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Testing of hardened concrete - Determination of electrical resistivity

Prüfung von Festbeton - Teil 19: Bestimmung des elektrischen Widerstands

Essais pour béton durci - Détermination de la résistivité électrique

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Prüfung von Festbeton - Teil 19: Bestimmung des elektrischen Widerstands

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EUROPEAN COMMITTEE FOR STANDARDIZATION
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European foreword

This document (EN 12390-19:2023) has been prepared by Technical Committee CEN/TC 104 “Concrete and related products”, Subcommittee SC1 “Concrete - Specification, performance, production and conformity”, the secretariat of which is held by SN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by August 2023, and conflicting national standards shall be withdrawn at the latest by August 2023.

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Introduction

This test method is one of a series concerned with testing hardened concrete.

This document is based on current national standards and in particular the Spanish standard UNE PNE 83988 Part 1 and Part 2.

Resistivity is a property that quantifies how strongly a given material opposes the flow of electric current. Resistivity is the electrical resistance of a unit volume (e.g. 1 m^3) of a concrete. It is the inverse of conductivity, and it is obtained from the ratio between the voltage drop and the current (Ohm's law).

The resistivity of a water-saturated concrete is mainly a function of the pore size distribution and the connectivity/tortuosity of the pore system. It also depends on the pore solution composition, which is strongly affected by the cement type, additions, w/c ratio, aggregate type and the degree of hydration of the cement.

Resistivity is also dependent on temperature and for quality control testing, the temperature of the concrete specimens should be held within a defined range for comparable results.

The document is applied to water saturated concretes because the resistivity is affected by the degree of water saturation. A reduction in the moisture content increases the resistivity. Loss of continuity of the pore system by drying can have more impact on the resistivity value than a change in the volume of capillary porosity because drying can produce changes of more than one order of magnitude while a change in capillary porosity can be reflected in changes of two or three times.

In this document a 4-electrode arrangement is recommended as it avoids the voltage drop produced by the concrete/electrode interfacial resistance. This interfacial resistance can appear when using only two electrodes placed on parallel faces of the specimen, electrodes which apply the current and measure the voltage at the same geometrical point. If two electrodes are used, calibration is recommended with the 4 electrodes arrangement described in this document.

The measured resistivity is also affected by the electrical frequency of testing ([1], [2], [3], [4]) and so the measured resistivity could be increased by reducing the electrical frequency. In addition, for the same electrical frequency, the measured resistivity is dependent on the specific pattern of the electrical field across the specimen. Notwithstanding these differences, where the electrical resistivity is determined in the same conditions, in a frequency range where the electrode polarization phenomena are independent of its variation, changes in resistivity reflect changes occurring in the concrete.

An electrically conductive or porous aggregate also influences the magnitude of concrete resistivity. This should be considered when establishing threshold values as it prevents a comparison of resistivity values between concretes if the aggregates show a difference of half an order of magnitude (higher or lower) of resistivity. The same effect of decreasing the measured resistivity is produced when metallic or electricity conducting fibres or particles, are present.

1 Scope

This document describes two methods for measuring the electrical resistivity of concrete in water saturated conditions: the volumetric method (see 3.1.3), which is the reference method, and the surface method (see 3.1.4). The document gives the procedure to calibrate the surface method by means of the reference-volumetric method. Both methods give the same resistivity result, provided the provisions of the present document (using the Form Factor (F_f) for equivalence between them) are followed.

NOTE The volumetric method is applicable to cast specimens or cores, while the surface method is suitable for use on cast specimens, cores and on construction sites, but not all of these applications are covered in this document.

The method can be applied to the normal range of concretes covered by current standards. It does not cover concretes containing metallic components or made with porous aggregates.

The use of resistivity to assess the potential for corrosion of reinforcement in existing structures is not specified in this document.

The use of resistivity to test cores taken from an existing structure, which require pre-conditioning by water saturation, is not covered in this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 12390-2, *Testing hardened concrete - Part 2: Making and curing specimens for strength tests*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— IEC Electropedia: available at https://www.electropedia.org/

— ISO Online browsing platform: available at https://www.iso.org/obp/ui

3.1.1
electrical resistance
$\boldsymbol{R_e}$
voltage drop divided by current (in Ohm)

$$R_e = \frac{U}{I} \quad (1)$$

where

U is the difference in voltage drop before and after the application of the current between the voltage electrode; and

I is current circulating through the current electrodes

3.1.2
resistivity of a concrete
ρ
material parameter independent of the geometry of the specimen which indicates the resistance of the material to the circulation of an electrical current (in Ohm· m)

$$\rho = R_e \times A / l \qquad (2)$$

Note 1 to entry: It is the proportionality constant between electrical resistance and geometry of the specimen. Assuming a regular geometry of a cube the resistivity is equal to the electrical resistance multiplied by the cross-section area (A) and divided by the width of the cube (l).

Note 2 to entry: Some commercial equipment expresses the resistivity in alternative units, e.g. kOhm·cm. The conversion between Ohm·m and kOhm·cm is: 1 Ohm·m = 0,1 kOhm·cm.

3.1.3
volumetric resistivity
ρ_V
resistivity when the electrodes for applying the current are placed on the top and bottom of a cylindrical, cubic or prismatic specimen and cover all these top and bottom surfaces

$$\rho_v = R_e \times F_{gv} = R_e \times \frac{\text{Cross} - \text{sectional area}}{\text{Distance between voltage electrodes}} \qquad (3)$$

Note 1 to entry: Its value results from multiplying the measured resistance R_e by the volumetric geometrical factor F_{gv}. The volumetric resistivity is taken as the reference value for the resistivity of a concrete.

Note 2 to entry: The volumetric geometrical factor F_{gv} is equal to the relation A/l in Formula (2). The voltage electrodes are the clamps as shown in Figure 2.

3.1.4
surface resistivity-infinite medium
$\rho_{s,inf}$
resistivity value obtained when four equally spaced electrodes of cylindrical shape are placed on the specimen surface

$$\rho_{s,inf} = R_e \times F_{gs} = R_e \times 2 \times \pi \times d \qquad (4)$$

Note 1 to entry: Its value results from multiplying the measured resistance by the surface geometrical factor F_{gs}, which is equal to 2π multiplied by the distance (d) between each of the four equally spaced electrodes.

Note 2 to entry: This is the electrical resistivity known as Wenner method for a quasi-infinite medium.

3.1.5
surface resistivity-finite medium
ρ_s
resistivity when four equally spaced electrodes are placed aligned on the specimen surface and the obtained value is multiplied by a form factor, F_f that depends on the geometry and size of the specimen and is required to equal the volumetric resistivity to the surface resistivity

$$\rho_s = \rho_{s,inf} \times F_f = \rho_v \qquad (5)$$

3.1.6
volumetric geometrical factor
$\mathbf{F_{gv}}$
in the volumetric method, relationship between the measured electrical resistance and the resistivity

Note 1 to entry: This factor is the cross-sectional area of the test specimen (*A*) divided by the distance between voltage electrodes (*d*):

$$F_{gv} = \frac{Cross - sectional\ area}{Distance\ between\ voltage\ electrodes} \tag{6}$$

3.1.7
surface geometrical factor
$\mathbf{F_{gs}}$
in an infinite medium using the four equally aligned electrodes arrangement, this factor is 2π times the distance, *d* between the electrodes (see Formula (4))

$$F_{gs} = 2 \cdot \pi \cdot d \tag{7}$$

3.1.8
form factor
$\mathbf{F_f}$
in the surface method, factor that equals the volumetric resistivity and the surface resistivity as indicated by Formula (8)

$$F_f = \frac{\rho_s}{\rho_{s,inf}} \tag{8}$$

3.2 Symbols

For the purposes of this document, the following symbols apply:

A	In the volumetric method, the cross-sectional area of the test specimen [m^2]
d	In the volumetric method, the distance between the voltage electrodes (see Figure 2); in the surface method, the centreline to centreline distance between each of the four electrodes (see Figure 3) [m]
I	Current flowing in the concrete specimen introduced by the outer pair of current electrodes [A]
U	Difference in potential drop before and after the application of the current between the inner pair of voltage electrodes [V]

4 Principle

In the volumetric method (Formulae (1) and (3)), the electrical resistance of a concrete cylinder, prism or cube is measured by passing a current of known magnitude (*I*) through the whole volume of the water-saturated specimen and measuring the resulting voltage drop (*U*) over the central part of the specimen. This procedure of placing the voltage electrodes in the central part of the specimen avoids the possible nonlinear ohmic-drop at the concrete/electrode interface.

In the surface method (Formulae (4) and (5)), the determination of concrete resistivity is by means of the application of a current between the two outer electrodes and the measurement of the difference in voltage drop between the two inner electrodes located in between and aligned with the outer two electrodes. All the four electrodes are placed on the surface of the cylinder, prism or cube. The measurement provides the concrete electrical resistance (R_e) with that arrangement of electrodes. Knowing the distance between electrodes and the dimensions of the specimen, the surface geometrical and form factors are applied to calculate the resistivity. Then, the surface resistivity is obtained by multiplying the 4-electrode resistivity by the form factor (see Formula (5) and Table 2 where the form factor is given as a function of the geometry of the specimen). Thanks to this form factor, the same resistivity value is obtained between the surface method and the volumetric (reference) method.

5 Apparatus

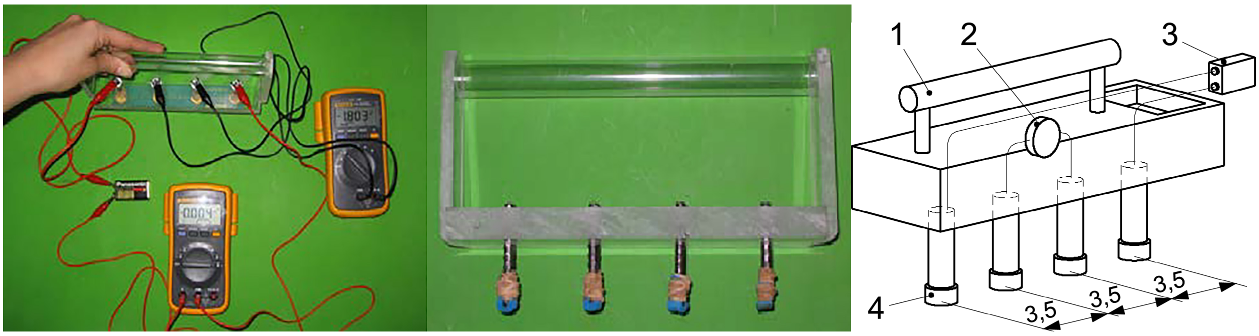
5.1 Resistivity meter

Resistivity meter or convenient voltage sources and multi-meters for measuring the voltage drop and current between the electrodes shall be used. If the equipment applies alternating current (AC) its frequency should be between 40 Hz and 10 000 Hz. If a direct current (DC) is applied, the measurement should be as short as possible and equipment should show/record results at least every second. The measurement is taken between 2 s and 5 s when a stable enough value is measured. Figure 1 shows an example of arrangement of hand-made resistivimeter based on a battery and two multimeters, in addition to the four points probe.

The resistivity meter shall be calibrated before each set of measurements or with the frequency deduced from its use. This calibration can be made through the measurement of good quality electrical resistors or a “dummy cell” of known resistance, as provided by some manufacturers. The resistors should be at least of 103, 104 and 105 ohms, in order to cover the range of possible values in the concrete. For the calibration, the measurement is made as a “two-electrode” system, provided that the resistors have only two terminals, by plugging one current and voltage terminal to one connection of the resistor and the other current and voltage terminals to the other side of the resistor. The offset with respect to the value of the resistor should be taken into account when measuring on concrete by correcting the values by that offset. The “dummy cells” provided by the manufacturer are made to directly insert the resitivimeter terminals.

NOTE 1 The use of DC current is only feasible if the measurement is lasting very short time, to avoid polarization of the electrodes. In the DC measurements the typical minimum applied voltage is of ≥ 4,5 V.

NOTE 2 The conversion from the time domain (DC measurement) to the frequency domain (AC measurement) is not straightforward, which prevents the calculation of the equivalent frequency from the waiting time, unless the amplitude of the AC signal or the voltage applied is known. The equivalence of DC resistivity values to the AC ones is based in empiric correlations.



Key

1 bracelet

2 voltage

3 battery (applying current through the external electrodes) ≥4,5 V

4 sponges

NOTE The left-hand side figure shows a hand-made resistivimeter with two multimeters and one battery. The central figure shows the probe with small sponges inserted in the bottom of the electrodes and fixed with an elastic rubber. The right-hand side figure shows the connections.

Figure 1 — Hand-made resistivimeter

5.2 Data logger

A data logger can be used for the simultaneous recording of voltage drop and current. It is optional but recommended.

NOTE Commercial equipment is available that fulfils the requirements in 5.1 and 5.2.

5.3 Electrodes

Electrodes of stainless steel or copper free from surface impurities (e.g. rust, other oxides) shall be used. For the volumetric method, they shall be a mesh or plain sheet with dimensions equal or larger in size/diameter to that of the contact faces of the specimens, i.e. for a 150 mm diameter cylinder, the electrode shall have a diameter of ≥ 150 mm. For the voltage drop measurement in the volumetric method, two stainless steel clamps of around 1 cm wide or copper wires with a diameter of 1 mm to 2 mm shall be placed to ensure good electrical contact with the concrete surface. If a 4-electrodes-type probe is to be used for measuring the resistivity, the volumetric method requires 4 cables with the corresponding plugs to connect the 4 electrodes of the probe to the two current and two voltage electrodes.

For the surface method the four electrodes shall be round bars of diameter in the range 4 mm to 10 mm made of stainless steel, carbon steel, copper or any other conducting metal free from surface impurities (e.g. rust, other oxides) and embedded in a non-conducting rigid framework at a centreline to centreline spacing in the range 35 mm to 50 mm.

The width/diameter of the specimen in the volumetric method and the distance between the current electrodes shall be at least 2,5 times the maximum aggregate size.

5.4 Sponges

Sponges (or equivalent concrete-contacting material such as some porous polymers), four synthetic sponges or equivalent conductors that cover the tips of the four electrodes in the surface method shall be used. In the volumetric method, two thin synthetic sponges with an identical area to that of the electrodes shall be used.