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Testing of hardened concrete — Determination of electrical resistivity

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National foreword

This British Standard is the UK implementation of EN 12390-19:2023.

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Contents

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of an identical text or by endorsement, at the latest by August 2023, and conflicting national standards shall be withdrawn at the latest by August 2023.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)

$$\rho = R_e \times A / l \tag{2}$$

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
$\boldsymbol{\rho_v}$
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

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

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

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

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
$\boldsymbol{\rho_s}$
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

$$\rho_s = \rho_{s,inf} \times F_f = \rho_v \tag{5}$$

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):

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

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))

$$F_{gs} = 2 \cdot \pi \cdot d \quad (7)$$

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)

$$F_f = \frac{\rho_s}{\rho_{s,inf}} \quad (8)$$

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.

5.5 Wetting liquid at the sponge/concrete interface

It can be sufficient to use potable water. However, a substance can be used to improve wettability (see NOTE 1). This substance shall neither cause the corrosion of the electrode, impair the surface of the specimen nor migrate into the specimen thereby affecting its resistivity.

NOTE 1 According to IEC 62631-3-1:2016 [6], a pharmaceutically obtainable jelly of the following composition is suitable as a conductive adhesive:

— anhydrous polyethylene glycol of molecular mass 600: 800 parts by mass;

— water: 200 parts by mass;

— soft soap (pharmaceutical grade): 1 part by mass;

— potassium chloride: 10 parts by mass.

NOTE 2 Soft soap is a non-corrosive, neutral soap used for medical purposes.

6 Preparation of test specimens

6.1 Minimum number of specimens/readings to obtain a test result for a concrete

The minimum number of test specimens and readings to obtain a test result for a specific concrete at a specific age is given in Table 1.

Table 1 — Minimum number of test specimens and readings to obtain a test result

Volumetric method	**Minimum number of test specimens**	**Number of averaged readings per test specimen** [a]	**Comments**
Cylinder	3	1	
Cube	2	1	
Prism	2	1	
Surface method			
Cylinder	1	6	Each test specimen is represented by the average value of six measurements on the cylindrical surface every 60° [a]
Cube	1	6	The size of the cube face should be larger than the distance between the two external electrodes
Prism	2	4	

[a] Commercial equipment often give an output that is the average of the number of individual readings. If this is not the case and the equipment gives a single reading, repeat the measurement at each test location at least three times and take the average value of the resistivity at that test location.

6.2 Test specimen preparation

Test specimens shall be either cylinders (e.g. 150 mm diameter × 300 mm), prisms, or cubes (e.g. 150 mm side) cast for the determination of concrete resistivity.

Resistivity measurements can be taken prior to testing the specimen for its compressive strength provided water curing is used.

All dimensions of the test specimens shall be at least 2,5 times the maximum aggregate size.

The volumetric method can be used on any specimen shape that has two parallel faces and a constant cross section (cubes, prims and cylinders).

For the surface method the specimen length shall be in accordance with the electrode spacing if one of the form factors in Table 2 is used (for example the length shall be at least 200 mm if the electrode spacing is 50 mm and of 150 mm if the electrode spacing is 35 mm). If the length is sufficient to fulfil the assumptions made for the form factors in Table 2, calibration of the form factor for the surface method shall be made by comparing the results obtained by the volumetric method with the arrangement of electrodes as specified in 7.1 and 7.2.

Test specimens that are specifically cast shall be made and cured in accordance with EN 12390-2 using the immersed in a curing tank procedure.

The specimens shall be removed from the curing tank just prior to testing and lightly dried with a towel to remove surface water.

Testing shall commence within five minutes after removing the specimen from the curing tank and completed without delay or where this is not feasible, the specimens shall be closely wrapped in polythene sheeting to prevent drying prior to testing and kept at the same temperature as in the curing tank. The weight of the specimen can be measured for verifying that the specimen has not lost water during its time wrapped in polythene sheeting.

7 Test procedure volumetric method (reference method)

7.1 Determination of the volumetric resistance

Specimens shall be taken directly from the curing tank and returned to the tank after the measurement. The measurements shall be carried out at (20 ± 2) °C.

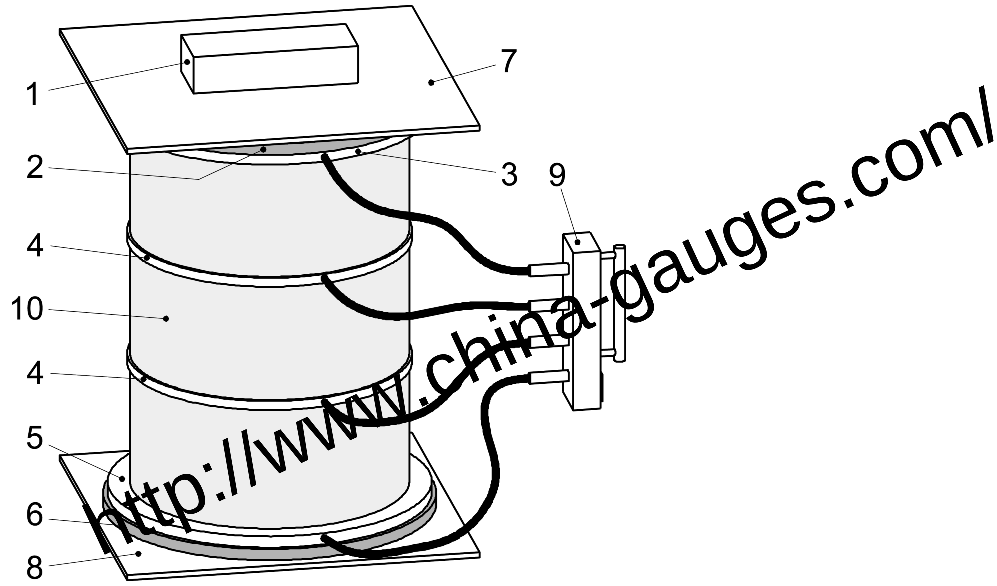
One current electrode is placed on a non-conducting surface, e.g. a plastic sheet (see Figure 2).

One sponge, soaked in potable water or potable water plus the wetting liquid, placed on the bottom current electrode.

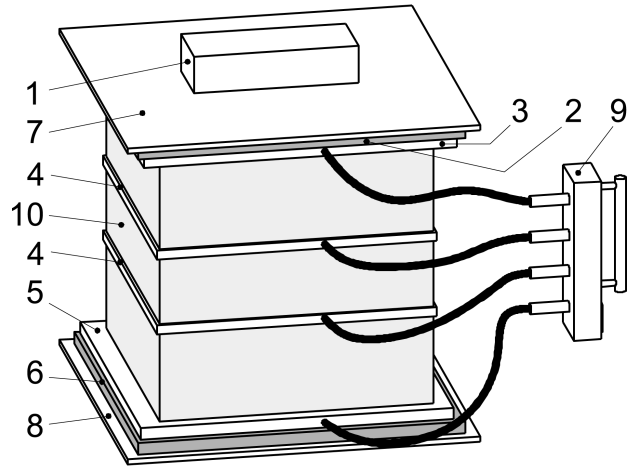
The specimen is placed centrally on the sponge, see Figure 2 a) and Figure 2 b).

The two voltage electrodes (metallic clamps) as shown in Figure 2 a) and Figure 2 b), are introduced from the top. The distance depends upon the size of the specimen. The distance from bottom and upper face and between them is 10 cm for cylinders of 30 cm in height (Figure 2 a)) or of 5 cm in cubes of 15 cm of side (Figure 2 b)). The clamps shall be adjusted to ensure good electrical contact to the concrete surface throughout the perimeter.

Once the voltage electrodes (metallic clamps) are fixed, the second upper sponge and electrode are placed on the top of the specimen.



a) Setup for volumetric resistance measurement (cylinders)



b) Setup for volumetric resistance measurement (cubes)

Key

1 non-conducting mass for pressing electrode
2 upper current electrode (circular for Figure 2 a))
3 sponge
4 voltage electrodes (metallic clamps)
5 sponge
6 bottom current electrode (circular for Figure 2 a))
7 plastic isolating sheet/grid
8 non-conducting support
9 resistivity meter
10 concrete specimen

Figure 2 — Arrangements for cylinders and cubes for measuring resistivity/resistance by the volumetric method

Finally, a plastic sheet/grid is placed on the top current electrode to locate a mass of about 2 kg to ensure a homogeneous contact of the current electrode with the top surface of the specimen. Any water that runs down the side of the specimen shall be removed prior to the resistivity measurement by drying with, for example, a paper towel.

NOTE 1 This geometrical arrangement of the 4 electrodes in the volumetric method makes the measurement independent of the frequency used and enables the calibration of any device of "equal 4-electrodes type" and any size of specimen.

An electrical current with a magnitude sufficient to measure in the range of the resistivity value of the specimen, is passed between the current electrodes located at the top and the bottom of the specimen. When the current has stabilized, the voltage drop between the two central voltage electrodes and current are simultaneously recorded or the resistivity is directly measured.

If an alternating current is used, the frequency should be between 40 Hz and 10 000 Hz. If a direct current is applied, the testing time should be shorter than 5 s.

If an alternating current with a frequency of less than 40 Hz is used, the correlation with the result obtained with direct current shall be demonstrated.

By switching the current or the resistivity meter on and off, the measurement is repeated:

- for a cylinder, at least a further two times giving a minimum of three sets of readings for each cylinder;
- for a cube, at least twice giving a minimum of three readings from the cube (from each pair of faces).

If a cube is being tested, the cube is turned so that the second pair of cast faces is tested using the same procedure.

If not automatically generated by the resistivity meter, the total concrete resistance is calculated using Formula (1) for each set of measurements.

NOTE 2 For this calculation to produce units of ohms, the voltage drop is in volts and the current is in amperes.

For each cylinder or cube, R_e is taken as the average of the three measurements.

7.2 *Two-electrode* arrangement

It is possible to use a *two-electrode* arrangement if the calibration with the above-described volumetric method using 4 electrodes has been carried out. In this setup, the electrodes connecting the metallic clamps in Figure 2 are connected to the upper and bottom electrodes: i.e. the voltage drop is measured in the same electrodes that apply the current. Such a two-electrode arrangement requires in addition the measurement of the resistivity of the sponges (positions 3 and 5 in Figure 2). This is possible by repeating the resistivity determination without the specimen, to measure only the contribution of the sponges. This resistivity value of the sponges should be subtracted from that with the specimen. In general, the value of the sponges alone is comparatively much lower. Other units can be used such as kOhm·cm.

8 Test procedure surface method

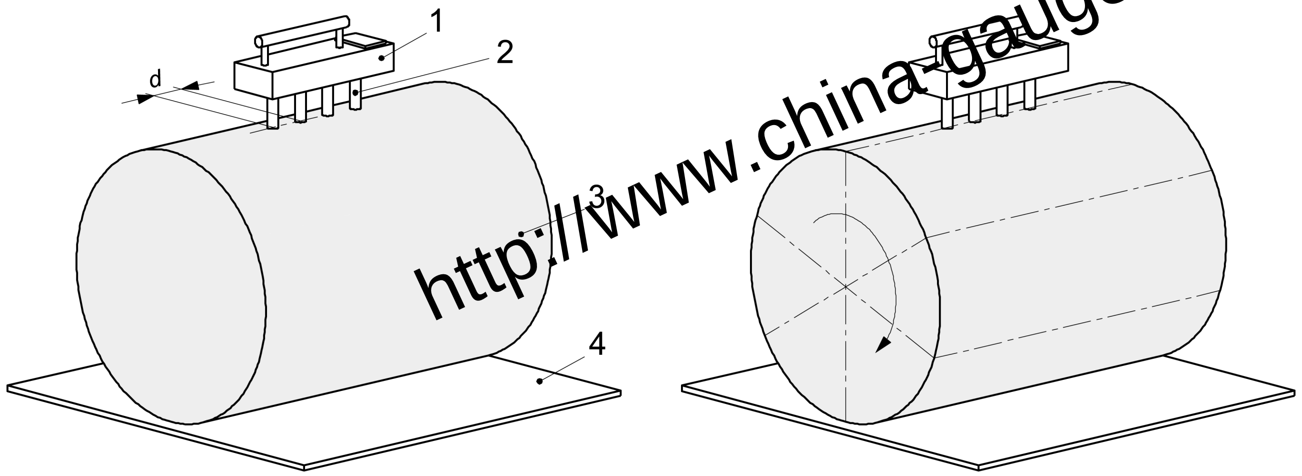
8.1 Measurements

8.1.1 Samples shall be taken directly from the curing tank and returned to the tank after the measurement. The measurements shall be carried out at (20 ± 2) °C.

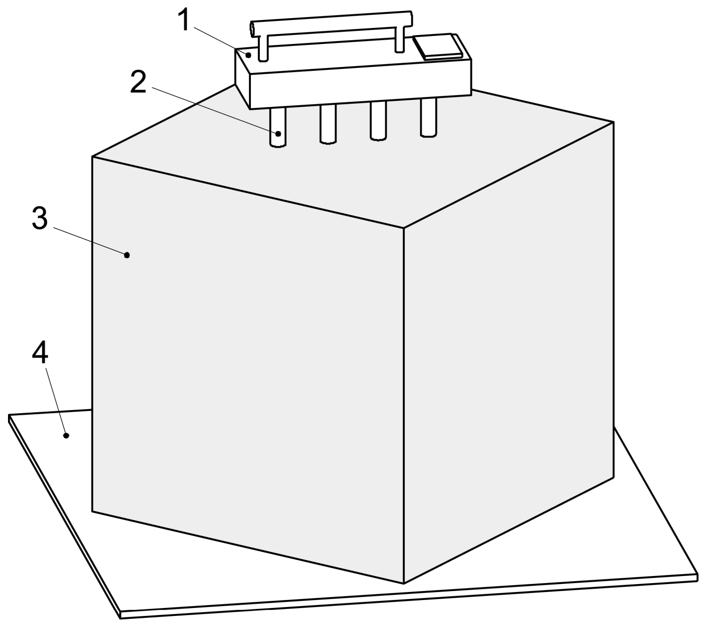
8.1.2 The four sponges or equivalents to be placed at the tips of the electrodes, shall be wetted with potable water or potable water plus wetting liquid and then fitted onto the four electrodes.

8.1.3 The test specimen after preparation in accordance with Clause 6 shall be laid on a non-conducting holder, e.g. plastic.

8.1.4 The test equipment placed on the specimen as shown in Figure 3, is pressed through the sponges or equivalent concrete-electrolytic contacting materials against the longitudinal axis (generatrix) of the cylindrical specimen or of the diagonal of the faces of a cube, and the voltage between the internal electrodes recorded. The current meter or resistivity meter is switched on and when the current is stabilized (usually no more than after 5 s) a simultaneous reading of current and voltage is recorded, or a direct reading of the resistivity is recorded.



a) arrangement for cylinders



b) arrangements for cubes

Key

1 resistivity meter

2 sponges

3 specimen

4 non-conducting support

d distance between electrodes

Figure 3 — Arrangement for cylinders (a) and cubes (b) measuring the resistivity/resistance using the surface method in a cast specimen

8.1.5 If the equipment does not automatically produce an averaged value, the measurement is repeated three times and the resistivity at each test location is based on the average of the three readings.

8.1.6 If a cylindrical specimen is being tested, it is then rotated 60 ° (see Figure 3 a)) and the procedure in 8.1.3 and 8.1.4 is repeated. This rotation is repeated until there are six sets of readings.

8.1.7 If cubes are being tested, the procedure in 8.1.3 and 8.1.4 is applied to each of the four lateral moulded sides (the bottom and upper faces are not tested). Both diagonals of each moulded side of a cube shall be measured giving 8 values per cube.

8.1.8 If prisms are being tested, the procedure in 8.1.3 and 8.1.4 is applied to each of the two lateral moulded long sides of prisms. Both diagonals of each moulded side shall be measured giving 4 values per prism.

8.2 Calculation of resistivity

8.2.1 General

The next sections describe the various methods of calculation of the resistivity, depending on the setup or commercial equipment used.

8.2.2 Volumetric method

The method implies the application of the current from two electrodes covering two parallel faces and the application of Formulae (1) and (3).

The resistance R_e is calculated using Formula (1).

NOTE 1 For this calculation to produce units of Ohms, the voltage drop is in volts and the current is in amperes.

NOTE 2 For this calculation, the voltage is the difference in voltage between the inner electrodes when the current is on and off.

NOTE 3 When using the *two-electrode* arrangement (see 7.2), the voltage is the difference between the two electrodes placed in the concrete surface that apply the current.

The volumetric resistivity ρ_v in Ohm·m is calculated from Formula (3). Other units can be used such as kOhm·cm.

In case the resistivimeter directly gives the resistivity, this value shall be divided by the surface geometrical factor F_{gs} (Formula (7) in 3.1.7) in order to obtain the resistance value to be introduced into Formula (3) to be multiplied by the volumetric geometrical factor F_{gv}.

Values of volumetric geometrical factors F_{gv} (Formula (6)) for different specimen shapes are given in Table 2.

8.2.3 Surface method

This method implies the use of a probe with four cylindrical electrodes applied to the specimen surface, and the application of Formulae (4), (5), (7) and (8).

In cylindrical specimens six measurements around the perimeter are recommended (see Table 1).

Usually, the resistivimeters directly give the resistivity value (the resistance multiplied by the surface geometrical factor F_{gs}). In that case, the results should be multiplied by one of the corresponding form factors given in Table 2 (Formulae (5) and (8)) depending on the shape and size of the specimen.

When the equipment is giving only the resistance R_e, the resistivity shall be obtained by multiplying it by the surface geometrical factor F_{gs} (Formula (7)) and by the form factor F_f (Formula (8)).

Table 2 — Values of the Factors F_{gv} and F_f

Specimen size (m)	**Volumetric Geometrical factor F_{gv} [m] F_{gv} = Area/distance between clamps**	**Form factor F_f [a]**		
		d = 0,035 m	**d = 0,037 m**	**d = 0,050 m**
Cylindrical 0,300 × 0,150	0,176 7 (separation of voltage clamps = 0,10 m)	0,73	0,71	0,60
Cylindrical 0,200 × 0,100	0,157 0 (separation of voltage clamps = 0,05 m)	0,57		0,38
Cylindrical 0,150 × 0,075	0,088 4 (separation of voltage clamps = 0,05 m)	0,38		
Prismatic 0,040 × 0,040 × 0,160	0,016 (separation of voltage clamps = 0,10 m)	0,172		
Cubes 0,150 × 0,150 × 0,150 m	0,45 (separation of voltage clamps = 0,05 m)		0,36	0,52

[a] Multiplication by this factor makes the resistivity values obtained through the surface method equal to the resistivity obtained through the volumetric (reference) method.

9 Test report

The test report shall contain at least the following information:

a) declaration that the test was undertaken in accordance with this document, i.e. EN 12390-19;

b) origin (cast concrete), size and marking of the specimens;

c) concrete reference (e.g. code number);

d) date of manufacture of concrete;

e) age of concrete when tested;

f) method of measurement (volumetric in accordance with Clause 7 or surface method in accordance with Clause 8) including the frequency used by the equipment;

g) temperature of curing and of the room where measurement is made;

h) any deviation from the test method (if applicable);

i) resistivity values of the various test specimens and mean resistivity in Ohm·m.

The test report can contain:

j) any observations with respect to the test results, e.g. unusually large spread of values;

k) laboratory accreditation for the test procedure, if any.

10 Precision

The precision estimates are given in Table 3. These estimates relate to the resistivity of a test specimen following the procedure in this document.

Table 3 — Precision estimates

Specimen geometry	**Cubes**			**Cylinders**		
Mean value, Ohm·m	49,27	169,70	728,88	182,53	475,13	778,12
Number of operators	3	4	4	3	3	3
Repeatability standard deviation, Ωm	0,84	3,60	23,63	4,55	3,46	15,11
Reproducibility standard deviation, Ohm·m	1,89	8,88	42,51	5,83	0,81	7,72
Repeatability CoV, %	1,70	2,12	3,24	2,49	0,73	1,94
Reproducibility CoV, %	3,84	5,23	5,83	3,19	0,17	0,99
Average Repeatability CoV, %	2,35			1,72		
Average Reproducibility CoV, %	4,97			1,45		
Average Repeatability CoV, %	2,04					
Average Reproducibility CoV, %	3,21					

NOTE The precision data were made at the Institute of Construction Sciences "Eduardo Torroja" of CSIC- Spain. The repeatability was performed with the volumetric method by placing and removing the clamps and electrodes in each measurement.

Annex A
(informative)

Determination of the precision of the equipment

If the repeatability of the equipment is not provided by the manufacturer, it should be estimated using the following procedure.

Perform at least 20 individual measurements in the same test location on a concrete specimen.

Determine the mean standard deviation and coefficient of variation of this set of measurements. The determined coefficient of variation can be taken as the coefficient of variation of the equipment for this type of concrete and the specific operator.

Repeat with a second concrete with a different level of resistivity. For example, select concretes that have resistivity of 50 Ohm·m and 200 Ohm·m.

The repeatability coefficient of variation for concretes with a resistivity between these values can be interpolated.

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