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16. ABSTRACT

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Soil stabilization, cement treated base, titration test, statistical methods, specifications, quality control, statistical sampling, cement content, analysis of variance

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HIGHWAY RESEARCH REPORT

CONTROL OF CEMENT IN CEMENT TREATED BASE

68-20

STATE OF CALIFORNIA

TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 631149

Prepared in Cooperation with the U.S. Department of Transportation, Bureau of Public Roads January, 1968

STATE OF CALIFORNIA—TRANSPORTATION AGENCY RONALD REAGAN, *Governor*

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

January 1968

M&R No. 631149

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

CONTROL OF CEMENT

IN

CEMENT TREATED BASE

GEORGE B. SHERMAN
Principal Investigator

ROBERT O. WATKINS
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Very truly yours,

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Materials and Research Engineer

REFERENCE: Sherman, G. B. and Watkins, R. O., "Control of Cement in Cement Treated Base", State of California, Department of Public Works, Division of Highways, Materials and Research Department, Research Report 631149, January 1968.

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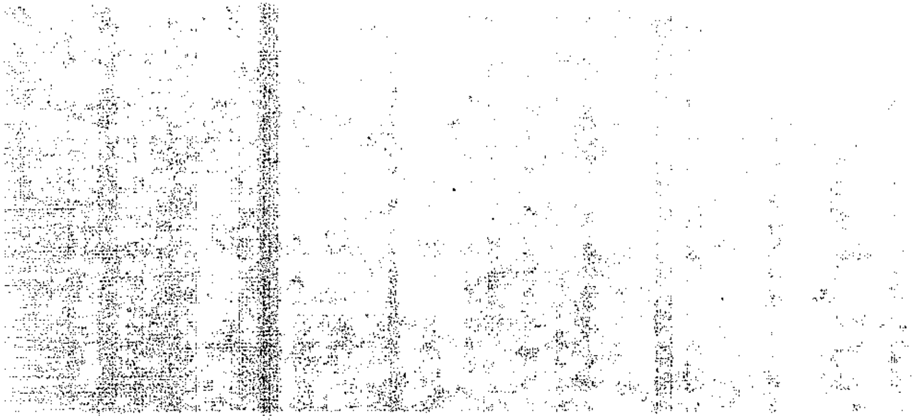
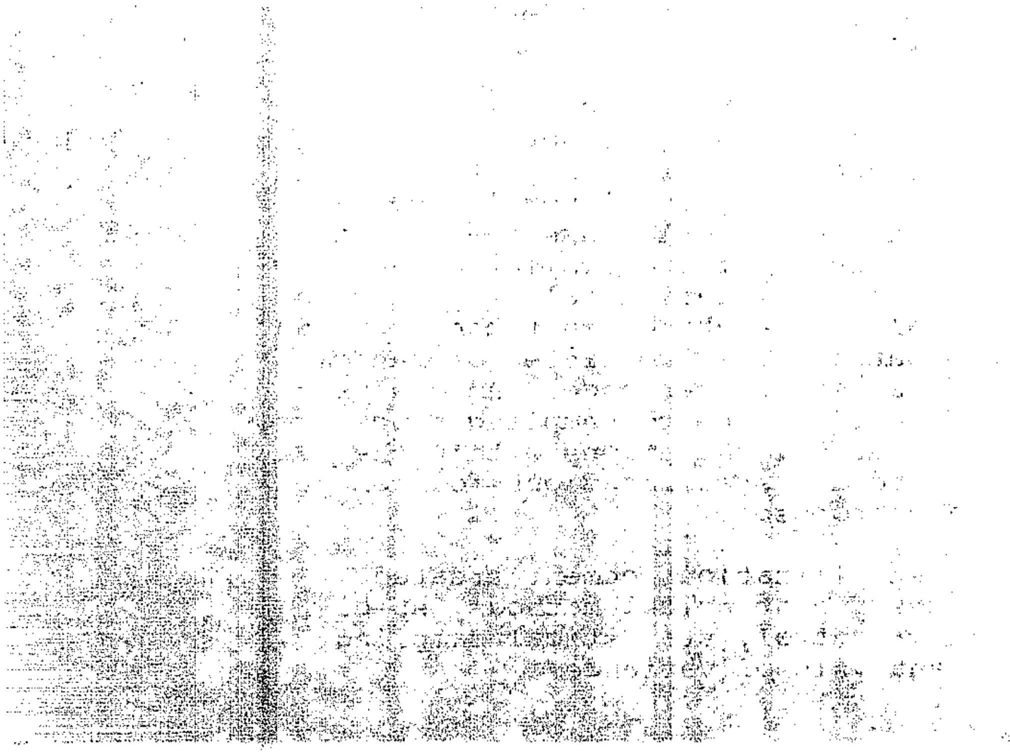
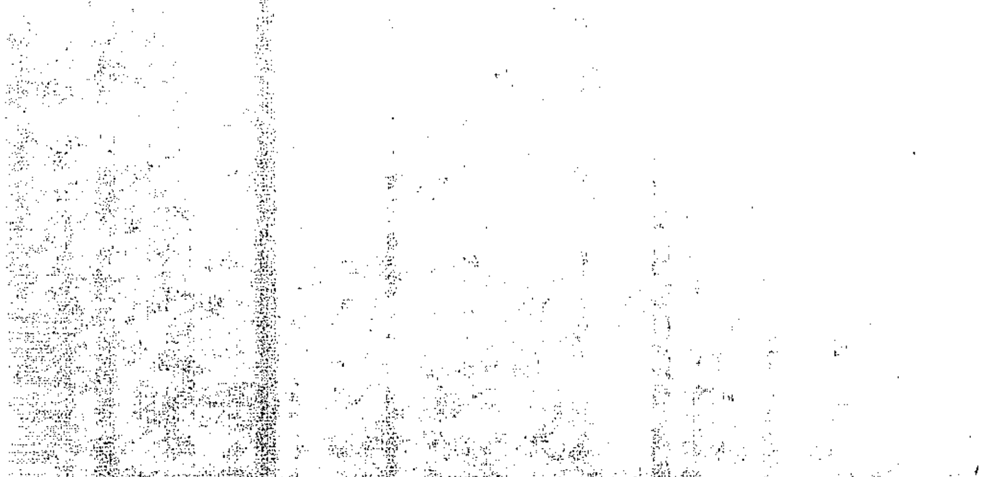






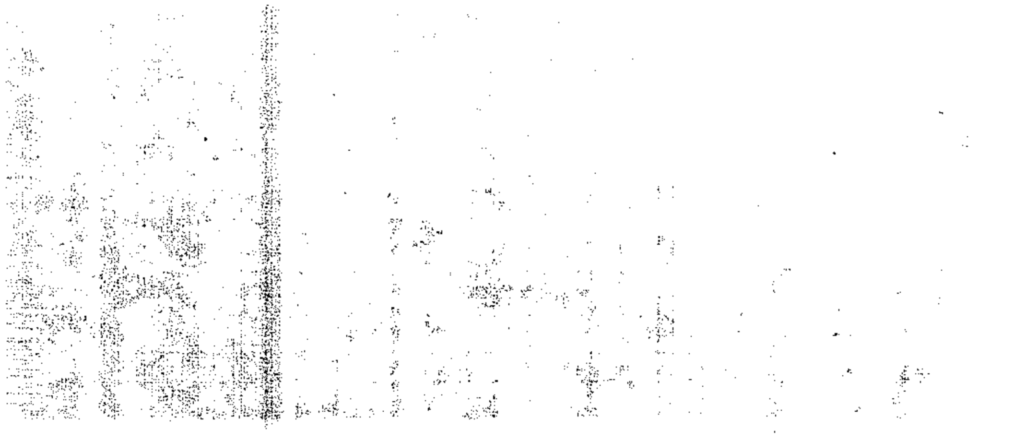
ACKNOWLEDGMENTS

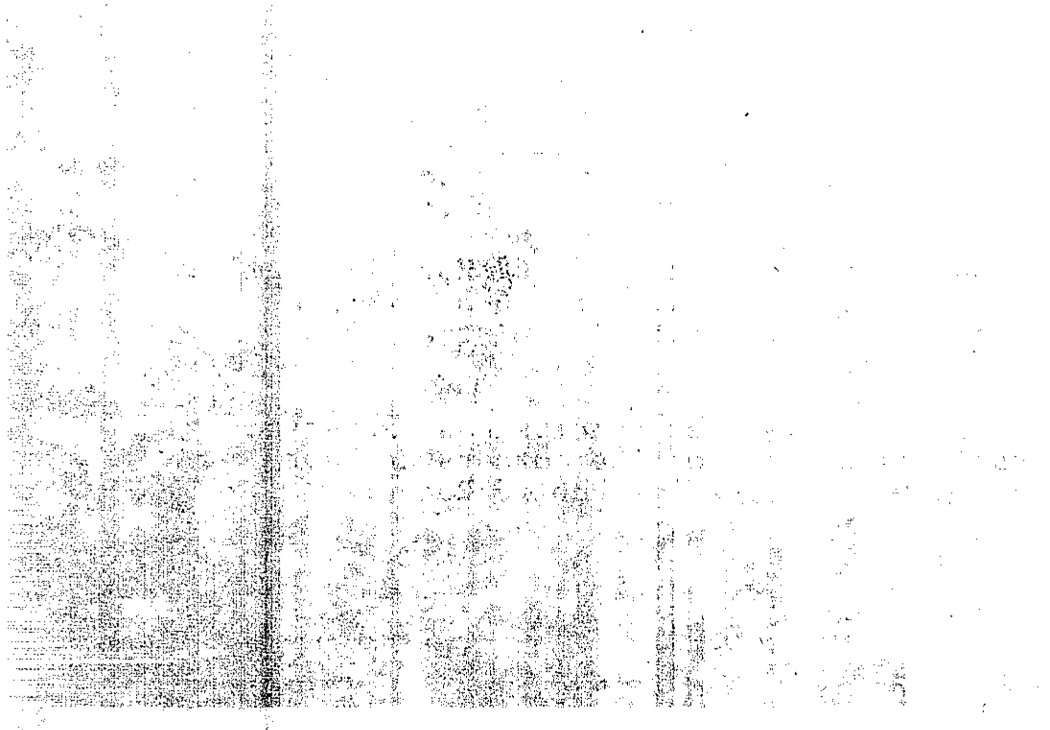
The authors wish to express their appreciation to Messrs. Ed Coble, Ed Silva and William Gilfillan, resident engineers on the projects studied, for their cooperation in obtaining data for this investigation.

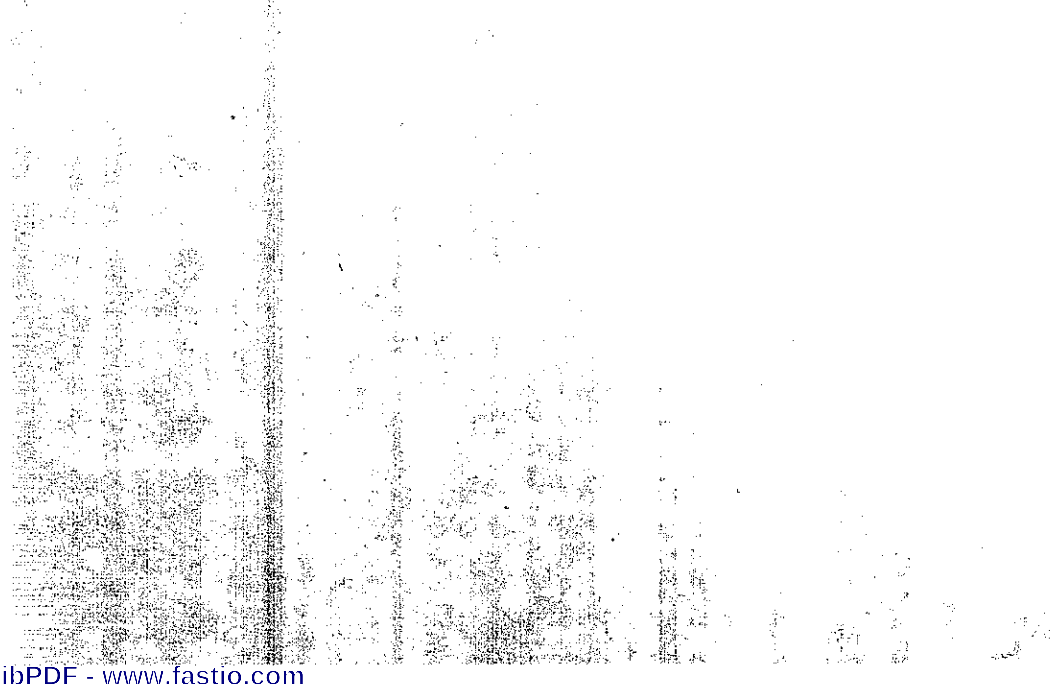
Special thanks are extended to Mr. Ernest Zube and his staff of the Pavement Section of the Materials and Research Department for providing the personnel to perform the field sampling and testing and for their helpful suggestions and review of this report.

This work was done under the 1967-68 Work Program HPR-1(5), F-1-4 in cooperation with the U.S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads.

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







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I. INTRODUCTION

This research project concerns the investigation of a new, fully automatic cement treated base (CTB) mixing plant. As modern equipment is developed or improved and production rates are increased, it is necessary to re-evaluate present specifications and control procedures. This study is one of a series of projects by the California Division of Highways in cooperation with the Bureau of Public Roads for statistically evaluating variations in construction materials.

Test Method No. Calif. 338[1] "Determination of Cement Content in Cement Treated Aggregate by the Method of Titration" was used for evaluating the uniformity of mixing and distribution of cement in cement treated base material during construction. Two different titration procedures are given for this method: first, an acid base method for use with aggregates that do not react to hydrochloric acid; and second, a constant neutralization method for use with aggregates that react to hydrochloric acid. The acid base test can be performed in about one hour and eight samples can be tested at one time. The constant neutralization test can be performed in about one hour and four samples can be tested at one time.

Although funds were provided for investigating one new fully automated cement treated base mixing plant, three other projects were investigated in a similar manner prior to this study. The test data from two of these projects (1 and 3) are included in this report. Project 2 is not reported since testing and sampling errors invalidate the data, which are not representative of the actual work done on the project.

II. OBJECTIVES

The study involved several different objectives:

1. To measure the variation in cement content which occurs in cement treated aggregate.

2. To determine the reliability of Test Method No. Calif. 338 "Determination of Cement Content in Cement Treated Aggregate by Method of Titration."

3. To determine variance due to sampling and testing, and materials variance.

4. To establish flexible specification limits and control procedures which will control the percent cement in cement treated base.

5. To evaluate the use of analysis of variance, using random samples, for evaluating improvements in technology.

III. CONCLUSIONS

It is concluded from data gathered in this study, and by comparison with data gathered from the previous study, that:

1. The titration test as described in Test Method No. Calif. 338 is accurate and reproducible for determining the amount of cement in a sample of cement treated base.

2. A more uniform distribution of cement was obtained when an automatically controlled, continuously fed mixing plant was used.

3. Based on this study, the variation of cement presently allowed in California specifications appears to be too restrictive. The absolute requirement is not always being met even on well controlled construction projects.

4. The procedure followed when sampling cement treated base, particularly from a windrow, is very important. Erroneous test data will, of course, result from non-representative samples. However, when the sampling is done properly, very little sampling variance is introduced into the final test results. Less sampling error is introduced when obtaining samples from material which has passed through a spreader box than when sampling from a windrow.

5. It is concluded (from the job control compressive strength records of the three projects studied) that sufficient cement is being used to compensate for the variation in cement distribution.

6. Overall, the variation in cement content of cement treated materials was greater than the sampling or testing variation.

7. The use of Analysis of Variance for evaluating the improvements brought about by changes in technology has proven to be very effective.

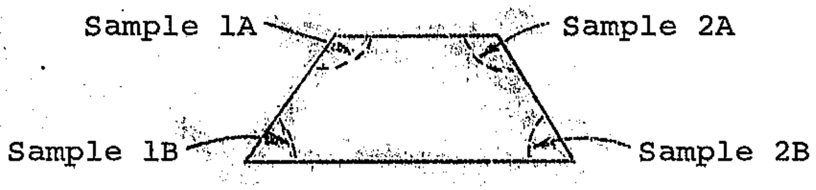
IV. MATERIALS, EQUIPMENT AND PROCEDURES

The data for three construction projects using plant-mixed cement treated base are presented for this study. The aggregates, mixing, handling and sampling techniques, as well as the equipment, differed to some extent on each of the projects.

Project 1:

On Project 1, a 3,000 pound Barber-Greene pug mill was used to mix the aggregate and cement. The mixed material was hauled to the job in bottom dump trucks, discharged into controlled windrows, and spread with a paving machine. The diagram below will help explain the sampling procedure used.

Cross-Section of Windrow



After removing the surface material, samples were taken at each toe of the windrow and at each of the top edges. Samples 1A and 1B, shown on the diagram, were combined and then split to make two test samples. This procedure was duplicated on the opposite side of the windrow. The acid base titration test method was used.

The planned cement content on this job ranged from 2.4 to 3.0 percent but was at 2.4 percent the majority of the time.

Project 2:

The data was not included because it was not considered valid due to sampling errors.

Project 3:

The CTB on Project 3 was mixed in a Heatherington-Berner continuous mix plant, hauled to the street in end dump trucks, and dumped directly into a spreader box. Samples were taken after the material was spread on the roadbed, but before compaction. Testing was performed according to the constant neutralization method. The planned cement content was at 3.0 percent.

Project 4:

The mixer used was a Barber-Greene continuous mixing pug mill which was modified and operated by the Universal Transport Company. The aggregate and cement were proportioned by use of continuous weighing belt scales (Figure 1).

Each of the aggregate weighing belts was suspended on a scale having a large dial face so that the weight of material on the belt could be observed at any time. Adjustments in aggregate weights were controlled by the use of electric motors which facilitated the movement of the gate of the hopper over the belts. These weighing belts were short and traveled at a constant speed so that each portion of the aggregate remained on the belt for exactly two seconds. In other words, two seconds elapsed between the time the aggregate passed through the hopper gate and the time it was discharged from the weighing belt.

The cement weighing belt was suspended on a beam balance. Adjustments to the weight of cement were automatically controlled by mercury switches and an electric motor which adjusted the gate of the cement hopper. This belt traveled considerably slower than the aggregate belts and any given portion of the cement remained on the belt for six seconds.

The cement storage hopper was designed by Universal Transport and was constructed so that the cement was being constantly circulated through the segmented storage silo and into the hopper. The hopper was kept full with the excess cement being recirculated back through the silo. The object of this system was to keep a constant head on the hopper and to insure a uniform cement supply. The plant was capable of producing around 550 tons of mixed material per hour.

The CTB mix was transported to the roadway in end dump trucks. A Jersey spreader mounted on a D6 Caterpillar was used to lay the mix in a twelve foot spread. The spread was then trimmed to grade with an automatic CMI subgrade trimmer. The samples were obtained before compaction. A 4.0 percent cement content was planned for the entire project but it was later decided to increase the cement content to 5.0 percent for the top lift of the mainline section over a portion of the project.

The CTB mixer was completely dismantled and moved to another section of roadway which was being constructed under this contract. The total moving and set up time required was about eight hours.

V. SAMPLING AND TESTING

The sampling and testing plan used for this research was essentially the plan presented to the various state highway departments by the U. S. Bureau of Public Roads through their regional workshops. The full details of this statistical survey outline may be found in either Reference 2 or 3. In general, it consisted of randomly locating fifty sampling locations on each of three projects; taking two independent samples at each testing location; and splitting the samples for independent tests on each sample portion. Thus, a total of four results were available for each sampling location. The duplicate sampling provided a measure of the variance in the sampling process and the duplicate testing on each sample provided a measure of the reproducibility of the test.

At the beginning of the earlier study (Projects 1 and 3), it was observed that some of the personnel assigned to do the sampling had the misconception that a random sample is a haphazardly obtained portion of the material taken at some unscheduled location. On the contrary, a random sample must be taken with care and accuracy and at a location specifically chosen by an accepted random procedure. For this study a table of random numbers was used to randomly determine the sampling location (Table A).

On Projects 1 and 3, sample locations were randomly selected on the basis of roadway stationing. For Project 4, a stratified random sampling procedure based on time was used whereby one sample was selected during each four-hour period of the normal eight-hour work day. Because of the normal time required to prepare and test a sample, the portion of the workday after 3 p.m. was excluded from sampling.

On Project 4, in addition to the sampling plan previously described, a series of 44 loads were tested by sampling four consecutive truck loads at eleven different locations, the purpose being to check the batching and mixing variations over short periods of time. These locations were not selected on a random basis but were added to the sampling schedule by taking supplemental samples between the random samples as time permitted.

VI. ANALYSIS OF DATA

The range in cement content varied from project to project but the overall average content on each project was very close to the amount specified by the Engineer for the particular project. In order to present all of the data in a single analysis, the individual test results were presented on the basis of their variation from the planned cement content.

The design of this experiment provided an estimate of the variance introduced by the testing process, the sampling process, and the variance inherent in the material being tested. The amount of variance attributed to each of these sources is shown in Figure 2. The small amount of variance attributed to the testing procedure indicates that the test method is reliable and reproducible.

The variance introduced by sampling is considerably greater for Project 1 than for Projects 3 and 4. As is discussed under "Materials, Equipment and Procedures", samples on Project 1 were taken from windrows while samples from Projects 3 and 4 were taken from in-place uncompacted material. Although it is not possible to draw definite conclusions from the limited information available, this study does indicate that less variance is introduced when sampling after the aggregate is spread.

Among the sources of variance, the actual variation in the cement content is by far the greatest single source. The extent of this variance differs greatly from project to project as seen in Figures 2, 3, and 4.

Comments on Project 4:

Due to the high speed mixing operation on Project 4, only 38 of the 50 randomly selected locations were actually sampled and tested before the project was completed. Six tests were in the area where 5.0 percent cement was planned and 32 were in the area where 4 percent cement was planned.

At one location the test results revealed a cement content of almost 2 percent more than the planned 4.0 percent. The results of the tests at this location were deleted from the final calculations because the high cement content was due to an assignable cause. The lack of control in the cement distribution was caused by the cement being in an extremely loose, free flowing condition. In this case, the cement acted like a fluid and flowed over the side of the weighing belt and disrupted the automatic weighing system. Due to this condition, the cement feed and weighing system was operated without the automatic controls for about four hours while this condition existed.

Samples of the cement obtained before, during, and after the problem of the free flowing cement were chemically analyzed. The analysis indicated no significant differences between the cements. However, there was some speculation that the cement contained an additive to make it free flowing, but this suspicion was not confirmed.

The overall variance is much lower on Project 4 using automated equipment than on Projects 1 or 2.

A summary of the test data gathered by the consecutive truck plan is also included in Figures 2 and 4. The overall standard deviation of these samples is estimated to be 0.243 when using the formula based on the range between values of the sub-samples in each of the groups of 4 tests.[4] Since one sample was taken from one truck of material, sampling and testing variances could not be determined and were assumed to be comparable with the variances determined by the original plan and the materials variance was determined by subtracting these assumed variances from the overall variance. Using this method of calculation, the material variance between 4 consecutive truck loads of material (0.037) is only slightly higher than when duplicate tests were made on two side-by-side samples (0.027).

VII. DISCUSSION OF PRESENT CONTROL PROCEDURES

According to the 1964 edition of the Standard Specifications of the California Division of Highways[5], the cement content of plant-mixed CTB is not to vary from the cement content designated by the Engineer by more than ± 0.4 percent based on the weight of the aggregate. The histogram presented in Figures 3 and 4 shows the range of cement content and the distribution of results for the three projects and the continuous truck samples from Project 4.

The basic premise of this study is that all samples were obtained from presently acceptable construction. All material included in this survey was accepted by the Resident Engineer using independent inspection and testing procedures. The sampling procedures used for this investigation were the same as those used for construction control except for random sampling.

As shown in Figure 3, approximately 31 percent of the CTB placed on Project 1 did not meet the ± 0.4 percent requirement; on Project 3, (Figure 3) 15 percent was found to exceed this requirement. On Project 4, (Figure 4) only 6 percent exceeded specification. This does not include the four tests with assignable cause for error. These values were based on the calculated standard deviation and the assumption that the material was normally distributed.

Routine test results, gathered independently of this study from many projects throughout the State since the adoption of the test method, show a reduction in the overall variation in cement distribution in CTB after the adoption of this test. Figure 5 demonstrates this improvement. Presently, approximately 20 percent of all routine job control tests fall beyond the specification limits, that is, outside of ± 0.4 percent of the intended cement content. These, of course, were not randomly selected samples. However, the random samples taken for this survey indicated an average of about 18 percent outside the limits for the three projects studied.

Both the test data gathered for this study and the distribution shown in Figure 5 indicate that the present requirements for the cement content of CTB are not being completely met. On each of the three projects, all the normal field control tests of seven-day compressive strength were above the 400 psi design strength. This indicates that the cement content is being set high enough to assure sufficient strength, thus compensating for the variation in percent of cement.

There are two related variables that should be considered in the control of CTB. The control can be relaxed providing additional cement is added to compensate for the increase in variation, thus assuring that minimum design standards are met. Since both cement and control cost money, there is a balance point between these two where costs are minimized. The exact determination of this point is beyond the scope of this study.

VIII. PROPOSED CONTROL PROCEDURES

The test data from Projects 1, 3, 4, and from the consecutive truck samples are presented in control chart form in Figures 6 and 7. These control charts and the histograms of Figures 2 and 3 indicate that the current specification limits for control of cement content are too restrictive. Even though each of the three projects was considered to represent acceptable construction, it would not be practicable to establish a limit which would encompass all of the test results observed.

However, the batching and mixing equipment used on Project 4 are probably the most efficient currently available and any proposed specifications should encompass the major portion of this material. Based on the variation which occurred on the three projects studied, the following specifications are suggested and generally should include the following points:

1. One sample should always consist of the average of four observations or sub-samples. Each sub-sample would be taken from different trucks or from different locations in the roadway. The one average value of the four tests would represent a lot of material. A lot of material could represent 4 or 8 or more hours of production.

2. The limits of the average cement content of a sample, as determined by averaging the four sub-sample results, shall be within the range of $\pm$ 0.5 percent from the planned cement content.

3. Unless waived by the engineer, no one individual titration test result shall differ from the planned cement content by more than $\pm$ 0.7 percent.

4. The Resident Engineer should have the prerogative to accept, reject, or correct the cement treated base when an individual result is outside the limit of $\pm$ 0.7 percent from the planned cement content providing the average is within $\pm$ 0.5 percent of the planned cement content.

The average of four sub-samples would provide an accurate measurement of the overall amount of cement being added to the aggregate while the variation of the individual sample results from the planned cement content would provide a good indication of the batching uniformity and mixing efficiency of the equipment. The variation in test data is reduced by averaging individual results. The reduction in variance is apparent to some extent in the control charts of Figures 6 and 7.

The overall average cement content on each of the three projects studied was close to the amount specified for the respective projects; therefore, too much cement at one location would indicate inadequate mixing and a deficiency at some other location. Thus the same restrictions should be applied to both the upper and lower limits.

In order to use the suggested procedures effectively, the location for obtaining a sample must be selected by some acceptable random sampling procedure. Each sample should consist of four observations, or sub-samples, obtained according to a pattern which will provide adequate test results to evaluate both the transverse and longitudinal distribution of the cement.

Sampling should be performed after the material has passed through the paving machine or spreader box and before compaction. Samples taken at this time will check the combined efficiency of the mixer and paving machine. If a large variation is found between the sub-samples, indicating poor mixing, it may be necessary to take special (non-control) samples in order to isolate the trouble.

IX. APPLICATION OF PROPOSED SPECIFICATIONS

As an example, the proposed specifications are applied to the three projects covered in this report. The data shown on the control charts (Figures 6 and 7) indicate the number of tests that are out of the proposed specification of ± 0.5 and 0.7 percent cement for the average and individual tests. A tabulation of the tests is shown on the following table:

NUMBER OF TESTS OUT OF THE PROPOSED SPECIFICATIONS

	Limits of ± 0.5% For Average Test Value Determined from Averaging 4 Subsamples		Limits of ± 0.7% For Individual Tests Varying from Their Average of 4 Tests	
PROJECT 1 N=46 Locations 184 individual tests	6*	(13%)	10**	(8%)
PROJECT 3 N=50 Locations 200 Individual tests	2	(1%)	1	(1%)
PROJECT 4 N=38 Locations 152 Individual tests	2***	(5%)	4****	(3%)
PROJECT 4a Continuous truck samples N=44 Locations or 11 Series 44 Individual tests	2	(5%)	1	(2%)

* The control chart (Figure 6) indicates 1 of the 6 average tests (4 sub-samples) to be out of control due to extremely wide variations in the 4 sub-samples.

** The control chart (Figure 6) indicates 4 of the 10 individual tests came from one sub-group of 4 samples.

*** The control chart (Figure 7) indicates 1 of the 2 average tests (4 sub-samples) was out of control due to the free flowing cement previously described in this text.

**** The control chart (Figure 7) indicates all 4 tests came from 1 group where nonuniformity was due to the free flowing cement.

Statistically speaking, 95 percent or more of all the averages of four tests and the individual test variations will meet the proposed specifications. The one exception is Project 1 where the average and individual values of 87 and 93 percent of the tests would comply. However, it is believed this project would also come close to complying 95 percent or more if the samples had been taken after spreading and not from the windrows. Those values were based on the calculated standard deviation and the assumption that the material was normally distributed.

An average and individual allowable variation in cement content of ± 0.5 and ± 0.7 percent appears to be a reasonable limit which would include nearly all of the material placed on the three properly controlled construction projects.

X. CLOSING REMARKS

It is recommended that the proposed specifications be used on a <u>trial basis</u> on several contracts for control purposes.

The use of control charts with the proposed specifications should provide the Resident Engineer with a valuable management tool for making decisions for accepting or rejecting material and for job records. A better overall picture of actual materials being placed on the job as well as trends also can be readily determined.

XI. REFERENCES

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3. Sherman, G. B., Watkins, R.O., and Prysock, R. H., "A Statistical Analysis of Embankment Compaction." Highway Research Record No. 177. Highway Research Board Publication No. 1508, 1967. pp. 157-185.

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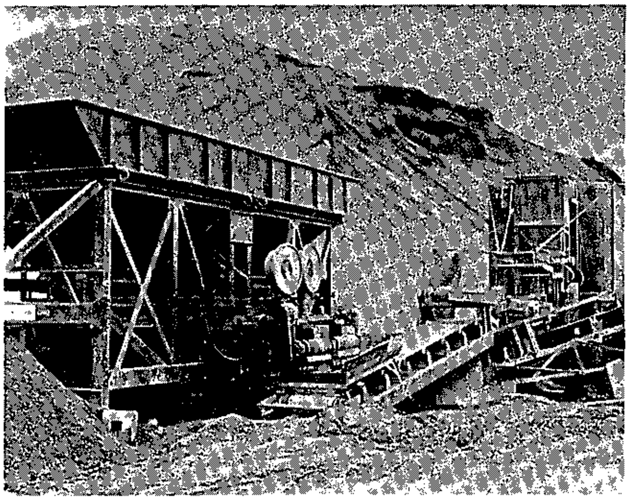
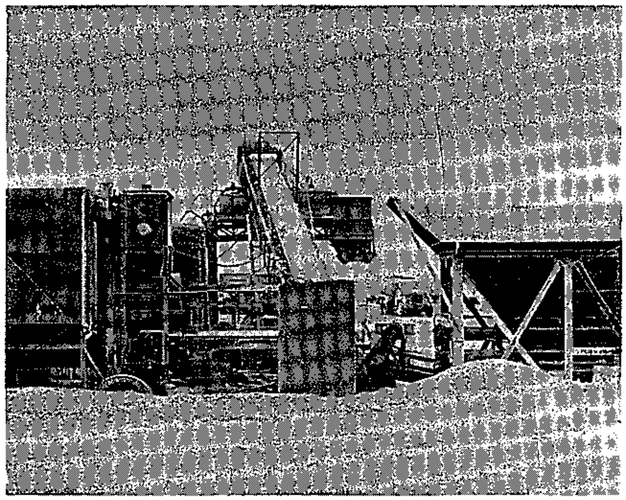
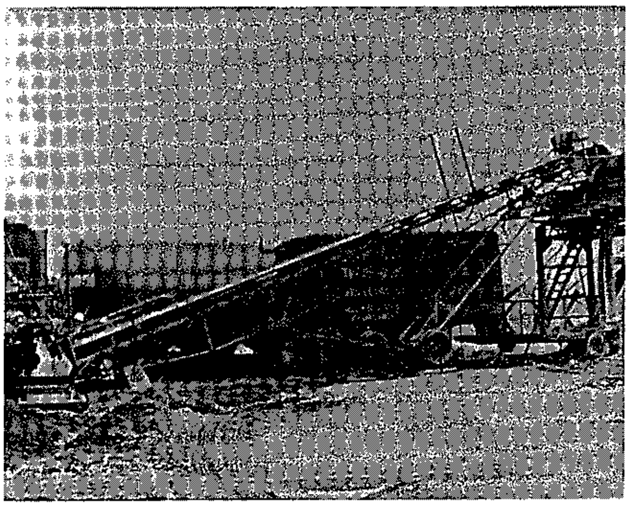
Figure 1



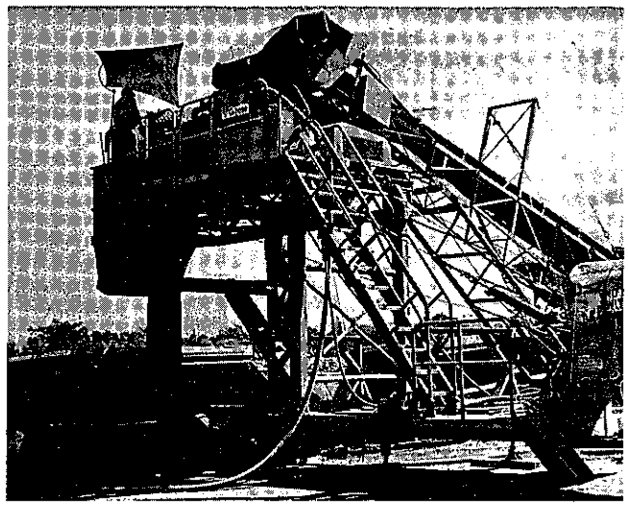
Aggregate storage bins and automatic weighing device on the left; cement storage bins and automatic weighing device on the right. Aggregate stockpile in the background.



Aggregate storage bins on the right; cement storage bins on the left; conveyer belt that carries the aggregate and cement to the pugmill in the middle.



Conveyer belt that carries the aggregate and cement to the pugmill. Cement silo and electrical generating unit in the background.



Barber-Greene pugmill for mixing the aggregate, cement and water.

Figure 2

PROJECT	1	3	4	4a *Truck Samples*
Planned Cement Content %	2.4 *Varies Usually*	3.0	4.0 & 5.0 *(Combined)*	4.0 & 5.0 *(Combined)*
Arithmetic Mean *(± From Planned Cement Content)*	+0.06	+0.02	+0.11	+0.16
Material Variance	0.066	0.058	0.027	0.037
Sampling Variance	0.067	0.006	0.007	0.007 *(Assumed)*
Testing Variance	0.020	0.014	0.015	0.015 *(Assumed)*
Overall Variance	0.153	0.078	0.050	0.059
Overall Standard Deviation	0.391	0.279	0.223	0.243
Number of Observations	184	200	148	44

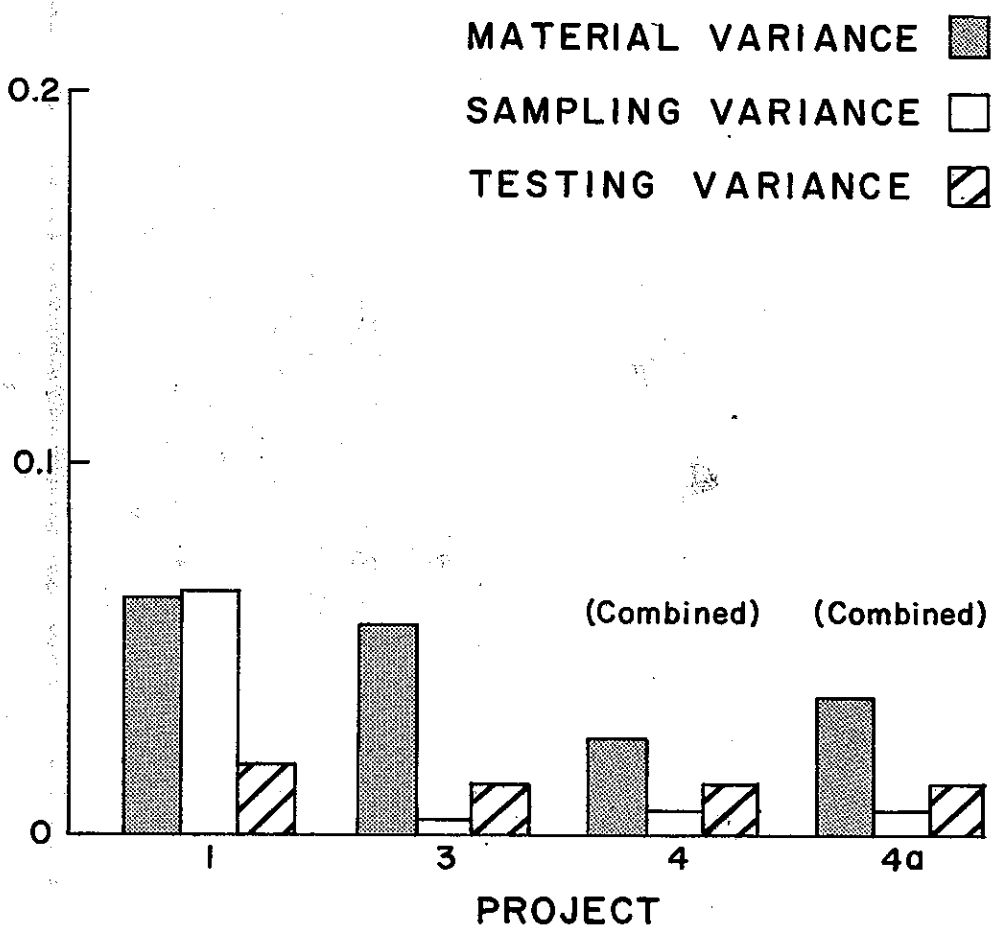


Figure 3

HISTOGRAM SHOWING DEVIATION OF PERCENT CEMENT BY TEST FROM PLANNED CEMENT CONTENT

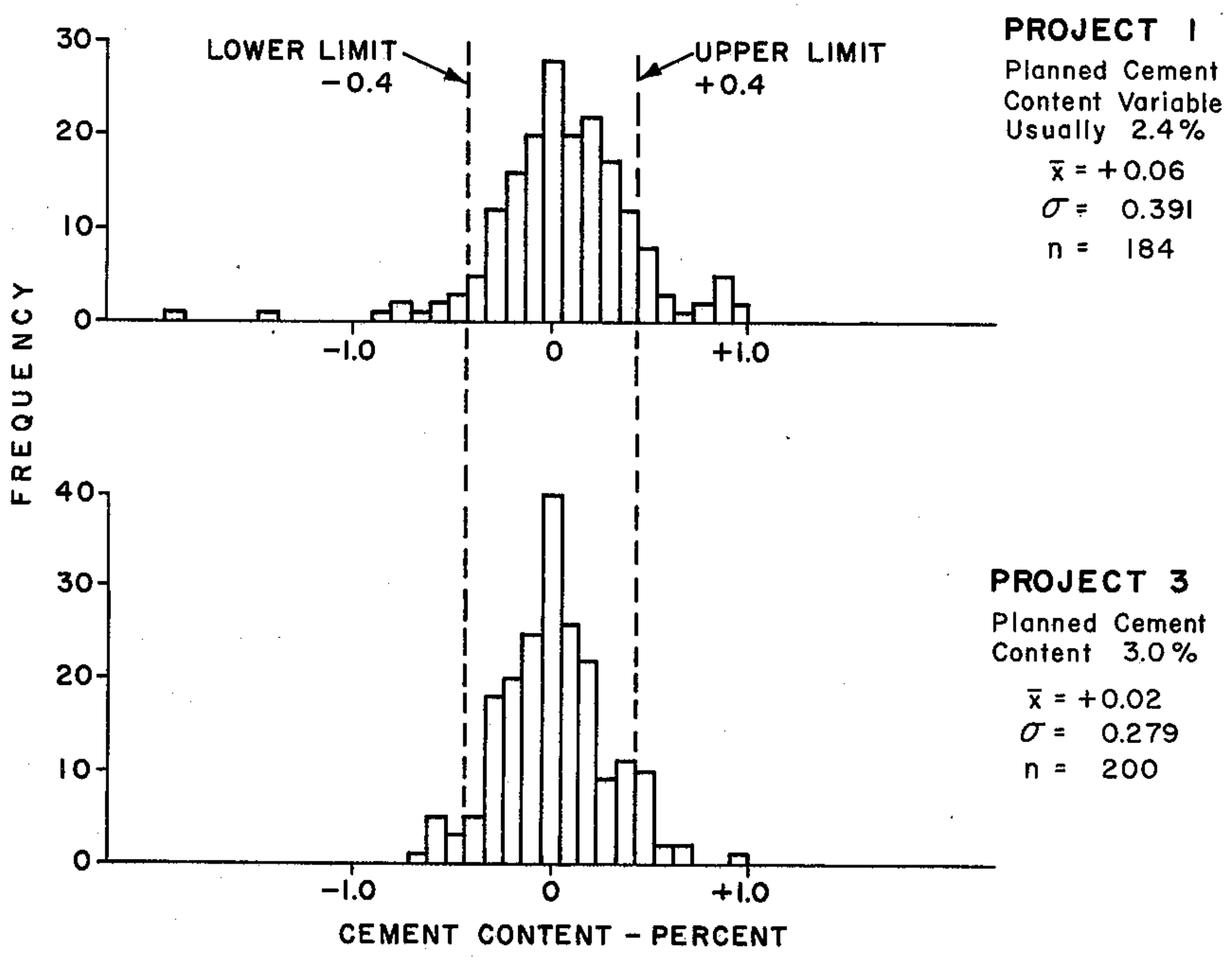


Figure 4

HISTOGRAM SHOWING DEVIATION OF PERCENT CEMENT BY TEST FROM PLANNED CEMENT CONTENT

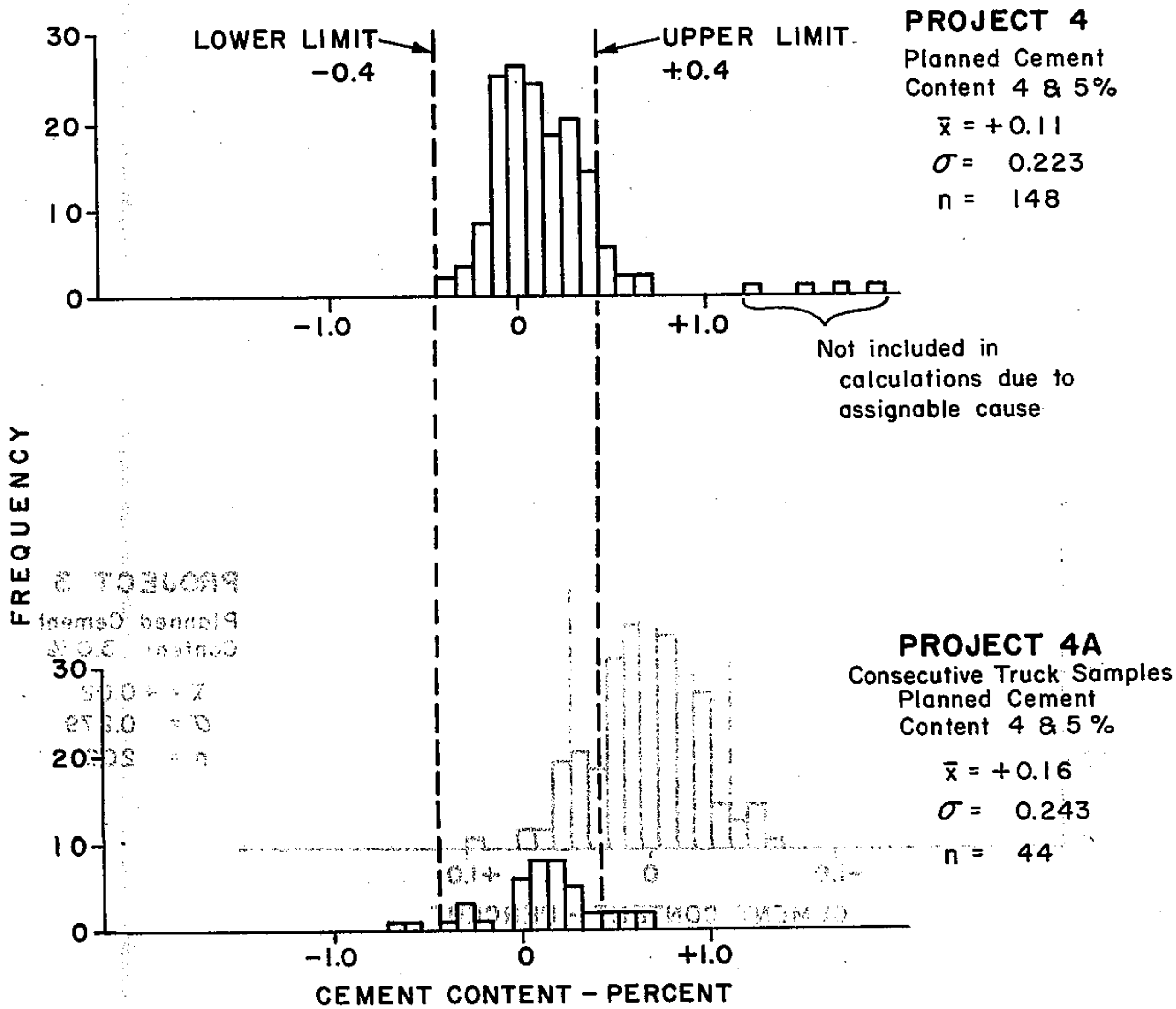


Figure 5

BATCH PLANTS

A CHART DEMONSTRATING THE IMPROVEMENT IN CTB CEMENT DISTRIBUTION WITH THE ADVENT OF THE JAN 1960 STD. SPECS. AND THE USE OF THE TITRATION TEST AS THE METHOD OF CONTROL

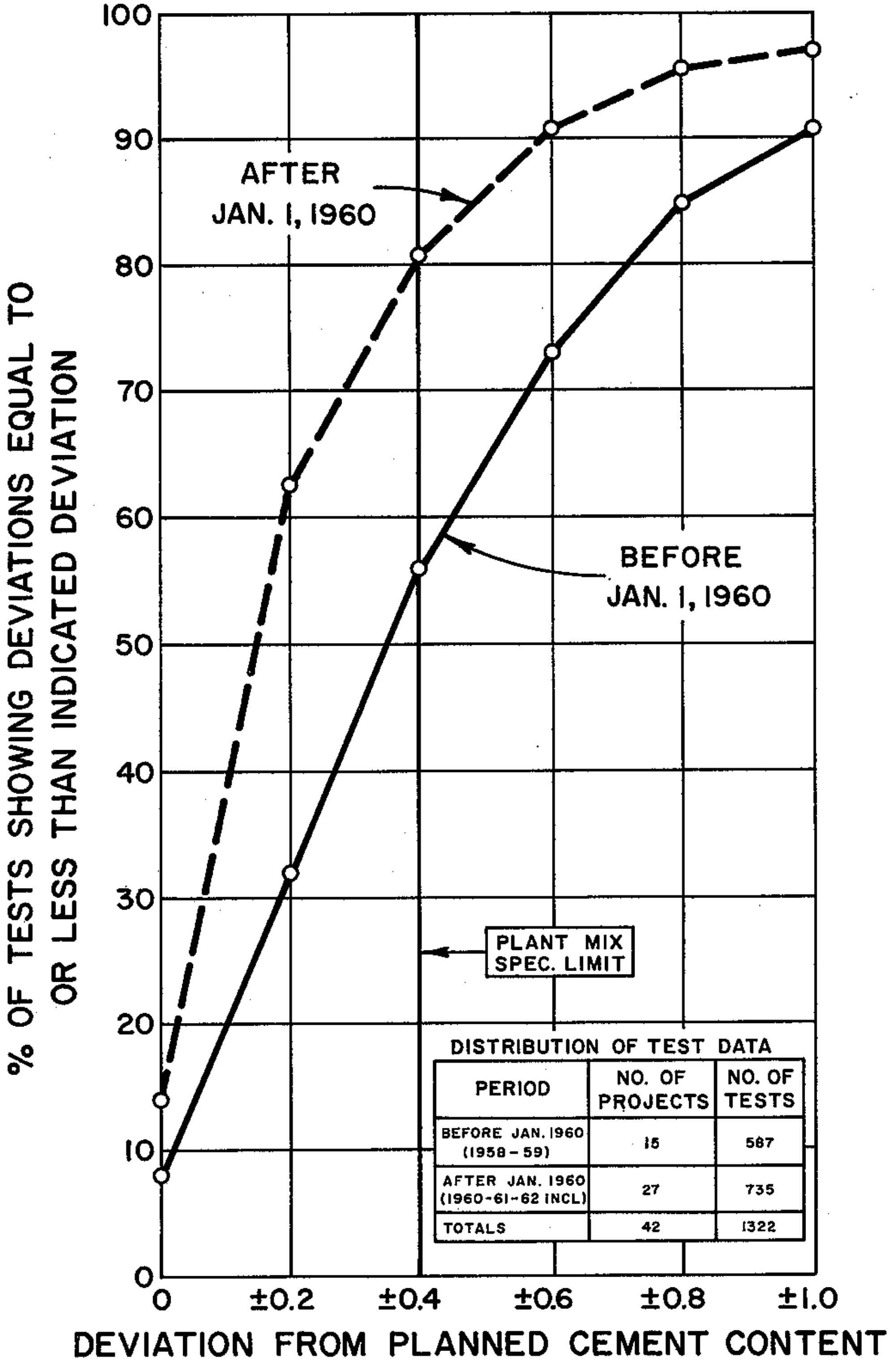
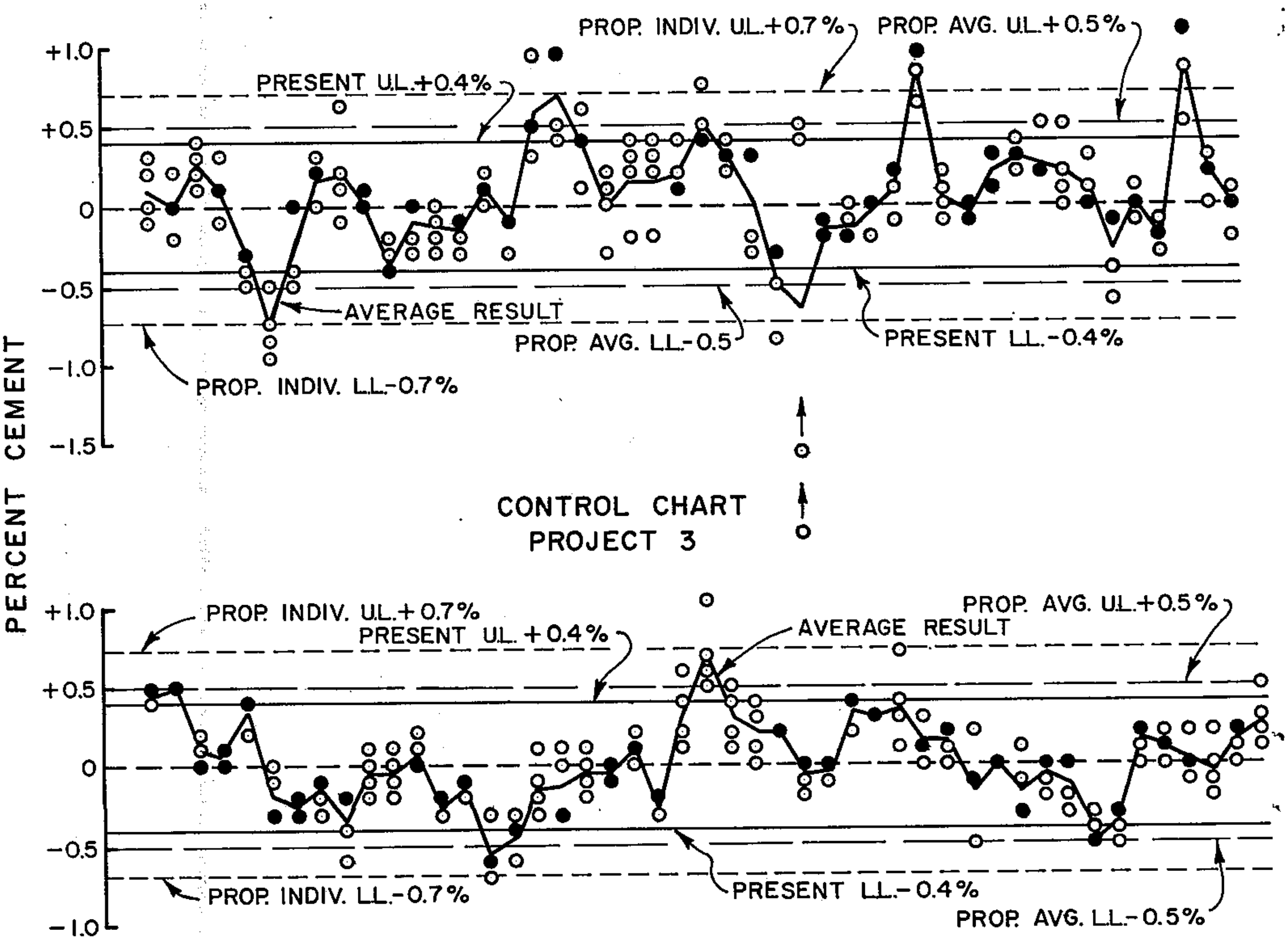


FIGURE 6

CONTROL CHART
PROJECT 1

Test data is shown on the basis of deviations from the planned cement content



o Individual Test Results
● More than one result for this value
– – – Planned Cement Content 2.4 & 3.0%

FIGURE 7

CONTROL CHART
PROJECT 4

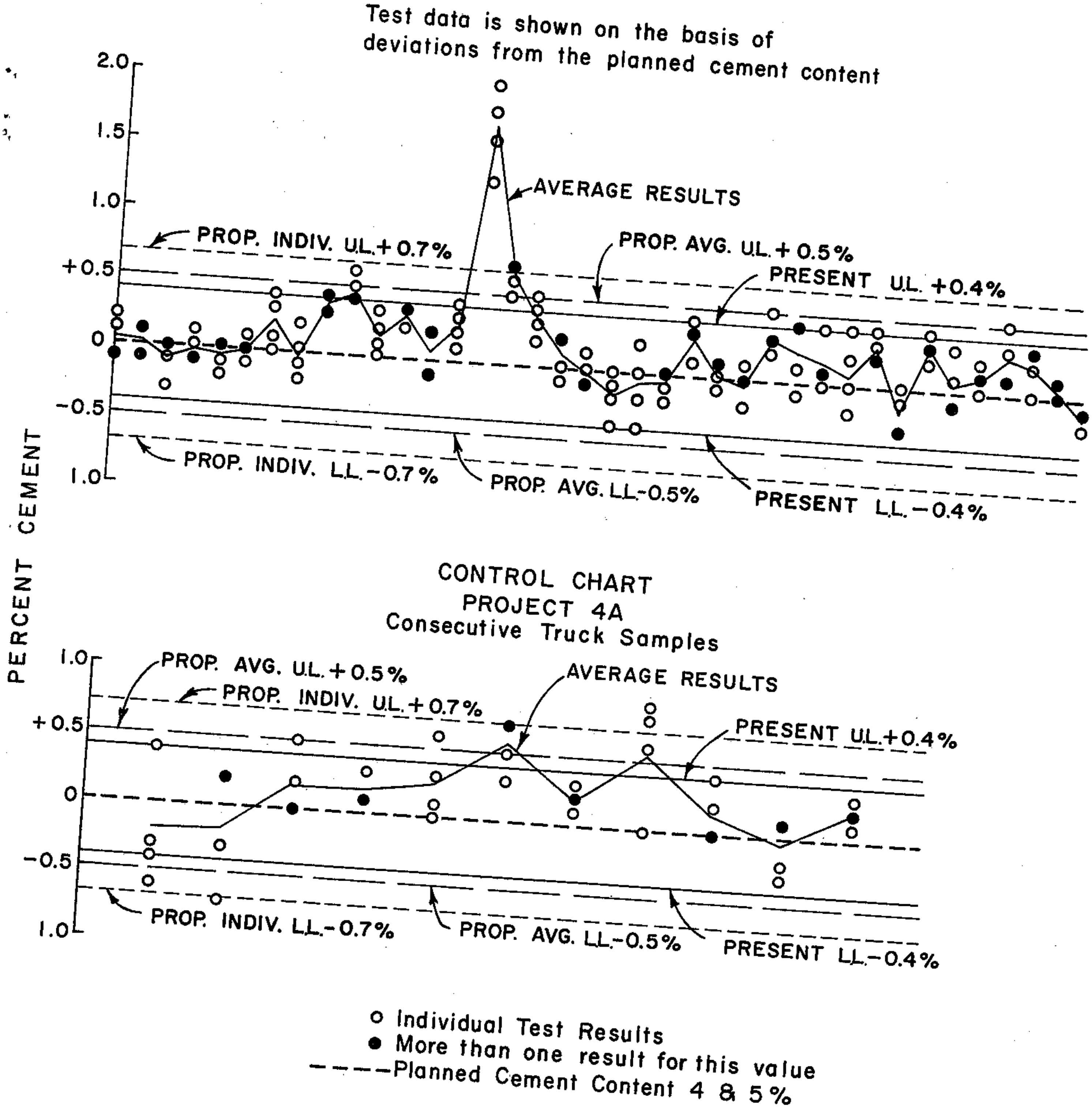


TABLE A

RANDOM NUMBERS

1		2		3		4		5	
A	B	A	B	A	B	A	B	A	B
.576	.730	.430	.754	.271	.870	.732	.721	.998	.239
.892	.948	.858	.025	.935	.114	.153	.508	.749	.291
.669	.726	.501	.402	.231	.505	.009	.420	.517	.858
.609	.482	.809	.140	.396	.025	.937	.310	.253	.761
.971	.824	.902	.470	.997	.392	.892	.957	.640	.463
.053	.899	.554	.627	.427	.760	.470	.040	.904	.993
.810	.159	.225	.163	.549	.405	.285	.542	.231	.919
.081	.277	.035	.039	.860	.507	.081	.538	.986	.501
.982	.468	.334	.921	.690	.806	.879	.414	.106	.031
.095	.801	.576	.417	.251	.884	.522	.235	.398	.222
.509	.025	.794	.850	.917	.887	.751	.608	.698	.683
.371	.059	.164	.838	.289	.169	.569	.977	.796	.996
.165	.996	.356	.375	.654	.979	.815	.592	.348	.743
.477	.535	.137	.155	.767	.187	.579	.787	.358	.595
.788	.101	.434	.638	.021	.894	.324	.871	.698	.539
.566	.815	.622	.548	.947	.169	.817	.472	.864	.466
.901	.342	.873	.964	.942	.985	.123	.086	.335	.212
.470	.682	.412	.064	.150	.962	.925	.355	.909	.019
.068	.242	.667	.356	.195	.313	.396	.460	.740	.247
.874	.420	.127	.284	.448	.215	.833	.652	.601	.326
.897	.877	.209	.862	.428	.117	.100	.259	.425	.284
.875	.969	.109	.843	.759	.239	.890	.317	.428	.802
.190	.696	.757	.283	.666	.491	.523	.665	.919	.146
.341	.688	.587	.908	.865	.333	.928	.404	.892	.696
.846	.355	.831	.218	.945	.364	.673	.305	.195	.887
.882	.227	.552	.077	.454	.731	.716	.265	.058	.075
.464	.658	.629	.269	.069	.998	.917	.217	.220	.659
.123	.791	.503	.447	.659	.463	.994	.307	.631	.422
.116	.120	.721	.137	.263	.176	.798	.879	.432	.391
.836	.206	.914	.574	.870	.390	.104	.755	.082	.939
.636	.195	.614	.486	.629	.663	.619	.007	.296	.456
.630	.673	.665	.666	.399	.592	.441	.649	.270	.612
.804	.112	.331	.606	.551	.928	.830	.841	.602	.183
.360	.193	.181	.399	.564	.772	.890	.062	.919	.875
.183	.651	.157	.150	.800	.875	.205	.446	.648	.685