Geophysical Research Abstracts
Vol. 13, EGU2011-6878, 2011
EGU General Assembly 2011

Full-waveform inversion of ground penetrating radar data to assess chloride and moisture content in concrete

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Corrosion of rebar within reinforced concrete is a major problem for countries where salt is applied to roads for de-icing. Concrete structures are periodically inspected in order to monitor possible damage caused by chloride-induced corrosion of the reinforcement. However, the available drilling and visual inspections do not supply sufficient spatial information or can only be assessed in advanced stages of corrosion, respectively. Consequently, the condition of bridge decks can only be assessed with low certainty. Therefore a spatially continuous and non-destructive method detecting chloride in concrete structures is desirable.

Here, we introduce a novel method to estimate material properties using the full-waveform inversion of bistatic off-ground ground penetrating radar data. In this way, all information present in the ground-penetrating radar (GPR) traces is used, which enables the estimation of quantitative values for electrical conductivity and dielectric permittivity, which are closely linked to chloride and moisture content, respectively. A critical step for full-waveform inversion is an accurate forward model that describes the medium properties and the electromagnetic wave propagation from source to the concrete specimen and back to the receiver that includes a proper characterization of our horn antenna GPR system. Here, we model the antennas as point sources that emit an effective wavelet and use exact Greens functions for the propagation in a horizontally layered medium. Using measurements over a metal plate the phase centre and the effective wavelet were estimated which now fully describe the GPR system and do not change when the antennas are placed in front of another specimen.

To improve the robustness of our full-waveform inversion strategy against local minima and to assure convergence towards the global minimum returning the true values of the electric features of the concrete slabs, we use the picked time-zero and the maximum and minimum of both air-concrete and concrete-aluminium reflections as start values in the inversion algorithm. Moreover, we use several start models in the inversion algorithm to investigate the convergence. For each start model a local optimization algorithm based on the simplex search algorithm is initiated and a local minimum is found. The local minimum with the smallest cost function is assumed to be the global minimum.

The GPR data was measured over nine concrete specimens having different moisture and chloride contents. The data set, measured with a 1.2 GHz antenna centre frequency, contained frequencies between 500 MHz and 2.1 GHz and the data were inverted using three different frequency ranges: 0.575–2.1 GHz, 1–2.1 GHz and 1–1.625 GHz. As expected, the inversion results for almost all specimens, showed for increasing chloride and humidity content specimens, increasing conductivity and permittivity values, respectively. The three different frequency ranges provided similar results showing the stability of the full-waveform inversion. In contrast to traditional ray-based techniques we were able to distinguish between moisture and chloride effects and obtain quantitative values for the permittivity and conductivity. For increasing chloride content increasing frequency-dependent conductivity values were obtained.