LPILE v2026
User's Manual

A Program for the Analysis of Deep Foundations Under Lateral Loading

by

Shin-Tower Wang
L. Gonzalo Vasquez
Jose A. Arrellaga
William M. Isenhower

ENSOFT, INC.

(Release: Feb. 2026)

COPYRIGHT

SOFTWARE LICENSE AGREEMENT & DISCLAIMER

IMPORTANT NOTICE: *Please carefully read the terms of the license agreement and disclaimer at the end of this book. You signify acceptance with those terms by usage of the software.*

Table of Contents

List of Figures

List of Tables

CHAPTER 1. Introduction

1.1 General Description

LPile is a special purpose program that can analyze any single deep foundation, either driven pile or a drilled shaft, that is subjected to lateral loading. The program estimates pile deflection, shear, bending moment, and soil response with respect to depth in nonlinear soils. Output from the program is presented in many charts and optional formatted report.

Various types of defined criteria for soils and rocks are modeled in LPile using nonlinear lateral load-transfer curves (*p-y* curves) based on published recommendations. The *p-y* curves are internally generated by the program. User-specified *p-y* curves of any type may also be assigned to any soil layer. Procedures are implemented in the program to compute equivalent *p-y* curves in layered soil profiles.

Several types of pile-head loading conditions and pile types may be selected by the user, and the structural properties of the pile may be varied along the pile length. Additionally, LPile provides guidelines for the layout of rebar arrangements and general design references for reinforced pile sections using the ACI 318 code. The nonlinear flexural response of most steel shapes contained in the AISC manual can be selected within LPile for any pile section.

1.2 Program Development History

1.2.1 LPile 1.0 for MS-DOS (1986)

When the IBM XT® personal computer was introduced in 1984, Dr. Lymon C. Reese, the founder of Ensoft, Inc., foresaw the benefits and improvements in analysis and design of pile foundations from using improved computer software. The development of LPile for its first commercial distribution begun in 1985 and was completed in 1986. The general theory and methodology of LPile 1.0 was similar in features to COM624, which run on large mainframe computers. LPile was completely rewritten using a new solver and features were provided for interactive input. LPile was developed for analyzing single piles and drilled shafts under lateral loading. This version of LPile was compiled using the IBM Fortran compiler to run on the IBM XT personal computer. LPile Version 1.0 had the following features:

- The program could generate p-y curves internally for soft clay, stiff clay with free water, stiff clay without free water, and sand. The program also allowed users to input user-defined p-y curves for a selected layer.
- Modifications of the p-y curves for layered soils were introduced in the program based on the recommendations of Georgiadis (1983).
- A total of four boundary conditions and loading types were available for the pile head. Distributed loading could also be specified at any pile depth.
- An interactive input was provided for the user to prepare the input data step-by-step.
- An analysis feature was provided for including tip-resistance curves.

1.2.2 LPile 2.0 for MS-DOS (1987)

With the introduction of improved graphics hardware for personal computers such as color graphics monitors and an improved processor on IBM® AT-class computers, the features for graphical display of computed pile deflection, bending moment, shear, and soil resistance became desirable for engineering software. LPile 2.0 was introduced in 1987 with a companion graphics program. Improvements were also made on the main program and input data editor.

1.2.3 LPile 3.0 for MS-DOS (1989)

With the wide adoption of LPile by government agencies, universities, and engineering firms during the first three years, improvements in ease-of-use were considered essential. LPile 3.0 was introduced in 1989 with an input data editor featuring pull-down menus, input tables, and on-screen help commands. Color graphics for CGA, EGA, and VGA displays were added to the output graphics post-processor program. The main program also added the new technical features:

- New *p-y* criteria for vuggy limestone/rock.
- Options for modifying internally-generated *p-y* curves for group action effects.
- The pile head could be positioned either above or below the ground surface.

1.2.4 LPile 4.0 for MS-DOS (1993)

LPile 4.0 was released in 1993, features added to this version were:

- New *p-y* criteria for cemented soils whose strength is represented using both cohesion and friction angle.
- New *p-y* criteria for sand based on the recommendations of the American Petroleum Institute's API-RP2A (1987).
- New *p-y* procedures for including the effect of sloping ground on *p-y* curves for clays and sands.
- New graphic plots for representing load versus deflection at the pile head and load versus maximum bending moment.

1.2.5 LPile Plus 1.0 for MS-DOS (1993)

New technology for pile foundations enabled the incorporation of nonlinear properties for the pile's flexural rigidity during analysis of their lateral deflections. Earlier, a companion computer program named STIFF was developed in 1987 to compute the relationship of applied moment versus flexural rigidity of a pile, and to compute the ultimate bending capacity for a specified structural section. LPile Plus was thus developed in 1993 by combining the capabilities of LPile 4.0 and STIFF. With the added functionality obtained from STIFF, LPile Plus had the capability to take into account the flexural rigidity of uncracked and cracked sections, which led to a improved solution for the flexibility of a pile under lateral loading.

1.2.6 LPile Plus 1.0 for Windows (1994)

The introduction of Windows 3.1 from Microsoft, Inc. as the new platform for personal computers pushed software development into a new era with a demand for user-friendly features. LPile Plus 1.0 for Windows was released in 1994 with input preprocessor and output post-processor developed specifically for the Windows operating system.

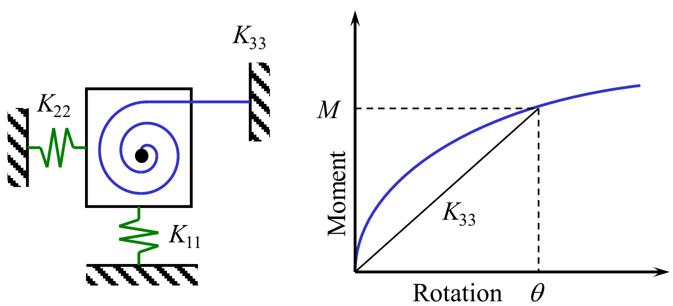
1.2.7 LPile Plus 2.0 for Windows (1995)

The initial windows version for LPile Plus was released in 1994. The preprocessor program used a mouse with pull-down menu, dialog boxes, grid tables, and push buttons to improve the process of data entry. The graphics program, also running within the Windows platform, supported any printer device recognized by the Windows environment. The main program added a feature for users to specify the rebar area at each location.

1.2.8 LPile Plus 3.0 for Windows (1997)

With the 32-bit operating systems provided by Microsoft Windows 95 and Windows NT, software developers were provided with tools to develop user interfaces with advanced, high-resolution graphics. LPile Plus 3.0 was developed based on the technological advances for new user interfaces. The significant new features of this upgrade are summarized as follows:

- A new soil criterion for weak rock was added to the previously existing eight soil types. The *p-y* criterion for weak rock is primarily applicable to the weathered sandstone, claystone, and limestone with uniaxial compressive strengths of less than 1,000 psi.
- An option was added to compute pile-head deflection versus pile length. This option generated a graph of pile length versus pile-head deflection that is helpful for determining the critical pile length.
- A feature was added to compute values for a foundation stiffness matrix that may be used in structural analysis models for a certain range of loads. In this new feature, the program creates curves of incremental loading versus foundation stiffness components K_{22}, K_{23}, K_{32}, and K_{33}, as shown in Figure 1.1.



$$\begin{bmatrix} K_{11} & 0 & 0 \\ 0 & K_{22} & K_{23} \\ 0 & K_{32} & K_{33} \end{bmatrix} \begin{Bmatrix} Q \\ H \\ M \end{Bmatrix} = \begin{Bmatrix} \delta_x \\ \delta_y \\ \theta \end{Bmatrix}$$

Figure 1.1 Pile-head Stiffness Components

- Improved features for file-management were also included to help the user. The user could use menu commands for data entry, computation, review of output, and display of graphics in a single computer program.
- Data could be input in either SI units or US customary units and existing data could be converted to the other system of units.
- All grid tables and entry fields for data entry were developed with functions that understand mathematics formulas and were aware of the current system of units.
- The graphical display of output curves features a new interface that provided the ability to zoom in on areas of particular interest. The user may thus observe detailed behavioral measurements of any portion of the modeled pile.

1.2.9 LPile Plus 3.0M (Soil Movement Version) for Windows (1998)

An advanced version for LPile Plus was developed and was released in 1998 as Version 3.0M. The LPile Plus 3.0M software is the standard LPile Plus 3.0 version with the addition of two additional capabilities:

- The user is able to input a profile of soil movements versus depth as additional loading on the pile. The soil movements of the soil may be produced from any action that causes soil movements, such as movements due to slope instability, lateral spreading during earthquakes, and seepage forces. Version 3.0M uses an alternative solver for the governing differential equation to account for the lateral movement of the soils.
- The user can input data for nonlinear curves of bending stiffness versus bending moment for different pile sections. This feature is useful for cases where the pile has different structural properties along its depth.

1.2.10 LPile Plus 4.0/4.0M for Windows (2000)

LPile 4.0/4.0M was developed for compatibility with Windows NT, 95, 98, and 2000. Modules used for computations were compiled as dynamic link library functions, which significantly improved performance. The new features for this upgrade can be summarized as follows:

- The program has the capability to generate and take into account nonlinear values of flexural stiffness (*EI*). These values are generated internally by the program based on cracked/uncracked concrete behavior and user-specified pile dimensions, and material properties for reinforced concrete sections. The program adds a new feature for analyzing prestressed concrete sections in Version 4.0.
- The user can specify both deflection and rotation at the pile as a new set of boundary conditions in Version 4.0.
- LPile Plus 4.0 can perform pushover analyses and analyze the pile behavior after a plastic hinge (yielding) develops.
- Soil-layer data structures and input dialogs are improved in Version 4 to help the user enter data conveniently with default values provided. More than 100 error-checking messages are added into Version 4.0
- Files opened recently will be listed under File Menu. New options for graphics title, legends and plot of rebar arrangement are incorporated into Version 4.0.
- New data and formats are added to the output file in Version 4.0

1.2.11 LPile Plus 5.0 for Windows (2004)

LPile Plus 5.0 was developed to meet needs for more versatility. Two more *p-y* criteria were added into the program. The feature of specifying soil movement became a standard in the program. The user can use a presentation graphics utility to prepare various engineering plots in high quality for presentations and reports. The new features for this version can be summarized as follows:

- Version 5 allows the user to define multiple sections with nonlinear bending properties. This feature permits the designer to place reinforcing steel on sections of a drilled shaft as needed, depending on the computed values of bending moment and shear.

- Version 5 allows the user to enter externally computed moment vs. *EI* curves for multiple sections.
- Version 5 can analyze the behavior of piles subjected to free-field soil movement in lateral direction. Free field displacements are soil motions that may be induced by earthquake, nearby excavations, or induced by unstable soils.
- The *p-y* criteria for liquefiable sand developed by Rollins, et al. (2005a, 2005b), and *p-y* criteria for stiff clay with user-specified initial *k* values, recommended by Brown (2002), were added into Version 5.0.
- The types and number of graphs generated by Version 5 have increased over previous versions. More importantly, the graphs may now be edited and modified by the user in an almost unlimited number of ways.
- Many hints and notes were added into input windows to assist the user in selecting proper data for each entry.

1.2.12 LPile 6 for Windows (2010)

The procedures for computation of flexural rigidity (*EI*) of pile were completely rewritten and introduced for Version 6. The new procedures are more numerically robust and generally produce moment-curvature relationships that are smoother and, in the case of reinforced concrete sections, slightly stiffer and stronger.

The input dialogs for structural sections now show the cross-section of the pile that updates to illustrate the current section data. The cross-section, number, and type of reinforcement are drawn to scale.

The user can specify either US customary units (pounds, inches, and feet) or SI units (kilonewtons, millimeters, and meters) for entering and displaying data. Most commonly used customary units such as lbs/ft^2 for shear strength and lbs/ft^3 for effective unit weight are used in Version 6.0. In general, units of inches or millimeters are used for cross-section dimensions, feet or meters are used for depth and length dimensions, and pounds or kilonewtons are used for force dimensions

Twelve *p-y* criteria for different types of soil and rock are included in Version 6.0.

The input dialogs for definition of soil properties have been improved to aid the user. Default values for some input properties are provided. Hints and notes are also shown on input dialogs to assist the user for data entry.

Over 175 error and warning messages have been provided, making it easy for occasional users to run the program and to solve run-time errors.

LPile Version 6 has the capability of performing analyses for Load and Resistance Factor Design. Up to 100 load combinations may be defined and up to 100 unfactored loads may be defined. Load case combinations are defined by entering the load factors for each load type and the resistance factors for both flexure and shear. Optionally, the user may enter the load and resistance factor combinations by reading an external plain-text file.

1.2.13 LPile v2012 – Data Format 6

LPile is currently being sold with a software maintenance contract. Users with active maintenance contracts may receive all updates and maintenance releases of LPile. In this system, the use of version numbers has been modified to permit the user to understand the basic differences between different releases of the program.

The first number is the calendar year of the release of the program. The second number is the data file format version number. Thus, all versions of the program that have the same data file format number can exchange data files without modification. The third number in the version number is the release version of the program since the data file format number was introduced.

The user should recognize that while all versions of the program with the same data file format number are largely compatible with one another, that the later release numbers of the program will often have additional features that earlier releases may lack. Thus, all users are encouraged to use the latest version of the program.

1.2.14 LPile v2013 – Data Format 7

LPile 2013-7-01 introduced three analysis features to LPile. The first analysis feature was a modification of the controls used for pile-head stiffness matrix values to permit more choices by the user over how the computations were controlled. The second analysis feature added was an automatic pushover analysis control that permitted the user to perform pushover analyses using pile-head fixity options that were either free-head, fixed-head, or both for a range of pile-head displacements controlled by the user. The third analysis feature was an automatic pile buckling analysis with options for different pile-head fixity conditions.

Additional changes were made the user-interface. More speed buttons were provides to enable quick access to input and editing of all types of data and for display of graphics. In addition, new features were provided to check the Internet for new versions of the software and to open the *User's Manual* and *Technical Manual*.

1.2.15 LPile v2015 – Data Format 8

LPile 2015 introduced several new features, along with general improvements in the user interface. The first analysis feature was the addition of

- The *p-y* curve for massive rock developed by Liang et al. (2009).
- Features to analyze multiple distributed loading profiles and multiple soil movement profiles defined for different load cases in conventional analysis. The original features to apply a single distributed load profile or a single soil movement profile to all cases were retained.
- The addition of input of a section's shear capacity for evaluation in Load and Resistance Factor Design analysis.
- Soil layer profiles were added to all speed graphs displaying pile performance results versus depth.
- The ability to import load test data for pile-head shear versus lateral deflection and bending moment versus depth for comparison to computed results.

Changes to the user interface included combination graphs of pile deflection, bending moment, and shear force versus depth and pile deflection, pile curvature, and bending moment versus depth, and modification of the existing graphs of soil movements versus depth to show multiple soil movement profiles.

1.2.16 LPile v2016 – Data Format 9

- The *p-y* curve for the hybrid model for liquefied sand developed by Franke and Rollins (2013).
- A feature to add additional sizes of reinforcing steel, including hollow bars and pipes. This feature is included under the Tools Menu.
- A feature for running a list of data files sequentially (also called batch run mode). This feature is included under the Tools Menu.

1.2.17 LPile v2018 – Data Format 10

- Expanded pile section with new feature to estimate the nonlinear flexural response of shafts with structural cores using H (weak or strong) or other wide flange sections.
- Another new feature on the structural model of pile sections is the ability to include the confinement effect for rectangular and circular shafts for moment-curvature analyses (following the Mander, Priestley & Park 1988 model for confined concrete).
- Users can now select longitudinal reinforcement with user-defined bar area in any structural section that includes longitudinal rebar. This is useful to model bars with some degree of degraded conditions (eg, from corrosion).
- For structural analyses of pile sections, LPILE can now automatically build the full interaction diagram for each section (Data > Axial Thrust Loads for Interaction Diagram).
- Users can choose to turn off the soil-layering correction criteria in models with multiple layers or to only use for layers of different soil types (*p-y* criteria).
- This version allows for the modeling and analysis of embedded piles where the pile head is below one or more soil layers. Previous versions required the pile head to be restricted within the top layer.
- An improved computation method is being incorporated for models that have both, soil movement and batter piles/sloping ground (either). In these models LPILE now uses a more conservative and theoretically-correct approach of opposite (different quadrants) *p-y* curves for computations of soil resistance and soil pressure.
- All result plots can be exported to formatted Microsoft Excel spreadsheets (data and graphics) for ease of presentation editing.

1.2.18 LPile v2019 – Data Format 11

- Equivalent Elastoplastic Moment Curvature. This is a definition used by engineers and consultants in seismic areas (based in technical documentation from CALTRANS) to define the formation of plastic hinges in piles analyzed under extreme loading or for push-over analyses. The post-hinge behavior is clearly defined in the deflection curves for pushover models.
- EnCPT Import. Ability to open data files with complete soil layering and properties defined by the new EnCPT v2019 program. This separate program allows geotechnical consultants to offer to their clients new services for detailed interpretation of their CPT

tests into various layering and soil properties that can be used quickly and customized in LPILE v2019 models.

- Optional input of a linear-elastic or nonlinear moment-vs-rotation curve at the pile tip that can be used to account for the response of short or very large diameter piles.
- Standard list of CFCC strands is now available for all prestressed pile sections.
- New option to Extend Printed p-y Curves up to Maximum Demand Displacement (under the Data > Program Options and Settings > Generate p-y Curves at User -Specified Depths). With a checkmark on this new option, the program will print the *p-y* curves after the analyses are completed and it will extend the *p-y* curve to the maximum demanded displacement (for all load cases).
- Improved computations of buckling to take into account increased flexural stiffness with increased axial loads in concrete sections (Data > Program Options and Settings > Compute Pile Buckling Analysis). Also added a new feature for users to specify a minimum compression load for buckling analysis.
- New 3D View graphics to easily observe and present LPILE models and main results (in outline graphics with optional display of maximum values).
- Program now keeps applicable values/properties of soils when users change the soil types. This is helpful to speed up unnecessary repeats of data entry.
- When inserting a new row entry of pile loads/boundary conditions the program now reproduces the entry that is just above the new row. This can help users entering similar load/boundary conditions.
- Improvements were made to calculations of rebar stress/strain in section analyses.

1.2.19 LPile v2022 – Data Format 12

- Introduces the ability to specify concentrated loads (bending moment and/or shear) at any point along the length of the pile.
- New features for analyzing the effects of short piles with large diameter: specification of Moment Resistance at Pile Tip and/or Moment due to Side Resistance along the Pile.
- Introduction of new *p-y* criteria for "Small Strain Sand" with refined study of the early response of sands under small lateral movements. The new *p-y* curves are associated to the shear wave velocity/shear wave modulus of sand layers.
- All changes to plot/graphics (titles, legends, etc) done by the user are now associated and saved with the LPile model.
- Introduces the option to analyze the effects of shear deformations in elastic pile sections.
- New optional estimation of resistance factors and shear capacity of reinforced concrete pile sections based on ACI 318-14 code specifications.
- Users are now able to evaluate and observe in one model the effects of varying pile penetrations (to check influence in deflection, bending moment and/or shear profiles).
- Definition of ground slope has been expanded so as to include a slope on one or both sides of the modeled pile.
- Pushover analyses of elastoplastic pile sections can now be stopped if a second plastic hinge is developed.

- Models with multiple load cases at pile head are now easier to prepare with new ability to Copy/Paste load definitions from clipboard or from external file.
- Users are now able to enjoy the new v2022 Technical Manual in standard PDF file format.
- Improvement in the Tools > Multi-File Analysis (Batch Run) Controls with ability to read an external text file containing the list of files for a large batch run (up to 100 files). Also improved the memory handling for large batch runs.
- Minor changes were also made throughout the program interface to improve data input and output displays.

1.2.20 LPile v2026 – Data Format 13

- Introducing three new *p-y* curve criteria:
    - Calcareous Soil/Rock (including Calcareous/Weak Carbonate Rock and Calcareous Sand) added to address the brittle nature of weak carbonate rocks.
    - Enhanced Model of Sand to provide users with more variables for the modification of the traditional sand criteria (Reese and/or API) with improved methods for the initial lateral response and for the maximum soil resistance on both small and large diameter piles.
    - ISO Clay, which is based on the latest ISO 19901-4 and recommended as an updated criteria for clays similar to those in the Gulf of Mexico or in the North Sea (Stiff or Soft), for both small and large diameter piles.
- Added a new feature to estimate shear demand along piles so it can be more efficiently used along with slope stability analyses (Ensoft's EnSlope) in models where piles are being evaluated to help stabilize slopes. Added a detailed example for piles used to stabilize slopes.
- A nominal interaction diagram can now be computed for all defined pile sections for Conventional and LRFD Analyses. For reinforced concrete sections, LPile provides a factored interaction diagram (using ACI 318) and can plot along with moment demands from all defined load cases.
- Cancel buttons have been added to many dialog boxes so users can choose to avoid making any changes before closing edited input data/tables (to revert back to when dialog box was first opened).
- Enhanced the Data > Pile Properties with many new pile section features:
    - Increased the internally available pile sections/shapes to include all the shapes from the AISC (American Institute of Steel Construction) manual.
    - Added nonlinear response of the C and Stiffened C pile sections that are often used for support of light structures such as those in most solar farms.
    - Added the option to define a second concentric layer of reinforcement for circular pile sections.
    - Allows for the selection of rebars greater than #10 for models with 3-bar bundles.
- Expanded the methods for Pushover Analysis to include usage of loading from Load Case 1 in addition to previously available fixed and free-head conditions.

- Introduced other interface improvements:
  - Consolidated many LRFD functions within the Data > Load and Resistance Cases.
  - Changed label from Cyclic Loading to Use Cyclic Model (if available) to better reflect the concept.
  - Added a Cancel button in the Data > Options and Settings dialog.
  - Improved the estimation of top deflection vs. pile embedment length (Compute Top y vs. L column in Data > Pile Head Loading). If an error occurs in any intermediate pile length, the program will continue to the next length increment and show only those results for pile lengths that were able to get convergence.
  - On program start it now displays the Graphics > Pile-Soil Geometry when opening an existing model.
  - Upon exit, LPile remembers the position and dimensions of the main interface window so it will use those settings in a subsequent program start.
  - Added the option to Copy from Clipboard (or file) unfactored load for LRFD analysis.
  - Improved the Multi Analysis Option (Batch Run) with an increased number of files to 200.
- Added a new Graphics > Load vs Ground Deflection to display the pile deflections at the level of the ground level (very useful for piles that have a stickup length above ground).
- Introduced a new Computation > Generate Report in MS Word to export a formatted report for Microsoft Word containing user-selected inputs, output tables and output graphics.

1.3 Contents of the LPILE Package

The standard single-user or local network license sent with LPILE consists of the following items:

- One USB Key, similar to Figure 1.2. This is a gray (new version) or black (old version) colored USB-based hardware security key (dongle), with a plastic tag indicating its unique serial number, licensed site (office name and location) and name of licensed software. Each USB Key is programmed with the purchased Ensoft Software. The USB Key for a single-user license can be used on any computer when plugged directly into a working USB port (it cannot be shared over a network). The USB Key for a local network license is plugged on a License Server.
- One USB Memory Stick, similar to Figure 1.3. This is a standard memory stick with either silver (new version) or white (old version) flip casing. This memory stick contains installation programs for all Ensoft Software that were available at the time of shipment. Manuals are installed with each software in electronic form using protected PDF files. The USB Memory Sticks may be discarded or reformatted for other uses. Latest updates of all Ensoft Software are always available at www.ensoftinc.com/downloads

a. New Gray Metal Casing b. Old Black Plastic Casing

Figure 1.2 Sample USB Key for Ensoft Software.

Figure 1.3 Sample USB Memory Stick.

In the optional Cloud Subscription Licensing of LPILE v2026 there is no longer any need for a shipment of USB Key or USB Memory Stick since users can download the software from Ensoft's website (www.ensoftinc.com) and sign-on licensing is verified online.

1.4 Default Installation Directories

The directories for installation of program files and for example files are selected by the user during program installation. Default values are provided by the installer and confirmed or changed by the user.

1.4.1 Directory for Main Program Files

Program files are installed by default in the following directory:

Root Drive:\Program Files\Ensoft\LPile2026

In most cases the *Root Drive* is the *c:* drive so the default is:

c:\Program Files\Ensoft\LPile2026

Main program files are the following:

LPile2026.exe is the main Windows-program module (executable/application),

Lpile13CE.dll is the program engine for direct computations, User's and Technical Manuals are also included in the main installation directory.

1.4.2 Directory for Example Files

Several modeling examples with input files (files with name/extension of the type *filename.lp13d*) are installed on a separate folder that defaults to:

Root Drive:\Ensoft\LPile2026-Examples

In most cases the *Root Drive* is the *c:* drive so the default is:

c:\Ensoft\LPile2026-Examples

1.5 Hardware Requirements

To use LPILE, the user needs the following minimum hardware configuration:

- Minimum 256 MB of storage space.
- 64-bit Windows 7 or newer operating system (Windows 10 or newer for Cloud Licenses).
- Minimum 128 MB of RAM memory.
- USB port, v2 or newer (not necessary for Cloud Licenses).
- Graphics card with OpenGL.
- A mouse or similar pointing device.
- (Optional) Any Windows-compatible printer.

1.6 Technical Support

Although the LPILE computer program was designed for ease of use in practical commercial applications, questions may be answered in the accompanying User's and Technical Manuals. The technical staff at ENSOFT strongly supports all licensed users with questions related to the installation or use of LPILE. For instance, we evaluate and troubleshoot when a specific model (input data file) provides some errors or when users have a specific question regarding an apparent discrepancy of results when comparing two different models/scenarios. However, our free services of technical support do not include free training or technical interpretations that would require engineering judgment.

New software purchases include free maintenance service for the first year (included in purchase price). After the first year the user is encouraged to purchase/renew the services for yearly maintenance. The yearly maintenance services include free download of the latest version and free technical support (as explained earlier).

1.6.1 Preferred Methods of Software Support

Software support is given, in order of preference, by the following methods:

- Electronic mail to: support@ensoftinc.com
- Telephone call to: (512) 244-6464, extension 2

Users are strongly encouraged to utilize electronic means of support via email. In all technical support requests via email, please include the following information:

1. full software version/release/update (obtained from the Help > About dialog),

2. a description of the user's problem or concern, along with any related screen captures,
3. attach a copy of the input-data file that is associated with the issue/concern (files with name/extension of the type *filename.lp13d*), and
4. name and telephone number of the contact person and of the licensed user (or name and office location of the licensed company site and/or serial number of the user's USB Key).

Although immediate answers are offered on most technical support requests, please allow up to two business days for a resolution in case of difficulties or schedule conflicts.

Technical help by means of direct calls to our local telephone number, (512) 244-6464, is available, but is limited to the business hours of 9 a.m. to 5 p.m. (US central time zone, UTC −6:00). The current policy of Ensoft is that all telephone calls for software support will be answered free of charge if the user has a valid maintenance contract.

1.6.2 Upgrade Verification and Internet Site

The software provides options for the user to check the most recent maintenance release through an internet connection by selecting Help > Check for Updates. This command starts the default internet browser and will display the user's maintenance expiration date, the user's software release number and the most recent release number that is available for downloading.

If the user's version is not the latest version and the maintenance has not been expired, the user can download the latest version from our web server directly (www.ensoftinc.com). Users may also consult our internet site for additional information on software updates, demos, and new applications; technical news; and company information.

1.1.1 Upgrade and/or Renewal of Yearly Maintenance

The cost to upgrade an old software license or to renew the yearly maintenance of a software depends on the software and length of time since the maintenance has been expired. There are small price increases with time after maintenance expiration. The pricing policy for renewing a program maintenance that has not expired can be found on the Ensoft website at https://www.ensoftinc.com/order_form

1.6.3 Changes of Support Policy

The software support policy and associated expenses are subject to change at ENSOFT's discretion and without specific mailed notices to the users. However, any change of rules will be verbally provided during telephone calls for software support.

CHAPTER 2. Installation and Getting Started

2.1 Installation Procedures

Program LPILE is distributed with an associated USB Key (hardware key or dongle). The USB Key consists of a device that should be attached to a working USB port (or USB hub) of the computer in use (or in the designated software server in the case of local network licenses). This method of software protection has been found to provide compatibility with existing operating systems, better stability than other alternatives, and allows users to obtain software updates or replacements via downloads from the internet.

Users with standard single-user licenses can check the following link to a PDF with Installation Notes:

https://www.ensoftinc.com/doc/Ensoft_Single-User_License_Installation_Booklet.pdf

Users with local network licenses can check the following link to a PDF with Network Installation Notes:

https://www.ensoftinc.com/doc/Ensoft_Network_License_Installation_Booklet.pdf

2.1.1 Installation of Single-User Version

This version of LPILE has been tested to be compatible with the following versions of the Microsoft Windows™ operating systems: 11, 10, 8.1, 8 or 7 in 64-bit releases.

The following guidelines are recommended during the installation process of LPILE for single-user licenses.

1. Plug the supplied USB Key (Figure 1.2) into one of the available and working USB ports in your computer. The USB Key is plug-and-play compatible so the operating system will recognize the USB Key automatically and a small but solid green light should appear at the end of the USB Key (a flickering green light or no light indicate problems with the standard windows driver or with the USB Key).
2. If the user installs from a distribution USB Memory Stick (Figure 1.3) and the main installation program does not start automatically upon insertion of the Memory Stick then click on the Windows Start Menu button and select Run. On the command line, type *d:\setup.exe* or *e:\setup.exe*, where *d:* or *e:* represents the drive that contains the distribution Memory Stick. Click OK to execute the command and start the main installation program for ENSOFT's software. A screen similar to the one in Figure 2.1 should appear.
3. If the user installs from a downloaded file, then please run the downloaded file (double click) and go to instruction #5.
4. Click anywhere on the Lpile 2026 icon and then click on the Install Standard button to start the installation of LPILE.
5. The user should read the license agreement shown in Figure 2.2. Users can review the License Agreement online in the following link:

   https://www.ensoftinc.com/doc/Ensoft%20License%20and%20Disclaimer.pdf

   The installer will place the same file (*Ensoft License and Disclaimer.pdf)* in the installation directory. Please click Yes if you agree and would like to proceed.
6. Select Single-User License in Figure 2.3 then click Next. For network installations please contact Ensoft support (support@ensoftinc.com).

7. The user will be provided with an option to select a drive and directory for the installation of example files (see Figure 2.4). Default installation directory is the following:

   (Root Drive):\Ensoft\Lpile2026-Examples

8. The user will also be asked to select a drive and directory for the installation of LPILE (see Figure 2.5). Default installation directory is the following:

   (Root Drive):\Program Files\Ensoft\Lpile2026

   If the desired directory does not exist, the installation program will automatically create a new directory in the chosen hard drive.

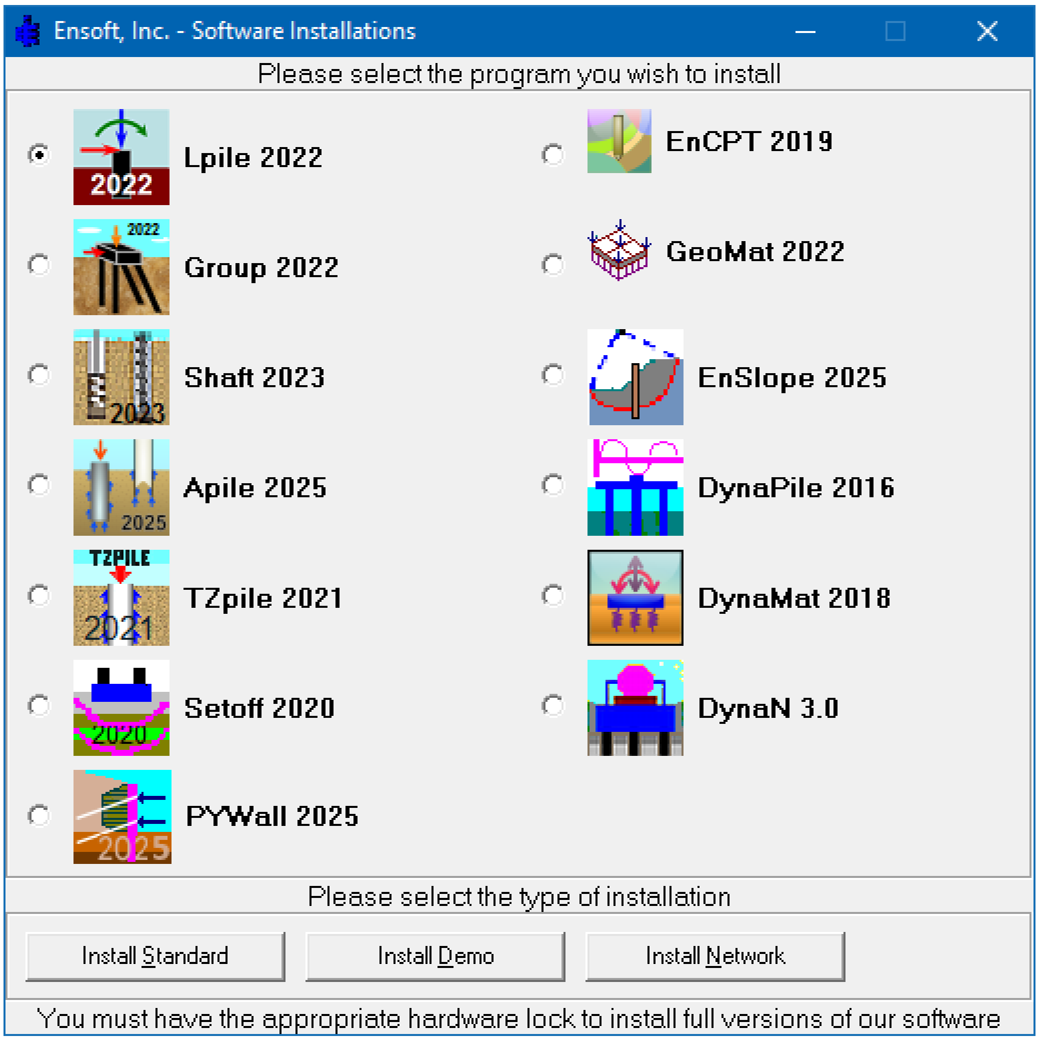


Figure 2.1 Main Installation Screen for ENSOFT Software (may change with time)

9. During the installation the user will be asked to set the file extension association for opening LPILE v2026 input data files (see Figure 2.6). If the user agrees (leaves the default check mark) then double clicking (or running) any input data file with extensions of the type *filename.lp13d* will start the installed LPILE v2026 software.

10. The user will be prompted to confirm the shortcut directory name that will be created in the Windows Start Menu (See Figure 2.7). The default is *Start Menu/Programs/Ensoft/Lpile2026*. Windows 11, 10 and 8 will automatically create an Ensoft tile with the same shortcuts.

After the installation is finished, it is usually not necessary to reboot Windows for the program to run. The user may run the program by selecting LPile v2026 from the standard links installed in the Microsoft Windows® Start Menu: Start Menu > All Programs > Ensoft > Lpile2026

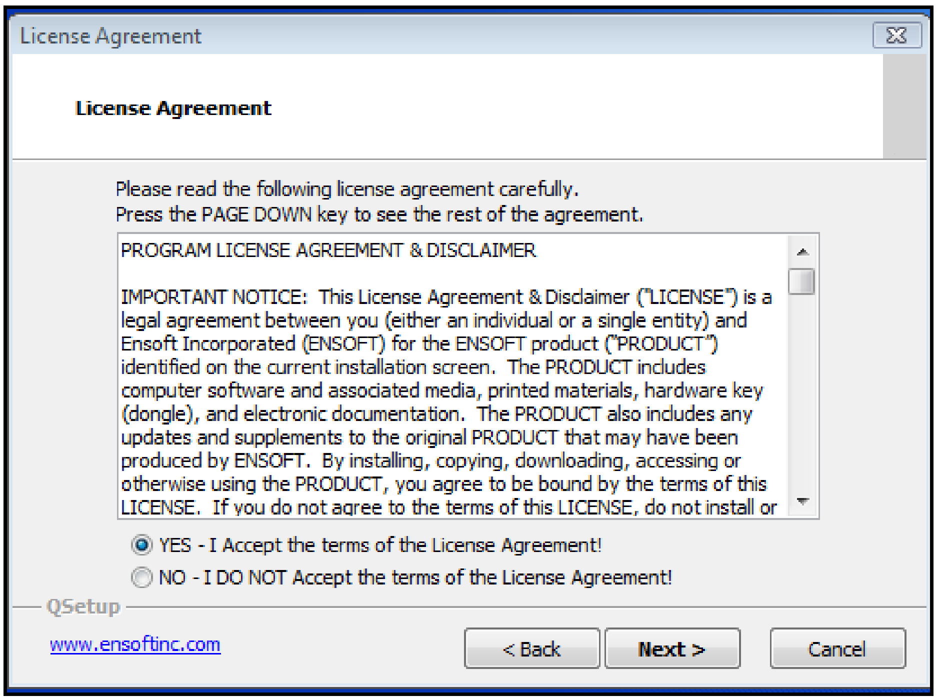


Figure 2.2 Installation Screen with License Agreement (may change with time)

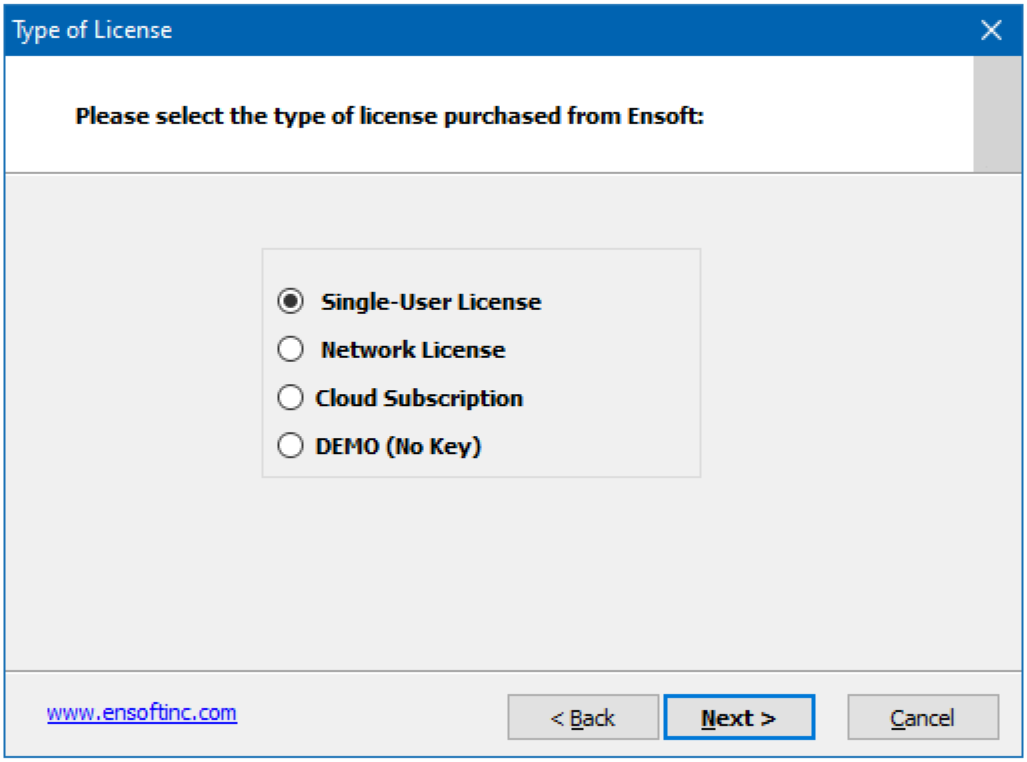


Figure 2.3 Selection of Single-User License (may change with time)

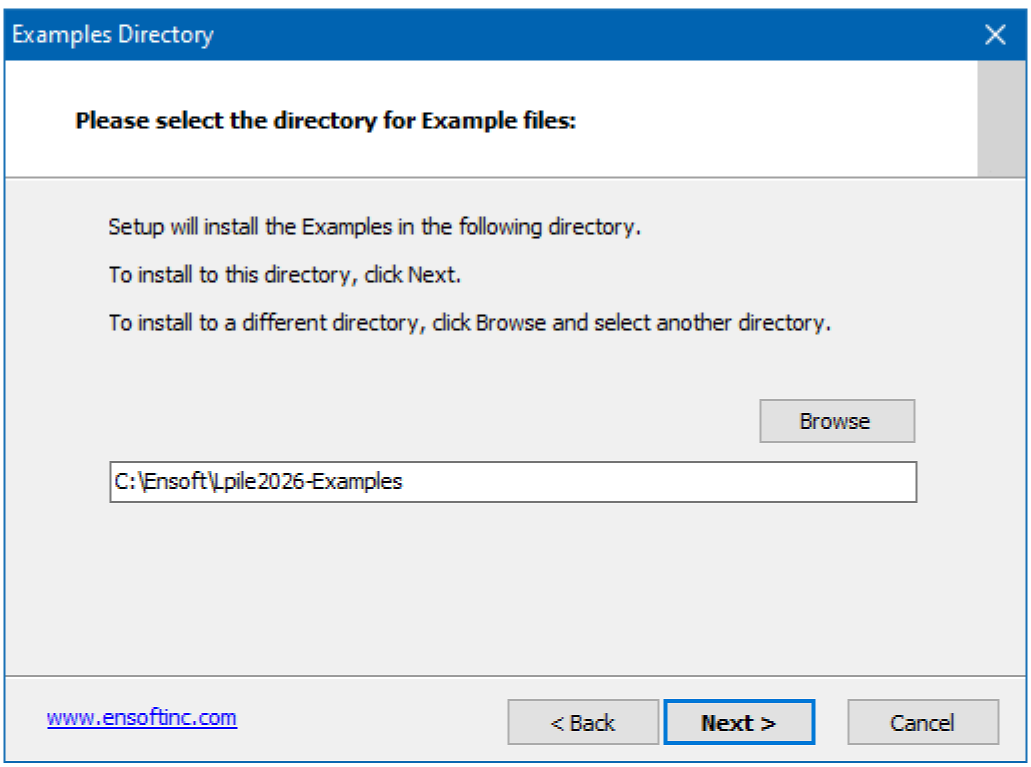


Figure 2.4 Default Installation Directory for Example Files (may change with time)

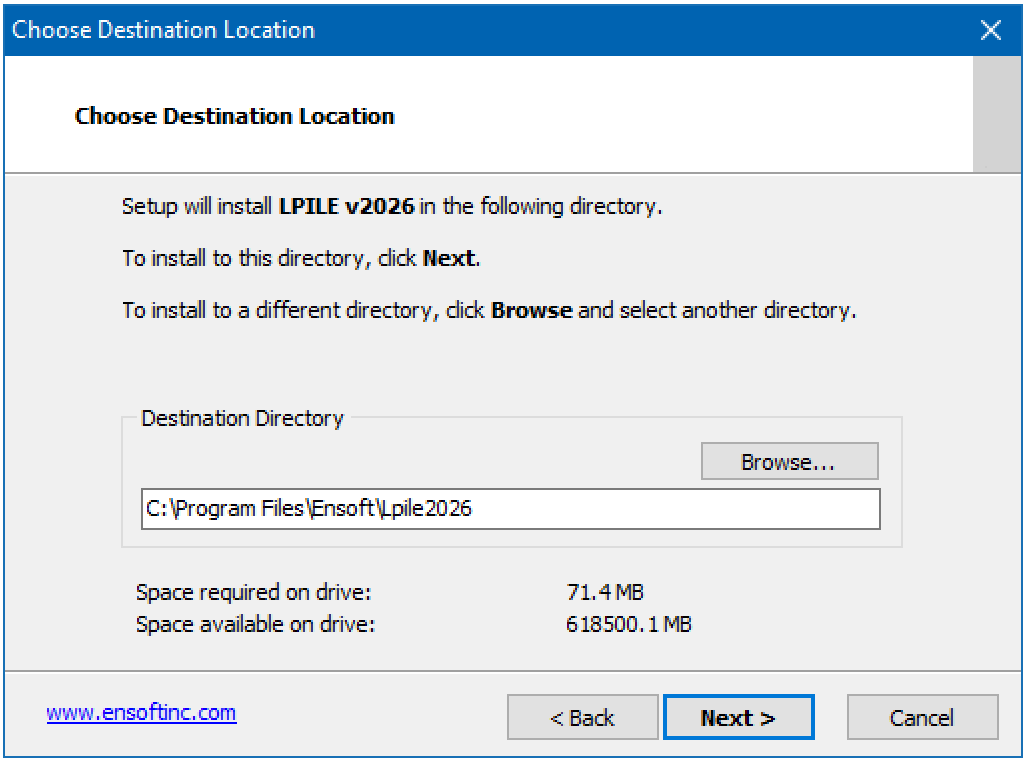


Figure 2.5 Default Installation Directory for Program Files (may change with time)

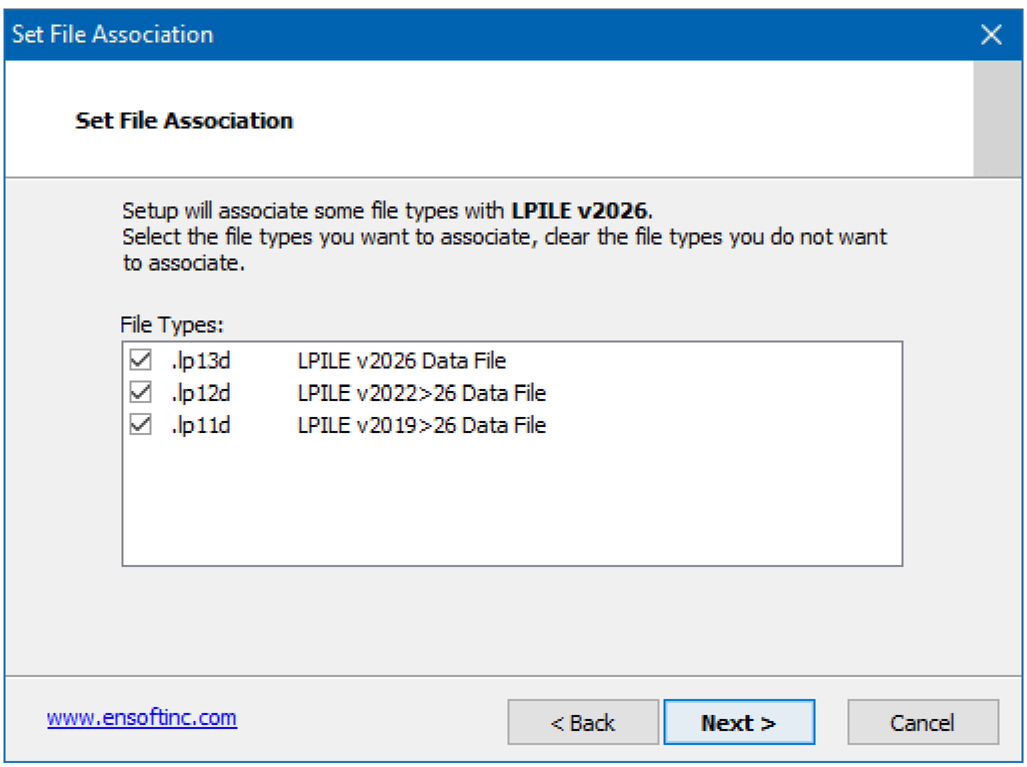
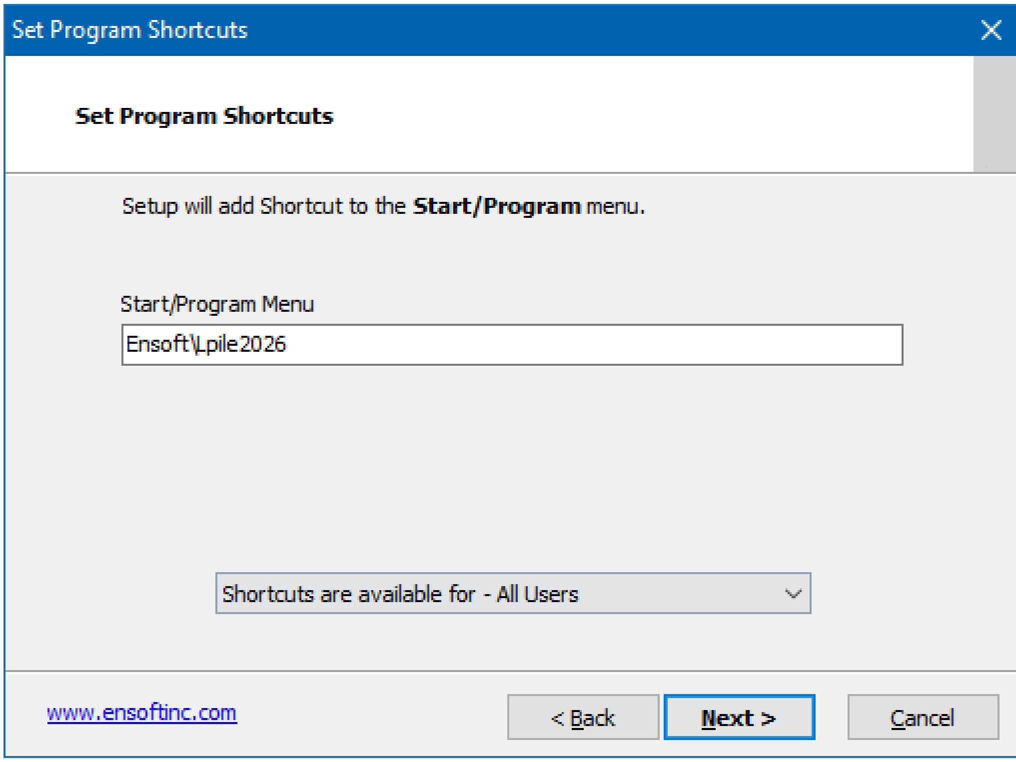


Figure 2.6 File Extension Association for LPILE Data Files (may change with time)



ENS

Figure 2.7 Default Shortcut Folder in Windows Start Menu (may change with time)

2.1.2 Installation of Cloud Subscription Version

This version of LPILE has been tested to be compatible with the following versions of the Microsoft Windows™ operating systems: 11, 10, 8.1, 8 or 7 in 64-bit releases. The following guidelines are recommended for the installation of cloud licenses.

1. Download the purchased Ensoft Software from our website using the following link:

   https://www.ensoftinc.com/downloads

   Run (double click) the downloaded executable file and select Next to continue.

2. The user should read the license agreement (partly shown in Figure 2.2). Users may also review the License Agreement online in the following link:

   https://www.ensoftinc.com/doc/Ensoft%20License%20and%20Disclaimer.pdf

3. The installer will place the same file (*Ensoft License and Disclaimer.pdf)* in the installation directory. Please click Yes if you agree and would like to proceed.

3. Select Cloud Subscription in Figure 2.3 then click Next.

4. Ensoft currently offers three types of Cloud Subscription Licenses: Personal, Office and Enterprise. The most common selection is Personal/Office since the Enterprise is only for very large customers (see Figure 2.8).

5. Only available for Enterprise Cloud Subscription licenses, the user may select to enter their identity provider identification (IdP) for the optional single sign on (SSO) licensing (see Figure 2.9). Users should consult their IT team for this type of installations.

6. The user will be provided with an option to select a drive and directory for the installation of example files (see Figure 2.4). Default installation directory is the following:

   (Root Drive):\Ensoft\Lpile2026-Examples

7. The user will also be asked to select a drive and directory for the installation of the software (see Figure 2.5). Default installation directory is the following:

   (Root Drive):\Program Files\Ensoft\Lpile2026

   If the desired directory does not exist, the installation program will automatically create a new directory in the chosen hard drive.

6. During installation the user will be asked to set the file extension association for opening LPILE v2026 input data files (see Figure 2.6). If the user agrees (leaves the default check mark) then double clicking (or running) any input data file with extensions of the type *filename.lp13d* will start the installed LPILE v2026 software.

7. The user will be prompted to confirm the shortcut directory name that will be created in the Windows Start Menu (See Figure 2.7). The default is *Start Menu/Programs/Ensoft/Lpile2026*. Windows 11, 10 and 8 will automatically create an Ensoft tile with the same shortcuts.

8. After copying files, the installer may check if the user's Windows OS has the necessary Microsoft Visual C++ drivers. If those are not found the user will be prompted to install (Figure 2.10) and must agree to terms and select the Install button. If the drivers are present, the user will be prompted with Figure 2.11 where you can simply select the Close button.

After the installation is finished, it is usually <u>not necessary</u> to reboot Windows for the program to run. The user may run the program by selecting Lpile v2026 from the standard links installed in the Microsoft Windows® Start Menu: Start Menu > All Programs > Ensoft > Lpile2026

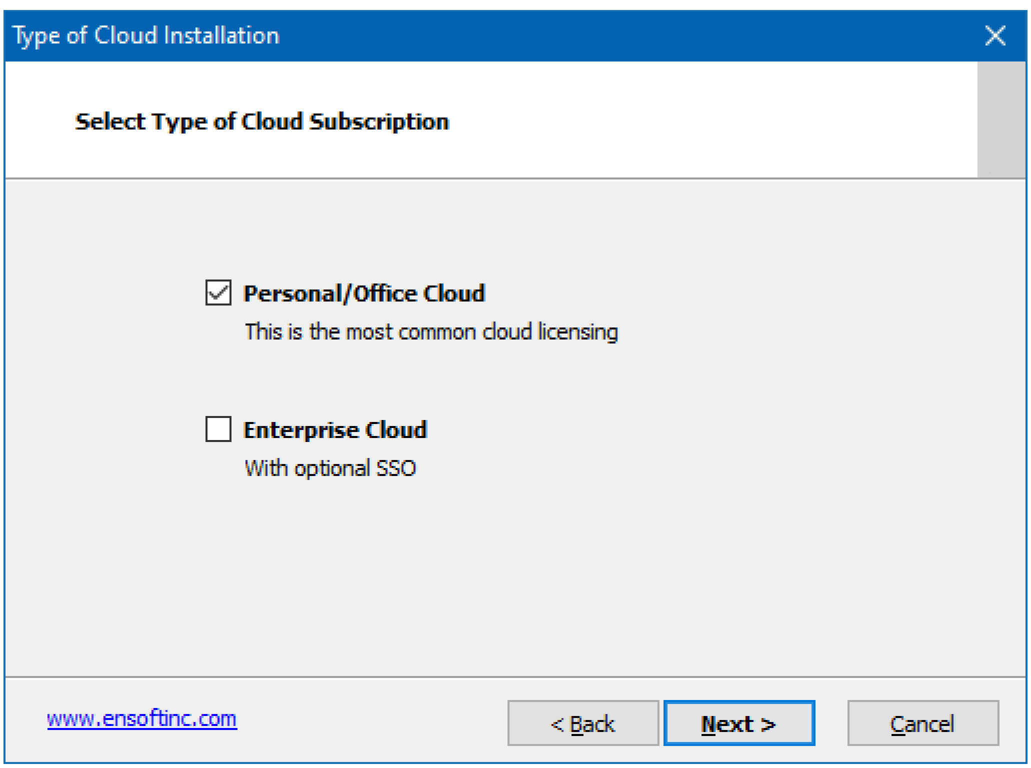


Figure 2.8 Selection of Type of Cloud Subscription (may change with time)

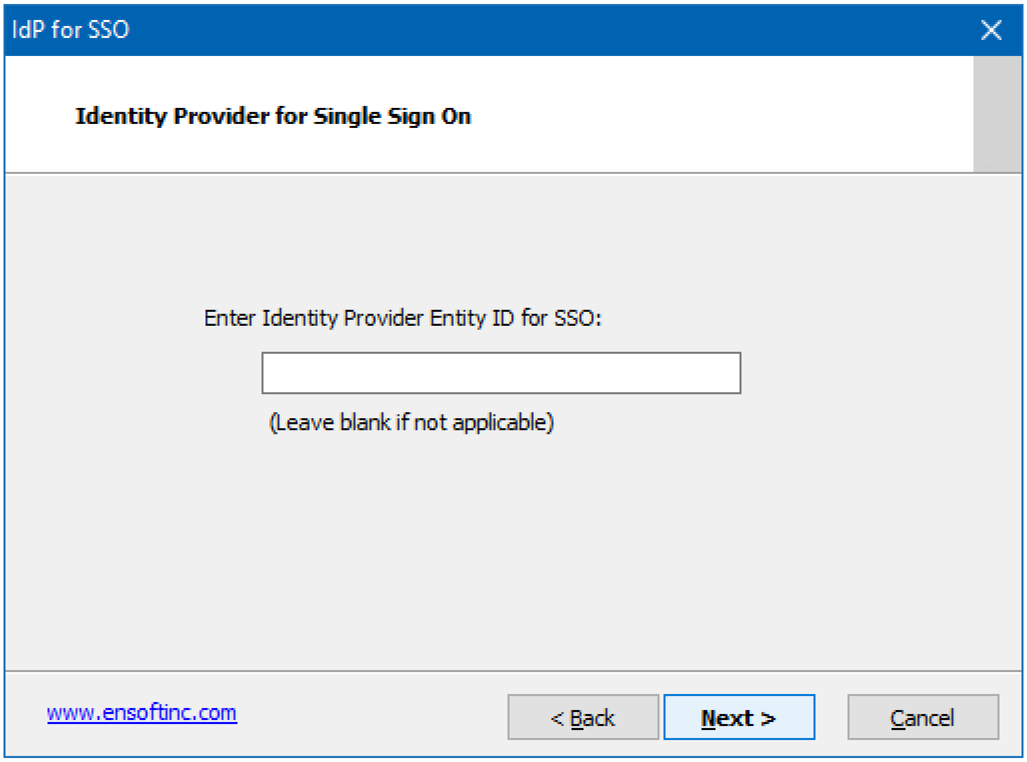


Figure 2.9 Selection of Identity Provided ID for SSO (may change with time)

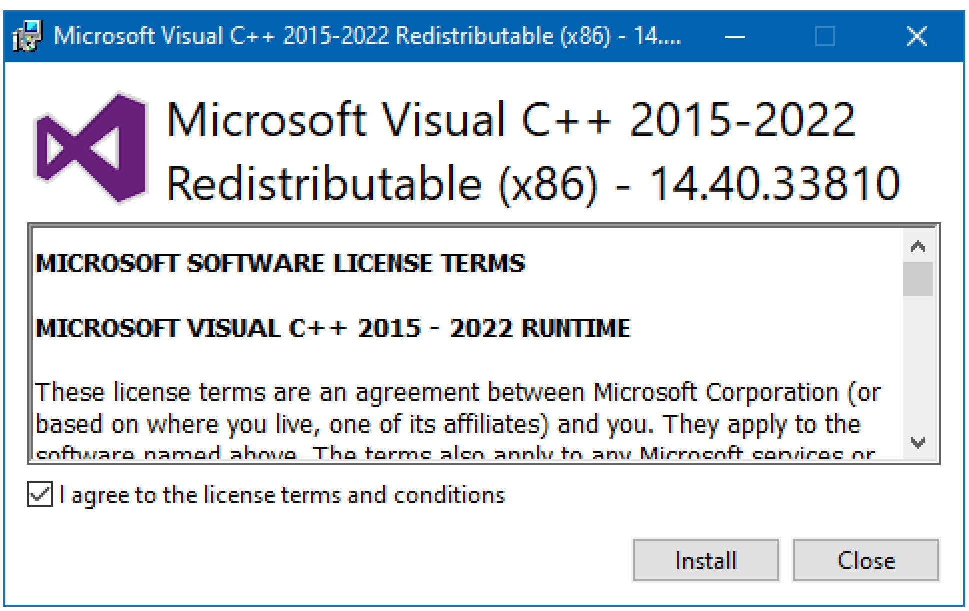


Figure 2.10 Consent for Installation of Microsoft Visual++ Drivers

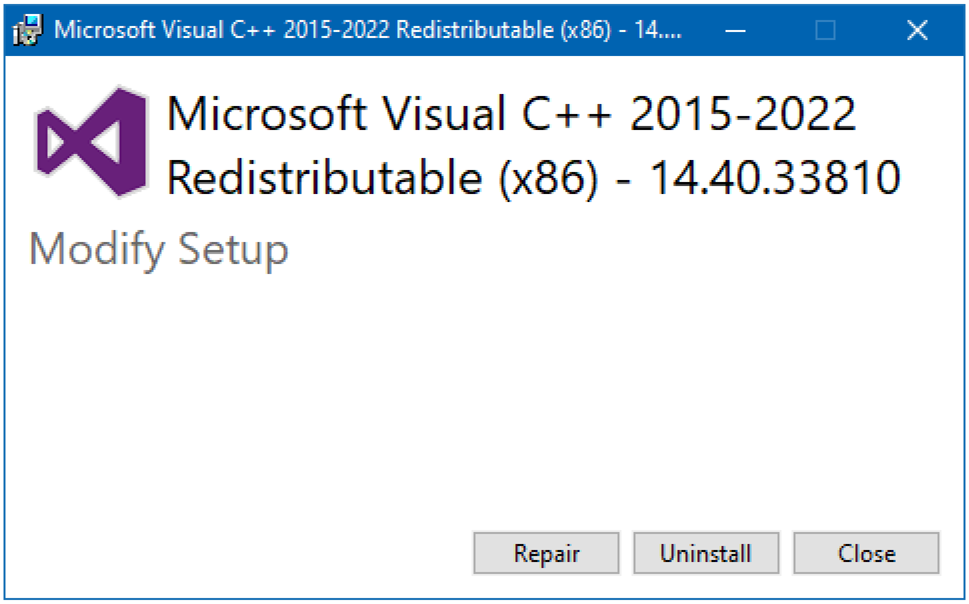


Figure 2.11 Found Installed Microsoft Visual++ Drivers

2.1.3 Introduction of Network Version

Special network licenses and Net USB Key (network hardware key) are available for users that desire to operate LPILE on their own company's Windows network. The network version is limited to users within a limited range of IP addresses that are white listed for employees of a defined licensed office site.

Network versions of LPILE have special subroutines written for installations in "software servers" (License Servers) and for installations of "individual clients" (Client Computers). The "software server" is the computer that will be carrying the network key provided by ENSOFT, INC. The software server is not necessarily the same as the existing network server. Any computer in the existing Windows network may be designated software server for LPILE as long as the Net USB Key is attached to a working USB port (or through an USB hub) and the "server" version of the software or of the Ensoft Utilities is installed on its hard drive.

Software "clients" are other computers of the network that are accessed by employees of the licensed office site and that have the software installed as client. Client computers do not need any hardware key or dongle attached to their local system. The program installed in "client computers" will be allowed to run as long as the computer designated as "software server" is accessible on the network with the proper operating system and with its network key secured in place.

Installers of network licenses should refer to a separate booklet with installation instructions for the Network version of this product. The document can be downloaded from the Ensoft web site:

https://www.ensoftinc.com/doc/Ensoft_Network_License_Installation_Booklet.pdf

1.1.2 Silent Installations of Single, Client or Cloud Licenses

For installation of single-user licenses, cloud subscription licenses and network licenses on local client computers (not on License Server) there is an option for command-based installations that are completely silent (performed without other user input). Instructions for silent installations can be downloaded from the Ensoft web site using the following link:

https://www.ensoftinc.com/doc/Silent_Single-Client-Cloud_Installations.pdf

Alternatively, the document can be requested via email to support@ensoftinc.com

2.1.4 Backup of Original Software

The distributed software may be copied for backup purposes. The program may be installed in several computers at the same time. However, unless network licenses are purchased, the program will only operate in the computer that carries the appropriate USB Key.

2.1.5 Software Updates on the Internet

Occasionally, ENSOFT will produce software improvements and/or fixes and place the latest software programs on ENSOFT's internet site. Users can check for available updates by selecting Help > Check for Updates from the LPILE menu. Software users may freely download the latest program update from the PRODUCTS > Downloads link in the following site: *http://www.ensoftinc.com*

2.2 Getting Started

A flow chart showing the menu choices and features of LPile is presented in Figure 2.12. The following paragraphs provide a description of the program functions and will guide the user in using the program.

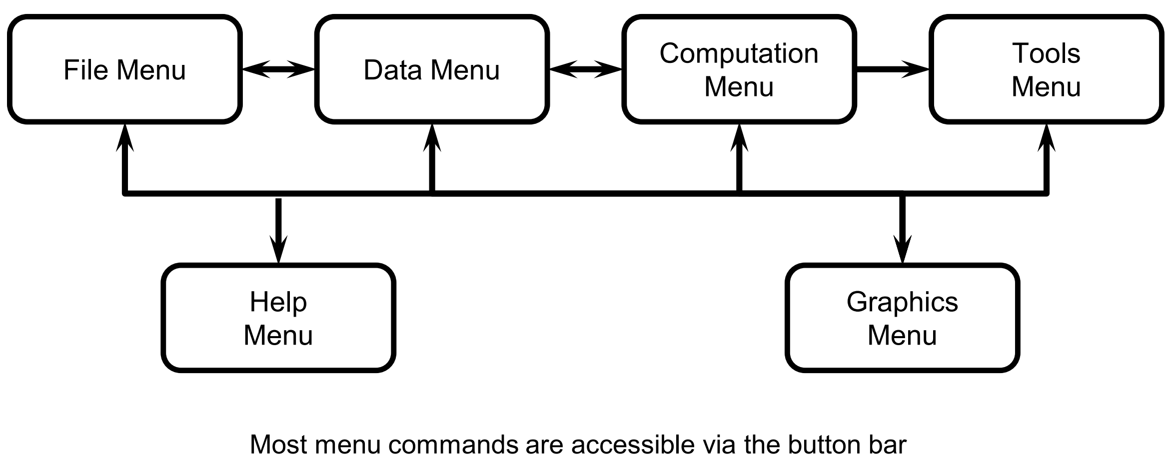


Figure 2.12 Principal Operations of LPile

1.1.3 Starting the Program

Start the program by navigating to the LPILE v2026 shortcut in the Windows Start Menu. In the very first start of the program, after a fresh installation, the user will be asked to personalize the installed copy of LPILE (Figure 2.13). This dialog allows the user to enter any name to personalize the software installation. The selected name will be included at the beginning of all output files that are generated by this particular installation of LPILE. The selected name can be changed any time afterwards from the Help > User Information menu.

In any subsequent software start after the first, the program displays the main interface with a blank screen containing the following top-menu choices: File, Data, Computation, Graphics, Tools, Window, and Help along with a variety of speed buttons (Figure 2.14). If the user starts the software from an existing model (using Windows OS file extension association), the software opens with a background display of main graphical features of the working model.

As a standard Windows feature, pressing the "Alt" key displays the menu operations with underlined letters. Pressing the underlined letter after pressing "Alt" is the same as clicking the operation. For example, to open a New File, the user could press "Alt+F" followed by "N", or "Ctrl+N", or click File > New. Hovering the mouse cursor over a speed button displays a quick reference of its function.

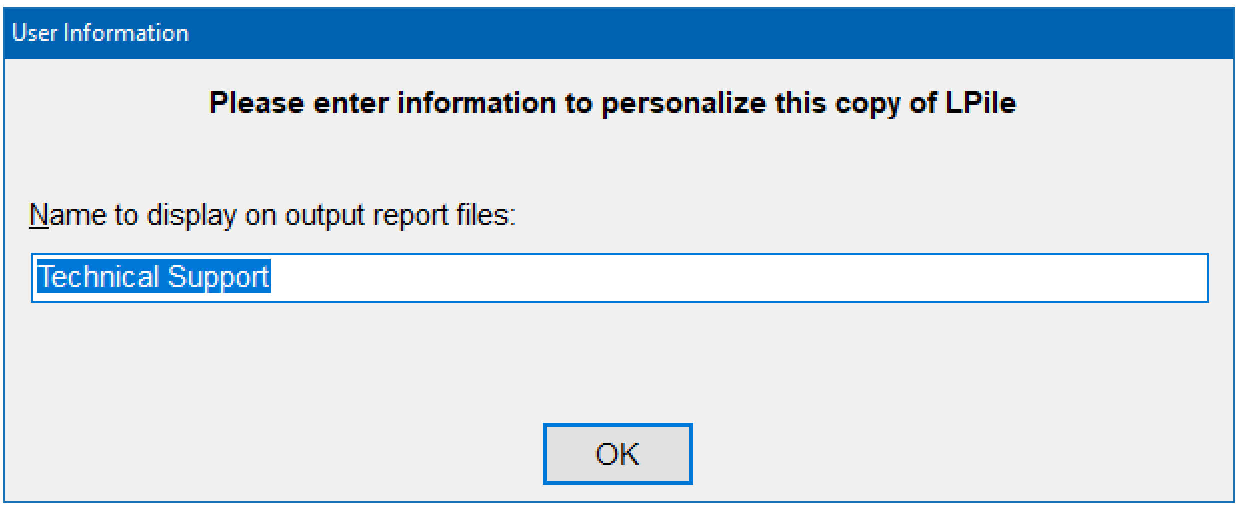


Figure 2.13 User Information on Initial Program Start (after a fresh installation).

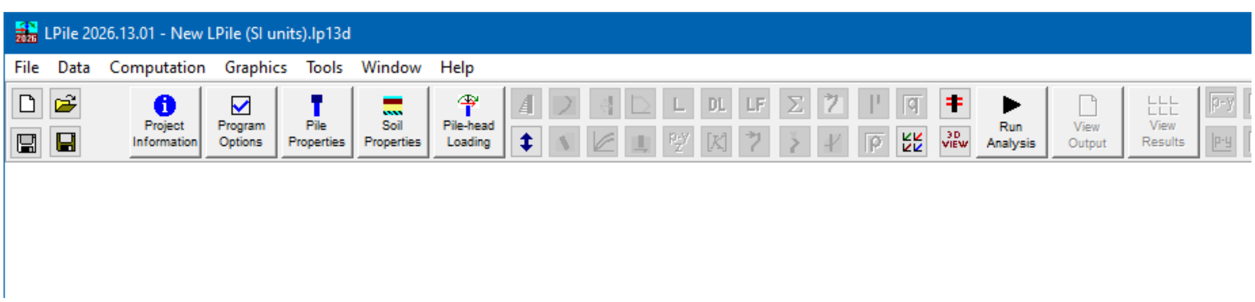


Figure 2.14 Blank Screen on Subsequent Program Starts.

1.1.4 File Menu and Buttons

The File menu shown is used to control basic file operations for input data files. Most of these program functions are also available from the button bar by pressing the button with the identical icon. The File menu option contains five standard entries, as shown in Figure 2.15; they are:

- New to create a new data file.
- Open… to open an existing data file.
- Save to save input data under the current file name.
- Save As… to save input data under a different file name.

- Exit to exit program LPILE.
- Other entries include quick access to a history of up to 10 recently-opened files.

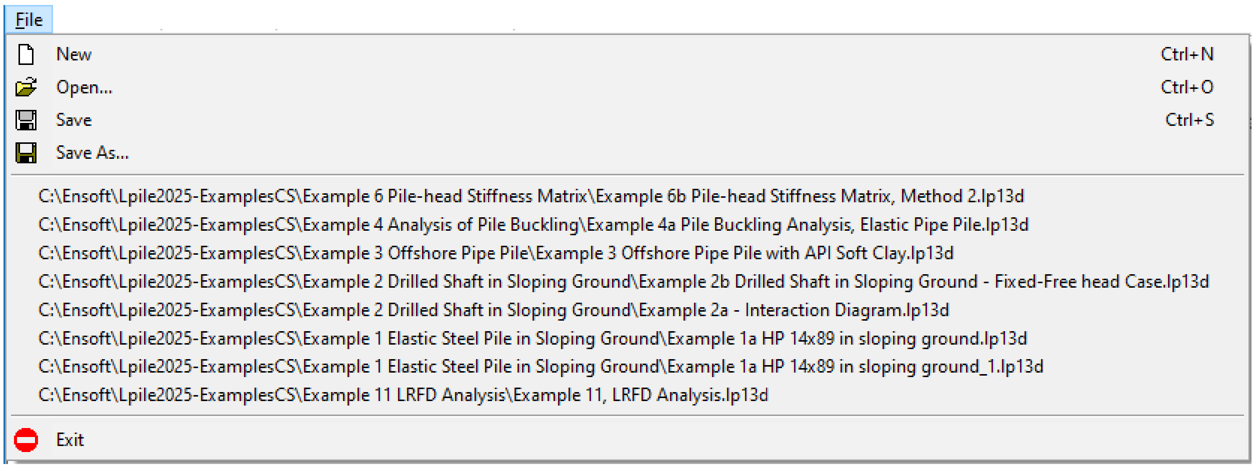


Figure 2.15 Sample File Menu

The group of four speed buttons at the left side of the button bar (shown in Figure 2.16) provide access to the New, Open, Save, and Save As commands.

Figure 2.16 Speed Buttons for File Management

2.2.1 Data Menu and Buttons

Please refer to Section 3.3 for a detailed discussion of this pull-down menu.

The group of speed buttons shown in Figure 2.17 provides access to the data editing commands in the different modes of analysis. Not all of these speed buttons are enabled, since they depend on specific options and features that are selected by the user for modeling.

(a) Buttons Available for Conventional Analysis

(b) Buttons Available for LRFD Analysis

(c) Buttons Available for Compute Nonlinear EI Only Analysis

Figure 2.17 Speed Buttons for Data Input for Different Analysis Modes

Five speed buttons are provided to review the input data in graphical form. The top middle button shown in Figure 2.18 displays the pile and soil layer profile in elevation view while the top right button displays a three-dimensional representation of the pile and soils. The lower right button presents a set of charts for reviewing the input soil and rock properties. The upper left button presents a graph of distributed lateral loading versus depth. The lower left button presents a three-panel graph of the *p*-modifier versus depth, *y*-modifier versus depth, and the ratio of *p*-modifier over *y*-modifier versus depth.

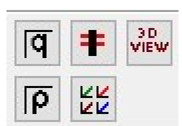


Figure 2.18 Speed Buttons for Input Data Review

2.2.2 Computation Menu and Buttons

The Computation menu, shown in Figure 2.19, is provided to access commands to analyze the input data and to view the output report files generated during an analysis. From this menu, the user may also select to Generate Report in MS Word so as to export selected output tables and graphics to a pre-formatted Microsoft Word document.

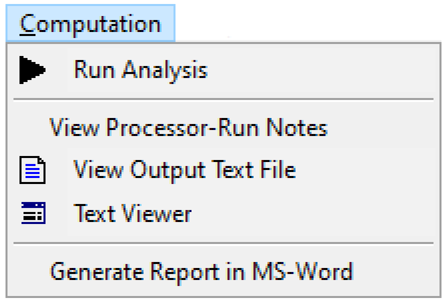


Figure 2.19 Computation Menu

The Run Analysis speed button, shown in Figure 2.20, analyzes the current input data (similar to Computation > Run Analysis) and the View Output speed button displays the model parameters and output tables on a basic text file (similar to Computation > View Output Text File) using the Text Viewer that is selected by the user (default is Notepad).

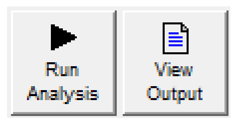


Figure 2.20 Speed Buttons for Run Analysis and View Output

2.2.2.1 Run Analysis

The Run Analysis (Computation > Run Analysis) can be performed successfully only after all data has been entered and saved. If the data has not been saved, LPile will prompt the user to save the data file. If the data file has already been named, the existing data set will automatically be re-saved to disk prior to running an analysis.

A general description of the files created by LPILE is presented in Table 2.1. Every successful run of LPILE generates several files in the same drive and directory where the input-data file was saved or opened. Most of the files may be opened with standard text editors or word processing programs.

File Description (format)	File Extension
Input file for LPile (binary)	*.lp13d
Output text file (text)	*.lp13o
Processor run notes file (text)	*.lp13r
Graphics titles file (text)	*.lp13t
LRFD summary of load and resistance combinations (text)	*.lp13m

Table 2.1 File Types and File Extensions

If there are input or runtime errors during execution, appropriate error messages will be displayed on a dialog box after computations. In most cases, the program will display information that explains the causes of error and suggest corrective actions. If the analysis is completed, but non-fatal warning messages for unusual situations warranting the attention of the user are generated, the appropriate warning will be shown prior to displaying a summary graph of the analytical results. If no error or warning messages are generated, a summary graph of results will be displayed after the analysis is completed.

2.2.2.2 View Processor Run Notes

The program begins each analysis by first saving the current data to disk, then starting the analysis routine that reads the input data from the saved disk file. If an error is detected, the program will display a message dialog that informs the user about the type of error and, in many cases, will suggest a solution for the error. Input errors may consist of missing data, erroneous data, or inconsistent data. Usually, the content of the error message dialog is copied to the Computation > View Processor-Run Notes file.

If the processor-run notes end without listing the line "The Execution is in progress…," the user should check the input associated to the last line that was read and to the line that immediately follows (that was not read). In some cases, the processor-run notes will also include an error message.

2.2.2.3 View Output Text File

The Computation > View Output Text File command opens the output file in the text editor. This command becomes available only after a successful run has been made. Some output files may be too large for Microsoft Notepad to handle, so other text editors (Microsoft WordPad, for example) might need to be used. Often, some versions of Microsoft Windows will automatically switch to the alternative program without intervention by the user. Output text files usually contain the following information:

- Licensed user name, company, and license ID (serial number) information.
- File names used for the analysis.
- The date and time of the analysis.
- Inputted data information will be echo printed on a section of the output text file. Users are strongly recommended to check this report of inputted data for mistakes.
- When nonlinear bending sections are part of the data, the output will contain results of computations of nominal bending moment capacity and nonlinear moment curvature, including bending stiffness as a function of axial thrust force.
- If selected, reports for selected p-y curves at user-specified output depths.
- Tables of computed values of estimated deflection, bending moment, shear, soil resistance, and related information, as a function of depth for the modeled pile.
- Summary tables, containing information about the results and number of iterations performed until convergence was reached.
- An optional summary table of pile-head deflection versus pile length.
- An optional summary table of pile buckling analysis.
- An optional summary table of foundation stiffness matrix components.

2.2.3 Graphics Menu and Buttons

Please refer Chapter 4 of this manual for a detailed discussion of the Graphics menu.

The group of speed buttons shown in Figure 2.21 provides access to the graphs generated by LPile. Not all speed buttons shown will be enabled, the speed buttons that are enabled depend on the options that were selected by the user and on the output generated in each analysis.

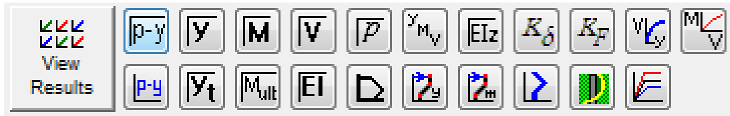


Figure 2.21 Graphics Speed Buttons

2.2.4 Tools Menu

The Tools menu has the entries shown in Figure 2.22 that are described as follows.

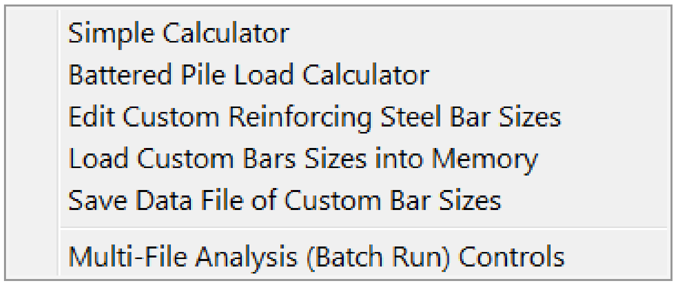


Figure 2.22 Tools Menu

Simple Calculator. This entry provides a simple calculator for the user's convenience.

Battered Pile Load Calculator. Provides a special calculator to compute axial and transverse forces acting on battered piles as computed from user-inputted horizontal and vertical loadings.

The third to fifth entries provide a means of entering additional sizes of reinforcing steel bar sizes to LPile. Note that this feature provides a means of entering hollow bars and steel access tubes.

Edit Custom Reinforcing Steel Bar Sizes. Displays an input table to enter and edit the data for the custom reinforcing bar sizes.

Load Custom Bar Sized into Memory. Transfers the data for custom reinforcing bars into the memory of LPile and enters the names of the bars into the drop-down combination edit controls for selection of the size of reinforcing bars. Note that the custom bar sizes are at the bottom of the drop-down lists for bar sizes available for normally reinforced concrete sections.

Save Data File of Custom Bar Sizes. Saves the custom bar sizes to a data file named *Custom_Rebar.dat*. This data file is stored in the same program folder as the main LPile program. When LPile is started, LPile checks the program folder for a file with this name. If the file is found, it is read and the data is stored into program memory. Thus, it is not necessary for the user to re-enter the custom bar data each time the program is run. Whenever the user wishes to exchange data files with another user, the data file for custom bar sizes should also be provided to the other user, as the list of custom bar sizes is not included as part of the LPile data file.

Multi-File Analysis. This entry provides a feature to define a list of existing LPile data files to be run as a batch and the command to perform the batch analysis. This feature is discussed in more detail in Chapter 5.

2.2.5 Window Menu

The Cascade command on the Windows menu organizes all open windows so that they are all visible.

2.2.6 Help Menu

The Help menu provides access to the software manuals (PDF files) and to some helpful utilities that the user may need when running the program. The software manuals are helpful references on topics such as: using the program, entering data, information about variables used in the program and methods of analyses. Options in the Help menu, shown in Figure 2.23, are briefly described below.

User's Manual this selection calls for any installed PDF reader (Adobe Acrobat, Acrobat Reader or similar) to open the User's Manual. This document is formatted as a protected PDF file with bookmarked table of contents. This manual describes all menu items to use the program, description of data entries and for output tables and graphs. It also contains a chapter with described example problems that help to explain various program features.

Technical Manual this selection calls for any installed PDF reader (Adobe Acrobat, Acrobat Reader or similar) to open the Technical Manual. This document is formatted as a protected PDF file with bookmarked table of contents. This manual contains background technical information and references regarding the theoretical methos used within the program.

Check for Updates starts the default Internet browser on a page that describes information about the user's license (release and maintenance expiration date) as well as the latest release that is available for downloading at the Ensoft site. Users may only run in full mode the maintenance updates that were released before the expiration date of the user's license.

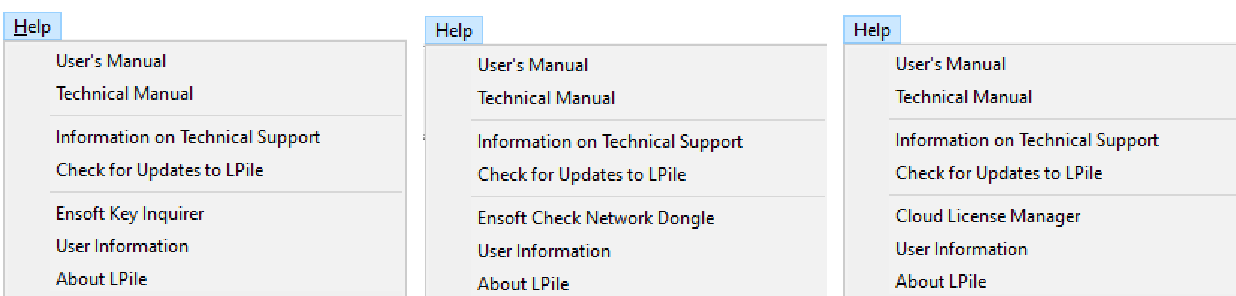
Ensoft Key Inquirer this choice is only available for USB-based, single-user licenses (not available in local network licenses or cloud licenses). This utility allows the user to check information contained in the USB Key that is attached to the computer in use. With this utility the user can see the following information: dongle serial number and expiration date, licensed program names and type of licenses, maintenance expiration date of each software license, licensed company name, allowed IP subnets. This utility is installed in the selected installation directory with the following filename: *ensoft_key_inquirer_v701.exe* (may change with time). This utility is necessary to perform remote updates of a license with expired maintenance.

Check Network Dongle this choice is only available in client computers of local network licenses (not available in single-user licenses or cloud licenses). This function calls the utility that is used to check the licensing and to troubleshoot communications with the License Server. This utility is very useful in case of problems in clients when trying to run the licensed software. This utility is installed in the selected installation directory with the following filename: *CheckNetworkDongle_ipv_512.exe* (may change with time).

Cloud License Manager — this selection is only available on cloud subscription installations of the software product (it is not available for users with USB-based installations, such as single-user or network licenses). This menu provides access to information and management of cloud subscriptions licenses.

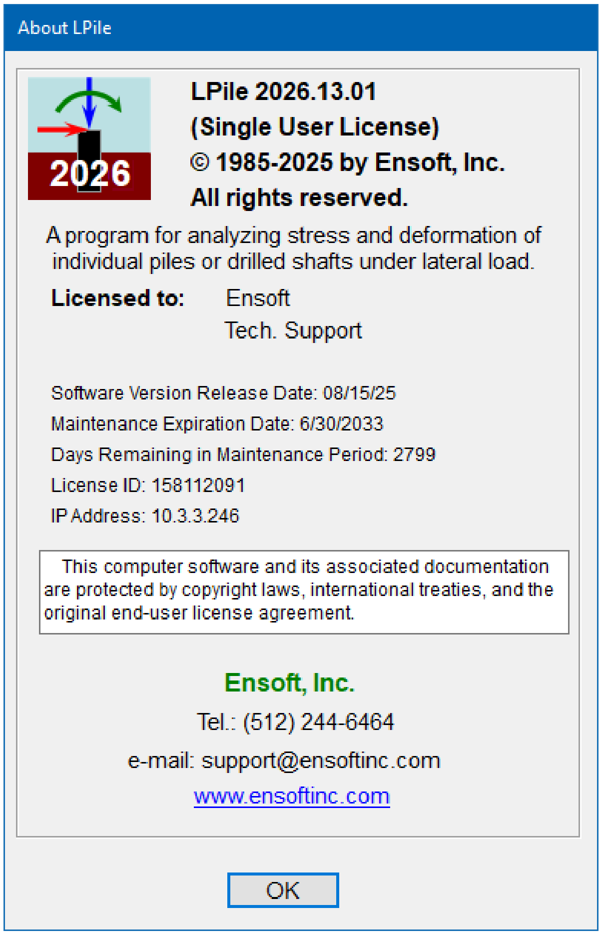
User Information — this is used to personalize the individual installation of LPILE. A screen capture of this dialog was previously shown in Figure 2.13. The user specified entry in this dialog will be included at the beginning of all output files that are generated by this particular installation of LPILE.

About LPile — this command provides a dialog describing the program version, date, and methods for accessing technical support. Other information about the program licensing and maintenance expiration date, program version, and program release date are also shown. Examples of the Help > About dialog for two different licensing options are shown in Figure 2.24.

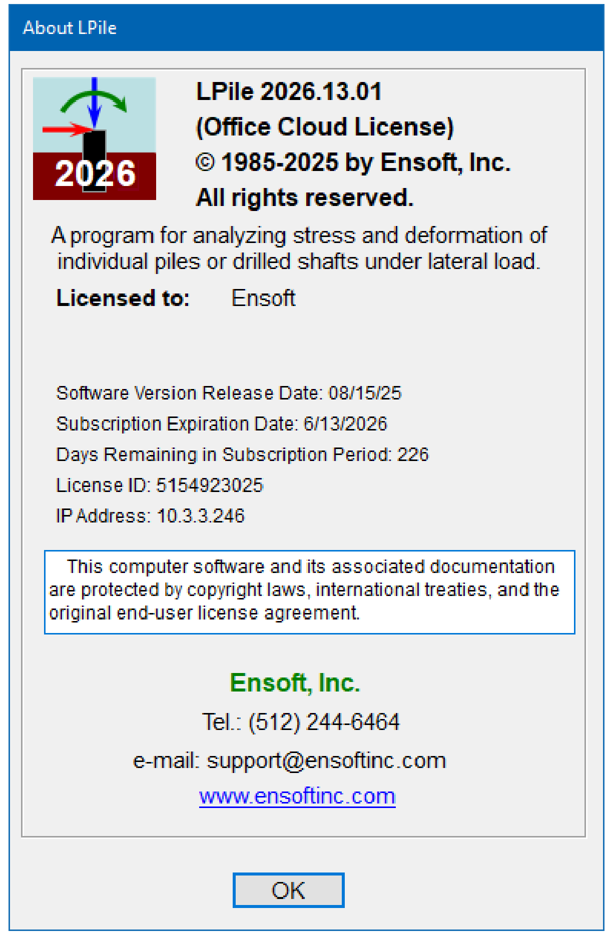


a. Single-User License　　b. Client on Local Network License　　c. Cloud Subscription License

Figure 2.23 Help Menu



a. Single-User License



b. Cloud Subscription License

Figure 2.24 Examples of About LPile Dialog

CHAPTER 3. Input of Data

3.1 General Notes for Data Input

The input of required data for an analysis is controlled by the options that are selected by the user (check marked) in the Data > Options and Settings dialog. It is recommended that the user selects and enters data in a progressive manner, starting from the top of the Data menu. Most Windows may optionally be left open on the screen. The selection of other menu commands may open additional windows on top of those that were left open. Many of the input dialogs will have buttons to add, delete, or insert rows for data. The Add Row button (Ctrl+A) always adds a new row to the end of all existing rows, and the Delete Row button (Ctrl+D) deletes the row where the cursor is currently located.

All entry cells that require numeric data may accept mathematical expressions as entries. In general, one may enter numerical expressions in the same manner as most spreadsheet programs allow, but one must omit the leading equal sign. Entering a mathematical expression works similarly to entering normal numeric data; the user simply types the expression then presses the "Enter" key.

A list of supported operations and numerical constants are shown in Table 3.1, along with the order of precedence of operations. Implicit mathematical operations using constants is not inferred. Instead, the user must enter an expression with an operator, e.g. 2*pi instead of 2pi. Negation of the constants π or e is not allowed directly, but these constants may be bracketed by parentheses. For instance, instead of entering –pi the user must enter –(pi). Scientific notation is inferred by the program if "e" or "E" is immediately following by a number (e.g. 29e6 or 0.5e–5) for input of large or small numbers. After an expression is evaluated, the computed numbers will be displayed using standard numerical notation.

Mathematical Operator (listed in order of precedence	Description
( )	Parenthesis (may be nested)
^	Exponentiation
*	Multiplication
/	Division
+	Addition
–	Subtraction/Negation
Mathematical Constant	Value
pi (π)	3.14159265358979324…
e (base of natural logarithms)	2.71828182845904524…

Table 3.1 Mathematical Operators and Numerical Constants Used in LPile Input Dialogs

3.2 Speed Buttons for Data Entry

The button bar contains a set of speed buttons to open various dialogs for the entry and manipulation of data. Please refer to the previous Section 2.2.1 for a listing of speed buttons that are normally for data entry.

3.3 Data Menu

The editing commands are presented on the Data menu shown in Figure 3.1. The commands in the upper four listings of the Data menu are enabled by default when LPile is started. However, most of the commands under the Data menu are enabled by activation of relevant program options. Not all buttons are enabled by default, the buttons that are enabled on the Data menu depend on the options that the user selected for each analysis (under Data > Options and Settings).

The icons shown in the Data menu are the same as those used to access the same editing dialogs via the speed button bar.

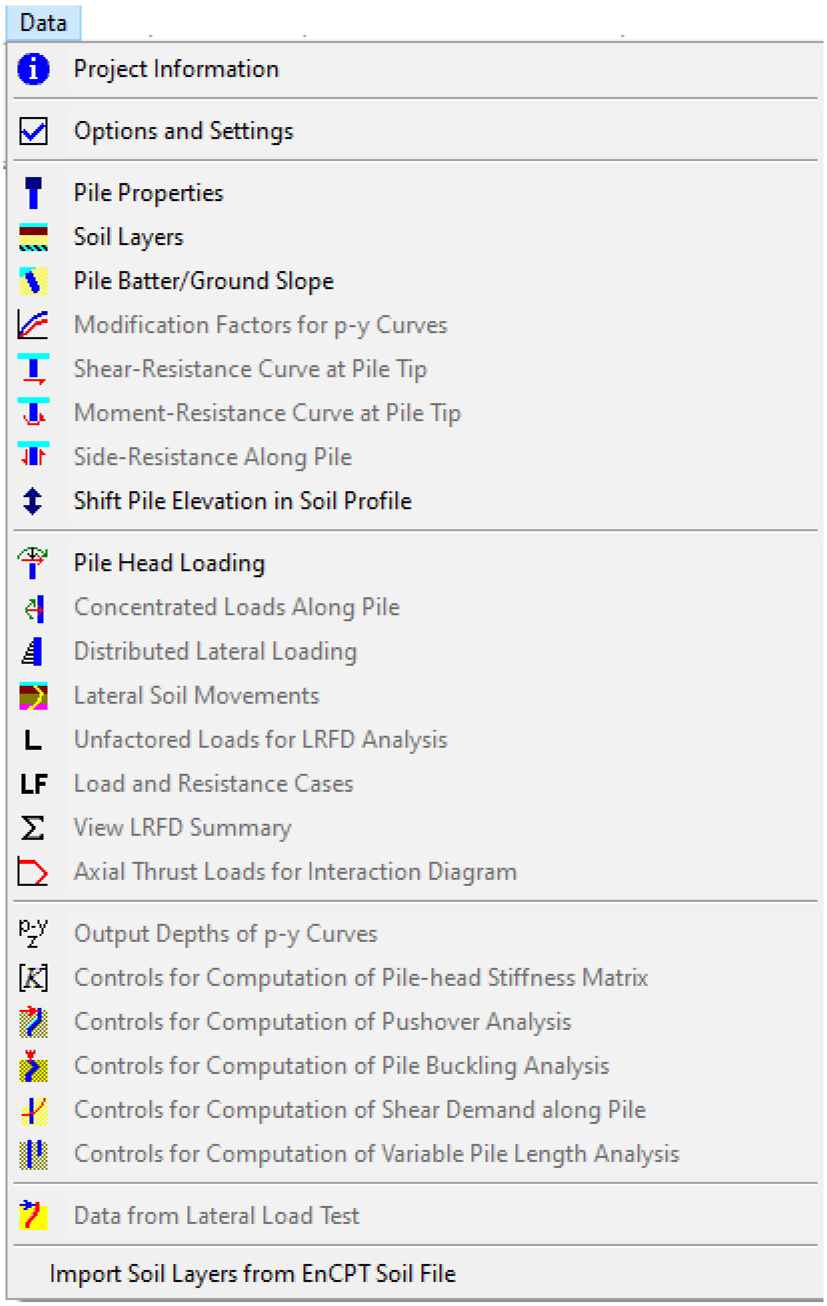


Figure 3.1 Data Menu

3.4 Project Information Dialog

The Data > Project Information dialog, shown in Figure 3.2, is used to enter identifying information for the current analysis. Entry of Project Information is optional. Five lines of information can be entered. Default prompts for project, job number, client, engineer's name, and description are provided, but may be over-written with any information provided by the User. Also shown in the dialog is additional information on file path, input and output filenames, date and time of analysis that is routinely written in the output report file.

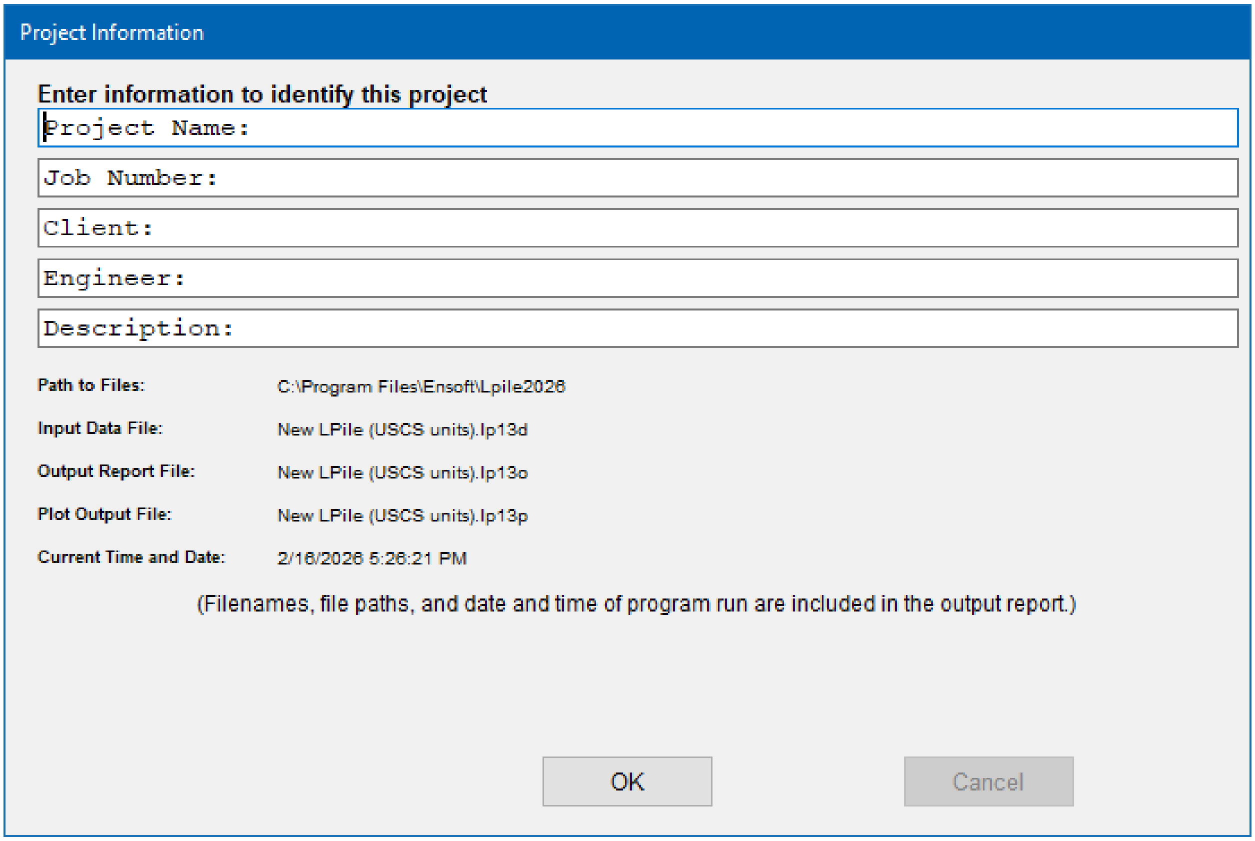


Figure 3.2 Default Data > Project Information Input Dialog

3.5 Options and Settings Dialog

Almost all program options have been consolidated into the Data > Options and Settings input dialog box. The Data > Options and Settings dialog is used to select options and settings for each set of data being analyzed by LPile. This input dialog provides options that are generally grouped into: Computational Options, Engineering Units Options, Analysis-Control Options, Output Options, Loading Options, and Text Viewer Options. There are default settings provided if the user does not have any desire to make a change. The user should remember to click the OK button in order to save the accepted selections; otherwise, the selections will not be stored when the dialog is closed.

There are several options displayed in the upper left corner of the Data > Options and Settings dialog shown in Figure 3.3. These options are described in the following sections.

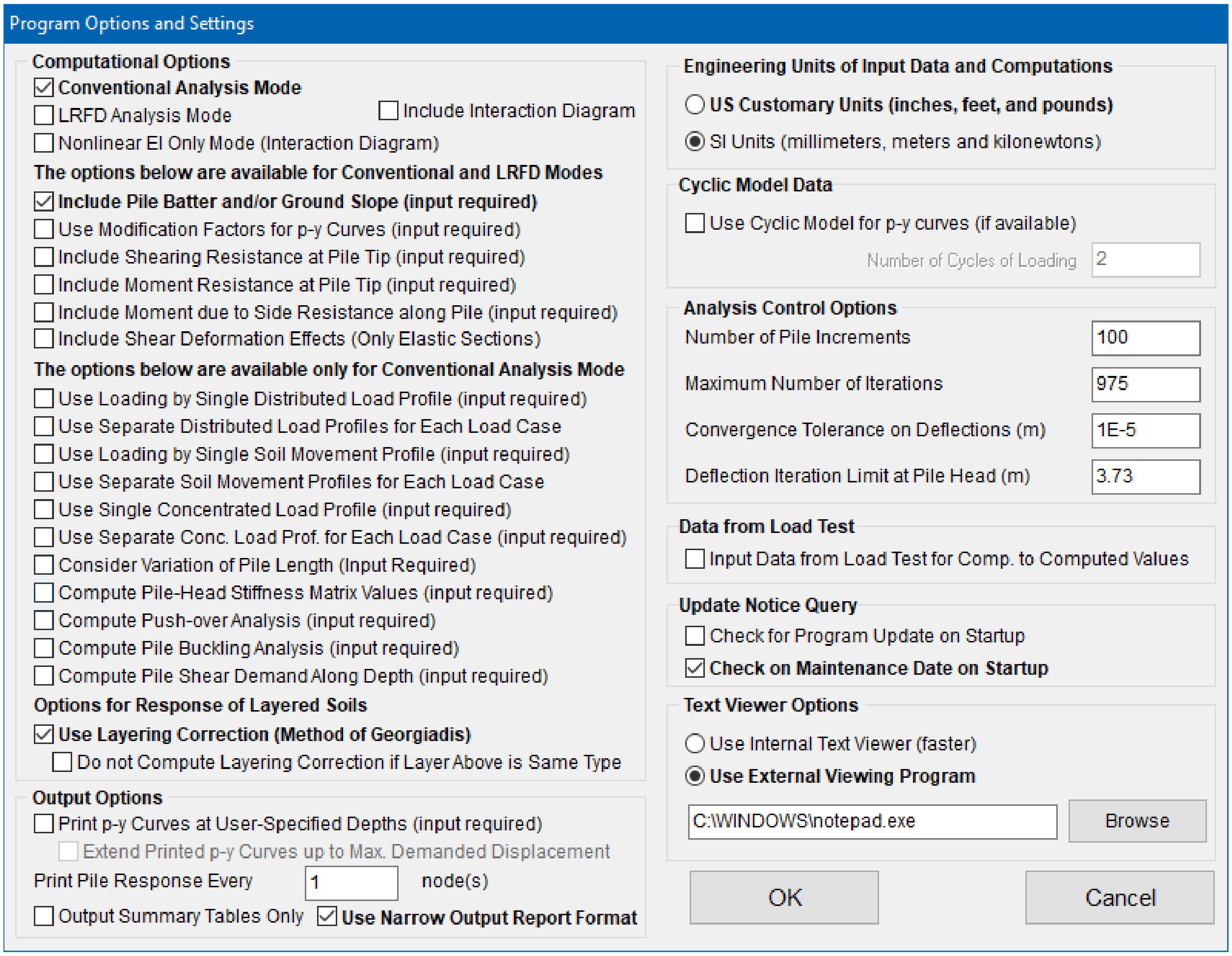


Figure 3.3 Program Options and Settings Dialog

3.5.1 Computational Options

The Computational Options are:

☑ Conventional Analysis Mode
If checked, LPile permits input of up to 100 load cases for various pile-head loading and displacement conditions. When Conventional Analysis Mode is selected, several additional options further below become active. Further reference provided in Section 3.14 of this manual.

☑ LRFD Analysis Mode (Load and Resistance Factors)
If checked, LPile will perform Load and Resistance Factor Design (LRFD) computations. In this mode, the user may enter up to 100 unfactored shear and moment loads of various loading types (dead load, live load, etc.). All loads are assumed to be for shear and moment pile-head loading conditions. The program will then add all loads of the same load type to obtain the total unfactored load for each loading type. This selection activates the Data > Unfactored Loads for LRFD Analysis and the Data > Load and Resistance Cases and the Data > View LRFD Summary menus. Further reference provided in Section 3.16 of this manual.

☑ Include Interaction Diagram
This option is available for either Conventional or LRFD Analysis Mode. When checked, LPile will compute a full interaction diagram for each pile section that the user defines in the model (under Data > Pile Properties).

☑ Nonlinear EI Only Mode
If checked, LPile will compute nonlinear moment-curvature relations and nominal (unfactored) and ultimate (factored) moment capacities of the pile sections for the specified axial thrust force values. Further reference provided in Section 3.17 of this manual.

The following options become active for Conventional and LRFD analyses.

☑ Include Pile Batter and/or Ground Slope
Activates the Data > Pile Batter/Ground Slope menu. Further reference provided in Section 3.8 of this manual.

☑ Use Modification Factors for p-y Curves
Activates the Data > Modification Factors for p-y Curves menu. These modification factors are usually employed to account for "Group Action" from closely-spaced piles. Further reference provided in Section 3.8 of this manual.

☑ Include Shearing Resistance at Pile Tip
Activates the Data > Shear-Resistance Curve at Pile-Tip menu. The impact of this optional input is usually only noticeable in piles of large diameter (3.5 feet/1 meter or larger) with considerable movements. Further reference provided in Section 3.10 of this manual.

☑ Include Moment Resistance at Pile Tip
Activates Data > Moment-Resistance Curve at Pile-Tip menu. The impact of this optional input is usually only noticeable in piles of large diameter (3.5 feet/1 meter or larger) with considerable movements. Further reference provided in Section 3.11 of this manual.

☑ Include Moment due to Side Resistance along Pile
Activates the Data > Side-Resistance Along Pile menu. The impact of this optional input is usually only noticeable in piles of large diameter (3.5 feet/1 meter or larger) with considerable movements. Further reference provided in Section 3.12 of this manual.

☑ Include Shear Deformation Effects
This is only available for Data > Pile Properties using Elastic sections (for those section names with the word "Elastic"). The influence for consideration of shear deformation is expected to be small for most cases. The theoretical background for this option is explained in the separate Technical Manual.

The following options become active only when using Conventional analyses.

☑ Use Loading by Single Distributed Load Profile
Activates the Data > Distributed Lateral Loading menu to enter a single distributed loading (for one or all load cases). Further reference provided in Section 3.14.2 of this manual.

☑ Use Separate Distributed Load Profiles for Each Load Case
Activates the Data > Distributed Lateral Loading menu to enter several data of distributed loading that can be associated to each load case. Further reference provided in Section 3.14.2 of this manual.

☑ Use Loading by Single Soil Movement Profile

Activates the Data > Lateral Soil Movements menu to enter a single set of soil movements (for one or all load cases). Further reference provided in Section 3.14.4 of this manual.

☑ Use Separate Soil Movement Profiles for Each Load Case
Activates the Data > Lateral Soil Movements menu to enter several data sets of soil movements that can be associated to each load case. Further reference provided in Section 3.14.4 of this manual.

☑ Use Single Concentrated Load Profile
Activates the Data > Concentrated Loads Along Pile menu to enter a single set of concentrated loads (Shear and/or Bending Moment) at any point along the length of the pile (for one or all load cases). Further reference provided in Section 3.14.2 of this manual.

☑ Use Separate Concentrated Load Profiles for Each Load Case
Activates the Data > Concentrated Loads Along Pile menu to enter several data sets of concentrated loads (Shear and/or Bending Moment) at any point along the length of the pile that can be associated to each load case. Further reference provided in Section 3.14.2 of this manual.

☑ Consider Variation of Pile Length
Activates the Data > Controls for Computation of Variable Pile Length Analysis menu discussed in Section 3.14.8 of this manual.

☑ Compute Pile-Head Stiffness Matrix Values
If this option is selected, LPile computes the pile-head stiffness matrix values according to the control values set by the user in the Data > Controls for Computation of Pile-head Stiffness Matrix dialog discussed in Section 3.14.5.

☑ Compute Push-over Analysis
If this option is selected, LPile computes the pushover analysis according to the controls set by the user in the Data > Controls for Computation of Pushover Analysis dialog discussed in Section 3.14.6.

☑ Compute Pile Buckling Analysis
If this option is selected, LPile computes the pile-buckling analysis according to the controls set by the user in the Data > Controls Computation of Pile Buckling Analysis discussed in Section 3.14.7.

☑ Compute Pile Shear Demand Along Depth
Activates the Data > Controls for Computation of Shear Demand along Pile menu. This option is useful when user is also performing slope-stability analyses (using separate software outside LPile). Further reference provided in Section 3.14.8 of this manual.

The following options are for the Response of Layered Soils:

☑ Use Layering Correction (Method of Georgiadis). The default is to compute layering corrections (see Technical Manual) but users may choose to avoid in order to evaluate special cases or load tests.

☑ Do not compute layering correction if layer above is of same type. Selecting this option avoids layering corrections only on layers with same type of soils.

3.5.2 Output Options

Several options are provided to control the output reports generated during LPile analyses. These options are enabled by checking the check boxes described below.

3.5.2.1 Generate p-y Curves at User-Specified Depths

Checking this option activates the feature to output *p-y* curves at the depths that are specified by the user under the separate Data > Output Depths of p-y Curves menu. Note that for battered piles, the specified depth is the vertical depth below the pile head, not the distance along the axis of the pile.

3.5.2.2 Extend Printed p-y Curves to Maximum Demanded Displacement

By default, the program prints the *p-y* curves setting the maximum value of lateral displacement based on the diameter of the pile and soil model. In some cases, the demanded displacement may be higher than this maximum default value, by clicking this option the program will print the *p-y* curves after the analyses are completed and if for any depth the demanded displacement is higher than the default maximum displacement the program will print the *p-y* curve up to that displacement.

3.5.2.3 Printing Increment

The user may specify the output increment for where results will be printed in the table of output. As a default, results are printed at every finite increment of pile length. This option is disabled if the user has a check mark on the separate Output Summary Tables Only option. A value of 1 prints the values at every node; 2 prints values at every other node, etc. Note that the printing increment is used only for the generation of the output text, but not for the generation of output graphs.

3.5.2.4 Output Summary Tables Only

Checking this option simplifies considerably the output text file by only printing summary tables (applicable to Conventional Analysis Mode and/or LRFD Analysis Mode).

3.5.2.5 Use Narrow Output Report Format

This option controls the printed width of the output text file, permitting printing on letter-size paper without word wrapping of long lines. It is necessary to specify a fixed-pitch font of 10 point or smaller size to display the output correctly. The user should be aware that only the most important columns of output results are displayed when this option is selected.

3.5.3 Engineering Units of Input Data and Computations

The user can specify either US Customary System (USCS) units using pounds, inches, and feet or SI Units for the International System of Units (*Système international d'unités* or SI) units using millimeters, meters, and kilonewtons for entering and displaying data. The prior setting for engineering units is remembered by the program. Thus, when LPile is started, the default units are the engineering units used in the prior analysis. If a data file is read by LPile, the engineering units are switched to the units specified in the data file.

All input data is converted to consistent units of length and force before computations are made. The consistent units are either pounds and inches or kilonewtons and meters.

3.5.4 Cyclic Model Data

The user can specify if the program should Use Cyclic Model for p-y curves when performing the analyses. Not all *p-y* criteria have cyclic models so the user should review the Technical Manual to see if the soil of their selection has different responses for cyclic and static loadings.

Selection of cyclic model is important when analyzing piles under lateral forces for certain soil types. Further information on the influence of loading type is included in the *Technical Manual*.

In general, the cyclic model is primarily used for low frequency, large amplitude storm wave or wind loads. Dynamic loading from earthquakes and machine vibrations are not the same as the cyclic loads considered in LPile.

When a cyclic model is selected, the user must also specify the Number of Cycles of Loading, ranging from 2 to 5,000 cycles. The effect of cyclic loading is to change how the soil resistance is computed in certain types of *p-y* curves, as described in the *Technical Manual*.

Dynamic loading from earthquakes can be analyzed by LPile if equivalent pseudo-static loads are provided as input. Pseudo-static loads are sized in a manner that results in computed moments and deflections that are roughly equivalent to those developed during seismic loading events.

Dynamic loading from machine vibrations or most other sources of harmonic loading should not be analyzed using LPile because LPile is not capable of determining the frequency response of the foundation and other inertial effects. Instead, the user is directed to the separate DynaN, DynaPile, and/or DynaMat software programs from Ensoft for the performance of dynamic response analyses.

3.5.5 Analysis Control Options

The Analysis Control Options are used to specify the Number of Pile Increments, the Maximum Number of Iterations, the Convergence Tolerance on Deflections, and the Deflection Iteration Limit at Pile Head.

3.5.5.1 Number of Pile Increments

The quality of the finite-difference numerical solution obtained by LPile is proportional to the square of the length of the pile increment. The length of the pile increment is computed by dividing the length of the pile by the number of pile increments.

The error in the solution computed by LPile is defined as the difference between the approximation and the exact analytical solution. The two sources of error in finite difference methods are round-off error, the loss of precision due to computer rounding of decimal quantities, and truncation error or discretization error, the difference between the exact solution of the finite difference equation and the exact quantity assuming perfect arithmetic (that is, assuming no round-off error).

The default number of pile increments is 100, the minimum number of pile increments is 40, and maximum number of pile increments is 500.

Users may choose a number of increments that produces computed results at specific rounded values of depth. For example, a user may choose 140 increments to obtain results for every 0.5 feet of depth for a 70-ft-long pile.

3.5.5.2 Maximum Number of Iterations

The maximum number of iterations performed by the program for the pile solution can be set by the user. Many problems will converge in fewer than 50 iterations unless a plastic hinge is being developed in an analysis using nonlinear *EI*. If a pushover analysis is being performed using the displacement and moment pile-head boundary condition, the iterations limit should be set to the maximum value of 1,000 iterations to allow plastic hinges to develop in the pile.

Recommended	500 to 750
Lower Limit	100
Upper Limit:	1,000

Table 3.2 Recommended Ranges for Maximum Number of Iterations

The user should be aware that specifying 1,000 iterations has a special feature. If the problem is solved using fewer than 1,000 iterations, the solution has met the convergence tolerance and excessive deflection criteria. However, if the program reached the limit of 1,000 iterations, the program is highly unlikely to obtain convergence. Instead, the program outputs the last iterative solution obtained and the solution stops.

3.5.5.3 Convergence Tolerance of Deflections

The value entered for convergence tolerance is used to stop an analysis when the absolute value of the change in deflection of every nodal point on the pile is less than the convergence tolerance. The default value for convergence tolerance is 0.00001 inches or 2.54×10^{-7} meters. Using a smaller value for convergence tolerance usually does not improve the quality of the solution and in some conditions may result in failure to obtain a solution. Using a larger convergence tolerance is sometimes required, but the user should be cautious when choosing values larger the 0.0001 inches or 2.54×10^{-6} meters.

3.5.5.4 Limit on Excessive Lateral Pile Deflection

The limit on excessive lateral pile deflection is used to end analyses in which the iterative solution is diverging without limit. The user should enter a value of deflection for the pile head that is grossly excessive to stop the analysis. The default value is 100 inches or 2.54 meters. If the user wishes to modify this value, a recommended value is 10 times the pile diameter. Lowering the Excessive Deflection Value to less than 100 inches or 2.54 meters is not recommended.

3.5.6 Data from Load Test

It is possible to enter and save load test data input into LPile and to display the load test data along with the comparable results computed by LPile. This is compared on the graphs of pile-head shear force versus pile-head deflection and also on the graph of bending moment versus depth if such was also measured in the load test and inputted into LPile. The ability to enter and save load test data is enabled by checking this option. Further reference provided in Section 3.14.8 of this manual.

3.5.7 Update Notice Query

The Check for Program Update on Startup asks the user when starting the program to open the default internet browser to checks if there are any updates or full versions of LPile that are newer than the one on the user's computer.

The Check Maintenance Date on Startup alerts the user when starting the program if the program maintenance is already expired.

3.5.8 Text Viewer Options

The user should enter the complete path and command line for their preferred text editor or word processor. As a default, the command line *c:\windows\notepad.exe* sets Microsoft Notepad as the default text editor. An internal text editor can also be selected with Use Internal Text Viewer. The selected text editor will be used for Computation > View Processor-Run Notes and for Computation > View Output Text File.

3.6 Pile Properties

3.6.1 General Description of Input

LPile has features to evaluate the nonlinear bending stiffness relationships for deep foundations made from normally-reinforced concrete, steel sections, and prestressed concrete. These features can determine how the effective bending stiffness varies as the concrete cracks in tension and the reinforcing steel yields.

The user must click the OK button in order to save the accepted selections; otherwise, the selections will not be saved when the input dialog is closed.

3.6.2 Section Type and Shape

A sample dialog for the Section Type tab is shown in Figure 3.4. Users may select any of multiple types of pile sections and a single LPile model may have up to 20 different sections with different section types and/or different section properties. The default section type is an Elastic Section (non-yielding). All other section types have non-linear moment-curvature relationships.

The sample dialog box shown in Figure 3.4 is for a concrete shaft (also referenced as 'drilled shaft' or 'bored pile' or 'augercast pile') defined as Round Concrete Shaft (Bored Pile) which uses non-linear material properties. Once the section shape and dimensions have been properly defined, a scale drawing of the section or section profile is displayed on the right side of the screen, as shown Figure 3.4.

The user should notice the tabs (pages) that are shown in the dialog of Figure 3.4. For an elastic section, only two tabs are displayed. For other types of sections, the number of tabs (pages) that are shown will depend on the section type that is selected by the user. In this particular example on Figure 3.4, there are tabs for Section Type, Shaft Dimensions, Concrete, Rebars, and Trans. Reinf.

The memo shown at the bottom of the tab pages provides a general description of the section type and may provide special guidance in its use and construction.

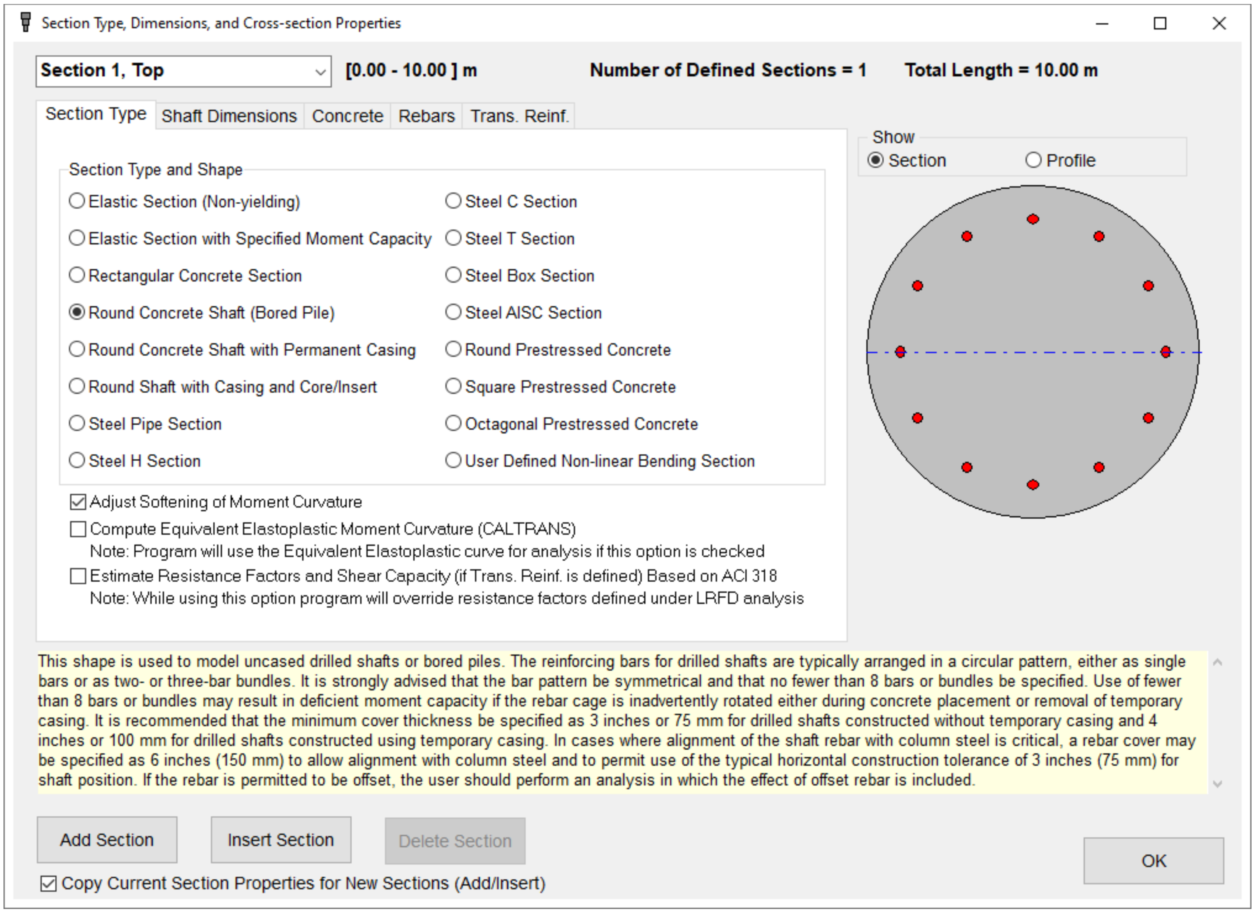


Figure 3.4 Sample Pile Section, Section Type Tab

3.6.3 Warning and Error Messages

LPile provides warning messages and advice for the user's external design with several structural types. The purpose for these warning messages is to alert the user with design geometries that may be difficult to construct and to alert if unusual parameters are specified by the user for their pile section. A short discussion of several types of the warning messages follows.

3.6.3.1 Spacing of Reinforcement

Warning messages are displayed for the drilled shaft sections when the spacing between reinforcing bars is less than five times the size of the coarse aggregate specified by the user. If the spacing is smaller than this limit, the likelihood of the occurrence of voids in the concrete is increased due to the inability of the fresh concrete to flow around the bars.

3.6.3.2 Percentage of Reinforcement

Warning messages are displayed for the drilled shaft sections when the percentage of axial reinforcement is either less than 0.5 percent or greater than 8 percent. A caution message will be displayed if the percentage of axial reinforcement is between 0.5 and 0.95 percent.

A lower limit for axial reinforcement was discussed on page 362 of O'Neill and Reese (1999). In cases where the moments and shear forces developed in the shaft are very small (i.e., at depth in long shafts), the minimum steel percentage can be less than 1 percent. Brown et al. (2018) mentions a lower bound of 0.5% longitudinal steel and suggested only for sections without moment demand and where the area of concrete is greater than required to resist axial compression.

Section 10.6.1.1 of ACI 318-14 and Section 5 of AASHTO state that the minimum area of longitudinal reinforcement must not be less than 1 percent of the gross concrete area. However, if the cross-section is larger than that required by consideration of structural resistance, then Section 10.3.1.2 of ACI 318-14 allows a reduced effective area not less than one half of the total area to be used to determine the minimum reinforcement and design strength. This criterion can be used in many cases where drilled shafts are designed with large diameters in order to develop large enough geotechnical side and base resistance in soils and some soft rocks.

The upper limit of 8 percent reinforcement is not attainable in all shaft sizes. From a practical perspective, it is necessary to use bundled bar arrangements to attain reinforcement ratios greater than 4.5 percent in many shaft diameters. In practice, many drilled shafts are typically designed with longitudinal reinforcements between 1% and 2% of gross area.

3.6.3.3 Level of Prestressing After Losses

LPile is capable of computing the level of prestress after losses for prestressed sections. LPile will display warning messages if the prestress after losses is less than 600 psi or more than 1,200 psi. Note that the value of prestress after losses depends on the types of piles available and generally cannot be specified ahead of time by the design engineer, so it is imperative that the design engineer obtain this information from the pile supplier.

3.6.4 Elastic Section

The Elastic Section is the only section that doesn’t have a defined moment capacity. As such, elastic sections are often used when it is desired to determine the lateral geotechnical capacity of the soil profile. In such cases, it is best to model the loading of the pile using the pushover analysis feature discussed in Section 3.14.6.

It is not recommended to use Elastic Sections for any type of pile section with concrete, since the flexural response in those sections is usually nonlinear (unless it is used for the purpose described above, to estimate the geotechnical capacity of the soil profile).

The various inputs that are available in the Dimensions and Properties tab for an Elastic Section are defined in the following sub-sections on this topic.

3.6.4.1 Length of Section

Elastic pile sections require input for the section length in feet or meters. This is just the length of the pile section that is being defined (or for the full pile length if the pile only has one section).

3.6.4.2 Structural Shape

Select the drop-down button for any of the following shapes:

- General can be used for any shape where the user enters the diameter, area and moment of inertia (calculate outside LPile) for the top (At Top) and bottom (At Bottom) of the pile section:
  - Equiv. Sect. Diam. is the equivalent diameter of the pile section.

  - Area is the cross-sectional area of the pile section.
  - Mom. of Inertia is the moment of inertia of the pile section.
- Rectangular shape is defined by the width and depth (which are used to compute area and moment of inertia – which can both be modified by the user if necessary) at top and bottom of the section.
  - Elas. Sect. Width is the width of the pile section (dimension parallel to axis of bending).
  - Elas. Sect. Depth is the depth of the pile section (dimension perpendicular to axis of bending).
  - Area is the cross-sectional area of the pile section.
  - Mom. of Inertia is the moment of inertia of the pile section.
- Circular without Void defined by diameter (used to compute area and moment of inertia – which can both be modified by the user if necessary) at top and bottom of the section.
  - Elas. Sect. Diameter is the outside diameter of the circular pile section.
  - Area is the cross-sectional area of the pile section.
  - Mom. of Inertia is the moment of inertia of the pile section.
- Pipe shape defined by outer diameter and wall thickness (used to compute area and moment of inertia – which can both be modified by the user if necessary) at top and bottom of the section.
  - Elas. Sect. Diameter is the outside diameter of the pipe pile section. This dimension is used for internal computations of the soil response *p-y* curves.
  - Wall Thickness is the thickness of the pipe pile section.
  - Area is the cross-sectional area of the pipe pile section.
  - Mom. of Inertia is the moment of inertia of the pipe pile section.
- H Section is for piles with H-shape sections and defaults to bending in the strong axis (web perpendicular to neutral axis), unless users click on Rotate Section (Weak Axis) which changes to bending in weak axis (web parallel to neutral axis).
  - H Section Wid. is the width of the pile section (dimension parallel to axis of bending when using strong axis bending). This dimension is used for internal computations of the soil response *p-y* curves when bending in strong axis (unless user places check mark on Use Eq. D. and enters Elas. Eq. Diam.).
  - H Section Depth is the depth of the pile section (dimension perpendicular to axis of bending when using strong axis bending). This dimension is used for internal computations of the soil response *p-y* curves when bending in weak axis (unless user places check mark on Use Eq. D. and enters Elas. Eq. Diam.).

- Area is the cross-sectional area of the pile section.
- Mom. of Inertia is the moment of inertia of the pile section.
- Flange Thickness is the thickness of the flanges (width section).
- Web Thickness is the thickness of the web (depth section).

- C Section is for piles with C-shape or stiffened C-shape sections bending in the strong axis (web perpendicular to neutral axis). Evaluation of weak axis bending for this type of pile section is not available in the initial release of LPILE v2025 but may be added later. Weak axis bending of this type of pile section is not symmetric since it has a different flexural stiffness when it is bent to one or the other direction.
    - C Section Wid. is the width of the pile section (dimension parallel to axis of bending when using strong axis bending). This dimension is used for internal computations of the soil response *p-y* curves when bending in strong axis (unless user places check mark on Use Eq. D. and enters Elas. Eq. Diam.).
    - C Section Depth is the depth of the pile section (dimension perpendicular to axis of bending when using strong axis bending). This dimension is used for internal computations of the soil response *p-y* curves when bending in weak axis (unless user places check mark on Use Eq. D. and enters Elas. Eq. Diam.).
    - Area is the cross-sectional area of the pile section.
    - Mom. of Inertia is the moment of inertia of the pile section.
    - Corner Radius to define the chamfer on corners.
    - Stiffener Length is the length of the stiffener end (leave as 0 if a regular C section).
    - Stiffener Thick. is the thickness of the stiffener end (leave as 0 if a regular C section).
    - Flange Thickness is the thickness of the flanges (width section).
    - Web Thickness is the thickness of the web (depth section).
- T Section is for piles with T-shape sections bending in the weak axis (web parallel to neutral axis). Evaluation of strong axis bending for this type of pile section is not available in the initial release of LPILE v2025 but may be added later. Strong axis bending of this type of pile section is not symmetric since it has a different flexural stiffness when it is bent to one or the other direction.
    - T Section Wid. is the width of the pile section (dimension perpendicular to axis of bending when using weak axis bending). This dimension is used for internal computations of the soil response *p-y* curves when bending in weak axis (unless user places check mark on Use Eq. D. and enters Elas. Eq. Diam.).

  - T Section Depth is the depth of the pile section (dimension parallel to axis of bending when using weak axis bending). This dimension is used for internal computations of the soil response *p-y* curves when bending in strong axis (unless user places check mark on Use Eq. D. and enters Elas. Eq. Diam.).
  - Area is the cross-sectional area of the pile section.
  - Mom. of Inertia is the moment of inertia of the pile section.
  - Flange Thickness is the thickness of the flange (width section).
  - Web Thickness is the thickness of the web (depth section).
- Box Section is for pile sections with a box shape.
  - Box Section Wid. is the width of the pile section (dimension perpendicular to axis of bending when using weak axis bending). This dimension is used for internal computations of the soil response *p-y* curves when bending in strong axis (unless user places check mark on Use Eq. D. and enters Elas. Eq. Diam.).
  - Box Section Depth is the depth of the pile section (dimension parallel to axis of bending when using weak axis bending). This dimension is used for internal computations of the soil response *p-y* curves when bending in strong axis (unless user places check mark on Use Eq. D. and enters Elas. Eq. Diam.).
  - Area is the cross-sectional area of the pile section.
  - Mom. of Inertia is the moment of inertia of the pile section.
  - Corner Radius to define the chamfer on all 4 corners.
  - Flange Thickness is the thickness of the flange (width section).
  - Web Thickness is the thickness of the web (depth section).
- AISC Section is for pile sections that use almost any shape listed in the American Institute of Steel Construction (AISC) manual: W, M, S, HP, C, MC, WT, MT, ST, HSS and PIPE. Click the Section Type dropdown to select shape followed by the Section Name dropdown to select the size.
- Embedded Pole is defined by diameter of drilled hole and bending properties of the embedded pole. In the embedded pole section, the *p-y* curves are computed using the diameter of the drilled hole and the bending stiffness is defined by the properties of the embedded pole. In general, it is advised that the embedded pole option be used only if the backfill placed around the pole is concreted or filled with a compacted material having a shear strength that is more than ten times the shear strength of the surrounding soil profile.
  - Emb. Pole Diam. is the diameter of the embedded pole (structural insert).
  - Area is the cross-sectional area of the pile section.

- Mom. of Inertia is the moment of inertia of the pile section. Notice that this value is multiplied by the input under Elastic Mod. (modulus of elasticity) to obtain the flexural stiffness of the pile section.
- Drilled Diameter is the diameter of the drilled hole (where the 'embedded pole' is inserted) and used to compute the *p-y* (response) curves of the soil.

3.6.4.3 Common Entries

Use Eq. D.

A checkmark on this entry is placed to enable and use Elas. Eq. Diam. so the user can enter an equivalent diameter in non-circular pile sections (Rectangular, H, C, T, Box, AISC).

Est. Equiv. D.

This button provides an estimated Elas. Eq. Diam. to use in non-circular pile sections (Rectangular, H, C, T, Box, AISC). The program estimates the Elas. Eq. Diam. (equivalent diameter) based on the inputted dimensions of the non-circular section.

Elas. Eq. Diam., p-y

This is the entry of equivalent diameter for non-circular pile sections (Rectangular, H, C, T, Box, AISC) that the program will use for the computations of *p-y* curves (soil response curves). The program continues to use the other inputted dimensions of the non-circular section to estimate the flexural properties (moment of inertia).

Elastic. Mod.

This entry is for the modulus of elasticity of the material in the pile section. This value is multiplied by the input under Mom. of Inertia (moment of inertia) to obtain the flexural stiffness of the pile section.

3.6.4.4 Notes on Tapered Sections

A tapered section is one with a variable dimension (diameter, width) at top (larger) and bottom (smaller). The General, Rectangular, Circular, Pipe and Embedded Pole pile sections may be tapered with depth. The other pile sections (H, C, T, Box, AISC) cannot be tapered with depth.

In the case of tapered sections, the section dimensions at top and bottom of section are checked to determine if the section is tapered or not. If the section is tapered, values of cross-sectional area and moment of inertia are recomputed internally by LPile based on the cross-sectional dimensions interpolated with depth <u>and</u> any inputted values for cross-sectional area and moment of inertia are ignored. If the section is not tapered, the input values for cross-sectional area and moment of inertia are used in computations.

The purpose of the input of section dimensions is to define the bending stiffness of the pile. LPile is capable of computing the moment of inertia at each nodal point in the section from the structural dimensions interpolated over the length of the pile. Thus, for many tapered sections the moment of inertia varies nonlinearly with depth.

3.6.5 Elastic Sections with Specified Moment Capacity

The elastic section with specified moment capacity is similar to the elastic section, with the additional feature of a user-specified moment capacity (Plas. Mom. Cap.). The resulting moment versus curvature relation is elastic-plastic, so if the moment in the pile does not reach the moment capacity, the results of computations will be the same as for an elastic section with the same dimensional properties.

3.6.6 Rectangular Concrete Piles

The bending stiffness and nominal moment capacity of the section are computed using the methods discussed in Chapter 5 of the *LPile Technical Manual*.

The properties for the rectangular concrete pile are defined by:

Length of Section, Section Width, and Section Depth; defined in the Rectangular Section Dimensions tab;

The Compressive Strength and Max. Coarse Aggregate Size of the concrete mix defined in the Concrete tab; and

The number, positions, yield stress, and modulus of elasticity of the reinforcing steel bars defined in the Rebars and optional Trans. Reinf. tabs.

Sample tab pages for the required input data are shown in Figure 3.5 through Figure 3.8.

In the Rebars tab (Figure 3.7), placement of a check mark under Plain Concrete – No Rebars allows for modeling of a section without any steel reinforcement.

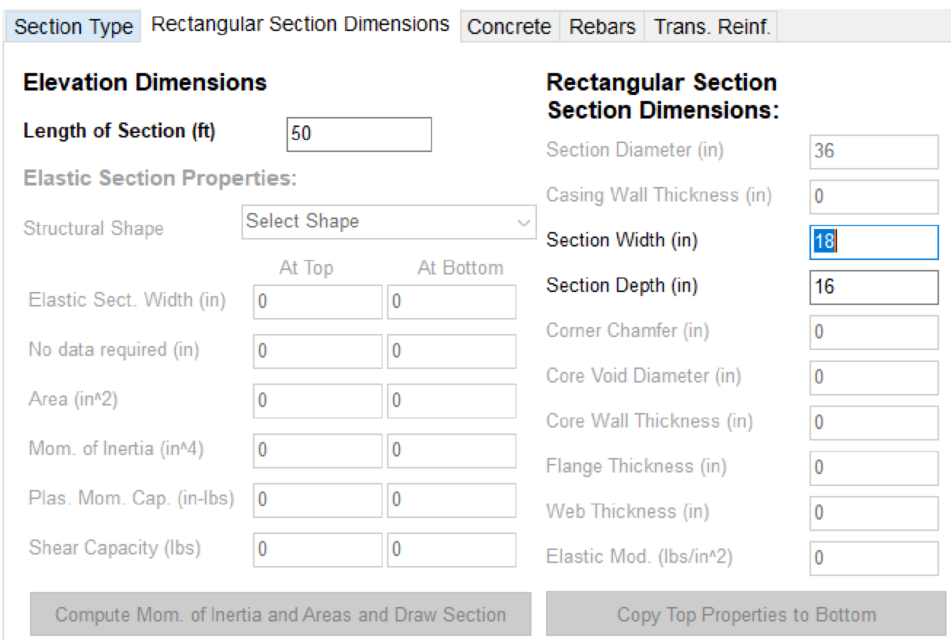


Figure 3.5 Dimensions Tab Page for Rectangular Concrete Section

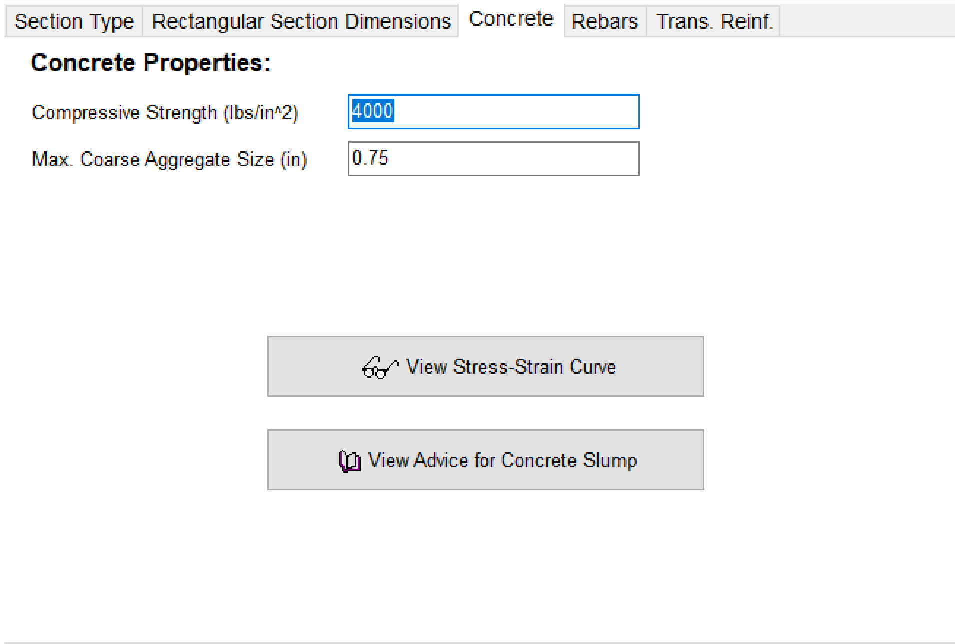


Figure 3.6 Concrete Tab Page for Rectangular Concrete Section

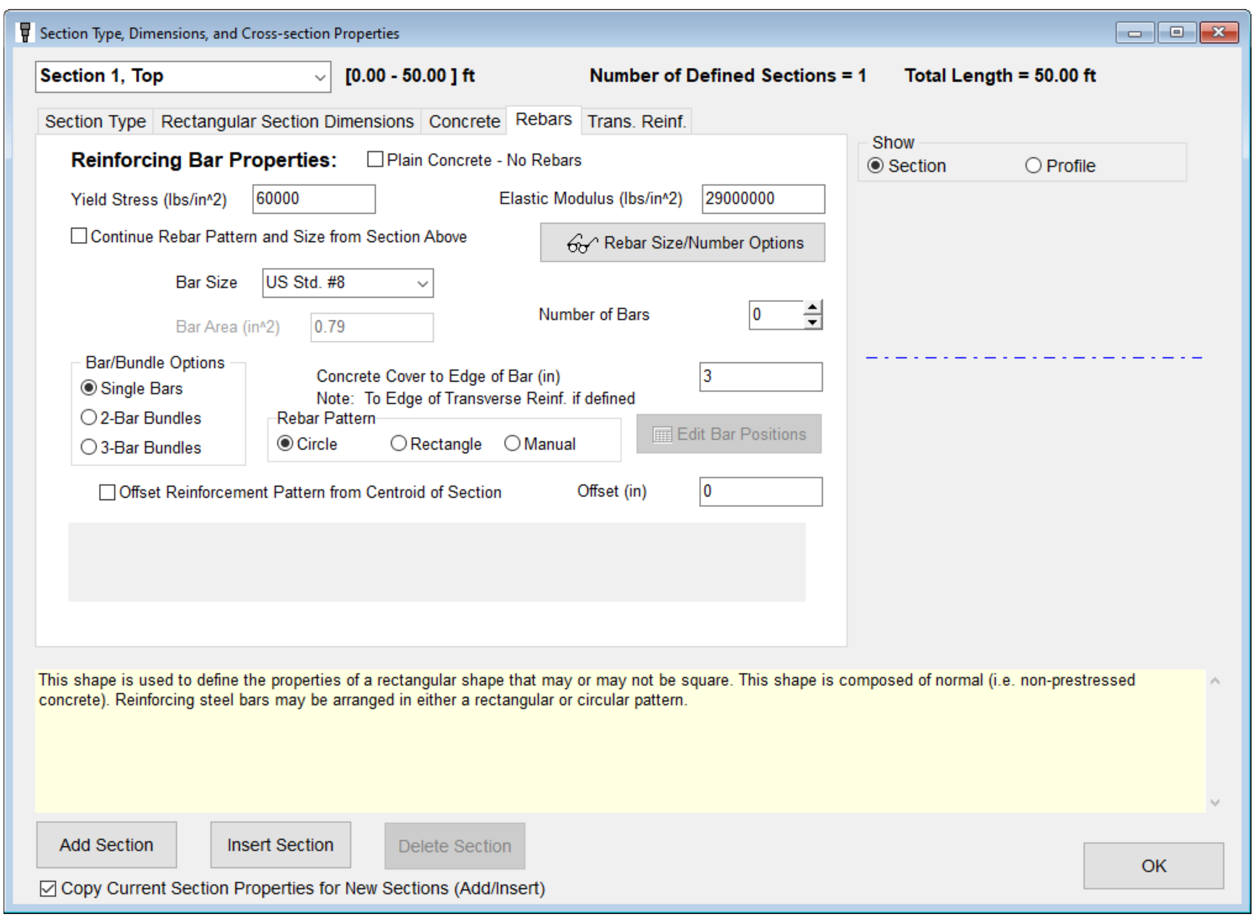


Figure 3.7 Rebars Tab Page for Rectangular Concrete Section

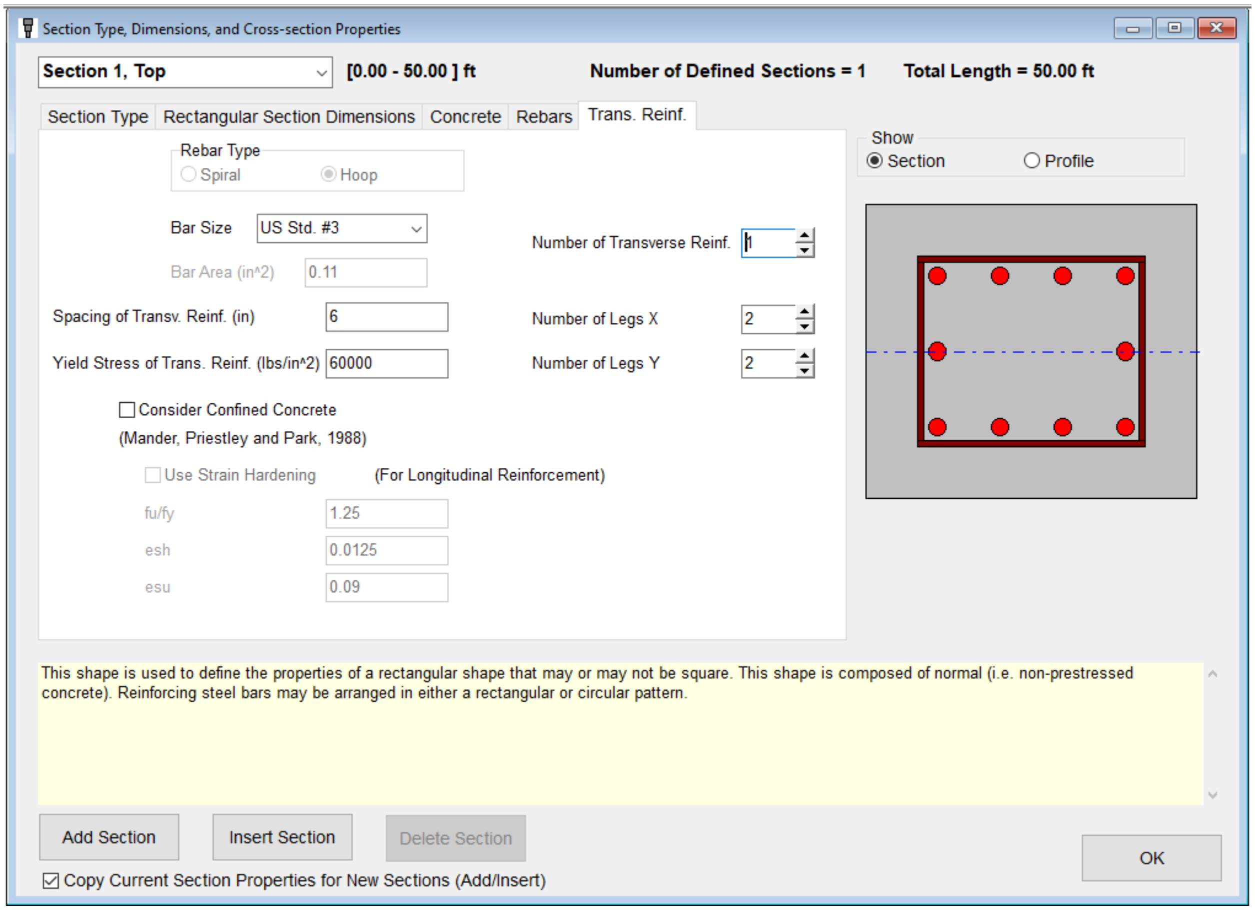


Figure 3.8 Trans. Reinf. Tab Page and Show of Section for Rectangular Concrete Section (after entries on all tabs)

If the user chooses to enter the distribution of longitudinal reinforcing bars manually (Rebar Pattern > Manual), the program will ask the user if the auto-generated layout should be copied onto the manual table for editing (see Figure 3.9). Selecting Yes may be helpful so the user simply edits the automated layout.

The positions of the reinforcing steel bars are defined using an *x-y* coordinate system with the origin positioned at the centroid of the section. The user must enter the positions of the bars and must select the size of bars from the available sizes programmed in LPile. The sample rebar layout table (from previous figures) is shown in Figure 3.10 but with a slight change on the X Coordinate of the central 4 bars (done for demonstration purposes). Once the position and size of reinforcing steel has been entered, LPile will display a scale drawing of the section as shown in Figure 3.11.

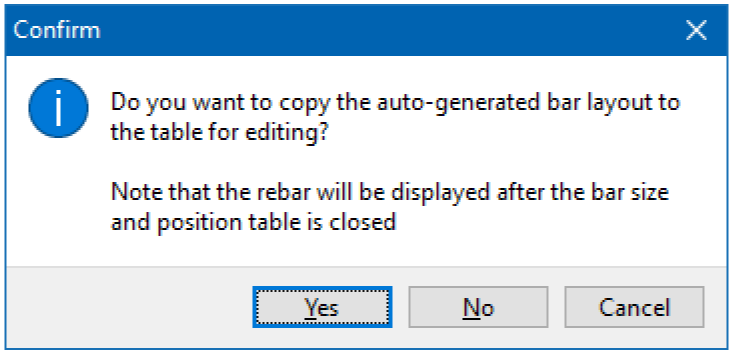


Figure 3.9 Confirmation Screen for Selection of Manual Rebar Pattern

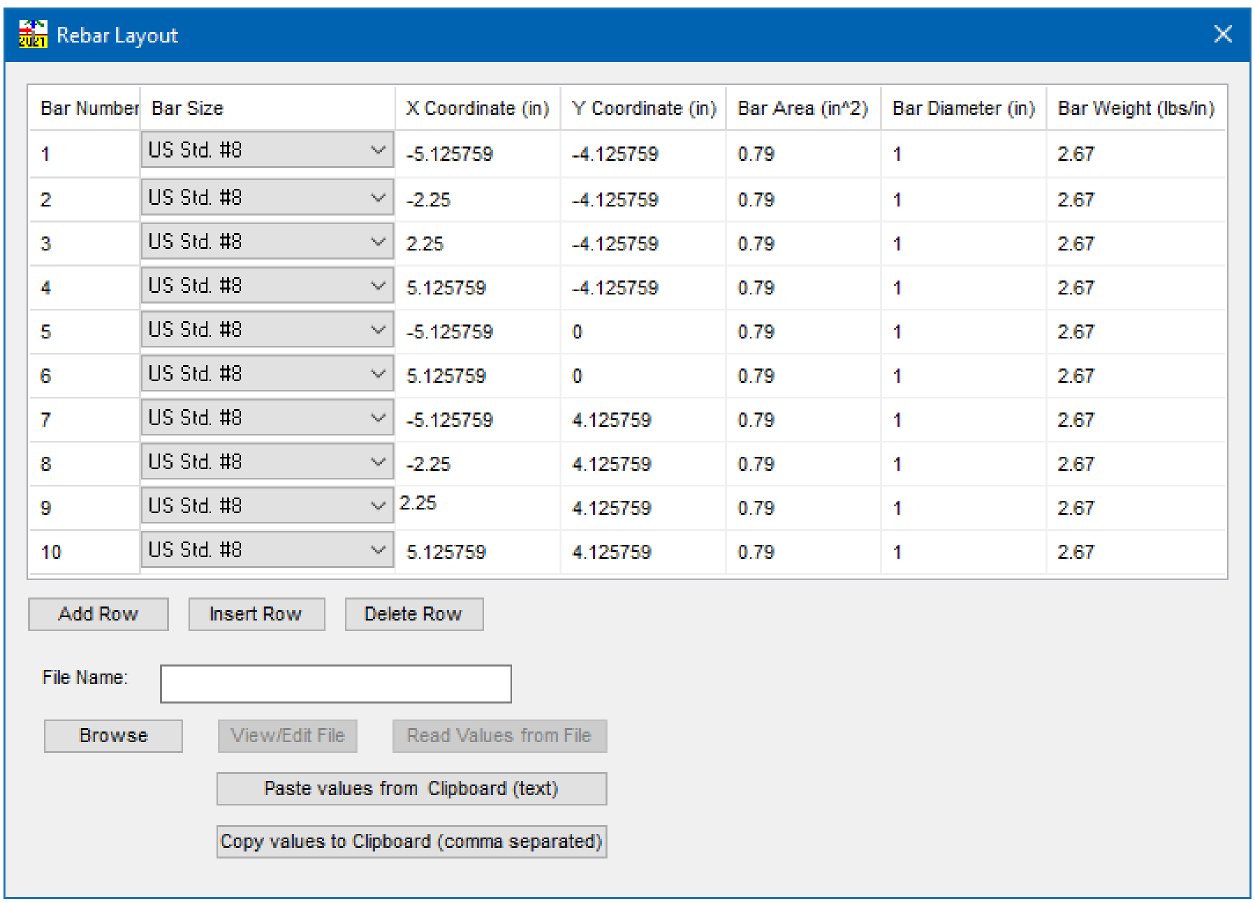


Figure 3.10 Sample Manual Rebar Layout Table for Rectangular Concrete Section

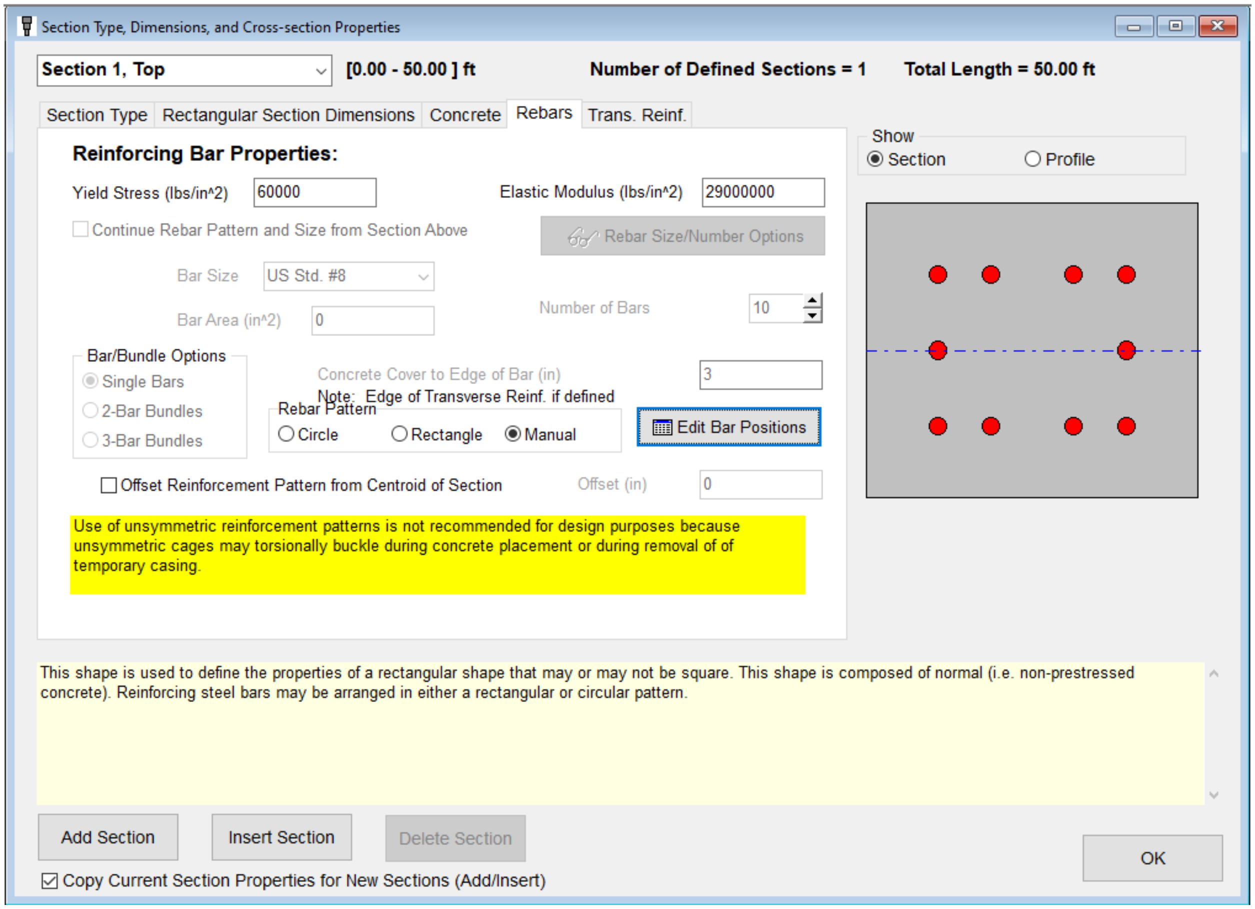


Figure 3.11 Section Type, Dimensions, and Cross-section Properties Dialog for Rectangular Concrete Section Showing Manual Rebar Layout After Definition

3.6.6.1 Round Concrete Shaft (Bored Pile)

The bending stiffness and nominal moment capacity of the section are computed using the methods discussed in Chapter 5 of the *LPile Technical Manual*.

The properties of drilled shafts (also called bored piles) are defined by the length and outer diameter of the shaft; the number, positions, yield stress, and modulus of elasticity of the reinforcing steel bars; and the compressive strength of concrete. Features are provided in LPile to compute the positions of circular bar arrangements with single-bar, two-bar, and three-bar bundles utilizing the clear cover dimension and any accidental offset of the bar cage from the shaft center. In addition, the position and size of bars can be manually edited if desired.

The dialog shown in Figure 3.12 is an example of the Section Type tab after the Round Concrete Shaft (Bored Pile) option has been selected. This drawing of the cross-section shows the current size, number, bundling, and positions of the reinforcing bars selected.

The Shaft Dimensions tab page is used to enter the Length of Section and the Section Diameter. All data entry cells for which input is not required are disabled.

The Concrete tab page, similar to the one shown previously in Figure 3.6, is to enter the Compressive Strength of concrete and the maximum size of coarse aggregate (Max. Coarse Aggregate Size) in the concrete mix. The maximum size of coarse aggregate is used when LPile checks the spacing dimension between bars to ensure that sufficient space is provided for the concrete to flow during placement of concrete.

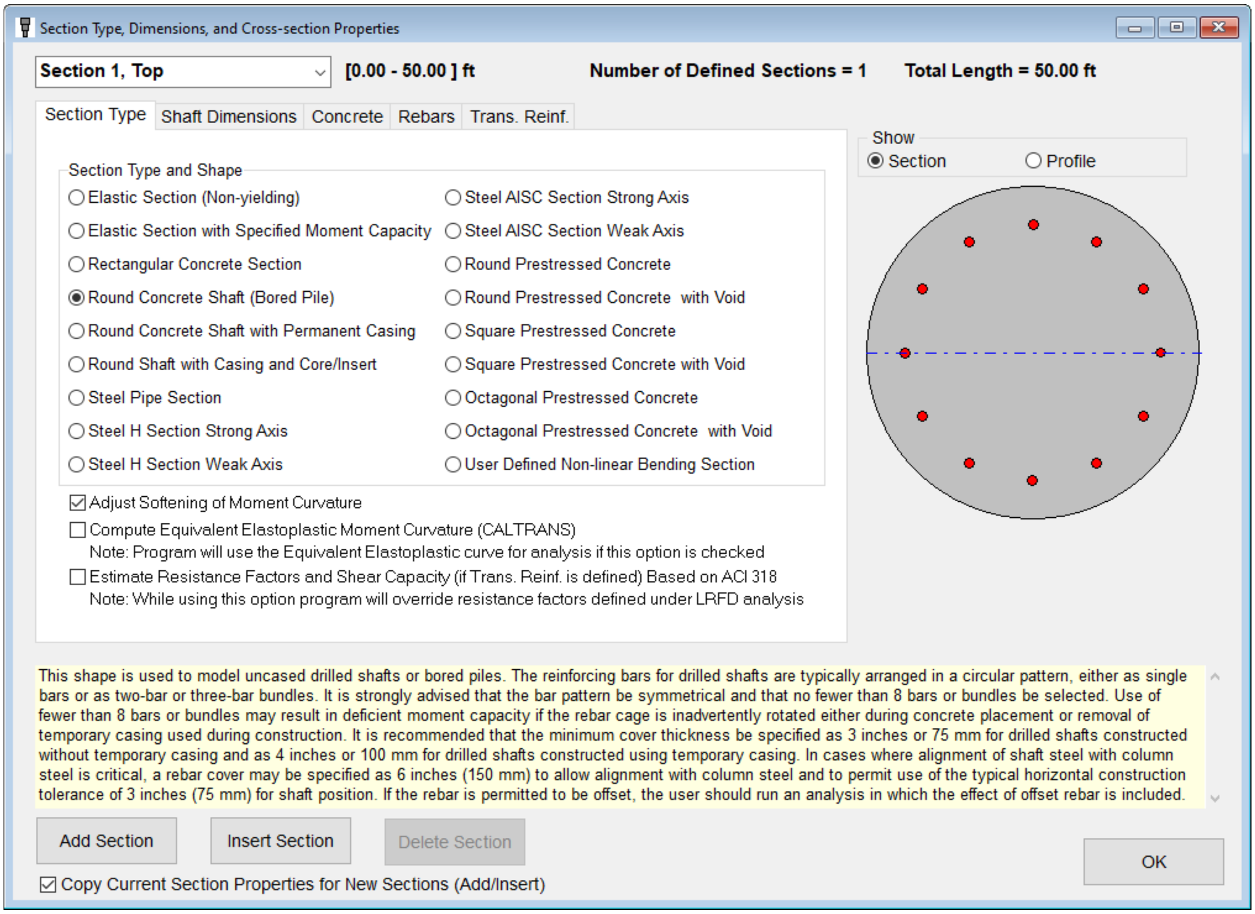


Figure 3.12 Tab for Selection of Section Type Showing Deafult Cross-Section of Round Concrete Shaft

The layout of reinforcement is defined in the Rebars tab by specifying the size of reinforcement, number of bars, bar bundle size, concrete cover thickness, and offset of the reinforcement cage from the centroid (if any) as shown in Figure 3.13. The drawing of the cross-section automatically updates to indicate any changes in the geometric properties of the reinforcing bars. In the Rebars tab (Figure 3.13), placement of a check mark under Plain Concrete – No Rebars allows for modeling of a section without any steel reinforcement.

Users also have an option to specify a second concentric layer of reinforcing bars by placing a check mark on Use second layer of reinforcement and by entering the Number of Bars 2nd layer and Rebar Dist. (radial distance center-to-center between the outside rebar layer and the inside rebar layer).

When entering data for the arrangement of reinforcing steel, the user's attention is drawn to the advice of the comment note in the lower part of the Rebars dialog box. It is important for the designer to anticipate whether or not temporary casing is used. When temporary casing is used in construction, best design practice is to specify a concrete cover thickness of 4 inches (100 mm) so that standard size shaft spacers (typically 3 inches or 75 mm) can be used to center the reinforcing steel inside the temporary casing. After concrete is placed and the temporary casing is removed, the concrete in the shaft will flow outward to fill the volume left by the casing and the annular space outside of the casing.

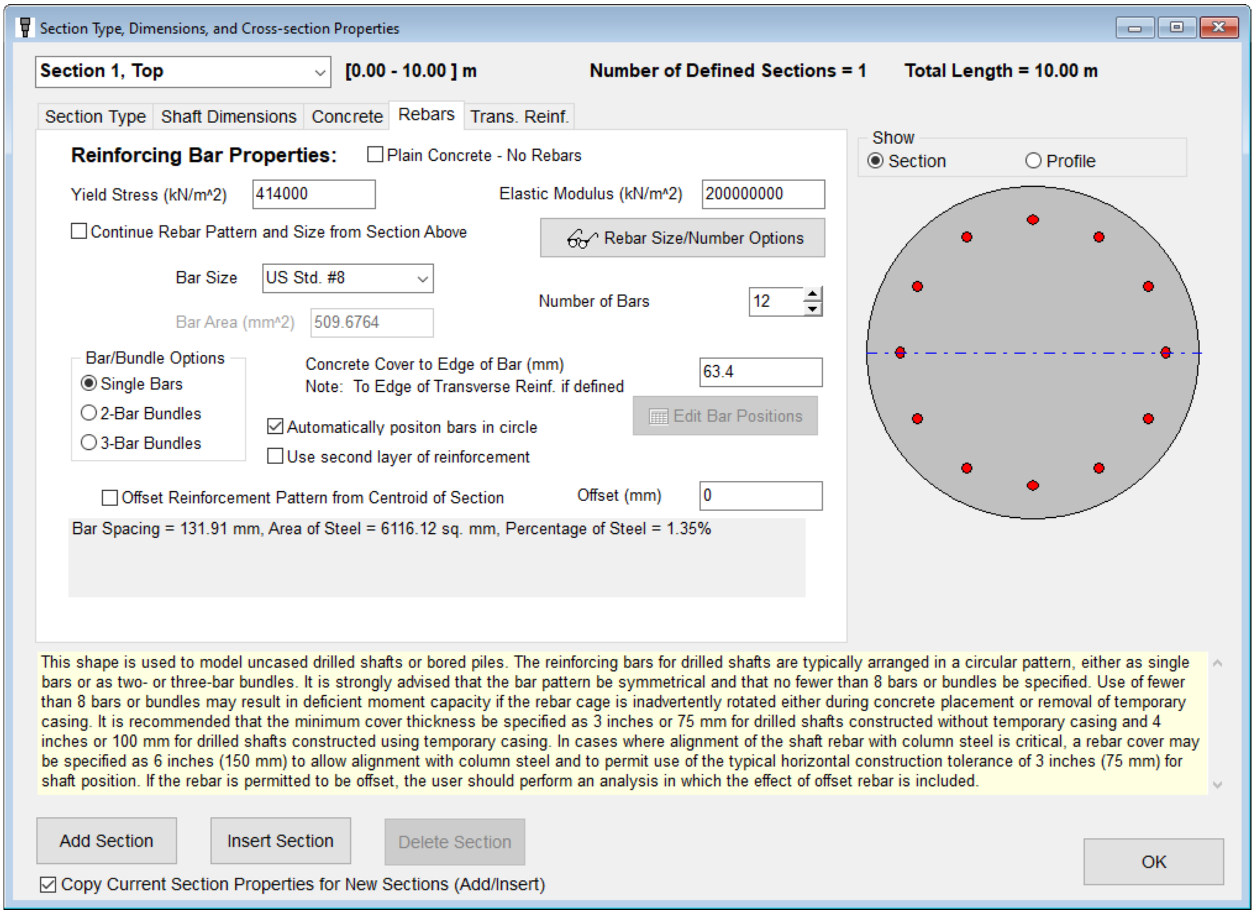


Figure 3.13 Rebars Tab for Reinforcing Bar Properties

Users may optionally enter details for the transverse reinforcement in the Trans. Reinf. tab (see Figure 3.14). After entering the transverse reinforcement, if the user also placed a check mark on Estimate Resistance Factors and Shear Capacity in the Section Type tab, the output text file will include references of the nominal shear structural capacity (concrete and steel contributions) based on the ACI 318 code.

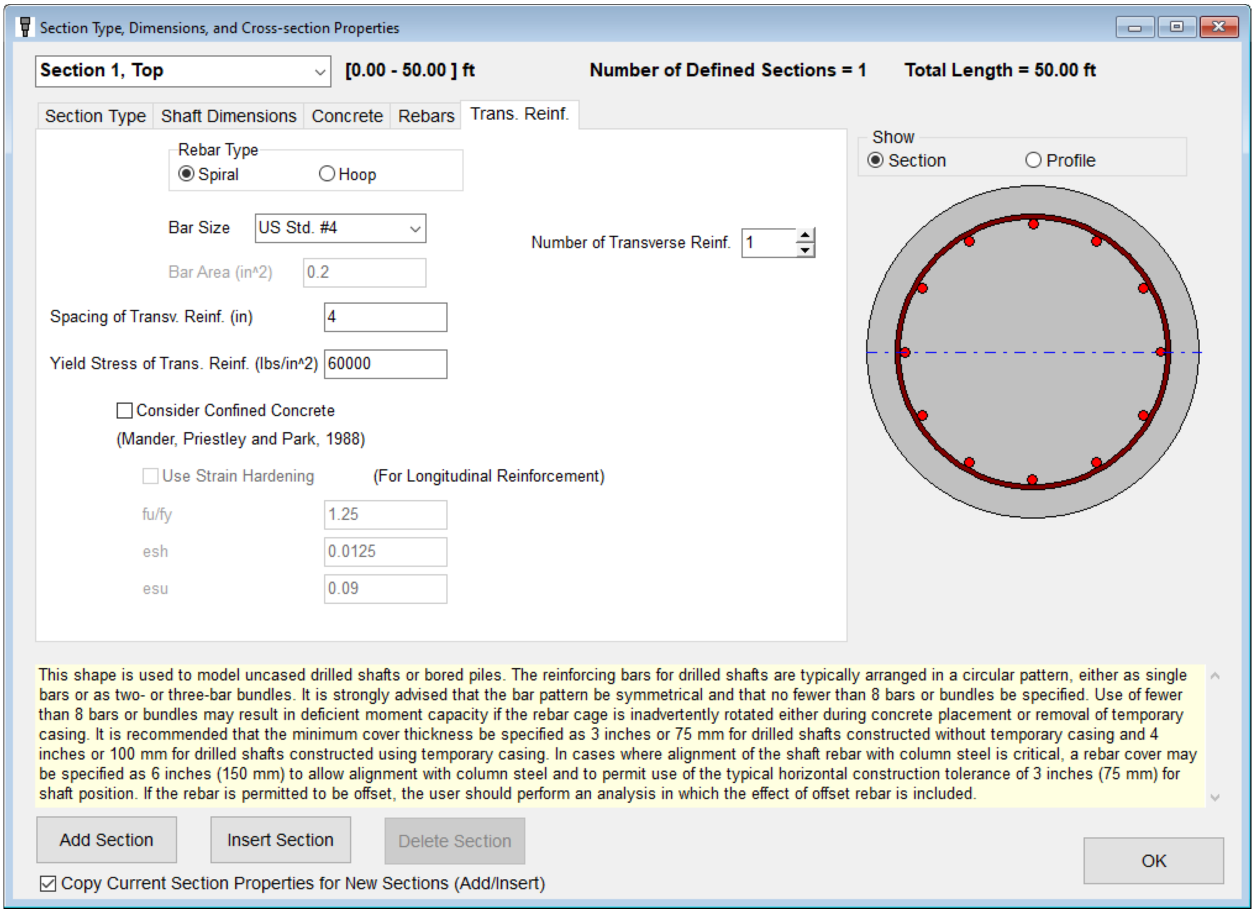


Figure 3.14 Sample Trans. Reinf. Tab

3.6.7 Round Concrete Shaft with Permanent Casing

The bending stiffness and nominal moment capacity of the section are computed using the methods discussed in Chapter 5 of the *LPile Technical Manual*.

The properties of Round Concrete Shaft with Permanent Casing are defined by the length and outer diameter of the casing; the wall thickness of the casing; the yield stress and modulus of elasticity of the casing; the number, positions, yield stress, and modulus of elasticity of the reinforcing steel bars; and the compressive strength of concrete.

The Shaft Dimensions tab page, shown in Figure 3.15 is to input the dimensions for the outside diameter of the permanent casing (Casing Outside Diam.) and the Casing Wall Thickness. The drawing of the cross-section will automatically update to show any changes in the shaft geometric properties for casing or reinforcing bars.

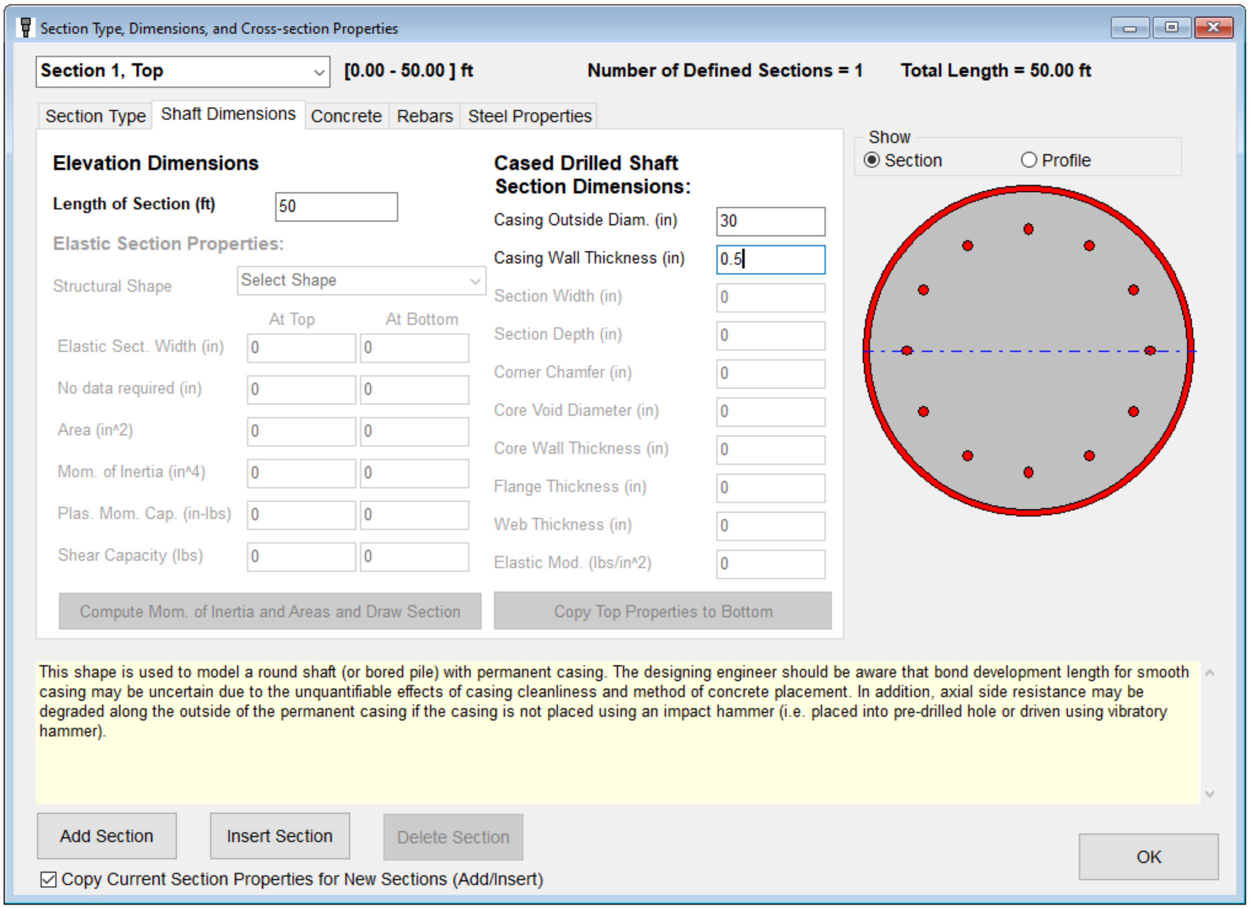


Figure 3.15 Tab Sheet for Shaft Dimensions for Drilled Shaft with Permanent Casing

The tab page for Rebars is similar to that used for drilled shafts, except that the label for the entry cell for concrete cover has to be modified to indicate that the cover dimension is measured inside the permanent casing, as shown in Figure 3.16. In the Rebars tab, placement of a check mark under Plain Concrete – No Rebars allows for modeling of a section without any steel reinforcement.

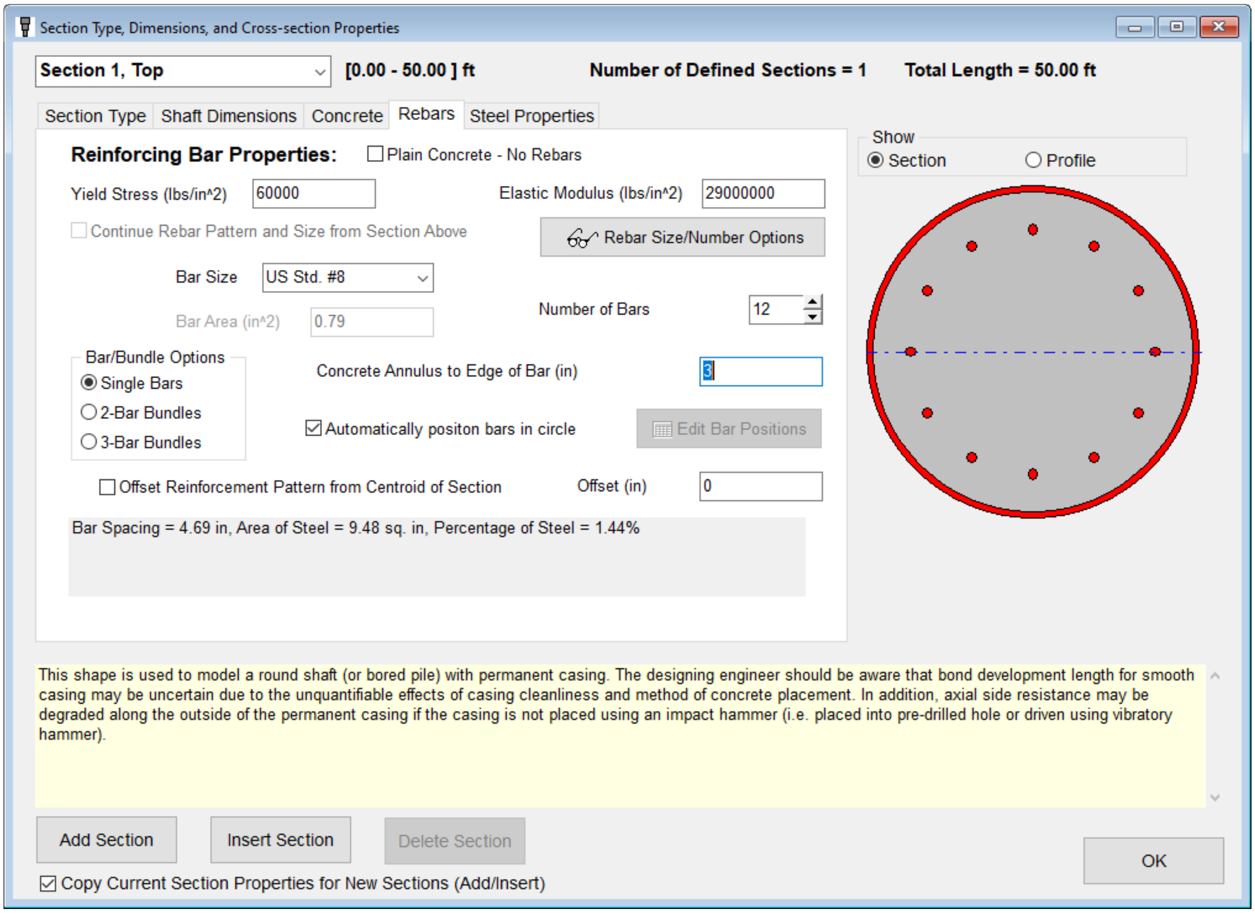


Figure 3.16 Tab Sheet for Rebars for Drilled Shaft with Permanent Casing

The Steel Properties tab page is used to enter casing material properties, as shown in Figure 3.17. This is visible only for the drilled shaft sections that utilize permanent casing. The material properties required for permanent casing are the yield stress and modulus of elasticity.

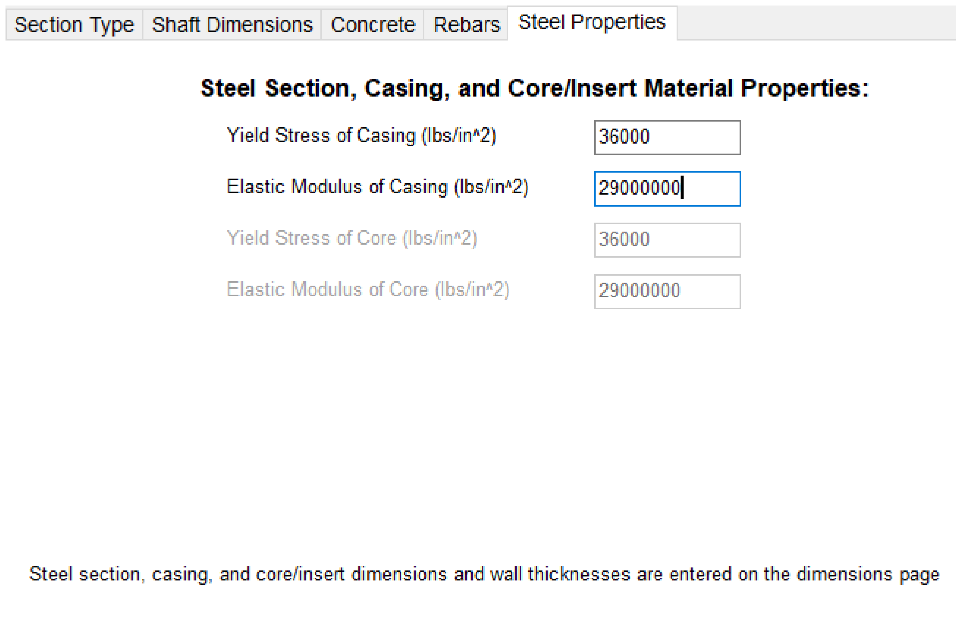


Figure 3.17 Tab Sheet for Steel Properties for Drilled Shaft with Permanent Casing

3.6.8 Round Concrete Shaft with Permanent Casing and Core/Insert

The bending stiffness and nominal moment capacity of the section are computed using the methods discussed in Chapter 5 of the *LPile Technical Manual*.

The properties of round concrete drilled shafts with permanent casing and core are defined by:

- the length and outer diameter of the casing;
- the wall thicknesses of the casing/core and dimensions of the core/insert;
- the yield stress and modulus of elasticity of the casing and core/insert;
- the number, positions, yield stress, and modulus of elasticity of the reinforcing steel bars (if any); and
- the compressive strength of concrete.

In addition, the user may specify if the core is filled with concrete (if core is a pipe) by checking the appropriate box on the Steel Properties tab page.

The Shaft Dimensions tab page for a drilled shaft with casing and core/insert is shown in Figure 3.18. The drawing of the cross-section will automatically update to show any changes in the shaft geometric properties for casing, core, or reinforcing bars.

The values entered for the wall thickness of the casing and/or core may be zero to model a shaft without a casing or core. This feature enables one to model a drilled shaft with a structural steel insert/core.

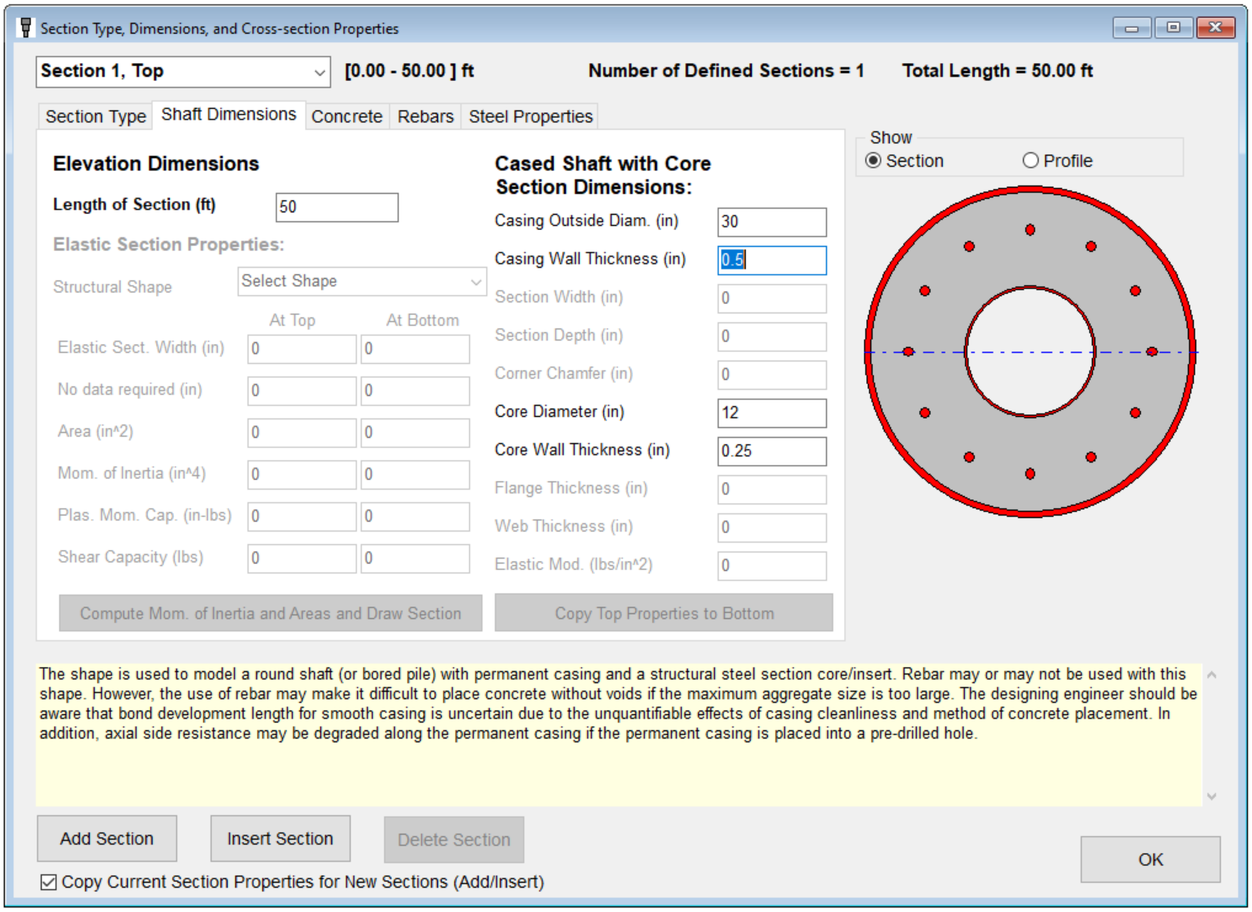


Figure 3.18 Tab Sheet forShaft Dimensions of Drilled Shaft with Casing and Core

The tab page for material properties of the casing and core is labeled Steel Properties and is shown in Figure 3.19. Also shown on this tab page is the check box to indicate if the core is filled or unfilled with concrete. In addition, the core type is selected in this section. Please note that the dimensions for the casing and core/insert are entered in the Shaft Dimensions tab.

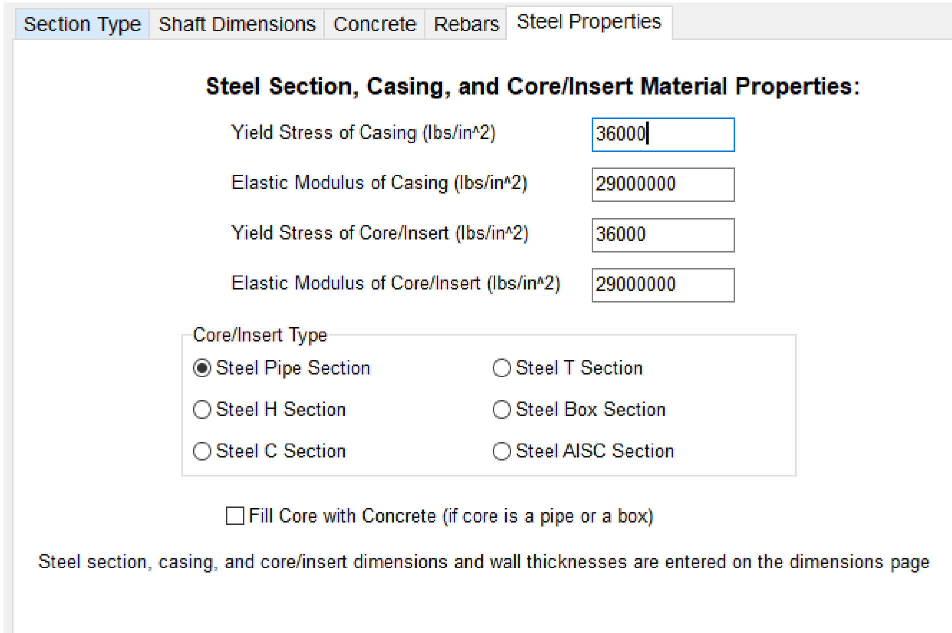


Figure 3.19 Tab Sheet for Casing and Core/Insert Material Properties

In most problems, the influence of the concrete inside the core has little effect on the computed bending stiffness, but may have a noticeable effect on the computed axial compressive structural capacity of the section.

The tab page for rebar is identical to that shown for drilled shaft with permanent casing. In the Rebars tab, placement of a check mark under Plain Concrete – No Rebars allows for modeling of a section without any steel reinforcement.

3.6.9 Steel Pipe Section

The properties of steel pipe piles are defined by the length, outside diameter, and wall thickness of the pile section and entered in the Pipe Pile Dimensions tab, as shown in the sample of Figure 3.20. The material properties are the yield stress and modulus of elasticity, entered in the Steel Properties tab, as shown in the sample of Figure 3.21.

The computed curve of moment versus curvature for a sample steel pipe pile is shown in Figure 3.22(a). Alternatively, a steel pile section could be modelled as an elastic-plastic section. However, the development of plastic yielding across the cross-section will not be modelled and the utilized moment versus curvature relationship is bilinear as shown in Figure 3.22(b).

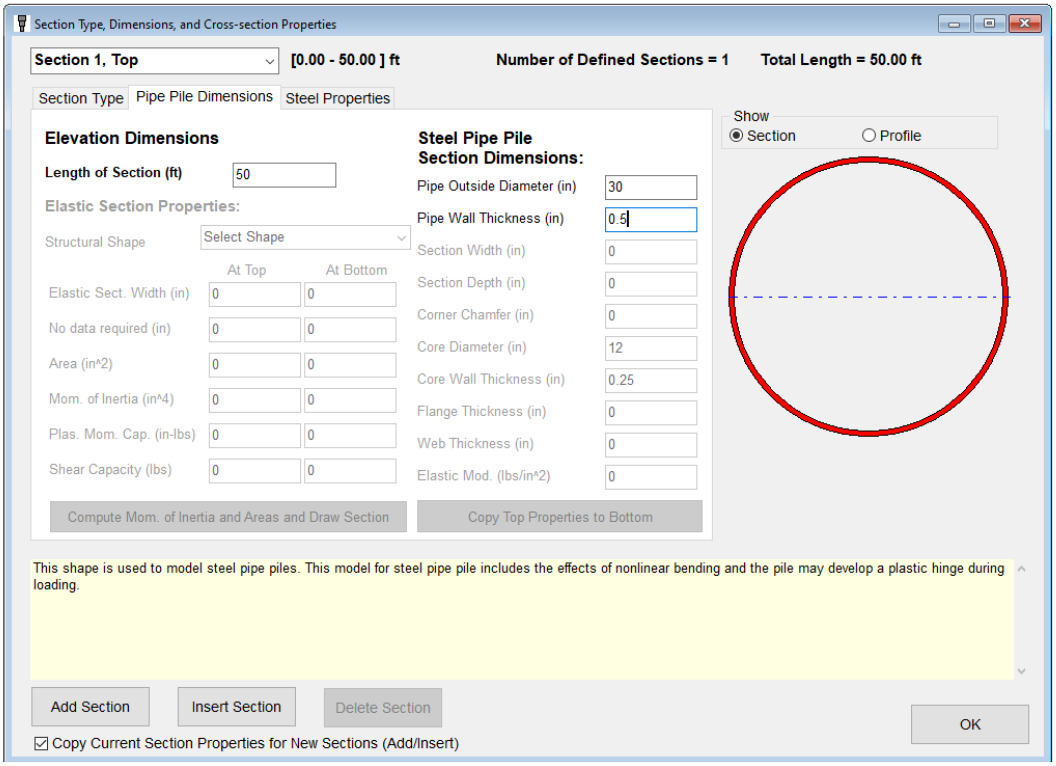


Figure 3.20 Pipe Pile Dimensions Tab Page for Steel Pipe Piles

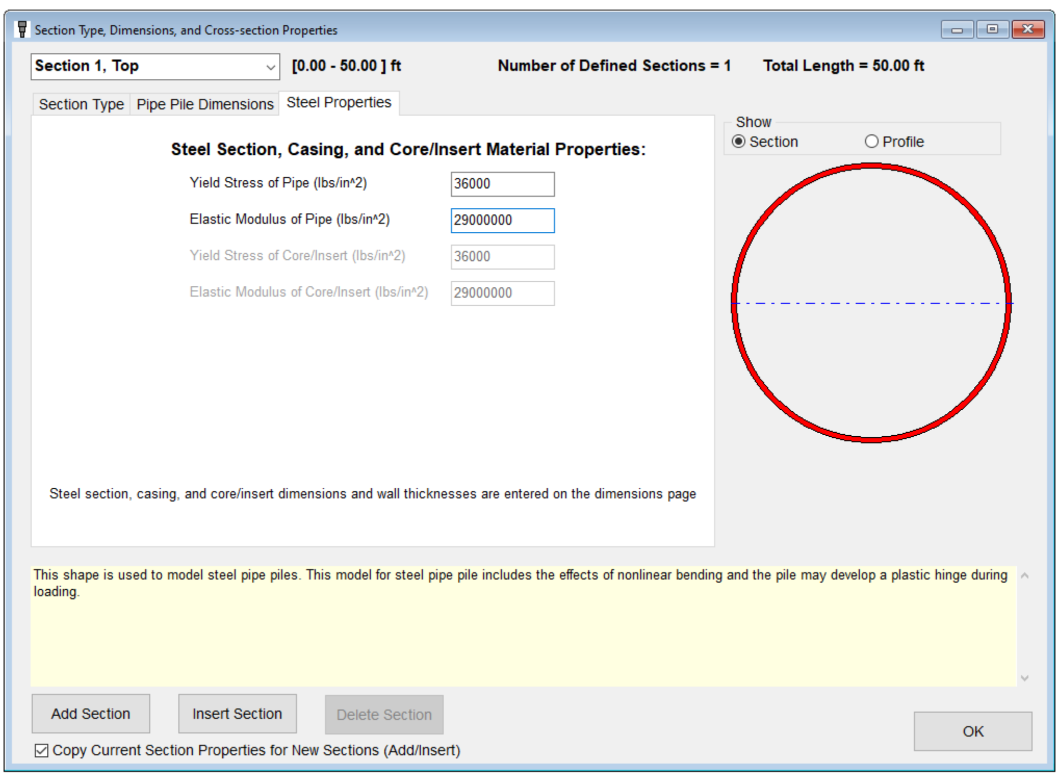


Figure 3.21 Pipe-Casing-Core Properties Tab Page for Steel Pipe Pile

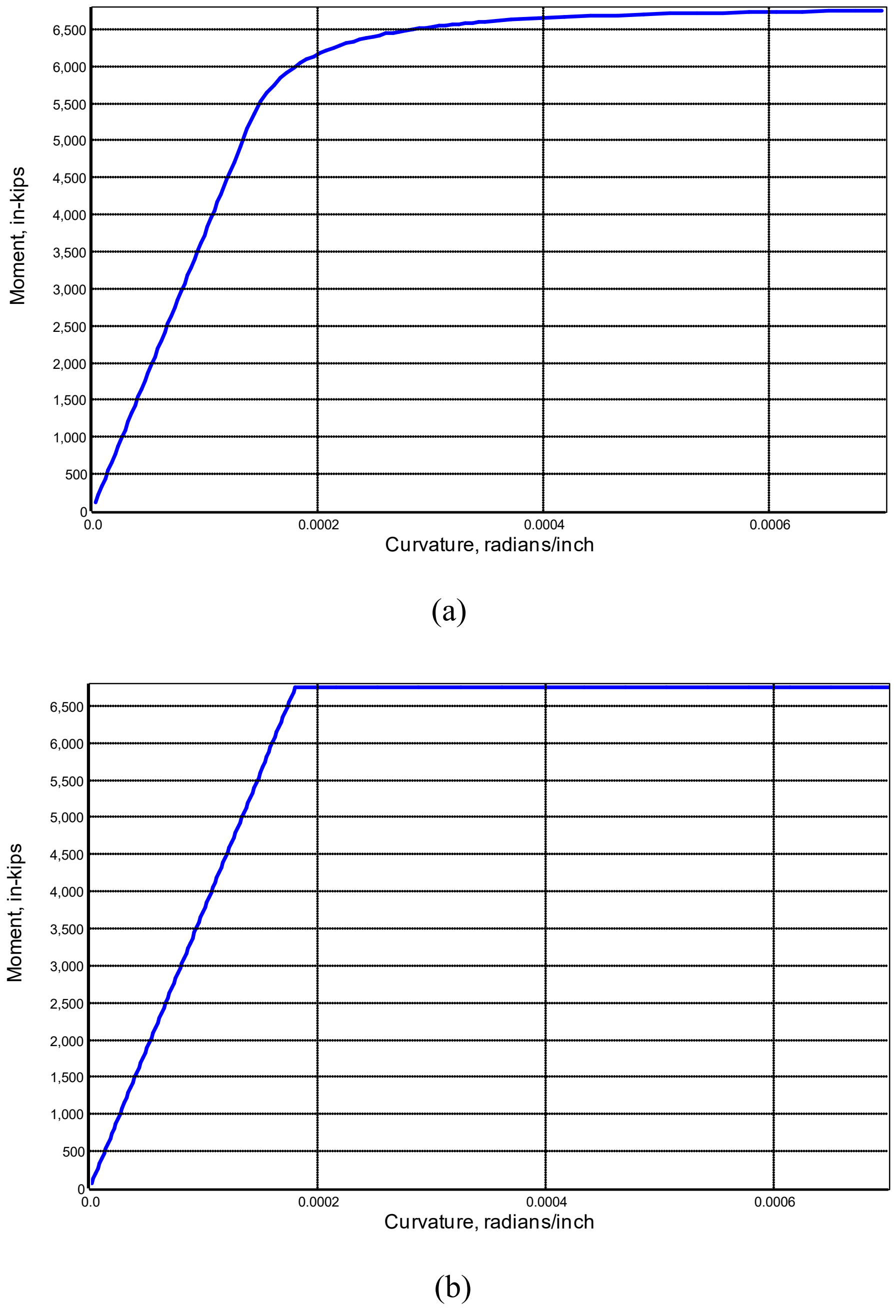


Figure 3.22 Comparison of Moment vs. Curvature for (a) Steel Pipe Pile and (b) Elastic-Plastic Pipe Pile with Similar Properties

3.6.10 Steel H Section

Steel H Section is for piles with H-shape sections and defaults to bending in the strong axis (web perpendicular to neutral axis), unless users click on Rotate Section (Weak Axis) which changes to bending in weak axis (web parallel to neutral axis).

The properties of steel H section piles (for strong and weak axis bending) are defined by the length, flange width, section depth, flange thickness, and wall thickness of the pile section as shown in sample of Figure 3.23, for the bending in the strong axis, and in sample Figure 3.24, for bending in the weak axis. The material properties are the yield stress and modulus of elasticity, similar to the Steel Pipe Section previously shown in Figure 3.21.

3.6.10.1 H Section Dimensions Tab

- Flange Width is the width of the flange of the pile section (dimension parallel to axis of bending when using strong axis bending). This dimension is used for internal computations of the soil response *p-y* curves when bending in strong axis (unless user places check mark on Use Eq. D. and enters Elas. Eq. Diam.).
- Section Depth is the depth of the pile section (dimension perpendicular to axis of bending when using strong axis bending). This dimension is used for internal computations of the soil response *p-y* curves when bending in weak axis (unless user places check mark on Use Eq. D. and enters Elas. Eq. Diam.).
- Flange Thickness is the thickness of the flanges (width section).
- Web Thickness is the thickness of the web (depth section).

3.6.10.2 Steel Properties Tab

- Yield Stress of H Section is where the user specifies the yield strength of the steel material of this pile section.
- Elastic Modulus of H Section is where the user specifies the modulus of elasticity of the steel material of this pile section.

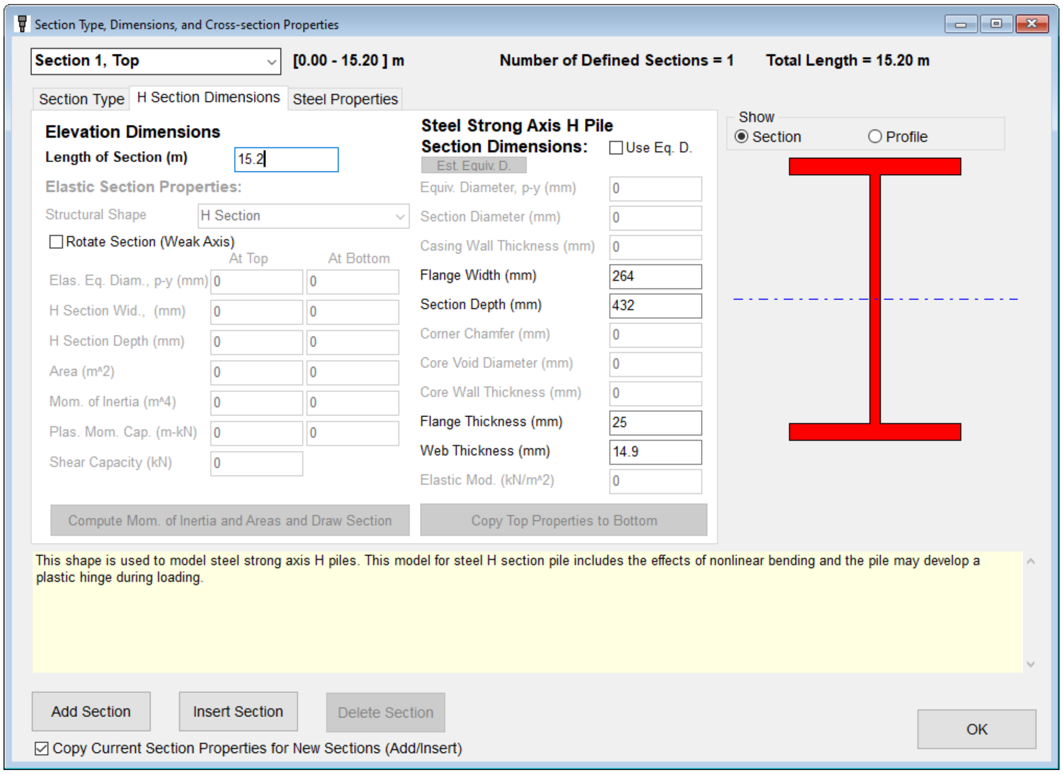


Figure 3.23 Dimensions Tab Page for Sample Strong Axis H Pile

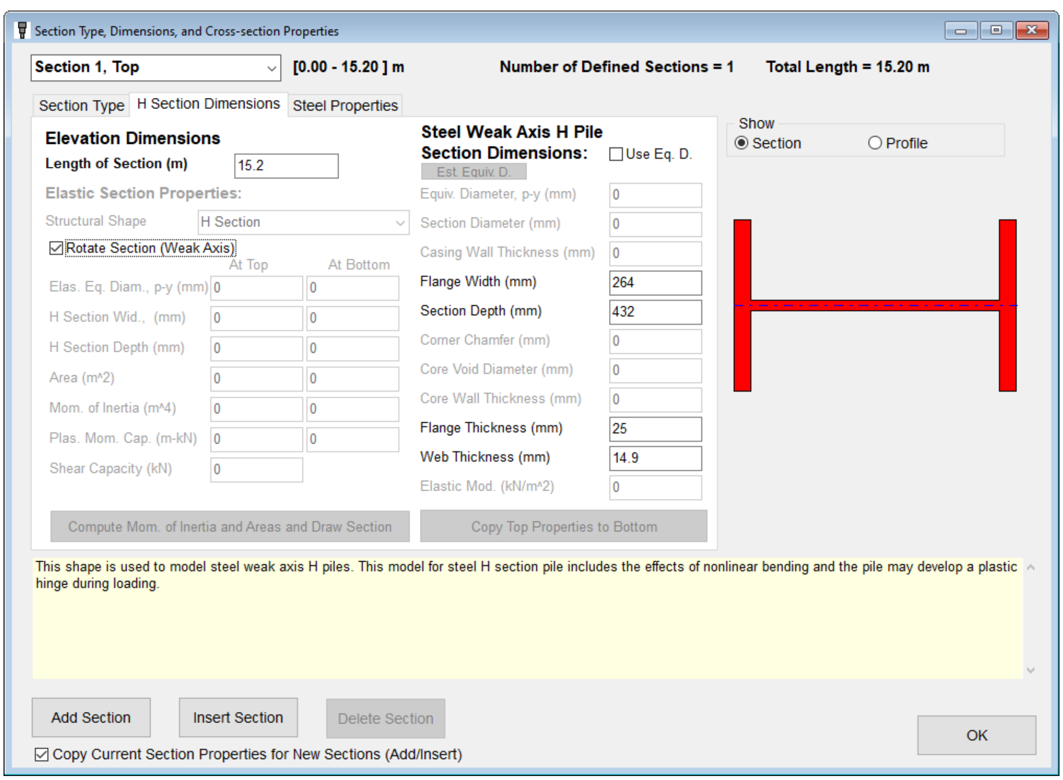


Figure 3.24 Dimensions Tab Page for Sample Weak Axis H Pile

3.6.11 Steel C Section

Steel C Section is for piles with C-shape or Stiffened C-shape sections bending in the strong axis (web perpendicular to neutral axis). This type of section is often used as supports for light-weight structures, such us in solar farm installations.

Evaluation of weak axis bending for this type of pile section is not available in the initial release of LPILE v2026 but may be added later. Weak axis bending of this type of pile section is not symmetric since it has a different flexural stiffness when it is bent to one or the other direction.

The properties of steel C section piles (for strong axis bending) are defined by the length, flange width, section depth, corner radius, flange thickness, and wall thickness of the pile section. A guide for the various dimensions is in Figure 3.25 and a sample dialog box in Figure 3.26. For Stiffened C sections the user may enter the stiffener length and stiffener thickness, as shown in sample on Figure 3.27. The material properties are the yield stress and modulus of elasticity.

3.6.11.1 C Section Dimensions Tab

- Flange Width is the width of the flange of the pile section (dimension parallel to axis of bending when using strong axis bending). This dimension is used for internal computations of the soil response *p-y* curves when bending in strong axis (unless user places check mark on Use Eq. D. and enters Elas. Eq. Diam.).
- Section Depth is the depth of the pile section (dimension perpendicular to axis of bending when using strong axis bending). This dimension is used for internal computations of the soil response *p-y* curves when bending in weak axis (unless user places check mark on Use Eq. D. and enters Elas. Eq. Diam.).
- Corner Radius is the radius at outside corners of flanges and web. Zero defines right angles. This feature is only applicable for sections with equal thickness (flange/web/stiffener thickness must be equal). When Corner Radius is defined, the program assumes that all section thicknesses are equal, so the user must make sure to enter the same values for flange/web/stiffener thickness.
- Stiffener Length is the length, if any, of the stiffeners at flange ends. Zero defines a standard, non-stiffened C section.
- Stiffener Thick. is the thickness of the stiffeners at flange ends. Leave as zero for a standard, non-stiffened C section.
- Flange Thickness is the thickness of the flanges (width section).
- Web Thickness is the thickness of the web (depth section).

3.6.11.2 Steel Properties Tab

- Yield Stress of C Section is where the user specifies the yield strength of the steel material of this pile section.
- Elastic Modulus of C Section is where the user specifies the modulus of elasticity of the steel material of this pile section.

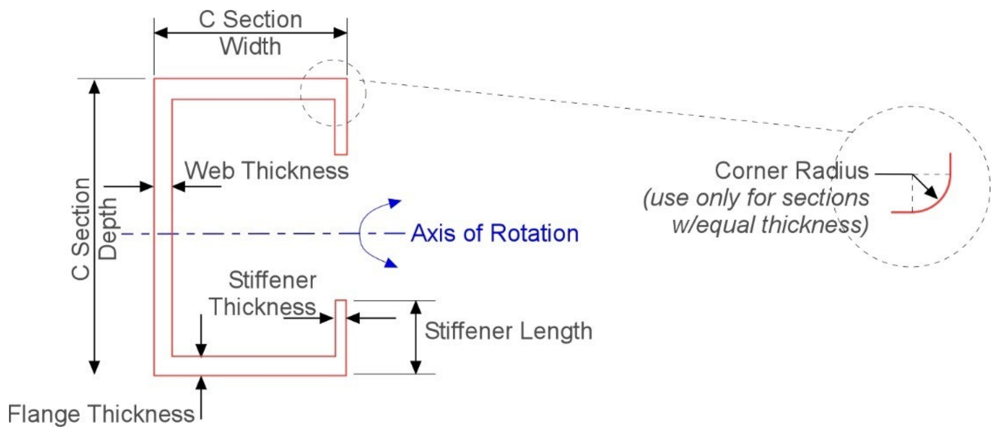


Figure 3.25 Reference Dimensions for C Section Pile

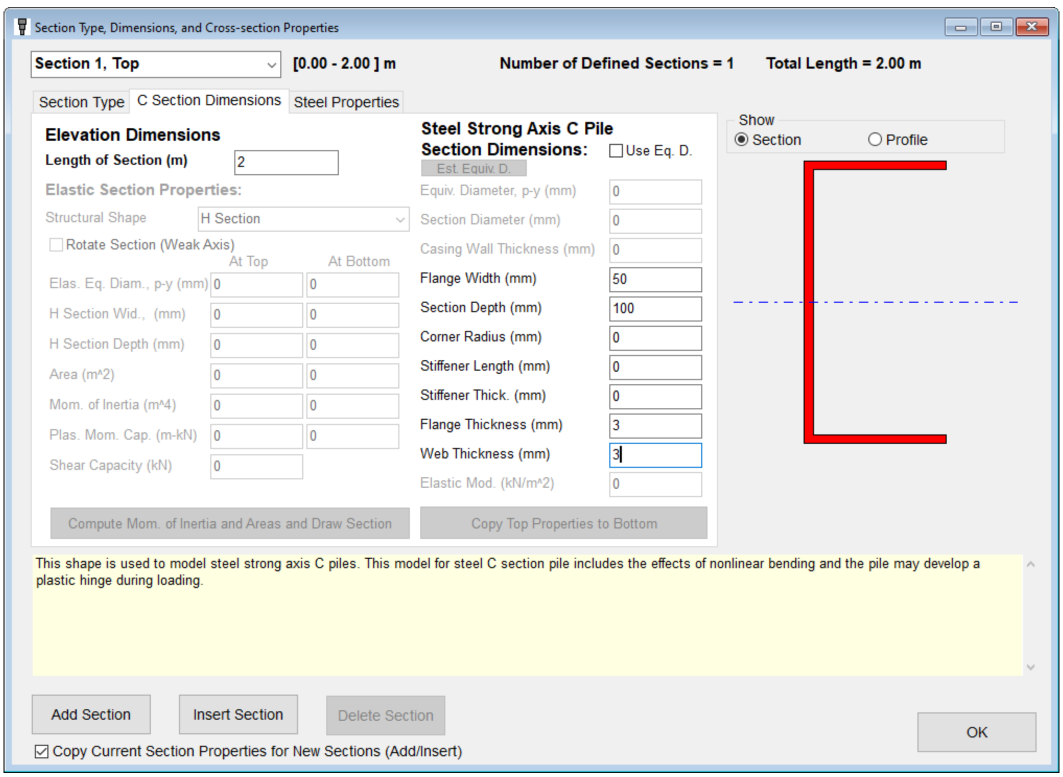


Figure 3.26 Dimensions Tab Page for Sample Strong Axis C Pile

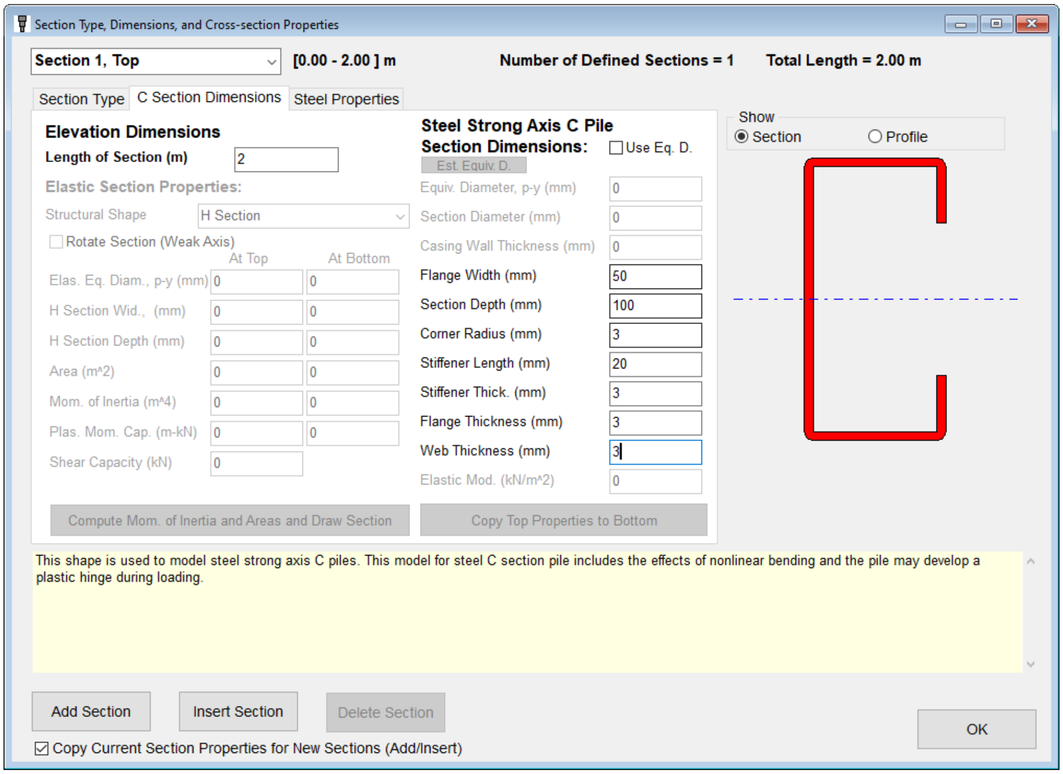


Figure 3.27 Dimensions Tab Page for Sample Strong Axis Stiffened C Pile

3.6.12 Steel T Section

Steel T Section is for piles with T-shape sections bending in the weak axis (flange perpendicular to neutral axis). This type of section is not normally used in pile structures but is provided as complement for theoretical evaluation and research.

Evaluation of strong axis bending for this type of pile section is not available in the initial release of LPILE v2026 but may be added later. Strong axis bending of this type of pile section is not symmetric since it has a different flexural stiffness when it is bent to one or the other direction.

The properties of steel T section piles (for strong axis bending) are defined by the length, flange width, section depth, flange thickness and wall thickness of the pile section as shown in Figure 3.28. The material properties are the yield stress and modulus of elasticity.

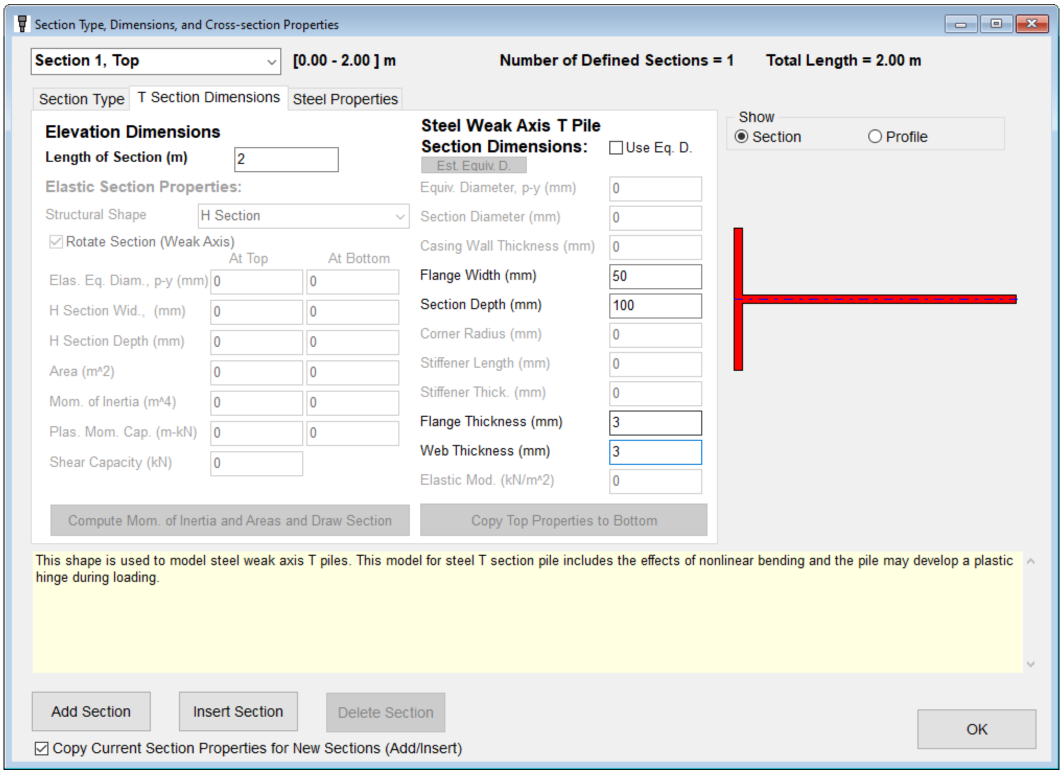


Figure 3.28 Dimensions Tab Page for Sample Weak Axis T Pile

3.6.13 Steel Box Section

Steel Box Section is for piles with a rectangular box shape. The properties of steel box section piles are defined by the length, flange width, section depth, corner radius, flange thickness, and wall thickness of the pile section. A guide for the various dimensions is in Figure 3.29 and a sample dialog box in Figure 3.30. The material properties are the yield stress and modulus of elasticity. This type of section is not normally used in large structures but may be suitable as supports for light-weight structures.

3.6.13.1 Box Section Dimensions Tab

- Flange Width is the width of the flange of the pile section (dimension parallel to axis of bending). This dimension is used for internal computations of the soil response *p-y* curves (unless user places check mark on Use Eq. D. and enters Elas. Eq. Diam.).
- Section Depth is the depth of the pile section (dimension perpendicular to axis of bending). This dimension is only used for internal computations of flexural stiffness and not for the soil response *p-y* curves.
- Corner Radius is the radius at outside corners of flanges. Zero defines right angles. This feature is only applicable for sections with equal thickness (flange/web thickness must be equal). When Corner Radius is defined, the program assumes that all section thicknesses are equal, so the user must make sure to enter the same values for flange/web thickness.
- Flange Thickness is the thickness of the flanges (width section).

- Web Thickness is the thickness of the web (depth section).

3.6.13.2 Steel Properties Tab

- Yield Stress of Box Section is where the user specifies the yield strength of the steel material of this pile section.
- Elastic Modulus of Box Section is where the user specifies the modulus of elasticity of the steel material of this pile section.

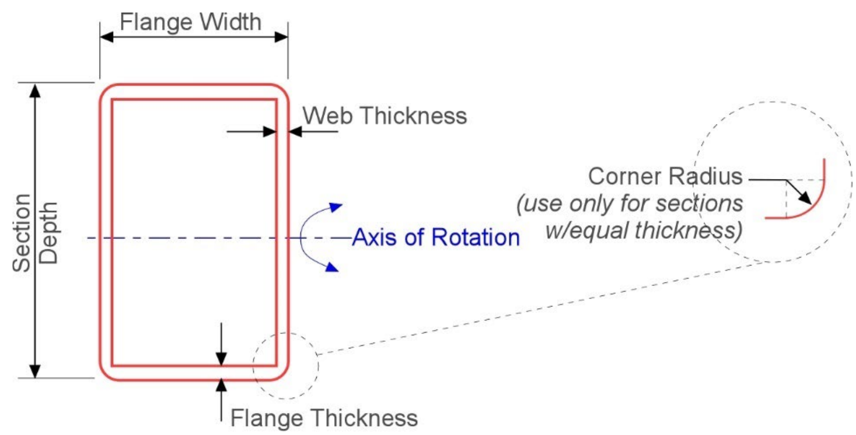


Figure 3.29 Reference Dimensions for Box Section Pile

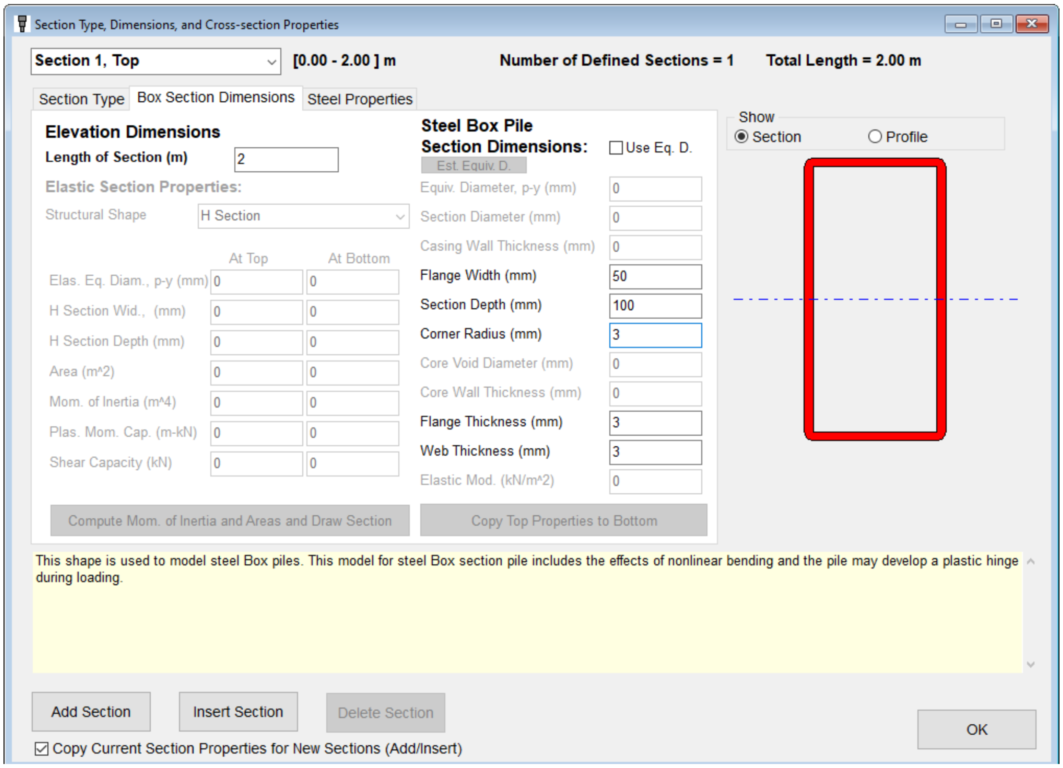


Figure 3.30 Dimensions Tab Page for Sample Box Section Pile

3.6.14 Steel AISC Section

The properties of Steel AISC Section piles are defined in the AISC Section Dimension tab by the Length of Section, and selection of the Section Type and of the Section Name at the bottom of the dialog. The program will fill the disabled dimensions (flange width, section depth, flange thickness, and wall thickness) of the pile section from the database.

A sample is shown in Figure 3.31, for bending in the strong axis, and in Figure 3.32 for bending in the weak axis (some Section Types are not possible to Rotate Section to Weak Axis bending). The material properties in the Steel Properties tab are the yield stress and modulus of elasticity are similar to the Steel Pipe Section previously shown in Figure 3.21.

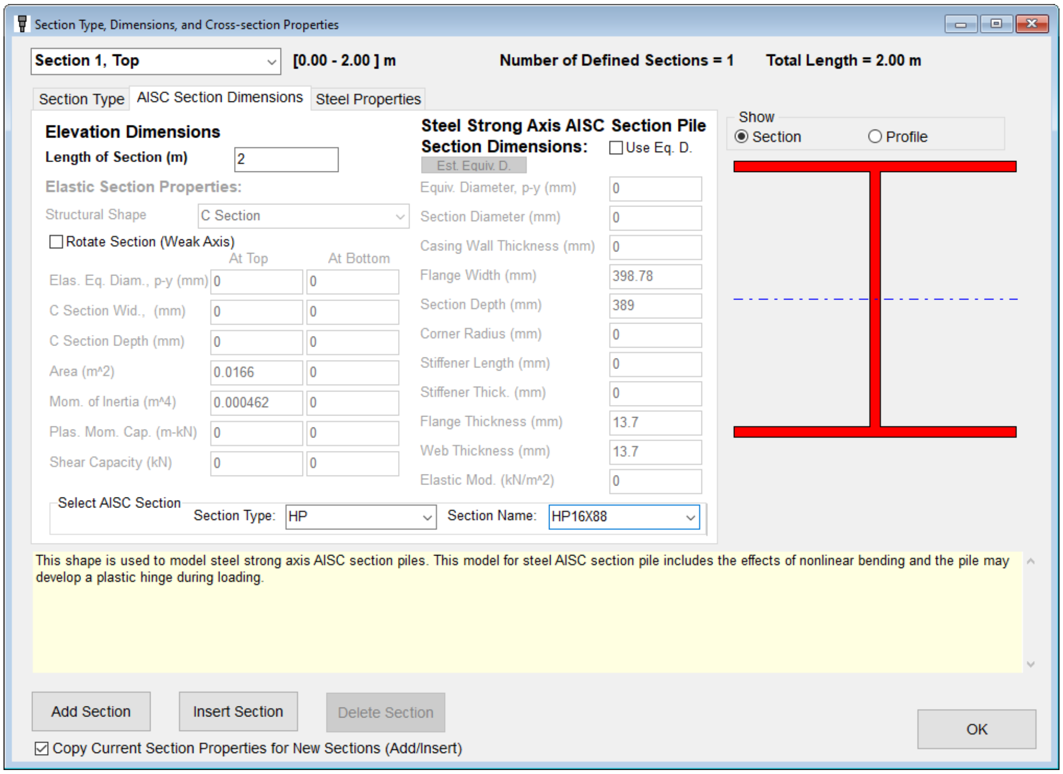


Figure 3.31 Dimensions Tab Page for Strong Axis AISC Piles

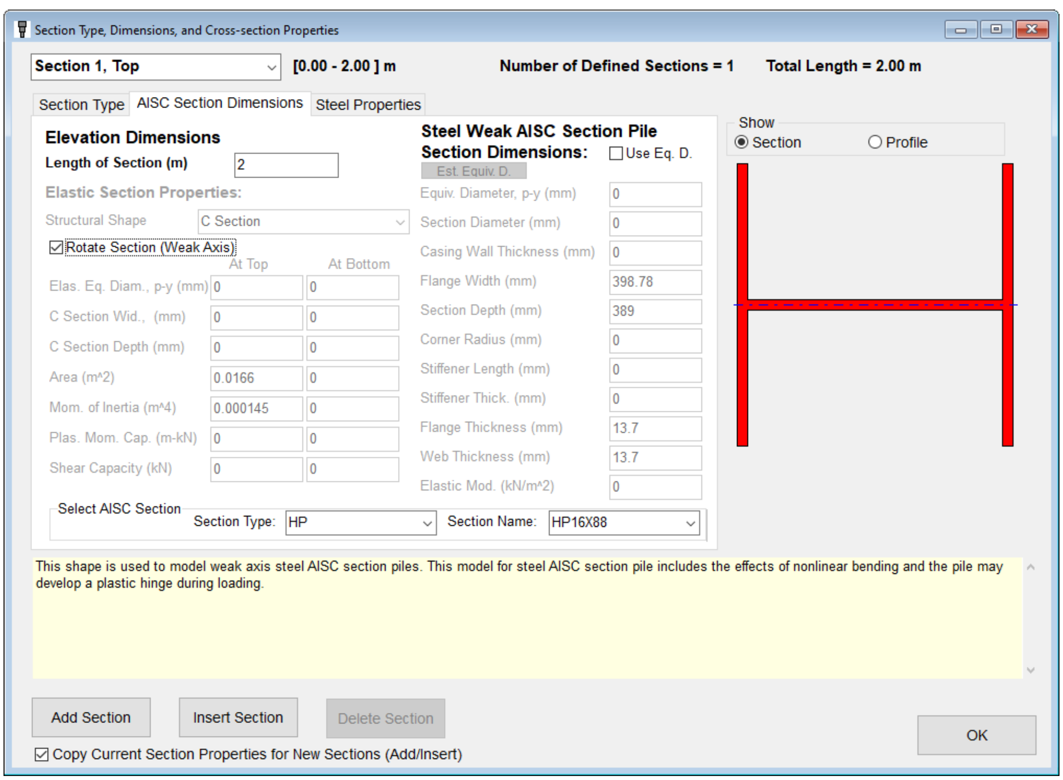


Figure 3.32 Dimensions Tab Page for Weak Axis AISC Piles

3.6.15 Round Prestressed Concrete

The properties of round prestressed concrete piles are defined by the length and diameter of the pile, the compressive strength of concrete, the prestressing reinforcement details, and the loss of prestress. A central void (with no concrete) can be defined by entering a value greater than zero under Void Diameter.

The usual procedure for the LPile user is to enter the pile dimensions, compressive strength of concrete, number and size of prestress reinforcement strands, and concrete cover dimension. The Prestressing tab page for entering prestressing data for all types of prestressed concrete piles is shown in Figure 3.33. Once the prestressing size, number, and geometry are entered, the cross-section of the pile should be drawn by LPile. If the cross-section is not drawn properly, there is an error in the input data.

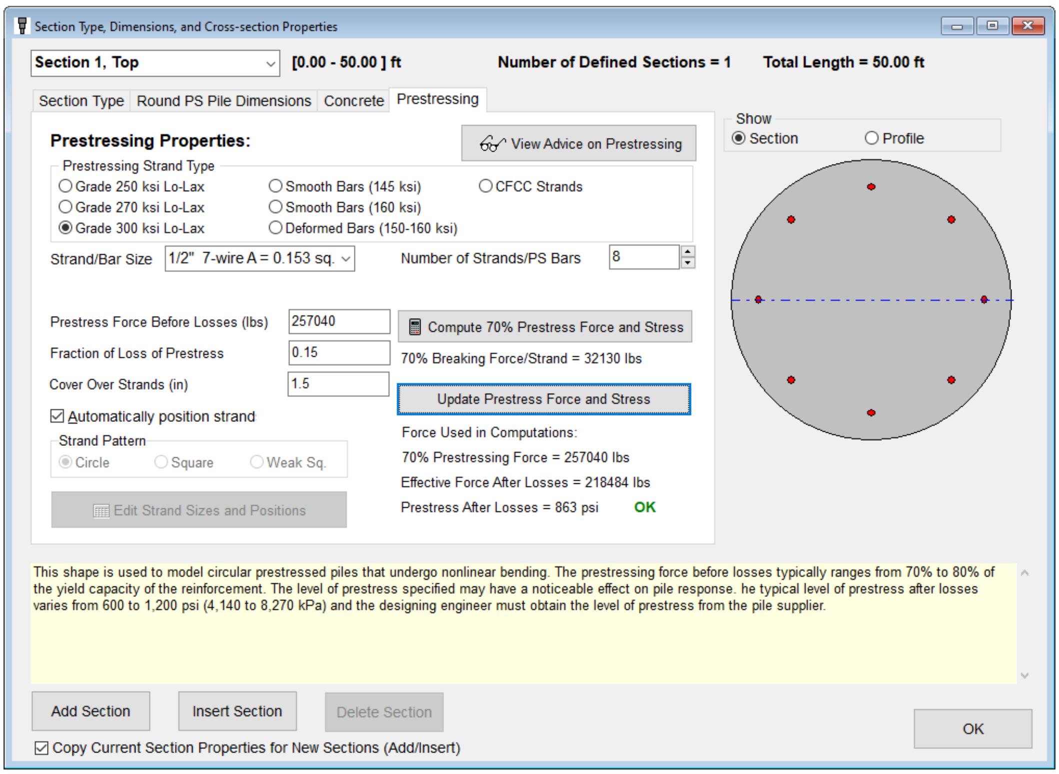


Figure 3.33 Prestressing Tab Page Common to All Prestressed Pile Types

As a designer, the engineer can specify the length, diameter, concrete compressive strength, and reinforcement of a prestressed pile, but must find out from the pile supplier what value the expected fraction of loss of prestress is expected to be. Sometimes, the supplier will provide the final prestress after losses. The engineer can then determine the fraction of loss of prestress if the initial prestressing forces before losses are also provided. The common practice for pile suppliers is to use 70 percent of the rated prestressing capacity of the reinforcement as the prestress force. This value is programmed in LPile for the listed sizes and types or prestress reinforcement.

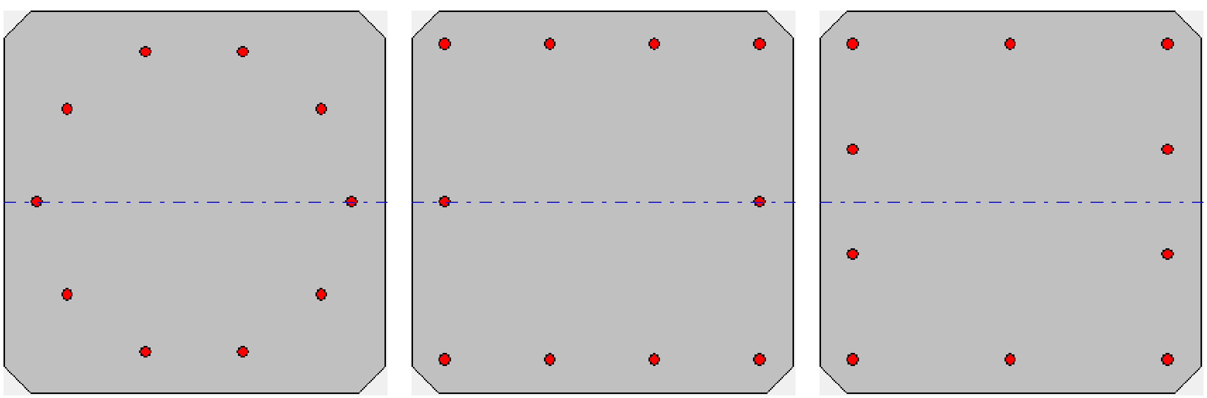
Next, the user enters the fraction of loss provided by the pile supplier. For preliminary computations prior to selecting a pile supplier, the user may enter a value in the typical range between 0.10 and 0.20. The value of prestress after losses is computed by LPile by pressing the button to Compute 70% Prestress Force and Stress. The value computed by LPile will be shown in the dialog and will be classified as OK if the prestress after losses is in the range of 600 to 1,200 psi (4.14 to 8.27 MPa), or as too high or too low if outside of this range.

3.6.16 Square Prestressed Concrete

The properties of square prestressed concrete piles are defined by the length and width of the pile, the size of the corner chamfer, the compressive strength of concrete, and the prestressing reinforcement and loss of prestress. A central void (with no concrete) can be defined by entering a value greater than zero under Void Diameter.

The input for the Square Prestressed Concrete pile is largely the same as for the Round Prestressed Concrete pile, with the exception of the entry of the dimensions for the Section Side/Width and Corner Chamfer. Please refer to the discussion in Section 3.6.15 for information about the computation of prestress after losses.

An additional feature for the square prestressed pile is the feature to generate automatically rectangular strand layouts with circular, square, or weak square arrangements as shown in Figure 3.34. The different layout patterns will be displayed in the cross-section drawing when the number of prestressing strands is varied.



(a) Circular (b) Square (c) Weak Square

Figure 3.34 Automatic Prestressing Arrangements for Square Prestressed Piles

3.6.17 Octagonal Prestressed Concrete

The properties of octagonal prestressed concrete piles are defined by the length and width of the pile, the compressive strength of concrete, and the prestressing reinforcement and loss of prestress. The procedures used to compute the nonlinear bending properties for the octagonal shape are identical to those used for the Square Prestressed Concrete except that the size of the corner chamfer is defined internally to produce the octagonal shape.

3.6.18 User Defined Nonlinear Bending Section

The properties of piles with nonlinear bending are defined by the length and diameter of the pile and the user-specified nonlinear bending properties. Nonlinear bending properties are defined by levels of axial thrust force and associated curves of either nonlinear bending stiffness versus bending moment or nonlinear bending moment versus bending curvature.

The type of nonlinear data is selected by the user by checking the appropriate radio button for the Type of Nonlinear Bending Input Data on the Nonlinear EI tab page shown in Figure 3.35. The buttons used to enter nonlinear bending data are enabled once the type of nonlinear bending data has been selected. Next, the user enters the values of axial thrust force for which curves for nonlinear bending are to be entered in the data table shown in Figure 3.36.

If more than one section with defined nonlinear bending is being defined, the values of axial thrust force of Section 1 are copied to the other section(s).

A curve of nonlinear bending data is required for each input value for axial thrust force by pressing the button to the right of the thrust force value shown in Figure 3.36 to open the input tables shown in Figure 3.37.

The table shown will depend on the type of nonlinear bending data that was selected. It is possible to enter nonlinear bending data by either reading an external text file or pasting values from the Windows clipboard.

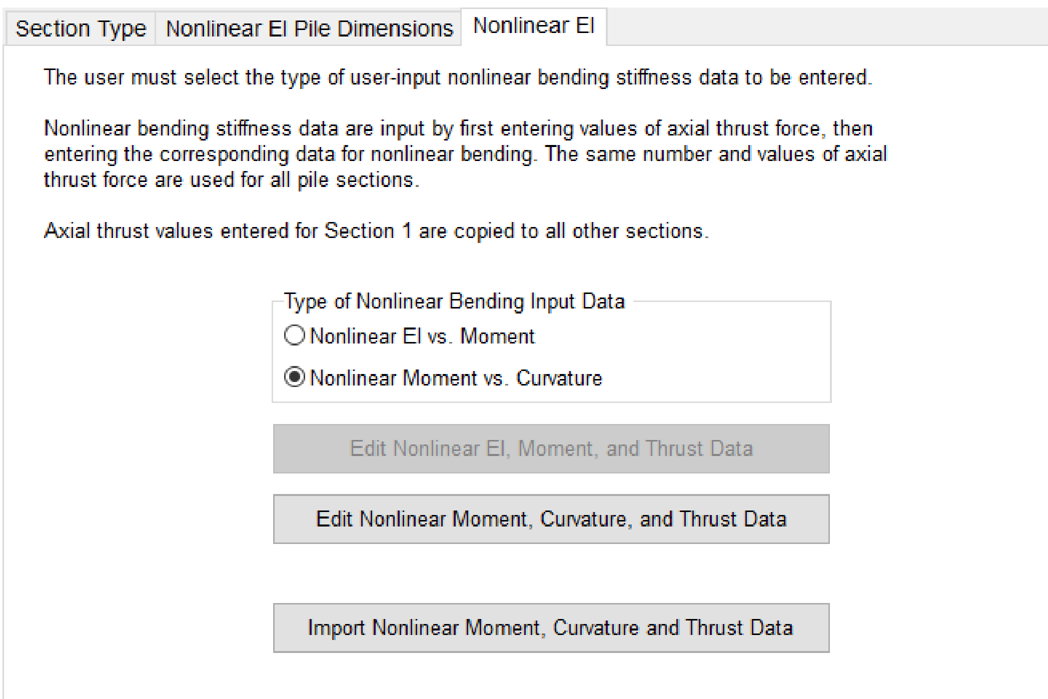


Figure 3.35 Nonlinear EI Tab Page

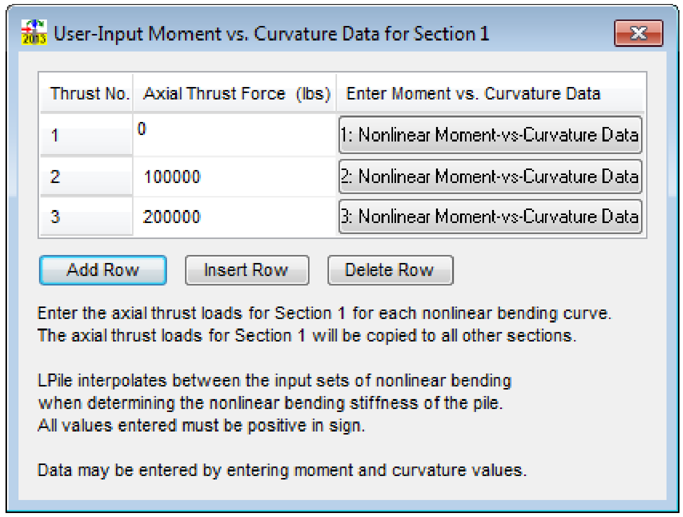
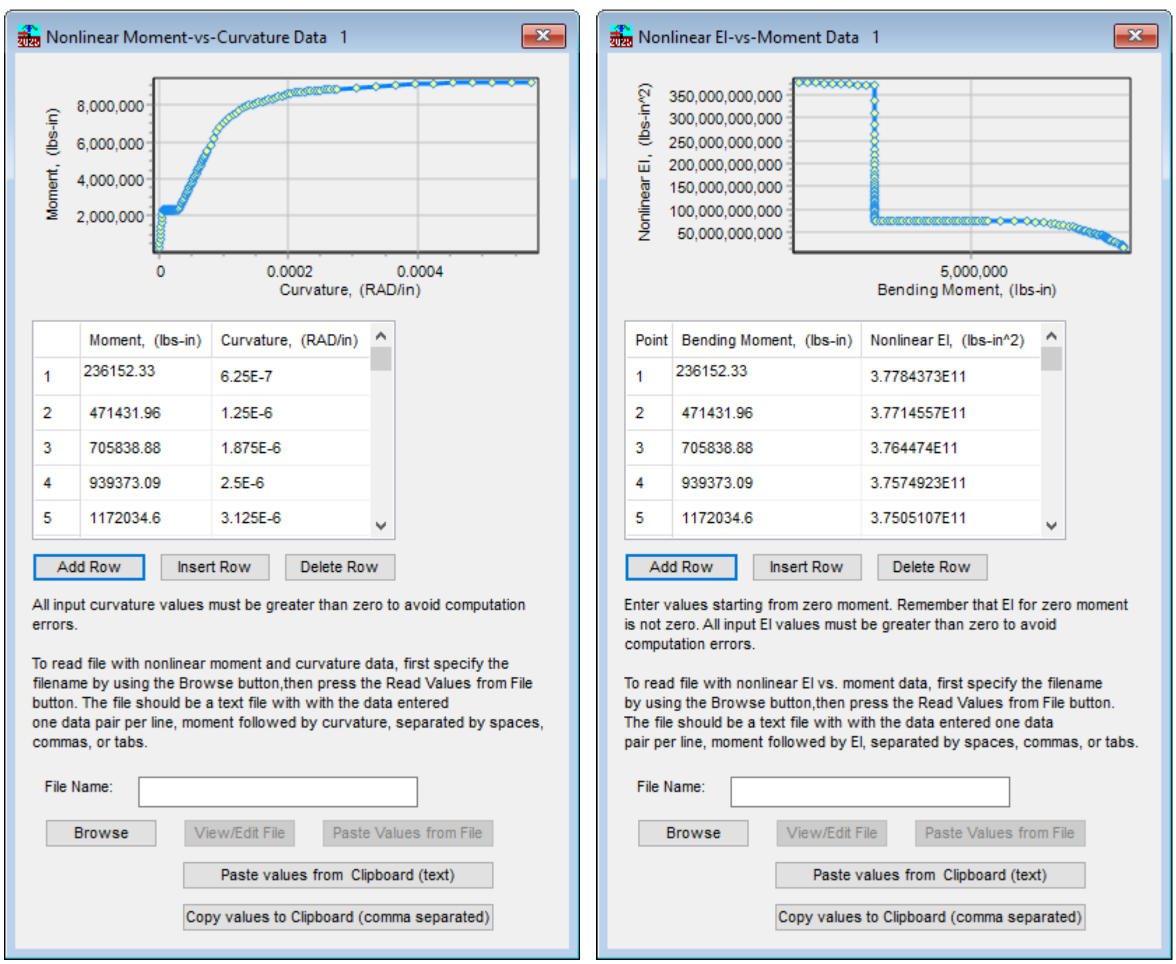


Figure 3.36 Table for Entering Axial Thrust Forces for Nonlinear Bending Data



(a) (b)

Figure 3.37 Tables for Entry of (a) Nonlinear Moment versus Curvature Data and (b) Nonlinear Moment versus Bending Stiffness

To enter data from an external text file, the user locates the text file using the Browse button and then pressing the Read Values from File button. The format of the external text file requires that values are entered with the moment value first and either the *EI* or curvature value second with one data pair per line. A maximum of 150 data points may be entered.

The Import Nonlinear Moment, Curvature and Thrust Data button in Figure 3.36 allows the user to import values from almost any LPile model (output text file) that was previously created using non-linear pile sections.

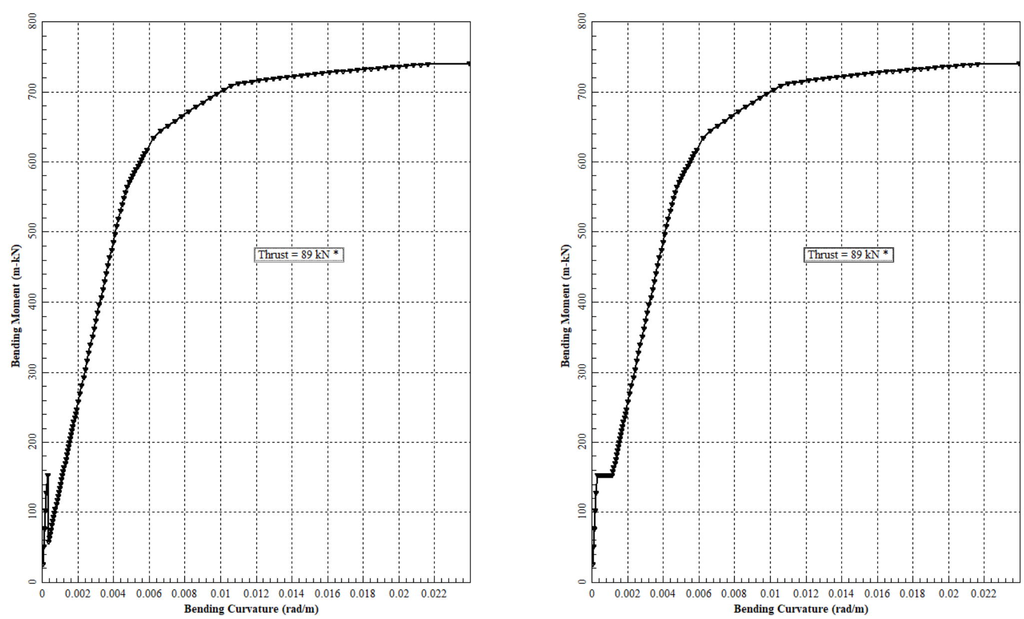
It is important for the user to understand that LPile cannot validate the input data for nonlinear bending. Consequently, it is left to the user to examine the charts of the input data and to verify that the input data is correct.

3.6.19 Options for Nonlinear Sections

For nonlinear sections, up to three options may be available. These optional checks are described in the following sections.

3.6.19.1 Adjust Softening of Moment Curvature

This option is available for sections with concrete. If this option is checked (default) the program will adjust the softening in the moment curvature curve due to cracking or crushing of the concrete. See a typical example in Figure 3.38.



(a) (b)

Figure 3.38 Example of Option Adjust Softening of Moment Curvature (a) Not Adjusted (b) Adjusted

3.6.19.2 Compute Equivalent Elastoplastic Moment Curvature (CALTRANS)

This option is available for all nonlinear sections except User-Defined Non-linear Bending Section. If this option is checked, the program will compute the equivalent elastoplastic moment curvature following CALTRANS recommendations. Please note that by selecting this option, the program will use the equivalent moment curvature for all the required analyses. An example is included in Figure 3.39.

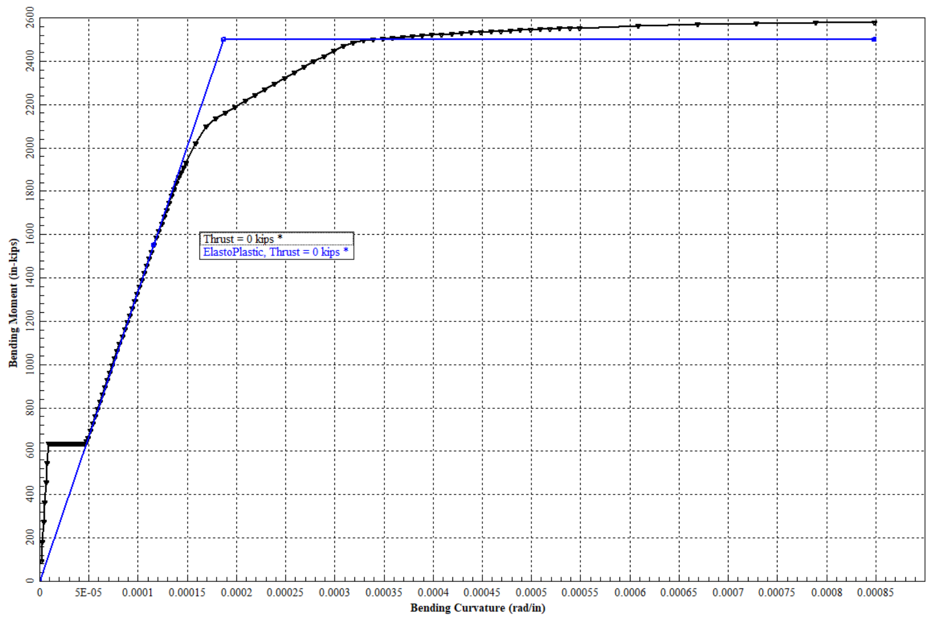


Figure 3.39 Example of Option Compute Equivalent Elatoplastic Moment Curvature (CALTRANS)

3.6.19.3 Estimate Resistance Factor and Shear Capacity

This option is available for all nonlinear reinforced concrete sections (Rectangular Concrete Section, Round Concrete Shaft, Round Concrete Shaft with Permanent Casing and Round Shaft with Casing and Core/Insert). If this option is checked, the program will compute the resistance factor and nominal shear capacity of the pile sections (concrete and steel contributions) using the ACI 318-14 code guidelines but user must enter data for transverse reinforcement under the Trans. Reinf. tab.

In models using the LRFD Analysis Mode, this checked selection will override any resistance factor that was inputted by the user for the LRFD analysis (under Data > Load and Resistance Cases).

3.7 Soil Layers

Three types of data can be entered in LPile to define the lateral load-transfer relationships between the pile and soil. Most basic of these are the definitions of soil layering, soil types, and soil properties used to compute the lateral load-transfer (*p-y*) curves. The soil layering and *p-y* curves are discussed in Section 3.7.1.

The *p-y* curves can be affected by the combined pile batter and ground slope. The input of pile batter and ground slope angles is discussed in Section 3.8.

The *p-y* curves may be modified by the *p-y* modification factors to account for the effects of group action for pile groups and earth retaining structures. The input of *p-y* modification factors is discussed in Section 3.9.

It is also possible to define lateral load-transfer at the tip of the pile in addition to *p-y* curves that define lateral load-transfer along the length of the pile. The tip shear versus tip movement curves are generally important only for short piles for which significant movement of the pile tip can develop. The development of tip shear is highly dependent on the construction practices used to install the pile. Consequently, no dependable methods have been developed to compute the curves of tip shear resistance and most relationships are determined from the results of site-specific load testing programs. The input of tip shear resistances is discussed in Section 3.10.

A key concept in LPile is the definition of the vertical coordinate system used to define soil layering and pile properties. The origin of this coordinate system is always located at the point of application of lateral loads (usually same as pile head). If it is desired to vary the vertical position of the pile head relative to the soil layering, it will be necessary to correct the data defining the soil layering. A utility function, Data > Shift Pile Elevation in Soil Profile, is included in LPile to assist in this task and is discussed in Section 3.13.

3.7.1 Soil Layers and *p-y* Curve Models

This dialog Data > Soil Layers is used to specify the different types of soil to be used for the automatic generation of lateral load-transfer curves (*p-y* curves). LPile will automatically generate the selected curves unless the user specifies and enters user-input *p-y* curves. An example of this dialog is shown in Figure 3.40.

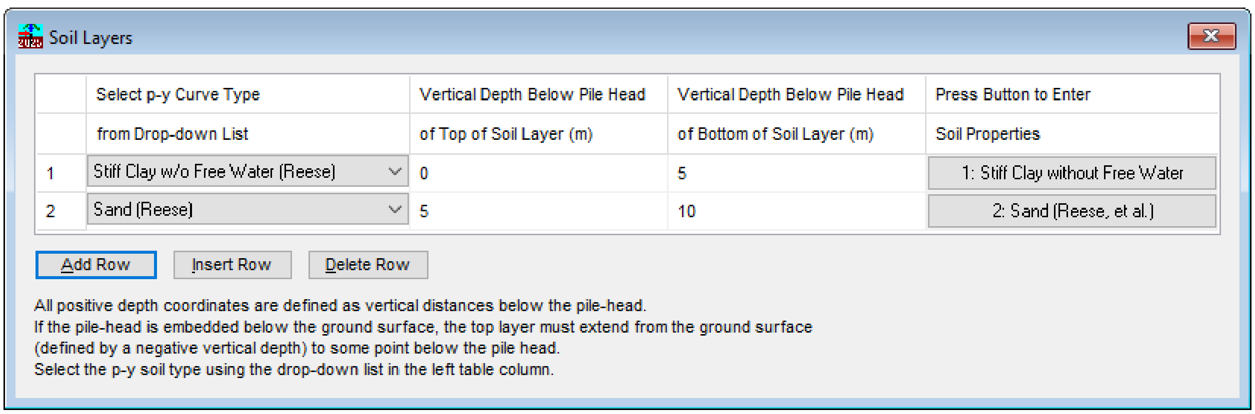


Figure 3.40 Sample Dialog for Definition of Soil Layering and Soil Properties

The following is a description of the input data for this dialog.

Layer Number

The soil layer number is assigned automatically to each soil layer with Layer 1 being the uppermost layer. This number is automatically provided by the program as additional rows of soil layers are created. The maximum number of soil layers that may be entered is 40.

Select p-y Curve Type

There are several internal types of soils plus user-input *p-y* curves that can be specified in LPile using this dropdown box. These types are:

Soft Clay (Matlock)
API Soft Clay w/User Defined J
Stiff Clay with Free Water (Reese)

Stiff Clay without Free Water (Reese)
Modified Stiff Clay without Free Water
ISO Clay (based on ISO 19901-4)
Sand (Reese) w/Enhanced Sand Option
API Sand (O'Neill) w/Enhanced Sand Option
Small Strain Sand
Liquefied Sand (Rollins)
Liquefied Sand Hybrid Model
Weak Rock (Reese)
Strong Rock (Vuggy Limestone)
Piedmont Residual
Massive rock
Loess
Silt/Cemented Soil
Calcareous Soil/Rock
Elastic Subgrade
User-input *p-y* curves

Vertical Depth Below Pile Head of Top of Soil Layer

Values for the top of the soil layer are entered relative to the origin of the depth coordinates. The origin of depth coordinates is usually the pile head, which is the point of application of boundary conditions and corresponding loads.

A positive value for the Top of Soil Layer entry indicates a distance measured downward from the top of the pile. A negative value indicates a distance measured above the top of the pile (only used when the pile head is embedded below the ground surface). The value of zero may be used in the first layer if the pile head is at the level of the ground surface.

Vertical Depth Below Pile Head of Bottom of Soil Layer

Values for the bottom of the soil layer are also entered according to the origin of coordinates. The coordinate of the bottom of each layer should always be equal to the coordinate of the top of the immediately consecutive layer. The bottom of the last soil layer must at least reach the same depth as the bottom of the modeled pile.

Soil Properties

The last column contains a context-sensitive button that varies depending on the *p-y* curve soil type selected. The table button activates a soil type specific data entry dialog where the user enters effective unit weight, shear strength parameters, and any other required soil/rock property parameters, depending on the soil type selected. Descriptions follow.

3.7.1.1 Comments on p-y Curve Models

The following comments are made about the different *p-y* curve models.

With the exception of the silt model for cemented c-ϕ materials, all of the models are based on load tests of full-sized piles in which the pile diameter is typically in the range of 300 to 1,200 mm (12 to 48 inches). While it is possible to test piles with larger diameters, it is usually not possible to load such large diameter pile to failure. Consequently, if a significant variation of lateral load transfer characteristics due to pile diameter exists, it may not be accurately modeled by the *p-y* curve formulations.

Stiff clay with free water, in general, is used to represent soil conditions where stiff clay is the top layer in the soil profile and there is water existing above the ground line or in any conditions where it is believed that any annular space between the pile and soil may fill with water.

A discussion of the theory of *p-y* curves for different types of soils is included in the *Technical Manual*.

3.7.1.2 Common Soil Properties for p-y Curves

Effective Unit Weight

Values of effective unit weight for each soil depth are entered in units of force per unit volume. The program will interpolate linearly the values of unit weight located between the top and bottom depths of the layer. Soil layers should be sub-divided anywhere step changes in values are needed, such as at the depth of the water table.

The effective unit weight is equal to the total unit weight when above the water table and equal to the submerged weight when below the water table. Values for the top and bottom of the layer are entered in standard units of force per unit volume (either lb/ft^3 or kN/m^3)

Non-Default k Value

This is the value for k used in the equation $E_s = k\,x$. This constant is in units of force per cubic length and depends on the type of soil and lateral loading imposed to the pile group.

It has two different uses: (1) to define the initial (maximum) value of E_s on internally generated *p-y* curves of stiff clays with free water and/or sands; and (2) to initialize the E_s array for the first iteration of pile analysis.

Recommended k values are included in the Technical Manual for each criteria where it is applicable. Different k values are recommended if the c-ϕ soils are like cemented sand or like quartz type of silty sand (non-cemented silt).

An input of zero for this entry instructs LPile to estimate the k value based on other inputted parameters, following tables in the Technical Manual. The user can verify the k value that was selected internally by choosing Data > Options and Settings > Print p-y Curves at User Specified Depths and looking at the printout in the output text file (see Section 3.19).

Both Reese and API criteria for piles in sand assume that the initial slope (stiffness) of *p-y* curves increase linearly with depth (i.e., $E_{py} = k_i\,x$). In the new Enhanced Sand Models (for both Reese and API criteria), the user can apply power components (m and n described in the Technical Manual) on the normalized pile diameter and depth of interest to modify E_{py} if pile diameters differ from those of the test piles which were used in deriving the original *p-y* curves.

Undrained Cohesion, c

Values of undrained shear strength (c_u) for clays and silts at each depth are entered in standard units of force per unit area. The undrained shear strength is not needed for sand layers. The undrained shear strength is generally taken as half of the unconfined compressive strengths.

Friction Angle

Values of the angle of internal friction ϕ for sands and/or silts at each soil depth are entered in degrees. The ultimate soil resistance of sand formulated by Reese, et al. (1974) already includes pile diameter as one of the variables. However, the sand layer may exhibit different relative density and consolidation histories which will affect the defaulted values of α and Ko. Options are now available in the new Enhanced Sand Models to enter user-specified α and Ko for any desired user refinements in the generation of these *p-y* curves.

Non-Default Strain Factor E50

Values of ε_{50} strain at 50% of the maximum stress. The strain factor ε_{50} for clays at each soil depth are entered in dimensionless units of strain.

If soil test data are available, the user may enter the value based on the stress-strain curves measured in the soil laboratory. The *p-y* curves for weak rocks need a strain parameter k_{rm} which is analogous to ε_{50}. More information regarding k_{rm} and ε_{50} can be found in the Technical Manual.

An input of zero for this entry instructs LPile to estimate the ε_{50} value based on other inputted parameters, following tables in the Technical Manual. The user can verify the ε_{50} value that was selected internally by choosing Data > Options and Settings > Print p-y Curves at User Specified Depths and looking at the printout in the output text file (see Section 3.19).

3.7.1.3 Properties for Weak Rock

Initial Modulus of Rock Mass (Weak Rock)

This is the initial mass modulus for weak rock. This value may be measured in the field using an appropriate test or may be obtained from the product of the modulus reduction ratio and Young's modulus measured on intact rock specimens in the laboratory.

Uniaxial Compressive Strength

This value is for the uniaxial compressive strength of rock at the specified depth. Values at elevations between the top and bottom elevations will be determined by linear interpolation.

Any input values that are considered unreasonable for the selected rock criteria are flagged in the output file and a warning dialog box is displayed. However, the analysis is performed normally.

RQD, Rock Quality Designation

The secondary structure of the weak rock is described using the Rock Quality Designation (*RQD*). Enter the value of *RQD* in percent for the weak rock.

Strain Factor krm

The parameter k_{rm} for weak rock typically ranges between 0.0005 and 0.00005. The input dialog for weak rock is shown in Figure 3.41 as an example.

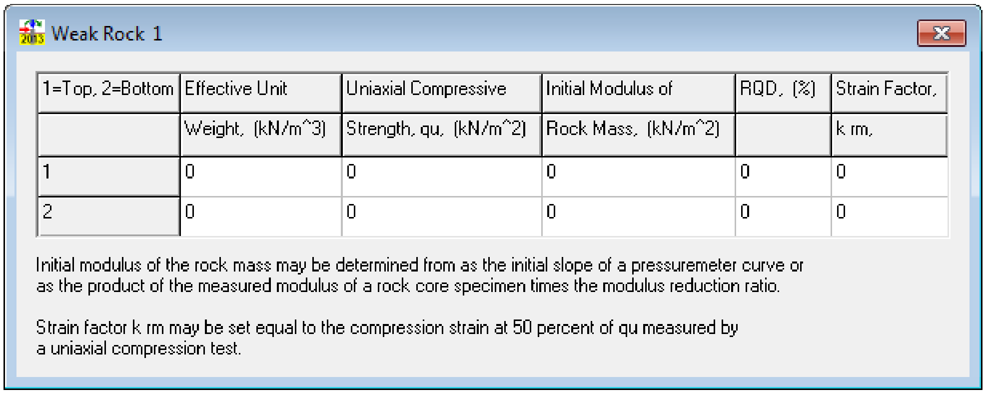


Figure 3.41 Dialog for Properties of Weak Rock

3.7.1.4 Properties for Massive Rock

The input for massive rock requires strength parameters defined using the Hoek-Brown strength criterion. In addition to effective unit weight and uniaxial compressive strength, these parameters include:

Hoek-Brown Material index, mi

> This is a dimensionless number ranging from 4 to 32 that depends on the type of rock.

Poisson's Ratio

> Guidance for selecting a value for Poisson's ratio as a function of the compression and shear wave velocities in rock is discussed in the Technical Manual.

Geologic Strength Index, GSI

> This is a dimensionless number ranging from zero to 100 that depends on the quality of the massive rock.

Two options are provided for determining the rock mass modulus for massive rock. For Option 1, the user inputs a value for the intact rock modulus and leaves the input for rock mass modulus equal to zero. In Option 1, the program computes a value of rock mass modulus based in the input data. For Option 2, the user inputs a non-zero value for rock mass modulus. In Option 2, the program will ignore any value input for the intact rock modulus. The input dialog for massive rock is shown in Figure 3.42 as an example.

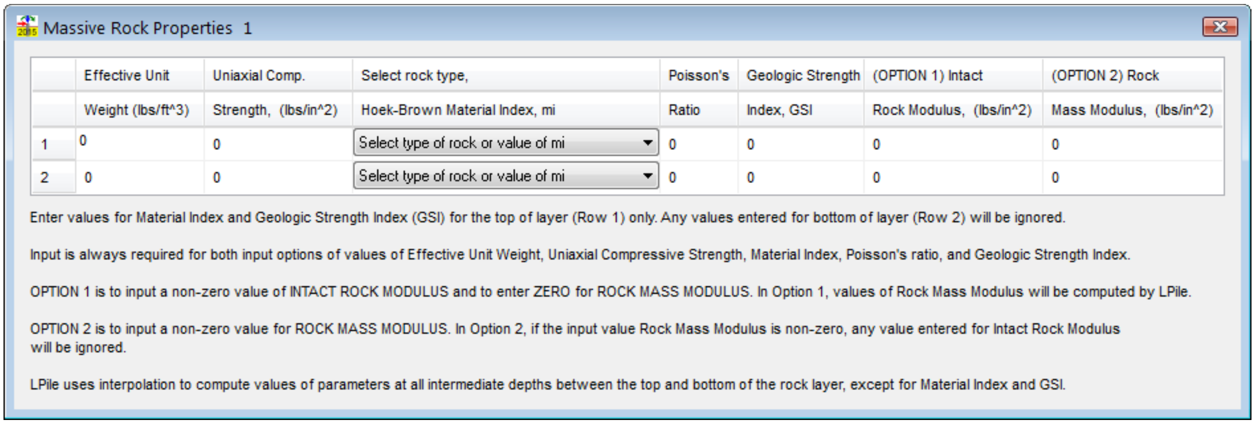


Figure 3.42 Dialog for Properties of Massive Rock

3.7.1.5 Properties for Piedmont Residual

Type of Soil Test

The drop-down menu allows users to select the type of in-situ test that is performed in the residual soil to define is p-y response curve: Standard Penetration Test (SPT), Cone Penetration Test (CPT), Dilatometer Test (DMT) or Pressuremeter Test (PMT).

According to the user's drop-down selection, the LPile program will use the value entered by the user in the corresponding column (others will be ignored).

SPT Blow Count

In this first drop-down choice and first column, the user should enter the uncorrected blow count (N60) for 30 cm.

Cone Penetration Tip Resistance

This is the tip resistance, q_c, obtained from a Cone Penetration Test (CPT).

Dilatometer Modulus

Value from Dilatometer Test (DMT) with the corresponding modulus (E_{DMT}) in psi or kPa.

Menard Pressuremeter Modulus

The modulus (E_{PMT} in psi or kPa) as obtained from a Pressuremeter Test (PMT).

The input dialog for Piedmont Residual is shown in Figure 3.43 as an example.

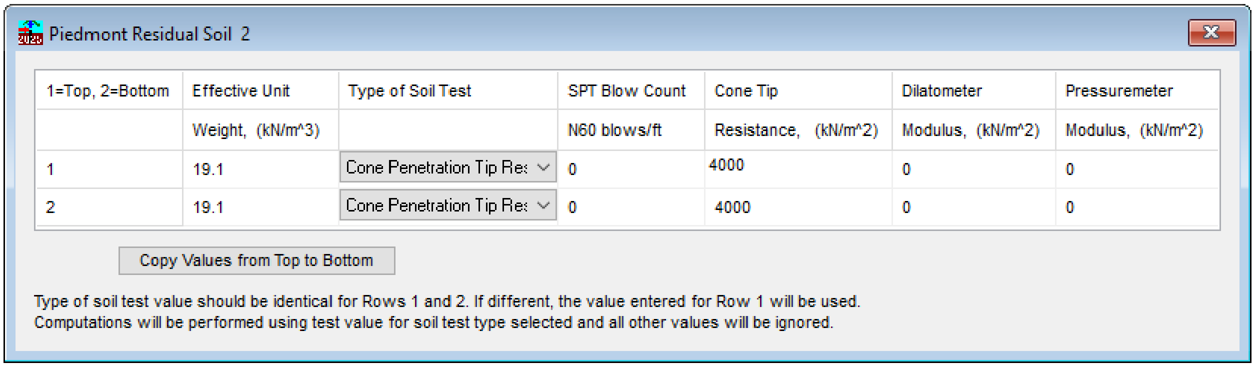


Figure 3.43 Dialog for Properties of Piedmont Residual

3.7.1.6 Properties for Calcareous Rock (Weak Carbonate Rock)

Residual Friction Angle

This is an entry for the residual friction angle (in degrees) is used to define the strength at large shear strains. As a background, carbonate materials frequently exhibit high peak friction angles near or above 40° but after very few cycles of shear the values frequently fall to a residual value between 24° and 33°. This reduction in friction angle is largely due to particle crushing which is dependent upon normal stress level and occurs much more in calcareous soils or carbonate rocks than in siliceous materials.

Unconfined Compressive Strength

This *p-y* curve model generally applies to calcareous soils or carbonate rock with unconfined compressive strength (sometimes referenced as Uniaxial Compressive Strength, it is usually twice the cohesive strength) in the range from 0.5 to 5 MPa (70 to 725 psi).

Displacement Factor After Peak

This entry represents a factor (less than 1) for the displacement fall from the initial to the residual curve (from the end of the intact rock response to the start of the residual friction response). The transition between the two curves is assumed to occur sharply in brittle materials.

If left as zero (as a default), this value is 0.1 thus representing an additional 10% displacement after the end of the intact rock response. Note that the fall from the peak to the residual curve at an additional displacement of 10% from the end of the initial intact rock resistance curve is arbitrary.

For further information, read notes in the Technical Manual and in the referenced technical paper.

The input dialog for Calcareous Rock is shown in Figure 3.44 as an example.

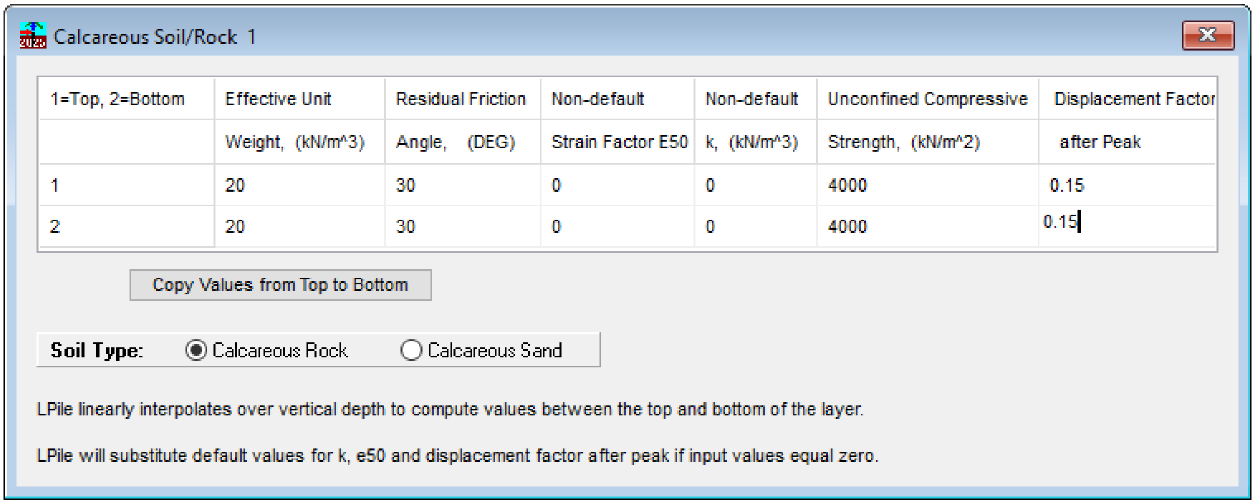


Figure 3.44 Dialog for Properties of Calcareous Rock

3.7.1.7 *Properties for Calcareous Sand*

Cone Tip Resistance

This is an entry for the cone tip resistance (q_c) as obtained from a Cone Penetration Test (CPT). It is the force required to push a 60-degree conical tip into the soil divided by the cross-sectional area of the base of the cone, entered in units of kPa or lbs/in².

Stiffness Factor

This is the ratio of E_s/q_c that should be used to define the bilinear *p-y* curve for calcareous sand. If left as zero, the value of 12 is used internally by LPile for this ratio.

The input dialog for Calcareous Sand is shown in Figure 3.45 as an example.

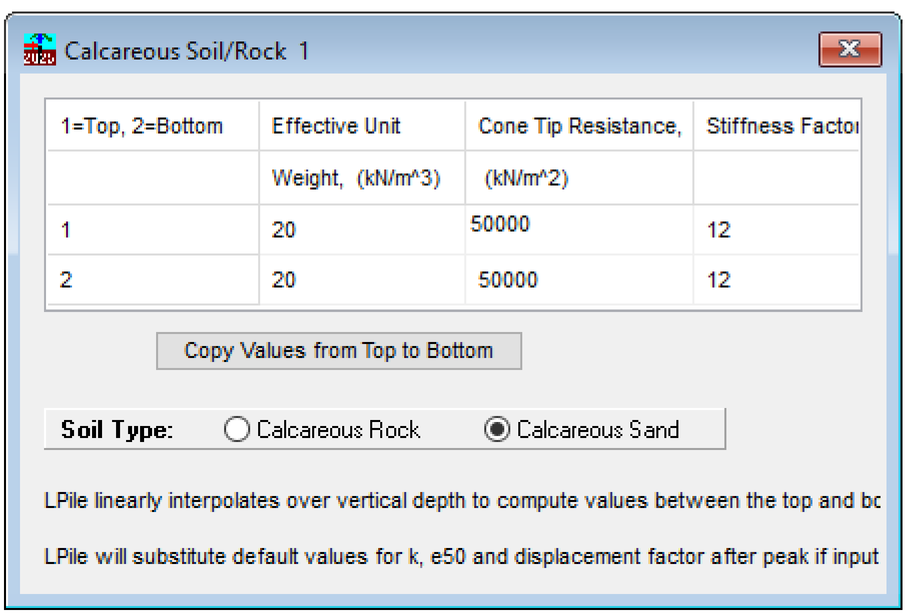


Figure 3.45 Dialog for Properties of Calcareous Sandstone

3.7.1.8 Properties for ISO Clay

The input dialog for ISO Clay is shown in Figure 3.43 as an example.

Type of soil test for shear strength

The drop-down menu allows users to select the type of test that is performed in the clay samples to define the *p-y* response curve: DSS test (is the Direct Simple Shear test performed in laboratory, which is the preferred method for the ISO Clay criteria), Triaxial Compression test, Triaxial Extension test, UU test, UC test, or SPT test (this is a field-based Standard Penetration Test). The tests, other than DSS, are converted internally by LPile to equivalent values.

Gapping Effect

This is to specify if a gap would form between pile and soil in the back side of the laterally loaded pile. The drop-down menu allows for the selection of Estimated by program (estimated by LPile based on other entries, as detailed in the ISO criteria), No gapping or Gapping considered.

Plasticity Index

Corrections according to the Plasticity Index (PI) are accounted internally by LPile when PI is higher than 30% or when PI is equal or lower than 30%.

Over-consolidation ratio (OCR)

The over-consolidation ratio is a required input from the user to shape the nonlinear stress-strain relationship.

TE/DSS Ratio

This is the average ratio of shear strength as obtained from Triaxial Extension over DSS within the depth of the soil wedge (upper length of pile, above the flow-around response). In the absence of site-specific data, a default value of 0.9 is recommended for very soft and soft clays like those of the Gulf of Mexico. The TE/DSS Ratio is only applicable when user selects Gapping considered (under Gapping Effect).

Depth of Rotation

The depth of rotation of the pile is defined as the first depth from the seafloor where the lateral displacement is zero. The depth of rotation of the pile may be estimated as $z_{rot} = 15D$ for initial analyses and revised depending on the results.

The Depth of Rotation (in feet or meters) is only applicable for cyclic loading (model).

Design Condition

The Design Condition is only applicable for cyclic loading (model). User should select the drop-down condition that most closely resembles to their site (Gulf of Mexico clay, North Sea soft clay or North Sea stiff clay).

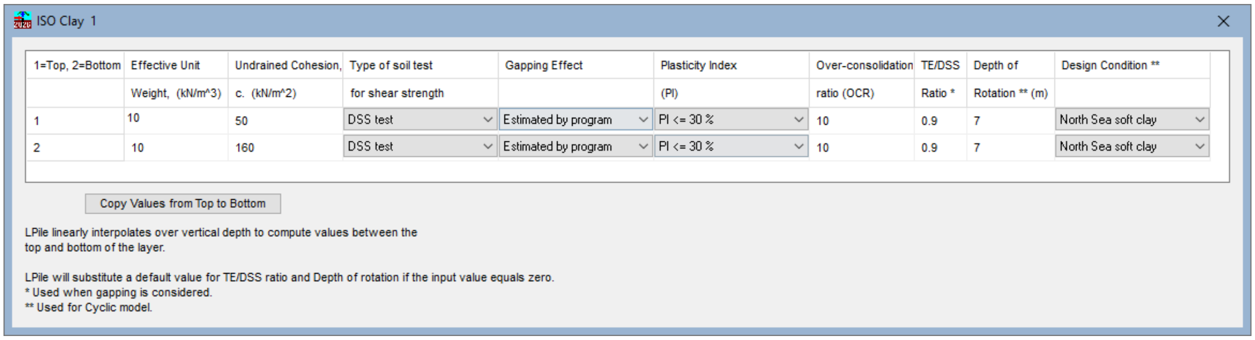


Figure 3.46 Dialog for Properties of ISO Clay

3.7.2 User Input p-y Curves

Data for user-specified *p-y* curves are inputted using two linked dialog boxes. The first dialog box (Figure 3.47) is used to enter values of effective unit weight at the top and bottom of the soil layer and to open the input dialog box for entry of the *p-y* curve data.

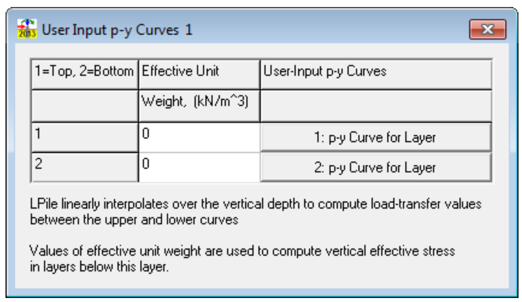


Figure 3.47 Dialog for Effective Unit Weights of User-input *p-y* Curves

The second input dialog box (Figure 3.48) is used to enter the *p-y* curve data. The user may enter data in one of three ways. The user may add enough rows to accommodate the data and enter the data manually, the user may paste the data into the table via the Windows clipboard, or the user may read an external text data file (clicking the Browse button).

A sample input dialog is shown below. The graph in the dialog shows the current data. It may be necessary for the user to move the cursor to an adjacent cell to update the graph of the *p-y* curve. An example of the input dialog for a user-input *p-y* curve is shown in Figure 3.48.

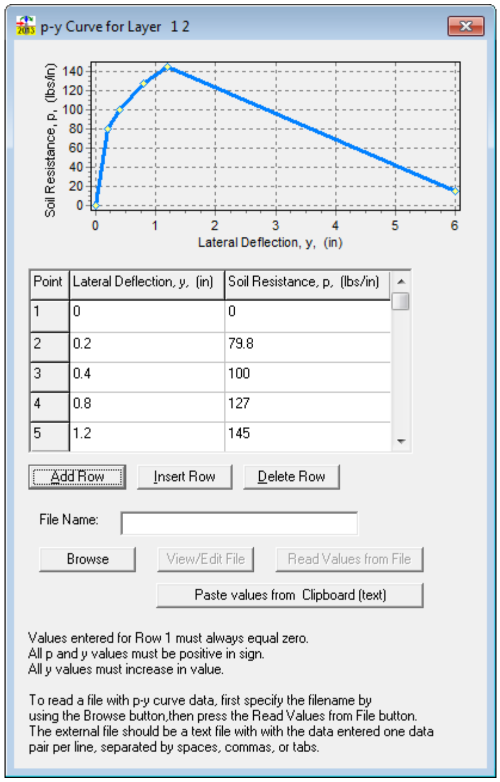


Figure 3.48 Dialog for User-input *p-y* Curve Values

This layer type allows the user to enter specific relationships of soil resistance (*p*) and lateral movement of the pile (*y*) at specified depths. These cases usually arise when local data for the soil response are available. To use external *p-y* curves (user-specified curves), the user needs to select User Input p-y Curves under the Select p-y Curve Type column in the Data > Soil Layers dialog. Then, clicking on the context-sensitive button in the far-right column opens a dialog where the user can input the effective unit weight of the soil. Finally, the user can define lateral deflection and soil resistance values for points in the top and bottom of the layer by clicking on the corresponding p-y Curve for Layer button in the far-right column. A general description for the data needed for User-Input p-y Curves is listed below.

Lateral Deflection

These are the *y*-values of lateral movement that must be entered in units of length. As a reference, a review of the theory of Experimental Measures of p-y Curves (Soil Response) is included in Section 3.2 of the Technical Manual.

Soil Resistance

These are the *p*-values of lateral load intensity must be entered in units of load per unit depth. As a reference, a review of the theory of Experimental Measures of p-y Curves (Soil Response) is included in Section 3.2 of the Technical Manual.

3.8 Pile Batter and Ground Slope

As explained in the Technical Manual (Section 3.14), modifications are necessary to the *p-y* curves when a pile is installed on a slope. The influence of pile batter on the *p-y* curves of soils is considered to be similar to that of sloping ground. The effects from sloping ground and pile batter can thus be added (or subtracted) depending on the direction of loading. This dialog option allows the user to enter ground slope and/or pile batter separately with a graphical display. The LPile program will internally perform the necessary modifications to the *p-y* curves.

This input dialog is enabled if the user placed a check mark under Data > Options and Settings > Include Pile Batter and/or Ground Slope. The user specifies the ground slope and batter angles using the Data > Pile Batter/Ground Slope dialog shown in Figure 3.49. The interactive drawing in the dialog realistically illustrates the ground slope and pile batter angles along with the sign convention for loading. If flat ground slope is selected and the pile is vertical, the angles will be zero. If necessary, users are able to specify different angles (or horizontal/zero slope) for a sloping ground to the right and left of the pile.

Ground Slope Angle

> This is the angle, in degrees, formed between a sloped ground surface and the horizontal surface. As indicated in the following figure, the value of the ground slope angle is positive if the pile tends to move downhill upon application of the lateral load. The lateral capacity provided by soils in a positive slope is thus reduced. Piles that tend to move uphill in a sloping ground use negative values of ground slope angle. The lateral capacity provided by soils in a negative ground slope is thus increased.

Pile Batter Angle

> The sign convention that is used to account for battered piles also depends on the direction of the applied lateral load and is shown in the figure.

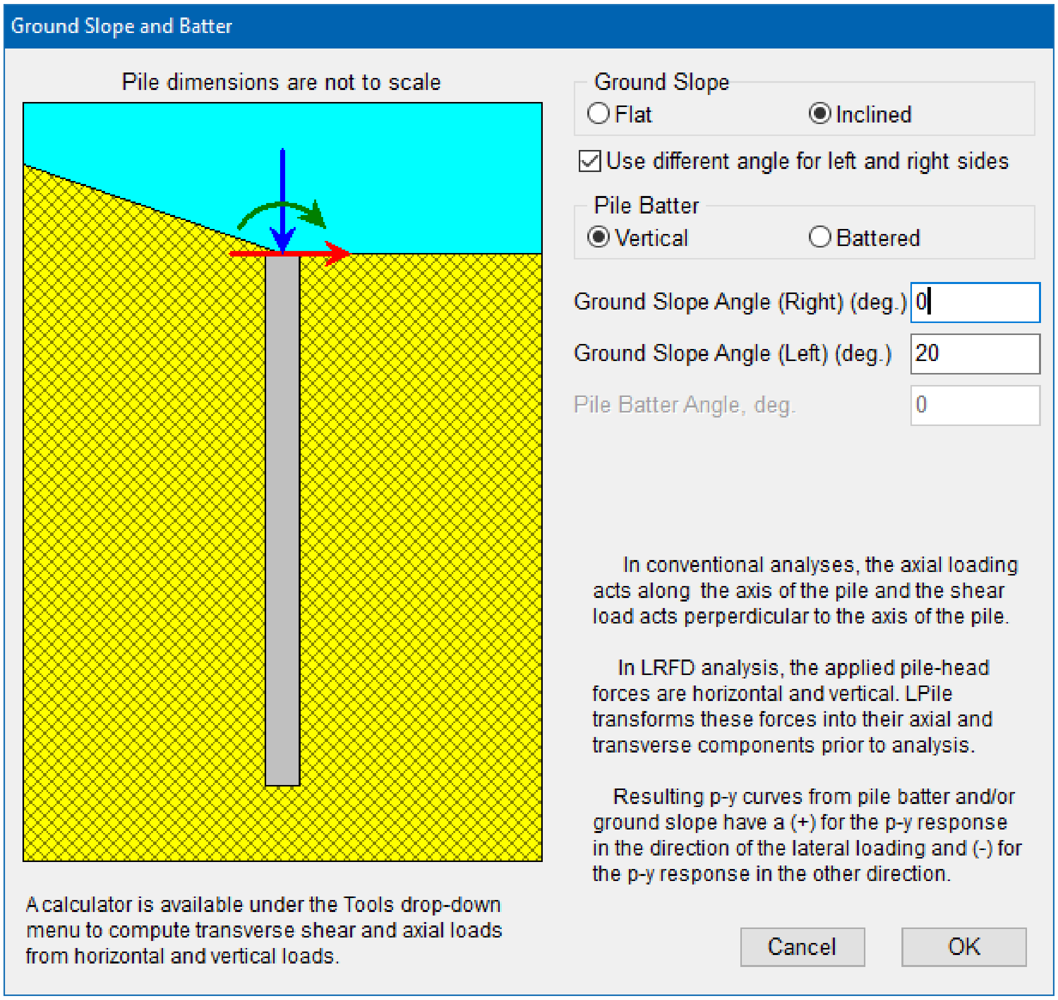


Figure 3.49 Dialog for Definition of Pile Batter and Slope of Ground Surface

3.9 *p-y* Modification Factors

This input dialog is enabled if the user placed a check mark under Data > Options and Settings > Use Modification Factors for p-y Curves. This input dialog is inactive under default conditions. The Data > Modification Factors for p-y Curves input dialog allows the user to enter modification factors for soil resistance (*p*) and/or lateral movement of the pile (*y*) at specified depths. A maximum of 80 entries of modification factors for *p-y* curves may be used in an analysis. The program allows the input of modification factors for any depths of the soil profile.

The *p-y* modification factors only apply to *p-y* curves that are internally generated by the program. If the user requests the printing and reporting of internally-generated *p-y* curves (Section 3.19), the output curves will include the changes produced by the specified *p-y* modification factors.

An example of this input dialog is shown in Figure 3.50.

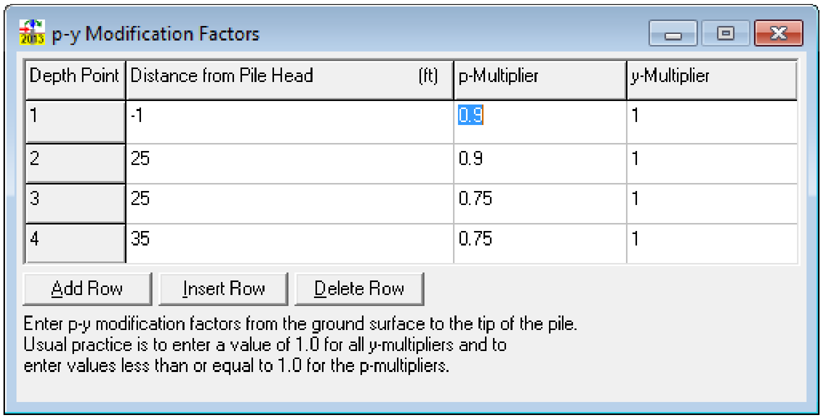


Figure 3.50 Dialog for *p*-Multipliers and *y*-Multipliers versus Depth Below Pile Head

Distance from Pile Head

These values represent the depths where modification factors for *p-y* curves are being specified. Intermediate values of *p-y* modification factors located between two specified depths are obtained by linear interpolation of the specified factors. It is therefore necessary to have at least two entries of modification factors. Modification factors must be entered in ascending order of depths.

p-Multiplier

The *p*-multiplier values may be larger or smaller than one. However, in most cases these values are smaller than one to account for group effect of closely-spaced piles or drilled shafts. A large reduction in *p*-values (and/or increase of *y*-values) may also be used to represent liquefiable layers of sand.

y-Multiplier

The *y*-multiplier values may be larger or smaller than one. However, in most cases these values are larger than one to account for group effect of closely-spaced piles. A large increase in *y*-values (and/or reduction of *p*-values) may also be used to represent liquefiable layers of sand.

3.10 Shear-Resistance Curve at Pile Tip

This input dialog is enabled if the user placed a check mark under Data > Options and Settings > Include Shearing Resistance at Pile Tip. The Data > Shear-Resistance Curve at Pile Tip dialog allows the user to enter a shear-resistance curve at the bottom of the pile. This input dialog is inactive under default conditions. A maximum of 50 points may be defined in the shear-resistance curve at the pile tip. A minimum of two points are required to form a curve. An example of this input dialog is shown in Figure 3.51.

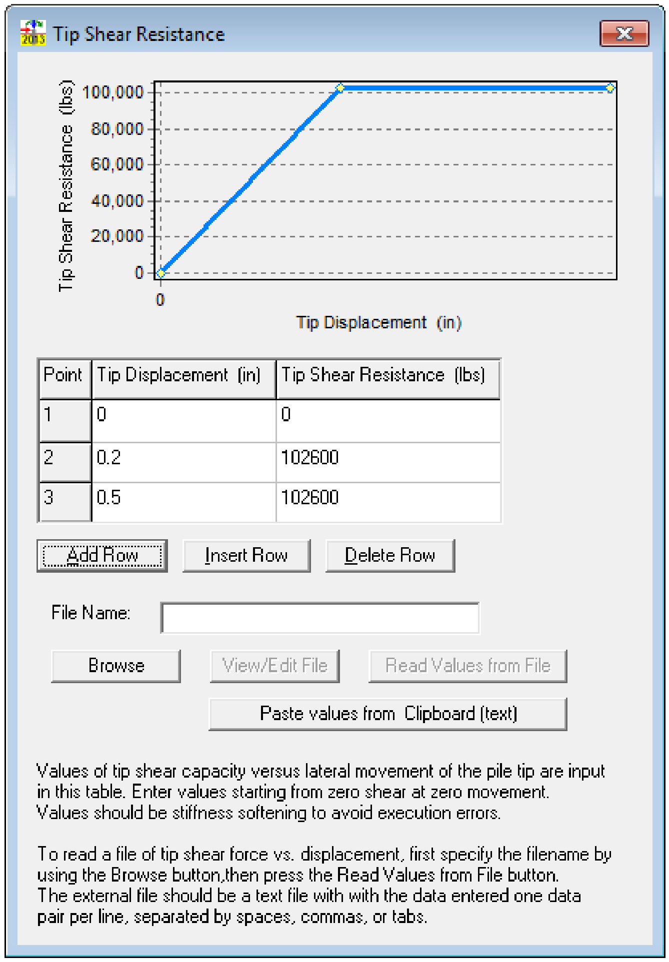


Figure 3.51 Sample Dialog for Tip Shear Resistance versus Lateral Tip Displacement

The input is the forces F_{bs} shown in pink in Figure 3.54 that will develop from lateral movements of the pile tip.

In general, shearing resistance at the pile tip would only be applicable to those cases where the pile is short (with only one point of zero deflection along their depth). In addition, these curves are likely to make noticeable differences only when using large diameter shafts that deform largely by rotation without large amounts of bending.

The user may enter data in one of three ways. The user may add enough rows to accommodate the data and enter the data manually, the user by paste the data into the table via the Windows clipboard, or read an external text data file. The input dialog is shown above. The graph in the dialog shows the current data. It may be necessary for the user to move the cursor to an adjacent cell to update the graph of the tip shear curve.

3.11 Moment-Resistance Curve at Pile Tip

This input dialog is enabled if the user placed a check mark under Data > Options and Settings > Include Moment Resistance at Pile Tip. The Data > Moment-Resistance Curve at Pile Tip dialog (see Figure 3.52) allows the user to enter a moment-resistance curve at the bottom of the pile. The rotation is in units of Radians while the corresponding Moment Resistance is in units of Force - Length. A maximum of 50 points may be defined in the moment-resistance curve at the pile tip. A minimum of two points (representing an elastic spring) are required for this entry.

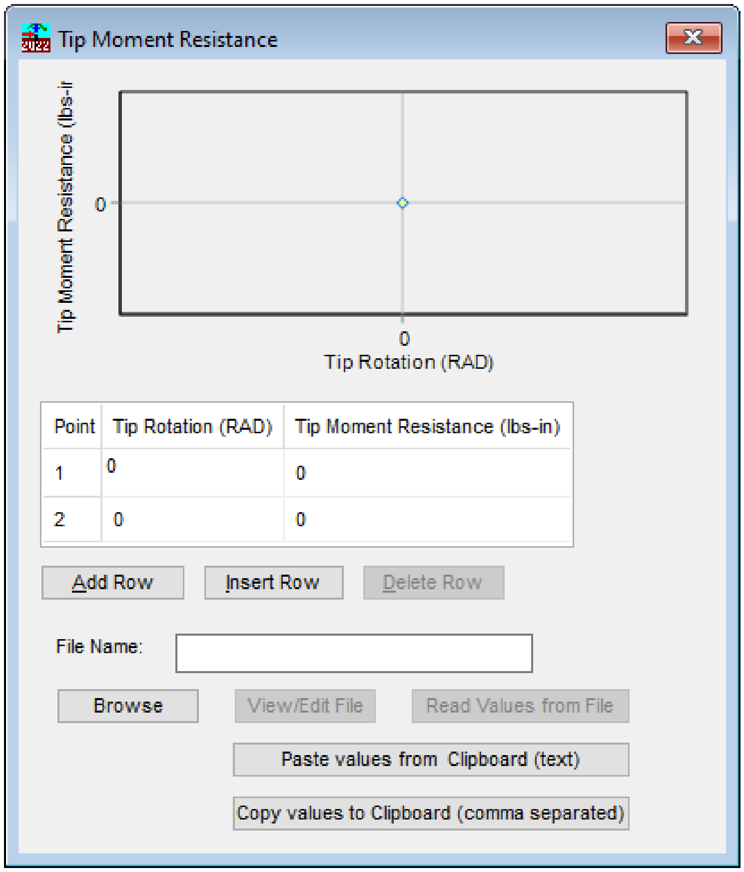


Figure 3.52 Sample Dialog Box for Moment-Resistance Curve at Pile Tip

The input is basically an equivalent nonlinear rotational spring that would represent the impact resulting from the F_{rb} forces shown in blue color in Figure 3.54.

In general, moment resistance at the pile tip would only be applicable to those cases where the pile is short (with only one point of zero deflection along the depth). In addition, these curves are likely to make noticeable differences only when using large diameter shafts that deform largely by rotation without large amounts of bending.

The user may enter data in one of three ways. The user may add enough rows to accommodate the data and enter the data manually, the user by paste the data into the table via the Windows clipboard, or read an external text data file. The input dialog is similar to the tip shear resistance input dialog. The graph in the dialog shows the current data. It may be necessary for the user to move the cursor to an adjacent cell to update the graph of the tip moment curve.

3.12 Side Resistance Along Pile

This input dialog is enabled if the user placed a check mark under Data > Options and Settings > Include Side Resistance Along Pile. This input dialog is inactive under default conditions. A maximum of 50 points may be defined in the table.

The Data > Side-Resistance Along Pile dialog (see Figure 3.53) allows the user to specify the unit side friction that shall be engaged at various depths along the pile. The unit side friction is in units of pressure: Force (Side Resistance) per Unit Area (Circumferential).

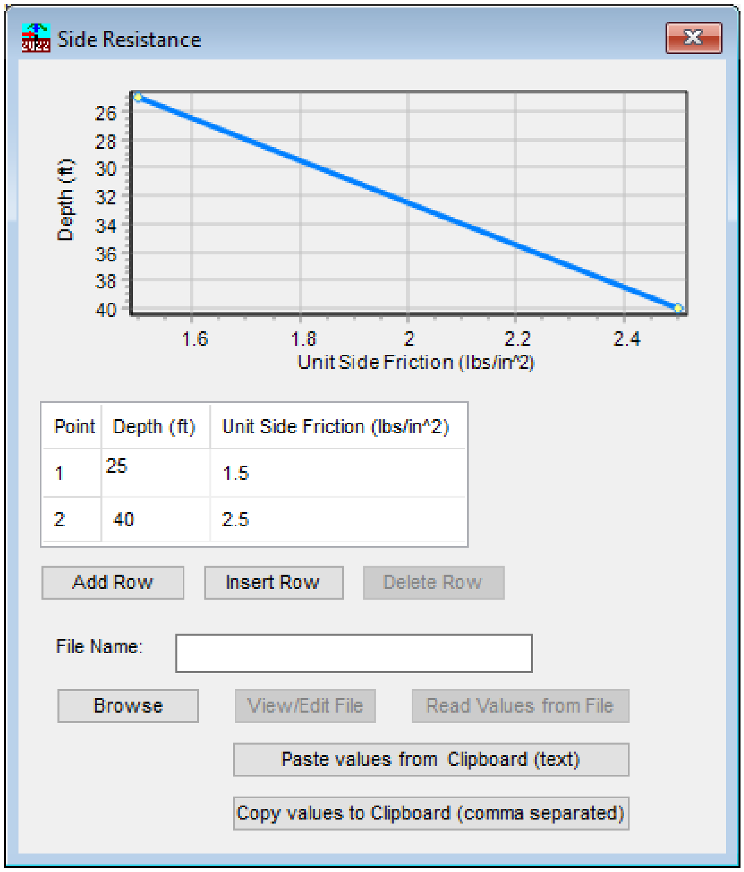


Figure 3.53 Sample Dialog Box for Side Resistance Along Pile

At every specified depth the program will compute a force couple (one in tension side and one in compression side, see F_s forces in red in Figure 3.54) based on the user's input of unit side friction and the circumferential area of the pile (calculated internally from the pile diameter). LPile has internal algorithms to reduce the force couples according to the distances from the neutral axis.

Users may take into account that the side resistances may not develop near the ground surface in clayey soils that may separate/gap from the pile.

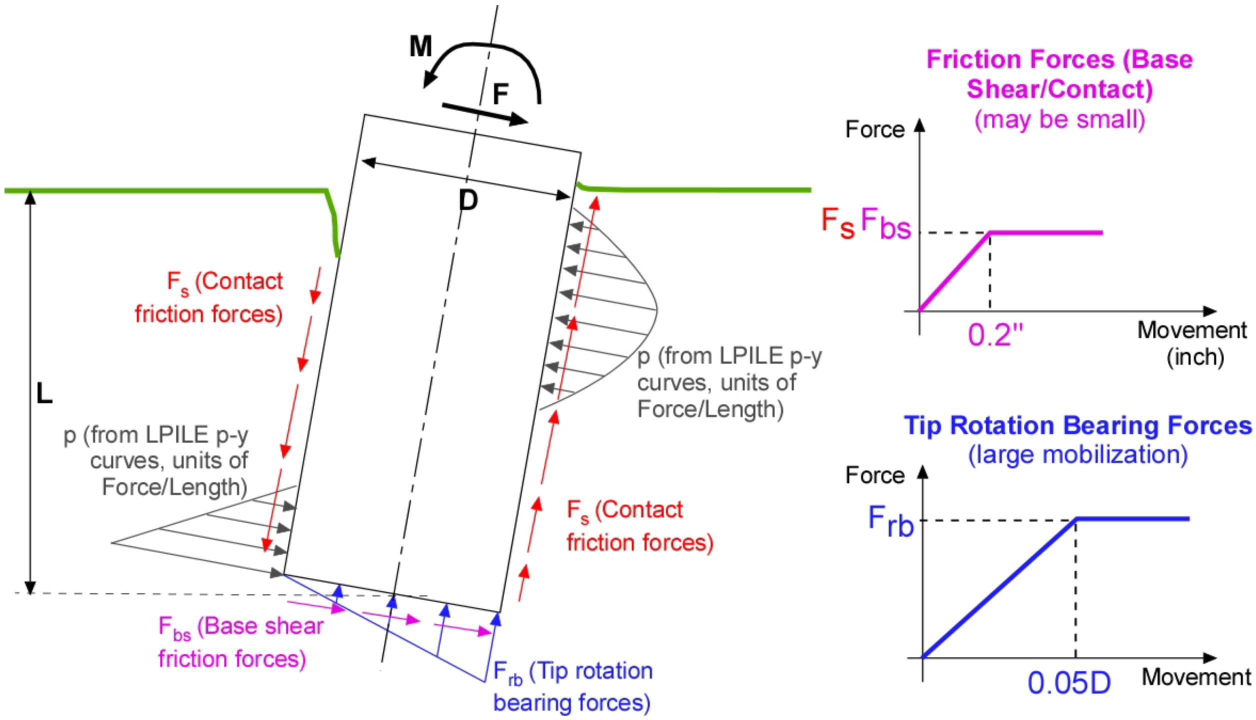


Figure 3.54 Schematics of Forces on Large Piles

In general, the side resistance along the pile is mostly applicable to models where the pile is relatively short (with only one point of zero deflection along the depth). In addition, these forces are likely to make noticeable differences only when using large diameter shafts that deform largely by rotation without considerable amounts of bending.

The user may enter data in one of three ways. The user may add enough rows to accommodate the data and enter the data manually, the user by paste the data into the table via the Windows clipboard, or read an external text data file. The input dialog is similar to the tip shear resistance input dialog. The graph in the dialog shows the current data. It may be necessary for the user to move the cursor to an adjacent cell to update the plot.

3.13 Shift Pile Elevation in Soil Profile

Occasionally the user may have the need to raise or lower the position of the pile in the soil profile or may desire to check the entry depths of soil and rock layers against elevation data for the project site. These actions can be performed by using the Shift Pile Elevation in Soil Profile command under the Data menu.

An example of the Shift Pile Elevation input dialog is shown in Figure 3.55. In this example, the pile head is initially positioned at the ground surface, so the depth of the top of layer 1 is zero (remember that the position of the pile head is the origin of the vertical coordinate system used in LPile).

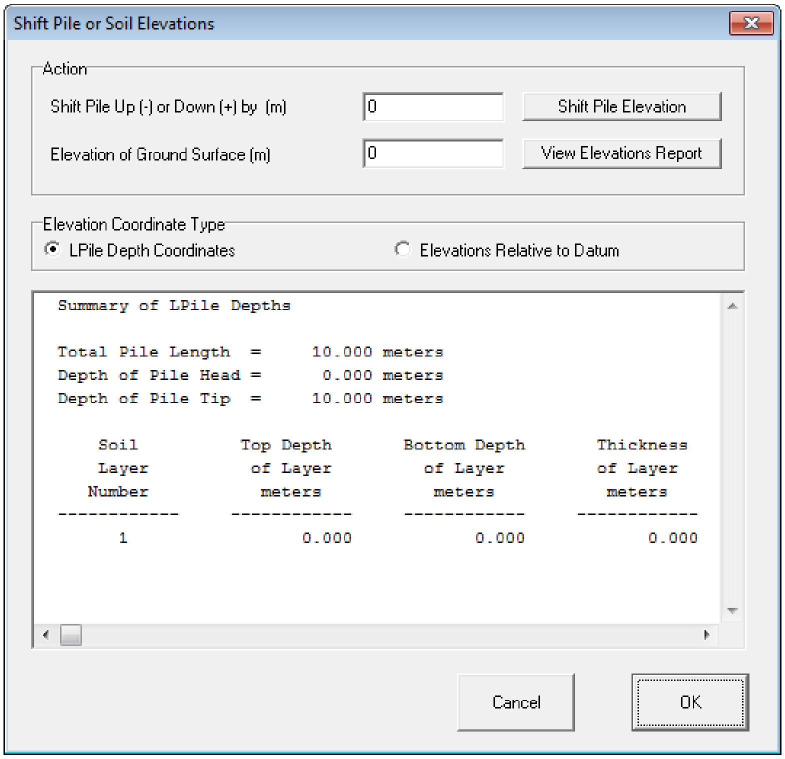


Figure 3.55 Dialog for Shifting of Pile Elevation Relative to Input Soil Profile Showing a Pile Head at the Top of the Soil Profile

If the user wishes to move the pile vertically within an entered soil profile, the user enters the elevation shift in the upper data edit box and presses the Shift Pile Elevation button. To move the pile downwards, the user enters a positive number and to move the pile upwards the user enters a negative number. The Shift Pile Elevation dialog shown below shows the results for a case in which the pile was moved down by 2 meters. The summary report shown in Figure 3.56 shows that the top of the first layer has been moved to −2 meters, but that the thicknesses of the layers are unchanged.

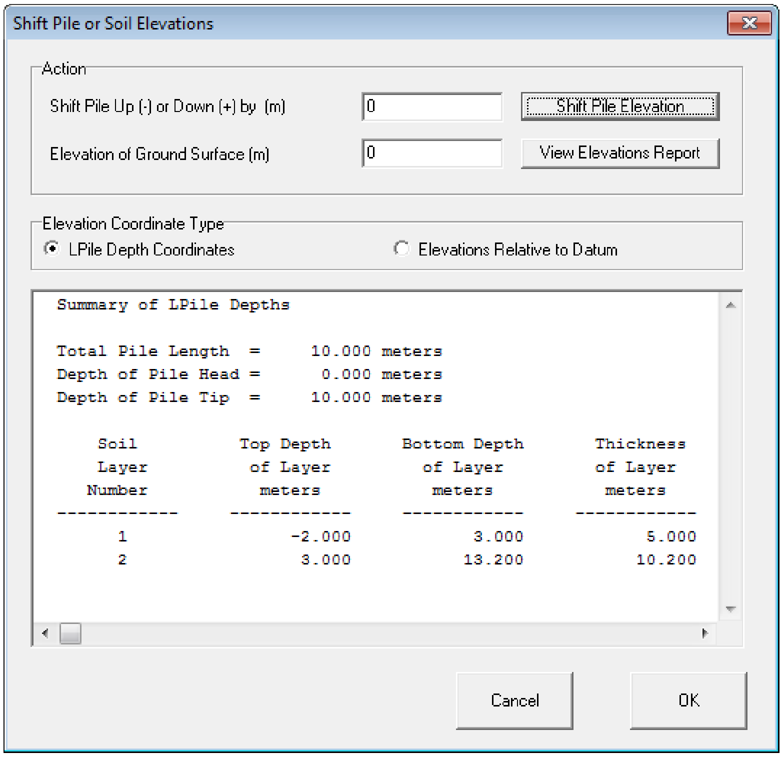


Figure 3.56 Dialog for Shifting of Pile Elevation Relative to Input Soil Profile After Shifting a Pile Head To Be Below the Ground Surface

If the user wishes to compare the depths of the soil layer profile to elevation data, the user enters a value for the elevation of the ground surface and presses the View Elevations Report button. The Shift Pile Elevation dialog can display the report in two formats that are selected by pressing the appropriate Elevation Coordinate Type radio button. The default format is the LPile Depth Coordinates and the other format is the Elevations Relative to Datum. The dialog box shown below is an example where the ground surface elevation is 6 meters and the Elevations Relative to Datum option has been selected.

3.14 Conventional Loading Analysis

In this type of analysis, up to 100 pile-head loadings of various types can be specified. In addition, distributed lateral loading can be specified and the distributed lateral loading will be applied to all pile-head loading cases.

3.14.1 Pile Head Loading

The Data > Pile Head Loading dialog shown in Figure 3.57 allows the user to enter the desired boundary conditions and corresponding loading at the pile head. There are five options for boundary conditions at the pile head. The user selects the desired boundary condition using a dropdown list of the choices described below.

The program allows up to 100 rows of boundary conditions and corresponding loading at the pile head. Users may choose to define multiple load cases/boundary conditions outside LPile on a spreadsheet or other program. Those definitions can be imported into LPile via Clipboard (Copy/Paste) or via text file (".txt" extension) with comma-separated values.

Each row of a text file used for loading definition (or each spreadsheet row) shall have six values to define each load entry. Up to 100 rows (load definitions) can be defined with the following guideline for each line (all numeric values separated by commas, no spaces in between):

Value1,Value2,Value3,Value4,Value5,Value6

Each of the six values above is a numeric entry and defined as indicated in Table 3.3

Variable	Definition	Value	Description
Value1	Pile-Head Loading Condition	1	Shear (Condition 1) [lb or kN] and Bending Moment (Condition 2) [in-lb or kN-m]
		2	Shear (Condition 1) [lb or kN] and Slope (Condition 2) [radians]
		3	Shear (Condition 1) [lb or kN] and Rotational Stiffness (Condition 2) [Moment/rad]
		4	Displacement (Condition 1) [in or m] and Bending Moment (Condition 2) [in-lb or kN-m]
		5	Displacement (Condition 1) [in or m] and Slope (Condition 2) [radians]
Value2	(Cond1)	*num*	*Enter numeric value*
Value3	(Cond2)	*num*	*Enter numeric value*
Value4	Axial Load	*num*	*Enter numeric value [lb or kN]*
Value5	Compute Top y vs. L?	1	No
		2	Yes
Value6	Run Analysis?	1	Yes
		2	No

Table 3.3 Guideline for Loading Definition File/Table

The user may instruct LPile for the computation of pile top deflection versus pile length for any of the specified load cases. However, users should read the notes in the Technical Manual for proper usage of this function. Also, use of this option is restricted to cases using any of the first three pile-head conditions, as the pile-head deflection will not vary for the fourth and fifth pile-head loading conditions.

3.14.1.1 Pile-Head Loading Condition

Shear and Moment: This boundary condition is selected to specify values of applied lateral load in units of force and applied moment in units of force × length at the pile head. This condition implies that the pile head is free to rotate and free to move laterally. The lateral force is considered positive when applied from left-to-right. The moment is considered positive when applied clockwise.

Shear and Slope: In this boundary condition, the user defines the applied lateral load in units of force and the slope in radians at the pile head. The lateral force is considered positive when applied from left-to-right. The slope is positive when the pile head rotates counterclockwise. A fixed-head condition (with no restrictions to lateral movements) may be modeled by specifying a slope equal to zero.

Shear and Rotational Stiffness: For this boundary condition, the user defines the applied lateral load in units of force and a value for rotational stiffness (moment per radian of rotation) at the pile head. The lateral force is considered positive applied from left-to-right. The values for rotational stiffness are always positive. A fixed-head condition (with no restrictions to lateral movements) may optionally be modeled by specifying a large value of rotational stiffness. This boundary condition should be selected if the user wants to model an elastically restrained pile-head connection.

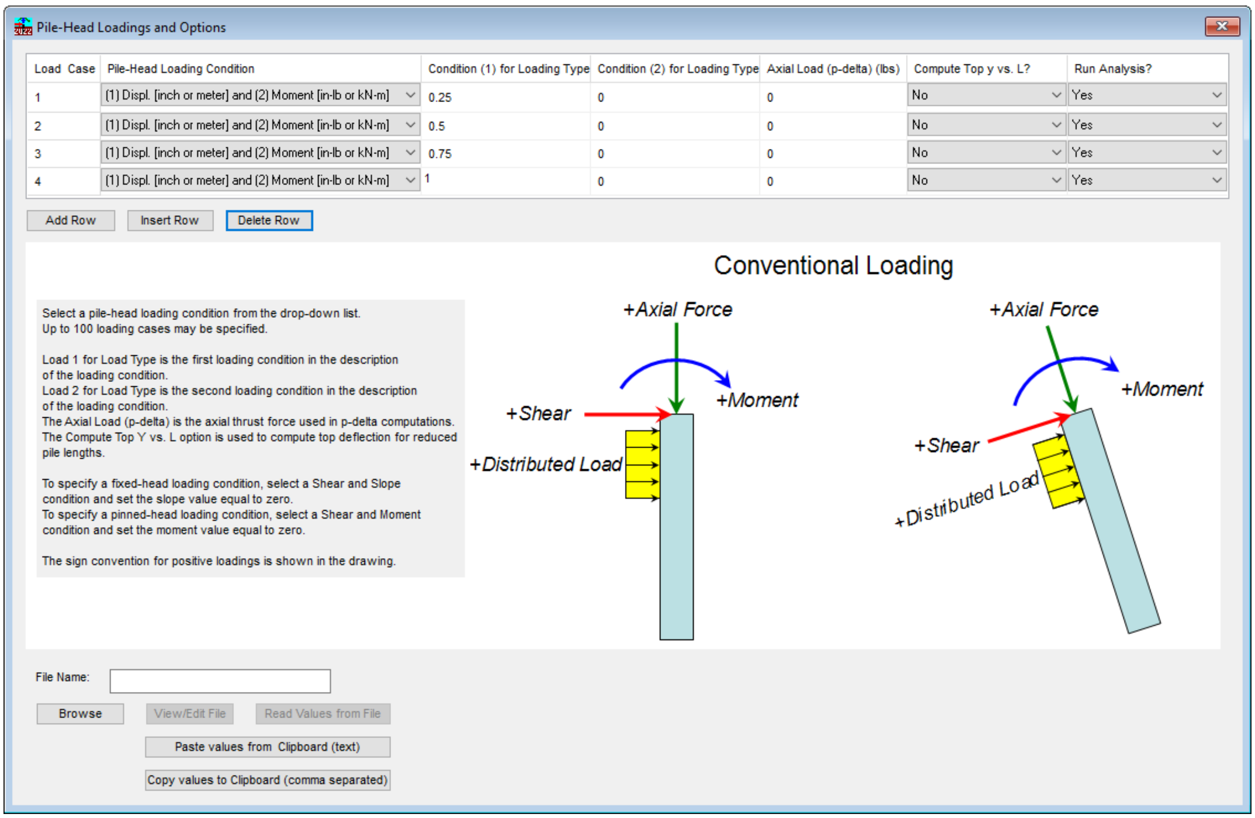


Figure 3.57 Sample Dialog for Input of Conventional Pile-head Loading

Displacement and Moment: This is selected to specify values of lateral displacement and moment at the pile head. The displacement is considered positive applied from left-to-right. The moment is considered positive when applied clockwise.

Displacement and Slope: This is selected to specify values of lateral displacement and the pile-head slope in radians. The displacement is considered positive applied from left-to-right. The slope is positive when the pile head rotates counterclockwise. A slope equal to zero is indicative of a fixed-head condition.

3.14.1.2 Condition 1

This value corresponds to the first (1) variable in the Pile-Head Loading Condition; shear force for the first three loading type conditions and displacement for the last two loading type conditions.

3.14.1.3 Condition 2

This value corresponds to the second (2) variable in the Pile-Head Loading Condition.

3.14.1.4 Axial Load

This value is input in units of force. It is applied at the pile head and may be entered after specifying the boundary conditions as well as the corresponding loading. Axial loads entered in this column are used in two parts of the computations. Firstly, the axial thrust force is used in the computations of nonlinear moment-curvature behavior. Secondly, the axial force is used to account for secondary moments produced when the pile deflects (also known as P-Δ effects).

3.14.1.5 Compute Top y versus L

This column contains a drop-down yes/no option for performing computations of top deflection versus pile length for this pile head loading condition if the selected pile-head loading condition does not prescribe the pile-head lateral deflection value. No computations of top deflection versus pile length will be made if either the Displacement-Moment or the Displacement-Slope pile-head condition is specified.

With a positive (Yes) request to generate the curve of top deflection versus pile length, LPILE takes the specified pile length along with ten consecutive reductions to half of the specified pile length, solving the analytical computations for each case. As output, the user is provided with the plot Top Deflection vs. Pile Length. In the output text the user is provided with a table that includes the pile-top results from each run with different pile length.

The outputted results may contain less than ten different points (pile lengths) if excessive pile deflections are found in the reduced pile lengths. A method that may increase the number of successful runs at reduced pile penetrations is to increase the Iterations limit (from the default of 100 to the limit of 500).

If few points or even no results are provided, it is possible that the pile penetration is already too close to the critical length and any further reduction causes excessive deflections and no successful computations. In those cases, it is suggested to increase the original pile length so that the program can calculate several points on the plot and summary of pile length versus top deflection. If the pile length is increased, the user must remember to specify soil parameters that reach the new pile tip. It is recommended to reduce the specified pile length if a horizontal line is observed in the plot of pile length versus top deflection.

It is recommended not to select this option on initial runs until the user knows to have a good working analytical model. This option is also not recommended for cases when the user also requests to compute Pile-Head Stiffness Matrix Components.

3.14.1.6 Run Analysis

This column contains a drop-down yes/no option for performing analysis for the current pile head loading condition. With a positive (Yes) request the program will perform the analysis; however, with a negative (No) request the program will not perform the analysis for the current pile head loading condition.

3.14.2 Concentrated Loads Along Pile

The input dialog Data > Concentrated Loads Along Pile is inactive by default but enabled if the user places a check mark under Data > Options and Settings > Use Single Concentrated Load Profile or under Data > Options and Settings > Use Separate Concentrated Load Profiles for Each Load Case. A maximum of 50 entries is allowed for definition of applied loads along the pile length. When selecting separate load profiles, the user must enter as many load profiles as load cases.

A sample input dialog for Concentrated Loads is shown in Figure 3.58. The user may enter data in one of three ways. The user may add enough rows to accommodate the data and enter the data manually, the user may paste the data into the table via the Windows clipboard, or read an external text data file.

Distance to Pile Head: These values represent the *x*-coordinate corresponding to the depths where the concentrated load is applied. Concentrated loads must be entered in ascending order of distances (depths).

Shear: The horizontal (lateral) load, or shear, may be positive when applied from left to right or negative from right to left. This is specified in units of force (lb or kN).

Moment: The bending moment may be positive when applied clockwise or negative when counter-clockwise. This is specified in units of force-length (lb-in or kN-m).

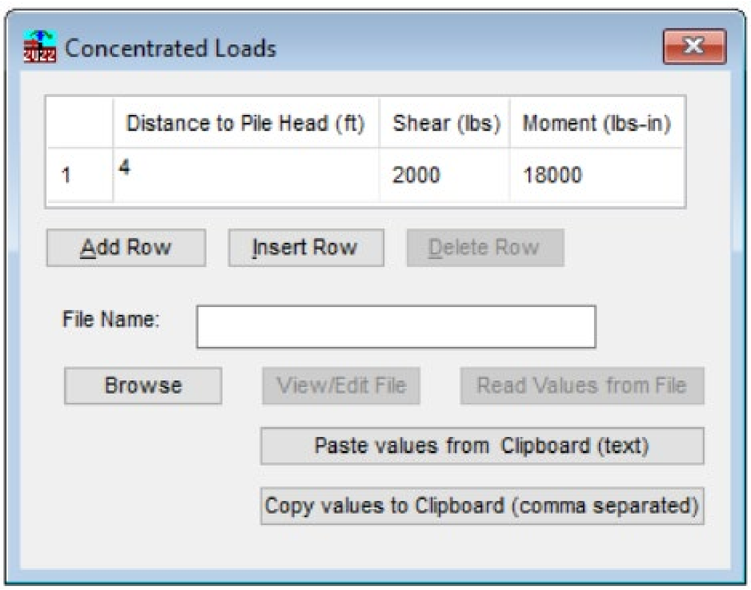


Figure 3.58 Sample Dialog for Input of Concentrated Loads Along Pile

3.14.3 Distributed Lateral Loading

The data entry for distributed lateral loading for conventional analysis is controlled either using a single input dialog if a single distributed load profile is used for all conventional loading cases or using two linked input dialogs if distributed loading profiles are defined independently for the various conventional loading cases.

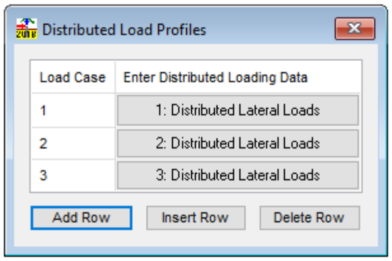
These dialog boxes are enabled if the user placed a check mark under Data > Options and Settings > Use Loading by Single Distributed Load Profile. or under Data > Options and Settings > Use Separate Distributed Load Profiles for Each Load Case. These input dialogs are inactive under default conditions. A maximum of 50 points may be defined in the table.

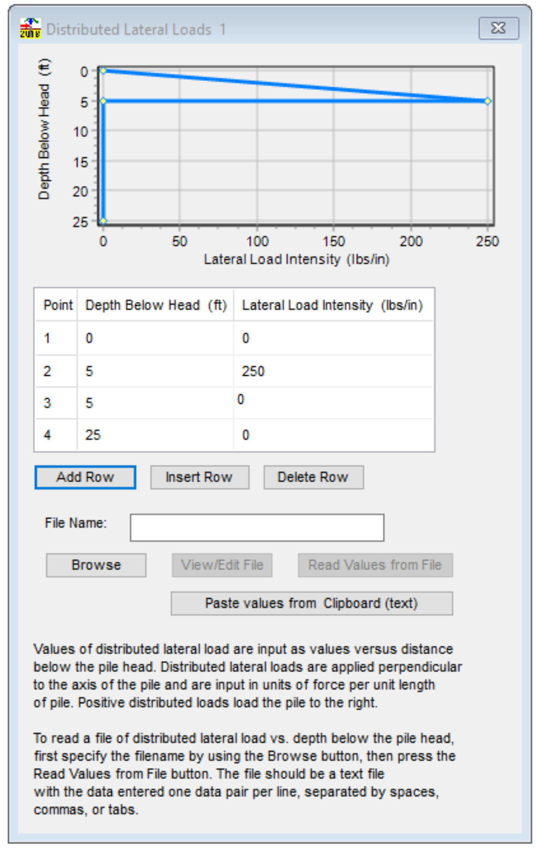
In the first dialog, the user checks whether to include distributed lateral loads. If the option is checked, the button to show the input dialog is enabled and the user may display the input dialog for distributed lateral loading. Examples of these dialogs are shown in Figure 3.59.

The program allows up to 50 different input points of lateral load values, which are placed in units of load per unit length of pile. The user must enter values in increasing magnitudes of depth. The program linearly interpolates the values of lateral loads existing between specified depths. A minimum of two entries (two depths) of distributed lateral loading are needed.

The user may enter data in three ways. The user may add enough rows to the table and enter the data manually, the user may paste the data into the table via the Windows clipboard, or the user may direct LPile to read an external text file containing the data. The Distributed Lateral Loads dialog is shown in Figure 3.60. The graph in the dialog shows the current data. It may be necessary for the user to move the cursor to a different cell to update the graph of the distributed lateral loading.

It is not possible for LPile to verify data. It is left to the user to view the graph of the distributed load data and to verify its correctness.





(a) (b)

Figure 3.59 Dialogs for Multiple Distributed Lateral Loads for Conventional Loading, (a) 3 Load Cases, (b) Distributed Load Profile Data for Load Case 1

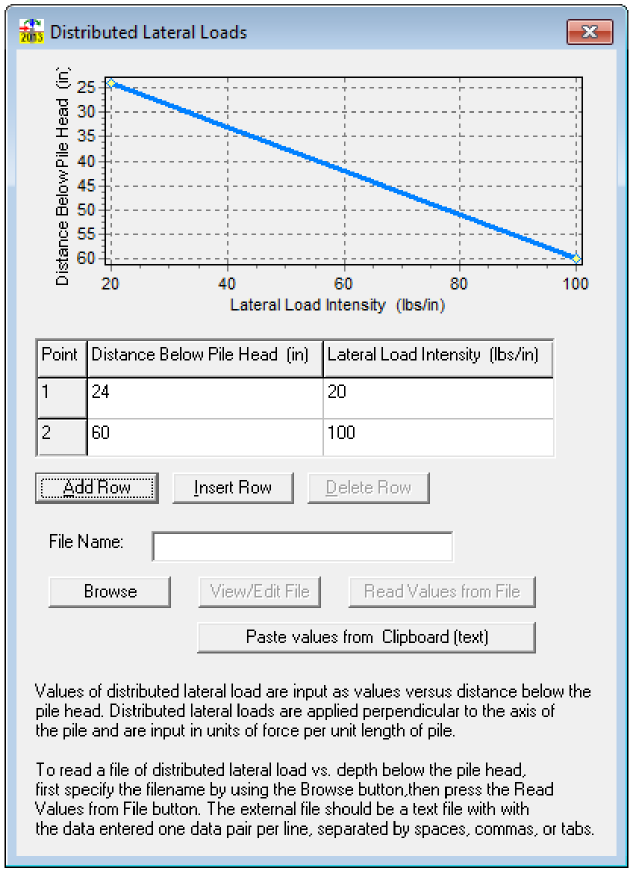


Figure 3.60 Dialog of Values of Distributed Lateral Loads versus Depth

3.14.3.1 Modeling of Point Shear Forces Below Pile Head

This modeling technique is useful to model the application of point shear loads and moments below the pile head. It is necessary for the user to understand how LPile applies the distributed lateral loads to the pile in order to model these loadings accurately. In performing the computations, LPile integrates along the distributed lateral load profile for each pile node from one-half a pile increment above the node to one-half a pile increment below the node. At the top and bottom nodes on the pile, the integration spans only one-half a pile increment either above or below the top or bottom increment as needed. The result of the integral is applied as a point force at the node in question.

In the case of an applied point shear value, the user may specify the distributed lateral load intensity acting over a small increment spanning the point of application. For example, if the pile is 50 feet long (600 inches) and has 100 increments, each pile increment is six inches long and the nodes are located at 0 inches, 6 inches, 12 inches, 18 inches, and so on down to the pile tip at 600 inches. If the point load is to be applied at 4 feet, 10 inches (58 inches), it is necessary to apply the distributed load in a way that effectively centers the applied load at the preferred location, while extending to the closest nodal point. In this example, the distributed lateral load should extend from the point of application (58 inches) to the closest nodal point (at 60 inches). The upper boundary of the applied zone should extend an equal distance above the point of application to 56 inches (see Figure 3.61). When LPile computes the equivalent nodal point loads for this example, one-third of the applied force result is applied at the nodal point above the point of load application and the remain two-thirds is applied at the closest node.

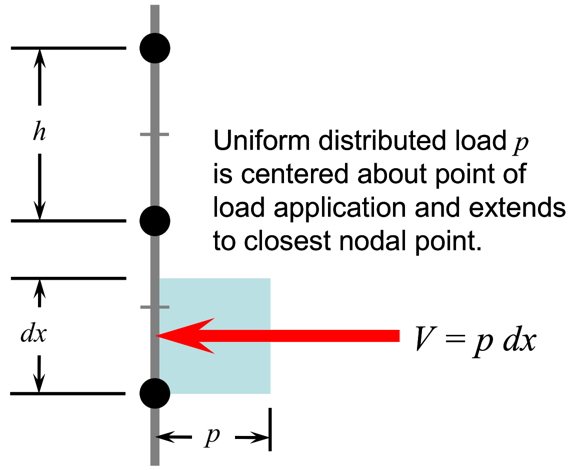


Figure 3.61 Recommendation for Modeling of Lateral Force Applied Below the Pile Head

It is important for the user to recognize that if the nodal point spacing changes for any reason, the boundaries of the equivalent loading zone must be re-computed by the user.

3.14.3.2 Modeling of Moments Below Pile Head

With the option of distributed loading the user may apply an equivalent concentrated moment about a nodal point. To model concentrated moments, it is necessary to apply equal and opposite in action distributed lateral loads to the nodal increments above and below the nodal point where the moment is to be applied. The reason for this is the integration of distributed lateral loads is performed for each nodal point. If the two distributed loads were applied over a single increment, the equal and opposite forces would cancel each other. Figure 3.62 illustrates the principle of applying equal and opposite equivalent forces to model a concentrated moment in the pile.

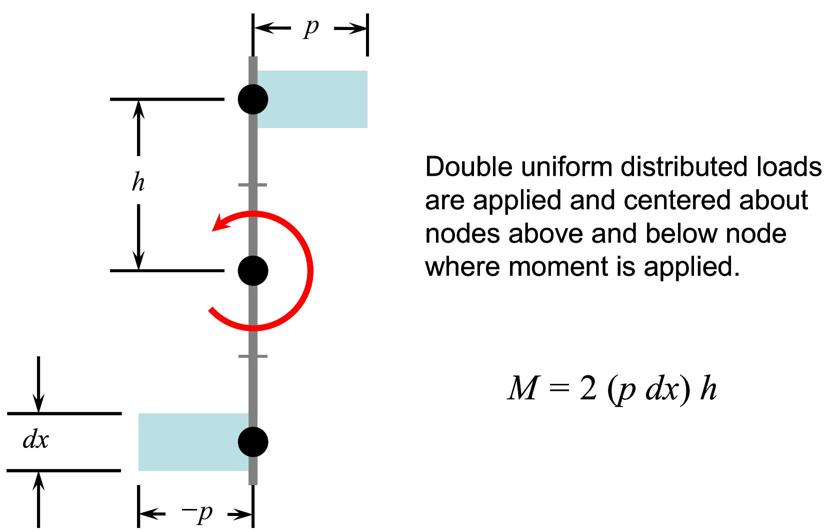


Figure 3.62 Recommendation for Modeling of Moment Applied Below the Pile Head

3.14.4 Lateral Soil Movements

The input dialog Data > Lateral Soil Movements is inactive by default but enabled if the user places a check mark under Data > Options and Settings > Use Loading by Single Soil Movement Profile or under Data > Options and Settings > Use Separate Soil Movement Profiles for Each Load Case. A maximum of 50 points may be defined in the table. A maximum of 50 entries is allowed for definition of the soil movement profile in an analysis.

LPile provides two options for specifying free-field soil movement in the soil profile. Either a single soil movement profile can be applied to all load cases or independent soil movement profiles can be specified for each conventional loading case. The soil movement profile may be defined only along a portion of the pile length if desired. In general, a pile under lateral load moves against a soil mass. However, in some cases, the soil itself will move and the soil loading or reaction must be considered by taking into account the relative movement between the soil and the pile. LPile will automatically generate the soil reaction at each pile node consistent with the relative movement between the soil and pile at that particular depth.

The input dialog for soil movements versus depth is shown in Figure 3.63. The user may enter data in one of three ways. The user may add enough rows to accommodate the data and enter the data manually, the user may paste the data into the table via the Windows clipboard, or read an external text data file. The graph in the dialog shows the current data. It may be necessary for the user to move the cursor to an adjacent cell to update the graph of lateral soil movement.

Depth Below Pile Head: These values represent the *x*-coordinate corresponding to the depths where the soil movement occurs. Intermediate values of soil movement located between two specified depths are obtained by linear interpolation of the specified values. It is therefore necessary to have at least two entries of depths. Soil movement must be entered in ascending order of depths.

Lateral Soil Movement: The soil movement values may be positive for soil moving from left to right or negative for soil moving from right to left. However, it is critical that the soil movement occurs in the same direction as the applied loads.

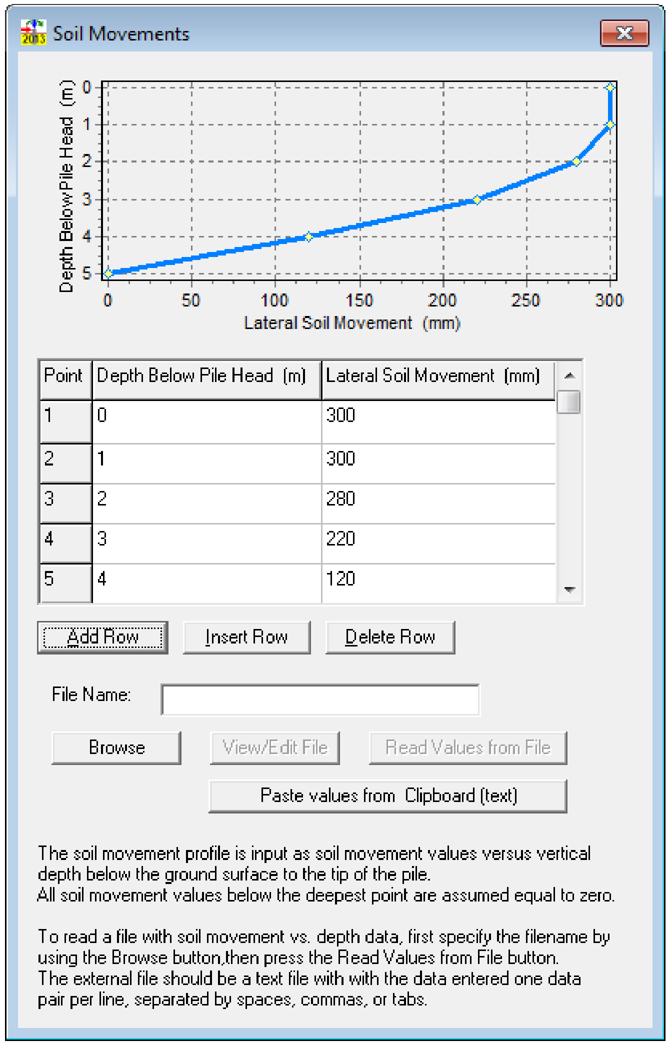


Figure 3.63 Dialog for Input of Soil Movements versus Depth Below Pile Head

3.14.5 Pile-head Stiffness Matrix Components

The dialog Data > Controls for Computation of Stiffness Matrix is shown in Figure 3.64. This dialog is inactive by default but enabled if the user places a check mark under Data > Options and Settings > Compute Pile-Head Stiffness Matrix Values.

The feature for computation of pile-head stiffness matrix values has three options to control how the values are computed. In the first method, which is identical to the method used in versions of LPile prior to LPile 2013, the loads used for computation of pile-head stiffness are those specified in load case 1 for conventional loading. This method does not allow the user to control the lateral displacement and pile-head rotation, so the second and third options were added to provide this capability. In the second method, the maximum displacement and rotation are set by the values computed for load case 1 for conventional loading. In the third method, the user may specify the maximum pile-head displacement and rotation.

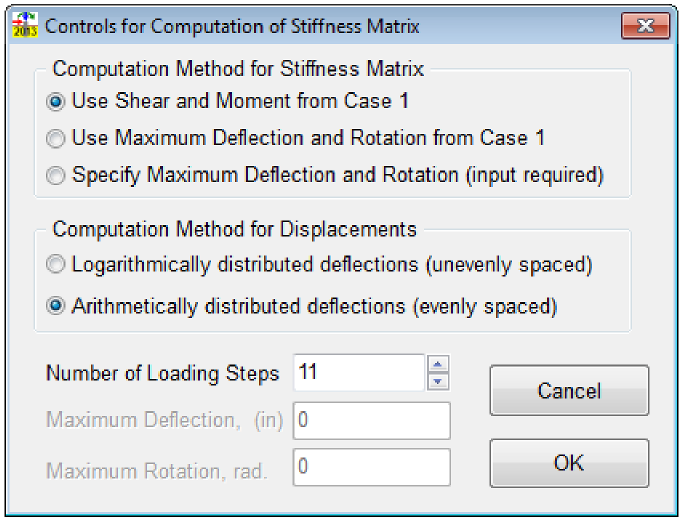


Figure 3.64 Dialog for Controls for Computation of Stiffness Matrix

The definitions of the pile-head stiffness values and their engineering units computed by LPile are the following:

$$K_{22} = \frac{\text{pile-head shear force reaction}}{\text{pile-head deflection}} = \frac{\text{lbs}}{\text{inch}} \text{ or } \frac{\text{kN}}{\text{meter}}$$

$$K_{32} = \frac{\text{pile-head moment reaction}}{\text{pile-head deflection}} = \frac{\text{in-lbs}}{\text{inch}} \text{ or } \frac{\text{kN-m}}{\text{meter}}$$

$$K_{23} = \frac{\text{pile-head shear force reaction}}{\text{pile-head rotation}} = \frac{\text{lbs}}{\text{radian}} \text{ or } \frac{\text{kN}}{\text{radian}}$$

$$K_{33} = \frac{\text{pile-head moment reaction}}{\text{pile-head rotation}} = \frac{\text{in-lbs}}{\text{radian}} \text{ or } \frac{\text{kN-m}}{\text{radian}}$$

3.14.6 Pushover Analysis

The input dialog Data > Controls for Computation of Pushover Analysis is inactive by default but enabled if the user places a check mark under Data > Options and Settings > Compute Push-over Analysis. The dialog for Controls for Pushover Analysis is presented in Figure 3.65.

LPile's features for pushover analysis has options for different pile-head fixity (including those from Load Case 1) and for setting the range and distribution of pushover deflection. The output of the pushover analysis is displayed in graphs of pile-head shear force versus deflection and maximum moment developed in the pile versus deflection.

When selecting Pushover Method > Based on Loading/Displacements of Load Case 1, the pushover is performed by running a series of analyses for displacements using proportional increases of the Condition 1 and Condition 2 that were specified under Data > Pile Head Loading for Load Case 1. The values in Condition 1 and Condition 2 are thus multiplied by the specified Minimum Load Factor and up to the specified Maximum Load Factor using the Defined Number of Loading Steps.

When selecting Based on Pile-Head Fixity Conditions for Pushover Method, the pushover analysis is performed by running a series of analyses for displacement-zero moment pile-head conditions for pinned head piles and analyses for displacement-zero slope pile-head conditions for fixed head piles.

The displacements used are controlled by the maximum and minimum displacement values specified and the displacement distribution method. The displacement distribution method may be either logarithmic (which requires a non-zero, positive minimum and maximum displacement values), arithmetic, or a set of user-specified pile-head displacement values. The number of loading steps sets the number of pile-head displacement values generated for the pushover analysis.

The Axial Thrust Force that is used in the pushover analysis, if any, must be entered in the Control for Pushover Analysis dialog. The defined Axial Trust Force overrides any Axial Load defined under Data > Pile Head Loading for Load Case 1 (they should preferably be the same).

If the pile being analyzed is not an elastic pile, the user should make sure that the axial thrust force entered matches one of the values for axial thrust entered in the conventional pile-head loadings table to make sure that the correct nonlinear bending properties are used in the pushover analysis. If the values do not match, the nonlinear bending properties for the next closest axial thrust will be used by LPile for the pushover analysis.

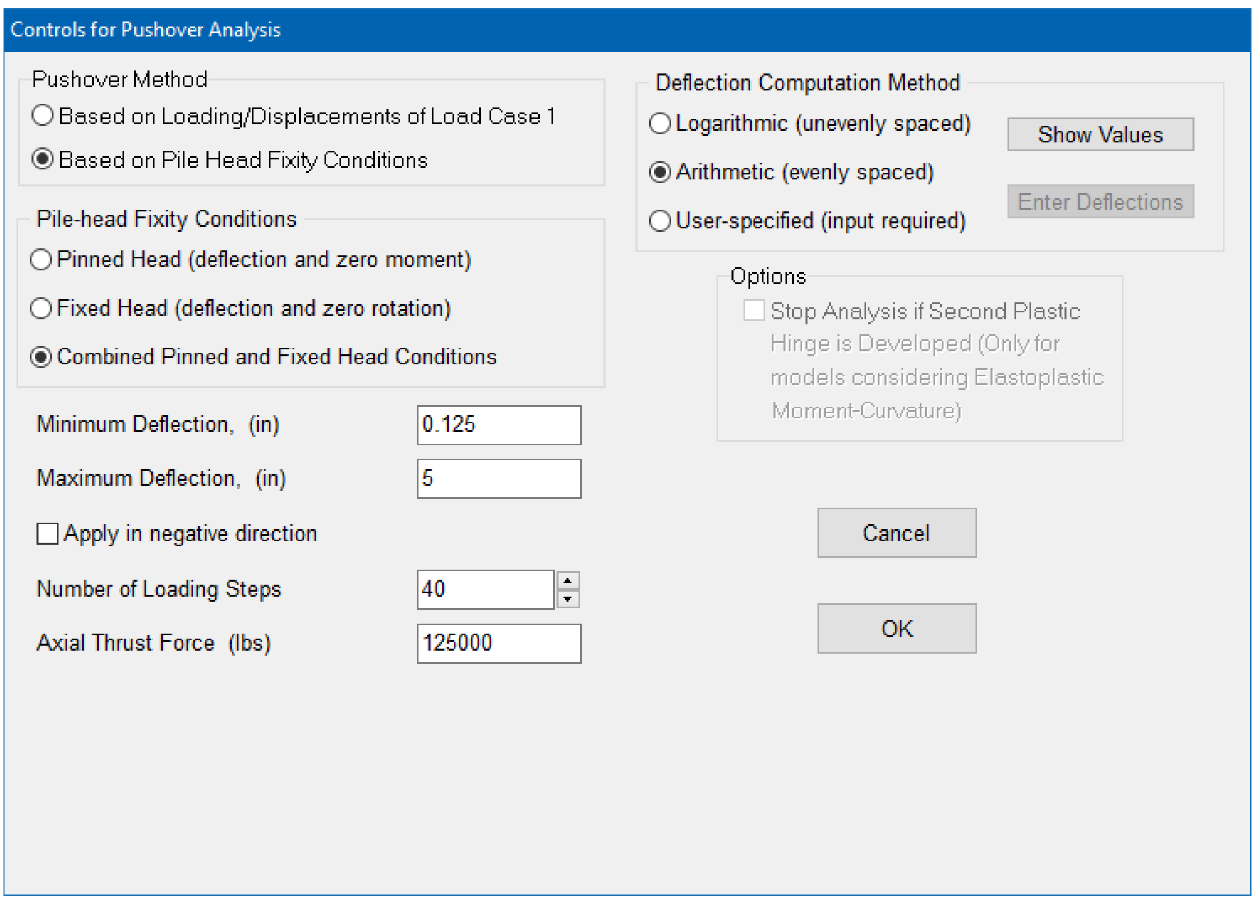


Figure 3.65 Dialog for Controls for Pushover Analysis

Results from a pushover analysis are presented in the following two figures. Figure 3.66 (similar plot obtained from Graphics > Pushover Shear vs. Top Deflection) presents the pile-head shear force versus displacement for pinned and fixed head conditions and indicates the maximum level of shear force that can be developed for the two conditions. Similarly, Figure 3.67 (similar plot obtained from Graphics > Pushover Moment vs. Top Deflection) presents the maximum moment developed in the pile (a prestressed concrete pile in this example) versus displacement and shows that a plastic hinge develops in the fixed head pile at a lower displacement than for the pinned head pile.

Unless the user selects the CALTRANS Equivalent ElastoPlastic Moment Curvature (Section 3.6.19.2), it is often not possible to identify the displacement at which a plastic hinge forms in the graph of pile-head shear force versus displacement. Instead, the user should examine the graph of maximum moment developed in the pile versus displacement to determine the lateral pile-head displacement at which the maximum developed moment is reached. The lateral displacements at which the plastic moment forms are indicated in Figure 3.66 and Figure 3.67.

For pile sections modeled as Equivalent ElastoPlastic Moment Curvature (Section 3.6.19.2), the user may select to Stop Analysis if Second Plastic Hinge is Developed. In such cases, if plastic hinges are developed the LPile program will indicate the formation of hinges in the Graphics > Pushover Shear vs. Top Deflection and in the Graphics > Pushover Moment vs. Top Deflection plots. A sample set of pushover result plots for an LPile model using pile section with Equivalent ElastoPlastic Moment Curvature is shown in Figure 3.68.

In general, it is not possible to develop more than one plastic hinge in a pile if the pile-head condition is pinned. It is sometimes possible to develop two plastic hinges in the pile if the pile-head condition is fixed.

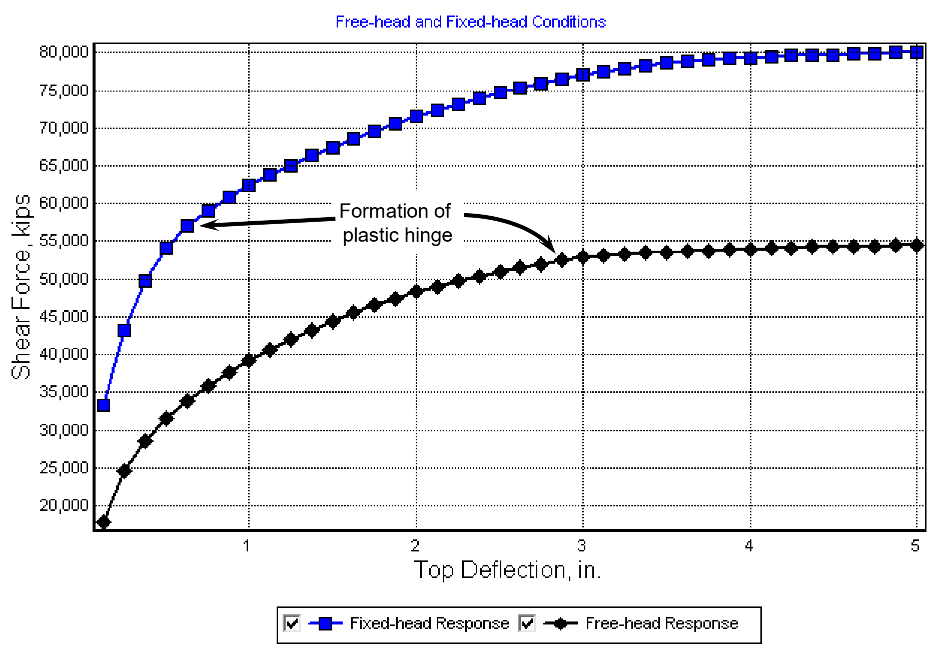


Figure 3.66 Pile-head Shear Force versus Displacement from Pushover Analysis

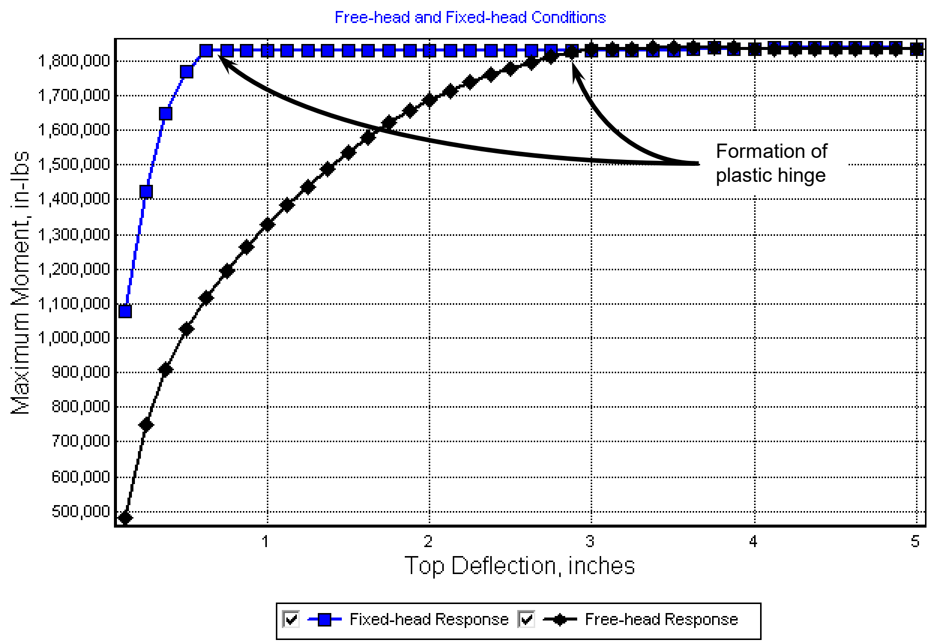


Figure 3.67 Maximum Moment in Pile versus Displacement from Pushover Analysis

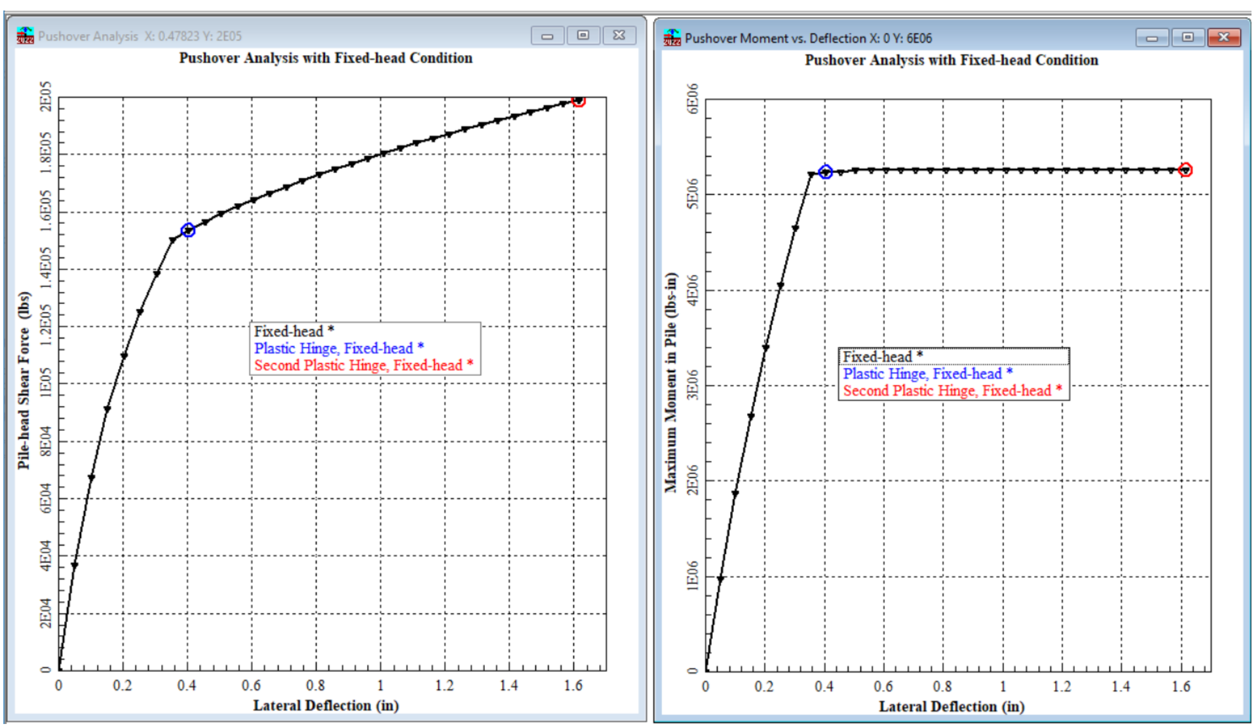


Figure 3.68 Sample Pushover Results for Pile Section with ElastoPlastic Moment Curvature

3.14.7 Pile Buckling Analysis

The input dialog Data > Controls for Computation of Pile Buckling Analysis is inactive by default but enabled if the user places a check mark under Data > Options and Settings > Compute Pile Buckling Analysis. The dialog for the Controls for Pile Buckling Analysis is shown in Figure 3.69.

The feature for performing an analysis of pile buckling has options for the pile-head fixity condition, pile-head loadings, maximum compression loading, and number of loading steps. The pile buckling analysis is performed by applying the pile-head loading conditions, then increasing the axial thrust loading from zero to the maximum compression load in the number of loading steps specified.

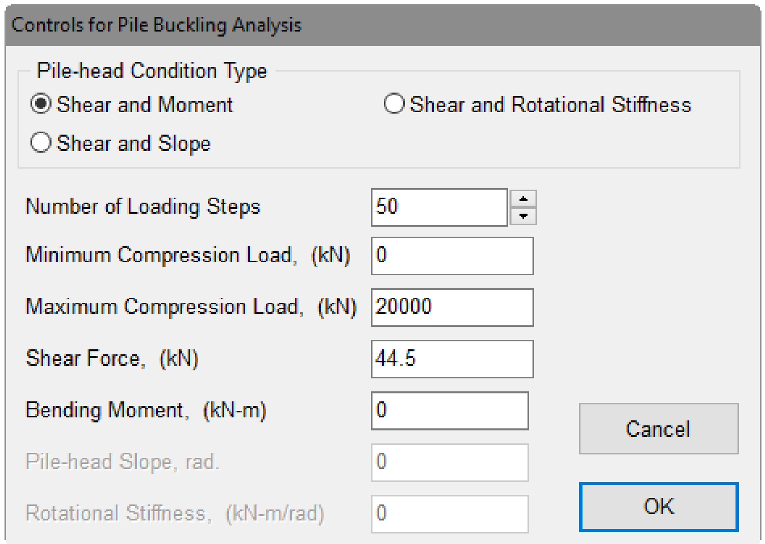


Figure 3.69 Dialog for Controls for Pile Buckling Analysis

The results of the pile buckling analysis are presented in a graph along with an estimate of the axial buckling capacity for the pile-head loading condition. This graph displays the pile-head lateral deflection versus axial thrust force, a fitted hyperbolic curve, and the estimated pile buckling capacity.

The hyperbolic curve is fitted to the computed results using the following procedure.

The typical results from the pile buckling analysis are similar to those shown in Figure 3.70. In this figure, P is the axial thrust force and y_0 is the pile-head deflection for the case of minimum axial load (P_0). These results are then redrawn with every deflection value shifted to the left by an amount equal to y_0, as shown in Figure 3.71.

The form of the hyperbolic curve to be fitted is

$$P = \frac{y - y_0}{b + a(y - y_0)} b + P_0$$

This may be rearranged in the form of straight line with a slope a and intercept b as

$$\frac{y - y_0}{P - P_0} = b + a(y - y_0)$$

The computed results are then redrawn as in Figure 3.72 and least-squares curve fitting is used to compute the curve fitting parameters a and b.

The estimate pile buckling capacity P_{crit} is computed using

$$P_{crit} - P_0 = \frac{1}{a}$$

LPile can graph the computed results, the fitted curve, and the estimated pile buckling capacity. A typical graph is shown in Figure 3.73.

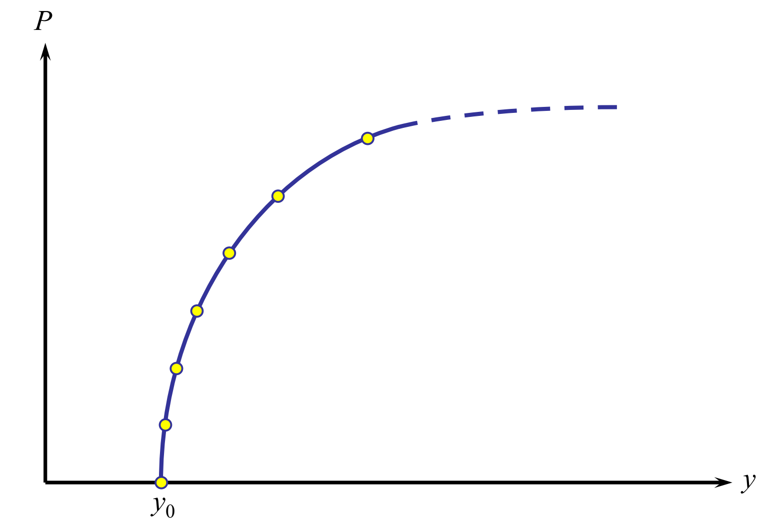


Figure 3.70 Typical Results for a Pile Buckling Analysis

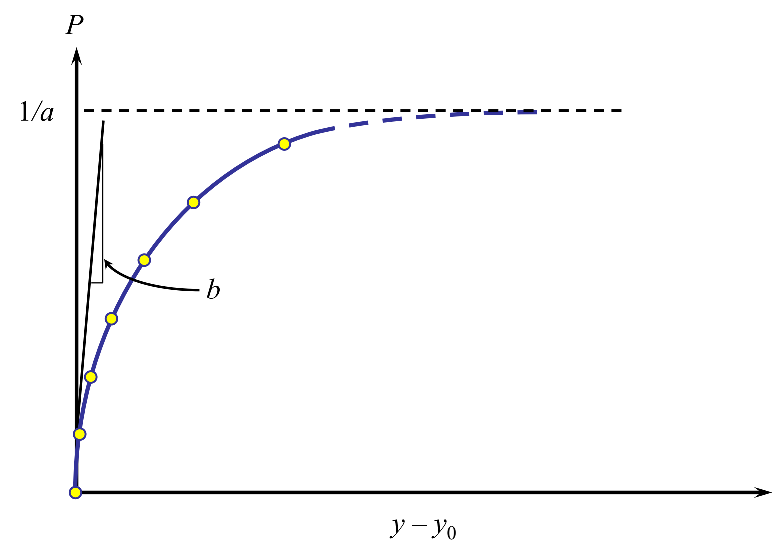


Figure 3.71 Computed Pile Buckling Result Shifted to the Left

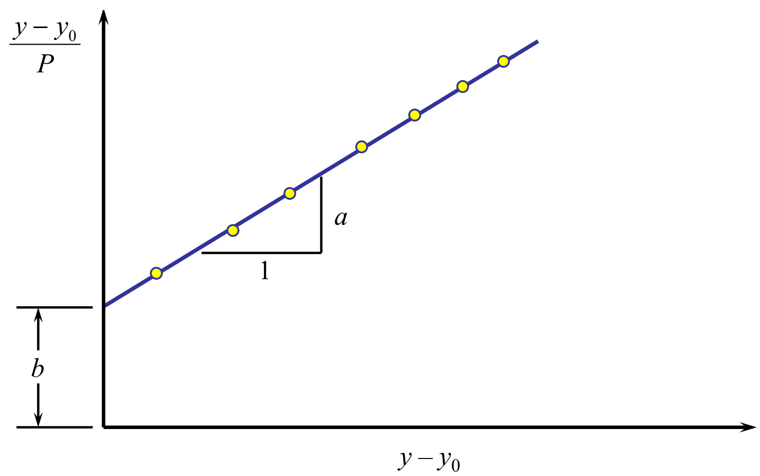


Figure 3.72 Redrawn Pile Buckling Results Used for Curve Fitting

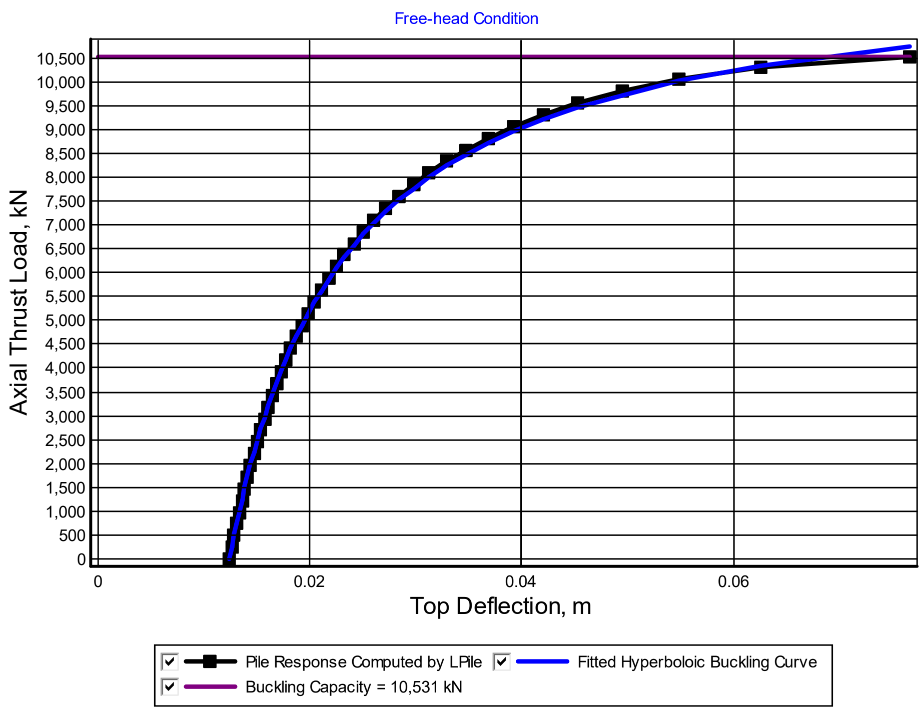


Figure 3.73 Results from Pile Buckling Analysis

In this graph, the response curve is plotted with symbols and the fitted curve is drawn without symbols. The filled curve overlies the curve for computed pile response, so the line for computed pile response is not visible but the symbols on the response curve are visible.

When performing a pile buckling analysis, the user must guard against specifying a maximum axial load that is too high. This can be checked by examining the sign of deflection of the lateral deflection value for zero axial load. In a proper analysis, the magnitude of lateral deflection at higher values of axial thrust will have the same sign as that for zero axial thrust and the deflection values will be larger in magnitude, as shown in Figure 3.73.

The estimated pile buckling capacity for elastic piles is computed from the shape of the pile-head response curve and is not based on the magnitude of maximum moment compared to the plastic moment capacity of the pile. For nonlinear piles, the buckling capacity may be determined by either the maximum axial compression capacity or plastic moment capacity of the pile. For piles with nonlinear bending behavior, the buckling capacity estimated by the hyperbolic curve may over-estimate the actual buckling capacity if the buckling capacity is controlled by the pile's plastic moment capacity. Thus, for analyses of nonlinear piles, the user should compare the maximum moment developed in the pile to the plastic moment capacity. If the two values are close, the buckling capacity should be reported as the last axial thrust value for which a solution was reported.

If the section is either a drilled shaft (bored pile) or prestressed concrete pile with low levels of reinforcement, it may be possible to obtain buckling results for axial thrust values higher than the axial buckling capacity, but the sign will be reversed. The reason for this is a large axial thrust value will create compression over the full section. This causes the moment capacity to be controlled by crushing of the concrete and not by yield of the reinforcement. An example of a pile buckling analysis that used axial thrust values that were too high is shown in Figure 3.74.

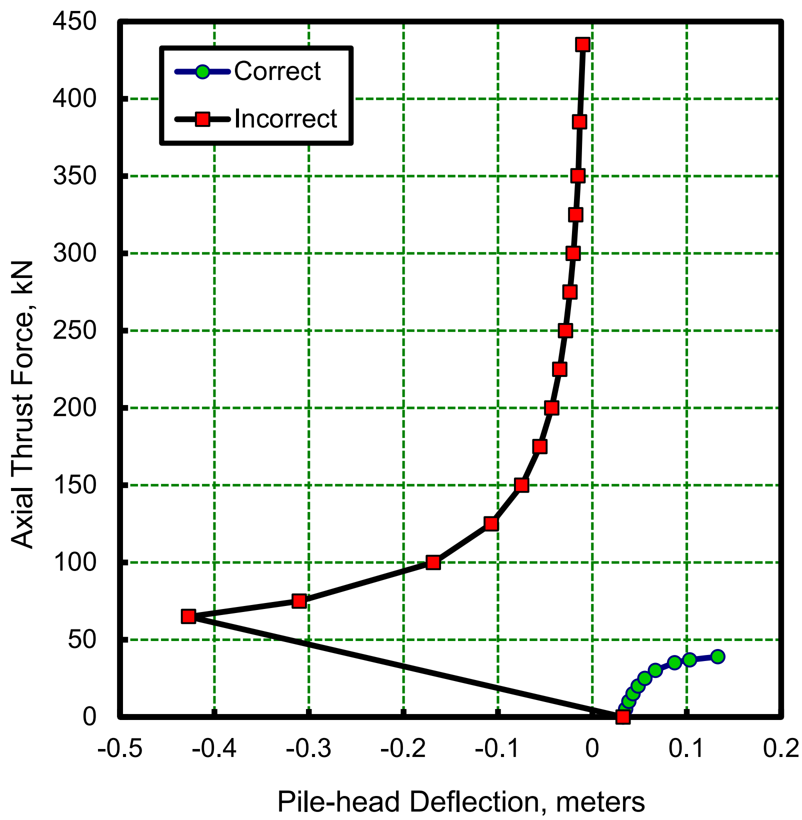


Figure 3.74 Example of Correct (green symbols) and Incorrect (red symbols) Pile Buckling Analyses

3.14.8 Shear Demand Along Pile

The input dialog Data > Controls for Computation of Shear Demand along Pile is inactive by default but enabled if the user places a check mark under Data > Options and Settings > Compute Pile Shear Demand Along Depth. The dialog for Controls for Shear Demand Along Pile is presented in Figure 3.76.

This optional feature basically produces a separate analysis using the pile that is defined in the model (under Data > Pile Properties) and the soils defined in the model (under Data > Soil Layers) along with the new loading that are defined in the Controls for Shear Demand Along Pile dialog. The result from this optional analytical feature is contained under one output chart, Graphics > Shear Demand vs Depth.

This feature is used for analyzing the impact of piles for stabilizing slopes. The effect of the piles can be included into the separate slope-stability program (such as EnSlope from Ensoft) as a shear demand placed at the depth where the critical slope crosses the pile.

Pile-head Loading Condition

The user must enter the pile-head boundary and loading conditions for the analysis of shear demand or the user can select to Copy the values from a defined Load Case. Guidance for these values is the same as those previously defined in Section 3.14.1.

Controls for Soil Movement

A soil movement must be defined for the length of pile that is above the critical slope surface. The user can enter Manual values of soil movement versus depth or Linear values with a specified Soil Movement at Ground and a specified Soil Movement at Pile Tip.

For each output length that is defined by the user, LPile will interpolate the soil movement that is used in each analysis linearly between the specified ground and tip movements.

Controls for Pile Length Output

These inputs specify the pile lengths at which the program will generate the outputs of shear demands. Users can select to Enter Number of Pile Lengths or Enter Pile Length Increment and enter the Number of Lengths or Increment Length as well as Minimum Length and Maximum Length. Alternatively, users may select a Manual option and Enter Pile Lengths using the Edit Pile Lengths button where the Lengths column must be entered from a smaller to a larger number.

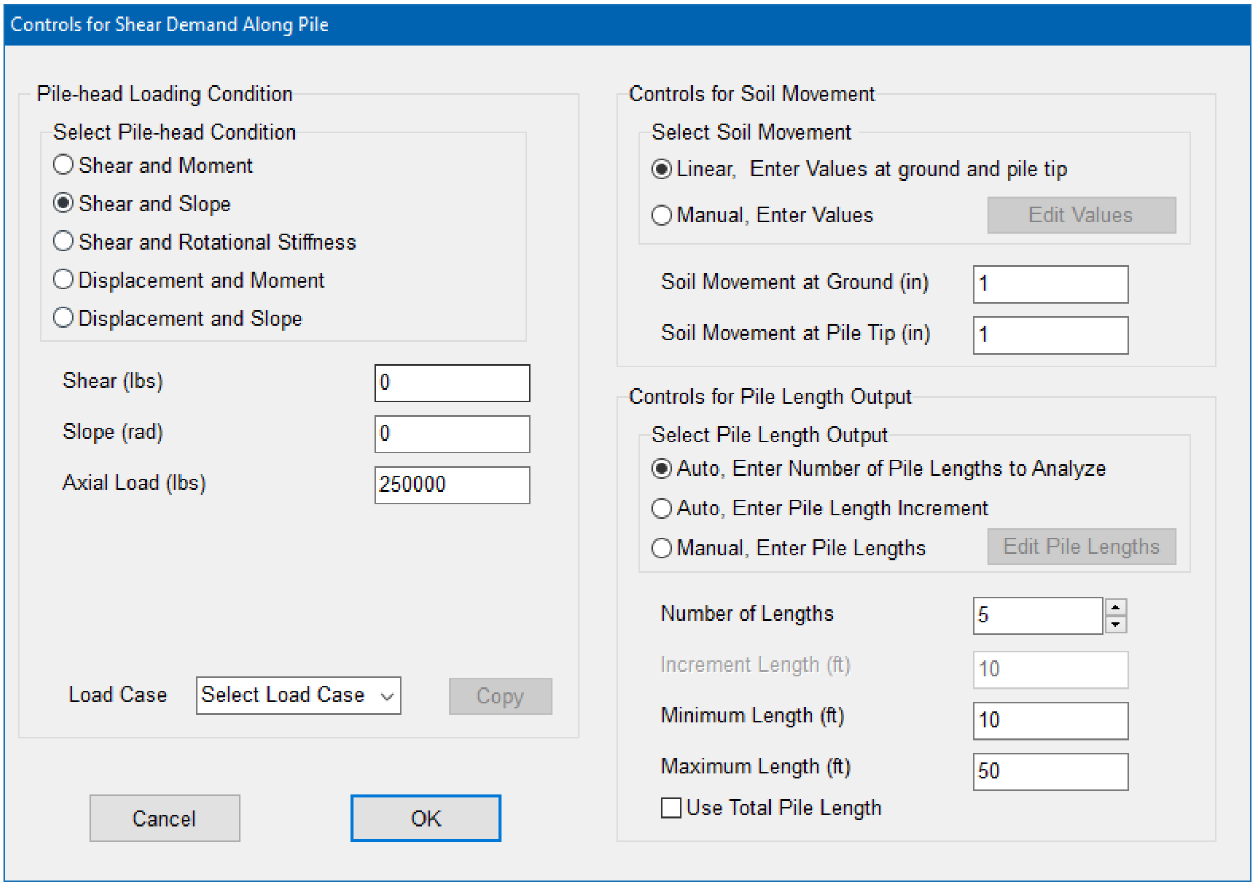


Figure 3.75 Sample Dialog for Controls for Shear Demand Along Pile

3.14.9 Variable Pile Length Analysis

The input dialog Data > Controls for Computation of Variable Pile Length Analysis is inactive by default but enabled if the user places a check mark under Data > Options and Settings > Consider Variation of Pile Length. The dialog for Controls for Variable Pile Length Analysis is presented in Figure 3.76.

This program feature allows users to evaluate the lateral response of multiple pile lengths. Users are provided with same basic loading options as those under Data > Pile Head Loading, which is disabled when using this feature. The dialog box allows users for automatic selection of pile lengths within certain limits, to select pile lengths based on increments specified by the user or to enter specific pile lengths manually.

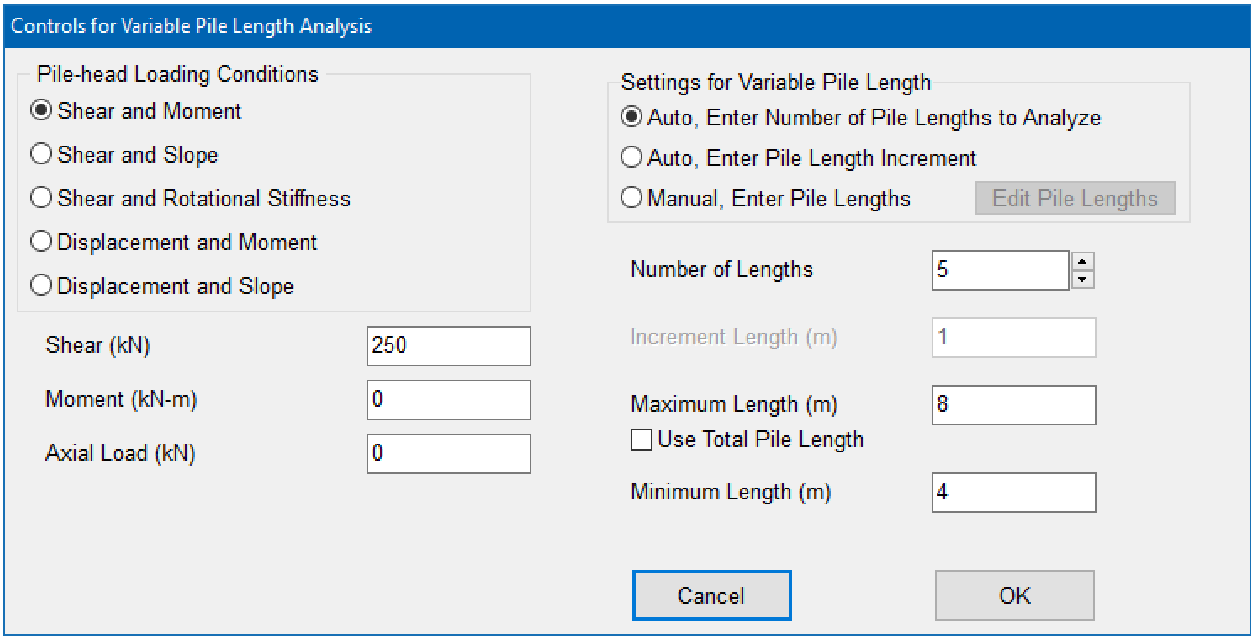


Figure 3.76 Sample Dialog for Controls for Variable Pile Length Analysis

All resulting graphs from this feature will show the results for all pile length evaluations that were defined by the user (and that provided a numerical solution). An example of output graph for lateral pile deflections is provided in Figure 3.77.

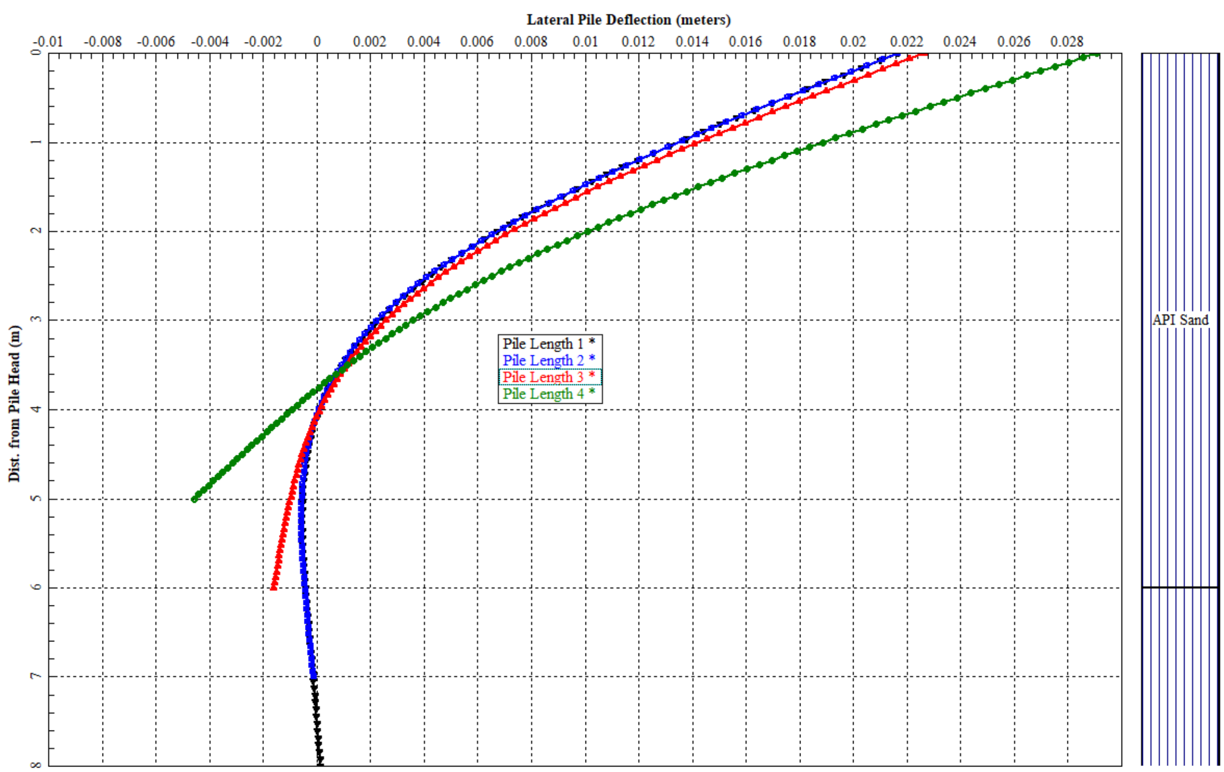


Figure 3.77 Sample Pile Deflection Graph for Various Pile Lengths

3.15 Data from Lateral Load Test

The input dialog Data > Data from Lateral Load Test is inactive by default but enabled if the user places a check mark under Data > Options and Settings > Input Data for Load Test for Comp. to Computed Values. The dialog for Lateral Load Test Data is presented in Figure 3.78.

Data for pile response measured during lateral load testing may be entered into LPile and displayed along with computed results. When this option is selected, the user is required to enter values of pile-head shear force loading versus lateral deformation. Optionally, the user may enter values of moment developed in the pile versus depth below the pile head for each pile-head shear force value.

3.15.1 Controls for Input of Load Test Data

Entry of load test data is controlled using the dialog box shown in Figure 3.78. The basic data entered are the pile-head shear versus displacement data. Optionally, the user may enter values of bending moment and/or lateral displacement versus depth. Lastly, the user may select whether or not the load test values are included in the graphs generated by LPile.

It is also possible for LPile to save load test data that has been entered as a text file and to read a text file containing the load test data.

The user should note that load test data is not saved as part of the LPile input data. Thus, each time LPile is restarted for a new analysis, it will be necessary to re-enter the load test data either by reading from the previously saved text file or by re-entering the data to LPile.

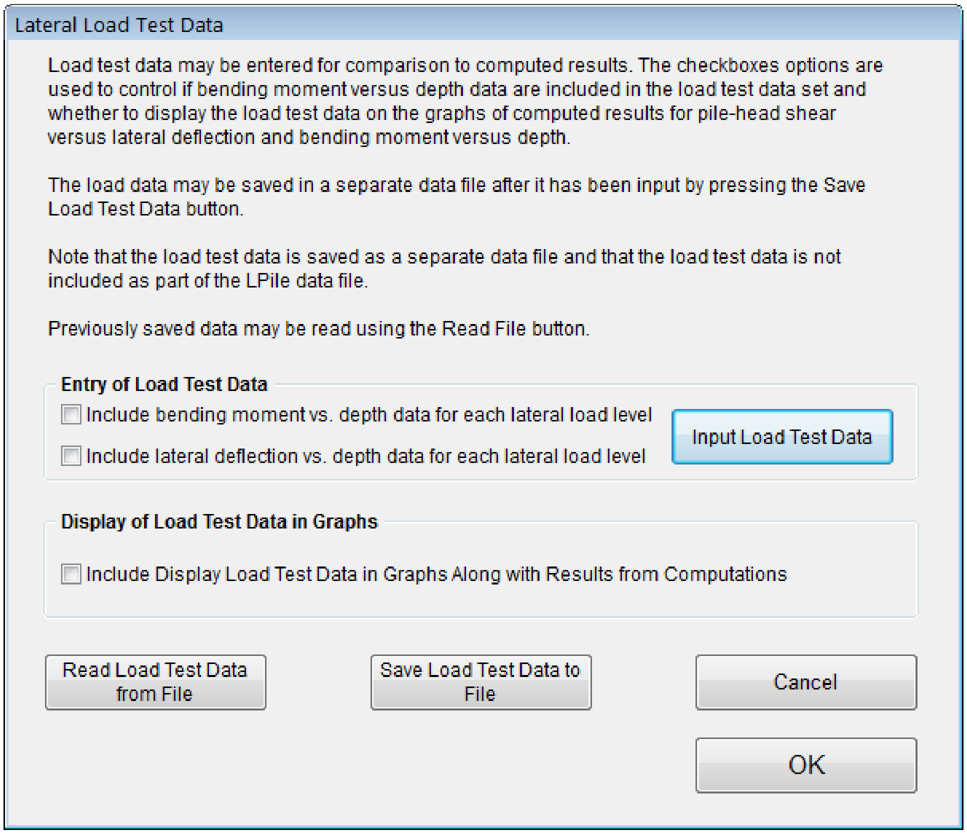


Figure 3.78 Dialog for Control of Input and Saving of Load Testing Data

3.15.2 Input of Load Test Data without Data for Bending Moments

An example of the dialog for entering pile-head shear force versus lateral deformation is shown in Figure 3.79. Data must be entered directly in the current system of units being used by LPile. However, if an existing file of load test data is being read via the load test data controls shown in Figure 3.78, the engineering units of the load test data is saved in the text file and the data will be converted, if needed, to the current system of units being used by LPile.

3.15.3 Input of Load Test Data for Bending Moments and Deflection versus Depth

If input of bending moment and/or lateral deflection data versus depth may be specified by marking the check boxes in Figure 3.78 to include data versus depth. The user may input a profile of bending moment and/or lateral deflection versus depth for each pile head loading level for which data is available via the data controls shown in Figure 3.80. The columns displayed will depend on the check boxes marked in the controls dialog. The input dialogs for bending moment and lateral deflections versus depth are shown in Figure 3.81.

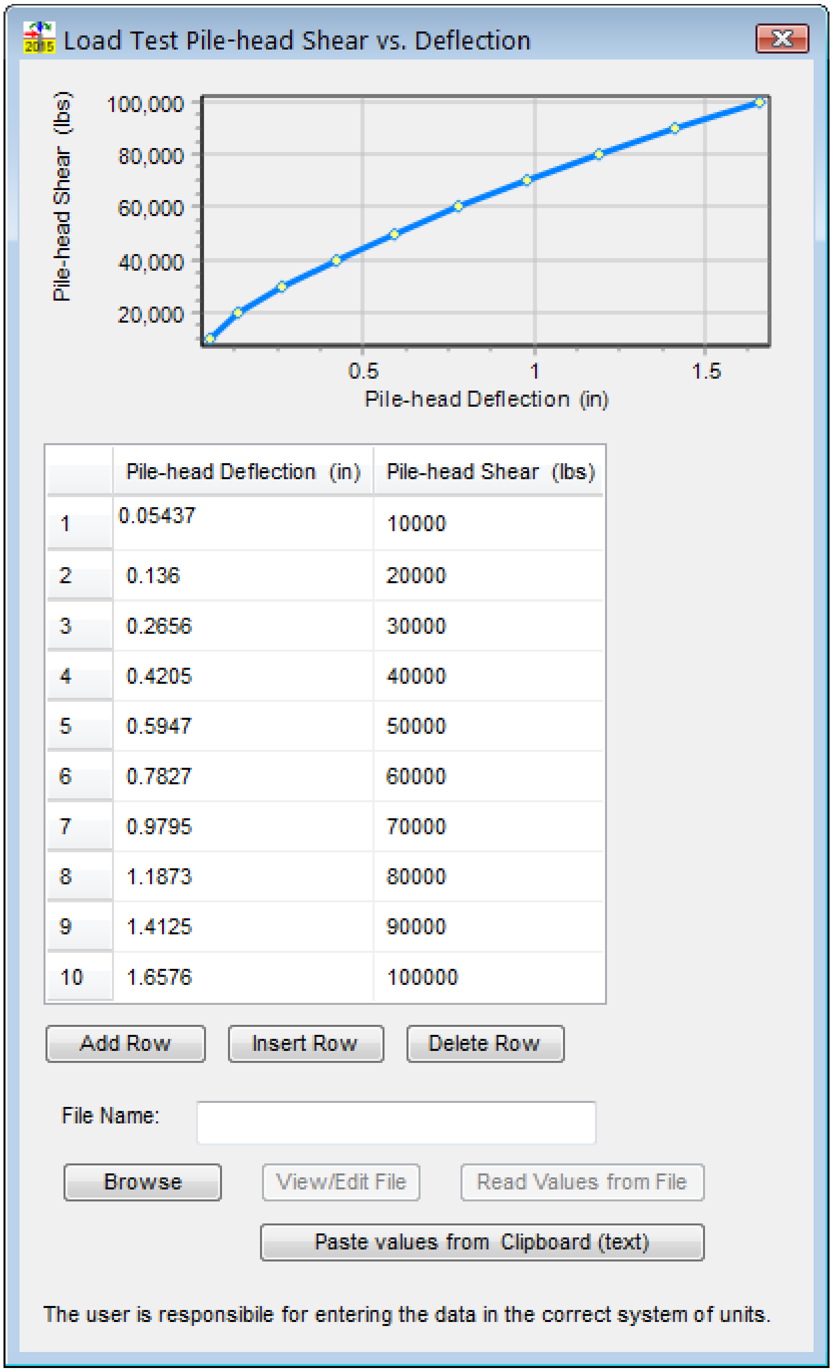


Figure 3.79 Dialog for Input of Pile-head Shear Force versus Lateral Deformation from Load Testing, if input of Bending Moment and/or Lateral Movement versus Depth is not specified.

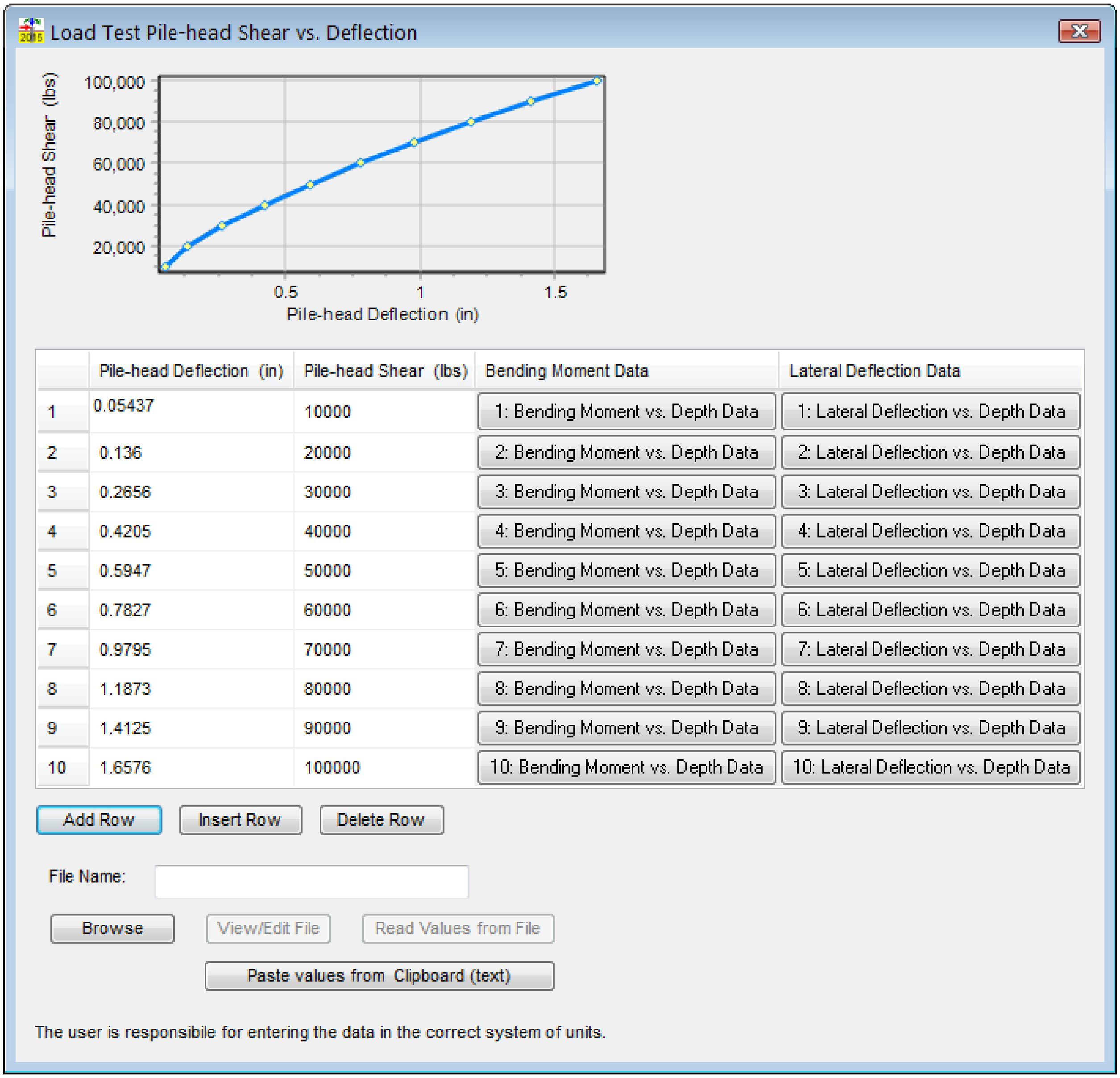
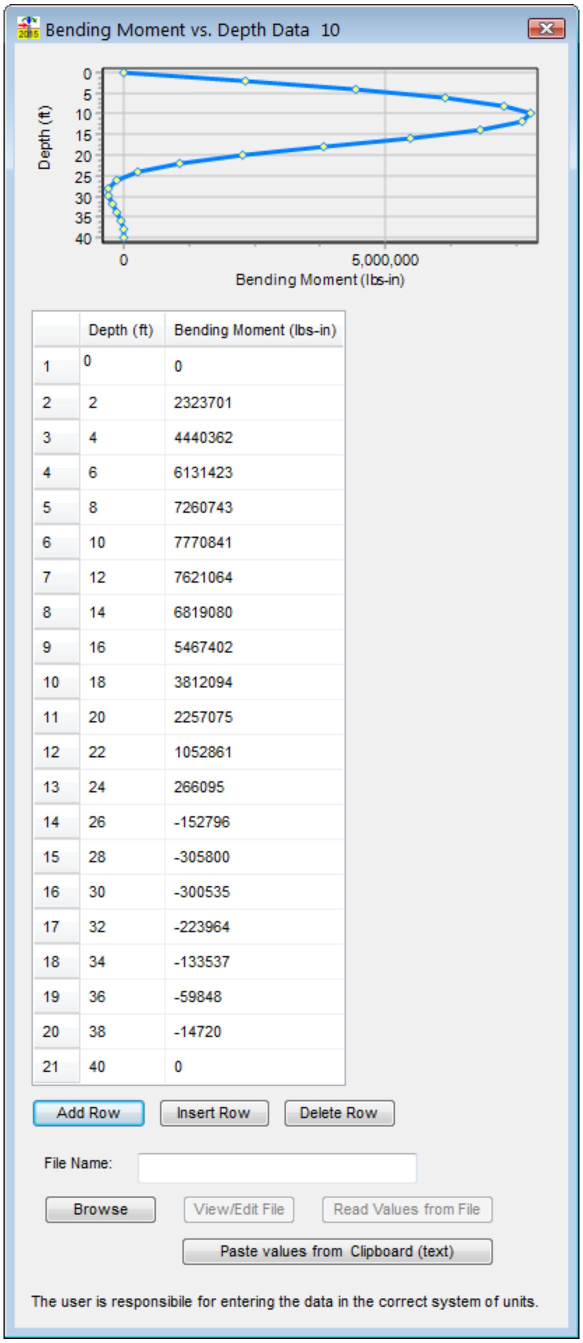


Figure 3.80 Dialog for Input of Pile-head Shear Force versus Lateral Deformation from Load Testing, if input of Bending Moment and Lateral Deflection versus Depth are specified.



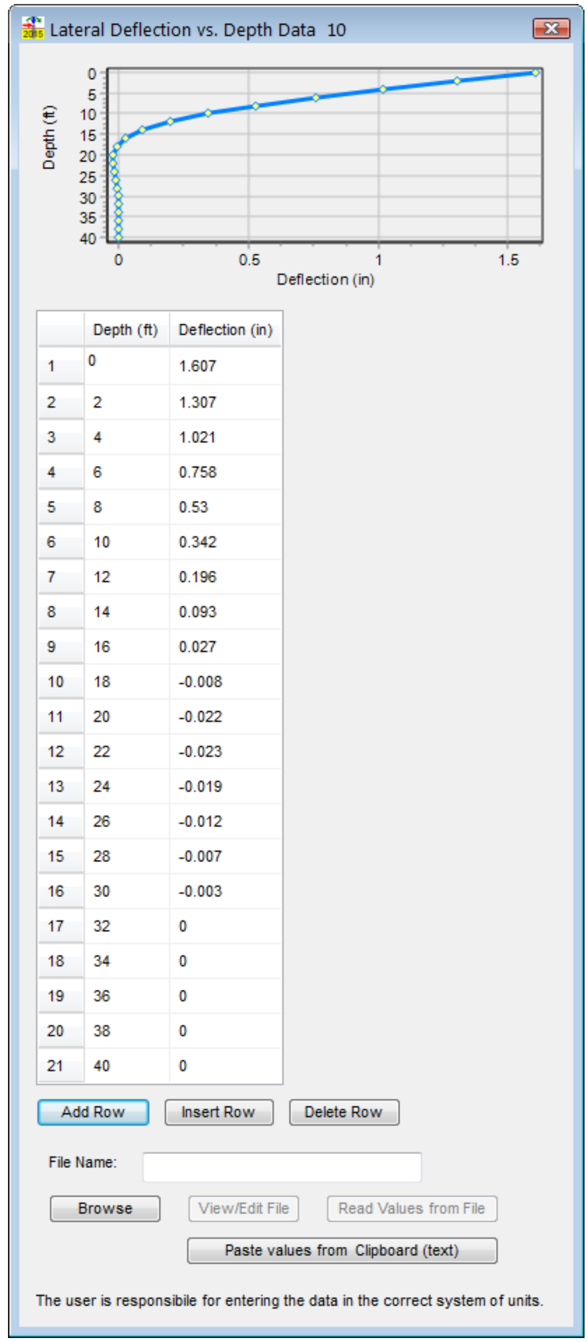


Figure 3.81 Dialogs for Input of Bending Moment and Lateral Deflection versus Depth from Load Testing.

3.16 Load and Resistance Factor Design

Features from Load and Resistance Factor Design (LRFD) are only available in models where the user places a check mark under Data > Options and Settings > LRFD Analysis Mode (see Section 3.5.1).

Data for load and resistance design computations is entered using two input dialogs. Unfactored loads are entered in one dialog and the definitions of load and resistance factors to be used are entered in the second dialog. A summary report of computed load cases is also provided to aid the user in verifying the factored loads computed for the defined load cases. The following sections describe these dialogs and the summary report.

3.16.1 Unfactored Loads for LRFD Analysis

The input dialog for unfactored loads shown in Figure 3.82 allows the user to define the type of load, horizontal force, vertical force, overturning moment, and to control the use and input of distributed loading data. All unfactored loads must be defined as combinations of horizontal shear force, over-turning moment, axial thrust force, and distributed lateral loads normal to the axis of the pile.

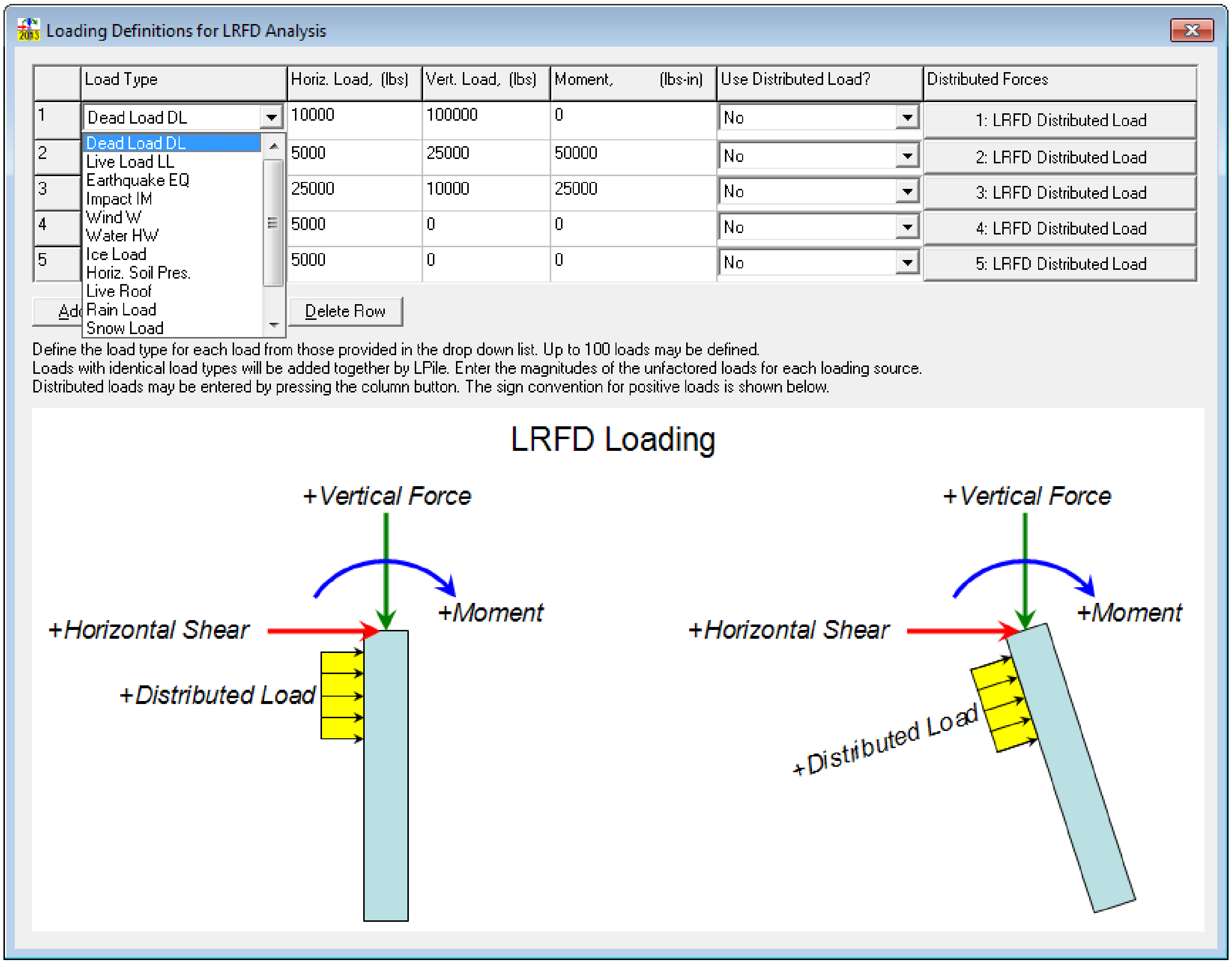


Figure 3.82 Dialog for Definition of Unfactored Pile-head Loadings for LRFD Analysis

The unfactored load definition includes the type of load. The load types are:

Dead load
Live load
Earthquake
Impact
Wind

Water
Ice
Horizontal Soil Pressure
Live Roof
Rain
Snow
Temperature
Special (for any type of load not listed above)

If the user wishes to enter data for a distributed lateral loading, an input dialog identical to that shown in Figure 3.60 is displayed.

3.16.2 Load and Resistance Cases

The Data > Load and Resistance Cases provides the options shown in Figure 3.83 with buttons that are explained in the following paragraphs.

Open LRFD Load Cases File

The user can select this button to open a previously created and saved load cases file (with extension '*filename.lrfd*'). As part of the standard installation, LPile includes a file named 'ACI318.lrfd' which defines the typical load and resistance factors plus load combinations suggested by the American Concrete Institute 318 Code from 2008.

Users can start from this installed file as reference, modify entries using the Edit Load and Resistance Cases and select Save Current LRFD Cases to save their entries into a file that can be opened and used in other LPile models.

Edit Load and Resistance Cases

This button is used to edit the loaded LRFD file or to enter data from scratch. The dialog shown in Figure 3.84 shows content when loading the optional 'ACI318.lrfd'file.

To include a load type in a load case combination, the user enters a positive, non-zero value. In addition, the user may enter the resistance factors for structure resistance in bending and shear capacity and may enter a descriptive name for the load case combination.

Save Current LRFD Cases

This button is used to save entries into a file that can be opened and later used in other LPile models.

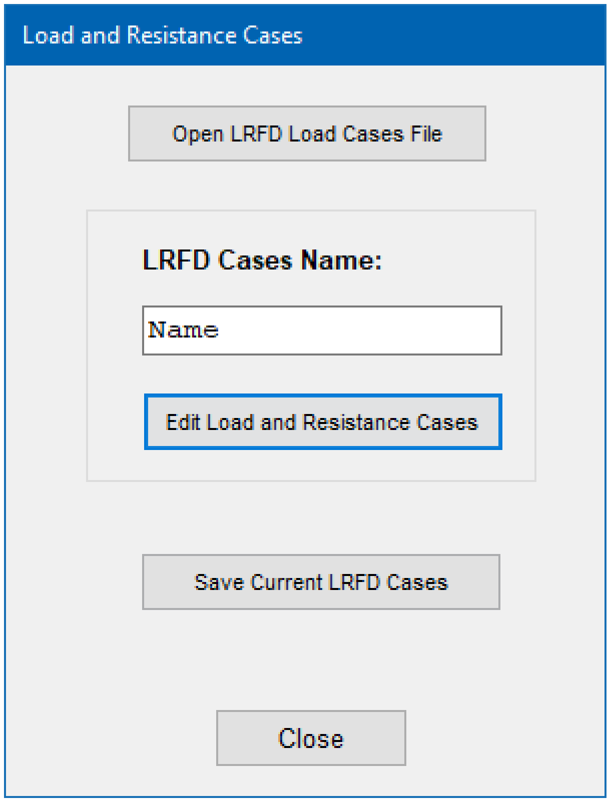
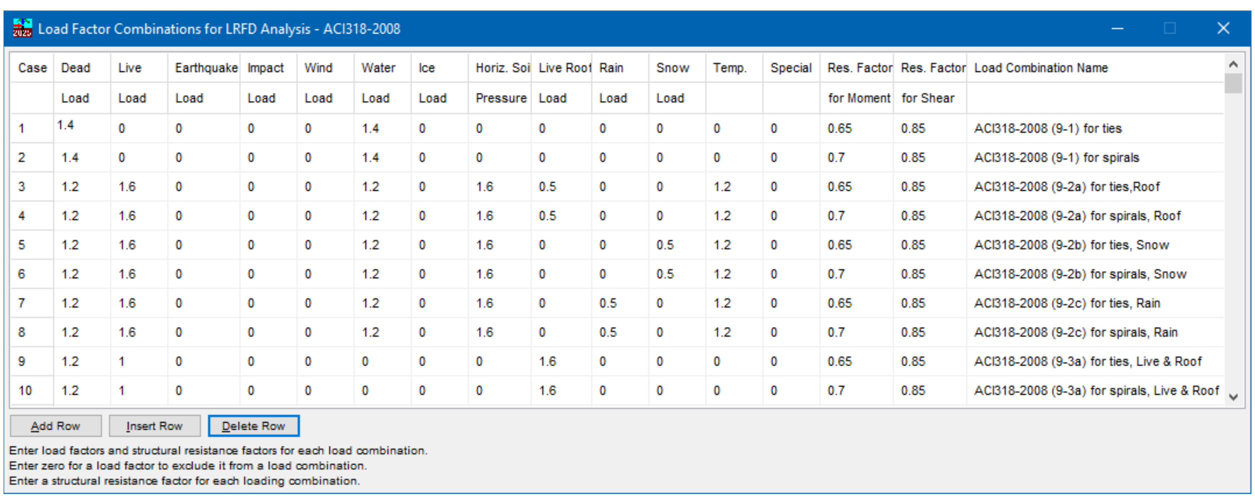


Figure 3.83 Dialog for LRFD Load and Resistance Cases



Case	Dead Load	Live Load	Earthquake Load	Impact Load	Wind Load	Water Load	Ice Load	Horiz. Soil Pressure	Live Roof Load	Rain Load	Snow Load	Temp.	Special	Res. Factor for Moment	Res. Factor for Shear	Load Combination Name
1	1.4	0	0	0	0	1.4	0	0	0	0	0	0	0	0.65	0.85	ACI318-2008 (9-1) for ties
2	1.4	0	0	0	0	1.4	0	0	0	0	0	0	0	0.7	0.85	ACI318-2008 (9-1) for spirals
3	1.2	1.6	0	0	0	1.2	0	1.6	0.5	0	0	1.2	0	0.65	0.85	ACI318-2008 (9-2a) for ties,Roof
4	1.2	1.6	0	0	0	1.2	0	1.6	0.5	0	0	1.2	0	0.7	0.85	ACI318-2008 (9-2a) for spirals, Roof
5	1.2	1.6	0	0	0	1.2	0	1.6	0	0	0.5	1.2	0	0.65	0.85	ACI318-2008 (9-2b) for ties, Snow
6	1.2	1.6	0	0	0	1.2	0	1.6	0	0	0.5	1.2	0	0.7	0.85	ACI318-2008 (9-2b) for spirals, Snow
7	1.2	1.6	0	0	0	1.2	0	1.6	0	0.5	0	1.2	0	0.65	0.85	ACI318-2008 (9-2c) for ties, Rain
8	1.2	1.6	0	0	0	1.2	0	1.6	0	0.5	0	1.2	0	0.7	0.85	ACI318-2008 (9-2c) for spirals, Rain
9	1.2	1	0	0	0	0	0	0	1.6	0	0	0	0	0.65	0.85	ACI318-2008 (9-3a) for ties, Live & Roof
10	1.2	1	0	0	0	0	0	0	1.6	0	0	0	0	0.7	0.85	ACI318-2008 (9-3a) for spirals, Live & Roof

Figure 3.84 Dialog for Load Factor Combinations for LRFD Analysis

In regards to shear, the current version of LPile does not compute structural shear capacity for all type of piles, but allows the user to input a value of shear capacity for each pile section. The factored shear capacity is computed by LPile by multiplying the resistance factor for shear by the input value for shear capacity. If the value of factored shear capacity is non-zero, LPile will evaluate the shear in the pile section by comparing the maximum developed shear force to the factored shear capacity in each pile section.

For Round Concrete Shaft and Rectangular Concrete Shaft, LPile can optionally select to Estimate Resistance Factors and Shear Capacity (if transverse reinforcement is also specified) according to the ACI 318-14 code. This is done by selecting the appropriate checkmark in the Data > Pile Properties dialog box. Results are included in sections of the output text file.

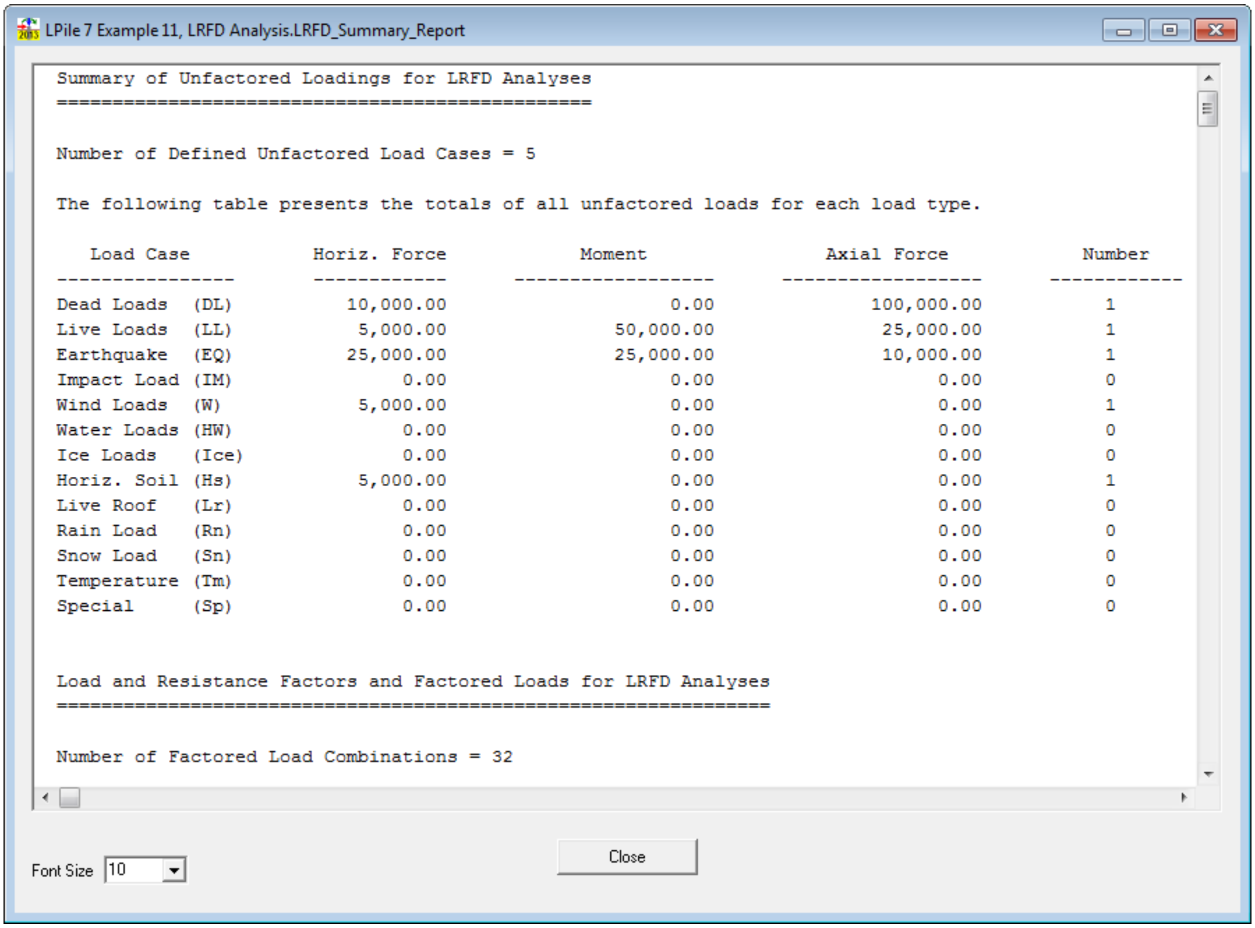
In the case of pile sections defined as elastic-plastic piles with tapered dimensions, the value of shear capacity at each pile nodal point is computed by interpolation between the values at the top and bottom of the section and the developed shear force is compared to the shear capacity at every nodal point in the section.

3.16.3 View LRFD Summary

The summary of factored load cases is provided for the user to view the factored loads computed by LPile. LPile computes this summary by first adding all pile-head loading of the same type together, then multiplying the sum by the relevant load factor.

In the case of distributed loads, the program integrates the individual distributed load profiles and computes the equivalent concentrated forces at nodes on the pile, adds all forces from the same load type together, and then multiplies the sum by the relevant load factor.

The summary report has three general sections. The first section shows the totals of the unfactored loads. The second part shows the computed factored loads for each load case in turn. The third part shows the factored load cases in tabular form. The content of the summary report is saved under the same filename of the data file but with the '*.lp13m*' file extension. An example of the summary report is shown in Figure 3.85.



LPile 7 Example 11, LRFD Analysis.LRFD_Summary_Report

Summary of Unfactored Loadings for LRFD Analyses
==

Number of Defined Unfactored Load Cases = 5

The following table presents the totals of all unfactored loads for each load type.

Load Case	Horiz. Force	Moment	Axial Force	Number
Dead Loads (DL)	10,000.00	0.00	100,000.00	1
Live Loads (LL)	5,000.00	50,000.00	25,000.00	1
Earthquake (EQ)	25,000.00	25,000.00	10,000.00	1
Impact Load (IM)	0.00	0.00	0.00	0
Wind Loads (W)	5,000.00	0.00	0.00	1
Water Loads (HW)	0.00	0.00	0.00	0
Ice Loads (Ice)	0.00	0.00	0.00	0
Horiz. Soil (Hs)	5,000.00	0.00	0.00	1
Live Roof (Lr)	0.00	0.00	0.00	0
Rain Load (Rn)	0.00	0.00	0.00	0
Snow Load (Sn)	0.00	0.00	0.00	0
Temperature (Tm)	0.00	0.00	0.00	0
Special (Sp)	0.00	0.00	0.00	0

Load and Resistance Factors and Factored Loads for LRFD Analyses
==

Number of Factored Load Combinations = 32

Font Size 10

Close

Figure 3.85 Summary Report of Computed Factored Load Combinations for LRFD Analysis

3.17 Computation of Nonlinear EI Only

This is used to analyze the flexural response of a structural pile section. This type of analysis becomes available in models where the user places a check mark under Data > Options and Settings > Nonlinear EI Only Mode (see Section 3.5.1).

This check mark enables the menu Data > Axial Thrust Loads for Interaction Diagram and disables most other dialogs (related to soils and loading) since they are no longer applicable for structural section analyses. Example 5, discussed in Section 6.5, demonstrates how to compute nonlinear *EI* only and how to produce both unfactored and factored interaction diagrams.

3.18 Axial Thrust Loads for Interaction Diagram

This menu is enabled if the user places a check mark under Data > Options and Settings > Include Interaction Diagram or under Data > Options and Settings > Nonlinear EI Only Mode (see Section 3.5.1). An example of the input dialog for this menu is shown in Figure 3.86. An example of the input dialog for entering axial thrust force values is shown in Figure 3.87.

With this option, the user may generate a structural interaction diagram by entering multiple axial thrust values. The thrust values may be entered in any order and LPile will sort the values from lowest to highest and remove duplicate entries before performing computations.

Example 5, discussed in Section 6.5, demonstrates how to compute nonlinear *EI* only and how to produce both unfactored and factored interaction diagrams.

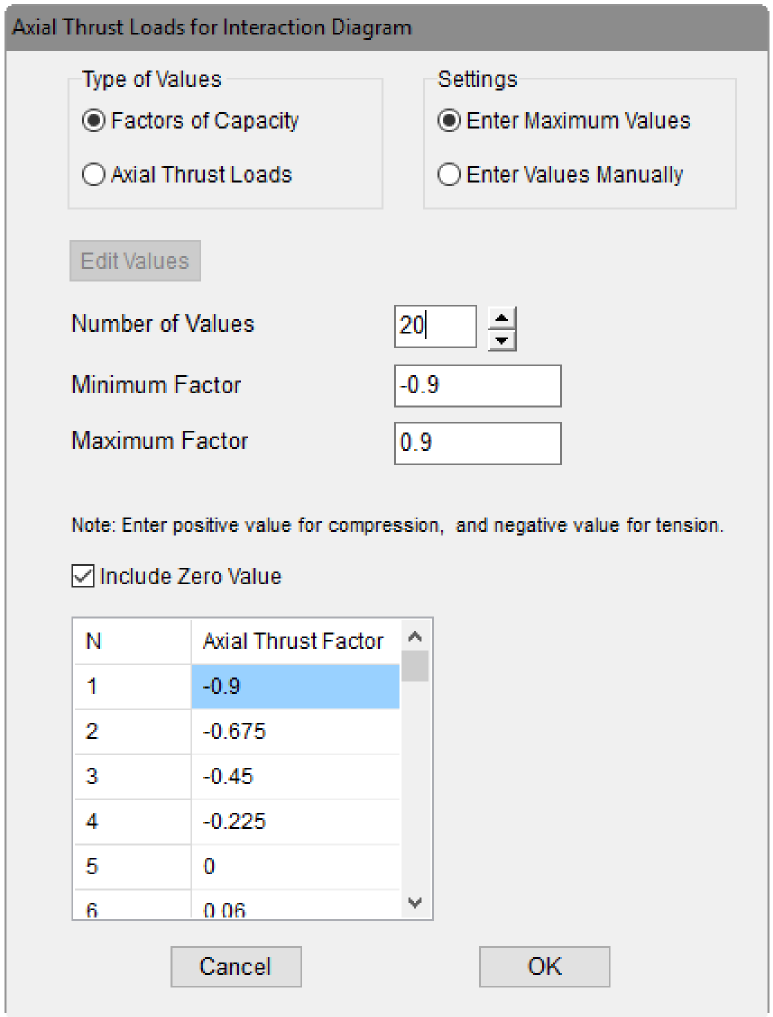


Figure 3.86 Dialog for Axial Thrust Loads for Interaction Diagram

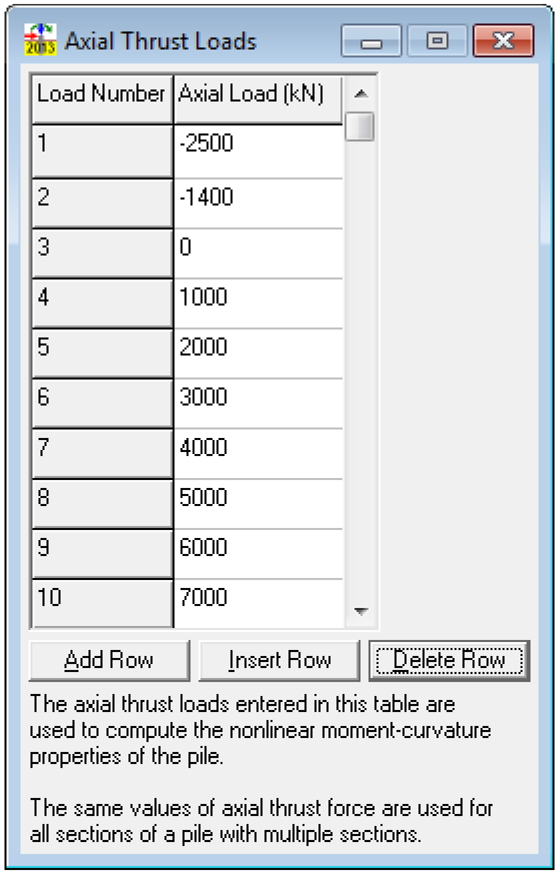


Figure 3.87 Dialog to Enter Axial Thrust Loads

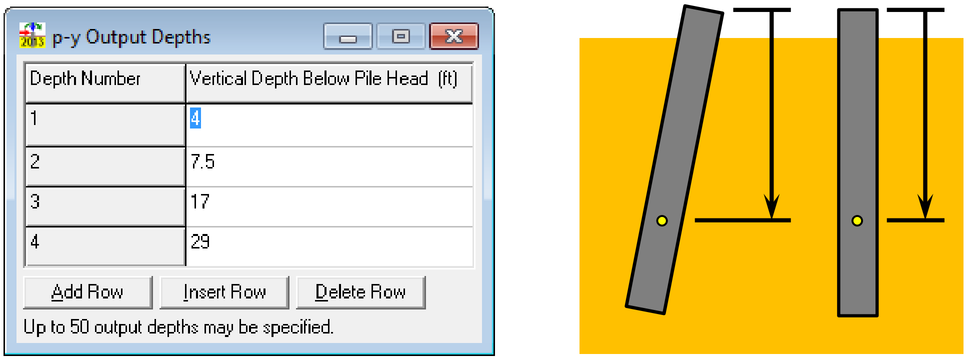
3.19 Output Depths of *p-y* Curves

The user may ask the program to plot internally-generated *p-y* curves at user-specified depths. Many of the various parameters needed to compute the output *p-y* curves are included in the output text file from LPile.

This input dialog is enabled if the user placed a check mark under Data > Options and Settings > Generate p-y Curves at User-Specified Depths. This input dialog is inactive under default conditions.

The depths can be entered in any order. LPile will sort the depth values from top to bottom and eliminate duplicate entries prior to performing computations. No *p-y* curves will be computed if an output depth is either above the ground surface or below the pile tip and a warning message will be provided by the program.

An example of the input dialog for Data > Output Depths of p-y Curves is shown in Figure 3.88. It should be noted that the depth is the vertical depth below the pile head, not the depth along the axis of the pile (important when analyzing batter piles).



(a) (b)

Figure 3.88 Output Depths of *p-y* Curves Below Pile Head, (a) Dialog for *p-y* Curve Output Depths, (b) Measurement of Vertical Depths

3.20 Import Soil Layers from EnCPT Soil File

The user may import the soil layering from a soil file generated by the separate EnCPT program. An example of the input dialog for Data > Import Soil Layers from EnCPT soil File is shown in Figure 3.89. It should be noted that when importing from EnCPT, the program will overwrite the current definition of soil layering.

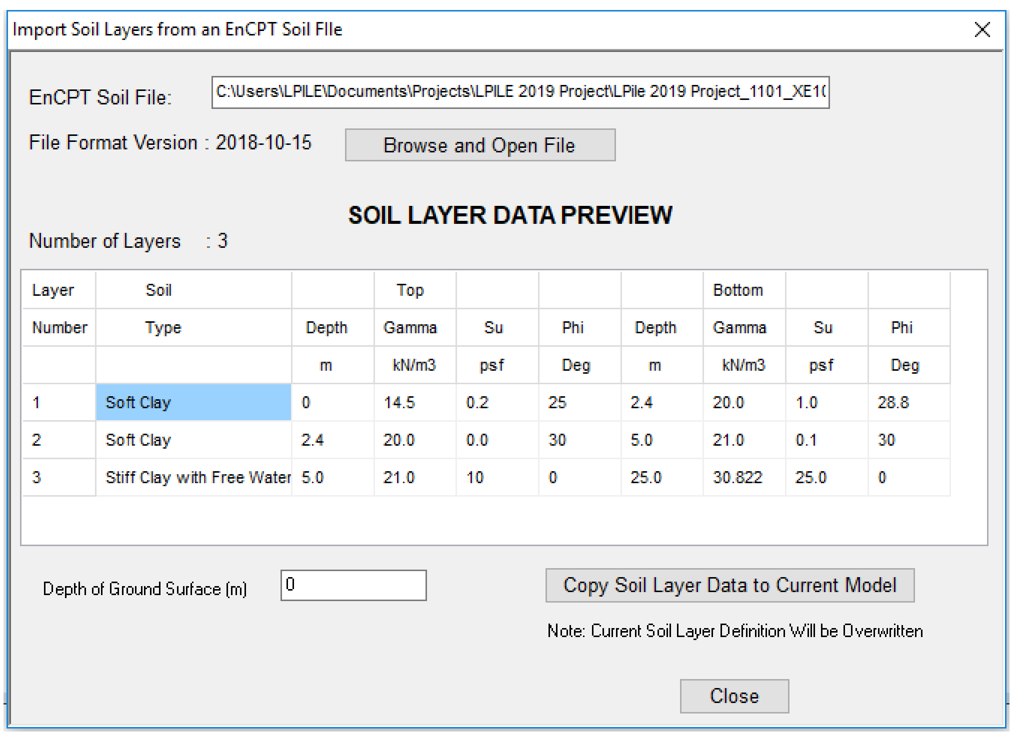


Figure 3.89 Sample Import Soil Layers from EnCPT Soil File.

3.21 Generate Report in MS-Word

The new Computation > Generate Report in MS Word menu allows to export a formatted report for Microsoft Word containing user-selected input, output tables and output graphics. A sample of this dialog box is in Figure 3.90.

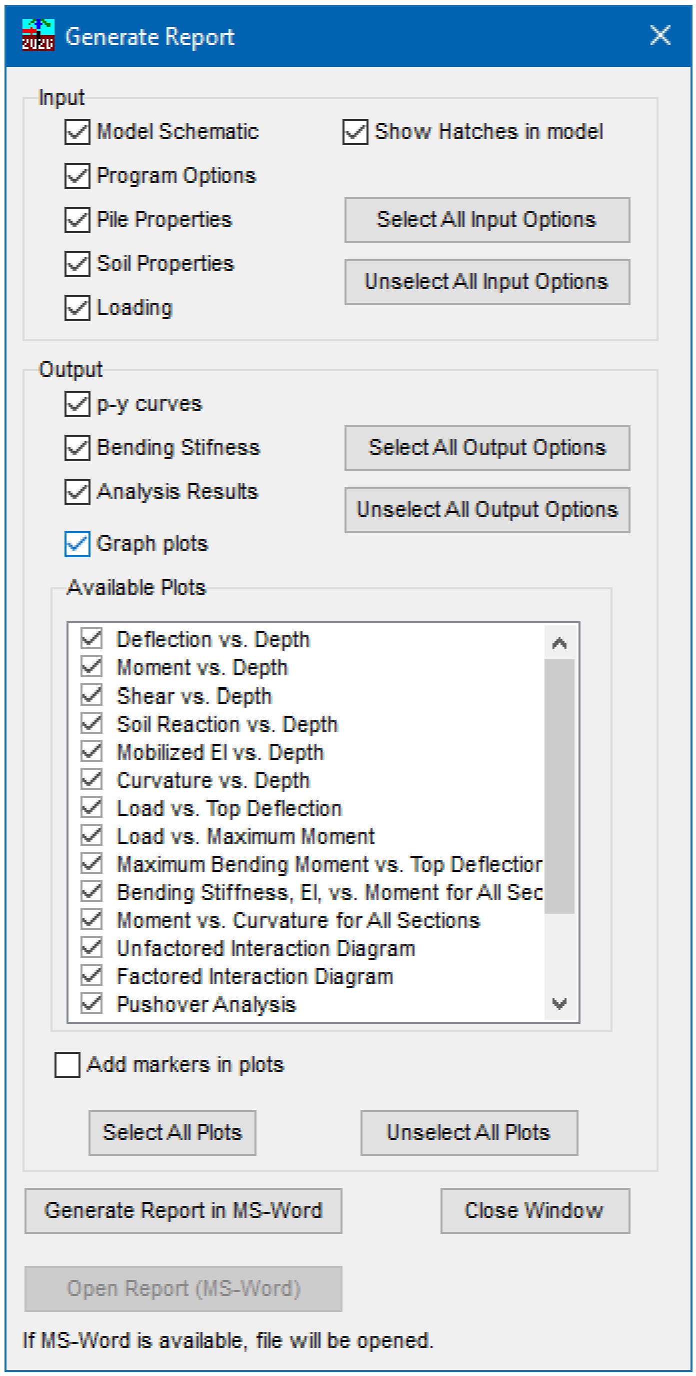


Figure 3.90 Sample Computation > Generate Report dialog box.

The Generate Report in MS-Word button allows the user to select a filename and directory where to save the new Microsoft Word file (by default it uses the same directory and filename as the

LPile model). The Open Report (WS-Word) button is enabled if a report is already saved (generated) but the user must have an installation of Microsoft Word to open the formatted report file.

CHAPTER 4. Display of Graphics

4.1 Introduction

The Graphics menu is used to display graphs of output data after a successful analysis. Options for the display of graphs under the Graphics menu are only enabled after a successful analysis has been made. Even after performing a successful analysis, some graphics may be disabled since the types of graphical output are controlled by the selected program options.

4.2 Types of Graphics

Two types of graphics are provided by LPile; fast graphics and presentation graphics. Fast graphics are graphs that can be displayed either from the Graphics menu or by clicking a button on the button bar. Fast graphics have limited features for modifying the graphs and their contents. Presentation charts are displayed using the Presentation Charts command from the Graphics menu or by pressing the  button on the button bar.

4.3 Graphics Mouse Commands

The following mouse commands are available within a graphic window:

Mouse Action	Event Description
Left click and drag down and right	Magnifies the area within the drag/release
Right click	Zoom out
Double click on legend entry	Turns the selected curve on or off

4.4 Graphics Buttons

The buttons shown in Figure 4.1 will display charts of the computed results when enabled after an analysis. If the program feature required to generate a graph is not activated, the corresponding button will not be enabled.

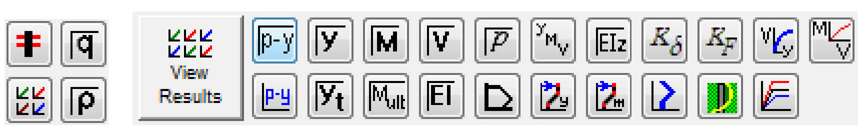


Figure 4.1 Speed Buttons for Graphics

4.5 Graphics Menu

A sample Graphics menu is shown in Figure 4.2. Graphs for which buttons exist on the button bar have the identical icon as shown in the Graphics menu entries. The various entries under the Graphics menu are explained in the following sections.

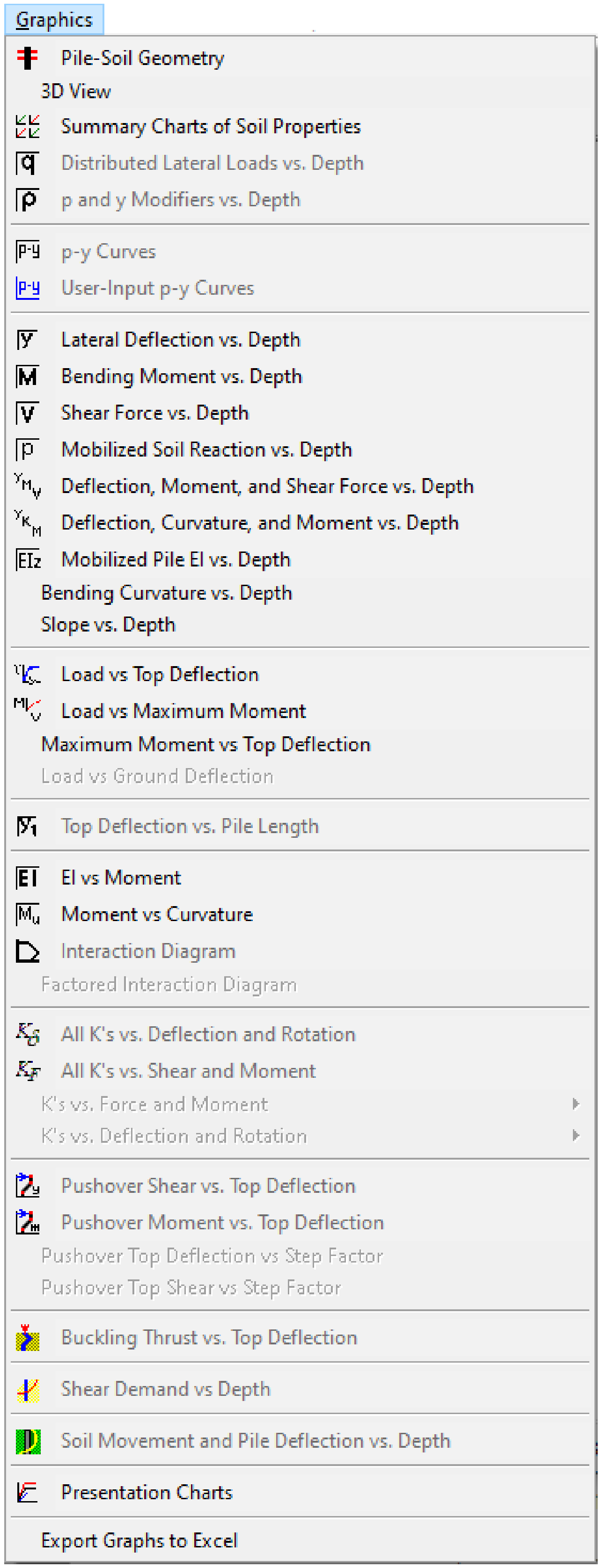


Figure 4.2 Sample Graphics Menu

4.6 Plot Menu

The Plot menu is visible only when a graphics is being displayed. A sample Plot menu is shown below.

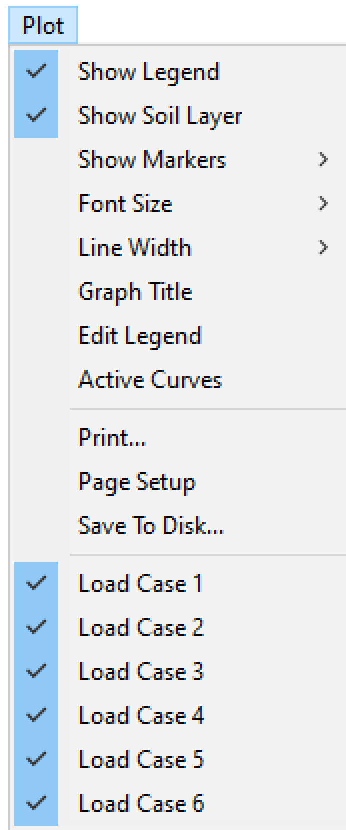


Figure 4.3 Sample Plot Menu

Show Legend turns the display of the graph's legend on or off.

Show Soil Layer turns the display of the soil profile on or off on graphs where applicable.

Show Markers can either turn the display of data point markers on or off or change the increment for the display of the markers. Markers can be displayed at every point, second point, fifth point, or tenth point.

Font Size is used to change the size of the fonts used on the graph.

Line Width is used to change the width of the graph lines.

Graph Title is used to enter a graph title and to specify the position of the graph title.

Edit Legend is used to edit the curve names displayed in the graph's legend.

Active Curves is used to turn the display of individual curves on or off.

Print is used to print the graph on the active printer.

Page Setup is used to change the active printer and to configure the page margins.

Save To Disk is used to save the currently displayed graph to disk as a bitmap file. The Graphics > Presentation Charts utility is used to save graph in other graphics file formats. See Section 4.9 for more information about the Presentation Charts utility.

4.7 Graphics of Input Data

4.7.1 Pile-Soil Geometry

This command in the Graphics menu displays a graphical representation of the side view of the modeled pile and soil layers. This command becomes active after data of Pile Properties, Soil Layers (Soil Weight and Soil Strength) have been entered under the Data menu, or when opening previously-executed data files. The angles of ground slope and pile batter and the proportions of the pile sections are accurately portrayed in this view.

4.7.2 3D View

This command in the Graphics menu displays a 3D graphical representation of the modeled pile and soil layers. The angles of ground slope and pile batter and the proportions of the pile sections are accurately portrayed in this view. The user has options to pan, zoom and rotate the view. While this view is active the Show 3DView menu will be visible that allows the user to hide parts of the model or show other features like axes, boundary conditions and distributed loading.

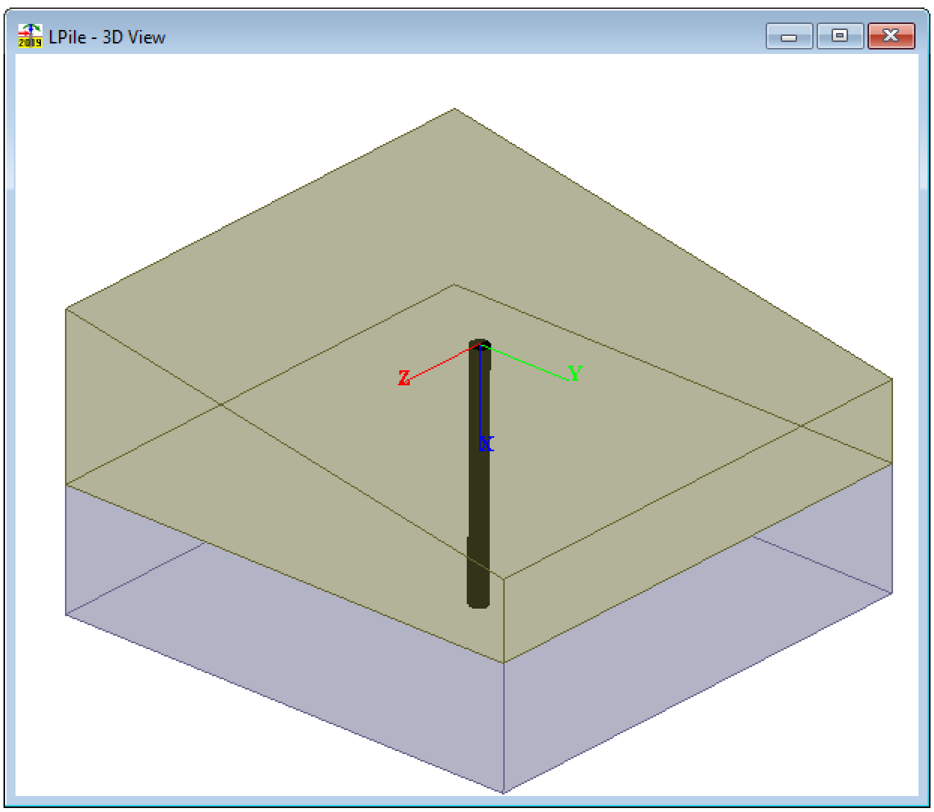


Figure 4.4 Sample 3D View

4.7.3 Summary Charts of Soil Properties

This Graphics menu command displays summary charts of soil properties. The number of charts varies from four to eight charts, depending on the soil layer types contained in the soil profile. An example of the Summary Charts of Soil Properties is shown in Figure 4.5.

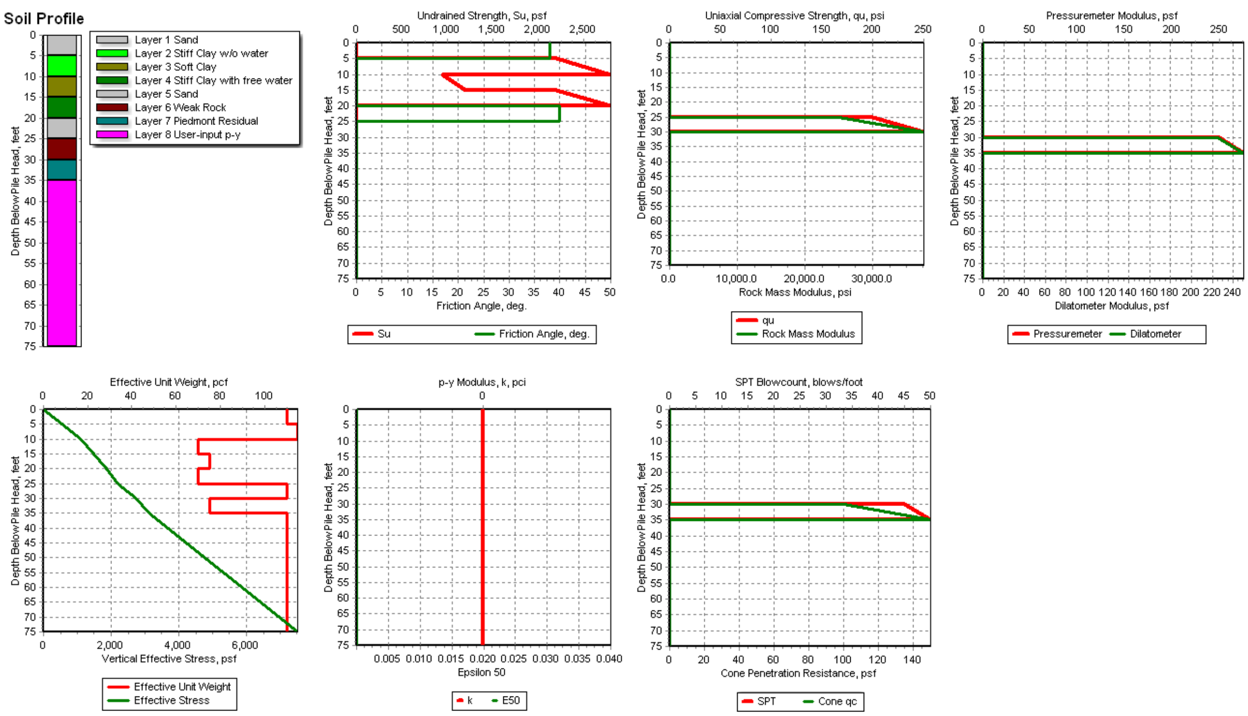


Figure 4.5 Example of Summary Graphs of Soil Properties

4.7.4 Distributed Lateral Loads vs. Depth

This menu is only enabled when users selected the Data > Program Options and Settings > Use Loading by Single Distributed Load Profile along with Data > Distributed Lateral Loading. This Graphics menu command displays charts of distributed lateral loads versus depth for both conventional analysis and LRFD analysis modes of computation.

4.7.5 *p* and *y* Modifiers versus Depth

This menu is only enabled when users selected the Data > Program Options and Settings > Use Modification Factors for p-y Curves along with Data > Modification Factors for p-y Curves. This Graphics menu command displays charts of *p* and *y* modifiers versus depth and the ratio of the *p* and *y* modifiers versus depth. In computations, the ratio of the *p* and *y* modifiers is used to adjust the *p-y* curves when computing the effective soil modulus. Thus, if the ratio is equal to the default ratio of 1, the *p-y* curves are not modified in the computations.

4.7.6 *p-y* Curves

This menu is only enabled when users selected the Data > Program Options and Settings > Generate p-y Curves at User-Specified Depths along with Data > Output Depths of p-y Curves.

Notice that the "*p*" values are in units of force per unit depth of pile and the "*y*" values are in units of lateral movement of the pile. Some *p-y* curves at ground surface may be all zeros and not display correctly so users may choose to print at some depth below ground surface.

4.7.7 User-Input *p-y* Curves

This Graphics menu command displays charts of any user-input *p-y* curves entered as data. If no curves are input, this Graphics command will not be enabled.

The user-input *p-y* curves displayed by this graphics command are plotted using the input data for the curves at the top and bottom of the soil layer. The curves displayed with this graphics command are not interpolated with depth.

4.8 Graphics of Computational Results

4.8.1 View Results

The View Results speed button displays summary charts of the principal results from the last computational model. The type and number of charts displayed in the View Results window depends on the various program options that were selected for the model. The minimum number of charts displayed is three and the maximum number of charts displayed is eight. An example of the View Results window is shown in Figure 4.6.

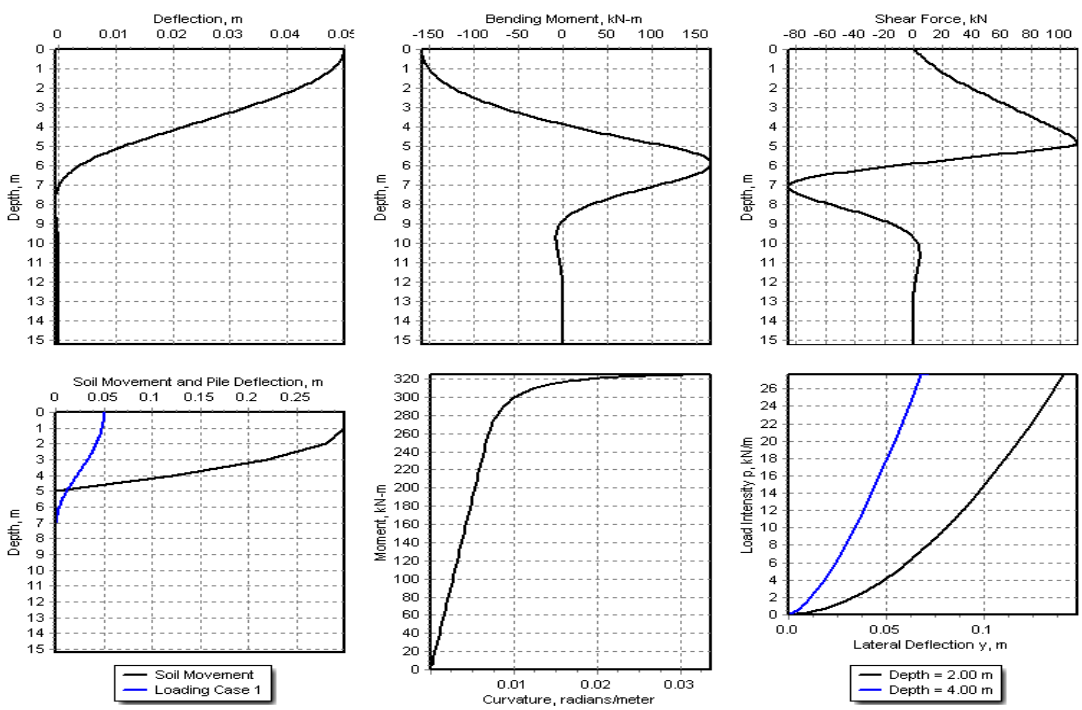


Figure 4.6 Example of View Results Window

4.8.2 Lateral Deflection versus Depth

This Graphics menu command displays a graph of lateral deflection versus depth for the modeled pile. This curve is automatically generated in all analytical runs for a laterally loaded pile. The number of points on the deflection curve is equal to the selected number of pile increments. Several curves may be contained in this graphics if the user selects to input several load cases. For models with multiple load cases, this plot only displays the results for the first twenty loads. To see the other results, the user must select the Plot > Active Curves menu.

4.8.3 Bending Moment versus Depth

This Graphics menu command displays a graph of the bending moment demand versus depth along the pile. This curve is automatically generated in all analytical runs for a laterally loaded pile. The number of points on the moment curve is equal to the selected number of pile increments. Several curves may be contained in this graphics if the user selects to input several load cases. For models with multiple load cases, this plot only displays the results for the first twenty loads. To see the other results, the user must select the Plot > Active Curves menu.

4.8.4 Shear Force versus Depth

This Graphics menu command displays a graph of the shear force demand versus depth along the pile. This curve is automatically generated in all analytical runs for a laterally loaded pile. The number of points on the shear curve is equal to the selected number of pile increments. Several curves may be contained in this graphics if the user selects to input several load cases. For models with multiple load cases, this plot only displays the results for the first twenty loads. To see the other results, the user must select the Plot > Active Curves menu.

4.8.5 Mobilized Soil Reaction versus Depth

This Graphics menu command displays a graph of the lateral soil reactions (‘*p*’ values from *p-y* curves) that are mobilized at each depth along the pile. This curve is automatically generated in all analytical runs for a laterally loaded pile. The number of points on the soil-reaction curve is equal to the selected number of pile increments. Several curves may be contained in this graphics if the user selects to input several load cases. For models with multiple load cases, this plot only displays the results for the first twenty loads. To see the other results, the user must select the Plot > Active Curves menu.

4.8.6 Deflection, Moment, and Shear Force versus Depth

This Graphics menu command displays three side-by-side graphs of pile deflection, bending moment, and shear force versus depth along the pile. This graphical display can be shown for all analytical runs for a laterally loaded pile. The scaling for the depth axis is the same for all three graphs and allows for comparison of pile deflection, bending moment and shear force values versus depth along the pile.

4.8.7 Deflection, Curvature, and Moment versus Depth

This Graphics menu command displays three side-by-side graphs of pile deflection, bending curvature, and bending moment versus depth along the pile. This graphical display can be shown for all analytical runs for a laterally loaded pile. The scaling for the depth axis is the same for all three graphs and allows for comparison of pile deflection, bending curvature, and bending moment values versus depth along the pile. This graph may be useful in analyses of pile response due to loading by lateral spread of soil after seismic events.

4.8.8 Mobilized Pile *EI* versus Depth

This Graphics menu command is available when the pile has a nonlinear moment-curvature relationship. This chart shows the values of mobilized flexural stiffness (*EI*) along the length of the pile. This chart is useful to display the sections with either cracked-section *EI* or where plastic hinges may develop.

4.8.9 Slope versus Depth

This Graphics menu shows the value of the slope (in radians) along the length of the pile.

4.8.10 Load versus Top Deflection

This Graphics menu command is enabled if the user specifies two or more load cases in the input data. The specified load cases must have varying lateral loads with or without changes in applied moments or applied axial loads. The user may select this command to display a graph of applied lateral loads versus estimated pile-top deflections.

4.8.11 Load versus Max Moment

This Graphics menu command is enabled if the user specifies two or more load cases in the input data. The specified load cases must have varying lateral loads with or without changes in applied moments or applied axial loads. The user may select this command to display a graph of applied lateral load versus estimated maximum bending moments along the pile length.

4.8.12 Load versus Ground Deflection

This Graphics menu command is enabled if the user specifies two or more load cases in the input data and if the pile head has a stickup length above ground. The specified load cases must have varying lateral loads with or without changes in applied moments or applied axial loads. The user may select this command to display a graph of applied lateral loads versus estimated pile deflections at ground level.

4.8.13 Top Deflection versus Pile Length

This Graphics menu command is enabled if the user selects Yes under Compute Top y vs L? (Generate Pile Length versus Top Deflection) in the Data > Pile Head Loading menu for a load case for conventional loading. The user may select this command to display a graph of pile length versus pile-head deflection for the load cases evaluated with this option.

4.8.14 EI versus Moment

This Graphics menu command is available when the pile has a nonlinear moment-curvature relationship. The user may select this command to display a graph of bending stiffness of the pile section versus bending moment. Values of bending stiffness shown in these curves are used internally in each finite increment of pile analysis when the user selects the analysis of pile response with nonlinear EI. The number of curves depends on the number of axial loads specified for section analysis.

4.8.15 Moment versus Curvature

This Graphics menu command is enabled whenever the nonlinear bending is evaluated for a pile section. The user may select this command to display a graph of bending moment versus curvature of the pile section. These curves are helpful to find the ultimate bending moment of the modeled cross section. The number of curves depends on the number of axial loads used for section analysis or the number of axial thrust forces defined by the pile-head loading conditions.

4.8.16 Interaction Diagram

This Graphics menu command is available when the user places a check mark under Data > Options and Settings > Include Interaction Diagram or under Data > Options and Settings > Nonlinear EI Only Mode (Section 3.5.1) and enters the necessary inputs under Axial Thrust Loads for Interaction Diagram (Section 3.18).

This command displays an unfactored interaction diagram (ultimate bending moment versus axial load) of the modeled pile cross sections. These curves are helpful to find the ultimate bending moment for several axial load cases in each pile cross section. The number of curves depends on the number of pile sections that are defined in the model.

4.8.16.1 Factored Interaction Diagram

The interaction diagrams (ultimate bending moment versus axial load) of the modeled pile cross sections described in the previous section (Section 4.8.16) are here provided after application of strength reduction factors. LPile produces graphs with three reduction factors (ϕ factors) of 0.65, 0.75 and 0.90 for the nominal interaction diagram for each pile section in the model.

Alternatively, for reinforced concrete sections (Data > Pile Properties > Section Type (tab) > Round Concrete Shaft), when the user places a check mark for Estimate Resistance Factors and Shear Capacity, this Factored Interaction Diagram will display an interaction diagram that follows the resistance factors recommended by the ACI318-2008 building code. A sample output is provided in Figure 4.7.

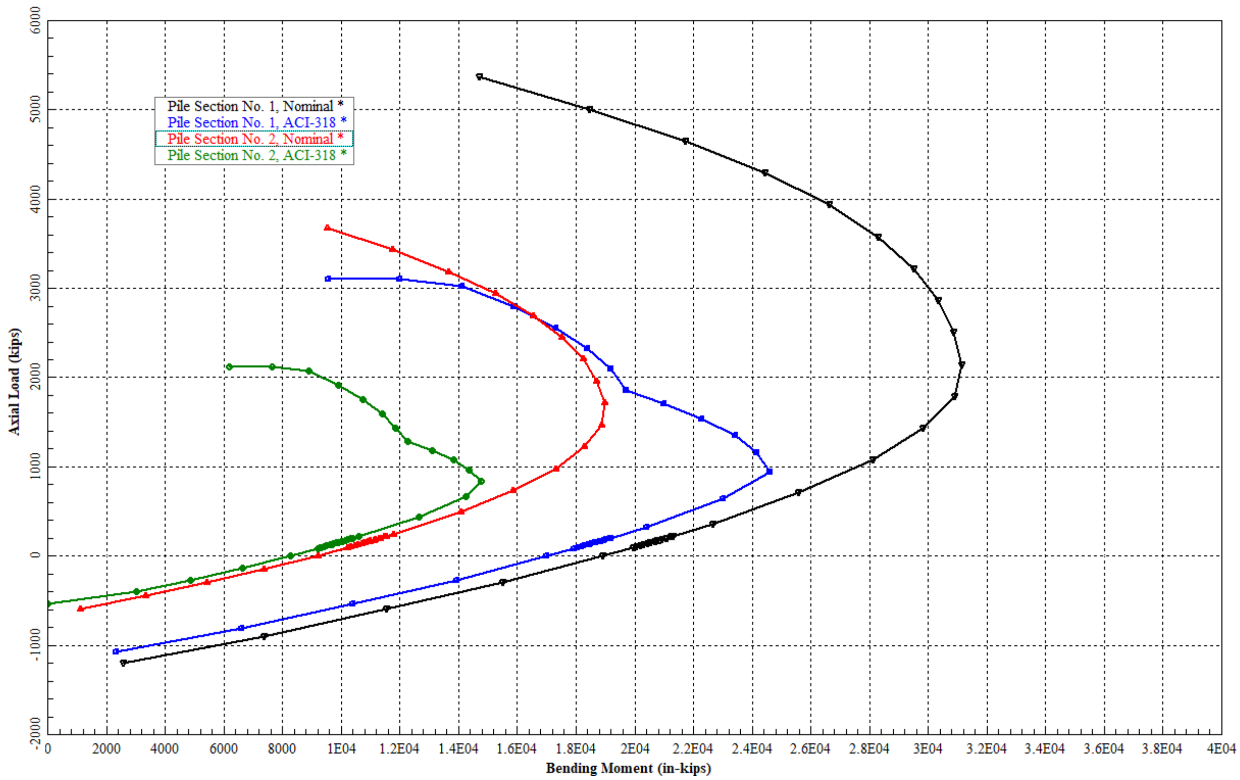


Figure 4.7 Sample Factored Interaction Diagram from ACI318 Code

4.8.16.2 Demand Interaction Diagram

The same factored interaction diagrams (of factored ultimate bending moment versus axial load) of the modeled pile cross sections described in the previous section (Section 4.8.16.1) are here provided along with plots of the maximum demands (of maximum bending moment for each applied axial load) on each pile type in the model. A sample output is provided in Figure 4.8

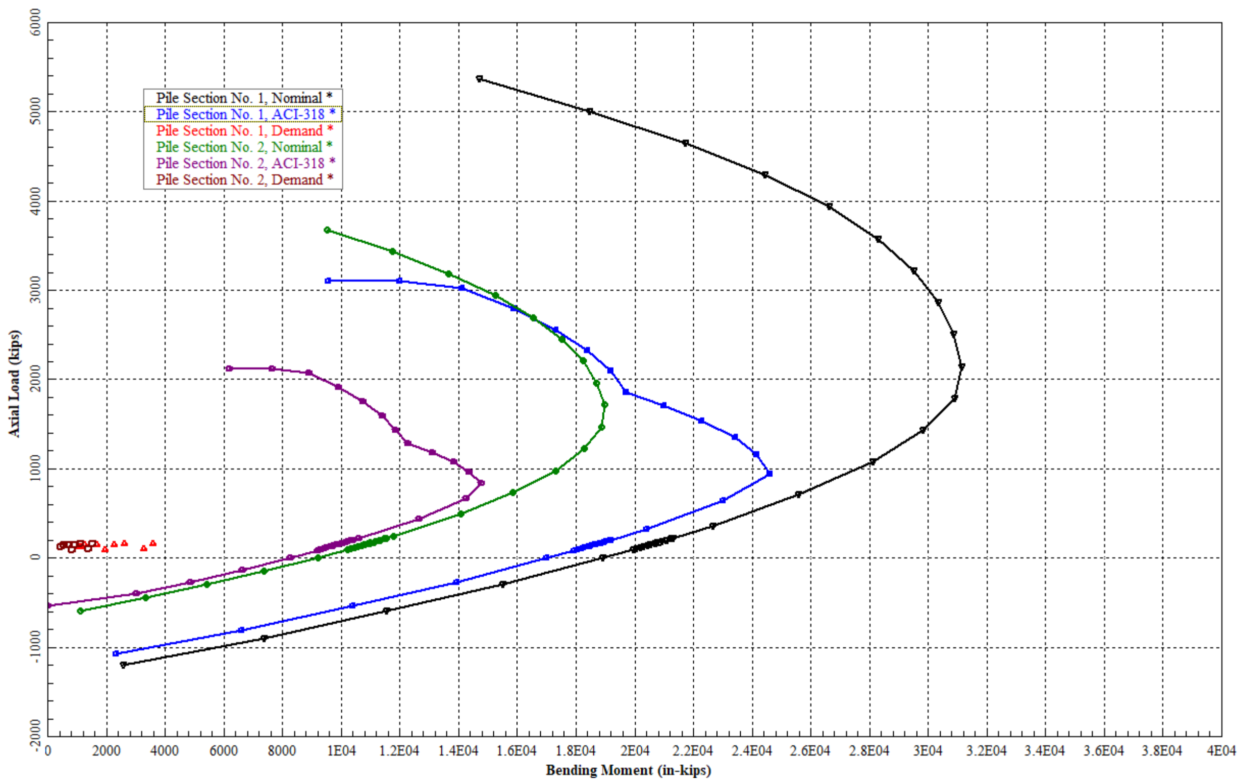


Figure 4.8 Sample Demand Interaction Diagram

4.8.17 All *K*'s versus Deflection and Rotation

This Graphics menu command displays six charts simultaneously of K_{22}, K_{23}, K_{32}, K_{33} versus pile-head displacement and rotation plus pile-head reactions and displacements for free-head and fixed-head pile fixity conditions.

4.8.18 All *K*'s versus Shear and Moment

The Graphics menu command displays six charts simultaneously of K_{22}, K_{23}, K_{32}, K_{33} versus pile-head shear and moment plus pile-head reactions and displacements for free-head and fixed-head pile fixity conditions.

4.8.19 Individual *K*'s versus Force and Moment

This Graphics menu command opens a submenu for displaying the individual curves of pile-head stiffnesses versus force and moments. The submenu is shown in Figure 4.9.

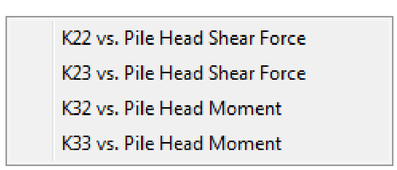


Figure 4.9 Sub-menu for Pile-head Stiffnesses versus Pile-head Force and Moment

4.8.19.1 K_{22} versus Pile-head Shear Force

This Graphics menu command is enabled when the Generate Foundations Stiffness option is selected. When enabled, the selection of this command will show a curve of the K_{22} (shear force/deflection) component of a 6×6 foundation stiffness matrix. The user should refer to Section 3.14.5 for more information about the feature for computing pile-head stiffnesses.

4.8.19.2 K_{23} versus Pile-head Shear Force

This Graphics menu command is enabled when the Generate Foundations Stiffness option is selected. When enabled, the selection of this command will show a curve of the K_{23} (shear force/rotation) component of a 6×6 foundation stiffness matrix. The user should refer to Section 3.14.5 for more information about the feature for computing pile-head stiffnesses.

4.8.19.3 K_{32} versus Pile-head Moment

This Graphics menu command is enabled when the Generate Foundations Stiffness option is selected. When enabled, the selection of this command will show a curve of the K_{32} (moment/deflection) component of a 6×6 foundation stiffness matrix. The user should refer to Section 3.14.5 for more information about the feature for computing pile-head stiffnesses.

4.8.19.4 K_{33} versus Pile-head Moment

This Graphics menu command is enabled when the Generate Foundations Stiffness option is selected. When enabled, the selection of this command will show a curve of the K_{33} (moment/rotation) component of a 6×6 foundation stiffness matrix. The user should refer to Section 3.14.5 for more information about the feature for computing pile-head stiffnesses.

4.8.20 Individual *K*'s versus Pile-head Deflection and Rotation

This Graphics menu command opens a submenu for displaying the individual curves of pile-head stiffnesses versus pile-head deflection and rotation. The submenu is shown in Figure 4.10.

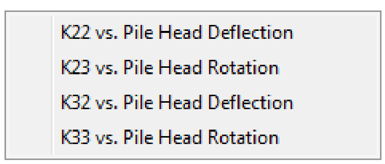


Figure 4.10 Submenu for Pile-head Stiffnesses versus Deflection and Rotation

4.8.20.1 K_{22} versus Pile-head Deflection

This Graphics menu command is enabled when the Generate Foundations Stiffness option is selected. When enabled, the selection of this command will show a curve of the K_{22} (shear force/deflection) versus pile top deflection.

4.8.20.2 K_{23} versus Pile-head Rotation

This Graphics menu command is enabled when the Generate Foundations Stiffness option is selected. When enabled, the selection of this command will show a curve of the K_{23} (shear force/rotation) versus pile top rotation.

4.8.20.3 K_{32} versus Pile-head Deflection

This Graphics menu command is enabled when the Generate Foundations Stiffness option is selected. When enabled, the selection of this command will show a curve of the K_{32} (moment/deflection) versus pile top deflection.

4.8.20.4 K_{33} versus Pile-head Rotation

This Graphics menu command is enabled when the Generate Foundations Stiffness option is selected. When enabled, the selection of this command will show a curve of the K_{33} (moment/rotation) versus pile top rotation.

4.8.21 Pushover Shear Force versus Top Deflection

This Graphics menu is available only if the user placed a check mark under Data > Options and Settings > Compute Push-over Analysis and performed a push-over analysis. This graph may contain either one or two curves depending on the pile-head fixity condition selected in the Data > Controls for Computation of Pushover Analysis.

This graph shows the pile-head shear force developed as a function of pile-head deflection. For piles with nonlinear bending, it may be possible to see the point at which a plastic hinge develops, but this point may be more easily seen in the graph of pushover moment versus top deflection, discussed subsequently.

For pile sections modeled as Equivalent ElastoPlastic Moment Curvature (Section 3.6.19.2), if plastic hinges are developed the LPile program will indicate the formation of hinges in the Graphics > Pushover Shear vs. Top Deflection and in the Graphics > Pushover Moment vs. Top Deflection plots.

4.8.22 Pushover Moment versus Top Deflection

This Graphics menu is available only if the user placed a check mark under Data > Options and Settings > Compute Push-over Analysis and performed a push-over analysis. This graph may contain either one or two curves depending on the pile-head fixity condition selected in the Data > Controls for Computation of Pushover Analysis.

The moment value displayed in the graph is the maximum moment developed in the pile. If the pile has a single section with nonlinear bending properties, it is possible to see at which value of top deflection the moment capacity is reached by where the curve becomes horizontal. If the pile has more than one section with different moment capacities, it may not be possible to determine when the moment capacity is reached in sections with lower moment capacities.

For pile sections modeled as Equivalent ElastoPlastic Moment Curvature (Section 3.6.19.2), if plastic hinges are developed the LPile program will indicate the formation of hinges in the Graphics > Pushover Shear vs. Top Deflection and in the Graphics > Pushover Moment vs. Top Deflection plots.

4.8.23 Pile Buckling Thrust versus Top Deflection

This Graphics menu is available only if the user placed a check mark under Data > Options and Settings > Compute Pile Buckling Analysis and performed a buckling analysis. The display of this graph depends on the parameters entered in the Data > Controls for Computation of Pile Buckling Analysis.

LPile can graph both the pile buckling thrust versus computed pile top deflection, the fitted hyperbolic curve, and the estimated pile buckling capacity determined from the fitted hyperbolic curve. A typical graph for pile buckling analysis is shown in Figure 3.73.

4.8.24 Soil Movement and Deflection versus Depth

This Graphics menu is available only if the user placed a check mark under Data > Options and Settings > Use Loading by Single Soil Movement Profile or Data > Options and Settings > Use Separate Soil Movement Profiles for each Load Case and entered the parameters under Data > Lateral Soil Movements. This graph displays a combined chart of lateral pile deflection and user-inputted soil movements versus depth.

4.9 Presentation Charts

This Graphics menu command opens a graphing tool to customize the various aspects of a presentation chart, such as font type, size, and style, line colors, styles, and widths, data point markers, legend text and font, and axis and grid scaling. A detailed description of each function and options are given in the associated Help file for the Presentation Charts tool.

The Presentation Charting utility can generate up to 28 different types of graphs. The type of chart is selected from the drop-down combo box above the chart. Note that only the charts capable of being drawn are offered in the drop-down combo box.

If desired by the user, two graphs can be displayed side-by-side. While both graphs may be edited and exported, chart templates can be saved and applied to only the left chart.

4.9.1 Saving and Applying Presentation Chart Templates

After the left chart has been edited for export, a chart template with these chart features and font styles may be saved for later application for each type of chart (i.e. use separate templates for graphs of *p-y* curves, lateral deflection vs. depth, moment vs. depth, etc.). The chart template files are saved in the same folder as the other data and output files for LPile. The chart template files will have the filename extension “tee.”

The chart settings saved in the chart template include the axis scaling settings. If a chart template contains fixed axis scaling settings, the chart may not display the complete range of results after it has been applied and require some editing to restore the display of the full range of results. Thus, it is recommended that the chart axis scaling remain in the automatic mode prior to saving the chart template.

4.9.2 Exporting Presentation Charts

It is possible to export and save the presentation charts in several graphics formats. In addition, it is possible to copy graphs to the Windows clipboard for pasting into word processing or graphical presentation programs such as Microsoft Word and Microsoft PowerPoint. Most users find using the Enhanced Windows Metafile graphics format to be most flexible in use, highest in quality, and to result in the smallest word processing file size.

4.10 3D-View Results

This Graphics menu command opens the 3D View Window which display a 3D representation of the model being analyzed. This option allows to display graphically some results as explained below.

4.10.1 Deformed Shape

The program will open the Deformed Shape Window which allows the user to select the load case to display. The user can also enter the magnification factor to be applied to the resulted deflections.

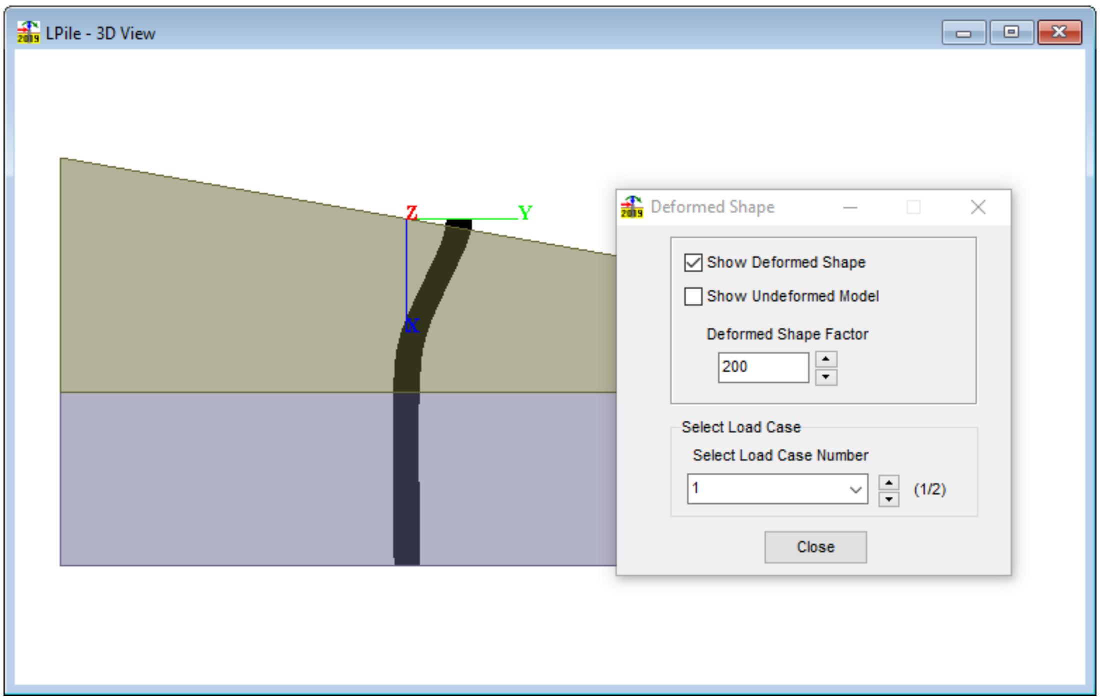


Figure 4.11 Example of Deformed Shape Option

4.10.2 Contour Plot

The program will open the Contour Plot Window which allows the user to select the load case and the type of result to display. The user can also change the maximum and minimum values of the contour if desired.

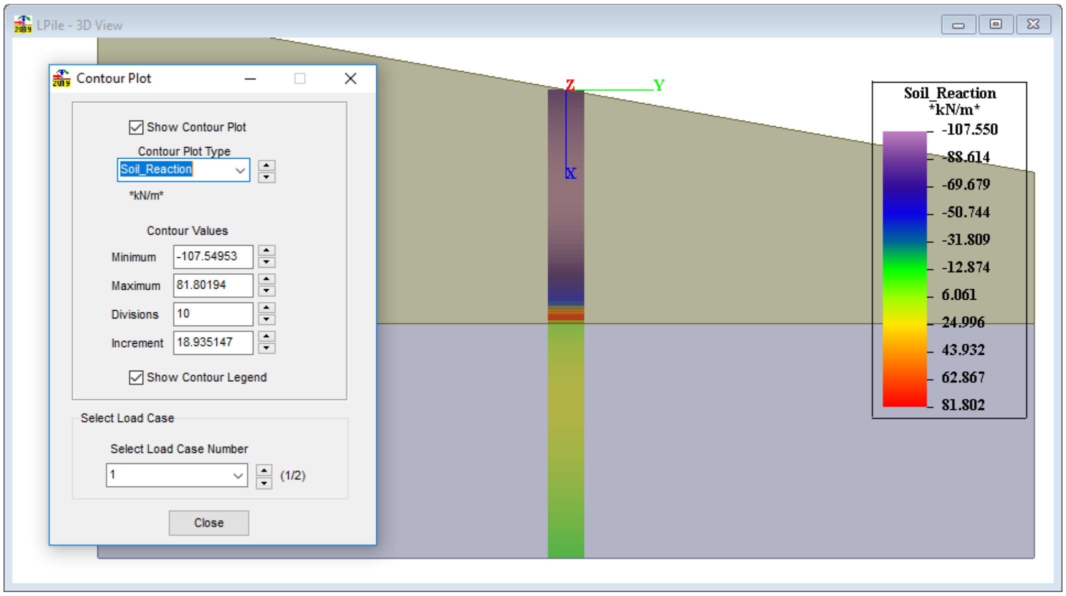


Figure 4.12 Example of Contour Plot Option

4.10.3 Pile Diagrams

The program will open the Pile Diagrams Window which allows the user to select the load case and the type of result to display. The user can also scale the values to display and select to display the maximum values.

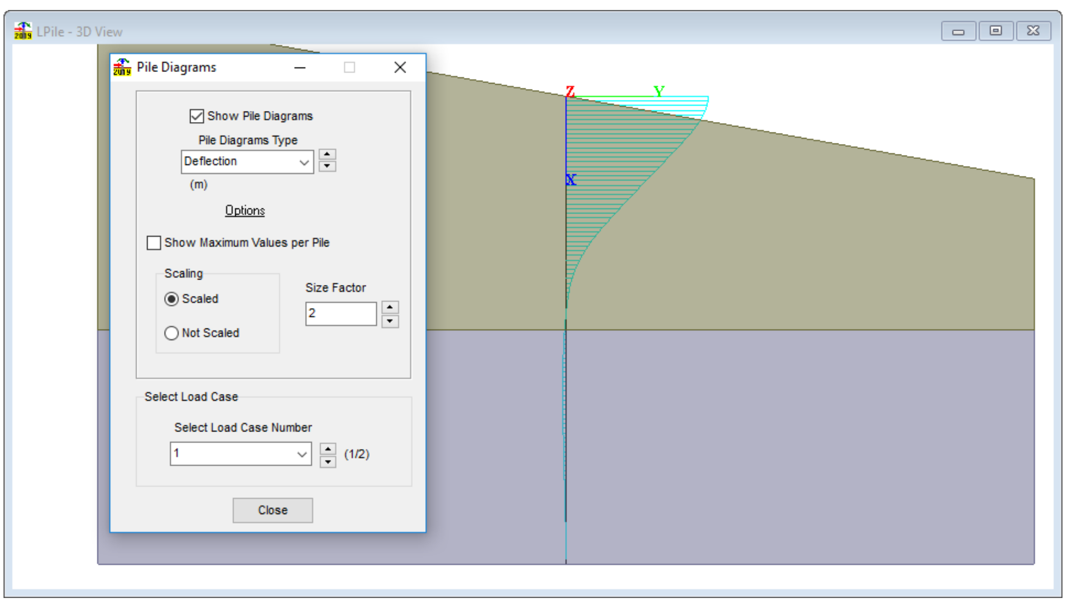


Figure 4.13 Example of Pile Diagrams Option

4.10.4 Pile Lateral Results

The program will open the Pile Lateral Results Window which allows the user to select the node of the model to show the numerical results. The user can also select la load case desired to display the values.

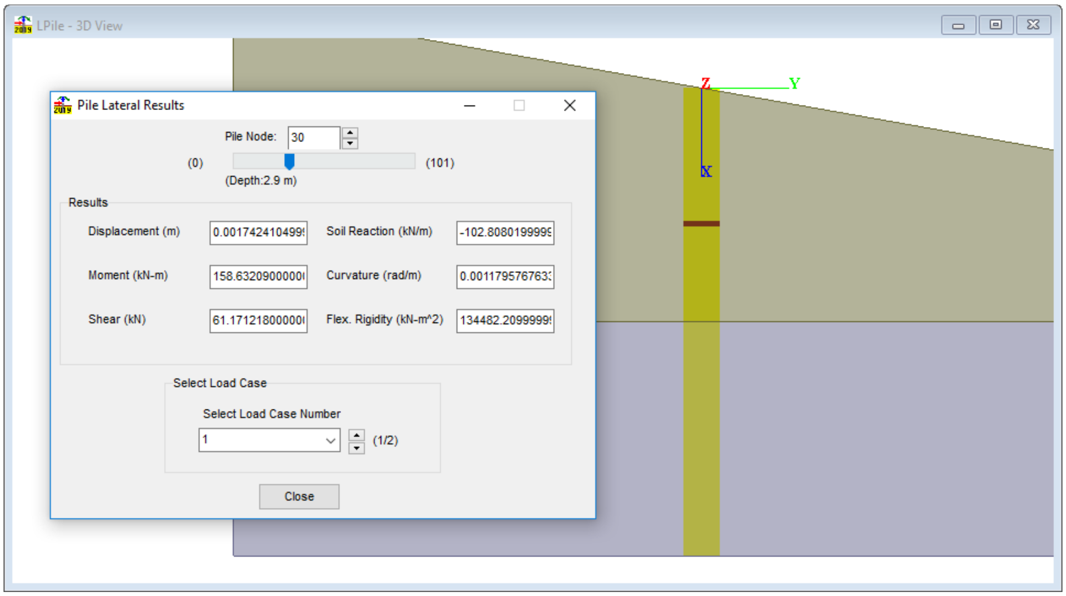


Figure 4.14 Example of Pile Lateral Results Option

4.11 Export Graphs to Excel

This Graphics menu allows the user to export the graphs to an excel file. After selecting this option, the Export to Excel Window will appear (similar to Figure 4.15, precise content will change based on the model parameters selected by the user). In this dialog box, select the graphs desired to export and then click on the Generate Excel File button. Please note that the user needs to save the excel file afterwards.

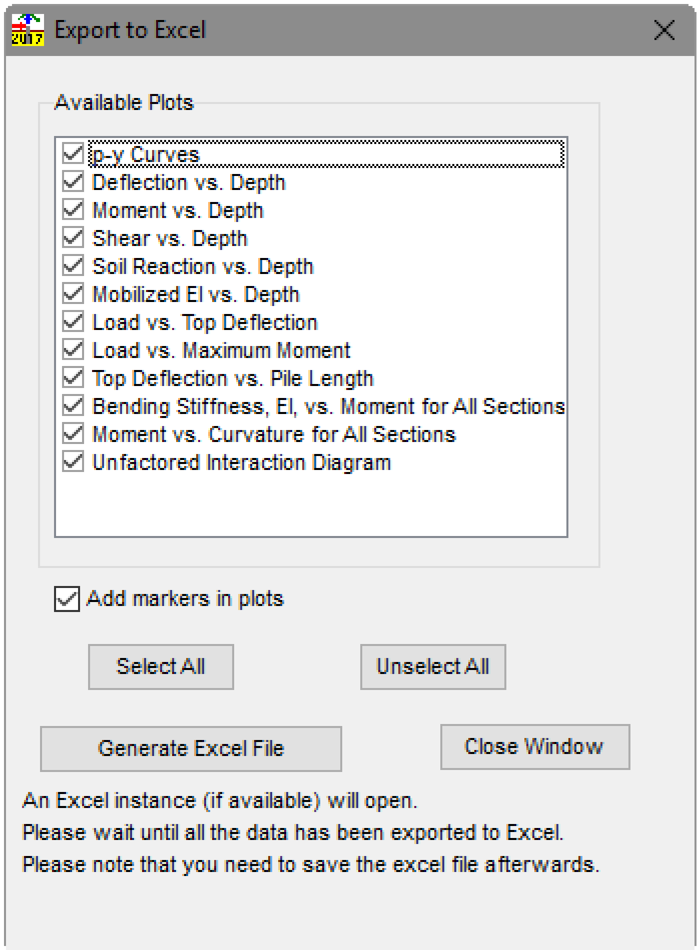


Figure 4.15 Sample Export to Excel Window

CHAPTER 5. Tools Menu

The Tools Menu is activated from the Main Menu bar of the program. The Tools Menu has six entries. The functions of these entries are discussed in the following sections of this chapter.

The Tools Menu has the six entries shown in Figure 5.1.

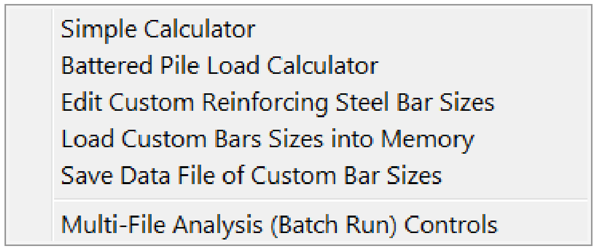


Figure 5.1 Tools Menu

5.1 Simple Calculator

The first entry of the Tools Menu provides a simple calculator for the user's convenience. When active, the simple calculator appears as shown in Figure 5.2.

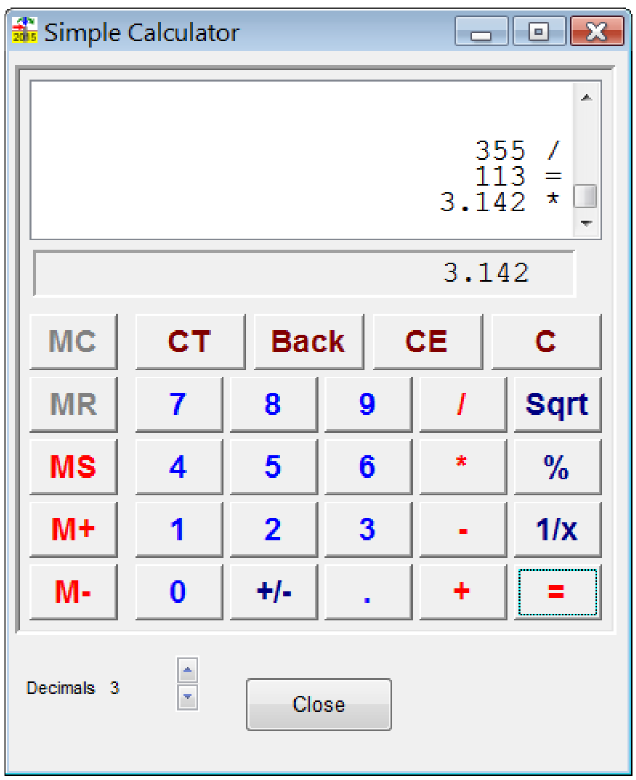


Figure 5.2 Simple Calculator

The calculator has two display areas. A "tape" display is shown on top. The tape display shows the sequence of calculator operations. The answer display is shown below the tape display.

The buttons on the top of the calculator buttons have the following functions:

CT Clears the content of the tape display,
Back Deletes the last digit entered (a backspace key),

CE Clears the last full number entered into the calculator, and
C Clears all the numbers entered into the calculator.

The function buttons on the right-hand side of the calculator have the following functions:

Sqrt Computes the square root of the current number,
% Divides the current number by 100 to express the number as a percentage, and
1/x Computes the reciprocal of the current number.

The buttons on the left-hand side of the calculator control the memory functions. The memory functions are:

MS Store a number to memory,
M+ Add the current number to the number stored in memory,
M– Subtract the current number from the number stored in memory,
MC Clear (erase) the number stored in memory, and
MR Recall the number stored in memory.

Note that the MC and MR buttons are enabled only when a number is stored in memory.

5.2 Battered Pile Load Calculator

The second entry of the Tools Menu provides a special-purpose calculator to compute axial and transverse forces acting on battered piles from horizontal and vertical loadings.

This calculator is intended only for use with conventional analyses in which lateral loading is applied perpendicular to the axis of the unbent pile and axial loads are applied along the axis of the pile.

This calculator obtains the batter angle of the pile from the input value for pile batter and the values of horizontal and vertical loading from the input fields of the calculator.

Values of transverse shear force and axial force for the specified batter angle are computed when the user presses the button to Compute and Chart Rotated Forces. The Chart that is generated shows how the rotated forces vary over batter angles ranging from –45 to +45 degrees. The symbols on the curves indicate the values for the specified batter angle.

The computation performed by the calculator is

$$\begin{Bmatrix} V_T \\ P_A \end{Bmatrix} = \begin{bmatrix} \cos\beta & \sin\beta \\ -\sin\beta & \cos\beta \end{bmatrix} \begin{Bmatrix} V_H \\ P_v \end{Bmatrix}$$

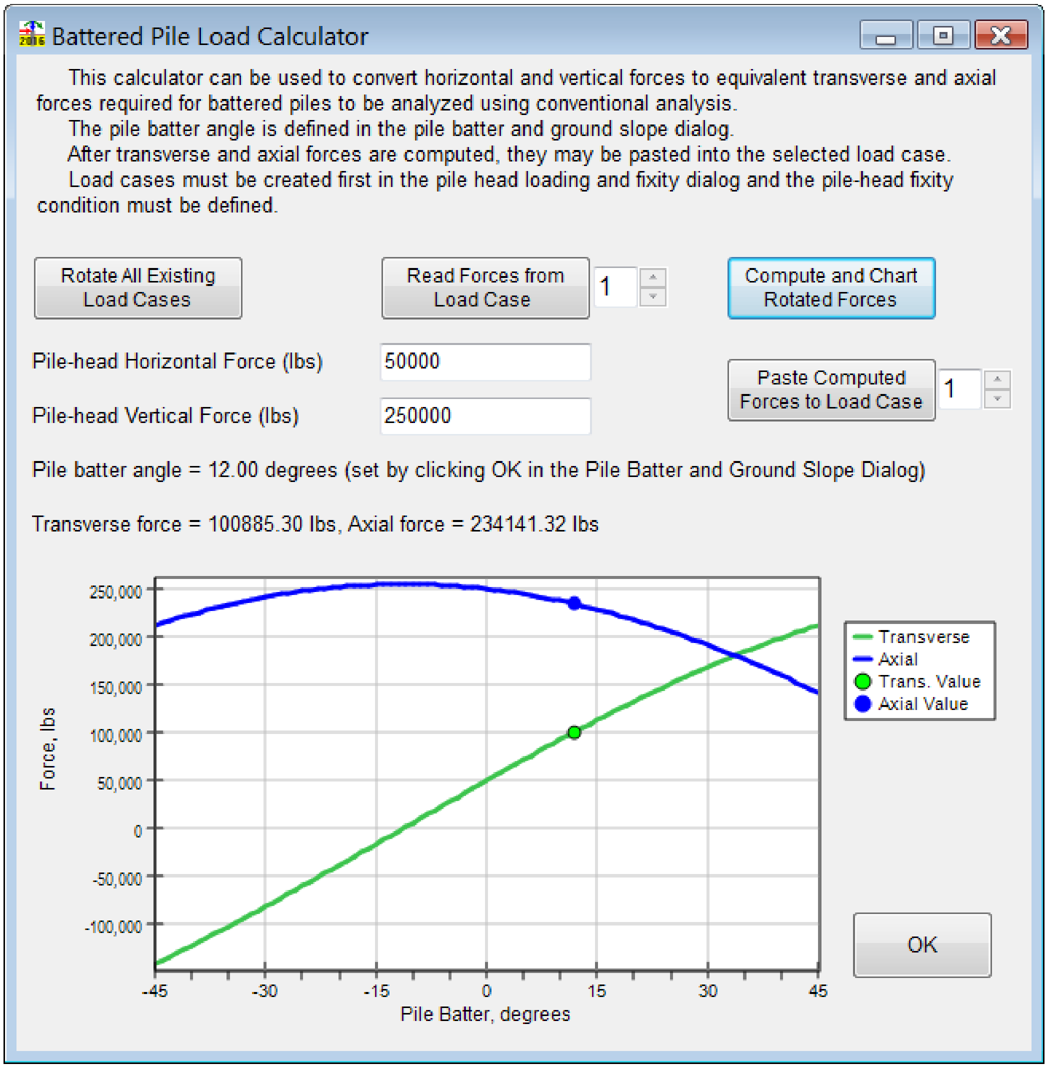


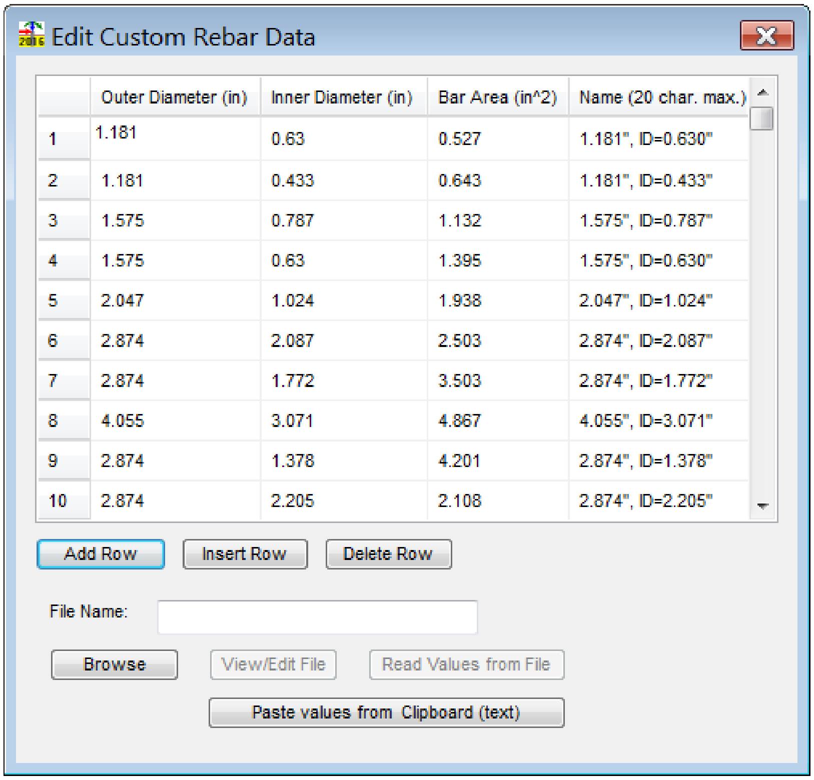
Figure 5.3 Battered Load Calculator

Where:

β	is the batter angle in radians,
V_H	is the horizontal force,
P_V	is the vertical force,
V_T	is the shear force perpendicular to the pile axis, and
P_A	is the axial force along the pile axis.

5.3 Custom Reinforcing Bar Data Entry and Editing

The third to fifth entries provide a means of entering addition sizes of reinforcing steel bar sizes to LPile. Note that this feature provides a means of entering hollow bars and steel access tubes.



	Outer Diameter (in)	Inner Diameter (in)	Bar Area (in^2)	Name (20 char. max.)
1	1.181	0.63	0.527	1.181", ID=0.630"
2	1.181	0.433	0.643	1.181", ID=0.433"
3	1.575	0.787	1.132	1.575", ID=0.787"
4	1.575	0.63	1.395	1.575", ID=0.630"
5	2.047	1.024	1.938	2.047", ID=1.024"
6	2.874	2.087	2.503	2.874", ID=2.087"
7	2.874	1.772	3.503	2.874", ID=1.772"
8	4.055	3.071	4.867	4.055", ID=3.071"
9	2.874	1.378	4.201	2.874", ID=1.378"
10	2.874	2.205	2.108	2.874", ID=2.205"

Figure 5.4 Dialog for Editing of Custom Rebar Data

The third entry displays an input table to enter and edit the data for the custom reinforcing bar sizes.

The fourth entry will transfer the data for custom reinforcing bars into the memory of LPile and enter the names of the bars into the drop-down combination edit controls for selection of the size of reinforcing bars. Note that the custom bar sizes are at the bottom of the drop-down lists for bar sizes available for normally reinforced concrete sections.

The fifth entry saves the custom bar sizes to a data file named Custom_Rebar.dat. This data file is stored in the same program folder as the main LPile program. When LPile is started, LPile checks the program folder for a file with this name. If the file is found, it is read and the data is stored into program memory. Thus, it is not necessary for the user to re-enter the custom bar data each time the program is run.

Whenever the user wishes to exchange data files with another user, the data file for custom bar sizes should also be provided to the other user, as the full list of custom bar sizes is not included as part of the LPile data file.

5.4 Multi-File Analysis (Batch Run Utility)

The sixth entry provides a feature to define a list of existing LPile data files to be run as a batch and the command to perform the batch analysis.

The control dialog for multi-file analysis is shown in Figure 5.5. The dialog is operated by adding a file to the list by pressing the Add File to List button. The Add File to List button will open an input dialog in which either single or multiple files can be selected from any folder. The list of selected files is shown in the upper text pane of the control dialog.

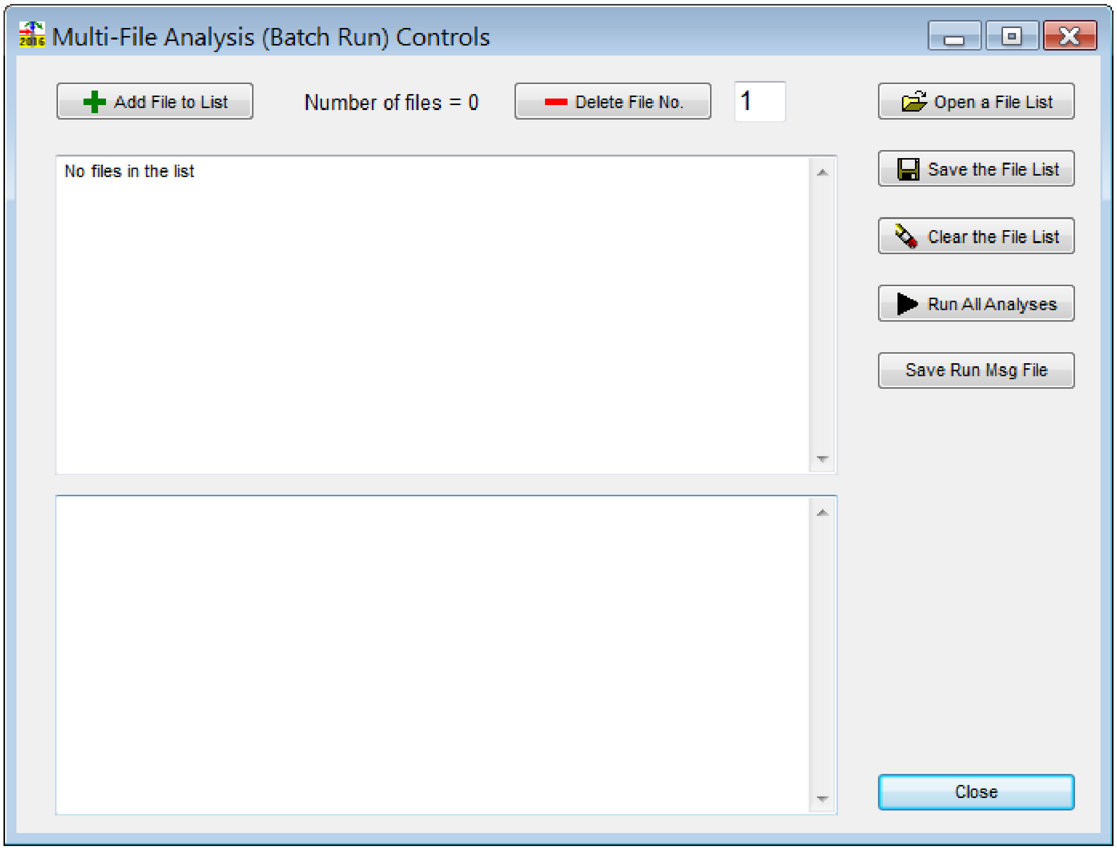


Figure 5.5 Dialog for Multi-File Analysis Controls

If needed, files can be deleted from the list by entering the file number and pressing the Delete File No. button.

The file list may be cleared by pressing the Clean the File List button.

Once the file list is complete, the user directs LPile to process the list of files by pressing the Run All Analyses button.

The processing time for each file and the warning or error message status of each file is shown in the lower text pane of the control dialog. This text pane displays the Run Messages

If desired the file list can be saved and re-opened by pressing the appropriate buttons.

Lastly, if the user wishes to save the Run Messages, he may do so by pressing the Save Run Msg File button.

CHAPTER 6. Example Problems

The problems in this chapter are provided as examples of the types of applications that may be solved using LPile. Each example focuses on a particular computational feature of the program. The input files for the examples are automatically copied to a sub-folder named *Lpile2026-Examples* under the common *Ensoft* folder on the root directory of the computer during installation. The data files are named with descriptive names and are copied to separate sub-folders. For example, the path to the directory for Example 1 is:

C:\Ensoft\Lpile2026-Examples\Example 1 Elastic Steel Pile in Sloping Ground

Example problems provide information on input and output of various cases, and present a quick tutorial for different applications. The user is encouraged to study these examples and, with modifications, may use them to solve similar problems. However, by no means can these limited examples explore the full functions and features provided by LPile.

The main features of each example included with LPile are summarized as follows.

Example 1 – Elastic steel pile in sloping ground.

- pile made of a standard structural steel shape, modeled as elastic pile with specified moment capacity,
- pile-head fixed against rotation,
- report of internally-generated *p-y* curves at different depths for verification purposes,
- application of several lateral loads, and
- sloping ground surface.

Example 2 – Nonlinear bored pile in sloping ground.

- pile is a drilled shaft,
- comparison of values obtained with pile head fixed and free against rotations,
- application of several lateral loads,
- analysis with nonlinear bending stiffness, and
- usage of sloping ground surface.

Example 3 – Steel pile supporting an offshore platform.

- pile made of two different steel sections,
- pile with head elastically restrained against rotations, and
- cyclic loading.

Example 4 – Buckling of a pile column.

- steel pipe pile (elastic and nonlinear),
- pile head free to rotate, and
- application of several axial loads.

Example 5 – Ultimate bending moment for bored piles.

- reinforced concrete pile of circular cross section,
- nonlinear materials,
- report of interaction diagram, and

- report of nonlinear flexural rigidity.

Example 6 – Foundation Stiffness of Concrete Pile with Nonlinear Flexural Rigidity. Includes the following program features:

- reinforced concrete pile of circular cross section,
- pile with head free to rotate,
- nonlinear materials,
- report of interaction diagram,
- report of nonlinear flexural rigidity, and
- generation of foundation stiffness components.

Example 7 – User Input of Distributed Load and External *p-y* Curves. Includes the following program features:

- reinforced concrete pile of circular cross section with two different section properties,
- pile with head free to rotate,
- input of distributed lateral load on a section length of pile with linear variation, and
- input of externally-specified *p-y* curves.

Example 8 – Case Study of Piles in Cemented Sands. Includes the following program features:

- reinforced concrete pile of circular cross section,
- pile with head free to rotate,
- input of several lateral loads, and
- use of internal *p-y* curves for silts.

Example 9 – Sample of Various Program Options. Includes the following program features:

- drilled shaft with reinforced concrete cross-section and belled bottom,
- pile with head free to rotate,
- sample coordinates for embedded pile head,
- use of *p*-reduction factors assuming closely spaced piles,
- use of several soil layers,
- input of shear-resistance curve at pile tip, and
- determination of top deflections versus varying pile lengths.

Example 10 – Drilled shaft in soft clay

- multi-section drilled shaft with under-ream and toe, and
- uniform rebar cage in upper sections.

Example 11 – LRFD analysis

- input of unfactored loads
- input of load and resistance factor combinations

Example 12 – Liquefied sand with lateral spread

- lateral spread modelled using lateral soil movement versus depth

Example 13 – Top deflection versus pile length for square elastic pile

- example compares standard and modified versions of *p-y* curves for stiff clay without free water, and
- computation of curves of top deflection versus pile length for multiple levels of loading.
- Example 14 – Pushover analysis of prestressed concrete pile

Example 15 – Pile with input nonlinear bending properties

Example 16 – Analysis of pile loaded by distributed lateral loads

Example 17 – Analysis of double-section, rock socketed drilled shaft

Example 18 – Analysis of drilled shaft with permanent casing

Example 19 – Analysis of drilled shaft with permanent casing and core

Example 20 – Design analysis of embedded pole

Example 21 – Analysis of a tapered elastic pile

Example 22 – Analysis of a tapered elastic-plastic pile

Example 23 – Output of *p-y* curves at user specified depths

Example 24 – Analysis of pile loaded by soil movements

Example 25 – Verification of elastic pile in elastic subgrade

Example 26 – Verification of the P-δ effect

Example 27 – Analysis of Prestressed Concrete Pile

Example 28 – Analysis of Lateral Spread

Example 29 – Input from Load Test

6.1 Example 1 – Steel Pile in Sloping Ground

The general description and geometrical configuration of Example 1 is shown in Figure 6.1. The pile is a standard structural steel shape (HP14×89), two layers of soil are present, and the ground surface is sloping downward with respect to the lateral loading.

In an actual design, the data shown in this example problem might be for a trial run. That is, the selection of the particular section for the pile and its length might change in the course of the computations. Furthermore, the soil profile has been idealized and in an actual case there would almost certainly be a need for consideration of the variation of the soil properties with depth and across the site.

The axial service load on the pile axis is 88.8 kN (20 kips). If the load factor (global factor of safety) is taken as 2.5, the axial load P to be used in the computations is 222 kN (50 kips). As it will be seen, the bending moment capacity is affected only slightly by the presence of the axial load.

The sketch of the pile in Figure 6.1 shows that its top is fixed against rotation. Thus, it is assumed that the top of the steel section projects a sufficient distance into the reinforced-concrete base of a pile cap so that no rotation of the top of the pile will occur. This assumption is not strictly true, but research is to be done to yield expressions for the rotation of an embedded steel member into a concrete mat. The assumption of pile-head fixity is conservative for forces, because the maximum bending moment will occur at the top of the pile and any rotation of the pile head will cause a decrease in the maximum moment. However, the pile-head fixity may not be conservative for displacements so users would need to check the influence of different fixity.

The computations that follow are aimed at finding the lateral load V that will cause a plastic hinge to develop at the top of the pile. Secondly, the computations should reveal if there is a possibility of excessive deflection.

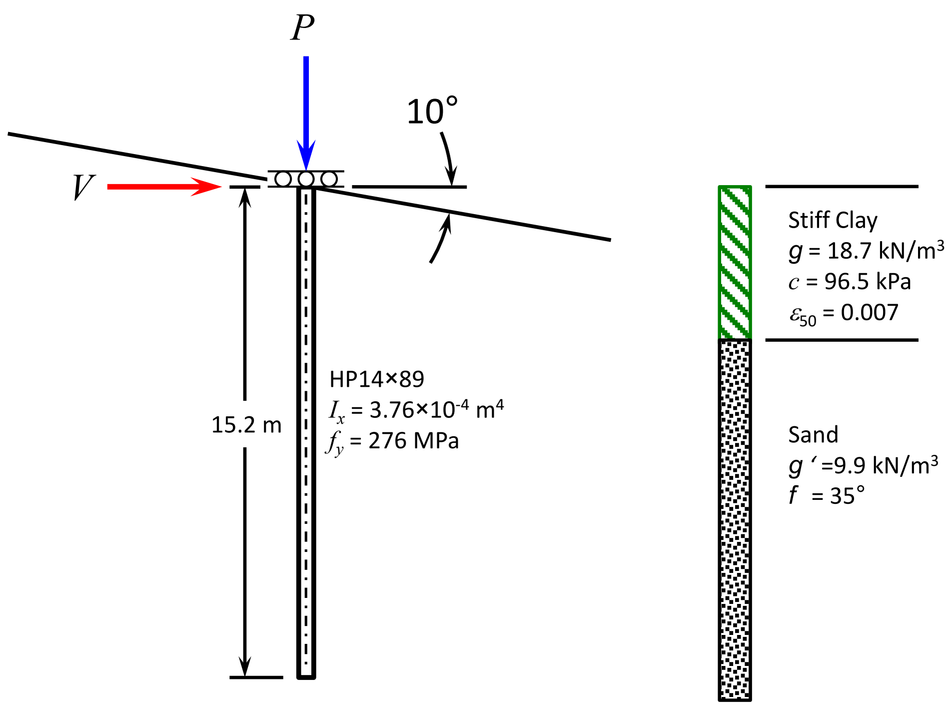


Figure 6.1 General Description of Example 1

The pile section type selected for the analysis is the Data > Pile Properties > Section Type > Elastic Pile with Specified Moment Capacity. With this type of section, it is possible to have the pile behave elastically up to the specified moment capacity then form a plastic-hinge when the moment in the pile equals the specified moment capacity.

The strong axis of the H-pile is perpendicular to the direction of loading, and data for this axis were included in Figure 6.1. From the steel handbook, the width of the section is 373 mm (14.696 in.) and the depth is 352 mm (13.86 in.).

An important consideration is the "diameter" to assign to the shape because the recommendations for *p-y* curves are based strongly on the results of experiments with cylindrical shapes. At the outset, it can be assumed that the soil in the flanges will move with the pile and that it will behave as a rectangular shape. Secondly, the equivalent diameter of the pile can be computed, as a first approximation, by finding a circular section with the same area as the rectangular section. Thus,

$$\frac{\pi d_e^{\,2}}{4} = (373\text{ mm})(351\text{ mm})$$

$$d_e = \sqrt{\frac{4(373\text{ mm})(351\text{ mm})}{\pi}} = 408\text{ mm} = 16.1\text{ inches}$$

As shown above, this computation yields a diameter that is less than 10 percent larger than the width of the steel section.

The equivalent diameter may be entered as the width of the pile, or, conservatively, as the actual width of 373 mm (14.686 in.). The decision of which value to be entered is left to the user, but the actual width will be used in this example. The values used in this example are shown in Figure 6.2 below.

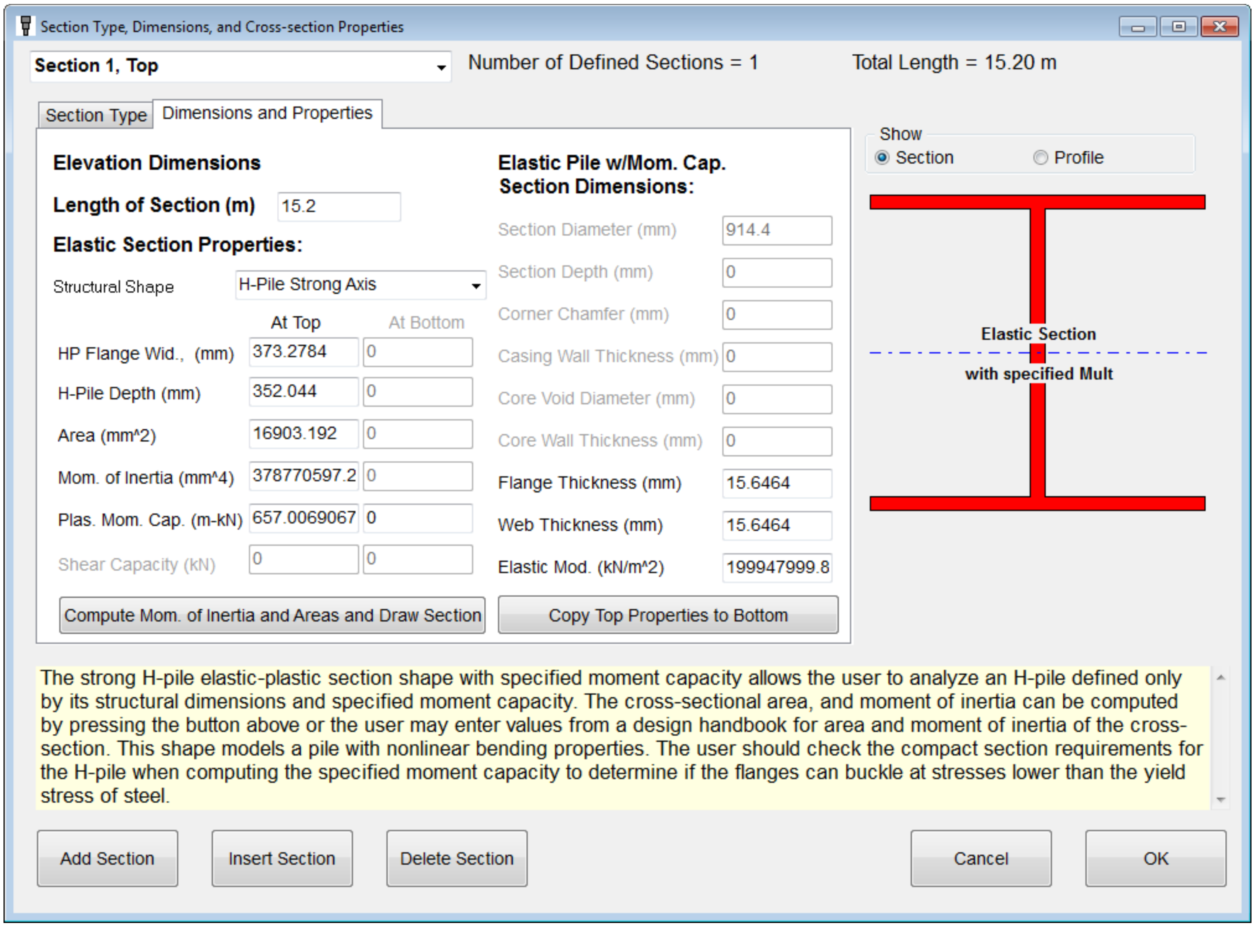


Figure 6.2 Dimensions and Properties Entered for Example 1

The user should understand how the values entered for Pile Properties can be manipulated to enter the desired data to LPile. LPile is programmed to compute values of cross-sectional area and moment of inertia from the input dimension values when the user presses the button to Compute Moment of Inertia and Areas and Draw Section. In the case of H-piles, often the computed areas of area and moment of inertia differ from the standard values published for design. If the user wishes to replace the computed value, the user may enter the standard values directly, but must remember not to press the button to compute values. If the user presses the button to compute values, the manually entered values will be replaced by the computed values.

The yield moment for the section may be computed by a procedure proposed by Horne (1978). With no axial compression load and with bending about the strong axis, the plastic moment strength is computed the product of the yield stress and plastic modulus as follows:

$$M_p = F_y Z$$

$$M_p = (276)(2.39 \times 10^{-3})$$

$$M_p = 0.660 \text{ MN - m}$$

$$M_p = 660 \text{ kN - m}$$

Considering the effect of axial load:

$$a = \frac{P_x}{2t_w f_y}$$

$$a = \frac{222}{(2)(0.0156)(276{,}000)}$$

$$a = 0.0258\,\text{mm}$$

$$M_p = M_p - t_w a\, f_y$$

$$M_p = 660 - (0.0156)(0.0258)^2(276{,}000)$$

$$M_p = 657\ \text{kN - m} = 5{,}815\ \text{in - kips}$$

In other cases where the pile extends above the ground surface, the designing engineer will need to consider the compact section properties of the pile. In some H-pile sections, the pile flanges may buckle at stress levels below the yield stress of steel and the section is called "non-compact." For this pile section, the compact section stress criterion is 131.7 MPa. To consider the compact section criterion one substitutes the compact section stress for the yield stress.

The loading in this model is a sustained static loading, not a cyclic load. In some cases, the designer is faced with the problem of estimating the consolidation and creep of the clay and/or the additional deflection due to vibration of the sand. The value of shear strength indicates that the clay is overconsolidated; thus, as a first approximation, no significant consolidation or creep is assumed. In addition, the sand, well below the ground surface, is assumed not to densify due to possible vibration. These assumptions will need to be carefully reviewed after a preliminary solution is obtained.

The above discussion shows that static loading is appropriate for both the clay and the sand. Further, the recommendations for stiff clay above the water table are considered most appropriate. The next step is to find the value of pile-head shear force, *V*, that will develop a bending moment in the pile of 657 kN-m (5,815 in.-kips).

The results of the preliminary computations using the displacement-slope pile-head condition are shown in Figure 6.3 and Figure 6.4. As may be seen, the computations show that the pile will fail structurally when the axial load is held at 222 kN (50 kips) and the lateral load reaches a value of 410 kN (92 kips). The pile-head deflection at the failure loading was computed to be about 27 mm (1.06 in.). This deflection is considered tolerable; therefore, the failure of the pile is taken to be due to the development of a plastic hinge.

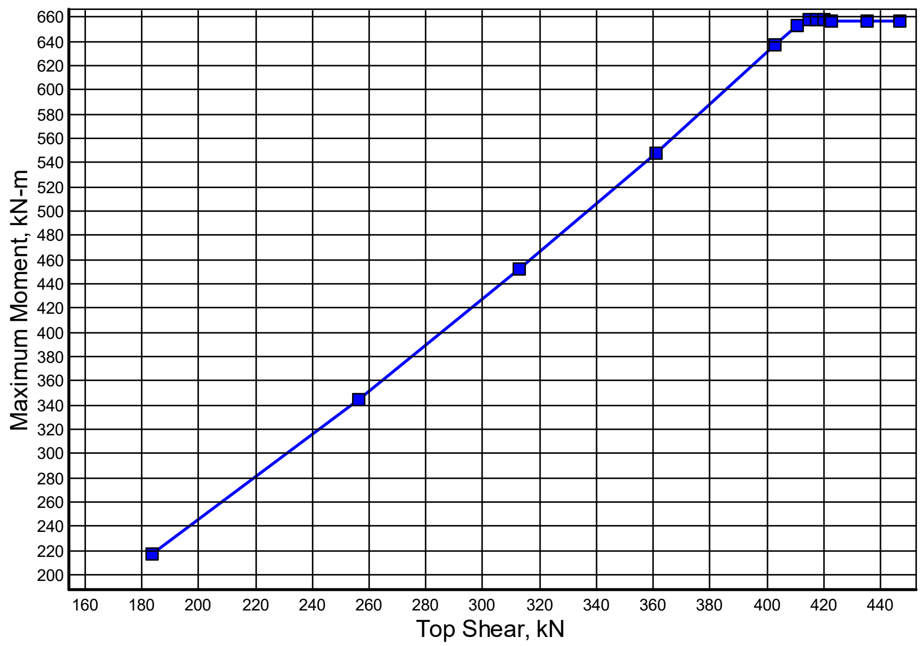


Figure 6.3 Generated Curve of Lateral Load versus Maximum Moment for Example 1.

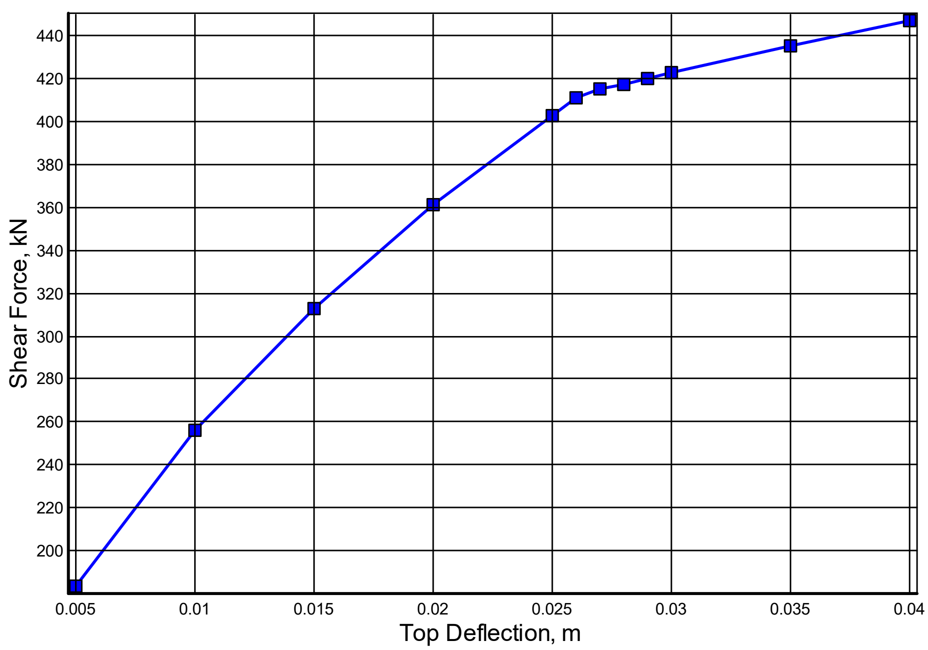


Figure 6.4 Generated Curve of Lateral Load versus Top Deflection for Example 1.

The safe loading level is found by dividing the loading at failure by 2.5, the global factor of safety, or V = 164 kN (37 kips) and P = 88.8 kN (20 kips).

The output report contains a summary of the input data, along with the values of four computed *p-y* curves that the user specified for output. The bottom section of the output report contains a table of pile response with the principal information needed by the engineer, where computed values are given as a function of depth. The table indicates that the length of the pile may be decreased to 10 m (33 ft) and that there will be three points of zero deflection, a sufficient number to ensure that the pile behaves as a long pile. By reducing the length of the pile, some unneeded output can be eliminated and, further, the amount of internal computations performed by the computer is reduced.

Plots of lateral deflection and bending moment as a function of depth are shown in Figure 6.5 and Figure 6.6. The loadings for the second analysis were a V of 164 kN (37 kips) and P of 88.8 kN (20 kips). The computed deflection at the top of the pile was to be 4.0 mm (0.16 in.) and the maximum bending moment was 186 kN-m (138.5 ft-kips), a value that is well below 657 kN-m (485 ft-kips) that would cause the pile to fail. The next step is to find the value of P_t that will develop a bending moment in the pile of 657 kN-m (5,815 in.-kips).

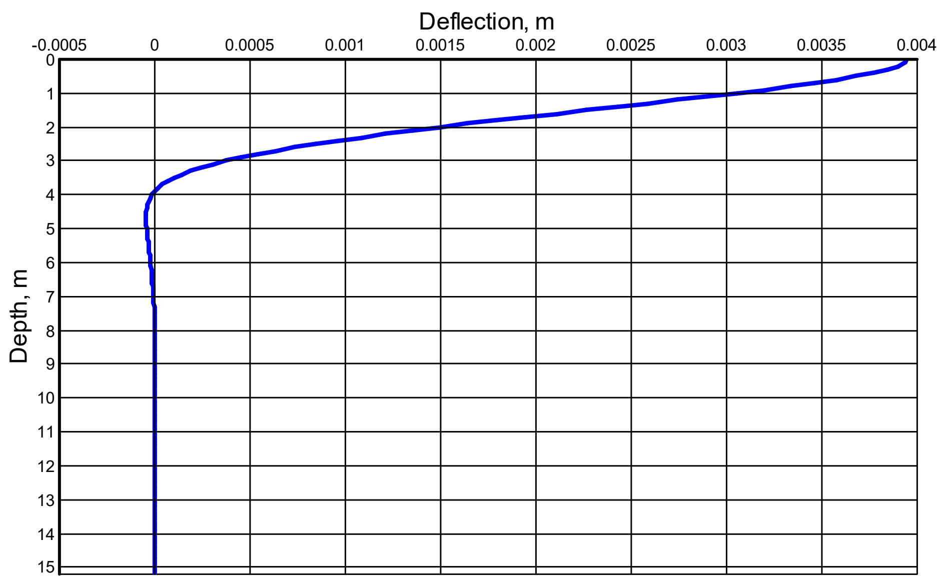


Figure 6.5 Curve of Deflection versus Depth for Example 1, Second Analysis

The curve shown in Figure 6.6 shows that the maximum bending moment occurs at the top of the pile, where it is fixed against rotation. If the pile head is permitted to rotate slightly, the negative moment at the pile head will decrease and the value of the maximum positive moment, now at a depth of 2.9 m (9.5 ft), will increase. Further, it is of interest to note that the bending moment is virtually zero at depths of 5 m (16.4 ft) and below.

The input data and output files have the filename *Example 1a HP 14x89 in sloping ground.lp12d*. These files are found in the Examples folder with the program. The output files are not shown in this User's Manual due to their length.

The filename for the second run is named *Example 1b HP 14x89 in sloping ground, second run.lp12d*. The input and output files are not shown here due to their length.

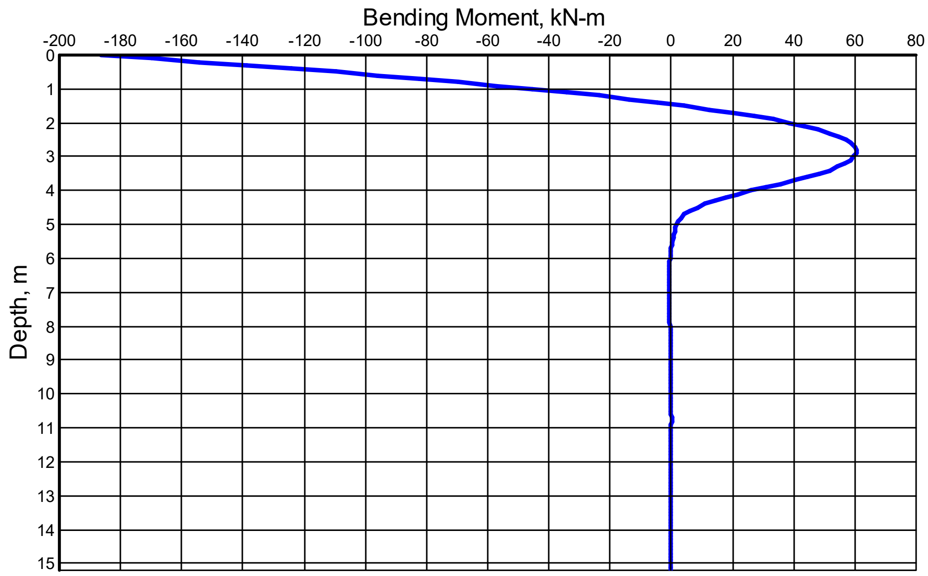


Figure 6.6 Bending Moment versus Depth for Example 1, Second Analysis

6.2 Example 2 – Drilled Shaft in Sloping Ground

This example is similar to Example 1, but in this case, the pile is replaced by a drilled shaft (bored pile). The soil properties and ground slope angle are the same as those used in Example 1. The design issue with a reinforced-concrete pile is to find the nominal bending moment capacity and an appropriate value of flexural stiffness (*EI*) to use in the computations.

As in Example 1, an axial thrust load of 88.8 kN (20 kips) is assumed. The pile head is assumed fixed against rotation in the first loading case and free to rotate in the second loading case. The problem is to find the lateral load for each case that will cause the shaft to fail. Both of these loading cases might be used in a practical problem to establish the bounds for the solution if the rotational restraint caused by embedment of the top of the pile causes the pile head to be between fixed and free.

A drilled shaft with an outside diameter of 760 mm (30 in.) and a length of 15.2 m (50 ft) is used in this example. The reinforcing steel consists of 12 bars with outside diameter of 25 mm (corresponding to No. 8 bars in US practice) and spaced equally around a 610 mm (24 in.) diameter circle as shown in Figure 6.7. The ultimate strengths of the reinforcing steel and the concrete are 414 MPa (60 ksi) and 27.6 MPa (4.0 ksi), respectively.

Example 2a is the computation and plotting of the unfactored interaction diagram. This problem is configured by selecting the Compute Nonlinear EI Only option in the Data > Options and Settings dialog and by entering the structural dimensions and material properties of the pile's cross-section.

When computing an interaction diagram, the user must enter the axial thrust forces for the analysis (Data > Axial Thrust Loads for Interaction Diagram). This means that the user must determine the maximum compressive and tensile axial capacities along with a number of intermediate axial thrust values. Usually, a bored pile in soil will fail by axial bearing capacity before the pile section will fail by crushing, so the upper limit may be limited by the computed axial bearing capacity, if this value is available. Otherwise, the user may opt to make two analyses, the first with zero axial thrust and the second with a number of axial thrust loads. After the first run, the user may read the estimated axial capacities of the pile section in compression and tension from the output text report and use these values to set the upper and lower values of axial thrust for the second analysis.

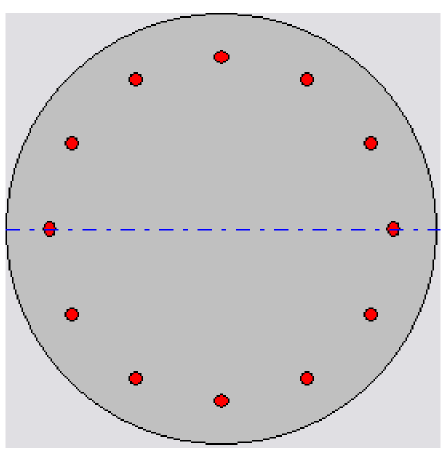


Figure 6.7 Cross-section of Drilled Shaft for Example 2.

An excerpt from the output report for Example 2a for the axial structural capacities is shown below:

```
Axial Structural Capacities:
----------------------------

Nom. Axial Structural Capacity = 0.85 Fc Ac + Fy As    =    13031.123 kN
Tensile Load for Cracking of Concrete                  =    -1424.929 kN
Nominal Axial Tensile Capacity                         =    -2532.072 kN
```

Using these values, axial thrust values were entered ranging from -2,500 to 13,000 kN. The resulting factored interaction diagram generated by the Presentation Graphics feature is shown in Figure 6.8.

The curves for moment versus curvature for multiple axial thrust forces are shown in Figure 6.9 and the curves for *EI* versus bending moment are shown in Figure 6.10.

Computations of nominal bending moment capacities are determined when the concrete compressive strain at failure equals 0.003. For the axial load of 88.8 kN, the nominal bending moment capacity, M_{nom}, was taken from the curve as 731.8 kN-m. For design, a resistance factor for moment capacity equal to 0.65 was assumed, which gives a factored (ultimate) moment capacity of 475.7 kN-m.

The computations for nominal moment capacity could have been done for only the one axial load level, however, the full interaction diagram was developed to demonstrate the influence of axial load for this particular problem. As seen in Figure 6.8, an increase in the axial load up to a point will increase the value of the moment capacity so the axial thrust load was not multiplied by the global factor of safety to get the moment capacity.

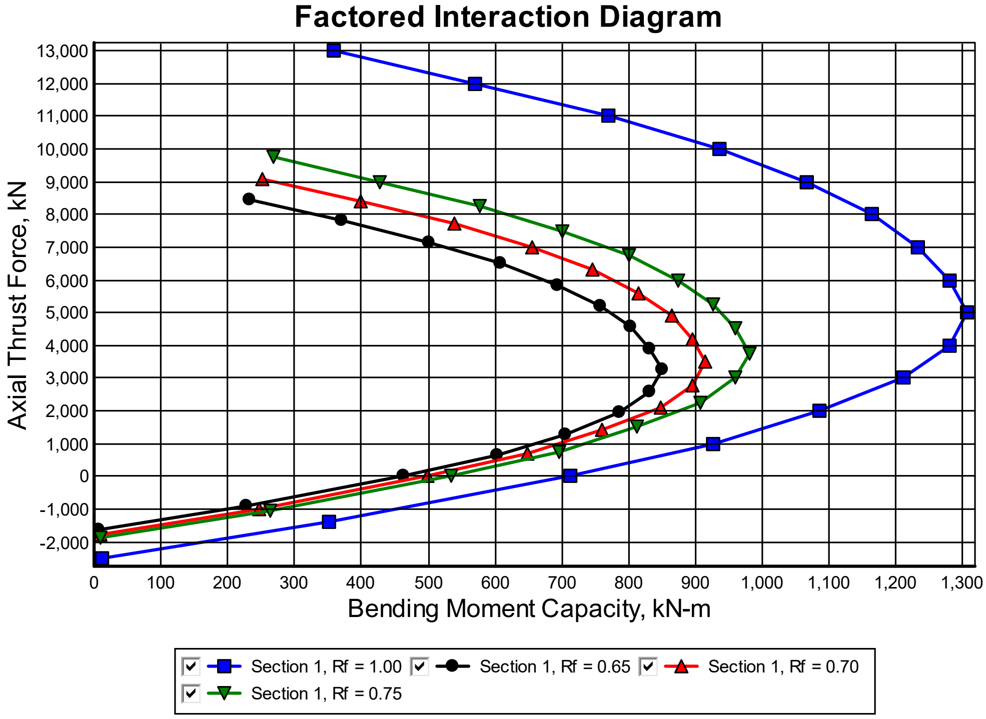


Figure 6.8 Factored Interaction Diagram for Example 2a.

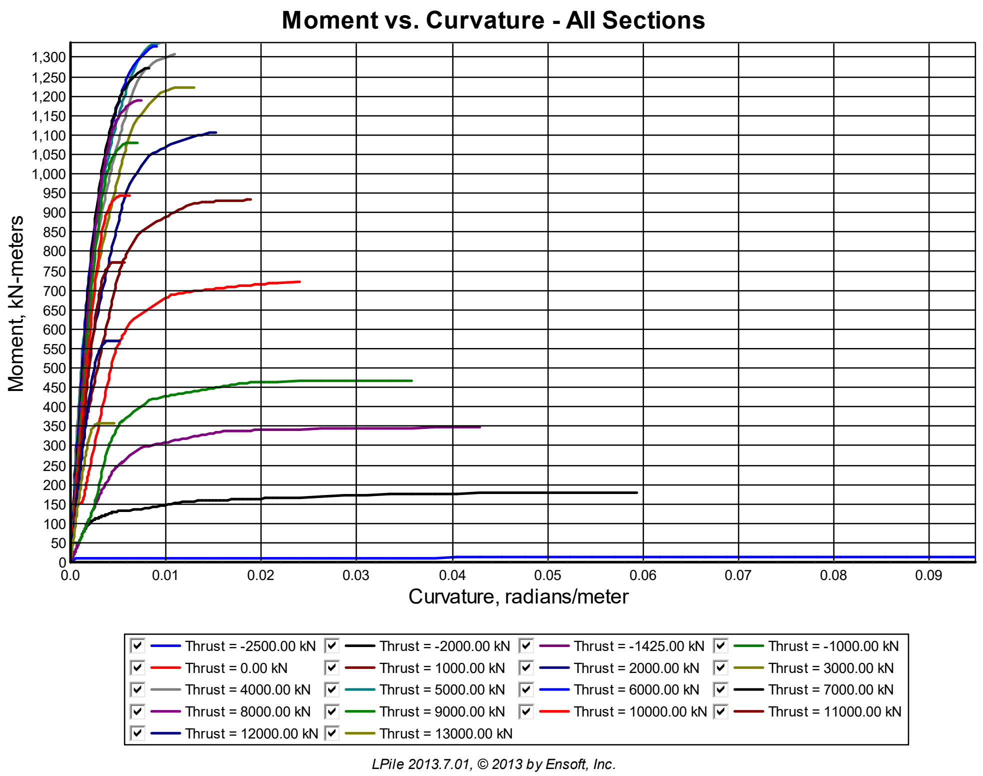


Figure 6.9 Moment-Curvature Diagram for Example 2a.

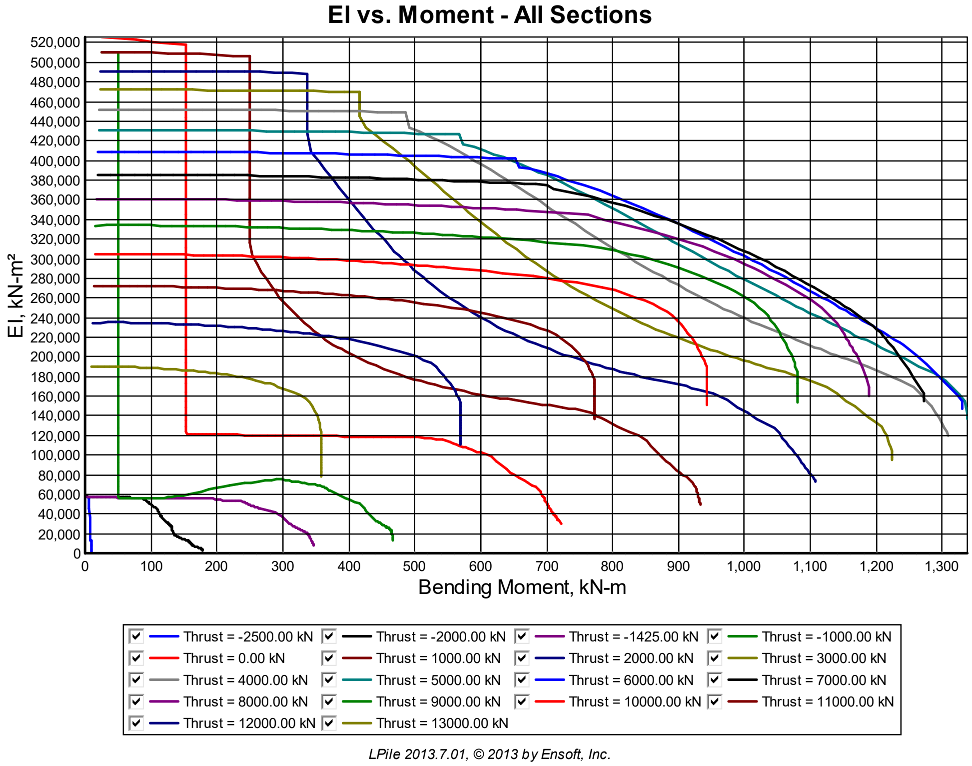


Figure 6.10 Bending Stiffness versus Bending Moment for Example 2a.

In earlier versions of LPile, the user had to select a constant value of bending stiffness to use in an analysis. This is no longer needed, as LPile will automatically vary the value of bending stiffness in proportion to the bending curvature developed in the pile.

The load-deflection curves and moment versus shear force curves for free-head conditions are shown in Figure 6.11 and for fixed-head conditions are shown in Figure 6.12. The scales of the two figures have been set equal to aid comparing the two sets of graphs.

The free-head shaft reaches its nominal moment capacity at a shear load of approximately 530 kN and its factored moment capacity at a shear load of 346 kN at a deflection of 0.035 m. The fixed-head shaft reaches it nominal moment capacity at a shear load of 550 kN and its factored moment capacity at a shear load of 352 kN at a deflection of 0.0076 m. By happenstance, the load-carrying capacity of the two pile-head conditions are nearly equal. However, the load-deflection response of the fixed-head shaft is substantially stiffer.

To illustrate the differences in deflection and bending moment versus depth for the two pile-head fixity conditions, a fourth analysis was performed for pile-head shear loads equal to 346 for the free-head shaft and 352 kN for the fixed-head shaft. The results of this analysis are shown in Figure 6.13.

The length of the pile may be reduced if there are more than two points of zero deflection, which ensures that the pile acts as a stable pile. LPile can perform a series of analyses with different lengths of piles, so the user can compare pile length versus deflection at the pile head. The curves of Graphics > Top Deflection vs Pile Length for free and fixed-head conditions is shown in Figure 6.14.

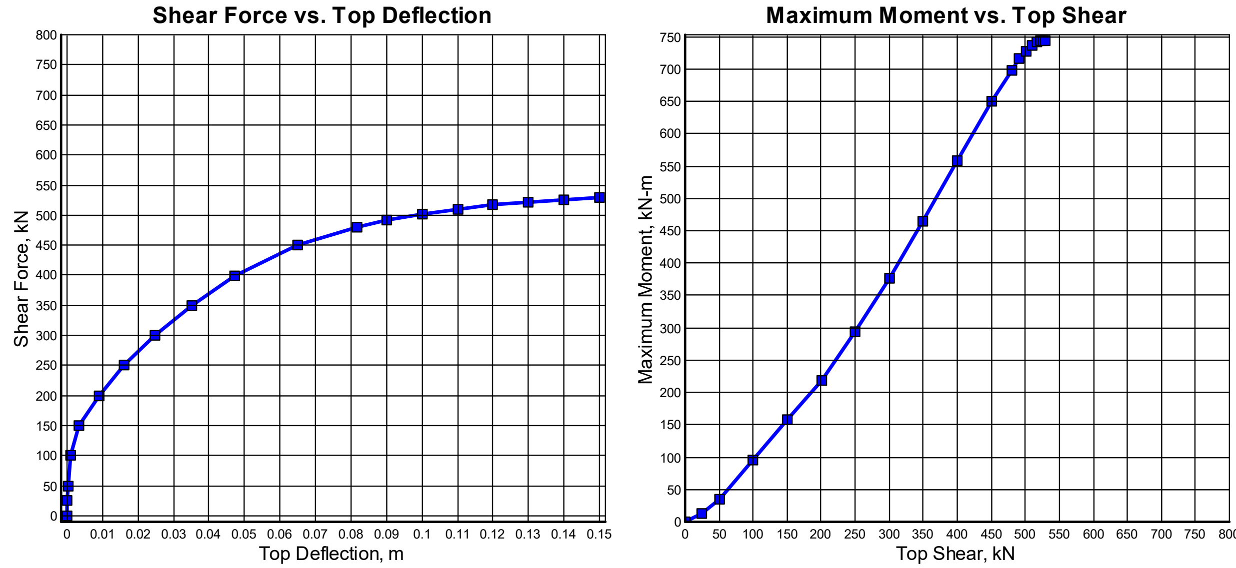


Figure 6.11 Shear Force versus Top Deflection and Maximum Bending Moment versus Top Shear Load for Free-head Conditions in Example 2b.

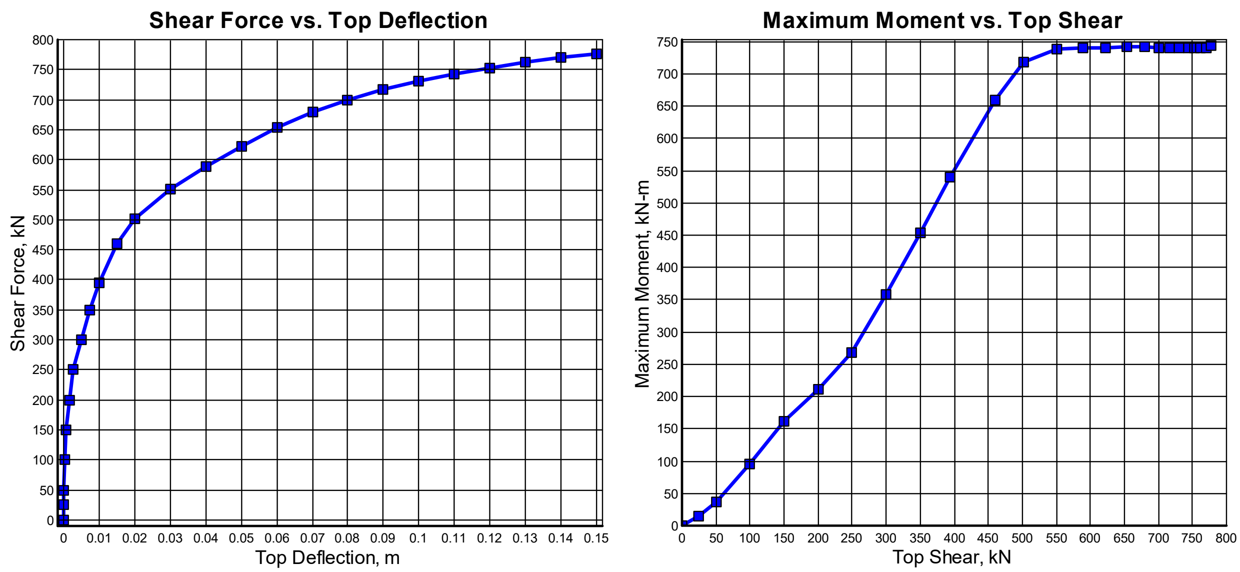


Figure 6.12 Shear Force versus Top Deflection and Maximum Bending Moment versus Top Shear Load for Fixed-head Conditions in Example 2c.

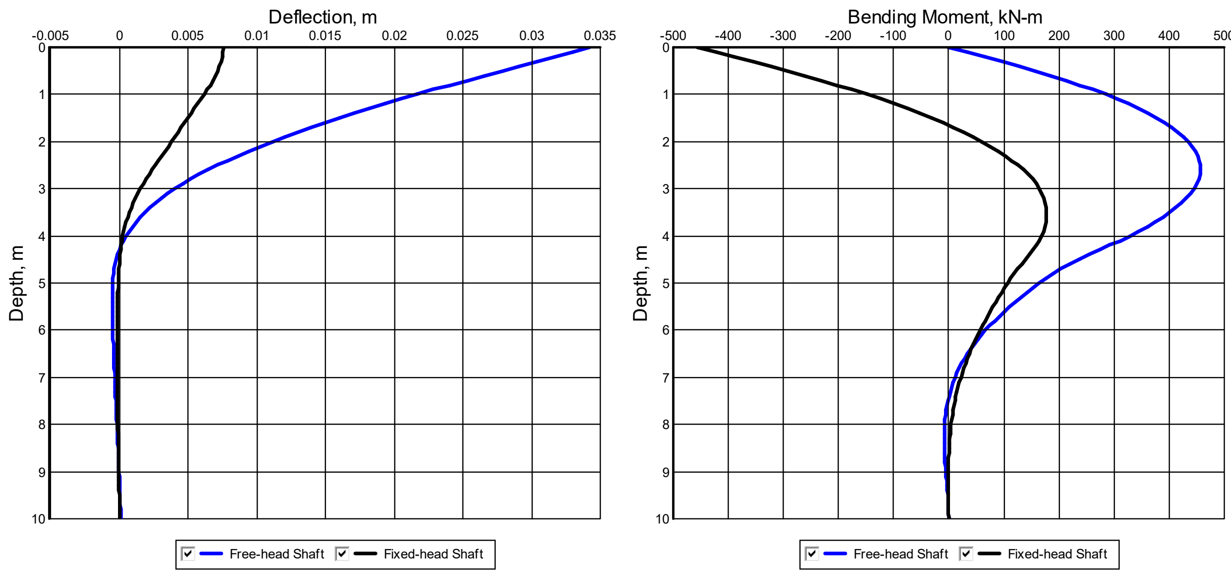


Figure 6.13 Results for Free-head and Fixed-head Loading Conditions for Example 2d

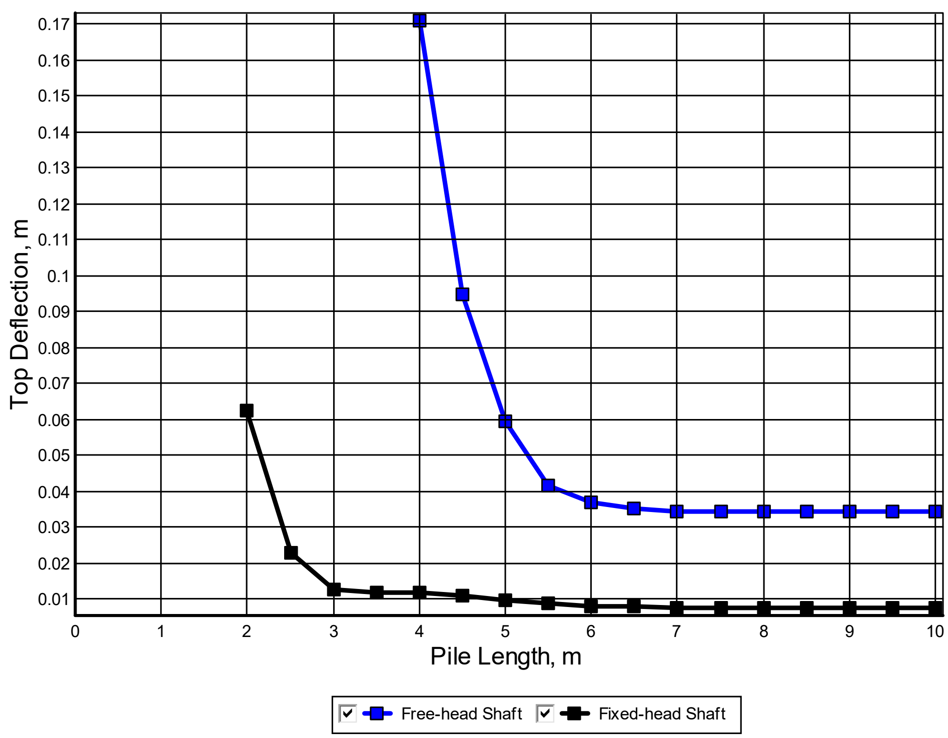


Figure 6.14 Top Deflection versus Pile Length for Example 2d

Perhaps it is of interest to note that the lateral loads that were computed for the steel pile and for the bored pile were of significant magnitude, indicating that different types of piles can be used economically to sustain lateral loads.

6.3 Example 3 – Offshore Pipe Pile

The illustration in Figure 6.15 shows an offshore platform of the type used in water depths of 100 m or more. Thousands of such structures have been built where a structure is fabricated on shore, barged or floated to the site, and placed by lifting or controlled submergence. For the case indicated, the weight of the jacket causes the extensions of the legs to push into the soil. With the top of the template above still water, piles are stabbed and driven through the main legs. The tops of the piles are trimmed, and welded to the jacket, and the annular space between the outside of the piles and the inside of the jacket leg is filled with grout. Finally, a deck section is lifted and its support columns are stabbed into the tops of the main legs and then welded.

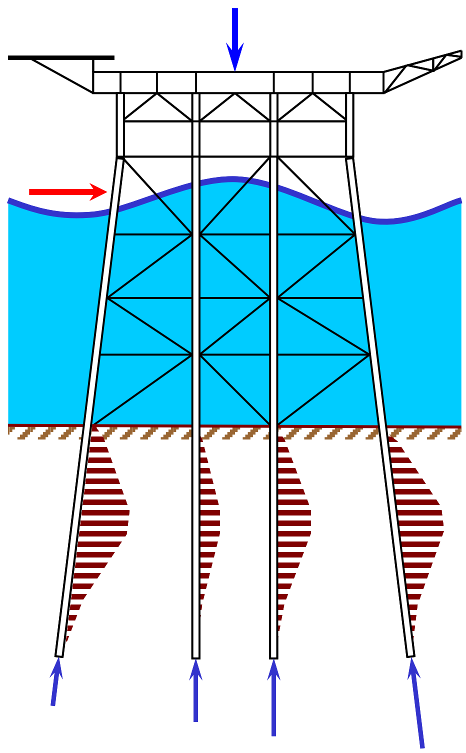


Figure 6.15 Idealized View of an Offshore Platform Subjected to Wave Loading, Example 3

The soil profile at the site is not shown in the sketch. In this example, it is soft clay with some overconsolidation due to wave action at the mudline, but with an increase in strength with depth as for normal consolidation. An assumption is made that some scour will occur around the piles to a depth of 1.5 meters (5 feet). The undrained strength of the clay at that depth is 24 kPa (500 psf) and the strength at 30 m is 72 kPa (1,500 psf). The submerged unit weight is 9.00 kN/m^3 (57 pcf); ε_{50} is 0.02 at 1.5 m (5.0 ft) and decreases to 0.01 at 30 meters (98 feet).

The sketches of Figure 6.16 show one of the piles from the structure with the rotational restraint given approximately by an equation. The number 3.5 indicates that the bracing has been discounted and that the member is acting as one whose far end is intermediate between fixed and free. The approximation is adequate for a preliminary solution but, for the final analysis, the superstructure and the piles should be considered as continuous, and the piles analyzed as a group.

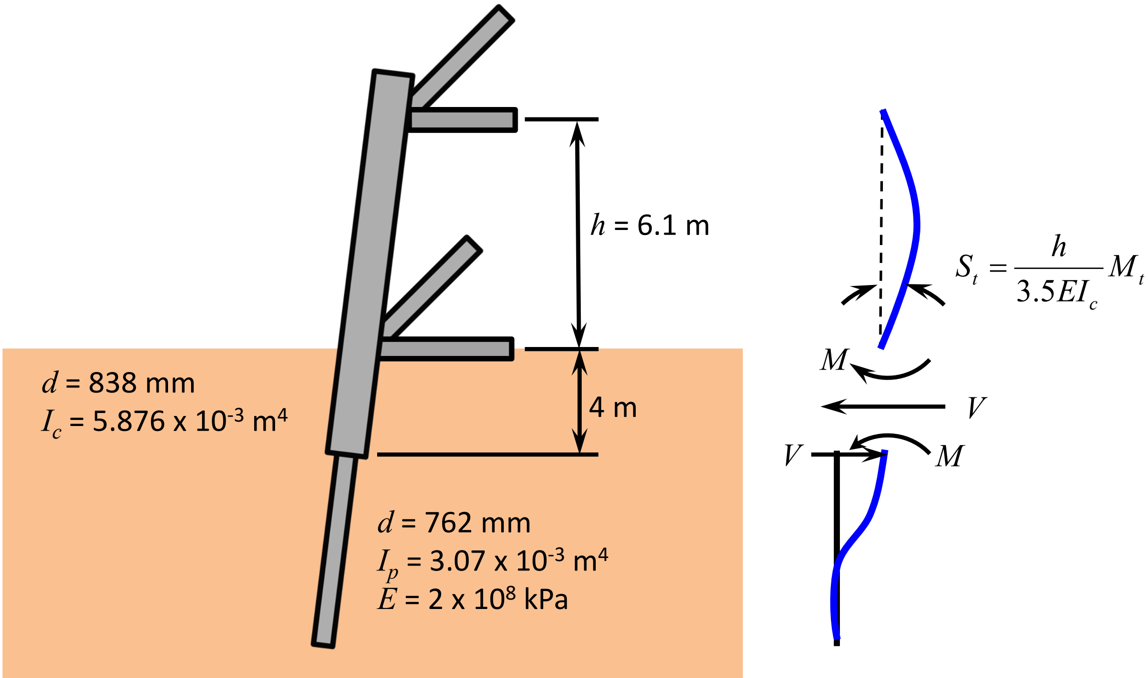


Figure 6.16 Superstructure and Pile Details, Example 3

The critical loading occurs during a severe storm, and Figure 6.15 shows the approximate position of a wave as it moves past the structure. The selection of a particular wave height and velocity of the wind is a problem in statistics, and the factor of safety to be employed is related to those selections. For this problem, it is assumed that a load factor of 2.4 is appropriate. The axial loading of the pile that is analyzed is 1,250 kN (281 kips); thus, the load in the design computations is 3,000 kN (674 kips). A solution consists of finding the lateral loading that will cause a plastic hinge to develop in the pile, and the safe load by dividing that load by the global factor of safety.

The sketch in Figure 6.16 shows that the pile to a distance of 4.0 m (13.1 ft) from its top consists of two pipes that are acting together. The outside diameter of this combined section is 838 mm (33 in.), the wall thickness is 28.14 mm (1.11 in.), and its moment of inertia is 5.876×10^{-3} m^4 (4,117 in^4). The lower section has an outside diameter of 762 mm (30 in.), a wall thickness of 19.05 mm (0.75 in.), and a moment of inertia of 3.070×10^{-3} m^4 (7,376 in^4). The ultimate strength of the steel for the piles is assumed is 0.395 MPa (57,290 psi).

Figure 6.17 shows the results of computations for the moment versus curvature analysis of the sections of the pile in the example. As shown in the *Technical Manual*, the stress-strain curve for the steel is assumed as bilinear; thus, the ultimate bending moment will continue to increase slightly as the full section of the pile approaches the plastic range. It was decided to accept the value of M_{nom} as the value where the maximum curvature is 0.015 radians/meter. For the upper section, a nominal moment capacity of 7,140 kN-m was computed. The corresponding value for the lower section of the pile was 4,040 kN-m.

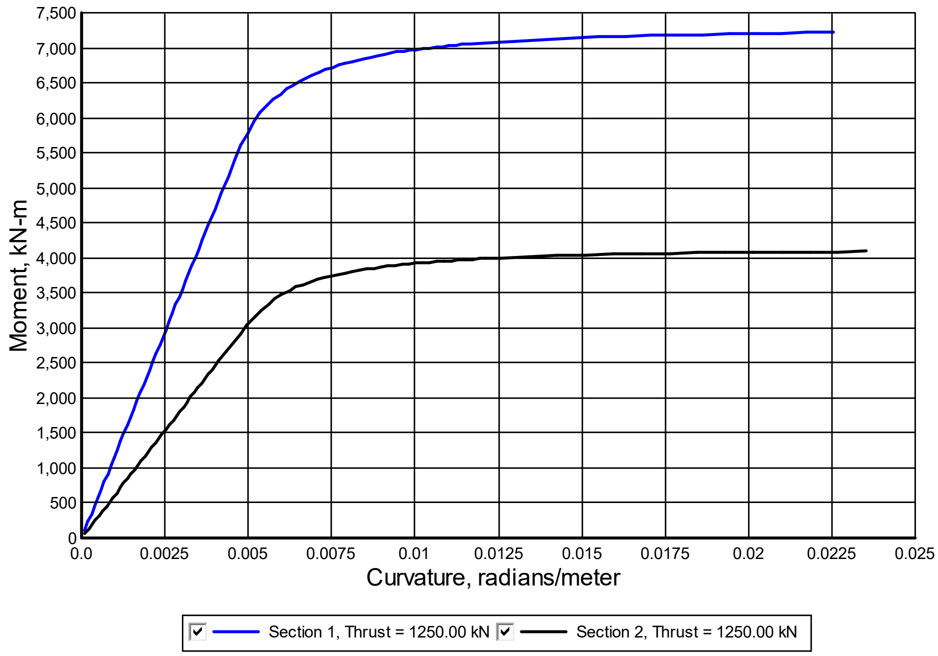


Figure 6.17 Moment versus Curvature, Example 3

The soil conditions at the site are in the range of soft clay below the water, and the recommendations for that soil are employed in the computations. Cyclic loading is employed because the design is to reflect the response of the structure to a storm.

Some comment is needed about the number of cycles of loading. If the documentation is reviewed for the experiments that resulted in the development of the recommendations, it will be noticed that the cycles of loading were continued until an apparent equilibrium was reached; thus, the criteria reflect the limiting condition (or worst condition). However, during a particular storm, there may be only a small number of loads of the largest magnitude during the peak of the storm. Therefore, the recommendations may be somewhat more conservative than necessary, but at the present, recommendations are unavailable to allow the introduction of the number of cycles into the procedure.

In reference to the previously shown Figure 6.16, initial computations were necessary to learn if the lateral loading on the selected pile would cause a critical moment in the upper or lower section. A series of computer runs and plots were made of the maximum moment as a function of V_{top} for both the upper and lower sections. Figure 6.18 shows that the maximum moment for the upper section, 7,140 kN-m and negative in sign, occurred with a lateral load of 1,200 kN. At that value of V_{top}, the maximum moment for the lower section was about 2,500 kN-m, which was far less than the yield value of 4,040 kN-m. Thus, the upper section of the pile controls the loading.

The deflection of the top of the pile, y_{top}, for the failure loading of 1,200 kN was computed to be 339 mm and, in some designs, the deflection might have controlled the loading. However, the computed deflection will be much less when the factored load is used; furthermore, excessive deflection is rarely a problem in the design of an offshore platform. It is true that personnel could experience distress on a deck that was moving radically; however, in normal circumstances, the personnel are removed from the platform during the occurrence of the design storm.

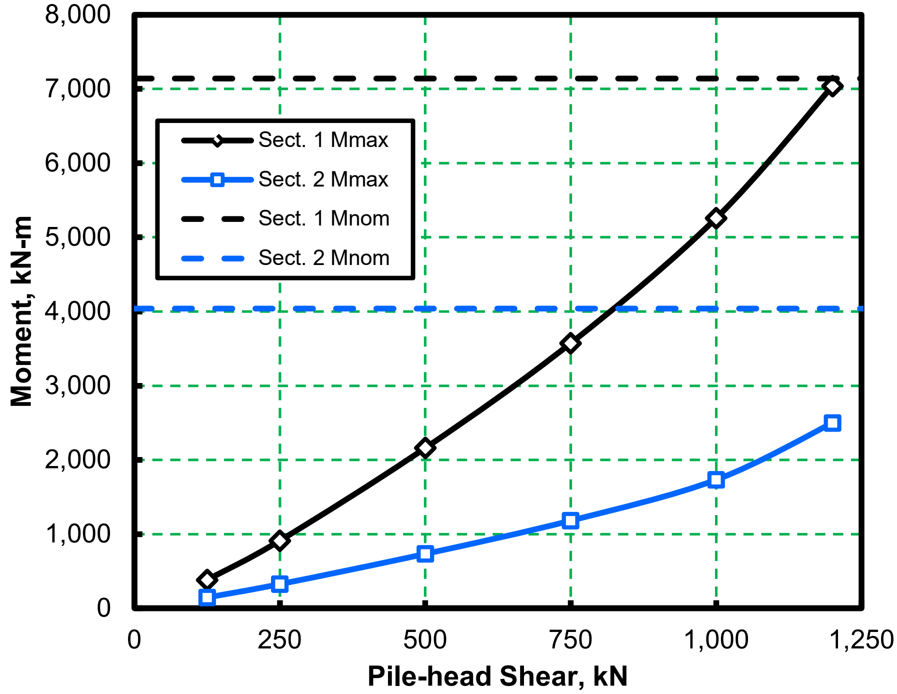


Figure 6.18 Results of Initial Computation with *p-y* Curves, Example 3

Employing a load factor of 2.4 (global factor of safety), the service value of pile-head shear force V_{top} is 500 kN and, as noted before, the axial thrust force Q is 1,250 kN. The resulting moment diagram is shown in Figure 6.19. The computed value of pile-head deflection y_{top}, not plotted here, was 62 mm, which is acceptable.

An examination of Figure 6.19 finds that the moment diagram is virtually zero below a depth of 21 m; therefore, the selection of the thickness of the wall of the pile below this depth will be based on the requirements of pile driving analysis and axial pile capacity, rather than lateral loading. Additionally, it is evident that the maximum bending moment could be reduced significantly if the designer has some control over the value of the rotational restraint at the mudline. Thus, the opportunity exists for minimizing the cost of the foundation by a judicious selection of the manner in which the piles are connected to the superstructure. For example, a less expensive solution could have been achieved if shims had been used at the bottom of jacket-leg extension and at the joints, with the result that no grouting would have been needed. Finally, the thick-walled section of the pile, whatever the final design, will be needed in the upper 21 m; therefore, the methods of installation must be such that the pile can be installed to the required penetration into the soil profile.

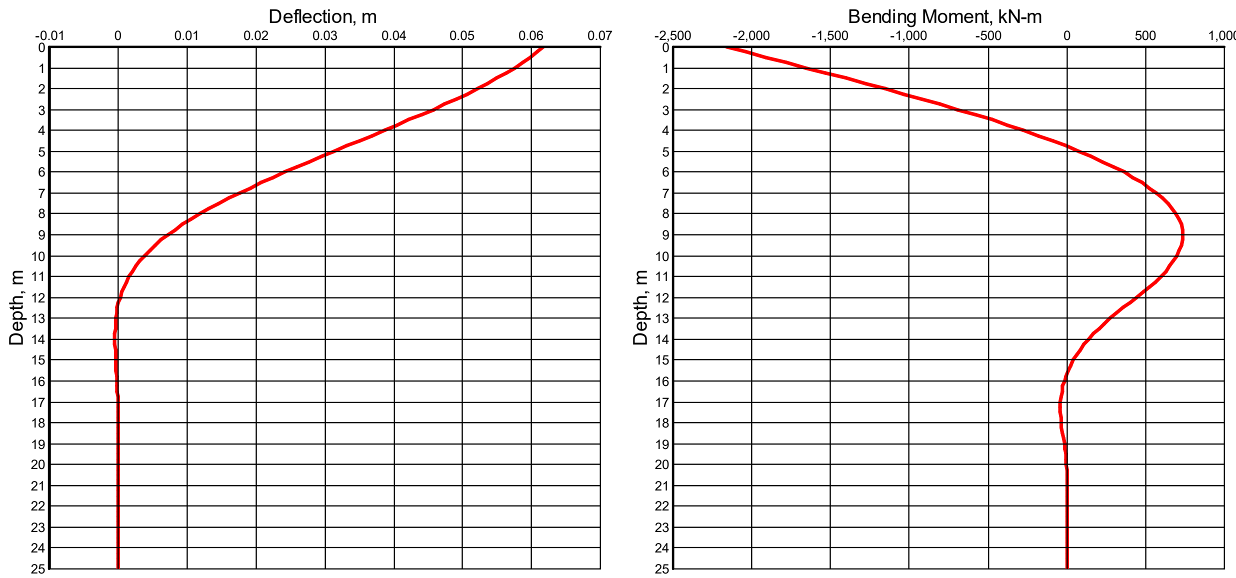


Figure 6.19 Pile Deflection and Bending Moment versus Depth for V_{top} = 500 kN, Example 3

6.4 Example 4 – Buckling of a Pile-Column

LPile can be used for the assessment of the buckling capacity of a pile. It is not often that such a problem is encountered in practice, but a rational solution is desired if such a problem occurs. Buckling may be a concern for small piles (micro piles) that are subjected to large axial loads and have a considerable stickup above ground or are embedded in very poor soils.

In this example, the lateral load at the pile head is 44.5 kN (10 kips) and the loading is static. The lateral load and the axial load are applied at the top of the pile, which is 2.5 m (8.3 ft) above the groundline. The bending moment at the pile head is zero.

The solution to the problem seeks the same answer as does the Euler solution for a column, but, because the response of the soil is nonlinear, an Eigen value solution is not applicable. Rather, the answer is obtained by successive solutions of the nonlinear, beam-column equation with the axial load being increased until excessive lateral deflection is computed or until the bending moment capacity of the pile is fully mobilized.

6.4.1 Example with Elastic Pile

Input data file: *Example 4a Pile Buckling Analysis, Elastic Pipe Pile.lp13d*

The first example is an elastic steel pipe, 609.6 mm (24 in.) in outside diameter, and with a wall thickness of 22.2 millimeters (0.875 inch). The pile's flexural stiffness *EI* is 353,886 kN-m^2 (1.233×10^{11} lb-in^2). The pile length is 15.2 meters (50 feet).

The soil profile is sand with an angle of internal friction of 35 degrees. The water table is below the tip of the pile. The effective unit weight of the sand is 19 kN/m^3 (121 pcf).

The *p-y* curves for static loading of sand above the water table are appropriate for the problem. Presumably, the soil properties are those that exist after the pile has been installed.

Entries to control the buckling analyses for this example are shown in Figure 6.20 (Data > Controls for Computations of Pile Buckling Analysis).

The results from the pile buckling analysis are shown in Figure 6.21 (Graphics > Buckling Thrust vs Top Deflection. The estimated buckling capacity is shown by the red line (19,592 kN). Notice that had the stickup length of the pile above the groundline been greater than 2.5 m (8.3 ft), the buckling load that was found would have been much lower than this computed value.

LPile estimates the pile buckling capacity by fitting a hyperbolic curve to the computed results of top deflection versus axial thrust force. The procedure used to fit the hyperbolic curve is discussed in Section 0 of the separate LPile Technical Manual.

While the solution to the problem appears to be rather straightforward using LPile, there presently are no other analytical solutions for pile buckling available to take the nonlinear load transfer from the pile to the soil into account. It is also important to note that the pile buckling analysis feature of LPile can also be used to investigate the effects of the eccentric application of axial loading and the effect of accidental batter.

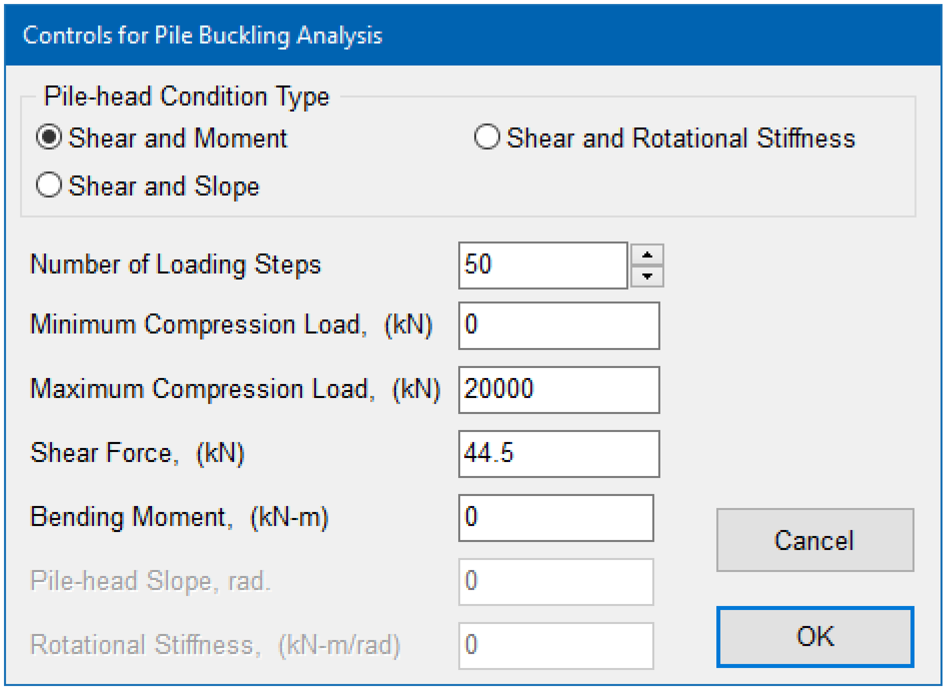


Figure 6.20 Buckling Analysis Controls for Example 4.

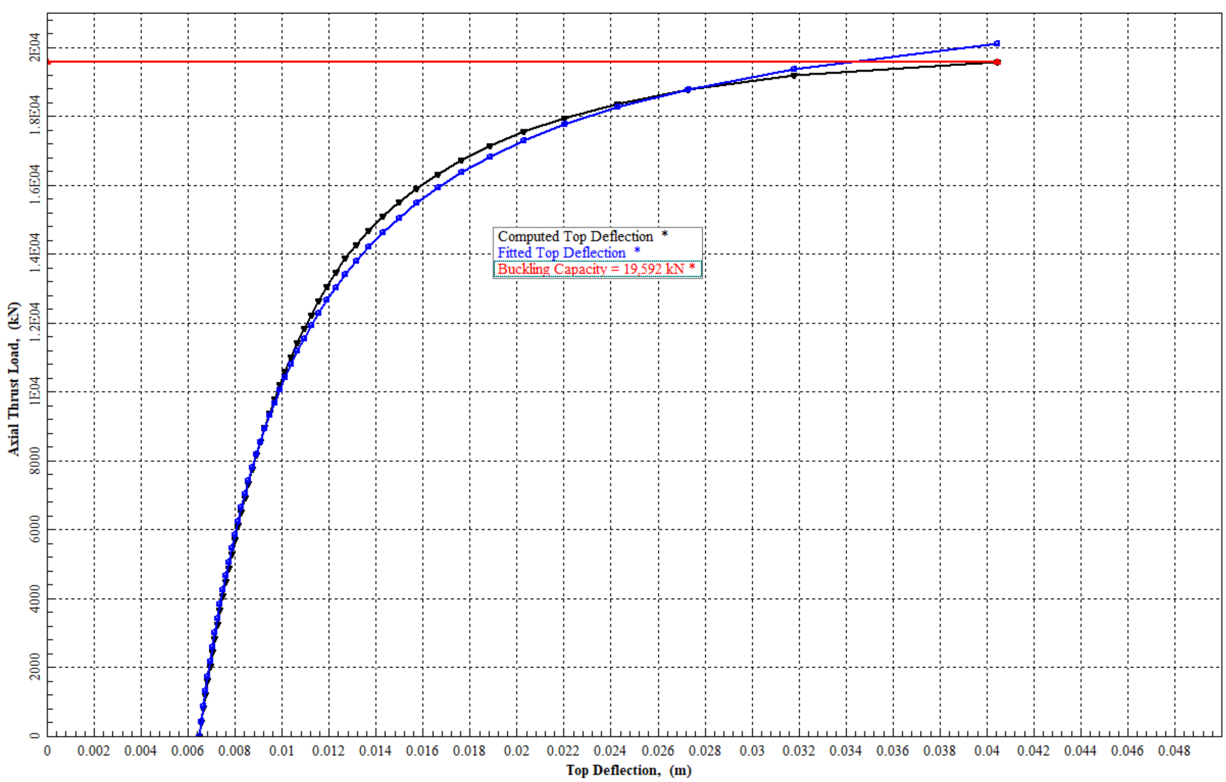


Figure 6.21 Results from LPile Solution for Buckling Analysis in Example 4.

The user may also choose to observe the results from the pile buckling analysis as presented in Figure 6.22. Note that this figure was drawn outside LPile, using results from the Graphics > Export Graphs to Excel feature of LPile. The deflection at the top of the pile, as a function of the axial thrust force is shown as the black line and the maximum bending moment as the blue line. The estimated buckling capacity is shown by the red line (19,592 kN).

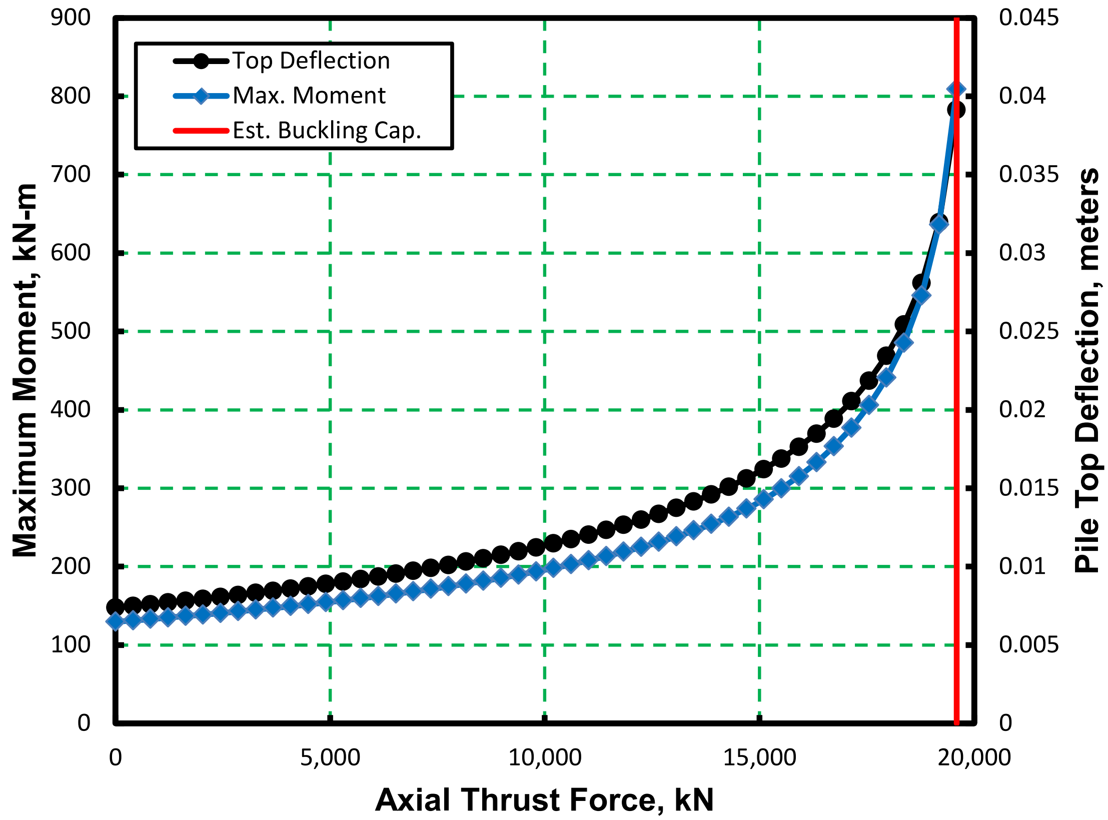


Figure 6.22 Pile-head Deflection and Maximum Bending Moment versus Axial Thrust Loading.

6.5 Example 5 – Computation of Nominal Moment Capacity and Interaction Diagram

Example 5 is presented to illustrate a feature of LPile for computation of the nominal bending moment capacity and to display an interaction diagram. A total of 17 axial loads were specified for the program to compute the ultimate bending moment at each axial load and to construct the interaction diagram (ultimate bending moment versus axial load).

The ultimate bending moment of a reinforces-concrete section is taken at a maximum compressive strain in concrete of 0.003 based on the ACI 318 code. It should be noted that the bending stiffness (*EI*), corresponding to the ultimate bending moment, is significantly lower than that of the uncracked *EI* value. Therefore, the user should also pay attention to the variation of *EI* versus moment for nonlinear piles. In general, the moment distribution in the pile is not affected much by the *EI* used in the computation. However, if the deflection is more critical for the design, then analysis using nonlinear values of *EI* should be done.

Curves showing the development of moment versus curvature for various axial thrust values are shown in Figure 6.23. The curves showing the greatest amount of ductility are the curves with tensile axial thrust loadings. In general, the amount of ductility decreases as the axial thrust level increases.

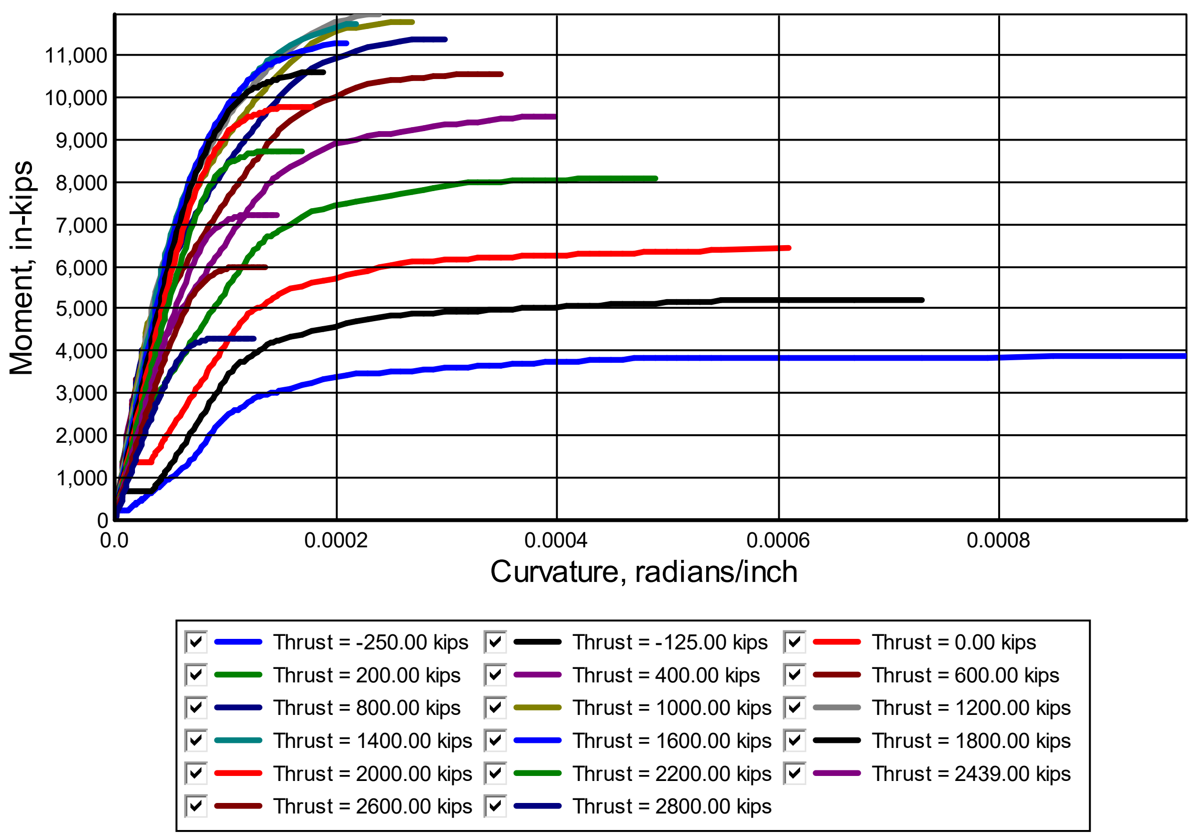


Figure 6.23 Moment versus Curvature for Example 5

Curves of bending stiffness versus bending moment are shown in Figure 6.24. In general, three ranges of *EI* magnitude can be found in the output. The first range of *EI* magnitude is associated with the uncracked stage. The concrete is uncracked and the *EI* is more-or-less constant and is equal to the calculated *EI* for the gross section. The second range of *EI* magnitude is for the cracked stage. A significant decrease in the *EI* value takes place as cracks continue propagating. The third range of *EI* magnitude is for the cracked and large strain stage. The *EI* value is further reduced because the concrete stress-strain curve (shown in the *Technical Manual*) is softened at large strains.

The curves for tensile axial thrust show a behavior that is not found for compressive axial thrusts. For these curves (see the blue and black curves in the lower left corner of the graph), the bending stiffness rises at higher levels of bending moment. The reason for this is the cracking and tensile thrust decreases the size of the compression zone in the cross-section. This causes a larger fraction of the moment to be carried by the reinforcing steel. Since the steel has a higher modulus than that for the concrete, the bending stiffness is seen to increase at higher levels of moment.

The resulting interaction diagram for the reinforced concrete section is shown in Figure 6.25. Note that this graph was produced using the presentation graph utility in order to show the factored curves.

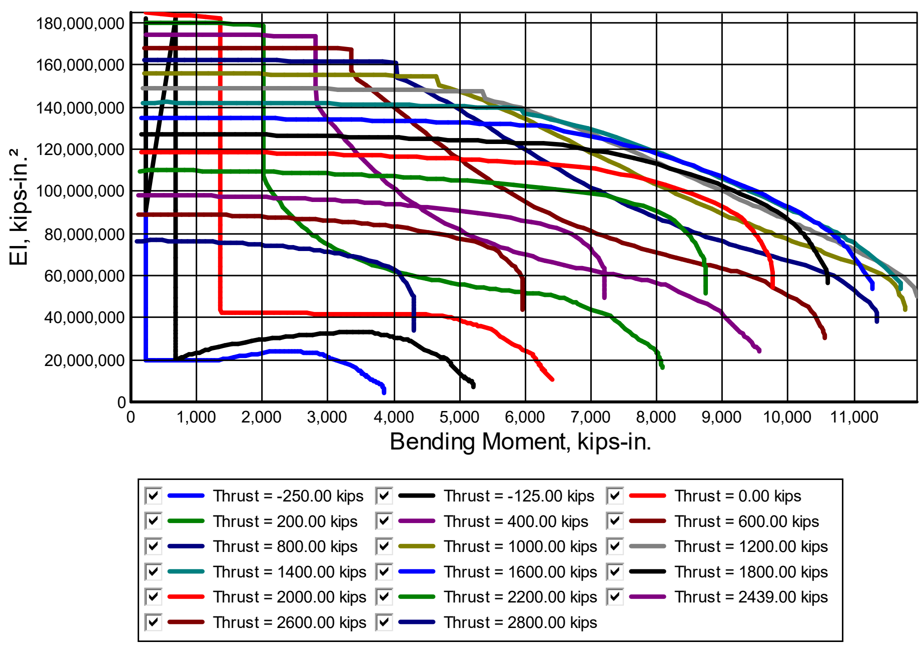


Figure 6.24 Bending Stiffness versus Bending Moment, Example 5

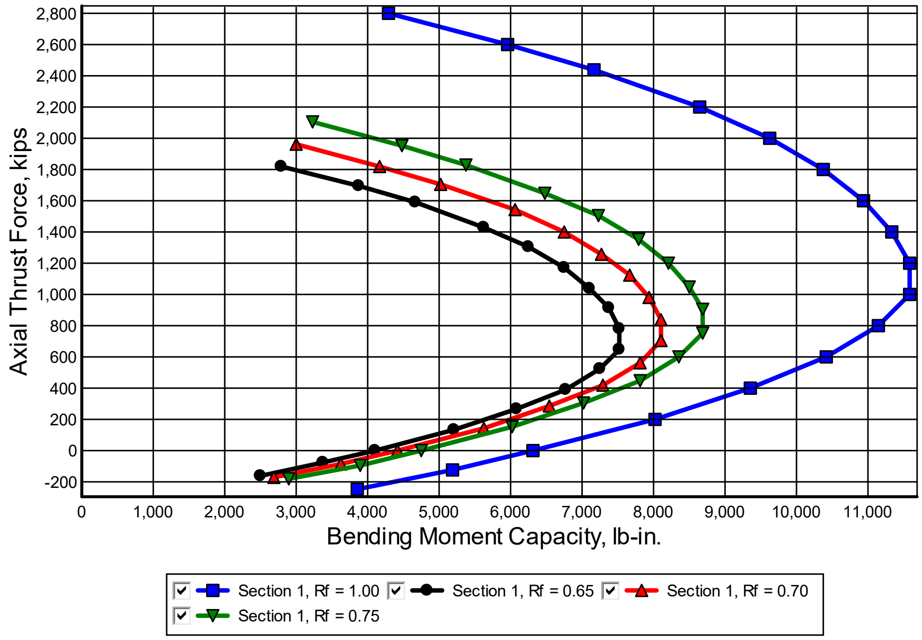


Figure 6.25 Factored Interaction Diagram of Reinforced-concrete Pile, Example 5

6.6 Example 6 – Pile-head Stiffness Matrix

This example is presented to illustrate the capability of LPile to perform analyses that can yield results of direct benefit to the designer of a reinforced-concrete pile. The pile is 30-inches in diameter and 25-ft in length. The pile is embedded in dense sand with an angle of internal friction of 38 degrees. The program will compute the nonlinear moment-curvature behavior and bending moment capacity as the first step. Loading and preliminary data on piles are selected, and the program yields values of pile deflection, moment, shear, and soil resistance as the second step. The third step in the analysis is to compute the optional special analyses, such as pile-head stiffness, pushover analysis, or pile buckling analysis.

The user can compute the ratio of the bending moment capacity computed in the first step to the maximum bending moment computed in the second step to compare to an allowable factor of safety. The properties of the pile can then be changed, if necessary, and further computations made to achieve the final selection of the properties of the pile.

The nonlinear *EI* values computed for a given pile may have a significant effect on the resulting deflections of the modeled pile. The relationship between bending moment, curvature in the pile, and *EI* is computed during the first part of the analysis.

In many computer programs used for superstructure analyses, the user is allowed to input spring stiffnesses in the form of a stiffness matrix to represent foundations under column bases. To demonstrate another useful tool of LPile, this example problem includes a check mark on the option to generate the foundation stiffness matrix. Since the program only deals with lateral loading, only four components of a 6×6 stiffness matrix are generated. Values for the axial spring stiffness and torsional pile response should be generated using other tools.

In general, values are nonlinear in nature and only valid for a certain range of loading. Iterations might be necessary to achieve convergence between superstructure and pile analyses. Output curves obtained from this example problem for stiffness matrix components are shown versus displacements in Figure 6.26 and versus forces in Figure 6.27.

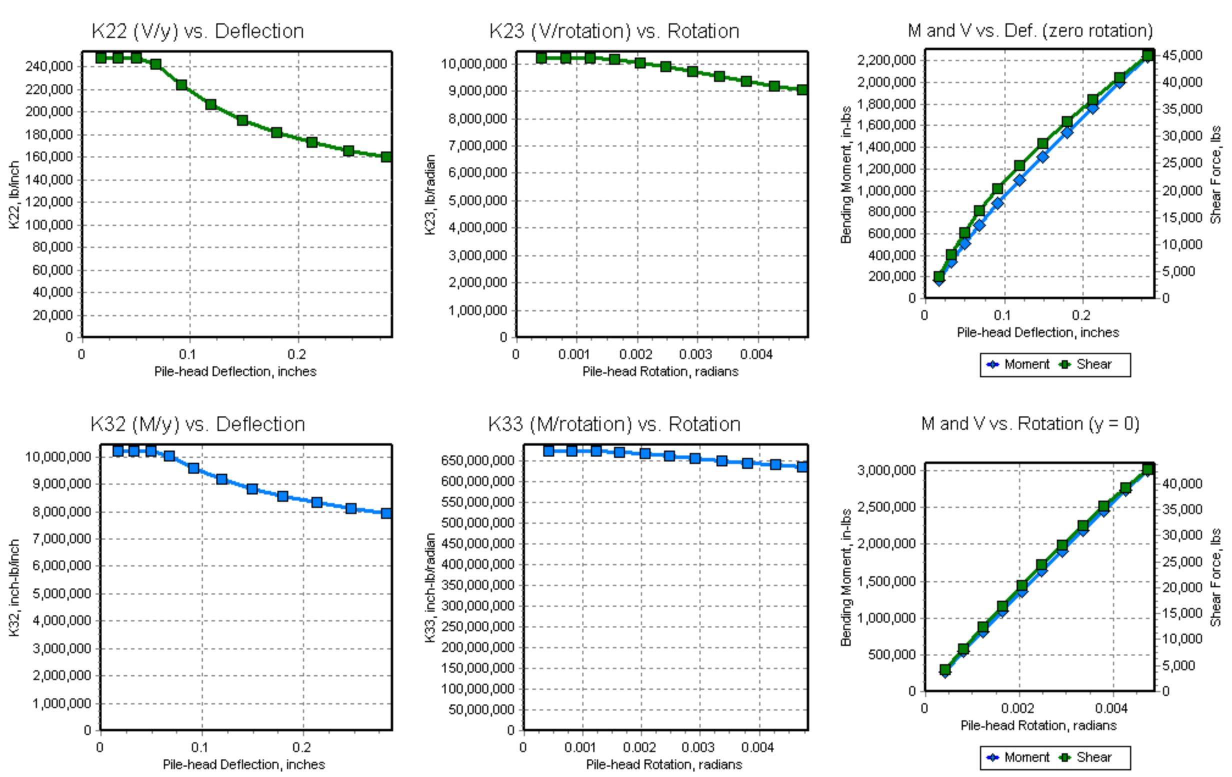


Figure 6.26 Stiffness Matrix Components versus Displacement and Rotation, Example 6

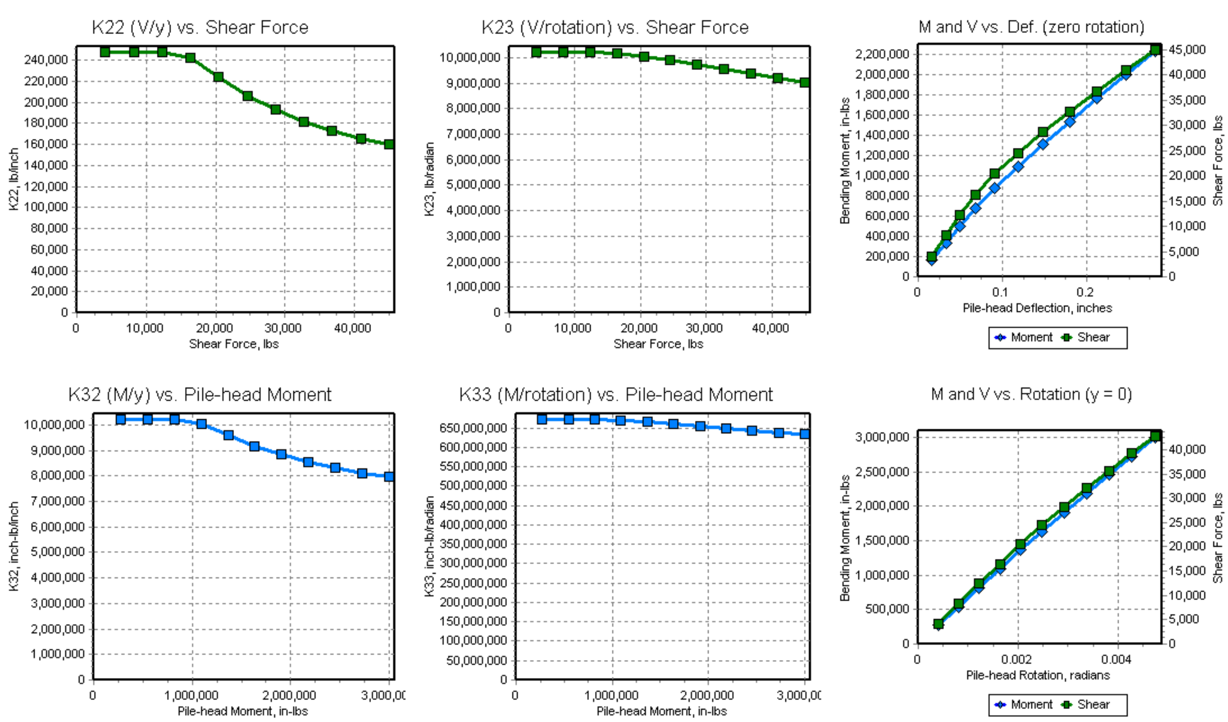


Figure 6.27 Stiffness Matrix Components versus Force and Moment, Example 6

6.7 Example 7 – Pile with User-Input *p-y* Curves and Distributed Load

This example is included to illustrate a common case in which a 16-in. (406 mm)-diameter pipe pile is subjected to both, concentrated loads at the pile head and distributed loads along the pile. The head of the pile will be assumed unrestrained against rotations (free-head case) with no applied moment. A lateral load of 5,000 lbs (22 kN) will be applied at the pile head. The non-uniform distributed loads are 20 lbs/in (3.5kN/m) at the depth of 2 ft (0.6 m) and linearly increase to 100 lbs/in. (17.5 kN/m) at the depth of 5 feet (1.5 meters). Figure 6.28 shows a general view of the pile and soil. The distributed load in this case occurs over a pile length of 3 feet (0.9 meters), and an increment length of 0.25 feet (0.075 meters); therefore, the distributed lateral load can be properly reflected by the 12 increments of length of the pile.

To demonstrate another feature of LPile, the *p-y* curves shown in Figure 6.29 will be entered for this problem. The program interpolates linearly between points on a *p-y* curve and between depths of *p-y* curves.

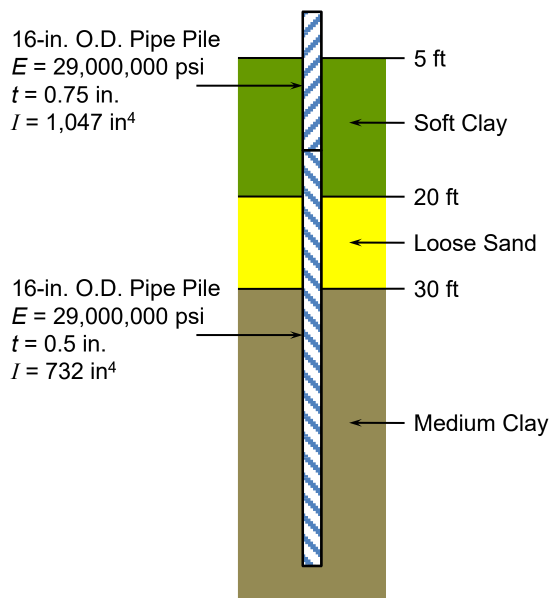


Figure 6.28 Pile and soil details for Example 7

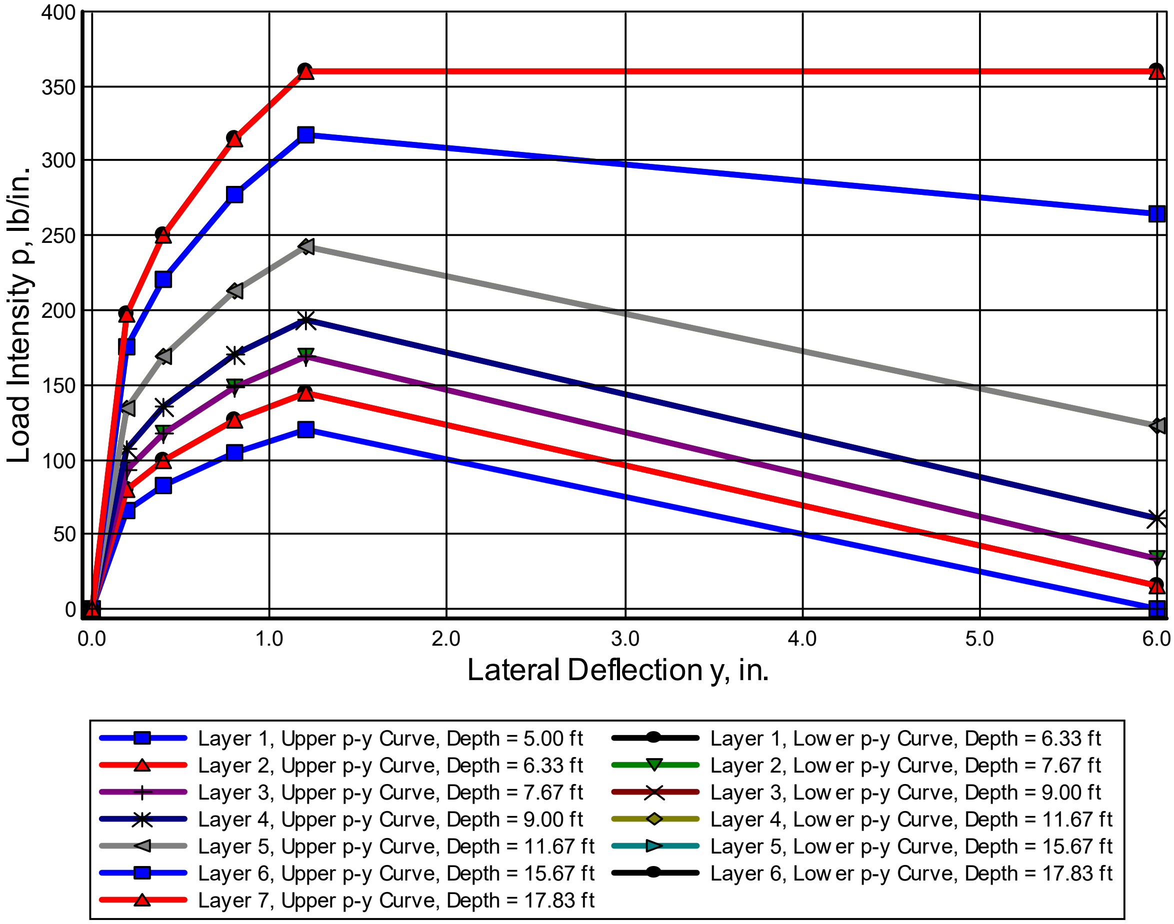


Figure 6.29 User-input *p-y* Curves for Example 7 (Lower curve for Layer 7 not shown)

6.8 Example 8 – Pile in Cemented Sand

A field test for behavior of laterally loaded, bored piles in cemented sands (c-ϕ soil) was conducted in Kuwait (Ismael, 1990). Twelve bored piles that were 0.3-m in diameter were tested. Piles 1 to 4 were 3-m long, while piles 5 to 12 were 5-m long. The study was on the behavior of both single piles and piles in a group. The measured load versus deflection curves at the pile head for a 3-m long single pile and a 5-m long single pile are presented in the paper and can be studied by using the soil criteria for c-ϕ soils.

The piles were reinforced with a 0.25-m diameter cage made of four 22-mm bars for the 3 m-long piles and six 22-mm bars for the 5 m-long piles. In addition, a 36-mm reinforcing bar was positioned at the center of each pile.

The flexural rigidity *EI* varies with the applied moment but a constant value was reported. After lateral-load tests were completed, the soil to a depth of 2 m was excavated to expose the level of the strain gauges for a calibration test. The pile was reloaded and the curvature was calculated from the measurements of strain. The moment in the pile at the strain gauges was determined from statics and the moment versus curvature relationship was determined. The reported flexural rigidity was calculated from the initial slope of the moment-curvature curves as 20.2 MN-m^2, which seems to be on the upper extreme of the normal range for a bored pile with the reported concrete and reinforcing properties.

The subsurface profile at the test site consisted of two layers as shown in Figure 6.30. The upper layer, described as medium dense cemented silty sand, was about 3 m in thickness. The values of c and ϕ for this layer were found by drained triaxial compression tests and were 20 kPa and 35 degrees respectively. The upper layer was underlain by medium dense to very dense silty sand with cemented lumps. The values of c and ϕ were zero kPa and 43 degrees, respectively.

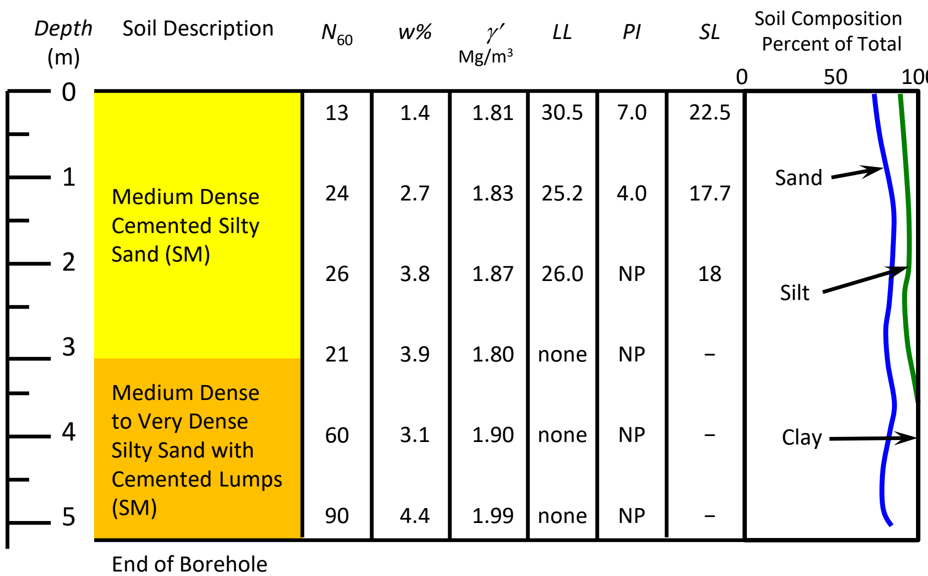


Figure 6.30 Soil details for Example 8

LPile, employing the c-ϕ criteria was used to predict curves of load versus deflection at the pile head for 5-m pile. Good agreement was found between measured and predicted behavior, for pile-head load versus deflection and is shown in Figure 6.31. A comparison between measured and predicted behavior for bending moment versus depth for a shear force of 50 kN is shown in Figure 6.32.

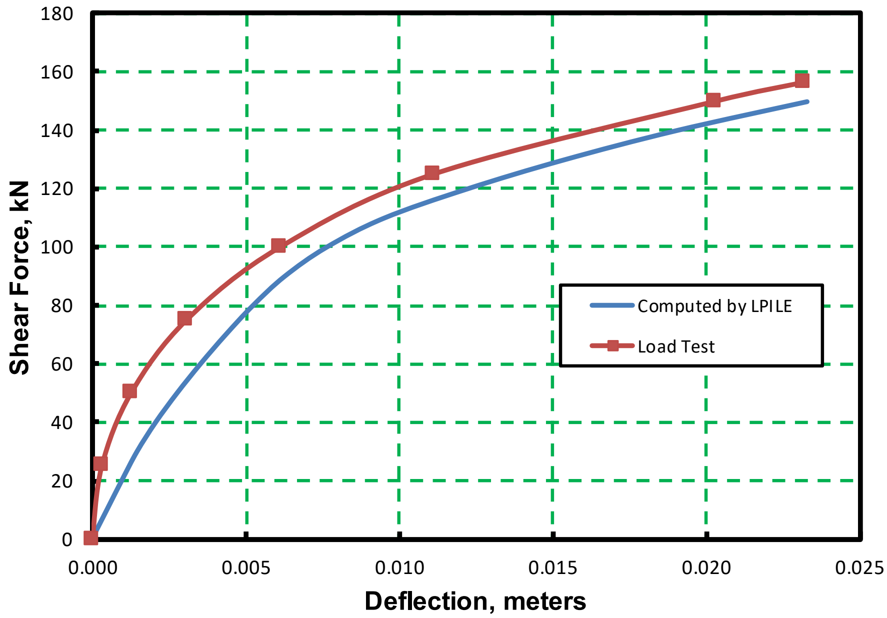


Figure 6.31 Comparison between Measured and Predicted Pile-head Load versus Deflection Curves for the 5-m Pile of Example 8

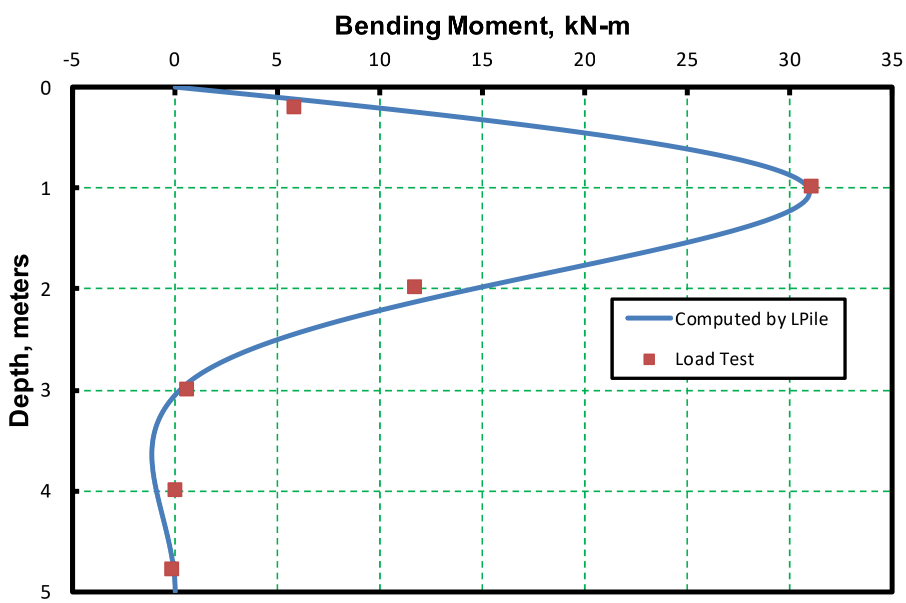


Figure 6.32 Comparison between Measured and Computed Bending Moment versus Depth for the 5-m Pile of Example 8

6.9 Example 9 – Drilled Shaft with Tip Resistance

This example application has been prepared for an idealized drilled shaft whose head is embedded 1 foot in soil. The general pile geometry and soil profile is shown in Figure 6.33.

The soil stratigraphy is composed of three different layers of sand, soft clay, and stiff clay. The soil properties are also shown in Figure 6.33. In addition, there is a water-bearing sand layer at a depth of 60 feet not shown in the figure.

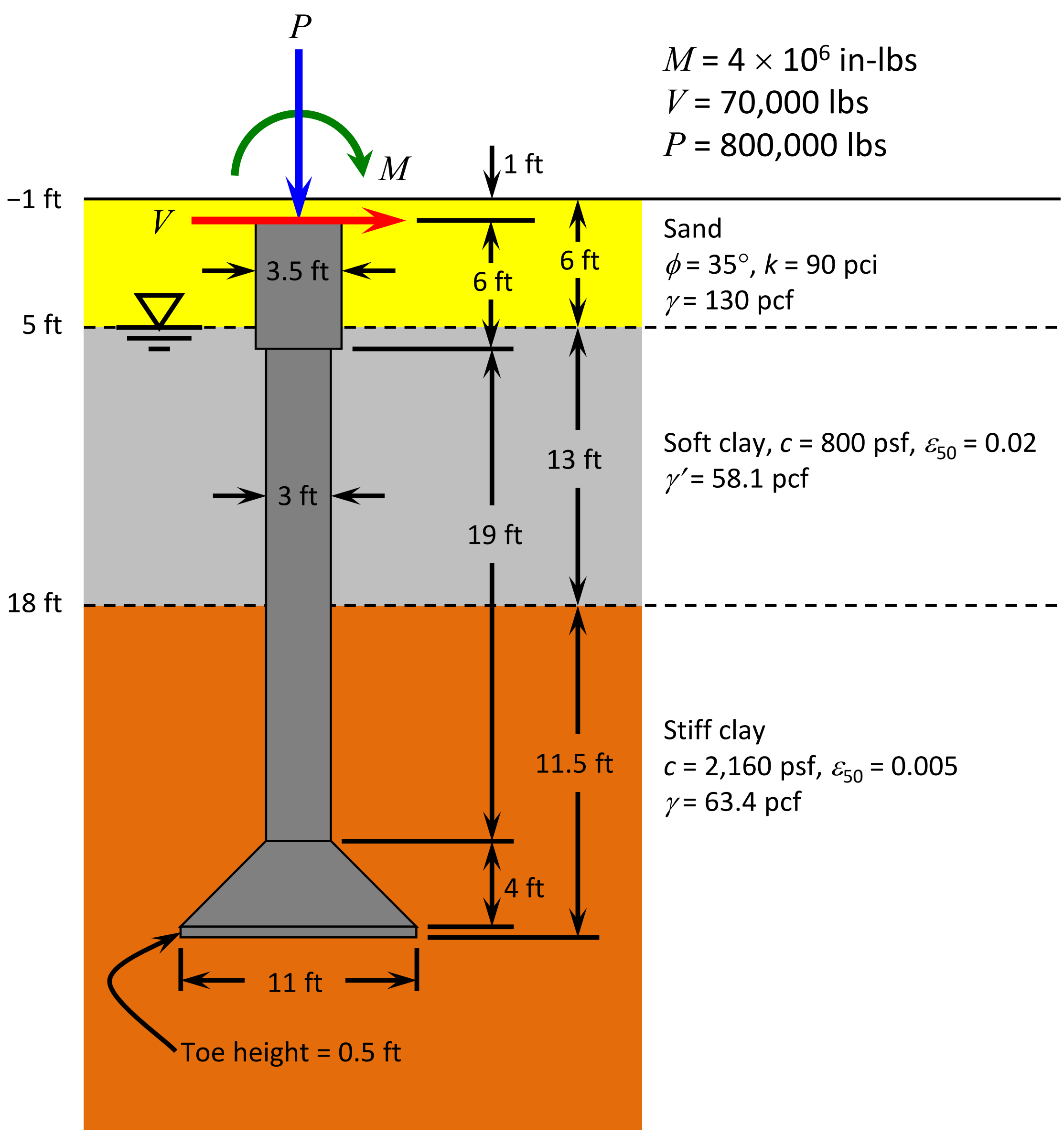


Figure 6.33 Shaft Geometry and Soil Properties for Example 9

The construction procedure for the shaft is to set a temporary surface casing through the upper sand layer and to seal the casing in the soft clay layer. Drilling through the soft clay layer into the stiff clay layer is accomplished in the dry. The use of the enlarged base was selected to avoid tipping the shaft in the underlying water-bearing sand layer. Had a straight-sided shaft been used, the overall shaft length would have been 30 feet longer and drilling with slurry would have been required. In this case, the use of a shorter shaft with an enlarged base would result in faster and more economical construction. The final shaft dimensions consists of four sections, which are a 6-ft long straight section of 42-in. diameter, 19-ft long straight section of 3-ft (0.91-m) diameter, a 4-ft (1.22-m) long section with a 11-ft (3.35-m) diameter enlarged base at the bottom with a 0.5-ft toe section.

The loads shown acting at the top of the pile are primarily axial and the axial bearing capacity and settlement must be checked to withstand the axial load using a separate analysis. The analysis using LPile is performed to check the lateral performance and to design the shaft reinforcement.

The reinforcement in the shaft was sized so that one reinforcement cage could be placed over the full length of the shaft. The reinforcement chosen was 14 No. 9 bars, sized with a diameter that had a 6-inch cover in the upper 42-inch section and a 3-inch cover in the 36 inch section. This amount of reinforcement provided 1.01% reinforcement in the 42-inch section and 1.38% reinforcement in the 36-inch section.

The enlarged base sections were modeled as elastic sections, with the specified dimensions and an elastic modulus of 3,500,000 psi.

A first run of the problem showed that the shaft acted mainly as a short pile with lateral movements observed at the bottom of the shaft. The design engineer then decided to account for the additional amount of soil resistance provided by the large shear forces developed at the enlarged base of the shaft. This was accomplished by checking the option in the Program Options and Settings dialog to include shear resistance at pile tip. Inclusion of tip shear resistance had little effect on the top deflection, reducing the top deflection from 0.994 inches without tip shear to 0.909 inches with tip shear.

The computer-generated *p-y* curves were adjusted to account for closely spaced piles by utilizing *p*-reduction factors that varied with depth from 0.75 for the straight shaft down to 0.3 at the bottom of the enlarged base.

Curves of moment versus curvature for Sections 1 (42-inch) and 2 (36-inch) are shown in Figure 6.34. The factored moment capacities for these two sections for a resistance factor of 0.65 are 14,000 and 11,600 in-kips respectively

The curves of lateral deflection and bending moment versus depth are shown in Figure 6.35.

In addition, the program was asked to generate a plot of pile length versus pile-top deflections in order to optimize the design length. The resulting plot included in Figure 6.36 shows that the pile length should not be further reduced in order to have an appreciable factor of safety from the critical length nor could the length of shaft be increased without the base of the shaft coming too close to the water-bearing sand layer below.

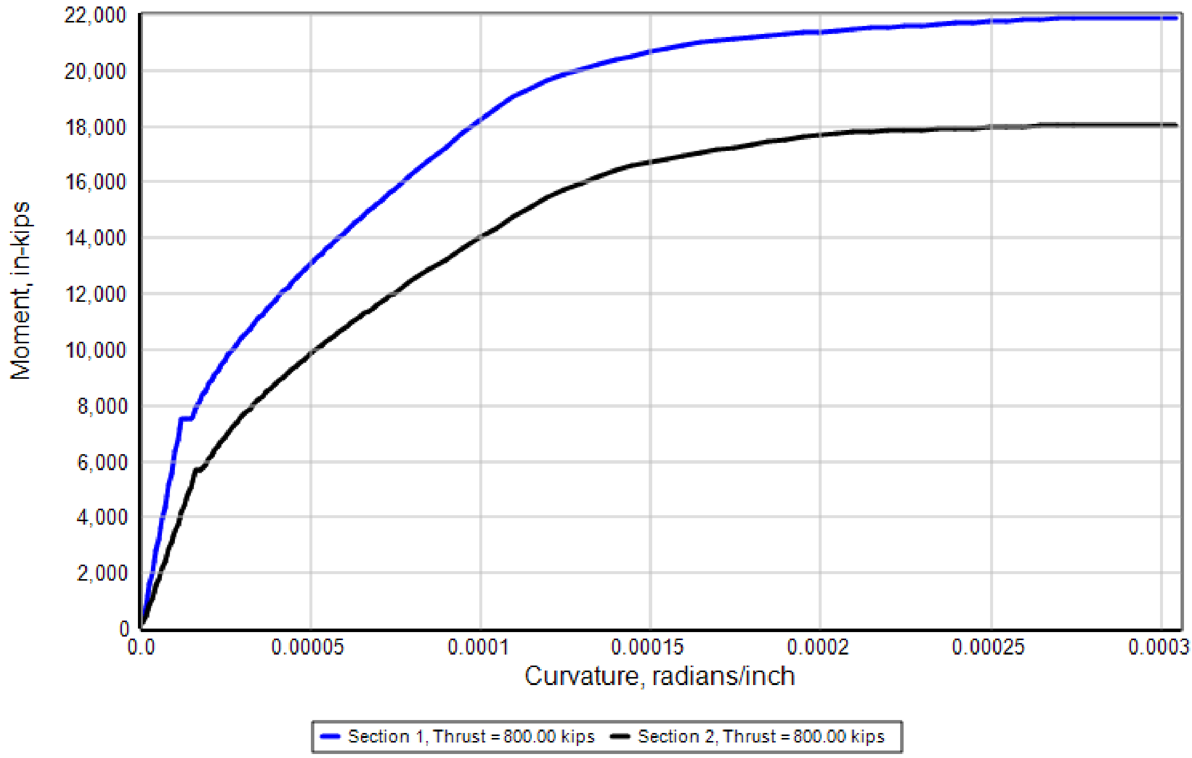


Figure 6.34 Moment versus Curvature for Sections 1 and 2, Example 9

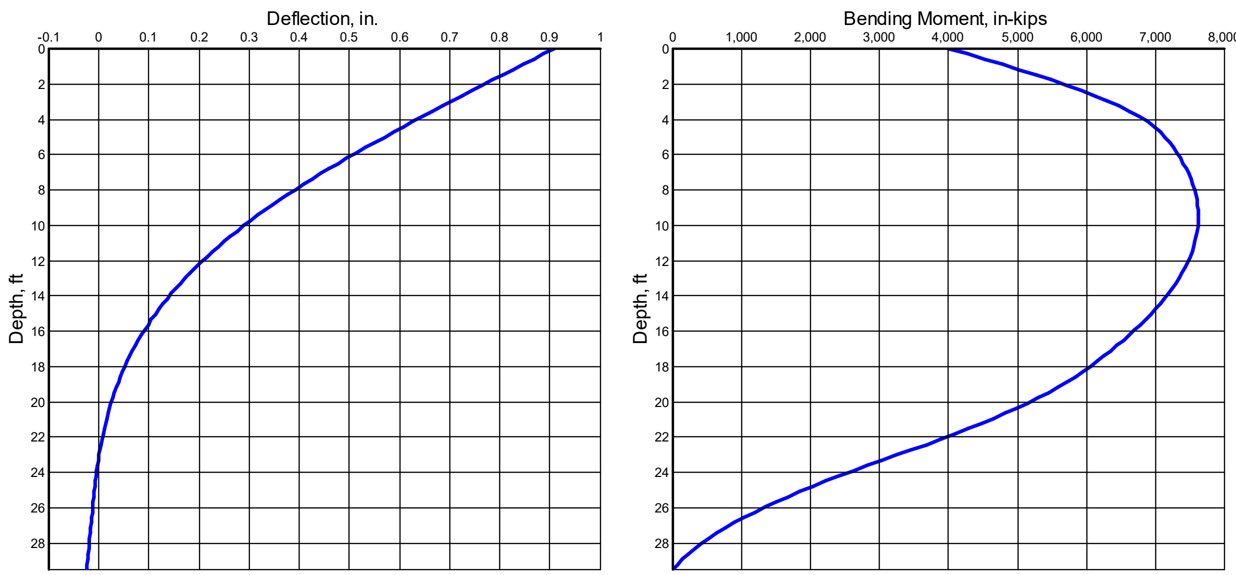


Figure 6.35 Lateral Deflection and Bending Moment versus Depth, Example 9

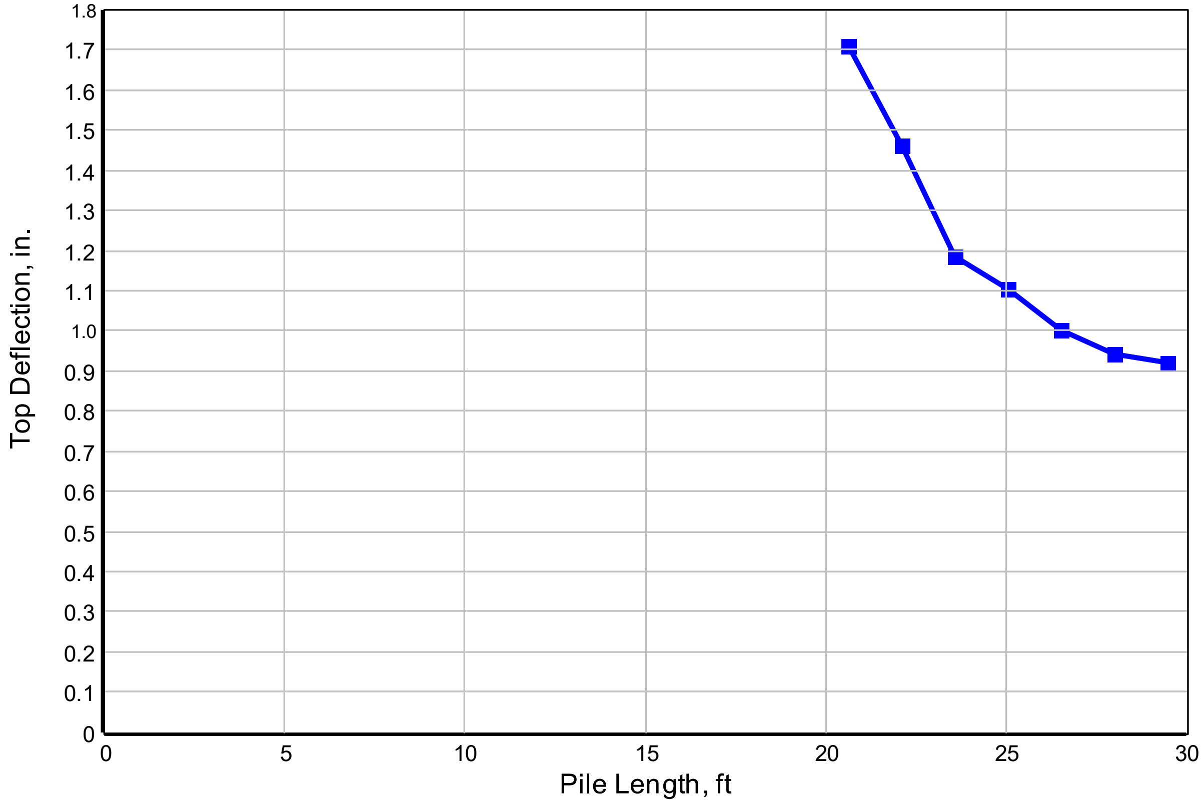


Figure 6.36 Top Deflection versus Pile Length, Example 9

6.10 Example 10 – Drilled Shaft in Soft Clay

This drilled shaft in this example is a 24-inch diameter drilled shaft with eight US#7 reinforcing bars. Often designers elect to use fewer than eight bars in small diameter drilled shafts. In general, using fewer than eight bars is not recommended because when fewer than eight bars are used there is a direction of loading effect on the moment capacity of the drilled shaft. When the number of bars is eight or more, the effect of the direction of loading is largely eliminated.

The summary plots of this analysis are shown in Figure 6.37. This analysis was made using the displacement-moment pile-head loading condition. By examining these graphs, user can see that the pile in not overloaded at the maximum deflection of 1.25 inches and that the moment developed in the shaft is sufficiently large for the cracked-section bending stiffness to be in effect for almost one half of the shaft length. Also, shown are the *p-y* curves for static loading at specified depths for output by the program.

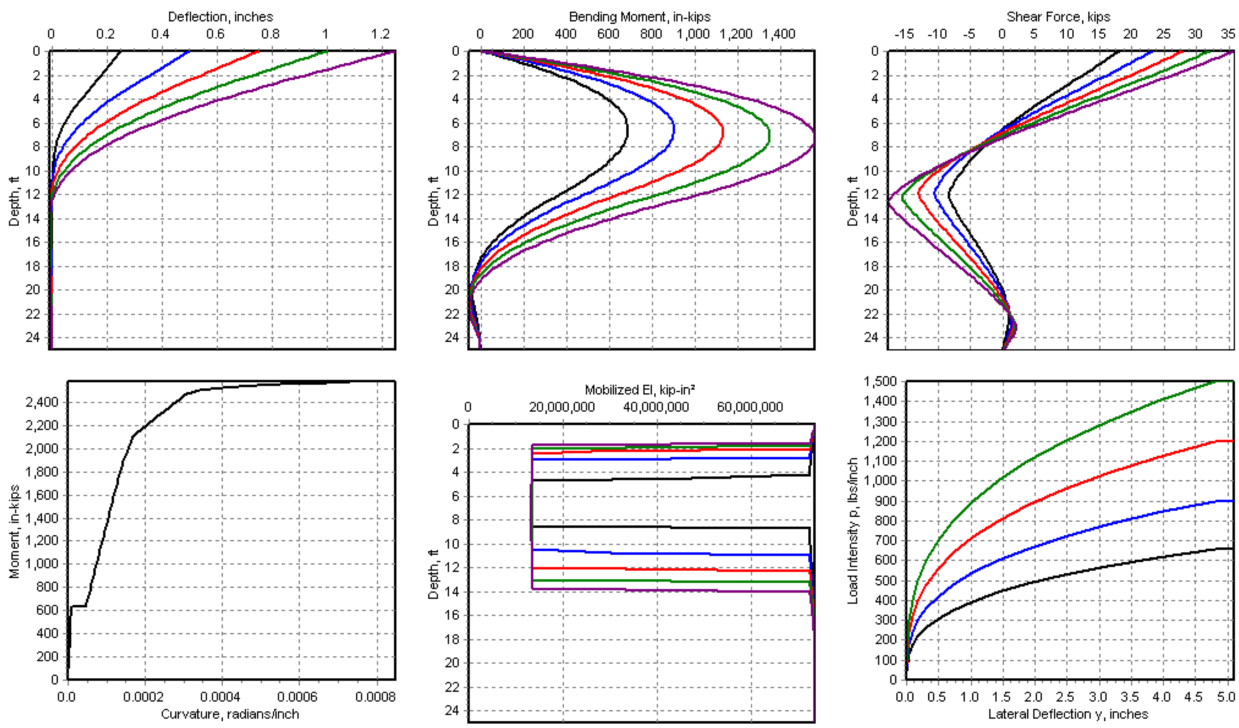


Figure 6.37 Summary Plots of Results for Example 10

6.11 Example 11 – LRFD Analysis

This example is provided as a demonstration of the LRFD analysis features of LPile. The LRFD features of LPile are discussed in Section 3.16.

The computational procedures for making an analysis in LRFD mode are the same as for conventional analysis, except for how the unfactored loads and the load and resistance factor combinations are entered. The entry of data for pile structural properties and for soil layering and properties is the same as for conventional analysis.

The user switches to LRFD mode by marking the check box for *LRFD Analysis Mode* in the Computational Options group of the Program Options and Settings dialog.

The user should be aware that it is possible to store the load and resistance factor combinations in a separate data file that can be re-used in subsequent analyses. The feature for reading of the load and resistance factor combinations is activated through the Program Options and Settings dialog. The saving of the load and resistance factor combinations is activated by the command on the File Menu. Please note that the File Menu command to save the load and resistance factor combinations is visible only when LPile is operating in LRFD Analysis Mode.

All load conditions must be horizontal shear, vertical load, and moment in the LRFD mode combined with distributed lateral loading. The pile-head loads will be converted to their axial and transverse components for battered piles.

One of the features of LPile is the capability to compute the factored load combinations. Once all unfactored loads are entered, LPile will sum all unfactored loads of the same type, including distributed loads, and compute the factored load combination. The factored load combinations can be reviewed prior to analysis by pressing the Display Summary of LRFD Loadings (the Σ button on the button bar). An excerpt from an example of a summary report is shown in Figure 6.38.

```
Summary of Unfactored Loadings for LRFD Analyses
================================================

Number of Defined Unfactored Load Cases = 10

The following table presents the totals of all unfactored loads for each load type.

   Load Case           Horiz. Force            Moment              Axial Force          Number
----------------      ------------      ------------------      ------------------      ------------
Dead Loads  (DL)         12,500.00            15,000.00              106,000.00              2
Live Loads  (LL)          7,500.00            65,000.00               25,000.00              2
Earthquake  (EQ)         25,000.00            25,000.00               10,000.00              1
Impact Load (IM)         10,000.00                 0.00                    0.00              1
Wind Loads  (W)           5,000.00                 0.00                    0.00              1
Water Loads (HW)              0.00                 0.00                    0.00              0
Ice Loads   (Ice)             0.00                 0.00                    0.00              0
Horiz. Soil (Hs)          5,000.00                 0.00                    0.00              1
Live Roof   (Lr)              0.00                 0.00                    0.00              0
Rain Load   (Rn)            100.00             1,000.00                    0.00              1
Snow Load   (Sn)              0.00            10,000.00                    0.00              1
Temperature (Tm)              0.00                 0.00                    0.00              0
Special     (Sp)              0.00                 0.00                    0.00              0


Load and Resistance Factors and Factored Loads for LRFD Analyses
================================================================

Number of Factored Load Combinations = 16

Load Combination No. 1
-----------------------
Load Combination Name = ACI318-2008 (9-1) for ties

Structural Resistance Factor for Flexure = 0.65
Structural Resistance Factor for Shear   = 0.85

Factored Load = 1.40*DL + 1.40*HW

Factored Horizontal Force = 17,500.00
Factored Vertical Force   = 148,400.00
```

Figure 6.38 Example from Summary Report of LRFD Loadings, Example 11

After running the LRFD analysis, an information message will be displayed to alert the user whether or not all load case combinations have been met. The message for a successful analysis is displayed as Figure 6.39.

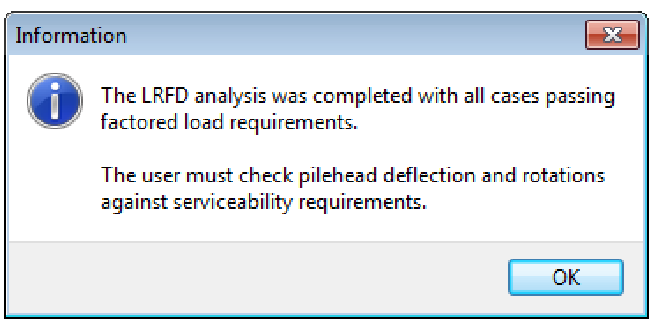


Figure 6.39 Message for Successful LRFD Analysis for Example 11

The LRFD analysis of LPile is currently limited to checking mobilized bending moment values in every pile section against the factored moment capacity of the section and mobilized shear force against input values of structural shear capacity. Checks for displacements and pile-head rotations (i.e. serviceability checks) depend on the purpose of the foundation and are left to the user. Internally computed values of structural shear capacity of the pile are not computed by LPile because standardized methods for computing shear capacity of all section types are between the design standards being followed. However, the user may enter an input value for structural shear capacity and LPile will check the mobilized shear force in the pile against the input value. If the input structural shear capacity is left equal to zero, the checks for shear capacity will be skipped.

6.12 Example 12 – Pile in Liquefied Sand with Lateral Spread

This example is provided as an example of seismic lateral spread loading of a pile. In this example, the pile-head is loaded only by axial load and all lateral loading on the pile is due to seismic lateral spread.

The pile is a 15.2 m-long pipe pile with a diameter of 373 mm and a wall thickness of 10 mm. The soil profile has liquefied sand in the upper 5 meters and a lateral spread profile with a maximum movement of 300 mm that is greatest at the ground surface and decreases down to zero at a depth of 5 meters. The pile and soil profile is shown in Figure 6.40 and the lateral spread profile versus depth is shown in Figure 6.41.

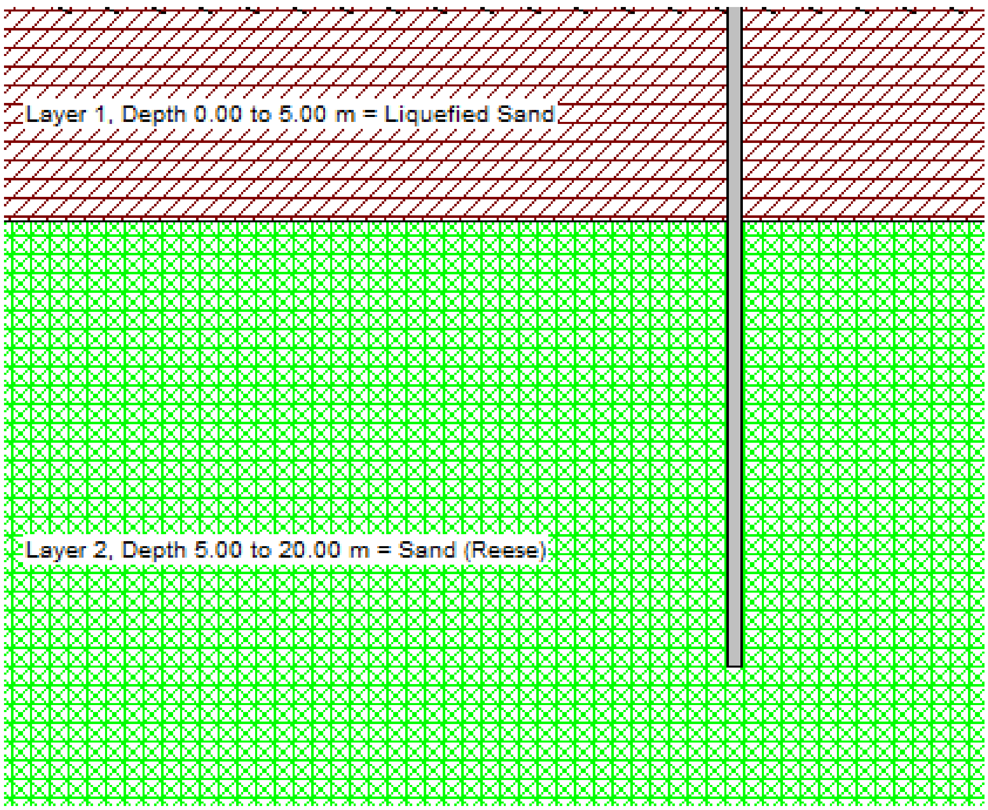


Figure 6.40 Pile and Soil Profile for Example 12

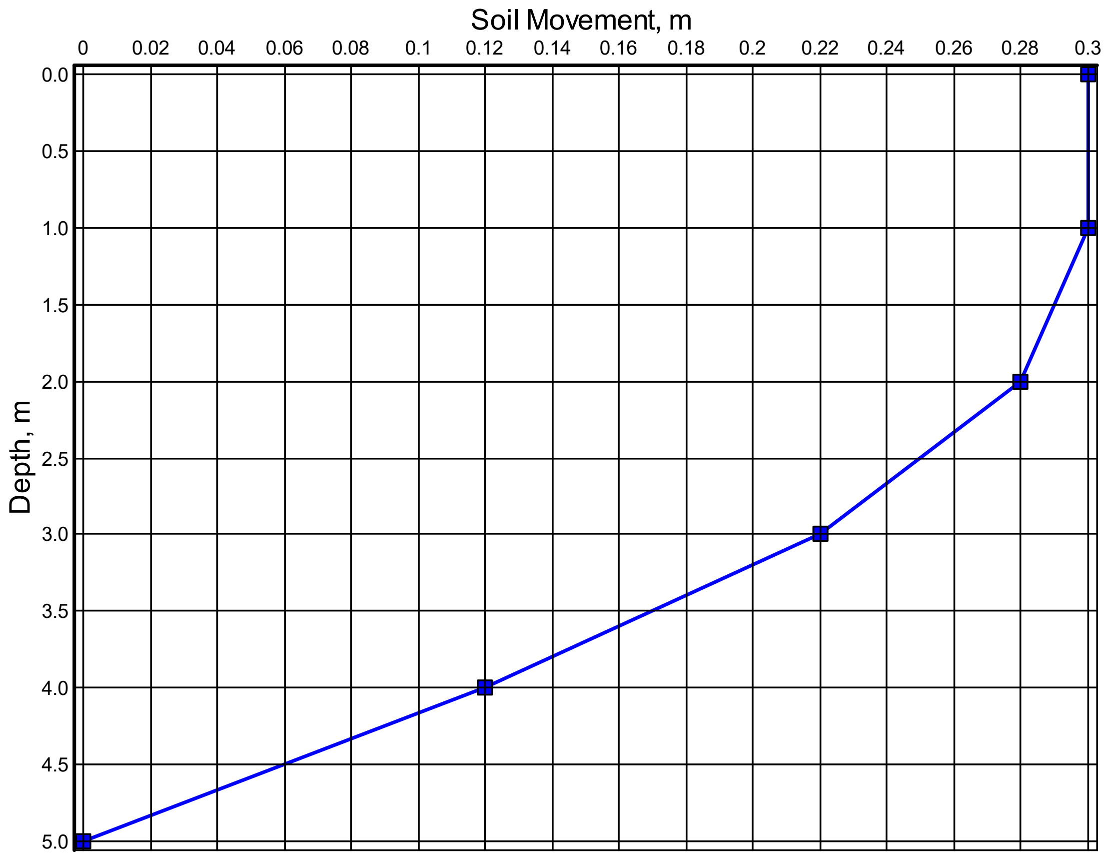


Figure 6.41 Lateral Spread Profile versus Depth for Example 12

The summary graphs of the analysis are shown in Figure 6.42. The graph of moment versus curvature indicates that the plastic moment capacity of the pile is 320 kN-m and the maximum moment developed in the pile is about 165 kN-m, so the pile remains elastic. The graph of lateral spread and pile deflection versus depth shows that the soil flows around the upper portion of the pile. The lateral deflection of the pile head is about 50 mm and the maximum lateral spread displacement is 300 mm, about six times higher.

The performance of the pile would have been significantly worse is a non-liquefied layer were present at the ground surface. In such a case, the non-liquefied layer would move on top of the liquefied layer, thereby creating a large displacement relative to the position of the pile. The lateral loading on the pile would depend on the load-transfer properties of the non-liquefied layer, but failure of the pile by formation of a plastic hinge would be probable.

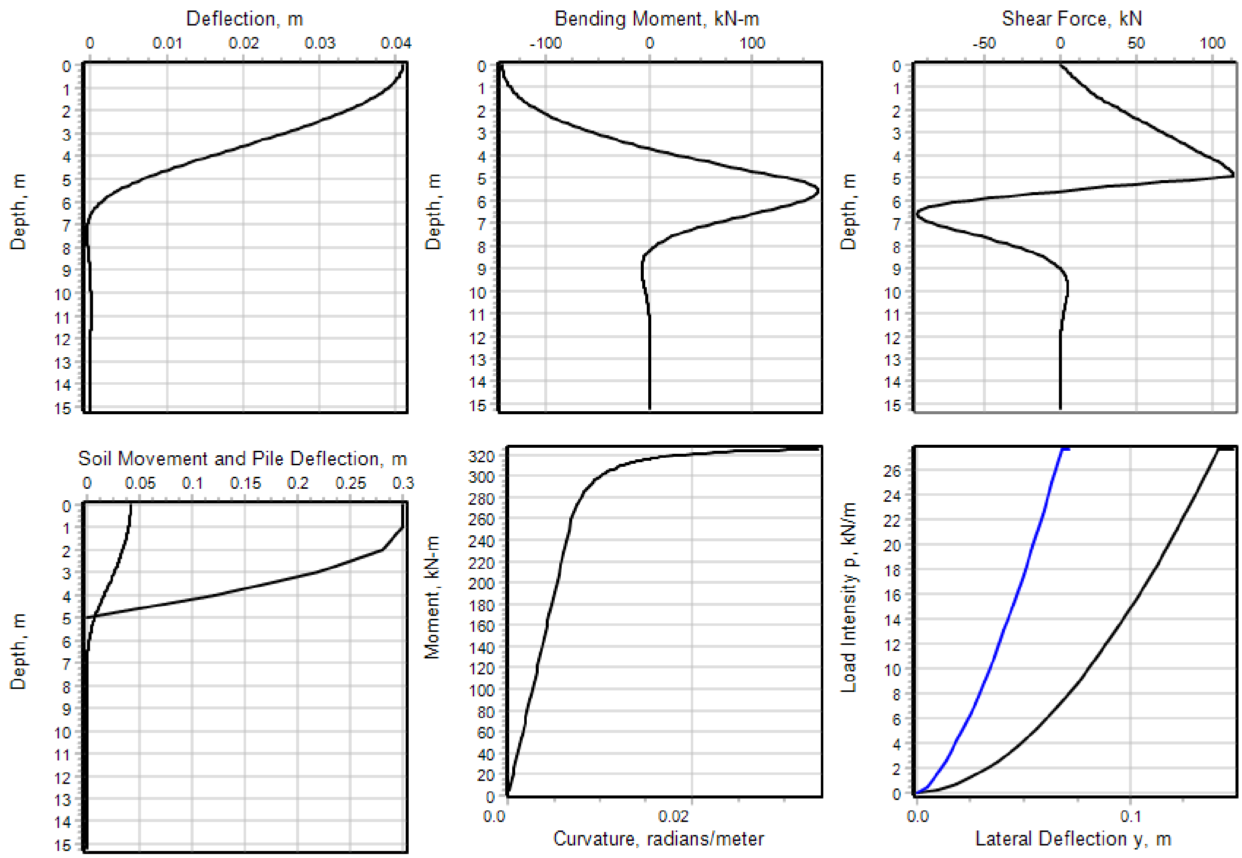


Figure 6.42 Summary Graphs for Example 12

6.13 Example 13 – Square Elastic Pile with Top Deflection versus Length

This example is to demonstrate the feature to compute pile top deflection versus pile length and the use of the modified stiff clay without water *p-y* curve. The pile is modeled as a 25-foot long, 14-inch square elastic pile with a Young's modulus of 3,500,000 psi.

The pile-head loads are shear forces of 5,000, 10,000, 20,000, 30,000, and 40,000 lbs, zero moment, and an axial thrust load of 150,000 lbs. The option to compute pile top deflection versus pile length is turned on in the Pile-head Loadings and Options dialog.

The properties of the modified stiff clay without free water are an effective unit weight of 108 pcf, undrained shear strength of 2,000 psf, *k* of 500 pci, and ε_{50} of 0.005.

The primary use of the modified stiff clay without free water is to generate a *p-y* curve with a softened initial slope. In some areas, load testing has found that the original *p-y* curve computations result in *p-y* curves that have initial slopes that are too stiff. As an example, pile-head load versus deflection curves were computed using both the original and modified *p-y* curve formulations. Theses curves along with the percentage of reduction in stiffness are graphed in Figure 6.43.

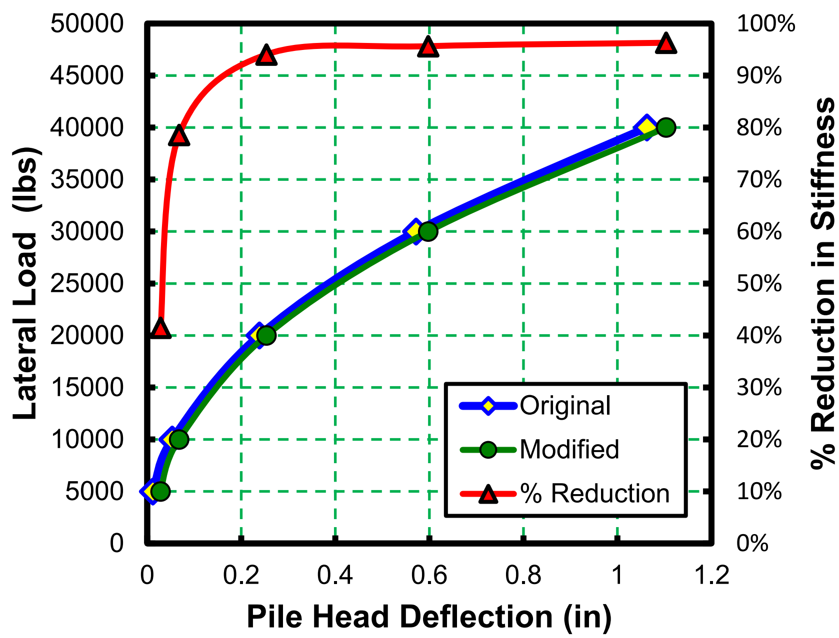


Figure 6.43 Pile-head Load versus Deflection Curves Using Original and Modified *p-y* Curves for Stiff Clay without Free Water and Percentage Reduction in Stiffness for Example 13

The curves of pile top deflection versus pile length are shown in Figure 6.44.

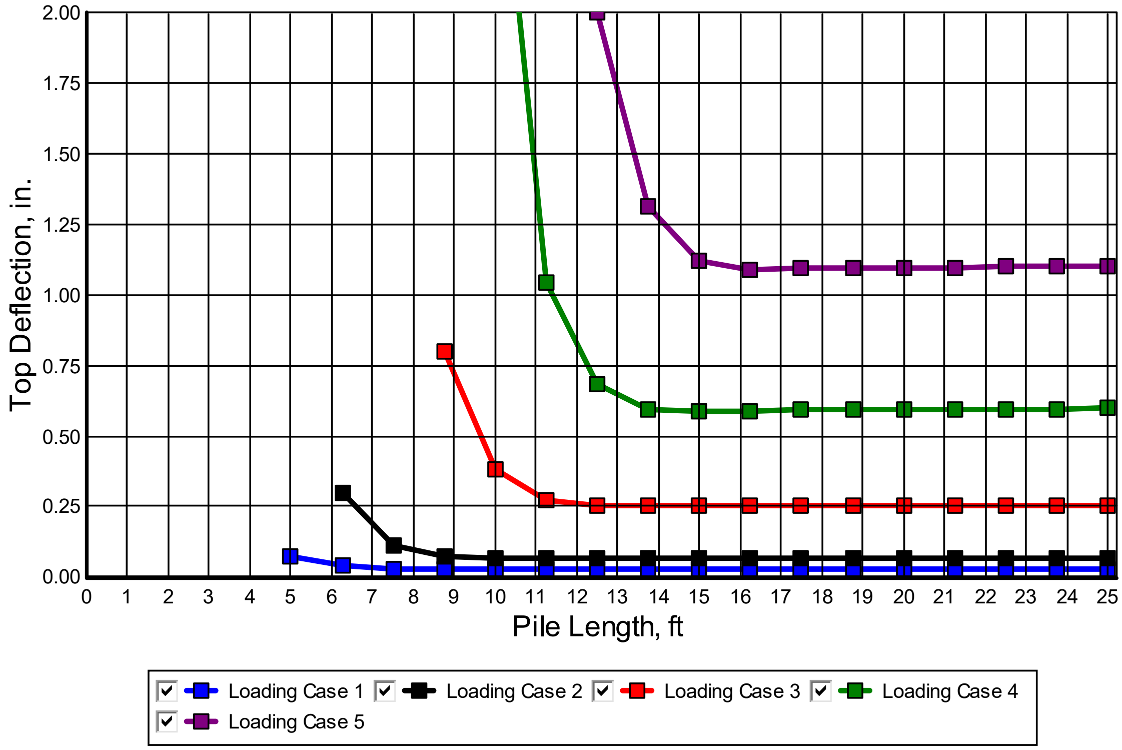


Figure 6.44 Curves of Pile Top Deflection versus Pile Length for Example 13

It should be noted that the length of pile needed to reach the "long pile" behavior (i.e. when the curve becomes horizontal) is depended on the level of loading being consider. Thus, it is important to specify the generation of the pile top deflection versus pile length curve for the maximum loading being considered. It should also be noted that if the pile top deflection is too large for the "long pile" portion of the curve, the deflection can be lowered only by re-configuring the foundation to use either larger diameter piles or more piles.

6.14 Example 14 – Pushover Analysis of Prestressed Concrete Pile

This example is provided as an example of a pushover analysis of a prestressed concrete pile. The pile is a 25-foot long, 14-inch wide, prestressed concrete pile with 1-inch chamfered corners. The reinforcement details for the pile are shown in Figure 6.45.

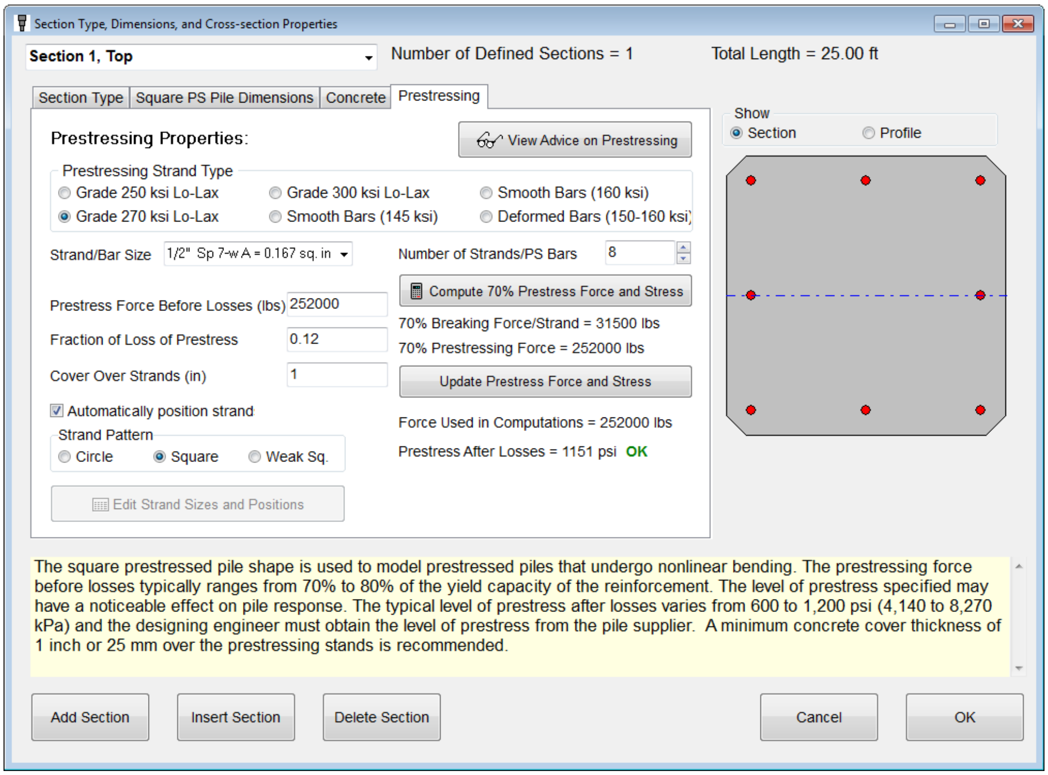


Figure 6.45 Reinforcement Details for Prestressed Concrete Pile of Example 14

It should be noted that the value for Fraction of Loss of Prestressed must be obtained from the pile manufacturer and that this number can vary from supplier to supplier because the procedures and materials used for the pile vary. The magnitude of prestressed after losses typically varies from 600 to 1,200 psi in the United States, with pile driven in softer soils typically having higher prestress values to permit higher resistance to tensile stresses during pile driving. The use of higher levels of prestress also permits lifting of longer piles without damage.

This example uses the Pushover Analysis option available in the Program Options and Settings dialog. One useful feature of the pushover analysis is to determine the lateral deflection and load required to fail a pile under lateral loading.

As will all LPile analyses for piles with nonlinear bending properties, LPile computes the curve of nonlinear bending versus curvature. The curve generated for Example 14 is shown in Figure 6.46 for the two values of axial thrust specified in the Pile-head Loading and Options dialog. The curve shown here indicates that the plastic moment capacity for the pile is approximately 2,100 in-kips.

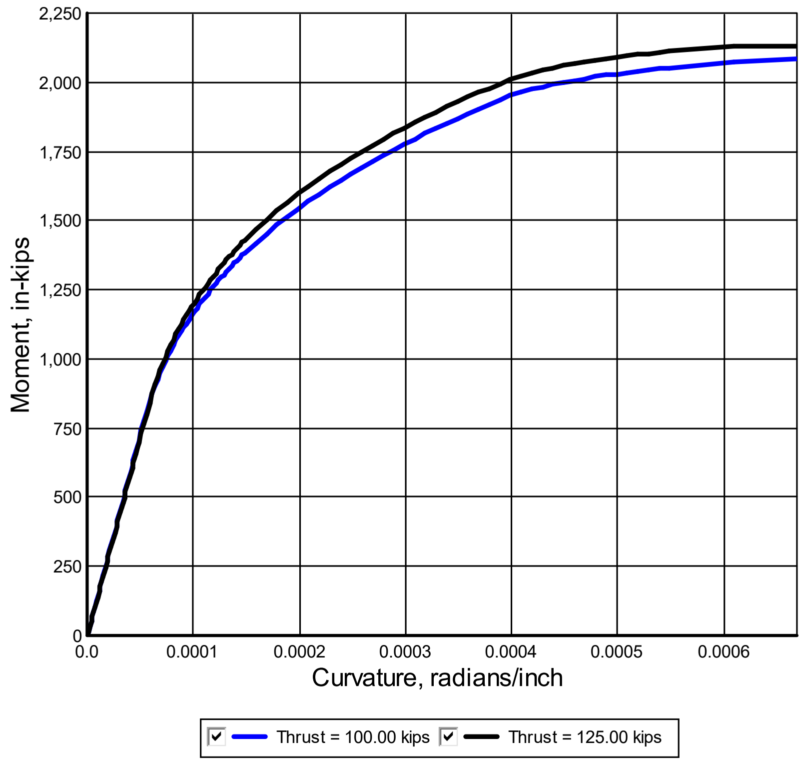


Figure 6.46 Moment versus Curvature of Prestressed Pile for Example 14

The results of the pushover analysis are shown in the two graphs of Figure 6.47. These graphs shown the results for both fixed-head and pinned-head loading conditions for lateral displacements up to 5 inches. For fixed-head conditions, the plastic moment capacity is mobilized at a pile top deflection of 0.625 inches and a shear load of 60,900 lbs. For free-head conditions, the plastic moment capacity is mobilized at a pile top deflection of 2.5 inches and a shear load of 52,400 lbs. Other information gained from these graphs is maximum lateral capacity is approximately 81,000 lbs for fixed-head conditions and is 52,000 lbs for pinned-head conditions.

When interpreting these results, the designer is faced with the decision about which curve is most representative of the pile design being analyzed. For prestressed concrete pile, the answer depends on the pile-head connection conditions utilized for the pile. If the pile is attached to the pile cap with dowels and an inset of a few inches, the pile-head fixity condition is very close to the free-head condition. If the pile is deeply embedded into the pile cap, say 2.5 pile widths or more, the pile-head fixity condition is very close to the fixed-head condition.

For pile-head embedments in between the two conditions discussed above, the pile-head fixity condition is likely to be elastically restrained. Evaluation of the stiffness of the elastic restraint will depend on the structural properties of the pile cap and the pile to pile cap reinforcement details. It will be necessary to use a special computer program to evaluate these conditions.

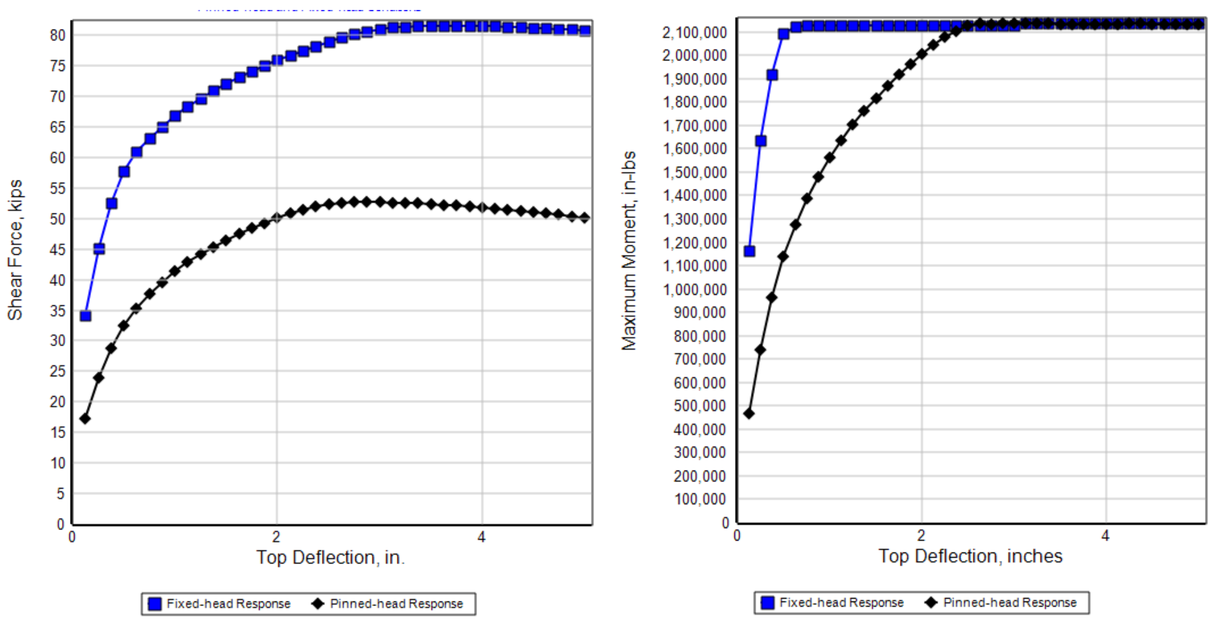


Figure 6.47 Results of Pushover Analysis of Prestressed Concrete Pile of Example 14

6.15 Example 15 – Pile with Defined Nonlinear Bending Properties

This example was provided as an example of a pile with defined nonlinear bending properties. Two analyses were made. The first analysis was of a drilled shaft with internally generated nonlinear bending properties. The second analysis was of a pile with defined nonlinear bending properties in which the output file of curvature and moment values was input. Both SI and USCS unit versions of these data files are provided. A check of the pile response computed by LPile for the two types of piles found that the pile responses were identical, as they should be.

6.16 Example 16 – Pile with Distributed Lateral Loadings

This example was provided as an example of pile with distributed lateral loading. In this example, the pile extends 20 feet above the ground surface and the distributed lateral load is a uniform loading of 50 lbs/inch.

The uniform distributed loading can be checked by evaluating the computed shear force and bending moment at the ground line. The computed shear force at the ground line is

$$V = \int_0^{20} p_{DL}\, dx = p_{DL}\, x \Big|_{(50)(0)}^{(50)(240)} = 12{,}000 \text{ lbs}$$

The computed bending moment at the ground line is

$$M = (p_{DL})(L)\left(\frac{L}{2}\right) = (50)(240)\left(\frac{240}{2}\right) = 1{,}440{,}000 \text{ in - lbs}$$

A check of the output report for values of shear and moment at a depth of 20 feet (240 inches) finds that the compute shear and moment are 12,000 lbs and 1,440,000 in-lbs as expected.

6.17 Example 17 – Analysis of a Drilled Shaft

This example is provided as an example of an analysis of a drilled shaft (bored pile) that was constructed with two sections of different diameters; 42 and 36 inches. The pile and soil profile for this example are shown in Figure 6.48. This is an example of a drilled shaft that was constructed using a temporary casing that extended through the upper sand layer and was sealed into the underlying clay layer. A single-diameter cage was inserted the full length of the shaft, with the diameter of the upper section six inches larger than the drilled diameter of the lower section. This results in the clear cover over the reinforcing steel to be 6 inches in the upper section and 3 inches in the lower section.

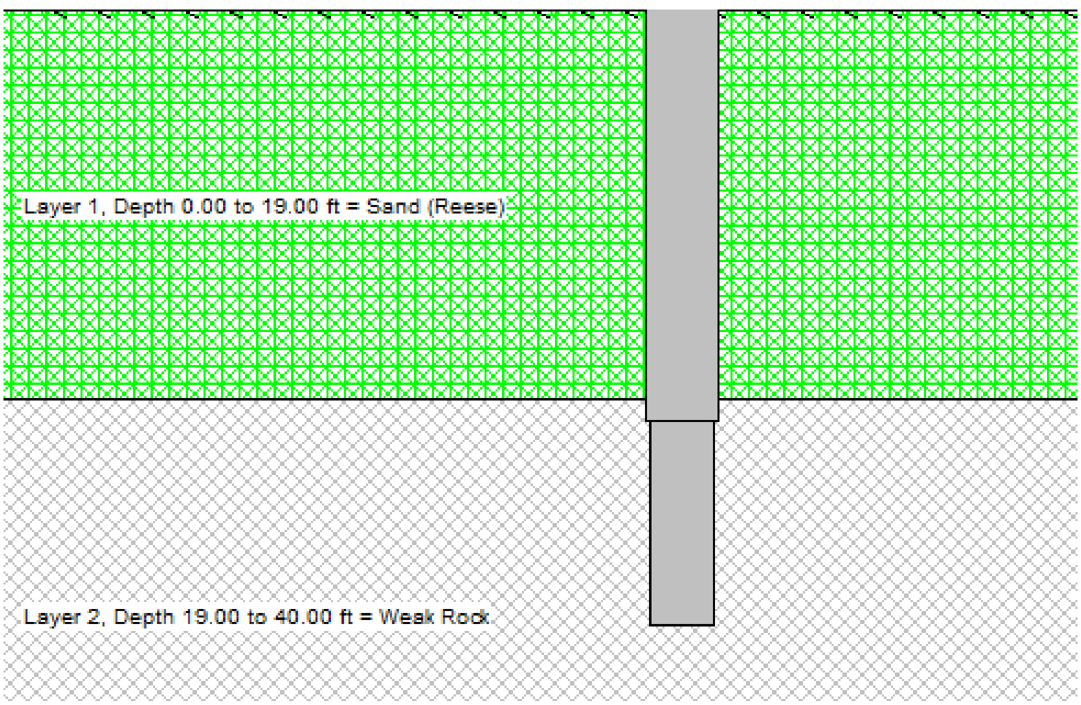


Figure 6.48 Pile and Soil Profile for Example 17

For this example, it was desired that the percent of steel in the shaft be no less than 1 percent. This resulted in a cage with 14 No. 9 bars that resulted in 1.01% steel in the upper section and 1.38% steel in the lower section. The curves of moment versus curvature for the two sections are shown in Figure 6.49. The nominal moment capacity of the upper and lower sections are 14,280 and 12,200 in-kips and the ultimate (factored using a resistance factor of 0.65) are 9,280 and 7,950 in-kips.

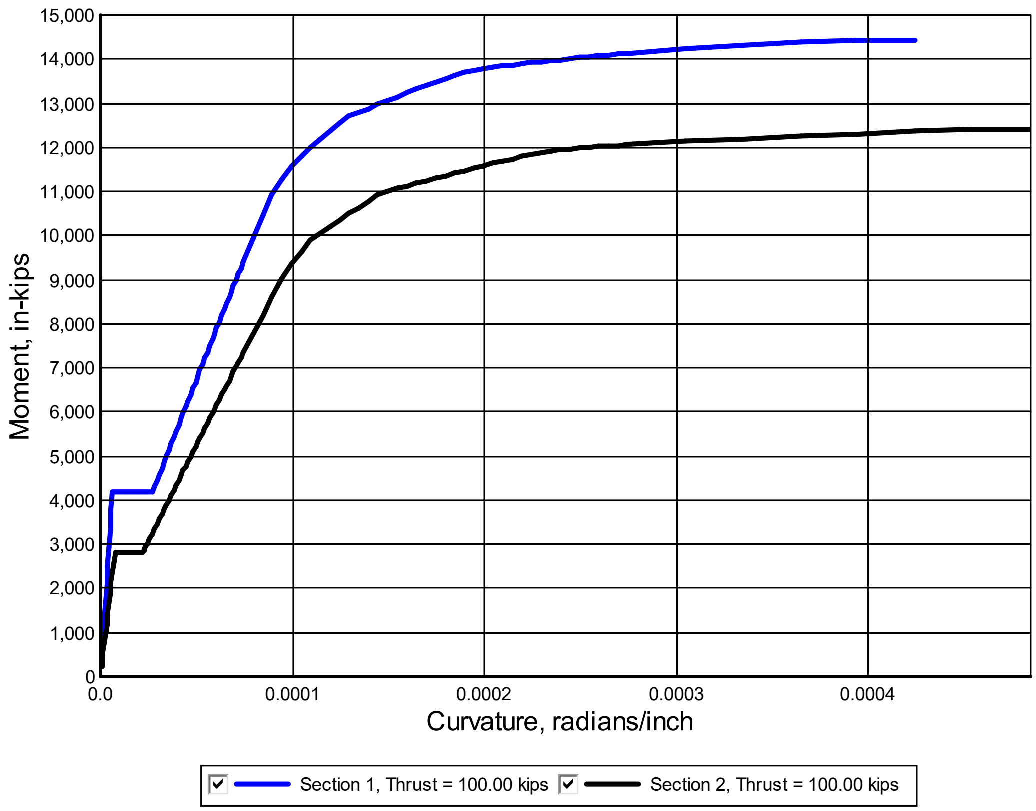


Figure 6.49 Moment versus Curvature for Dual Section Drilled Shaft of Example 17

6.18 Example 18 – Analysis of Drilled Shaft with Permanent Casing

This example is based on Example 17, except that a permanent casing is modeled for the upper section. The nominal moment capacities of the upper and lower sections are 47,900 and 12,200 in-kips and the ultimate (factored using a resistance factor of 0.65) are 31,100 and 7,950 in-kips. The moment capacity of the second section is identical to the second section of Example 17 because the section properties are identical. The curves of moment versus capacity are shown in Figure 6.50.

6.19 Example 19 – Analysis of Drilled Shaft with Casing and Core

This example is based on Example 18, except that a permanent core has been added. In modeling of this pile, it was assumed that the core extended over the full length of the shaft and that the interior of the core was void of concrete.

When modeling the lower section, the section type was drilled shaft with casing and core, but the wall thickness of the casing was set equal to zero to model the section with an interior core only.

The nominal moment capacity of the upper and lower sections are 51,900 and 16,990 in-kips and the ultimate (factored using a resistance factor of 0.65) are 33,700 and 11,040 in-kips. The curves of moment versus curvature are shown in Figure 6.51.

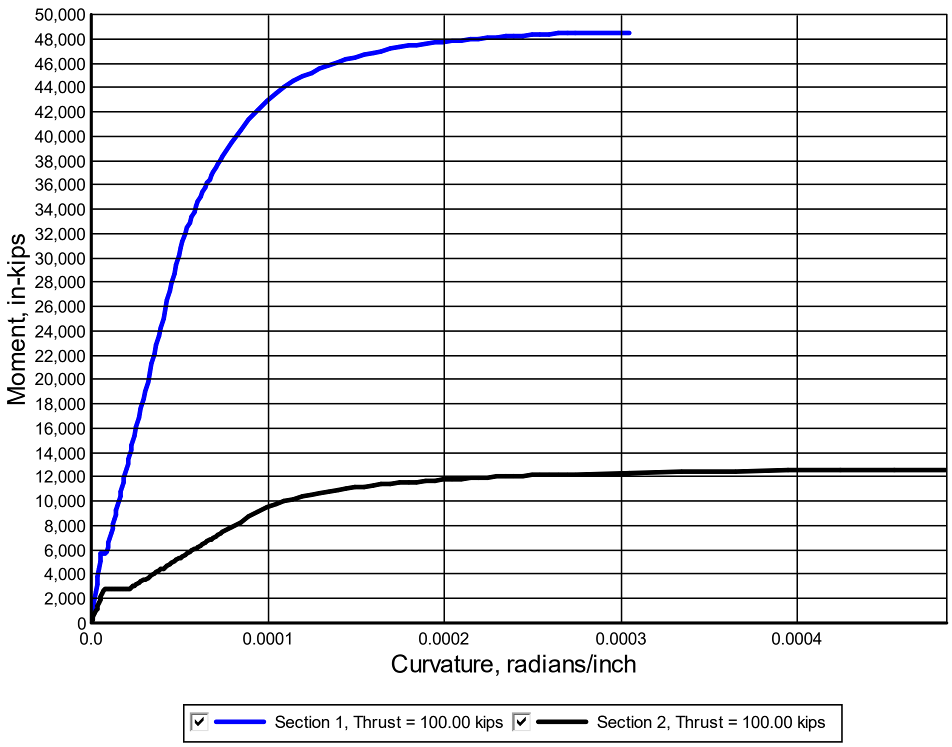


Figure 6.50 Moment versus Curvature for Dual Section Drilled Shaft with Permanent Casing of Example 18

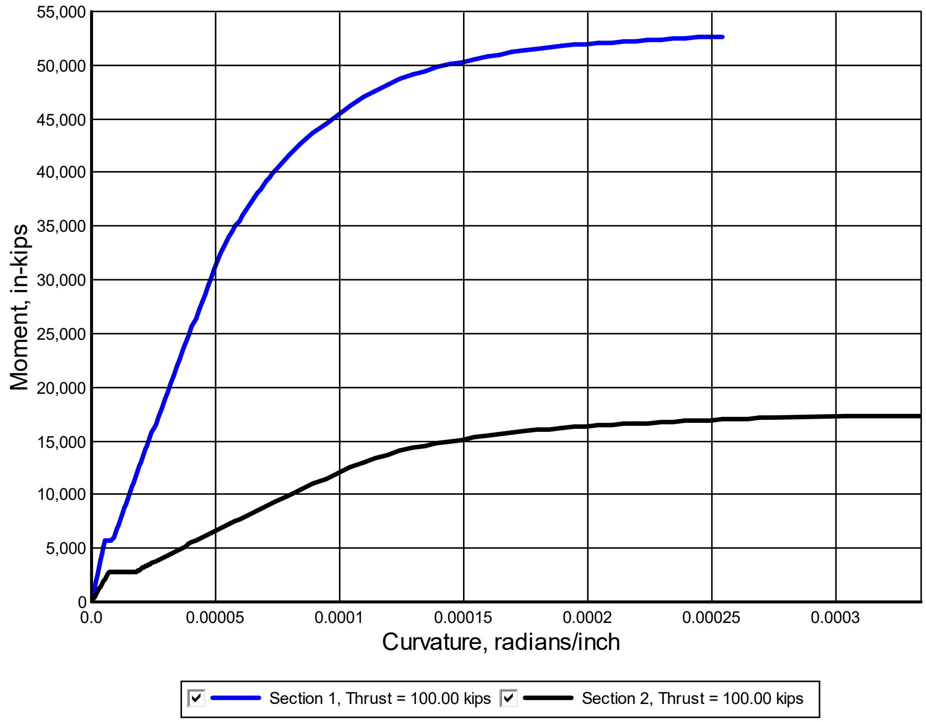


Figure 6.51 Moment versus Curvature for Dual Section Drilled Shaft with Permanent Casing and Core of Example 19

6.20 Example 20 – Analysis of Embedded Pole

This model is provided as an example with the embedded pole option for structural sections. Embedded poles are commonly used in the electrical utility industry. The pole in Example 20 is requested to have a length of 34 feet above ground and the example needs to determine the pole properties and length of embedment. The pile and soil profile along with soil properties for this example are shown in Figure 6.52.

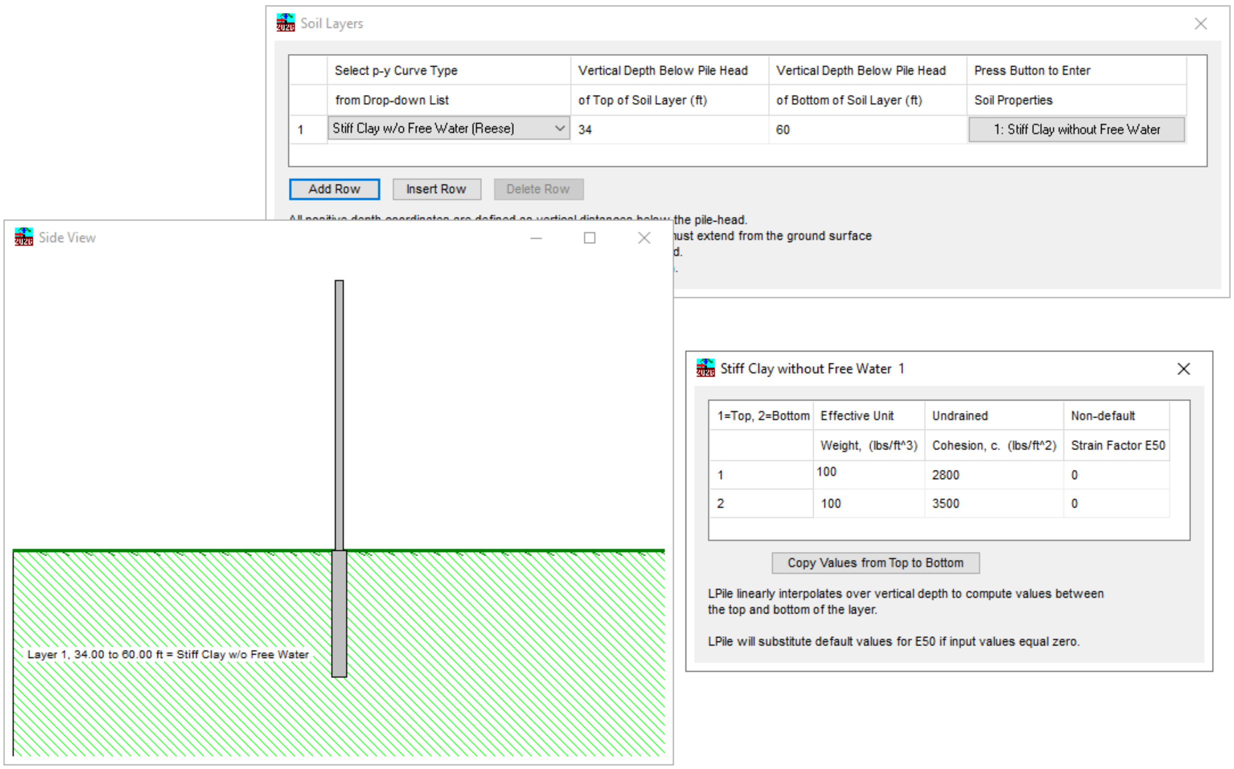


Figure 6.52 Pile and Soil Profile plus Soil Properties for Example 20.

6.20.1 Initial Model

A simple initial model can be created with basic pole properties using a size that is common or readily available for the site. The objective is to get an initial successful run in LPILE.

6.20.1.1 Initial Loading

The loading on the pole shall be computed according to the applicable code criteria to the site, but for simplicity this example assumes an unfactored uniform pressure of 40 psf acting over the projected area of the pole and transformer, with an assumed area of 3 ft x 5 ft at the top of the pole. The associated entries are made under Data > Distributed Lateral Loading. The weight of the transformer is assumed as 1,000 lbs and was added in the Data > Pile Head Loading as Axial Load.

6.20.1.2 Initial Pile Sections

The initial LPILE model defines a pile with two sections. The (top) Section 1 (Data > Structural Dimensions and Material Properties) is defined as Elastic Section with a section length of 34 ft using a Pipe as Structural Shape with 12-in OD and 0.375-in wall thickness (same from top to bottom).

The (bottom) Section 2 (Data > Structural Dimensions and Material Properties) is also defined as Elastic Section but with a section length of 6 ft and using Embedded Pole as Structural Shape with Emb. Pole Diam. (Embedded Pole Diameter) of 12 inches from top to bottom (using the same Area and Moment of Inertia as those of the top Section 1 with a 0.375-in wall thickness). For both sections the Steel Properties tab defines a pole material with 29,000,000 lbs/in^2 for Elastic Modulus of Pipe (Modulus of Elasticity) and 36,000 lbs/in^2 for Yield Stress of Pipe.

6.20.1.3 Comments on Embedded Poles

In some of the practical applications for electric utilities, an oversize hole is drilled to the specified depth, with the steel pole (or wood pole) inserted on the hole, and with backfill compacted in the open void. This type of application would be very difficult to model, since the lateral response of the foundation system is directly related to the stiffness/response of the compacted soil around the embedded pole. It would be difficult to ascertain if the backfill has the proper level of humidity for compaction and if it is well compacted and without voids along the full depth of excavation.

If the modeler assumes that the soil is “well compacted” around the pole then the model in LPILE should conservatively use for the bottom Section 2 (Embedded Pole) the same value of Drilled Diameter entry as that of the actual pole diameter (12 inches for this example). The Drilled Diameter entry defines the diameter that will be used for the internal generation of the lateral response (*p-y*) curves from the soil.

In other applications, the pole is placed in the center of the oversized hole and a cement-stabilized, flowable fill (or flowable concrete) is placed in the annular space around the pole. In this case the annular space between the embedded pole and the soil is going to be solid and likely without voids. This situation is the one modeled in the LPILE example with a Drilled Diameter entry equal to that of the oversized hole, which in this example was assumed to be 24 inches. This is the most recommended installation and modeling procedure for the case of embedded poles.

6.20.1.4 Initial Results

The initial model, saved as *Example 20 Embedded pole -initial.lp13d* runs successfully in LPILE, providing results with an estimated pile-head deflection near 4 inches and ground line deflection of approximately 0.05 inches.

6.20.2 Strength Model

The modeler must follow the local code and/or Owner’s Requirements, but in most cases may be required to check that the structural strength of the pole is acceptable when under ultimate loading (also known as strength or factored loads).

The simple initial model can be created with basic pole properties using a size that is common or readily available for the site. The objective is to get an initial successful run in LPILE.

6.20.2.1 Strength Loading

Many codes prescribe load combinations with several factors. For simplicity, this example assumes a combination with 1.2 dead load factor and 1.6 wind load factor (1.2D+1.6W). The initial loads are thus changed to 1,200 lbs in the Data > Pile Head Loading > Axial Load and the initial Data > Distributed Lateral Loading are multiplied by the 1.6 load factor.

6.20.2.2 Nonlinear Pile Sections

The pile for the strength model should be using nonlinear sections so the model better reflects deformations and load demands. The (top) Section 1 (Data > Structural Dimensions and Material Properties) is now changed to Steel Pipe Section with the same section length and pipe plus material properties as in the initial elastic model.

The (bottom) Section 2 (Data > Structural Dimensions and Material Properties) is changed to Round Shaft with Casing and Core/Insert with the following properties under the Shaft Dimensions tab:

> Casing Outside Diam. of 24 inches (there is no 'casing' so use the outside diameter of the bored hole that is filled with concrete)
>
> Casing Wall Thickness of 0 inches (no casing)
>
> Core Diameter of 12 inches (for the embedded pole)
>
> Core Wall Thickness of 0.375 for the embedded pole)

The Concrete tab should have the properties for the concrete that was used to filled hole. In this example it is assumed to have a Compressive Strength of 4,000 psi and Max. Aggregate Size of 0.75 inches (used to determine if there is sufficient spacing between longitudinal rebars, if those are also used in the section).

A checkmark was placed under Plain Concrete – No Rebars in the Rebars tab since there are no additional longitudinal rebars. Please notice that the selection of Round Shaft with Casing and Core/Insert assumes that the core and the concrete are a composite section. Many codes, such as the ACI 318 (Columns/Reinforcement limits), require a minimum area of longitudinal and transverse reinforcement to prevent concrete spalling and to ensure that the concrete outside the core behaves as reinforced concrete.

For the (bottom) Section 2, the designer may alternatively (and conservatively) place a checkmark under Use Eq. D. of 24 inches in the Shaft Dimensions tab and use a Casing Outside Diameter of 12 inches with a Casing Wall Thickness of 0. This will conservatively use the flexural stiffness of the core only (no concrete) but still engage the *p-y* lateral response curves for the larger 24-in drilled hole.

The Steel Properties tab uses the same properties as those for the initial elastic section (properties for the casing are not used in this example). The Fill Core with Concrete has no checkmark for a conservative assumption that the concrete will not be able to penetrate inside the embedded pole.

6.20.2.3 Strength Checks

The strength model, saved as *Example 20 Embedded pole -strength.lp13d* runs successfully in LPILE. The demands from this model are a maximum bending moment of xxx in-kips on Section 1 and yyy in-kips on Section 2. Those values should be compared to the code-determined capacities of these structural sections. As a very general reference, the user may choose the Nominal Moment Capacity suggested from LPILE (in output text file) and reduce it by the applicable resistance factor. For instance:

Section 1 Nom. Mom. Capacity = in-kips (check w/your local code)

Assume $\phi = 0.9$ (check w/your local code)

Section 1 Fact. Mom. Capacity = in-kips > xxx in-kips OK

Section 2 Nom. Mom. Capacity = in-kips

Assume $\phi = 0.9$ (check w/your local code)

Section 2 Fact. Mom. Capacity = in-kips > xxx in-kips OK

6.21 Example 21 – Analysis of Tapered Elastic Pile

This example is provided to demonstrate the modeling of a tapered elastic pile and to show that the values of cross-sectional area and moment of inertia are computed from the interpolated dimensional properties along the length of the tapered section.

It is possible to check two different results computed by LPile; the computed values of total stress and bending stiffness. The pile in this example is a 30-foot long tapered pipe pile with a top diameter of 16 inches, a tip diameter of 10 inches, a wall thickness of 0.5 inches, and a modulus of elasticity of 29,000,000 psi. Values of cross-sectional area and moment of inertia are computed using:

$$A = \pi \frac{d_o^2 - (d_o - 2t)^2}{4}$$

$$I = \pi \frac{d_o^4 - (d_o - 2t)^4}{64}$$

The table below shows the values of interpolated dimensional properties, cross-sectional area, moment of inertia, theoretical bending stiffness *EI*, and bending stiffness computed by LPile. The values of theoretical bending stiffness and bending stiffness computed by LPile are identical.

Depth, ft	d_o, in.	t, in.	A, in^2	I, in^4	EI, lb-in^2	LPile EI, lb-in^2
0	16	0.5	24.347	731.942	2.123×10^{10}	2.123×10^{10}
5	15	0.5	22.776	599.308	1.738×10^{10}	1.738×10^{10}
10	14	0.5	21.205	483.756	1.403×10^{10}	1.403×10^{10}
15	13	0.5	19.634	384.109	1.114×10^{10}	1.114×10^{10}
20	12	0.5	18.064	299.188	8.676×10^{9}	8.676×10^{9}
25	11	0.5	16.493	227.815	6.607×10^{9}	6.607×10^{9}
30	10	0.5	14.923	168.812	4.896×10^{9}	4.896×10^{9}

Table 6.1 Dimensions, Cross-sectional Area, and Bending Stiffness of Tapered Pile

Values of maximum total stress are computed utilizing the absolute value of bending moment and using

$$\sigma_{total} = \frac{P}{A} + \frac{|M|c}{I}$$

The axial thrust specified in this example is 30,000 lbs. The table below shows values of interpolated dimensional properties, cross-sectional area, moment of inertia, bending moment computed by LPile, theoretical total stress, and total stress computed by LPile. The values of total stress computed by LPile are identical to the theoretical values, with the exception of the digits after the decimal point, where the difference is due to the limited output precision of LPile. The internal value computed by LPile is identical.

Depth, ft	d_o, inches	c, inches	A, in^2	I, in^4	M, in-lbs	σ, psi	LPile σ, psi
0	16	8.0	24.347	731.942	720,000	9101.64	9102.00
5	15	7.5	22.777	599.308	1,0660.050	14658.16	14658.00
10	14	7.0	21.206	483.756	359,980	6623.66	6624.00
15	13	6.5	19.635	384.109	-34,446	2110.79	2111.00
20	12	6.0	18.064	299.188	-5,783	1776.72	1777.00
25	11	5.5	16.493	227.815	931	1841.39	1841.0
30	10	5.0	14.923	168.812	0	2010.38	2010.0

Table 6.2 Interpolated Dimensional Properties, Cross-sectional Area, Moment of Inertia, Bending Moment of Tapered Pile Computed by LPile

6.22 Example 22 – Analysis of Tapered Elastic-Plastic Pile

This example is a variation of Example 21, except that the pile section type has been changed to an "Elastic Section with Specified Moment Capacity" with a plastic moment capacity at the pile head equal to 3,293,739 in-lbs. The plastic moment capacity was computed as the yield moment for a pipe section with 16-inch diameter, 0.5-inch wall thickness, and 36,000-psi yield stress. A graph of moment and computed yield moment versus depth is shown in Figure 6.53.

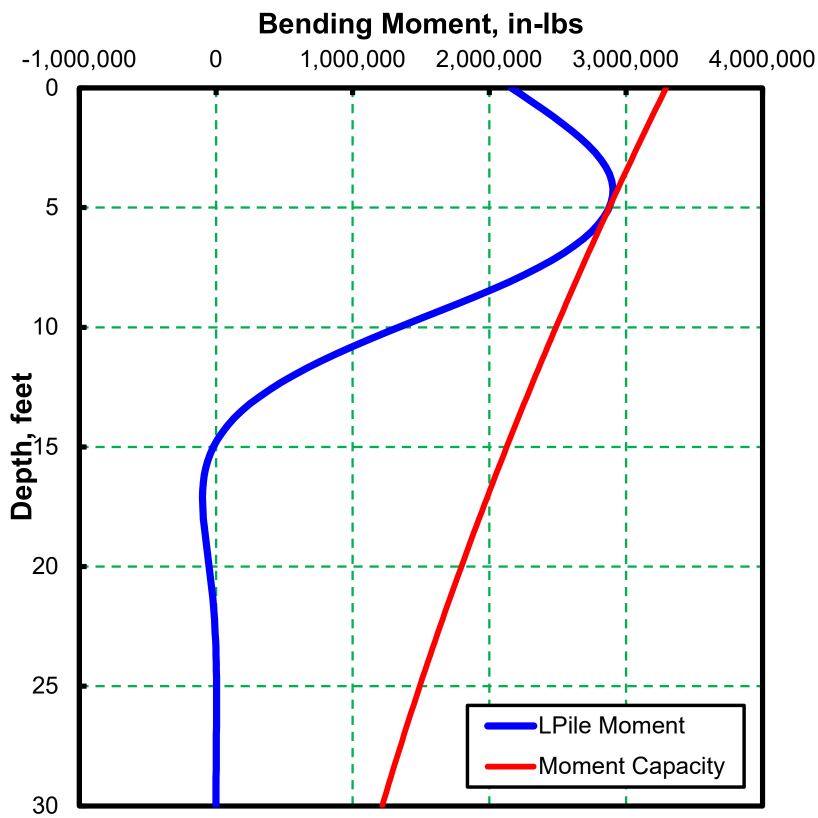


Figure 6.53 Bending Moment and Plastic Moment Capacity versus Depth for Example 22

A close examination of Figure 6.53 will find that the variation in plastic moment capacity is nonlinear with depth due to the tapered dimensions. This is because LPile will compute the yield stress of the pile material from the dimensional properties and input value of plastic moment capacity at the top of the section. LPile then computes the plastic moment capacity at other points in the section using the dimensions interpolated with depth and the interpreted value of yield stress.

LPile does not perform computations for tapered sections if the geometric shape is specified as an H-pile section. In those cases, the plastic moment capacity of the full section is set equal to the input value for plastic moment capacity for the section.

6.23 Example 23 – Output of *p-y* Curves

LPile is capable of generating 17-point *p-y* curves at user-specified depths. Example 23 is provided as a demonstration of this feature of LPile. The feature to generate *p-y* curves for output is enabled by checking the box in the Output Options of the Program Options and Settings dialog as shown in Figure 6.54.

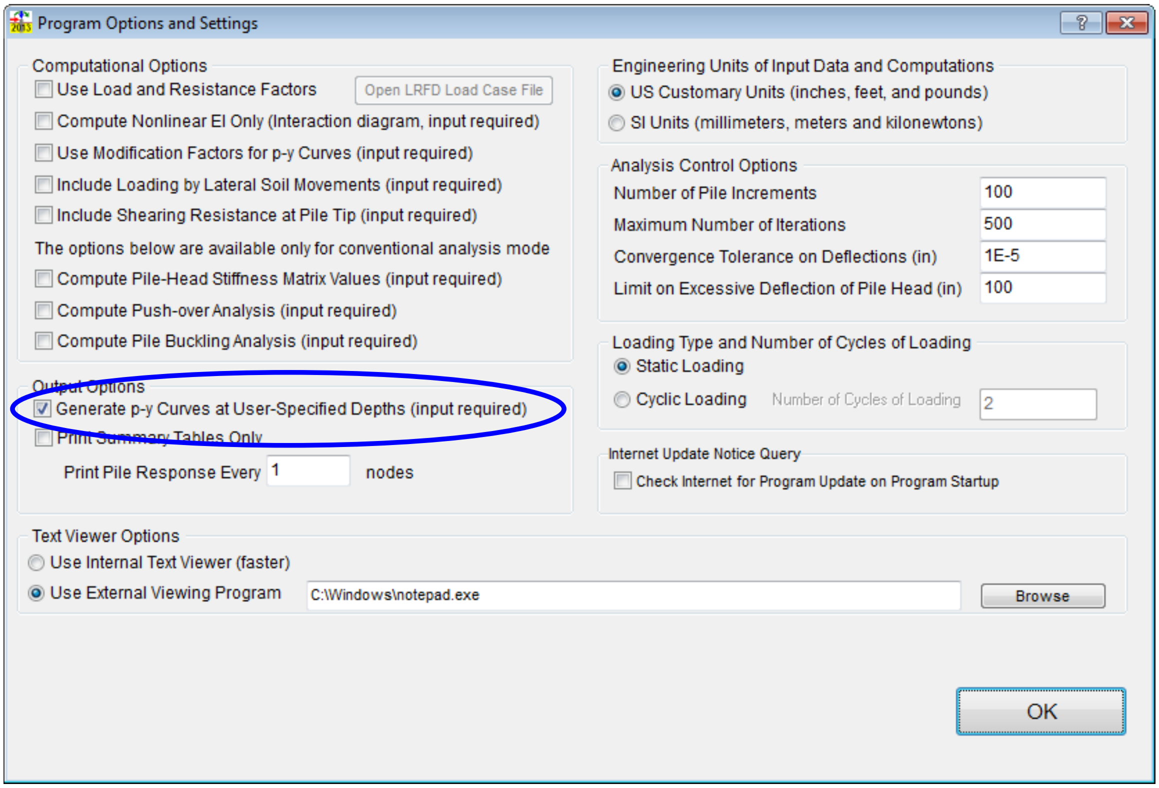


Figure 6.54 Program and Setting Dialog Showing Check for Generation of *p-y* Curves

The pile and soil profile for Example 23 is shown in Figure 6.55. The soil profile is composed of a number of different soil types, plus the lowest layer is defined as having user-input *p-y* curves.

When the graph of *p-y* curves is created, 17-points along the curves are generated. The spacing of the points depends on the formulation of the *p-y* curves. For most types of *p-y* curves, the points are representative of the shape of the curves, but for others, the *y*-values are chosen as fixed fractions of the pile diameter. In these cases, the plotted shape of the *p-y* curve is accurate only at the data points. The graph of *p-y* curves for Example 23 is shown in Figure 6.56.

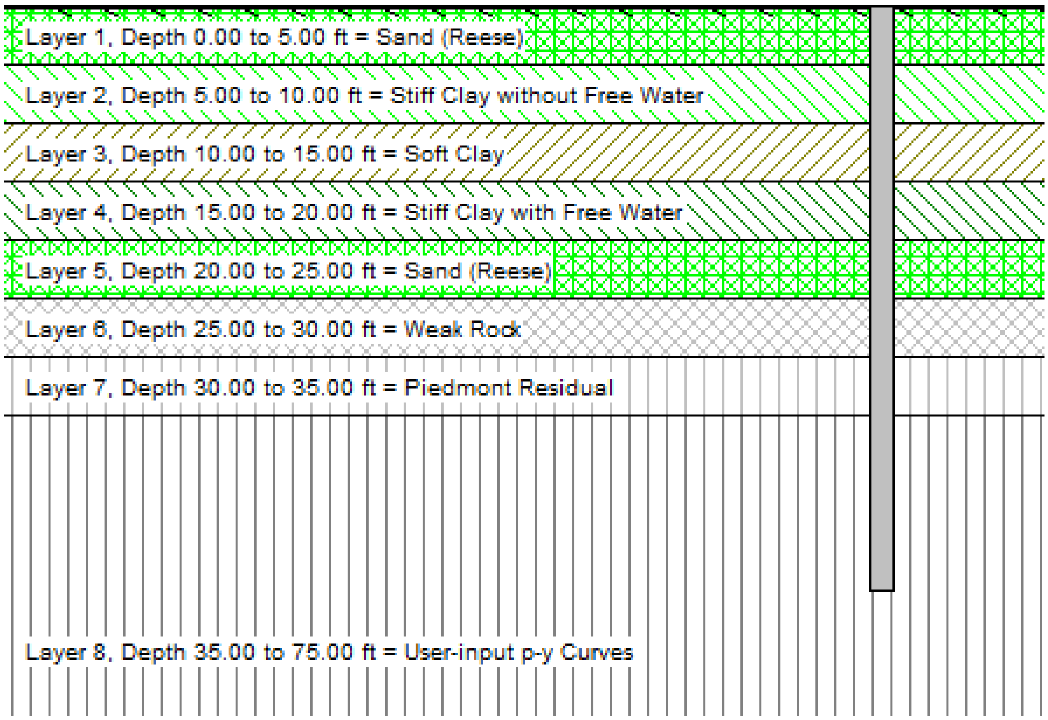


Figure 6.55 Pile and Soil Profile for Example 23

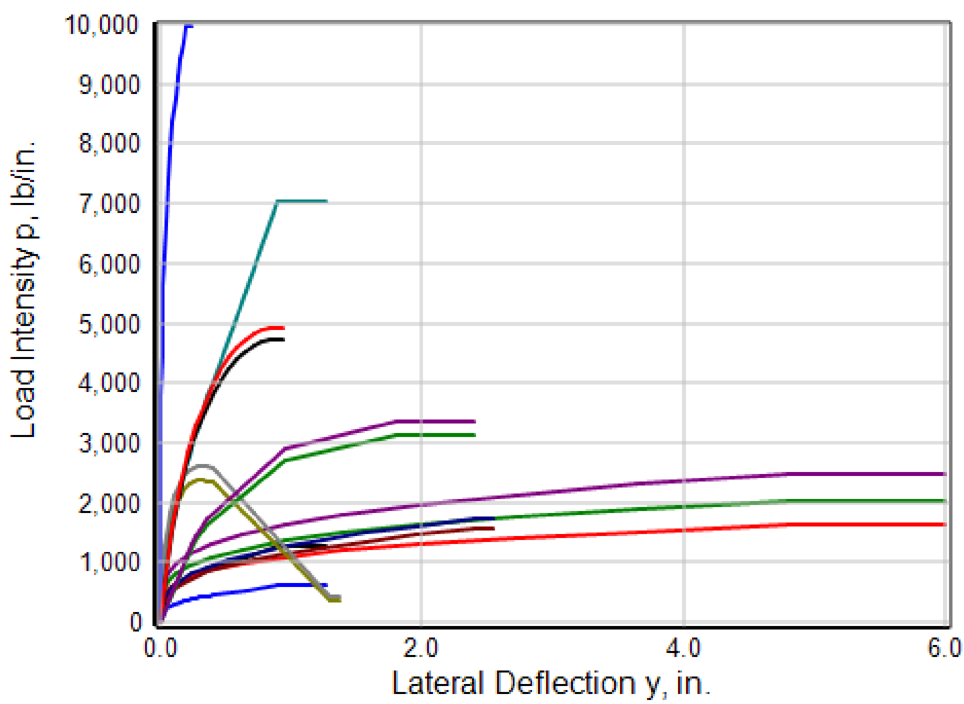


Figure 6.56 Standard Output of 17-point *p-y* Curves for Example 23

Figure 6.57 is the same as Figure 6.56 except that the display of the curves for the upper depths is turned off. The user-input curves are defined using only five points, not 17 and the curves are defined at the top and bottom of the layer at 35 and 75 feet below the pile head. The curves displayed in Figure 6.57 are composed of 17 points and the curves are interpolated with depth at 40 and 49 feet below the pile head.

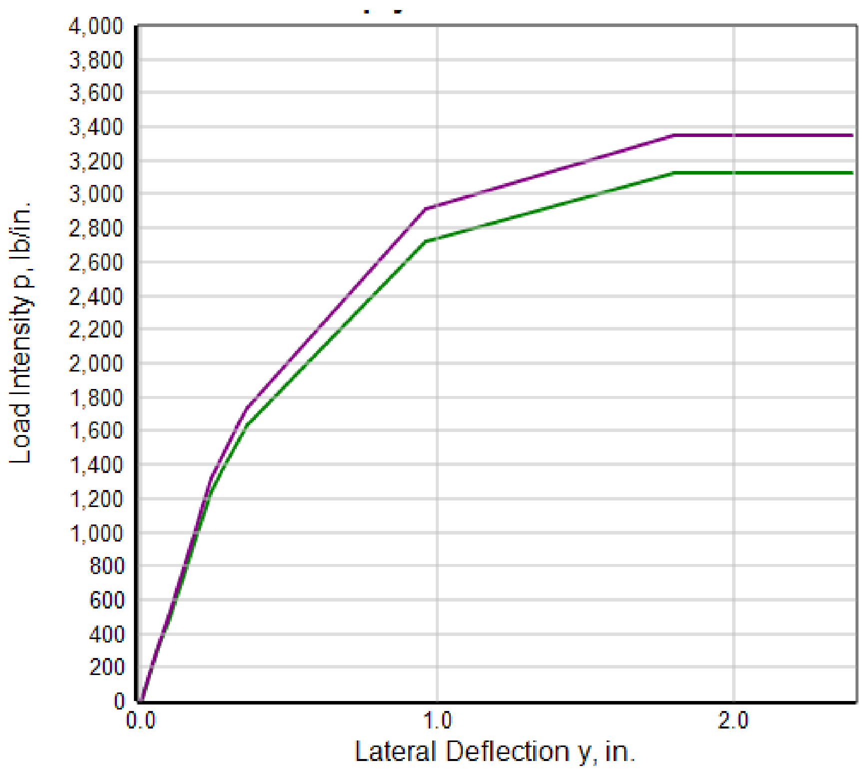


Figure 6.57 User-input *p-y* Curves Interpolated with Depth Using 17 Points for Example 23

LPile can also output the user-input *p-y* curves using the defined points at the top and bottom of the layer defined as a user-input *p-y* curve. An example of the user input *p-y* curve is shown as Figure 6.58.

A common feature of all output *p-y* curves is a truncation of the curve once it becomes horizontal. This is done to avoid hiding the shorter curves.

The user should be aware how LPile uses *p-y* curves in computations. LPile generates the *p*-values from the *p-y* curve formulation at every *y*-value at every node on the pile for every iterative solution of pile response. In other words, no interpolation along or in between curves is performed, except in the layer defined as user-input *p-y* curves. Thus, the *p*-values used by the program are the most accurate values possible.

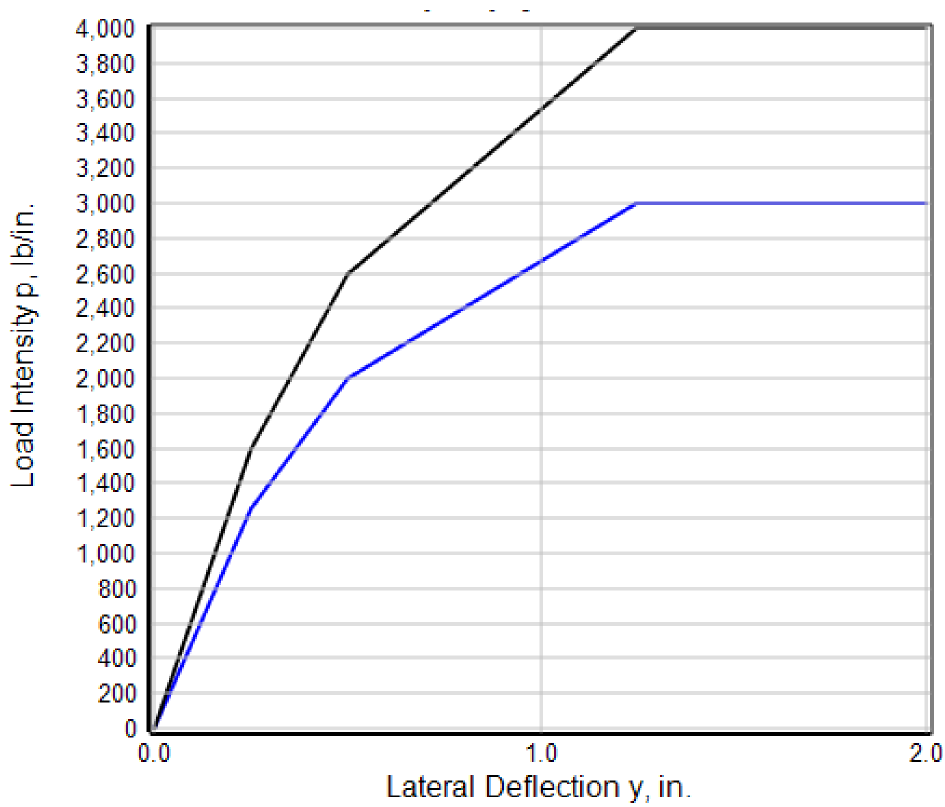


Figure 6.58 Output of User-input *p-y* Curves with Five Points for Example 23

6.24 Example 24 – Analysis with Lateral Soil Movements

This example is provided as a demonstration of how to model a pile foundation subjected to lateral spreading. The pile and soil profile for this problem is shown in Figure 6.59. The soil profile is composed of a stiff clay crust, overlying a layer of liquefied sand, overlying a deep layer of stiff clay with free water. This soil profile was used because it represents the type of soil profile for which lateral spread problems are most severe.

The pile is a 48-inch drilled shaft with 18 No. 9 reinforcing bars. This reinforcement provides 0.99 percent steel. The nominal moment capacity of the shaft was computed to be 21,360,000 in-lbs and the factored moment capacities ranged from 13,880,000 in-lbs to 16,020,000 in-lbs for resistance factors of 0.65 to 0.75.

The option for loading by soil movements is enabled by checking the box for "Include Loading by Lateral Soil Movements" in the Program Options and Settings dialog, shown in Figure 6.60. Once this box is checked, the input of the lateral soil movement profile versus depth is activated. The input dialog for lateral soil movements is shown in Figure 6.61.

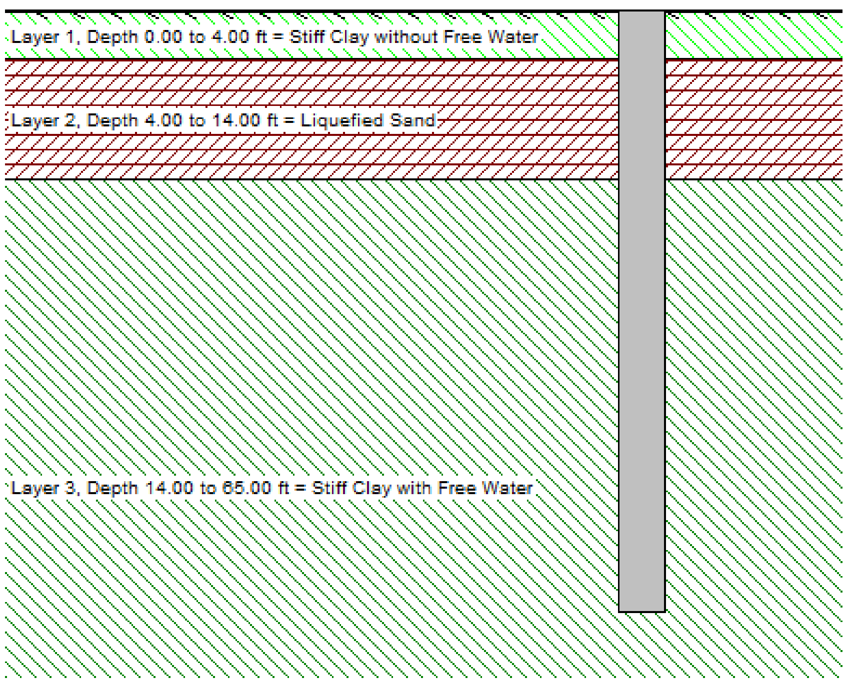


Figure 6.59 Pile and Soil Profile for Example 24

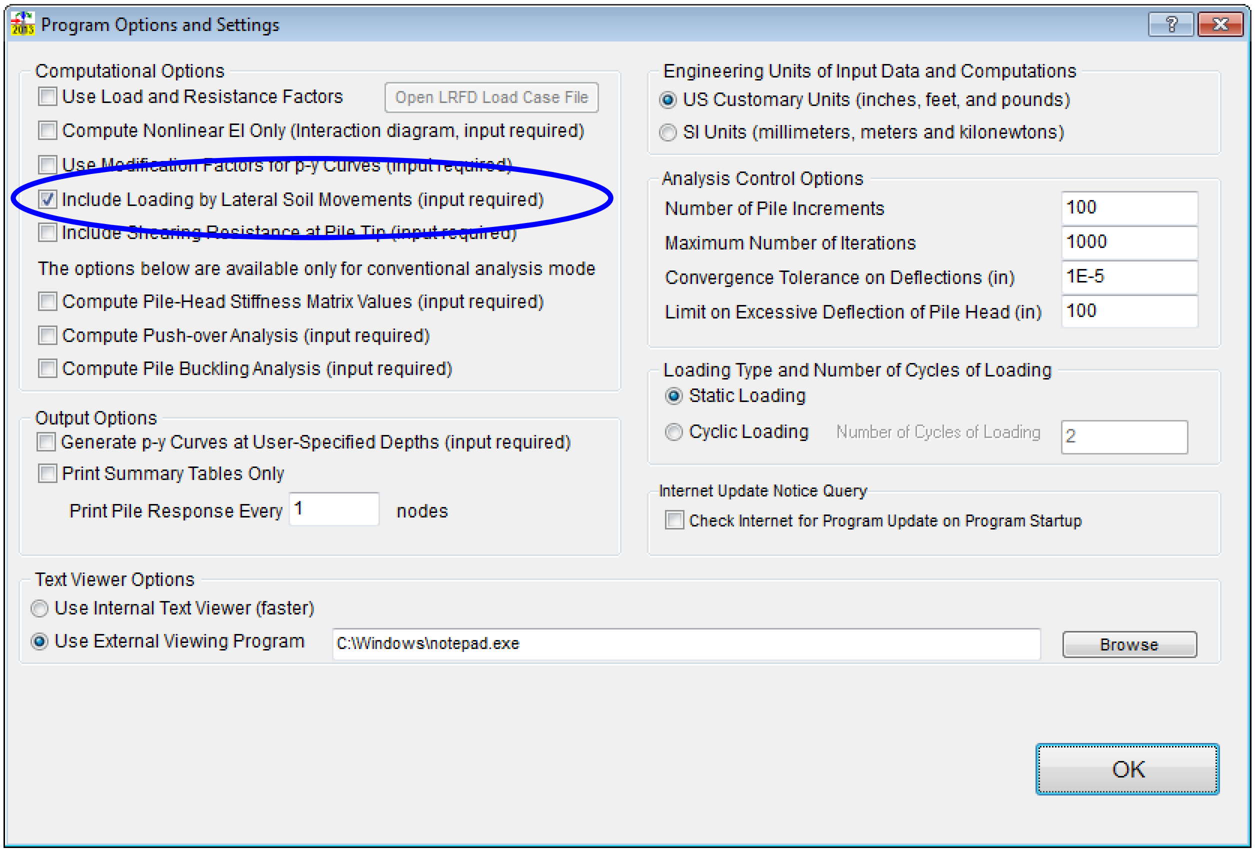


Figure 6.60 Program and Setting Dialog Showing Check for Inclusion of Loadings by Lateral Soil Movements

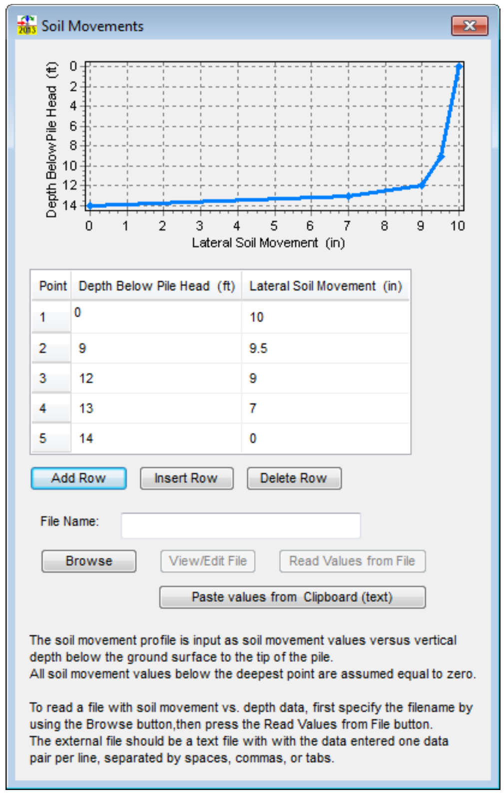


Figure 6.61 Input Dialog for Lateral Soil Movements versus Depth for Example 24

The results of the analysis with loading by soil movements are shown in Figure 6.62. In this problem, the upper clay crust moves along with the spreading liquefied sand layer. As a result, the maximum moment developed in the drilled shaft is 17,990,000 in-lbs and the factored moment capacity of the shaft is exceeded.

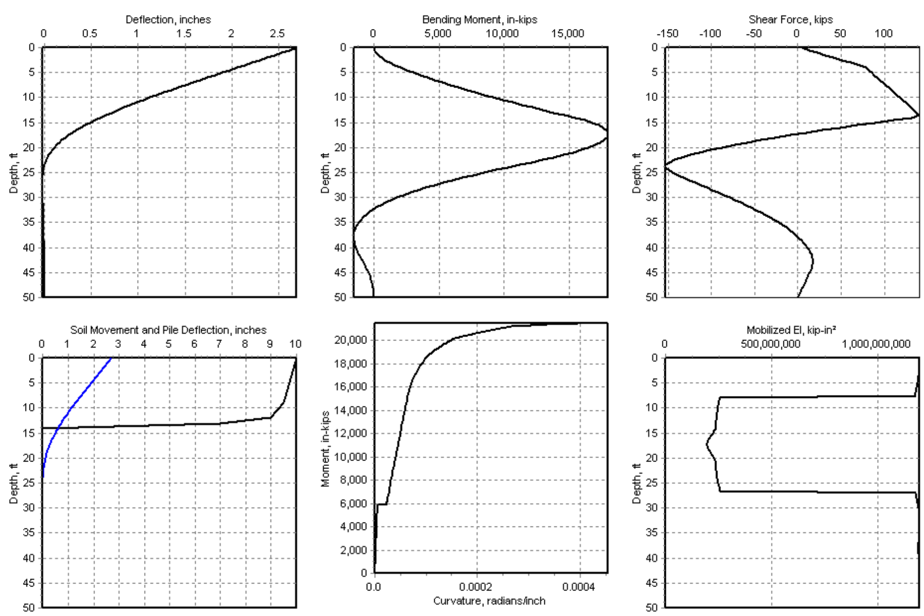


Figure 6.62 Results of Analysis for Example 24

The important factor to recognize in this example is the presence of the clay crust above the layer of spreading liquefied sand can result in loading conditions that are severe and that these conditions loading will fail all but the strongest of foundations.

6.25 Example 25- Verification of Elastic Pile in Elastic Subgrade Soil

This example is provided for comparison to closed-form solutions.

Closed-form solutions for the behavior of a semi-infinite elastic beam on an elastic foundation have been presented by numerous authors. These solutions are the only means of checking the solutions obtained using LPile by hand computation because any problem that involves either a nonlinear *p-y* curve or a beam with nonlinear moment-curvature behavior does not have a corresponding closed-form solution.

For the case of a semi-infinite beam with shear and moment applied to the end, the close-form solutions for deflection, bending moment, and shear force in the beam are the following.

Define the modulus of elasticity, E, and moment of inertia, I, of the beam, and the subgrade constant, k. Compute the constant β as

$$\beta = \sqrt[4]{\frac{k}{4EI}}$$

Timoshenko (1941) states that the pile is considered "long" if the product of β and the pile length (βL) is greater than 4.

The closed-form solution for pile deflection, y, moment, M, and shear force, V, along the length of the pile (x) as a function of pile-head shear, V_t, and pile-head moment, M_t, is

$$y = \frac{e^{-\beta x}}{2EI\beta^2}\left[\frac{V_t}{\beta}\cos\beta x + M_t(\cos\beta x - \sin\beta x)\right]$$

$$M = e^{-\beta x}\left[\frac{V_t}{\beta}\sin\beta x + M_t(\sin\beta x + \cos\beta x)\right]$$

$$V = e^{-\beta x}\left[V_t(\cos\beta x - \sin\beta x) - 2M_t\beta\sin\beta x\right]$$

Analyses of elastic piles in elastic soils can be performed using LPile using the elastic subgrade soil model. The elastic subgrade constant k is computed as the product of the pile diameter times the elastic modulus of subgrade reaction.

For the verification problem, define the following input for LPile.

An elastic pile with diameter = 12 inches, a wall thickness of 0.5 inch, and a Young's modulus of elasticity of 29,000,000 psi. This results in a moment of inertia of

$$I = \pi\frac{d_o^4 - d_i^4}{64} = \pi\frac{12^4 - 11^4}{64} = 299.187613 \text{ in}^4$$

Use the elastic subgrade soil model in LPile with a subgrade modulus of 500 pci. Compute the elastic subgrade constant k using

$$k = E_s d = (500)(12) = 6{,}000 \text{ psi}$$

Define V_t = 10,000 lbs and M_t = 250,000 in-lbs

To provide the best check on the accuracy of the computations performed by LPile, the equations above were programed in an electronic spreadsheet program and the computed results were imported into the spreadsheet program from the plot output file in which all output is written in scientific notation. Graphs of closed-form versus computed solutions were prepared for lateral deflection, bending moment, and shear force. The graphs of the closed-form versus computed results are presented in Figure 6-63 through Figure 6-65, along with regression equations. As can be seen, for a linear regression, the coefficient of determination, R^2, is 1.0 in all cases, indicating that the accuracy of the solution is excellent.

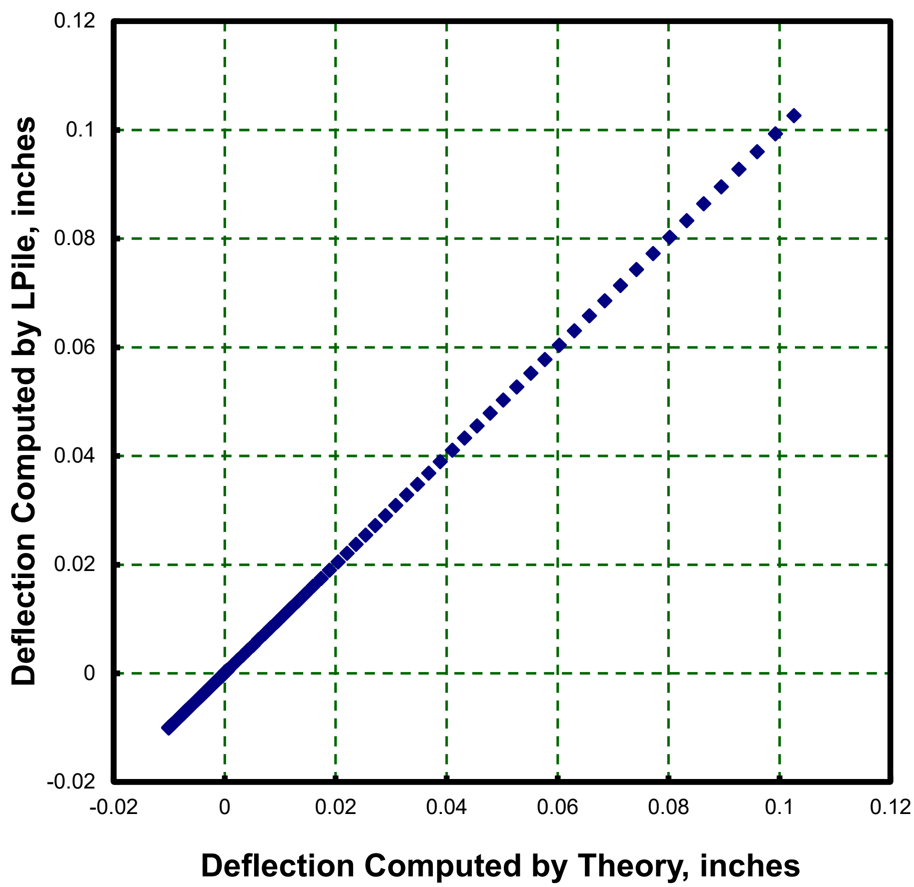


Figure 6-63 Verification of Pile Deflections

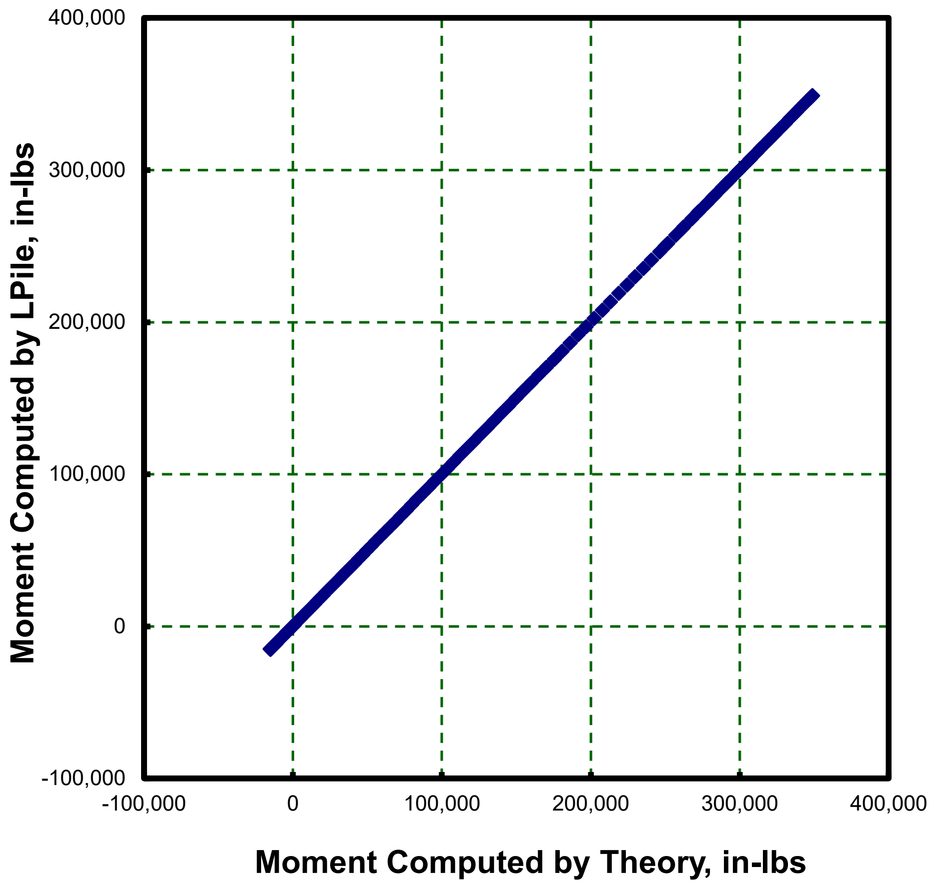


Figure 6-64 Verification of Bending Moments

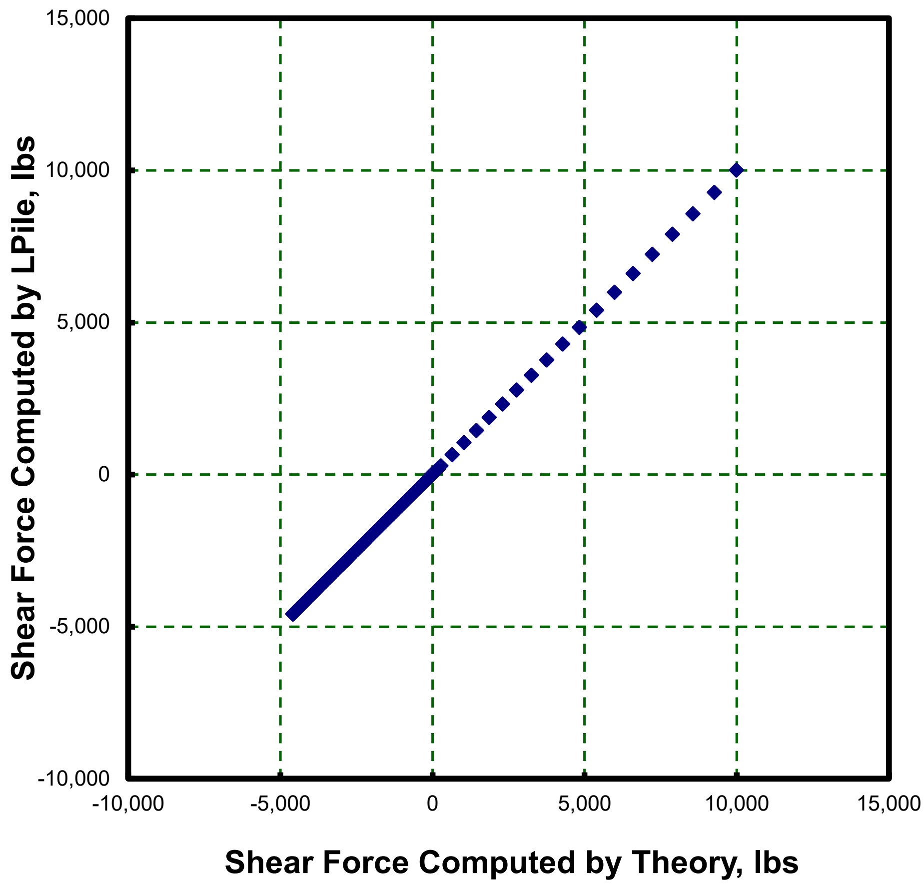


Figure 6-65 Verification of Shear Forces

6.26 Example 26 – Verification of *P-Delta* Effect

LPile includes the *P-Delta* (P-δ) effect in its computations of bending moment for axially loaded piles subjected to lateral loading. Example 26 is a simple verification of the P-δ effect.

The pile geometry and soil profile for the verification problem is shown in Figure 6.66. The pile is an elastic pipe section, 36 inches in diameter with a wall thickness of 0.5 inches. The pile length is 60 feet and the pile extends 25 feet above the ground surface (L_e). The upper soil layer is soft clay and the lower soil layer is sand. The pile is modeled using 240 increments with a convergence tolerance of 0.00001 inches.

The axial load on the pile is 100,000 lbs. The pile is loaded using the displacement-moment loading condition with a pile-head deflection specified equal to 1.0 inches and the pile-head moment equal to zero.

The computed shear force at the pile head, V_{top}, is 9,491.0656 lbs and the computed ground line deflection, y_{GL}, is 0.1317227 inches (these numbers were retrieved from the *filename.lp13p* file in order to obtain the maximum number of significant digits).

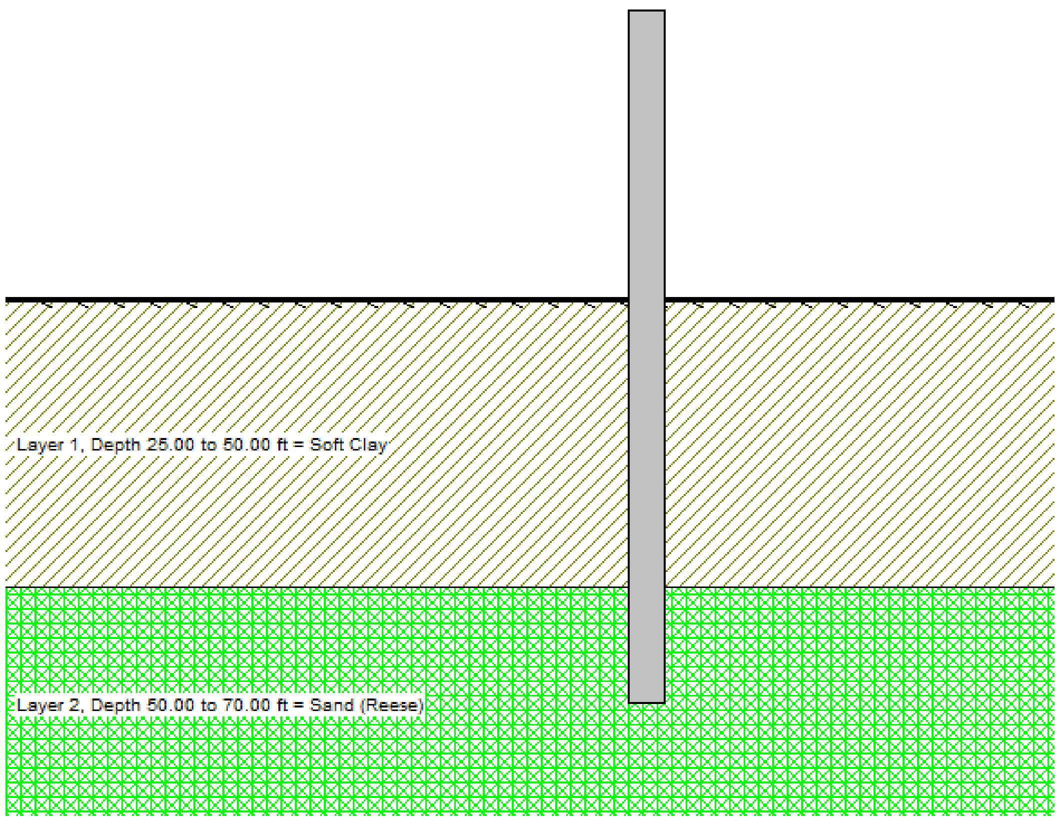


Figure 6.66 Pile and Soil Profile for Verification of *P-Delta* Effect

The moment at the ground line, M_V, from the pile-head shear force is

$$M_V = V_{top} L_e = (9{,}491.0656 \text{ lb})(300 \text{ in.}) = 2{,}847{,}319.68 \text{ in-lbs}$$

The P-δ moment due to the eccentricity of the axial load, M_P, is equal to the relative displacement of the pile-head to the ground line displacement multiplied by the axial thrust force.

$M_P = P(y_{top} - y_{GL}) = 100{,}000.\text{ lbs}(1.0\text{ in.} - 0.1317227\text{ in.}) = 86{,}827.73$ in-lbs

The total moment at the ground line due to the shear force and eccentric axial load is

$M_{total} = M_V + M_P = 2{,}934{,}147.41$ in-lbs

The computed moment by LPile at the ground line is 2,934,147.4 in-lbs.

The error in the computed moment is 0.01 in-lbs. This is an error of 3.4×10^{-7} percent.

6.27 Example 27 – Applications of ISO and API Clay Criteria

The PISA (PIle Soil Analysis) joint industry project was established in 2013 to develop new design methods specifically tailored for offshore wind turbine monopoles (Byrne et al 2017). Cowden, a clay site in north-east England, was selected to represent the typical stiff clay deposits found at many North Sea wind farm sites. The test program was centered around a base pile geometry with a diameter of 0.762 m and a L/D ratio of 5.25. From this base geometry, the diameter was varied from large (2.0 m) to small (0.273 m) diameter field tests.

Long Pile of Small/Medium Diameter

Test Pile CM3 at Cowden site has a diameter of 0.762 m with 7.62-m embedment in stiff over-consolidated clay with PI less than 30% (Cowden Till). The OCR is approximately equal to 10 for the top 4 m of stiff clay and it may be between 2 and 4 for clay below the depth of 4 m. The wall thickness of this steel pile is 25 mm. With a length over diameter ratio (L/D) of 10, this test pile is thus considered as relatively long and slender. The shear strength and initial shear modulus of Cowden Till are presented in Figure 6.67. The lateral loads were applied at 10 m above the ground.

As presented in Figure 6.68, the measured deflection of Test Pile CM3 at the ground surface and the predicted deflection based on API Clay criteria have a close agreement. Since Test Pile CM3 is a relatively long pile, the tip resistance may not add noticeable contribution on the overall lateral resistance.

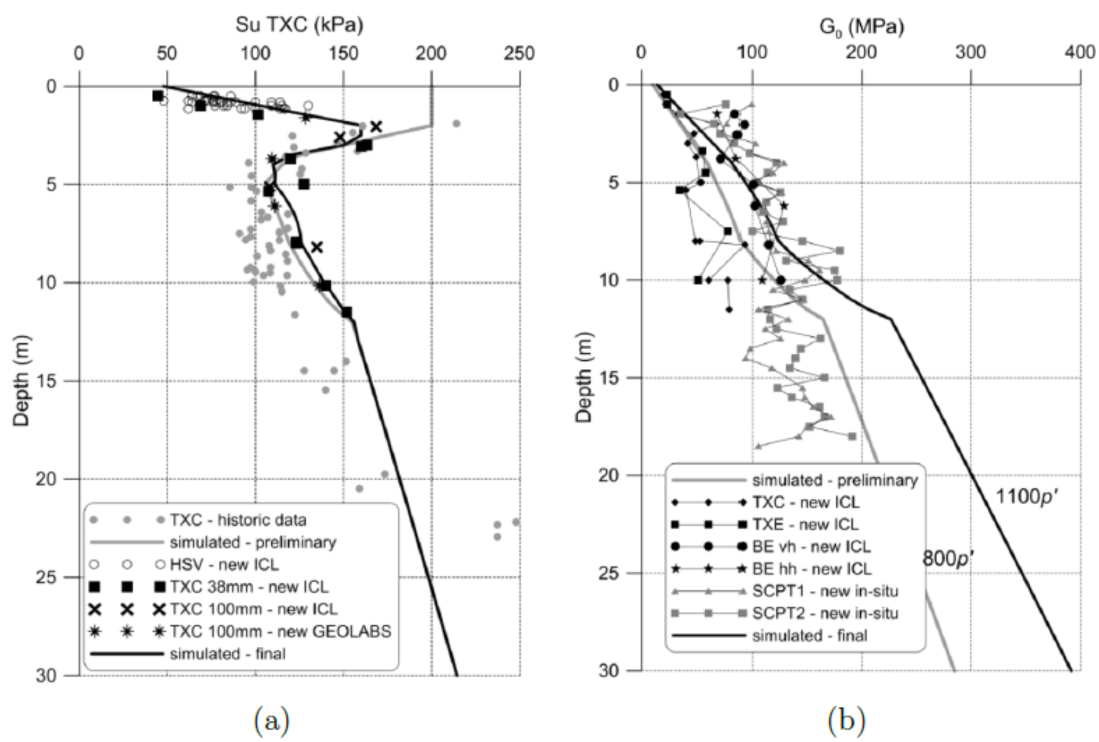


Figure 6.67 Shear strength and initial shear modulus of Cowden Till (Byrne et al 2017).

In the same Figure 6.68, the predicted deflection based on the ISO Clay criteria is also very close to the measured deflection for this long pile with a diameter of less than 1 meter (3.3 ft). For this test it is concluded that both, the API Clay criteria and the ISO Clay criteria form LPILE, are good for predicting the lateral behavior of long piles with diameters of up to about one meter.

Test Pile CL2 at Cowden site has a diameter of 2.0 m with 10.5-m embedment in the same Cowden Till. The wall thickness of this steel pile is 25 mm. The length over diameter ratio (L/D) is 5.25 and is thus considered as a relatively short pile. The lateral loads were also applied at 10 m above the ground. As presented in Figure 6.69, the measured deflection of Test Pile CL2 at the ground surface and the predicted deflection based on API clay criteria do not exhibit a good match. Since Test Pile CL2 is a relatively short pile with a large diameter, the contribution from the new *p-y* curves for ISO Clay is evident as demonstrated in Figure 6.69.

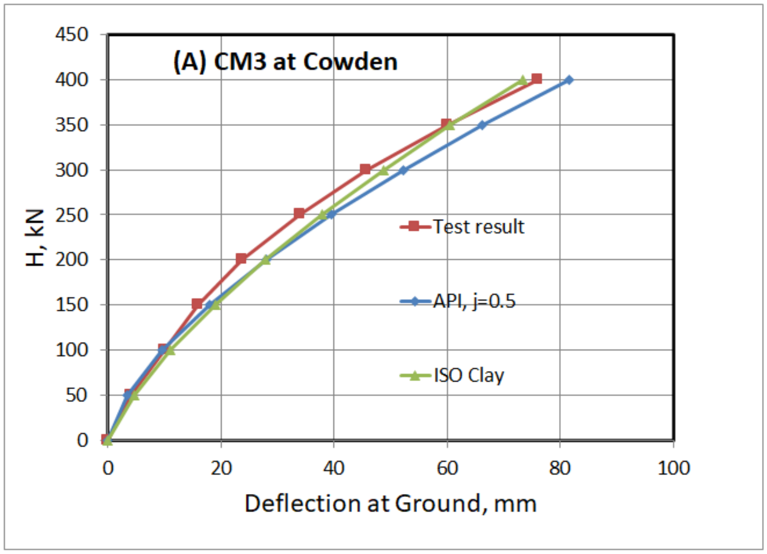


Figure 6.68 Measured and predicted deflections at ground level for Test Pile CM3 (D=0.76m, L/D=10) at Cowden Site.

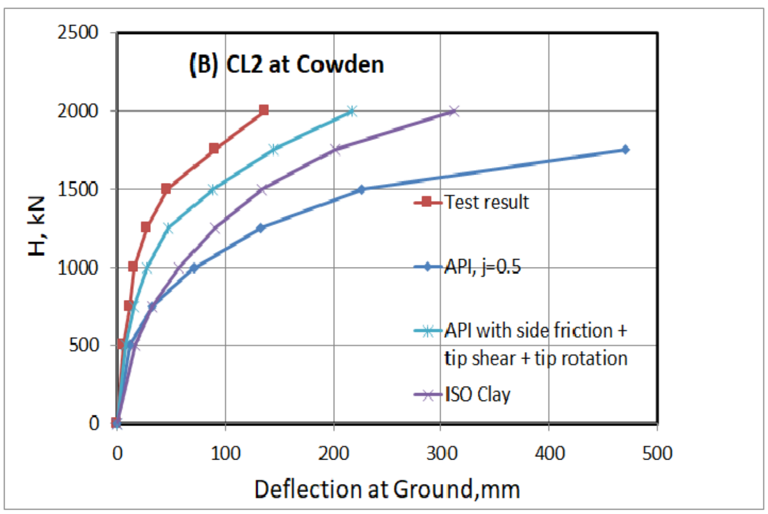


Figure 6.69 Measured and predicted deflections at ground level for Test Pile CL2 (D=2m, L/D=5.25) at Cowden Site.

The discrepancies between the measured deflection and the predicted deflection based on either ISO Clay criteria or API Clay criteria are still significant. However, adding contributions from the side friction on the pile longitudinal surface and from the shear and rotational resistance at the pile tip bring the predicted deflections closer to the measured test data, as indicated by the light blue curve in Figure 6.69.

It is interesting and useful to compare the *p-y* curves calculated by the API Clay criteria and by the ISO Clay criteria at the Cowden site for Test Pile CL2 which has a diameter of 2.0 m with 10.5-m embedment in the Cowden Till. The *p-y* curves generated at depths of 4 m (z/D = 2) and 10.5 m (z/D = 5.25) below the ground are presented in Figure 6.70. It is clear that the soil resistance (*p-y* data) calculated based on the new ISO Clay criteria are greater and stiffer than those from the API Clay criteria for relatively large diameter piles.

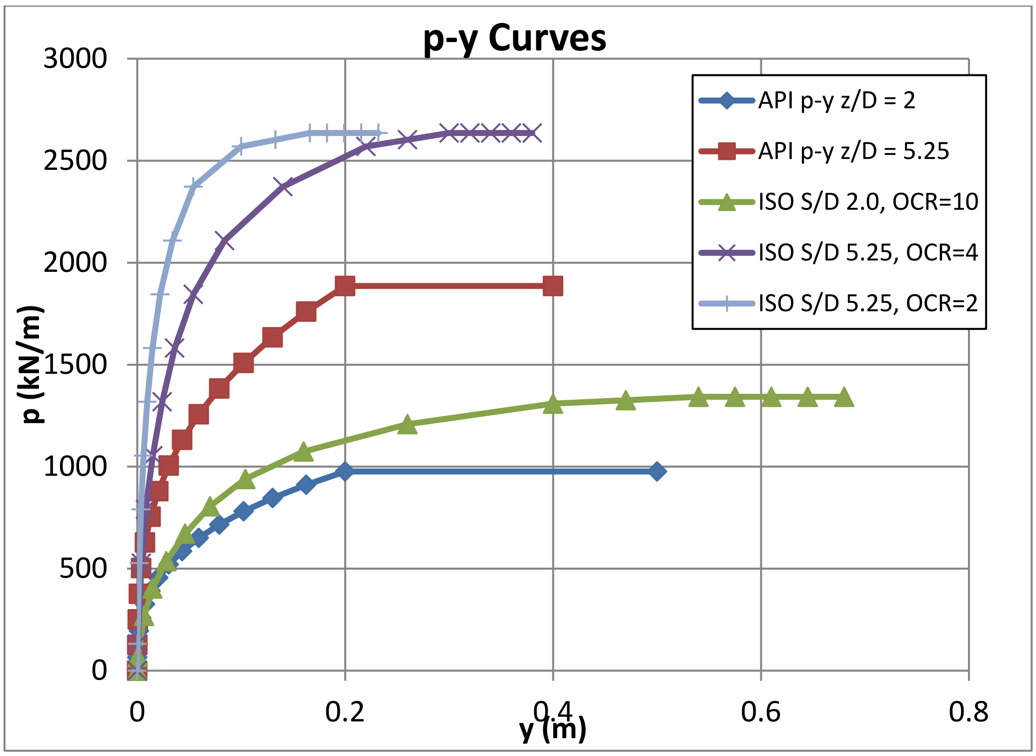


Figure 6.70 Comparison of *p-y* curves from API Clay and ISO Clay criteria on piles of 2-m OD at Cowden site.

6.28 Example 28 – Shear Demand for Slope Stability Analyses

This example demonstrates how to model the shear resistance of drilled shafts in a slope stability analysis. A schematic of the slope and the planned location of the dilled shafts is shown in Figure 6.71. The slope is 55 ft tall with a slope angle of 38.2°. The soil profile consists of two layers. The soil on the top layer has a cohesion of 450 psf and a friction angle of 18°. The bottom layer has a cohesion of 1800 psf. The safety factor of the original slope (without drilled shafts) is 1.164, as obtained from limit-equilibrium analyses with Ensoft's EnSlope software using the simplified Bishop method.

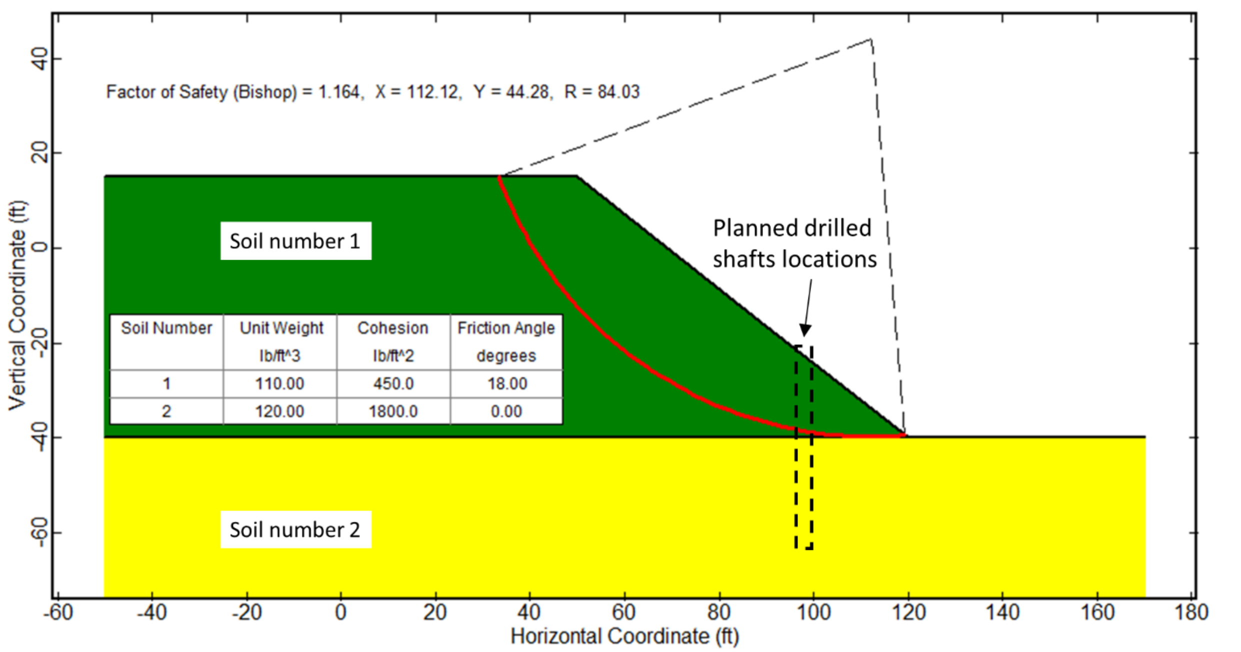


Figure 6.71 Scheme for Installing a Row of Piles in a Slope Subject to Sliding

A row of 40 ft long piles is installed at one-third the height of the slope. The piles are 36-inch diameter drilled shafts with ten #14 reinforcing bars. The reinforcement provides 2.21 percent steel. The nominal moment capacity of each shaft was computed to be 9,553 in-kips. Using a resistance factor of 0.9 for drilled shafts with no axial loading, the ultimate moment capacity is 8,597 in-kips. The center-to-center spacing between drilled shafts is 5 ft. Since the spacing is larger than the pile diameter, soil can flow around the pile. A slope failure can thus occur without the pile reaching a shear failure. Instead of the shear capacity of the pile, the shear demand of the pile associated with a tolerable soil movement (e.g., 4 inches) above the slip surface is a better estimation of the shear resistance for slope stability analyses.

In LPILE, the options for shear-demand calculations are enabled under the 'Data > Options and Settings' menu by checking (1) the 'Use Separate Soil Movement Profiles for Each Load Case' and (2) the 'Compute Pile Shear Demand Along Depth' (see Figure 6.72).

> The 'Use Separate Soil Movement Profiles for Each Load Case' option allows for an arbitrary soil movement profile to be used in the shear-demand calculation. Results from this option are obtained from one soil movement profile for each loading case and are presented in the LPILE program.
>
> The 'Compute Pile Shear Demand Along Depth' option computes shear demands at multiple slip-surface locations along the pile for a *step-type* soil movement profile. Results from this option are obtained from the 'Graphics > Shear Demand vs. Depth' menu and are also tabulated in the output file. The shear demands at various depths saved in the output file can be imported into Ensoft's EnSlope software and used as pile shear resistance in the slope stability analyses.

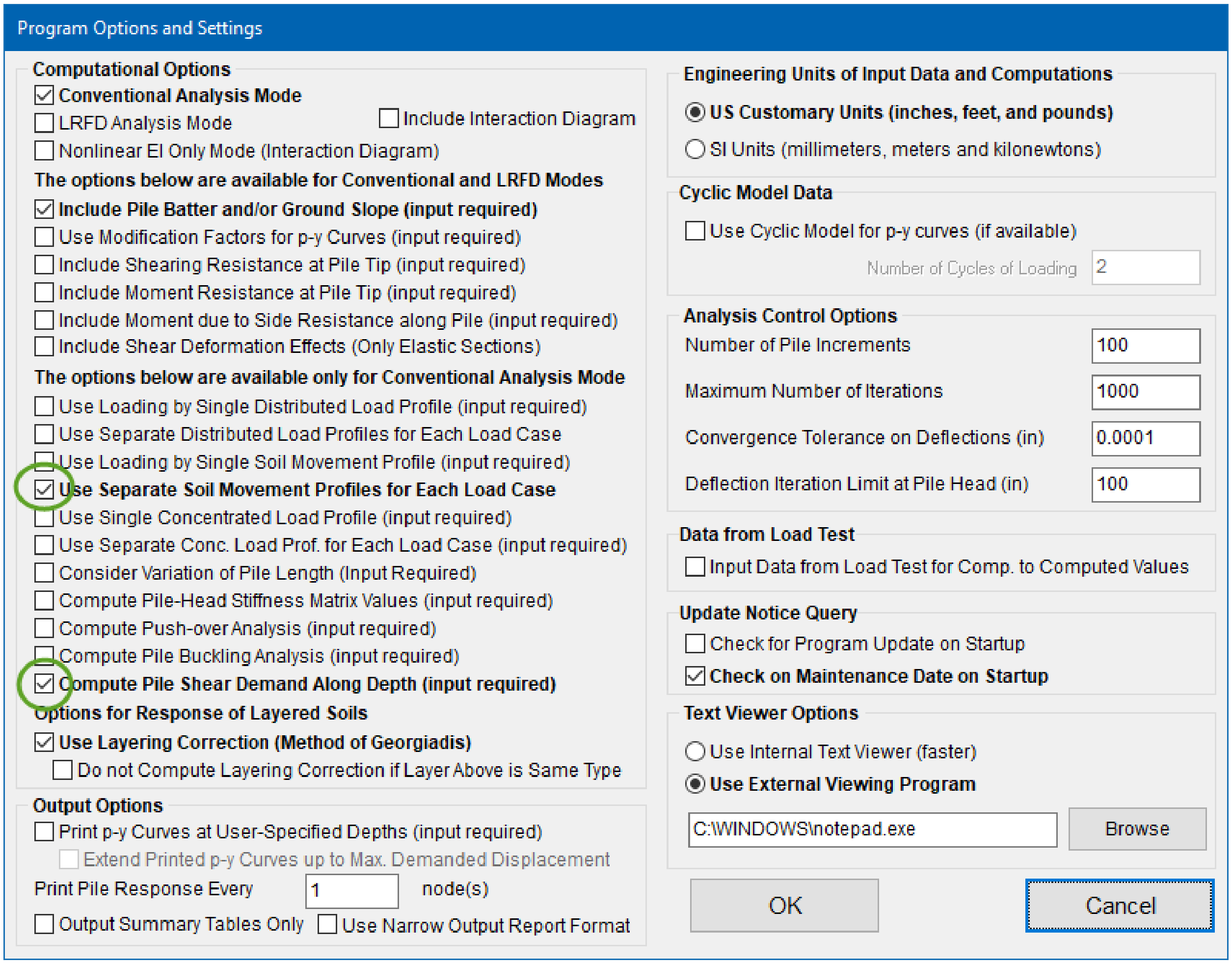


Figure 6.72 Shear-Demand Options & Settings in LPILE

6.1.1 Use Separate Soil Movement Profiles for Each Load Case

With this option, users can define various lateral soil movements along the pile (Data > Lateral Soil Movement). LPILE calculates the resulting lateral displacement, shear, and moment profiles from the assigned soil movement profile. For limit equilibrium analyses, a step profile is often assumed with a constant soil movement (e.g., 4 inches) above the slip surface and zero soil movement below the slip surface. However, other linear or nonlinear soil movement profiles can also be analyzed. Figure 6.73 shows the results from 4-inch soil movements above a slip surface at 19.5 ft below the ground surface. The resulting shear demand is 54.0 kips. As shown in the figure, the deflection at the top of the pile is close to 5 inches. This is greater than the soil movement. Consequently, the mobilized soil reaction is negative in the top 6.5 ft. A stiffer and longer pile with less deformation can increase soil resistance. It is also interesting to see that the maximum moment occurs at 27.2 ft below the ground surface, which is about 7 ft below the slip surface. The maximum moment of 5,997 in-kips is below the ultimate pile capacity of 8,597 in-kips.

This option is ideal for analyzing a specified slip surface. If the exact depth of the critical slip surface is unknown, the method in the next section (compute pile shear demand along depth) can be used to search for the critical slip surface.

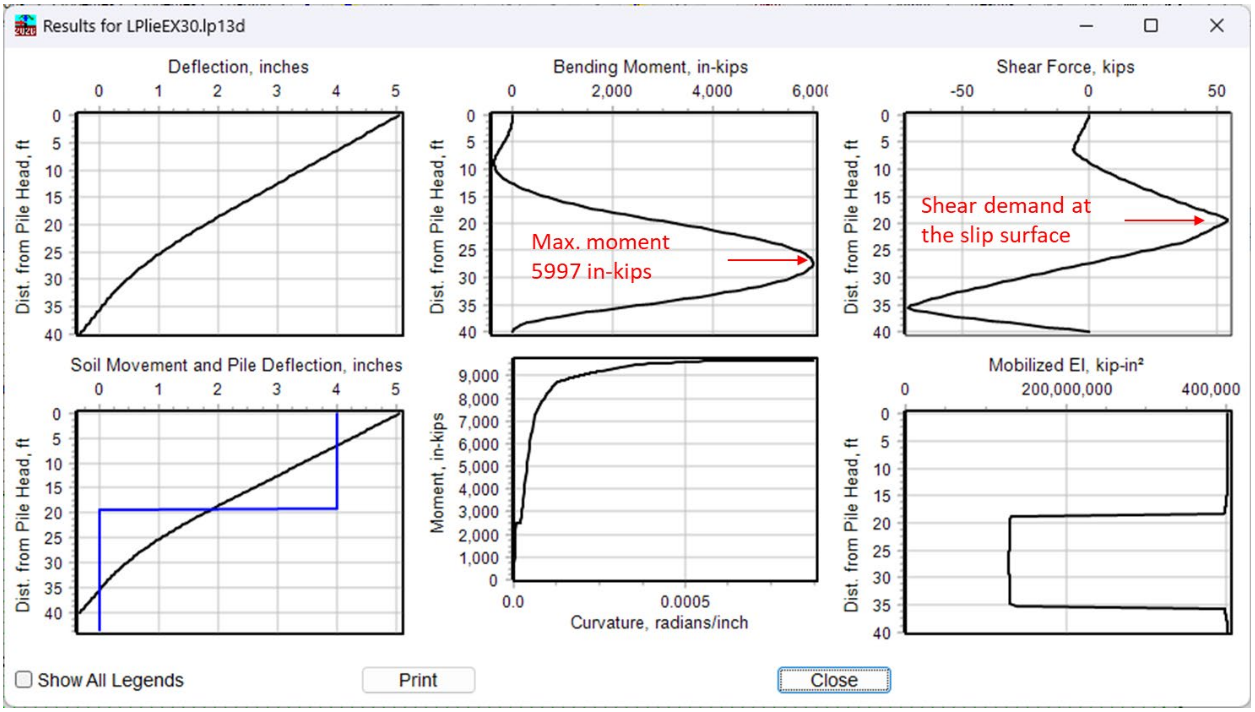


Figure 6.73 Results from 4-inch Soil Movement above a Slip Surface19.5 ft below Ground

6.1.2 Compute Pile Shear Demand Along Depth

With this option, LPILE calculates shear demands along the pile (Data > Control for Computation of Shear Demand along Pile). Users can define the soil movements both above and below a slip surface. Only a step soil-movement profile is available in this option. Soil above the slip surface is assumed to move as a block with a uniform lateral displacement. In most cases, soil movements below the slip surface are assumed to be zero. In the example settings shown in Figure 6.74, slip surfaces are assigned at 20 locations. At each location, the soil movement above the slip surface is assumed to be 4 inches. Shear demands are calculated separately for each location. The outputs are presented in the Graphics > Shear Demand vs. Depth dialog (Figure 6.75) and a tabulated output is saved at the end of the output file (Figure 6.76) (Computation > View Output Text File). The resulting shear at each section divided by the pile spacing can be imported into Ensoft's EnSlope (Figure 6.77) as shear resistance when modeling piles as reinforcements. In this example, the resulting safety factor with the 5 ft spacing drilled shafts is 1.312, as compared to 1.164 of the original slope without piles, based on the simplified Bishop method (Figure 6.78).

6.1.3 Other Considerations

The maximum moment in the pile is saved in the output file. As shown in the table of Figure 6.76, the maximum moment of 6,749 in-kips occurs when the slip surface is located at a depth of 11.26 ft. The maximum moment of 6,749 in-kips is below the ultimate capacity of 8,597 in-kips. The resulting moment at each section is also saved in the output file. The magnitude of the moment at each section is generally greater than zero, indicating that the resulting shear demands acts predominantly above the slip surface. For moment-based limit equilibrium analyses, assuming that the shear demand acts on the slip surface may result in a higher safety factor. As shown in Figure 6.78, the critical slip surface is located near the bottom of the top soil layer, approximately 19.5 ft below the slope surface. Dividing the bending moment at section by the shear force at section yields a distance of 6.17 ft (= 3384444/45710.78/12, Figure 6.76), which is approximately 7% of the radius of the critical slip surface (88.11 ft). Users can reanalyze the slope stability by reimporting the shear demand from LPILE and entering a multiplication factor of 0.93 in EnSlope. The resulting factor of safety is 1.301.

In this example, only soil movement perpendicular to the pile axis is considered and soil movements above the slip surface are assumed to be uniform. For a circular slip surface, soil movements may increase with increasing distance from the center of the slip surface and often include components that are both perpendicular and parallel to the pile. Engineers can select the 'Use Separate Soil Movement Profiles for Each Load Case' option to evaluate the effects of different soil movement profiles. For movements parallel to the pile axis, "*t-z*" analyses may be performed to determine the pile resistances that are mobilized by soil movement in the axial direction (using the TZPILE software from Ensoft). In most cases, pile axial resistance exceeds lateral resistance. Consequently, safety factors derived by considering only soil movements perpendicular to the pile are likely to be conservative compared with those obtained by considering soil movements in both the perpendicular and parallel directions.

The 4 inches of soil movement selected in this example is intended to simulate the ultimate capacity. In some applications, 4 inches of soil movement may be excessive. Engineers may select a smaller value that is more appropriate for the specific application.

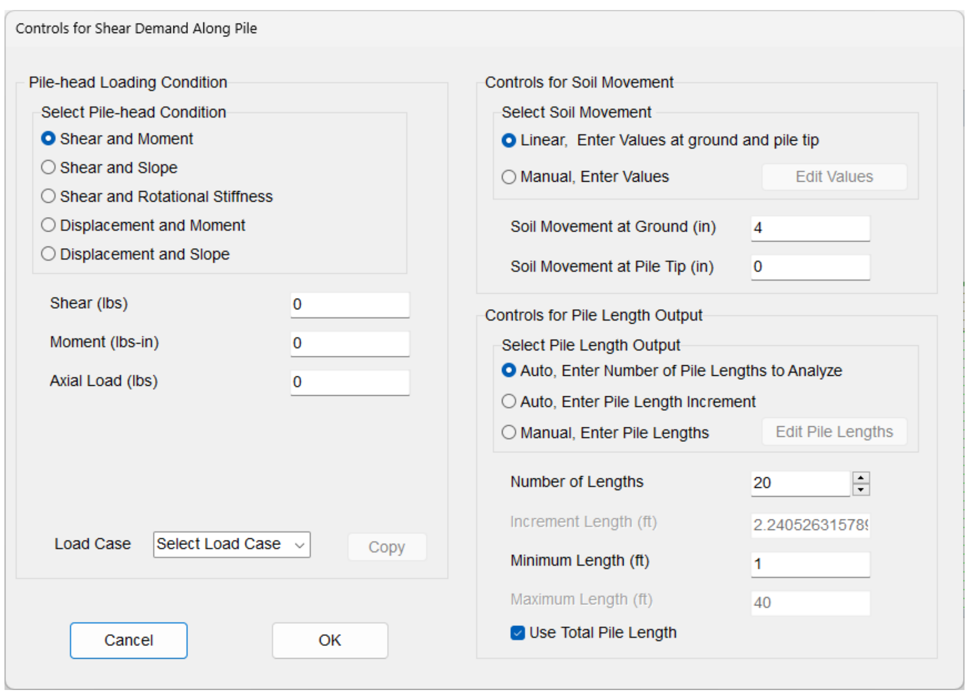


Figure 6.74 Sample Controls for Shear Demand Along Pile

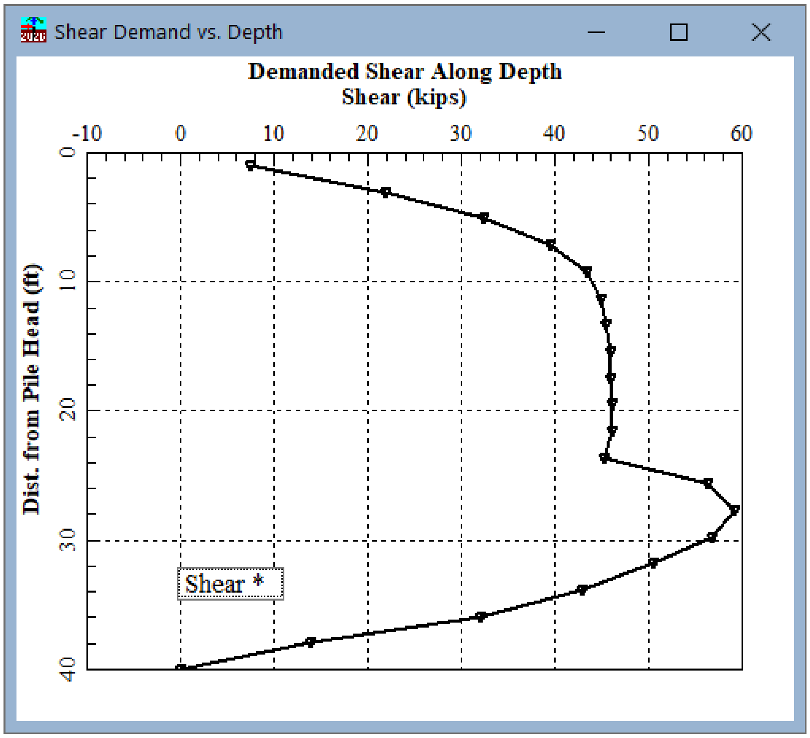


Figure 6.75 Sample Shear Demand vs. Depth Plot

LPlieEX30.lp13o

File Edit View

Pile-head loading condition = shear and moment
- Shear = 0.0000 lbs
- Moment = 0.0000 in-lbs
- Axial Load = 0.0000 lbs

Point Number	Section Length feet	Pile-head Deflection inches	Pile-head Slope radians	Pile-head Shear lbs	Pile-head Moment in-lb	Moment at Sect. in-lb	Shear at Sect. lbs	Maximum Moment in-lb
1	1.0000	0.06914	-3.97E-04	0.00	1.93E-06	49058.25	7024.498	711902.3
2	3.0526	0.6328	-0.00286	-4.03E-07	1.93E-05	417397.2	21556.76	2593745.
3	5.1053	1.7233	-0.00733	-1.21E-06	-1.55E-05	1025449.	32130.95	4130252.
4	7.1579	2.6002	-0.01037	0.00	-2.01E-04	1741062.	39356.95	5467823.
5	9.2105	3.3839	-0.01256	8.06E-07	-5.57E-04	2326019.	43383.43	6448214.
6	11.2632	3.7992	-0.01335	-8.06E-07	-4.02E-04	2816432.	44759.28	6749016.
7	13.3158	4.0058	-0.01332	0.00	-6.19E-05	3097293.	45174.66	6737422.
8	15.3684	4.0863	-0.01284	1.61E-06	2.47E-04	3215433.	45467.62	6536206.
9	17.4211	4.1437	-0.01234	0.00	5.26E-04	3305208.	45611.37	6234508.
10	19.4737	4.1817	-0.01185	0.00	3.09E-05	3384444.	45710.78	5853629.
11	21.5263	4.2024	-0.01139	-1.61E-06	6.19E-05	3465199.	45890.42	5397995.
12	23.5789	4.2039	-0.01091	-1.61E-06	-5.57E-04	3584446.	45203.13	4885102.
13	25.6316	4.1641	-0.00945	-1.61E-06	2.78E-04	666738.0	55771.54	2794383.
14	27.6842	4.1146	-0.00883	0.00	-1.24E-04	-484123.	58312.30	1876331.
15	29.7368	4.0721	-0.00850	1.61E-06	-2.17E-04	-981313.	55599.27	2473385.
16	31.7895	4.0201	-0.00830	-1.61E-06	4.02E-04	-1035455.	49267.77	2355439.
17	33.8421	3.9996	-0.00827	0.00	-1.08E-04	-934964.	41833.73	2013636.
18	35.8947	3.9998	-0.00833	0.00	4.64E-05	-602697.	31291.04	1364256.
19	37.9474	4.0000	-0.00833	0.00	3.09E-05	-123162.	13617.05	399595.3
20	40.0000	4.0000	-0.00833	0.00	1.24E-04	0.00	0.00	1.39E-04

The analysis ended normally.

Ln 787, Col 30 | 54,053 characters | Plain text | 100% | Windows (CRLF) | ANSI

Figure 6.76 Sample Tabulated Output from Compute Pile Shear Demand Along Depth

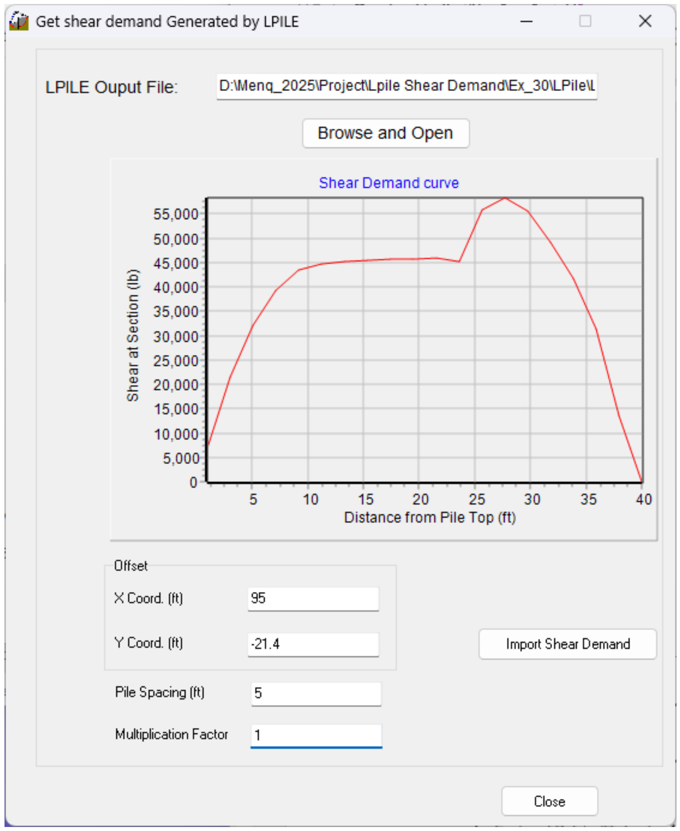


Figure 6.77 Sample Import Shear Demand Dialog from LPILE Output File in EnSlope

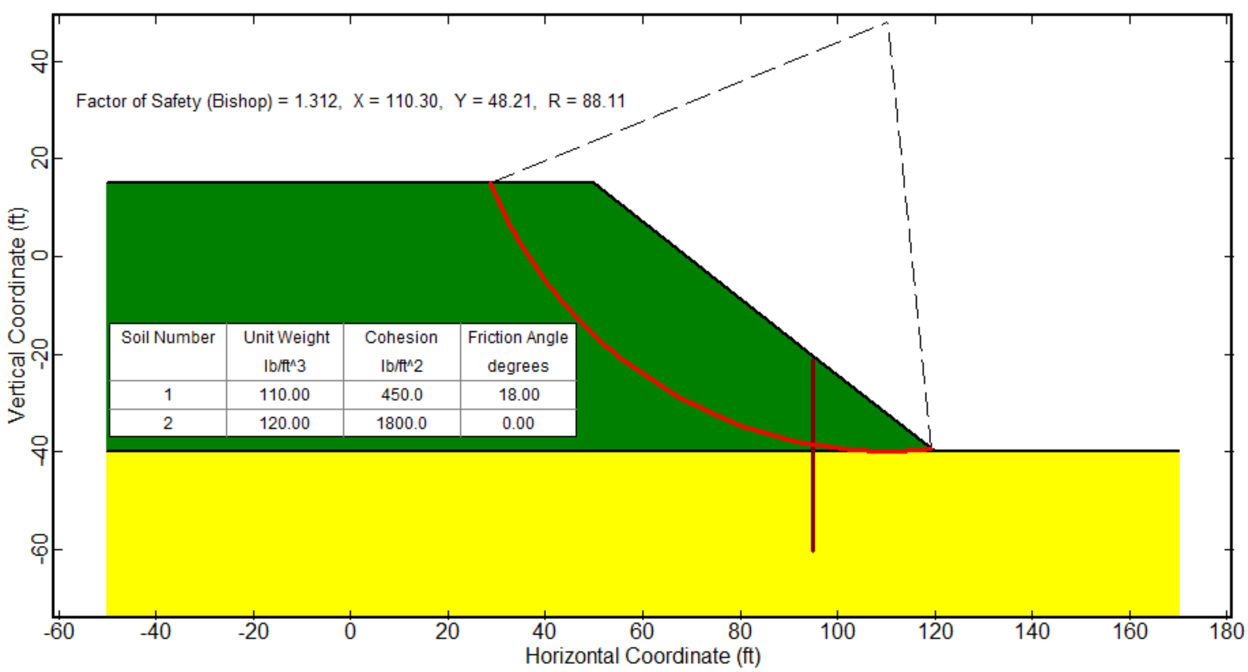


Figure 6.78 Limit Equilibrium Analyses with a Row of 5-ft-Spaced Drilled Shafts

CHAPTER 7. References & EULA

7.1 References

American Petroleum Institute, 1987. *Recommended Practice for Planning, Designing, and Constructing Fixed, Offshore Platforms, API Recommended Practice 2A (RP 2A),* 17th Edition, April 1, 1987.

Brown, D. A., 2002. Personal Communication about "Specifying Initial *k* for Stiff Clay with No Free Water."

Brown, D. A.; Turner, J. P.; Castelli, R. J. and Loehr, E. J., 2018. "Drilled Shafts: Construction Procedures and Design Methods," NHI Course No. 132014, Geotechnical Engineering Circular No. 10, Report No. FHWA-NHI-18-024, National Highway Institute, US Department of Transportation, Federal Highway Administration.

Byrne, B. W.; McAdam, R.; Burd, H. J.; Houlsby, G. T.; Martin, C. M.; Beuckelaers, W. J.; L. Zdravkovic, D. M. G. Tarboda, D. M. Potts, R. J. Jardine, E. Ushev, T. Liu, D. Abadias, K. Gavin, D. Igoe, P. Doherty, J. Skov Gretlund, M. Pacheco Andrade, A. Muir Wood, F. C. Schroeder, S. Turner and M. A. L. Plummer, PISA: new design methods for offshore wind turbine monopiles, `Proceedings of the 8th Offshore Site Investigation & Geotechnics (OSIG) International Conference', London, U.K. (2017).

CALTRANS, 2013. Seismic Design Criteria.

Georgiadis, M., 1983. "Development of *p-y* Curves for Layered Soils," *Proceedings*, Geotechnical Practice in Offshore Engineering, ASCE, April, pp. 536-545.

Horne, M., 1978. *Plastic Theory of Structures*, Permagon Press, New York.

Liang, R.; Yang, K.; and Nusairat, J., 2009. "*p-y* Criterion for Rock Mass," *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 135, No. 1, pp. 26-36.

Matlock, H., and Reese, L. C., 1962. "Generalized Solution for Laterally Loaded Piles," *Transactions*, ASCE, Vol. 127, Part I, pp. 1220-1251.

O'Neill, M. W., and Reese, L. C., 1999. "Drilled Shafts: Construction Procedures and Design Methods," Report No. FHWA-IF-99-025, US Department of Transportation, Federal Highway Administration.

Reese, L. C., 1984. "Handbook on Design of Piles and Drilled Shafts Under Lateral Load,: Report No. FHWA-IP-84-11, US Department of Transportation, Federal Highway Administration.

Reese, L. C., and Van Impe, W., 2011. *Single Piles and Pile Groups Under Lateral Loading, 2nd Edition*, CRC Press (Balkema), 507 p.

Rollins, K. M.; Gerber, T. M.; Lane, J. D.; and Ashford, S. A., 2005a. "Lateral Resistance of a Full-Scale Pile Group in Liquefied Sand", *Journal of the Geotechnical and Geoenvironmental Engineering Division*, ASCE, Vol. 131, pp. 115-125.

Rollins, K. M.; Hales, L. J.; and Ashford, S. A., 2005b. "*p-y* Curves for Large Diameter Shafts in Liquefied Sands from Blast Liquefaction Tests," *Seismic Performance and Simulation of Pile Foundations in Liquefied and Laterally Spreading Ground*, Geotechnical Special Publication No. 145, ASCE, p. 11-23.

Timoshenko, S. P., 1941. *Strength of Materials, Part II, Advanced Theory and Problems*, 10th Printing, Van Nostrand, New York.

7.2 EULA

PROGRAM LICENSE AGREEMENT & DISCLAIMER

IMPORTANT NOTICE: The software you are about to install or previously have installed from Ensoft Incorporated (“ENSOFT”) is licensed only on the condition that you agree to the terms and conditions set forth below. Please read the terms of this License Agreement & Disclaimer ("LICENSE") carefully.

If you agree to be bound by the terms of this LICENSE, please check mark the box labeled “YES – I Accept the terms of this License Agreement!” during software installation so it can be installed on your computer.

If you do not agree to the terms of this LICENSE, please check mark the box labeled “NO – I DO NOT Accept the terms of this License Agreement!” which will terminate the software installation.

If the software is already installed and licensed, you have already agreed to the terms and conditions of this license, or someone has done so on your behalf.

This LICENSE is a legal agreement between you (“USER”) – either an individual or a single entity– and ENSOFT for the ENSOFT software product that you are about to install or previously have installed (“PRODUCT”). The PRODUCT collectively includes computer software and associated media, printed materials, hardware key (dongle), and electronic documentation. The PRODUCT also includes any updates and supplements to the original PRODUCT that may have been produced by ENSOFT. By installing, copying, downloading, accessing or otherwise using the PRODUCT, the USER agrees to be bound by the terms of this LICENSE. If you (the USER) do not agree to the terms of this LICENSE, do not install or use the PRODUCT.

SOFTWARE LICENSE & DISCLAIMER

The PRODUCT is protected by copyright laws and international copyright treaties, as well as other intellectual property laws and treaties. The PRODUCT is licensed, not sold.

1. GRANT OF LICENSE

This LICENSE grants you the following rights:

1.1 INSTALLATION AND USE

1.1.1 Single-User Licenses

This software is licensed only to the USER (company or individual) whose name is registered with ENSOFT and for one specific physical site (“SITE”) registered with ENSOFT. You may install and use the PRODUCT on any number of computers at the licensed SITE. However, the PRODUCT is fully operational only in the SITE computer that carries the appropriate PRODUCT’s hardware key (“KEY”) that is used as software protection device.

1.1.2 Network Licenses

This software is licensed only to the USER (company or individual) whose name is registered with ENSOFT and for the specific physical site(s) (“SITE(S)”) and IP range registered with ENSOFT. Each network seat that is purchased is provided with access for SITE(S) clients located within up to 2 subnets with unique third octets (“CLIENT SUBNETS”). The minimum two-seat network license can be associated to a maximum of 4 CLIENT SUBNETS (within up to 4 unique third octets). Purchase of additional network seats can extend the allowable range of CLIENT SUBNETS.

The USER may install and use the PRODUCT on any computer in the licensed SITE(S) that is within the allowable CLIENT SUBNETS registered with ENSOFT. Any one computer in the network can be designated as license server for the PRODUCT by carrying the appropriate PRODUCT’s hardware key (“KEY”) that is used as software protection device.

This Network License strictly prohibits the PRODUCT to be used in or from computers located in office locations that are different than the licensed SITE(S) or outside the registered CLIENT SUBNETS. Users in physical office locations other than the registered SITE(S) with ENSOFT are required to purchase additional licenses of the PRODUCT, even if the COMPANY is the same and/or if the additional offices are located in the same city.

2. OTHER RIGHTS AND LIMITATIONS

2.1 EDUCATIONAL VERSION

If the PRODUCT was licensed with educational discounts, the use of the PRODUCT is strictly limited to academic or research activities of educators and/or students. Any other usage voids all the rights under this LICENSE. If in doubt, please contact ENSOFT to determine if you have a PRODUCT version that was licensed for educational purposes.

2.2 LIMITATIONS ON REVERSE ENGINEERING, DECOMPILATION, AND DISASSEMBLY

You may not reverse engineer, decompile, or disassemble the PRODUCT, except and only to the extent that such activity is expressly permitted by applicable law notwithstanding this limitation.

2.3 RENTAL

You may not rent, lease or lend the PRODUCT to third parties.

2.4 TRADEMARKS

This LICENSE does not grant you any rights in connection with any trademarks or service marks of ENSOFT.

2.5 SUPPORT SERVICES

ENSOFT shall provide you with limited support and maintenance services (“SUPPORT”) related to the PRODUCT during the initial year after purchase and for any additional SUPPORT term that the COMPANY elects to purchase for PRODUCT after the initial warranty period expires.

Use of SUPPORT is limited to the ENSOFT policies and programs described in the PRODUCT’s User’s Manual, in documentation on the ENSOFT web site, and/or in other materials provided by ENSOFT.

Any supplemental software code that may be provided to you as part of the SUPPORT or that is downloaded from the ENSOFT web site shall be considered part of the PRODUCT and subject to the terms and conditions of this LICENSE. With respect to technical information you provide to ENSOFT as part of the SUPPORT, ENSOFT may use such information for its business purposes, including for product support, development or advertisements. However, ENSOFT will not utilize such technical information in a form that personally identifies the USER.

2.6 SOFTWARE TRANSFER

The initial user of the PRODUCT may make a permanent transfer of this LICENSE and PRODUCT and only directly to an end user. This transfer must include all of the PRODUCT (including all component parts, the media and printed materials, any upgrades, this LICENSE, and the PRODUCT’s appropriate hardware KEY). Such transfer may not be by way of consignment or any other indirect transfer. The transferee of such one-time transfer must agree to comply with the terms of this LICENSE, including the obligation not to further transfer this LICENSE and PRODUCT.

2.7 TERMINATION

Without prejudice to any other rights, ENSOFT may terminate this LICENSE immediately if you fail to comply with the terms and conditions of this LICENSE. In such event, you must destroy all copies of the PRODUCT and all of its component parts and provide evidence of such destruction in writing to ENSOFT within 3 business days.

2.8 INDEMNIFICATION

Within and during the terms of this LICENSE, ENSOFT warrants that the use of the initially provided PRODUCT does not infringe any patent, copyright, or trademark in the United States, and ENSOFT shall indemnify and hold USER harmless against any and all losses, damages and expenses, (including attorney's fees) which USER may sustain or incur as a result of a breach of this warranty.

2.9 CONFIDENTIAL INFORMATION

ENSOFT and the USER may have access to certain proprietary information and materials of the other that are confidential and of substantial value to the respective party, which value would be impaired if such information were disclosed to third parties ("CONFIDENTIAL INFORMATION"). ENSOFT and the USER agree that neither shall disclose any CONFIDENTIAL INFORMATION to any third party and shall take every reasonable precaution to protect CONFIDENTIAL INFORMATION.

The provisions of this section shall not apply to any information which (i) is or becomes available to the public other than by breach of the LICENSE agreement by the receiving party, (ii) is rightfully received by receiving party from a third party without confidential limitations, (iii) is independently developed by receiving party's employees without access to CONFIDENTIAL INFORMATION, or (iv) is known to the receiving party without any restriction on its use or disclosure prior to first receipt of it from the disclosing party.

3. COPYRIGHT

All title and intellectual property rights in and to the PRODUCT (including but not limited to any images, photographs, animations, video, audio, music, and text that may be incorporated into the PRODUCT), the accompanying printed materials, and any copies of the PRODUCT are owned by ENSOFT. All title and intellectual property rights in and to the content which may be accessed through use of the PRODUCT is the property of the respective content owner and may be protected by applicable copyright or other intellectual property laws and treaties. This LICENSE grants you no rights to use such content. All rights not expressly granted are reserved by ENSOFT. This PRODUCT is protected by the United States Copyright Law and International Copyright Treaty.

4. SOFTWARE DISCLAIMER

Although the PRODUCT has been used with apparent success in many analyses, new information is developed continuously and new or updated PRODUCT releases may be written from time to time. All users are requested to inform ENSOFT immediately if any errors are found in the PRODUCT. As modifications, updates, or new versions are produced, the latest codes are posted on ENSOFT's web site and made available to all visitors for free downloading.

No warranty, expressed or implied, is offered as to the accuracy of results from ENSOFT's PRODUCT. The PRODUCT should not be used for design unless caution is exercised in interpreting the results and independent calculations are available to verify the general correctness of the results. Users are assumed to be knowledgeable of the information in the printed documentation that is distributed with the digital media. Users are assumed to recognize that the input parameters, eg., soil properties, increment length, tolerance on solution convergence, and many others, can have a significant effect on the solution and must be chosen carefully. Users should have a thorough understanding of the relevant theoretical criteria (appropriate references are suggested in the software documentation).

5. GOVERNING LAW

This LICENSE is governed by the laws of the State of Texas and laws and treaties of the United States of America.

6. CONTACT INFORMATION

Should you have any questions concerning this LICENSE or if you desire to contact ENSOFT for any reason, please use the following:

Ensoft Incorporated
3003 West Howard Lane
Austin, Texas 78728
United States of America

NO OTHER WARRANTIES

TO THE MAXIMUM EXTENT PERMITTED BY APPLICABLE LAW, ENSOFT DISCLAIMS ALL OTHER WARRANTIES AND CONDITIONS, EITHER EXPRESSED OR IMPLIED, INCLUDING, BUT NOT LIMITED TO, IMPLIED WARRANTIES OR CONDITIONS OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND TITLE, WITH REGARD TO THE PRODUCT, AND THE PROVISION OF SUPPORT SERVICES. THIS LIMITED WARRANTY GIVES YOU SPECIFIC LEGAL RIGHTS. YOU MAY HAVE OTHERS, WHICH VARY FROM STATE/JURISDICTION TO STATE/JURISDICTION.

LIMITATION OF LIABILITY

TO THE MAXIMUM EXTENT PERMITTED BY APPLICABLE LAW, IN NO EVENT SHALL ENSOFT BE LIABLE FOR ANY SPECIAL, INCIDENTAL, INDIRECT, OR CONSEQUENTIAL DAMAGES WHATSOEVER (INCLUDING, WITHOUT LIMITATION, DAMAGES FOR LOSS OF BUSINESS PROFITS, BUSINESS INTERRUPTION, LOSS OF BUSINESS INFORMATION, OR ANY OTHER PECUNIARY LOSS) ARISING OUT OF THE USE OF OR INABILITY TO USE THE SOFTWARE PRODUCT OR THE FAILURE TO PROVIDE SUPPORT, EVEN IF ENSOFT HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. IN ANY CASE, ENSOFT'S ENTIRE LIABILITY UNDER ANY PROVISION OF THIS LICENSE AGREEMENT SHALL BE LIMITED TO THE GREATER OF THE AMOUNT ACTUALLY PAID BY YOU FOR THE PRODUCT OR U.S.$1.00.

Appendix 1 – Input Error Messages

Un-numbered: Version mismatch between main program and dynamic link library for computation files.

Input Data Error No. 1: An error was detected in the input data for computing a *p-y* curve using the API sand criteria. A value of zero was input for the friction angle of the sand.

Input Data Error No. 2: An error was detected in the input data when computing a *p-y* curve using the API criteria for sand. The angle of the ground slope cannot be greater than the internal friction angle of the sand at the ground surface.

Input Data Error No. 3: The pile tip is below the deepest extent of the input data for soil shear strength versus depth.

Input Data Error No. 4: The pile extends below the deepest extent of the input data for soil shear strength versus depth.

Input Data Error No. 5: The pile tip is below the deepest extent of the input curve for soil shear strength versus depth.

Input Data Error No. 6: Use of *p-y* multipliers cannot be specified for use with user-specified *p-y* curves.

Input Data Error No. 7: The number of points defining effective unit weight versus depth is zero and number of input *p-y* curves is also zero.

Input Data Error No. 8: A value of zero was input for the friction angle for a sand when computing a *p-y* curve using the Reese et al. criteria.

Input Data Error No. 9: The angle of the slope cannot be greater than the friction angle of the sand at the ground surface.

Input Data Error No. 10: A negative or zero value was input for the friction angle for silt.

Input Data Error No. 11: The angle of the ground surface slope cannot be greater than the angle of internal friction angle of the silt (c-phi) soil at the ground surface.

Input Data Error No. 12: An error was detected that is related to an incompatibility between the input data defining soil layering and soil shear strength values when computing a *p-y* curve using the Matlock soft clay criteria.

Input Data Error No. 13: A cohesion of zero was input for a stiff clay without free water.

Input Data Error No. 14: An error was detected in the input data used to compute *p-y* curves in stiff clay with free water. A value of zero was input for the cohesion of a stiff clay.

Input Data Error No. 15: The pile extends below the deepest extent of the input curve for effective unit weight versus depth.

Input Data Error No. 16: The input value for the compressive strength of a weak rock was input as negative or zero.

Input Data Error No. 17: The value number of points to define the pile properties is 2 to 40. Either too few or too many points were input for the definition of pile properties.

Input Data Error No. 18: The depth at the bottom of the last layer is higher than the tip of the pile.

Input Data Error No. 19: The depth of the first point of the data for effective unit is not located at the ground surface.

Input Data Error No. 20: The depth of the first point of the soil strength profile is not located at the ground surface.

Input Data Error No. 21: The depth for the first data point for p-multipliers is not located at the ground surface.

Input Data Error No. 22: Loading was specified to be cyclic, but the number of cycles of loading was specified outside the range of 2 to 5000.

Input Data Error No. 23: Deleted.

Input Data Error No. 24: Deleted.

Input Data Error No. 25: The input file is empty. No analysis can be performed.

Input Data Error No. 26: The number of rebar cannot exceed 300 in this version of LPile.

Input Data Error No. 27: Zero values were entered for one of pile diameter, pile area, or moment of inertia.

Input Data Error No. 28: Cyclic loading type was specified and the number of cycles of loading are outside the valid range of 2 to 5,000.

Input Data Error No. 29: A depth above the ground surface was specified for the printing of a *p-y* curve.

Input Data Error No. 30: A depth below the pile tip was specified for the printing of a *p-y* curve.

Input Data Error No. 31: The pile extends below the deepest extent of the input data for RQD versus depth.

Input Data Error No. 32: Type of reinforcement is unrecognized by LPile.

Input Data Error No. 33: Tapered rebar option type is unrecognized.

Input Data Error No. 34: Specified rebar cover is greater than one-half of pile diameter.

Input Data Error No. 35: Too many pile sections specified for analysis.

Input Data Error No. 36: Deleted.

Input Data Error No. 37: Deleted.

Input Data Error No. 38: Deleted.

Input Data Error No. 39: Deleted.

Input Data Error No. 40: Deleted.

Input Data Error No. 41: Deleted.

Input Data Error No. 42: Deleted.

Input Data Error No. 43: Pile section type unrecognized.

Input Data Error No. 44: Units of computation option unrecognized by program.

Input Data Error No. 45: Input data for pile properties specifies a negative pile station coordinate.

Input Data Error No. 46: Input data for pile properties specified a pile station below the pile tip.

Input Data Error No. 47: The depth of the top of a layering is greater than or equal to the depth of the bottom of the layer.

Input Data Error No. 48: A negative or zero value was input for the cohesion for silt.

Input Data Error No. 49: The interpolated value of RQD used for *p-y* curves in weak rock was found to be invalid because it was either less than zero or more than 100 percent.

Input Data Error No. 50: The pile-tip movement data for shear resistance at the pile tip is in error. Either the first point is not zero or one of the other points is less than or equal to the previous point.

Input Data Error No. 51: The nonlinear bending stiffness input by the user varies by more than a factor of 100 for a given axial thrust force. This indicates that either unrealistic or erroneous data was input.

Input Data Error No. 52: The nonlinear bending stiffness input by the user exhibits strain hardening behavior. LPile can handle nonlinear bending cases only with strain softening behavior.

Input Data Error No. 53: The number of lines of soil movement data is outside the range of 2 to 50.

Input Data Error No. 54: The top and bottom elevations for weak rock layer are equal.

Input Data Error No. 55: The specified number of pile increments is less than 40.

Input Data Error No. 56: The specified number of pile increments is more than 500.

Input Data Error No. 57: The input value for pile length is zero.

Input Data Error No. 58: The pile tip is below the deepest extent of the input curve for weak rock parameter k_{rm} versus depth.

Input Data Error No. 59: The number of input pile diameters is more than 40.

Input Data Error No. 60: An error was detected in the shear strength of soil input data when interpolating to obtain values of cohesion or uniaxial compressive strength. The depth increment between the upper and lower soil depths in a layer is zero.

Input Data Error No. 61: The depth of the bottom of the top soil layer is less than or equal to zero. This will cause the algorithm for layering correction to *p-y* curves to generate incorrect *p-y* curves for layers below the top layer.

Input Data Error No. 62: An error was detected for input values for uniaxial compressive strength. Values cannot be less than zero.

Input Data Error No. 63: The input value of k_{rm} is less than or equal to zero for weak rock.

Input Data Error No. 64: The input value for the number of iterations is less than 40 or more than 1000.

Input Data Error No. 65: The input value for the convergence tolerance cannot be smaller than 1×10^{-10} inches.

Input Data Error No. 66: The input value for the convergence tolerance cannot be larger than 0.001 inches.

Input Data Error No. 67: The input value for the convergence tolerance cannot be smaller than 2.54×10^{-12} meters.

Input Data Error No. 68: The input value for the convergence tolerance cannot be larger than 2.54×10^{-5} meters.

Input Data Error No. 69: The input value for the excessive deflection limit is smaller than 10 percent of the pile diameter.

Input Data Error No. 70: The input value for the number of cycles of loading is greater than 10 and one of the soil layers is loess. The soil model for loess is valid only for 1 to 10 cycles of loading.

Input Data Error No. 71: An error was detected in the soil shear strength values to be used for computing a *p-y* curve using the Matlock soft clay with user-defined *J* criteria. A negative or zero value of cohesion was input for a soft clay soil.

Input Data Errors 72-94 are reserved for future use.

Input Data Error No. 95: An input line was unrecognized. See the output report for further details.

Input Data Error No. 99: An input line was unrecognized. See the output report for further details.

Appendix 2 – Runtime Error Messages

Runtime Error No. 1: Internal error occurred in the LPile computation dynamic link library. This error is reported when the dynamic link library fails to load into memory.

Runtime Error No. 2: Contents of file NAMES.DAT is corrupted. This file contains the path and name of all data and output files used by LPile.

Runtime Error No. 3: The name of the input data file is corrupted.

Runtime Error No. 4: The name of the output report file is corrupted.

Runtime Error No. 5: The name of the plot output file is corrupted.

Runtime Error No. 6: The name of the runtime message file is corrupted.

Runtime Error No. 7: The user name is corrupted.

Runtime Error No. 8: User company name is corrupted.

Runtime Error No. 9: The computed deflection of the pile head is larger than the allowable deflection. This error may be due to overloading the pile or bad input data.

Runtime Error No. 10: LPile was unable to obtain an answer within the specified convergence tolerance within the specified limit on iterations.

Runtime Error No. 11: The numerical solution failed due to a small pivot number.

Runtime Error No. 12: An error occurred because the computed value of compressive strain in concrete is larger than 0.001. This indicates that that the drilled shaft has failed due to crushing of concrete.

Runtime Error No. 13: Deleted.

Runtime Error No. 14: An internal error occurred in computing area of concrete for prestressing computations.

Runtime Error No. 15: An error occurred in computing area of steel for prestressing computations.

Runtime Error No. 16: The location of neutral axis was not found within 1,000 iterations during computation of non-linear moment-curvature behavior.

Runtime Error No. 17: Filename information corrupted. No analysis can be performed.

Runtime Error Nos. 18-21: Deleted.

Runtime Error No. 22: A runtime error was caused by the input value k_{rm} being less than or equal to 0.

Runtime Error No. 23: A runtime error was caused by the input value for combined ground slope and pile batter being greater than the angle of friction of a silt layer.

Runtime Error No. 24: The input value for axial thrust force is greater than the structural capacity in compression.

Runtime Error No. 25: The input value for axial thrust force is greater than the structural capacity in tension.

Runtime Error No. 26: An LRFD load case value for axial thrust force is greater than the structural capacity in compression.

Runtime Error No. 27: An LRFD load case value for axial thrust force is greater than the structural capacity in tension.

Runtime Error No. 28: An unrecoverable numerical error has occurred. Either pile-top deflection or computed maximum change in deflection is not a number and further computations are impossible.

Runtime Error No. 29: A layer thickness was too thin to contain a nodal point. This prevents the correct computation of the layer's *p-y* curve.

Runtime Error No. 30: An error occurred in the computation of the undrained shear strength value for a soil layer.

Runtime Error No. 31: The computed value of soil modulus computed in Reese sand is not-a-number. This is due to one or more of the required soil properties being equal to zero. See the output report for more information.

Runtime Error No. 32: The default value of soil modulus computed in Reese sand is not-a-number. This is due to one or more of the required soil properties being equal to zero. See the output report for more information.

Runtime Error No. 33: The default value of soil modulus computed in soft clay is not-a-number. This is due to one or more of the required soil properties being equal to zero. See the output report for more information.

Runtime Error No. 34: The computed value of soil modulus computed in soft clay is not-a-number. This is due to one or more of the required soil properties being equal to zero. See the output report for more information.

Runtime Error No. 35: The default value of soil modulus computed in API soft clay is not-a-number. This is due to one or more of the required soil properties being equal to zero. See the output report for more information.

Runtime Error No. 36: The computed value of soil modulus computed in API soft clay is not-a-number. This is due to one or more of the required soil properties being equal to zero. See the output report for more information.

Appendix 3 – Warning Messages[1]

[1] Note, the warning message number is not displayed by LPile

Warning Message No. 300: Multiple warning messages have been generated. See the output report file for more details.

Warning Message No. 301: An unreasonable input value for *k* has been specified See the output report file for more details.

Warning Message No. 302: An unreasonable input value for friction angle has been specified for a soil layer defined using the sand criteria. See the output report file for more details.

Warning Message No. 303: An unreasonable input value for friction angle has been specified for a soil layer defined using the API sand criteria. See the output report file for more details.

Warning Message No. 304: An unreasonable input value for shear strength has been specified for a soil layer defined using the soft clay criteria. See the output report file for more details.

Warning Message No. 3041: An unreasonable input value for shear strength has been specified for a layer defined using the soft clay criteria. The input value is greater than 1,250 psf (8.68 psi).

Warning Message No. 3042: An unreasonable input value for shear strength has been specified for a layer defined using the soft clay criteria. The input value is greater than 59.85 kPa. See the output report file for more details.

Warning Message No. 305: Too many values were calculated for moment-curvature. This may indicate that the pile is too weak or is under-reinforced. You should examine your input data and increase the amount of steel reinforcement if necessary.

Warning Message No. 3051: An unreasonable input value for shear strength has been specified for a layer defined using the stiff clay with free water criteria. The input value is less than 500 psf (3.47 psi).

Warning Message No. 3052: An unreasonable input value for shear strength has been specified for a layer defined using the stiff clay with free water criteria. The input value is greater than 8,000 psf (55.55 psi).

Warning Message No. 3053: An unreasonable input value for shear strength has been specified for a layer defined using the stiff clay with free water criteria. The input value is less than 23.94 kPa.

Warning Message No. 3054: An unreasonable input value for shear strength has been specified for a layer defined using the stiff clay with free water criteria. The input value is greater than 383.04 kPa. See the output report file for more details.

Warning Message No. 306: Negative values of bending moment were computed in nonlinear EI computations. This may indicate that the pile is too weak or is under-reinforced and that all reinforcing steel has yielded.

Warning Message No. 3061: An unreasonable input value for shear strength has been specified for a layer defined using the stiff clay without free water criteria. The input value is less than 500 psf (3.47 psi).

Warning Message No. 3062: An unreasonable input value for shear strength has been specified for a layer defined using the stiff clay without free water criteria. The input value is greater than 8,000 psf (55.55 psi).

Warning Message No. 3063: An unreasonable input value for shear strength has been specified for a layer defined using the stiff clay without free water criteria. The input value is less than 23.94 kPa.

Warning Message No. 3064: An unreasonable input value for shear strength has been specified for a layer defined using the stiff clay without free water criteria. The input value is greater than 383.04 kPa.

Warning Message No. 307: The input data for nonlinear bending appears to be have been input incorrectly. Negative values of bending moment should not be input.

Warning Message No. 3071: An unreasonable input value for the uniaxial compressive strength has been specified for a layer defined using the weak rock criteria. The input value is less than 100 psi.

Warning Message No. 3072: An unreasonable input value for unconfined compressive strength has been specified for a soil defined using the weak rock criteria. The input value is greater than 1,000 psi.

Warning Message No. 3073: An unreasonable input value for unconfined compressive strength has been specified for a soil defined using the weak rock criteria. The input value is less than 689.5 kPa.

Warning Message No. 3074: An unreasonable input value for unconfined compressive strength has been specified for a soil defined using the weak rock criteria. The input value is greater than 6895 kPa.

Warning Message No. 308: An unreasonable input value for uniaxial compressive strength has been specified for a layer defined using the vuggy limestone (strong rock) criteria.

Warning Message No. 309: An unreasonable input value for compressive strength of concrete has been specified.

Warning Message No. 3091: An unreasonable input value for compressive strength of concrete has been specified. The input value is either smaller than 2,000 psi or larger than 8,000 psi.

Warning Message No. 3092: An unreasonable input value for compressive strength of concrete has been specified. The input value is either smaller than 13,790 kPa or larger than 55,160 kPa.

Warning Message No. 310: An unreasonable input value for modulus of elasticity for steel has been specified.

Warning Message No. 311: An unreasonable input value for yield strength of reinforcement has been specified.

Warning Message No. 3101: An unreasonable input value for modulus of elasticity has been specified for the reinforcing steel. The input value is either smaller than 27,500,000 psi or larger than 30,500,000 psi.

Warning Message No. 3102: An unreasonable input value for modulus of elasticity has been specified for the reinforcing steel. The input value is either smaller than 189,600,000 kPa or larger than 210,300,000 kPa.

Warning Message No. 3111: An unreasonable input value for yield strength of reinforcing steel has been specified. The input value is either smaller than 38,000 psi or larger than 80,000 psi.

Warning Message No. 3112: An unreasonable input value for yield strength of reinforcing steel has been specified. The input value is either smaller than 262,000 kPa or larger than 551,600 kPa.

Warning Message No. 312: An input value for cover of reinforcement has been specified that may be unreasonable.

Warning Message No. 3121: An unreasonable input value for concrete cover thickness has been specified. The input value is either smaller than 0.8 inches or larger than 6 inches.

Warning Message No. 3122: An unreasonable input value for concrete cover thickness has been specified. The input value is either smaller than 0.02 meters or larger than 0.16 meters. You should check your input for accuracy.

Warning Message No. 313: An unreasonable input value for loss of prestress has been specified.

Warning Message No. 314: An unreasonable input value for prestressing force has been specified.

Warning Message No. 315: Pile deflection has exceeded the failure deflection for the vuggy limestone criteria for one or more of the loading cases analyzed. You should check the computed output for both deflection and bending moment.

Warning Message No. 316: The input value for k_{rm} used by the weak rock criteria is smaller than 0.00005. This value is outside the recommended range of 0.00005 to 0.0005.

Warning Message No. 317: The input value for k_{rm} used by the weak rock criteria is larger than 0.0005. This value is outside the recommended range of 0.00005 to 0.0005. You should check your input data for accuracy.

Warning Message No. 318: The pile deflection is less than 1×10^{-14}. LPile used the limiting value of soil modulus when computing the *p-y* curve for soft clay.

Warning Message No. 3261: An unreasonable input value for shear strength has been specified for a layer defined using the stiff clay without free water criteria with user-defined *k*. The input value is less than 500 psf (3.47 psi).

Warning Message No. 3262: An unreasonable input value for shear strength has been specified for a layer defined using the stiff clay without free water criteria with user-defined *k*. The input value is greater than 8,000 psf (55.55 psi).

Warning Message No. 3263: An unreasonable input value for shear strength has been specified for a layer defined using the stiff clay without free water criteria with user-defined *k*. The input value is less than 23.94 kPa.

Warning Message No. 3264: An unreasonable input value for shear strength has been specified for a layer defined using the stiff clay without free water criteria with user-defined *k*. The input value is greater than 383.04 kPa.

Warning Message No. 351: Values entered for effective unit weights of soil were outside the limits of 0.011574 pci (20 pcf) or 0.0810019 pci (140 pcf). This data may be erroneous.

Warning Message No. 352: Values entered for effective unit weights of soil were outside the limits of 3.15 kN/m^3 or 22 kN/m^3. This data may be erroneous.

Warning Message No. 353: Values of effective unit weight cannot be checked because general units have been selected.

Warning Message No. 354: The maximum depth of a soil layer defined as liquefiable sand is greater than meters or 236.22 inches. This is greater than the maximum depth recommended for this *p-y* curve criteria.

Warning Message No. 355: Computation of nonlinear bending stiffness found that moment capacity was developed at compressive strains smaller than 0.003. This usually indicates that a section is under-reinforced or the level of prestressing is too small.

Warning Message No. 400: One or more of the LRFD load cases have overloaded the structural capacity of the pile. See the LRFD Performance by Load Case Combination section of the output report file for more details.