EXPERIENCE WITH CONCRETE PAVEMENT VIBRATORS IN KANSAS

By R D Finney

Engineer of Materials, Kansas Highway Department

SYNOPSIS

Three types of vibrators were used on the different projects studied in this report A front screed vibrator was used on one project, a vibrating pan on another, and the vibrating tube on five projects In addition to study of the projects upon which vibration was used, nearby projects using the same aggregates and cements were studied in an effort to determine the effects produced by vibration

A fair degree of satisfaction has been obtained by using vibrators in this State Although gains in slab quality have not been as great as it is possible to obtain, only experience can bring about high efficiency The statement that the higher the frequency, with proper amplitude, the better the results, is found true in Kansas as in other places It is believed also that the more internally a vibrator may be made to work, the more favorable the result

Vibration as a means of handling and placing concrete has had a limited use in Kansas for several years In the Highway Research Board Proceedings for 1935, Mr R B Wills reported upon some of the earlier experiences The 1937 construction season has seen a very definite swing towards vibration in Kansas concrete paving practice The specifications for concrete pavement construction in Kansas are based upon a maximum water content of 5 75 gallons per bag of cement, and a minimum cement content of 1 25 barrels per cubic yard of concrete This specification applies where the aggregate consists of a suitable combination of fine and coarse aggregate With such mixtures the use of a vibrator is optional with the contractor In constructing pavements in which the quantity of coarse aggregate is insufficient, the use of a vibrator is not permitted

This year's increase in the use of vibration has come from realization by the contractors that it is not possible to reduce the cement factor to a figure approaching 1 25 bbl per cu yd without vibration, and the added fact that the recently developed tube type of vibrator is low in cost and readily adapted to the existing handling and placing machinery

Three types of vibrators were used on the projects studied in this report A front screed vibrator was used on one project, a vibrating pan on one, and the vibrating tube on five Nearby projects using the same aggregates and cements but without vibration were also studied in an effort to determine the effects of vibration

Design of Concrete Mixtures. No set method for the design of the concrete mixture is used on Kansas projects Essentially the trial mix method is used, and in some cases preliminary figures based upon the mortar voids theory and Abrams Fineness Modulus theory are developed, depending upon the experience of the engineer in charge Complete data as to proportions used, and the weight of the resulting concrete were always available, and from this the constants shown in Table II were computed

It is believed these figures show that very satisfactory results were obtained in the design of the mixes used

COMPARISON OF JOB RESULTS BETWEEN REGULAR AND VIBRATORY PLACEMENT

Group 1 In Group 1, job 1 was laid with an Ord finishing machine by the same contractor as job 1A, in which he used a tubular vibrator attached to the same finishing machine The aggregates, crushed limestone for coarse aggregate and river gravel for fine aggregate, were from identical sources and had almost identical gradings. Job 1 consisted of 7.12 miles of single slab and job 1A of 11.0 miles of single slab. The vibrator was able satisfactorily to compact a mix using a slump of $1\frac{3}{8}$ in., where the regular finishing machine needed concrete with a $2\frac{1}{4}$ in. slump. About $2\frac{1}{2}$ per cent less sand, by volume, was in the mix compacted by the vibrator with about the same ease of finishing. The differences in results secured by the vibrating and non-vibrating processes are shown by the following figures:

Specific gravity of cores, vibrated 2.33, tamped 2.29.

Weight of green concrete, lb. per cu. ft., vibrated 151.5, tamped 149.5.

Cement factor, bbl. per cu. yd., vibrated 1.26, tamped 1.33.

Compressive strength, lb. per sq. in., vibrated 5426, tamped 5022.

On this job the tube was attached to an old type Ord Finishing Machine, which was lighter than the present day model. At the very beginning it was evident that the finishing machine would not have enough traction to move the tube forward through the mass of concrete. Weighting the machine with railroad rails did not prevent slippage of the wheels and caused the forms to settle. The contractor then devised a four wheel drive for the machine with only a little added weight which enabled the machine to go forward more rapidly, though slippage was not entirely eliminated. Only one pass was made with the vibrating tube. The second time over only the screeds were used.

A mix was designed for this vibrator job for a total Fineness Modulus of 6.15, an increase of 0.20 over the Fineness Modulus of a calculated normal mix using those aggregates. By normal mix is meant one calculated for a job to be finished with ordinary methods. It is interesting to note that in designing a concrete mix for use with the vibrator an increase in b/bo of 0.06 over the ratio of a normal mix was necessary to give a satisfactory sand content.

Group 2: In Group 2 on jobs 2, 2A and 2B a regular finishing machine, a vibrator pan and a tubular vibrator were used respectively. Cement factors were about the same, 1.33. Very little difference was given by the vibrator.

The aggregate on job 2B contained 28 per cent of sand by volume, which is obviously low. The coarse aggregate was obtained by crushing a very highly cemented sandstone. The fine portion of this aggregate (minus 4 mesh) consisted mainly of fine sand, therefore, the indicated sand percentage is rather misleading. The fine aggregate was river sand. That in turn explains why the ratio of b/bo of 0.85 could be used. On most of these jobs the ratio b/bo was raised by 0.06 above that necessary to obtain a satisfactory job using a regular finishing machine. In this case it was raised 0.10, which, if the fine and coarse aggregate were combined and separated again, would produce a ratio of b/bo of 0.81.

Figure 1. Skip Discharging Ready for Vibration

On this job, as in Group 1, the use of the tubular vibrator presented a problem since it was placed on a very poor finishing machine. This machine was not quite as light as the one used on job 1A, but it had seen too many years service to have sufficient traction to move the tube through the concrete in a satisfactory manner. Possibly another factor entering into this was the fact that the fines in the coarse aggregate were somewhat of a quicksand variety, which did not give a very workable mix even though the percentage was low. Test data on cores are not yet available.

Group 3: Job 3 was placed with a regular finishing machine with tamper. Jobs 3A and 3B were placed with the front screed vibrator. The aggregates were of similar grading in all three cases. The coarse aggregate was crushed limestone and river gravel was the fine aggregate. This vibrator allowed about the same increase in Fineness Modulus and ratio

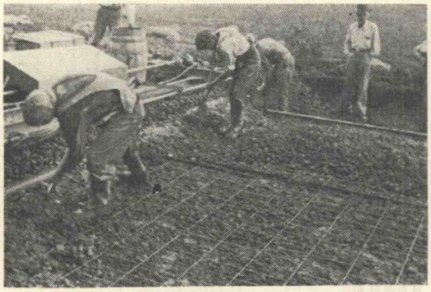

Figure 2. Vibrator in Action

of b/bo over the mix used in the regular finishing machine as did the tubular vibrator. The Fineness Modulus was 6.20 and the b/bo ratio was 0.87. The tabulated data presents most of the information of interest on this job. The cores taken from the pavement recently show it to be in excellent condition as respects honey-comb, but as yet the specific gravity results are not available.

Group 4: In Group 4, job 4 was placed and finished with a Lakewood finishing machine, and job 4A with a tubular vibrator attached to an ordinary finishing machine. It is interesting to note the effect of using a coarse aggregate consisting of rounded hill gravel. Ordinarily coarse aggregate in Kansas consists of crushed limestone with a specific gravity of about 2.62. The specific gravity of this particular hill gravel coarse aggregate was 2.42. As shown in Table I it was not deemed good practice to reduce the sand content below that used in concrete for placement and finish by an ordinary finishing machine. However, the slump was reduced from 2 in. using the ordinary finishing machine to $\frac{7}{8}$ in. using the vibrator. That reduction in slump did not do much toward reducing the cement factor, due to the fact that less coarse aggregate was used in the vibrated mix than in the mix with the regular finishing machine. Compressive strengths were increased from 5315 to 5840 lb. per sq. in. by the vibrator. Average core specific gravities of 2.23 are considered good for these aggregates.

Group 5: A comparison of these two jobs, 5 using the regular finishing machine and 5A using the tubular vibrator, merely serves to support the information shown above, mainly that an increase of 0.2 in the Fineness Modulus and of 0.06 in the ratio of b/bo seems to be about right in converting from a normal to a vibrated mix.

As on other jobs the finishing machine did not have enough traction to push the tube vibrator through the mass without slippage. A reduction in cement factor from 1.30 to 1.265 was possible through the use of the vibrator. In terms of money saved in cement costs, this amounts to about $250 per mile, with other possible economies in finishing operations, due to the fact that the finished slab after the vibrator has been across it does not have "hard" and "soft" spots, thus producing a better riding surface with less work. It is not unlikely that the elimination of these frequent "hard" and "soft" spots in the green concrete will subsequently provide a better riding surface.

Group 6: Both of these jobs, 6 and 6A, were placed with the tubular vibrator. Due to the fact that there are no jobs built in the vicinity of these chat aggre-

TABLE I
CHARACTERISTICS OF AGGREGATES

Group		Length	Sp gr of		Dry and rodded wt		Ab vol of		Voids		Sieve analysis															
											Fine aggregate percentage retained								Coarse aggregate percentage retained							
No	Sec		Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	⅜	4	8	16	30	50	100	G F *	2″	1½″	1″	¾″	⅜″	4	8	16
1	1	9 566	2 62	2 62	111	102	6789	6239	3211	3761	0	1	10	30	58	93	100	2 92	0		45		88	97		
	1A	5 50	2 62	2 62	111	100	6789	6117	3211	3883	0	2	10	32	56	93	100	2 93		20	52	66	87	99		
2	2	6 262	2 63	2 62	107	100	652	612	348	388	0	0	0	12	58	94	100	2 64	0		43		88	96		
	2A	2 456	2 64	2 62	109	100	6616	6117	3384	3883			1	28	68	94	100	2 91	1		52		83	97		
	2B	2 279	2 61	2 63	113	110	6938	6093	3062	3907	0	2	13	32	55	82	99	2 84	0	25	52	66	87	96	98	98
3	3	607	2 63	2 64	111	95	68	575			0	1	7	27	60	94	100	2 89		0		55	83	97		
	3A	3 423	2 63	2 64	111	95	67	58			0	1	7	23	52	95	99	2 77	0		52		89	97		
	3B	3 287	2 62	2 60	109	93	6667	5732	3333	4268	0	1	8	21	53	93	100	2 76	4	27	50	64	85	98		
4	4	6 725	2 62	2 42	112	93	685	614	315	386	0	1	13	30	56	87	98	2 85		5		56	85	97		
	4A	10 59	2 62	2 42	112	93	6851	6160	3149	3840	0	1	14	38	66	92	99	3 10		4		53	84	97		
5	5	1 987	2 62	2 63	110	94 5	6728	5759	3272	4241	0	0	7	27	59	93	99	2 88	0		47		85	97		
	5A	2 240	2 63	2 64	110	95	6703	5769	3297	4231	0	2	8	29	59	93	99	2 88	0		49		86	98		
6	6	4 344	2 62	2 61	103	93	63	57	37	43	0	0	2	23	59	81	91	2 56					13	69	92	97
	6A	3 869	2 60	2 50	95	85	586	545	414	455	0	0	2	22	54	78	89	2 45					5	67	96	99

* Graduation Factor or Fineness Modulus

gates since Kansas has been on the $5\frac{3}{4}$ gallons of water per sack of cement, no comparisons of a normal chat mix placed with the regular finishing machine with tamper and those placed with the vibrator are available. However, considerable interest was shown in these particular jobs because from a theoretical combination of coarse and fine chat aggregates, the cement factor would approximate 1.80 bbl. per cu. yd. The use of the vibrator, however, permitted slumps of between $\frac{1}{4}$ and $\frac{3}{8}$ in., which in turn lowered the cement factor to 1.58, indicating a considerable saving in the cost of cement. Chats consist of very hard cherty stone having exceedingly sharp fractures, and the grading of this by-product of zinc mining is very poor (Table I). Under normal conditions it takes an excessive amount of mortar paste to provide lubrication enough for such a combination of aggregates to be in a workable condition without the use of some external means of compaction. Apparently the tubular vibrator gives the necessary aid to allow the sharp particles to slip readily by one another into place.

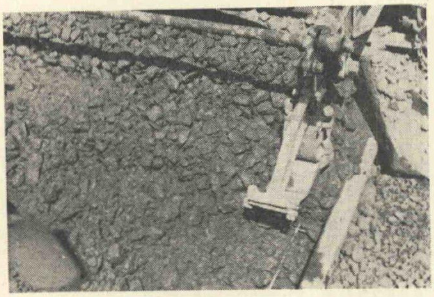

Figure 3. Closeup of Action

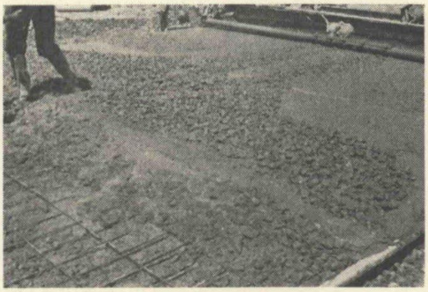

Figure 4. Vibrator Withdrawn

Another point of interest is the exceedingly low apparent specific gravity of the cores taken from these pavements. They are quite indicative of the porous structure of the slab, but it will be noted that the compressive strengths were quite high.

A design mix for chat aggregates is difficult to work out due to their peculiar characteristics and to the fact that various sources do not produce similarly graded aggregates of similar specific gravity. A comparison of these two projects, each of which obtained their aggregate from different sources, will demonstrate the variety of gradings and specific gravities that are obtained from these chat fields.

GENERAL COMPARISONS

(1)—A study of the summarized results indicates that at least satisfactory quality of pavement concrete is produced by either method of compaction and finishing. Several projects have shown results obtained by vibration to be superior. Generally, the apparent specific gravity of cores taken from the pavement have been slightly higher for vibrated concrete. The average 90 day compressive strengths have also been greater for vibrated pavements. This may or may not be attributed to vibration.

From the contractors standpoint there may be a slight advantage in finishing costs and cement costs.

(2)—One important factor which should be brought out in this discussion is the rigid requirement that the concrete as it is placed between the forms must be in its final position before any tube vibrator or other finishing machine passes over it On practically all vibrated paving jobs the first point of observation was the fact that the puddlers, or the laborers in front of the finishing machine, had the impression that the purpose of passing the vibrator over the concrete was to move the mass deposited by the mixer into the voids that had been left in placing the concrete between the forms This without question is one of the practices that must be overcome before placing concrete by vibration will be highly successful The purpose of the vibrator is not to level off the mass of concrete that is deposited on the grade between the forms, but to pack the aggregates that have been placed in their final position by the mixer and the puddlers combined, into the closest possible space

Generally speaking, and particularly with a vibrated concrete mix, the edges of any concrete mass consist mainly of coarse aggregate Obviously, when the percentage of excess mortar is reduced for proper vibration, there will not be sufficient mortar carried forward by the vibrating unit to fill in the "nests" of coarse aggregate occurring at the base of each adjacent pile For this reason it is essential that the concrete mass be in a condition that only compaction is required for final placement

The foregoing discussion is simply a part of the educational program that must be instituted if we are to receive the utmost in benefits from vibration of concrete As soon as the engineer on the job begins to understand the real purpose of vibration and how the vibrator can be made to act most efficiently, then will we be getting the true benefits that accompany slab vibration

(3)—*Concrete Mix Design* Very satisfactory results have been obtained on certain jobs by designing normal concrete mixes by using the Abrams Fineness Modulus theory Briefly, that is, for any maximum size aggregate, there is quite definitely a given Fineness Modulus that should be used which will give a balanced proportion of rock and sand Thus, regardless of the grading of any ordinary individual aggregate, fine or coarse, a workable mix may still be produced, which is neither harsh nor fat by using the total Fineness Modulus indicated for that maximum size. In adapting this method to vibrated mixes it is simply a matter of raising the Fineness Modulus over that which would be used for a normal mix Accumulated information indicates the increment should be about 0 2 While this method of design is not perfect, if used correctly, it is workable with only minor adjustments

Regarding the use of the Talbot Richards formula, particularly the b/bo or workability factor, more study must be made However, the values as shown in Table II indicate that for each workable mix there are probably variable b/bo values depending upon the individual aggregates, but as soon as the proper b/bo value is determined for a normal mix, increasing that value produces a ratio of rock to sand that is quite close to that desired for the vibration process

(4)—*Types of Vibrators* Mixes and results obtained from three types of vibrators have been given Comments as to their relative efficiency cannot be made until more information concerning their use and results is secured However, regardless of the type of vibrator used, the finishing machine to which it is attached must be in excellent structural condition, have reserve power and have good traction This statement is probably more true for the tubular vibrator than for other types because of the fact that a tubular vibrator may be extended into the mass of the concrete to a depth at which it takes great force to move it forward through the mass Regardless of the efficiency of the vibrator itself,

TABLE II

CONCRETE

Group No	Group Sec	Mix	Slump in	Wt per cu ft green concrete	Cement factors Yield	Cement factors Actual	Cement factors Theor	Ave 90 days compressive	Specific gravity of cores	Type of slab compaction	Sand by vol %	Total fineness modulus	a/c	b/bo	Theor sp ave M/V	Theor sp ave Gr green concrete	Theor sp ave Sp gr cores
1																	
	1	1 2 06 3 78	2¼	149 5	1 33	1 34	1 34	5022	2 29	Regular finishing machine	35 3	5 95	2 62	75	1 87	2 44	2 29
	1A	1 2 11 4 30	1⅜	151 5	1 262	1 31	1 27	5426	2 34	Jackson Tube Vib (Gas-Elec) on regular finishing machine	33 0	6 14	2 91	81	1 61	2 45	2 33
2																	
	2	1 2 16 3 84	2	150 0	1 34	1 35	1 34	5974		Regular finishing machine	36 0	5 88	2 87	76	1 79	2 42	
	2A	1 2 14 4 16	1½	151 5	1 325	1 355	1 29	5932	2 35	Vibrating pan between screeds of regular finishing machine	34 0	6 04	2 88	81	1 65	2 48	2 35
	2B	1 1 67 4 29	1¼	151 5	1 30	1 343	1 30			Jackson Tube Vib (Gas-Elec) preceding regular finishing machine	28 0	6 04	2 37	85	1 44	2 44	
3																	
	3	1 2 02 3 88	2	150 5	1 38	1 45	1 37	6064		Regular finishing machine	34 0	5 97	2 79	80	1 59	2 44	
	3A	{1 2 28 4 36	1¼	150 0	1 252	1 29	1 27 }	6148		Front screed electric vibrator	{34 0	6 04	3 12	82	1 53}	2 41	
		1 2 39 4 24}	1	150 0	1 253	1 33	1 266}				36 0}	5 94	3 27	80	1 64}		
	3B	1 2 06 4 60	1½	148 0	1 26	1 28	1 264			Front screed electric vibrator	31 0	6 20	2 79	87	1 35	2 43	
4																	
	4	1 2 26 4 21	2	144 5	1 252	1 282	1 25	5315		Regular finishing machine	35 0	5 83	3 16	78	1 73	2 34	
	4A	1 2 19 4 06	⅞	144 0	1 27	1 29	1 28	5840		Jackson Tube vibrator preceding regular finishing machine	35 0	5 88	3 06	77	1 73	2 33	2 23
5																	
	5	1 2 28 4 05	2¼	150 5	1 30	1 345	1 31	5755	2 33	Regular finishing machine	36 0	5 94	3 12	79	1 58	2 44	2 34
	5A	1 2 16 4 54	1¼	152 0	1 265	1 31	1 26		2 30	Jackson tube vib (Gas-Elec) preceding regular finishing machine	32 0	6 17	2 96	85	1 42	2 44	2 31
6																	
	6	1 2 10 2 80	⅜	142 0	1 56	1 58		6255	2 17	Jackson tube vib (Gas-Elec) preceding regular finishing machine	40 0		2 69	67	2 14	2 38	2 17
	6A	1 2 10 2 80	¼	137 0	1 59	1 65	1 68	5053	2 07	Jackson tube vib (Gas-Elec) preceding regular finishing machine	40 0		2 51	70	1 94	2 33	2 07

* Average of 30 or more beams

the benefit derived from vibration is destroyed, or lessened considerably, if the finishing machine is not in good condition

The subject of frequency of vibrators may be dismissed with the statement, which is in agreement with those who have used vibrators to any extent, that the higher the frequency, with proper amplitude, the better the results that will be obtained Sufficient data are not at hand to indicate proper values for frequency and amplitude

Results from using vibrators in Kansas have been fairly satisfactory While probably not as much has been gained in slab quality as may be possible through the use of vibration, it is certain that nothing has been lost through their use Only through experience will high efficiency be obtained from them

The Kansas Highway Department is insisting at the present time, however, that if a vibrator is to be used for pavement concrete, the finishing machine must be up to standard, and the engineer on the job must insist upon careful placement of the concrete The concrete must be in its final position between the forms prior to vibration The vibrator is to be used only as a means of settling the mass and not as a means of spreading

It is believed that of the several types of vibrators used on this work, the more internally a vibrator may be made to work, the better the results will be