CONTENTS

1.0 SCOPE AND APPLICATION

This standard operating procedure (SOP) outlines the procedure for the determination of the coefficient of permeability by a constant-head method for granular soils.

2.0 METHOD SUMMARY

This test method covers the determination of the coefficient of permeability by a constant-head method for the laminar flow of water through granular soils. In order to limit consolidation influences during testing, this procedure is limited to disturbed granular soils containing not more than 10 percent (%) soil passing the 75-micron (µm) (No. 200) sieve.

3.0 SAMPLE PRESERVATION, CONTAINERS, HANDLING, AND STORAGE

No preservation is necessary. For this test, samples are typically collected in soil sampling tubes or cores. Disturbed samples should be stored in glass jars. Analyses are typically performed at room temperature. All samples should be allowed to equilibrate to ambient temperature prior to analysis.

4.0 INTERFERENCES AND POTENTIAL PROBLEMS

The following are operating procedures required for testing under constant head conditions:

- Continuity of flow with no soil volume change during a test;
- Flow with the soil voids saturated with water and no air bubbles in the soil voids;
- Flow in the steady state with no changes in hydraulic gradient; and
- Direct proportionality of velocity of flow with hydraulic gradients below certain values, at which turbulent flow starts.

All other types of flow involving partial saturation of soil voids, turbulent flow, and unsteady state of flow are transient in character and yield variable and time-dependent coefficients of permeability; therefore, they require special test conditions and procedures.

5.0 EQUIPMENT/APPARATUS

1. Constant-Head Permeameter

   This device should have metal or transparent plastic containers with minimum diameters approximately 8 or 12 times the maximum particle size in accordance with Table 1, Appendix A. This device is shown in Attachment 1, Appendix B. The permeameter should be fitted with the following:

   - A porous disk or suitable reinforced screen at the bottom with a permeability greater than that of the soil specimen, but with openings sufficiently small (not larger than 10% finer size) to prevent movement of particles;
   - Manometer outlets for measuring the loss of head, *h*, over a length, *l*, equivalent to at least the diameter of the cylinder;
   - A porous disk or suitable reinforced screen with a spring attached to the top, or any other

device, for applying a light spring pressure of 22 to 45-Newtons (N)[(5 to 10-pound feet (lbf)] total load, when the top plate is attached in place. This will hold the placement density and volume of soil without significant change during the saturation of the specimen and the permeability testing to satisfy the required test conditions, as stated in Section 4.0.

2. Constant-Head Filter Tank, fitted with suitable control valves, to supply water and remove most of the air from the tap water.

3. Funnels, large, fitted with special cylindrical spouts 25 millimeters (mm) [one inch (in.)] in diameter for 9.5-mm (d-in.) maximum size particles, and 13 mm (½ in.) in diameter for 2.00 mm (No. 10) maximum size particles. The length of the spout should be greater than the full length of the permeability chamber which is at least 150 mm (6 in.).

4. Specimen Compaction Equipment, consisting of:

- Vibrating tamper fitted with a tamping foot 51 mm (2 in.) in diameter
- Sliding tamper with a tamping foot 51 mm (2 in.) in diameter, and a rod for sliding weights of 100 grams (g) (0.25 lb.) for sands to 1 kilogram (kg) (2.25 lb.) for soils with a large gravel content, having an adjustable height of drop of 102 mm (4 in.) for sands and 203 mm (8 in.) for soils with large gravel contents.

5. Vacuum pump or water-faucet aspirator (Attachment 2, Appendix B), for evacuating and saturating soil specimens under full vacuum.

6. Manometer tubes, with metric scales for measuring head of water.

7. Balance, capable of weighing up to 2-kg (4.4-lb) capacity, and sensitive to 1 g (0.002 lb).

8. Scoop, capable of holding about 100 g (0.25 lb) of soil.

9. Miscellaneous apparatus, consisting of:

- Thermometers
- Stopwatch
- Graduated cylinder, 250 milliliters (mL)
- Quart jar
- Mixing pan

6.0 REAGENTS

Water, deonized with low mineral content, or native water.

7.0 PROCEDURES

7.1 Sample Sieving and Mixing

1. Air dry the sample. Pass the air-dried sample through a No. 200 sieve (75 µm). Sieve until enough sample is retained on the No. 200 sieve to meet the requirements prescribed

in 7.1.2 and 7.1.3. Select sufficient sample using the method of quartering.

2. Perform a sieve analysis on a representative portion of the soil sample prior to conducting the permeability test. Any particles larger than 19 mm (3/4 in.) must be separated out by sieving. This oversize material shall not be used for the permeability test, but the percentage of the oversize material by mass should be recorded.

3. From the material from which the oversize has been removed, select by the method of quartering, a sample for testing equal to an amount approximately twice that required for filling the permeameter chamber.

7.2 Soil Sample Preparation for Permeability Test

1. Choose the size of permeameter to be used as specified in Table 1, Appendix A.

2. Measure and record the following initial measurements in centimeters (cm) or square centimeters (cm^2) on the data sheet (Attachment 3, Appendix B); inside diameter (D), of the permeameter; length (L), between manometer outlets; depth (H_1), measured at four symmetrically spaced points from the upper surface of the top plate of the permeability cylinder to the top of the upper porous stone or screen temporarily placed on the lower porous plate or screen. This automatically deducts the thickness of the upper porous plate or screen from the height measurements. This measurement is used to determine the volume of soil placed in the permeability cylinder. Use a duplicate top plate containing four large symmetrically spaced openings through which the necessary measurements can be made to determine the average value for H_1. Calculate the cross-sectional area (A), of the specimen.

3. Take a small portion of the sample (step 3, section 7.1) for water content determination. Record the weight of the remaining air-dried sample in the mixing pan (W_1).

4. Place the prepared soil by one of the following procedures in uniform thin layers approximately equal in thickness after compaction to the maximum size of particle, but not less than approximately 15 mm (0.60 in.).

- For soils having a maximum size of 9.5 mm (d in.) or less, place the appropriate size of funnel (section 5.0) in the permeability device with the spout in contact with the lower porous plate or screen. Fill the funnel with sufficient soil to form a layer, taking it from different areas of the sample in the pan. Lift the funnel approximately 15 mm or the approximate thickness of the layer and spread the soil with a slow spiral motion, working from the perimeter of the device toward the center, so that a uniform layer is formed. Remix the soil in the pan for each successive layer.

- For soils with a maximum size greater than 9.5 mm (d in.), spread the soil from a scoop. Uniform spreading can be obtained by sliding a scoopful of soil in a nearly horizontal position down along the inside surface of the device to the bottom or to the formed layer, then tilting the scoop and drawing it toward the center with a single slow motion; this allows the soil to run smoothly from the scoop in a windrow without segregation. Turn the permeability cylinder sufficiently for the next scoopful, thus progressing around the inside perimeter to form a uniform compacted layer of a thickness equal to the maximum particle size.

5. Compact successive layers of the soil to the desired relative density using one of the procedures listed below to a height approximately 2 cm (0.8 in.) above the upper manometer outlet (see Attachment 1, Appendix B).

- Minimum Density (0% Relative Density)

  Continue placing layers of soil in succession by one of the procedures described in step 4 above until the device is filled to the proper level.

- Maximum Density (100% Relative Density)

  Choose one of the following methods of compaction:

  1. Compaction by Vibrating Tamper - Compact each layer of soil thoroughly with the vibrating tamper, distributing the light tamping action uniformly over the surface of the layer in a regular pattern. The pressure of contact and the length of time of the vibrating action at each spot should not cause soil to escape from beneath the edges of the tamping foot, thus tending to loosen the layer. Make a sufficient number of coverages to produce maximum density, as evidenced by practically no visible motion of surface particles adjacent to the edges of the tamping foot.

  2. Compaction by Sliding Weight Tamper - Compact each layer of soil thoroughly by tamping blows uniformly distributed over the surface of the layer. Adjust the height of drop and give sufficient coverages to produce maximum density, depending on the coarseness and gravel content of the soil.

  3. Compaction by Other Methods - Compaction may be accomplished by other approved methods, such as by vibratory packer equipment, where care is taken to obtain a uniform specimen without segregation of particle sizes.

- Intermediate Density Between Zero and 100%

  By trial in separate container of the same diameter as the permeability cylinder, adjust the compaction to obtain reproducible values of relative density. Compact the soil in the permeability cylinder by these procedures in thin layers to a height about 2.0 cm (0.80 in.) above the upper manometer outlet.

6. Prepare the sample for the permeability test as follows:

- Level the upper surface of the soil by placing the upper porous plate or screen in position and by rotating it gently back and forth.

- Measure and record the final height of the sample (H_1 - H_2), by measuring the depth, H_2, from the top of the perforated top plate employed to measure H_1 to the top of the upper porous plate or screen at four symmetrically spaced points after compressing the spring lightly to seat the porous plate or screen during the measurements. Calculate the final weight of air-dried soil used in the test (W_1 - W_2) by weighing the remainder of soil, W_2, left in the pan. Compute and record the unit weights, void ratio, and relative density of the test sample.

- With its gasket in place, press down the top plate against the spring and attach it securely to the top of the permeameter cylinder, making an air-tight seal.

- Using a vacuum pump or suitable aspirator, evacuate the specimen under 50 cm (20 in.) Hg minimum for 15 min. to remove air adhering to soil particles and present in the voids.

- Following air evacuation, slowly saturate the sample from the bottom upward under full vacuum in order to free any remaining air in the specimen. Continued saturation of the sample can be maintained more adequately by the use of either de-aired water or water at a temperature sufficiently high to cause a decreasing temperature gradient in the sample during the test. Native water or water of low mineral content should be used for the test, but in any case the type of water used should be documented on the report form.

- After the sample has been saturated and the permeameter is full of water, close the bottom valve on the outlet tube and disconnect the vacuum. Care should be taken to ensure that the permeability flow system and the manometer system are free of air and are working satisfactorily. Fill the inlet tube with water from the constant-head tank by slightly opening the filter tank valve. Then connect the inlet tube to the top of the permeameter, open the inlet valve slightly and open the manometer outlets slightly, to allow water to flow, thus freeing them of air. Connect the water manometer tubes to the manometer outlets and fill with water to remove the air. Close the inlet valve and open the outlet valve to allow the water in the manometer tubes to reach their stable water level under zero head.

7.3 Testing Procedure

1. Open the inlet valve on the filter tank slightly for the first run to ensure flow is in the steady state with no changes in the hydraulic gradient. Once no appreciable drift in the water manometer levels is observed, measure and record the head (h), defined as the difference in manometer levels, time (t), amount of flow (Q), and water temperature (T).

2. Repeat test runs at heads increasing by 0.5 cm in order to accurately establish the region of laminar flow with velocity (v), where v = Q/At. This is directly proportional to the hydraulic gradient (i), where i = h/L. When departures from this linear relationship are observed, it indicates the beginning of turbulent flow conditions. One-cm intervals of head may be used to carry the test run sufficiently along in the region of turbulent flow to define this region, if it is significant for field conditions.

3. At the completion of the permeability test, drain the sample using the outlet valve, and inspect the sample to determine if the sample is essentially homogeneous and isotropic in

character. Any light and dark alternating horizontal streaks or layers are evidence of segregation of fines.

8.0 CALCULATIONS

8.1 Coefficient of Permeability

Calculate the coefficient of permeability (k) using the following equation:

$$k = Q \bullet L/A \bullet t \bullet h$$

where:

k = coefficient of permeability,
Q = quantity of water discharged,
L = distance between manometers,
A = cross-sectional area of specimen,
t = total time of discharge,
h = difference in head on manometers.

8.2 Permeability Correction Factor

Correct the permeability to that for 20 degrees Celsius (^{o}C) [68 degrees Fahrenheit (^{o}F)] by multiplying the permeability coefficient (k) by the ratio of the viscosity of water at test temperature to the viscosity of water at 20^{o}C.

9.0 QUALITY ASSURANCE/QUALITY CONTROL

All instrumentation must be operated in accordance with the manufacturer's instructions. Equipment check-out procedures and calibration activities must be performed.

All data must be documented in laboratory notebooks. The permeability test report (Attachment 3, Appendix B) includes the following information:

- Project, dates, sample number, location, depth, and any other pertinent information,
- Grain size analysis, classification, maximum particle size, and percentage of any oversize material not used,
- Dry unit weight, void ratio, relative density as placed, and maximum and minimum densities,
- Any modifications from the test conditions, so the results can be evaluated and used. Complete test data, as indicated in the laboratory form for test data, and
- Test curves plotting velocity, *Q/At*, versus hydraulic gradient, *h/L*, covering the ranges of soil identifications and of relative densities.

10.0 DATA VALIDATION

Data validation will not be conducted on the results of this physical test. However, all data generated will be reviewed and verified by the Engineering Evaluation Unit (EEU) prior to release.

11.0 HEALTH AND SAFETY

General laboratory safety practices should be followed. Waste samples should be handled with care due to the uncertainty of the properties and contents involved. All excess samples, used samples, and waste material generated during analysis must be disposed in accordance with SERAS SOP #1501, *Hazardous Waste Management.*

When working with potentially hazardous materials, follow United States Environmental Protection Agency (U.S. EPA), Occupational Safety and health Administration (OSHA), and Lockheed Martin health and safety procedures. More specifically, refer to SERAS SOP #3013, *Laboratory Safety Program.*

12.0 REFERENCES

American Society of Testing and Materials (ASTM). 1991. *Annual Book of ASTM Standards*, Designation D2434 - 68: Standard Test Method for Permeability of Granular Soils (Constant Head).

13.0 APPENDICES

A - Cylinder Diameter Table
B - Attachments

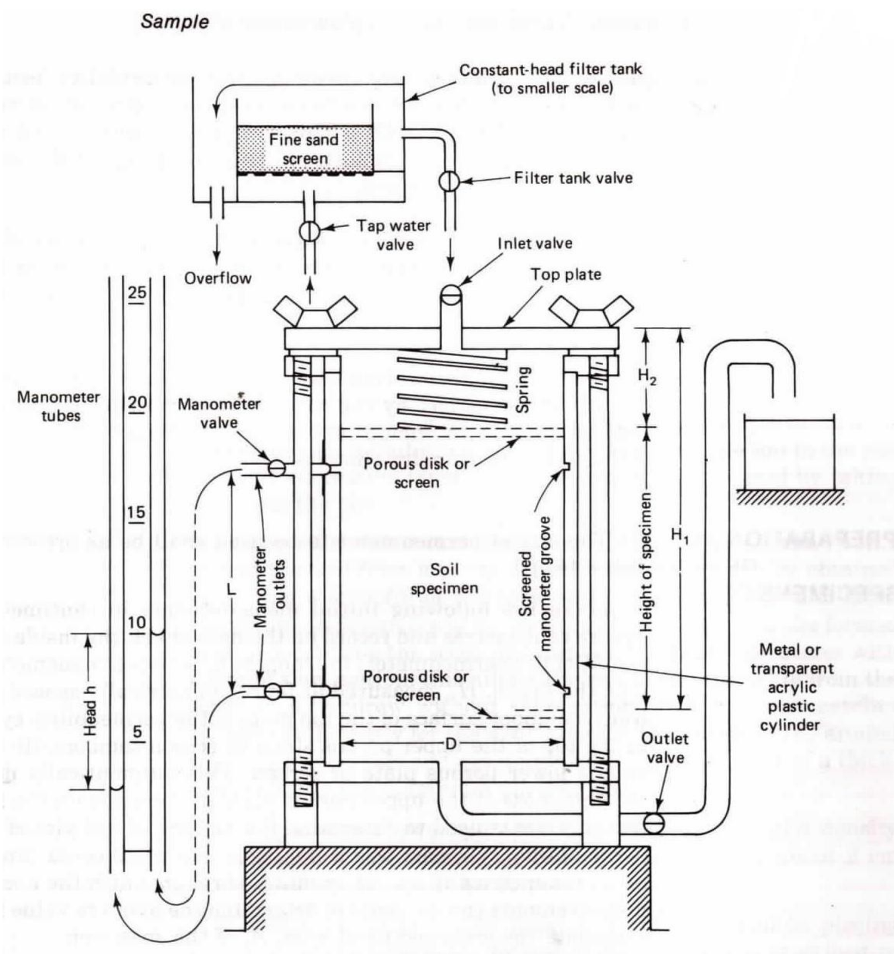
APPENDIX A
Cylinder Diameter Table
SOP #1842
June 2003

TABLE 1. Cylinder Diameter Table

Maximum Particle Size Lies Between Sieve Openings	Minimum Cylinder Diameter			
	Less than 35% of Total Soil Retained on Sieve Opening		More than 35% of Total Soil Retained on Sieve Opening	
	2.00-mm (No. 10)	9.5-mm (d in.)	2.00-mm (No. 10)	9.5-mm (d in.)
2.00-mm (No. 10) and 9.5-mm (d in.)	76 mm (3 in.)	- -	114 mm (4.5 in.)	- -
9.5-mm (d in.) and 19.0-mm (¾ in.)	- -	152 mm (6 in.)	- -	229 mm (9 in.)

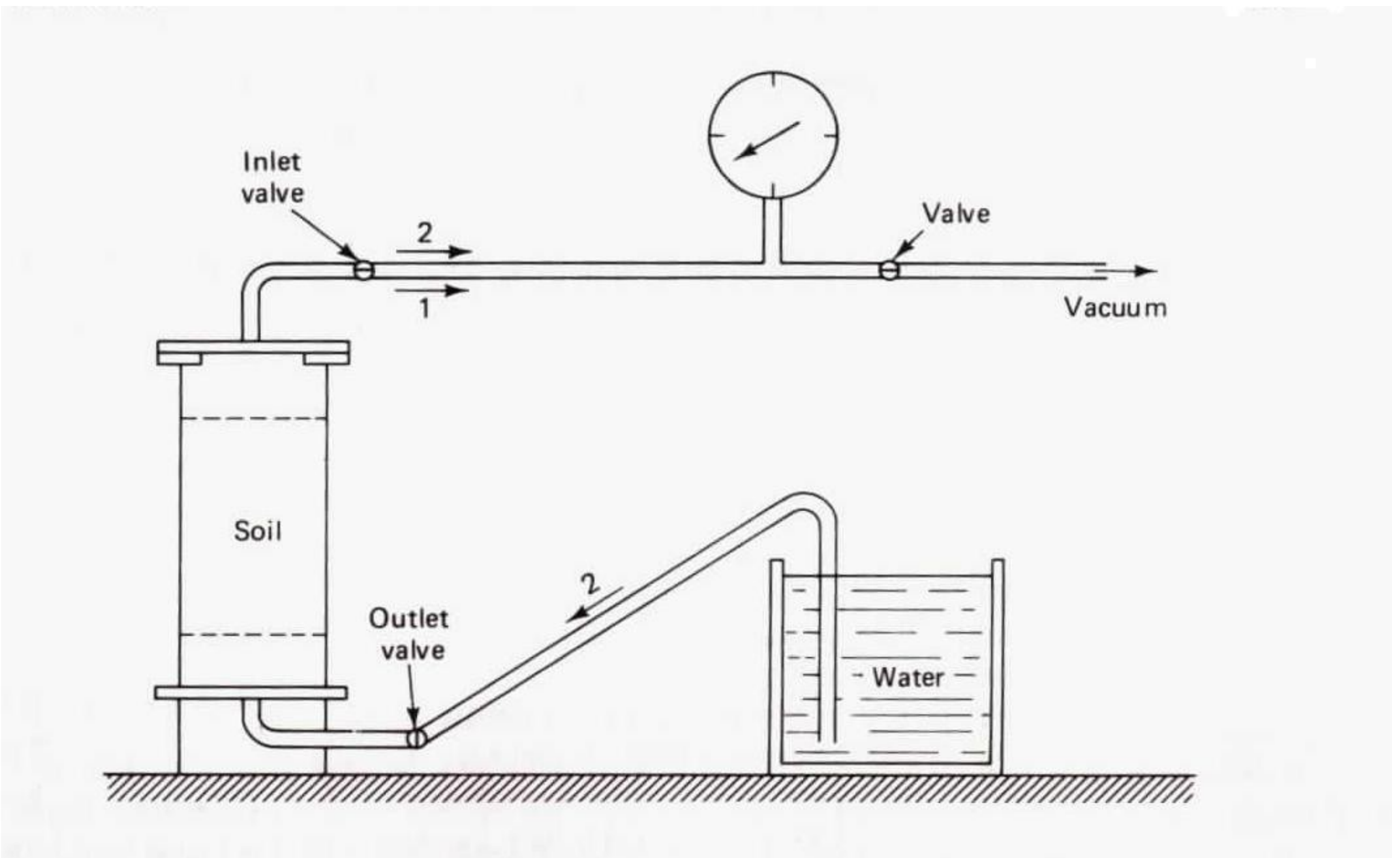
APPENDIX B
Attachments
SOP #1842
June 2003

ATTACHMENT 1. Constant-Head Permeameter



Cheng Liu and Jack B. Evett, SOIL PROPERTIES, Testing, Measurement and Evaluation, Second Edition, Prentice Hall, Englewood Cliffs, New Jersey 1990, p. 203

ATTACHMENT 2. Device for Evacuating and Saturating the Sample



Cheng Liu and Jack B. Evett, SOIL PROPERTIES, Testing, Measurement and Evaluation, Second Edition, Prentice Hall, Englewood Cliffs, New Jersey1990, p. 207.

ATTACHMENT 3. Permeability Test Data Sheet

Work Assignment Name: ____________________ Work Assignment No. __________
Sample No.: ______________ Location: ________________ Sample Depth: ________________
Sampling Date: ____________ Test Date: ________________
Description of Soil: ____
Materials Used: ____

Unit Weight Determination:
Diameter, D, cm: ____________ Height Before, H_1: ______________ Weight Before, W_1: ___________
Area, A, cm^2: ____________ Height After, H_2: ______________ Weight After, W_2: ___________
Length, L, cm: ____________ Height Net, cm: ______________ Weight Net, g: ___________
W (max): ____________ Moisture Content (air-dried): ______________________
W (min): ____________ Dry Unit Weight, lb/ft^3, W: ______________________
Void Ratio, e: ______________________
Relative Density, RD: ______________________

Permeability Test (Degree of Compactness)

Test No.	Manometer		Head, h, cm	Q, cm^3	t s	Q/At	h/L	Temperature, °C	k,cm/s
	H_1	H_2							
1									
2									
3									
4									
5									
6									