PUBLIC ROADS

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UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

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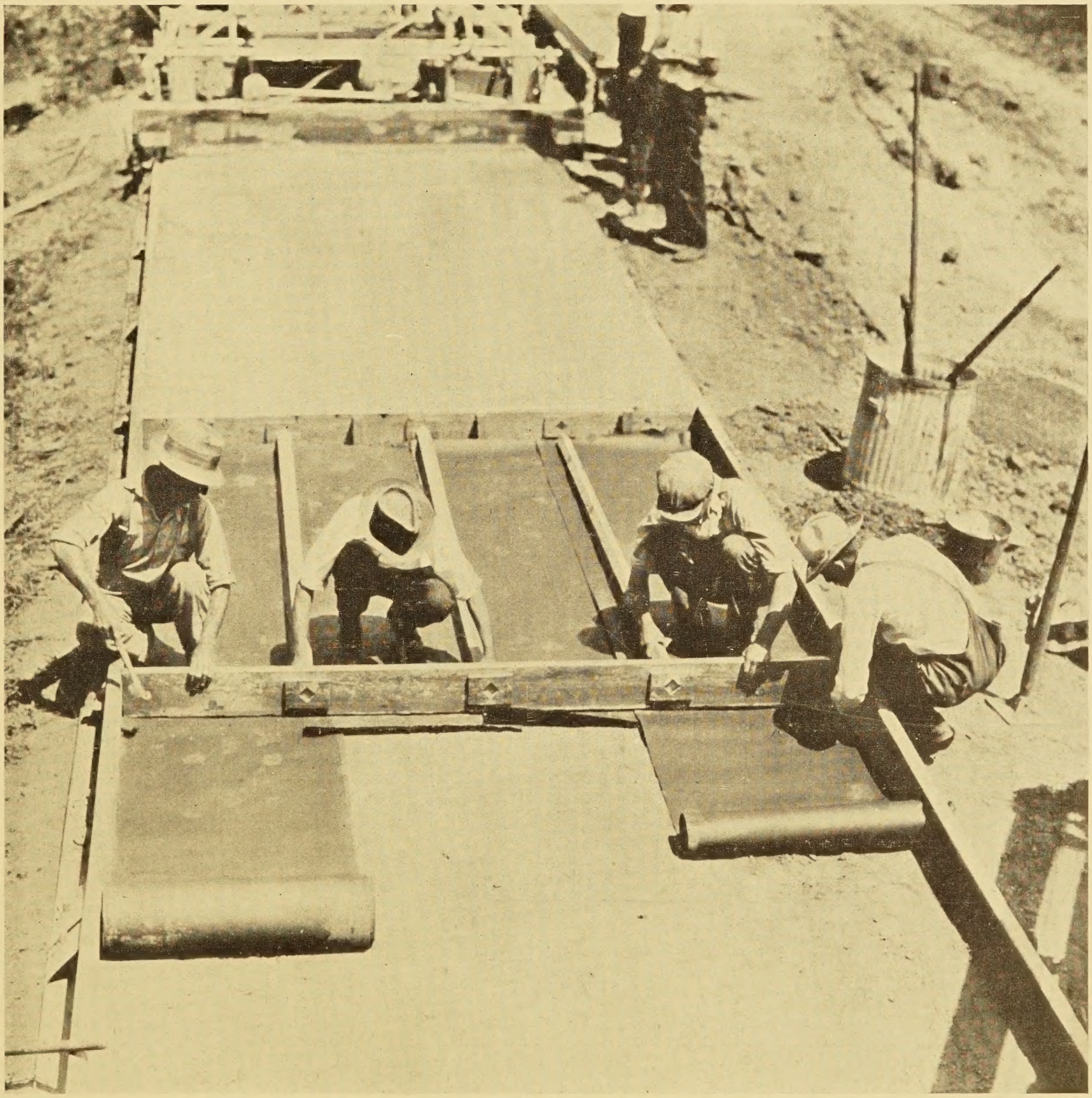

PREPARING TEST SLABS FOR STUDIES OF PAVING CONCRETE

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STUDIES OF PAVING CONCRETE [1]

By F. H. JACKSON, Senior Engineer of Tests, and W. F. KELLERMANN, Associate Materials Engineer, U. S. Bureau of Public Roads

THE tests which are reported in this paper were undertaken primarily for the purpose of determining the effect of variations in the quantity of coarse aggregate upon the strength, density, and other properties of concrete pavement slabs which had been placed and finished in accordance with normal field practice. Experience in the use of multiple sizes of coarse aggregate in concrete pavement work in North Carolina and other States during the past few years has indicated the possibility of increasing the quantity of coarse aggregate per unit of volume of concrete beyond the limit which had previously been considered good practice and in this way producing a denser as well as a more economical mixture, provided only that the uniformity of the grading of the coarse aggregate and therefore its void content was controlled rigidly by handling and measuring it in separate sizes.

It was realized at the outset that an investigation of this sort, involving as it did that most elusive property of concrete which we call "workability," could not be performed satisfactorily in the laboratory. In spite of strenuous efforts on the part of many investigators, no satisfactory laboratory test for workability has as yet been developed. Furthermore, this whole matter of workability is tied up so intimately with methods of handling and finishing used on the job that it is impossible to set up any laboratory standard which will give more than comparative results. In other words, a concrete which by some laboratory standard may be rated as "unworkable" may be quite workable under certain job conditions. For this investigation the percentage of visible honeycomb in the concrete, as revealed by a careful examination of the slabs, all of which were constructed in accordance with standard field practice, together with the uniformity of strength as determined by testing beams taken directly from the pavement, has been used to measure the uniformity and therefore the workability of the concrete. On this basis any concrete mixture which can be so handled as to produce a uniform homogeneous slab without unduly raising labor costs or reducing efficiency in operation is "workable" concrete, and any concrete which can not be so handled is not workable, in spite of any rating which it may receive by some arbitrary test.

Most of the information which we have regarding the properties of concrete at the present time has been obtained in the laboratory on small-sized beams and cylinders. While these data are of great value in helping us to understand some of the fundamental relationships governing the quality of concrete, as, for instance, the relation between water-cement ratio and strength, we must realize that it is the finished structure with which we are primarily concerned and that we are not in a position to make the best use of laboratory test data until we know to just what extent tests on molded specimens measure the quality of the concrete in the structure. This investigation furnished an excellent opportunity to study these relationships, both for crushing strength, through the use of molded cylinders compared with cores drilled from the pavement, and for transverse strength, through the use of molded beams compared with large beams taken from the pavement.

PROJECT DESCRIBED

In order to develop information along these lines, the Bureau of Public Roads during the summer of 1929 constructed an experimental concrete pavement 9 feet wide and approximately one-half mile long, using standard construction methods and appliances throughout, except that provision was made for creating planes of weakness to permit the removal of the pavement in sections for test purposes. The pavement was built at the Arlington Experiment Station of the Department of Agriculture at Arlington, Va., on the right of way of an abandoned electric line. This provided a graded, well drained, level subgrade which proved ideal for the purpose.

A total of 265 sections, each 9 feet in length, was constructed. The program called for the construction of six sections per day, three sections of each of two proportions, using a given type and gradation of coarse aggregate and method of finishing. In each group of three the water content was varied so as to produce a variable consistency ranging from the driest mix which it appeared possible to place without undue effort on the part of the finishers to a consistency approximating a 2 to 3 inch slump. No effort was made to produce wet consistencies such as have sometimes been used in the past, because it was felt that the dangers of overwet concrete are sufficiently well known and require no demonstration. On the other hand, the water-cement ratio method of proportioning, the adoption of which is being strongly urged, encourages the use of dry concrete, so that it seemed desirable to study mixtures of this sort rather than the wet consistencies which are recognized as undesirable by everyone.

MATERIALS AND PROPORTIONS

In order to cover adequately the question of type of coarse aggregate as it affected the workability of the concrete and therefore the limiting quantity which might be used with safety, a siliceous limestone having a rather sharp angular fracture and a bank gravel containing some crushed fragments were used in the tests. In addition, a limited number of sections were laid with blast furnace slag as coarse aggregate.

The cement was a standard brand Portland, meeting all requirements of the American Society for Testing Materials. It was shipped by car direct from the mill to the site of the work and all of the cement came from one bin. The results of physical tests of this cement are given in Table 1.

The fine aggregate consisted of sand from the Potomac River, having a fineness modulus of 2.65. Average test data are given in Table 1. It was realized, of course, that the grading and other characteristics of the sand used in these experiments would have a marked effect upon the amount of coarse aggregate which could

[1] The bureau desires to express its appreciation of the courtesy extended by the following companies in loaning the equipment indicated in each case for use during the construction of the test pavement:
National Equipment Co., 27E paver.
Blaw-Knox Co., 2-compartment bin with weighing batcher and steel road forms.
Heltzel Steel Form & Iron Co., 2-compartment bin with weighing batcher and teel road forms.
Lakewood Engineering Co., Lakewood combination single screed and tamper finishing machine.
A. W. French Co., Ord double-screed finishing machine.
Duquesne Slag Products Co., crushed slag.

Table 1.—*Physical properties of cement and fine aggregate*

1. Portland cement:	
Fineness, percentage retained on 200-mesh sieve	14. 7
Time of set (Gillmore)—	
Initial	3 hours, 8 minutes.
Final	6 hours, 3 minutes.
Steam test for soundness	Satisfactory.
Normal consistency, per cent	22. 6
Tensile strength (pounds per square inch, 1:3 Ottawa sand mortar)—	
At 7 days	315
At 28 days	400
(Results are average of 14 samples tested.)	
2. Fine aggregate:	
Sieve analysis [1]—	
Total retained on ¼-inch screen, per cent	1
Total retained on No. 10 sieve, per cent	14
Total retained on No. 20 sieve, per cent	32
Total retained on No. 30 sieve, per cent	45
Total retained on No. 40 sieve, per cent	69
Total retained on No. 50 sieve, per cent	86
Total retained on No. 80 sieve, per cent	94
Total retained on No. 100 sieve, per cent	96
Total retained on No. 200 sieve, per cent	97
Silt and clay, per cent	2. 8
Apparent specific gravity	2. 65
Weight per cubic foot (dry-rodded), pounds	102
Absorption (Rea's method), per cent	0. 7
Voids, per cent	38
Organic matter (color test)	Satisfactory.
Strength ratio—	
7 days	96
28 days	113
Description: Sand consists essentially of angular quartz grains, containing some chert, feldspar, and mica.	

[1] Sieve analysis is average of 96 samples tested.

Table 2.—*Physical properties of coarse aggregates*

Type of aggregate	Specific gravity	Absorption	Wear	Weight per cubic foot (dry rodded)	Voids
		Per cent	*Per cent*	*Pounds*	*Per cent*
Gravel, grading A	2. 67	0. 27	14. 3	108	35
Gravel, grading B	2. 64	. 43		105	36
Stone, grading A	2. 72	. 12	[1] 4. 4	102	40
Stone, grading B	2. 72	. 12		101	41
Slag	2. 47	----------	12. 2	87	44

[1] Not standard test; made with crushed rock.

Table 3.—*Gradings of coarse aggregate*

Aggregate	Grading	Per cent by weight passing round-opening screens			
		2½-inch	1¼-inch	¾-inch	¼-inch
Gravel	A	100	50	25	0
Do	B	----------	100	60	0
Stone	A	100	50	25	0
Do	B	100	37	10	0
Slag	A	100	50	25	0

be used. It is well known that in general the finer the sand the higher the percentage of coarse aggregate by volume which may be employed without exceeding the limits of workability. However, it was obviously impossible to study any great range in fine aggregate gradations in a program such as this. It was decided, therefore, to use a single sand of average gradation with varying percentages of coarse aggregate, beginning at a value sufficiently low to insure a well-oversanded mix for the particular type of sand selected and increasing the amount of coarse aggregate by definite steps until a distinctly undersanded mix, as judged by laboratory standards, had been obtained.

The results of the physical tests of the three coarse aggregates are given in Table 2. The limestone was obtained from Martinsburg, W. Va.; the gravel from Fredericksburg, Va.; and the slag from Birdsboro, Pa. Each aggregate was ordered shipped to the job in three separate sizes, as follows: ¼-inch to ¾-inch, ¾-inch to 1¼-inch, 1¼-inch to 2½-inch. The separated sizes were combined by weight to give the combined aggregate gradations indicated in Table 3.

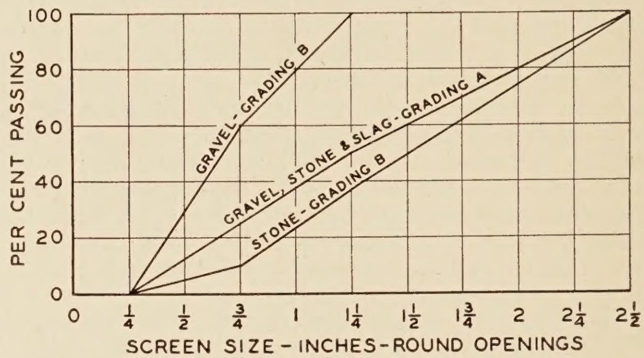


Figure 1.—Gradings of Coarse Aggregates as Designed

It will be noted that in the case of the gravel and the crushed stone two gradings were employed. Grading A is the so-called straight-line grading, showing an even distribution of sizes from the maximum down to ¼-inch. Grading B in the case of the gravel ranged in size from ¼-inch to 1¼-inch, with a surplus in the finer sizes. This grading was used because of the economic importance of this type of gravel in certain sections of the country. Grading B for the crushed stone showed a deficiency in the finer sizes and was used to simulate a condition often met with in practice whenever a demand exists for these finer sizes for bituminous work, resulting in a tendency to rob the concrete aggregate of these sizes. The sieve analysis curves for the combined gradings are shown in Figure 1.

MORTAR-VOIDS ANALYSIS MADE

In the preparation of this report an analysis was made of the base mix, 1: 2: 3½, used in these tests according to the Talbot-Richart mortar-voids theory.[2] Results of mortar-voids tests on the sand used, which were made by Professor Richart, of the University of Illinois, form the basis of this analysis. According to the mortar-voids theory, for materials similar in quality, the strength of concrete is a function of the ratio of the volume of voids to the volume of cement in the mix. The theory also holds that, for the type of plastic mix ordinarily employed in construction, the void characteristics of the mortar constituent may be used in investigating the probable strength of the concrete. This is possible because, for such mixes, the volume of mortar is greater than the volume of voids in the coarse aggregate, and the voids in the concrete may therefore be considered as made up of the sum of the air and water voids in the mortar. The results of the mortar-voids analysis are omitted from the present report for lack of space.

In the method of designing concrete described by Talbot and Richart the maximum quantity of coarse aggregate to use is determined by means of the ratio $\frac{b}{b_0}$ in which b is the absolute volume of coarse aggregate in a unit volume of concrete and b_0 is the absolute volume of coarse aggregate in a unit volume of coarse

[2] Bulletin 137, University of Illinois Engineering Experiment Station, 1923.

aggregate. This ratio expresses directly the bulk volume (absolute volume plus voids) of coarse aggregate which is present in a unit volume of concrete. Since the voids in a given volume of coarse aggregate are always increased by the addition of mortar, the volume of resulting concrete will always be larger than the bulk volume of coarse aggregate used, and the ratio $\frac{b}{b_0}$ will always be less than 1. In designing concrete mixes the practical application of this theory involves the determination of b for a given b_0 on the basis of an assumed value for the ratio, the magnitude of which will vary with the several conditions affecting workability, such as type of coarse aggregate, methods of placing and finishing, etc. A number of State highway departments are using this ratio in designing their paving mixtures, the value being based, in most cases, upon field practice. For this reason the values for $\frac{b}{b_0}$ corresponding to the various arbitrary mixes selected for this study have been calculated and are given in Table 11. The value of the ratio for each mix has been calculated on the basis of the average amount of water used in the various sections in which the mix was employed.

CONSTRUCTION METHODS OUTLINED

Batching materials.—Although the basic proportions were determined by dry-rodded volumes, all of the materials for each batch, with the exception of water, were weighed. The aggregates were weighed in regulation batchers; the cement was weighed in the original sacks on platform scales. In order to handle the coarse aggregate in three sizes, two 2-bin batcher plants were used. One of these handled two sizes of coarse aggregate, while the other handled the third size and the sand. The batcher plants were of different make, one being provided with an automatic dial for indicating the weight and the other with a beam and rider. The latter was equipped also with an automatic tell-tale for indicating over or under weight. The weighing hoppers on both batchers were so arranged that any excess material could be conveniently removed. A view of the batcher plant layout is shown in Figure 2.

As the bins were filled, sieve analyses were made of the separate sizes of coarse aggregate and these data later used in determining the weights of each size necessary to give the theoretical grading required. It was ascertained from these analyses that certain of the sizes contained appreciable quantities of material which passed the smaller screen designating that particular size. However, the percentage of fines in each size did not vary to any extent from day to day, so that, a correction having been established for the undersize material, it was not necessary to change it often.

Filling of the sand hopper was not begun until the morning on which the material was to be used. In this way variations in moisture content within the hopper were eliminated to a large extent. Moisture determinations were made as the hopper was filled, and these percentages were used in calculating the weight of dry sand required for each batch. As the sand was delivered into the skip of the mixer, additional samples were taken and these samples sent to the laboratory for mechanical analysis and a check on the moisture content.

Hauling material from batching plant to mixer.—The materials were conveyed from the batching plant by dump trucks, each truck hauling one batch. The trucks first received two separate sizes of coarse aggregate from one batcher, then pulled under the second batcher for the third size and the sand, and then passed by the cement house where the cement was loaded in sacks and partial sacks. Immediately prior to the approach of the trucks to the mixer these sack were opened and the cement spread over the aggregate. Canvas spread over the damp sand in the trucks prevented loss of moisture during the interval between loading and dumping into the skip of the mixer.

Construction of test slabs.—The concrete was laid as a pavement 9 feet in width, 7 inches thick, and on a flat subgrade which had been very carefully prepared. In order to insure uniform subgrade conditions, single-ply felt tar paper was placed on the subgrade prior to laying

Figure 2.—Proportioning Plant Used in Construction of Test Sections

the concrete. Transverse headers 9 feet apart separated the sections, each of which therefore had a volume of 47 cubic feet, or just a little less than the volume of two standard-size batches of a 27E paver. As the concrete was actually to be taken up and tested, three 2-inch by 2-inch wooden separators were placed between the headers in such a manner as to create longitudianl planes of weakness and to divide each 9-foot by 9-foot section into four slabs each 27 inches wide by 9 feet in length. These 2-inch by 2-inch strips were placed at the center of the 7-inch section, and, being dry when placed, absorbed sufficient moisture from the concrete to cause swelling, with subsequent longitudinal cracking in the concrete. A view of the subgrade showing the separators in place is shown on the cover. A completed section appears in the background. Before the concrete had set, a line of ¾-inch holes was punched across each section 2 feet from each end. Immediately prior to testing, plugs and feathers were inserted in these holes and the 2-foot end strips broken off. Thus there were obtained from each section four slabs approximately 27 inches wide by 5 feet in length by 7 inches in depth. These slabs were tested in flexure by a method described later.

Mixing concrete.—For mixing the concrete, a new 27E paver was employed. It was equipped with a tank for measuring water, which was filled by gravity from an auxiliary tank mounted on top of the mixer. The auxiliary tank had a greater capacity than the measuring tank and provided a means of supplying the mixer with water while hose connections to the water line were being changed. The use of the auxiliary tank also relieved the measuring tank of all pipe-line pressure, thereby making water measurements more positive.

All batches were mixed for one minute, the mixer being provided with a timing device and indicator bell.

The mixer ran between the side forms, and the first batch for each section was deposited in such a manner as to fill one-half of the section for its entire length. After the second batch was deposited the mixer was moved forward and the next section prepared by placing the tar paper, headers, and separators while the section just placed was being finished. Figure 3 shows the first batch being dumped. Figure 4 shows the finishing machine beginning the operation of spreading the concrete. At the beginning of each day's run

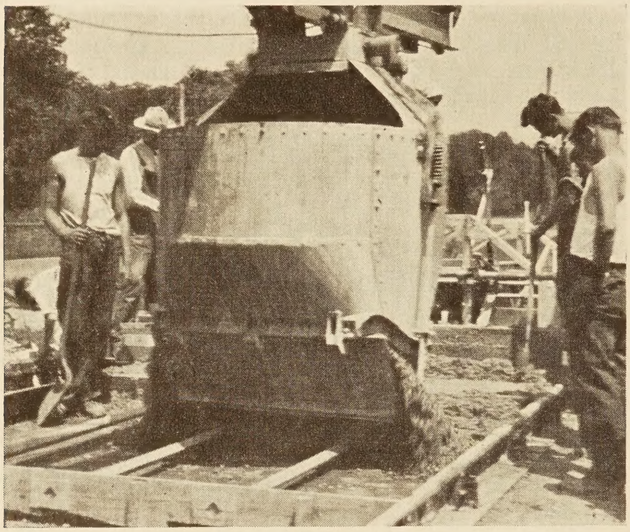


FIGURE 3.—DUMPING FIRST BATCH

a preliminary one-half batch was run and discarded, in order to place the inside of the drum in the same condition for the first batch as for all subsequent batches. Mixing operations for each day were continuous, so that it was not necessary to repeat this operation.

Determining weights for each batch.—The quantity of concrete required for each section plus that necessary for the control specimens amounted to about 51 cubic feet. It was decided to make two 27 cubic-foot batches for each test section. This was accomplished by computing the quantities of the constituent materials on the basis of absolute volume for each mix. The only change necessary was an adjustment in water content at the mixer in order to have three consistencies for each proportion. This did not necessitate any change in the weights at the batching plant as the water-cement ratio used in the computations was that required for the driest consistency. It did result, however, in slightly higher yields for the wetter consistencies.

Finishing.—Two finishing machines were employed for finishing the concrete, a combination single screed and tamper, and a double-screed machine. In the first round of tests the tamper was used with the single-screed machine while in the second round the screed was used without the tamper. The double screed was used in each round of tests. In the tables and charts the single screed with tamper is referred to as type A, the single screed without tamper as type B, and the double screed as type C. Both machines were equipped with belts so that no hand belting was necessary. Figures 5, 6, and 7 show typical views of the finishing operations as performed by type A, the single screed and tamper, and type C, the double-screed machine. Figure 5 illustrates, for the two types of machine, the typical appearance of the concrete before the first passage of the finisher and the appearance after the passage of the screeds. Figure 6 shows the final appearance of the section after belting. A finish of this character was obtained on practically all sections. Figure 7 illustrates the finishing operations in detail.

TABLE 4.—*Schedule of test sections giving type of coarse aggregate and finishing machine used on each section*

ROUND 1

Section Nos.	Coarse aggregate	Finishing machine
1–18	Gravel, grading A	Type A.[1]
19–33	Gravel, grading B	Do.
34–51	Gravel, grading A	Type C.[2]
52–68	Gravel, grading B	Do.
69–83	Crushed stone, grading A	Type A.
84–97	Crushed stone, grading B	Do.
98–112	Crushed stone, grading A	Type C.
113–127	Crushed stone, grading B	Do.

ROUND 2

Section Nos.	Coarse aggregate	Finishing machine
128–145	Gravel, grading A	Type C.
146–160	Gravel, grading B	Do.
161–178	Gravel, grading A	Type B.[3]
179–193	Gravel, grading B	Do.
194–208	Crushed stone, grading A	Do.
209–223	Crushed stone, grading B	Do.
224–238	Crushed stone, grading A	Type C.
239–253	Crushed stone, grading B	Do.
254–265	Crushed slag, grading A	Do.

[1] Single screed with tamper.
[2] Double screed.
[3] Single screed without tamper.

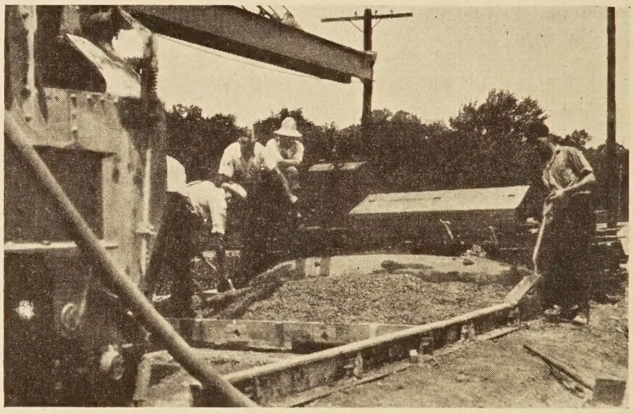
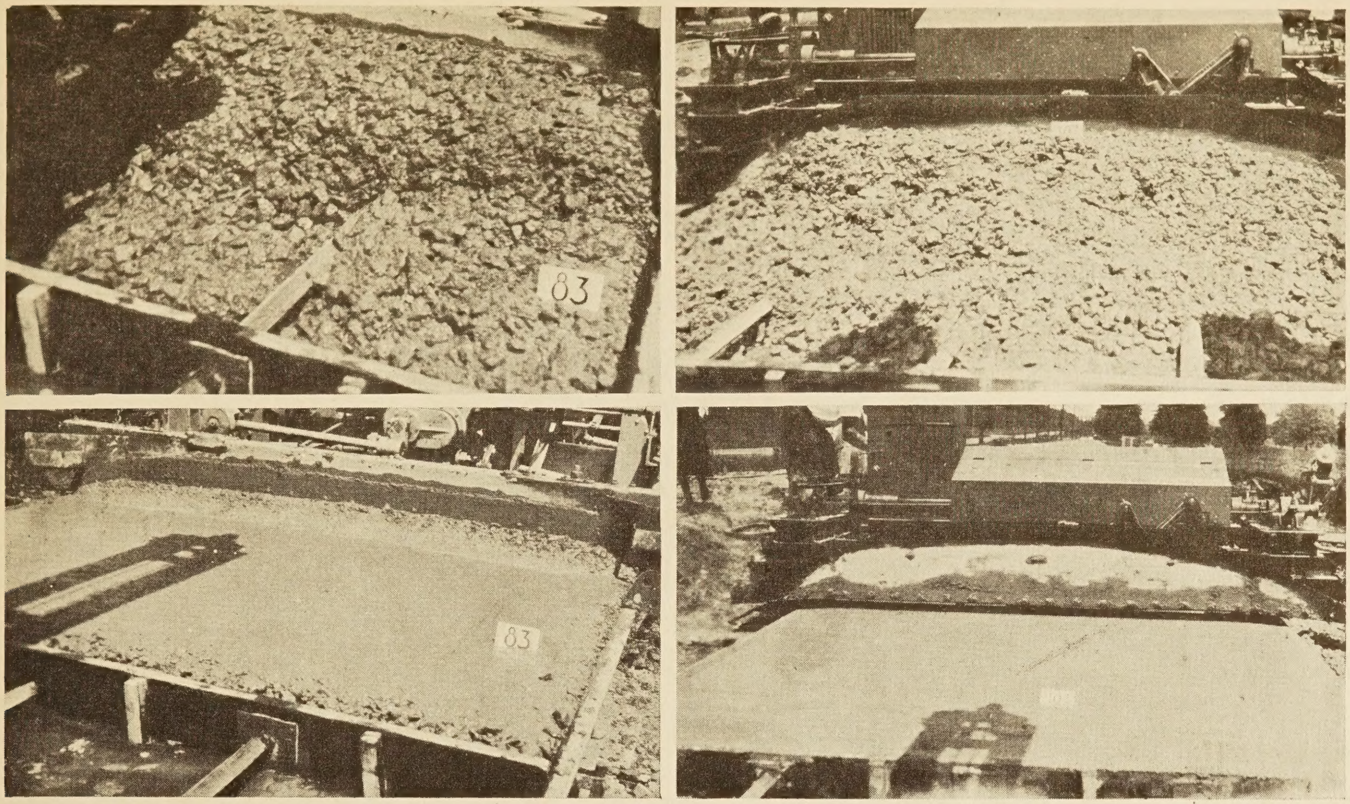


FIGURE 4.—FINISHER SPREADING CONCRETE

The machines were operated according to the schedule given in Table 4.

In general, the number of passes of the finishing machine was limited to three, with the idea that this would be about the economic limit from the standpoint of production management on an actual job. However, no more finishing was done, in any case, than was necessary to secure a satisfactory surface finish. Complete notes were taken giving the number of passes of the finishing machine over each test section, the number of times the concrete was tamped in the case of type A machine and the amount of hand work, if any, necessary. These notes are tabulated in Table 12.

Curing.—Wet burlap was applied to the pavement as soon after laying as the surface would permit. This burlap was kept wet during the day on which the pavement was laid. On the following morning the burlap was removed and a layer of earth about 2 inches deep was applied. This earth was kept wet for 10 days, after which it was left on the slab but not wet down. Fourteen days prior to testing the earth was wet down and kept wet until the individual sections were tested.



Type A finisher in operation on 1:2:4¾ crushed stone concrete, grading A, slump 2 inches

Type C finisher in operation on 1:2:4½ crushed stone concrete, grading A, slump 1½ inches

FIGURE 5.—FINISHING OPERATIONS ON SECTIONS 83 AND 107

CONTROL TESTS CONDUCTED FOR EACH TEST SECTION

Four beams and four cylinders were made as control specimens for each test section. The beam molds were 7 by 7 by 30 inches in size, four to a gang, and were made of wood. The cylinder molds were 6 by 12 inches, were of steel, and rested on machined base plates. These plates in turn rested on a wooden platform which also served as a base for the beam molds. The platform was placed on a level bearing about 4 feet from the roadway, thus permitting sufficient space for the finishing machine and workmen on the test section. Very little water was lost from within the specimens. This end was accomplished by using two thicknesses of felt paper between the beam molds and base and heavy grease between the cylinder molds and plates. Wet burlap was placed over the test specimens to prevent loss of water by evaporation.

The concrete for the control specimens was taken in the following manner: After the first batch was dumped from the mixer a sample weighing about 350 pounds was shoveled into two water-tight pans, in equal parts. A second sample similarly divided was taken after the second batch was dumped, placed in the pans together with the samples from the first batch, and the two samples in each pan thoroughly mixed with shovels. Great care was exercised to obtain representative samples. Slump and flow tests were then made, beams and cylinders fabricated, and the excess concrete returned to the test section. In making the beam specimens the following procedure was followed: The molds were filled in two layers, each layer being rodded 75 times with a ⅝-inch steel rod, bullet-shaped on the end, and then spaded on the sides and ends. After

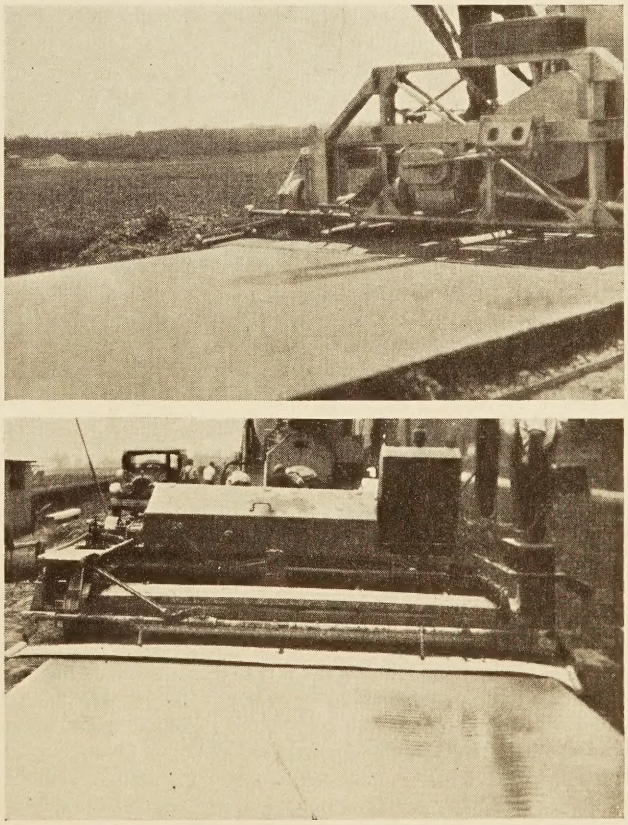
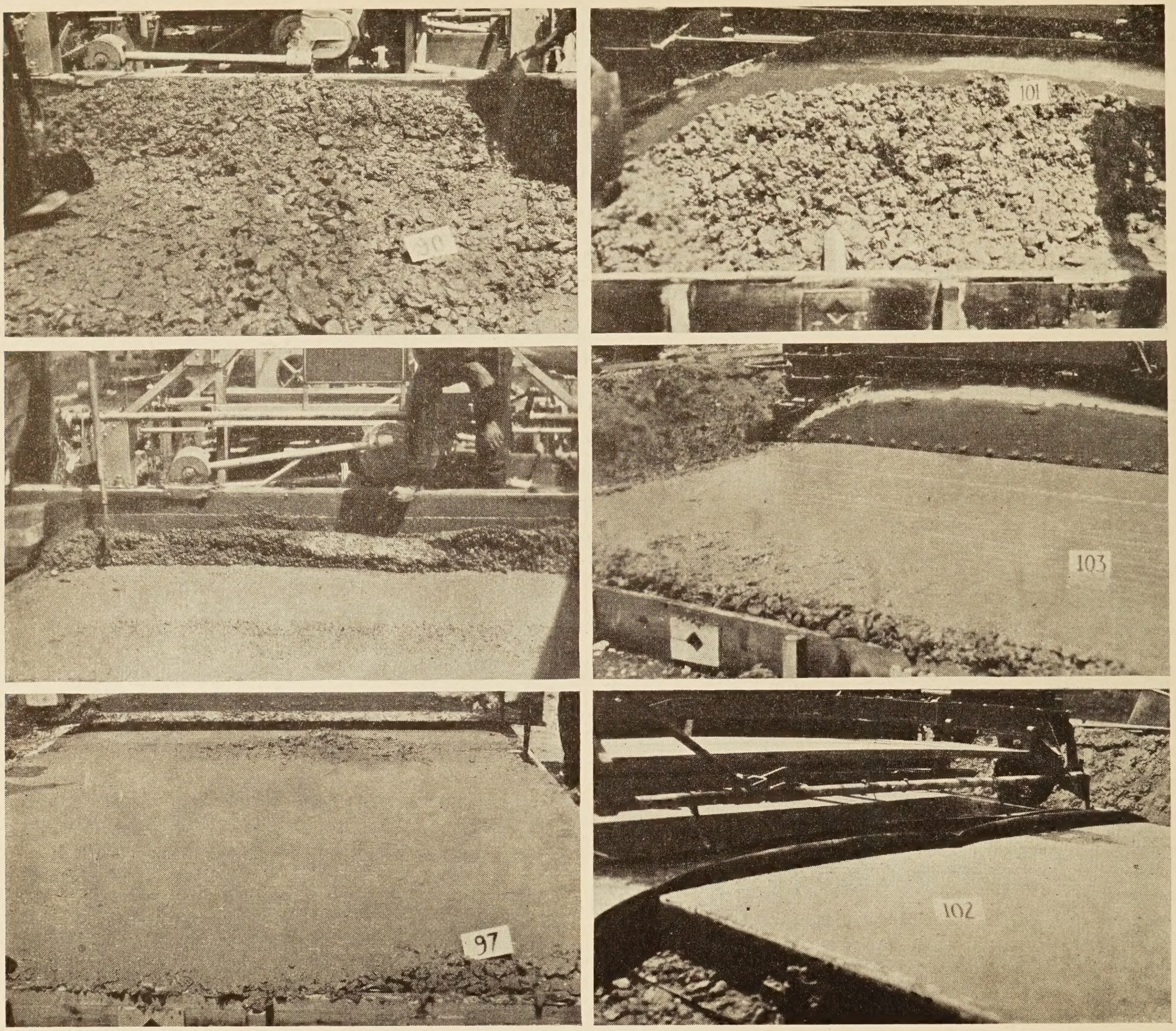


FIGURE 6.—TYPICAL APPEARANCE OF FINISHED SECTIONS. TOP, TYPE A FINISHER; BOTTOM, TYPE C FINISHER



Type A finisher Type C finisher

FIGURE 7.—TYPICAL VIEWS OF FINISHERS IN OPERATION

the second layer was completed the top was struck off and finished with a wooden float. The cylinders were made in three layers in accordance with the practice of the American Society for Testing Materials and finished with a wooden float. After about 22 hours the specimens were removed from the molds and placed by the side of the test section. They were covered with wet earth at the time the slab was covered.

The slump tests were made in accordance with the tentative method of test for consistency of Portland cement concrete of the American Society for Testing Materials. The flow tests were made on a 30-inch flow table, the test consisting of 15 drops of ½-inch in 10 seconds, as described in the publication, "A. S. T. M. serial designation C 39–27, Standard Method of Making Compression Tests of Concrete." The values are given in Table 5.

Two of the four control beams were tested at 28 days and the other two at 9 months. The corresponding cylinders were tested at 28 days and 10 months. All control specimens were immersed in water for 24 hours before testing to insure uniform moisture content.

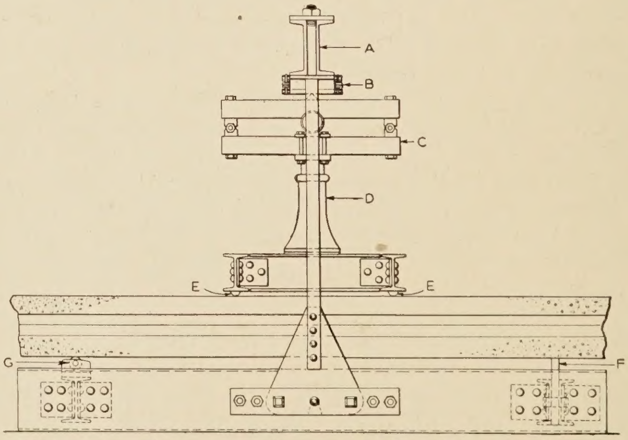


FIGURE 8.—PORTABLE APPARATUS FOR TESTING SLABS

In the case of the 28-day cylinders the specimens were removed from the subgrade at an age of 11 days and brought to the laboratory to be capped. They were then returned to wet-earth storage until 24 hours before testing. The 10-month cylinders were handled in the same manner except that they were removed from the subgrade one month before testing instead of 17 days as in the case of the 28-day specimens.

Flexure tests were made on a 100,000-pound universal testing machine, the idle crosshead speed being 0.05 inch per minute. The beams were tested with the bottom as molded in tension, span 27 inches, load applied at the third points.

FIGURE 9.—TESTING SLAB FOR FLEXURAL STRENGTH

SPECIAL APPARATUS CONSTRUCTED FOR TESTING SLABS

Because of the large number of flexure tests to be made on the 27 by 60 inch slabs it was quite impracticable to make the tests in the laboratory, and field testing was mandatory. The importance of the data given by the flexure tests was such that accuracy commensurate with that obtained in the laboratory was essential. For these reasons special consideration was given to the items of accuracy and mobility in the design of the apparatus for making these tests.

The general design was such that the machines could be quickly disassembled into units which could be picked up and moved by hand; and, yet with a designed load capacity of 20,000 pounds, the total load on the specimen could be determined within about 25 pounds.

Figure 8 shows a side elevation of one of the testing machines. It consists of a structural steel base frame which supports a transverse rocker bearing F and roller G on which the slab to be tested is supported. At the center of each side member of the base frame a vertical tension member is attached by two easily removable pins. Passing transversely across the slab at the upper end of these two tension members is a steel beam A, which takes the reaction when a load is applied on the slab. The load is applied by means of a ball-bearing ratchet jack D and is distributed to the third points of the span by a structural frame E. For determining the magnitude of the applied load a pair of heat-treated steel beams C is inserted between the head of the jack and the reaction beam A. The combined deflection of the two beams is measured with a micrometer dial reading in ten-thousandths of an inch. The load-deflection characteristics of the beam combination having been determined in advance by calibration, it becomes a simple matter to translate the dial readings into terms of total applied load. This method of measuring load has been used previously (see PUBLIC ROADS, vol. 7, No. 2, April, 1926) and has proved to be very satisfactory. To assure an even bearing of the knife edge located in the center of the upper beam against the reaction a cylindrical bearing block B was provided.

In order to take care of the number of tests which had to be made, two complete machines and an extra base frame were built. This permitted the load-applying equipment to be shifted, after the slab failed, to an unbroken specimen set up for test on the extra base, greatly expediting the work.

TESTS OF PAVEMENT SLABS DESCRIBED

As previously explained, the installation of planes of weakness during construction had caused the formation of three equally spaced longitudinal cracks in each 9-foot slab, so that there were available for testing four slabs each 27 inches wide and 9 feet long. Each of these slabs was reduced in length to 5 feet just prior to testing by breaking off a section 2 feet in length from each end. These end sections were discarded entirely because it was felt that, because of the resistance offered by the header boards to free movement of the concrete, the material in the end sections might not be truly representative.

Since the test slabs weighed approximately 1,000 pounds each, it was necessary to use a special rig for mounting them on the testing machine. A number of A frames sufficiently long to span the entire test section and equipped with trolley and chain hoist were employed for this purpose. Four clamps slipped under the edges of the slabs near the corners and connected with the chain hoist by means of chains provided with hooks proved entirely adequate for handling these slabs.

A uniform bearing across the entire width of slab at E, F, and G was obtained by using plaster of Paris and thin metal strips. Rubber strips were substituted for plaster of Paris at E whenever the top of the slab was smooth enough to permit it.

The specimens were tested by applying the load by hand as shown in Figure 9. The magnitude of the load at failure was determined by measuring the deflection of the calibrated beams with the micrometer dial, also shown in the figure. It was necessary to note the maximum reading of the dial, as the hand returned to zero the instant the slab broke. It was not difficult to catch this reading, since the hand on the dial would move very slowly as the maximum loading was approached. In general, two observers read the dial independently and checked their readings after failure.

CORES DRILLED FROM PAVEMENT

The breaking of the four test slabs of each section produced 8 half slabs. Cores were drilled from 2 of these 8 pieces, and the cores were tested for absorption at an age of approximately 9½ months. The specimens were boiled in water for 5 hours and then dried in an oven at a temperature of about 160° C. to constant weight. Additional cores were drilled from the broken slabs and tested in compression at 15 months. These cores were immersed in water for 24 hours before testing.

In order to provide specimens for durability tests, additional cores from a number of typical sections were drilled for each mix and are being subjected to alternate freezing and thawing at this time. A report covering this phase of the investigation will be issued later.

TEST RESULTS ANALYZED IN DETAIL

The data resulting from these tests are presented both in tabular and in graphic form. The results are shown in detail section by section and are also summarized in various ways in order to bring out certain relationships which appear to have been established.

The discussion is developed along the following lines: Certain general relationships which appear to exist between the strength and uniformity of the concrete and each of the variables which have been introduced are first considered. This preliminary analysis is followed by a discussion of the detail results for the purpose of ascertaining to what extent the results for individual sections deviate from the average trends and to determine if possible the reasons for such deviations. The following variables are discussed in the order named, the three coarse aggregates, gravel, crushed stone, and slag being considered separately in each case:

1. Relation between strength of concrete and mix.
2. Relation between strength of concrete and variations in cement factor resulting from change in mix.
3. Relation between strength of concrete and variations in water-cement ratio resulting from change in mix.
4. Effect of type of finishing machine.
5. Effect of grading of coarse aggregate.
6. Effect of honeycomb in slabs on modulus of rupture for each type of finishing machine.
7. Relation between honeycomb in slabs and mix.
8. Relation between honeycomb in slabs and consistency.
9. Uniformity of concrete.
10. Absorption tests.

The detailed data of the tests arranged section by section in the order of laying are shown in Tables 5 and 6. These tables contain all of the data from which the tables and charts showing average values were prepared, with the exception of the material relative to uniformity, honeycombing, and absorption.

TABLE 5.—*Proportions and consistency of concrete*

Section No.	Date laid (1929)	Proportions	Water-cement ratio	Slump in inches	Flow	Theoretical cement factor in sacks per cubic yard
ROUND 1, GRAVEL AGGREGATE, GRADING A, TYPE A FINISHER						
1	July 10	1:2:3½	0.85	2	----------	5.56
2	July 11	1:2:3½	.82	1¼	125	5.59
3	July 10	1:2:3½	.83	¼	----------	5.58
4	do	1:2:4	.90	1¼	----------	5.16
5	do	1:2:4	.87	1	----------	5.18
6	do	1:2:4	.93	1¾	----------	5.12
7	July 11	1:2:4½	.90	1¼	125	4.86
8	do	1:2:4½	.86	1	122	4.89
9	do	1:2:4½	.99	2½	144	4.78
10	do	1:2:4¾	1.00	4	155	4.64
11	do	1:2:4¾	.95	3	150	4.68
12	July 12	1:2:4¾	.87	1	125	4.74
13	do	1:2:5	.92	1¾	130	4.57
14	do	1:2:5	1.01	5	160	4.50
15	do	1:2:5	.96	3	148	4.53
16	do	1:2:5¼	.96	2¾	138	4.42
17	do	1:2:5¼	.91	1¾	132	4.46
18	do	1:2:5¼	1.03	4¾	164	4.37
ROUND 1, GRAVEL AGGREGATE, GRADING B, TYPE A FINISHER						
19	July 15	1:2:3½	0.89	1	124	5.54
20	do	1:2:3½	.93	2¼	144	5.50
21	do	1:2:3½	.90	1¼	127	5.53
22	do	1:2:4	.85	1¼	127	5.24
23	do	1:2:4	.92	2	132	5.17
24	do	1:2:4	.96	2½	136	5.14
25	July 16	1:2:4½	.94	1¼	117	4.86
26	do	1:2:4½	1.01	1¾	138	4.80
27	do	1:2:4½	1.05	3	135	4.76
28	do	1:2:4¾	1.05	2	139	4.63
29	do	1:2:4¾	.99	2	139	4.68
30	do	1:2:4¾	.96	1¼	119	4.70
31	July 17	1:2:5	1.04	2	138	4.52
32	do	1:2:5	.92	¾	120	4.61
33	do	1:2:5	.96	1	116	4.58
ROUND 1, GRAVEL AGGREGATE, GRADING A, TYPE C FINISHER						
34	July 18	1:2:3½	0.86	1	123	5.54
35	do	1:2:3½	.90	2½	138	5.50
36	do	1:2:3½	.87	1¾	134	5.53
37	do	1:2:4	.86	¾	128	5.19
38	do	1:2:4	.93	1	123	5.12
39	do	1:2:4	.94	1¾	130	5.11
40	July 19	1:2:4½	.91	1½	120	4.85
41	do	1:2:4½	.88	1	122	4.87
42	do	1:2:4½	.97	1¾	130	4.80
43	do	1:2:4¾	.90	1	118	4.71
44	do	1:2:4¾	.98	1¾	125	4.64
45	do	1:2:4¾	1.03	1½	144	4.61
46	July 22	1:2:5	.93	1¼	115	4.56
47	do	1:2:5	1.00	2	122	4.51
48	do	1:2:5	1.03	3	144	4.49
49	do	1:2:5¼	.93	1¾	130	4.44
50	do	1:2:5¼	.90	¼	111	4.46
51	do	1:2:5¼	1.03	2½	140	4.37
ROUND 1, GRAVEL AGGREGATE, GRADING B, TYPE C FINISHER						
52	July 23	1:2:3½	0.84	¾	125	5.60
53	do	1:2:3½	.89	1½	135	5.54
54	do	1:2:3½	.93	2¾	143	5.50
55	do	1:2:4	.88	1¼	127	5.21
56	do	1:2:4	.95	2½	140	5.14
57	do	1:2:4	.99	3	142	5.10
58	July 24	1:2:4½	.93	1½	128	4.86
59	do	1:2:4½	.98	¾	126	4.82
60	do	1:2:4½	1.04	2	142	4.77
61	do	1:2:4¾	.96	1¼	122	4.70
62	do	1:2:4¾	1.03	2¼	134	4.65

TABLE 5.—*Proportions and consistency of concrete*—Continued

ROUND 1, GRAVEL AGGREGATE, GRADING B, TYPE C FINISHER—Continued

Section No.	Date laid (1929)	Proportions	Water-cement ratio	Slump in inches	Flow	Theoretical cement factor in sacks per cubic yard
63	July 24	1:2:4¾	1.10	3	146	4.59
64	July 25	1:2:5	1.02	¾	122	4.53
65	do	1:2:5	1.10	2	132	4.47
66	do	1:2:5	1.13	3	148	4.45
67	do	1:2:5¼	1.05	2	131	4.39
68	do	1:2:5¼	.98	0	115	4.44

ROUND 1, STONE AGGREGATE, GRADING A, TYPE A FINISHER

69	July 26	1:2:3½	0.84	2½	133	5.77
70	do	1:2:3½	.81	1¼	125	5.81
71	do	1:2:3½	.75	¼	110	5.88
72	do	1:2:4	.84	1½	127	5.42
73	do	1:2:4	.90	2¼	132	5.36
74	do	1:2:4	.80	½	112	5.47
75	July 29	1:2:4¼	.88	¾	120	5.22
76	do	1:2:4¼	.94	2¼	146	5.16
77	do	1:2:4¼	.85	¼	117	5.25
78	do	1:2:4½	.85	½	120	5.10
79	do	1:2:4½	.90	1½	123	5.06
80	do	1:2:4½	.94	2¼	134	5.02
81	July 30	1:2:4¾	.87	½	115	4.95
82	do	1:2:4¾	.91	1½	120	4.91
83	do	1:2:4¾	.99	2	133	4.84

ROUND 1, STONE AGGREGATE, GRADING B, TYPE A FINISHER

84	July 30	1:2:3½	0.85	2	138	5.81
85	do	1:2:3½	.81	½	116	5.86
86	do	1:2:3½	.89	2¼	132	5.76
87	July 31	1:2:4	.87	1	124	5.43
88	do	1:2:4	.91	1¾	138	5.39
89	do	1:2:4	.94	2½	146	5.36
90	do	1:2:4¼	.89	1½	130	5.25
91	do	1:2:4¼	.94	2	128	5.20
92	do	1:2:4¼	.97	2¾	144	5.17
93	Aug. 1	1:2:4½	.89	0	120	5.10
94	do	1:2:4½	.95	1¾	132	5.05
95	do	1:2:4½	.99	1	150	5.00
96	do	1:2:4¾	.92	1¼	134	4.95
97	do	1:2:4¾	1.05	2	158	4.83

ROUND 1, STONE AGGREGATE, GRADING A, TYPE C FINISHER

98	Aug. 2	1:2:3½	0.83	1	118	5.78
99	do	1:2:3½	.88	1¾	140	5.72
100	do	1:2:3½	.81	½	118	5.81
101	do	1:2:4	.85	¾	120	5.41
102	do	1:2:4	.90	1¾	135	5.36
103	do	1:2:4	.95	2½	145	5.30
104	Aug. 5	1:2:4¼	.87	1¼	122	5.23
105	do	1:2:4¼	.94	3	144	5.16
106	do	1:2:4¼	.87	1½	122	5.23
107	do	1:2:4½	.91	1½	128	5.05
108	do	1:2:4½	.95	2¾	130	5.00
109	do	1:2:4½	.99	2½	142	4.97
110	Aug. 6	1:2:4¾	.92	½	112	4.90
111	do	1:2:4¾	.99	1½	125	4.84
112	do	1:2:4¾	1.04	2½	150	4.80

ROUND 1, STONE AGGREGATE, GRADING B, TYPE C FINISHER

113	Aug. 6	1:2:3½	0.85	1¾	127	5.81
114	do	1:2:3½	.89	½	136	5.76
115	do	1:2:3½	.92	3	155	5.72
116	Aug. 7	1:2:4	.91	2	140	5.39
117	do	1:2:4	.87	1¾	144	5.43
118	do	1:2:4	.94	1¾	142	5.36
119	do	1:2:4¼	.97	3	156	5.17
120	do	1:2:4¼	.91	2	146	5.23
121	do	1:2:4¼	.85	1	118	5.29
122	Aug. 8	1:2:4½	.89	½	117	5.10
123	do	1:2:4½	.95	1½	138	5.05
124	do	1:2:4½	.98	3	160	5.02
125	do	1:2:4¾	.96	2½	147	4.91
126	do	1:2:4¾	.94	2¾	147	4.93
127	do	1:2:4¾	1.03	3	180	4.85

ROUND 2, GRAVEL AGGREGATE, GRADING A, TYPE C FINISHER

128	Aug. 9	1:2:3½	0.85	1½	127	5.57
129	do	1:2:3½	.83	1½	122	5.59
130	do	1:2:3½	.90	2	130	5.51
131	do	1:2:4	.95	2½	152	5.10
132	do	1:2:4	.89	2½	121	5.16
133	do	1:2:4	.86	1	124	5.19
134	Aug. 14	1:2:4½	.88	1½	132	4.87

ROUND 2, GRAVEL AGGREGATE, GRADING A, TYPE C FINISHER—Continued

Section No.	Date laid (1929)	Proportions	Water-cement ratio	Slump in inches	Flow	Theoretical cement factor in sacks per cubic yard
135	Aug. 14	1:2:4½	.98	2	148	4.79
136	do	1:2:4½	.92	2¾	147	4.84
137	do	1:2:4¾	.91	1½	123	4.70
138	do	1:2:4¾	.96	2	138	4.66
139	do	1:2:4¾	1.02	2½	151	4.62
140	Aug. 15	1:2:5	.93	1½	118	4.56
141	do	1:2:5	.99	2	144	4.52
142	do	1:2:5	1.02	2¾	130	4.49
143	do	1:2:5¼	.94	1½	130	4.43
144	do	1:2:5¼	.98	1¼	119	4.40
145	do	1:2:5¼	1.03	2¼	142	4.37

ROUND 2, GRAVEL AGGREGATE, GRADING B, TYPE C FINISHER

146	Aug. 16	1:2:3½	0.84	1	122	5.60
147	do	1:2:3½	.89	1½	132	5.54
148	do	1:2:3½	.94	2¾	148	5.49
149	do	1:2:4	.87	½	117	5.22
150	do	1:2:4	.92	1¾	125	5.17
151	do	1:2:4	.97	2	129	5.12
152	Aug. 19	1:2:4½	1.03	2	133	4.78
153	do	1:2:4½	.98	1½	123	4.83
154	do	1:2:4½	.99	1	124	4.81
155	do	1:2:4¾	.94	1	111	4.72
156	do	1:2:4¾	1.00	2	127	4.67
157	do	1:2:4¾	1.05	2¾	130	4.63
158	Aug. 20	1:2:5	1.01	1½	115	4.54
159	do	1:2:5	1.07	1½	129	4.49
160	do	1:2:5	1.13	2¾	148	4.45

ROUND 2, GRAVEL AGGREGATE, GRADING A, TYPE B FINISHER

161	Aug. 21	1:2:3½	0.83	¾	124	5.58
162	do	1:2:3½	.88	1	120	5.52
163	do	1:2:3½	.93	2	136	5.47
164	do	1:2:4	.90	1½	124	5.15
165	do	1:2:4	.95	2¼	132	5.10
166	do	1:2:4	.88	1	127	5.17
167	Aug. 22	1:2:4½	.88	1	115	4.87
168	do	1:2:4½	.92	1½	118	4.84
169	do	1:2:4½	.98	1¾	124	4.79
170	do	1:2:4¾	.91	1¼	123	4.70
171	do	1:2:4¾	.96	1¾	124	4.66
172	do	1:2:4¾	1.02	2	133	4.62
173	Aug. 23	1:2:5	1.07	3	152	4.46
174	do	1:2:5	.99	1	141	4.52
175	do	1:2:5	.92	1	124	4.57
176	do	1:2:5¼	1.03	2¼	138	4.37
177	do	1:2:5¼	.98	1	130	4.40
178	do	1:2:5¼	.94	1½	125	4.43

ROUND 2, GRAVEL AGGREGATE, GRADING B, TYPE B FINISHER

179	Aug. 26	1:2:3½	0.89	2	133	5.54
180	do	1:2:3½	.85	1	126	5.59
181	do	1:2:3½	.94	2¼	139	5.49
182	do	1:2:4	.97	2½	147	5.12
183	do	1:2:4	.92	1½	133	5.17
184	do	1:2:4	.87	¾	113	5.22
185	Aug. 27	1:2:4½	1.04	3½	138	4.77
186	do	1:2:4½	.98	1¾	137	4.82
187	do	1:2:4½	.94	1¾	124	4.86
188	do	1:2:4¾	1.05	2	145	4.63
189	do	1:2:4¾	1.00	1¾	139	4.67
190	do	1:2:4¾	.94	1¼	125	4.72
191	Aug. 28	1:2:5	1.13	2½	146	4.45
192	do	1:2:5	1.07	1	163	4.49
193	do	1:2:5	1.01	1	134	4.54

ROUND 2, STONE AGGREGATE, GRADING A, TYPE B FINISHER

194	Aug. 29	1:2:3½	0.88	1½	134	5.72
195	do	1:2:3½	.92	2¼	156	5.67
196	do	1:2:3½	.97	4	155	5.61
197	do	1:2:4	.95	2¼	146	5.30
198	do	1:2:4	.90	1¼	131	5.36
199	do	1:2:4	1.00	3	157	5.25
200	Aug. 30	1:2:4¼	.94	2½	138	5.16
201	do	1:2:4¼	.99	3	157	5.11
202	do	1:2:4¼	.89	2	128	5.21
203	do	1:2:4½	.99	2¾	169	4.97
204	do	1:2:4½	.94	2¼	147	5.02
205	do	1:2:4½	.89	1¾	137	5.07
206	Sept. 3	1:2:4¾	1.04	3¼	143	4.80
207	do	1:2:4¾	.99	2¼	146	4.84
208	do	1:2:4¾	.93	1½	131	4.89

TABLE 5.—*Proportions and consistency of concrete*—Continued

ROUND 2, STONE AGGREGATE, GRADING B, TYPE B FINISHER

Section No.	Date laid (1929)	Proportions	Water-cement ratio	Slump in inches	Flow	Theoretical cement factor in sacks per cubic yard
209	Sept. 3	1:2:3½	0.92	2¼	150	5.72
210	do	1:2:3½	.87	2	135	5.78
211	do	1:2:3½	.84	1½	134	5.82
212	Sept. 4	1:2:4	.96	2	144	5.34
213	do	1:2:4	.92	1¾	142	5.38
214	do	1:2:4	.87	¾	137	5.43
215	do	1:2:4¼	1.00	2½	160	5.14
216	do	1:2:4¼	.95	1¾	138	5.19
217	do	1:2:4¼	.90	1¾	142	5.24
218	Sept. 5	1:2:4½	1.05	3¼	166	4.95
219	do	1:2:4½	.99	2¼	162	5.01
220	do	1:2:4½	.91	2¼	142	5.08
221	do	1:2:4¾	1.08	4	170	4.80
222	do	1:2:4¾	.94	1¾	144	4.93
223	do	1:2:4¾	.90	2	135	4.96

ROUND 2, STONE AGGREGATE, GRADING A, TYPE C FINISHER

Section No.	Date laid (1929)	Proportions	Water-cement ratio	Slump in inches	Flow	Theoretical cement factor in sacks per cubic yard
224	Sept. 6	1:2:3½	0.97	4	161	5.61
225	do	1:2:3½	.92	2¼	156	5.67
226	do	1:2:3½	.85	1½	130	5.76
227	do	1:2:4	1.00	3¾	150	5.25
228	do	1:2:4	.92	2¼	143	5.34
229	do	1:2:4	.87	1½	130	5.39
230	Sept. 9	1:2:4¼	.89	1¼	132	5.21
231	do	1:2:4¼	.94	2	143	5.16
232	do	1:2:4¼	.99	3	145	5.11
233	do	1:2:4½	.92	1¼	135	5.04
234	do	1:2:4½	.97	2¼	133	4.99
235	do	1:2:4½	1.02	2½	138	4.95
236	Sept. 10	1:2:4¾	.93	2	131	4.89
237	do	1:2:4¾	.99	2¼	145	4.84
238	do	1:2:4¾	1.04	3½	166	4.80

ROUND 2, STONE AGGREGATE, GRADING B, TYPE C FINISHER

Section No.	Date laid (1929)	Proportions	Water-cement ratio	Slump in inches	Flow	Theoretical cement factor in sacks per cubic yard
239	Sept. 10	1:2:3½	0.84	2	142	5.82
240	do	1:2:3½	.87	2¼	147	5.78
241	do	1:2:3½	.92	2¾	158	5.72
242	Sept. 11	1:2:4	.87	1½	123	5.43
243	do	1:2:4	.92	2¼	134	5.38
244	do	1:2:4	.97	1¾	154	5.33
245	do	1:2:4¼	.89	1½	123	5.25
246	do	1:2:4¼	.94	2	130	5.20
247	do	1:2:4¼	.84	1	120	5.30
248	Sept. 12	1:2:4½	.92	¾	128	5.07
249	do	1:2:4½	.88	2	133	5.11
250	do	1:2:4½	.99	3¼	145	5.01
251	do	1:2:4¾	.90	2¼	128	4.96
252	do	1:2:4¾	.96	2	138	4.91
253	do	1:2:4¾	.98	2¼	145	4.89

ROUND 1, SLAG AGGREGATE, GRADING A, TYPE C FINISHER

Section No.	Date laid (1929)	Proportions	Water-cement ratio	Slump in inches	Flow	Theoretical cement factor in sacks per cubic yard
254	Sept. 13	1:2:3½	0.87	1½	126	5.91
255	do	1:2:3½	.92	1¾	128	5.84
256	do	1:2:3½	.83	¾	115	5.96
257	do	1:2:4	.87	½	108	5.57
258	do	1:2:4	.92	2	124	5.51
259	do	1:2:4	.99	2¼	138	5.43
260	Sept. 16	1:2:4¼	.94	1½	125	5.34
261	do	1:2:4¼	.99	1¾	114	5.28
262	do	1:2:4¼	.92	1	118	5.36
263	do	1:2:4½	.98	1¾	130	5.15
264	do	1:2:4½	1.03	2½	128	5.10
265	do	1:2:4½	.95	1¼	130	5.18

TABLE 6.—*Results of strength tests*

ROUND 1, GRAVEL AGGREGATE, GRADING A, TYPE A FINISHER

Section No.	Proportions	Modulus of rupture in pounds per square inch			Compressive strength in pounds per square inch		
		Beams		Slabs, 9 months	Cylinders		Cores, 15 months
		28 days	9 months		28 days	10 months	
1	1:2:3½	434	479	542	3,085	3,980	5,320
2	1:2:3½	468	581	573	2,940	3,900	4,780
3	1:2:3½	508	582	504	3,300	4,460	4,920
4	1:2:4	427	515	554	2,900	3,940	4,660
5	1:2:4	392	525	532	3,260	4,480	5,120
6	1:2:4	434	471	520	2,475	3,460	3,950
7	1:2:4½	478	501	529	2,785	3,910	4,700
8	1:2:4½	489	549	575	2,940	3,950	5,400
9	1:2:4½	442	491	544	2,410	3,600	4,290
10	1:2:4¾	404	453	530	2,250	3,160	4,240
11	1:2:4¾	448	490	564	2,495	3,260	4,440
12	1:2:4¾	460	434	497	3,145	3,680	4,420
13	1:2:5	452	471	557	3,130	3,880	4,320
14	1:2:5	454	458	529	2,330	3,130	4,270
15	1:2:5	484	455	562	2,690	3,240	4,140
16	1:2:5¼	448	409	500	2,340	3,210	3,920
17	1:2:5¼	456	526	453	2,975	3,720	4,420
18	1:2:5¼	388	460	535	2,100	3,040	3,900

ROUND 1, GRAVEL AGGREGATE, GRADING B, TYPE A FINISHER

Section No.	Proportions	Beams, 28 days	Beams, 9 months	Slabs, 9 months	Cylinders, 28 days	Cylinders, 10 months	Cores, 15 months
19	1:2:3½	446	624	609	3,310	5,000	4,900
20	1:2:3½	491	661	590	3,515	4,520	5,100
21	1:2:3½	527	602	580	3,590	4,530	5,260
22	1:2:4	518	614	542	3,580	4,580	5,120
23	1:2:4	556	593	559	3,730	4,670	5,080
24	1:2:4	457	653	561	2,970	4,420	4,360
25	1:2:4½	510	605	466	3,660	4,450	4,660
26	1:2:4½	489	585	593	3,200	4,160	4,960
27	1:2:4½	470	554	566	3,210	3,800	3,940
28	1:2:4¾	458	519	541	2,540	3,740	4,660
29	1:2:4¾	440	561	503	3,415	4,420	4,150
30	1:2:4¾	491	506	468	3,500	4,410	4,620
31	1:2:5	399	478	519	2,470	3,040	4,140
32	1:2:5	469	660	430	3.440	4,750	5,170
33	1:2:5	462	642	447	3,305	4,410	4,770

ROUND 1, GRAVEL AGGREGATE, GRADING A, TYPE C FINISHER

Section No.	Proportions	Modulus of rupture in pounds per square inch			Compressive strength in pounds per square inch		
		Beams		Slabs, 9 months	Cylinders		Cores, 15 months
		28 days	9 months		28 days	10 months	
34	1:2:3½	482	662	583	3,360	4,600	5,170
35	1:2:3½	534	679	547	3.315	4,540	4,820
36	1:2:3½	544	701	583	3,360	4,310	5,020
37	1:2:4	510	682	594	3,535	4,010	4,880
38	1:2:4	523	670	511	3,165	4,080	4,740
39	1:2:4	494	690	508	3,260	3,920	4,840
40	1:2:4½	522	500	452	3,280	3,980	4,440
41	1:2:4½	441	485	518	3,430	4,740	4,450
42	1:2:4½	426	525	540	2,755	4,040	4,440
43	1:2:4¾	441	573	537	3,215	3,600	4,600
44	1:2:4¾	448	488	535	3,185	3,820	4,360
45	1:2:4¾	461	487	543	2,750	3,700	4.180
46	1:2:5	411	479	537	3,095	3,540	4,140
47	1:2:5	405	516	483	2,570	3,340	4,750
48	1:2:5	396	538	520	2,430	2,800	4,210
49	1:2:5¼	393	509	464	2,885	3,370	4,100
50	1:2:5¼	386	562	432	3,305	4,380	4,580
51	1:2:5¼	397	428	565	2,490	3,470	4,420

ROUND 1, GRAVEL AGGREGATE, GRADING B, TYPE C FINISHER

Section No.	Proportions	Beams, 28 days	Beams, 9 months	Slabs, 9 months	Cylinders, 28 days	Cylinders, 10 months	Cores, 15 months
52	1:2:3½	555	569	447	3,985	4,300	4.310
53	1:2:3½	588	633	571	3,760	4,280	4,410
54	1:2:3½	491	553	572	3,480	4,110	4,640
55	1:2:4	427	566	585	3,525	4,190	4,460
56	1:2:4	519	513	555	3,325	3,980	4,430
57	1:2:4	495	545	579	3,270	3,900	4,360
58	1:2:4½	490	579	451	3,645	4,370	4,230
59	1:2:4½	503	562	516	3,335	4,280	4,490
60	1:2:4½	470	511	551	3,145	3,740	4,470
61	1:2:4¾	496	599	537	3,715	4,200	4,450
62	1:2:4¾	407	530	536	2,970	3,750	4,220
63	1:2:4¾	469	495	547	2,785	3,410	3,680
64	1:2:5	371	483	413	3,075	3,810	4,390
65	1:2:5	475	544	477	2,805	3,450	3,850
66	1:2:5	474	590	535	2,645	3,190	3,760
67	1:2:5¼	496	524	501	3,110	3,880	3,990
68	1:2:5¼	436	593	448	3,175	4,110	3,980

TABLE 6.—*Results of strength tests*—Continued

ROUND 1, STONE AGGREGATE, GRADING A, TYPE A FINISHER

Section No.	Proportions	Modulus of rupture in pounds per square inch			Compressive strength in pounds per square inch		
		Beams		Slabs, 9 months	Cylinders		Cores, 15 months
		28 days	9 months		28 days	10 months	
69	1:2:3½	611	716	732	3,430	4,390	5,410
70	1:2:3½	614	810	725	3,830	4,600	5,190
71	1:2:3½	721	822	690	3,990	5,020	5,200
72	1:2:4	702	735	687	3,795	4,430	5,010
73	1:2:4	632	751	697	3,720	4,500	4,860
74	1:2:4	705	793	632	3,890	4,710	5,190
75	1:2:4¼	637	791	725	3,380	3,980	4,920
76	1:2:4¼	580	788	660	2,685	3,500	4,500
77	1:2:4¼	643	860	708	3,575	4,130	5,040
78	1:2:4½	691	880	670	3,650	4,080	5,340
79	1:2:4½	647	777	700	3,335	4,140	4,780
80	1:2:4½	526	738	711	3,020	3,970	4,540
81	1:2:4¾	506	754	657	3,070	3,720	4,580
82	1:2:4¾	474	786	681	2,725	4,050	4,910
83	1:2:4¾	510	752	678	2,420	3,080	4,050

ROUND 1, STONE AGGREGATE, GRADING B, TYPE A FINISHER

Section No.	Proportions	Beams, 28 days	Beams, 9 months	Slabs, 9 months	Cylinders, 28 days	Cylinders, 10 months	Cores, 15 months
84	1:2:3½	541	640	742	3,385	3,930	4,760
85	1:2:3½	556	713	653	3,480	4,670	4,480
86	1:2:3½	591	608	683	2,940	3,860	4,400
87	1:2:4	592	724	714	3,445	3,900	4,210
88	1:2:4	571	678	702	2,910	3,770	4,460
89	1:2:4	769	631	711	2,755	3,430	4,200
90	1:2:4¼	568	729	695	3,380	4,010	4,760
91	1:2:4¼	652	739	732	2,935	3,890	4,520
92	1:2:4¼	577	703	666	2,590	3,320	4,180
93	1:2:4½	590	746	684	2,865	3,840	4,760
94	1:2:4½	506	769	628	2,655	3,310	4,710
95	1:2:4½	587	742	654	2,905	3,180	4,410
96	1:2:4¾	607	791	678	3,110	3,920	4,620
97	1:2:4¾	561	603	613	2,035	3,060	3,330

ROUND 1, STONE AGGREGATE, GRADING A, TYPE C FINISHER

Section No.	Proportions	Beams, 28 days	Beams, 9 months	Slabs, 9 months	Cylinders, 28 days	Cylinders, 10 months	Cores, 15 months
98	1:2:3½	655	869	670	3,960	4,530	4,960
99	1:2:3½	679	807	714	3,910	4,380	4,620
100	1:2:3½	686	865	694	4,180	4,680	4,910
101	1:2:4	686	786	702	3,370	4,510	4,780
102	1:2:4	628	727	725	3,245	4,300	4,600
103	1:2:4	599	762	676	3,565	4,190	4,600
104	1:2:4¼	591	772	652	3,720	4,520	4,620
105	1:2:4¼	609	739	747	3,810	4,040	4,730
106	1:2:4¼	783	749	662	3,420	4,440	4,920
107	1:2:4½	643	715	694	3,395	4,560	5,490
108	1:2:4½	695	727	739	3,125	4,110	4,870
109	1:2:4½	588	727	670	3,055	3,640	4,070
110	1:2:4¾	549	641	712	3,330	4,160	4,630
111	1:2:4¾	553	698	690	2,940	3,600	4,670
112	1:2:4¾	532	577	672	2,090	2,740	4,220

ROUND 1, STONE AGGREGATE, GRADING B, TYPE C FINISHER

Section No.	Proportions	Beams, 28 days	Beams, 9 months	Slabs, 9 months	Cylinders, 28 days	Cylinders, 10 months	Cores, 15 months
113	1:2:3½	569	613	685	3,350	3,850	4,860
114	1:2:3½	621	654	703	3,010	3,760	4,770
115	1:2:3½	514	521	644	2,790	3,620	4,550
116	1:2:4	559	719	664	3,045	4,220	4,310
117	1:2:4	608	622	602	3,370	4,180	4,800
118	1:2:4	566	635	676	2,680	3,140	4,640
119	1:2:4¼	538	613	713	2,595	2,900	4,410
120	1:2:4¼	457	686	645	3,140	3,630	4,620
121	1:2:4¼	522	672	640	3,355	4,040	4,720
122	1:2:4½	559	703	583	2,890	3,460	4,420
123	1:2:4½	484	682	670	2,330	3,070	4,200
124	1:2:4½	586	650	666	2,580	2,880	3,880
125	1:2:4¾	511	621	625	2,545	3,340	4,100
126	1:2:4¾	576	715	666	2,780	3,580	4,500
127	1:2:4¾	637	480	666	2,010	2,320	4,030

ROUND 2, GRAVEL AGGREGATE, GRADING A, TYPE C FINISHER

Section No.	Proportions	Beams, 28 days	Beams, 9 months	Slabs, 9 months	Cylinders, 28 days	Cylinders, 10 months	Cores, 15 months
128	1:2:3½	469	502	540	3,415	4,050	4,520
129	1:2:3½	430	492	536	3,525	4,140	4,380
130	1:2:3½	475	466	576	3,145	3,920	4,260
131	1:2:4	443	440	543	2,905	3,760	4,350
132	1:2:4	476	530	556	3,030	3,440	4,270
133	1:2:4	412	498	440	3,260	3,920	4,760
134	1:2:4½	449	493	505	3,150	3,410	4,220
135	1:2:4½	475	516	512	3,020	3,450	4,220
136	1:2:4½	463	460	528	3,425	3,890	4,080
137	1:2:4¾	490	450	426	3,255	4,000	4,270
138	1:2:4¾	471	446	501	2,725	3,320	4,160
139	1:2:4¾	476	470	557	2,280	2,990	4,010
140	1:2:5	514	498	544	3,125	3,740	4,420
141	1:2:5	452	440	547	2,715	3,380	3,920
142	1:2:5	519	490	553	2,790	3,100	3,940
143	1:2:5¼	488	468	532	3,020	3,640	4,610
144	1:2:5¼	452	478	543	2,975	3,470	3,970
145	1:2:5¼	477	488	535	2,520	3,060	3,860

ROUND 2, GRAVEL AGGREGATE, GRADING B, TYPE C FINISHER

Section No.	Proportions	Modulus of rupture in pounds per square inch			Compressive strength in pounds per square inch		
		Beams		Slabs, 9 months	Cylinders		Cores, 15 months
		28 days	9 months		28 days	10 months	
146	1:2:3½	520	649	568	3,915	4,860	4,620
147	1:2:3½	516	482	579	3,585	4,550	4,370
148	1:2:3½	519	490	621	3,680	4,460	4,510
149	1:2:4	484	548	439	3,830	4,970	3,950
150	1:2:4	497	552	568	3,765	4,610	4,450
151	1:2:4	518	482	556	3,370	4,200	4,400
152	1:2:4½	450	502	541	3,065	3,670	3,840
153	1:2:4½	461	563	512	3,375	4,100	3,830
154	1:2:4½	475	526	519	3,175	4,060	4,000
155	1:2:4¾	472	526	469	3,750	4,260	4,400
156	1:2:4¾	470	535	464	3,255	4,080	3,960
157	1:2:4¾	440	482	454	2,765	3,580	3,600
158	1:2:5	426	521	540	3,220	3,980	3,840
159	1:2:5	466	497	476	2,620	3,440	3,940
160	1:2:5	440	578	561	2,715	3,760	3,720

ROUND 2, GRAVEL AGGREGATE, GRADING A, TYPE B FINISHER

Section No.	Proportions	Beams, 28 days	Beams, 9 months	Slabs, 9 months	Cylinders, 28 days	Cylinders, 10 months	Cores, 15 months
161	1:2:3½	492	550	605	3,900	4,620	4,370
162	1:2:3½	526	571	641	3,610	4,380	4,480
163	1:2:3½	533	538	545	3,215	4,030	4,730
164	1:2:4	488	536	614	3,065	4,320	4,560
165	1:2:4	538	518	574	3,500	4,030	4,380
166	1:2:4	532	565	623	3,820	4,600	4,600
167	1:2:4½	509	494	609	3,150	4,000	4,940
168	1:2:4½	515	481	558	3,225	4,080	4,520
169	1:2:4½	466	495	623	2,915	3,740	4,360
170	1:2:4¾	520	540	558	3,205	3,980	4,060
171	1:2:4¾	488	516	555	3,220	4,050	3,810
172	1:2:4¾	496	536	559	2,840	3,700	4,160
173	1:2:5	465	509	567	2,020	3,000	3,720
174	1:2:5	478	[1] 391	554	2,265	2,780	3,940
175	1:2:5	456	443	524	2,860	3,680	4,420
176	1:2:5¼	439	470	578	2,515	2,980	3,800
177	1:2:5¼	422	492	514	2,130	2,840	3,980
178	1:2:5¼	476	508	540	2,325	3,440	4,130

ROUND 2, GRAVEL AGGREGATE, GRADING B, TYPE B FINISHER

Section No.	Proportions	Beams, 28 days	Beams, 9 months	Slabs, 9 months	Cylinders, 28 days	Cylinders, 10 months	Cores, 15 months
179	1:2:3½	488	597	640	3,460	4,470	4,170
180	1:2:3½	490	606	552	3,800	4,880	4,480
181	1:2:3½	446	526	608	3,255	4,240	4,080
182	1:2:4	470	526	600	3,210	3,980	4,350
183	1:2:4	461	544	564	3,525	4,460	4,260
184	1:2:4	530	552	531	4,140	5,040	3,780
185	1:2:4½	475	516	574	2,780	3,640	3,840
186	1:2:4½	542	468	584	3,130	4,060	4,010
187	1:2:4½	503	523	504	3,410	4,200	4,070
188	1:2:4¾	490	546	580	2,860	3,860	3,760
189	1:2:4¾	506	494	560	3,105	4,100	4,220
190	1:2:4¾	474	508	451	3,100	3,490	4,020
191	1:2:5	432	478	545	2,250	3,240	3,770
192	1:2:5	452	486	482	2,510	3,540	3,960
193	1:2:5	399	469	510	2,525	3,710	3,680

ROUND 2, STONE AGGREGATE, GRADING A, TYPE B FINISHER

Section No.	Proportions	Beams, 28 days	Beams, 9 months	Slabs, 9 months	Cylinders, 28 days	Cylinders, 10 months	Cores, 15 months
194	1:2:3½	772	706	716	3,450	4,820	4,890
195	1:2:3½	692	710	736	3,540	4,430	4,770
196	1:2:3½	639	646	748	2,975	3,830	4,740
197	1:2:4	710	700	766	2,865	4,000	4,830
198	1:2:4	662	747	702	3,170	4,340	4,680
199	1:2:4	620	696	743	2,815	3,780	4,810
200	1:2:4¼	643	602	665	2,905	3,820	4,650
201	1:2:4¼	602	634	778	2,425	3,300	4,370
202	1:2:4¼	575	628	676	3,355	4,420	4,760
203	1:2:4½	632	568	741	2,845	3,660	4,620
204	1:2:4½	626	590	685	2,910	4,000	4,730
205	1:2:4½	620	714	684	3,185	3,980	4,860
206	1:2:4¾	618	718	683	2,340	3,260	4,140
207	1:2:4¾	633	694	731	2,680	3,560	4,280
208	1:2:4¾	593	711	702	2,760	3,660	4,380

ROUND 2, STONE AGGREGATE, GRADING B, TYPE B FINISHER

Section No.	Proportions	Beams, 28 days	Beams, 9 months	Slabs, 9 months	Cylinders, 28 days	Cylinders, 10 months	Cores, 15 months
209	1:2:3½	604	597	727	2,890	4,110	4,360
210	1:2:3½	602	676	714	3,000	4,080	4,580
211	1:2:3½	703	746	670	3,300	4,290	4,740
212	1:2:4	620	749	686	2,750	3,260	4,390
213	1:2:4	593	688	716	2,710	3,460	4,120
214	1:2:4	616	760	716	2,950	3,780	5,000
215	1:2:4¼	577	704	736	2,070	2,840	4,080
216	1:2:4¼	565	737	708	2,740	3,600	4,350
217	1:2:4¼	590	714	638	3,000	4,150	4,260
218	1:2:4½	576	621	696	1,830	2,830	3,660
219	1:2:4½	566	592	716	2,020	2,560	4,200
220	1:2:4½	609	772	703	2,700	3,570	4,200
221	1:2:4¾	565	700	734	1,590	2,040	3,670
222	1:2:4¾	622	756	701	2,410	3,000	4,400
223	1:2:4¾	632	750	651	2,900	3,400	4,700

[1] One beam only.

TABLE 6.—*Results of strength tests*—Continued

Section No.	Proportions	Modulus of rupture in pounds per square inch: Beams, 28 days	Beams, 9 months	Slabs, 9 months	Compressive strength in pounds per square inch: Cylinders, 28 days	Cylinders, 10 months	Cores, 15 months
ROUND 2, STONE AGGREGATE, GRADING A, TYPE C FINISHER							
224	1:2:3½	603	680	691	2,750	3,500	4,420
225	1:2:3½	567	735	736	2,890	3,940	4,460
226	1:2:3½	603	686	730	2,930	3,820	4,660
227	1:2:4	646	706	752	2,700	3,320	4,180
228	1:2:4	598	682	691	2,870	3,640	4,420
229	1:2:4	593	684	700	2,920	4,380	4,450
230	1:2:4¼	584	812	662	3,220	4,410	4,800
231	1:2:4¼	588	790	723	2,900	4,060	4,410
232	1:2:4¼	543	772	737	2,480	3,760	4,500
233	1:2:4½	614	651	687	2,980	4,140	4,580
234	1:2:4½	586	812	701	2,690	3,820	4,300
235	1:2:4½	504	728	650	2,430	3,360	4,200
236	1:2:4¾	556	656	700	2,880	4,020	4,290
237	1:2:4¾	590	716	665	2,510	3,720	4,320
238	1:2:4¾	557	626	772	2,140	2,930	3,940
ROUND 2, STONE AGGREGATE, GRADING B, TYPE C FINISHER							
239	1:2:3½	660	802	726	3,170	4,260	4,690
240	1:2:3½	577	684	761	2,850	4,020	4,320
241	1:2:3½	662	631	690	2,540	3,520	4,840
242	1:2:4	636	772	739	3,060	3,860	5,150
243	1:2:4	608	678	702	2,700	3,770	4,880
244	1:2:4	623	686	708	2,430	3,260	4,720
245	1:2:4¼	629	698	691	2,720	3,840	5,180
246	1:2:4¼	578	704	726	2,190	3,570	4,760
247	1:2:4¼	665	762	605	3,290	4,440	5,000
248	1:2:4½	664	696	726	2,350	3,080	4,900
249	1:2:4½	656	711	675	2,730	3,200	5,080
250	1:2:4½	553	596	724	2,090	2,770	4,690
251	1:2:4¾	610	698	611	2,770	3,120	4,930
252	1:2:4¾	554	675	700	2,370	3,120	4,760
253	1:2:4¾	565	734	701	2,360	2,920	4,760
ROUND 1, SLAG AGGREGATE, GRADING A, TYPE C FINISHER							
254	1:2:3½	623	618	650	3,160	4,290	4,860
255	1:2:3½	598	620	679	3,300	4,040	4,940
256	1:2:3½	604	584	603	3,740	4,500	4,890
257	1:2:4	598	586	642	3,480	4,660	4,880
258	1:2:4	579	630	592	3,080	4,220	4,190
259	1:2:4	603	623	668	2,620	4,150	4,440
260	1:2:4¼	553	616	635	2,830	3,860	4,660
261	1:2:4¼	551	624	636	2,530	3,760	4,760
262	1:2:4¼	618	646	650	3,130	4,460	5,110
263	1:2:4½	570	593	592	2,770	3,780	4,660
264	1:2:4½	516	580	653	2,600	3,520	4,700
265	1:2:4½	547	620	576	2,950	4,300	4,710

TABLE 7.—*Water-cement ratio, cement factor, and strength tests* [1]

Proportions	Water-cement ratio by volume	Theoretical cement factor in sacks per cubic yard	Modulus of rupture in pounds per square inch: Beams, 28 days	Beams, 9 months	Slabs, 9 months	Compressive strength in pounds per square inch: Cylinders, 28 days	Cylinders, 10 months	Cores, 15 months
GRAVEL, GRADING A								
1:2:3½	0.86	5.53	492	567	565	3,350	4,240	4,730
1:2:4	.91	5.15	472	554	547	3,180	4,000	4,590
1:2:4½	.92	4.84	473	499	541	3,040	3,900	4,500
1:2:4¾	.96	4.67	467	490	530	2,880	3,600	4,230
1:2:5	.98	4.52	458	477	540	2,680	3,300	4,180
1:2:5¼	.97	4.41	435	483	516	2,630	3,380	4,140
GRAVEL, GRADING B								
1:2:3½	0.89	5.54	506	582	578	3,620	4,520	4,570
1:2:4	.92	5.17	494	557	553	3,520	4,420	4,420
1:2:4½	.99	4.81	486	541	532	3,260	4,040	4,200
1:2:4¾	1.01	4.67	468	525	509	3,140	3,940	4,150
1:2:5	1.05	4.51	439	536	494	2,800	3,690	4,080
1:2:5¼ [2]	1.02	4.42	466	558	475	3,140	4,000	3,980
STONE, GRADING A								
1:2:3½	0.87	5.73	654	754	715	3,480	4,330	4,850
1:2:4	.91	5.35	648	730	706	3,240	4,180	4,700
1:2:4¼	.92	5.18	615	744	700	3,160	4,030	4,680
1:2:4½	.94	5.02	614	718	694	3,050	3,960	4,700
1:2:4¾	.97	4.86	556	694	695	2,660	3,540	4,370
STONE, GRADING B								
1:2:3½	0.87	5.78	600	658	700	3,060	4,000	4,620
1:2:4	.91	5.39	614	695	694	2,900	3,680	4,570
1:2:4¼	.92	5.22	576	705	683	2,840	3,690	4,570
1:2:4½	.95	5.04	578	690	677	2,500	3,150	4,430
1:2:4¾ [3]	.97	4.90	584	684	668	2,450	3,070	4,350
SLAG, GRADING A								
1:2:3½	0.87	5.90	608	607	644	3,400	4,280	4,900
1:2:4	.93	5.50	593	613	634	3,060	4,340	4,500
1:2:4¼	.95	5.33	574	629	640	2,830	4,030	4,840
1:2:4½	.99	5.14	544	598	607	2,770	3,870	4,690

[1] Except where otherwise indicated, each value is the average for 12 sections in the case of gravel and stone and 3 sections in the case of slag.
[2] 2 sections only.
[3] 11 sections only.

RELATION BETWEEN STRENGTH OF CONCRETE AND MIX

The average results of strength tests on the concrete for each grading of aggregate for each mix are shown in Table 7. The average results of all tests for each aggregate are plotted in graphic form in Figures 10, 11, and 12. Each plotted value in these figures represents the average of all tests for the particular mix and type of aggregate indicated. In the case of gravel and stone, each point therefore represents the average of tests on 24 sections, except the 1:2:5¼ mix, gravel, which represents 14 sections, and the 1:2:4¾ mix, stone, which represents 23 sections. In the case of slag, each point represents the average of tests on only three sections. Twenty-eight day and nine-month tests on control specimens for each section are the average of tests on two beams and two cylinders. The tests on the slabs are the average of the four beams taken from the section and the tests on the cores are the averages of tests of two cores drilled from the section. Each point, therefore, with the exceptions noted above, becomes the average of 48 individual tests in the case of the beams, cores, and cylinders and the average of 96 individual tests in the case of the pavement slabs.

Let us first examine Figure 10, on which the results for the gravel concrete are plotted. A fairly consistent decrease in both flexural and compression strength is noted for increases in the percentages of coarse aggregate in the mix. It will be observed, however, that, whereas the flexure specimens show about the same percentage of decrease for the slabs at nine months as for the beams at 28 days and 9 months, the cores tested in compression at 15 months show a somewhat smaller rate of decrease than the cylinders at either 28 days or 10 months. It will be observed also that the percentage of increase in strength from 28 days to 9 months in the case of the beams and from 28 days to 10 months in the case of the cylinders is approximately the same for all mixes, although the average percentage of increase is greater in the case of the compression tests. A very close agreement is shown between the results of beam and slab tests at nine months for all mixes. The data indicate that in general the results of tests on beam control specimens may be considered to represent very closely the strengths of the slabs. However, these are average relations and it will be shown later during the discussion of the individual test results that such close agreement does not apply under all conditions.

Unfortunately it was impossible to test the cores at the same age as the 10-months cylinders, so that an accurate comparison in compression can not be made. The observed increase in cylinder strengths from 28 days to 10 months would indicate, at least in the case of the richer mixtures, a probable further increase to approximately the strengths obtained from the cores at 15 months. It is difficult to predict just what the rela-

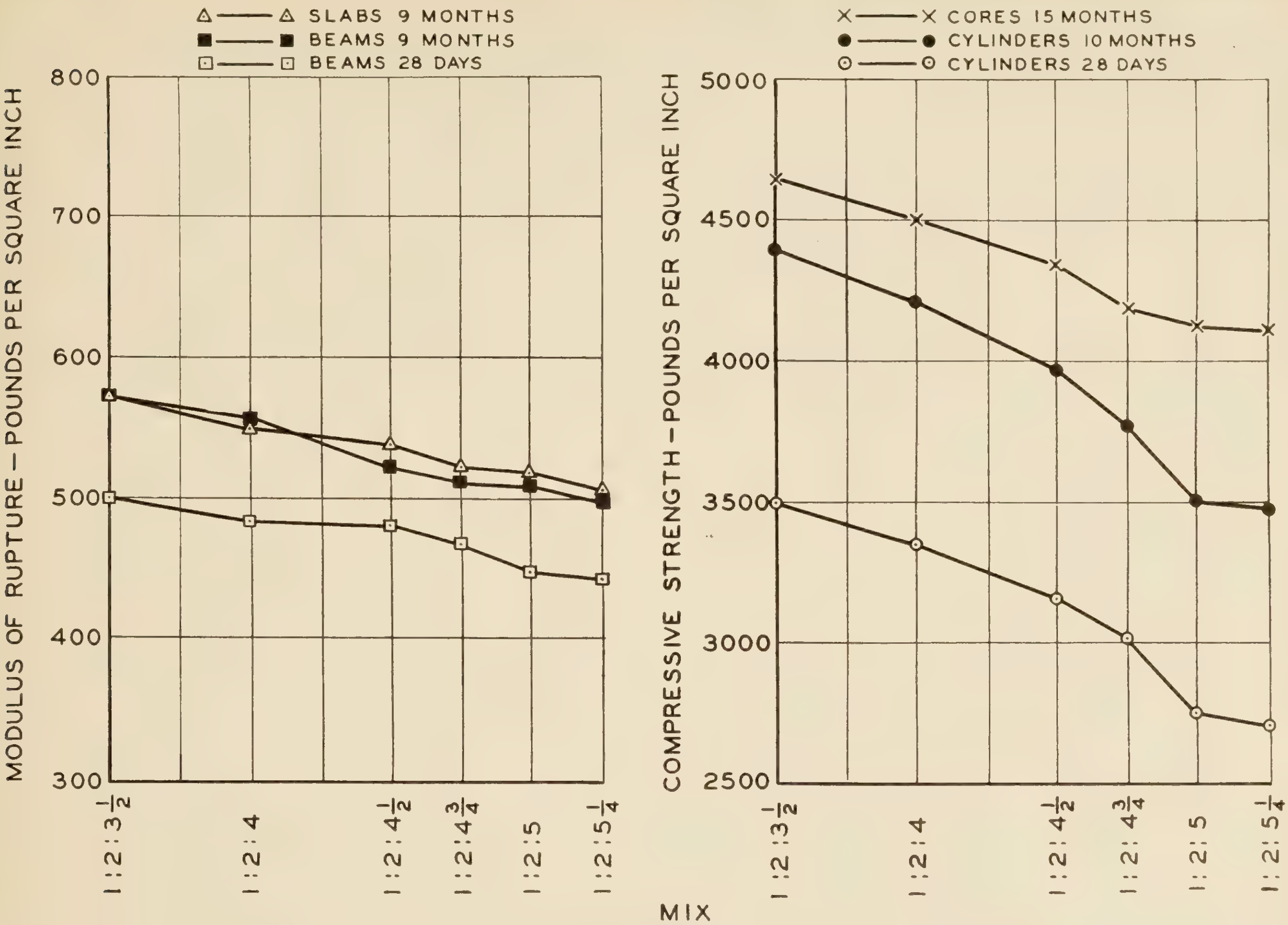


Figure 10.—Relation Between Strength of Gravel Concrete and Mix

tion would have been for the mixes containing larger quantities of coarse aggregate, because of the fact that the cylinder strengths decreased with increase of coarse aggregate at a somewhat greater rate than the core strengths. In general, the data from the gravel concrete group seem to indicate that the results of tests on molded cylinders are a fair indication of the crushing strength of the concrete in the pavement.

The corresponding values for the crushed stone concrete are shown in Figure 11. The same general trends are noted as in the case of the gravel concrete. The average reduction in flexural strength for a corresponding increase in coarse aggregate content does not, however, appear to be as great. For instance, in the case of the crushed-stone slabs, an increase in coarse aggregate from 3½ to 4¾ parts resulted in a decrease in modulus of rupture of only 26 pounds per square inch, or approximately 4 per cent. (See also Table 7.) The corresponding reduction for the gravel concrete was 52 pounds per square inch, or about 9 per cent. A similar increase in the amount of coarse aggregate reduced the crushing strength of the stone concrete cores 380 pounds per square inch, or 8 per cent, and the gravel concrete 460 pounds per square inch, or 10 per cent. There is not the same agreement between results of 9-month beam and slab strengths for the stone concrete as for the gravel concrete. This is particularly true of the 1:2:4¼ mix. In the case of stone concrete the relation between flexural strength and mix is more consistent for the slabs than for the beams, possibly because of the difficulty of molding uniform beam specimens of comparatively small section (7 inches by 7 inches) when an angular aggregate is used.

Comparing now the results of compression tests on the stone concrete, as shown in Figure 11, with the corresponding values in Figure 10, one will observe that the difference between cylinder strengths at 10 months and core strengths at 15 months is considerably greater than for the gravel concrete, although, as in the case of the gravel concrete, the rate of decrease with increased percentages of coarse aggregate is greater for the cylinders than for the cores. Since the average curing conditions and other factors which might affect the rate of increase in strength were similar, it seems reasonable to assume, in the case of the stone concrete, that the cylinders would not have increased in strength between 10 and 15 months at any greater rate than the gravel concrete. This would indicate the possibility that in the case of the crushed stone concrete, the core strengths at a given age might have been somewhat higher than the control cylinder strengths. The difference, if any, would have been relatively small.

Relations between the strength of the slag concrete and mix are shown in Figure 12. As has been indicated, each value in this case represents the average of tests on three slabs only, the only variable for each proportion being the consistency. Type C finisher only was used with A grading for the slag. In spite of the fact that the results are not so consistent as for the other aggregates, the same general trends may be observed. The

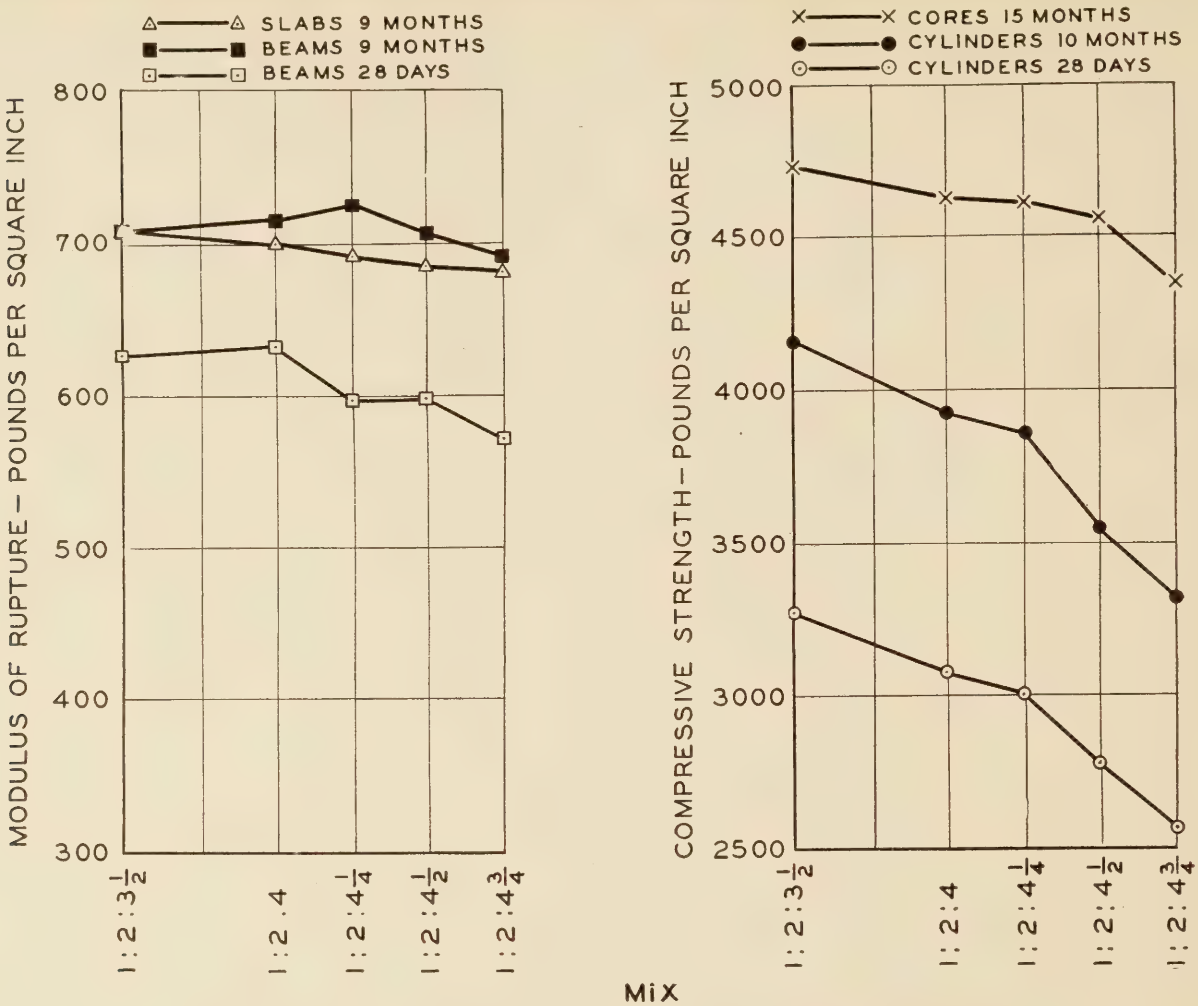


Figure 11.—Relation Between Strength of Stone Concrete and Mix

most puzzling deviations are the beam tests at 9 months for the 1:2:3½ and 1:2:4 mixes. There appears to be no explanation for these low values, nor for the erratic results in compression for the 1:2:4 mix at 10 months and 15 months. It seems reasonable to assume that these erratic results are purely accidental and that much more consistent values would have been obtained had a larger number of specimens been tested.

RELATION BETWEEN STRENGTH OF CONCRETE AND CEMENT FACTOR

The average results for flexural and compressive strength which have just been discussed from the standpoint of mix are plotted in Figures 13, 14, and 15 against the cement content in bags per cubic yard of concrete resulting from the arbitrary proportions which were used. It seemed desirable to study the data from this standpoint because of the difference in cement factor for a given nominal mix caused by difference in the voids in the coarse aggregate. Reference to Table 2 will show that, for the same grading, the gravel contained 5 per cent less voids than the crushed stone and 9 per cent less voids than the crushed slag. These differences are reflected in a variation in yield of concrete to the extent of approximately 0.2 bag per cubic yard in the case of gravel compared with crushed stone and about 0.35 bag per cubic yard in the case of gravel compared with slag. (See also Table 7.) This difference is, of course, due to the fact that the base proportions were determined by bulk volume. For identical proportions by absolute volume the yields would have been the same regardless of the difference in void content of the different aggregates.

Certain interesting relationships may be pointed out. For instance, from Figures 13 and 14 it is seen that for the flexure specimens and for the cores the decrease in strength with reductions in cement content progresses at a fairly uniform rate, whereas in the case of the cylinders, the rate of reduction in the strength of the concrete increases as the cement content is reduced. This applies to both the gravel and the stone concrete. For a variation in coarse aggregate from 3½ to 4¾ parts, which is the extreme range for the stone concrete, the average decrease in flexural strength of slab (the average including both stone and gravel concrete) is about 6 per cent (see Table 7). The corresponding average decrease in cement content is approximately 15 per cent. The same increase in coarse aggregate reduced the average crushing strength of the cores about 9 per cent with the same decrease in cement factor. Attention is called to the fact that the reduction in strength with increasing quantities of coarse aggregate in the mix is, according to the water-cement ratio theory, caused by the dilution of the cement paste, which in turn is brought about by increasing the water content in order to maintain workability. This phase of the matter is discussed in the next section.

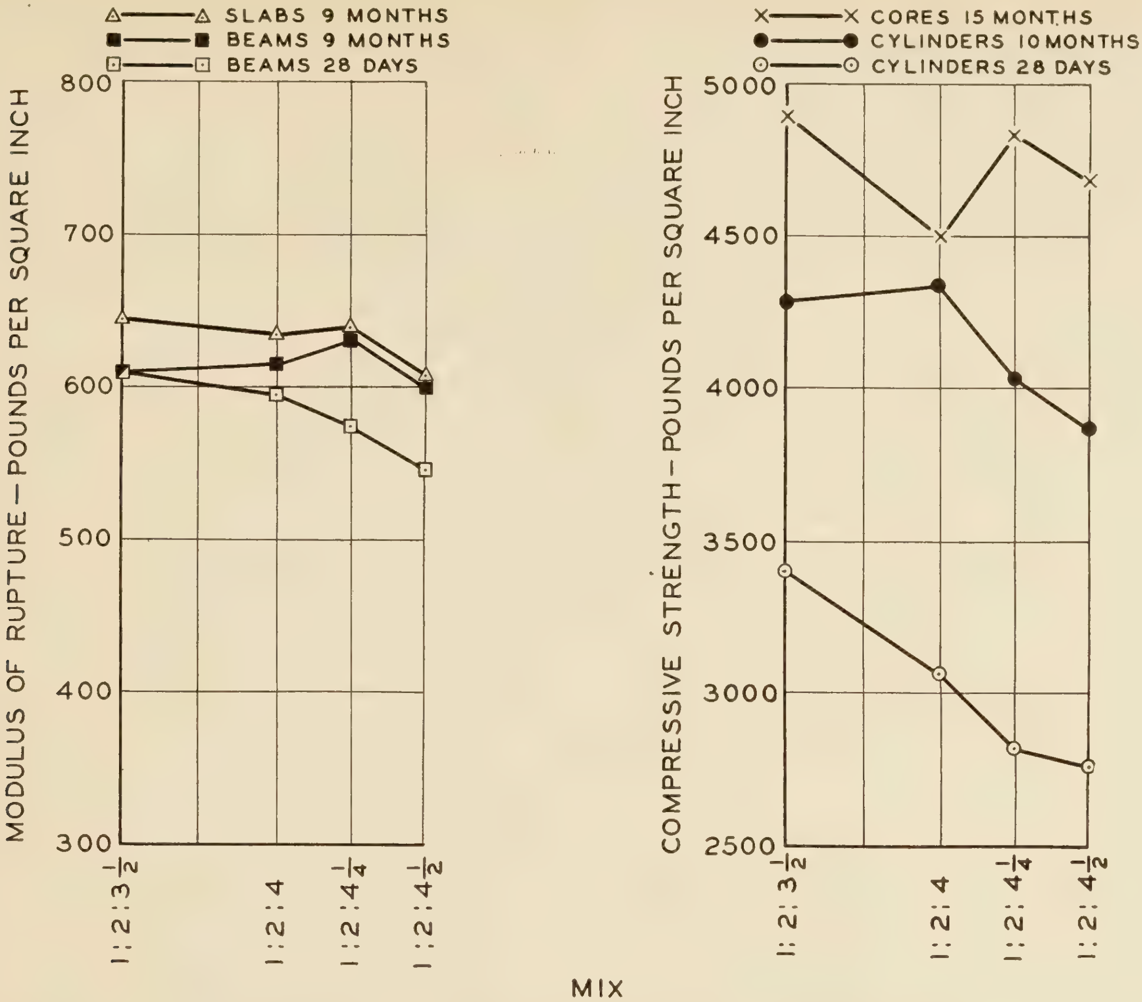


Figure 12.—Relation Between Strength of Slag Concrete and Mix

RELATION BETWEEN STRENGTH AND WATER-CEMENT RATIO

The effect on strength of change in the water-cement ratio brought about by increasing the quantity of coarse aggregate is shown in Figures 16 and 17. The values for water-cement ratio indicated in these charts are approximate net water ratios after correctng for absorption of water by the sand but without making any correction for absorption by the coarse aggregate. The coarse aggregates were assumed to be in a saturated surface-dry condition when used and hence no correction should be made in calculating the net water ratio. On the other hand the total amount of water used in the concrete as reported in Table 7 was determined by adding the total water carried by the sand to the quantity introduced at the mixer. This would of course require a correction to take care of absorption in the sand. Based on 0.7 per cent absorption this correction amounts approximately to 0.02 so that the net water-cement ratios shown on the charts are 0.02 lower than the average values calculated from Table 7.

It was found impossible to determine accurately the absorption in the slag. Niether does it appear possible to assume that the slag was in a saturated surface dry condition when used. For these reasons values for net water ratio for the slag concrete were not calculated and no chart is shown for this material.

Examination of Figures 16 and 17 reveals the conventional relation between water-cement ratio and strength. It will be observed also that, for a given water-cement ratio, the crushing strengths of the stone concrete cores are approximately the same as those of the gravel concrete cores, whereas, in the case of the control cylinders, the gravel concretes show considerably higher crushing strengths than the stone concretes. The difference appears also to become greater as the water-cement ratio increases.

In flexure the crushed stone concrete, for equivalent water ratios, is considerably higher in both beam and slab strength, probably because of certain aggregate characteristics inherent in these particular materials.

EFFECT OF TYPE OF FINISHING MACHINE

The average values for modulus of rupture of the slabs and crushing strength of the cores have been plotted by types of finishing machine in Figures 18 and 19. The data were taken from Tables 8 and 9. In these charts each plotted value represents the average of tests on six test sections, in the case of types A and B finisher, and twelve test sections in the case of type C finisher, except for the 1:2:5¼ mix, gravel concrete, and the 1:2:4¾ mix, stone concrete.

According to these curves, the type B finisher gives higher results in flexure than either type A or type C. In compression on the other hand, type A is high and type B low. These comparisons apply to both types of aggregate although the high values for both flexure and compression are more pronounced in the case of the gravel concrete than for the stone. It will be re-

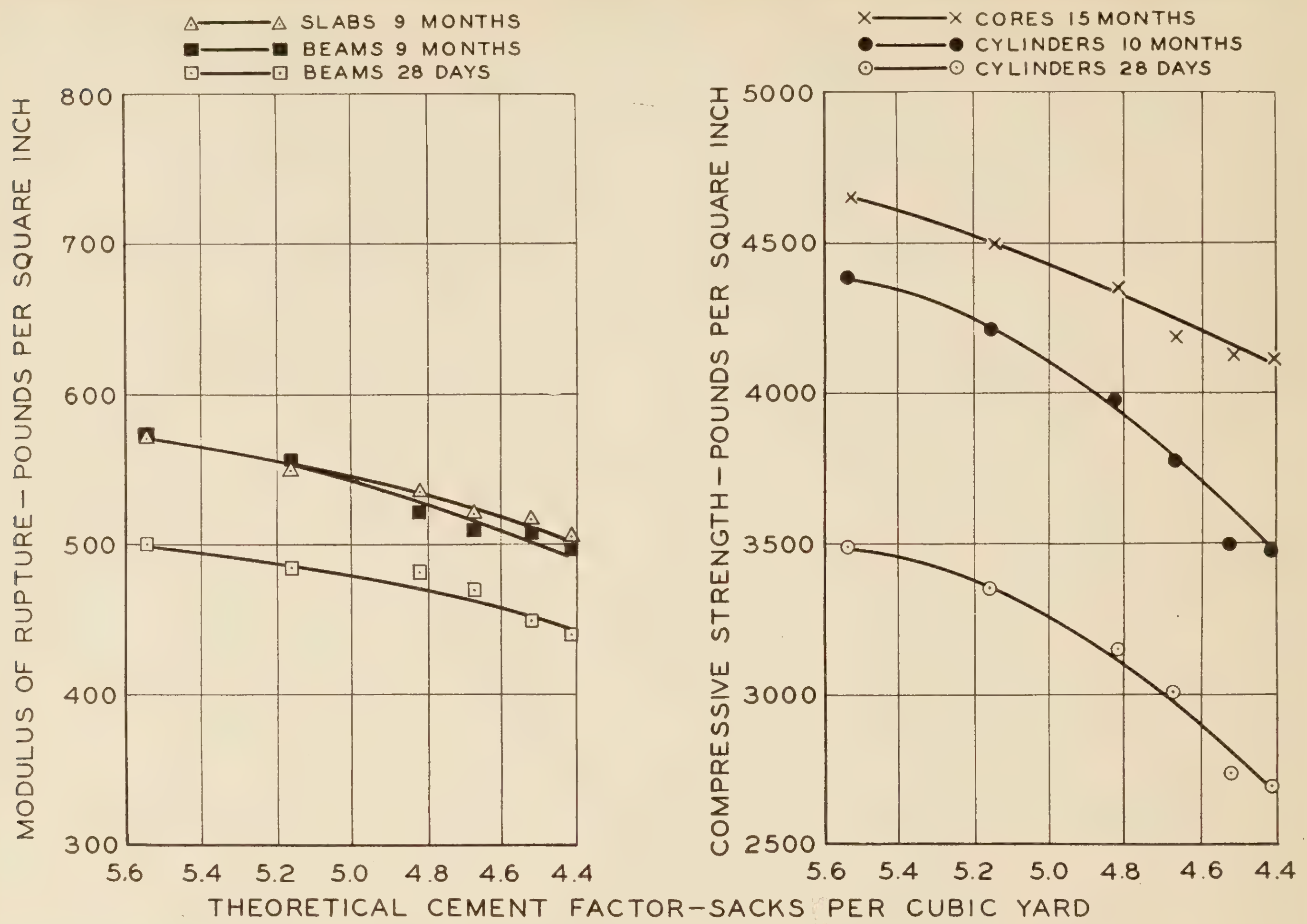


Figure 13.—Relation Between Strength of Gravel Concrete and Cement Factor

called that the flexure tests were made on the slabs with the load applied on top and with the bottom in tension. It seems rather difficult to explain just why type B finisher should have given values for modulus of rupture higher than either of the other types. This, it will be recalled, was a single-screed machine and there seems at first sight no reason why it should have compacted the concrete any more thoroughly than the double screed. However, the screed on the type B machine was tilted slightly by raising the front of the screed about one-half inch, whereas the screeds on the type C machine were flat. The tilted screed might possibly have a tendency to compact the concrete slightly more than a screed of the type C design.

In order to determine whether the relatively high values of modulus of rupture for type B finisher might have been due to some other factor, as for instance more favorable curing conditions, the average results of the slab tests for each mix, grading, and type of finisher have been compared directly with the average results

Table 8.—*Effect of type of finishing machine on strength of gravel concrete* [1]

MODULUS OF RUPTURE OF SLABS AT 9 MONTHS, IN POUNDS PER SQUARE INCH

Grading	Proportions	Finisher used: Type A, round 1	Type B, round 2	Type C: Round 1	Type C: Round 2
A	1:2:3½	540	597	571	551
	1:2:4	535	604	535	513
	1:2:4½	549	597	506	515
	1:2:4¾	530	557	538	495
	1:2:5	549	548	513	548
	1:2:5¼	496	544	487	537
B	1:2:3½	593	600	530	589
	1:2:4	554	565	573	521
	1:2:4½	542	554	506	524
	1:2:4¾	504	530	540	[2] 462
	1:2:5	465	512	475	526
	1:2:5¼	----------	----------	[3] 475	----------

COMPRESSIVE STRENGTH OF CORES AT 15 MONTHS, IN POUNDS PER SQUARE INCH

Grading	Proportions	Finisher used: Type A, round 1	Type B, round 2	Type C: Round 1	Type C: Round 2
A	1:2:3½	5, 010	4, 530	5, 000	4, 390
	1:2:4	4, 580	4, 510	4, 820	4, 460
	1:2:4½	4, 800	4, 610	4, 440	4, 170
	1:2:4¾	4, 370	4, 010	4, 380	4, 150
	1:2:5	4, 240	4, 030	4, 370	4, 090
	1:2:5¼	4, 080	3, 970	4, 370	4, 150
B	1:2:3½	5, 090	4, 240	4, 450	4, 500
	1:2:4	4, 850	4, 130	4, 420	4, 270
	1:2:4½	4, 520	3, 970	4, 400	3, 890
	1:2:4¾	4, 480	4, 000	4, 120	3, 990
	1:2:5	4, 690	3, 800	4, 000	3, 830
	1:2:5¼	----------	----------	[4] 3, 980	----------

[1] Except where otherwise indicated, each value is the average for 12 specimens in the case of modulus of rupture and 6 specimens in the case of compressive strength.
[2] Average of 11 specimens.
[3] Average of 8 specimens.
[4] Average of 4 specimens.

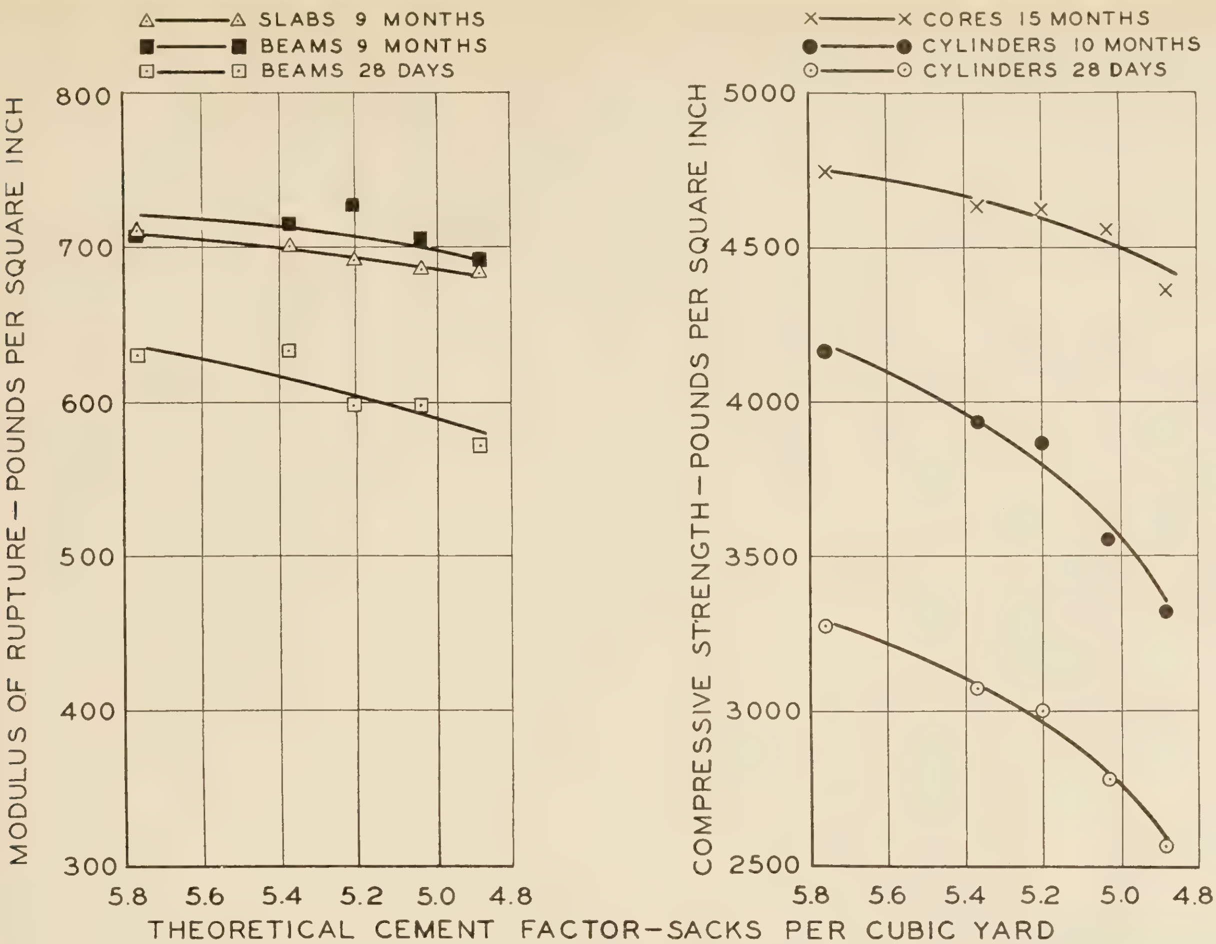


FIGURE 14.—RELATION BETWEEN STRENGTH OF STONE CONCRETE AND CEMENT FACTOR

TABLE 9.—*Effect of type of finishing machine on strength of stone concrete* [1]

	MODULUS OF RUPTURE OF SLABS AT 9 MONTHS, IN POUNDS PER SQUARE INCH					COMPRESSIVE STRENGTH OF CORES AT 15 MONTHS, IN POUNDS PER SQUARE INCH			
		Finisher used				Finisher used			
Grading	Proportions	Type A, round 1	Type B, round 2	Type C Round 1	Type C Round 2	Type A, round 1	Type B, round 2	Type C Round 1	Type C Round 2
A	1:2:3½	715	733	693	719	5,270	4,800	4,830	4,510
	1:2:4	672	737	701	714	5,020	4,770	4,660	4,350
	1:2:4¼	698	706	687	707	4,820	4,590	4,760	4,570
	1:2:4½	694	703	701	679	4,890	4,740	4,810	4,360
	1:2:4¾	672	705	691	712	4,510	4,270	4,510	4,180
B	1:2:3½	693	704	[2] 677	726	4,550	4,560	4,730	4,620
	1:2:4	709	706	647	716	4,290	4,500	4,580	4,920
	1:2:4¼	698	694	666	674	4,490	4,230	4,580	4,980
	1:2:4½	655	705	640	708	4,630	4,020	4,170	4,890
	1:2:4¾	[3] 646	695	652	671	[4] 3,980	4,260	4,210	4,820

[1] Except where otherwise indicated, each value is the average for 12 specimens in the case of modulus of rupture and 6 specimens in the case of compressive strength.
[2] Average of 11 specimens.
[3] Average of 8 specimens.
[4] Average of 4 specimens.

for the corresponding control beams. The "strength ratios," obtained by dividing the average slab strength by the average beam strength are used to express the relative efficiency of the different finishers. These "strength ratios" are given in Table 10 for each type of machine, type of aggregate, and grading of aggregate.

It will be observed that in the case of the gravel concrete and also in the case of the stone concrete, grading A, type B finisher is still high. However, there appears to be no trend in the case of the stone concrete, grading B. Another point of interest is that in the case of the gravel concrete, grading A, there is a tendency for the slabs to show higher strength in proportion to the beams with increasing amounts of coarse aggregate. This applies to all types of finisher. On the other hand, for the gravel concrete, grading B, the reverse seems to be true except for finisher B. The tendency for the gravel concrete, grading B, to honeycomb, particularly in the leaner mixes, with consequent falling off in slab strength, probably accounts for this. The effect of honeycombing on strength is discussed later.

In the case of the stone concrete there appears to be very little trend as regards the effect of increasing percentages of coarse aggregate except that for grading B the 1:2:3½ mix seems to give relatively high strength ratios for all three types of finisher.

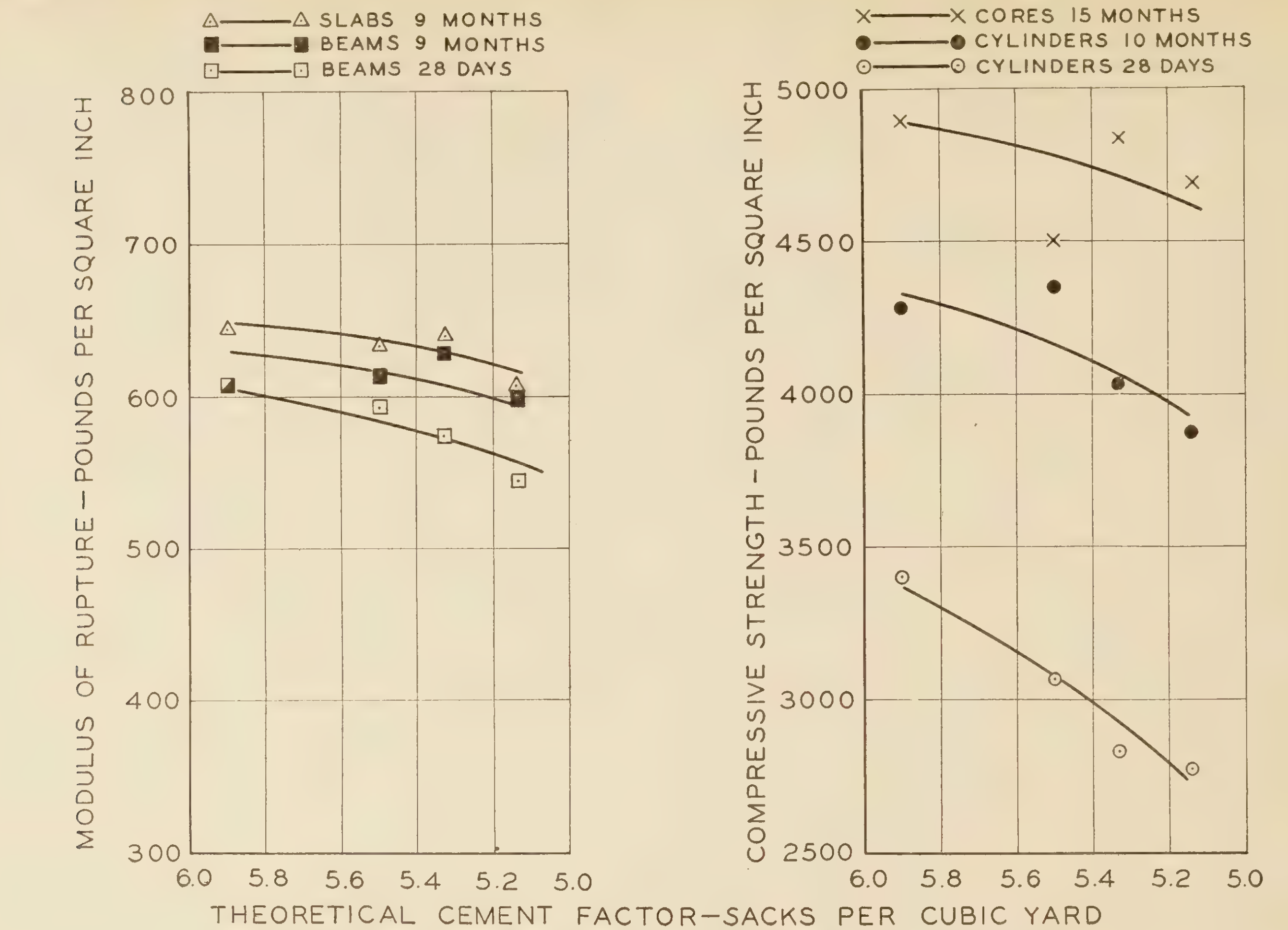


Figure 15.—Relation Between Strength of Slag Concrete and Cement Factor

Table 10.—*Ratio of flexural strengths of slabs to strengths of corresponding control beams at 9 months* [1]

Type of finisher	Coarse aggregate	Proportions							Average
		1:2:3½	1:2:4	1:2:4¼	1:2:4½	1:2:4¾	1:2:5	1:2:5¼	
A	Gravel-A	0.99	1.06	-------	1.07	1.15	1.19	1.07	1.09
B	do	1.08	1.12	-------	1.22	1.05	1.19	1.11	1.13
C	do	.99	.92	-------	1.03	1.07	1.08	1.05	1.02
Average	do	1.02	1.03	-------	1.11	1.09	1.15	1.08	1.08
A	Gravel-B	.94	.89	-------	.93	.95	.78	-------	.90
B	do	1.04	1.04	-------	1.10	1.03	1.07	-------	1.06
C	do	1.00	1.03	-------	.96	.95	.94	-------	.98
Average	do	.99	.99	-------	1.00	.98	.93	-------	.98
A	Stone-A	.91	.86	.86	.87	.88	-------	-------	.88
B	do	1.07	1.03	1.14	1.13	1.00	-------	-------	1.07
C	do	.93	.98	.90	.95	1.08	-------	-------	.97
Average	do	.97	.96	.97	.98	.99	-------	-------	.97
A	Stone-B	1.06	1.05	.96	.87	.93	-------	-------	.97
B	do	1.05	.96	.97	1.06	.95	-------	-------	1.00
C	do	1.09	1.00	.98	1.00	1.02	-------	-------	1.02
Average	do	1.07	1.00	.97	.98	.97	-------	-------	1.00

[1] Values obtained by averaging ratios given by individual sections.

In general it may be said that, aside from a slight advantage in favor of the type B finisher, the analysis of the data indicates that the three types of finishing machine give essentially the same results and also that beam strength is a fairly good indication of the actual flexural strength of the concrete in the structure. In this connection, however, attention should be called to the discussion on the effect of honeycombing which is given in a subsequent part of the report. In this discussion the fact is brought out that this relation does not apply in the case of very dry mixes which honeycomb on placing.

In connection with the discussion on finishing, Table 12 gives the number of passes of the finisher and, in the case of type A, the number of passes of the tamper for each section, together with notes on workability and finish made during construction. These data may be used in connection with a study of the detailed test results plotted in Figures 33 to 37.

EFFECT OF GRADING OF COARSE AGGREGATE

The average effect of grading of the coarse aggregate upon the slab and core strengths of the concrete is shown in Figures 20 and 21. The data were taken from Table 7. The concrete containing the well-graded coarse aggregate shows somewhat higher strength values than that containing the more poorly graded aggregate, although the differences are not very great. For mixes containing more than 4½ parts coarse aggregate there appears to be a tendency for the concrete containing the small size gravel (grading B) to decrease in flexural strength at a greater rate with increasing amounts of aggregate than the large-size material. As has been noted, this is no doubt due to the tendency of the poorly graded concrete to honeycomb in the leaner mixes. Attention should also be called to the fact that a wider variation in strength results from changes in consistency in a given mix than from the average variations due to changes in grading. This may be verified by analyzing the data for the individual sec-

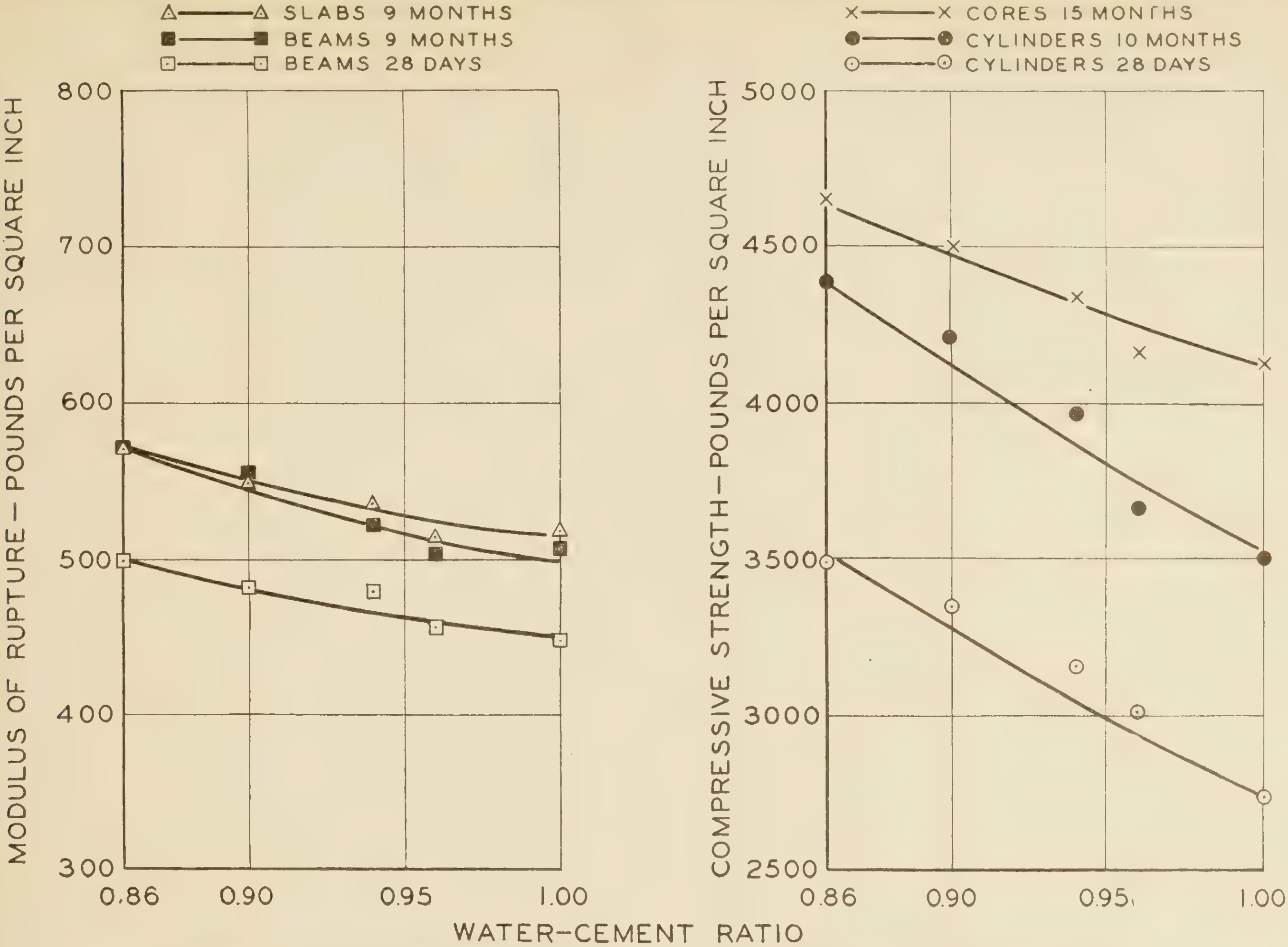


FIGURE 16.—RELATION BETWEEN STRENGTH OF GRAVEL CONCRETE AND WATER-CEMENT RATIO

tions as shown in Table 6 and in Figures 33 to 37, inclusive, as well as in Figures 25, 26, and 27. This is particularly true for the mixes containing from 3½ to 4½ parts coarse aggregate. For the mixes high in coarse aggregate the tendency of grading B aggregate to produce honeycomb results in a considerable difference due to this cause.

FACTORS INFLUENCING HONEYCOMB IN SLABS STUDIED

In order to analyze the manner in which honeycombing is affected by the several variables which have been introduced into this study, as well as to bring out the effect of honeycombing in slabs upon flexural strength, a series of charts have been prepared which will be discussed in the following section of this report.

The percentage of honeycomb in each test slab was determined by averaging two values, the percentage of the total area of the bottom of the slab showing honeycomb and the percentage of the total area of the cross section at the break which showed honeycomb. It was felt that this method gave a reasonably satisfactory measure of the homogenity of the concrete in the test slab.

The relation between average percentages of honeycomb in each mix for each type and gradation of coarse aggregate is shown in Figure 22; and the corresponding average relation between honeycomb and consistency as indicated by slump tests, is shown in Figure 23. A similar relation between honeycomb and consistency but with the values classified by types of finisher is shown in Figure 24. In these figures each point represents the average of the percentages of honeycomb in all the sections having the particular combination of variables involved. The data are taken from Table 13, which shows the percentage of honeycomb for each section and Table 5, which gives the slump and flow test values for each section. In the case of Figures 22 and 23, the plotted points do not always represent the average of tests on the same number of slabs because of the fact that the same slumps were not always obtained on each of the three sections in each group. In drawing in the average lines each point was weighted in accordance with the number of tests which it represented.

These figures are of interest in showing (1) that the average amount of honeycomb increases slightly with increases in the percentage of coarse aggregate in the mix (fig. 22); (2) that where the small-size gravel aggregate containing an excess of fine material was used the average amount of honeycomb was considerably increased (fig. 22); (3) that the average amount of honeycomb was increased by decreasing the slump (fig. 23); and (4) that honeycombing was somewhat decreased by the use of type A finishing machine (fig. 24).

One of the most interesting features in connection with the occurrence of honeycomb in the concrete is the effect of B grading in the gravel mixes. Reference

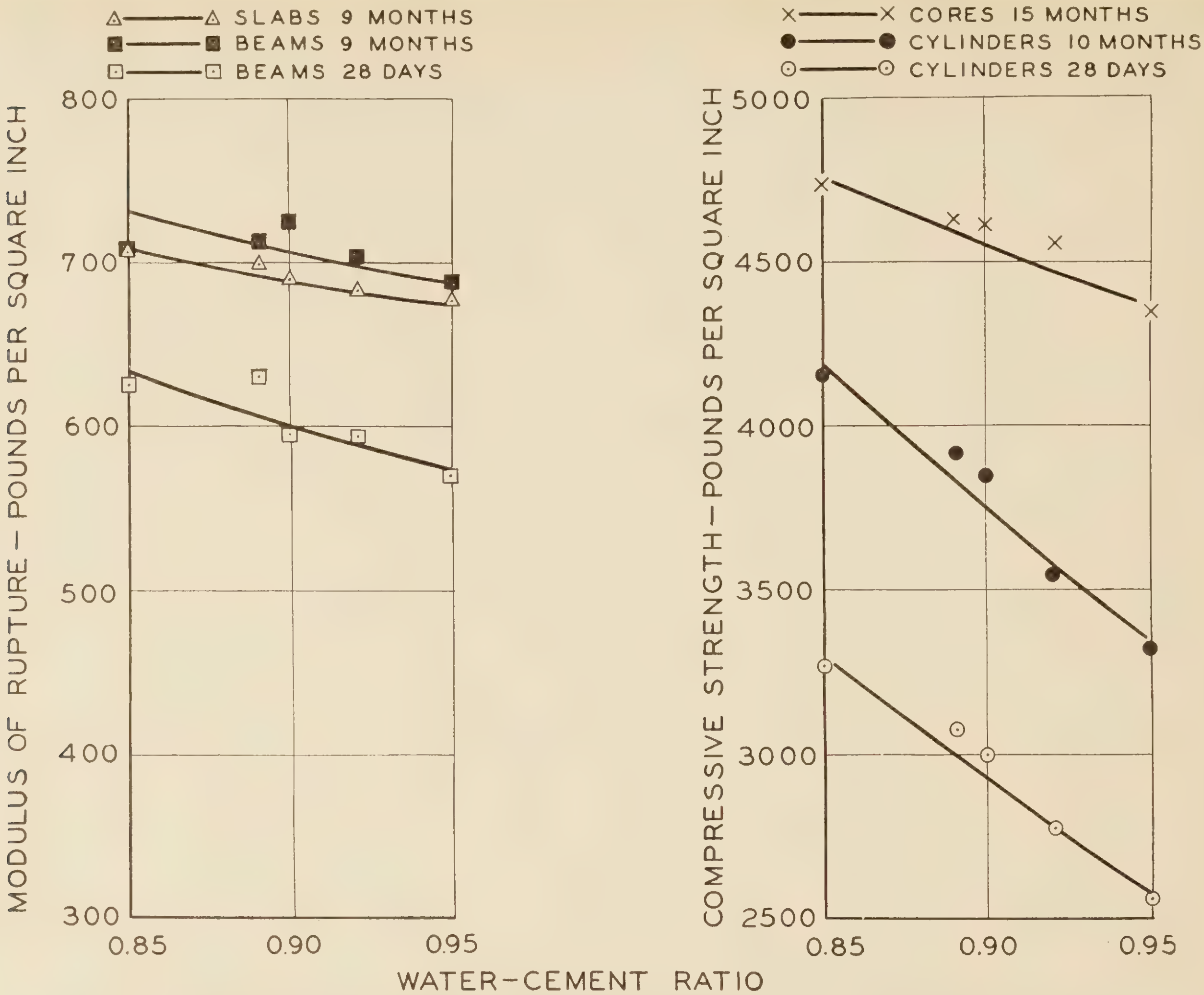


FIGURE 17.—RELATION BETWEEN STRENGTH OF STONE CONCRETE AND WATER-CEMENT RATIO

to Figure 1 will show that this material was graded from 1¼-inch to ¼-inch with 60 per cent passing the ¾-inch screen. The void content was 36 per cent, dry-rodded, or 1 per cent greater than the A grading. This would seem to be a small difference in voids for so wide a variation in grading. However, repeated tests showed that these values were correct.

Reference to Table 11 will show that the values for the ratio of b to b_0 and for the mortar-voids ratio (volume of mortar as determined by adding the absolute volumes of cement and sand and the volume of water, divided by the volume of voids in the dry-rodded coarse aggregate) were substantially the same for corresponding mixes using A and B grading. Moreover, the values for these ratios in the 1:2:4 mixes using gravel are just about the same as for the 1:2:3½ mixes using crushed stone. On the assumption that these ratios are significant in controlling workability, this would indicate that the workability of the two gravel concretes should be about the same and also that the 1:2:4 gravel concrete should have about the same workability as the 1:2:3½ stone concrete. Referring, however, to Figure 22 and assuming that the presence of honeycomb in the finished structure is a reasonably satisfactory measure of the workability of the concrete going into the structure, we find an average of about 1 per cent honeycomb in the 1:2:3½ stone concrete, about 1½ per cent in the 1:2:4 gravel concrete, grading A, and over 6 per cent in the 1:2:4

TABLE 11.—*Mortar-void ratio and* $\frac{b}{b_0}$ *for all proportions* [1]

Coarse aggregate	Proportions	Average water-cement ratio	Theoretical cement factor	Mortar-voids [2] ratio	$\frac{b}{b_0}$
			Sacks per cubic yard		
Gravel, grading A; $b_0=0.65$; voids 35 per cent.	1:2:3½	0.86	5.53	2.13	0.717
	1:2:4	.91	5.14	1.89	.762
	1:2:4½	.92	4.84	1.68	.806
	1:2:4¾	.96	4.66	1.63	.820
	1:2:5	.98	4.52	1.55	.838
	1:2:5¼	.97	4.41	1.47	.858
Gravel, grading B; $b_0=0.64$; voids 36 per cent.	1:2:3½	.89	5.54	2.09	.719
	1:2:4	.92	5.17	1.85	.766
	1:2:4½	.99	4.81	1.69	.802
	1:2:4¾	1.01	4.66	1.61	.820
	1:2:5	1.05	4.51	1.55	.835
	1:2:5¼	1.02	4.41	1.46	.858
Stone, Grading A; $b_0=0.60$; voids 40 per cent.	1:2:3½	.87	5.73	1.86	.743
	1:2:4	.91	5.35	1.66	.792
	1:2:4¼	.92	5.18	1.56	.816
	1:2:4½	.94	5.02	1.49	.836
	1:2:4¾	.97	4.86	1.43	.854
Stone, grading B; $b_0=0.59$; voids 41 per cent.	1:2:3½	.87	5.78	1.81	.749
	1:2:4	.91	5.39	1.62	.798
	1:2:4¼	.92	5.22	1.53	.822
	1:2:4½	.95	5.05	1.46	.841
	1:2:4¾	.97	4.90	1.39	.862
Slag, grading A; $b_0=0.56$; voids 44 per cent.	1:2:3½	.87	5.91	1.69	.766
	1:2:4	.93	5.50	1.52	.815
	1:2:4¼	.95	5.33	1.44	.838
	1:2:4½	.99	5.14	1.38	.857

[1] Computations were made on the basis of 38 per cent voids for sand and 50 per cent voids (assumed) for cement.

[2] The mortar-voids ratio for a given mix is obtained by dividing the sum of the absolute volumes of cement and sand plus the volume of water by the volume of voids in the dry-rodded coarse aggregate. This term should not be confused with the same term as used in the discussion of the mortar-voids theory.

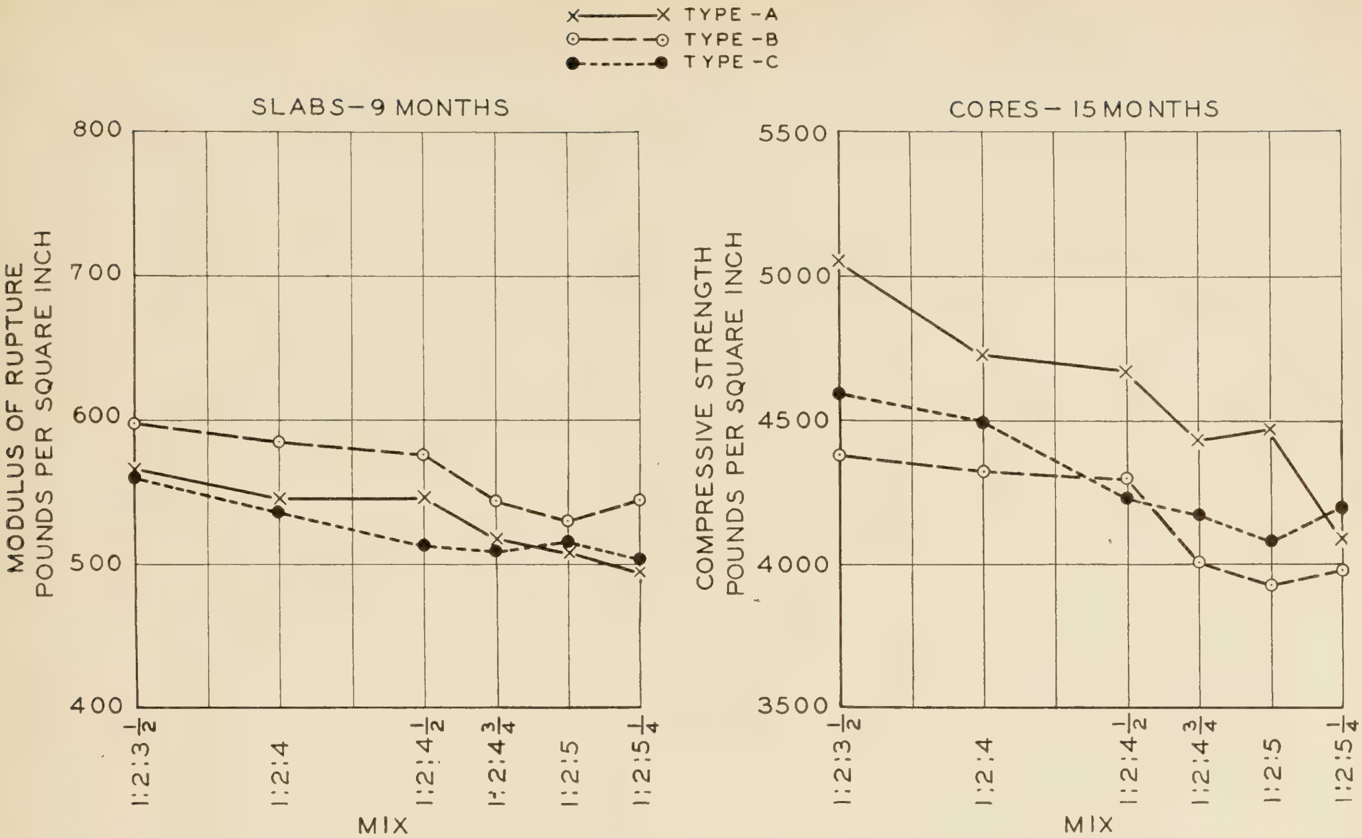


Figure 18.—Relation Between Strength of Gravel Concrete and Type of Finishing Machine

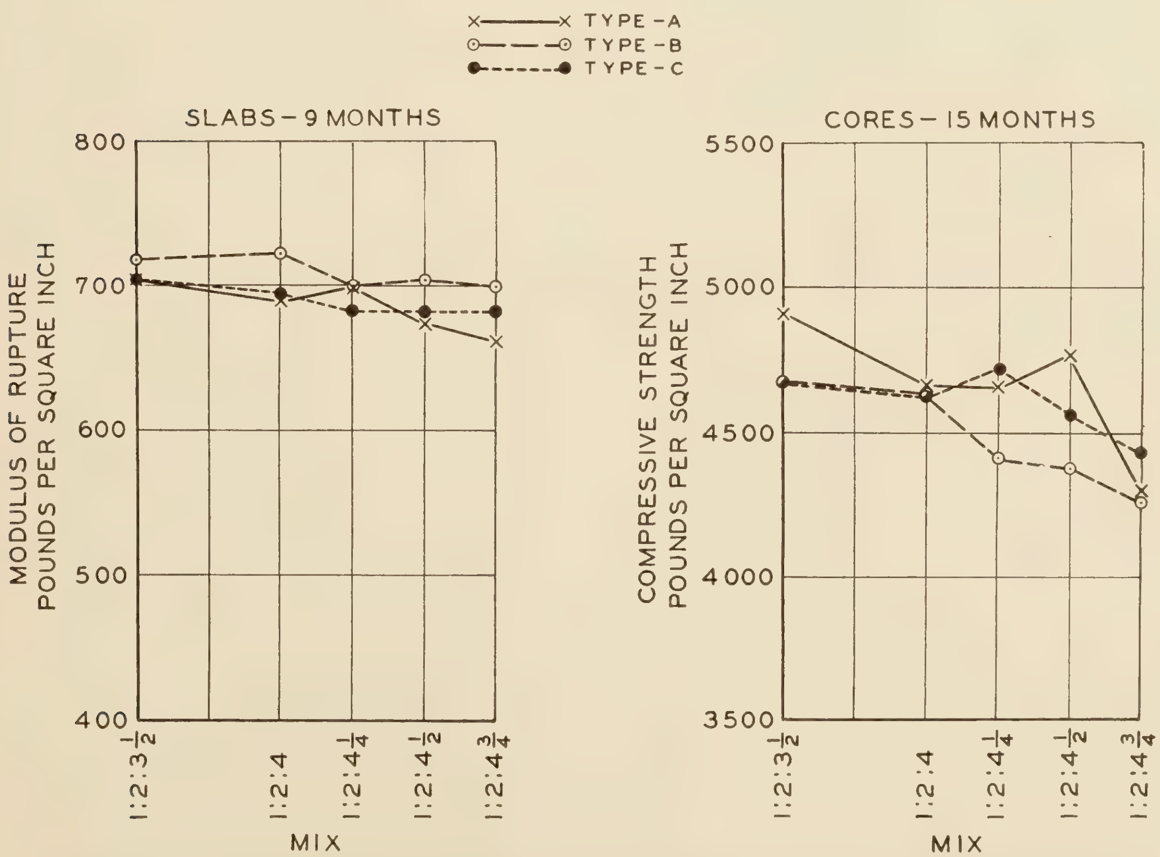


Figure 19.—Relation Between Strength of Stone Concrete and Type of Finishing Machine

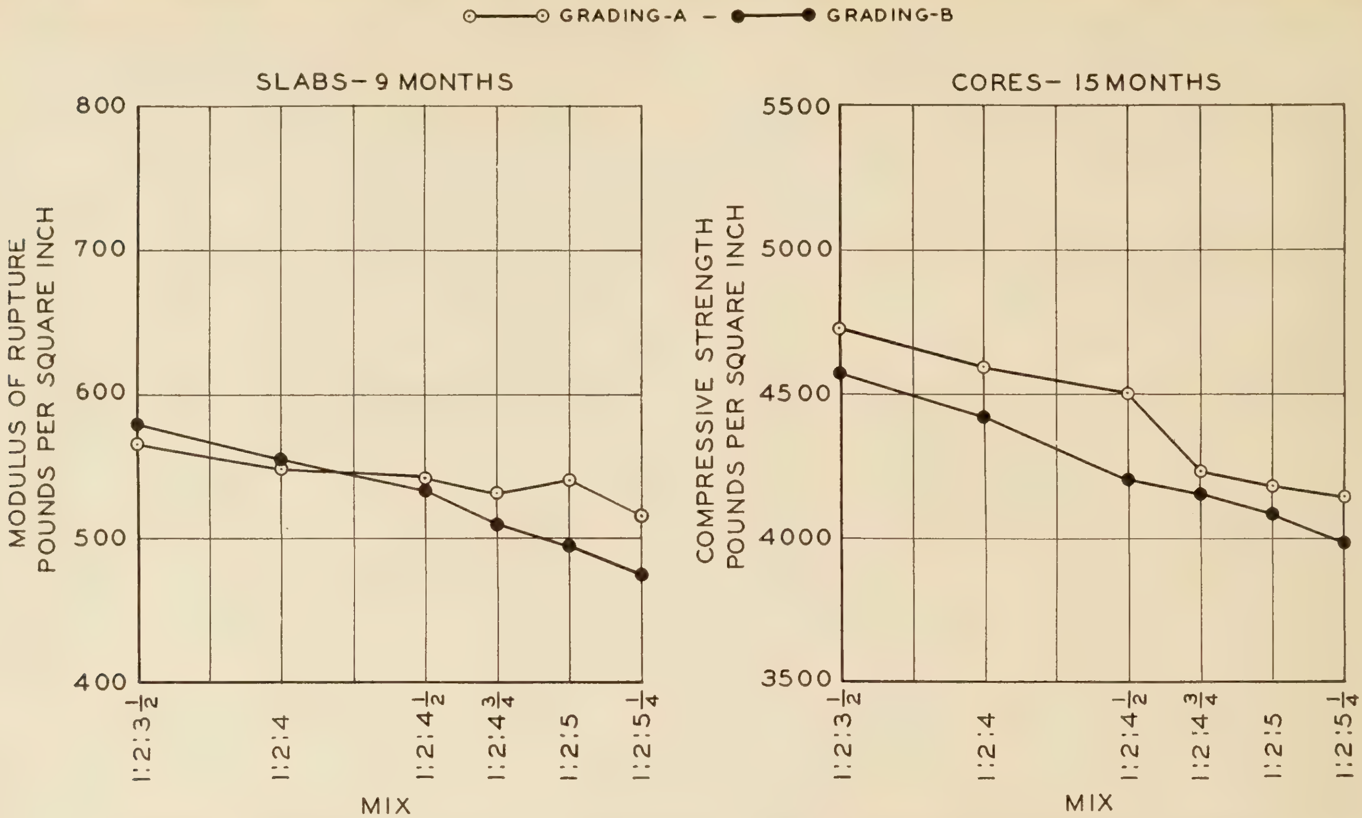


FIGURE 20.—INFLUENCE OF GRADING OF COARSE AGGREGATE AND MIX UPON STRENGTH OF GRAVEL CONCRETE

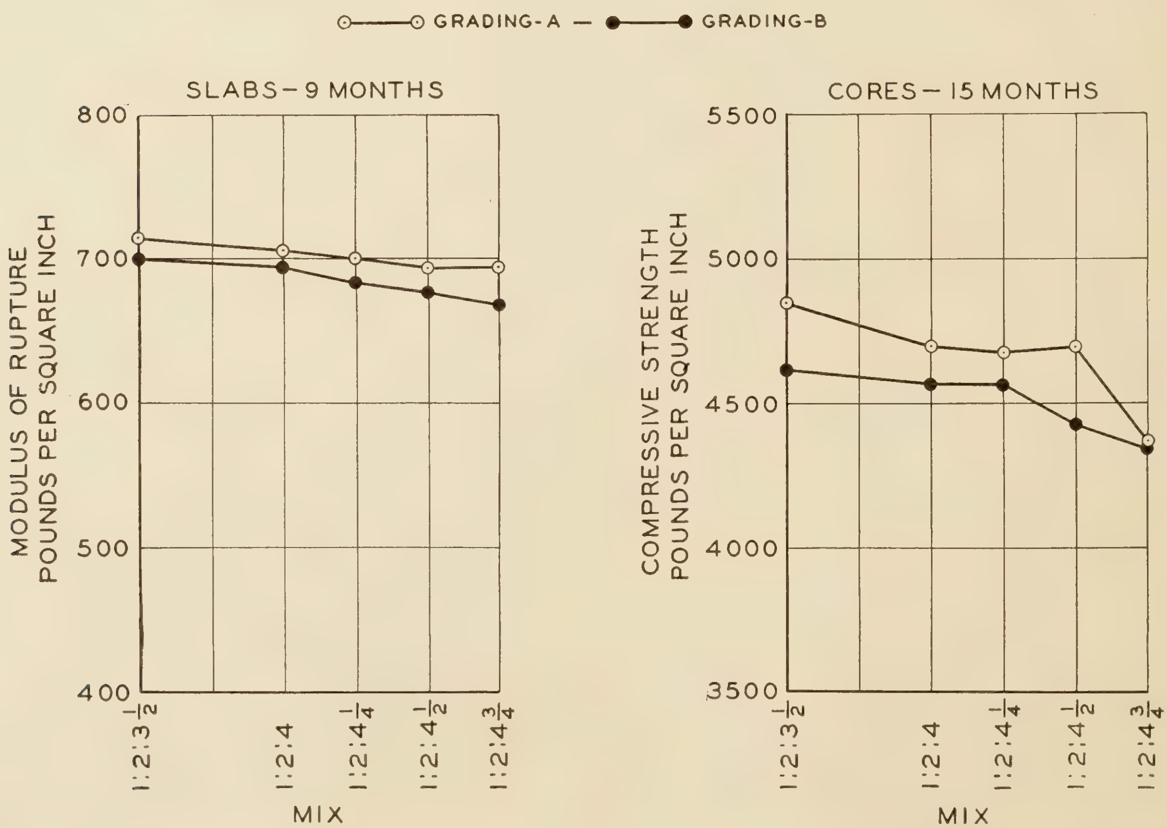


FIGURE 21.—INFLUENCE OF GRADING OF COARSE AGGREGATE AND MIX UPON STRENGTH OF STONE CONCRETE

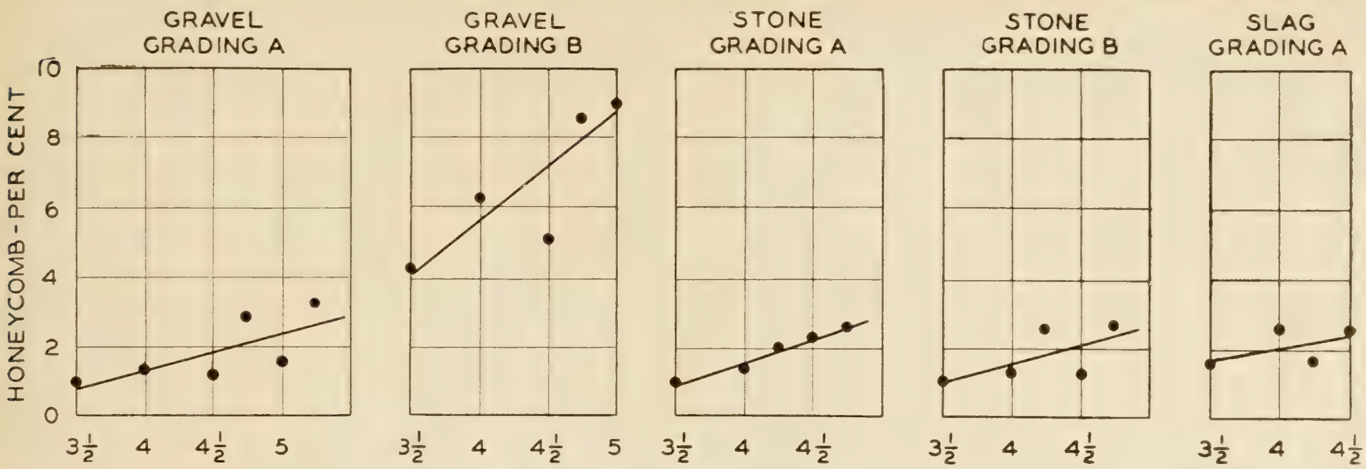


FIGURE 22.—RELATION BETWEEN HONEYCOMB AND MIX

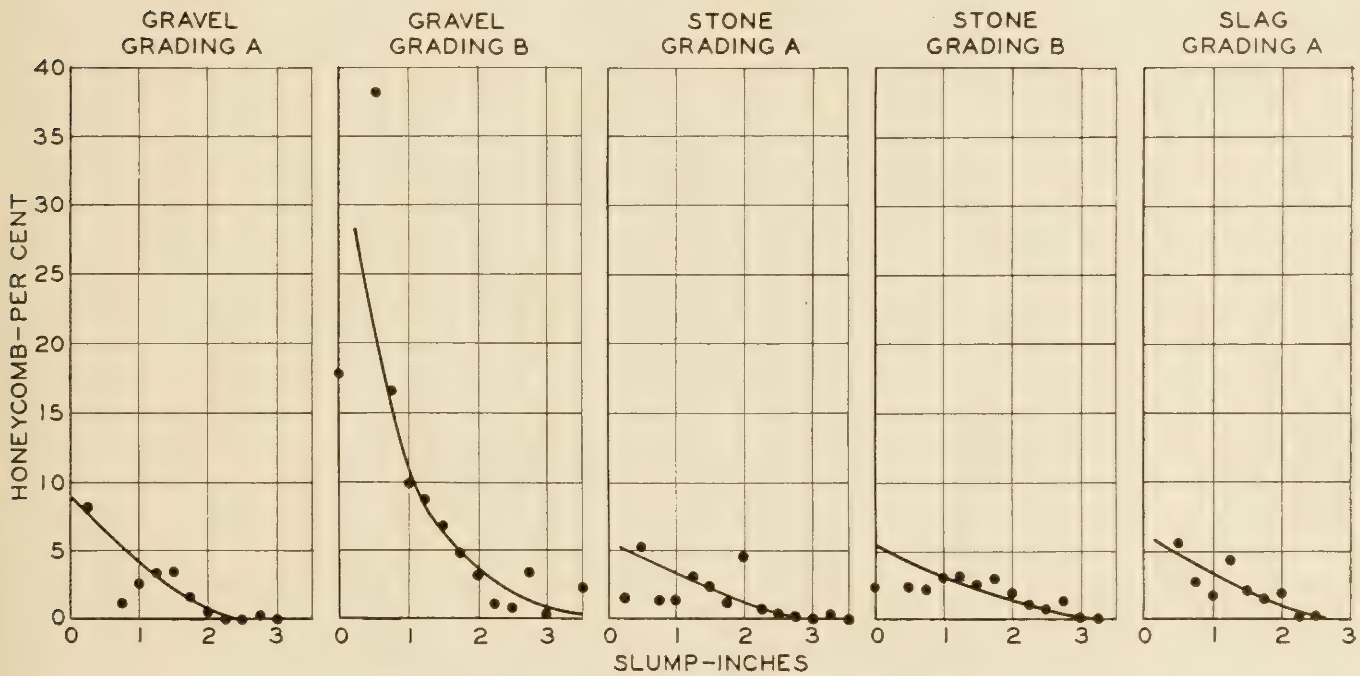


FIGURE 23.—RELATION BETWEEN HONEYCOMB AND SLUMP

gravel concrete, grading B. Even the 1:2:3½ concrete, gravel grading B, showed 4 per cent honeycomb in spite of the fact that this was a distinctly oversanded mix, when analyzed either by mortar voids or fineness modulus theories. In the latter connection it may be noted that, for a 1:2:3½ mix, the volume of fine aggregate is 36 per cent of the sum of the volumes of fine and coarse aggregates This is more sand than would be called for by the fineness modulus theory for these particular aggregates.

These tests also indicate that the slump test can not be used to compare workability of concretes in which different gradings of coarse aggregate are used. This is illustrated by reference to Figure 23. It will be seen that for a given slump, say one inch, the amount of honeycomb in the case of grading B gravel was much higher than for any other combination.

These data appear also to demonstrate that the use of any function depending directly upon the void content of the coarse aggregate, such as the ratio b/b_0 or the mortar-voids ratio, does not necessarily control the workability of the mix as determined by the uniformity and freedom from honeycomb of the concrete in the structure. They also indicate that, for a given coarse aggregate type and grading, there is a distinct relation between the consistency of the concrete as measured by the slump test and the percentage of honeycomb which is apt to develop under the methods of finishing now in common use.

EFFECT OF HONEYCOMB ON FLEXURAL STRENGTH OF SLABS

It will be of interest now to study the influence of honeycomb upon the strength of the concrete. In Figures 25, 26, and 27, there have been plotted the results of flexure tests on the individual sections arranged by types of finisher and type and gradation of coarse aggregate. Values for strength have been plotted as follows: Open circles designating all slabs having less than 1 per cent honeycomb; crosses, all slabs having 1 to 10 per cent honeycomb; and solid circles, all slabs having more than 10 per cent honeycomb. The three values in each vertical line denote

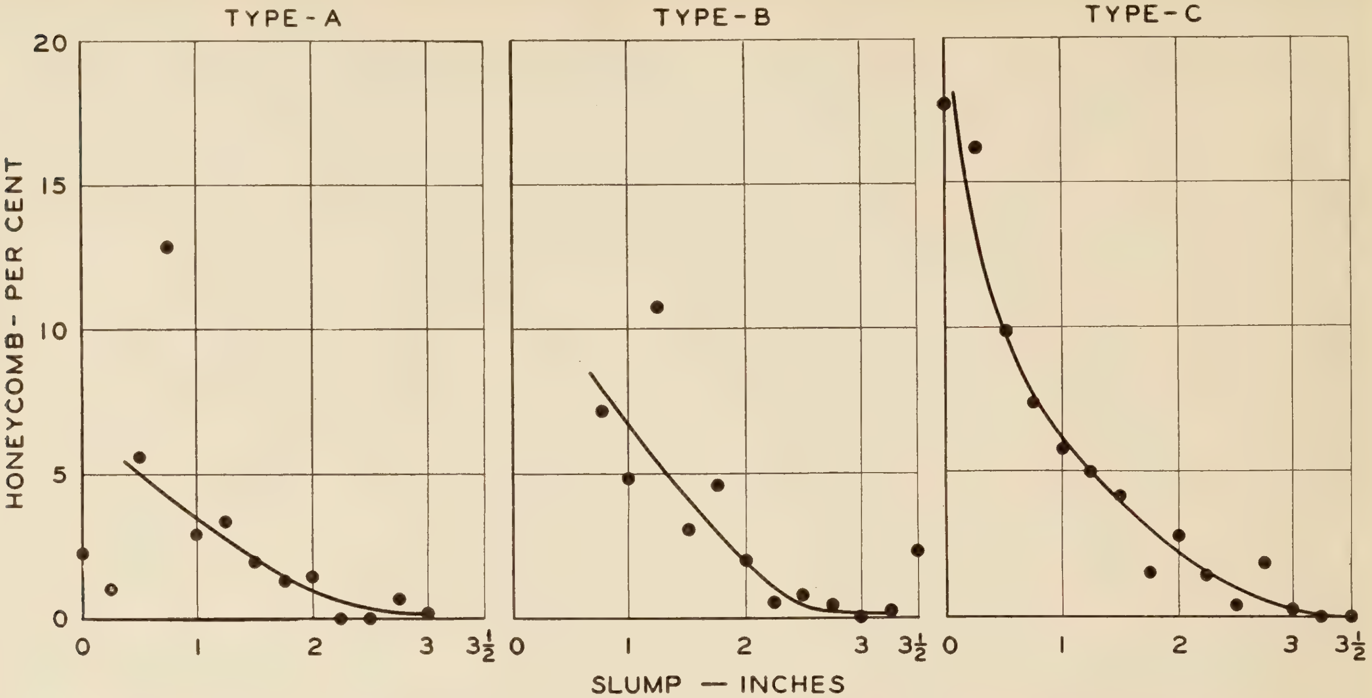


FIGURE 24.—RELATION BETWEEN HONEYCOMB AND SLUMP FOR DIFFERENT TYPES OF FINISHING MACHINE

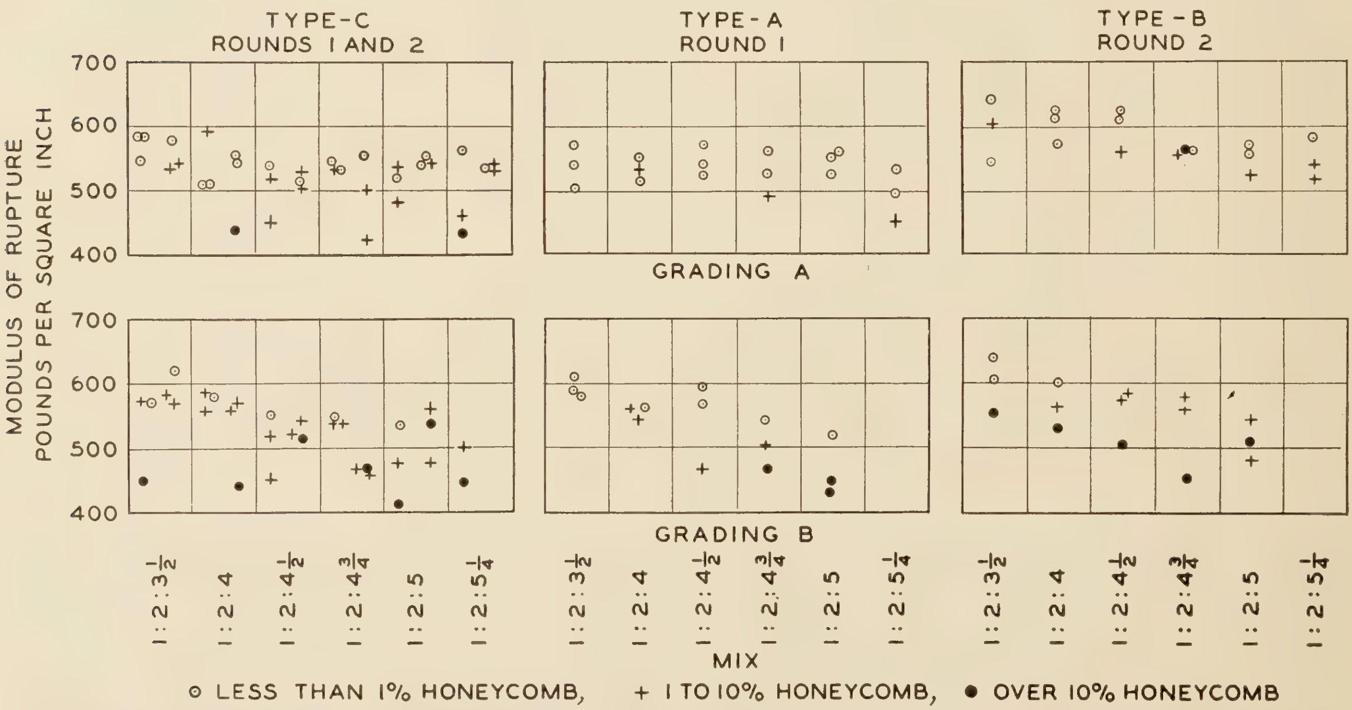


FIGURE 25.—COMPARISON OF VALUES OF MODULUS OF RUPTURE OBTAINED FOR GRAVEL CONCRETE SLABS PLACED WITH DIFFERENT TYPES OF FINISHING MACHINE. WHERE TWO GROUPS OF VALUES ARE PLOTTED FOR A GIVEN MIX THOSE ON THE LEFT REPRESENT ROUND 1 AND THOSE ON THE RIGHT REPRESENT ROUND 2

tests on the three sections in which the concrete varied only in consistency.

In order to bring out the interrelated effects of honeycomb, strength, and consistency, these figures should be considered in connection with the detailed results shown in tabulated form in Tables 5, 6, and 13 and in graphic form in Figures 33 to 37, inclusive. Reference to the detailed charts will show a very close relation between honeycomb and consistency in all cases. The concrete in each group of three having the lowest water-cement ratio is almost invariably the concrete having the lowest slump and the largest percentage of honeycomb, if any.

If we refer again to the charts showing relation between honeycomb and strength (figs. 25, 26, and 27), we find that the data indicate conclusively the danger of permitting any condition which will tend to the formation of honeycomb. In the whole group (265 sections) there are 19 sections having more than 10 per cent honeycomb, 15 of which were in the gravel, B grading, group. In all but four cases the badly honeycombed section was distinctly lower in strength than the other

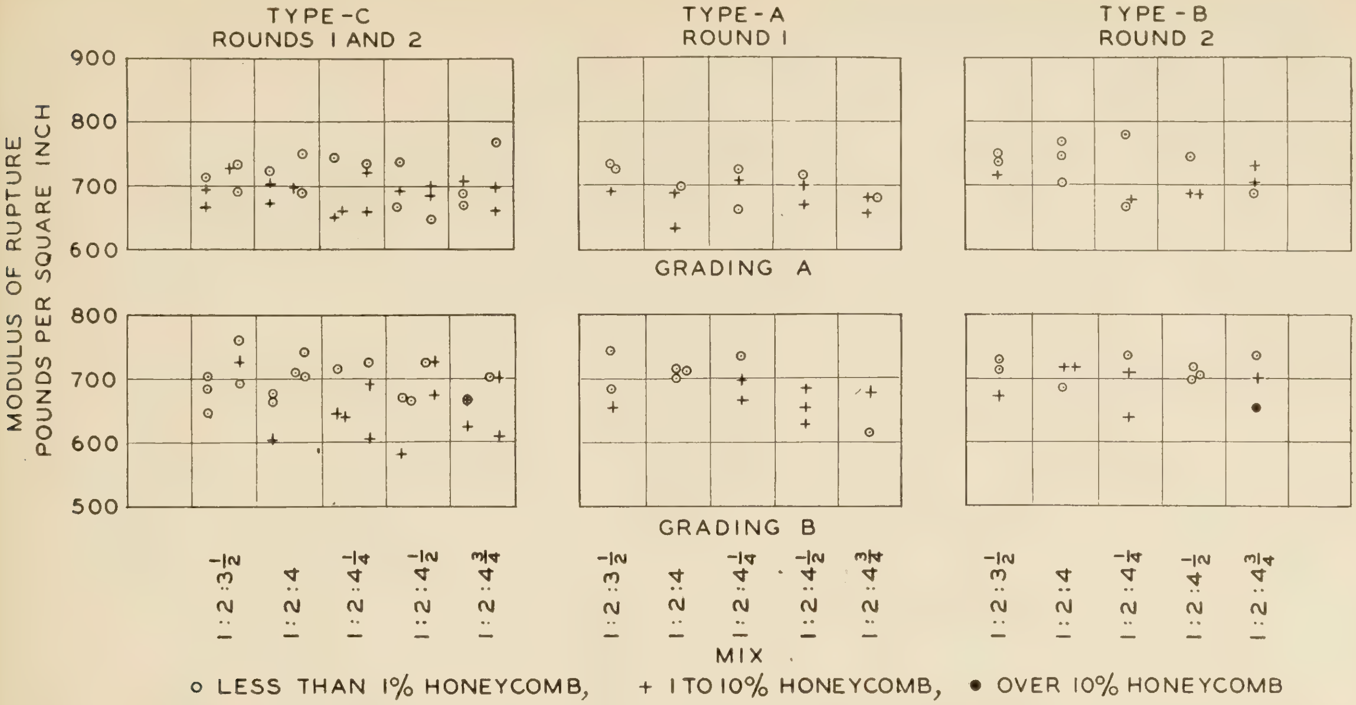


Figure 26.—Comparison of Values of Modulus of Rupture Obtained for Stone Concrete Slabs Placed with Different Types of Finishing Machine. Where Two Values are Plotted for a Given Mix Those on the Left Represent Round 1 and Those on the Right Represent Round 2

sections of the same group. The same relation exists for the slabs showing from 1 to 10 per cent honeycomb. There were 119 such sections. In only 26 of these was the strength of the honeycombed slab as high or higher than any section in the group showing less than 1 per cent honeycomb. These results emphasize again the danger of using very dry concrete with our present methods of finishing.

A number of interesting detail comparisons may be made by reference to Figures 25, 26, and 27. For instance, it will be noted that there was almost a complete absence of honeycomb in the sections containing gravel, grading A, and finished with type A machine. (Fig. 25.) The corresponding group using stone had a considerably larger number of slabs showing from 1 to 10 per cent honeycomb. Concrete, gravel, B grading, also showed somewhat less honeycombing when finished with type A machine than with either of the other types, although, as has previously been pointed out, the amount of honeycombing in general was much greater for grading B than for grading A. (Fig. 25.) The type of finisher appeared to make little difference in the case of the stone concrete, sections finished with each type showing about the same amount of honeycomb.

The average strength level on the other hand is somewhat higher for type B finisher than for the other types.

In order to form some idea as to the effect of honeycombing on the relation between the strengths of the slabs and the strength of control beams tested at the same age, Figures 28, 29, and 30 have been prepared. These figures indicate for each of the three degrees of honeycombing and for each type and grading of aggregate, the average modulus of rupture for the slabs and the average modulus of rupture for the corresponding beams. It will be understood that each point in this case represents the average strength of all slabs having the amount of honeycomb within the range indicated, with the corresponding values for the beams representing the average strength of the control beams corresponding to those slabs.

These data indicate, in general, the tendency of the slab strengths to decrease with respect to the strengths

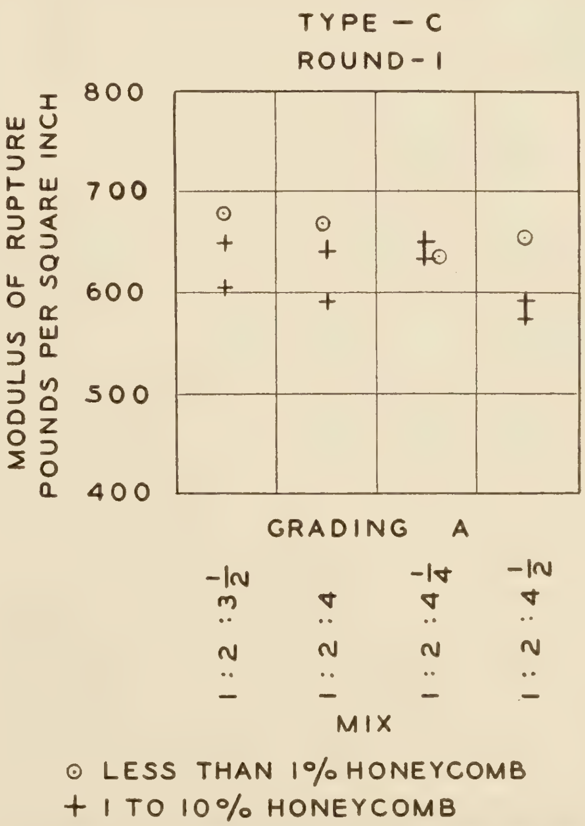


Figure 27.—Values of Modulus of Rupture Obtained for Slag Concrete Slabs Placed with Type C Finishing Machine

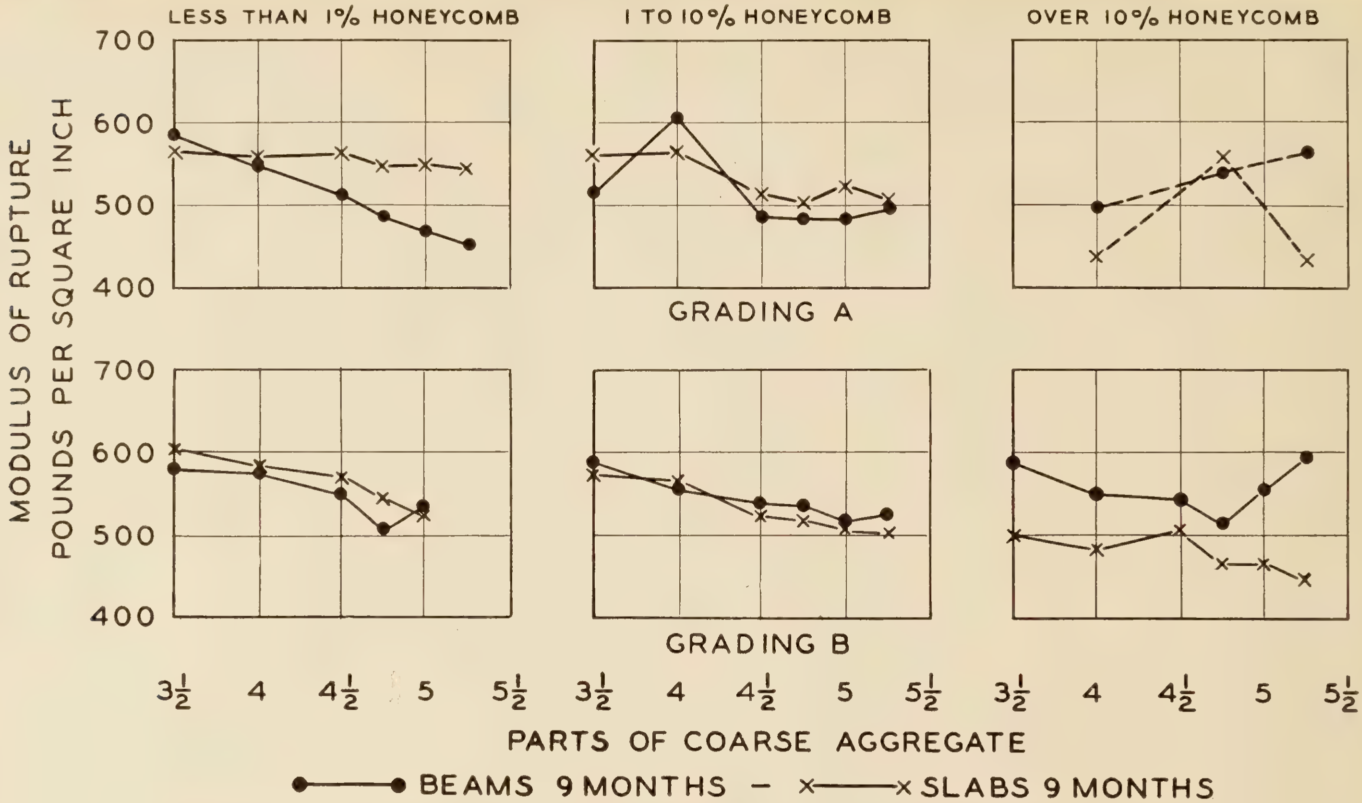


FIGURE 28.—EFFECT ON HONEYCOMB IN SLABS ON MODULUS OF RUPTURE OF GRAVEL CONCRETE

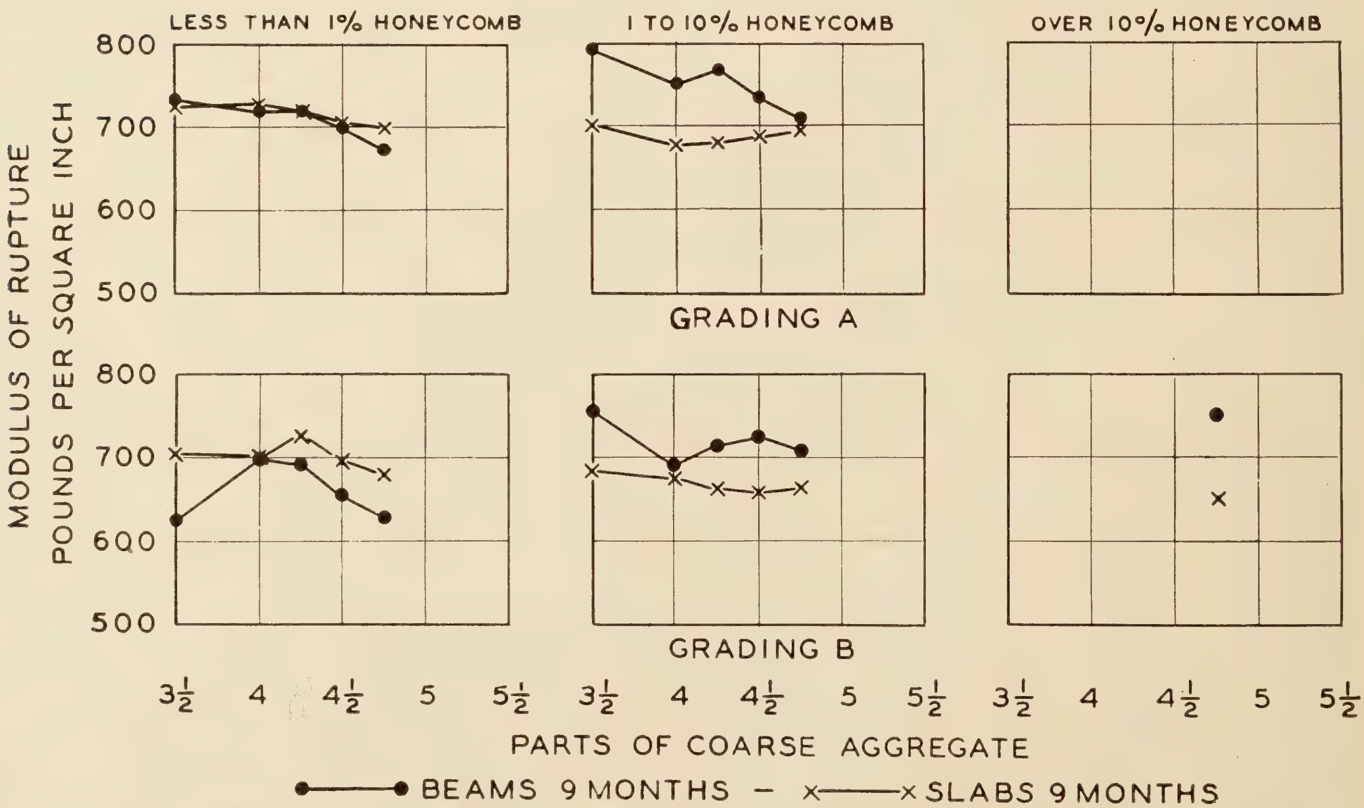


FIGURE 29.—EFFECT OF HONEYCOMB IN SLABS ON MODULUS OF RUPTURE OF STONE CONCRETE

of the control beams for increasing percentages of honeycomb. There are a number of individual values out of line, but the trend is easily followed. It is interesting to observe that in practically all cases where the slabs show less than 1 per cent honeycomb the average slab strengths are as high as or higher than the beam strengths, whereas the reverse is generally true for the slabs showing more than 1 per cent honeycomb.

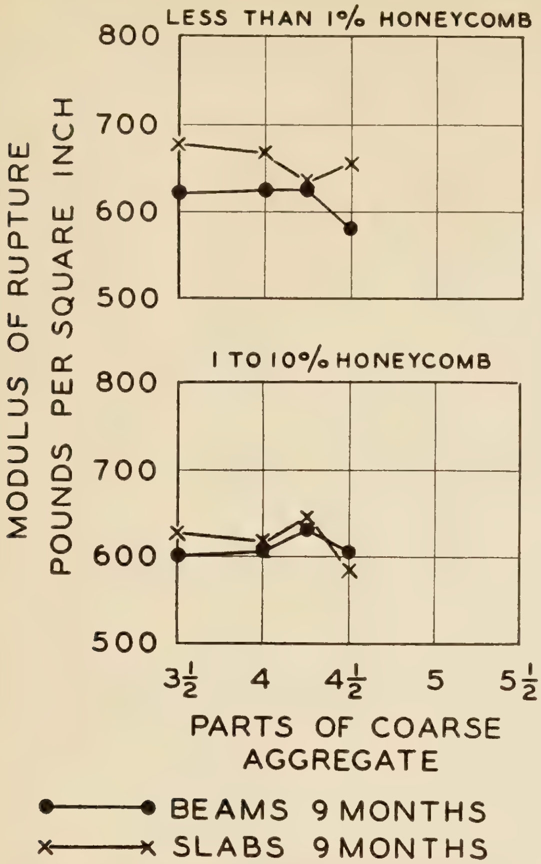


FIGURE 30.—EFFECT OF HONEYCOMB IN SLABS ON MODULUS OF RUPTURE OF SLAG CONCRETE

TABLE 12.—*Notes on finish and workability*

Section No.	Type of finisher	Number passes of screed: Front	Number passes of screed: Rear	Number of tamps	Finish	Workability	Remarks
1	A	3		1	Good	Good	
2	A	4		2	Good	Fair	
3	A	3		2	Good	do	Maximum workable stiffness.
4	A	3		2	Very good	Good	
5	A	4		3	Good	Fair	Some patching.
6	A				Very good	Good	
7	A	2		2	Good	do	
8	A	4		3	Fair	Fair	Maximum workable stiffness; some patching.
9	A	2		1	Good	Good	
10	A	3		2	do	do	
11	A	3		1	do	do	
12	A	4		1	do	do	
13	A	3		2	do	do	
14	A	3		0	do	do	
15	A	4		0	do	do	
16	A	3		0	do	do	
17	A	3		1	do	do	
18	A	4		0	do	do	
19	A	3		1	do	do	Stiff consistency.
20	A	3		1	do	do	
21	A	3		1	do	Very good	
22	A	3		2	do	Good	
23	A	3		2	do	Very good	
24	A	3		2	do	do	
25	A	3		2	do	Good	
26	A	3		2	do	do	
27	A	3		1	do	do	
28	A	2		1	do	do	
29	A	3		1	do	Fair	Somewhat harsh.
30	A	3		1	do	Good	
31	A	3		1	do	do	Do.
32	A	3		3	Fair	Fair	Difficult to handle.
33	A	3		2	Good	do	
34	C	3	3		Fair	Good	
35	C	2	4		Good	Very good	
36	C	2	3		do	do	

TABLE 12.—*Notes on finish and workability*—Continued

Section No.	Type of finisher	Number passes of screed: Front	Number passes of screed: Rear	Number of tamps	Finish	Workability	Remarks
37	C	2	3		Fair	Good	C. A. rolled under belt.
38	C	3	3		do	do	
39	C	2	3		do	do	
40	C	3	3		do	do	Do.
41	C	2	3		do	Fair	Do.
42	C	2	3		Good	Good	
43	C	2	5		Fair	Fair	Some patching.
44	C	2	2		Good	Very good	
45	C	2	2		do	do	
46	C	6	4		do	Fair	Slight segregation.
47	C	3	3		do	Good	
48	C	3	3		do	do	
49	C	3	4		do	Fair	Harsh, some segregation.
50	C	3	3		Fair	Poor	Dry, rather harsh.
51	C	2	2		Good	Good	
52	C	3	4		do	Fair	
53	C	2	2		do	Good	
54	C	2	3		do	do	
55	C	3	3		do	do	
56	C	3	3		do	Very good	
57	C	2	3		do	Good	
58	C	2	2		do	do	
59	C	3	4		do	do	
60	C	3	2		do	do	
61	C	4	3		do	Fair	Some patching.
62	C	2	3		do	Good	
63	C	3	3		do	do	Little mortar in front of screed.
64	C	2	4		Fair	do	C. A. rolled under belt.
65	C	3	3		do	Fair	Harsh.
66	C	2	3		do	Good	C. A. rolled under belt.
67	C	2	4		do	Fair	Harsh.
68	C	3	3		Very poor	Unworkable	Very harsh, segregated.
69	A	3		1	Good	Very good	
70	A	3		1	Fair	Good	C. A. rolled under belt.
71	A	5		4	Poor	Very poor	Part of surface rough.
72	A	3		1	Fair	Good	C. A. rolled under belt.
73	A	2		0	do	Very good	Do.
74	A	3		1	do	Good	Do.
75	A	3		2	do	do	C. A. rolled under screed and belt.
76	A	3		1	do	Very good	Too dry when belted.
77	A	3		2	Rough	Poor	Very dry.
78	A	3		3	do	Fair	Very dry, some patching.
79	A	3		1	Fair	Good	C. A. rolled under belt.
80	A	3		1	Good	do	
81	A	3		3	Poor	Unworkable	
82	A	3		2	Fair	Fair	Some patching.
83	A	3		1	Good	Good	
84	A	4		2	Fair	Very good	Belted too dry.
85	A	3		2	do	Fair	Some patching.
86	A	3		1	Good	Very good	
87	A	3		2	Rough	Fair	Do.
88	A	4		1	Fair	Good	
89	A	4		1	Good	do	
90	A	4		3	Fair	Fair	Somewhat harsh.
91	A	3		2	Good	Good	
92	A	3		1	do	do	
93	A	3		2	Fair	Fair	
94	A	3		1	Good	do	Do.
95	A	3		1	do	Good	
96	A	3		3	Rough	Poor	Rough patches.
97	A	3		0	Good	Good	Rather wet.
98	C	3	3		do	do	
99	C	3	2		do	do	
100	C	3	3		Fair	Fair	Some patching.
101	C	2	3		do	do	
102	C	2	2		Good	Very good	
103	C	2	3		do	do	
104	C	3	3		Fair	Fair	C. A. rolled under screed and belt.
105	C	2	3		Good	Good	
106	C	2	3		Fair	Fair	
107	C	2	3		do	do	
108	C	2	3		Good	Good	
109	C	2	3		do	do	
110	C	3	3		Fair	Fair	Somewhat harsh.
111	C	2	3		Good	Good	
112	C	2	3		do	do	
113	C	2	3		do	Fair	
114	C	3	3		do	Good	
115	C	2	3		do	do	
116	C	2	3		do	do	
117	C	2	3		do	Fair	
118	C	2	3		do	Good	
119	C	2	2		do	do	
120	C	2	2		do	do	
121	C	3	3		Fair	Poor	
122	C	2	3		do	Fair	Some patching.
123	C	2	3		Good	Good	
124	C	2	2		do	do	
125	C	3	3		do	do	Some segregation.
126	C	3	3		do	Fair	Do.
127	C	2	3		do	do	Do.

TABLE 12.—*Notes on finish and workability*—Continued

Section No.	Type of finisher	Number passes of screed: Front	Number passes of screed: Rear	Number of tamps	Finish	Workability	Remarks
128	C	2	2		Good	Good	
129	C	2	2		Fair	Fair	
130	C	2	2		Good	Good	
131	C	2	2		do	do	
132	C	2	2		do	do	
133	C	2	3		do	Fair	
134	C	2	3		Fair	do	
135	C	2	2		Good	Good	
136	C	2	2		do	do	
137	C	2	3		do	Fair	
138	C	2	2		do	Good	
139	C	2	2		do	do	
140	C	3	4		Rough	Fair	
141	C	2	2		Good	Good	
142	C	2	2		do	do	
143	C	2	2		do	Fair	
144	C	2	2		do	do	
145	C	2	2		do	Good	
146	C	2	3		Poor	Fair	Too dry.
147	C	2	2		Good	Good	
148	C	2	3		do	do	
149	C	2	3		Fair	Fair	
150	C	2	2		Good	do	
151	C	2	2		do	Good	
152	C	2	2		do	do	
153	C	2	2		do	do	
154	C	2	2		do	do	
155	C	3	3		Very poor	Poor	Unworkable in spots.
156	C	2	2		Good	Good	
157	C	2	2		do	do	
158	C	3	3		Poor	Poor	
159	C	2	3		Good	Fair	
160	C	2	2		do	Good	
161	B	4			Fair	Fair	C. A. rolled under belt.
162	B	4			do	Good	Do.
163	B	3			Good	do	
164	B	3			Fair	do	Do.
165	B	3			do	do	Do.
166	B	3			do	Fair	
167	B	5			do	do	Harsh.
168	B	3			do	do	
169	B	3			Good	Good	
170	B	3			Poor	Poor	Hand finishing necessary.
171	B	3			Good	Good	
172	B	3			do	do	
173	B	3			do	do	
174	B	3			Fair	do	Some segregation.
175	B	3			Poor	Poor	Hand finishing necessary.
176	B	3			Good	Good	Some segregation.
177	B	3			do	do	
178	B	4			Poor	Poor	Harsh.
179	B	3			Good	Good	
180	B	3			Fair	Fair	
181	B	3			Good	Good	
182	B	3			do	do	
183	B	3			do	do	
184	B	4			Rough	Poor	Hand finishing necessary.
185	B	3			Good	Good	
186	B	3			do	do	
187	B	3			do	Fair	
188	B	3			do	Very good	
189	B	3			do	Fair	
190	B	3			do	do	
191	B	3			do	Very good	
192	B	3			do	Good	
193	B	3			do	Fair	
194	B	4			Rough	Unworkable	
195	B	3			Good	Good	
196	B	3			do	do	
197	B	3			do	do	
198	B	2			Fair	Fair	Two extra screeds on half of section.
199	B	3			Good	Good	
200	B	3			do	do	
201	B	3			do	do	
202	B	3			do	do	
203	B	3			do	do	
204	B	3			do	Fair	
205	B	3			Rough	Unworkable	
206	B	3			Good	Good	
207	B	3			do	do	
208	B	4			Rough	Fair	Some patching.
209	B	3			Good	do	
210	B	3			Fair	Poor	
211	B	4			Poor	Unworkable	Patching necessary.
212	B	3			Good	Very good	
213	B	3			do	Good	
214	B	4			Fair	Fair	Do.
215	B	3			Good	Good	
216	B	3			do	do	
217	B	3			Poor	Unworkable	Third of surface hand finished.
218	B	3			Good	Good	Harsh, wet, some segregation.
219	B	3			do	do	Do.
220	B	3			Poor	Poor	Patching due to segregation.
221	B	3			Good	Good	Harsh, wet, some segregation.
222	B	3			do	Fair	Patching due to segregation.
223	B	4			Rough	Very poor	Do.
224	C	2	2		Good	Very good	
225	C	2	2		do	do	
226	C	2	2		do	Fair	
227	C	2	2		do	Good	
228	C	2	2		do	do	
229	C	2	2		Fair	Fair	
230	C	2	3		do	do	
231	C	2	2		Good	Good	
232	C	2	2		do	Very good	
233	C	2	2		do	Good	
234	C	2	2		do	do	
235	C	2	2		do	do	
236	C	2	2		do	Fair	Rather harsh.
237	C	2	2		do	Good	
238	C	2	2		do	Very good	
239	C	2	2		Fair	Fair	
240	C	2	2		Good	Good	
241	C	2	2		do	Very good	
242	C	2	2		do	Fair	
243	C	2	2		do	Good	
244	C	2	2		do	do	
245	C	2	2		do	Fair	
246	C	2	2		do	Good	
247	C	2	3		Rough	Poor	
248	C	2	2		Good	Good	
249	C	2	2		do	Fair	
250	C	2	2		do	Good	
251	C	2	2		do	Fair	
252	C	2	2		do	do	
253	C	2	2		do	do	
254	C	2	2		do	do	
255	C	2	2		do	Good	
256	C	2	2		Rough	Poor	Hand finishing necessary.
257	C	2	2		Poor	Very poor	Do.
258	C	2	2		Good	Fair	Some patching.
259	C	2	2		do	Good	
260	C	2	2		Fair	Fair	
261	C	2	2		Good	Good	
262	C	2	2		Fair	Poor	Patching necessary.
263	C	2	2		Good	Good	
264	C	2	2		do	do	
265	C	2	2		Fair	Poor	Do.

UNIFORMITY OF CONCRETE ANALYZED

It will be recalled that the value for the modulus of rupture of each test slab was obtained by averaging the results of tests on the four slabs which made up the section. A study of the variation in strength among the four slabs should give some idea, therefore, of the uniformity of the concrete within the section.

Table 13 gives for each test section the results of flexure tests on the individual slabs, together with the percentage variation of each slab from the average for the section and the average percentage variation for the section. This latter figure may be used as the index of uniformity for the section. In Figure 31 the average percentage variation in strength for all of the gravel concrete sections and all of the stone concrete sections for each proportion have been plotted. It will be seen that there is a reasonably consistent reduction in uniformity with increase in coarse aggregate content for both types of coarse aggregate. The average deviation varies from about 4 per cent to about 7 per cent for the entire range. By breaking these average values up into group averages corresponding to grading of aggregate, type of finisher, etc., similar results are obtained. The difference between the effects of A and B grading in

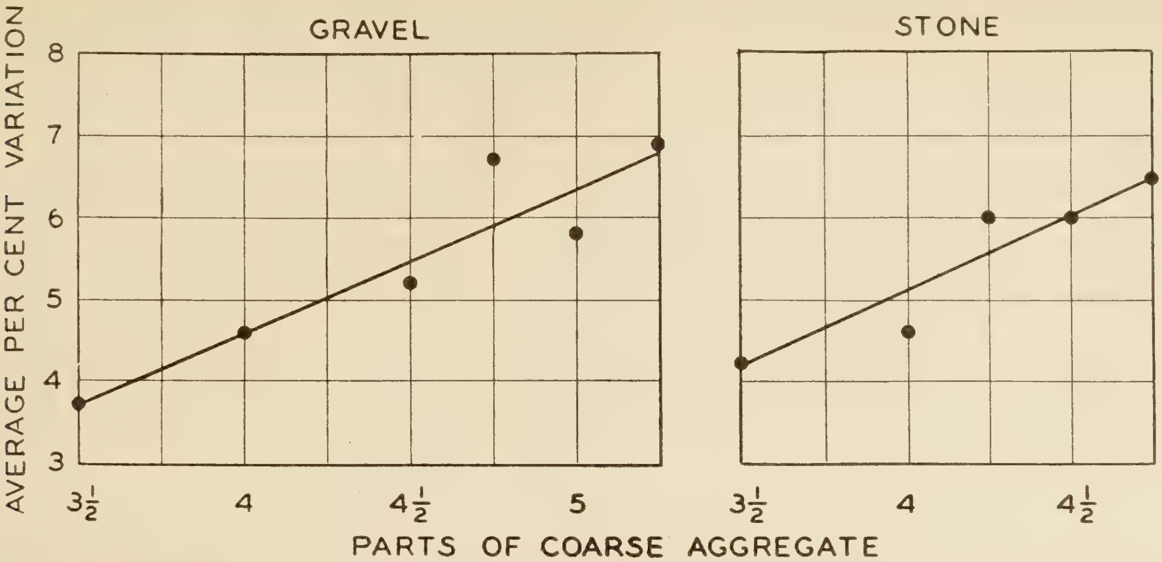


FIGURE 31.—UNIFORMITY OF CONCRETE: AVERAGE PERCENTAGE VARIATION OF MODULUS OF RUPTURE OF INDIVIDUAL SLABS FROM AVERAGE MODULUS OF RUPTURE FOR THE SECTION OF 4 SLABS

the gravel which is so marked as regards honeycombing does not appear from the standpoint of uniformity. Neither can any consistent difference in uniformity be observed as the result of using the different methods of finishing. Each method gives about the same average degree of uniformity.

However, study of Table 13 indicates some relation between honeycombing and uniformity. For instance, the average deviation for the 19 sections showing more than 10 per cent honeycomb is 9.2 per cent against a grand average of 5.4 for the entire series. Conversely, the 127 sections having less than 1 per cent honeycomb showed an average deviation of only 3.8 per cent. These values are given to illustrate trends only as there are several cases where honeycombed slabs show good uniformity and vice versa. The trend, however, is in the direction which would naturally be expected and further illustrates the importance of guarding against danger of honeycombing in the construction of concrete pavements.

TABLE 13.—*Variation in modulus of rupture, of individual slabs from average for the section of 4 slabs, and percentage of honeycomb*

Section No.	Modulus of rupture in pounds per square inch					Percentage variation from average					Honeycomb
	1	2	3	4	Average	1	2	3	4	Average	
											Per cent
1	539	545	552	531	542	0.6	0.6	1.8	2.0	1.2	0.1
2	586	562	535	608	573	2.3	1.9	6.6	6.1	4.2	0
3	508	498	514	497	504	.8	1.2	2.0	1.4	1.4	.2
4	532	582	523	577	554	4.0	5.1	5.6	4.2	4.7	0
5	429	457	538	702	532	19.4	14.1	1.1	32.0	16.6	1.3
6	481	547	511	540	520	7.5	5.2	1.7	3.8	4.6	.6
7	531	493	558	535	529	.4	6.8	5.5	1.1	3.4	0
8	587	574	552	585	575	2.1	.2	4.0	1.7	2.0	.6
9	556	534	509	576	544	2.2	1.8	6.4	5.9	4.1	.2
10	542	500	542	537	530	2.3	5.7	2.3	1.3	2.9	0
11	561	512	586	597	564	.5	9.2	3.9	5.9	4.9	0
12	580	398	487	523	497	16.7	19.9	2.0	5.2	11.0	3.8
13	515	501	589	624	557	7.5	10.1	5.7	12.0	8.8	.1
14	500	562	525	530	529	5.5	6.2	.8	.2	3.2	0
15	556	539	565	587	562	1.1	4.1	.5	4.4	2.5	0
16	483	505	500	511	500	3.4	1.0	0	2.2	1.6	0
17	447	421	488	457	453	1.3	7.1	7.7	.9	4.2	5.2
18	506	539	542	553	535	5.4	.7	1.3	3.4	2.7	0
19	611	565	613	647	609	.3	7.2	.7	6.2	3.6	.9
20	627	570	586	578	590	6.3	3.4	.7	2.0	3.1	0
21	599	548	572	602	580	3.3	5.5	1.4	3.8	3.5	0
22	557	529	582	499	542	2.8	2.4	7.4	7.9	5.1	2.9
23	558	569	560	547	559	.2	1.8	.2	2.1	1.1	3.2

TABLE 13.—*Variation in modulus of rupture, of individual slabs from average for the section of 4 slabs, and percentage of honeycomb*—Continued

Section No.	Modulus of rupture in pounds per square inch					Percentage variation from average					Honeycomb
	1	2	3	4	Average	1	2	3	4	Average	
											Pe icen
24	547	546	577	575	561	2.5	2.7	2.9	2.5	2.6	0
25	471	488	459	448	466	1.1	4.7	1.5	3.9	2.8	6.3
26	549	580	651	591	593	7.4	2.2	9.8	.3	4.9	.6
27	588	572	547	557	566	3.9	1.1	3.4	1.6	2.5	.6
28	483	571	563	547	541	10.7	5.5	4.1	1.1	5.4	.2
29	443	532	511	525	503	11.9	5.8	1.6	4.4	5.9	5.8
30	509	491	415	455	468	8.8	4.9	11.3	2.8	7.0	19.2
31	498	586	499	494	519	4.0	12.9	3.9	4.8	6.4	.6
32	442	409	431	439	430	2.8	4.9	.2	2.1	2.5	25.4
33	476	481	470	362	447	6.5	7.6	5.1	19.0	9.6	12.9
34	569	591	600	573	583	2.4	1.4	2.9	1.7	2.1	0
35	502	517	554	613	547	8.2	5.5	1.3	12.1	6.8	0
36	567	569	600	596	583	2.7	2.4	2.9	2.2	2.6	0
37	626	552	592	607	594	5.4	7.1	.3	2.2	3.8	1.2
38	484	567	494	500	511	5.3	11.0	3.3	2.2	5.4	.5
39	527	500	483	520	508	3.7	1.6	4.9	2.4	3.2	.1
40	510	387	393	516	452	12.8	14.4	13.1	14.2	13.6	2.1
41	535	517	451	570	518	3.3	.2	12.9	10.0	6.6	1.0
42	512	545	547	557	540	5.2	.9	1.3	3.1	2.6	0
43	521	603	583	441	537	3.0	12.3	8.6	17.9	10.4	4.3
44	541	552	510	536	535	1.1	3.2	4.7	.2	2.3	0
45	570	554	458	588	543	5.0	2.0	15.7	8.3	7.8	0
46	548	540	536	525	537	2.0	.6	.2	2.2	1.2	3.9
47	504	501	485	441	483	4.3	3.7	.4	8.7	4.3	2.8
48	547	492	502	540	520	5.2	5.4	3.5	3.8	4.5	0
49	535	539	361	419	464	15.3	16.2	22.2	9.7	15.8	6.6
50	504	532	281	411	432	16.7	23.1	35.0	4.9	19.9	16.2
51	574	546	544	595	565	1.6	3.4	3.7	5.3	3.5	0
52	531	470	447	339	447	18.8	5.1	0	24.2	12.0	20.5
53	613	565	596	510	571	7.4	1.1	4.4	10.7	5.9	8.2
54	613	558	565	552	572	7.2	2.4	1.2	3.5	3.6	0
55	600	593	605	542	585	2.6	1.4	3.4	7.4	3.7	7.5
56	561	480	576	601	555	1.1	13.5	3.8	8.3	6.7	1.2
57	597	577	585	556	579	3.1	.3	1.0	4.0	2.1	.4
58	500	366	480	459	451	10.9	18.8	6.4	1.8	9.5	9.8
59	579	539	513	435	516	12.2	4.5	.6	15.7	8.2	4.8
60	577	544	516	566	551	4.7	1.3	6.4	2.7	3.8	0
61	565	509	545	528	537	5.2	5.2	1.5	1.7	3.4	6.2
62	539	462	556	587	536	.6	13.8	3.7	9.5	6.9	3.2
63	538	538	564	546	547	1.6	1.6	3.1	.2	1.6	0
64	498	422	268	463	413	20.6	2.2	35.1	12.1	17.5	24.5
65	558	417	438	493	477	17.0	12.6	8.2	3.4	10.3	7.0
66	504	511	539	586	535	5.8	4.5	.7	9.5	5.1	.5
67	512	495	542	454	501	2.2	1.2	8.2	9.4	5.2	4.8
68	410	471	479	432	448	8.5	5.1	6.9	3.6	6.0	17.8
69	762	736	755	677	732	4.1	.5	3.1	7.5	3.8	0
70	715	723	732	730	725	1.4	.3	1.0	.7	.8	0
71	590	729	735	705	690	14.5	5.7	6.5	2.2	7.2	2.2
72	755	648	669	675	687	9.9	5.7	2.6	1.7	5.0	1.2
73	705	705	700	677	697	1.1	1.1	.4	2.9	1.4	0
74	516	664	714	636	632	18.4	5.1	13.0	.6	9.3	8.4
75	790	715	659	736	725	9.0	1.4	9.1	1.5	5.2	.5
76	567	685	746	643	660	14.1	3.8	13.0	2.6	8.4	0
77	683	687	724	739	708	3.5	3.0	2.3	4.4	3.3	2.1
78	721	559	780	621	670	7.6	16.6	16.4	7.3	12.0	6.5
79	739	730	655	675	700	5.6	4.3	6.4	3.6	5.0	2

TABLE 13.—*Variation in modulus of rupture, of individual slabs from average for the section of 4 slabs, and percentage of honeycomb*—Continued

Section No.	Modulus of rupture in pounds per square inch					Percentage variation from average					Honeycomb
	1	2	3	4	Average	1	2	3	4	Average	Per cent
80	723	705	713	704	711	1.7	.8	.3	1.0	1.0	.3
81	628	712	555	732	657	4.4	8.4	15.5	11.4	9.9	4.5
82	704	577	738	705	681	3.4	15.3	8.4	3.5	7.6	6.2
83	696	661	639	714	678	2.7	2.5	5.8	5.3	4.1	.6
84	817	695	745	709	742	10.1	6.3	.4	4.4	5.3	.5
85	675	634	656	648	653	3.4	2.9	.5	.8	1.9	2.8
86	724	632	700	677	683	6.0	7.5	2.5	.9	4.2	0
87	745	735	653	722	714	4.3	2.9	8.5	1.1	4.2	0
88	643	693	753	719	702	8.4	1.3	7.3	2.4	4.8	0
89	769	657	704	715	711	8.2	7.6	1.0	.5	4.3	0
90	749	596	749	687	695	7.8	14.2	7.8	1.2	7.8	1.6
91	696	616	798	817	732	4.9	15.8	9.0	11.6	10.3	.8
92	709	632	638	685	666	6.5	5.1	4.2	2.9	4.7	1.4
93	757	695	588	697	684	10.7	1.6	14.0	1.9	7.0	2.3
94	693	673	504	642	628	10.4	7.2	19.7	2.2	9.9	1.9
95	671	636	699	611	654	2.6	2.8	6.9	6.6	4.7	1.0
96	562	645	783	722	678	17.1	4.9	15.5	6.5	11.0	4.2
97	623	647	627	556	613	1.6	5.5	2.3	9.3	4.7	.4
98	620	670	631	761	670	7.5	0	5.8	13.6	6.7	1.4
99	673	705	759	721	714	5.7	1.3	6.3	1.0	3.6	0
100	723	696	660	697	694	4.2	.3	.4	4.9	2.4	3.7
101	726	712	629	743	702	3.4	1.4	10.4	5.8	5.2	2.3
102	709	735	714	743	725	2.2	1.4	1.5	2.5	1.9	0
103	721	707	566	711	676	6.7	4.6	16.3	5.2	8.2	1.3
104	664	637	618	690	652	1.8	2.3	5.2	5.8	3.8	1.5
105	792	701	772	722	747	6.0	6.2	3.3	3.3	4.7	.2
106	672	563	703	710	662	1.5	15.0	6.2	7.3	7.5	3.6
107	733	726	622	696	694	5.6	4.6	10.4	.3	5.2	2.0
108	768	694	766	727	739	3.9	6.1	3.7	1.6	3.8	0
109	750	623	657	648	670	11.9	7.0	1.9	3.3	6.0	0
110	722	726	693	705	712	1.4	2.0	2.7	1.0	1.8	3.4
111	735	644	721	659	690	6.5	6.7	4.5	4.5	5.6	.9
112	677	681	655	675	672	.7	1.3	2.5	.4	1.2	0
113	------	637	697	721	685	------	7.0	1.8	5.3	4.7	.6
114	721	691	718	683	703	2.6	1.7	2.1	2.8	2.3	0
115	653	647	631	646	644	1.4	.5	2.0	.3	1.0	0
116	679	688	609	682	664	2.3	3.6	8.3	2.7	4.2	0
117	689	597	573	551	602	14.5	.8	4.8	8.5	7.2	9.5
118	691	659	670	685	676	2.2	2.5	.9	1.3	1.7	0
119	747	711	668	725	713	4.8	.3	6.3	1.7	3.3	0
120	751	498	672	658	645	16.4	22.8	4.2	2.0	11.4	2.6
121	549	691	692	626	640	14.2	8.0	8.1	2.2	8.1	3.8
122	458	657	588	630	583	21.4	12.7	.9	8.1	10.8	3.8
123	639	693	675	673	670	4.6	3.4	.7	.4	2.3	.6
124	711	619	674	659	666	6.8	7.0	1.2	1.0	4.0	0
125	632	617	616	634	625	1.1	1.3	1.4	1.4	1.3	1.7
126	730	532	705	699	666	9.6	20.1	5.9	5.0	10.2	2.2
127	678	672	679	633	666	1.8	.9	2.0	5.0	2.4	0
128	560	555	501	542	540	3.7	2.8	7.2	.4	3.5	1.8
129	488	582	555	519	536	9.0	8.6	3.5	3.2	6.1	8.1
130	578	575	572	577	576	.3	.2	.7	.2	.4	0
131	561	527	524	561	543	3.3	2.9	3.5	3.3	3.2	0
132	583	564	518	560	556	4.9	1.4	6.8	.7	3.4	0
133	484	370	445	463	440	10.0	15.9	1.1	5.2	8.0	12.0
134	501	420	533	565	505	.8	16.8	5.5	11.9	8.8	6.4
135	551	516	498	484	512	7.6	.8	2.7	5.5	4.2	0
136	521	507	536	546	528	1.3	4.0	1.5	3.4	2.6	1.0
137	314	419	483	489	426	26.3	1.6	13.4	14.8	14.0	8.0
138	549	484	445	526	501	9.6	3.4	11.2	5.0	7.3	1.6
139	537	633	536	521	557	3.6	13.6	3.8	6.5	6.9	0
140	523	534	557	562	544	3.8	1.8	2.4	3.3	2.8	2.9
141	554	564	544	525	547	1.3	3.1	.5	4.0	2.2	0
142	560	518	561	573	553	1.3	6.3	1.4	3.6	3.2	.2
143	563	527	550	488	532	5.8	.9	3.4	8.3	4.6	2.0
144	521	555	577	520	543	4.1	2.2	6.3	4.2	4.2	2.6
145	581	510	523	525	535	8.6	4.7	2.2	1.9	4.4	.3
146	519	587	599	568	568	8.6	3.3	5.5	0	4.4	5.0
147	587	570	549	609	579	1.4	1.6	5.2	5.2	3.4	2.9
148	632	616	626	611	621	1.8	.8	.8	1.7	1.3	.4
149	356	458	498	445	439	18.9	4.3	13.4	1.4	9.5	38.2
150	568	560	552	593	568	0	1.4	2.8	4.4	2.2	1.4
151	544	567	546	566	556	2.2	2.0	1.8	1.8	2.0	1.6
152	538	550	538	539	541	.6	1.6	.6	.4	.8	2.4
153	578	520	511	440	512	12.9	1.6	.2	14.1	7.2	13.0
154	505	569	529	473	519	2.7	9.6	1.9	8.9	5.8	4.2
155	485	528	425	438	469	3.4	12.6	9.4	6.6	8.0	24.2
156	444	482	456	476	464	4.3	3.9	1.7	2.6	3.1	9.6
157	453	488	421	------	454	.2	7.5	7.3	------	5.0	9.9
158	538	552	501	569	540	.4	2.2	7.2	5.4	3.8	11.3
159	519	457	448	482	476	9.0	4.0	5.9	1.3	5.0	4.4
160	559	550	547	589	561	.4	2.0	2.5	5.0	2.5	2.5
161	612	601	630	577	605	1.2	.7	4.1	4.6	2.6	1.3
162	620	644	619	681	641	3.3	.5	3.4	6.2	3.4	0
163	564	524	502	591	545	3.5	3.9	7.9	8.4	5.9	0
164	664	589	580	623	614	8.1	4.1	5.5	1.5	4.8	.3
165	613	586	527	569	574	6.8	2.1	8.2	.9	4.5	0
166	647	621	599	626	623	3.9	.3	3.9	.5	2.2	.4
167	635	620	569	612	609	4.2	1.8	6.6	.5	3.3	.5
168	577	571	492	592	558	3.4	2.3	11.8	6.1	5.9	2.8
169	618	649	612	612	623	.8	4.2	1.8	1.8	2.2	0
170	624	585	408	617	558	11.8	4.8	26.9	10.6	13.5	13.7
171	556	609	503	551	555	.2	9.7	9.4	.7	5.0	3.4
172	589	563	533	551	559	5.4	.7	4.7	1.4	3.0	0

Section No.	Modulus of rupture in pounds per square inch					Percentage variation from average					Honeycomb
	1	2	3	4	Average	1	2	3	4	Average	Per cent
173	602	526	566	573	567	6.2	7.2	.2	1.1	3.7	0
174	566	503	562	582	553	2.4	9.0	1.6	5.2	4.6	0
175	611	520	396	568	524	16.6	.8	24.4	8.4	12.6	9.0
176	641	534	532	607	578	10.9	7.6	8.0	5.0	7.9	0
177	588	553	451	466	514	14.4	7.6	12.3	9.3	10.9	2.8
178	549	586	519	505	540	1.7	8.5	3.9	6.5	5.2	4.0
179	626	613	666	657	640	2.2	4.3	4.1	2.7	3.3	.3
180	571	563	518	556	552	3.4	2.0	6.2	.7	3.1	13.5
181	601	600	619	612	608	1.2	1.3	1.8	.7	1.2	0
182	630	585	591	592	600	5.0	2.5	1.5	1.3	2.6	0
183	594	505	574	584	564	5.3	10.5	1.8	3.5	5.3	1.8
184	546	------	513	535	531	2.8	------	3.4	.8	2.3	17.8
185	539	588	598	571	574	6.1	2.4	4.2	.5	3.3	2.3
186	627	525	597	586	584	7.4	10.1	2.2	.3	5.0	2.9
187	543	457	581	436	504	7.7	9.3	15.3	13.5	11.4	14.2
188	650	561	550	561	580	12.0	3.3	5.2	3.3	6.0	2.0
189	607	507	547	578	560	8.4	9.5	2.3	3.2	5.8	5.2
190	502	388	518	397	451	11.3	14.0	14.9	12.0	13.0	18.2
191	531	520	573	556	545	2.6	4.6	5.1	2.0	3.6	1.6
192	503	393	501	529	482	4.4	18.5	3.9	9.8	9.2	7.4
193	530	465	572	475	510	3.9	8.8	12.2	6.9	8.0	10.2
194	767	674	761	661	716	7.1	5.9	6.3	7.7	6.8	2.1
195	799	696	749	699	736	8.6	5.4	1.8	5.0	5.2	.2
196	793	728	716	753	748	6.0	2.7	4.3	.7	3.4	0
197	816	729	779	741	766	6.5	4.8	1.7	3.3	4.1	0
198	720	680	705	704	702	2.6	3.1	.4	.3	1.6	.6
199	745	727	737	763	743	.3	2.2	.8	2.7	1.5	0
200	735	606	717	603	665	10.5	8.9	7.8	9.3	9.1	.8
201	781	772	753	806	778	.4	.8	3.2	3.6	2.0	0
202	715	581	708	702	676	5.8	14.1	4.7	3.8	7.1	3.9
203	686	741	739	799	741	7.4	0	.3	7.8	3.9	.4
204	691	593	727	728	685	.9	13.4	6.1	6.3	6.7	1.5
205	614	630	740	750	684	10.2	7.9	8.2	9.6	9.0	3.3
206	697	689	655	691	683	2.0	.9	4.1	1.2	2.0	.4
207	682	674	788	779	731	6.7	7.8	7.8	6.6	7.2	2.8
208	700	629	708	772	702	.3	10.4	.9	10.0	5.4	3.0
209	729	671	692	816	727	.3	7.7	4.8	12.2	6.2	0
210	728	691	658	777	714	2.0	3.2	7.8	8.8	5.4	0
211	613	638	759	670	670	8.5	4.8	13.3	0	6.6	7.8
212	662	671	674	735	686	3.5	2.2	1.7	7.1	3.6	0
213	723	575	777	791	716	1.0	19.7	8.5	10.5	9.9	1.8
214	690	633	780	759	716	3.6	11.6	8.9	6.0	7.5	2.6
215	766	722	688	766	736	4.1	1.9	6.5	4.1	4.2	0
216	742	629	717	745	708	4.8	11.2	1.3	5.2	5.6	2.2
217	662	493	759	636	638	3.8	22.7	19.0	.3	11.4	9.6
218	738	686	665	693	696	6.0	1.4	4.5	.4	3.1	0
219	702	687	730	745	716	2.0	4.0	2.0	4.1	3.0	0
220	710	655	690	757	703	1.0	6.8	1.8	7.7	4.3	.5
221	740	721	742	735	734	.8	1.8	1.1	.1	1.0	0
222	713	624	704	762	701	1.7	11.0	.4	8.7	5.4	3.0
223	627	507	729	742	651	3.7	22.1	11.6	14.0	12.8	10.2
224	653	682	694	734	691	5.5	1.3	.4	6.2	3.4	0
225	700	761	747	736	736	4.9	3.4	1.5	0	2.4	0
226	777	665	737	743	730	6.4	8.9	1.0	1.8	4.5	1.8
227	705	807	724	774	752	6.3	7.3	3.7	2.9	5.0	0
228	728	673	697	665	691	5.4	2.6	.9	3.8	3.2	0
229	760	748	604	690	700	8.6	6.9	13.7	1.4	7.6	3.6
230	710	550	710	677	662	7.3	16.9	7.3	2.3	8.4	4.7
231	727	623	798	743	723	.6	13.8	10.4	2.8	6.9	6.2
232	751	721	773	704	737	1.9	2.2	4.9	4.5	3.4	0
233	699	520	752	777	687	1.7	24.3	9.5	13.1	12.2	8.8
234	718	687	712	688	701	2.4	2.0	1.6	1.9	2.0	2.2
235	719	565	655	662	650	10.6	13.1	.8	1.8	6.6	.1
236	797	789	445	770	700	13.9	12.7	36.4	10.0	18.2	7.9
237	628	651	717	663	665	5.6	2.1	7.8	.3	4.0	1.1
238	808	789	758	731	772	4.7	2.2	1.8	5.3	3.5	0
239	730	800	629	747	726	.6	10.2	13.4	2.9	6.8	1.9
240	787	753	727	777	761	3.4	1.1	4.5	2.1	2.8	0
241	727	678	694	662	690	5.4	1.7	.6	4.1	3.0	0
242	753	776	670	758	739	1.9	5.0	9.3	2.6	4.7	.4
243	690	716	663	737	702	1.7	2.0	5.6	5.0	3.6	.8
244	721	705	678	726	708	1.8	.4	4.2	2.5	2.2	0
245	718	717	637	691	691	3.9	3.8	7.8	0	3.9	1.4
246	731	755	683	735	726	.7	4.0	5.9	1.2	3.0	0
247	615	605	596	603	605	1.7	0	1.5	.3	.9	7.4
248	784	713	635	771	726	8.0	1.8	12.5	6.2	7.1	1.6
249	647	666	634	753	675	4.1	1.3	6.0	11.6	5.8	4.2
250	776	603	712	806	724	7.2	16.7	1.7	11.3	9.2	0
251	658	688	447	650	611	7.7	12.6	26.8	6.4	13.4	5.8
252	728	742	570	760	700	4.0	6.0	18.6	8.6	9.3	1.8
253	756	675	630	744	701	7.8	3.7	10.1	6.1	6.9	.4
254	690	606	650	652	650	6.2	6.8	0	.3	3.3	1.4
255	672	708	670	667	679	1.0	4.3	1.3	1.8	2.1	.6
256	595	620	532	664	603	1.3	2.8	11.8	10.1	6.5	2.8
257	542	678	665	684	642	15.6	5.6	3.6	6.5	7.8	5.5
258	645	493	587	642	592	9.0	16.7	.8	8.4	8.7	2.0
259	709	661	658	644	668	6.1	1.0	1.5	3.6	3.0	.2
260	664	651	566	659	635	4.6	2.5	10.9	3.8	5.4	2.8
261	662	588	617	675	636	4.1	7.5	3.0	6.1	5.2	.6
262	682	603	614	699	650	4.9	7.2	5.5	7.5	6.3	1.8
263	520	923	535	688	592	12.2	5.2	9.6	16.2	10.8	3.2
264	673	653	638	647	653	3.1	0	2.3	.9	1.6	.3
265	666	523	515	600	576	15.6	9.2	10.6	4.2	9.9	4.4

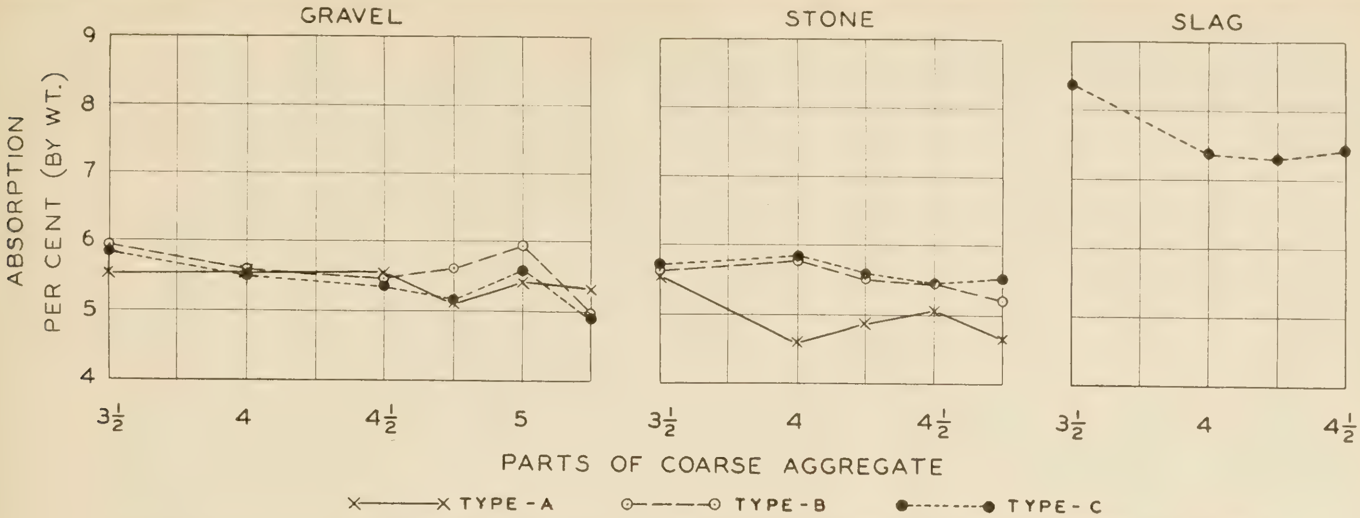


FIGURE 32.—RELATION BETWEEN ABSORPTION OF CORES AT NINE MONTHS AND TYPE OF FINISHING MACHINE

RESULTS OF ABSORPTION TESTS DISCUSSED

In order to develop information which might be of assistance in studying the relative durability of the various mixes, a series of absorption tests was made on 6-inch cores drilled from the test sections. These tests were made in accordance with the standard method calling for 5-hour immersion in boiling water, as specified by the American Society for Testing Materials. The average percentage by weight of water absorbed for each proportion and for each type of finishing machine is given in Figure 32. The average absorption is about 5.5 per cent for all conditions with the exception of the slag concrete, which averages about 7.5 per cent, and the stone concrete finished with type A finisher, which shows about 5 per cent. There is a slight tendency for the absorption to decrease with increasing quantities of coarse aggregate.

These tests are being supplemented now with a series of freezing and thawing tests on a similar series of cores. It is hoped that it will be possible to present a report covering this portion of the investigation at an early date.

STUDIES OF INDIVIDUAL TEST SECTIONS

In order to make it possible to study the manner in which the several variables which were being investigated affected the relative strength of individual sections, it was considered advisable to plot the results of tests section by section. This has been done in Figures 33 to 37, inclusive, in which the results of the various strength tests on each section have been indicated, together with the mix, slump, water-cement ratio, and averge percentages of honeycomb. In each group of three sections the concrete having the lowest slump appears to the left and the concrete having the highest slump to the right. In each group of three sections lines have been drawn between the plotted values of compressive strength and modulus of rupture to indicate the trend of variation of strength with increasing slump. These curves should not be looked upon as indicating a quantative relation, since the abscissa does not represent a variable. The various trends to which attention has been called may easily be traced throughout the entire series by reference to these figures. There are several points to which attention is especially called.

1. For each group of tests a very distinct relation exists between the consistency of the concrete as measured by the slump test and the water-cement ratio. Almost invariably it will be found that, in each group of three sections, a direct relation exists which indicates that the slump test is a very good measure of the relative amount of water in a given concrete, even within the rather narrow limits covered by this study.

2. In general, the additional water required to maintain workability in the mixtures containing high percentages of coarse aggregate does not result in an increase in slump. The upper, left-hand panel of Figure 33 is an exception to this rule.

3. The crushing strength of the concrete in the individual sections follows, in general, the water-cement ratio law. Exceptions may be observed in certain instances, many of which may be explained by the use of concrete which is too dry to be workable. It must be remembered, of course, that in these charts each point represents the average of only two tests in the case of the control specimens and the cores and four tests in the case of the slabs. Individual variations from the general rule are therefore not surprising.

4. There is a marked tendency for the flexural strength of both beams and slabs to fall off for the dry mixes. The tendency is more marked in the case of the slabs, probably because of the fact that under the standard method of molding employed for the control beams it was possible to fabricate more uniform specimens with the drier mixes than by the methods employed in placing the slabs. This tendency is illustrated by reference to sections 3, 17, 25, 32, 50, 71, 85, 122, 149, 180, 211, 230, and 247.

5. In 60 out of a total of 89 groups of three sections each, the section having the highest water-cement ratio showed a slab strength as high as or higher than the corresponding section in the same group having the lowest water-cement ratio. Attention is called to the fact that in each group of three sections the range in water-cement ratio was only sufficient to produce a variation in consistency from dry to medium and that in no case was the water-cement ratio high enough to produce concrete of wet or sloppy consistency.

It should also be noted that whereas the drier mixes would for the most part be rated as workable by laboratory standards, such mixes were not in general found to be workable under the methods of placing and finishing pavement slabs now commonly used. The dry mixes may therefore be considered as lying outside

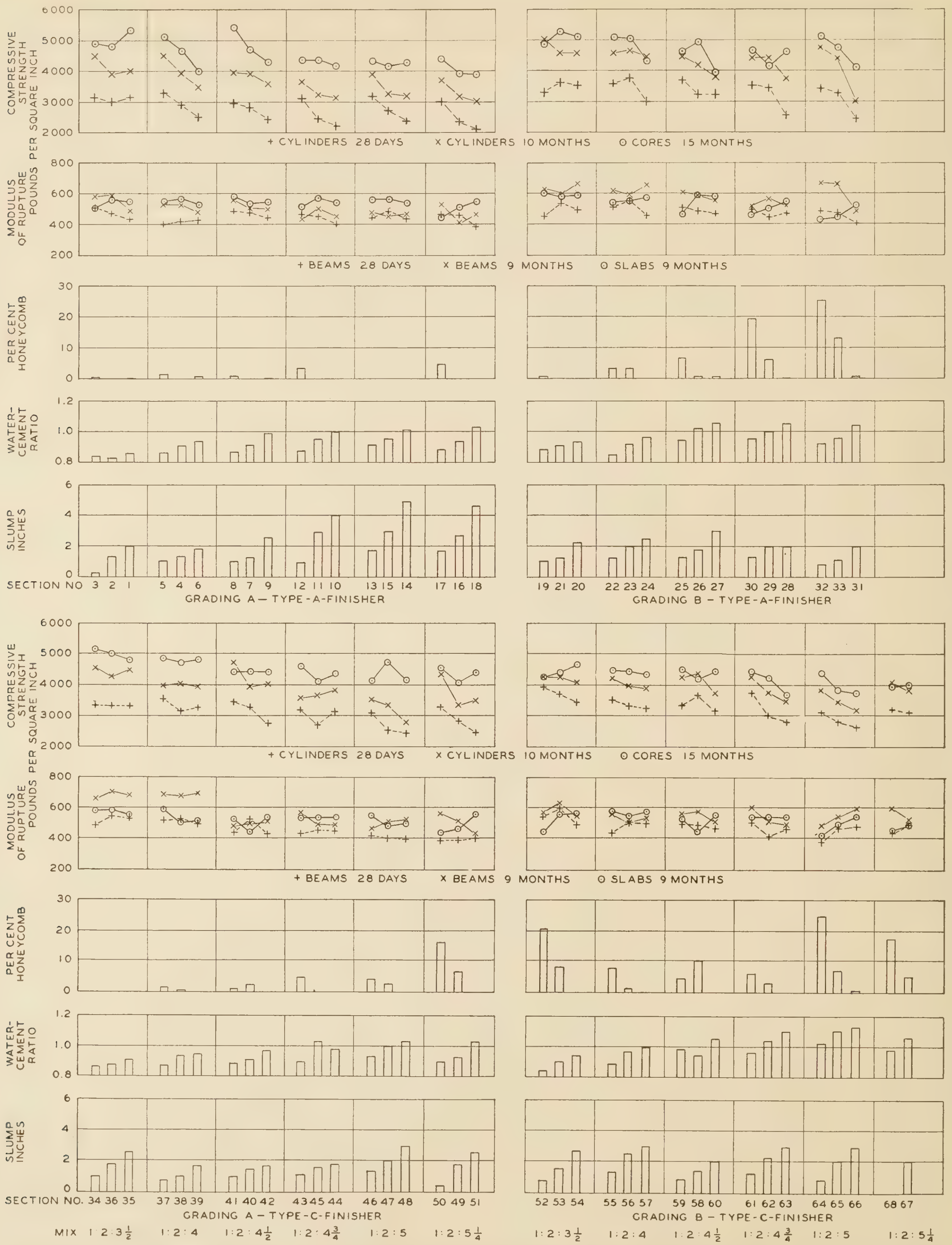


Figure 33.—Comparison of Values of Compressive Strength, Modulus of Rupture, Per Cent Honeycomb, Water-Cement Ratio, and Slump for All Sections of Gravel Concrete, Round 1

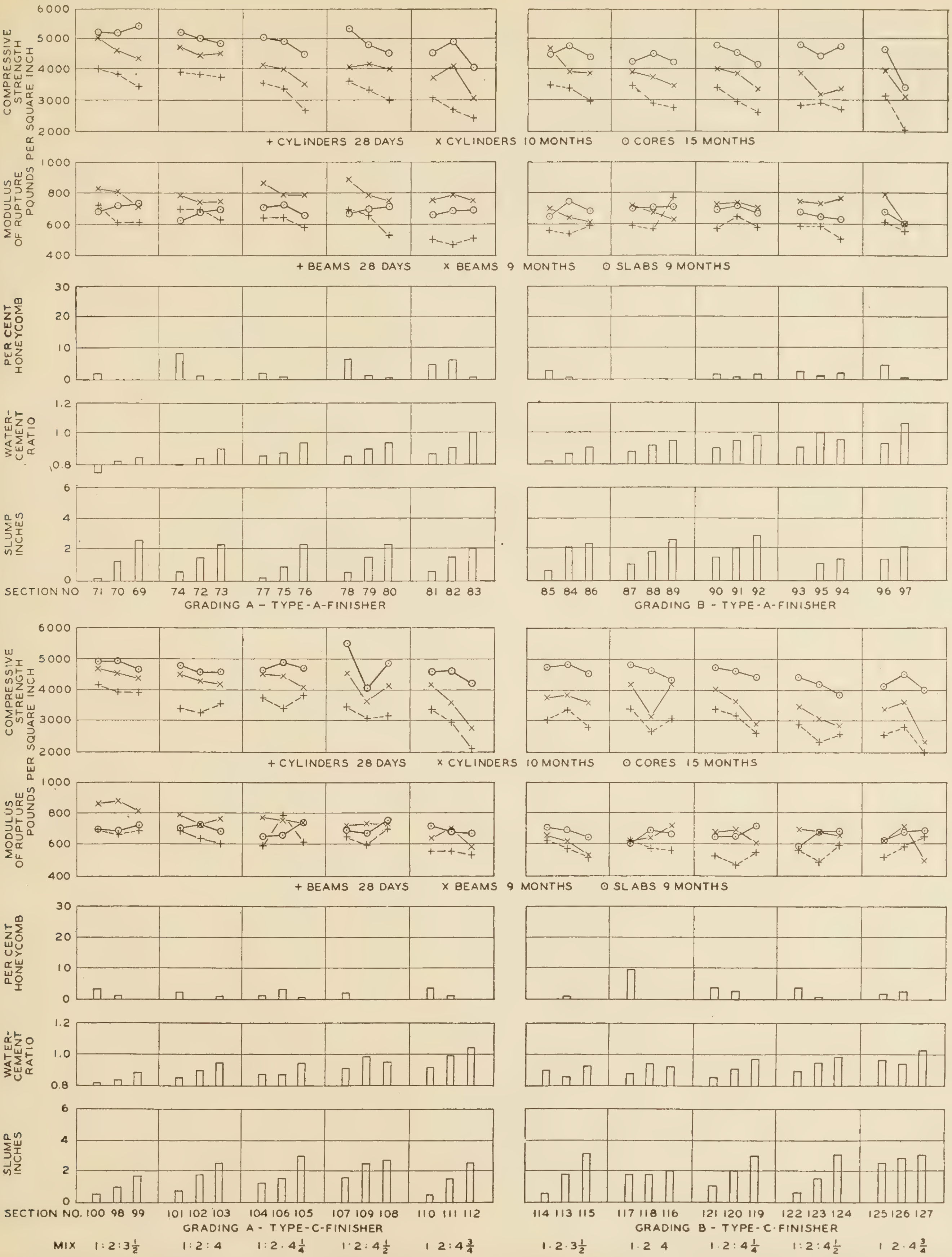


Figure 34.—Comparison of Values of Compressive Strength, Modulus of Rupture, Per Cent Honeycomb, Water-Cement Ratio, and Slump for All Sections of Stone Concrete, Round 1

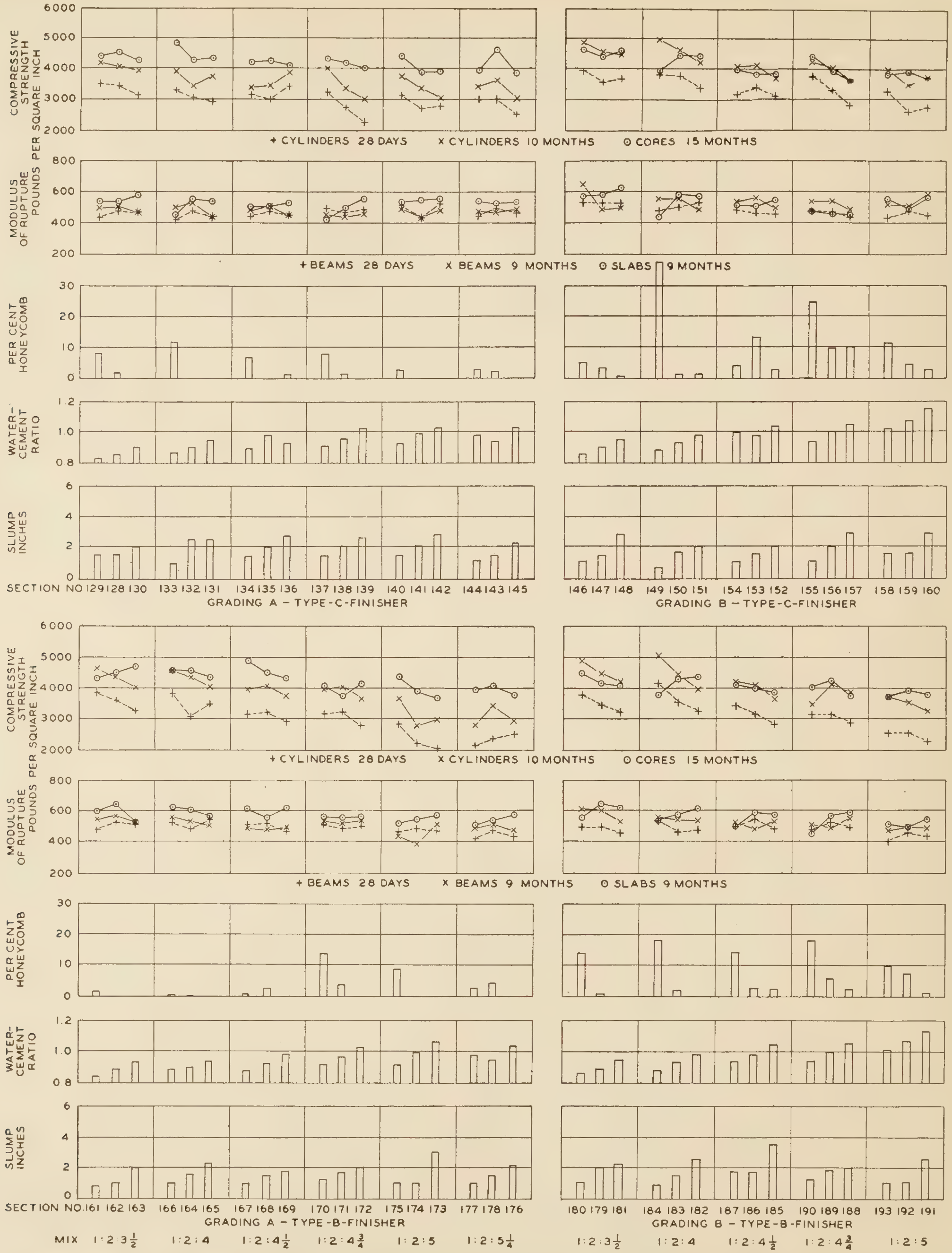


FIGURE 35.—COMPARISON OF VALUES OF COMPRESSIVE STRENGTH, MODULUS OF RUPTURE, PER CENT HONEYCOMB, WATER-CEMENT RATIO, AND SLUMP FOR ALL SECTIONS OF GRAVEL CONCRETE, ROUND 2

Figure 36.—Comparison of Values of Compressive Strength, Modulus of Rupture, Per Cent Honeycomb, Water-Cement Ratio, and Slump for All Sections of Stone Concrete, Round 2

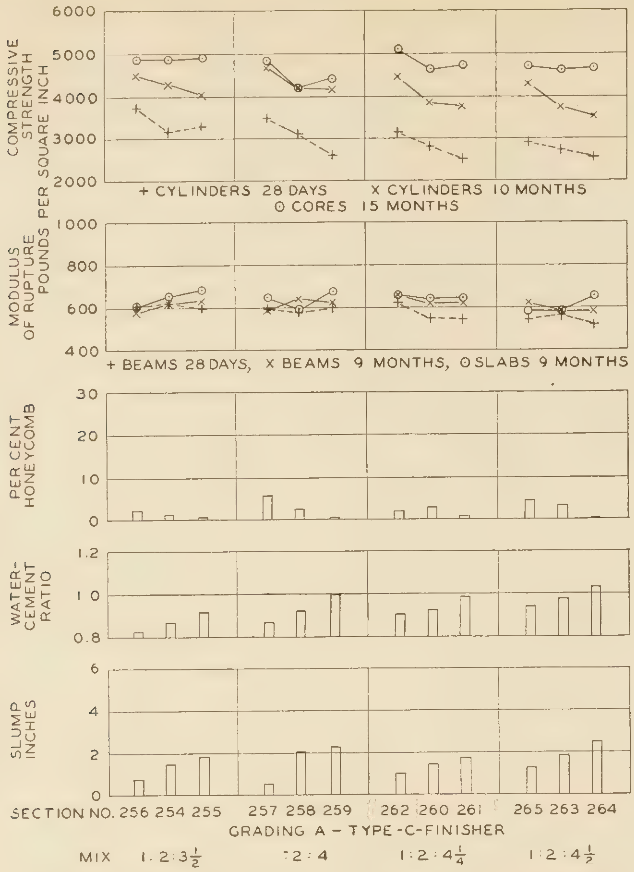


Figure 37.—Comparison of Values of Compressive Strength, Modulus of Rupture, Per Cent Honeycomb, War-Cement Ratio, and Slump for All Sections of Slag Concrete

of the range of plastic mixes to which the water-cement ratio law applies, and this fact accounts for the falling off in strength.

6. In these same 60 groups, the section in each group having the lowest water-cement ratio was honeycombed in all cases. On the other hand, in 40 out of the 60 groups, honeycomb was entirely absent from the section having the highest water-cement ratio, with 13 out of the remaining 20 showing less than 1 per cent honeycomb.

7. The slump for the driest mix in each group averaged from one-fourth inch to 1 inch, while the slump for the corresponding section in each group having the highest water-cement ratio averaged from 2 to 3 inches.

The above indications point emphatically to the danger of using mixes of less than 2-inch slump in concrete paving work with the methods of finishing in common use to-day. The use of medium consistencies such as were obtained in these tests with a 2 to 3 inch slump will not only give as high or higher slab strength than the drier mixes but will greatly decrease the tendency to honeycomb and thus will promote uniformity.

8. In general, the presence of honeycomb in the slabs, although very seriously affecting the flexural strengths of the slabs themselves, was not accompanied by lower crushing strengths of the cores drilled from the slabs. Neither was there any relation between the extent of honeycomb in the test slabs and the amount of honeycomb in the cores drilled therefrom. These observations lead to the conclusion that neither the crushing strength nor freedom from honeycomb of cores is necessarily an indication of the homogeneity of the concrete in the slab.

CONCLUSIONS STATED

For the materials, proportions, and methods of placing used in these tests the results of the investigation justify the following conclusions:

1. For a constant sand-cement ratio an increase in the quantity of coarse aggregate beyond the limits ordinarily employed in practice decreased the strength of the concrete in the pavement substantially in proportion to the amount of additional water required to maintain workability.

2. For corresponding increases in the water-cement ratio the percentage of reduction in flexural strength was somewhat less than the percentage of reduction in crushing strength.

3. The workability and uniformity in strength of the concrete was decreased in proportion to the amount of coarse aggregate added.

4. The workability of the concrete was greatly reduced by decreasing the maximum size and at the same time increasing the amount of fines in the gravel coarse aggregate, even though the corresponding variations in the percentage of voids in the gravel and in the value of $\frac{b}{b_0}$ for the concrete were small.

5. For the gravel concrete the reduction in workability for any mix caused by the use of the poorly graded gravel was greater than the reduction in workability caused by increasing the percentage of coarse aggregate in the concrete containing the well graded material. (See fig. 22.)

6. For a given consistency as measured by the slump test, different gradations of gravel produced different degrees of workability. (Fig. 23.)

7. For a given gradation of coarse aggregate the consistency as determined by the slump test measured the workability of the concrete.

8. For a given proportion, higher slab strengths were obtained with concrete having a medium consistency (2 to 3 inches slump) than with very dry concrete (¼ to 1 inch slump).

9. In order to obtain satisfactory uniformity and freedom from honeycomb it was necessary to use a consistency corresponding to a slump of approximately 2 to 3 inches.

10. The various types of finishing machine employed in these tests gave approximately the same results.

11. For concrete reasonably free from honeycomb, the strength of the control beams appeared to be a satisfactory measure of the strength of the corresponding pavement slab.

12. Neither the amount of honeycombing observed in the drilled cores or the crushing strengths developed by the drilled cores measured the extent of honeycomb in the pavement slabs or the flexural strength developed by the pavement slabs.

RECOMMENDATIONS

On the basis of the information produced by these tests, the following recommendations are made:

a. That all specifications for concrete for pavements contain a definite requirement covering consistency. The slump test is recommended for this purpose.

b. That the use of paving mixes showing less than 2-inch slump should be discouraged.

c. That specifications for consistency of paving concrete to be finished by any of the methods now in use be revised when necessary to provide that the concrete have a consistency corresponding to a slump of from 2 to 3 inches.

ROAD PUBLICATIONS OF 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 nor 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, 1930.

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 BULLETIN

No. 55T. Highway Bridge Surveys.

SEPARATE REPRINTS FROM THE YEARBOOK

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

MISCELLANEOUS CIRCULARS

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

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

109M. 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.

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* Department supply exhausted.

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

CURRENT STATUS OF FEDERAL-AID AND EMERGENCY ROAD CONSTRUCTION

AS OF

JULY 31, 1931

STATE	COMPLETED MILEAGE	UNDER CONSTRUCTION: Estimated Total Cost	UNDER CONSTRUCTION: Federal Aid Allotted	UNDER CONSTRUCTION: Emergency Advance Fund	UNDER CONSTRUCTION: Mileage: Initial	UNDER CONSTRUCTION: Mileage: Stage*	UNDER CONSTRUCTION: Mileage: Total	APPROVED FOR CONSTRUCTION: Estimated Total Cost	APPROVED FOR CONSTRUCTION: Federal Aid Allotted	APPROVED FOR CONSTRUCTION: Emergency Advance Fund	APPROVED FOR CONSTRUCTION: Mileage: Initial	APPROVED FOR CONSTRUCTION: Mileage: Stage*	APPROVED FOR CONSTRUCTION: Mileage: Total	BALANCE OF FEDERAL AID FUNDS AVAILABLE FOR NEW PROJECTS	STATE
Alabama	2,130.9	$ 6,955,569.62	$ 3,393,349.82	$ 1,533,095.32	229.8	106.7	336.5	$ 93,312.53	$ 46,656.28	$ 34,891.58	1.4	2.7	4.1	$ 3,272,118.88	Alabama
Arizona	881.2	5,932,100.55	3,887,127.50	963,500.88	260.0	189.9	449.9	84,143.72	54,813.77	13,504.20	2.5	5.1	7.6	388,825.20	Arizona
Arkansas	1,751.1	8,813,129.59	4,183,953.44	1,318,157.00	230.5	102.0	332.5	1,433,750.98	684,625.55		30.4	29.9	60.3	48,942.04	Arkansas
California	1,935.3	12,122,500.76	5,095,074.10	2,733,179.23	315.8	109.7	425.5	2,589,846.52	978,511.29	219,622.21	75.1	1.5	76.6	337,393.88	California
Colorado	1,343.1	5,913,200.75	3,189,288.15	1,357,364.65	213.9	97.5	311.4	420,677.29	224,411.60	73,000.00	13.5	12.9	26.4	1,788,436.71	Colorado
Connecticut	260.0	4,981,188.80	1,855,739.03	520,491.00	51.1		51.1	86,763.25	43,381.62		.2		.2	4,388.65	Connecticut
Delaware	306.0	1,041,247.28	519,869.13	400,000.00	52.6		52.6	180,024.00	90,012.00		7.4		7.4	73,516.71	Delaware
Florida	539.9	6,527,676.69	3,058,613.83	1,042,604.35	188.8		188.8							1,611,780.06	Florida
Georgia	2,795.5	9,538,502.58	4,564,215.68	1,844,815.35	328.5	120.3	448.8	3,327,236.55	1,380,655.00	400.00	41.3	82.3	123.6	72,047.45	Georgia
Idaho	1,299.1	4,092,380.38	2,304,237.71	953,187.90	273.2	41.0	314.2	588,694.92	344,792.93	30,000.00	35.5	44.6	80.1	398,802.77	Idaho
Illinois	2,341.3	26,686,068.89	12,319,599.60	2,985,175.46	806.6	31.9	838.5	5,492,122.77	2,431,406.95	384,100.00	183.2	4.7	187.9	111,377.87	Illinois
Indiana	1,579.0	12,990,266.18	5,890,234.06	1,890,269.33	354.1		354.1	1,526,586.29	763,290.61	152,081.46	74.3		74.3	91,364.18	Indiana
Iowa	3,142.6	7,707,081.74	3,251,723.67	2,090,547.86	167.2	82.5	249.7	228,965.73	74,810.23			7.0	7.0	4,059.10	Iowa
Kansas	3,219.3	7,962,557.83	3,818,244.74	1,818,143.59	478.8	46.6	525.4	2,086,202.46	983,635.94	80,609.31	96.3	38.8	135.1	6,190.70	Kansas
Kentucky	1,567.0	6,543,969.18	2,882,004.78	1,266,680.50	268.2	124.9	393.1	570,813.18	273,043.45	150,100.00	42.4	15.0	57.4	145,522.67	Kentucky
Louisiana	1,460.9	7,725,357.51	3,658,561.75	1,147,927.00	208.2	19.9	228.1	751,852.47	265,038.41			.4	.4		Louisiana
Maine	610.4	4,453,990.05	1,709,858.83	659,464.50	101.5		101.5	1,425,923.17	597,157.58	20,000.00	24.8		24.8	332,495.47	Maine
Maryland	707.0	1,930,463.15	898,585.68	651,112.37	60.1	4.2	64.3	484,346.30	155,381.33		16.6		16.6		Maryland
Massachusetts	726.2	10,141,004.40	2,683,922.51	1,011,460.00	89.4		89.4	2,245,295.43	834,811.12	130,000.00	23.6		23.6	894,663.37	Massachusetts
Michigan	1,785.8	12,427,342.26	5,270,855.21	1,907,452.99	366.5	51.2	417.7	1,440,885.86	621,981.60	96,000.00	66.5	1.8	68.3	1,491,915.00	Michigan
Minnesota	3,971.0	8,005,316.98	3,511,057.31	2,159,993.00	74.8	302.9	377.7	486,553.78	200,740.40	90,000.00	5.1	14.8	19.9	37,280.63	Minnesota
Mississippi	1,765.3	4,262,333.39	2,100,361.31	1,429,736.00	184.5	87.9	272.4	275,748.23	136,432.57	5,000.00	.1	12.6	12.7	3,737,806.93	Mississippi
Missouri	2,674.2	9,711,425.99	3,886,078.09	2,375,333.55	262.3	73.5	335.8	980,001.25	420,535.03	69,371.38	25.8	10.7	36.5	114,404.25	Missouri
Montana	1,935.0	10,889,446.08	6,134,075.28	1,568,403.11	806.9	143.5	950.4	1,638,725.81	957,259.58	7,500.00	76.8	72.0	148.8	1,381,452.54	Montana
Nebraska	3,857.9	9,984,022.50	4,675,696.90	1,573,939.72	269.3	210.4	479.7	1,854,076.55	892,110.25	111,892.90	87.2	59.5	146.7	358,654.60	Nebraska
Nevada	1,105.4	2,862,636.57	1,853,366.18	882,286.13	91.1	253.4	344.5	588,951.49	417,947.39	135,567.49	17.5	31.0	48.5	195,605.64	Nevada
New Hampshire	387.8	1,702,782.59	608,709.41	365,000.00	29.5	6.1	35.6	82,697.78	26,581.93	35,000.00	1.4	2.1	3.5	102,463.60	New Hampshire
New Jersey	566.4	5,496,011.40	1,647,370.30	1,033,572.44	63.8		63.8	1,064,842.66	520,148.17	3,036.41	6.9	.6	7.5	631,954.98	New Jersey
New Mexico	1,992.7	5,831,530.10	3,529,782.93	1,095,589.90	233.4	98.9	332.3	107,277.63	67,700.35		.2		.2	118,929.22	New Mexico
New York	2,701.9	39,114,210.33	14,146,256.00	3,914,566.00	734.8	7.0	741.8	4,741,600.00	1,701,489.22	54,000.00	84.0		84.0		New York
North Carolina	1,968.5	6,555,667.66	3,182,285.87	1,736,501.58	204.0	54.5	258.5	586,181.75	285,079.74	58,000.00	35.1	4.0	39.1	1,599,497.42	North Carolina
North Dakota	4,598.2	3,732,298.80	1,910,368.15	891,314.95	411.9	315.7	727.6	988,015.78	497,083.41	74,100.00	65.3	238.6	303.9	872,633.67	North Dakota
Ohio	2,582.1	15,443,910.72	5,120,885.94	2,525,015.96	261.3	22.7	284.0	4,380,383.12	1,637,921.93	473,522.04	66.3	33.9	100.2	677,697.33	Ohio
Oklahoma	2,011.3	8,047,790.09	3,851,227.47	1,775,760.06	297.7	121.1	418.8	457,401.02	237,287.68	90,587.35	5.6	10.6	16.2	72,517.85	Oklahoma
Oregon	1,285.8	7,574,826.53	4,211,981.47	1,149,997.89	265.7	82.8	348.5	419,000.40	216,273.88	104,414.51	31.5	8.4	39.9	367,606.50	Oregon
Pennsylvania	2,676.1	13,154,512.56	5,666,408.68	3,234,280.51	301.0		301.0	2,140,567.22	976,687.95	278,662.49	70.6		70.6	665,822.19	Pennsylvania
Rhode Island	220.4	2,427,028.37	907,421.64	334,000.00	37.2		37.2							118,133.37	Rhode Island
South Carolina	1,869.8	5,028,123.08	2,286,629.96	1,042,586.00	78.2	136.5	214.7							255,042.23	South Carolina
South Dakota	3,854.3	5,347,167.95	2,814,090.89	1,188,363.14	326.0	184.3	510.3	632,942.43	341,169.23	15,000.00	.3	107.8	108.1	103,536.95	South Dakota
Tennessee	1,531.4	3,220,349.97	1,577,146.63	1,237,000.21	131.5	9.5	141.0	380,641.70	190,320.84		26.0		26.0	1,842,657.37	Tennessee
Texas	7,041.3	19,903,882.64	9,160,075.15	4,786,885.33	786.3	323.0	1,109.3	3,592,649.33	1,559,903.99	185,000.00	137.0	54.6	191.6	2,532,266.93	Texas
Utah	1,041.0	2,101,308.31	1,182,748.90	684,674.35	113.7	65.9	179.6	519,359.34	343,155.24	72,262.45	24.9	40.9	65.8	503,583.76	Utah
Vermont	301.6	1,496,025.70	608,121.37	400,000.00	37.1	4.7	41.8							3,136.16	Vermont
Virginia	1,647.2	5,730,133.96	2,583,323.11	1,336,362.06	241.0	46.4	287.4	565,847.70	282,923.85		21.2		21.2	502,645.31	Virginia
Washington	998.2	5,938,510.95	2,608,229.56	1,187,441.86	175.4	36.3	211.7	518,090.02	256,853.38	15,000.00	14.1	7.7	21.8	827,152.35	Washington
West Virginia	760.4	5,694,514.72	2,295,189.68	847,554.00	136.5	25.4	161.9	356,373.41	168,782.94	27,830.00	9.0		9.0	178,305.72	West Virginia
Wisconsin	2,439.5	8,250,061.49	3,562,416.37	1,850,910.00	223.5	70.6	294.1	1,547,527.77	452,156.90	96,301.21	60.5	15.3	75.8		Wisconsin
Wyoming	1,657.0	4,583,090.07	2,725,277.21	940,157.83	343.0	222.7	565.7	235,693.88	117,845.00	78,000.00	17.2	32.2	49.4	171,498.31	Wyoming
Hawaii	47.5	1,429,014.40	580,743.37	394,528.83	41.1		41.1	286,652.62	97,414.57		3.8		3.8	1,505,429.60	Hawaii
TOTALS	89,870.8	388,003,532.09	173,362,384.15	72,036,383.69	12,207.3	4,034.0	16,241.3	54,545,245.07	23,850,221.66	3,464,136.99	1,628.4	1,004.0	2,632.4	30,543,556.80	TOTALS

(*) 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.

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