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A note on a *pseudo*-natural SSI frequency for coupled soil–pile–structure systems

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ABSTRACT

The notion of a pseudo-natural SSI frequency was introduced in a recent publication by the authors, as the frequency where foundation motion is minimized with respect to the free field surface motion. This frequency is determined analytically in this paper, for a single-degree-of-freedom structure supported on a pile foundation. The analytical solution is compared to numerical results from rigorous finite element analyses for different pile and structural configurations. The relationship between pseudo-natural (f_{pSSI}) and effective natural SSI frequency (f_{SSI}) of the coupled system is also analytically quantified. It is concluded that f_{pSSI} may deviate substantially from f_{SSI} when a stiff squatty structure is founded on a stiff and/or short end-bearing pile for which foundation translation prevails. Conversely, when a flexible tall structure is supported on a flexible pile, f_{pSSI} and f_{SSI} nearly coincide due to dominant base rocking effects. In the latter case the effective natural SSI frequency can be predicted by standard identification procedures even when free-field recordings are missing. Effective damping effects are also discussed.

1. Introduction

Knowledge of the characteristic frequencies that dominate seismic response of soil–superstructure systems is important for evaluating the performance of structures founded on soft soil. In the important case of pile-supported systems, soil compliance near the pile head possesses a significant role in controlling the dynamic characteristics of the structure and the effective seismic motion imposed at the foundation. A variety of numerical and analytical methods have been proposed for the analysis of such problems leading to empirical and analytical solutions for the effective natural frequency and damping ratio of the complete system [1–5]. Elements of the above studies have been incorporated into modern seismic codes, specifying conditions where soil–pile–structure interaction should be taken into account [6]. System identification techniques have also been adopted for quantifying SSI effects in the absence of recordings for base rocking and/or free field response [7–9].

Within the identification of the characteristic frequencies that dominate pile-head response in coupled soil–pile–structure systems, Rovithis et al. [10] introduced the notion of a *pseudo*-natural SSI frequency (f_{pSSI}) as the frequency where pile head motion is minimized with respect to both superstructure and free field surface motion. A qualitative relationship was found to exist between the *pseudo*-natural frequency and the conventional effective natural frequency (f_{SSI}) suggesting that the latter is always lower than f_{pSSI} while the deviation of these frequencies becomes pronounced for stiff structures founded on stiff and/or short end-bearing piles.

The herein-reported study extends the previous work to derive an analytical solution for the pseudo-natural frequency of coupled soil–pile–structure systems in the realm of elastodynamic considerations, and to examine the role of foundation vibrational modes in connection to pile properties. To this end, the case of partial base fixity, as defined by Stewart and Fenves [7], is explored by focusing on a single-degree-of-freedom structure supported on a single end-bearing pile. Frequency-dependent impedance functions of the pile foundation and exact solutions for effective damping are employed—contrary to common approximations that ignore these effects [1,11]. The analytical solution is compared to numerical results from a three-dimensional (3D) finite-element (FE) model analyzed in the frequency domain. The relationship between pseudo-natural and conventional effective natural SSI frequency is quantified analytically for a wide set of salient dimensionless parameters, allowing identification of the coupled soil–pile–structure systems when pseudo-natural frequency is a governing parameter of SSI response.

2. *Pseudo*-natural frequency of *SSI* systems

An extended parametric investigation of the seismic response of coupled soil–pile–structure systems has been recently presented in

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