FIELD EQUIPMENT FOR VIBRATORY COMPACTION OF SOILS AND BASE COURSES

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SUMMARY

This report reviews briefly the types of vibratory compaction equipment available for field use in the United States and summarizes the results reported from various sources Results obtained with lightweight equipment in preparing experimental pavement sections at the Technical Development and Evaluation Center of the Civil Aeronautics Administration are described in considerable detail

Although the field information is not extensive, it is concluded that vibratory equipment has potential value in three types of compaction operations (1) compaction of fine-grained noncohesive materials, (2) compaction in restricted areas, and (3) use as auxiliary equipment in compaction of coarse-graded noncohesive materials Further development and exploratory testing are needed in order to show the full extent of these potentialities

INTRODUCTION

Modern rolling equipment is quite efficient for compaction of the usual cohesive soils and soil mixtures, provided the moisture content of the material is near the optimum value. There are indications, however, that vibration (or a combination of vibration and static loading) might be more effective and economical in compacting granular or noncohesive materials In some applications, vibratory equipment may also have an advantage due to the possible use of small lightweight units

Although the interest in vibratory compaction has been evident for a number of years and several types of equipment have been developed, there is practically no published information on the field results obtainable by this method of compaction As a consequence, the person with a cursory interest in the subject has no ready means of evaluating vibratory compaction or of determining its possible application to his own problems This report summarizes the results of a brief survey of the manufacturers and users of vibratory compaction equipment. While this survey is not exhaustive, it furnishes some guidance to those who may be contemplating the use of vibratory compaction equipment The report also includes the results of experience with small vibratory compactors at TDEC

EQUIPMENT AVAILABLE

Correspondence and personal contacts with manufacturers disclosed a wide variety of vibratory compaction equipment available in the United States for field use The types of equipment offered by various manufacturers are described briefly in the following

Buffalo-Springfield Roller Company, Springfield, Ohio

The Buffalo-Springfield Company has developed a roller, shown in Fig 1, which appears to be a variation of the earlier Petershaab roller from Denmark A vibrating roll replaces the conventional middle roll of the Model KX25, 12 3/4- to 19 1/4-ton, 3-axle tandem roller A 55-horsepower (hp) gasoline engine supplies power through a chain drive for the vibrator in the center roll The weight of the roll is 2,640 pounds, and the vibration frequency ranges from 1,800 to 3,600 vibrations per minute The equipment may also be operated as a conventional roller.

The machine has been tested extensively at the manufacturer's plant and also has undergone a series of tests by the Corps of Engineers, U S Department of the Army, at Fort Belvoir, Virginia Information concerning actual field use is rather meager, and it is understood that only experimental models have been constructed to date

Electric Tamper and Equipment Company, Ludington, Michigan

The Electric Tamper and Equipment Company manufactures the "Jackson" line of small vibrating plate units which it recommends for small-scale work on asphaltic concrete as well as on embankment and base-course materials The design of this equipment has been changed from time to time over a period of about four years with increasing emphasis on greater weight, higher impact forces, and reduced contact area A floating shock-mounted counterweight has been used on all except the earliest models

On various models the base plate is about two and a half feet long and about one foot six inches wide and has been furnished

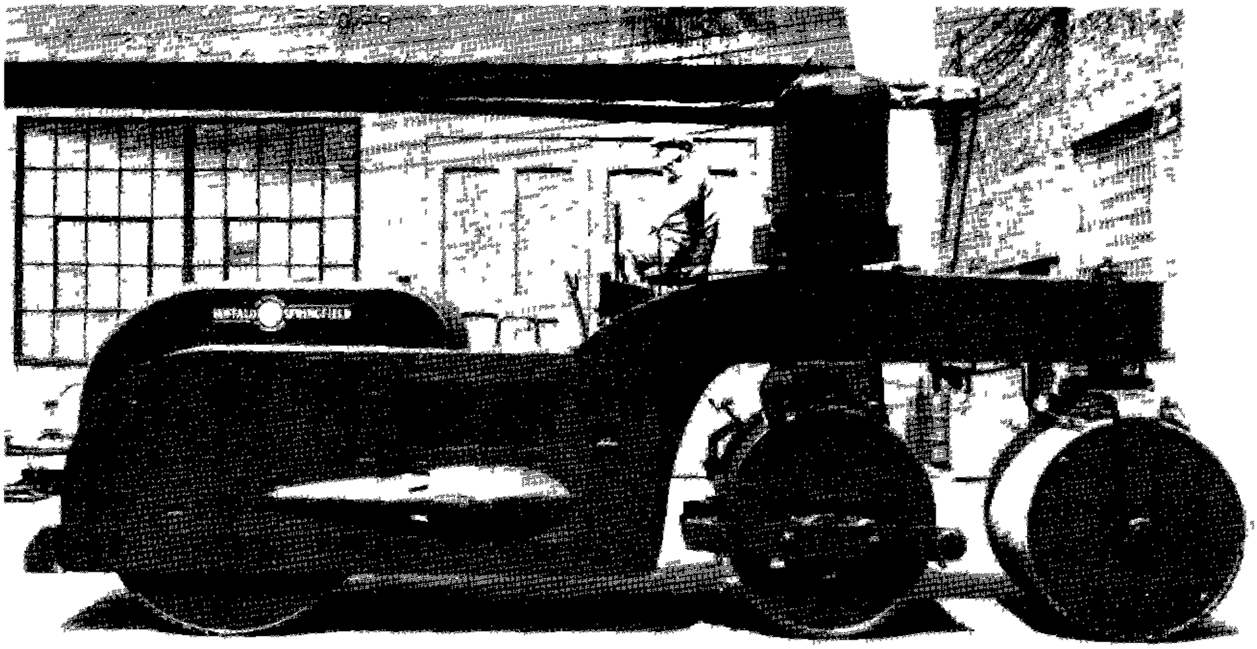


Fig 1 Buffalo-Springfield Vibrating Roller

with either a grooved or a flat bearing surface In some instances the contact area has been decreased by attaching one or more narrow strips to the bottom of the base plate at right angles to the direction of travel, in order to increase unit pressure

The present production model weighs 400 pounds including counterweight and is illustrated in Fig 2 Vibration is induced by means of an unbalanced weight rotated by a squirrel-cage 3,600-revolution per minute (rpm) motor with the axis at right angles to the line of travel The amount of unbalance is 5 44 inch-pounds The position of the unbalanced weight, slightly ahead of the center of gravity, produces a forward motion of the machine A heavier vibrator with 8 0 inch-pounds of unbalance is contemplated

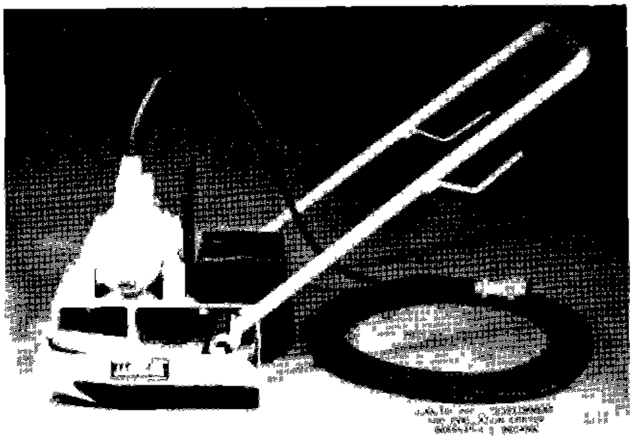


Fig 2 Lightweight Jackson Vibrator

The Jackson equipment includes a portable gasoline engine generator which provides a 3-phase, 60-cycle per second (cps), 110-volt power supply at rated speed The operating frequency of the vibrator can be varied up to a maximum of about 4,200 vibrations per minute by varying the generator speed Such speed also changes the magnitude of the centrifugal force and the resulting impact

About 300 units of the various models of this small compactor have been manufactured and sold The manufacturer also reports the development and assembly of a pilot model of a heavy-duty multiple-unit compactor designed for large-scale airport and highway construction The general design of this machine is illustrated in Fig 3

C A Lowe Machine Works, Inc ,
Columbus, Ohio

The Lowe company manufactures "The Ideal Vibra-Tamper" shown in Fig 4 This also is a small vibrating-plate unit with interchangeable tamping plates 2 1/2 inches wide and either 21 or 25 inches long The static weight of the machine is 235 pounds

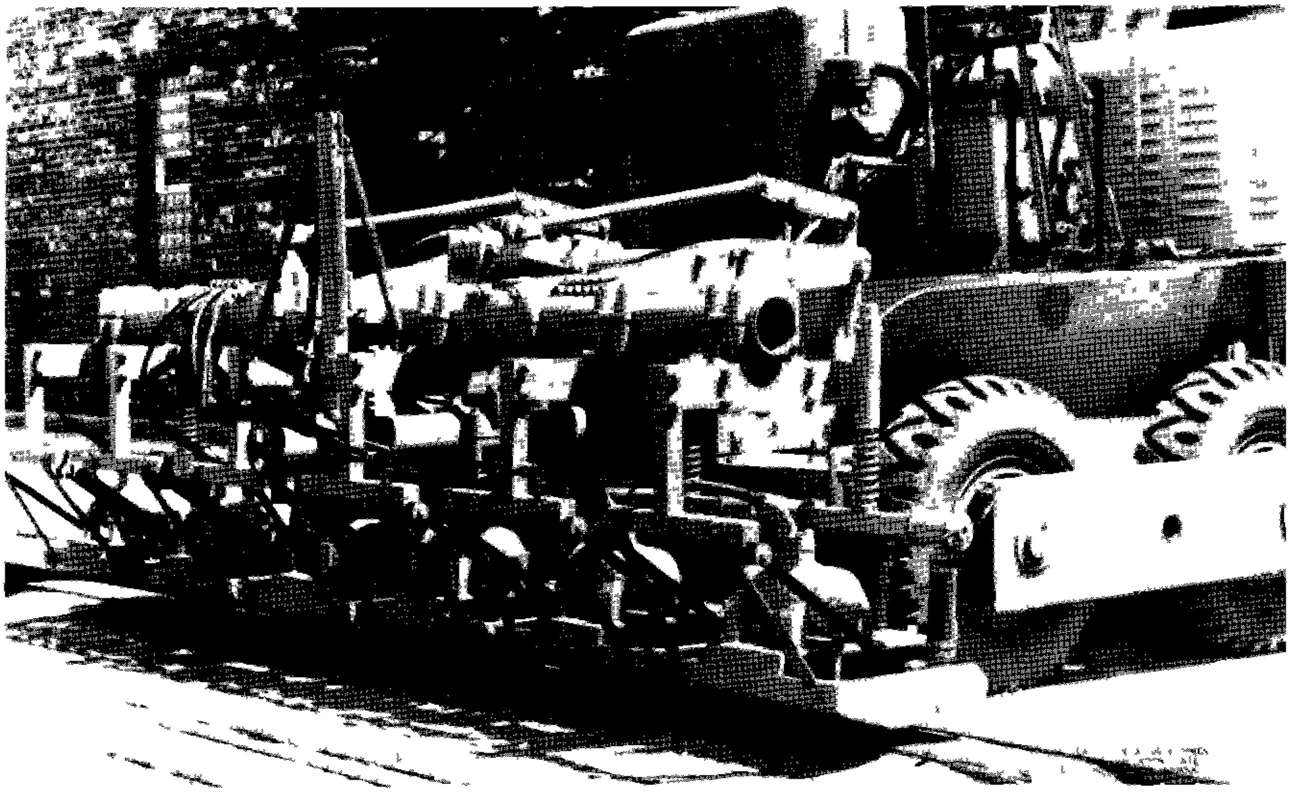


Fig 3 Multiple-Unit Jackson Vibratory Compactor

Power is furnished by an integrally mounted 2-hp gasoline engine which operates at about 2,000 rpm and induces gyratory motion of the entire machine through an eccentrically weighted shaft The machine is designed in such a manner that the exhaust heat from the engine is used to warm the tamping plate This is intended to help prevent the plate from sticking to hot asphalt mixtures

The rubber-tired wheels are used only in moving the equipment from place to place All of the weight is supported on the contact plate during operation Forward motion can be governed by the operator simply by tipping the machine to vary the fore-and-aft distribution of weight on the contact area The normal rate of movement is about 25 to 30 feet per minute

Iowa Manufacturing Company,
Cedar Rapids, Iowa

The "Cedarapids" compactor built by the Iowa Manufacturing Company is a heavy, two-wheeled, rubber-tired roller with a vibrating unit connected directly to the axle It requires a separate towing tractor The compactor has a maximum weight of either 25,000 or 60,000 pounds, depending on the

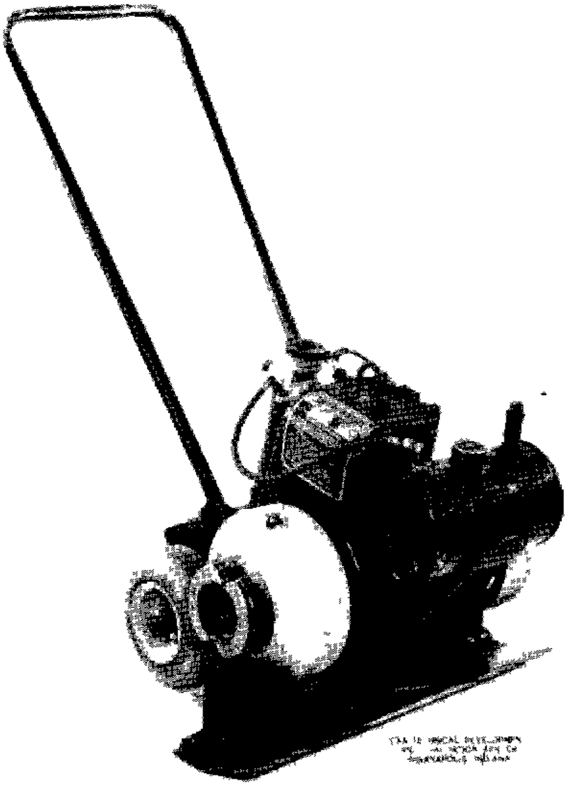


Fig 4 Ideal Vibra-Tamper

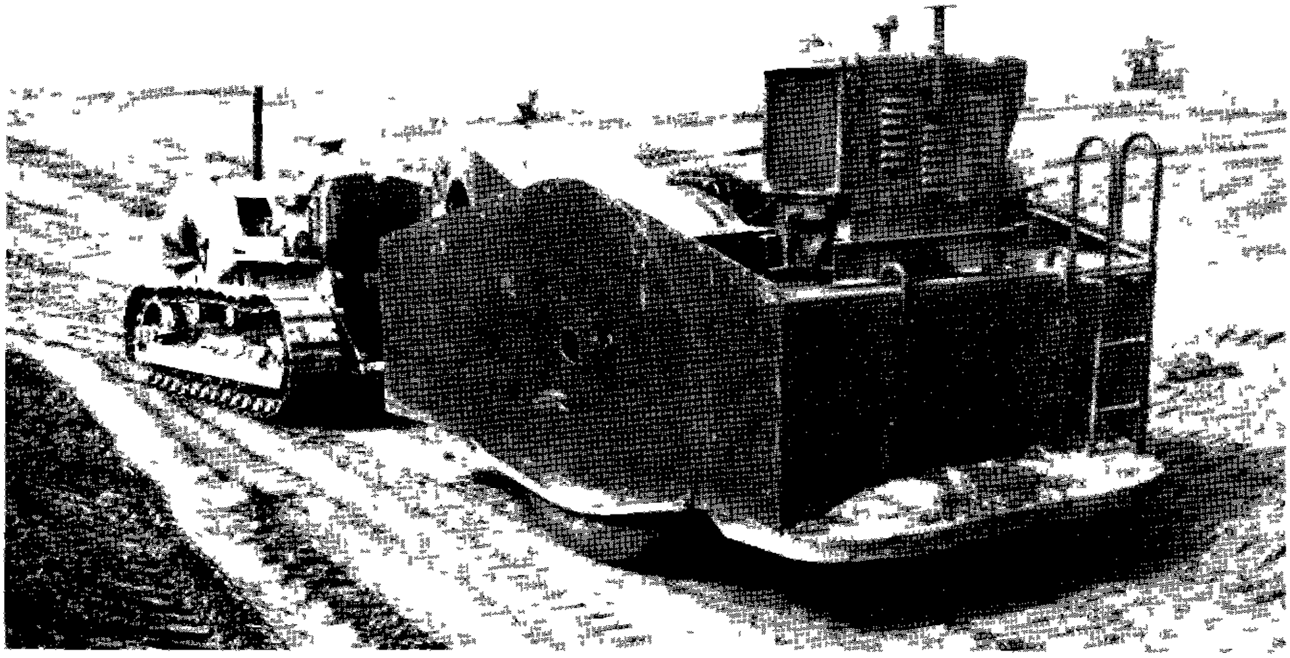


Fig 5 Cedarapids Vibrating Roller

model selected The heavier model is illustrated in Fig 5 About one-half of the total weight is composed of ballast, and the weight of body and ballast is spring-supported It is possible to vary both the total weight and the tire inflation pressure within wide limits in order to meet local conditions

A separate power unit operates the vibrator at a rate which is adjustable between 600 and 1,400 cycles per minute Vertical vibrations are produced by counterrotating eccentric weights The equipment can be operated as a conventional roller without the vibrator if desired.

The International Vibration Company,
Cleveland, Ohio

The "Vibro-Tamper" of the International Vibration Company is one of the better-known heavy vibrators It is a multiple-plate type with a gross static weight of about 9,000 pounds Its principal design features are shown in Fig 6

The main frame of the machine is carried on crawler tracks with motive power furnished by an 85-hp gasoline engine The rate of travel can be varied from 16 to 45 feet per minute

There are six vibrating shoes that weigh 435 pounds each and cover a 12-foot strip in one pass of the equipment The shoes are vibrated by power taken from the same source that propels the machine The rate of vibration is 2,000 to 2,800 vibrations per minute

Vibro-Plus Products, Inc ,
Woodside, Long Island, New York

The Vibro-Plus "Terrapac" soil compactor pictured in Fig 7 is recommended by the manufacturer for compacting embankments, backfills, earth dams, base courses, and foundations It has a heavy vibrating base plate which is 65 by 45 inches and is in direct contact with the soil The vibrator element which is hinged to the base plate uses two eccentrics which rotate synchronously in opposite directions The combined centrifugal force of the eccentrics is given as 9,000 pounds and the frequency as 950 vibrations per minute The static weight is 3,300 pounds

The compactor is powered by a Diesel engine of about 10 hp mounted on an elastically supported base The machine is self-propelling at speeds of 19 to 26 feet per minute on level ground, and the movement can be governed by means of a wheel fitted on the steering handle The rate of travel can be increased by towing the machine with a tractor when compacting large areas

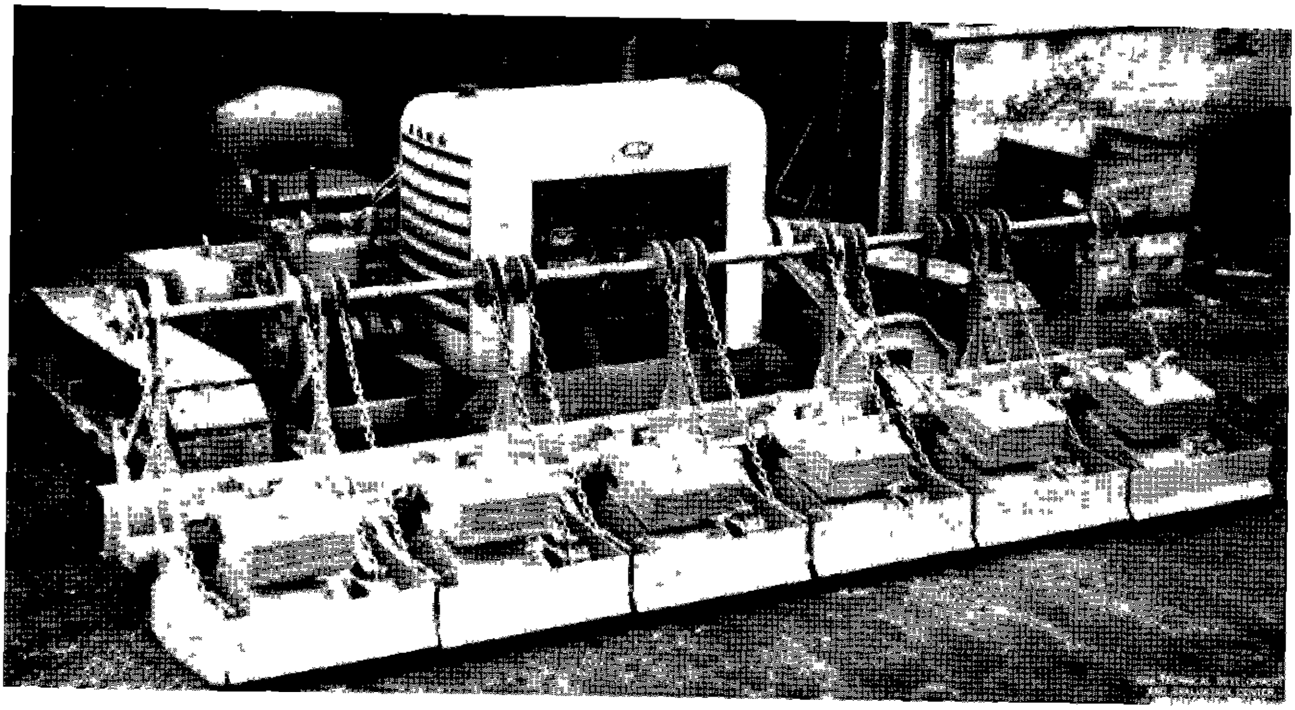


Fig 6 Multiple-Unit International Vibro-Tamper

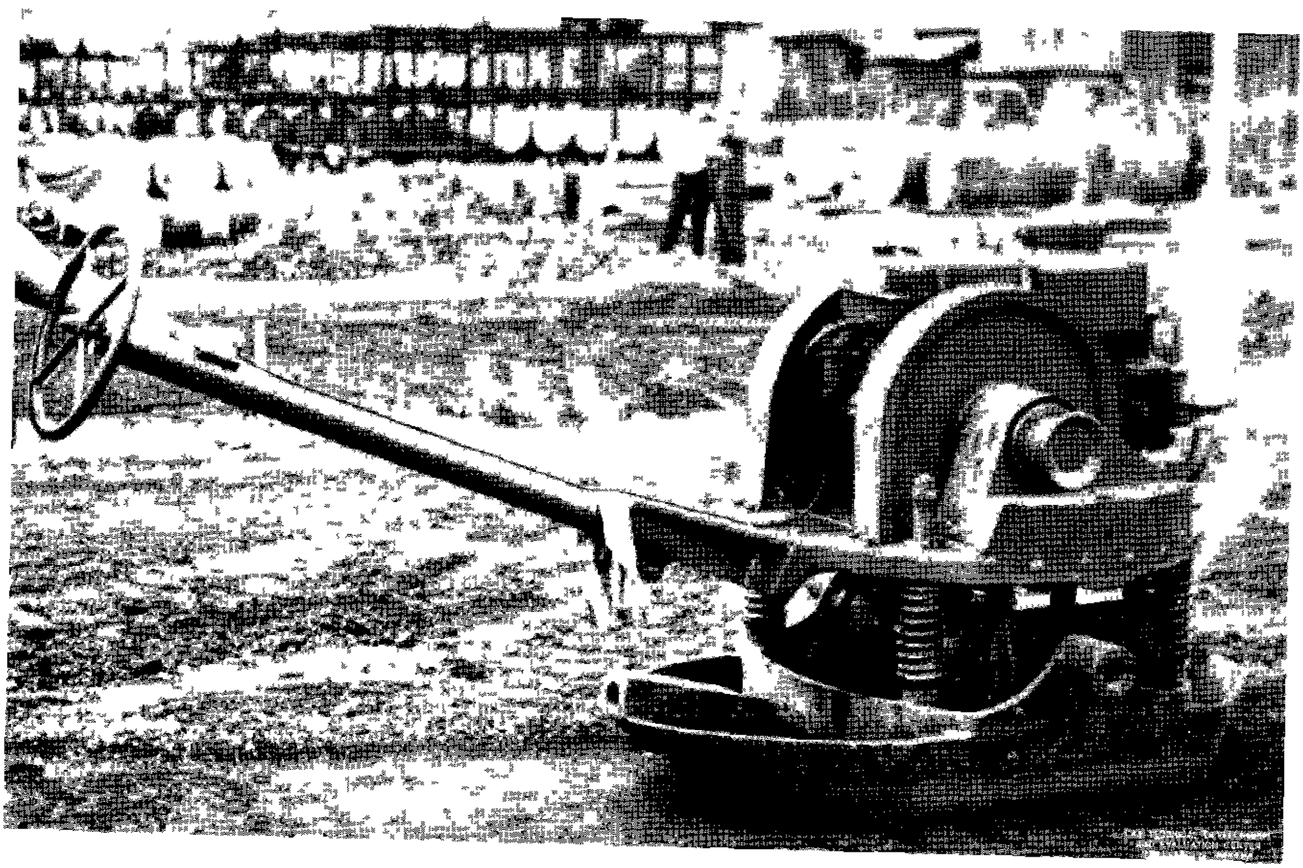


Fig 7 Vibro-Plus Terrapac Vibratory Compactor

Fig 8 Wayer Impactor

Wayer Impactor, Inc ,
Columbus, Ohio

The Wayer "Impactor" shown in Fig 8 appears similar to the Ideal Vibra-Tamper in its basic design and operating characteristics It weighs 240 pounds, is powered by a 2 1/2-hp gasoline engine, and is self-propelled at a speed of 22 to 30 feet per minute Gyratory motion of the entire machine is induced by rotation of an eccentric weight at a frequency of 1,900 rpm The tamping plate is 25 inches by 2 1/2 inches in area and is warmed by the engine exhaust The engine features a special carburetor designed to avoid disturbance of gas flow due to vibration Although designed originally for small-scale asphalt work, the equipment has been used extensively for backfill compaction of both granular and plastic materials

Miscellaneous.

There are a number of small tampers on the market which were not included in this compilation because of their limited capacity

RESULTS OF USER SURVEY

The survey of those using vibratory compaction equipment was not exhaustive because of time limitations, but it did cover a representative group of prospective users Letters were sent first to the highway departments of all the states and the District of Columbia, because they represent the largest single group which might have authoritative and unbiased information These preliminary inquiries were followed by further letters and in some instances by interviews Replies were received from all but six organizations and are summarized in Table I

TABLE I

SUMMARY
OF HIGHWAY DEPARTMENT SURVEY
ON VIBRATORY COMPACTION

State Highway Department	Indication of Interest	Experience
Alabama	Yes	Negligible
Arizona	---	No
Arkansas	---	No
California	Yes	Slight
Colorado	---	No
Connecticut	---	No
Delaware	Yes	No
Dist of Col	---	No
Florida	Yes	Yes
Georgia	---	No
Idaho	---	No
Illinois	---	No
Indiana	---	No
Kentucky	Yes	No
Louisiana	---	No
Maine	---	No
Maryland	---	No
Massachusetts	Yes	No
Michigan	Yes	Yes
Minnesota	Yes	No
Mississippi	---	No
Missouri	---	No
Montana	---	No
Nebraska	Yes	No
New Hampshire	---	No
New Mexico	Yes	No
New York	Yes	Yes
North Carolina	Yes	No
Ohio	Yes	Yes
Oregon	Yes	No
Rhode Island	---	No
South Carolina	---	No
South Dakota	Yes	No
Tennessee	Yes	No
Texas	Yes	Yes
Utah	Yes	No
Vermont	---	No
Virginia	Yes	Yes
Washington	Yes	Yes
West Virginia	Yes	Yes
Wisconsin	---	No
Wyoming	---	No

While the response to this survey indicated wide interest in the subject, there were only eight states reporting any experience with vibratory equipment in the compaction of soils and base-course materials either in the field or in the laboratory Abstracts of these and of other reports follow

Florida

The 60,000-pound Cedarapids compactor has given very good results in compacting 6- and 8-inch thicknesses of lime rock base The 25,000-pound model has been used successfully in placing embankment and subgrade materials in 6-inch layers One hundred per cent of standard Proctor density has been reported

Michigan

The Michigan standard highway specifications require that all structure backfill be placed and compacted to a specified density The material is generally granular Both the Wayer Impactor and the Chicago Pneumatic Tri-Plex tampers have been used successfully for this purpose

One contractor in the Detroit area used a Vibro-Plus compactor on sand backfill in a water-line trench. Densities of approximately 98 per cent standard Proctor were obtained at depths of 18 to 24 inches with four to six passes of the equipment It was especially noted that this compactor operates at 950 vibrations per minute, although previous Michigan experience had indicated 2,700 to 4,000 as the most efficient rate

Many contractors throughout the state have used the small Jackson vibrator with very good results The main objection to this equipment is its small size, which limits its practical application to small areas only

New York

Considerable success was reported in the use of the Jackson equipment for compaction of noncohesive materials in confined areas Experience indicates that the effectiveness may be greatly reduced by amounts of fine material (minus 200-mesh sieve) as low as ten per cent

Ohio

Early work with vibratory equipment on macadam construction has been reported in the 1947 "Proceedings of the Highway Research Board"[1] Equipment included the International Vibro-Tamper and a three-axle, eight-ton roller with vibrating center roll furnished by the Buffalo-Springfield Company Both were very efficient in placing dry screenings even in 8-inch layers of coarse aggregate, but neither was effective in keying the course stone The vibrating center roll on the Buffalo-Springfield equipment was beneficial in leveling small irregularities caused by uneven spreading of aggregate

On subsequent contracts, the Vibro-Tamper was used together with conventional rollers in placing water-bound macadam in lifts of about four inches Densities of approximately 115 pounds per cubic foot were obtained with slag and of approximately 135 pounds per cubic foot with limestone

In view of the satisfactory performance obtained on experimental jobs in Ohio, the state highway specifications for water-bound macadam have been modified to permit the use of vibratory equipment in lieu of part of the rolling

Texas

An unstable river-bed sand with a natural density of 97 to 101 pounds per cubic foot and an effective size of 0 06 millimeter (mm) was densified in place to about 105 pounds per cubic foot by use of a vibrating tube This equipment had a frequency of 9,000 vibrations per minute and was designed presumably for internal vibration of concrete It was inserted vertically to a depth of about 8 1/2 feet and withdrawn slowly, and a tamping motion was used to close the hole below it It was effective through a column of sand approximately two feet in diameter

A slurry of the same sand was densified to 113 pounds per cubic foot by using the same vibrator in a bucket in the laboratory Approximately the same density was obtained on a vibrating table at 4,000 vibrations per minute The latter equipment was also used with other sands

Virginia

The International Vibro-Tamper and the Buffalo-Springfield roller were used, each on one macadam project Good results from both were reported

Washington.

The State of Washington reported that it had had no experience with vibratory compaction in the field but that it had conducted in the laboratory a series of tests using the small Jackson vibrator to compact two gradations of clean sand The sieve analyses are given in Table II, and the results of various laboratory density determinations on the plaster sand are shown in Table III

[1]Charles W Allen and S O Linzell, "Use of Vibration in Placing Screenings in Macadam Bases," Proceedings of the Twenty-Seventh Annual Meeting, Highway Research Board, 1947

TABLE II

GRADING OF SANDS USED IN WASHINGTON TESTS

Sieve Size	Plaster Sand Passing (per cent)	Building Sand Passing (per cent)
1/4-inch	100	100
No 4	100	97
No 10	99	85
No 40	35	26
No 200	1	1

The standard Proctor density was quite low because of the disturbing action of the tamper foot in the noncohesive material Results with the Triaxial Institute mechanical compactor were similar

Table IV summarizes the results obtained with the Jackson vibrator under various conditions All tests were run with the gasoline-engine generator operating at full speed

When thicker lifts were used, good compaction was obtained only to a depth of about 12 inches Successive passes, up to a maximum of five, increased the density by small increments Because of the permeability of the material, it was very difficult to ascertain the effect of moisture content with any degree of certainty The investigators believe that a condition near saturation is advantageous

The Jackson machine was most effective when moving across the surface at slow speed. For the materials used in these tests, it was estimated that the equipment would compact about 12 cubic yards per hour

West Virginia

A Wayer Impactor was used in compacting a clay backfill over a storm sewer The soil was classified as A-6 (9), with a liquid limit of 39 and a plasticity index of 13 The soil contained 32 per cent silt and 43 per cent clay with all material passing the No 10 sieve Standard Proctor density ranged from 101 to 109 pounds per cubic foot

The material was compacted in 4-inch lifts The highest field density was 112 pounds per cubic foot One extremely low field density of 87 pounds per cubic foot was reported, but this was attributed to the presence of cinders in this particular sample

TABLE III

LABORATORY COMPACTION TESTS OF PLASTER SAND

Test Conditions	Dry Density (lbs per cu ft)
Loose, dry (cu ft bucket)	93 6
Loose, saturated (cu ft bucket)	98 2
Std AASHO density (Proctor)	96 6
Mechanical compactor (Triaxial Institute Model)	97 6
Vibrated (Syntron vibrator) dry	106 3
Vibrated (Syntron vibrator) saturated	106 3

Other

As a supplement to the information obtained from state highway departments, some of the manufacturers provided other records of field use of their equipment In a few instances, additional information or corroboration was obtained from outside sources These records are grouped and summarized according to the type or make of equipment

The Buffalo-Springfield Company mentions tests of their roller by the U S Army Corps of Engineers at Fort Belvoir, but apparently these tests did not yield conclusive results Tests on similar equipment such as the Petershaab three-wheel vibrating roller have been reported from Canada [2] Good results were noted on bituminous surface-course mixtures, but considerable difficulty was encountered in sand because of displacement ahead of the roller Some mechanical difficulties were encountered

On several airport grading projects where the Cedarapids equipment was used, the Iowa Manufacturing Company reports densities of 88 to 105 per cent that of modified Proctor density of soil The projects

[2] J Walter, Highway Engineer, "Experimental Test of Petershaab Vibrating Roller," Department of Highways Report, Ontario, Canada

TABLE IV

RESULTS OF TESTS WITH JACKSON VIBRATORY COMPACTOR

Test No	Moisture Content	Dry Density		Description of Test
	Dry Weight (per cent)	(lbs per cu ft)	Standard Proctor (per cent)	
1	5 5	105 1	108 8	Plaster sand, 3 passes, normal speed, 6-inch layer
2	4 6	104 1	107 8	Plaster sand, 1 pass, normal speed, upper half of 11-inch layer
3	6 6	106.5	110 2	Plaster sand, 1 pass, normal speed, lower half of 11-inch layer
4	7.0	109 0	112 8	Plaster sand, 5 passes, normal speed, upper half of 11-inch layer
5	15 3	110 0	113 9	Plaster sand, 5 passes, normal speed, lower half of 11-inch layer
6	5 0	108 6	112 4	Building sand, 23-inch layer, 5 passes, normal speed, 0- to 5-inch depth
7	6 2	105 6	109 3	Building sand, 23-inch layer, 5 passes, normal speed, 8 1/2- to 13-inch depth.
8	6 8	97 4	100 8	Building sand, 23-inch layer, normal speed, 14- to 20-inch depth
9	3 4	103 8	107 5	Plaster sand, 1 pass leveling plus 1 pass at 2 feet per minute
10	5 0	101 1	104 7	Plaster sand, 1 pass leveling plus 1 pass at 12 feet per minute
11	4 3	106 2	109 9	Plaster sand, 1 pass at 2 feet per minute
12	3 7	100 1	103 6	Plaster sand, 1 pass at 6 feet per minute

represent a wide geographical range and a variety of soil types (clay, sandy clay, and decomposed rock)

The International Vibration Company has an imposing list of highway and airport projects upon which the Vibro-Tamper has been used successfully Gains in efficiency and economy have been attested by engineers and contractors connected with a number of the projects The efficient consolidation of macadam and crushed aggregate construction, the effective distribution of screenings in macadam base, and the economies in using thicker lifts of base material are particularly emphasized It should be noted that the conventional rolling equipment is required to compact the top thin layer (one to two inches) which remains in a loose condition after the passage of the tamper The Vibro-Tamper is approved under CAA Standard Specifications for use on federal-aid airport projects

The manufacturer of the Vibro-Plus equipment presents the results of field compaction tests from several airport and highway projects in Sweden In these tests conducted on soils ranging from fine sand to

TABLE V

A CHARACTERISTICS OF MATERIALS USED IN PRELIMINARY TDEC TESTS

Grading (sieve size)	Crushed Stone (per cent passing)	Gravel (per cent passing)	Sand (per cent passing)
1 1/2-in	100 0	100 0	100 0
3/4-in.	87 2	90 4	100 0
3/8-in	58 5	79.4	100.0
No 4	40 9	69.4	99 4
No 8	29 7	58.3	97 4
No 16	25 1	44 7	69 6
No. 30	20.9	26.7	37 6
No 50	18 5	14 9	12 4
No 100	16 7	8 4	3 8
No 200	15 0	7.2	2 7

B COMPARATIVE COMPACTION BY MODIFIED AND STANDARD PROCTOR TESTS USING MATERIALS SHOWN IN TABLE A*

Material Used	Modified Proctor (lbs. per cu. ft.)	Modified Proctor Optimum Moisture (per cent dry wt.)	Standard Proctor (lbs. per cu ft)	Standard Proctor Optimum Moisture (per cent dry wt.)
Crushed Stone	140	6 3	126	6 6
Gravel	142	6 2	135	8.0
Sand	133	8 2	121	13.2

*Compaction tests were run on the whole sample without removal of material retained on the No. 4 sieve.

very coarse gravel, the Vibro-Plus compactor produced higher densities than were obtained by use of either a vibrating roller, a tamping roller, a smooth roller, or a rubber-tired roller Layers of material as thick as 40 inches were used in the tests on coarse gravel

Although the record of these tests is impressive it should be noted that some of the competing equipment was not necessarily the heaviest or most efficient of its type For instance, the vibrating roller had a ground pressure of only 130 pounds per inch of roll and a total weight of 7 1/2 tons, the tire inflation pressure used for the rubber-tired roller was only 43 pounds per square inch, and the tamping roller provided a contact pressure of only 200 pounds per square inch Densities are compared on the basis of the increase obtained with each pass of the equipment, but no comparative data are furnished on the cost of operation for equivalent results Experience with the Vibro-Plus compactor in the United States apparently has been limited to the compaction of trench backfill and similar small areas

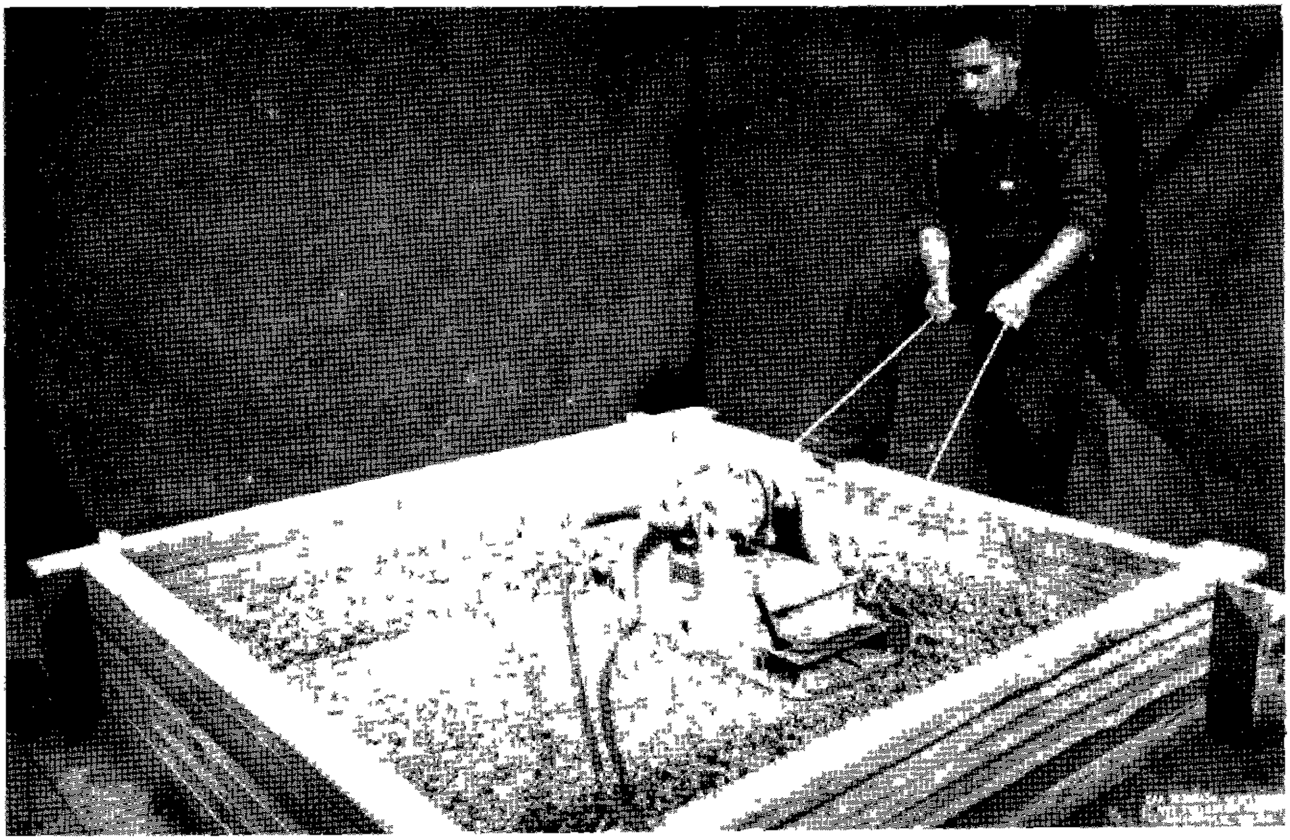


Fig 9 Laboratory Compaction of Crushed Stone with the Jackson Compactor

TDEC EXPERIENCE WITH SMALL VIBRATORY COMPACTORS

The load transmission project now in progress at this Center[3] requires frequent construction of flexible pavement sections 10 feet square and ranging from 4 to 24 inches in thickness These pavements are constructed upon a spring-supported testing platform, simulating a rather weak subgrade The testing platform is enclosed by plank bulkheads As the size of the test sections and other considerations precluded the use of conventional rolling equipment, this project has afforded an excellent opportunity to study the use of small vibratory compactors in small-scale construction operations The Jackson Vibrator and the Ideal Vibra-Tamper were selected for possible use

[3]Raymond C Herner and William M Aldous, "The Load Transmission Test for Flexible Paving and Base Courses, Part I, A Description of the Testing Apparatus, Operating Methods, and Anticipated Uses of Test Data," CAA Technical Development Report No 108, April 1950

Results from Preliminary Tests

Preliminary tests were run in order to determine the practicability of using the vibratory compaction equipment and to perfect operating techniques These tests were performed in a sturdy wooden box 5 1/2 feet square The floor of the box consisted of two layers of one-inch tongue-and-groove lumber with the grain of one layer at right angles to that of the other This flooring was supported by closely spaced two-inch by four-inch cleats resting flatwise on the concrete floor of the laboratory This construction provided a slight resiliency comparable to that of a well-compacted soil subgrade Sand, gravel, and crushed limestone were used in the tests Characteristics of representative materials are given in Table V

Materials were usually placed in 6-inch lifts, loose measurement, but some tests were run on 12-inch layers. Densities were determined by bulk measurements and by routine sampling methods such as the sand-density and the balloon-density tests

Fig 9 shows the Jackson Vibrator on its first pass over a dense-graded crushed limestone The early models of this equipment used in these tests vary widely from the present models The dead weight of the original equipment was only 150 pounds This was increased progressively up to 210 pounds by welding weights to the base plate These were replaced in some of the later tests by a floating, shock-mounted, 165-pound weight which increased the total dead weight to 315 pounds

Tests on sand using the Jackson equipment produced dry densities ranging from 110 to 120 pounds per cubic foot for various combinations of compaction time, moisture, and equipment The effect of added weight was beneficial especially when shock-mounted, whereas the effect of multiple passes of the equipment was negligible Best results were obtained when the sand was either dry or approximately at the optimum moisture content as determined by the modified Proctor test Extremely high water contents were detrimental, because the compaction box was too tightly constructed to let excess water escape.

In tests on gravel, the Jackson Vibrator (210- and 315-pound models) produced densities up to a maximum of 142 pounds per cubic foot at water contents between 6 0 and 8 0 per cent Densities obtained in eight passes were only slightly higher than those obtained in two passes Densities measured in the bottom half of a course laid 12 inches thick, loose measurement, indicated that such a thick course was definitely beyond the capacity of this equipment

Densities up to 145 pounds per cubic foot were obtained on crushed stone with the Jackson equipment Moisture contents ranged between 4 8 and 7 0 per cent The 315-pound compactor produced densities of 140 pounds per cubic foot in about half the time required for the 210-pound machine

Efforts to use the Ideal Vibra-Tamper in compacting the sand were unsuccessful because of excessive penetration of loose noncohesive material by the narrow contact plate

Tests with the Ideal Vibra-Tamper on gravel at moisture contents between 5 7 and 7 6 per cent resulted in several density measurements above 145 pounds per cubic foot The effects of lift thickness and number of passes were similar to those observed with the Jackson equipment

Results from the Ideal Vibra-Tamper when used on crushed stone were about the same as those from the heavier of the two Jackson machines Each required about 12 seconds operation per square foot to produce a density of 140 pounds per cubic foot in a loose layer six inches in thickness

From the above tests, it was concluded that adequate compaction of the load transmission test sections could be obtained with the small vibratory equipment The Jackson machine was chosen as the primary unit because (1) it produced a more even surface, (2) it was more free of mechanical troubles, (3) being electrically driven, it could be operated from the commercial power supply and thus would eliminate engine fumes in the laboratory, and (4) use of electric power made it possible to measure energy consumption very conveniently and accurately

Results of Compaction
of Load Transmission Test Sections

About 75 pavement sections for load transmission tests have been constructed thus far Most of these were composed of dense-graded gravel similar to that used in the preliminary tests already described However, individual sections varied quite widely in gradation and moisture content

A 370-pound model of the Jackson compactor was used in compacting most of the sections. Except for the additional weight and a somewhat larger motor, this model is similar to the 315-pound model used earlier The corrugated base plate was found to be inefficient for compacting gravel and was modified by welding two flat steel strips across it at right angles to the direction of travel. These strips were 1/4 inch thick and 1 1/4 inches wide

Material was deposited in loose layers about six inches deep and compacted to a final thickness of four inches The amount of material placed for each lift was computed to yield a dry density of about 135 pounds per cubic foot The moisture content was usually a little less than optimum, which made it rather difficult to obtain the desired densities but increased the stability of the pavement sections

In discussions of laboratory compaction, one often hears the expression "equal compactive effort" used in comparing the results from different sets of apparatus, applying the same energy input per unit volume but in a different manner The equipment for measuring electrical energy shown in Fig 10 was set up for the purpose of determining whether energy input is a valid indicator of the densification which may be expected The equipment is calibrated in watt-minutes

The density of a given lift of material tended to increase with successive passes of the compactor, but the increase per pass (or per unit of energy expended) became progressively less until the material reached a

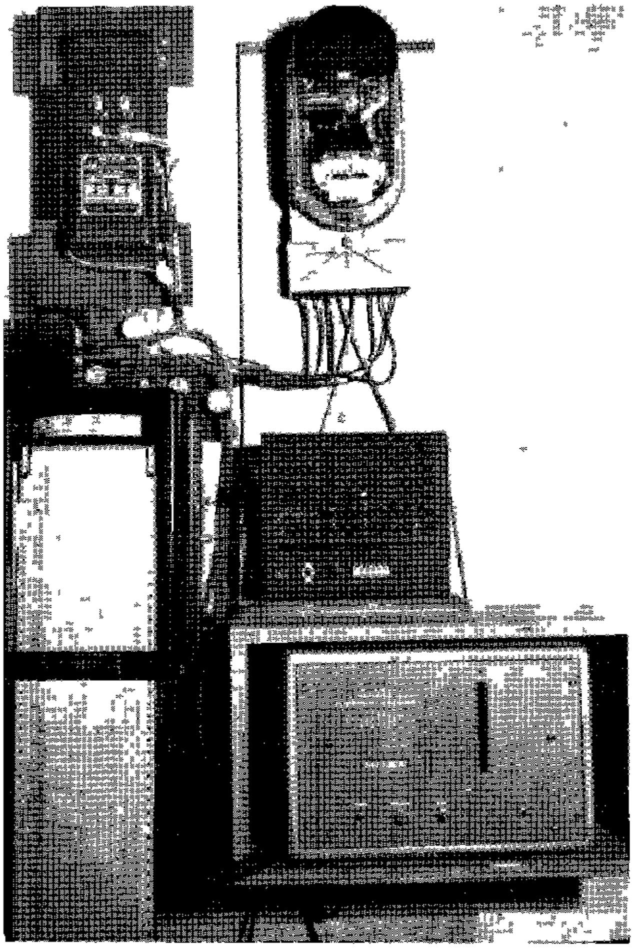


Fig 10 Equipment for Measuring Electrical Energy Input

"point of refusal " In some instances it was necessary to apply a very large amount of energy in order to obtain the final small increase in density needed to arrive at the target value Some experimentation with different designs of the compactor showed that each model had a performance ceiling Energy comparisons were meaningless, therefore, when referring to different machines

Fig 11 summarizes graphically the data obtained from 135 lifts of gravel all compacted with the 370-pound Jackson machine The various graphs show the statistical distribution of values for each variable The net energy used in these graphs is equal to the gross energy measured by the watt-minute meter during compaction of a lift minus the energy used in operating the compactor for the same period of time while suspended in air For practical purposes, it represents the energy transmitted to the gravel less purely mechanical losses

In the graph of Fig 11A, the shaded area includes those tests in which the energy consumption fell within an intermediate range of 5,000 to 25,000 foot-pounds per cubic foot of compacted material This represents 74 per cent of the total tests

In the graph of Fig 11B, the shaded area includes those tests which had an intermediate density range of 133 to 137 pounds per cubic foot and which also fell within the intermediate energy range of graph A The size of this group (68 per cent of the total) compared to that of graph A indicates a close relationship between energy and density Often, however, this relationship was obscured by the effect of small changes in grading or in moisture content

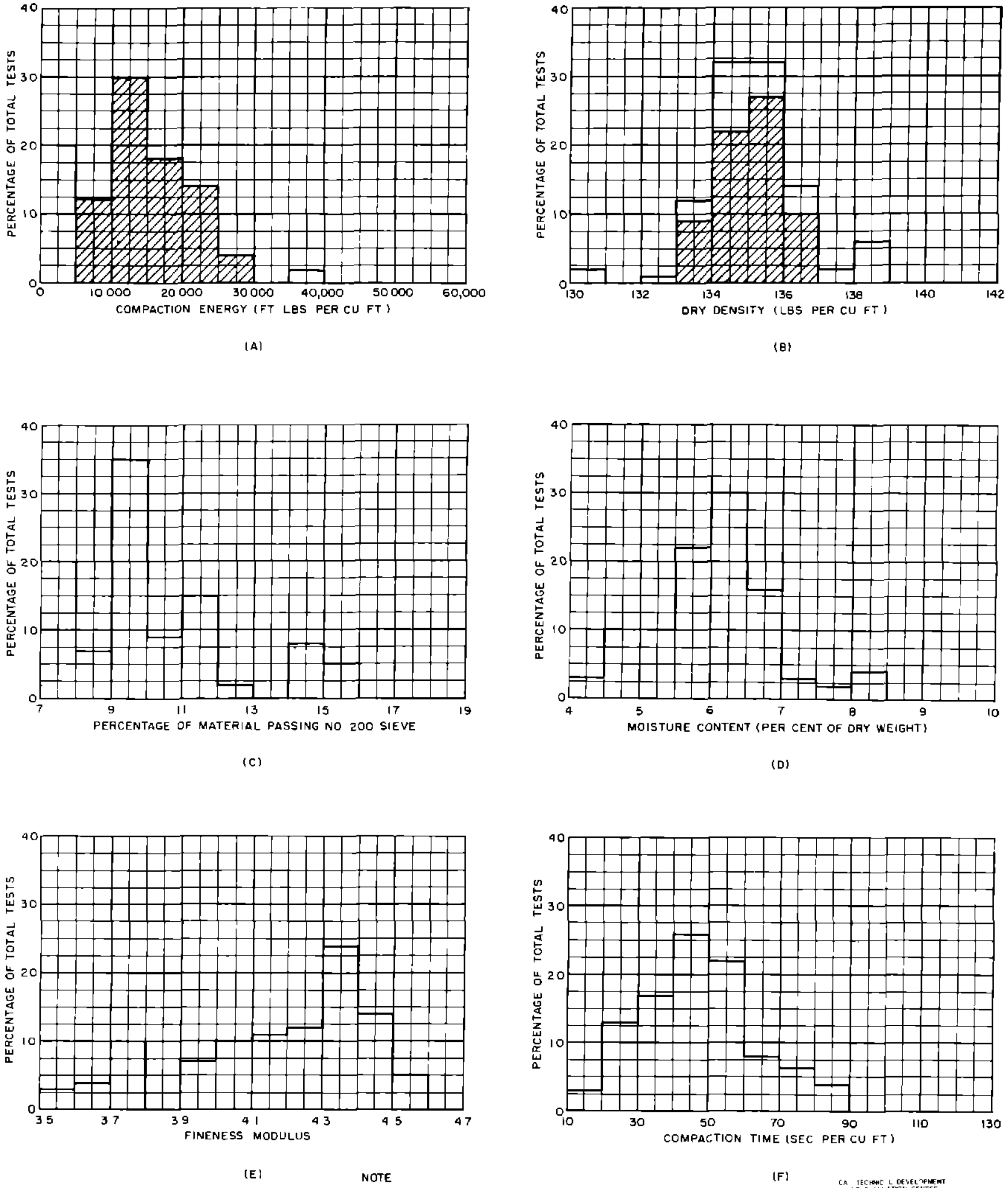
Graphs in Figs 11C to F show rather wide variations in various characteristics of the material, but these variations are no wider than those normally encountered in construction practice While they apparently had a strong effect on energy consumption and time of compaction, it has not been possible to associate the factors in any definite and predictable manner For purposes of these tests, the important point is that the equipment was capable of producing acceptable densities in a typical gravel material

The Jackson equipment was also used on a few sections composed of crushed limestone and on a few surface courses made of asphaltic concrete Satisfactory results were obtained on both materials

DISCUSSION AND CONCLUSIONS

Although there is wide interest in the subject of vibratory compaction, there still is surprisingly little information available on field performance of vibratory equipment Many varieties of equipment have been developed, but some apparently have been used only in pilot tests with little authentic test data on record Because of the inconclusive nature of the evidence, it would be unwise to attempt a complete and authoritative evaluation of equipment. It may be worth-while, however, to review briefly the information which has been collected and to express an informal opinion concerning the best field of use for different types of equipment Discussion of mechanical features and possible maintenance difficulties is beyond the scope of this report

There are three major fields of usefulness for vibratory compactors (1) compaction of fine noncohesive materials where conventional rollers are relatively inefficient, (2) compaction of more plastic materials in small and restricted areas (trench backfill,



NOTE

DENSITY AS INDICATED IN SHADED AREA OF (B) IS OBTAINED FROM ENERGY EXPENDED AS INDICATED IN SHADED AREA OF (A)

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Fig 11 Vibratory Compaction Data From Load Transmission Test Sections (135 4-Inch Lifts of Dense-Graded Gravel, 370-Pound Jackson Compactor) driveways, pavement patches, bridge approaches, backfill for building floors, and similar applications) where conventional equipment is too bulky and unhandy to use, and (3) compaction of coarse granular materials used in macadam or dense-graded base-course construction In the last case, the vibratory equipment is used to supplement the use of heavy rollers

Fine-grained noncohesive materials are responsive to high-frequency, low-amplitude vibration without the need of high static weight This is exemplified by the Texas experience with the vibrating tube and by the universally satisfactory performance of the lightweight Jackson equipment when used on such material The multiple Jackson equipment or the International Vibro-Tamper should be more economical for compacting large areas In any case, the contact area should be relatively large in order to confine the material Equipment with high unit dead-weight loading or a heavy tamping action will tend to disturb the surface and to penetrate into the material

More plastic materials such as sand-clay, clay-loam, stabilized gravel, and asphaltic mixtures require more dead weight and more of a tamping rather than a vibrating action The frequency can be quite low For such materials, the Ideal Vibra-Tamper or the Wayer Impactor could be used effectively on small areas The Jackson equipment could also be used by modifying the striking plate to provide a smaller contact area, as was done in the tests described in this report Larger areas of the moderately plastic materials can be handled by conventional equipment or by either the Cedarapids or the Buffalo-Springfield vibratory roller Incidentally, either of the latter rollers is heavy enough to do a reasonably efficient job without the vibrating attachment The Vibro-Plus compactor should also be effective on the moderately plastic or cohesive materials It represents an intermediate range in size and capacity

Practically all types of vibrating equipment have been used with some degree of success in the compaction of noncohesive coarse-graded materials The best results have been obtained, however, with a combination of heavy vibratory and conventional rolling equipment One real advantage of using such combination equipment is the ability to place thicker lifts of material The International Vibro-Tamper has proved particularly effective in placing the fines (fine aggregate) in macadam base-course construction

The full potentialities of vibratory compaction cannot be realized until more experimental and exploratory work is done This will come about eventually through occasional experimental field projects, although a more comprehensive evaluation of present equipment and a fundamental study of vibration as applied to all types and conditions of materials would be most desirable

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