A GPR-based simulation approach for the analysis of railway ballast

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

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Laboratory set-up

Scenarios


Clean ballast 50 cm


Clean ballast 40 cm
Fouled ballast 10 cm


Clean ballast 20 cm
Fouled ballast 30 cm


Clean ballast 30 cm
Fouled ballast 20 cm

Ground-Penetrating Radar systems

IDS INGEGNERIA DEI SISTEMI

Ground-coupled configuration

- 600 MHz
- 1600 MHz

Air-coupled configuration

- 1000 MHz
- 2000 MHz
- 2000 MHz depowered, USA

This study aims at proposing a model capable to assess the physical conditions of railway ballast, in terms of percentage of fouling within the material, by analyzing its electromagnetic response.

For the calibration of such a model, a laboratory set-up was implemented in order to reproduce a real-scale railway environment. In more details, a 1.47 m long 1.47 m wide 0.48 m high plexiglass formwork was laid over a metal sheet, to define a proper domain of investigation. The formwork was then filled up with railway ballast, progressively fouled with a fine-grained pollutant material, namely, an A4 soil type according to the ASSHTO soil classification. At each step of fouling percentage, electromagnetic surveys were carried out by employing several ground-penetrating radar (GPR) systems, in both ground-coupled and air-coupled configurations.

On the other hand, the validation of the model was performed through a simulation-based approach. In particular, the main physical and geometrical properties of each ballast-pollutant configuration were reproduced by means of a random sequence absorption (RSA) approach. For the representation of the shape of the solid matrix of the ballast, a relatively complex geometry was here adopted. Finally, the developed geometries were processed by the GprMax 2D numerical simulator, employing a finite-difference time domain (FDTD) model capable of generating a synthetic GPR response for the several configurations analysed in laboratory environment.

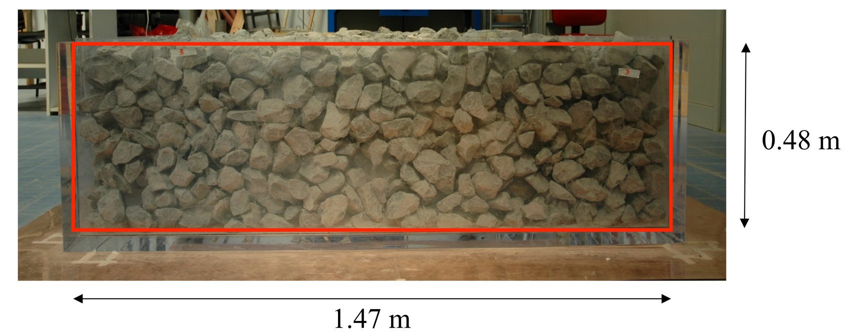
As result, the potential of the combined use of RSA and FDTD approaches is demonstrated, and a model for characterizing such a complex coarse-grained heterogeneous material is finally proposed.

Acknowledgement
The Authors thank COST, for funding the Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar."

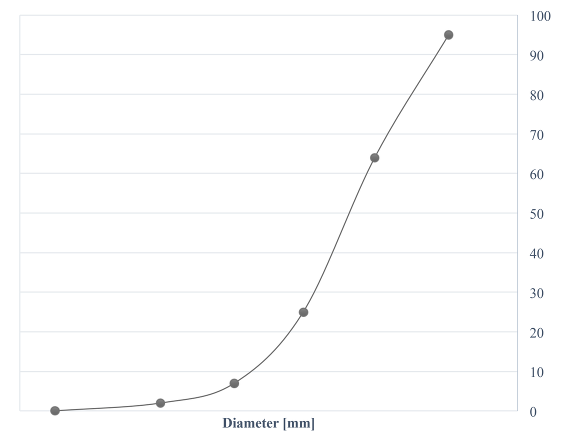
Numerical simulation of railway ballast

INPUT

Simulation Domain



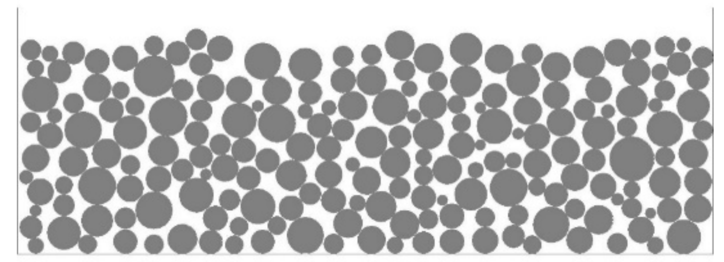
Ballast grading curve



C++ Code

Based on Random Sequence Absorption (RSA) approach

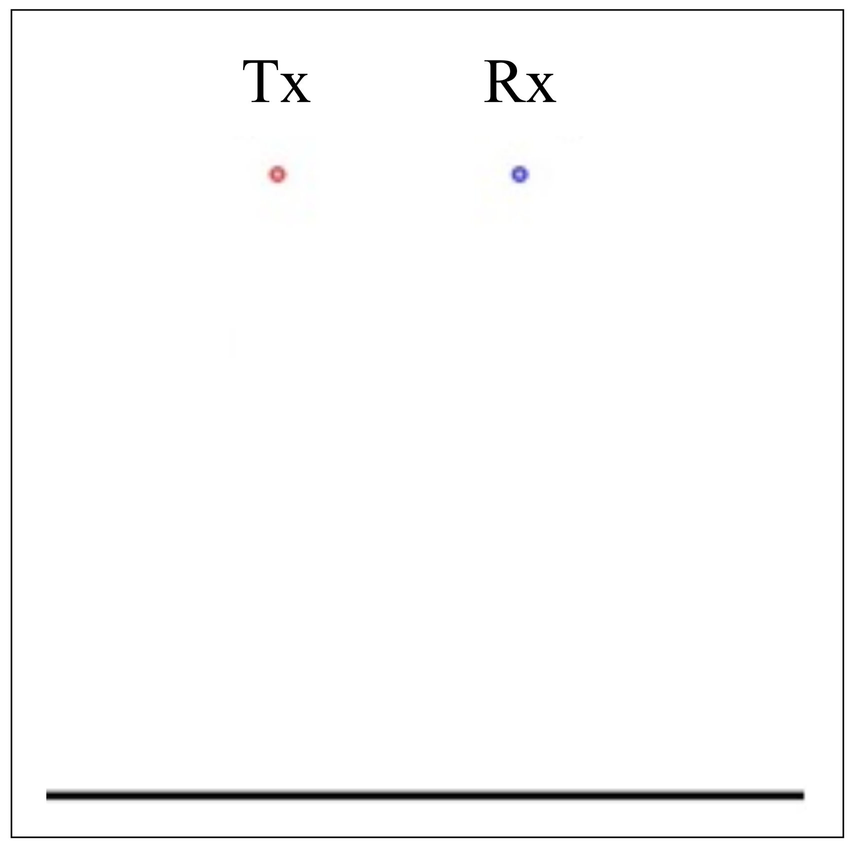
OUTPUT



The sample after the compaction process

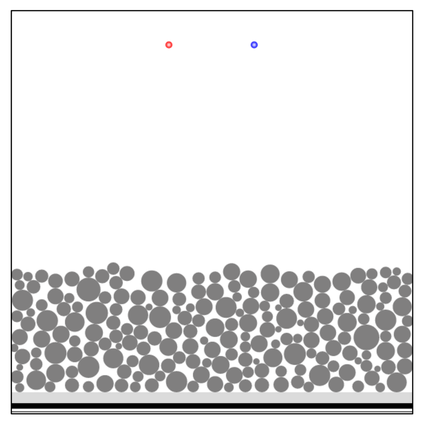
Simulation scenarios

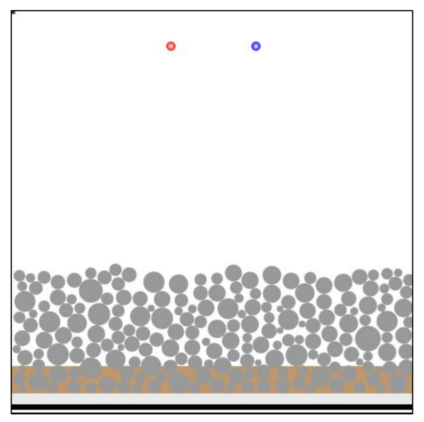
Antenna horn – frequency 1000 MHz

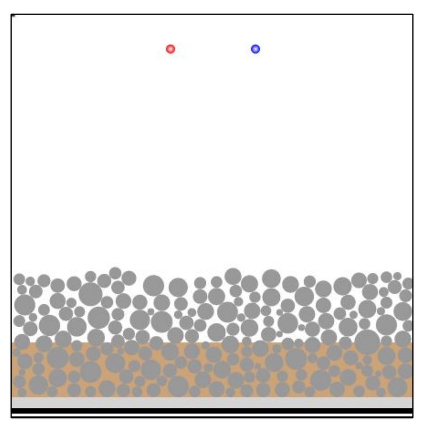


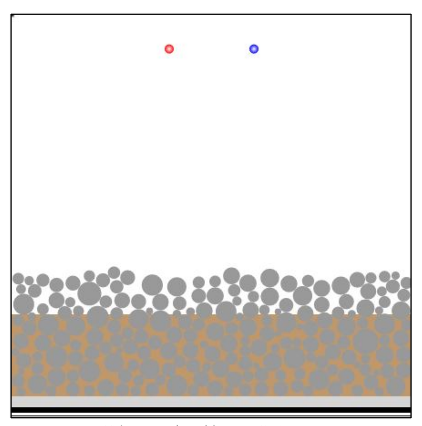
$d_{Tx\text{-}Rx}$ =31cm

E²GPR


Clean ballast 50 cm


Clean ballast 40 cm
Fouled ballast 10 cm

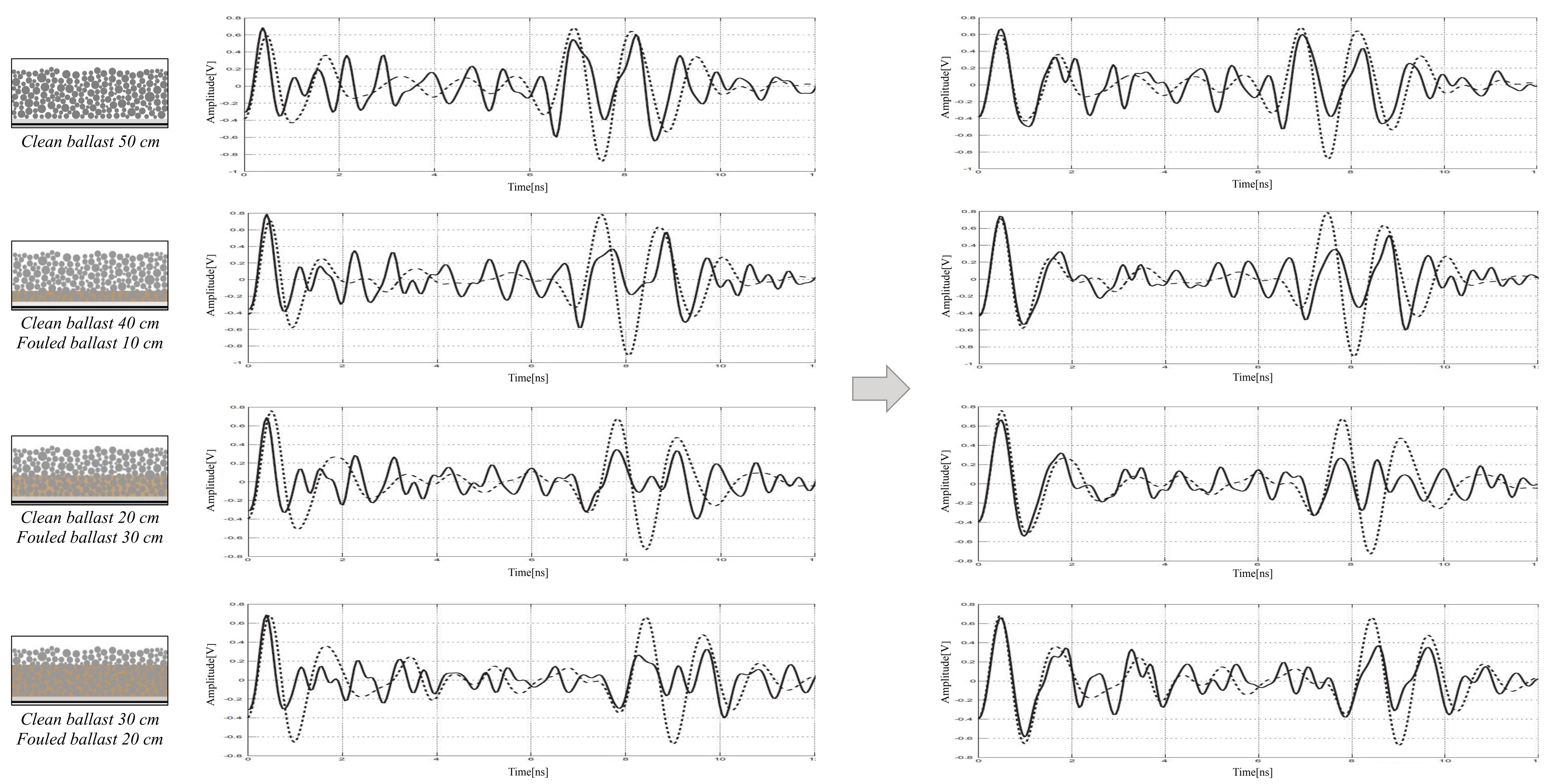

Clean ballast 20 cm
Fouled ballast 30 cm


Clean ballast 30 cm
Fouled ballast 20 cm

Main results

GPRMax 2D numerical simulator

Pre-Processing | Post-Processing



Real signal - - - - - - Simulated signal ———

Fouling prediction model

ε_{tot} ballast layer
Ballast grading curve

Volumetric Mixing Formulae

γ 2D to 3D conversion coefficient