DEPARTMENT OF MATERIALS AND CONSTRUCTION

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USE OF VIBRATION IN PLACING SCREENINGS IN MACADAM BASES

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SYNOPSIS

In an effort to improve the construction of drybound and waterbound macadam bases, tests were made using vibratory methods of placing the screenings. Some limited observations were also made on the ability of vibratory methods to key coarse aggregate.

Two types of machines were used to place the screenings. One was essentially a three axle tandem roller. The center roll was an idler which could be vibrated at the rate of 3600 pulsations per minute. The other consisted of a crawler propelled frame which moved a battery of six vibrating shoes over the course. The shoes vibrated at the rate of 2800 pulsations per minute.

The projects using two types of aggregates, different thicknesses of courses and different rates of application of screenings are described. It was discovered that vibration was of questionable value in the keying of the coarse aggregate but remarkably efficient in the placing of the screenings.

Using generally accepted methods of construction, an excessive amount of hand labor is required to build a well bound, smooth surface macadam base. Other types of construction have forged ahead partially due to the advancements being made in the invention and design of construction machinery and the improvements in construction methods. Some attention has been paid to the design of mechanical spreading equipment. However, the construction of macadam bases was still a slow process. Recently engineers and machinery manufacturers have become interested in further improvements of the machinery and construction techniques used in macadam construction. The possibility of using vibration to build smoother macadam bases, speed up their construction and reduce construction costs was envisioned by Ohio Highway Department engineers. It remained for manufacturers of machinery to produce machines utilizing this principle, and applicable to macadam construction.

PLAN OF PROCEDURE

Two manufacturers came forward in 1946 and expressed a desire to cooperate by developing such machinery. The Buffalo Springfield Roller Company who had long been in the business of building rollers, the principal tools used in macadam construction, and the International Vibration Company of Cleveland, who had built vibration machinery utilized in the construction of street railways and concrete repair and construction work.

Fortunately each of these manufacturers had a different approach to the problem. The Buffalo Springfield Roller Company's approach was to combine in one machine vibration with rolling. The International Vibration Company believed in the application of vibration by a machine designed solely for this purpose.

These manufacturers agreed to furnish machines for preliminary demonstration and experimental work, if the highway department would set up experimental projects to try out these machines. Both manufacturers first tried out their machines on driveways at their own plants or on other privately arranged demonstrations. These demonstrations were viewed by engineers of the highway department and other interested parties. At these demonstrations the performance of the machines was discussed and suggestions were made regarding modifications needed in the designs and arrangements made for further demonstrations on state highway jobs. As soon as the manufacturers were ready other demonstrations were made on jobs supervised by highway department engineers.

DESCRIPTION OF MACHINES

The Buffalo Springfield Roller Company, through one of its foreign associates, had learned of a vibrating roller manufactured by the Pedershaab Machine Works of Denmark. It was claimed by its manufacturer that the machine built macadam pavements smoother and cheaper than by the conventional methods. The Buffalo Springfield Roller Company had one of these rollers (minus the engine) shipped to its plant, where they installed an American made engine. This roller was basically an 8-ton tandem roller with a third roll of the same width as the front and rear rolls but slightly smaller in diameter and mounted between them. This third roll was an idler roll furnishing no tractive effort but capable of being vibrated. The vibration was accomplished by an unbalanced shaft rotating at a high speed. It could be operated with the third roll floating or locked in position so that the rolling surface was tangent to the other rolls or could be elevated so that it was inoperative. This roller is shown in Figure 1. The general dimensions and specifications of this machine are given in Table 1.

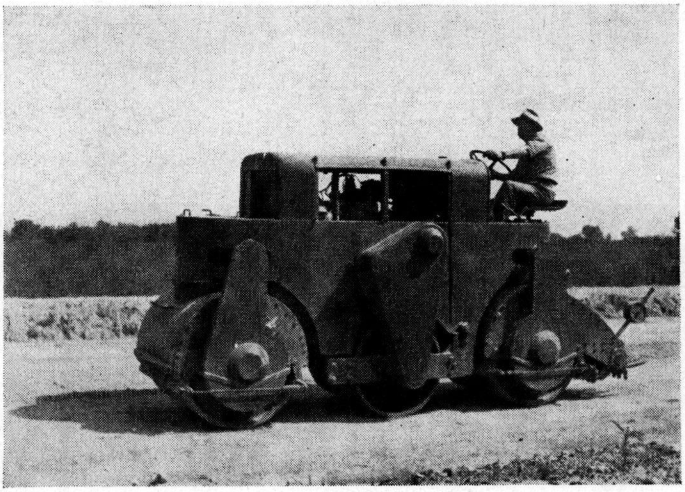

Figure 1. Perdershaab—Buffalo Springfield Vibratory Roller

The International Vibration Company's vibrator was a machine of radically different design. It consisted of a crawler propelled frame which moved a battery of six vibrating shoes over the base. Although each shoe received its power from the same source and was free to move up and down independently of any of the other shoes, each shoe had its own vibrating mechanism. The vibration was accomplished by a rotating unbalanced shaft mounted on each shoe (See Fig. 2). The general dimensions and specifications of the original machine are given in Table 2.

The later improved model was redesigned to include two basic improvements.

1. A crawler track assembly which increased the length of track on ground and materially reduced the tendency of the machine to rock while in operation.

2. A new vibration mechanism consisting of twin opposed unbalanced gears mounted on each shoe. This device controls and gives direction of the vibratory forces eliminating the horizontal components. In the original model the horizontal components of vibration were dissipated through the frame of the machine instead of being transmitted to the pavement (Fig. 3). Specifications for the improved model are given in Table 3.

Experimental Projects—When the first tryouts on macadam bases were made no one knew what to expect from the use of vibration. Could these machines key the coarse aggregate? Could they place screenings and effectively fill the voids? Would they tend to

TABLE 1
BUFFALO SPRINGFIELD ROLLER SPECIFICATIONS

Weight	
Metal Weight, *lb.*	15,430
Full Water Ballast Weight, *lb.*	17,650
Rolls	
Diameter Of Guide And Drive Rolls, *in.*	39.4
Width Of Guide And Drive Rolls, *in.*	39.4
Diameter Of Vibrating Roll, *in.*	32.3
Width of Vibrating Roll, *in.*	39.4
Weight Of Vibrating Roll Assembly, *lb.*	2000
Vibration Frequency, *vib. per min.*	3600
Dimensions	
Overall Length, *in.*	160
Overall Width, *in.*	55.2
Transmission Speeds	
1st, *mph.*	0.49
2nd, *mph.*	0.96
3rd, *mph.*	1.92
4th, *mph.*	3.98
Compressions	
Without Ballast—With Vibrator Raised—Guide And Drive Roll, *lb. per linear in.*	196
With Ballast—With Vibrator Raised—Guide And Drive Roll, *lb. per linear in.*	224
Without Ballast—With Vibrator Locked Tangent—All Rolls, *lb. per linear in.*	129
With Ballast—With Vibrator Locked Tangent—All Rolls, *lb. per linear in.*	151

loosen up the coarse stone rather than bind it? Would the density and stability of the resulting macadam be as great as when built by conventional methods? The subsequent work answered all of these questions but the last. Figures 4 to 15 are photographs taken during the tests.

An industrial driveway 10 by 300 ft. at the Buffalo Springfield Roller Company's plant at Springfield, Ohio, was selected for the initial demonstration of the vibrating roller. The driveway was divided into test sections to test the effectiveness of the vibrating roller in keying and filling courses 4, 6, 8, and 10 in. thick. The thinnest section was a 4-in. first course and 6-in. second course and the thickest a 4-in. first course and 8-in. second course. A 1-in. layer of stone screenings was placed on the subgrade before the coarse aggregate was spread to act as an inverted choke. The coarse aggregate used was $3\frac{1}{2}$- to $1\frac{1}{2}$-in. crushed limestone, and $\frac{3}{8}$-in. to No. 100 mesh limestone screenings. The work was done according to the accepted construction methods set forth in the Ohio Highway Department specifications except that:

1. The coarse aggregate was tailgate-spread and levelled with a blade grader and hand labor,
2. A portion of the job was constructed 8 in. thick in one course,
3. Screenings were placed using a vibratory roller in much larger increments than would normally have been permitted.

Figure 2. First Model Vibro-Tamper Manufactured by International Vibration Company

It was soon evident after construction was started that keying of the coarse aggregate was being accomplished just as readily without the application of vibration as with vibration. Ohio's specifications for waterbound construction require that the roller used for keying the aggregate have at least 380-lb. compression per lin. in. width of driving roll.

There is some question as to whether or not the vibratory roller, which weighed only 196-lb. per lin. in., keyed the stone as well as they can be keyed with the heavier roller. Some portions were subjected to as many as eight passes with the roller without a satisfactory key being obtained. This could not be blamed on a spongy sub-base as it held true on the second course as well as on the first course and on subgrade that would be considered amply stable. However, the ability to lock the third roll tangent to the other rolls made it possible to iron out bumps resulting from faulty spreading of the coarse aggregate. Here the application of vibration was beneficial. Bumps $\frac{3}{4}$ in. high could be ironed out in a few passes of the roller. If the bumps were much higher than this they would cause so much weight to be lifted off the front roll that the rear roll started to spin displacing the coarse aggregate. Certain improved features are being incorporated in the design of the vibrating roll assembly which will make it more efficient in rolling out bumps and should make it virtually impossible to stall the roller.

The outstanding feature of the demonstration was the placement of screenings by vibration. Dry screenings spread at the normal rate of about 15 lb. per sq. yd. for the first application, vanished completely after one pass with the roller vibrating. Larger and larger amounts of screenings were added until it was found that on a 4-in. macadam course 1 to $1\frac{1}{2}$ in. of loose screenings could be vibrated with two passes of the roller to completely fill the voids. On the portion where 10 in. was constructed in one course a spread of over 3

TABLE 2
INTERNATIONAL VIBRATOR SPECIFICATIONS

Overall Width, *ft.*	12
Length Of Crawler Track On Ground, *in.*	13
Width Of Crawler Treads, *in.*	16
Travel Speed, *ft. per min.*	12 to 24
Weight Of Machine, *lb.*	5200
Vibrator Engine Power, *HP. at 2000 rpm.*	19
Crawler Engine Power, *HP. at 2000 rpm.*	9
Number Of Vibrator Shoes	6
Vibrator Shoe Dimension, *in.*	16 by 24
Surface Contact Area Of Each Shoe, *sq. in.*	180
Total Weight Of Each Vibrator Shoe Assembly, *lb.*	130
Unbalanced Weights Of Vibrator Mechanisms, *lb.*	6.6, 10.5, and 13.2
Vibration Frequency, *vib. per min.*	3000
Amplitude Of Vibration In Suspension, *in.*	0.025

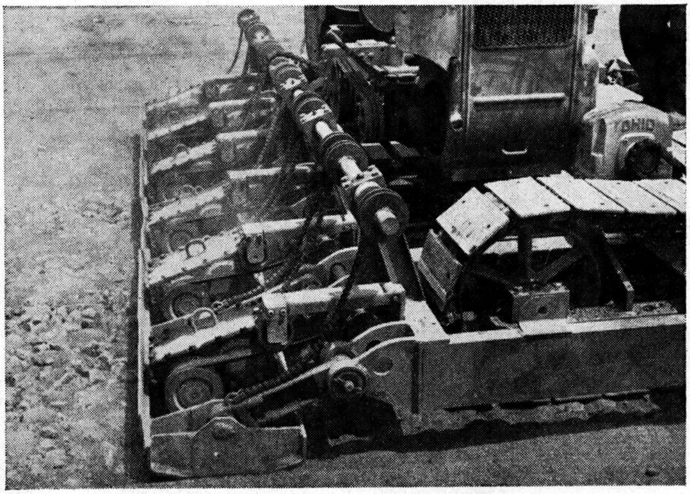

Figure 3. Second Model Vibro-Tamper

TABLE 3
SPECIFICATIONS FOR INTERNATIONAL VIBRO-TAMPER

Overall Width, *ft.*	12.6
Length Of Crawler Track On Ground, *in.*	47
Width Of Crawler Treads, *in.*	12
Travel Speed, *ft. per min.*	10 to 140
Weight Of Machine, *lb.*	6400
Vibrator Enginer Power, *HP. at 2000 rpm.*	30
Crawler Engine Power, *HP. at 2000 rpm.*	20
Number Of Vibrator Shoes	6
Vibrator Shoe Dimensions, *in.*	20 by 25
Surface Contact Area Of Each Shoe, *sq. in.*	306
Total Weight Of Each Vibrator Shoe Assembly, *lb.*	180
Unbalanced Weight Of Vibrator Mechanism, *lb.*	16
Vibration Frequency, *vib. per min.*	2800
Amplitude Of Vibration In Suspension, *in.*	0.080

in. of screenings was vibrated into place to completely fill the voids in three passes of the vibratory roller (See Fig. 7). On this project the screenings were very dry and particle shape of both aggregates was very good. In this experiment it was impossible to judge just how much fine aggregate would be required to fill the voids in any one spot. As a result some spots had an excess of screenings

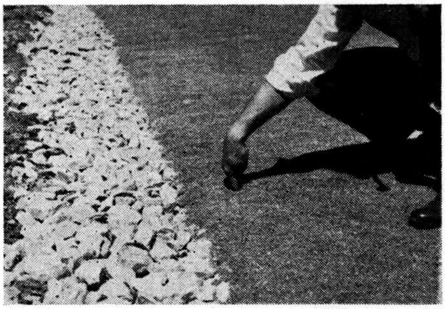

Figure 4. Approximately 1½ in. of Screenings Spread Prior to Rolling with Vibratory Roller.

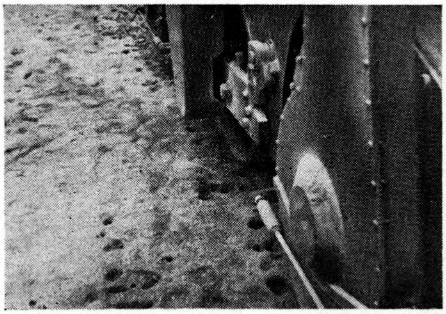

Figure 5. Same Area as Figure 4—Note screenings being vibrated into place on first pass of roller.

while other spots were short of screenings, requiring some brooming off or addition of screenings in spots to obtain uniform filling. Holes were dug in various places to check the adequacy of screening and rolling, and in no instances were unfilled voids observed.

A second experiment was tried with the vibratory roller on a state highway job constructed by the maintenance forces. This project consisted of acceleration and deceleration lanes adjoining an existing pavement on U. S. Route 40, 2 miles west of Columbus, Ohio. The job naturally divided itself into two operations so it was decided to build the deceleration lane in two 4-in. courses and the acceleration lane in one 8-in. course. The aggregates were 3½- to 1½-in. crushed limestone and ⅜-in. to No. 100 mesh limestone screenings.

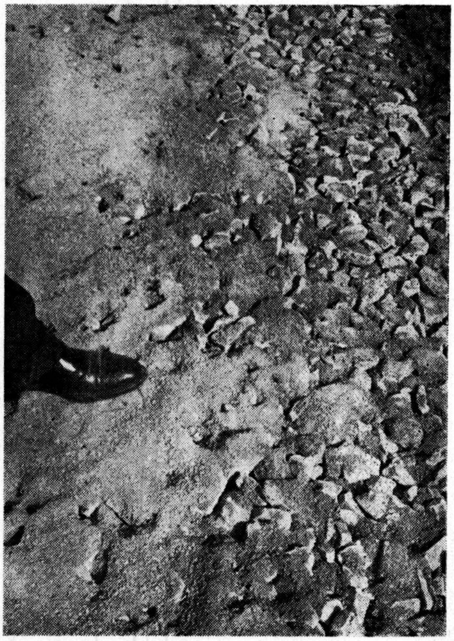

Figure 6. Same Area as Figure 4 after Two Passes of Vibratory Roller.

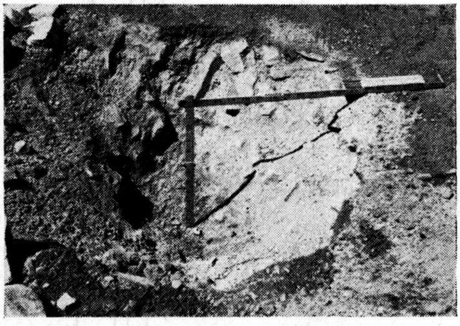

Figure 7. Eight-Inch Course Filled with One 3-In. Application of Screenings and Five Passes of Vibratory Roller.

The coarse aggregate was spread through a spreader box and levelled up by hand labor, the screenings were spread through a mechanical spreader of the rotating cylinder type. Though the vibrating feature of the roller did little toward keying the coarse aggregate it was of material help in the levelling operation. It was not necessary to correct bumps by hand repair work after rolling was started. Manipulation of the vibratory roller with the vibrator floating first and then locked tangent to the other two rolls, made it possible to iron out any high spots.

Placement of screenings was accomplished after spreading by vibration. It was possible to dry fill the voids in the 4-in. course of coarse aggregate with one spread of screenings and two passes of the vibrating roller. However, variation in the grading of the coarse aggregate and the variable void ratio resulted in some spots being overfilled. When an excess of screenings was present "pancaking" occurred with damp screenings. With dry screenings over-rolling and over-vibrating caused the coarse aggregate to loose its key and float to the top. Only one instance of this was observed, and this was done deliberately to observe the result of overfilling and over-rolling. Ten passes with the roller vibrating was required to bring this about.

The portion built in one 8-in. course required four passes with the roller and one application of screenings to fill the voids. The experience gained on this and the previous job indicated that the practical method to vibrate screenings into a macadam base would be to apply about 50 to 75 percent of the estimated amount of total screenings required for the course in the first application following this with one or more applications varying the quantity to obtain uniform filling. Both of these jobs received a prime and seal treatment with liquid bituminous materials and cover aggregate shortly after construction of the base and are giving excellent service.

During the year another series of demonstrations was carried out using the International Vibration Company's Vibro-Tamper. The first demonstration was also an industrial driveway built at the plant of the Columbus Coated Fabrics Company in Columbus. The drive was about 300 by 20 ft. plus some parking and turning area, constructed of drybound macadam 10 in. thick in two courses. Three and one-half- to $1\frac{1}{2}$-in. crushed limestone aggregate and $\frac{3}{8}$-in. to No. 100 mesh limestone screenings were used in the base construction. The vibrator in this case was used as supplementary equipment, most of the keying and filling being done with the aid of an 8-ton three-wheeled roller. The vibrator was first tried as a means of keying the coarse aggregate. The results obtained were not as satisfactory as those obtained with the standard macadam three-wheeled roller. On the filling operation more favorable results were observed. The vibrating shoes on the machine had vibration mechanisms designed to furnish vibratory forces of three intensities. The shoe on the extreme right which received the maximum vibration performed very satisfactorily. The other shoes were not so effective. This is shown in Figure 8. Screenings spread in one application 1 in. thick were

Figure 8. Surface After One Pass of First Model Vibro-Tamper—Note increase effectiveness of heavier unbalanced weight on right hand shoe.

vibrated into place with one pass of the vibrator along the path travelled by this shoe. Mechanical difficulties and unfavorable weather conditions hindered the work, nevertheless it was demonstrated that vibration without excessive weight on the vibrating element could satisfactorily place the screenings. The manufacturer of the machine also discovered many of the shortcomings of the pilot model. As mentioned before the length of track on ground was too short resulting in a rocking motion when the machine was working and the unbalanced shaft vibrating elements resulted in as much work being dissipated through the machine as was transmitted to the pavement through the shoes.

A second machine was built eliminating these two undesirable features, and was tried out on a contract project on U. S. Route 250 near Mt. Eaton, Ohio in Wayne Co., later in the season. This project consisted of 3.42 miles of 8-in. waterbound macadam base course laid on 6 in. of selected sub-base material and topped off with a liquid bituminous surface treatment. The materials used in the base course were $3\frac{1}{2}$- to $1\frac{1}{2}$-in. blast furnace slag and $\frac{3}{8}$-in. to No. 100 mesh slag screenings. The macadam was laid in two 4-in. courses built in all respects to conform to the standard specifications, the

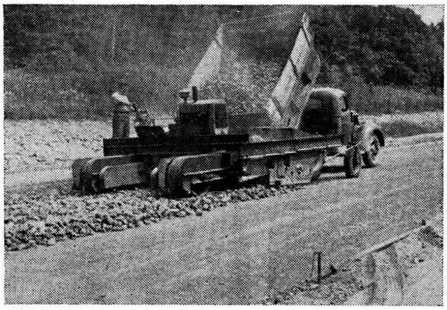

Figure 9. Spreading Coarse Aggregate with Self-Propelled Oscillating Screed Type Spreader.

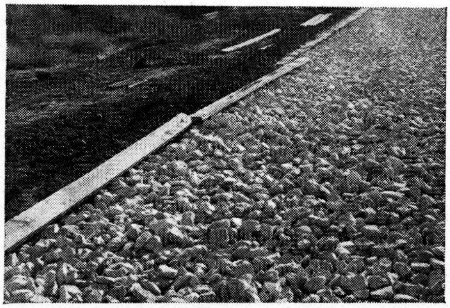

Figure 10. Coarse Aggregate with Forms Removed Ready for Keying.

Vibro-Tamper machine being used to place the screenings. No compromise was made in the construction procedure as the minimum number of roller hours clause of the specifications was enforced even though placement of the screenings was accomplished by vibration. Thus this job had more rolling than would normally be required for keying the coarse aggregate and waterbinding.

The coarse aggregate was spread with a self-propelled hopper type spreader with an oscillating screed type leveller. Wooden 2- by 6-in. planks were used for side forms to confine and assist in the levelling of the coarse aggregate. After some hand levelling was

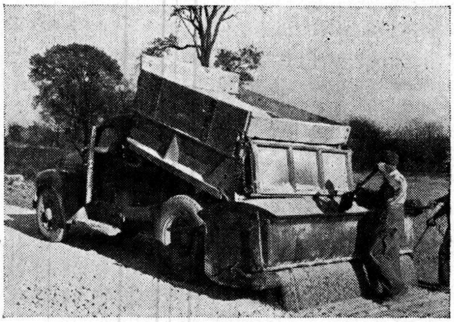

Figure 11. Spreading Screenings on Keyed Coarse Aggregate with Roll Type Spreader.

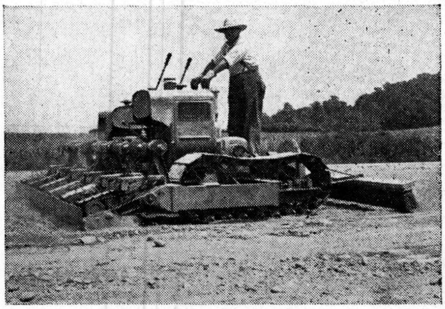

Figure 12. Vibrating Screenings with Vibro-Tamper

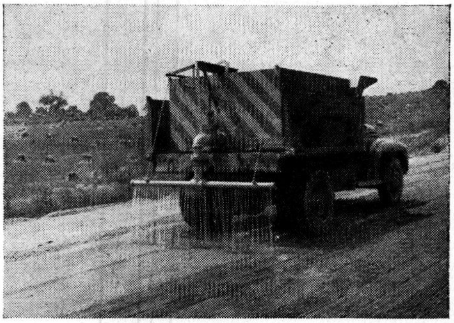

Figure 13. Applying Water to Filled Area.

done the forms were removed and the coarse aggregate keyed by three or four complete rollings with a 10-ton three-wheeled roller. On each rolling the track of the driving wheels was required to lap the track of the driver on the adjoining pass. Immediately thereafter slag screenings amounting to about one-third that estimated to be required were spread over the keyed coarse aggregate through a revolving cylinder type spreader and vibrated into place with one pass of the vibrating machine. The remainder of the screenings were applied in the same manner in two increments. Occasionally some hand spotting and additional vibration was used if more screenings were required. After the dry filling, the base was thoroughly wet down followed by additional rolling or vibration and application of screenings, this cycle being repeated until the interstices were filled to the top of the coarse aggregate. Usually two light applications of screenings followed by wetting and rolling were required. The second course was a repetition of the first.

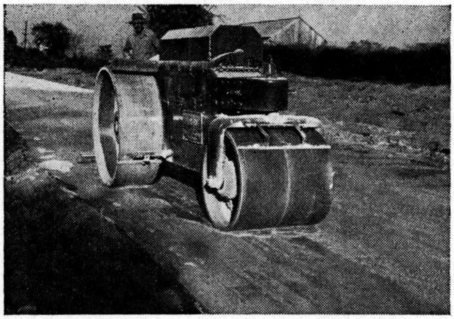

Figure 14. Waterbinding Course—Note grout in front of rolls.

Actual data obtained after completion of the Wayne Co. job are given in Table 4.

Another contract project utilizing the International Vibration machine was constructed on U. S. Route 42 at Bellepoint about 5 miles southwest of Delaware, Ohio. This project consisted of 2.79 mi. of 24.5 ft. wide and 8 in. thick macadam base course laid on 7 to 12 in. of granular sub-base and topped off with a liquid bituminous prime and surface treatment. In this case stone aggregate 3½ to 1½ in. in size and stone screenings ⅜ in. to No. 100 mesh were used. Construction procedure was the same as that followed on the previous job. Upon completion of the macadam base course the data in Table 4 for Delaware Co. were obtained.

An interesting observation was made during the construction. The contractor who had had no previous experience with macadam construction opened up approximately ½ mile of the job to traffic immediately after completion of the water-binding and before any bituminous prime had been applied. The traffic was about 1900 vehicles per day of which 24 percent was commercial. Two weeks after this traffic was routed over this

TABLE 4

Wayne County, U. S. Route 250	
Area 8-In. Course, *sq. yd.*	31772
Total Weight Of Aggregates (Slag), *T.*	10920
Weight Of Coarse Aggregate (Slag), *T.*	7642
Weight of Screenings (Slag), *T.*	3278
Aggregate Rate, *T. per in. per sq. yd.*	0.0430
Delaware County, U. S. Route 42	
Area 9-In. Course, *sq. yd.*	19653
Total Weight Aggregate Used (Limestone), *T.*	9001
Weight Of Coarse Aggregate Used, *T.*	6702
Weight Of Screenings Used, *T.*	2299
Aggregate Rate, *T. per in. per sq. yd.*	0.0509
Area 8-In. Course, *sq. yd.*	8488
Total Weight Aggregate Used (Limestone), *T.*	3431
Weight Of Coarse Aggregate Used, *T.*	2555
Weight Of Screenings Used, *T.*	876
Aggregate Rate, *T. per in. per sq. yd.*	0.0506

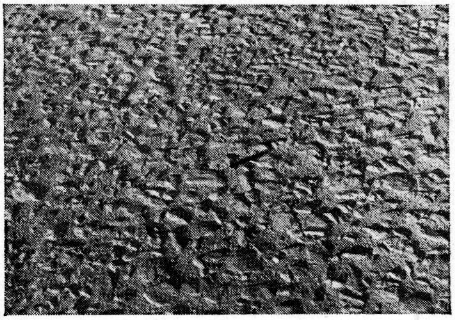

Figure 15. Surface Texture Completed Macadam Base Course After Two Weeks Traffic.

section, and two weeks without rain at that, no ravelling or disintegration of the macadam base was observed. Another inspection was made six weeks after opening this section to traffic. The pavement was still in good condition even though no bituminous prime had been applied (See Fig. 15).

The contractors on both of these jobs were enthusiastic about the performance of the Vibro-Tamper in placing screenings.

CONCLUSIONS

Though too little actual data or service experience has been acquired to date to form sound conclusions, the following are indicated:

1. The value of vibration as an aid in keying coarse aggregate is questionable.

2. Vibration materially reduced the labor and equipment hours required in filling macadam pavements.

3. Macadam pavements filled by vibratory methods appear at least as dense and stable as those built by the conventional methods.

EFFECT OF AIR ENTRAINMENT ON THE DURABILITY CHARACTERISTICS OF CONCRETE AGGREGATES

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SYNOPSIS

This paper reports a study of the relative durability of air-entrained concrete compared to normal portland cement (cement to which no air-entraining agent has been added) concrete using coarse aggregates with varying field performances. Two gravels, one bad and one fair in field performance, and two limestones, one bad and one good in field performance, were used as coarse aggregates in this study. The moisture condition of the aggregate was controlled by immersing it for 24 hours or by evacuating and saturating it. Two hundred and forty 3- by 4- by 16-in. beams were made, representing 48 batches of 5 beams each. A maximum size aggregate of 1 in. and a cement factor of approximately 6 bags per cu. yd. of concrete were employed. The air content of the concrete was measured by the pressure method and varied from 0.1 percent to 7.5 percent. The beams were subjected to alternate cycles of freezing at −8 F. partially submerged in water, and thawing at 60 F. in running water until their dynamic modulus of elasticity was reduced 30 percent or until 100 cycles of freezing and thawing had been completed.

The presence of entrained air caused a slight reduction in the water requirement, the flexural strength, and the dynamic modulus of elasticity of concrete, and increased the durability from 5 to 50 times depending upon the quantity of entrained air and the coarse aggregate. Laboratory results for normal portland cement concrete closely paralleled the aggregates' field performance. Increases in the air content of only 0.3 percent in normal portland mixes (with air contents in the range of 0 percent to 1 percent) significantly increased the durability of the concrete. With a given aggregate the most durable concrete was made with air entrainment and immersed aggregate; the least durable concrete was made with normal portland cement and evacuated aggregate. An air content of three percent appeared to be adequate to produce durable concrete except for very porous coarse aggregates placed in concrete in a highly saturated condition.

This paper reports a study of the relative durability of air-entrained concrete compared to that of normal portland cement concrete. Durability in this report is defined as the resistance to repeated laboratory cycles of freezing and thawing and is measured in number of cycles. The work was conducted under the combined auspices of the Bureau of Materials and Tests of the State Highway Commission of Indiana and the Joint Highway Research Project of Purdue University and was financed by the State Highway Commission of Indiana.

The work described in this paper is a result of a previous study which was reported to the Highway Research Board in 1945 by Woods, Sweet, and Shelburne (*1*)[1] which contained the results of a 3,300-mile survey of rigid pavement performance in Indiana. The 1945

[1] Italicized figures in parenthesis refer to list of references at the end of the paper.