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EFFECT OF MIXING TIME ON QUALITY OF CONCRETE PRODUCED IN LARGE MIXERS

BY THE DIVISION OF MANAGEMENT, BUREAU OF PUBLIC ROADS

Reported by WILLIAM A. BLANCHETTE, Highway Engineer

STUDIES have been conducted by the Bureau of Public Roads at two concrete central-mixing plants to determine the effect of the length of the mixing time on the uniformity of distribution of the ingredients and on the strength of the concrete as mixed in large-capacity mixers. The grinding of the aggregates during the mixing action was also studied.

These studies show that the mixers did not distribute the materials uniformly throughout the batch; the degree of uniformity of distribution of materials was not changed by changes in mixing time from 1 to 4 minutes; and such changes in mixing time did not materially affect the strength. Increases in mixing time increased the amount of grinding of fine aggregate.

TESTS AT PLANT 1 DESCRIBED

The tests at plant 1 were made with a stationary no. 84–S mixer, 96 inches in diameter and 78 inches long and revolved 10.5 times per minute. The proportions of the aggregate by dry weight were as follows:

	Pounds
Cement	1, 750
Fine aggregate	4, 495
Coarse aggregate	6, 403
Net water	1, 162
Absorbed water	100

These quantities gave a batch with an absolute volume of 94 cubic feet.

The sand used as fine aggregate was analyzed as follows:

Sieve number:	*Percent retained*
4	4. 0
8	18. 9
14	32. 9
28	51. 4
48	82. 4
100	96. 0

The coarse aggregate consisted of two sizes of gravel combined to give the following analysis:

Screen opening:	*Percent retained*
2½ inches	0. 0
1½ inches	0. 0
¾ inch	35. 3
⅜ inch	73. 9
No. 4	96. 5

Strength specimens were cured in a moist room and broken at 28 days. Beams were broken by 3-point loading, 1 break being obtained on each beam.

In the tests at plant 1 batches of concrete were sampled after being mixed for 1, 2, 3, and 4 minutes. Samples from 5 different batches were obtained for each mixing time with the exception of 3 minutes. Six batches were sampled after 3 minutes of mixing. As each batch of concrete was being discharged from the mixer, three 200-pound samples were obtained; one at the beginning of the discharge, one in the middle, and one at the end of the discharge period. From a 200-pound sample, one slump test was made, one 30-pound sample was analyzed to determine the proportion of each ingredient contained in it, and two 6- by 12-inch cylinders and one 6- by 6- by 21-inch beam were made. This made 3 uniformity tests, 6 cylinders and 3 beams for each batch or a total of 15 uniformity tests, 30 cylinders and 15 beams for each of the 1-, 2-, and 4-minute mixing periods and 18 uniformity tests, 36 cylinders and 18 beams for the 3-minute mixing period.

ANALYSES TO DETERMINE COMPOSITION OF SAMPLES REQUIRE CAREFUL PROCEDURE

Conclusions as to the uniformity of distribution of materials were reached by determining the content of cement, water, fine aggregate and coarse aggregate in the 30-pound samples on a percentage basis and comparing them with the corresponding percentages for the batch as a whole. Materials for the batch as a whole were accurately weighed and variations of the coarse and fine aggregates from the limiting no. 4 and no. 100 sieves determined. The reasons for the latter determinations will appear in the following paragraphs.

The percentages of materials in a 30-pound sample of concrete were determined as follows. The sample of wet concrete was first weighed in air and then in water. The sample was then placed in a special washing machine[1] which washed out the cement and other material passing the no. 100 sieve and separated the aggregate into fine and coarse material by a no. 4 sieve. The fine and coarse aggregate were each weighed in water and after applying several correction factors the dry weight of coarse aggregate and dry weight of fine aggregate and cement were determined by the following formula:

$$\text{Dry weight of material} = \frac{\text{Specific gravity} \times \text{immersed weight}}{\text{Specific gravity} - 1}$$

The factors referred to were corrections on account (1) the grinding of aggregate in mixing, (2) material in the coarse aggregate (as weighed for the whole batch) finer than the no. 4 and no. 100 sieve, and (3) material in the fine aggregate (as weighed for the whole batch) coarser than the no. 4 sieve and finer than the no. 100 sieve. The correction for aggregate finer than the no. 100 sieve was necessary since the material washed through the no. 100 sieve after being corrected for aggregate content (including that resulting from grinding) was considered as the cement content of the sample.

The difference between the weight of the immersed sample and combined weights of immersed aggregate, after proper correction gave the immersed weight of cement.

The difference between the weight of the sample in air and the dry weights of cement, fine aggregate, and coarse aggregate gave the amount of water in the sample.

[1] Washing Machine Designed for Use in Determining Constituents of Fresh Concrete, PUBLIC ROADS, vol. 13, no. 9, November 1932.

METHOD OF DETERMINING CORRECTION FACTORS FOR THE GRINDING ACTION DESCRIBED

It was found that grinding may or may not take place during the mixing of a batch. The extent of grinding is probably affected by some or all of the following factors: Type and gradation of both fine and coarse aggregate, proportion of each in mix, number of revolutions of mixer drum, ratio of capacity of mixer drum to volume of batch, and the mixing action in the drum including the amount of drop of the aggregates. There is no simple method by which the amount of grinding that takes place during the mixing of a batch of concrete can be determined with precision. Even though the entire mixed batch could be analyzed to determine the amount of material finer than the no. 100 sieve, corrections must be made for the amount of each ingredient passing this sieve before the mixing. These corrections are not exact since they are based on samples that are only a small part of the ingredients in the batch.

Grinding is indicated when analyses of samples show consistently a greater amount of cement (material passing no. 100 sieve) in the samples after mixing than is indicated by the batch proportions, proper allowance being made for the aggregate passing the no. 100 sieve before mixing. Where grinding was indicated, tests were made to determine the percentage of both coarse and fine aggregate so reduced in size during the mixing action that it passed the no. 100 sieve.

Coarse aggregate and water in the same relative proportions as in the batches being sampled were placed in the mixer. At the end of 1, 2, 3, and 4 minutes of mixing 30-pound samples were removed from the mixer and washed in the washing machine. The percentage of aggregate passing the no. 100 sieve was determined. The test was repeated using fine aggregate and water and again using fine aggregate, coarse aggregate, and water. Several determinations were made with each combination. These tests showed that with coarse aggregate and water there was no appreciable grinding for any mixing period used. The same was true for the fine aggregate and water mixture. For the fine and coarse aggregate and water mixture the amount of aggregate passing the no. 100 sieve, in excess of that passing before mixing, was appreciable and increased with the length of the mixing period.

These facts indicate that the mixer drum acts as a ball mill. Particles of sand are pulverized by the particles of coarse aggregate falling on them. There appeared to be no pulverizing of the fine particles of coarse aggregate by the larger particles and there appeared to be no wearing away of either aggregate due to friction with the drum, blades, and buckets.

As a further check in establishing the amount of grinding the following procedure was followed. The analysis of every sample of concrete showed the percentage variation (plus or minus) of the cement, fine and coarse aggregate and water from the original proportions of each of these ingredients. The complete analysis of all samples for all mixing periods showed a consistent plus variation for what was called cement, and a consistent minus variation for fine aggregate. There was no evidence that the coarse aggregate was ground up to pass either the no. 4 or no. 100 sieves. From the average of all variations in cement and all variations in fine aggregate for each mixing period, the apparent gain in cement due to grinding of fine aggregate was computed for each mixing time. Correction factors as computed in this manner checked closely with those determined as previously outlined. The average of the factors determined by both methods was then applied in recomputing the variations in all samples.

VARIATIONS IN UNIFORMITY FOUND IN ALL BATCHES

Table 1 contains the results of tests for uniformity of mix. This table shows the proportions of each ingredient that went into each batch sampled, the proportions of each ingredient found by analysis to be contained in each 30-pound sample of concrete removed from each batch, and the percentage variation in the proportion of each ingredient in each sample from the proportion of the corresponding ingredient in the batch as a whole. Variations above the actual batch proportion are shown as plus and variations below the actual batch proportion are shown as minus. The percentage variations shown in table 1 are summarized in table 2 which shows for all samples under each mixing time, the maximum individual plus and minus variations, the average plus and minus variations and the average of all variations regardless of sign. Figure 1 shows graphically the percentage variations in the proportions of materials as shown in table 1. Figure 2 shows the percentage variations computed for assumed samples each composed of the three samples taken from a batch.

Lack of uniformity in the distribution of the ingredients in each batch of concrete is shown by the data in the tables and diagrams. Had the mixing action resulted in a homogeneous mixture in which the materials were uniformly distributed throughout the batch, all samples would have contained materials in the same proportions as were used in charging the mixer. The results show that homogeniety did not exist in any batch of concrete tested. The summary in table 2 indicates that increasing the mixing time had no considerable effect in improving the uniformity of distribution of the ingredients. There is practically as great a lack of uniformity in the 4-minute concrete as there is in the 1-minute concrete.

Variations in the proportions of the ingredients in the different parts of the same batch were as high as 18 percent in some batches. Maximum spreads in the proportions in different parts of a group of batches for a given mixing time were from 10 to 24 percent. The spread between the average plus and average minus values for a given material ranged from 3 to 12 percent. The averages of all variations for a given material and mixing time and disregarding signs as shown in table 2 range from 1.6 to 5.7.

STRENGTH NOT IMPROVED BY INCREASING MIXING TIME FROM 1 TO 4 MINUTES

Table 3 gives the results of the strength tests. It shows the slump of the concrete in each sample, the compressive and flexural strength of individual specimens made from each sample, the average strength of all cylinders and beams made from each batch for each mixing time, and the percentage variation in the strength of every specimen from these averages. It shows the spread from the maximum individual to the minimum individual strength for both compression and flexure. Table 4 is a summary of the strength results, and shows the maximum and minimum individual strengths, the maximum spreads, and the average strengths of all specimens for each mixing time. Figures 3 and 4 show graphically the compressive and flexural strength, respectively, for the individual specimens made from each sample for each batch.

Table 1.—*Results of tests for uniformity of mix at plant 1*

Batch No.	Mixing time	Computed proportions in 30-pound sample based on proportions of total batch										Sample designation	Proportions 30-pound sample by dry weight								Percentage variations in sample from proportions of original material			
		Cement		Fine aggregate		Coarse aggregate		Water					Cement		Fine aggregate		Coarse aggregate		Net water					
								Net		Absorbed														
		Weight in pounds	Percent	Weight in pounds	Percent	Weight in pounds	Percent	Weight in pounds	Percent	Weight in pounds	Percent		Weight in pounds	Percent	Weight in pounds	Percent	Weight in pounds	Percent	Weight in pounds	Percent	Cement	Fine aggregate	Coarse aggregate	Net water
	Min.											A	3.56	11.9	9.79	32.6	14.08	47.0	2.35	7.8	−5.8	+1.5	+1.5	−5.6
6	1	3.78	12.6	9.65	32.1	13.87	46.3	2.49	8.3	0.21	0.7	B	3.96	13.2	9.52	31.8	13.89	46.3	2.41	8.0	+4.8	−1.3	+0.1	−3.2
												C	3.65	12.2	9.01	30.1	14.86	49.5	2.25	7.5	−3.4	−6.6	+7.1	−9.6
												A	3.66	12.2	10.47	34.9	13.35	44.5	2.31	7.7	−2.7	+7.6	−3.0	−8.7
9	1	3.76	12.5	9.73	32.5	13.77	45.9	2.53	8.4	.21	.7	B	3.61	12.0	10.62	35.4	13.20	44.0	2.36	7.9	−4.0	+9.1	−4.1	−6.7
												C	3.71	12.4	10.62	35.4	13.10	43.6	2.36	7.9	−1.3	+9.1	−4.9	−6.7
												A	3.97	13.2	9.00	30.0	14.51	48.4	2.30	7.7	+4.2	−6.6	+4.3	−5.3
12	1	3.81	12.7	9.64	32.1	13.91	46.4	2.43	8.1	.21	.7	B	3.71	12.4	9.31	31.0	14.43	48.1	2.33	7.8	−2.6	−3.4	+3.7	−4.1
												C	4.03	13.4	9.35	31.2	14.08	46.9	2.32	7.8	+5.8	−3.0	+1.2	−4.5
												A	4.45	14.8	9.53	31.8	13.30	44.3	2.51	8.4	+18.7	−2.8	−3.1	−0.4
16	1	3.75	12.5	9.80	32.7	13.72	45.7	2.52	8.4	.21	.7	B	4.19	14.0	9.60	32.0	13.50	45.0	2.50	8.3	+11.7	−2.0	−1.6	−0.8
												C	4.12	13.7	9.50	31.7	13.64	45.5	2.53	8.4	+9.9	−3.1	−0.6	+0.4
												A	3.68	12.3	10.31	34.4	13.45	44.8	2.35	7.8	−2.9	+7.4	−3.0	−7.1
22	1	3.79	12.6	9.60	32.0	13.87	46.3	2.53	8.4	.21	.7	B	3.80	12.7	10.46	34.9	13.11	43.7	2.42	8.1	+0.3	+9.0	−5.5	−4.3
												C	3.76	12.5	9.75	32.5	13.91	46.4	2.36	7.9	−0.8	−0.1	+0.3	−6.6
												A	3.47	11.6	9.34	31.1	14.42	48.1	2.55	8.5	−8.0	−3.7	+4.7	+0.4
1	2	3.77	12.6	9.70	32.3	13.77	45.9	2.54	8.5	.22	.7	B	3.65	12.2	9.69	32.3	13.83	46.1	2.61	8.7	−3.2	−0.1	+0.4	+2.8
												C												
												A	3.67	12.2	10.45	34.8	12.89	43.0	2.78	9.3	−2.1	+8.5	−6.0	+3.0
8	2	3.75	12.5	9.63	32.1	13.71	45.7	2.70	9.0	.21	.7	B	3.51	11.7	10.12	33.8	13.42	44.7	2.74	9.1	−6.4	+5.1	−2.1	+1.5
												C	3.68	12.3	10.16	33.9	13.17	43.8	2.78	9.3	−1.9	+5.5	−3.9	+3.0
												A	3.99	13.3	9.51	31.7	13.74	45.8	2.54	8.5	+6.1	−1.7	−0.2	−1.9
11	2	3.76	12.5	9.67	32.3	13.77	45.9	2.59	8.6	.21	.7	B	3.85	12.8	9.21	30.7	14.18	47.3	2.54	8.5	+2.4	−4.8	+3.0	−1.9
												C	3.99	13.3	9.66	32.2	13.51	45.0	2.63	8.8	+6.1	−0.1	−1.9	+1.5
												A	3.37	11.2	10.17	33.9	13.86	46.2	2.38	8.0	−10.6	+3.6	+0.4	−0.4
15	2	3.77	12.6	9.82	32.7	13.80	46.0	2.39	8.0	.22	.7	B	3.36	11.2	10.24	34.2	13.81	46.0	2.37	7.9	−10.9	+4.3	+0.1	−0.8
												C	3.37	11.2	10.24	34.2	13.75	45.8	2.42	8.1	−10.6	+4.3	+0.4	+1.3
												A	3.65	12.2	9.61	32.1	14.17	47.2	2.35	7.8	−3.4	−0.4	+3.1	−10.0
18	2	3.78	12.6	9.65	32.2	13.75	45.8	2.61	8.7	.21	.7	B	3.85	12.8	10.04	33.5	13.42	44.7	2.48	8.3	+1.9	+4.0	−2.4	−5.0
												C	3.83	12.8	9.57	31.9	13.90	46.3	2.48	8.3	+1.3	−0.8	+1.1	−5.0
												A	3.56	11.9	9.70	32.3	14.07	46.9	2.45	8.2	−5.1	−0.2	+1.7	−1.2
3	3	3.75	12.5	9.72	32.4	13.83	46.1	2.48	8.3	.22	.7	B	3.90	13.0	10.49	35.0	12.74	42.4	2.67	8.9	+4.0	+7.9	−7.9	+7.7
												C	3.79	12.6	8.96	29.9	14.68	48.9	2.35	7.8	+1.1	−7.8	+6.1	−5.2
												A	3.78	12.6	9.83	32.7	13.85	46.2	2.32	7.7	−1.0	−0.3	+0.2	+1.3
4	3	3.82	12.7	9.86	32.9	13.82	46.1	2.29	7.6	.21	.7	B	3.99	13.3	9.75	32.5	13.62	45.3	2.43	8.1	+4.5	−1.1	−1.4	+6.1
												C	3.52	11.7	9.24	30.8	14.78	49.3	2.23	7.4	−7.8	−6.3	+6.9	−2.6
												A	4.01	13.3	9.18	30.6	14.18	47.3	2.41	8.0	+5.8	−4.7	+2.1	−2.8
10	3	3.79	12.6	9.63	32.1	13.89	46.3	2.48	8.3	.21	.7	B	4.18	13.9	8.83	29.4	14.35	47.8	2.43	8.1	+10.3	−8.3	+3.3	−2.0
												C	3.85	12.8	9.33	31.1	14.19	47.3	2.41	8.0	+1.6	−3.1	+2.2	−2.8
												A	4.10	13.7	9.29	31.0	13.95	46.5	2.44	8.1	+7.9	−4.4	+0.6	+1.2
14	3	3.80	12.7	9.72	32.4	13.86	46.2	2.41	8.0	.21	.7	B	4.12	13.7	9.37	31.2	13.96	46.5	2.33	7.9	+8.4	−3.6	+0.7	−3.3
												C	3.71	12.4	8.91	29.7	14.84	49.4	2.32	7.7	−2.4	−8.3	+7.1	−3.7
												A	3.62	12.1	9.85	32.8	13.91	46.3	2.40	8.0	−3.5	+0.6	+1.6	−5.9
19	3	3.75	12.5	9.79	32.7	13.69	45.6	2.56	8.5	.21	.7	B	3.61	12.0	9.73	32.4	14.04	46.8	2.40	8.0	−3.7	−0.6	+2.6	−5.9
												C	3.59	12.0	9.65	32.2	14.13	47.1	2.41	8.0	−4.3	−1.4	+3.2	−5.9
												A	3.41	11.4	10.33	34.4	13.63	45.3	2.42	8.2	−9.8	+6.6	−1.7	−1.6
23	3	3.78	12.6	9.69	32.3	13.86	46.2	2.46	8.2	.21	.7	B	3.33	11.1	9.89	33.0	14.21	47.3	2.35	7.8	−11.9	+2.1	+2.5	−4.5
												C	3.46	11.5	9.86	32.9	14.15	47.2	2.31	7.7	−8.5	+1.8	+2.1	−6.1
												A	3.90	13.0	9.34	31.1	14.22	47.3	2.32	7.7	+2.9	−4.9	+3.0	−2.1
2	4	3.79	12.6	9.82	32.8	13.80	46.0	2.37	7.9	.22	.7	B	3.87	12.9	9.59	32.0	14.00	46.7	2.32	7.7	+2.1	−2.3	+1.4	−2.1
												C	3.82	12.7	9.69	32.9	13.89	46.3	2.60	8.7	+0.8	−1.3	+0.7	+9.7
												A	3.77	12.6	9.66	32.2	13.80	46.0	2.55	8.5	0.0	+0.7	+0.4	−5.9
5	4	3.77	12.6	9.57	31.9	13.74	45.8	2.71	9.0	.21	.7	B	3.80	12.7	9.74	32.5	13.68	45.6	2.57	8.6	+0.8	+1.8	−0.4	−5.2
												C	3.87	12.9	9.60	32.0	13.70	45.7	2.62	8.7	+2.7	+0.3	−0.3	−3.3
												A	3.54	11.8	10.39	34.6	13.21	44.0	2.65	8.8	−5.1	+7.3	−3.4	−1.5
7	4	3.73	12.4	9.68	32.3	13.67	45.6	2.71	9.0	.21	.7	B	3.45	11.5	10.15	33.8	13.60	45.3	2.59	8.6	−7.5	+4.9	−0.5	−4.4
												C	3.46	11.5	9.73	32.4	14.01	46.7	2.58	8.7	−7.2	+0.5	+2.5	−4.8
												A	4.29	14.3	8.86	29.5	14.01	46.7	2.63	8.8	+13.2	−9.0	+0.9	+10.5
13	4	3.79	12.6	9.74	32.5	13.88	46.3	2.38	7.9	.21	.7	B	4.31	14.4	8.77	29.2	14.09	47.0	2.62	8.7	+13.7	−10.0	+1.5	+10.1
												C	3.62	12.1	9.66	32.2	13.98	46.6	2.52	8.4	−4.5	−0.8	+0.1	+5.9
												A	3.88	12.9	8.51	28.4	14.88	46.3	2.51	8.4	+0.8	−10.7	+6.4	+3.4
20	4	3.85	12.8	9.53	31.8	13.98	46.6	2.43	8.1	.21	.7	B	3.94	13.1	8.86	29.5	14.39	48.0	2.60	8.7	+2.9	−7.0	+2.9	+7.0
												C	4.07	13.6	9.07	3.02	13.99	46.6	2.65	8.8	+5.7	−4.8	+0.1	+9.0

In considering the strength results it should be remembered that different batches of concrete were used for each mixing time, and that there was some variation in the proportions of the ingredients in the different batches as constant weights were used and no correction was made for moisture in the aggregates. Lack of uniformity in the distribution of the ingredients in the concrete, may have produced considerable variation in the proportions of the ingredients in the strength specimens.

Since variations in batch proportions existed for all batches and since the uniformity results show no considerable difference in the lack of uniformity for any mixing time, study of the effect of the length of the mixing time on the strength of concrete will be based on the spread in strengths and the average strength of all test specimens for each of the four mixing periods. Table 4 contains the data for this comparison. The average compressive strength of all specimens for the 1-minute mixing time is 3,590 pounds. The corresponding strength for the 4-minute mixing time is 3,738 pounds, an increase of 148 pounds or 4 percent. The significance of this small increase however is minimized by the fact that the spreads in strength from maximum to minimum for individual breaks, range from 1,220 to 1,700 pounds for the four mixing times, and by the fact that the average strength of the 2-minute concrete is less than that of the 1-minute concrete and the average strength of the 3-minute concrete is greater than that of the 4-minute concrete.

The average flexural strength for the 1-minute concrete is 518 pounds. The corresponding strength for

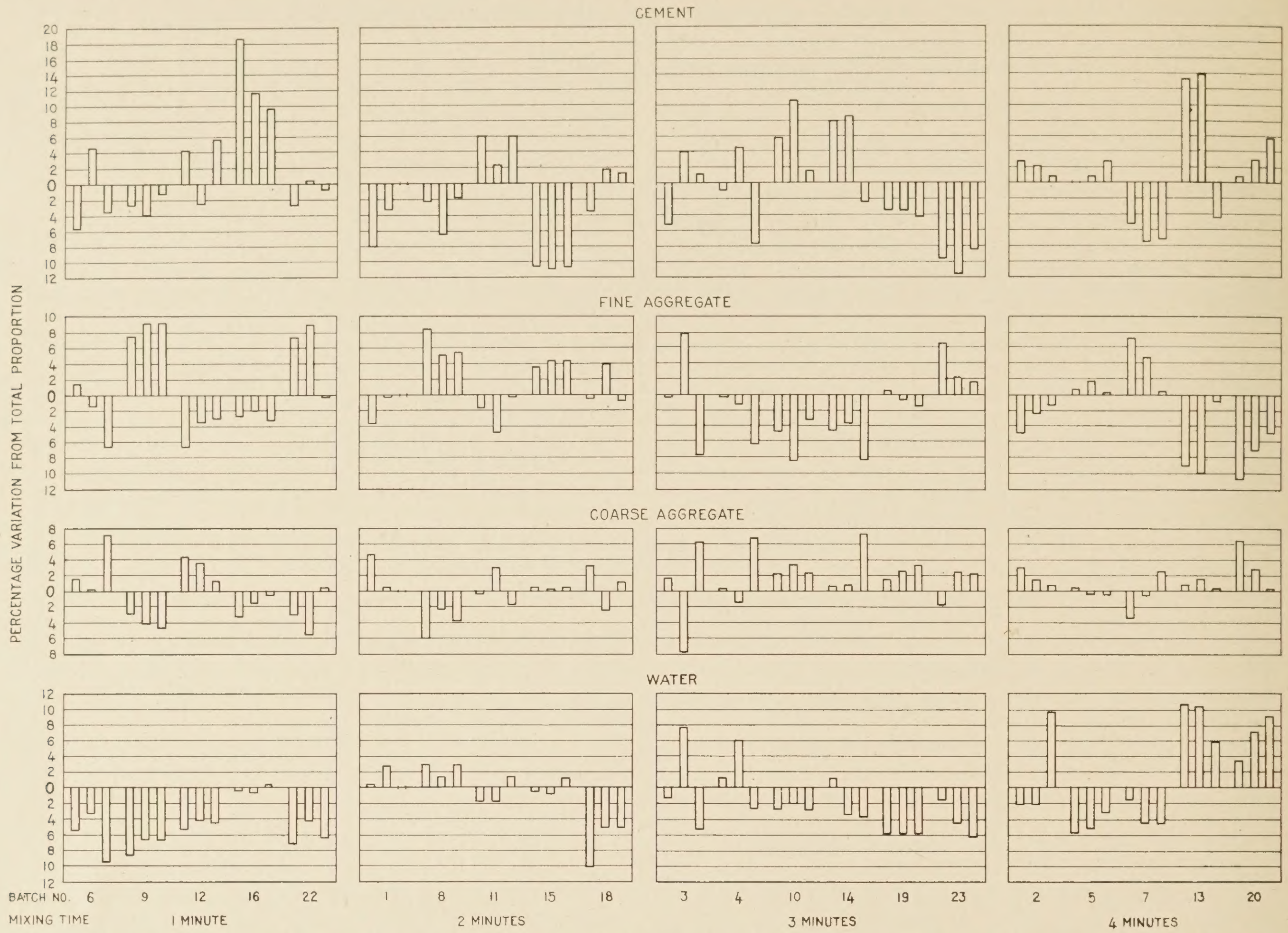


FIGURE 1.—PERCENTAGE VARIATIONS OF MATERIALS IN SAMPLES FROM BATCH PROPORTIONS AS FOUND IN TESTS AT PLANT 1. SAMPLES FROM EACH BATCH ARRANGED IN THE ORDER A, B, C.

TABLE 2.—*Summary of variations of proportions of ingredients in samples from actual batch proportions in tests at plant 1*

Ingredient	Kind of variation	Mixing time in minutes: 1	2	3	4
		Percent	*Percent*	*Percent*	*Percent*
Cement	Maximum individual plus	18.7	6.1	10.3	13.7
	Maximum individual minus	5.8	10.9	11.9	7.5
	Average plus	7.9	3.6	5.4	4.6
	Average minus	2.9	6.4	5.8	6.1
	Average plus and minus disregarding sign.	5.3	5.3	5.6	4.7
Sand	Maximum individual plus	9.1	8.5	7.9	7.3
	Maximum individual minus	6.6	4.8	8.3	10.7
	Average plus	7.3	5.0	3.8	2.6
	Average minus	3.2	1.7	3.9	5.6
	Average plus and minus disregarding sign.	4.8	3.3	3.8	4.4
Gravel	Maximum individual plus	7.1	4.7	7.1	6.4
	Maximum individual minus	5.5	6.0	7.9	3.4
	Average plus	2.6	1.8	2.9	1.8
	Average minus	3.2	2.4	3.7	1.2
	Average plus and minus disregarding sign.	2.9	2.1	3.0	1.6
Water	Maximum individual plus	.4	3.0	7.7	10.5
	Maximum individual minus	9.6	10.0	6.1	5.9
	Average plus	.4	1.9	4.1	8.0
	Average minus	5.3	3.6	3.8	3.7
	Average plus and minus disregarding sign.	4.9	2.7	3.9	5.7

the 4-minute concrete is 553 pounds, an increase of 35 pounds or 7 percent. The spread in strengths however is between 91 and 145 pounds for the four mixing times, and the average strength of the 2-minute concrete is greater than the strengths for the other mixing times. It seems reasonable to conclude from these results that the length of the mixing time between 1 and 4 minutes, had no considerable effect on the strength of the concrete.

FINE AGGREGATE GROUND BY ACTION IN MIXER

At plant 1, grinding of the aggregate took place during the mixing. The grinding of the coarse aggregate to pass the no. 100 sieve was negligible. The grinding of the fine aggregate was appreciable and increased with the mixing time. Determination was made of the amount of sand passing the no. 100 sieve in the material before mixing and also of sand ground up in mixing so that it passed the no. 100 sieve. Determinations were made for the 4 regular mixing periods and for extended mixing periods up to 70 minutes. The results are shown in table 5.

This table shows that the length of the mixing time had a marked effect on the gradation of the fine aggregate. The increase in the amount of fine aggregate passing the no. 100 sieve with increased mixing time does not increase the strength of the concrete.

Designs of concrete mixtures are based in part on the gradation of fine aggregate and, if this gradation is changed by grinding, the concrete produced will not represent the design. Increasing the length of the mixing time presents the possibility of producing harmful effects on the gradation and on the resulting concrete.

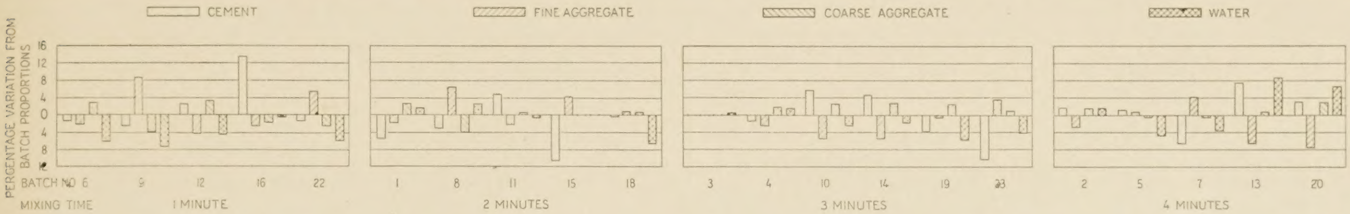


FIGURE 2.—PERCENTAGE VARIATIONS OF MATERIALS FROM BATCH PROPORTIONS COMPUTED FOR ASSUMED SAMPLES COMPOSED OF THREE SAMPLES FROM A BATCH.

TABLE 3.—*Results of strength tests at plant 1*

Batch No.	Mixing time	Sample designation	Slump	Cylinders: Compressive strength	Cylinders: Per cent-age variation from average for batch	Beams: Flexural strength	Beams: Per cent-age variation from average for batch
	Minutes		*Inches*	*Pounds per square inch*		*Pounds per square inch*	
6	1	A	3¾	4,130 3,920	+6.4 +1.0	535	+1.9
		B	2½	3,990 3,850	+2.8 −0.8	480	−8.6
		C	3¼	3,540 3,850	−8.8 −0.8	561	+6.9
		Average		3,880		525	
		Maximum spread		590	15.2	81	15.5
9	1	A	1¾	3,130 3,210	−6.7 −4.3	507	+1.0
		B	3¼	3,470 3,550	+3.5 +5.9	519	+3.4
		C	4¾	3,510 3,250	+4.7 −3.1	480	−4.4
		Average		3,353		502	
		Maximum spread		420	12.6	39	7.8
12	1	A	2¼	3,850 3,690	−2.9 −6.9	531	+2.3
		B	3¼	3,950 3,900	−0.4 −1.6	518	−0.2
		C	2¾	4,320 4,080	+9.0 +2.9	509	−2.0
		Average		3,965		519	
		Maximum spread		630	15.9	22	4.3
16	1	A	6½	3,150 3,080	−3.1 −5.2	557	+9.9
		B	6½	3,310 3,510	−1.8 +8.0	494	−2.6
		C	6¾	3,470 2,980	+6.8 −8.3	470	−7.3
		Average		3,250		507	
		Maximum spread		530	16.3	87	17.2
22	1	A	3½	3,490 3,500	−0.3 −0.1	556	+3.7
		B	3¾	3,420 3,560	−2.3 +1.7	522	−2.6
		C	3	3,410 3,630	−2.6 +3.6	530	−1.1
		Average		3,502		536	
		Maximum spread		220	6.2	34	6.3
1	2	A	2¼	3,800 3,960	−2.2 +1.9	582	+4.2
		B	2	4,060 3,850	+4.5 −0.9	536	−4.1
		C	2	3,850 3,790	−0.9 +2.4	558	−0.2
		Average		3,885		559	
		Maximum spread		270	6.9	46	8.3
8	2	A	4	2,770 3,020	−1.8 +7.0	560	−1.9
		B	5	2,730 2,810	−3.3 −0.4	541	−5.3
		C	6¼	2,920 2,680	+3.5 −5.0	612	+7.2
		Average		2,822		571	
		Maximum spread		340	12.0	71	12.5

TABLE 3.—*Results of strength tests at plant 1*—Continued

Batch No.	Mixing time	Sample designation	Slump	Cylinders: Compressive strength	Cylinders: Per cent-age variation from average for batch	Beams: Flexural strength	Beams: Per cent-age variation from average for batch
	Minutes		*Inches*	*Pounds per square inch*		*Pounds per square inch*	
11	2	A	5	3,630 3,620	−2.7 −3.0	518	−0.8
		B	5¾	3,670 3,920	−1.6 +5.0	480	−8.1
		C	5¾	3,770 3,780	+1.0 +1.3	569	+9.0
		Average		3,732		522	
		Maximum spread		300	8.0	89	17.1
15	2	A	5½	3,330 3,270	+3.0 +1.2	606	+0.2
		B	5¾	3,360 3,150	+3.9 −2.6	590	−2.5
		C	5½	3,090 3,190	−4.4 −1.3	619	+2.3
		Average		3,233		605	
		Maximum spread		270	8.3	29	4.8
18	2	A	5½	3,990 4,140	−5.2 −1.7	608	+2.4
		B	6	4,300 4,280	+2.1 +1.7	584	−1.7
		C	3¼	4,380 4,180	+4.0 −0.7	589	−0.8
		Average		4,221		594	
		Maximum spread		390	9.2	24	4.1
3	3	A	4¾	3,810 3,480	+4.4 −4.3	562	+1.6
		B	7	3,710 3,860	+1.7 +5.8	593	+3.5
		C	5¼	3,480 3,540	−4.6 −3.0	543	−5.2
		Average		3,648		573	
		Maximum spread		380	10.4	50	8.7
4	3	A	3½	4,250 4,200	+2.1 +0.9	540	+0.9
		B	5	4,230 4,050	+1.6 −2.7	535	0.0
		C	2½	4,180 4,070	+0.4 −2.2	529	−0.7
		Average		4,163		535	
		Maximum spread		200	4.8	11	1.6
10	3	A	6½	3,980 3,870	−0.7 −3.4	603	+9.0
		B	6	4,060 3,980	+1.3 −0.7	474	−14.3
		C	7½	4,080 4,070	+1.8 +1.6	582	+5.3
		Average		4,007		553	
		Maximum spread		210	5.2	129	23.3
14	3	A	5¾	4,070 4,150	−4.0 −2.1	552	−5.8
		B	6	4,320 4,260	+1.9 +0.5	619	+5.8
		C	5¾	4,110 4,490	−3.1 +5.9	585	0.0
		Average		4,240		585	
		Maximum spread		420	9.9	67	11.6

Table 3.—*Results of strength tests at plant 1*—Continued

Batch No.	Mixing time	Sample designation	Slump	Cylinders: Compressive strength	Cylinders: Percentage variation from average for batch	Beams: Flexural strength	Beams: Percentage variation from average for batch
	Minutes		*Inches*	*Pounds per square inch*		*Pounds per square inch*	
19	3	A	5½	4,080 4,160	−3.4 −1.5	606	+3.1
		B	5¾	4,400 4,360	+4.2 +3.2	612	+4.1
		C	6	4,340 4,000	+2.8 −5.3	545	−7.3
		Average		4,223		588	
		Maximum spread		400	9.5	67	11.4
23	3	A	3¼	3,390 3,430	−2.2 −1.1	535	+3.9
		B	3¾	3,690 3,550	+6.7 +2.4	492	−4.5
		C	5	3,270 3,470	−5.7 +0.1	518	+0.6
		Average		3,467		515	
		Maximum spread		420	12.4	43	8.4
2	4	A	5½	4,030 4,040	−2.5 −2.3	592	−1.0
		B	5	4,030 4,260	−2.5 +3.0	608	+1.7
		C	4¼	4,250 4,200	+2.8 +1.6	595	−0.5
		Average		4,135		598	
		Maximum spread		230	5.5	16	2.7
5	4	A	4¾	3,610 3,530	−4.5 −6.6	541	−0.7
		B	5½	3,730 4,060	−1.3 +7.4	535	−1.8
		C	4	3,820 3,940	+1.0 +4.2	558	+2.4
		Average		3,781		545	
		Maximum spread		530	14.0	23	4.2
7	4	A	3¾	3,130 3,040	−1.8 −4.6	546	+4.8
		B	4¾	3,090 3,140	−3.0 −1.5	507	−2.7
		C	5	3,410 3,310	+7.1 +3.6	511	−1.9
		Average		3,187		521	
		Maximum spread		370	11.7	39	7.5
13	4	A	5½	4,130 4,100	−2.1 −2.8	600	+2.0
		B	5¾	4,360 4,090	+3.4 −3.0	585	−0.5
		C	5½	4,290 4,340	+1.7 +2.9	579	−1.5
		Average		4,218		588	
		Maximum spread		270	6.4	21	3.5
20	4	A	5¾	3,440 3,560	+2.1 +5.7	--------	--------
		B	6¼	3,160 3,360	−6.2 −0.2	495	+1.4
		C	6¼	3,300 3,390	−2.0 +0.7	481	−1.4
		Average		3,368		488	
		Maximum spread		400	11.9	14	2.8

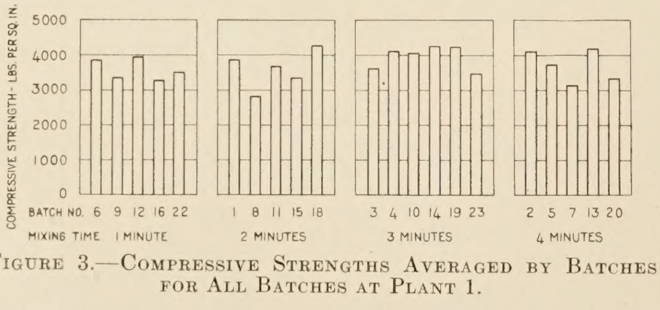


Figure 3.—Compressive Strengths Averaged by Batches for All Batches at Plant 1.

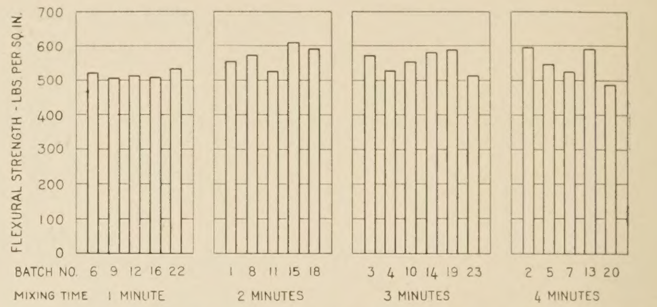


Figure 4.—Flexural Strengths Averaged by Batches for All Batches at Plant 1.

Table 4.—*Summary of strength test results at plant 1*

COMPRESSIVE STRENGTH

Mixing time	Maximum individual	Minimum individual	Maximum spread	Average strength
Minutes	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*
1	4,320	2,980	1,340	3,590
2	4,380	2,680	1,700	3,576
3	4,490	3,270	1,220	3,957
4	4,360	3,040	1,320	3,738

FLEXURAL STRENGTH

Mixing time	Maximum individual	Minimum individual	Maximum spread	Average strength
1	561	470	91	518
2	619	480	139	570
3	619	474	145	558
4	608	481	127	553

Table 5.—*Percentage of sand passing the no. 100 sieve*

Mixing time in minutes:	*Percentage of sand passing*
0	4.0
1	6.0
2	7.5
3	9.0
4	10.5
18	14.0
37	16.0
45	18.5
70	23.0

STUDIES MADE AT A SECOND PLANT

A series of studies were made at a second plant using a stationary no. 126–S mixer. The drum was 108 inches in diameter, 90 inches in length and was revolved 11 times per minute.

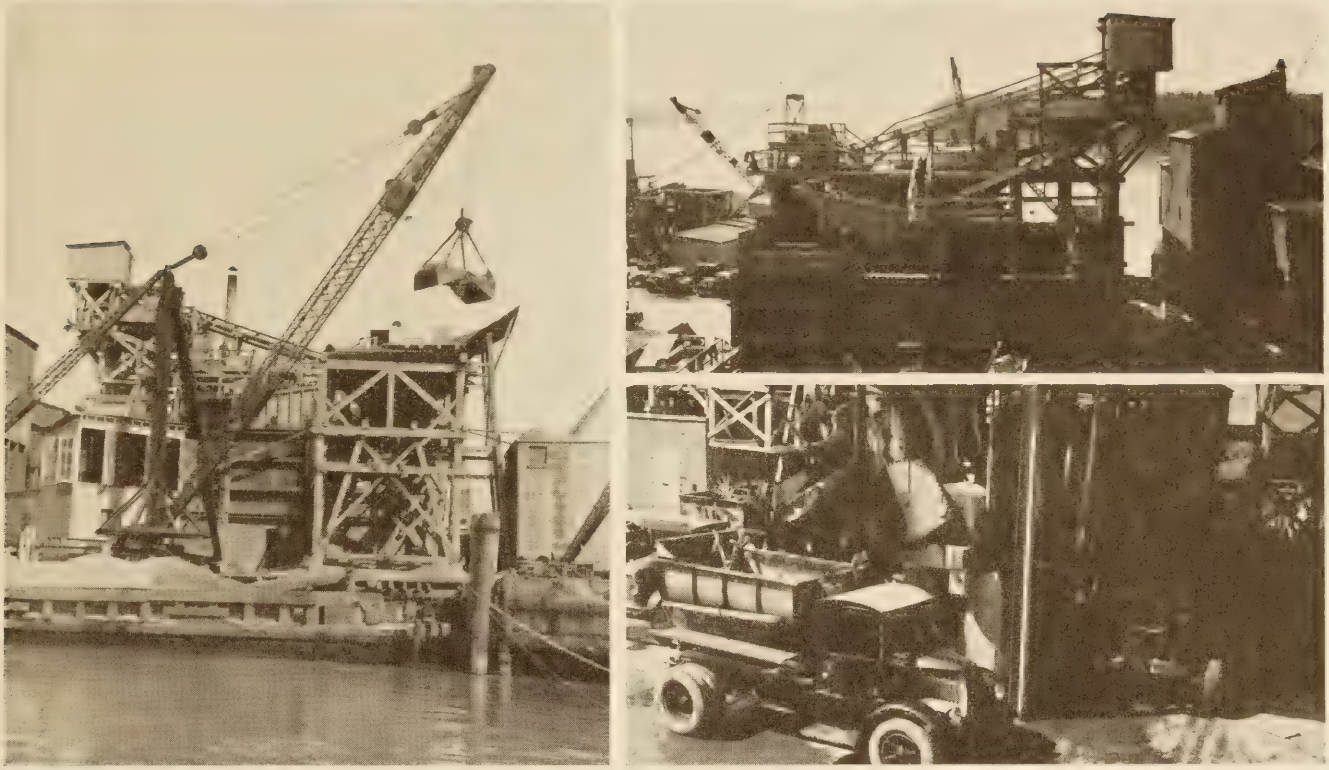
The proportions by dry weight of the average batch were as follows:

	Pounds
Cement	2,363
Fine aggregate	6,789
Coarse aggregate	9,465
Net water	1,866
Absorbed water	62

These quantities produced a batch with an absolute volume of 140 cubic feet.

The sand used as fine aggregate was analyzed as follows:

	Percentage retained
Sieve no. 4	7
Sieve no. 8	19
Sieve no. 14	33
Sieve no. 28	57
Sieve no. 48	90
Sieve no. 100	99



Equipment at Plant No. 1.

Gravel was used as coarse aggregate. Two different sizes were used, one having a maximum size of 1¼ inches and the other a maximum size of three-fourths inch. These gravels were used, each in different series of tests. Their gradations were as follows:

Screen opening	Maximum size ¾ inch, percentage retained	Maximum size 1¼ inches, percentage retained
1½ inches	0	0
¾-inch	16	65
⅜-inch	72	90
No. 4	98	98

In general the procedure followed at plant 2 was different from that followed at plant 1. One set of batches was used for the uniformity tests and another set of batches was used for the strength tests. Both the strength and uniformity tests were divided into two series, one in which the maximum size of coarse aggregate was 1¼ inches, and one in which the maximum size of coarse aggregate was three-fourths inch. The mixing periods were 1, 2, 3, and 4 minutes.

TESTS AT PLANT 2 SHOW LACK OF UNIFORMITY FOR ALL MIXING TIMES

In the uniformity tests a different batch of concrete was used for each mixing period. After a batch had been mixed for a given time it was discharged from the mixer and samples were taken by intercepting the flow. Five 30-pound samples were taken, the first at the beginning of the discharge, the last near the end of the discharge and the three intermediate samples were obtained at uniform intervals of time during the discharge. The samples were analyzed and the proportions determined and compared with the proportions of the batch before mixing in the same manner as in the tests at plant 1. Three batches with ¾-inch coarse aggregate and three with 1¼-inch coarse aggregate for each of the four mixing periods were analyzed. This involved the analysis of fifteen 30-pound samples for each mixing period for each size of coarse aggregate.

The results of the tests for uniformity of mix are shown in table 6. The data in this table correspond with that in table 1 for the uniformity studies at plant 1. Table 7 summarizes the percentage variations contained in table 6, and corresponds with the data in table 2 for plant 1. Figures 5 and 6 show graphically the percentage variations in the proportions of cement, fine aggregate, coarse aggregate and water in each sample removed from each batch from the proportions of the corresponding ingredients in the batch from which the samples were removed. Figure 7 shows the percentage variations computed for assumed samples, each composed of the five samples taken from a batch.

The tables and figures mentioned above show a consistent lack of uniformity in the samples taken at plant 2. Variations in the proportions of the ingredients in different parts of the same batch were higher than 20 percent in some batches. Maximum spreads in the proportions in different parts of a group of batches for a given mixing time were from 8 to 40 percent. The spread between the average plus and the average minus values for a given material ranged from 4 to 18 percent. The average variation in the proportion of each ingredient from the actual batch proportion was between 2.1 and 8.8 percent, as shown in table 7. An analysis of these data indicates that the length of the mixing time had no considerable effect on the uniformity of distribution of the ingredients.

TESTS AT PLANT 2 SHOW NO APPRECIABLE GAIN IN STRENGTH WITH INCREASE IN MIXING TIME

Samples for strength tests were obtained from a given batch after 1, 2, 3, and 4 minutes of mixing by inserting

Table 6.—*Results of tests for uniformity of mix at plant 2*

CONCRETE WITH ¾-INCH COARSE AGGREGATE

Batch No.	Mixing time	Computed proportions in 30-pound sample based on proportions of total batch: Cement, Weight in pounds	Cement, Percent	Fine aggregate, Weight in pounds	Fine aggregate, Percent	Coarse aggregate, Weight in pounds	Coarse aggregate, Percent	Water, Net, Weight in pounds	Water, Net, Percent	Water, Absorbed, Weight in pounds	Water, Absorbed, Percent	Sample designation	Proportions of 30-pound sample by dry weight: Cement, Weight in pounds	Cement, Percent	Fine aggregate, Weight in pounds	Fine aggregate, Percent	Coarse aggregate, Weight in pounds	Coarse aggregate, Percent	Net water, Weight in pounds	Net water, Percent	Percentage variations in sample from proportions of original material: Cement	Fine aggregate	Coarse aggregate	Net water
	Minutes											A	3.53	11.8	9.33	31.1	14.63	48.8	2.42	8.1	+4.1	−10.2	+8.8	−9.7
												B	3.33	11.1	10.19	34.0	13.87	46.2	2.52	8.4	−1.8	−1.9	+3.1	−5.2
6-U	1	3.39	11.3	10.39	34.6	13.45	44.9	2.68	8.9	.09	0.3	C	3.33	11.1	10.35	34.5	13.63	45.4	2.60	8.7	−1.8	−0.4	+1.3	−3.0
												D	3.42	11.4	10.75	35.8	13.03	43.4	2.71	9.0	+0.9	+3.5	−3.1	+1.1
												E	3.43	11.4	10.22	34.1	13.63	54.4	2.63	8.8	+1.2	−1.6	+1.3	−1.9
												A	3.80	12.7	10.11	33.7	13.25	44.2	2.75	9.2	+12.4	−2.8	−1.0	+0.4
												B	3.58	11.9	9.69	32.3	14.00	46.7	2.64	8.8	+5.9	−6.8	+4.6	−3.6
7-U	1	3.38	11.3	10.40	34.7	13.39	44.6	2.74	9.1	.09	.3	C	3.61	12.0	10.04	33.5	13.48	44.9	2.78	9.3	+6.8	−3.5	+0.7	+1.5
												D	3.55	11.8	10.14	33.8	13.34	44.5	2.88	9.6	+5.0	−2.5	−0.4	+5.1
												E	3.68	12.3	9.70	32.3	13.78	45.9	2.75	9.2	+8.9	−6.7	+2.9	+0.4
												A	3.77	12.6	10.09	33.6	13.44	44.8	2.61	8.7	+9.0	−3.3	+1.1	−4.0
												B	3.24	10.8	10.26	34.2	13.71	45.7	2.70	9.0	−6.4	−1.6	+3.1	−0.7
10-U	1	3.46	11.5	10.43	34.8	13.30	44.3	2.72	9.1	.09	.3	C	3.40	11.3	10.49	35.0	13.30	44.3	2.72	9.1	−1.7	+0.6	0.0	0.0
												D	3.38	11.3	10.24	34.1	13.67	45.6	2.62	8.7	−2.3	−1.8	+2.8	−3.7
												E	3.30	11.0	8.98	29.9	15.17	50.6	2.45	8.2	−4.6	−13.9	+14.1	−9.9
												A	3.39	11.3	10.87	36.2	12.77	42.6	2.88	9.6	0.0	+5.2	−3.9	−0.7
												B	3.13	10.4	10.65	35.5	13.44	44.8	2.69	9.0	−7.7	+3.1	+1.1	−7.2
1-U	2	3.39	11.3	10.33	34.4	13.29	44.3	2.90	9.7	.09	.3	C	3.32	11.1	10.83	36.1	12.93	43.1	2.83	9.4	−2.1	+4.8	−2.7	−2.4
												D	3.32	11.1	10.72	35.7	13.16	43.9	2.71	9.0	−2.1	+3.8	−0.9	−6.6
												E	3.36	11.2	10.78	35.9	12.93	43.1	2.84	9.5	−0.9	+4.4	−2.7	−2.1
												A	3.49	11.6	9.72	32.4	14.04	46.8	2.66	8.9	+2.9	−4.8	+4.4	−7.0
												B	3.23	10.8	9.87	32.9	14.13	47.1	2.68	8.9	−4.7	−3.3	+5.1	−6.3
2-U	2	3.39	11.3	10.21	34.1	13.45	44.8	2.86	9.5	.09	.3	C	3.30	11.0	9.97	33.2	13.91	46.4	2.73	9.1	+2.7	−2.3	+3.4	−4.5
												D	3.30	11.0	10.55	35.2	13.24	44.1	2.82	9.4	+2.7	+3.3	−1.6	−1.4
												E	3.55	11.8	10.35	34.5	13.14	43.8	2.87	9.6	+4.7	+1.4	−2.3	+0.3
												A	4.03	13.4	10.62	35.4	12.61	42.1	2.65	8.8	+20.3	+2.1	−5.7	−4.7
												B	3.65	12.2	10.63	35.4	12.93	43.1	2.70	9.0	+9.0	+2.2	−3.4	−2.9
9-U	2	3.35	11.2	10.40	34.7	13.38	44.5	2.78	9.3	.09	.3	C	3.66	12.2	10.43	34.8	13.11	43.7	2.71	9.0	+9.3	+0.3	−2.0	−2.5
												D	3.55	11.8	10.73	35.8	12.84	42.8	2.79	9.3	+6.0	+3.2	−4.0	+0.4
												E	3.52	11.7	9.54	31.8	14.31	47.7	2.64	8.5	+5.1	−8.3	+6.9	−8.6
												A	3.64	12.1	9.82	32.8	13.75	45.8	2.70	9.0	+6.7	−5.1	+3.6	−6.2
												B	3.36	11.2	10.18	33.9	13.56	45.2	2.81	9.4	−1.5	−1.6	+2.2	−2.4
3-U	3	3.41	11.4	10.35	34.5	13.27	44.2	2.88	9.6	.09	.3	C	3.51	11.7	10.12	33.7	13.45	44.9	2.83	9.4	+2.9	−2.2	+1.4	−1.7
												D	3.55	11.8	10.22	34.1	13.23	44.1	2.91	9.7	+4.1	−1.3	−0.1	+1.0
												E	3.48	11.6	10.08	33.6	13.52	45.1	2.83	9.4	+2.0	−2.6	+1.9	−1.7
												A	3.52	11.7	9.70	32.3	14.15	47.2	2.54	8.5	+3.5	−6.4	+4.7	−3.4
												B	3.48	11.6	9.78	32.6	13.98	46.6	2.67	8.9	+2.3	−5.6	+3.4	+1.5
4-U	3	3.40	11.3	10.36	34.5	13.52	45.1	2.63	8.8	.09	.3	C	3.51	11.7	9.72	32.4	14.00	46.7	2.68	8.9	+3.1	−6.2	+3.5	+1.9
												D	3.42	11.4	9.50	31.7	14.35	47.8	2.64	8.8	+0.6	−8.3	+6.1	+1.4
												E	3.27	10.9	9.07	30.3	15.06	50.2	2.50	8.3	−3.8	−12.4	+11.4	−4.9
												A	4.12	13.7	9.30	31.0	13.97	46.6	2.52	8.4	+21.1	−10.5	+4.1	−6.7
												B	3.33	11.1	10.03	33.4	13.90	46.4	2.65	8.8	−2.1	−3.5	+3.6	−1.9
11-U	3	3.40	11.3	10.39	34.6	13.42	44.8	2.70	9.0	.09	.3	C	3.21	10.7	10.12	33.7	13.92	46.4	2.66	8.9	−5.6	−2.6	+3.7	−1.5
												D	3.35	11.2	10.17	33.9	13.67	45.5	2.72	9.1	−1.5	−2.1	+1.9	+0.7
												E	3.24	10.8	9.83	32.8	14.23	47.4	2.61	8.7	−4.7	−5.4	+6.0	−3.3
												A	3.38	11.3	10.36	34.5	13.51	45.0	2.66	8.9	−0.9	−0.4	+1.6	−5.0
												B	3.27	10.9	10.51	35.0	13.36	44.0	2.77	9.2	−4.1	+1.1	+0.5	−1.1
8-U	4	3.41	11.4	10.40	34.7	13.30	44.3	2.80	9.3	.09	.3	C	3.32	11.1	10.35	34.5	13.51	45.0	2.73	9.1	−2.6	−0.5	+1.6	−2.5
												D	3.35	11.2	10.36	34.5	13.44	44.8	2.76	9.2	−1.8	−0.4	+1.1	−1.4
												E	2.98	9.9	10.11	33.8	14.26	47.5	2.56	8.5	−12.6	−2.8	+7.2	−8.6
												A	3.89	13.0	10.53	35.1	12.74	42.4	2.75	9.2	+13.7	+1.6	−4.6	−0.7
												B	3.71	12.4	10.59	35.3	12.84	42.8	2.77	9.2	+8.5	+2.2	−3.9	0.0
12-U	4	3.42	11.4	10.36	34.5	13.36	44.6	2.77	9.2	.09	.3	C	3.77	12.6	10.15	33.8	13.20	44.0	2.79	9.3	+10.2	−2.0	−1.2	+0.7
												D	3.65	12.2	10.43	34.8	13.06	43.5	2.77	9.2	+6.7	+0.7	−2.2	0.0
												E	3.67	12.2	9.77	32.6	13.77	45.9	2.70	9.0	+7.3	−5.7	+3.1	−2.5
												A	3.86	12.9	10.44	34.8	12.83	42.7	2.78	9.3	+13.9	+1.1	−3.9	−2.1
												B	3.59	12.0	10.02	33.4	13.53	45.1	2.77	9.2	+5.9	−3.0	+1.3	−2.5
13-U	4	3.39	11.3	10.33	34.4	13.35	44.5	2.84	9.5	.09	.3	C	3.42	11.4	10.34	34.5	13.26	44.2	2.89	9.6	+0.9	+0.1	−0.7	+1.8
												D	3.47	11.6	9.83	32.8	14.04	46.8	2.57	8.6	+2.5	−4.8	+5.2	−9.5
												E	3.62	12.1	9.85	32.8	13.61	45.4	2.83	9.4	+6.8	−4.6	+1.9	−0.4

CONCRETE WITH 1¼-INCH COARSE AGGREGATE

Batch No.	Mixing time	Computed: Cement, Weight in pounds	Cement, Percent	Fine aggregate, Weight in pounds	Fine aggregate, Percent	Coarse aggregate, Weight in pounds	Coarse aggregate, Percent	Water, Net, Weight in pounds	Water, Net, Percent	Water, Absorbed, Weight in pounds	Water, Absorbed, Percent	Sample designation	Sample: Cement, Weight in pounds	Cement, Percent	Fine aggregate, Weight in pounds	Fine aggregate, Percent	Coarse aggregate, Weight in pounds	Coarse aggregate, Percent	Net water, Weight in pounds	Net water, Percent	Variation: Cement	Fine aggregate	Coarse aggregate	Net water
												A	3.36	11.2	8.83	29.4	15.51	51.7	2.21	7.4	−1.8	−6.9	+5.9	−7.1
												B	3.20	11.7	8.83	29.4	15.68	52.3	2.20	7.3	−6.4	−6.9	+7.1	−7.6
5-U	1	3.42	11.4	9.48	31.6	14.64	48.8	2.38	7.9	.08	.3	C	3.36	11.2	9.71	32.4	14.43	48.1	2.41	8.0	−1.8	+2.4	−1.4	+1.3
												D	3.11	10.4	9.07	30.3	15.49	51.6	2.23	7.4	−9.1	−4.3	+5.8	−6.3
												E	3.17	10.6	8.83	29.4	15.55	51.8	2.36	7.9	−7.3	−6.9	+6.2	−.8
												A	4.32	14.4	8.51	28.4	14.57	48.5	2.52	8.4	+27.1	−10.6	+2.6	−9.7
												B	3.37	11.2	9.06	30.2	14.85	49.5	2.63	8.8	−.9	−4.8	+4.6	−5.7
15-U	1	3.40	11.3	9.52	31.8	14.20	47.3	2.79	9.3	.09	.3	C	3.58	11.9	8.76	29.2	14.91	49.7	2.67	8.9	+5.3	−8.0	+5.0	−4.3
												D	3.57	11.9	9.33	31.1	14.32	47.7	2.69	9.0	+5.0	−2.0	+.8	−3.6
												E	3.67	12.2	9.02	30.1	14.50	48.3	2.72	9.1	+7.9	−5.3	+2.1	−2.5
												A	4.48	14.9	9.81	32.7	12.86	42.9	2.76	9.2	+31.7	+2.1	−9.4	+1.8
												B	3.19	10.6	9.05	30.2	15.17	50.6	2.49	8.3	−6.2	−5.8	+6.9	−8.1
16-U	1	3.40	11.3	9.61	32.1	14.19	47.3	2.71	9.0	.09	.3	C	3.51	11.7	9.66	32.2	14.08	46.9	2.66	8.9	+3.2	+.5	−.8	−1.8
												D	3.28	10.9	9.30	31.0	14.68	49.0	2.65	8.8	−3.5	−3.2	+3.5	−2.2
												E	3.19	10.6	8.64	28.8	15.59	52.0	2.49	8.3	−6.2	−10.1	+9.9	−8.1
												A	3.24	10.8	9.07	30.2	14.91	49.7	2.69	9.0	−4.7	−5.3	+5.0	−2.2
												B	3.11	10.4	8.65	28.8	15.63	52.1	2.52	8.4	−8.0	−9.7	+10.1	−8.4
21-U	2	3.38	11.3	9.58	31.9	14.20	47.3	2.75	9.2	.09	.3	C	3.10	10.3	8.88	29.6	15.27	50.9	2.66	8.9	−8.3	−7.3	+7.5	−3.3
												D	3.30	11.0	9.27	30.9	14.57	48.6	2.77	9.2	−2.4	−3.2	+2.6	+.7
												E	3.53	11.8	9.74	32.5	13.73	45.7	2.91	9.7	+4.4	+1.7	−3.3	+5.8
												A	3.21	10.7	8.50	28.3	15.60	52.0	2.60	8.7	−5.6	−11.1	+9.6	−4.1
												B	3.29	11.0	9.22	30.7	14.69	49.0	2.71	9.0	−3.1	−3.6	+3.2	.0
22-U	2	3.40	11.3	9.56	31.9	14.24	47.5	2.71	9.0	.09	.3	C	3.24	10.8	8.92	29.7	15.05	50.2	2.70	9.0	−4.7	−6.7	+5.7	−.4
												D	3.36	11.2	9.14	30.5	14.64	48.8	2.77	9.2	−1.2	−4.4	+2.8	+2.2
												E	3.27	10.9	9.22	30.7	14.67	48.9	2.75	9.2	−3.8	−3.6	+3.0	+1.5

TABLE 6.—*Results of tests for uniformity of mix at plant 2*—Continued

CONCRETE WITH 1¼-INCH COARSE AGGREGATE—Continued

Batch No.	Mixing time	Computed proportions in 30-pound sample based on proportions of total batch: Cement, Weight in pounds	Cement, Percent	Fine aggregate, Weight in pounds	Fine aggregate, Percent	Coarse aggregate, Weight in pounds	Coarse aggregate, Percent	Water, Net, Weight in pounds	Water, Net, Percent	Water, Absorbed, Weight in pounds	Water, Absorbed, Percent	Sample designation	Proportions of 30-pound sample by dry weight: Cement, Weight in pounds	Cement, Percent	Fine aggregate, Weight in pounds	Fine aggregate, Percent	Coarse aggregate, Weigh in pounds	Coarse aggregate, Percent	Net water, Weight in pounds	Net water, Percent	Percentage variations in sample from proportions of original material: Cement	Fine aggregate	Coarse aggregate	Net water
												A	3.46	11.5	9.58	31.9	14.14	47.2	2.73	9.1	+2.4	+.4	+.6	−6.8
	Min.											B	3.76	12.5	10.29	34.3	12.98	43.3	2.88	9.6	+11.2	+7.9	−7.7	−1.7
24-U	2	3.38	11.3	9.54	31.8	14.06	46.8	2.93	9.8	.09	.3	C	3.55	11.8	10.35	34.5	13.16	43.9	2.85	9.5	+5.0	+8.5	−6.4	−2.7
												D	3.61	12.0	10.39	34.6	13.04	43.5	2.87	9.6	+6.8	+8.9	−7.3	−2.0
												E	3.77	12.6	10.26	34.2	12.99	43.3	2.89	9.6	+9.2	+7.5	−7.6	−1.4
												A	4.01	13.4	9.16	30.5	13.83	46.1	2.91	9.7	+18.3	−4.5	−1.4	−.3
												B	3.31	11.0	9.08	30.3	14.80	49.3	2.72	9.1	−2.4	−5.3	+5.5	−6.2
14-U	3	3.39	11.3	9.59	32.0	14.03	46.7	2.90	9.7	.09	.3	C	3.73	12.4	9.00	30.0	14.41	48.1	2.77	9.2	+10.6	−6.1	+2.8	−4.5
												D	3.76	12.5	9.24	30.8	14.09	47.0	2.82	9.4	+10.9	−3.6	+.4	−2.8
												E	3.71	12.4	8.94	29.8	14.47	48.2	2.80	9.3	+9.4	−6.8	+3.1	−3.4
												A	4.67	15.6	9.13	30.4	13.39	44.6	2.72	9.1	+37.7	−5.9	−5.6	+3.0
												B	3.20	10.7	9.27	30.9	14.76	49.2	2.68	8.9	−5.6	−4.1	+4.1	+1.5
17-U	3	3.39	11.3	9.70	32.3	14.18	47.3	2.64	8.8	.09	.3	C	3.33	11.1	9.74	32.5	14.11	47.0	2.74	9.1	−2.1	+.1	−.5	+3.8
												D	3.42	11.4	9.74	32.5	14.03	46.7	2.72	9.1	+.9	+.4	−1.1	+3.0
												E	3.49	11.6	9.16	30.5	14.50	48.3	2.76	9.2	+2.9	−5.6	+2.3	+4.5
												A	3.68	12.3	10.75	35.8	12.66	42.2	2.82	9.4	−4.3	−.1	+1.2	−2.8
												B	3.64	12.1	11.23	37.4	12.16	40.0	2.87	9.6	−5.3	+4.4	−2.8	−1.0
18-U	3	3.74	12.5	10.76	35.8	12.51	41.7	2.90	9.7	.09	.3	C	3.64	12.1	11.25	37.5	12.10	40.4	2.91	9.7	−5.3	+4.6	−3.3	+.3
												D	3.36	11.2	11.25	37.5	12.43	41.5	2.86	9.5	−10.2	+4.6	−.6	−1.4
												E	3.51	11.7	10.75	35.8	12.83	42.8	2.82	9.4	−6.1	−.1	+2.6	−2.8
												A	3.70	12.3	7.94	26.5	15.90	53.0	2.37	7.9	−.8	−9.4	+5.9	−2.1
												B	3.63	12.1	8.54	28.5	15.37	51.2	2.37	7.9	−2.1	−2.4	+2.4	−2.1
19-U	4	3.72	12.4	8.75	29.2	15.01	50.0	2.42	8.1	.10	.3	C	3.82	12.7	8.77	29.2	14.76	49.2	2.57	8.6	+2.4	+.2	−1.7	+6.2
												D	3.90	13.0	9.30	31.0	14.14	47.1	2.57	8.6	+4.6	+6.3	−5.8	+6.2
												E	3.87	12.9	9.10	30.3	14.36	47.9	2.58	8.6	+3.8	+4.0	−4.3	+6.6
												A	3.87	12.9	8.90	29.6	14.51	48.4	2.64	8.8	+3.8	+.7	−2.7	+8.6
												B	3.52	11.7	8.78	29.3	14.98	49.9	2.63	8.8	−5.6	−.7	+.5	+8.2
20-U	4	3.73	12.4	8.84	29.5	14.91	49.7	2.43	8.1	.09	.3	C	3.58	11.9	8.74	29.1	15.04	50.2	2.55	8.5	−4.0	−1.1	+.9	+4.9
												D	3.74	12.5	8.90	29.6	14.65	48.8	2.63	8.8	+.3	+.7	−1.7	+8.2
												E	3.90	13.0	9.37	31.2	13.90	46.4	2.74	9.1	+4.6	+6.0	−6.8	+12.7
												A	3.78	12.6	8.36	27.9	15.27	50.9	2.50	8.3	+1.1	−3.4	+1.9	−1.2
												B	3.83	12.8	8.68	28.9	14.83	49.4	2.58	8.6	+2.4	+.3	−1.1	+2.0
23-U	4	3.74	12.5	8.65	28.8	14.99	50.0	2.53	8.4	.09	.3	C	3.84	12.8	8.68	28.9	14.81	48.4	2.59	8.6	+2.7	+.3	−1.2	+2.4
												D	3.96	13.2	8.99	30.0	14.36	47.8	2.60	8.7	+5.9	+3.9	−4.2	+2.8
												E	3.71	12.4	8.06	26.9	15.62	52.0	2.52	8.4	−.8	−6.8	+4.2	+.4

TABLE 7.—*Summary of variations of proportions of ingredients in samples from actual batch proportions in tests at plant 2*

Ingredients	Kind of variation	¾-inch gravel				1¼-inch gravel			
		Mixing time in minutes							
		1	2	3	4	1	2	3	4
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Cement	Maximum individual plus	12.4	20.3	21.1	13.9	31.7	11.2	37.7	5.9
	Maximum individual minus	6.4	7.7	5.6	12.6	9.1	8.3	10.2	5.6
	Average plus	6.0	7.0	5.1	7.6	13.4	6.5	13.0	3.2
	Average minus	3.1	3.5	3.2	4.4	4.8	4.6	5.2	2.7
	Average plus and minus, disregarding sign.	4.9	5.3	4.4	6.6	8.2	5.4	8.8	3.0
Sand	Maximum individual plus	3.5	5.2	-----	2.2	2.4	8.9	4.6	6.3
	Maximum individual minus	13.9	8.3	12.4	5.7	10.6	11.1	6.8	9.4
	Average plus	2.0	3.1	-----	1.1	1.7	5.8	2.8	2.5
	Average minus	4.4	4.7	5.1	2.7	6.2	6.1	4.2	4.0
	Average plus and minus, disregarding sign.	4.1	3.5	5.1	2.1	5.3	6.0	3.7	3.1
Gravel	Maximum individual plus	14.1	6.9	11.4	7.2	9.9	10.1	5.5	5.9
	Maximum individual minus	3.1	5.7	.1	4.6	9.4	7.7	5.6	6.8
	Average plus	4.0	4.2	4.1	2.6	5.0	5.0	2.8	2.6
	Average minus	1.5	2.9	.1	2.8	3.9	6.5	2.2	3.3
	Average plus and minus. disregarding sign.	3.2	3.3	3.8	2.7	4.8	5.5	2.5	3.0
Water	Maximum individual plus	5.1	.4	1.9	1.8	1.8	5.8	4.5	12.7
	Maximum individual minus	9.9	8.6	6.7	9.5	9.7	8.4	6.2	2.1
	Average plus	1.7	.3	1.3	1.2	1.6	2.6	2.7	5.8
	Average minus	4.6	4.4	3.4	3.3	5.2	3.3	2.8	1.8
	Average plus and minus, disregarding sign.	3.3	3.8	2.7	2.6	4.7	2.9	2.8	5.0

an auxiliary chute into the drum at the end of each of these mixing periods. A sample weighed approximately 150 pounds and was used to make two 6- by 12-inch cylinders and one 6- by 21-inch beam and one slump test.

Strength specimens were cured in moist sand and were broken at 28 days. Beams were broken as cantilevers, two breaks being obtained from each beam. Ten batches with ¾-inch gravel and 10 with 1¼-inch gravel were sampled permitting 20 compression tests and 20 flexure tests for each mixing period for each size of aggregate.

Table 8 shows the results of the strength tests in detail. Table 9 is a summary of the strength results and shows data corresponding to that in table 4 for plant 1. Figure 8 shows graphically the compressive and flexural strengths for the individual specimens made from each batch for each mixing time.

There was some variation in the proportions of the ingredients in the different batches of concrete. This was the result of the use of constant weights in batching with no correction for variations in moisture content of the aggregates. Using the data of table 9 as a basis for determining the effect of the length of the mixing time on the strength of the concrete, the following results are shown:

The average compressive strength of concrete with ¾-inch aggregate, mixed for 4 minutes, is 197 pounds or 9 percent higher than the corresponding strength of the 1-minute concrete. The average compressive strengths increase with the mixing time. The spread in strengths for the four sets of specimens is between 520 and 1,040 pounds.

The average compressive strength of the 4-minute concrete with 1¼-inch aggregate is 118 pounds or 5 percent higher than the corresponding strength of the

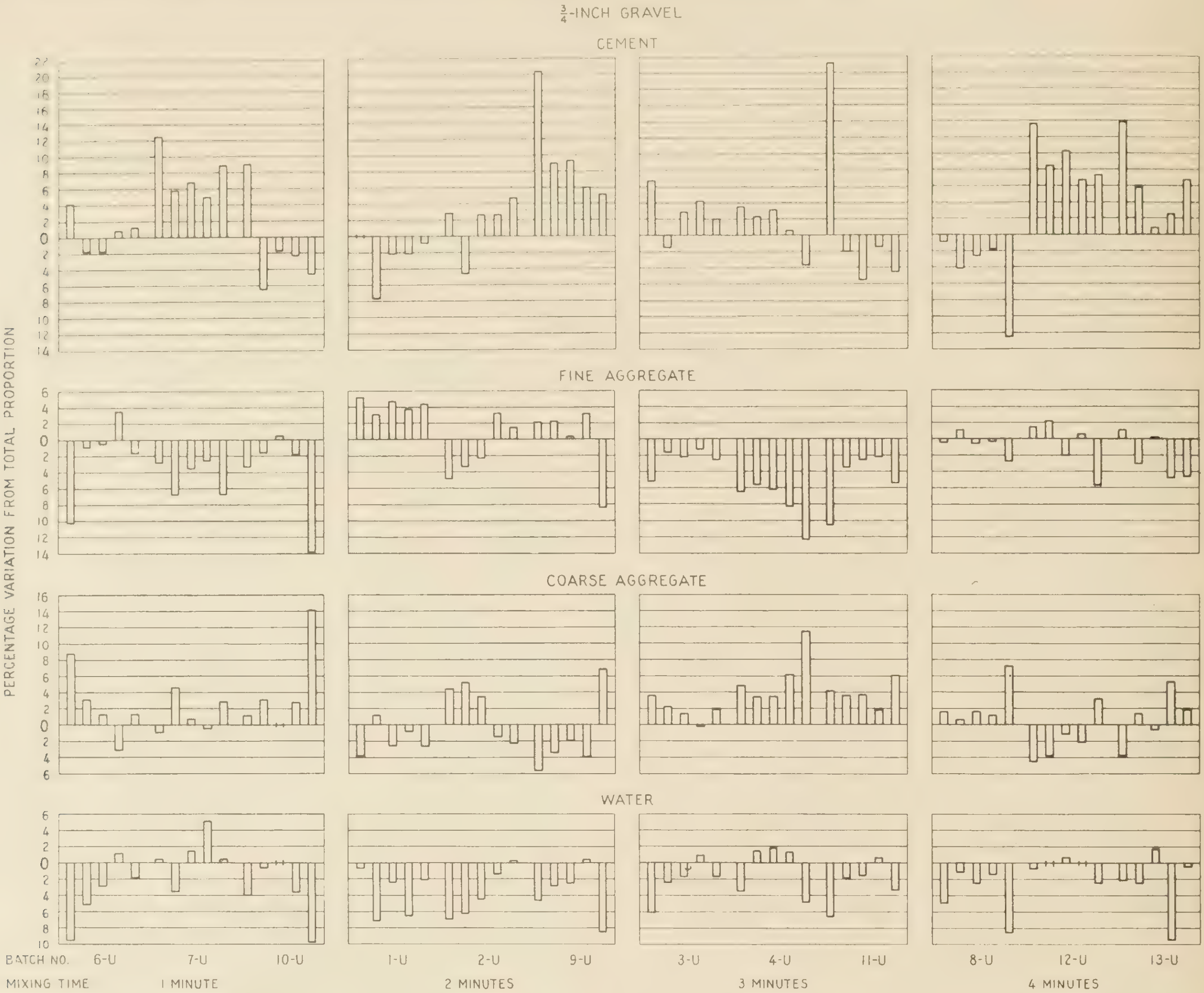


FIGURE 5.—PERCENTAGE VARIATIONS OF MATERIALS IN SAMPLES FROM BATCH PROPORTIONS AS FOUND IN TESTS USING ¾-INCH GRAVEL AT PLANT 2. SAMPLES FROM EACH BATCH ARRANGED IN ORDER A, B, C, D, AND E.

TABLE 8.—*Results of strength tests at plant 2*

CONCRETE WITH ¾-INCH COARSE AGGREGATE

Batch No.	1-minute mixing			2-minute mixing			3-minute mixing			4-minute mixing		
	Slump	Compressive strength	Flexural strength	Slump	Compressive strength	Flexural strength	Slump	Compressive strength	Flexural strength	Slump	Compressive strength	Flexural strength
	Inches	*Pounds per square inch*	*Pounds per square inch*	*Inches*	*Pounds per square inch*	*Pounds per square inch*	*Inches*	*Pounds per square inch*	*Pounds per square inch*	*Inches*	*Pounds per square inch*	*Pounds per square inch*
1	7¼	2, 170	436	7	2, 410	529	7½	2, 190	519	7	2, 380	455
		2, 350	455		2, 320	520		2, 220	528		2, 440	478
Average		2, 260	445		2, 365	524		2, 205	523		2, 410	467
2	6½	2, 310	426	4½	2, 690	422	7¼	2, 550	449	6	2, 400	385
		2, 510	482		2, 640	461		2, 370	435		2, 550	454
Average		2, 410	454		2, 665	442		2, 460	442		2, 475	420
3		----------	----------	6½	2, 410	438	6¾	2, 400	454	7½	1, 790	428
					2, 320	482		2, 260	422		1, 910	423
Average		----------	----------		2, 365	460		2, 330	438		1, 850	425
4	6	2, 150	442	6	2, 330	451	6	2, 570	424	6	2, 430	486
		2, 160	449		2, 130	486		2, 380	495		2, 640	474
Average		2, 155	446		2, 230	468		2, 475	460		2, 535	480

TABLE 8.—*Results of strength tests at plant 2*—Continued

CONCRETE WITH ¾-INCH COARSE AGGREGATE—Continued

Batch No.	1-minute mixing			2-minute mixing			3-minute mixing			4-minute mixing		
	Slump	Compressive strength	Flexural strength	Slump	Compressive strength	Flexural strength	Slump	Compressive strength	Flexural strength	Slump	Compressive strength	Flexural strength
	Inches	*Pounds per square inch*	*Pounds per square inch*	*Inches*	*Pounds per square inch*	*Pounds per square inch*	*Inches*	*Pounds per square inch*	*Pounds per square inch*	*Inches*	*Pounds per square inch*	*Pounds per square inch*
6	6½	2, 210 2, 400	528 448	8	2, 380 2, 100	390 476	6½	2, 420 2, 340	456 444	6	2, 390 2, 510	417 469
Average		2, 305	488		2, 240	433		2, 380	450		2, 450	443
13	8	2, 050 1, 930	546 530	8½	2, 160 2, 150	482 479	7¾	2, 340 2, 350	520 502	7	2, 230 2, 350	476 478
Average		1, 990	538		2, 155	481		2, 345	511		2, 290	477
14	7	2, 500 2, 490	521 530	3¾	2, 250 2, 140	505 538	4	2, 380 2, 390	510 521	3½	2, 630 2, 690	446 496
Average		2, 495	525		2, 195	522		2, 385	515		2, 660	471
15	8	2, 310 2, 420	481 463	9	2, 350 2, 470	468 411	8½	2, 090 2, 410	402 427	6¾	2, 830 2, 690	395 455
Average		2, 365	472		2, 410	440		2, 250	415		2, 760	425
18	7	1, 980 2, 010	513 531	8½	1, 940 2, 170	410 466	7½	2, 190 2, 050	440 468	5¼	2, 270 2, 390	455 437
Average		1, 995	522		2, 055	438		2, 120	454		2, 330	446
19	8¼	1, 940 1. 890	382 434	8¾	1, 980 1. 950	418 464	8½	2, 230 2. 160	430 426	7	2, 310 2. 310	458 496
Average		1, 915	408		1, 965	441		2, 195	428		2, 310	477
Grand average		2, 210	477		2, 265	465		2, 315	464		2, 407	453

CONCRETE WITH 1¼-INCH AGGREGATE

Batch No.	1-minute mixing			2-minute mixing			3-minute mixing			4-minute mixing		
	Slump	Compressive strength	Flexural strength	Slump	Compressive strength	Flexural strength	Slump	Compressive strength	Flexural strength	Slump	Compressive strength	Flexural strength
5	8¾	1, 780 2, 130	513 448	8½	2, 290 2, 230	487 545	8½	2, 210 2, 190	433 473	8	2, 480 2, 280	427 453
Average		1, 955	481		2, 260	516		2, 200	453		2, 380	440
7		------------	------------	6½	2, 430 ------------	447 483	6¾	2, 390 2, 510	450 493	6	2, 520 2, 520	479 440
Average		------------	------------		2, 430	465		2, 450	471		2, 520	460
8	7½	3, 210 3, 140	490 559	5¾	2, 770 2, 640	500 475	5½	3, 090 3, 060	490 507	4¾	3, 020 3, 020	524 472
Average		3, 175	524		2, 705	488		3, 075	498		3, 020	498
9	8	2, 230 2, 110	485 462	8	2, 290 2, 410	424 477	7	2, 460 2, 670	530 449	5¾	2, 570 2, 520	394 445
Average		2, 170	473		2, 350	451		2, 565	490		2, 545	420
10	8	2, 500 2, 560	480 451	7½	2, 690 2, 720	453 512	7¼	2, 810 3, 030	442 523	6½	3, 010 2, 970	459 474
Average		2, 530	465		2, 705	483		2, 920	482		2, 990	467
11	6¼	2, 710 2, 680	467 465	7	2, 950 2, 890	480 532	7¼	2, 910 2, 750	488 471	6½	2, 870 2, 950	464 464
Average		2, 695	466		2, 920	506		2, 830	478		2, 910	464
12	8½	2, 630 2, 770	482 457	7½	2, 780 2, 550	463 493	6¼	2, 440 2, 610	485 473	3¾	2, 870 2, 410	367 473
Average		2, 700	470		2, 665	478		2, 525	479		2, 640	420
16	6½	3, 110 3, 320	530 515	8	2, 450 2, 620	459 463	6½	2, 630 2, 790	423 513	5¼	2, 790 2, 840	502 497
Average		3, 215	522		2, 535	461		2, 710	468		2, 815	500
17	5¼	2, 960 3, 240	468 511	5¾	2, 440 2, 940	458 463	6	2, 470 2, 780	433 473	4¾	3, 050 3, 240	396 462
Average		3, 100	490		2, 690	460		2, 625	453		3, 145	429
20	9½	1, 730 1. 850	408 461	9	2, 170 2. 090	471 483	8	2, 460 2. 470	443 476	8½	2, 030 2. 230	467 449
Average		1, 790	434		2, 130	477		2, 465	460		2, 130	458
Grand average		2, 592	481		2, 545	478		2, 636	468		2, 710	455

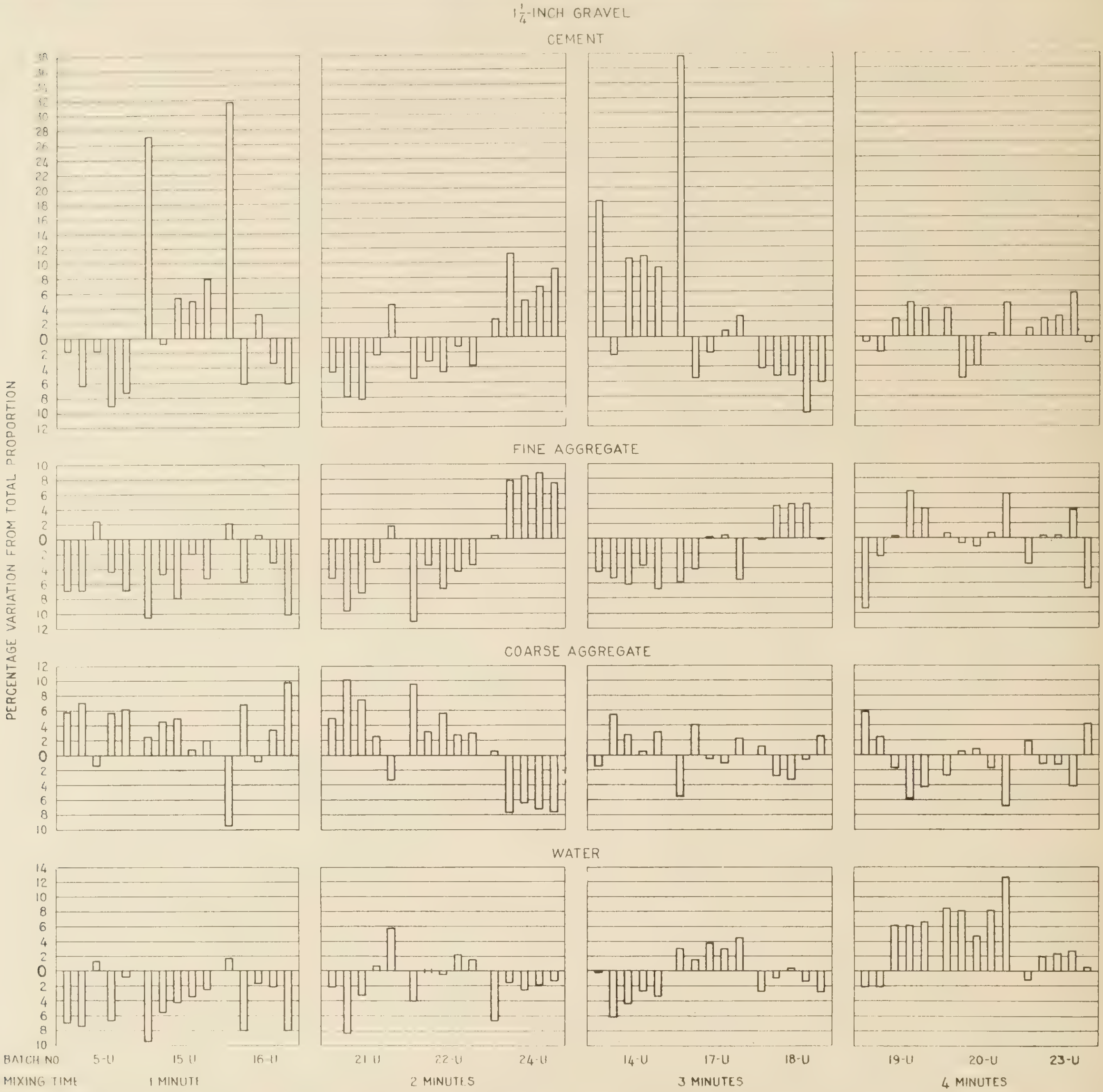


Figure 6.—Percentage Variations of Materials in Samples from Batch Proportions as Found in Tests Using 1¼-inch Gravel at Plant 2. Samples from Each Batch Arranged in Order A, B, C, D, and E.

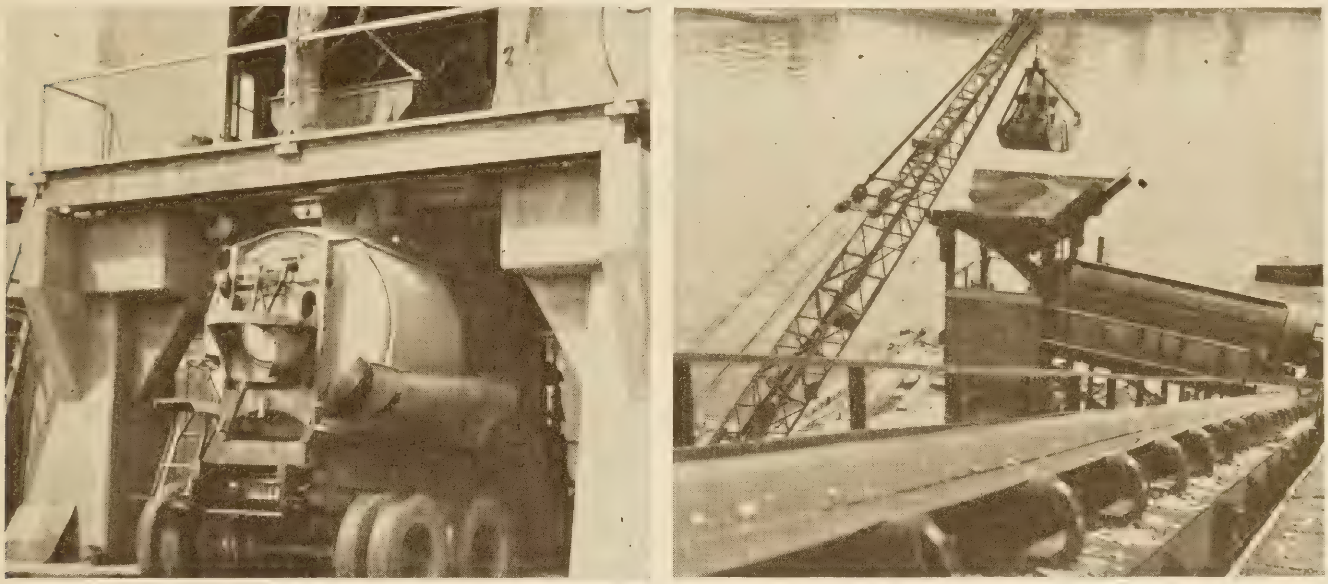
1-minute concrete. With the exception of the 2-minute concrete the average compressive strengths increase with the mixing time. The spread in strengths for these four sets of specimens is between 860 and 1,590 pounds.

The average flexural strength of the 4-minute concrete with ¾-inch aggregate is 5 pounds or 24 percent lower than the corresponding strength of the 1-minute concrete. These average flexural strengths decrease as the mixing time increases. The spread in strengths for these four sets of specimens is between 111 and 164 pounds.

The average flexural strength of the 4-minute concrete with 1¼-inch aggregate is 26 pounds or 5 percent lower than the corresponding strength of the 1-minute concrete. These average flexural strengths decrease as the mixing time increases. The spread in strengths for these four sets of specimens is between 107 and 157 pounds. These results indicate that the length of the mixing time had no appreciable effect on the strength of the concrete.

LESS GRINDING OF FINE AGGREGATE IN TESTS AT PLANT 2

The grinding of the coarse aggregate during the mixing action so that it passed the no. 100 sieve was negligible. The amount of fine aggregate passing the no. 100 sieve before entering the mixer and the amount of fine aggregate passing this sieve after the concrete had been mixed for each of the four mixing periods are shown below.



EQUIPMENT AT PLANT NO. 2.

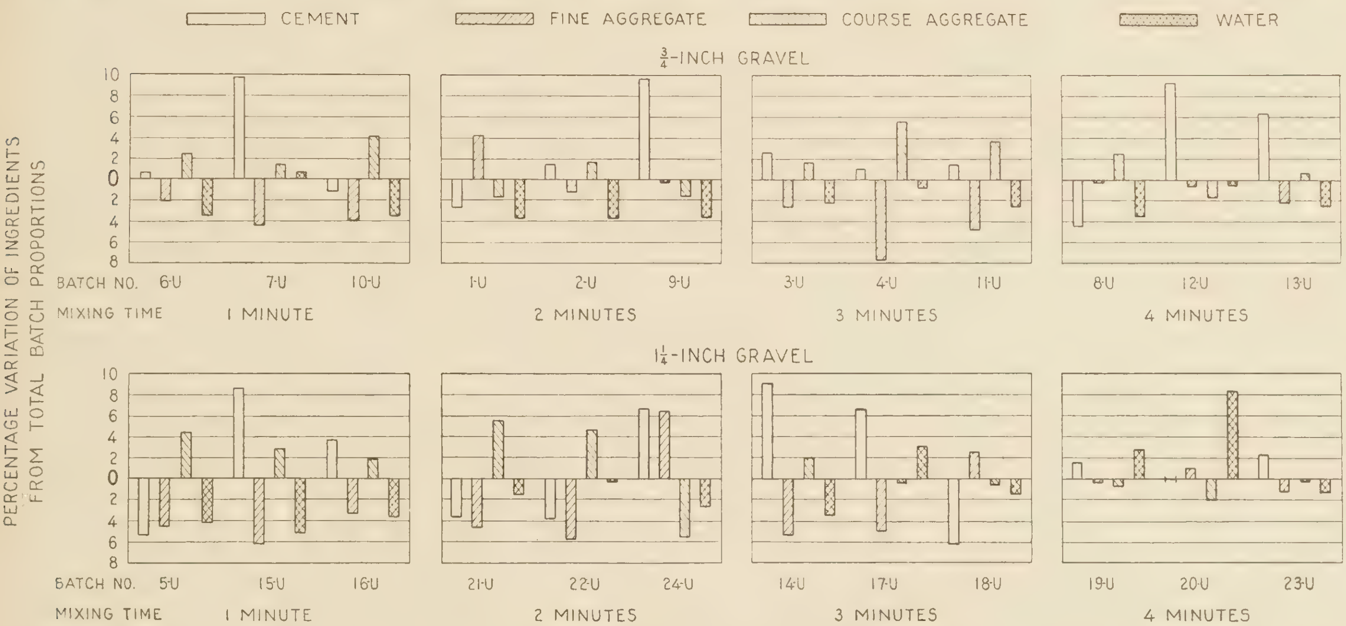


FIGURE 7.—PERCENTAGE VARIATIONS OF MATERIALS FROM BATCH PROPORTIONS COMPUTED FOR ASSUMED SAMPLES COMPOSED OF FIVE SAMPLES FROM EACH BATCH.

TABLE 9.—*Summary of results of strength tests at plant 2*

CONCRETE WITH ¾-INCH AGGREGATE

Mixing time (minutes)	Compressive strength				Flexural strength			
	Maximum individual	Minimum individual	Maximum spread	Average	Maximum individual	Minimum individual	Maximum spread	Average
	Pounds per square inch	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*
1	2, 510	1, 890	620	2, 210	546	382	164	477
2	2, 690	1, 940	750	2, 265	538	390	148	465
3	2, 570	2, 050	520	2, 315	528	402	126	464
4	2, 830	1, 790	1, 040	2, 407	496	385	111	453

CONCRETE WITH 1¼-INCH AGGREGATE

Mixing time (minutes)	Compressive strength				Flexural strength			
	Maximum individual	Minimum individual	Maximum spread	Average	Maximum individual	Minimum individual	Maximum spread	Average
	Pounds per square inch	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*	*Pounds per square inch*
1	3, 320	1, 730	1, 590	2, 592	559	408	151	481
2	2, 950	2, 090	860	2, 545	545	424	121	478
3	3, 090	2, 190	900	2, 636	530	423	107	468
4	3, 240	2, 030	1, 210	2, 710	524	367	157	455

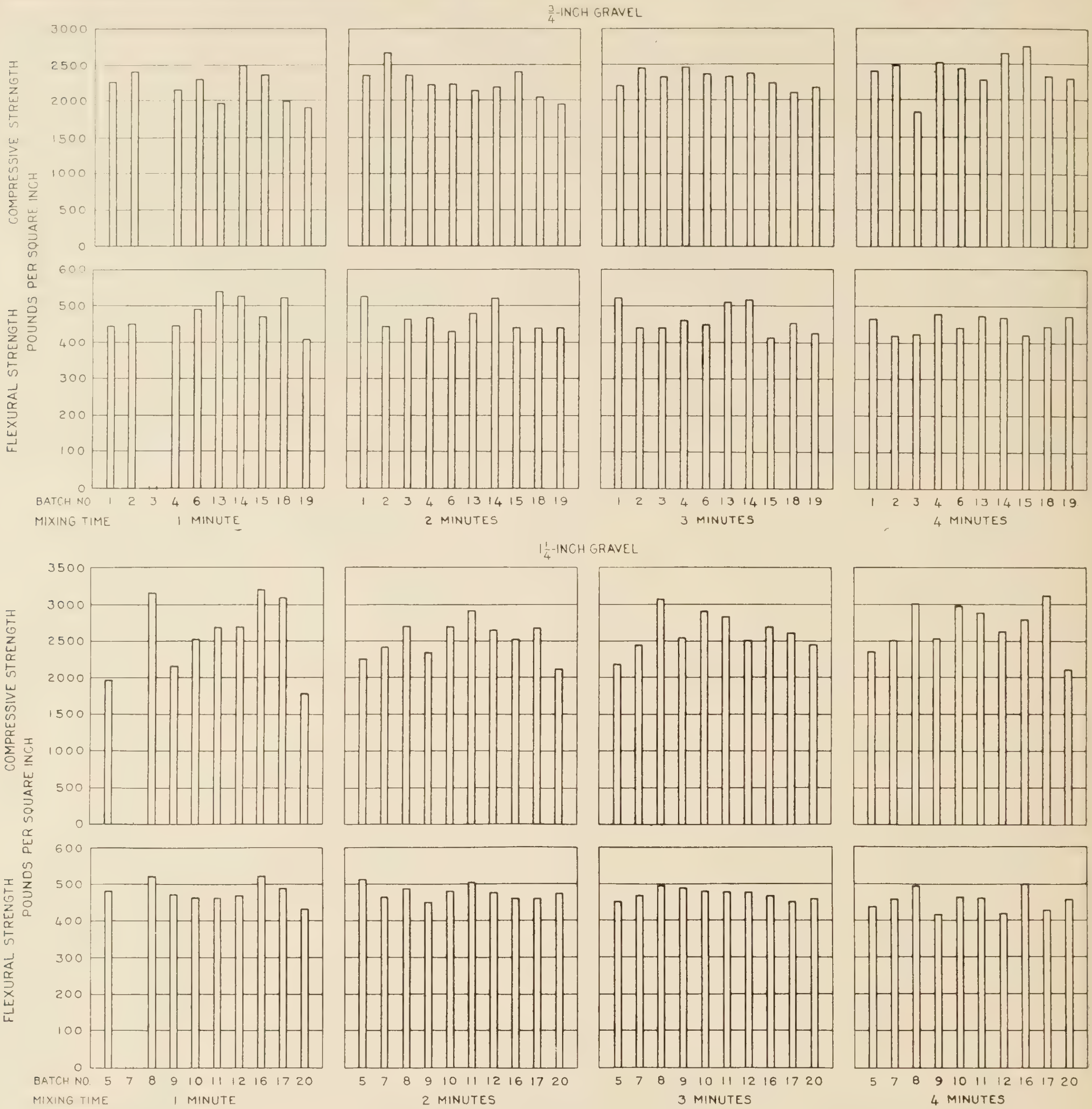


Figure 8.—Compressive and Flexural Strengths Averaged by Batches for All Batches Tested for Strength Plant 2.

Mixing time in minutes:	Percentage of aggregate passing no. 100 sieve
0	1.8
1	2.5
2	2.9
3	3.7
4	6.0

CONCLUSIONS

The following conclusions are based on the results of these tests:

1. Standard, revolving drum, batch mixers do not mix concrete so that the cement, aggregates, and water are uniformly distributed throughout all parts of the batch.
2. The degree of uniformity of distribution of the ingredients is not materially changed by changes in the mixing time from 1 to 4 minutes.
3. The length of the mixing time between 1 and 4 minutes appears to have little effect on the strength of concrete as mixed in standard, revolving drum, batch mixers.
4. Standard, revolving drum, batch mixers act as a ball mill in reducing the size of particles of the fine aggregate.
5. The amount of grinding of fine aggregate so that it passes the no. 100 sieve increases with the length of the mixing time.

FURTHER TESTS OF COTTON MATS FOR CURING CONCRETE

BY THE DIVISION OF TESTS, BUREAU OF PUBLIC ROADS

In the report on the studies of the use of cotton mats for curing concrete pavements, which was published in the July 1933 issue of PUBLIC ROADS, it was suggested that mats of the type described might be effective as a protection against freezing during sudden drops of air temperature such as occur overnight at certain seasons of the year.

During the past winter several sets of observations were made at the Arlington Experiment Farm which throw some light upon the effectiveness of cotton mats of various thicknesses when used for this purpose.

A number of small 6-inch concrete slabs were cast with their upper surfaces level with the surface of the ground. In the center of the upper surface of each slab a copper constantan thermocouple was embedded at a depth of one-fourth inch. One of these slabs was left uncovered while others were covered with cotton filled mats of the following weights:

Designation:	*Approximate weight of cotton filler in ounces per square yard*
A	10
B	30
C	60
D	90
E	110
F	170

COTTON MATS GIVE EFFECTIVE PROTECTION DURING SHORT FREEZING PERIODS

The mats were made of cotton fiber held in place between sheets of loosely woven covering cloth by stitching or tying. The mats designated as D, E, and F were the 3-, 6-, and 9-ply mats referred to in the previous report.

The slabs were 3 feet square and the covering mats were made 5 feet square in order that they might extend beyond the slab edges and thus avoid the possibility of a circulation of air between the mats and the concrete slabs.

In addition to the slabs covered with the cotton-filled mats, and the bare slab for comparative purposes, one slab was covered with a double thickness of dry burlap, one with 2 inches of dry earth, and one with 4 inches of dry loose straw. Apparatus was placed to determine the temperature of the subgrade 12 inches below the bottom of the bare slab.

The data obtained during three periods of observation at times when relatively large drops in temperature occurred are shown in figures 1 to 4, inclusive. The air temperature fell below 32° F. on only one of these occassions. Figures 1 to 3 show the temperature cycles of the air, the subgrade, the bare slab, the straw-covered slab, and the slabs covered with the lightest and heaviest weights of cotton-filled mats. Because of the close grouping of the temperatures of all of the slabs covered with the cotton-filled mats the data for the intermediate weights of mats have been omitted. It will be noted that the difference in temperature beneath the heaviest and the lightest mats at no time exceeded 2° F.

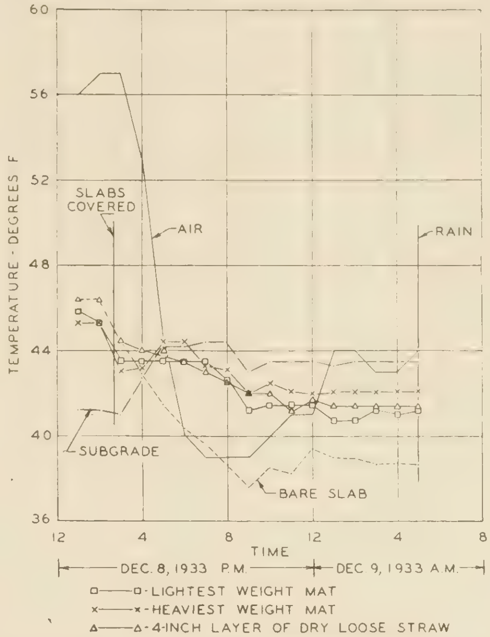


FIGURE 1.—VARIATIONS IN AIR TEMPERATURE AND CORRESPONDING TEMPERATURES OF SLABS WITH DIFFERENT PROTECTIVE COVERINGS.

The observations made on December 8 and 9, 1933, were terminated by rain which began at about 5 a. m., but on the other two occasions the observations covered a full 24-hour period.

Figure 4 shows a comparison between the temperature cycles of the slabs covered with the lightest weight of cotton-filled mat, 2 inches of dry earth and dry double burlap during the same period as was shown in figure 2, the data being separated for clarity of presentation.

A concrete pavement can acquire or lose heat in either of two directions. The lower surface is in intimate contact with the earth of the subgrade while the upper surface is ordinarily in direct contact with the air. The temperature of the subgrade undergoes annual and diurnal cycles of change similar to those of the air but of lesser magnitude. In the daily changes there is a considerable lag resulting from the low thermal conductivity of the pavement. The lag is evident in all of the data, the temperature of the subgrade rising to a maximum at about the time that the air temperature has fallen to its minimum value.

If a protective cover for a pavement slab is to be effective in preventing freezing of the concrete during a sudden drop in air temperature, two conditions must obtain: First, the subgrade must have a temperature sufficiently above the freezing point of the concrete to provide a flow of heat from the subgrade to the slab; and second, the protective cover on the pavement must provide sufficient insulation to insure that the heat will not be dissipated from the slab surface more rapidly than it is received from the subgrade. It is apparent that the absolute amount of insulation

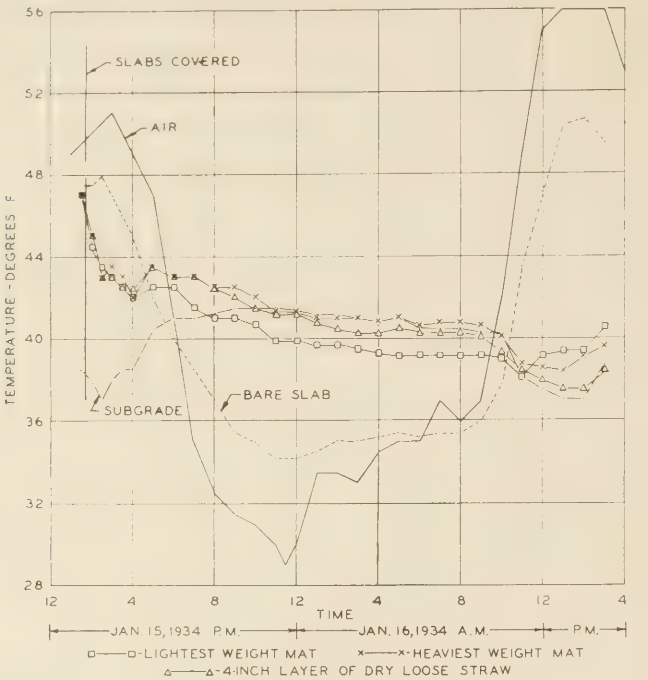


Figure 2.—Variations in Air Temperature and Corresponding Temperatures of Slabs with Different Protective Coverings.

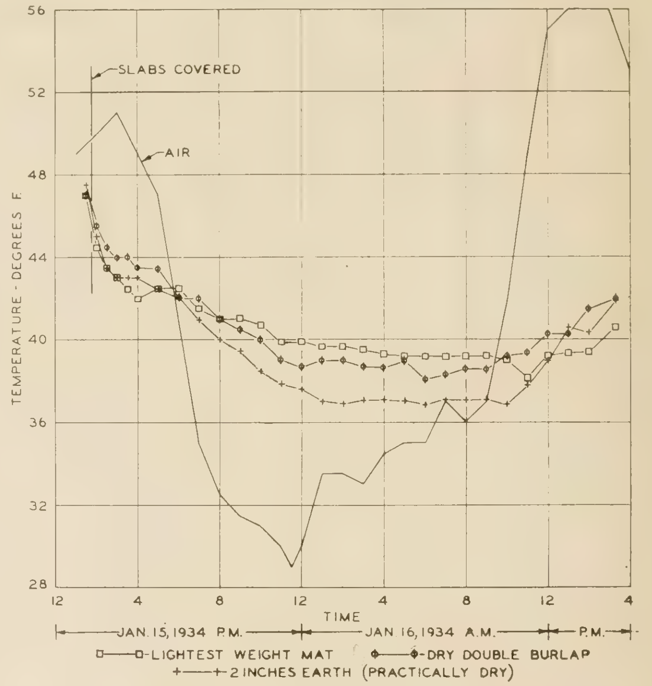


Figure 4.—Variations in Air Temperature and Corresponding Temperatures of Slabs with Different Protective Coverings.

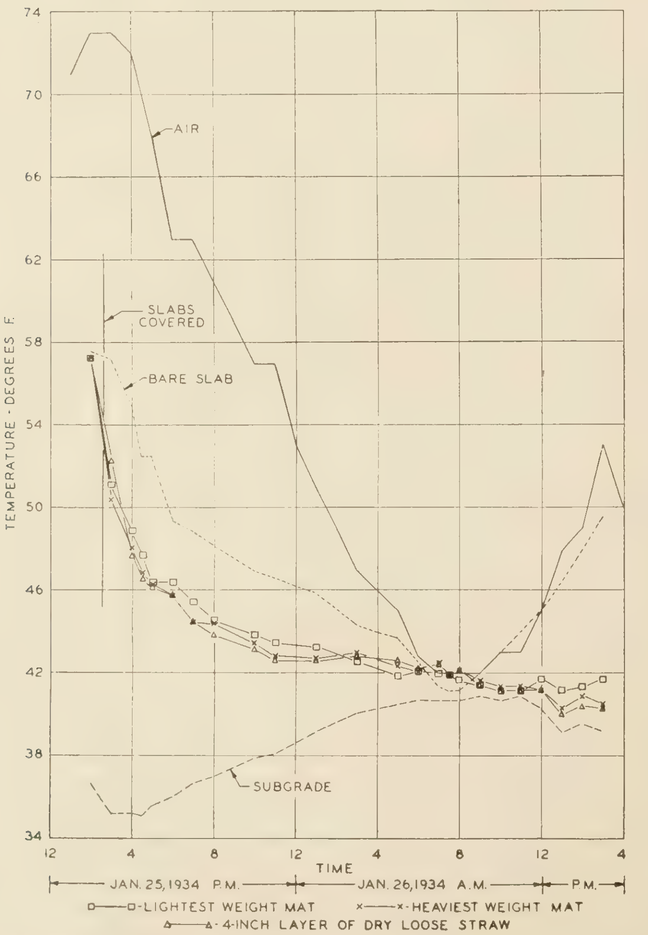


Figure 3.—Variations in Air Temperature and Corresponding Temperatures of Slabs with Different Protective Coverings.

required to accomplish this is not a constant but will depend upon the temperature differential existing between the two sides of the protective cover.

In pavement construction it is not the usual practice to place concrete on frozen ground, during freezing weather, or even when freezing temperatures are anticipated. It is to guard against damage due to an overnight drop in air temperature, from a level of possibly 40° or 50° F. to one of 20° or 25° F. that protective covers are most often needed. Ordinarily the temperature of the subgrade is considerably above freezing, the difference between the air and pavement temperatures is not large (from an insulation requirement standpoint at least) and the duration of the subfreezing air temperature is not protracted. For these reasons the requirements for insulation efficiency are not severe. These facts are rather obvious but it is well to bear them in mind when examining the data shown in the accompanying figures.

Probably the most striking indication of these data is that for overnight drops in temperature where a rise on the following day is to be expected, there is but little difference between the protection afforded by the lightest and heaviest of the cotton-filled mats. Both are apparently effective in holding the slab temperature near the temperature of the subgrade during the period of minimum air temperature. It is also indicated, as would be expected, that in case of a protracted period of subfreezing air temperatures neither mat would provide sufficient insulation to hold the temperature of the slab and of the subgrade above the freezing point.

It is interesting to note the similarity of the temperatures of the slabs covered with the cotton-filled mats with those of the slab covered with 4 inches of dry, loose, straw. Although the differences are small it will be noted that the straw cover is consistently more effective than the lightest weight mat and less effective than the heaviest mat.

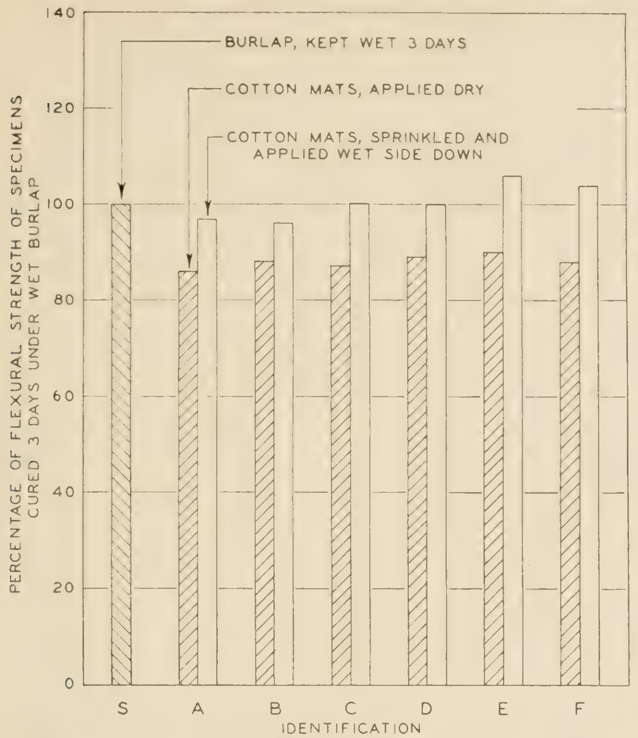


Figure 5.—Comparative Flexural Strengths of Mortar Specimens Cured under Burlap and Cotton Mats.

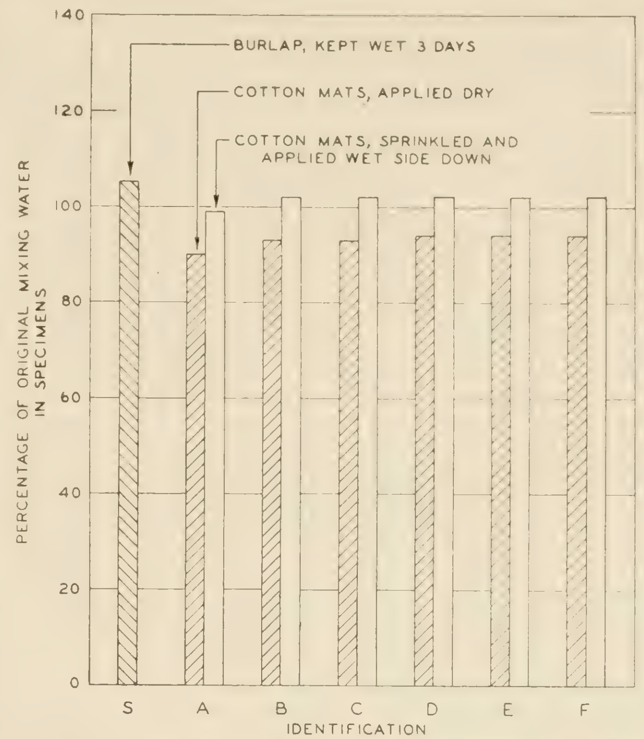


Figure 6.—Comparative Moisture Contents of Mortar Specimens after 3 Days Curing under Burlap and Cotton Mats.

Figure 4 shows data obtained on January 15 and 16, 1934, in addition to those shown in figure 2. These permit a comparison of the lightest weight cotton-filled mat, a covering of dry double burlap, and a 2-inch layer of earth which was practically dry. All of these coverings give some degree of protection, the lightest weight mat being the best of the three. It is apparent from figures 2 and 4 that 4 inches of dry loose straw is a better insulator than 2 inches of earth. The two sheets of dry burlap offer more protection than the earth and less than the cotton-filled mats. The burlap used was a good grade, rather heavy-weight material and was practically new. Being dry, there was a relatively large amount of entrapped air among the fibers. Had this air been replaced by moisture it is probable that the effectiveness of the burlap cover would have been greatly reduced. No data covering this point were obtained.

These few tests do not provide a basis for definite conclusions but it is indicated that, for an overnight drop of air temperature to below 32° F., a considerable amount of protection against damage from freezing can be afforded a concrete paving slab by covering with a cotton-filled mat of relatively light weight.

SPECIMENS TESTED FOR STRENGTH AND MOISTURE LOSS

In addition to the insulation tests, two series of tests were run to determine the flexural strength at 28 days of mortar specimens cured for 3 days under cotton mats of various thicknesses as compared to the strength of similar specimens cured for 3 days under a double thickness of burlap kept continuously wet. Measurements of the gain or loss in moisture of the specimens at the end of 3 days curing as compared to the original water content were also made. In one series the cotton mats were applied dry, while in the other they were thoroughly wet on one side and then applied with the wet side in contact with the specimen. Wetting was done by means of a spray applied to one side of the mat continuously for 10 minutes. The test procedure was identical with that employed in the tests reported last year and was briefly as follows:

The specimens were of 1 : 2 mortar, by weight, containing 14 percent water. They were cast in watertight molds, 11 inches in length, 6½ inches in width, and 2 inches in thickness. The burlap and cotton mats were applied about 2½ hours after molding. At the end of 3 days the mats were removed and the specimens allowed to cure in the air of the laboratory until the age of 26 days, after which they were immersed in water for 2 days and then tested for flexural strength.

For each series, three rounds of tests were run so that each result as shown in figures 5 and 6 is the average of three determinations, except in the case of the burlap cured specimens where the values shown represent the average of 6 specimens, 3 for each series.

DISCUSSION

The chief purpose of these tests was to compare the curing efficiency of the thinner mats with the comparatively heavy mats (3-ply and over) originally proposed for this purpose. Referring to figure 5 which shows the results of the strength tests, it will be observed that in all cases specimens cured with dry mats showed appreciably lower strengths at 28 days than those cured under the wet burlap. The average strength for all specimens cured under dry mats is roughly 88 percent of the strength of specimens cured by the standard method, which checks approximately the results previously obtained.

The reason for the lower strengths is, of course, the moisture loss suffered by the specimens during the 3-day curing period. These moisture losses, shown graphically in figure 6, average approximately 7 percent of the original water content. On the other hand, the specimens cured for 3 days under wet burlap showed an increase in moisture content of about 5 percent, indicating that water was taken up by the specimens during this period. It may be noted also that the very thin mat designated A, seemed somewhat less effective in retaining water than the others.

In the case of the mats which were thoroughly wet before application, the specimens developed an average strength at 28 days approximately equal to that of specimens cured by the standard method. The thinnest mats (A and B) resulted in slightly lower strengths, while in the case of the thickest mats (E and F) the strengths were slightly above the standard. The differences in strength, however, were not great and the apparent trend may be accidental.

The only specimens to show any moisture loss under the wet-mat curing were those covered by the thinnest mat designated A. In all other cases the specimens showed a gain in moisture content, averaging about 2 percent, or about 3 percent less than the standard burlap-cured specimens. Therefore, from the standpoint of the effect of moisture retention on strength, there is no reason to expect a higher strength for any of the specimens cured with wet mats than was shown by the burlap-cured specimens.

The differences in strength shown by the specimens cured with wet mats, with the possible exception of the strength of those cured with mat A, are not thought to be significant. In this case of mat A a very small water loss was recorded. It is probable that if the two thinnest mats, A and B, had been kept continuously wet during the 3-day curing period, strengths at least as high as the standard would have been obtained.

In any event, the differences are not great enough to affect the conclusion that, within the limits of these tests, substantially the same results are obtained with the various thicknesses of cotton mats as with the wet burlap, provided the mats are wet when applied. However, it should be remembered that these tests were conducted in the laboratory and not under field conditions. Had the mats been subjected to the direct rays of the sun it is quite possible that the thinnest mats would have permitted a higher moisture loss than was noted in the laboratory. Under these conditions the strengths would probably have been lower than was shown by the tests.

In view of this possibility, it is recommended that such mats be used only under the conditions specified for burlap; that is, kept continuously wet during the 3-day curing period.

With these limitations in mind, these tests substantiate the previously published conclusion to the effect that cotton mats of the thicknesses and weights shown, if wet once and applied with the wet side down, are as effective in curing as a double thickness of burlap kept wet continuously for 3 days and also that mats applied dry are less effective than either the wet mats or the burlap.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 1.—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF OCTOBER 31, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 3,947,753	$ 2,129,921	$ 3,217,035	$ 1,779,907		143.9	$ 3,632,056	$ 2,004,338	$ 35,889	245.6	$ 58,042	$ 234,036	31.1	$ 105,466	$ 1,859,996
Arizona	3,878,555	1,338,712	3,229,330	3,120,866		231.3	1,832,621	721,725	561,683	94.0	4,655	132,624	10.1	31,309	644,405
Arkansas	3,374,167	1,714,000	1,658,062	1,338,633		68.8	2,105,709	1,855,595		104.8	90,381		.8	89,558	1,714,000
California	7,912,928	3,966,103	6,415,717	4,764,610		223.9	4,866,088	3,142,764		92.9		840,249	12.0	5,554	3,125,854
Colorado	3,437,265	2,424,504	3,011,807	2,991,547		139.3	1,645,476	420,186	1,120,562	73.9		429,012	21.5	25,532	874,930
Connecticut	1,404,213	607,500	189,823	189,823		3.0	1,385,153	1,213,805		27.8	584	498,023	5.4		109,477
Delaware	892,544	461,697	534,663	532,569		12.9	778,119	348,977	413,964	15.8		38,568		10,997	9,166
Florida	2,519,010	1,330,672	2,593,605	1,898,376		87.4	671,195	533,266		29.3	58,425	147,474	5.1	28,945	1,183,198
Georgia	5,045,592	2,556,745	2,622,100	2,599,351		174.6	1,805,833	1,661,688		112.1	103,654		7.3	680,899	2,556,745
Idaho	2,166,858	1,131,910	1,667,250	1,602,139	$ 14,243	161.5	719,507	477,909	190,779	31.9	65,191	207,220	7.0	21,619	719,668
Illinois	4,468,247	3,060,041	1,016,493	1,015,828		23.8	3,132,392	3,040,483	66,025	30.9	411,937	203,180	7.5		2,790,835
Indiana	5,018,921	2,843,478	1,786,187	1,786,187		65.9	2,543,333	2,542,646		69.1	274,201		3.9	415,887	2,843,478
Iowa	5,027,830	2,217,361	4,090,435	3,916,401		219.9	2,122,544	1,083,300	859,845	137.9		797,980	53.5	28,129	559,536
Kansas	5,044,802	2,558,837	4,596,421	4,548,636		388.0	1,166,220	494,856	426,655	92.6	1,310	1,443,776	200.4		688,406
Kentucky	3,751,605	1,527,324	2,456,368	2,430,010		188.9	1,453,201	1,219,454		65.2	102,087	437,595	57.0	54	1,089,729
Louisiana	2,681,152	1,380,419	1,219,648	1,218,415		49.6	1,936,619	1,429,968		28.7	12,232	441,169	7.8	20,537	939,250
Maine	1,617,560	793,644	1,040,886	1,030,005		34.3	899,091	489,260	385,144	18.0		356,402	10.9	98,294	52,098
Maryland	1,782,263	289,610	527,930	518,281		10.5	771,257	664,671	106,586	16.0	514,436		8.5	84,874	183,023
Massachusetts	1,101,716	1,632,874	1,087,315	798,064		30.4	330,026	226,326		7.4				77,327	1,632,874
Michigan	6,113,389	3,226,284	2,257,950	2,257,950		103.0	4,203,300	3,806,675	347,625	181.4	40,000	649,975	21.6	8,764	2,228,684
Minnesota	4,561,011	2,642,244	4,033,889	3,832,083	143,462	713.3	1,940,107	718,154	1,205,053	154.8		521,649	74.8	10,775	772,080
Mississippi	3,489,337	2,301,148	2,042,971	1,087,665		111.7	3,446,251	1,895,439		178.4	261,144	645,313	57.2	245,090	1,655,835
Missouri	5,237,532	2,778,183	3,994,052	3,467,044		163.7	2,240,425	1,604,114	506,160	65.7	521	925,737	27.4	165,853	1,346,286
Montana	4,463,849	2,714,208	4,752,589	4,269,577		368.0	1,079,457	175,080	687,460	93.9		829,473	93.6	19,192	1,197,275
Nebraska	3,914,481	1,982,182	4,196,160	3,145,355		289.5	1,294,851	768,306	132,308	87.2		834,754	45.4	820	1,015,120
Nevada	2,909,387	1,350,356	2,315,717	2,272,390		225.8	700,064	570,608	129,457	48.0		352,099	30.6	66,389	868,800
New Hampshire	725,739	484,731	656,954	646,720		10.8	165,251	79,019	73,827	2.3		70,880	1.7		340,024
New Jersey	3,099,371	951,379	986,187	978,648		19.5	2,180,942	2,032,931		27.6				87,792	951,379
New Mexico	2,846,648	1,470,850	2,874,956	2,731,026		274.1	604,060	49,538	554,522	63.7	18,762	593,666	38.9	47,322	322,662
New York	10,465,672	2,872,521	5,634,973	4,850,659		128.4	10,200,979	5,463,772	2,036,400	184.3	83,867	650,080	28.6	67,374	186,041
North Carolina	4,761,147	2,420,471	3,242,435	2,685,983		386.8	1,815,131	1,364,584	223,033	252.4	282,108	365,910	56.8	428,472	1,831,528
North Dakota	2,902,224	1,469,483	2,729,628	2,430,566		888.7	485,817	333,732		99.9	56,509	355,412	174.3	81,417	1,114,071
Ohio	7,277,758	3,539,255	6,281,274	5,997,319		153.8	1,334,350	1,203,403		38.1		1,091,120	24.2	77,036	2,448,135
Oklahoma	4,608,399	2,342,590	3,098,126	3,061,068		228.9	1,271,484	1,265,248		75.0	181,001	451,592	34.5	101,082	1,890,998
Oregon	3,053,448	1,548,906	3,259,987	2,967,249		182.2	724,450	48,707	617,999	37.2	10,790	364,356	10.9	26,701	566,551
Pennsylvania	6,691,194	4,554,082	3,475,594	3,469,559		91.9	4,291,169	3,126,928	817,284	56.0	11,906	1,877,477	44.1	82,801	1,859,321
Rhode Island	979,367	464,572	996,030	933,162		20.5					46,204	215,718	8.1		248,854
South Carolina	2,729,583	1,385,477	1,077,089	1,074,214		98.8	1,705,118	1,614,304	74,381	143.0		42,697	4.3	41,065	1,268,399
South Dakota	3,005,739	1,523,821	2,240,238	1,996,500		374.3	1,149,922	912,894		167.0	85,244		9.5	11,101	1,523,821
Tennessee	4,246,309	2,105,453	3,042,570	2,537,098		123.4	1,611,515	1,436,972	71,689	59.7	246,035	439,835	29.0	26,205	1,593,930
Texas	11,588,643	6,145,627	8,910,718	8,518,665		810.1	2,903,190	2,805,414		202.1	223,868	527,519	50.2	40,695	5,618,108
Utah	2,374,205	1,066,345	2,282,452	2,180,699	30,000	199.2	954,534	156,147	649,880	66.6		28,000	1.4	37,358	358,466
Vermont	928,184	466,042	681,514	649,355		30.5	325,976	268,159	57,000	19.2	10,670	241,637	11.9		167,404
Virginia	3,708,379	1,882,693	2,988,297	2,877,915		133.3	647,796	537,698		10.1	27,139	272,506	15.8	265,628	1,610,188
Washington	3,057,934	1,553,206	2,140,029	2,131,477		83.5	1,255,591	883,426	372,165	31.7	15,918	258,273	6.7	27,112	922,768
West Virginia	2,013,405	1,140,167	1,268,556	1,262,556		40.5	1,224,619	724,650	486,506	50.6	9,320	208,412	7.4	16,879	445,249
Wisconsin	4,615,429	2,223,827	3,962,419	3,846,773	500	183.0	993,100	755,783	202,000	58.3		67,528	5.8	12,873	1,953,798
Wyoming	2,250,663	1,143,856	2,272,370	1,979,042	67,583	453.5	934,310	249,276	655,311	115.8		96,327	17.1	22,346	324,635
District of Columbia															
Hawaii	1,683,956	598,778	196,115	144,003		10.4	1;824,472	1,471,913		28.5	66,000		.7	2,040	598,778
TOTALS	135,375,363	94,314,089	130,852,914	118,361,968	255,788	9,159.0	87,304,671	59,894,091	14,067,192	3,912.4	3,374,141	19,185,253	1,382.3	3,745,163	60,805,856

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 3.—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF OCTOBER 31, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,032,452	$ 1,064,960	$ 141,660	$ 141,660		11.2	$ 1,645,596	$ 1,645,596		117.5	$ 233,719		13.3	$ 11,478	$ 1,064,960
Arizona	525,423	998,032	532,326	520,199		42.3	43,151		$ 38,779	4.2		$ 72,129	9.1	5,223	887,124
Arkansas	1,484,634	857,024	386,277	386,023		85.7	834,792	834,540		63.1	126,995		11.9	137,076	857,024
California	3,480,440	1,983,051	2,633,976	2,207,363		121.0	1,305,103	1,102,369		57.6	170,708	135,400	5.7		1,847,651
Colorado	1,718,632	871,502	1,534,805	1,499,932		152.7	826,136	190,000	219,868	148.5		84,686	6.0	28,700	566,948
Connecticut	659,120	420,868					664,916	659,120		14.5					420,868
Delaware	443,864	230,849	20,825	20,825			359,115	263,305	95,810	35.3	164,733	94,702	24.4		40,337
Florida	1,302,816	665,335	1,099,164	1,096,571		67.0	181,681	181,681		7.8		307,694	11.0	24,563	357,641
Georgia	2,320,973	1,278,373	758,544	758,544		66.1	717,591	717,591		59.0	411,249		21.4	433,589	1,278,373
Idaho	1,121,562	824,450	975,778	922,800		124.8	386,797	198,762	169,218	42.4		256,128	25.6		399,104
Illinois	5,410,040	3,345,525	1,288,914	1,287,340		89.4	4,088,891	3,981,326	107,565	235.9	126,849	1,215,599	66.7	14,525	2,022,362
Indiana	602,271	209,900	123,526	123,526		7.1	475,245	475,245		69.7	3,500				209,900
Iowa	2,413,358	1,590,000	1,185,309	1,137,750		158.8	1,477,943	1,193,850	115,900	199.9	38,200	615,900	185.0	43,558	858,200
Kansas	2,522,401	1,279,419	1,139,988	1,139,628		109.2	1,423,935	1,382,773	41,162	80.0		857,545	94.2		380,711
Kentucky	1,837,926	1,336,409	1,447,143	1,427,762		176.8	408,547	407,162		38.9		600,839	66.1	3,002	735,571
Louisiana	1,398,862	838,953	392,358	392,078		21.0	819,553	819,553		28.1	62,079		10.3	125,152	838,953
Maine	842,479	427,897	913,935	829,471		78.8	380,666	5,000	375,666	34.2		14,254	.8	8,008	37,976
Maryland	891,132	1,067,934	547,146	547,146		43.1	413,472	310,953	88,593	26.1	8,541	208,838	9.4	24,492	770,503
Massachusetts	488,185	870,000	367,128	367,128		11.5	102,614	102,614		3.7				18,443	870,000
Michigan	3,184,057	1,613,142	1,145,700	1,145,700		83.9	2,075,630	2,005,730	55,000	143.9		77,900		32,627	1,480,242
Minnesota	2,376,415	1,361,813	1,937,784	1,925,939		195.5	651,948	406,751	142,797	48.0	5,000	281,448	22.8	38,725	937,568
Mississippi	1,744,669	354,022					1,308,456	1,308,456		142.3	262,337		23.8	173,876	354,023
Missouri	2,923,273	1,852,122	2,372,385	2,333,795		466.4	608,877	485,548	123,330	102.0	31,337	739,457	238.3	72,594	989,335
Montana	1,859,937	942,434	1,862,628	1,852,179		226.1						196,412	12.8	7,758	746,022
Nebraska	1,957,240	991,091	1,133,084	1,131,917		172.8	1,197,598	774,004	423,344	139.4		130,372	114.9	51,320	437,374
Nevada	1,136,479	852,000	942,370	941,736		96.7	335,684	141,930	123,385	38.3				52,813	728,615
New Hampshire	477,460	242,365	361,321	320,333		18.5	199,796	156,630	43,166	9.2		46,396	2.4	497	152,803
New Jersey	56,550	460,000	56,550	56,550		.5									460,000
New Mexico	1,272,129	735,425	1,040,951	1,040,951		187.6	205,164	205,164		32.5		78,376	18.8	26,014	657,049
New York	3,608,768	4,252,400	1,664,926	1,554,851	$ 4,200	42.6	4,551,950	2,041,475	1,508,200	126.6		540,000	39.0	12,442	2,200,000
North Carolina	2,380,573	1,210,235	1,604,153	1,603,375		149.7	520,199	485,672	34,527	80.2	221,132	250,507	33.2	70,393	925,201
North Dakota	1,451,112	734,742	476,386	476,386		123.8	496,262	496,262		192.0	156,213		59.3	322,251	734,742
Ohio	3,871,148	1,966,253	3,210,759	2,989,855		275.8	956,710	825,793	39,400	34.9	55,500	16,400	2.0		1,910,453
Oklahoma	2,304,199	1,171,295	775,830	772,276		136.0	1,550,848	1,479,905		135.1	36,825		6.5	15,192	1,171,295
Oregon	1,526,724	774,454	1,309,653	1,140,753		98.0	409,651	376,968	13,322	11.8		419,376	35.1	9,004	341,756
Pennsylvania	7,344,822	2,639,003	4,486,689	4,455,145		395.5	3,637,057	2,884,052	697,795	308.5	5,625	754,808	24.9		1,186,400
Rhode Island	439,716	295,000	311,329	311,329		26.2	101,136	101,136		7.0				27,251	295,000
South Carolina	1,364,791	692,739	639,106	639,106		68.4	597,275	597,275		76.3	54,249	66,601	9.0	74,161	626,137
South Dakota	1,502,870	761,911	972,551	972,551		278.2	424,628	424,628		115.2	105,691		54.2		761,911
Tennessee	2,123,155	1,075,748	1,093,686	1,074,462		95.7	887,896	887,896		49.7	95,909	241,040	16.5	64,888	834,708
Texas	6,012,518	3,072,813	4,848,090	4,396,419		655.7	1,537,498	1,503,599		111.0	112,500		.3		3,072,813
Utah	1,048,677	533,173	930,376	849,709	18,000	146.6	397,202	187,945	158,815	71.5				11,022	356,358
Vermont	438,880	241,354	241,226	228,439		16.9	293,597	210,441	48,768	22.8		114,822	7.3		77,765
Virginia	1,699,920	941,347	1,183,454	1,140,929		171.9	522,733	493,980		33.4	11,450	88,960	11.4	53,561	852,387
Washington	1,080,673	776,603	798,173	780,915		53.6	299,031	299,031		14.1		34,467	2.0	727	742,136
West Virginia	1,118,559	570,083	254,836	247,758		9.3	752,311	727,177		44.6	84,518		3.3	59,107	570,083
Wisconsin	2,425,385	1,482,551	1,967,961	1,844,514		144.2	647,271	482,656	72,857	29.7	94,317	161,449	9.2	3,898	1,248,246
Wyoming	1,125,332	571,928	1,093,342	1,072,650		147.5	31,654	15,200	15,352	4.9		89,303	8.1	37,482	467,273
District of Columbia	950,234	730,382	645,466	645,466		5.6	478,389	286,117	192,272	4.6		46,263	.2	18,652	491,846
Hawaii	187,106	351,000					177,718	177,718		4.9				9,388	351,000
TOTALS	92,494,941	54,409,909	54,849,567	52,751,734	22,200	5,855.7	42,409,913	34,940,579	4,944,891	3,400.8	2,679,176	8,838,071	1,316.2	2,123,452	40,604,747

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 2.—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF OCTOBER 31, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,389,928	$ 1,064,961	$ 690,033	$ 690,033		15.8	$ 1,431,678	$ 1,431,678		45.8	$ 85,150		1.7	$ 183,066	$ 1,064,961
Arizona	807,982	305,191	514,898	514,133		12.6	113,806	105,318	$ 6,592	.6	134,051	$ 30,635	1.6	54,480	267,963
Arkansas	1,889,534	857,025	1,014,458	927,912		27.3	875,248	846,420		16.4	115,202		1.4		857,025
California	4,213,986	1,983,052	3,003,723	2,652,781		35.5	1,900,735	1,547,993		17.2		222,000	1.8	13,213	1,761,052
Colorado	1,718,633	190,000	1,743,175	1,693,217		34.9	46,849	23,394	23,455	2.2				2,021	166,546
Connecticut	802,407	426,500	806,490	802,407		10.2						162,813	1.2		263,688
Delaware	477,680	230,849	301,059	292,778		2.5	229,083	174,903	54,180	5.6	4,919			5,082	176,669
Florida	1,410,008	665,336	910,277	673,146		10.3	722,468	721,625		7.9	12,073	26,603	.6	3,163	638,733
Georgia	2,724,620	1,278,373	888,093	887,087		38.9	890,472	890,472		25.5	280,978		3.0	666,083	1,278,373
Idaho	1,197,829	321,126	600,374	584,233	$ 2,643	17.0	561,927	540,850	7,000	3.0		40,000	.1	72,746	271,483
Illinois	7,692,483	2,515,835	4,194,238	4,176,496		50.2	3,221,345	3,221,345		20.6	180,009	225,746	2.6	114,632	2,290,089
Indiana	4,416,651	2,035,585	1,339,333	1,335,683		34.5	2,516,177	2,516,177		34.9	240,621		3.4	324,170	2,035,585
Iowa	2,614,472	1,311,000	1,557,845	1,494,464		45.0	914,238	858,408	3,580	9.8	261,600	156,270	10.9		1,151,150
Kansas	2,522,401	1,279,419	2,094,852	2,086,483		35.4	580,706	435,745	107	1.9	173	287,926	7.4		991,386
Kentucky	1,927,828	954,578	709,188	693,874		17.1	665,972	664,862		12.7	440,404	255,119	6.8	128,688	699,459
Louisiana	1,748,577	744,560	549,063	549,063		12.9	907,934	881,341		13.3	93,228	21,233	2.6	224,945	723,327
Maine	909,878	490,045	575,933	573,728		12.3	266,996	266,100		4.5				70,050	490,045
Maryland	891,132	452,514	235,592	231,442		2.1	1,064,342	250,821		2.5				408,869	452,515
Massachusetts	5,007,199	847,600	946,315	904,770		6.5	4,007,709	3,982,733		10.1				119,696	847,600
Michigan	3,438,781	1,613,142	1,357,045	1,354,895		19.3	2,375,150	2,076,400	286,250	25.3	6,461	459,950	3.2	1,025	866,942
Minnesota	3,719,143	1,421,494	2,210,089	2,181,230	1,522	88.2	1,246,020	988,069	257,951	20.3		60,852	8.3	549,844	1,101,169
Mississippi	1,744,669	885,057	421,386	408,926		14.8	670,530	670,530		24.0	260,301	107,937	9.0	404,911	777,119
Missouri	4,019,501	1,543,435	1,631,272	1,509,151		44.5	2,228,169	1,798,654	54,043	13.5	316,213	430,463	5.9	395,483	1,058,929
Montana	1,115,962	113,092	1,053,303	1,053,303		31.8	66,377	42,764		2.6	15,713	27,272	5.2	4,183	85,820
Nebraska	1,957,240	991,091	898,503	890,726		25.7	1,068,416	1,019,425	48,991	8.1		238,181	5.2	47,089	703,919
Nevada	500,051	100,000	309,533	309,533		6.2	195,019	172,014		2.6		1,000		18,504	99,000
New Hampshire	706,640	242,366	700,621	685,137		15.6	156,384		156,384	3.0				21,503	85,982
New Jersey	3,190,118	1,809,500	868,718	868,406		6.3	2,292,475	2,238,342		16.5				83,370	1,809,500
New Mexico	1,674,158	735,425	1,110,242	1,110,242		28.9	594,431	411,223	183,208	10.8	51,015		.5	101,677	552,217
New York	8,255,661	4,203,000	3,356,953	3,318,387		33.3	5,883,204	4,929,556	475,400	34.7		915,900	8.2	7,718	2,811,700
North Carolina	2,380,573	1,210,235	1,730,973	1,728,525		63.5	347,356	331,048	15,730	14.6	206,099	52,048	4.7	114,901	1,142,457
North Dakota	1,451,112	734,742	879,100	878,338		36.2	274,409	274,409		12.9	284,200	743	10.9	14,166	733,999
Ohio	4,335,686	2,359,504	3,829,413	3,395,517		49.8	1,018,270	910,697		9.6		190,000	2.2	29,472	2,169,504
Oklahoma	2,304,200	1,171,295	1,526,479	1,514,844		32.9	491,778	490,998		10.1	272,583		4.1	25,775	1,171,295
Oregon	1,526,724	774,454	1,113,828	1,097,661		22.6	377,473	377,473		5.2	30,841		.6	20,749	774,454
Pennsylvania	4,854,988	2,397,703	2,806,056	2,741,310	1,500	48.3	2,005,155	1,878,560	100,855	13.7	163,752	441,970	10.7	71,366	1,853,377
Rhode Island	579,625	255,000	393,937	393,038		6.4	148,206	148,206		1.0				38,381	255,000
South Carolina	1,364,791	692,738	485,674	485,269		15.2	681,858	681,858		26.3	52,573	4,464	1.5	145,092	688,275
South Dakota	1,502,870	761,911	1,036,479	1,036,478		34.9	122,113	122,113		4.9	71,580		1.8	272,699	761,911
Tennessee	2,123,155	1,121,790	1,289,525	1,287,502		19.6	560,116	560,116		5.4	254,550	71,313	3.6	20,988	1,050,476
Texas	6,642,863	3,072,813	3,181,706	3,088,727		90.0	2,351,258	2,342,481		24.7	908,416	21,024	5.3	303,240	3,051,790
Utah	771,826	533,173	670,205	644,383		16.6	122,508	8,700	99,829	5.1		60,000	2.6	118,743	373,343
Vermont	500,509	240,611	414,449	393,500		11.6	111,734	107,009		2.9					240,611
Virginia	2,008,458	941,347	1,222,156	1,194,634		23.9	649,868	465,296		1.1	57,612	155,688	3.4	290,916	785,658
Washington	1,977,260	776,603	1,584,811	1,567,840		29.9	465,741	370,864	94,877	5.5		92,772	2.4	38,557	588,953
West Virginia	1,342,270	570,085	508,131	508,131		10.8	842,261	792,662	25,253	10.5				41,476	544,832
Wisconsin	2,684,067	1,235,459	2,184,460	2,148,738		46.3	525,988	450,505	66,146	8.4		13,743	1.5	84,823	1,155,571
Wyoming	1,125,332	571,928	768,420	767,913		19.6	361,845	357,419	3,845	5.0		3,021	.3		565,062
District of Columbia	968,235	243,460	596,475	596,475		3.9	587,074	357,994	229,080	2.7				13,765	14,381
Hawaii															
TOTALS	116,129,696	51,276,002	62,814,881	60,922,489	5,665	1,317.6	49,738,871	44,735,570	2,192,756	565.5	4,800,317	4,776,686	146.2	5,671,320	44,300,895

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

SUMMARY OF CLASSES 1, 2, AND 3.

AS OF OCTOBER 31, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,259,842	$ 4,048,727	$ 2,611,600		170.9	$ 6,709,330	$ 5,081,612	$ 35,889	408.9	$ 376,911	$ 234,036	46.2	$ 300,010	$ 3,989,917
Arizona	5,211,960	2,641,935	4,276,554	4,155,198		286.1	1,989,578	827,043	607,055	98.8	138,706	235,389	20.8	91,012	1,799,492
Arkansas	6,748,335	3,428,049	3,058,797	2,652,568		181.8	3,815,749	3,536,556		184.4	332,577		14.1	226,634	3,428,049
California	15,607,354	7,932,206	12,053,416	9,624,753		380.4	8,071,927	5,793,125		167.7	170,708	1,197,649	19.5	18,767	6,734,557
Colorado	6,874,530	3,486,006	6,289,787	6,184,696		326.8	2,518,460	633,580	1,363,884	234.6		513,698	27.5	56,253	1,608,424
Connecticut	2,865,740	1,454,868	996,313	992,230		13.2	2,050,069	1,872,925		42.3	584	660,835	6.6		794,033
Delaware	1,819,088	923,395	856,547	846,172		15.4	1,366,316	787,185	563,953	56.6	169,652	133,270	24.4	16,079	226,172
Florida	5,231,834	2,661,343	4,603,047	3,668,093		164.6	1,575,345	1,436,572		45.0	70,498	481,771	16.7	56,671	2,179,572
Georgia	10,091,185	5,113,491	4,268,736	4,244,982		279.7	3,413,896	3,269,752		196.6	795,881		31.8	1,780,571	5,113,491
Idaho	4,486,249	2,277,486	3,243,402	3,109,172	$ 16,886	303.2	1,668,231	1,217,522	366,997	77.3	65,191	503,348	32.7	94,365	1,390,255
Illinois	17,570,770	8,921,401	6,499,645	6,479,664		163.4	10,442,628	10,243,154	173,590	287.4	718,795	1,644,525	76.8	129,157	7,103,286
Indiana	10,037,843	5,088,963	3,249,045	3,245,396		107.4	5,534,755	5,534,067		173.7	518,322		7.3	740,057	5,088,963
Iowa	10,055,660	5,118,361	6,833,589	6,548,615		423.7	4,514,725	3,135,558	979,325	347.6	299,800	1,570,150	249.4	71,687	2,568,886
Kansas	10,089,604	5,117,675	7,831,260	7,774,748		532.6	3,170,861	2,313,373	467,925	174.5	1,484	2,589,247	301.9		2,060,503
Kentucky	7,517,359	3,818,311	4,612,699	4,551,647		382.8	2,527,719	2,291,478		116.8	542,491	1,293,552	129.9	131,744	2,524,759
Louisiana	5,828,591	2,963,932	2,161,069	2,159,556		83.5	3,664,107	3,130,862		70.1	167,539	462,402	20.6	370,634	2,501,530
Maine	3,369,917	1,711,586	2,530,754	2,433,205		125.4	1,546,754	760,360	760,811	56.7		370,656	11.7	176,352	580,119
Maryland	3,564,527	1,810,058	1,310,668	1,296,869		55.7	2,249,072	1,226,445	195,179	44.6	522,977	208,838	17.9	518,235	1,406,041
Massachusetts	6,597,100	3,350,474	2,400,758	2,069,962		48.4	4,440,348	4,311,672		21.2				215,466	3,350,474
Michigan	12,736,227	6,452,568	4,760,695	4,758,545		206.3	8,654,080	7,888,805	688,875	350.6	46,461	1,187,825	24.8	42,416	4,575,868
Minnesota	10,656,569	5,425,551	8,181,763	7,939,252	144,984	996.9	3,838,075	2,112,973	1,605,802	223.1	5,000	863,948	105.9	599,344	2,810,817
Mississippi	6,978,675	3,540,227	2,464,357	1,496,591		126.5	5,425,237	3,874,425		344.8	783,782	753,250	90.0	823,877	2,786,977
Missouri	12,180,306	6,173,740	7,997,710	7,309,990		674.6	5,077,471	3,888,316	683,533	181.1	348,070	2,095,657	271.6	633,930	3,394,550
Montana	7,439,748	3,769,734	7,668,520	7,175,059		625.8	1,145,835	217,843	687,460	96.5	15,713	1,053,157	111.5	31,133	2,029,117
Nebraska	7,828,961	3,964,364	6,227,747	5,167,998		488.0	3,560,865	2,561,734	604,644	234.7		1,203,307	165.5	99,229	2,156,413
Nevada	4,545,917	2,302,356	3,567,621	3,523,659		328.7	1,230,767	884,553	252,841	88.9		353,099	30.6	137,706	1,696,415
New Hampshire	1,909,839	969,462	1,718,896	1,652,189		44.9	521,432	235,650	273,377	14.6		117,276	4.1	22,000	578,809
New Jersey	6,346,039	3,220,879	1,911,455	1,903,604		26.4	4,473,417	4,271,273		44.0				171,162	3,220,879
New Mexico	5,792,935	2,941,700	5,026,149	4,882,220		490.5	1,403,655	665,925	737,729	106.9	69,777	672,042	58.3	175,013	1,531,928
New York	22,330,101	11,327,921	10,656,853	9,723,897	4,200	204.3	20,636,132	12,434,803	4,020,000	345.6	83,867	2,105,980	75.7	87,534	5,197,741
North Carolina	9,522,293	4,840,941	6,577,560	6,017,883		600.0	2,682,686	2,181,304	273,290	347.3	709,340	668,465	94.7	613,766	3,899,186
North Dakota	5,804,448	2,938,967	4,085,114	3,785,289		1,048.7	1,256,487	1,104,402		304.8	496,922	356,155	244.5	417,834	2,582,812
Ohio	15,484,592	7,865,012	13,321,447	12,382,691		479.4	3,309,330	2,939,893	39,400	82.6	55,500	1,297,520	28.4	106,508	6,528,092
Oklahoma	9,216,798	4,685,180	5,400,435	5,348,188		397.8	3,314,109	3,236,152		220.1	490,409	451,592	45.2	142,049	4,233,588
Oregon	6,106,896	3,097,814	5,683,467	5,205,663		302.9	1,511,574	803,148	631,321	54.1	41,631	783,732	46.7	56,454	1,682,761
Pennsylvania	18,891,004	9,590,788	10,768,339	10,666,014	1,500	535.7	9,933,381	7,889,540	1,615,934	378.2	181,284	3,074,256	79.6	154,167	4,899,098
Rhode Island	1,998,708	1,014,572	1,701,296	1,637,530		53.2	249,342	249,342		7.9	46,205	215,718	8.1	65,632	798,854
South Carolina	5,459,165	2,770,954	2,201,868	2,198,588		182.4	2,984,251	2,893,436	74,381	245.6	106,823	113,762	14.9	260,318	2,582,811
South Dakota	6,011,479	3,047,643	4,249,267	4,005,529		687.4	1,696,663	1,459,635		287.2	262,515		65.6	283,800	3,047,643
Tennessee	8,492,619	4,302,991	5,425,782	4,899,061		238.8	3,059,527	2,884,984	71,689	114.8	596,493	752,188	49.1	112,081	3,479,114
Texas	24,244,024	12,291,253	16,940,514	16,003,811		1,555.8	6,791,946	6,651,494		337.8	1,244,784	548,543	55.8	343,935	11,742,711
Utah	4,194,708	2,132,691	3,883,033	3,674,792	48,000	362.4	1,474,244	352,793	908,524	163.3		88,000	3.9	167,123	1,088,167
Vermont	1,867,573	948,007	1,337,190	1,271,294		59.1	731,307	585,609	105,768	44.9	10,670	356,459	19.2		485,780
Virginia	7,416,757	3,765,387	5,393,907	5,213,477		329.1	1,820,397	1,496,975		44.7	96,200	517,154	30.6	610,105	3,248,233
Washington	6,115,867	3,106,412	4,523,013	4,480,232		167.0	2,020,363	1,553,321	467,042	51.3	15,918	385,513	11.0	66,396	2,253,857
West Virginia	4,474,234	2,280,335	2,031,523	2,018,445		60.6	2,819,191	2,244,489	511,759	105.7	93,837	208,412	10.7	117,462	1,560,164
Wisconsin	9,724,881	4,941,837	8,114,840	7,840,025	500	373.5	2,166,358	1,688,945	341,002	96.5	94,317	242,720	16.5	101,594	4,357,615
Wyoming	4,501,327	2,287,712	4,134,132	3,819,605	67,583	620.6	1,327,810	621,895	674,508	125.6		188,651	25.5	59,828	1,356,970
District of Columbia	1,918,469	973,842	1,241,941	1,241,941		9.6	1,065,463	644,111	421,352	7.3		46,263	.2	32,417	506,227
Hawaii	1,871,062	949,778	196,115	144,003		10.4	2,002,190	1,649,631		33.4	66,000		.7	11,428	949,778
TOTALS	394,000,000	200,000,000	248,517,362	232,036,191	283,653	16,332.3	179,453,455	139,570,240	21,204,839	7,878.7	10,853,634	32,800,010	2,844.7	11,539,935	145,711,498

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