Construction and Building Materials 187 (2018) 531–544

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

A new methodology for concrete resistivity assessment using the instantaneous polarization response of its metal reinforcement framework

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HIGHLIGHTS

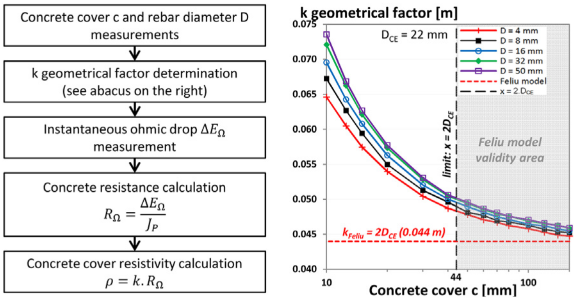
- A new concrete resistivity assessment methodology is proposed.
- Resistivity is calculated with a reverse calculation based on 3D numerical model.
- The geometrical factor depends on CE diameter, concrete cover and rebar diameter.
- The numerically developed method was experimentally validated in water.
- The geometrical factor does not depend on rebar framework density.

ARTICLE INFO

Article history:
Received 13 January 2018
Received in revised form 19 July 2018
Accepted 22 July 2018

Keywords:
Resistivity
Reinforced concrete structures
Corrosion
Geometrical factor
One-electrode method
Rebar spacing

GRAPHICAL ABSTRACT



ABSTRACT

A new methodology is developed to assess concrete cover resistivity using the instantaneous response of the polarization of a metal rebar (galvanostatic pulse method). The instantaneous ohmic drop is linked only with the concrete resistance, which depends on the concrete cover and resistivity, and rebar diameter. A numerical model was developed in Comsol Multiphysics® in order to create a graph linking concrete resistivity to concrete resistance for concrete cover ranging between 1 and 160 mm. This graph and the measured ohmic drop can be used to determine concrete resistivity for any rebar diameter/concrete cover configuration. The theory developed numerically was then confirmed using an experimental setup with controlled water resistivity. The theory is then generalized for counter electrode (CE) diameter ranging from 20 to 70 mm. Finally, the study reveals that the graph developed for a single rebar can be used for any rebar framework density.

1. Introduction

The corrosion of steel bars is a major issue in the durability of reinforced concrete structures [1]. Corrosion initiation and propagation depend on the concrete durability parameters (porosity, diffusivity, absorption, permeability). However, assessing these parameters on-site is time consuming, expensive and/or requires destructive tests. Resistivity is being increasingly considered as a reliable durability index for assessing the long-term performance of reinforced concrete structures [2–4].

Electrical resistivity is defined as the resistance against the flow of an electrical current. It is a specific, geometry-independent property of a material. For concrete, it may vary from 10 to 10^5 Ω.m [5]. The electrical current is carried by the dissolved ions in the pore solution [6] so resistivity depends on the pore structure, the degree of saturation and the distribution of the ion concentrations in the pore fluid. Concrete resistivity depends on both the

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https://doi.org/10.1016/j.conbuildmat.2018.07.158
0950-0618/

concrete production process (water/cement ratio, cement type, mineral admixtures, degree of hydration, curing) and the properties of the concrete in situ (temperature, degree of saturation, ion concentrations in the pore solution) [7]. The latter parameters depend on the production process and the history of external environmental conditions (temperature, relative humidity, air chloride content).

The work presented here is part of the DIAMOND project [8], which aims to create an electrochemical device to assess the corrosion state of reinforced concrete structures by measuring the half-cell corrosion potential E_{corr}, the concrete resistivity ρ and the corrosion rate i_{corr}, with the same device. This article focusses on measuring concrete resistivity. The measurement will be performed with a galvanostatic pulse measurement. This technique is employed since around 30 years to determine the corrosion rate of the rebar/concrete interface and the measurement procedure can be found in many papers [9–15]. However, in all these papers, the galvanostatic pulse technique is used to determine the corrosion rate. In these studies, the instantaneous ohmic drop measured, linked with the global concrete electric resistance, is subtracted to the potential response in steady-state regime (in a one dimension way – Randles model) to determine the polarization resistance of the concrete rebar interface (and thus calculate the corrosion rate). We propose here to use this instantaneous ohmic drop to determine the concrete cover resistivity more than the only global resistance. The principle of this resistivity measurement technique is based on the approach initiated by Newman [16] and Feliu et al. [17].

The aim here is to overcome the limitations described in Feliu's article and to propose a method that could be used for any rebar diameter/concrete cover configuration that may be found on-site and for a wide range of counter-electrode diameter (from 20 to 70 mm).

Our approach is based on a 3D numerical model. The numerically obtained results are used to do a reverse calculation of the resistivity with the instantaneous concrete ohmic resistance measured with the galvanostatic pulse method.

The various existing resistivity measurement techniques are presented first, followed by the newly developed method. The experimental device (DIAMOND probe and experimental validation setup) are introduced. The measurement is modelled numerically using COMSOL software in order to obtain the geometrical factor k, linking the concrete resistance R_{Ω} to the concrete resistivity ρ for all steel bar diameter/concrete cover configurations. The geometrical factor is also calculated for different counter-electrode (CE) diameter and presented in appendix. The theory developed is then confirmed using the experimental setup. Finally, we demonstrated that the model developed on a single rebar can be applied without modifications for a more or less dense rebar framework which is more representative of what is found on-site.

2. Theoretical background: resistivity measurement

There are several resistivity measurement techniques that can be employed. For all of them, the relationship between the resistivity ρ [Ω.m] and the measured resistance R_{Ω} is given in Eq. (1).

$$\rho = kR_{\Omega} \tag{1}$$

where R_{Ω} [Ω] is the concrete resistance (e.g. ratio between applied current and measured potential drop) and k [m] is a geometrical factor that depends on the technique employed and the sample geometry [18]. The two-electrode (or direct) method uses a regular geometry with two electrodes placed face to face (Fig. 1 (a)). An alternating current is applied and the potential drop between the electrodes is measured. Usually, a low frequency is employed (from 100 to 1000 Hz). The resistivity ρ [Ω.m] is then calculated with:

$$\rho = \frac{S}{l} R_{\Omega} \tag{2}$$

where S [m^2] is the cross-sectional area perpendicular to the current and l [m] is the height of the prismatic or cylindrical concrete sample. However, on-site, this technique cannot be implemented without destructive coring.

On-site, the method most commonly used for resistivity measurement is the Wenner method (four-point method) [19]. Four electrodes are equally spaced (electrode spacing a [m]) on the concrete surface (Fig. 1 (b)). The two outer electrodes apply a alternating current and the difference in potential is measured by the inner electrodes. The measured resistance R_{Ω} must be converted into resistivity using the following equation:

$$\rho = 2\pi a R_{\Omega} \tag{3}$$

The resistivity obtained is usually called the apparent resistivity. Eq. (3) is applied for homogeneous semi-infinite volumes. However, experiments have indicated that sample size and the presence of steel bar(s) can lead to erroneous results [4,20–22] and these aspects have to be considered carefully to obtain the correct resistivity value [7]. Both two-electrode and Wenner

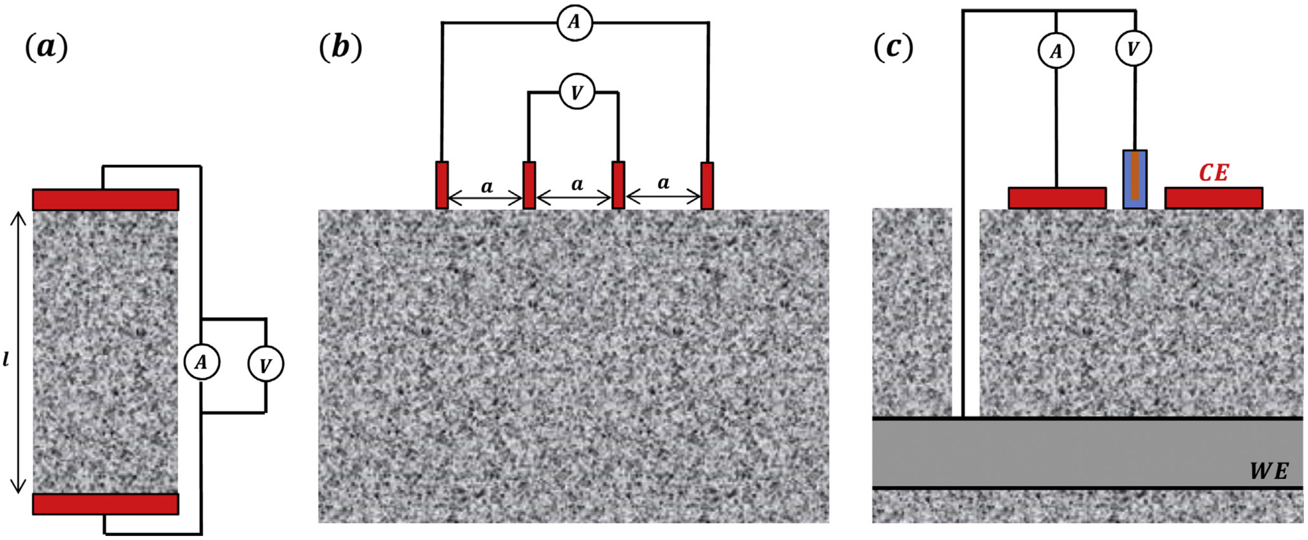

Fig. 1. Principles of resistivity measurements. Two-electrode method (a). Wenner probe (b). one-electrode method (c).