SECTION IX

IMPROVEMENT OF THE MECHANICAL PROPERTIES OF SOIL

SUB-SECTION IXb

GENERAL CONSIDERATIONS

IXb4

PROVIDENCE VIBRATED DENSITY TEST

KENNETH S. LANE

Chief, Soils & geology Branch, Garrison Distr., Corps of Engineers, Bismarck, N. Dakota.

SUMMARY

Difficulties with cohesionless soils in an impact compaction test (aggregate breakage and maximum test density below good field results) led to compacting samples of such soils by vibration while confined by a surface load. Procidure and apparatus are described, which are suitable for either a central or field laboratory. The test result is termed "feasible maximum density" for cohesionless soils. It is considered to reasonably represent maximum density attainable in the field as well as the very high density produced immediately beneath a flexible pavement by traffic compaction. In lieu of gaging field densities with the insensitive function "percent of compacted test density," it is preferred to express the degree of compaction as a "density ratio" showing extent to which compaction has profressed from minimum ot maximum test density.

In application to cohesionless soils, particularly sands and gravels, the Proctor compaction test has presented two difficulties. Being an impact type of test (5½ pound hammer falling 12 inches), it causes considerable breakage of aggregate when applied to a soil possessing weaker fragments - to a greater degree than breakage generally observed under rolling equipment of the fill. Where an appreciable percentage of softer fragments is present, the more variable gradation caused by aggregate breakage may result in a higher test density than obtained on the fill. Furthermore, it makes it impractical to use the same material for other subsequent tests, as permeability and shear. In the second case, with a soil of harder fragments not broken from impact, the test density tends to be consistently less than that easily attained on the fill - especially with the trends of recent years to employ heavier compacting equipment and to compact pervious soils with a crawler tractor.

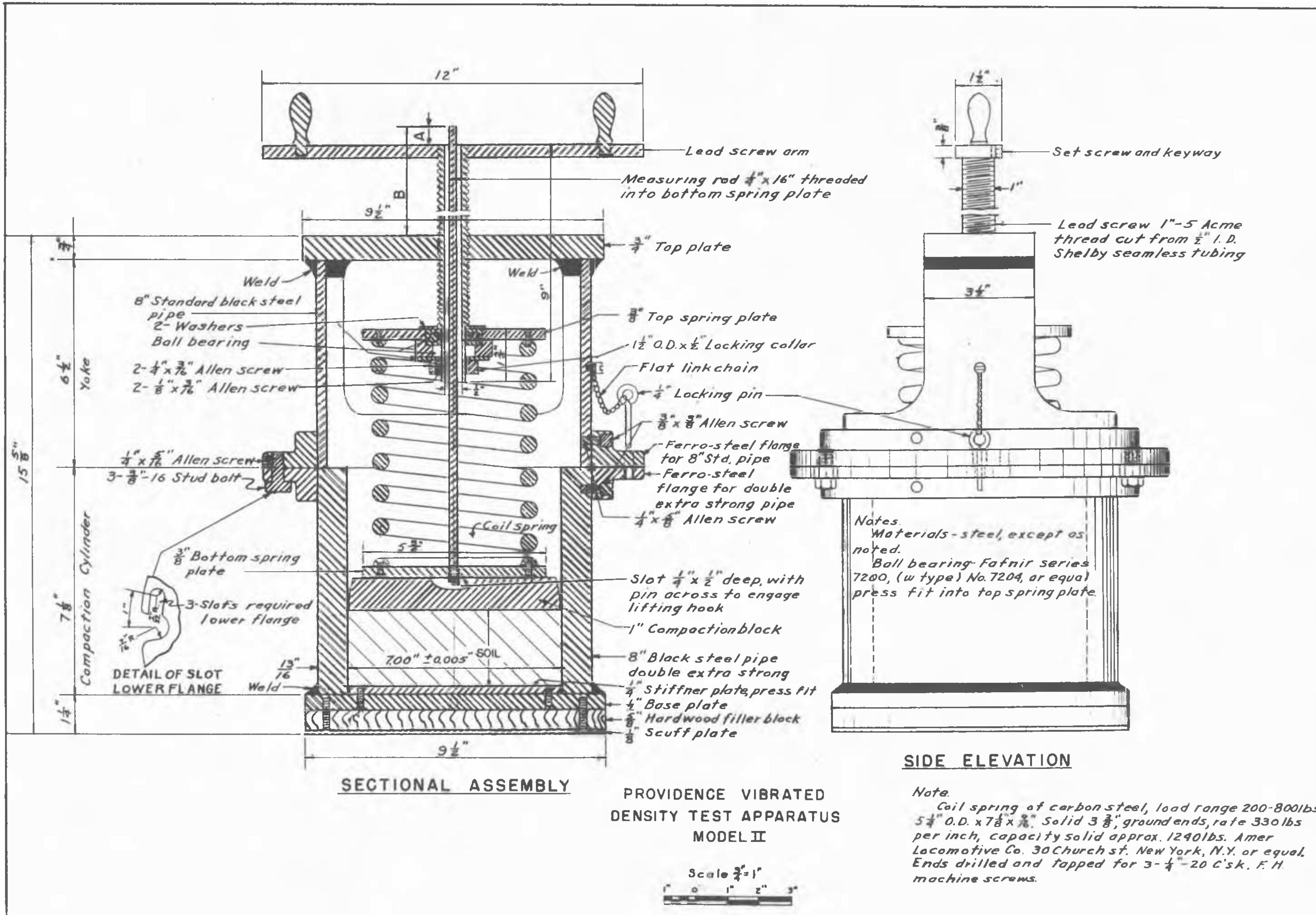
On dams, the main effect has been a continual embarrassment to laboratory men from their inability to equal what field men easily obtained with fills of hard aggregate cohesionless soils. In highway work the need for requiring a density greater than that from the Proctor test in upper part of the subgrade was recognized by those who were striving to improve pavement load capacity by increasing subgrade strength. With one of the pioneers in this effort, the State of California Division of Highways, it is understood that considerable study resulted in 1939 in replacing the Proctor test with static compaction under a load of 2000 p.s.i. 1). From war accelarated airport construction, the need for greater compaction beneath pavements resulted about 1943 in the promulgation of the Modified Proctor test (10 pound hammer falling 18 inches). While fairly successful with cohesive soils, with cohesionless soils this Modified Proctor test narrowed but did not close the gap between laboratory and field densities - this being accomplished at the expense of increased aggregate breakage and of much more effort for performing the test.

In 1942, several years accumulated dissatisfaction with the Proctor test apparatus for cohesionless soils led the author to search for a test which would give a maximum density better equalling good field practice. At that time the author was in charge of the Soils of Section of the Providence (R.I.) District, Corps of Engineers, where established practice included determining "maximum densities" of cohesionless pervious soils by prolonged rodding in a 4-inch diameter Proctor mold and then easily compacting them on the fill to considerably higher densities. This field compaction was accomplished with a heavy crawler tractor plus wetting to substantial saturation to retain compaction secured.

A further objective was to minimize the percentage of coarse aggregate to be screened out in the test since a parallel investigation showed the usual correction formula (assuming material screened out can be replaced by a single voidless fragment) to be increasingly unreliable for amounts screened out above about 15% by weight. Passing over the many other methods tried, the highest densities were most consistently obtained by vibrating the sample when confined by a moderate surface load.

Fig. 1 shows the apparatus developed from this investigation. The confiningload is maintained by adjusting the calibrated spring as the sample compacts. The 7-inch cylinder diameter permits including coarse aggregate up to 2½-inch size; so the percentage screened out is usually very small and correction for this can be made in the usual manner. A feature of the apparatus is the dual purpose measuring rod where dimension A indicates load exerted by the calibrated spring and dimension B measures the height of the compacted sample.

The test is designed only for cohesionless materials (usually pervious), which are compacted dry since trials with wet and moist samples gave equal or lower results. After trying several different confining loads, a spring load of 1000 pounds (about 26 p.s.i.) was se-



12"
A
B
9½"
Lead screw arm
Measuring rod ¼" x 16" threaded into bottom spring plate
¾" Top plate
Weld
9"
8" Standard black steel pipe
2- Washers
Ball bearing
2- ¼" x 3/16" Allen screw
2- ⅛" x 3/16" Allen screw
⅜" Top spring plate
1½" O.D. x ½" Locking collar
Flat link chain
¼" Locking pin
⅜" x ⅜" Allen screw
Ferro-steel flange for 8" Std. pipe
Ferro-steel flange for double extra strong pipe
¼" x ⅝" Allen screw
¼" x 5/16" Allen screw
3-⅜"-16 Stud bolt
Yoke
6½"
15⅝"
Compaction Cylinder
7⅛"
1¼"
Coil spring
5⅜"
⅜" Bottom spring plate
3-Slots required lower flange
DETAIL OF SLOT LOWER FLANGE
Slot ¼" x ½" deep, with pin across to engage lifting hook
1" Compaction block
7.00" ± 0.005" SOIL
8" Black steel pipe double extra strong
13/16"
Weld
¼" Stiffner plate, press fit
½" Base plate
⅝" Hardwood filler block
⅛" Scuff plate
9½"
SECTIONAL ASSEMBLY
1½"
Set screw and keyway
1"
Lead screw 1"-5 Acme thread cut from ½" I. D. Shelby seamless tubing
3½"
Notes.
Materials - steel, except as noted.
Ball bearing- Fafnir series 7200, (w type) No. 7204, or equal press fit into top spring plate.
SIDE ELEVATION
PROVIDENCE VIBRATED DENSITY TEST APPARATUS MODEL II
Scale ¾" = 1"
1" 0 1" 2" 3"
Note.
Coil spring of carbon steel, load range 200-800 lbs. 5¼" O.D. x 7⅛" x 9/16", Solid 3⅜", ground ends, rate 330 lbs per inch, capacity solid approx. 1240 lbs. Amer Locomotive Co. 30 Church st. New York, N.Y. or equal. Ends drilled and tapped for 3-¼"-20 C'sk. F.H. machine screws.

FIG. 1

lected as suitable, since very much higher confining loads (up to 2000 p.s.i.) at the most gave only minor increases in density. While vibration can be obtained in several ways, including an expensive motor-powered vibrating table, it was found feasible to obtain the same result by striking the cylinder sides with a hammer. The latter method was adopted as it met the desirable objective of using the same equipment both in a central laboratory and in small field control laboratories.

In the detailed test procedure, a known weight of dry soil is placed in the cylinder with care in avoiding segregation - usually 8 pounds with 1-inch maximum aggregate increasing with aggregate size up to 12 pounds for 2½ inch maximum aggregate. Surface of the soil is approximately leveled and then covered by lowering the 1-inch compaction block with a hooked rod engaging the pin at top of this block. The block is tapped to a level position and checked with a short level. The yoke with spring attached is then put on and secured by engaging the locking pin. The spring is compressed by turning the lead screw to register a load of 1000 pounds on the measuring rod, dimension A in Fig. 1. For this, it is desirable to place calibration marks on the rod to show the spring load.

The test is then conducted by distributing blows of a 2½-pound hammer over the exterior of the cylinder, using sharp forceful blows with the hammer driven from shoulder height. The test is continued until change in sample height (dimension B) becomes less than 0.001 feet, meanwhile adjusting the spring as necessary to maintain the 1000 pound load. Only two or three such adjustments are usually necessary; and the test is generally quickly concluded in about 5 minutes with 50 - 75 hammer blows. A depth gage is a convenient means of measuring dimension B which gives the height of the compacted sample.

This test has been termed the Providence Vibrated Density Test from its adoption by the Providence District in 1943 for cohesionless soils.
Subsequently, it has been used by several other districts of the Corps of Engineers.

In application, the density of the fill or of natural ground may be evaluated as a direct percentage of the test density, or in terms of a ratio representing the extent of compaction from minimum to maximum test density as follows:

$$\text{Density ratio} = D_r = \frac{d_n - d_o}{d_{100v} - d_o}, \quad \text{where}$$

d_n = dry density, pcf, in field (natural ground or fill).

d_o = dry density, pcf, loosest state from laboratory test for minimum density. (This is determined by placing dry soil in a cylinder using a spoon to prevent appreciable fall. A 4-inch diameter Proctor cylinder is used for sands; for gravels, either a 6 or 7-inch diameter cylinder).

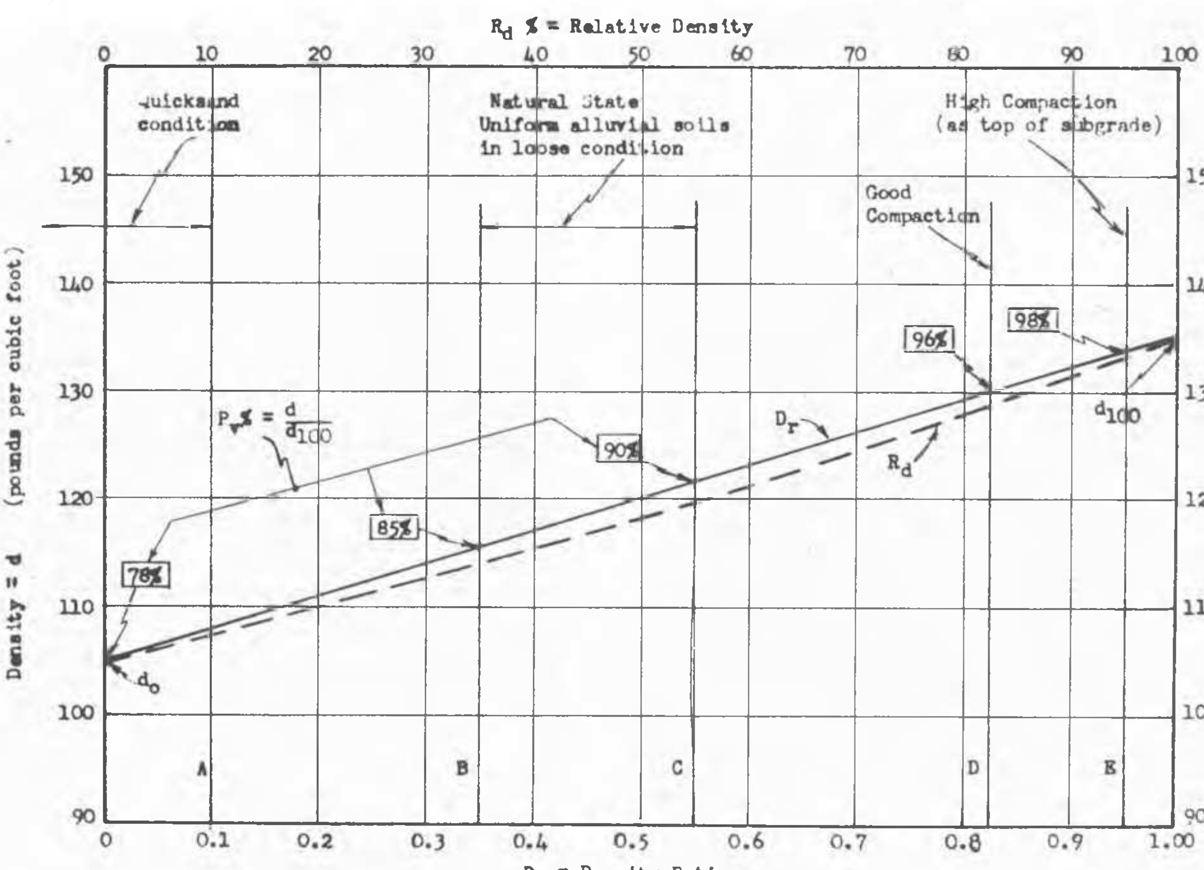
d_{100v} = dry density, pcf, feasible maximum density from Providence Vibrated Density test.

With the fill at minimum density, $D_r = 0$; when it is at maximum density, $D_r = 1.00$.

This expression is very similar to Terzaghi's equation for relative density:

Relative Density =

$$R_d\% = \frac{e_o - e_n}{e_o - e_{100}} \, 100\%$$



For a typical gravelly sand, specific gravity = 2.70

FIG. 2

where e_n, e_1 and e_{100} represent void ratios in the field, at the loosest state and at the densest state respectively.

As shown on Fig. 2, the two expressions give nearly identical results. The use of the equation for D_r is preferred since it is simpler to compute directly from observed densities. The equation for R_d requires an extra computation to obtain e from density which is the value directly measured, either in a field or laboratory determination. While the density ratio could be expressed as a percentage, a ratio has been used instead to avoid conflict with the expression used by some for a limit.

The result from the Providence Vibrated Density test has been termed "feasible maximum density". It is considered as representing the maximum which can be reached in the field with very decided effort - in this respect correlating better with several examples of outstanding compaction than any of the other different tests tried. Furthermore, it is considered as adequately representing the particularly high density reached directly beneath a flexible pavement as a result of traffic compaction, the effect of which has been frequently measured as a significant settlement over originally well compacted cohesionless soils.

Pavement	Soil	Time of Test	Average Density Ratio
2½" asphaltic concrete, 4½" dry bound macadam base - crushed stone, 7" Total	Uniform, medium sand	Top 6" of subgrade after 2½ yrs. of moderate to heavy traffic	0.99 Avg. of 12 tests
	do	End of construction, avg. of control tests on fills	0.81 Avg. of 100 tests
	do	Natural density, before construction.	0.5
2½" penetration macadam, 8" dry bound macadam base - gravel, 10½" Total	Gravel base	After 8½ yrs. of light to moderate traffic	0.98 Avg. of 7 tests
	Gravelly sand, top 6" of subgrade	do	1.02 Avg. of 10 tests
	do	End of construction	No record.

percentage of maximum test density - often termed "percent of compacted test density"

$$P_v\% = \frac{d_n}{d_{100}} \; 100\%$$

For cohesionless soils, the function D_r is preferred for gaging the extent of compaction rather than the percentage P_v. For average conditions, ranges in density ratio for different degrees of compaction are about as shown by the heavy lines, A to E, on Fig. 2. At these same five points, Fig. 2 also shows values of P_v for a typical gravelly sand. The function P_v is very insensitive and has often caused the soil technician to be considered an "intolerant hairsplitter" whenever he requests the contractor to increase compaction from 93 to 97%. Moreover, it is inconsistent with the usual conception of a percentage to describe about the loosest possible state as P_v = 78% compacted. Since its much greater sensitivity avoids these difficulties, density ratio is preferred for designating the degree of compaction of cohesionless soils.

The function D_r has not been applied to cohesive soils because of the lack of a suitable test for minimum density, the percentage P_v being used instead. A tolerable approximation to permit using the preferred function, density ratio, might be to arbitrarily designate the lower state of compaction of cohesive soils as the density computed for 100% saturation at a water content equal to the liquid

As typical examples, Table 1 gives average results obtained at two New England airports by measuring density in cohesionless subgrades after 2½ and 8½ years of traffic compaction. Density ratio values of 0.99 and 1.02 indicate the high compaction found in the 6 inches of subgrade directly below bottom of the base course. For heavier traffic, or application over a longer period, it is expected the density ratio might be slightly greater. Moreover, the density from this vibrated compaction test about equals that from static compaction under 2000 p.s.i., which O.J. Porter 2) in California has considered as approximately representing the density reached after traffic compaction.

This vibrated compaction test is intended only for cohesionless soils (particularly for pervious material) and determines only one point, a maximum density. With this type of soil an impact compaction test generally shows no definite optimum water content and field compaction is best accomplished with a crawler tractor, or other vibratory equipment, plus liberal use of water to effect substantial saturation. In contrast, cohesive soils are generally better compacted by a tamper type roller at optimum water content, which is definitely indicated by an impact compaction test with a test density higher than that from the vibrated test. Hence, for borderline soils, comparison of results from the two types of tests helps to judge the more suitable type of field compaction: (a) tamper roller when density from the impact test exceeds that from the vibrated test, and (b) vibratory or tractor compaction when the reverse is true.

CONCLUSIONS.

The Providence Vibrated Density test for cohesionless soils (usually pervious) is believed superior to the impact compaction test (either standard or modified Proctor test) since it avoids aggregate breakage and its higher result better represents a feasible maximum field density. Together with the 2000 p.s.i. static compaction test, it gives a result reasonably representing the very high density caused beneath flexible pavements by traffic compaction. In comparison with the static compaction test, the vibrated test uses a simpler apparatus and one better adapted to use in the field. Of the three types of tests, impact, static and vibrated, the latter is the quicker to perform.

ACKNOWLEDGEMENT is made of the very considerable assistance of Mr. Earl C. Wilson, who conducted much of the development investigation on this test and devised several features of the apparatus.

REFERENCES.

1) "Foundations for Flexible Pavements," by O.J. Porter, Proceedings, Highway Research Board, Vol. 22, 1942, p. 124. (See also "Compaction of Embankments," by T.E. Stanton, ibid, Vol. 18, Part II, 1938, p. 151)
2) ibid, p.108.

-o-o-o-o-o-o-

IX b 5

RESEARCH ON SOIL COMPACTION AT THE ROAD RESEARCH LABORATOR (GREAT BRITAIN)

D.J. MACLEAN

F.H.P. WILLIAMS

INTRODUCTION.

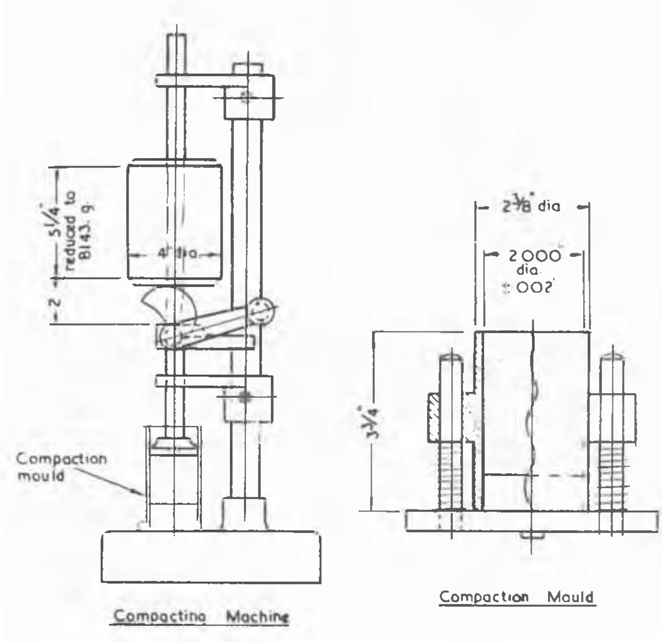
This paper describes some of the more important researches on soil compaction that have been undertaken in recent years at the Road Research Laboratory (Great Britain). The investigations are still in progress, and the results given in this Paper are presented for the information of other research workers in this subject. The work is treated under the following three headings:-
1) Laboratory studies.
2) Full-scale investigations of roller compaction.
3) Field investigations of the compaction of earthworks.

LABORATORY STUDIES.

Comparison of Standard A.S.S.H.O. Compaction Test and Dietert Test.

The basis of the field control of soil compaction is the determination of the maximum dry density and optimum moisture content of the soil. A comittee of the British Standards Institution has recently been concerned with the standardization of a method of determining these soil properties, and consideration has been given both to the American standard method (A.A.S.H.O. T99-38) 1) and to a method involving the use of a modified Dietert compactor 2) (Fig. 1), which was advocated on the grounds that the test was simpler to do and involved the use of less loil. A comparison of the two methods was therefore made with a sand, a sandy clay and a heavy clay to determine whether the test results given by the two methods were in agreement.

The American standard compaction test will not be described here, as details of this method are well-known. In the Dietert test, 150 gm. of the dry soil is brought to the required moisture content and compacted in the



Dietert compactor.

FIG.1

mould (Fig. 1) by first applying 10 blows of the weight by rotating the handle and then inverting the mould and applying a further 10 blows. In other respects, the test is similar to the American standard test. The bulk density of the compacted soil in the mould is determined by measuring the length of the specimen which has the diameter of the mould and whose weight is known.

The results of the comparison of these