Platforms for Modeling Electromagnetic and Ultrasonic Waves in Concrete

Technical Brief — *Nondestructive Evaluation, P41.04.01*

Introduction

This technical brief summarizes the current options for modeling and simulating electromagnetic and ultrasonic waves in concrete. The research is part of a study with Électricité de France (EDF) and the Materials Ageing Institute to deploy modeling plaforms for propagation of waves in concrete and to compare the results of the simulation to data collected from mockups. Modeling and simulation tools can provide valuable information regarding an expected scenario prior to an inspection. They are also valuable training tools, allowing personnel to become familiar with the collected data that are similar to data collected in the field. One platform for modeling electromagnetic waves and another for modeling ultrasonic waves will be selected to perform simulation scenarios of the mockups.

Platforms for Modeling and Simulation of Electromagnetic Waves

Multiple platforms are available for the modeling and simulation of electromagnetic waves or ground-penetrating radar (GPR) for concrete applications. These platforms range from customized codes that can be run on different languages to commercially available platforms dedicated to the modeling and simulation of GPR in concrete and soils. This section briefly describes the different platforms.

Customized Algorithms

Numerical modeling can be performed with different mathematical functions and algorithms. Different numerical analysis methods, such as finite-difference time-domain (FDTD), the finite-element method, moment method, and transmission line method algorithm can be used, depending on the application [1]. The development of customized codes and algorithms can be time-consuming and require programming languages and different software for analysis, interpretation, and visualization of test results. For these reasons, it was decided that a customized algorithm was not going to be developed for this project.

GPR sim

GPR sim is a commercially available software dedicated to modeling and simulation specifically for GPR. The software was first developed in 1989 in Fortran, and over the years, it has evolved into a Windows-based platform with a graphical user interface. The algorithm is based on the generation of synthetic radargrams using the infinite slope method and general optics theory to describe the transmission and reflection of electromagnetic waves [2]. The software generates two-dimensional (2D) simulations of soils and concrete with embedments that allow the user to create radargrams or color-coded images typical of GPR data. Multiple layers of materials and geometries can be placed in the platform to generate a simulation with user-defined settings for the materials and embedments. The results from the simulation can be input into other compatible software for analysis. GPR sim is a candidate for application in this project.

Decipher GPR

This main purpose of this commercially available software is to provide training and education to individuals interested in interpreting GPR signals [3]. The company producing this software has GPR certification classes, and it uses the software to evaluate the proficiency of candidates seeking certification. The software generates random patterns of embedments in concrete. The user traces lines across the computer screen, and radar B-scans appear in a sub-window. The B-scans are generated with a proprietary algorithm. The objective is to give the user endless scenarios of GPR images to allow them to practice. The platform also supports settings from a few of the major commercial GPR vendors; the user can select a specific system and antenna settings for their training session. The vendor of the service indicated that the platform was not created specifically for modeling, but the parameters could be adjusted to model any desired scenario as long as the properties of the concrete and configuration of the embedments were known. Decipher GPR is another good candidate for this project that is being considered.

GPRmax

GPRmax is one of the most widely used simulation platforms of electromagnetic waves for applications that include engineering, infrastructure, and medicine, among many others. The software is open-source, and it uses the FDTD method in the simulation algorithm. The software is written in Python, and the input file is generated on a line-by-line code. A different software can be used to visualize the input parameters. The input file can also be generated from another software platform, such as MATLAB. Commercially available antenna inputs are available in the Python libraries for users to implement in the code. The code is flexible, and advanced programmers can develop their own antennas to simulate the desired inputs. The simulations can be done in 2D and 3D. A simple 2D simulation can be run in a regular desktop or laptop computer. Larger 3D simulations can be run on high-performance computers to reduce the computational time. GPRmax will be used for the simulation of electromagnetic waves in the continuation of this project. EDF has performed a preliminary study with multiple applications of GPRmax [4].

Modeling Ultrasonic Waves

The options for modeling and simulation of ultrasonic waves in concrete are more limited than for electromagnetic waves. A customized tool is needed, or a code in a specific analysis program must be written. One of the biggest challenges in the simulation of ultrasound in concrete is the presence of aggregates and air voids that affect the signals passing through the concrete. The simplest way to perform modeling includes creating a homogenous medium to simplify the simulation process. This section presents some of the possible approaches to modeling ultrasonic waves in concrete.

Customized Algorithms

Customized algorithms can be developed using mathematical models and finite-element analysis for simulation of the propagation of waves. One of the most-used approaches is to develop a code in MATLAB that can run the mathematical simulations. One challenge with this application is that the user must have at least basic familiarity with MATLAB for running the simulations. Another is that the accessibility to MATLAB might be limited, making this approach difficult and sometimes cost-prohibitive when considering the frequency at which these types of simulations are performed.

Open-Source Codes and Algorithms

The mathematical algorithms for simulation of ultrasound have been used in other fields and are available as open source in repositories such as github. This project will compile algorithms from open-source codes and apply them to the simulation of ultrasonic waves in concrete. Open-source software and codes allow others to apply the same principles using existing mathematical algorithms and extend the application to a large community of users without incurring a large expense to run the simulations or purchase software.

Summary and Conclusions

Modeling platforms for electromagnetic and ultrasonic waves in concrete will be applied under this effort.

GPRmax will be used for modeling electromagnetic waves through concrete. The algorithms are open source and allow others to explore the same application. Data input has been identified as one of the challenges for this application. A simplified way to input the parameters will be searched and executed.

Open-source mathematical algorithms will be searched and applied for the modeling and simulation of ultrasonic waves in concrete. These applications are not readily available for use in concrete materials, but the mathematical algorithms from other disciplines can be applied to this effort.

Open-source algorithms will give a larger community access to the modeling and simulation process, thus bypassing costly commercial licenses and promoting wider adoption of the algorithms.

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