Modeling Anthropogenic Cavities as Elastic Meta-Interfaces: Implications for Seismic Surface Displacements

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Abstract

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Seismic design codes require accurate characterization of the elastic properties of soils down to depth of a few tens of meters below the Earth's surface. Indeed, at these depths, the sismic signal can be significantly modified by the heterogeneity of the geomaterials or the geometry of the U-shaped basins creating multiple wave reflections. For rocky terrains, there is no recommendations for wave propagation in the presence of cavities or networks of near-surface underground cavities, often of anthropogenic origin. For example, this may be buried quarries forming dense clusters of regularly spaced cavities. However, these "defect" networks can significantly influence surface displacements.

In order to identify the impact of these near-surface void structures on the dynamic response of buildings, it is necessary to develop a simple model that can be directly implemented in building displacement calculations. For example, it is crucial to study whether the H/V (horizontal/vertical) displacement ratio at the surface is amplified or reduced, and whether filling the cavities with a material or fluid could mitigate these displacements.

Building on recent advances in elastic meta-interfaces, we propose a two-scale homogenization approach to model a cavity network as an effective interface. We show that this seismic meta-interface introduces discontinuities in elastic displacements and normal stresses, involving effective parameters whose values explicitly depend on the geometry of the actual network. Initially applied to an infinite elastic medium (1), the method is extended here to an elastic half-space (the ground) with a free surface subjected to a zero normal stress condition. This analytical model, based on idealized assumptions (perfectly periodic quarry, homogeneous elastic ground), meets the simplicity requirement and demonstrates remarkable reliability when compared to numerical simulations of the full problem. The agreement is particularly good in the frequency range of interest for seismic waves in earthquake engineering ($<$ 50 Hz).
(1) Pham, K., Maurel, A., & Marigo, J. J. (2021). Revisiting imperfect interface laws for two-dimensional elastodynamics. Proceedings of the Royal Society A, 477(2245), 20200519

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