sure is effected by a lever. The test is performed quickly, thereby avoiding any friction of the soil particles. The test cylinders have a diameter of 1 in. and a height of $1\frac{1}{2}$ in.

COMPACTION TESTS

The compaction test determines the densities for varying moisture contents of such a range as to show the maximum dry density. The procedure and application of this test are discussed on pages 27 to 30 of these Proceedings.

The compaction devices reported by various laboratories are listed in Table 4. Three groups are considered:

I. Impact, Figure 45.
S. Static, Figure 46.
V. Vibration, Figure 47.

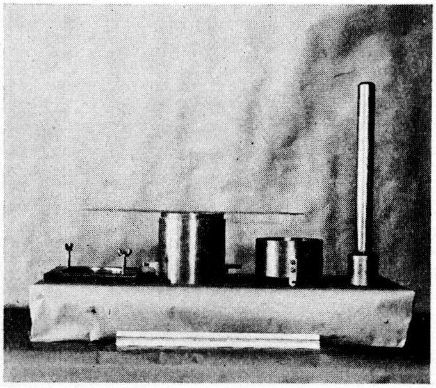

Figure 45. Impact Compaction Apparatus

Some details of the Proctor apparatus not included in the table, as described by A.A.S.H.O. method T 99–38, consist of:

(a) A cylindrical metal mold known as the density or Proctor cylinder, approximately 4 in. in diameter and $4\frac{1}{2}$ in. high and having a capacity of $\frac{1}{30}$ cu. ft. This mold is fitted with a detachable base plate and a removable extension approximately $2\frac{1}{2}$ in. in height. (See Fig. 45).

(b) A metal tamper having a striking face 2 in. in diameter, weighing $5\frac{1}{2}$ lb. and equipped with suitable guides for controlling the direction and height of drop.

Material passing the No. 4 sieve is compacted in three layers, each receiving 25 blows from the tamper dropped 12 inches.

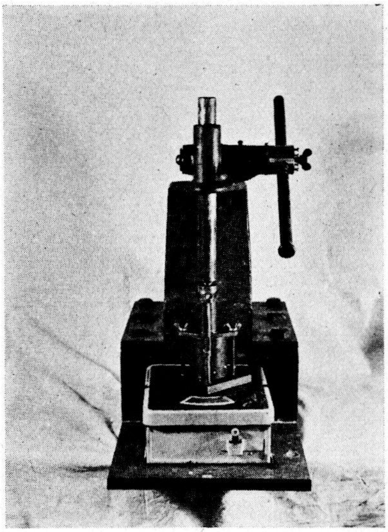

Figure 46. Static Compaction Device

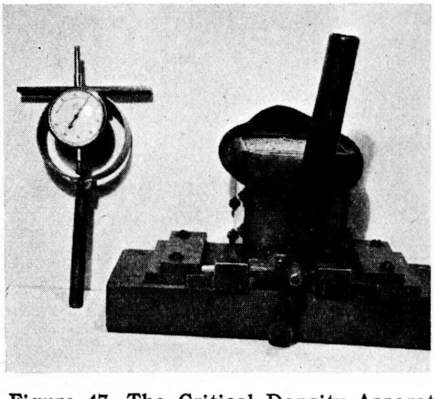

Figure 47. The Critical Density Apparatus for Determining the Limiting Loose and Dense States and the Critical Density of Cohesionless Granular Materials. Penetration Test Readings Indicate Differences in Penetration Resistance for these Conditions. Vibratory Compaction Type.

IMPACT COMPACTION DEVICES

T. E. Stanton, Jr.: Our field compaction testing equipment consists of a sensitive 5 lb. scale and a $2\frac{7}{8}$-in. diameter cylinder fitted with a cap, tamping shaft,

TABLE 4

COMPACTION DEVICES

State or Country	Organization	Type	Description	Contributor
Arizona	Arizona Highway Dept.	I	Proctor	W. G. O'Harra
New York	Brooklyn Polytechnic Inst.	I	Proctor	Prof. L. F. Rader
California	California Div. of Hwys.	I	2¾ in. by 12 in. cylinder	T. E. Stanton, Jr.
		S	2000 lb. per sq.in.	
California	California, Univ. of	I	Proctor	Prof. H. E. Davis
Colorado	Colorado Highway Dept.	I	Proctor	K. C. Vail
New York	Columbia University	I	Proctor	Prof. D. M. Burmister
		I	6 by 6 in. cylinder	
		V	Distortion box	
Delaware	Delaware Highway Dept.	I	Proctor	M. A. Wilson
Florida	Florida Road Department	I	Proctor	H. C. Weathers
Dist. of Col.	George Washington Univ.	I	Proctor	
		S	Series of pressures	C. A. Hogentogler, Jr.
Idaho	Idaho Dept. of Public Wks.	IS	Tamping & 2000 lb. per sq.in.	R. M. Jewell
Idaho	Idaho, University of	S	2000 lb. per sq.in.	Prof. A. S. Janssen
Idaho	Idaho, University of	I	Proctor	Prof. A. S. Janssen
Illinois	Illinois Div. of Highways	I	Proctor	V. L. Glover
Illinois	Illinois, University of	I	Proctor	Prof. E. E. Bauer
Kansas	Kansas Highway Comm.	I	Proctor, 18-in. drop	A. W. Johnson
Kansas	Kansas State College	I	Proctor	Prof. C. H. Scholer
Pennsylvania	Koppers Co., Pittsburgh	S	300 lb. per sq.in.	E. O. Rhodes
Louisiana	Louisiana Highway Comm.	I	Proctor	H. L. Lehmann
Maine	Maine Hwy. Dept., & Univ. of	I	Proctor	E. F. Bennett
Michigan	Michigan Highway Dept.	I	Proctor, mold 5 in. high	Prof. W. S. Housel
Montana	Montana Highway Comm.	I	Proctor, 18-in. drop	G. J. Johnson
Nebraska	Nebraska Dept. of Rds. and Irrigation	I	Proctor, mold 5 in. high	R. E. Bollen
New Hampshire	New Hampshire Hwy. Dept.	I	Proctor	P. S. Otis
New York	New York Dept. of Pub. Wks.	I	Proctor	Ira Paul
North Dakota	North Dakota Hwy. Dept.	I	Proctor	L. A. French
Ohio	Ohio Department of Hwys.	I	Proctor	K. B. Woods
Oklahoma	Oklahoma Highway Comm.	I	Proctor, 18-in. drop	C. R. Reid
Oregon	Oregon State College	I	Proctor	Prof. S. H. Graf
Dist. of Col.	Park Service, National	I	Proctor	E. F. Preece
Illinois	Portland Cement Assoc.	I	Proctor	M. D. Catton
New Jersey	Princeton University	I	Proctor	Prof. G. P. Tschebotareff
Dist. of Col.	Public Roads, U. S. Bureau of	I	Proctor	C. A. Hogentogler
		S	Series of pressures	
		V	Vibratory machine	
Dist. of Col.	Reclamation, U. S. Bureau of	I	Proctor, mold 6 in. high 18-in. drop	
		I	Sheepsfoot compactor	J. C. Page
Texas	Texas Highway Department	I	Proctor	W. H. Wood
Utah	Utah Road Commission	I	Proctor	Levi Muir
Virginia	Virginia Dept. of Hwys.	I	Proctor	Schreve Clark
Washington	Washington Dept. of Hwys.	I	Proctor	Bailey Tremper
Washington	Washington, University of	I	Proctor	Prof. R. G. Hennes
West Virginia	West Virginia Road Comm.	I	Proctor	A. M. Miller
Wisconsin	Wisconsin Highway Comm.	I	Proctor	G. H. Larson
Wisconsin	Wisconsin, University of	I	Proctor	Prof. H. F. Janda
Canada	University of Toronto	I	Proctor	Prof. C. R. Young
France	Laboratory for Study of Soils and Foundations	I	Proctor	Dr. A. Mayer
Germany	Prussian Research Station	V	Jolting Machine	Prof. R. Seifert
Netherlands	Laboratory for Soil Mechanics, Delft	I	Proctor	Dr. T. K. Huizinga

piston, and wrench (see Fig. 5, page 152). Dry soil smaller than 1 in. is measured into the cylinder to a height of 10 in. to 13 in. The dry soil is moistened to a consistency which will give maximum compaction when five layers are subjected to 20 blows of the tamper dropping 18 in. After compacting the fifth layer the piston is placed on top of the soil in the cylinder and seated by five 18-in. free drops of the tamper. With the tamping shaft resting on the piston, the indicated height of soil to the nearest $\frac{1}{10}$ in. is read at a point level with the top of the tube.

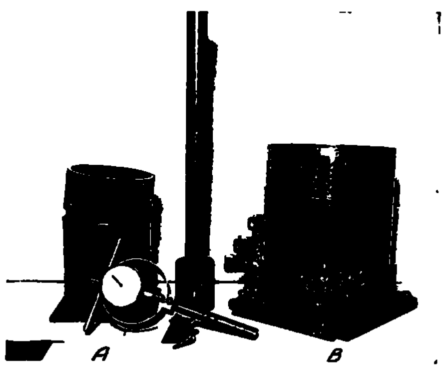

Figure 48. Compaction Test Cylinders. Burmister. A—Standard size Proctor compaction Cylinder, 4 in. x 4½ in. B—Special large size cylinder, 6 in. x 6 in., adapted for making direct shear tests.

Prof. D. M. Burmister: The second device, Figure 48, is a cylinder 6 in. in diameter and 6 in. high, for use with the whole soil up to particle sizes of ¾ in. This cylinder has been adapted to making direct shear tests on compacted soil in the regular shear bench to determine shear characteristics at different moisture contents.

Prof. E. E. Bauer: The mold is made of aluminum and the cylinder is slightly tapered. To control the height of fall. a sleeve made of 2-in. pipe is used. For removing the soil cake, a home-made push-out device is used.

A. W. Johnson: A specially constructed hammer, Figure 49, delivers a blow equivalent to a 5½-lb. hammer dropping 18 in. Ordinary soils are compacted in three layers but clays with plasticity indices greater than 25 are compacted in four layers.

E. F. Preece: Compactions are performed with the cylinder resting on a sand base which consists of a box, approximately 18 in. square and 2 ft. deep, filled with coarse sand and covered with canvas.

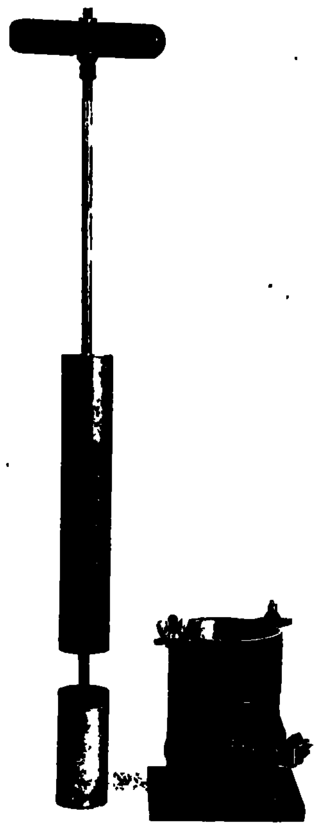

Figure 49. Compaction Hammer. Johnson

C. A. Hogentogler: The 12-in. drop is controlled by a pipe which encloses the tamper and has a stop at the upper end. The device for pushing the compacted soil from the mold is shown in Figure 50.

W. H. Wood: The split mold and collar we use are made of bronze, while the remainder of the device is of steel. The split mold clamps on a round turntable

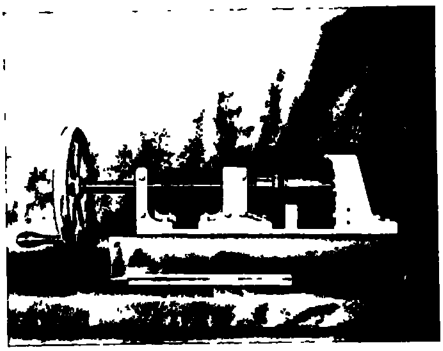

Figure 50. Device for Pushing Compacted Soil From Mold. Hogentogler

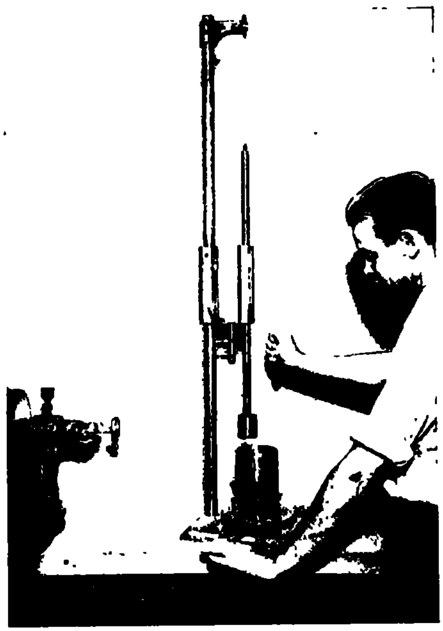

Figure 51. Compaction Testing Equipment Used in the Texas State Highway Department Laboratory. W. H. Wood.

which rotates around a centering bearing that protrudes into its center from the main base below. The turntable is notched in 12 places, spaced equidistant apart around the outside edge. A lever and pawl, with a connecting spring, is used to turn the cylinder $\frac{1}{12}$ of a revolution after each drop of the rammer. The cord used for raising the rammer passes over a pulley which travels on a ball-bearing race, Figure 51.

STATIC COMPACTION DEVICES

T. E. Stanton, Jr.: In the testing machine method sufficient dry loose soil is measured to fill a 6 by 8-in. cylinder mold and then removed and moistened to a consistency which will give maximum compaction under a compressive load of 2000 lb. per sq. in.

C. A. Hogentogler, Jr.: Approximately 30 grams of minus 40 material are thoroughly mixed with water applied in a fine spray and the moist soil is placed in a 3 in. high cylinder having a cross-sectional area of 1 sq. in. A loose fitting plunger is placed in the top of the cylinder and a vernier scale is attached in such a manner that the height of the sample can be read directly. The assembly is then placed on a platform balance and given compacting loads applied through a form of press as in Figure 46. The height of the sample is recorded after compacting loads of 50, 100, 150, 200, 250 and 300 lb. per sq. in., are applied for 30 sec. The sample is then removed, weighed, and the moisture content determined by oven-drying a small sample. This procedure is repeated for approximately six different moisture contents ranging from very dry to very wet states.

R. M. Jewell: A 5000 gram soil sample is moistened enough to give good compaction. About half the material is placed in the mold and compacted with 50 blows of a 2-lb. hand tamper. The rest of the material is similarly placed. The compacting head is placed in the mold and 2000 lb. per sq. in. applied by a testing machine. The height of the specimen is measured after the compacting head is removed.

E. O. Rhodes: Sixteen-gram portions

of the dry soil (passing No. 10 sieve) are mixed with varying percentages of water, each mixture containing also 4 percent of tar (base on dry soil). Two briquettes, containing 8 grams of dry soil, are formed from each mixture by 300 lb. static compaction in 1-in. diameter molds.

C. A. Hogentogler: The 1, 2 and 4 in. diameter consolidation devices are used for statically compacting soils to various densities to be subsequently tested for permeability, swell, consolidation, and shear.

VIBRATION COMPACTION DEVICES

Prof. D. M. Burmister: The maximum density of granular materials is obtained with the apparatus shown in Figure 47 by giving the handle a slight vibrating motion until the material stiffens up to its maximum value. The dimensions should be varied in some relation to the maximum 20 percent size of the material. The critical density may be obtained by imparting an appreciable shearing motion.

Prof. R. Seifert: The maximum density of sand and gravel only is determined in this laboratory. This measurement is necessary for the estimation of the amount of consolidation. A weighed portion of dried soil is washed into a cylinder of known volume which is placed in a jolting apparatus and jolted until no more settling of the sand is obtained. The excess water is then removed and the pore space determined.

CAPILLARITY TESTS

Capillarity tests are used to determine the amount, rate and height of water taken up or held by soils.

The capillarity devices reported by various laboratories are listed in Table 5. Four groups are considered:

O. Open tube, Figure 52.
N. Negative head, Figure 53.
C. Compressed air, Figure 54.
I. Indicator.

In Table 5 active indicates that the soil controls the applied pressure and passive indicates that the pressure (or vacuum) is increased until air is forced through the soil. Centrifuge moisture equivalent is abbreviated to C.M.E. and field moisture equivalent to F.M.E.

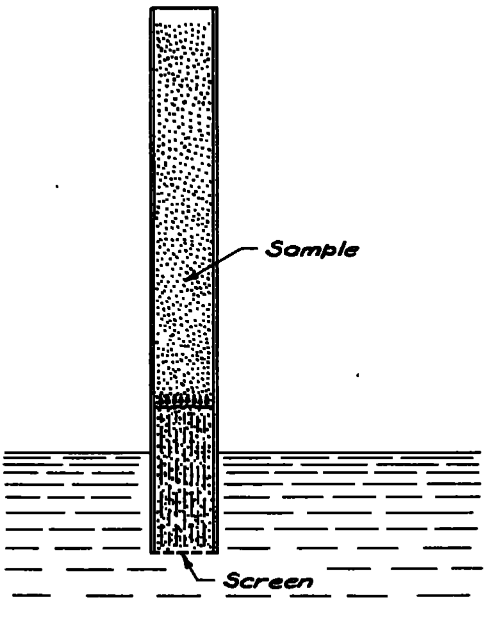

Figure 52. Open Tube Capillarity Tester

OPEN TUBE DEVICES

Dr. D. P. Krynine: Capillary movement of water in soils has been studied using a specially designed table (Fig. 55). The level of water in a box, A, is maintained constant by using an overturned flask, B, filled with water. The glass top, C, (30 by 30 in.) with a hole, D, $\frac{1}{2}$ in. in diameter, lies in the horizontal plane determined by the water level in box A, so there is no hydraulic head at hole, D. A bottomless box, E, is placed on the glass top, C, and filled with dry soil. The capillary water as seen through the glass, C, spreads in the form of circles, depending on the physical properties of