THE EFFECTS OF FREQUENCY OF VIBRATION IN MAKING CONCRETE BEAMS

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SYNOPSIS

Results of cross bending, compression, and density tests together with visual observations on 56 6 by 8 by 72-in plain concrete beams placed by vibratory methods are reported The principal objective was the determination of the effect of varying the frequency of vibration on the time required to place concrete in beam forms with an internal vibrator held in one end of the mold throughout the compacting period Variables included concretes of 5000 and 3000 lb per sq in compressive strength made with two water-cement ratios, 0 47 to 0 62, by weight, two consistencies, one very dry and the other having a half-inch slump, variations in frequency from 3000 to 7000 r p m , variations in time of vibration, a well-graded and a very fine grained sand A few tests were also run with an external vibrator using different amplitudes of vibration

The data show that there was a marked reduction in time required to compact the beams when the higher frequencies of vibration were used The effect of the higher frequencies was most marked on the beams made with the very dry consistency

INTRODUCTION

For many years manufacturers have utilized dry consistencies and vibration in making concrete products The dense, strong, and durable types of artificial stone thus produced are examples of the possibilities of such methods of operation It seems that it should be possible to make on the job similar concrete with its inherent advantages of uniformity, water tightness, low shrinkage and low plastic flow Thus far, however, most of the concrete placed by vibration has been of far wetter consistency than that used in making products If the field engineer could be assured that such dry consistencies could be successfully placed with vibrators, their use would become general and better concrete would be obtained The belief that the application of higher frequencies of vibration would aid greatly in reducing the time required to compact such dry mixes was the incentive for the experiments herein reported

The variables covered in the 56 beams tested are listed in Table I Proportions, cement contents, percentages of water, and slumps are nominal values For data for individual beams, see Tables II and III

The tests were made in the Materials Testing Laboratory at The University of Wisconsin through funds granted by the Wisconsin Alumni Research Foundation Able assistance was furnished in conducting the tests and working up the data by Messrs L E Bidwell, E K Neroda, and F M Sutton, of the civil engineering class of 1935 An internal vibrator was loaned for these experiments by The Viber Company, Ltd , and an external vibrator by the Electric Tamper and Equipment Company The Electrical Laboratory at the University loaned instruments for regulating speed and measuring power

VIBRATORS

Figure 1 shows the internal vibrator spud $1\frac{3}{4}$-in in diameter and 20 in long which was attached by a flexible shaft to a

TABLE I

SCOPE OF TESTS ON 6 BY 8 BY 72-INCH VIBRATED CONCRETE BEAMS

Beams		Kind of Sand	Average Mix Proportions by Weight	Mix Designation	Nominal Percentage of Free Water by Weight of Dry Material	w/c, by Weight	Nominal Slump, in	Average Cement Content, Sacks per cu yd	Range in Frequency Variables in 1000 r p m	Kind of Vibrator
Mark	No									
J1, J3 to J23	12	J	1 2 5 6 0	J5	5 0	0 47	0	4 4	4 to 6	Internal
J2, J4 to J16	8	J	1 2 2 5 3	J55	5 5	0 47	½	4 9	3 to 6	Internal
C1, C3 to C19 C25 to C39	18	J	1 3 8 7 8	C5	4 9	0 62	0	3 4	3 6 to 7	Internal
C2, C4 to C12	6	J	1 3 3 7 0	C55	5 5	0 62	½	3 7	4 to 6	Internal
U1, U3 to U15	8	U	1 3 3 8 7	U48	4 8	0 62	0	3 2	4 to 6	Internal
J25, J27	2	J	1 2 6 5 8	J5	5 0	0 47	0	4 5	3 6	External*
C21, C23	2	J	1 3 7 7 4	C5	5 1	0 62	0	3 4	3 6	External*

* Vibrator placed on top of beam, amplitude one-third and maximum setting

universal ½ h p motor designed to run at 4500 r p m on a 110 volt, D C or single phase A C. circuit By connecting the motor shown to a 220 volt A C circuit and inserting a rheostat in the circuit, it was possible to vary the speed from 0 to 6000 r p m with the vibrator completely buried in concrete The amplitude, or displacement of the spud on one side of the neutral position, when suspended in air and run at 5000 to 7000 r p m was approximately 0 15 in This displacement was caused by the rotation of a rod carrying an eccentric cylindrical segment The total weight of the spud was 7 7 lb The rod and segment weighed 3 35 lb and the center gravity of the combination was 0 2 in away from the longitudinal axis of the spud

Beams C25 to 39 were compacted by attaching the flexible shaft to a 5-h p, 3-phase A C motor which was run at nominal speeds of 3600, 5400 and 7200 r p m Readings were simultaneously taken on speed, voltage, amperage, and wattage during compaction From these readings and the known characteristics of the motor, the output required to run the vibrator at different speeds was determined, see Fig 17

The external vibrator shown in Figure 2 consisted of a ½-h p induction motor

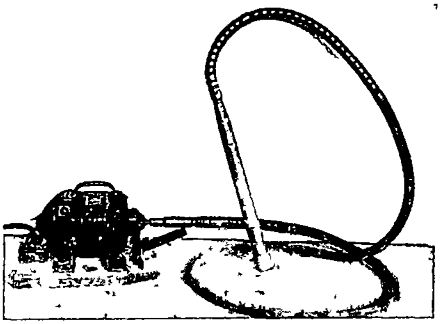

Figure 1. Internal Vibrator Spud 1¾ by 20 In One-Half Horsepower Motor 4500 R P M

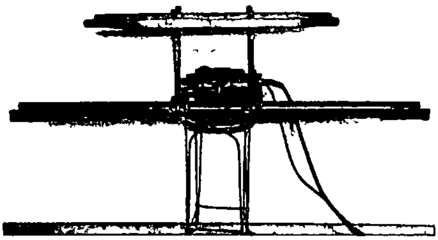

Figure 2. External Vibrator Attached to 5-In. 11 5-lb. Channel One-Half Horsepower Motor 3600 R.P.M.

operating on a 3-phase 60-cycle 220-volt circuit at a nominal speed of 3600 r p m The left end of the rotor shaft carried a pair of unbalancing weights which could be rotated about the shaft to produce six variations in amplitude of vibration In these tests the vibrator was attached to a 68-in length of 5-in 11½-lb steel channel The wooden handles were mounted on springs to lessen the effect of the vibratory reaction on the operators However, this improvised mounting was not satisfactory, since the finger tips were numbed for some time after using the vibrator The entire weight of the device was 132 lb The amplitude of the vertical vibration (half displacement) of the center of the channel when the latter was supported on two sponge rubber pads placed 6 in apart with the unbalancing weights set for maximum amplitude was 0 055 in Similarly supported with the weights set at one-third setting, the amplitude was 0 030 in

MATERIALS

Cement The cement conformed to A S T M Standard Specifications for Portland Cement, C9–30 Its tensile strength in 1 3 standard sand mortar briquettes was 339 and 398 lb per sq in at 7 and 28 days, respectively Its initial set occurred in 3 hr and final set in 5½ hr The specific gravity was 3 13

Sand Forty-eight of the beams were made from a well graded sand from Janesville, Wisconsin This sand passed a ¼-in screen, had a fineness modulus of 2 63 and contained 15 to 20 per cent of material passing a No 48 sieve Its weight per cu ft dry and rodded was 110 lb , its bulk specific gravity was 2 69, and its absorption when air dry 0 6 per cent

Eight beams were made with a fine grained sand from University pit which passed a No 16 sieve, had a fineness modulus of 1 5, contained 50 per cent of grains passing a No 48 sieve and 8 per cent passing a No 100 sieve This sand weighed 107 lb per cu ft dry and loose Its bulk specific gravity was 2 64 and its absorption when air dry was 0 5 per cent

Janesville gravel, consisting principally of dolomitic pebbles with about one-half the particles crushed, was graded and used in the following proportions, by weight.

1 part No 1—between ¼ and ⅜ in screens

2 parts No 2—between ⅜ and ¾ in. mesh

3 parts No 3—between ¾ and 1½ in mesh

Both sand and gravel were air dried prior to screening Frequent tests were made on the absorption in order to make proper allowances in measuring the mixing water

MAKING SPECIMENS

Proportions From previous experiments with mixes placed by vibration[1] the proper w/c ratio to produce concrete of 3000 lb per sq in compressive strength at 28 days was computed to be 0 62 by weight, the proper sand-aggregate ratio for this concrete was estimated at 0 32 For concrete with a 28-day compressive strength of 5000 lb per sq in the calculated w/c ratio was 0 47, by weight, the proper sand-aggregate ratio was estimated at 0 3 For concrete of either strength and of the driest practicable consistency the free water in terms of the total weight of cement, sand and gravel was approximately 5 per cent Mixes made of this consistency therefore were

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[1] See *Jour Am Conc Inst*, May-June 1935

appropriately marked C5, U48 (= U 4 8) and J5 to indicate w/c ratio, type of sand, and percentage of water used All beams made of concrete of this consistency were given odd numbers which were similarly prefixed with the letters C, U or J for designation

For concrete of $\frac{1}{2}$-in slump the free water content was found to be approximately 5 5 per cent Hence such mixes with w/c ratio of 0 47 are designated J55 and those with w/c ratio of 0 62 are designated C55 Beams made with concrete of this consistency were given even numbers prefixed by J or C to designate the w/c ratio.

Mixing Concrete was mixed in batches weighing approximately 900 lb which was a sufficient quantity to make two beams and six 6 by 12-in cylinders Materials were separately and carefully weighed on a scales sensitive and accurate to 0 1 lb and the sum of the weights checked on a larger scale under the batch hopper

Mixing was done in a double-cone tilting drum mixer of 6 cu ft capacity The mixer was thoroughly cleaned after each batch and was wetted and allowed to drain 5 min before charging Gravel, sand and cement were charged into a hopper in the order named and then run into the mixer Water was then added and mixing continued for two minutes after all materials had been charged After the batch was discharged, it was conveyed by wheelbarrows to a moistened steel pan The batch was then covered with damp canvas to permit the aggregate to absorb moisture

When the mixer was cleaned, all mortar and aggregate was washed into a wheelbarrow After allowing this material to settle, the clear water was then poured off and the volume and weight of the remaining slurry—consisting of cement, sand and gravel—were determined The slurry was then washed on a large No 48 sieve, the material held on the sieve was dried, and the amounts coarser than a No 4 and No 48 sieve determined Knowing the above quantities, the sieve analysis of the sand and the specific gravity of each ingredient, the amounts of cement, sand, and gravel losses were calculated The mix proportions given in Tables I, II and III have been adjusted for these mixer losses

Placing After the concrete had remained 30 to 50 minutes under the damp canvas it was thoroughly mixed by hand, shoveled into the cylinder molds, and spread uniformly in one of the beam molds without spading or tamping Figure 3 shows typical appearance of concrete for the odd numbered beams of batches C5, J5 and U48 Figure 4 shows the typical appearance of such concrete in a mold prior to vibration

Before the spud of the internal vibrator was immersed in the concrete, the rheostat was adjusted until the tachometer held on the free end of the motor shaft registered somewhat above the desired speed The spud was then inserted and the rheostat further adjusted to maintain the given speed In compacting the beams the spud was inclined to the axis of the beam, as shown in Figure 4, and kept out of contact with the molds As the concrete settled, the molds were refilled Time was noted as soon as the spud was inserted in the concrete, again when water appeared at the remote end of the beam, and a few seconds later when the beam was judged to be completely vibrated At the conclusion of the vibration period the spud, still vibrating, was slowly withdrawn from the beam

After the first beam of a pair had been

vibrated the second beam mold was filled and vibrated. In most cases different frequencies were used on the beams made from a given batch.

Tops of beams were surfaced with a plastering trowel. Figure 5 shows beams after vibration with tops in various stages of finishing.

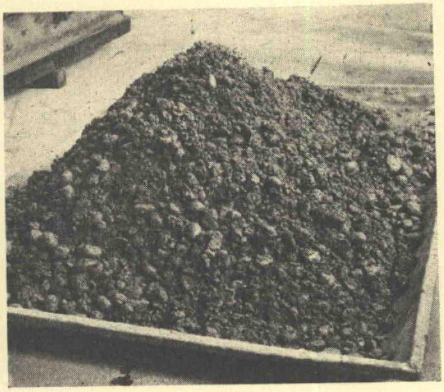

Figure 3. Appearance of No-Slump Concrete Made for Beams C9 and C11

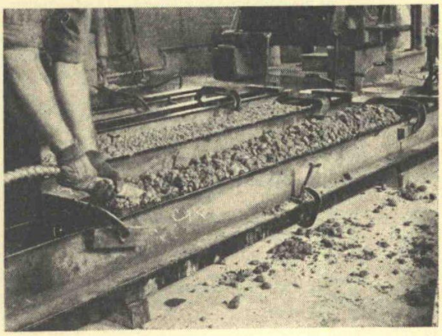

Figure 4. Vibrator Ready to Compact No-Slump Concrete in Beam J15

In vibrating the cylinder molds the spud was held with its axis vertical and given a slight gyratory motion as it was moved up and down in the mold. The time required for compaction of the cylinders usually ranged between 10 and 20 sec.

When the external vibrator was used the main function of the two operators was to keep the channel on the vibrator away from the beam molds. Vibration was continued until the mix flowed freely over the sides of the mold. Nevertheless, the period on three of the beams was too short for perfect compaction.

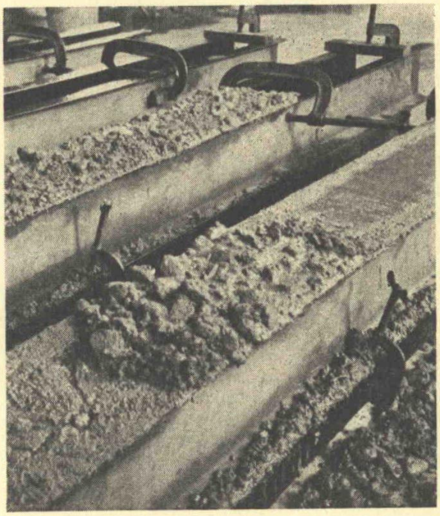

Figure 5. Beam C9 After Vibrating. Beam C11 Partly Finished

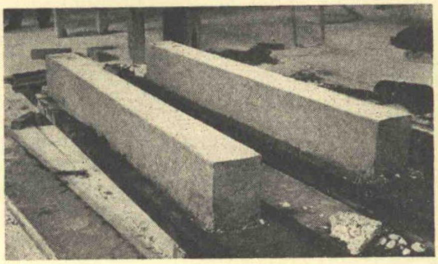

Figure 6. Beam C9 Vibrated 40 Sec. at 6000 R.P.M. Beam C11 Vibrated 150 Sec. at 4000 R.P.M.

Curing. All specimens were covered with wet canvas and held in the molds 18 to 24 hours. They were then stripped, numbered, and the end of each beam nearest the vibrator was marked V. Figure 6

TABLE II

Data on Time of Vibration, Extent of Pockets, and Specific Weight of the 6 by 8 by 72-inch Concrete Beams

Beam No	Mix by Weight	Mix Designation	Kind of Sand	w/c by Wt	Slump in	Ave Speed r p m	Ave Time in Seconds		Estimated Time for Satisfactory Vibration	Average Extent of Pockets in	Specific Weight	
							Water at End	Total			Ave, lb /ft³	Range %
J13	1 2 57 5 87	J5	J	0 47	0	6000	33	35		3	154 9	1 1
J9	1 2 56 5 78		J	0 47	0	6000	40	50	50		153 2	1 8
J1	1 2 33 6 22		J	0 47	0	6000	50	60			155 2	2 2
J15	1 2 57 5 87		J	0 47	0	5000	40	40			155 4	1 5
J3	1 2 33 6 22		J	0 47	0	5000	55	55		20	155 3	1 6
J17	1 2 59 5 97		J	0 47	0	5000	58	70	80	13	155 1	1 8
J21	1 2 59 5 94		J	0 47	0	5000	60	90			154 7	1 9
J5	1 2 41 6 00		J	0 47	0	5000	104	104			156 1	1 5
J19	1 2 59 5 97		J	0 47	0	4000	63	120		18	154 5	3 9
J7	1 2 41 6 02		J	0 47	0	4100	180	180	300+	20	155 3	3 3
J23	1 2 59 5 94		J	0 47	0	4000	220	230		18	155 2	2 3
J11	1 2 56 5 78		J	0 47	0	4100	200	240		20	153 3	3 1
C37*	1 3 88 7 70	C5	J	0 62	0	6950	30	40	40		154 3	1 8
C39*	1 3 88 7 70		J	0 62	0	6940	40	55			153 8	1 4
C9	1 3 78 7 52		J	0 62	0	6000	30	40			152 7	2 0
C13	1 3 67 7 30		J	0 62	0	6000	30	40	50		152 7	1 9
C1	1 3 6 8 4		J	0 62	0	6000	50	60		24	153 0	3 0
C29	1 3 84 7 67	C5	J	0 62	0	5400	50	80		3	154 3	2 1
C33	1 3 86 7 68		J	0 62	0	5400	45	60			153 9	1 5
C35*	1 3 86 7 68		J	0 62	0	5320	40	55	65		154 2	1 9
C31*	1 3 84 7 67		J	0 62	0	5280	45	65			153 2	3 0
C15	1 3 67 7 30		J	0 62	0	5000	40	65			153 0	1 9
C17	1 3 67 7 25		J	0 62	0	5000	40	80	85		153 5	2 0
C5	1 3 82 7 81		J	0 62	0	5000	85	100			154 5	0 7
C3	1 3 6 8 4		J	0 62	0	5000	40	130		24†	154 6	3 7
C11	1 3 78 7 52		J	0 62	0	4000	130	150		4	153 0	1 8
C7	1 3 82 7 81		J	0 62	0	4100	130	160	200		154 6	2 4
C19	1 3 67 7 25		J	0 62	0	4000	140	180		5	153 6	2 9
C25	1 3 83 7 75		J	0 62	0	3600	12″ from end	300	300+	22	152 0	4 6
C27*	1 3 83 7 75		J	0 62	0	3600	12″ from end	300		14	153 0	3 5
J10	1 2 23 5 26	J55	J	0 47	½	6000	16	25	25		154 5	0 8
J2	1 2 06 5 48		J	0 47	½	6000	25	40			155 0	1 5
J4	1 2 06 5 48		J	0 47	½	5000	8	10		24	154 5	1 5
J6	1 2 27 5 19		J	0 47	½	5000	45	45	45		154 4	1 6
J8	1 2 27 5 19		J	0 47	½	4100	20	30		13	154 5	1 9
J14	1 2 31 5 36		J	0 47	½	4000	35	70	100	3	154 6	1 1
J12	1 2 23 5 26		J	0 47	½	4100	40	80		3	154 3	1 0
J16	1 2 31 5 36		J	0 47	½	3000	180	300	300+	27	154 5	2 7

* Vibrator driven by 5 h p motor

† Molds leaked

TABLE II—*Concluded*

Beam No.	Mix by Weight	Mix Designation	Kind of Sand	w/c by Wt.	Slump in.	Ave. Speed r.p.m.	Ave. Time in Seconds		Estimated Time for Satisfactory Vibration	Average Extent of Pockets in.	Specific Weight	
							Water at End	Total			Ave. lb./ft.³	Range %
C2	1:3.18:7.38	C55	J	0.62	½	6000	20	20	25	4	154.1	1.4
C10	1:3.36:6.79		J	0.62	½	6000	10	20			153.4	1.6
C4	1:3.18:7.38		J	0.62	½	5000	35	35	40	15	153.2	3.2
C6	1:3.27:6.86		J	0.62	½	5000	25	35			154.1	1.0
C12	1:3.36:6.79		J	0.62	½	4000	40	45		2	153.5	1.8
C8	1:3.27:6.86		J	0.62	½	4100	60	110	80		154.4	2.3
U1	1:3.37:8.77	U48	U	0.62	0	6000	48	70			152.3	2.0
U5	1:3.26:8.59		U	0.62	0	6000	44	60	60		152.5	2.0
U9	1:3.36:8.83		U	0.62	0	6000	63	80			151.7	4.5
U13	1:3.36:8.70		U	0.62	0	6000	30	35			152.1	1.4
U7	1:3.26:8.59		U	0.62	0	5000	55	80	80		153.0	2.2
U15	1:3.36:8.7		U	0.62	0	5000	30	45			152.0	1.8
U3	1:3.37:8.77		U	0.62	0	4000	360	360		24	152.3	3.9
U11	1:3.36:8.83		U	0.62	0	4000	260	300	360+	8	152.8	4.3
J25	1:2.56:5.82	J5	J	0.47	0	3600‡	13	20	20		154.8	0.6
J27	1:2.56:5.82		J	0.47	0	3600§	9	18	50	40	153.7	1.8
C21	1:3.67:7.42	C5	J	0.62	0	3600‡	12	32	40	20	152.9	1.1
C23	1:3.67:7.42		J	0.62	0	3600§	12	32	50	40	152.0	1.5

‡ External vibrator with full amplitude setting.

§ External vibrator with one-third amplitude setting.

shows appearance of beam C9 which was well compacted throughout and beam C11 which was insufficiently compacted at the right end which was remote from the vibrator. After marking, specimens were placed in a moist room in which the air was saturated and maintained at 68 to 70°F. They were kept in the moist closet until they were tested at 28 days. Care was taken to prevent drying during interval between removal from moist closet and breakage.

METHOD OF TESTING

Cross-bending. A hydraulic cross-bending machine with a 50,000-lb. weighing platform was used in making the transverse loading tests on the beams. In order to secure information on the variation in strength, each beam was broken into six fragments by center loading portions 20 in. long beginning at the end away from the vibrator, as shown in Figure 7. In all tests the bottom fibers as molded were subjected to tension.

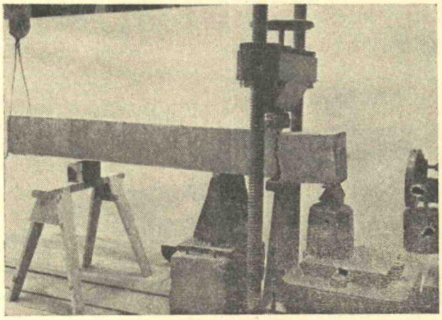

Figure 7. Method of Loading Beams on 20-In. Span

TABLE III

Cement Contents, Densities, and Strengths of the 6 by 8 by 72-inch Vibrated Concrete Beams

Beam No	Mix by Weight	Ave Cement Content		Solidity Ratio ρ	Cement Voids Ratio c/v	Modulus of Rupture			Compressive Strength		
		Sacks per cu yd	Absolute Volume, c			Ave S_m, lb/in²	Coeff of Var n %	Dev of Min from Ave %	Ave S_c lb/in²	Coeff of Var n' %	Dev of Min from Ave %
J13	1 2 57 5 87	4 46	0 0795	0 8597	0 566	695	4 6	5 9	5068	3 3	6 4
J9	1 2 56 5 78	4 45	0 0793	0 8491	0 526	658	3 3	5 6	4984	6 7	10 0
J1	1 2 33 6 22	4 41	0 0787	0 8614	0 568	673	4 8	7 3	4961	7 3	12 4
J15	1 2 57 5 87	4 47	0 0797	0 8629	0 582	713	6 0	6 3	5207	4 5	7 4
J3	1 2 33 6 22	4 41	0 0787	0 8614	0 568	614	6 0	8 8	3696	15 5	26 8
J17	1 2 59 5 97	4 41	0 0787	0 8629	0 574	691	6 3	10 3	4833	12 2	21 9
J21	1 2 59 5 94	4 41	0 0787	0 8608	0 565	675	4 5	5 2	5188	3 9	5 7
J5	1 2 41 6 00	4 50	0 0802	0 8668	0 602	717	5 0	6 1	5199	3 0	1 8
J19	1 2 59 5 97	4 39	0 0783	0 8688	0 554	641	15 9	30 6	4939	9 9	20 1
J7	1 2 41 6 02	4 46	0 0796	0 8606	0 571	689	8 4	14 2	4635	16 9	33 8
J23	1 2 59 5 94	4 43	0 0790	0 8628	0 576	557	7 0	9 0	4973	9 9	18 7
J11	1 2 56 5 78	4 45	0 0794	0 8495	0 528	594	20 0	36 0	3947	24 0	43 5
C37*	1 3 88 7 70	3 34	0 0596	0 8633	0 436	580	7 1	9 5	3983	5 5	8 2
C39*	1 3 88 7 70	3 33	0 0594	0 8601	0 424	604	2 0	2 5	3837	5 9	7 6
C9	1 3 78 7 52	3 37	0 0601	0 8496	0 400	556	4 8	7 9	3532	4 1	5 6
C13	1 3 67 7 30	3 46	0 0618	0 8500	0 412	560	3 9	5 9	3657	4 8	5 5
C1	1 3 6 8 4	3 20	0 0571	0 8544	0 392	533	9 1	15 4	3188	10 0	16 6
C29	1 3 84 7 67	3 36	0 0599	0 8619	0 434	572	2 2	3 5	3720	4 7	9 1
C33	1 3 86 7 68	3 34	0 0596	0 8591	0 423	595	5 6	9 9	3756	3 3	4 7
C35*	1 3 86 7 68	3 34	0 0596	0 8598	0 425	584	6 5	12 0	3688	3 2	3 8
C31*	1 3 84 7 67	3 36	0 0594	0 8556	0 411	633	3 9	5 8	3572	5 6	8 2
C15	1 3 67 7 30	3 47	0 0619	0 8514	0 416	551	6 5	4 7	3865	2 0	2 8
C17	1 3 67 7 25	3 49	0 0623	0 8530	0 424	562	5 6	6 2	3895	5 9	8 3
C5	1 3 82 7 81	3 32	0 0592	0 8609	0 426	533	9 9	14 8	3507	5 2	7 9
C3	1 3 6 8 4	3 23	0 0577	0 8638	0 424	522	7 1	12 1	2951	11 4	14 1
C11	1 3 78 7 52	3 37	0 0602	0 8525	0 408	528	2 5	4 2	3588	5 9	6 8
C7	1 3 82 7 81	3 32	0 0593	0 8615	0 428	510	2 5	3 5	3501	1 8	2 0
C19	1 3 67 7 25	3 49	0 0623	0 8541	0 427	548	8 0	7 8	3543	7 3	12 6
C25	1 3 83 7 75	3 28	0 0585	0 8462	0 380	479	9 3	16 7	3193	24 7	45 4
C27*	1 3 83 7 75	3 31	0 0590	0 8520	0 398	496	9 3	10 5	3353	12 1	22 5
J10	1 2 23 5 26	4 90	0 0875	0 8498	0 582	689	5 4	9 4	5152	4 9	7 4
J2	1 2 06 5 48	4 90	0 0874	0 8542	0 600	683	4 5	8 3	4787	5 3	5 4
J4	1 3 06 5 48	4 88	0 0871	0 8507	0 584	637	4 2	5 0	4362	8 2	13 8
J6	1 2 27 5 19	4 92	0 0877	0 8492	0 582	655	5 8	9 0	5158	6 1	8 9
J8	1 2 27 5 19	4 93	0 0880	0 8517	0 594	593	7 5	14 5	4593	9 3	12 9
J14	1 2 31 5 36	4 83	0 0861	0 8443	0 553	660	4 8	7 3	5059	4 2	7 1
J12	1·2 23 5 26	4 90	0 0875	0 8498	0 582	689	2 8	4 2	4825	6 8	10 7
J16	1 2 31 5 36	4 83	0 0861	0 8443	0 553	577	9 3	16 1	4064	15 8	27 7

* Vibrator driven by 5 h p motor

TABLE III—*Concluded*

Beam No	Mix by Weight	Ave Cement Content		Solidity Ratio ρ	Cement Voids Ratio c/v	Modulus of Rupture			Compressive Strength		
		Sacks per cu yd	Absolute Volume, c			Ave S_m, lb/in²	Coeff of Var n %	Dev of Min from Ave %	Ave S_c lb/in²	Coeff of Var n' %	Dev of Min from Ave %
C2	1 3 18 7 38	3 60	0 0642	0 8529	0 436	483	3 2	3 9	3024	4 3	5 2
C10	1 3 36 6 79	3 71	0 0662	0 8478	0 435	554	3 1	4 7	3797	1 9	3 2
C4	1 3 18 7 38	3 58	0 0639	0 8491	0 424	471	7 1	12 1	2664	16 1	23 9
C6	1 3 27 6 86	3 73	0 0666	0 8522	0 451	543	4 0	5 5	3631	4 7	5 8
C12	1 3 36 6 79	3 72	0 0663	0 8495	0 440	535	1 5	2 4	3846	4 2	6 4
C8	1 3 27 6 86	3 74	0 0667	0 8530	0 454	522	11 4	14 6	3442	3 1	6 2
U1	1 3 37 8 77	3 16	0 0464	0 8577	0 396	514	7 3	6 6	3458	5 1	5 1
U5	1 3 26 8 59	3 23	0 0576	0 8576	0 404	532	6 9	4 3	3520	15 7	4 0
U9	1 3 36 8 83	3 13	0 0559	0 8546	0 385	495	4 9	8 1	3325	2 3	3 8
U13	1 3 36 8 70	3 17	0 0565	0 8552	0 390	516	5 9	6 4	3371	2 7	3 7
U7	1 3 26 8 59	3 24	0 0578	0 8599	0 412	485	3 1	2 9	3430	4 5	6 0
U15	1 3 36 8 7	3 17	0 0565	0 8550	0 390	526	9 8	8 7	3367	4 1	7 2
U3	1 3 37 8 77	3 16	0 0564	0 8579	0 397	405	27 1	45 2	2752	31 1	51 1
U11	1 3 36 8 83	3 17	0 0565	0 8637	0 414	461	9 7	9 5	2944	15 7	32 6
J25†	1 2 56 5 82	4 48	0 0800	0 8599	0 571	624	4 8	7 5	4646	5 3	9 6
J27‡	1 2 56 5 82	4 45	0 0794	0 8531	0 540	609	12 5	13 0	5110	4 7	6 9
C21†	1 3 67 7 42	3 43	0 0613	0 8533	0 418	532	12 2	18 8	3930	2 4	4 5
C23‡	1 3 67 7 42	3 42	0 0610	0 8482	0 402	496	9 4	9 9	3458	9 0	13 7

† External vibrator with full amplitude setting
‡ External vibrator with one-third amplitude setting

The moment of the overhanding end was offset by applying the requisite upward pull through the spring balance shown at the left in Figure 7 The pull at the balance was adjusted by a chain hoist not shown Care was taken to avoid torsion at supports and point of loading Span, load point distances, and cross sectional dimensions at center were carefully measured prior to each break, and notes on condition of surfaces of beam were also taken The speed of stressing the extreme fiber was approximately 100 lb per sq in per min Fragments were marked in order of severance, see Figure 10

Specific Weight Every fragment of each beam was weighed in air and under water From these weights the specific weights were given in Tables II and III

Compression After the specific weight determinations were made the fragments were capped on the surfaces which formed portions of the top and bottom of the beam A mixture of 1 part Incor cement and water tempered with 2 per cent of calcium chloride, by weight of the cement, served well for this purpose Capped specimens were stored under damp canvas over night and tested at a speed of 0 06 in per min on the next day. Loading was done as shown in Figure 8

RESULTS OF TESTS

The principal results of the tests on beams and fragments are given in Tables

II and III. Beams made with the same mix designation, sand, and frequency have been grouped together. Owing to lack of allowance for mixer losses in the batches for beams C1 to C4 and J1 to J4, these beams were somewhat undersanded and the results are not so satisfactory as those obtained from the beams made later.

Time-Frequency Relationships. From the data in Table II the average time required for water to appear at the unvibrated end of the beam, the total time of vibration, and the estimated time required for satisfactory vibration for each group of beams of a given mix, aggregate and frequency of vibration were computed and plotted against frequency in Figure 9. The curves show that the extent of influence of this internal vibrator did not reach the remote ends of the beams made with the dry mixes—J5, C5, U48—within a reasonable length of time when the frequency was 4000 r.p.m. or less. At 5000 r.p.m. the estimated time required for complete vibration of beams of these mixes was approximately 80 sec., at 6000 r.p.m. about 50 sec., and at 7000 r.p.m. approximately 40 sec.

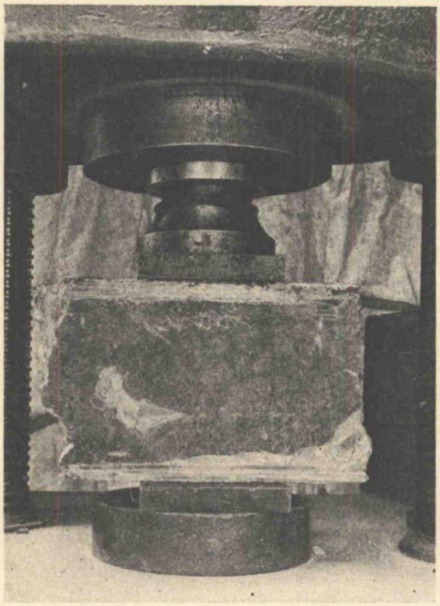

Figure 8. Method of Crushing Fragments of Beams

For the mixes of ½-in. slump—J55 and C55—the time required for this internal vibrator to extend its influence to the remote end was unduly long at 3000 r.p.m. as shown in Figure 9. At 4000 r.p.m. the estimated time required for satisfactory vibration averaged about 90 sec., at 5000 r.p.m. about 45 sec., and at 6000 r.p.m. approximately 25 sec.

Variation in Properties Along Beam. To illustrate the difference in extent of vibration due to use of different frequencies, the results from tests on beam J5 vibrated at 5000 r.p.m. for 104 sec. and beam J7 vibrated at 4100 r.p.m. for 180 sec. are shown in Figures 10 and 11. Figure 10 shows that pockets were present along the two sides of beam J7 for an average distance of 20 in. from the unvibrated end whereas beam J5 exhibited no pockets. In Figure 11 the strengths, densities, and cement-void ratios for the parts of beams J5 and J7 are plotted opposite the portions of the beam which they represent. It will be observed that the properties increase in value toward the vibrated end and that the range in properties is greater for beam J7 than for beam J5.

Further evidence of the more uniform surface appearance obtained with a high frequency is obtained from a comparison of beams J6 and J8 in the upper part of Figure 10. When beam J8 was vibrated the top surface indications pointed to completion of compaction after vibrating for 30 sec. but the end portion farthest from the vibrator was badly pocketed as shown. A vibration period of 80 sec. at

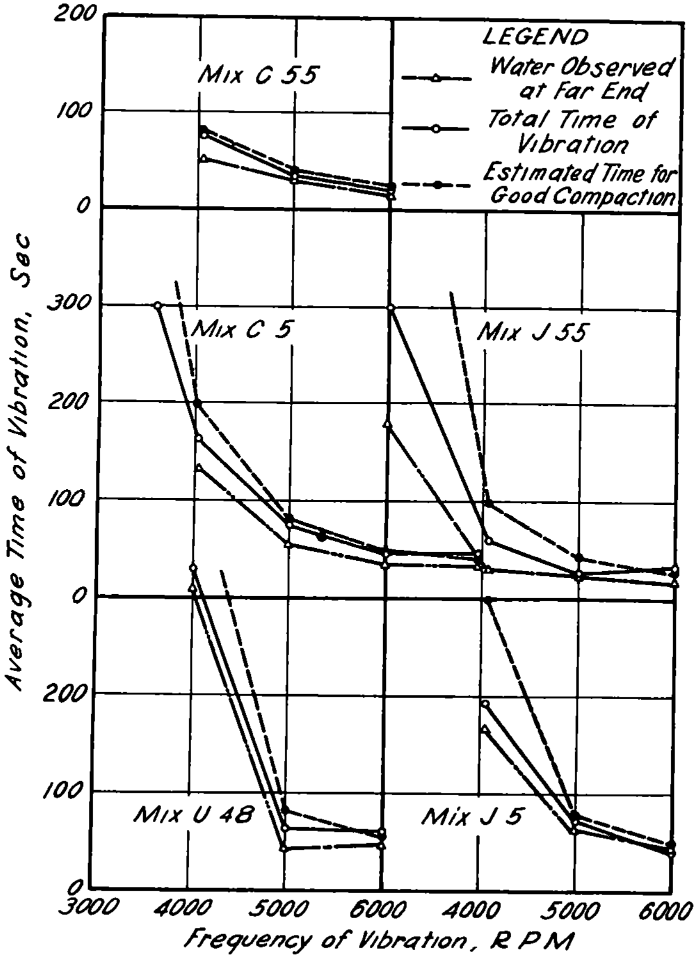

Figure 9. Time-Frequency Relationships for Various Mixes

4100 r p m would doubtless have produced satisfactory surfaces throughout this beam

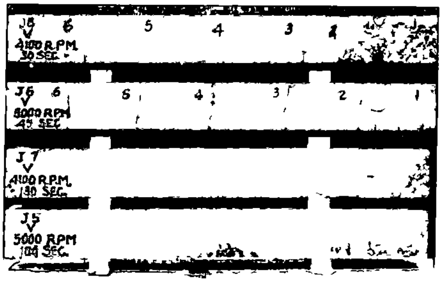

Figure 10. Examples of Insufficient and Sufficient Vibration in Placement

In Figure 12 beams J10 and J9 vibrated at 6000 r p m exhibit better surfaces than beams J12 and J11 vibrated at 4100 r p m Furthermore, the time required at the higher frequency was in both cases much less than for the beam of corresponding mix vibrated at the lower frequency The data in both Figures 10 and 12 show the substantial difference in the time required to vibrate the even numbered beams of mix J55 having ½-inch slump as compared to that required for the odd

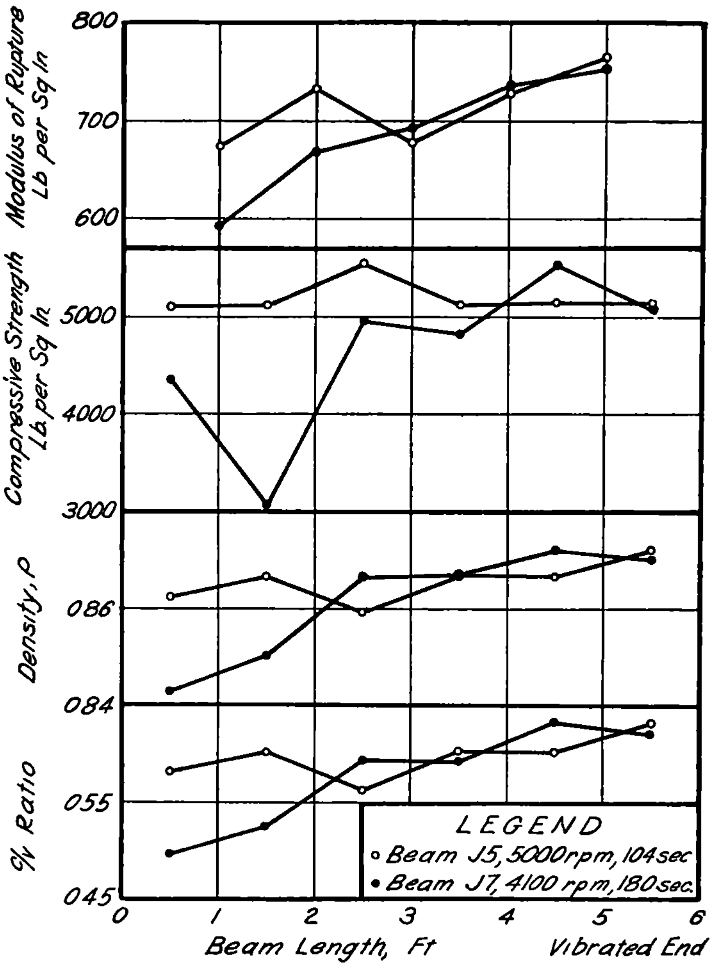

Figure 11. Effects of Vibration along Beams J5 and J7

numbered beams of mix J5 having no slump

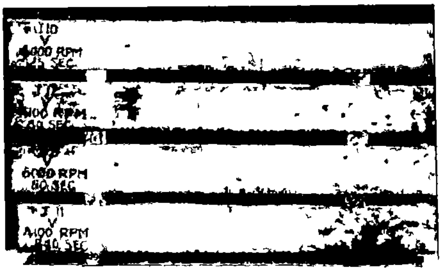

Figure 12 The Effectiveness of High Frequency Vibration in Placement

Relationships between Frequency and Physical Properties From Figure 13 may be visualized the relationships between the strengths of the individual beams vibrated for different lengths of time at various frequencies These data indicate that despite the longer periods of vibration used at the lower frequencies, both bending and compressive strength were best in the beams vibrated at the highest frequencies

In Figure 14 have been plotted the data showing the effect of frequency and time

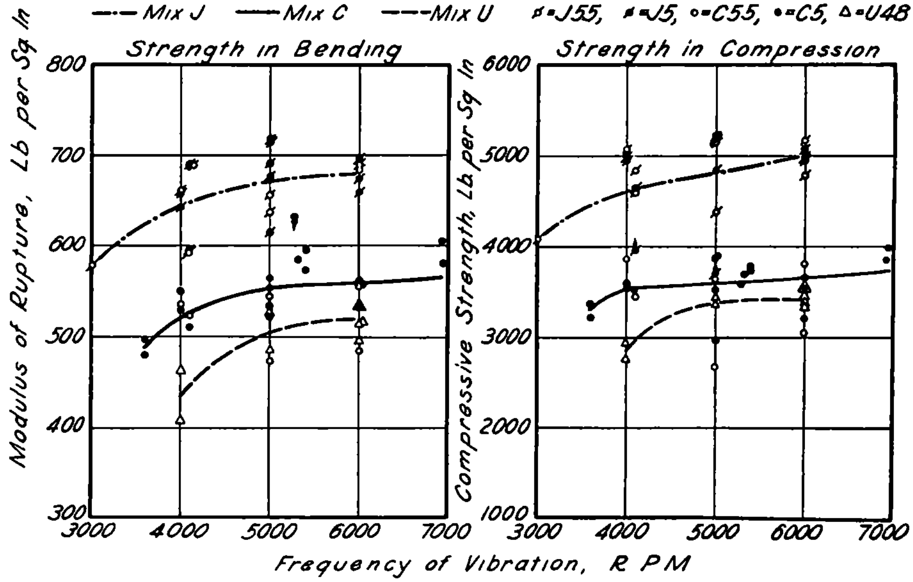

Figure 13 Relation of Frequency of Vibration to Strength (Time Variable)

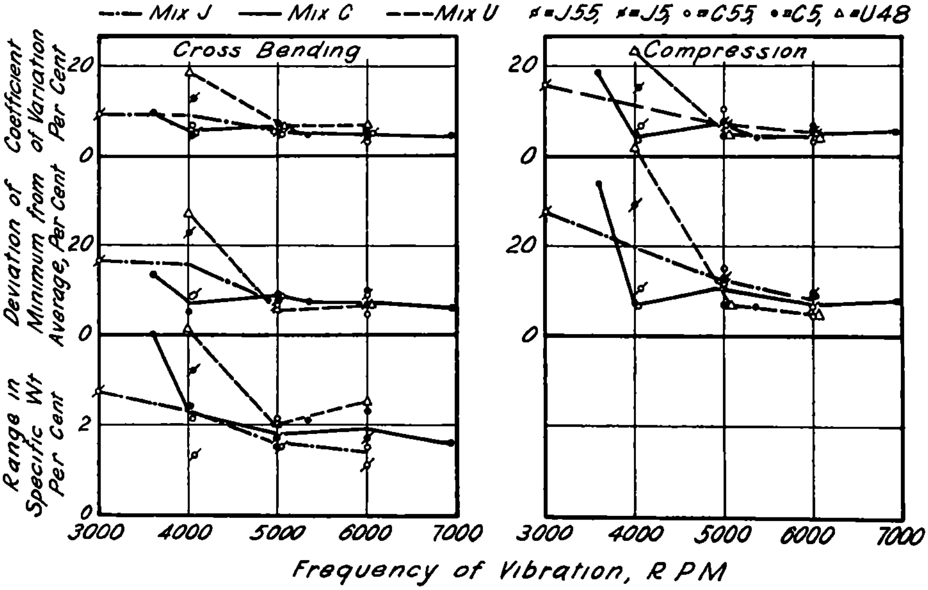

Figure 14 The Influence of Frequency of Vibration in Promoting Uniformity in Strength and Density of Concrete. (Time Variable)

of vibration on the uniformity[2] in strength and density The plotted points represent averages for the beams tested at the same frequencies These data show that greater uniformity in strength and density was obtained when the vibrator was run at the higher frequencies

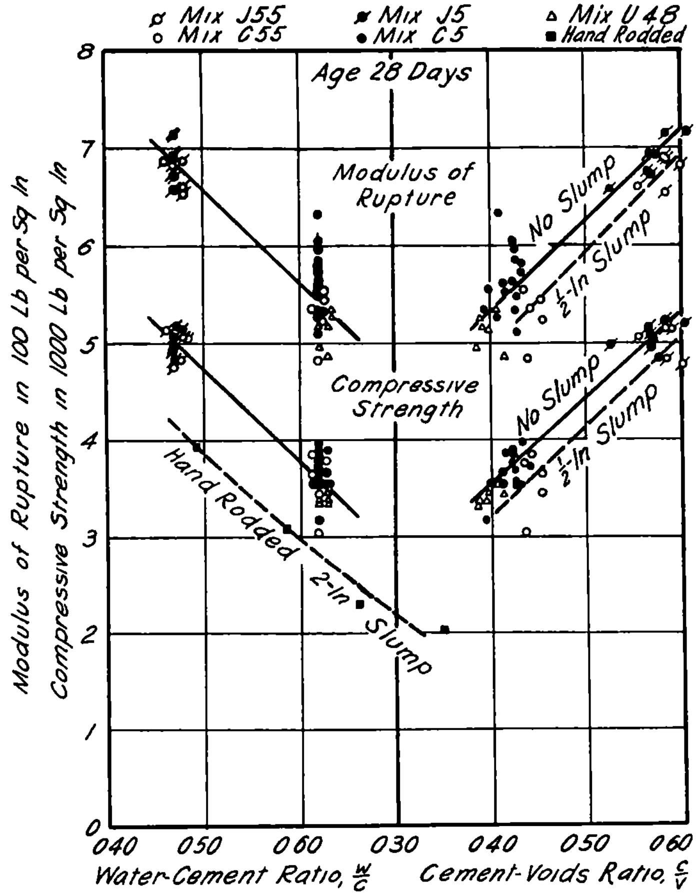

Figure 15 Influence of w/c and c/v on Strength of Well-Vibrated Beams

Power Consumption of Vibrator In order to obtain information on the power consumption of the internal vibrator when run at various frequencies, the flexible cable and spud were attached to a 5-h p high speed motor From readings of voltage, amperage, wattage, and a knowledge of the characteristics of the motor, Figure 17 was drawn These data show that the power consumed by the vibrator varied approximately as the cube of the frequency

Relation of Strength to w/c, c/v and Cement Content Considering only well vibrated beams the average modulus of rupture of each beam and the average compressive strength of the fragments

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[2] The coefficient of variation was computed from

$$100\left[\frac{(\text{Deviation from Average})^2}{\text{Number Averaged}}\right]^{\frac{1}{2}} - \text{Average}$$

from each beam have been plotted against the water-cement ratio, by weight, and also against the cement-voids ratio, in Figure 15. Including only well vibrated specimens the average ratio of the compressive strength of 6 by 12-in. vibrated cylinders to the compressive strength of companion beam fragments was 0.97 for the mixes with w/c = 0.47, and 0.95 for the mixes with w/c = 0.62. Hence the compressive strength of the beam fragments averaged about 4 per cent more than the strength of the standard type of cylindrical test specimen. This fact should be remembered in comparing the compressive strengths of the fragments with other data based on strength of standard cylinders. The data[3] on hand-rodded concrete in Figures 15 and 16 were obtained from tests on 6 by 12-in. cylinders made in standard manner with the same cement and aggregates as used in the vibrated beams. Each point represents four tests. It will be noted that the compressive strengths of the vibrated fragments were considerably more

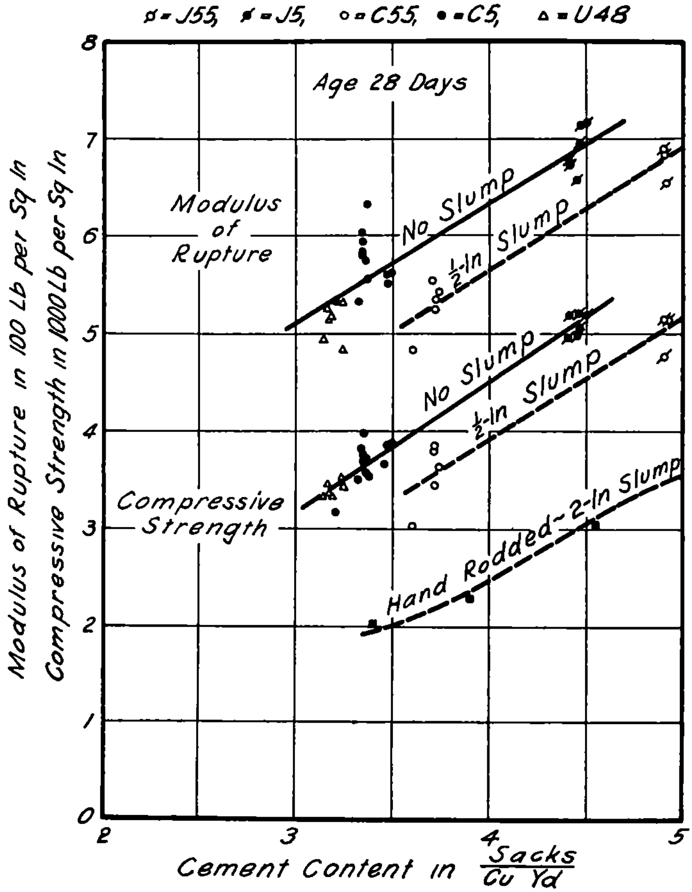

Figure 16. Strength-Cement Content Relationships for Well-Vibrated Concrete Beams

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[3] These data were obtained by Mr. G. W. Washa, Instructor in Mechanics at The University of Wisconsin, in connection with other tests which he is performing on vibrated mixes.

than 4 per cent higher than the hand-rodded concrete cylinders

The moduli of rupture results are also high for the w/c ratios represented

In the diagrams of Figure 15 showing relation of strength to the cement-voids ratio, c/v by absolute volume, the results for the drier mixes seem to be somewhat higher than those for the beams made with concrete having $\frac{1}{2}$ in slump The concrete of these well vibrated beams had unusually low void contents and hence high cement-void ratios in proportion to their cement contents

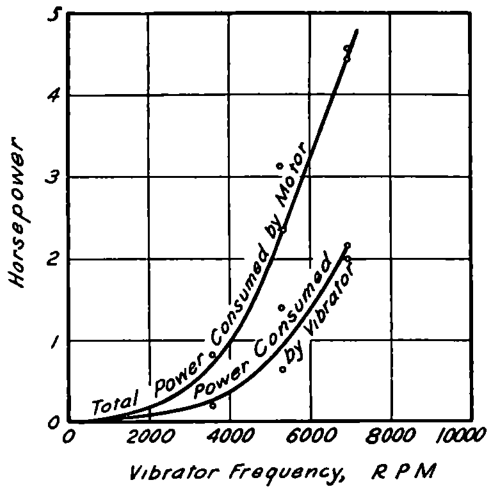

Figure 17. Power Consumed by 1$\frac{3}{4}$-In. Internal Vibrator at Various Frequencies

The data in Figure 16 show the high strengths obtained with relatively low cement contents in these well vibrated concrete beams The marked superiority of the vibrated concrete to the hand-rodded concrete made with a 2-in slump is noteworthy For a compressive strength of 3500 lb per sq in , the hand-rodded concrete required 50 per cent more cement than the no-slump vibrated Likewise for a cement content of 3 5 sacks per cu yd the no-slump vibrated concrete was nearly twice as strong as the hand-rodded

Influence of Power of Motor In the tests made on beams C25 to C35 in which the frequency was varied from 3600 to 5400 r p m , no marked difference was noted in the efficiency of the vibrator whether it was run by the regular $\frac{1}{2}$ h p motor or by the 5 h p motor Comparison of the strengths and densities of beams made at the same speeds with these different motors (see Tables II and III) shows these properties to be practically the same

Concrete Made with Fine Grained Sand Figures 15 and 16 show that the vibrated concrete beams of mix U48 made with the fine grained sand exhibited somewhat lower moduli of rupture values than the beams of similar mix, C5, made with well graded Janesville sand In compression, however, the tests of fragments of the U beams agreed well with the results of the beams made of C5 mix with Janesville sand

Beams Externally Vibrated From the tests of beams C21, C23, J25 and J27 it was apparent that vibrating with the full amplitude setting was much more effective than with the one-third amplitude setting Tests in which the effects of longer periods of vibration and higher frequencies could be studied are highly desirable

CONCLUSIONS

These conclusions are restricted to the type of equipment used It should be appreciated that no service tests were made of the internal vibrator at the high frequencies Hence, no predictions of the rate of depreciation of the flexible shaft or vibrator spud if run at high speeds can be made The motor, though not harmed by the overloading during these tests, was not designed for the higher speeds to which it was subjected

1 There was a marked decrease in the length of time required to compact properly no-slump concrete mixes as the frequency of the vibrator was raised from 4000 to 5000 r p m With such consistencies it would not appear practicable to use frequencies less than 5000 r p m The data indicate that the time of compaction can be further reduced and the homogeneity and strength somewhat increased by using still higher frequencies

2 Mixes of ½-in slump could be satisfactorily compacted by this internal vibrator at a frequency of 4000 r p m but the time of vibration was materially shortened by the use of higher frequencies

3 The estimated lengths of time required for satisfactory compaction of these beams by this 1¾-in internal vibrator follow

Slump	Time in Seconds for Satisfactory Vibration for Various Frequencies			
	4000	5000	6000	7000
½ inch	90	45	25	Not tested
None (5% water)	Over 200	80	50	40

4 With the higher frequencies of vibration and proper time intervals, surface pockets were eliminated but more or less air bubbles still remained

5 The power consumption of the internal vibrator increased approximately as the cube of the frequency

6 Considering that the internal vibrator was held throughout the vibration period at one end of a beam, the uniformly high strength and high density data obtained from the beams of no-slump concrete vibrated at the higher frequencies are remarkable

7 The strength data from the well vibrated beams furnish additional proof of the superior strength of vibrated concrete to that of hand-rodded concrete of like cement content, also they emphasize the superior economy of vibrated concrete over rodded concrete when made of equal strength

8 The well vibrated beams made with the fine grained sand had satisfactory strengths for their cement contents and exhibited good surfaces With high frequency vibration for placement of concrete, it would appear possible to use such sands much more effectively than with puddling or pouring methods of placement

9 From the data secured regarding the effect of frequency on the performance of the internal vibrator and the effect of amplitude on the external vibrator, it seems probable that more tests on the influence of variations in frequency and amplitude on the effectiveness of external vibrators when placed above beams or slabs would produce information of particular value in concrete pavement construction

DISCUSSION ON VIBRATION

Mr E W Bauman, *Department of Highways and Public Works, Tennessee* In the papers on "Vibration of Concrete for Pavements," it is noted that the strength factor of the vibrated concrete was given primary consideration, and only incidentally did one of the papers touch on the effect of honeycombing when using vibrators While the strength factor is very important, I believe atten-