MICHIGAN
STATE HIGHWAY DEPARTMENT
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VIBRATED CONCRETE PAVEMENT

IN MICHIGAN

A summary of information on experimental
vibrated concrete pavements in Michigan
Prepared for the American Road Builders' Association
Committee on Consolidation in Placement of Concrete

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VIBRATED CONCRETE PAVEMENT IN MICHIGAN

It is the purpose of this report to summarize, under one cover, all available information on the five experimental vibrated concrete pavement projects completed to date in Michigan. These experimental vibrated concrete pavement studies are identified with the following construction projects, and their locations, with respect to Lansing and to each other, are shown in Figure 1.

1. Projects 33-21, 06, and 19-27, 02 - on M-78, N.E. of Lansing.
   Reported by J. W. Kushing, Engineering News Record, April 26, 1934.

2. Project 38-41, 06 - on US-12, east of Jackson.
   Reported by R. S. Fulton, Departmental Report, December 21, 1936.

3. Project 33-39, C1, and 19-3, C12 - on US-27, N. limits of Lansing.
   Reported by C. H. Cash, Departmental Report, Research Project 36 B-2, November, 1939.

4. Project 61-27, C5 - on M-126 (now US-16), Muskegon.
   Reported by C. H. Cash, Departmental Report, Research Project 36 B-2, November, 1939.

5. Project 41-34, C6 - on Grand Rapids East Belt (now by-pass US-131).
   Reported by W. A. Keranen, Departmental Report, Research Project 39 F-7 (5), December 15, 1941.

All available information concerning these projects has been collected and presented as separate reports. The reported material, with the exception of recent condition survey information, is in the exact wording of the authors who first reported on their respective projects.

In the first experiment, electrically powered vibrators were attached directly to the forward screed of the finishing machine. Concrete mixes of higher coarse aggregate and reduced water and cement contents were successfully placed, but the strains and stresses developed by the vibrating units on the equipment and forms were entirely too great. This resulted in the rejection of vibrated concrete as a method for general pavement construction practice.

For the second experimental stage, vibrating tubes of 10- and 20-foot lengths were included on lane and full-width construction. These tubes were supported by the finishing machine ahead of the forward screed, and could be mechanically raised and lowered for transverse joint installations or other obstructions. The strain on the equipment was reduced somewhat, but the vibration frequencies throughout the length of the tubes were not uniform. The vibratory tubes, when in use, materially retarded the forward motion of the finishing machines.

Another design of vibratory equipment was given a trial on the Grand Rapids project in 1941. In this case, the placement of the concrete was made with a screw spreader having a vibrating board attached directly behind the screw, that acted simultaneously as a vibrator and strike-off for the surface of the concrete. The finishing machine followed the concrete screw spreader, and this unit also had a vibrating board attached ahead of the front screed. The vibrating board consisted of two-inch planks set on end in five-foot lengths, with vibrators connected directly to the boards. As the concrete pavement was constructed in eleven-foot lanes, two such vibrating units of five-foot lengths were attached to the spreader and finisher. The application of this method of concrete vibration did not produce results as expected, and therefore was discontinued on the balance of the project, which was finished in 1942.

The primary purpose of these vibrated concrete projects was to study the effect of vibration on the economy and quality of concrete pavement surfaces. From the standpoint of economy, the work demonstrated the possibility of placing harsh mixtures with a lower water content, and with a reduction in cement, as compared with normal portland cement mixtures; the economy is mainly in the reduced quantity of cement, which, as indicated through increased strength, would approximate 10 percent. In the matter of quality, there is no substantial evidence to prove that the quality of the vibrated concrete, with reference to scaling and structural performance, is any better than that placed without vibration.

In the case of vibrated air-entrained concrete, data so far available indicates no material advantage of vibrated concrete over that of non-vibrated concrete.

Present Status of Projects

Condition surveys have been made in 1951 of Projects No. 3 and No. 5. The results of these surveys have been appended to the reports for the respective projects.

Project No. 2 was covered with bituminous concrete in 1947; therefore, no condition survey could be made.

Construction records for Project No. 1 were destroyed in the State Office Building fire, so the exact location of the vibrated areas cannot be identified for condition survey.

Since the primary purpose of Project No. 4 was to study the operating efficiency of a 20-foot finishing machine with vibratory tube, rather than a comparison of vibrated and unvibrated concrete, no condition survey has been made.

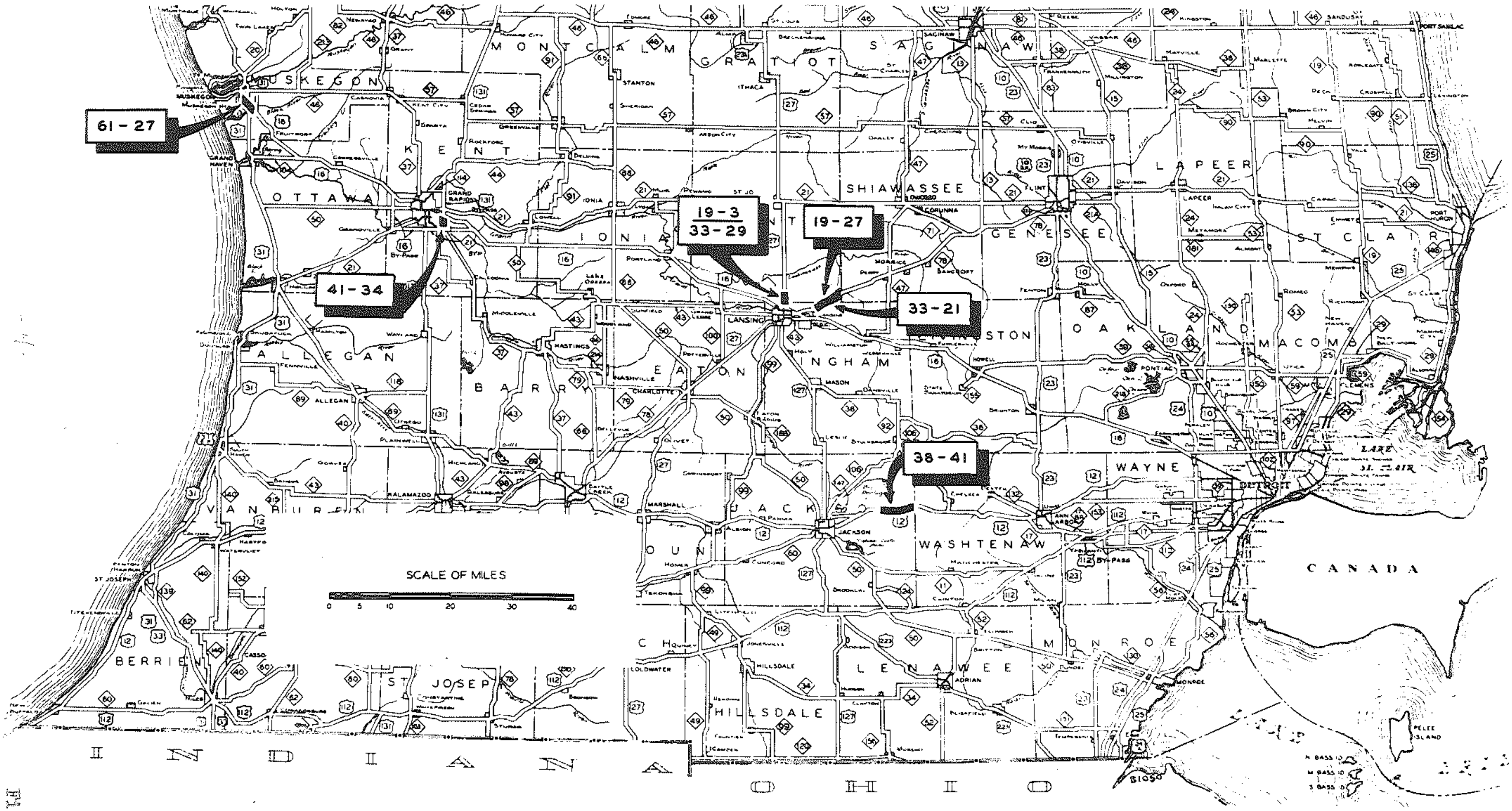


Figure 1

LOCATION OF VIBRATED CONCRETE PROJECTS IN MICHIGAN

VIBRATED CONCRETE PAVEMENT ON M-78

PROJECTS 19-27, C2, AND 33-31, C6 - 1933

J. W. Kushing

Experiment No. 1

VIBRATED CONCRETE PAVEMENT M-78
Projects 19-27, C2 and 33-21, C6 - 1933

To explore the possibilities of economy and improved quality in concrete-pavement construction by the use of vibratory finishing machines, the Michigan state highway department conducted a comparative investigation on vibratory and regular finished sections of pavement. The investigation proper was conducted in 1933, but preliminary tests were made in 1932. The preliminary tests demonstrated:

1. That vibratory machines could handle extremely dry concrete.

2. That 1:2:2-1/2 mix by volume contained excess mortar for this type of finishing.

3. That mixes having 1/2-in. slump or less were difficult to spread in front of the finishing machine by hand, and that it was practically impossible for hand finishers to remove high spots.

4. That it was impossible to place premolded joint material to proper depth and alignment with such mixes.

In view of the above conclusions, it was decided to use in the investigation proper only such mixture as could be spread and finished in the routine manner with results comparable to standard finishing methods.

Testing Methods

The investigation was conducted on Trunk Line Highway No. 78, near Lansing, Michigan, where a 9-in. uniform pavement 20 ft. wide was being constructed. Reinforcement was used in the greater part of its length. The subgrade varied from clay and clay loam to sand.

Gravel and crushed limestone were used as coarse aggregate, but as gravel was being used throughout the project, greater attention was given to this material. Coarse aggregates were furnished in two sizes proportioned 50 per cent of each by weight and batched by the same method. The mixtures were designed on the mortar-voids theory.

Vibration was secured by means of electric-motor vibrators and was transmitted to the concrete through screeds on the finishing machine, the front screed being equipped with three vibrators and the rear with two.

The investigation can be considered as divided into twelve sections according to the different mixes used as shown in Table IV. Design data are also shown in this table for the various mixes, and the results as to modulus of rupture are shown in Table V. The concrete beam-test specimens, 6- by 8- by-36-in., were molded from concrete incorporated in the work, and every effort was made to produce concrete in the test molds like that produced by the vibratory finishing machine in the pavement. The vibration of the molds was obtained by means of a table with vibrator attached.

Conclusion from tests

Any conclusions to be drawn at this time must necessarily be based on field observation and the beam breaks, as the cores that were taken will not be broken until one year old.

Analyzing field reports, it was found that mix 6-G was the most nearly ideal from the standpoint of mixing, placing, handling and finishing. A smooth surface was obtained, and it was possible to install the longitudinal contraction joint in a satisfactory manner, these results being secured with the same amount of labor as with standard gravel mix. Because of these facts about 4,320 lin.-ft. of this mix were laid.

TABLE IV

DESIGN OF CONCRETE MIXTURES FOR VIBRATION TESTS OF CONCRETE
PAVEMENT BY MICHIGAN HIGHWAY DEPARTMENT

Section	R.W.C.	Excess Paste Per Cent	b/b_o	a_m/a_o	w/c	N Sacks	N_m Sacks	Mix per sack of cement: Sand, Lb.	Mix per sack of cement: C.A., Lb.	Mix per sack of cement: Water, Lb.	Volumetric Proportions (Approx.)	Specific Gravity	Voids, Per Cent
							GRAVEL						
*1-G-S	1.23	20	.76	.80	.692	6.00	11.10	203	350	43.2	1:1.92:3.43	Cement, 3.12 Sand, 2.66 Gravel, 2.70	Sand, 36.1 Gravel, 39.5
1-G	1.35	16	.85	.84	.684	5.10	10.41	231	460	42.7	1:2.18:4.51		
2-G	1.35	16	.80	.84	.684	5.40	10.41	231	409	42.7	1:2.18:4.01		
3-G	1.35	20	.85	.80	.638	5.64	11.53	199	415	39.8	1:1.88:4.07		
4-G	1.35	12	.80	.88	.758	4.82	9.29	271	457	47.3	1:2.56:4.48		
5-G	1.35	15	.875	.85	.699	4.80	10.13	240	502	43.6	1:2.26:4.92		
6-G	1.40	18	.825	.82	.699	5.36	10.64	221	424	43.6	1:2.08:4.16		
							STONE						
*1-S-S	1.23	20	.76	.80	.729	6.00	10.20	232	308	45.5	1:2.19:3.42	Cement 3.12 Sand, 2.66 Stone, 2.67	Sand, 36.1 Stone, 46.0
1-S	1.35	16	.825	.84	.684	5.77	10.41	231	347	42.7	1:2.18:3.86		
2-S	1.35	16	.85	.84	.684	5.63	10.41	231	367	42.7	1:2.18:4.08		
3-S	1.30	16	.875	.84	.638	5.70	10.80	223	374	39.8	1:2.10:4.16		
4-S	1.35	16	.85	.84	.684	5.63	10.41	231	367	42.7	1:2.18:4.08		

Nomenclature and explanation: *Standard mix not vibrated.
R.W.C.—relative water content.
Excess paste—per cent by volume.
b/b_o—vol. of loose coarse aggregate in a cu. ft. of concrete.
a_m/a_o—vol. of loose fine aggregate in a cu. ft. of mortar.
w/c—water-cement ratio by volume.
N—sacks of cement per cu. yd. of concrete.
N_m—sacks of cement per cu. yd. of mortar.

In comparing mix 6-G with the standard gravel mix it will be noted that the 7- and 28-day flexural strengths average practically the same for a total of 14 beam-test specimens, or 28 breaks for each period of time.

It is also to be noted that in general the slumps for the standard mix and 6-G were 2-1/2 and 3/4 in., respectively; that the cement per cubic yard of concrete was reduced from six sacks; and that the water-cement ratio increased slightly from 0.692 to 0.699. For each sack of cement the weight of fine aggregate was increased from 203 to 221 lb.; the gravel coarse aggregate was increased from 350 to 424 lb.; the water was increased slightly from 43.2 to 43.6 lb. The excess paste was decreased from 20 to 18 per cent, and the excess mortar from 24 to 17.5 per cent.

In conclusion, it may be stated that the vibratory finishing machine was efficient in handling, compacting and finishing dry harsh mixtures. Its efficiency, however, could not be entirely utilized due to difficulties encountered with hand-spreading and hand-finishing operations.

In spite of this fact, early results of the investigation seem to indicate the possibility of reducing the cost of concrete in pavements, without sacrifice of quality, by reducing the cement content per cubic yard of concrete.

TABLE V

DATA OF MIXTURES OF GRAVEL AND STONE AND RESULTS OF STRENGTH TESTS OF CONCRETE BEAMS MADE DURING INVESTIGATION OF VIBRATORY FINISHING MACHINE

Section	Mix Per Sack of Cement								Water-Cement Ratio		Slump	Modulus of Rupture Lb. Per Sq. In.			
	Sand,	Coarse Aggregate			Water							7 days		28 days	
	Lbs.	4A Lb.	10A Lb.	Total Lb.	Theo. Lb.	Theo. Lb.	Used Gal.	Used Gal.	Theoret-ical	Actual	Inches	No. of Breaks	Aver.	No. of Breaks	Aver
							GRAVEL								
1-G-S	203	175	175	350	43.2	5.2	44.9	5.4	.692	.719	2-1/2	28	668	28	805
1-G	231	230	230	460	42.7	5.1	49.5	5.9	.684	.793	3/4	4	673	4	826
2-G	231	204.5	204.5	409	42.7	5.1	50.9	6.1	.684	.816	3/4	4	735	4	810
3-G	199	207.5	207.5	415	39.8	4.8	47.4	5.7	.638	.760	3/4	4	716	4	906
4-G	271	228.5	228.5	457	47.3	5.7	52.4	6.3	.758	.840	3/4	4	518	4	617
5-G	240	251	251	502	43.6	5.2	51.9	6.2	.699	.832	7/8	4	523	4	707
6-G	221	212	212	424	43.6	5.2	46.7	5.6	.699	.749	3/4	28	663	28	785
							STONE								
1-S-S	232	154	154	308	45.5	5.5	53.0	6.4	.729	.849	2	4	631	4	830
1-S	231	173.5	173.5	347	42.7	5.1	44.2	5.3	.684	.708	1/4	4	628	4	871
2-S	231	183.5	183.5	367	42.7	5.1	48.0	5.8	.684	.769	1/2	4	599	4	800
3-S	223	187	187	374	39.8	4.8	48.0	5.8	.638	.769	1/4	4	783	4	937
4-S	231	183.5	183.5	367	42.7	5.1	50.8	6.1	.684	.814	1/2	4	633	4	767

Lakewood Vibratory Screed used on Projects 19-27 and 33-21
Spreading concrete, first run

Lakewood Vibratory Screed, final run

VIBRATED CONCRETE PAVEMENT ON US-12

PROJECT 38-41, C6 - 1936

Roy S. Fulton

Experiment No. 2

VIBRATED CONCRETE ON PROJECT F 38-41, 06 (FA 267 A-2)

US-12 - 1936

A new type of vibrator for concrete pavements has been installed on the finishing machine used on the above project by the R. D. Baker Company. The vibrator is manufactured by the Electric Tamper & Equipment Co., of Ludington, Michigan, whose claim is that a denser concrete is produced by its use and, consequently, greater strength obtained with possible decrease in cement content.

The machine consists of a horizontal tubular unit upon which is integrally mounted an unbalanced rotor motor which imparts a vibratory motion throughout the length of the tube. This unit is mounted on the forward end of the frame of the finishing machine, and is raised and lowered by means of a lever placed conveniently near the operator's hand. The one horse power motor is run by means of a portable gas-electric generator of 2 KVA capacity, which also is mounted on the finishing machine. The motor driving the tube turns at 3450 R.P.M. for an eleven foot pavement section.

The tubular unit is in a position to be lowered into the freshly placed concrete approximately one foot ahead of the front screed of the finishing machine. While operating, the tube is partially or wholly submerged in the concrete as desired. The lower side of the tube can be dipped to approximately 2 inches below the finished surface, or slightly above the reinforcing steel, and can be raised to a position clearing the concrete entirely. The finishing machine itself is of standard make and was unaltered for the use of the vibrator.

It was decided to experiment with the concrete proportions to find a mixture more suitable than the regular paving mixture for placing with the vibrator. At the same time, it was hoped that greater economy could be obtained with the standard cement content by an increase in strength. Also, by maintaining the same strength, a decrease in the cement content might be possible.

The first variation from the regular paving mixture was made with an increase in the proportion of coarse aggregate with the cement content remaining at 6 sacks per cubic yard and the relative water content remaining at 1.23. Table I contains the various proportions used and shows the variation of the material constants of the experimental mixtures. This mixture (No. 2) was very slightly harsher than the regular mix, and in the beginning only a few batches were made of it. The second change (mix No. 3) showed more noticeable evidence of the increase in gravel content, and the mixture was continued for study.

The vibrator puddled the mixture very nicely with the first passage of the finisher. There seemed to be an excess of mortar for finishing, and it was necessary for the screeds to pass over the concrete the second time for the fine finish. At first, on the second passage of the machine, the vibrator was allowed to ride the concrete just at the surface to bring up mortar for the final finishing purposes, but in so doing it caused much water and laitance to gather there. This not only retarded final finishing, but left a surface that might be subject to scaling. Therefore, the second passage of the vibrator was discontinued, and no further difficulty was encountered.

Mix No. 3 was continued for approximately a day when Mr. McCarthy, of the Electric Tamper & Equipment Co., requested that the gravel factor be reduced from $b/b_0 = 0.84$ to $b/b_0 = 0.80$. The mixture appeared to him as not finishing properly with the higher gravel content.

During the early part of the period that the vibrator was used, the casting took place on a super-elevated curve on the side of a hill. According to the cement count an excessive over-run had occurred while the vibrator was used. The contractor believed the vibrator, as well as the mix, to be the cause, and objected to the mix being used as not producing sufficient yield.

Therefore, a trial batch of three cubic feet of concrete was made up using the proportions from the chart. This material was measured in an accurately calibrated steel cubic foot box. The box was shaken and spaded vigorously while being filled, then was struck off by a straight edge. The under-run of materials was approximately 0.3 percent. Substantiating this was the yield obtained on the first level section of several hundred feet which was vibrated, and only a slight over-run of cement existed. Mr. A. Forrest, Superintendent, was present during the yield test.

Mix No. 4 was used for only 18 batches. The yield checked out as estimated, but the concrete appeared very harsh and difficult to finish. The shovelers worked much harder to spread the concrete, and the vibrator failed to bring up a sufficient quantity for finishing, necessitating additional excess finishing.

Further adjustments in the proportions are contemplated, and may be used later. Meanwhile, the contractor requested that he be allowed to proceed using the regular paving chart.

It is intended that cores will be taken of the section from station 528+60 to 529+30, where mix No. 4 was cast, to determine the compressive strength. The water-cement ratio of that mix was 5.40 gallons per sack of cement, as compared to 5.27 for the regular paving mixture.

A characteristic of the vibrated concrete that met with the Superintendent's approval was that after the vibrator had done its work, the concrete was of more firm texture and allowed the finishers to work much closer to the paver. The concrete would bear a person's weight shortly after the finishing machine had passed.

Possibly with further experimentation of the proportions a mixture might be developed that would permit a reduction of cement content and yet meet the requirements desired for vibratory placement as well as good finishing qualities. Attached to this report are the concrete proportioning charts used during the experiment.

TABLE I

Experimental Mixtures for Vibratory Method

of Placement for Concrete Pavement

Cement		Specific Gravity	3.10		
Fine Aggregate		" "	2.63	Absorption	1.3 %
Coarse Aggregate	4A	" "	2.60	"	2.1 %
Coarse Aggregate	10A	" "	2.58	"	2.3 %

Weight of (Bone Dry) Loose Coarse Aggregate - 100 lbs. per cubic foot.

Mix No.	Cement Content Sacks per Cu. Yd.	R.W.C.	b/b_o	Water-Cement Ratio Gal./Sack	Mix per Sack of Cement: Sand	Coarse Aggregate	Water Free and Absorbed lbs.
1*	6.0	1.23	0.76	5.27	189.0	342.0	53.8
2	6.0	1.23	0.80	5.09	174.0	362.0	52.6
3	6.0	1.23	0.84	4.92	160.0	379.0	51.4
4	5.5	1.23	0.80	5.40	201.0	393.0	56.2

* Regular paving chart

Note: The cement was obtained from the Peerless Cement Co. of Detroit, and the aggregates from the Brown & Rosenbarger Co., plant at Grass Lake.

Present Condition of Pavement

This project was resurfaced with bituminous concrete in 1947. No record of the physical condition of the concrete at the time of resurfacing is available. It is known, however, that the project scaled badly, with areas showing marked disintegration from the surface downward.

VIBRATED CONCRETE PAVEMENT ON US-27

PROJECTS F 33-39, C1, AND 19-3, C12 - 1937-1938

C. H. Cash

Experiment No. 3

THE U. S. 27 PROJECT
1937 - 1938

This project was designated as State projects F 33-39 C-1 (F.A. 68-A) and F 19-3 C-12 (F.A. 68-B-C-D). It consisted of 1.727 miles of 24' concrete widening, 1.113 miles of 42' concrete pavement and 0.384 miles of 20' concrete pavement and had a total length of 3.224 miles. It is located on U. S. 27 in Ingham and Clinton counties and extends from the intersection Ferris and Larch Streets in Lansing, in a northerly direction to Chandlers Marsh.

The portion between stations 0 and 25, within the city of Lansing, is a municipal section with concrete curbs and storm sewers while the remainder is of rural design with 8' shoulders and open ditches. This road carries moderately heavy traffic throughout the year and is subjected to mechanical and chemical snow and ice removal methods during the winter.

The pavement is of standard cross section with each lane having a thickness of 8" at the center and 10" at the edges. It is reinforced with mesh reinforcement weighing 5.4 pounds per square yard. Load transfer expansion joints were placed through the pavement at intervals of 60 feet and intermediate plane of weakness joints were placed midway between expansion joints to divide the pavement into sections 30' in length. The 42' pavement was divided into 4 lanes having widths of 11' for the two outside lanes and 10' for the two center lanes. Each lane was tied to the adjacent lane by means of 1/2" X 4' round deformed dowel bars spaced 40" apart and by 1 1/2" X 3 1/2" keyways. The 24' concrete widening was made up of 11' slabs and 1' filler strips on each side of an existing 18' concrete pavement. The filler strips which separated the widening slabs from the existing pavement were 10" thick, were tied to the 11' widening slabs by 5/8" X 4' round deformed bars spaced 40" apart and by 1 1/4" X 3 1/2" keyways. The total width of the old and new pavement was 42'.

The replacements which were made in the old pavement and the easterly widening lane between stations 32 and 150 were poured in October and November 1937 using the standard paving mixture with standard methods for placing and finishing the concrete. The remainder was poured in May and June 1938 and all except the easterly lane between stations 0 and 32 was placed by the vibratory method. The portion which was poured in 1937 was cured by the wetted straw method excepting areas which were poured during cold weather, in which case the integral, dry powder, calcium chloride method was used and the pavement was protected by a 12" layer of straw. The portion which was poured in 1938 was cured by the wetted earth method.

Description and Operation of Equipment

Mixer.-The paver was a 27E Koehring about 10 years old. Because of its age it was a constant source of mechanical trouble. The contractor attributed much of this trouble to the additional load required to agitate the harsher, dryer mixtures. However, similar troubles were encountered with the regular paving mixture. More power is required for harsh dry mixtures than is required to mix more fluid concrete but it is doubtful whether the mixtures used on this project would have caused any trouble to a modern paver.

At first the governor was set so that the drum turned at the rate of 17 r.p.m. but the motor did not have power enough to move the paver ahead and turn the drum at the same time. For this reason the speed of the drum was increased to operate at a higher rate of speed.

A 7 sack batch having a mixed volume of 31.5 cubic feet was used with the regular paving mixture. Six sack batches which produced volume of 28.2 to 32.4 cubic feet of concrete per batch were used for all mixtures which were placed by vibration. New mixing blades were installed in the paver before paving was started.

There was some segregation of the coarse aggregate during the discharging of the batch from the drum into the bucket. The larger stones had a tendency to roll to the back side of the bucket while the finer material flowed to the front side. This segregation was noticeable in all mixtures regardless of their harshness or consistency and was attributed entirely to the design of the equipment. It tended to produce stone pockets and thus affected workability.

When concrete having a slump of less than one-half inch was produced it was discharged from the bucket with difficulty. It was often necessary for the puddlers to assist in starting the flow of the concrete or to dislodge concrete which stayed in the bucket. This bucket was obviously designed for use with more fluid mixtures.

The pavement was all poured in single lanes having widths of 10' and 11'. During most of the time the paver operated outside of the subgrade and the boom operated on an angle. This reduced the reach of the boom so that it could not properly distribute the batches over the subgrade. For this reason it was necessary to use 5 or 6 puddlers at all times to spread the concrete.

Vibratory Equipment.-The equipment used was the Jackson Vibratory Paving Tube manufactured by the Electric Tamper and Equipment Co., Ludington, Michigan. The tube consisted of a 4 inch seamless steel tube upon the back of which was welded a 4 inch channel. It was in 2 parts, joined in the center by a saddle casting upon which was mounted an especially designed induction motor having unbalanced weights on its rotor shaft to produce the vibrations. It was powered by a 3 - phase, 110 volt, 60-80 cycle A C generator driven by a 5 H. P. air cooled gasoline engine. The tube, suspended in belting, was held in place by adjustable brackets which were raised and lowered by a hydraulic ram controlled from the operator's deck.

When in operation, the tube was submerged until the bottom was about 1 1/2 inches below the grade of the top of the pavement. Sufficient concrete was carried ahead of the front screed so that the vibratory tube was entirely submerged. Under working conditions the frequency was 3900 to 4200 vibrations per minute and the amplitude was .04 to .08 inches. The weight of the vibrating unit was 360 pounds for the 10 foot width of pavement and 375 pounds for the 11 foot width of pavement.

The finishing machine.-The finishing machine was a Type C Lakewood having two screeds. When operating normally without the vibrator it traveled at a speed of about 12 feet per minute. When the vibrator was in operation the finishing machine traveled at a speed of 6 to 8 feet per minute depending on the size of the load ahead of the screed. The motor did not seem to lag due to the additional load when the vibrator was engaged but the difference in speed appeared to be caused by slippage of the drive wheels on the forms.

Field Mixtures

The standard mixture which was used in the easterly lane for the entire length of the project, in the one foot filler strips which divided the widening slabs from the old pavement, and in replacements of the existing pavement. This mix had a cement content of 6.0 sacks per cubic yard of concrete, b/b_o of 0.76, and a relative water content of 1.23 which

Table I

VIBRATED CONCRETE PAVEMENT

Data on Field Mixtures

Pour No.	Cement Content	b/b_o	R. W. C.	a/c	Sacks of Cement per cu. yd. of Mortar	w/c	Cement Brand	Sta. to Sta.	Date Poured
1	5.75	0.78	1.20	2.58	11.15	0.630	Aetna	0+38-4+30 L	5-16-38
2	5.75	0.80	1.20	2.39	11.44	0.670	"	4+30-9+14 L	5-17-38
3	5.75	0.80	1.20	2.39	11.44	0.670	"	32+42-39+71 L	5-20-38
25	5.75	0.82	1.20	2.35	11.60	0.665	"	17+54-25+65 LC	6-14-38
4	5.50	0.80	1.20	2.73	10.93	0.619	Huron	39+71-52+06 L	5-21-38
5	5.50	0.84	1.20	2.53	11.57	0.594	"	52+06-53+94 L	5-25-38
6	5.50	0.82	1.20	2.63	11.21	0.607	"	53+94-59+80 L	5-26-38
7	5.50	0.80	1.20	2.73	10.93	0.619	"	59+80-63+39 L 67+17-69+44 L	5-26-38
18	5.50	0.80	1.20	2.76	10.84	0.622	"	9+14-16+30 L	6- 9-38
19	5.50	0.80	1.20	2.59	10.82	0.695	Aetna	16+30-21+21 L	6- 9-38
20	5.50	0.80	1.20	2.59	10.82	0.695	"	21+21-23+96 L	6-10-38
21	5.50	0.80	1.20	2.59	10.82	0.695	"	23+96-27+65 L	6-11-38
26	5.50	0.82	1.20	2.49	11.13	0.684	"	25+65-31+50 LC	6-14-38
27	5.50	0.82	1.20	2.49	11.13	0.684	"	0+38-16+76 RC	6-15-38
28	5.50	0.82	1.20	2.49	11.13	0.684	"	16+76-28+62 RC	6-16-38
8	5.25	0.80	1.20	2.89	10.47	0.639	Huron	69+44-83+53 L	5-31-38
9	5.25	0.80	1.20	2.89	10.47	0.639	"	83+53-94+75 L	6- 1-38
10	5.25	0.80	1.20	2.89	10.47	0.639	"	94+75-100+50 L	6- 2-38
23	5.25	0.78	1.20	2.85	9.85	0.724	Aetna	0+38-8+00 LC	6-13-38
24	5.25	0.82	1.20	2.66	10.62	0.703	"	8+00-17+54 LC	6-13-38
11	5.00	0.80	1.20	3.09	9.94	0.669	Huron	100+50-106+75 L	6- 3-38
12	5.00	0.80	1.20	3.09	9.94	0.669	"	106+75-116+48 L	6- 4-38
13	5.00	0.80	1.20	3.09	9.94	0.669	"	116+48-124+00 L	6- 6-38
14	5.00	0.80	1.20	3.13	9.85	0.673	"	124+00-129+41 L	6- 6-38
15	5.00	0.80	1.20	3.13	9.85	0.673	"	129+41-139+00 L	6- 7-38
16	5.00	0.78	1.20	3.21	9.65	0.684	"	139+00-146+27 L	6- 7-38
17	5.00	0.78	1.20	3.21	9.65	0.684	"	146+27-153+69 L	6- 8-38
22	5.00	0.80	1.20	2.96	9.86	0.673	Aetna	27+65-32+42 L	6-11-38
29	6.0	0.80	1.20	2.26	11.00	0.654	"	28+62-29+74 RC	6-16-38
30	6.0	0.76	1.23	2.40	11.29	0.694	"	29+74-31+82 RC	6-16-38

produced concrete having a slump of 1 1/2 to 2 1/2 inches. Aetna cement was used in the regular mix between stations 0 and 32R and Huron cement was used in the remainder of the unvibrated pavement.

In the mixtures which were placed with the vibratory equipment the slump was maintained at 1/2" to 1". Previous investigation had indicated that dryer mixtures could be placed by means of vibration but that such mixtures clogged the paver and were difficult to discharge from the bucket. For the combinations of materials being used, a relative water content 1.20 was found to produce the proper consistency for all mixtures. Cement contents of 6.0, 5.75, 5.50, 5.25 and 5.00 sacks per cubic yard of concrete were used with b/b_o factors ranging from 0.76 to 0.84. Data pertaining to the various mixtures are shown in table No. I and the locations of the pours are shown in figure 1.

Placing and Finishing the Concrete

The first layer of concrete below the reinforcement was placed in the usual manner and struck off. After placing the mesh the second layer was deposited so that it heaped up above the forms to provide a substantial excess. The finishing machine then made its first pass with the vibratory tube in operation. Enough concrete was carried ahead of the front screed so that the tube was entirely covered. This was necessary in order to effectively transmit the vibrations through the mass of concrete. This made the concrete more fluid so that it was leveled into place by the front screed. The second screed carried a roll of concrete 2 or 3 inches in diameter which seldom contained coarse aggregate larger than 1/2 inch in size. At times it was necessary to carry concrete back and deposit it in front of the back screed. The second pass of the finishing machine was made in the usual manner with the vibrator raised and not in use. When the operations were properly conducted two passes of the finishing machine were sufficient.

The hand floating which followed the machine finishing was practically the same as with the standard mix except that it followed finishing machine operations more closely. There was seldom any free water to be raked off from the surface. The finishers were working with mortar of good quality and there was a desired absence of soupy material.

Vibrating a Standard Paving Mix

To determine what effect vibration would have on our standard paving mix, 208' of 10' pavement between stations 29+74 and 31+82 RC was placed using the standard paving mix with a 2" slump. The mix was obviously heavily over-sanded and too wet for vibratory placement. A thick layer of excess mortar was brought to the surface and the top inch of concrete was almost entirely devoid of coarse aggregate. The impression gained was that the pavement had been over-finished and that scaling would probably result.

Spading of Sidewalls

The vibratory tube was equipped with a tool on each end which was designed to spade the sidewall. Representatives of the manufacturer had stated that very good results had been obtained with these attachments on previous projects. This was the first time it had been used to spade a keyway joint. During the first day no hand spading was done. When the forms were removed on the following day it was found that the attachments had been ineffective in the area below the keyways. Hand spading was required thereafter.

Mechanical Trouble

About 2 miles of 11' slab had been poured without trouble using various mixtures when the vibratory equipment became less effective. The trouble was first noticed at station 120L when the mix appeared harsh and three trips of the finishing machine were required to finish the pavement. It continued for several days during which time checks were made on every detail of proportioning, equipment, materials, etc. which might affect the mixture. At station 139L it was necessary to decrease b/b_o to 0.78 and to increase the slump to 1 1/2 inches. As was well known, such a mixture could have been placed without the aid of vibratory equipment. It was finally discovered that concrete had become deposited on a switch in such a manner as to cause single phasing of the 3 phase electric motor. The manufacturers representative expressed the opinion that the single phasing had been intermittent and that a continuous short circuit of this kind would have burned out the motor. Our vibration frequency determinations were made by use of an r.p.m. counter operated from the shaft of the gasoline engine and for that reason failed to detect the trouble. For the remainder of the pours a vibrometer was used to determine the frequency. As a result of this trouble the manufacturer decided to enclose the switch on the new models of this equipment. The pavement area affected was the westerly widening slab between stations 120 and 153+69. After the switch had been repaired the harsher mixtures were again placed without trouble.

Workability of Mixtures

It was found that a mixture having a b/b_o factor of 0.80 was at least as workable when placed by vibratory means as a standard mixture having a b/b_o factor of 0.76 when placed by ordinary means. Mixtures having a b/b_o of 0.78 had more surplus mortar than necessary and the one mix having a b/b_o of 0.76 which was placed by vibration had a heavy surplus of mortar on top of the coarse aggregate. Mixtures having a b/b_o of 0.82 could be placed without undue difficulty and mixtures having a b/b_o of 0.84 were obviously too harsh. It was noted that the finer cement produced the more workable mix for the same b/b_o. A b/b_o of 0.82 would have been very satisfactory for general use with the finer cement while it would have been rather harsh for general use the coarser ground cement. In the same manner the amount of fines in the fine aggregate noticeably affected the workability. In the fine aggregate being used the material passing the No. 50 sieve varied from 6% to 10%. 10% was found to be highly desirable and 8% is suggested as a minimum.

Casting and Testing of Beams

The field beams were cast by use of the same equipment and in the same manner as the laboratory beams except that a vibration period of 10 seconds was used for all vibrated beams. In each series of 6 beams, 4 were vibrated and the other 2 were cast by the standard hand method. The beams were buried along the edge of the pavement slab and cured for a period of 7 days by the wetted earth method, the same as the adjacent pavement. At the end of 7 days, 2 of the vibrated beams and one standard beam were broken. The other 3 beams were cured for the remainder of the 28 day period when they were broken. The results of these tests are shown in table No. II. The strength of most of the 28 day beams exceeded the capacity of the beam breaker. For that reason they provide a poor basis for comparison. They do indicate, however, that satisfactory strengths were obtained with the low cement contents used.

TABLE NO. II

MODULUS OF RUPTURE OF VIBRATED AND UNVIBRATED BEAMS

6" x 8" x 36" FIELD SPECIMENS

Series No.	Vibrated Beams 7 Day	Vibrated Beams 28 Day	Unvibrated Beams 7 Day	Unvibrated Beams 28 Day	Cement Content	b/b_o	R.W.C.	a/c	w/c	Sacks of Cement per cu. yd. Mortar
1	855	938+	844	828	5.75	0.78	1.20	2.58	0.630	11.15
	872	938+								
2	837	819	853	834	5.75	0.80	1.20	2.39	0.670	11.44
	846	769								
3	773	844+	844	797	5.75	0.80	1.20	2.39	0.670	11.44
	764	844+								
Ave.	824	859+	847	820	5.75					
4	783	938+	778	778	5.50	0.80	1.20	2.73	0.619	10.93
	861	938+								
5	769	938+	853	844	5.50	0.84	1.20	2.53	0.594	11.57
	591	844+								
6	769	938+	810	938+	5.50	0.82	1.20	2.63	0.607	11.21
	788	938+								
14	750	938+	750	938+	5.50	0.80	1.20	2.76	0.622	10.84
	787	938+								
16	741	938+	741	938+	5.50	0.82	1.20	2.49	0.684	11.13
	759	938+								
Ave.	760	929+	786	887+	5.50					
7	806	938+	741	844+	5.25	0.80	1.20	2.89	0.639	10.47
	759	872								
8	816	938+	825	872	5.25	0.80	1.20	2.89	0.639	10.47
	722	938+								
9	897	938+	853	928	5.25	0.80	1.20	2.89	0.639	10.47
	750	938+								
15	778	938+	666	938+	5.25	0.82	1.20	2.66	0.703	10.62
	787	938+								
Ave.	789	930+	771	896+	5.25					
10	709	938+	615	919	5.00	0.80	1.20	3.09	0.669	9.94
	713	938+								
11	844+	938+	834	923	5.00	0.80	1.20	3.09	0.669	9.94
	844+	938+								
12	703	933	628	775	5.00	0.80	1.20	3.13	0.673	9.85
	703	909								
13	797	938+	741	938+	5.00	0.78	1.20	3.21	0.684	9.65
	834	938+								
Ave.	768+	934+	705	889+	5.00					

Each modulus of rupture shown is the average of 2 breaks.

The plus signs indicate that the total load applied failed to break the beam.

Comparison on Water Cement Ratio Basis

Workability comparison of the various mixtures placed by the vibratory equipment indicated that a mixture having b/b_o of 0.80 and a relative water content of 1.20 could be placed as readily as the standard mix with standard paving equipment. The weights per cubic foot of loose bone dry coarse aggregate on this project were 103 lbs. and 104 lbs. By using these values for vibratory placement and the standard values for the standard method of placement, the cement contents for vibratory placement which would provide a water cement ratio equal to that provided in the standard mixture have been determined. This comparison is shown in table No. III and indicates that on an average a cement content of 5.5 sacks per cubic yard for vibratory placement provides the same water cement ratio as a cement content of 6.0 sacks per cubic yard for the standard paving mixture.

Condition of the Surface after One Years Service

The surface of the pavement was examined in August 1939 after it had been in use for a period of one year. Surface scaling had taken place on the municipal section between stations 0 and 25 on both the vibrated and standard pavement. The vibrated pavement widening on the rural section between stations 25 and 154 was entirely free of scaling and the standard pavement on the same section had only slight scaling in front of business places between stations 115 and 125. The harshest mix at station 52+06- 53+94L, the pavement at station 135-139L where excessive hand finishing was required due to trouble with the vibrator, and the standard pavement mix at station 29+74-31+82RC which was finished with the vibrator, were all

TABLE III

COMPARISON OF CEMENT CONTENTS OF VIBRATED AND UNVIBRATED
MIXES HAVING THE SAME WATER-CEMENT RATIO

Huron Cement

	Vibrated		Unvibrated	
Wt. per cu. ft. Coarse Aggregate	103	104	103	104
b/b_o	0.80	0.80	0.76	0.76
R.W.C.	1.20	1.20	1.23	1.23
Sacks cement per cu. yd. Mortar	10.78	10.83	11.29	11.38
a/c	2.78	2.76	2.59	2.56
w/c	0.625	0.622	0.625	0.622
Sacks cement per cu. yd. Concrete	5.46	5.45	6.0	6.0

Aetna Cement

	Vibrated		Unvibrated	
Wt. per cu. ft. Coarse Aggregate	103	104	103	104
b/b_o	0.80	0.80	0.76	0.76
R.W.C.	1.20	1.20	1.23	1.23
Sacks cement per cu. yd. Mortar	10.88	11.02	11.29	11.38
a/c	2.57	2.52	2.40	2.37
w/c	0.694	0.688	0.694	0.688
Sacks cement per cu. yd. Concrete	5.52	5.55	6.0	6.0

entirely free from scaling. On the municipal section, scaling was most severe along the gutter lines and at the bottom of a grade at station 0-4.

Comparisons were made in the amount of scaling as related to cement contents, harshness of mixtures, wet and dry mixtures, vibrated and unvibrated pavement, properly finished and over finished areas, and different brands of cement. These comparisons failed to indicate that the scaling in this case could be attributed to any of these factors. Scaling was most severe on areas which had been subjected to the heaviest concentrations of calcium chloride for the removal of ice and snow. On the two center lanes where the solution of calcium chloride and melted snow and ice drained to the sides or was whipped off by traffic, scaling was relatively light. Where the concentration had been increased by drainage to the gutter lines the scaling had been increased. On the inside of a super-elevated curve and at the bottom of a grade where the areas of this drainage were the largest, the scaling was the most severe. On the rural section where the applications were lighter and where there were no curbs or other obstructions to prevent the solution from draining to the shoulders, there was no scaling whatever.

<u>Summary of Results on the U. S. 27 Project</u>

1. Mixer.-The paver was inadequate for this type of work and the harsh dry mixtures taxed its power to the limit. Frequent repairs were necessary but the age of the mixer was believed to be largely responsible. Concrete having a slump less than one inch was difficult to discharge from the bucket.

2. Finishing Machine.-The finishing machine operated satisfactorily while pushing the vibratory unit and finishing 10' and 11' widths of pavement. It's speed was reduced from 12' per minute to 8' per minute during this operation by slippage of the drive wheels on the forms. It is doubtful whether this machine would have had enough traction to push the vibrator and finish a 20' pavement.

3. Vibratory Equipment.-This equipment placed harsh dry mixtures satisfactorily. A frequency of 4000 vibrations per minute was adequate when the finishing machine speed was 6 to 8 feet per minute.

4. Design of Mixtures.-Concrete design factors of $b/b_o = 0.80$ and R.W.C. = 1.20 provided the most desirable mixture for vibratory placement. When these factors were used a cement factor of 5.50 sacks per cubic yard provided the same water cement ratio as was required for a cement content of 6.0 sacks per cubic yard in a standard paving mixture.

5. Spading Sidewalls.-The attachments for spading the sidewalls were not effective in the case of a keyway joint.

6. Beam Strengths.-Adequate beam strengths were obtained with cement contents as low as 5.0 sacks per cubic yard. As the strengths of practically all of the 28 day beams exceeded the capacity of the beam breaker, a comparison of the effect of the various factors was not obtained.

7. Surface Scaling.-The chemical resistance of the pavement apparently was not increased by vibratory placement. Surface scaling occurred during the first year of service on both the vibrated and unvibrated sections of pavement.

Present Physical Condition of US 27 Project

In October 1952 a condition survey was made of the entire project to determine the relative physical condition of the vibrated and unvibrated sections of this project. The results of this survey are given in Table IV in terms of cracking and sealing. The data is presented under Sections A, B and C. The only difference in the three sections being the cement content in the vibrated portions, 5, 50, 5, 25 and 500 respectively.

With reference to Table IV the extent of cracking in the vibrated portion was found to be considerably more than in the unvibrated portion. However in the case of scaling, with the exception of section A, the amount of scaling was about equal in the balance of the project.

The entire project from Station 0+38 to Station 37+75 scaled so badly that it was resurfaced with bituminous concrete in 1948.

TABLE IV

CONDITION SURVEY DATA
US-27 Project, 1951

Sec.	Type	Lin Ft.	Sacks of Cement/C.Y.	Cracking Total: No. of Slabs	Cracking Total: L. F. Grade	Cracking Total: No. of Slabs	Scaling: No. of Slabs	Scaling: Sq. Ft. Scale	Scaling: % Scaling of Total Area
A 39+71	V	2973	5.50	27	321	80	42	2004	6.12%
to 69+44	R	2973	6.00	27	293	80	36	4404	13.5%
B 69+44	V	3106	5.25	54	605	105	42	1245	3.65%
to 100+50	R	3106	6.00	23	244	105	43	1710	4.93%
C 100+50	V	4750	5.00	45	436	162	60	3471	6.66%
to 148+00	R	4750	6.00	23	282	162	57	3705	7.08%

Type V = Vibrated Concrete

Type R = Regular Concrete

Concrete Pours - Project No. F 19-3 C12 ; F 33-39 C1

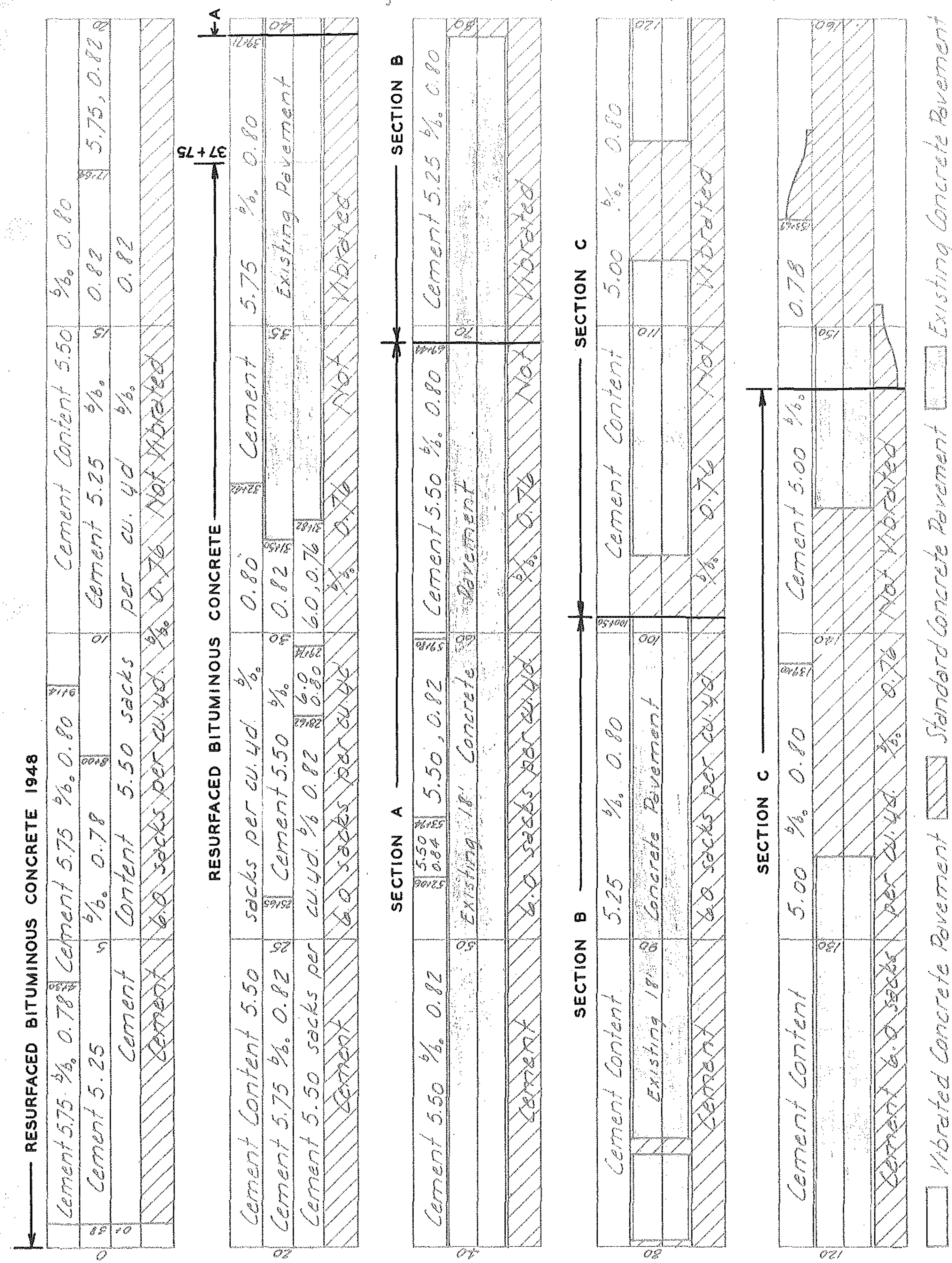


Fig. 6

Eleven-foot Jackson Vibratory Tube used on Projects 33-39 and 19-3

Vibratory tube in operation, Projects 33-39 and 19-3

VIBRATED CONCRETE PAVEMENT ON M-126 - NOW US-16

PROJECT 63-27, C5 - 1938

C. H. Cash

Experiment No. 4

THE M-126 PROJECT
1938

Location.-The project consisted of 1.387 miles of 20' concrete pavement on state project M 61-27- C-5 which was located on trunk line M-126 from Peck Street, Muskegon Heights, southeast to Getty Avenue.

Purpose.-A number of things were not determined on the U. S. 27 project largely due to the manner in which the contractor elected to do the work. Two questions in particular arose because the pavement was placed one lane at a time. First: Would a standard finishing machine have enough power and traction to push the vibratory unit and properly finish a 2 lane pavement? Second: Could the plane of weakness center joint be properly installed in vibrated pavement with the standard equipment now used for that purpose. Further enlightenment on these two points were the principal objectives of the investigation on this project.

History.-The pavement was poured during September 1938. The experimental work in connection with the vibratory placement of concrete pavement was carried on in conjunction with several other research projects. These investigations dealt with the use of a Portland-Natural cement blend, a pozzolanic admixture, contraction and expansion joints, surface finishing and curing. Some of these factors may have more effect upon the durability and surface appearance of the pavement than the vibratory method of placement. The effect of all factors should be considered in future surface-condition surveys.

General Construction Details

The pavement was unreinforced and was of standard cross section, 7 inches thick at the center and 9 inches thick at the edges. The crown was 3/4 inch for a 20 foot slab. Expansion joints were spaced 120 feet apart and plane of weakness joints were spaced at intervals of 20 feet on part of the project and at intervals of 30 feet on the remainder. Curing was by application of asphalt emulsion immediately after finishing. The subgrade soil was Lake Michigan dune sand which was kept well sprinkled ahead of the paver.

Materials

The materials used were gravel coarse aggregates and natural sand from Grand Rapids Gravel Company, plant No. 4, and Huron cement from the Muskegon warehouse. On parts of the project the Portland cement was blanded with Luxment natural cement from Utica, Illinois. A summary of the detailed analyses of these materials is given in the Department report on the Use of Portland-Natural Cement Blends and Pozzolith Admixture in Concrete Pavements, dated October 28, 1938, but has not been repeated here because it is not pertinent to this report.

Mixture Design Factors

The design factors which were found to produce the most satisfactory mixture on the U. S. 27 projects were used on this project. They were: cement content - 5.5 sacks per cubic yard; $b/b_o = 0.80$; R.W.C. = 1.20.

TABLE NO. I

Concrete Proportioning

Surface Dry Weights

Sta. - Sta.	Mix	Proportions by Weight	Wts. Per Sack Cement			Weights per Cubic Yard of Concrete						w/c	b/b_o	s/c	Slump
			Gravel	Sand	Water	Gravel	Sand	Water	Portland Cement	Natural Cement	Pozzolith				
0 +73 - 22+00	Standard	1:2.22:4.32	406.5	208.5	42.7	2236	1147	235	517			.684	.80	2.64	1 1/2"
22+00 - 29+15	Blend	1:218:4.55	428	205.5	37.5	2355	1130	212	431	86		.601	.84	2.60	1 "
29+15 - 30+80	Standard	1:2.22:4.32	406.5	208.5	42.7	2236	1147	235	517			.684	.80	2.64	1 1/2"
30+80 - 39+73	Standard	1:2.40:4.32	406.5	224	41.0	2236	1232	225	517			.657	.80	2.83	1 3/4"
39+73 - 40+23	Pozzolith Adm.	1:2.40:4.32	406.5	224	34.0	2236	1232	187	517		11	.545	.80	2.83	1 3/8"
40+23 - 43+84	Standard	1:2.40:4.32	406.5	224	41.0	2236	1232	225	517			.657	.80	2.83	1 3/4"
43+84 - 64+40	Standard	1:2.22:4.32	406.5	208.5	42.7	2236	1147	235	517			.684	.80	2.64	1 1/2"
64+40 - 65+84	Blend	1:2.34:4.59	431	220.5	34.4	2370	1213	189	431	86		.551	.845	2.79	1 1/2"
65+84 - 68+00	Blend	1:2.32:4.55	428	218.5	34.2	2355	1202	188	431	86		.548	.84	2.76	1 3/8"
68+00 - 71+70	Blend	1:2.27:4.55	428	213.5	35.8	2355	1174	197	431	86		.574	.84	2.71	1 1/4"
71+70 - 74+02	Standard	1:2.22:4.55	406.5	208.5	42.7	2236	1147	235	517			.684	.80	2.64	1 1/2"

This mixture was used for all pours except where blended cements were used. A tabulation of the data is shown in table I and the locations of the pours are shown in figure 1.

Paving Equipment

In general the paving equipment on this project was the absolute minimum of our requirements. Troubles with the paver, finishing machine, forms and batching equipment caused numerous delays and heavy overruns on cement. The paver frequently became clogged and mechanical troubles caused several delays. The water gauge was checked before the paver started but subsequently became damaged and was found to measure inaccurately after the project was nearly completed. The forms were of an old type which had strips welded onto the base to meet the bearing area requirements. The tops were semicircular in shape and provided a bearing area only 3/8 to 1/2 inch wide for the wheels of the finishing machine. The finishing machine was an old type Ord which was of lighter construction and traveled at a lower rate of speed than any of the modern machines. Inaccuracy of the batchery scales caused overruns on cement of 6% to 12% thruout most of the project. Although they were repaired and checked several times during the paving period, a loose knife edge which had been causing the trouble, was not discovered until most of the pavement had been placed.

Vibratory Equipment

The vibratory equipment was the same as that used on the U. S. 27 project except that it was a 20' machine. It was equipped with new type spading attachments for eliminating porousity along the forms. These attachments consisted of pieces of sheet metal about 1/8 of an inch in thickness which vibrated with the tube and which penetrated the concrete about two-thirds the depth of the slab about an inch from each form. They were very effective in spading the sidewalls and no additional hand spading was necessary.

Placing and Finishing Operations

The concrete was placed and finished in a manner similar to that on the U. S. 27 project except that the pavement was poured in a 20 foot width. The finishing machine operated at a speed of one to three feet per minute on the first pass while pushing the vibrator and at a speed of about 6 feet per minute while making the second pass with the tube raised. A frequency of 3600 vibrations per minute was used between stations 31 and 63 but this appeared to agitate the concrete more than was necessary because of the slow speed of the finishing machine. For the remainder of the project the vibrator was operated at a frequency of 3200 vibrations per minute which provided a better consistency and ample workability.

The slow speed of the finishing machine was caused by excessive slippage of the drive wheels on the forms. At first this caused the machine to run off from the forms at frequent intervals. It was necessary to install double flanged wheels on the two front drive wheels and to weight the back of the machine down with a railroad rail, weighing about 500 pounds, to remedy this condition and to prevent the finishing machine from tipping forward when the vibratory tube was raised. The contractor used a small crew and did not attempt heavy production because he considered the project too short to warrant such procedure. For that reason, the finishing machine was able to keep up with paver in spite of its slow speed.

Installation of Contraction Joints

The longitudinal center joint and the transverse plane of weakness joints were of the ribbon type and were installed by means of a cleft joint machine. In general, no difficulty was encountered in this operation under normal conditions. The joints were very difficult to install at points where delays occurred between the placing and finishing operations. It was necessary to have the center joint machine follow the finishing machine as closely as possible.

Test Results

Vibrated and unvibrated beams were cast in the same manner and by use of the same equipment as was used on the U. S. 27 project. The test results are shown in table II.

TABLE NO. II

Modulus of Rupture

6x8x36" Beams

Series No.	Mix	Cement Bags/cu. yd.	w/c	b/b_o	Slump	Vibrated Beams 7 Days	Vibrated Beams 28 Days	Unvibrated Beams 7 Days	Unvibrated Beams 28 Days
1	Standard	5.5	.657	.80	1 3/4	488	862	699	883
						656	900	773	883
						676	855		
						694	883		
2	Standard	5.5	.684	.80	1 1/2			682	871
								746	855
								746	865
								673	869
3	Portland-Natural Cement Blend	5.5	.574	.84	1 1/4	682	865	688	874
						655	873	727	900
						670	880		
						652	900		
4	Standard	5.5	.684	.80	1 1/2	700	863	718	887
						662	855	690	855
						674	856		
						709	900		
5	Standard	5.5	.684	.80	1 1/2	673	881	698	887
						682	889	700	877
						699	847		
						694	883		
6	Standard	5.5	.684	.80	1 1/2	691	871	691	874
						708	881	719	874
						693	868		
						694	886		
Average Standard						627	874	711	874
Average Blend						665	880	708	887

Average Day Time Temperatures

7 AM	1 PM	5 PM	Average
55	69	63	62.5

Summary of Results on the M-126 Project

1. This project further emphasized the desirability of using heavy powerful equipment in connection with vibratory placement.

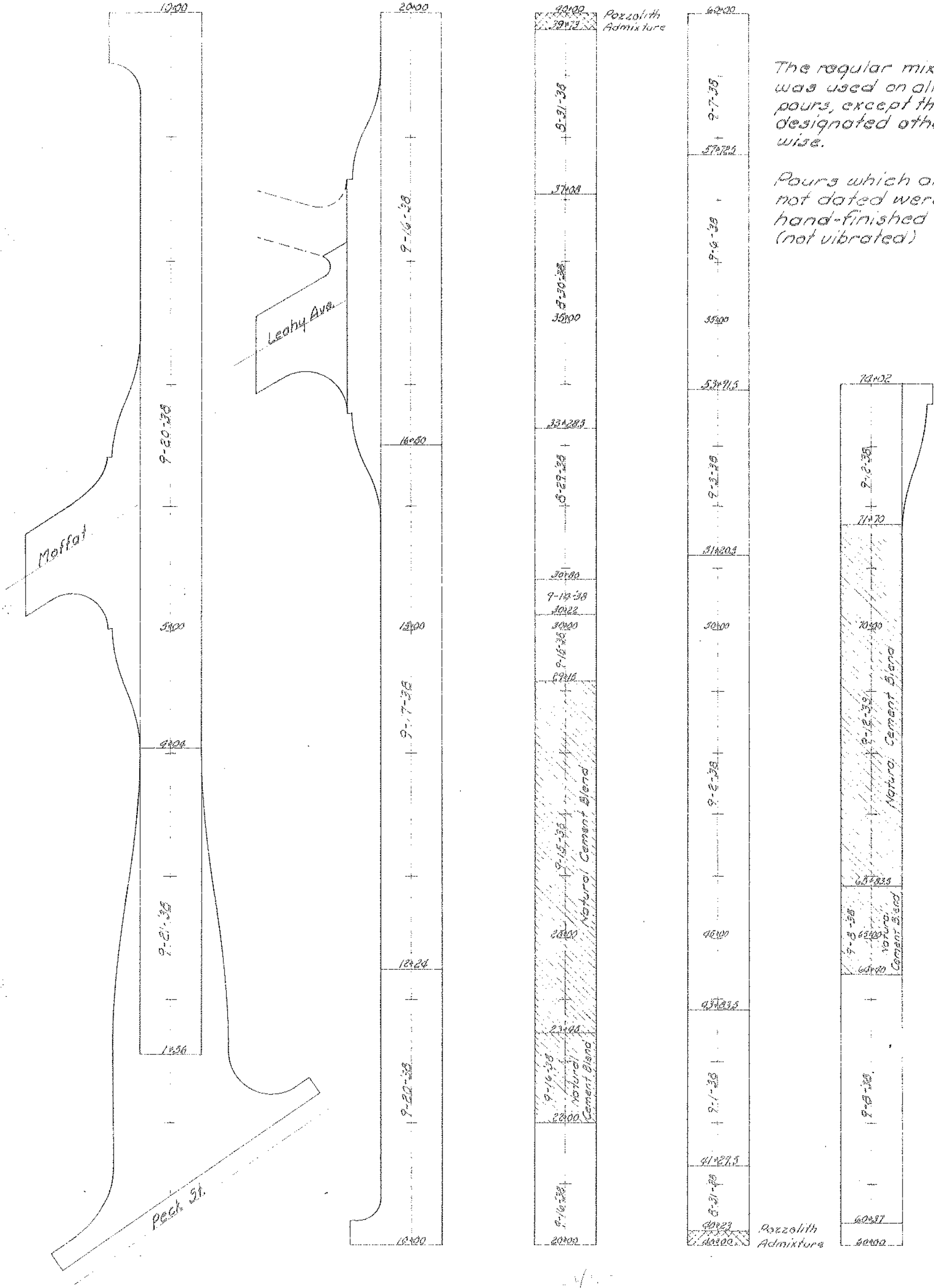
2. Longitudinal and transverse plane of weakness joints were not particularly difficult to install in the vibrated pavement.

3. The new spading attachment was very effective in eliminating porosity along the forms.

4. A lower vibration frequency was required on this project than had been previously used because of the slower speed of the finishing machine.

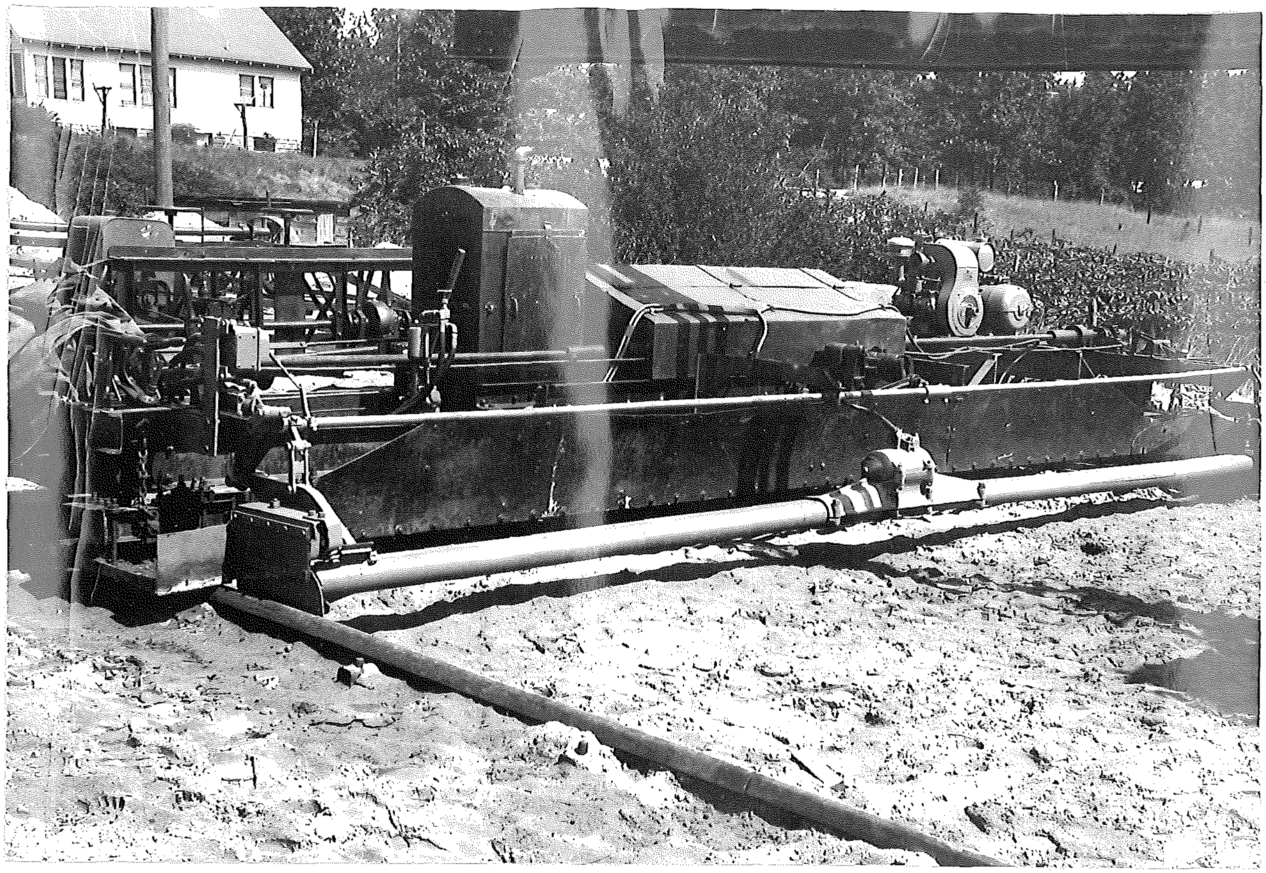
5. Satisfactory modulus of rupture strengths were obtained using a cement content of 5.5 sacks per cubic yard of concrete. There was very little difference between the strengths of the vibrated and unvibrated beams.

VIBRATED CONCRETE POURS 61-27



The regular mix was used on all pours, except those designated otherwise.

Pours which are not dated were hand-finished (not vibrated)



Twenty-foot Jackson Vibratory Tube used on Project 61-27, C5

Vibratory Tube in operation

VIBRATED CONCRETE PAVEMENT ON BY-PASS US-131, GRAND RAPIDS EAST BELT

PROJECT F 41-34, C6

W. A. Keranen

Experiment No. 5

GRAND RAPIDS EAST BELT, BY-PASS US-131

1941 - 1942

This report covers the field inspection work done on the vibrated concrete pavement, project F 41-34, 06, located on by-pass US-131, Grand Rapids east belt between US-16 and 28th Street, or south belt, Grand Rapids.

This project was set up to determine the feasibility of the use of low consistency concrete with the mechanical and vibratory methods of placement and consolidation now being developed. This project should have given these methods a fair test under ideal conditions. Natural sand and gravel, all from one source, was specified in order to eliminate crushed sand and gravel, which the advocates of vibratory methods admit will not work satisfactorily by their methods. The maximum grade on the section of these tests was +2.84%. The earth grade was constructed with a one-foot sand cushion over clay. Unfortunately, just before the contract was let, priority designations required that reinforcing steel be kept at a minimum, causing the elimination of all steel except the tie bars at the center joints.

This fact did reduce the effect obtained from the vibratory equipment to a considerable extent, and then too, we were unable to evaluate the difference in effect of vibration on a 10" - 8 - 10" reinforced slab as compared to the same treatment on an equivalent 9" uniform unreinforced pavement.

Equipment:

1. One 27-E Multi-Foote paver.
2. One eleven-foot screw type Jaeger spreader with a (plank) vibratory strike-off.

3. One eleven-foot Jaeger-Lakewood finishing machine with a (plank) vibratory strike-off on the back of the front screed.

4. One Cleveland form tamper.

5. Steel forms 9" x 10'.

All equipment was in good condition with the exception of the finishing machine, which did not have a "bull-nose" screed, as specified, and also had a very irregular and crooked front screed.

Materials:

1. Huron cement.

2. Breen natural sand and gravel, Grand Rapids.

3. Orvus.

4. Vultex joint seal.

Order of Work:

The vibrated section was started at station 0/22 on September 22, 1941, and the right, or east, eleven-foot slab was poured to station 87/55. During this pour, the paver traveled on the outside of the forms on the west half of the grade, and the subgrade planer was pulled by an R.D.-6 tractor. Center joint steel was held in place on the east slab by wooden strips bolted to the center form. The paver was then returned to the point of beginning, and after finishing the intersection the west eleven-foot slab was poured. From station 5/00 to station 50/72, the paver rode the east slab with the subgrade planer behind an R.D.-6. At station 50/72 the paver was placed between the forms and completed the job to station 87/55 that way.

Construction Procedure:

After the forms were set the subgrade was prepared by a planer and sprinkled with water, if dry.

The concrete was deposited on the subgrade in such a manner and in such quantities that only one pass of the spreader was necessary to completely fill the space between the forms to the required depth and grade. Immediately behind the horizontal screw of the spreader, a vibratory board strike-off provided the initial consolidation of the concrete mass. The mechanical spreader was followed by a finishing machine with a vertical vibratory board attached to the rear of the front screed. The finishing machine did not have a "bull-nosed" screed as specified. At station 5+44 a half-round steel bar was attached to the front bottom of the forward screed. According to the Jaeger factory representative, this bar was supposed to do the same work as a "bull-nosed" screed. The finishing machine with the vibrator was to furnish the final consolidation of the concrete with one pass. We found that it was necessary to make two passes of the finishing machine at all times, and on plus grades three passes were sometimes necessary. It was also hoped to reduce hand finishing to a minimum, but hand finishing was necessary over the entire job.

<u>Mixes Tried:</u>

	Admixture	b/b_o	R.W.C.		Station	to Station
1.	Orvus 0.05#/bbl.	0.80	1.15		0+22	2+29 R
2.	Orvus 0.05#/bbl.	0.84	1.15		2+29	4+19 R
3.	Orvus 0.05#/bbl.	0.84	1.10		4+19	5+00 R
4.	Orvus 0.05#/bbl.	0.80	1.10		5+00	8+50 R
5.	Orvus 0.05#/bbl.	0.76	1.10		8+50	28+50 R
6.	Orvus 0.05#/bbl.	0.80	1.00	(Modified by Cash)	28+50	38+50 R
7.	Orvus 0.04#/bbl.	0.80	1.00	(Modified by Cash)	38+50	67+24 R
8.	Orvus 0.05#/bbl.	0.80	1.00	(Modified by Cash)	67+24	75+00 R
9.	Orvus 0.05#/bbl.	0.80	1.00	(" by Fulton)	75+00	87+55 R
10.				(Left Strip)	0+22	36+45 L
10.	None	0.80	1.00	(Left Strip)	36+45	54+20 L
11.	Orvus 0.05#/bbl.	0.80	1.00	(Left Strip)	54+20	63+94 L
12.	None	0.73	1.10	(Left Strip)	63+94	66+70 L
13.	Orvus 0.05#/bbl.	0.73	1.10	(Left Strip)	66+70	70+20 L

The (bone dry) loose weight of sand, 4A and 10A coarse aggregate per bag of cement for the above mixes was as follows. The amount of water in pounds is also given.

b/b_o	R.W.C.	Sand#	4A#	10A#	Water#
0.80	1.15	218	225	224	48.4
0.84	1.15	204	236	236	47.0
0.84	1.10	206	236	236	45.4
0.80	1.10	222	225	224	46.6
0.76	1.10	237	213	213	47.9
0.80	1.00	233	225	224	42.4 (Modified by Cash)
0.80	1.00	225	225	224	42.6 (Modified by Fulton)
0.80	1.00	247	225	224	43.4 (Without Orvus)
0.73	1.10	273	205	205	51.4 (Without Orvus)
0.73	1.10	260	205	405	50.0 (With 0.05# Orvus per bbl. of cement)

The modulus of rupture strength tests indicate a failure to meet requirements of grade "A" concrete, particularly on the seven-day test results. But the addition of Orvus does not seem to be the factor, because concrete without the admixture also failed to meet minimum specification requirements. The twenty-eight day tests compare favorably with the required strengths. The concrete mix being a five sack per cubic yard, although vibrated, could be compared with grade "B" concrete. If the concrete is so considered, the results would in most cases be satisfactory.

Orvus Admixture	b/b_o	R. W. C.	Modulus of Rupture 7 days	Modulus of Rupture 28 days
None	0.76	1.20	497	806
			544	722
None	0.80	1.00	435	713
			460	816
04#/bbl.	0.80	1.00	543	731
			516	788
05#/bbl.	0.80	1.00	464	722
			421	628
			554	718
			544	769
			356*	610*
			272*	506*
05#/bbl.	0.80	1.10	553	713
			572	685
Specification requirements Grade A			550	650
Specification requirements Grade B			475	575

* These beams very porous, affecting modulus of rupture strength.

Mixes 1 to 4 looked harsh. The spreader and finishing machine left them very compact and dense, but uneven. The finisher could not float anything but the thin layer of mortar on top, so he could not fill the larger and deeper irregularities. Mix #5 looked and worked fine, but it was found with all these mixes that if we used the amount of water calculated from the chart the mix was sloppy wet. Consequently, the water at the paver was kept from four to six gallons under chart figures. This fact, and a low fine grade, contributed to an average over-run in cement of 6% for the first three days. The mix was then modified to obtain the calculated yield. In the process of modifying, more sand was added to the mix, giving more fines on top and contributing materially to the ease of finishing operations.

One day's run was made without Orvus and a $b/b_o = 0.80$ and R.W.C. = 1.00. This mix looked harsh and dry. Water came to the top in larger quantities than with mixes using Orvus, but did not seem to carry much cement. Considerable segregation was noticeable when the concrete was dumped from the skip. The concrete was very compact behind the finishing machine, making it difficult to pound in the weakness joint strips. When the spreader and finishing machine did a good job, hand finishing was easy. Most of the time the spreader left holes which the finishing machine did not cover, and for which the finisher could not float enough mortar. Consequently, concrete had to be carried back.

A mix with $b/b_o = 0.73$ and a R.W.C. of 1.10 was tried with and without Orvus. The mix without the Orvus looked over-sanded for a vibrated mix.

Considerable segregation was noticeable which was not corrected by the spreader. With the addition of Orvus, the segregation was corrected, but the mix looked as though it would work better without vibration.

Observations during construction:

There were many delays during the first days due to lack of organization and inexperience on the part of the operators.

The front screed of the finishing machine was too short, pushing concrete over the forms at every pass. This was corrected by welding extensions to the end of the screed.

A series of hollows and bumps appeared behind the finishing machine. They appeared to be five or six feet apart on plus grades, and farther apart and flatter on minus grades. These irregularities were very hard for the finisher to float out. If small, he could float mortar into them, but if large, the only solution seemed to be to take a third pass over the section with the finishing machine, as he could not cut into the dense, compact concrete just under the thin layer of mortar. In trying to eliminate these irregularities, the manufacturer's representative experimented with various frequencies of vibration, and also tried running without vibration on the spreader. It was found that the higher frequencies of vibration did not improve the situation. Finally, it was decided to make a trial without vibration on the spreader and a low frequency on the finishing machine. So two passes were made with the finishing machine; the second pass without vibration, and without use of the front screed, unless too large a load built up in front. This method seemed to give better results at the time, but it seems as if this was due to the fact that we just happened to pass the P.I. of a vertical curve, and go from a +2.84% grade to a -0.03% grade. Subsequently, we tried vibration on the spreader (low frequency) and two passes of the finishing machine, the second without vibration, and achieved the same result. Later the toe of the rear finisher screed was lowered to try to eliminate this condition, but it did not have any noticeable effect. The bumps seemed to be caused by the flow of the mix which contained Orvus and were noticeable during the entire job. The mix with Orvus also slumped toward the lower form. Several times it became necessary to go back over an especially bad spot with a third pass of the finishing machine.

Throughout the entire east strip there was very bad honeycomb underneath the wood strip that held the center steel in place. There were also some sections of the pavement quite badly honeycombed on the outside edges of the pavement. It is obvious, from observing the vibrators, that there is a dead spot at both ends of the vibratory strike-off and the only solution is to use a hand vibrator at the forms and expansion joints. There is undoubtedly honeycomb at expansion joints, as the vibrators were lifted over the joint and the concrete did not get any vibration at that point.

Conclusions - Paving and Vibration

1. It does not appear that the vibrators, with their present set-up, do the work claimed for them. As shown by the honeycomb at the edges, the forms are not being vibrated enough and the same probably holds true for the expansion joints. Until the vibratory screeds can do better work at the forms and joints, hand vibrators should be specified. Higher frequencies of vibration do not seem to be the answer to the problem, so maybe a low frequency with greater amplitude might work.

2. The spreader certainly did extra work on the top of the mix, but it did not correct a pile that was dumped out of the skip and segregated upon hitting the subgrade.

3. It does not seem possible with the present set-up to reduce the final finishing to an advantageous point. As long as the equipment leaves irregularities, the pavement must be hand finished. And, in order to hand finish, some mortar must be on top, which will eventually spall off.

4. The mixes with Orvus in them roll in front of the finishing machine screeds, instead of shoving ahead as mixes without Orvus do. This is the reason the finishing machine does not fill the larger cavities left by the spreader. It is also noticeable that the dense Orvus mixes work as much as three feet behind the rear screed of the finishing machine.

Present Condition - Grand Rapids East Belt Project

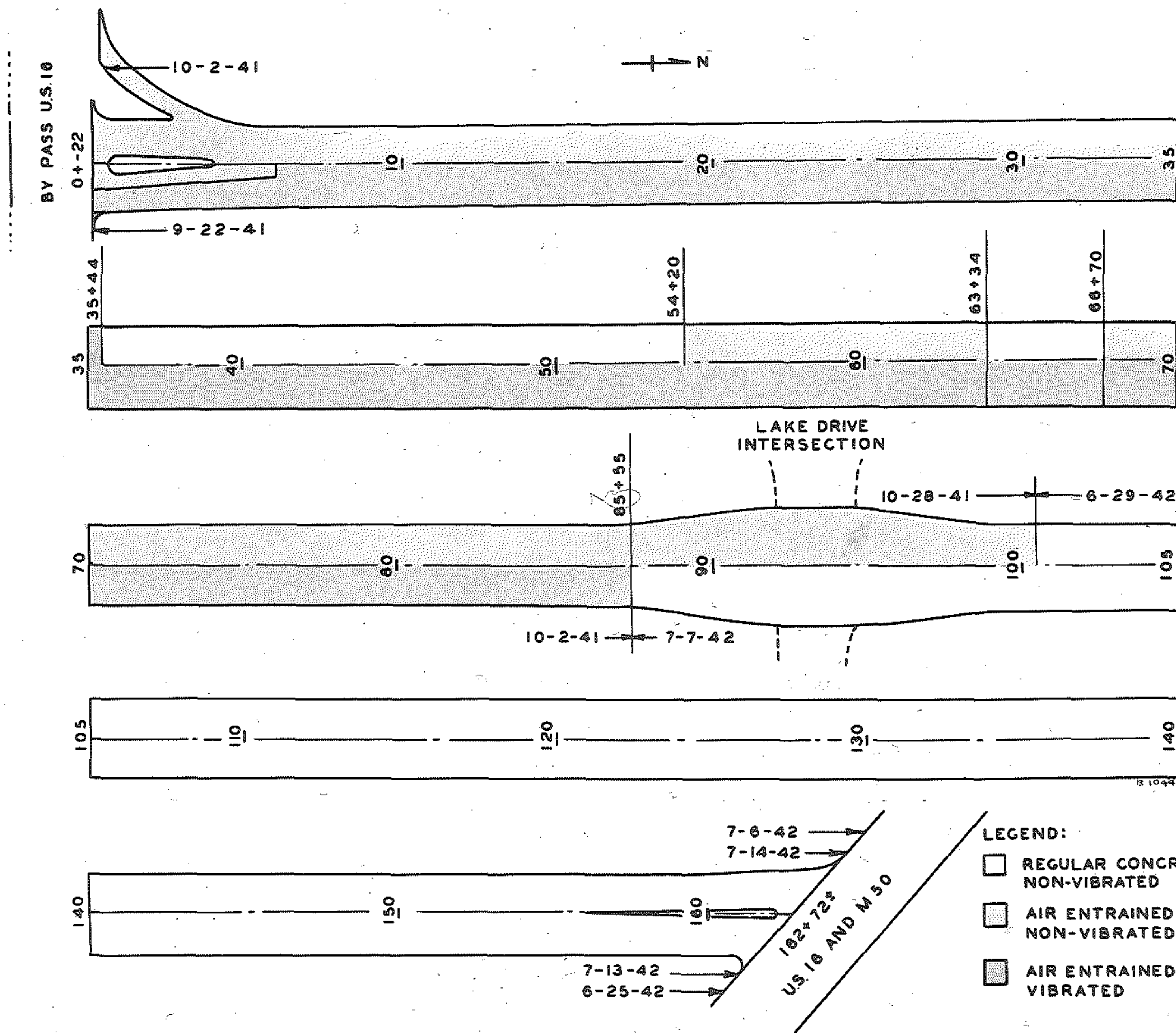
A condition survey of the Grand Rapids project was made in February, 1951. The results of this survey are shown in the following table. The data present covers three sections of the project, in which the performance of the vibrated and unvibrated concrete can be directly compared. The data so far does not indicate any significant difference in pavement performance due to the two methods of construction.

CONDITION SURVEY DATA - GRAND RAPIDS PROJECT

Sec.	Type	Lin. Ft.	Sacks of Cement/Cy.	Cracking No. of Slabs	Cracking Lin. Ft. Cracks	Total No. Slabs	Sealing No. of Slabs	Sealing Sq. Ft. Sealing
A 0+22 to 35+44	V	3522	5	9	96	174	0	0
	R	3522	5	5	39	174	0	0
B 54+20 to 63+94	V	974	5	0	0	49	1	6
	R	974	5	0	0	49	0	0
C 66+70 to 81+55	V	2085	5	1	11	104	0	0
	R	2085	5	1	11	104	1	80

Type V = Vibrated Concrete with Orvus

Type R = Regular Concrete with Orvus

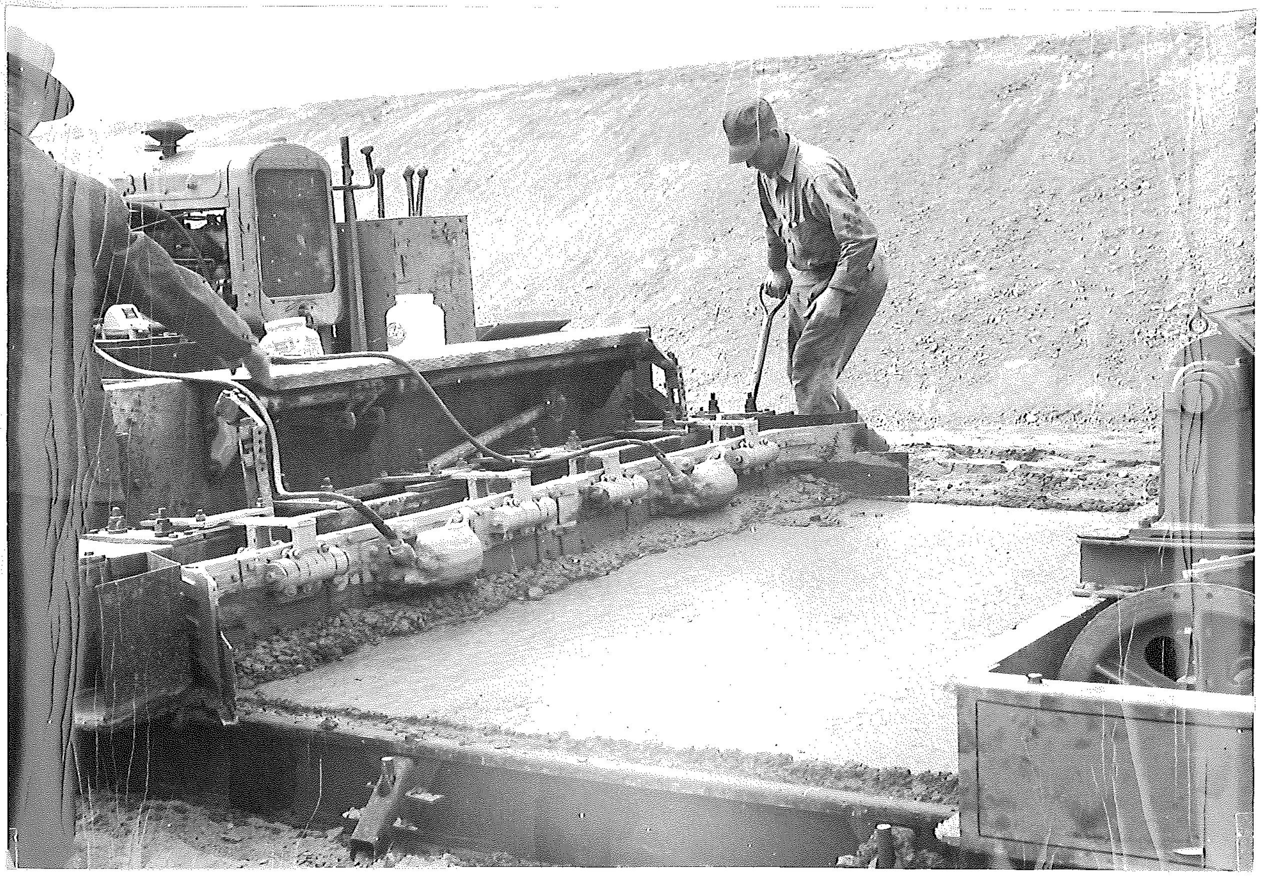


LEGEND:

- REGULAR CONCRETE NON-VIBRATED
- AIR ENTRAINED CONCRETE NON-VIBRATED
- AIR ENTRAINED CONCRETE VIBRATED

PLAN OF GRAND RAPIDS EXPERIMENTAL PROJECT

F-41-34-C6 39-F7-(5)



Vibrating screed on finishing machine, Project 41-34, C6

Jaeger Screw-type Spreader
with a plank vibratory strike-off. Project 41-34, C6