APPENDIX VII:

PERMEABILITY TESTS

1. DARCY'S LAW FOR FLOW OF WATER THROUGH SOIL. The flow of water through a soil medium is assumed to follow Darcy's law:

$$q = k\,i\,A$$

where q = rate of discharge through a soil of cross-sectional area A
k = coefficient of permeability
i = hydraulic gradient: the loss of hydraulic head per unit distance of flow

The application of Darcy's law to a specimen of soil in the laboratory is illustrated in Figure 1. The coefficient of permeability, k (often termed

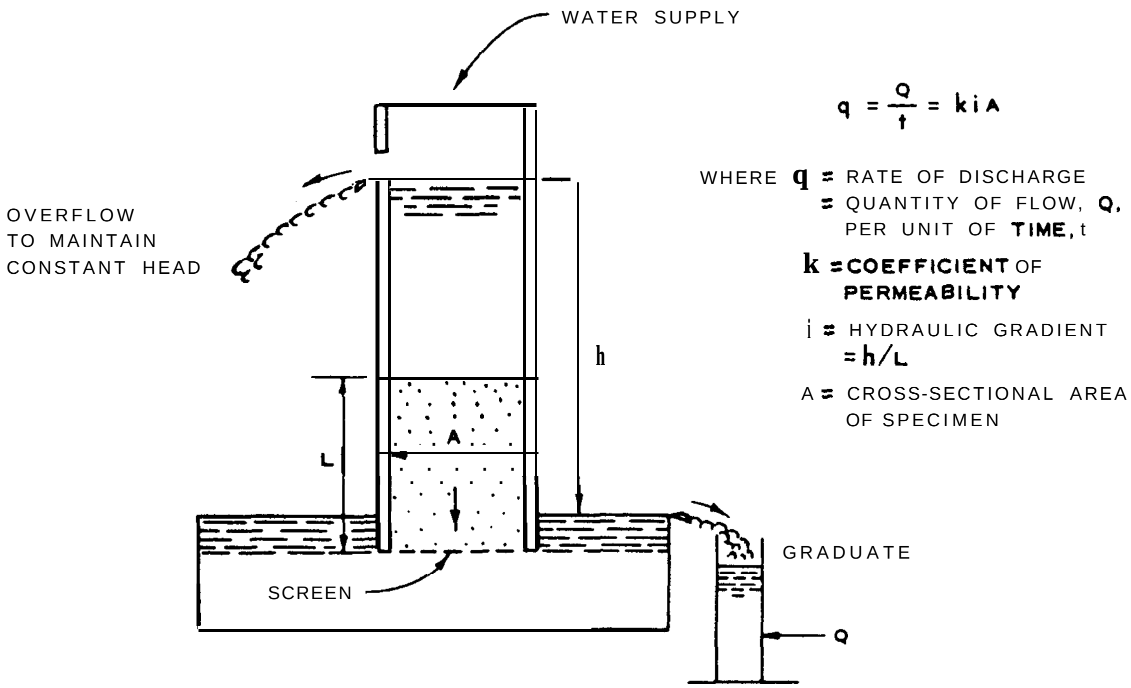


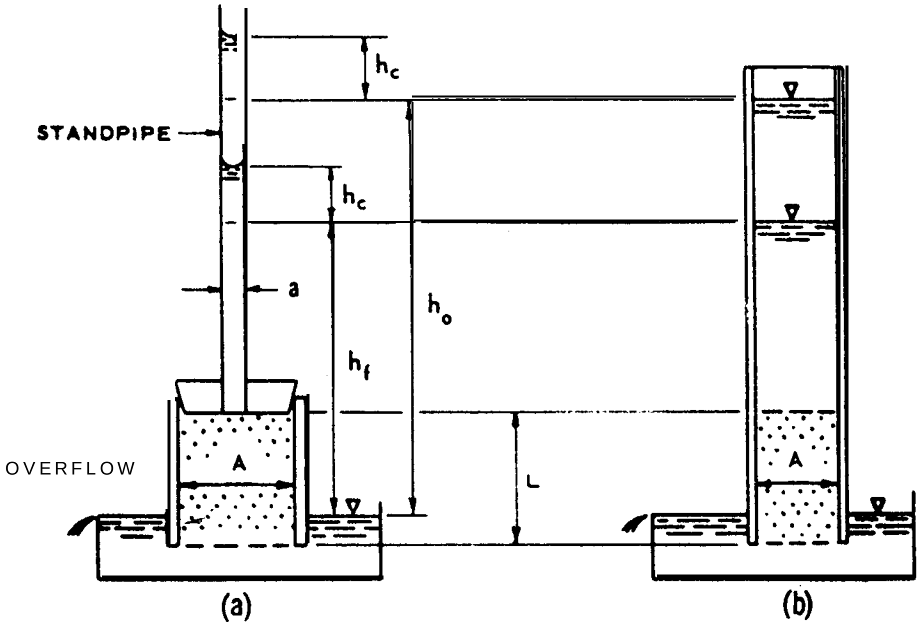
Figure 1. Flow of water through soil

"permeability"), is defined as the rate of discharge of water at a temperature of 20 C under conditions of laminar flow through a unit cross-sectional area of a soil medium under a unit hydraulic gradient. The coefficient of permeability has the dimensions of a velocity and is usually expressed in centimeters per second. The permeability of a soil depends primarily on the size and shape of the soil grains, the void ratio of the soil, the shape and arrangement of the voids, and the degree of saturation.

Permeability computed on the basis of Darcy's law is limited to the conditions of laminar flow and complete saturation of the voids. In turbulent flow, the flow is no longer proportional to the first power of the hydraulic gradient. Under conditions of incomplete saturation, the flow is in a transient state and is time-dependent. The laboratory procedures presented herein for determining the coefficient of permeability are based on the Darcy conditions of flow. Unless otherwise required, the coefficient of permeability shall be determined for a condition of complete saturation of the specimen. Departure from the Darcy flow conditions to simulate natural conditions is sometimes necessary; however, the effects of turbulent flow and incomplete saturation on the permeability should be recognized and taken into consideration.

2. TYPES OF TESTS AND EQUIPMENT. a. Types of Tests. (1) Constant-head test. The simplest of all methods for determining the coefficient of permeability is the constant-head type of test illustrated in Figure 1. This test is performed by measuring the quantity of water, Q, flowing through the soil specimen, the length of the soil specimen, L, the head of water, h, and the elapsed time, t. The head of water is kept constant throughout the test. For fine-grained soils, Q is small and may be difficult to measure accurately. Therefore, the constant-head test is used principally for coarse-grained soils (clean sands and gravels) with k values greater than about 10×10^{-4} cm per sec.

(2) Falling-head test. The principle of the falling-head test is illustrated in Figure 2. This test is conducted in the same manner as



USING SETUP SHOWN IN (a), THE COEFFICIENT OF PERMEABILITY IS DETERMINED AS FOLLOWS:

$$k = \frac{La}{At} \ln \frac{h_o}{h_f} = 2.303 \frac{La}{At} \log_{10} \frac{h_o}{h_f}$$

USING SETUP SHOWN IN (b), THE COEFFICIENT OF PERMEABILITY IS DETERMINED AS FOLLOWS:

$$k = \frac{L}{t} \ln \frac{h_o}{h_f} = 2.303 \frac{L}{t} \log_{10} \frac{h_o}{h_f}$$

WHERE: h_c = HEIGHT OF CAPILLARY RISE
a = INSIDE AREA OF STANDPIPE
A = CROSS-SECTIONAL AREA OF SPECIMEN
L = LENGTH OF SPECIMEN
h_o = HEIGHT OF WATER IN STANDPIPE ABOVE DISCHARGE LEVEL MINUS h_c AT TIME, t_o
h_f = HEIGHT OF WATER IN STANDPIPE ABOVE DISCHARGE LEVEL MINUS h_c AT TIME, t_f
t = ELAPSED TIME, $t_f - t_o$

Figure 2. Principle of falling-head test

the constant-head test, except that the head of water is not maintained constant but is permitted to fall within the upper part of the specimen container or in a standpipe directly connected to the specimen. The quantity of water flowing through the specimen is determined indirectly by computation. The falling-head test is generally used for less pervious soils (fine sands to fat clays) with k values less than 10×10^{-4} cm per sec.

b. Equipment. The apparatus used for permeability testing may vary considerably in detail depending primarily on the condition and character of the sample to be tested. Whether the sample is fine-grained or coarse-grained, undisturbed, remolded, or compacted, saturated or nonsaturated will influence the type of apparatus to be employed. The basic types of apparatus, grouped according to the type of specimen container (permeameter), are as follows:

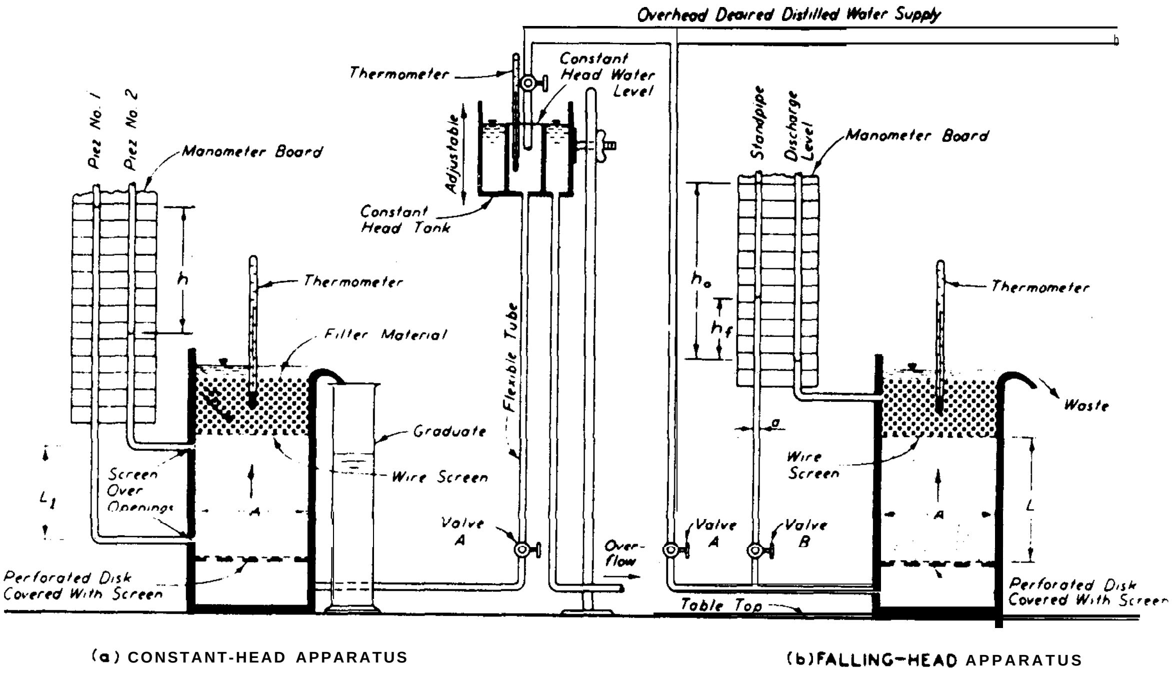
(1) Permeameter cylinders
(2) Sampling tubes
(3) Pressure cylinders
(4) Consolidometers

The permeability of remolded cohesionless soils is determined in permeameter cylinders, while the permeability of undisturbed cohesionless soils in a vertical direction can be determined using the sampling tube as a permeameter. The permeability of remolded cohesionless soils is generally used to approximate the permeability of undisturbed cohesionless soils in a horizontal direction. Pressure cylinders and consolidometers are used for fine-grained soils in the remolded, undisturbed, or compacted state. Fine-grained soils can be tested with the specimen oriented to obtain the permeability in either the vertical or horizontal direction. The above-listed devices are described in detail under the individual test procedures. Permeability tests utilizing the different types of apparatus, together with recommendations regarding their use, are discussed in the following paragraphs.

3. CONSTANT-HEAD PERMEABILITY TEST WITH PERMEAMETER CYLINDER. a. Use. The constant-head permeability test with the permeameter cylinder shall in general be used for determining the permeability of remolded samples of coarse-grained soils such as clean sands and gravels having a permeability greater than about 10×10^{-4} cm per sec.

b. Apparatus. The apparatus and accessory equipment should consist of the following:

(1) A permeameter cylinder similar to that shown schematically in Figure 3a. The permeameter cylinder should be constructed of a transparent plastic material, The inside diameter of the cylinder should be not less than about 10 times the diameter of the largest soil particles, except when the specimenis encased ina rubber membrane as in the permeability test with pressure chamber, in which case the diameter of the cylinder should be at least six times the diameter of the largest soil particles.



(a) CONSTANT-HEAD APPARATUS (b) FALLING-HEAD APPARATUS

Figure 3. Schematic diagram of constant-head and falling -head permeability apparatus

Piezometer taps along the side of the permeameter within limits to be occupied by the sample are advantageous in that the head loss within the sample is always measured across a fixed distance and rapid determination of hydraulic gradient can be made.

(2) Perforated metal or plastic disks and circular wire screens, 35 to 100 mesh, cut for a close fit inside the permeameter.

(3) Glass tubing, rubber or plastic tubing, stoppers, screw clamps, etc., necessary to make connections as shown in Figure 3a.

(4) Filter materials such as Ottawa sand, coarse sand, and gravel of various gradations.

(5) A device for maintaining a constant-head water supply.

(6) Deaired distilled† water. Tapwater contains dissolved air and gases which separate from solution in the initial layers of a test specimen of soil in the form of small bubbles. These bubbles reduce the permeability of the soil by decreasing the void space available for the flow of water. The most common method for removing dissolved air from water is by boiling the water and then cooling it at reduced pressures. This method is applicable only with small quantities of water. Freshly distilled water also has a very negligible amount of air. Large quantities of deaired distilled water may be prepared and retained for subsequent use by spraying distilled water in a fine stream into a container from which the air has been evacuated (see Fig. 4). Permeability tests on saturated specimens should show no significant decrease in permeability with time if properly deaired distilled water is used. However, if such a decrease in permeability occurs during a test, then a prefilter, consisting of a layer of the same material as the test specimen, should be used between the deaired distilled water reservoir and the test specimen to remove the air remaining in solution. ‡

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† Demineralized water or tapwater when it is known to be relatively free of minerals may be used in place of distilled water.

‡ G. E. Bertram, An Experimental Investigation of Protective Filters, Soil Mechanics Series No. 7, Harvard University (Cambridge, Mass., January 1940, reprinted May 1959).

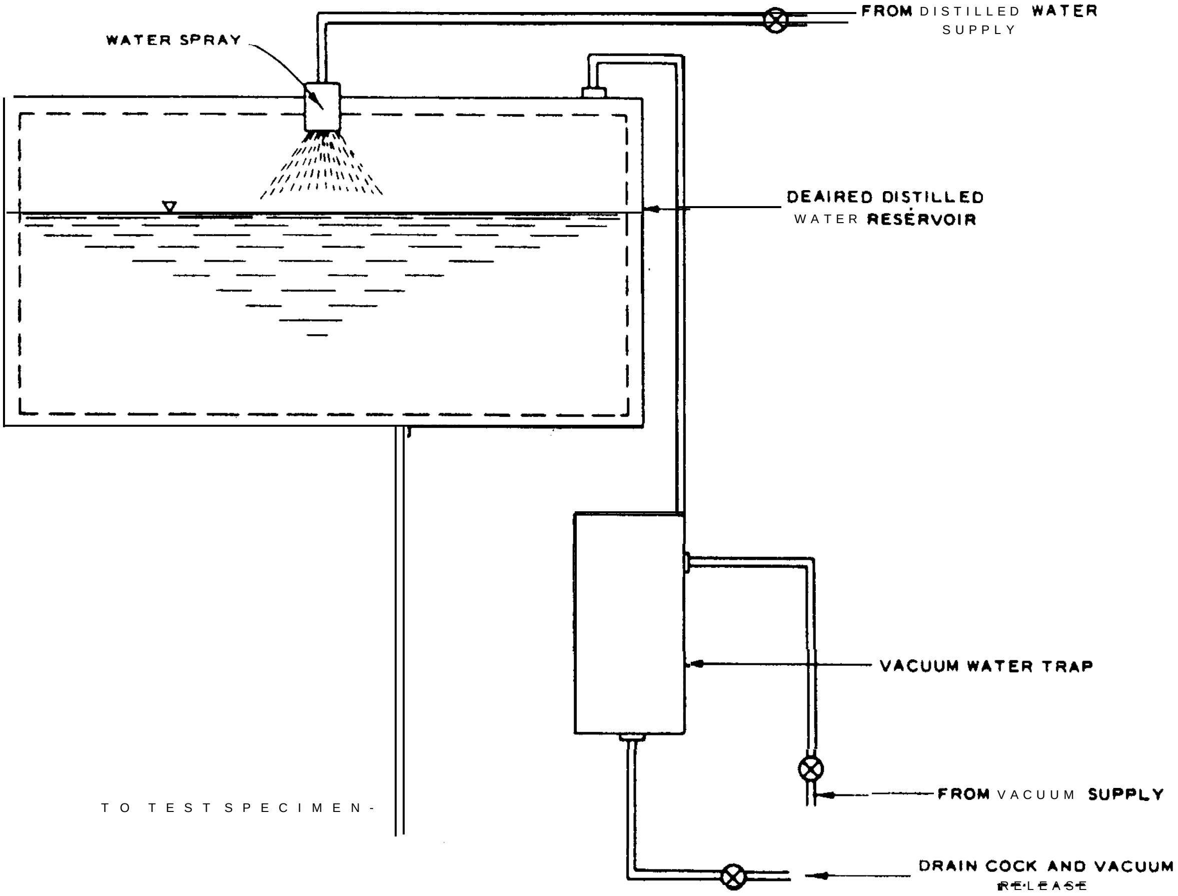

Figure 4. Schematic diagram of apparatus for preparing deaired distilled water

(7) Manometer board with tubing leading from the piezometer taps. If piezometer taps are not provided, equipment to measure the distance between the constant-head source and tailwater is required.

(8) Timing device, a watch or clock with second hand.

(9) Graduated cylinder, 100 -ml capacity.

(10) Centigrade thermometer, range 0 to 50C, accurate to 0.1 c.

(11) Balance, sensitive to 0.1 g.

(12) Oven (see Appendix I, WATER CONTENT - GENERAL).

(13) Scale, graduated in centimeters.

c. Placement and Saturation of Specimen. Placement and saturation of the specimen shall be done in the following steps:

(1) Record all identifying information for the specimen, such as project, boring number, sample number, or other pertinent data, on a data sheet (Plate VII-1 is a suggested form).

(2) Oven-dry the specimen, Allow it to cool and weigh to the nearest 0.1 g. Record the oven-dry weight of material on the data sheet opposite W_s. The amount of mate_rial should be sufficient to provide a specimen in the permeameter having a minimum length of about one to two times the diameter of the specimen.

(3) Place a wire screen, with openings small enough to retain the specimen, over a perforated disk near the bottom of the permeameter above the inlet. The screen openings should be approximately equal to the 10 percent size of the specimen.

(4) Allow deaired distilled water to enter the water inlet of the permeameter to a height of about 1/2 in. above the bottom of the screen, taking care that no air bubbles are trapped under the screen.

(5) Mix the material thoroughly and place in the permeameter to avoid segregation. The material should be dropped just at the water surface, keeping the water surface about 1/2 in. above the top of the soil during placement. A funnel or a special spoon as shown in Figure 5 is convenient for this purpose.

(6) The placement procedure outlined above will result in a saturated specimen of uniform density although in a relatively loose condition. To produce a higher density in the specimen, the sides of the permeameter containing the soil sample are tapped uniformly along its circumference and length with a rubber mallet to produce an increase in density; however, extreme caution should be exercised so that fines are not put into suspension and segregated within the sample. As an alternative to this procedure, the specimen may be placed in the in the dry using a funnel or

spoon which permits the material to fall a constant height. The desired density may be achieved by vibrating the specimen to obtain a specimen of predetermined height, Compacting the specimen in layers is not recommended as a film of dust may be formed at the surface of the compacted layer which might affect the permeability results, After placement, apply a vacuum to the top of the specimen and permit water to enter the evacuated specimen through the base of the permeameter.

(7) After the specimen has been placed, weigh the excess material, if any, and the container. The specimen weight is the difference between the original weight of sarnple and the weight of the excess material. Care must be taken so that no material is lost d' ring placement of the specimen. If there is evidence that material has been lost, oven-dry the specimen and weigh after the test as a check.

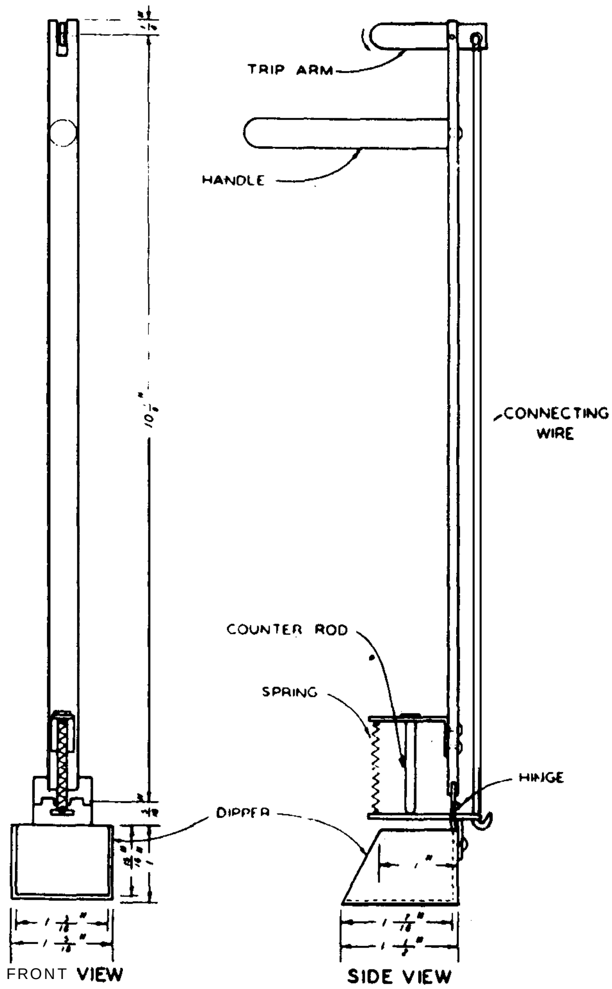

Figure 5. Spoon for placing cohesionless soils

(8) Level the top of the specimen, cover with a wire screen similar to that used at the base, and fill the remainder of the permeameter with a filter material.

(9) Measure the length of the specimen and inside diameter of the permeameter to the nearest 0.1 cm and record on the data sheet as initial height and diameter of specimen.

(10) Test the specimen at the estimated natural void ratio or

at a series of different void ratios, produced by increasing the amount of vibration after each permeability determination. Measure and record the length (height) of specimen in the permeameter prior to each determination. Permeability determinations at three different void ratios are usually sufficient to establish the relation of void ratio to permeability.

d. Procedure. The procedure shall consist of the following steps:

(1) Measure the distance, L_1, between the centers of the piezometer taps to the nearest 0.01 cm and record on the data sheet.

(2) Adjust the height of the constant-head tank to obtain the desired hydraulic gradient. The hydraulic gradient should be selected so that the flow through the specimen is laminar. The range of laminar flow conditions can be determined by plotting discharge versus hydraulic gradient. A straight-line relation indicates laminar flow, while deviations from the straight-line at high gradients indicate turbulent flow. Laminar flow for fine sands is limited to hydraulic gradients less than approximately 0.3. It is usually not practicable to achieve laminar flow for coarser soils, and the tests generally should be run at the hydraulic gradient anticipated in the field.

(3) Open valve A (see Fig. 3a) and record the initial piezometer readings after the flow has become stable. Exercise care in building up heads in the permeameter so that the specimen is not disturbed.

(4) After allowing a few minutes for equilibrium conditions to be reached, measure by means of a graduate the quantity of discharge corresponding to a given time interval. Measure the piezometric heads and the water temperature in the permeameter.

(5) Record the quantity of flow, piezometer readings, water temperature, and the time interval during which the quantity of flow was measured on the data sheet, Plate VII-1.

(6) Repeat steps (4) and (5) several times over a period of about 1 hr, and compute the coefficient of permeability corresponding to each set of measured data. If there is no substantial change in the

permeability, then the computed permeability is probably reliable. If there is a slight decrease in the permeability, then the permeability computed from the initial measurements, rather than the average, should be reported, so long as a plot of permeability versus time shows that the initial measurements are consistent with the subsequent measurements; a difference in permeability may result from a change in density caused by inadvertent jarring of the specimen in the permeameter. If there is any substantial decrease of the permeability with time, a prefilter should be used between the water reservoir and the permeameter (see paragraph 3b(6)). The criterion for judging whether a change in the computed permeability is "substantial" depends on the desired accuracy of the coefficient of permeability.

(7) If desired, reduce the void ratio as previously described and repeat the constant-head test.

e. Computations. The computations consist of the following steps:

(1) Compute the test void ratios in accordance with Appendix II, UNIT WEIGHTS, VOID RATIO, POROSITY, AND DEGREE OF SATURATION, The specific gravity shall be estimated or determined in accordance with Appendix IV, SPECIFIC GRAVITY.

(2) Compute the coefficient of permeability, k, by 'means of the following equation:

$$k_{20} = \frac{Q \times L \times R_T}{h \times A \times t}$$

where k_{20} = coefficient of permeability, cm per sec at 20 C

Q = quantity of flow, cc

L = length of specimen over which head loss is measured, cm. If piezometer taps are used, $L = L_1$ = distance between piezometer taps, cm

R_T = temperature correction factor for viscosity of water obtained from Table VII-1

h = loss of head in length, L, or difference in piezometer readings $= h_1 - h_2$, cm

A = cross-sectional area of specimen, sq cm

t = elapsed time, sec

Table VII-1

Correction Factor, R_T, for Viscosity of Water at Various Temperatures

Temperature Degrees C	Tenths of Degrees 0	1	2	3	4	5	6	7	8	9
0.0	1.783	1.777	1.771	1.765	1.759	1.753	1.747	1.741	1.735	1.729
1.0	1.723	1.717	1.711	1.705	1.699	1.694	1.688	1.682	1.676	1.670
2.0	1.664	1.659	1.654	1.648	1.643	1.638	1.632	1.627	1.622	1.616
3.0	1.611	1.606	1.601	1.596	1.590	1.585	1.580	1.575	1.570	1.565
4.0	1.560	1.555	1.550	1.545	1.540	1.535	1.531	1.526	1.521	1.516
5.0	1.511	1.507	1.502	1.498	1.493	1.488	1.484	1.479	1.475	1.470
6.0	1.465	1.461	1.457	1.452	1.448	1.443	1.439	1.435	1.430	1.426
7.0	1.421	1.417	1.413	1.409	1.404	1.400	1.396	1.392	1.388	1.383
8.0	1.379	1.375	1.371	1.367	1.363	1.359	1.355	1.351	1.347	1.343
9.0	1.339	1.336	1.332	1.328	1.324	1.320	1.317	1.313	1.309	1.305
10.0	1.301	1.298	1.294	1.290	1.287	1.283	1.279	1.276	1.272	1.269
11.0	1.265	1.262	1.258	1.255	1.251	1.248	1.244	1.241	1.237	1.234
12.0	1.230	1.227	1.223	1.220	1.217	1.213	1.210	1.207	1.203	1.200
13.0	1.197	1.194	1.190	1.187	1.184	1.181	1.178	1.175	1.171	1.168
14.0	1.165	1.162	1.159	1.156	1.153	1.150	1.147	1.144	1.141	1.138
15.0	1.135	1.132	1.129	1.126	1.123	1.120	1.117	1.114	1.111	1.108
16.0	1.106	1.103	1.100	1.097	1.094	1.091	1.089	1.086	1.083	1.080
17.0	1.077	1.075	1.072	1.069	1.067	1.064	1.061	1.059	1.056	1.053
18.0	1.051	1.048	1.045	1.043	1.040	1.038	1.035	1.033	1.030	1.027
19.0	1.025	1.022	1.020	1.017	1.015	1.012	1.010	1.007	1.005	1.002
20.0	1.000	0.998	0.995	0.993	0.990	0.988	0.986	0.983	0.981	0.979
21.0	0.976	0.974	0.972	0.969	0.967	0.965	0.962	0.960	0.958	0.955
22.0	0.953	0.951	0.949	0.947	0.944	0.942	0.940	0.938	0.936	0.933
23.0	0.931	0.929	0.927	0.925	0.923	0.920	0.918	0.916	0.914	0.912
24.0	0.910	0.908	0.906	0.904	0.901	0.899	0.897	0.895	0.893	0.891
25.0	0.889	0.887	0.885	0.883	0.881	0.879	0.877	0.875	0.873	0.871
26.0	0.869	0.867	0.866	0.864	0.862	0.860	0.858	0.856	0.854	0.852
27.0	0.850	0.848	0.847	0.845	0.843	0.841	0.839	0.837	0.836	0.834
28.0	0.832	0.830	0.828	0.826	0.825	0.823	0.821	0.819	0.818	0.816
29.0	0.814	0.812	0.810	0.809	0.807	0.805	0.804	0.802	0.800	0.798
30.0	0.797	0.795	0.793	0.792	0.790	0.788	0.787	0.785	0.783	0.782
31.0	0.780	0.778	0.777	0.775	0.774	0.772	0.770	0.769	0.767	0.766
32.0	0.764	0.763	0.761	0.759	0.758	0.756	0.755	0.753	0.752	0.750
33.0	0.749	0.747	0.746	0.744	0.743	0.741	0.739	0.738	0.736	0.735
34.0	0.733	0.732	0.731	0.729	0.728	0.726	0.725	0.723	0.722	0.720
35.0	0.719	0.718	0.716	0.715	0.713	0.712	0.711	0.709	0.708	0.706
36.0	0.705	0.704	0.702	0.701	0.699	0.698	0.697	0.695	0.694	0.693
37.0	0.691	0.690	0.689	0.687	0.686	0.685	0.683	0.682	0.681	0.679
38.0	0.678	0.677	0.675	0.674	0.673	0.672	0.670	0.669	0.668	0.666
39.0	0.665	0.664	0.663	0.661	0.660	0.659	0.658	0.656	0.655	0.654
40.0	0.653	0.652	0.650	0.649	0.648	0.647	0.646	0.644	0.643	0.642
41.0	0.641	0.639	0.638	0.637	0.636	0.635	0.634	0.632	0.631	0.630
42.0	0.629	0.628	0.627	0.626	0.624	0.623	0.622	0.621	0.620	0.619
43.0	0.618	0.616	0.615	0.614	0.613	0.612	0.611	0.610	0.609	0.608
44.0	0.607	0.606	0.604	0.603	0.602	0.601	0.600	0.599	0.598	0.597
45.0	0.596	0.595	0.594	0.593	0.592	0.591	0.590	0.588	0.587	0.586
46.0	0.585	0.584	0.583	0.582	0.581	0.580	0.579	0.578	0.577	0.576
47.0	0.575	0.574	0.573	0.572	0.571	0.570	0.569	0.568	0.567	0.566
48.0	0.565	0.564	0.564	0.563	0.562	0.561	0.560	0.559	0.558	0.557
49.0	0.556	0.555	0.554	0.553	0.552	0.551	0.550	0.549	0.548	0.548

Computed from Table 170 - Smithsonian Physical Tables - 8th Edition
Correction factor, R_T, is found by dividing the viscosity of water at the test temperature by the viscosity of water at 20 C.

f. Presentation of Results. The coefficient of permeability shall be reported in units with coefficients of 1.0, 1×10^{-4}, and 1×10^{-9} cm per sec. The void ratio of the specimen shall be reported with all values of k. The coefficient of permeability, k, is logarithmically dependent upon the void ratio of the soil. Where k is determined at several void ratios, the test results shall be presented on a semilogarithmic chart as shown in Figure 6 in which k is plotted on the abscissa (logarithmic scale) and the void ratio is plotted on the ordinate (arithmetic scale).

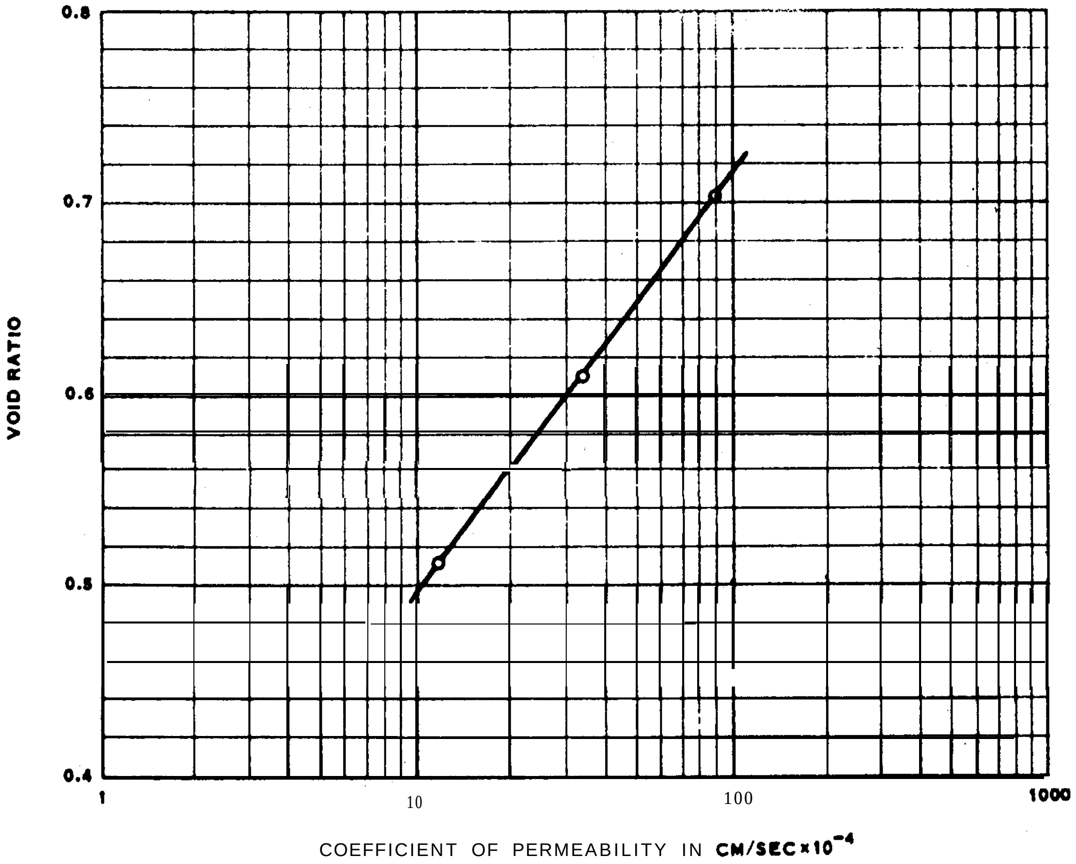

Figure 6. Relation between permeability and void ratio for cohesionless soils

4. FALLING-HEAD PERMEABILITY TEST WITH PERMEAMETER CYLINDER. a. Use. The falling-head test with the permeameter

cylinder should in general be used for determining the permeability of remolded samples of cohesionless soils having a permeability less than about 10×10^{-4} cm per sec.

b. Apparatus. The apparatus and accessory equipment should consist of the following:

(1) A permeameter cylinder similar to that shown schematically in Figure 3b, or modified versions thereof. The permeameter cylinder should be constructed of a transparent plastic material. The inside diameter of the cylinder should be not less than about 10 times the diameter of the largest soil particles. The use of two piezometer taps, as shown by Figure 3b, connected to a standpipe and discharge level tube eliminates the necessity for taking into account the height of capillary rise which would be necessary in the case of a single standpipe of small size. The height of capillary rise for a given tube and condition can be measured simply by standing the tube upright in a beaker full of water. The size of standpipe to be used is generally based on experience with the equipment used and soils tested. In order to accelerate testing, air pressure may be applied to the standpipe to increase the hydraulic gradient.

(2) Perforated metal or plastic disks and circular wire screens, 35 to 100 mesh, cut for a close fit inside the permeameter.

(3) Glass tubing, rubber or plastic tubing, stoppers, screw clamps, etc., necessary to make connections as shown in Figure 3b.

(4) Filter materials such as Ottawa sand, coarse sand, and gravel of various gradations.

(5) Deaired distilled water, prepared according to paragraph 3b(6).

(6) Manometer board or suitable scales for measuring levels in piezometers or standpipe.

(7) Timing device, a watch or clock with second hand.

(8) Centigrade thermometer, range 0 to 50 C, accurate to 0.1 C.

(9) Balance, sensitive to 0.1 g.

(10) Oven (see Appendix I, WATER CONTENT - GENERAL).

(if) Scale, graduated in centimeters.

c. Placement and Saturation of Specimen. Placement and saturation of the specimen shall be done as described in paragraph 3c. Identifying information for the sample and test data shall be entered *on* a data sheet similar to Plate VII-2.

d. Procedure. The procedure shall consist of the following steps:

(1) Measure and record the height of the specimen, L, and the cross-sectional area of the specimen, A.

(2) With valve B open (see Fig. 3b), crack valve A and slowly bring the water level up to the discharge level of the permeameter.

(3) Raise the head of water in the standpipe above the discharge level of the permeameter. The difference in head should not result in an excessively high hydraulic gradient during the test. Close valves A and B.

(4) Begin the test by opening valve B. Start the timer. As the water flows through the specimen, measure and record the height of water in the standpipe above the discharge level, h_o, in centimeters, at time t_o, and the height of water above the discharge level, h_f, in centimeters, at time t_f.

(5) Observe and record the temperature of the water in the permeameter.

(6) Repeat the determination of permeability, and if the computed values differ by an appreciable amount, repeat the test until consistent values of permeability are obtained.

e. Computations. The computations consist of the following steps:

(1) Compute the test void ratios as outlined in paragraph 3e(1).

(2) Compute the coefficient of permeability, k, by means of the following equation:

$$k = 2.303 \frac{a}{A} \frac{L}{t} \left(\log \frac{h_o}{h_f}\right) R_T$$

where a = inside area of standpipe, sq cm

A = cross-sectional area of specimen, sq cm

L = length of specimen, cm

t = elapsed time ($t_f - t_o$), sec

h_o = height of water in standpipe above discharge level at time t_o, cm

h_f = height of water in standpipe above discharge level at time t_f, cm

R_T = temperature correction factor for viscosity of water obtained from Table VII-1, degrees C

If a single standpipe of small diameter is used as shown in Figure 2, the height of capillary rise, h_c, should be subtracted from the standpipe readings to obtain h_o and h_f.

f. Presentation of Results. The results of the falling-head permeability test shall be reported as described in paragraph 3 f.

5. PERMEABILITY TESTS WITH SAMPLING TUBES. Permeability tests may be performed directly on undisturbed samples without removing them from the sampling tubes. The sampling tube serves as the permeamete r cylinder. The method is applicable primarily to cohesionless soils which cannot be removed from the sampling tube without excessive disturbance. The permeability obtained is in the direction in which the sample was taken, i.e. generally vertical. The permeability obtained in a vertical direction may be substantially less than that obtained in a horizontal direction.

Permeability tests with sampling tubes may be performed under constant-head or falling-head conditions of flow, depending on the estimated permeability of the sample (see paragraph 2a). The equipment should be capable of reproducing the conditions of flow in the constant-head or falling-head tests. It is important that all disturbed material or material containing drilling mud he removed from the top and bottom of the sample. The ends of the sample should be protected by screens held in place by perforated packers. The test procedure and computations are the same as those described previously for each test.

6. PERMEABILITY TEST WITH PRESSURE CHAMBER. In the permeability test with a pressure chamber, see Figure 7, a cylindrical specimen is confined in a rubber membrane and subjected to an external hydrostatic pressure during the permeability test. The advantages of this type of test are: (a) leakage along the sides of the specimen, which would occur if the specimen were tested in a permeameter, is prevented, and (b) the specimen can be tested under conditions of loading expected in the field. The test is applicable primarily to cohesive soils in the undisturbed, remolded or compacted state. Complete saturation of the specimen, if it is not fully saturated initially, is practically impossible. Consequently, this test should be used only for soils that are fully saturated, unless values of permeability are purposely desired for soils in an unsaturated condition. The permeability test with the pressure chamber is usually performed as a falling-head test.

The permeability specimens for use in the pressure chamber generally should be 2.8 in. in diameter, as rubber membranes and equipment for cutting and trimming specimens of this size are available for triaxial testing apparatus (see Appendix X, TRIAXIAL COMPRESSION TESTS). A specimen length of about 4 in. is adequate. (The dimensions of a test specimen may be varied if equipment and supplies are available to make a suitable test setup.) The pressure in the chamber should not be less than the maximum head on the specimen during the test. The other test procedure and computations are the same as those described for the falling-head test. The linear relation between permeability and void ratio on a semilogarithmic plot as shown in Figure 6 is usually not applicable to fine-grained soils, particularly when compacted. Other methods of presenting permeability-void ratio data may be desirable.

7. PERMEABILITY TESTS WITH BACK PRESSURE.

a. Description. Gas bubbles in the pores of a compacted or undisturbed specimen of fine-grained soil will invalidate the results of the

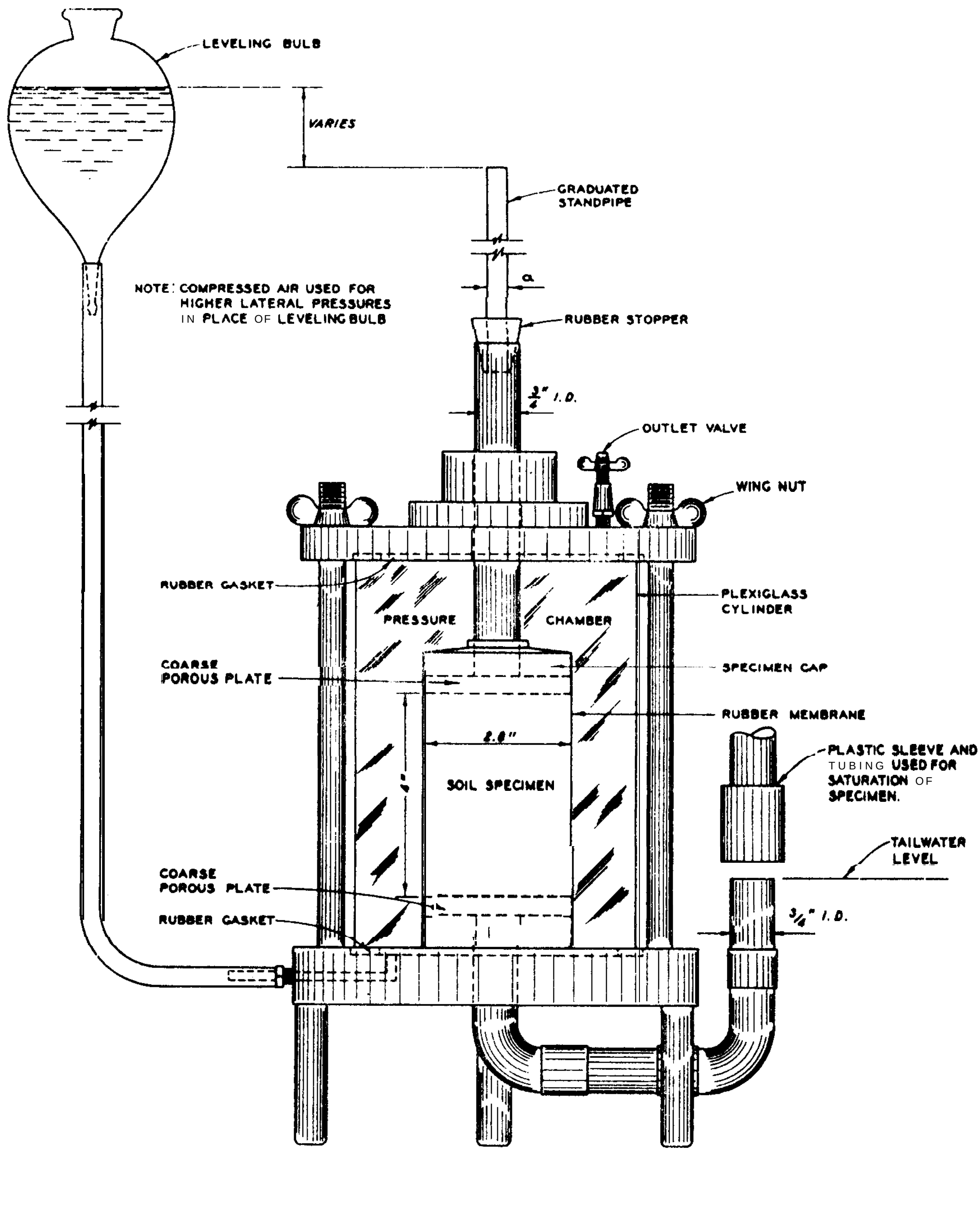

Figure 7. Pressure chamber for permeability test

permeability tests described in the preceding paragraphs. It is known that an increase in pressure will cause a reduction in volume of gas bubbles and also an increased weight of gas dissolved in water. To each degree of saturation there corresponds a certain additional pressure (back pressure) which, if applied to the pore fluid of the specimen, will cause complete saturation. The permeability test with back pressure is performed in a pressure chamber such as that shown in Figure 8, utilizing equipment that permits increasing the chamber pressure and pore pressure simultaneously, maintaining their difference constant The method is generally applicable to fine-grained soils that are not fully saturated. Apparatus and procedures have been described by A. Casagrande† and L. Bjerrum and J. Huder.‡

b. Procedure (see Fig. 8). The procedure shall, consist of the following steps :

(1) After having determined the dimensions and wet weight of the test specimen, place it in the triaxial apparatus, using the same procedure as for setting up a specimen for an R triaxial test with pore pressure measurements except that filter strips should not be used (see para 7, APPENDIX X, TRIAXIAL COMPRESSION TESTS).

(2) Saturate the specimen and verify 100 percent saturation using the procedure described in paragraph 7b, APPENDIX X, TRIAXIAL COMPRESSION TESTS. Burette "A" is utilized during this operation.

(3) With the drainage valves closed, increase the chamber

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† Casagrande, A., "Third Progress Report on Investigation of Stress Deformation and Strength Characteristics of Compacted Clays," Soil Mechanics Series No. 70, Nov 1963, Harvard University, Cambridge, Mass., pp 30 and 31.

‡ Bjerrum, L. and Huder, J., "Measurement of the Permeability of Compacted Clays," Proceedings, Fourth International Conference on Soil Mechanics and Foundation Engineering, London, Vol 1, Aug 1957, pp 6-8.

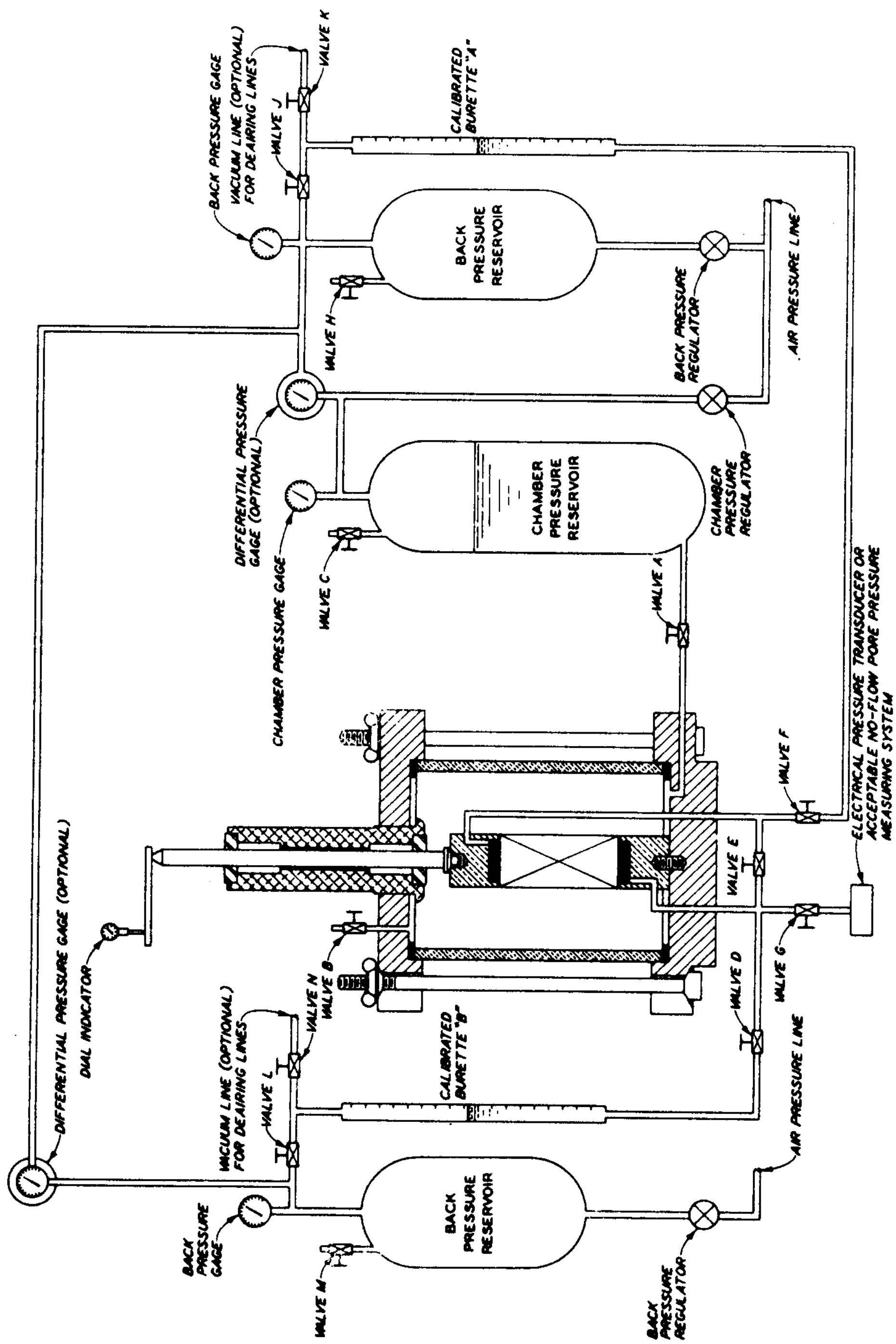

Figure 8. Schematic diagram of typical triaxial compression apparatus for permeability tests with back pressure

pressure to attain the desired effective consolidation pressure (chamber pressure minus back pressure). At zero elapsed time, open valves E and F.

(4) Record time, dial indicator reading, and burette reading at elapsed times of 0, 15, and 30 sec, 1, 2, 4, 8, and 15 min, and 1, 2, 4, and 8 hr, etc. Plot the dial indicator readings and burette readings on an arithmetic scale versus elapsed time on a log scale. When the consolidation curves indicate that primary consolidation is complete close valves E and F.

(5) Apply a pressure to burette B greater than that in burette A. The difference between the pressures in burettes B and A is equal to the head loss h; h divided by the height of the specimen after consolidation, L, is the hydraulic gradient. The difference between the two pressures should be kept as small as practicable, consistent with the requirement that the rate of flow be large enough to make accurate measurements of the quantity of flow within a reasonable period of time. Because the difference in the two pressures may be very small in comparison to the pressures at the ends of the specimen, and because the head loss must be maintained constant throughout the test, the difference between the pressures within the burettes must be measured accurately; a differential pressure gage is very useful for this purpose. The difference between the elevations of the water within the burettes should also be considered (1 in. of water = 0.036 psi of pressure).

(6) Open valves D and F. Record the burette readings at any zero elapsed time. Make readings of burettes A and B and of temperature at various elapsed times (the interval between successive readings depends upon the permeability of the soil and the dimensions of the specimen). Plot arithmetically the change in readings of both burettes versus time. Continue making readings until the two curves become parallel and straight over a sufficient length of time to accurately determine the rate of flow (slope of the curves).

(7) If it is desired to determine the permeability at several void ratios, steps 3 through 6 can be repeated, using different consolidation pressures in step 3.

(8) At the end of the permeability determinations, close all drainage valves and reduce the chamber pressure to zero; disassemble the apparatus.

(9) Determine the wet and dry weights of the specimen.

c. Computations. The computations consist of the following steps.

(1) Compute the test void ratios as outlined in paragraph 3e(1).

(2) Computations of coefficients of permeability are the same as those described for the constant-head permeability test.

8. PERMEABILITY TESTS WITH CONSOLIDOMETER. A permeability test in a consolidometer (see Appendix VIII, CONSOLIDATION TEST) is essentially similar to that conducted in a pressure chamber, except that the specimen is placed within a relatively rigid ring and is loaded vertically. The test can be used as an alternate to the permeability test in the pressure chamber. The test is applicable primarily to cohesive soils in a fully saturated condition. Testing is usually performed under falling-head conditions.

A schematic diagram of the consolidation apparatus set up for a falling-head permeability test is shown in Figure 9. Identifying information for the specimen and subsequent test data are entered on a data sheet (Plate VII-3 is a suggested form). The specimen should be placed in the specimen ring and the apparatus assembled as outlined under Appendix VIII, CONSOLIDATION TEST. The specimen is consolidated under the desired load and the falling-head test is performed as previously described. The

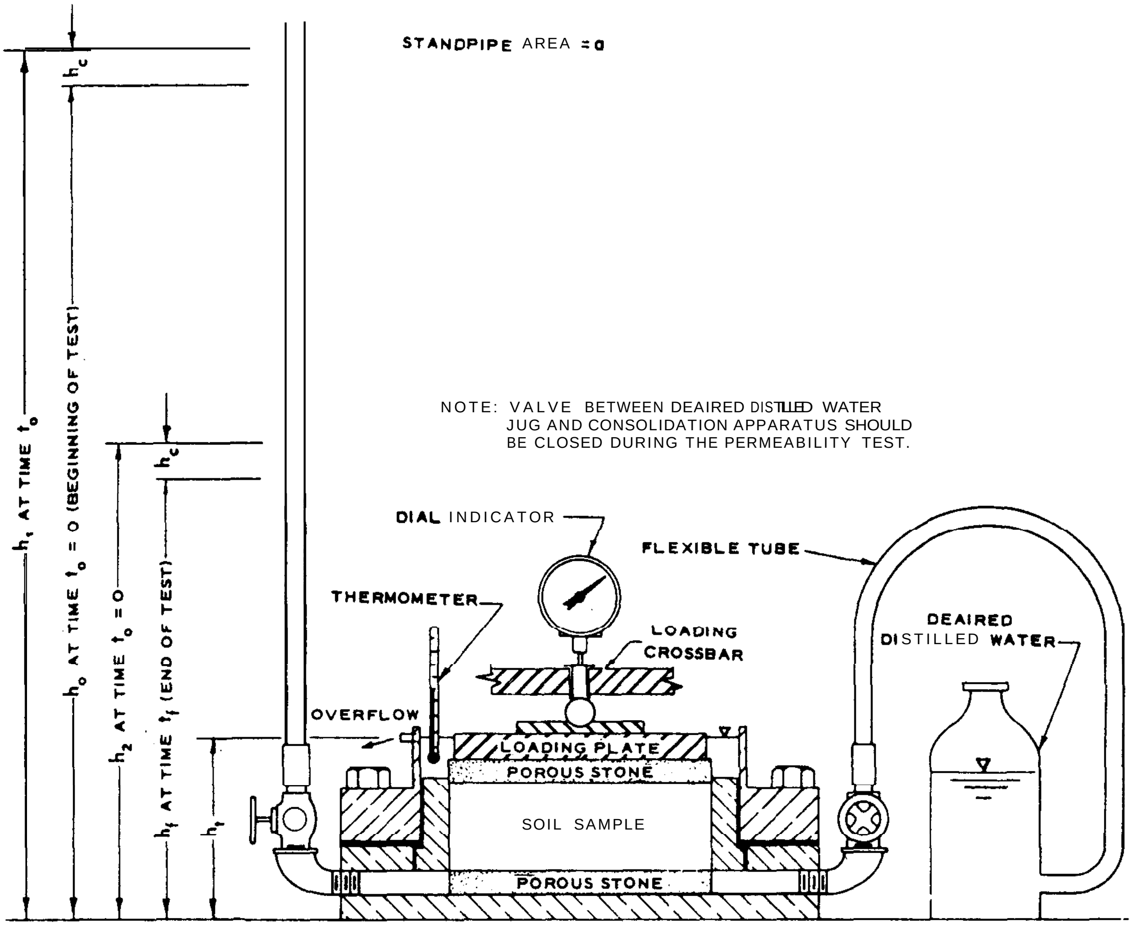

Figure 9. Schematic diagram of falling-head device for permeability test in consolidometer

net head on the specimen may be increased by use of air pressure; however, the pressure on the pore water should not exceed 25 to 30 percent of the vertical pressure under which the specimen has consolidated. Dial indicator readings are observed before and after consolidation to permit computation of void ratios. The determination of the coefficient of permeability may be made in conjunction with the consolidation test, in which case the test is performed at the end of the consolidation phase under each load increment. Computations are similar to those described for the falling-head test with the permeameter cylinder.

The permeability may also be determined indirectly from computations using data obtained during the consolidation test; however the assumptions on which the method is based are seldom satisfied, and consequently, the direct determination of permeability should be employed where reliable values of permeability are required.

9. POSSIBLE ERRORS. Following are possible errors that would cause inaccurate determinations of the coefficient of permeability:

a. Stratification or nonuniform compaction of cohesionless soils. If the specimen is compacted in layers, any accumulation of fines at the surface of the layers will reduce the measured coefficient of permeability.

b. Incomplete initial saturation of specimen.

c. Excessive hydraulic gradient. Darcy's law is applicable only to conditions of laminar flow.

d. Air dissolved in water. No other source of error is as troublesome as the accumulation of air in the specimen from the flowing water. As water enters the specimen, small quantities of air dissolved in the water will tend to collect as fine bubbles at the soil-water interface and reduce the permeability at this interface with increasing time. The method for detecting and avoiding this problem is described in paragraph 3d(6). (It should be noted that air accumulation will not affect the coefficient of permeability determined by the constant-head test if piezometer taps along the side of the specimen are used to measure the head loss.)

e. Leakage along side of specimen in permeameter. One major advantage to the use of the triaxial compression chamber for permeability tests (see paragraphs 6 and 7) is that the specimen is confined by a flexible membrane which is pressed tightly against the specimen by the chamber pressure.

CONSTANT-HEAD PERMEABILITY TEST

DATE ______

PROJECT ______

BORING NO. ______

Sample or Specimen No.

Wt in grams: Tare plus dry soil			Diameter of specimen, cm	D	
Tare			Area of specimen, sq cm	A	
Dry soil	W_s		Initial height of specimen, cm	L	
Specific gravity	G		Initial vol of spec, cc = AL	V	
Vol of solids, cc = $W_s \div G$	V_s		Initial void ratio = $(V - V_s) \div V_s$	e	

Distance between piezometer taps, cm	L_1	

Test No.		1		2		3	
Height of specimen, cm	L						
Void ratio = $(AL - V_s) \div V_s$	e						
		1a	1b	2a	2b	3a	3b
Reading of piez 1, cm	h_1						
Reading of piez 2, cm	h_2						
Head loss, cm = $h_1 - h_2$	h						
Quantity of flow, cc	Q						
Elapsed time, sec	t						
Water temperature, °C	T						
Viscosity correction factor(1)	R_T						
Coefficient of permeability,(2) cm/sec	k_{20}						
	Avg						

(1) Correction factor for viscosity of water at 20 C obtained from table VII-1.

(2) $k_{20} = \frac{Q \times L \times R_T}{h \times A \times t}$.

where L = height of specimen or distance between piezometer taps if used.

Remarks ______

Technician ______ Computed by ______ Checked by ______

ENG FORM 3844
1 JUN 65

FALLING-HEAD PERMEABILITY TEST

DATE ______

PROJECT ______

BORING NO. ______

SAMPLE OR SPECIMEN NO.					
WT IN GRAMS: TARE PLUS DRY SOIL			DIAMETER OF SPECIMEN, CM	D	
WT IN GRAMS: TARE			AREA OF SPECIMEN, SQ CM	A	
WT IN GRAMS: DRY SOIL	W_s		INITIAL HEIGHT OF SPECIMEN, CM	L	
SPECIFIC GRAVITY	G		INITIAL VOL OF SPEC, CC = AL	V	
VOL OF SOLIDS, CC = $W_s \div G$	V_s		INITIAL VOID RATIO = $(V - V_s) \div V_s$	e	
AREA OF STANDPIPE, SQ CM	a		CONSTANT = $(2.303 \times a) \div A$	C	

TEST NO.		1		2		3	
HEIGHT OF SPECIMEN, CM	L						
VOID RATIO = $(AL - V_s) \div V_s$	e						
		1a	1b	2a	2b	3a	3b
INITIAL TIME	t_o						
FINAL TIME	t_f						
ELAPSED TIME, SEC = $t_f - t_o$	t						
INITIAL HEAD, CM	h_o						
FINAL HEAD, CM	h_f						
LOG $(h_o \div h_f)$							
WATER TEMPERATURE, °C	T						
VISCOSITY CORRECTION FACTOR (1)	R_T						
COEFFICIENT OF PERMEABILITY, (2) CM/SEC	k_{20}						
	AVG						

(1) CORRECTION FACTOR FOR VISCOSITY OF WATER AT 20 C OBTAINED FROM TABLE VII-1.

(2) $k_{20} = 2.303 \frac{a}{A}\frac{L}{t} \text{LOG} \frac{h_o}{h_f} \times R_T = \frac{CL}{t}\left(\text{LOG}\frac{h_o}{h_f}\right)R_T$

REMARKS ______

TECHNICIAN ______ COMPUTED BY ______ CHECKED BY ______

ENG FORM 3845
30 JUNE 70

PLATE VII-2

FALLING-HEAD PERMEABILITY TEST WITH CONSOLIDOMETER

DATE ____________

PROJECT ____________

BORING NO. ____________

SAMPLE OR SPECIMEN NO.

WT IN GRAMS: TARE PLUS DRY SOIL			DIAMETER OF SPECIMEN, CM	D	
WT IN GRAMS: TARE			AREA OF SPECIMEN, SQ CM	A	
WT IN GRAMS: DRY SOIL	W_s		INITIAL HEIGHT OF SPECIMEN, CM	L	
SPECIFIC GRAVITY	G_s		INITIAL VOL OF SPEC, CC = AL	V	
VOL OF SOLIDS, CC = $W_s \div G_s$	V_s		INITIAL VOID RATIO = $(V - V_s) \div V_s$	e	
AREA OF STANDPIPE, SQ CM	a		CONSTANT = $(2.303 \times a) \div A$	C	
CAPILLARY RISE, CM	h_c		INITIAL DIAL READING, IN.	D_o	
HEIGHT OF TAILWATER, CM	h_t		CORRECTED TAILWATER, CM, $h_t + h_c$	Δh	

TEST NO.		1		2		3	
LOAD INCREMENT, T/SQ FT	P						
DIAL READING AT START, IN.	D_1						
CHANGE IN HT OF SPEC, IN. = $D_o - D_1$	ΔD						
HT OF SPEC, CM = L − 2.54 ΔD	L						
VOID RATIO = $(AL - V_s) \div V_s$	e						
		1a	1b	2a	2b	3a	3b
INITIAL TIME	t_o						
FINAL TIME	t_f						
ELAPSED TIME, SEC = $t_f - t_o$	t						
INITIAL HEIGHT, CM	h_1						
FINAL HEIGHT, CM	h_2						
WATER TEMPERATURE, °C	T						
VISCOSITY CORRECTION FACTOR (1)	R_T						
COEFFICIENT OF PERMEABILITY, (2) CM/SEC	k_{20}						
	AVG						

(1) CORRECTION FACTOR FOR VISCOSITY OF WATER AT 20 C OBTAINED FROM TABLE VII-1.

(2) $k_{20} = 2.303 \frac{a}{A} \frac{L}{t} \left(\log \frac{h_1 - \Delta h}{h_2 - \Delta h} \right) R_T = \frac{CL}{t} \left(\log \frac{h_1 - \Delta h}{h_2 - \Delta h} \right) R_T$

REMARKS ____________

TECHNICIAN ____________ COMPUTED BY ____________ CHECKED BY ____________

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30 JUNE 70

PLATE VII-3