

strength that would normally result without vibration using the normal cement content. As pointed out earlier, the cement content of the vibratory finished job covered by this account could have been reduced approximately 15 per cent or one sack in a seven sack batch and the usual strength of our pavement concrete obtained.



Figure 20

Further, it was demonstrated that the two vibratory finishers could handle satisfactorily, concrete in which calcium chloride was used as an admixture. It showed also that calcium chloride as an admixture and as surface application, compared favorably with water curing, so far as strength of the resulting concrete was concerned.

It showed that test cylinders and beams made by the usual rodding process were correctly representative of strength of concrete finished by the vibratory method with consistencies such as were used on this job.

The effect which different brands of cement have on the strength of the concrete in which it is used is very clearly demonstrated in this study. The strength of concrete containing Brand F was consistently lower than of that made with two other brands on the job.

It also showed that the two vibratory finishers were for all practical purposes equally effective, with each possessing individual features which might result in one contractor preferring one and another, the other.

Following the practice of identifying test sections on the Ohio Highway system, the several sections on the Putnam County job have been marked with standard signs (Figure 20) and a corresponding record made available at the laboratory in Columbus. It is thus possible for those who are interested to make their own observations as opportunity presents.

VIBRATING PAN TYPE FINISHING MACHINE FOR CONCRETE PAVEMENTS

BY F V REAGEL AND T F WILLIS

Missouri State Highway Department

SYNOPSIS

For the purpose of investigating the efficacy of the vibrating pan type of finishing machine, one of these machines was used in the construction of a 20 foot concrete pavement. Two series of concrete mixtures were used. In one the cement factor was kept constant while the ratio of fine to coarse aggregate was varied, in the other series the cement factor was varied. Beams, 2 ft by 5 ft were removed from the pavement, tested for flexural strength and observed for honeycombing, and tested for density. One set was then tested for compressive strength and the other set subjected to freezing and thawing in an attempt to determine relative durability.

The results indicate that this type of machine can finish concrete mixtures which are much leaner, harsher and drier than mixtures ordinarily considered suitable for pavement concrete.

Highway engineers have recently shown 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 mixtures are shown diagrammatically in Figure 2.

The mixtures of the first series, designated A2, A3, A4, and A5, were proportioned so that 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 sand to total aggregate was varied from 38 to 31 per cent and the

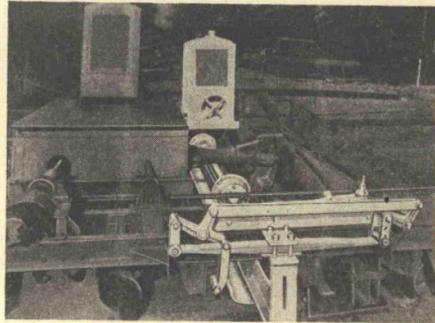


Figure 1. Vibrating attachment on finishing machine

water-cement ratio was varied so as to maintain 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

noted 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

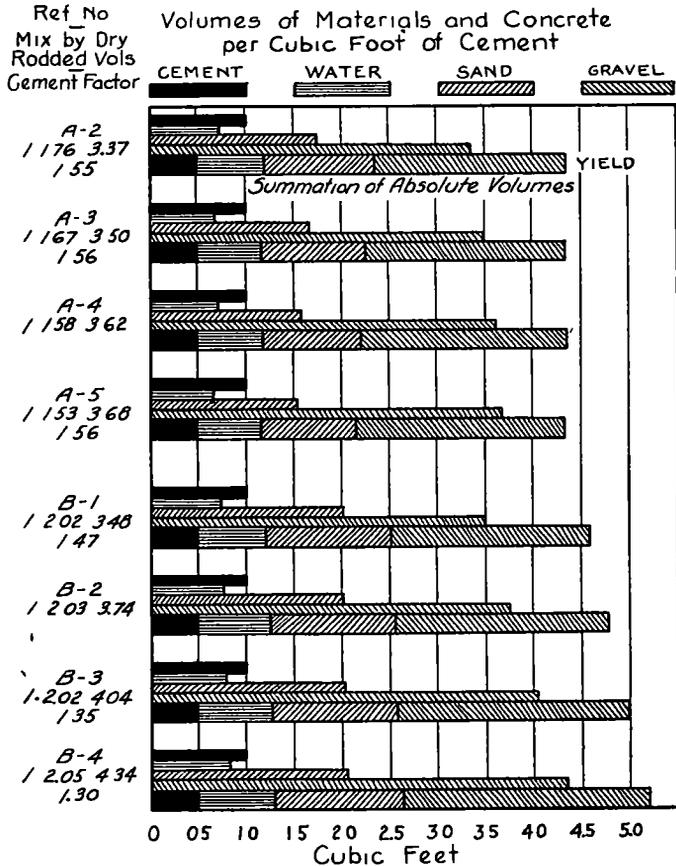


Figure 2. Comparison of mixtures showing proportions of materials and yield

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 alter-

those on the test sections of any other mixture.

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

- 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 by 7 ft 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, 20 ft 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 7 ft 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 7 in thick and was covered with tar paper. A batch of concrete was dumped between the head-

ers and spread by hand to a uniform depth. Then four 2 by 2-in wooden separators were set parallel to the centerline, and at the mid-depth of the slab, to provide planes of weakness at 2-ft 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 ft wide by 7 ft 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 preparation of a test panel are pictured in Figures 3, 4 and 5.

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

PLATE II

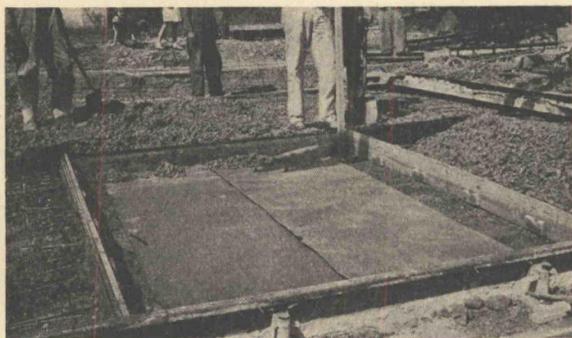


Figure 3. Headers set and tar paper spread on subgrade, preparatory to dumping first batch of concrete for test panel

Figure 4. First batch of concrete deposited on subgrade



Figure 5. First batch spread and separators set preparatory to dumping second batch of concrete

PLATE III

Figure 6. General view of slab testing operations

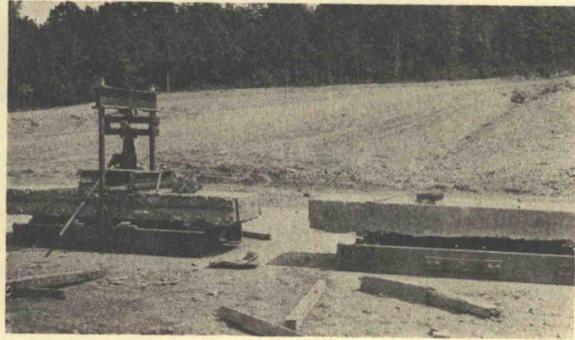
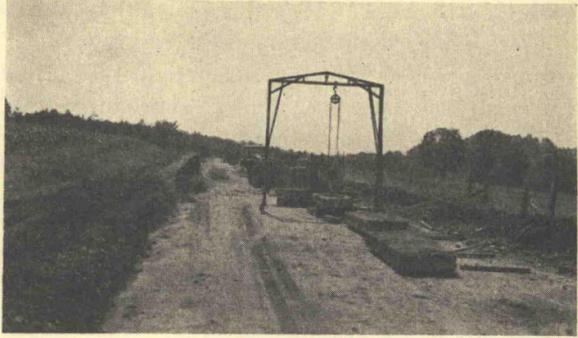
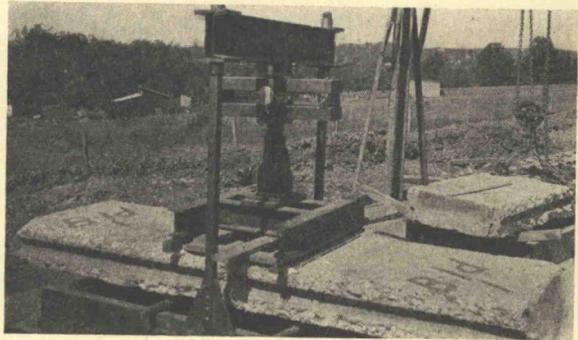


Figure 7. Specimen in machine ready for testing

Figure 8. Detail view of testing apparatus



making the proper allowance for settlement and compaction of the concrete under the vibrator

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. Figures 6, 7 and 8 show 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 percentage 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 22 days old five 6-in. diameter cores were drilled from each test section, shipped to the laboratory, soaked in water for 24 hours, and tested in compression (saturated) at the age of 28 days. When the pavement was 90 days old six 4 5-in. cores were drilled from representative test sections of each mixture. This set of cores was taken to the laboratory, soaked in water for 24 hours, and then subjected to cycles of freezing and thawing. A second set of 4 5-in. 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.

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 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 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-in 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 excessive 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-in 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 distribute properly the concrete and "strike off" the surface in a satisfactory manner prior to vibration, also the amount of honeycombing in the finished pavement in 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 proj-

TABLE I
COMPARISON OF MIXTURES

Basis of Comparison	A-2	A-3	A-4	A-5	B-1	B-2	B-3	B-4
<i>Mixture</i>								
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	3 908
Sand in Aggregate (% by Solid Vol)	36	34	32	31	38 5	37	35	34
Cement Factor (Barrels per Cubic Yard)	1 55	1 56	1 55	1 56	1 47	1 41	1 35	1 30
Per cent Excess Mortar	72	60	50	45	82	71	59	51
Water-Cement Ratio (Average)	0 71	0 67	0 69	0 66	0 72	0 76	0 79	0 81
<i>Slab Specimens</i>								
Slump, Inches (Average)	1½	1	¾	1½	1½	¾	¾	¾
Water-Cement Ratio	0 72	0 65	0 71	0 66	0 72	0 75	0 79	0 81
Visual Rating (Average)	2 47	2 48	2 58	2 72	2 42	2 65	2 73	3 02
Per cent Honeycomb	0 0	0 75	4 42	6 25	0 10	1 9	5 50	6 50
Modulus of Rupture	629	677	672	646	656	598	555	554
Mean Variation (Average)	33	37	45	44	45	70	42	55
<i>Core Specimens</i>								
Slump, Inches (Average)	1¼	1¼	¾	1½	1½	1	1½	¾
Water-Cement Ratio	0 71	0 66	0 68	0 66	0 72	0 77	0 79	0 81
Visual Rating	2 37	2 22	2 16	2 21	2 23	2 25	2 27	2 31
Compressive Strength (Average)	4559	4856	4832	4758	4342	4254	4108	4166
Mean Variation (Average)	498	435	347	371	395	368	310	358
Absorption, %	4 8	4 6	4 9	4 45	5 2	5 3	5 4	4 9
Voids, %	11 3	11 1	11 2	11 0	12 0	12 3	11 9	11 9

creased materially when concrete of lower consistency was used

TEST DATA AND DISCUSSION

Unfortunately equipment was not available on this project for placing test

ects where the same materials were used shows that 575 lb per sq in and 4050 lb per sq in flexural and compressive strength respectively, are fair average strengths for the standard mixture finished by ordinary methods. In the fol-

lowing discussion, 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,

tests on the 2 by 7-ft beams taken from the pavement are depicted graphically in Figures 9, 10 and 11. Figure 9 shows that as the cement factor was reduced from 156 (which was used in all

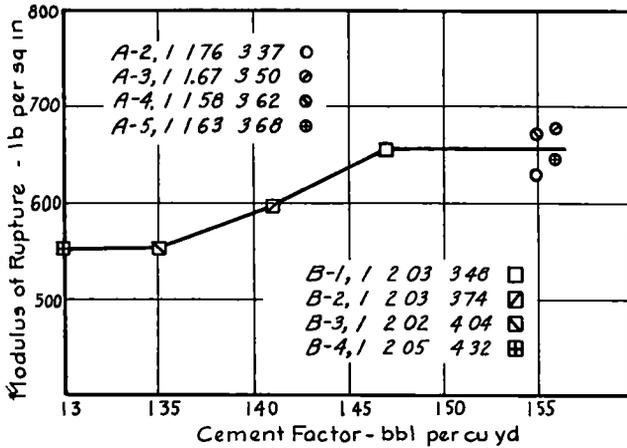


Figure 9. Relation between flexural strength of slabs and cement factor of concrete

are based on observations on other projects and the above averages.

The detailed data from the tests of individual specimens¹ 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 I and the discussion is based principally on these averages.

Several relationships between 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

¹ Tabulations of the individual test data may be secured from the Highway Research Board on request.

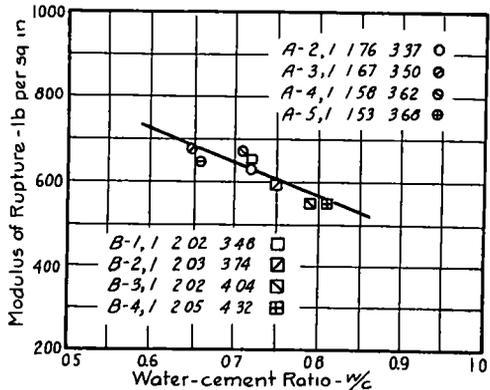


Figure 10. Relation of flexural strength of slabs from pavement to water-cement ratio of concrete

the Series A mixtures) to 130 the modulus of rupture decreased from 677 to 544 lb per sq in. The reduction in cement amounted to 17 per cent and the loss in flexural strength 18 per cent. 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 10 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 deter-

pavement were weaker than slabs Number 2, 3, and 4, 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 11 also shows the amount of honeycombing, along the cross-section at the flexure break in the specimens, with respect to location in the pavement. The greatest amount of honeycombing was found in slabs Num-

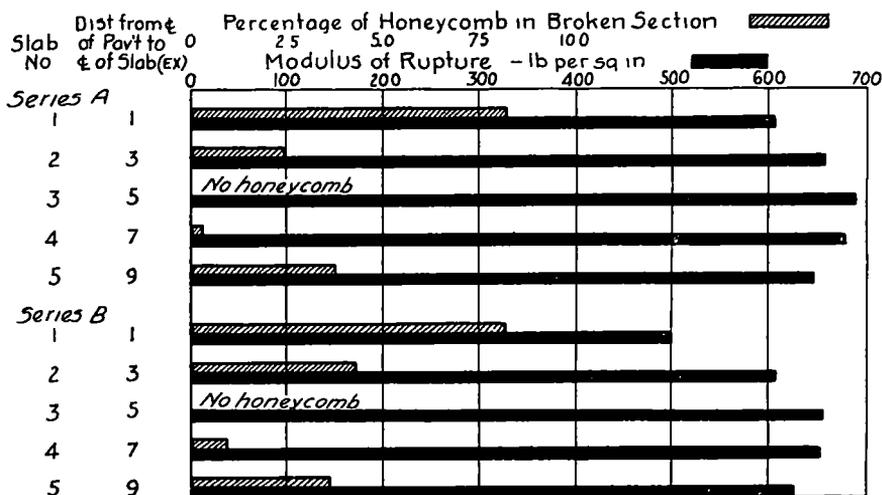


Figure 11. Relation between flexural strength and percentage of honeycomb in broken section of slab located at various distances from centerline of pavement.

minant of the flexural strength of the concrete

Regardless of the mixture, it was noted that the strength of a slab was influenced by its location in the test panel. This is shown in Figure 11 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 No 1 slab, which lay adjacent to the centerline of the pavement, and the No 5 test slab which lay along the outer edge of the

ber 1 and 5 located respectively on the inside and outside edges of the test panels, no honeycombing was found in any of the No 3 specimens. It is apparent from the diagram that the flexural strengths of the specimens were 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,

honeycombing varied inversely with the excess mortar. For any given percentage of 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.

Compressive Strength of Cores Unlike the slab specimens removed from the pavement, the cores were drilled from points at a fixed distance from the center-

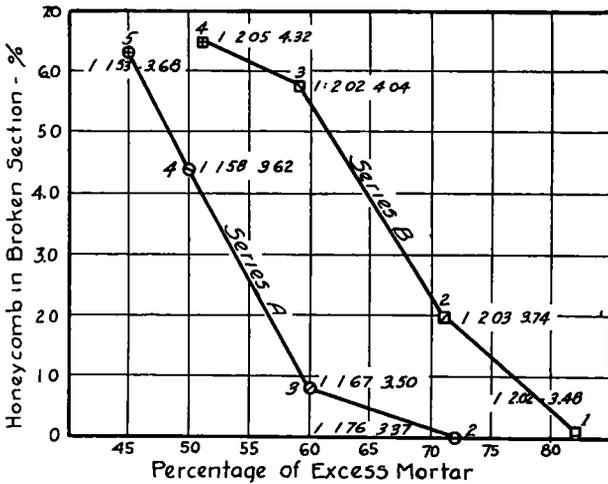


Figure 12 Relation between percentage of honeycomb in broken section of slabs and percentage of excess mortar in concrete

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 percentage of honeycombing and percentage of mortar in excess of that necessary to fill the voids in the coarse aggregate, expressed as a percentage of the void space in the coarse aggregate) is shown in Figure 12. For both Series A and B mixtures the

line of the pavement in order that they might be representative of the same conditions of spreading and intensity of vibration in all test sections. This distance was selected to avoid longitudinal junctions between batches where honeycombing is most likely to occur. Naturally, this procedure caused the average quality of the concrete to appear better when measured by the core test than when measured by the slab tests. The core tests may be considered to show the relationship between the different mix-

tures when placed under optimum conditions

Reference to the average core strengths in Table II shows that the differences between the individual mixtures of either series were small. All the mixtures of Series A gave higher strength than any of those of Series B, and on the average were about 750 lb 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 lb per sq in stronger than the standard mixtures.

In Figure 14 the core strengths of the various test sections are plotted against the corresponding water-cement ratios. 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 so far as the effect on strength is concerned, is the fact that the

TABLE II

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	84 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	9 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

The relative compressive strengths of the various mixtures are shown in Figure 13 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 Figure 9, 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 lb per sq in. This is a loss in strength of about 15 per cent and resulted from a 17 per cent reduction in cement.

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 Figure 14. 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.

A fairly consistent relation between

modulus of rupture of slabs and compressive strength of cores was noted and is shown in Figure 15. On the average the flexural strength for each mixture was about 14 per cent of the compressive strength.

Absorption and Density Test of Cores
The average absorption and density for

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 II. The values shown are the average percentages lost from the cores of each mixture at the end of the number

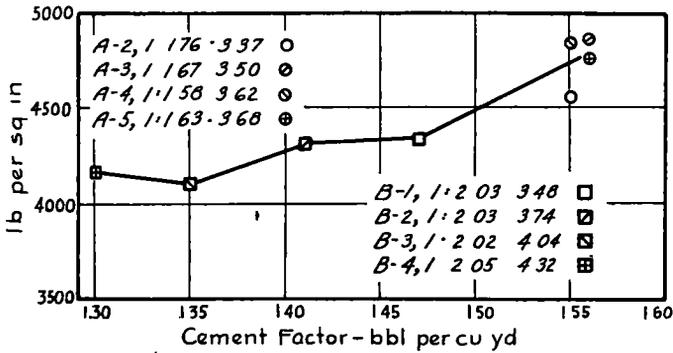


Figure 13. Relation between compressive strength of cores and cement factor of concrete

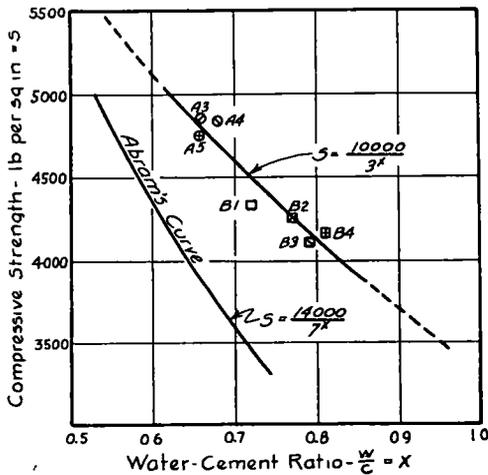


Figure 14. Relation between compressive strength of cores and water-cement ratio of concrete

the cores of the various mixtures are charted in Figure 16. 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 mix-

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 favor-

ably 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

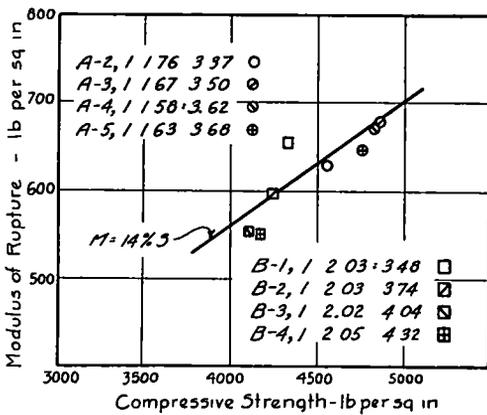


Figure 15 Relation between modulus of rupture of slabs and compressive strength of cores removed from pavement

ect 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 mold-

ing 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 18 months old. All sections 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

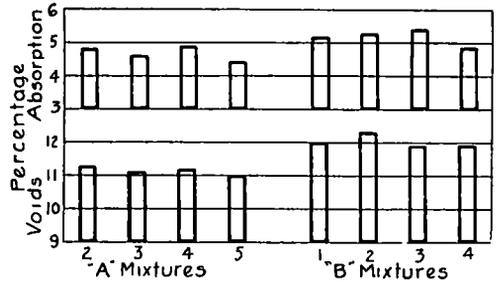


Figure 16 Results of absorption and density tests

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 pre-

CONCLUSIONS

As previously pointed out the data of this investigation were derived from tests of concrete on an ordinary construc-



Figure 17. Cross-section at flexure break of badly honeycombed slabs

viously, 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.

tion project and were affected by the unforeseen and 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 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.

2 Vibratory finishing necessitates the use of concrete mixtures of lower mortar content and drier consistency than are considered satisfactory for ordinary finishing. Wet or over-mortared 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.

3 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 distribute properly 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.

4 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.

5 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.

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