10 Constant-Head Permeability Test in Sand

10.1 Introduction

The rate of flow of water through a soil specimen of gross cross-sectional area A can be expressed as

$$q = kiA \tag{10.1}$$

where q = flow in unit time
k = coefficient of permeability
i = hydraulic gradient

Table 10.1 lists the general ranges of the coefficient of permeability k for various types of soil.

The coefficient of permeability of sand can be determined easily in the laboratory by two simple methods, (1) the constant-head test and (2) the variable-head test. In this chapter the *constant-head test method* will be discussed.

10.2 Equipment

1. Constant-head permeameter
2. Graduated cylinder (250 cm^3 or 500 cm^3)
3. Balance sensitive to 0.1 g
4. Thermometer sensitive to 0.1°C
5. Rubber tubing
6. Stopwatch

Table 10.1. Range of *k* for Various Soil Types

Soil	k (cm/s)
Clean gravel	10^2–10^0
Coarse sand	10^0–10^{-2}
Fine sand	10^{-2}–10^{-3}
Silty clay	10^{-3}–10^{-5}
Clay	Less than 10^{-6}

10.3 Constant-Head Permeameter

A schematic diagram of a constant-head permeameter is shown in Fig. 10.1. This instrument can be assembled in the laboratory at very low cost. It essentially consists of a plastic soil specimen cylinder, two porous stones, two rubber stoppers, one spring, one constant-head chamber, a large funnel, a stand, a scale, three clamps, and some plastic tubes. The plastic cylinder may have an inside diameter of 2.5 in. (63.5 mm). This is because 2.5-in. (63.5-mm)-diameter porous stones are usually available in most soil laboratories. The length of the specimen tube may be about 12 in. (304.8 mm).

It is important to keep in mind that the minimum inside diameter of the specimen cylinder should be about 8 to 12 times the maximum particle size of the soil to be tested (ASTM, 2007). Table 10.2 gives some recommended diameters of specimen cylinders.

10.4 Procedure

1. Determine the mass of the plastic specimen tube, the porous stones, the spring, and the two rubber stoppers, M_1.
2. Slip the bottom porous stone into the specimen tube and then fix the bottom rubber stopper to the specimen tube.
3. Collect oven-dry sand in a container. Using a spoon, pour the sand into the specimen tube in small layers, and compact it by vibration and/or other compacting means. (*Note:* By changing the degree of compaction, a number of test specimens having different void ratios can be prepared.)
4. When the length of the specimen tube is about two-thirds the length of the tube, slip the top porous stone into the tube to rest firmly on the specimen.
5. Place a spring on the top porous stone, if necessary.
6. Fix a rubber stopper to the top of the specimen tube. (*Note:* The spring in the assembled position will not allow any expansion of the specimen volume, and thus the void ratio, during the test).

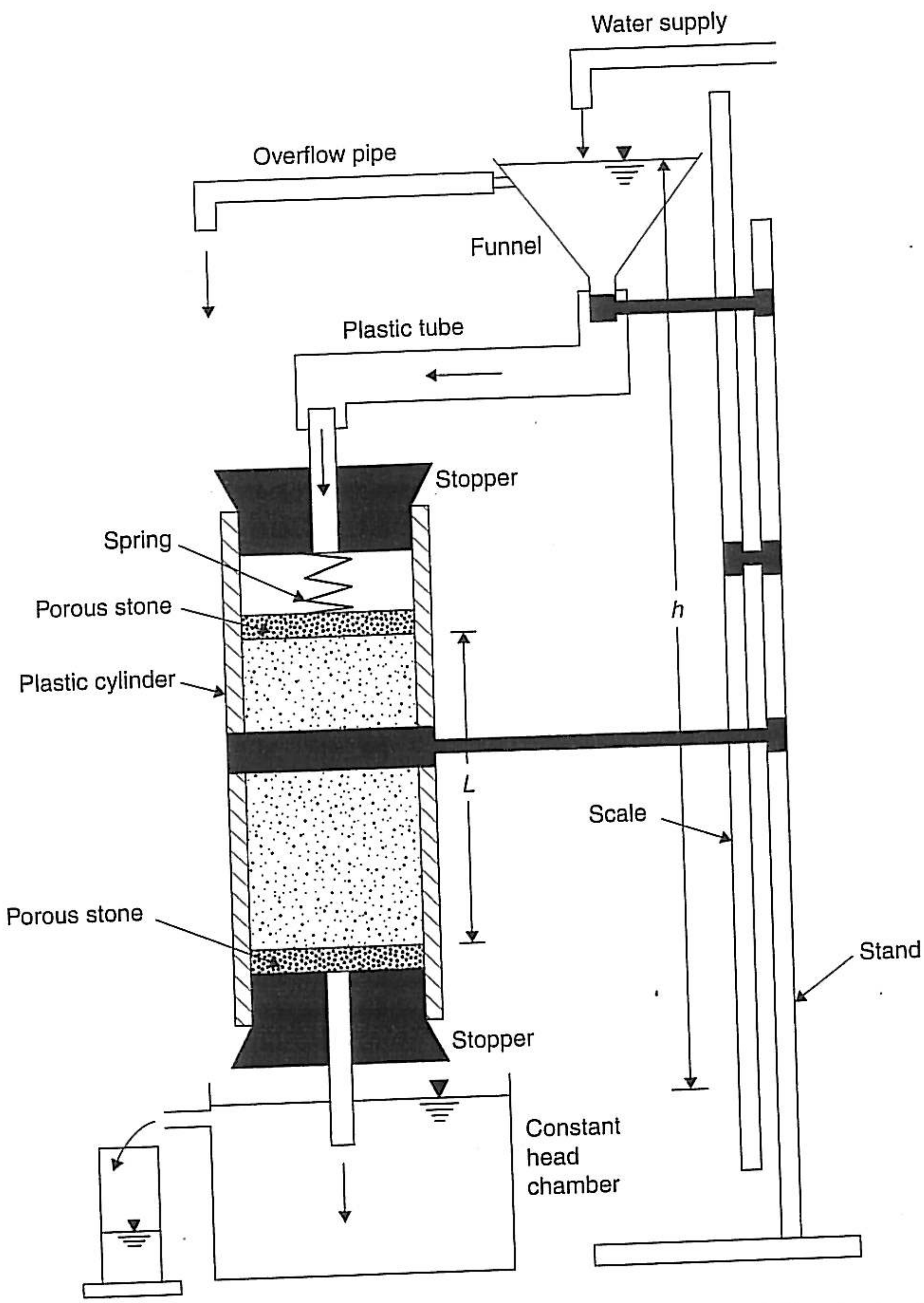

Figure 10.1. Schematic diagram of constant-head permeability test setup.

7. Determine the mass of the assembly, M_2 (Step 6).
8. Measure the length L of the compacted specimen in the tube.
9. Assemble the permeameter near a sink, as shown in Fig. 10.1.
10. Run water into the top of the large funnel fixed to the stand through a plastic tube from the water inlet. The water will flow through the specimen to the constant-head chamber.

Table 10.2. Recommended Inside Diameters of Specimen Cylinders*

Maximum Particle Size Range	Sieve Analysis	Minimum Cylinder Diameter
No. 10 (2-mm) sieve to 3/8-in. (9.5-mm) sieve	Less than 35% of total soil retained on No. 10 sieve	3 in. (76 mm)
	More than 35% of total soil retained on No. 10 sieve	4.5 in. (114 mm)
3/8-in. (9.5-mm) sieve to 3/4-in. (19.0-mm) sieve	Less than 35% of total soil retained on 3/8-in. (9.5-mm) sieve	6 in. (152 mm)
	More than 35% of total soil retained on 3/8-in. (9.5-mm) sieve	9 in. (229 mm)

* ASTM (2007).

After some time the water will flow into the sink through the outlet in the constant-head chamber. (*Note:* Make sure that water does not leak from the specimen tube.)

11. Adjust the supply of water to the funnel so that the water level in the funnel remains constant. At the same time, allow the flow to continue for about 10 minutes in order to saturate the specimen. (*Note:* Some air bubbles may appear in the plastic tube connecting the funnel to the specimen tube. Remove the air bubbles.)
12. After a steady flow is established (that is, once the head difference h becomes constant), collect the water Q flowing out of the constant-head chamber in a graduated cylinder. Record the collection time t with a stopwatch.
13. Repeat Step 12 three times. Keep the collection time t the same and determine Q. Then find the average value of Q.
14. Change the head difference h and repeat Steps 11, 12, and 13 about three times.
15. Record the temperature T of the water to the nearest degree. (*Note:* This value is sufficiently accurate for this type of test.)

10.5 Calculations

1. Calculate the void ratio of the compacted specimen as follows. The dry density ρ_d of the soil specimen is

$$\rho_d = \frac{M_2 - M_1}{(\pi/4)D^2L}$$

Thus,

$$e = \frac{G_s \rho_w}{\rho_d} - 1 \tag{10.2}$$

where G_s = specific gravity of soil solids
ρ_w = density of water
D = diameter of specimen
L = length of specimen

2. Calculate k,

$$k = \frac{QL}{Aht} \tag{10.3}$$

where A is the area of the specimen,

$$A = \frac{\pi}{4} D^2$$

3. The value of k is usually given for water at a test temperature of 20°C. So calculate $k_{20°C}$,

$$k_{20°C} = k_{T°C} \frac{\eta_{T°C}}{\eta_{20°C}} \tag{10.4}$$

where $\eta_{T°C}$ and $\eta_{20°C}$ are the viscosities of water at T°C and 20°C, respectively. Table 10.3 gives the values of $\eta_{T°C}/\eta_{20°C}$ for various values of T (in °C).

Tables 10.4 and 10.5 show sample calculations for the permeability test.

10.6 General Comments

Several relations between k and the void ratio e for sandy soils have been proposed. They are of the form

$$k \propto e^2 \tag{10.5}$$

$$k \propto \frac{e^2}{1+e} \tag{10.6}$$

$$k \propto \frac{e^3}{1+e} \tag{10.7}$$

It is important, however, to point out that these relationships are approximate, and the actual value of k may vary widely.

Table 10.3. Variation of $\eta_{T°C}/\eta_{20°C}$

Temperature T(°C)	$\eta_{T°C}/\eta_{20°C}$	Temperature T(°C)	$\eta_{T°C}/\eta_{20°C}$
15	1.135	23	0.931
16	1.106	24	0.910
17	1.077	25	0.889
18	1.051	26	0.869
19	1.025	27	0.850
20	1.000	28	0.832
21	0.976	29	0.814
22	0.953	30	0.797

Table 10.4. Determination of Void Ratio of Specimen—Constant-Head Permeability Test

Description of soil Uniform sand Sample no. ______

Location ______

Length of specimen L 13.2 cm Diameter of specimen D 6.35 cm

Tested by ______ Date ______

Volume of specimen, $V = \frac{\pi}{4}D^2L\,(\text{cm}^3)$	418.03
Specific gravity of soil solids, G_s	2.66
Mass of specimen tube with fittings, M_1 (g)	238.4
Mass of tube with fittings and specimen, M_2 (g)	965.3
Dry density of specimen, $\rho_d = \frac{M_2 - M_1}{V}\,(\text{g/cm}^3)$	1.74

Void ratio of specimen $e = \frac{G_s\rho_w}{\rho_d} - 1 =$ 0.53

(*Note:* $\rho_w = 1$ g/cm^3)

Table 10.5. Determination of Coefficient of Permeability—Constant-Head Permeability Test

Description of soil *Uniform sand* Sample no. ______

Location ______

Length of specimen L *13.2* cm Diameter of specimen D *6.35* cm

Tested by ______ Date ______

Test No.	1	2	3
Average flow, Q (cm^3)	305	375	395
Time of collection, t (s)	60	60	60
Temperature of water, T(°C)	25	25	25
Head difference, h (cm)	60	70	80
Diameter of specimen, D (cm)	6.35	6.35	6.35
Length of specimen, L (cm)	13.2	13.2	13.2
Area of specimen, $A = \frac{\pi}{4}D^2$ (cm^2)	31.67	31.67	361.67
$k = \frac{QL}{Aht}$ (cm/s)	0.035	0.037	0.034

Average k = *0.035* cm/s

$k_{20^\circ C} = k_{T^\circ C}\frac{\eta_{T^\circ C}}{\eta_{20^\circ C}}$ = *0.035 × 0.889* = *0.031* cm/s

Constant-Head Permeability Test

Determination of Void Ratio of Specimen

Description of soil ______________________ Sample no. ________

Location ______________________

Length of specimen L __________ cm Diameter of specimen D __________ cm

Tested by ______________________ Date ________

Volume of specimen, $V = \frac{\pi}{4} D^2 L$ (cm^3)	
Specific gravity of soil solids, G_s	
Mass of specimen tube with fittings, M_1 (g)	
Mass of tube with fittings and specimen, M_2 (g)	
Dry density of specimen, $\rho_d = \frac{M_2 - M_1}{V}$ (g/cm^3)	

Void ratio of specimen $e = \frac{G_s \rho_w}{\rho_d} - 1 =$ ________

(*Note:* $\rho_w = 1$ g/cm^3)

Constant-Head Permeability Test

Determination of Coefficient of Permeability

Description of soil ______________________ Sample no. ________

Location ____

Length of specimen L ____________ cm Diameter of specimen D ____________ cm

Tested by ______________________________ Date ________

Test No.	1	2	3
Average flow, Q (cm^3)			
Time of collection, t (s)			
Temperature of water, T(°C)			
Head difference, h (cm)			
Diameter of specimen, D (cm)			
Length of specimen, L (cm)			
Area of specimen, $A = \frac{\pi}{4}D^2$ (cm^2)			
$k = \frac{QL}{Aht}$ (cm/s)			

Average k = ____________ cm/s

$k_{20°C} = k_{T°C}\frac{\eta_{T°C}}{\eta_{20°C}}$ = ____________ = ____________ cm/s