A Study of 34-E Pavers

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This paper summarizes data obtained in 16 studies of the mixing of portland cement concrete in 34-E dual-drum pavers, conducted by 13 state highway departments. Determinations were made of the desirable time of mixing and the amount of overload which could be permitted. The results indicated that the highest strengths were attained at a 60-sec mixing time, exclusive of transfer time, and that an overload of 10 or 20 percent could be tolerated. It was also found that little loss in strength of the concrete resulted when the mixing time was reduced to 40 sec, exclusive of transfer time, but when the mixing time was reduced to 30 sec a loss in strength of 5 to 6 percent occurred. A mixing time of more than 60 sec exclusive of transfer time, was found to be undesirable because it involved waste of effort and resulted in loss of strength without gain in the uniformity of the concrete.

●IN DECEMBER 1957, the U. S. Bureau of Public Roads suggested that a study of the production of portland cement concrete in 34-E dual-drum pavers be made by interested state highway departments, to determine the most desirable mixing time and the permissible overload, if any. State highway specifications showed that, exclusive of the transfer time required to move the concrete from the first to the second drum, some states permitted a mixing time of as little as 50 sec, while other states required mixing times of as much as up to 120 sec. Some state specifications permitted no overload, but others allowed overloads of from 10 to 20 percent. It was believed that factual information on the effect of mixing time and of amount of overload might permit the more rapid production of concrete without reduction in quality. Lower cost of the concrete in place should then be obtained.

The program proposed by the U. S. Bureau of Public Roads suggested that mixing times of 30, 60, and 90 sec, exclusive of transfer time, be used. Because most states used a mixing time of about 60 sec, this was taken as a standard of comparison. The 30-sec time was suggested as part of the program to provide concrete which might possibly be undermixed; the 90-sec time was intended to determine if extended mixing of concrete would abrade the aggregate to such an extent that excessive fines would be produced, causing the strength of the concrete to suffer. The states were informed, however, that these times could be changed to suit their particular interests, if they so desired.

As proposed in the program, many states used an overload of 10 percent in their studies, and in some cases an overload of 20 percent was used. Where the project contractors objected to the larger overload because of possible resultant wear on their equipment and waste of material, the 20 percent overload was omitted.

The suggested program also recommended that for a given combination of mixing time and overload, samples for test be taken from each tenth batch of 90 consecutive batches of concrete. It was further recommended that three samples be taken from each batch sampled, one sample representing each one-third of the concrete as discharged from the bucket. Specimens for compression and flexure tests were made from certain of the batches sampled and tests for air content, unit weight, and uniformity of composition were made on certain other batches.

SCOPE OF DATA

The studies of the effect of mixing time and overload on the quality of portland cement concrete produced in 34-E dual-drum pavers were made by 13 state highway departments; 2 studies were made by each of 3 states, resulting in a total of 16 studies. The locations of the studies are given in Table 1. Information concerning the type of mixer used, the coarse aggregate, the nominal mixing times, and the overloads, is given in Table 2.

Data from the studies are presented on the effect of mixing time and overload on the compressive and flexural strengths of concrete. Also reported are determinations intended to show the uniformity (or lack of it) of single batches of concrete, as well as variations from batch to batch of concrete prepared under presumably the same mixing conditions. The types of tests made by the several states are given in Table 3.

Some of the states prepared formal reports at the conclusion of their individual studies, while others supplied test results in an informal manner. The data obtained by all states were so extensive that only a review of them can be included in this paper.

TABLE 1

HIGHWAY CONSTRUCTION PROJECTS IN THE STUDY OF 34-E DUAL-DRUM PAVERS

State	Project Number	Date of Study	Highway Route Number	Location
Alabama	I-65-3 (14) (15)	Oct. 1958	U.S. 31	25 miles north of Birmingham
California	III-Pla-17-A, Roc, B.	July 1959	U.S. 40	Near Roseville
Delaware	F-12 (4) S-US-48 (2)	July 1958	Del. 8	Dover, Division St. and Forrest Ave.
District of Columbia	F-55 (1)	June 1958		Irving St. N.E.
Florida	I-4-1 (2)	July 1958	U.S. 4	Near Plant City
Kansas	F-0 92	Oct. 1958	U.S. 36	Beattie Corner to Nemaha County line
Michigan	I-02-5 (6)	June 1958	U.S. 12	Upsilanti, near Willow Run Airport
Nebraska	F-250 (7)	Oct. 1958	U.S. 77	Wymore to Kansas State line
New York (1)	BT-57-1	Aug. 1958		Near East Chatham 20 miles west of Albany
New York (2)	I-1119 (11)	Oct. 1958		
Ohio (1)	I-196 (5)	June 1958	U.S. 25	Wapakoneta bypass
Ohio (2)	I-529 (11)	Aug. 1958	U.S. 40	Kirkersville bypass
Virginia (1)	F-FG-018-1 (1)	Sept. 1958	U.S. 29	Lynchburg bypass
Virginia (2)	U-101-1 (3)	Oct. 1958	U.S. 29	Arlington County, Lee Highway
Washington	Cont. 5733	Oct. 1958		Olympia
West Virginia	S-2 (4)	Oct. 1958	W.Va. 14	Charleston to airport

TABLE 2

TYPE OF PAVER, AGGREGATE, AND PRINCIPAL VARIABLES USED IN THE 16 STUDY PROJECTS

State	Paver	Coarse Aggregate: Type	Coarse Aggregate: Maximum Size	Principal Variables: Nominal Mixing Times Used	Principal Variables: Overload
			Inches	Seconds	Percent
Alabama	A	Stone	1½	30-50-90	0-10-20
California	B	Gravel	1½	30-50-70	0-10-20
Delaware	A	Stone	2	40-70-90	0-10-20
District of Columbia	A	Gravel	2	30-50-70	0-10-20
Florida	B	Stone	2	30-60-90	0-10-20
Kansas	A	Sand-gravel	1	50-60-70-90	0-10-20
Michigan	A	Slag	2	30-50-70	0-10-20
Nebraska	C	Stone	1	30-50-60-90	0-10-20
New York 1	B	Stone	2	40-50-60-90-120	0-10-12-20
New York 2	B	Crushed gravel	2	60-90-120	10-20
Ohio 1	B	Stone	1½	40-50-75	0-10-20
Ohio 2	A	Gravel		50-75	0-10-20
Virginia 1	B	Stone	2½	30-60-90	0-10-20
Virginia 2	D	Gravel	2½	30-60-90	0-10
Washington	B	Gravel		45-60	10-20
West Virginia	C	Gravel	2	30-40-50-60	0-10

Of particular interest, among data excluded here, were those that would permit comparing the air content of concrete as determined by the Chace air meter and standard pressure or volumetric meters, and comparisons between the results of slump cone and Kelly ball tests. It is expected that these data will be summarized and reported at a future time.

The study was unusual in that it involved considerable effort and cooperation on the part of a number of state highway departments and highway contractors. The skillful handling of difficult field testing operations by the personnel involved, often under un-

TABLE 3

VARIOUS TESTS ON CONCRETE PERFORMED BY THE STATES[1]

State	Tests for Compressive Strength on Cylinders[2]			Tests for Flexural Strength[3]			Tests for Uniformity of Plastic Concrete: Washout							
							Washout		Unit Weight	Air Content[4]		Slump	Kelly ball	Willis-Hime
	7 days	14 days	28 days	7 days	14 days	28 days	Fine	Coarse		Pressure	Chace			
Alabama	x	-	x	x	-	x	x	-	x	x	x	x	x	-
California	-	x	-	-	-	-	x	x	-	x	-	-	x	-
Delaware	x	x	x	-	x	-	x	x	x	x	x	x	x	-
District of Columbia	x	x	x	-	x	-	x	x	x	x	x	x	x	x
Florida	x	x	x	x	x	x	-	-	x	x	x	x	x	-
Michigan	-	-	x	-	-	x	x	x	x	-	x	x	x	-
Nebraska	x	-	x	x	-	x	-	x	x	x	x	x	x	-
New York	-	-	-	-	-	-	-	x	x	x	x	x	-	x
Ohio 1	-	-	x	x	x	-	-	x	x	x	x	x	x	-
Ohio 2	-	-	x	x	x	-	-	x	x	x	x	x	x	-
Virginia 1	-	-	x	-	x	-	x	x	x	x	x	x	x	x
Virginia 2	x	x	x	x	-	x	x	x	x	x	x	x	x	x
Washington	-	-	x	-	-	x	-	-	x	-	-	x	x	-
West Virginia	x	x	x	x	x	-	x	x	x	x	x	x	x	-

[1]No information was received from Kansas
[2]Michigan and New York used cores to test compressive strength
[3]The District of Columbia conducted a 3-day test for flexural strength
[4]Alabama and Michigan used the rollermeter method for testing air content

favorable conditions, contributed greatly to the success and value of the study.

PROCEDURE PROBLEMS

In determinations of the mixing time, in this article, the transfer time between drums was not included. It has been stated by some that the concrete is mixed during this transfer process. However, in their reports different states reported different lengths of transfer time, even for the same make of paver, and it was believed that it would simplify the presentation of the material if only the mixing time in the drums was considered. The values reported by the states for mixing times are shown in Table 4.

The original program proposal recommended sampling of every 10th batch for testing. Some states believed that sampling of every 10th batch might be too frequent, and sampled every 20th batch instead. Where the testing staff was limited, this allowed ample time for the test procedures. Some states questioned some of the methods of test proposed, and modified or eliminated them in accordance with their experience or needs. One state cast only a few specimens for strength tests, and drilled cores from the pavement for the strength tests of record. Other differences were found among the individual studies. In general, however, the recommended program was followed sufficiently to permit use of most of the data obtained.

One of the most controversial items in the suggested program was the method of obtaining the three samples of concrete representing a single batch or bucket load. It was recommended originally that three pans be placed on the subgrade, slightly separated to cover the area over which a bucket load of concrete would be distributed. However, some difficulty was found with this method of sampling. When the pans were placed directly on the subgrade, the wave of concrete from the bucket frequently knocked the pans aside. On some projects, to correct this difficulty, the pans were held in

TABLE 4

AVERAGE MIXING TIME, IN SECONDS, AS GIVEN BY THOSE STATES WHERE MIXING AND TRANSFER TIMES WERE RECORDED[1]

State	Nominal Mixing Time	No Overload: Transfer Time	No Overload: Actual Mixing Time	10 Percent Overload: Transfer Time	10 Percent Overload: Actual Mixing Time	20 Percent Overload: Transfer Time	20 Percent Overload: Actual Mixing Time	Average Actual Mixing Time
Alabama	30	11	30	15	30	11	29	30
	50	11	49	11	49	11	49	49
	90	11	79	11	75	11	79	78
California	30	10	21	10	23	10	24	23
	50	10	40	10	39	10	38	39
	70	10	60	10	60	10	60	60
Delaware	40	9	41	9	41	9	41	41
	70	9	70	9	70	9	70	70
	90	9	90	9	90	9	90	90
District of Columbia	30	12	29	12	30	12	30	30
	50	12	45	12	45	12	50	47
	70	12	70	12	70	12	69	70
Kansas	50	10	39	10	54	10	51	48
	60	10	60	10	57	10	53	57
	70	10	60	10	62	10	61	61
	90	10	75	10	76	10	77	76
Ohio 1	40	8	41	9	43	8	42	42
	50	8	51	9	54	9	51	52
	75	9	66	9	66	9	65	66
Ohio 2	50	10	50	10	50	12	49	50
	75	10	65	10	65	12	64	65
Virginia 1	30	-	27	-	28	-	28	28
	60	-	58	-	60	-	60	59
	90	-	89	-	87	-	90	89
Virginia 2	30	-	29	-	36	-	-	32
	60	-	58	-	63	-	-	60
	90	-	93	-	96	-	-	94

[1]Florida (30, 60, 90 sec), Michigan (30, 50, 70 sec), Nebraska (30, 50, 60, 90 sec), and West Virginia (30, 40, 50, 60 sec) did not include transfer time in mixing times stated. New York included a transfer time of 9 sec in mixing times of 40, 50, 60, 90 and 120 sec. No information of transfer time was furnished by Washington (45, 60 sec).

place by concrete shoveled against their sides. Another method found to be effective was mounting the pans on legs about 12 in. high (Fig. 1).

Some states adopted the practice of having the bucket load dumped on the subgrade either in a ribbon or in an oval-shaped pile. Samples possibly representing different sections of the bucket-load were then taken from the concrete. At first it was questionable whether the samples so obtained could be considered to represent the first, middle, and last third of the concrete batch discharged from the mixer. However, it was pointed out that the first one-third of the concrete discharged from the bucket might not be the same as the first third of the concrete discharged from the mixer. Due to restraint of the sides of the bucket, the first one-third of concrete discharged from the bucket may include some of the second one-third of the concrete discharged into the bucket. For this reason, no consideration was given in this report to differences between the methods used to obtain these one-third-bucket-load samples. Although such differences existed, it may be considered that the collective samples for each mixing time and overload are reasonably representative of the entire mixing load.

EFFECT OF MIXING TIME ON STRENGTH

As shown in Table 2, the states used widely different nominal mixing times, and some differences in overloads. There also was a variance in the materials used and in the methods of testing compressive and flexural strengths. To place each set of data on a uniform basis for comparison, the strength obtained for a 60-sec mixing time, or with no overload, was adopted as the standard of comparison. Strengths obtained for other mixing times, or for overloads, were then compared with these values.

In six of the studies, a 60-sec mixing time was not used. To permit comparison of the data obtained with those for the other projects, the determined strengths were plotted against mixing time and a curve drawn through the points. The value shown on this curve at intersection with the 60-sec abscissa was taken as the base measure.

To keep the reporting of data concerning mixing time within reasonable bounds, some liberties have been taken in their presentation. The mixing times are shown at 5-sec intervals, and a value for strength obtained with an acutal mixing time of 48 sec, for example, is shown for 50 sec. However, if there was only one determination of strength of concrete for a given time of mixing, this was not shown in the charts. In many instances the elimination of these single values removed wild results and showed to better advantage the trend of the remaining mutually supporting data.

Data reported by each state of the effect of mixing time on the compressive and flexural strength of concrete are shown in Figures 2 and 3. The varying strengths reflect the materials used and the methods of testing employed. Some states used cantilever beam testing machines and obtained flexural strengths much higher than those using center-point loading.

Data averaged for all of the studies to show the effect of mixing time on the compressive strength are plotted in Figure 4. The curve in each portion of the figure presents the best considered average. In the lowest portion of the figure, the curve represents an average of the other three curves. Similar curves for flexural strength are shown in Figure 5.

The same finding (that the compressive and flexural strengths of concrete prepared with the mixers and materials used were at a maximum for a mixing time of 60 sec) is evident in Figures 4 and 5. Marked increase or decrease in mixing time resulted in a reduction in strength, but this reduction was of no great moment. For a mixing time of only 30 sec the compressive strength was reduced only 6 percent and the flexural strength only 5 percent. For a mixing time of 90 sec the compressive strength was reduced only 7 percent and the flexural strength only 3 percent. A reduction in mixing time to 50 sec caused a reduction in compressive strength of about 0.5 percent and no decrease in flexural strength.

Figures 6 and 7 present the effect of overload on the compressive and flexural strengths of the samples tested. The curve representing the average for all determinations of compressive strength shows that a decrease of 5 percent in strength resulted for an overload of 10 percent. For a 20 percent overload, a decrease in strength of

Figure 1. One of the methods used in obtaining sample concrete.

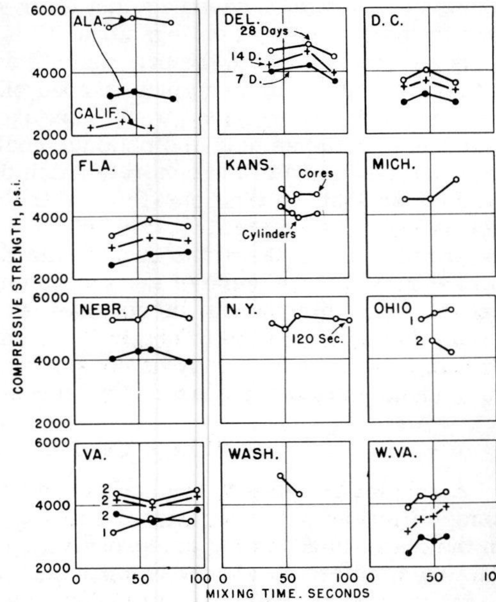

Figure 2. Effect of mixing time on compressive strength, by state.

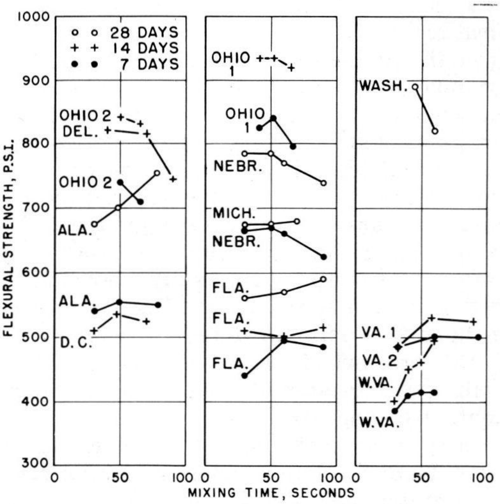

Figure 3. Effect of mixing time on flexural strength, by state.

only 1 percent resulted. In the flexural strength determinations, overloads of 10 and 20 percent each caused a reduction in strength of only 2 percent.

Some inquiry has been made of the reason for the lower compressive strength of concrete prepared with an overload of 10 percent than with an overload of 20 percent. It was speculated that the greater overload caused the drum to operate more efficiently; however, if this were the reason a mixer with an overload of 10 percent would be expected to operate more efficiently than one with no overload. Such was not found to be the case if strength tests of concrete are used to judge the efficiency

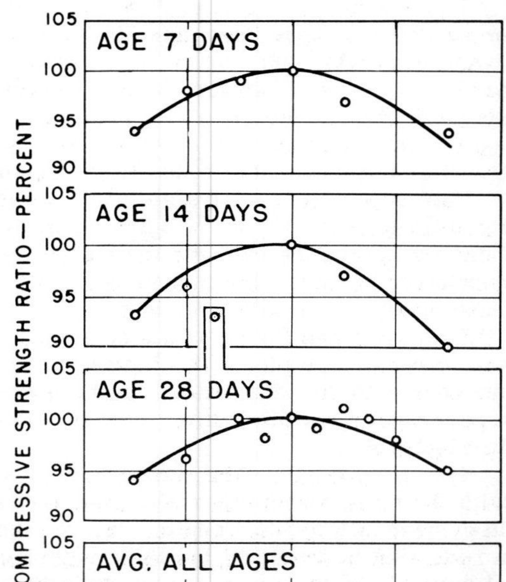

Figure 4. Average effect of mixing time on compressive strength.

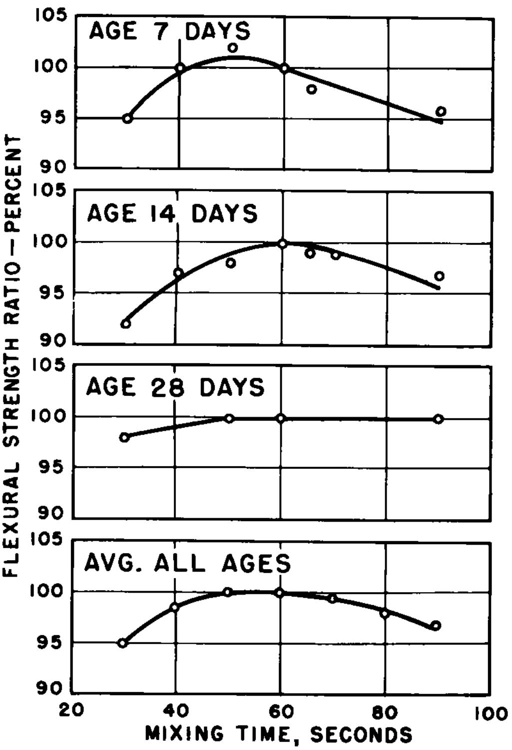

Figure 5. Average effect of mixing time on flexural strength.

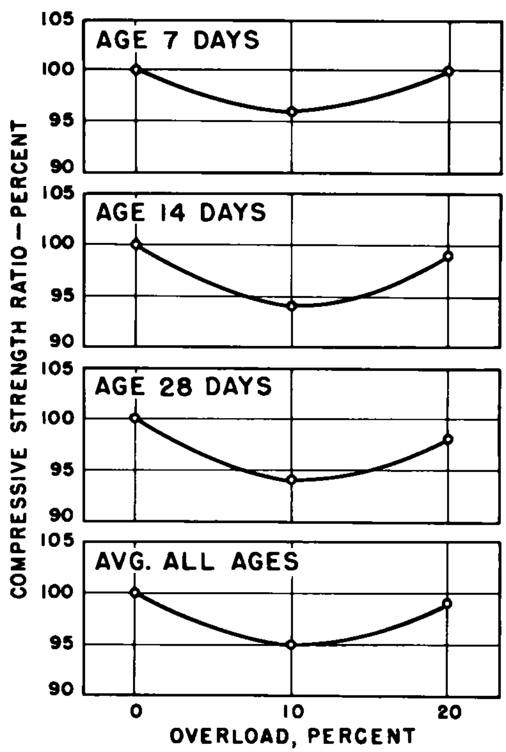

Figure 6. Average effect of overload on compressive strength.

or rather the effectiveness of a mixer. Some other reason must apply to these test results.

Most specimens were prepared, cured and tested in accordance with standard ASTM methods. No concern need be given to this phase of each investigation, as the data were apparently affected but little by variations in the preparation of specimens. With this accepted, it may be assumed that variations in the strength of the concrete are due to the mixing procedures used, or the weather conditions over which there was no control.

Further study was given to the effect of overload on the compressive strength of concrete, reported in Table 5. It was observed that in Florida the strength for no overload was considerably higher than that for 10 percent overload at all ages and for 20 percent overload at an age of 7 days. It was believed that a detailed study of the results from this state might be warranted. It was also noted that in the Virginia No. 2 study and in the West Virginia study the results for a 10 percent overload ranged from slightly lower to considerably lower than for no overload, and that no tests were made for an overload of 20 percent. It was believed that these results might have influenced the general average to an unwarranted extent and that they might well be excluded from consideration.

To examine more carefully the results of the Florida tests, the compressive strengths obtained for each combination of mixing time and overload were plotted against age at test. It was believed that if there had been any unusual features affecting the test results, these would be shown by some exceptional behavior in rate of gain of strength. As shown in Figure 8, all of the Florida tests made for concrete prepared with 90-sec mixing time produced an unusual behavior in rate of gain of strength. In two of the three cases, the strength at an age of 14 days was lower than that at 7 days. In the third case, the strength at 7 days appears to be quite low and that at 14 days somewhat high.

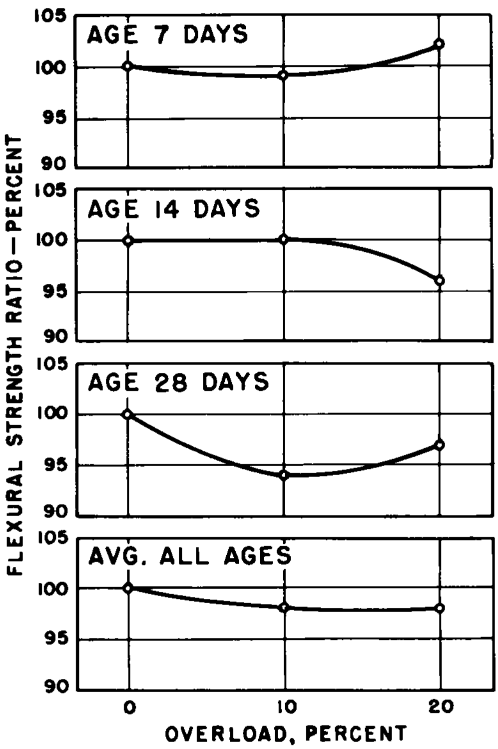

Figure 7. Average effect of overload on flexural strength.

Why these results had this unusual behavior is not known, but there is indication that they were caused by some feature other than the variables of record and it is believed that these results may justifiably be excluded from consideration. Consequently, in consideration of the effect of overload on compressive strength, all three sets of specimens mixed for 90 sec in Florida were rejected.

Figure 9 presents revised trends of the effect of overload on compressive strength with the questionable and incomplete data excluded. Even with these data excluded, it was found that the strength for an overload of 10 percent was slightly lower than that for an overload of 20 percent, and both overloads furnished less strength than no overload. The maximum amount of reduction in strength is only 4 percent which in view of the more rapid production of concrete gained by overloading, may be considered of minor consequence.

In the tests to determine the effect of overload on flexural strength, certain test specimens yielded irregular results, as shown in Table 6 and Figure 10. In no case however, were all specimens for a given time of mixing involved, and all data

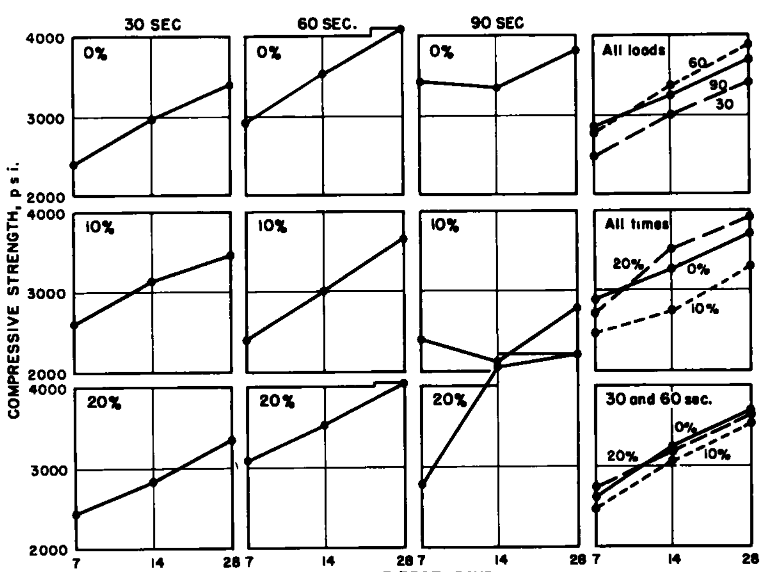

Figure 8. Compressive strength for each set of variables using Florida test data.

TABLE 5

EFFECT OF OVERLOAD ON COMPRESSIVE STRENGTH

State	Tests at 7 Days for Unit Compressive Strength					Tests at 14 Days for Unit Compressive Strength					Tests at 28 Days for Unit Compressive Strength				
		10 Percent Overload		20 Percent Overload			10 Percent Overload		20 Percent Overload			10 Percent Overload		20 Percent Overload	
	No Overload (psi)	Strength (psi)	Strength Ratio[1]	Strength (psi)	Strength Ratio[1]	No Overload (psi)	Strength (psi)	Strength Ratio[1]	Strength (psi)	Strength Ratio[1]	No Overload (psi)	Strength (psi)	Strength Ratio[1]	Strength (psi)	Strength Ratio[1]
Alabama	2,890	2,950	102	3,320	115	-	-	-	-	-	5,720	5,260	92	5,740	100
California	-	-	-	-	-	2,300	2,240	97	2,130	93	-	-	-	-	-
Delaware	4,010	4,020	100	3,760	94	4,280	4,310	101	4,120	96	4,730	4,640	98	4,550	96
District of Columbia	3,140	3,130	100	2,950	94	3,580	3,560	99	3,380	94	3,880	3,800	98	3,660	94
Florida	2,920	2,470	85	2,760	95	3,290	2,750	84	3,560	108	3,760	3,360	88	3,940	105
Kansas[2]	-	-	-	-	-	-	-	-	-	-	4,560	3,620	80	4,150	91
Michigan	-	-	-	-	-	-	-	-	-	-	4,630	4,920	106	4,610	100
Nebraska	4,160	4,000	96	4,320	104	-	-	-	-	-	5,560	5,390	97	5,300	95
Ohio 1	-	-	-	-	-	-	-	-	-	-	5,370	5,440	101	5,450	101
Ohio 2	-	-	-	-	-	-	-	-	-	-	4,300	4,050	94	4,790	111
Virginia 1	-	-	-	-	-	-	-	-	-	-	3,620	3,330	92	3,240	90
Virginia 2	3,740	3,690	99	-	-	4,260	3,990	94	-	-	4,440	4,170	94	-	-
Washington	-	-	-	-	-	-	-	-	-	-	-	4,630	-	4,660	-
West Virginia	2,940	2,560	87	-	-	3,640	3,410	94	-	-	4,240	4,100	97	-	-
Average	-	-	96	-	100	-	-	95	-	98	-	-	94	-	98

[1] Ratio to strength for no overload

[2] Kansas tested cores at 28 days with the following results No overload, 5,030 psi, 10 percent overload, 4,430 psi, 20 percent overload, 4,530 psi

TABLE 6

EFFECT OF OVERLOAD ON FLEXURAL STRENGTH

State[1]	Tests at 7 Days for Unit Flexural Strength					Tests at 14 Days for Unit Flexural Strength					Tests at 28 Days for Unit Flexural Strength				
		10 Percent Overload		20 Percent Overload			10 Percent Overload		20 Percent Overload			10 Percent Overload		20 Percent Overload	
	No Overload (psi)	Strength (psi)	Strength Ratio[2]	Strength (psi)	Strength Ratio[2]	No Overload (psi)	Strength (psi)	Strength Ratio[2]	Strength (psi)	Strength Ratio[2]	No Overload (psi)	Strength (psi)	Strength Ratio[2]	Strength (psi)	Strength Ratio[2]
Alabama	515	550	107	575	112	-	-	-	-	-	785	640	82	710	90
Delaware	-	-	-	-	-	795	820	103	760	96	-	-	-	-	-
District of Columbia	-	-	-	-	-	545	530	97	500	92	-	-	-	-	-
Florida	470	490	104	460	98	525	515	98	480	91	555	595	107	575	104
Kansas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Michigan	-	-	-	-	-	-	-	-	-	-	680	665	98	680	100
Nebraska	680	640	94	640	94	-	-	-	-	-	810	735	90	765	94
New York	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ohio 1	825	800	97	835	101	955	875	92	960	101	-	-	-	-	-
Ohio 2	720	730	101	730	101	840	845	101	820	98	-	-	-	-	-
Virginia 1	-	-	-	-	-	515	520	101	505	98	-	-	-	-	-
Virginia 2	505	485	96	-	-	-	-	-	-	-	-	-	-	-	-
Washington	-	-	-	-	-	-	-	-	-	-	-	865	-	845	-
West Virginia	415	400	96	-	-	430	470	109	-	-	-	-	-	-	-
Average[3]	-	-	99	-	102	-	-	100	-	96	-	-	94	-	97

[1] California Kansas, and New York reported no tests for flexural strength

[2] Ratio to strength for no overload

[3] The average ratio to strength for no overload at all ages was 98 for both 10 and 20 percent overload

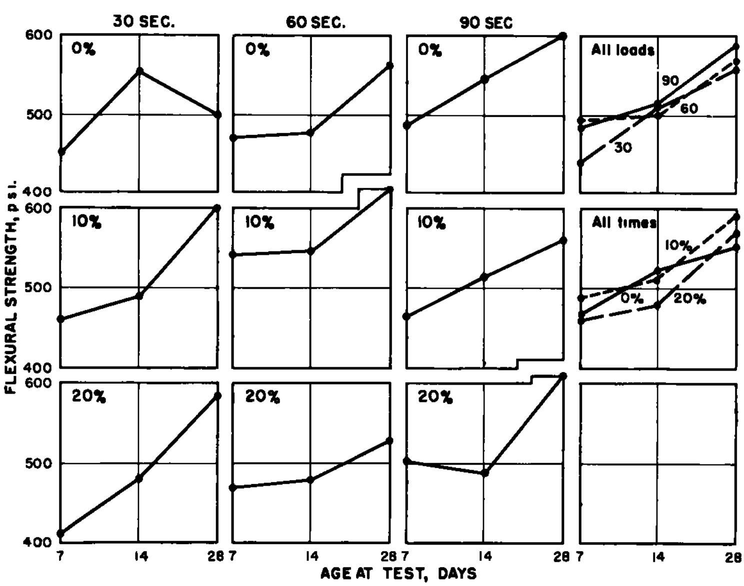

Figure 9. Average effect of overload on compressive strength excluding questionable and incomplete data.

obtained were used to determine average trends for all of the studies.

EFFECT OF MAKE OF PAVER

It was hoped that sufficient data could be obtained from the projects using the same make of paver to determine whether that make of paver processed concrete in a manner sufficiently different from the other pavers to warrant comment. It was considered desirable to limit the data used to that representing two or more projects and four mixing times.

The results obtained for a single make of paver showing the effect of mixing time on strength are shown in Figure 11. By comparison with Figures 4 and 5, it will be seen that there is little differences between the curves for this single make of mixer and the curves for all makes over the range of 50- to 70-sec mixing time. It is probable that more difference in effectiveness of mixing will be found between individual mixers of any make than between groups of mixers of different makes. In two of these studies the mixers used were found, on initial inspection, to contain a considerable amount of hardened concrete. Removal of this concrete unquestionably improved the effectiveness of the mixers.

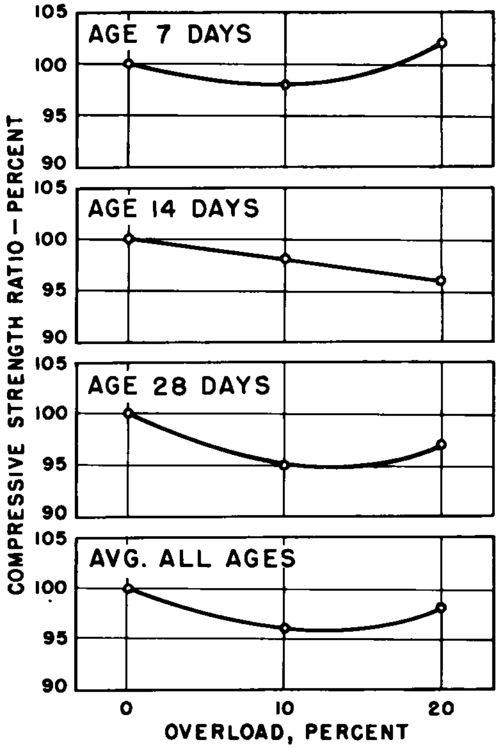

Figure 10. Flexural strengths for each set of variables.

TESTS FOR UNIFORMITY OF PLASTIC CONCRETE

It would be expected that insufficient mixing would be evidenced by marked differences in the results of tests of the three portions of a bucket of concrete, possibly by a greater than normal weight per cubic foot, and by low air content. Excessive mixing would be expected to be detected by excessive fines in the concrete, and possibly by a low air content.

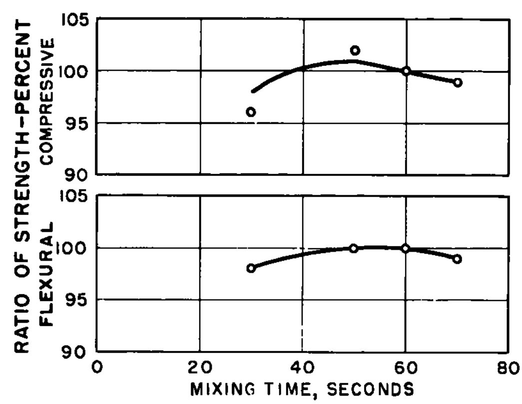

Figure 11. Effect of mixing time on strength, determined from one make of paver.

Almost all of the states made and reported test determinations which were intended to be used to show the uniformity of the plastic concrete. These tests included determinations of the cement content by the Willis-Hime and Dunagan methods, washout tests for fine or coarse aggregates, tests for unit weight of concrete, tests for consistency using the slump cone and Kelly ball methods, and pressure, volumetric, and Chace tests, for air content.

The data furnished by the states were studied, and a selection of these data was made to determine the uniformity of the concrete produced with the various mixing times and overloads. For ease in presentation and comparison, these data are shown in Figures 12-20. In each figure, sample data reflecting various characteristics of the concrete are shown with reference to individual combinations of mxing time and overload. Data for the first one-third of the bucket load of concrete are indicated by a circle; for the second third, the data are indicated by a cross; and for the last third, by a triangle. The solid lines in the figures connect the average value for a bucket load.

Generally, the data plotted for each one-third portion is an average taken from three loads of concrete. These loads, obtained from different batches and on different days, could have been influenced by changing weather conditions, characteristics of the materials used, or by the personal equation of the operators. However, the sample loads indicate a general trend which may be considered adequate for this study and are not intended to cover all minute details which might influence such determinations.

For most of the reporting states, data covering tests for unit weight, washout, and air content were available. In the other states, data for slump were available.

Unit Weight

A marked variation in unit weight of concrete for a single batch of concrete or for several batches mixed under the same conditions would indicate either a harsh concrete or insufficient mixing. If a marked variation was found, and the same one-third portion generally had the greatest or least weight of the samples representing the same bucket load, it was assumed that the mixer was not operating properly and was furnishing undermixed concrete. For a given combination of aggregates, high unit weights, closely grouped, indicated well-mixed concrete.

General trends for all data from short to long mixing times were also of interest. If the trend appeared toward greater weight, an improvement in mixing was assumed. If the trend was toward lesser weight, this was taken to indicate overmixing and reduction in size of the aggregate.

Washout

The results of the washout tests were shown by several different methods. In some cases, the states determined and reported the amount of fine aggregate in the concrete or the grading and fineness modulus of the aggregate. In others, the amount of coarse aggregate was determined. Some states reported the grading of all aggregate, and choice had to be made as to which data would give the most information.

The results of these tests were expected to determine if extended mixing of concrete would abrade the aggregate to a marked extent. This could be demonstrated if there was a decrease in the fineness modulus of the fine aggregate, or an increase in the amount of fine aggregate and decrease in the amount of coarse aggregate. Undermixing of the concrete was indicated by the nonuniformity of the distribution of aggregate in the three portions of a bucket load.

Air Content

The air content of the concrete was determined by use of pressure or volumetric methods, including the Chace air meter test as one of the latter methods. When available, data obtained with a pressure meter, or a volumetric method using a large sample of concrete, were preferred over data obtained with the Chace air meter.

The air content of air-entrained concrete was believed to be an excellent indication of the thoroughness of mixing the concrete. Insufficient mixing would be indicated by low amounts of air and by variation of the amounts of air between portions of a batch. With excessive mixing, it was believed that some of the air would be lost, but in this case the air in each portion of a batch would be practically constant.

Slump

The slump is a measure of the workability of concrete. A concrete can have a high water-cement ratio and at the same time have a low slump due to harshness of the mix.

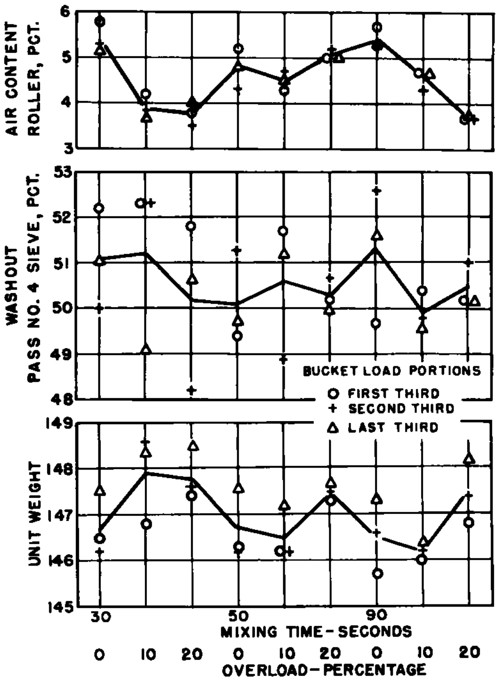

Figure 12. Test determinations on uniformity of concrete in the Alabama project.

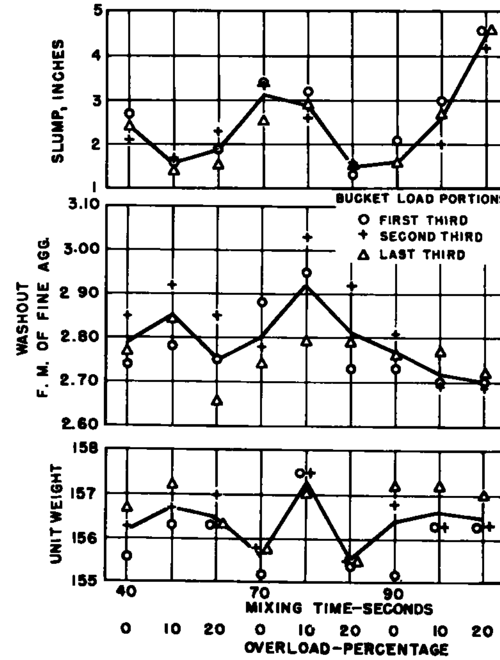

Figure 13. Test determinations on uniformity of concrete in the Delaware project.

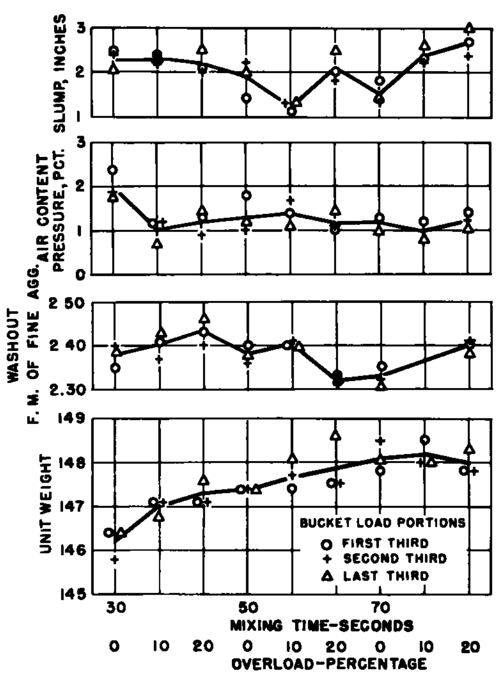

Figure 14. Test determinations on uniformity of concrete in the District of Columbia project.

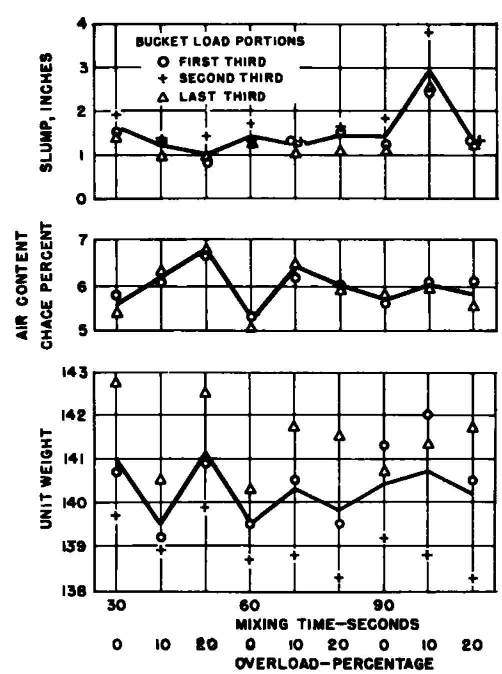

Figure 15. Test determinations on uniformity of concrete in the Florida project.

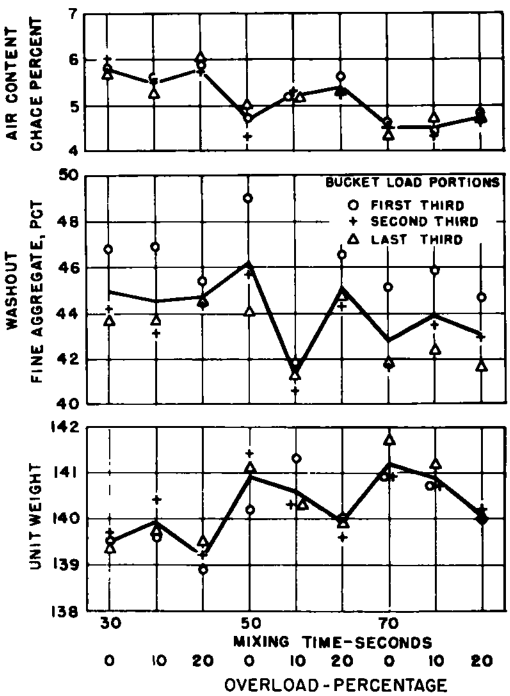

Figure 16. Test determinations on uniformity of concrete in the Michigan project.

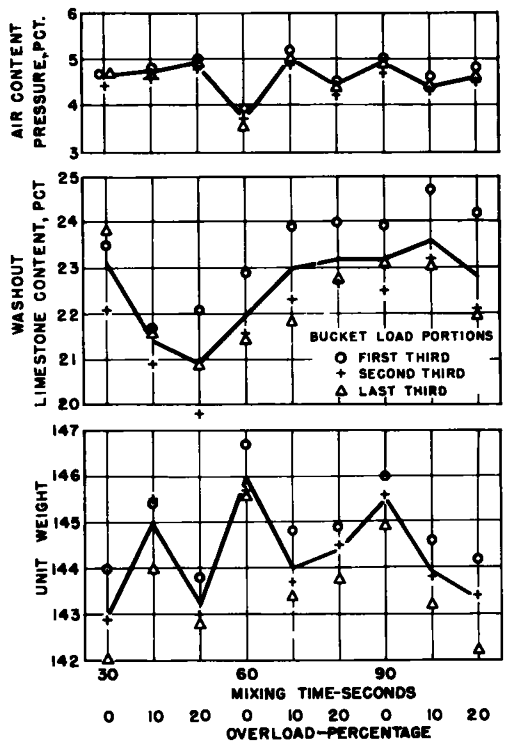

Figure 17. Test determinations on uniformity of concrete in the Nebraska project.

In very few instances were the concretes produced in these studies found to have poor workability, and it is believed that these cases can be ignored. The slump can be used with other data to deduce whether thoroughness of mixing was obtained.

Other Determinations

Other determinations made on portions of a bucket load of concrete included the Willis-Hime test (1) for the cement content of concrete, and the Dunagan method (2) for determining the composition of concrete. The Willis-Hime test, made by the District of Columbia, New York and Virginia, yielded disappointing results in that they differed greatly from the known cement content. It was found that the principal reason for the results obtained was failure to dry the samples sufficiently. Because all of the water was not driven off, the cement grains still retained water and were not separated from the sand portion of the mortar during the centrifuging operation. This resulted in a test determination showing a low cement content of the concrete.

The District of Columbia made determinations of the composition of the fresh concrete using the Dunagan method. The results varied tremendously and indicated variations within and between batches of concrete which were beyond the realm of the possibility. Without doubt, some feature was overlooked in the performance of these tests which resulted in inappropriate test data.

REVIEW OF UNIFORMITY BY STATES

A review of the data for some of the individual state projects was made to determine information of interest with respect to uniformity of concrete. Such information is presented in the following:

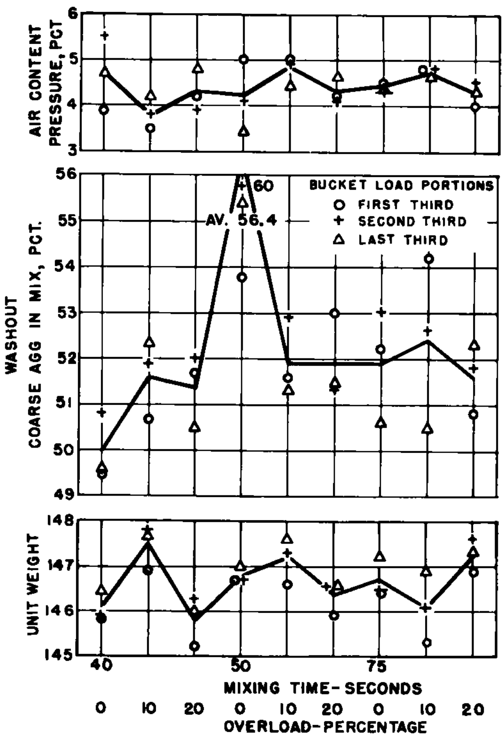

Figure 18. Test determinations on uniformity of concrete in Ohio project No. 1.

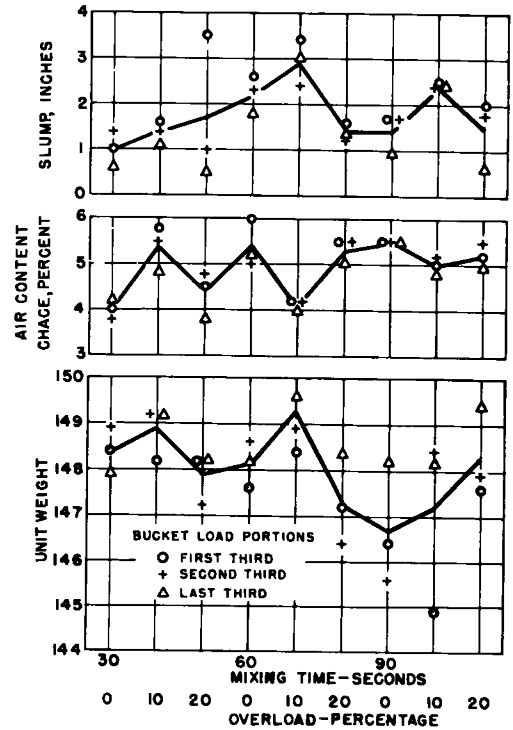

Figure 19. Test determinations on uniformity of concrete in Virginia project No. 1.

Alabama

The results from the Alabama project (Fig. 12) showed a slight over-all decrease in unit weight with increase in mixing time. With an overload of 20 percent, however, higher weights were obtained for each mixing time than for no overload. In 8 of the 9 combinations of mixing time and overload, the last portion of the concrete discharged by the bucket had the greatest weight. These facts collectively were assumed to indicate that the mixer was not operating to best advantage, and that an overload of 20 percent was an aid in obtaining better mixing of the concrete.

Determinations of the material passing the No. 4 sieve in the washout test showed some wide variations within a bucket load of concrete—especially for the 30-sec mixing time. Each of the loads had an equal amount of sand, or more in the first one-third of the bucket load than in the second or last third portions. These variations indicated an insufficient mixing for a 30-sec period. The general trend for all washout test results showed no increase in amount of fine aggregate with increase in mixing time and overload. This would indicate that even for a 90-sec mixing time, there was no more abrasion of aggregates than for shorter periods of mixing time.

The air content tests, using a volumetric method, produced uniform values for the different portions of a bucket load. In two of the three mixing times, increase in loading resulted in a reduction in the amount of air. The air contents for a 30-sec mixing time with no overload and with 20 percent overload were the same as those for the same loads at a 90-sec mixing time. It would appear from these results that a 30-sec mixing time is sufficient to obtain well-mixed concrete, and that further mixing is of little value.

Delaware

Data from the study in Delaware (Fig. 13) showed no over-all trend for unit weight except for a higher weight for each mixing time with a 10 percent overload. In 7 of the 9 cases, the weight of the last portion from the bucket was equal to or greater than that of other portions. This indicated that a greater percentage of stone was present in the last portion and further suggested that the mixer was not functioning properly.

In the washout tests, the high value of fineness modulus of sand for the 70-sec mixing time with a 10 percent overload was matched by a similar high value for unit weight. These values were considered as sports, representing a nonuniform condition such as the use of unusually coarse sand. The other values for the washout tests showed no unusual features other than the prevalence of coarser sand from the center of the bucket load and the progressive decrease in fineness modulus for the 90-sec mixing time.

The progressive increase in fineness of the fine aggregate was almost matched by an increase in the slump of the concrete for the batches involved. Althougth data for the water content of the concrete were not immediately available, the variations in the values of slump were related to the variations in the unit weight values or the fineness modulus of the fine aggregate. Where an increase or decrease in slump occurred a decrease or increase in unit weight was found or an increase or decrease in the fineness modulus of the sand occurred. Considering all values given, the previously mentioned failure of the mixer to furnish well-mixed concrete must be repeated. It appeared that extended mixing of the concrete did abrade the aggregate to some extent. It was also found that the first sample taken from each bucket load generally had a lower-than-average unit weight, a finer-than-average sand, and a higher-than-average slump.

District of Columbia

The results obtained in the District of Columbia study (Fig. 14) were unique in showing an increase in unit weight for each increase in mixing time and overload except for the 20 percent overload at 70-sec mixing time. No corresponding trends were developed in the data for fineness modulus of fine aggregate, air content, or slump. It appeared that the uniformity of concrete was improved by increase in mixing time and load, the additional overload serving to promote the mixing action.

Florida

The results obtained in the Florida study (Fig. 15) in some respects were quite unusual. Except for one nonconforming group of data, uniform results were obtained for the slump of concrete. The tests for air content made by the Chace method, also produced one sport, but otherwise the variations were insignificant. Neither set of data can be used to explain variations found in the tests for unit weight. In the concretes mixed for 60 and 90 sec, those with a 10 percent overload

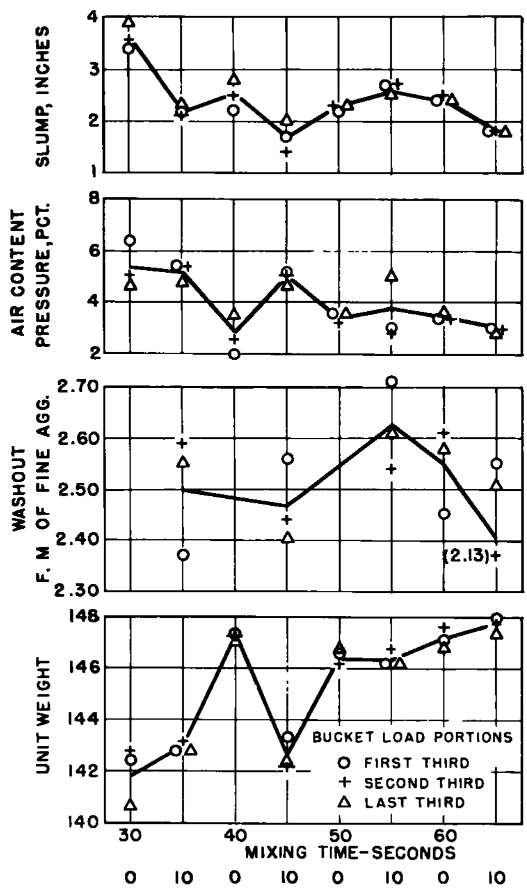

Figure 20. Test determinations on uniformity of concrete in the West Virginia project.

had slightly greater average weights than those with no overload or 20 percent overload; whereas in the concretes mixed for 30 sec, those with a 10 percent overload had the least weight.

In view of the marked variation in unit weight for the separate portions of all batches of concrete, and the fact that the last portion of each bucket load had the greatest weight in 7 of the 9 combinations of mixing time and overload, it appeared that the concrete mix was harsh and failed to respond adequately to increases in mixing time. A possible exception to this may be shown by the low slump. With a slump averaging only 1¼ in., more variation in unit weight must be tolerated within a batch than for higher slump concrete.

Michigan

Data results obtained in the Michigan study (Fig. 16) in which slag was used as the coarse aggregate, reflected in some respects the opinion that slag concrete is usually somewhat harsh. However, similar behavior was detected in data from other projects in which gravel was used.

In the tests for unit weight, an increase in time of mixing was accompanied by an increase in the weight of the concrete. In the concretes mixed for 50 or 70 sec, increase in overload resulted in a decrease in the unit weight, and in the concretes mixed for 30 sec, those with a 20 percent overload had lower weights than those with no overload. These data indicate that an increase in mixing time and elimination of overload may furnish more uniformly mixed concrete for the particular mixer and concrete used in this project.

The washout tests showed a slight decrease in the amount of fine aggregate with an increase in mixing time and overload. The results of the air content tests showed a reduction in the amount of air with increase in mixing time and overload. This could mean that a 30-sec mixing period was sufficient to develop maximum air content in the concrete, and that longer mixing periods permitted some of the air to be lost. It is noted that the data for air content and unit weight are associated. An increase of air content was associated with a decrease in weight, and selection of a most desirable set of mixing conditions definitely does not result in these determinations.

Nebraska

For the study in Nebraska (Fig. 17), the aggregate used was a mixture of sand-gravel and limestone. In conducting the washout tests, one determination made was the amount of crushed limestone found in the mixed concrete.

The tests for unit weight of concrete indicated some large variations both within and among batches. The general trend of these data indicated a slightly higher unit weight for concrete mixed for 60 sec than for the other concretes included in the study. In 8 of the 9 combinations, the heavier concrete was found in the first portion of a bucket load, indicating that more large aggregate was contained in this portion than in the second or third portions. No relation between unit weight and air content results were found except for one batch mixed for 60 sec with no overload. This concrete had the highest unit weight as well as the lowest air content.

The Nebraska report stated that a visual inspection of all test batches used did not disclose any poorly mixed concrete. This is of considerable importance as it may indicate that the variations shown in Figure 17 may be of no significance with respect to concrete placed on the roadway.

Ohio Project No. 1

In the first of the two studies conducted in Ohio (Fig. 18), marked variations in unit weight were found, but the data showed no trends which could be associated directly with amount of mixing time or overload. The amount of coarse aggregate recovered from the concrete in the washout tests appeared irregular for the 40-sec mixing time, and one group of results for the 50-sec mixing time indicated a temporary lack of control at the batching plant. However, the results found for air content appeared to be quite uniform.

It was reported that inspection of the concrete as it was placed on the subgrade revealed only a few batches on which question might be raised regarding uniformity of mixing. Possibly uniformity in grading of the coarse aggregate and in batching the materials were of equal importance to the performance of the mixer.

Virginia Project No. 1

It was reported for Virginia project No. 1 that the concrete was harsh and difficult to finish but this was corrected during the study. However, some of the variations of the data shown (Fig. 19) may have been caused by this condition. Consequently, only a few comments on these data may be warranted.

It is interesting to note that the unit weight of the 30-sec concrete was reasonably uniform, and that greater variations within batches were found for concrete mixed for 90 sec. On the other hand, the air content for the 30-sec concrete varied more from batch to batch than for the 90-sec concrete. In the slump tests, the concrete mixed for 30 sec with a 20 percent overload had a wide range between portions of the bucket load, but this could have resulted from use of the harsh concrete.

West Virginia

The study in West Virginia (Fig. 20) was hampered by cold weather and therefore some of the washout tests were not made. The notable variations in unit weight were in close agreement with corresponding variations in air content and slump. In general, the concrete mixed for 50 or 60 sec was more uniform among batches than the concrete mixed for shorter periods, whereas very uniform concrete throughout a bucket load was found for all mixing times.

CONCLUSIONS

The data obtained by the states were so extensive that only a considerable condensed review can be included in this paper. Based on a painstaking study of all material reported, the following conclusions have been drawn.

The results of strength tests included in this investigation showed that for 34-E dual-drum pavers, the greatest strength was obtained with a mixing time of 60 sec, not including transfer time between drums. This mixing time could be reduced to 40 sec, exclusive of transfer time, with but very little reduction in the strength of the concrete. Reduction of the mixing time to 30 sec, exclusive of transfer time, caused a reduction in strength of 5 to 6 percent. Concrete mixed for 30 sec occasionally showed segregation but generally could be placed and finished without difficulty. In some studies it was found desirable to increase the water-cement ratio slightly for concrete mixed for only 30 sec.

A mixing time of more than 60 sec, exclusive of transfer time, was found to be undesirable, because it involved waste of effort and resulted in loss of strength without gain in the uniformity of the concrete. Little evidence of excessive abrasion of the aggregate was noted, however, even with mixing times as long as 90 sec.

Overloading of 34-E dual-drum pavers above their rated capacity caused a reduction in strength of 1 to 2 percent for an overload of 20 percent, and a reduction of 2 to 4 percent for an overload of 10 percent. The greater reduction for the smaller overload may have been fallacious, or it may have been possible that the mixers used in these tests actually performed better with a greater load. Data to clarify this point were not available.

In studies of the uniformity of concrete produced by 34-E dual-drum pavers, it was found that the quality of concrete depended on the operations preceding the paver mixing operation. If a harsh mix was fed to the paver, extended mixing time still furnished a harsh concrete. If a properly sized and proportioned mix was used, most, if not all, of the mixers studied in this investigation furnished well mixed concrete after only 30 sec of mixing.

It should be noted that some contractors objected to an overload of more than 10 percent on the grounds that their equipment would not handle it. Also, some contractors were not able to use a mixing time shorter than 50 sec, due to their inability to supply materials to the paver.

In general, it is believed that the results of the strength tests of concrete were more indicative of the effectiveness of the mixers used than were the results of tests for uniformity of concrete. The tests made for the latter purpose were of considerable value, but if studies of this type should be conducted in the future, a marked increase in the number of tests for compressive strength would be recommended, with elimination of the flexural strength tests and a reduction in the tests for uniformity. If it could be devised, a test for cement content in the mixed concrete which could be made in entirety on the project would be recommended, with another test for water content of the concrete.

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2. Dunagan, W. M., "Method of Determining the Constituents of Fresh Concrete." Proc., Am. Conc. Inst., 26:202-210 (1930).