STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

AN INVESTIGATION OF THE OPERATIONAL CHARACTERISTICS OF THE HEADQUARTERS LABORATORY MODEL SAND EQUIVALENT AGITATOR

October 10, 1956

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MATERIALS & RESEARCH DEPARTMENT

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

October 10, 1956

Research No. 22R3038

Mr. F. N. Hveem
Materials and Research Engineer
Division of Highways
Sacramento, California

Dear Sir:

Submitted for your consideration is:

AN INVESTIGATION OF

THE OPERATIONAL CHARACTERISTICS

OF THE HEADQUARTERS LABORATORY

MODEL SAND EQUIVALENT AGITATOR

Study made by . . . . . R-Value Group
Work supervised by . . . . . George Sherman
Report prepared by . . . . . Daniel R. Howe
Laboratory operations
directed by. . . . . Robert Bridges

Very truly yours,

E. Zube

E. Zube
Supervising Materials & Research
Engineer

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Investigation of the Headquarters Laboratory Model Sand Equivalent Agitator

Introduction

This is a report on the investigation of the Sand Equivalent mechanical agitator which was designed and constructed at Headquarters laboratory in the summer of 1955. Since the feasibility of mechanical agitation was previously established in connection with the study of a working model designed and submitted by Mr. Henry E. Davis as a merit award suggestion (reported by memo., Mr. F. N. Hveem to Mr. A. I. Rivett dated March 10, 1955) this report will be concerned primarily with an analysis of the operational characteristics of the present design.

Essentially the Headquarters laboratory model utilizes a rocker arm type of action to move a horizontally placed S.E. tube in a gentle arc on about a 13" radius and through a fixed chord distance of 8". Motivation is supplied to the machine by means of a V-belt power takeoff from a standard Tyler sieve shaker which provides agitation at the rate of 180 cycles per minute. The general arrangement of the device is illustrated by the Schematic diagram given in Figure 1.

The objectives pursued in this study consisted of two main items. They were (1) to determine the reliability and precision of the Sand Equivalent test when using the new model mechanical agitator and (2) determine the number of cycles this device should complete in a test, which would produce results representative of those obtained using manual agitation.

In general this study indicates that Sand Equivalent results obtained through the use of the Headquarters laboratory agitator are satisfactory from both a reliability and precision standpoint. Also it appears that operating the agitator for 125 cycles at the rate of 180 cycles per minute through a distance of 8 inches will produce test values that are most representative of those occurring with the current procedure of manual agitation.

Testing Program and Analysis of Data

For the purposes of the study, two samples of material were obtained from the Teichert & Sons Aggregate plant at Perkins, California in sufficient quantity to perform a statewide series of tests. The samples, 55-2619 and 55-2620, were purposefully selected to represent the moderately high and the low range of Sand Equivalent values respectively. The grading of the passing #4 mesh material is indicated in Table I for both samples.

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Table I

Sample No.	Sieve Analysis (% Passing) Sieve Size								
	#4	#8	#16	#30	#50	#100	#200	5u	1u
55-2619	100	80	64	41	23	15	11	2	1
55-2620	100	91	81	64	50	39	32	10	6

In the first test series 20 repetitive tests using 4 tubes were performed on each sample. The procedure used conformed to the standard method Calif. No. 217-B except for the substitution of mechanical agitation for the usual manual type. One hundred cycles of agitation were completed for each test. Table II lists the test results obtained from this series.

Table II

Tabulation of Sand Equivalent Results for Samples No. 55-2619 and 55-2620 when using Mechanical Agitation

Sample No.	Tube No.	Sand Reading	Clay Reading	Sand Equivalent
55-2619	A	35	46	77
	A	31	40	78
	A	34	45	76
	A	33	43	77
	A	35	46	77
	B	34	44	77
	B	32	40	80
	B	31	42	74
	B	32	42	77
	B	37	51	73
	C	36	50	72
	C	28	35	80
	C	30	37	82
	C	31	42	74
	C	32	42	77
	D	37	50	74
	D	36	50	72
	D	35	47	75
	D	29	37	79
	D	34	44	78
			Average S.E.	77

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Table II (Cont'd.)

Sample No.	Tube No.	Sand Reading	Clay Reading	Sand Equivalent
55-2620	A	24	106	23
	A	24	105	23
	A	23	100	23
	A	22	99	23
	A	24	101	24
	B	27	115	24
	B	23	91	26
	B	24	101	24
	B	22	95	24
	B	27	112	25
	C	23	100	23
	C	21	99	22
	C	23	100	23
	C	23	101	23
	C	23	101	23
	D	24	108	23
	D	23	105	22
	D	23	111	21
	D	24	115	21
	D	25	110	23
			Average S.E.	23

Statistical determination of the reliability of the test method when using the mechanical agitator was made from the above data on the basis of the control chart method. A control chart is essentially a graphic representation of measurement data, presented in such a manner as to indicate the presence or absence of assignable causes of variability in the data. The ASTM Manual on "Quality Control of Materials" furnished the details, formulas and factors for this analysis.

Since it is necessary to subdivide the data into logically selected subgroups in order to perform the required calculations, it was found convenient to subgroup according to the individual graduated cylinders (tubes) used. Thus five tests using one particular tube represents a subgroup.

Control charts based upon averages for each sample are shown in Figures 2 and 3. The dashed lines on the control charts designate the upper and lower control limits for which the calculations are indicated on the chart. The central solid line represents the grand average for the whole sample and the individual plotted points are the averages of the subgroups. If it is to be said that there is no assignable cause for error indicated by the data then these points must lie on or inside of the control limits.

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It is noted that all the plotted points for sample 55-2619 shown in Figure 2 lie well within the control limits. Sample 55-2620 (Figure 3) however indicates a borderline case involving both the upper and lower control limits. It is felt that due to the unusually narrow range between the control limits that the assignability of a definite cause for variation is still fairly remote. On the whole considering both samples there is a fair probability that the test method is reliable when performed using the mechanical agitator.

With the reliability of the test reasonably established, it was then appropriate to evalute the precision by which the results were reproducible. The universal measure, standard deviation, was calculated for this purpose from the data in Table II. Also determined was the "relative standard deviation" or "coefficient of variation", as it is often referred to, which is the standard deviation divided by the mean and expressed as a percentage. It is generally considered that data exhibiting a coefficient of variation of 10% or less has a significantly good degree of precision. Table III lists these calculated values for both samples.

Table III

Statistical Analysis of S.E. Test Performed with Mechanical Agitation

Statistic	55-2619	55-2620
Upper control limit	80	24
Lower control limit	73	22
*Average sand equivalent	77	23
Subgroup averages		
Tube A	77	23
B	76	24
C	77	23
D	76	22
Standard Deviation	1.88	1.10
Coefficient of variation	2.5%	4.8%

*Based on 100 shakes--later data indicates 125 shakes are required to reach the equivalent of average hand shaking.

The above values reflect a good degree of precision for both samples and indicates the effectiveness of the mechanical agitator in reproducing results.

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The second phase of this study involved the determination of the proper number of cycles through which the mechanical agitator should operate in order to produce representative results within the intent of the original developmental investigations and the correct standard specifications. As a means of accomplishing this it was decided to evaluate the sand equivalents of several samples of material when using manual agitation in the standard manner and determine by test the number of cycles of mechanical agitation which are required to obtain the same Sand Equivalents. However, past experience has indicated that individual differences between operators performing manual agitation, even when they are apparently complying with standard procedures, will often result in a broad range of Sand Equivalent values for a given sample. This makes it quite difficult to establish representative values to which mechanical agitation may be compared.

Therefore, in an effort to evaluate the effect of the "Personal equation", samples were tested on a state-wide basis in order to obtain an average for a large number of operators. Each District laboratory received 30, three ounce tins of 55-2619 and 55-2620, respectively, under letters of transmittal dated October 21, 1955, from Mr. F. N. Hveem. They were requested to have as many experienced men as were readily available (up to a maximum of 10) perform the Sand Equivalent test on each sample in triplicate.

Results of these tests which were performed by 106 operators are given in Figures 4 through 7. These figures include the control limits (shown as solid lines) calculated on the basis of all tests performed and subgrouped by individual operators. The central solid line is the average S.E. of all tests and the plotted points represent the average of three tests for each operator. Table IV lists all pertinent statistical data pertaining to both samples in this test series.

Table IV

Statistical Analysis of all State-wide S.E. Tests Performed with Manual Agitation

Statistic	55-2619	55-2620
Upper Control Limit	83	27
Lower Control Limit	62	18
No. of Tests not in Control	3	5
% of Tests not in Control	2.8%	4.7%
Ave. Sand Equivalent	72	22
Standard Deviation	4.3	1.8
Coefficient of Variation	6.0%	8.8%

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Comparison of these values with those for mechanical agitation given in Table III provides evidence that Headquarters laboratory Model S.E. agitator results in a higher degree of reproducibility and precision than does manual agitation with different operatives.

While the state-wide data given above in Table IV illustrates the effect of manual agitation, it is felt that further statistical refinement is necessary in order to bring forth a clearer conception of the S.E. values which are most representative of the materials tested. In an effort to accomplish this, new control limits were calculated excluding data which exhibited abnormally broad dispersion from the mean central line and indicated the probable presence of assignable causes of variability. These new limits represent the ultimate possible control lines which encompass the most representative Sand Equivalent values.

Table V lists the statistical data resulting from the recalculations and the dashed lines in Figures 4 through 7 illustrate the new control limits.

Table V

Statistical Recalculation of State-wide S.E. Tests Based Upon the Exclusion of Test Data Indicating Assignable Causes of Variability

Statistic	55-2619	55-2620
Upper Control Limit	78	23
Lower Control Limit	66	19
No. of Tests not in Control*	11	13
% of Tests not in Control	10.3%	12.3%
Ave. Sand Equivalent	72	21
Standard Deviation	2.29	0.63
Coefficient of Variation	3.2%	3.3%

*These tests are not included in the control limit or standard deviation calculations.

The average Sand Equivalents of 72 and 21 for samples 55-2619 and 55-2620, respectively, given in Table V above are now considered representative of the materials and provides the means for the final determination of the correct number of cycles through which the mechanical agitator should operate. However, to complete this study, it was necessary to perform another test series on the same samples (55-2619 and 2620) utilizing various numbers of cycles of mechanical agitation. Figures 8 and 9 illustrate the cycle curves thus obtained.

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From these curves it may be seen that it requires 126 cycles for sample 55-2619 to duplicate the representative S.E. of 72 and likewise 122 cycles for sample 55-2620 to reproduce the S.E. 21.

Conclusions and Recommendations

1. Use of the Headquarters Laboratory Model Mechanical agitator in Sand Equivalent test procedure produces test results with a higher order of reliability, reproducibility and precision than the present standard method of manual agitation.

2. Operation of the mechanical agitator for a total of 125 cycles per test will produce results which are representative within the intent of the original test method.

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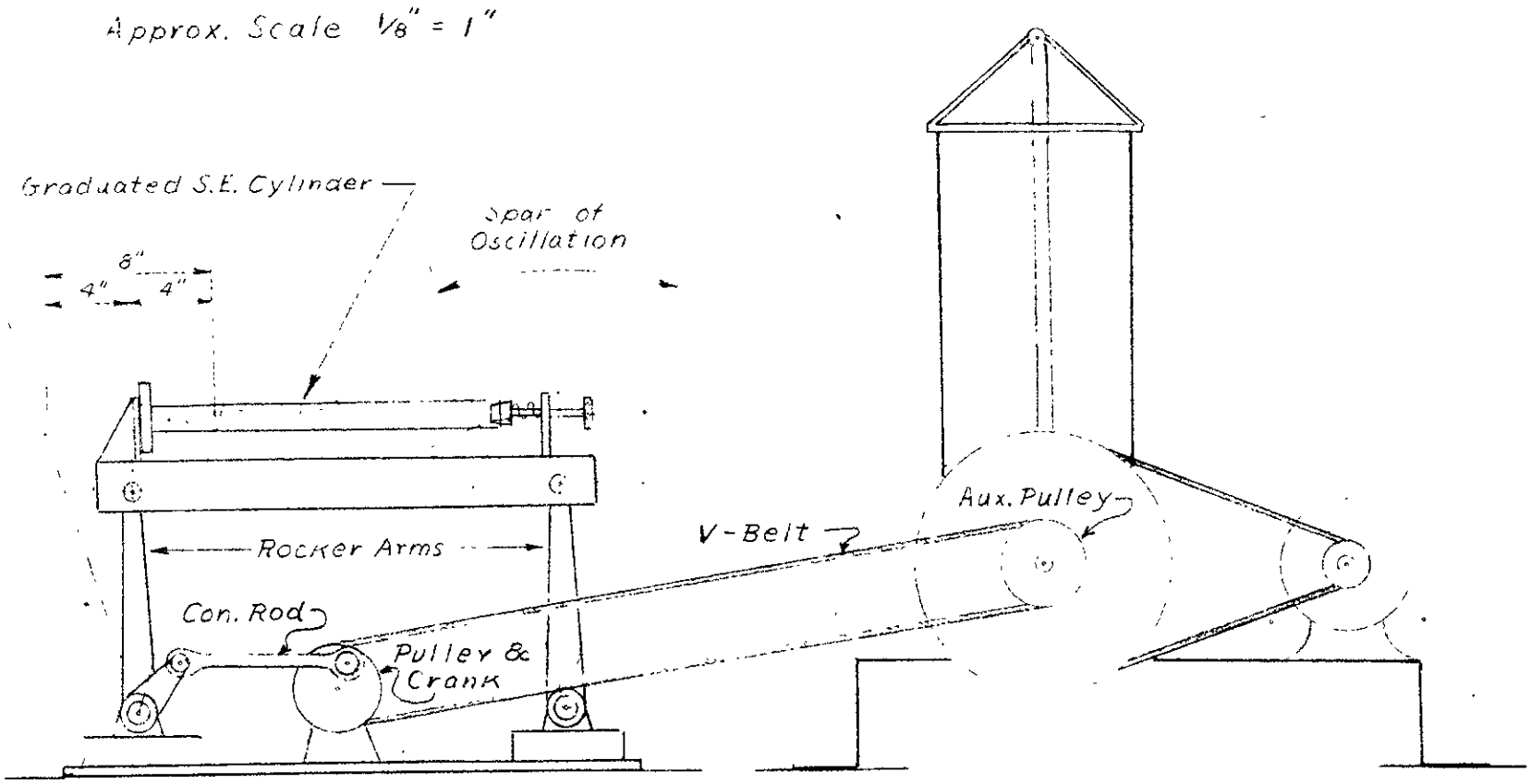
FIGURE 1

SCHEMATIC DIAGRAM OF THE HEADQUARTER'S LABORATORY SAND EQUIVALENT AGITATOR MODEL 1955



H.Q.'S LAB. MODEL S.E. AGITATOR

TYLER SIEVE SHAKER
(For Power Supply)

FIGURE 1

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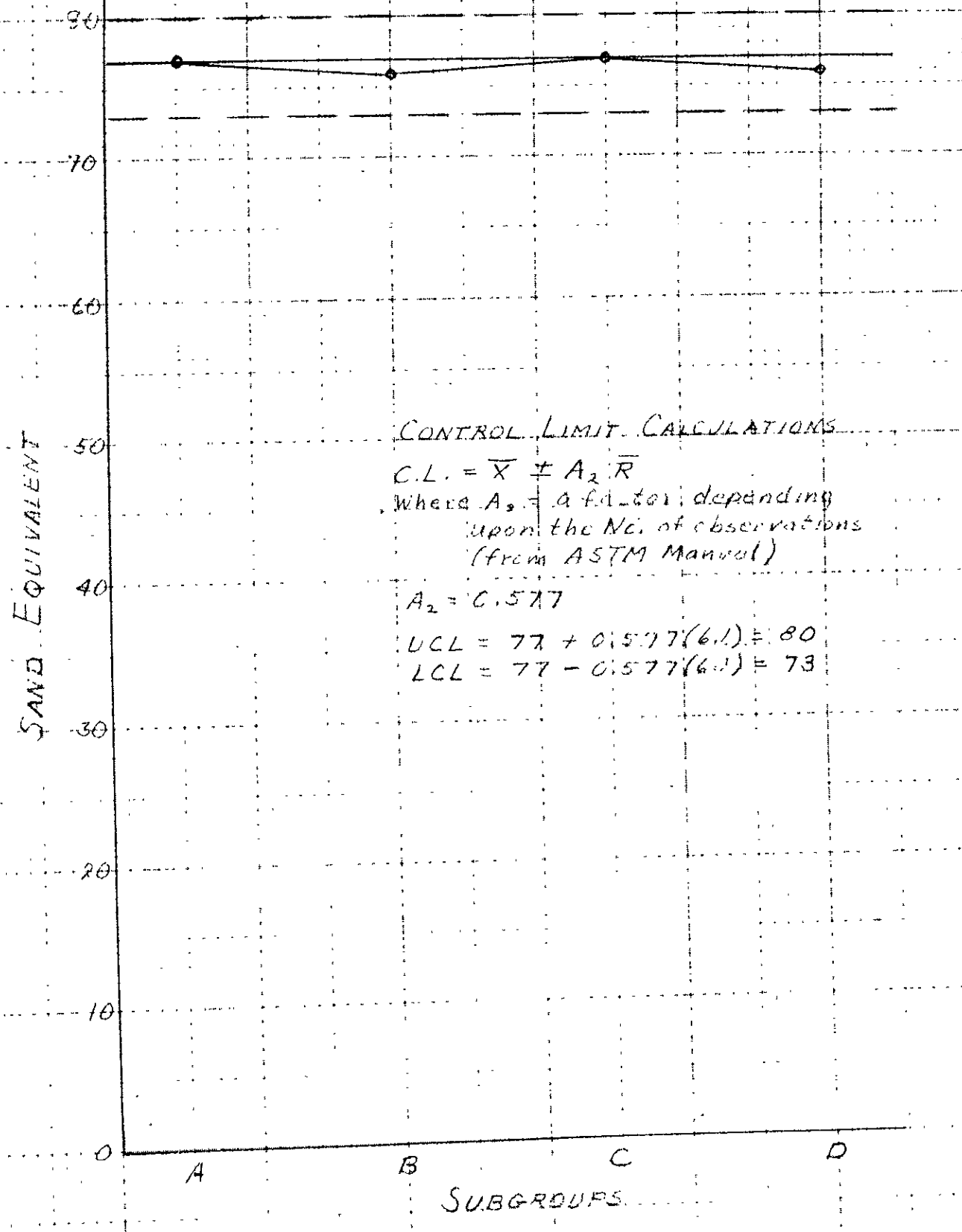
FIGURE 2
CONTROL CHART
(Based on Averages)

Sample No. 55-2619 July 9, 1956



CONTROL LIMIT CALCULATIONS

$C.L. = \overline{X} \pm A_2 \overline{R}$

Where A_2 = a factor depending upon the No. of observations (from ASTM Manual)

$A_2 = 0.577$

$UCL = 77 + 0.577(6.1) = 80$

$LCL = 77 - 0.577(6.1) = 73$

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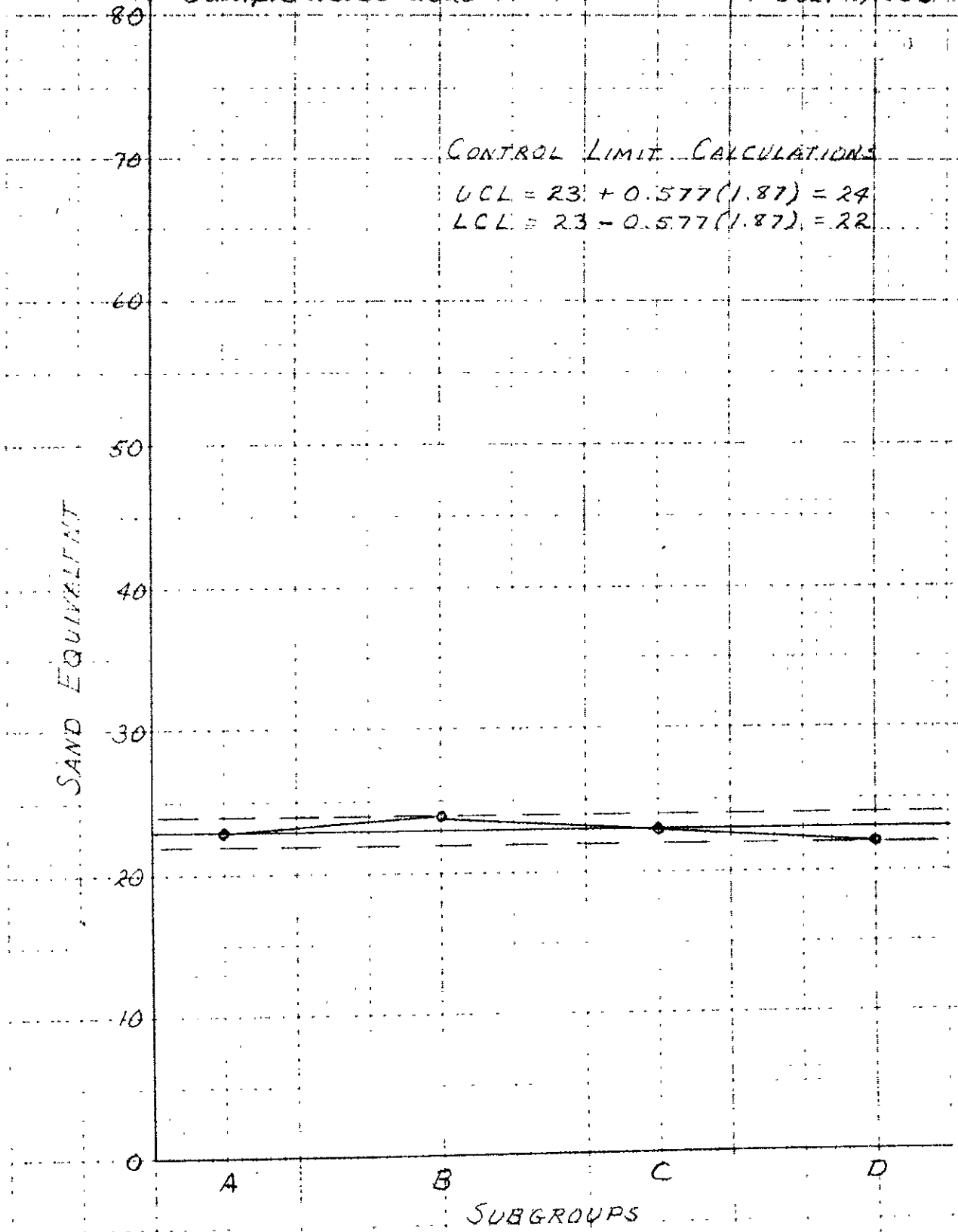
FIGURE 3

CONTROL CHART

(Based Upon Averages)

Sample No. 55-2620 JULY 9, 1956



CONTROL LIMIT CALCULATIONS

$UCL = 23 + 0.577(1.87) = 24$

$LCL = 23 - 0.577(1.87) = 22$

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FIGURE 8.

CYCLE CURVE FOR SAND EQUIVALENT TEST PERFORMED WITH H.Q. LAB. MODEL MECH. AGITATOR

SAMPLE No. 55-2619

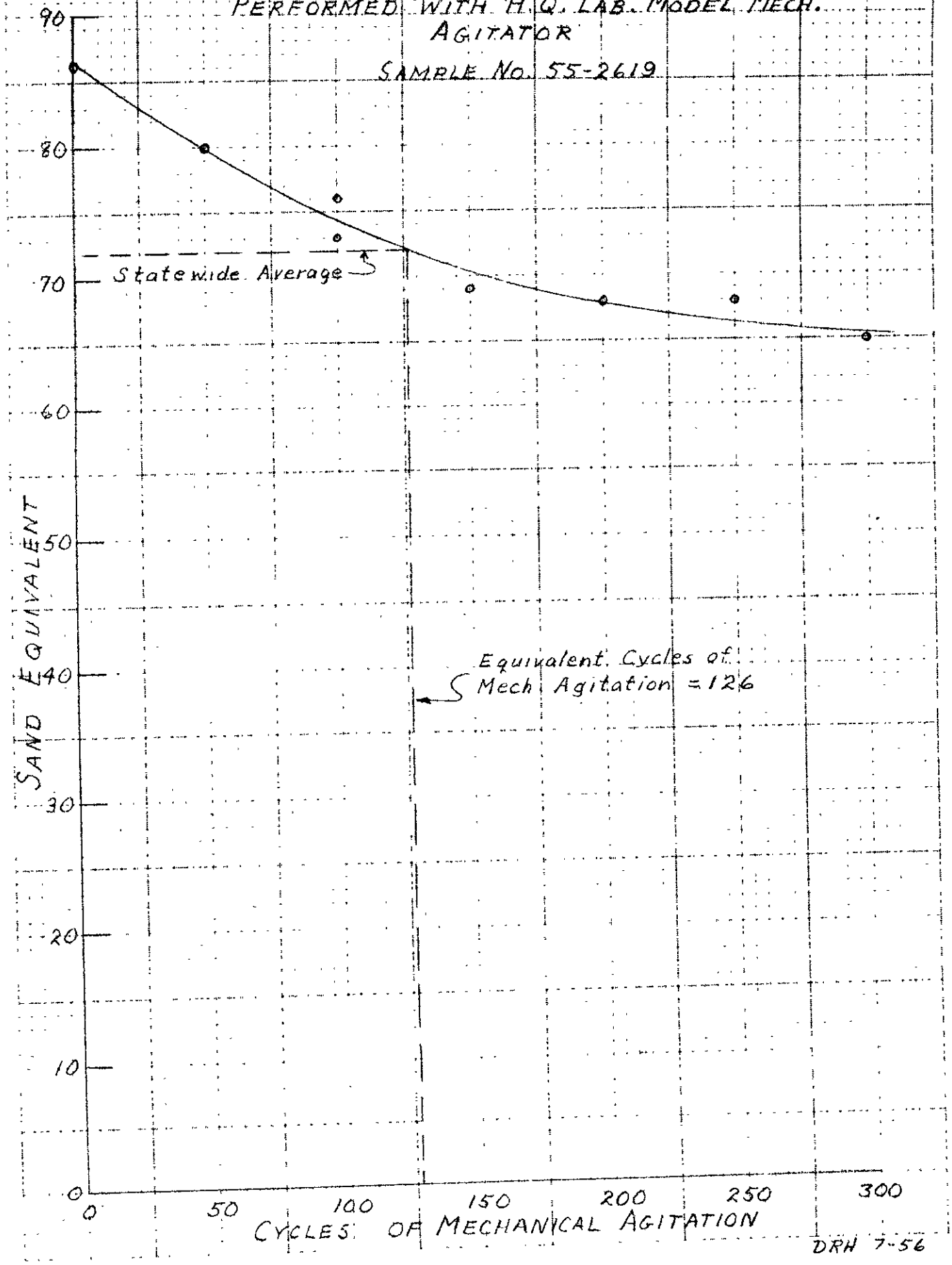

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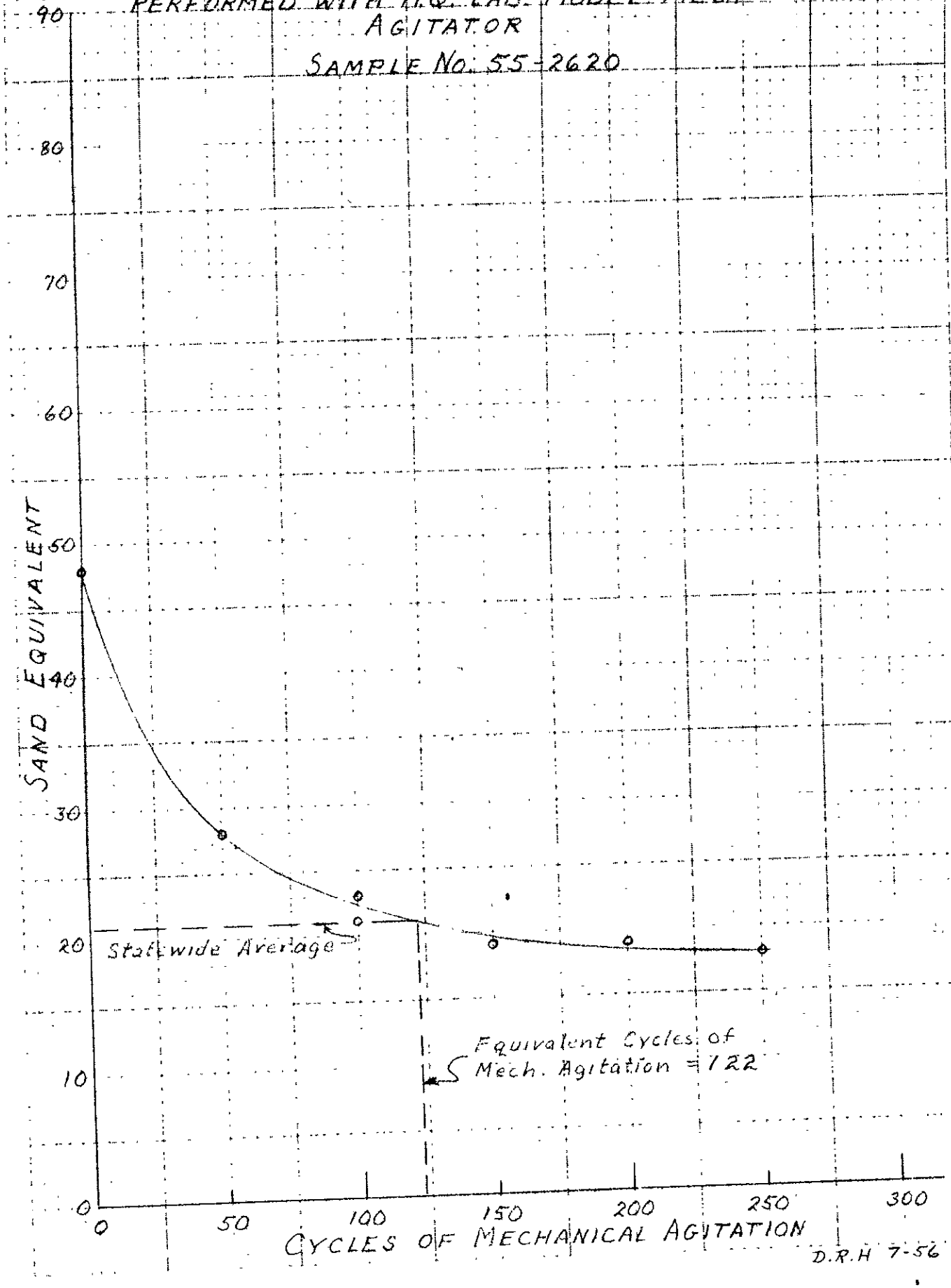
FIGURE 9

CYCLE CURVE FOR SAND EQUIVALENT TEST PERFORMED WITH H.Q. LAB. MODEL MECH. AGITATOR

SAMPLE NO. 55-2620



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