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PileAnalysis: A Python-Based GUI Program for Pile Foundation Analysis

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Extended Abstract

Pile foundations are widely used in bridge and other civil engineering structures, and their mechanical response is governed by complex pile-soil interaction under axial, lateral, and combined loading conditions. Accurate estimation of this interaction is essential for evaluating structural performance under extreme seismic events. However, existing pile foundation analysis software often lacks effective integration of conventional engineering approaches and advanced numerical methods. Many commercial software products (such as LPILE and RSPile) are closed-source, making methodological extension, transparent verification, and customized model development difficult. Conversely, open-source platforms like OpenSeesPy offer powerful nonlinear modeling capabilities but generally require significant programming expertise, manual nodal and elemental construction, and complex post-processing scripts, which reduces modeling efficiency for both engineering and research applications. To address these limitations, this study develops *PileAnalysis*, an open-source Python-based GUI program for pile foundation analysis. The software successfully integrates both the traditional linear elastic m-method and nonlinear Winkler-based pile-soil interaction analysis within a unified graphical framework. It significantly lowers the technical barrier by eliminating the need for users to write complex finite element scripts, while its open-source nature facilitates modular extensibility.

PileAnalysis adopts a modular architecture comprising three main components: a launcher, an m-method module, and a nonlinear springs-based module, as shown in Fig.1. The launcher is developed using PySide6 and loads each analysis program as an independent subprocess, ensuring effective isolation between the two runtime environments. The m-method module consists of three subcomponents: parameter processing, a Fortran solver, and results visualization. The Fortran solver supports three analysis modes: Pile Group Stiffness, Single Pile Stiffness, and Back Analysis. All three modes can handle layered soil profiles, aboveground free-length segments, circular and square pile cross-sections, and a variety of boundary conditions. Similarly, the nonlinear module consists of a parameter-processing component, an

OpenSeesPy solver, and a results-visualization component. Both analytical modules provide a graphical user interface, allowing users to complete parameter input, model construction, and result visualization without scripting.

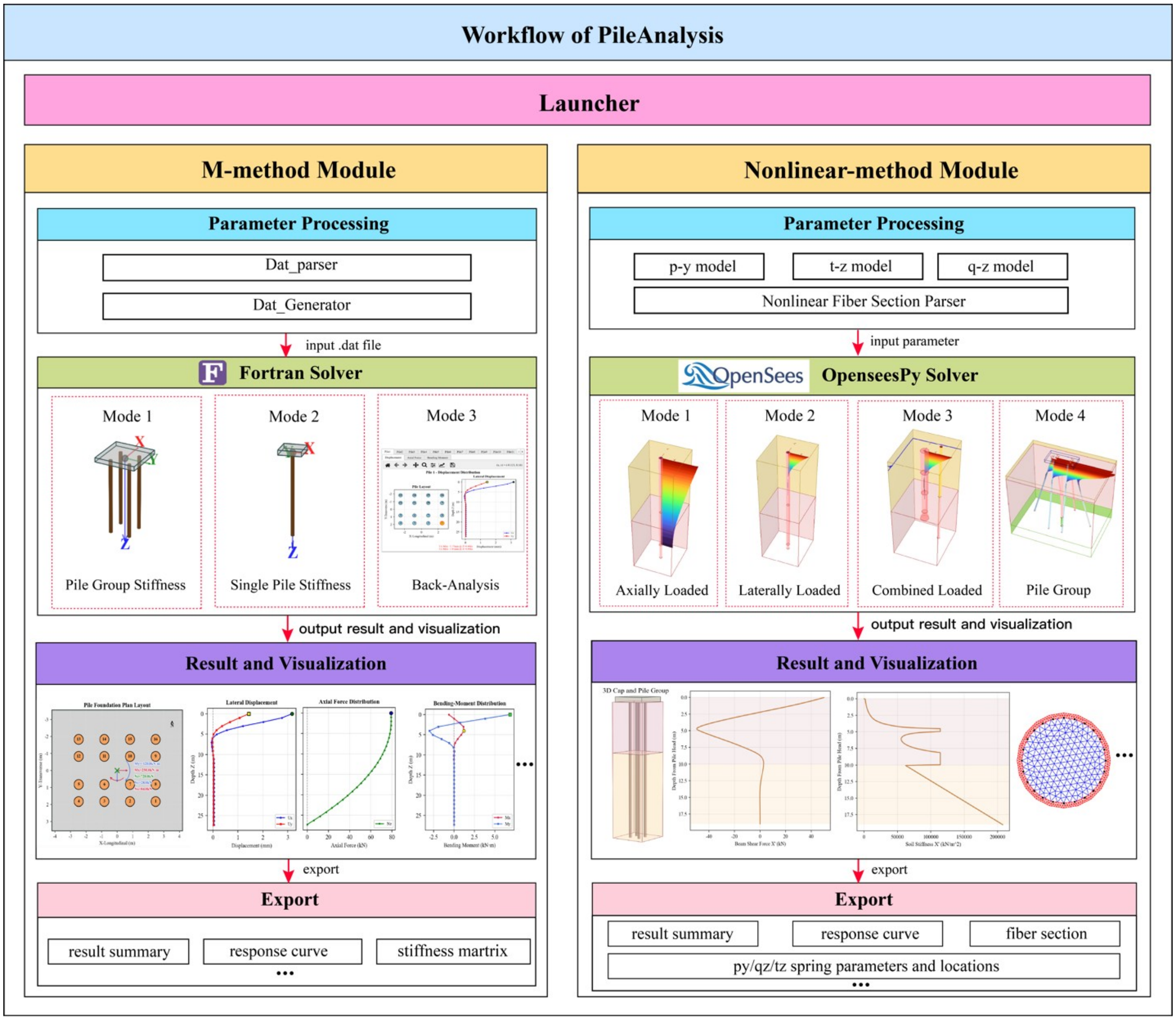

Fig.1. Main components and workflow of PileAnalysis

In the nonlinear analysis framework, *PileAnalysis* constructs soil-pile interaction models based on the Beam on Nonlinear Winkler Foundation (BNWF) theory, supporting axial, lateral, combined-loading, and group-pile analyses. The pile is discretized into beam elements, while nonlinear *p-y* springs, *t-z* springs, and *q-z* springs are assigned along the finite element nodes to simulate lateral soil resistance, shaft friction, and tip resistance, respectively. Based on the specified soil type and selected empirical model, the program automatically generates the corresponding *p-y*, *t-z*, and *q-z* spring backbone curves and associated spring parameters, which are then passed to the OpenSeesPy solver for finite element analysis. In addition, the framework integrates a Nonlinear Fiber Section Parser that supports importing and parsing fiber-section data generated by SectionMCPy and stored in HDF5 databases, enabling incorporation of pile material nonlinearity into the overall pile–soil interaction analysis. Fig. 2 shows the BNWF-based soil–pile interaction model, representative hysteretic responses of p-y, t-z, and q-z springs, and the visualization of the nonlinear fiber section.

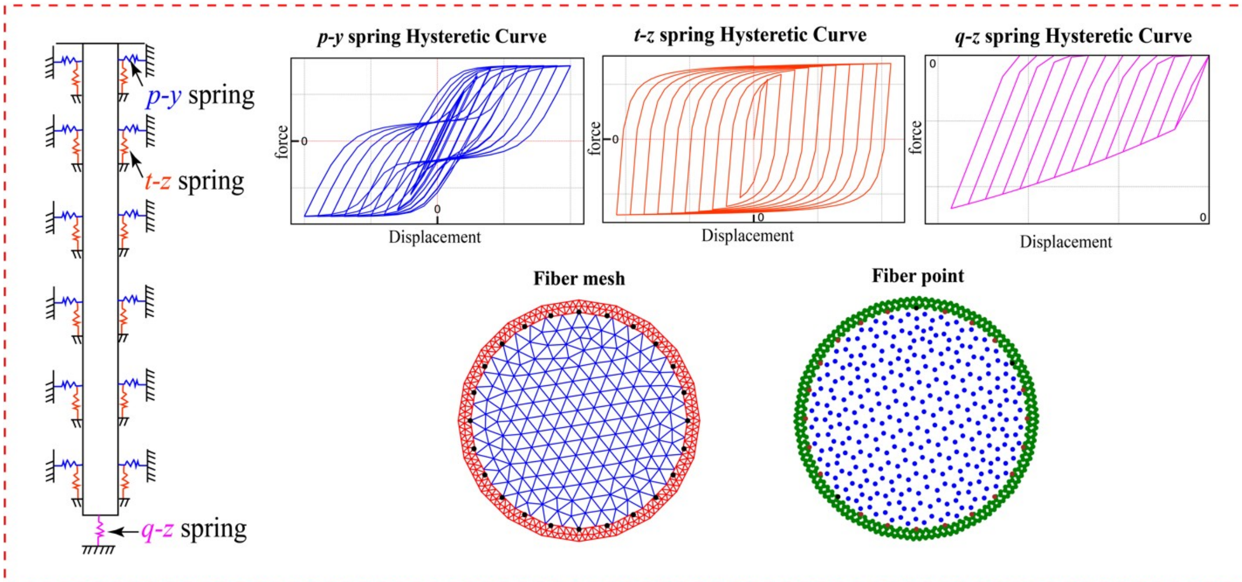

Fig.2. BNWF-based soil-pile interaction models and fiber section visualization.

Validation against the commercial software RSPile confirms the computational accuracy and reliability of PileAnalysis, with the maximum discrepancies of key response quantities remaining within 20%. Beyond static analysis, the stiffness matrices and soil spring parameters exported by *PileAnalysis* provide robust modeling support for bridge seismic design and multi-level seismic demand evaluation. Its m-method module can efficiently compute the stiffness matrix of single piles and pile groups, providing practical stiffness values for linear-spring-based pile-soil interaction models used in structural finite element analysis. Furthermore, the nonlinear module supports exporting the *p-y*, *q-z*, and *t-z* spring parameters, along with node coordinates, for each pile. This feature facilitates the construction of pile-soil interaction models in external platforms, effectively reducing the need for repeated model derivation and improving modeling efficiency for subsequent dynamic analyses, such as seismic response analysis. Although the current version focuses on static analysis, future work will further introduce a dynamic analysis module to support seismic response calculations.

Keywords: *Pile Foundations; Pile-soil interaction; M-method; P-y curve*