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A Joint Inversion Approach of Capacitive and Resistive Measurements for the Estimation of Water Saturation Profiles in Concrete Structures

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1 Introduction

Nondestructive (ND) methods are promising to assess the durability of concrete. The saturation degree conditions the penetration of aggressive agents. This study handles two kinds of measurements: the DC-electrical resistivity and the dielectric permittivity. The method consists of performing resistivity and permittivity measurements at the surface of the structure; then, an inversion procedure is required to retrieve the electromagnetic depth profiles. Finally, water saturation is obtained by means of calibration of the electromagnetic properties. The inversion of measurements has been performed using either the resistivity or the permittivity data (Fares, 2016). However, inversion results may lack reliability. Therefore, a possible solution relies in combining the two types of data, the electrical resistivity and the dielectric permittivity, taking advantage on their complementarity.

2 Electromagnetic Properties of Concrete

The DC-electrical resistivity of concrete, noted ρ [Ω.m], expresses the ability of the material to oppose the flow of free electric charges when it is subjected to an electric field. The dielectric permittivity, noted ε [F/m], is related to the phenomenon of electric polarization which results from the relative displacement of the bound charges in the material under the action of an external electric field. Note that the measured apparent resistivites and permittivities must enter an inversion procedure in order to obtain the true resistivity or permittivity distribution in the concrete medium.

3 Saturation Profile

A parametric model is considered using a Weibull curve with the following expression:

$$S(z) = (\theta_1 - \theta_2)\exp(-(\frac{z}{\theta_3})^{\theta_4}) + \theta_2 \tag{1}$$

The calibration of each of ρ and ε as functions of S can be expressed by the model:

$$\rho = AS^{-B} \tag{2}$$

$$\varepsilon = aS + b \tag{3}$$

where A, B, a and b depend on the concrete specimen tested, θ_1 is the saturation ratio on the surface, θ_2 is the saturation ratio in the structure depth, θ_3 is the scale factor, and θ_4 is the shape factor.

3.1 Forward Model

The forward model has been implemented numerically using the commercial finite element (FE) modeling software COMSOL Multiphysics® (v.5.4). The 3D-concrete model is defined. Then, the saturation profile is defined by the Weibull curve defined by Eq. (1). Knowing the saturation profile in concrete depth, the imposed resistivity or permittivity depth profile is obtained using Eq. (2) or Eq. (3). Then, the forward model resolution leads to the computation of the apparent resistivities or permittivites.

3.2 Inverse Problem

We choose the Levenberg-Marquardt algorithm to minimize the least-squares mismatch between the measurements and their prediction corresponding to a given saturation profile. The joint inversion procedure is an iterative process, which starts with an initial saturation profile given by the initial parameters. Then the resistivity profile is obtained using Eq. (2) and the permittivity profile using Eq. (3). Afterwards, the simulated data, that is, the apparent resistivities and permittivities, are computed and compared to the measured data in the joint least-squares criterion given in Eq. (4) ψ, where W_ρ and W_ε are weight parameters given to capacitive and resistive data respectively.

$$\psi = W_\rho \sum_i (\rho_{a_{mod_i}} - \rho_{a_{mes_i}})^2 + W_\varepsilon \sum_j (\varepsilon_{a_{mod_j}} - \varepsilon_{a_{mes_j}})^2 \tag{4}$$

4 Numerical Experiments

In this section, numerical experiments are performed in order to validate the proposed joint inversion approach. Synthetic data are computed, where a saturation profile is generated according to Eq. (1) and represents the ‘true’ saturation profile. The initial saturation profile in the optimization procedure is chosen such that the relative error compared to the true profile is equal to 10%. Referring to previous noise assessment studies (Du Plooy, 2013), a set of computations is carried out and considers noise on both resistivity and permittivity data (CV_r=4% and CV_p=2%, respectively). Individual and joint inversions are performed. The relative error between the true profile parameters and the estimated one as well as the iteration number are computed. The results of this study show that the relative error and the iteration number are the lowest for the joint inversion (6 iterations and 0.25% relative error).

5 Conclusion

In this study, we developed a new joint inversion approach for resistivity and permittivity data in concrete structures. Experiments were carried out using synthetic noisy data that showed that the profile estimation is improved by carrying out joint inversion as the relative error between the true and estimated parameters decreases as well as the iteration number compared to the separate inversions.

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