
Standard Method of Test for Electrical Resistivity of a Concrete Cylinder Tested in a Uniaxial Resistance Test

AASHTO Designation: T 402-23¹

Adopted without Revisions: 2023

Technical Subcommittee: 3c, Hardened Concrete



**American Association of State Highway and Transportation Officials
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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 ionic transport (e.g., the penetration of chloride ions).
- 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.*
- 1.4. *The quality of the results produced by this standard are dependent on the competence of the personnel performing the procedure and the capability, calibration, and maintenance of the equipment used. Agencies that meet the criteria of R 18 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with R 18 alone does not completely assure reliable results. Reliable results depend on many factors; following the suggestions of R 18 or some similar acceptable guideline provides a means of evaluating and controlling some of those factors.*

2. REFERENCED DOCUMENTS

- 2.1. *AASHTO Standards:*
 - R 18, Establishing and Implementing a Quality Management System for Construction Materials Testing Laboratories
 - R 39M/R 39, Making and Curing Concrete Test Specimens in the Laboratory
 - R 101, Developing Performance Engineered Concrete Pavement Mixtures
 - T 24M/T 24, Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
 - T 277, Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration
 - TP 135, Determining the Total Pore Volume in Hardened Concrete Using Vacuum Saturation
- 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

2.3.

Other Documents:

- Castro, J., R. Spragg, P. Kompare, and W. J. Weiss. *Portland Cement Concrete Pavement Permeability Performance*, FHWA/IN/JTRP-2010/29. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, IN, 2010.
- Chini, A. R., L. C. Muszynski, and J. Hicks, *Determination of Acceptance Permeability Characteristics for Performance-Related Specifications for Portland Cement Concrete*. Final Report (Contract No. BC 354-41) submitted to Florida Department of Transportation, Tallahassee, FL, July 2003.
- Coyle, A., R. Spragg, P. Suraneni, A. Amirkhanian, and W. J. Weiss. Comparison of Linear Temperature Corrections and Activation Energy Temperature Corrections for Electrical Resistivity Measurements of Concrete. *Advances in Civil Engineering Materials*, Vol. 7, No. 1, 2018, pp. 174–187. Available from doi.org/10.1520/ACEM20170135
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- Newlands, M., R. Jones, S. Kandasami, and T. Harrison. “Sensitivity of Electrode Contact Solutions and Contact Pressure in Assessing Electrical Resistivity of Concrete.” In *Materials and Structures*, Vol. 41, No. 4. International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM), Bagneux, France, 2007, pp. 621–632.
- Snyder, K. A. “The Relationship between the Formation Factor and the Diffusion Coefficient of Porous Materials Saturated with Concentrated Electrolytes: Theoretical and Experimental Considerations.” In *Concrete Science and Engineering*, Vol. 3, No. 12. International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM), Bagneux, France, 2001, pp. 216–224.
- Spragg, R. Development of Concrete Performance Specifications that Include Formation Factor. Purdue University Ph.D. Dissertation, 2017.
- Spragg, R. P., Y. Bu, and W. J. Weiss. *Electrical Testing of Cement Based Materials: Role of Testing Techniques, Sample Conditioning, and Accelerated Curing*. Final Report (Contracts SPR-3509 and SPR-3657) submitted to the Indiana Department of Transportation, Indianapolis, IN, July 2013.
- Spragg, R. P., J. Castro, T. E. Nantung, M. A. Paredes, and W. J. Weiss. Variability Analysis of the Uniaxial Resistivity Measured Using Concrete Cylinders. *Advances in Civil Engineering Materials*, Vol. 1, No. 1. ASTM International, West Conshohocken, PA, 2012.
- Spragg, R. P., S. Jones, Y. Bu, Y. Lu, D. P. Bentz, K. A. Snyder, and W. J. Weiss. Leaching of Conductive Species: Implications to Measurements of Electrical Resistivity. *Cement and Concrete Composites*, Vol. 79, February 2017. Available from doi.org/10.1016/j.cemconcomp.2017.02.003
- Spragg, R. P., C. Villani, K. Snyder, D. P. Bentz, J. W. Bullard, and W. J. Weiss. Factors that Influence Electrical Resistivity Measurements in Cementitious Systems. In *Transportation Research Record 2342*, Transportation Research Board, National Research Council, Washington, D.C., 2013, pp. 90–98. Available from doi.org/10.3141/2342-11
- Weiss, W. J., T. J. Barrett, C. Qiao, and H. Todak. Toward a Specification for Transport Properties of Concrete Based on the Formation Factor of a Sealed Specimen. *Advances in Civil Engineering Materials*, Vol. 5, No. 1, 2016, pp. 179–194. Available from doi.org/10.1520/ACEM20160004
- Weiss, W. J., K. Snyder, J. W. Bullard, and D. P. Bentz. Using a Saturation Function to Interpret the Electrical Properties of Partially Saturated Concrete. *Journal of Materials in*

3. TERMINOLOGY

3.1. Definitions:

- 3.1.1. *apparent surface resistivity*—a value correlated to surface resistivity that is dependent on the specimen size and geometry of the testing configuration. Apparent surface resistivity does not account for the effect of the finite size of the specimen with respect to the probe spacing.
- 3.1.1.1. *Discussion*—On many commercial units, the apparent surface resistivity is automatically calculated and displayed on the screen, but they offer no indication that this correction is applied nor is it often clearly identified that the value displayed is apparent surface resistivity.
- 3.1.2. *electrical resistance*—the measure of the opposition to the flow of electric current, which is dependent of the size and shape of the specimen and the geometry of how it is measured.
- 3.1.2.1. *Discussion*—Some suppliers of testing units will utilize the term *impedance* instead of *resistance*. Impedance is analogous to resistance and, for most moist-cured concretes, the terms are considered equivalent.
- 3.1.3. *electrical resistivity*—an intrinsic property that quantifies how strongly a material resists the flow of an electric current.
- 3.1.4. *geometric correction*—corrections to measured values to determine intrinsic material properties. The corrections are typically a function of electrode configuration, specimen size, and specimen shape.
- 3.1.5. *surface resistivity*—the electrical resistivity when tested on the surface of a specimen, most often on the circumference of cast or cored cylinder. It requires the application of a unitless geometric correction to the apparent surface resistivity to account for the non-infinite geometry. Surface resistivity is analogous to a material's electrical resistivity, with *surface* indicating that it was measured using a surface test.
- 3.1.6. *uniaxial resistivity or bulk resistivity*—the electrical resistivity when tested along the longest axis of a specimen with uniform cross-section (e.g., prism or cylinder). It requires the application of a geometric correction to the measured resistance. Uniaxial resistivity is analogous to a material's electrical resistivity, with *uniaxial* indicating it was measured using a uniaxial test. The two terms (uniaxial resistivity or bulk resistivity) can be used interchangeably.
- 3.1.7. *Wenner array probe*—an equally spaced, four-probe device that applies an alternating current between the outer probes and measures the voltage between the inner probes. The ratio of voltage and current is multiplied by a factor of $2\pi a$, where a is the spacing between the probes, to determine the apparent surface resistivity.
- 3.1.7.1. *Discussion*—The Wenner probe was originally developed for an infinite half-space geometry.
- 3.2. *Units and Unit Conversions:*
- 3.2.1. Resistance is measured in units of ohms (Ω), with the use of SI prefixes.

- 3.2.2. Resistivity is measured in units of ohm meter ($\Omega\cdot\text{m}$), with SI prefixes often being used. Another common unit of resistivity is kilohm centimeter ($\text{k}\Omega\cdot\text{cm}$), and has a conversion of $10\Omega\cdot\text{m} = 1\text{k}\Omega\cdot\text{cm}$.
- 3.2.2.1. *Discussion*—Both *apparent surface resistivity* and *surface resistivity* are measured in units of ohm meter, which complicates properly differentiating between these two types of measurements.

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 parallel to its longitudinal axis of the geometry (also referred to as bulk resistivity).
Note 1—Alternative geometries can be used, and the appropriate geometry factor should be used to convert measured resistance to uniaxial resistivity.
- 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 also describes an alternate method to determine the uniaxial resistivity 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 chloride ion penetration.
- 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 rate of chloride ingress tests, such as ASTM C1556, on companion cylinders cast from the same concrete mixtures (Castro et al., 2010; Chini et al., 2003).
- 5.4. Resistivity can be related to the formation factor and diffusion coefficient of chloride ions by the Nernst-Einstein equation (Hamilton et al., 2007).
- 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 $\text{ohm}\cdot\text{m}$) from this test method must be evaluated 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—The resistivity of concrete specimens should be compared only when subjected to the same conditioning procedures (Spragg, Villani et al., 2013).

Note 3—A relationship has been developed using Ohm's law for vacuum-saturated specimens from the results determined according to T 277, and it shows good agreement with relationships provided in the literature (Newlands et al., 2007).

Note 4—Specimen age may have significant effects on the test results, depending on the type of concrete and the curing and conditioning procedures. 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 (Spragg et al., 2013).

5.8. Other factors that are known to affect resistivity as well as chloride ion penetration include water/cement ratio, use of pozzolans or slag cement, the presence of polymeric admixtures, air-void system, aggregate type and degree of consolidation, paste volume, curing time, and curing method.

Note 5—Preliminary results indicate exposing concretes to extremely low temperatures at early ages (between casting and demolding) can significantly reduce resistivity values measured at later ages.

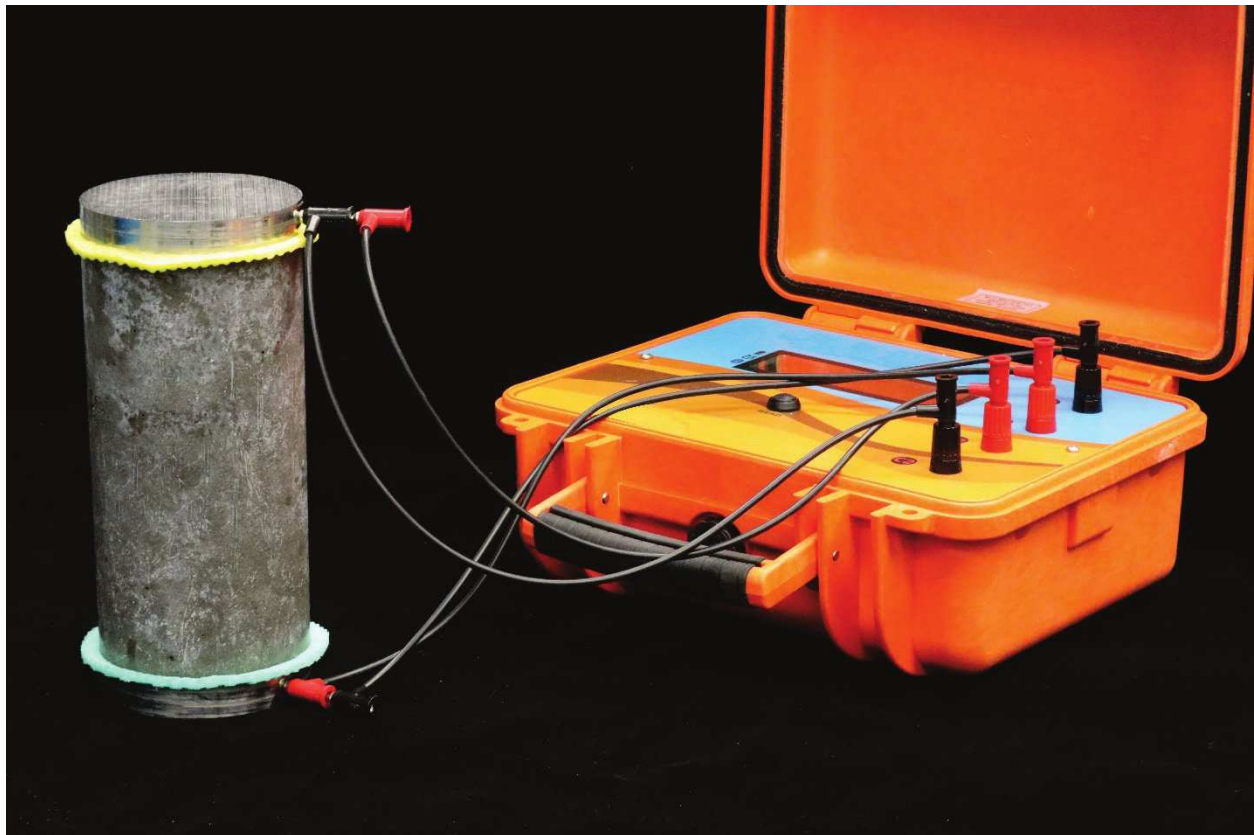


Figure 1—Test Setup for Determination of Uniaxial Resistivity

6. INTERFERENCES

6.1. This test method may produce misleading results when conductive admixtures (e.g., calcium nitrite) have been used in concrete mixtures. The results from this test on some such concretes indicate lower resistivity values, that is, lower resistance to chloride ion penetration, than from