
Standard Method of Test for

Determining In-Place Density and Moisture Content of Soil and Soil-Aggregate Using Complex Impedance Methodology

AASHTO Designation: T 399-22¹

Adopted: 2022

Technical Subcommittee: 1b, Geotechnical Exploration, Instrumentation, Stabilization, and Field Testing



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1. SCOPE

- 1.1. This practice describes the procedures for determining the density and moisture content of aggregate and soil–aggregate. The practice allows for electromagnetic testing of porous construction materials in the laboratory that is used to calibrate the apparatus to these specific porous construction materials. With such calibration, the field apparatus can then be used on the construction site to test the density and moisture of the porous construction materials without the need for field calibration using a complex impedance measuring instrument (CIMI). The CIMI measures the electrical properties of the material being tested and correlates the electrical properties to the physical properties during a laboratory or field material calibration procedure. The electrical properties are typically unique for the material. During the material calibration procedure, empirically derived correlations relate the electrical and physical properties of the material using the correlation mathematics. The subsequent electrical testing of the material utilizes the established relationship of the electrical and physical characteristics to calculate the material density and moisture content. The CIMI is composed of solid state electronics that are calibrated at the time of manufacturing and no additional instrument is thereafter required.
- 1.2. *Density*—The total or wet density of aggregate and soil–aggregate mixtures is determined by applying a known frequency of alternating current and measuring it through the material. The complex impedance is calculated based on the measurements and relationships previously established with a known material model.
- 1.2.1. The density in mass per unit volume is determined by comparison of the readings calculated and the calibration with a representative material model over a range of known densities.
- 1.3. *Moisture*—The moisture content of the aggregate and soil–aggregate mixtures is determined by applying a known frequency of alternating current and measuring it through the material. The complex impedance is calculated based on the measurements and relationships previously established with a known material model.
- 1.3.1. The moisture content in mass per unit volume is determined by comparison of the readings calculated and the calibration with a representative model of known moisture content.
- 1.4. *SI Units*—The values stated in SI units are to be regarded as the standard. The inch-pound equivalents may be approximate. It is common practice in the engineering profession to

concurrently use pounds to represent both a unit of mass (lbm) and of force (lbf). This implicitly combines two systems of units, that is, the absolute system and the gravitational system.

- 1.5. This standard has been written using the absolute system for water content (kg/m^3) in SI units. Conversion to the gravitational system of weight in lb/ft^3 is scientifically incorrect; however, the gravitational system should not be regarded as nonconformance with the standard.
- 1.6. In the English system, the pound (lbf) represents a unit of force (weight). However, the use of balances or scales recording pounds of mass (lbm), or recording of density (lbm/ft^3) should not be regarded as nonconformance with this standard.
- 1.7. *This procedure does not purport to exhaustively address safety concerns 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. See Section 6 for Hazards.*
- 1.8. *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
 - T 99, Moisture–Density Relations of Soils using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop
 - T 180, Moisture–Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop

3. SIGNIFICANCE AND USE

- 3.1. The method is a rapid, nondestructive technique for determining the in-place density and moisture content of soil and soil aggregate based on electrical measurements.
- 3.2. The test method may be used for quality control and acceptance testing of compacted soil and soil–aggregate mixtures for construction, as well as for research and development projects. The nondestructive nature of the test method allows repetitive measurements at a single test location and statistical analysis of the results.
- 3.3. It is difficult to address an infinite variety of aggregate in this standard. This test method does not address the various types of soils and soil–aggregate on which the CIMI method may or may not be applicable, such as very high salinity materials or materials with high metallic contents like iron tailings.
- 3.4. The procedures used to specify how data are collected, recorded, or calculated in this standard are regarded as the industry standard. In addition they are representative of the significant digits that generally should be retained.

4. INTERFERENCES

- 4.1. Variations in the test material with electrical impedance properties significantly different from construction soils and aggregate evaluated during model development, such as metal objects or organic material, may affect the accuracy of the test method.
- 4.2. Incorrect density measurements may occur when air voids that comprise a large volume relative to the total volume of material are present. If the volume of material being tested in the field includes oversize particles or large voids, these irregularities may cause errors in measurements of electrical properties. Where lack of uniformity in the material due to layering, aggregate, or voids is suspected, the test site should be excavated and visually examined to determine if the test material is representative of the in-place material in general and if an oversize correction is required. For the most accurate results, materials should be homogeneous and practically free of rocks that are more than 5 cm (2 in.) in diameter and construction debris. Technicians performing tests with the CIMI shall review the material specification for the project and when possible shall look at the source material being used for the compacted fill.
- 4.3. Statistical variance may increase for material that is significantly drier or wetter than optimum moisture content (2.5 percent over optimum or 6.0 percent below optimum) as determined using T 99 or T 180. Based on experience, statistical variance may increase for material that is compacted to less than 88 percent of the maximum dry density as determined using T 99 or T 180. The CIMI is generally more accurate when the material model range is broader than the range of density and moisture content being tested in the field.
- 4.4. All electrical values are equilibrated to 15.55°C (60°F). Temperature differences between the in-place material being measured and the model may introduce an error. Therefore, the temperature is measured with a material temperature probe for the model calibration and actual material testing and the electrical material signals are corrected by a temperature compensation algorithm. The equilibration is necessary because the material temperature affects the electrical signals that are measured. The material temperature is measured with a commercial thermistor that is supplied with the CIMI.
- 4.5. The electrical properties of material change considerably as the material temperature approaches the freezing point of the entrained water; therefore, this test method only applies to aggregate and to soil–aggregate that is not frozen.

5. APPARATUS

- 5.1. *Complex Impedance Measuring Instrument*—Although exact details of construction of the apparatus and the electric circuits therein may vary, the system shall consist of the following:
- 5.1.1. *Laboratory Material Sensor Unit and Field Sensor Unit*—Battery-powered electrical data collection sensors that are programmed for use for the collection of electrical data during laboratory and field procedures, which are wirelessly linked to computers for the data storage and analysis. The laboratory sensor is used to collect electrical data during a proctor test. It correlates the electrical properties of the material being tested to the material density and moisture content. The field sensor is used to measure the electrical properties of the in-situ compacted material base and calculate the material field density and moisture content.
- 5.1.2. *Radio Frequency Source*—The frequency source is applied to the material under test through either laboratory or field electrodes. The radio frequency current that passes through the electrodes into the material in the laboratory is used to establish a correlation between the electrical properties and physical properties of the material under test.