PLACEMENT OF CONCRETE BY VIBRATION ON FEDERAL AID PROJECT 425-E IN WISCONSIN

By Guy H Larson and William H Zamzow

Senior Assistant Highway Engineers, Wisconsin State Highway Commission

SYNOPSIS

In a field experiment conducted on a nine-mile paving project, the usual equipment found on the modern paving job was supplemented by a concrete vibrator of the Jackson tubular type, and by a mechanical longitudinal float The percentage of sand in the aggregate was reduced from that specified for ordinary placing methods in an effort to take advantage of the ability of the vibrator to handle harsher and drier mixes Test specimens consisted of cylinders and cores drilled from the pavement

The consistency and workability of the concrete on this job was controlled more by the floating and finishing operations than by the ability of the vibrator to compact concrete of a given consistency The use of the vibrator resulted in a 10 per cent increase in strength of the concrete on this project

During the season of 1937 the Wisconsin Highway Commission undertook a test project on which a Jackson Tubular Vibrator was used in laying 9 81 miles of concrete pavement The test was made in order to observe the vibrator and determine whether the beneficial effects of vibration demonstrated in the laboratory [1] could be obtained in a comparatively thin, flat section such as the slab on a paving project

The work was done on Federal Aid Project 425-E on United States Highway 16, between Columbus and Portage, in Columbia County The soil on the east end of the project was a sandy loam, grading to sand about the middle of the job, and to a sand-clay mixture at the west end The project was graded and the sand and sandy-loam sections, approximately six miles, were resurfaced with salvaged gravel and the entire project opened to traffic the season before the pavement was laid The section of sand-clay mixture compacted very well under traffic and was not resurfaced

The slab was of the standard thickened edge section for 20-ft pavement, 9 inches at the edges and tapering to a $6\frac{1}{2}$-in uniform thickness 2 ft in from the edges The concrete was reinforced with No 4 gage cold-drawn steel wire fabric (6 by 6-in centers) placed 2 in beneath the surface of the finished pavement The area of the wires in the single layer of reinforcing used in the slab amounted to approximately 0 1 percent of the total end area of the slab

MATERIALS

Cement —The following are the average results of routine tests on the Marquette cement which was used on the project Fineness 92 6 percent, initial set 3 hr 15 min , final set 4 hr 50 min , tensile strength, 3 day 264 lb per sq in , 7 day 345 lb per sq in

Aggregates The aggregates were produced from a local deposit located near the project A sample of the pitrun material was washed, screened and tested, to determine the cement content and proportions to be used A portable screening and washing plant was then

[1] Journal of Research of the National Bureau of Standards, November, 1937, R P 1048

Journal of the American Concrete Institute, Reprint No 41, "Freezing and Thawing, Permeability and Strength Tests on Vibrated Concrete Cylinders of Low Cement Content" By M O Withey, Professor of Mechanics, University of Wisconsin

Proceedings of Sixteenth Annual Meeting, Highway Research Board, "Bond of Vibrated Concrete" By M O Withey, Professor of Mechanics, University of Wisconsin set up by the contractor to produce aggregates especially for this project Routine laboratory test data pertaining to the aggregates were as given in Table 1

The sand had approximately 1 5 percent silt by volume (average of field determinations 3 5 percent), and the colorimetric test showed it to contain no organic matter The mortar required 10 5 percent water for normal consistency, and developed tensile strength

TABLE 1

Characteristics of Aggregates

	Sand	Gravel
Wt lb per cu ft	117 0	109 9
Specific Gravity	2 69	2 69
Voids, per cent	30 4	34 7
Absorption, per cent	1 34	1 49

Sieve Analysis

Sand		Gravel	
Sieve number	Retained per cent	Sieve size in	Retained per cent
4	1	1½	0
8	25	¾	59
14	48	⅜	82
28	68	No 4	98
48	89		
100	98		
Fineness modulus	3 27		7 39

which was 171 percent of the standard at three days, 152 percent at seven days, and 145 percent at twenty-eight days

Water—The water was obtained from a small, spring-fed creek adjacent to the project Soundness, time of set, and strength tests on cement paste and mortar in which this water was used showed no change from those tests in which city tap water was used

EQUIPMENT

Mixer, Finishing Machine, and Joint Installer The mixer was a 1932 model, 27-E Rex, handling 33 cubic feet of concrete per batch It was equipped with automatic water-measuring and timing devices The mixing time was one minute The finishing machine was a 1930 model Lakewood with two screeds It carried the vibrator and accessories A Cleft-plane joint installer was used to install the premolded asphaltic ribbon used to form the longitudinal center joint of the slab This equipment was supplemented by the vibrator and a mechanical float

Mechanical Float: A power-driven mechanical float manufactured by the Koehring Company of Milwaukee was used for longitudinal floating of the surface This machine consisted of a heavy steel frame approximately 12 by 20 ft mounted on wheels traveling on the side forms and carrying a steel screed The screed was 1 ft wide and 10 ft long, with a 2-in turn-up at both ends The machine operated the screed back and forth longitudinally parallel to the center line of the pavement, and at the same time moved it diagonally across the pavement The overlap on the return trip was such that the surface was covered twice This float was experimental and is not a standard requirement in Wisconsin

Vibrator The vibrator was a Jackson Tubular Vibrator manufactured by the Electric Tamper & Equipment Company of Ludington, Michigan It consisted of a 4-in O D by 3/16 in wall, cold-drawn seamless steel (Shelby) tube, and a vibrating motor mounted slightly to one side of the middle of the tube A 4-in, 7¼-lb channel, held in place by steel clamps, was used to back up the tube The weight of the tube and channel member for a 19½-ft length was 293 lb In operation it was submerged in the mass of concrete in front of the screed to such a depth that the bottom of the tube was approximately 1½-in below the top of the finished pavement

The induction type vibrating motor was submersible and was designed with eccentric weights on its rotor shaft to produce vibration. It was attached directly to the vibrating tube by means of two steel clamps. The motor operated on a 110-volt, 3-phase, 60-cycle circuit and had a vibrating frequency variable from 3,600 to 4,800 r.p.m. It weighed 100 lb. A special-shaped filler plate weighing 60 lb., complete with clamps and bolts, was placed between the motor and tube. The weight of the complete vibrating assembly (tube, motor, filler plate, and clamps) was 483 lb.

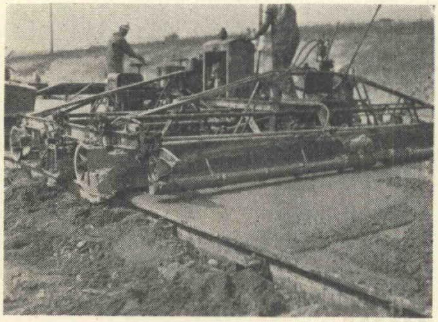


Figure 1. The vibrator in the raised position, showing the tube with vibrating motor mounted near the middle, and the mounting of the vibrating assembly ahead of the finishing machine screed. (The metal strips appearing as light-colored "posts" on the tube carry the needles used in making smoked-glass tracings of the movement of the vibrator.)

The vibrator mounting was of the hinged-arm type with cast steel frame and tube hanger brackets. From these brackets the tube was flexibly suspended on the finishing machine approximately 15 in. ahead of the front screed, with its ends about 3 in. from the forms. It was guided vertically in the horizontal position between the forms by means of heavy straps and rubber cushions or shock-absorbers. The brackets were adjustable to provide control of depth of submersion of the vibrator. The lifting ram was hydraulic, with a hand-operated pump mounted at the operator's position on the finishing machine and connected to the ram by means of a hose.

The power unit, mounted on the rear of the finishing machine was a 2,500-watt, self-excited, 60 to 80-cycle, 3-phase alternator, developing 110 to 140 volts. It was driven by a single cylinder, air-cooled, four to five horsepower gasoline engine, having a variable speed fly-ball governor.

Figure 1 shows a view of the vibrator in the raised position ahead of the finishing machine screed. Figure 2 shows the mass of concrete in front of the screed in which the vibrator was submerged and operated.

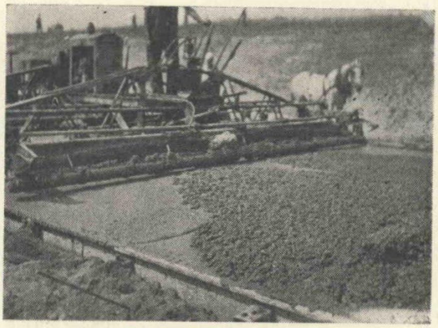


Figure 2. Mass of concrete in front of screed in which vibrator is submerged. Tops of metal "posts" visible above concrete.

SPECIAL PROVISIONS FOR VIBRATION

The State Highway Commission of Wisconsin "Standard Specifications for Road and Bridge Construction" were supplemented by the following "Special Provisions" covering the vibration of concrete on this project:

"*Concrete Pavement. Vibratory Finishing:* In addition to the requirements for striking off and consolidating the concrete pavement slab set forth in Subsection 401.13 (b) of the Standard Specifications, the concrete as soon as it has been placed shall be consolidated by means of a vibratory machine capable of transmitting the vibrations directly to the mass of concrete carried ahead of the front screed of the finishing machine. The vibrating element shall operate at not less than 3600 impulses per minute. The machine shall be of such design as not to produce excess mortar or laitance on the surface of the pavement, and shall not displace side forms, reinforcement or joints.

"It is desired to study the effect of vibration on the concrete and therefore the right is reserved to vary the proportions of the fine to coarse aggregates, by reducing the amount of fine aggregate, and proportionately increasing the amount of coarse aggregate, and also to reduce the amount of mixing water, to such a degree as will still produce workable concrete of proper consistency, with minimum amounts of fine aggregate and water, and maximum amounts of coarse aggregates; however the sum total amount of aggregate per sack of cement obtained by adding the amounts of fine and coarse aggregates, as set forth for the job mix for the particular source of aggregates will remain constant."

OPERATIONS

Preparation of Subgrade and Pouring Concrete: When paving operations were started the compacted surface of the grade was not disturbed. A cushion of fine sand of sufficient depth (approximately one inch) to clear high spots and level the surface was placed on the grade just ahead of fine grading operations. The subgrade was then shaped with the fine grader, compacted with a three-ton, self-propelled roller, and cut to true grade by means of a subgrade planer attached to the back of the mixer.

The concrete was placed in two layers; the first was struck off 2 in. below the top of the finished pavement. The steel fabric reinforcement was then placed, and the second layer of concrete was poured. When pouring the second layer the concrete batches were split and dumped in three longitudinal rows.

Vibrating and Finishing: The finishing machine made its first pass after the second layer of concrete was poured. During the first pass the vibrator was lowered and was operating in the mass of concrete just ahead of the screed as previously described. The second pass of the finishing machine was made with the vibrator raised and not operating. At the beginning of the work the vibrator was kept in operation right up to the transverse joints. It was found that this procedure pushed the joints over and, in spite of vibrating on the far side, left them in a tilted position. This difficulty was remedied by stopping the vibrator about 18 in. from the joint, raising it, and lowering it again just on the far side of the joint. The concrete generally presented a smooth, finished surface after

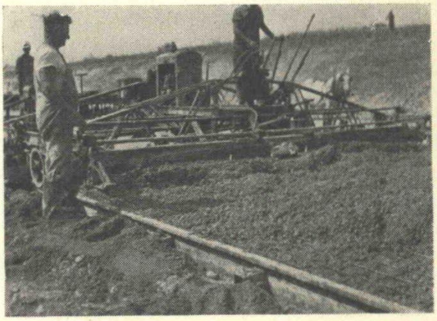


Figure 3. Finishing machine backing up after first pass. Note "dragging back" of concrete due to insufficient "left" of tube.

the first pass of the finishing machine. However, there appeared to be some "swell" or bulging of the concrete immediately back of the screed, due probably to pressure from the mass of concrete carried ahead and the setting of the screed. The screed picked up a considerable amount of concrete on the second pass of the finishing machine. Another factor contributing to this was that the "lift" of the vibrator was insufficient to completely clear the mass of concrete in which it operated so that when the finishing machine backed up there was a tendency for the vibrator tube to drag the concrete back a considerable distance on the surface, as shown in Figure 3.

The vibrator-finishing machine combination had no difficulty handling any of the consistencies and mixes used on the project. A few dry batches indicated that concrete with a considerably stiffer consistency could have been handled by this combination. Some honey-combing at the edges, however, indicated that the vibration was not as effective as it might have been at this point, and spading of the edges was necessary, particularly in the lower layer of concrete.

Placing of the asphaltic ribbon used to form the longitudinal plane of weakness or joint by means of the Cleft-plane joint installer resulted in some disturbance of the concrete at the middle of the

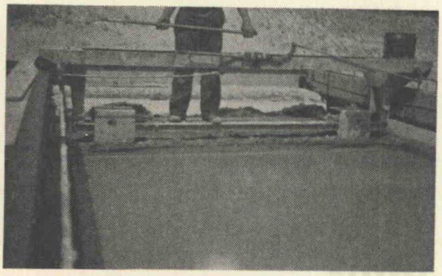


Figure 4. The mechanical float

slab, and was the cause of some trouble with the mechanical float which immediately followed the joint installer.

Longitudinal floating of the pavement was done by the mechanical float described. Figure 4 shows the mechanical float in operation.

Some difficulty was experienced with the float cutting into and gouging the concrete. This tendency seemed to be aggravated by reductions in the percentage of sand in the aggregate, and by drier consistencies of the concrete. The trouble, however, was not due solely to the change in the mix since some difficulty was experienced with all mixes. The machine is a new development and improvements that are bound to be made should enable it to function very satisfactorily in any of the mixes used on the project. In this test, however, dryness and harshness of the concrete were controlled by the plasticity required for floating and finishing operations rather than by the inability of the vibrator to handle drier and harsher mixes. Straightedging, belting, brooming, and edging, all hand operations, followed the floating operation.

Curing: The concrete slab was cured by means of a wet burlap covering for the first 24 hours, followed by an impervious paper covering kept in place for 72 hours.

CONCRETE PROPORTIONS—SPECIMENS

Proportions: When the proportions for concrete for paving were designed for the particular materials used on this project, it was not contemplated that the concrete would be placed with the vibration method, and the mix specified was 1: 2.5: 4.3 by weight, which provided 37 percent sand in the aggregate. Some sections of pavement, using these proportions, were laid in the usual manner without vibration and some were laid with vibration. During the course of the test the percentage of sand in the aggregate was decreased by 2 percent intervals from the 37 percent originally specified to a minimum of 31.0 percent. Concrete having the reduced percentages of sand was placed by vibration. Changes in the proportion of fine to coarse aggregate were so made as to maintain the sum of the absolute volumes of these materials constant. Specifications limited the water to a maximum of 5.5 gal. per sack of cement, but the amount actually used was adjusted to the minimum that would produce the workability required by the various operations and conditions. Table 2 gives the mixes by weight and the proportions used per sack of cement.

The theoretical cement content of the concrete, using the above proportions with 95 percent of the maximum water, was 5 4 sacks per cubic yard of concrete An attempt was made to pour a section of 250 ft with each mix each day The order of pouring was changed so that a given mix would not be poured at the same time each day

Specimens Specimens for transverse strength tests consisted of 6 by 8 by 42-in beams cast in steel molds in accordance with the following procedure Immediately after the batch was dumped, concrete was shoveled from the batch into the mold The mold was filled slightly more than half full, and the concrete rodded 50 times with a ½-in rod The second layer, filling the mold to overflowing, was rodded 50 times and the edges of the specimen spaded with a 6-in sidewalk scraper The concrete was then struck off flush with the mold and finished with a steel trowel The specimens were covered with a piece of pavement curing paper The beams were placed alongside the slab upon being removed from the molds the following day, and were cured the same as the pavement until the seven-day tests were made Following the seven-day tests they were banked with sand with their upper surfaces exposed until subsequent tests Beams were made from the regular specified mix (No 1) only, because cylinders were also made from the concrete at the time of pouring, and it was planned to take cores from the pavement to determine the effects of vibration and make comparisons of compressive strengths and properties of the concrete from the various mixes as actually placed in the slab

The cylinders were cast in steel molds in accordance with A S T M standard procedure from the mixes poured each day They were cured the same as the pavement for four to five days, after which they were brought to the laboratory, placed outside and covered with damp sand until taken inside and prepared for testing Cores were drilled from the pavement when approximately two and one-half months of age They were taken to the laboratory and tested for absorption, density, specific weight, and strength

TABLE 2

Concrete Proportions

Mix No	Mixes (by weight)	Method of Placing	Proportions per sack of cement				
			Sand		Gravel (pounds)		Water
			Pounds	Per cent	¼ to ¾ in	¾ to 1½ in	Gallons per sack
5	1 2 51 4 32	Normal	236	37 0	162	244	Adjusted according to conditions Maximum of 5 5 gallons
1	1 2 51 4 32	Vibrated	236	37 0	162	244	
2	1 2 39 4 44	"	225	35 0	166	251	
3	1 2 26 4 57	"	212	33 0	172	258	
4	1 2 12 4 71	"	199	31 0	177	266	

TESTING

Transverse Tests The specimens were tested in a portable field-testing machine under center loading

Compressive Tests These specimens were tested in a 200,000-lb capacity Riehle testing machine with a free-moving head speed of 0 06 in per min Cylinders were removed from the sand and placed in water at room temperature for at least 18 hours before being capped at both ends with plaster of paris and tested Cores were capped at both ends with a 1 1 cement-sand mortar and tested in compression after the completion of absorption, unit weight, and density tests All cores and cylinders were in a saturated condition when tested

Absorption, Unit Weight, and Density Tests Upon being received at the laboratory the cores were examined for honey-comb and measured to determine their height, or the thickness of the pavement Then the lower end was trimmed preparatory to capping and the cores were allowed to dry in the laboratory air for two weeks They were then thoroughly brushed with a wire brush and weighed Following this the cores

TABLE 3

GENERATOR READINGS AND VIBRATOR FREQUENCY

Generator readings		Vibrator frequency R P M	Load on vibrator
Voltage	Amperes		
115	6 8	3500	Full
125	7 4	3600	"
105	3 4	3900	None

were allowed to soak in water at room temperature for 48 hours, after which they were re-weighed in air and in water The absorption in an air-dry condition and the weight per cubic foot of the concrete were computed from these data The density was obtained by dividing the unit weight thus determined by the computed unit weight of a solid mass of cement and aggregate in the proportions used on the job

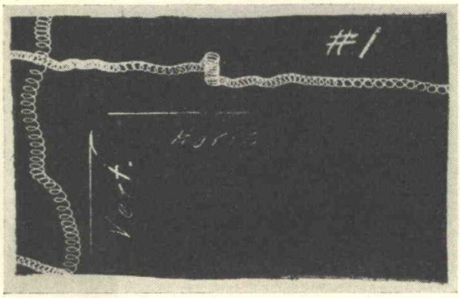
Frequency and Amplitude of Vibration The frequency of vibration of the vibrator was obtained by means of a "Frahm" hand-type, reed tachometer An attempt was made to obtain the amplitude of vibration by making smoked-glass tracings of the motion of the vibrator and taking measurements of these tracings Metal strips approximately 1 by 5¾ in were clamped in a vertical position at four different points on one-half the length of the vibrating tube It was assumed that vibrations of the tube would be symmetrical about its middle A phonograph needle was soldered in place in a hole in each of the metal strips 5½ in above its base These strips are visible in Figure 1, and Figure 3 Tracings of the motion of the submerged vibrator as it operated in the concrete were obtained by holding smoked-glass plates in contact with the needle points and moving them slowly in a vertical or horizontal direction Full-size pictures of a typical set of these tracings, taken simultaneously at the four points, are shown on Figure 5 A small section of each tracing, at a point where the motion of the glass was practically horizontal, or vertical, as the case might be, was enlarged ten diameters by means of photographic equipment Measurements were made of the enlarged tracings and the figures divided by ten to obtain the actual displacement The results are not considered to be accurate measurements of the amplitude of vibration, but it is felt that they afford a good indication of the comparative amplitudes and character of vibration at different points along the vibrator Different tracings indicated that amplitude and character of vibration varied with speed, and with the size and position of the mass of concrete on the tube The "combined amplitude" given beneath each plate is the square root of the sum of the squares of the vertical and horizontal amplitudes (one-half the displacement in each case)

Generator Readings · Simultaneous readings were taken of the voltage and current on the generator, and of the frequency of vibration of the vibrator under load and no-load conditions Table 3 shows a typical set of these readings

TEST RESULTS

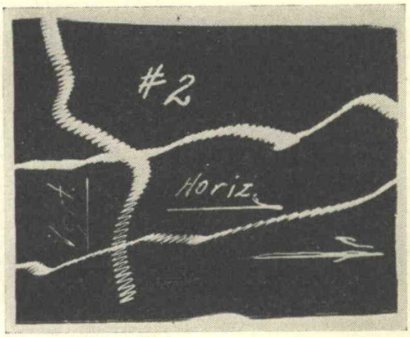
Comparison of Physical Properties. A general summary of individual test data, grouped according to mixes, is given in Table 4.

Referring to Table 4, mixes Nos. 1 and 5 had the proportions specified for nor-



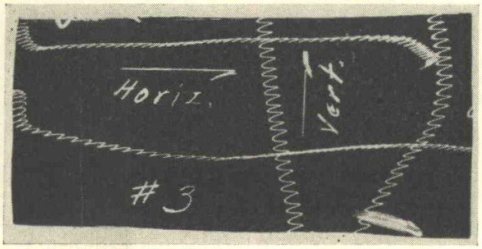
10 feet. 2 inches from right end

Vertical Amplitude .... 0.023 in.
Horizontal Amplitude .... 0.037 in.
Combined Amplitude .... 0.039 in.



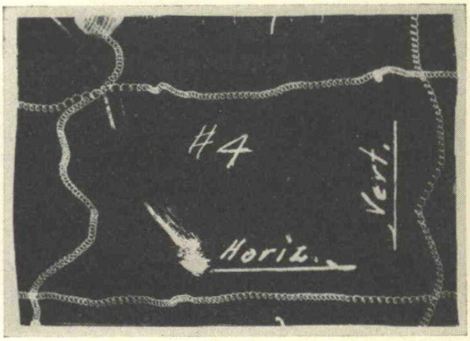
6 feet, 2 inches from right end

Vertical Amplitude .... 0.017 in.
Horizontal Amplitude .... 0.040 in.
Combined Amplitude .... 0.044 in.



2 feet, 2 inches from right end

Vertical Amplitude .... 0.008 in.
Horizontal Amplitude .... 0.038 in.
Combined Amplitude .... 0.039 in.



at right end

Vertical Amplitude .... 0.017 in.
Horizontal Amplitude .... 0.018 in.
Combined Amplitude .... 0.025 in.

Note: Pictures show actual size of tracings. "Right end" in notations above refers to the right end of the vibrator when facing the same direction as the finishing machine. Arrows indicate the horizontal and vertical directions with respect to the tracings.

Figure 5. Smoked-glass tracings of motion of vibrating tube. (Taken simultaneously at four different points on the tube.)

mal placing of the concrete; mix No. 5 was poured without vibration, while mix No. 1 was vibrated. Mixes Nos. 2, 3, and 4 had successive reductions in the percentage of sand and were all vibrated. There were practically no differences in the water-cement ratios and slump of these mixes, the only material variation being a tendency for mix No. 4 (31 percent sand) to slump less than the others.

Effect of Reductions in the Percentage of Sand: Reductions in the percentage

TABLE 4
SUMMARY OF DATA

	Cement[1] content		Water[2]		Slump in	Strength—lb per sq in									Core Tests[4]		
						Beams			Cylinders			Cores					
						Age—Days			Age—Days			Position[3]					
	A	B	G	W/C		7	14	28	7	28	97	E	M	C	Sp weight lb	Density per cent	Absorption per cent
Mix No 1—Vibrated—36 8 Per cent Sand																	
No of Spec	19	19	19	19	18	14	1	15	17	17	17	12	12	12	12	12	12
Maximum	5 52	5 45	5 41	0 72	1 50	740		817	4500	5020	5680	7150	7560	7300	158 2	92 5	1 552
Minimum	5 36	5 37	4 68	0 62	0 75	540		635	2430	2950	3830	5550	5190	5520	155 5	90 8	0 870
Average	5 40	5 42	5 07	0 67	1 08	625	710	726	3270	4075	4781	6443	6318	6222	156 4	91 5	1 179
Mix No 2—Vibrated—35 0 Per cent Sand																	
No of Spec	16	16	16	16	16				10	10	10	13	13	13	13	13	13
Maximum	5 44	5 57	5 32	0 71	1 00				4110	5050	6160	6460	6960	7100	157 5	92 1	1 536
Minimum	5 36	5 39	4 09	0 55	0 75				2660	3250	3400	5150	3030	4920	155 1	90 7	0 955
Average	5 39	5 45	4 89	0 65	0 97				3223	4026	4774	6026	5802	5958	156 3	91 4	1 199
Mix No 3—Vibrated—33 Per cent Sand																	
No of Spec	12	12	12	12	11				6	6	6	10	10	10	10	10	10
Maximum	5 44	5 57	5 30	0 70	2 25				3800	4750	5330	6720	7400	7070	157 2	92 0	1 646
Minimum	5 36	5 39	4 09	0 64	0 05				2688	3170	4110	4620	4830	4520	154 4	90 3	0 981
Average	5 39	5 44	4 93	0 65	1 05				3059	3643	4380	5691	5917	6042	156 2	91 4	1 233
Mix No 4—Vibrated—31 Per cent Sand																	
No of Spec	7	7	7	7	7				5	5	5	7	7	7	7	7	7
Maximum	5 44	5 54	5 26	0 70	1 00				3763	5240	5340	6220	6510	6770	157 8	92 3	1 424
Minimum	5 36	5 39	4 30	0 57	0 00				2240	2610	3430	5270	4660	5190	155 9	91 2	0 916
Average	5 39	5 45	4 85	0 65	0 61				3035	3838	4344	5897	5719	5930	156 7	91 7	1 202
Mix No 5—Not Vibrated—36 8 Per cent Sand																	
No of Spec	8	8	8	8	8							8	8	8			
Maximum	5 44	5 48	5 26	0 70	1 5					Same As		6350	6720	6640	155 8	91 1	1 790
Minimum	5 36	5 39	4 68	0 62	0 5					Mix No 1		4950	4730	3830	154 1	90 1	1 030
Average	5 39	5 42	5 06	0 67	1 06				3270	4075	4781	5774	5913	5505	155 2	90 7	1 369

1—A is as computed from cement used and area of pavement
B is as computed from the absolute volumes of the materials, including water
2—G = gallons per sack of cement, W/C = water-cement ratio by volume
3—E = 8 ft 3 in from center line of pavement, M = 5 ft from center line, C = 1 ft 3 in from center line
4—Averages for three cores listed under E, M, C

of sand did not permit any consistent reduction in the amount of water. The cement content computed from the absolute volumes of the materials varied slightly with changes in the amount of water, but had a close relationship with the cement content as computed from the amount of cement used and area of pavement laid. The compressive strength as indicated by the cylinders apparently dropped as the percentage of sand dropped. Referring again to Table 4, which shows the results of tests on concrete in the pavement as represented by the cores, there is no appreciable increase in specific weight and density, or change in absorption with reductions in the percentage of sand. The compressive strengths of the cores taken from the pavement exhibit the same tendency as was indicated by the strengths of field cylinders; that is, a slight decrease in strength with reductions in the percentage of sand.

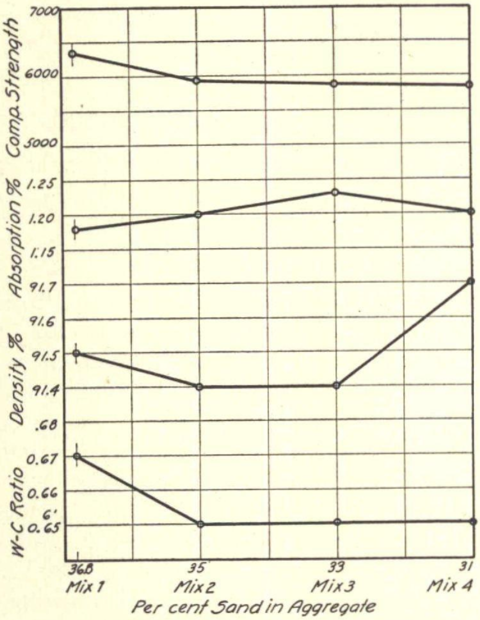


Figure 6. Relation between percentage of sand, water-cement ratio, density, absorption and strength of concrete in pavements.

Figure 6, showing "Relation Between Percentage of Sand and Density, Water-cement Ratio, Absorption, and Strength of Concrete in Pavement," is a graphical presentation of the data obtained from the cores. Figure 7 shows a representative core from each mix. There was little apparent difference between these cores except that the bottoms appeared to become slightly rougher as the sand was reduced. Mix No. 4, with 31 percent of sand but which was vibrated when placed, showed fully as good a bottom as mix No. 5 with 37 percent of sand, but which was not vibrated when placed.

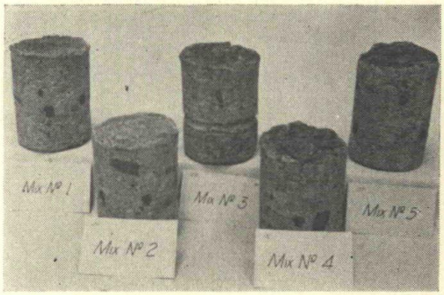


Figure 7. Representative cores from the different mixes

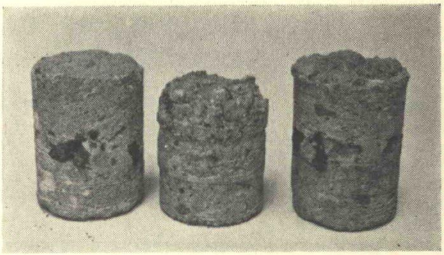


Figure 8. Cores showing honey-comb, mix number 5

Figure 8 shows the only cores having honey-comb. The end cores were honey-combed at the steel and the middle core had a slightly honey-combed bottom. These cores all came from mix No. 5, non-vibrated concrete having 37 percent sand.

Effect of Vibration Table 5 shows the results of tests on cores taken from vibrated and non-vibrated concrete using the same proportions Vibration resulted in a very slight increase in specific weight and density, a slight decrease in absorption, and an increase of 10 5 percent in strength

TABLE 5

EFFECT OF VIBRATION ON CONCRETE AS INDICATED BY RESULTS OF TESTS ON CORES

Mix Number	W/C by volume	Unit weight (lb per cu ft)	Density (per cent)	Absorption (per cent)	Compressive strength (lb per sq in)
1 Vibrated	0 67	156 4	91 5	1 18	6330
5 Non-vibrated	0 67	155 2	90 7	1 37	5730
Ratio $\frac{\text{Vibrated}}{\text{Non-Vibrated}}$	1 00	1 008	1 008	0 86	1 105

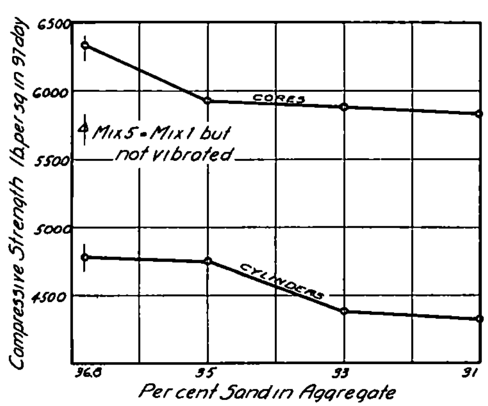


Figure 9 Relation between compressive strengths of cores and cylinders at same age

Strength of Concrete as Indicated by Test Cylinders and as Indicated by the Cores Figure 9 shows the average results of compressive strength tests on cores and cylinders from the various mixes Results on the cores indicate that the strength of the concrete in the pavement is from 24 to 35 percent greater for the vibrated concrete, and 20 percent greater for non-vibrated concrete than that indicated by the test cylinders made at the time the concrete was poured

Strength of Concrete at Different Points in the Slab. It was noted that the vibrating tube did not vibrate exactly the same throughout its length Cores were taken at different distances from the center line of the pavement to ascertain the effect of this difference in vibration on the concrete The results of strength tests on cores taken near the center line, at the middle of the 10-foot slab, and near the edge, are shown in Table 4 The figures indicate that there was no consistent difference in the strength of the concrete at these points

Comparison of Concrete on Vibrated and Non-Vibrated Sides of Joints As stated under "Vibrating and Finishing," it was impracticable to continue vibration right up to the joint as the finishing machine approached it Table 6 shows comparative test results obtained on cores taken from the vibrated and non-vibrated sides of the joint The results indicate there were no differences in the strengths, densities, or absorption of the concrete on the two sides of the joint Cores taken directly over the joint showed the concrete to be dense and well compacted adjacent to it

SUMMARY

In concluding, we wish to repeat that the consistency and workability of the

TABLE 6

SUMMARY OF TESTS ON CORES TAKEN ADJACENT TO JOINTS

Vibrated side of joint				Non-vibrated side of joint			
Core Number	Strength	Density	Absorption	Core Number	Strength	Density	Absorption
157	6,280	90 9	1 3	156	6,230	90 8	1 3
160	7,260	91 6	1 1	159	7,160	91 9	1 0
162	5,040	91 6	1 3	161	5,470	91 0	1 5
164	6,000	92 0	1 4	163	5,840	90 2	1 4
Average	6,150	91 5	1 3	Average	6,180	91 0	1 3

concrete on this project appeared to be controlled by the plasticity required in the operations of floating and finishing subsequent to vibration, rather than by the ability of the vibrator to compact concrete of a given consistency The results obtained under the conditions prevailing may be summarized as follows

1 Use of the vibrator in placing the concrete resulted in an increase in strength of approximately 10 per cent

2 Reductions in the percentage of sand in the aggregate were not effective in increasing strength, probably because other factors prevented reductions in the amount of water

3 Variations in vibration of the tube at different points did not seem to be reflected in the strength of the concrete

4 Vibration seemed to be effective on both sides of the joint even though the vibrator did not operate right up to the joint on the approach side

5 The concrete in the pavement was considerably stronger than was indicated by compressive test specimens cast at the time the concrete was poured, and cured outside in damp sand

It is intended to study the behavior of the slab under traffic and climatic conditions in order to determine if possible what effect vibration may have on the service of the pavement