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Nonlinear site response analyses for sands: investigating the influence of fabric anisotropy

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Nonlinear effective stress site response analyses (SRAs) are commonly used to estimate dynamic soil behaviour, seismic wave propagation through the soil medium, and resulting ground motions [1]. These analyses can be used to identify potential hazards (e.g., landslides, settlements, liquefaction) and to estimate dynamic loads on superstructures in areas that are prone to natural or induced earthquakes, which can help with disaster planning and risk mitigation efforts. In this study, the influence of fabric anisotropy, which is induced during the soil formation process, on the response of sand deposits has been assessed through one-dimensional site response and response spectrum analyses (RSAs). First, a novel anisotropic critical state theory (ACST) based semi-micromechanical constitutive model accounting for the effect of fabric anisotropy has been incorporated into a fully coupled dynamic code employing the *u*-*p* formulation. Then, the initial fabric anisotropy has quantitatively (both with respect to intensity F_{in} and orientation θ_{in}) been changed to imitate different anisotropic formations observed in natural deposits. The proposed numerical procedure shows that fabric effects stemming from the anisotropic nature of sands can significantly influence the dynamic behaviour of sand deposits, leading to significant variations in ground motions and therefore resulting in diverse spectral accelerations at the ground surface.

The loading direction dependent behaviour of sands, which can be associated with their anisotropic nature originating from the arrangement of the soil inner microstructure, is generally described/idealized using a second order fabric tensor by ACST based models. Similarly, in this study, a contact normal based second order fabric tensor together with a plastic strain driven fabric evolution formulation has been employed to link the influence of the changing inner microstructure to the relevant constitutive formulations. Further details on the fabric formulations and their multilaminate specific extension can be found in ref. [2] and [3]. Although numerous experimental studies have been conducted to investigate the influence of fabric on the undrained response of sands and advanced constitutive models have been developed to account for it, the majority of research efforts involving anisotropy have concentrated on the element test level, while practical boundary value problem (BVP) simulations are usually omitted. In order to ameliorate that trend, the practical aspects of the fabric effects in BVPs will be investigated in the next section.

To investigate the repercussions of incorporating fabric effects, two identical SRAs with different initial fabric configurations, i.e., initially isotropic and anisotropic, have been carried out and the resultant response spectrums are presented in Figure 1. These SRAs were performed for a one-dimensional column of 10 m height with a water table located at 1 m depth, subjected to a seismic load taken from the 1987 Superstition Hills earthquake. The initial field stresses were determined assuming $K_0 = 0.5$. Even though the different initial anisotropic configurations produce similar RSA trends over the range of the period T, a significant difference in peak values is observed at $T = 0.39$ sec. Whereas the initially isotropic sand returns a peak value of $S_a/PGA \cong 3.03$, its anisotropic counterpart yields $S_a/PGA \cong 4.08$ (i.e., 34.6% higher), in which S_a and PGA are the spectral and peak ground accelerations, respectively. Figure 1 illustrates two different types of structure, a one storey building and a four storey building,

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with approximate natural periods of 0.1sec and 0.5sec, respectively. Since most of the variation in the RSA is observed in the range $0.1 < T < 1.0$, it is expected that structures residing in that period range will be affected most by the fabric anisotropy.

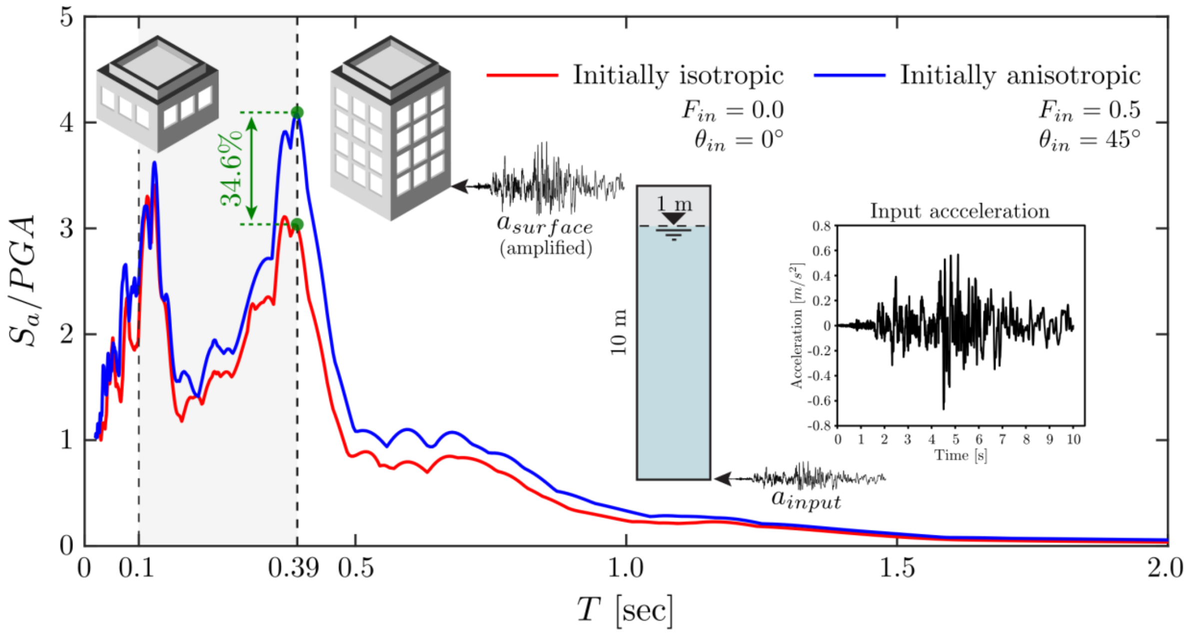

Figure 1: Response spectra of initially isotropic and anisotropic simulations.

Contributor statement

Hilmi Bayraktaroglu: Conceptualization, Methodology, Formal analysis, Visualization, Writing – Original Draft, Writing – Review & Editing; Jose L. González Acosta: Conceptualization, Methodology, Formal analysis, Visualization, Writing – Original Draft, Writing – Review & Editing; Abraham P. van den Eijnden: Conceptualization, Writing – Review & Editing; Mandy Korff: Conceptualization, Funding acquisition, Writing – Review & Editing; Michael A. Hicks: Conceptualization, Funding acquisition, Writing – Review & Editing.

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