# PUBLIC ROADS

## A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

VOL. 12, NO. 11 ▽ JANUARY, 1932


PAVING OPERATIONS ON MOUNT VERNON MEMORIAL HIGHWAY

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## TABLE OF CONTENTS



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# EFFECT OF SIZE OF BATCH AND LENGTH OF MIXING PERIOD ON RATE OF PRODUCTION AND QUALITY OF CONCRETE MIXED IN STANDARD 27E PAVERS

Reported by T. C. THEE, Assistant Highway Engineer, Division of Management, U. S. Bureau of Public Roads

THE rate at which any given concrete paver can produce concrete depends very largely on the size of the batch and the length of time which it must be mixed. Definite data as to the relation which the size of batch, number of sizes of coarse aggregate, and the length of mixing bears to the rate of production and to the quality of the concrete produced, when larger than normal batches are used, have been lacking. A rather extensive study was undertaken in 1930 to determine, if possible, how large a batch can safely be handled by standard 27E pavers, under present operating conditions and with present mixing time specifications, without any detriment to the strength and uniformity of the mix. It was also desired to learn whether or not concrete which is of satisfactory strength and uniformity of mix can be produced with 27E pavers using a 33-cubic-foot batch and a mixing time of 60 seconds or less.

The projects selected for this study involved rather extreme conditions and are described in the following paragraphs.

Two Wisconsin projects were studied, State-aid project 2916, 9.88 miles in length, and State-aid project 2926, 11.27 miles, both in Sheboygan County. The following description applies to both jobs: 20-foot section, 9–6.5–9 inch thickness; a normal concrete having a slump of about 1½ inches, a constant cement and water content, and a practically constant proportion of gravel and sand, three sizes of coarse aggregate uniformly graded with a maximum size of 2½ inches and a workability factor, $b/b_0$, averaging 0.75 and varying by design hardly an appreciable amount. The aggregates were proportioned by weight and bulk cement was used. The water devices on the four different mixers used on these two jobs were fairly accurate. The blades and buckets in all the mixers were new and in excellent condition.

A study was also made on Federal-aid project 259 A and B, Jefferson County, Ark. Following is a description of the project: Length, 16.97 miles; 18-foot section, 9–6–9 inch thickness; a relatively dry concrete with an approximate slump of 1¼ inches, a constant cement and water content, and a fairly uniform sand and stone content, two sizes of well-graded, crushed trap rock as coarse aggregate, with a maximum size of 2½ inches, and a workability factor, $b/b_0$, averaging approximately 0.75 and varying only within a narrow range by design. The aggregates were proportioned by weight and sack cement was used. A dual water tank open to atmospheric pressure measured the water fairly accurately. The blades and buckets of the mixer drum were in fair condition.

It is believed that these three jobs are fairly representative of present good practice in the production of concrete for highway paving purposes in the United States, and that the most probable dangers or difficulties that are likely to arise in connection with the use of batches larger than those normally used, a reduced mixing time, and multiple-sized aggregates, would be evidenced on one or more of these jobs during the course of the studies.

### SIZE OF BATCH VARIED

On the Wisconsin jobs the contractors presented alternate bids for constructing the pavement when using 27, 30, 33, and 35 cubic-foot batches to an extent sufficient to provide for the construction of at least 1 mile of concrete with each of these different sized batches when using a mixing time of 60 seconds. Although no provisions had been made in the bids to use other than a 60-second mixing time, near the close of the jobs the batchmeter was actually set at 50, 60, and 80 seconds for both 30 and 33 cubic-foot batches.

On State-aid project 2926 the successful contractor bid the following:

| Size of batch | Bid per square yard [1] |
|---|---|
| 27 cubic feet | $0. 97 |
| 30 cubic feet | . 94 |
| 33 cubic feet | . 93 |
| 35 cubic feet | . 93 |

On State-aid project 2916 the successful contractor bid the following:

| Size of batch | Bid per square yard [1] |
|---|---|
| 27 cubic feet | $1. 04 |
| 30 cubic feet | . 99 |
| 33 cubic feet | . 97 |
| 35 cubic feet | . 98 |

Prior to this time the maximum allowable batch in Wisconsin was 30 cubic feet, and the contractors did not reflect as large a reduction in bid prices between the 30 and 33-cubic-foot batches as between the 27 and 30 cubic foot batches, probably because there was some doubt in their minds concerning the ability to handle the larger batches in the trucks or in the mixer. As the large sized batches were tried out in actual operation, the contractors on these jobs found that the 33-cubic-foot batch was handled with as much ease as the smaller batches, and even the 35-cubic-foot batches were handled by the new mixers without any difficulty.

On the Arkansas job the investigation was primarily arranged for quality and not for production, although detailed stop-watch studies were made on the different batch sizes to determine how the mixer cycle was affected.

### UNIFORM PROCEDURE ADOPTED FOR OBTAINING TEST SAMPLES

In order to obtain data on these three jobs as nearly comparable as possible, the same general procedure of sampling and testing was used on all jobs in determining, for each of the four corners and the center of each batch, the exact amount of gravel, sand, cement, and water contained in the concrete at these respective points. One cylinder for a compression test was also made from the concrete taken at each of these points. Three beams were made from each sampled batch and the molds for these were so placed that, in general, a beam break would be obtained for each of the five points from which the cylinders were taken.

Figure 1 shows the five sample buckets and three beam molds placed on the subgrade. The spreader bucket was dumped over these buckets and beam molds in the same way on all the jobs, so that the first beam mold

[1] State furnished cement.

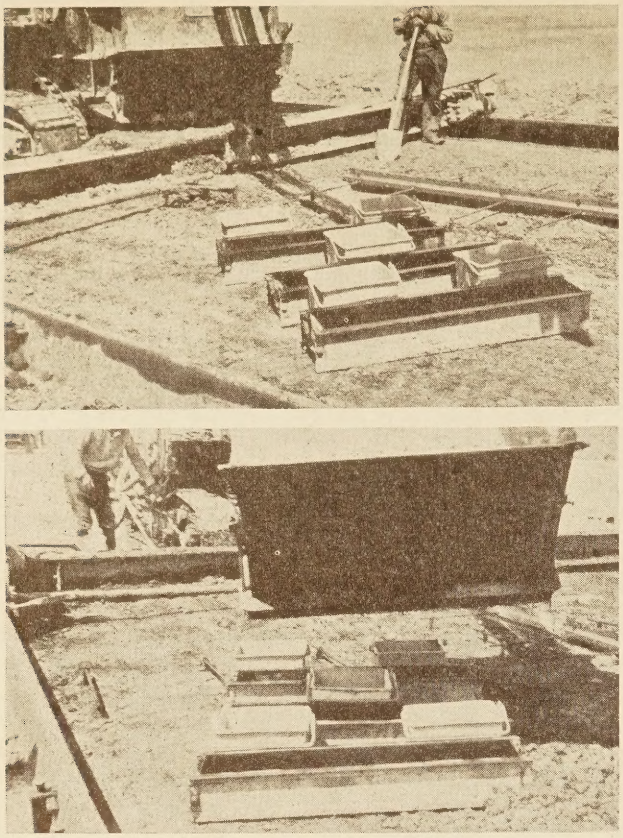


Figure 1.—Metal Sample Buckets and Metal Beam Molds in Position to Receive Concrete as Dumped from Mixer Spreader-Bucket

and two buckets received the first part of the batch, the next beam mold and bucket was filled from the middle part of the batch and the remaining beam mold and buckets received samples from the last part of the batch. As soon as this operation was completed, the sample buckets and beam molds, properly identified, were removed to the berm of the roadway as shown in the upper left-hand photograph of Figure 2. The procedure was then as follows: The concrete obtained in the first bucket was dumped into a large pan and small scoopfuls of concrete were placed alternately in a cylinder and in a pail for the separation test. This operation was repeated consecutively for each of the other buckets. The cylinder molds rested on a steel plate and were arranged in the same order as that in which the buckets were placed on the subgrade. Each cylinder was tamped twenty times along the edge and five times at various places in the center of each one-third point as they were being filled.

While these operations were in progress another man spaded the beams twenty times along each side and four times along each end with a trowel, then rodded along the edges with a bullet-pointed ⅝-inch rod in a like manner, and finally repeated the spading with the trowel after which the surface was struck off and finished. Every effort was made to leave the mass of concrete in the center of the beams undisturbed. These specimens, both beams and cylinders, were cured on the berm under wet burlap about 24 hours and then hauled in damp sand to the central curing point. In Arkansas the specimens were cured near the job in a large lake which had practically a constant temperature of about 80° F. In Wisconsin the specimens were cured in wet sand which had a fairly constant temperature of about 80° F. The beams on all the jobs were cured at the field curing station until broken. The cylinders were left to cure for about 21 days and then hauled to the State testing laboratory, where they were placed in a moist closet until they were broken at 28 days. All the beams on these four jobs were broken by the same type of portable cantilever testing machine and on each job the same operator made all the breaks. In testing the beams the load was applied on the dynamometer at the rate of 40 pounds in 10 seconds. (See fig. 2.)

#### PROPORTIONS OF MATERIALS IN EACH SAMPLE DETERMINED BY WASH TEST

A 25-pound sample of concrete was always used for the separation or wash test. All weighing was done on a 35-pound scale sensitive to one-sixteenth of an ounce. All weights were recorded in ounces and fractions of an ounce. The procedure was as follows: Each sample representing one of the four corners of the batch or the center was immediately weighed and adjusted to 25 pounds in air, and then weighed under water. (See fig. 3.) It was then placed in a nest of sieves, consisting of one No. 4, one 48-mesh, and one 100-mesh sieve, and washed over a large tub in order to retain all the wash water. The material retained on the No. 4 sieve was classified as coarse aggregate, and that retained on the 100-mesh sieve as sand. The weight of sand was later corrected to include the weight of material passing the 100-mesh sieve, which was determined by a separate auxiliary test. This material was first weighed under water, then air dried, weighed, and subjected to a sieve analysis. The sand was also weighed directly under water. The weight of the cement under water was then computed by obtaining the difference between the weight of the total sample under water and the sum of the corrected weights of the gravel and sand under water. The weight of cement for the center sample was checked by permitting the cement washed from the center sample to settle in the tub and weighing the cement thus collected under water. The weight of water was obtained by taking the difference between the total sample, or 400 ounces, and the sum of the weights of the gravel, sand, and cement. (See fig. 4.) The specific gravity of the gravel and the sand was determined with a metal pycnometer.

In order to determine the percentage of moisture in the aggregates, samples of the gravel and sand for each batch tested were taken at the plant while the truck was loading, and tested. This sample was then washed through a nest of sieves to determine the correction factor for the material passing the 100-mesh sieve.

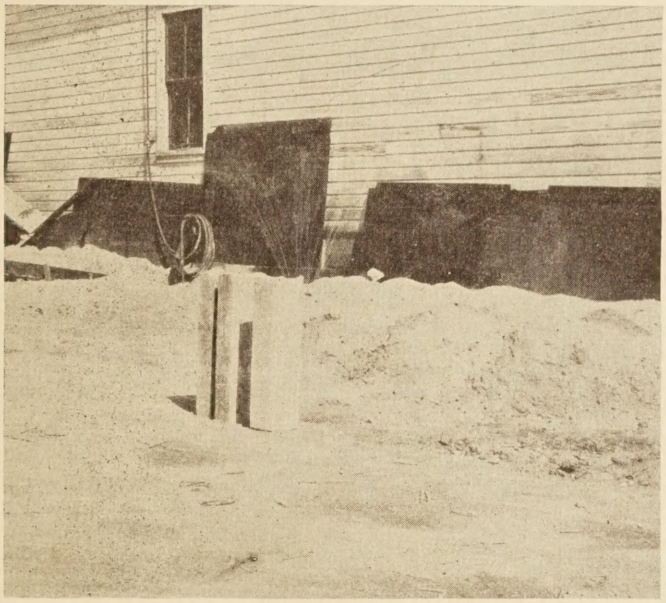
#### DETAILED PRODUCTION STUDIES MADE ON WISCONSIN JOBS

On the two Wisconsin jobs daily detailed production studies were made. At least a mile of pavement was constructed for each batch size of 27, 30, 33, and 35 cubic feet. The batchmeter was generally set at 60 seconds, which resulted in an actual mixing time of about 55 seconds for all solid materials. A little over a mile of pavement was also constructed on which a 33-cubic-foot batch was used, with the batchmeter set at 50 seconds, making the actual mixing time of all solid materials about 45 seconds.

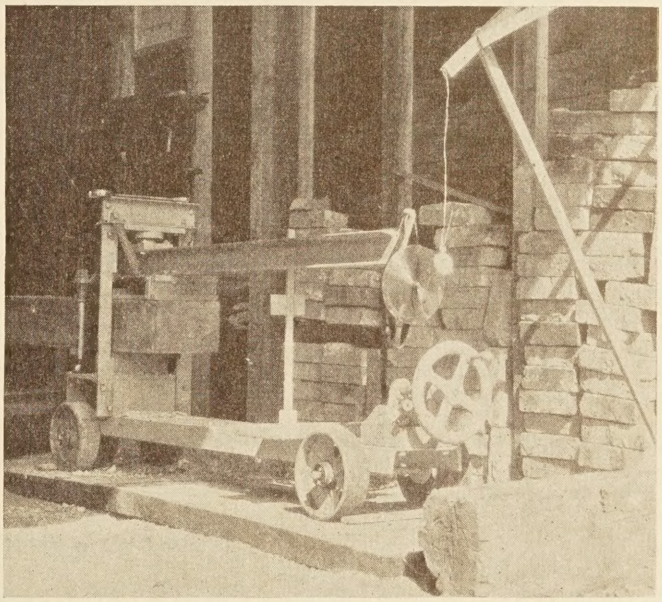
By means of stop-watch studies of the key equipment for two or more hours every day, the effect on production and unit costs was determined for each batch size and each mixing time. Three to four batches were usually sampled each day. The different sized batches

REMOVING SAMPLE BUCKETS AND BEAMS FROM THE SUBGRADE TO THE BERM OF THE ROAD, WHERE ANALYSIS WAS MADE OF THE FIVE PARTS OF THE BATCH FOR THE EXACT AMOUNT OF GRAVEL, SAND, CEMENT, AND WATER.

CYLINDERS WERE MADE ACCORDING TO THE A. S. T. M. METHODS. BEAMS WERE RODDED ONLY AT THE EDGES WITHOUT DISTURBING THE CENTER MASS OF THE CONCRETE.



BEAM SPECIMENS WERE CURED IN DAMP SAND FOR 28 DAYS AND TESTED IN THE FIELD.



THE BEAM-TESTING MACHINE AND THE LOAD APPLICATION WERE CONTROLLED SO AS TO BE THE SAME ON ALL SPECIMENS, AND ALL TESTS WERE MADE BY THE SAME OPERATOR.

FIGURE 2.—SAMPLES FOR TEST CYLINDERS AND WASH ANALYSES WERE OBTAINED FROM 4 CORNERS AND CENTER OF EACH BATCH AS PLACED; THREE BEAMS REPRESENTATIVE OF THE SAME PORTIONS OF THE BATCH WERE ALSO CAST

were alternated in order to make all conditions comparable. For example, in the morning a 27-cubic-foot batch would be sampled; just before noon a 30-cubic-foot batch; immediately after noon a 33-cubic-foot batch; and later a 35-cubic-foot batch. The following day this order would be changed. When batches to be sampled were either smaller or larger than those being run, about nine to twelve batches of the new size would be run through the mixer before the sample was taken so that the mixer would be operating normally under the changed batch size. The water at the mixer was always changed in proportion to the batch size being tested.

As soon as the work in Wisconsin was well under way the quality tests and production studies indicated that it would be decidedly more economical to use a 33 than a 30-cubic-foot batch, and that this could be done without any sacrifice of quality in regard to either uniformity of mix or strength. The 33-cubic-foot batch was therefore adopted and used entirely, except for such few modifications as were necessary in order to obtain the required test samples.

Three-year-old mixers, 1927 models, were used by both the contractors on the Wisconsin jobs during the first part of the studies. A complete series of tests and production studies were made on both of these jobs while the old pavers were still in operation, using 27, 30, 33, and 35 cubic-foot batches. Later the old mixers were replaced with new 1930 model 27E mixers and another complete study of 27, 30, 33, and 35 cubic-foot batches was made on each job for quality and production.

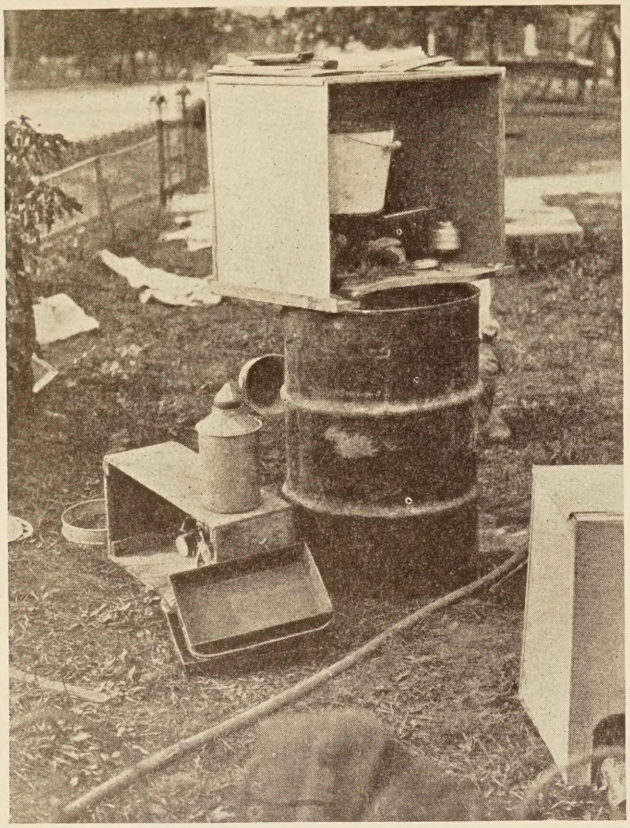


FIGURE 3.—EACH SAMPLE WAS WEIGHED IN AIR AND THEN IN WATER, WITH THE APPARATUS SHOWN. WEIGHING WAS ACCURATE TO ONE-SIXTEENTH OUNCE

FIGURE 4.—FIELD EQUIPMENT FOR WASH TEST ANALYSIS. LOWER PHOTOGRAPH SHOWS PROCESS OF WASHING THE CEMENT OUT OF THE SAMPLES OF CONCRETE THROUGH A NEST COMPOSED OF A NO. 4, A 48, AND A 100-MESH SIEVE

Before the Wisconsin studies were closed a series of tests with 30 and 33 cubic-foot batches was tried, using respectively, a 50, 60, and 80 second mixing time setting of the batchmeter. A complete study was made for each of these combinations. In all of this investigation the batchmeter was set at the nominal mixing time of 50, 60, or 80 seconds, so that the actual mixing time with all the solid materials in the drum was, in reality, about 45, 55, and 75 seconds, respectively.

#### DETAILED AND SUMMARY TABLES PREPARED

Detailed tables and summaries of which Table 1 is an example, were made for the studies on each job.

TABLE 1.—*Effect of size of batch on uniformity of mix and strength of concrete, for State-aid project 2926, Sheboygan County, Wis.; 27-cubic-foot batch; 27E paver, old model, good condition; aggregates, good limestone gravel, pit sand*

| Batch No. and date made (1930) | Part of batch | Proportions by weight | | | | Sample variation factor | Workability factor $b/b_0$ | Cylinders, 28 days | | Beams | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | 7 days | | 28 days | | | |
| | | | | | | | | | | | | End break | | Center break | |
| | | Gravel | Sand | Cement | Water | | | Strength | Variation | Strength | Variation | Strength | Variation | Strength | Variation |
| | | *Per cent* | *Per cent* | *Per cent* | *Per cent* | *Per cent* | | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* |
| No. 4 (Aug. 4) | A | 49.34 | 32.75 | 11.02 | 6.88 | 1.68 | 0.691 | 2,950 | 4.90 | 605 | 4.01 | 782 | 2.21 | 805 | 2.98 |
| | B | 49.31 | 31.25 | 12.42 | 7.01 | 4.41 | .691 | 2,840 | 8.44 | | | | | | |
| | Center | 50.32 | 32.32 | 10.65 | 6.70 | 1.98 | .708 | 3,330 | 7.35 | 540 | 7.17 | 857 | 7.16 | 815 | 4.26 |
| | C | 50.69 | 31.05 | 11.62 | 6.64 | 2.53 | .713 | 3,200 | 3.16 | 600 | 3.15 | 760 | 4.96 | 725 | 7.25 |
| | D | 48.52 | 34.12 | 10.87 | 6.47 | 3.96 | .684 | 3,190 | 2.84 | | | | | | |
| Average | | 49.64 | 32.30 | 11.32 | 6.74 | 2.91 | .697 | 3,102 | 5.34 | 582 | 4.78 | 800 | 4.78 | 782 | 4.83 |
| Batch variation per cent | | 1.38 | 2.84 | 4.99 | 2.43 | | | | | | | | | | |
| No. 7 (Aug. 6) | A | 52.53 | 30.70 | 11.31 | 5.46 | 2.16 | .749 | 3,030 | .03 | 638 | 16.01 | 835 | 5.70 | 780 | 4.29 |
| | B | 50.81 | 31.87 | 11.86 | 5.45 | 4.91 | .724 | 3,230 | 6.64 | | | | | | |
| | Center | 50.86 | 32.07 | 11.86 | 5.20 | 3.83 | .727 | 2,695 | 11.02 | 525 | 4.54 | 735 | 6.97 | 790 | 3.07 |
| | C | 58.34 | 26.80 | 10.35 | 4.51 | 10.70 | .845 | 2,900 | 4.26 | 487 | 11.46 | 800 | 1.27 | 875 | 7.37 |
| | D | | | | | | | 3,290 | 8.61 | | | | | | |
| Average | | 53.13 | 30.36 | 11.35 | 5.15 | 5.40 | .761 | 3,029 | 6.11 | 550 | 10.67 | 790 | 4.65 | 815 | 4.91 |
| Batch variation per cent | | 4.89 | 5.85 | 4.53 | 6.33 | | | | | | | | | | |
| No. 10 (Aug. 17) | A | 50.37 | 31.75 | 11.62 | 6.25 | 2.22 | .713 | 3,080 | 1.48 | 510 | 1.30 | 800 | 4.19 | 770 | 5.67 |
| | B | 50.17 | 31.82 | 11.85 | 6.15 | 2.47 | .750 | 3,160 | 4.12 | | | | | | |
| | Center | 51.86 | 30.35 | 11.67 | 6.11 | .80 | .736 | 2,945 | 2.96 | 480 | 7.10 | 885 | 5.99 | 824 | .94 |
| | C | 54.14 | 28.95 | 10.96 | 5.95 | 4.53 | .767 | 2,810 | 7.41 | 560 | 8.39 | 820 | 1.80 | 855 | 4.76 |
| | D | 51.90 | 30.40 | 11.45 | 6.24 | .84 | .734 | 3,180 | 4.78 | | | | | | |
| Average | | 51.69 | 30.65 | 11.51 | 6.14 | 2.17 | .740 | 3,035 | 4.15 | 517 | 5.60 | 835 | 4.00 | 816 | 3.79 |
| Batch variation per cent | | 2.19 | 2.95 | 2.12 | 1.43 | | | | | | | | | | |

TABLE 1.—*Effect of size of batch on uniformity of mix and strength of concrete, for State-aid project 2926, Sheboygan County, Wis.; 27-cubic-foot batch; 27E paver, old model, good condition; aggregates, good limestone gravel, pit sand*—Continued

| Batch No. and date made (1930) | Part of batch | Proportions by weight | | | | Sample variation factor | Workability factor $b/b_0$ | Cylinders, 28 days | | Beams | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | 7 days | | 28 days | | | |
| | | | | | | | | | | | | End break | | Center break | |
| | | Gravel | Sand | Cement | Water | | | Strength | Variation | Strength | Variation | Strength | Variation | Strength | Variation |
| | | *Per cent* | *Per cent* | *Per cent* | *Per cent* | *Per cent* | | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* |
| No. 14 (Aug. 8) | A | 48.20 | 32.75 | 12.37 | 6.67 | 6.26 | 0.686 | 3,290 | 1.48 | 480 | 11.23 | 970 | 8.50 | 865 | 3.59 |
| | B | 52.51 | 30.30 | 11.47 | 5.71 | 3.61 | .752 | 3,410 | 5.18 | | | | | | |
| | Center | 50.48 | 30.72 | 12.15 | 6.64 | 2.92 | .708 | 3,310 | 2.10 | 552 | 2.09 | 857 | 4.13 | 820 | 1.80 |
| | C | 53.81 | 29.12 | 11.17 | 5.89 | 5.11 | .767 | 3,070 | 5.30 | 590 | 9.12 | 855 | 4.36 | 820 | 1.80 |
| | D | 51.34 | 30.45 | 12.30 | 5.91 | 2.09 | .738 | 3,130 | 3.45 | | | | | | |
| Average | | 51.27 | 30.67 | 11.89 | 6.16 | 4.00 | .730 | 3,242 | 3.50 | 541 | 7.48 | 894 | 5.66 | 835 | 2.40 |
| Batch variation per cent | | 3.00 | 2.78 | 3.84 | 6.37 | | | | | | | | | | |
| No. 23 (Aug. 13) | A | 52.19 | 30.45 | 11.27 | 6.09 | 3.81 | .738 | 4,220 | 9.55 | 670 | 2.66 | 1,020 | 4.08 | 1,055 | 1.10 |
| | B | 49.42 | 32.37 | 11.77 | 6.42 | 9.27 | .697 | 4,260 | 10.59 | | | | | | |
| | Center | 54.42 | 29.02 | 10.70 | 5.85 | 1.12 | .773 | 3,330 | 13.58 | 705 | 2.43 | 985 | .51 | 1,100 | 3.12 |
| | C | 59.58 | 25.70 | 9.40 | 5.32 | 11.28 | .854 | 3,740 | 2.91 | 690 | .24 | 935 | 4.59 | 1,045 | 2.04 |
| | D | 54.62 | 29.20 | 10.02 | 6.15 | 2.58 | .752 | 3,710 | 3.68 | | | | | | |
| Average | | 54.05 | 29.35 | 10.63 | 5.97 | 5.61 | .763 | 3,852 | 8.06 | 688 | 1.78 | 980 | 3.06 | 1,067 | 2.09 |
| Batch variation per cent | | 4.79 | 5.62 | 6.94 | 5.10 | | | | | | | | | | |
| No. 29 (Aug. 15) | A | 52.45 | 30.75 | 10.80 | 5.99 | 3.21 | .743 | 2,970 | 1.07 | 632 | 10.30 | 930 | 2.96 | 845 | .20 |
| | B | 48.12 | 34.12 | 11.35 | 6.40 | 4.44 | .679 | 3,100 | 3.26 | | | | | | |
| | Center | 51.78 | 31.12 | 10.85 | 6.24 | 1.48 | .734 | 2,790 | 7.06 | 595 | 3.84 | 840 | 7.01 | 870 | 2.75 |
| | C | 52.23 | 30.75 | 10.57 | 6.44 | 2.79 | .737 | 3,010 | .27 | 492 | 14.14 | 940 | 4.06 | 825 | 2.56 |
| | D | 50.11 | 32.20 | 11.17 | 6.51 | 1.98 | .706 | 3,140 | 4.59 | | | | | | |
| Average | | 50.94 | 31.79 | 10.95 | 6.32 | 2.78 | .720 | 3,002 | 3.25 | 573 | 9.43 | 903 | 4.68 | 847 | 1.84 |
| Batch variation per cent | | 2.86 | 3.45 | 2.28 | 2.53 | | | | | | | | | | |
| No. 32 (Aug. 16) | A | 52.98 | 30.05 | 10.95 | 6.01 | 3.20 | .747 | 3,460 | 13.43 | 585 | 6.00 | 935 | 4.91 | 880 | 11.12 |
| | B | 51.75 | 31.05 | 10.95 | 6.25 | .97 | .728 | 2,750 | 9.82 | | | | | | |
| | Center | 48.48 | 32.62 | 12.15 | 6.74 | 6.62 | .681 | 3,040 | .33 | 612 | 1.65 | 950 | 3.39 | 1,020 | 3.03 |
| | C | 52.86 | 30.05 | 10.92 | 6.16 | 2.62 | .747 | 2,910 | 4.58 | 670 | 7.66 | 1,065 | 8.31 | 1,070 | 8.08 |
| | D | 51.45 | 31.15 | 10.95 | 6.45 | 1.20 | .725 | 3,090 | 1.31 | | | | | | |
| Average | | 51.51 | 30.98 | 11.18 | 6.32 | 2.92 | .726 | 3,050 | 5.89 | 622 | 5.11 | 983 | 5.54 | 990 | 7.41 |
| Batch variation per cent | | 2.39 | 2.42 | 3.44 | 3.45 | | | | | | | | | | |
| No. 34 (Aug. 18) | A | 47.95 | 34.00 | 11.90 | 6.15 | 2.98 | .676 | 4,020 | 1.30 | 755 | 1.25 | 980 | 4.45 | 965 | 9.88 |
| | B | 48.86 | 33.25 | 11.72 | 6.16 | 1.60 | .691 | 4,160 | 2.14 | | | | | | |
| | Center | 48.04 | 33.62 | 12.10 | 6.23 | 3.49 | .680 | 4,055 | .44 | 795 | 6.61 | 895 | 4.61 | 835 | 4.93 |
| | C | 50.82 | 32.00 | 11.31 | 5.86 | 2.47 | .723 | 3,990 | 2.04 | 687 | 7.87 | 940 | .18 | 835 | 4.93 |
| | D | 52.47 | 31.00 | 10.60 | 5.93 | 5.32 | .744 | 4,140 | 1.64 | | | | | | |
| Average | | 49.63 | 32.77 | 11.52 | 6.06 | 3.17 | .703 | 4,073 | 1.51 | 746 | 5.24 | 938 | 3.08 | 878 | 6.58 |
| Batch variation per cent | | 3.25 | 3.11 | 3.98 | 2.34 | | | | | | | | | | |
| No. 38 (Aug. 19) | A | 50.31 | 31.52 | 12.05 | 6.11 | .66 | .715 | 3,560 | 3.49 | 665 | 4.28 | 1,025 | 3.71 | 905 | 3.21 |
| | B | 47.45 | 33.85 | 12.09 | 6.61 | 5.85 | .667 | 3,760 | 9.30 | | | | | | |
| | Center | 50.51 | 31.37 | 12.07 | 6.03 | .98 | .717 | 3,380 | 1.74 | 643 | .83 | 905 | 8.43 | 930 | .53 |
| | C | 45.51 | 34.90 | 12.90 | 6.68 | 9.63 | .641 | 3,390 | 1.45 | 605 | 5.13 | 1,035 | 4.73 | 970 | 3.74 |
| | D | 58.75 | 25.87 | 10.15 | 5.22 | 15.86 | .842 | 3,110 | 9.59 | | | | | | |
| Average | | 50.51 | 31.50 | 11.85 | 6.13 | 6.60 | .716 | 3,440 | 5.11 | 638 | 3.41 | 988 | 5.62 | 935 | 2.49 |
| Batch variation per cent | | 6.55 | 7.33 | 5.76 | 6.76 | | | | | | | | | | |

AVERAGES

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | 50.70 | 31.64 | 11.48 | 6.18 | 2.91 | .717 | 3,398 | 4.08 | 616 | 6.34 | 920 | 4.52 | 875 | 4.67 |
| | B | 49.82 | 32.21 | 11.72 | 6.24 | 4.17 | .708 | 3,408 | 6.61 | | | | | | |
| | Center | 50.75 | 31.47 | 11.58 | 6.19 | 2.58 | .718 | 3,208 | 5.18 | 605 | 4.03 | 879 | 5.36 | 889 | 2.71 |
| | C | 53.11 | 29.11 | 11.02 | 5.94 | 5.74 | .755 | 3,224 | 3.49 | 598 | 7.46 | 905 | 3.81 | 891 | 4.73 |
| | D | 52.39 | 30.55 | 10.94 | 6.11 | 4.23 | .741 | 3,331 | 4.50 | | | | | | |
| Grand average | | 51.35 | 31.16 | 11.35 | 6.13 | 3.95 | .727 | 3,314 | 4.77 | 606 | 5.94 | 901 | 4.56 | 885 | 4.04 |
| Batch variation per cent | | 3.48 | 4.04 | 4.21 | 4.08 | | | | | | | | | | |
| Design values | | 53.17 | 29.97 | 11.01 | 5.85 | | .770 | | | | | 650 | | 650 | |

These tables give the results of the analysis of each sample, the percentage of coarse aggregate, sand, cement, and water it contained; the average percentage variation of each material within the batch; the variation factor within the sample, and the compressive and transverse strength of the respective cylinders and beams. Column 2 of each of these tables identifies the part of the batch from which the sample was taken as follows: Looking away from the mixer, sample A was taken from the left front corner of the batch, B from the right front corner, that called Center from the central portion of the batch, C from the left rear, and D from the right rear corner.

Under the caption "Proportions by weight" thes tables show in percentage by weight the values give by the analysis for the gravel, sand, cement, an water found in each sample. Each batch has also bee summarized, and then all batches sampled on eac job for a given batch size have been averaged togethe to obtain the summaries shown at the bottom of each of the various tables, and also combined into the smaller summary tables for each job or study.

If it were possible so to proportion and mix the concrete as to obtain the same amount of gravel, sand, cement, and water in all parts of the batch, the percentage variation would, of course, be zero. However,

TABLE 2.—*General summary showing effect of size of batch on uniformity of mix and strength of concrete, for State-aid project 2926, Sheboygan County, Wis.; 27E paver, 1927 model, good condition; aggregates, good limestone gravel, pit sand*

| Size of batch | Part of batch | Proportions by weight: Gravel | Proportions by weight: Sand | Proportions by weight: Cement | Proportions by weight: Water | Average sample variation factor | Workability factor $b/b_0$ | Cylinders, 28 days: Strength | Cylinders, 28 days: Variation | Beams, 7 days: Strength | Beams, 7 days: Variation | Beams, 28 days, End break: Strength | Beams, 28 days, End break: Variation | Beams, 28 days, Center break: Strength | Beams, 28 days, Center break: Variation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Per cent* | *Per cent* | *Per cent* | *Per cent* | *Per cent* | | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* |
| 27 cubic feet | A | 50.70 | 31.64 | 11.48 | 6.18 | 2.91 | 0.717 | 3,398 | 4.08 | 616 | 6.34 | 920 | 4.52 | 875 | 4.67 |
| | B | 49.82 | 32.21 | 11.72 | 6.24 | 4.17 | .708 | 3,408 | 6.61 | | | | | | |
| | Center | 50.75 | 31.47 | 11.58 | 6.19 | 2.58 | .718 | 3,208 | 5.18 | 605 | 4.03 | 879 | 5.36 | 889 | 2.71 |
| | C | 53.11 | 29.11 | 11.02 | 5.94 | 5.74 | .755 | 3,224 | 3.49 | 598 | 7.46 | 905 | 3.81 | 891 | 4.73 |
| | D | 52.39 | 30.55 | 10.94 | 6.11 | 4.23 | .741 | 3,331 | 4.50 | | | | | | |
| Average | | 51.35 | 31.16 | 11.35 | 6.13 | 3.95 | .727 | 3,314 | 4.77 | 606 | 5.94 | 901 | 4.56 | 885 | 4.04 |
| Batch variation per cent | | 3.48 | 4.04 | 4.21 | 4.08 | | | | | | | | | | |
| 30 cubic feet | A | 50.05 | 32.34 | 11.28 | 6.31 | 5.32 | .708 | 3,252 | 7.13 | 582 | 5.37 | 868 | 4.12 | 818 | 4.66 |
| | B | 49.21 | 32.62 | 11.67 | 6.49 | 6.67 | .692 | 3,433 | 6.23 | | | | | | |
| | Center | 52.11 | 30.82 | 10.83 | 6.22 | 2.57 | .739 | 3,262 | 4.33 | 586 | 2.06 | 855 | 3.90 | 870 | 4.78 |
| | C | 56.56 | 27.76 | 10.15 | 5.52 | 8.51 | .810 | 3,178 | 8.99 | 568 | 5.45 | 859 | 2.74 | 882 | 6.03 |
| | D | 54.21 | 29.36 | 10.57 | 5.86 | 4.03 | .771 | 3,372 | 9.21 | | | | | | |
| Average | | 52.43 | 30.58 | 10.90 | 6.08 | 5.42 | .744 | 3,300 | 7.20 | 579 | 4.25 | 861 | 3.59 | 856 | 5.17 |
| Batch variation per cent | | 4.77 | 5.69 | 5.70 | 5.52 | | | | | | | | | | |
| 33 cubic feet | A | 49.97 | 31.87 | 11.92 | 6.24 | 3.78 | .708 | 3,508 | 6.39 | 612 | 4.22 | 861 | 5.66 | 868 | 5.02 |
| | B | 49.80 | 31.98 | 11.94 | 6.28 | 5.02 | .704 | 3,433 | 6.16 | | | | | | |
| | Center | 51.93 | 30.30 | 11.65 | 6.10 | 4.45 | .737 | 3,539 | 5.18 | 642 | 3.64 | 920 | 4.05 | 882 | 5.03 |
| | C | 54.60 | 28.51 | 10.94 | 5.96 | 6.90 | .776 | 3,474 | 3.98 | 636 | 3.49 | 919 | 3.18 | 951 | 8.02 |
| | D | 52.50 | 30.23 | 11.21 | 6.04 | 4.65 | .745 | 3,608 | 6.60 | | | | | | |
| Average | | 51.76 | 30.58 | 11.53 | 6.12 | 4.96 | .734 | 3,512 | 5.66 | 630 | 3.78 | 901 | 4.29 | 900 | 6.03 |
| Batch variation per cent | | 4.41 | 5.04 | 5.46 | 4.94 | | | | | | | | | | |
| 35 cubic feet | A | 50.99 | 31.63 | 11.25 | 6.12 | 2.76 | .716 | 3,148 | 4.94 | 602 | 2.91 | 882 | 5.21 | 897 | 5.04 |
| | B | 51.21 | 31.53 | 11.09 | 6.16 | 3.59 | .732 | 3,102 | 6.66 | | | | | | |
| | Center | 49.85 | 32.14 | 11.67 | 6.33 | 5.17 | .705 | 3,359 | 5.77 | 607 | 3.73 | 886 | 3.14 | 903 | 5.53 |
| | C | 53.23 | 30.29 | 10.53 | 5.93 | 5.80 | .756 | 3,069 | 6.20 | 611 | 3.17 | 861 | 3.35 | 854 | 3.95 |
| | D | 54.08 | 29.57 | 10.63 | 5.71 | 5.66 | .770 | 3,211 | 8.79 | | | | | | |
| Average | | 51.88 | 31.03 | 11.04 | 6.05 | 4.59 | .735 | 3,178 | 6.47 | 607 | 3.27 | 876 | 3.90 | 885 | 4.84 |
| Batch variation per cent | | 3.97 | 4.06 | 5.99 | 4.37 | | | | | | | | | | |

TABLE 3.—*General summary showing effect of size of batch on uniformity of mix and strength of concrete, for State-aid project 2926, Sheboygan County, Wis.; 27E paver, new; aggregate, good limestone gravel, pit sand*

| Size of batch | Part of batch | Proportions by weight: Gravel | Proportions by weight: Sand | Proportions by weight: Cement | Proportions by weight: Water | Average sample variation factor | Workability factor $b/b_0$ | Cylinders, 28 days: Strength | Cylinders, 28 days: Variation | Beams, 7 days: Strength | Beams, 7 days: Variation | Beams, 28 days, End break: Strength | Beams, 28 days, End break: Variation | Beams, 28 days, Center break: Strength | Beams, 28 days, Center break: Variation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Per cent* | *Per cent* | *Per cent* | *Per cent* | *Per cent* | | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* |
| 27 cubic feet | A | 52.89 | 29.63 | 11.51 | 5.96 | 3.65 | 0.753 | 3,616 | 10.29 | 613 | 5.45 | 890 | 3.80 | 859 | 4.39 |
| | B | 52.76 | 29.95 | 11.55 | 5.73 | 3.07 | .751 | 3,491 | 5.40 | | | | | | |
| | Center | 53.79 | 29.07 | 11.36 | 5.77 | 3.69 | .766 | 3,370 | 8.21 | 573 | 3.95 | 837 | 4.56 | 824 | 4.81 |
| | C | 52.78 | 29.76 | 11.59 | 5.87 | 2.72 | .751 | 3,623 | 4.60 | 593 | 2.76 | 878 | 2.71 | 880 | 5.56 |
| | D | 52.78 | 29.82 | 11.60 | 5.81 | 4.24 | .752 | 3,671 | 8 90 | | | | | | |
| Average | | 53.00 | 29.65 | 11.52 | 5.83 | 3.48 | .755 | 3,554 | 7.48 | 593 | 4.05 | 868 | 3.69 | 854 | 4.92 |
| Batch variation per cent | | 2.59 | 3.40 | 4.14 | 3.77 | | | | | | | | | | |
| 30 cubic feet | A | 52.13 | 30.07 | 11.88 | 5.92 | 3.36 | .740 | 3,678 | 8.91 | 611 | 5.34 | 913 | 4.48 | 903 | 7.33 |
| | B | 53.38 | 29.34 | 11.59 | 5.68 | 2.69 | .762 | 3,711 | 4.99 | | | | | | |
| | Center | 53.93 | 28.70 | 11.62 | 5.74 | 4.69 | .769 | 3,494 | 4.47 | 619 | 3.83 | 919 | 3.58 | 921 | 4.81 |
| | C | 53.35 | 29.04 | 11.66 | 5.94 | 4.98 | .760 | 3,577 | 9.96 | 614 | 4.05 | 873 | 4.82 | 890 | 4.89 |
| | D | 51.43 | 30.58 | 12.01 | 5.98 | 4.17 | .728 | 3,729 | 5.39 | | | | | | |
| Average | | 52.84 | 29.55 | 11.75 | 5.85 | 3.98 | .752 | 3,658 | 6.75 | 615 | 4.41 | 901 | 4.29 | 904 | 5.64 |
| Batch variation per cent | | 3.18 | 3.72 | 3.50 | 5.52 | | | | | | | | | | |
| 33 cubic feet | A | 51.87 | 30.69 | 11.53 | 5.91 | 2.36 | .736 | 3,911 | 6.29 | 623 | 4.20 | 905 | 4.10 | 864 | 4.63 |
| | B | 52.65 | 30.18 | 11.26 | 5.91 | 4.00 | .748 | 3,956 | 5.70 | | | | | | |
| | Center | 52.44 | 30.02 | 11.59 | 5.94 | 4.31 | .744 | 3,819 | 4.86 | 609 | 3.58 | 906 | 2.72 | 900 | 4.13 |
| | C | 50.80 | 31.29 | 11.92 | 5.44 | 4.03 | .721 | 3,947 | 5.32 | 624 | 5.77 | 914 | 3.77 | 864 | 4.91 |
| | D | 52.42 | 30.65 | 11.16 | 5.10 | 3.19 | .747 | 3,874 | 6.89 | | | | | | |
| Average | | 52.04 | 30.56 | 11.49 | 5.90 | 3.58 | .739 | 3,901 | 5.81 | 619 | 4.49 | 908 | 3.53 | 876 | 4.56 |
| Batch variation per cent | | 2.87 | 3.66 | 4.20 | 3.59 | | | | | | | | | | |
| 35 cubic feet | A | 51.65 | 30.85 | 11.69 | 5.81 | 2.70 | .735 | 3,858 | 4.83 | 610 | 6.83 | 916 | 4.80 | 913 | 3.86 |
| | B | 52.58 | 30.27 | 11.43 | 5.71 | 3.23 | .749 | 4,025 | 6.36 | | | | | | |
| | Center | 51.69 | 30.57 | 11.87 | 5.86 | 3.31 | .736 | 3,809 | 5.89 | 600 | 6.11 | 945 | 4.88 | 870 | 5.15 |
| | C | 53.01 | 29.76 | 11.38 | 5.85 | 4.69 | .753 | 3,818 | 4.77 | 611 | 3.19 | 910 | 5.83 | 936 | 4.62 |
| | D | 53.52 | 29.48 | 11.40 | 5.58 | 4.75 | .763 | 3,719 | 7.34 | | | | | | |
| Average | | 52.50 | 30.18 | 11.55 | 5.77 | 3.74 | .748 | 3,846 | 5.84 | 607 | 5.34 | 922 | 5.17 | 903 | 4.54 |
| Batch variation per cent | | 2.92 | 3.74 | 3.89 | 4.39 | | | | | | | | | | |

since it is largely by chance that the individual particles which make up the concrete go where they do, there will be variations in the distribution of some or all of the ingredients. The greater this variation, the less will be the uniformity of samples taken from point to point within a batch. To compare the amount of variation within a batch, a factor of variation, or percentage variation factor, has been computed and is shown in these tables for each individual sample. This variation factor has been computed as follows: The percentages of gravel, sand, cement, and water for the five parts of each separate batch have been averaged and the arithmetical average of the percentage variation of each of the four ingredients in a sample from the average of the like ingredients for the batch, when expressed as a percentage, equals the variation factor for the sample. This factor is given in the seventh column of Table 1. The larger the number the greater the variation, and the smaller the number the greater the apparent uniformity. The percentage variation of each ingredient from the average of the batch is shown below the average of the percentage by weight of the four ingredients (gravel, sand, cement, and water) and was computed for each batch and also for the summary sheets.

The workability factor, $b/b_o$, tabulated in the eighth column, is the ratio which the solid or absolute volume of the coarse aggregates in a cubic foot of the concrete bears to the solid or absolute volume of a cubic foot of the coarse aggregate. The percentage of excess mortar is equal to $1-b/b_o$. For any given set of job conditions, this factor appears to be a good index of how workable the batch will be. Under the heading "Cylinders, 28 days" is shown the compressive strength for each cylinder as well as the average of all cylinders made from each batch. These data are so arranged as to correspond to the other factors shown for the same parts of the batch. The beam strengths are shown in like manner.

On the Arkansas and Wisconsin projects definite amounts of cement and water were specified and the grading of the coarse aggregate was closely controlled by the use of separate sizes. The mix was designed entirely by State engineers. Comparable conditions were therefore obtained throughout the tests, and the same materials were used for each series of tests.

### SIZE OF BATCH SHOWS NO ESSENTIAL INFLUENCE ON CONCRETE QUALITY

Tables 2, 3, 4, and 5 give a concise summary of the principal part of the work on the two Wisconsin jobs. An examination of the values given in these tables for the average variations of the concrete ingredients within the batch, the average compressive and transverse strengths, and the average percentage variations of these strengths within a batch, indicates that with a 60-second setting of the batchmeter no essential difference can be detected between a 27-cubic-foot batch and a 35-cubic-foot batch for any of the four mixers used on those two jobs. For example, if we combine the work on the two Wisconsin jobs for the period during which the new mixers were used, as this would illustrate the results which can be obtained under the most favorable conditions, we have the values given in Table 6.

If we now turn to the period when 3-year-old mixers were used on these two jobs as representing the re-

TABLE 4.—*General summary showing effect of size of batch on uniformity of mix and strength of concrete, for State-aid project 2916, Sheboygan County, Wis.; 27E paver, 1927 model, good condition; aggregates, good limestone gravel, pit sand*

| Size of batch | Part of batch | Proportions by weight | | | | Average sample variation factor | Workability factor $b/b_0$ | Cylinders, 28 days | | Beams | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | 7 days | | 28 days | | | |
| | | | | | | | | | | | | End break | | Center break | |
| | | Gravel | Sand | Cement | Water | | | Strength | Variation | Strength | Variation | Strength | Variation | Strength | Variation |
| | | *Per cent* | *Per cent* | *Per cent* | *Per cent* | *Per cent* | | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* |
| 27 cubic feet | A | 50.28 | 31.79 | 11.16 | 6.09 | 6.33 | 0.716 | 3,726 | 5.96 | 578 | 4.48 | 900 | 4.57 | 887 | 3.19 |
| | B | 50.87 | 31.28 | 10.89 | 6.29 | 6.06 | .728 | 3,572 | 5.97 | | | | | | |
| | Center. | 55.99 | 27.58 | 10.06 | 5.69 | 7.10 | .803 | 3,340 | 9.58 | 590 | 7.23 | 890 | 5.34 | 872 | 1.77 |
| | C | 53.47 | 29.21 | 10.82 | 5.84 | 5.17 | .770 | 3,557 | 4.98 | 567 | 4.86 | 879 | 3.46 | 825 | 3.90 |
| | D | 53.75 | 29.28 | 10.50 | 5.79 | 6.45 | .773 | 3,550 | 4.99 | | | | | | |
| Average | | 52.87 | 29.83 | 10.68 | 5.94 | 6.22 | .760 | 3,549 | 6.30 | 578 | 5.52 | 890 | 4.46 | 865 | 2.88 |
| Batch variation per cent | | 5.07 | 6.45 | 6.94 | 6.42 | | | | | | | | | | |
| 30 cubic feet | A | 49.89 | 31.46 | 11.89 | 6.00 | 4.60 | .710 | 3,803 | 6.17 | 631 | 3.48 | 926 | 4.55 | 884 | 7.15 |
| | B | 50.74 | 31.19 | 11.12 | 6.14 | 3.43 | .732 | 3,863 | 7.13 | | | | | | |
| | Center. | 53.64 | 29.38 | 10.46 | 5.69 | 5.96 | .783 | 3,500 | 8.20 | 633 | 3.31 | 938 | 3.22 | 886 | 6.32 |
| | C | 53.61 | 29.34 | 10.42 | 5.89 | 5.78 | .788 | 3,821 | 5.44 | 619 | 4.50 | 915 | 4.01 | 905 | 5.06 |
| | D | 50.81 | 31.18 | 11.19 | 6.02 | 3.44 | .738 | 3,678 | 5.48 | | | | | | |
| Average | | 51.73 | 30.50 | 11.01 | 5.94 | 4.62 | .749 | 3,733 | 6.48 | 628 | 3.74 | 927 | 3.92 | 890 | 6.35 |
| Batch variation per cent | | 3.62 | 4.30 | 6.60 | 3.94 | | | | | | | | | | |
| 33 cubic feet | A | 50.68 | 31.00 | 11.45 | 6.16 | 4.48 | .724 | 3,653 | 3.73 | 603 | 4.55 | 893 | 4.46 | 896 | 3.45 |
| | B | 50.44 | 31.43 | 11.16 | 6.21 | 3.41 | .721 | 3,614 | 6.02 | | | | | | |
| | Center. | 53.09 | 29.77 | 10.48 | 5.91 | 4.49 | .765 | 3,568 | 3.97 | 595 | 3.63 | 896 | 6.11 | 882 | 3.77 |
| | C | 51.74 | 30.37 | 11.13 | 6.05 | 3.55 | .738 | 3,823 | 4.40 | 617 | 4.40 | 940 | 5.64 | 899 | 3.03 |
| | D | 51.95 | 30.57 | 10.84 | 5.94 | 3.88 | .746 | 3,742 | 4.12 | | | | | | |
| Average | | 51.59 | 30.63 | 11.01 | 6.05 | 3.96 | .738 | 3,680 | 4.45 | 605 | 4.20 | 910 | 5.40 | 892 | 3.42 |
| Batch variation per cent | | 2.97 | 3.16 | 5.88 | 3.85 | | | | | | | | | | |
| 35 cubic feet | A | 51.18 | 31.37 | 10.88 | 5.89 | 5.51 | .735 | 4,015 | 3.74 | 600 | 3.37 | 936 | 3.74 | 919 | 3.82 |
| | B | 51.50 | 30.89 | 10.91 | 6.04 | 3.76 | .737 | 3,962 | 5.03 | | | | | | |
| | Center. | 50.73 | 31.51 | 11.44 | 5.66 | 4.09 | .729 | 3,827 | 3.39 | 613 | 5.01 | 925 | 5.93 | 899 | 2.81 |
| | C | 54.01 | 29.28 | 10.25 | 5.74 | 6.06 | .777 | 3,846 | 5.59 | 597 | 3.95 | 930 | 6.61 | 916 | 2.98 |
| | D | 52.79 | 29.88 | 11.18 | 5.47 | 4.67 | .762 | 3,865 | 8.71 | | | | | | |
| Average | | 52.00 | 30.61 | 10.95 | 5.76 | 4.79 | .747 | 3,903 | 5.29 | 603 | 4.11 | 930 | 5.43 | 913 | 3.22 |
| Batch variation per cent | | 3.03 | 3.58 | 6.50 | 6.05 | | | | | | | | | | |

TABLE 5.—*General summary showing effect of size of batch on uniformity of mix and strength of concrete, for State-aid project 2916, Sheboygan County, Wis.; 27-E paver, new; aggregates, good limestone gravel, pit sand*

| Size of batch | Part of batch | Proportions by weight | | | | Average sample variation factor | Workability factor $b/b_0$ | Cylinders, 28 days | | Beams | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | 7 days | | 28 days | | | |
| | | | | | | | | | | | | End break | | Center break | |
| | | Gravel | Sand | Cement | Water | | | Strength | Variation | Strength | Variation | Strength | Variation | Strength | Variation |
| | | *Per cent* | *Per cent* | *Per cent* | *Per cent* | *Per cent* | | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* |
| 27 cubic feet | A | 51.31 | 30.95 | 11.85 | 5.56 | 4.27 | 0.739 | 3,632 | 5.71 | 574 | 5.88 | 853 | 3.17 | 832 | 5.67 |
| | B | 51.54 | 30.82 | 11.69 | 5.56 | 3.46 | .741 | 3,601 | 4.75 | | | | | | |
| | Center | 54.24 | 28.94 | 11.03 | 5.41 | 4.68 | .779 | 3,480 | 6.15 | 570 | 6.11 | 810 | 5.29 | 842 | 4.87 |
| | C | 52.98 | 29.56 | 11.61 | 5.46 | 4.33 | .766 | 3,708 | 7.37 | 592 | 4.24 | 845 | 5.24 | 877 | 6.54 |
| | D | 52.10 | 30.19 | 11.87 | 5.53 | 3.50 | .750 | 3,748 | 6.24 | | | | | | |
| Average | | 52.43 | 30.09 | 11.61 | 5.51 | 4.05 | .755 | 3,634 | 6.04 | 579 | 5.41 | 836 | 4.57 | 850 | 5.69 |
| Batch variation per cent | | 3.19 | 4.39 | 4.49 | 4.13 | | | | | | | | | | |
| 30 cubic feet | A | 50.85 | 31.08 | 12.23 | 5.55 | 3.57 | .733 | 3,660 | 4.10 | 586 | 4.47 | 846 | 5.15 | 873 | 6.62 |
| | B | 51.45 | 30.66 | 12.14 | 5.48 | 3.26 | .743 | 3,664 | 4.21 | | | | | | |
| | Center | 52.10 | 30.33 | 11.79 | 5.48 | 3.06 | .751 | 3,569 | 3.44 | 581 | 4.40 | 831 | 4.70 | 875 | 5.79 |
| | C | 51.95 | 30.40 | 11.95 | 5.45 | 3.89 | .752 | 3,809 | 3.63 | 598 | 5.64 | 857 | 6.53 | 857 | 6.13 |
| | D | 50.66 | 31.10 | 12.58 | 5.36 | 4.46 | .732 | 3,679 | 6.19 | | | | | | |
| Average | | 51.40 | 30.71 | 12.14 | 5.46 | 3.65 | .744 | 3,676 | 4.31 | 588 | 4.84 | 845 | 5.46 | 869 | 6.18 |
| Batch variation per cent | | 2.38 | 2.96 | 5.17 | 4.08 | | | | | | | | | | |
| 33 cubic feet | A | 52.38 | 30.06 | 11.38 | 5.72 | 3.03 | .755 | 3,496 | 5.77 | 592 | 5.79 | 856 | 5.17 | 853 | 5.69 |
| | B | 51.64 | 30.82 | 11.54 | 5.65 | 4.07 | .753 | 3,488 | 3.51 | | | | | | |
| | Center | 52.69 | 29.72 | 11.66 | 5.60 | 3.59 | .758 | 3,277 | 8.08 | 588 | 4.61 | 851 | 4.65 | 851 | 5.97 |
| | C | 53.50 | 29.00 | 11.34 | 5.75 | 5.11 | .767 | 3,550 | 5.59 | 590 | 3.44 | 854 | 7.37 | 844 | 7.66 |
| | D | 53.17 | 29.56 | 11.37 | 5.49 | 3.27 | .767 | 3,541 | 9.14 | | | | | | |
| Average | | 52.68 | 29.83 | 11.46 | 5.64 | 3.81 | .757 | 3,470 | 6.42 | 590 | 4.65 | 854 | 5.61 | 852 | 6.40 |
| Batch variation per cent | | 2.91 | 3.97 | 4.48 | 3.91 | | | | | | | | | | |
| 35 cubic feet | A | 50.98 | 31.20 | 11.81 | 5.61 | 3.66 | .732 | 3,648 | 5.83 | 586 | 5.67 | 830 | 6.80 | 825 | 5.08 |
| | B | 51.80 | 31.15 | 10.97 | 5.68 | 3.93 | .742 | 3,862 | 7.12 | | | | | | |
| | Center | 51.95 | 30.52 | 11.70 | 5.40 | 3.79 | .750 | 3,662 | 4.23 | 606 | 5.50 | 846 | 8.00 | 815 | 4.72 |
| | C | 53.97 | 29.38 | 10.82 | 5.46 | 4.62 | .778 | 3,806 | 4.58 | 584 | 4.35 | 798 | 6.06 | 795 | 6.77 |
| | D | 52.00 | 30.41 | 11.53 | 5.68 | 3.44 | .747 | 3,686 | 8.19 | | | | | | |
| Average | | 52.14 | 30.53 | 11.37 | 5.56 | 3.89 | .749 | 3,733 | 5.99 | 592 | 5.17 | 825 | 6.95 | 812 | 5.48 |
| Batch variation per cent | | 2.55 | 3.15 | 5.30 | 4.56 | | | | | | | | | | |

sults which might be expected when old equipment is used, we have the values given in Table 7.

TABLE 6.—*Combined average values of compressive strength, modulus of rupture, and variation factor obtained on Wisconsin State-aid projects 2916 and 2926 for periods during which new mixers were used*

| Size of batch | Compressive strength of cylinders at 28 days | Modulus of rupture at 28 days | Average variation | | Variation factor within batch |
|---|---|---|---|---|---|
| | | | Cylinders | Beams | |
| | *Lbs. per sq. in.* | *Lbs. per sq. in.* | *Per cent* | *Per cent* | *Per cent* |
| 27 cubic feet | 3,594 | 852 | 6.76 | 4.72 | 3.76 |
| 30 cubic feet | 3,667 | 880 | 5.53 | 5.39 | 3.81 |
| 33 cubic feet | 3,685 | 872 | 6.11 | 5.02 | 3.70 |
| 35 cubic feet | 3,790 | 866 | 5.92 | 5.53 | 3.81 |
| General average | 3,684 | 867 | 6.08 | 5.16 | 3.77 |

TABLE 7.—*Combined average values of compressive strength, modulus of rupture, and variation factor obtained on Wisconsin State-aid projects 2916 and 2926 for periods during which old mixers were used*

| Size of batch | Compressive strength of cylinders at 28 days | Modulus of rupture at 28 days | Average variation | | Variation factor within batch |
|---|---|---|---|---|---|
| | | | Cylinders | Beams | |
| | *Lbs. per sq. in.* | *Lbs. per sq. in.* | *Per cent* | *Per cent* | *Per cent* |
| 27 cubic feet | 3,431 | 885 | 5.53 | 3.98 | 5.08 |
| 30 cubic feet | 3,516 | 883 | 6.84 | 4.76 | 5.02 |
| 33 cubic feet | 3,596 | 901 | 5.05 | 4.78 | 4.46 |
| 35 cubic feet | 3,540 | 901 | 5.88 | 4.35 | 4.69 |
| General average | 3,518 | 892 | 5.82 | 4.47 | 4.81 |

We find nothing here that indicates any significant difference. For the period during which the old mixers were used the cylinder strengths average a trifle lower, but the beams were stronger, and, while the batch variation was a little higher for the old mixers, because of spreader-bucket design, the variation of both beam and cylinder strengths was less. The value of the concrete produced by the old mixers, therefore, seems equal to that produced by the new mixers, but, as will be shown later, the rate at which concrete could be produced was considerably greater for the new mixers.

Analyzing the summary table for Arkansas (Table 8) for the same variation factors as to uniformity and strength, we find that these data indicate that the quality of concrete was not appreciably affected by the use of batches varying from 27 to 37 cubic feet.

### INCREASE IN BATCHMETER SETTING ABOVE 50 SECONDS PRODUCED LITTLE EFFECT

In order to investigate further the effect of the mixing time when larger than normal batches are used the setting of the batchmeter was varied to give mixing times of 50, 60, and 80 seconds during one series of tests on the Wisconsin jobs. Both 30 and 33 cubic-foot batches were tested in this manner. These data are summarized in Tables 9 and 10, for the 30 and 33 cubic-foot batches, respectively. Average values for both sizes of batch are given in Table 11. As shown in this outline, mixing either the 30 or the 33 cubic-foot batch more than 50 seconds (batchmeter setting) did not produce higher strength and resulted in only a very slight apparent improvement in uniformity of mixing.

Further light on the variations in uniformity and strength of the concrete on the several jobs under discussion may be obtained from a study of the data given in Table 12. The detailed tables, of which Table 1 is

TABLE 8.—*General summary showing effect of size of batch on uniformity of mix and strength of concrete, for Federal-aid project 259–A, Jefferson County, Ark., 27E paver, good condition; aggregates, trap rock, river sand*

| Size of batch | Part of batch | Proportions by weight: Stone | Proportions by weight: Sand | Proportions by weight: Cement | Proportions by weight: Water | Average sample variation factor | Workability factor $b/b_0$ | Cylinders, 28 days: Strength | Cylinders, 28 days: Variation | Beams, 7 days: Strength | Beams, 7 days: Variation | Beams, 28 days, End break: Strength | Beams, 28 days, End break: Variation | Beams, 28 days, Center break: Strength | Beams, 28 days, Center break: Variation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Per cent* | *Per cent* | *Per cent* | *Per cent* | *Per cent* | | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* |
| 27 cubic feet | A | 47.58 | 33.56 | 12.08 | 6.53 | 5.62 | 0.733 | 4,548 | 5.76 | 721 | 9.36 | 705 | 8.04 | 715 | 4.37 |
| | B | 49.60 | 32.27 | 11.83 | 6.05 | 3.92 | .771 | | | | | | | | |
| | Center | 49.33 | 32.48 | 11.90 | 6.06 | 4.38 | .767 | | | 627 | 5.23 | 681 | 6.14 | 716 | 5.22 |
| | C | 50.61 | 31.78 | 11.27 | 6.08 | 6.35 | .783 | 4,594 | 5.76 | 637 | 7.06 | 735 | 7.37 | 683 | 5.80 |
| | D | 52.74 | 29.72 | 11.53 | 5.76 | 5.06 | .818 | | | | | | | | |
| Average | | 49.90 | 32.02 | 11.73 | 6.11 | 5.07 | .773 | 4,571 | 5.76 | 662 | 7.22 | 707 | 7.18 | 705 | 5.13 |
| Batch variation, per cent | | 3.97 | 4.35 | 5.44 | 6.51 | | | | | | | | | | |
| 30 cubic feet | A | 46.43 | 34.57 | 12.39 | 6.35 | 4.87 | .716 | 4,526 | 7.00 | 641 | 5.81 | 693 | 6.64 | 677 | 6.13 |
| | B | 48.17 | 33.22 | 12.20 | 6.15 | 5.15 | .750 | | | | | | | | |
| | Center | 48.65 | 33.22 | 11.73 | 6.15 | 5.19 | .752 | | | 641 | 6.84 | 680 | 8.66 | 692 | 6.77 |
| | C | 48.24 | 33.14 | 12.61 | 5.77 | 6.08 | .751 | 4,555 | 7.00 | 633 | 6.37 | 712 | 4.25 | 686 | 3.22 |
| | D | 50.38 | 32.35 | 11.07 | 5.96 | 6.27 | .779 | | | | | | | | |
| Average | | 48.37 | 33.30 | 12.00 | 6.08 | 5.51 | .749 | 4,540 | 7.00 | 638 | 6.34 | 695 | 6.52 | 685 | 5.37 |
| Batch variation, per cent | | 4.74 | 4.44 | 8.45 | 4.42 | | | | | | | | | | |
| 32 cubic feet | A | 46.78 | 34.88 | 11.85 | 6.24 | 3.90 | .721 | 5,327 | 5.15 | 689 | 7.77 | 745 | 3.77 | 695 | 3.38 |
| | B | 49.52 | 32.84 | 11.35 | 6.04 | 4.57 | .767 | | | | | | | | |
| | Center | 47.36 | 34.37 | 11.86 | 6.16 | 3.94 | .731 | | | 678 | 4.38 | 750 | 4.62 | 704 | 4.53 |
| | C | 47.14 | 34.52 | 12.05 | 6.05 | 6.30 | .733 | 5,579 | 5.15 | 658 | 8.39 | 717 | 2.95 | 714 | 4.25 |
| | D | 48.56 | 33.71 | 11.61 | 5.88 | 5.18 | .752 | | | | | | | | |
| Average | | 47.87 | 34.06 | 11.74 | 6.07 | 4.78 | .741 | 5,453 | 5.15 | 675 | 6.85 | 737 | 3.78 | 704 | 4.05 |
| Batch variation, per cent | | 4.14 | 3.97 | 6.65 | 4.35 | | | | | | | | | | |
| 34 cubic feet | A | 48.04 | 33.96 | 11.57 | 6.18 | 4.71 | .742 | 5,596 | 4.83 | 761 | 6.09 | 753 | 3.59 | 756 | 8.05 |
| | B | 47.65 | 34.41 | 11.81 | 5.88 | 3.14 | .732 | | | | | | | | |
| | Center | 47.80 | 34.32 | 11.71 | 5.92 | 3.07 | .742 | | | 719 | 5.55 | 774 | 6.07 | 696 | 5.48 |
| | C | 49.46 | 33.01 | 11.33 | 5.94 | 4.58 | .766 | 5,534 | 4.83 | 671 | 7.72 | 718 | 6.33 | 672 | 6.70 |
| | D | 49.13 | 33.13 | 11.68 | 5.80 | 4.18 | .764 | | | | | | | | |
| Average | | 48.39 | 33.79 | 11.62 | 5.95 | 3.92 | .749 | 5,565 | 4.83 | 717 | 6.45 | 748 | 5.33 | 708 | 6.74 |
| Batch variation, per cent | | 3.14 | 3.26 | 5.29 | 4.00 | | | | | | | | | | |
| 37 cubic feet | A | 47.30 | | 12.15 | 6.11 | 5.36 | .739 | 4,971 | 6.68 | 681 | 3.98 | 705 | 7.15 | 676 | 5.77 |
| | B | 48.69 | 33.72 | 11.30 | 6.04 | 3.71 | .752 | | | | | | | | |
| | Center | 47.64 | 34.07 | 12.23 | 5.82 | 3.62 | .738 | | | 702 | 7.22 | 718 | 7.53 | 695 | 5.35 |
| | C | 50.20 | 32.47 | 11.58 | 5.51 | 5.21 | .775 | 5,060 | 6.68 | 667 | 6.88 | 758 | 7.86 | 690 | 7.14 |
| | D | 48.16 | 34.03 | 11.73 | 5.83 | 4.53 | .731 | | | | | | | | |
| Average | | 48.40 | 33.70 | 11.80 | 5.86 | 4.49 | .747 | 5,016 | 6.68 | 683 | 6.03 | 726 | 7.50 | 687 | 6.08 |
| Batch variation, per cent | | 3.30 | 2.94 | 6.61 | 5.10 | | | | | | | | | | |
| General average | | | | | | 4.75 | .752 | 5,029 | 5.88 | 675 | 6.58 | 722 | 6.06 | 698 | 5.47 |

an example, were examined to determine, for each batch on all jobs, the maximum and minimum values of variation factor, compressive strength and percentage variation, and flexural strength and percentage variation. These values were then averaged for each job on the basis of batch size and mixing time. The results of this computation are given in Table 12. A final condensed summary of average values for each of the three jobs is given in Table 13.

It is interesting to note that the average job values of the cement content and water content on the Wisconsin and Arkansas jobs were very nearly equal. The specifications for the Wisconsin jobs called for a minimum cement content of 5 sacks per cubic yard of concrete and 6 gallons of water per sack of cement; but as the work progressed, it was found that less water was required for workability than was anticipated, with the result that a cement content of slightly more than 5 sacks per cubic yard was obtained. The specifications for the Arkansas project required a minimum cement content of 5.40 sacks of cement per cubic yard of concrete and 5.25 gallons of water per sack of cement; but, because of the extremely high temperatures and low humidity experienced during much of the time of this study, more water was required than the engineer had anticipated. The coarse aggregate used on the Arkansas job was a crushed trap rock, while the coarse aggregate used on the Wisconsin jobs was a limestone gravel. The maximum size of aggregate on all three jobs was approximately 2½ inches.

Except in the case of the two Wisconsin jobs, both of which used the same brand of cement and the same kinds of aggregate, the beam and cylinder strengths are not really comparable one job with another, because different kinds of aggregates and cement were used on the other job.

With these qualifications in mind, it may be said for the three jobs studied that the data on uniformity of mixing and resultant strength indicate that as good concrete can be produced from batches at least as large as 34 cubic feet as from batches of any smaller size between 27 and 34 cubic feet, when all solid materials are mixed 55 seconds (i. e., with a batchmeter setting of 60 seconds). They also indicate that where State or county engineers control the mix, the size of the batch can be at least as large as 33 cubic feet and still produce equally good concrete with a batchmeter setting of 50 seconds, or an actual mixing time of 45 seconds for all solid materials in standard 27E mixers with the blades and buckets in fair condition.

Another point noted in the course of this work was that when the amount of water per cubic yard of concrete was less than 28 gallons the mix was so dry that the finishing operations were likely to be delayed.

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TABLE 9.—*General summary showing effect of size of batch and length of mixing time on uniformity of mix and strength of concrete mixed in batches of 30 cubic feet on State-aid project 2926, Sheboygan County, Wis.; 27E paver, new; aggregates, good limestone gravel, pit sand*

| Mixing time | Part of batch | Proportions by weight | | | | Average sample variation factor | Workability factor $b/b_0$ | Cylinders, 28 days | | Beams: 7 days | | Beams: 28 days, End break | | Beams: 28 days, Center break | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Gravel | Sand | Cement | Water | | | Strength | Variation | Strength | Variation | Strength | Variation | Strength | Variation |
| | | *Per cent* | *Per cent* | *Per cent* | *Per cent* | *Per cent* | | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* |
| 50 seconds | A | 53.29 | 29.79 | 10.96 | 5.97 | 3.58 | 0.757 | 3,804 | 7.52 | 570 | 6.17 | 801 | 5.43 | 794 | 4.99 |
| | B | 51.98 | 30.40 | 11.65 | 5.97 | 3.24 | .738 | 3,683 | 6.33 | | | | | | |
| | Center | 53.34 | 29.37 | 11.18 | 6.10 | 2.76 | .754 | 3,787 | 3.27 | 561 | 7.21 | 875 | 3.62 | 844 | 3.07 |
| | C | 52.01 | 30.40 | 11.40 | 6.18 | 2.76 | .734 | 3,893 | 6.51 | 587 | 8.04 | 867 | 3.07 | 865 | 4.20 |
| | D | 52.35 | 30.30 | 11.19 | 6.15 | 2.87 | .736 | 4,119 | 6.50 | | | | | | |
| Average | | 52.59 | 30.05 | 11.28 | 6.08 | 3.04 | .744 | 3,857 | 6.03 | 573 | 7.14 | 847 | 4.04 | 835 | 4.09 |
| Batch variation ... per cent | | 2.61 | 2.91 | 3.37 | 3.28 | | | | | | | | | | |
| 60 seconds | A | 52.45 | 30.55 | 11.07 | 5.92 | 2.37 | .741 | 4,007 | 5.36 | 576 | 6.28 | 857 | 4.96 | 815 | 4.06 |
| | B | 52.07 | 30.62 | 11.28 | 6.03 | 3.25 | .736 | 3,940 | 7.70 | | | | | | |
| | Center | 55.61 | 28.06 | 10.58 | 5.74 | 5.01 | .790 | 3,557 | 8.86 | 587 | 3.80 | 825 | 3.86 | 837 | 3.16 |
| | C | 53.22 | 29.63 | 11.11 | 6.03 | 3.02 | .752 | 3,899 | 8.89 | 575 | 3.80 | 866 | 4.11 | 875 | 3.78 |
| | D | 53.08 | 30.06 | 10.82 | 6.03 | 3.08 | .751 | 3,773 | 5.23 | | | | | | |
| Average | | 53.29 | 29.78 | 10.97 | 5.96 | 3.35 | .754 | 3,835 | 7.21 | 597 | 4.63 | 849 | 4.31 | 842 | 3.67 |
| Batch variation ... per cent | | 2.80 | 3.59 | 2.87 | 4.19 | | | | | | | | | | |
| 80 seconds | A | 52.36 | 30.21 | 11.33 | 6.12 | 3.76 | .742 | 3,906 | 5.48 | 579 | 3.62 | 809 | 2.18 | 818 | 5.62 |
| | B | 52.26 | 30.17 | 11.42 | 6.14 | 4.19 | .740 | 3,826 | 3.65 | | | | | | |
| | Center | 54.56 | 28.66 | 10.82 | 5.95 | 4.73 | .775 | 3,762 | 4.00 | 566 | 3.32 | 806 | 4.00 | 819 | 3.11 |
| | C | 52.71 | 29.96 | 11.15 | 6.17 | 3.38 | .747 | 3,844 | 3.90 | 569 | 1.61 | 819 | 3.31 | 840 | 3.85 |
| | D | 51.77 | 30.60 | 11.40 | 6.23 | 2.41 | .733 | 3,907 | 5.45 | | | | | | |
| Average | | 52.73 | 29.92 | 11.22 | 6.13 | 3.69 | .747 | 3,849 | 4.49 | 571 | 2.85 | 811 | 3.16 | 826 | 4.19 |
| Batch variation ... per cent | | 3.17 | 3.68 | 3.86 | 4.04 | | | | | | | | | | |

TABLE 10.—*General summary showing effect of size of batch and length of mixing time on uniformity of mix and strength of concrete mixed in batches of 33 cubic feet on State-aid project 2926, Sheboygan County, Wis.; 27E paver, new; aggregates, good limestone gravel, pit sand*

| Mixing time | Part of batch | Proportions by weight | | | | Average sample variation factor | Workability factor $b/b_0$ | Cylinders, 28 days | | Beams: 7 days | | Beams: 28 days, End break | | Beams: 28 days, Center break | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Gravel | Sand | Cement | Water | | | Strength | Variation | Strength | Variation | Strength | Variation | Strength | Variation |
| | | *Per cent* | *Per cent* | *Per cent* | *Per cent* | *Per cent* | | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* | *Lbs. per sq. in.* | *Per cent* |
| 50 seconds | A | 52.47 | 29.73 | 11.73 | 6.07 | 2.38 | 0.743 | 4,080 | 6.69 | 590 | 2.71 | 859 | 2.61 | 855 | 4.16 |
| | B | 53.00 | 29.61 | 11.40 | 5.97 | 3.81 | .752 | 3,857 | 7.18 | | | | | | |
| | Center | 52.53 | 29.65 | 11.71 | 6.10 | 2.96 | .744 | 3,611 | 6.28 | 617 | 4.75 | 833 | 4.28 | 838 | 2.96 |
| | C | 52.19 | 30.35 | 11.23 | 6.22 | 3.35 | .737 | 3,703 | 6.94 | 596 | 4.93 | 840 | 4.53 | 785 | 4.89 |
| | D | 52.52 | 30.06 | 11.35 | 6.06 | 3.52 | .743 | 4,026 | 5.43 | | | | | | |
| Average | | 52.54 | 29.88 | 11.48 | 6.09 | 3.20 | .744 | 3,855 | 6.50 | 601 | 4.13 | 844 | 3.81 | 826 | 4.06 |
| Batch variation ... per cent | | 2.51 | 3.23 | 3.47 | 3.61 | | | | | | | | | | |
| 60 seconds | A | 54.30 | 28.79 | 11.15 | 5.76 | 2.03 | .773 | 4,049 | 12.11 | 580 | 4.91 | 839 | 3.15 | 852 | 4.35 |
| | B | 53.68 | 29.13 | 11.39 | 5.79 | 2.67 | .765 | 3,983 | 5.98 | | | | | | |
| | Center | 54.97 | 28.14 | 11.03 | 5.84 | 3.60 | .780 | 3,654 | 7.10 | 590 | 3.64 | 836 | 5.48 | 862 | 3.60 |
| | C | 53.41 | 29.34 | 11.21 | 6.03 | 4.42 | .758 | 3,759 | 7.02 | 574 | 4.32 | 822 | 3.36 | 828 | 5.80 |
| | D | 53.44 | 29.34 | 11.30 | 5.91 | 2.17 | .760 | 3,740 | 5.67 | | | | | | |
| Average | | 53.96 | 28.95 | 11.21 | 5.87 | 2.98 | .767 | 3,837 | 7.58 | 581 | 4.29 | 832 | 4.00 | 847 | 4.59 |
| Batch variation ... per cent | | 2.35 | 3.11 | 2.59 | 3.85 | | | | | | | | | | |
| 80 seconds | A | 52.94 | 29.69 | 11.44 | 5.92 | 3.63 | .753 | 4,090 | 8.81 | 594 | 4.47 | 822 | 4.85 | 839 | 4.05 |
| | B | 52.96 | 29.39 | 11.69 | 5.96 | 3.59 | .752 | 4,014 | 6.83 | | | | | | |
| | Center | 53.66 | 29.22 | 11.17 | 5.95 | 2.68 | .762 | 3,518 | 6.95 | 571 | 6.73 | 839 | 4.70 | 884 | 7.33 |
| | C | 54.99 | 28.13 | 11.03 | 5.84 | 5.31 | .782 | 3,579 | 7.33 | 580 | 4.83 | 826 | 2.01 | 948 | 5.95 |
| | D | 53.68 | 29.10 | 11.42 | 5.80 | 5.15 | .765 | 3,603 | 4.60 | | | | | | |
| Average | | 53.65 | 29.11 | 11.35 | 5.89 | 4.07 | .763 | 3,761 | 6.90 | 582 | 5.34 | 829 | 3.85 | 843 | 5.70 |
| Batch variation ... per cent | | 3.55 | 4.38 | 4.36 | 4.01 | | | | | | | | | | |

Furthermore, workability ratios ($b/b_0$) above 0.85 for gravel and 0.75 for stone proved to be in general undesirable, in that there was too much coarse aggregate in the mix for the present method of placing and finishing, a condition which tends to delay the finishing operations. The data also seem to indicate that there is a fairly close relationship between the cement and water contents and the resulting compressive and transverse strengths.

Variations within a batch can not be entirely eliminated by mechanical mixing, no matter what the size of the batch or the length of the mixer cycle. That this is so becomes apparent when one considers that the distribution of the particles of aggregate, cement,

TABLE 11.—*Effect of size of batch and length of mixing time on uniformity of mix and strength of concrete mixed in batches of 30 and 33 cubic feet on State-aid project 2926, Sheboygan County, Wis.*

| Mixing time | Batch size | Compressive strength of cylinders at 28 days | Modulus of rupture at 28 days | Average variation: Cylinders | Average variation: Beams | Variation factor within batch |
|---|---|---|---|---|---|---|
| | *Cubic feet* | *Lbs. per sq. in.* | *Lbs. per sq. in.* | *Per cent* | *Per cent* | *Per cent* |
| 50 seconds | 30 | 3, 857 | 841 | 6. 03 | 4. 07 | 3. 04 |
| | 33 | 3, 855 | 835 | 6. 50 | 3. 94 | 3. 20 |
| 60 seconds | 30 | 3, 835 | 846 | 7. 21 | 3. 99 | 3. 35 |
| | 33 | 3, 837 | 840 | 7. 58 | 4. 30 | 2. 98 |
| 80 seconds | 30 | 3, 849 | 818 | 4. 49 | 3. 67 | 3. 69 |
| | 33 | 3, 761 | 836 | 6. 90 | 4. 78 | 4. 07 |
| General average | 30 | 3, 847 | 835 | 5. 91 | 3. 91 | 3. 36 |
| | 33 | 3, 818 | 837 | 6. 99 | 4. 34 | 3. 42 |
| Both | ---- | 3, 832 | 836 | 6. 45 | 4. 12 | 3. 39 |

FIGURE 5.—THE LAST CUBIC FOOT OF CONCRETE DISCHARGED FROM ANY MAKE OF MIXER HAS A PREDOMINANCE OF COARSE AGGREGATE. THE DESIGN OF MIXER SPREADER-BUCKETS ALSO AFFECTS SEGREGATION. THE RESULTS OF THESE TWO EFFECTS CAUSED A BATCH TO APPEAR AS SHOWN

and water within the batch is very largely a matter of chance. Consequently, a point is soon reached at which the mixing action during each instant displaces as many particles from their proper positions as are rightly placed. After this point is reached, further mixing is evidently a useless expense in so far as securing greater uniformity is concerned.

Figure 5 shows a badly segregated batch. Though this is not a typical condition, the photograph is presented to point out the extent to which variation sometimes takes place within a batch. This variation is largely present as the batch is discharged from the mixer drum, and then a further segregation seems to occur while the concrete is discharged from the spreader bucket. Mixer manufacturers each year have been improving the spreader bucket from the typical box-shaped bucket of a few years ago to the present oblong bucket designed to eliminate a greater part of this further segregation. The two types of bucket are shown in Figure 6.

In all pavers which have been observed, not only on these jobs but also on hundreds of other jobs, the last one-half to 1 cubic foot of material discharged from the mixer drum has a predominance of coarse aggregate. It is recommended, therefore, that during continuous operation about a cubic foot of concrete always be retained in the drum to eliminate this trouble.

In Table 14 values of the variation factor within batch and of the variation in strength of cylinders are tabulated for each batch on Wisconsin State-aid project 2926. The data are arranged to bring out any differences in the magnitude of these variation factors which may be traceable to the use of varying sizes of batch

TABLE 12.—*Values of maximum and minimum variation factor, compressive strength, and flexural strength for each batch, averaged for each job on the basis of batch size and mixing time*

| Job | Batch size | Mixing time | Variation factor within batch: Maximum | Variation factor within batch: Minimum | Cylinders at 28 days, Strength: Maximum | Cylinders at 28 days, Strength: Minimum | Cylinders at 28 days, Variation: Maximum | Cylinders at 28 days, Variation: Minimum | Beams at 28 days, end break, Strength: Maximum | Beams at 28 days, end break, Strength: Minimum | Beams at 28 days, end break, Variation: Maximum | Beams at 28 days, end break, Variation: Minimum | Beams at 28 days, center break, Strength: Maximum | Beams at 28 days, center break, Strength: Minimum | Beams at 28 days, center break, Variation: Maximum | Beams at 28 days, center break, Variation: Minimum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Cu. ft.* | *Seconds* | *Per cent* | *Per cent* | *Lbs. per sq. in.* | *Lbs. per sq. in.* | *Per cent* | *Per cent* | *Lbs. per sq. in.* | *Lbs. per sq. in.* | *Per cent* | *Per cent* | *Lbs. per sq. in.* | *Lbs. per sq. in.* | *Per cent* | *Per cent* |
| Wisconsin State-aid project 2926, old paver | 27 | 60 | 7. 71 | 1. 40 | 3, 554 | 3, 043 | 8. 39 | 1. 25 | 954 | 851 | 6. 84 | 2. 24 | 932 | 846 | 6. 05 | 2. 06 |
| | 30 | 60 | 9. 72 | 1. 99 | 3, 733 | 2, 921 | 14. 38 | 2. 23 | 901 | 819 | 5. 38 | 1. 21 | 908 | 799 | 7. 49 | 3. 33 |
| | 33 | 60 | 8. 79 | 1. 92 | 3, 823 | 3, 203 | 10. 35 | 2. 07 | 950 | 846 | 6. 44 | 1. 24 | 976 | 840 | 9. 04 | 3. 27 |
| | 35 | 60 | 9. 06 | 1. 66 | 3, 488 | 2, 751 | 14. 20 | 1. 91 | 921 | 833 | 5. 85 | 1. 57 | 946 | 826 | 7. 26 | 1. 37 |
| Wisconsin State-aid project 2926, new paver | 27 | 60 | 5. 47 | 1. 60 | 4, 029 | 3, 151 | 15. 83 | 1. 40 | 911 | 824 | 5. 54 | 1. 20 | 909 | 806 | 7. 38 | 2. 49 |
| | 30 | 60 | 7. 75 | 1. 16 | 4, 086 | 3, 230 | 13. 59 | 1. 35 | 961 | 846 | 6. 44 | 1. 80 | 968 | 849 | 7. 90 | 3. 19 |
| | 33 | 60 | 6. 26 | 1. 44 | 4, 269 | 3, 545 | 10. 38 | 1. 10 | 952 | 871 | 5. 29 | 1. 68 | 928 | 826 | 6. 83 | 2. 29 |
| | 35 | 60 | 7. 13 | 1. 39 | 4, 215 | 3, 471 | 11. 44 | 1. 31 | 982 | 863 | 7. 75 | 2. 47 | 951 | 850 | 6. 82 | 2. 41 |
| Wisconsin State-aid project 2916, old paver | 27 | 60 | 10. 87 | 2. 66 | 3, 942 | 3, 187 | 12. 76 | 1. 69 | 947 | 844 | 6. 68 | 1. 83 | 901 | 815 | 3. 60 | 1. 57 |
| | 30 | 60 | 9. 11 | 1. 83 | 4, 090 | 3, 312 | 11. 88 | 1. 56 | 968 | 876 | 5. 69 | 1. 92 | 935 | 810 | 7. 94 | 5. 32 |
| | 33 | 60 | 6. 34 | 1. 86 | 3, 967 | 3, 415 | 8. 99 | 1. 03 | 967 | 840 | 8. 11 | 2. 26 | 932 | 852 | 5. 13 | 1. 25 |
| | 35 | 60 | 8. 16 | 2. 22 | 4, 245 | 3, 570 | 10. 38 | 1. 28 | 993 | 865 | 8. 14 | 2. 39 | 949 | 877 | 4. 51 | 1. 82 |
| Wisconsin State-aid project 2916, new paver | 27 | 60 | 6. 28 | 2. 02 | 3, 942 | 3, 228 | 10. 87 | 2. 10 | 883 | 784 | 6. 85 | 1. 91 | 919 | 792 | 8. 54 | 2. 43 |
| | 30 | 60 | 5. 75 | 1. 93 | 3, 932 | 3, 380 | 8. 84 | . 56 | 902 | 786 | 8. 19 | 2. 66 | 927 | 792 | 9. 28 | 2. 91 |
| | 33 | 60 | 6. 60 | 1. 60 | 3, 859 | 3, 152 | 11. 52 | 2. 35 | 908 | 790 | 7. 86 | 2. 74 | 915 | 781 | 9. 20 | 2. 76 |
| | 35 | 60 | 6. 19 | 2. 03 | 4, 122 | 3, 356 | 12. 72 | 1. 98 | 906 | 769 | 9. 71 | 4. 31 | 869 | 759 | 7. 95 | 2. 41 |
| Wisconsin State-aid project 2926, new paver | 30 | 50 | 4. 96 | 1. 39 | 4, 262 | 3, 490 | 10. 63 | 2. 18 | 886 | 799 | 6. 06 | 1. 79 | 876 | 792 | 6. 13 | 2. 03 |
| | 30 | 60 | 5. 70 | 1. 41 | 4, 296 | 3, 368 | 12. 59 | 1. 67 | 899 | 803 | 6. 46 | 1. 93 | 881 | 799 | 5. 50 | 1. 64 |
| | 30 | 80 | 6. 00 | 1. 92 | 4, 097 | 3, 558 | 8. 69 | 1. 46 | 846 | 779 | 4. 75 | 1. 32 | 871 | 775 | 6. 29 | . 96 |
| Wisconsin State-aid project 2926, new paver | 33 | 50 | 5. 45 | 1. 71 | 4, 271 | 3, 499 | 11. 01 | 1. 98 | 889 | 804 | 5. 71 | 1. 33 | 871 | 784 | 5. 80 | 1. 19 |
| | 33 | 60 | 5. 30 | 1. 14 | 4, 389 | 3, 358 | 15. 29 | 1. 79 | 876 | 785 | 5. 99 | 1. 15 | 889 | 798 | 6. 88 | 2. 35 |
| | 33 | 80 | 7. 22 | 1. 34 | 4, 147 | 3, 319 | 13. 33 | 1. 67 | 873 | 784 | 5. 78 | 1. 10 | 896 | 776 | 8. 14 | 2. 33 |
| Federal-aid project 259–A, Jefferson County, Ark | 27 | 60 | 7. 74 | 2. 67 | 4, 831 | 4, 311 | 5. 76 | 5. 76 | 775 | 655 | 10. 78 | 4. 50 | 755 | 654 | 7. 56 | 1. 62 |
| | 30 | 60 | 9. 27 | 3. 00 | 4, 832 | 4, 249 | 7. 00 | 7. 00 | 751 | 637 | 9. 77 | 2. 63 | 733 | 637 | 8. 06 | 2. 18 |
| | 32 | 60 | 7. 67 | 1. 96 | 5, 736 | 3, 170 | 5. 15 | 5. 15 | 775 | 706 | 5. 67 | 1. 54 | 743 | 668 | 6. 08 | 1. 63 |
| | 34 | 60 | 6. 70 | 2. 02 | 5, 820 | 5, 311 | 4. 83 | 4. 83 | 806 | 702 | 8. 00 | 1. 88 | 777 | 649 | 10. 05 | 2. 23 |
| | 37 | 60 | 6. 57 | 2. 41 | 5, 343 | 4, 688 | 6. 68 | 6. 68 | 786 | 653 | 10. 83 | 3. 13 | 732 | 630 | 10. 92 | 3. 24 |

TABLE 13.—*Final summary of average values for the Wisconsin and Arkansas jobs*

| Item | Wisconsin State-aid project 2926 | Wisconsin State-aid project 2916 | Federal-aid project 259-A, Jefferson, Co., Ark. |
|---|---|---|---|
| Number of batches sampled | 118 | 80 | 44 |
| Proportions by weight, per cent: | | | |
| Coarse aggregate | 52.56 | 52.11 | 48.56 |
| Sand | 30.11 | 30.34 | 33.40 |
| Cement | 11.35 | 11.28 | 11.78 |
| Water | 5.97 | 5.73 | 6.01 |
| Variation factor within batch, per cent | 3.90 | 4.37 | 4.75 |
| Cement content, sacks per cubic yard | 5.16 | 5.18 | 5.19 |
| Water content, gallons per sack of cement | 5.96 | 5.81 | 5.82 |
| Ratios by absolute volume: | | | |
| $a/c$ (sand to cement) | 3.02 | 3.03 | 3.38 |
| $b/a$ (gravel to sand) | 1.72 | 1.72 | 1.45 |
| $b/b_0$ (see p. 275) | .746 | .750 | .751 |
| Mix by weight: | | | |
| Sand | 2.67 | 2.71 | 2.86 |
| Coarse aggregate | 4.67 | 4.68 | 4.18 |
| AVERAGE STRENGTH DATA | | | |
| Compressive strength of cylinders at 28 days, pounds per square inch | 3,646 | 3,672 | 5,039 |
| Variation, per cent | 6.33 | 5.66 | 5.89 |
| Flexural strength of beams in pounds per square inch: | | | |
| At 7 days | 598 | 595 | 676 |
| Variation, per cent | 4.55 | 4.70 | 6.56 |
| End break at 28 days | 872 | 877 | 723 |
| Variation, per cent | 4.03 | 5.22 | 6.04 |
| Center break at 28 days | 866 | 868 | 698 |
| Variation, per cent | 4.76 | 4.95 | 5.48 |
| SIEVE ANALYSIS | | | |
| Percentage retained on— | | | |
| 2½-inch | 4 | 3.6 | ---------- |
| 1½-inch | 14.8 | 13.6 | 21.1 |
| ¾-inch | 44.3 | 38.1 | 56.3 |
| ¼-inch | 36.9 | 44.6 | 22.6 |
| MAXIMUM AND MINIMUM VALUES [1] | | | |
| Maximum cement content, sacks per cubic yard | 5.49 | 5.64 | 5.72 |
| Minimum cement content, sacks per cubic yard | 4.83 | 4.69 | 4.63 |
| Maximum water content, gallons per sack of cement | 6.38 | 6.55 | 6.69 |
| Minimum water content, gallons per sack of cement | 5.58 | 5.15 | 5.12 |
| Strength of cylinders at 28 days in pounds per square inch: | | | |
| Maximum | 4,031 | 4,012 | 5,323 |
| Minimum | 3,266 | 3,325 | 4,756 |
| 7-day beam strength in pounds per square inch: | | | |
| Maximum | 633 | 631 | 737 |
| Minimum | 562 | 560 | 621 |
| 28-day beam strength in pounds per square inch: | | | |
| End-break maximum | 919 | 934 | 779 |
| End-break minimum | 826 | 819 | 673 |
| Center-break maximum | 919 | 918 | 748 |
| Center-break minimum | 814 | 810 | 648 |

[1] Averages of maximum and minimum values obtained on each batch.

or to differences in the performance of the old and new pavers. It is apparent from an inspection of this table that no definite relation can be established between size of batch and batch uniformity or uniformity of breaking strength. It is also evident that the uniformity values given by the old mixer are of the same order as those given by the new.

### STOP-WATCH STUDIES ANALYZED

The data regarding the distribution of the materials obtained on these jobs by means of the separation or wash analyses and the data on breaking strength of both beams and cylinders indicate rather clearly that, when two or more sizes of coarse aggregates are used, the modern 27E paver, in good condition, will mix a 35-cubic-foot batch to as high a degree of uniformity as it will a 27-cubic-foot batch, and that the strength of the concrete from the larger batch will be equally as good as that from the smaller. This does not prove that the larger batch will always be the most economical. While theoretical considerations, as well as the unit prices of the successful bidders on the two Wisconsin projects, indicate a certain advantage for the

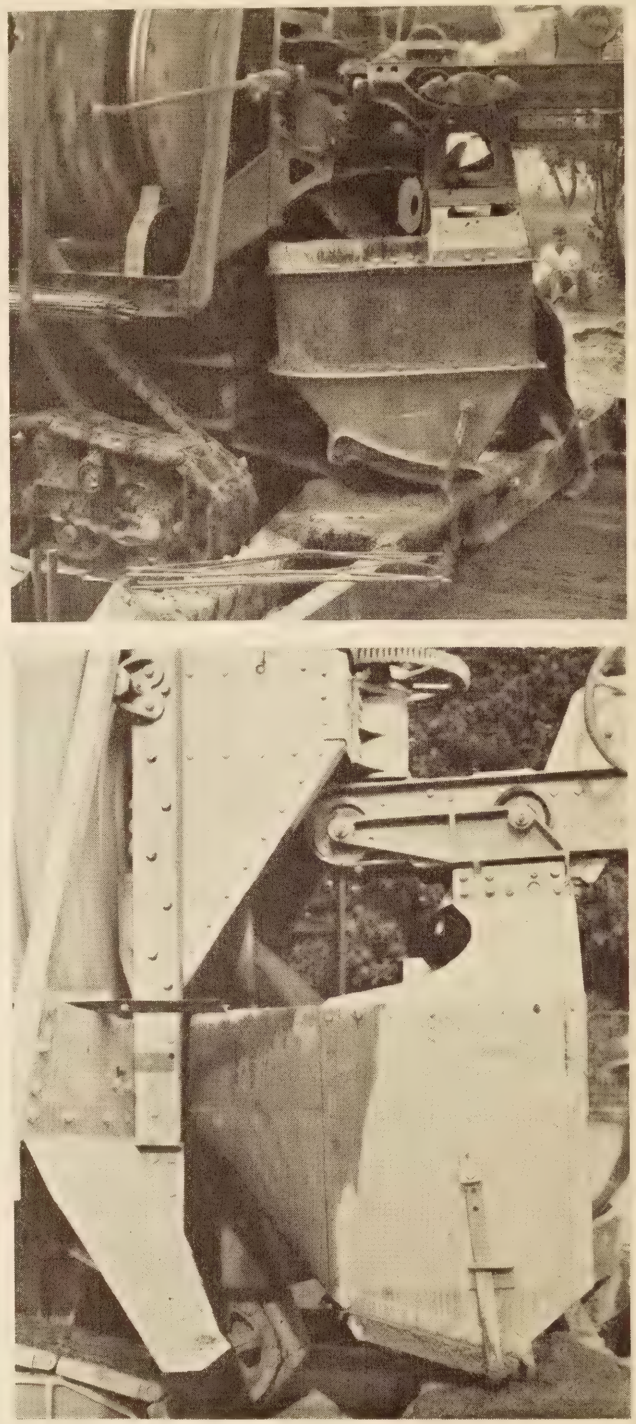

FIGURE 6.—UPPER PHOTOGRAPH SHOWS TYPICAL SPREADER-BUCKET DESIGN USED ON OLD PAVERS. BELOW IS SHOWN NEW DESIGN OF SPREADER BUCKET FOR 1930 AND 1931 PAVERS

larger batch, these are not conclusive, as is shown by the fact that several bidders bid the same price for all of the proposed batch sizes. Very careful and detailed production studies were made on these jobs in order to obtain some actual data as to what effect the use of the larger batches might have on the rate of production. These included daily stop-watch studies of the mixer for 1 hour in the morning and 1 hour in the afternoon

TABLE 14.—*Degree of nonuniformity in mixing and variation in breaking strength of standard cylinders, as shown by data obtained on Wisconsin State-aid project 2926. Average values are given for five samples and five cylinders from each batch*

OLD MIXER

[Size of batch in cubic feet]

| 27 | | 30 | | 33 | | 35 | |
|---|---|---|---|---|---|---|---|
| Batch variation | Cylinder variation | Batch variation | Cylinder variation | Batch variation | Cylinder variation | Batch variation | Cylinder variation |
| *Per cent* | *Per cent* | *Per cent* | *Per cent* | *Per cent* | *Per cent* | *Per cent* | *Per cent* |
| 2. 91 | 5. 34 | 3. 81 | 4. 59 | 5. 20 | 4. 65 | 6. 48 | 7. 63 |
| 5. 40 | 6. 11 | 5. 79 | 8. 38 | 5. 10 | 4. 79 | 3. 32 | 4. 32 |
| 2. 17 | 4. 15 | 4. 98 | 5. 21 | 6. 12 | 8. 38 | 8. 41 | 2. 65 |
| 4. 00 | 3. 50 | 9. 33 | 11. 27 | 6. 52 | 5. 29 | 5. 49 | 5. 23 |
| 5. 61 | 8. 06 | 4. 61 | 3. 62 | 5. 68 | 5. 08 | 3. 32 | 6. 69 |
| 2. 78 | 3. 25 | 4. 33 | 9. 16 | 1. 43 | 3. 83 | 4. 99 | 3. 36 |
| 2. 92 | 5. 89 | 7. 72 | 4. 77 | 4. 53 | 6. 47 | 3. 49 | 7. 92 |
| 3. 17 | 1. 51 | 5. 47 | 5. 97 | 5. 83 | 8. 22 | 3. 83 | 6. 72 |
| 6. 60 | 5. 11 | 2. 75 | 11. 80 | 4. 25 | 4. 28 | 2. 03 | 13. 63 |
| Av. 3. 95 | 4. 77 | 5. 42 | 7. 20 | 4. 96 | 5. 66 | 4. 59 | 6. 47 |

NEW MIXER

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 4. 13 | 5. 67 | 4. 38 | 6. 57 | 3. 86 | 4. 04 | 3. 80 | 6. 25 |
| 3. 69 | 5. 91 | 4. 13 | 4. 65 | 2. 54 | 3. 55 | 5. 65 | 6. 19 |
| 2. 86 | 5. 90 | 4. 30 | 4. 15 | 2. 45 | 4. 59 | 3. 21 | 4. 86 |
| 4. 56 | 2. 75 | 2. 89 | 4. 70 | 2. 09 | 4. 96 | 3. 02 | 7. 60 |
| 4. 73 | 6. 70 | 4. 01 | 13. 41 | 5. 11 | 10. 22 | 2. 51 | 2. 64 |
| 2. 74 | 14. 51 | 3. 67 | 4. 77 | 4. 49 | 5. 27 | 3. 28 | 4. 20 |
| 2. 03 | 10. 43 | 2. 90 | 5. 05 | 4. 62 | 5. 35 | 5. 21 | 4. 06 |
| 2. 63 | 3. 43 | 4. 48 | 6. 80 | 4. 31 | 7. 98 | 3. 08 | 6. 36 |
| 2. 79 | 7. 03 | 6. 65 | 10. 59 | 4. 11 | 4. 20 | 2. 09 | 6. 95 |
| 4. 59 | 12. 50 | 2. 38 | 6. 78 | 2. 21 | 7. 90 | 5. 54 | 9. 34 |
| Av. 3.48 | 7. 48 | 3. 98 | 6. 75 | 3. 58 | 5. 81 | 3. 74 | 5. 84 |

to determine both the average mixer cycle and the duration and cause of all time losses or interruptions to continuous mixer operation. During the stop-watch studies the time in seconds required to raise the skip, the time to mix, and the time from the bell to the instant the skip began to rise for another cycle, were determined. If an interruption occurred at any point in the mixer cycle, the duration and the cause of each stop or delay were recorded. If the delay or stop was 15 minutes or more in duration it was classified as a major delay, and if it was less than 15 minutes it was classified as a minor delay.

Auxiliary stop-watch studies were also made of the several component parts of the mixer-operating cycle and included the following: Time to raise the skip; the instant the water and solid materials began to enter the mixer drum, the time required to discharge the water and solid materials into the drum; the time from the instant the skip reached a vertical position until the batchmeter bell rang; the time from when the bell rang until the instant the concrete appeared in the discharge chute; the time to discharge the concrete; the time from the bell until the skip again started up; and finally, the revolutions of the mixer drum. The mixer drum was also carefully watched for overloading, spillage, leakage, clogging, possible retarding of the mixer drum speed, and the appearance of the batch in the mixer drum (whether it appeared to be uniformly mixed, etc.). A careful check was made each day of the contractor's personnel, unit costs, amount of concrete placed, yield, etc.

#### EFFICIENCY OF PLANT AND EQUIPMENT STUDIED

In order to fix definitely the casues of such delays as occurred or were anticipated, the auxiliary equipment, such as the cranes, batcher bins, and finishing machines, were studied to determine their relation to the rate of production. Views of the plant layouts on the two Wisconsin jobs are shown in Figures 7, 8, 9, and 10. Figure 11 shows the type of 1927 Model 27E paver used on the Wisconsin jobs. The contractors on these two jobs each had old pavers of this type when the projects were started. As soon as the different-sized batches had been studied in regard to quality tests and production on the old pavers, new 1930 Model 27E pavers were loaned by the manufacturers for similar studies.

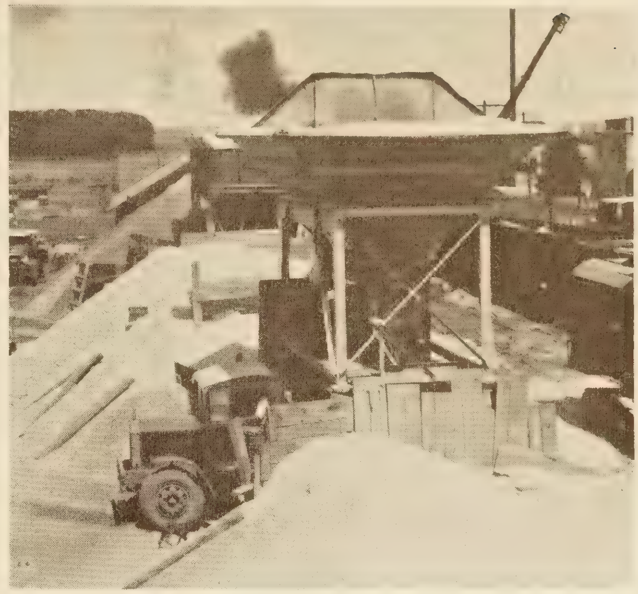

FIGURE 7.—PLANT SET-UP USED ON STATE-AID PROJECT 2916, SHEBOYGAN COUNTY, WIS., ON WHICH THREE SIZES OF COARSE AGGREGATE AND ONE OF SAND WERE USED. MATERIALS USED WERE DELIVERED BY RAIL

FIGURE 8.—TYPICAL PLANT SET-UP USED ON STATE-AID PROJECT 2926, SHEBOYGAN COUNTY, WIS. MATERIALS HAULED IN BY TRUCK FROM A LOCAL PIT. COARSE AGGREGATE SEPARATED IN THREE SIZES

#### PRODUCTION RATE OF NEW PAVERS SHOWS SUBSTANTIAL INCREASE OVER OLD TYPE

On the old mixers a 2½-inch strip of metal was placed around the back part of the spreader-buckets to increase their carrying capacity. Even with this extra metal strip it was found that the 35 cubic-foot batches could not be discharged in one operation. As a consequence, double discharge had to be used for the 35-cubic-foot batches, which proved to be uneconomical. However, if the spreader buckets had been slightly larger a saving could have been made by using the larger 35-cubic-foot batch. No alterations had to be made on the spreader buckets of the new pavers in order to carry the 35-cubic-foot batches, which the new pavers could handle with ease.

The mixer drums of both the old and new pavers mixed up to 35-cubic-foot batches without spillage, leakage, or clogging. The computed values given in Table 15 were made from measurements of the mixer drum to illustrate the theoretical carrying capacity of the old and the new pavers when used on level grade and on a 6 per cent grade.

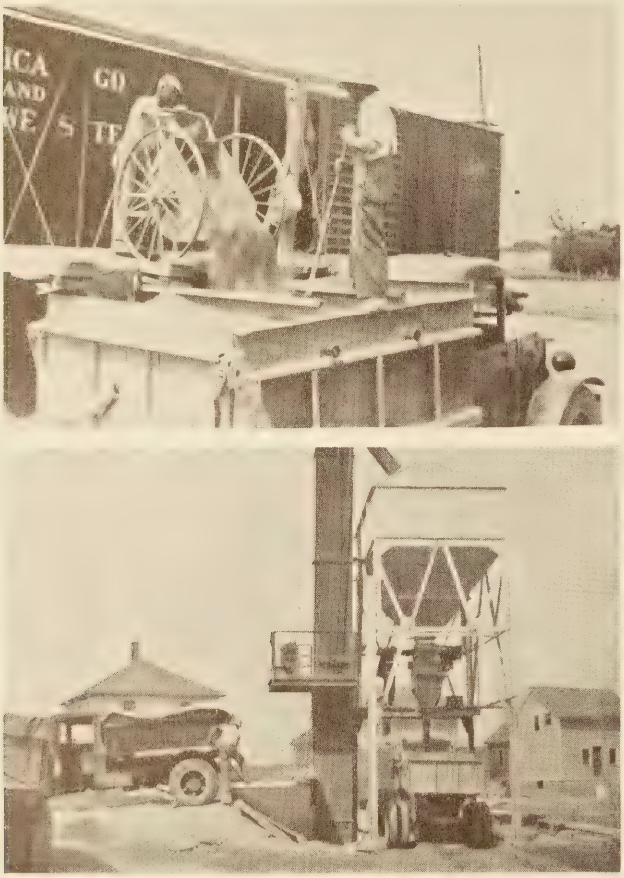


Figure 9.—Methods of Handling Bulk Cement on Wisconsin State-Aid Projects 2916 and 2926

Table 15.—*Computed capacity, in cubic feet, of mixer drums of old and new 27E Pavers*

| | Total volume content | Water level content, level grade | Capacity of buckets and blades, level grade | Working content on level grade | Water level content, 6 per cent, grade | Capacity of buckets and blades, 6 per cent grade | Working content on 6 per cent grade |
|---|---|---|---|---|---|---|---|
| Old paver: 6 blades, 6 buckets, boom bucket, capacity, 36¾ cubic feet | 94.75 | 25.84 | 11.00 | 36.84 | 22.00 | 11.00 | 33.20 |
| New paver: 5 blades, 10 buckets; boom bucket, capacity, 42 cubic feet | 100.18 | 28.50 | 10.20 | 38.50 | 24.60 | 10.20 | 34.80 |

The larger batch sizes increased the mixer cycle slightly because of the longer time required to discharge the batch from the drum and the longer time required for the materials to discharge from the skip into the mixer drum. Tables 16 and 17 show the actual average mixer cycles as determined by the stop-watch studies for a batchmeter setting of 60 seconds, as most generally used on the two Wisconsin jobs, together with the effect of the various batch sizes on the maximum possible rate of production. Tables 18 and 19 show the same data on the basis of actually mixing all the solid materials for either 50 or 60 seconds. It should be noted that the mixing time of the concrete does not terminate when the batchmeter rings but continues

Figure 10.—Local Pit Plant Layout Equipped for Producing Three Sizes of Coarse Aggregate for Wisconsin State-Aid Project 2926

until the concrete appears in the discharge chute. This time interval is usually termed the discharge lag.

Allowance should be made in the batchmeter setting to take care of this lag. In setting the batchmeter the following formula should be used:

$$A+B-C=D$$

where $A$ is the mixing time, $B$ the lag of the solid materials after the skip reaches the vertical $C$ the discharge lag from the bell to the appearance of the concrete in the discharge chute, and $D$ the batchmeter setting in seconds. The water added at the paver should enter

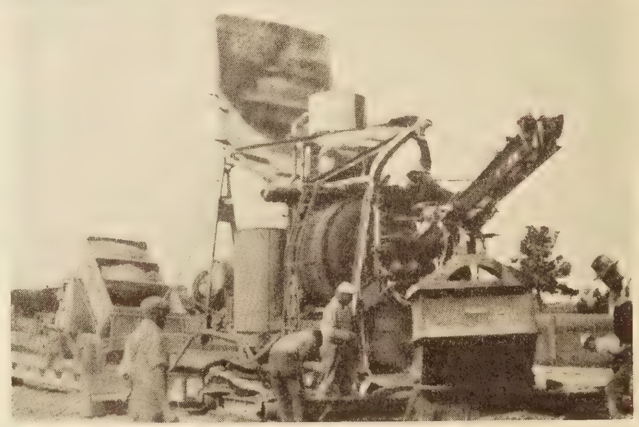

Figure 11.—Type of 1926 Model 27E Paver Used on Wisconsin State-Aid Projects 2916 and 2926

the paver drum about 1½ seconds before the solid materials (aggregate and cement) and lag after the solid materials no more than 10 seconds. This combination of lags will result in more efficient charging of the materials and will keep the throat of the mixer clear, as well as the blades and buckets.

There is also a mixing action in progress on a considerable portion of the batch while the drum is being both charged and discharged. This, however, is entirely omitted in determining the length or duration of the mixing time.

The difference in the mixer cycles between the old paver and the new paver was found to be surprisingly

TABLE 16.—*Analysis of production of 3-year old 27E paver as affected by batch size, with the batchmeter setting at 60 seconds*

| Batch size (cubic feet) | 27 | 30 | 33 |
|---|---|---|---|
| Mixer cycle, seconds | 74.90 | 76 | 77.14 |
| Possible batches per hour | 48.06 | 47.37 | 46.67 |
| Percentage decrease in batches per hour due to batch size | ------- | 1.43 | 2.89 |
| Possible cubic yards per hour | 48.06 | 52.63 | 57.04 |
| Percentage net increase in possible production due to batch size | ------- | 9.5 | 18.7 |

TABLE 17.—*Analysis of production of new 27E paver as affected by batch size, with the batchmeter setting at 60 seconds*

| Batch size (cubic feet) | 27 | 30 | 33 | 35 |
|---|---|---|---|---|
| Mixer cycle, seconds | 68.60 | 68.60 | 69.16 | 69.77 |
| Possible batches per hour | 52.48 | 52.48 | 52.05 | 51.60 |
| Percentage decrease in batches per hour due to batch size | ------- | ------- | .82 | 1.70 |
| Possible cubic yards per hour | 52.48 | 58.31 | 63.62 | 66.87 |
| Percentage net increase in possible production due to batch size | ------- | 11.1 | 21.2 | 27.4 |

TABLE 18.—*Analysis of production of 3-year old 27E paver as affected by batch size and mixing time*

| Batch size (cubic feet) | 27 | 30 | 33 | 27 | 30 | 33 |
|---|---|---|---|---|---|---|
| Mixing time of all solid materials, seconds | 60 | 60 | 60 | 50 | 50 | 50 |
| Mixer cycle, seconds | 76 | 77.82 | 79.69 | 66 | 67.82 | 69.69 |
| Possible batches per hour | 47.37 | 46.26 | 45.18 | 54.54 | 53.08 | 51.66 |
| Percentage decrease in possible batches per hour due to batch size, based on a 27-cubic-foot batch | ------- | 2.34 | 4.66 | ------- | 2.68 | 5.28 |
| Possible cubic yards per hour | 47.37 | 51.40 | 55.22 | 54.54 | 59 | 63.15 |
| Percentage net increase in possible production due to batch size, based on a 27-cubic-foot batch mixed 60 seconds | ------- | 8.5 | 16.6 | 15.2 | 24.6 | 33.3 |

TABLE 19.—*Analysis of production of new 27E paver as affected by batch size and mixing time*

| Batch size (cubic feet) | 27 | 30 | 33 | 27 | 30 | 33 |
|---|---|---|---|---|---|---|
| Mixing time of all solid materials, (seconds) | 60 | 60 | 60 | 50 | 50 | 50 |
| Mixer cycle (seconds) | 69.45 | 70.69 | 71.89 | 59.45 | 60.69 | 61.89 |
| Possible batches per hour | 51.84 | 50.93 | 50.08 | 60.55 | 59.32 | 58.17 |
| Percentage decrease in possible batches per hour due to batch size, based on a 27-cubic-foot batch | ------- | 1.75 | 3.40 | ------- | 2.02 | 3.92 |
| Possible cubic yards per hour | 51.84 | 56.59 | 61.21 | 60.55 | 65.93 | 71.09 |
| Percentage net increase in possible production due to batch size and mixing time, based on a 27-cubic-foot batch mixed 60 seconds | ------- | 9.2 | 18.1 | 16.8 | 27.2 | 37.2 |

large. Because of this shorter mixing cycle alone, it is possible to obtain an increase of 10 per cent or more in production by using the new pavers. This fact is brought out by the data given in Table 20.

Because of the shorter mixing cycle and the better mechanical condition of the new paver, its actual advantage in effecting increased production was even greater than indicated above. The actual average hourly rates of production on Wisconsin State-aid project 2926 from the old and the new pavers for each batch size during the period of the studies are given in Table 21.

#### AUXILIARY EQUIPMENT KEPT PACE WITH PAVERS

During the time when the 50-second mixing time and the 33-cubic-foot batches were used, the finishing machine and finishing operations could, and did, readily keep up. This is true as well for the other auxiliary operations. This combination of mixing time and batch size did not therefore require more equipment or larger equipment. The rate of production

TABLE 20.—*Comparison of rates of production of old and new 27E pavers*

| Size of batch (cubic feet) | 27 | 30 | 33 | 27 | 30 | 33 |
|---|---|---|---|---|---|---|
| Mixing time of all solid materials (seconds) | 60 | 60 | 60 | 50 | 50 | 50 |
| Possible production per hour for new paver (square feet) | 119.83 | 130.81 | 141.49 | 140 | 152.44 | 164.37 |
| Possible production per hour for old paver (square feet) | 109.50 | 118.82 | 127.65 | 126.10 | 136.39 | 145.97 |
| Percentage increase in possible production with new paver | 9.4 | 10.1 | 10.8 | 11.0 | 11.8 | 12.6 |

TABLE 21.—*Average hourly rates of production on Wisconsin job 2916 obtained with old and new pavers, for a 60-second setting of batchmeter*

| Size of batch | Square yards per hour | | Percentage increase over old paver using 27-cubic foot batch |
|---|---|---|---|
| | Old paver | New paver | |
| 27 cubic feet | 188.1 | 217.2 | 15.5 |
| 30 cubic feet | 218.5 | 257.6 | 36.9 |
| 33 cubic feet | 222.5 | 260 | 37.3 |
| 35 cubic feet | ------- | 271 | 44.1 |

was still well within the capacity of the other coordinating units with no particular increase in labor or equipment. It seems likely, however, that a greater output than that now possible with the 33-cubic-foot batch mixed 50 seconds will, under present methods of operation, require additional or larger equipment.

On the basis of this investigation the State of Wisconsin is now permitting the use of a 33-cubic-foot batch and a 50-second mixing time for all the solid materials. The 33-cubic-foot batch allowance in Wisconsin is based on the fact that the spreader bucket of practically all 27E pavers now in use will hold this size batch in one discharge. The two old pavers and the two new pavers as used on these jobs handled the 33-cubic-foot batch equally as well as they did the smaller-sized batches.

#### CHART SHOWS METHOD OF DESIGNING MIXES

The mixes on both jobs were designed for the minimum allowable cement content and maximum allowable water content. The workability of the concrete was maintained through the adjustment of the gravel and sand content by means of the workability factor, $b/b_o$, as developed by Talbot and Richart.[2] Figure 12 is a chart designed for the purpose of obtaining the proportions of sand and coarse aggregate required to produce concrete having the desired workability factor. The chart is based on a cement content of 5 sacks per cubic yard of concrete and 6 gallons of water per sack of cement, which were the specifications for the Wisconsin jobs.

The process of determining the proportions of the mix is illustrated by the dash lines on the chart, which give the solution for a workability factor of 0.76, a value which seemed to work best on both of these jobs.

The percentage of voids in the course aggregate (dry loose) as used for the example in Figure 12 is 36. Enter the chart at the bottom where the figures for the voids in the coarse aggregate are given. Proceed from the number 36 and follow the dash line upward to the ordinate (point 1) where it intersects the workability ratio, $b/b_o = 0.76$. The absolute volume of

[2] Bulletin No. 137, Engineering Experiment Station, University of Illinois, 1923.

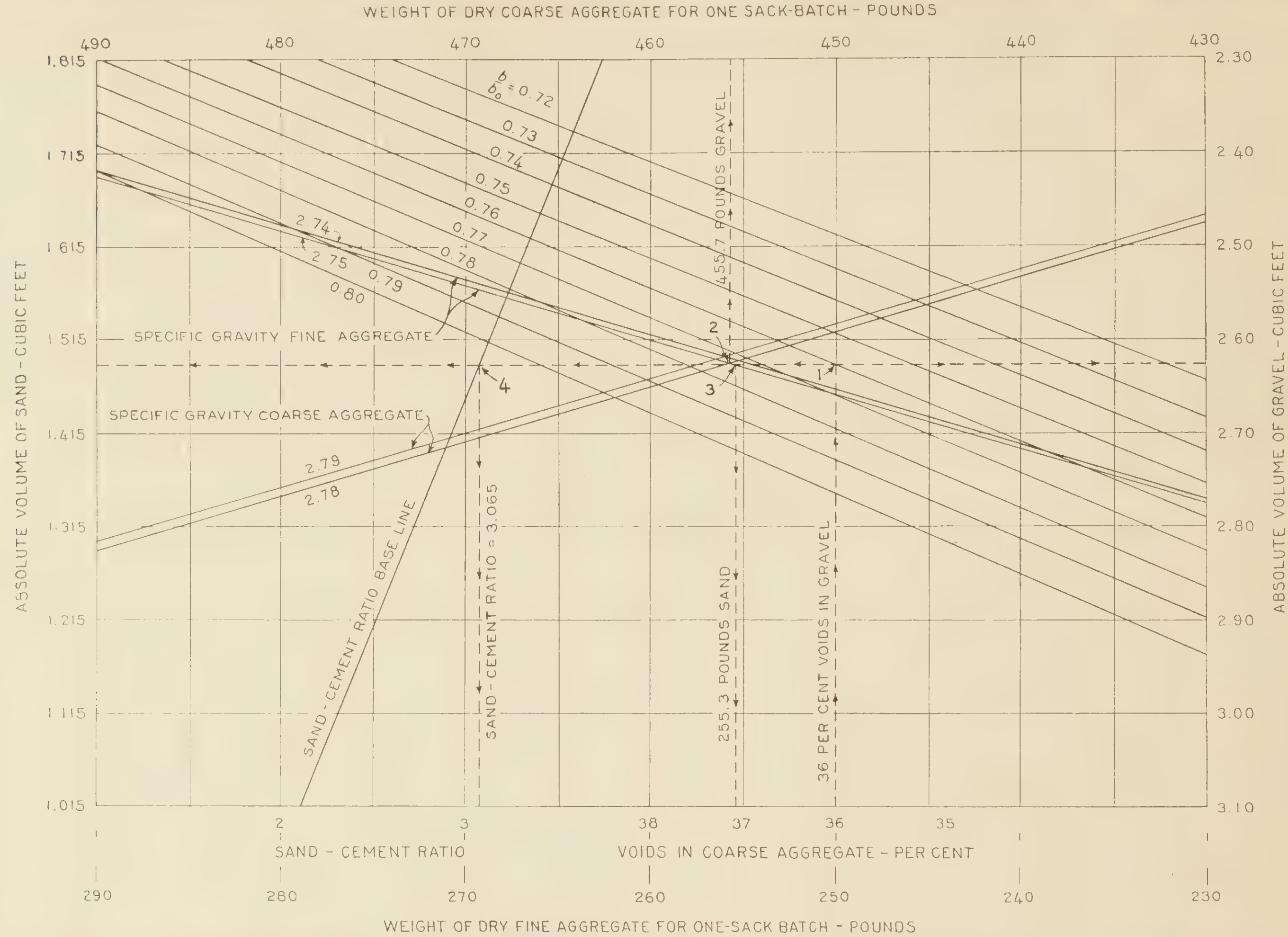


Figure 12.—Chart for Obtaining Required Proportions of Batch for a Given Value of $b/b_0$, on Wisconsin State-Aid Projects 2916 and 2926. Chart is Based on a Cement Content of 5 Sacks of Cement per Cubic Yard of Concrete and 6 Gallons of Water per Sack of Cement

coarse aggregate is given by the same ordinate on the right-hand scale. Follow the dashline to the left to the specific gravity line of 2.78 for the coarse aggregate (point 2) and upward, and read the weight of dry coarse aggregate for a 1-sack batch, 455.7 pounds, on the upper scale. Follow the dash line from the percentage of voids in the coarse aggregate (36) again to the value $b/b_0 = 0.76$, then to the left to the specific gravity of 2.75 for the fine aggregate (point 3), and then down, to read the weight of 255.3 pounds of sand for a 1-sack batch on the lower scale at the bottom of the chart. Proceed again from the intersection of the 36 per cent voids line with the value $b/b_0 = 0.76$ and follow the dash line to the left to the sand-cement ratio base line (point 4), and then downward, to read the sand-cement ratio by absolute volume, 3.065, on the upper left-hand scale at the bottom of the chart. The absolute volume of the sand is read on the left-hand scale.

### PROPORTIONING AND SIEVE ANALYSIS OF AGGREGATES DISCUSSED

The three sizes of aggregates were also recombined experimentally, different percentages of each size being used, in order to obtain as low a void content as practicable without sacrifice of gradation in obtaining a workable concrete.

The proportions of the various sizes of coarse aggregate for Wisconsin State-aid project 2926, as required by the specifications, and the sieve analyses of these aggregates are given in Table 22. Sieve analyses of the sand used on both Wisconsin jobs are given in Table 23.

### PLANT LAYOUTS SHOWN

Figure 13 shows the plant layout and set-up for using three sizes of coarse aggregate on Wisconsin State-aid project 2916. It is obvious that a very crowded condition existed. In fact, the plant set-up was such that trucks lost on an average of 2 minutes per load more than necessary for a typical set-up, a condition which required the use of one and sometimes two trucks more than would have been used normally. An extra crane was also required. The materials were delivered by rail.

Figure 14 is the same plant site but with equipment and stock-piles planned for handling two sizes of coarse aggregate. In so far as the cost of handling the aggregates and batching is concerned, this set-up would not result in any more cost for handling the two sizes than if only one size of coarse aggregate were used.

Figure 15 is the plant layout for one of the set-ups on Wisconsin State-aid project 2926, showing the number of turns and maneuvers that the trucks had to make in order to obtain a load. Figure 16 shows the same set-up but with a recommended change that could be used on similar jobs. Turning time for the

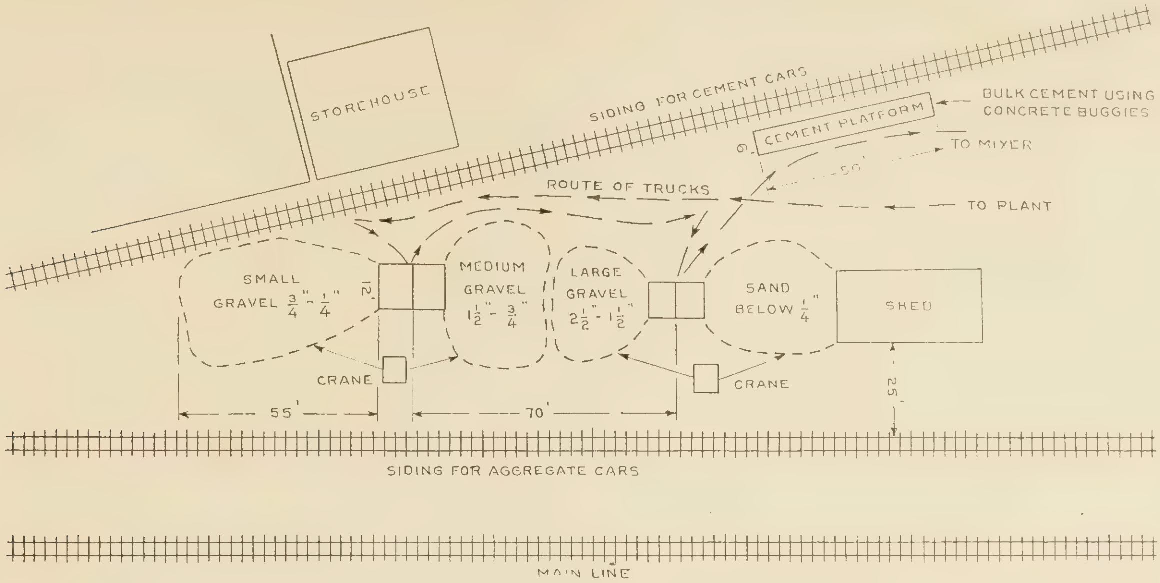


FIGURE 13.—PLANT LAYOUT FOR WISCONSIN STATE-AID PROJECT 2916, THREE SIZES OF COARSE AGGREGATE

TABLE 22.—*Proportions and sieve analyses of coarse aggregates used on Wisconsin State-aid project 2926*

PROPORTIONS

| No. | Size | Proportions |
|---|---|---|
| | | *Per cent* |
| 1 | 2½ to 1½ inches | 30–35 |
| 2 | 1½ to ¾ inch | 45–50 |
| 3 | ¾ to ¼ inch | 15–25 |

SIEVE ANALYSES

| | Per cent |
|---|---|
| No. 1 coarse aggregate— | |
| Retained on 3-inch circular opening | 0 |
| Retained on 2½-inch circular opening | 0– 10 |
| Retained on 1½-inch circular opening | 90–100 |
| Retained on 1¼-inch circular opening | 100 |
| No. 2 coarse aggregate— | |
| Retained on 1¾-inch circular opening | 0 |
| Retained on 1½-inch circular opening | 0– 10 |
| Retained on ¾-inch circular opening | 90–100 |
| Retained on ½-inch circular opening | 100 |
| No. 3 coarse aggregate— | |
| Retained on 1-inch circular opening | 0 |
| Retained on ¾-inch circular opening | 0 |
| Retained on ¼-inch circular opening | 95–100 |
| Retained on No. 10 sieve | 100 |

TABLE 23.—*Sieve analyses of sands used on Wisconsin State-aid projects 2916 and 2926*

| | Per cent |
|---|---|
| Project 2916: | |
| Retained on No. 4 sieve | 6. 86 |
| Retained on No. 20 sieve | 48. 28 |
| Retained on No. 50 sieve | 79. 79 |
| Retained on No. 100 sieve | 93. 39 |
| Project 2926: | |
| Retained on No. 4 sieve | 1. 56 |
| Retained on No. 20 sieve | 39. 28 |
| Retained on No. 50 sieve | 83. 82 |
| Retained on No. 100 sieve | 95. 12 |

trucks would then be eliminated. If only two sizes of coarse aggregate had been specified, a 3-compartment bin could have been used which would have required but one stop for the trucks. This would have been a most economical set-up and would still have utilized the advantage of multiple-sized aggregates. On this job the material was delivered by truck from a local pit and only one crane was necessary to supply the mixer demand for aggregates. This crane supplied material for the mixer when a 33-cubic-foot batch and a 50-second mixing time were used. An average of fifty-five 33-cubic-foot batches an hour were taken care of by the crane. This means that the crane handled an average of 238,931 pounds of sand and gravel, or about 80 cubic yards of material, per hour.

Figure 17 shows a set-up observed during the summer of 1930 handled by one crane and utilizing a method of straight-line loading. Bulk cement was placed in the batch between the stone and sand, eliminating the time usually required for covering the cement. This method proved very satisfactory. Some engineers, however, prefer to have the order of loading changed to second-size aggregate, sand, cement, and then coarse aggregate.

Incidentally, this contractor was using sack cement but obtained permission to try bulk cement, which resulted in a saving of 11 cents on each barrel of cement. This item alone was worth while. This procedure also assured the proper weight of cement each time, enabled the contractor to maintain a constant maximum batch, and eliminated the cost of handling the empty sacks. The cement retained in the empty sacks averaged about 0.4 pound per sack. A State buying cement can therefore make a large saving by eliminating this item. As the advantage of bulk cement becomes more generally appreciated it is believed that its use will be extended. Up to the present time the most popular way of handling bulk cement at the batcher plant, and the way used in this case, is by the use of 2-wheeled concrete buggies. Two cars of cement are unloaded at the same time. A wooden platform is constructed to the same elevation as the box-car floor with a length sufficient to reach the doors of both cars. Usually two men are used in each car for loading the buggies, two men to wheel the buggies to a platform scale, two men to weigh and finally dump the cement into the trucks.

On Wisconsin job 2916, as noted in the sketches, the bulk cement was delivered by rail and concrete buggies were employed to handle the cement. On Wisconsin job 2926 the cement was delivered to the batching plant in trucks and the cement loaded mechanically. Both methods proved very satisfactory and the trucks could be loaded rapidly with no apparent loss of cement during loading or in transit. The sand

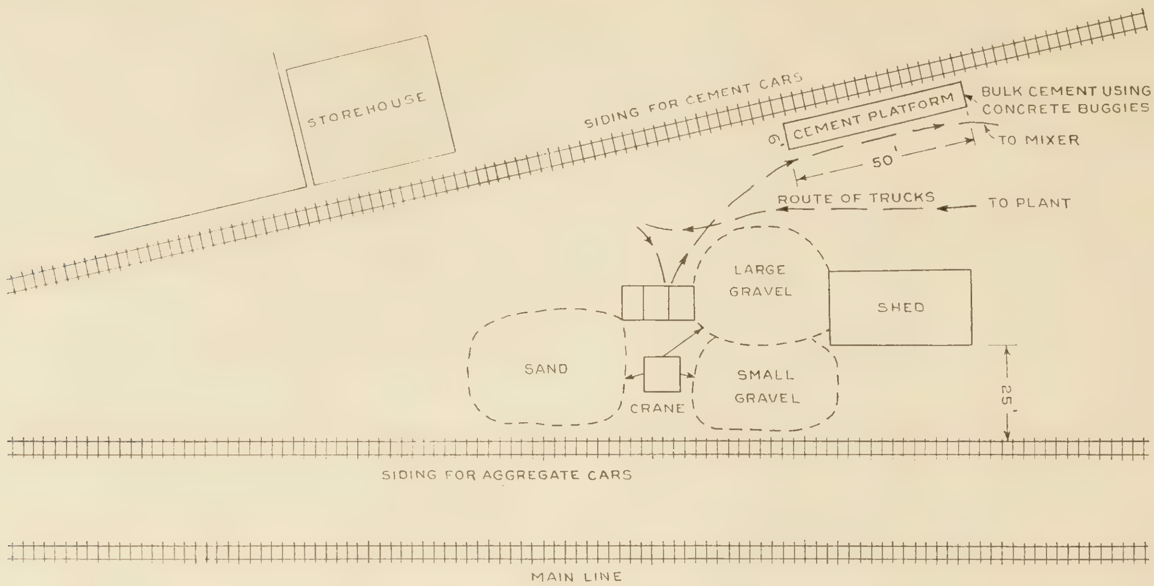


Figure 14.—Suggested Improvement in Plant Layout for Wisconsin State-Aid Project 2916, Two Sizes of Coarse Aggregate

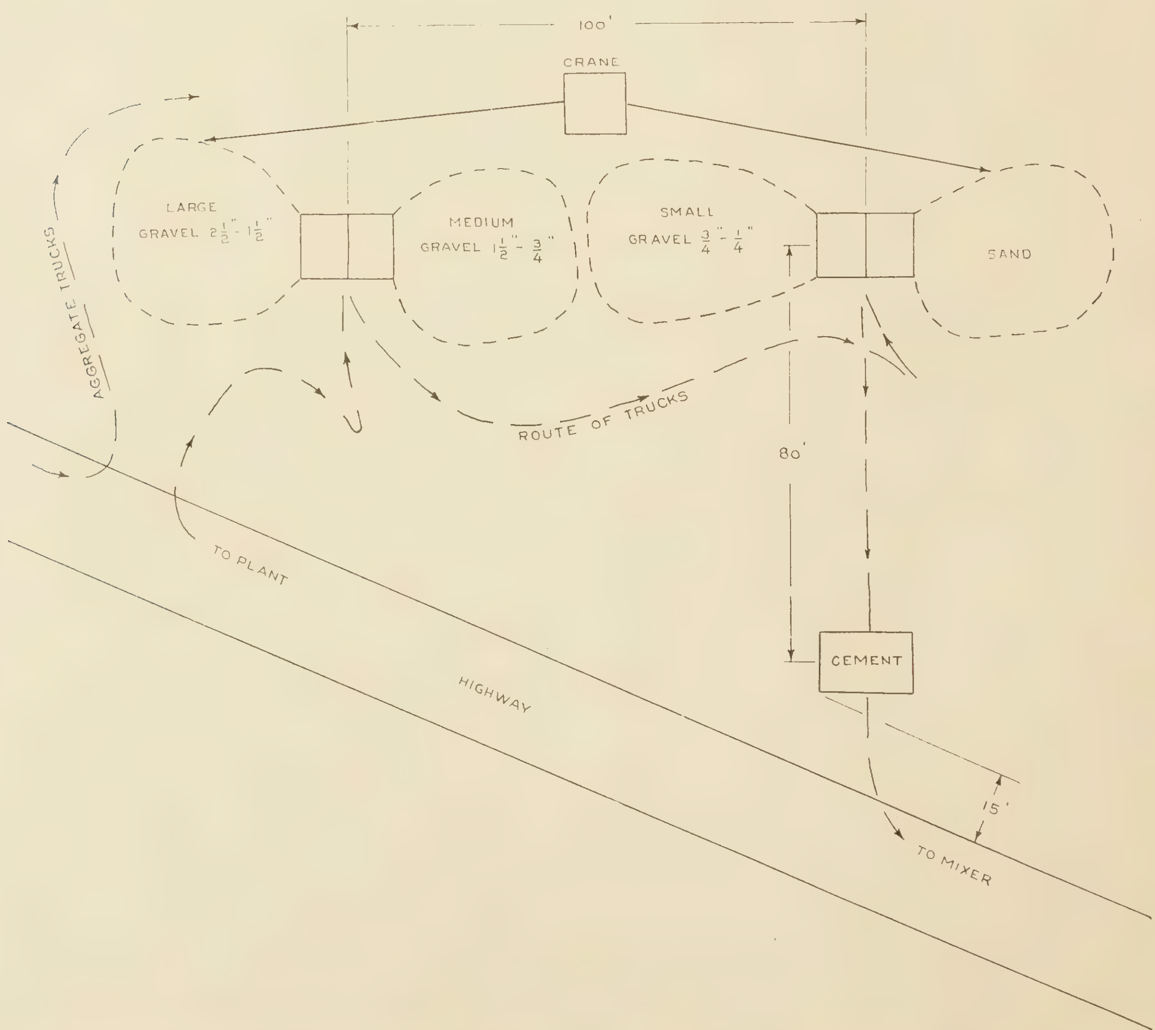


Figure 15.—Plant Layout for Wisconsin State-Aid Project 2926, Three Sizes of Coarse Aggregate

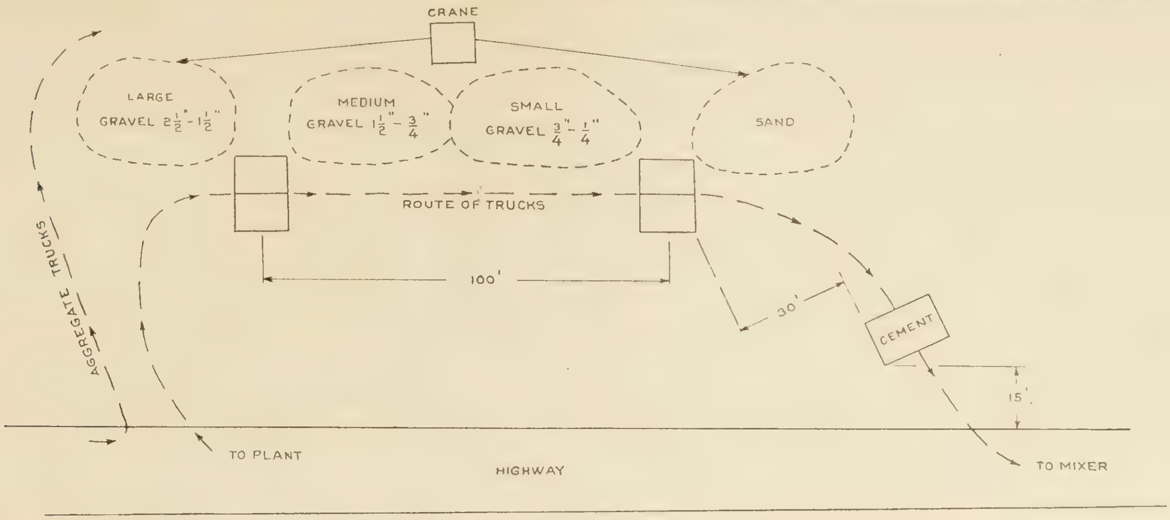


Figure 16.—Suggested Improvement in Plant Layout for Wisconsin State-Aid Project 2926, Three Sizes of Coarse Aggregate

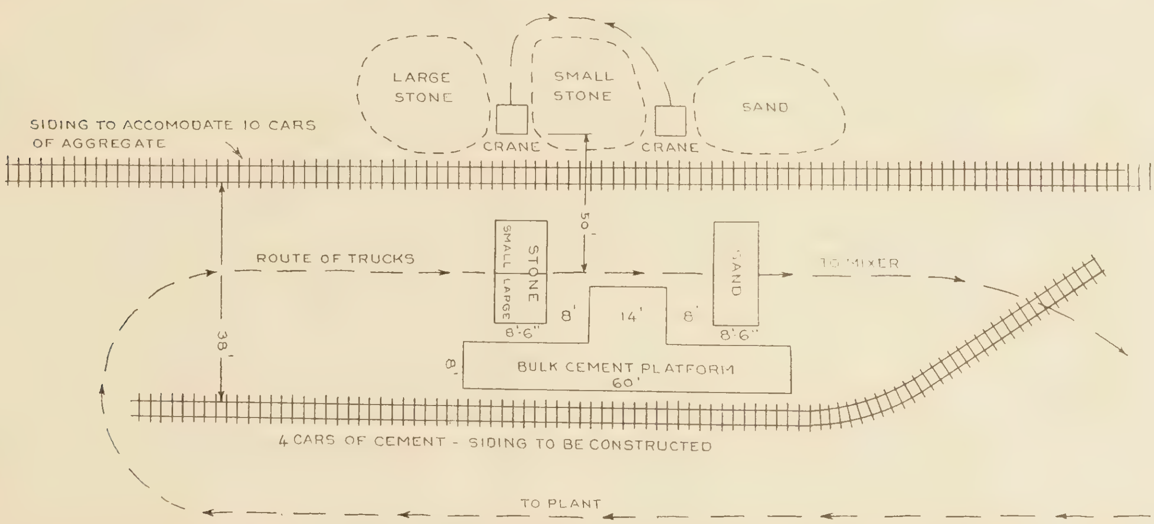


Figure 17.—Typical Plant Layout for Straight-Line Loading, Adapted to Bulk Cement. Trucks Loaded Mechanically or with Concrete Buggies; Sand Used for Cement Coverage

was dumped on the coarse aggregate so that it could be pocketed and the bulk cement covered with the loose sand.

Under no condition should the bulk cement be dumped at the rear of the truck body, as this retards the flow of material into the skip, clogs the skip throat and mixer throat, and causes the blades and buckets to be badly coated, which results in delaying the mixer operations.

Both jobs employed a straight-line loading of the trucks for the bulk cement, which reduced the amount of turning and backing required in taking on a load. Delaying a 3-batch truck 1 minute represents a loss of about 5 cents. This item may seem small but it accumulates rapidly into a large sum. Delaying the mixer 1 minute often represents the loss of about $1. On a paving job where operations should synchronize and coordinate, minutes lost are dollars wasted. An efficient batching plant removes many chances for delay.

#### STOP-WATCH ANALYSIS SHOWS FEW DELAYS CAUSED BY USE OF SEPARATE-SIZED AGGREGATES

Tables 24 and 25 are summaries from the time studies which were made during the period from June to October on the two Wisconsin jobs. These data were obtained by means of careful, daily stop-watch studies of all operations connected with the mixer. Delays less than 15 minutes in duration were classified as minor delays, and delays greater than 15 minute in duration were grouped as major delays.

These data indicate clearly that delays caused by the use of separate sizes of coarse aggregate were negligible, except on the first Wisconsin job where the plant space was so limited that the use of four stock-piles produced such crowded conditions that it was very difficult to maintain efficient truck operation. The job started with one crane but as production was improved another crane had to be put on the job. Probable causes of other delays were also indicated from time to time by the stop-watch studies, but the ready cooperation and alertness of the contractors in acting on these suggestions obviated all delays of any consequence due to handling the separated aggregates even under these rather unfavorable conditions.

#### CHARTS SHOW DISTRIBUTION OF COSTS

Figures 18 to 23 show some of the pertinent data collected on the two Wisconsin jobs. These charts illustrate the costs involved in constructing the concrete pavement. These two jobs had practically the

Table 24.—*Summary of time losses and their effect on production, for Wisconsin State-aid project 2916, June 23 to August 21, 1930*

MAJOR DELAYS OCCURRING DURING AVAILABLE WORKING TIME

| Character of delays | Hours | Per cent |
|---|---|---|
| Hauling supply | 0. 25 | 0. 05 |
| Mixer trouble, mechanical | 4. 08 | . 75 |
| Water supply | 3. 63 | . 67 |
| Lack of materials at yard | . 77 | . 14 |
| Crane trouble, mechanical | 10. 27 | 1. 88 |
| Moving | 83. 45 | 15. 30 |
| Rain | 13. 80 | 2. 53 |
| Wet subgrade | 21. 25 | 3. 90 |
| Miscellaneous | 1. 61 | . 30 |
| Total | 139. 11 | 25. 52 |
| Time major equipment actually operated | 406. 07 | 74. 48 |
| Available working time | 545. 18 | 100. 00 |

MINOR DELAYS OCCURRING DURING TIME OF ACTUAL OPERATION

| Character of delays | Hours | Per cent |
|---|---|---|
| Hauling supply | 14. 95 | 3. 68 |
| Hauling operation | 11. 09 | 2. 73 |
| Dumping | 2. 62 | . 64 |
| Mixer trouble, mechanical | 3. 66 | . 90 |
| Mixer operation | 9. 47 | 2. 33 |
| Water supply | 12. 88 | 3. 17 |
| Lack of materials at yard | . 33 | . 08 |
| Set parting strip | . 51 | . 13 |
| Subgrade not prepared | 6. 98 | 1. 72 |
| Place reinforcing steel | 1. 34 | . 33 |
| Wait for finishers | 2. 04 | . 50 |
| Sand batch, lip curb | 1. 49 | . 37 |
| Expansion joint | . 38 | . 09 |
| Crane operation | 3. 03 | . 75 |
| Miscellaneous | 2. 88 | . 71 |
| Total | 73. 65 | 18. 14 |
| Time major equipment operated at 100 per cent efficiency | 332. 42 | 81. 86 |
| | 406. 07 | 100. 00 |

Actual production, 15,945 batches, 93,395 square yards; over-all efficiency of major equipment operation, 83.1 per cent.


Figure 18.—Materials Cost Data for Wisconsin State-Aid Project 2916. Costs are Expressed as Percentages of Total Cost of Materials

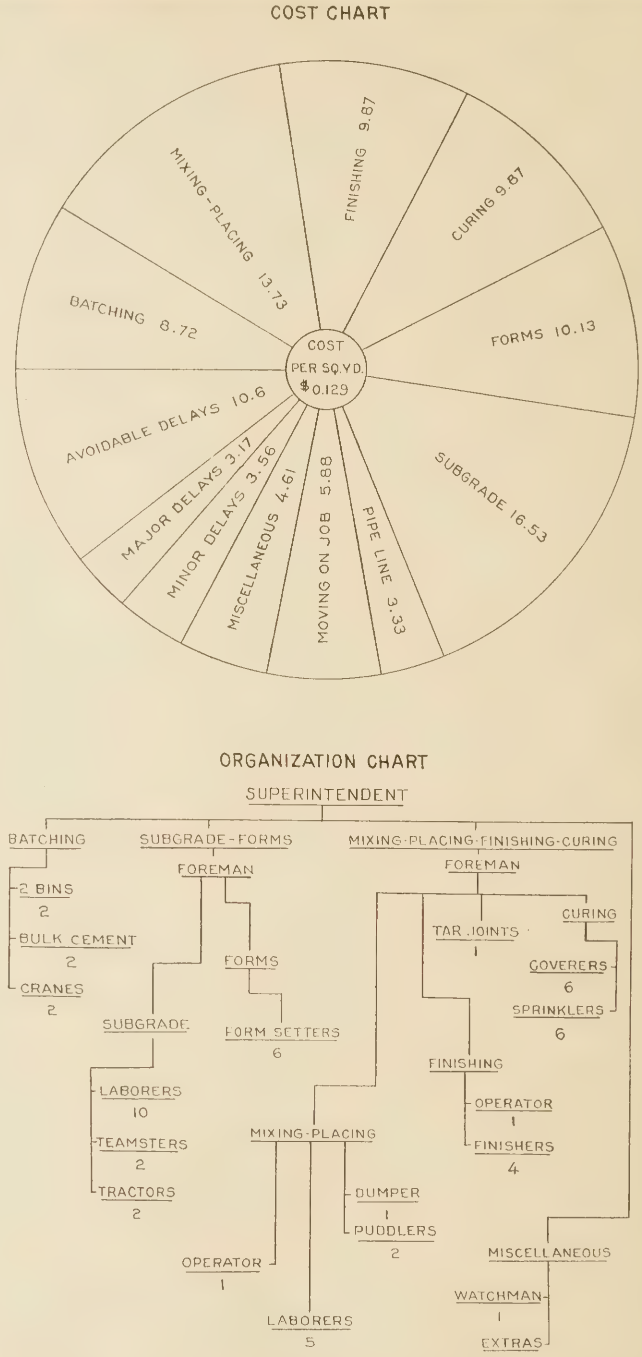


Figure 19.—Labor Cost Data and Organization Chart for Wisconsin State-Aid Project 2916. Costs are Expressed as Percentages of Total Cost of Labor

same truck haul with the over-all efficiency of one contractor 83.1 per cent and that of the other 88 per cent. One job used local aggregate and the other commercial aggregate. Five sacks of cement per cubic yard were used on each job.

Further reductions in hauling, labor, and depreciation will probably be made this year in Wisconsin by the use of a 33-cubic-foot batch and a 50-second mixing time after all solid materials are in the drum.

On these two Wisconsin jobs and on the job in Arkansas, all of which used separate sizes of coarse aggregates, 242 batches were sampled as they were dumped on the subgrade and tests made to determine the distribution of coarse aggregate, sand, cement, and water in samples taken from the four corners and the center of the batch. From these same batches beams and cylinders were also made. A total of 1,276 cylinders and 726 beams were made in these tests. All of these tests indicate that a high degree of uniformity was obtained not only within the batches but also between batches.

TABLE 25.—*Summary of time losses and their effect on production, for Wisconsin State-aid project 2926*

MAJOR DELAYS OCCURRING DURING AVAILABLE WORKING HOURS

| Character of delays | Hours | Per cent |
|---|---|---|
| Rain | 31.75 | 5.19 |
| Wet grade | 32.50 | 5.30 |
| Moving during job | 35.25 | 5.75 |
| Material supply | 26.25 | 4.28 |
| Subgrade | 8.00 | 1.30 |
| Mixer trouble, mechanical | 3.07 | .50 |
| Water supply | 2.83 | .46 |
| Batcher | 5.28 | .86 |
| Finishing machine | 1.95 | .32 |
| Crane | 5.50 | .90 |
| Joints | 1.50 | .26 |
| Miscellaneous | 5.85 | .96 |
| Total | 159.73 | 26.08 |
| Time paver actually operated | 453.27 | 73.92 |
| Available working time | 613.00 | 100.00 |

MINOR DELAYS OCCURRING DURING TIME OF ACTUAL OPERATION

| Character of delays | Hours | Per cent |
|---|---|---|
| Hauling supply | 7.65 | 1.69 |
| Hauling operation | 4.31 | .95 |
| Dumping | 6.25 | 1.38 |
| Mixer trouble, mechanical | 4.90 | 1.08 |
| Mixer operation | 8.46 | 1.86 |
| Water supply | 11.30 | 2.49 |
| Joints and steel | 4.93 | 1.09 |
| Subgrade | 3.60 | .79 |
| Miscellaneous | 12.79 | 2.82 |
| Total | 64.19 | 14.15 |
| Time paver operated at 100 per cent efficiency | 389.08 | 85.85 |
| | 453.27 | 100.00 |

Over-all efficiency of paver, 88.0 per cent; total production, 116,347 square yards.

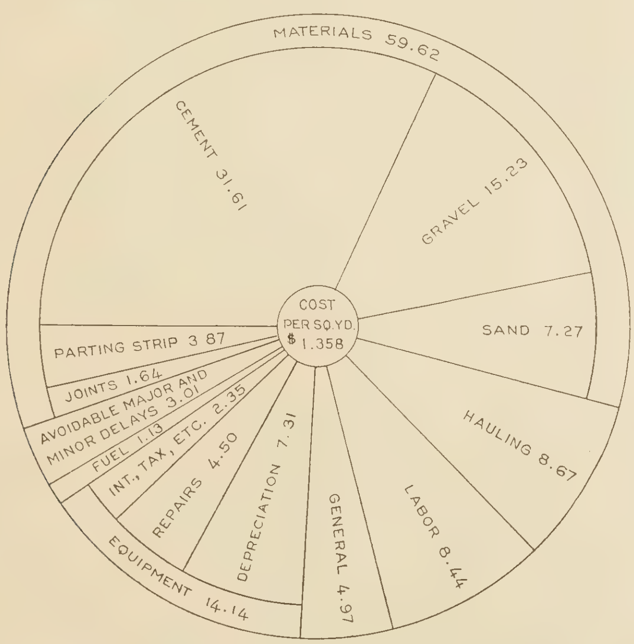


FIGURE 20.—SUMMARY OF COST DATA FOR WISCONSIN STATE-AID PROJECT 2916. COSTS ARE EXPRESSED AS PERCENTAGES OF TOTAL COST OF PROJECT

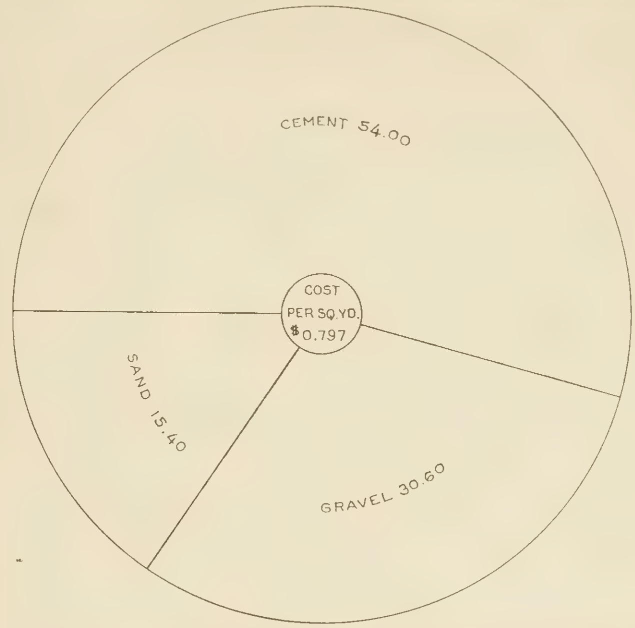


FIGURE 21.—MATERIALS COST DATA FOR WISCONSIN STATE-AID PROJECT 2926. COSTS ARE EXPRESSED AS PERCENTAGES OF TOTAL COST OF MATERIALS

#### CONCLUSIONS SUMMARIZED

From the data presented in the quality and production studies of 27E pavers in good condition the following conclusions seem reasonably clear:

1. The uniformity of the mixing and the resulting strength of the concrete are equally good for 35-cubic-foot batches as for 27-cubic-foot batches when mixed for 60 seconds.

2. The uniformity of the mixing and the resulting strength of the concrete are equally good for a 30 or 33 cubic-foot batch when mixed for 50 seconds as when mixed for 80 seconds.

3. Under present actual job conditions and customary auxiliary equipment, the most economical batch for the 27E paver seems to be 33 cubic feet with a mixing time of 50 seconds for all solid materials.

4. The large-sized batches, up to 35 cubic feet, and on grades less than 6 per cent, did not cause spillage, leakage, or clogging of either the old or the new pavers, and may be advisable when a mixing time longer than 50 seconds is required.

5. The mixers did not show any signs of breakage related to overloading from using the larger-sized batches.

6. Practically no increse in the present standard auxiliary equipment or labor set-up, nor any change in this equipment or labor set-up, is necessary to use a 33-cubic-foot batch mixed 50 seconds.

7. If oversanded mixes are still retained after the introduction of the use of aggregates of multiple sizes, the resulting concrete will not only cost more than it otherwise would but quality will be sacrificed. By using separated sizes intelligently a lower mortar ratio

(Continued on page 292)

# RELATION BETWEEN THE STRENGTH OF CEMENT AND THE STRENGTH OF CONCRETE

By F. H. JACKSON, Senior Engineer of Tests, U. S. Bureau of Public Roads

ABOUT four years ago the Bureau of Public Roads began a series of laboratory tests for the purpose of determining the extent to which the strength of concrete may be expected to vary as the result of variations in the quality of the Portland cement used in its manufacture. At that time engineers were just becoming interested in the use of relatively rapid hardening or high early strength cements in concrete road construction. It was felt that the use of such cements would be justified for economic reasons through the earlier opening of highways to traffic, provided assurance could be had that the ultimate strength and durability of the concrete would not suffer. The standard requirements of the American Society for Testing Materials had not then been raised to the present values and the general level of briquet strengths shown by Portland cements was not as high as it now is.

Because of this recent trend toward the manufacture of cements of higher early strength, the results of these tests may not have quite the significance which they otherwise would have. However, it is believed that the data will be of some interest, first in showing to what extent briquet strengths reflect the corresponding concrete strengths developed by various Portland cements at different ages, and second, the extent to which variations in the quality of Portland cement affect the conventional water-cement ratio strength relation.

### DESCRIPTION OF TESTS

Samples of eight brands of Portland cement were obtained from warehouse stocks in the Washington, D. C., market, and a series of concrete tests were made in which the attempt was made to eliminate every variable except the quality of the cement. A nominal 1:2:4 volumetric mix (dry rodded) was employed, using Potomac River sand and gravel and a sufficient quantity of water to give a slump of about two inches. The actual quantity of water was varied slightly, because of differences in the normal consistencies of the cements. However, the maximum difference in water-cement ratio due to this cause was so slight (amounting to only about 0.04) as to be of no significance as regards its effect on strength, and the water content may be said to have been substantially constant.

All specimens were fabricated and stored in accordance with American Society for Testing Materials standard practice. The briquets were stored in water in pans which were in turn stored in the concrete moist closet. The sand showed a fineness modulus of approximately 2.70 and passed all of the usual specification requirements. The gravel was graded uniformly from one and one-half inch down to one-fourth inch and was measured in three separate sizes.

The concrete was tested in compression, bending, and direct tension at periods of 7 and 28 days, six months, one year, and three years. Compression specimens were the usual 6 by 12-inch cylinders, transverse specimens 6 by 6 by 30-inch beams, tested as cantilevers and tension specimens 6 by 21-inch cylinders, tested by means of the gripping device developed in the laboratory of the Portland Cement Association.[1]

[1] Descriptions of the cantilever testing machine and the tension testing device appear in PUBLIC ROADS, vol. 10, No. 4, June, 1929, p. 74.

A complete series of the standard cement tests, including 20 sets of mortar briquets (three briquets to each set) was also made. This made it possible to test 12 briquets at each of the five ages indicated. Average results of all of the cement tests, with the exception of strength, are given in Table 1. The mortar tension tests for each cement for various periods up to three years and the corresponding concrete test results are given in Table 2.

TABLE 1.—*Routine tests of cements*

| Cement | Time of set | | | | Soundness | Fineness retained on No. 200 sieve | Normal consistency |
|---|---|---|---|---|---|---|---|
| | Initial | | Final | | | | |
| | *Hrs.* | *Min.* | *Hrs.* | *Min.* | | *Per cent* | *Per cent* |
| A | 3 | 45 | ([a]) | | Satisfactory | 15.1 | 23.0 |
| B | 3 | 35 | 8 | 30 | do | 16.6 | 23.0 |
| C | 4 | 20 | 8 | 30 | do | 14.8 | 21.8 |
| D | 4 | 35 | 8 | 35 | do | 13.9 | 23.8 |
| E | 4 | 06 | ([a]) | | do | 15.9 | 24.0 |
| F | 3 | 35 | 7 | 30 | do | 14.3 | 23.0 |
| G | 3 | 40 | 7 | 40 | do | 14.1 | 23.0 |
| H | 4 | 20 | 6 | 35 | do | 15.9 | 23.5 |

[a] More than 7 but less than 9 hours.

### DISCUSSION OF RESULTS

The variations in strength obtained for a constant water-cement ratio, as shown by the results of 28-day compression tests given in Table 2, cover a range in strength from 2,005 to 2,775 pounds per square inch, as compared to an average for the eight brands of 2,414 pounds per square inch. This is a total range of 770 pounds, or 32 per cent of the average value. According to the general relation $S=\frac{14,000}{7^x}$, in which $S$ represents crushing strength and $x$ the water-cement ratio, the crushing strength corresponding to the water-cement ratio used (0.95) should be about 2,200 pounds per square inch. Based on this value, the concrete of highest strength showed a deviation of 26 per cent from the theoretical value, with the other concretes showing proportionately smaller deviations.

The average for the eight brands (2,414 pounds per square inch) was, however, close to the theoretical strength called for by the conventional formula.

These tests indicate that the maximum deviation in crushing strength at 28 days due to variation in the quality of the Portland cement, was approximately equal to the variation in strength which would be obtained by changing the water-cement ratio one gallon per sack of cement. The results corroborate, in general, such other data as are available, which indicate that the quality of the Portland cement may have a rather marked effect upon the 28-day strength of the concrete.

It will be of interest to compare the variations in concrete strength at 28 days with the variations in strength which were observed at later periods. An inspection of Table 2 shows about the same total variation in strength at each of the five ages at which tests were made, with a somewhat greater spread at the shortest and longest testing periods (7 days and 3 years) than for the intermediate periods. The relative order of the strength values did not, however, remain the same, certain of the cements which were high at the early periods showing comparatively low values

TABLE 2.—*Effect of quality of cement on the quality of concrete* [1]

| Age | Cement | Briquet strength,[2] pounds per square inch | Strength of concrete in pounds per square inch | | |
|---|---|---|---|---|---|
| | | | Flexure | Compression | Tension |
| 7 days | A | 325 | 261 | 1,349 | 144 |
| | B | 290 | 249 | 1,402 | 130 |
| | C | 265 | 211 | 1,092 | 126 |
| | D | 295 | 276 | 1,530 | 146 |
| | E | 310 | 265 | 1,830 | 160 |
| | F | 290 | 247 | 1,430 | 132 |
| | G | 265 | 230 | 1,299 | 112 |
| | H | 360 | 372 | 1,940 | 202 |
| | Av. | 300 | 264 | 1,484 | 144 |
| 28 days | A | 375 | 391 | 2,160 | 227 |
| | B | 365 | 338 | 2,005 | 224 |
| | C | 345 | 330 | 2,100 | 198 |
| | D | 385 | 395 | 2,700 | 244 |
| | E | 385 | 401 | 2,775 | 222 |
| | F | 395 | 392 | 2,680 | 231 |
| | G | 350 | 384 | 2,428 | 212 |
| | H | 410 | 432 | 2,462 | 246 |
| | Av. | 376 | 383 | 2,414 | 226 |
| 6 months | A | 405 | 540 | 3,149 | 229 |
| | B | 395 | 509 | 3,379 | 242 |
| | C | 395 | 563 | 3,861 | 240 |
| | D | 380 | 532 | 3,701 | 228 |
| | E | 340 | 533 | 3,560 | 249 |
| | F | 335 | 509 | 3,745 | 217 |
| | G | 400 | 541 | 3,706 | 222 |
| | H | 365 | 492 | 3,410 | 227 |
| | Av. | 377 | 527 | 3,564 | 232 |
| 1 year | A | 405 | 482 | 3,539 | 244 |
| | B | 380 | 517 | 3,780 | 224 |
| | C | 400 | 519 | 4,086 | 233 |
| | D | 375 | 559 | 4,026 | 260 |
| | E | 355 | 523 | 4,064 | 235 |
| | F | 360 | 564 | 4,328 | 241 |
| | G | 410 | 564 | 4,225 | 238 |
| | H | 390 | 563 | 3,811 | 229 |
| | Av. | 384 | 536 | 3,982 | 238 |
| 3 years | A | 375 | 549 | 3,490 | 251 |
| | B | 370 | 561 | [3] 3,410 | 248 |
| | C | 375 | 583 | 4,140 | 286 |
| | D | 395 | 564 | 3,670 | 264 |
| | E | 355 | 540 | 4,170 | 267 |
| | F | 370 | 575 | [3] 4,490 | ---------- |
| | G | 345 | 554 | 3,650 | 235 |
| | H | 350 | 566 | [3] 3,590 | 254 |
| | Av. | 367 | 562 | 3,830 | 258 |

[1] Mix 1:2:4 by volume; water-cement ratio, 0.95; consistency, 2-inch slump. Each value for modulus of rupture, average of 4 tests on 2 beams. Each value for compression, average of 4 tests, except as noted. Each value for tension, average of 4 tests on 2 cylinders.

[2] Tensile strength of 1:3 Ottawa sand mortar briquets. Each result is the average of 12 tests. Briquets stored in moist closet 24 hours; balance of time in water contained in pans stored in moist room.

[3] Average of 3 tests.

later. This is shown in Table 3, which gives the relative order of the eight cements for each testing period and for each type of test.

In general, it will be seen that, for the two earlier periods, 7 and 28 days, the briquet strengths of the various cements indicate quite definitely the relative order of the concrete strengths which will be developed by the same cements at the same ages. The only outstanding exception to this rule is cement A which shows a 7-day briquet strength quite out of line with the concrete strengths developed with this cement. At 28 days it will be noted that this cement has dropped to fifth place in briquet strength, which is about the order of strength in concrete for this cement at both 7 and 28 days.

After the 28-day period practically all trends as regards the relationship between briquet strength and concrete strength disappear. This is true, not only of the 7 and 28 day briquet strength as compared to concrete strength at various periods, but is true also of the long time briquet strengths as compared to concrete

TABLE 3.—*Relative order of eight cements in mortar and concrete at various ages*

| Age | Order | Tension tests of mortar briquets | Concrete tests | | |
|---|---|---|---|---|---|
| | | | Tension | Flexure | Compression |
| 7 days | 1 | H | H | H | H |
| | 2 | A | E | D | E |
| | 3 | E | D | E | D |
| | 4 | D | A | B | F |
| | 5 | F | F | F | B |
| | 6 | B | B | A | A |
| | 7 | G | C | G | G |
| | 8 | C | G | C | C |
| 28 days | 1 | H | H | H | E |
| | 2 | F | D | E | D |
| | 3 | E | F | D | F |
| | 4 | D | A | F | H |
| | 5 | A | B | A | G |
| | 6 | B | E | G | A |
| | 7 | G | G | B | C |
| | 8 | C | C | C | B |
| 6 months | 1 | A | E | C | C |
| | 2 | G | B | G | F |
| | 3 | B | C | A | G |
| | 4 | C | A | E | D |
| | 5 | D | D | D | E |
| | 6 | H | H | F | H |
| | 7 | E | G | B | B |
| | 8 | F | F | H | A |
| 1 year | 1 | G | D | F | F |
| | 2 | A | A | G | G |
| | 3 | C | F | H | C |
| | 4 | H | G | D | E |
| | 5 | B | E | E | D |
| | 6 | D | C | C | H |
| | 7 | F | H | B | B |
| | 8 | E | B | A | A |
| 3 years | 1 | D | ---------- | C | F |
| | 2 | A | ---------- | F | E |
| | 3 | C | ---------- | H | C |
| | 4 | B | ---------- | D | D |
| | 5 | F | ---------- | B | G |
| | 6 | E | ---------- | G | H |
| | 7 | H | ---------- | A | A |
| | 8 | G | ---------- | E | B |

strengths at the corresponding ages. Here again the data are in accord with other available information on the subject, which in general, indicates that at ages of six months and over, cements which give relatively low briquet strengths at 7 and 28 days, may show as high or higher concrete tests as those cements which give high 7 and 28 day test results.

From an examination of Table 2 it will be observed that there was a very definite retrogression in the strength of mortar briquets at three years, in all cases except that of cement D, and in some cases at earlier ages. This tendency is not reflected in any systematic way in the concrete tension tests, and we may, therefore, conclude that it was not caused by the particular cements used, but by some other factor, such as type of specimen, method of storage, etc., common to all specimens. In flexure also there was very little tendency toward retrogression in strength, except in the case of cements C, E, and A at one year and cement G at three years. These decreases may be accidental, although the same tendency appears in the tension tests in the case of cements C and E. On the other hand, none of these cements show retrogression in crushing strength at one year, although cements G, B, D, A, and E show a decrease at three years. In only one case (cement G) is there a corresponding reduction in the flexure and concrete tension strengths. It seems reasonable to assume that any marked tendency for a particular cement to cause retrogression in strength would be reflected in all of the concrete tests. It is believed that, in general, the reduction in crushing strength at three years was caused, not by the use of particular cements, but by some factor which can not be determined by the data available.

(Continued on page 292)

(Continued from page 289)

can generally be used and as a consequence the cement factor may be reduced.

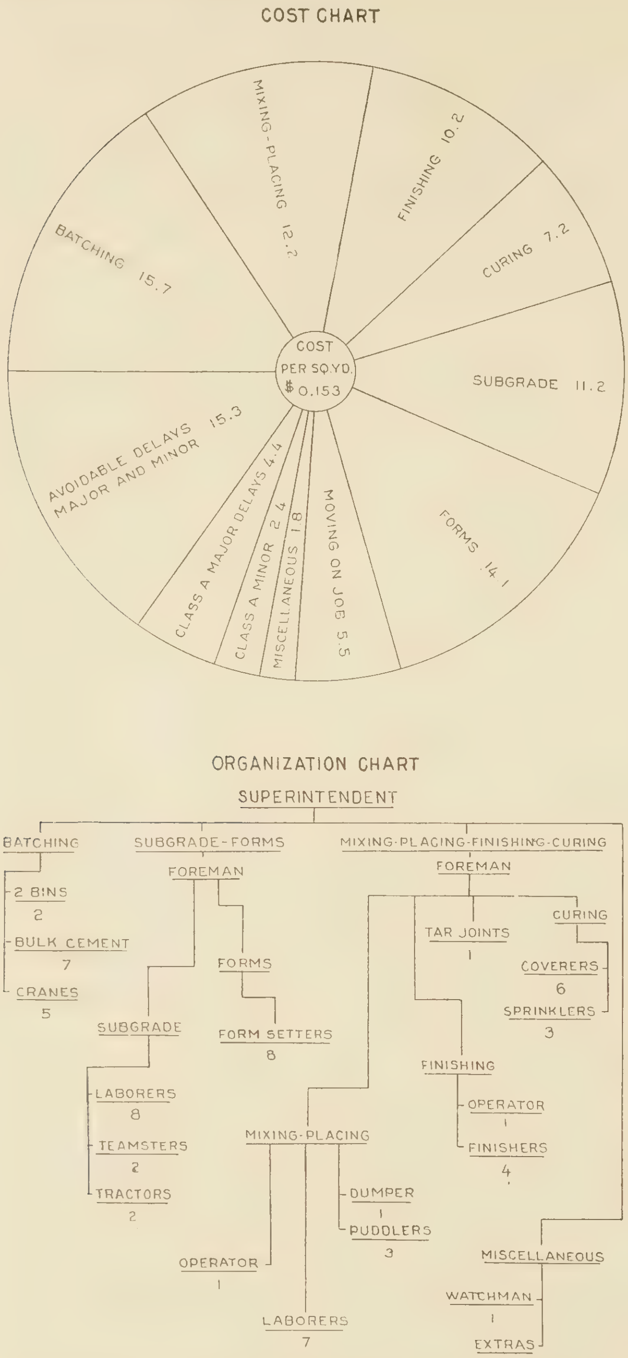


Figure 22.—Labor Cost Data and Organization Chart for Wisconsin State-Aid Project 2926. Costs are Expressed as Percentages of Total Cost of Labor

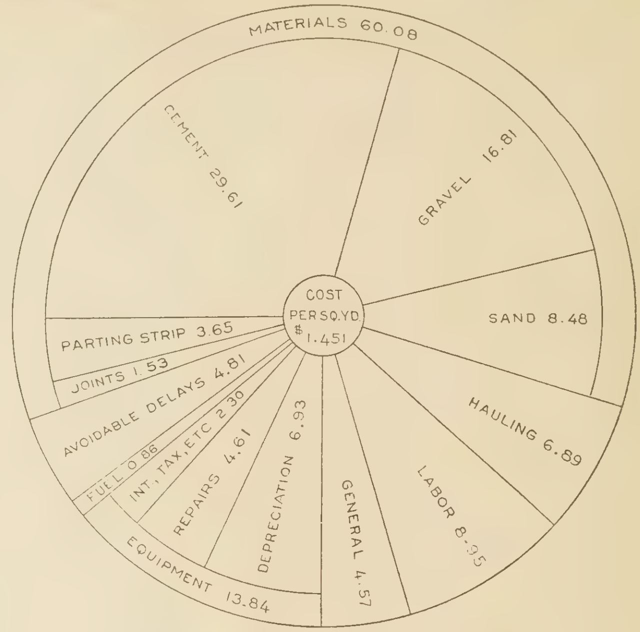


Figure 23.—Summary of Cost Data for Wisconsin State-Aid Project 2926. Costs are Expressed as Percentages of Total Cost of Project

(Continued from page 291)

These tests substantiate the general conclusions which have been reached by concrete engineers to the effect that the 7 and 28 day briquet strengths of Portland cement are no measure of the comparative strengths of the concrete at later periods (say six months and over). The tests do indicate, however, that routine briquet strengths at 7 and 28 days measure, in a general way, the comparative strengths which will be developed in concrete at corresponding periods.

## INDEX TO VOLUME 11 OF PUBLIC ROADS AVAILABLE

An index to volume 11 of Public Roads, which includes the issues from March, 1930, to February, 1931, is now available for distribution, and copies may be obtained without charge from the Bureau of Public Roads, United States Department of Agriculture, Washington, D. C. Indexes to volumes 6, 7, 8, 9, and 10 have previously been published, and a supply of these indexes is still on hand. The index to volume 12 is now being prepared.

# ROAD PUBLICATIONS OF THE BUREAU OF PUBLIC ROADS

*Applicants are urgently requested to ask only for those publications in which they are particularly interested. The Department can not undertake to supply complete sets not to send free more than one copy of any publication to any one person. The editions of some of the publications are necessarily limited, and when the Department's free supply is exhausted and no funds are available for procuring additional copies, applicants are referred to the Superintendent of Documents, Government Printing Office, this city, who has them for sale at a nominal price, under the law of January 12, 1895. Those publications in this list, the Department supply of which is exhausted can only be secured by purchase from the Superintendent of Documents, who is not authorized to furnish publications free.*

## ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1924.

Report of the Chief of the Bureau of Public Roads, 1925.

Report of the Chief of the Bureau of Public Roads, 1927.

Report of the Chief of the Bureau of Public Roads, 1928.

Report of the Chief of the Bureau of Public Roads, 1929.

Report of the Chief of the Bureau of Public Roads, 1931.

## DEPARTMENT BULLETINS

No. *136D. Highway Bonds. 20c.

*347D. Methods for the Determination of the Physical Properties of Road-Building Rock. 10c.

*532D. The Expansion and Contraction of Concrete and Concrete Roads. 10c.

*583D. Reports on Experimental Convict Road Camp, Fulton County, Ga. 25c.

*660D. Highway Cost Keeping. 10c.

1279D. Rural Highway Mileage, Income, and Expenditures 1921 and 1922.

1486D. Highway Bridge Location.

## DEPARTMENT CIRCULAR

No. 331C. Standard Specifications for Corrugated Metal Pipe Culverts.

## TECHNICAL BULLETINS

No. 55T. Highway Bridge Surveys.

265T. Electrical Equipment on Movable Bridges.

## SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y. Road Work on Farm Outlets Needs Skill and Right Equipment.

## MISCELLANEOUS CIRCULARS

No. 62MC. Standards Governing Plans, Specifications, Contract Forms, and Estimates for Federal-Aid Highway Projects.

*93MC. Direct Production Costs of Broken Stone. 25c.

109MC. Federal Legislation and Regulations Relating to the Improvement of Federal-Aid Roads and National-Forest Roads and Trails, Flood Relief, and Miscellaneous Matters.

## MISCELLANEOUS PUBLICATION

No. 76MP. The Results of Physical Tests of Road-Building Rock.

## TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio. (1927)

Report of a Survey of Transportation on the State Highways of Vermont. (1927)

Report of a Survey of Transportation on the State Highways of New Hampshire. (1927)

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio. (1928)

Report of a Survey of Transportation on the State Highways of Pennsylvania. (1928)

## REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH

Vol. 5, No. 17, D- 2. Effect of Controllable Variables upon the Penetration Test for Asphalts and Asphalt Cements.

Vol. 5, No. 19, D- 3. Relation Between Properties of Hardness and Toughness of Road-Building Rock.

Vol. 5, No. 24, D- 6. A New Penetration Needle for Use in Testing Bituminous Materials.

Vol. 11, No. 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.

*Department supply exhausted.

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

# CURRENT STATUS OF FEDERAL-AID ROAD CONSTRUCTION

AS OF

## DECEMBER 31, 1931

| STATE | COMPLETED MILEAGE | UNDER CONSTRUCTION | | | | | APPROVED FOR CONSTRUCTION | | | | | BALANCE OF FEDERAL-AID FUNDS AVAILABLE FOR NEW PROJECTS | STATE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Estimated total cost | Federal-aid allotted | MILEAGE | | | Estimated total cost | Federal-aid allotted | MILEAGE | | | | |
| | | | | Initial | Stage | Total | | | Initial | Stage[1] | Total | | |
| Alabama | 2,388.2 | $ 1,777,588.89 | $ 864,676.57 | 79.8 | | 79.8 | | | | | | $ 5,379,923.57 | Alabama |
| Arizona | 1,117.0 | 3,562,907.58 | 2,343,687.11 | 145.2 | 64.7 | 209.9 | $ 300,861.26 | $ 226,518.42 | 22.8 | 19.8 | 42.6 | 1,600,099.18 | Arizona |
| Arkansas | 1,910.6 | 4,068,522.55 | 1,909,018.01 | 96.4 | 72.7 | 169.1 | 362,032.53 | 181,016.26 | 17.3 | | 17.3 | 1,991,140.13 | Arkansas |
| California | 2,158.0 | 11,434,880.17 | 4,616,110.99 | 254.9 | 52.4 | 307.3 | 1,980,622.58 | 970,432.19 | 44.9 | .5 | 45.4 | 2,721,765.29 | California |
| Colorado | 1,507.0 | 5,416,815.46 | 2,742,198.39 | 231.7 | 66.0 | 297.7 | 703,739.90 | 313,512.72 | 9.2 | 4.5 | 13.7 | 2,005,136.74 | Colorado |
| Connecticut | 282.7 | 3,627,221.97 | 1,279,199.52 | 28.7 | | 28.7 | | | | | | 706,266.13 | Connecticut |
| Delaware | 361.3 | 206,946.00 | 103,473.00 | 4.6 | | 4.6 | 395,470.75 | 197,735.37 | 19.1 | | 19.1 | 372,952.56 | Delaware |
| Florida | 557.4 | 5,946,262.29 | 2,785,791.55 | 171.4 | | 171.4 | | | | | | 3,046,471.31 | Florida |
| Georgia | 3,002.5 | 6,598,761.25 | 3,071,219.80 | 167.1 | 143.9 | 311.0 | 1,853,857.89 | 901,318.59 | 61.7 | 37.1 | 98.8 | 1,606,162.05 | Georgia |
| Idaho | 1,474.3 | 1,794,657.51 | 1,031,277.61 | 89.0 | 87.9 | 176.9 | 204,243.49 | 122,522.12 | 9.0 | | 9.0 | 1,471,202.64 | Idaho |
| Illinois | 2,631.3 | 21,041,452.50 | 9,705,184.95 | 612.7 | 28.7 | 641.4 | 4,079,085.62 | 1,803,097.17 | 134.6 | 4.7 | 139.3 | 3,553,117.70 | Illinois |
| Indiana | 1,764.5 | 7,820,417.43 | 3,872,008.57 | 212.4 | | 212.4 | 1,916,780.29 | 917,959.90 | 67.7 | 12.5 | 80.2 | 2,442,964.90 | Indiana |
| Iowa | 3,379.0 | 331,333.50 | 138,397.76 | | 11.9 | 11.9 | 875,554.99 | 412,779.20 | 17.8 | 15.3 | 33.1 | 2,387,026.00 | Iowa |
| Kansas | 3,638.1 | 3,356,531.65 | 1,567,281.94 | 172.9 | 15.2 | 188.1 | 805,943.50 | 399,036.29 | 71.9 | | 71.9 | 2,760,080.01 | Kansas |
| Kentucky | 1,878.8 | 2,144,959.57 | 965,595.15 | 130.5 | 4.0 | 134.5 | 80,102.42 | 40,061.21 | 5.5 | | 5.5 | 2,031,876.08 | Kentucky |
| Louisiana | 1,538.6 | 7,319,502.67 | 2,867,785.52 | 117.7 | 10.6 | 128.3 | 1,295,507.93 | 68,270.07 | .5 | | .5 | 1,644,337.95 | Louisiana |
| Maine | 706.0 | 1,804,346.15 | 789,080.76 | 31.4 | | 31.4 | 37,546.34 | 14,085.00 | .9 | | .9 | 1,304,944.37 | Maine |
| Maryland | 769.2 | 465,159.40 | 161,463.01 | 14.4 | | 14.4 | 250,874.75 | 125,437.37 | 11.8 | | 11.8 | 785,651.09 | Maryland |
| Massachusetts | 767.9 | 10,698,242.29 | 3,438,156.15 | 99.5 | | 99.5 | 967,832.21 | 355,459.70 | 12.2 | | 12.2 | 868,329.01 | Massachusetts |
| Michigan | 1,974.3 | 9,833,130.95 | 4,207,272.69 | 340.4 | 58.1 | 398.5 | 672,750.00 | 336,375.00 | 32.7 | | 32.7 | 3,526,676.69 | Michigan |
| Minnesota | 4,291.3 | 2,047,501.22 | 779,785.46 | 20.7 | 58.8 | 79.5 | 6,679,825.80 | 2,146,085.76 | 119.4 | 172.2 | 291.6 | 527,121.61 | Minnesota |
| Mississippi | 1,809.7 | 3,462,676.29 | 1,715,852.10 | 166.7 | 60.8 | 227.5 | 446,856.30 | 200,118.74 | 2.2 | 17.3 | 19.5 | 5,487,995.36 | Mississippi |
| Missouri | 2,910.0 | 3,600,974.93 | 1,496,071.62 | 95.7 | 14.0 | 109.7 | 1,366,595.12 | 606,208.31 | 47.8 | 3.5 | 51.3 | 3,070,214.11 | Missouri |
| Montana | 2,602.6 | 5,641,159.72 | 3,157,553.44 | 440.5 | 22.8 | 463.3 | 461,551.57 | 261,257.46 | 74.0 | 1.4 | 75.4 | 3,199,372.54 | Montana |
| Nebraska | 4,110.9 | 6,282,652.45 | 2,987,340.32 | 236.7 | 90.1 | 326.8 | | | | | | 2,620,865.46 | Nebraska |
| Nevada | 1,307.8 | 1,450,416.78 | 1,098,118.53 | 41.4 | 116.9 | 158.3 | | | | | | 1,553,046.51 | Nevada |
| New Hampshire | 418.8 | 636,114.46 | 246,912.44 | 12.1 | 2.5 | 14.6 | | | | | | 547,810.24 | New Hampshire |
| New Jersey | 574.1 | 6,233,030.43 | 2,156,623.60 | 67.4 | .6 | 68.0 | | | | | | 1,704,126.69 | New Jersey |
| New Mexico | 2,177.7 | 2,868,433.47 | 1,834,223.29 | 135.7 | 13.8 | 149.5 | 107,277.63 | 67,700.35 | .3 | | .3 | 1,445,528.99 | New Mexico |
| New York | 3,204.0 | 14,783,200.00 | 6,219,225.00 | 317.3 | | 317.3 | 2,479,500.00 | 963,025.00 | 49.6 | | 49.6 | 4,794,623.59 | New York |
| North Carolina | 2,209.8 | 1,503,642.53 | 730,848.59 | 72.0 | | 72.0 | 223,477.16 | 111,738.56 | 17.4 | 4.0 | 21.4 | 3,864,930.24 | North Carolina |
| North Dakota | 5,113.0 | 1,882,481.70 | 944,932.80 | 166.9 | 171.9 | 338.8 | 1,327,226.48 | 679,096.29 | 149.6 | 259.5 | 409.1 | 1,961,206.41 | North Dakota |
| Ohio | 2,814.7 | 7,403,122.99 | 2,579,944.47 | 114.1 | 29.8 | 143.9 | 1,108,207.63 | 547,514.39 | 6.6 | .4 | 7.0 | 4,146,278.47 | Ohio |
| Oklahoma | 2,183.5 | 5,289,782.65 | 2,572,923.28 | 137.3 | 84.0 | 221.3 | 54,280.31 | 30,017.00 | .1 | | .1 | 2,534,175.20 | Oklahoma |
| Oregon | 1,537.6 | 3,289,149.12 | 1,824,448.62 | 92.1 | 35.7 | 127.8 | 108,061.90 | 65,447.84 | 3.7 | 11.1 | 14.8 | 2,144,258.56 | Oregon |
| Pennsylvania | 2,991.4 | 4,776,384.08 | 2,173,477.80 | 66.5 | | 66.5 | | | | | | 5,155,863.62 | Pennsylvania |
| Rhode Island | 257.5 | 811,653.61 | 427,281.05 | 16.6 | | 16.6 | 81,305.62 | 40,652.81 | 2.1 | | 2.1 | 325,046.93 | Rhode Island |
| South Carolina | 1,987.2 | 2,899,736.33 | 1,258,506.90 | 63.0 | 53.5 | 116.5 | | | | | | 1,369,843.00 | South Carolina |
| South Dakota | 4,035.9 | 2,861,923.36 | 1,578,778.43 | 174.8 | 175.3 | 350.1 | 317,827.24 | 180,943.91 | 35.1 | | 35.1 | 1,416,988.47 | South Dakota |
| Tennessee | 1,663.7 | 848,984.19 | 422,357.41 | 24.2 | 8.7 | 32.9 | 437,068.09 | 202,974.45 | 13.6 | 6.4 | 20.0 | 3,870,857.58 | Tennessee |
| Texas | 7,581.8 | 13,504,192.79 | 6,069,551.28 | 672.0 | 140.6 | 812.6 | 1,827,496.02 | 819,984.59 | 136.7 | 53.4 | 190.1 | 7,325,508.50 | Texas |
| Utah | 1,218.6 | 650,176.96 | 452,772.23 | 59.5 | .4 | 59.9 | 215,919.55 | 159,755.43 | 13.5 | 3.2 | 16.7 | 1,403,504.03 | Utah |
| Vermont | 339.1 | 104,832.58 | 52,345.06 | 4.3 | | 4.3 | | | | | | 547,165.83 | Vermont |
| Virginia | 1,821.9 | 3,371,853.57 | 1,588,186.92 | 160.6 | 29.3 | 189.9 | 166,304.09 | 83,152.04 | 5.4 | | 5.4 | 2,086,417.78 | Virginia |
| Washington | 1,177.7 | 2,253,263.80 | 1,079,786.83 | 67.6 | 6.5 | 74.1 | 588,062.89 | 223,000.00 | 26.6 | | 26.6 | 1,790,375.81 | Washington |
| West Virginia | 861.6 | 2,256,068.25 | 989,293.85 | 67.1 | 10.5 | 77.6 | 234,360.46 | 109,369.58 | .7 | | .7 | 1,198,368.17 | West Virginia |
| Wisconsin | 2,647.6 | 3,684,198.61 | 1,402,097.76 | 139.3 | 34.4 | 173.7 | | | | | | 2,716,712.05 | Wisconsin |
| Wyoming | 2,050.4 | 2,308,842.10 | 1,368,659.97 | 157.5 | 76.6 | 234.1 | 307,627.38 | 198,458.66 | | 35.8 | 35.8 | 858,687.26 | Wyoming |
| Hawaii | 63.1 | 904,811.18 | 414,072.39 | 27.9 | | 27.9 | 151,626.85 | 54,354.00 | 3.6 | | 3.6 | 2,018,071.60 | Hawaii |
| TOTALS | 99,777.4 | 216,849,699.93 | 98,079,850.48 | 6,818.2 | 1,853.6 | 8,671.8 | 35,473,244.54 | 15,134,461.75 | 1,247.6 | 662.6 | 1,910.2 | 113,879,088.01 | TOTALS |

[1] The term stage construction refers to additional work done on projects previously improved with Federal-aid. In general, such additional work consists of the construction of a surface of higher type than was provided in the initial improvement.

U. S. GOVERNMENT PRINTING OFFICE: 1932