Numerical study on the Wave Propagation and Attenuation in Generative Soil System - FDTD simulation of ultrasound propagation with different porosity & SSA in soil system

Institute of Science Tokyo [1], NARO[2], ○Xiaotian Sun[1], Munehiro Ebato[2]

Kentaro Nakamura[1], Marie Tabaru[1]

E-mail: sun.x.ai@m.titech.ac.jp

Background

Conventional soil characterization methods and traditional DEM simulations are limited [1], focusing primarily on surface particle structures while neglecting holistic soil-wave interactions. We present an integrated FDTD-based framework that establishes a comprehensive soil simulation environment, enabling precise characterization of wave propagation through soils with varying properties and particle size. The system demonstrates robust correlations between soil porosity and ultrasonic propagation, providing quantitative insights into soil-wave interactions.

Method

Our methodology integrates a staggered-grid FDTD framework with a GA-based soil generation system to analyze bulk soil properties through wave propagation phenomena. The GA simulation incorporates soil particles with Young's modulus ranging from 200 MPa to 280 MPa and density variations from 1000 kg/m³ to 2000 kg/m³ and radii from 0.0005 m to 0.001 m. Due to soil particle radii ranging being smaller than grid spacing (0.05 m), we implement velocity averaging per grid cell for coarse-precision iterative calculations. The FDTD framework operates with water velocity 1500 m/s and velocity distribution from GA wave velocity over 0.02 s duration, utilizing a 1 kHz center frequency pulse from t = 0 s. The 10 × 10 m computational domain employs PML absorbing boundaries, with porosity variations of 20-50% at 267 SSA.

Results

Fig.1A illustrates the simulated wave propagation patterns in the soil environment. Wave frequency distributions under varying soil porosity conditions are presented in Fig.1B. Analysis of Fig.1C demonstrates optimal frequency concentration at 30% porosity, suggesting a critical condition in wave transmission characteristics at this porosity level. These 4 groups of results indicate an optimal structural configuration for wave propagation at 30% porosity.

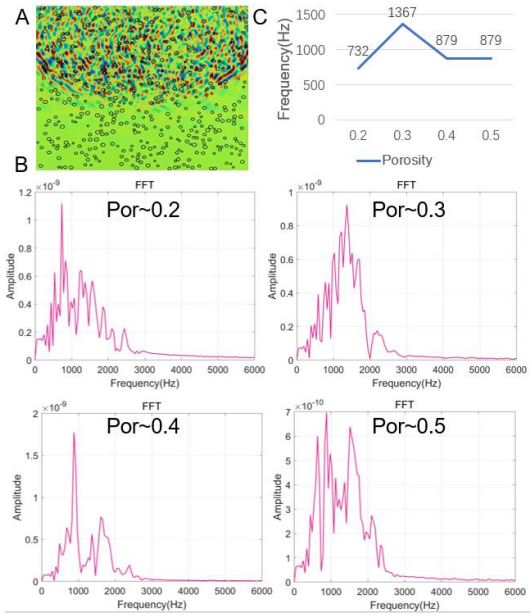

Fig.1 Simulation propagation phenomenon: A.Propagetion velocity map (t = 0.012 s); B. FFT at different porosities; C. Frequency distribution statistics at different porosities

Conclusion

We established an integrated framework combining ultrasonic wave propagation analysis with numerical modeling simulation, which enables precise parameter control for investigating ultrasonic wave propagation patterns in shallow soils with varying properties.

Reference

[1] S. Huang *et al.*, *Computers and Electronics in Agriculture*, vol. 190, p. 106477, Nov. 2021.