are determined by binometer, and the flow volume is determined by means of a calibrated orifice for particular downstream pressure. Calibration of this apparatus has not yet been accomplished and it is not yet used as a routine test. The apparatus appears to have certain definite advantages in that permeabilities of very dense materials may be obtained readily and permeabilities may be deter-

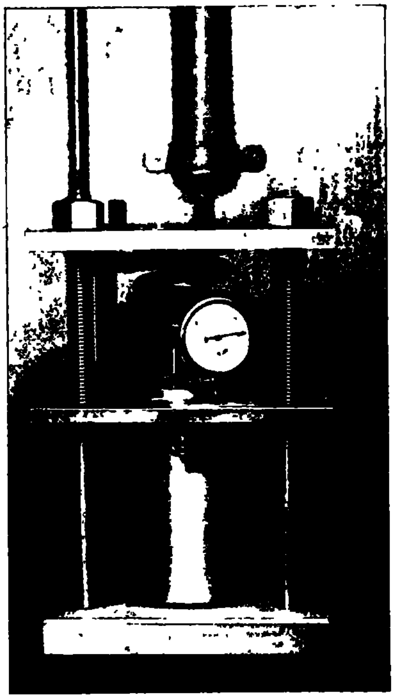

Figure 64. Permeability Cylinder. Housel

mined at various stages of a progressive test without saturating the sample.

Prof. R. Seifert: Test borings, in their original undisturbed condition, are so placed in a sufficiently wide glass cylinder (Fig. 65) that the underside of the sample rests on a sand filter; the space between sample and glass wall being filled with sizing treated with Formalin. A layer of sand is placed over the soil sample and covered with a sieve plate which can be loaded. Using a container giving an unchanging head of water, the daily passage of water through the sample is measured.

If the soils are those to be used in dams or other consolidation works, the sample is compressed to the density it will have in the structure and to a height of about 10 cm. in a glass ring, the sides of which are coated with grease and beeswax. The daily water passage is then measured.

The oedometer of Terzaghi is a better and more thorough instrument. However, it is more involved and hence costlier. In this case the soil is placed in the apparatus in the form of a slurry. The water is then squeezed out under various loads and the consolidation of the soil measured. The test results are calculated through the use of Darcy's formula from the time, area and head of water.

Dr. L. Bendel: The construction of the apparatus used in Zurich is shown in Figure 66.

VARIABLE HEAD PERMEAMETERS

Prof. D. M. Burmister: The permeability device, illustrated in Figure 67, consists of a base and a top containing porous stones, and various lengths of 3-in. brass tubing into which the soil is placed in the desired degree of compactness. For undisturbed samples a length of the 3-in. sample is cut without removal from the sample tube, the filter heads being fitted and clamped into place, and a water-tight seal effected by means of a special sealing ring. The device is connected to a suitable stand-pipe in a bank of stand-pipe sizes ranging from gauge glass to capillary size, and the device is operated as a variable head permeameter. The scale for the stand-pipe is calibrated for head in centimeters and quantity in cubic centimeters. A correction curve for the loss of head through the system independent of the soil is determined for each stand-pipe.

Dr. D. P. Krynine: For coarse sands and gravels a very simple device is used, as shown in Figure 68. There are two metallic containers, A and B. The bottom of the inner cylinder, A, is perforated and covered with a filter paper. The soil sample is placed on this paper so that sample is allowed to absorb as much as it can. Additional water should be added gradually in order to maintain a constant level in the outer cylinder.

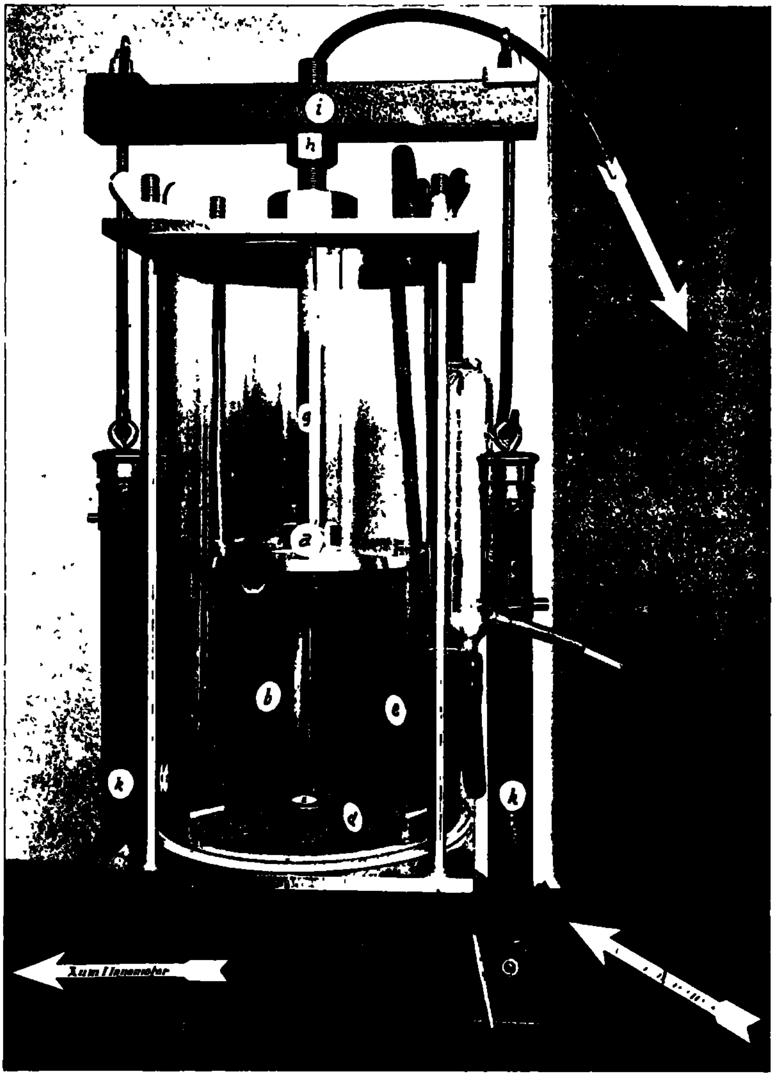

Figure 65. Permeability by Tiedemann. Seifert. a—Sieve plate. b—Sample. d—Sand filter. e—Sizing between glass wall and sample. k—Springs for varying loads on sieves. l—Pressure meter.

its upper surface corresponds to the edge of the outer cylinder. The edge serves as an overflow device. First, the outer cylinder is filled with water, and the Afterwards the inner cylinder is carefully filled without disturbing the surface of the sample, and percolation begins immediately. When the water level in the inner cylinder has dropped to a distance, a, from a mark, M, the time interval is recorded.

Dr. A. Casagrande: The falling or variable head permeameter, introduced by Terzaghi, is the most important laboratory method. In general, the trend is away from the more complicated contrivances used years ago, to simpler devices which consist only of a glass or "Lucite" tube, closed at the bottom with a brass screen and clamp and connected on the top to a stand pipe. For the more pervious soils this tube, which contains the sample, is provided long enough so that the upper range also serves as stand pipe. The simplicity of such devices has helped materially in reducing sources of errors and the time required for testing.

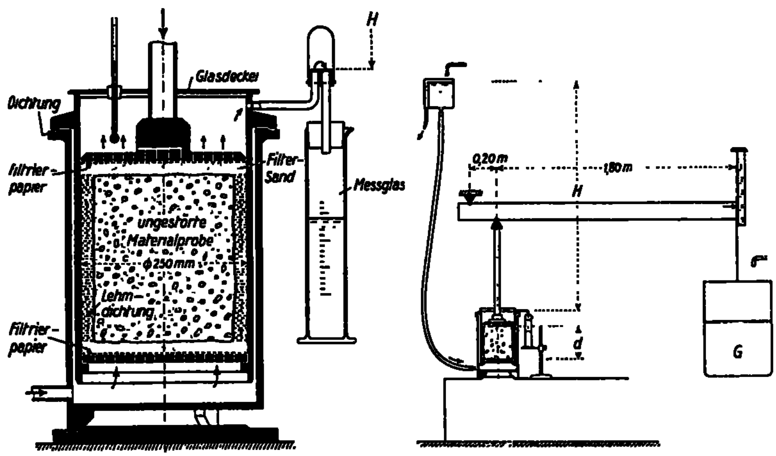

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Figure 66. Zurich Constant Head Permeability Apparatus. Bendel

Figure 67. Permeability Device. Two Filter Heads with either Screens or Coarse Grade Porous Stones. Various Lengths of 3-in. Brass Tubing for Samples. Burmister.

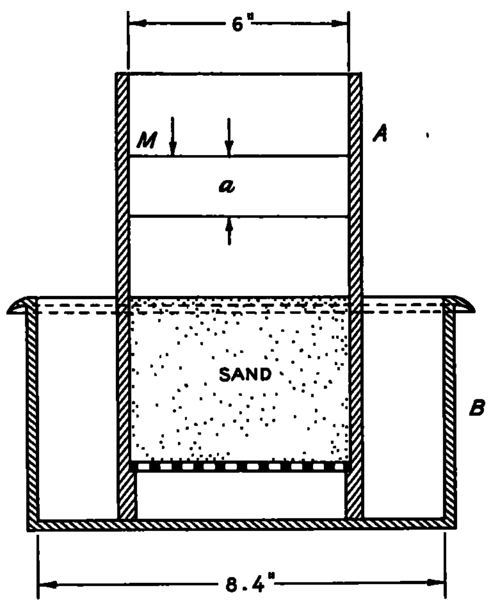

Figure 68. Variable Head Permeameter. Krynine

Deposition of air in the sample during testing is the cause of a large reduction in the coefficient of permeability. The use of boiled or distilled water does not sufficiently reduce this error. It was found by Professor G. M. Fair, Head of the Sanitary Engineering Department at Harvard University, that the deposition of air in the sample during testing can be effectively eliminated by the use of deaerated water, prepared by spraying tap water or distilled water in a fine stream into a glass carboy from which the air has been evacuated. This preparation reduces the normal dissolved air content of tap water from approximately eight parts per million to about five parts per million, the exact reduction depending on the temperature. Such a reduction of the dissolved air content is fully enough to reverse the usual action of water so that it takes air (if available) into solution as it passes through the sample.

When using a permeameter in which the water is flowing in a downward direction through the soil, particular care should be taken to prevent the formation of a filter skin on top of the sample. Such silting up of the surface will occur when the surface is disturbed under water and the disturbed material is allowed to settled. This effect can be eliminated by first carefully cleaning the surface, for example, with a gentle jet of water with the sample in a submerged condition, and then covering the surface with a layer of clean sand which is considerably coarser than the sample.

To close the space between the sample and the surrounding cylinder, a Bentonite gel was used successfully on an extensive series of tests performed in the Harvard Soil Mechanics Laboratory. The arrangement is shown in Figure 61. The sample was placed inside the cylinder on a moist glass plate and the annular space filled to a height of about one quarter of an inch with molten paraffin and allowed to cool. This ring of paraffin provides sufficient support for the sample during the further operation in which the remainder of the annular space is filled with Bentonite gel. This filling is conveniently done by injecting the gel through a thin glass tube attached to a rubber bulb containing the gel. Care must be exercised to prevent any deposition of gel on the top of the sample. After filling the space, the sample is allowed to stand for a time to permit the gel to stiffen. Then the surface of the sample is carefully cleaned once more of any foreign material and a thin layer of fine sand is placed on top of the Bentonite gel for protection. The entire sample is then covered with a layer of Ottawa standard sand and carefully lifted from the glass plate. Any paraffin which might adhere to the bottom of the sample is removed, and a brass screen is clamped over the bottom to hold the sample in place.

The dimensions of the device shown in Figure 61 can be chosen between wide limits, depending on the size and character of the available samples. The cylinder or the stand pipe can be clamped to vertical rods in any desired elevation. A series of vertical rods which are conveniently fixed at their upper ends, numerous clamps, glass or lucite cylinders of different diameters and lengths with properly fitting rubber stoppers, different types of stand pipes, and a tank or several individual dishes for the tail water level, comprise the special equipment needed for the accurate and efficient determination of the coefficient of permeability of a wide range of materials, in the undisturbed as well as disturbed state.

The consolidation apparatus permits the direct testing of the permeability by the attachment of a stand pipe to the base of the apparatus. For clays the special attachment, shown in Figure 69, was developed by the author. This attachment permits the performance of perme-

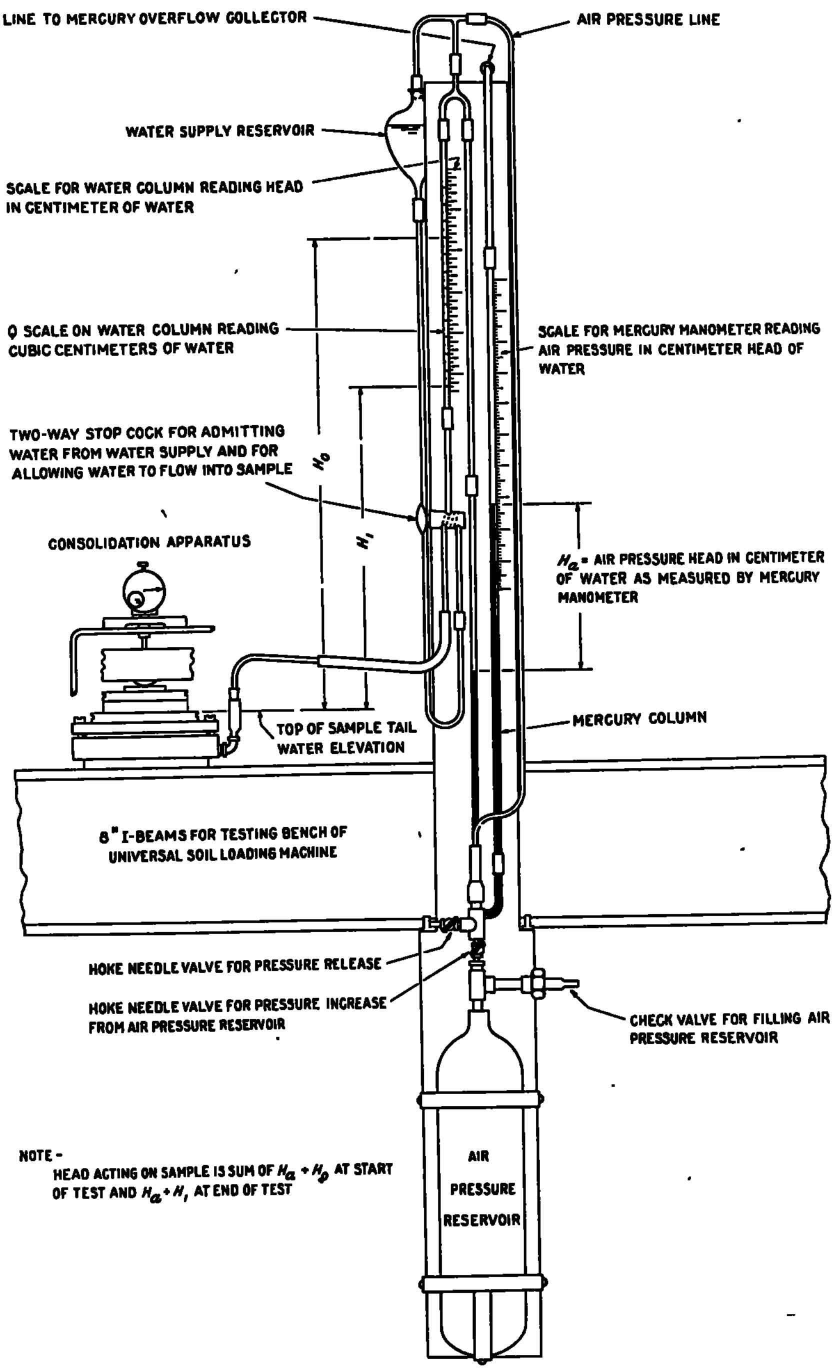

Figure 69. Permeability Attachment for Use with Consolidation Apparatus. Casagrande

ability tests on clay samples in a few hours which, with a low-head stand pipe would require days. The large errors due to temperature fluctuations are also very much reduced when using this attachment.

The consolidation apparatus can be use for soils with coefficients of permeability less than 10 by 10^{-4} cm. per sec. For more pervious soils the loss of head in the stand pipe and through the porous stone in the base increases to such a magnitude that it cannot be neglected. For upward flowing water the sample must be properly confined to prevent a loosening of the soil structure.

The use of the consolidation apparatus for permeability tests is particularly recommended for compressible soils, because it permits the determination of the permeability at different void ratios.

Prof. E. E. Bauer: The sample is packed in a glass tube 40 mm. in diameter and 19 cm. long. 100-mesh wire sieve cloth is used at bottom and top. A 50-cc. burette is mounted above and connected to the glass tube with rubber tubing. The lower end of the sample is placed in a glass beaker. Fine sand is used as the material.

E. F. Preece: Samples arriving from the field are tested by jabbing a stand pipe into the soil and filling the pipe with water. When dripping begins we stop filling the pipe and make the determination of permeability by the falling head method.

Prof. G. P. Tschebotareff: Permeability tests on clays are performed in the consolidometer, for which falling head permeater attachments are available. Granular materials are tested in brass cylinders of 4 in. inner diameter and 5 in. height. These cylinders are used in connection with both falling head and constant head permeaters. Equipment for the horizontal capillarity test is available but is seldom used. One further permeater cylinder of 4½ in. inner diameter and 6 in. height is provided with standpipe tube attachments which allow the control determination of the water head at ⅓ points of the height of the sample at its centre.

C. A. Hogentogler: The Proctor mold, modified for consolidation tests, is used to determine the permeability of statically compacted samples while under load as shown in Figure 70. Water is forced through the base with the aspirator bottle until the system is free of air bubbles. After the sample is saturated, permeability readings are taken.

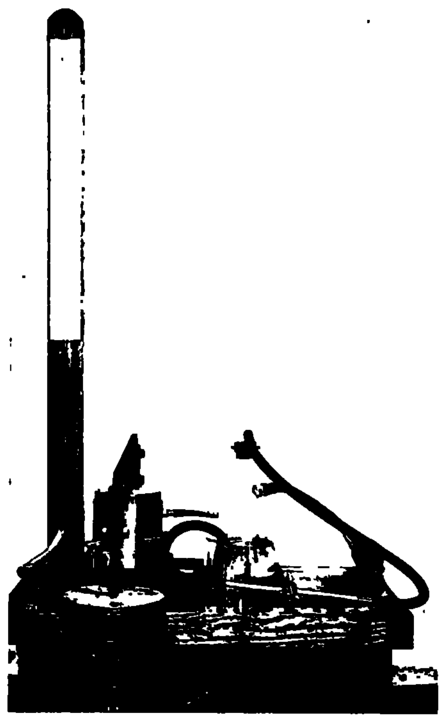

Figure 70. Proctor Mold for Determining Permeability of Samples under Load. Hogentogler.

Tests on sand have been made in 2 in. diameter glass cylinders with a sieve attached to the bottom.

Dr. T. K. Huizinga: For this purpose the common consolidation apparatus has been slightly changed. In order to prevent seepage between the sample and the inside wall of the ring, the sample is cut to a 3 mm. smaller diameter. The space between the sample and the ring is filled up with an elastic, impermeable substance (glue and formaline). Another device is used for disturbed samples.

PENETRATION AND EXTRUSION TESTS

Penetration and extrusion tests are used to indicate the relative bearing capacity of soil samples. Some may be used to test soil in place.

Table 7 gives a list of the apparatus reported by various laboratories. Four groups are considered:

N. Needle, Figure 71.
C. Cone, Figure 72.
B. Bearing, Figure 73.
E. Extrusion, Figure 74.

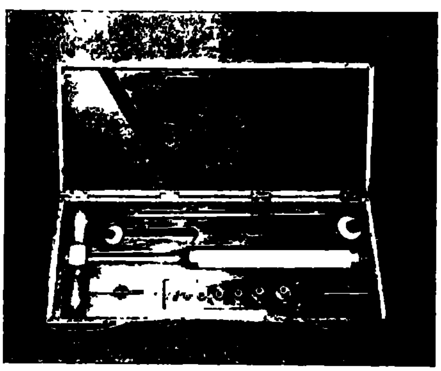

Figure 71. Proctor Needle

NEEDLE PENETRATION DEVICES

C. A. Hogentogler, Jr.: The apparatus shown in Figure 75 is an arbor press which insures vertical movement of the plunger, accurate measurement of the depth and control of the rate of penetration, with provision for applying constant load. The pressures are determined by use of a 300-lb. capacity platform balance not subject to appreciable vertical movement. Depth of penetration is measured by a pointer referring to graduations on the needle stem. There are seven penetration footings with end areas ranging from $\frac{1}{20}$ to 1 sq.

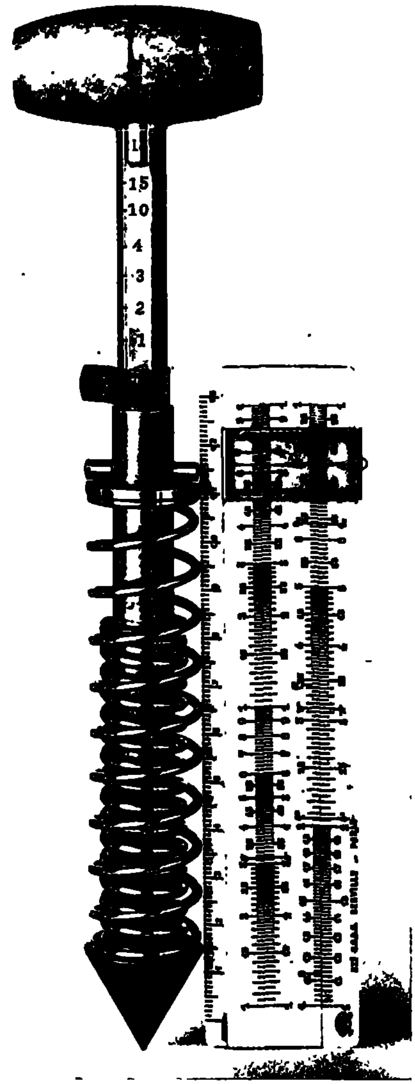

Figure 72. Spring-Scale Cone of Godskesen

in. Pressures up to 6000 lb. per sq. in. can be measured.

H. L. Lehmann: The Proctor plasticity needle is used for measuring the force required to cause penetration of rods of