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Report on A Statistical Analysis of Penetration Test Results of 85-100 Grade Paving Asphalt

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16. ABSTRACT

Abstract

This report deals with the present specifications, variation in test results, and control of testing procedures for 85-100 grade paving asphalts. Test records on file for the 85-100 grade paving asphalts were evaluated. It was found that all but one percent of the results fell in a normal distribution with a range of 78 to 106. It was concluded that this range represents reasonable control limits for acceptable material. A revised specification based on economic and statistical considerations which will allow the purchase of the material within this range is presented. It was also found that, in this case, full adherence to the principles of statistics is not warranted.

The need for some system to indicate laboratory operational control is cited and a method for setting up a statistical control chart procedure is presented.

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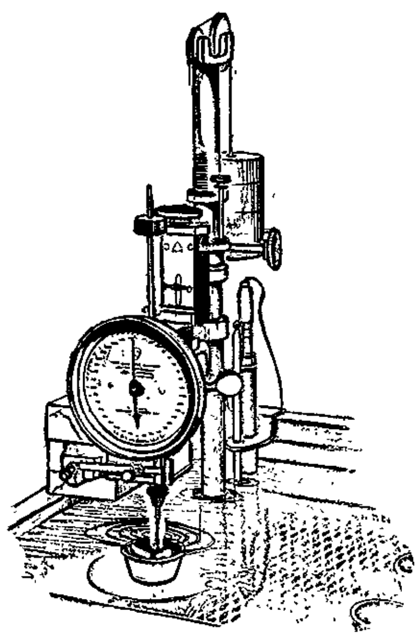
A STATISTICAL ANALYSIS OF PENETRATION TEST RESULTS

85–100 PAVING ASPHALT



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STATE OF CALIFORNIA

TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 210338-1

Prepared in Cooperation with The U.S. Department of Commerce, Bureau of Public Roads May, 1965

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

May 5, 1965

MR 14033
HPR 1 (2) 6F0101
EXP. AUTH. 210338

Mr. George A. Hill
Asst. State Highway Engineer
Division of Highways
Sacramento, California

Dear Sir:

Submitted for your consideration is:

REPORT

on

A STATISTICAL ANALYSIS

of

PENETRATION TEST RESULTS OF 85-100 GRADE

PAVING ASPHALT

Study made by	General Services Section
Under Direction of	G. B. Sherman
Project Supervisor	R. O. Watkins
Report Prepared by	R. O. Watkins
	B. G. Page

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

Attachments
cc: LRGillis
ACEstep
CGBeer (9)
JFJorgensen
PCSheridan

This is one of a series of reports to be issued under a project titled "Statistical Study of Materials." The work was done under the 1964-65 Work Program HPR 1 (2) 6 F-1-1 in cooperation with the U. S. Department of Commerce, Bureau of Public Roads.

FOREWORD

In an effort to obtain more uniformity in highway construction processes and materials throughout the nation, the Office of Research and Development of the Bureau of Public Roads is advocating the use of statistical methods of quality control.

The first phase in evaluating these new control procedures is to determine what is being achieved with present construction procedures and specifications. This is being accomplished by statistically surveying current or recently completed acceptable construction projects. Since this phase of the program is essentially a fact finding survey, it presents no great engineering difficulties.

The second phase of the B. P. R. program includes preparing and evaluating statistical specifications for various construction items. For this phase, construction items may be divided into two groups: First, items or materials manufactured or fabricated commercially; and second, end products of construction built under direct field control, normally of local native materials (rock, sand, earth, etc.). Problems associated with the first group of items in varying degrees have been solved by the producers, most of whom have their own system or method of quality control. The difficult and direct problems for highway engineers are found in the second group of construction items.

As part of this nationwide survey, the California Division of Highways is studying the control of nine different items. This report covers the survey findings on one of these materials -- paving asphalt, a commercially processed item.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Messrs. E. Zube and J. B. Skog for help and cooperation in the preparation of material for this report.

The authors also wish to thank Mr. G. Kemp and his staff for performing the necessary special testing.

This work was done in cooperation with the U. S. Department of Commerce, Bureau of Public Roads.

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ABSTRACT

This report deals with the present specifications, variation in test results, and control of testing procedures for 85-100 grade paving asphalts. Test records on file for the 85-100 grade paving asphalts were evaluated. It was found that all but one percent of the results fell in a normal distribution with a range of 78 to 106. It was concluded that this range represents reasonable control limits for acceptable material. A revised specification based on economic and statistical considerations which will allow the purchase of the material within this range is presented. It was also found that, in this case, full adherence to the principles of statistics is not warranted.

The need for some system to indicate laboratory operational control is cited and a method for setting up a statistical control chart procedure is presented.

INTRODUCTION

An evaluation of the asphalt penetration test has been included in the Statistical Study of Materials. This report is limited to the evaluation of the Penetration Test on 85-100 grade paving asphalt, and it is intended that these findings will be included in the summary report for the project titled "Statistical Study of Materials".

The purpose of this analysis is to evaluate the variance between samples received in the laboratory, to determine the variance due to processing and testing in the laboratory, and to evaluate the present control and specification for 85-100 grade paving asphalt.[1]

MATERIAL AND PROCEDURE

The 85-100 grade paving asphalt was selected for this study because it represents 75% of all paving asphalt used by the California Division of Highways. Randomly selected test records which represented the testing performed by the Headquarters Laboratory during 1962 and 1963 and by the branch laboratories in Los Angeles and Bakersfield during 1963 were included in this study.

In addition, a special series of tests were conducted on 101 normal control samples in the Headquarters Laboratory. The special tests made it possible to determine the variance between samples and the variance introduced by preparing and testing the material. These samples were tested in duplicate, set aside, reheated, and retested in duplicate at a later date.

[1] For definition of terms see Appendix A.

ANALYSIS OF DATA

All materials included in this study were supplied by the producers as 85-100 grade asphalt. A plot of the test results reveals that a great majority falls into a normal, or bell-shaped distribution.

Of the 4765 test results reviewed, 93% fell within the 85-100 limits of the present specification. A normal curve with the same mean and standard deviation as the histogram would have only 78% of the material within these limits. Thus, the characteristics of the normal curve are greatly distorted by a few extreme values. Figures I through V show varying degrees of this distortion. Figure VI shows the result of discarding the extreme values. This normal curve closely approximates the histogram after only 0.96% of the test results were eliminated.

It has been concluded that these extreme results could be identified with causable factors, such as contamination of the asphalt or errors in labeling and, therefore, should not be included in any study of the basic random variation in the product.

For this study, the limits of the random sample were defined as "all observations lying between the limits of 75 and 110"; thus, the observations outside this range were rejected. This rejection was based entirely on engineering judgment and no attempt was made to justify this action with the use of theoretical mathematical procedures such as ASTM Designation E 178 or the Pierce-Chauvenet criterion. These limits are intended to reflect the best possible control that can be expected with the present production and control procedures.

As shown in Table III, the adjusted distribution has an average of 92.2 and a standard deviation of 4.6. The normal curve, with this average and variance, has 3σ limits of 78 and 106. This approximates the range of material that is actually being purchased with the present 85-100 specification.

There are several reasons why this range exceeds the limits of the specifications. For example, tolerances are allowed for variation in the testing method, and retesting of off-grade samples is part of the normal procedure. These actions have been taken because in reality it is desirable to purchase all the material falling within this normal universe. To do otherwise would be costly and require significant improvements in the overall technology of paving asphalt production and control.

CAUSES OF VARIATION

There are many causes of variance in test results. It is possible to identify the major causes and measure the variance they introduce.

Messrs. E. Zube and J. Skog[2] found that for 85-100 penetration asphalt, the variance between laboratories using normal testing procedures is somewhere between 16 and 22. They also found that the variance between tests run by the refinery and the customer on samples taken from the same shipment to be 18.5.

---

[2] E. Zube and J. Skog, Correlation Between Laboratories on Results of ASTM Tests for Asphalts; ASTM, STP212.

With the data from this present study combined with the earlier work of Zube and Skog, it is possible to make the estimates of the variances presented in the table below.

TABLE I - ANALYSIS OF VARIANCE

Source	Variance	Based on Sample Size
Between tests on the same sample (poured and tested at same time).	1.4	101
Between tests on the same sample but prepared at different times (reheating required).	3.8	101
Between samples from the same shipment (sampling error only).	2.5(Calculated)	--
Between samples from many shipments received at one laboratory.	11.5(Min. Value)	101
Between laboratories on very similar samples.	16 to 22	23
Between results of tests run by refinery and by customer on samples from same shipment.	18.5	2460
Overall variance of test results from one laboratory (excluding results below 75 and above 110).	17 to 22	1000
Total variance in test results of many tests from one shipment at one laboratory.	10.5(Calculated)	--

LABORATORY CONTROL

The tabulation of the causes of variance shows that the variance between laboratories is relatively large. In the study by Zube and Skog four of the nineteen laboratories surveyed were found to have operational difficulties with the penetration test. Because the calibration of the equipment used in asphalt laboratories requires difficult fundamental measurements of time, temperature, length, and mass, these laboratory control problems are not surprising.

It is believed that a procedure is needed which will indicate when the laboratory is out of control. Since the test results exhibit normal, random behavior, the laws of probability can be applied and control chart procedures can be used.

The most common procedure is to utilize a control chart which will indicate the difference between the daily average and the long-term average. To start with, the long-term average could be based on the findings of this type of study. It would no doubt have to be revised periodically with current data.

Appendix B outlines the necessary steps for setting up a laboratory control chart procedure. If, in the course of charting, a daily average is found to fall beyond either the upper or lower limit, it must be assumed that a control problem exists and steps would be taken to identify the problem.

Figure VII shows a control chart calculated for the period of July 28 through November 12, 1964. It is noted that the daily control limits are determined by the number of tests; that is, the more daily tests the more restrictive the limits.

The daily average exceeded the upper limit on August 14. It is speculated that the technicians did not observe this condition and did not correct the problem until August 19. This would explain the sudden drop at this point. Had a control chart been in regular use it is probable that the trend would have been observed and earlier action taken.

CONTROL OF SHIPMENTS OR LOTS

In the final analysis, most engineering is based upon minimum or maximum limits. It is usually the extreme value which limits the design rather than the average. Stating this another way, we are primarily interested in the weakest link of the chain. Once design limits are established and the variance of the production or procedure is determined, it is possible to prepare a specification that will give assurance that these limits will be maintained.

As pointed out earlier, the acceptable material which is now being purchased falls within the penetration range of 78 to 106. Since experience has shown that this material meets our engineering needs, these limits should be used as the basis for any new specifications.

This does not mean that we can simply change our specifications from 85-100 to 78-106 because this would be inviting the producers to lessen their controls. With present asphalt technology, the probability of getting a test result of 78 from an acceptable lot is less than 1 in 1000.

If we were to statistically judge a shipment on the basis of one test only with a result of 78, we would have to conclude that the lot was defective. On the other hand, if one of four results taken from four samples from one shipment was 78 and the average of the four was 87, it would be reasonable to assume that the lot falls within the normal universe shown in Figure VI and it should be accepted for use.

A properly designed statistical sampling and testing plan could provide the needed assurance that the material purchased would fall within the 78-106 limits. Such a plan would require that three or four independent samples be tested from each shipment and that the average of these test results be within a specified range, say 87 to 96. This procedure would be more costly than the present plan and, since it is recognized that we wish to continue purchasing approximately the same range of material, the plan would accomplish very little. Therefore, a specification is needed that will provide reasonable assurance that the refineries maintain a high quality level and, at the same time, provide for the acceptance of the asphalt within the limits of 78 to 106, or 79 to 106 for symmetry about the present 85-100 range.

It is believed that the following specification will meet these two requirements without appreciably increasing the cost of testing. This specification is not based solely on statistical principles, but rather on a combination of economic and statistical considerations. In addition, the numerical limits of 85 and 100 are still used, thus allowing the designation of the grade to remain unchanged.

PROPOSED SPECIFICATION FOR PENETRATION REQUIREMENTS FOR 85-100 GRADE PAVING ASPHALT

The asphalt shall be tested in accordance with the standard methods of tests of the AASHO and shall conform to the following requirements, when determined in accordance with California Test Method No. __________.

Requirement #1:

A single penetration determination at 77°F by Test Method T49 shall be within the range tabulated below.

Grade	Acceptable Compliance Range
40-50	
60-70	
85-100	79 through 106
120-150	
200-300	

Requirement #2:

The average penetration determination calculated in accordance with California Test Method ______________ shall be within the range used to designate the Grade (See Appendix C).

Materials not meeting both requirements one and two shall be ______________.

Even though this specification is only partially based on statistical principles, it is possible to estimate the risk of rejecting good material. With the average and standard deviation determined in this study, the risk is approximately 3% and in actual practice this would involve mostly borderline materials.

The risk of accepting material which should be rejected is not a constant, but is a function of how far the true average of the lot has shifted from the 92.5 average implied in the specification, 85-100. If the producer were to operate only slightly out of control, the risk of accepting his product would be great, but the quality of his product would still be within reasonable limits. Conversely, if the product was considerably out of control, there would be only a small risk of the control tests indicating acceptable material.

EFFECTS OF REHEATING

The test results of the duplicate test series show that the mean of the test results on reheated samples decreases approximately one point (1.02) from the mean of the initial samples. Statistically, this decrease is significant at the 90% confidence level.[3]

Hardening of the material by reheating should be considered when checking the work of others or retesting samples within one laboratory.

[3] There is a 90% probability that the following statement is true: "Reheating measureably reduces the penetration test results and the most probable value for this reduction is one point".

CONCLUSIONS

A plot of the penetration test results of 85-100 grade paving asphalt reveals that a great majority of these results fall in a normally distributed universe. It is concluded that about one percent of the observations fall outside this universe because of some assignable cause, such as contamination or mislabeling of the shipment. It is also concluded that all material falling within the normal universe, which has limits of approximately 78 and 106, is acceptable material and is presently purchased with our 85-100 penetration specifications.

Any attempt to strictly enforce the present 85-100 specifications would require significant revision in the existing production, handling and control procedures.

A statistical specification can be written which would allow the purchase of the material falling in the normal universe, shown in Figure VI, while still excluding practically all materials affected by assignable causes, but this specification would require considerably more sampling and testing than our present specification.

A workable compromise specification based on both economic and statistical considerations should be considered. Such a specification has been presented in this report. Its adoption should provide reasonable assurance that the refineries will maintain an adequate level of quality control.

It is further concluded that it is possible for laboratory test results to be out of control for a day or two due to assignable causes without the knowledge of the operator. A statistical control chart of daily averages would be a satisfactory instrument for indicating this condition at the end of each day.

APPENDIX A

Definitions

In general, the definitions of terms used in this report agree with the definitions in ASTM Special Technical Publication 15-C. The more common terms are defined below.

The standard deviation, σ (Sigma), is a measure of the dispersion of the measurements from their average. The mathematical definition is:

$$\sigma = \sqrt{\frac{\sum (X_i - \bar{X})^2}{n}}$$

Where $\bar{X}$ is the average, X_i is each individual observation and n is the number of observations. The range of a large sample ($n \geqq 30$) drawn from a normal universe is approximately equal to the limits of $\bar{X} \pm 3\sigma$.

The standard error, $\sigma_{\bar{x}}$, is the standard deviation of the averages of several samples, and is estimated as follows:

$$\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$$

The variance, σ^2, is the square of the standard deviation. Quality control people usually think in terms of variance rather than standard deviations because variances, unlike standard deviations, are additive.

The following example may give some insight into this subject. The thickness measurements from two courses of roadway aggregate were each found to have a standard deviation of $\pm$ 0.2". It would not be expected that the thickest (or thinnest) areas of these courses would coincide. Statistically, based on the theory of variances, this overall standard deviation of the thickness of the two courses would be:

$$\sum \sigma = \sqrt{0.2^2 + 0.2^2} = 0.28''$$

An observation, X_i, is one test reading or result.

A sample is a group of readings or observations. If six cores were taken to represent a section of pavement, this would be one sample of six observations.

The universe is defined as all the possible observations or measurements of a given lot, area, etc. Thus, if a sample of six cores were tested to represent a section of roadway, the universe would be "the test results of all the possible cores that could be taken from the section of roadway".

A normal universe: When the distribution of the observations from a universe forms a bell-shape curve it is said to be a Gaussian or normal universe. (See Figure VI).

A histogram is a bar graph representation of a frequency distribution. (See Figure VI).

The Confidence Level, P, is a measure of probability; it is the ratio of the number of occurrences to the total possible number of occurrences. The statement $\bar{X} = 93.5 \pm .3$ (P = .95) means there is a 95% probability that the true $\bar{X}'$ is within the range 93.2 to 93.8.

APPENDIX B

Use of Control Charts for Averages

Control charts may be used to indicate when a testing laboratory is operating "out of control"; that is, when some assignable cause is adversely affecting the results. Thus, control charts provide a check on equipment calibration, personnel aptitude and proficiency, and laboratory environment. Indicators which are sometimes charted are average, range, variance, and percent out of specifications.

When the test results exhibit a normal distribution, a plot of the daily average is sufficient. Maintaining additional charts is usually unnecessary, costly, and can lead to general disinterest.

When preparing a daily average control chart for most highway material tests, only two statistical parameters need be measured; the long-term average, $\bar{X}$, and the long-term standard deviation, σ. These two parameters should be determined monthly and combined with the three previous monthly results to provide the long-term measurements.

The upper and lower control limits are based on the standard deviation, but the setting of these limits requires a judgment decision. The decision should be based on the seriousness of operating slightly out of control and the cost of recalibrating the laboratory equipment. When the limits are set to plus or minus two standard errors ($\pm 2 \frac{\sigma}{\sqrt{n}}$) the chart will quickly indicate problems; however, there is a five percent risk of indicating a problem when in fact there is none. Plus or minus three standard errors ($\pm 3 \frac{\sigma}{\sqrt{n}}$) is often used. These limits are less sensitive and will seldom give a false indication of a control problem. It should be noted that the daily control limits are a function of the number of daily observations, and thus fluctuate.

A complete discussion of control charts is presented in ASTM Special Technical Publication 15-C, part 3.

Preparation of Daily Average Control Charts for the Penetration Test 85-100 Grade Paving Asphalt

Procedure	Example
Step One: Determine the long-term average exclusive of unusual results (below 75 or above 110).	See Figure IX for tabular procedure for determining monthly average. Average monthly results for past four months. $\frac{(88.3+90.1+90.6+91.4)}{4} = 90.01$ Use $\bar{X} = 90.0$
Step Two: Determine the average standard deviation of the test results for past four months, exclusive of unusual results.	See Figure IX for determination of standard deviation. Average results for past four months. $\frac{(4.6+6.3+3.9+4.1)}{4} = 4.72$ Use $\sigma = 4.7$
Step Three: Determine the standard error.	$\text{Standard Error} = \frac{\sigma}{\sqrt{n}}$ n = Number of observations for any given day.
Step Four: Make a judgment decision about the limits of the control chart. This decision should depend on how serious it is to operate out of control and how expensive it is to recalibrate the laboratory equipment.	Use limits of $\bar{X} \pm 3$ standard errors.

Procedure	Example
Step Five:	
Prepare the chart.	See Figure VIII
Step Six:	
Prepare a table of the limits for daily averages.	See Table II
Step Seven:	
Calculate and plot the daily average, exclusive of any extreme values (below 75 or above 110). Evaluate each daily average.	See Figure VIII

TABLE II

Example of
Three Standard Error Limits
for Daily Averages

No. of Daily Observations (n)	Tolerance $\pm 3 \frac{\sigma}{\sqrt{n}}$	Lower Limit $90.0-3 \frac{\sigma}{\sqrt{n}}$	Upper Limit $90.0+3 \frac{\sigma}{\sqrt{n}}$
4	7.1	82.9	97.1
5	6.3	83.7	96.3
10	4.5	85.5	94.5
15	3.6	86.4	93.6
25	2.8	87.2	92.8
50	2.0	88.0	92.0
75	1.6	88.4	91.6

APPENDIX C

Calif. Test Method No. ____

TENTATIVE METHOD FOR DETERMINING COMPLIANCE WITH PENETRATION TEST REQUIREMENTS FOR PAVING GRADE ASPHALTS

Scope

This method provides a means for determining compliance with penetration test requirements for paving grade asphalts.

Procedure

A. Field Samples

All field samples from any specific contract or purchase order shall be numbered in consecutive order of sampling. That is, the first sample from a specific contract shall be numbered 1; the second 2; etc.

B. Testing

All samples shall be tested by a single penetration determination at 77°F (AASHO Test Method T49) in a designated laboratory.

C. Compliance Requirements

1. Requirement No. 1

All field samples of paving grade asphalt shall have a penetration within the range given in the specifications when tested in the designated laboratory. Samples which do not comply with this requirement shall be considered unacceptable.

2. Requirement No. 2

The average penetration test result, determined by averaging the result from the sample being considered with the result from the last previous sample from the same contract or purchase order which met the specification for requirement #1, shall fall within the range specified for the grade in the specifications.

The following table is an example, and does not necessarily agree with the requirements set forth in the specifications.

Grade and Average Range Specification (Requirement No. 2)	Compliance Range (Requirement No. 1)
40-50	
60-70	
85-100	79 through 106
120-150	
200-300	

Example - 85-100 Grade

Contract No. _______

Sample No.	Penetration Result	Average	Remarks
1	76	-	Rejected
2	82	-	Accepted
3	84	83	Rejected
4	96	90	Accepted
5	74	-	Rejected
6	69	-	Rejected
7	80	88	Accepted
8	94	87	Accepted
9	94	94	Accepted
10	104	99	Accepted
11	108	-	Rejected
12	96	100	Accepted

ANALYSIS OF PENETRATION TEST RESULTS ON 85-100 GRADE PAVING ASPHALT AASHO - T 49, 77°F

NON ADJUSTED DATA

Source [1]	No. of Observations	$\bar{X}'(P=.95)$*	$\sigma'(P=.95)$*	Range
Sacto. Lab. 1962	n = 1000	94.5 ± .5	7.9 ± .3	70 - 250
Sacto Lab. 1963	n = 990	91.7 ± .4	6.7 ± .3	63 - 170
L.A. Lab. 1963	n = 1670	90.9 ± .2	4.4 ± .1	62 - 115
Bakersfield 1963	n = 1000	93.7 ± .3	4.8 ± .2	63 - 138
Combined Data	n = 4660	92.5 ± .2	6.1 ± .1	62 - 250

ADJUSTED DATA

Source [2]	No. of Observations	$\bar{X}'(P=.95)$*	$\sigma'(P=.95)$*	PERCENT EXCLUDED	
				BELOW 75	ABOVE 110
Sacto. Lab. 1962	n = 982	93.9 ± .3	4.7 ± .2	0.30	1.70
Sacto. Lab. 1963	n = 981	91.3 ± .3	4.7 ± .2	0.10	0.91
L.A. Lab. 1963	n = 1663	91.0 ± .2	4.1 ± .1	0.18	0.24
Bakersfield 1963	n = 994	93.6 ± .2	4.1 ± .2	0.20	0.60
Combined Data	n = 4620	92.2 ± .1	4.6 ± .1	0.19	0.77

Source [3]	No. of Observations	$\bar{X}'(P=.95)$*	$\sigma'(P=.95)$*	PERCENT EXCLUDED	
				BELOW 75	ABOVE 110
Sacto. Lab. 1964	n = 101 (Initial)	90.2 ± .8	3.8 ± .5	0	0
Special Study	n = 101 (Reheated)	89.3 ± .8	4.1 ± .6	0	0

1. All results on 85-100 Grade Paving Asphalts
2. Only those test results falling within the range of 75-110 are included.
3. Results of special test series; see text.

* P = Level of statistical confidence. (Prime notation signifies the true values)

Table III

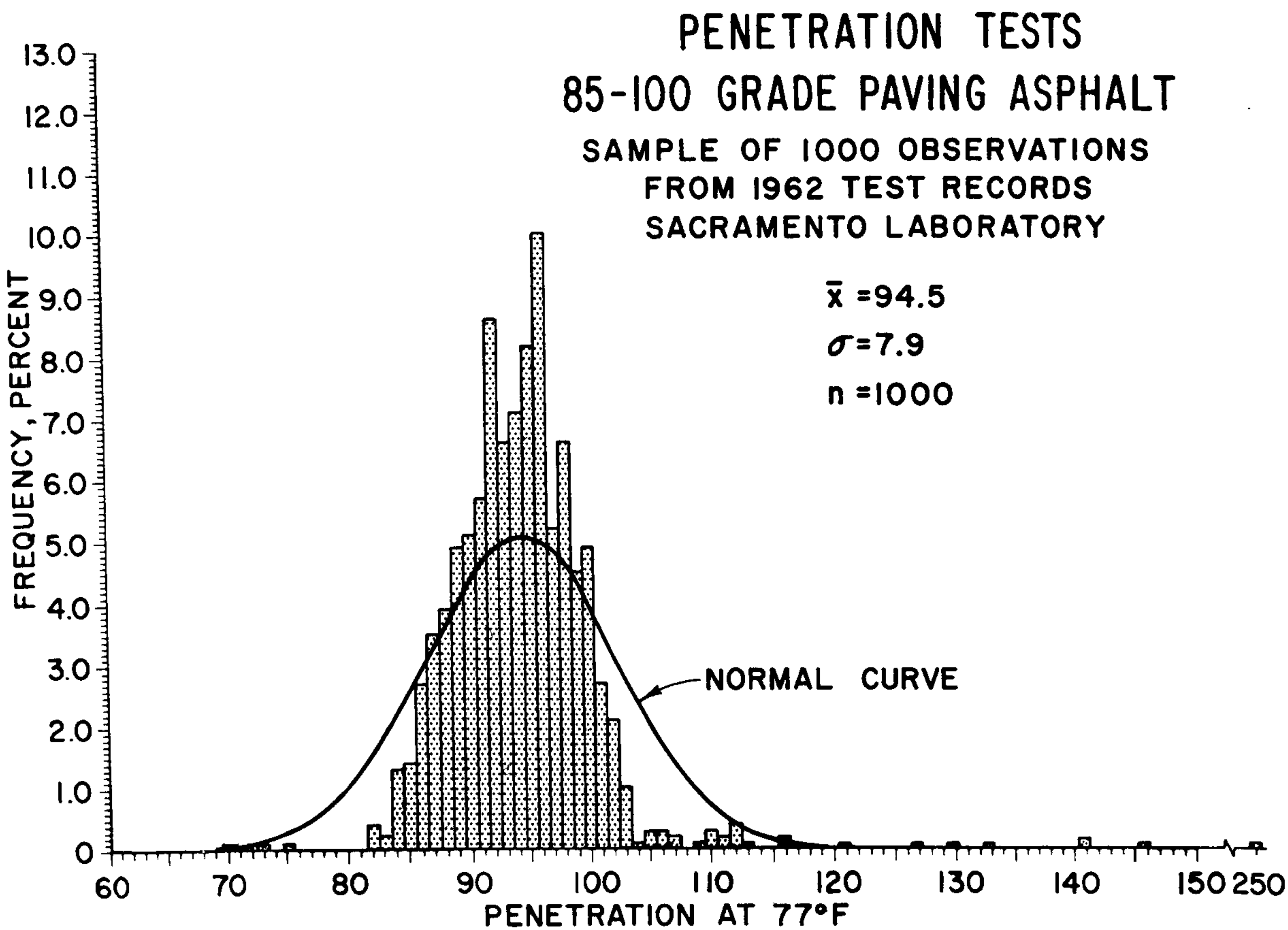
PENETRATION TESTS
85-100 GRADE PAVING ASPHALT
SAMPLE OF 1000 OBSERVATIONS
FROM 1962 TEST RECORDS
SACRAMENTO LABORATORY
x̄ =94.5
σ=7.9
n =1000
NORMAL CURVE
FREQUENCY, PERCENT
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
60
70
80
90
100
110
120
130
140
150
250
PENETRATION AT 77°F

FIGURE I

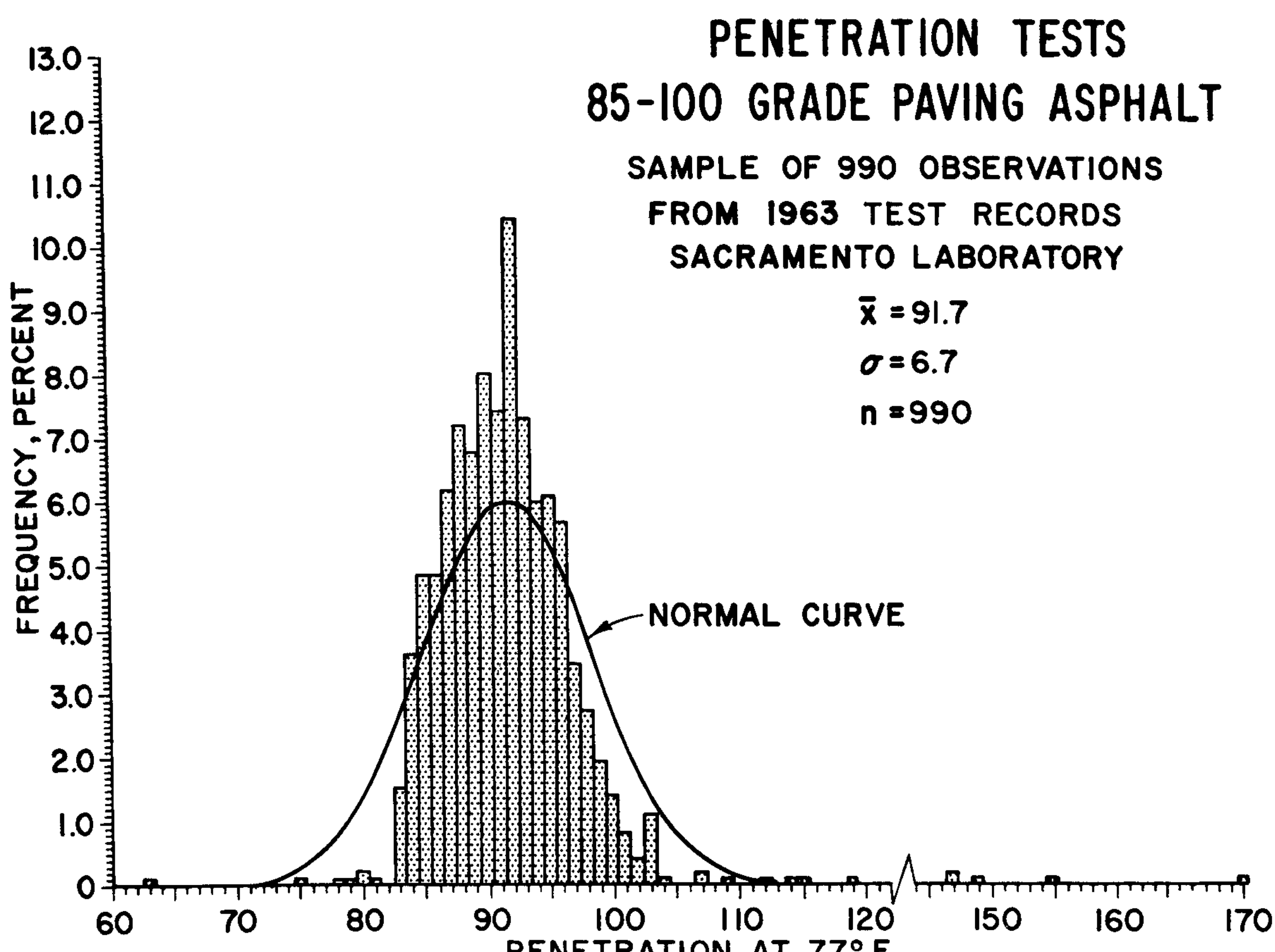
PENETRATION TESTS
85-100 GRADE PAVING ASPHALT
SAMPLE OF 990 OBSERVATIONS
FROM 1963 TEST RECORDS
SACRAMENTO LABORATORY
x̄ = 91.7
σ = 6.7
n = 990
NORMAL CURVE
FREQUENCY, PERCENT
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
60
70
80
90
100
110
120
150
160
170
PENETRATION AT 77° F

FIGURE II

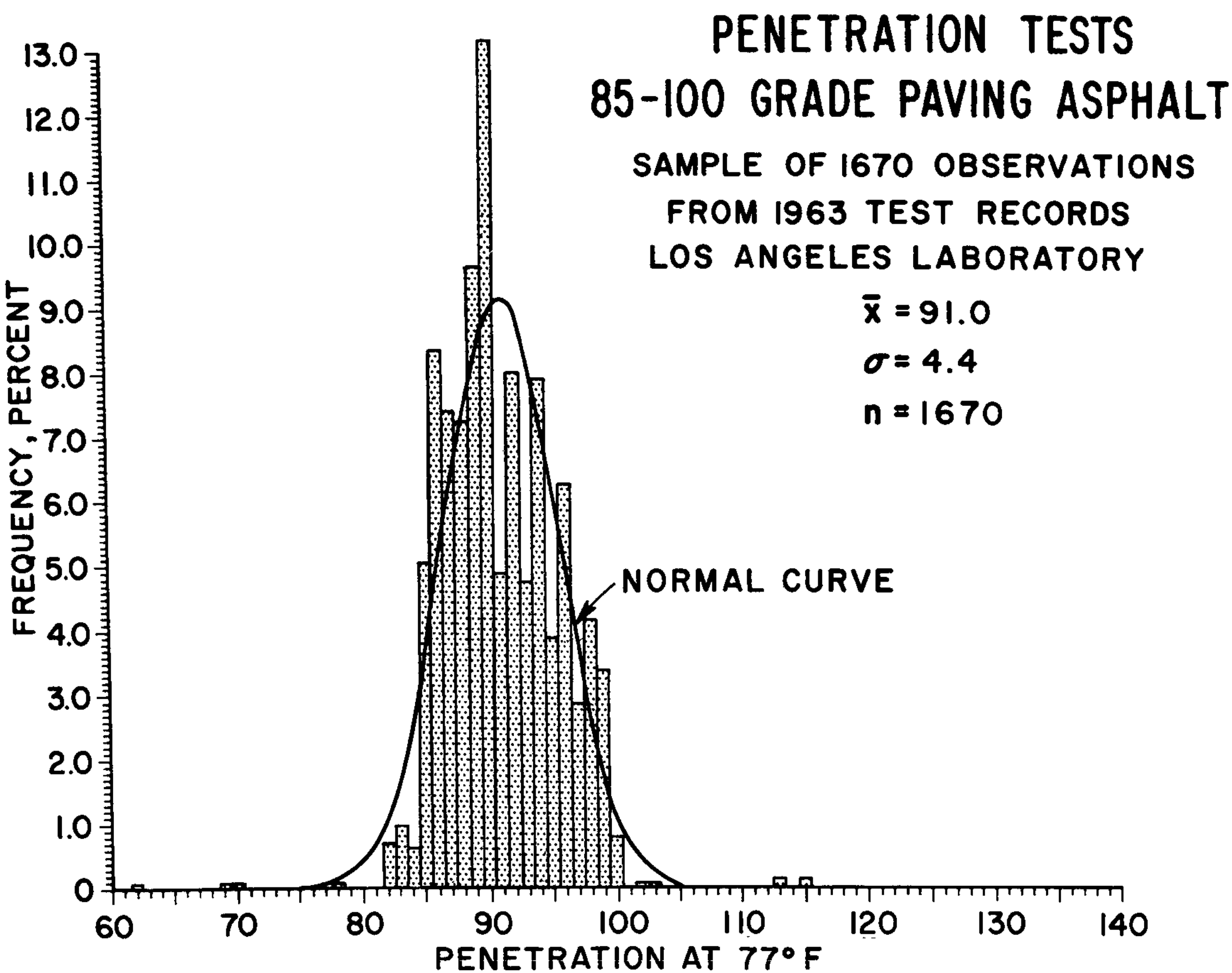
PENETRATION TESTS
85-100 GRADE PAVING ASPHALT
SAMPLE OF 1670 OBSERVATIONS
FROM 1963 TEST RECORDS
LOS ANGELES LABORATORY
$\bar{x}$ = 91.0
σ = 4.4
n = 1670
NORMAL CURVE
FREQUENCY, PERCENT
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
60
70
80
90
100
110
120
130
140
PENETRATION AT 77° F

FIGURE III

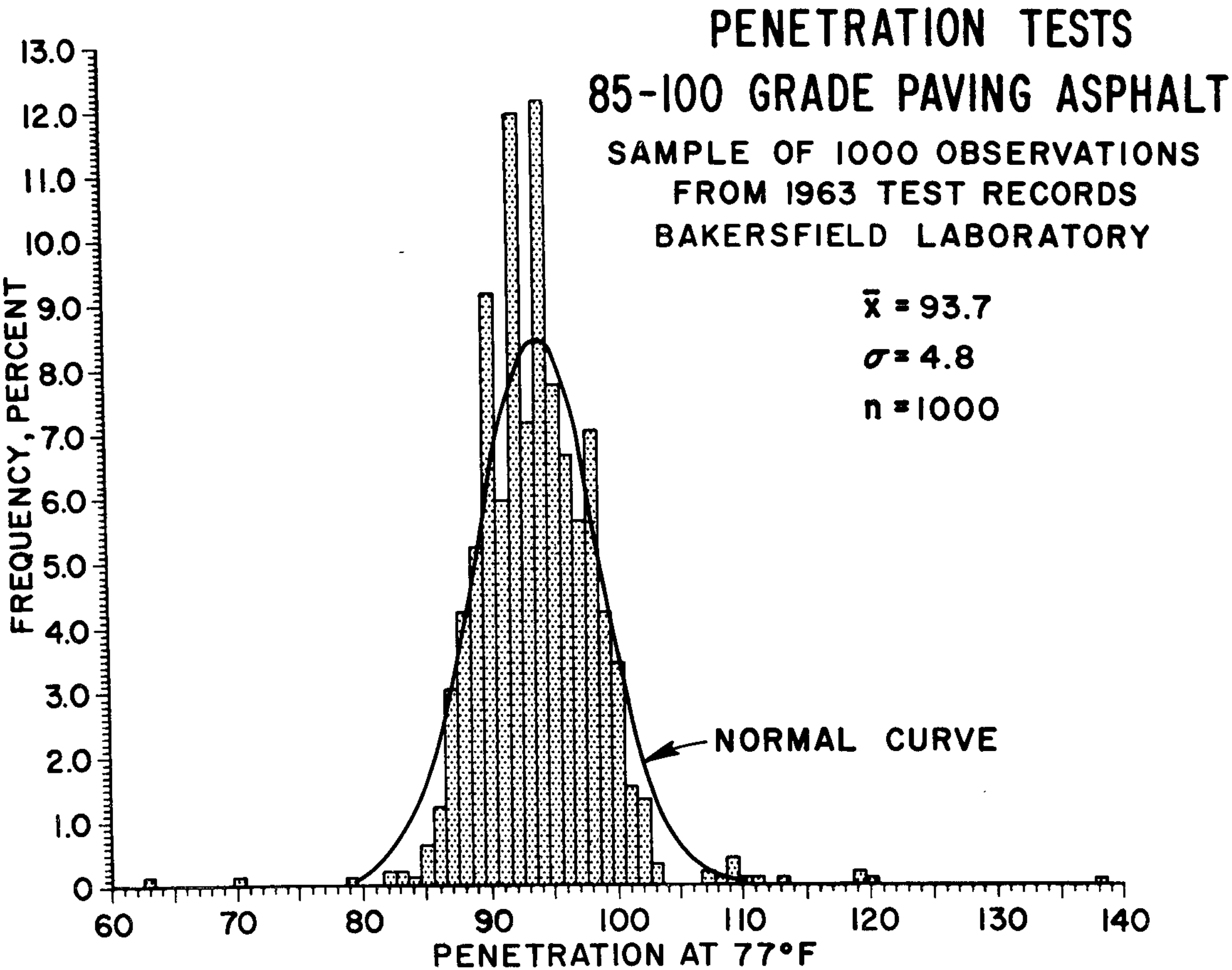
PENETRATION TESTS
85-100 GRADE PAVING ASPHALT
SAMPLE OF 1000 OBSERVATIONS
FROM 1963 TEST RECORDS
BAKERSFIELD LABORATORY
$\bar{x} = 93.7$
$\sigma = 4.8$
$n = 1000$
NORMAL CURVE
FREQUENCY, PERCENT
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
60
70
80
90
100
110
120
130
140
PENETRATION AT 77°F

FIGURE IV

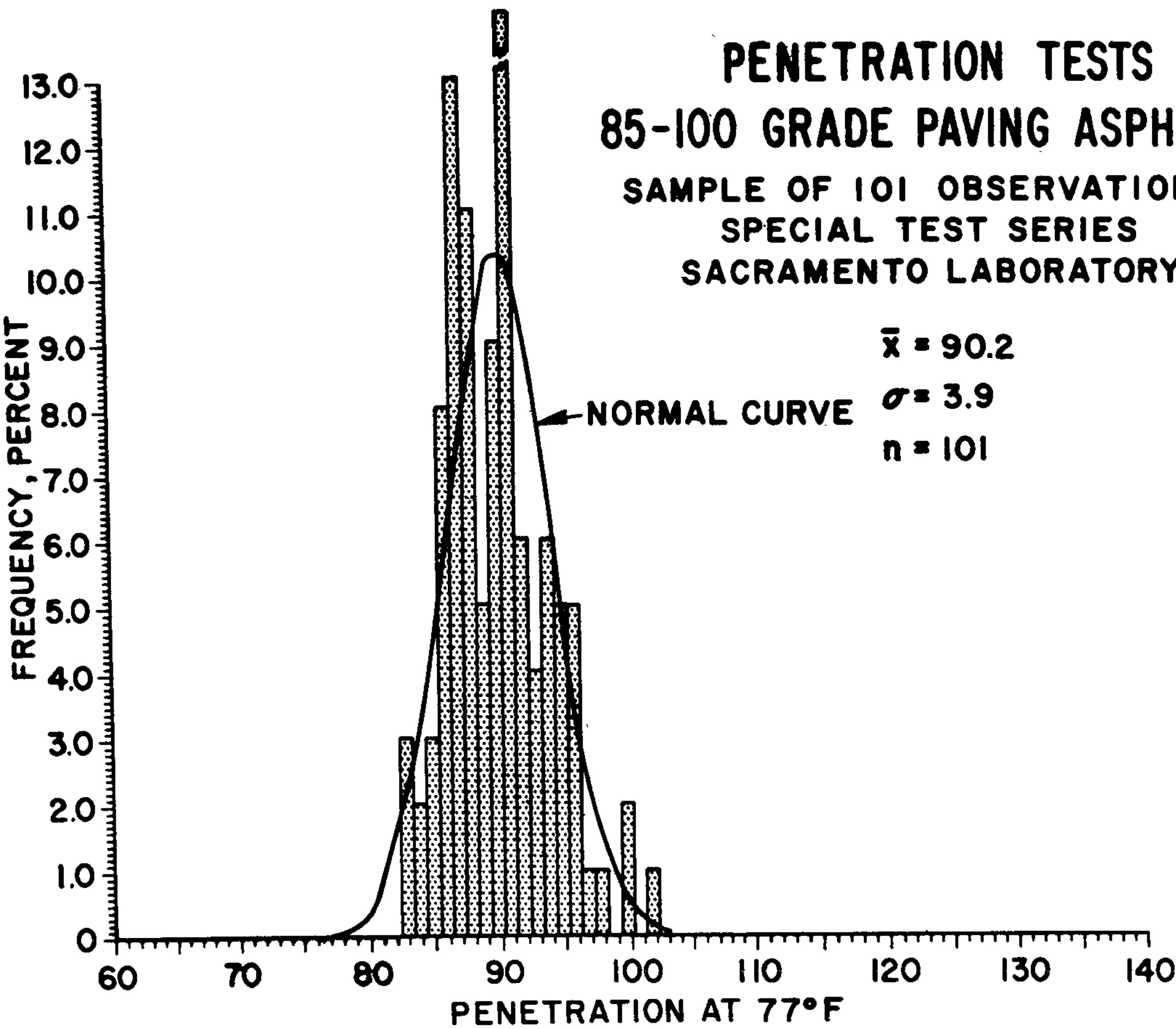
PENETRATION TESTS
85-100 GRADE PAVING ASPHALT
SAMPLE OF 101 OBSERVATIONS
SPECIAL TEST SERIES
SACRAMENTO LABORATORY
x̄ = 90.2
σ = 3.9
n = 101
NORMAL CURVE
FREQUENCY, PERCENT
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
60
70
80
90
100
110
120
130
140
PENETRATION AT 77°F

FIGURE V

PENETRATION TESTS
85-100 GRADE PAVING ASPHALT

SUMMATION OF ALL TEST
RESULTS FALLING BETWEEN 75—110

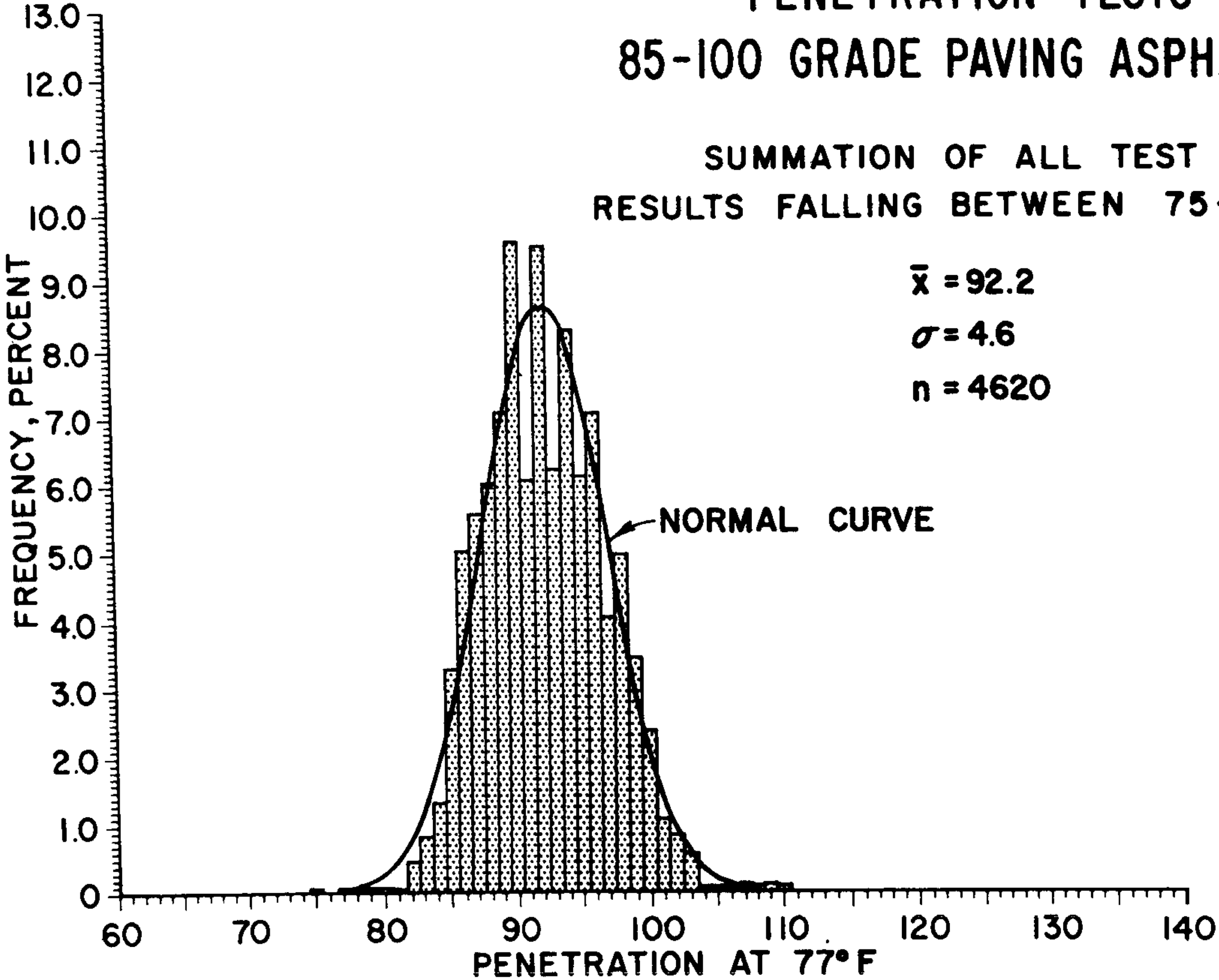

FIGURE VI

CONTROL CHART
85-100 GRADE PAVING ASPHALT
Daily Sample Average

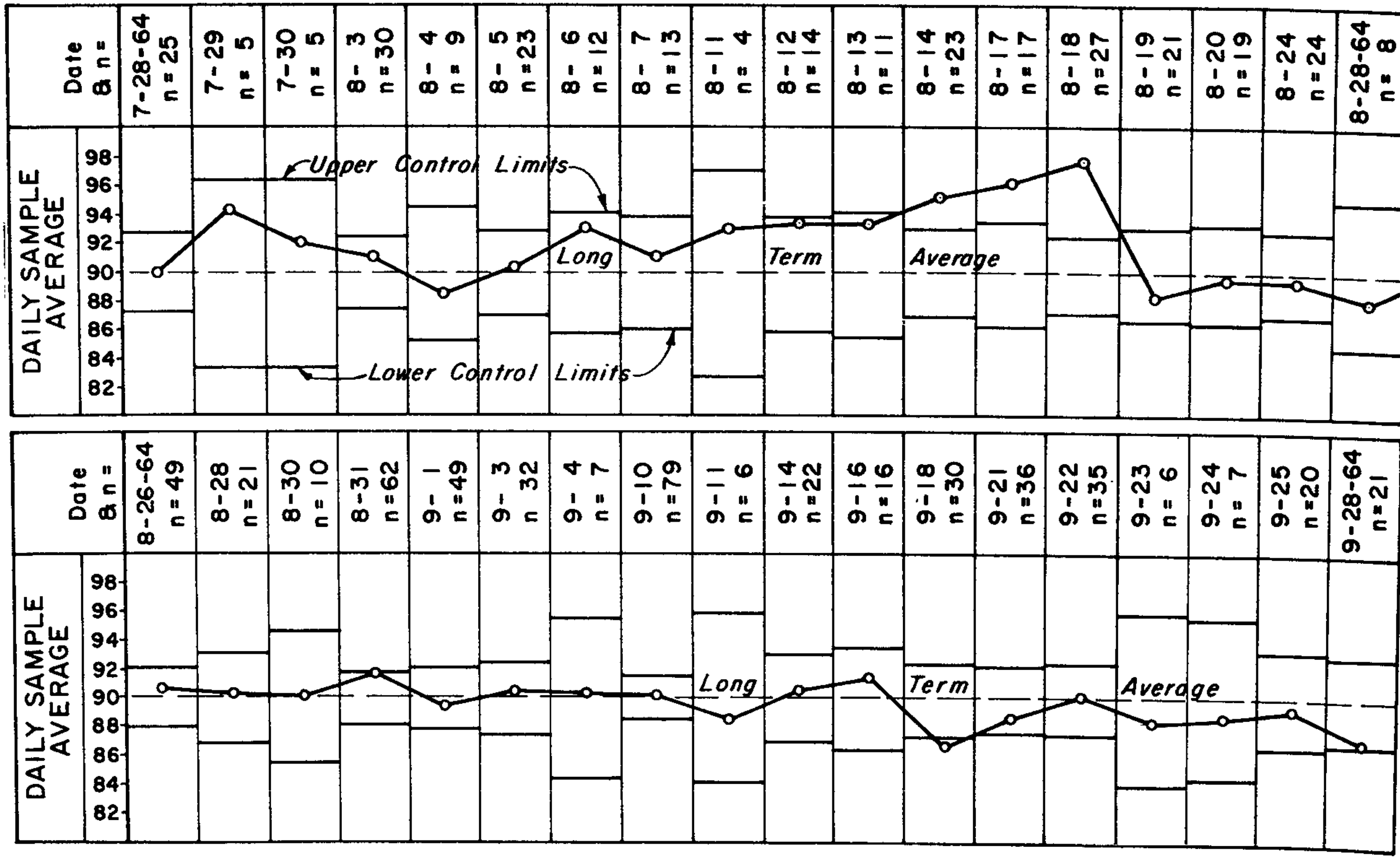

Figure VII a

CONTROL CHART
85-100 GRADE PAVING ASPHALT
Daily Sample Average

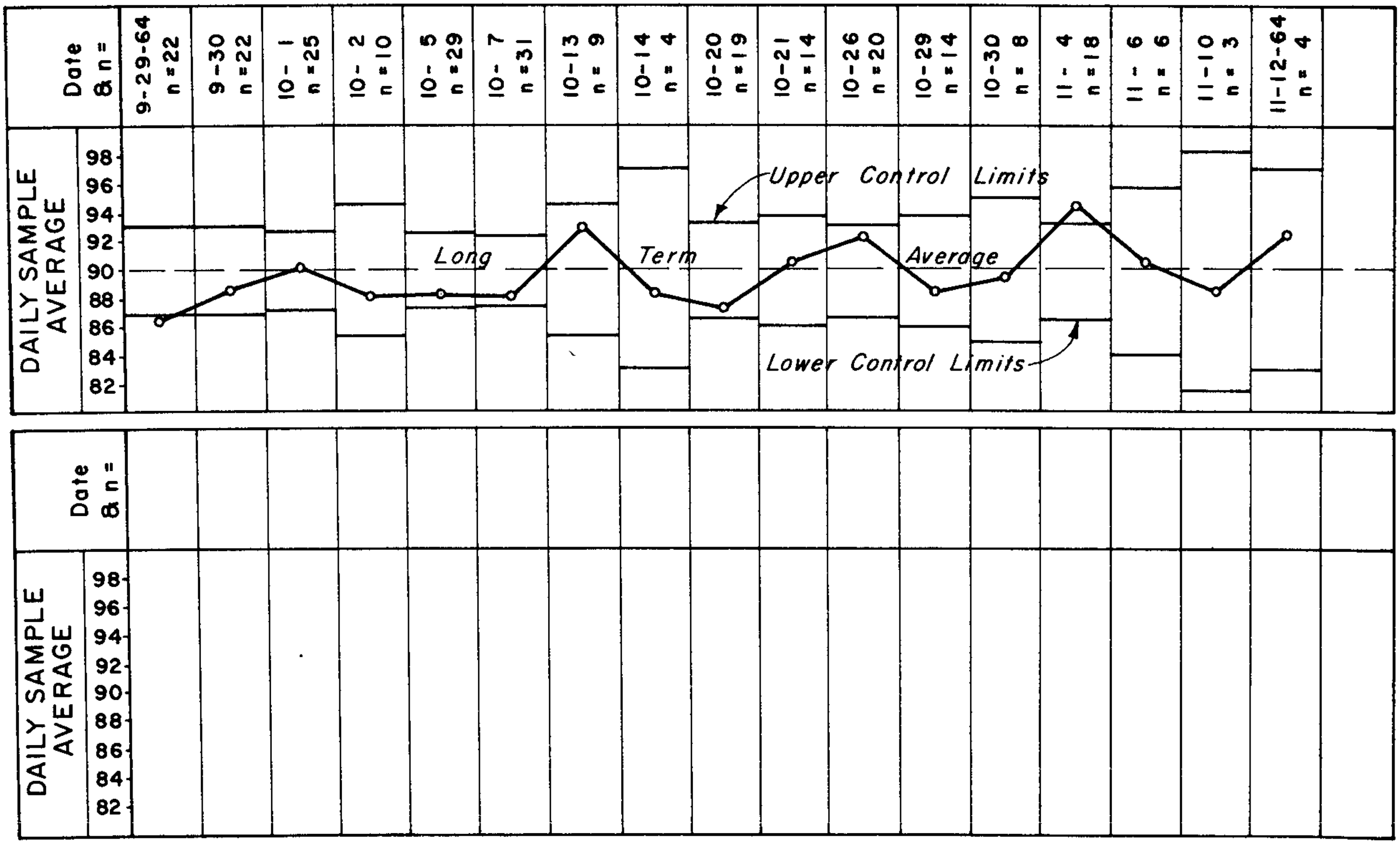

Figure VII b

CONTROL CHART

Date: From 8-3-64 to 8-31-64
Long Term Standard Deviation 4.7 (4 months)

Section Asphalt
Test Penetration 85-100 Asp.

DATE	OPERATORS	N=	COMMENTS
8/3	R.W.-W.C.	30	
8/4	R.W.	9	John Doe started to work today.
8/5	R.W.-W.C.	23	One reading of 145 excluded.
8/6	R.W.-J.D.	12	
8/7	R.W.-J.D.	13	
8/11	R.W.	4	
8/12	W.C.-J.D.	14	
8/13	W.C.-J.D.	11	
8/14	R.W.-J.D.	23	Checked bath temp., pen. needle, timer. OK
8/17	R.W.-J.D.	17	Checked bath temp., pen. needle. — OK
8/18	R.W.-W.C.	27	Timer found to be faulty.
8/19	W.C.-J.D.	21	Replaced timer.
8/20	W.C.-J.D.	19	
8/24	J.D.-R.W.	24	
8/25	J.D.	8	
8/26	R.W.-J.D.	49	
8/28	R.W.-J.D.	21	
8/30	J.D.	10	
8/31	R.W.-J.D. W.C.	62	Checked needle, OK

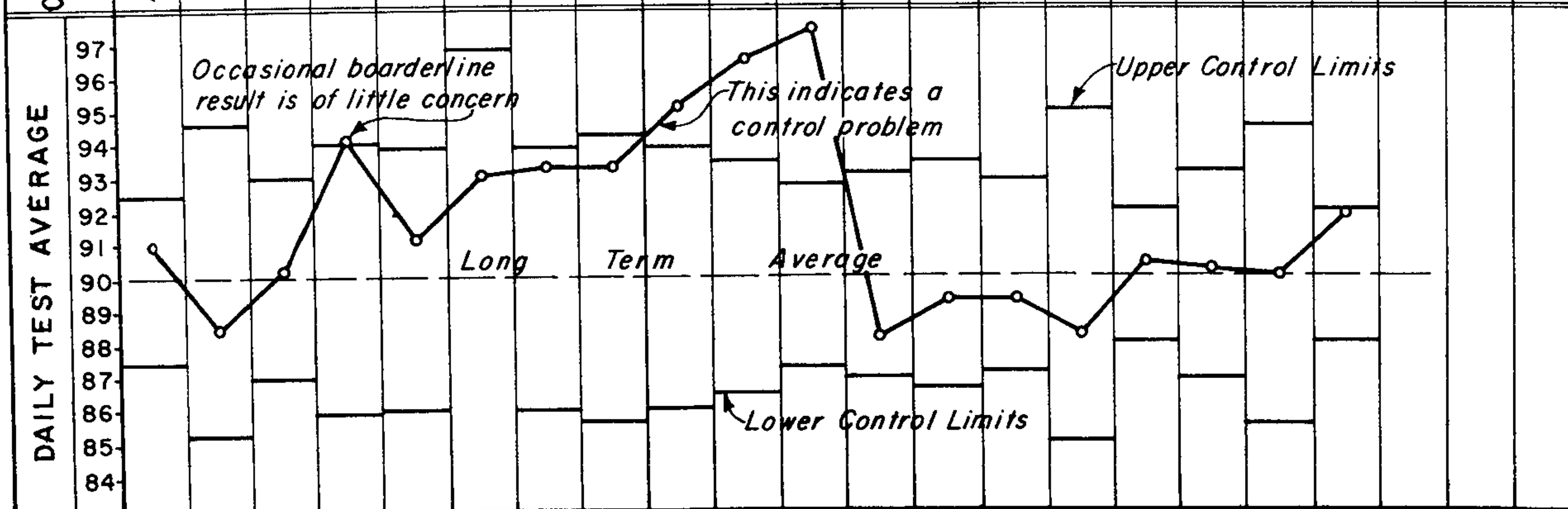

Figure VIII

MATERIALS & RESEARCH DEPARTMENT

MONTHLY SUMMARY OF PENETRATION TEST RESULTS ON 85-100 GRADE PAVING ASPHALTS

Column 1 Pen.	Column 2 Deviation From 90	Column 3 Square of Deviation From 90	COLUMN 4 DAILY TOTALS — DATE 1/1	1/4	1/5	1/6	1/7	1/8	1/11	1/12	1/13	1/14	1/15	1/18	1/19	1/20	1/21	1/22	1/25	1/26	1/27	1/28	1/29	—	—	Column 5 Sum of Daily Totals	Column 6 Col. 2 x Col. 5	Column 7 Col. 3 x Col. 5
75	- 15	225							1																	1	- 15	225
76	- 14	196																										
77	- 13	169																										
78	- 12	144																										
79	- 11	121	1						1																	2	- 22	242
80	- 10	100																										
81	- 9	81												1												1	- 9	81
82	- 8	64																										
83	- 7	49																										
84	- 6	36																										
85	- 5	25	2	1	2			3	1		4	2			1		2			1	1					20	- 100	500
86	- 4	16	1	5			2				2				6		1			2		1	1			21	- 84	336
87	- 3	9			3	4			2			3			2			2	1		3		3			23	- 69	207
88	- 2	4		2			4	1		6	2		3	2		3	2	2	6	1		3	2			39	- 78	156
89	- 1	1	5			2		3	2				2			3		1	1	2	1					22	- 22	22
90	0	0				6	1		2	2		4	4	3	2		5		2		3					34	0	0
91	+ 1	1	3		4		3	2			3		1	1	2		1	4				4				28	+ 28	28
92	+ 2	4		3	2				4	2						4			2	1	1	1	6			26	+ 52	104
93	+ 3	9			2					1		2		3				1				1				10	+ 30	90
94	+ 4	16	2			1		4		2			1	1			2			1			2			16	+ 64	256
95	+ 5	25		2			4				2					4										12	+ 60	300
96	+ 6	36										3						4								7	+ 42	252
97	+ 7	49											3							1						4	+ 28	196
98	+ 8	64																	2			2				4	+ 32	256
99	+ 9	81																		2						2	+ 18	162
100	+10	100																	1		3					4	+ 40	400
101	+11	121																										
102	+12	144																				1				1	+ 12	144
103	+13	169																										
104	+14	196																										
105	+15	225																										
106	+16	256																										
107	+17	289																										
108	+18	324																										
109	+19	361																		1						1	+ 19	361
110	+20	400																										
Daily Totals			14	13	13	13	14	13	13	13	13	14	14	11	13	14	13	14	15	12	12	13	14	—	—	A = 278	B = + 26	C = 4318
Results Other Than 75–110					128															119 124						Totals Div. By "A"	$\frac{B}{A} = .094$	$\frac{C}{A} = 15.532$

$$\bar{X} = 90 + \frac{B}{A} = 90.09$$

$$\sigma = \sqrt{\frac{C}{A} - \left(\frac{B}{A}\right)^2} = \sqrt{15.532 - .009} = \sqrt{15.523} = 3.94$$

DATE: FROM Jan. 1 TO Jan. 30 1964

LABORATORY: Sacto., Asphalt

Figure IX