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16. ABSTRACT

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It was found that on all three structural conccrete projects, variance inherent in the material was the largest contributor to overall standard deviation. It was concluded that the Kelly Ball Test in its present form is a reproducible method of determining the consistency of fresh concrete. It was also concluded that certain changes in the present specifications would probably result in more effective control of the consistency of fresh concrete.

Proposed for adoption on a trial basis are several new control procedures, including the use of control charts on field construction projects and the random selection of material for testing.

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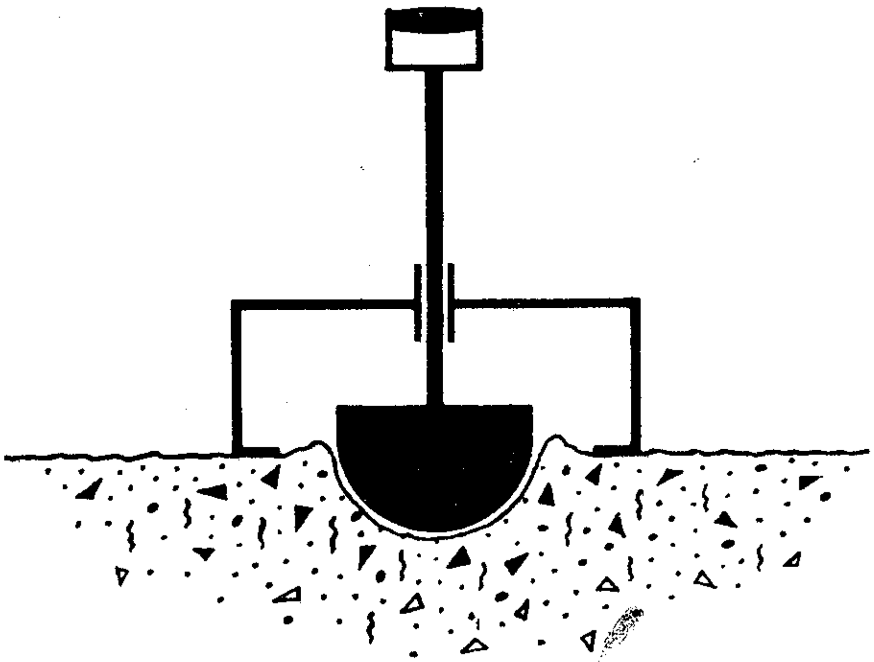
A STATISTICAL ANALYSIS
of the
KELLY BALL TEST



66-23

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 631133-4

Prepared in Cooperation with the U.S. Department of Commerce, Bureau of Public Roads   August 1966

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

October 1966

HPR 1(2) F-1-1
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Mr. J. C. Womack
State Highway Engineer
Division of Highways
Sacramento, California

Dear Sir:

Submitted for your consideration is:

A STATISTICAL ANALYSIS

of the

KELLY BALL TEST

Study made by . . . . General Services Section
Under direction of . . . . G. B. Sherman
Project supervisor . . . . R. O. Watkins
Report prepared by . . . . T. P. Colbert, M. L. Alexander and J. J. Folsom

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

Attachment

cc: LRGillis
ACEstep
CGBeer (14)
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), F-1-1 in cooperation with the U. S. Department of Commerce, Bureau of Public Roads.

ACKNOWLEDGMENTS

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The authors also wish to thank Messrs. W. Ames, J. Woodstrom and D. Spellman of the Concrete Section, Materials and Research Department, for their assistance in preparation and review of this report.

TABLE OF CONTENTS

TABLES AND FIGURES

APPENDICES

A - Tentative Method for Sampling and Determining Compliance with the Proposed Specifications for the Consistency of Fresh Concrete

B - Example Calculations on Random Selection; Routine Running Averages; and Determination of Maximum Running Average Limit

C - Copy of Calif. Test Method No. 520-C, Method of Test for Slump of Portland Cement Concrete

ABSTRACT

Present testing procedures, specifications, and variation of test results for consistency of portland cement concrete as determined by the Kelly Ball Test are discussed.

Three bridge projects using transit mix structural concrete and one highway project using centrally mixed paving concrete were selected for this study. The sampling and testing plan was designed so that the variance in test results could be calculated and identified according to its cause. Variance has thus been separated into that introduced by sampling, by testing, and by the inherent variability of the material.

It was found that on all three structural concrete projects, variance inherent in the material was the largest contributor to overall standard deviation. It was concluded that the Kelly Ball Test in its present form is a reproducible method of determining the consistency of fresh concrete. It was also concluded that certain changes in the present specifications would probably result in more effective control of the consistency of fresh concrete.

Proposed for adoption on a trial basis are several new control procedures, including the use of control charts on field construction projects and the random selection of material for testing.

INTRODUCTION

With the recent trend toward the statistical approach to quality control in highway construction, the California Division of Highways, in cooperation with the Bureau of Public Roads, is engaged in a project titled "A Statistical Study of Materials". This project consists of (1) evaluation of existing control procedures through statistical survey, and (2) preparation and evaluation of statistical specifications for various construction items.

One control test which California investigated was the Kelly Ball Test for determining the consistency of fresh concrete. The Kelly Ball Test was adopted in 1953 by the California Division of Highways as a replacement for the slump cone method.

The purpose of this study was to evaluate the reproducibility of the Kelly Ball Test and to determine whether modifications in the testing procedures or the specifications for consistency of concrete are desirable. The basic premise of this study was that the contractors were all producing good, acceptable concrete and that the specifications and test methods would be evaluated using this assumption.

Although it is realized the validity of such an assumption may be very questionable in the minds of some engineers, it is not the intent of this research project to resolve this problem.

It should be noted that the word "slump" in the following report refers to consistency as measured by the California Kelly Ball Test Method. The California Kelly Ball is graduated so that a 1 inch penetration of the ball indicates 2 inches of slump. Consistency determined in this manner is approximately equal to the slump as measured with the slump cone; however, the coefficient for converting penetration of the Kelly Ball to slump by the slump cone has been shown to vary from 1.66 to 2.14.[1]

[1]Numbers refer to references at the end of the report.

CONCLUSIONS

The following conclusions are drawn from this study:

1. The Kelly Ball Test, California Test Method No. 520, is shown to be an accurate, reliable test for determining the consistency of fresh concrete when based on an average of three penetration readings.
2. This study showed a large variance in the concrete tested, indicating that the practice of averaging three readings is desirable. However, the present practice of eliminating readings until three are found to be in agreement within 1 inch of slump is unnecessary and statistically improper. It is thus concluded that test results should be based on the average of the <u>first three</u> valid penetration readings. This will result in a wider range of test data, which can be compensated for by expanding the specification limits to more realistic values. Invalid test readings, e.g., when the yoke of the Kelly Ball binds on the shaft and the yoke feet are pressed into the concrete, would of course be excluded.

3. The data indicate that the "nominal" slump limits as shown in the present Standard Specifications[2] are not adhered to. Since this study was based on the assumption that the concrete being received was of acceptable quality, the specification should be relaxed accordingly. It is suggested that the nominal limits be replaced by a maximum "running average" limit which could not be exceeded by the arithmetic mean of the 5 most recent Kelly Ball Test results. This would provide better overall job control.

4. The present specified maximum slump values were found to be adhered to on all but one project and it is believed that the wide variation found in the consistency of transit-mix concrete could be reduced by rejecting concrete whose slump exceeds these values.

5. Statistical considerations indicate that more efficient identification of out-of-specification material would result from:

   a. Establishment of a specific frequency of testing.

   b. Random selection of testing location.

   c. Utilization of control charts on the job.

These procedures would provide test results which are more representative of the work and should give a better overall picture of concrete being placed on the job. It is suggested that these procedures be adopted on a trial basis to determine their practicability under field conditions.

It should be noted that establishment of an exact frequency of testing and random material selection would not preclude inspection of every load placed on the job. Material which appeared to be out of specifications, e.g., obviously overwet material, would still be tested and rejected if it was not within the specified limits.

MATERIALS AND TESTING PROCEDURES

PROJECTS 1 thru 3:

Transit-mixed concrete was selected for the first three projects of this study because of its wide use in bridge construction. The Bridge Department selected the projects to be studied, each of which was assumed to be producing good, acceptable structural concrete typical of that being placed on Division of Highways contracts. Both sampling and testing were conducted under the direction of the Bridge Department representative on the job.

Tests were performed on fifty randomly chosen truck-loads of fresh concrete from each selected project. Sample A was taken after approximately 25 percent of the load had been discharged, and Sample B was taken after approximately 75 percent of the load had been discharged. Two test results were obtained from each sample. Each test result was the <u>average of three</u> slump readings.

This schedule of testing was established because it was believed that tests on the first and last quarter points would reasonably represent the entire load.

PROJECT 4

For purposes of comparison and in order to provide a more complete evaluation of existing slump specifications, it was decided that a study of paving concrete was warranted. A project suggested by the Construction Department was selected.

The concrete was mixed at a central batch plant, hauled in dump trucks to the paving site, and placed by spreader boxes in two broad windrows just ahead of a slipform paving machine. After passing through the spreader box, each 8 cubic yard batch of concrete was approximately 10 feet wide, 25 feet long, and 12-14 inches high.

Fifty test locations were predetermined by random selection of sampling time, random selection of windrow to be sampled, and random determination of sampling point available at the random time. Duplicate samples were obtained at each location by testing a point approximately 4-6 feet away from the original randomly selected point in the direction of travel of the paving machine. Testing was done by personnel from Headquarters Laboratory of the Materials and Research Department.

A Change in the Test Procedures:

The present California Test Method for determining concrete consistency by the Kelly Ball requires that a minimum of three penetration readings be taken for each slump determination. If the difference between the maximum and minimum readings is more than 1 inch (of slump), additional measurements must be made until three readings have been obtained which agree within 1 inch of slump (½ inch of penetration). After discarding the readings which do not agree, the three readings which agree within 1 inch are averaged, and this average is reported as the test result. Since the purpose of this study was to evaluate the reproducibility of the test, this discarding procedure was not adhered to and the first three readings were recorded regardless of their value. Although this change slightly increases the overall variance figures, it would have little effect on the results of this study.

COMMENT ON THE CALIFORNIA TEST METHOD FOR SLUMP

The California method of test for slump of portland cement concrete differs in many respects from the methods of test specified by ASTM[3] and AASHO[4], Designations C-360 and T-183, respectively. Although the limitations of this study precluded any tests to evaluate these differences, it is believed that a discussion of them would be useful.

One difference in California's test method from that of ASTM and AASHO is in the requirements for depth of concrete and clearance to the nearest wall. California specifies a minimum depth of 6 inches of concrete and a minimum clearance of 6 inches from the center of the ball to the nearest wall or other obstruction; whereas, ASTM and AASHO specify a minimum depth of 8 inches of concrete and a minimum clearance of 9 inches. During this study several comments were received from Bridge Department inspectors to the effect that California's clearance and depth requirements are not great enough, although no testing was done to verify this.

ASTM and AASHO specify that if the first three readings fail to agree within 1 inch of penetration, additional readings must be taken until three successive readings are obtained which agree within 1 inch of penetration. California's test method states that if the first three readings fail to agree within 1 inch of slump (½ inch of penetration), additional measurements must be taken until three readings are obtained which agree within 1 inch of slump. California does not stipulate that the three readings which agree within 1 inch are to be successive readings.

Data obtained during this study show that use of the tolerance specified by ASTM and AASHO for acceptance of penetration readings would have required taking additional readings on the structural concrete 5 percent of the time, whereas use of California's tolerance would have required additional readings more than 30 percent of the time.

Another difference in the test methods has to do with the calibration of the shafts. For all three test methods, the shaft of the penetration apparatus is graduated in ¼ inch intervals. By the ASTM and the AASHO test methods, readings are taken to the nearest ¼ inch, and the consistency of the concrete is recorded in terms of "inches of penetration". By the California method, each ¼ inch graduation indicates ½ inch of slump; that is, each inch of penetration of the Kelly Ball is read as 2 inches of slump on the Kelly Ball Shaft. California's readings are to be taken to the nearest ¼ inch of slump, i.e., the nearest 1/8 inch of penetration.

It can be readily agreed that if California would adopt the ASTM and AASHO methods of reporting test results, that is, in inches of penetration, confusion that arises from erroneous direct correlation with the slump cone results and when communicating with other agencies could be eliminated. The present procedure referring to the consistency of plastic concrete in terms of "inches of slump" as determined by the slump cone method do not necessarily correlate with the "slump" values obtained from the California Kelly Ball Test Method.

ANALYSIS OF DATA

Frequency histograms of the data collected during this study appear in Figures 1 to 4. An analysis of test data from the three structural concrete projects indicates average values of 3.7, 3.9, and 4.0 inches for slump with overall standard deviations of 0.91, 0.94, and 1.27 inches, respectively. The paving concrete project averaged 1.7 inches of slump with a standard deviation of 0.65 inches.

Although it is common knowledge that more uniform concrete is generally obtained from central mixing plants, these standard deviation figures give a good measure of the actual differences in uniformity obtained on these projects. These differences result from the many uncontrolled variables in the transit mix operation. Even though the addition of water, mixing time, etc. are supposedly standardized, there is much room for variability in these areas.

The distributions of data approach normalcy for all four projects surveyed; however, it will be noted that a slight positive skewness exists in each distribution. This skewness may be attributed to the natural limiting value of slump below which placement of concrete under specific conditions is difficult or nearly impossible. The data indicate that this limiting value is approximately 1.5

inches of slump for placement of structural concrete and 0.5 inches for placement of paving concrete. The resulting distribution is very much like a Poisson distribution[5] which has a lower limit but tails off at high values.

There are many sources of variance in Kelly Ball Test results; for example, variance due to sampling, testing, variation in moisture content, gradation of aggregates, degradation of aggregates during mixing, improper mixing of materials, variation in mixing time, variation in proportioning, temperature of ingredients, etc. The procedure by which this study was made separates variance into only three classifications: variance due to sampling, σS^2; variance due to testing, σT^2; and, variance inherent in the material, σA^2. This final classification includes all variance except that due to sampling and testing. No attempt has been made to separate the material variance into its several components. It is noted that the three components of variance are added together to produce the total variance and that the square root of the total variance is the overall standard deviation.

There are several relationships indicated by the data of Table 1 and Figure 5. The sum of sampling and testing variances was approximately the same for all projects. The relatively large total variances found in structural concrete test results were comprised mainly of material variance, while the total paving concrete variance, which was relatively small, contained little material variance.

Considering the magnitude of sampling and testing variances, it may be concluded that the test method is reasonably accurate and reproducible when the test result is based on the first three valid penetration readings.

The variation in slump within any load of concrete appears in Figure 6. These values were obtained by taking the difference between Sample A and Sample B for the three structural concrete jobs. There was no significant difference in slump between the first and last quarter of the load.

DISCUSSION

The California Standard Specifications[2] list the following as requirements for slump of fresh concrete:

PRESENT CALIFORNIA SPECIFICATION

Type of Work	Nominal Slump Inches	Maximum Slump Inches
Concrete pavement	0 - 2	3
Non-reinforced concrete facilities	0 - 3	4
Reinforced concrete structures:		
Heavy sections	0 - 3	5
Thin sections and columns	0 - 4	6
Concrete placed under water	6 - 8	9

The nominal and maximum limits are further defined in the Standard Specifications. Material is considered to be within specifications if it lies within the range shown as nominal slump; however, material with slump as high as the maximum slump may be accepted, provided that measures are immediately taken to modify production in order to produce material with slump lying within the nominal range.

Considering the assumption that all material sampled was of good, acceptable quality, it could be concluded that present specification limits for the nominal slump are too restrictive, since they are generally not being adhered to.

However, in drawing this conclusion, one must keep in mind that the intended slump value on two of the three projects was as high as 4½ inches, which is already ½ inch greater than the standard specification nominal limit allows. Since the concrete was considered acceptable, there appears to be a need to set more realistic specification limits on the nominal slump values.

However, the present maximum slump limits appear quite adequate since the data show they are usually being attained. So, unless we intend to improve quality requirements, these maximum values should be maintained.

Because the nominal slump range is not being adhered to in current construction, it is suggested that it be deleted in favor of a maximum running average specification and that the present limits for maximum slump be retained. These limits could also be accompanied by a third value, "recommended average slump". Statistical analyses indicate that if the contractor will maintain the recommended average, the concrete will consistently meet the slump requirements. The recommended average would not constitute a requirement, but would merely serve as a guide to the contractor. This helpful procedure of including a guide in the specifications is not without precedent[6].

The "running average" would perform the function of overall job control and complement the maximum slump requirement in order to eliminate acceptance of large quantities of borderline material which should actually be rejected. This control would provide for correction of the mixing operation when test results are approaching the specification limits. The running average would be calculated by determining the arithmetic mean of a specified number of recent test results. However, rejected material would not be included in this running average figure since this concrete would not be placed in the structure.

Appendix B contains an example of a calculation of the running average based on the five most recent test results.

With the acceptance of this parameter for new specifications, the problem remaining is that of setting practical limits. For purposes of comparison, the average slump values necessary to produce concrete which will <u>meet present specifications</u> 95 percent of the time have been calculated and appear below, along with the averages obtained during this study.

Use of Concrete	Necessary* Average Slump to Meet Present Specifications with a Probability of 0.95	Average Slump Obtained on These Projects
Pavement	1.4	1.7
Reinforced structures		
Heavy sections	2.0	
Thin sections-columns	3.0	3.7, 3.9, 4.0

It is evident from the above comparison that revision in the present specification will be necessary to bring control procedures in line with present construction practice, specifically the "nominal range" needs to be less restrictive. In the following proposal the "nominal range" has been deleted and the running average, which should be more enforceable (and assure more uniformity of quality), has been substituted.

PROPOSED SPECIFICATION REVISION

A revision in slump specifications should contain statements to the following effects:

1. The amount of water used in the mixture shall be the amount required so that none of the concrete produced will have a slump greater than that shown for "Maximum Slump" in the following table, except as provided in the paragraph following the table. The running average of slump as determined according to the proposed test method in Appendix A shall not exceed the values shown in the table in the column titled "Maximum Running Average for Slump".

*Based on the assumption that 15 percent of the slump results may be above the nominal limit.

2. When a test result exceeds the tabulated value of "Maximum Slump", the load shall be rejected. Tempering of overwet loads with cement to reduce slump will not be permitted.

3. When the running average exceeds the tabulated limits, the most recent load tested shall be rejected and only a load which lowers the running average to an acceptable value will be accepted.

4. Studies have indicated that in order to consistently meet these specifications, the overall average of the slump of concrete supplied to the job should be equal to or less than the value tabulated below as "Recommended Average Slump".

Use of Concrete	Recommended Average Slump (in.)	Maximum Allowable Running Average of Slump (in.)	Maximum Slump (in.)
Pavement	1.5	2.2	3.0
Reinforced structures:			
Heavy sections	3.0	4.0	5.0
Thin sections - columns	4.0	4.8	6.0

The above table should be followed with any other statement similar to those paragraphs in the present specifications that are necessary to insure adequate control of concrete slump.

The running average will allow a constant check from one batch to the next, thus assuring the contractor that maintenance of good quality control will enable him to continue operations without rejection of concrete due to normal variation. In addition, these control charts make it possible to observe trends in the material being received and thus make corrections before out-of-specification concrete is batched for the job.

The maximum running average limit in the above proposal is based on the probable variance to be expected from the overall mean slump value when five samples are being averaged. The overall average slump obtained on these three structural projects was 3.9 inches with a standard deviation approximately equal to 1 inch of slump.

Using these values, the maximum running average figure (based on a sample size of five, when the overall average is 3.9 inches) is 4.8 inches of slump. The details of this calculation will be found in Appendix B.

If it is felt that the above specified concrete needs to be upgraded, the allowable running averages can be changed accordingly. However, based on the results of this study, it is neither recommended or even implied that higher quality concrete be obtained or that there is any general need for high quality concrete. This controversial issue, with its many ramifications, involves too many variables to be resolved with the data available here.

Should the proposed specifications be adopted on a trial basis, a well defined method of determining where and when to sample will be needed along with the maintenance of good records. Presently, the Construction Manual[7] requires that Kelly Ball Tests be made only when test cylinders are fabricated and when consistency or uniformity is questionable. Since the frequency of making test specimens varies from project to project, the frequency of testing for consistency varies also and, consequently, widely variable project control is possible.

Reports from various resident engineers and Bridge Department representatives have indicated that the frequency of testing for slump is highly inconsistent. Extremes have been reported which range from testing every load of concrete delivered to testing only a few loads, even on large projects.

On the other hand, it is felt that the adoption of this proposal covers the essential elements of any good specification. That is, it gives practical and attainable limits, it requires a method of record keeping to aid in compliance, and there remains a documented record of what quality concrete was received on the job.

PROPOSED CONTROL PROCEDURE

In conjunction with the above proposals, it is believed that more uniform and effective control of consistency could be obtained by establishing a sampling frequency similar to that shown below and through rejecting material which does not meet the proposed slump requirements. A more detailed procedure is outlined in Appendix A for large projects.

Frequency of Testing:

For inclusion in the Construction Manual under "Sampling and Testing":

PCC - Bridges and Major Structures

1. When difficulty is encountered in controlling the consistency of concrete, test every load.

2. On short-term projects, where no unusual difficulties are encountered, test one randomly selected load out of every three loads.
3. On long-term projects where good control has been shown to exist, test one randomly selected load out of every five loads.

PCC - Pavement

1. Where difficulty is encountered in controlling the consistency of concrete, test every load or at four randomly selected times and locations per hour.
2. During normal operation, test one randomly selected time and location per hour.

Provision for Control Chart:

Even though a satisfactory frequency of testing may be employed, it is believed that control of slump will be assured only if test records are maintained and used to control production. For this reason, an example of a control chart has been prepared, and an illustration of its use is shown in Figure 7. The data on this chart are typical of that obtained in this study. A record of this type could serve the resident engineer in two ways:

1. It would provide data for detecting daily or weekly trends in the consistency of the concrete being produced.

2. It would provide the resident engineer with a record of the overall quality of concrete being placed on the project.

Random Sampling:

The procedure outlined above will be workable only if the requirement of random selection of testing location is strictly adhered to. The very nature of the measurement allows the inspector to prejudge the material. In fact, some inspectors pride themselves on their ability to estimate the Kelly Ball Test results. With the variation in material and the inspectors ability to predict results, it is imperative that the process of randomly selecting samples be strictly adhered to. A procedure for random sampling is given in Appendix B.

CLOSURE

The results of this study would indicate in brief that the application of statistical principles to the use and interpretation of the Kelly Ball Test would improve the use of the test as a quality control procedure. The adoption of the AASHO and ASTM methods of test might prove beneficial in test interpretation. And finally, that present specifications appear to be too restrictive for the construction industry to meet.

In addition, these findings are also in general agreement with those reported by the Bureau of Public Roads on their recent review concerning slump control of concrete on thirty California Federal-Aid construction projects[9]. It is felt that the control procedure outlined in this study will help eliminate the deficiencies noted by the Bureau's Inspection Report, particularly with respect to the frequency of sampling to insure more uniform control, and documentation of test results by utilizing control charts.

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

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DATA AND RESULTS-KELLY BALL TEST

σ_A^2 = Variance due to material
σ_S^2 = Variance due to sampling
σ_T^2 = Variance due to testing

	LOADS OF CONCRETE DELIVERED DURING TESTING	NUMBER LOADS SAMPLED	TOTAL SAMPLES (2 PER TRUCKLOAD)	TOTAL TESTS (2 PER SAMPLE)	TOTAL NUMBER OF PENETRATION READINGS
1	400	50	100	200	600
2	250	50	100	200	600
3	300	50	100	200	600
	FEET OF 2-LANE PAVEMENT PLACED DURING TESTING	NUMBER OF TEST LOCATIONS	TOTAL SAMPLES	TOTAL TESTS	TOTAL READINGS
4	16,600	50	100	200	600

PROJECT	n	$\overline{X}$ (IN.)	σ_A^2	σ_S^2	σ_T^2	σ_T (IN.)	σ_{S+T} (IN.)	σ_{A+S+T} (IN.)
1	200	3.69	0.61	0.14	0.08	0.03	0.05	0.91
2	200	3.85	0.63	0.04	0.22	0.47	0.51	0.94
3	200	4.00	1.39	0.10	0.13	0.36	0.48	1.27
4	200	1.74	0.10	0.00*	0.32	0.57	0.57	0.65

* Small negative variance-set equal to zero

NOTES: THE VALUES INDICATED HERE ARE INCHES OF SLUMP. ONE INCH OF PENETRATION IS READ AS TWO INCHES OF SLUMP ON THE CALIFORNIA KELLY BALL.

TABLE I

PROJECT NO. 1
DISTRIBUTION OF DATA-KELLY BALL TEST
(AVERAGE OF THREE OBSERVATIONS)

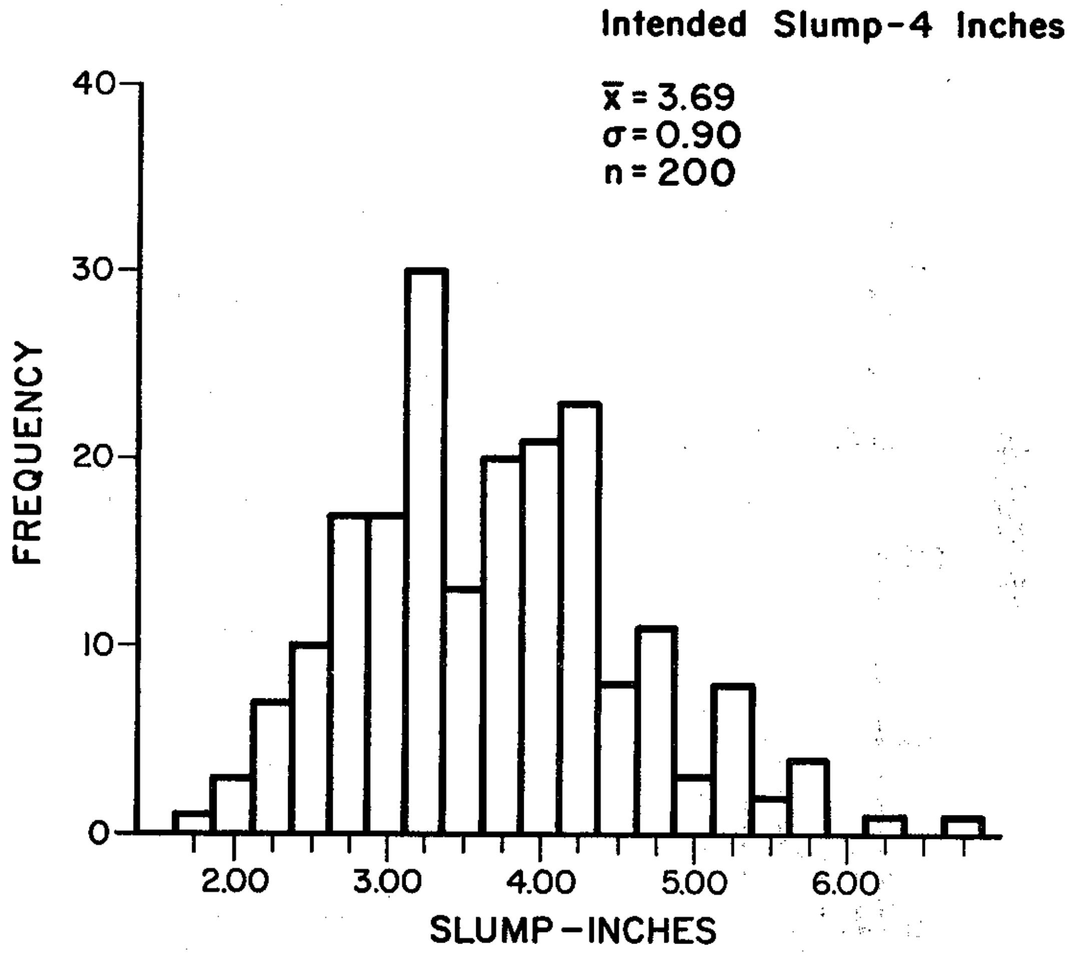


FIGURE 1

PROJECT NO. 2
DISTRIBUTION OF DATA
KELLY BALL TEST
(AVERAGE OF THREE OBSERVATIONS)

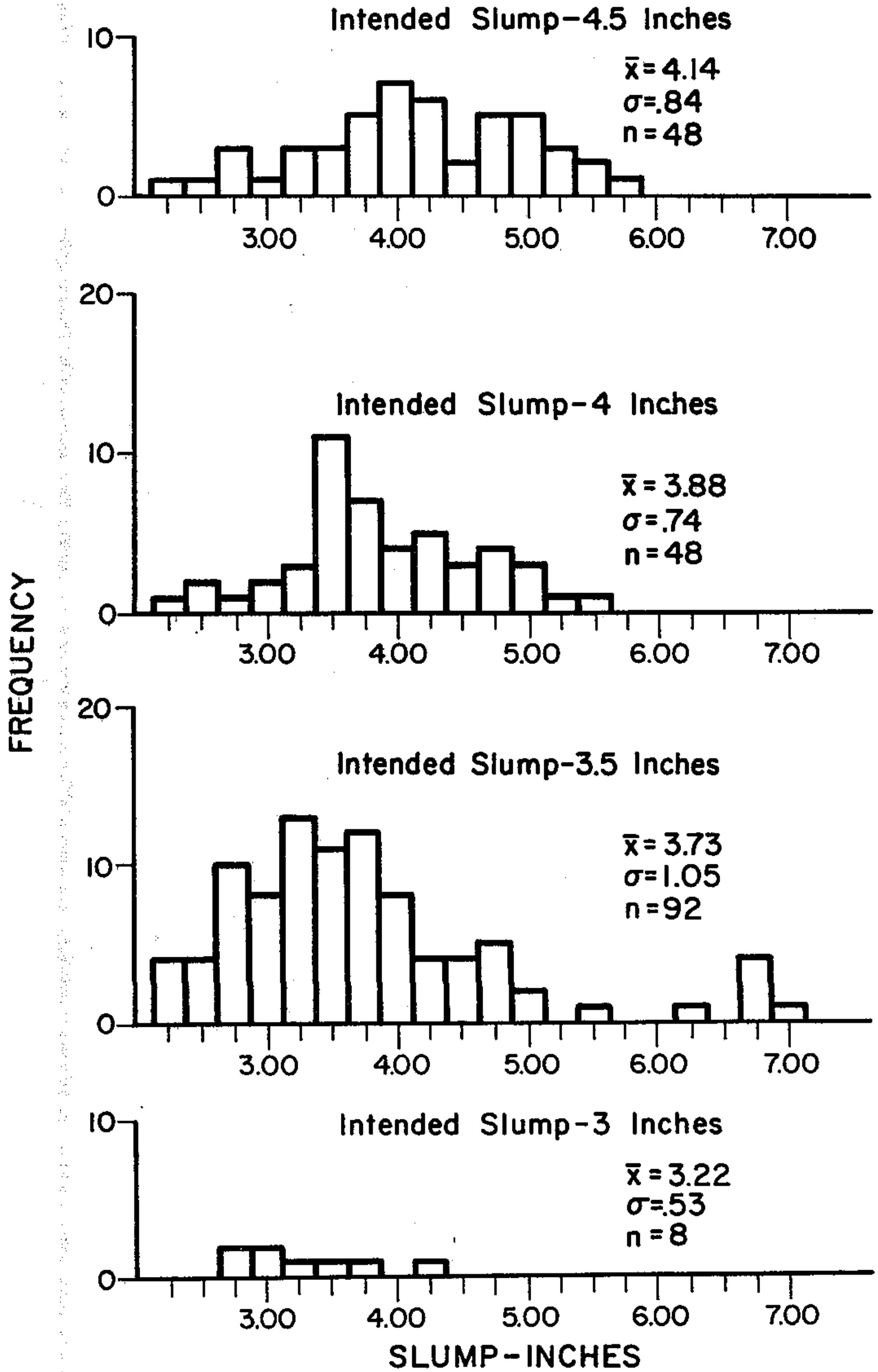
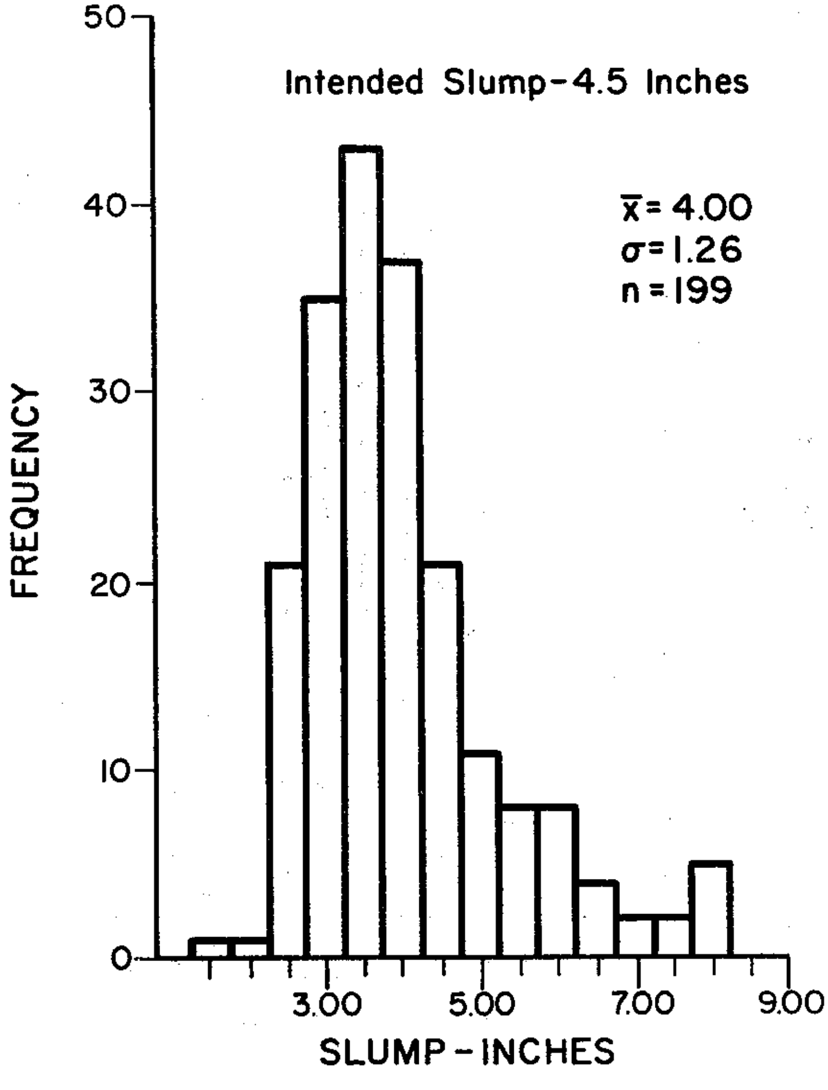


FIGURE 2

PROJECT NO. 3
DISTRIBUTION OF DATA-KELLY BALL TEST
(AVERAGE OF THREE OBSERVATIONS)



NOTE: Slump was read to nearest 1/2 inch on this project.

FIGURE 3

PROJECT NO. 4
DISTRIBUTION OF DATA-KELLY BALL TEST
(AVERAGE OF THREE OBSERVATIONS)

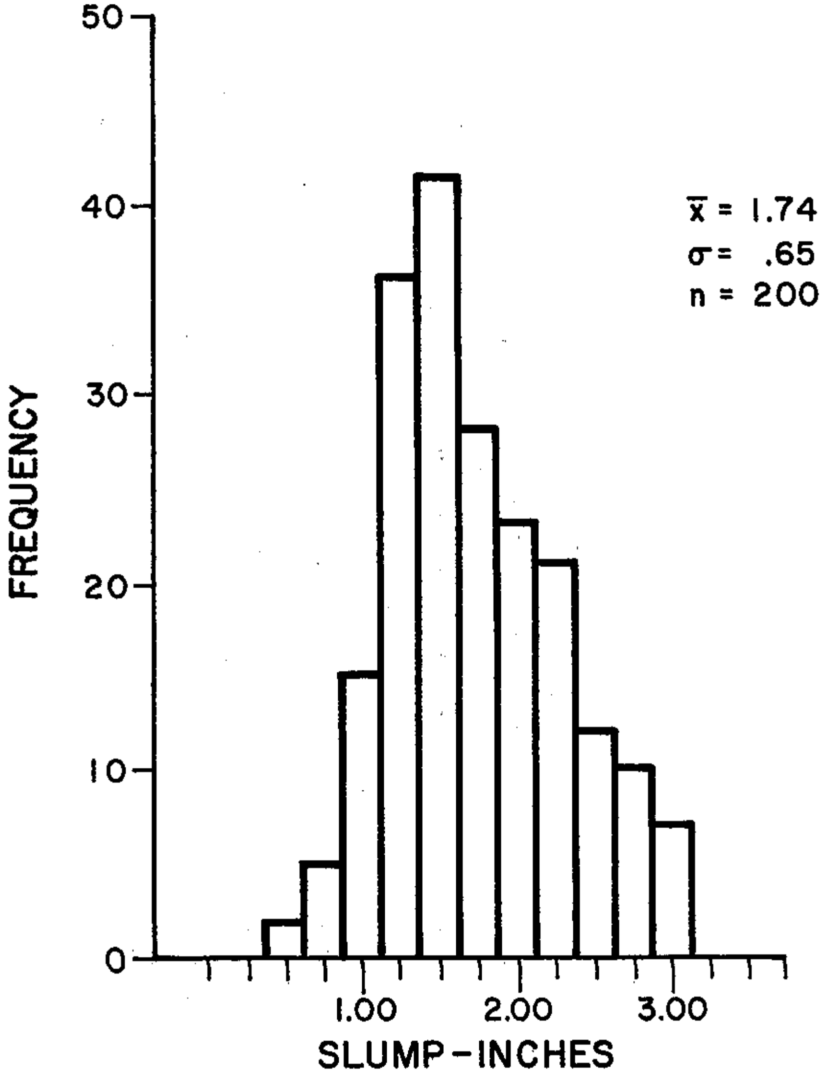


FIGURE 4

SOURCES OF VARIANCE—KELLY BALL TEST

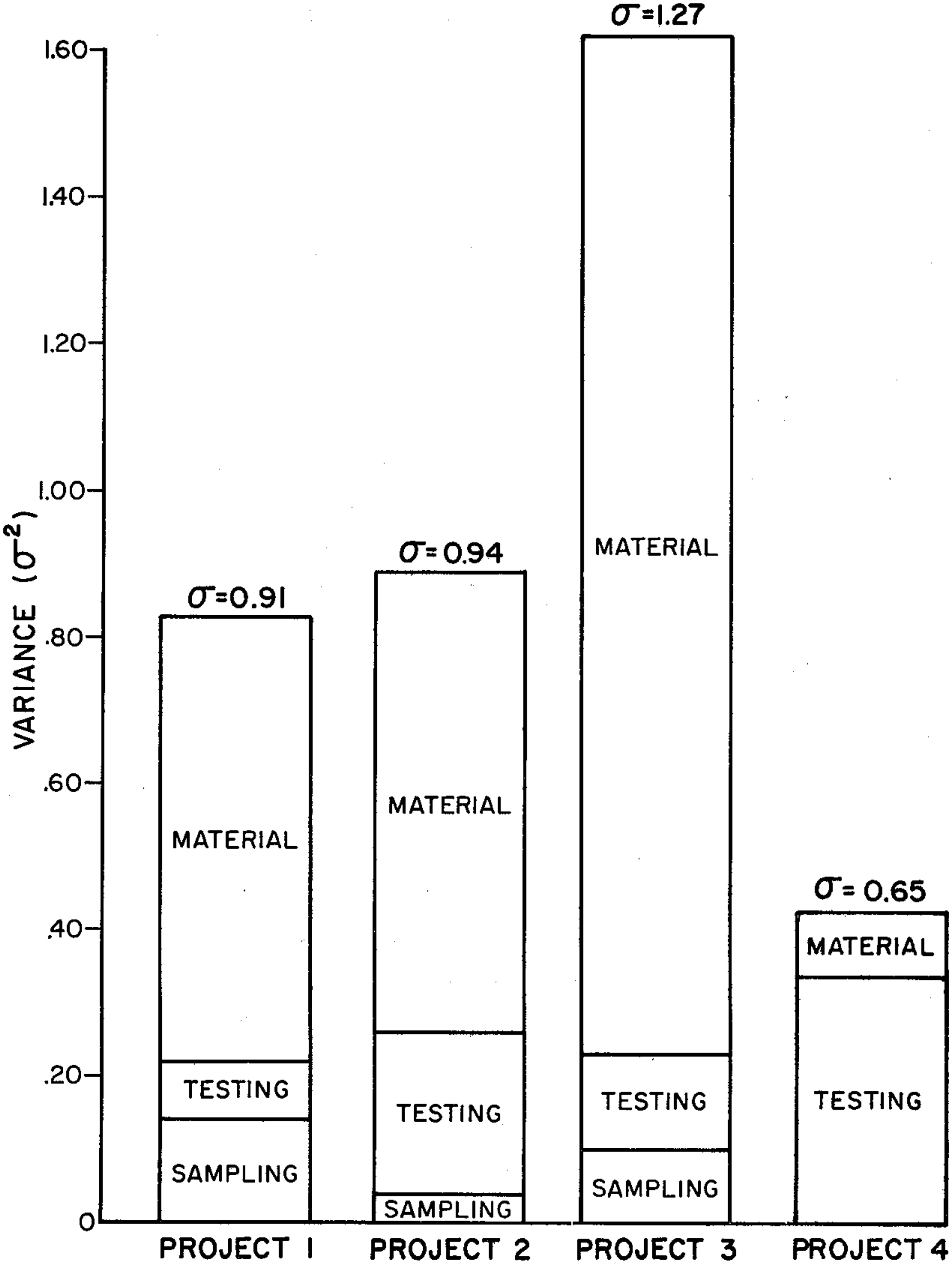


FIGURE 5

VARIATION OF SLUMP WITHIN A LOAD OF CONCRETE

DIFFERENCE BETWEEN TEST RESULTS OBTAINED AFTER 25% AND 75% OF LOAD HAS BEEN DISCHARGED

SAMPLE	TAKEN AFTER
A	25% DISCHARGE
B	75% DISCHARGE

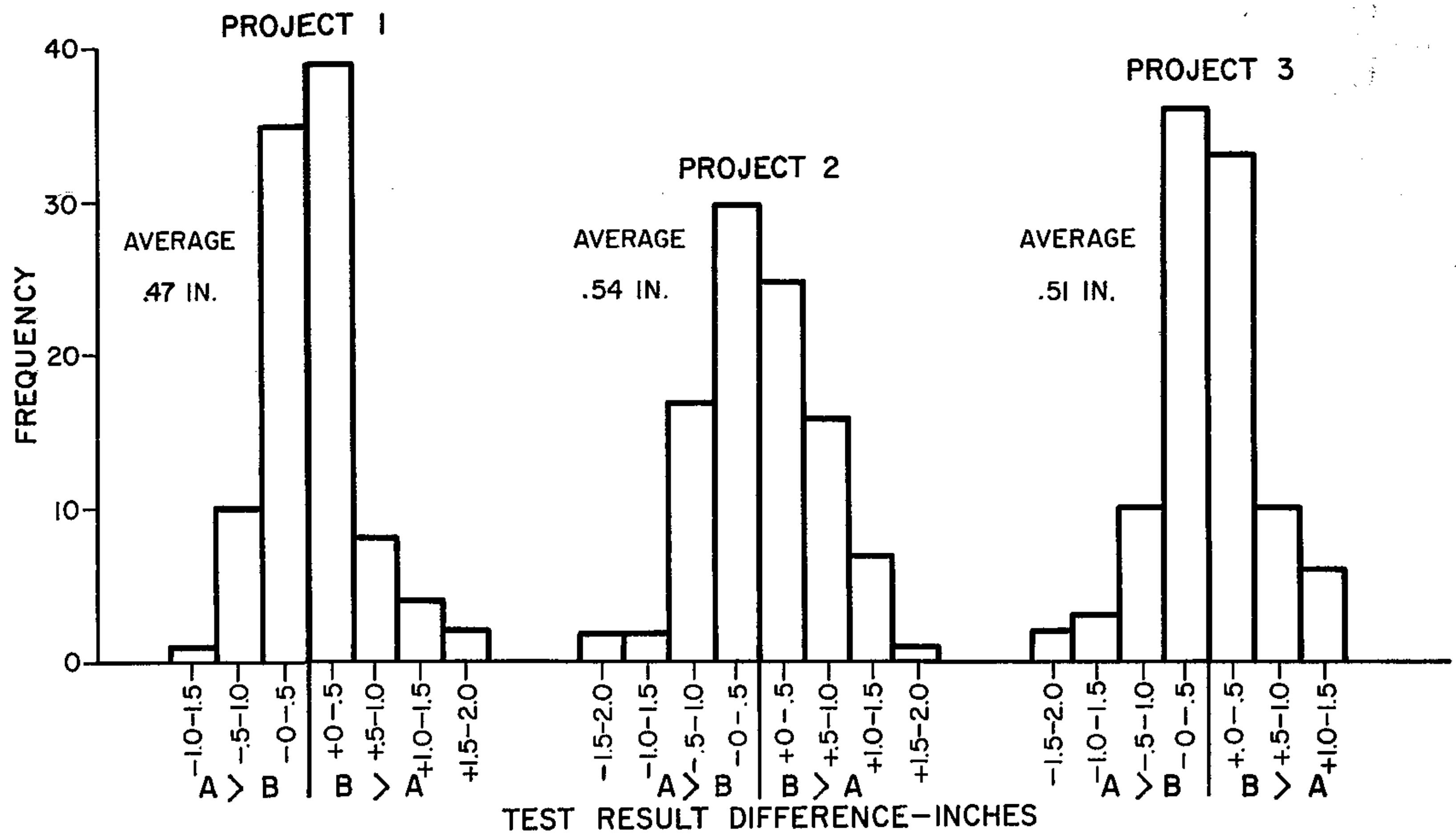
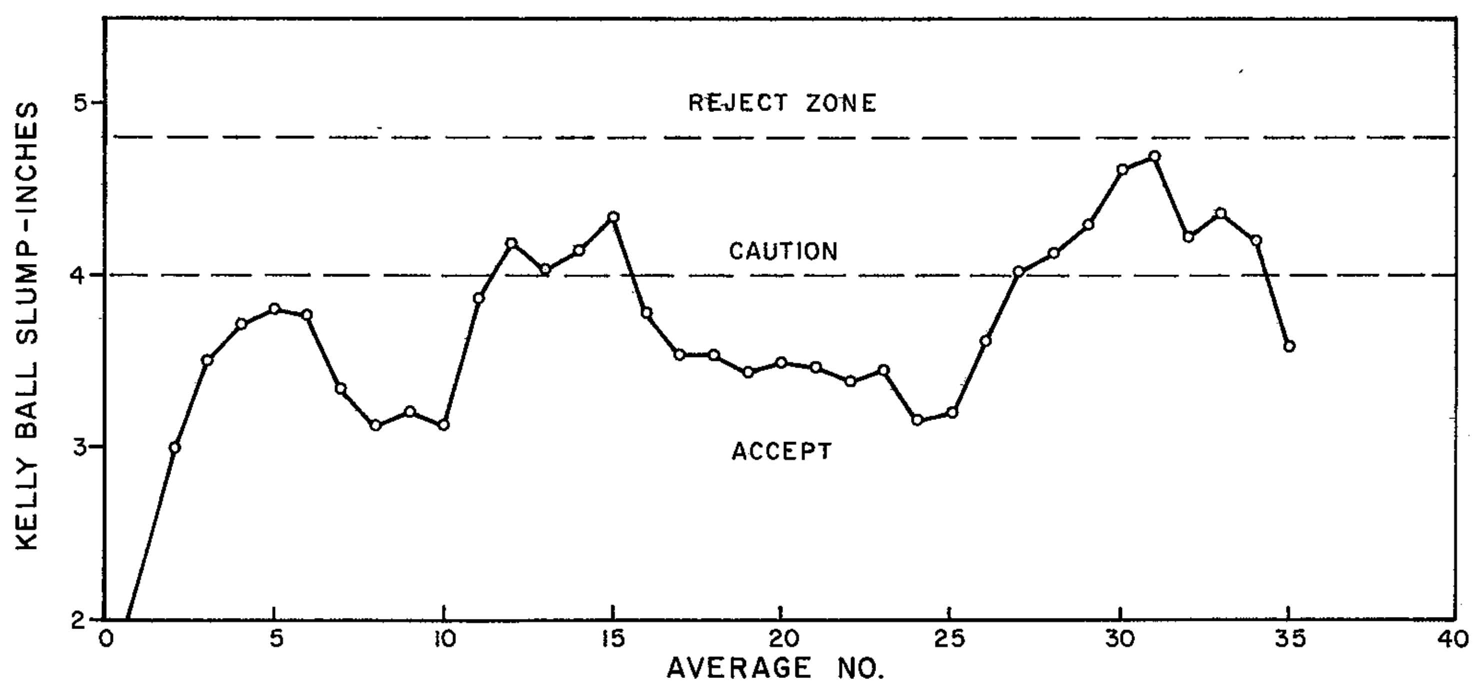


FIGURE 6

CONTROL CHART FOR THE RUNNING AVERAGE OF 5 KELLY BALL TESTS STRUCTURAL CONCRETE

No.	Result	Sum	*Avg.	No.	Result	Sum	*Avg.	No.	Result	Sum	*Avg.
1	2.50	2.50	1.50	13	2.67	20.17	4.04	25	4.33	16.00	3.20
2	5.00	7.50	3.00	14	4.67	20.67	4.13	26	5.17	18.17	3.68
3	4.50	12.00	3.50	15	3.83	21.67	4.34	27	5.00	20.17	4.03
4	3.83	15.83	3.71	16	3.17	18.84	3.77	28	3.50	20.67	4.13
5	3.17	19.00	3.80	17	3.33	17.67	3.54	29	3.50	21.50	4.30
6	2.33	18.83	3.77	18	2.67	17.67	3.54	30	6.00	23.17	4.63
7	2.83	16.66	3.33	19	4.17	17.17	3.44	31	5.50	23.50	4.70
8	3.50	15.66	3.13	20	4.17	17.51	3.50	32	2.83	21.33	4.26
9	4.17	16.00	3.20	21	3.00	17.34	3.47	33	4.00	21.83	4.37
10	2.83	15.66	3.13	22	3.00	17.01	3.40	34	2.83	21.16	4.24
11	6.00	19.33	3.87	23	3.00	17.34	3.47	35	2.83	17.99	3.60
12	4.50	21.00	4.20	24	2.67	15.84	3.17				



*Running average – see appendix A for method of calculating.

FIGURE 7

APPENDIX A

Tentative Method for Sampling and Determining Compliance with the Proposed Specifications for the Consistency of Fresh Concrete

SCOPE

This method provides a sampling procedure and a system for determining compliance with the proposed specifications for consistency of fresh concrete.

PROCEDURE

A. Sampling

1. Concrete delivered to the job site in ready-mix trucks:

   Sample all material which does not appear to meet specifications. For material which appears to meet specifications, sample every truck until four consecutive loads have met specifications, then randomly sample one load out of every three until four consecutive tests pass the requirements. Sampling shall then continue at the level of one randomly selected load out of every five. At any time a truck load of material is found to not meet specifications, the material shall be rejected and the above sampling plan shall be repeated.

2. Sampling material delivered to the job site from a central mixing plant:

   Sample any material which does not appear to meet specifications. At the beginning of a project take four tests at randomly selected locations every hour. After taking four consecutive tests which meet specifications, the sampling frequency may be reduced to taking two tests every hour at randomly selected locations. After taking four tests which meet specifications at the frequency of two every hour, the sampling frequency may again be reduced to only one test every hour at a randomly selected location. If at any time a test reveals the concrete does not meet specifications, the material shall be rejected and the sampling frequency shall be increased to four tests every hour and the procedure described above shall be repeated.

B. Random Selection

Any random method may be used to determine the sampling location or the truck from which the sample is to be drawn. The rolling of a die, the drawing of a number, or the use of random number tables are fully acceptable methods of randomizing providing all of the material being received on the job has an equal chance of being sampled. Appendix B contains two examples of random selection using a table of random numbers.

C. Testing

All samples shall be tested using California Test Method No. 520* as soon as possible after discharge from the mixer.

D. Calculations

After each test is completed, the test result shall be used in calculating a "running average". This parameter is obtained by the following procedure:

Test No. 1 Running Avg. = Result No. 1 - 1.00 inch

Test No. 2 Running Avg. = Avg. of Results 1 & 2 - 0.75 inch

Test No. 3 Running Avg. = Avg. of Results 1, 2, & 3 - 0.50 inch

Test No. 4 Running Avg. = Avg. of Results 1 thru 4 - 0.25 inch

Test No. 5 Running Avg. = Avg. of Results 1 thru 5

Test No. 6 Running Avg. = Avg. of Results 2 thru 6

Subsequent running average figures shall be calculated using the most recent five test results. Any test results from material which is rejected shall not be included in the Running Average.

E. Compliance Requirements

1. All test results must have values less than the Maximum Allowable Slump given in the specifications.
2. All Running Averages must have values less than the Maximum Running Average given in the specifications.
3. Material which does not comply with the above requirements shall be rejected.

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*See Appendix C for copy of test method.

APPENDIX B

Example Calculation on Random Selection;
Routine Running Averages; and
Determination of Maximum Running Average Limit

Random selection is based on the premise that any portion of a universe has the same chance of selection as any other portion. Therefore, any method that meets this requirement is satisfactory for use with the sampling procedures outlined in Appendix A.

For illustrative purposes, however, the following examples have been prepared with random selection being based on a table of random numbers.

EXAMPLE 1

Sampling from a Group

Assume that good control of concrete has been demonstrated by a contractor who is producing structural concrete. The inspector, according to specifications, is to test one randomly selected truck out of every five.

Using the table of random numbers attached, the sampler selects the truck to be sampled in the following manner. Starting at any point in the table, the sampler selects the first random number and multiplies it by 5. The truck is selected by rounding the answer upward to the next whole number. For example, if the product of the random number and 5 were 0.2, the sampler would sample truck No. 1 of the first group of five trucks. If the product were 3.5, truck No. 4 would be sampled, etc.

From the first random number, the sampler would proceed down the column of the random number table he had selected, being certain not to skip any numbers. It may be seen that any number of trucks or other items in a lot could be used as a base for determining which truck or item to sample.

Example:

Group	Number of Items	Random Number*	Sample From Item No.
1	5	.576 (Top of column 1-A)	2.88 - 3
2	5	.892	4.56 - 5
3	5	.669	3.35 - 4

EXAMPLE 2

Random Sampling Using Time

An inspector has determined from specifications that four randomly selected locations are to be tested during the next hour of production of paving concrete. The sampler obtains the first four random numbers from the table, starting at any point in the table and proceeding up or down, not skipping any numbers.

Each of the randomly selected numbers is multiplied by 60 minutes and rounded upward. The resulting numbers represent the time segments during which tests are to be performed.

---

*Table of Random Numbers attached.

Example: The hour to be tested begins at 11:00 a.m.

Random Number	No. Segments	Segment Tested	Time of Test
.685	60	41	11:41
.875	60	53	11:53
.183	60	11	11:11
.612	60	37	11:37

Additional segments may be selected as alternates if it appears that one test will not be completed before it is time for another to begin. The problem presented by construction delays can be solved by counting time only while the contractor is operating.

EXAMPLE 3

Calculation of the Running Average

Maximum Running Average = 4.8 inches (Proposed Specifications)

Test No.	Result	Sum	Running Avg.
1	3.50		2.50
			Material Rejected
2	4.50	8.00	3.25
3	3.83	11.83	3.44
4	3.50	15.33	3.59
5	2.67	18.00	3.60
6	2.50	17.00	3.40
7	3.83	16.33	3.27

EXAMPLE 4

Determination of Maximum Running Average Limit for Structural Concrete Based on the Results of This Study

Basic Statistical Relationship:

$$\bar{\bar{X}} = \bar{X} \pm \frac{2\sigma}{\sqrt{n}}$$

$\bar{\bar{X}}$ = The overall average slump value obtained by combining the results of these three structural projects:

$$\bar{\bar{X}} = (3.7 + 3.9 + 4.0) \div 3 = 3.9 \text{ inches}$$

$\bar{X}$ = Average to be expected from a small number of n samples. For setting slump limits $\bar{X}$ is set as the upper limit of the specification.

n = Number of samples included in $\bar{X}$. In this case n = 5.

σ = Standard Deviation. A measure of the expected spread of individual results around the overall average ($\bar{\bar{X}}$). Based on this study σ is approximately equal to 1.

2 = A factor corresponding to a probability of about 45 parts in 1000.

For upper specification limit $\bar{X} = \bar{\bar{X}} + \frac{2\sigma}{\sqrt{n}} = 3.9 + \frac{2(1)}{\sqrt{5}}$

$\bar{X} = 3.9 + \frac{2}{2.24} = 3.9 + .9 = 4.8$ inches = Maximum Running Average.

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

APPENDIX C

Copy of Calif. Test Method No. 520-C,
Method of Test for Slump of Portland
Cement Concrete

METHOD OF TEST FOR SLUMP OF PORTLAND CEMENT CONCRETE

(Kelly Ball Method)

Scope

The slump of concrete by the Kelly ball method is a procedure for determining the consistency of fresh concrete. This method is a modification of A.S.T.M. Designation: C 360 and A.A.S.H.O. Designation T 183.

A. Apparatus

The Kelley ball apparatus consists of a steel penetrator having a 6-in. diameter hemispherical tip which is machined to a special finish. The penetrator is attached to a graduated shaft on which the smallest graduations (¼ inch apart) correspond to ½ inch of slump. Thus, "Kelly Ball slump" is read directly using the scale on the shaft. The weight of the apparatus, exclusive of the yoke, is 30 ± 0.05 pound.

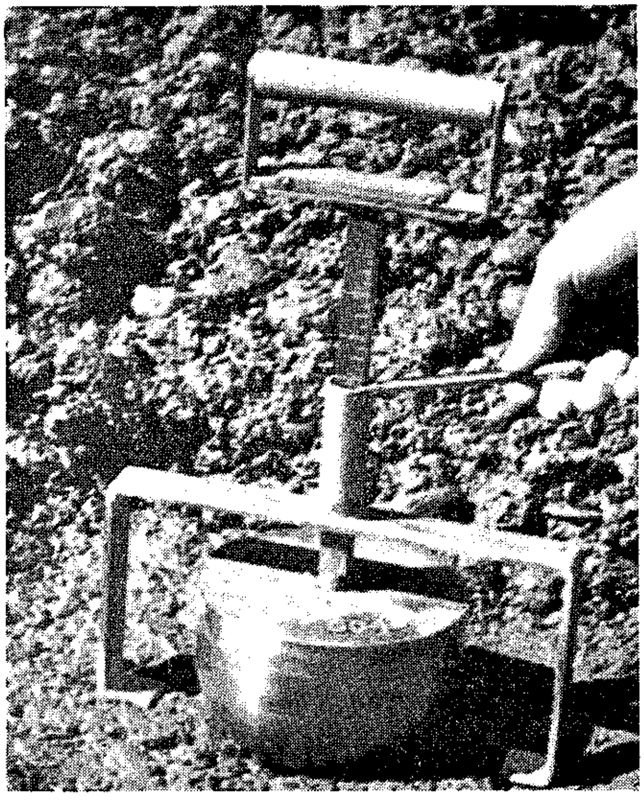

FIGURE 1
KELLY BALL SLUMP TEST

Readings are made at the top of the tubular sleeve attached to the yoke. (Zero reading is established by screwing the graduated shaft either in or out of the penetrator when the feet of the yoke and the bottom of the penetrator are on the same plane; the jam nut is then tightened) (see Fig. I).

B. Test Procedure

1. The Kelly ball slump test may be made on concrete in a wheelbarrow, buggy or other container, or after it has been deposited in the forms or on the subgrade. The only restrictions for normal highway concrete are that the concrete be at least 6 in. deep (above the bottom of the container or buried reinforcement), and that there be at least 6 in. of clearance from the center of the ball to the nearest wall or other obstruction (see Notes).

2. The concrete is tested as it comes from the mixer. It is not tamped, vibrated or consolidated in any way. Large pieces of aggregate are *not* removed. It is preferable to perform the test as soon as possible after discharge from the mixer (see Notes).

3. The surface of the concrete is struck off level over an area of two to three square feet. (The amount of screeding should be the minimum required to secure a reasonably level surface because overworking will flush excess mortar to the surface and the indicated slump will then be too high).

4. Holding the device by the handle, lower it slowly over the prepared area until the feet of the yoke touch the surface of the concrete. Make certain the shaft is in a vertical position and free to slide through the yoke. Gradually lower the ball into the concrete, maintaining enough restraint on the handle so that penetration is due to the dead weight of the ball only and not to any force generated by acceleration of the mass. When the ball comes to rest, release the handle and read the slump to the nearest ¼-inch. Settlement of the feet of more than ⅛-inch is an indication that the concrete has been over-worked in screeding the surface, or that the yoke is binding on the shaft.

5. Take a minimum of three individual readings for each slump determination. Individual readings shall be at least nine inches between centers. If the difference between maximum and minimum readings is more than one inch slump, make additional measurements until three readings have been obtained which agree within one inch of slump. Failure to obtain readings which agree within one inch may be due to excessive mortar at one location, or due to a piece of large aggregate near the surface and immediately under the ball.

6. When tests have been completed, wipe the apparatus clean and return to carrying case.

C. Reporting of Results

Report, to the nearest ¼ inch, the average of three readings as "_______ inches slump, Kelly ball".

Notes

1. If tests cannot conveniently be made elsewhere, they may be made between form walls spaced not less than 8-in. apart, provided there is no reinforcement within 6-in. of the leveled surface.

2. One important reason for testing concrete promptly after discharge from the mixer is the possibility that certain cements may cause premature stiffening, or false set, within 30 to 60 seconds after the completion of mixing. When this occurs, the concrete stiffens markedly, even to the extent that it can be walked upon without leaving appreciable foot marks. Obviously, a slump test that is made after false set has taken place will indicate the concrete to be dryer than it was when mixed but it is improper to add excess water in trying to overcome premature stiffening. There are all degrees of premature stiffening and, if only slight, it may be difficult to recognize. Therefore, it is important to measure the slump promptly. The Kelly ball has a marked advantage over the slump cone in the time required to make the test.

3. "False set" or premature stiffening is so called because the original consistency of the concrete can be restored by reworking it sufficiently. It is troublesome to the contractor, but it should not be compensated for by the use of extra mixing water, because this will result in impairment of the quality of the concrete. False set is less likely to occur in ready-mixed concrete because the period of mixing and agitation usually is sufficiently long to overcome any stiffening effect that might have occurred after a shorter mixing time.

4. The minimum depth of concrete for a satisfactory test depends on both the penetration and the maximum size of aggregate. The minimum clearance under the ball after penetration should be about twice the maximum size of aggregate. The penetration of the ball in inches is equal to approximately one-half the slump as measured by a standard slump cone. Thus, a 6-in. depth of concrete is sufficient both for concrete containing 1½-in. aggregate for slumps up to 6-in. (3-in. penetration), and for concrete containing 2½-in. aggregate for slumps up to 2-in. (1-in. penetration).

5. Accuracy is impaired if the surface of the Kelly ball is roughened by scratches, dents or adhering mortar. It should be cleaned carefully after each test and always kept in the carrying case when not in use, in order to help prevent springing the yoke out of shape and to decrease the consequent need for frequent adjustment of the zero setting.

REFERENCES

A.S.T.M. Designation: C 360
A.A.S.H.O. Designation: T 183

End of Text on Calif. 520-C