Assessment of interaction between soil and metro station structure using the finite difference method

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Abstract

The underground metro system is a key solution to urban traffic congestion, increasingly adopted in major cities worldwide. In this study, a two-story, three-span underground metro station was modeled in FLAC3D within a 9-layer soil profile extending 80 meters in depth and 200 meters in length. After achieving static equilibrium, the model was subjected to dynamic loading using three earthquake records (Bam, Manjil-Rudbar, and El Centro), scaled and applied at a depth of 80 m using SHAKE2000. Shear and vertical stresses were evaluated across 7 longitudinal sections and 18 depth levels per section. Results revealed that stress distribution was highly dependent on soil properties, depth, and ground motion characteristics. Significant stress concentrations were observed near the station, particularly at the soil-structure interface and retaining walls. Differences in vertical stress (σ_{xx}) between left and right walls were attributed to the nature of the earthquake input. Farther from the station, stresses were more uniformly distributed, with variations driven by frequency content and PGA. Bam earthquake caused the highest vertical stresses due to its high PGA, while Manjil produced greater shear stress in shallow soils. Numerical vertical stresses showed good agreement with the Seed and Idriss empirical formula beneath columns and walls (within 10-15% error range). Stress reductions at mid-spans were linked to column stiffness and rocking behavior. Finally, the horizontal pressures on retaining walls were compared with Mononobe-Okabe theory and Iranian codes (Instructions 308 and 804, and Chapter 7 of the National Building Code). The numerical results were often higher than code predictions, especially in stress concentration zones. Discrepancies exceeding 30% highlighted limitations of empirical formulas for deep, semi-flexible underground structures. The study confirms that detailed numerical analysis incorporating soil-structure interaction provides a more realistic basis for seismic design of underground stations and supports revisiting national design standards.

Keywords: FDM, metro station, soil-structure interaction, underground structure, FLAC3D, SHAKE2000, dynamic analysis, Elcentro earthquake.