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Semi-empirical model for the assessment of railway ballast using GPR

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Over time, railways have become a very competitive mean of transportation, especially for long distances. In order to ensure high level of safety, comfort and regularity of transportation, an efficient maintenance of the railway track-bed is crucial. In fact, the cyclic loads passing on the rails produce a progressive deterioration of railway ballast beneath the sleepers, and a breakdown of its particles that causes a general decrease of railway performances.
This work aims at proposing a semi-empirical model for the characterisation of railway ballast grading, through the spectral analysis of Ground-Penetrating Radar (GPR) signal. To this effect, a theoretical study has been preliminary conducted to investigate the propagation and scattering phenomena of the electromagnetic waves within a ballast layer.
To confirm the theoretical assumptions, high-frequency GPR signals have been both collected in laboratory and virtual environment. Concerning the latter, progressively more complex numerical domains have been designed and subjected to synthetic GPR test, by a Finite Different Time Domain (FTDT) procedure, run in GPR Max 2D simulator. As first simulation steps, ballast aggregates simplified through circles have been accounted for, with increasing values of radius. Subsequently, real-scale scenarios characterized by multi-size ballast particles, consistent with three different grain size distribution from railway network standards, have been reproduced by the employment of Random Sequential Adsorption - RSA algorithm.
As far as the laboratory procedures, real GPR tests have been carried out on an experimental framework purposely set up, and composed of a methacrylate tank filled up with limestone-derived railway ballast. The ballast aggregates grading has been retrieved by means of an automatic image analysis algorithm, run on the lateral sight of the transparent tank.
Through their spectral analysis, an empirical relationship between the position of the amplitude peak in the spectra, and the size of ballast particles was retrieved. As a result, this work opens new perspectives in railway track-bed maintenance. Indeed, it allows at monitoring the progressive evolution of ballast fragmentation and pollution phenomena, non-destructively and without need for any calibration.

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