CRD-C 163-92

Test Method for Water Permeability of Concrete Using Triaxial Cell

1. Scope

1.1 This test method covers the procedure for determining the water permeability of concrete using a triaxial (or Hassler) cell. The calculations of intrinsic permeability are based on Darcy's equation for flow in a permeable medium (Note 1).

Note 1. Intrinsic permeability (k) is a property of the permeable medium alone and is independent of the properties of the permeating fluid. It is related to hydraulic conductivity (K), a property of the permeable medium and the properties of the fluid, by the following relationship:

$$K = \frac{\gamma}{\mu} k$$

where

μ = dynamic viscosity of the fluid and

γ = specific gravity of the fluid.

1.2 The values stated in SI units are to be regarded as the standard.

1.3 *This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Reference Documents

2.1 ASTM Standards

C 31 Practice for Making and Curing Concrete Test Specimens in the Field (CRD-C 11)

C 42 Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete (CRD-C 27)

C 192 Practice for Making and Curing Concrete Test Specimens in the Laboratory (CRD-C 10)

D 1193 Specification for Reagent Water

2.2 Corps of Engineers Standards

CRD-C 62 Method of Testing Cylindrical Test Specimens for Planeness and Parallelism of Ends and Perpendicularity of Sides

3. Summary of Test Method

3.1 This test method involves the establishment of a steady-state flow condition in a cylindrical concrete specimen housed in a triaxial permeability cell. A pressure gradient is maintained across the sample with one end exposed to ambient pressure and the opposite end at the test drive pressure. A radial confining pressure is maintained around the specimen. The effluent is collected, and volume flow rate is determined. Once steady-state flow conditions are obtained, the intrinsic permeability is calculated.

4. Apparatus

4.1 The permeability apparatus is shown schematically in Figure 1. Major components include a triaxial cell, regulated gas pressure source, gas-over-water accumulator, effluent volume metering device, and appropriate valves and tubing.

4.2 An exploded view of a typical triaxial cell for permeability testing is shown in Figure 2. Although the details of the triaxial cell may vary from those shown in Figure 2, the basic components of the cell are as shown in the figure. Apparatus of this sort is available to accommodate cylindrical specimens of a variety of diameters and lengths from 20 to 100 mm in diameter and up to 280 mm in length. The cell shall be capable of isolating the confining pressure from the drive pressure. The cell shall be complete with end plates, typically made from stainless steel. The end plates shall be grooved radially and circumferentially to permit fluid to reach approximately 15 percent of the surface of the sample ends.

4.3 A regulated compressed nitrogen gas source shall be used to provide both the confining and drive pressures. Delivery of the drive pressure to the triaxial cell shall be obtained through a gas-over-water accumulator. The accumulator is a sealed pressure vessel with an internal diaphragm to isolate the gas from the water. Separation of gas and water shall be maintained because gas can be forced into solution in the water thus changing the effective viscosity of the water and contaminating the test fluid. A gas-pressure-regulating valve is installed in the supply line from the pressure source to the accumulator to control the drive pressure. A second gas-pressure-regulating valve is installed in the supply line from the pressure source to the confining pressure inlet of the triaxial cell. This allows the

driving pressure and confining pressure to be independently controlled.

4.4 The effluent volume shall be measured by a suitable device such as a graduated pipette or column. Other alternative methods of measuring effluent volume

Figure 1. Schematic diagram of test configuration

Figure 2. Exploded view of a typical triaxial permeability cell

such as scales, load cells, etc. may be substituted if automation of the test is desired.

5. Specimen

5.1   Specimens shall be cores drilled from concrete in accordance with the applicable sections of CRD-C 27 (ASTM C 42) or shall be cylinders made and cured in the laboratory in accordance with the applicable sections of CRD-C 10 (ASTM C 192) or shall be made and cured in the field in accordance with applicable sections of CRD-C 11 (ASTM C 31).

5.2   *Specimen Dimensions.* The length shall be no less than the greater of the following:

(1) 3 times the nominal maximum aggregate size, or

(2) 1/2 the diameter of the specimen.

Note 2.   Movement of water through the concrete occurs through porosity that exists in the cementitious matrix of concrete, as well as through the porosity that exists at the paste-aggregate boundaries. The minimum specimen length must be great enough to provide a representative sample of both the cementitious matrix and the paste-aggregate boundaries.

6. Procedures

6.1   The planeness of the ends of the specimen and perpendicularity of the sides of the specimen shall be determined in accordance with the applicable sections of Method CRD-C 62. Neither end of the test specimen when tested shall depart from perpendicularity to the axis by more than 0.5°. Specimens shall be sawed or ground until the ends of the specimens are plane within 0.050 mm. Record the average length and average diameter of the specimen to the nearest 1 mm.

6.2   The specimen shall be vacuum saturated in deionized water for a minimum of 72 h. The deionized water shall comply with the requirements for Type IV of ASTM D 1193. Vacuum saturation shall be accomplished by placing the specimen in a suitable container, covering the specimen with deionized water, reducing the pressure in the container to at least 133 Pa (1 mm Hg), and maintaining the reduced pressure for at least 72 h.

Note 3.   For some specimens the specimen may be completely saturated at the end of 72 h. For other less permeable specimens, the initial portion of the permeability test will complete the saturation process.
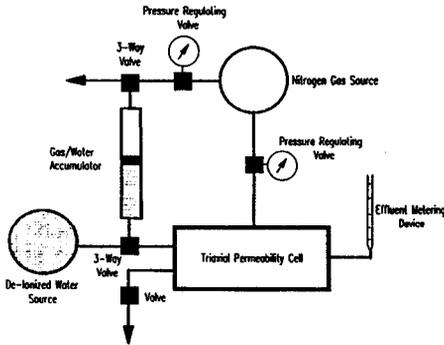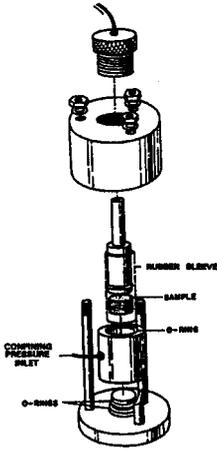
6.3 *Assembly.* Attach the end plates to the specimen with two layers of electrical tape prior to assembly. A 0.95-mm-thick rubber sleeve shall be placed around the specimen with stainless steel perforated end plates against specimen ends. A porous 0.16-mm-thick layer of stainless steel mesh shall be used on each end of specimen between the specimen and the end plates. The rubber sleeve shall be clamped to the end plates using hose clamps. Place the assembly inside the holder. Install the end plates on the triaxial cell. The cell shall be tilled with deionized water through the side valve. Bleed all entrapped air from the interior of the triaxial cell using the side valves.

6.4 *Selection of Driving and Confining Pressures.* The confining pressure shall be no greater than one-half the estimated unconfined compressive strength of the concrete specimen. The drive pressure shall be no greater than 80 percent of the confining pressure.

6.5 *Operation.*   Apply the confining pressure through the confining pressure regulating valve. Apply the drive pressure to the gas/water accumulator system through the drive pressure regulating valve. Record the date, time to the nearest minute, drive pressure, and confining pressure. Periodically record the date, time, drive pressure, confining pressure, and effluent volume in mL. Make any adjustments necessary to the pressure regulating valves in both the drive and confining systems to maintain them within ± 5% of the predetermined levels. The required time interval between measurements will vary with the permeability of the specimen from a few minutes to several hours. Plot the total volume of fluid collected versus elapsed time for the test. When the resulting curve is linear over five or more readings (Figure 3), steady-state flow is obtained.

Note 4.   Linearity of the volume-time curve may be determined graphically or by a least-squares linear regression procedure. If linear regression is used, a regression coefficient of R ≥ 0.95 is recommended as adequate for determining linearity.

7. Calculation

7.1   Calculate the area of the specimen (in m^2) perpendicular to the direction of flow.

7.2 *Pressure gradient.* Calculate the pressure gradient across the specimen as follows:

$$\Delta P = P_{drive} - P_{ambient}$$

where

P_{drive} = Drive pressure, Pa

$P_{ambient}$ = Atmospheric pressure, Pa

Note 5.   Standard atmospheric pressure is 101.325 Pa.

7.3 *Effluent Volumetric Flow Rate.* Compute the effluent volumetric flow rate (Q) for each reading during the steady-state portion of the test (Section 6.5) as follows:

$$Q \text{ (mL/s)} = \frac{\Delta V}{\Delta t}$$

where

ΔV = incremental effluent volume collected, mL

Δt = time interval during which the volume was collected, s.

The steady-state volumetric flow rate shall be taken as the average volumetric flow rate over five or more time intervals.

7.4 *Intrinsic Permeability.* The intrinsic permeability of concrete is calculated as follows:

$$k = \frac{Q \, \mu_w \, L}{A \, \Delta P} \times 10^{-6}$$

where

k = intrinsic permeability, m^2 (Note 6)

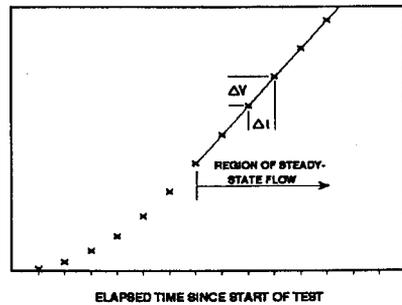Q = Effluent steady-state volumetric flow rate, mL/s

Figure 3.   Determination of Steady-State Flow

μ_w = Viscosity of water, Pa • s (Note 7)

L = Length of specimen, m

A = Cross-sectional area of specimen perpendicular to direction of flow, m^2

ΔP = Pressure gradient, Pa

Note 6. The customary unit for intrinsic permeability is the darcy. It has units of $(length)^2$ and is defined as follows:

$$1\ darcy = \frac{(1\ centipoise \times 1\ mL/s)}{1\ cm^2 \times 1\ atmosphere/cm}$$

One darcy is equivalent to $9.869233 \times 10^{13}\ m^2$.

Note 7. The customary unit for the viscosity of water is the centipoise. A centipoise is equivalent to 1.000 Pa • s. The viscosity of water at 23 C is 9.325×10^{-4} Pa • s (0.9325 centipoise). This value must be changed if other permeating fluid is used.

8. Report

8.1 The report shall include the following:

8.1.1 Specimen identification.

8.1.2 Pertinent data on the characteristics of the concrete used in the specimens including nominal maximum aggregate size.

8.1.3 The age at which the specimens were tested.

8.1.4 Length and diameter of specimen.

8.1.5 Drive and confining pressures.

8.1.6 Effluent volumetric flow rate.

8.1.7 Values for intrinsic permeability of each specimen.

8.1.8 Notations of any unusual features of the testing procedure.

9. Precision and Bias

9.1 The precision and bias of this method have not been determined.