A 3D Finite Element User-Interface for Soil-Foundation Seismic Response

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ABSTRACT
This paper presents an approach aimed at simplification in the use of finite elements for seismic response of soil-structure systems. Specific focus is given to the pre- and post-processor OpenSeesPL. The OpenSeesPL processor is a special purpose user-friendly interface allowing convenient studies of 3D seismic (earthquake) and/or push-over pile analyses. Analysis engine for this interface is the PEER finite element code OpenSees. Challenges related to defining and entering numerical parameters in complex pile modeling environments are addressed. Elements of the OpenSeesPL processor are discussed.

KEYWORDS: Finite element, pile analysis, soil structure interaction.

INTRODUCTION

In numerical simulations, preparation of data files is a step that requires careful attention to detail. A minor oversight might go undetected leading to erroneous results. Numerous opportunities for such small errors abound. A user-friendly interface can significantly alleviate this problem allowing for high efficiency and much increased confidence.

Commercial computer codes usually offer powerful pre- and post-processing capabilities, which increase efficiency and reduce the chance for error. Currently, the tools for creating such user-friendly interfaces are becoming commonplace, allowing specialized numerical codes to be more easily utilized. Windows-based coding techniques allow for broad usage on a world-wide scale.

In this paper, a Windows-based user interface program (OpenSeesPL) is described. This program allows for executing the finite element code OpenSees for pile analysis. Adaptation for use with other finite element programs is straightforward.

OPENSEESPL

The current version of the Windows-based program OpenSeesPL (Figure 1) is available at http://cyclic.ucsd.edu/openseespl. This program allows for the execution of single pile simulations under seismic excitation scenarios as well as push-over situations. The theoretical background is discussed in Parra (1996), Elgamal et al. (2002a; 2002b; 2003), and Yang (2000; 2002; 2003).

OpenSeesPL includes a pre-processor for: 1) definition of the pile geometry and material properties, 2) definition of the 3D spatial soil domain, 3) definition of the boundary conditions and input excitation or push-over analysis parameters, and 4) selection of soil materials from an available menu of cohesionless and cohesive soil materials (Figure 2). The menu of soil materials (Table 1) includes a complementary set of soil modeling parameters representing loose, medium and dense cohesionless materials (with silt, sand or gravel permeability), and soft, medium and stiff clay (J_2 plasticity cyclic model). Representative soil properties are pre-defined for each of these soils (Table 1).

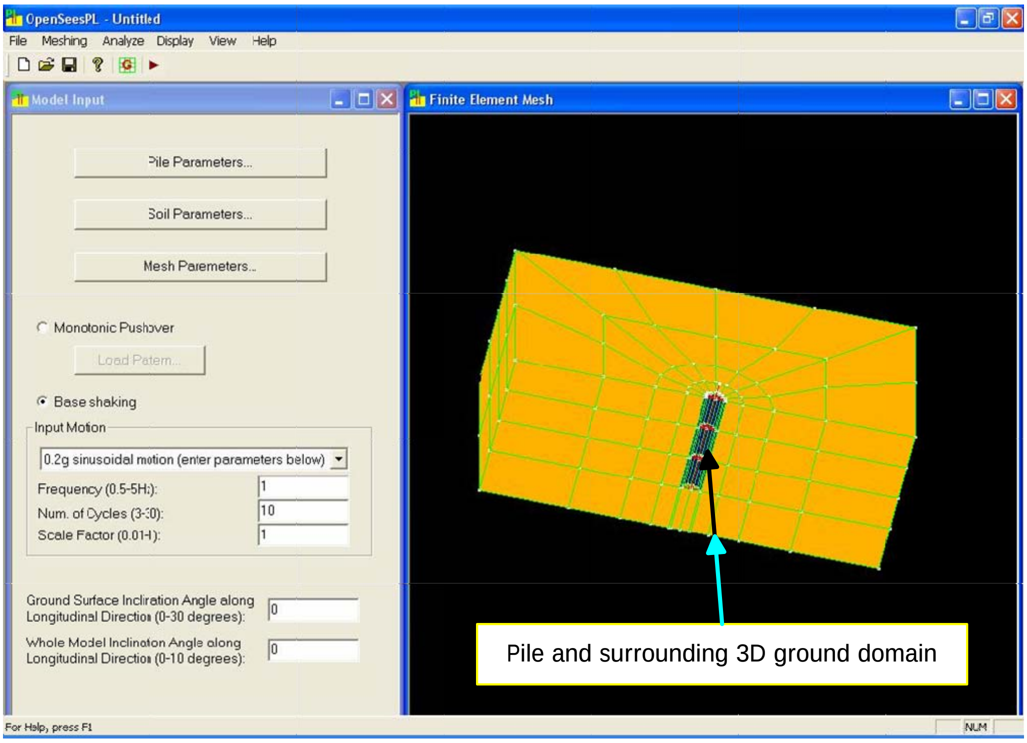

Figure 1: OpenSeesPL user interface (the mesh shows a circular pile in level ground (view of ½ mesh employed due to symmetry for uni-directional lateral loading)).

Table 1: Representative set of basic material parameters (data based on Seed and Idriss (1970), Holtz and Kovacs (1981), Das (1983), and Das (1995)).

Cohesionless Soils	Shear wave velocity* at 10m depth (m/s)	Friction angle (degrees)	Possion's ratio	Mass density (kg/m^3)
Loose	185	29	0.4	1.7x10^3
Medium	205	31.5	0.4	1.9x10^3
Medium-dense	225	35	0.4	2.0x10^3
Dense	255	40	0.4	2.1x10^3
Cohesive Soils	Shear wave velocity (m/s)	Undrained shear strength (kPa)	Possion's ratio	Mass density (kg/m^3)
Soft clay	100	18.0	0.4	1.3x10^3
Medium clay	200	37.0	0.4	1.5x10^3
Stiff clay	300	75.0	0.4	1.8x10^3

* Shear wave velocity of cohesionless soils in proportion to $(p_m)^{1/4}$ where p_m is effective mean confinement.

These representative properties attempt to embody the inevitable inaccuracies associated with measurement, testing, and standard site investigation procedures. However, the definition of these properties (e.g., for use in liquefaction analysis) lacks due scrutiny and acceptance (e.g., via a peer review process), and in this regard remains of only limited value. Nevertheless, such pre-defined soil properties are: 1) indicators of ranges for values of the different parameters, 2) collectively as a set, allow the constitutive model to reproduce a response bracketed by observations (and some validation) based on the underlying employed data sets (from full-scale downhole array measurements, sample laboratory testing, and centrifuge testing data sets).

OpenSeesPL also allows users to control soil parameters such as yield strength (S_u) for instance, making the definition of properties as simple as the user wishes and the situation demands. In addition, appropriate windows can be created for users to include their own material models in OpenSees, and access these materials through the finite element program OpenSees (McKenna 1997; McKenna and Fenves 2001).

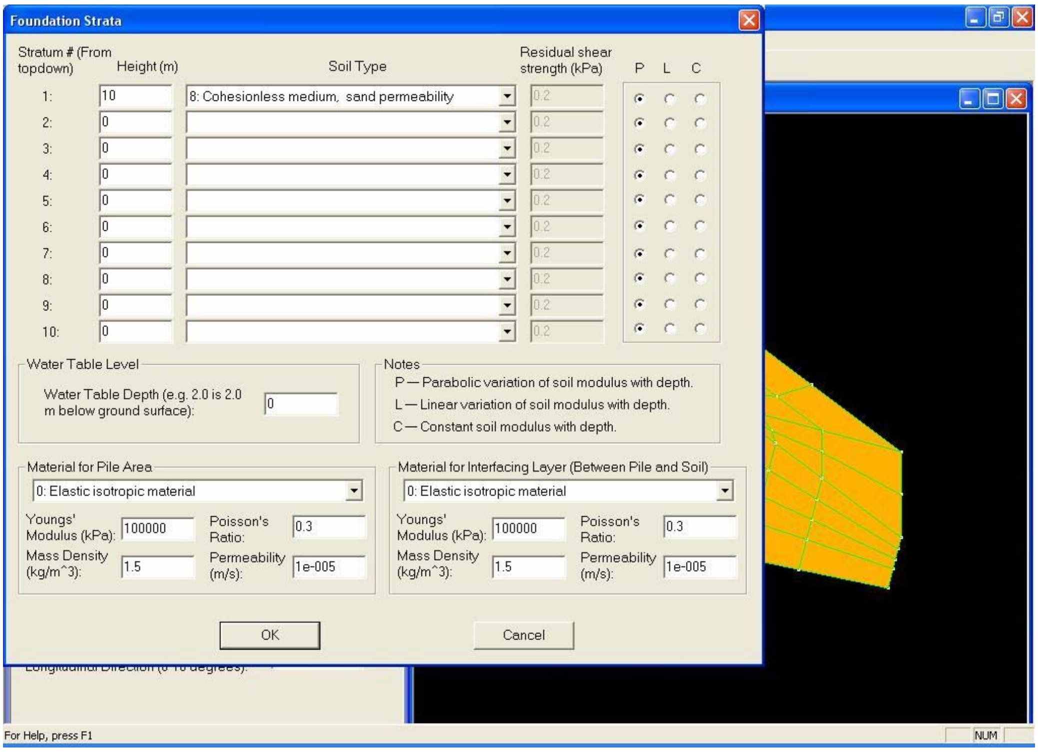

Figure 2: Definition of foundation/soil properties.

PILE DEFINITION

Definition of pile dimension and material properties is an important part in OpenSeesPL. In this interface, pile cross section can be circular or square. The interface can generate meshes for piles in slopes, knowing that this problem is one of much significance (Figure 3). Options of quarter mesh, half mesh and full mesh (Figure 4) are available for use (to reduce computational effort depending on the situation at hand). In addition, OpenSeesPL allows for simulations for any size of pile diameters. In this regards, it can be used for analysis of large diameter shafts, an extremely involved modeling problem, for which p-y type (L-Pile style) analyses may be more difficult to calibrate.

The interface benefits from a versatile nonlinear beam-column element that is already part of OpenSees. This allows for specifying the steel and concrete configuration (including for instance an outer steel shell when used), and thereafter conducting a study where pile yielding might occur as dictated by the selected steel/concrete configuration. Figure 5 shows the window to define pile geometry and material properties.

The interface can easily include a bridge super-structure as well, permitting inertial loads from the bridge (in all 3 directions) to act on the foundation (Shaft or pile group). Every element of this problem can be specified as linear or nonlinear permitting unprecedented convenience in conducting such a Soil-Structure Interaction (SSI) problem.

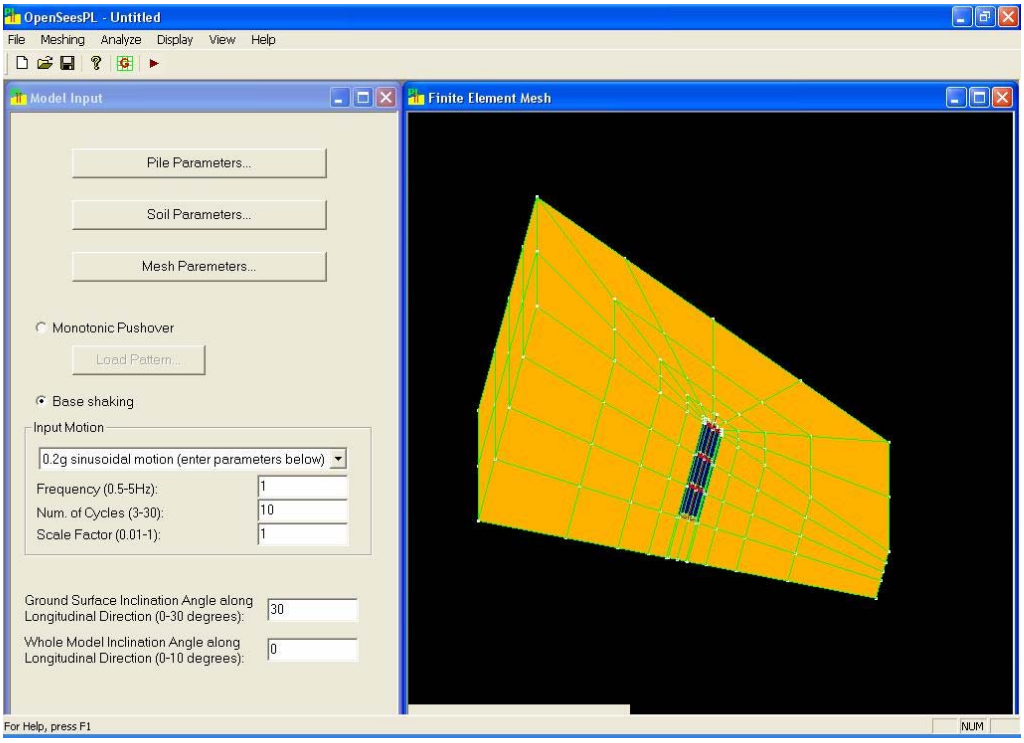

Figure 3: Square pile in slope: filled view of ½ mesh due to symmetry.

ANALYSIS OPTIONS

The interface allows for running push-over type analyses (with load/moment specified at any height above ground surface, and the pile shaft extending to this height). It also allows for running seismic (shaking) analyses, using any specified input ground excitation. A small library of recorded seismic motions is already part of the package (a scaling parameter allows for increasing/decreasing the amplitudes of each record). This part of the interface can be extended with virtually unlimited recorded motions from the PEER strong motion library, and with all kinds of scaling options (such as matching spectral accelerations at a given period for instance).

FUTURE WORK

With continued work, the interface will allow for direct analysis of pile groups. The interface can eventually generate meshes for pile groups, and allow us to benefit from insights as relates to this problem as well. Eventually, the interface can also include a capability to simulate ground modification strategies (i.e., locally change soil/foundation properties in order to develop an acceptable response), among many other possibilities. Options for probabilistic analysis along the lines of PEER PBEE can be implemented as well.

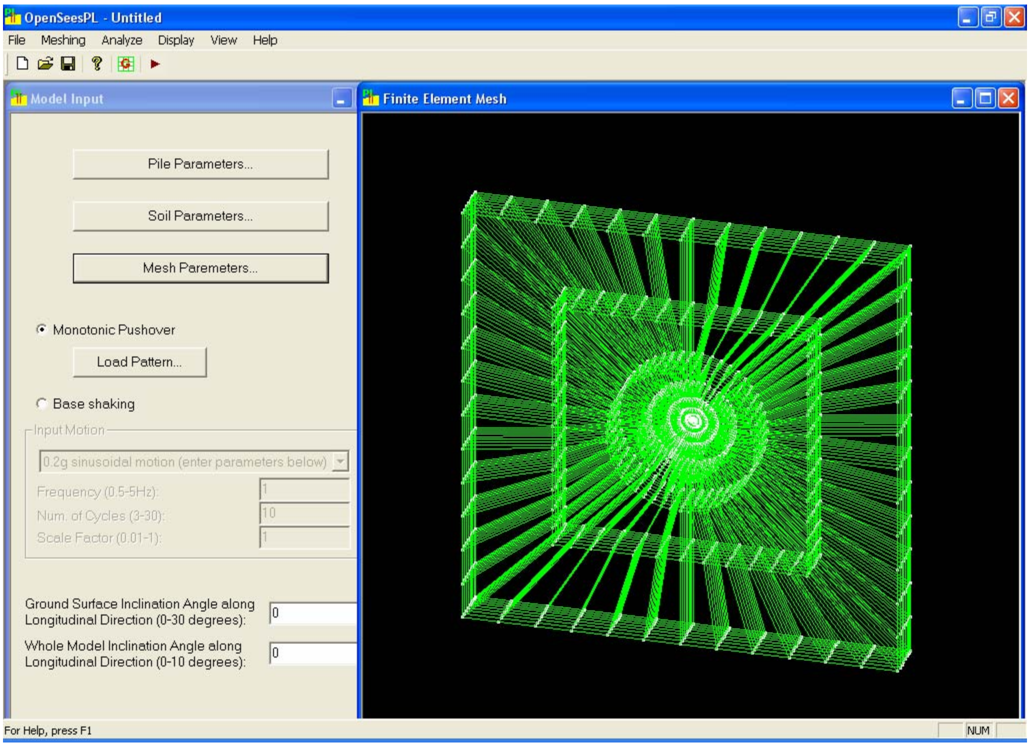

Figure 4: View (unfilled) of 3D fine full-mesh (for combined x-y loading).

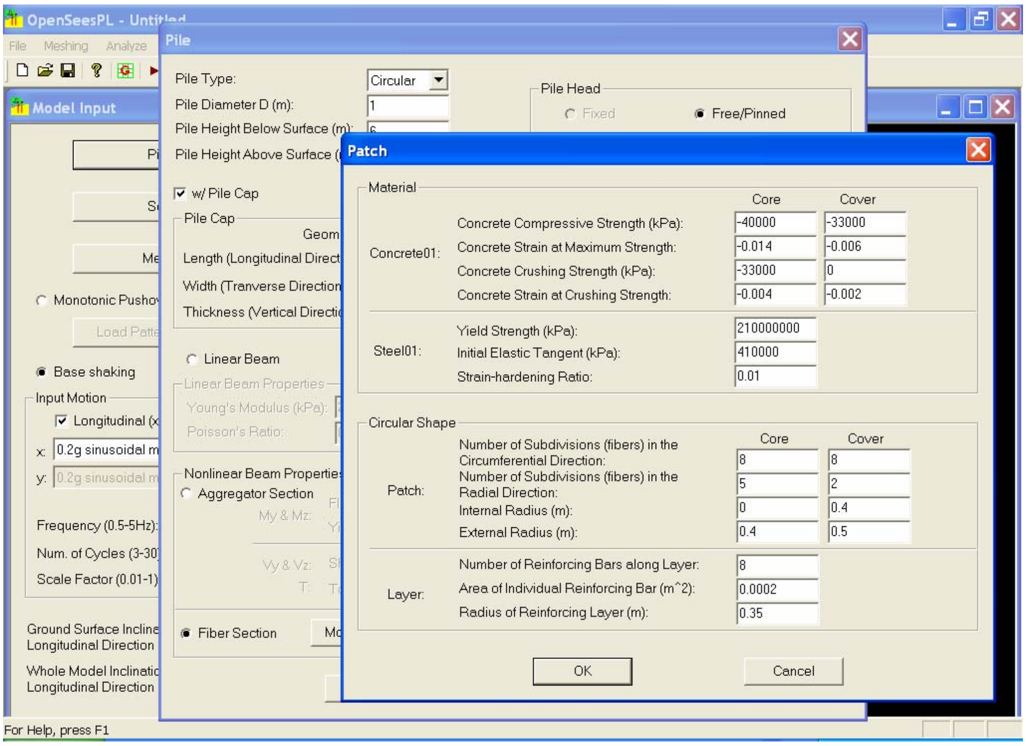

Figure 5: Definition of nonlinear pile properties.

Finally, the interface already has an effective post-processor for display of output in many ways (including animation), and we would like to further enhance this option providing a way to automatically save selected graphs and other outputs to a Microsoft WORD document which practically is a ready to go report of the results.

ADDITIONAL COMMENTS

1) It is important to note that the interface actually just creates and saves an "Input file" for the OpenSees program to use in running the problem (and thereafter displays the results). In this regard, users can employ the interface to develop any mesh they wish, and then just save the file, and thereafter open this input file and manually make any desired modifications (e.g., change properties of a given element in this mesh).

2) OpenSeesPL is very useful for looking at all scenarios, including those of satisfactory pile/ground performance (for design purposes, without objectionable levels of nonlinearity), i.e., it is not meant only for highly nonlinear scenarios and permanent deformation estimates (which it also does).

3) This interface will open the door for routine analyses using 3D finite elements to deliver estimates of moment and pile displacement. In this regards, such estimates can be made directly instead of going through the process of defining interface springs (the p-y concept).

4) It is important to note that this interface is not only meant to conduct complex analyses, but can be used for simple and insightful configurations. In either case, the problem definition and program execution might actually be as convenient as using simplified programs such as L-Pile for instance. The outcome no doubt will be a great complement to insights from programs such as L-Pile, but actually will also allow for studying configurations that far exceed those possible by p-y logics.

5) Analysis of the interface platform being developed using OpenGL (the current microsoft standard) lends itself to relatively easy adaptation for use in many other problem specific applications in structural engineering and in SSI. In this regard, 1D site amplification problems, 2D site amplification/shallow foundation/deep foundation, earthdam analyses, and the this 3D interface are all based on exchangeable modules that allow one package to jump start developments for the other, in a most efficient manner.

SUMMARY AND CONCLUSIONS

In an attempt to increase efficiency and reduce the chance for error, a user-friendly interface is being developed to facilitate use of otherwise complicated computational environments with numerous (often vaguely defined) input parameters. The effort is a first step in the direction of allowing for more convenient exposure and utilization of such computational tools. A peer review process is needed to verify and provide extra credibility to the pre-defined structural and soil model parameters and the resulting response. In a more general framework, the process can facilitate collaborative efforts, and comparisons between constitutive models and numerical formulations of different researchers, as envisioned by the UC Berkeley OpenSees platform developments.

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