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Experimental synthesis of seismic horizontal free-field motion of soil in finite-domain simulations with absorbing boundary

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ABSTRACT

In this paper, a fundamental assessment of the method of physical wave-absorbing boundary and centrifuge modeling is presented in the context of experimental simulations of seismic free-field ground motion. Focusing on the characteristics of a sand stratum, a series of seismic tests on models of uniform density and a large width-to-depth ratio with Duxseal as the side boundary were performed using an in-box shake-table system. By means of the transfer function approach in the frequency domain, the complex three-dimensional nature of the dynamic response of the finite soil model with the boundary treatment is demonstrated in terms of its variable resonant frequency distribution at different g-levels. Apart from being helpful in quantifying the difficulty in interpreting the finite-domain response simulations using one-dimensional theories or homogenized representations, the measured data substantiates the need and usefulness of coupling the Duxseal boundary approach with a three-dimensional elastodynamic synthesis. With the aid of a corresponding boundary element implementation, the feasibility of identifying the soil's in-flight shear modulus variation, Poisson's ratio and horizontal-to-vertical earth pressure ratio from the centrifuge model's free-field measurements is also explored.

1. Introduction

To advance the understanding of realistic soil dynamics and seismic soil–foundation-structure interaction (SFSI) effects, fundamental physical simulations are invaluable owing to the well-known complexity of soil behavior under dynamic loading. To replicate the strong dependence of the mechanical response of soils on the stress state and the role of gravity, scaled modeling on a centrifuge has been a powerful and economical investigative method for exploring many geotechnical problems (e.g. Schofield [1], Ng et al. [2]). For simulating dynamic excitations that involve an unbounded soil domain, however, there has been the perennial fundamental question of how close the response of a finite-size soil model truly corresponds to the prototype situation as a function of geometry and boundary treatments (e.g., see Wood [3]). To simulate one-dimensional horizontal earthquake free-field motion problems with only depth-wise variation in the soil response such as those caused by vertically polarized plane shear waves in a horizontally uniform soil, the idea of a laminar box (Hushmand et al. [4]) has been found to be most useful for centrifuge modeling. Under the end-to-end rigid kinematic constraints from the stacked laminar frames and motions of sufficient amplitude to overcome the interlaminate friction for instance, the approach can create close to uniform deformation on a horizontal plane of a horizontally uniform deposit under horizontal rigid-base excitations. Building upon its logic and performance, a number of implementations and refinements have been proposed over the years (e.g., Law et al. [5], Fiegel and Kutter [6], Kutter [7], Madabhushi et al. [8], Zeng and Schofield [9]). For other three-dimensional dynamic problems of structural and foundation engineering interest such as building–foundation interaction and foundation vibration problems wherein the induced soil motion or soil properties need to be allowed to vary spatially, however, physical absorbing boundary by means of Duxseal has remained a prevalent treatment for both small- and large-deformation problems (see Coe et al. [10], Cheney et al. [11], Lenke et al. [12], Campbell et al. [13], Weissman and Prevost [14], Chazalas et al. [15], Chakrabortty et al. [16], Pitilakisa et al. [17], Murillo et al. [18], Cilingir and Madabhushi [19]). Going beyond specific simulations and feasibility studies, for example, the approach has been employed successfully in fundamental studies of shallow and deep foundations under multi-directional forced excitations (e.g., Pak and Guzina [20], Pak et al. [21,22], Ashlock and Pak [23]). As to its rigorous application to seismic simulations with arbitrary soil–foundation-structure configuration and incident ground motion, however, there are still fundamental questions (e.g., Kutter [24], Gazetas and Anastasopoulos [25]) concerning the degree and nature of the correspondence between the finite-domain scaled models and their prototype infinite-domain counterparts.

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