				96	X		"
4-2-66	66	100	94	100				98	X		"
"	67	94	91	98	86			92		X	"
4-6-66	68	103	97	99	103	96	96	99	X		"
"	69	101	99	102				101	X		"
4-8-66	70	98	94	97	91	97	97	96	X		"
9-29-65	1	80	72	83				78		X	Original Ground
10-18-65	2	106	101	105	101	107	107	104	X		"
11-12-65	3	85	94	93	92	78	86	88		X	"
12-9-65	4	90	99	94	92	96	97	95		X	"
2-18-66	1	96	95	100	95	100	99	98	X		Aggregate Subbase
2-26-66	2	98	100	98	104	103	99	100	X		"
"	3	96	98	98	94	98	94	96	X		"
2-28-66	4	96	96	92	97	94	101	96	X		"
3-3-66	5	91	94	94	98	98	104	96		X	"
"	6	98	101	101	100	101	89	98	X		"
"	7	97	98	94				96	X		" (Retest of Test #5)
"	8	98	101	102				100	X		"
3-4-66	9	96	96	101				98	X		"
3-18-66	10	99	96	104	96	99	100	99	X		"
3-19-66	11	85	100	80	82	100	83	88		X	"
3-26-66	12	101	100	106	103	101	101	102	X		"

95% R. C. Required

TABLE VI-contd.

SUMMARY OF RELATIVE COMPACTION DATA

Rte. 180-SBt

Cont. 021214

Date	Test No.	#1	#2	#3	#4	#5	#6	Avg.	Accept	Reject	Remarks
		Relative Compaction, %									
3-26-66	13	101	94	100	103	96	100	99	X		Aggregate Subbase
3-28-66	14	97	92	99	100	100	100	98	X		" "
3-29-66	15	104	102	101	104	104	99	100	X		" "
"	16	103	103	100	101	103	101	100	X		" "
"	17	105	101	97	99	99	98	100	X		" "
3-30-66	18	102	100	96	98	102	92	98	X		" "
"	19	97	97	96	100	97	105	99	X		" "
"	20	100	99	99	101	93	100	99	X		" "
4-9-66	21	99	96	98				98	X		" "
4-11-66	22	94	94	100	87			93		X	" "
"	23	100	103	105	101	104	102	100	X		" " (Retest of #22)
"	24	96	103	101					X		" "
3-11-66	1	95	97	99	101	95	96	97	X		Aggregate Base
"	2	96	99	97	97	99	101	98	X		" "
"	3	94	97	99	98	93	102	97	X		" "
3-14-66	4	97	94	102	97	98	97	98	X		" "
4-1-66	5	99	93	97	101	100	101	98	X		" "
"	6	101	102	91	99	100	98	98	X		" "
4-4-66	7	94	97	94	100	98	95	96	X		" "
"	8	92	97	94	99	95	95	95	X		" "
"	9	96	97	103	101	98	98	99	X		" "
"	10	98	101	98				99	X		" "
4-8-66	11	95	102	100	100	101	96	99	X		" "
"	12	101	97	98	100	101	95	99	X		" "
4-9-66	13	103	102	97	104	99	103	101	X		" "
"	14	96	101	97	93	97	101	97	X		" "
4-12-66	15	96	99	92	96	92	95	95	X		" "
"	16	97	98	95	97	99	101	98	X		" "
"	17	95	95	103	101	94	101	98	X		" "

95% R.C. Required

TABLE VI-contd.

SUMMARY OF RELATIVE COMPACTION DATA

Rte. 180-SBt — Cont. 021214

Date	Test No.	Relative Compaction, % #1	#2	#3	#4	#5	#6	Avg.	Accept	Reject	Remarks
4-13-66	18	94	98	97	97	101	100	98	X		Aggregate Base
4-18-66	19	99	98	102	96	103	96	99	X		" "
"	20	99	99	100				99	X		" "
10-21-66	1	101	100	92				98	X		Structure Backfill
"	2	95	95	100				97	X		" "
11-3-65	11	110	97	104				103	X		" "
11-4-65	13	95	92	89				92		X	" "
"	14	108	100	102				103	X		" " Retest of #13
12-9-65	16	81	92	96				89		X	" "
12-9-65	17	94	101	88				94		X	" " Retest of #16
12-10-65	18	96	101	111				103	X		" " Retest of #17
"	19	100	101	96				99	X		" "
3-21-66	22	96	98	97				97	X		" "
3-23-66	23	102	100	100				100	X		" "

TABLE VII

Percentage of Total Tests that Failed to Meet the Minimum Requirements by the 2/3 Areas Passing, Average Passing, and Both

	No. of Tests	Percentage of Total Tests
Number of test areas which failed due to the 2/3 requirement and the average was at or above the minimum specification	5	17
Number of test areas which failed due to minimum average RC requirement and less than 1/3 failed	1	4
Number of failing test areas which do not satisfy both the 2/3 and minimum average RC requirements	23	79

TABLE VIII

Record of Nuclear Gage Malfunctions

NUCLEAR CHICAGO 99

Description of Malfunction	Date Gage Out	Date Back on Job	Downtime Working Days
Moisture count was erratic Broken wire in scaler.	10-5-65	10-8-65	2
Superfluous density count Replaced moisture & density toggle switch on the probe.	10-27-65	10-28-65	1
Scaler stopped counting after two hours of operation. Nuclear gage had not been used for six weeks and the battery had not been fully charged.	1-18-66	1-19-66	1
		Total	4

APPENDIX A

MATERIALS AND RESEARCH DEPARTMENT

State of California
Department of Public Works
Division of Highways

Test Method No. Calif. T-231-B
December 30, 1964
(4 pages)

METHOD OF TEST FOR RELATIVE COMPACTION OF SOILS BY NUCLEAR METHODS

SCOPE

The nuclear method of test shall be used to determine the in-place moisture and density of compacted soils and aggregates. The in-place density is the density of a soil as it exists in either the natural ground, in constructed earthwork, or after being processed and compacted. The test maximum density shall be determined as specified in Test Method No. Calif. 312 for Classes A and B Cement Treated Base and in Test Method No. Calif. 216 for untreated materials, Classes C and D Cement Treated Base and lime treated soils and aggregates.

A. APPARATUS

1. A nuclear gage for determining soil moisture and density.
2. A portable scaler to count the radiation received by the detector in the nuclear gage.
3. A standardizing device to check the operation of the gage and scaler.

B. STANDARDIZATION OF EQUIPMENT

1. At least twice a day standardize the gage to check the operation of the equipment.
2. Place the gage upon the standardizing device and take counts after the scaler has been turned on for at least fifteen minutes with the gage connected. Make five or more one-minute counts.
3. Discard any counts deviating from the average by over 200 counts and average the remaining counts. This average is to be within 250 counts of the average supplied with the equipment.

C. CALIBRATION

1. Calibration curves relating the counts obtained with the nuclear gage to the soil moisture and density will be supplied with the gage at the start of the contract.
2. Obtain comparative sand volume tests at selected intervals at the same locations as the nuclear tests. Perform the sand volume test as described in Test Method No. Calif. 216. This must be done for each general soil type encountered on the project.
3. After obtaining several comparisons the calibration relating nuclear counts to density may be modified by the method of least squares assuming a linear relationship.

D. DETERMINATION OF NUCLEAR COUNTS

1. Preparatory to making a nuclear determination, clear away all loose surface material and obtain a plane surface at least 2 feet square. In areas compacted by pneumatic-tired or smooth-wheel rollers, remove disturbed surface material to a depth of not less than 2 inches below the final surface on which the rollers have operated. 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 disturbance by the roller. The nuclear test may be conducted when the surface is plane to within 1/8 inch under the area covered by the gage.

2. Where a transmission type density gage is to be used, make a small hole 12 to 15 inches deep with the equipment supplied. This hole must be at 90 degrees with the plane surface. No hole is required for backscatter type gage.

3. Fill in the minor depressions, not exceeding 1/8 inch, with native fines. Place the nuclear gage on the soil surface so that all points of the bottom of the gage are in contact with the soil. Place the transmission type gage so that the rod on the gage is over the hole, and then push the rod into the hole to the desired depth.

4. Obtain a reading over a one-minute interval. Then rotate the gage 90 degrees over the same center point and obtain another one-minute reading. If these two readings do not check within 250 counts, obtain two additional readings by rotating the gage over the same center point. Average the two or more readings which are within 250 counts. This average reading constitutes one nuclear test.

E. DETERMINATION OF MOISTURE AND DENSITY OF THE SOIL

1. Using the calibration curves, convert the averaged readings to wet density and moisture content. Show the wet density in pounds of material per cubic foot and show the moisture content in pounds of water per cubic foot.

2. Determine the dry unit weight by subtracting the moisture from the wet density.

F. NUMBER AND LOCATION OF NUCLEAR TESTS

1. The nuclear test will utilize the area concept. That is, a series of tests will determine whether to accept or reject an entire area. Perform six or more nuclear tests in each area. The engineer shall determine the area based on uniformity of factors affecting nuclear testing.

2. Divide the area into two or more sections of approximately equal size. Perform two or more nuclear tests upon each section with the locations of the nuclear tests being of a random nature. (For special cases one section may be tested with three nuclear tests and considered an area). Determine the moisture and density of the soil by the nuclear tests as described in part D and E above.

F. NUMBER AND LOCATION OF NUCLEAR TESTS (Continued)

3. Average these six or more tests and perform the maximum density test on the soil obtained from the location of the nuclear test which has a value just below the average value. Determine the maximum density as specified in Test Method No. Calif. 312 for classes A and B CTB and Test Method No. Calif. 216 for all other treated and untreated soils and aggregates.

4. Care must be taken that the same soil type exists over the given area. This is so that the one maximum density test is consistent with the nuclear tests.

5. Using the maximum density test, calculate the per cent relative compaction for each nuclear test. The average of all of the nuclear determined relative compaction tests must be above the required compaction value. No more than one third of the individual tests may be below the required compaction value. If the average of all tests in one section fail to meet the required compaction value, this section may be failed even though the other sections may be passed. Thus, either sections or areas may be passed or failed.

6. When sufficient maximum density tests have been obtained, a value may be established for a soil type and only occasional check maximum densities made on that soil type.

G. DETERMINATION OF RELATIVE COMPACTION

Determine the relative compaction by either of the following:

1. Per Cent Relative Compaction

$$= \frac{\text{In-Place dry density}}{\text{Test maximum dry density}} \times 100$$

Where

In-place dry density is determined by the use of the nuclear gages as herein described.

Test maximum dry density is determined as described in Test Method No. Calif. 312 for Classes A and B CTB and Test Method No. Calif. 216 for all other treated and untreated soils and aggregates.

G. DETERMINATION OF RELATIVE COMPACTION (Continued)

2. Per Cent Relative Compaction = $\frac{L_{(nuclear)}}{g_m} \times 100$

Where

$L_{(nuclear)}$ = in-place wet density as determined by the use of the nuclear gages herein described.

g_m = maximum adjusted wet density of the compacted test specimens as described in Test Method No. Calif. 216.

REFERENCES

Test Method No. Calif. 216
Test Method No. Calif. 312
End of Text on Calif. T-231-B

APPENDIX B

Resident Engineer's Final Report
Nuclear Compaction Testing
05-SBt-180 - 12.2/15.7
Between 2 mile So. of Hollister and Tres Pinos
05502 - 021214

As requested, we are submitting a report on the Nuclear Test Method No. Calif. T-231, used to determine Relative Compaction on Contract 021214, Road 05-SBt-180 - 12.1/15.7, commonly known as the Tres Pinos Project in District 05.

This method proved to be quite satisfactory and a definite advance in obtaining soil moisture and density determinations. Relative compaction tests were taken with greater frequency, less effort, in a shorter period of time and, in our opinion, with greater accuracy. As an example of the speed of this test method, it was determined that 6 to 8 Nuclear Compaction tests were taken in the same amount of time it takes to run one sand-volume test.

Equipment

The Nuclear-Chicago instrument with a "Backscatter" probe was the only nuclear instrument used on the project and this instrument was employed on the project from August 16, 1965, to April 26, 1966. In that time three breakdowns were recorded: 1) A faulty wire connection in the scaler, 2) a loose switch on the gage, and 3) the battery charger failed to charge correctly. However, in each case the Nuclear-Chicago people (Palo Alto Office) immediately responded to repair the instrument. In all cases of breakdown, repair was accomplished in sufficient time to avert any delay in testing.

The box originally mounted in the pickup to carry the instrument, was inadequate. It was necessary to disconnect the hose between the scaler and gage when moving from one compaction site to another. In addition, the hose, which was sometimes wet and muddy, had to be wrapped around the instruments in order to close the lit. The only other alternative was for the hose to remain attached to the instruments, but then, the lid to the box could not be closed. Therefore, a new and more efficient carrier box was designed and built in the field to correct the hose problems.

Personnel

Our instrument operator was thoroughly trained for this work and did an outstanding job. However, our biggest problem was the lack of trained personnel to "back-up" the operator. We were definitely handicapped by having only one authorized operator in the area. The only other operator being in the southern part of the District. In one instance, when the operator went on sick leave, we were without compaction tests for one full day.

It is recommended that on large projects, two authorized operators be assigned. On smaller projects, a substitute or "back-up" operator be available in the area and not 150 miles away as occurred in our case.

The Resident Engineer received no instructions or information concerning the operation of the nuclear instrument prior to its use on the project. Although we do not recommend that the Resident Engineer be trained and authorized to operate the instrument, we do recommend that he should be made familiar with its operation and the theory of nuclear soil gages and radiation. This lack of knowledge did present a definite handicap to the Resident Engineer at the start of the project.

Testing

Two density curves on Roadway Embankment material were derived, one for a silty-clay-shale mixture and the other for a silty-clay composition.

A density curve was run for structure backfill material (Sand), one for Cl. 2 Aggregate Base and one for Cl. 4 Aggregate Subbase material. A total of five curves were derived for the project. It took the operator, under ideal conditions, at least two days to obtain data for a density curve. We are talking about 10 to 15 nuclear compaction tests (averages) plus the same amount of sand volume tests in addition to the maximum dry density test. We found that by assigning two assistants to aid the operator, a curve could be completed in one day. These assistants were used solely for running the sand volume tests.

The N.C. operator cannot work on any other work in the field laboratory. As in our case, the operator's time was fully utilized in taking compaction tests, checking, maintaining and recharging the instruments. The paper work involved also took considerable time.

We had considerable difficulty in obtaining a successful test on structure backfill material in a trench where a minimum of 0.5 ft. of material was placed over the pipe. The nuclear gage had to be placed at least 1.5 ft. from the side of the trench or erroneous readings would result. Therefore, it was found to be impossible to take a valid test between the pipe and trench wall.

Due to some rocky embankment material (shale and gravel), it was extremely difficult to prepare level test sites within the specified 1/8 inch tolerance. In this type of material it took approximately two hours for one man to complete six test sites over 1,000 ft. of embankment. We also found that large rocks cause erratic readings with the gage and in some cases necessitated the abandonment of test sites. This was necessary since we could not obtain two counts that checked within the specified 250 counts. However, an investigation of the embankment material proved that because of the rocks encountered it would be very doubtful whether a sand volume test in this material would be valid.

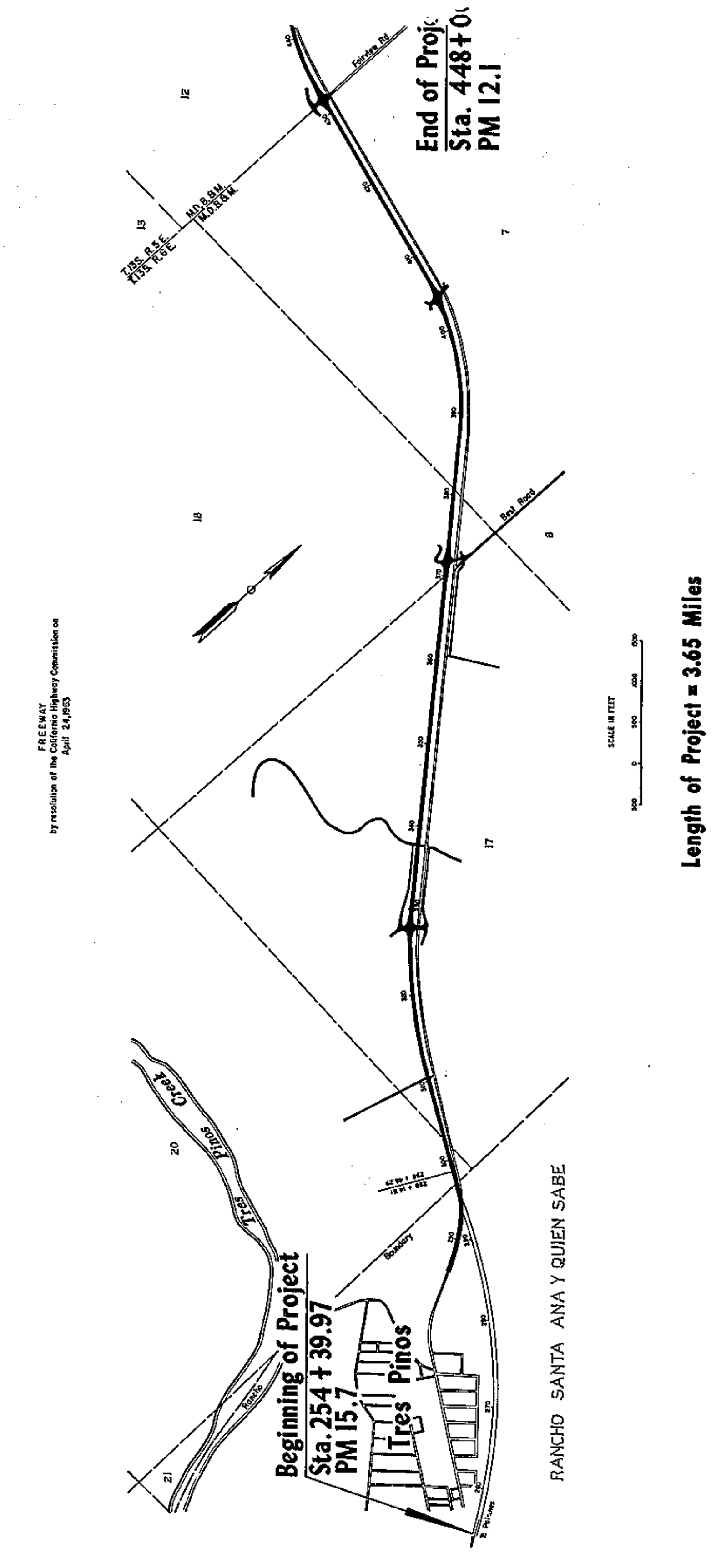
We recommend that a study be made for an efficient method (or equipment) prepare test sites on the grade particularly in embankment material. Considerable time was consumed in preparing test sites prior to testing. This problem, of course, was not found in the testing of import materials such as Aggregate Base or Aggregate Subbase.

Conclusion

Although we have indicated the problems and weaknesses encountered with the use of the Nuclear-Chicago Instrument used on this project, we believe that the State has found a procedure that far exceeds the old sand volume method. Upon the determination of a density curve, compaction results can be instantaneous on the grade. We can test a greater area with more tests which results in a better average that benefits both the Contractor and the State.

The Contractor was greatly pleased with this new procedure. Not only because we could give him immediate compaction results, but he could regulate his compaction equipment accordingly. For an example, at the start of Aggregate Base operations the Contractor had employed two rollers with compaction results at 100%+. By only using one roller we were able to give him the instant results of 97%, as a result the other roller was sent to a different location on the grade where another Aggregate Base spreading operation was started. In other words, he was able to almost double his production within a short period of time. The Contractor's superintendent indicated that there was an estimated two cents savings per square yard in compacting the structural section material. They would take this under consideration on future job estimates where the use of the nuclear compaction test procedure is specified.

In San Benito County
between 2.0 miles south of Hollister and Tres Pinos

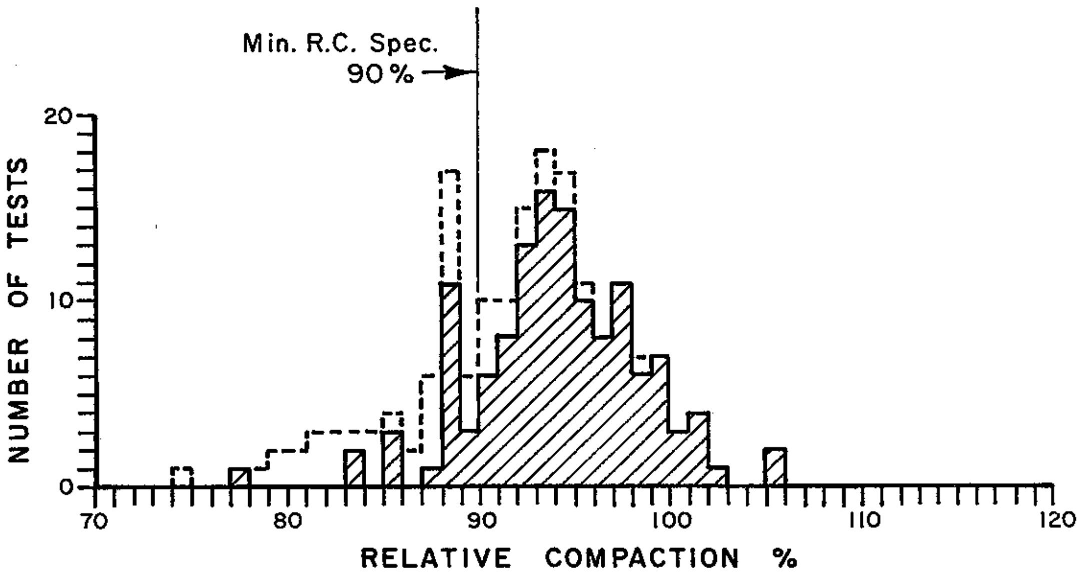


FREQUENCY DISTRIBUTION OF RELATIVE COMPACTIONS AT INDIVIDUAL TEST SITES

EMBANKMENT

- 131 TESTS FROM PASSING AREAS
- 47 TESTS FROM FAILING AREAS

178 TOTAL



FREQUENCY DISTRIBUTION OF IMPACT COMPACTION MAXIMUM DRY DENSITIES

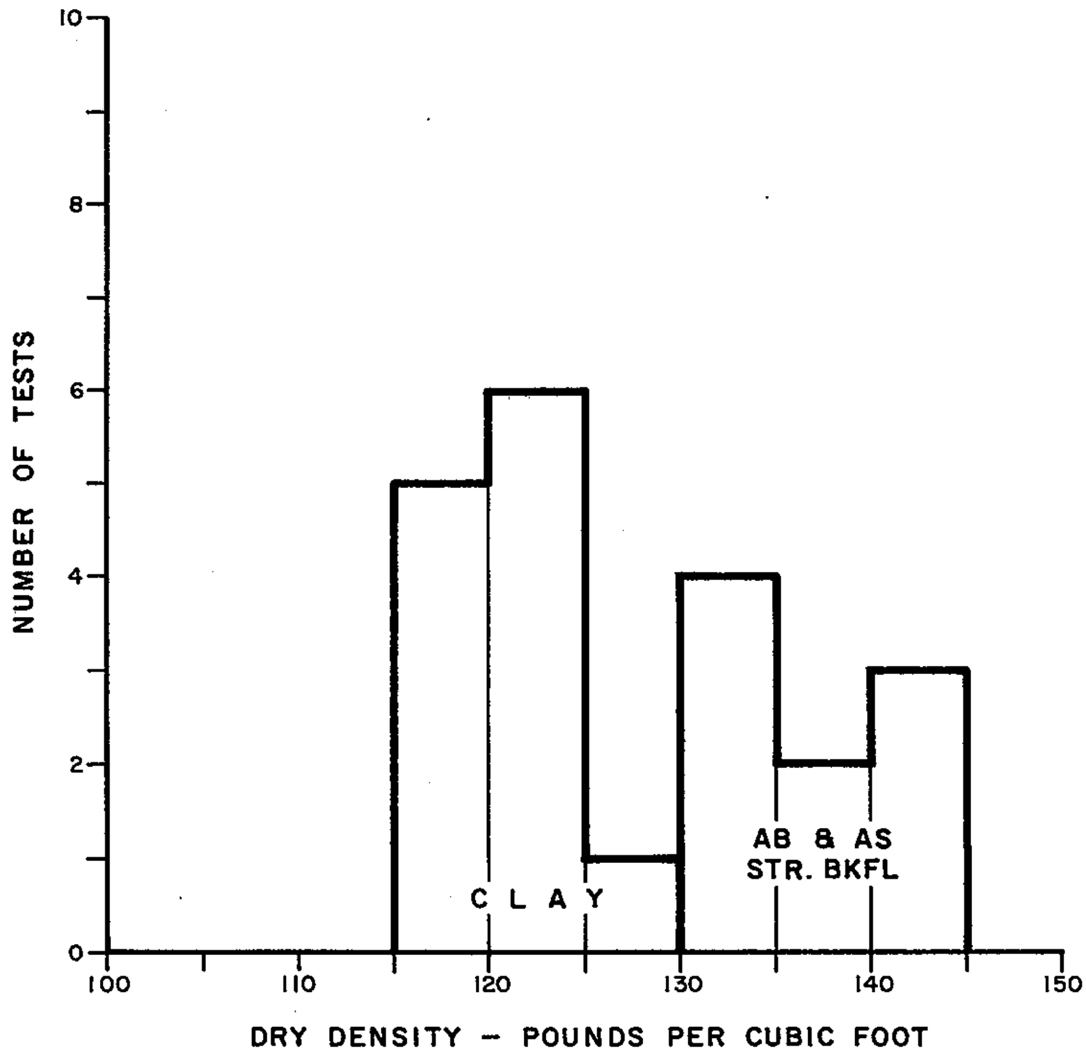
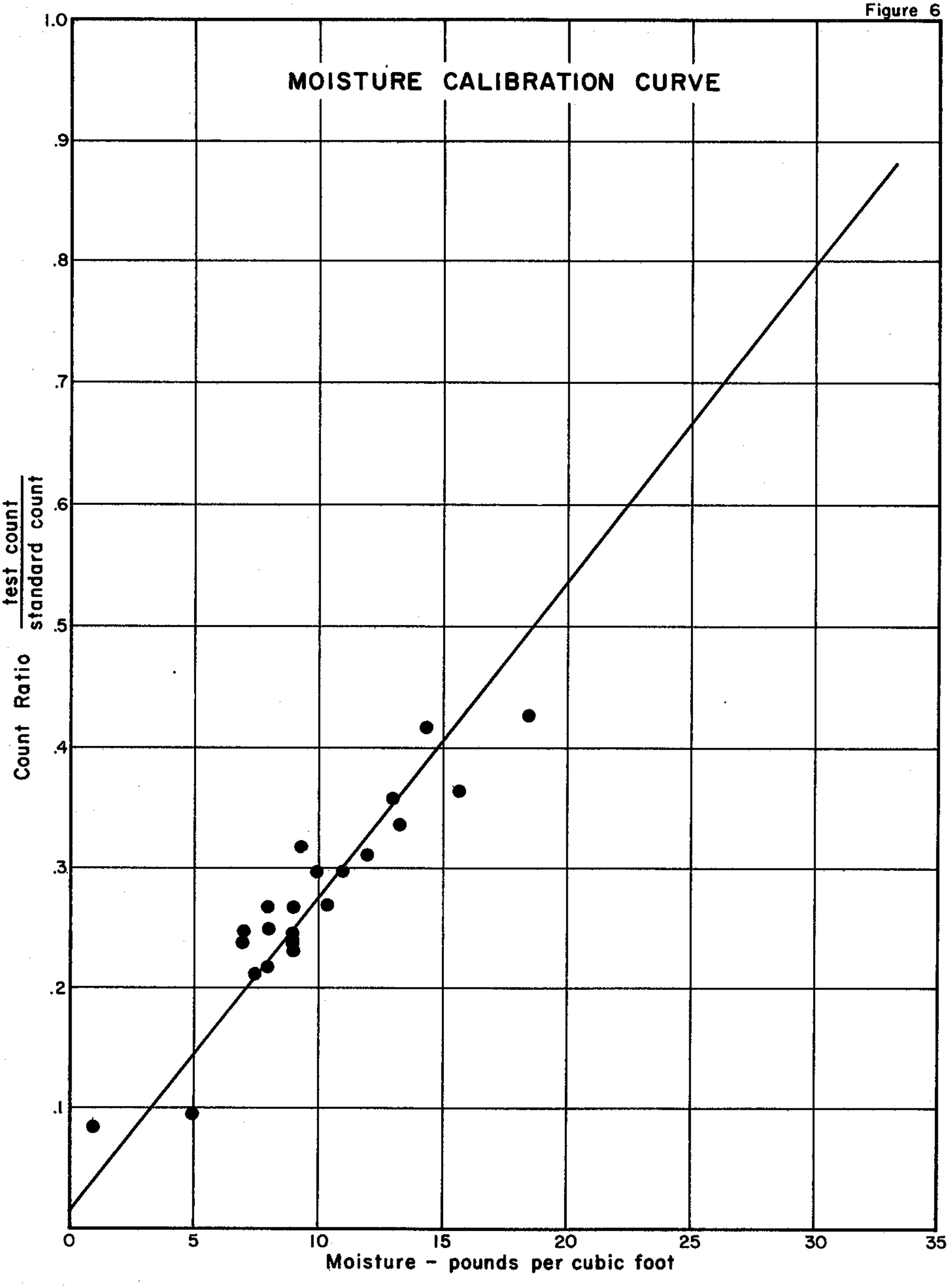


Figure 6


MOISTURE CALIBRATION CURVE
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
Count Ratio test count / standard count
0
5
10
15
20
25
30
35
Moisture - pounds per cubic foot

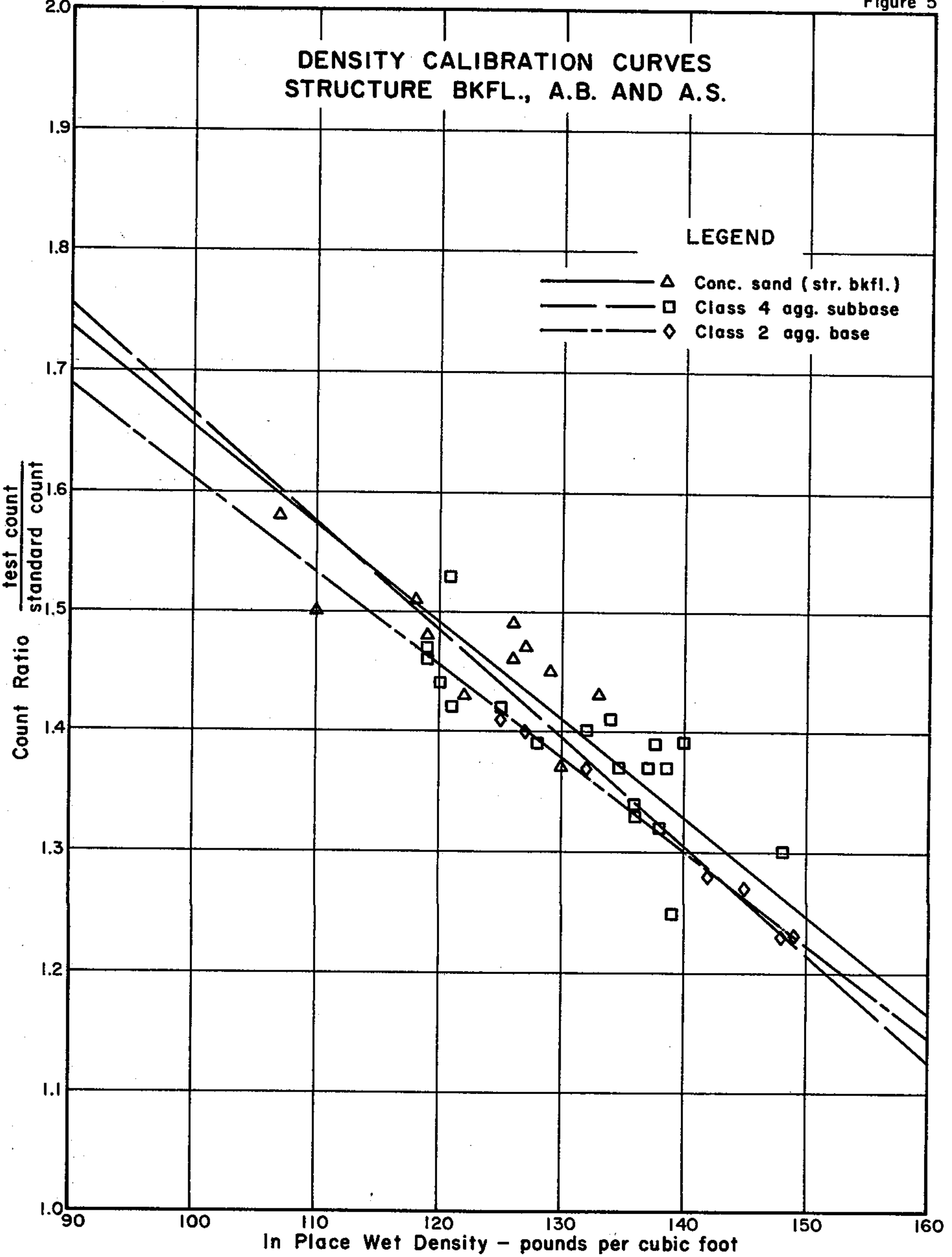

DENSITY CALIBRATION CURVES
STRUCTURE BKFL., A.B. AND A.S.
LEGEND
Conc. sand (str. bkfl.)
Class 4 agg. subbase
Class 2 agg. base
Count Ratio test count / standard count
In Place Wet Density – pounds per cubic foot
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
90
100
110
120
130
140
150
160

Figure 4

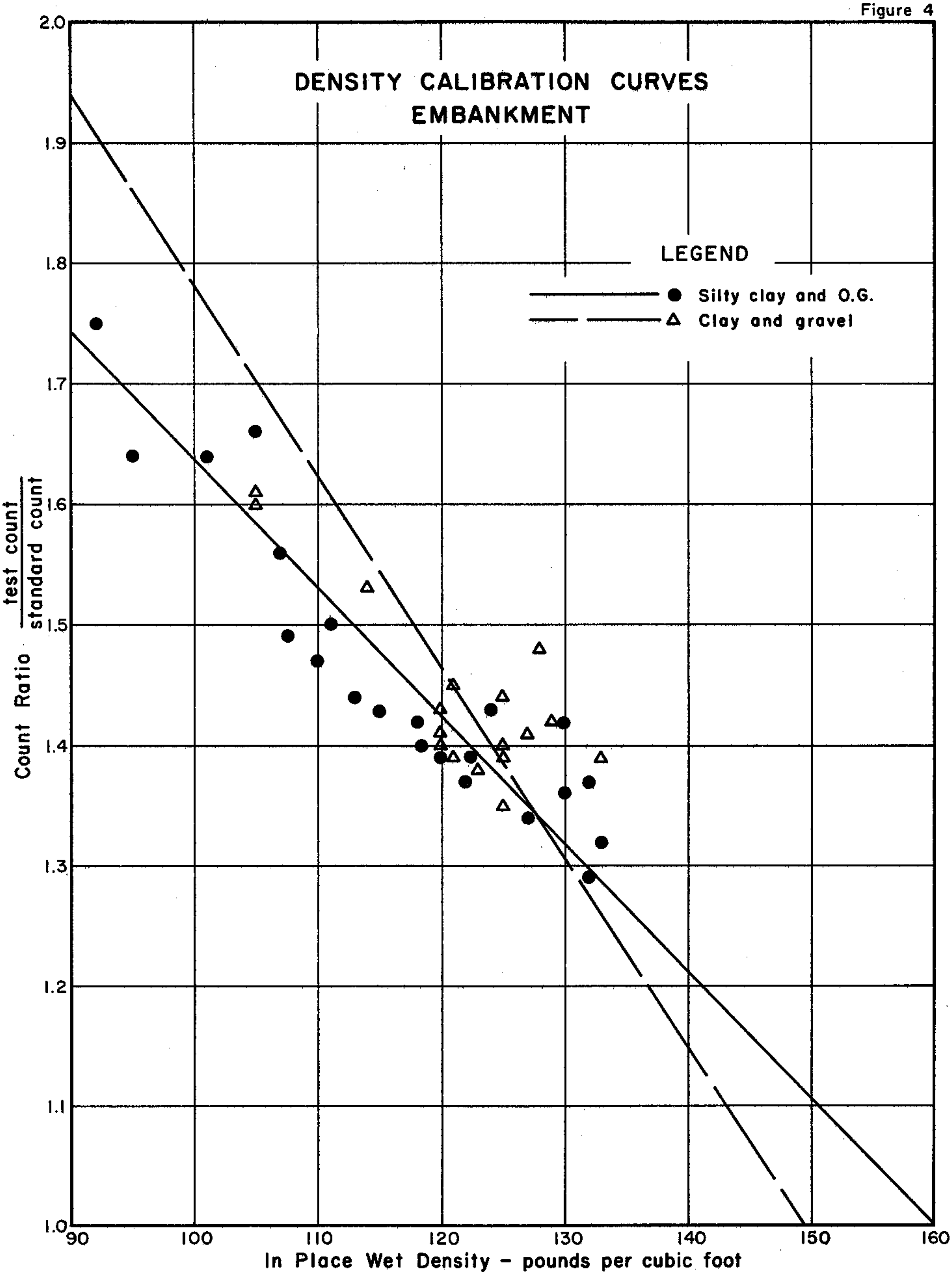

DENSITY CALIBRATION CURVES
EMBANKMENT
LEGEND
Silty clay and O.G.
Clay and gravel
Count Ratio test count / standard count
In Place Wet Density - pounds per cubic foot
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
90
100
110
120
130
140
150
160

Figure 3

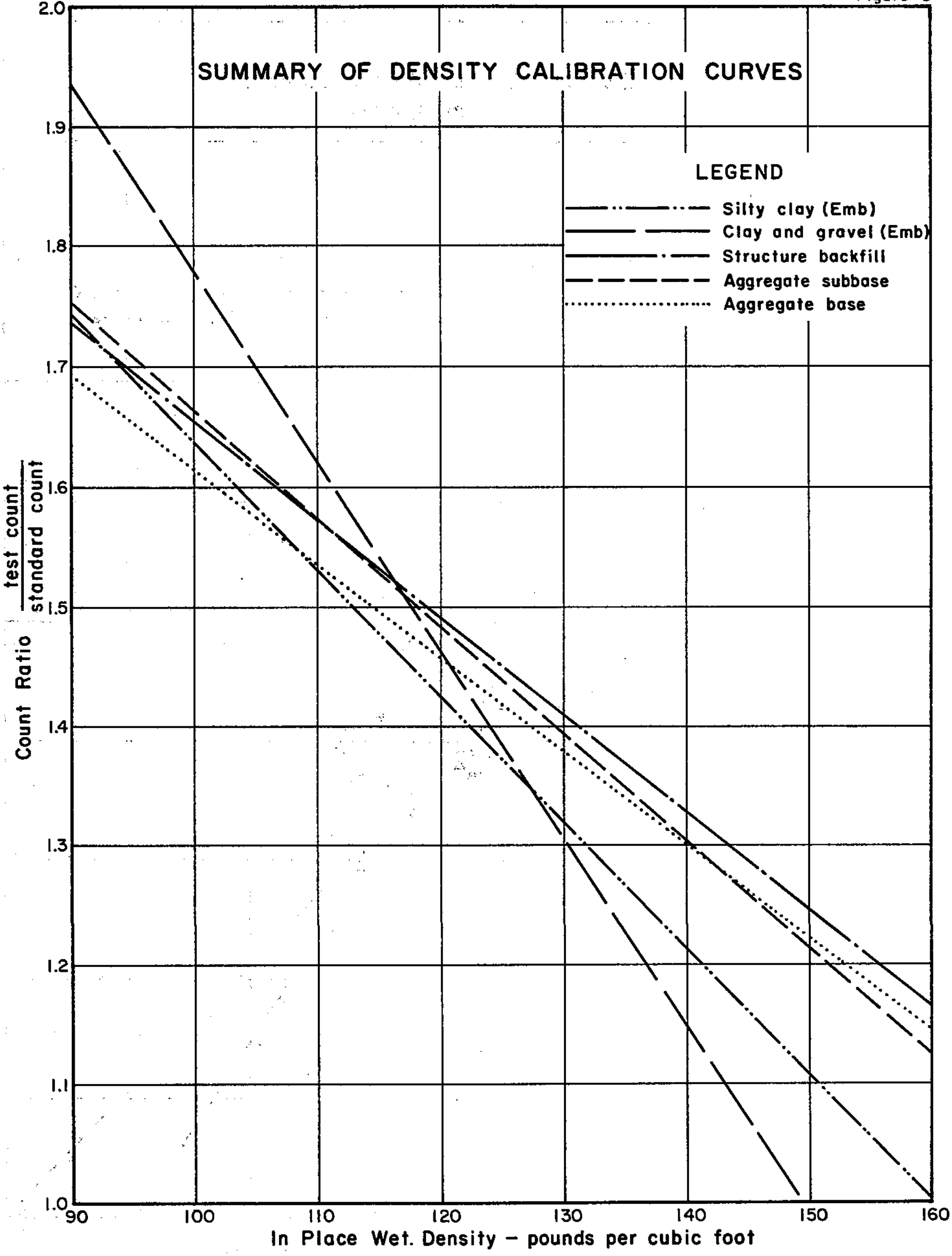
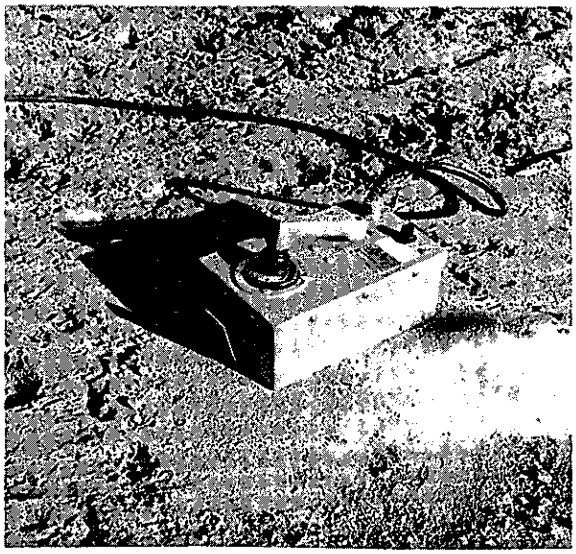

SUMMARY OF DENSITY CALIBRATION CURVES
LEGEND
Silty clay (Emb)
Clay and gravel (Emb)
Structure backfill
Aggregate subbase
Aggregate base
Count Ratio test count / standard count
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
90
100
110
120
130
140
150
160
In Place Wet. Density – pounds per cubic foot

FIGURE 2



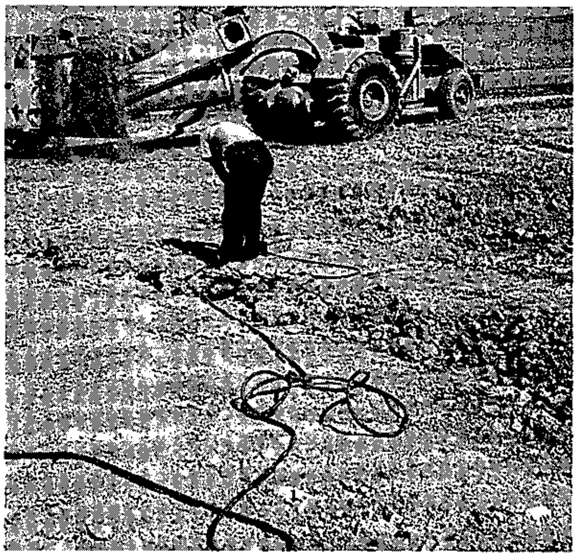
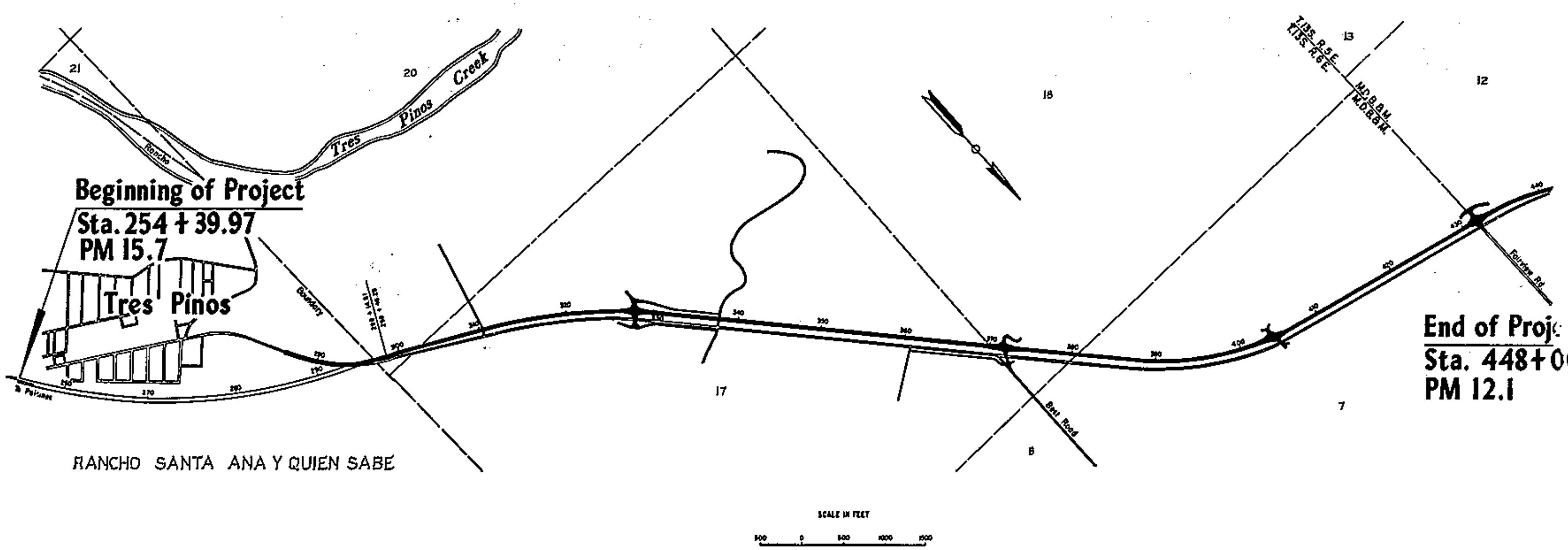


FIGURE 1

In San Benito County
between 2.0 miles south of Hollister and Tres Pinos

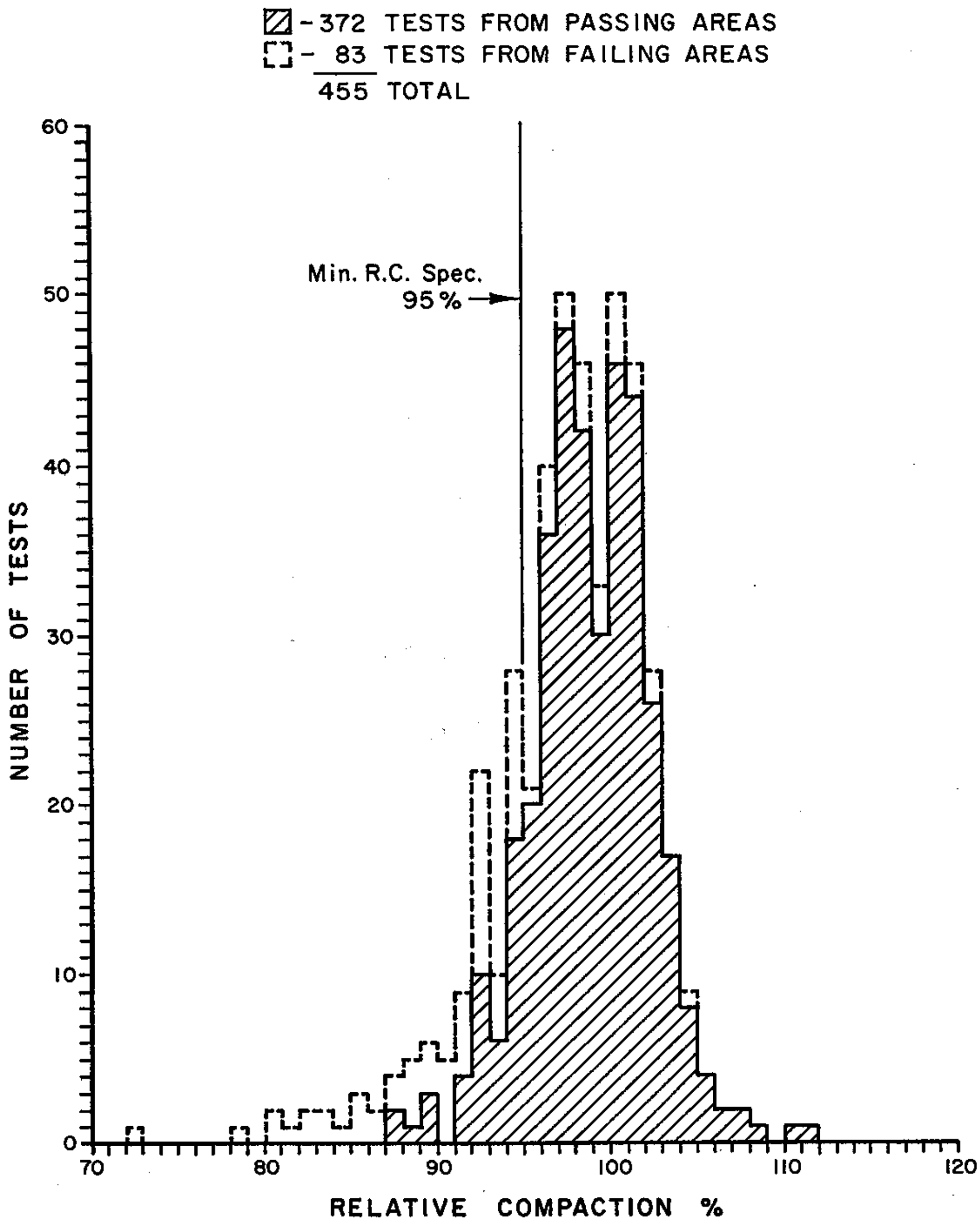
FREEWAY
by resolution of the California Highway Commission on
April 24, 1963



Length of Project = 3.65 Miles

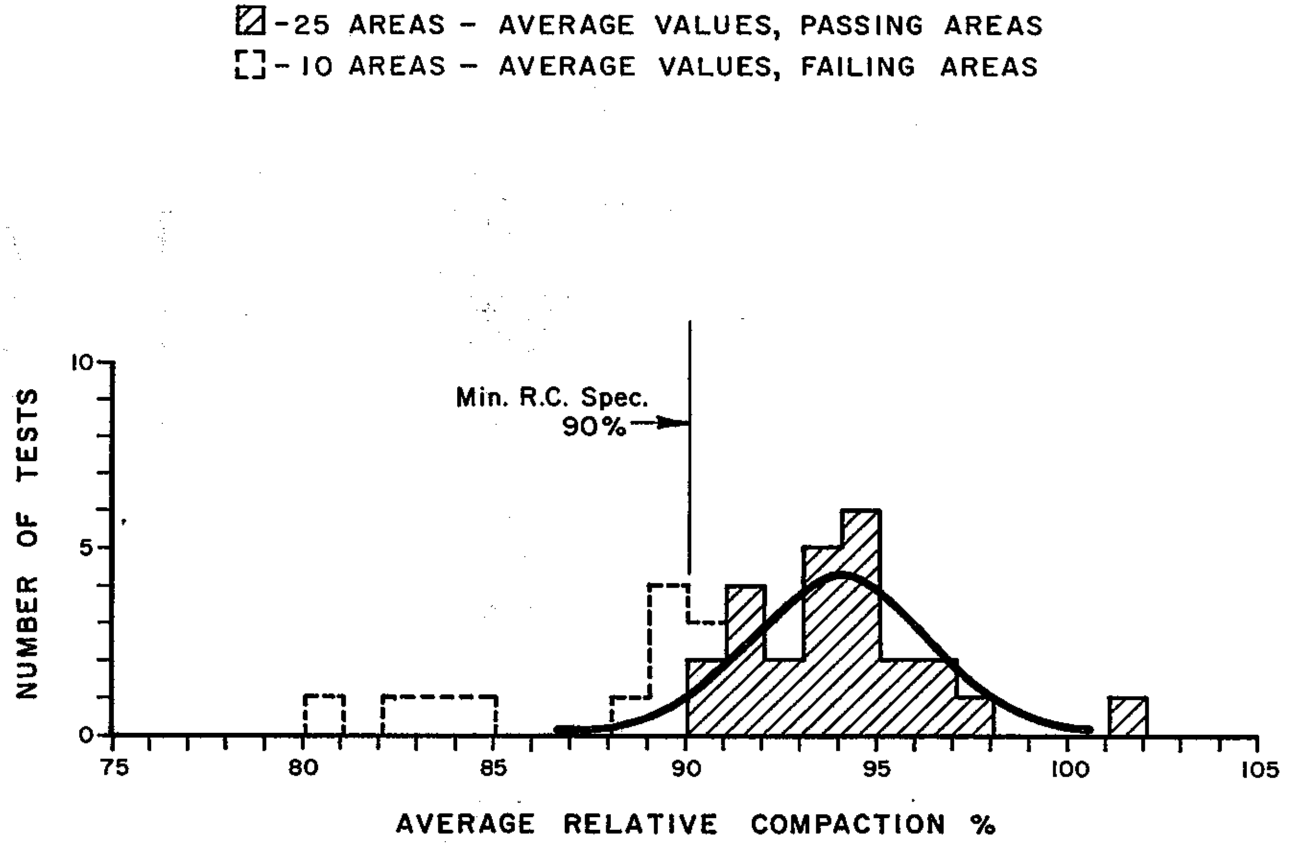
FREQUENCY DISTRIBUTION OF RELATIVE COMPACTIONS AT INDIVIDUAL TEST SITES

STRUCTURE BACKFILL OG, AS, & AB



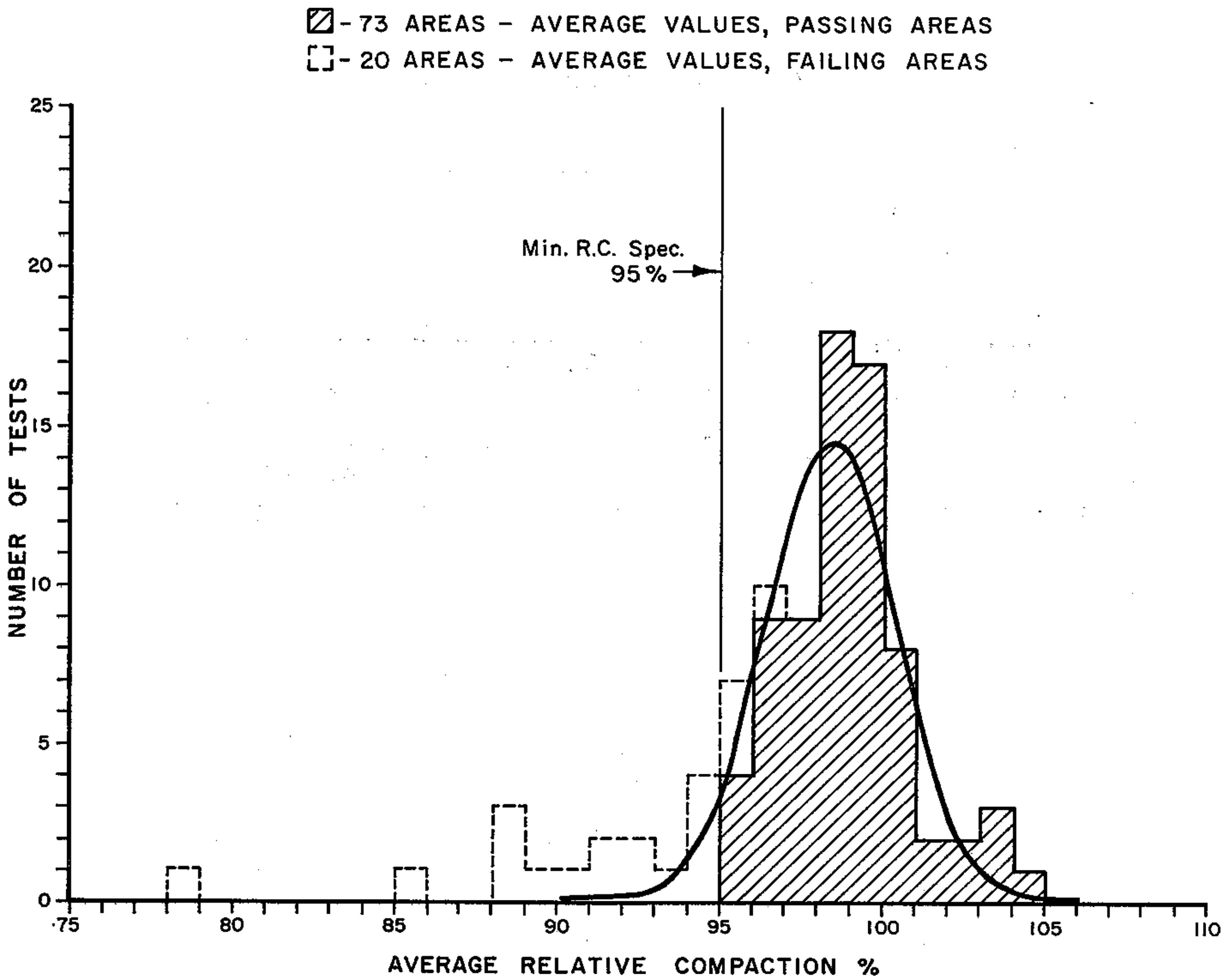
FREQUENCY DISTRIBUTION OF AVERAGE RELATIVE COMPACTIONS FOR AREAS

EMBANKMENT



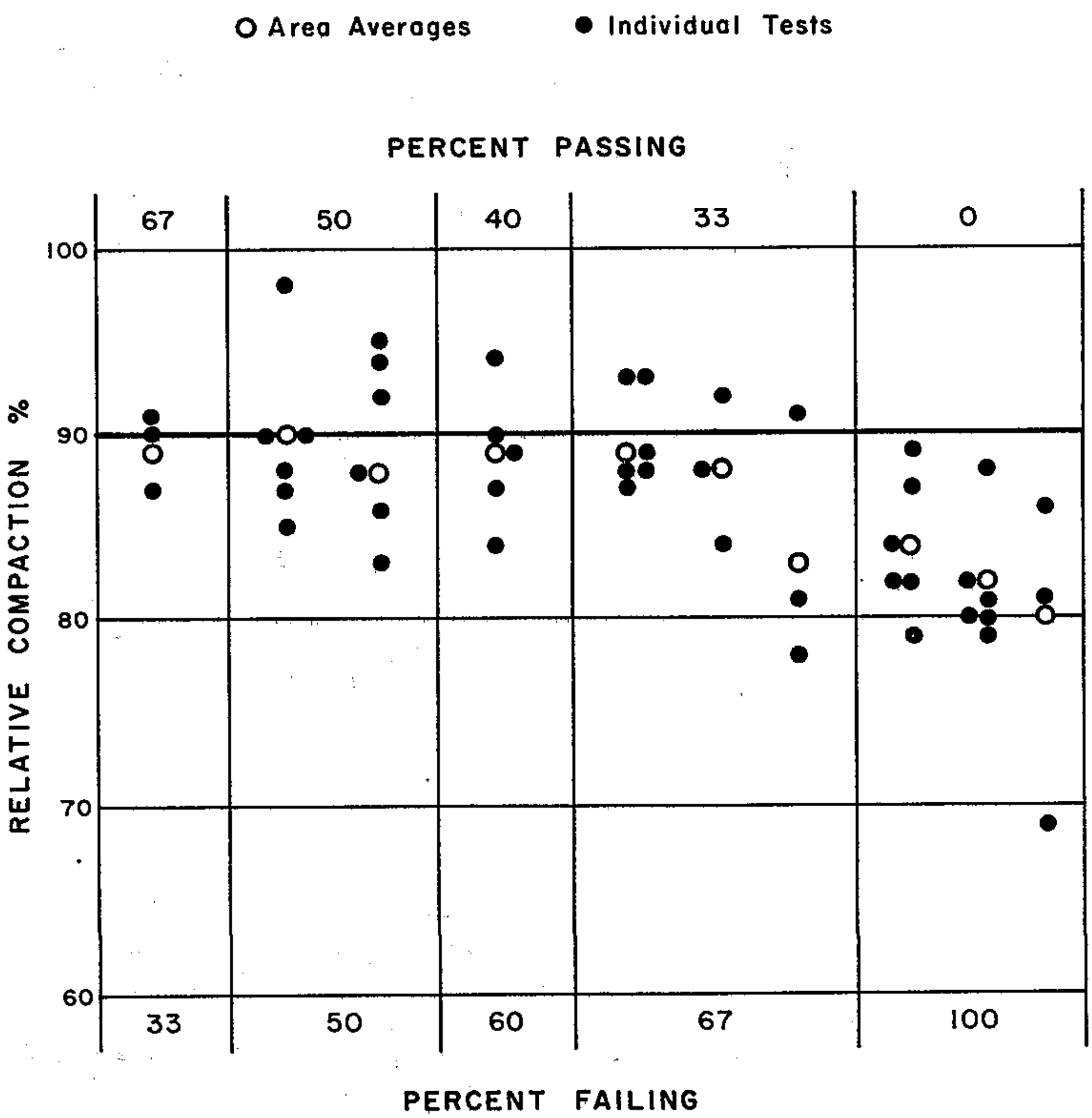
FREQUENCY DISTRIBUTION OF AVERAGE RELATIVE COMPACTIONS FOR AREAS

STRUCTURE BACKFILL OG, AS, & AB



EMBANKMENT

AREAS WHICH FAILED TO MEET 90% MINIMUM REQUIREMENTS



STRUCTURE BACKFILL OG, AB & SB

AREAS WHICH FAILED TO MEET 95% MINIMUM REQUIREMENTS

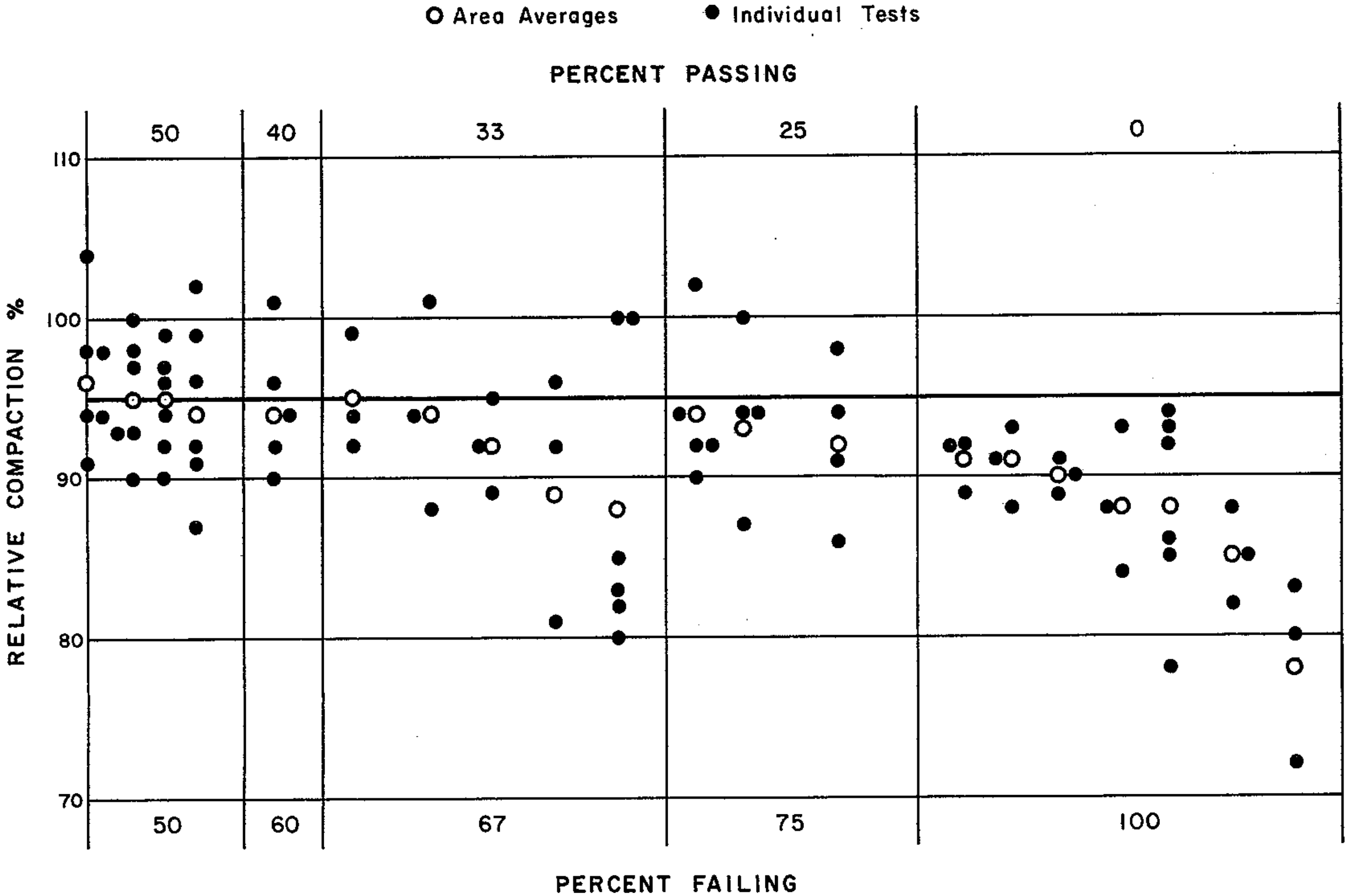


Figure 13