MISSOURI STATE HIGHWAY DEPARTMENT

Investigation 34-3

VIBRATING PAN TYPE OF FINISHING MACHINE FOR CONCRETE PAVEMENTS.

Bureau of Materials
Research Division

Jefferson City, Mo.
January 1936.

VIBRATING PAN TYPE FINISHING MACHINE FOR CONCRETE PAVEMENTS

Reported by F.V. Reagel and
T.F. Willis

SUMMARY AND CONCLUSIONS

This report describes the methods used, and the results obtained, in an investigation of the vibrating pan type of finishing machine for concrete pavements.* The manufacturer of the machine claimed that it would finish drier and 'leaner' mixtures than could be handled by an ordinary finisher. If this were true, concrete of improved quality could be obtained by using drier mixtures with the usual cement content, or costs could be decreased without sacrificing quality by using 'leaner' mixtures. The investigation proposed to determine the merit of the manufacturer' contention and the extent to which the quality of the concrete could be increased or the cost decreased.

Various concrete mixtures were tried on sections of pavement finished with the vibratory finisher. The action of the finisher was observed; slabs were removed from the pavement, tested for flexure strength and the degree of 'honeycombing' noted; also, cores were drilled from the pavement, some of which were tested for compressive strength and others for durability by subjecting them to repeated cycles of freezing and thawing.

The data of the investigation were derived from tests of concrete on an ordinary construction project and were affected by the uncontrolled variables always present in such tests. For this reason the conclusions should probably be classed as indications. These may be summarized as follows:

1. The vibrating pan type of finisher is capable of finishing concrete mixtures which are much leaner, harsher and drier than mixtures ordinarily considered suitable for pavement concrete. However, it cannot spread and 'strike off' as dry and harsh mixtures as were handled with the vibratory screed type of machine on another project. With proper equipment for spreading and 'striking' the concrete off to the right depth, it is possible that this finisher could puddle and compact even harsher mixtures than were used in this investigation. As in previous investigations, it was the general opinion that the vibratory finishing machine had the capacity for puddling drier and harsher concrete, but the inability of the hand labor to spread this kind of concrete prevented its trial.

---

* Previously an investigation and report on the vibrating screed type of finishing machine had been made.

2. With the materials and methods of handling the concrete used on this project, the A-4 mixture (1:1,54:3.68) was considered the best if improvement in quality without increased cost is desired; the B-3 mixture (1:2.02:4.04) was considered the best if the maximum decrease in cost without sacrifice of quality is desired.

3. With the mixture recommended for improved quality, the strength was increased about 16% but the other measures of quality were not changed appreciably.

4. 4. With the mixture recommended for decreased cost about 15% of the cost of the cement was saved.

5. Vibratory finishing necessitates the use of concrete mixtures of lower mortar content and drier consistency than are considered satisfactory for ordinary finishing. Wet or overmortared mixtures are uneconomical as the vibration works to the surface an excessive amount of mortar which must be wasted over the forms at the edge of the pavement.

6. A consistency of three-fourths of an inch to one inch slump is the minimum that could be successfully used on this project. This was especially true of the mixtures containing the larger proportions of coarse aggregate. Concrete of lower consistency could not be handled by the hand labor and the construction equipment was unable to properly distribute the concrete and 'strike off' the surface in a satisfactory manner prior to vibration; also the amount of honeycombing in the finished pavement increased materially when concrete of lower consistency was used.

7. All the concrete mixtures tested had satisfactory strength, density, and durability, where placed under optimum conditions. With some of the mixtures, the slab specimens from certain locations in the pavement showed considerable honeycombing. The tests showed that the vibratory finisher cannot overcome effects of segregation caused by non-uniform spreading of the concrete mixture and emphasized that to develop the full advantage of vibration, some form of mechanical spreader is necessary.

8. In general, both the compression and flexure test results corroborated previous studies in showing that vibrated concrete follows the water-cement ratio strength law.

VIBRATING PAN TYPE FINISHING MACHINE

FOR CONCRETE PAVEMENTS

By: F. V. Reagel and
T. F. Willis

INTRODUCTION

Highway engineers have recently evidenced considerable interest in the use of vibration for placement and finishing of concrete pavements. In the course of the past several years the United States Bureau of Public Roads and the State Highway Departments of Illinois, Michigan, Missouri, New Jersey, Ohio, Texas and others have experimented with the use of several types of vibratory finishing machines. Much of this work was directed toward investigation of the vibratory screed type of machine. In this machine vibration units are attached to the screeds and vibration is transmitted to the concrete through these screeds as the finishing operation is carried on. Several of the investigators have found this type of machine to be effective in the placement and finishing of concrete mixtures much leaner and harsher than the ordinary finishing machine could handle. More recently another type of vibrator has been developed which is designated as the vibrating pan type. In this machine the tamping bar, which is ordinarily suspended between the front and rear screeds, is replaced by a flat pan shaped member on which the vibrating units are attached. This pan is slightly shorter than the width of the pavement and hence rests directly on the concrete at all times, vibrating it as the finishing operation progresses.

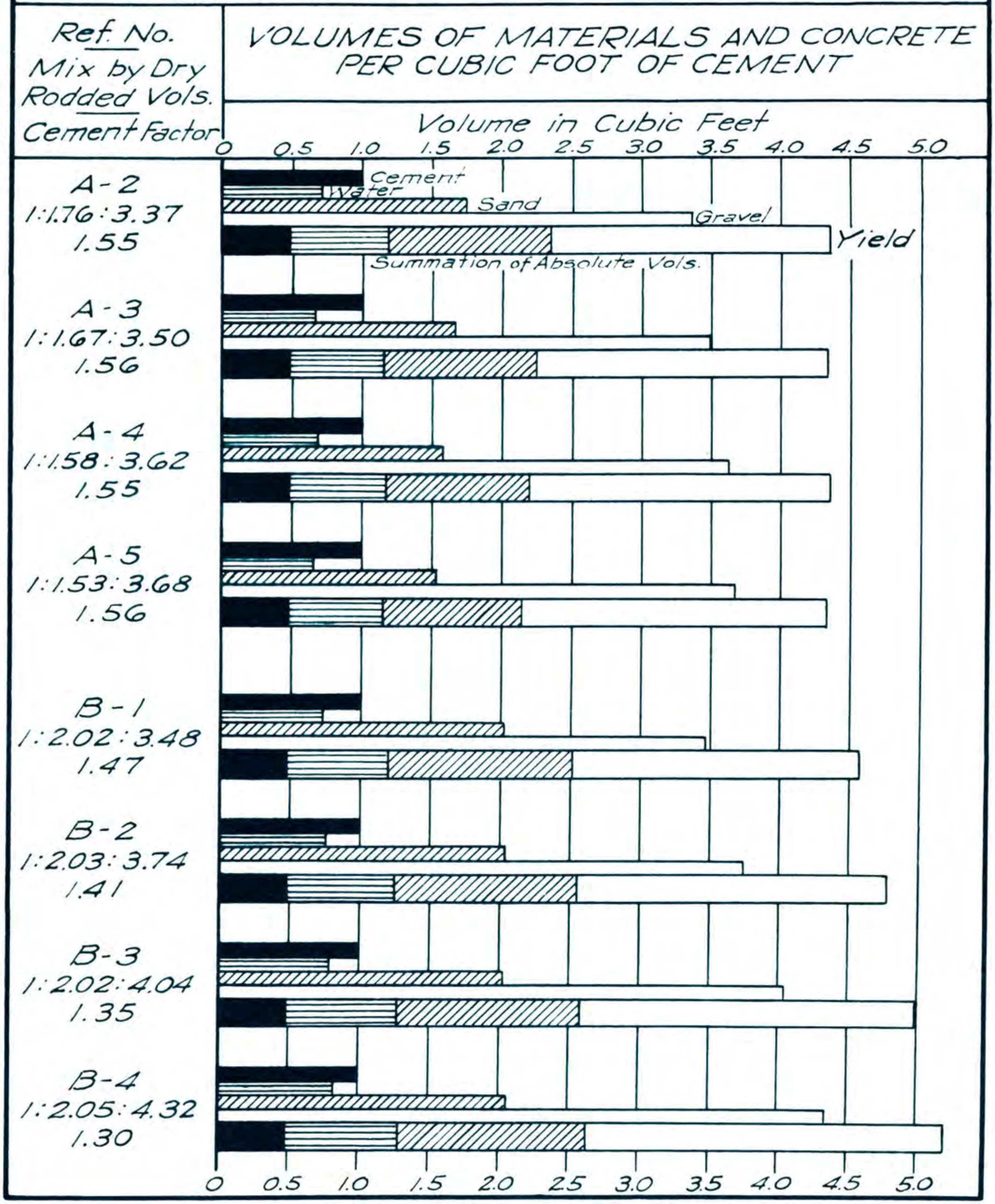
For the purpose of investigating this type of finisher the Missouri State Highway Department used one on the construction of 4 miles of concrete pavement. The U. S. Bureau of Public Roads cooperated in outlining the investigation and furnished the apparatus for testing the beams which were removed from the pavement. The principle objective of the investigation was to determine the range of concrete mixtures which could be properly placed and finished.

Guided by the results of previous investigations and preliminary experiments performed on this project, two series of concrete mixtures were designed. The proportions and yield of the various mixture are shown diagrammatically in Fig. 1.

The mixtures of the first series, designated A2, A3, A4, and A5, were proportioned so that the cement factor, i. e., the cement content per cubic yard of concrete, was constant and equal to that which had been used with the same aggregates on projects where an ordinary finishing machine was used. The ratio of the sand to the total aggregate was varied from 38 to 31 per cent and

FIG. I

COMPARISON OF MIXTURES
SHOWING
PROPORTIONS OF MATERIALS AND YIELD



the water-cement ratio varied so as to maintain an approximately constant consistency of the concrete. The purpose of this series was to obtain information regarding the increase in strength and quality of the concrete which might result from the anticipated reduction of the water-cement ratio. Since the cement content was maintained constant, and this is the most expensive ingredient in the mixture, the cost of each mixture was approximately the same as that of the standard mixture.

The second series of mixtures designated B1, B2, B3, and B4 was proportioned so as to have four different cement factors varying from 1.45 to 1.30 barrels of cement per cubic yard of concrete. The purpose of this series was to determine (for the aggregates used on this job) the ability of this type of vibrator to finish mixtures with lower cement contents, than would ordinarily be used, without resulting in any objectionable decrease in strength and quality of the concrete; or in other words what decrease in cost of materials might be effected through the use of this vibratory finisher.

Each mixture of each series was used in the construction of five sections of pavement, each section being at least 100 feet long. The test sections were alternated throughout the construction of the job so that no two of the five tests of one mixture would be conducted on the same day or at the same time on different days. This was done so that the effects of weather and temperature on the five test sections of any one mixture would on the average, be about the same as those on the test sections of any other mixture.

Tests and observations of the quality and strength of the concrete consisted of the following:

1. Observation of the surface during and after the finishing operation.

2. Observation of the pavement edges for honeycombing.

3. Removal, observation for honeycombing, and testing for flexural strength at 28 days of five 2' x 7' slabs from each test section.

4. Removal, visual examination, and testing for compressive strength at 28 days of five cores from each test section.

5. Removal and testing for durability by subjecting to alternate cycles of freezing and thawing of six cores from each mixture.

6. Removal and testing for density and absorption of six cores from each mixture.

The tests were carried on during the construction of a regular paving project, FAP NRH 380A, Texas County. Plans and specifications called for a standard A.A.S.H.O. 9-7-9 cross-section, twenty feet wide. The aggregates used were local creek gravel and sand, the gravel consisting of rather angular chert and the sand a chert-quartz mixture, the particles of which were angular. The same materials had previously been used on another paving project where ordinary finishing methods were specified and were considered somewhat harsh. The mixture designated by the concrete control division for use, and considered satisfactory, on this other project was 1:1.87:3.23 by dry rodded volumes, which is somewhat richer than the Missouri standard mixture of 1:2:3.5

Provision for Removal of Slabs from Pavement At some point in each test section a special test panel was provided which was seven feet long and extended one-half the width of the pavement. Wooden headers were placed at the ends of the panel and along the center joint. The subgrade was formed so that the slab would be uniformly seven inches thick and was covered with tar paper. A batch of concrete was dumped between the headers and spread by hand to a uniform depth. Then four 2" x 2" wooden separators were set parallel to the centerline, and at the mid-depth of the slab, to provide planes of weakness at two foot intervals across the panel. The second batch of concrete was then dumped, hand spread, and the test panel along with the rest of the pavement vibrated and finished by the usual procedure. After completion of the finishing operations the transverse headers were removed. As the concrete hardened, the wooden separators absorbed moisture, swelled, and formed longitudinal cracks which divided the panels into five slabs 2' wide by 7' long. These slabs were left in place and subjected to the same curing and weather conditions as the pavement until 28 days old, when they were removed and tested. The steps in the preparatic of a test panel are pictured in Plate 2.

Operation of the Vibratory Finisher The operation of the finishing machine was supervised by the manufacturer's representative. At different times during the experiment the number of vibrations was varied from 3400 to 3900 per minute but most of the time the finishing was carried on at 3600 vibrations per minute. More than ordinary skill was required to coordinate the operation of the finishing screeds and vibrating pan. The surface of the concrete behind the vibrator was ordinarily too compact and rigid to be manipulated by hand screeding and floating; thus, when any roughness or unevenness of the surface was left by the finishing machine considerable work was required to float it out. Frequent occurrence of high spots on these test sections proved the importance of striking the concrete off with the front screed to a uniform depth, and making the proper allowance for settlement and compaction of the concrete under the vibrator.

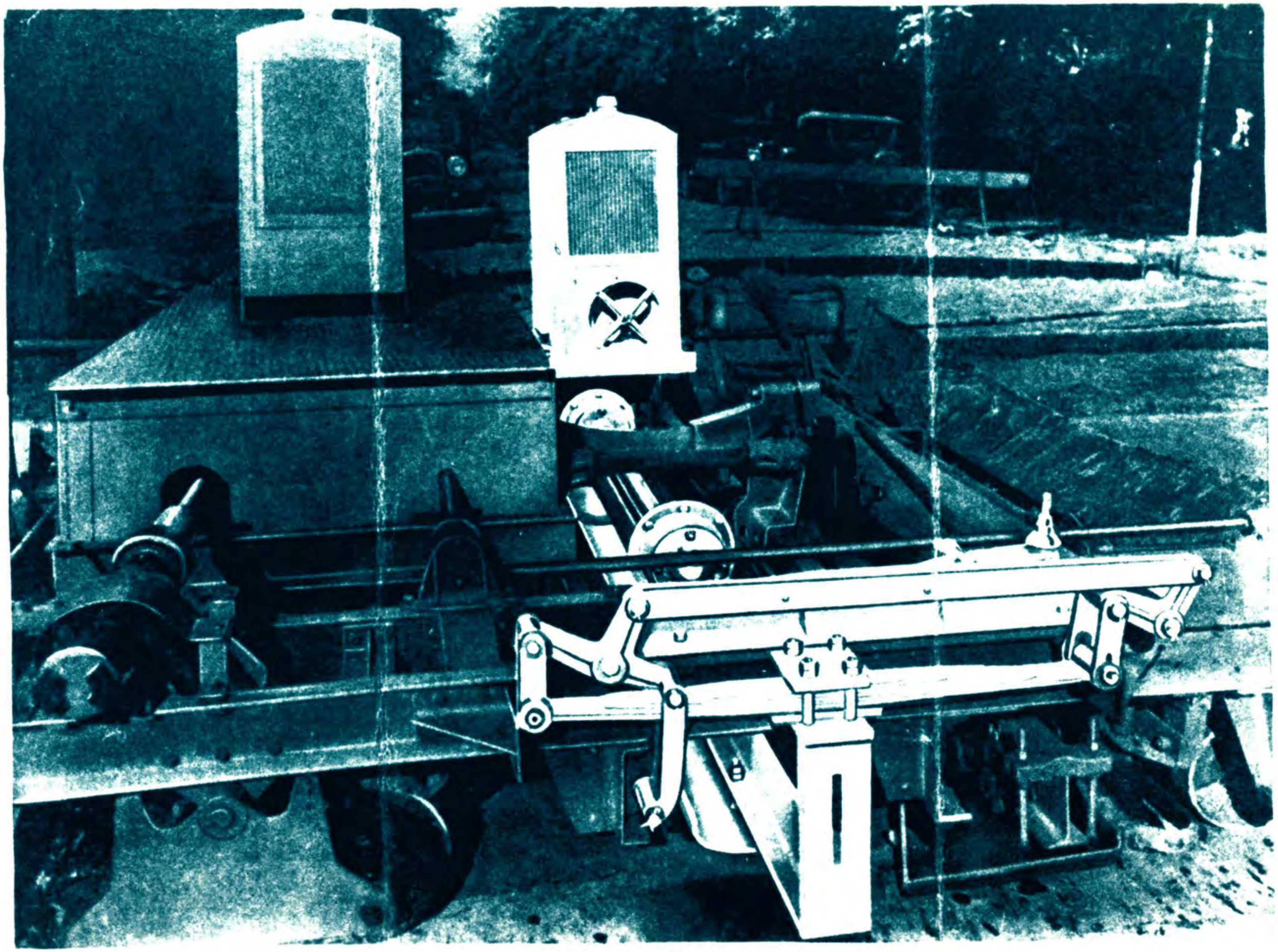


PLATE I - CLAW-TYPE VIBRATING ATTACHMENT FOR OLD FINISHERS

Headers set and tar paper spread on subgrade, preparatory to dumping first batch of concrete for test panel.

First batch of concrete deposited on subgrade.

First batch spread and separators set preparatory to dumping second batch of concrete.

PLATE II.

Comparison of the action of the vibrating pan type of finishing machine with that of the vibratory screed type of machine, used on another project, brought out that the former cannot spread and 'strike off' as dry and harsh mixtures as can be handled by the latter. With proper equipment for spreading and 'striking' the concrete off to the right depth, it is possible that this finisher could puddle and compact even harsher mixtures than were used in this investigation. As in previous investigations, it was the general opinion that the vibratory finishing machine had the capacity for puddling drier and harsher concrete, but the inability of the hand labor to spread this kind of concrete prevented its trial.

During the course of these tests several mechanical imperfections in the vibratory finishing machine developed. However, changes in the design are supposed to have corrected all these faults.

Testing Procedure The slabs were removed from the test panels by means of a special hoist and tested for flexural strength, when 28 days old, in a special testing apparatus provided by the U. S. Bureau of Public Roads. Plate 3 shows views of the testing of the slabs. As each slab was tested a sketch was made showing the location and shape of the break and the location and amount of honeycomb in the broken section. The honeycombed area was expressed as a per cent of the total area of the cross-section at the break. This estimate of the amount of honeycomb was later checked by breaking the two halves of each slab with a sledge to expose other faces about a foot on each side of the original flexure break.

At the time of pouring the pavement, certain locations in each test section were selected as containing concrete typical of that designed for the test section, properly distributed and finished, from which cores could be drilled. When the pavement was twenty-two days old five 6" diameter cores were drilled from each test section, shipped to the laboratory, soaked in water for twenty-four hours, and tested in compression (saturated) at the age of twenty eight days. When the pavement was ninety days old six 4 1/2" cores were drilled from representative test sections of each mixture. This set of cores was taken to the laboratory, soaked in water for twenty-four hours, and then subjected to cycles of freezing and thawing. A second set of 4 1/2" cores was drilled at the same time, from the same areas, and tested in the laboratory for density and absorption. All core tests were performed according to the A. S. T. M. Standard or the latest A. S. T. M. Committee recommendations.

General view of slab testing operations.

Specimen in machine ready for testing.

Detail view of testing apparatus.

PLATE III.

Observations on Workability of Mixtures

Observation of the workability of the various mixtures, as judged by the ease with which the hand labor placed and spread the concrete, segregation within the batches, and the finished surface, may be summarized as follows:

> The A-1 mixture (cement factor 1.55, per cent sand 38.5), the standard mixture for these materials when finished by the ordinary methods, was used in preliminary observations only. It was found to be unsatisfactory, regardless of the consistency, because the vibrating finisher worked an excessive amount of mortar to the surface which had to be wasted over the forms.
>
> The A-2 mixture (cement factor 1.55, per cent sand 36.0) was very workable as compared to other mixtures used and could be easily handled and spread by the hand labor. If kept very dry and not over-vibrated, it could be finished satisfactorily. However, at ordinary consistencies (one inch slump or above), the vibrator brought an excessive amount of mortar to the surface.
>
> The A-3 mixture (cement factor 1.56, per cent sand 34.0) could be spread and puddled readily and finished satisfactorily by the vibrator. However, unless the consistency was kept below a 1" slump more mortar than necessary was brought to the surface by the vibrator.
>
> The A-4 mixture (cement factor 1.55, per cent sand 32.0) was considered most nearly ideal for all the conditions prevailing on this project. It contained sufficient mortar for proper surface finishing without having an excess. In common with all the Series A mixtures it had a relatively large cement content which produced a "rich", "fat" mortar. With such a mortar, variations in the consistency caused by variations in the amount of water were not so detrimental as they were in the case of the B-4 mixture which had the same quantity of mortar. However, the A-4 mixture required care in placing to prevent excdssive segregation of the coarse aggregate. For this reason, it was considered that the limit, to which the coarse aggregate could be increased was reached in this mixture.
>
> The A-5 mixture was harsh, unworkable and, with hand spreading, the coarse aggregate segregated badly. Also, considerable difficulty was experienced in leveling the concrete to the proper contour. When spread uniformly, the mixture contained sufficient mortar for proper finishing and would probably be satisfactory if used with a mechanical spreading device.

The B-1 mixture (cement factor 1.47, per cent sand 38.5) was readily spread by the hand labor. However, the excessive mortar content was conducive to waste.

The B-2 mixture (cement factor 1.41, per cent sand 37.0) was sufficiently workable but a slightly wet consistency caused loss of mortar over the forms.

The B-3 mixture (cement factor 1.35, per cent sand 35.0) was considered the most satisfactory of the lean mixtures under the conditions existing on this project. It could be handled and placed easily without excessive segregation. Like all of the B mixtures, its workability was sensitive to small changes in the quantity of water. When poured at a consistency of approximately 1" slump, there was sufficient mortar for satisfactory finishing without waste over the forms. However, the mortar was sandy and lacked plasticity which made the surface rather difficult to "float". This mixture was considered to be about as lean as could be used satisfactorily under the conditions of this job. After completion of the test sections it was approved for use on the remainder of the project.

The B-4 mixture (cement factor 1.30, per cent sand 34.0) was harsh, unworkable, difficult to spread, and tended to segregate badly. The vibrator brought up sufficient mortar for finishing the surface, except in areas where the coarse aggregate was concentrated. However, the mortar was of poor quality. This mixture might have been satisfactory with better control of the quantity of mixing water and if spread with a mechanical spreader, but it was not practical under the conditions on this project.

A consistency of three-fourths of an inch to one inch slump is the minimum that could be successfully used on this project. This was especially true of the mixtures containing the larger proportions of coarse aggregate. Concrete of lower consistency could not be handled by the hand labor and the construction equipment was unable to properly distribute the concrete and "strike off" the surface in a satisfactory manner prior to vibration; also the amount of honeycombing in the finished pavement increased materially when concrete of lower consistency was used.

TEST DATA AND DISCUSSION

Unfortunately equipment was not available on this project for placing test sections of the standard mixture and finishing by the ordinary methods, hence no direct quantitative comparison of the vibrating pan and ordinary finishers can be made. However, study of other projects where the same materials were used shows that 575 lbs. per sq. in. and 4050 lbs. per sq. in. flexural and compressive strength respectively, are fair average strengths for the standard mixture finished by ordinary methods. In the discussion following, any statements bearing on the advantages of one method of finishing over another, or of the relative strengths of the mixtures used in this investigation and the standard mixtures, are based on observations on other projects and the above averages.

For the convenience of anyone interested the detailed data from the tests of individual specimens are presented in Tables I and II. Inspection will show the great variation both in the conditions under which the tests were made and in the results obtained, caused by the uncontrolled variables always present in a field experiment of this nature. For this reason the data are averaged and summarized in Table III and the discussion following is based principally on these averages.

A number of the relationships between some of the variables are shown graphically. In some instances, the selection of the variables plotted is somewhat arbitrary and the curve has no quantitative significance, merely indicating the trend of the data of this experiment.

Results of Tests of Slabs Removed from Pavement

The results of the flexural tests on the 2' x 7' beams taken from the pavement are depicted graphically in Figures 2 to 4. In Figure 2 the modulus of rupture is plotted against the cement factor of the mixture. The graph shows that as the cement factor was reduced from 1.56 (which was used in all the Series A mixtures) to 1.30 the modulus of rupture decreased from 677 to 544 lbs. per sq. in. The reduction in cement amounted to 17% and the loss in flexural strength 18%. The decrease in modulus of rupture was not the same for each increment in reduction of cement, which was, due to the influence of other factors such as water-cement ratio, amount of honeycombing, etc.

Figure 3 shows the relation between the flexural strength and the water-cement ratio of the concrete. The curve shows a characteristic trend; namely, a decrease in strength with an increase in water-cement ratio. Even under the unusual conditions of this experiment, i.e., the use of a variety of mixtures ordinarily classed as unworkable and vibratory finishing, it is obvious that the water-cement ratio was a major determinant of the flexural strength of the concrete.

TABLE 2

SUMMARY OF TEST DATA - SERIES "A"

AVEMENT SLABS (8"x7" [illegible] BEAMS) WATER-CEMENT RATIO	RATING NUMBER	% HONEY-COMB	MODULUS OF RUPTURE	TESTS OF MOLDED BEAMS MODULUS OF RUPTURE	TESTS OF PAVEMENT CORES (6 INCHES DIAMETER) STATION	DISTANCE FROM CENTERLINE	SLUMP	WATER CEMENT RATIO	VISUAL RATING NUMBER	VOID SPACE PER CENT	ABSORPTION PER CENT	COMPRESSIVE STRENGTH
.711	Not rated	0	594		[illegible]	L-2'		.715	3			4175
		0	705	945 985	[illegible]	L-4'		.715	2 1/3			5015
		0	680	1060 1070	[illegible]	R-7'		.715	2			5836
		0	644	1070 1070	[illegible]	R-2'		.715	2			4109
		0	680 (656)	Avg. [illegible]	251+10	R-7'		.711(.715)	2 (2.25)			4084 (4681)
.667	3	0	687		287+[illegible]	R-2'	1 3/8"	.656	2	9.7	4.9	5519
	Specimen broken			900 854	287+[illegible]	L-2'	7/8"	.656	2			5082
	Specimen broken			880 970	287+[illegible]	R-7'	7/8"	.656	2 2/3			4442
	3	0	700	1070 1070	287+[illegible]	R-4'	1 5/8"	.656	1 1/3			6284
	3 (3.00)	0	640 (668)	Avg. 967	287+[illegible]	L-7'	1 5/8"	.656(.660)	2 (2.00)			5505 (5380)
.680	2½	0	594		306+[illegible]	L-2'	1 1/4"	.676	2	11.5	5.6	4120
	Specimen broken			1070 1070	306+[illegible]	R-7'	1 3/4"	.680	2	11.3	5.4	4636
	2½	0	585	1070 1070	307+[illegible]	R-2'		.680	1 2/3			3345
	2½	0	584	1070 1070	307+[illegible]	L-4'		.675	2 1/3			4805
	2½(2.50)	0	585 (580)	Avg. 1070	307+[illegible]	L-6'		.680(.676)	2 (2.00)			4545 (4294)
.793	2	0	528		317+50	R-6'		.744	2	12.1	4.7	4235
	2	0	587	1025 1050	317+77	R-2'		.805	4			3765
	3	0	655	1070 1070	317+96	R-4'	1 1/8"	.783	2			3720
	2	0	612	940 1040	318+10	L-2'		.783	2			3055
	2 (2.20)	0	605 (579)	Avg. [illegible]	318+50	L-6'		.783(.779)	2 (2.40)			4595 (3876)
.721	2½	0	647		329+00	R-2'		.726	2 2/3	11.7	4.0	5035
	Specimen broken			875 875	329+15	R-4'		.726	2 1/3	11.7	4.8	3915
	2½	0	718	965 960	329+50	R-6'	1 1/4"	.726	2			4330
	2½	0	757	780 800	329+40	L-6'	1 1/4"	.726	2			4570
	2 (2.38)	0	[illegible] (690)	Avg. [illegible]	329+65	L-2'	1 1/4"	.726(.726)	2 1/3(2.35)			4750 (4480)
.716	2.47	0	[illegible]	981			1 1/4"	.707	2.37	11.3	4.6	4559
.682	Not tested			680 107	263+10	L-2'	1"	.667	2 1/3			4380
				880 1070	263+25	R-4'	1"	.667	2			6355
				1060 1070	263+50	R-7'		.682	2 1/3			5190
				1070 1070	263+65	L-2'		.682	2			5066
				Avg. 1037	263+75	L-7'	1"	.682(.676)	2 (2.13)			4098 (5015)
.707	3	0	642		288+75	R-2'		.707	2	11.6	5.9	4094
	Specimen broken			975 857	289+00	L-7'	1"	.707	2			4360
	Specimen broken			940 820	289+15	R-7'	1"	.707	2			5010
	2½	0	622	950 860	289+30	R-4'		.726	1 2/3			4101
	4 (3.17)	8.7	605 (623)	Avg. 900	289+50	L-2'		.726(.715)	1 2/3 (1.87)			3419 (4197)
.689	2	0	710		301+27	R-7'		.700	2 2/3	10.1	4.6	3910
	2½	0	691	945 1070	301+50	L-2'	1 1/8"	.700	2 1/3	10.9	5.0	5210
	2½	0	705	1070 1070	301+75	L-4'		.700	3			4615
		0	740	1070 1070	301+85	L-7'	1/2"	.700	2			4465
	3 (2.50)	4.6	609 (691)	Avg. 1049	301+95	R-2'		.700(.700)	2 (2.40)			3455 (4331)
.633	2	0	651		319+30	L-2'	1 1/4"	.710	2 1/3	11.2	4.2	4590
	2	0	645	960 1070	319+45	L-6'	1 1/4"	.650	2 1/3			5175
	3	0	729	1020 980	319+45	R-6'	1 1/4"	.650	1 2/3			4745
	2	0	666	1070 1070	319+65	R-4'		.633	2 1/3			4775
	2½(2.30)	0	603 (659)	Avg. 1018	319+90	R-2'		.633(.655)	3 (2.33)			5325 (4922)
.613	2½	0	674		503+69	L-4'	1"	.613	2 2/3	10.9	3.8	4916
	2½	0	561	870 976	503+50	L-6'		.613	2	11.6	3.8	4736
	2½	0	747	890 1020	503+60	R-6'		.613	2			4796
	2	0	742	1020 1020	503+35	R-2'		.613	2			5447
	2½(2.40)	1.2	692 (683)	Avg. 966	503+20	L-2'		.632(.617)	2 1/3(2.20)			5743 (5128)
.604	2½	1.2	695	None Molded	493+35	R-6'	2 1/2"	.600	2			5402
	2½	0	776		493+35	R-2'	2 1/2"	.600	2 1/3			4848
	2½	0	766		492+80	L-6'	1 1/2"	.604	3			5671
	2	0	744		492+70	L-2'		.604	2 2/3			5788
	2 (2.30)	1.5	655 (727)		492+70	L-4'		.604(.602)	2 (2.40)			5997 (5541)
.649	2.48	.75	677	994			1 1/4"	.660	2.22	11.1	4.6	4856
.691	Not tested				264+00	L-2'		.701	2			4346
				1070 1070	264+25	L-4'		.682	3			4973
				985 960	264+45	L-7'		.682	2 1/3			5117
				930 1070	265+00	R-2'		.682	2 1/3			4940
				Avg. 1014	265+65	R-7'	1 1/4"	.691(.687)	2 (2.33)			5117 (4899)
.702	2	6.0	508		290+20	R-2'	3"	.702	2	11.1	5.7	4382
	2	0	646	880 960	290+32	R-7'		.702	2			4598
	2	0	644	945 975	290+45	L-7'		.702	2			5093
	2	0	651	980 1016	290+75	L-2'		.702	1 2/3			3992
	3 (2.20)	11.1	703 (634)	Avg. 959	291+00	L-4'		.702(.702)	2 1/3(2.00)			5270 (4667)
.732	3	33.8	567		302+80	R-2'	1"	.694	2	10.7	5.5	5020
	3	20.6	675	1040 1060	303+00	L-7'	1"	.694	2	11.5	5.9	5125
	2½	0	766	1070 1070	303+85	L-2'		.741	2			4640
	2½	0	697	1070 1070	304+12	R-4'	5/8"	.713	2			3480
	3 (2.80)	8.5	682 (665)	Avg. 1063	304+25	R-7'	5/8"	.713(.711)	2 2/3(2.13)			5490 (4751)
.670	3	13.8	586		309+15	R-2'	1 1/4"	.700	2 1/3	11.5	3.9	4730
	Specimen broken			965 975	309+45	L-2'		.689	2			4690
	2½	0	676	1050 1016	309+75	L-4'		.670	2			4965
	2½	0	697	1070 1070	310+12	R-6'	7/8"	.605	2			5110
	3 (2.75)	2.2	646 (636)	Avg. 1025	310+25	L-6'	7/8"	.605(.654)	2 (2.07)			4945 (4888)
.707	2½	0	676		330+10	L-2'	3/4"	.667	2	11.1	4.2	4695
	2½	0	644	980 980	330+35	L-6'		.667	3			4340
	2½	0	780	1070 985	330+50	R-4'	3/8"	.726	2 2/3			3695
	3	1.1	680	1040 1010	330+73	R-6'	3/8"	.707	2			5100
	2½(2.60)	1.7	749 (700)	Avg. 996	331+12	R-2'	1 3/4"	.707(.695)	2 (2.33)			5100 (4626)
.648	3	5.5	718	None Molded	495+35	R-4'		.663	2	11.1	4.3	5684
	2½	0	749		495+00	R-6'	5/8"	.648	2 1/3			4883
	2½	0	718		494+65	L-6'	5/8"	.653	2			4296
	2½	0	683		494+65	L-2'	5/8"	.648	2			5664
	2½(2.60)	1.8	756 (724)		494+65	R-2'	5/8"	.648(.654)	2 (2.07)			5294 (5164)
.710	2.50	4.42	672	1011			7/8"	.680	2.16	11.2	4.9	4832
.680	4	18.5	505		294+16	R-7'	2 3/4"	.658	2			4213
	2½	0	643	945 1080	294+20	L-4'	2 3/4"	.658	2			4770
	2½	0	661	920 1050	294+50	R-2'	2"	.648	2 1/3			5380
	2	0	697	1070 1070	294+60	L-2'		.645	2 1/3			5557
	3 (2.80)	5.5	625 (629)	Avg. 1019	295+97	L-7'		.658(.654)	2 (2.13)			5345 (5053)
.667	3	18.7	580		307+75	R-6'	1 1/8"	.648	2	11.3	5.5	4370
	2½	0	651	880 965	307+90	L-6'	1 1/8"	.648	2			4560
	2½	0	629	1070 1070	308+05	L-2'	1"	.667	2			4445
	2½	1.7	507	1050 1070	308+20	L-4'	1"	.667	3			4180
	3 (2.70)	19.0	621 (598)	Avg. 1011	308+40	R-2'	1 1/4"	.667(.659)	2 (2.20)			4480 (4411)
.676	3	4.9	681		312+20	L-2'		.676	2 1/3	11.3	4.9	5370
	2½	0	799	1080 1040	312+41	R-4'	1 1/8"	.676	2	10.9	3.9	5445
	2½	0	740	970 1010	312+50	R-2'	1 1/8"	.676	2			4800
	2½	0	789	1070 1070	312+64	R-6'		.685	2			4795
	2½(2.60)	1.7	685 (720)	Avg. [illegible]	312+85	L-6'		.705(.684)	2 (2.07)			4700 (5022)
.694	4	29.0	529		[illegible]	R-4'	1/4"	.694	2	10.9	4.3	4720
	3	16.1	604	1030 986	[illegible]	L-2'		.725	2			4805
	3	0	705	965 960	[illegible]	R-2'		.688	2			4600
	2½	4.0	673	1025 1020	[illegible]	L-6'	1 1/8"	.688	2 1/3			3215
	3 (3.10)	[illegible]	656 (629)	Avg. [illegible]	[illegible]	R-6'		.717(.700)	2 (2.07)			4745 (4417)
.697	3	[illegible]	581		[illegible]	L-4'	1"	.607	2	10.9	4.1	4401
	3	0	597	985 988	[illegible]	L-6'	1"	.607	2	10.5	4.0	5800
	2½	0	680	1070 1070	[illegible]	R-6'	1"	.577	3			5092
	2	0	694	940 1070	[illegible]	R-2'		.577	4			4105
	2½(2.40)	1.2	644 (640)	Avg. [illegible]	499+75	L-6'		.577(.589)	2 (2.60)			5142 (4886)
.680	2.72	6.25	648	1018			1 1/8"	.657	2.21	11.0	4.45	4758

TABLE II

SUMMARY OF TEST DATA - SERIES "B"

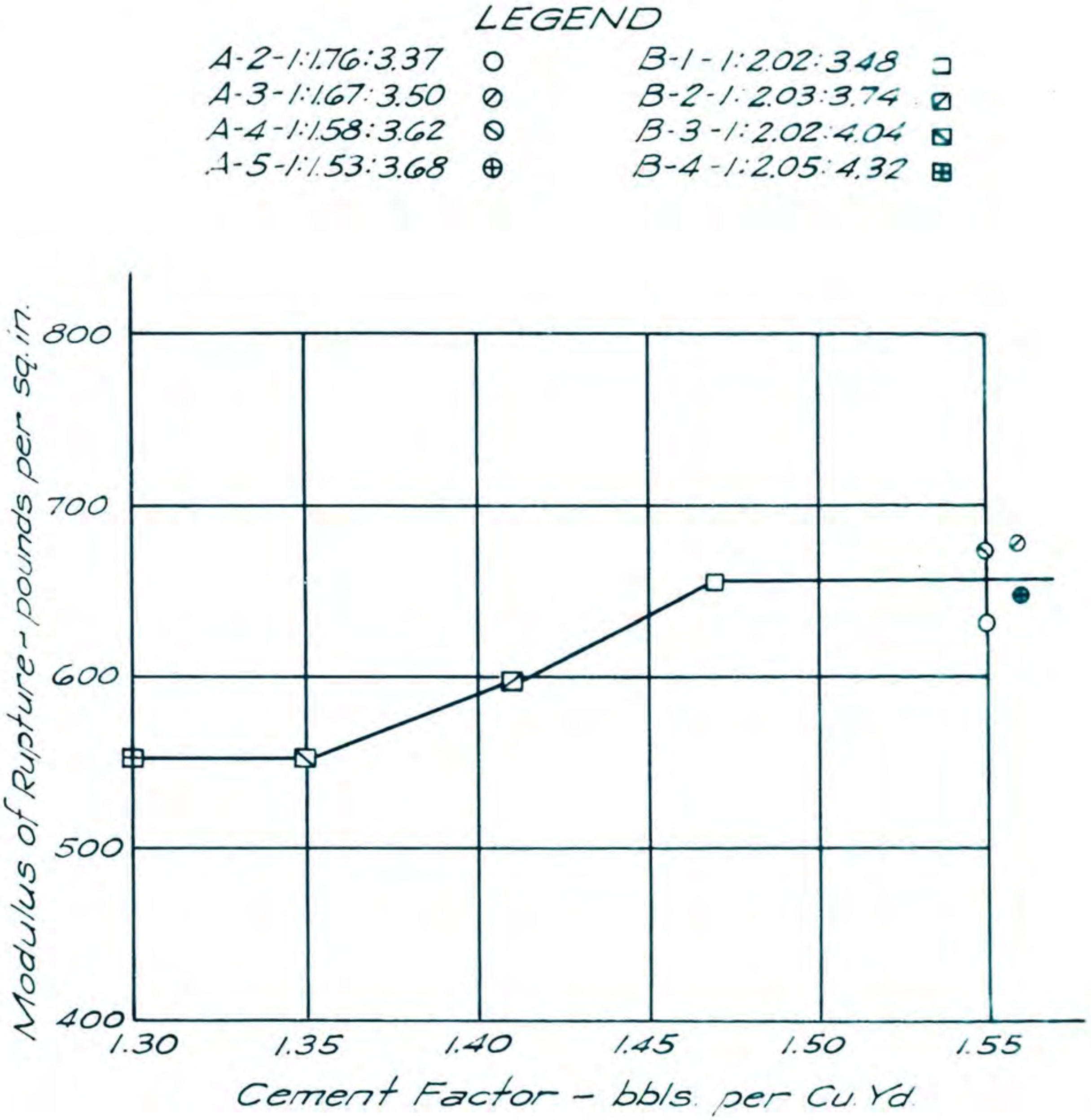
S OF PAVEMENT SLABS (2' x 7' FLEXURE BEAMS)						TESTS OF MOLDED BEAMS	TESTS OF PAVEMENT CORES (6 INCHES DIAMETER)							
N	SLUMP	WATER CEMENT RATIO	RATING NUMBER	% HONEY-COMB	MODULUS OF RUPTURE	MODULUS OF RUPTURE	STATION	DISTANCE FROM CENTERLINE	SLUMP	WATER CEMENT RATIO	VISUAL RATING NUMBER	VOID SPACE PER CENT	ABSORPTION PER CENT	COMPRESSIVE STRENGTH
	1 1/8"	.718		0	508		284+65	L-2'	1 3/8"	.739	2			3885
				0	693	1010 1070	284+65	R-4'	1 3/8"	.739	3			3081
			Not rated	0	653	850 930	284+95	R-7'	1 1/8"	.718	3			4660
				0	626	950 1070	285+10	R-2'		.718	1 2/3			4792
				0	654 (627)	Avg. 980	285+30	L-7'	5/8"	.718 (.726)	2 2/3 (2.50)			3933 (4070)
	1 3/4"	.737	2½	0	661		297+75	L-7'	5/8"	.737	2			4395
			2	0	706	1060 990	297+75	R-2'	5/8"	.737	2 1/3			4995
			2	0	775	1020 1020	298+01	R-7'	1 3/4"	.737	2	10.7	5.4	5825
			2½	0	740	1070 1070	298+20	R-4'	1 1/2"	.737	2			5565
			3 (2.40)	0	746 (726)	Avg. 1038	298+20	L-2'	1 1/2"	.737 (.737)	2 (2.07)			5040 (5165)
	1 3/4"	.758	2½	0	398		304+70	R-2'	7/8"	.768	2 2/3			4615
			2½	0	642	825 915	305+22	R-7'	1 3/4"	.758	2 1/3			3630
			2½	0	659	1080 840	305+75	L-7'	1 3/4"	.768	2	13.1	6.6	4120
			2	0	678	1070 1070	306+00	R-4'	1"	.768	2 2/3	11.9	6.2	3715
			2½ (2.40)	0	636 (603)	Avg. 967	306+20	L-2'		.768 (.766)	2 (2.33)			3490 (3914)
	1 3/8"	.754	2½	0	650		331+65	L-2'	1 1/8"	.754	2 1/3			4870
			Specimen broken			835 815	331+90	L-4'	1"	.754	2			4125
			2½	0	658	786 795	332+09	R-7'	1"	.754	2	11.9	4.1	4360
			2½	0	634	865 865	332+25	L-2'	1"	.754	2			3400
			2½ (2.50)	0	604 (636)	Avg. 827	332+40	L-6'	1"	.754 (.754)	2 (2.07)			4590 (4269)
	1 1/4"	.624	3	2.8	707		497+10	L-6'		.624	2 1/3			4145
			2½	0	735	1080 990	496+95	R-6'	1"	.624	2	12.3	4.4	4544
			2½	0	646	940 920	496+83	L-4'	1 1/4"	.602	2 1/3	12.3	4.7	3884
			2	0	722	835 1030	496+57	L-2'		.602	2 1/3			4213
			2 (2.40)	0	631 (688)	Avg. 966	496+45	L-2'		.602 (.611)	2 (2.20)			4677 (4293)
	1 1/2"	.718	2.42	0.1	656	956			1 1/8"	.719	2.23	12.0	5.2	4342
	3/4"	.699		0	590		282+50	L-2'	1 1/8"	.868	2			3629
				0	616	890 890	282+70	R-2'		.891	2 1/3			3544
			Not rated	0	700	885 885	283+60	L-4'		.720	2 2/3			4389
				0	626	845 950	283+90	R-7'	3/4"	.699	2			4534
				6.0	755 (657)	Avg. 891	284+20	L-7'	3/8"	.699 (.775)	2 (2.20)			4670 (4153)
	1"	.718	3	10.1	323		293+00	L-2'		.731	2			4655
			2½	0	632	850 950	293+20	L-2'		.731	2			5026
			2½	0	581	850 906	293+41	R-7'	1 1/4"	.718	2	12.1	6.2	4592
			2½	0	659	845 985	293+50	L-7'	1 1/4"	.744	2			4575
			3 (2.70)	0	610 (561)	Avg. 898	293+70	R-4'	1 1/2"	.762 (.737)	2 (2.00)			4585 (4687)
	5/8"	.827	3	7.0	471		314+55	L-2'	1 3/4"	.806	3			4195
			4	19.3	565	1070 1070	314+60	L-4'		.806	2			4495
			2½	0	674	1070 1070	314+80	R-6'	5/8"	.827	2	11.7	4.4	4655
			2½	0	662	990 1070	315+00	L-6'	3/4"	.827	2	12.8	4.3	4405
			2½ (2.90)	4.1	631 (601)	Avg. 1057	315+20	R-2'	3/4"	.827 (.819)	4 (2.60)			2900 (4150)
	7/8"	.795	2½	0	368		320+15	L-2'	3/4"	.762	2			4695
			2½	0	605	905 955	320+50	L-4'	3/4"	.795	3			3810
			2½	0	710	935 935	320+65	L-6'		.795	3	11.3	4.2	3505
			2½	0	636	847 847	320+65	R-2'		.795	2			3570
			2½ (2.50)	0	594 (583)	Avg. 904	321+24	R-6'	7/8"	.795 (.788)	2 (2.40)			4265 (3969)
	1"	.723		1.1	500		14+25	L-4'	1"	.723	2			4920
				0	612	765 835	14+39	R-6'		.723	2	12.8	6.3	3825
				0	612	820 795	14+50	L-2'		.723	1 2/3	12.8	6.3	4600
			2½	0	652	815 860	14+60	R-2'		.723	2 2/3			4360
			2 (2.25)	0	571 (589)	Avg. 815	14+60	L-6'		.723 (.723)	2 (2.07)			3950 (4331)
	7/8"	.752	2.65	1.9	598	913			1"	.768	2.25	12.3	5.3	4254
	7/8"			0	529		281+00	R-2'	1 1/4"	.904	2			2855
				0	565	970 930	281+00	L-7'	1/4"	.904	2 1/3			4757
		.904	Not rated	0	471	1070 1070	281+35	R-7'		.904	2			3865
				0	591	955 935	281+50	R-4'		.892	2			5002
				0	642 (554)	Avg. 988	281+50	L-2'		.892 (.899)	2 (2.07)			4056 (4109)
	1 1/4"	.811	4	33.7	412		296+20	R-2'		.830	3			4305
			3½	11.8	592	930 1010	296+50	R-4'		.830	2	11.3	5.6	4145
			2½	0	672	1070 1070	296+61	R-7'	1 1/2"	.830	3			3895
			3	0	657	1070 1070	297+00	L-2'		.811	2			4655
			2½ (3.10)	0	613 (590)	Avg. 1037	297+13	L-7'		.811 (.822)	2 (2.40)			4510 (4302)
	5/8"	.757	4	32.5	471		310+80	R-2'	1 1/2"	.735	2 2/3			3405
			3	21.3	489	1010 1030	311+04	L-2'		.735	2			4565
			Specimen broken			1070 1070	311+22	R-6'	5/8"	.735	2	11.3	5.0	3900
			3	12.5	486	965 920	311+43	R-4'		.735	2	11.3	4.7	3945
			4 (3.50)	20.1	457 (476)	Avg. 1011	311+60	L-6'		.757 (.739)	2 (2.13)			3930 (3949)
	3/8"	.767	2½	0	487		326+50	L-6'		.767	2 1/3			4600
			2½	0	543	920 920	326+60	R-4'	1 3/8"	.767	2			4110
			2½	0	592	870 1030	326+78	R-4'	5/8"	.767	2 2/3	11.7	5.0	4805
			2½	0	662	880 732	327+15	R-2'		.757	2 2/3			4445
			3 (2.60)	0	615 (580)	Avg. 892	327+40	R-2'		.760 (.764)	3 (2.50)			4250 (4442)
	1 1/2"	.742	2	0	510		12+05	L-4'		.742	2			3750
			2	0	579	795 865	12+50	L-6'		.742	2			3670
			2	0	600	870 840	12+67	R-6'	1 1/2"	.742	2	13.2	6.3	4360
			2½	0	591	820 890	12+80	R-2'	1 1/2"	.742	2 2/3	12.4	6.0	3325
			2½ (2.20)	0	596 (575)	Avg. 850	13+00	L-2'	1/4"	.718 (.737)	2 2/3 (2.25)			3595 (3740)
	7/8"	.796	2.73	5.5	555	956			1 1/8"	.792	2.27	11.9	5.4	4108
	1"	.739	Not rated	0	630		286+00	R-2'		.739	2 2/3			5016
				0	572	920 944	286+17	R-7'	1"	.739	2 2/3			4055
			Specimen broken			910 1000	286+25	L-7'	1"	.751	2			4049
			2½	0	607	1040 870	286+50	L-4'	1 1/4"	.751	2			4265
			3 (2.75)	8.7	535 (586)	Avg. 947	286+65	L-2'	1 1/4"	.751 (.747)	2 (2.25)			3804 (4234)
	3/4"	.912	3	10.2	521		299+67	R-7'	3/4"	.912	3			3965
			3	1.1	685	900 940	299+89	L-7'	3/4"	.912	2			3125
			3	0	569	1070 1070	300+00	L-2'	3/4"	.912	2 1/3	10.9	5.1	4550
			3	2.6	635	1070 1070	300+69	L-4'	1 1/4"	.912	3			3340
			4 (3.20)	16.8	549 (592)	Avg. 1020	300+90	R-2'	3/4"	.912 (.912)	2 (2.50)			4200 (3836)
	3/4"	.875	4	24.5	382		316+20	L-2'		.933	2			3480
			4	9.7	588	980 1070	316+50	R-2'	1 7/8"	.851	2	12.4	4.7	3500
			3	0	515	1020 1000	316+77	R-6'	3/4"	.851	2	11.6	4.3	4225
			3	0	569	960 930	316+99	R-4'		.875	2			4965
			4 (3.60)	17.4	466 (504)	Avg. 993	317+10	L-6'		.875 (.877)	2 1/3 (2.07)			4500 (4134)
	3/8"	.788	2½	0	581		321+80	R-4'		.800	3			4685
			3	18.6	476	910 900	321+95	L-2'		.785	2			3990
			3	0	637	865 885	322+05	R-6'	3/8"	.785	2	11.2	4.7	4605
			2½	0	570	847 853	322+28	L-6'		.800	2 2/3			5030
			2½ (2.70)	0	648 (582)	Avg. 875	322+75	R-2'		.823 (.799)	2 2/3 (2.50)			4535 (4569)
	7/8"	.726	4	42.5	332		505+40	L-2'		.716	2 2/3			3776
			2½	0	564	700 886	505+20	L-4'		.716	2			4385
			2	0	569	880 900	504+88	L-6'	7/8"	.716	2	12.4	5.2	4285
			2½	4.0	508	960 705	504+75	R-2'	7/8"	.726	2 1/3	12.8	5.2	3960
			2½ (2.70)	0	555 (506)	Avg. 839	504+50	R-6'	1"	.726 (.720)	2 1/3 (2.25)			3874 (4056)
	3/4"	.808	3.02	6.5	554	934			7/8"	.811	2.31	11.9	4.9	4166

TABLE III - COMPARISON OF MIXTURES

Basis of Comparison	A-2	A-3	A-4	A-5	B-1	B-2	B-3	B-4
Mixture:								
Mix (Dry-rodded volumes)	1:1.76:3.37	1:1.67:3.50	1:1.58:3.62	1:1.53:3.68	1:2.02:3.48	1:2.03:3.74	1:2.02:4.04	1:2.05:4.32
Parts Aggregate (Solid Volume)	3.155	3.174	3.188	3.186	3.383	3.548	3.718	[illegible]
Sand in Aggregate (% by Solid Vol.)	36	34	32	31	38.5	37	[illegible]	34
Cement Factor (Barrels per Cubic Yard)	1.55	1.56	1.55	1.56	1.47	1.41	1.35	[illegible]
Per cent Excess Mortar	72	60	50	45	82	71	59	[illegible]
Water-Cement Ratio (Average)	.71	.67	.69	[illegible]	.72	.76	.79	[illegible]
SLAB SPECIMENS								
Slump, Inches (Average)	1½	1	3/4	[illegible]	1 1/2	[illegible]	[illegible]	[illegible]
Water-Cement Ratio	.72	.65	.71	[illegible]	.72	[illegible]	[illegible]	[illegible]
Visual Rating (Average)	[illegible]	2.49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Per cent Honeycomb	0.0	0.75	4.42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Modulus of Rupture	629	677	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mean Variation (Average)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
CORE SPECIMENS								
Slump, Inches (Average)	1 1/4	1 1/4	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]
Water-Cement Ratio	[illegible]	[illegible]	[illegible]	[illegible]	.72	[illegible]	[illegible]	[illegible]
Visual Rating	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Compressive Strength (Average)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mean Variation (Average)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
Hand Molded Beams	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
Absorption [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]

FIG. 2

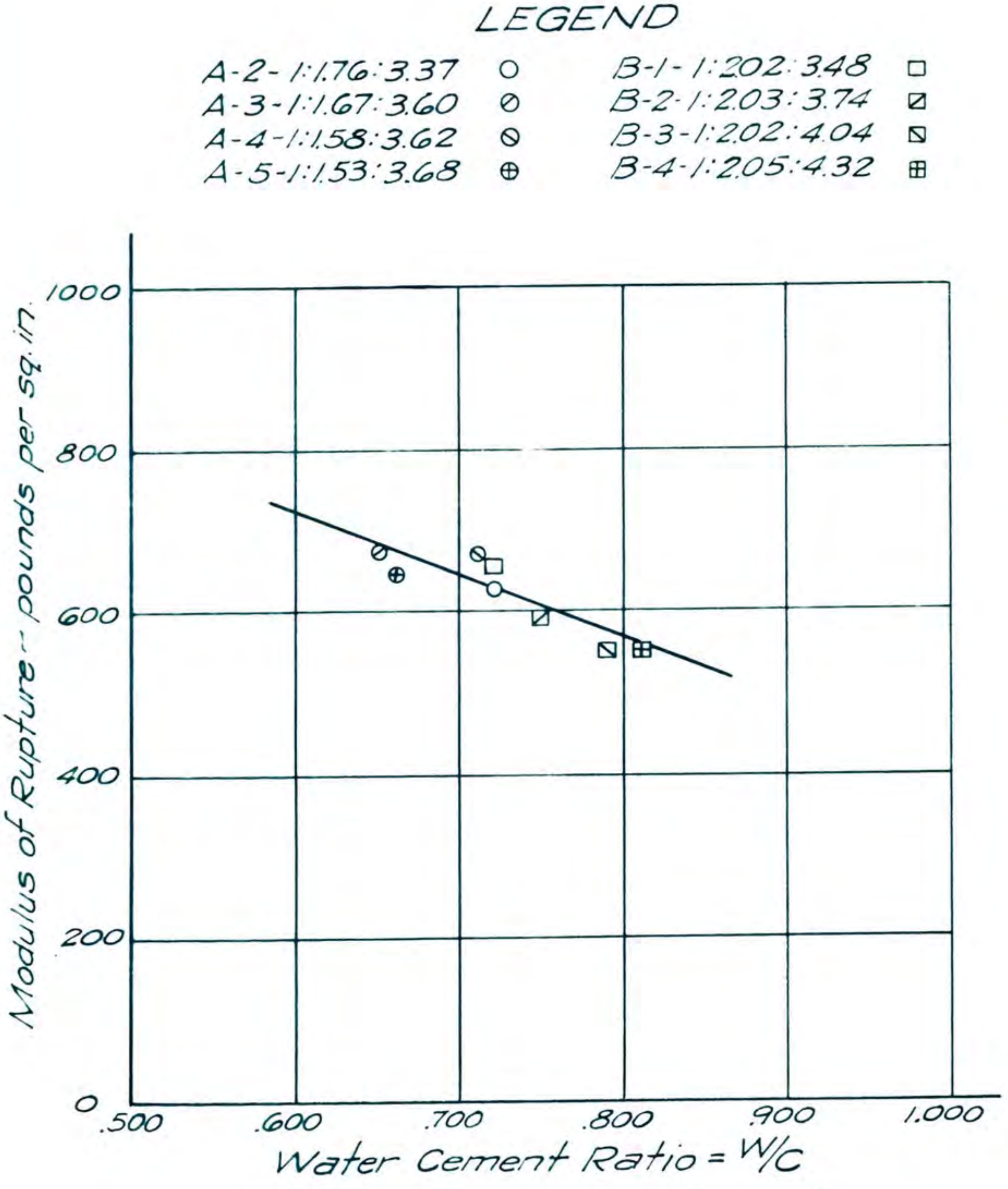
RELATION BETWEEN FLEXURAL STRENGTH OF SLABS AND CEMENT FACTOR OF CONCRETE



Each plotted point represents the average of 25 tests (5 slabs from each of 5 test sections).

FIG. 3

RELATION OF FLEXURAL STRENGTH OF SLABS FROM PAVEMENT TO WATER CEMENT RATIO OF CONCRETE



Each plotted point represents
the average of 25 tests
(one from each slab).

Regardless of the mixture used, it was noted that strength of a slab was influenced by its location in the test panel. This is shown in Figure 4 where the average strength of the slabs from all the mixtures, at the same location in the pavement is plotted for each series. The figure shows definitely that the #1 slab, which lay adjacent to the centerline of the pavement, and the #5 test slab which lay along the outer edge of the pavement were weaker than the numbers 2, 3 and 4 slabs, which came from the central portion of the test panels. Observation during the pouring of the concrete lead the observers to believe that this was caused by poor distribution of the concrete prior to screeding and vibrating. Figure 4 also shows the amount of honeycombing, along the cross-section at the flexure break in the specimens, with respect to their location in the pavement. The greatest amount of honeycombing was found in slab numbers 1 and 5 located respectively on the inside and outside edges of the test panels; no honeycombing was found in any of the #3 specimens. It is apparent from the diagram that the flexural strength of the specimens was influenced by the amount of honeycombing.

The use of the wooden separators in the test panels for forming the slabs introduced possible obstacles to the spreading and compaction of the concrete which would not be present in the remainder of the pavement. Perhaps if the slabs had been removed from portions of pavement where no separators were used the degree of honeycombing would have been less. However, the slabs of the more workable mixtures had little or no honeycombing, and the honeycombed slabs of the least workable mixtures were generally honeycombed the full width of the cross-section, rather than just at the edges near the separators. This indicates that the separators were not the major factors in causing honeycomb and that specimens taken from areas in the various sections, outside the test panels, would have had the same relative amount of honeycomb. The results indicate that the least workable mixtures approached the limit of harshness that can be handled by this vibratory finisher.

The relation between the per cent honeycombing and the per cent excess mortar in the mixture (i.e. the amount of mortar in excess of that necessary to fill the voids in the coarse aggregate, expressed as a per cent of the void space in the coarse aggregate) is shown in Figure 5. For both Series A and Series B mixtures the per cent honeycombing varied inversely with the per cent excess mortar. For any given per cent excess mortar the Series A mixtures showed less honeycombing than those of Series B. This can be explained by the fact that the Series A mixtures contained a more workable mortar, due to their relatively higher cement contents, than the Series B mixtures.

RELATION BETWEEN FLEXURAL STRENGTH AND PERCENT HONEYCOMB IN BROKEN SECTION OF SLAB LOCATED AT VARIOUS DISTANCES FROM CENTERLINE OF PAVEMENT

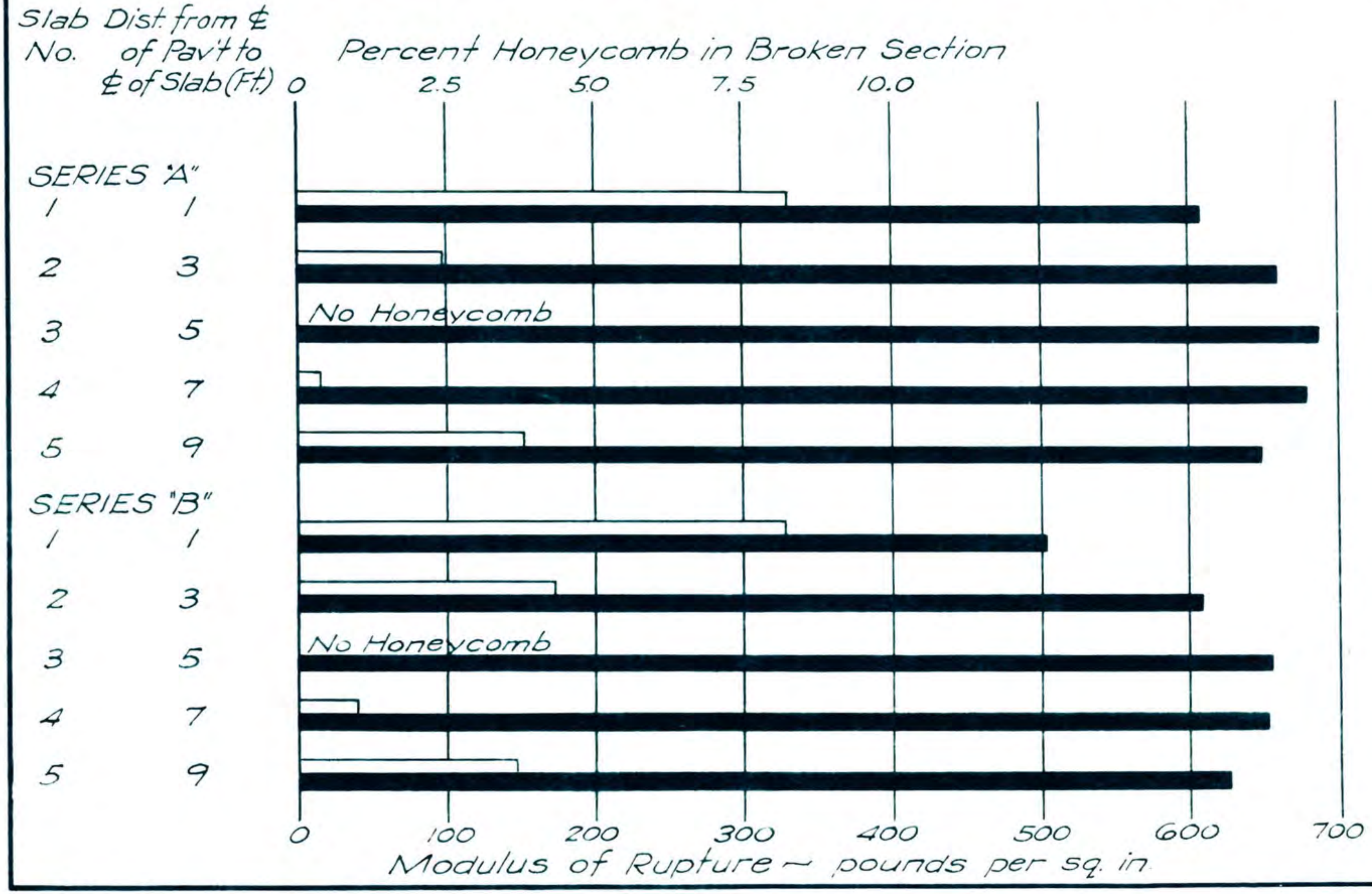
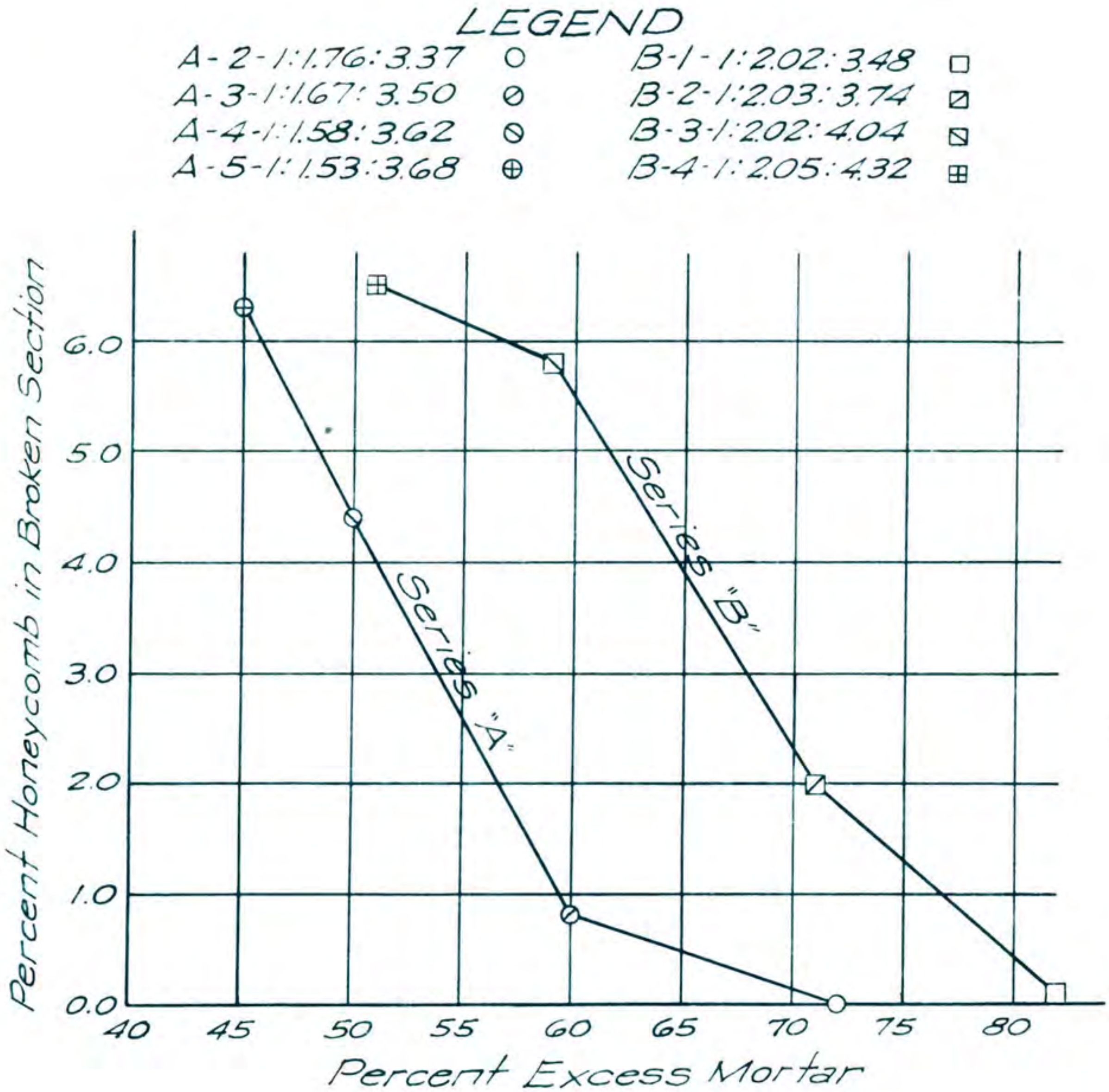


FIG. 4

FIG. 5

RELATION BETWEEN PERCENT HONEYCOMB IN BROKEN SECTION OF SLABS AND PERCENT EXCESS MORTAR IN CONCRETE



Each plotted point represents the average of 25 tests (5 slabs from each of 5 test sections).

Compressive Strength of Cores

Unlike the slab specimens removed from the pavement, the cores were drilled from points at a fixed distance from the centerline of the pavement in order that they be representative of the same conditions of spreading and intensity of vibration in all test sections. This distance was selected so as to avoid longitudinal junctions between batches where honeycombing is most apt to occur. Naturally, this procedure caused the average quality of the concrete to appear better when measured by the core test results than when measured by the slab tests. The core tests may be considered to show the relationship between the different mixtures when placed under optimum conditions.

Reference to the average core strengths in Table III shows that the difference between the individual mixtures of either series was small. All the mixtures of Series A gave higher strength than any of those of Series B, and on the average about 750 lbs. per. sq. in. higher than would have been expected of the standard mixtures finished by ordinary methods. The Series B mixtures were, on the average, about 200 lbs. per sq. in. stronger than the standard mixtures.

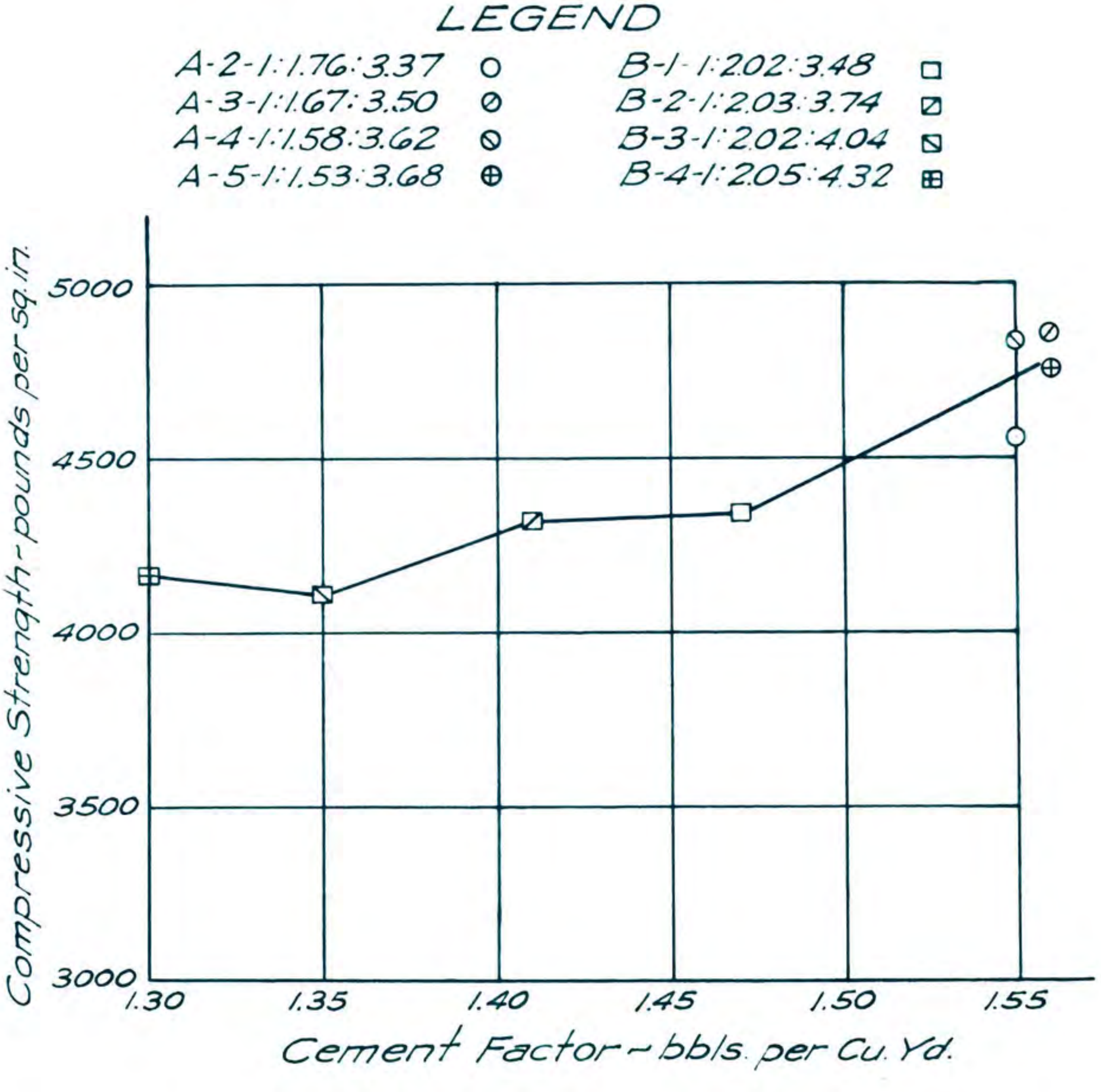
The relative compressive strengths of the various mixtures is shown in Fig. 6 where the average core strength for each mixture has been plotted against its cement factor. This figure shows the same relation for the core strength as is shown for the flexural strength of the slabs by Fig. 2, and the same remarks apply in general. Reduction of the cement factor from 1.56 to 1.30 was accompanied by a decrease in compressive strength of approximately 700 lbs. per sq. in. This is a loss in strength of about 15% and resulted from a 17% reduction in cement.

In Fig. 7 the core strengths of the various test sections are plotted against the corresponding water-cement ratio. The curve through the points has the characteristic trend of water-cement ratio, strength curves for workable mixtures. That the results of these tests, made on mixtures which with ordinary finishing methods would be classed as unworkable, follow the water-cement ratio, strength law is significant. It indicates that the principal advantage of the vibratory finisher, in as far as the effect on strength is concerned, is gained from the fact that the use of vibration permits the manipulation of harsher mixtures with lower water content, thus bringing them into the category of workable mixtures.

For purposes of comparison, Abrams' water-cement ratio curve is also shown in Fig. 7. While the two curves are not parallel the general trends are the same. The difference in strength shown by the two curves for a given water-cement ratio is undoubtedly due to the fact that modern cement is considerably stronger than that with which Abrams performed his experiments.

FIG. 6

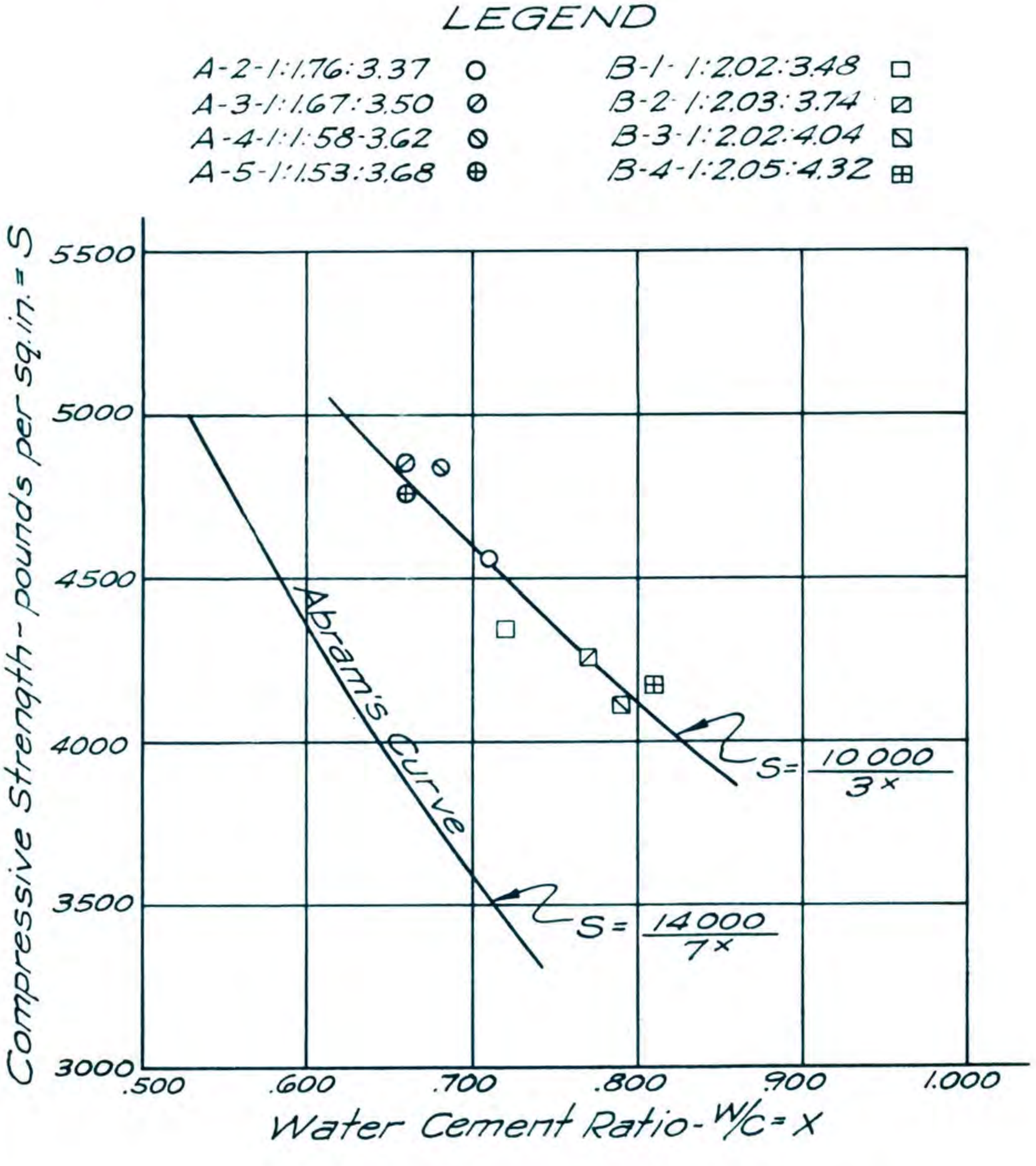
RELATION BETWEEN COMPRESSIVE STRENGTH OF CORES AND CEMENT FACTOR OF CONCRETE



Each plotted point represents the average of 25 tests (5 cores from each of 5 test sections).

FIG. 7

RELATION BETWEEN COMPRESSIVE STRENGTH OF CORES AND WATER CEMENT RATIO OF CONCRETE



Each plotted point represents the average of 25 tests (5 cores from each of 5 test sections).

A fairly consistent relation between the modulus of rupture of the slabs and the compressive strength of the cores was noted and is shown in Fig. 8. On the average the flexural strength for each mixture was about 14% of the compressive strength.

Absorption and Density Test of Cores The average absorption and density for the cores of the various mixtures are charted in Fig. 9. The chart indicates that the Series B mixtures had slightly greater absorption and higher voids (lower density) than the Series A mixtures. From a practical standpoint the difference is so small that it is insignificant. Further, no individual mixture of either series showed any advantage over the other mixtures of the series.

Durability Tests of Cores The results of the freezing and thawing on cores from the various mixtures are tabulated in Table 4. The values shown are the average per cents lost from the cores of each mixture at the end of the number of cycles of freezing and thawing indicated. Perusal of the table will show that there is no consistent relation between the concrete proportions and the results of the freezing and thawing tests. None of the mixtures were definitely lacking in resistance to freezing and thawing, and all of them compare favorably with tests of standard concrete pavement mixtures now in general use.

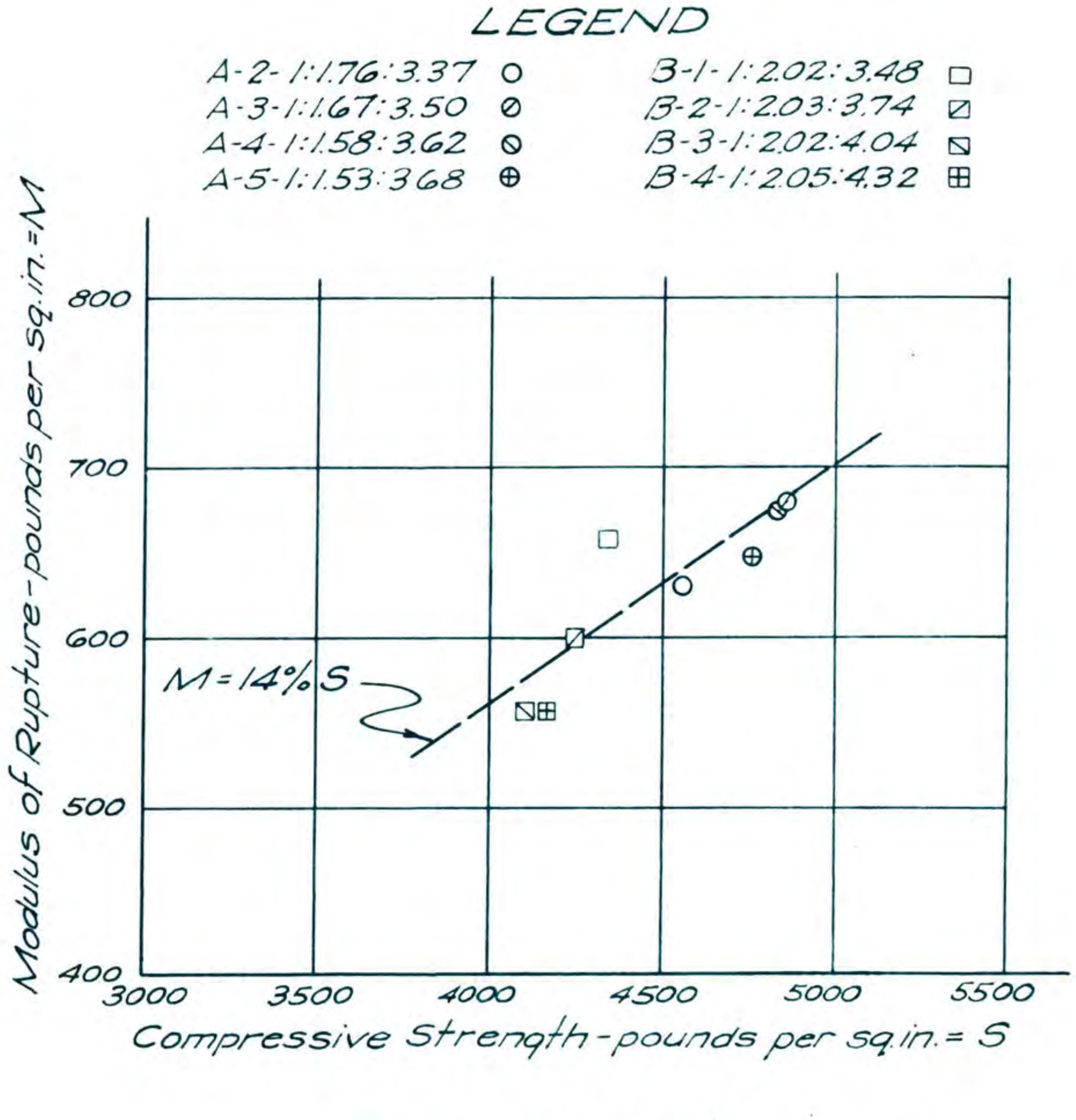
Observations of Finished Pavement Observations of the surface of the various test sections, made the morning following the day of pouring, did not reveal any outstanding difference in surface characteristics except for some of the A-5 and B-4 test sections. On these an occasional area was observed in which the coarse aggregate particles were not sufficiently covered with mortar to give a smooth surface texture. Aside from these areas the surface of the entire project was reasonably uniform and similar in texture to that on other projects where the same materials had been used with ordinary finishing methods.

Observations of the edges of the pavement after the forms had been removed showed little honeycombing below the lip curb but a considerable amount was found in the lip curbing on practically all the test sections. This is attributed not only to the harshness of the mixture but also to the loss of workability caused by the concrete drying out in the interval between the time of mixing and the molding of the curb. Where these harsh mixtures are used on a project it will be necessary either to improve the method of molding the lip curb or to provide batches of workable concrete for that purpose.

A detailed condition survey of all the test sections was made when the pavement was eighteen months old. All sections

FIG. 8

RELATION BETWEEN MODULUS OF RUPTURE OF SLABS & COMPRESSIVE STRENGTH OF CORES REMOVED FROM PAVEM'T



Each plotted point represents the average of 25 tests (5 from each of five test sections).

FIG. 9

RESULTS OF ABSORPTION AND DENSITY TESTS

Each block represents the average of six tests from four test sections.

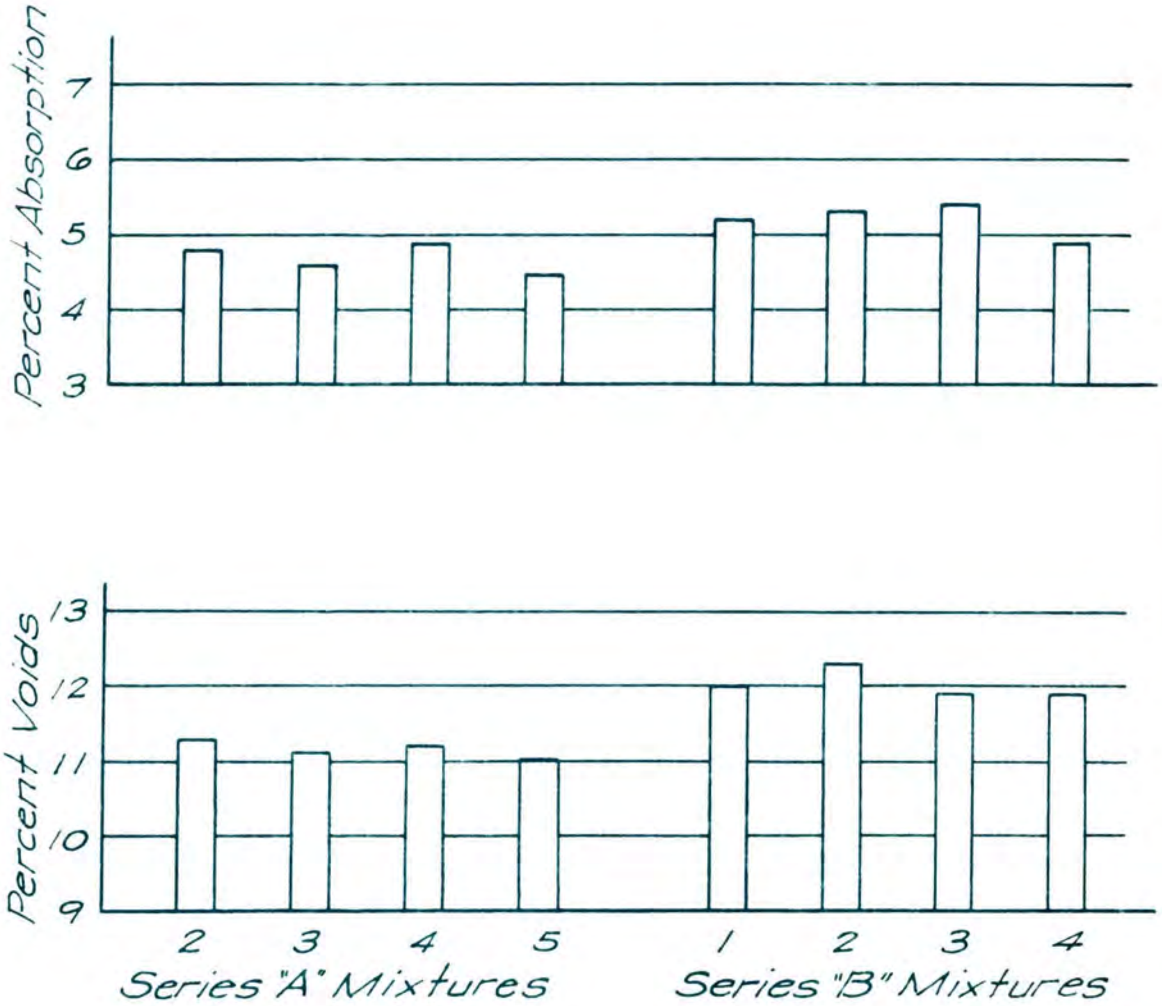


TABLE 4. SUMMARY OF RESULTS OF FREEZING AND THAWING TESTS
Per Cent Loss in Weight of Specimens After the
Indicated Number of Test Cycles. Average of Six
Cores From Each Mix.

Mix	Cycles of Freezing and Thawing										
	30	60	83	94	110	125	140	155	170	185	205
A2	0.1	0.8	2.7	4.2	6.2	10.1	18.4	28.0	43.9	55.6	64.2
A3	0.1	1.6	5.9	8.0	11.1	19.4	41.2	56.2	82.7	84.9	90.8
A4	0.0	0.2	3.2	6.9	9.2	20.2	27.4	36.2	68.8	86.9	100.0
A5	0.0	0.9	3.8	5.9	9.1	20.7	31.3	41.8	68.6	86.6	97.6
B1	0.1	1.9	4.5	5.9	9.1	20.5	24.3	28.2	33.9	53.7	79.5
B2	0.4	2.4	6.4	10.1	16.8	35.4	40.0	45.7	56.2	88.3	96.2
B3	0.0	1.0	3.2	5.5	8.7	17.3	29.0	46.0	74.0	92.1	93.7
B4	0.1	3.3	12.6	16.1	19.1	22.2	26.1	33.7	51.8	61.2	77.8

were found to be in good condition and no defects which would indicate differences in the structural quality of the various test sections were noted. There were numerous small areas of a thin, laitance scale throughout the project, but there was no relation between the concrete proportions and the occurrence of this scale. This type of scale often occurs on pavements finished by ordinary methods. It is not considered objectionable as it never progresses in depth.

Best Mixtures for Materials Used

Based on all the observations and tests, with the materials and methods of handling the concrete used on this project, the A-4 mixture (1:1.54:3.68) was considered the best if improvement in quality without increased cost is desired; the B-3 mixture (1:2.02:4.04) was considered the best if the maximum decrease in cost without sacrifice of quality is desired. The large increase in the amount of honeycombing in the slabs of these two mixtures over that in the A-3 and B-2 mixtures would indicate that the latter should be recommended for use. However, as pointed out previously, it is believed that the use of the wooden separators in forming the slabs caused more honeycombing than would have occurred where the separators were not present, and that the use of the A-4 and B-3 mixtures is justified.