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FRITZ ENGINEERING LABORATORY
LEHIGH UNIVERSITY
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A STUDY OF THE ANALYSIS OF FRESH CONCRETE WITH THE DUNAGAN BUOYANCY APPARATUS

by

H. R. Nettles*

and

J. M. Holme*

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1. Introduction and Summary - This paper presents the results of an investigation which was carried out in the Fritz Engineering Laboratory of Lehigh University for the determination of the efficiency of the Dunagan Buoyancy Apparatus for the analysis of fresh concrete. The tests were begun in November, 1930, and were completed in March, 1932. While the major part dealt with the analysis of mixes, considerable attention was given to the properties of the cement and aggregates used in these mixes.

In brief, the results of the cement and aggregate tests showed that:

1. The specific gravity determination of cement was affected by the length of time of immersion. Samples of cement which were immersed and stirred only upon introduction into the weighing bucket showed a two per cent increase in specific gravity. Samples of cement which were stirred frequently during the immersion showed an eight per cent decrease in specific gravity.

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2. The specific gravity determination of fine aggregates was also affected by the length of time of immersion. Samples of fine aggregate which were stirred frequently during immersion showed an increase, while samples which were allowed to remain undisturbed were found to show a decrease in specific gravity.

3. The specific gravity determination of coarse aggregates increased with the length of time of immersion, and its determination was unaffected by stirring.

4. The large variations in grading of any one cement or aggregate required a large number of tests in order to determine the correction factors to be used for the No. 100 sieve.

The results of the analysis of the concrete showed that:

1. Under field conditions the analyses showed variations in determined water content of 1.0 [illegible] gallon per sack.

2. Under laboratory conditions the analyses showed a variation in determined water content as great as 1.1 gallons per sack.

3. With correction factors for the fineness of the materials eliminated, the determined water content showed a maximum variation of 0.45 gallons per sack from that for which the mix was designed.

4. With the error in sampling eliminated, a variation of 0.3 gallons per sack was found between individual samples.

5. When both fineness and sampling had been eliminated the variation in water content was as great as 0.35 gallons per sack.

6. A study of significant figures showed that slide rule computations were sufficiently accurate for the analysis of the mix.

2. Cement - Studies of cement were made to determine two factors; (1) variation in specific gravity with length of time of immersion, and (2) variation in grading. In the first study three different test procedures were used.

In the first procedure a 1000-gram sample of cement was carefully poured into the weighing bucket which was partly filled with water. After thorough stirring, the bucket was filled with water and allowed to stand for three minutes before weighing. The bucket then remained undisturbed until the test was completed. The data are presented in Fig. 1 and indicate that the specific gravity of the cement increased considerably during the first hour of immersion. Thereafter the increase was relatively slow.

The second procedure was essentially the same as the first except that the cement was stirred thoroughly at three minutes prior to each weighing. Bubbles of air or gas were observed to escape during the stirring. The data from the second series of tests are also plotted in Fig.1. The specific gravity of the cement decreased as the length of time of immersion increased. This is contrary to the results found with the first procedure.

The curves marked "Stirred" and "Unstirred" in Fig.1 indicate that it is possible to have a variation as great as ten per cent in the specific gravity of the cement. Consequently the observed cement content might vary by ten per cent and the water content by a corresponding amount.

For the third procedure, tests were made using Le Chatelier Flasks. The standard method of test was followed exeept that water instead of kerosene was used as liquid. The flasks were not disturbed after the initial reading. Several attempts were made to find the effect of released gasses or air, but it was impossible to free visible beads or globules. The data which are plotted in Fig.1 show a close agreement between the results obtained on unstirred cement by using the Le Chatelier Flask and the Dunagan apparatus.

The authors offer as an explanation of the results showing a decrease in specific gravity, the instability of the cement particles in water. When the cement was placed in the water and left unstirred, bubbles were seen to escape only upon its introduction. When stirred, a considerable quantity of air or gas was seen to escape and the gravity was found to decrease. From this it is concluded that stirring accelerates the reaction between cement and water with the evolution of a gas and a resulting loss in weight and volume.

The percentages of cement retained on the No.100 sieve was determined both by dry and wet sieving. Approximately 0.2 of one per cent more was retained by dry than by wet sieving.

3. Fine Aggregate - The variation in the specific gravity of sand with the length of time of immersion was determined by two different methods.

In the first method a 1000-gram sample of dried sand was placed in the weighing bucket, stirred to free entrapped air and weighed immersed. Without further disturbance, the sample was weighed at regular intervals during a two-hour period. The weights instead of increasing, actually decreased up to 1-1/2 hours, showing a 1.2 per cent decrease in the specific gravity. This would indicate that the volume of the sand and the entrapped air increased during the immersion. The test was repeated on sand from a different source and the results agreed quite well, as shown in Fig. 2. In order to check these results, a test was made using the Chapman Flask. The dried sand was carefully introduced into the flask which contained 200 cc. of water. Except for a thorough shaking immediately after the sample had been introduced, the flask was not disturbed. The results were found to agree with those for the Dunagan apparatus.

In the second method the sample was thoroughly stirred about two minutes prior to each reading. Both the Dunagan Apparatus and the Chapman Flask were used. With the former, air bubbles were seen to escape from the sand when stirred the first five or six times. The results showed an increase in the specific gravity, indicating an absorption of water by the sand (Fig.2). With the Chapman Flask it was impossible to remove the entrapped air from the flask. The results were therefore in disagreement with those obtained with the Dunagan Apparatus.

The apparent decrease in the specific gravity of immersed sand with length of time was considered due to the slow displacement of air from the interior to the exterior of the grains by the penetrating water. The bubbles were probably too small to escape by their own buoyancy and remained attached to the sand grains in larger volume than they occupied within the grains before being driven out by the inflowing water.

The fineness of the sand was considered of great importance because the variation in the percentage of sand passing a No.100 sieve (termed as silt) enters directly into the computation of an analysis made with the Dunagan Apparatus. One per cent variation in the silt factor results in a change of 0.1 or more gallons per sack in the water content for a 1:6 concrete mix having an actual water content of 7.5 gallons per sack.

The sand used in this investigation was a well graded concrete sand which contained only about 1.6 per cent silt. Five samples of sand were sieved, both dry and wet. The results showed that dry sieving gave 0.3 per cent more silt through the No. 100 sieve than did washing.

The amount of sand retained on the No.4 sieve was of minor importance, because the vital ingredients of concrete (cement and water) are affected only when there is a considerable difference in the specific gravities of the fine and the coarse aggregates. The fine and coarse aggregates used in this study had approximately the same specific gravity.

4. <u>Coarse Aggregate</u> - The tests on the coarse aggregate were conducted in the same manner as were those on the fine aggregate. The results of the specific gravity determination are plotted in Fig. 2 and show that the maximum variation was 0.4 per cent. Stirring at intervals during the period of immersion had no effect on the rate of absorption.

Tests were also made on the amount of coarse aggregate passing the No. 4 and No. 100 sieves. The percentage of coarse aggregate passing the No. 100 sieve varied from 0.2 to 0.6 per cent.

5. Concrete Mixes - This investigation included five series of analyses of concrete mixes. In each series the results are believed to be representative of the adaptability of the Dunagan Apparatus when used under some particular set of operating conditions.

The first series were made in the Fritz Engineering Laboratory of Lehigh University during the test of the Clinton Conveyor*, under circumstances closely approximating actual field conditions. An effort was made to secure representative samples weighing approximately 5000 grams each. The samples were weighed in air immediately and then set aside until it was convenient to analyze them. Corrections were made for the amount of aggregates passing and for the amount of cement retained on the No. 100 sieve. In Fig. 3 the results have been plotted on the basis of the volumetric composition of a unit volume of concrete. The extremely small scale used in this method of plotting fails to make evident the difference between the designed and the observed percentages of any one ingredient of the concrete. This is particularly unfortunate when the cement and the water are considered.

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* TESTS OF CONCRETE CONVEYED FROM A CENTRAL MIXING PLANT by Willis A. Slater, Proceedings, A.S.T.M. Vol. 31, Part II, page 510

The results were therefore plotted in terms of designed and observed water contents and mixes (aggregate-cement ratio). Fig. 3 showed close agreement between the designed and observed percentages of ingredients in a unit volume of concrete. Fig. 4, however, shows that the water content ~~in one case~~ differed as much as 1.0 gallon per sack ~~in excess of~~ from the designed water content. The observed mix varied from 1:5.6 to 1:7.0, while the designed mix was 1:6.5.

In the second series of tests the effects of (1) time elapsed between mixing and analyzing, and (2) personal equations of operators, were studied. These tests are assumed to be representative of results obtainable with the Dunagan Apparatus under laboratory conditions. One cubic foot of concrete was divided into fifteen samples, all of which were weighed in air within ten minutes following the mixing. Corrections were made for cement retained on, and aggregates passing the No.100 sieve. A correction was also made for the absorption of water by the aggregates. The results as plotted in Fig. 5 show a variation between designed and observed water of 0.8 gallons per sack. The designed mix was 1:6.5 and the observed mix varied from 1:6.1 to 1:7.1.

Little if any effect was found to be due to the personal equations of the two operators or to the time elapsed between mixing and analyzing.

Series 3, 4 and 5 were made to determine the effect of sampling. In Series 3 the aggregates were washed in order to eliminate a silt correction. Saturated aggregate and absolute specific gravity were used to eliminate a correction for moisture content. The cement has been passed through a No.100 sieve, and all tests were performed by the same operator. The mixing was done by hand and the batch was divided into five samples. Both the individual and the total weights were used in the computations of the analyses and the results are plotted in Fig. 6. The water content of the individual samples showed a maximum variation from the designed of 0.45 gallons per sack, while the total differed by 0.30 gallons per sack. The observed mix varied from 1:4.7 to 1:7.0. The total mix was 1:6.2, while the designed mix was 1:6.0. Although the results for the total batch were in closer agreement with the actual conditions than were the results obtained from the individual samples, the disagreement was of sufficient magnitude to show that sampling was not the only error involved.

The seven samples in Series 4 contained 500 grams of cement, 1000 grams of sand, and 1500 grams of gravel each. The ingredients were weighed directly into the weighing bucket.

The sand and gravel from each sample were dried thoroughly and weighed after the test. These weights were used in determining the specific gravities of the aggregates. In computing the results, corrections were made for the cement retained on, and the aggregates passing the No. 100 sieve. The results as plotted in Fig. 7 show a maximum variation of 0.3 gallons per sack between the various samples, and 0.2 gallons per sack from the water content used in the design of the mix. The designed mix was a 1:5.0 and the observed mix varied from 1:4.9 to 1:5.3.

In Series 5 variations in the fineness of the cement and aggregates, and in the method of sampling were eliminated. The cement had passed a No. 100 sieve and the aggregates were retained on a No. 50 sieve. Both fine and coarse aggregates were washed and dried thoroughly before weighing. After weighing the aggregates were soaked for 48 hours. The cement was weighed in air and added to the saturated aggregates in the weighing bucket. In computing the results the absolute specific gravity of the aggregates was used. The value used for the specific gravity of the cement was that which corresponded to the time interval during which the cement had been immersed. The results as plotted in Fig. 8 show that discrepancies were not entirely eliminated, although every controllable variable had been taken into account. The only uncertain quantity in the analyses was the specific gravity of cement and the authors feel that they are justified in attributing the discrepancies primarily to this factor. The water content showed a variation of 0.35 gallons per sack from the designed water content of 6.75 gallons per sack. The designed mix was 1:6.5 and the observed mix varied from a 1:6.0 to a 1:6.3.

6. Effect of Errors on Analyses Results - A study of the significant figures involved in the computation of the analyses of fresh concrete, revealed that a slide rule computation was as accurate as warranted by the observations. If the specific gravity is determined to ±0.05, a variation in water content of as much as 0.7 gallons per sack may be caused by the coarse aggregates, 0.5 gallons per sack by the fine aggregate, and 0.5 gallons per sack by the cement. These figures are based on a 1:2.4:3.6 mix.

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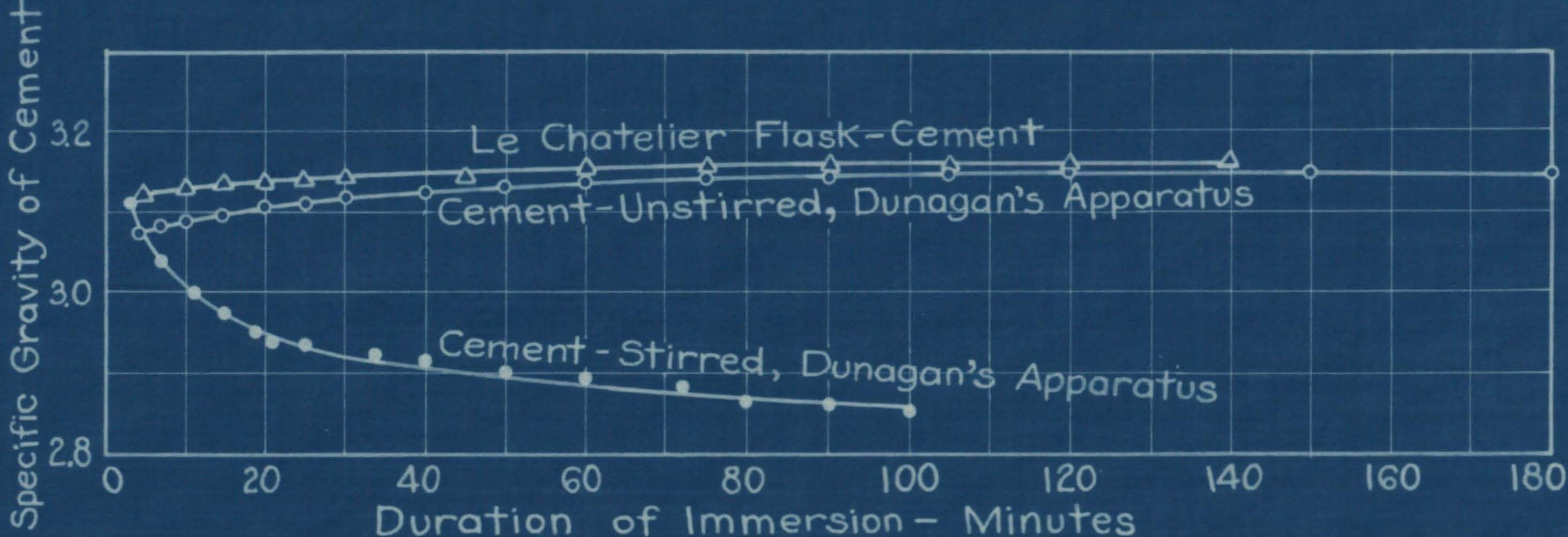

Fig. 1 - Variation in Specific Gravity of Cement with Duration of Immersion

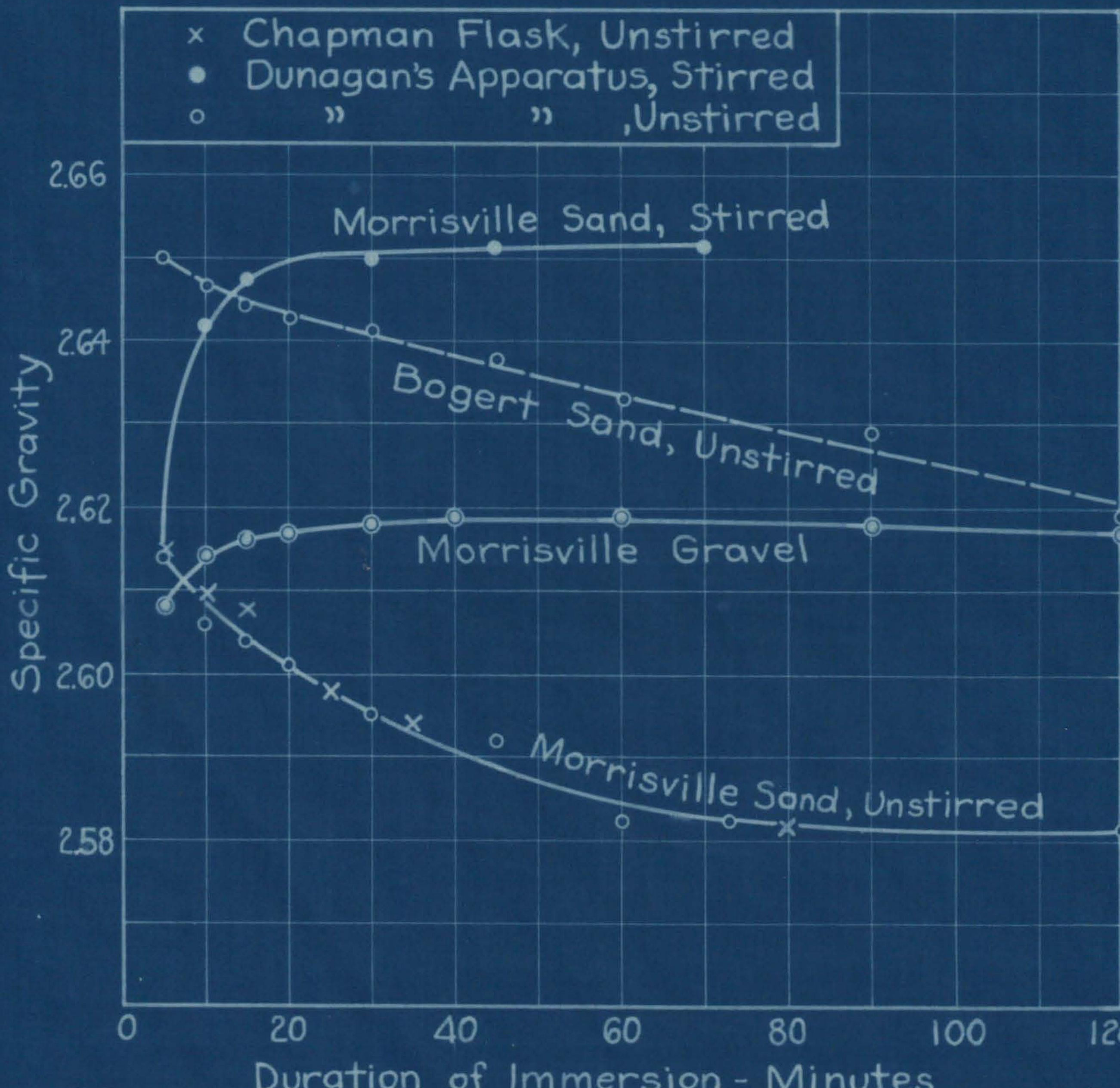

Fig. 2 – Variation in Specific Gravity of Sand and Gravel with Duration of Immersion

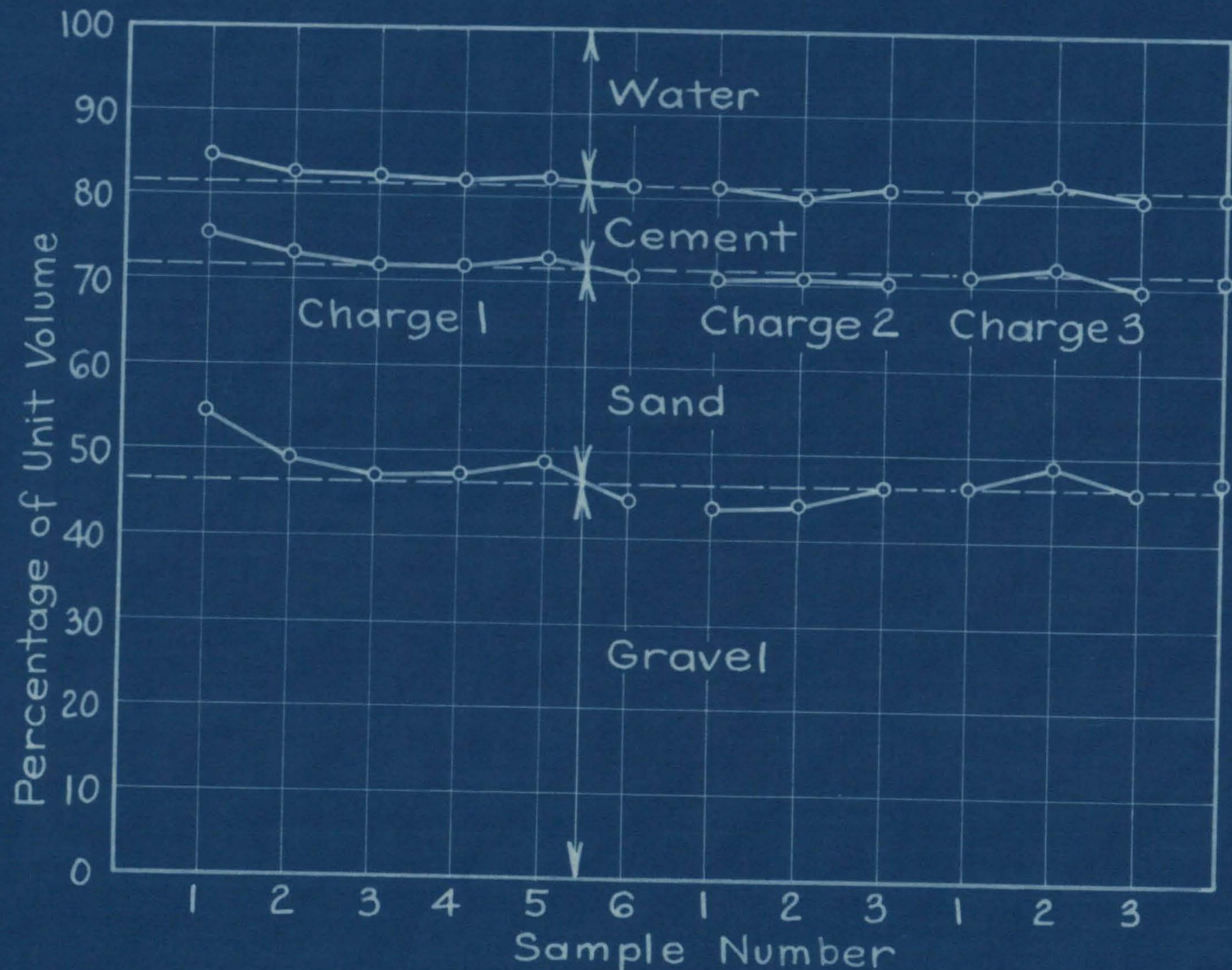

Fig. 3- Variation of Analyses of Samples from Charges having the Same Proportions.

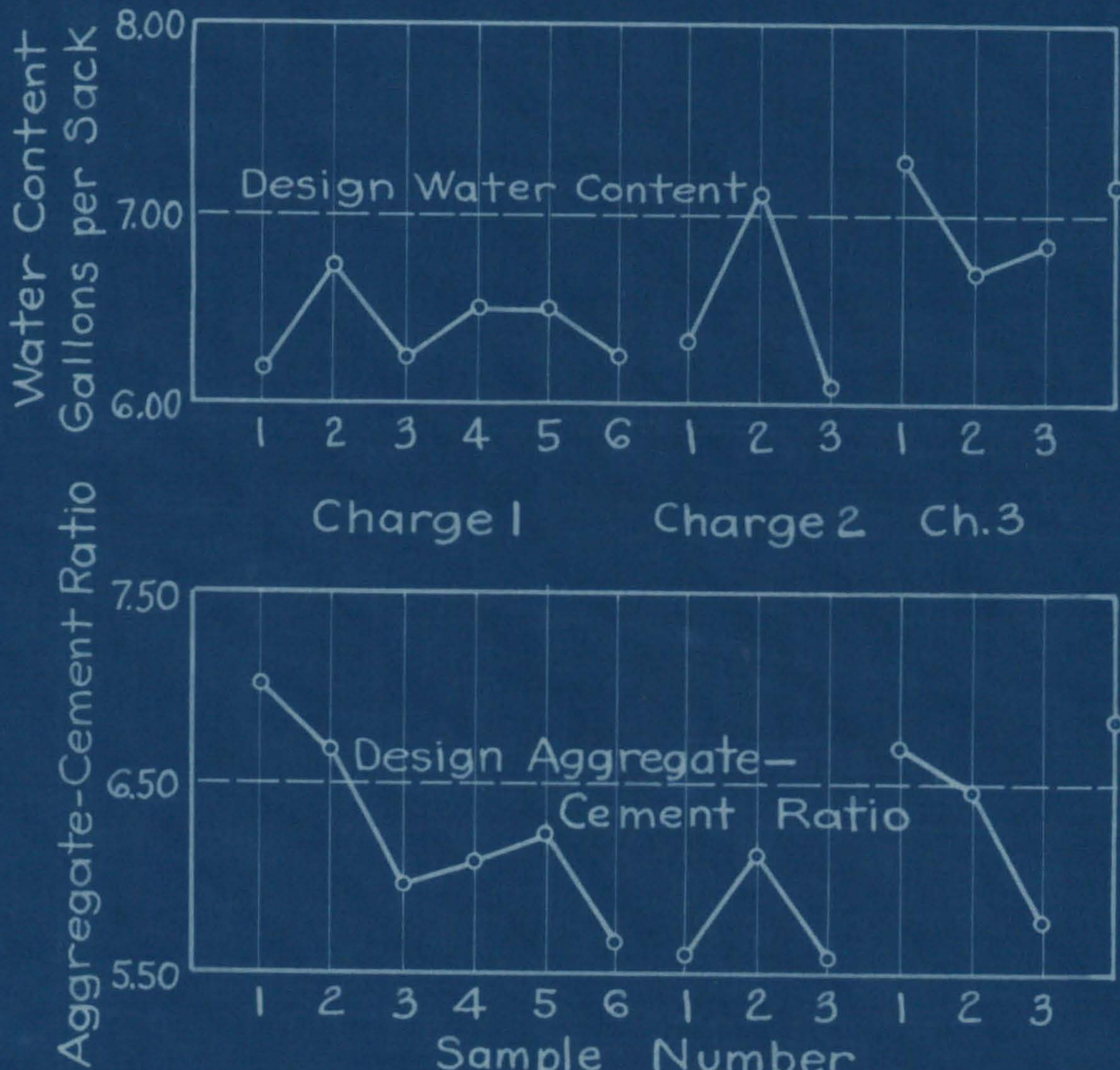

Fig.4-Variations of Water Content and Mix from Analyses of Samples from Charges having the Same Proportions

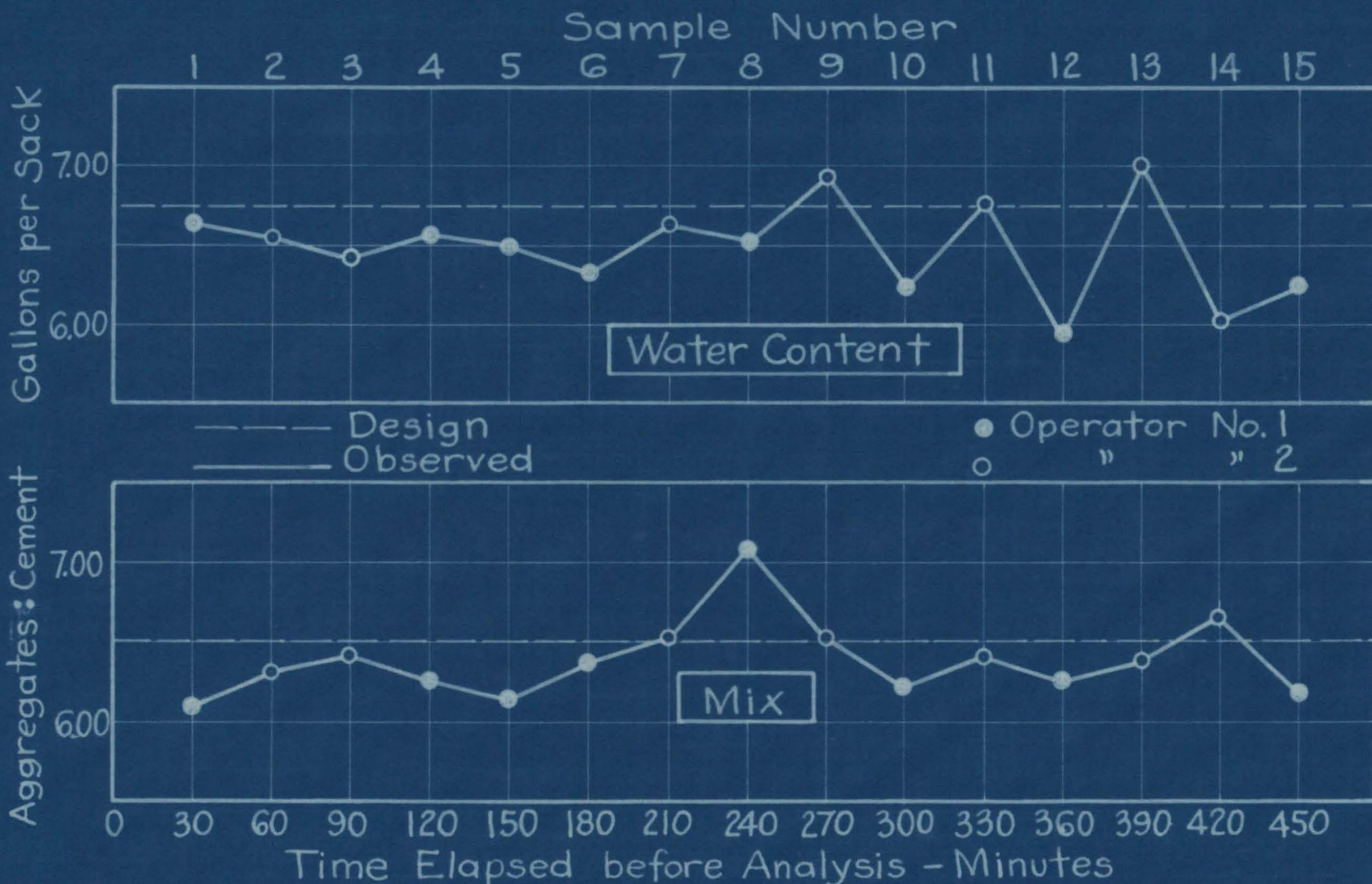

Fig.5-Variation in Water Content and Mix of Samples from the same Batch

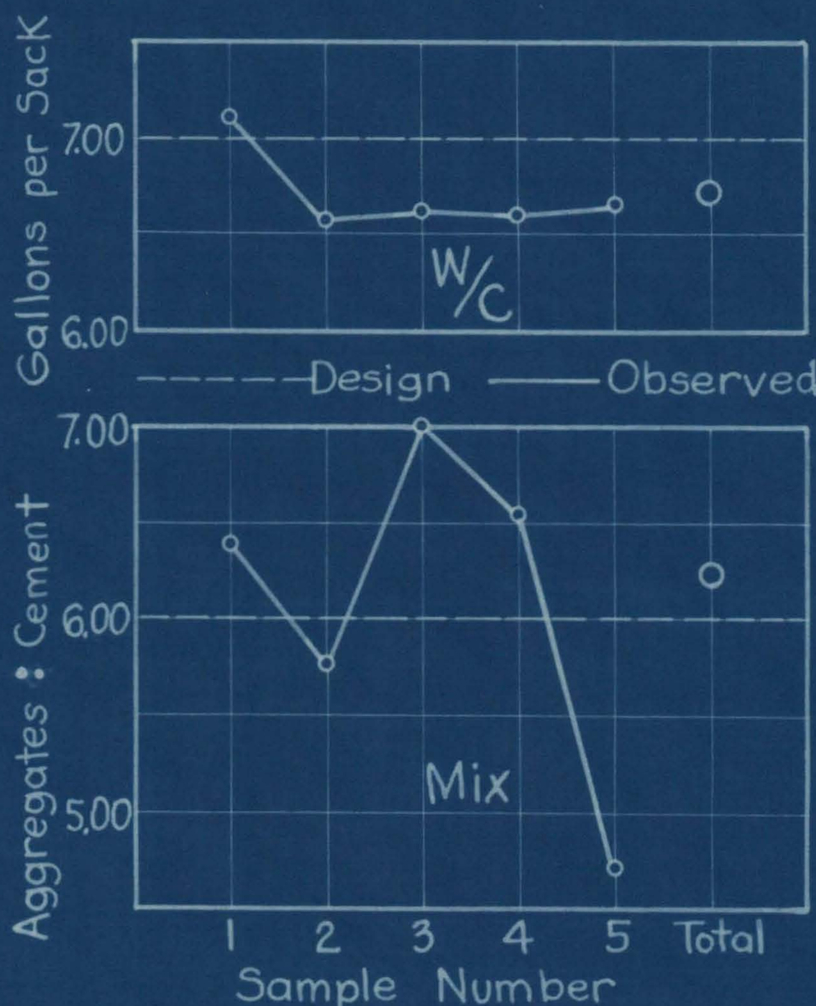

Fig. 6 - Variation in Ingredients as determined from Samples from one Batch - Corrections Eliminated

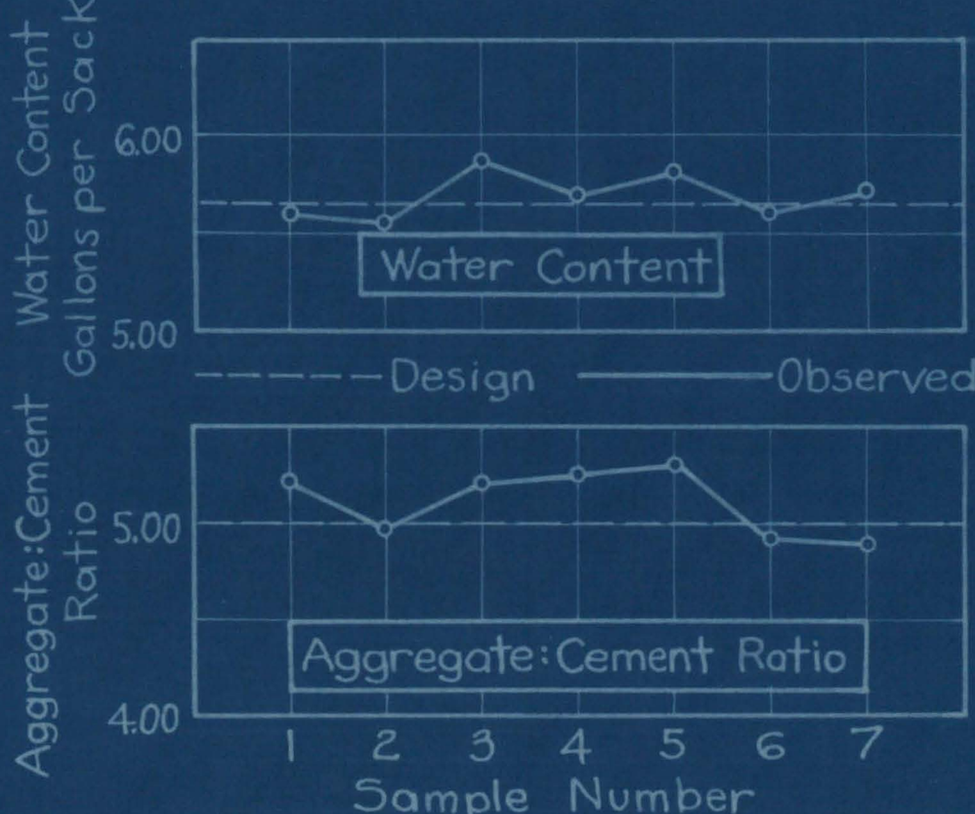

Fig. 7- Variation in Water Content and Mix of Concrete having Sampling Eliminated.

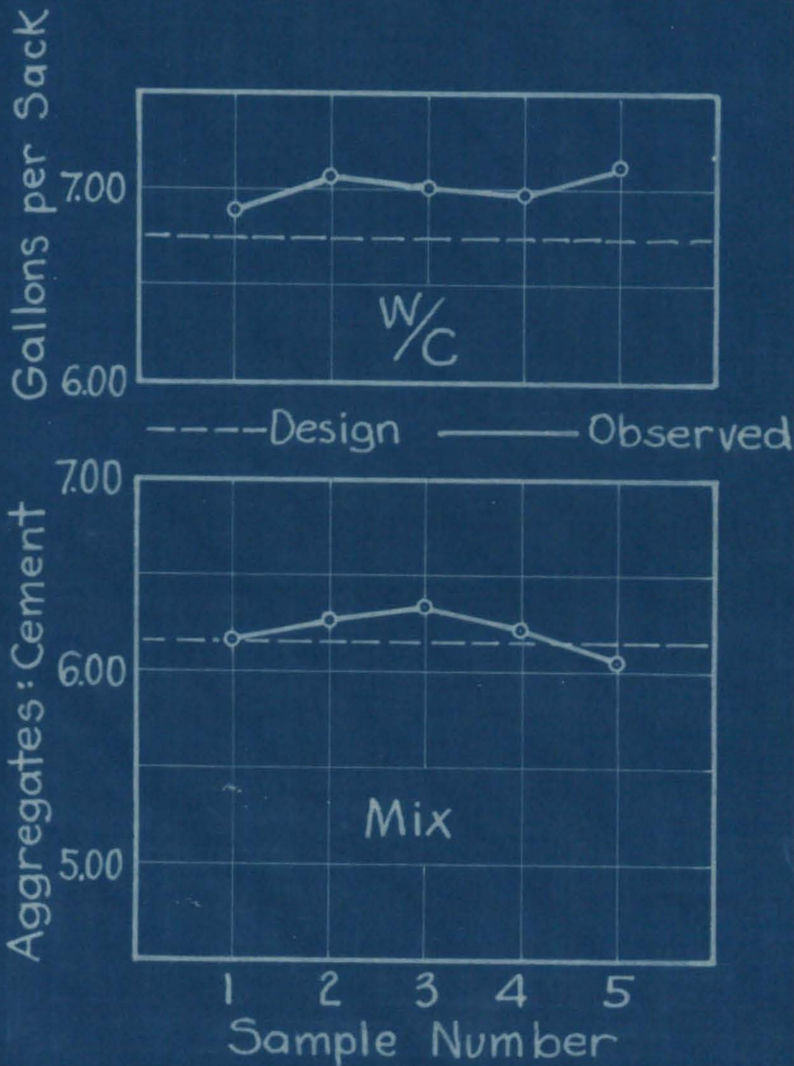

Fig. 8 - Variation in Ingredients as determined from Individual Samples ~ Corrections Eliminated.

Discussion of "A Study of the Analysis of Fresh Concrete with the Dunagan Buoyancy Apparatus" by H. R. Nettles and J. M. Holme

By. W. M. Dunagan.

The paper presented by these authors deserves careful scrutiny because it is the result of actual use of the Buoyancy method of control; this actual use phase of their paper should be emphasized in order that the full value of the information secured may be realized. To do this my discussion will be in the form of a paper based upon the data taken in the study 4' from which they secured the samples shown in their figure 3. In this paper the data of Mr. Nettles and

4' Willis A. Slater, Tests of Concrete Conveyed from a Central Mixing Plant. Proc. A.S.T.M., Part II, 1931. Tech. Papers.

Mr. Holme is discussed indirectly as follows:

1. By comparison with the complete data taken at Lehigh University to which has been applied the method of statistical analysis summarized by Mr. R. W. Crum 9'; from this type of tabulation judgment as to the

9' Symposium on Significance of Tests of Concrete and Concrete Materials. "The Number of Specimens or Tests Required for a Reasonable Accuracy of the Average." (Report of C-9)

accuracy of the test as compared to other field tests is placed upon its performance in a large number of tests rather than upon the fourteen abstracted by Mr. Nettles and Mr. Holme.

2. By discussion of specific phases of their paper and other items which are of special value at this time. The items under consideration are ones which have caused some confusion in field testing; they are specific gravity variations, sampling methods, grinding action of mixing and allowable deviations in concrete field control. The original Lehigh data are supplemented by additional investigations made at Iowa State College and at other places.

A STUDY OF THE ANALYSIS OF FRESH CONCRETE UNDER FIELD CONDITIONS

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Introduction

During the tests of the conveyor for concrete in the Fritz Engineering Laboratory at Lehigh University 4/, a large number of analyses of fresh concrete were made by the buoyancy method. These samples were taken for the purpose of determining the effect of the action of a particular type of conveyance upon the uniformity of the concrete, since the tests for which these data were taken were performed for this purpose the interpretation of the data should be considered primarily in that light; however these tests may be considered as bearing upon the entire field of the control of the mixing of concrete.

4/ Willis A. Slater, Tests of Concrete Conveyed from a Central Mixing Plant, Proceedings A.S.T.M., Part II, 1931. Tech. Papers.

The analyses of this concrete revealed several important factors in the behavior of concrete; it contributed important information as to the accuracy of proportioning under the existing conditions and furnished some practical data relative to the accuracy with which samples of concrete may be analyzed.

Methods of Testing

It is important that the conditions of the study be scrutnized carefully. They were as follows:

1. To introduce a two-cubic yard batch of concrete into the

conveyor two mixers were used, four batches being required from each mixer.

2. The proportioning was by the weighing of all ingredients.

3. The aggregates were stored for three days in a moist condition on a concrete floor. Moisture determinations were made to approximate the moisture conditions of these aggregates although extreme care was not taken for each batch; it was evident that the moisture fluctuated to some extent particularly in the coarse aggregate piles. The aggregates were kept wet to avoid the influence of the rate of absorption. The aggregates were not carefully separated on the No. 4 sieve and generally the conditions were quite representative of field procedure.

4. The mixing efficiency of the mixers was checked. One of the mixers was charged, operated and sampled at increments of 15 seconds after the introduction of the batch in order to determine the time at which the mix became uniform. This was found to be $1\frac{1}{2}$ minutes.

5. The mixers were charged, operated for one and one-half minutes and dumped. During the discharge samples were taken by means of pans held in the path of the out-flow. The first two samples were caught upon a small flat shovel which did not favor securing representative samples.

6. The conveyor, after being filled, was driven about for several hours, returning to the laboratory for sampling at six intervals over a period of three hours.

7. This procedure was repeated four times with the same mix.

8. All samples taken were from ten to twelve pounds and were

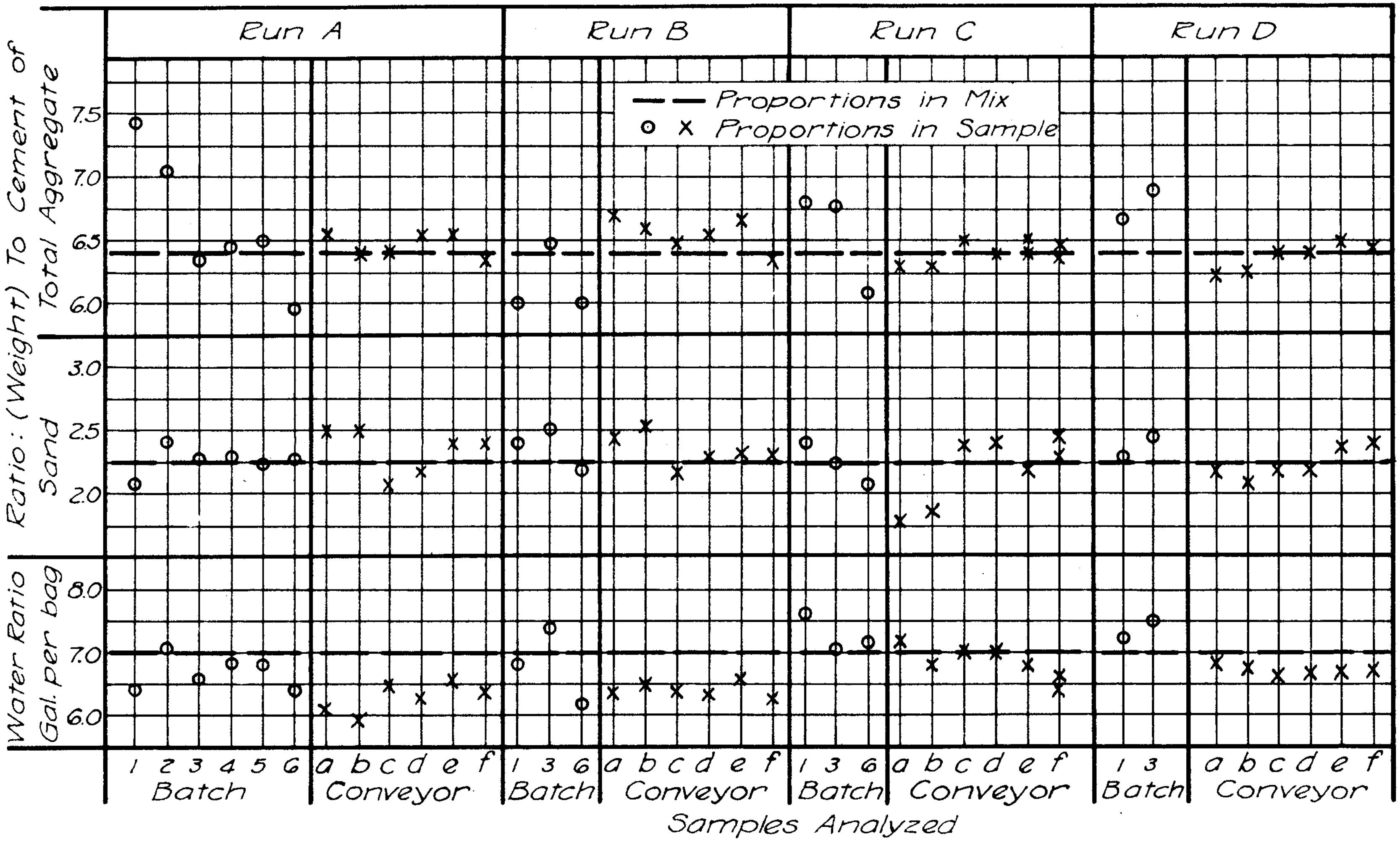

Fig. 14. Uniformity of Mixed Concrete as Shown by Analysis. Runs A, B, & C are successive trials using same mix. Tests performed on Clinton Conveyor at Lehigh University. (4)

analyzed by the method under discussion 6/.

6/ W. M. Dunagan. Proposed Method of Test for the Field Determination of the Constituents of Fresh Concrete. Proc. A.S.T.M. 1931 Part II, Tech. Papers.

Discussion

The data obtained are shown graphically in Figure 14; typical analyses and computations as taken are shown in Table 3. pg. 8

With these data as a basis for discussion observations will be made along the following lines:

1. How much grinding of aggregates occurs in long-time mixing and hauling and by what means may correction factors be obtained should analyses of the fresh concrete be performed?

2. How closely may analyses of concrete be performed by means of the test used and how nearly should they be expected to check the batch intended with all factors favorable to deviation considered?

3. How closely in definite percentage may an intended mix of concrete be introduced into a mixer and how uniformly maintained from batch to batch when the aggregates are in a field condition and are proportioned by weighing? This should furnish information as to the uniformity of mix that may be expected under these conditions by an actual measure.

4. Can uniformity deviations be detected by such methods of tests?

Increase in Fines Due to Grinding Action of Mixing

The first computations made after the tests were completed indicated the presence of some factor not previously considered which caused a serious deviation in results. This factor so constantly increased with the time of mixing that it was easily traced to the grinding action during mixing. Close study of the data led to the conclusion that the accuracy of the test was such that the rate of this grinding could be definitely computed. This was done as follows:

The intended mix was

	lb.	Sp. Gr.	
Rock	520	2.64	
Sand	291	2.68	
Cement	125	3.15	
Water	77.7	1.00	$\frac{W}{C}$, 6.9 gal. per bag.

A perfect sample of the intended mix, if analyzed by the method used, would have furnished the following data:

	Immersed wt. in gm.		% of Imm. Wt.	
Sample	5902			
Rock		3230	54.8)	84.8
Sand	5050	1820	30.8)	
Cement	850		14.4	

Fifteen actual samples taken from the mixer after 1½ minutes of mixing before placing in the conveyor averaged:

	% of Imm. Wt.	
Rock	55.3)	84.8
Sand	29.5)	
Cemnt (fines)	15.7	

Thus the fines have increased 15.7 - 14.4 equals 1.3% of the immersed weight of the entire sample. This grinding action in 1½ minutes and the original silt combine to increase the immersed weight of the fines found by 1.3 : 15.7 equals <u>8.4%</u>. (This figure represents 1.54% of the actual weight of the aggregates.) All samples taken at the mixer should be corrected by taking this percentage from the fines (immersed weight) and since in this case most of the grinding occurs in the sand adding it to the sand. (Figure 16). Such a correction has been applied to the mixer samples shown in figure 14.

Figures 15 and 16 show the rate of grinding as it occured in the conveyor as shown by the variation in the immersed weights of

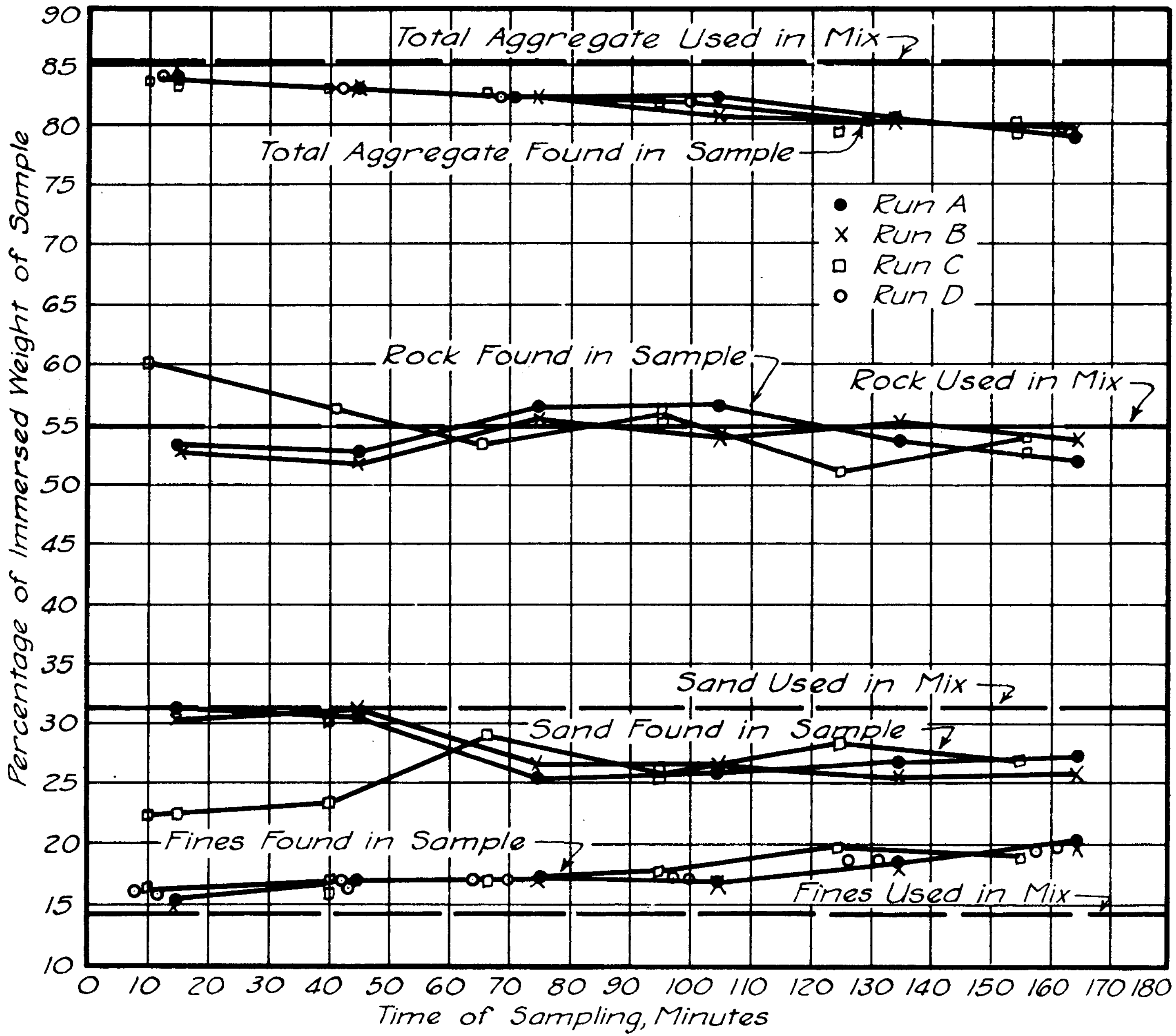

Fig. 15. Pulverizing Effect of Mixing. Tests performed on Clinton Conveyor (4). Individual Tests.

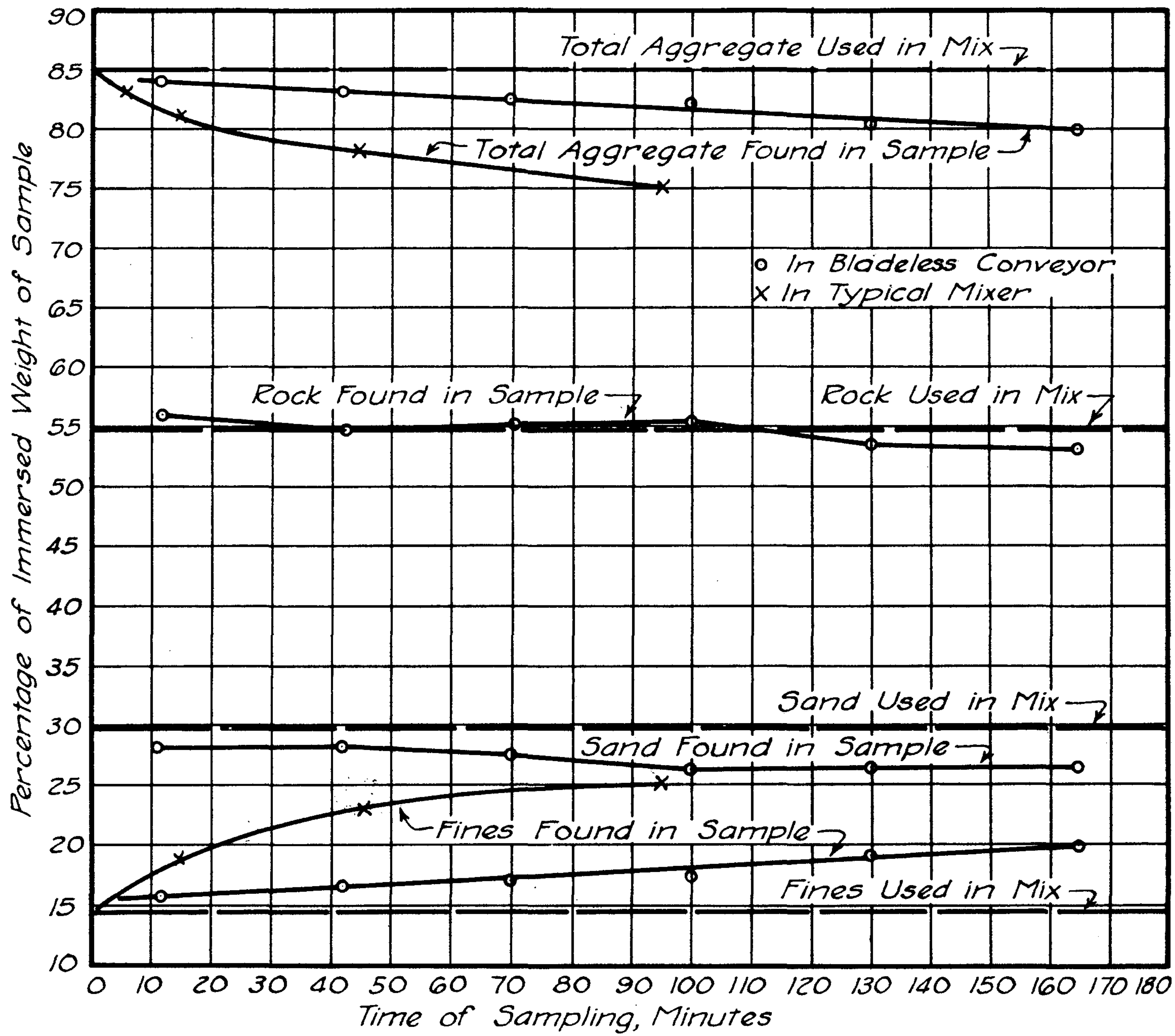

Fig. 16. Pulverizing Effect of Mixing. Tests performed on Clinton Conveyor (4). Averages for all Tests with comparison to a typical mixer.

the ingredients of samples during testing. It is evident that samples taken under such conditions being ground for increasing periods must each be corrected according to their time of mixing. Since these samples were taken at six intervals all nearly the same for each run, the correction factor for them may be arrived at as follows. (The percentages are taken from figure 16.)

Table 1

(% of immersed wt.)

Time, min.	15	45	70	100	130	180
Sample No.	1	2	3	4	5	6
Rock	55.9	54.8	55.3	55.6	53.6	53.3
Sand	28.1	28.4	27.2	26.5	26.9	26.5
Cement (fines)	15.9	16.7	17.2	17.4	19.1	19.9

The fines in these samples varies from the perfect sample by the following amounts:

Table 2

	%	"C"	
1½ M.	Mixer discharge = 1.3	38.4	
15 M.	15.9 - 14.4 = 1.5	1.5 ÷ 15.9 = 9.4%	(Fines to be re-
45 M.	16.7 - 14.4 = 2.3	2.3 ÷ 16.7 = 13.8	" " duced)
70 M.	17.2 - 14.4 = 2.8	2.8 ÷ 17.2 = 16.3	
100 M.	17.4 - 14.4 = 3.0	3.0 ÷ 17.4 = 17.3	
130 M.	19.1 - 14.4 = 4.7	4.7 ÷ 19.1 = 24.6	
180 M.	19.9 - 14.4 = 5.5	5.5 ÷ 19.9 = 27.6	

Thus a factor "C" is reached by which to correct for all variations in the fines for all runs. The correction is applied by subtracting these percentages from the observed immersed weights of the fines in the sample and adding it to that of the sand. The conveyor samples in figure 14 have all been corrected by these factors.

With it thus established that this grinding could be so definitely examined the author conducted a subsequent study in the Laboratory at Iowa State College. The results of this study are plotted in figure 7. The same sand was used in each case at Iowa State but two types of coarse aggregate were used (1) a tough gravel, French Coefficient 10, (2) and a softer Limestone, French Coefficient 6. Inspection of the curves in figure 7 indicate that under these conditions the same grinding occurred in each case; in one case the tough aggregate ground the sand and in the other the sand ground the softer aggregate. To further investigate this matter the data taken in the mixer calibration at Lehigh were plotted on the same figures; since this run was made with the same aggregates as those ground in the conveyor the conclusion is obvious that the grinding is a factor of the type of agitation.

It should be emphasized that "grinding action" will always vary with conditions and can only be approximately anticipated. For such an approximate anticipation the reduction curve shown in figure 7 was prepared; its application should be as follows:- when a batch of fresh concrete has been mixed for a long period due to hauling in an agitating conveyor the time mixed should be noted and the factor "C" found on this curve used should analyses of samples from it be made.

This study of grinding and its application was tested by the author at a Des Moines, Iowa ready-mix plant. When a given batch was placed in a truck a sample was taken, another sample was taken at the completion of a trip during which the mixing was for approximately ten minutes; reduction of the "fines" by 15 percent (figure 7) brought about a close agreement between the two samples.

<u>Deviation in Results of Analyzed Samples and their Causes</u>

The source of deviations from the intended mix may best be shown by citing specific cases under definite headings.

a. Deviations explained from conditions at time of test.

(1) Samples from batches 1 and 2 of Run A Figure 14 were of

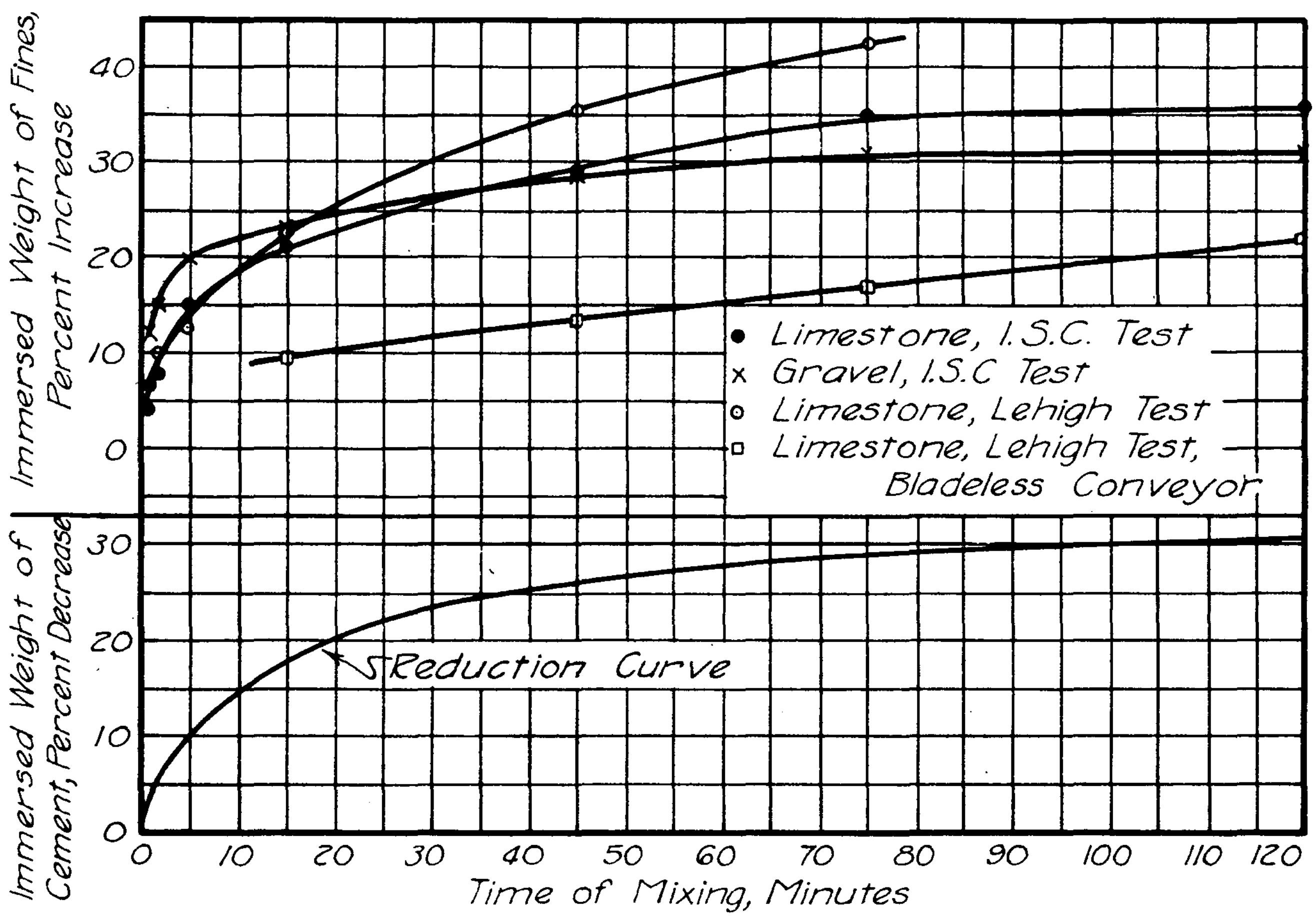

Fig. 7. Pulverizing Effect of Mixing, and Average Cement Reduction Curve for Correction of Analyses.

a known difference in water content, the water in #1 being weighed 6.6# in error, which is exactly shown in the analysis. The fact that these samples show a large amount of coarse aggregate is a reflection of the sampling methods which were changed in the succeeding batches as this condition was observable before testing.

(2) Two samples taken in Run F table 5 (not shown in figure 14) were not representative since they were taken after the batch was dumped upon the ground to detect segregation occuring during the dumping of the conveyor.

(3) Run D, Table 3, Fig. 14 is a splendid example of a test for uniformity. (a) Two samples taken during mixing conform with the batch intended except that the water is a little high, which may have been true of this run a fact borne out by the slump and strength tests. table 4, page 9 / (b) Six analyses taken during the operation of the drum have a remarkable uniformity in every respect, the water varying not more than .2 gal. per bag of cement; the aggregates varying from the mix used only as to their distinction as to separation on the No. 4 sieve and that variation is constant for the six samples. This run came after three other trials; since this entire investigation was a pioneer study of concrete under these conditions this Run D should furnish a basis for judgment as to the standard of accuracy to be expected when future studies are made.

b. Actual differences in daily conditions. Runs A, B, C and D were at various intervals over three days. Figure 14 indicates that each run had an individual characteristic as shown by the results of the analyses; these differences are verified by the slump and strength records.

TABLE 3

Run D. (Charge 4)
Showing data as taken and computed with application of grinding factor correction "C"

	Immersed Wts. As Taken		(C)	Corrected	Wt. in air. (Computed)		Proportions Found
	Two samples from two of eight batches.						
Sample	2770					4774	
Rock		1557			2508		4.40
Sand		792	+55	827	1318		2.3
S + R	2350						
Cement	420		-35	385	568	4394	1
Water						380	7.4 gal.
2.	2524.5					4350	
		1390.5			2243		4.40
	2145.5	755.0	+31	786	1255		2.46
	379		-31	348	510	4008	1
						342	7.[illegible]5
	Samples taken from conveyor at intervals of time.						
a.	2773					4765	
		1528			2460		4.05
15 M.	2316	788	+43	831	1326		2.2
	457		-43	414	611	4397	1
						368	6.8 gal
b.	2785					4775	
		1580			2544		4.2
45 M.	2308	728	+66	794	1267		2.09
	477		-66	411	606	4417	1
						358	6.7 gal.
c.	2637					4511	
		1470			2367		4.2
70 M.	2180	710	+74	784	1350		2.21
	457		-74	383	565	4182	1
						329	6.6 gal.
d.	2747					4706	
		1531			2465		4.21
100 M.	2266	735	+83	818	1305		2.22
	481		-83	398	587	4357	1
						349	6.7 gal.
e.	2660					4554	
		1443			2323		4.15
130 M.	2156	714	+124	837	1335		2.38
	504		-124	380	561	4219	1
						335	6.7 gal.
f.	2432					4169	
		1302			2100		4.05
3 hr.	1946	644	+135	799	1243		2.40
	486		-135	351	518	3851	1
						308	6.7 gal.

Table 4

Tabulation of averages for Runs A, B, C, D:

Run	Slump*	Ratio water to cement from analysis.	Compressive Strength of cylinders taken at the mixer.
A	$2\frac{1}{2}$	6.5 gal.	4163
B	4	6.6 gal.	3255
C.	7	7.1 gal.	2810
D	7	7.3 gal.	2613

*Slump taken as an average characteristic of the batch from the curve of slumps over entire 3 hour period rather than at 0 time.

Statistical Analysis of Results

The results of these analyses cannot be statistically analyzed so that deviations due to the method of test for analyzing the concrete can be isolated; its accuracy must be judged from the following viewpoint:- During the entire operation of moisture determinations, proportioning, mixing and handling, sampling and analyzing what deviations from the intended proportion was found to exist by the analysis of the samples?

Although the trend of such deviations is graphically shown in figure 14 a measure of them can be obtained through the application of such a method as Mr. Crum suggests. All of the data taken in the Lehigh series were tabulated after applying the grinding factor correction and his uniformity coefficient found. It should be noted that no tests are omitted even though their deviation might be explained by conditions of the study. Since figure 14 shows an evidently greater uniformity in samples taken after the mixer charges have been consolidated in the conveyor, samples taken from the mixer should be distinguished from those taken from the conveyor. In the statistical analysis the study was so made:

Summary of Deviations

A. Mixer Variations.

1. Samples taken, 15. Runs 5.

2. Average mix found by test 1 : 2.30 : 4.24 (by wt.) 6.98 gal.

	Item		%
3. Maximum deviation	Aggregate	.89 parts by wt.	13.7
	Water	.62 gal.	11.2
4. Average deviation	Aggregate	.33 parts by wt.	5.1
	Water	.35 gal.	5.0
5. Standard deviation	Aggregate	.45 parts by wt.	6.9
	Water	.40 gal.	5.7

B. Conveyor Variations.

1. Samples taken 30 - 5 runs.

2. Average Mix found 1 : 2.30 : 4.20 -- 6.61 gal.

	Item		%
3. Maximum deviations	Aggregate	.46 parts	7.1
	Water	.76 gal.	11.5
4. Average deviation	Aggregate	.17 parts	2.65
	Water	.26 gal.	3.93
5. Standard deviation	Aggregate	.24 parts	3.70
	Water	.325 gal.	4.90

Additional deviations found in the performance of this test for analyzing fresh concrete were obtained from published data from a study by the Bureau of Public Roads 8'. The significantly

8' T. C. Thee. "Effect of Size of Batch and Length of Mixing Period on Quality of Concrete." Public Roads Vol. 12, No. 11, January 1932.

different conditions were (a) although the same principal of test was used different types of equipment were used (b) larger samples were taken in the B.P.R. tests and (c) that dryer mixes were used which permits easier sampling. These data are plotted graphically in figure 13. This frequency curve locates the "Standard Deviation"

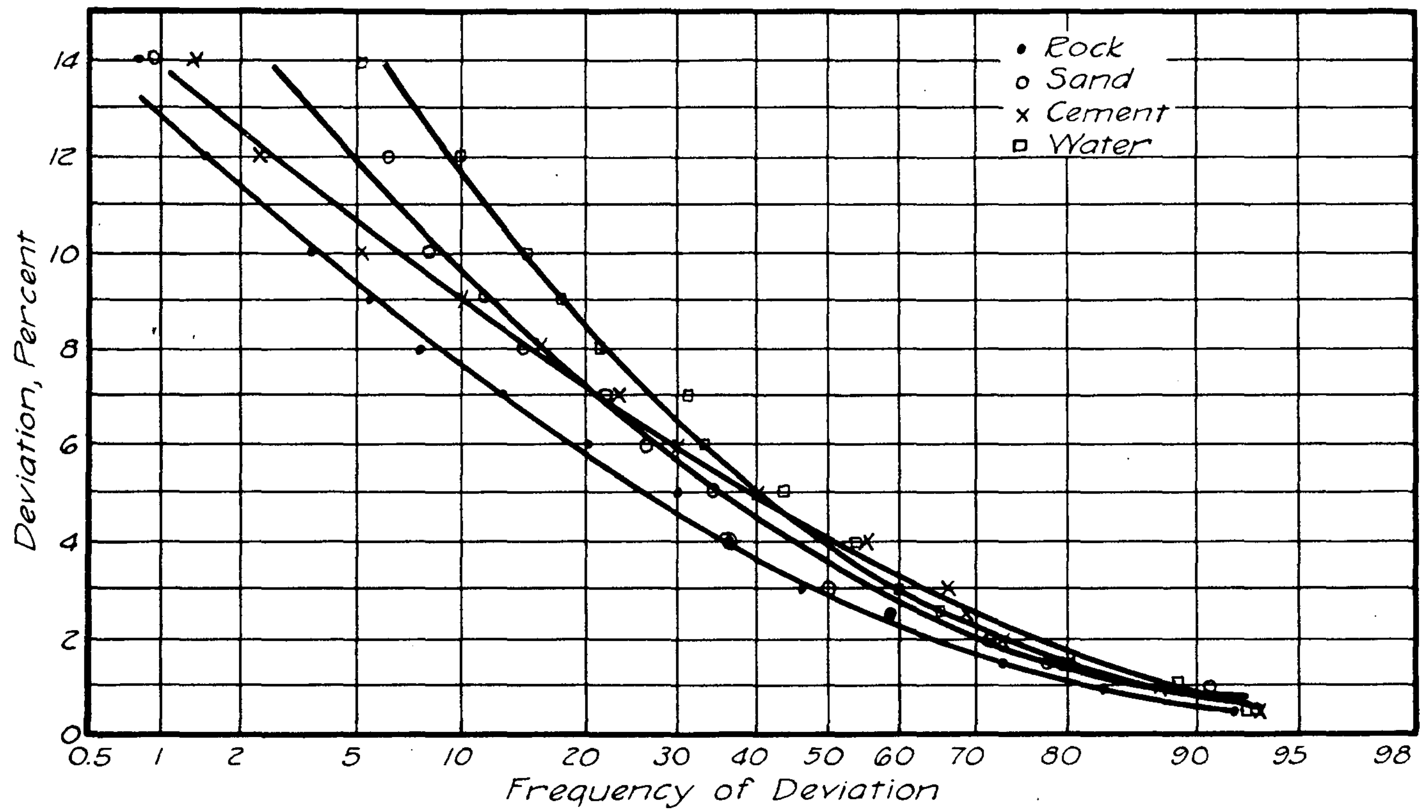

Fig. 13. Frequency Curves for Deviation from Intended Mix as shown by Analyses of 25-Pound Samples, 130 Field Tests by Bureau of Public Roads (8).

as being the 50% deviation, or the percentage of error which the average test will not exceed; it is found in their studies to be less than 4 % for all materials. This agrees closely with the figures found by Crum's method when applied to the Lehigh data.

Strength Data

The author has used the term "intended Water-Cement Ratio" advisedly in this paper; figure 20 is presented to vindicate the use of this term.

Figure 20 represents data abstracted from three separate studies (a) Uniformity studies made at Oregon Agricultural College *5', those made at Lehigh University 4', and an unpublished column study at Iowa State College 7'. The same indications are to be discovered in a more recent study published since the writing of this paper 10'.

*5' Burdett Glenn. "A Study of the Uniformity of Portland Cement Concrete", M.S. Thesis, Iowa State College. 1931.

4' Loco Cit.

7' W. M. Dunagan "Study of the Uniformity of Concrete placed in Tall Columns", Unpublished Manuscript.

10' F. H. Jackson and W. F. Kellerman. "Segregation at Water in Concrete Placed in Deep Forms", Public Roads, Vol. 13, No. 4. June 1932.

In figure 20 it is evident that the resulting strengths are more nearly indicated by the results of the analyses than by the water-cement ratio value intended; in every case the location of the points on the line representing this ratio would result in their being farther from an accepted water-cement ratio curve than plotted according to the results of the analysis. This is particularly true of the Lehigh University data. This fact is emphasized here because of the fact that all runs A, B, C and D were made at the same "intended water ratio" and the author believes that the strength deviations in the direction indicated by the results of analyses has bearing upon the accuracy of the test method. (See table 4, page 9.)

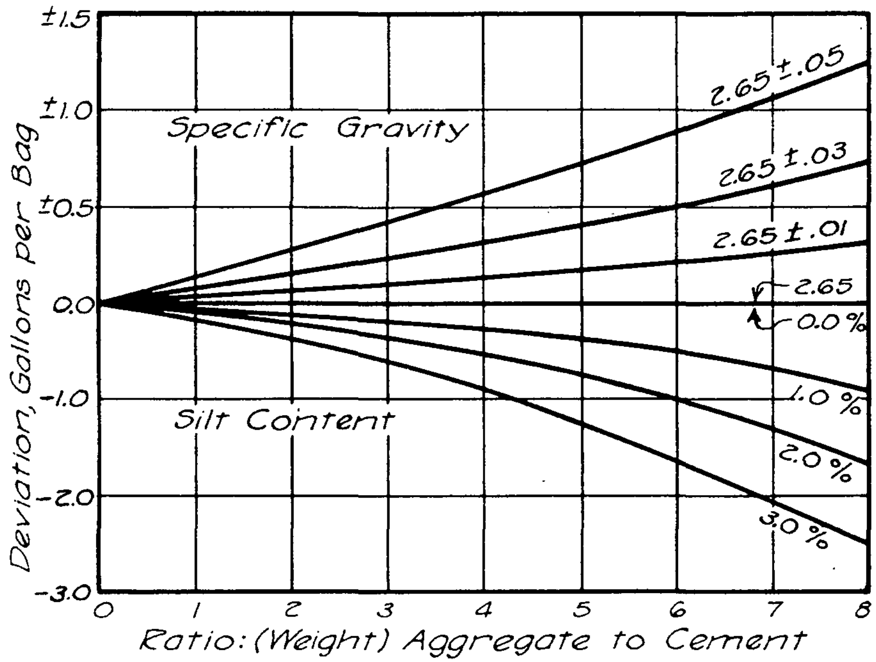

Fig. 5. Effect upon Result of Analysis of Specific Gravity Variations and Silt Content of Aggregates.

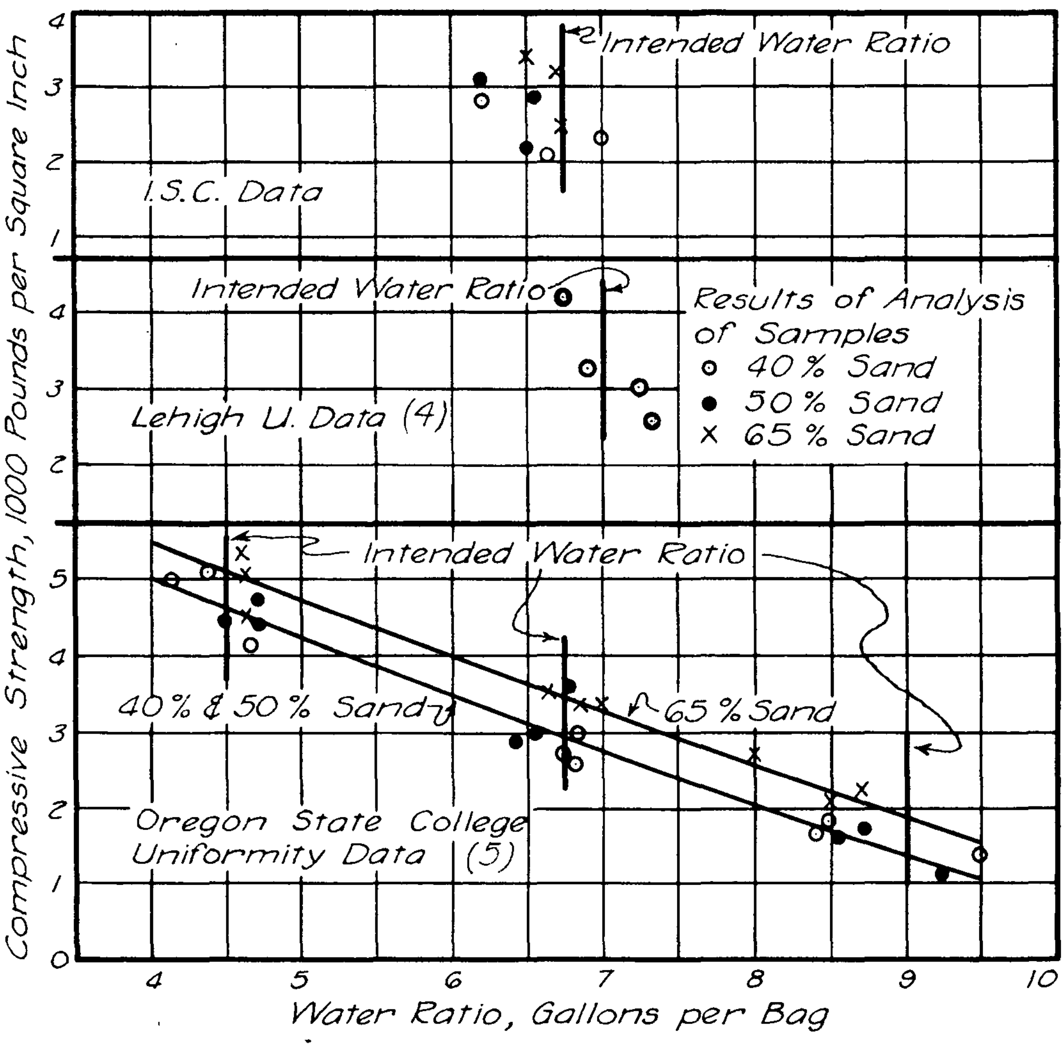

Fig. 20. Relationship between Compressive Strength and Water-Cement Ratio as found by Analysis of Samples taken from the Mixed Concrete.

Factors Which Limit the Performance of Tests for the Analysis of Fresh Concrete.

Freshly mixed concrete cannot be analyzed for its constituents by any method now in use, (a) when the ingredients cannot be separated by means of sieves or when conditions are such that corrections cannot be applied from data on the original aggregates for "fines" which will be confused with the cement, and (b) under conditions when absorption characteristics will not permit a precise definition of the net water. With the buoyancy method this definition is established during the preliminary Specific Gravity determination, with other methods by means of an absorption determination; in either case the condition is identical. The method of analyzing under discussion does not differ from any other process in these conditions, when they exist samples of the concrete cannot be analyzed by any method yet devised.

Mr. Nettles and Mr. Holme have considered three factors to be of sufficient importance for special investigation. These factors are: Silt content, variation in specific gravity of aggregates and variations in specific gravity of Portland Cement. To clarify the effect of the first two of these factors figure 5 has been prepared. This figure shows clearly that when these factors are not considered the results will be effected in accordance with their relative amounts and with the ratio of aggregates to cement used in the concrete. It should be noted that with a silt content of 2% a sand ratio of more than 6 parts would be necessary to cause a deviation of one gallon of water per bag of cement, and that, with a deviation in specific gravity of from 2.65 to 2.70, .50 gallons of water error would be introduced. with 4 parts of sand

The effect of variations in specific gravity of Portland

Cement will be left to the judgment of the reader:- The tests performed at Lehigh University covered in this paper were performed at times varying from 10 minutes to 6 hours, with some delayed 24 hours by freezing, after the mixing. If this factor had influence it cannot be detected in the results. A more precise study of this factor is presented by the author in a bulletin to be published by the Iowa Engineering Experiment Station.

The effect of variations in specific gravity of the aggregates used on the Lehigh project may be judged by the deviations found in the entire series. This project was controlled throughout by the system of tests based upon the buoyancy principal which utilizes the apparent Specific Gravity value for all tests. Statistical analysis establishes the uniformity coefficient at a Standard Deviation of approximately 4%; since this factor represents all deviations from all sources, from moisture determinations through the mixing, conveying and through the test for analysis to the final computations it would seem that the specific gravity variations were either quite small or were entirely erased due to the mixing so that when uniform concrete was produced the materials of variable specific gravity were also uniformly mixed in the batch.

Summary

A. Conclusions concerning proportioning and mixing drawn from the Lehigh tests and verified by subsequent studies.

1. Practical methods for the field weighing of ingredients even on small projects should hold all proportions to a Uniformity Coefficient of 4%, which in this case meant a control within .3 gallons of water per bag of cement to that intended. Such a figure derived from these data assumes that the analyses made contain no error and that all deviations are due to control methods; if some of the deviation is attributed to the method for analyzing the samples a correspondingly lower figure may be applied.

2. A progressive grinding action occurs during the entire action of mixing and of agitation type of hauling. This grinding action is still subject to additional investigation. In the studies made to date the grinding equalled as much as 12% of the weight of the aggregates.

3. Proportioning which may culminate in the necessity for analysis of samples from the mix must be a part of an established "control system" which clearly defines the net ingredients. This should be true whether analyses are made or not.

B. Conclusions concerning the accuracy with which samples of concrete may be analysed by the buoyancy principal.

1. In these tests the analyses were performed more closely than the proportions could be maintained without undue attention to details of control. This con-

clusion may be substantiated from the data as follows:-

(a) Batched 1 and 2 of Run A (Figure 14) were of a known difference in water content (6.6# of water was omitted from batch 1). This was exactly shown in the analyses.

(b) Where the mixer samples evidenced variations due to actual difference in batches and these same batches are then consolidated in the conveyor successive samples show no such deviation (Figure 14.).

(c) Runs on successive days with the same intended proportions show individuality in analyses; these differences are reflected in the slump and strength data obtained. (See table 4, page 9.)

(d) Such duplicate samples as were taken show closer agreement to each other than successive mixer runs; this is shown in samples 1, 4 and 6 of Run C.

2. When sampling concrete great care must be taken if the samples are to be precisely representative. Many tests of fresh concrete performed with the expectation that the results exactly check the proportioning fail due to poor sampling. Deviations thus obtained must be considered in establishing a coefficient which defines uniformity.

3. The method of test was satisfactory as a means for determining the efficiency of the mixing operations. This is evidenced by the results as summarized in the form of Standard Deviations. (See summary of deviations, page 10)

Table 5
Run F. (Charge 5.)

Showing data as taken and computed with application of grinding factor correction "C"

Run	Immersed Weights As taken		"C"	Corrected	Wt. in Air (Computed		Proportions Found
	Sample taken from mixer discharge						
1	2694.5					4647	
		1511.5		1511.5	2436		4.32
	2279.0	767.5	+35	802.5	1280		2.27
	415.5		-35	380.5	563	4279	1
						368	7.35 gal.
	Sample taken from top of conveyor before dumping						
a	2430					4163	
		1333		1333	2145		4.37
	2045	712	+53	765	1221		2.49
	385		-53	332	490	3856	1
						307	7.07 gal.
	Sample from first portion emerging from conveyor						
b	3162					5421	
		1790		1790	2880		4.56
	2667	877	+68	945	1507		2.39
	495		-68	427	630	5017	1
						404	7.2 gal.
	Sample from last flow on dumping conveyor						
c	2340					4001	
		1420		1420	2285		5.10
	1988	568	+49	617	984		2.20
	352		-49	303	447	3716	1
						285	7.2 gal.

200 × 12

2400

450

15 1/2

6

9 1/2