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16. ABSTRACT

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It was concluded that the thickness of galvanizing on corrugated metal culvert pipe being supplied meets present engineering needs and, further, that the present AASHO specifications are adequate; however, a statistical control procedure which will reduce inspection and testing costs has been presented.

Rather than a lot by lot analysis, this procedure, using control charts, provides the engineer with reasonable assurance that the overall process is in control. It is also pointed out that resampling of material which fails to meet the specifications may allow the use of material swhich should be rejected.

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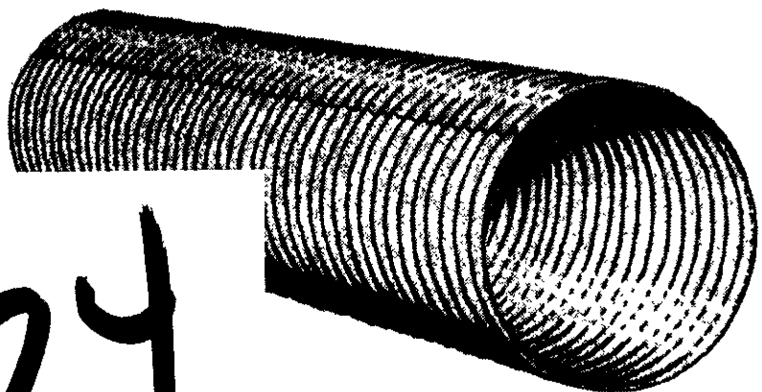
A STATISTICAL STUDY OF THE WEIGHT OF ZINC COATING ON CORRUGATED METAL PIPE



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MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 210338-2

Prepared in Cooperation with The U.S. Department of Commerce, Bureau of Public Roads March, 1966

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

March 14, 1966

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

Dear Sir:

Submitted for your consideration is a report on:

A STATISTICAL STUDY OF

THE WEIGHT OF ZINC COATING ON CMP

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

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

Attachments

cc: LRGillis
ACEstep
CGBeer (14)
JFJorgensen
PCSheridan

This is the second 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.

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ABSTRACT

A statistical analysis of the thickness of galvanized corrugated metal culvert pipe is reported. Records of routine tests performed by the Headquarters Laboratory of the California Division of Highways were analyzed.

It was concluded that the thickness of galvanizing on corrugated metal culvert pipe being supplied meets present engineering needs and, further, that the present AASHO specifications are adequate; however, a statistical control procedure which will reduce inspection and testing costs has been presented.

Rather than a lot by lot analysis, this procedure, using control charts, provides the engineer with reasonable assurance that the overall process is in control. It is also pointed out that resampling of material which fails to meet the specifications may allow the use of material which should be rejected.

INTRODUCTION

The quality of corrugated metal pipe is dependent upon several factors such as the tensile strength, yield point and chemical composition of the base metal, and the weight and purity of the zinc coating. Past experience has shown that the CMP suppliers for the California Division of Highways usually have good quality control procedures on these items.

Certified test results have generally been accepted from the manufacturer as evidence of the quality of the material. This certificate covers items other than the unit weight of the galvanizing. It has been the practice of the Division of Highways to test a sample from each lot or heat of corrugated metal to determine the unit weight of the coating. Tests on the base metal are performed only occasionally.

The study reported herein is limited to a statistical evaluation of the present procedures used by the California Division of Highways for the control of the unit weight of the zinc coating. This is but one phase of a larger statistical study covering several construction items.

The purpose of this study is to determine if a more realistic or more economical control procedure might be used.

FINDINGS

1. It is concluded that the thickness of zinc coating on corrugated metal pipe presently being supplied is sufficient to meet present engineering needs. Therefore, the present AASHO Specification M36 is both realistic and adequate.
2. AASHO Specification M36 indicates that it is desirable to reject all material having a zinc coating of less than 1.8 ounces per square foot. The data shows that for practical purposes the material being supplied meets this lower limit. It is, therefore, concluded that all major suppliers whose products were tested for this study have adequate quality control procedures.
3. It is concluded that, with present production technology, it is necessary for a producer to maintain a minimum average weight of coating of approximately 2.35 ounces per square foot in order to consistently supply galvanizing that will meet the present specifications.
4. It is concluded that the present level of quality can be maintained at a reduced inspection cost by performing less control tests but utilizing control charts, showing the average thickness of coating, to provide assurance that each supplier is in operational control.

5. It is concluded that the established control process could be further improved by not allowing resampling. Rejection of Culvert Material is usually based on an average of test results on three to five coupons. Thus, resampling is not needed unless the test method is in obvious error. There is no provision in the AASHO specifications for resampling and, since this procedure tends to allow the use of material which should be rejected, it should not be an accepted practice.

MATERIALS AND PROCEDURES

Five gages of corrugated metal pipe were selected for the study - 8, 10, 12, 14, and 16-gage. The materials used for the tests were supplied by six different companies with three suppliers furnishing the majority of the material. The test data were taken from records of tests on file which were performed within the period of approximately six months. All tests were performed by the Headquarters Laboratory in accordance with ASTM Test Method A 90-53. The samples were selected in accordance with Specification for Corrugated Metal Culvert Pipe (AASHO M36). No test results from resampled materials were used in this analysis because it was reasoned that a less biased representation of the true universe would result using only initial test results.

In order to perform a more detailed analysis, a larger amount of test data from 12-gage pipe were used. The 12-gage material was selected because it is the most commonly used.

ANALYSIS OF DATA

Figures 1 through 5 show frequency distribution histograms of the weight of zinc coating on various gages of steel culverts. These histograms are fitted with a normal curve which indicates the distribution of all possible test results.

The distributions of test results for each gage are approximately normal; however, some skewness is apparent. Since this skewness is always positive, it is reasoned to be the result of an assignable cause. It possibly could be due to the manufacturer's selective quality control procedure which tends to reject lower quality material.

An analysis of the histograms in Figures 6, 7 and 8 indicates that the major suppliers are furnishing approximately the same quality material. A small percentage of individual test results fell below 1.8 ounces per square foot, and the curves indicate that we can expect to have some material as low as 1.6 ounces per square foot.

Present experience indicates that it is desirable to reject all material with less than 1.8 ounces of zinc per square foot. With the data gathered here, it was determined that the risk to the State of accepting material below this quality level is presently approximately one percent. This is based on knowledge that the present overall average is approximately 2.35 ounces per square foot. Should this average be lowered or should the basic manufacturing process be changed in a way that would result in an increase in the dispersion of the universe, as measured by the standard deviation, the "approximately one percent below" would no longer hold true.

ACCEPTABLE QUALITY LEVEL

The weight of galvanizing on the CMP presently being supplied to the Division of Highways meets current engineering requirements. This department has extensively investigated the service life of galvanized corrugated metal pipe and has developed a mathematical method for predicting serviceability when considering such environmental conditions as hydrogen-ion concentration and electrical resistance of the soil. (See References 1, 2 and 3). From these durability studies, it can be concluded that the only present need is to assure that the present quality level is maintained. Any upgrading of the quality of this material would have to be justified by additional study of economic and engineering conditions. Quality must be judged by the entire product: the fabrication of the pipe; the strength of the base metal; the purity and adhesion of the coating; and last, but not least, the unit weight of the coating. This study is limited to the consideration of the unit weight of the coating.

On the basis of the data gathered in this study, it is believed that the present level of control of the unit weight of galvanizing can be assured with fewer tests and a reduction of inspection costs if the control charts detailed in Appendix C are maintained.

PROPOSED QUALITY CONTROL PROCESS

In the process of analyzing the data, it was possible to determine some of the sources of variance in the test results, and these results are presented here as a matter of interest. It was found, by analyzing four test results from each of seventy-five different heats of steel, that the average standard deviation of test results from one heat is 0.11 ounces per square foot. Since the overall standard deviation was found to be about 0.24, it was determined by Pythagorean subtraction that the standard deviation between heats is about 0.21 ounces per square foot.

It is not concluded that the variance within one heat is low because of any specific property of the base metal, but rather it is thought that the material was probably galvanized at one time and later all the tests were performed at once by the same chemist, thus resulting in a minimum of variation in both thickness of the galvanizing and the testing procedure.

Note that the test results from the various manufacturers do not have the same distribution. Comparing Figures 6, 7 and 8, observe that when the dispersion is high, the average is also high. Thus, the risk of accepting material which should be rejected is about the same for all the suppliers studied.

The data presented in Figures 1, 2 and 3 show that the present specification for the weight of galvanizing is, in general, being met; however, a review of the records indicates that on rare occasions, material is being accepted through the practice of resampling and retesting. As explained in Appendix B, the process of resampling variable borderline material tends to allow the use of material which should be rejected.

Since the initial rejection is generally based on the average of three to five test results, it is argued that resampling should not be allowed unless there is reason to suspect that the test was performed incorrectly. There is no provision in the present specification for resampling. The specification requires that the average of three to five test results shall be not less than 2.0 ounces per square foot and no individual test result shall be below 1.8. When the tests performed on the coupons initially sampled indicate that the material does not comply, the material should be rejected without further testing.

Even though the present specification and control procedure is judged to be fully adequate, the control procedure presented in Appendix C has been developed for economic reasons. This procedure requires the maintenance of control charts for adequate control information, but reduces the number of tests and, consequently, the overall inspection cost.

This control chart procedure is based on the "option to test". As long as the control charts indicate that the manufacturer's operation is in control, very few tests are performed. When operational difficulties are encountered or an unknown manufacturer supplies material, the option to test all material is exercised until the charts indicate that control is established.

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4. American Society for Testing and Materials. ASTM Manual on Quality Control of Materials. (Special Technical Publication 15-C), January 1951.

APPENDIX A

Definitions of Statistical Terms

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

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

A sample is a group of readings or observations. If five items or tests were taken to represent a lot of material, this would be one sample of five observations.

The mean (or average), $\overline{X}$, is the arithmetical average of all measurements or test results. The mean may be expressed mathematically as:

$$\overline{X} = \frac{\Sigma X_i}{n}$$

Where n = number of measurements or test results.

The standard deviation, σ (sigma), is a measure of the dispersion of the measurements or test results from their average. The mathematical expression is:

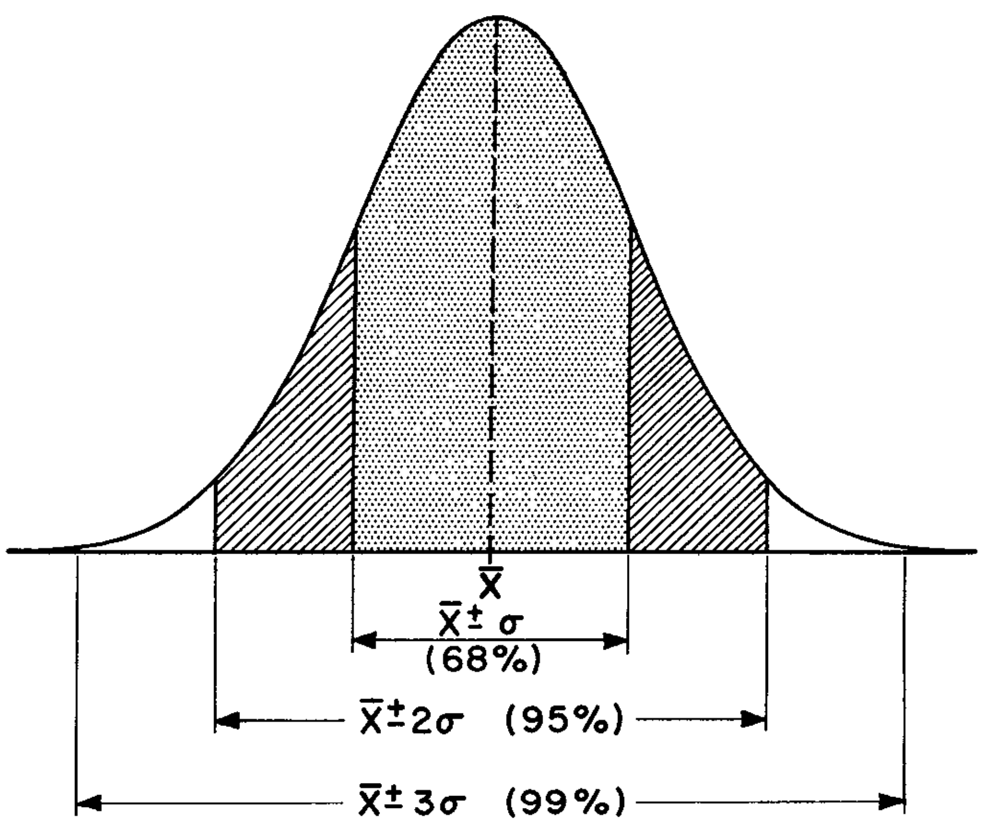
$$\sigma = \sqrt{\frac{\Sigma (X_i - \overline{X})^2}{n}}$$

The range of a large sample ($n \geqq 30$) drawn from a normal universe is approximately equal to the limits of $\overline{X} \pm 3\sigma$. Standard deviations are not directly additive but, when independent, may be combined by Pythagorean addition.

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

A normal universe: When the distribution of the observations from a universe forms a bell-shaped curve, it is said to be a Gaussian or a normal universe. A typical normal curve is shown below.

TYPICAL NORMAL CURVE



<u>The confidence level</u>, P, is a measure of probability. It is the ratio of the number of occurrences to the total possible number of occurrences. The statement $\bar{X} = 93.5 \pm 0.3$, $(P = 0.95)$, means there is a 95 percent probability that the true mean, $\bar{X}'$, is within the range 93.2 to 93.8.

<u>A histogram</u> is a bar graph representation of a frequency distribution.

APPENDIX B

Effects of Resampling

Resampling of previously tested materials is one factor that contributes to the acceptance of material which should be rejected.

Figure 9 shows how a resampling procedure will affect the probability of accepting this material. To explain, it is assumed that the decision to pass or retest a particular lot of material of borderline quality will be based on the average of five observations. It is also assumed that a distribution of results of tests on the unit weight of zinc on this material is such that only 50 percent of all possible tests would be above the 2.0 ounces per square foot limit. This means that the probability of the average of the five tests on the first sample being below the specification limit is 50 percent.

With the resampling procedure, if the average of the first five observations falls below the specification limit, a second sample would be taken and five additional observations would be made. Since nothing has been done to change the quality of the material, a second series of observations would still have a 50 percent chance of passing.

The total probability of accepting the material, however, must be obtained from the probabilities of both the first and second series of tests. Therefore, the total probability of acceptance is 75 percent as shown in Figure 9.

APPENDIX C

Use of Control Charts

It is postulated that maintenance of the present level of unit weight of the zinc coating of metal pipe can be assured by using control charts as described below. This procedure is not intended to replace the present specifications, but rather is intended to detect any long-term change in operational control. Any significant long-term change would be indicated by variations in test results that are greater than would be expected by chance.

With the present production procedures, an overall average of 2.3 ounces per square foot is sufficient to assure that all but a very limited number of single observations will fall above the minimum allowable limit of 1.8 ounces per square foot.

Although other factors could be used, the average unit weight and the range of test results in unit weight of coating for each sample tested are judged to be best to assure stability of the production process.

The sample control chart in Figure 10 is taken from actual test records on material from one supplier. For purposes of this example, the time has been expanded from approximately one year to five years. Thus, the example and chart present actual data but the dates are hypothetical.

This chart is based on the assumption that at least one test will be made each month for each major supplier.

In this example, the charted results exhibited statistical stability during the period from November 1960 to November 1961. The test made on December 28, 1961 showed that the range in weight exceeded the limit and the option to test all materials was then exercised until the samples again showed statistical stability.

Observe on the control chart that when the range in unit weight first exceeded the established limit, the engineer exercised his option to do additional testing and samples were requested from each of the subsequent four heats of material. The range in thickness of one of these samples again exceeded the maximum limit so it was again requested that the next four heats be sampled. One of these four samples again showed a coating variation greater than the allowable range. Test samples from the next four heats indicated that statistical stability had been restored but, since the range had exceeded the desired limits on three different tests in less than a month, three more tests were made as a check. Each of these samples showed adequate control in the range, but the average unit weight of the coating on one sample fell below the desired limit. Samples from the next four heats were tested with the result that each of the additional samples showed adequate control and the monthly testing was resumed on the basis of this data.

In June of 1962, February 1965, and July 1965, the monthly results exceeded the desired limits and additional testing was required to check the quality of the materials being produced.

During the period covered by these control charts, no material was rejected because of its failure to meet current specifications. Statistical stability of the coating thickness was assured through monthly checks and additional tests when the periodical results exceeded the established limits.

If the test results on the first sample fail to meet the AASHO specifications, the particular lot or heat of material represented should be rejected without further testing. The engineer in charge should then require testing of additional lots until the cause of the failure has been corrected or until he is satisfied that the manufacturing process is again under control. No lot of material would be rejected without sampling and testing that particular lot.

The formula shown below for determining the control chart limits is based upon the ASTM Manual on Quality Control of Materials, STP-15C, January 1951.

Control Limit for $R = D_4 \overline{R}$

Where:

R = range or difference between the largest observation and the smallest observation of a sample.

$\overline{R}$ = the average or long-term value for range R.

D_4 = a factor for control limits from ASTM Manual and is a function of n, the number of observations in a sample.

Although a formula is also presented in the ASTM Manual for setting of the control limit for $\overline{X}$, the calculated limit is more restrictive than is considered necessary for adequate control.

A point one-third the distance from the present specification limit of 2.0 ounces per square foot to the average value of past tests of 2.3 was arbitrarily selected.

FIGURE 1

WEIGHT OF ZINC COATING ON 8 GAGE STEEL

n = 167
$\bar{x}' = 2.40 \pm .03$ (P=.95)
$\sigma = 0.20$

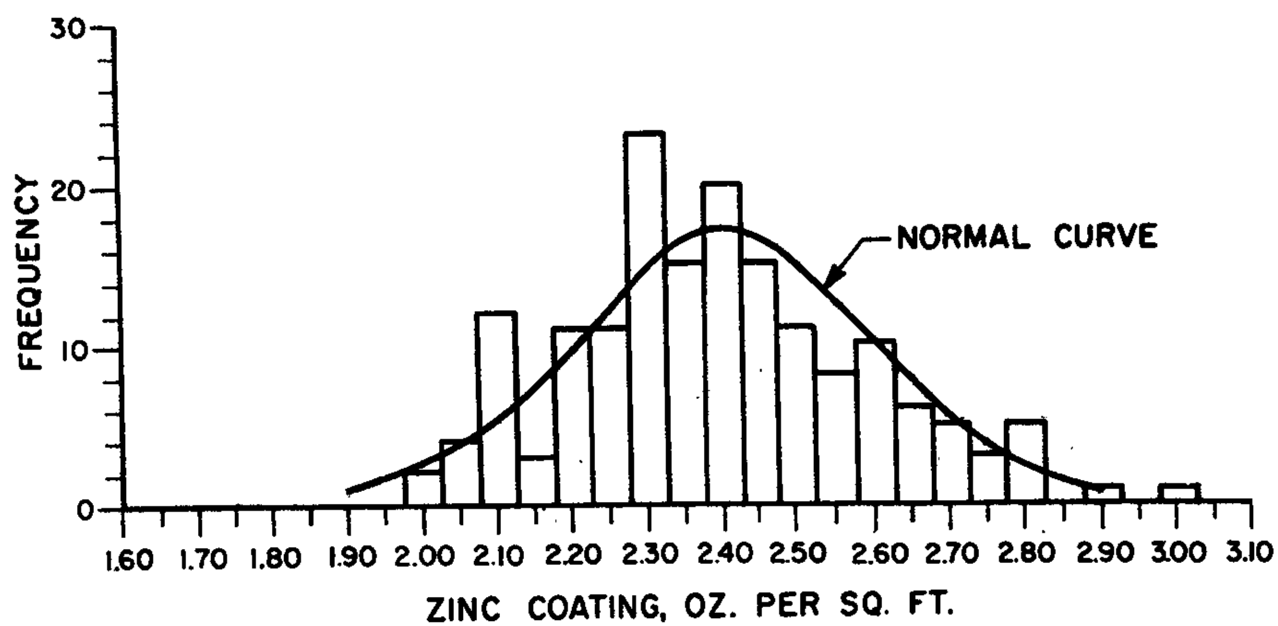


FIGURE 2

WEIGHT OF ZINC COATING ON 10 GAGE STEEL

$n = 211$
$\bar{x}' = 2.35 \pm .04\ (P = .95)$
$\sigma = 0.26$

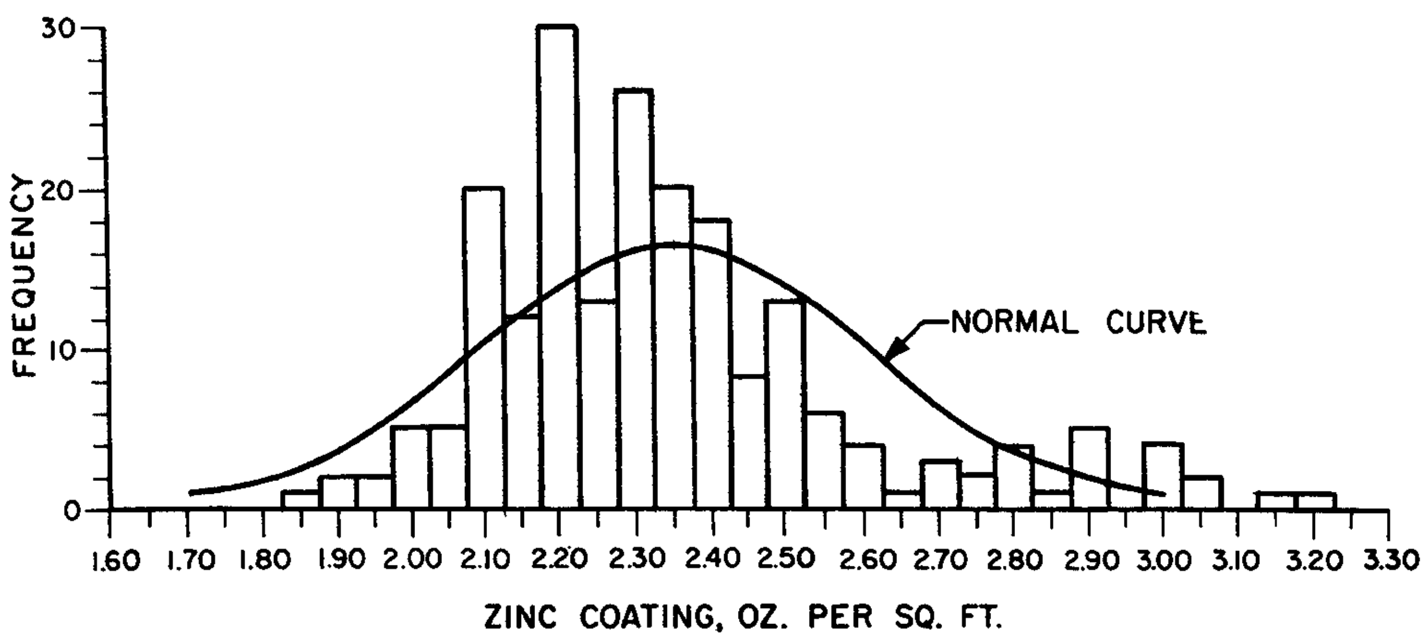
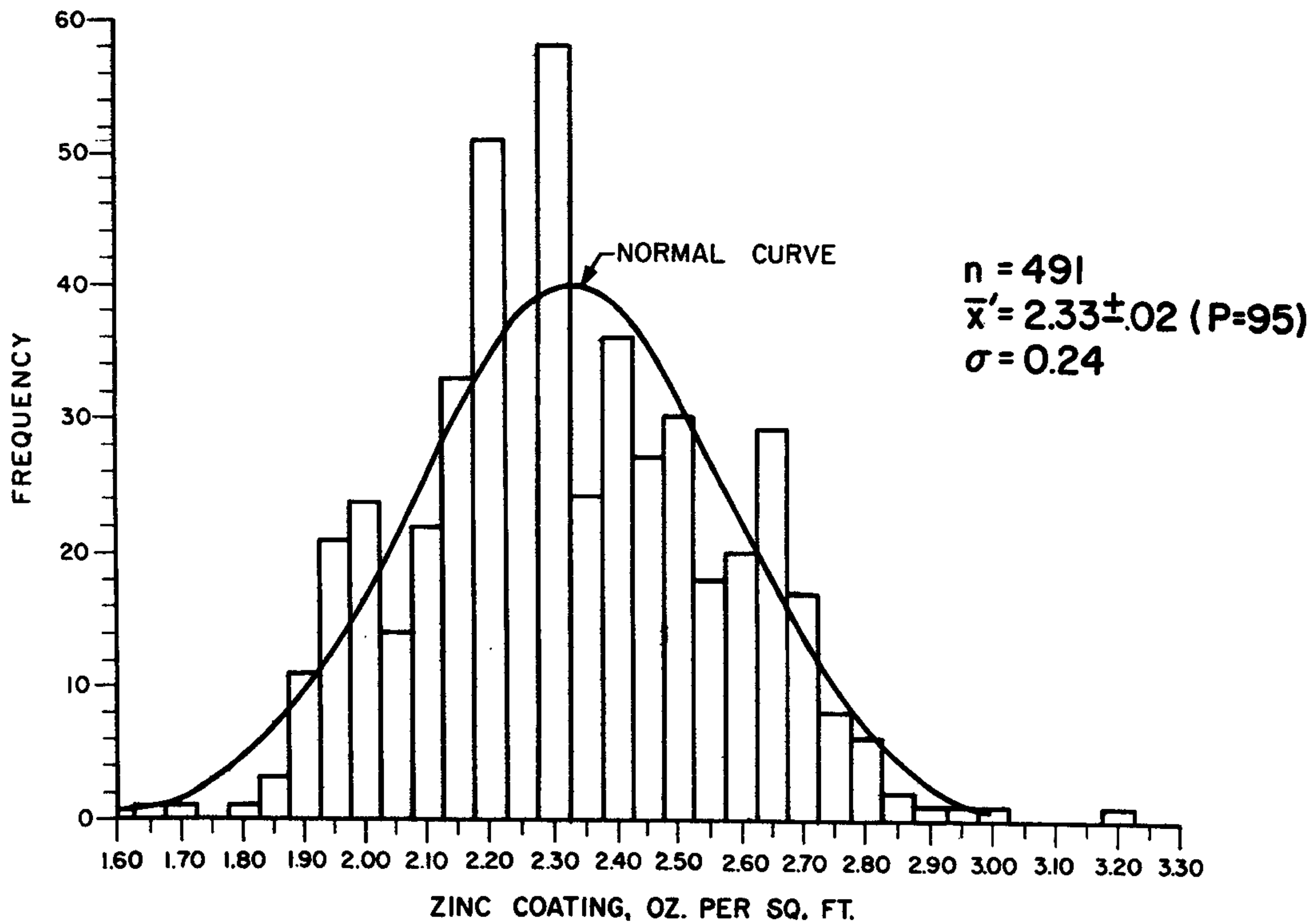


FIGURE 3

WEIGHT OF ZINC COATING ON 12 GAGE STEEL



WEIGHT OF ZINC COATING ON 14 GAGE STEEL

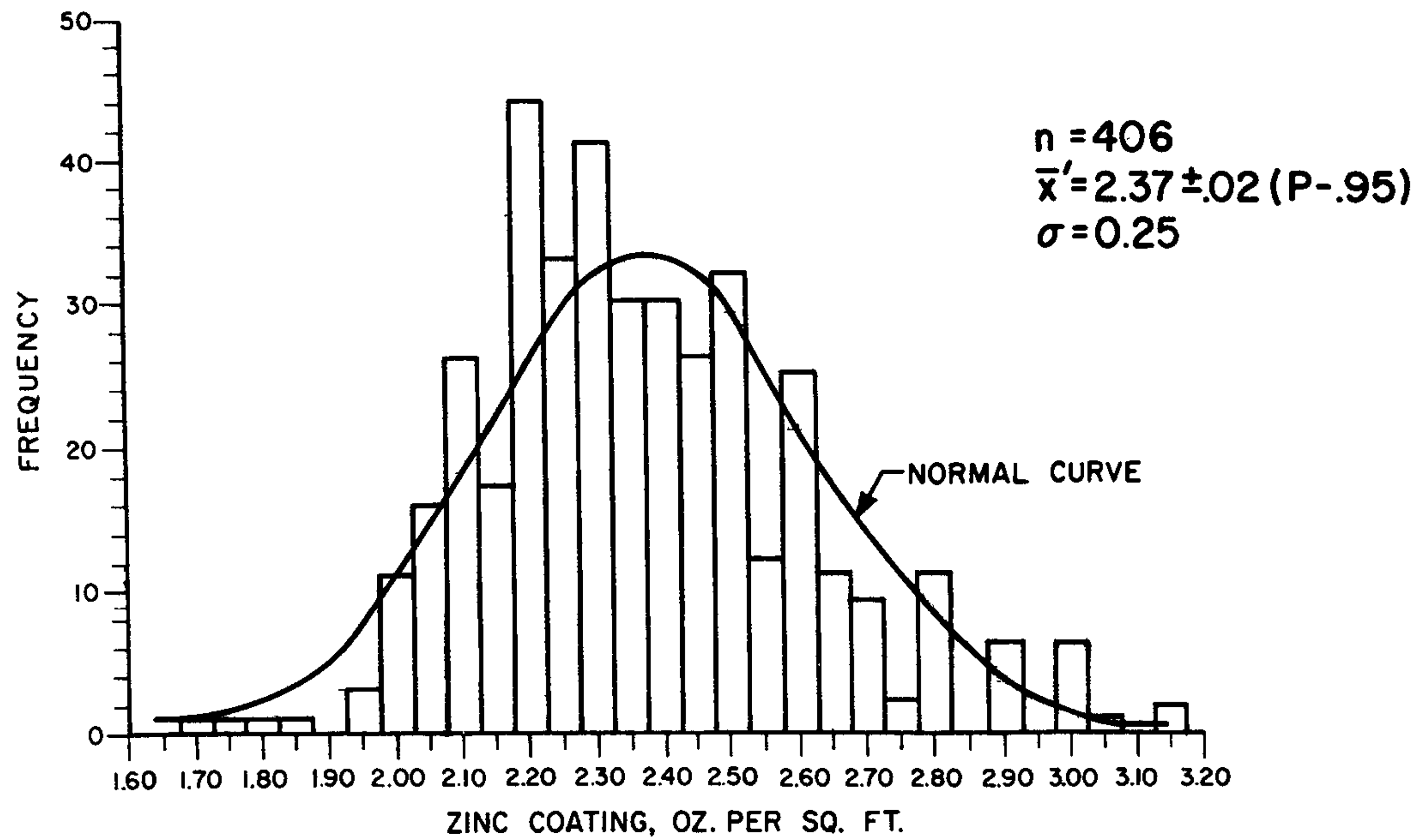


FIGURE 4

WEIGHT OF ZINC COATING ON 16 GAGE STEEL

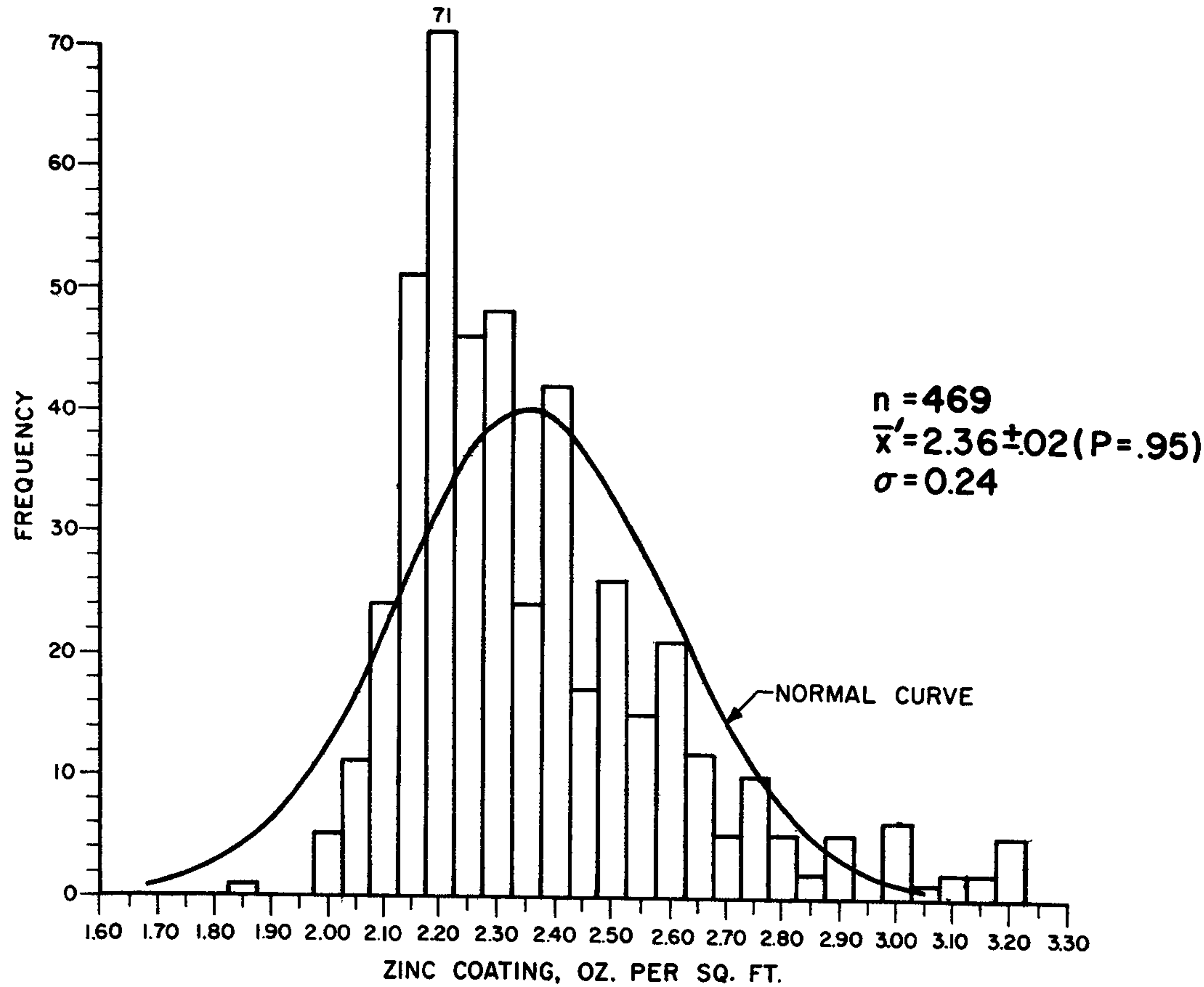


FIGURE 5

FIGURE 6

WEIGHT OF ZINC COATING ON 12 GAGE STEEL
Manufacturer A

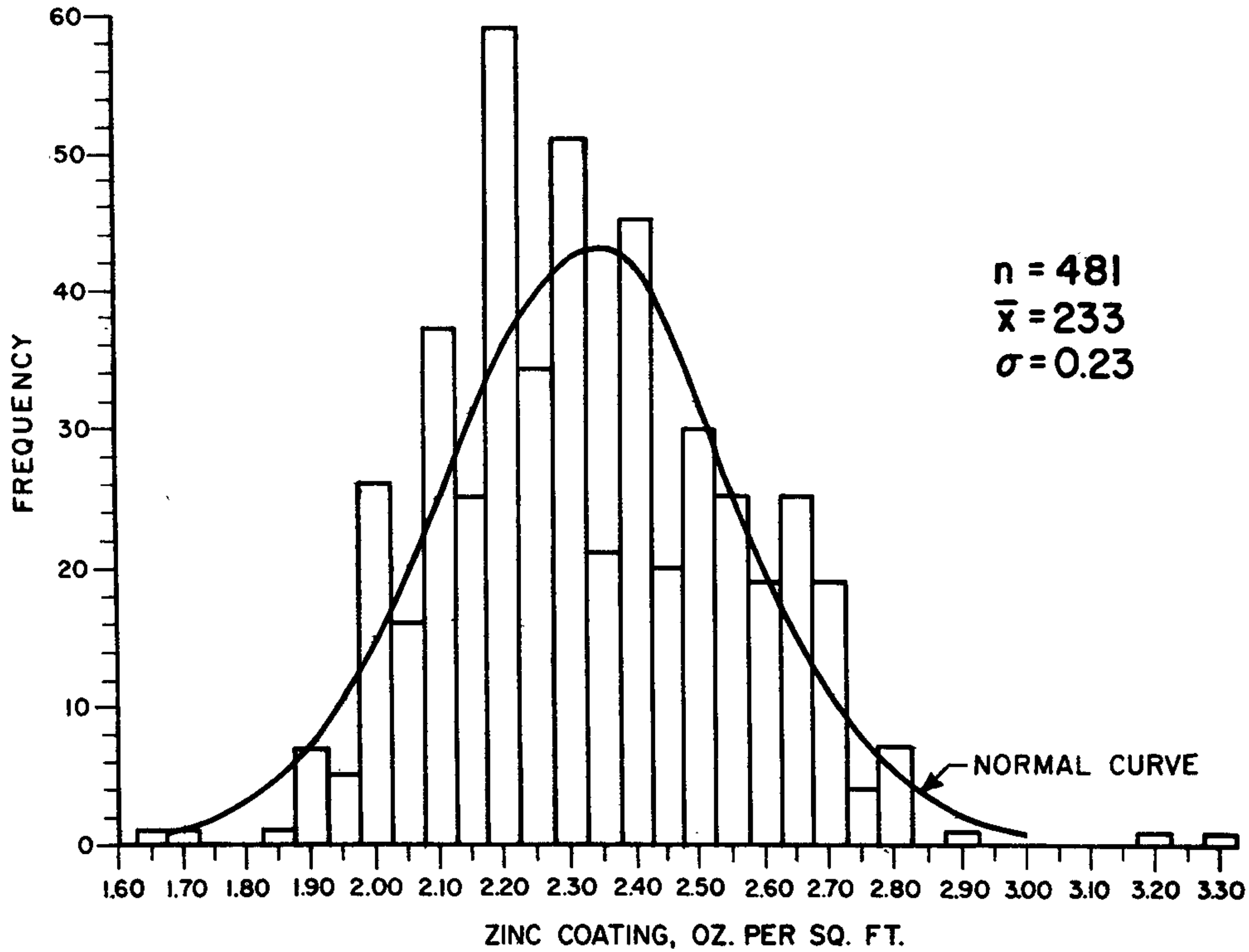


FIGURE 7

WEIGHT OF ZINC COATING ON 12 GAGE STEEL
Manufacturer B

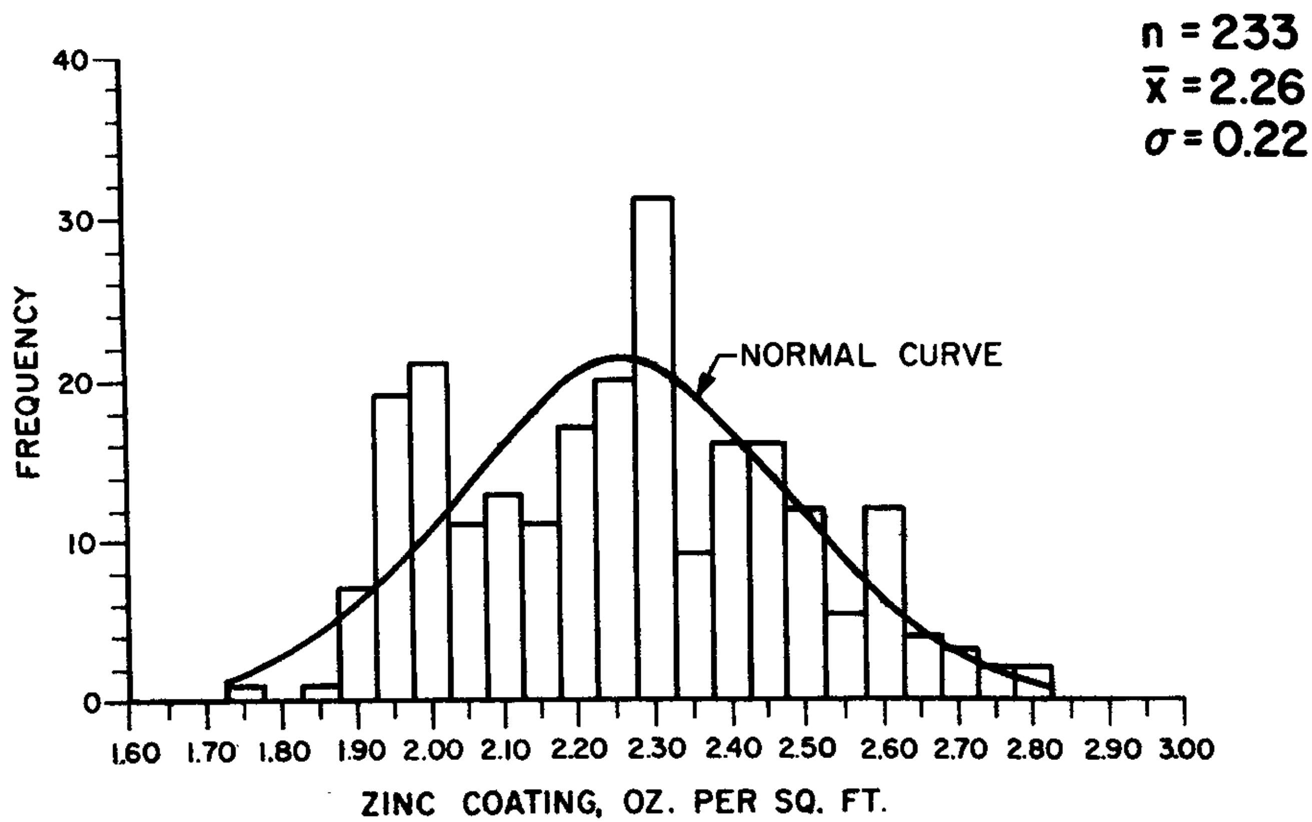
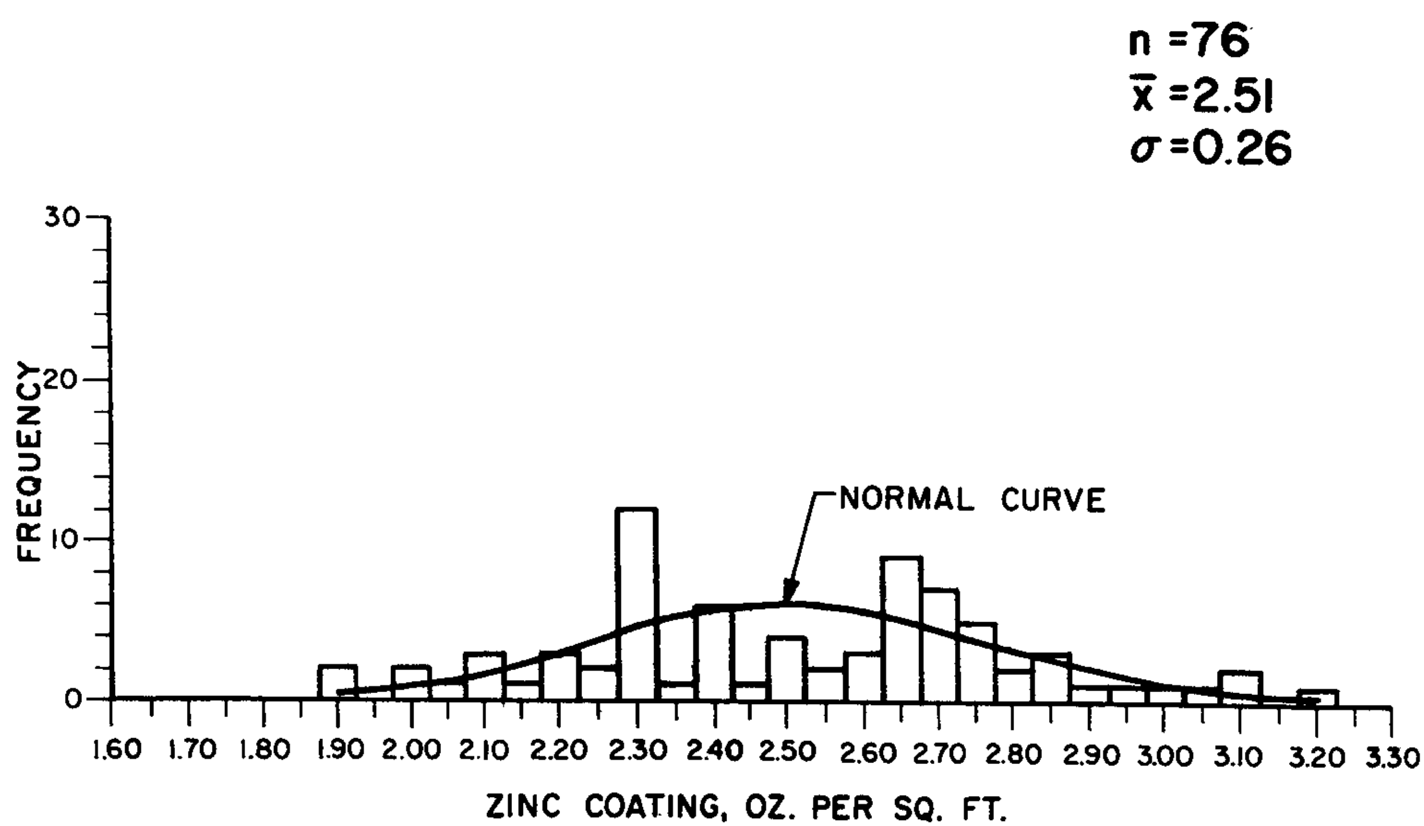
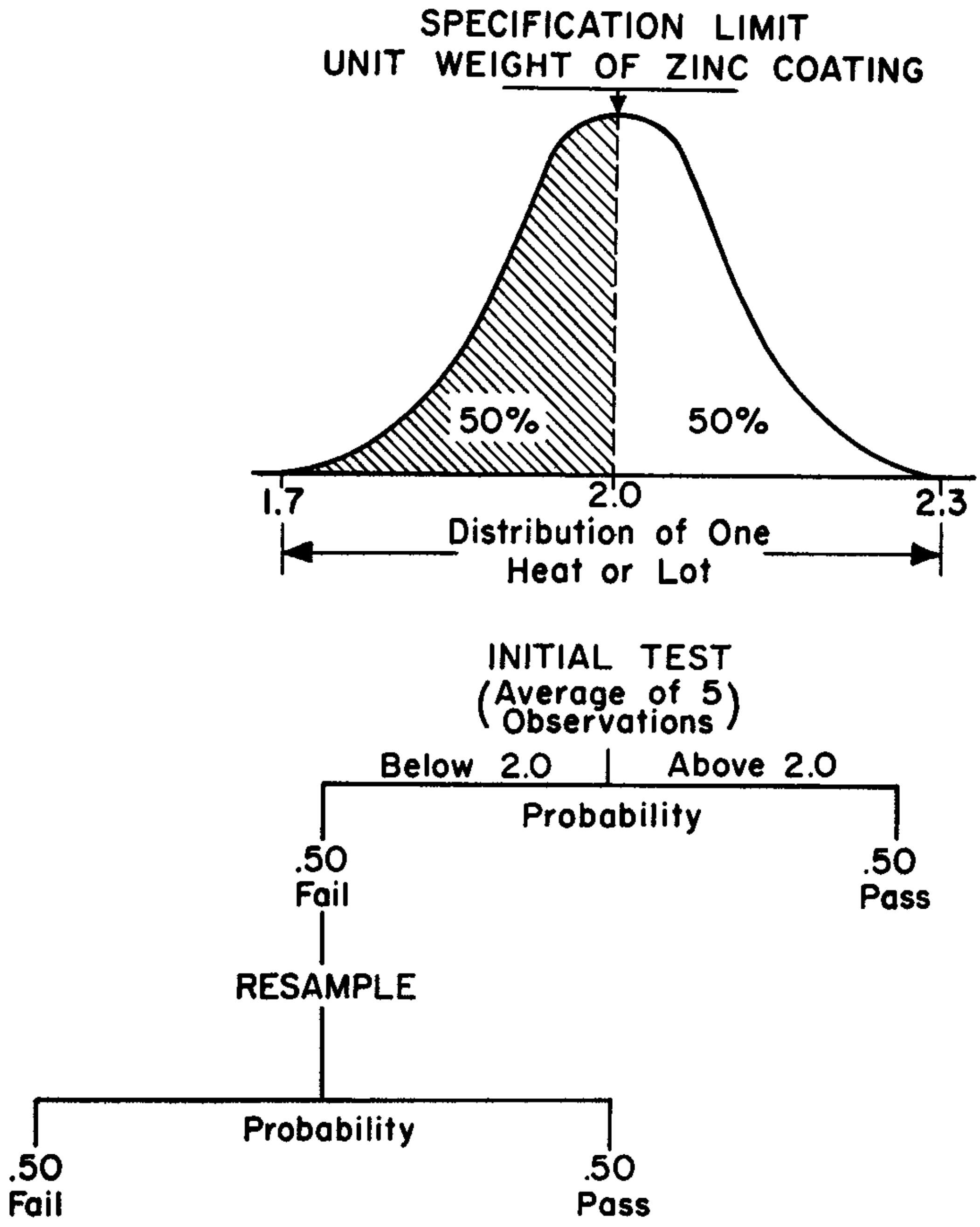


FIGURE 8

WEIGHT OF ZINC COATING ON 12 GAGE STEEL
Manufacturer C



PROBABILITY OF ACCEPTING BORDERLINE MATERIAL WHEN RESAMPLING



OVERALL PROBABILITY

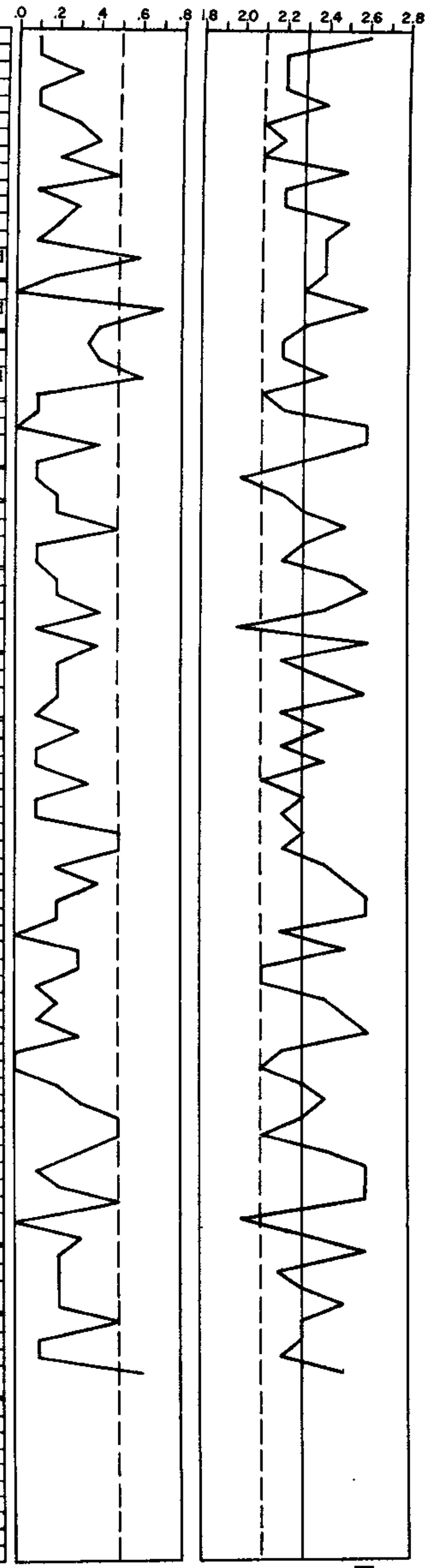
Passing .50 + (.50 x .50) = .50 + .25 = .75

Failing .50 x .50 = .25

CONTROL CHART FOR C.M.P.

MANUFACTURER X

GAGE	HEAT NUMBER	NO. OF TESTS	SAMPLE I.D. NO.	DATE SAMPLED	REMARKS
12		5		11-18-60	OK
12		5		12-16-60	OK
12		5		1-19-61	OK
12		4		2-17-61	OK
12		4		3-23-61	OK
12		5		4-20-61	OK
12		5		5-25-61	OK
12		5		6-23-61	OK
12		4		7-22-61	OK
12		4		8-31-61	OK
12		3		9-27-61	OK
12		3		10-29-61	OK
12		4		11-25-61	OK
12		4		12-28-61	range exceeded limits requested
12		3		1-3-62	OK samples from next 4 heats
12		5		1-3-62	OK
12		5		1-3-62	range exceeded limits requested
12		5		1-5-62	OK samples from next 4 heats
12		5		1-7-62	OK
12		5		1-12-62	OK
12		5		1-12-62	range exceeded limits requested
12		4		1-18-62	OK samples from next 4 heats
12		4		1-18-62	OK
12		5		1-19-62	OK
12		4		1-19-62	appears OK, but req. samples
12		5		1-24-62	OK from next 3 heats to check
12		5		1-24-62	avg. unit wt. below limits req.
12		5		1-24-62	OK samples from next 3 heats
12		5		1-26-62	OK
12		5		1-27-62	OK
12		5		1-28-62	appears satisfactory, will
12		5		2-25-62	OK resume monthly testing
12		5		3-30-62	OK
12		5		4-26-62	OK
12		5		5-23-62	OK
12		5		6-28-62	unit weight below limits, req.
12		5		7-1-62	OK samples from next 4 heats
12		5		7-1-62	OK
12		5		7-2-62	OK
12		5		7-3-62	appears satisfactory, will
12		5		8-5-62	OK resume monthly testing
12		5		9-7-62	OK
12		4		10-5-62	OK
12		5		11-9-62	OK
12		5		12-6-62	OK
12		5		1-6-63	OK
12		5		2-8-63	OK
12		5		3-7-63	OK
12		5		4-12-63	OK
12		5		5-10-63	OK
12		5		6-13-63	OK
12		5		7-11-63	OK
12		5		8-15-63	OK
12		4		9-13-63	OK
12		3		10-11-63	OK
12		3		11-16-63	OK
12		3		12-14-63	OK
12		4		1-17-64	OK
12		5		2-16-64	OK
12		5		3-16-64	OK
12		5		4-19-64	OK
12		3		5-17-64	OK
12		3		6-14-64	OK
12		3		7-18-64	OK
12		5		8-22-64	OK
12		5		9-19-64	OK
12		5		10-20-64	OK
12		5		11-17-64	OK
12		5		12-15-64	OK
12		3		1-18-65	OK
12		5		2-15-65	unit weight below limits, req.
12		5		2-19-65	OK samples from next 4 heats
12		5		2-19-65	OK
12		5		2-19-65	OK
12		5		2-20-65	appears satisfactory, will
12		4		3-22-65	OK resume monthly testing
12		5		4-19-65	OK
12		3		5-16-65	OK
12		5		6-21-65	OK
12		5		7-24-65	range exceeded limits, req. samples from next 4 heats



RANGE, R

AVERAGE, $\overline{X}$