VIBRATION IN PLACEMENT OF CONCRETE

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SYNOPSIS

This report is sponsored by the Joint Committee of the Highway Research Board and the American Road Builders' Association on Development of Highway Construction Equipment. This committee was formed with the thought that many problems exist regarding construction equipment which are directly of interest to both the engineer and manufacturer and that cooperation through such a committee would be of mutual benefit in developing the most satisfactory road machinery. A symposium on the subject of vibratory equipment was presented at the last meeting of the A R B.A. and great interest was exhibited by the engineers, contractors, and equipment manufacturers The acknowledged benefits by all concerned have made it difficult to understand why vibration has not been more generally accepted for the placing of concrete

To supplement available data on other types of equipment it was considered that study of internal vibrators from the practical standpoint—that is, on a construction project, would be of value and would tend to stimulate further interest in this type of equipment The study was carried on as a cooperative project between the Public Roads Administration and the Engineer Department of the District of Columbia on a federal aid concrete paving project It was not, therefore, carried out with the intent of determining comparative efficiencies of various machines or even the definite efficiency of any one machine, but rather as a study to determine the practical application of internal vibration. As would be expected conditions on such a field project could not be sufficiently well controlled to permit of more than general study A study to determine the comparative efficiency of various types of machines should be carried on under carefully controlled conditions as followed by the P R A in their several investigations, rather than on a general contract where research control is difficult to maintain

The project was started in June, but due to delay caused by the necessity of unexpected underground construction was not completed until October, so that weather conditions were quite varied during the respective construction periods A delay in the last test, caused by an extended rainy period, likewise materially affected the control as to uniformity of aggregate Storage conditions for aggregates are very limited in the District of Columbia and though it was planned to segregate the aggregate for this project in order to use the same material throughout, the delay required the use of different aggregates in the construction of the various sections These points are emphasized particularly so that no attempt will be made to construe that variations in the data indicate greater efficiency of one type of machine over another

EQUIPMENT DEVELOPMENTS

The value of vibration in imparting greater durability and uniformity to concrete has been demonstrated on many projects The Public Roads Administration has studied the application and progress of the use of vibratory methods in highway construction for approximately ten years. The economy and quality properties of concrete as effected by surface vibrators of the bull nose screed and pan types, have been reported.[1]

[1] *Public Roads*, Oct. 1933 and April 1937.

Several types of vibrators are being utilized throughout the country with at least six major companies manufacturing equipment differing in many physical respects, although designed to effect the same general improvement in quality of concrete attendant upon efficient placing and compaction of lower slump mixes.

The importance of speed in present day construction of highways has brought about the development of equipment of greater capacity, for example, larger concrete mixers (34E), and necessitated con-

sideration of changes in handling the placement of concrete in order to utilize economically the increased output. Too, the development of concrete spreaders, which were so successfully used on the Pennsylvania Turnpike has made the use of vibrators, which require dry and harsh concrete mixes which are difficult mixes to handle, much more practical.

It seems that the use of vibration in the placing of concrete may play an important part in increasing the rate at which concrete can be properly placed, especially when used in connection with concrete spreaders. This seems probable from the experience reported on this experimental project Although the contractor's organization was not experienced, or in anyway familiar with the use of vibrators, and delays were occasioned by the experimental program, still a construction schedule was maintained which exceeded any previously attained by this contractor under ordinary methods of placing and finishing Admittedly the use of a concrete spreader would have greatly facilitated distribution of the harsh concrete used on this project and its use would have resulted in the attainment of still greater capacity.

OUTLINE OF PROJECT

The experimental vibratory sections were part of a regular Federal Aid project, Minnesota Avenue (a 40-ft. roadway extending for approximately 2 miles). A portion of the 20-ft. center slab, approximately 2,400 ft. long, was used for the vibration experiment.

Equipment· Vibratory equipment may be divided into two general classes, viz, the internal and surface types. Two different machines, each of the internal vibratory tube design, with the vibratory element attached to, and extended in front of, a standard finishing machine were used in this experiment. The special vibrating equipment required for this work was manufactured by the Jackson Vibrators, Inc, Ludington, Michigan, and the Mall Tool Company, Chicago, Illinois. Representatives of both companies offered the fullest cooperation.

Jackson (Machine "A") The first type of vibrator studied consisted of internal vibratory tubes constructed in three sections, each of which was powered by an electric motor. A motor generator unit mounted on the finishing machine was the source of current for these motors Metal blades or "shoes" were attached to the bottoms of the tube sections, at intervals of 9 in Machine "A" was operated at a frequency of 5,200 to 5,600 v p m.

Mall (Machine "B") The second type consisted of an internal vibratory tube constructed in two sections, each of which was powered by a gasoline motor, mounted on the finishing machine. Power was transmitted from the two motors to the vibratory elements by flexible shafts. The speed of the motors was controlled by means of a single gas control lever Machine "B" was operated at a frequency of 5,500 to 5,700 v p m

A vibrating reed tachometer, furnished by the James G Biddle Company, was used to check the frequency of vibration

Test Sections In order to permit examination of the slabs and afford test specimens of concrete subjected to the action of the vibrators, approximately 36 special test sections were constructed. Each section afforded five test specimens, 24 in. wide by 6 ft. long, so that 180 specimens were available for study

CONSTRUCTION

Time of Construction: As previously stated, the first experimental section was constructed during the month of June and the second during the month of October of the same year

Materials. The aggregates were Potomac River sand and gravel conforming to the requirements of Federal Specification SS-A-281a. The cement was "Capitol," a standard brand of portland cement conforming to the requirements of Federal Specifications SS-C-191a. The coarse aggregate, 2-in. maximum size, was separated on the 1-in. sieve and recombined at the proportioning plant in the ratio of 60

per cent of the coarser to 40 per cent of the finer size Typical gradations of the aggregates are shown in Table 1 The sand was stored for 24 to 48 hr. in a special bin in order that the moisture content would be fairly constant.

The aggregates were delivered to the project from the proportioning plant in batch trucks, and the moisture content of the aggregates was indicated on the materials inspection ticket with each load. The amount of water added at the concrete mixer was adjusted in accordance with the moisture in the aggregates. The mixing time was 1½ min. for each batch and the mixing operation was carried out in a 27-E paver.

Proportioning · The proportioning of the materials together with the physical characteristics of the mix for each portion of the experiment are shown in Table 2. These data should be studied carefully in view of the fact that the differences in the standard mixes noted for the individual sections, and the variations in aggregates and climatic conditions at the time of constructing the respective sections, are reflected in the physical tests. It should be pointed out in this connection that the criterion in each case was to secure a standard mix which would produce concrete of a suitable consistency considering the method of placement being utilized.

TABLE 1

AVERAGE GRADINGS OF FINE AGGREGATE

Section	Per cent passing					
	No 4	No 8	No 16	No 30	No 50	No 100
"A"						
Standard (non-vibrated)	97 0	81 7	66 3	43 0	12 2	2 1
Constant C F. (vibrated)	96 7	78 3	62 8	39 2	10 7	2 8
Constant W/C less cement (vibrated)	97 5	84 3	70 6	47 3	15 2	3 3
"B"						
Standard (non-vibrated)	95 4	79 0	63 2	40 0	11 0	1 4
Constant C F. (vibrated)	96 3	81 0	65 0	42 1	13 8	2 0
Constant W/C less cement (vibrated)	96 6	81 2	64 6	41 2	14 4	2 0

TABLE 2

MIX DESIGN DATA

Section	Proportion by weight	Slump	W/C by vol	$\frac{b}{b_o}$	M/V	W_c	Sand to total agg	Cement bags per cu yd
"A"		in					%	
Standard (non-vibrated)	94 187 310	2¼	0 66	0 68	2 45	156	37 6	6 45
Constant C F. (vibrated)	94 163 350	1¼	0 65	0 75	2 03	151	31 8	6 3
Constant W/C less cement (vibrated)	94 182 388	1	0 66	0 76	1 93	143	32 0	5 8
"B"								
Standard (non-vibrated)	94 184 312	1¾	0 76	0 67	2 53	177	37 2	6 3
Constant C. F. (vibrated)	94.165 350	1	0 61	0 75	2 02	144	32 1	6 3
Constant W/C less cement (vibrated)	94 186 396	1	0 73	0 76	1 97	153	32 0	5 6

Slab Design: The portion of the pavement slab in which the test sections were constructed had a uniform thickness of 8 in. Expansion joints $\frac{1}{2}$ in. wide were spaced at intervals of 30 ft. The 20-ft. slab was constructed with a center longitudinal steel contraction joint with $\frac{1}{2}$-in. deformed steel tie bars spaced at $2\frac{1}{2}$-ft. intervals. Except in the case of the special test sections, steel mesh reinforcing weighing 50 lb. per 100 sq. ft. was installed during placing of concrete at depths from 2 to 3 in. below the finishing surface.

Operations of the Vibrators: Figures 1 and 2 illustrate the design and mounting arrangement as well as the operation of the two vibrators under load.

Figure 1. Machine "A"

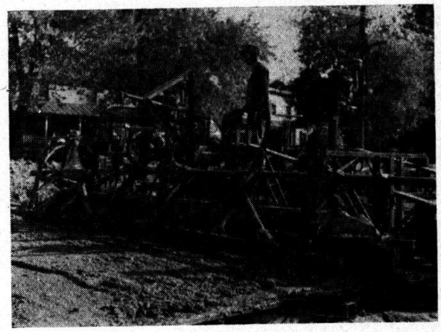

Figure 2. Machine "B"

Machine "A" was operated at a frequency of 5,200 to 5,600 v.p.m. Machine "B" was operated at a frequency of 5,500 to 5,700 v.p.m. A vibrating reed tachometer, furnished by the James G. Biddle Company, was used to check the frequency of vibration.

It will be of interest to note that, compared to the standard paving mix used without vibration, the experimental mixes which were used with the vibrators were quite harsh and that the finishing machine could not satisfactorily screed this concrete when the vibrators were not operating. However, with the vibrators operating, no difficulty was experienced in screeding or in obtaining a satisfactory finish. In this connection, attention is directed to the fact that the standard mix was quite plastic and well sanded, the ratio of the volume of mortar to the voids in the coarse aggregate being approximately 2.5. For the vibrated mixtures, the mortar voids ratio varied from 1.93 to 2.03, or an average of about 2.0. (See Table 2.)

It was the original intention to include in this experiment mixes containing crushed stone as coarse aggregate. However, satisfactory arrangements for this detail could not be made. As a result it was not possible to investigate the performance of the internal vibrators with very harsh mixes such as result from the use of angular aggregate and low cement factors.

A further point of interest in connection with the use of vibrators was that with the exception of the first test run (during the period the contractor's crew was becoming acquainted with the operation of the equipment) normal daily progress was exceeded.

Extent of Vibration: A study of unique interest in connection with this project, and on which a representative of the National Bureau of Standards will report in detail,[2] pertained to the extent and amplitude of vibratory wave produced by the various machines; the direct purpose being to ascertain the rate of

[2] See page 279, this volume.

dampening of the wave. Briefly, the apparatus consisted of a portable vibrograph constructed for measuring vibration in the fresh concrete during the process of placing by vibration. An electro-magnetic pickup unit, submerged with definite orientation within the concrete picks up the vibrations and conveys an electric response through either of three circuits and then through an amplifier to a cathode-ray oscillograph. Particle displacements were measured in the horizontal plane by means of the pickup unit inclosed in a 2-in cube. In order to obtain graphic representation the pickup element was placed in the plastic concrete at various locations with respect to the vibrating tubes.

Test Sections: Special test sections, each consisting of five slabs approximately 6 ft. long, 2 ft. wide, and 7 in. thick, were constructed within the four vibrated pavement sections and also within the two standard pavement sections without vibration. Six test sections were constructed for each mixture, making a total of 36 sections, or 180 test slabs. Concrete in the test sections was proportioned, mixed, placed, vibrated, and finished in exactly the same manner as the concrete in the adjacent pavement, except that no reinforcement was used. The test sections were divided into the five test slabs by punching four rows of $\frac{3}{4}$-in. holes at 4-in. centers in the concrete, approximately one hour after placing. When the test sections had been in place 14 days they were separated into test slabs by means of "plugs and feathers" driven in the $\frac{3}{4}$-in. holes. The slabs were then removed from the pavement and taken to the testing location The specimens were cured with wet burlap before and after removal from the pavement until they were tested for modulus of rupture at the age of 28 days.

TABLE 3

PHYSICAL TEST DATA

Section	28 day modulus of rupture		Compressive strength		Specific gravity	Density lb per cu ft	Absorption	
	Test slabs lb per sq in	Control beams lb per sq in	Cores lb per sq in	Beam ends lb per sq in			24 hr cold %	5 hr boiling %
"A"			4 mo	28 days				
Standard (non-vibrated)	685	573	5,160	5,010	2 30	143 5	4 7	4 9
Constant C F (vibrated)	677	607	5,477	5,854	2 36	147 2	3 1	4 2
Constant W/C less cement (vibrated)	687	600	5,010	5,550	2 36	147 2	3 5	4 7
"B"			7 mo	28 days				
Standard (non-vibrated)	610	562	4,710	4,390	2 30	143 5	4 2	4 3
Constant C F. (vibrated)	697	596	5,640	4,640	2 39	149 1	2 5	3 5
Constant W/C less cement (vibrated) ..	698	548	5,070	4,550	2 36	147 2	3 1	3 8

Supplementing information on the flexural strength of the specimens removed from the experimental sections, cores were drilled from each test slab and tested for absorption, specific gravity, and compressive strength. Control beams were also made and tested (see Table 3).

TEST RESULTS

Test data relating to this project are summarized in Tables 3 and 4 which cover flexural strength of the control beams and special test sections removed from the pavement slab; compressive strength, ab-

sorption, and density of cores drilled from these sections; as well as the percentage of honeycombed areas, noted from an examination of the bottom of the slabs. For convenience, some of the basic data offered in Table 2 have been repeated to facilitate comparison.

Strength and Density: The special transverse test sections weighing approximately 1,000 lb. each were handled by means of a truck hoist. The testing machine (3rd point loading on a span of 54 in.) illustrated in Figure 3 was furnished by the Public Roads Administration.

In view of the different periods of construction the results using the two types of vibrators are to be compared with the corresponding standard sections noted. In reference to Machine "A" it may be observed from Table 2 that relatively little reduction in the water-cement factor was effected in the vibrated mixes, the ratio being maintained the same as for the standard mix. This can, without doubt, be attributed to the comparatively lower water-cement ratio utilized in this particular standard to produce concrete of suitable consistency. Comparison of the fine aggregate gradings together with a consideration of the different conditions prevailing during the respective construction periods may in part explain this behavior. Accordingly, comparisons have been limited to the relation between the standard and the vibrated section having the same water-cement ratio but with approximately 10 per cent less cement. In the case of the reduced (10 per cent less) cement content, maintaining the same water-cement ratio, the flexure and compressive strengths developed were equal to that of the standard. Increased density in the case of the vibrated mixes are to be noted from Table 3.

Data offered in Table 3 for Machine "B" differ somewhat from those discussed above, in that the standard for this section had a somewhat higher water-cement ratio. In comparing the standard and the vibrated sections having approximately the same water-cement ratio, but a reduced cement content, it is to be noted that the average flexural strength of the vibrated section was somewhat greater than that of the standard, as may likewise be observed from a comparison of the average compressive strength of cores.

TABLE 4

Section	Uniformity of flexural strength test slabs — average percentage variation from mean		Honeycombed areas average percentages	
	A	B	A	B
	%	%	%	%
Standard (non-vibrated)	4.2	5.2	2.0	0.3
Constant C. F. (vibrated)	3.7	4.7	1.1	2.2
Constant W/C less cement (vibrated)	3.3	4.8	1.9	0.9

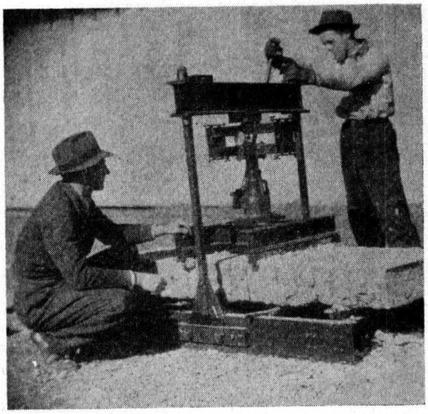

Figure 3. Beam Testing Machine

As with Machine "A," there was a noticeable increase in density of the resulting concrete when placed with the assistance of the vibrator.

In addition to the greater density noted for the vibrated mixes, it was also evident from a comparison of the test results on the individual flexural test specimens that uniformity was also improved, as shown in Table 4, that is to say, there was less variation from the mean strength in the case of the vibrated as compared to the standard mixes.

Absorption Table 3 shows the percentage absorption of core specimens drilled from the special sections and includes both 24-hour cold water absorption and 5-hour boiling water absorption conducted on approximately one-quarter the number of specimens represented by the former series. It is to be noted that in both series of tests the percentage absorption was lower in the case of the vibrated than in the case of the standard mixes.

Honeycombing: Table 4 shows the percentage of honeycomb as observed on the bottoms of the special test sections which were removed from the roadway. In rating these sections a screen grid was used and the same procedure followed as in the case of the studies reported by the Public Roads Administration in *Public Roads,* April 1937. Although differing to some extent, and in some respects showing the standard to be equal to or better than the vibrated sections, it should be pointed out that all sections exhibited extremely low percentages of honeycombed areas in comparison to the results observed by the Public Roads Administration in the studies referred to. The maximum extent of honeycombing on this project was $\frac{3}{4}$ in. deep with an average of approximately $\frac{1}{2}$ in In all instances the areas affected were confined to the slab ends where, due to the bulkhead construction to facilitate removal of the special sections, it was impracticable to secure compaction to the extent observed in the remaining sections of the slab These observations do, however, tie in with the results observed in the study to ascertain the rate of dampening of the vibration wave, and corroborate the finding that the magnitude of the wave is so slight at relatively small distances from the vibrating element as to be ineffective

Extent of Vibration A detailed report on this subject together with diagrams is to be offered as a subsequent paper by Mr. Hornibrook of the National Bureau of Standards In general it may be observed that for Machine "A" the region of rapid transition (which coincides with the limit of visible effect) extended approximately 6 in beyond the shoes, the displacement amplitude rapidly decreased from 0 003 in. to 0 00003 in. In the case of Machine "B" similar results were noted. For example, the displacement amplitude was 0.0025 in at a distance of 9 in. from the vibrating tube and but 0 0003 in. at a distance of 24 in. from the vibratory tube. These values are indicative of the zone within which vibration may be considered to be effective.

SUMMARY

Analysis of these data indicates the benefits of internal vibration in the placement of concrete, particularly as to lowered absorption and increased density in the case of the vibrated mixes.