

# **Procedure for the Determination of the Permeability of Clayey Soils in a Triaxial Cell Using the Accelerated Permeability Test**

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**Keywords**

Accelerated, Permeability, British Standard, Landfill, Liner, Clay, Triaxial Cell.

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## **1. GENERAL**

- 1.1 The following outlines the test procedure to be adopted in the Accelerated Permeability Tests (AP tests) in determining the permeability of clayey soils. The procedure is consistent with that adopted in the Environment Agency R&D Contract Project No. P1-3398 'Validation of the Accelerated Permeability Test as an Alternative to the British Standard Triaxial Permeability Test'.
- 1.2 The limitations in the recommended use of the test for landfill linings and cappings is detailed in both the Project Record and Technical Report of Environment Agency R&D Contract Project No. P1-3398. An interpretation of the AP test permeability results in relation to the British Standard constant head triaxial test (BS 1377:1990 Part 6, Method 6) is also detailed in these documents.
- 1.3 In the AP test, the preparation of specimens, equipment to be used and testing requirements shall be in accordance with B.S.1377: 1990 other than as detailed in the following.
- 1.4 The basic test does not include measurements to assess the incremental volume and moisture content (or density) changes of the specimen during the test, or determination of the degree of saturation from B value determinations. However, included are procedures for the volumetric and moisture content determinations, and a procedure for the determination of the degree of saturation at the end of the AP test. It should be noted that the procedures for assessing volume and moisture content change of the specimen during the test are prone to errors using conventional laboratory equipment and require very careful appraisal of the data to obtain meaningful results. Included are comments on volume and moisture content error corrections should the Engineer desire such measurements to be made, though these would not be considered a standard requirement of the AP test.

## **2. SAMPLE PREPARATION**

- 2.1 Each compacted specimen prepared for permeability testing shall have a nominal diameter of 100mm and length of 100mm.
- 2.2 Measurements of the length and diameter of the specimens prepared for permeability testing shall be made to the nearest 0.1mm. The diameter shall be recorded at 2 perpendicular diameters at the top, base and near the mid-length of the specimen. Measurements of the length shall be made along 3 lines approximately 120° apart around the curved surface of the specimen.
- 2.3 The weight of the specimens shall be measured and recorded to the nearest 0.01g and the densities determined to an accuracy of 0.001Mg/m<sup>3</sup>.

### 3. SETTING UP THE TEST IN THE TRIAXIAL CELL

- 3.1 Two volume-change indicators are to be used in each test: one on each of the back pressure lines. These volume-change indicators are to record the volume of water leaving and entering the specimen. A third volume-change indicator on the cell line will be necessary if measurements of the volume change of the specimen are required. Where volume change burettes are to be used, these should be flushed out prior to use. In this operation, work the indicators at least twice to their limits of travel replacing escaped water with freshly de-aerated water from the pressure system.
  - 3.2 If a separate base porous disc is used in the triaxial test, slide the saturated disc onto a layer of water on the triaxial base pedestal without entrapping air. Remove any surplus water standing on the disc, ensuring that the pores remain saturated. Place the specimen on the disc without delay and without entrapping air.
  - 3.3 If a base pedestal with a bonded-in porous disc is used, ensure that the porous disc is saturated without any free water standing above it. Place the specimen on the base pedestal without delay and without entrapping air.
  - 3.4 Place the saturated porous disc, with excess water removed, on top of the specimen.
  - 3.5 Place the soaked rubber membrane, after allowing surplus water to drain off, around the specimen using a membrane stretcher. An unused leak-free membrane shall be used for every test. The membrane shall be soaked overnight before use.
  - 3.6 Seal the membrane to the base pedestal using two rubber O-rings.
- Note 1:** A smear of silicone grease on the curved surface of the pedestal and top cap improves the seal and is to be used. Grease shall not be allowed to come into contact with the porous disc.
- 3.7 Remove air pockets from between the membrane and the specimen by lightly stroking upward. No further water shall be inserted between the specimen and the membrane.
  - 3.8 Fit two O-rings around the drainage lead connected to the top loading cap.
  - 3.9 Open the back pressure valve momentarily to moisten the top cap and fit it onto the porous disc without entrapping air. Seal the membrane on to the top cap with the two O-rings rings, using the split-ring stretcher. As for the base pedestal, a smear of silicone grease shall be used to improve the seal (see Note to 3.6).
  - 3.10 Ensure that the specimen axis is vertical and that the top drainage line will not interfere with fitting the cell body.
  - 3.11 Assemble the cell body with de-aerated water, ensuring that all the air is displaced through the bleed hole.
  - 3.12 Keep the bleed plug open until the cell is to be pressurised, in order to maintain the pressure at atmospheric.

3.13 Check that the volume change indicators have sufficient travel. Make adjustments as necessary.

3.14 The pressures to be used in the test shall be as follows:

|                              |        |
|------------------------------|--------|
| Outlet (top) back pressure   | 300kPa |
| Inlet (bottom) back pressure | 425kPa |
| Cell confining pressure      | 550kPa |

**Note 2:** The water flow direction is upwards being in at the bottom of the specimen and out at the top.

3.15 Pressurise the cell by opening the cell pressure valve slowly.

**Note 3:** If volume change of the specimen is to be determined, the cell shall be calibrated and the volume of water used in the cell recorded to allow a measure to be made of the volume change of the specimen during the pressurising of the cell.

**Note 4:** The testing of the Environment Agency R&D Research Project No. P1-398, highlights errors which may occur in triaxial cell permeability testing using standard laboratory equipment. A major potential error is in the reading of the cell volume change indicator set prior to opening of the taps to the pressure lines. The influence of trapped air bubbles and seating/assembly errors may be eradicated by careful examination of the volume measurements and redefining the zero reading.

## **4. ACCELERATED PERMEABILITY TEST PROCEDURE**

4.1 Open the inlet (bottom back pressure) valve, then slowly open the outlet (top back pressure) valve.

**Note 5:** Corrections may be necessary in the initial zero readings of the volume change indicators set prior to opening of the taps to the pressure lines. This does not influence the determination of the onset of steady state flow conditions but does influence the apparent uptake or reduction of water in the specimen. The liberation of air from solution can also influence volume flow measurements.

**Note 6 :** Initially the volume change indicators will vary, possibly indicating net negative flow of water from or into the specimen, but should settle down.

4.2 Monitor the rate of flow in and out of the specimen at suitable time intervals to obtain a continuous uninterrupted plot including any initial negative flow of water. Continue the test until the relationship of both volume change indicators are linear and parallel and both volume change indicators indicate a roughly similar rate of flow.

**Note 7:** The following conditions should be satisfied unless material specific testing shows otherwise –

Minimum flow time for steady state conditions of 2500min

Minimum test duration time, following the establishment of steady state conditions, of 2500mins to ensure linearity of flow plots and that the top and bottom flow plots are roughly parallel.

The ratio of the maximum to minimum of inflow and outflow rates should not be greater than 1.7.

- 4.3 If required, monitor the volume change of the specimen at suitable time intervals to obtain a continuous uninterrupted plot of volume change during the testing.
- 4.4 Plot a graph of cumulative flow of water 'Q' (in ml), as recorded from each volume change indicator as ordinates, against time (in mins) as abscissa, on a linear scale.
- 4.5 If required, sufficient measurements shall be made to allow determine of the volume change of the specimen, the moisture content change of the specimen and the density change of the specimen throughout the test including during any saturation check.
- 4.6 If required by the Engineer, a saturation check shall be carried out by determination of the B value in accordance with section 5.
- 4.7 Record the temperature in the vicinity of the triaxial cell to 0.5°C.
- 4.8 Stop the permeability test by closing both the back pressure valves (inlet then outlet).

## 5. SATURATION CHECK

- 5.1 If not already inserted, connect a pore water pressure transducer to the inflow base line.
- 5.2 With the inlet and outlet valves closed, allow the pore water pressure in the specimen to equalise and until it has not shown a change of more than 1kPa over a period of at least one hour.
- 5.3 Increase the cell pressure by 100kPa.
- 5.4 The pore pressure within the specimen as indicated by the transducer will increase. Monitor the pore pressure until it is steady and does not show a change of more than 1kPa over a period of at least one hour. Record the time and pore pressure.
- 5.5 Determine the pore pressure parameter B from the following and record it.

$$B = \delta u / \delta \sigma_3$$

Where,  $\delta u$  = the change in pore pressure  
 $\delta \sigma_3$  = change in cell pressure = 100kPa  
 $\delta u = u - 300\text{kPa}$

**Note 8:** The criterion  $B \geq 0.95$  is usually accepted as an indication of near-saturated conditions at the start of a BS test. However, in carrying out the saturation check at the end of the AP test the specimen will have been consolidated and in stiff clays it is recognised that it may not be possible to obtain a ratio of  $B \geq 0.95$ . A value of  $B \geq 0.90$  which remains unchanged after two further successive increments of cell pressure and back-pressure is then considered acceptable.

5.6 Where necessary, ensure that the specimen volume-change indicator is read during the saturation check stage and that the measurements provide a continuation of those during the permeability test.

## 6. CALCULATIONS

6.1 Calculate the cross-sectional area of the soil specimen  $A$  (in  $\text{mm}^2$ ) from the measurements prior to testing.

6.2 From the cumulative flow plot of section 2.4, determine the mean slope of the linear portions. This slope equals the mean rate of flow 'q' (in ml/min), during steady flow conditions in the test.

6.3 Determine the pressure difference ( $p_1 - p_2$ ),

Where,  $p_1$  = the inlet back pressure,  
 $p_2$  = the outlet back pressure.

6.4 Calculate the coefficient of permeability in the vertical direction,  $k_v$  (in m/s), from the equation,

$$k_v = \frac{(1.63 \times q \times L)}{A(p_1 - p_2) - p_c} \times R_t \times 10^{-4}$$

Where,  $q$  = the mean rate of flow through the soil specimen (in mL/min),  
 $L$  is the length of the specimen prior to testing (in mm)  
 $(p_1 - p_2)$  is the pressure difference between the pressure applied to the top and base pressure lines (in kPa)  
 $p_c$  is the pressure loss in the system (in kPa) for the rate of flow  $q$ , obtained from the calibration graph.  
 $R_t$  is the temperature correction factor for the viscosity of water.

## 7. MEASUREMENTS OF SPECIMENS AFTER TESTING

7.1 Measurements of the length and diameter of the specimen to the nearest 0.1mm shall be made after testing. As for the measurements prior to testing, the diameter shall be recorded at 2 perpendicular diameters at the top, base and near the mid-length of the specimen. Measurements of the length shall be made along 3 lines approximately  $120^\circ$  apart around the curved surface of the specimen.

7.2 The weight of the specimen after testing shall be measured and recorded to the nearest 0.01g and the density determined to an accuracy of 0.001Mg/m<sup>3</sup>.

## 8. REPORTING OF RESULTS

8.1 The test report for each specimen tested shall include the following information:

- (i) Confirmation of methodology employed in specimen preparation and testing highlighting any deviation from the procedures detailed above;
  - (ii) The results of all calibration checks and allowances for potential errors;
  - (iii) Initial specimen dimensional measurements;
  - (iv) Comments on the initial specimen condition and structure which might influence permeability measurements;
  - (v) Initial bulk density, dry density, moisture content and air voids content of the specimen;
  - (vi) Results of the measurements from the volume-change indicators;
  - (vii) The coefficient of permeability  $k$  (in m/s), at 20°C, to 2 significant figures;
  - (viii) The mean effective stress at which the permeability was measured;
  - (ix) The hydraulic gradient across the specimen during the test;
  - (x) The volume of the specimen, the density of the specimen and the moisture content of the specimen at regular intervals throughout the test if required by the Engineer;
  - (xi) Final specimen dimensional measurements;
  - (xii) Comments on the final specimen condition and structure which might influence permeability measurements;
  - (xiii) Final bulk density, dry density and overall moisture content of the specimen;
  - (xiv) The results of the Saturation Check if required by the Engineer;
  - (xv) The laboratory is requested to provide any additional information or observations that it considers relevant.
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