CONSTRUCTION VIEW POINTS ON VIBRATED CONCRETE

By R B Wills

Engineer of Construction, State Highway Commission of Kansas

SYNOPSIS

Data for this paper were obtained from personal observation and study in the field and from reports submitted by various project engineers on construction work The study includes internal vibrators on structures and vibrators on six pavement projects, covering work with mixed aggregates and coarse aggregates as used in highway construction in Kansas

Generally, vibrators were entirely satisfactory, as the vibrated concrete had strength comparable with non-vibrated concrete having a greater cement content

This paper on vibrators from the construction engineer's point of view was prepared from personal observation and reports submitted by a number of project engineers of the Kansas Highway Commission, along with supporting tests made by the Highway laboratory

Vibrators for concrete pavement were used in Kansas early in the spring of 1935 and have been adopted quite extensively since Results have been very satisfactory with possibly one exception Finishing machine vibrators have been of two general classes: those operating as a screed as well as a vibrator at the front of the machine, and those operating as an individual vibrator unit, placed behind the screed

A definite water cement ratio is specified by the Kansas Highway Department on all classes of concrete, hence a device which would permit the addition of more aggregates to specified amounts of water and cement, and still give workability, should cause a material saving in lower concrete costs, or should give concrete of greater strength because of the possible reduction in the amount of water used

Crushed stone and fine aggregate mixes are generally used in eastern Kansas In the western part of the State, rock is exceedingly scarce and local mixed aggregate can be obtained from dry pits or stream beds for use in pavements and structures

The vibrator was of major importance in the construction of mixed aggregate concrete pavements Under the present specifications, with a maximum cement factor of 1 55 barrels per cubic yard, it was almost impossible to obtain mixed aggregate which would give a cement content below this amount The use of the vibrator allowed the use of less mixing water thereby materially reducing the cement content Where formerly it was necessary to add crushed stone to mixed aggregate to get below the maximum cement factor, it was now possible to obtain satisfactory cement contents with the vibrator

Specifications for slump, gradation of materials, and amount of water per sack of cement for concrete pavement are as follows:

Bbls cement per cu yd concrete
 Minimum, 1 25, maximum, 1 55
Gals water per sack of cement 5 75
 including water in aggregate

	Inches
Slump for crushed stone or gravel and fine sand	2 00–2 50
Slump for mixed aggregate	1 00–1 50

Slumps other than those shown above may be used, when in the opinion of the Engineer, conditions are such that satisfactory workability can not be obtained within limits specified

MIXED AGGREGATE

Mixed aggregate is defined as that material where fine sand makes up more than 50 per cent of total aggregate, with specification as follows

Passing 2 inch mesh sieve	100%
Passing 4 mesh sieve not less than	60%
Passing 30 mesh sieve not less than	15%
Gradation factor, not less than	3 75

Concrete made with aggregates specified above, will be referred to as mixed aggregate concrete

COARSE AGGREGATE

Passing 1½ inch mesh sieve	95–100%
Passing ¾ inch mesh sieve	35– 65%
Passing ⅜ inch mesh sieve	10– 30%
Passing 4 mesh sieve, not more than	5%
Passing 2 inch mesh sieve	95–100%
Passing 2 inch mesh sieve	35– 65%
Passing ⅜ inch mesh sieve	10– 30%
Passing 4 mesh sieve, not more than	5%

Fine aggregate was either sand or flint sand A combination of fine sand with correct amounts of either coarse aggregate listed above will be referred to as coarse aggregate concrete

CONCRETE STRUCTURES

Aggregates for structures were similar to those specified for concrete pavement and reference to them will be made under the same headings, that is, as mixed aggregate concrete and coarse aggregate concrete The amount of water and minimum and maximum cement content for class A structure concrete is listed below·

Type of Aggregate	Cement per Cu Yd Bbls Mins	Cement per Cu Yd Max	Gals water per Sack of Cement
Crushed stone or gravel and fine aggregate	1 25	1 65	6 25
Mixed aggregate	1 35	1 90	6 25

Approximate slumps used without vibrator

	Inches
Mixed aggregate	2 00–4 00
Coarse aggregate concrete	3 00–5 5

VIBRATORS FOR STRUCTURES

Generally, vibrators used for structures have been of two types One is electrically driven, with a gas engine of two or two and one-half horsepower generating electricity which operates a motor installed in the vibrator Tubing is used to carry the wiring and to raise and lower the vibrator in the forms The vibrator on this type of machine is rather large and for that reason is better adapted to work where the reinforcing bars are spaced far enough apart, or far enough from the forms, so as not to handicap its use This machine has a large advantage because its power supply can be stationary and the vibrator moved about over a considerable amount of work The frequency range is between 1800 to 3500 V P M , and it is found to operate very satisfactorily on 2800 V P M

Another type of internal vibrator used quite extensively has power furnished by a gasoline air cooled motor, to which is attached flexible tubing at the end of which is the vibrator The revolutions are about the same on both types

Experiments with the two types of vibrators were run on structures of mixed aggregate concrete in which slumps varied from 1 0 to 3.0 in The vibrators were operated at various frequencies and were permitted to agitate the concrete from five to thirty seconds The surfaces, in some cases, were sand streaked and, generally, the finish was no better than that obtained by hand puddling methods However, a substantial saving in cement was obtained because mixed aggregate concrete which would normally be poured with slumps from 2 0 to 4 0 in was vibrated and poured with slumps of 1 0 to 3 0 in

Vibrators used with coarse aggregate concretes have proven entirely satisfactory It was found that the same machine could be used for all classes of aggregate common in Kansas Also, that machines with large vibrators puddled coarse aggregate concrete in less time than machines equipped with small size vibrators On structures of bulk concrete, such as footings, collision walls and thick floors, the vibrator gave excellent results, causing free flow of concrete with slumps which could not be handled satisfactorily without mechanical means of agitation Care must be used in vibrating rock concrete mixes, to avoid the formation of mortar pockets

VIBRATORS FOR PAVEMENTS

Several different types of pavement vibrators have been used in the state with both coarse and mixed aggregate materials

On a mixed aggregate concrete pavement project recently completed, the finishing machine was equipped with a vibrating, oscillating front screed of bull nose design Three electric motors mounted on this screed set up approximately 4000 vibrations per minute The front of the 16-in contact surface of the screed was raised slightly giving a compressive action to the concrete as the machine proceeded An oscillating screed was also operated at the rear of the machine

It was found that mixes with $\frac{3}{8}$- to $\frac{1}{2}$-in slump gave the best results When wetter mixes were used the concrete slumped away at the crown Specifications provided for the use of $5\frac{3}{4}$ gal. of water per sack of cement with a maximum cement factor of 1 55 and a minimum cement factor of 1 25 Without the use of a vibrator in this particular case the cement content would have been at or slightly over 1 55 barrels per cubic yard, whereas with the vibrator it was reduced to 1 42 barrels per cubic yard This is an example of the use of local material, whereas it would have been impossible without a vibrator

Some special tests and experiments were tried in connection with this project A cardboard box, the thickness of the slab, was placed on the subgrade, filled with concrete and left in place during the vibrating and finishing of the slab The box was then very carefully removed and taken to the research laboratory At the time of removing this box from the slab a flow of mortar through the slab was noticed which indicated that vibration affected the concrete for the full depth of the slab At the laboratory this block of concrete was cut through the center and the sections thus exposed seemed to show the concrete to be a little denser for about two inches down from the top However, the remaining depth of the slab looked uniform Specific gravity of 2 34 was determined on this specimen The specific gravity of a test beam made on this project was 2 35 It was computed that the theoretical specific gravity should be about 2 40 Cores taken from the slab in five different places showed the concrete to be uniform from top to bottom with no honeycomb at the bottom The test beams were made by placing the filled beam molds on the vibrator and allowing them to vibrate for five seconds The resulting beams were uniform and gave satisfactory four day strengths

TABLE I

DATA ON TRANSVERSE STRENGTH OF TEST BEAMS

Mixed Aggregate Vibrating Oscillating Front Screed

Station No	Beam No	Transverse Strength				Yield in Bbls per Cu Yd
		Age in Days	Lb per Sq In	Age in Days	Lb per Sq In	
76+75	1A	4	638	10	735	1 41
92+40	3A	4	625	10	632	1 44
104+40	4A	4	581	10	629	1 44
118+40	5B	4	468	10	602	1 44
123+50	6B	4	534	10	676	1 44
139+75	8A	4	515	10	690	1 44
149+90	9A	4	459	10	720	1 40
160+80	10A	5	555	12	606	1 39
171+70	11A	5	501	11	584	1 39
184+30	12A	5	477	10	618	1 37
194+60	13A	6	613	10	675	1 46
199+05	14A	6	586	10	671	1 39
209+50	15A	5	460	11	635	1 39
220+80	16A	6	663	10	685	1 46
229+00	17A	3	500	10	642	1 40
240+00	18A	4	515	10	611	
Average						1 417*

* The average estimated cement factor without vibrator was 1 55 bbl per cu yd

The average specific gravity of cores 2 29

Wire mesh reinforcing placed 2 in from the surface was found to have settled 1 1 in more. Part of this settlement might have been caused by workmen tramping around on the mesh.

While the slump on this project was exceedingly small, we found that the vibrator provided sufficient mortar for all finishing purposes

TABLE II

DATA ON TRANSVERSE STRENGTH OF TEST BEAMS, COMPRESSION STRENGTHS OF CORES AND BEAM ENDS, CEMENT FACTOR AND SPECIFIC GRAVITY* OF CONCRETE

Coarse Aggregate Finishing Machine with Integral Electric Vibrator

Station No	Beam No	Transverse Strength				90 Day Comp Strength on Beam End in Lb per Sq In	90 Day Comp Strength on Cores in Lb per Sq In Approx Sta	Yield in Bbls per Cu Yd
		Age in Days	Lb per Sq In	Age in Days	Lb per Sq In			
471+10	1A	4	463	10	617	4722	2765	1 52
461+52	2B	4	410	10	553	4194	2651	1 52
445+85	4A	4	544	10	755	6361	3677	1 33
429+20	5B			10	614	5722	3204	1 34
411+75	7A	4	522			5347	3738	1 33
398+52	9A	4	452	10	556	5889	3344	1 33
381+88	10B	4	440	10	518	5097	5089	1 33
362+75	12A	4	595	10	651	6042	4584	1 35
343+35	14A	4	438	10	584	5111	5237	1 36
332+50	15B	4	501	10	589	5278	3687	1 27
314+50	17A	4	586	10	638	5889	3081	1 26
295+00	18B			10	600	4778	3325	1 29
276+05	20A	4	485	10	517	4778	2855	1 27
263+60	21A	4	473	10	637	4917		
7+90	22B	4	549	10	592	4778	3637	1 29
23+85	24A	4	561	10	561	5750	3839	1 36
35+00	25B	4	562	10	583	6194	5099	1 35
53+60	27A	4	571	10	649	5875	4408	1 35
70+20	28B	3	560	10	577	5292	4235	1 37
90+00	30A	3	517	10	497	6264	4793	1 36
106+60	31B	3	508	10	584	5597	3956	1 36
117+50	32B	3	475	10	479	4444	5048	1 36
136+40	34A	3	538	10	700	5639	5929	1 36
154+70	35B	4	551	10	670	6014	5079	1 36
168+50	37A	3	578	10	678	5944	3723	1 37
187+75	38B	3	472	10	564	6472	3906	1 36
207+35	40A	3	514	11	597	5639	3622	1 34
226+35	41B	4	569	11	670	5903	4073	1 35
244+50	43A	3	485	10	534	5861	4024	1 36
259+90	44B	3	505	10	595	5921	5213	1 36
Average						5524	4063	1 35†

* Average specific gravities were beams 2 31, cores 2 28

† The estimated average cement factor without vibrator was 1 43 bbl per cu yd

It was stated before that trouble was experienced from flattening of the crown This might be due to the fact that the vibrator manufacturers were not particular enough in placing the correct curvature in the vibrator screeds Table I gives transverse strengths found on test beams Sufficient time has not elasped to make available compression tests on beam ends or cores

On another project an electric finishing machine with integral electric vibrator was used In addition to the vibrating screed the equipment carried a front and rear oscillating screed This machine weighed approximately 6000 pounds The vibrator was run with a frequency of between 3500 and 3700 V P M This vibrator furnished sufficient mortar to finish satisfactorily coarse aggregate concrete with a slump of 1½ in The slump was reduced approximately one inch over that which would have been necessary had the vibrator not been used The cement content on this project averaged 1 35 barrels per cubic yard of concrete Assuming that no vibrator had been used approximately 1 45 barrels of cement per cubic yard of concrete would have been required On this type of machine the manufacturer likewise had paid little attention to the crown in the vibrator screed For this reason vibration tended to eliminate the crown at the quarter points and gave some difficulty in obtaining a satisfactory curvature for the surface of the pavement Due to the weight of the finishing machine, coupled with a sandy soil condition, the forms were difficult to hold and some settlement resulted Inspection of cores taken from this particular pavement revealed very good results had been obtained Cores tested for compression also gave average strengths Table II gives transverse strength of test beams, compression strengths of core and beam ends and specific gravity of concrete

This type machine was also used on another coarse aggregate project

TABLE III

DATA ON TRANSVERSE STRENGTH OF BEAMS, COMPRESSION STRENGTH OF BEAM ENDS AND CORES, CEMENT FACTOR AND SPECIFIC GRAVITY*

Coarse Aggregate Finishing Machine with Integral Electric Vibrator

Station No	Beam No	Transverse Strength				90 Day Comp Strength on Beam End in Lb per Sq In	90 Day Comp Strength on Cores in Lb per Sq In Approx Sta	Yield in Bbls per Cu Yd
		Age in Days	Lb per Sq In	Age in Days	Lb per Sq In			
482+90	1A	5	498	10	605	5111	4564	1 33
488+50	2A	4	598	10	694	4778	4395	1 33
495+00	3A	4	691	10	840	4889	4648	1 275
508+00	4B	4	637	10	670	5694	3913	1 26
515+35	5B	4	641	10	740	4750	3672	1 26
520+00	7A	3	592	6	717	7069	5246	1 26
526+20	8A	6	796			7097	4151	1 26
532+00	10A	4	696	7	663	6486	4432	1 28
541+50	12A	4	702	7	774	6014	4360	
548+00	13B	4	642	7	786	6486	4538	1 26
558+50	14B	4	568	7	696	4750	3654	1 26
568+75	15B	4	562	7	620	5194	4233	1 26
579+35	16B	4	629	7	630	5833	4961	1 26
585+00	17B	5	626	7	657	5292	4651	1 26
589+00	19A	3	649	8	737	6417	3612	1 26
Average						5724	4335	1 272†

* Average specific gravities were beams 2 37, cores 2 28

† The average estimated cement factor without vibration was 1 38 bbl per cu yd

The average mix was 1:1 98:4 56, proportioned by weight, with a cement content of 1 26 and 1 27 barrels per cubic yard With this mix, usually considered harsh, no scarcity of mortar was noticeable and the finish was satisfactory Also good results were obtained from test beams broken at four days The beams seemed to ındicate somewhat hıgher earlıer strength than that obtaıned wıth ordinary finıshıng equıpment There was about ⅛ ın settlement ın the forms due to the weıght of the machıne Table III

TABLE IV

DATA ON TRANSVERSE STRENGTH OF BEAMS COMPRESSION STRENGTH OF BEAM ENDS AND CORES, CEMENT FACTOR AND SPECIFIC GRAVITY*

Coarse Aggregate Vıbrator between Front and Rear Oscıllatıng Screeds, Gasolıne Engıne

Station No	Beam No	Transverse Strength				90 Day Comp Strength on Beam End ın Lb per Sq In	90 Day Comp Strength on Cores ın Lb per Sq In Approx Sta	Yield ın Bbls per Cu Yd
		Age ın Days	Lb per Sq In	Age ın Days	Lb per Sq In			
177+25	1-B-1	5	429	10	596	5528	2372	1 38
165+50	3A	6	547 4			4833	2938	1 39
151+70	4B	6	376 2			6139	3573	1 44
134+06	6A	10	529			4722	3462	1 43
125+72	7B	10	534			5639	3447	1 43
116+10	8B	10	521			5333		1 43
104+46	9B	6	422	10	535	5667	3203	1 405
98+40	10B	10	546			4445	2398	1 43
80+25	12A	6	458			4806		1 45
69+64	13A	6	560	10	510	5139		1 48
60+82	14A	7	413			6445		1 43
50+97	15A	6	498	10	573	5834		1 41
47+20	16A	6	345			4028		1 51
Average						5274	3056	1 431†

* Average specıfic gravıty of cores was 2 15

† The average estımated cement factor wıthout vıbratıon was 1 53 bbl per cu yd

shows strengths obtaıned on test specımens

On a three mıle sectıon of mıxed aggregate pavement a finıshıng machıne was used with vıbrator attachment Thıs vıbrator was operated by a separate 15 horsepower four cylınder gasolıne engıne wıth a frequency of between 3600 and 4200 V P M The vıbrator was mounted between regular front and rear oscıllatıng screeds The surface of the vıbrator ın contact wıth the concrete was concave wıth well rounded ends It had a contact surface of about 6 ın Slumps as low as ⅛ ın were trıed but dıscarded because apparently there was not enough moısture present to lubrıcate the materıals The first cores taken wıth thıs extremely small slump were found to be porous In thıs machıne as ın others, the manufacturer had faıled to recognıze the ımportance of buıldıng the crown of the vıbrator beam the same as the specıfied crown of the finıshed pavement It mıght be desırable, ın some materıals, to have a crown ın excess of that desıred by the finıshed product Another crıtıcısm of thıs partıcular vıbrator was that concrete would pıle on top, thus dampenıng the vıbratıng effect It was necessary at all tımes to keep all excess concrete from the top of the vıbrator beam

Cores obtaıned from the slab and tested at the research laboratory, appeared to have abnormal porosıty and low densıty The specımens seemed to show denser concrete near the surface and the bottom of the cores, than was found about the center Due to the fact that thıs machıne dıd not produce satısfactory concrete, blanket approval of ıts use on mıxed aggregate pavements has been wıthheld untıl further experıments can be made wıth ıt

Later thıs same finısher and vıbrator was used on a project where coarse aggregate was used The machıne was operated at a frequency of about 3500 V P M The proportıons of materıals were finally adjusted to a mıx of 1.2 1.4 35, proportıoned by weıght, wıth a 1 29 cement factor The slump used was from 1½ to

TABLE V

DATA ON TRANSVERSE STRENGTH OF BEAMS, COMPRESSION STRENGTH OF BEAM ENDS AND CORES, SPECIFIC GRAVITY* AND CEMENT FACTOR

Coarse Aggregate Vibrator between Front and Rear Oscillating Screeds, Gasoline Engine

Station No	Beam No	Transverse Strength				90 Day Comp Strength on Beam End in Lb per Sq In	90 Day Comp Strength on Cores in Lb per Sq In Approx Sta	Yield in Bbls per Cu Yd
		Age in Days	Lb per Sq In	Age in Days	Lb per Sq In			
Section A								
649+00	1B	5	650	10	644	6819		1 32
642+25	3B	5	561	10	628	5333	4185	1 32
631+40	5B	6	511	10	625	4500		1 34
620+50	7A	4	525	10	799	6167	4350	1 34
609+40	8B	4	484	10	625		4396	1 34
600+50	9B	4	572	10	576	5611	3320	1 30
588+50	10B	4	556	10	563	4519	3232	1 30
575+00	12A	4	599	10	701	4944	3378	1 27
557+80	14A	4	571	10	705	4653	4604	1 28
549+00	15B	4	623	11	749	5639	2963	1 28
542+50	16B	4	374	10	707	5306	4291	1 27
530+00	17B	4	396			4111	3848	1 30
520+00	18B	4	432			3139	3372	1 30
511+00	19B	7	511			3222		1 29
502+00	20B	6	595			4972	3175	1 29
493+00	22B	4	533	10	574	5056	3302	1 32
Section B								
474+00	1B	4	547	10	654	6528		1 31
263+00	2A	4	639	10	751	5875	3494	1 31
278+00	4A	4	608	10	683	6486	4395	1 29
291+00	5B	4	652	10	537	5930	2989	1 27
300+00	6B	4	586	11	606	5250	3440	1 27
311+00	7B	4	623	10	630	6681	4161	1 27
321+00	8B	4	512	10	478	4778	4626	1 27
330+00	9B	4	641	10	554	5819	3327	1 28
340+00	10B	4	608	10	728	6444	4191	1 28
349+00	11B	5	672	10	551	7153	4987	1 28
359+00	12B	5	533	9	688	6278	4894	1 28
370+00	13B	4	575	10	662	4861		1 28
382+00	14B	4	575	10	642	6236	4086	1 28

* Average specific gravities were beams 2 35, cores 2 31

TABLE V—*Concluded*

Station No	Beam No	Transverse Strength				90 Day Comp Strength on Beam End in Lb per Sq In	90 Day Comp Strength on Cores in Lb per Sq In Approx Sta	Yield in Bbls per Cu Yd
		Age in Days	Lb per Sq In	Age in Days	Lb per Sq In			
Section B—*Concluded*								
391+00	15B	4	597	10	652	6083	4070	1 28
404+00	16B	4	560	10	504	6264	2500	1 28
410+00	17A	4	606	10	693	6083	3542	1 28
420+00	18B	4	575	10	711	5139		1 26
430+00	19B	4	540	10	693	4944	3726	1 26
440+00	20B	4	541	10	648	5000	4123	1 26
448+50	21B	4	659	10	754	5472		1 26
460+00	23A	5	627	10	670	5083	3627	1 26
Average						5455	3820	1 288†

† Average estimated cement factor without vibration was 1 42 bbl per cu yd

TABLE VI

DATA ON TRANSVERSE STRENGTH OF BEAMS USING DIFFERENT WATER CEMENT RATIOS

Coarse Aggregate Vibrator between Front and Rear Oscillating Screeds, Gasoline Engine

Station No	Beam No	Transverse Strength				Yield in Bbls per Cu Yd
		Age in Days	Lb per Sq In	Age in Days	Lb per Sq In	
75+98*	18B	5	545	10	612	1 16
274+08*	19B	5	485	10	582	1 15
Average						1 155
57+30†	22A	5	562	10	529	1 35
255+00†	22B	5	578	10	700	1 35
252+90†	23A	5	632	10	552	1 35
249+90†	24A	5	455	10	671	1 34
248+50†	24B	5	513	10	619	1 35
Average						1 35‡

* 7 00 gals water used

† 5 75 gals water used

‡ The average estimated cement factor without vibrator was 1 40 bbl per cu yd

2 in This gave enough mortar for all finishing purposes Attempts to lower the moisture content and cement factor resulted in a mix that was too dry and harsh to finish properly Comparison by computation was made to determine savings due to the vibrator The vibrator allowed the use of more stone, required less sand and from 3 to 6 per cent less cement All beams tested showed required strength or better Check levels taken on the forms indicated that the vibrator caused the forms to settle about $\frac{1}{8}$ in In most instances where a vibrator is used in connection with the finishing machine, settlement of the forms has been found and it is a factor that will have to be taken into consideration when preparing the subgrade Tables IV and V show various strengths obtained with test specimens

This same finisher was again used in vibrating some sections on a five mile experimental concrete pavement project This job was particularly interesting for the reason that a Goldbeck pressure cell was installed in the subgrade in an effort to find if the vibrations were carried through the concrete The machine was stopped so that the vibrator was directly over the instrument which was adjusted so the light was not illuminated When the vibrator was started the light immediately came on As the vibrations ceased the light flickered, showing that vibrations were actually being carried through to the subgrade The mix used in this particular case was rock with $33\frac{1}{2}$ per cent sand by volume with 7 gal of water per sack of cement and the slump was 2 in This test was repeated again with $5\frac{3}{4}$ gal of water with a 1-in slump and 30 per cent sand by volume The light was distinctly weaker than during the first experiment, indicating that vibrations were not being carried through to the base with as much intensity as was noted with the wetter mix The frequency on this machine was between 3600 and 4200 V P M

In this same experiment a tamper was used As the tamper approached the cell the light came on giving a more intense light than when used with the vibrator Table VI gives various strengths obtained on test specimens

CONCLUSIONS

From these observations the writer believes that the following conclusions are justified

1 That vibrators used in connection with structural or pavement concretes will allow a reduction in cement content or if the aggregates are kept constant will give greater strength due to decrease in the amount of water needed

2 The amount of vibration must be governed according to the particular aggregates used

3 That the use of vibrators will in no way permit any laxness in the writing of material specifications

4 With pavement vibrators form settlement must be taken into consideration