Formation Factor Test Summary

The objective of the test is to quantify the ability of a concrete mixture to resist transport of fluids through the matrix.

The test is based on the premise that electrical charge is more easily transported through pore solution than through solid hydration products, thus measurements of resistivity are an indication of the amount and connectivity of pores in the system. Resistivity is affected by a number of factors including degree of hydration, pore solution chemistry, temperature and formation factor. Formation factor is a physical property of the system and is assessed as the ratio of resistivity of the sample over the resistivity of the pore solution.

This test seeks to control variables such as pore solution chemistry and temperature for samples evaluated over a range of ages.

To determine the resistivity and formation factor, refer to AASHTO TP 119-15 (Revision date 6/17/2018) and AASHTO T 358-17.   Either standard may be utilized for the testing, but the sample conditioning in TP119-15 (Option A) is preferred. Guidance on determining the formation factor is provided in AASHTO PP84.

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Standard Method of Test for

Electrical Resistivity of a Concrete Cylinder Tested in a Uniaxial Resistance Test

AASHTO Designation: TP 119-15 (2017)[1]

Technical Section: 3c, Hardened Concrete

Release: Group 1 (April 2017), Last Revised 6/17/2018

AASHTO

1.   SCOPE

1.1.   This test method covers the determination of the electrical resistivity of concrete to provide a very rapid indication of its resistance to ionic transport (e.g., the penetration of chloride ions). This test method is applicable to types of concrete where correlations have been established between this test procedure and long-term durability performance.

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, if any, 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.   REFERENCED DOCUMENTS

2.1.   *AASHTO Standards*:
- R 39, Making and Curing Concrete Test Specimens in the Laboratory
- T 22, Compressive Strength of Cylindrical Concrete Specimens
- T 23, Making and Curing Concrete Test Specimens in the Field
- T 24M/T 24, Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

2.2.   *ASTM Standards*:
- C670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- C1202, Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration
- C1556, Standard Test Method for Determining the Apparent Chloride Diffusion Coefficient of Cementitious Mixtures by Bulk Diffusion

3.   TERMINOLOGY

Electrical resistivity: an intrinsic property that quantifies how strongly a material resists the flow of an electric current.

4. SUMMARY OF TEST METHOD

4.1.   This test method consists of measuring the electrical resistance/resistivity of 200-mm (8-in.) or 300-mm (12-in.) nominal length, and 100-mm (4-in.) or 150-mm (6-in.) nominal diameter cores or cylinders through the longitudinal axis of the geometry.

    Note 1: Alternative geometries can be used, with proper determination of the geometry factor.

4.2.   A set of stainless steel electrode plates is used as the electrodes, between which the test specimen is placed.

4.3.   An AC current is applied to the electrode plates, and the corresponding voltage is measured (Figure 1). From this, the resistance is determined and normalized by the ratio of cross-sectional area to the length, termed uniaxial resistivity. The resistivity is related to ionic transport.

4.4.   This method highlights how uniaxial resistivity can be determined using a commercially available Wenner probe array. This equipment consists of a four pin array of electrodes used in the measurement of surface resistivity. Current is passed between the outer probes, while potential is measured between the inside probes. The electronic display of these units most often directly calculates the apparent surface resistivity. In these cases, to compute uniaxial resistivity, an additional factor of $2\pi a$ is needed, where a represents the spacing of the probes. This is described in more detail in Section 12.

5. SIGNIFICANCE AND USE

5.1.   This test method covers the laboratory evaluation of the uniaxial electrical resistivity of concrete specimens to provide a very rapid indication of their resistance to ionic transport.

5.2.   The electrical resistivity of concrete is a material property that depends on the resistivity of the solution within the pores, the pore structure, and the degree of saturation.

5.3.   Research has shown a favorable correlation between resistivity and chloride exposure tests, such as ASTM C1556, on companion cylinders cast from the same concrete mixtures (Sections 16.2 and 16.3).

5.4.   Resistivity can be related to the formation factor and diffusion coefficient of chloride ions by the Nernst-Einstein equation (Section 16.4).

5.5.   This test method is suitable for evaluation of materials and mixture proportions for design purposes, quality control, and research and development.

5.6.   The numerical results (resistivity, in ohm·m) from this test method must be used with caution, especially in applications such as quality control and acceptance testing due to the influence of temperature, aging and degree of saturation.

    Note 2: Concrete specimens should only be compared when exposed to the same conditioning procedures (Section 16.11).

    Note 3: A relationship has been developed using Ohm's law for vacuum saturated specimens from the classification provided by ASTM C1202 and show good agreement with relationships provided in literature (Section 16.7).

Note 4: Specimen age may have significant effects on the test results, depending on the type of concrete and the curing procedure. Most concretes, if properly cured, become progressively and significantly less permeable (more resistive) with time.

5.7.   The details of the test method apply to 100-mm (4 in.) and 150-mm (6 in.) nominal diameter specimens. Other specimen diameters or geometries may be tested with appropriate changes in the geometry factor employed in the calculating equation. (See Reference 16.8.)
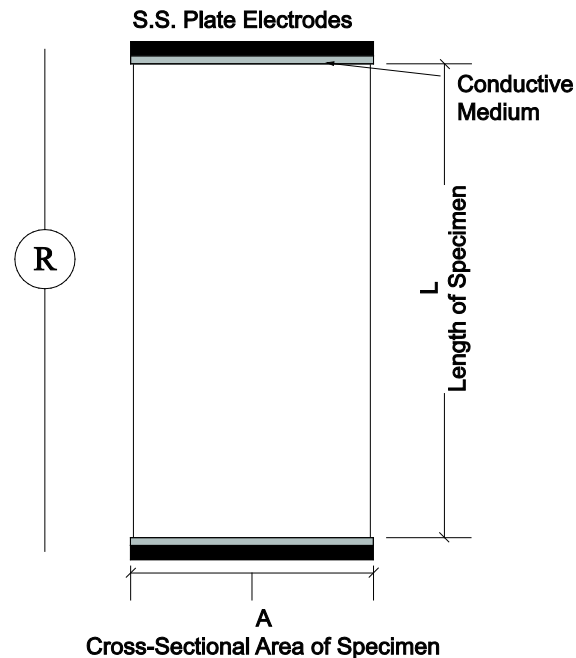
Figure 1—Uniaxial Electrical Test Setup

6.   INTERFERENCES

6.1.   This test method can produce misleading results when conductive admixtures (e.g., calcium nitrite) have been admixed into a concrete. The results from this test on some such concretes indicate lower resistivity values, that is, lower resistance to chloride ion penetration, than from tests on identical concrete mixtures (controls) without conductive admixtures.

Note 5—Other admixtures might affect results of this test similarly. Long-term diffusion tests are recommended if an admixture effect is suspected.

Note 6 - Alternatively, the pore solution can be accounted for using the formation factor described in AASHTO PP-84 using Task 1.2a.

6.2.   Since the test results are a function of the electrical resistance of the specimen, the presence of reinforcing steel or other embedded electrically conductive materials may have a significant effect. The test is not valid for specimens containing reinforcement or steel fibers.

6.3.   The curing condition is known to have a large impact on measured resistivity values. Lime water curing can significantly influence the resistivity of the solution inside the pores of the concrete. As

such, it is suggested the volume of solution surrounding the test specimens during curing be minimized and not to exceed a volumetric ratio of 3.0 (solution to specimen) (Section 16.9).

6.4.   The degree of saturation of the pores inside the test specimen is known to greatly influence the measured resistivity (Reference 16.13).

Note 7: Care should be exercised when conducting measurements on specimens with unknown moisture contents or histories.

Note 8: The storage of specimens under water in lime water curing does not guarantee that they achieve a saturated state (reference).

6.5.   The temperature of the test specimen significantly influences measurements of uniaxial resistivity. As the temperature of the specimen increases, the resistivity decreases; decreases in temperature produce an increase in resistivity. For a proper comparison, the specimens should always be tested and conditioned at standard temperatures, i.e., $23 \pm 2°C$. Temperature corrections for measurements outside this range are discussed in AASHTO Task 1.2c and in Section 16.12.
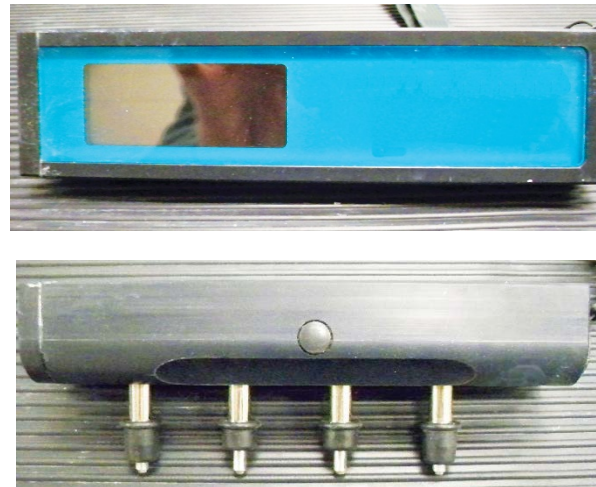
7.   APPARATUS

7.1.   *Resistivity Apparatus*—An alternating current resistivity meter shall be used. Common types are those used in the measurement of surface resistivity.

Note 9: Examples of typical testing apparati are shown in Figure 2.
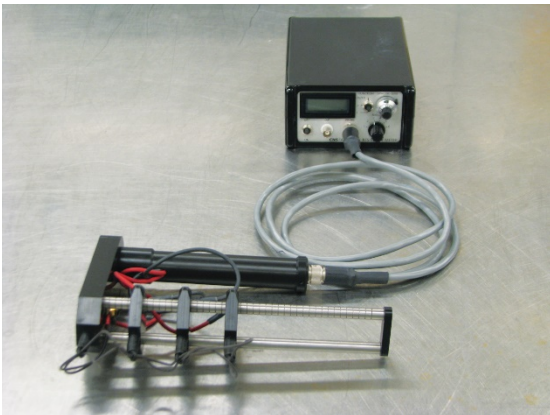
(a)   (b)

(c)   (d)

Figure 2—Examples of the Geometries of Resistivity Meters: (a) – (c)

7.2.   *Conductive Medium*—Good electrical contact shall be provided between the test specimen and the electrodes using a conductive medium with a maximum thickness of 6 mm. -The medium shall be, at minimum the size of the cross section of the test specimens.

           Note 10–Examples of Conductive media include paper towels saturated with lime water, conductive gel, and a set of sponges.

           Note 11: Typical sponge are 6 +/- 2 mm. These have been successfully used in practice (16.2).

           Note 12: The conductive media may introduce errors however this can be corrected as described in Section 12
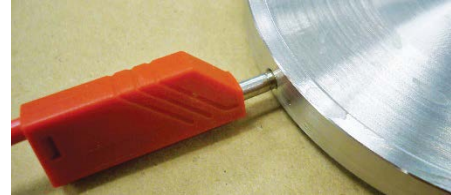
7.3.   *Stainless Steel Electrode Plates*—The stainless steel electrode plates shall be at least the size of the cross section of the test specimens. Thickness shall be 6 +/- 2 mm. The electrodes shall be connected to the resistivity test meter using conductive cables and connections.

(a)   (b)   (c)

Figure 3—Example of Connections to Stainless Steel Electrode plates: 1) a screw-eyelet connection, 2) an alligator clip connection, 3) a pin connection.

7.4.   *Cable*— the stainless steel electrode plates shall be connected to the resistivity meter. Use a minimum of 18 AWG stranded copper wire with two conductors (or equivalent). The cable shall be fixed on one end with the connections to the electrode plates and on the other end with connections to the resistivity meter.

7.5.   Calipers – capable of measuring the length to the nearest mm.

7.6.   Cloth or Absorbent Paper – for blotting water from the surface of the specimens.

7.7.   Non Conductive specimens support

7.8.   Thermometer capable of providing temperature measurements in the range of 0C to 60C with an accuracy of +/- 0.1C

7.9.   Verification component – A resistor of known resistance shall be used to verify the accuracy of the measurement device is within 5% of the known value.

           Note 13: Some prefer to use both a known resistor and capacitor as concrete has both a resistive and capacitive (16.14)

8.   REAGENTS AND MATERIALS

8.1.   Calcium Hydroxide (Ca(OH)$_2$)

8.2.   Sodium Hydroxide (NaOH)

8.3.   Potassium Hydroxide (KOH)

9.   TEST SPECIMENS

9.1.   A minimum of two replicate specimens shall be tested.

9.2.   Specimen preparation and selection depends on the purpose of the test (Note 14).

Note 14—The maximum allowable aggregate size has not been established for this test. Users have indicated that test repeatability is satisfactory on specimens from the same concrete batch for aggregates up to 37.0-mm (1.5-in.) nominal maximum size (Reference 16.9).

9.2.1.   For evaluation of materials or their proportions, specimens may be one of the following:

9.2.1.1.   Cores from test slabs;

9.2.1.2.   100-mm (4-in.) diameter cast cylinders; or

9.2.1.3.   150-mm (6-in.) diameter cast cylinders.

9.2.2.   For evaluation of cylinders, specimens may be one of the following:

9.2.2.1.   100-mm (4-in.) diameter cylinders cast and cured at the field site, or

9.2.2.2.   150-mm (6-in.) diameter cylinders cast and cured at the field site.

9.2.3.   Specimens cast in the laboratory shall be prepared following procedures in Section 10. (Note 15).

Note 15—This test method has been used with various curing durations and curing regimens to meet agency guidelines or specifications. Care should be exercised when comparing results obtained from specimens subjected to differing curing conditions.

9.2.4.   When specimens are cast in the field ends of the specimens shall be finished flat (As indicated in AASHTO T22).

9.3.   Transport the cores or field-cured cylinders to the laboratory in moist condition in sealed (tied) plastic bags. If specimens must be shipped, they should be packed with insulation to be properly protected from freezing and damage in transit or storage.

9.4.   Special processing is necessary for core specimens where the surface has been modified, for example by texturing or by applying curing compounds, sealers, or other surface treatments, and where the intent of the test is not to include the effect of the modifications. In those cases, the modified portion of the core shall be removed.

10.   CONDITIONING

10.1.   Specimens shall be conditioned using either Option A (Immersion in a calcium hydroxide saturated simulated pore solution), Option B (Sealed) or Option C (Vacuum saturation)

10.2.   Option A – Immersion of specimens in a calcium hydroxide saturated simulated pore solution.

10.2.1.   Immerse two 100-mm × 200-mm specimens in a single 5-gal bucket with sufficient calcium hydroxide saturated simulated solution to cover the specimens by 38 mm.

10.2.2.   The calcium hydroxide simulated pore solution shall consist of 7.6g/L NaOH (0.19M); 10.64g/L KOH (0.19M); 2g/L $Ca(OH)_2$.
Note 16: this can be made in a 5 gal bucket to provide 18.9 L of solution using 13250 g water, 102.6g NaOH, 143.90g KOH and 27g $Ca(OH)_2$.

10.2.3.   The sample shall be placed in the solution immediately after demolding.

10.2.4.   A minimum of 6 days in solution is required for a valid test.

10.3.   Option B – Sealed Sample

10.3.1.   Two 100-mm × 200-mm specimens shall be sealed from the time of casting.

10.3.2.   The samples can be sealed by maintaining them in the cylinder mold or demolding them and placing them in two 6 mil double sealed bags.

10.3.3.   The samples shall be weighted and the mass shall not vary by more than 0.05%.

10.4.   Option C – Vacuum Saturated

10.4.1.   The sample shall be oven dried at 105 +/- 5C for 24 hours

10.4.2.   The sample shall be vacuum saturated following the procedure described in Task 6a.

10.4.3.   Immediately after vacuum saturation, immerse specimens in lime saturated pore solution. The volume of solution surrounding the specimens shall range from two to three times the volume of the specimen.
Note 17: A lime saturated solution shall consist of atleast 2g/L $Ca(OH)_2$.

Note 18: The length of the sample can be varied and the geometry factor shall be adjusted.

10.5.   During specimen conditioning, maintain the temperature at $23 \pm 2°C$.

Note 19: Temperature corrections for measurements outside this range are discussed in AASHTO Task 1.2c (16.12)

10.6.   Alternative specimen curing regimes are allowed as approved by the sponsoring agency. Care shall be taken when comparing specimens subjected to different curing regimes. More information is available in Section 16.7.

10.7.   When using alternative curing regimes, specimens conditioning shall be carefully designed and maintained. The electrical resistivity obtained using alternative curing regimes shall be corrected for the degree of saturation (Section 16.13)

11. PROCEDURE

**11.1.** During testing the specimen temperature shall be maintained at $23 \pm 2°C$.

11.2. Testing shall be conducted on a nonconductive surface.

Note 20: This might include a rubber or plastic base or mat.

11.3. Before removing specimens from conditioning environment, connect the electrode plates, cables and meter.

11.3.1. If a surface resistivity meter is used, connect the two left two probe tips shall be connected to one electrode plate and the right two tips to the opposite electrode plate.

Note 21: An example of how to utilize a surface resistivity meter to perform the uniaxial test is depicted in Figure 4. Attach the probes properly to provide sufficient electrical contact shall be ensured. Examples of typical connections are provided in Figure 2.
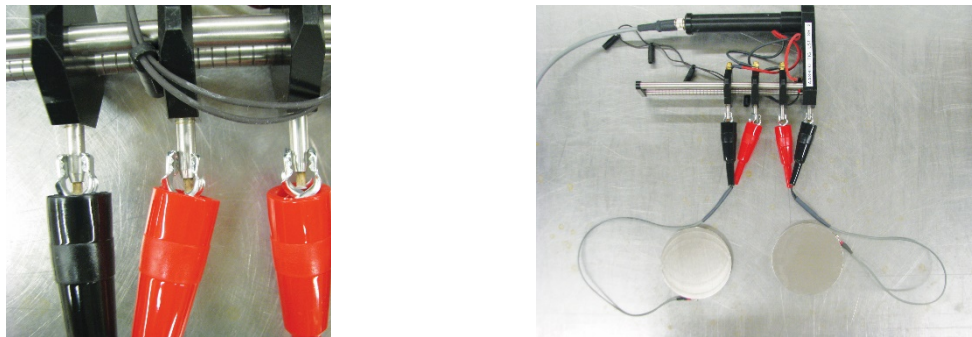
Figure 4—Connections of Electrode Plates to Probe Tips on a Wenner Surface Resistivity Meter

11.4. *Resistance of the Conductive Medium*:

11.4.1. Immerse sponges in the same solution that was used to used to store the tests specimens in section 10. For the samples that are sealed, the saturated lime solution can be used to condition the sponges. These sponges are the conductive medium.

11.4.2. The resistance of each of conductive medium (i.e., sponge) used on the top and bottom of the specimen shall be measured, as shown in Figure 5 for the correction described in section 11.5.

11.4.2.1. For the top sponge, the top electrode plate shall be placed as a weight as shown in Figure 5(a). The measurement provided is $R_{\text{top sponge}}$.

11.4.2.2. For the bottom sponge, the top electrode plate and the cylinder should be used to provide the weight as shown in Figure 5(b). The measurement provided is $R_{\text{bottom sponge}}$.

Note 22: The resistance of each individual sponge is largely dependent on its moisture content. The moisture content of the sponge is dependent on the weight placed on top it (e.g., large weights push more water from the sponge).

11.4.3. The sponges should be rewetted between tests.

Note 23: Many sponges show a constant resistance, so these can be measured periodically and their resistances can be assumed to remain unchanged between measurements.
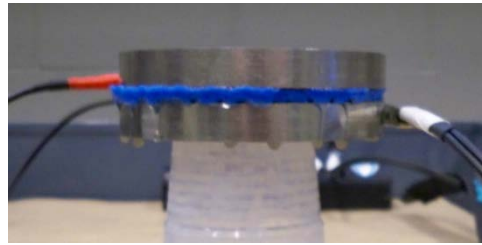
(a)   (b)

Figure 5—Measurement of the Resistance of the Conductive Medium on the Top (a) and Bottom (b)

11.5.	*Measurement of the Test Specimen*:

11.5.   *Measurement of the Test Specimen*:

11.5.1.   For curing conditions A and C.

11.5.1.1.   Remove one specimen at a time from the solution it is stored in.

11.5.1.2.   Blot off the excess water using a damp paper towel or cloth, and place the cylinder on top of the bottom electrode plate and bottom sponge.

11.5.1.3.   The top sponge and top electrode plate shall be set upon the top of the cylinder.

11.5.1.4.   Measure the resistance of the specimen, $R_{measured}$.

11.5.1.5.   A configuration of the test specimen is shown in Figure 6.

11.5.2.   For curing condition B.

11.5.2.1.   Remove one specimen at a time from the sealed container it is stored in.

11.5.2.2.   The top sponge and top electrode plate shall be set upon the top of the cylinder.

11.5.2.3.   Measure the resistance of the specimen, $R_{measured}$.

11.5.2.4.   A configuration of the test specimen is shown in Figure 6.

11.5.3.   After testing the resistance, measure the temperature of the test specimen to the nearest +/- 0.1C.

11.5.4.   Complete the measurements of each specimen within 2 minutes.

11.5.5.   Measure the diameter and the length of each specimen to the nearest +/- 1 mm.

11.5.6.   Repeat 11.5.1 through 11.5.5 for the remaining specimens.

Figure 6—Measurement of the Resistance of the Test Specimen

12.   CALCULATION AND INTERPRETATION OF RESULTS

12.1.   *Utilizing a Resistivity Meter*:

12.1.1.   Calculate the resistivity of each specimen.

12.1.2.   The measured resistance of each specimen, $R_{measured}$, shall be decreased by the sponge resistances, $R_{top\ sponge}$ and $R_{bottom\ sponge}$, shown in Equation 1.

$$R_{cylinder} = R_{measured} - R_{top\ sponge} - R_{bottom\ sponge} \qquad (1)$$

Where:

$R_{cylinder}$ = resistance of the specimen (ohms)

R~measured~ = measured resistance, including the resistance of the conductivity media (Ohms)

R ~bottom sponge~ = resistance of the conductive medium (bottom sponge) (Ohms)

R ~top sponge~ = resistance of the conductive medium (top sponge) (Ohms)

12.1.3. Calculate the electrical resistivity of the specimen according to equation 2:

$$\rho = R_{Cylinder}\left(\frac{A}{L}\right) \tag{2}$$

Where:

ρ = electrical resistivity of specimen (Ohm m)

R~cylinder~ = resistance of the specimen (ohm)

A = cross sectional area of specimen (m^2)

L = Length of specimen (m)

12.2. *Utilizing a Surface Resistivity Meter*:

12.2.1. If a surface resistivity meter is used to measure the resistivity determine whether the meter provides a direct measure of resistance or whether the meter displays the apparent surface resistivity. If resistance is measured directly proceed to section 12.3. If the apparent surface resistivity is measured the resistance needs to be determined using 12.2.2

12.2.2. Calculate the measured resistance from the apparent surface resistivity ($\rho_{apparent}$)

12.2.2.1. The apparent surface resistivity should be divided by $2\pi a$ as shown in equation 3.

$$R_{Measured} = \frac{\rho_{apparent}}{2\pi a} \tag{3}$$

Where

a is the probe tip spacing in units consistent with the units of the resistivity meter.

Note 25: For surface resistivity meters with a 38-mm probe spacing, considered standard for T 358, the value of $2\pi a$ is 24.

12.2.3. Calculate the resistivity of each specimen.

12.2.4. The measured resistance of each specimen, $R_{measured}$, shall be decreased by the sponge resistances, $R_{top\ sponge}$ and $R_{bottom\ sponge}$, shown in Equation 4.

$$R_{cylinder} = R_{measured} - R_{top\ sponge} - R_{bottom\ sponge} \tag{4}$$

Where:

R~cylinder~ = resistance of the specimen (ohms)

R~measured~ = measured resistance, including the resistance of the conductivity media (Ohms)

R ~bottom sponge~ = resistance of the conductive medium (bottom sponge) (Ohms)

R ~top sponge~ = resistance of the conductive medium (top sponge) (Ohms)

12.2.5. Calculate the electrical resistivity of the specimen according to equation 5:

$$\rho = R_{Cylinder} \left(\frac{A}{L}\right) \qquad\qquad (5)$$

Where:

ρ = electrical resistivity of specimen (Ohm m)

$R_{cylinder}$ = resistance of the specimen (ohm)

A = cross sectional area of specimen (m^2)

L = Length of specimen (m)

13. REPORT

13.1.   *Report the following if known*:

13.1.1.   Source of core or cast cylinder, in terms of the particular location the core or cylinder represents;

13.1.2.   Identification number of core or cylinder;

13.1.3.   Type of concrete, including binder type, water-cement ratio, and other relevant data supplied with specimens;

13.1.4.   Curing history of specimen;

13.1.5.   Conditioning of the specimen as described in section 10;

13.1.6.   Unusual specimen preparation, such as, removal of surface treatment or any alternative conditioning

13.1.7.   Temperature of the specimen at time of testing to the nearest +/- 0.1C;

13.1.8.   Diameter and length of each specimen to the nearest +/- 1 mm.

13.1.9.   Test results, reported as the resistivity of each individual specimen and the average of the replicates; and

14. PRECISION AND BIAS

14.1.   *Precision*:

14.1.1.   *Single-Operator Precision*—The single-operator coefficient of variation of a single test result has been found to be 4.4 percent (Reference 16.10). Therefore, the results of two properly conducted tests by the same operator on the same concrete material at the same age are not expected to differ by more than 12.3 percent of their average (note 26).

Note 26: A test result is a test determination on a single replicate specimen.

14.1.2.   *Multi-laboratory Precision*—The multi-laboratory coefficient of variation was found to be 13.2 percent the same concrete material at the same age are not expected to differ by more than 37.4 percent of their average.

Note 27: These numbers represent, respectively, the (1s percent) and (d2s percent) limits as described in ASTM C670. The precision statements are based on the variations in tests on twelve different concretes, each tested in ten laboratories. The nominal specimen geometries were 100-mm × 200-mm test cylinders (Section 16.10).

The percentage cited represents the (d2s percent) limit based on the value for the multi-laboratory coefficient of variation.

14.2.   *Bias*—The procedure of this test method for measuring the resistance of concrete to chloride ion penetration has no bias because the value of this resistance can be defined only in terms of a test method.

15.   KEYWORDS

15.1.   Chloride penetration; concrete; electrical properties; microstructure characterization; resistivity; uniaxial resistivity.

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[1] This provisional standard was first published in 2015.