SECTION 10

PERMEABILITY TEST

References

- ASTM D 2434 - Standard Test Methods for Permeability of Granular Soil (Constant Head).
- Bardet, Jean-Pierre (1997), Experimental Soil Mechanics. Prentice-Hall, Inc.
- Lambe, T.W., Soil Testing for Engineers.
- Bowles, Joseph E., Engineering Properties of Soils and Their Measurement (4th Edition)
- ASTM D 6026 - 06 – using Significant Digits in Geotechnical Data

General Discussion

This test method is for the determination of the coefficient of permeability of soil which is a constant of proportionality to the ease with which fluid passes through a porous medium. Soils are permeable (water may flow through them) because they consist not only of solid particles, but a network of interconnected pores. The degree to which soils are permeable depends upon a number of factors, such as soil type, grain size distribution and soil history. This degree of permeability is characterized by the coefficient of permeability.

In the design of geotechnical engineering projects, one of the most important soil properties of interest to the soils engineer is permeability. To some degree, permeability will play a role in the design of almost any structure. For example, the durability of concrete is related to its permeability. In designs that make use of earthen materials (soils and rock, etc.) the permeability of these materials will usually be of great importance.

To illustrate the importance of permeability in geotechnical design, consider the following applications where knowledge of permeability is required:

a. Permeability influences the rate of settlement of a saturated soil under load.

b. The stability of slopes and retaining structures can be greatly affected by the permeability of the soils involved.

c. The design of earth dams is very much based upon the permeability of the soils used.

d. Filters to prevent piping and erosion are designed based upon their permeability.

e. The rate of flow to wells from an aquifer is dependent on permeability.

f. The performance of landfill liners is based upon their permeability.

The coefficient of permeability, *k*, is a product of Darcy's Law. In 1856, Darcy established an empirical relationship for the flow of water through porous media. His relationship has evolved into Darcy's Law, which states:

$$Q = kiA$$

Where:

Q = flow rate (volume/time)

i = hydraulic gradient (unit less)

A = cross-sectional area of flow (area)

k = coefficient of permeability (length/time)

It should be noted that the coefficient of permeability is often referred to as hydraulic conductivity by hydrologists and environmental scientists. In their notation, permeability has a entirely different definition. Some typical values of the coefficient of permeability are shown in Table 10-1:

Table 10-1: Some Typical Values of the Coefficient of Permeability.

Soil	**Coeff. of Permea., k cm/sec**	**Degree of Permeability**
Gravel	$>10^{-1}$	Very high
Sandy gravel, clean sand, fine sand	$10^{-1} > k > 10^{-3}$	High to Medium
Sand, dirty sand, silty sand	$_{10}$-3 $> k > 10^{-5}$	Low
Silt, silty clay	$_{10}$-5 $> k > 10^{-7}$	Very low
Clay	$<10^{-7}$	Virtually impermeable

The coefficient of permeability of a homogeneous, isotropic soil mass depends primarily on the following factors:

a. The viscosity of the pore fluid (usually water). The viscosity of water decreases with the increasing temperature which increases the coefficient of permeability. The coefficient of permeability is standardized at 20°C, and the coefficient of permeability at any temperature T is related to k_{20} by the following ratio

$$k_{20} = k_T \frac{\eta_T}{\eta_{20}} .$$

Where, η_T = Viscosity at temperature T^0C

η_{20} = Viscosity at temperature 20°C

b. The void ratio (e)of the soil. The relation of void ratio and coefficient of permeability can be given as:

$$k_2 = k_1 \frac{e_2^3 (1+e_1)}{e_1^3 (1+e_2)}$$

c. The size and shape of the soil particles. Angular and platy particles tend to reduce k more than when rounded and spherical particles predominate in the soil. According to Allan Hazen for clean sand and gravels coefficient of permeability could be expressed using the D_{10} grain size approximately as

$$k = 100\ D_{10}^2 \text{ cm/s} \qquad (0.01 < D_{10} < 0.3\text{cm})$$

d. The degree of Saturation S. As the degree of saturation increases, the apparent coefficient of permeability also increases.

A number of different methods for determining the coefficient of permeability for soils exist, including in-situ (field) methods and laboratory methods. In the laboratory, two common tests are generally used to determine this soil property. These two tests are the falling head permeability test and the constant head permeability test. Which test is used depends upon the type of soil to be tested. For soils of high permeability (sands and gravels) a constant head test is used. For soils of intermediate to low permeability, a falling head test is used.

In the constant head test, a constant total head difference is applied to the soil specimen, and the resulting quantity of seepage can then be measured. This works very well for coarse-grained soils, but with clays and silts, the quantity of seepage is much too small to be accurately measured. The falling head test is different in that it does not fix the total head difference across the specimen. Instead, a standpipe is connected to the inflow, and the water level in this standpipe is then allowed to drop as water flows through the specimen. This will not work well for coarse-grained soils, because they are so permeable that the head drops too rapidly to be accurately measured.

Neither the constant-head nor the falling-head laboratory method provides completely reliable value for the coefficient of permeability of a soil as conditions at the boundary are not the same as the laboratory and orientation of the in situ stratum to the flow of water is probably not duplicated. Laboratory tests often require the use of deaerated water. It has some merit, since the influence of a bubble of air coming

out of solution in the small laboratory sample may be very important compared with the effect of a bubble of the same size in the field soil.

Constant Head Test

Equipment.

a. **Special – Permeameter**. The equipment (permeameter) consist of the items as shown in Figure 10-1. It is generally used for soil samples with maximum particles diameter lower than 7.5 mm. The perspex cylinder has a perforated plate, placed in the lower part and a bayonet clutch, for keeping the sample. The piezometric glass tubes are placed in vertical position on a proper wooden panel. Connections between permeability cell and piezometric glass tubes are made by rubber tubes. The equipment has a aspirator tank, 2 litres capacity, for applying the hydraulic head.

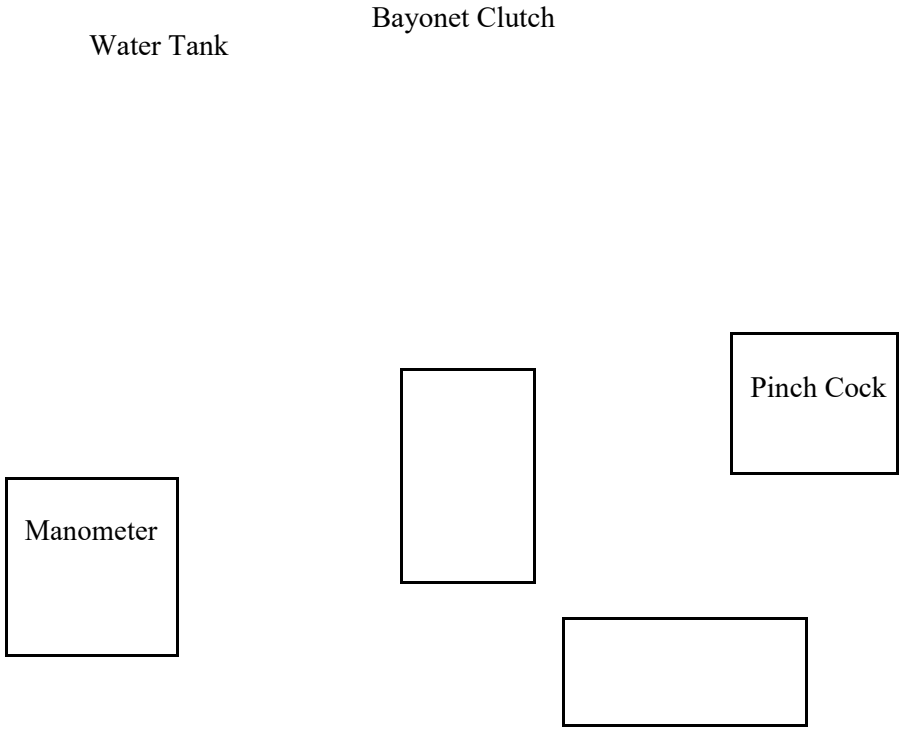


Figure 10-1: Equipment for Constant Head Permeability Test.

b. **Other Equipment**

- Measuring cylinders with capacity from 100 to 1000 ml.
- De-airing tank for water 7 litre capacity (optional**).**
- Nylon tubing 10 m coil (optional).

- Water trap (Optional).
- Portable vacuum pump (Optional).
- Rubber tube 6.5 x 16.5 mm dia 2 m long for vacuum (optional).
- Vacuum control panel for permeameter(optional).

c. **General**

- Balance (0.1 g sensitivity).
- Drying oven.
- Desiccators.
- Scale.
- Thermometer (0.1º sensitivity).
- Stop clock.
- Evaporating dish.
- Funnel.
- Stop watch.

Assembly of Apparatus.

The apparatus should be arranged as shown in Figure 10-2.

Figure 10-2: Schematic Diagram Showing Arrangement of Equipments for Constant Head Permeability TesT

Preparation of Water for the Test

Generally, when a permeability test is performed in the laboratory for use in the design of a civil engineering project, the water used should be identical to the native water, that in the field. For all but the most important projects, such water can be practically unattainable. Therefore, de-aired tap water is generally used. Tap water contains dissolved oxygen, and when flowing through a porous media, such as soil, this dissolved oxygen can actually come out of solution, and deposit air bubbles within the pore structure of the soil specimen. These tiny air bubbles would impede the flow of water through the specimen, thereby giving erroneous results. In order to circumvent this problem, water used in the permeability test should be freed of all (or most) of its dissolved oxygen content. This is done by spraying water into a sealed tank kept under vacuum pressure. ***If vacuum pump is not available, water may be boiled for a long duration, stirred and cooled, before supplying into the system.***

Preparation of Sample for the Test

A representative sample should be obtained from original soil. Sieving should be done the 6.25 mm sieve to eliminate the particles larger than 1/12 of the diameter of the permeameter cell. From the obtained sample a portion is to be extracted to determine the moisture content and calculate the dry weight. The test sample should not be dried so as to cause difficulty during the saturation stage. A large plastic funnel connected to a flexible tube about 35 cm long should be used. The stored sample should be taken and with a scoop the material should be poured into the funnel. The tube should be kept vertical and the permeameter should be started to fill checking that the distance from the end of the tube to the surface of the placed material is maintained constant. The tube should be moved around in a spiral motion from the periphery towards the center, to avoid the segregation of fine particles. Different densities can be obtained by varying the height of drop and tube diameter.

Saturation of Dry Sample

a. When preparation of dry samples either by pouring or compacting has been completed, the upper filler, the top plate should be fitted and the position of the pistons should be adjusted described above for samples poured into water. The connection lines between glands should be checked and manometer tubes are properly fitted.

b. The pitch cocks of the tubes near the glands should be tighten, to avoid sucking of air.

c. The vacuum pump should be run to apply vacuum to the sample. At the same time the lower valve of the cell should be opened to flow de-aired water within the sample.

d. When the level of water is about 1/3 of the sample height, the lower valve should be closed so that vacuum can operate to suck any air bubbles. When no air bubbles are observed, the lower

valve should be re-opened and let the water raise up to 2/3 of the sample height. The procedure as above should be repeated with the lower valve closed.

e. Flow of water should be continued upwards to reach the upper filter. The procedure should be repeated with the vacuum until no air bubbles are observed within the cylinder.

f. Vacuum should be lowered to zero and the pinch cocks should be released from the manometer tubes, so that water can saturate the lines. To obtain a complete saturation it may be necessary to remove the manometer tubes from the panel operating on the clips that fasten the tubes.

g. Lower valve of the permeameter cell and lower valve of the de-airing tank should be closed. The piece of tube should be removed and the connection should be checked from constant head water tank to the top of the cylinder is properly fitted.

h. It should be remembered:

(1) In the permeability tests the presence of air bubbles inside the sample can affect the precision of measurements.

(2) During the test formation of air bubbles reduces the hydraulic flow and gives lower values of lower permeability.

(3) To eliminate this type of error use of de-aired water and saturation of the sample before the test are recommended.

Test Performance Test and Data Recording

a. It must be checked that the valve at the base of the cell is open and the pinch cock of the flexible tube connected to the top outlet should be released, to the flow water downwards.

b. When water flows from the valve at the base of the cell and the water level in the monometer tubes becomes stable, test measurements should be started. A measuring cylinder of suitable capacity should be placed under the outlet valve and at the same time the stop watch should be started. A proper time interval should be selected for data recording so that an amount of an about 50-100cm^3 of water is measured. If necessary the distance from the parameter to the tank to obtain the required hydraulic head.

c. For each time interval record the following data:

(1) Elapsed time from the beginning of measurement.

(2) Amount and temperature of water within the graduated cylinder.

(3) Level of water in the manometer tubes.

d. The amount of water should be divided by the time interval to calculate the rate of flow "q" in cm/sec and this data vs. time should be plotted to evaluate when the flow becomes steady. A better evaluation is also obtained by plotting the rate of

flow "q" vs. $\frac{1}{time}$.

e. When the rate of flow is steady, the test can be stopped. If a series of tests with different hydraulic gradients is required, the procedure herein described should be repeated by increasing the height of the inlet reservoir.

f. When a sufficient number of readings have been obtained, the valve at the base of the cell should be closed and the average height of the sample should be measured.

g. From the sample a certain amount should be taken for moisture content measurement and sample final unit weight calculation.

Data Analysis.

a. From the measurements carried out the following data are available:

M_i	= Initial wet mass of the soil used to prepare the sample (gm)
M_f	= Mass of the dried soil remaining after setting up the sample (gm)
W_0	= Moisture content of the initial sample (%)
A_c	= Cross section of the sample (cm^2)
L_c	= Mean height of the sample after the test (cm)
L_1,L_2,L_3	= Distance of the gland points from the base of the permeameter (cm)

b. For a given time interval (min) measured in the conditions of steady flow the following data are recorded:

Q	= Volume of water collected in the graduated cylinder (cm^3)
H_1	= Level of water within the manometer tube connected to the lower gland (cm)
H_2	= Level of water within the manometer tube connected to the intermediate gland (cm)
H_3	= Level of water within the manometer tube connected to the tube upper gland (cm)
T	= Temperature of water (^oC)

c. The coefficient of permeability (m/sec) can be calculated from the following:

$$k = \frac{Q \times 10^{-2}}{60 \times i \times t \times A_c}$$

d. The hydraulic gradient "i" is the average of i_1, i_2 and i_3.

$$i_1 = \frac{H_1 - H_2}{L_1 - L_2}\ ;\ i_2 = \frac{H_2 - H_3}{L_2 - L_3}\ ;\ i_3 = \frac{H_3 - H_1}{L_3 - L_1}$$

e. Theoretically the 3 values of "i" should be similar. During the test some discrepancies are also possible for different reasons:

(1) The sample has not been prepared uniformly.

(2) A manometer tuber does not work properly.

(3) Within the sample a flow of the finest particles or a preferential flow of water has been installed.

f. To standardize the permeability to 20^0 C, the calculated values can be corrected as follows:

(1) Ratio of the viscosity of water for different temperatures:

$$k_{20} = k_T \frac{\eta_T}{\eta_{20}}\ .$$

(2) The dry density of the sample can be calculated as follows:

$$\gamma_d = \frac{\frac{M_i}{(1 + \frac{W_0}{100})} - M_f}{A_c * L_c}$$

Variable Head Test

Equipment

a. **Special – Permeameter** The equipment (Figure 10-3) allow operating with both undisturbed and remolded samples. The range of permeability that can be investigated by variable head tests can vary from 10^{-2} to 10^{-6} cm/sec. Lower permeability coefficients are generally measured by indirect methods with undisturbed specimens (generally saturated) in the consolidation tests. Figure 10-3 shows the permeameter used in variable head test.

(1) Cutting edge compaction permeameter, 4" in diameter, suitable for undisturbed sampling or for preparing test samples from block samples. The cell is with 75 microns circular filter, perforated base plate, water container with overflow tube, valves and connection lines.

(2) Measuring panel consisting of 4 glass standpipe tubes with different diameters, placed vertically on a wooden panel, used apply and measure the hydraulic falling head.

4 Glass Stand Pipes



Figure 10-3: Equipments for Variable Head Permeability Test.

b. **General**.

- Balance (0.1 g sensitivity).
- Drying oven.

- Desiccators.
- Scale.
- Thermometer (0.1º sensitivity).
- Stop clock.
- Evaporating dish.
- Funnel.
- Stop watch.

c. Observations in Equipment

(1) As indicated before for constant head permeability tests, the apparatus is completed by the same equipment to produce de-aired water and to saturate the sample.

(2) Unlike the scheme of assembly for constant head test, the control panel is connected to the permeability cell and the measuring panel with glass standpipes.

(3) The control and panel has been designed in order to be used for constant and falling head

Assembly of Equipment

The apparatus should be arranged as shown in Figure 10-4.

Figure 10-4: Schematic Diagram Showing Arrangement of Equipment for Variable Head Permeability Test

Preparation of Sample.

a. For taking the undisturbed sample, use of the proper cutting edge cylinder should be made, by pushing it directly into the soil; it should be taken care to prepare the surface of the sample so that it is reasonably plane and undisturbed.

b. During this procedure, it should be made sure that the sample is a tight fit in the body and that there are no cavities around the perimeter through which water could pass compromising the test results. If necessary, the finer particles of the samples should be used for packing the cavities.

c. The cylinder should be pushed into the soil, by taking whichever device to avoid bending movements, which could disturb the soil and create undesired micro cracks along the side surfaces.

d. When the cylinder contains the required length of sample plus a small excess, the sample should be cut off along the base surfaces by means of wire saw and straightedge and continue till the two surfaces are perfectly plane. During this operation sleeking the surface should be avoided, which can close the micro pore of the soil and reduce the measured permeability.

e. Finally, it can be pointed out that, if the soil sampling is performed with its axis horizontal (or parallel to bedding) it is possible to measure the horizontal permeability.

Saturating Sample.

a. The cell should be prepared by placing the cell body, cutting edge downwards, on the base plate, separated by the filter disc and a strip of filter paper.

b. Then another strip of filter paper should be placed on the upper surface of the sample, the filter disc and the permeameter head should be assembeled, taking care that the sealing ring is in the correct position. In this procedure, the line from valve N to O is not connected.

c. The cell should be placed the immersion tank and filled it with de-aired water up to the overflow level. It should be made sure that during these operations and after during the test the temperature of water is equal to room temperature.

d. Valve O should be opened and checked water level in the tank falls owing to water absorption by the sample; this process should be allowed to continue overnight for at least 12 hours or longer for low permeability soils.

e. Valve O should be connected to the line from valve E, both valves should be opened. The saturation process should be continued by applying a low suction by vacuum pump and increasing it if necessary, until the water is drawn up into the line from valve O to valve E. Before turning the vacuum pump off, it must be checked that no air bubbles are coming up through the vacuum line.

f. Vacuum should be reduced to a minimum, valves C and F should be opened for establishing pressure equilibrium. Valve O should be opened and the tube coming from valve E should be disconnected. Then valve C and F should be closed.

g. The hydraulic line should be connected from valve N to valve O, checking the lines are completely filled with water. During these operations air bubbles entrapped over valve O must be avoided.

h. Subsequently the manometer tubes should be filled by opening valves H, I, L, M. At the same time the sealing of each line must be checked.

Test Performance Test and Data Recording.

a. It should be checked valves B and O are closed (Figure 10-4) and the valve corresponding to the glass standpipe to be used for the test is open.

b. It should be checked that the water level in the water container is up to the overflow and a thermometer should be placed in it. Then a glass container of suitable capacity should be placed for pouring water coming out from overflow tube.

c. The lower part of the paper should be filled in, indicating the sample height L, the level of water H_0 in the standpipe used for the test and the temperature T measured in the outflow tank.

d. It should be checked that valve G is closed, N is opened and only one valve of H, I, L, M is opened.

e. Valve O should be opened and at the same time the stop watch should be started. At present intervals of time (generally the procedure suggests to follow a geometrical progression of times: 1min, 2, 3, 4, 8, 15 etc.) the level of water in the manometer tube should be recorded and indicated it as H_1.

f. When a sufficient number of readings have been recorded, the test should be stopped and calculations should be made according to the procedure indicated in the following paragraph.

g. Before dismantling the apparatus the mold with sample should be taken from the water tank and the final height of the sample should be measured in several points to obtain an average value.

h. From the soil sample a certain amount should be taken for moisture content measurement and sample final unit weight calculation.

Data Analysis.

a. The coefficient of k can be computed from

$$k = 2.3 \frac{aL}{A * (t_2 - t_o)} \log_{10} \frac{H_o}{H_1}$$

where, a = cross sectional area of standpipe

L = Length of the soil sample in permeameter

A = cross sectional of permeameter

L = Length of soil of soil sample in permeameter t_0 = time when water in stand pipe is at h_0
t_1 = time when water in stand pipe is at h_1
H_0, H_1 = heads between which the permeability is desired

b. To standardize the permeability to 20^0 C, the calculated values can be corrected as follows:

$$k_{20} = k_T \frac{\eta_T}{\eta_{20}}$$

Method of Presentation of Results and Report Writing

The results of permeability test are usually presented in the form of a plot of some function of void ratio, e, against some function of permeability, k_{20} **.**

Often two plots are made:

a. k vs. e^2, $e^2/(1+e)$, $e^3/(1+e)$.

b. e vs. log k

Significant Figures

1. The value hydraulic head should be expressed to 3 significant digits.
2. The value hydraulic conductivity should be expressed to 2 or 3 significant digits.
3. The value of velocity should be expressed to 3 significant digits.

WORKED OUT EXAMPLE

Permeability Test (Constant Head Method)

Test Serial No: 10

Date Tested: **October 25, 2008**

Tested By: Specific Gravity of Soil, G_S: **2.58**

Project Name: **Hatirjheel Project** Sample Number: **S-1, 25'-6″**

Visual Classification of Soil: **Coarse Sand**

Initial Wet Mass of the Soil Used, M_i

Weight of empty permeameter = 2709.5 gm

Weight of permeameter with filled wet soil = 3973.2 gm

Weight of wet soil, M_i = (3973.2 - 2709.5) = 1263.7 gm

Moisture Content of the Sample, W_0:

Sample No	**1**	**2**	**3**
Container #	**5**	**7**	**24**
Container Wt (gm)	**60.1**	**59.6**	**60.1**
Wet Wt + Container (gm)	**148.0**	**158.6**	**145.9**
Dry Wt + Container (gm)	**138.5**	**147.8**	**136.7**
Wt of Water (gm)	**9.5**	**10.8**	**9.2**
Dry Wt of Soil (gm)	**78.4**	**88.2**	**76.6**
Water Content (%)	**12.11**	**12.24**	**12.01**
Average (Water Content)		**12.12%**	

Mass of Dried Soil Remaining after Setting-up the Sample, M_f

Weight of dry soil used, M_f = 1263.7 / (1+w)

= 1263.7 / (1+0.1212) = 1127.1 gm

Permeameter Diameter: 7.5 cm

Permeameter Area, A_c: 44.18 cm^2

Determination of Hydraylic Gradient

Obsn No	L_1 cm	L_2 cm	L_3 cm	H_1 cm	H_2 cm	H_3 cm	i_1	i_2	i_3	Average i
1.	7.5	12.5	17.5	45.5	18.5	0	5.4	3.7	4.55	4.55
2.	7.5	12.5	17.5	43.0	19.0	0	4.8	3.8	4.3	4.3
3.	7.5	12.5	17.5	51.5	23	0	5.7	4.6	5.15	5.15

Sample Calculations (For Observation # 1)

$$i_1 = \frac{H_1 - H_2}{L_1 - L_2} = \frac{45.5 - 18.5}{7.5 - 12.5} = \frac{27}{-5} = -5.4 \qquad i_2 = \frac{H_2 - H_3}{L_2 - L_3} = \frac{18.5 - 0}{12.5 - 17.5} = \frac{18.5}{-5} = -3.7 \qquad i_3 = \frac{H_3 - H_1}{L_3 - L_1} = \frac{0 - 45.5}{17.5 - 7.5} = -\frac{45.5}{10} = -4.55$$

Obsn No	Sample Length, L_c (cm)	Temp. (˚C)	Amount of Water Collected, Q (cm^3)	Collection Time, t (sec)	Hydraulic Gradient, i	Permeability at T˚C, K_T (cm/sec)	Viscosity Ratio, η_T/η_{20}	Permeability at 20˚C, K_{20} (cm/sec)	Void Ratio, e
1.	20.7	24	500	42	4.55	0.0592	0.908	0.0538	1.093
2.	19.8	24	700	71	4.3	0.0519	0.908	0.047	1.002
3.	19.3	24	1000	92	5.15	0.048	0.908	0.0436	0.952

Note: Weight of wet soil was kept constant for each test.

Sample Calculations (For Observation # 1)

Coefficient of permeability at T°C, K_T

$$= \frac{Q}{i \times t \times A_c} = \frac{500}{4.55 \times 42 \times 44.18} = 0.0592\ cm/\sec$$

Permeability at 20°C, K_{20} $= k \dfrac{\eta_T}{\eta_{20}} = 0.0592 \times 0.908 = 0.0538 cm/\sec$ **.**

Volume of Soil Used, V_s = Weight of dry soil used / (Sp. Gravity of soil x Density of water) = 1127.1 / (2.58 x 1) = 436.86 cm^3

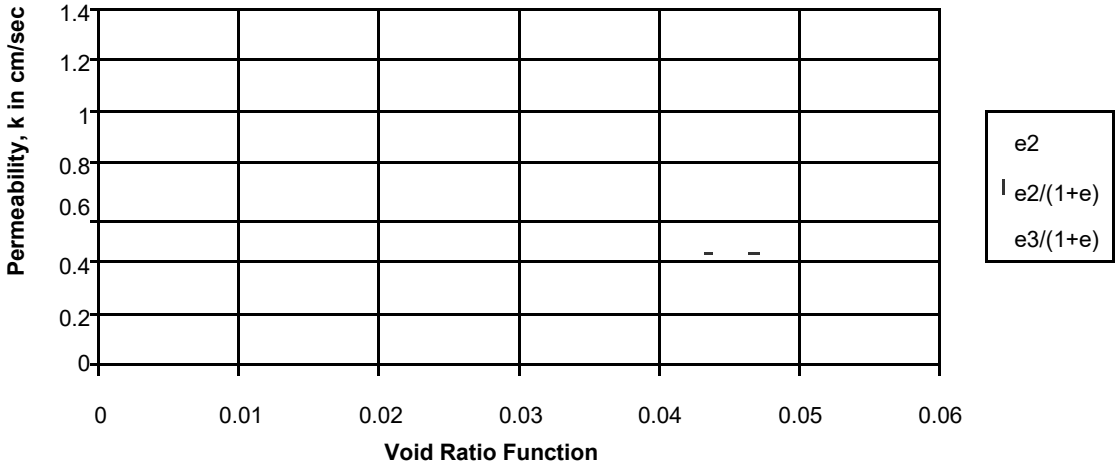
Total volume of soil, $V = \pi$ x $(d/2)^2$ x L_c = π x $(7.5/2)^2$ x 20.7 = 914.5 cm^3

Volume of soils, V_v = ($V - V_s$) = (914.5 – 436.86) = 477.64 cm^3

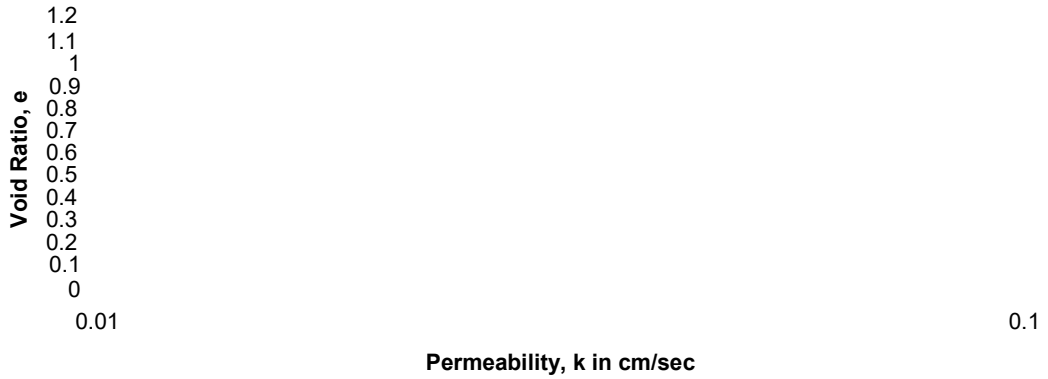
Void ratio, e = V_v / V_s = (477.64 / 436.86) = 1.093

Observation No	Void Ratio, e	e^2	$e^2/(1+e)$	$e^3/(1+e)$
1.	1.093	1.195	0.571	0.624
2.	1.002	1.004	0.501	0.503
3.	0.952	0.906	0.464	0.442

Permeability vs. Void Ratio Function Plot



Void Ratio vs. Permeability Plot



WORKED OUT EXAMPLE

Permeability Test (Variable Head Method)

Date Tested: **October 29, 2008**

Tested By: _____ Specific Gravity of Soil, G_S: **2.61**

Project Name: **Hatirjheel Project** Sample Number: **S-2, 35'-0″**

Visual Classification of Soil: **Sandy Silt, SM**

Obsn No	Weight of Empty Permeameter in gm	Weight of Permeameter with Wet Soil in gm	Weight of Wet Soil in gm	Moisture Content of Sample in %	Weight of Dry Soil Used in gm
1.	2480.0	4062.1	1582.1	7.5	1471.7
2.	2480.0	4011.1	1531.1	7.5	1424.28
3.	2480.0	4232.9	1752.9	7.5	1630.6

Sample Calculations (For

Observation # 1)

Weight of empty permeameter = 2480.0 gm

Weight of permeameter with filled wet soil = 4062.1 gm

Weight of wet soil, M_i = (4062.1 – 2480.0) = 1582.1 gm

Moisture Content of the Sample, W_0:

Sample No	1	2	3
Container #	20	19	1
Container Wt (gm)	60	60	60
Wet Wt + Container (gm)	112.8	119.4	115.2
Dry Wt + Container (gm)	109.1	115.2	111.4
Wt of Water (gm)	3.7	4.2	3.8
Dry Wt of Soil (gm)	49.1	55.2	51.4
Water Content (%)	7.5	7.6	7.4
Average (Water Content)		7.5%	

Weight of dry soil used, M_r = 1582.1 / (1+0.075) = 1471.7 gm

Other Measured Data

Permeameter Diameter = 10 cm

Permeameter Area, A = 78.54 cm_2

Stand Pipe Diameter = 2.1 cm

Stand Pipe Area, a = 3.46 cm_2

Obsn No	Sample Length, L (cm)	Temp (°C)	Initial Head, H_0 (cm)	Final Head, H_1 (cm)	Time Difference for Head Fall, (t_0-t_1) sec	Permeability at T°C, K_T (cm/sec)	Viscosity Ratio, η_T/η_{20}	Permeability at 20°C, K_{20} (cm/sec)	Void Ratio, e
1.	14	24	125	50	80	0.00706	0.908	0.0064	0.95
2.	14	24	100	25	105	0.00813	0.908	0.00738	1.002
3.	14	24	125	25	200	0.00496	0.908	0.0045	0.76

Sample Calculations (For Observation # 1)

Coefficient of permeability at T°C, K_T $= 2.3 \dfrac{aL}{A \times (t_1 - t_o)} \log_{10} \dfrac{H_o}{H_1} = 2.3 \times \dfrac{3.46 \times 14}{78.54 \times 80} \log_{10} \dfrac{125}{50} = 0.00706 cm/\sec$

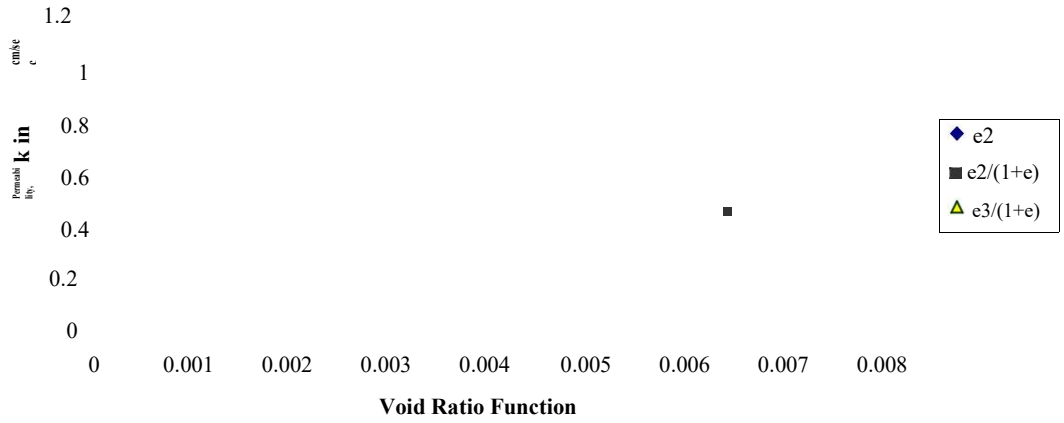
Permeability at 20°C, K_{20} $= k \dfrac{\eta_T}{{}_T\eta_{20}} = 0.00706 \times 0.908 = 0.0064 cm/\sec$ **.**

Volume of Soil Used, V_s = Weight of dry soil used / (Sp. Gravity of soil x Density of water) = 1471.7 / (2.61 x 1) = 563.88 cm^3 Total volume of soil, $V = \pi$ x $(d/2)^2$ x $L_c = \pi$ x $(10/2)^2$ x 14 = 1099.56 cm^3

Volume of soils, $V_v = (V - V_s) = (1099.56 - 564.88) = 535.68$ cm^3 Void ratio, $e = V_v / V_s = (535.68 / 563.88) = 0.95$

Obsn No	Void Ratio, e	e^2	$e^2/(1+e)$	$e^3/(1+e)$
1.	0.95	0.9025	0.4628	0.4397
2.	1.002	1.004	0.5015	0.5025
3.	0.76	0.5776	0.3282	0.2494

Permeability vs. Void Ratio Function Plot



Void Ratio vs. Permeability Plot

