Research Project Highlight

OpenSees implementation of 3D embedded pile element for enhanced soil-pile interaction analysis of bridge systems subject to liquefaction and lateral spreading

TSRP Topic – PBE Tools – T2

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Abstract

With the current growth in computational power, numerical modeling of seismic events has become a viable tool used in the structural design of bridge systems. Events like the Maule earthquake in Chile (2010), where several bridges collapsed partly or completely due to forces exerted by lateral spreading of the soil prove that soil-structure interaction continues to be an important aspect to consider in numerical analyses of bridge systems. The interaction between the soil and pile foundation is highly nonlinear and inherently complex in nature. Several factors contribute to this nonlinearity including the constitutive behavior of the surrounding soil, constitutive behavior of the pile itself, geometrical nonlinearities of the pile structure, and the interface behavior between the soil and the pile. One-dimensional springs (p-y springs), representing the nonlinear response of both the soil and interface, are commonly used and are available in OpenSees. These elements rely heavily on empirical data and are validated mostly against static or quasi-static experimental data; in general using simple foundation configurations. Their use in large foundation models where the soil is represented by 2D and 3D finite elements is questionable; since these elements cannot represent the complete 3D soil-pile domain and geometry. More advanced contact models based on node-to-node and node-to-solid contact formulations have been proposed and several of such elements are implemented in OpenSees. In particular, the author proposed and implemented in OpenSees a beam-to- solid contact element that greatly simplifies the representation of structural components using 1D beam elements. In this element the contact between the soil and pile surface imposes the impenetrability geometrical condition at nodes and introduces singular point loads to impose the constraint. Although computationally expensive, these elements have proven very effective for static and quasi-static analyses. For complex geometries, however, discretization of the model to incorporate such elements is cumbersome. This problem is exacerbated in dynamic analyses of complete infrastructure systems (e.g. complete bridge) that include pile groups with

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many piles and/or drilled shafts. To address (alleviate) this problem, in this proposal an embedded beam element formulation is proposed to be implemented in OpenSees. The element formulation is based on the early work of Turello (2016) as modified by Ghofrani (2018). A schematic of embedded elements showing a regular FEM grid, beam elements, and contact interface surfaces is shown in Figure 1. This formulation imposes interaction constraints between 1D beam elements embedded inside a regular 3D solid element over an explicitly defined interface surface. By imposing the constraints in a weak sense along an imaginary interface surface, a uniform contact pressure can be generated. In contrast to other contact formulations, in this case the soil domain can be uniformly discretized as the new embedded element removes any dependency on discretization. Interface behavior is attained using traditional contact mechanics such that the impenetrability condition is satisfied in a weak sense along the interaction surface and elasto-plastic behavior is used to represent the near-field soil behavior. This formulation eliminates the need to discretize the soil surrounding the pile to match the pile geometry and greatly simplifies mesh generation and post-processing. This is most important, in dynamic analysis of large and complicated systems where the response of the foundation is not the only aspect to be considered

Deliverables

The embedded element will be implemented in OpenSees and distributed OpenSource. The OpenSees manual will be updated to include this element and examples will be provided. A PEER report and several conference and journal papers describing the embedded element formulation, implementation details and examples will be produced.

Research Impact

The main objective of the proposed work is to facilitate representation of SSI by embedding elements in regular FEM meshes. In this way, embedded beam elements can be used to perform relatively fast and straightforward analysis of seismic and aseismic numerical simulations of foundation systems. They can be used for analysis and design of bridge pile foundations subject to axial and lateral loads, seismic excitations, lateral spreading and liquefaction flow failures. The proposed elements can also be used for validation and verification of current design methodologies as well as analysis of complicated engineering problems. Their application to practice is natural and in sync with other efforts in commercial codes like FLAC and PLAXIS.

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The proposed work complements other PEER research efforts related to OpenSees implementation and validation of constitutive models for soils and of structural elements. Soil structure Interaction (SSI) is the obligatory link necessary to connect the geotechnical and structural domains. This works aims to improve current functionality in OpenSees to facilitate dynamic analysis of pile foundation systems.

Project Image

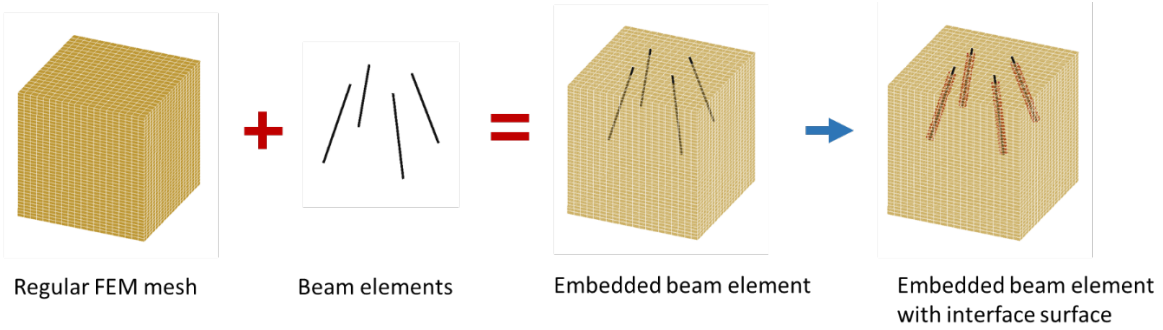

Figure 1: Schematic of embedded element.

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