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.

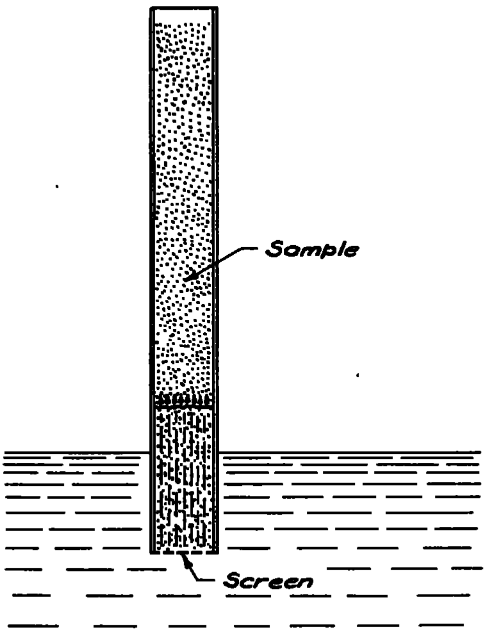


**Figure 52. Open Tube Capillarity Tester**

### 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

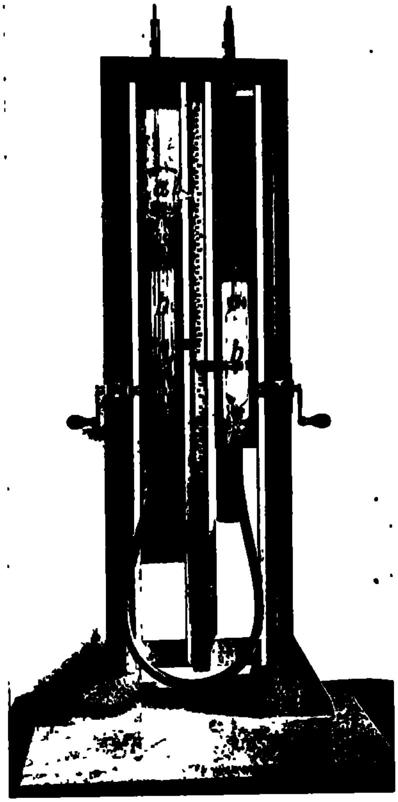

**Figure 53. Beskow Capillarimeter. a—Recepticle for soil sample with filter plate. b—Glass holder with hose connection and mercury filling to obtain the difference in pressure.**

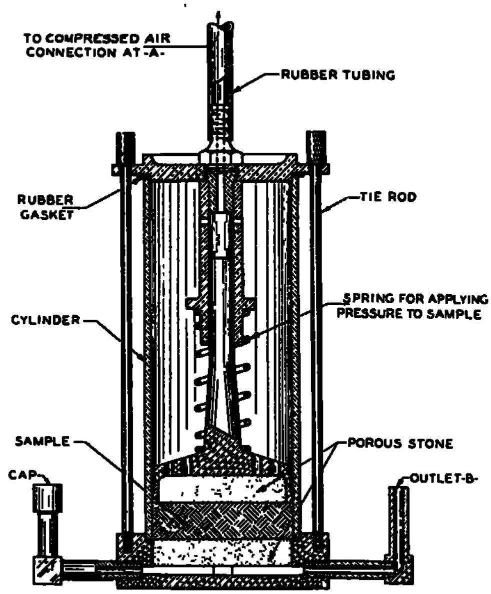


**Figure 54. Test for Capillarity—Fine Grained Soils. Compressed Air Type**

TABLE 5

CAPILLARITY DEVICES

| State or Country | Organization | Type | Description | Contributor |
|---|---|---|---|---|
| Arizona | Arizona Highway Department | I | C.M.E. | W. G. O'Harra |
| New York | Brooklyn Polytechnic Institute | O | Horizontal | Prof. L. F. Rader |
| Colorado | Colorado Highway Department | I | F.M.E. | K. C. Vail |
| New York | Columbia University | N | Active | Prof. D. M. Burmister |
| Connecticut | Conn. Highway Dept. (Yale Univ.) | O | Spherical | Dr. D. P. Krynine |
| Idaho | Idaho Dept. of Public Works | I | C.M.E. | R. M. Jewell |
| Illinois | Illinois, Univ. of | I | C.M.E. | Prof. E. E. Bauer |
| Kansas | Kansas State College | O | Vertical | Prof. C. H. Scholer |
| Michigan | Michigan Highway Dept. | N | Active | Prof. W. S. Housel |
| Missouri | Missouri, Univ. of | I | Slaking | Dr. H. F. Winterkorn |
| Nebraska | Nebraska Dept. of Roads and Irri. | I | Slaking | R. E. Bollen |
| North Dakota | North Dakota Highway Dept. | I | C.M.E. | L. A. French |
| Dist. of Col. | Park Service, National | N | Passive | E. F. Preece |
| New Jersey | Princeton University | O | Horizontal | Prof. G. P. Tschebotareff |
| Dist. of Col. | Public Roads, U. S. Bureau of | O | Vertical | C. A. Hogentogler |
| | | N | Passive | |
| | | C | Passive | |
| Denmark | Danish Road Laboratory | N | Passive (Beskow) | Axel Riis |
| Denmark | Danish Geological Survey | N | Passive (Beskow) | Mrs. E. L. Mertz |
| Germany | Prussian Research Station | O | Vertical | |
| | | N | Passive (Beskow) | Prof. R. Seifert |
| Netherlands | Laboratory for Soil Mechanics, Delft | O | Vertical | Dr. T. K. Huizinga |
| | | N | Active, Passive | |
| Switzerland | Testing Institute of Dr. Bendel | C | Active | Dr. L. Bendel |

soil and on the way of placing dry soil into box, E.

**Prof. C. H. Scholer:** Tests for capillary properties of soil have been made in long glass tubes about 1½ in. in diameter by 60 in. long. Both ends of the tube are open, the lower end is placed in water and the upper end left open to the atmosphere.

**Dr. T. K. Huizinga:** A glass tube open at each end is filled with dry sand. The lower end is placed in a basin of water. For some time the upward movement is observed and from these data a rough idea of the maximum capillary lift can be obtained.

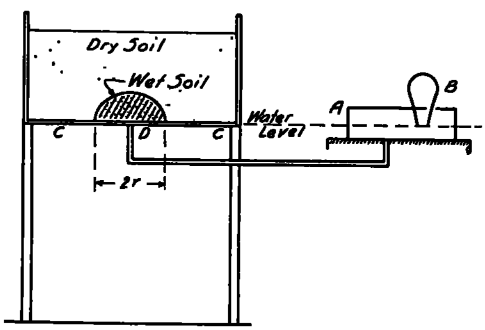


**Figure 55. Table for Studying Capillary Phenomena. Krynine**

NEGATIVE HEAD CAPILLARITY DEVICES

**Prof. D. M. Burmister:** The device consists of a special cup with a porous stone set in the chamber at the bottom. A mercury manometer is connected to this chamber for determining the suction or capillary pressure of soil. Undisturbed samples, where they can be obtained and trimmed to shape, may be fitted and sealed into place with paraffin for determining the capillarity of the natural soil.

**Prof. W. S. Housel:** The test for capillarity which has been adopted by the Michigan State Highway Laboratory is the so-called capillary potential test. A battery of glass capillary tubes similar to the one in Figure 56 is set up, each containing the same soil in an inundated condition in the funnel. During the test the temperature should remain constant. As the mercury is pulled up by the capil-

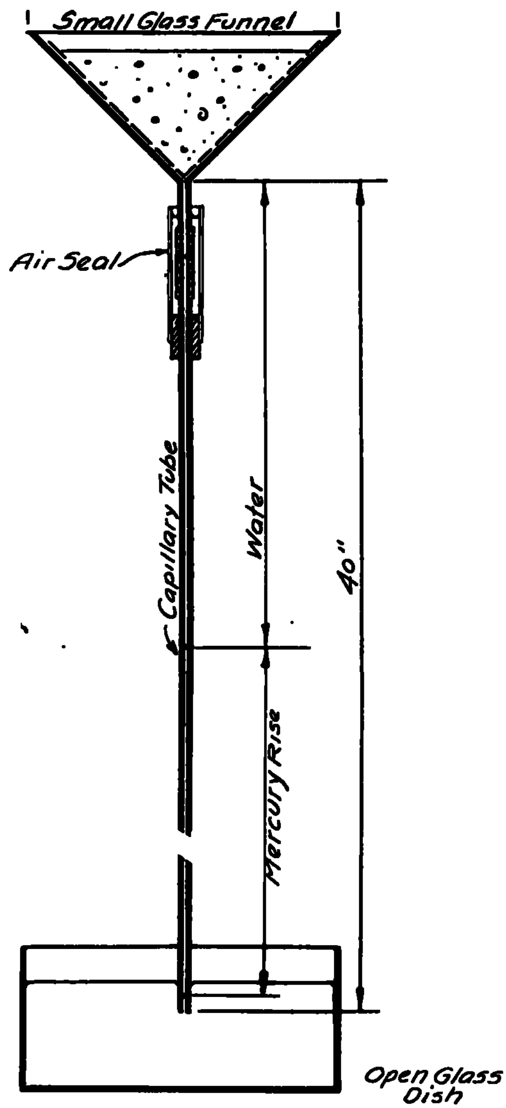


**Figure 56. Negative Head Capillarity Apparatus. Housel**

larity of the wet soil in the funnel the test is stopped on the individual tubes after such a time that each tube represents an appreciable rise of mercury over the previous one. At the time when the test is stopped a moisture determination of the soil in the funnel is made.

**E. F. Preece:** The capillary test with negative pressure uses a vacuum pump and manometer.

**C. A. Hogentogler:** Figure 57 shows the apparatus used for testing materials of relatively low capillarity. It consists of a glass filter funnel to which is attached a glass tube having the same diameter (approximately $\frac{3}{16}$ in.) as the tube forming the lower part of the funnel. The funnel and tube are supported in a glass jacket so that the tube hangs vertically in the center of the jacket. A cork disk is fitted into the shoulders of the funnel to support a sieve. This sieve is changed for different size materials and should never have openings much smaller than the minimum size of the material to be tested to avoid any capillary effect of the sieve.

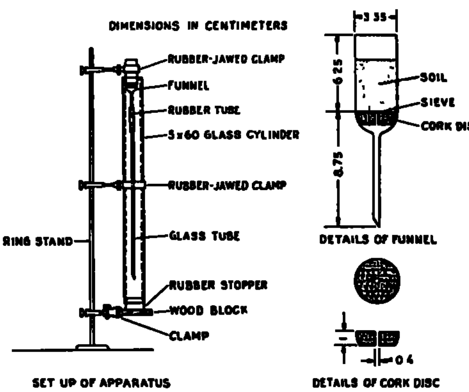


**Figure 57. Capillary Apparatus for Materials of Relatively Low Capillarity. Hogentogler**

In making a test the apparatus is filled with liquid (usually water) to a level 4 cm. above the sieve. The material (usually soil) is then poured, without tamping, into the funnel to a height of 4 cm. Next the apparatus is adjusted so that the height of the liquid in the cylindrical glass jacket is level with the bottom of the cork disk. After the material has drained, the jacket is lowered slowly by small increments with a short pause for drainage between each lowering. The test is completed when the column of liquid in the funnel tube breaks. The total distance through which the jacket is lowered, which is the distance between the bottom of the sample and the level of the liquid in the jacket when the column of liquid in the inner tube breaks, gives the height of a column of liquid supported by the capillary attraction of the materials.

**Prof. R. Seifert:** Our Beskow Capil-

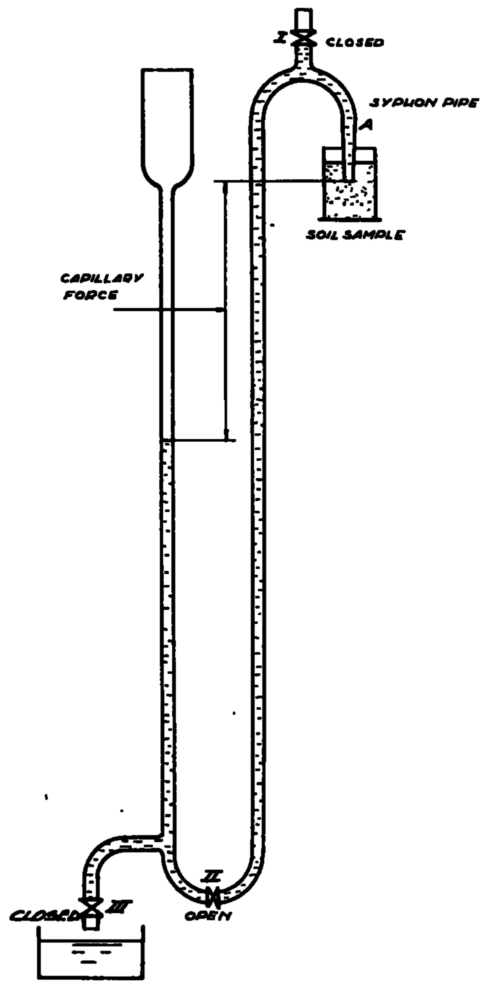


**Figure 58. Geuze Capillarimeter. Huizinga**

larimeter is shown in Figure 53. The difference in level between the containers, b, is increased by means of the cranks until the soil's capillarity is overcome.

**Dr. T. K. Huizinga**: Three kinds of apparatus are described:

1. The sample is placed in a glass tube on a metal sieve. At the bottom a rubber tube is fixed and placed with the pipe A. The cocks I and II are then closed. After this cock III has to be closed and cock II has to be opened.

The dry sample sucks up the water. This causes a decrease of height of the water level in the left tube.

When this decrease comes to an end, the maximum capillary height of the sample is attained.

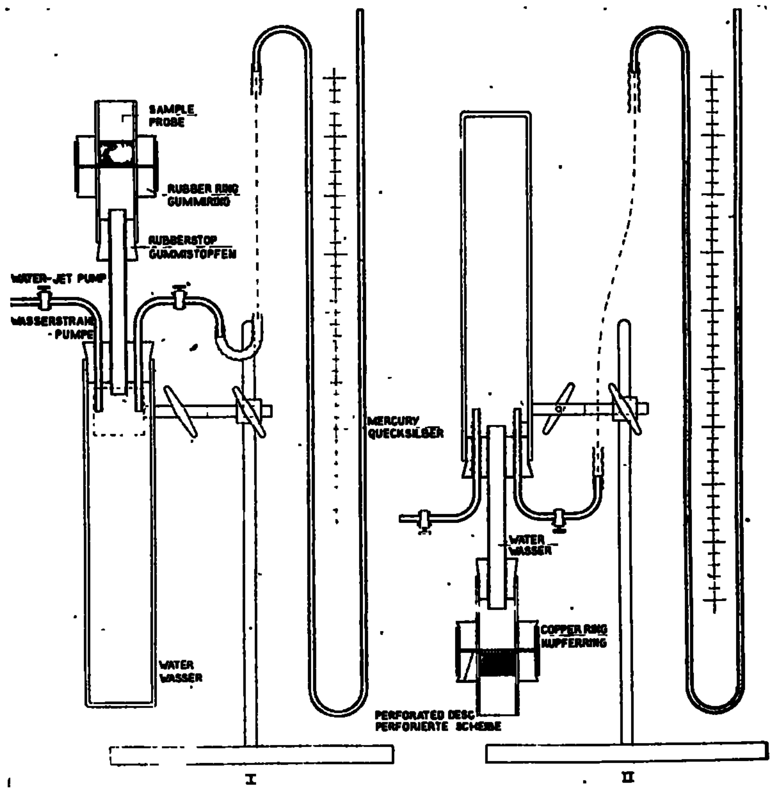


**Figure 59. Capillary Meter. Huizinga**

other end in a water basin. Under the sample the glass and rubber tubes are filled with water. Gradually the glass tube with sample is raised until the optimum capillary force is attained and air enters through the sample.

2. The construction of this apparatus is shown in Figure 58. The test starts with the water level in the left tube at the same height as the end of the syphon-

The apparatus was designed by E. C. W. A. Geuze, graduate engineer at our laboratory. It can be used for very fine sands and loam. In the latter case the lower part of the U-shaped tube is filled with mercury.

3. The apparatus shown in Figure 59 is suitable for cohesive soils. The sample is placed in a glass tube on a perforated disk.

The pressure of the air in the space beneath the sample can be diminished by means of a water jet pump. Then the apparatus is turned upside down. When the pressure of the air in the apparatus is low enough, air will percolate through the sample. The air pressure is measured by a mercury gauge.

COMPRESSED AIR CAPILLARITY DEVICES

**C. A. Hogentogler:** The apparatus shown in Figure 54 illustrates a method to determine the capillary attraction of fine grained soil consolidated at different pressures. It utilizes a modification of the basic principle described by Jamin and others, in 1896. The sample may be saturated, loaded by a spring, and have compressed air applied to the upper surface. Actually consolidation devices of the type shown in Figure 2 are used for this purpose by the Bureau of Public Roads. The sample is consolidated at the desired pressure by lever loading. One of the tubes which provides for application of water to the bottom of the sample is then capped, the other is attached to the compressed air reservoir. The loading lever is clamped to prevent rise of the sample when the compressed air is applied. Pressure is allowed to build up gradually until the gage indicates rapidly falling pressure. The maximum reading recorded from the gage is the force required to overcome the capillary pressure of the soil.

**Dr. L. Bendel:** The capillarity is determined by means of a capillarimeter, specially designed for the purpose, in which the sample of soil is subjected to pressure. When the soil is brought in contact with water, counterpressure is applied by means of air, in order to prevent the water from rising. This apparatus offers the advantage that the corresponding capillarity can be determined for each consistency of the materials and also for each type of bed. This device was invented by Engineer Maag.

INDICATOR CAPILLARITY DEVICES

**D. H. F. Winterkorn:** A good indication of undesirable capillary properties is given by the results of the slaking test of the Russian pedologists. In the test as used by our laboratory the specimen is formed by manual compression of the moist soil in the mold used for preparing cement mortar test specimens. Then the specimen is permitted to dry to constant weight, first in air then over concentrated sulphuric acid and coated on both ends with paraffin to leave a bare center ¼ in. wide. Hereafter, it is suspended in water, which covers the specimen completely, and the time is recorded in which the bottom half of the specimen separates from the rest. Also, the change in appearance of the specimen during the time of immersion is noted.

**R. E. Bollen:** Three oven dried briquettes of soil are placed in a flat-bottom pan containing water one-half inch in depth so that each briquette is not closer than 2 in. to the sides of the pan or to another briquette. The time required for the water to rise and wet the top of the briquette is recorded as the capillarity time. The time required for the briquette to fall apart or slake down is recorded as the absorption failure. If the briquette falls apart or slakes down before its entire top is wet with capillary water, the capillarity time is recorded as being longer than the absorption failure time.

## PERMEABILITY TESTS

Permeability tests are used to determine the quantity of water under pressure that will flow through soils in various conditions.

The permeameters reported by various laboratories are listed in Table 6 and are arbitrarily divided into three types, depending upon the method of applying the head of percolating water. These are:

C. Constant head, Figure 60.