COMPENDIUM ON SOIL TESTING APPARATUS

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This report lists the physical tests of soils for engineering purposes and the types of apparatus used by laboratories of the United States, Canada and Europe. The design features of the devices are described and the types used in the various laboratories are illustrated by examples. For details of apparatus construction and procedures for performing the various tests, readers are referred to the contributors.

The material is arranged in nine sections:

CONSOLIDATION TESTS

Consolidation tests furnish information on the amount and rate of consolidation of soil samples due to pressure. The theory of the test and the data obtainable have been described in pages 13 to 18.

In all types of testing devices for this purpose the sample is placed between two porous stones, provision is made for the escape of the water squeezed from samples and a piston is used for transmitting pressure to the sample.

The apparatus is arranged in five groups:

1. Cylinder with hollow piston, Figure 1.
2. Cylinder with mushroom piston, Figure 2.
3. Fixed ring, Figure 3.
4. Floating ring, Figure 4.
5. Piston with floating ring, Figure 5.

Loads are applied in three ways: by jack (screw) (J) by spring (S) or by weights and simple levers (W).

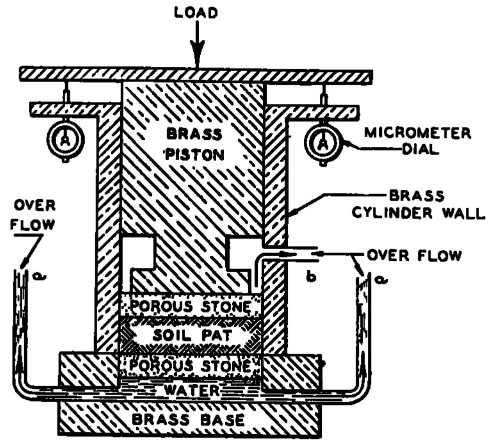

Figure 1. Essential Elements of Terzaghi Consolidation Device. Cylinder with Hollow Pisotn.

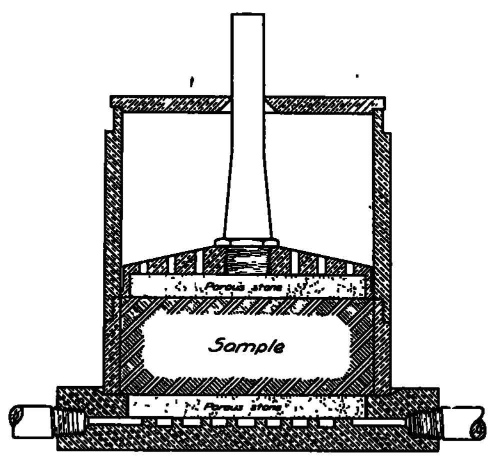

Figure 2. Cylinder with Mushroom Piston

The types of consolidometers and loading equipment reported by the various laboratories are shown in Table 1. In

TABLE 1

CONSOLIDOMETERS

State or Country	Organization	Type	Sample Dimensions: Diameter, Inches	Sample Dimensions: Thickness, Inches	Contributor
New York	Brooklyn Polytechnic Institute	1W	3.5	....	Prof. L. F. Rader
		4W	2.5	....	
California	California, University of	5S	2.5	1.0	Prof. H. E. Davis
		5S	4.87	1.0	
New York	Columbia University	3W	4.25	1.5	Prof. D. M. Burmister
		3W	2.5	0.625	
		4W	3.5	1.0	
Connecticut	Conn. Highway Department and Yale University	3W	4.21	0.5, 1.0, 1.5, 2.0	Dr. D. P. Krynine
New Hampshire	Dartmouth College	4W	2.5	...	Prof. W. P. Kimball
Pennsylvania	Engineer Office, U. S., Pittsburgh, Pa.	3J	...	...	R. R. Philippe
District of Columbia	George Washington University	3W	2.52	1.0	C. A. Hogentogler, Jr.
Massachusetts	Harvard University	3W	...		Dr. A. Casagrande
		4W	4.22	0.5	
Territory of Hawaii	Hawaii, University of	1W	...	....	Prof. C. B. Andrews
Idaho	Idaho, University of	1W	...	...	Prof. A. S. Janssen
Illinois	Illinois Division of Highways	1W	....	..	V. L. Glover
Illinois	Illinois, University of	3W	4.25	1.5, 1.75, 2.0	Prof. E. E. Bauer
		3W	2.75	1.0, 1.25 1.5, 2.0	
Kansas	Kansas State College	3J	....	....	Prof. C. H. Scholer
Louisiana	Louisiana Highway Commission	3W	2.75	1.0	H. L. Lehmann
		1W	2.75	....	
Maine	Maine Highway Commission and University	3W	5.0	....	E. F. Bennett
Montana	Montana Highway Commission	3W	....	....	G. J. Johnson
Ohio	Ohio Dept. of Highways	3J	..	....	K. B. Woods
Oregon	Oregon State College	....	...	....	Prof. S. H. Graf
Dist. of Col.	Park Service, National	3W	2.52	1.0	E. F. Preece
New Jersey	Princeton University	3J	2.76	0.5	Prof. G. P. Tschebotareff
Dist. of Col.	Public Roads, U. S. Bureau of	1W	3.75	1.25	C. A. Hogentogler
		1W	2.75	0.42	
		2W	4.0	1.56	
		2W	2.1	0.5	
Dist. of Col.	Reclamation, U. S. Bureau of	3S	8	3	J. C. Page
California	Shell Development Company	...	..	..	V. A. Endersby
Washington	Washington Dept. of Highways	1W	....	....	Bailey Tremper
Washington	Washington, University of	1W	2.766	....	Prof. R. G. Hennes
		3J	3.5	....	
West Virginia	West Virginia Road Commission	1W	...	....	A. M. Miller
Dist. of Col.	Yards and Docks, U. S. Bureau of	1W	2	0.5	C. H. Bramhall
Canada	Toronto, University of	3J	...	..	Prof. C. R. Young
Denmark	Royal Technical College of Denmark	1W	....	....	Axel Riis
France	Laboratory for the Study of Soil and Foundations	1W	....	....	
		....	....	....	Dr. A. Mayer
Germany	Prussian Research Station for Hydraulic, Earth, and Marine Work	1W	...	..	Prof. R. Seifert
Netherlands	Laboratory for Soil Mechanics, Delft	4W	2.56	0.788	Dr. T. K. Huizinga
		4W	....	....	
		1W	....	...	
Switzerland	Federal Tech. High School	1W	....	....	Dr. L. Bendel
Switzerland	Ecole d'Ingenieurs	1W	....	....	Dr. L. Bendel
Switzerland	Dr. L. Bendel	1W	....	...	Dr. L. Bendel

column 3, numerals indicate the type of apparatus and letters the type of loading. For instance, symbol 3J means that the consolidometer is of the fixed ring type and is loaded by means of a jack.

Differences in design may be attributed generally to differences in cost of construction and variations of opinion relative to ease of operation and to elimination of experimental errors including those due to friction.

Figure 1. About a year later a second stone, that shown at the top of the sample, was added as an improvement.

Recognizing the possibility of friction in the necessarily close fit of the piston within the cylinder, a slightly larger similar apparatus which utilized ball bearings between the two walls was constructed sometime later.

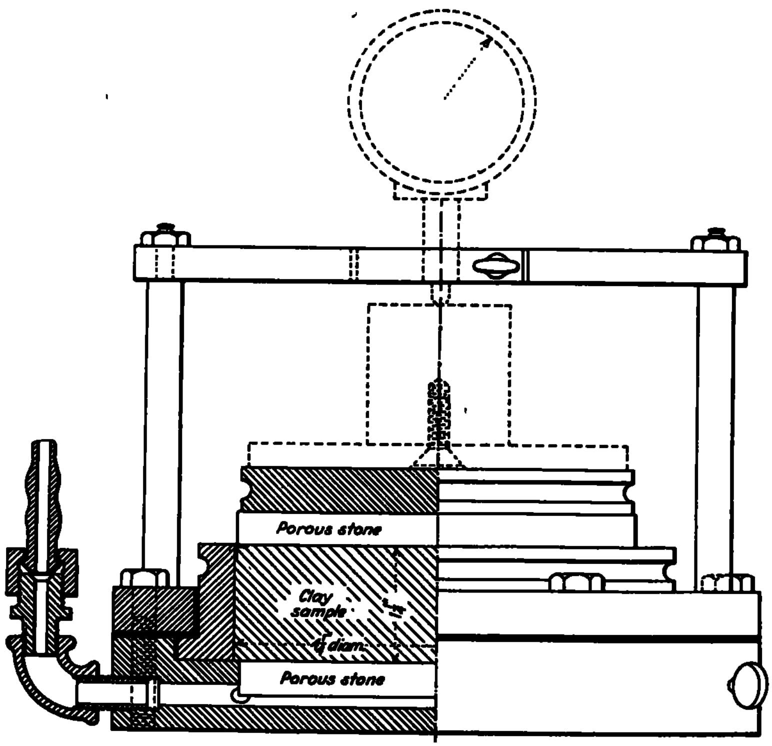

Figure 3. Fixed Ring Consolidation Device

However, comparison of data from the two types of apparatus gave no indication of friction in the original designs and they have given satisfactory service since.

CONSOLIDOMETERS—CYLINDER WITH HOLLOW PISTON

C. A. Hogentogler: In 1926 the Bureau of Public Roads constructed three consolidometers of the hollow piston type in accordance with plans furnished by Dr. Charles Terzaghi. The original design calls for but one porous stone, that shown at the base of the apparatus in

H. L. Lehmann: We are using two types of soil compression devices. One is the Casagrande design described by P. C. Rutledge in a paper entitled "Recent Improvements in Soil Testing Apparatus," Harvard University Publication School of Engineering No. 165,

FLOATING RING CONSOLIDOMETERS

Dr. A. Casagrande: The need for a much cheaper consolidation apparatus, particularly for the use of students, led to the development of the type shown in Figure 4. Since only in a few instances is use made of the attachment for direct permeability tests, this feature was not provided in the new type. The sample ring can be supported on a large porous stone, or it can be set up as a "floating" ring, by using the same size porous stone for the base as for the top. By using rings which have a height of one-eighth of the diameter the use of the floating arrangement reduces the effective height to the extent that the effect of the side friction is practically eliminated. The base of the apparatus is a dish-shaped casting which carries the extensometer yoke and allows easy control of the outside water level. A simplified piston to transmit the load from the loading yoke to the sample was also designed.

This simplified consolidation apparatus costs only about one-third of that of the type shown in Figure 9, and is much simpler in operation. While originally intended only for student's use, it was found so satisfactory that it can be recommended for general use.

Dr. T. K. Huizinga: Five different kinds of apparatus are used: The consolidation-apparatus, a cell-apparatus (triaxial compression), an old consolidation-apparatus, the Terzaghi oedometer, and the consolidation apparatus with direct loading.

In normal cases the first apparatus is used; the sample has a diameter of 6.5 cm. and a height of 2 cm. It is placed between two porous stones in a ring with an inner diameter of 6.5 cm. and a length of 5 cm. The sample is centrally loaded by means of a lever, counterweighted to zero-load. The micrometer dial ("Stoppani") is fixed to the upper level at a point situated exactly over the center of the sample. To prevent the drying out of the sample, the ring is placed in a water basin with a constant level.

In the cell-apparatus, the difference in test conditions with normal consolidation-apparatus is the absence of a rigid ring. Here the sample can undergo a small lateral deformation. The lateral pressure as well as the lateral deformation can be measured. The sample is lowered inside the apparatus and surrounded by the rubber envelope, which is pressed slightly against it. To prevent capillary forces, the sample is kept under water.

PISTON WITH FLOATING RING

Prof. H. E. Davis: The apparatus shown in Figure 5, is the Terzaghi type as modified by Moran in connection with tests of foundation material for the San Francisco-Oakland Bay Bridge. The effect of deep submergence may be imitated by applying pressure to the water surrounding the sample. See *Engineering News-Record* Vol. III, No. 14, Oct. 5, 1933.

The spring load is applied in a low-capacity testing machine. Initial loads are 1 to 6 lb. per sq. in., load increments during principal part of run are 10, 20, 40, etc. lb. per sq. in. Recoveries are noted. Samples are prepared in the humid room, by trimming and tirring into a transfer ring and then pressing into the ring container for test. Consolidation under load is determined by dial gages.

DIRECT SHEAR TESTS

Shear tests determine the resistance of soils to distortion. A discussion of the data obtained from shear tests is presented in pages 18 to 27. The apparatus is arranged in four groups:

1. Box, Figure 12
2. Plate, Figure 13
3. Double, Figure 14
4. Torsion, Figure 15

Normal loads are applied in three ways:

C. Compressed fluid

J. Jack (screw)

W. Weights and simple levers

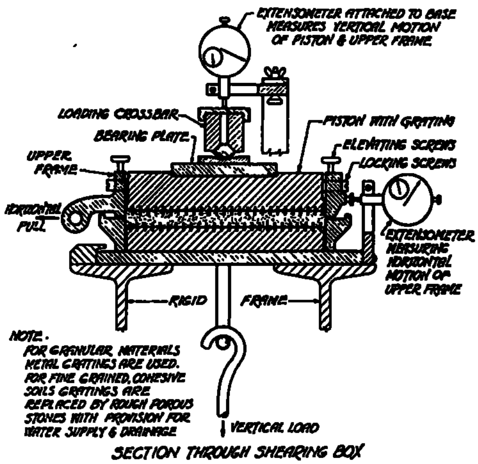

Figure 12. Box, Type Shearing Apparatus

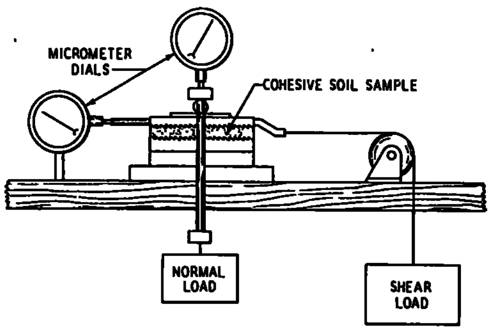

Figure 13. Essential Features of Plate Shear Test

Shearing loads are applied in five ways:

C, J and W as above

B. Bell crank and weights

P. Pulley and weights

Table 2 summarizes the equipment reported by the various laboratories. The symbol for type in column three is explained by an example. Thus, 3C J means the shearing device is of type 3, double, the normal load is applied by a compressed fluid and the shearing load is applied by a screw jack.

DIRECT SHEAR DEVICES—BOX

Prof. D. M. Burmister: The shear apparatus illustrated in Figure 16, is of the Harvard-shear box type, $2\frac{1}{2}$ by $3\frac{1}{2}$ in. equipped with either gratings or porous stones. The horizontal shearing deformation and the vertical expansion or compression of the specimen during shearing are measured by Ames dials. Vertical normal loads are applied by counterbalanced lever systems and dead weights. The shearing load is applied by a motor operated gear reduction device through a loading bar which permits

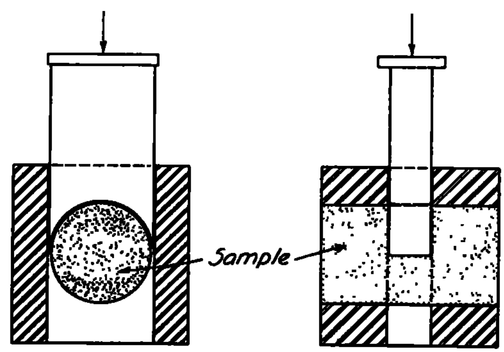

Figure 14. Double Shear

either one of two shear tests to be made independently of the other. The load is measured by means of a calibrated loading ring fitted with an Ames dial. The shear loading device is of the "constant strain type," the rate being controlled by means of a rheostat to 0.1 or 0.05 in. per min. for most soils. This rate requires about 5 to 10 min. to complete the test.

Sample Preparation: A sample of the undisturbed soil is fitted into a sample box by means of a fitting knife as for the consolidation test. The natural moisture content of the soil is determined for each test. The sample box is lined up with the upper frame of the shear box piston and cylinder end are put in place, the piston will rest against the rubber diaphragm.

Air connections are now made to the air reservoir, the cylinder is placed in the saddle, and the apparatus is placed in the Hubbard-Field press. The pin is removed and the air pressure is run up to 100 lb. per sq. in. for a period of one minute, then decreased to 75 lb. per sq. in., at which pressure the test is run. The load is then applied at the rate of 0.8 in. (40 turns) per minute; this rate is maintained until the gage indicates a maximum has been passed.

Prof. W. S. Housel: In finding the shear resistance at the yield point of a cohesive material the equipment shown in Figure 30 is used. It consists chiefly of a steel cylinder $1\frac{3}{8}$ in. inside diameter, so constructed that a section 1 in. long can be moved freely in causing failure of a cylindrical core sample in double shear. Loading to failure is accomplished in six or seven increments of lead shot, with time intervals of ten minutes for each increment to allow for complete elastic deformation.

The shear cylinder used for strictly granular material of small particles is of the same size as the one used in the test for cohesive materials and differs only in that provision is made for the application of normal load by the mechanical balance machine. For larger granular materials and mixtures of granular and cohesive materials such as stabilized road bases, the large 16 sq. in. cylinder shown in Figure 31 has been developed. In principal, it is exactly the same as the smaller cylinder and differs in detail only in the application of normal load by means of air pressure.

DIRECT SHEAR DEVICES—TORSION

Prof. R. Seifert: Shear resistance is measured in our laboratory by Tiedemann's apparatus as shown in Figure 15.

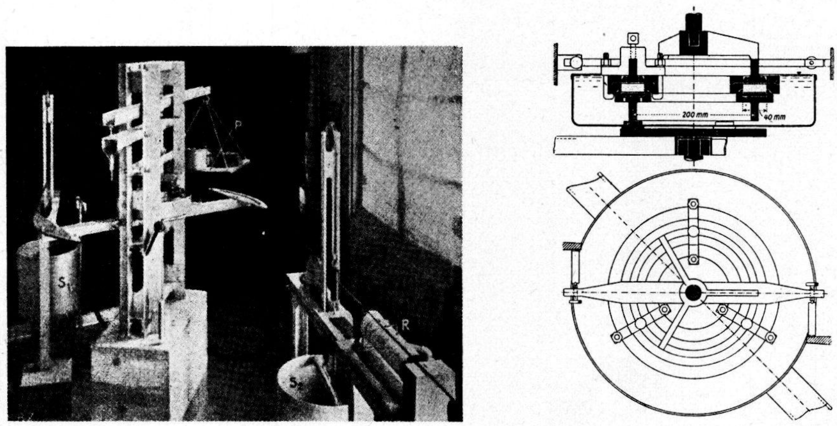

Figure 32. Torsion Test. Bendel

Dr. L. Bendel: The torsional apparatus we use is shown in Figure 32.

COMPRESSION TESTS

Compression tests on cylinders furnish information on the volume change and distortion of soils when subjected to measured compressive stresses. The sample may be confined on all faces as in triaxial shear or stabilometer devices or may be unconfined and loaded only on the ends.

A discussion of the data obtained from the tests is included in these Proceedings, pages 21 to 27.

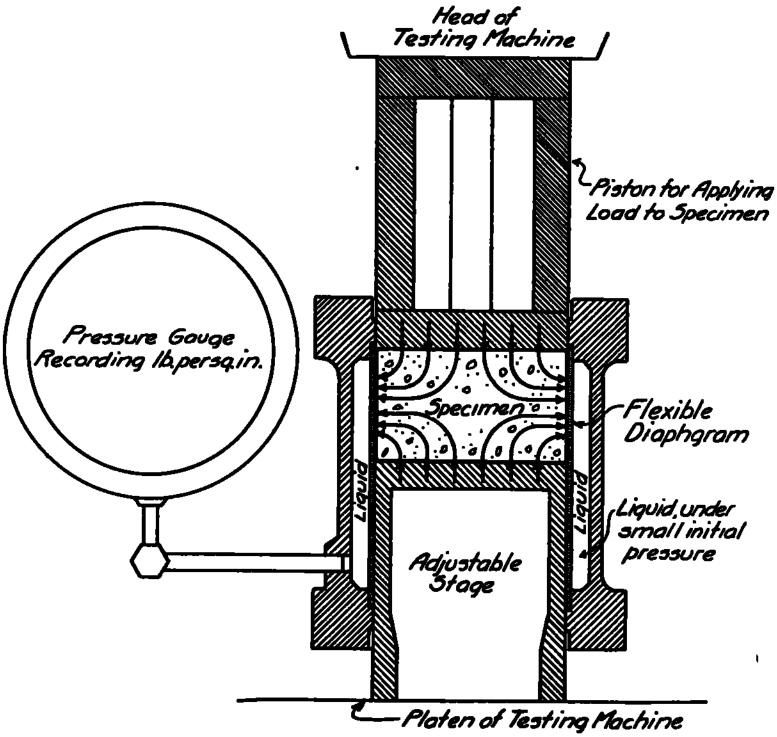

Figure 33. Fixed Rubber Compression Device (Hveem Stabilometer)

There are three types of apparatus:

1. Fixed rubber, Figure 33
2. Free rubber, Figure 34
3. Unconfined, Figure 35

The compression devices used by various laboratories are listed in Table 3.

FIXED RUBBER COMPRESSION DEVICES

Prof. H. E. Davis: For experimental purpose, some tests have been made in which the sample, 4.85 in. dia. by 7½ in. long, is fitted into a double-walled rubber sack, thus permitting air pressure to be applied to the cylindrical surface of the specimen. Axial load is applied by a spring loaded plunger. The method is not highly satisfactory.

The lateral pressure due to vertical loads on remolded soils have also been investigated experimentally in a preliminary way. The apparatus consists essentially of an 8-in. cubical steel box in one

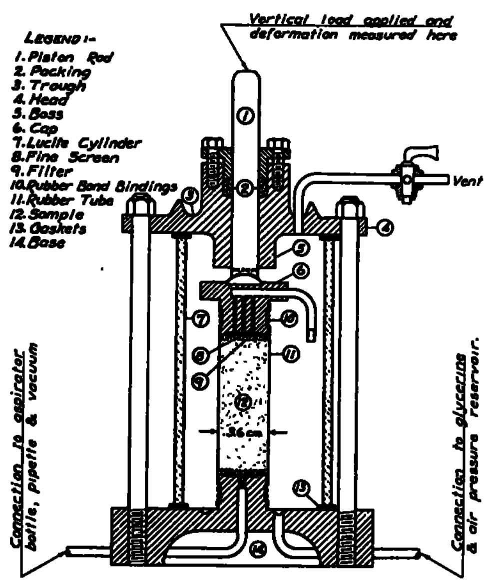

Figure 34. Sectional Sketch of Triaxial Compression Chamber. Free Rubber Device.

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.

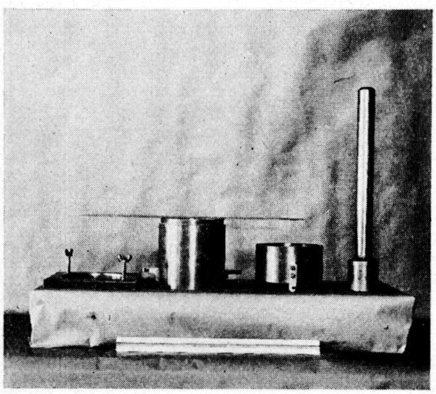

Figure 45. Impact Compaction Apparatus

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.

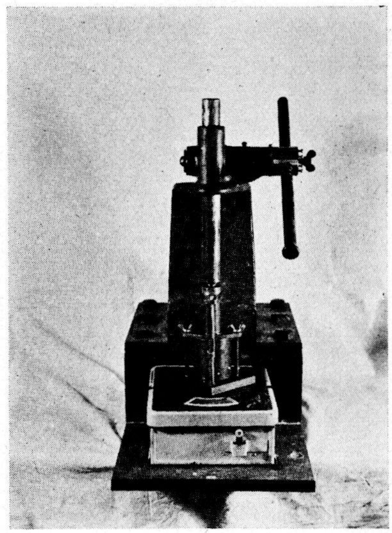

Figure 46. Static Compaction Device

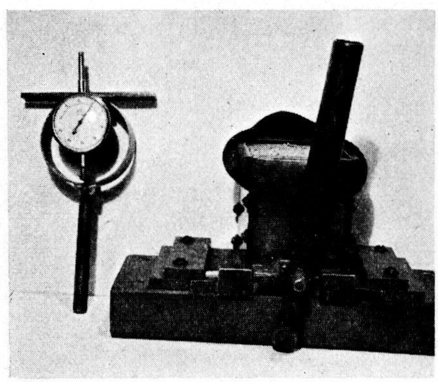

Figure 47. The Critical Density Apparatus for Determining the Limiting Loose and Dense States and the Critical Density of Cohesionless Granular Materials. Penetration Test Readings Indicate Differences in Penetration Resistance for these Conditions. Vibratory Compaction Type.

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, 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.

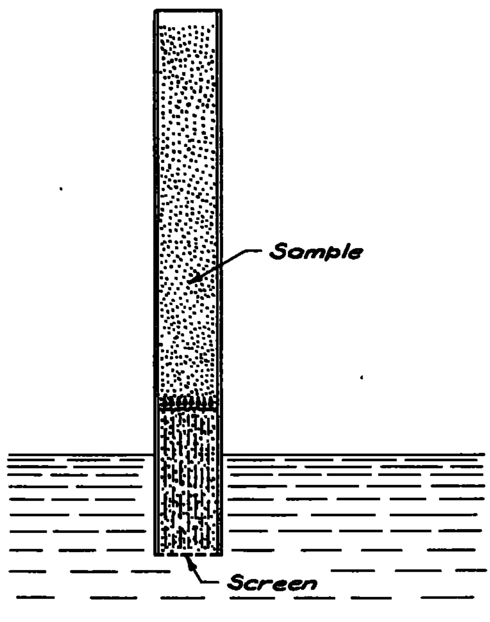

Figure 52. Open Tube Capillarity Tester

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, ½ 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