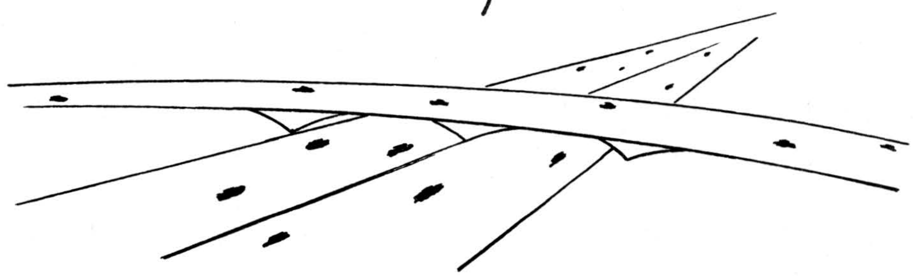

DEPARTMENTAL RESEARCH

Report Number: 63-2

ACCEPTABLE DEVIATION IN DENSITY CONTROL OF FLEXIBLE BASE

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TEXAS HIGHWAY DEPARTMENT

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I INTRODUCTION

In recent years highway engineers have become more and more aware of materials sampling and evaluation techniques. This is particularly true in connection with "record sampling program" instituted by the state highway department in conjunction with the Bureau of Public Roads. These testing programs plus the difficulties in reconciling strict legal interpretation of specification limits and the recognized variability in test results, point to the need for some change in our present material acceptance techniques.

Highway engineers are accustomed to thinking of specification control in terms of absolute values and specifications are worded accordingly. It has long been recognized, however, that there are variations inherent in road building materials, in human testing capability and construction operations, all of which produce variations in finished products. In the past such variations have been considered by the engineer on the basis of "engineering judgement" and a material has been accepted when the material was found to be "in substantial satisfaction of the specifications".

Materials quality tests and controlled testing, such as moisture content and density of highway embankments and bases, should recognize and keep abreast of modern construction techniques in order that more rapid and reliable results can be obtained. The volume of work has expanded until it behoves the highway engineer to make use of recognized statistical and mathematical techniques to help him judge the quality of specification materials.

There are three types of variation involved in specification control. First is the measurement or testing error associated with the testing equipment or operator.

The second type of variation is the inherent variability present in any group or batch of objects or materials due to the impossibility of making any two things exactly alike. These variations are not due to substandard material, equipment malfunction, improper construction practices or careless performance. They are the deviations from the norm which are always present. They may have positive or negative influence and taken together they largely offset each other, following a pattern which in general conforms to the well known frequency distribution curve.

The third and final type of variations are the really significant variations in quality, those caused by poor materials, poor equipment and/or improper construction procedures. These variations are different from the previous two types of variation in that they are susceptable to control and must be detected by the engineer so that timely corrective action may be taken. The highway engineer today must have at his command an effective quality control system which is capable of distinquishing between the types of variation and determining those which are attributable to conditions which can be remedied.

The following report is based upon a series of moisture and density tests made under reasonably normal operating conditions to show the usual deviations that may be expected from the first two types of variations mentioned above.

II EXPERIMENT

This report deals with three projects in District 14 for which frequency distribution curves and standard deviations were determined for density only. With this information as a criterion, routine tests could be made on a job with similar parameters and those results compared with the characteristic range of deviation. In this way, really significant variations in quality are filtered out and pinpointed.

Results are studied graphically so that test results can be evaluated at the time they are made. The record produced provides a ready reference which eliminates the need for reviewing stacks of test reports or long tabulations of figures. In addition, it is effective in illustrating to the layman the results achieved in the construction control.

An example of the application of this system is given for construction control of bases. The normal frequency distribution curve for this material and the arithmetic mean of the test results from which it was constructed are shown. A typical analysis is made and explained.

This example demonstrates the difficulty involved in using an absolute value as a specification criterion. If the value of the arithmetic mean is specified as the acceptable limit, we are in effect requiring higher performance than the material is inherently capable of producing. If the lower limit of the range of normal variation is specified as the acceptable limit, we run the risk of having the contractor aim for this level and thus, in effect, degrading the quality which normally and reasonably can be achieved. If the upper limit of the range is specified, we are obviously creating an impossible situation.

In contrast, the use of a range of values based on the characteristic variability of the material or product provides an acceptance criterion which is compatible with its nature, and which permits a much more meaningful

TABLE 1

PROJECTS FOR DENSITY CONTROL STUDY

Fig. No.	County	Highway	Limits	Number of Volumeter Tests	Required Compaction Ratio, Dry Density, #/Cu. Ft.	Material Triaxial Class	Specification *
1	Williamson	SH 95	From 3.1 Mi. S. of Taylor (Browns Gin) to Travis County Line	136	129	1	Item 802 Gype A Grade 4
	Williamson	US 79	From Bull Branch Bridge in Taylor to 0.7 Mi. W. of Thrall	"	"	"	Item 802 & Specl.
2	Blanco	US 281 & US 290	From 0.5 Mi. N. of Johnson City S. to the Intersection of US 281 & 290, 5.3 Mi. S. of Johnson City	142	126.4	2.8	Flexible Base Special
3.	Williamson	US 79	Bull Branch Bridge in Taylor to 0.7 Mi. West of Thrall	69	123.0	1	Item 802 & Special

*For Additional Information see Appendix A.

interpretation of test results in evaluating its density and moisture.

Test results which fall within this range or band - indicate normal, acceptable performance; any which fall outside the band indicate a need for immediate investigation. In plotting test results on the chart, any adverse trend due to a gradual development of a malfunction or other irregularity, frequently becomes evident in advance of any serious permanent effects from it.

In adopting a system of this kind, it is, of course, necessary to determine characteristic variations inherent in the items to which it is applied. This involves a program of investigation to determine patterns or variations and to thoroughly test the appropriate band criteria.

III RESULTS

Three projects in District 14 were selected for inclusion in this pilot study (see Table 1). Each project had sufficient number volumeter test results to allow a valid statistical analysis of the data.

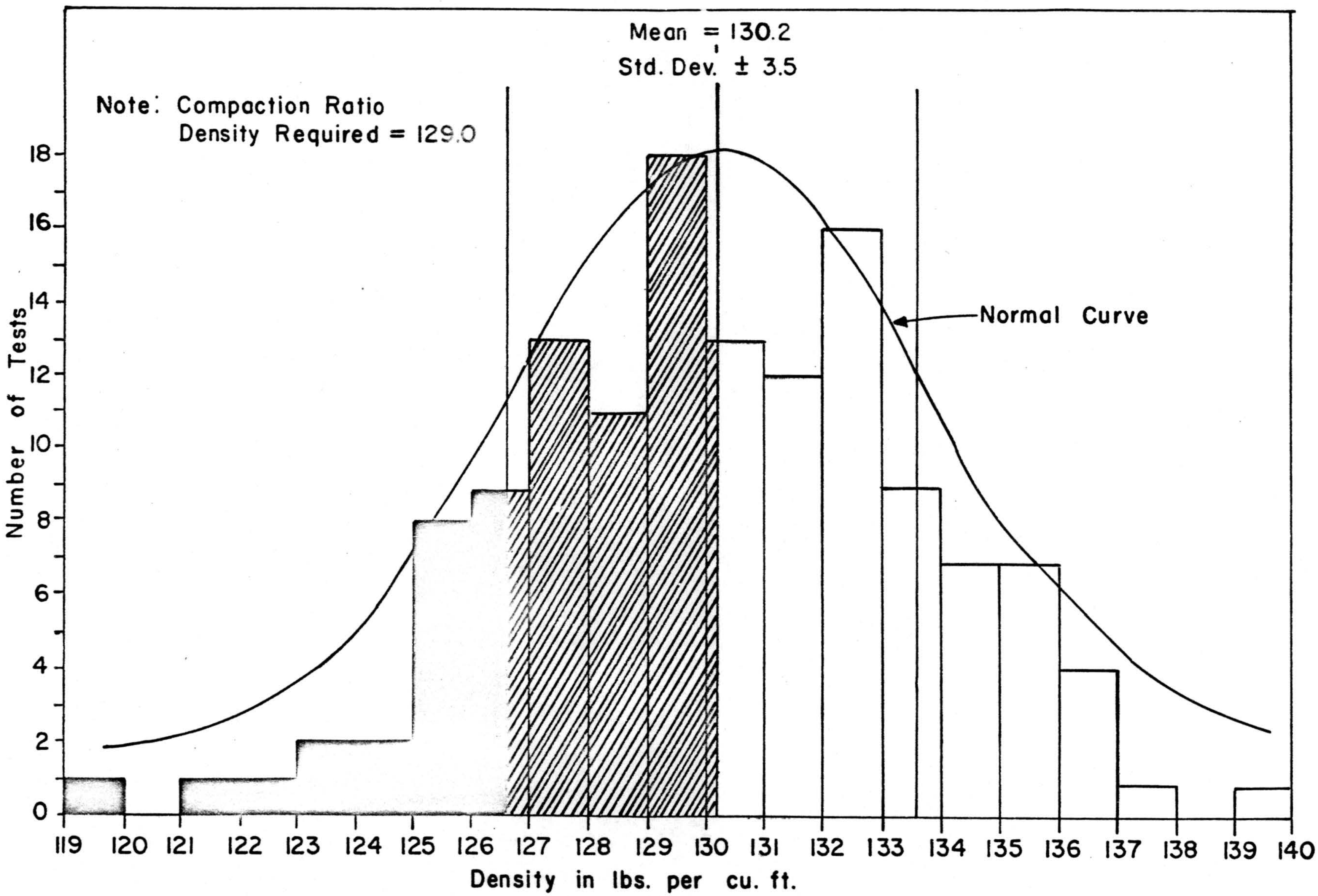
The following assumptions were made for all three projects independently:

(1) Material - the three sources of base remained constant for the three projects, therefore, base material was assumed to remain relatively constant throughout each individual project.

(2) Required Density - the required compaction ratio density as developed in the laboratory was held constant for the material from each pit through the life of each project.

(3) Testing - the criteria for making a volumeter test was that in the opinion of the engineer/inspector

Fig. 1



FREQUENCY DISTRIBUTION CURVE
FOR VOLUMETER TEST RESULTS

the land of base in question appeared to be acceptable for final construction control testing.

(4) Data Selection - All test results, passing and failing, were assumed to be of equal value and to be valid tests. No initial test results were screened out, and no "second" test results taken in areas of earlier failure were included.

Frequency Distribution

Figures 1, 2, and 3 show the frequency distribution curve (grouped in one pound increments) for the dry densities of each project. A normal distribution curve is superimposed for comparison. The distribution of these limited tests shows some departure from the normal curve, and no attempt has been made to determine by statistical procedure whether the curve can be considered normal in the statistical sense. However, it is known that where more extensive and possibly reliable data are available, a normal distribution is usually obtained. Therefore, it was considered that the data were amenable to further treatment by established statistical procedures to demonstrate how they might be used to develop realistic specification limits for a highway material and criteria for judging compliance.

Discussion of Curves

Figure 1 - This project had a required compaction ratio density of 129.0 pounds per cubic foot and the arithmetic mean for the project was 130.2 pounds per cubic foot. The mean density exceeded the required density by plus (+)1.2 pounds and the frequency distribution curve follows expected conditions fairly close indicating that this job had as good construction control as could be expected by current practice and that the selection of the required compaction ratio density was proper and representative for the base material and construction procedure used.

Figure 2 - This project had a required compaction ratio density of 12[illegible].4 pounds per cubic foot and the

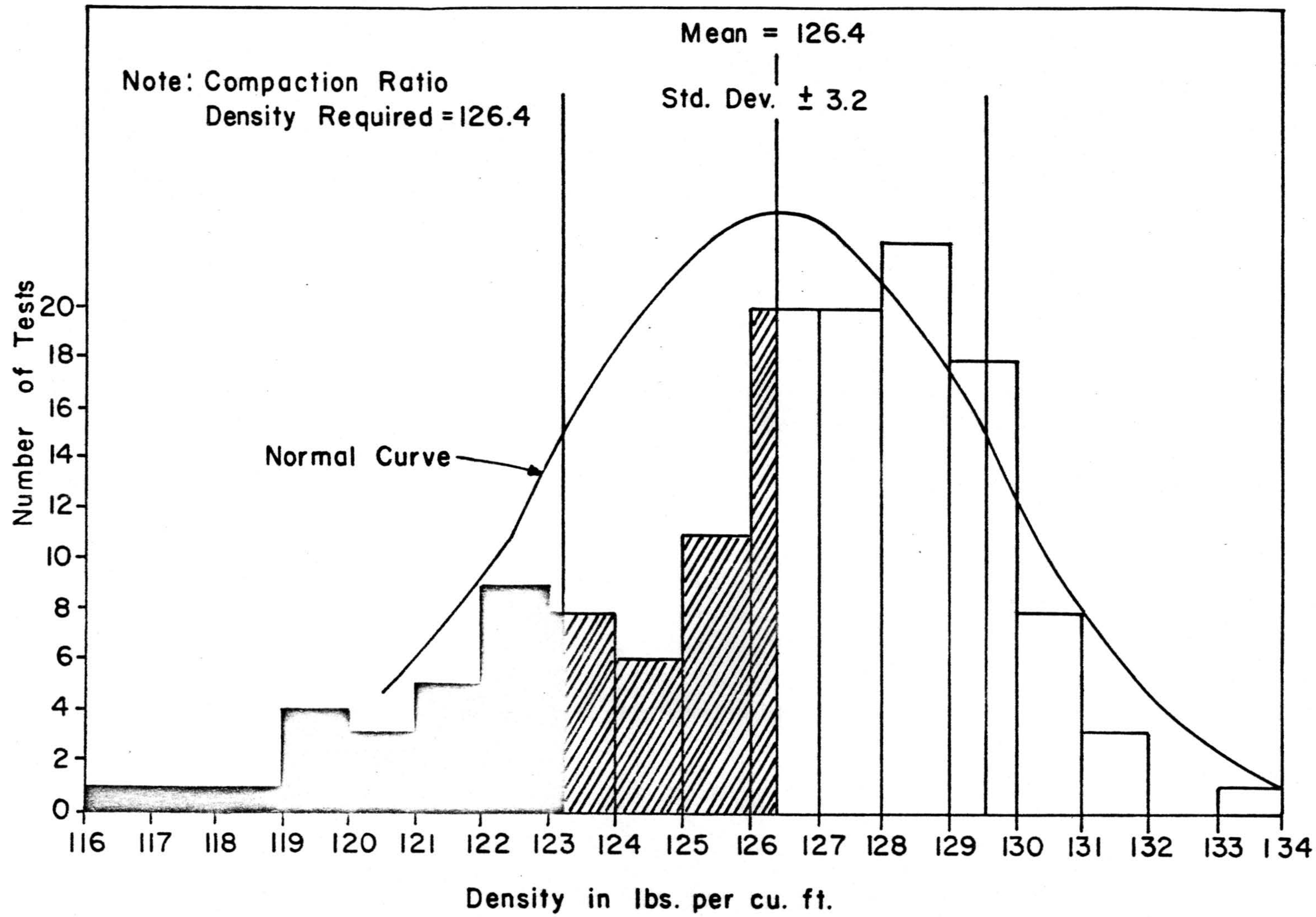
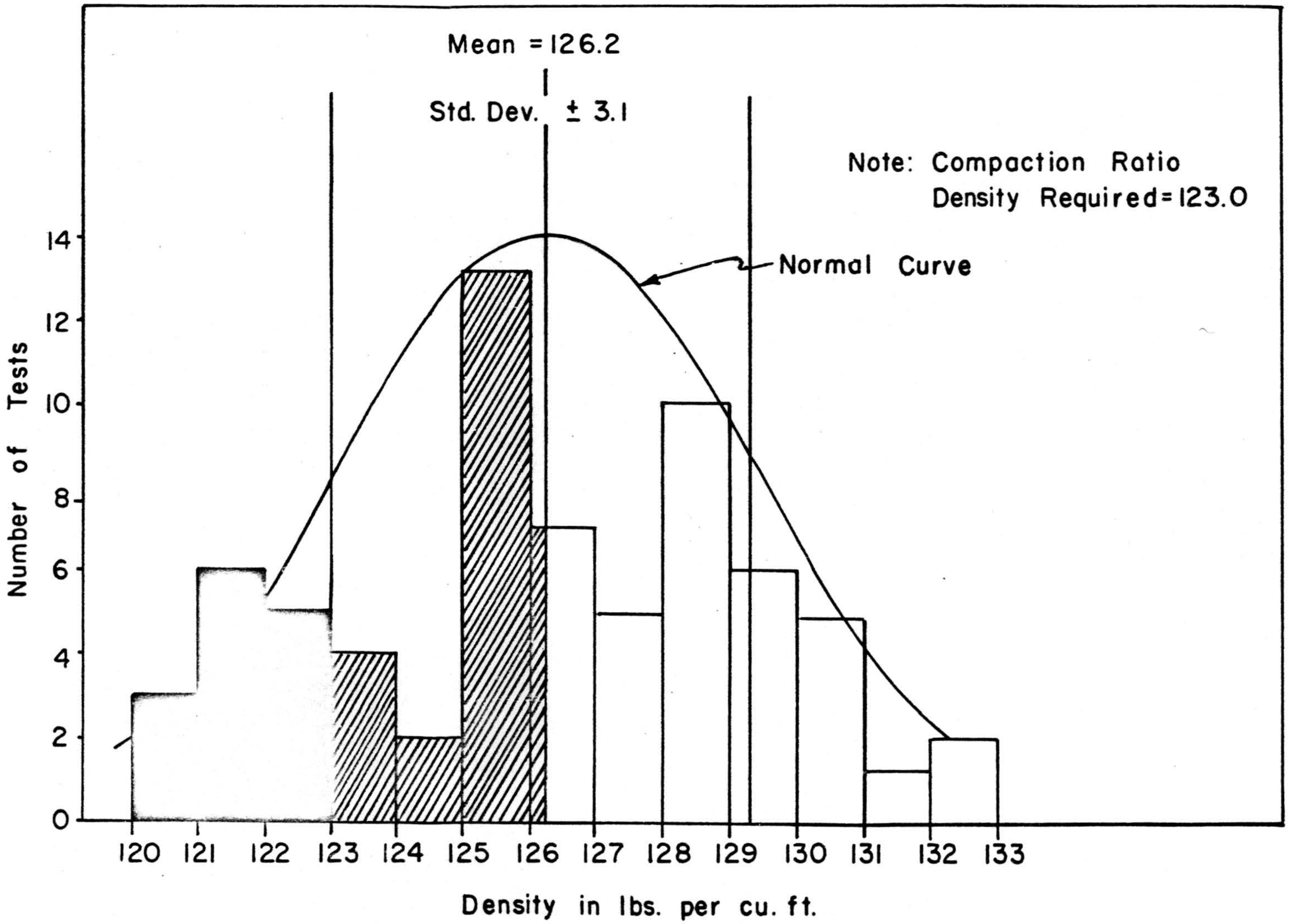


Fig. 2

FREQUENCY DISTRIBUTION CURVE
FOR VOLUMETER TEST RESULTS

Fig. 3



FREQUENCY DISTRIBUTION CURVE
FOR VOLUMETER TEST RESULTS

arithmetic mean for the project was 126.4 pounds per cubic foot. The mean density and the required density were the same. However, the frequency distribution curve is skewed to the right and peaks at a higher density than the mean density. It appears that the selection of the compaction ratio density was proper and representative, however, the large number of low value tests indicate that perhaps some change in construction control would have been in order. Possibly, some change in sprinkling, rolling, handling (to minimize segregation), or testing procedure may have lessened the number of low values.

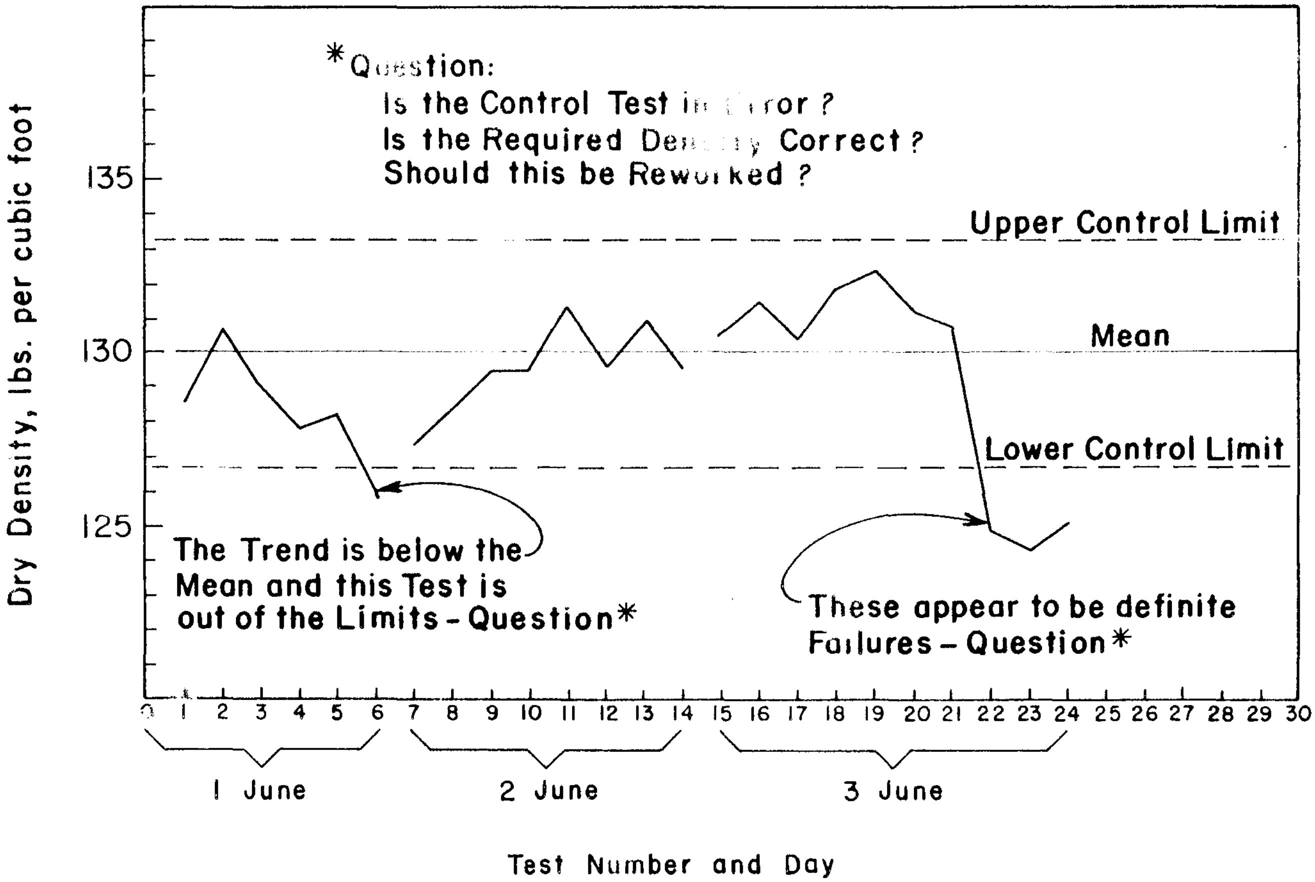
Figure 3 - This project had a required compaction ratio density of 123.0 pounds per cubic foot and an arithmetic mean for the project of 126.2 pounds per cubic foot. The mean density exceeded the required density by plus (+)3.2 pounds and the frequency distribution curve does not follow normally expected conditions very well. It appears that the compaction ratio density selected was not representative of the base material used and that again some change in construction or testing control would have been in order.

IV DISCUSSION AND CONCLUSIONS

Test Results Evaluated by Quality Control Chart Procedures

The "Quality Control Chart", Figure 4, was prepared in accordance with the procedures as described in ASTM Special Technical Publication 15C ("ASTM Manual on Quality Control of Materials").

The chart assumes one standard deviation as an acceptable variation. The purpose is to provide criteria for detecting departures from a specific requirement that are due to causes other than chance or normal expectation. These criteria are derived from the laws of chance variation and failure to satisfy them is taken as evidence of an assignable cause of variation - i.e., the material is actually off



TEST RESULTS:

Number of Tests	30
Density Required (Average)	130.0 lbs. per cu. ft.
Center Line	130.0 lbs. per cu. ft.
Standard Deviation (σ) From Similar Previous Job	± 3.2 lbs. per cu. ft.
Control Limits*	± 3.2 lbs. per cu. ft.

* To be selected by the Engineer

SAMPLE
QUALITY CONTROL CHART

Fig. 4

specification. In this sense, the chart can be considered a basis for action such as rejection of the density of the base or adjustment of the construction technique. It is known that in some cases selected densities have not proven to be entirely realistic and useable. Thus the employment of statistical data analysis offers a means of solving the problem.

The above illustration presents a method for analyzing volumeter tests results. This is an area where control limits have been established by empirical methods. The selection of the control limits are subject to further study as experience is gained.

In the above example, one standard deviation was used to establish the control limits on Figure 4. Using this criteria theoretically 68 per cent of all the test results in this report would fall between the control limits and 84 per cent would be above the allowable lower limit of minus one standard deviation. Project 1 (Figure 1) had 86 per cent of all tests above the allowable lower limit Project 2 (Figure 2) had 83 per cent, and Project 3 (Figure 3) had 80 per cent. This is all the tests included in the white or gray area. If two standard deviations had been used for setting the control limits about 95 per cent of all test results would have fallen between the established limits.

Thus, by determining the proper control limits for a given material, operation or test based on job performance, a realistic control can be established. The selection of one standard deviation as an acceptable limit is arbitrary. For the three projects studied one standard deviation varied from 3.1 to 3.5 pounds per cubic foot. The authors suggest that tighter controls be used and recommend the "probable error" (the standard deviation x 0.6745) be selected as an acceptable variation. This would be approximately 2 per cent in this study.

The specific purpose of this report is to establish a means for analyzing compaction control test data when using the volumeter in order to establish a basis for correlating and comparing nuclear type instrument results to volumeter results. However, the principles used herein have application in many other areas that should not be overlooked.

V RECOMMENDATIONS

It is recommended that this same study be repeated on an interstate project using a high type uniform base material specification such as Standard Specification Item 248, good quality control, and under the most ideal conditions. Volumeter and nuclear type instruments should be run in parallel for compaction control and results reported in the "purest" form possible (both wet density and moisture in pounds per cubic foot) and all irregularities documeted (segregation of base, not representative material, test run for contractor's information, etc.).

It is recommended we engage in education, search, and development on this type of approach to quality control in all areas and particularly as a part of the overall project of nuclear type instrument evaluation. This objective would be to develop a practicable system for the improved construction control of moisture and density in base compaction. This should include detailed procedures and operating techniques, thoroughly test, evaluate and adjust the system by means of experimental applications to the various phases of construction on actual projects and identify and formulate specification revisions necessary to the effective implementation of the system.

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A P P E N D I X

SPECIFICATIONS

US 281 & 290 - Blanco County
From 0.5 Miles North of Johnson City South to the Intersection of US Highways 281 & 290. 5.3 Mi. South of Johnson City

Flexible Base - Special

Ret.	2" Screen	0%	L.L. not to exceed	35
	¼" "	45-75%	P.I.	5-12
	#40 Sieve	60-80%	Linear Shrinkage	7%

Triaxial Class = 2.8

Desired Density = 126.4 Lbs. Cubic Foot

SH 95 - Williamson County - C 321-1-15
From 3.1 Miles South of Taylor (Browns Gin) to Travis C/L

Flexible Base   Item 802   Type A   Grade 4

Ret.	2" Screen	0%	L.L. not to exceed	45
"	1 3/4" "	0-10%	P.I.	4-12
"	#4 Sieve	45-75%	Wet Ball	50%
"	#40 "	65-85%		

Compaction Requirements   2nd Course   100%

Triaxial Class = 1

Desired Density = 129.0 Lbs. Cu. Ft.

US 79 - Williamson County - C 204-4-16
From Bull Branch Bridge in Taylor to 0.7 Mi. West of Thrall

Flexible Base   Item 802 and Special

Ret.	1 3/4" Screen	0-10%	L.L. not to exceed	45
"	#4 Sieve	45-75%	P.I.	4-12
"	#40 "	65-85%	Wet Ball	50%

Compaction Requirements   2nd Course   100%

Triaxial Class = 1

Desired Density = 129.0 & 123.0 Lbs. Cu. Ft.

ACKNOWLEDGEMENT

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