Research Project Highlight

Implementation of Frequency-Dependent Impedance Functions in OpenSees

TSRP Topic: PBE Tools - T2

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Abstract
To accurately analyze structures, Soil-Structure Interaction (SSI) effects must be taken into account. One approach to analyze SSI effects is to create and analyze a complete Finite Element Model (FEM) of the full system wherein the soil medium is represented as a semi-infinite domain. This so-called "direct" method approach is frequently adopted in research studies. But, it is typically avoided in engineering practice due to the labor-intensive finite element model development, and the high computational cost. In practice, SSI analysis is mostly carried out through a substructure approach as shown in *Figure 1*. In this approach, the superstructure is usually modeled through a very detailed FE model and is placed on a soil-foundation substructure which is represented by a system called Impedance Function (IF). Then, the entire system is analyzed under Foundation Input Motions (FIMs) obtained from Free-Field Motions (FFMs) considering Kinematic Interaction (KI) effects. While the method is theoretically designed for linear-elastic behavior due to superposition assumption, the substructure method can be partially applied to nonlinear systems for which the condensation process is performed only on the viscous elastic soil-foundation.

Although IFs for various soil and foundation configurations can be obtained from analytical, numerical, or experimental analyses, their implementation in the time-domain is not trivial because they are frequency-dependent with unlimited bandwidth. A simple solution for this problem has been to convert these IFs to some lumped-parameter physical models with frequency-independent components, but there is no straightforward way to connect these components. More importantly, the coefficients of these components could be non-physical parameters that cannot be modeled in FE software like OpenSees or the final lumped model could be unstable. To resolve the aforementioned problems with the physical models, the IFs can be represented through rational polynomial approximation or equivalently recursive

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discrete-time filters. An example of such time-domain approximation is shown in *Figure 2* for the rocking IF of a rigid disk on elastic half-space. While the implementation of this solution in OpenSees looks simple, the stability of the entire system is not guaranteed even if the IF filter is itself stable. In this project, we propose to implement any analytically or numerically calculated frequency-dependent IF through recursive filters in OpenSees and such that the dynamic analysis of the entire structural system with SSI can be stable.

Deliverables
A PEER report and several conference and journal papers describing the methodology and verification examples along with the OpenSees module for frequency-dependent IF implementation.

Research Impact
The dynamic nonlinear time-history analysis plays a critical role in PEER Performance-Based Engineering (PBE). While nonlinear behavior of the structures can be modeled with relatively good accuracy, the soil-foundation subsystem is still highly uncertain. One of the sources of the uncertainties is the frequency-dependent behavior of the soil-foundation impedance function. Current FE modeling softwares are not capable of including frequency-dependency in the time domain unless IF is modeled through physical lumped parameter models. However, there is no unique and general way to develop such lumped models for any IF. Also, there is no solution to guarantee the stability of the entire system. This project will provide engineers and researchers with an extended version of the OpenSees by which they can carry out more accurate nonlinear time-history analysis while frequency-dependent soil-structure interaction effects are taken into account.

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Project Images

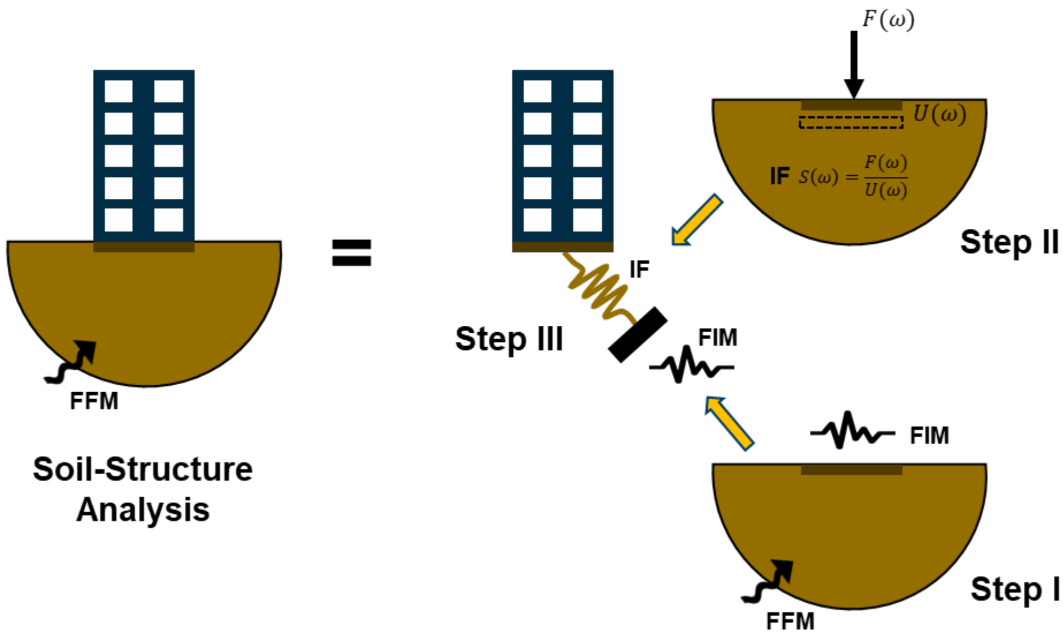

Figure 1. Substructure method

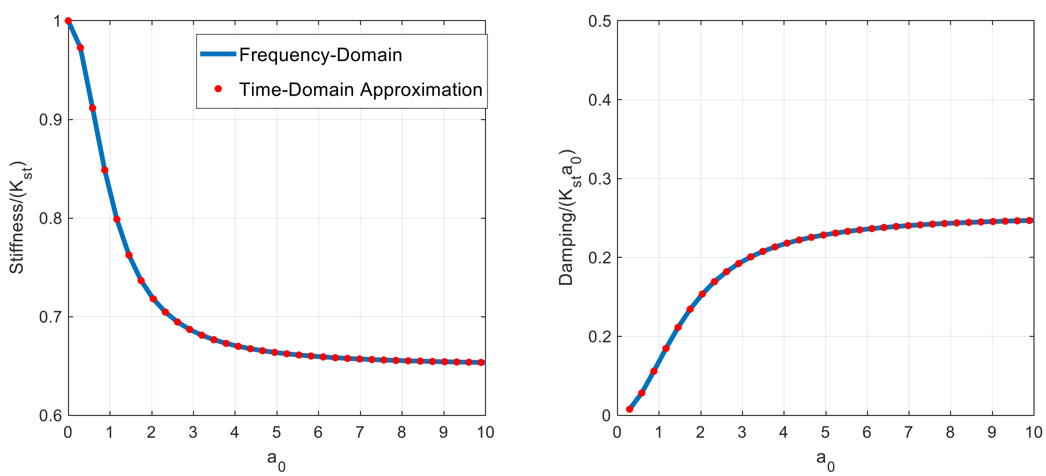

Figure 2. Exact and time-domain approximation of frequency-dependent stiffness and damping terms of impedance function versus dimensionless frequency.

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