Research Project Highlight

Reduced-Order Models for Dynamic Soil-Structure Interaction Analyses of Buried Structures

TSRP Topic – PBE Tools – T2

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Start-End Dates:
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Abstract
We propose to develop a reduced-order-model (ROM) for dynamic soil-buried structure interaction (SbSI) to evaluate the seismic performance of circular buried structures, such as tunnels, pipelines, and culverts. State-of-the-art SbSI models of buried structures are based on the theory of beam on nonlinear Winkler foundation (BNWF), where the soil surrounding the structure is replaced by a set of springs and dashpots (aka. soil impedance functions, SIF) formulated to represent its macroscopic reaction to differential deformations between soil and structure. Most, if not all, of these models, however, ignore the dynamic nature of seismic loading, and resort to frequency-independent SIFs that cannot account for transient differential strains induced by wave passage effects (e.g. surface waves from basin effects). Recent studies, however, have showed that in SSI problems of buried structures, frequency dependency of SIF is more important than in the case of either shallow or deep foundations, because the free surface distorts the path of radiated energy away from the vibrating tunnel or pipeline (cf. Figure 1).

In this project, we propose to perform a systematic study on the effects of frequency in seismic SSI analyses of buried structures. We will specifically use high-fidelity finite element models (FEM) to investigate the frequency-dependency of SIFs and the conditions under which this dependency cannot be ignored, and we will derive analytical expressions that can be incorporated in PBE methodologies for the design of buried structures. The proposed ROM will need to simultaneously consider the frequency- and deformation-dependency of SIFs. To our knowledge, such a model has not yet been developed.

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We will develop the model for a homogeneous (or weakly heterogeneous) half-space, and we will extend it to study SbSI effects of a buried tunnel crossing a basin (cf. Figure 2). We will verify the proposed non-linear, frequency-dependent ROM by comparison to 3D FEM of soil and buried structures; and potentially will validate it using published experimental results, if available. We will lastly use the ROM to study the effects of asynchronous excitation on the performance of an idealized circular tunnel in a homogeneous half-space and a sedimentary basin.

Deliverables

Community database of dynamic SbSI functions (springs and dashpots), implementation of a uniaxial material model in OpenSEES, OpenSEES scripts for tunnel parametric studies, PEER meeting presentations, two journal papers, and a PEER report.

Research Impact

The frequency-dependency of SIF for the design of shallow and deep foundations has been established and widely accepted by the profession. However, there are no equivalent methods to account for the frequency-dependence of SIF in the case of horizontally oriented buried structures. Our recently published and ongoing work has shown that the response of these structures to dynamic loading is both strongly nonlinear (as opposed to the bilinear state-of-the-art assumptions) and strongly frequency dependent. The proposed research will benefit this problem two-fold: (i) the community database of dynamic SbSI functions (springs and dashpots) will be generated in a tabulated or graphical form, to enable their use by practitioners who are interested in selecting the most appropriate values of springs and dashpots for this class of problems; and (ii) the proposed OpenSEES uniaxial material model that will account for the frequency-dependence of nonlinear SIF will provide a robust and versatile tool to improve the analysis of buried structures under seismic excitation, while maintaining computational efficiency. This in turn will benefit performance-based earthquake engineering methods by providing a physics-based model to account for the effects of spatial variability and incoherency in the seismic demand of extended structures.

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Project Images

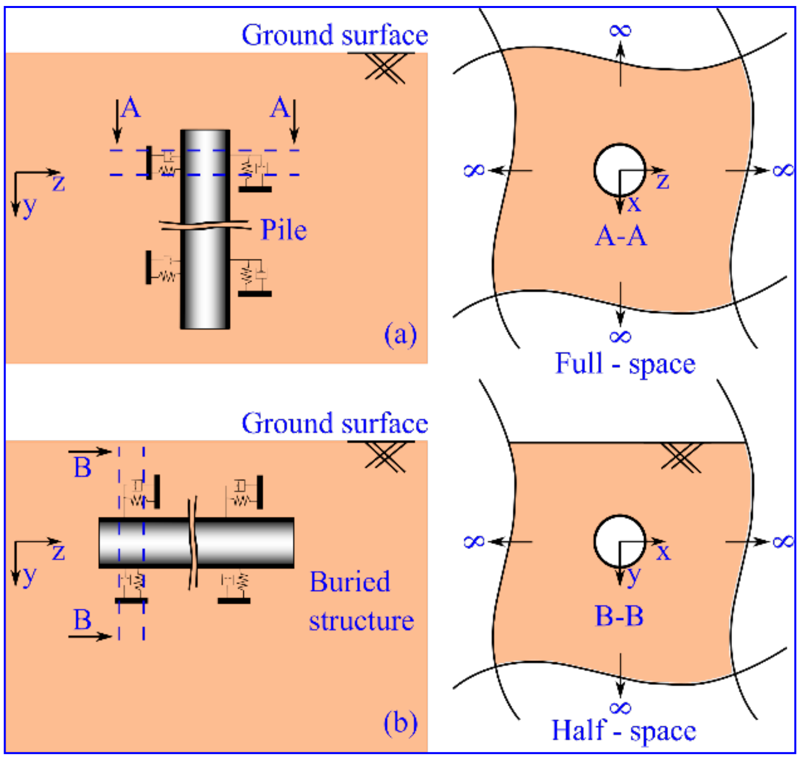

Figure 1: Schematic of full-space and half-space problems

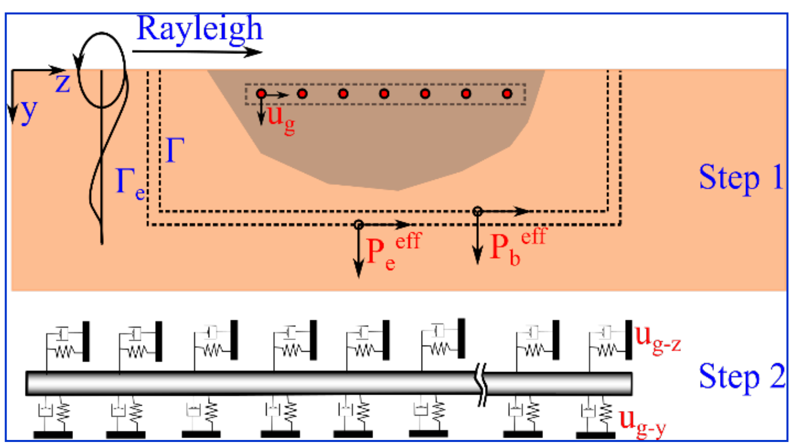

Figure 2: Two-step analysis for tunnel crossing a basin

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