PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 14, NO. 8 ▽ OCTOBER 1933

THE MOUNT VERNON MEMORIAL HIGHWAY

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - - - - - - - - - See Page 2 of cover for prices

PUBLIC ROADS ▸ ▸ ▸ *A Journal of Highway Research*

Issued by the

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

G. P. St. CLAIR, *Editor*

Volume 14, No. 8 October 1933

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions

In This Issue

THE BUREAU OF PUBLIC ROADS - - - - Willard Building, Washington, D.C.

REGIONAL HEADQUARTERS - - - - - - - - - Mark Sheldon Building, San Francisco, Calif.

▼

DISTRICT OFFICES

DISTRICT No. 1. Oregon, Washington, and Montana.
Post Office Building, Portland, Oreg.

DISTRICT No. 2. California. Arizona, and Nevada.
Mark Sheldon Building, 461 Market St., San Francisco, Calif.

DISTRICT No. 3. Colorado, New Mexico, and Wyoming.
237 Custom House, Nineteenth and Stout Sts., Denver, Colo.

DISTRICT No. 4. Minnesota, North Dakota, South Dakota, and Wisconsin.
410 Hamm Building, St. Paul, Minn.

DISTRICT No. 5. Iowa, Kansas, Missouri, and Nebraska.
Saunders-Kennedy Building, Omaha, Nebr.

DISTRICT No. 6. Arkansas, Louisiana, Oklahoma, and Texas.
Old Post Office Building, Fort Worth, Tex.

DISTRICT No. 7. Illinois, Indiana, Kentucky, and Michigan.
South Chicago Post Office Building, Chicago, Ill.

DISTRICT No. 8. Alabama, Georgia, Florida, Mississippi, South Carolina, and Tennessee.
Shepherd Building, P.O. Box J, Montgomery, Ala.

DISTRICT No. 9. Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont.
Federal Building, Troy, N.Y.

DISTRICT No. 10. Delaware, Maryland, North Carolina, Ohio, Pennsylvania, Virginia, and West Virginia.
Willard Building, Washington, D.C.

DISTRICT No. 11. Alaska.
Room 419, Federal and Territorial Building, Juneau, Alaska.

DISTRICT No. 12. Idaho and Utah.
Federal Building, Ogden, Utah

Because of the necessarily limited edition of this publication it is impossible to distribute it free to any person or institutions other than State and county officials actually engaged in planning or constructing public highways, instructors in highway engineering, and periodicals upon an exchange basis. At the present time additions to the free mailing list can be made only as vacancies occur. Those desiring to obtain Public Roads can do so by sending $1 per year (foreign subscription $1.50) or 10 cents per single copy, to the Superintendent of Documents, United States Government Printing Office, Washington, D.C.

CERTIFICATE: By direction of the Secretary of Agriculture, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

THE EFFECT OF VIBRATION AND DELAYED FINISHING ON PAVEMENT SLABS

Reported by **F. H. JACKSON**, Senior Engineer of Tests, and **W. F. KELLERMANN**, Associate Materials Engineer, Division of Tests, United States Bureau of Public Roads

IN THE August 1931 issue of PUBLIC ROADS there was published a report describing the results of an investigation conducted by the Bureau of Public Roads to determine the effect of certain controllable variables on the quality of pavement concrete. The test procedure used in this work differed from the conventional laboratory investigation in that observations and tests were made on actual pavement sections, placed and finished under working conditions, rather than on small-size test specimens. In this way it was possible to measure the effect of variations in workability by studying the quality and uniformity of the concrete in the finished structure rather than by attempting to investigate this indefinite property through the use of some arbitary laboratory test such as flow, penetration, etc.

SLUMP NOT LESS THAN 2 INCHES REQUIRED IN PRESENT CONSTRUCTION METHODS

In the tests which have already been reported a study was made of the effect of varying the quantity of coarse aggregate in the mix for various types and gradings of coarse aggregate and for various consistencies. The concrete was mixed and placed in accordance with accepted construction practice, which included finishing by the use of the conventional type of power-driven screeds, with and without tamper attachment. These initial tests developed certain information of value. For instance, it was quite definitely determined that with the methods of machine finishing now commonly employed a consistency corresponding to a slump of at least 2 inches must be used if honeycomb is to be avoided. Of course, such a concrete does not have as high a potential strength and density as a somewhat drier mix. Actually, however, it was found that both strength and uniformity were improved by the use of the wetter consistency. This result is explained by the fact that the segregation and honeycombing which accompanies the use of the drier mix actually tends to lower the strength of the pavement slab to a point considerably below the strength which would be expected theoretically from the water-cement ratio strength law. This means that under our present construction practice concretes mixed in the proportions used in paving work and with normal aggregates are not "workable" as paving mixes if the slumps are less than 2 inches. In other words, it is not possible to take advantage of the higher strength and density which should accompany the use of a lower water content than is required to give a 2-inch slump.

DEVELOPMENT OF METHODS FOR USING DRIER MIXES OBJECTIVE OF INVESTIGATION

A realization of this fact led naturally to a consideration of methods of placing which would permit the use of drier mixes without sacrificing strength or uniformity of strength. The use of vibratory screeds for this purpose presented interesting possibilities and it was decided to continue the experiments using a standard finishing machine equipped with vibrators mounted directly on the screeds. The present paper discusses the results of these tests, as well as another series in which a method of removing excess water from the concrete after it was deposited on the subgrade was investigated. It will be noted that in both cases the ultimate object was the same; that is, the production of a pavement slab of uniform quality with a lower net water content and consequently higher strength and greater density than would be possible with a standard finishing machine.

For the purpose of discussion the two series of tests are treated separately, the results obtained by the use of vibrators (series A) being presented first. This portion of the report is followed by a discussion of the tests which involved the principle of delayed finishing for the purpose of removing excess water, otherwise known as the Johnson method (series B). In both cases the general testing procedure outlined in the report of August 1931 was followed, except that the finishing operations were carried out in each case as indicated in detail below. The slabs were cast on the bare subgrade, whereas in the former tests the subgrade was covered with tar paper before placing the concrete.

The same general types of crushed limestone, gravel and blast-furnace slag were used as coarse aggregate. However, in the tests reported herein the aggregates were used in two separate sizes only instead of three, as in the earlier investigation. Two sands, differing considerably in gradation, were also used instead of one, as in the first series. In this way it was possible, in the case of series A, to investigate six combinations of aggregates varying as to character and gradation; that is, crushed stone, gravel, and slag, each in combination with a fine sand and a coarse sand. Blast furnace slag was omitted from the Johnson series and in its place was

TABLE 1.—*Properties of aggregates*

SIEVE[1] ANALYSIS

Total retained on—	Coarse sand	Fine sand	Gravel	Crushed stone	Crushed slag	Platte River combination
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1½-inch sieve			21	17	4	
¾-inch sieve			68	76	65	
⅜-inch sieve			90	95	99	11
No. 4 sieve	5	0	99	99	100	31
No. 8 sieve	24	2	100	100	100	46
No. 14 sieve	36	8	100	100	100	55
No. 28 sieve	54	30	100	100	100	67
No. 48 sieve	83	77	100	100	100	89
No. 100 sieve	96	96	100	100	100	98
Fineness modulus	2.98	2.13	7.78	7.87	7.68	3.97

PHYSICAL PROPERTIES

	Coarse sand	Fine sand	Gravel	Crushed stone	Crushed slag	Platte River combination
Approximate specific gravity	2.66	2.65	2.54	2.78	2.32	2.63
Absorption, percent	.82	.70	1.20	.36	4.25	.91
Decantation loss, percent	2.70	2.10				
Voids, percent[2]	37.00	41.00	32.00	40.00	43.00	31.00
Wear, percent[3]			9.60	3.40	7.70	

[1] Square openings.
[2] Dry-rodded.
[3] Abrasion tests conducted in accordance with methods applicable in each case.

substituted a sand-gravel combination conforming in grading to the so-called "Platte River gravel" used in Nebraska, Kansas, and Iowa. The essential test data pertaining to the aggregates used in this investigation are given in table 1. The same cement, a standard portland cement meeting all American Society for Testing Materials requirements, was used throughout. The proportions, consistency, etc., of the concrete for series A are shown in table 2 with similar data for series B in table 3.

TABLE 2.—*Data on mixes: Series A*

ROUND 1

Aggregates	Section no.[1]	Proportions by volume, dry-rodded	Cement factor in sacks per cubic yard	Water-cement ratio corrected	b/b_0	Slump
						Inches
A. Coarse sand and gravel	1-S	1:1.6:3.45	5.9	0.75	0.75	2¼
	2-V	1:1.6:3.45	5.9	.69	.76	1
	3-V	1:1.6:3.45	6.0	.65	.77	0
	4-V	1:1.6:3.70	5.7	.74	.78	2½
	5-V	1:1.6:3.95	5.5	.74	.80	1¼
	6-V	1:1.6:4.20	5.3	.73	.82	1
B. Fine sand and gravel	7-S	1:1.5:3.45	6.1	.73	.77	1½
	8-V	1:1.5:3.45	6.1	.68	.78	½
	9-V	1:1.5:3.45	6.1	.67	.78	¼
	10-V	1:1.5:3.70	5.8	.74	.80	1¼
	11-V	1:1.5:3.95	5.6	.73	.82	1
	12-V	1:1.5:4.20	5.5	.72	.85	0
C. Coarse sand and stone	13-S	1:1.9:3.30	6.1	.75	.75	1½
	14-V	1:1.9:3.30	6.2	.69	.76	¾
	15-V	1:1.9:3.30	6.2	.67	.76	0
	16-V	1:1.9:3.55	5.9	.75	.78	1½
	17-V	1:1.9:3.80	5.7	.74	.81	1½
	18-V	1:1.9:4.05	5.5	.74	.83	1¼
D. Fine sand and stone	19-S	1:1.7:3.30	6.4	.76	.78	1½
	20-V	1:1.7:3.30	6.5	.70	.79	1
	21-V	1:1.7:3.30	6.5	.68	.79	¾
	22-V	1:1.7:3.55	6.2	.75	.81	1¼
	23-V	1:1.7:3.80	6.0	.75	.84	1¼
	24-V	1:1.7:4.05	5.8	.75	.87	¾
E. Coarse sand and slag	25-S	1:2.1:3.20	6.2	.75	.73	2
	26-V	1:2.1:3.20	6.3	.67	.74	1
	27-V	1:2.1:3.20	6.3	.63	.75	½
	28-V	1:2.1:3.45	6.0	.73	.76	1¼
	29-V	1:2.1:3.70	5.8	.72	.80	1
	30-V	1:2.1:3.95	5.7	.70	.83	¾
F. Fine sand and slag	31-V	1:1.9:3.20	6.4	.79	.76	1
	32-S	1:1.9:3.20	6.3	.83	.75	2
	33-V	1:1.9:3.20	6.4	.75	.76	½
	34-V	1:1.9:3.45	6.1	.82	.78	1
	35-V	1:1.9:3.70	6.0	.81	.82	1
	36-V	1:1.9:3.95	5.8	.79	.85	½

ROUND 2

Aggregates	Section no.[1]	Proportions by volume, dry-rodded	Cement factor in sacks per cubic yard	Water-cement ratio corrected	b/b_0	Slump
G. Coarse sand and gravel	37-S	1:1.6:3.45	6.0	0.67	0.76	2¼
	38-V	1:1.6:3.45	6.0	.61	.77	1
	39-V	1:1.6:3.45	6.1	.58	.78	¼
	40-V	1:1.6:3.70	5.8	.66	.79	1¼
	41-V	1:1.6:3.95	5.6	.66	.81	1¼
	42-V	1:1.6:4.20	5.4	.66	.84	1
H. Fine sand and gravel	43-V	1:1.5:3.45	6.1	.67	.78	1¼
	44-S	1:1.5:3.45	6.1	.72	.78	2½
	45-V	1:1.5:3.45	6.2	.61	.80	1
	46-V	1:1.5:3.70	5.9	.71	.80	2
	47-V	1:1.5:3.95	5.7	.71	.83	1½
	48-V	1:1.5:4.20	5.5	.70	.85	1¼
I. Coarse sand and stone	49-S	1:1.9:3.30	6.1	.75	.75	1¾
	50-V	1:1.9:3.30	6.2	.69	.76	1¼
	51-V	1:1.9:3.30	6.2	.65	.76	¼
	52-V	1:1.9:3.55	5.9	.75	.77	1¾
	53-V	1:1.9:3.80	5.7	.75	.80	1¾
	54-V	1:1.9:4.05	5.5	.75	.83	1
J. Fine sand and stone	55-S	1:1.7:3.30	6.4	.76	.78	2
	56-V	1:1.7:3.30	6.5	.70	.79	1½
	57-V	1:1.7:3.30	6.5	.66	.80	½
	58-V	1:1.7:3.55	6.2	.76	.81	2
	59-V	1:1.7:3.80	6.0	.76	.84	1½
	60-V	1:1.7:4.05	5.8	.76	.86	¼
K. Coarse sand and slag	61-S	1:2.1:3.20	6.2	.75	.73	2¾
	62-V	1:2.1:3.20	6.3	.66	.74	1½
	63-V	1:2.1:3.20	6.3	.62	.75	½
	64-V	1:2.1:3.45	6.0	.73	.75	1½
	65-V	1:2.1:3.70	5.8	.72	.80	1¼
	66-V	1:2.1:3.95	5.7	.70	.83	1

TABLE 3—*Data on mixes—Series B*

ROUND 1

Aggregates	Section no.	Proportions by volume, dry-rodded	Cement factor in sacks per cubic yard	Water-cement ratio corrected	b/b_0	Slump
						Inches
A. Coarse sand and gravel	67-S	1:1.6:3.45	6.0	0.67	0.76	1¾
	68-J	1:1.6:3.45	5.9	.71	.76	2½
	69-S	1:2.1:4.45	4.8	.76	.79	1½
	70-J	1:2.1:4.45	4.8	.82	.79	2½
B. Fine sand and gravel	71-S	1:1.5:3.45	6.1	.69	.78	1¼
	72-J	1:1.5:3.45	6.0	.76	.77	2¾
	73-S	1:2.0:4.45	4.8	.88	.80	1
	74-J	1:2.0:4.45	4.8	.95	.79	2
C. Coarse sand and stone	75-S	1:1.9:3.30	6.1	.75	.75	2½
	76-J	1:1.9:3.30	6.1	.77	.74	2¾
	77-S	1:2.4:4.30	5.0	.87	.79	1½
	78-J	1:2.4:4.30	4.9	.95	.78	3
D. Fine sand and stone	79-S	1:1.7:3.30	6.4	.76	.78	2½
	80-J	1:1.7:3.30	6.3	.80	.77	3½
	81-S	1:2.2:4.30	5.1	.96	.81	2
	82-J	1:2.2:4.30	5.1	.96	.81	2¼

ROUND 2

Aggregates	Section no.	Proportions by volume, dry-rodded	Cement factor in sacks per cubic yard	Water-cement ratio corrected	b/b_0	Slump
E. Coarse sand and gravel	83-S	1:1.6:3.45	6.0	0.67	0.76	2
	84-J	1:1.6:3.45	5.9	.71	.76	3
	85-S	1:2.1:4.45	4.8	.79	.79	2¾
	86-J	1:2.1:4.45	4.8	.82	.79	3½
F. Fine sand and gravel	87-S	1:1.5:3.45	6.1	.72	.77	3
	88-J	1:1.5:3.45	6.1	.72	.77	2¾
	89-S	1:2.0:4.45	4.8	.87	.80	2¼
	90-J	1:2.0:4.45	4.8	.90	.79	3
G. Coarse sand and stone	91-S	1:1.9:3.30	6.1	.77	.74	2
	92-J	1:1.9:3.30	6.0	.80	.74	3¾
	93-S	1:2.4:4.30	4.9	.97	.77	2½
	94-J	1:2.4:4.30	4.8	.99	.77	3¾
H. Fine sand and stone	95-S	1:1.7:3.30	6.4	.77	.78	2
	96-J	1:1.7:3.30	6.3	.79	.77	3
	97-S	1:2.2:4.30	5.1	.95	.81	2
	98-J	1:2.2:4.30	5.0	.98	.80	3
I. Platte River gravel	99-S	1:4	6.4	.93	------	1½
	103-J	1:4	6.3	1.03	------	2½
	101-S	1:4.5	5.8	1.05	------	2
	105-J	1:4.5	5.7	1.10	------	2
J. Platte River gravel	100-S	1:4	6.4	.97	------	1¾
	104-J	1:4	6.3	1.00	------	2
	102-S	1:4.5	5.8	1.05	------	1½
	106-J	1:4.5	5.7	1.10	------	2¼

TESTING PROCEDURE DESCRIBED

Strength tests.—As in the earlier tests, the flexural strength of each 9-foot pavement section was obtained by averaging the results of flexure tests on four slabs removed from the section and tested in accordance with the method described in the first report. The actual test slabs were 27 inches in width, 60 inches in length, and 7 inches in depth. They were loaded at the third points of a 54-inch span. The same general procedure as regards control specimens was followed in the present series as in the previous tests. These specimens consisted of beams tested at the age of 7 months and cylinders tested at the age of 9 months. These periods corresponded to the ages at which the pavement slabs and cores drilled therefrom were tested. All strength tests were made on saturated specimens. The average results of all strength tests are shown in table 4. In table 5 are given the results of flexure tests on the individual slabs.

Absorption and density tests.—Four 6-inch cores were drilled from each test section, 2 each from 2 of the half slabs remaining after the flexure tests. In drilling the cores considerable care was taken to select portions of the slabs free from honeycomb in order to insure the use of sound, homogeneous cores for testing purposes. Two of the cores, 1 from each slab, were tested in compression while the other 2 were tested for absorption and density. The following procedure was employed in making the absorption and density tests: The cores

---

[1] Symbols used in this column, and in corresponding columns of subsequent tables have the following meanings: "S"—standard; "V"—vibrated; "J"—Johnson method.

TABLE 4.—*Results of strength tests*

Section no.	Modulus of rupture (in pounds per square inch)		Crushing strength (in pounds per square inch)	
	Pavement slabs at 7 months[1]	Control beams at 7 months[2]	Pavement cores at 9 months[3]	Control cylinders at 9 months[2]
1-S	737	578	6, 240	4, 910
2-V	712	658	6, 620	5, 700
3-V	624	566	6, 950	4, 800
4-V	780	692	6, 460	5, 100
5-V	689	682	6, 680	5, 100
6-V	648	700	6, 640	4, 280
7-S	743	656	6, 880	4, 700
8-V	711	604	7, 040	5, 550
9-V	691	643	6, 760	5, 590
10-V	714	629	6, 650	4, 590
11-V	659	638	6, 490	4, 840
12-V	606	562	6, 230	5, 180
13-S	852	892	6, 780	6, 410
14-V	917	892	7, 580	6, 870
15-V	880	858	7, 550	6, 980
16-V	961	864	7, 460	6, 740
17-V	944	845	7, 540	6, 350
18-V	895	868	7, 590	6, 510
19-S	890	857	6, 240	6, 520
20-V	905	853	7, 450	7, 020
21-V	863	894	7, 040	6, 920
22-V	1, 006	928	5, 980	6, 380
23-V	914	915	7, 080	6, 450
24-V	813	852	6, 740	5, 590
25-S	802	704	6, 540	5, 960
26-V	762	744	6, 170	6, 680
27-V	678	722	6, 730	6, 940
28-V	780	696	6, 810	6, 680
29-V	751	708	6, 300	5, 920
30-V	807	730	6, 340	6, 380
31-V	754	678	6, 500	6, 120
32-S	730	680	6, 450	6, 180
33-V	764	682	6, 620	5, 820
34-V	815	716	5, 900	6, 100
35-V	824	720	6, 480	6, 100
36-V	727	706	6, 210	5, 860
37-S	697	705	6, 740	5, 870
38-V	735	684	6, 740	5, 960
39-V	642	631	8, 400	4, 800
40-V	714	632	7, 180	4, 980
41-V	675	646	6, 690	5, 710
42-V	669	615	7, 020	5, 890
43-V	692	640	5, 640	5, 060
44-S	723	624	7, 270	6, 110
45-V	730	598	7, 540	6, 120
46-V	720	659	6, 910	5, 450
47-V	708	607	6, 960	5, 180
48-V	664	700	6, 800	6, 020
49-S	854	819	7, 630	6, 580
50-V	961	914	8, 240	7, 380
51-V	828	776	8, 040	5, 780
52-V	949	862	7, 080	7, 030
53-V	1, 010	909	7, 920	6, 620
54-V	877	834	7, 450	6, 300
55-S	908	812	6, 980	5, 880
56-V	965	811	7, 300	7, 140
57-V	947	819	7, 760	6, 440
58-V	989	900	7, 240	6, 480
59-V	962	803	7, 160	6, 740
60-V	951	824	7, 330	6, 610
61-S	802	742	6, 550	6, 170
62-V	818	734	7, 230	6, 560
63-V	860	762	7, 490	6, 760
64-V	862	678	6, 620	5, 160
65-V	825	726	6, 980	6, 310
66-V	819	715	6, 670	6, 160
67-S	724	642	7, 280	6, 760
68-J	777	664	7, 800	6, 080
69-S	658	645	6, 930	5, 870
70-J	680	604	6, 830	5, 580
71-S	666	683	6, 380	5, 800
72-J	753	587	7, 070	5, 960
73-S	628	602	5, 900	4, 960
74-J	681	543	6, 340	4, 800
75-S	884	862	7, 710	6, 440
76-J	918	865	8, 220	6, 890
77-S	709	756	6, 040	6, 100
78-J	908	698	8, 060	5, 370
79-S	934	836	7, 320	7, 010
80-J	1, 062	801	8, 280	6, 700
81-S	784	670	5, 940	5, 180
82-J	910	688	7, 180	5, 280
83-S	688	668	7, 440	6, 230
84-J	724	638	7, 690	5, 580
85-S	672	572	5, 660	5, 180
86-J	697	598	6, 640	4, 690
87-S	712	666	6, 400	5, 920
88-J	756	667	7, 040	5, 720
89-S	643	566	5, 160	4, 800
90-J	660	518	6, 000	4, 640
91-S	849	860	7, 520	6, 590
92-J	934	775	8, 000	5, 830
93-S	814	703	5, 700	4, 660
94-J	882	622	7, 220	4, 040
95-S	849	858	7, 060	6, 720
96-J	978	807	8, 000	6, 640
97-S	771	694	5, 500	5, 300
98-J	811	628	7, 050	4, 280
99-S	584	601	4, 900	4, 380
103-J	729	598	5, 910	4, 580
101-S	637	564	4, 200	4, 260
105-J	680	500	5, 720	3, 720
100-S	694	640	4, 740	4, 900
104-J	728	626	6, 060	4, 750
102-S	638	534	4, 080	3, 960
106-J	700	599	5, 840	3, 930

[1] Each value average of 4 tests on 1 section.
[2] Each value average of 2 tests.
[3] Each value average of 2 tests on 1 section.

were first dried to constant weight in an electric oven where the temperature was maintained at approximately 150° C. They were then cooled, weighed, immersed in water and boiled for 5 hours. The specimens were then allowed to cool for 18 hours, after which they were removed from the water, surface-dried, and weighed. They were then weighed in water and from the three weights thus obtained the absorption, weight per cubic foot, and specific gravity were computed.

Values for the density of the hardened concrete were obtained by dividing the weight of a given volume of the concrete by the theoretical weight of solids in the same volume as calculated from the proportions and specific gravities of each of the constituent materials. In the case of series B, a value which may be termed the theoretical density of the plastic concrete was also obtained. This value is the ratio of the volume of solids (cement and aggregate) to the total volume of

TABLE 5.—*Individual slab strengths, uniformity, and honeycomb*

Section no.	Slab no.	Modulus of rupture	Variation from average	Honeycomb	
				Break	Bottom
		Lbs. per sq.in.	*Per-cent*	*Per-cent*	*Per-cent*
1-S	1	698	5. 3	3. 2	22. 6
	2	738	. 1	. 6	20. 6
	3	766	3. 9	0	5. 1
	4	747	1. 4	0	0
Average		737	2. 7	1. 0	12. 1
2-V	1	694	2. 5	0	4. 3
	2	704	1. 1	0	0
	3	740	3. 9	0	0
	4	708	. 6	. 5	8. 3
Average		712	2. 0	. 1	3. 2
3-V	1	561	10. 1	17. 5	75. 4
	2	590	5. 4	12. 5	62. 1
	3	763	22. 3	0	0
	4	580	7. 1	13. 5	55. 8
Average		624	11. 2	10. 8	48. 3
4-V	1	789	1. 2	0	1. 7
	2	742	4. 9	0	0
	3	785	. 6	0	0
	4	804	3. 1	0	0
Average		780	2. 4	0	. 4
5-V	1	635	7. 8	7. 5	14. 8
	2	660	4. 2	0	4. 4
	3	724	5. 1	0	0
	4	738	7. 1	0	0
Average		689	6. 0	1. 8	4. 8
6-V	1	619	4. 5	9. 4	21. 6
	2	623	3. 9	0	0
	3	700	8. 0	0	0
	4	649	. 1	. 5	2. 7
Average		648	4. 1	2. 4	6. 1
7-S	1	774	4. 2	0	7. 9
	2	700	5. 8	0	11. 1
	3	712	4. 2	0	6. 1
	4	785	5. 7	0	1. 9
Average		743	5. 0	0	6. 8
8-V	1	683	3. 9	0	3. 2
	2	753	5. 9	0	0
	3	726	2. 1	0	0
	4	682	4. 1	1. 5	16. 2
Average		711	4. 0	. 4	4. 8
9-V	1	684	1. 0	3. 8	25. 8
	2	690	. 1	0	0
	3	712	3. 0	0	2. 6
	4	678	1. 9	2. 1	16. 6
Average		691	1. 5	1. 5	11. 2
10-V	1	718	. 6	0	0
	2	683	4. 3	0	0
	3	743	4. 1	0	0
	4	713	. 1	0	0
Average		714	2. 3	0	0
11-V	1	657	. 3	0	4. 7
	2	670	1. 7	0	0
	3	680	3. 2	0	0
	4	629	4. 6	3. 0	15. 8
Average		659	2. 4	. 8	5. 1
12-V	1	624	3. 0	5. 2	22. 4
	2	660	8. 9	0	0
	3	641	5. 8	0	9. 6
	4	499	17. 7	7. 1	74. 5
Average		606	8. 8	3. 1	26. 6
13-S	1	828	2. 8	4. 8	8. 9
	2	793	6. 9	1. 6	26. 8
	3	954	12. 0	0	1. 4
	4	831	2. 5	4. 8	7. 0
Average		852	6. 0	2. 8	11. 0
14-V	1	861	6. 1	2. 6	16. 5
	2	917	0	0	0
	3	976	6. 4	0	0
	4	915	. 2	3. 6	17. 9
Average		917	3. 2	1. 6	8. 6
15-V	1	790	10. 2	6. 3	14. 4
	2	1, 028	16. 8	0	4. 2
	3	979	11. 2	0	0
	4	724	17. 7	14. 4	48. 4
Average		880	14. 0	5. 1	16. 8
16-V	1	988	2. 8	0	0
	2	941	2. 1	0	0
	3	985	2. 5	0	0
	4	929	3. 3	3. 6	11. 9
Average		961	2. 7	. 9	3. 0
17-V	1	955	1. 2	0	2. 1
	2	963	2. 0	0	0
	3	997	5. 6	0	0
	4	861	8. 8	4. 6	10. 2
Average		944	4. 4	1. 2	3. 1
18-V	1	857	4. 2	1. 0	0
	2	801	10. 5	4. 3	11. 4
	3	953	6. 5	0	0
	4	968	8. 2	3. 6	24. 9
Average		895	7. 4	2. 2	9. 1
19-S	1	929	4. 4	3. 8	0
	2	775	12. 9	4. 2	30. 2
	3	963	8. 2	1. 0	8. 1
	4	895	. 6	3. 1	26. 5
Average		890	6. 5	3. 0	16. 2
20-V	1	868	4. 1	5. 3	30. 2
	2	926	2. 3	0	20. 6
	3	1, 039	14. 8	0	0
	4	788	12. 9	6. 7	35. 6
Average		905	8. 5	3. 0	21. 6
21-V	1	858	. 6	4. 6	30. 1
	2	878	1. 7	2. 6	33. 4
	3	961	11. 3	1. 6	16. 0
	4	756	12. 4	8. 2	70. 4
Average		863	6. 5	4. 3	37. 5
22-V	1	998	. 8	0	0
	2	1, 001	. 5	0	0
	3	1, 050	4. 4	0	0
	4	975	3. 1	1. 5	2. 8
Average		1, 006	2. 2	. 4	. 7
23-V	1	886	3. 1	. 5	4. 9
	2	793	13. 2	2. 7	18. 3
	3	1, 036	13. 3	0	0
	4	941	3. 0	. 5	0
Average		914	8. 2	. 9	5. 8
24-V	1	817	. 5	5. 3	36. 2
	2	820	. 9	2. 1	23. 5
	3	889	9. 3	0	0
	4	725	10. 8	10. 8	21. 5
Average		813	5. 4	4. 5	20. 3
25-S	1	873	8. 9	0	3. 2
	2	757	5. 6	1. 6	22. 2
	3	807	. 6	0	11. 8
	4	771	3. 9	0	13. 0
Average		802	4. 8	. 4	12. 6
26-V	1	738	3. 1	1. 1	17. 0
	2	747	2. 0	1. 6	21. 4
	3	818	7. 3	0	3. 4
	4	743	2. 5	2. 1	32. 5
Average		762	3. 7	1. 2	18. 6
27-V	1	654	3. 5	6. 6	40. 4
	2	694	2. 4	6. 7	51. 7
	3	748	10. 3	2. 6	50. 1
	4	616	9. 1	6. 6	69. 5
Average		678	6. 3	5. 6	52. 9
28-V	1	795	1. 9	0	0
	2	782	. 3	0	7. 9
	3	821	5. 3	0	0
	4	722	7. 4	0	1. 5
Average		780	3. 7	0	2. 4
29-V	1	758	. 9	0	1. 2
	2	798	6. 3	0	0
	3	796	6. 0	0	0
	4	652	13. 2	9. 1	33. 8
Average		751	6. 6	2. 3	8. 8
30-V	1	761	5. 7	3. 8	15. 9
	2	843	4. 5	0	11. 9
	3	885	9. 7	0	7. 1
	4	739	8. 4	6. 7	29. 6
Average		807	7. 1	2. 6	16. 1
31-V	1	797	5. 7	0	0
	2	689	8. 6	0	0
	3	746	1. 1	0	0
	4	785	4. 1	0	0
Average		754	4. 9	0	0
32-S	1	854	17. 0	0	0
	2	701	4. 0	5. 2	20. 0
	3	738	1. 1	3. 1	11. 7
	4	625	14. 4	6. 3	29. 3
Average		730	9. 1	3. 7	15. 2

TABLE 5.—*Individual slab strengths, uniformity, and honeycomb*—Continued

Section no.	Slab no.	Modulus of rupture	Variation from average	Honeycomb	
				Break	Bottom
		Lbs. per sq.in.	*Percent*	*Percent*	*Percent*
33-V	1	716	6.3	1.0	0.7
	2	754	1.3	.5	0
	3	759	.7	0	0
	4	828	8.4	0	1.0
Average		764	4.2	.4	.4
34-V	1	835	2.5	0	0
	2	827	1.5	0	0
	3	821	.7	0	0
	4	777	4.7	0	0
Average		815	2.4	0	0
35-V	1	841	2.1	0	0
	2	829	.6	0	0
	3	811	1.6	0	0
	4	814	1.2	0	6.5
Average		824	1.4	0	1.6
36-V	1	613	15.7	6.7	42.8
	2	728	.1	0	21.0
	3	833	14.6	0	0
	4	734	1.0	2.1	8.2
Average		727	7.8	2.2	18.0
37-S	1	683	2.0	0	0
	2	736	5.6	1.1	7.1
	3	696	.1	0	0
	4	674	3.3	0	0
Average		697	2.8	.3	1.8
38-V	1	657	10.6	3.7	30.9
	2	756	2.9	0	0
	3	814	10.7	0	0
	4	714	2.9	.5	0
Average		735	6.8	1.0	7.7
39-V	1	547	14.8	10.8	54.9
	2	642	0	1.1	29.7
	3	763	18.8	0	13.0
	4	615	4.2	5.3	32.8
Average		642	9.4	4.3	32.6
40-V	1	751	5.2	0	0
	2	720	.8	0	0
	3	659	7.7	0	0
	4	724	1.4	0	0
Average		714	3.8	0	0
41-V	1	672	.4	0	0
	2	692	2.5	0	0
	3	635	5.9	0	0
	4	700	3.7	0	0
Average		675	3.1	0	0
42-V	1	663	.9	2.5	13.5
	2	674	.7	1.6	8.7
	3	676	1.0	0	0
	4	664	0.7	1.1	20.4
Average		669	0.8	1.3	10.6
43-V	1	776	12.1	0	0
	2	672	2.9	0	0
	3	689	.4	0	0
	4	631	8.8	1.0	0
Average		692	6.0	.2	0
44-S	1	703	2.8	0	2.2
	2	711	1.7	0	3.6
	3	725	.3	0	0
	4	754	4.3	0	0
Average		723	2.3	0	1.4
45-V	1	736	.8	0	3.7
	2	720	1.4	0	1.5
	3	728	.3	0	0
	4	735	.7	0	0
Average		730	.8	0	1.3
46-V	1	774	7.5	0	0
	2	690	4.2	0	0
	3	735	2.1	0	0
	4	679	5.7	0	0
Average		720	4.9	0	0
47-V	1	741	4.7	0	0
	2	691	2.4	0	0
	3	701	1.0	0	0
	4	699	1.3	0	0
Average		708	2.4	0	0
48-V	1	667	.5	0	0
	2	593	10.7	2.6	3.1
	3	684	3.0	0	0
	4	710	6.9	0	0
Average		664	5.3	.6	.8
49-S	1	901	5.5	1.1	0
	2	757	11.4	5.7	44.9
	3	850	.5	1.0	1.5
	4	909	6.4	1.0	2.0
Average		854	6.0	2.2	12.1
50-V	1	936	2.6	0	0
	2	920	4.3	0	5.4
	3	1,017	5.8	0	0
	4	970	.9	0	0
Average		961	3.4	0	1.4
51-V	1	766	7.5	5.5	32.6
	2	745	10.0	6.2	54.8
	3	912	10.1	0	10.3
	4	890	7.5	4.1	16.3
Average		828	8.8	3.9	28.5
52-V	1	954	.5	0	0
	2	880	7.3	3.1	0
	3	1,029	8.4	0	0
	4	932	1.8	0	0
Average		949	4.5	.8	0
53-V	1	992	1.8	0	0
	2	1,017	.7	0	5.6
	3	1,067	5.6	0	0
	4	962	4.7	0	0
Average		1,010	3.2	0	1.4
54-V	1	834	4.9	1.6	14.0
	2	854	2.6	2.1	20.5
	3	964	9.9	0	0
	4	857	2.3	1.6	5.9
Average		877	4.9	1.3	10.1
55-S	1	952	4.9	0	0
	2	863	5.0	.5	18.9
	3	936	3.1	0	10.9
	4	879	3.2	0	5.7
Average		908	4.0	.1	8.9
56-V	1	955	1.0	0	0
	2	959	.6	.5	4.2
	3	948	1.8	0	0
	4	998	3.4	0	0
Average		965	1.7	.1	1.0
57-V	1	1,010	6.7	0	0
	2	884	6.6	4.3	28.7
	3	976	3.1	0	0
	4	917	3.2	1.5	5.2
Average		947	4.9	1.4	8.5
58-V	1	1,006	1.7	0	0
	2	945	4.4	0	0
	3	1,024	3.5	0	0
	4	982	.7	0	0
Average		989	2.6	0	0
59-V	1	972	1.0	0	0
	2	930	3.3	0	0
	3	976	1.5	0	0
	4	970	.8	0	0
Average		962	1.6	0	0
60-V	1	871	8.4	0	0
	2	881	7.4	0	0
	3	1,151	21.0	0	0
	4	900	5.4	0	0
Average		951	10.6	0	0
61-S	1	767	4.4	0	0
	2	793	1.1	0	3.5
	3	794	1.0	0	3.3
	4	854	6.5	0	0
Average		802	3.2	0	1.7
62-V	1	[1] 462	------	0	0
	2	[1] 220	------	0	0
	3	833	1.8	0	0
	4	802	2.0	0	0
Average		818	1.9	0	0
63-V	1	858	.2	0	0
	2	889	3.4	0	0
	3	856	.5	0	0
	4	837	2.7	1.0	2.7
Average		860	1.7	.2	.7
64-V	1	867	.6	0	0
	2	857	.6	0	0
	3	882	2.3	0	0
	4	841	2.4	0	0
Average		862	1.5	0	0

[1] Not included in average.

TABLE 5.—*Individual slab strengths, uniformity, and honeycomb*—Continued

Section no.	Slab no.	Modulus of rupture	Variation from average	Honeycomb	
				Break	Bottom
		Lbs. per sq.in.	*Percent*	*Percent*	*Percent*
65-V	1	860	4.2	0	0
	2	813	1.5	0	0
	3	838	1.6	0	0
	4	790	4.2	2.0	2.8
Average		825	2.9	.5	.7
66-V	1	828	1.1	0	0
	2	831	1.5	0	0
	3	843	2.9	0	0
	4	775	5.4	3.1	4.3
Average		819	2.7	.8	1.1
67-S	1	789	9.0	0	3.0
	2	703	2.9	4.2	27.7
	3	694	4.1	0	0
	4	712	1.7	.5	4.6
Average		724	4.4	1.1	8.8
68-J	1	829	6.7	0	0
	2	737	5.1	2.7	19.9
	3	787	1.3	0	0
	4	756	2.7	2.1	15.2
Average		777	4.0	1.2	8.8
69-S	1	703	6.8	3.6	1.7
	2	618	6.1	4.2	28.4
	3	645	2.0	7.3	4.1
	4	668	1.5	2.0	13.4
Average		658	4.1	4.3	11.9
70-J	1	723	6.3	0	0
	2	684	.6	2.6	22.1
	3	633	6.9	.5	0
	4	681	.1	2.1	4.0
Average		680	3.5	1.3	6.5
71-S	1	701	5.3	.5	4.3
	2	611	8.3	3.6	57.2
	3	690	3.6	1.0	9.2
	4	661	.8	3.0	30.9
Average		666	4.5	2.0	25.4
72-J	1	711	5.6	0	0
	2	743	1.3	0	0
	3	812	7.8	0	3.7
	4	747	.8	0	0
Average		753	3.9	0	.9
73-S	1	598	4.8	3.1	3.2
	2	600	4.5	2.1	25.6
	3	660	5.1	0	0
	4	652	3.8	0	0
Average		628	4.6	1.3	7.2
74-J	1	655	3.8	0	0
	2	678	.4	1.6	9.4
	3	708	4.0	0	0
	4	684	.4	0	0
Average		681	2.2	.4	2.4
75-S	1	994	12.4	0	0
	2	842	4.8	5.8	23.5
	3	931	5.3	0	2.0
	4	771	12.8	5.2	3.7
Average		884	8.8	2.7	7.3
76-J	1	915	.3	0	0
	2	942	2.6	0	0
	3	908	1.1	0	0
	4	905	1.4	2.5	12.5
Average		918	1.4	.6	3.1
77-S	1	831	17.2	2.5	9.4
	2	745	5.1	11.3	36.9
	3	551	22.3	19.1	22.4
	4	710	.1	10.7	21.4
Average		709	11.2	10.9	22.5
78-J	1	818	9.9	0	0
	2	965	6.3	0	0
	3	977	7.6	0	0
	4	871	4.1	0	3.1
Average		908	7.0	0	.8
79-S	1	918	1.7	0	0
	2	870	6.8	2.1	9.5
	3	959	2.7	0	6.0
	4	987	5.7	0	3.4
Average		934	4.2	.5	4.7
80-J	1	1,096	3.2	0	0
	2	1,030	3.0	0	3
	3	1,075	1.2	0	0
	4	1,048	1.3	0	0
Average		1,062	2.2	0	.8
81-S	1	842	7.4	0	0
	2	617	21.3	10.3	15.4
	3	875	11.6	0	0
	4	802	2.3	2.1	1.6
Average		784	10.6	3.1	4.2
82-J	1	904	.7	0	0
	2	900	1.1	.5	4
	3	921	1.2	0	0
	4	917	.8	0	0
Average		910	1.0	.1	1
83-S	1	666	3.2	2.0	15.8
	2	678	1.5	1.0	20.7
	3	685	.4	3.8	27.2
	4	721	4.8	2.1	3.4
Average		688	2.5	2.2	16.8
84-J	1	696	3.9	0	0
	2	698	3.6	0	0
	3	753	4.0	.5	10.2
	4	748	3.3	0	0
Average		724	3.7	.1	2.6
85-S	1	638	5.1	0	0
	2	699	4.0	0	0
	3	674	.3	1.6	2.0
	4	678	.9	0	.7
Average		672	2.6	.4	.7
86-J	1	733	5.2	0	0
	2	711	2.0	0	0
	3	667	4.3	0	0
	4	678	2.7	0	0
Average		697	3.6	0	0
87-S	1	720	1.1	0	5.2
	2	709	.4	0	5.6
	3	683	4.1	0	4.9
	4	735	3.2	0	0
Average		712	2.2	0	3.9
88-J	1	733	3.0	1.1	0
	2	785	3.8	0	0
	3	765	1.2	1.0	2.8
	4	740	2.1	2.5	7.3
Average		756	2.5	1.2	2.5
89-S	1	612	4.8	1.0	0
	2	621	3.4	0	0
	3	651	1.2	.5	11.8
	4	688	7.0	0	0
Average		643	4.1	.4	3.0
90-J	1	654	.9	.5	.5
	2	665	.8	0	0
	3	670	1.5	.5	10.4
	4	653	1.1	0	4.7
Average		660	1.1	.3	3.9
91-S	1	924	8.8	0	0
	2	874	2.9	0	4.0
	3	738	13.1	12.9	23.0
	4	860	1.3	2.0	0
Average		849	6.5	3.7	6.8
92-J	1	910	2.6	0	0
	2	948	1.5	0	0
	3	906	3.0	1.5	4.7
	4	974	4.3	0	.4
Average		934	2.8	.4	1.3
93-S	1	794	2.5	0	0
	2	890	9.3	0	0
	3	760	6.6	3.3	17.4
	4	812	.2	4.0	.4
Average		814	4.6	1.8	4.4
94-J	1	872	1.1	0	0
	2	928	5.2	0	0
	3	918	4.1	0	0
	4	810	8.2	0	0
Average		882	4.6	0	0
95-S	1	892	5.1	.5	8.3
	2	884	4.1	0	11.6
	3	785	7.5	3.5	26.2
	4	834	1.8	1.0	0
Average		849	4.6	1.3	11.5
96-J	1	1,018	4.1	0	0
	2	1,016	3.9	0	0.9
	3	1,018	4.1	0	2.8
	4	862	11.9	0	0
Average		978	6.0	0	0.9

Table 5.—*Individual slab strengths, uniformity, and honeycomb*—Continued

Section No.	Slab No.	Modulus of rupture	Variation from average	Honeycomb		Section No.	Slab No.	Modulus of rupture	Variation from average	Honeycomb	
				Break	Bottom					Break	Bottom
		Lbs. per sq.in.	*Percent*	*Percent*	*Percent*			*Lbs. per sq.in.*	*Percent*	*Percent*	*Percent*
97-S	1	826	7.1	0	7.9	102-S	1	629	1.4	0	0
	2	832	7.9	0	10.3		2	649	1.7	0	0
	3	636	17.5	10.6	38.5		3	620	2.8	0	0
	4	789	2.3	2.7	2.2		4	654	2.5	0	0
Average	-----	771	8.7	3.2	14.7	Average	-----	638	2.1	0	0
98-J	1	852	5.1	0	2.9	103-J	1	717	1.6	0	0
	2	873	7.6	0	0		2	723	.8	0	0
	3	725	10.6	7.9	23.9		3	754	3.4	.5	0
	4	795	2.0	.5	4.1		4	721	1.1	0	0
Average	-----	811	6.3	2.1	7.7	Average	-----	729	1.7	.1	0
99-S	1	552	5.5	2.5	0	104-J	1	699	4.0	0	0
	2	532	8.9	2.5	0		2	763	4.8	0	0
	3	581	.5	.5	0		3	742	1.9	.5	0
	4	670	14.7	0	0		4	706	3.0	0	0
Average	-----	584	7.4	1.4	0	Average	-----	728	3.4	.1	0
100-S	1	689	.7	0	0	105-J	1	634	6.8	0	0
	2	677	2.4	0	0		2	704	3.5	0	0
	3	701	1.0	0	0		3	714	5.0	0	0
	4	708	2.0	0	0		4	667	1.9	0	0
Average	-----	694	1.5	0	0	Average	-----	680	4.3	0	0
101-S	1	618	3.0	0	0	106-J	1	705	.7	0	0
	2	639	.3	0	0		2	750	7.1	0	0
	3	634	.5	0	0		3	677	3.3	0	0
	4	657	3.1	0	0		4	668	4.6	0	0
Average	-----	637	1.7	0	0	Average	-----	700	3.9	0	0

concrete calculated on the assumption that the freshly mixed concrete is free from air voids. This, of course, is not absolutely true. However, tests of concrete similar to that used in series B, where the difference in consistency of the concretes finished by the two methods was not great (ranging from about 1½ inches to 3 inches in slump), have shown that the error introduced by not correcting for air voids is small and reasonably constant and therefore may be neglected. On this basis a comparison of the two values for density may be used as a rough measure of the amount of water loss taking place during consolidation. In other words, it may be assumed that the increase in density of the hardened concrete as compared with the density of the plastic concrete is due to the elimination of water only. The significance of these values is discussed in that portion of the report dealing with series B.

Values for absorption, apparent specific gravity, and final density are shown in table 6.

Determination of honeycomb.—The extent and distribution of visible honeycomb in the test slabs was carefully determined by measurement of the fractured slabs remaining after the flexure test. The actual area of honeycomb on the bottom of each 27-inch by 60-inch slab was determined by means of a wire grid having 1-inch square openings laid upon the surface. (See fig. 1.) The amount of honeycomb in the cross section at the break was determined by plotting the honeycomb area on cross-section paper. These procedures provided an accurate method of determining the percentage of the bottom surface which contained honeycomb areas exceeding approximately one fourth inch in depth and the percentage of honeycomb at the break. The average percentage of honeycomb for an entire section as used in the discussion is the average of 8 determinations, 1 on the bottom and 1 at the plane of fracture for each of the 4 test slabs composing the section. The results of all determinations of honeycomb are shown in table 5, in connection with the results of flexure tests on the individual slabs.

Table 6.—*Specific gravity, density, and absorption tests of cores*

Section no. and finish	Specific gravity			Density			Absorption		
	(1)	(2)	Average	(1)	(2)	Average	(1)	(2)	Average
				Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1-S	2.32	2.31	2.32	88.1	87.7	87.9	5.00	5.14	5.07
2-V	2.34	2.31	2.32	88.8	87.7	88.2	4.07	5.23	4.65
3-V	2.32	2.33	2.32	88.1	88.4	88.2	5.19	4.46	4.82
4-V	2.33	2.31	2.32	88.5	87.8	88.2	5.01	5.35	5.18
5-V	2.37	2.31	2.34	90.2	87.9	89.0	4.10	5.20	4.65
6-V	2.35	2.32	2.34	89.5	88.4	89.0	4.31	4.96	4.64
7-S	2.28	2.28	2.28	86.4	86.4	86.4	5.57	5.73	5.65
8-V	2.28	2.31	2.30	86.4	87.6	87.0	5.42	5.10	5.26
9-V	2.29	2.30	2.30	86.8	87.2	87.0	4.70	4.86	4.78
10-V	2.27	2.30	2.28	86.2	87.4	86.8	5.96	5.06	5.51
11-V	2.33	2.28	2.30	88.6	86.7	87.6	4.93	5.13	5.03
12-V	2.28	2.33	2.30	86.8	88.7	87.8	5.18	4.64	4.91
13-S	2.35	2.36	2.36	84.8	85.1	85.0	5.40	5.21	5.30
14-V	2.36	2.38	2.37	85.1	85.9	85.5	5.16	4.38	4.77
15-V	2.36	2.38	2.37	85.1	85.9	85.5	4.97	4.70	4.84
16-V	2.38	2.37	2.38	85.9	85.5	85.7	5.10	5.18	5.14
17-V	2.38	2.36	2.37	85.9	85.1	85.5	4.97	4.91	4.94
18-V	2.39	2.39	2.39	86.2	86.2	86.2	4.38	4.72	4.55
19-S	2.36	2.38	2.37	84.9	85.6	85.2	5.44	5.01	5.22
20-V	2.37	2.38	2.38	85.3	85.6	85.4	4.66	4.66	4.66
21-V	2.38	2.37	2.38	85.6	85.3	85.4	4.63	4.96	4.80
22-V	2.39	2.38	2.38	86.0	85.6	85.8	4.93	5.07	5.00
23-V	2.36	2.39	2.38	84.9	86.0	85.4	5.00	5.03	5.02
24-V	2.38	2.38	2.38	85.6	85.6	85.6	4.74	4.64	4.69
25-S	2.15	2.26	2.20	84.2	88.5	86.4	7.38	6.70	7.04
26-V	2.16	2.19	2.18	84.6	85.8	85.2	6.99	6.37	6.68
27-V	2.16	2.16	2.16	84.6	84.6	84.6	6.97	6.63	6.80
28-V	2.18	2.19	2.18	86.0	86.4	86.2	6.71	6.43	6.57
29-V	2.16	2.17	2.16	85.3	85.7	85.5	6.94	6.59	6.76
30-V	2.17	2.20	2.18	85.9	87.1	86.5	6.96	6.31	6.64
31-V	2.14	2.15	2.14	84.1	84.5	84.3	8.10	7.98	8.04
32-S	2.15	2.13	2.14	84.5	83.7	84.1	8.36	8.09	8.22
33-V	2.14	2.17	2.16	84.1	85.3	84.7	7.51	7.46	7.48
34-V	2.12	2.16	2.14	83.9	85.5	84.7	8.19	7.97	8.08
35-V	2.15	2.13	2.14	85.3	84.5	84.9	7.94	8.24	8.09
36-V	2.14	2.14	2.14	85.0	85.0	85.0	7.86	7.61	7.74
37-S	2.32	2.29	2.30	88.1	86.9	87.5	4.77	5.13	4.95
38-V	2.32	2.32	2.32	88.1	88.1	88.1	4.81	4.83	4.82
39-V	2.31	2.33	2.32	87.7	88.4	88.0	4.84	4.28	4.56
40-V	2.33	2.33	2.33	88.5	88.5	88.5	4.26	4.35	4.30
41-V	2.35	2.33	2.34	89.4	88.7	89.0	3.83	4.32	4.08
42-V	2.37	2.36	2.36	90.3	89.9	90.1	3.95	3.62	3.78
43-V	2.29	2.32	2.30	86.8	88.0	87.4	5.30	4.88	5.09
44-S	2.28	2.29	2.28	86.4	86.8	86.6	5.47	5.28	5.38
45-V	2.33	2.30	2.32	88.3	87.2	87.8	4.84	5.07	4.96
46-V	2.32	2.32	2.32	88.1	88.1	88.1	4.94	4.74	4.84
47-V	2.32	2.32	2.32	88.2	88.2	88.2	5.12	4.83	4.98
48-V	2.33	2.33	2.33	88.7	88.7	88.7	4.70	4.75	4.72
49-S	2.37	2.38	2.38	85.5	85.9	85.7	4.44	4.99	4.72
50-V	2.41	2.41	2.41	86.9	86.9	86.9	4.40	3.77	4.08
51-V	2.38	2.39	2.38	85.9	86.2	86.0	4.86	4.53	4.70
52-V	2.38	2.40	2.39	85.9	86.6	86.2	4.80	4.64	4.72
53-V	2.38	2.42	2.40	85.9	87.3	86.6	4.82	3.92	4.37
54-V	2.42	2.42	2.42	87.3	87.3	87.3	4.32	3.84	4.08
55-S	2.34	2.38	2.36	84.2	85.6	84.9	5.80	4.56	5.18
56-V	2.37	2.37	2.37	85.3	85.3	85.3	5.05	4.64	4.84
57-V	2.36	2.37	2.36	84.9	85.3	85.1	5.08	5.10	5.09
58-V	2.37	2.37	2.37	85.3	85.3	85.3	5.31	5.31	5.31
59-V	2.39	2.40	2.40	86.0	86.3	86.2	4.48	5.04	4.76
60-V	2.42	2.40	2.41	87.1	86.3	86.7	4.37	4.63	4.50
61-S	2.16	2.14	2.15	84.6	83.9	84.2	7.91	8.32	8.12
62-V	2.17	2.16	2.16	85.0	84.6	84.8	7.36	7.29	7.32
63-V	2.21	2.17	2.19	86.6	85.0	85.8	6.89	7.03	6.96
64-V	2.19	2.18	2.18	86.4	86.0	86.2	7.41	7.34	7.38
65-V	2.19	2.17	2.18	86.5	85.7	86.1	7.24	7.21	7.22
66-V	2.16	2.18	2.17	85.5	86.3	85.9	7.14	6.87	7.00
67-S	2.30	2.31	2.30	87.3	87.7	87.5	5.28	5.02	5.15
68-J	2.36	2.33	2.34	89.6	88.4	89.0	4.11	4.88	4.50
69-S	2.31	2.35	2.33	88.0	89.5	88.8	4.77	4.45	4.61
70-J	2.32	2.36	2.34	88.4	89.9	89.2	4.75	4.35	4.55
71-S	2.28	2.32	2.30	86.4	88.0	87.2	5.26	4.90	5.08
72-J	2.31	2.30	2.30	87.6	87.2	87.4	5.20	5.36	5.28
73-S	2.24	2.30	2.27	85.4	87.7	86.6	5.79	5.18	5.48
74-J	2.31	2.31	2.31	88.0	88.0	88.0	5.02	5.01	5.02
75-S	2.38	2.40	2.39	85.8	86.6	86.2	5.04	4.79	4.92
76-J	2.39	2.40	2.40	86.2	86.6	86.4	4.15	4.70	4.42
77-S	2.37	2.37	2.37	85.6	85.6	85.6	4.74	5.22	4.98
78-J	2.39	2.40	2.40	86.4	86.7	86.6	4.90	4.87	4.88
79-S	2.37	2.34	2.36	85.2	84.2	84.7	5.54	5.95	5.74
80-J	2.40	2.37	2.38	86.3	85.2	85.8	4.69	5.45	5.07
81-S	2.35	2.34	2.34	84.9	84.5	84.7	5.55	5.75	5.65
82-J	2.37	2.39	2.38	85.6	86.3	86.0	5.17	4.97	5.07
83-S	2.29	2.33	2.31	86.9	88.4	87.6	5.37	5.44	5.40
84-J	2.34	2.36	2.35	88.8	89.6	89.2	4.59	3.82	4.20
85-S	2.31	2.29	2.30	88.0	87.2	87.6	4.97	5.23	5.10
86-J	2.30	2.36	2.33	87.6	89.9	88.8	5.30	3.85	4.58
87-S	2.32	2.28	2.30	88.0	86.4	87.2	4.66	5.39	5.02
88-J	2.29	2.35	2.32	86.8	89.1	88.0	5.43	3.93	4.68
89-S	2.29	2.28	2.28	87.3	86.9	87.1	5.11	5.39	5.25
90-J	2.27	2.31	2.29	86.5	88.0	87.2	5.55	5.11	5.33
91-S	2.35	2.39	2.37	84.8	86.2	85.5	5.42	4.29	4.86
92-J	2.38	2.43	2.40	85.8	87.7	86.8	4.77	4.20	4.48
93-S	2.38	2.39	2.38	86.0	86.4	86.2	3.92	4.09	4.00
94-J	2.40	2.38	2.39	86.7	86.0	86.4	4.03	4.89	4.46
95-S	2.36	2.36	2.36	84.9	84.9	84.9	5.51	5.40	5.46
96-J	2.36	2.39	2.38	84.9	86.0	85.4	5.30	4.84	5.07
97-S	2.31	2.35	2.33	83.4	84.9	84.2	6.05	5.63	5.84
98-J	2.36	2.37	2.36	85.2	85.6	85.4	5.19	5.26	5.22
99-S	2.08	2.08	2.08	77.2	77.2	77.2	8.16	7.97	8.06
103-J	2.10	2.13	2.12	78.0	79.1	78.6	7.78	7.46	7.62
101-S	2.08	2.08	2.08	77.4	77.4	77.4	8.11	8.09	8.10
105-J	2.14	2.14	2.14	79.6	79.6	79.6	7.17	7.02	7.10
100-S	2.09	2.07	2.08	77.6	76.8	77.2	7.80	8.56	8.18
104-J	2.12	2.14	2.13	78.7	79.4	79.0	7.40	7.03	7.22
102-S	2.06	2.06	2.06	76.6	76.6	76.6	8.43	7.90	8.16
106-J	2.15	2.15	2.15	80.0	80.0	80.0	6.64	7.09	6.86

FIGURE 1.—ILLUSTRATING USE OF GRID WITH 1-INCH SQUARE OPENINGS FOR MEASURING HONEYCOMB.

Determination of surface wear.—Determinations of the surface hardness of the test slabs were made with a special device designed by the Bureau and described in detail in Public Roads for July 1929. The hardness testing machine consists essentially of a vertical shaft carrying a frame upon which are mounted three steel wheels. The wheels roll on the concrete in a circular path 21 inches in diameter and gradually wear a narrow groove in the surface, the depth of which, after a given number of revolutions, is used as a measure of the hardness of the mortar surface. Care is taken to see that the wear is confined to the mortar surface only so as to avoid variations due to any difference in hardness of the mortar and the coarse aggregate. (See fig. 2.)

The results of the strength tests, together with data showing the amount of honeycombing existing in each test slab, the density, absorption, and resistance to wear of the concrete, form the basis of comparison used in this report to determine the effect of the methods of finishing on quality.

In all, one hundred and six 9-foot sections were cast during this investigation, 66 in connection with the investigation of the effect of vibration and 40 in connection with the tests of the Johnson method. The first slabs were cast on September 10, 1931, and the last on October 5, 1931, progress being at the rate of 6 slabs per day for the vibration series and 8 slabs per day for the Johnson series.

FIGURE 2.—GROOVE WORN IN SURFACE AFTER 600 REVOLUTIONS OF HARDNESS TESTING MACHINE; CIRCLE 21 INCHES IN DIAMETER.

SERIES A: TESTS TO DETERMINE EFFECT OF VIBRATION

For this series of tests a standard double-screed finishing machine was equipped with 3 high-frequency vibrators, 2 mounted on the front screed and 1 on the rear screed. (See fig. 4.) Each vibrator consisted of a ⅓-horsepower electric motor operating at an approximate speed of 3,600 revolutions per minute. There was attached to the rotor of each motor an eccentric weight which, revolving at high speed, imparted a vibratory motion to the screed. The motors were operated with current supplied from a gasoline-electric generator unit mounted on the finishing machine.

The only modification of the finishing machine as ordinarily used, other than the installation of the vibrators, was the use of a "bull-nose" strike-off which was riveted to the front screed. A view of the finishing machine showing the special strike-off is shown in figure 3. This device was furnished and recommended by the manufacturer of the finishing machine on the theory that the rounded surface of the "bull-nose" would tend to consolidate as well as strike off the surface of the concrete.

In general, the finishing machine was operated at about the same forward speed as is customarily used. The number of passes was limited to three as in the former tests, this being considered the maximum allowable from the standpoint of production. However, it was found necessary to exceed two passes in only five cases.

With the set-up as described above the vibrations could be distinctly felt by a person standing on the ground outside the line of forms. Attention, however, should be called to the fact that the usual standard-weight screeds were employed in this work. These screeds with attachments weigh approximately the same per foot of length for various widths of road. It is probable that a somewhat greater vibratory effect would have been obtained had the machine been equipped with lighter screeds. A somewhat greater effect would probably have been obtained, even with the standard screeds, had an 18- or 20-foot section been tested instead of a 9-foot section.

DRIER MIXES SATISFACTORY IF CONCRETE IS VIBRATED

Results of tests in which vibrated concrete is compared with concrete placed by the standard method lead to the following conclusions:

1. By the use of vibrating equipment of the same general type as employed in connection with these tests it should be possible satisfactorily to place and finish considerably drier concrete than is possible with methods now in common use.

2. For conditions comparable to these tests, it should be possible satisfactorily to place and finish by vibration concrete having a minimum slump of 1 inch as compared to a minimum slump of 2½ inches for methods now in common use.

3. These tests indicate that, depending on the type of coarse aggregate used, concrete containing from one fourth to three fourths part more coarse aggregate than the base mix, if vibrated, should show as great uniformity and as high flexural strength as the base mix finished by methods now in common use. Such a mix will contain approximately from 0.2 to 0.6 sack of cement per cubic yard less than the base mix.

4. The indications are that the effect of vibration is more marked where angular coarse aggregates are used than where aggregates having rounded surfaces are used.

5. In general, it appears from the results of these tests that the proper use of the vibratory method of finishing should result in an improvement of the quality of concrete pavements.

BASE MIX ESTABLISHED FOR STANDARD OF COMPARISON

For each combination of fine and coarse aggregate, a so-called "base mix" was established. This base mix was designed so that the combinations containing the coarse sand would have a cement factor of approximately 6 sacks per cubic yard. For the corresponding mixes with fine sand the proportion of sand was reduced so as to compensate for the differences in grading without changing the water-cement ratio or the proportion of coarse aggregate. Preliminary laboratory tests indicated a reduction in sand content of one tenth part in the case of gravel and two tenths part in the case of stone and slag. This procedure resulted in the use of slightly higher cement factors for the fine sand mixes, the maximum difference being 0.3 sack in the case of the stone concrete. Values of b/b_0, dry-rodded, ranged from 0.73 to 0.78, depending upon the materials being combined. Each of these base mixes was designed to produce concrete with a slump of about 2 inches and was used in a section constructed without vibration as a standard of comparison. For each standard section there were contructed five sections in all of which the concrete was somewhat drier than the standard and all of which were vibrated. In two of the vibrated sections the proportions were the same as the standard or base mix and the drier consistency was obtained by lowering the water content until slumps of approximately one inch and one half inch were obtained. In the other three the water-cement ratio used in the standard or base mix was maintained constant and the drier consistency was secured by adding respectively one fourth, one half, and three fourths parts coarse aggregate by volume to the base proportion. A set of 6 sections, 1 screeded and 5 vibrated, formed 1 day's run. As previously noted, the proportions, slump, water-cement ratio and other data for each section comprising series A are shown in table 2. With the exception of the slag in combination with fine sand, two complete rounds were run, making a total of 66 sections, two with each aggregate combination.

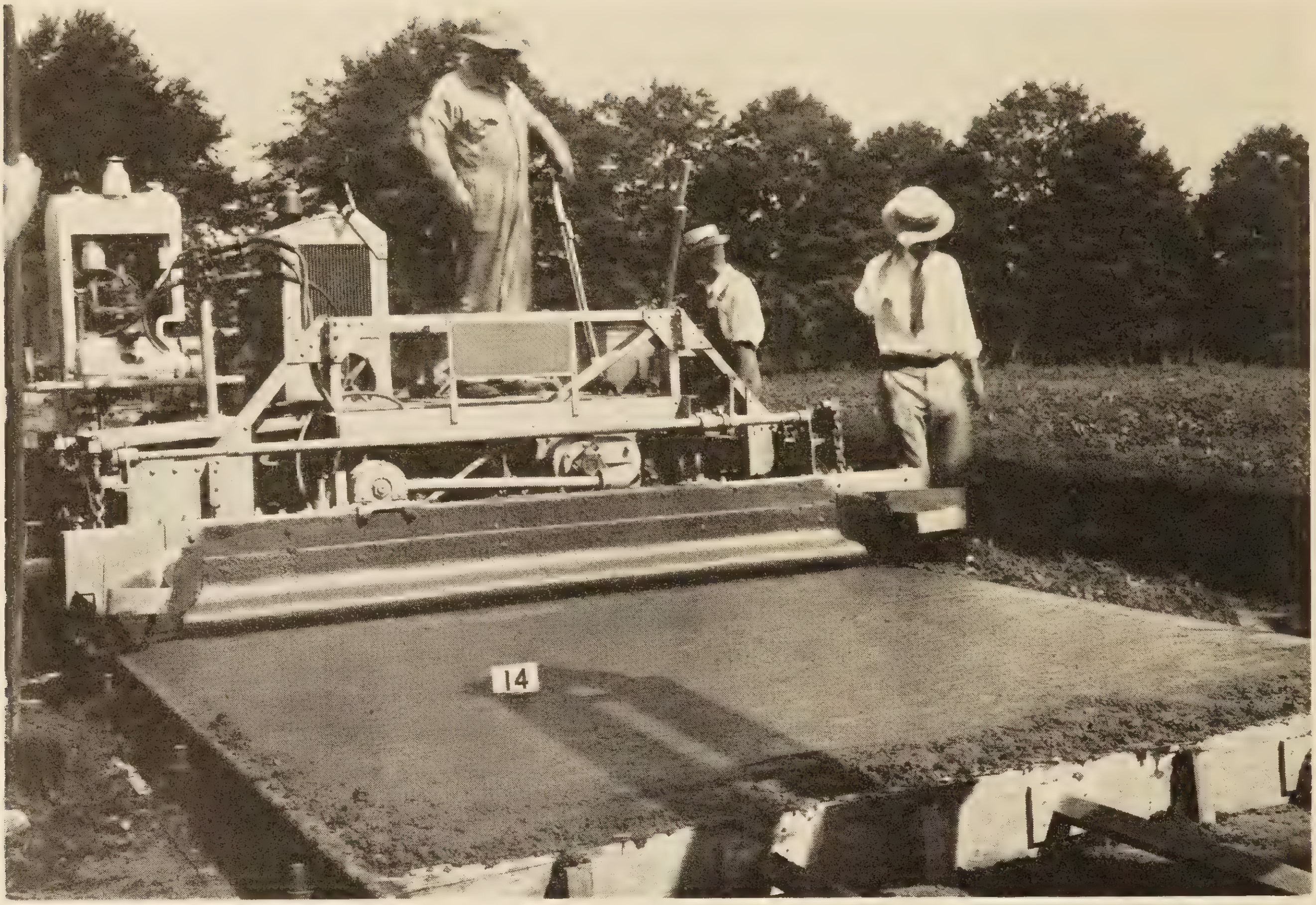


Figure 3.—Section 14 After First Passage of Finishing Machine, Showing "Bull-Nose" Attached to Front Screed.

RESULTS OF TESTS DISCUSSED IN DETAIL

The data are discussed first with the idea of showing in a broad general way the effect of vibration on the average of all comparable concretes containing the various aggregate combinations as compared to the base mix which was placed as the standard of comparison. Thus, on the basis of proportions as shown in table 2, the results of tests on sections 2, 8, 14, 20, 38, 43, 50, and 56 have been averaged and are compared to a similar average of the eight corresponding base sections (sections 1, 7, 13, 19, 37, etc.) to give a general picture of the effect of reducing the slump to about 1 inch without changing the proportions. In a similar way, the average results on sections 3, 9, 15, 21, etc., are compared to the base mix, and so on. It will be noted that each average value for slab strength obtained as above noted includes the results of two tests on each of four aggregate combinations; that is, gravel with coarse sand, gravel with fine sand, crushed stone with coarse sand, and crushed stone with fine sand. Each value therefore represents the average of 32 individual tests. It is felt that these four combinations represent fairly well the typical aggregates in use at the present time. The results for slag are not included in this grouping, first, because slag is not a typical aggregate from the standpoint of distribution and, second, because in the second round slag was not tested in combination with fine sand so that an average including slag could not be obtained from a series containing an equal number of tests of each combination.

The discussion of the data from the above standpoint is followed by a comparison of the effect of variations in material type combinations; that is, the effect of vibration on gravel concrete versus crushed stone concrete, etc. This, in turn, is followed by a detailed discussion of uniformity as revealed by a comparison of the strength and percentage of honeycomb in each of the four test slabs comprising each test section. It is felt that a study of the data from this standpoint is equally as important as a discussion of average results because of the fact that uniformity of quality may be considered as important a characteristic as average quality.

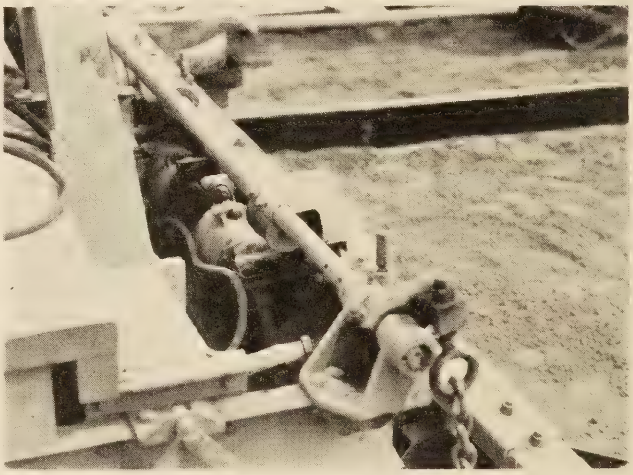
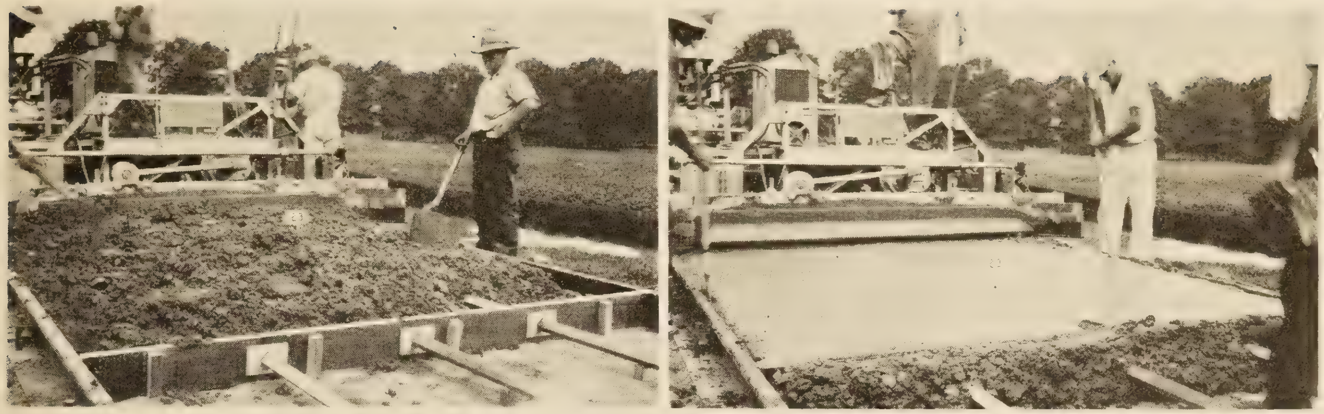


Figure 4.—Showing Electric Vibrating Motor Mounted on Front Screed.



Before Finishing. *After First Passage of Finishing Machine.*

Figure 5.—Section 23, Vibrated. Aggregates, Fine Sand and Crushed Stone; Proportions, 1:1.7:3.8; Slump, 1¼ Inches.

AVERAGE RESULTS SHOW EFFECT OF VIBRATION FAVORABLE WITH 1-INCH SLUMP; ½-INCH SLUMP TOO DRY

The average values for the test results calculated as indicated above are shown in figure 6. In this graph and in those which follow lines have been drawn between the plotted values of crushing strength, modulus of rupture, honeycomb, and strength variation in order to show the trends in the values of these quantities with the indicated variations in slump, water-cement ratio, proportions, and type of finish. These curves should not be looked upon as indicating definite quantitative relations, since the abscissa in no case represents a scalar quantity.

An inspection of this chart reveals a number of interesting general relations. For instance, it will be noted that the vibrated slabs containing the base mix at 1-inch slump (values shown in the second column of figure 6) show somewhat higher strengths and somewhat less honeycomb than the standard-finish base mix at 2-inch slump (column 1). In view of our experience in the first series, where the use of a consistency less than 2-inch slump when finished in the usual way resulted in lower slab strength and increased honeycomb, it seems reasonable to assume that the improvement in quality is due to the method of finishing; that is, the use of vibration. However, when we come to the vibrated base mix at ½-inch slump (column 3) we find a decrease in slab strength as well as a marked increase in honeycomb and less uniformity in strength. This would indicate obviously that the ½-inch slump is too dry for satisfactory placement, even with the use of vibrators as operated in these tests. The only increase in strength for this mix is noted in connection with the crushing strength of cores drilled from the sections. However, this lack of concordance between flexural and crushing strength is not surprising for the following reason: As noted previously, considerable care was taken in drilling cores to select portions of the slabs free from honeycomb. Since a badly honeycombed core would not be tested in ordinary work it was deemed best to confine these tests to sound, homogeneous concrete insofar as possible and to study the effect of honeycomb through a study of variations in flexural strength as well as by direct measurement of the amount of honeycomb in each slab. With the exception of the sections in group 3 (½-inch slump) the spread between core and cylinder strength is just about as great for the standard-finish sections as for the vibrated sections. This would indicate that, except in the case of the very dry mixes, the relatively higher core strengths are not due to the effect of vibration. In the case of the concrete having a ½-inch slump it is probable that vibration did tend to increase the crushing strength of the con-

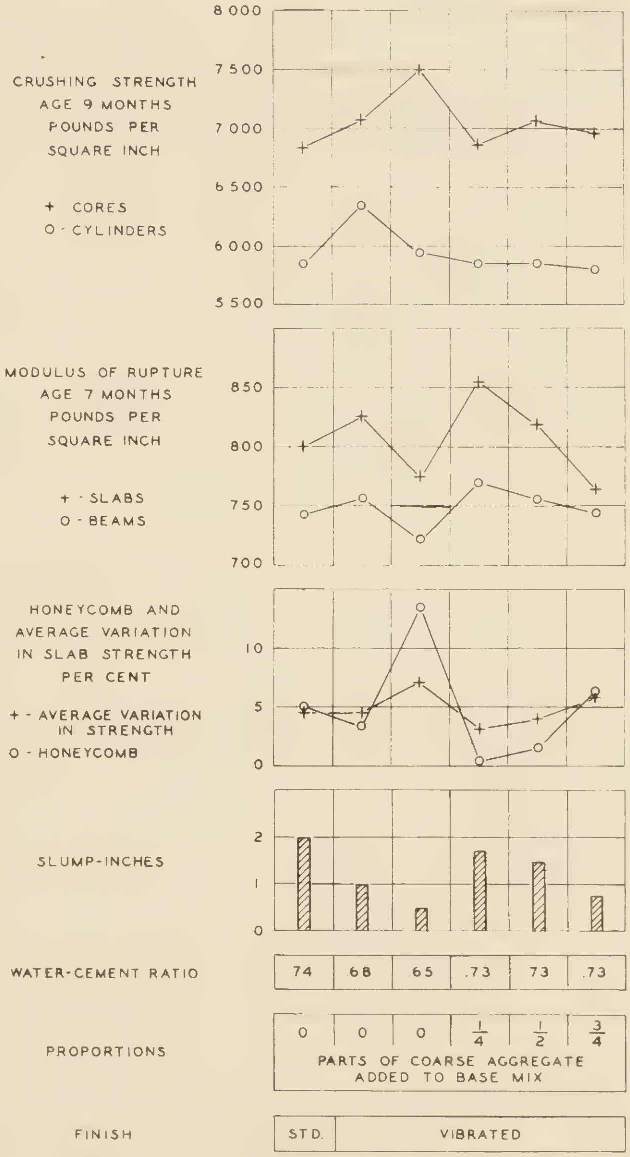


Figure 6.—Series A, Effect of Vibration; Averages for Sections Containing Gravel and Crushed Stone.

crete. On the other hand, the cylinders showed a decrease due to the fact that the ½-inch slump concrete was probably outside the range of consistency to which the laboratory relation between water-cement ratio and strength applies.

ADDITION OF ONE-FOURTH PART COARSE AGGREGATE INCREASES FLEXURAL STRENGTH AND UNIFORMITY OF VIBRATED SECTIONS

Let us examine next the three groups of sections in which the slump was decreased by increasing the proportion of coarse aggregate instead of reducing the water-cement ratio (columns 4, 5, and 6). It will be observed that the addition of coarse aggregate does not affect the crushing strength of the concrete, but that the flexural strength of the vibrated slabs is increased by the addition of one-fourth part coarse aggregate and is reduced as the amount of coarse aggregate is increased beyond one-fourth part. These trends seem entirely reasonable when we consider that the core strengths are not affected to the same extent as flexural strength by variations in the uniformity of the concrete in the slab. It is interesting to note that, from the standpoint of average flexural strength, as well as from that of uniformity in strength, the sections in group 4, containing one-fourth part additional coarse aggregate, show the best results. It is true that variations in neither strength nor uniformity are of considerable magnitude, the maximum difference in slab strength (column 4 as compared to column 6) being only about 12 percent of the strength of the base mix. The various trends, however, are so consistent and appear so reasonable from a theoretical point of view that they may be assumed to be indicative of real variations in quality and so may be used as the basis for conclusions as to the effect of finishing on the results.

AGGREGATE COMBINATIONS STUDIED SEPARATELY

The next step will be to examine the various material combinations individually in order to ascertain to what extent variations in materials may affect the results. The values for each of the six combinations from which the general averages were obtained have been regrouped in figures 7, 8, and 10, so as to bring out these relationships. The results obtained with gravel as coarse aggregate are plotted in figure 7, with similar data for crushed stone in figure 8. It will be observed that for similar mixes and methods of finishing the sections containing crushed stone, as coarse aggregate show somewhat higher crushing strengths and considerably higher flexural strengths than the sections containing gravel. Attention should be called to the fact that these differences are due to variations in the physical properties of

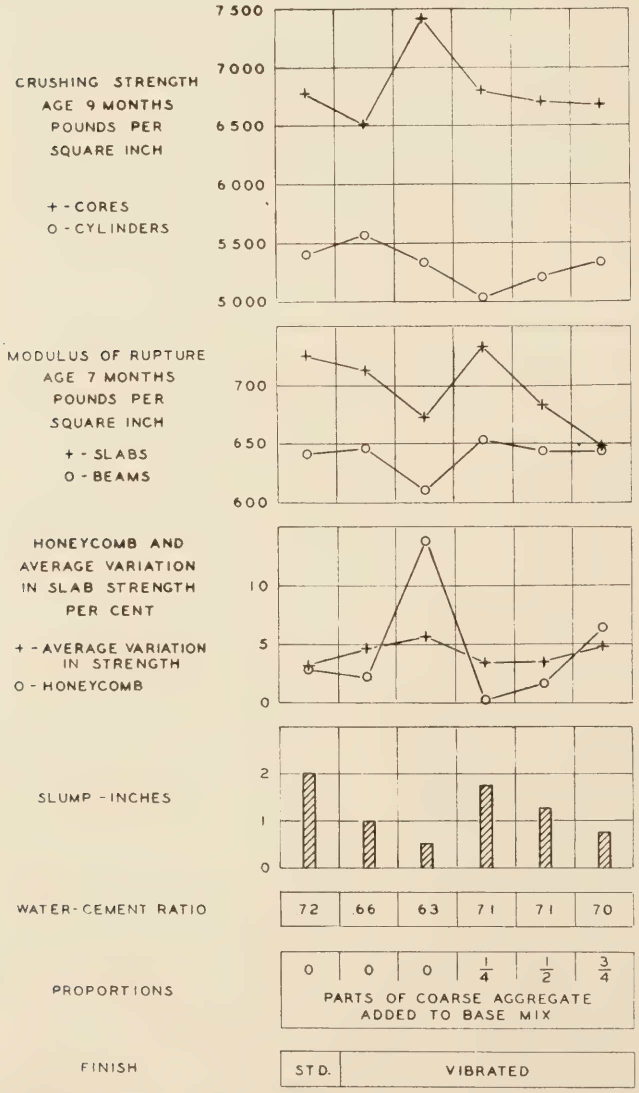


Figure 7.—Series A, Effect of Vibration; Averages for Sections Containing Gravel.

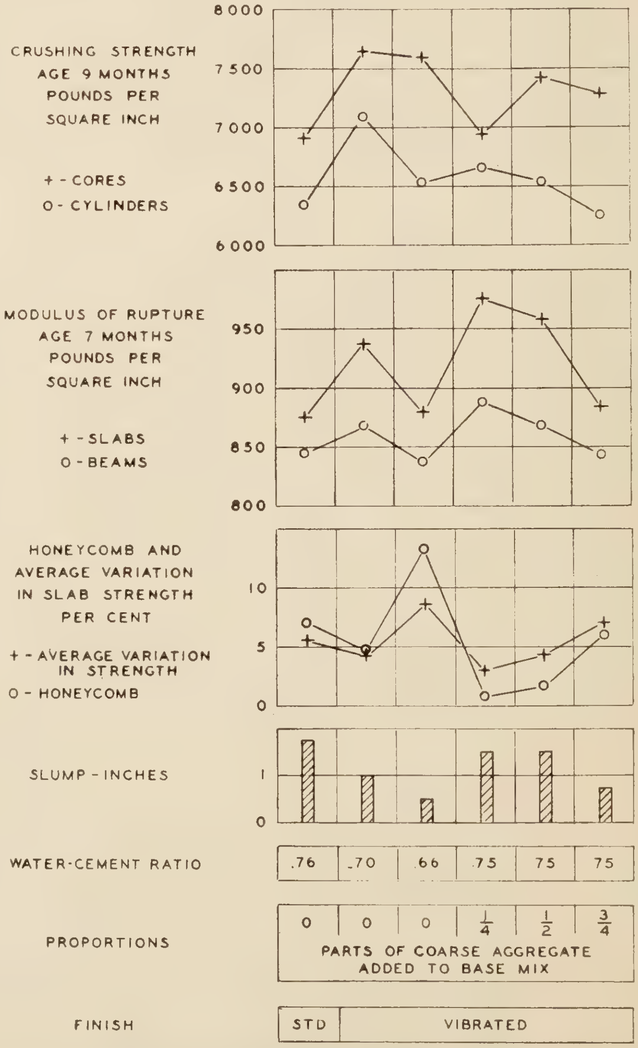


Figure 8.—Series A, Effect of Vibration; Averages for Sections Containing Crushed Stone.

the particular aggregates used in these tests and not merely to the fact that one aggregate happens to be crushed stone and the other gravel. Aggregates from other sources might well have shown entirely different relative strengths both in compression and in flexure. In figure 10 the average results of tests on concrete containing gravel and crushed stone in combination with coarse sand are compared to the corresponding averages for concrete containing fine sand. The results obtained with slag, which were not included in the general average are shown in figure 9.

An inspection of each chart reveals, in general, the same trends as are shown in figure 6. In all cases the highest slab strength as well as the least honeycomb is found in the vibrated group containing one fourth part additional coarse aggregate (column 4 in each figure). Likewise, increasing the quantity of coarse aggregate beyond one fourth part in all cases decreased the slab strength as well as the uniformity of the concrete as compared with results obtained with one fourth additional part. The curves showing these relations are remarkably consistent for all three coarse aggregate types. It will be noted also that in the sections containing crushed stone and slag even the concrete containing the largest amount of coarse aggregate (column 6 of figs. 8 and 9) is higher in flexural strength than the base mix unvibrated. Uniformity, also, is just about as good.

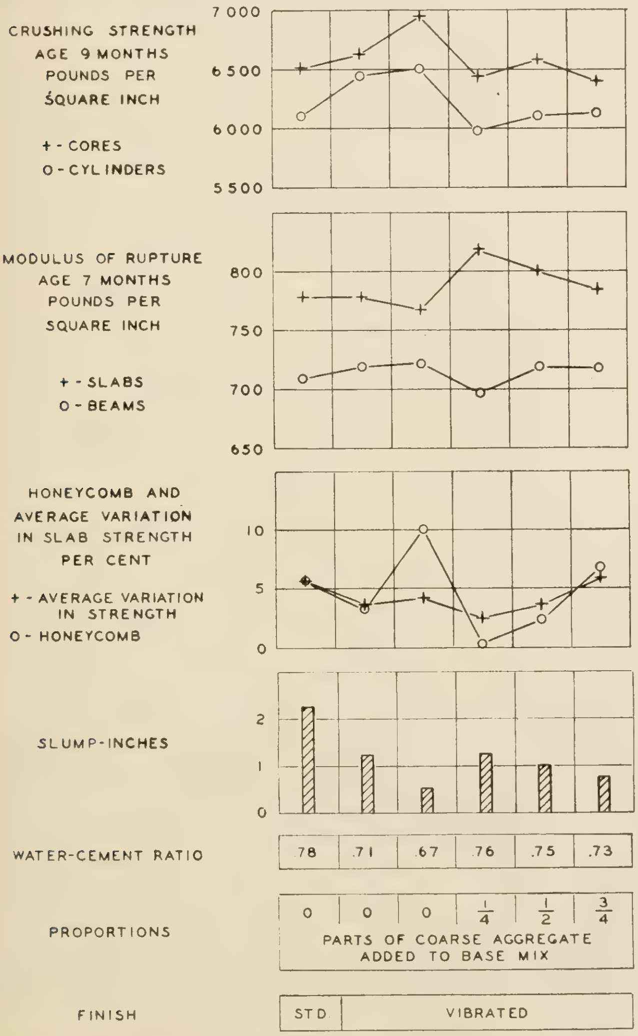


FIGURE 9.—SERIES A, EFFECT OF VIBRATION; AVERAGES FOR SECTIONS CONTAINING SLAG.

The effect of vibration on slab strength is most marked in the case of crushed stone (fig. 8) and least in the case of gravel (fig. 7). This may be observed by comparing the slab strength of the unvibrated concrete (column 1 in each case) with the strengths of the corresponding vibrated sections. In the case of crushed stone all but the very dry concretes (columns 3 and 6) show marked increase in slab strength under vibration. In the case of gravel, group 4 containing one fourth part additional coarse aggregate, is the only one showing higher slab strength than the base or unvibrated concrete. In the case of slag, the three sections carrying additional coarse aggregate are higher in strength than the unvibrated base mix. Both the crushed stone and slag concretes containing the drier mixes (columns 3 and 6 of figs. 8 and 9) show slab strength about equal to the unvibrated concrete in spite of the fact that group 3 in each case has considerably more honeycomb than the base mix. It is interesting to note that, in general, the uniformity of the slag concrete is as good as that shown for crushed stone and gravel.

The inability of the vibrators to finish very dry croncrete (½-inch slump) is shown by the relatively low strengths and high percentages of honeycomb in the slabs comprising the third group in each case (column 3 of figs. 7, 8, and 9). Variation in consistency apparently had a smaller effect on the slab strength of slag concrete than either of the other coarse aggregates. Somewhat less honeycomb in the case of the dry mix (group 3) may also be noted. The marked difference in crushing strength of gravel concrete cylinders with respect to cores as compared to similar results with crushed stone and slag should also be noted. In the former case the cores average about 1,500 pounds per square inch higher than the cylinders, which is a considerably greater difference than is shown for either the stone or slag concrete.

COARSE VERSUS FINE SAND

In figure 10, the test results for all sections using crushed stone and gravel in combination with coarse sand as fine aggregate have been averaged and are compared to the results for the corresponding concretes in which the fine sand was used.

The same general relationships appear except that the adverse effect of using the dry mix is more marked in the case of coarse sand. The average slump is, however, considerably lower; that is, ⅛ inch as compared to ½ inch for the fine sand. The average difference in slab strength as compared to beam strength is more marked in the case of the fine sand, especially for the unvibrated concrete and for the two groups of vibrated concrete containing the base mix with lower water-cement ratio. The tendency for the slab strengths to drop at a greater rate than the beam strengths for increasing percentages of coarse aggregate should also be noted in this as well as in the other graphs. The general agreement between the results of strength tests on cores, cylinders, and beams for concretes having practically the same water-cement ratio (columns 1, 4, 5, and 6) is also of interest.

UNIFORMITY OF INDIVIDUAL SECTIONS COMPARED

In order to bring out clearly the effect of honeycomb on slab strength the results of the tests for flexural strength of each of the four 27-inch slabs in each test section have been plotted in figures 12, 13, and 14. The data are also shown in table 5. These are the

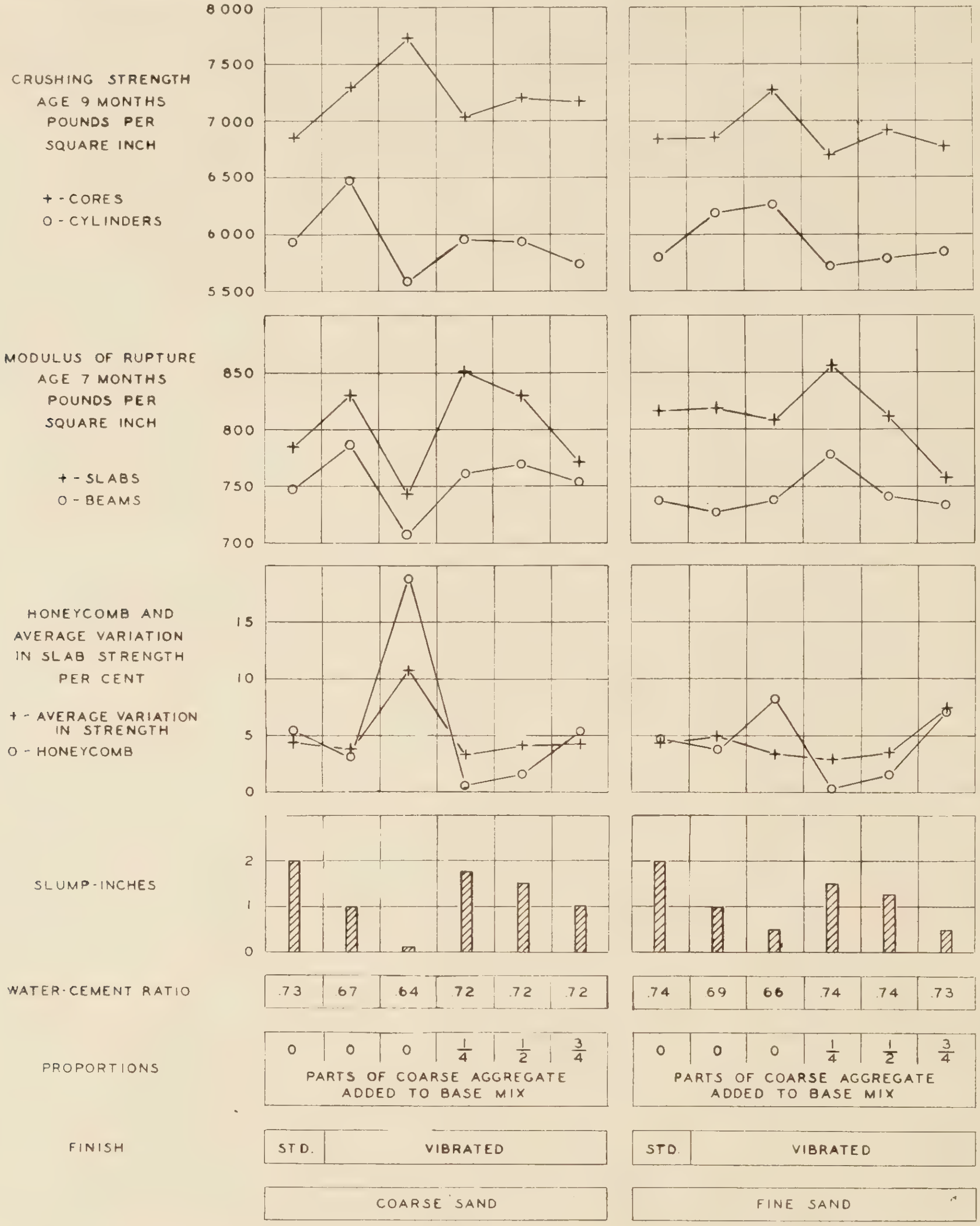
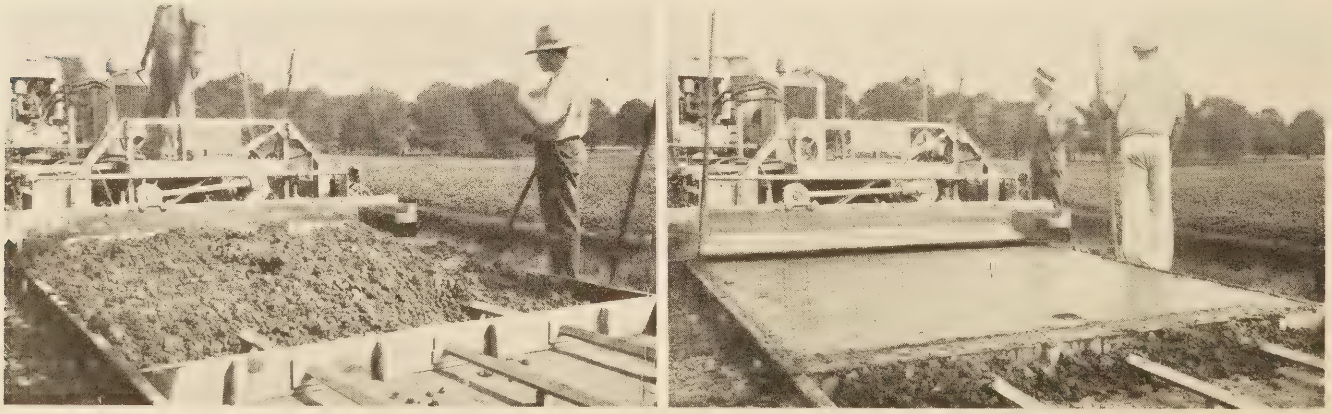


Figure 10.—Series A, Effect of Vibration; Averages for Sections Containing Gravel and Crushed Stone, Separated According to Fine Aggregates Used.



Before Finishing. *After Finishing.*

Figure 11.—Section 31, Vibrated. Aggregates, Fine Sand and Slag; Proportions, 1:1.9:3.2; Slump, 1 Inch.

individual values from which the average values shown in figures 6, 7, 8, 9, and 10 were derived. The effect of honeycombing on strength is immediately apparent. In practically every case we find that the highest strengths obtained for any test section were on slabs containing less than 3 percent honeycomb, whereas those slabs showing an excess of 10 percent honeycomb developed much lower strengths. The effect of using dry consistencies on the extent of honeycomb is also brought out. Marked examples of the effect of honeycomb on strength and the effect of consistency on the amount of honeycombing are sections 3, 12, and 39 in figure 12 (all of which showed ¼ inch or less slump), sections 15, 21, 24, and 51 of figure 13 (all ¾-inch slump or less) and section 27 in figure 14. On the other hand, those sections showing the least honeycomb and greatest uniformity are, in general, the vibrated sections in which the slump was in excess of 1 inch. There are some exceptions to this, as for instance, section 45 (fig. 12) with 1-inch slump and less than 3 percent honeycomb in any slab. This section also showed a high degree of uniformity. It will be noted that honeycombing exists in almost all of the standard-finish sections for an average slump of 2¼ inches or less. Section 44 (fig. 12) with 2½-inch slump, and section 61 (fig. 14) with 2¾-inch slump, were the only ones with all slabs showing less than 3 percent honeycomb.

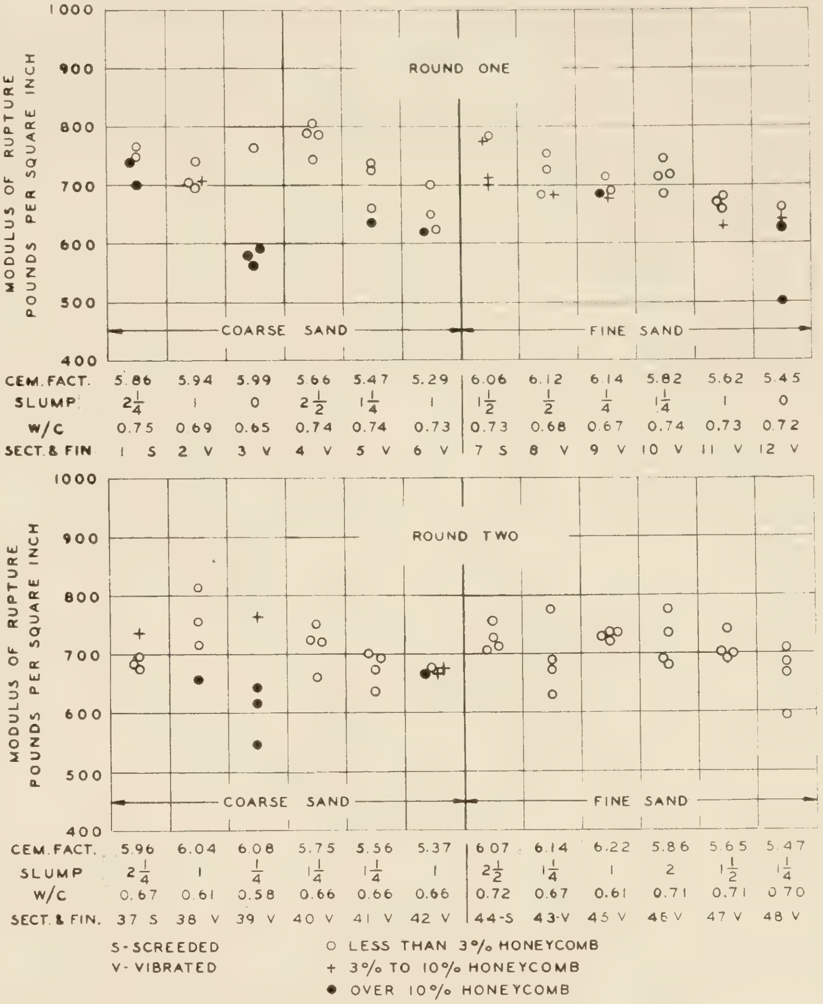


FIGURE 12.—SERIES A, EFFECT OF VIBRATION; FLEXURAL STRENGTH AT 7 MONTHS OF GRAVEL CONCRETE PAVEMENT SLABS.

VARIATION OF CONSISTENCY BETWEEN ROUNDS 1 AND 2 NOTED

Further reference to figures 12, 13, and 14 reveals another interesting fact. It will be noted that, in general, there is considerably less honeycombing in the sections constructed during the second round than in those built during round 1. For instance, 40, or 28 percent, of the 144 individual slabs tested in round 1 showed more than 10 percent honeycomb, whereas only 11, or 9 percent, of 118 slabs tested during the second round showed more than 10 percent. Two groups in the second round were practically free from honeycomb exceeding 3 percent, gravel concrete with fine sand (fig. 12) and slag with coarse sand (fig. 14), the latter group containing only one slab with more than 3 percent honeycomb, whereas the former contained no slabs showing honeycomb in excess of 3 percent. The difference between the first and second round in the case of the fine sand and gravel concrete may be explained by the fact that during the second round the slump was considerably greater than during round 1 although the same proportions were used in both cases. As a matter of fact the average net water-cement ratio during round 2 was somewhat lower than during the first round. This difference in consistency may possibly be explained by the comparatively low relative humidity of the atmosphere (48 percent) on the day on which sections 7 to 12 were laid as compared with the humidity noted during the construction of sections 43 to 48 (65 percent). Both days were sunny and hot, with average temperatures over 90° F. There seems to be no other reason which would account for the marked difference in consistency which was observed.

This difference in consistency illustrates very forcibly the difficulty of controlling this very essential property of concrete under field conditions. Here we have a condition where variations in the humidity undoubtedly affected the consistency to a marked degree. Under such conditions it is impossible to maintain both proportions and water-cement ratio and to expect the consistency to also remain constant. Therefore, inasmuch as consistency must be closely controlled, and it is impractical to be constantly changing batch weights in order to take care of variations therein, the question arises as to whether we should attempt to construct concrete pavements under a straight water-cement ratio specification, rather than a specification in which the proportions and consistency are fixed and the water content is allowed to vary up to a fixed maximum.

In the case of the coarse sand and slag combination (fig. 14) the marked difference in honeycombing observed between the two rounds is not explained by differences in consistency. Only in the case of the unvibrated concrete was the difference in slump more than one half inch. Sections 27 and 63 show the greatest divergence as far as workability is concerned. The slump in both cases was one half inch. Sections 25 to 30 (round 1) were laid on a damp, cloudy day (average temperature 76° F., relative humidity 88 percent) whereas sections 61 to 66 were laid on a rather cool, clear day with average temperature of 69° F. and relative humidity of 46 percent. Under such conditions it would be reasonable to suppose that the concrete laid during round 1 when the relative humidity was 88 percent would not dry out so fast as the concrete laid during round 2 when the atmosphere was much drier. Actually, the reverse appeared to be the case.

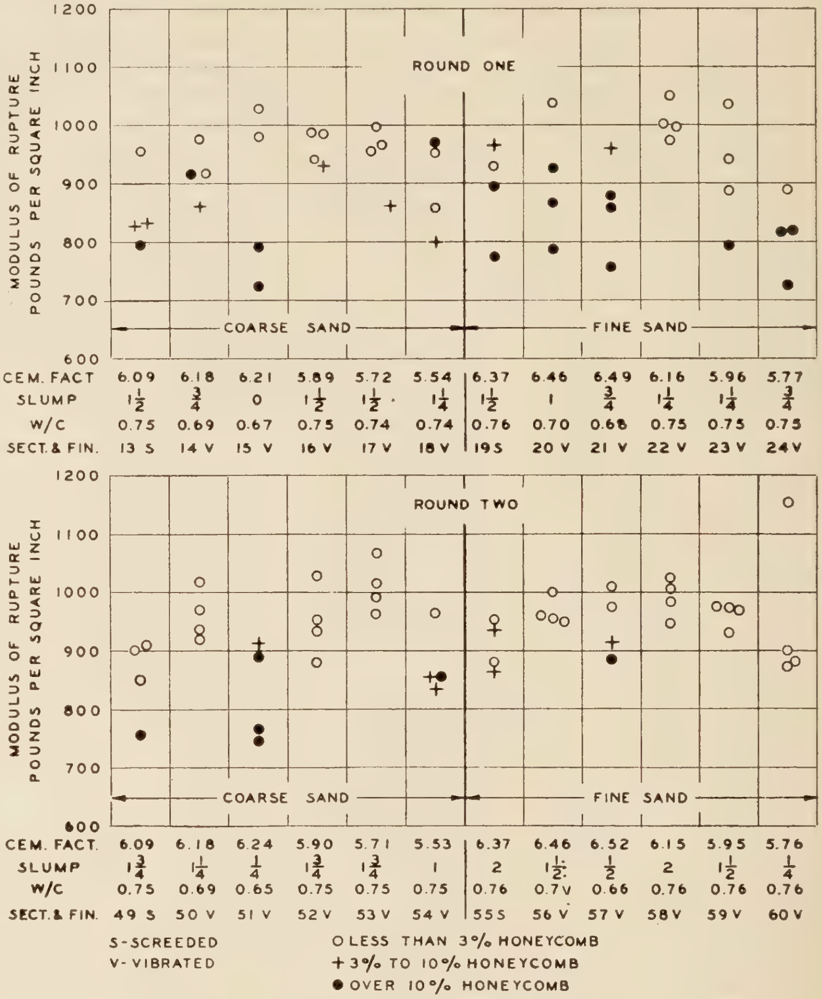


FIGURE 13.—SERIES A, EFFECT OF VIBRATION; FLEXURAL STRENGTH AT 7 MONTHS OF STONE CONCRETE PAVEMENT SLABS.

RELATION BETWEEN WORKABILITY AND SLUMP

To show the average effect of variation in consistency (slump) on the workability of both the vibrated and unvibrated concrete, the average percentage of honeycomb in all slabs constructed of concrete having a given consistency and finished in a given manner has been determined for each value of slump within the range studied, that is, between 0 and 3 inches. The results are shown graphically in figure 17. In this figure, the curve showing the relation between slump and percentage of honeycomb for each method of finishing has been drawn so as to represent a weighted average of the various points. In other words, in establishing the average line, due consideration was given to the number of individual tests represented by each point. This number varied from 1 to 14, depending upon the number of sections having a given slump.

It will be observed in figure 17 that, for a given consistency, the average amount of honeycomb in the slabs finished by vibration is considerably less than in the slabs finished by the standard method. It would appear from these data that the 2-inch minimum slump recommended in the previous report for paving mixes to be finished under standard methods did not, under the conditions of these tests, completely eliminate honeycomb. As a matter of fact, at 2-inch slump an average amount of honeycomb of approximately 5 percent is noted, whereas in the first series honeycombing was almost entirely eliminated at 2-inch slump, except where the so-called "B grading" gravel was used as coarse aggregate. (See fig. 23, PUBLIC ROADS, August 1931.)

Several explanations may be advanced to account for this difference. In the first place the coarse aggregate used in the first series was divided in 3 sizes, whereas only 2 sizes were used in the present series. This may possibly account for the difference in workability. Again in the original series the subgrade was protected with tar paper, whereas, in the present series, the slabs were cast direct upon the subgrade. It is possible that the tar paper, acting somewhat as a form, prevented the segregation of mortar and coarse aggregate on the bottom surface of the slab, thus reducing the percentage of visible honeycomb to a certain extent.

Of course, from the standpoint of this investigation, the most important consideration is the difference in slump for standard-finished concrete as compared with vibrated concrete of the same degree of workability (percentage of honeycomb). This difference seems to be in the neighborhood of 1½ inches. For instance, in order to insure concrete substantially free from honeycomb (and for the purpose of this discussion 3 percent will be considered the upper limit for this condition) a minimum slump of about 2½ inches will be required when the concrete is finished in the usual way compared with about a 1-inch slump when the concrete is vibrated. It will be seen therefore that, if anything, the minimum slump of 2 inches recommended in the first report instead of being higher than necessary was not high enough to eliminate honeycombing. In other words, the results of the present series not only substantiate the conclusions reached in the first report, but seem to indicate that a minimum slump of 2½ inches instead of 2 inches may be advisable in cases where the concrete is finished in the usual way.

TENDENCY TO HONEYCOMB IN VALLEY BETWEEN BATCHES SHOWN IN STANDARD SECTIONS

A study of the distribution of honeycomb on the bottom of the four 27-inch slabs composing each test section of series A reveals some interesting facts. For the purpose of this discussion the four slabs in a test section will be numbered from 1 to 4, beginning on the right-hand side when facing in the direction of the movement of the paver. Two 27-cubic-foot batches of concrete were required to construct each section. The first batch was dumped from a position in the center of slab 3 and spread both ways into slabs 2 and 4. The second batch was dumped from over the center of slab 1 and spread out into slab 2, overlapping the concrete from the first batch. The longitudinal valley between adjacent batches was therefore in slab 2. It may be noted that of the 11 standard-finished sections in series A, slab 2 showed the greatest amount of honeycomb in 9 cases, with slabs 1 and 4 each showing the maximum in 1 case. This would indicate a distinct tendency to honeycomb in the valley between the two batches and points to the necessity for care in spotting batches of concrete during actual construction in order to minimize this condition.

Of the 43 vibrated sections showing honeycomb, slab 2 contained the largest amount in 10 cases, slab 4 in 22 cases, and slab 1 in 11 cases. This distribution shows the greatest amount of honeycomb in the end slabs (nos. 1 and 4) in about 75 percent of the cases and is quite different from that occurring with the screeded sections, where 82 percent of the sections showed maximum honeycomb in slab 2. Inasmuch as the procedure used in dumping was exactly the same, an explanation of the difference may lie in the vibratory effect which was possibly somewhat greater in the center of the screed than at the ends.

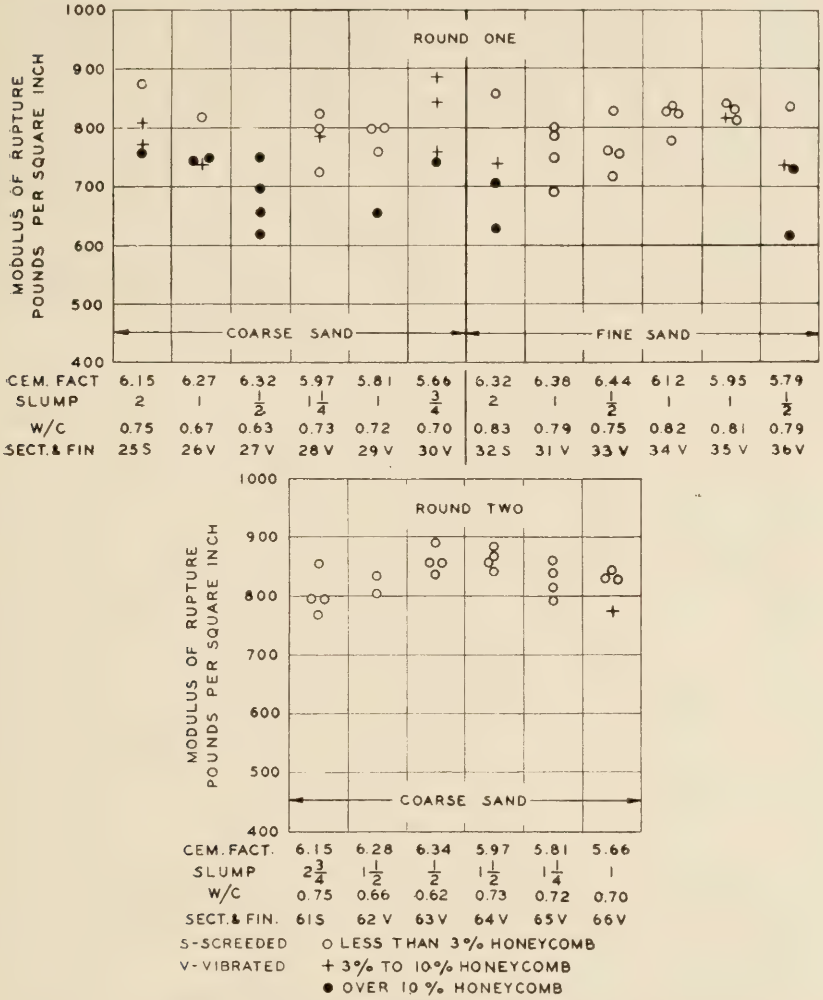


FIGURE 14.—SERIES A, EFFECT OF VIBRATION; FLEXURAL STRENGTH AT 7 MONTHS OF SLAG CONCRETE PAVEMENT SLABS.

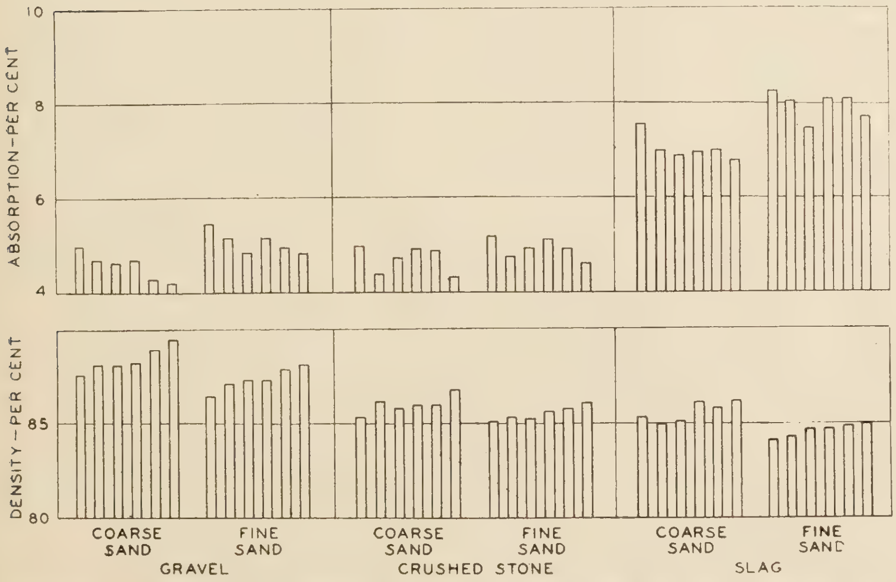


FIGURE 15.—SERIES A, EFFECT OF VIBRATION; RESULTS OF DENSITY AND ABSORPTION TESTS. SECTIONS IN EACH GROUP ARRANGED FROM LEFT TO RIGHT AS IN FIGURE 6.

NO TENDENCY OF SEPARATORS TO CAUSE HONEYCOMB OBSERVED

At the time of the former investigation, a question was raised as to the effect of the wooden separators installed for the purpose of creating planes of weakness on the amount and distribution of honeycomb in the slabs. It was felt that the separators might have interfered with the distribution of concrete on the subgrade resulting in the concentration of honeycomb areas at and near the separators. A very careful inspection of all of the test slabs comprising this series has failed to reveal any particular trend along this line and it is felt that there was no tendency in this direction. In other words, it seems safe to assume that, other things being equal, the same amount and distribution of honeycomb would have occurred on an actual pavement as was observed in this test.

Before Finishing. *After Finishing.*

Figure 16.—Section 40, Vibrated. Aggregates, Coarse Sand and Gravel; Proportions, 1:1.6:3.7; Slump, 1¼ Inches.

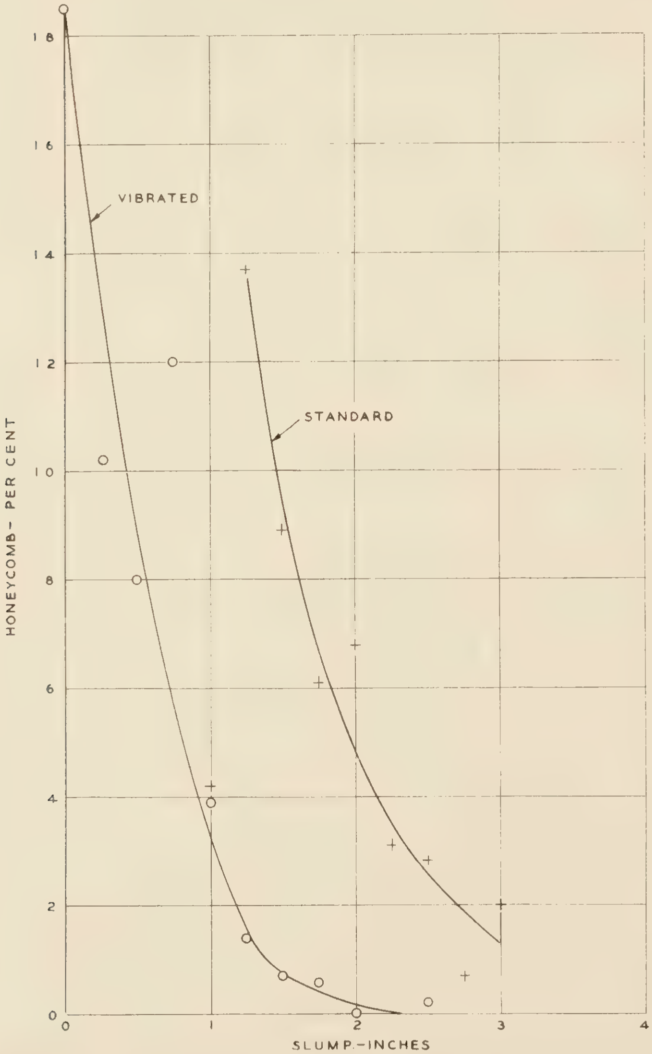


Figure 17.—Series A, Effect of Vibration; Relation Between Honeycomb and Slump.

VIBRATION DOES NOT ADVERSELY AFFECT SURFACE WEAR

The results of the tests for surface wear are shown in figure 18. The depth of wear is reported at the end of both 400 and 600 revolutions. Each value is the average of either 2 or 3 individual tests on different slabs. For each group of 6, the average hardness of the surface of the 5 vibrated sections may be compared directly to the standard-finish section for that particular group. In general, the vibrated sections show slightly less surface wear, although the difference is not sufficiently marked to warrant any general conclusion regarding this property of the concrete. It may safely be assumed, however, on the basis of these tests, that vibration does not adversely affect the surface hardness of the pavement.

It is of interest to note that the hardness of the standard-finish concrete appears to be slightly affected by the material combinations. Sections containing the fine sand seem to be somewhat lower in resistance to wear than the corresponding sections with coarse sand. The same comment applies to the crushed-stone concrete as compared to gravel. In the latter case the difference in hardness is probably due to the fact that a somewhat higher water-cement ratio was used in the crushed stone concrete. Inasmuch as wear was confined to the mortar surface, the type of coarse aggregate did not, of course, directly affect the results.

DENSITY AND ABSORPTION DISCUSSED

In figure 15, there have been plotted average values for density and absorption of cores drilled from the sections in series A. It will be seen that in each group the final densities of the vibrated concretes are, with the exception of groups 2 and 3 in the case of slag with coarse sand, all higher than the densities of the corresponding base mixes; and that, in general, the density increases with increased coarse-aggregate content (nos. 4, 5, and 6 in each group). These variations in density could, of course, be accounted for on the basis of the decreased water or increased proportion of coarse aggregate in the mix provided it could be assumed that the freshly mixed concretes were, in all cases, free from air voids. However, it is felt that in the case of series A where all of the vibrated sections were drier than the base mix and where several carried more coarse aggregate, this assumption cannot be made. In other words, it seems reasonable to assume that in the case of the vibrated sections all of the freshly mixed concrete contained more air voids than the base mix. The fact that the final densities arrange themselves in about the same relative order as the densities of the freshly mixed concretes calculated without correction for air voids is an indication that air voids were eliminated during the finishing operation. Of course, the important feature,

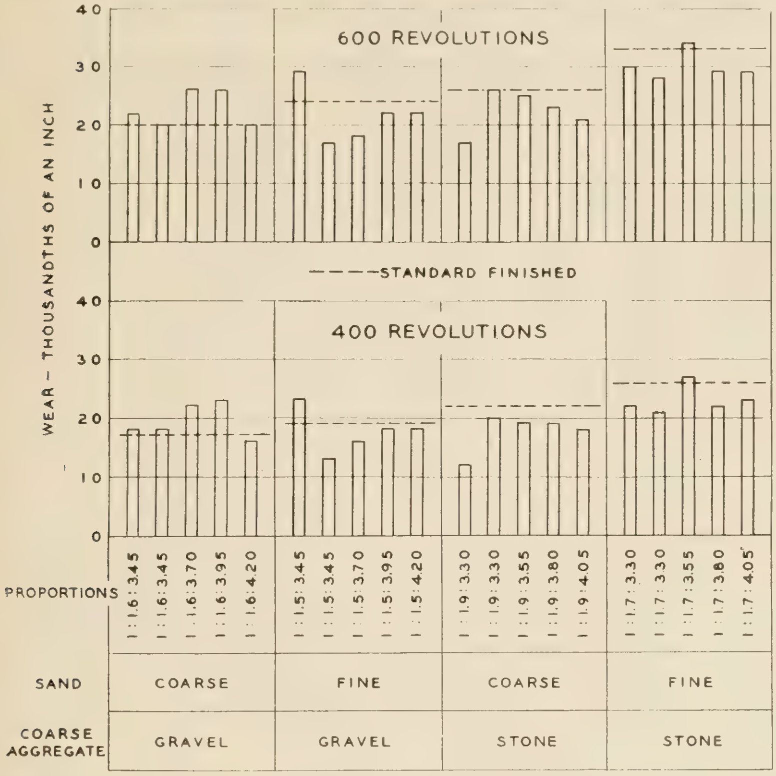


FIGURE 18.—SERIES A, EFFECT OF VIBRATION ON SURFACE WEAR.

so far as these tests are concerned, is that we actually obtained, by the use of the vibratory method of finishing, the increased densities corresponding to the changes in the quantity of water and coarse aggregate which were made. Although density tests were not made during the former tests it is extremely improbable, in view of the inability of the conventional finishing machine to place the harsher mixes properly, that corresponding increases in density were obtained.

Absorption tests, in general, parallel the density tests as would be expected. Absorption is, of course, of interest as a possible measure of the relative ultimate durability of the concrete. The slag concrete, as would also be expected, shows considerably higher absorption than either of the other coarse aggregates.

SERIES B: TESTS TO DETERMINE EFFECT OF DELAYED FINISHING (JOHNSON METHOD)

In this series a method of finishing concrete pavement slabs proposed by Mr. T. H. Johnson, of Sioux City, Iowa, and known as the "Johnson method", was investigated.[1] In all 40 sections were constructed, 16 with gravel as coarse aggregate, 16 with crushed stone as coarse aggregate, and 8 in which the total aggregate was a sand-gravel mixture approximating in grading the so-called "Platte River gravel" used extensively in Nebraska and western Iowa. The gravel and crushed-stone sections were further subdivided as to fine aggregate, an equal number of sections in each group being constructed with coarse and fine sand. Aggregate gradings and other characteristics are given in table 1.

JOHNSON METHOD INCREASES STRENGTH AND DENSITY OF CONCRETE

The following conclusions have been derived from tests comparing the Johnson method of finishing pavement concrete with the standard method.

1. The use of the Johnson method of finishing as carried out in these tests will increase the density and strength of concrete pavement slabs by eliminating a larger quantity of excess water before final consolidation than is accomplished by the methods now in common use.

2. The application of the Johnson method of finishing to a mix containing approximately one half part more fine and one part more coarse aggregate than the base mix will produce pavement slabs having substantially the same crushing and flexural strength as the base mix finished by methods now in common use. Such a mix will contain approximately one sack of cement per cubic yard of concrete less than the base mix.

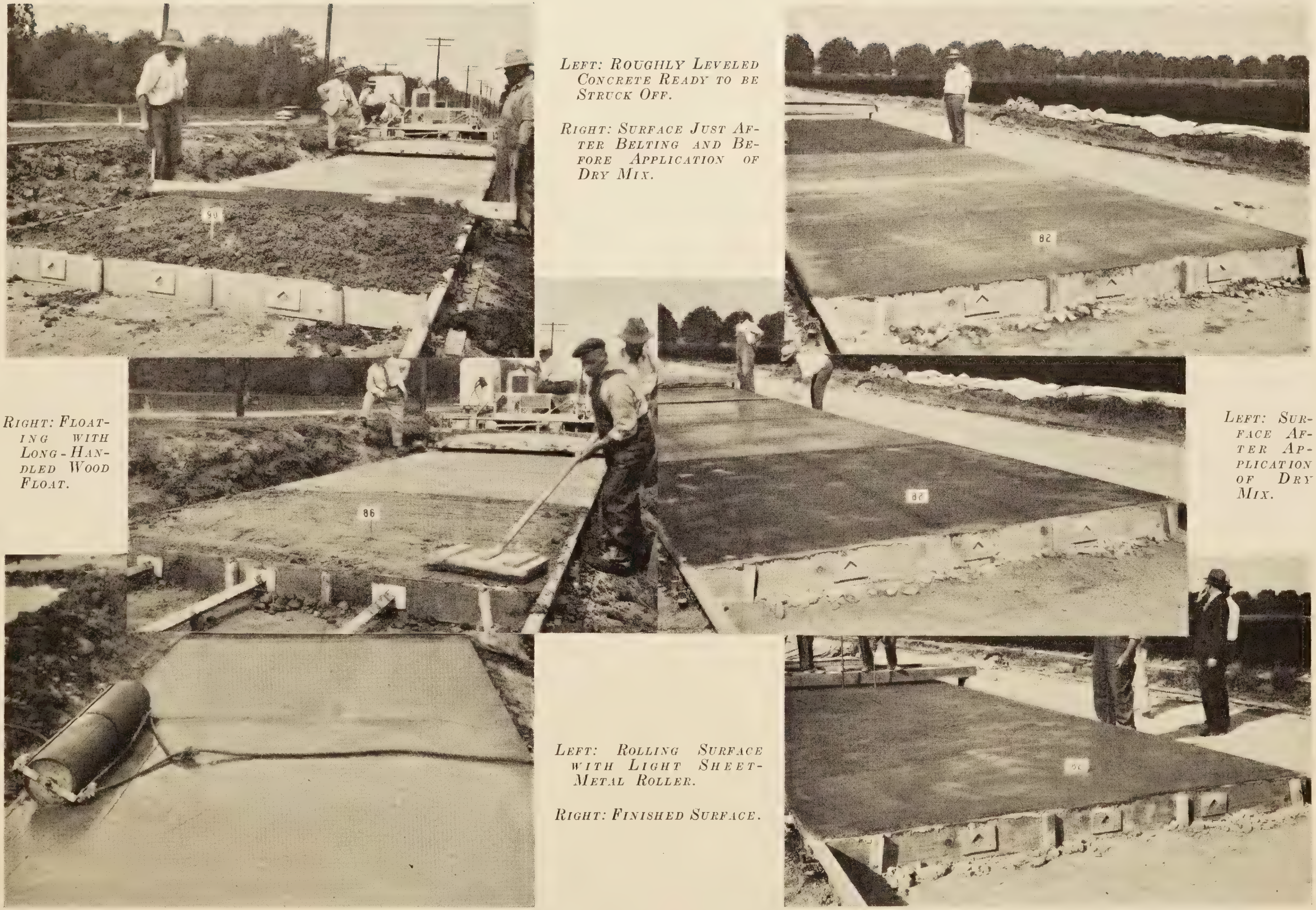
3. In general, the indications of these tests are that the proper use of the Johnson method of finishing should result in an improvement in the quality of concrete pavements.

SAME STANDARD MIX AS IN SERIES A USED AS BASIS OF COMPARISON

For each aggregate combination, except the Platte River gravel, a base mix of the same proportions as used in series A was set up as the standard of comparison. This base mix was finished with the standard double-screed finishing machine in the usual way. For direct comparison with this standard or base mix there were constructed three sections with mixes varying from the base as indicated below. This made a total of four sections per round for each aggregate combination.

---

[1] A detailed discussion of the theory underlying this method was presented by Mr. Johnson at the twenty-third annual meeting of the American Concrete Institute in 1927. (See Proc. A.C.I., vol. 23, p. 458.)



LEFT: ROUGHLY LEVELED CONCRETE READY TO BE STRUCK OFF.

RIGHT: SURFACE JUST AFTER BELTING AND BEFORE APPLICATION OF DRY MIX.

RIGHT: FLOATING WITH LONG-HANDLED WOOD FLOAT.

LEFT: SURFACE AFTER APPLICATION OF DRY MIX.

LEFT: ROLLING SURFACE WITH LIGHT SHEET-METAL ROLLER.

RIGHT: FINISHED SURFACE.

FIGURE 19.—FINISHING CONCRETE BY THE JOHNSON METHOD.

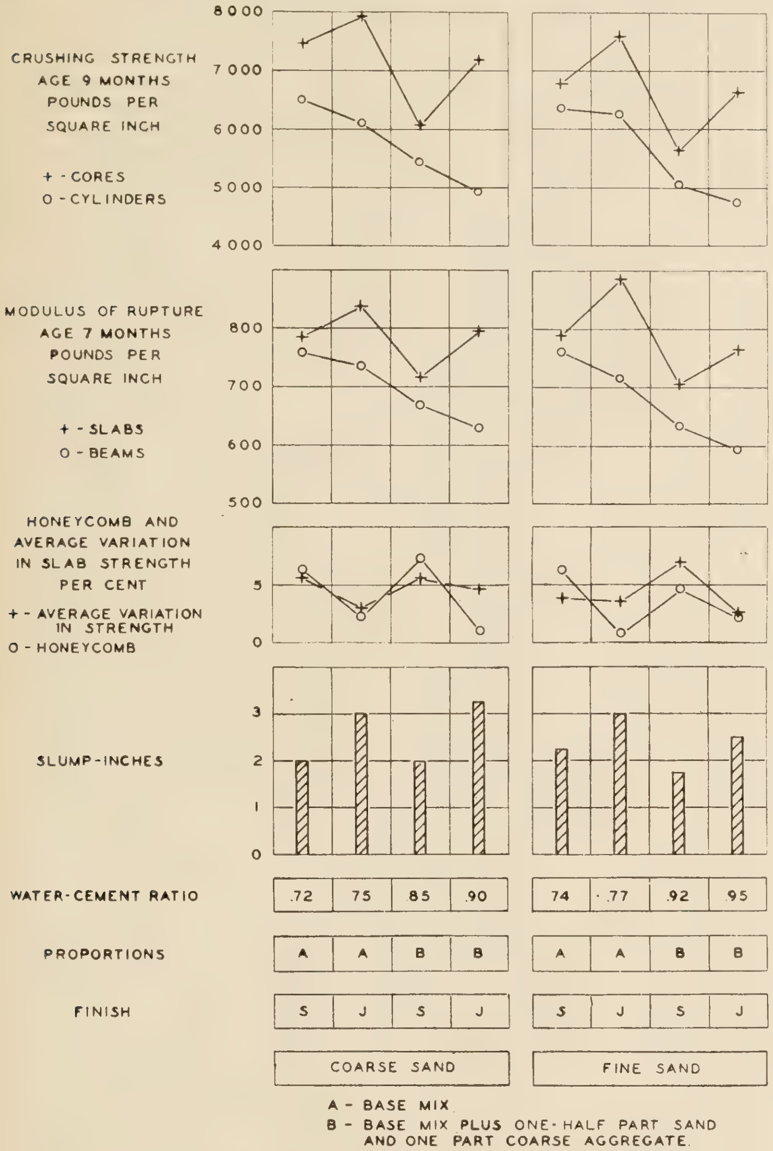


Figure 20.—Series B, Effect of Johnson Finish; Averages for Sections Containing Gravel and Crushed Stone.

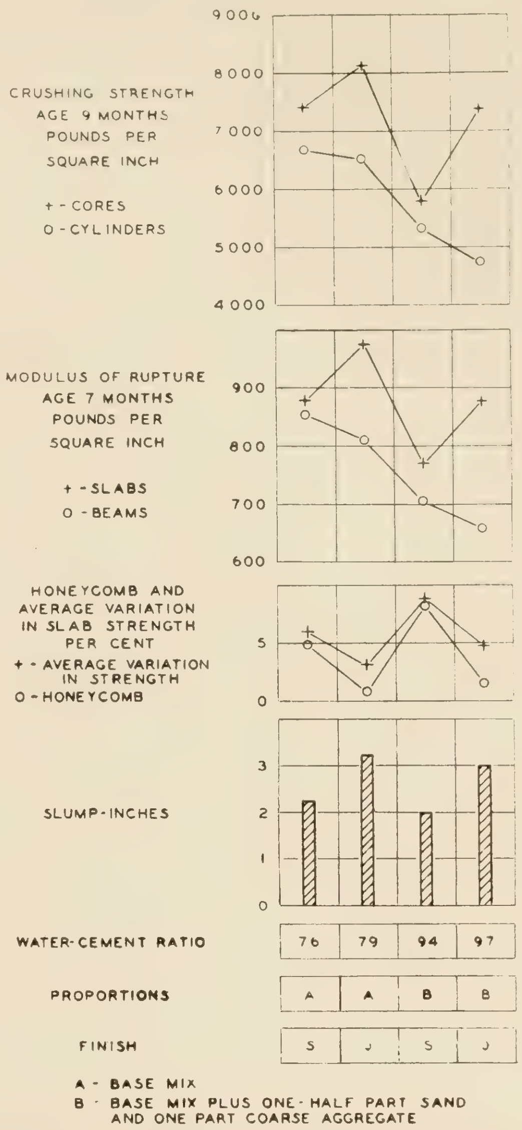


Figure 21.—Series B, Effect of Johnson Finish; Averages for Sections Containing Crushed Stone.

For the second section of each group the base proportion was used but the water content was increased to give a slump of approximately 3 inches instead of 2 inches. This section was finished by the Johnson method. The third section in each group was proportioned to contain one half part more fine aggregate and one part more coarse aggregate by volume than the base mix and was finished in the standard manner. The water content in this section was adjusted to give a slump of about 2 inches and the water-cement ratio averaged about 0.15 higher than that of the base mix. The cement factor averaged 1.2 bags per cubic yard less than in the case of the base. The fourth section was a mix similar to the third except that the water content was increased to give approximately 1 inch greater slump. This section was finished by the Johnson method in the same manner as the second section in the group. In table 3 the proportions, slump, water-cement ratio, and method of finishing for each of the sections in series B are given. These data are similar to the data shown in table 2 for series A.

It will be seen that this arrangement makes it possible to compare for each group of four sections the results obtained by the Johnson method with the standard, first, on the basis of the same mix except for a somewhat wetter consistency; and, second, on the basis of not only a wetter but also a considerably leaner mix than the base. It is also possible to compare the lean-mix Johnson-finished sections with a similar mix containing less water and finished in the usual way.

The data for the eight sections in which the sand-gravel mix was used are also shown in table 3. Here the base mix, standard finish, was 1:4 by volume, with sufficient water to give approximately a 2-inch slump. As a comparison, a similar mix with more water was finished by the Johnson method. The group of 4 was completed by 2 sections, 1:4½ mix by volume, 1 finished by the standard method, and 1, somewhat wetter, by the Johnson method. Two complete rounds of tests for each aggregate combination were run in series B, making the total of 40 sections in groups of 4 each as above indicated.

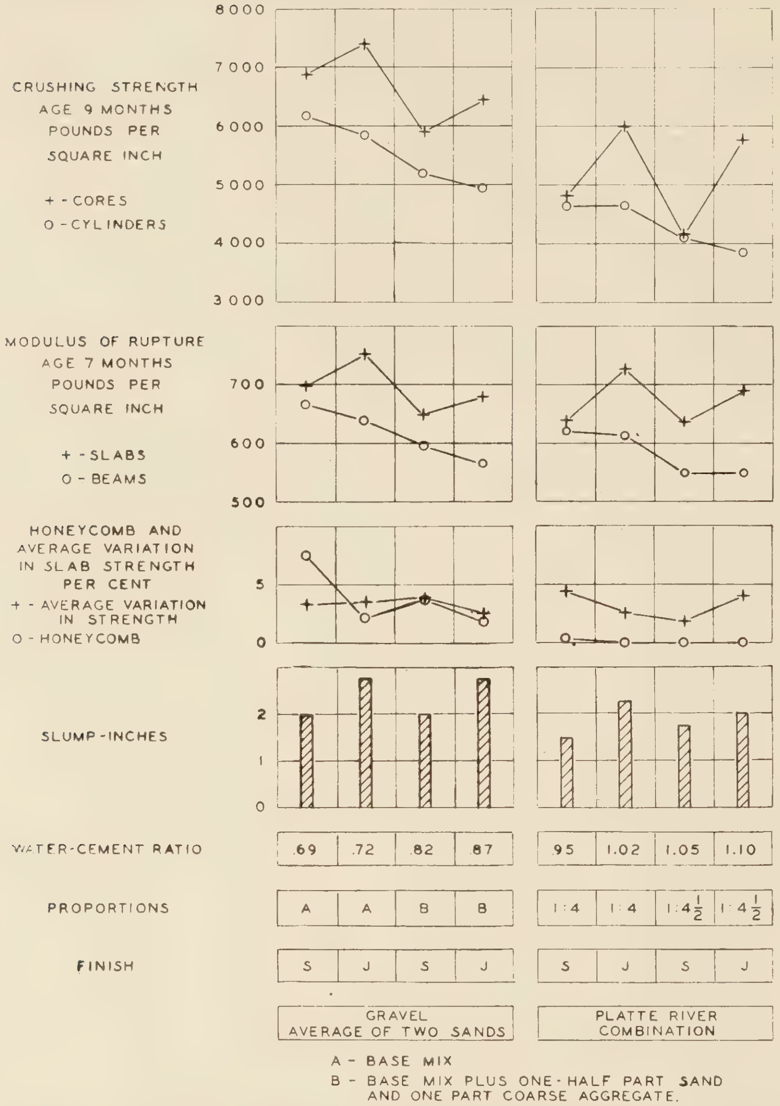


FIGURE 22.—SERIES B, EFFECT OF JOHNSON FINISH; AVERAGES FOR SECTIONS CONTAINING GRAVEL AND FOR SECTIONS CONTAINING PLATTE RIVER COMBINATION.

The laying of these sections was started September 29, 1931, and completed October 5, 1931, progress being at the rate of 8 sections per day.

METHODS OF FINISHING DESCRIBED

The procedure used in finishing the concrete by the Johnson method was as follows. Immediately after the concrete was deposited on the subgrade it was struck off with a hand screed. It was then floated with a long-handled wooden float 12 inches wide, 20 inches long, and 2¼ inches thick. The thickness was obtained through the use of a 1¾-inch cypress plank with a ½-inch oak plank nailed to the bottom, the oak making contact with the concrete. After floating, the surface was rolled with a light-weight sheet-metal roller. The roller was operated from side to side of the pavement and was advanced about 1 foot longitudinally with each passage. The entire surface was rolled three times, after which it was belted. This was followed by the application of the so-called "dry mix" to the surface. This mixture was made up of 1 part cement to 1 part of fine sand by volume and was spread over the surface with shovels at a rate of 1 sack of cement per 20 square yards of pavement. For a 7-inch pavement this would be equivalent to increasing the total amount of cement used about 0.25 bag per cubic yard of concrete. Just enough of the mixture was applied to give a very thin continuous cover. (See fig. 19.) The sand used for this purpose was the same as the fine sand used in the concrete mixture and contained approximately 5 percent of moisture when mixed with the cement. After an interval of 11 to 50 minutes, depending upon the amount of water brought to the surface by the dry mix, the surface was again belted.

The second belting was followed by floating with hand floats at intervals until there was little moisture brought to the surface and the concrete became sticky and was drawn along by the float. This general procedure was sometimes varied by belting between floating operations and by additional rollings. The number of floatings necessary to bring the surface to the required condition after the dry mix was applied varied from 3 to 7 and the elapsed time from the placing of the concrete to the final floating varied from 2¼ to 3¾ hours. The various details of the operation as described above are illustrated in figure 19.

COMPARATIVE RESULTS BY JOHNSON AND STANDARD METHODS ANALYZED

The effect of the Johnson method of finishing on the strength and uniformity of the concrete is shown graphically in figures 20 to 25, inclusive. The data are shown in the same manner as the corresponding data for series A, and include average results of crushing-strength tests on cores and cylinders, tests for modulus of rupture on slabs and control beams, and determinations of uniformity, measured by (*a*) the amount of honeycomb in the slabs and (*b*) the average percentage variation in slab strength. In figure 20 the average results of tests for the crushed stone and the gravel concrete for each sand are shown. Figure 21 gives similar data for the crushed stone concrete only, while in figure 22 the corresponding results for the gravel and the Platte River combination are shown. In the case of the crushed stone and gravel concrete (figs. 21 and 22) the values for the sections containing the fine and coarse sand have been averaged. Figures 23, 24, and 25 give, for series B, the results of tests on individual slabs taken from the test sections.

It will be noted that in the case of figures 20, 21, and 22 the results are plotted so as to provide, for each proportion, a direct comparison between the strengths obtained under the Johnson method and those obtained under the standard method. Each point represents the average of tests on four sections, except that in the case of the Platte River concrete (fig. 22, right-hand panel) each point averages only two sections. An inspection of these figures shows at once some very interesting trends.

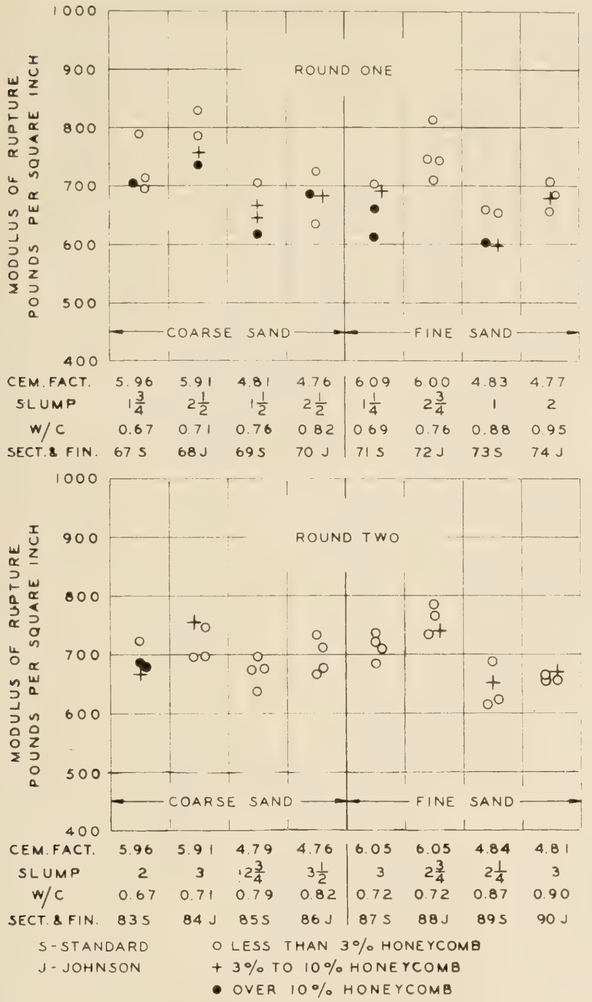


Figure 23.—Series B, Effect of Johnson Finish; Flexural Strength at 7 Months of Gravel Concrete Pavement Slabs.

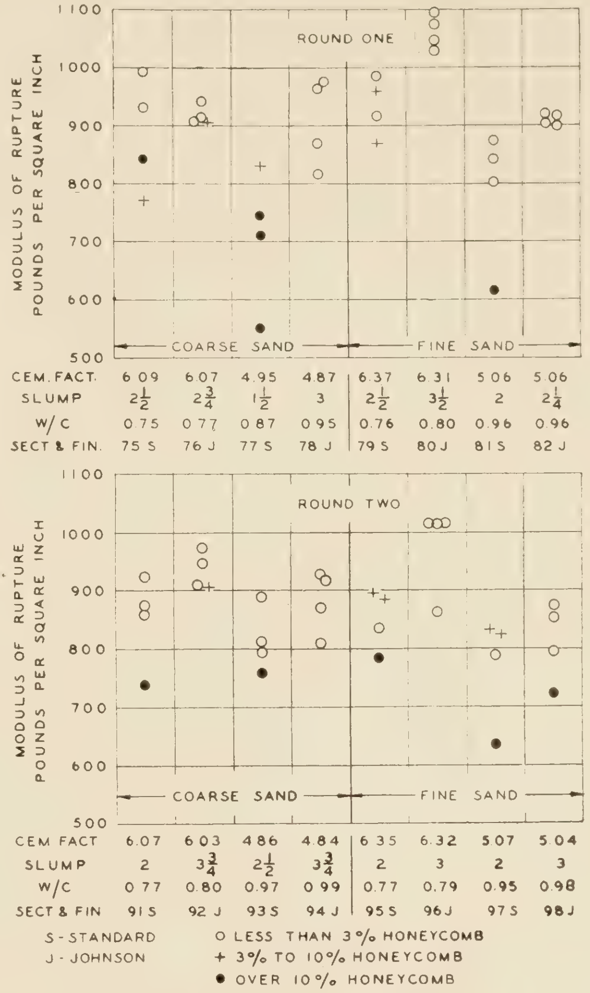


Figure 24.—Series B, Effect of Johnson Finish; Flexural Strength at 7 Months of Stone Concrete Pavement Slabs.

JOHNSON METHOD SHOWS HIGHER CORE AND SLAB STRENGTHS

For instance, it will be noted that, although a somewhat wetter mix and consequently higher water-cement ratio was used in each Johnson-finished section as compared with the corresponding standard-finished concrete, in every case higher core and slab strengths were obtained on the sections finished by the Johnson method. On the other hand, the strengths of the control specimens representing the concrete going into the Johnson-finished slabs were lower than those representing the corresponding standard sections. This, of course, would be expected because of the higher water ratios. The fact that higher strengths were obtained for the Johnson finish is undoubtedly due, at least insofar as crushing strength is concerned, to the special manipulation which was given the concrete, resulting in the removal of considerable water before final consolidation took place. The control specimens were, of course, not subjected to this manipulation and consequently retained the excess water with a resultant lowering of the strength. As to the increased slab strength shown by the Johnson finished concrete, it is possible that a portion of the increase is due to the influence of consistency on honeycombing and, consequently, on slab strength, entirely apart from the removal of water during the finishing operation.

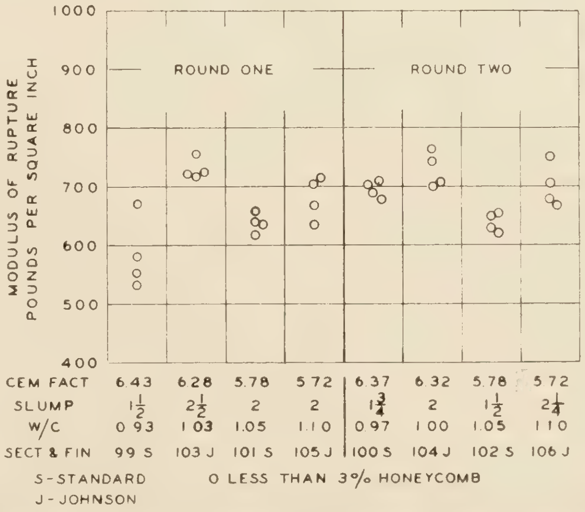


Figure 25.—Series B, Effect of Johnson Finish; Flexural Strength at 7 Months of Pavement Slabs Made with Platte River Combination.

Referring now specifically to figure 20, let us compare first the results of the core tests for the base mix (proportion A). The average crushing strength of sections containing both coarse and fine sand shows an increase for the Johnson sections of about 600 pounds per square inch or approximately 8 percent of the average strength of the standard-finish base mix. The corresponding control cylinders show a slight decrease in strength as would be expected. This decrease averages about 250 pounds per square inch and corresponds to an increase in water-cement ratio of 0.03. For the leaner mix (proportion B) the average increase in core strength is about 1,000 pounds per square inch, or approximately 18 percent. The grand average increase, including all sections, is therefore about 13 percent in favor of the Johnson method of finishing. Inasmuch as the only difference, aside from water content and consistency, was the method of finishing, it may be concluded that the higher average strength shown for the cores drilled from the Johnson sections is due to the method of finishing. It is also interesting to note that the average core strength of the Johnson-finished slabs in the lean mix (ave. $w/c=0.93$) is only about 200 pounds per square inch lower than that of the corresponding cores for the richer mix (ave. $w/c=0.73$) with standard finish. The cylinders are about 1,600 pounds per square inch lower in strength.

The same general trends follow in the case of flexure. For proportion A, the average increase in modulus of rupture in favor of the Johnson finish is about 75 pounds per square inch or roughly 9 percent. For proportion B, the increase is about the same. The control beams, which were, of course, fabricated in the usual way show no increase but, on the other hand, a decrease in strength with increase in water content in the same manner as the control cylinders. Considering the small number of specimens represented by each point (8 in the case of cores, cylinders, and beams, and 16 in the case of slabs) the results are remarkably concordant. As in the case of the cores the Johnson-finished slabs containing the lean mix show an average modulus of rupture only very slightly lower (about 10 pounds per square inch) than the standard-finish slabs containing the base mix. On the other hand, the average decrease in the strength of the control beams is approximately 150 pounds per square inch.

It will also be noted that although there was quite an appreciable difference in the grading of the two sands (see table 1) the strengths of the sections containing the coarse sand are not greatly different from corresponding sections containing fine sand, although there is a tendency for somewhat lower strengths in the latter case. The same comment was made in connection with series A. Reference to table 3 shows that in the case of gravel the concretes containing the fine sand contained one tenth part less sand by volume than the corresponding coarse-sand concretes. In the case of crushed stone, the decrease in sand content was 0.2 part. These changes in sand content resulted in an increase in cement content not exceeding in any case 0.30 sack per cubic yard.

HONEYCOMB LESS IN JOHNSON-FINISHED SLABS

With respect to uniformity, figure 20 shows the following facts: The average percentage of honeycomb in all cases is less for the Johnson-finish slabs, the average being about 2 percent as compared to 6 percent for the standard finish. This difference in honeycomb is probably due primarily to differences in consistency. Referring back to figure 17, it will be noted that, under the conditions of these tests, the percentage of honeycomb in the standard-finish slabs was reduced to less than 3 percent only by the use of a minimum slump of 2½ inches. Referring again to figure 20, it will be seen that the average slump of the standard-finish concrete was 2⅛ inches for proportion A and 1⅞ inches for proportion B. The Johnson-finished concrete, on the other hand, showed an average slump of 3 inches in the case of proportion A and 2⅞ inches in the case of proportion B. Knowing the effect of honeycombing on slab strength (see figs. 12, 13, 14, 23, 24, and 25) the question arises as to how much of the increased slab strength shown for the Johnson method was due to the fact that less honeycomb developed than in the standard-finish concrete and how much was due to the elimination of water. This particular point will be discussed in detail in connection with the discussion of individual slab-strength results.

Figure 21 shows data similar to figure 20, except that in this case only the crushed-stone concrete is considered. The results are the average of sections containing the fine and coarse sand. The corresponding values for the gravel concrete are shown in the left-hand panel of figure 22. In connection with the difference in the strengths shown by the crushed stone and the gravel concrete, attention is called to the discussion of figure 6 under series A, in which it was emphasized that this difference is due to the particular aggregates used in this work and does not express a general relation. A comparison of these figures indicates that the increase in strength shown for the Johnson mix is, in general, more marked in the case of the crushed-stone concrete.

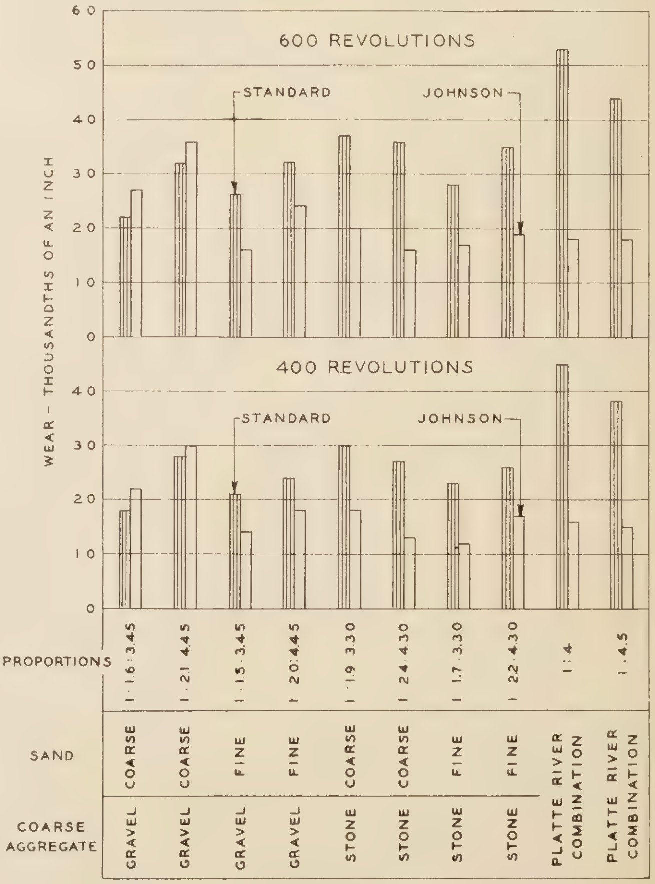


Figure 26.—Series B, Effect of Johnson Method of Finishing on Surface Wear.

For instance, for proportion A the increase in core strength is about 700 pounds per square inch for crushed stone as compared to about 500 pounds per square inch for gravel. In the leaner mix the difference is more marked, being about 1,600 pounds per square inch for the crushed-stone concrete as compared to about 550 pounds per square inch for the gravel concrete.

In flexure the differences are of the same order. For proportion A the Johnson mix shows an increase for crushed stone of about 95 pounds per square inch as against approximately 55 pounds per square inch for the gravel concrete. For the leaner mix the difference is about 110 pounds per square inch for crushed-stone concrete as compared to only about 30 pounds per square inch for the gravel concrete. That the large increase shown for the crushed-stone concrete in the lean mix in favor of the Johnson method is due in part to variations in workability is evidenced by the relatively large amount of honeycomb (8 percent) shown for standard-finish sections having this particular combination as compared to only 1½ percent for the corresponding Johnson mix. Here again the question arises as to how much of the difference in slab strength is due to difference in honeycomb and how much to the elimination of water by the Johnson finishing method. This question, however, cannot be raised in the case of the cores because, it will be recalled, special efforts were made to select only sound, uniform cores free from honeycomb. It has already been shown that the crushing strengths of cores taken from the Johnson slabs averaged about 13 percent higher in strength than cores from the corresponding standard-finish sections.

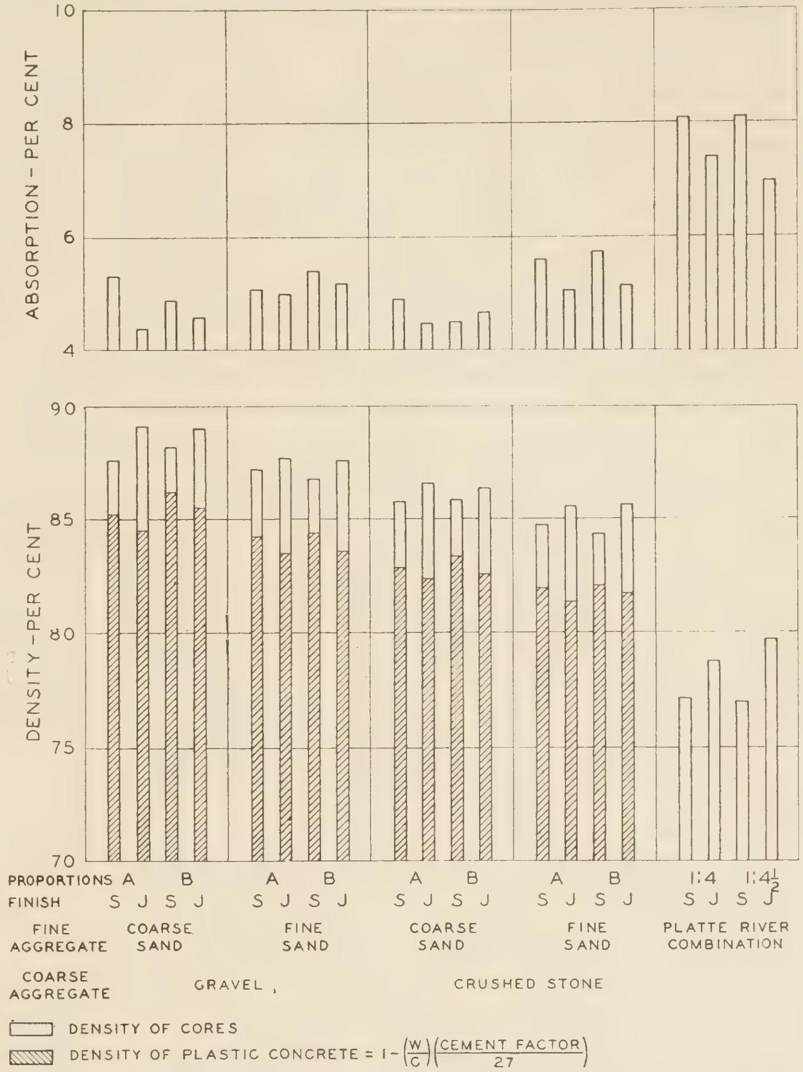


FIGURE 27.—SERIES B, EFFECT OF JOHNSON FINISH; RESULTS OF DENSITY AND ABSORPTION TESTS.

CRUSHING AND FLEXURAL STRENGTH OF CONCRETE MADE WITH PLATTE RIVER COMBINATION INCREASED BY USE OF JOHNSON METHOD

In the right-hand panel of figure 22 there have been plotted the results of tests on the concrete containing aggregates graded similarly to the Platte River gravel. (See table 1.) Two mixes were used, 1:4 and 1:4½ by volume. This aggregate contained practically no material over one half inch in size, and consequently the concrete was not honeycombed in the same sense as the concretes containing normally graded coarse aggregate. Reference to the figure will show the same trends as regards strength as were noted in the case of the gravel and crushed-stone concrete. The increase in crushing strength for the Johnson-finished concrete averages about 1,400 pounds per square inch for the two mixes, with the 1:4½ Johnson-finshed concrete about 1,000 pounds per square inch higher than the 1:4 standard-finish sections. In flexure the same trend is noted. Here the average strength of Johnson-finish slabs is about 70 pounds per square inch higher than the corresponding standard-finish slabs, with the 1:4½ Johnson-finish concrete about 50 pounds per square inch higher than the 1:4 standard finish. Inasmuch as the Platte River "concrete" is, to all intents and purposes, a mortar and not a concrete at all, honeycombing, due to segregation of coarse aggregate is entirely missing. Therefore, the question which may be raised in connection with the standard coarse aggregate concrete as to the effect of honeycombing on strength would not apply in this case. Nevertheless, a very substantial increase in slab strength is noted. This fact, coupled with the undoubted effect of the Johnson method of finishing on crushing strength, leads to the conclusion that, entirely aside from the effect of honeycomb on strength, the flexural strength of concrete is increased by this method of manipulation.

RELATIONS SHOWN BETWEEN CONSISTENCY, HONEYCOMB, AND STRENGTH

In figures, 23, 24, and 25, the relation between consistency, honeycomb, and slab strength for each test slab in series B is shown. It will be of interest to note and comment upon some of these relationships. In the first place it will be seen that the groups of slabs representing the Johnson-finish sections show, in general, somewhat higher strengths and somewhat less honeycomb than the corresponding standard-finish slabs.

The relation between honeycomb and consistency may also be traced. In general, the sections substantially free from honeycomb are those in which the slump is greater than 2½ inches. The sections containing the drier mixes (2-inches slump or less) are, in general, the ones which contain the most honeycomb. There are some exceptions to this broad classification, principally in the range in consistency between 2 inches and 2½ inches. The adverse effect of honeycomb on the strength of individual slabs is very marked in the case of the crushed stone concrete (see fig. 24).

It will be of interest to compare the flexural strength of the standard-finished and Johnson-finished sections on the basis of those slabs which show less than 3 percent honeycomb (the open circles of figs. 23 and 24). A comparison of strength in this manner should eliminate to a large degree the influence of honeycomb on strength. On this basis it is possible to make 15 direct comparisons between the two methods of finishing. Sections 77-S and 78-J cannot, of course, be compared, because of the fact that all four slabs in section 77-S show more than 3 percent honeycomb.

Referring now to figures 23 and 24 it may be noted that 12 out of the 15 pairs of sections which can be compared in this way show higher strengths for the Johnson finish than for the standard finish. For instance, the average strength of the 2 slabs represented by the open circles in section 68-J, figure 23, is higher than the average strength of the 3 slabs represented by the open circles in section 67-S, and so on. This would indicate that a part at least of the higher average flexural strength previously noted for the Johnson mix is due to the elimination of excess water and not to honeycomb. This conclusion is substantiated by reference to figure 25, where all of the slabs are free from honeycomb. Four comparisons can be made in this case, all of which show higher strengths for the Johnson finish.

Analyzing figure 23 on the above basis, that is, considering only those slabs which show less than 3 percent honeycomb, we find that 9 slabs in the 4 standard mix gravel sections (nos. 67, 71, 83, and 87) have an average flexural strength of about 720 pounds per square inch as compared to an average of approximately 680 pounds per square inch for 12 slabs in the 4 corresponding Johnson-mix, Johnson-finish sections (nos. 70, 74, 86, and 90). In figure 24 it will be found that 8 slabs in sections 75, 79, 91, and 95 have an average flexural strength of approximately 915 pounds per square inch as against an average of about 890 pounds per square inch for 15 slabs in sections 78, 82, 94, and 98. This is an average difference for the 2 types of aggregate of about 30 pounds per square inch or a little less than 4 percent as compared with a drop, for the control beams representing these sections, of 150 pounds per square inch or roughly 20 percent. A reduction in flexural strength of 150 pounds per square inch corresponds fairly closely to the reduction which would normally be expected from an increase in the water-cement ratio of 0.2, which is approximately the difference between the average water-cement ratio used in the standard mix, standard finish, and the Johnson mix, Johnson finish. (See fig. 20.) These figures show that, entirely aside from the matter of honeycomb and its effect on strength, the Johnson-finish slabs in the leaner mix approached very nearly in strength the standard-finish slabs containing the richer mix.

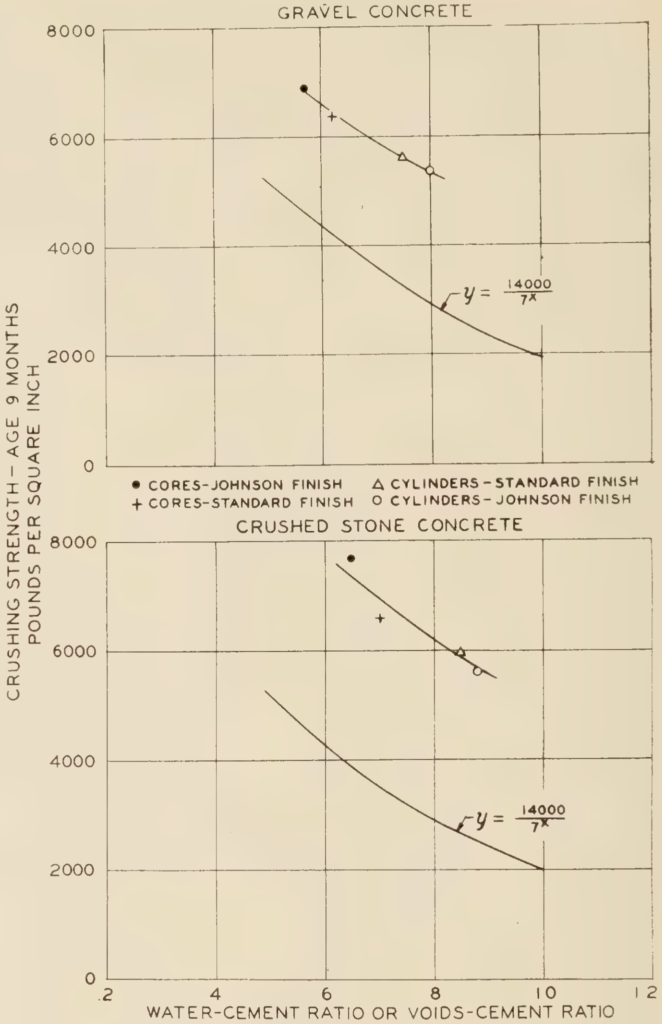


Figure 28.—Series B, Effect of Johnson Finish; Relation Between Water-Cement Ratio, Voids-Cement Ratio, and Strength.

SURFACE WEAR TESTS FAVORABLE TO JOHNSON FINISH

The results of wear tests on the slabs in series B are shown graphically in figure 26. The data are plotted so as to show directly the depth of wear of the Johnson-finish slabs in comparison to the standard finish for each proportion and material combination. Each value is the average of 3 tests (1 on each of 2 or 3 separate slabs). It will be observed that, in every case, with the exception of the gravel concrete with coarse sand, the Johnson-finish slabs show appreciably less wear than the standard finish. Just why, in this particular case, the reverse is true is not clear. However, the difference is not very marked, whereas, for several of the other combinations, particularly the crushed stone and coarse sand, and the "Platte River concrete", there is a very distinct advanvantage in favor of the Johnson sections. The conclusion reached from these tests is that the Johnson method of delayed finishing certainly does not adversely affect the surface hardness of the pavement and very probably tends to increase it, because of the elimination of a portion of the water from the surface.

The results of these tests substantiate the observations which have been made on Johnson-finished pavements in service to the effect that the method of finishing employed in this process thoroughly incorporates the dry sand-cement mixture into the body of the concrete, and does not cause scaling.

REMOVAL OF SURPLUS WATER HELD MAIN REASON FOR GOOD SHOWING OF JOHNSON METHOD

Values for density and absorption of each material combination and for each method of finishing are shown in figure 27. In the case of series B two values for density are shown, (1) the density of the plastic concrete calculated from the initial water content, and (2) the density of the hardened concrete calculated from the specific gravity of the cores. Inasmuch as the assumption that the plastic concrete is essentially free from air voids does not hold for the "Platte River concrete", values for density calculated from water content have been omitted in this case. Referring now to figure 27 and comparing the density of each standard-finished concrete with the corresponding concrete finished by the Johnson method we find that, whereas the density of the plastic concrete is greater in the case of the mixes which were finished by the standard method, because of the fact that less water was used, the final density is greater in the case of the Johnson-finished concrete. This indicates that the Johnson method removed a considerably larger proportion of the total water before final consolidation took place than was accomplished by the standard method. This ties in very well with the increased crushing strength shown by the Johnson-finished cores.

This is shown graphically in figure 28. In this figure the crushing strength of cylinders representing concrete used in the standard and Johnson-finished sections have been plotted against the corresponding initial water-cement ratios together with the results of core tests on the same concrete plotted against the void-cement ratios which were obtained from the values for density of the hardened concrete. Each point represents the average of 16 tests on 8 sections. It will be observed that, for both coarse aggregate types, all points, both cores and cylinders, lie substantially on a curve paralleling the conventional water-cement ratio strength curve. It should be borne in mind that the core tests were made on the same concrete, insofar as proportions were concerned, as the corresponding cylinder tests. The core tests, however, were made on the concrete after final consolidation had taken place and a considerable amount of water removed. The cylinders, of course, were not subjected to the finishing operation and retained most of the water. These data appear to indicate quite definitely the reason for the increased strength of the cores as compared to the cylinders, as well as the increased strength of the Johnson-finished cores as compared with the standard finish. It is all a matter of the final or net water-cement ratio which, in this case, seems to be measured quite accurately by the actual void-cement ratio of the cores as determined by test.

As indicated above, the "Platte River concrete" cannot be analyzed in this way due to the presence of air voids. Here the actual void-cement ratio of the plastic concrete is much higher than the water-cement ratio. Consequently the density bears no relation to relative water content.

On the assumption that the difference between the initial water-cement ratio and the final void-cement ratio is a measure of water loss during consolidation it will be of interest to compare the average difference for each finishing method and for each type of coarse aggregate. Reference to figure 28 will show that this average difference in the case of the Johnson-finished gravel concrete was 0.23 (from 0.57 to 0.80) as against 0.13 for the standard-finished gravel concrete (0.62 to 0.75). The difference between 0.13 and 0.23, or 0.10, may therefore be said to represent the additional decrease in the volume of voids per unit bulk volume of cement (the void-cement ratio) obtained by the application of the Johnson method. The corresponding value for the crushed-stone concrete is 0.08. On this basis, it seems safe to assume that the use of the Johnson method of finishing is equivalent, insofar as improvement in strength and density are concerned, to a reduction in water-cement ratio of about 0.10.

The effect of this additional increase in density on the ultimate durability of the concrete has not been investigated, although it is planned to make a series of tests along this line as a continuation of the present investigation. All available information on the subject indicates that, for a given mix, a very definite relationship exists between density and durability. It would seem, therefore, that any process which would result in an increase in density would be desirable from this standpoint alone, entirely aside from the effect on strength.

CONCLUDING STATEMENT

The major facts developed by this investigation are summarized in the following paragraphs.

SERIES A: EFFECT OF VIBRATION

1. When finished by the standard method, the minimum slump required to insure pavement slabs substantially free from honeycomb was found to be approximately 2½ inches.

2. When finished by vibration, the minimum slump required to insure the same degree of uniformity was found to be approximately 1 inch. (In the previous investigation it was found that standard-finished pavement slabs constructed of concrete having a 1-inch slump were less uniform in quality than similar slabs in which 2-inch to 3-inch slump concrete was used.)

3. The average flexural strength of all vibrated pavement slabs in which the concrete showed an average slump of 1 inch was somewhat higher than the average strength of the standard-finished concrete of the same proportions in which the average slump was 2 inches. (In the previous investigation standard-finished slabs constructed of 1-inch slump concrete were generally lower in flexural strength than similar concrete having a 2-inch slump.)

4. The average increase noted under (3) was due to the marked increase in strength for the group of sections in which crushed stone was used as coarse aggregate. For the sections containing gravel as coarse aggregate, the vibrated concrete having a 1-inch slump showed a lower average flexural strength than the standard-finished concrete having a 2-inch slump. In the case of slag, the strengths for the two slumps were about the same.

5. The average flexural strength of all vibrated pavement slabs in which the concrete showed an aver-

age slump of ½ inch was lower than the average strength of the standard-finished concrete of the same proportions in which the slump averaged 2 inches.

6. The average decrease noted under (5) was due to the marked decrease in strength for the group of sections in which gravel was used as coarse aggregate. In the case of stone and slag the average strength of the vibrated concrete having a ½-inch slump was about the same as the average strength of the standard-finish sections having a 2-inch slump.

7. The average flexural strength of all vibrated pavement slabs constructed of concrete having the same proportions of cement, fine aggregate, and water but containing one fourth part more coarse aggregate by volume than the standard-finished concrete, was considerably higher than that of the standard-finished concrete. (In the previous investigation, concrete containing more coarse aggregate by volume than the base mix when finished by the standard method showed lower flexural strengths than the base mix, the decrease being roughly proportioned to the amount of coarse aggregate added.)

8. The increase noted under (7) was most marked in the case of the crushed stone concrete and least in the case of the gravel concrete.

9. The average flexural strength of all vibrated concrete slabs containing one half part more coarse aggregate than the standard-finished concrete was somewhat higher than that of the standard-finished concrete. The sections containing crushed stone gave considerably higher values, the sections containing slag slightly higher, and the sections containing gravel lower.

10. The average flexural strength of all vibrated concrete slabs containing three fourths part more coarse aggregate than the standard-finished concrete was lower than that of the standard-finished concrete. The sections containing crushed stone and slag gave about the same results, whereas the sections containing gravel showed a decrease.

11. For concrete having the same water-cement ratio, finishing by vibration did not increase the crushing strength of cores drilled from the pavement slabs containing gravel and slag as coarse aggregate. In the case of crushed stone a considerable increase in crushing strength was noted for the vibrated concrete containing one half and three fourths parts additional coarse aggregate.

12. The process of finishing by vibration did not adversely affect the hardness of the surface.

SERIES B: EFFECT OF DELAYED FINISHING BY THE JOHNSON METHOD

1. Pavement slabs finished by the Johnson method showed higher crushing and flexural strengths than standard-finished concrete of the same proportion but mixed with less water. This observation applies to both of the proportions studied.

2. Pavement slabs finished by the Johnson method developed substantially the same crushing and flexural strengths as standard-finished slabs containing one half part less fine aggregate and one part less coarse aggregate. The Johnson-finished slabs, after correction for the amount of cement in the "dry mix", contained approximately one sack of cement less per cubic yard of concrete than the standard finished slabs.

3. Although, for each proportion, the water-cement ratio at the time of mixing was lower in the case of the standard-finished concrete, the final density of the concrete as revealed by tests on the cores was higher in the case of the Johnson-finished slabs.

4. Variations in crushing and flexural strength due to changes in proportions and methods of finishing were more marked in the crushed stone concrete than in the gravel concrete.

5. The process of finishing by the Johnson method did not adversely affect the hardness of the concrete.

6. The process of finishing by the Johnson method resulted in decreasing the void-cement ratio approximately 0.1 more than the corresponding decrease shown for the standard-finish concrete.

CURRENT STATUS OF NATIONAL RECOVERY ROAD CONSTRUCTION AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS I—NATIONAL RECOVERY HIGHWAY PROJECTS

(ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES)

AS OF SEPTEMBER 30, 1933

STATE	NATIONAL RECOVERY FUNDS ASSIGNED FOR CLASS I PROJECTS ON THE FEDERAL AID HIGHWAY SYSTEM	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF NATIONAL RECOVERY FUNDS AVAILABLE FOR NEW CLASS I PROJECTS
		Total cost	National recovery funds	Regular Federal aid	Mileage	Estimated total cost	National recovery funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	National recovery funds allotted	Mileage	
	$					$	$	$			$		$
Alabama	4,185,067										614,613.59	42.1	3,570,453.41
Arizona	3,804,731					341,934.93	339,780.69		3.5	26.6	915,672.59	59.8	2,549,277.72
Arkansas	3,374,167					157,051.86	78,525.93	78,525.93	1.3	.2	189,564.16	3.3	3,106,076.91
California	7,803,677					91,922.04	55,464.33			.4	4,780,084.60	184.7	2,968,128.07
Colorado	3,437,265					487,554.21	487,554.21		4.3	31.0	634,513.71	24.2	2,315,197.08
Connecticut	1,404,213										202,625.72	2.9	1,201,587.28
Delaware	909,544					113,840.45	113,840.45		1.8	1.2	352,476.85	20.7	443,226.70
Florida	2,615,917										881,371.61	56.2	1,734,545.39
Georgia	5,045,592												5,045,592.00
Idaho	2,243,125					1,047,250.42	1,047,151.42		6.2	86.5	417,428.20	25.4	778,545.38
Illinois	4,431,348										85,811.02	.9	4,345,536.98
Indiana	4,717,786										2,272,727.86	80.3	2,445,058.14
Iowa	5,027,830					2,044,459.11	1,923,800.00		11.1	93.1	1,792,400.00	94.7	1,311,630.00
Kansas	5,044,802										2,216,413.22	266.7	2,828,388.78
Kentucky	3,608,332										1,568,028.46	134.2	2,040,303.54
Louisiana	2,914,295					419,189.70	419,189.70			18.0	926,685.80	9.1	1,568,419.50
Maine	1,684,959					538,434.87	538,434.87		13.7	22.3	276,778.22	5.0	869,745.91
Maryland	1,782,263										173,428.09	4.8	1,608,834.91
Massachusetts	1,932,950					266,711.51	137,412.16	124,984.24	32.0	7.4	58,525.35	5.7	1,737,012.49
Michigan	5,094,491					660,500.00	660,500.00		4.7	27.7	700,000.00	57.3	3,733,991.00
Minnesota	5,115,153					1,072,674.82	1,072,674.82		14.1	171.6	995,796.77	182.0	3,046,681.41
Mississippi	3,489,337					195,020.80	105,718.33	89,302.47		8.9	106,530.65	9.6	3,277,088.02
Missouri	6,090,153					447,056.18	388,331.43		1.0	13.8	2,567,159.51	101.9	3,134,662.06
Montana	3,719,874					1,784,361.58	1,604,361.58	100,000.00	8.9	130.1	1,029,066.77	90.0	1,086,445.65
Nebraska	3,914,481					1,761,592.34	1,402,902.80		13.0	152.9	1,139,126.46	137.4	1,372,451.74
Nevada	2,909,387					142,181.52	142,181.52		8.4	26.0	371,808.43	65.8	2,395,397.05
New Hampshire	954,919					143,242.86	110,000.00		.9	2.4	212,892.65	5.2	632,026.35
New Jersey	3,065,137										374,227.67	6.1	2,690,909.33
New Mexico	2,896,467					722,971.10	722,971.10		6.8	100.5	971,567.19	107.7	1,201,928.71
New York	10,830,099					4,456,800.00	4,216,610.00	240,000.00	4.1	96.1	4,415,040.00	83.3	2,198,449.00
North Carolina	4,761,147					598,096.51	299,048.29	299,048.22	2.0	70.5	226,944.44	66.0	4,235,154.27
North Dakota	2,902,224					338,303.54	338,303.54		2.1	142.3	1,392,522.76	461.8	1,171,397.70
Ohio	6,968,066					1,420,820.00	1,420,820.00		1.0	42.1	3,893,845.00	84.4	1,653,401.00
Oklahoma	4,608,399					22,165.59	22,165.59		4.5	3.8	2,971,916.39	175.9	1,614,317.02
Oregon	3,053,448					1,097,865.86	1,060,851.85		10.3	82.2	1,144,892.10	46.6	847,704.05
Pennsylvania	5,757,978										1,627,200.00	44.2	4,130,778.00
Rhode Island	999,354					233,128.00	233,128.00		1.3	6.6	733,837.82	13.3	32,388.18
South Carolina	2,729,583					74,882.33	72,152.71	2,729.62		19.2	1,135,439.20	125.1	1,521,991.09
South Dakota	3,005,739					546,992.49	546,992.49		7.9	73.6	904,465.42	147.2	1,554,281.09
Tennessee	4,246,309										429,668.21	15.5	3,816,640.79
Texas	12,122,012					1,013,160.70	801,491.63		3.1	81.4	2,878,310.37	384.1	8,442,210.00
Utah	2,097,354					1,104,247.51	1,104,247.51		34.3	136.9	404,077.41	28.9	589,029.08
Vermont	931,919					553,013.21	553,013.21		6.3	25.3	1,949.75	.4	376,956.04
Virginia	3,708,379					69,463.18	69,463.18			2.3	824,678.48	40.3	2,814,237.34
Washington	3,057,934					841,058.58	837,701.76	3,356.82	6.0	35.5	866,984.93	32.3	1,353,247.31
West Virginia	2,013,405					573,068.56	573,068.56		1.0	24.4	1,138,827.63	42.9	301,508.81
Wisconsin	4,862,441					1,781,909.98	1,760,409.98	21,500.00	22.2	71.0	843,838.61	36.4	2,258,192.41
Wyoming	2,250,663					911,611.13	882,769.08		11.0	184.1	1,098,878.29	221.5	269,015.63
District of Columbia													
Hawaii	1,683,956										43,500.88	5.1	1,640,455.12
TOTALS	185,807,671					28,074,537.47	26,143,032.72	959,447.30	9.0	2,017.9	53,804,142.84	3,838.9	105,860,495.44

CURRENT STATUS OF NATIONAL RECOVERY ROAD CONSTRUCTION AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS II—NATIONAL RECOVERY MUNICIPAL HIGHWAY PROJECTS

(ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES)

AS OF SEPTEMBER 30, 1933

STATE	NATIONAL RECOVERY FUNDS ASSIGNED FOR CLASS II PROJECTS IN MUNICIPALITIES	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF NATIONAL RECOVERY FUNDS AVAILABLE FOR NEW CLASS II PROJECTS
		Total cost	National recovery funds	Regular Federal aid	Mileage	Estimated total cost	National recovery funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	National recovery funds allotted	Mileage	
	$					$	$				$		$
Alabama	2,092,533										21,544.05	1.7	2,070,988.95
Arizona	781,794					5,345.26	5,345.26			0.4	6,631.04	.6	769,817.70
Arkansas	1,687,084										32,936.12	.5	1,654,147.[illegible]
California	3,901,839					38,291.40	33,871.86			.8	291,255.96	3.3	3,576,711.18
Colorado	1,718,633					100,849.92	100,849.92		2.0	2.7	4,106.96	.7	1,613,676.12
Connecticut	802,407										380,970.16	3.2	421,436.84
Delaware	454,772					30,801.70	30,801.70			.7	39,357.50	.2	384,612.80
Florida	1,307,959										76,807.52	2.9	1,231,151.48
Georgia	2,724,620												2,724,620.00
Idaho	1,121,562					38,360.76	38,360.76		5.2	2.9	1,112.10	.1	1,082,089.14
Illinois	6,877,199												6,877,199.00
Indiana	4,818,165												4,818,165.00
Iowa	2,815,585					139,570.61	131,400.00		11.4	3.9	642,400.00	18.2	2,041,785.00
Kansas	2,522,401					21,868.02	21,868.02				57,694.87	6.4	2,442,838.11
Kentucky	2,029,687										31,123.23	1.5	1,998,563.77
Louisiana	1,457,148										379,759.02	9.3	1,077,388.98
Maine	842,479					70,960.63	70,960.63		28.2	2.6	141,049.29	2.0	630,469.08
Maryland	891,132										13,706.65	.6	877,425.35
Massachusetts	4,136,382					271,359.00	161,737.14	103,375.00	4.3	2.6	726,380.47	4.4	3,248,264.39
Michigan	4,457,679					24,000.00	24,000.00			.9	229,700.00	7.4	4,203,979.00
Minnesota	3,410,102					439,204.01	439,204.01		3.9	22.3	831,452.70	29.3	2,139,445.29
Mississippi	1,744,669										17,357.43	1.8	1,727,311.57
Missouri	3,045,077					29,333.57	29,333.57			.7	615,389.36	7.0	2,400,354.07
Montana	1,859,937					5,275.14	5,275.14		75.8	.4	25,871.92	2.3	1,828,789.94
Nebraska	1,957,240					103,831.27	103,831.27		5.8	5.0	113,436.30	7.2	1,739,972.43
Nevada	500,051					57,689.61	57,689.61		5.2	1.2			442,361.39
New Hampshire	477,460										20,000.00	.3	457,460.00
New Jersey	3,217,442										1,215,595.66	7.8	2,001,846.34
New Mexico	1,448,234										72,429.57	2.3	1,375,804.43
New York	7,837,865					1,214,070.00	1,214,070.00		.7	8.0	2,553,200.00	23.1	4,070,595.00
North Carolina	2,380,573					22,158.73	22,158.73			1.1	79,888.38	7.9	2,278,525.89
North Dakota	1,451,112					7,557.18	7,557.18			3.4	15,409.26	3.1	1,428,145.56
Ohio	4,645,378					54,350.00	54,350.00			1.0	766,365.00	10.5	3,824,663.00
Oklahoma	2,304,200					3,272.08	3,272.08			.5	51,564.75	4.1	2,249,363.17
Oregon	1,526,724										218,414.35	4.6	1,308,309.65
Pennsylvania	5,416,051										364,900.00	9.0	5,051,151.00
Rhode Island	499,677												499,677.00
South Carolina	1,364,791					6,542.28	6,137.27	405.01		1.6	79,228.79	7.5	1,279,424.94
South Dakota	1,502,870					21,164.62	21,164.62			2.1	30,130.16	3.3	1,451,575.22
Tennessee	2,123,155										26,417.32	1.3	2,096,737.68
Texas	6,061,006					28,593.48	28,593.48			.4	185,110.13	22.7	5,847,302.39
Utah	1,048,677					191,813.07	180,653.07		8.9	5.4	297,055.21	8.0	570,968.72
Vermont	470,628					13,707.96	13,707.96			.9			456,920.04
Virginia	1,854,189										90,385.97	2.6	1,763,803.03
Washington	1,877,571					37,211.64	37,211.64		26.9	1.5	103,981.60	2.6	1,736,377.76
West Virginia	1,342,270					39,929.76	39,929.76			.4	96,749.27	.5	1,205,590.97
Wisconsin	2,431,220					368,256.89	368,256.89		8.1	12.5	327,398.62	6.3	1,735,564.49
Wyoming	1,125,332										267,476.57	5.1	857,855.43
District of Columbia	1,151,081					169,320.65	169,320.65		4.1	1.1	748,503.00	2.8	233,257.35
Hawaii													
TOTALS	113,515,642					3,554,689.24	3,420,912.22	103,780.01	4.3	87.0	12,290,246.26	246.0	97,804,483.52

CURRENT STATUS OF NATIONAL RECOVERY ROAD CONSTRUCTION
AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS III—NATIONAL RECOVERY SECONDARY HIGHWAY PROJECTS

(On Secondary or Feeder Roads not now included in the approved system of Federal-aid highways, but which are either part of the State highway system or are important local highways leading to shipping points, or which will permit the coordination or extension of existing transportation facilities)

AS OF SEPTEMBER 30,1933

STATE	NATIONAL RECOVERY FUNDS ASSIGNED FOR CLASS III PROJECTS ON SECONDARY HIGHWAYS	COMPLETED			UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION		BALANCE OF NATIONAL RECOVERY FUNDS AVAILABLE FOR NEW CLASS III PROJECTS	STATE
		Total cost	National recovery funds	Mileage	Estimated total cost	National recovery funds allotted	Percentage completed	Mileage	National recovery funds allotted	Mileage		
	$				$	$			$		$	
Alabama	2,092,533										2,092,533.00	Alabama
Arizona	625,435										625,435.00	Arizona
Arkansas	1,687,084										1,687,084.00	Arkansas
California	3,901,838								235,928.19	5.5	3,665,909.81	California
Colorado	1,718,632										1,718,632.00	Colorado
Connecticut	659,120										659,120.00	Connecticut
Delaware	454,772										454,772.00	Delaware
Florida	1,307,958										1,307,958.00	Florida
Georgia	2,320,973										2,320,973.00	Georgia
Idaho	1,121,562				11,625.34	10,713.08		2.8			1,110,848.92	Idaho
Illinois	6,262,223										6,262,223.00	Illinois
Indiana	501,892										501,892.00	Indiana
Iowa	2,212,245				3,718.11	3,500.00		.6	514,700.00	33.8	1,694,045.00	Iowa
Kansas	2,522,401								12,972.27	3.8	2,509,428.73	Kansas
Kentucky	1,879,340								364,518.00	33.3	1,514,822.00	Kentucky
Louisiana	1,457,148								59,390.34	2.3	1,397,757.66	Louisiana
Maine	842,479				703,465.36	703,465.36	15.1	83.3	137,934.64	10.6	1,079.00	Maine
Maryland	891,132										891,132.00	Maryland
Massachusetts	527,768				384,331.26	384,331.26	6.2	11.5			143,436.74	Massachusetts
Michigan	3,184,057										3,184,057.00	Michigan
Minnesota	2,131,314				114,079.73	114,079.73	.9	14.6	413,755.16	27.3	1,603,479.11	Minnesota
Mississippi	1,744,669										1,744,669.00	Mississippi
Missouri	3,045,076								424,647.24	86.4	2,620,428.76	Missouri
Montana	1,859,937										1,859,937.00	Montana
Nebraska	1,957,240								308,248.08	19.5	1,648,991.92	Nebraska
Nevada	1,136,479								196,097.57	14.4	940,381.43	Nevada
New Hampshire	477,460										477,460.00	New Hampshire
New Jersey	63,460										63,460.00	New Jersey
New Mexico	1,448,234										1,448,234.00	New Mexico
New York	3,662,137				1,509,141.00	1,505,620.00	2.7	34.7	1,578,390.00	27.8	578,127.00	New York
North Carolina	2,380,573				68,099.79	68,099.79		9.3	86,666.14	7.6	2,225,807.07	North Carolina
North Dakota	1,451,112										1,451,112.00	North Dakota
Ohio	3,871,148								151,064.90	1.2	3,720,083.10	Ohio
Oklahoma	2,304,199										2,304,199.00	Oklahoma
Oregon	1,526,724								217,862.70	52.6	1,308,861.30	Oregon
Pennsylvania	7,716,975										7,716,975.00	Pennsylvania
Rhode Island	499,677										499,677.00	Rhode Island
South Carolina	1,364,791								322,186.38	41.6	1,042,604.62	South Carolina
South Dakota	1,502,870								12,525.42	3.8	1,490,344.58	South Dakota
Tennessee	2,123,155										2,123,155.00	Tennessee
Texas	6,061,006				83,781.20	83,781.20		12.9	566,063.55	124.5	5,411,161.25	Texas
Utah	1,048,677				19,060.36	19,060.36	31.5	7.0	39,640.75	1.0	989,975.89	Utah
Vermont	465,026										465,026.00	Vermont
Virginia	1,854,189								158,524.75	11.6	1,695,664.25	Virginia
Washington	1,180,362				223,949.30	223,949.30		9.2	77,925.76	14.4	878,486.94	Washington
West Virginia	1,118,559										1,118,559.00	West Virginia
Wisconsin	2,431,220				148,927.19	148,927.19	.7	13.1	542,518.16	37.7	1,739,774.65	Wisconsin
Wyoming	1,125,332										1,125,332.00	Wyoming
District of Columbia	767,388				62,897.00	62,897.00	1.6	1.5	262,447.00	1.9	442,044.00	District of Columbia
Hawaii	187,106										187,106.00	Hawaii
TOTALS	94,676,687				3,333,075.64	3,328,424.27	5.4	200.5	6,684,007.00	562.6	84,664,255.73	TOTALS

CURRENT STATUS OF NATIONAL RECOVERY ROAD CONSTRUCTION
AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

SUMMARY OF CLASSES I, II, AND III

AS OF SEPTEMBER 30,1933

STATE	TOTAL APPORTIONMENT OF NATIONAL RECOVERY FUNDS	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF NATIONAL RECOVERY FUNDS AVAILABLE FOR ALL NEW PROJECTS
		Total cost	National recovery funds	Regular Federal aid	Mileage	Estimated total cost	National recovery funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	National recovery funds allotted	Mileage	
	$					$	$	$			$		$
Alabama	8,370,133										636,157.64	43.8	7,733,975.36
Arizona	5,211,960					347,280.19	345,125.95		3.5	27.0	922,303.63	60.4	3,944,530.42
Arkansas	6,748,335					157,051.86	78,525.93	78,525.93	1.3	.2	222,500.28	3.8	6,447,308.79
California	15,607,354					130,213.44	89,336.19			1.2	5,307,268.75	193.5	10,210,749.06
Colorado	6,874,530					588,404.13	588,404.13		3.9	33.7	638,620.67	24.9	5,647,505.20
Connecticut	2,865,740										583,595.88	6.1	2,282,144.12
Delaware	1,819,088					144,642.15	144,642.15		1.4	1.9	391,834.35	20.9	1,282,611.50
Florida	5,231,834										958,179.13	59.1	4,273,654.87
Georgia	10,091,185												10,091,185.00
Idaho	4,486,249					1,097,236.52	1,096,225.26		6.1	92.3	418,540.30	25.5	2,971,483.44
Illinois	17,570,770										85,811.02	.9	17,484,958.98
Indiana	10,037,843										2,272,727.86	80.3	7,765,115.14
Iowa	10,055,660					2,187,747.83	2,058,700.00		11.1	97.6	2,949,500.00	146.7	5,047,460.00
Kansas	10,089,604					21,868.02	21,868.02				2,287,080.36	276.8	7,780,655.62
Kentucky	7,517,359										1,963,669.69	169.0	5,553,689.31
Louisiana	5,828,591					419,189.70	419,189.70			18.0	1,365,835.16	20.7	4,043,566.14
Maine	3,369,917					1,312,860.86	1,312,860.86		15.2	108.3	555,762.15	17.6	1,501,293.99
Maryland	3,564,527										187,134.74	5.4	3,377,392.26
Massachusetts	6,597,100					922,401.77	683,480.56	228,359.24	11.0	21.5	784,905.82	10.2	5,128,713.62
Michigan	12,736,227					684,500.00	684,500.00		4.5	28.6	929,700.00	64.7	11,122,027.00
Minnesota	10,656,569					1,625,958.56	1,625,958.56		10.4	208.5	2,241,004.63	238.6	6,789,605.81
Mississippi	6,978,675					195,020.80	105,718.33	89,302.47		8.9	123,888.08	11.3	6,749,068.59
Missouri	12,180,306					476,389.75	417,665.00		1.0	14.5	3,607,196.11	195.4	8,155,444.89
Montana	7,439,748					1,789,636.72	1,609,636.72	100,000.00	9.1	130.5	1,054,938.69	92.4	4,775,172.59
Nebraska	7,828,961					1,865,423.61	1,506,734.07		12.5	157.9	1,560,810.84	164.2	4,761,416.09
Nevada	4,545,917					199,871.13	199,871.13		7.5	27.1	567,906.00	80.2	3,778,139.87
New Hampshire	1,909,839					143,242.86	110,000.00		.9	2.4	232,892.65	5.5	1,566,946.35
New Jersey	6,346,039										1,589,823.33	13.9	4,756,215.67
New Mexico	5,792,935					722,971.10	722,971.10		6.8	100.5	1,043,996.76	109.9	4,025,967.14
New York	22,330,101					7,180,011.00	6,936,300.00	240,000.00	3.2	138.8	8,546,630.00	134.2	6,847,171.00
North Carolina	9,522,293					688,355.03	389,306.81	299,048.22	1.5	80.9	393,498.96	81.5	8,739,487.23
North Dakota	5,804,448					345,860.72	345,860.72		2.0	145.7	1,407,932.02	464.9	4,050,655.26
Ohio	15,484,592					1,475,170.00	1,475,170.00		.9	43.1	4,811,274.90	96.1	9,198,147.10
Oklahoma	9,216,798					25,437.67	25,437.67		3.9	4.2	3,023,481.14	180.0	6,167,879.19
Oregon	6,106,896					1,097,865.86	1,060,851.85		10.3	82.2	1,581,169.15	103.7	3,464,875.00
Pennsylvania	18,891,004										1,992,100.00	53.2	16,898,904.00
Rhode Island	1,998,708					233,128.00	233,128.00		1.3	6.5	733,837.82	13.3	1,031,742.18
South Carolina	5,459,165					81,424.61	78,289.98	3,134.63		20.9	1,536,854.37	174.2	3,844,020.65
South Dakota	6,011,479					568,157.11	568,157.11		7.6	75.7	947,121.00	154.3	4,496,200.89
Tennessee	8,492,619										456,085.53	16.8	8,036,533.47
Texas	24,244,024					1,125,535.38	913,866.31		2.7	94.8	3,629,484.05	531.3	19,700,673.64
Utah	4,194,708					1,315,120.94	1,303,960.94		30.8	149.3	740,773.37	37.8	2,149,973.69
Vermont	1,867,573					566,721.17	566,721.17		6.2	26.2	1,949.75	.4	1,298,902.08
Virginia	7,416,757					69,463.18	69,463.18			2.3	1,073,589.20	54.5	6,273,704.62
Washington	6,115,867					1,102,219.52	1,098,862.70	3,356.82	5.5	46.2	1,048,892.29	49.3	3,968,112.01
West Virginia	4,474,234					612,998.32	612,998.32		1.0	24.8	1,235,576.90	43.4	2,625,658.78
Wisconsin	9,724,881					2,299,094.06	2,277,594.06	21,500.00	18.5	96.6	1,713,755.39	80.5	5,733,531.55
Wyoming	4,501,327					911,611.13	882,769.08		11.0	184.0	1,366,354.86	226.6	2,252,203.06
District of Columbia	1,918,469					232,217.65	232,217.65		3.4	2.6	1,010,950.00	4.7	675,301.35
Hawaii	1,871,062										43,500.88	5.1	1,827,561.12
TOTALS	394,000,000					34,962,302.35	32,892,369.21	1,063,227.31	8.1	2,305.4	72,778,396.10	4,647.5	288,329,234.69

U. S. GOVERNMENT PRINTING OFFICE: 1933