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 $\frac{1}{2}$-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 $1\frac{3}{4}$-in internal vibrator follow

Slump	Time in Seconds for Satisfactory Vibration for Various Frequencies			
	4000	5000	6000	7000
$\frac{1}{2}$ 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 attention to the possibility of eliminating honeycombing should also come in for its share of interest In my opinion the real value of vibrating concrete for pavements lies more in the elimination of honeycombing than in the increase of strength

Within the past year the trend on the part of highway designing engineers is to cut down the length of pavement sections between expansion joints, so that the possibility for honeycombed sections in the center of the pavement at the point where the transverse joint intersects the longitudinal joint, is increased as the number of joints are increased In the thickened edge design most commonly employed, too often the thickness at the center is already at a critical minimum If the thickness at this zone is reduced by honeycombing at the bottom of the pavement, so-called corner breaks in the center of the pavement and joint intersections are bound to develop

In Tennessee, we investigated the extent to which honeycombing occurred at this section of concrete pavements by having cores drilled 4, 6, and 8 in back from the transverse joint and along the edge of the longitudinal joints Two-thirds of the cores taken from the 4-in and 6-in intervals had honeycombing at the bottom of the cores, varying from $\frac{3}{4}$-in. to $1\frac{1}{2}$-in. It is in the elimination of this condition that I view with interest the possibilities of vibrating concrete for pavement construction

Mr F H. Jackson, *U S Bureau of Public Roads* I might add that the internal vibrator has been used quite successfully for vibrating concrete in the proximity of transverse joints

I am interested also in surface scaling. A number of construction engineers with whom I have talked have raised the question of the possible scaling of a vibrated surface due to over-manipulation At the Bureau we have been investigating durability somewhat as a continuation of our 1931 experiments We have been freezing and thawing selected cores taken from certain test sections and we now have, I think, in the neighborhood of 400 alternations of freezing and thawing We find no more tendency toward scaling in the cores taken from the vibrated sections than we do in the cores from the non-vibrated sections In general, the vibrated cores are in much better condition now than those taken from sections which were non-vibrated

In connection with the work in Missouri, Mr Willis mentioned the fact that we have about reached the ultimate in the way of harsh dry mixes due to the limitations of the present equipment for mixing and distributing the concrete There is no question but that the present types of external vibrators are capable of satisfactorily compacting much drier, harsher concrete than can be efficiently handled by the other units in the construction operation I think we should emphasize from now on the necessity of developing these other features, namely, mixer design, distributing operations, etc , so as to be able to handle the very dry concrete which we believe can be placed provided we can get it to the vibrators

Mr R. B Gage, *New Jersey Highway Department*· I am particularly interested in the statements made by Mr Litehiser with reference to the variation in the relative strengths of the concrete secured on the different contracts, and on the same contract Apparently several different brands of cement were used, and the compressive strengths of the concrete thus produced appear to vary greatly with these different cements

I am curious to know what, if anything, has been done about the future use of those cements that produce low strength concrete Is it the intention to continue to use these cements or is it intended to have the manufacturers improve the quality of their product so that the concrete constructed from it will be comparable with that secured from other cements? The standardization of the cements that are being used appears to be of vital importance

The average compressive strength at 28-days of the cores taken from all pavements constructed during the first six-months of 1935 has been a little over 6100 lb , and about 5900 lb for the cores from pavements constructed since July 1st The average compressive strength for the season has not yet been computed but I feel fairly certain that the average will not be less than 6000 pounds

It may be that the equipment and methods used in the construction of the concrete mentioned by Mr Litehiser is responsible in part for the low strength secured, but they cannot be entirely to blame, for even when we finished concrete by hand and the materials were not so well graded as those we are using today, we usually secured compressive strength of not less than 4500 lb at 28-days, and considered the concrete very poor if the compressive strength did not go over 4000 lb

Unfortunately very little data were given regarding the methods of preparation of the concrete, that is, the grading of the aggregates, mixing time, mixing water used, etc , and whether the aggregates were of the proper cleanliness If these conditions were normal, I cannot understand why they did not get better results There must be something wrong when one State requires the use of concrete that has a compressive strength of 5000 lb and usually secures 6000 lb , while another State only secures 4000 lb , especially if the quantity of cement used per cubic yard is about the same

Securing the strengths which we are now getting in New Jersey, requires us to use special precautions in preparation of the mixtures, method of mixing, water content, and the manner in which the pavements are finished If the sand is not of the right composition, the aggregates dirty or improperly graded, or excess mixing water is permitted, it is self-evident that very few, if any, cements will overcome the handicap to which they are thus subjected It is frequently claimed that unless excess mixing water is used, the pavements will be porous and full of voids, but with properly balanced mixtures and the elimination of abbreviated mixing periods, no such defects have developed on any of the pavements constructed in New Jersey during the past season In other words, there has been no honeycombing, and the density of the concrete is equal to or exceeds that which would be secured with a sloppy concrete mixture

Mr Goldbeck Do you attach much importance to the presence of fines in the sand

Mr Gage Yes We have a minimum requirement on that

Mr Goldbeck What is it?

Mr Gage Not less than 12 per cent shall pass a 50-mesh sieve, and we prefer to have from 15 to 18 per cent When the sand is deficient in such fine material, both the density and workability of the concrete is affected When the concrete does not naturally have the desired workability, it is safe to assume that the contractor will make it work by adding more water, also, harsh and unworkable concrete mixtures do not have the plasticity needed for proper and easy placement When these various factors are properly controlled, we have very little if any trouble with the workability of the concrete and in securing the desired density and strength

MR R R LITEHISER, *Ohio State Highway Department:* I can hardly let this pass without some minor comment On this particular project which Mr Gage is referring to we had concrete of around 4000 lb at seven days and a little over 5000 lb at 28 days Now that is, I will say, above the average of our usual practice It may be that we have not reached the proficiency in Ohio as far as concrete practice is concerned that my friend Mr. Gage has in New Jersey Again, it may be that the climate is more favorable to the development of higher compressive strength in New Jersey than in Ohio I won't attempt to explain all of that

I would like to call attention to one thing that was presented in the chronological strength batch We start with 5000 pounds at seven days Now we were featuring this project largely from the contractor's point of view and it was not practical to finish that 5000 pound concrete the way we desired it Perhaps with a little more experience we can acquire some of the increased proficiency they have in New Jersey I think we can get 5000 pound concrete in Ohio and perhaps a little more as we go along So far as placing penalties on low strength cements is concerned we do not do that We do not have a strength specification On every job we endeavor to get as good concrete as we can I realize that is not a complete answer I doubt if a complete answer could be given