User's Manual for LPile 2016
(Using Data Format Version 9)

A Program to Analyze Deep Foundations Under Lateral Loading

by

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Chapter 1
Introduction

1-1 General Description

LPile is a special purpose program that can analyze a pile or drilled shaft under lateral loading. The program computes deflection, shear, bending moment, and soil response with respect to depth in nonlinear soils. The program has graphical features for presentation of results and has additional features for special analyses.

The soil and rock is modeled using lateral load-transfer curves (*p-y* curves) based on published recommendations for various types of soils and rocks. The *p-y* curves are internally generated by the program. Alternatively, the user can input values for *p-y* curves for a soil layer. The program also contains specialized procedures for computing *p-y* curves in layered soil profiles.

Several types of pile-head loading conditions may be selected, and the structural properties of the pile may be varied along the pile length. Additionally, LPile can compute the nominal-moment capacity and provide design information for rebar arrangements.

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 was begun in 1985 and was completed in 1986. The general theory and methodology of LPile 1.0 was similar in features to COM624, which was 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, about four years after the previous upgrade. 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.

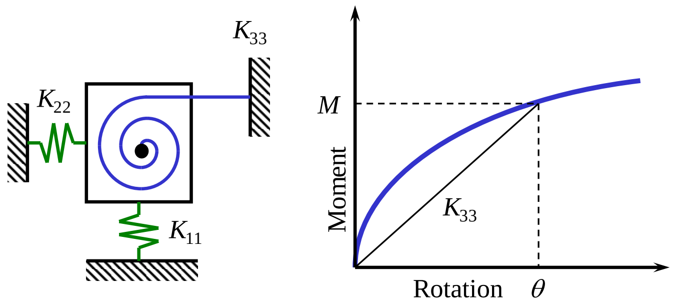
1-2-7 LPile Plus 2.0 for Windows (1995)

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 2012 for Windows, 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 2013 for Windows, 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 2015 for Windows, 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 2016 for Windows, Data Format 9

LPile 2016 introduced several new features. These features include:

- 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.

The user interface and program options and settings remain similar to those used in LPile 2015.

1-3 Technical Support

Although LPile was programmed for ease of use and increased feedback to the user, some users may still have questions with regard to technical issues. The Ensoft technical support staff recommends users to request technical support via email. In all technical support requests via email, please include the following information:

- Software version, including maintenance release number (obtained from the Help/About dialog),
- a description of the user's problem or concern,
- attach a copy of input-data file (files with extension .lp9d) to the email, and
- name and telephone number of the contact person and of the registered user (or name and office location of the registered company).

Although immediate answers are offered on most technical support requests, please allow up to two business days for a response 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. The maintenance support is free of charge within the first year of the software purchase. One calendar year of maintenance is in effect for the first year after purchase. Annual maintenance policy and the invoice will be sent to the user in advance before the maintenance contract expired.

1-3-1 Upgrade Notifications and Ensoft's Website

Subscriptions for software updates are available for a fee (contact Ensoft for latest pricing). All users who are subscribed to the software update compact disk service and who keep their current address on file with Ensoft will receive update compact disks by mail quarterly when new versions become available.

All users with active maintenance subscriptions may also obtain updates from Internet via the Ensoft website at http://www.ensoftinc.com, plus additional information on software updates, program demos, and new applications; technical news, and company information.

1-3-2 Renewal of Program Maintenance

The cost to renew program maintenance will depend on the length of time for which the program maintenance has been expired. The pricing policy for renewing program maintenance can be found on the Ensoft website at http://www.ensoftinc.com.

1-3-3 Changes of Support Policy

The software support policy and associated expenses are subject to change without notice, as many of the costs associated with technical support are outside of Ensoft's direct control. However, any change of policy will be provided during telephone calls for software support.

Chapter 2
Installation and Getting Started

2-1 Installation and Computing Hardware Requirements

LPile is distributed with a black USB security device. This method of distribution is compatible with Windows operating systems from Windows 95 through Windows Seven, has better capabilities over other alternatives, and allows users to obtain software updates or replacements via the Internet.

Before installing, your personal computer should be equipped with the following:

- An open USB port
- At least 50MB of free space on the hard disk drive
- At least 2 GB of random access memory (RAM)
- At least 128 MB of video memory
- A monitor with a display resolution of 1,280 by 1,028 pixels or greater
- Windows 2000, Windows XP, Windows Vista, Windows 7, or Windows 8 operating systems with the latest service packs installed. While LPile is compiled as a 32-bit application, it is compatible with both 32-bit and 64-bit operating systems.

To install the software from the distribution CD-ROM:

1. Insert the Ensoft USB security device into any open USB port.
2. Insert the compact disk from Ensoft. If the Autoplay disk feature is enabled, Windows will ask you if you want to run Setup.exe. If Autoplay is not enabled then from *My Computer*, double-click the drive into which the installation compact disk is inserted.
3. Select to install LPile, and then select on the radio button in the dialog shown in Figure 2-1 for “Single-User License” if installing a single-user version of the software or select “Network License” if installing a network version of the software. Note: if the wrong version for the license is selected and program installation is completed, it will be necessary to completely uninstall the software prior to re-installation for the correct license version

2-1-1 Single User Version

If your license is for a single-user, select that option and click next. Follow the directions in the dialog boxes until the installation is completed.

2-1-2 Network Version

At the following dialog shown in Figure 2-2, choose the appropriate option for either “Client Computer” or “Software Server.”

Note that the “Server” version should be installed by the network administrator while logged in with full administrative privileges enabled and must be installed only on one server computer. The USB security device must be plugged in to the software server after the software installation is completed, and the Server computer must be logged onto the network in order for “Client” users to access LPile.

Follow the displayed instructions until the installation process is complete.

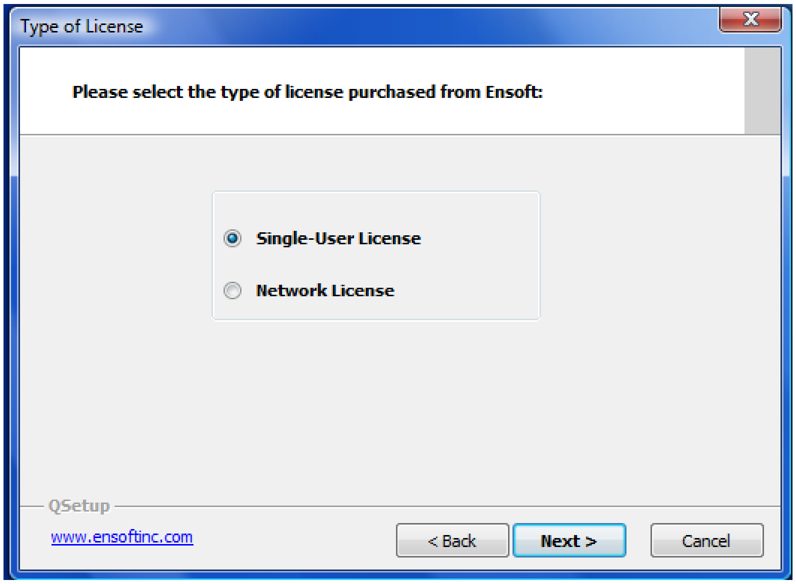


Figure 2-1 Options for Type of License Installation

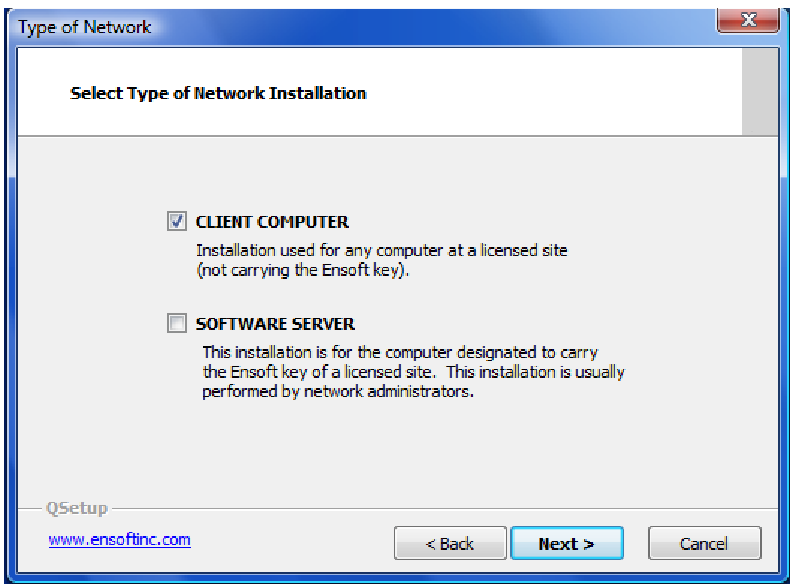


Figure 2-2 Options for Type of Network Installation

2-1-3 Software Updates

Ensoft will maintain the software, produce software improvements and/or fixes and place the latest software programs on Ensoft's website. Users with current maintenance contracts may download the latest program update from *http://www.ensoftinc.com*. Downloads are free for the user during the maintenance contract period.

2-1-4 Installation of Software Updates

LPile can display a query to check the Internet during program start up to see if there is a newer version of the program, as shown in Figure 2-3. The user may turn off the automatic display of this query during program start up by checking the box labeled "Do not show this message again." The user may restore the setting to display this query automatically using the Program Options and Settings dialog.

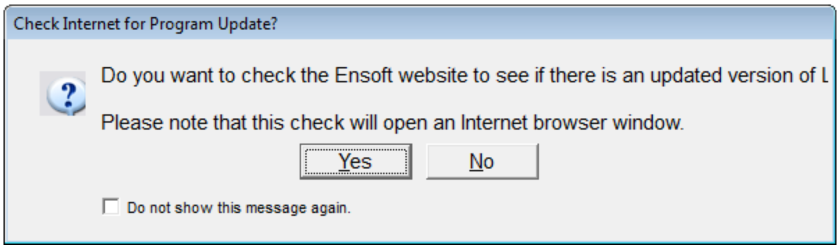


Figure 2-3 Check for Update Query

If the user clicks Yes, LPile will start the default Internet browser on the computer, connect to the Internet, and check the current version of the program against the latest update version available for download from *www.ensoftinc.com*.

2-2 Getting Started

A flow chart showing the menu choices and features of LPile is presented in Figure 2-4. The following paragraphs provide a description of the program functions and will guide the user in using the program.

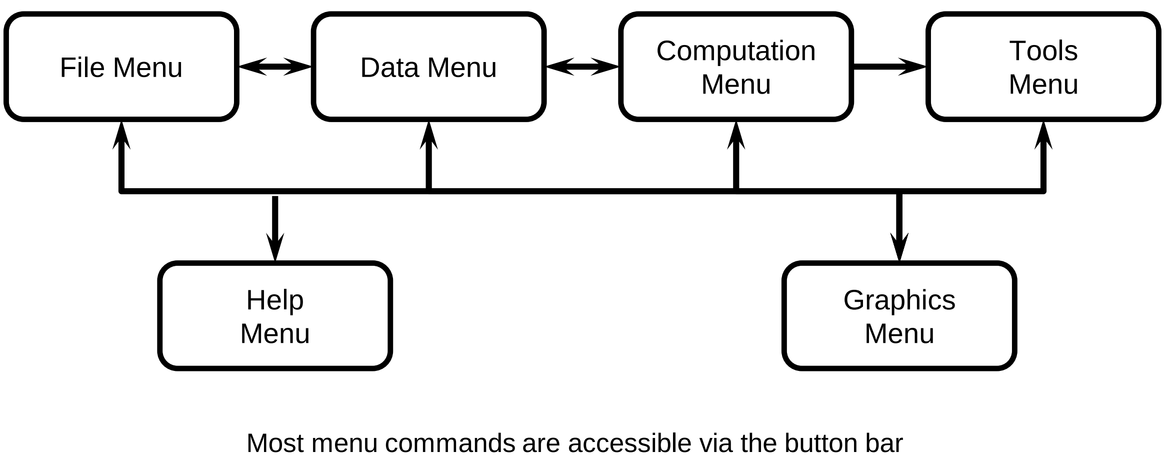


Figure 2-4 Principal Operations of LPile

Start the program by navigating to the shortcut in the start menu and clicking on it. The main program window will appear, as shown in Figure 2-5. You should see a program window with a toolbar at the top with the following choices: File, Data, Computation, Graphics, Tools, Window, and Help. A button bar is displayed under the menu bar that provides quick access to most of the features of LPile.

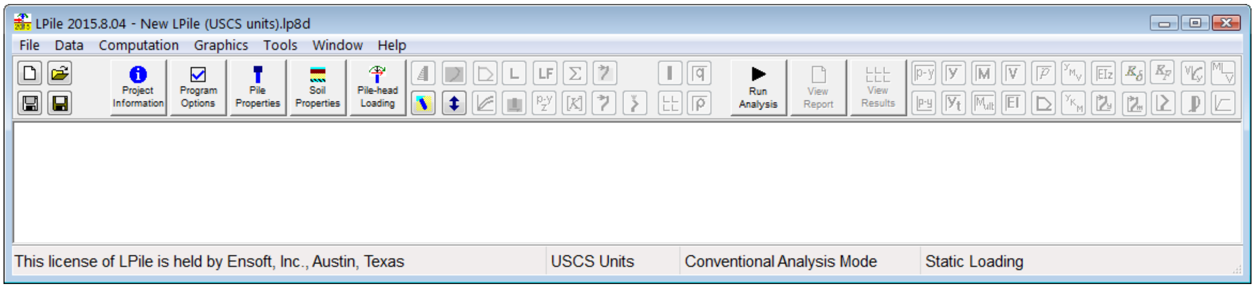


Figure 2-5 Main Window of LPile

As a standard Windows feature, pressing Alt 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, N, in sequence, Ctrl+N, or click **File** then **New**. Additionally, holding the mouse cursor over a button will show a help bubble that describes the button's function.

2-2-1 File Menu and Buttons

The File Menu shown in Figure 2-6 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.

Figure 2-6 File Menu

A list of most-recently-used files is displayed in between **Save As…** and **Exit**.

- **New**: Create a new data file.
- **Open…**: Open an existing data file. If a partially completed LPile input file, or an invalid data file is opened, an information dialog reporting that an "invalid or incomplete" file is being opened. Clicking OK dismisses the message, and the previously saved data should be available. If a complete input file is loaded, an information dialog reporting that "Data File: (name of file), has been read by LPile" should appear, and the user should click OK.
- **Save**: Save input data under the current file name.
- **Save As…**: Save input data under a different file name.
- **Save LRFD Combos…**: Save LRFD Combinations in separate data file (visible only when in LRFD mode)
- **Exit**: Exit the program. If the input file was modified but unsaved, a prompt will appear asking if the user would like to save changes.

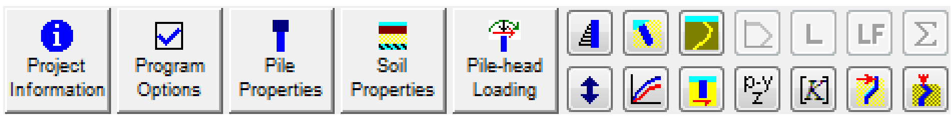
The group of four speed buttons at the left side of the button bar (shown in Figure 2-7) provide access to the New, Open, Save, and Save As commands.

Figure 2-7 File Speed Buttons

2-2-2 Data Menu and Buttons

Please refer to Section 3-1 for a detailed discussion of this pull-down menu.

The group of buttons shown in Figure 2-8 provides access to the data editing commands in the different modes of analysis.



(a) Buttons Available for Conventional Analysis

(b) Buttons Available for LRFD Analysis

(c) Buttons Available for Compute Nonlinear *EI* Only Analysis

Figure 2-8 Speed Buttons for Data Input for Different Analysis Modes

Four buttons are provided to review the input data in graphical form. The upper left button shown in Figure 2-9 displays the pile and soil layer profile and the lower left button presents a set of charts for reviewing the input soil and rock properties. The upper right button presents a graph of distributed lateral loading versus depth. The lower right 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.

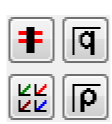


Figure 2-9 Input Data Review Buttons

2-2-3 Computation Menu and Buttons

The Computation Menu shown in Figure 2-10 is provided to access commands to analyze the input data and to view the input and output report files generated during an analysis.

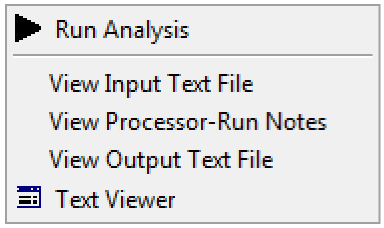


Figure 2-10 Computation Menu

The Run Analysis Button shown in Figure 2-11 analyzes the current input data and the View Report button displays the current output report. Analyses 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 file. If the data file has been named, the existing data set will automatically be re-saved to disk prior to running an analysis.

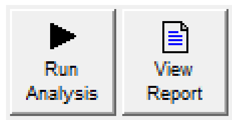


Figure 2-11 Run Analysis and View Report Buttons

2-2-3-1 Run Analysis:

The Run Analysis command processes the current input data. Analyses 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 file. If the data file has been named, the existing data set will automatically be re-saved to disk prior to running an analysis.

The following files are produced by LPile:

Table 2-1 File Types and File Extensions

File Description	File Extension*
Input file for LPile	*.lp#d
Output report file	*.lp#o
Processor run notes file	*.lp#r
Graphics titles file	*.lp#t
LRFD load and resistance combinations	*.lrfd
Moment-curvature output files	*.txt

* Where # denotes the file format version number.

All output files will be created in the same directory folder as the input file.

If there are input or runtime errors during execution, appropriate error messages will appear in the dialog box. 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 generate, the summary graph of results will be displayed after the analysis is completed.

2-2-3-2 View Input Text:

This command activates the user-specified text editor to display the analytical input data in plain-text format. This command is available after the input data has been saved to disk, or when opening an existing input-data file. It is useful for experienced users who may just want to change quickly one or two parameters using the text editor, or for users wishing to observe the prepared input data in text mode.

2-2-3-3 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 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 corresponding to the last line read and the line that immediately follows (that was not read). In some cases, the processor-run notes will also include an error message.

2-2-3-4 View Output Report:

This command opens the output report 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 report files usually contain the following information:

1. Authorized user name, company, and security device serial number information.
2. The date and time of the analysis.
3. 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, including a report of the input data as well as tables of the computational results.
4. A report of input data for pile analysis. Users are strongly recommended to check this report of input data for mistakes.
5. If selected, reports for selected *p*-*y* curves at user-specified output depths.
6. Tables of computed values of deflection, bending moment, shear, soil resistance, and related information, as a function of depth for the pile.
7. Reports of convergence performance of the finite-difference approximations, providing data about the maximum moment and lateral force imbalances observed during execution (maximum imbalances should usually consist of small numbers).
8. Summary tables, containing information about the results and number of iterations performed until convergence was reached.
9. An optional summary table of pile-head deflection versus pile length.
10. An optional summary table of foundation stiffness matrix components.

2-2-4 Graphics Menu and Buttons

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

The group of buttons shown in Figure 2-12 provides access to the graphs generated by LPile. The enabling of buttons depends on the options selected and the output generated in the analysis.

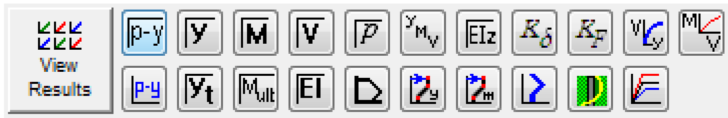


Figure 2-12 Graphics Buttons

2-2-5 Tools Menu

The Tools Menu has the five entries shown in Figure 2-13.

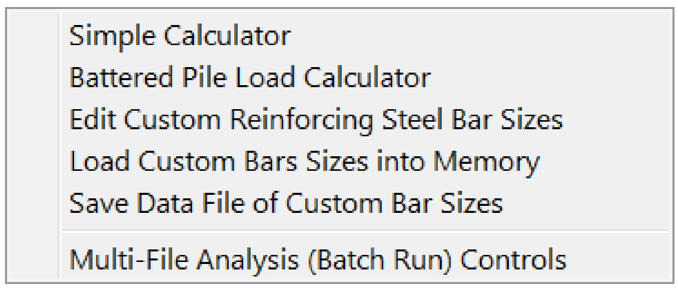


Figure 2-13 Tools Menu

The first entry provides a simple calculator for the user's convenience.

The second entry provides a special calculator to compute axial and transverse forces acting on battered piles from horizontal and vertical loadings.

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.

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 list of custom bar sizes is not included as part of the LPile data file.

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. This feature is discussed in more detail in the chapter on the Tools Menu.

2-2-6 Window Menu

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

2-2-7 Help Menu

The Help Menu provides commands to view the manuals for LPile, descriptions of messages, information on technical support, and program updates to LPile. The Help pull-down menu is shown in Figure 2-14. Descriptions of the pull-down menu commands are described in the following sections.

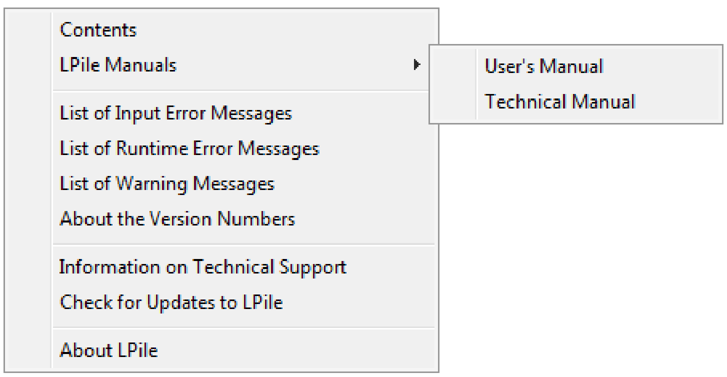


Figure 2-14 Help Menu

2-2-7-1 Contents:

The on-line help system is accessed through this command.

2-2-7-2 LPile Manuals

This command opens a side menu to commands to view the *User's Manual* and *Technical Manual* for LPile. These manuals can also be opened from the Windows Start Menu.

2-2-7-3 List of Input Error Messages

This command opens a dialog that lists the input error messages generated by LPile. The full list of input error messages is listed in Appendix 1.

2-2-7-4 List of Runtime Error Messages

This command opens a dialog that lists the runtime error messages generated by LPile. The full list of runtime error messages is listed in Appendix 2.

2-2-7-5 List of Warning Messages

This command opens a dialog that lists the warning messages generated by LPile. Note that when warning message are displayed computations can be performed by LPile, but that the results of the computations may be in error due to input values that may not be appropriate. The purpose of the warning messages is to call the user's attention to input values that may not be correct. The full list of warning messages is listed in Appendix 3.

2-2-7-6 About the Version Numbers

Displays information about how the version numbers current used for LPile are defined.

2-2-7-7 Technical Support Information

Displays information about eligibility for receiving technical support and how to receive technical support from Ensoft.

2-2-7-8 Check for Updates

Opens the LPile update page in the user's default browser.

Note that some anti-virus programs may require the user to grant permission to LPile to open the Internet browser program.

2-2-7-9 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. An example is shown below.

Figure 2-15 Example of About LPile Dialog

Chapter 3
Input of Data

The input of required data for an analysis is controlled by the options chosen in the Program Options and Settings dialog. It is recommended that the user select and enter 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 will then 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 always adds a new row to the end of all existing rows, and the Delete Row button 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.

Table 3-1 Mathematical Operators and Numerical Constants Used in LPile Input Dialogs

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…

3-1 Data Menu

The editing commands are presented on the Data Menu shown in Figure 3-1. The commands in the upper three sections of the Data Menu are enabled by default when LPile is started. The commands in the bottom section of the Data Menu are enabled by activation of the relevant program options.

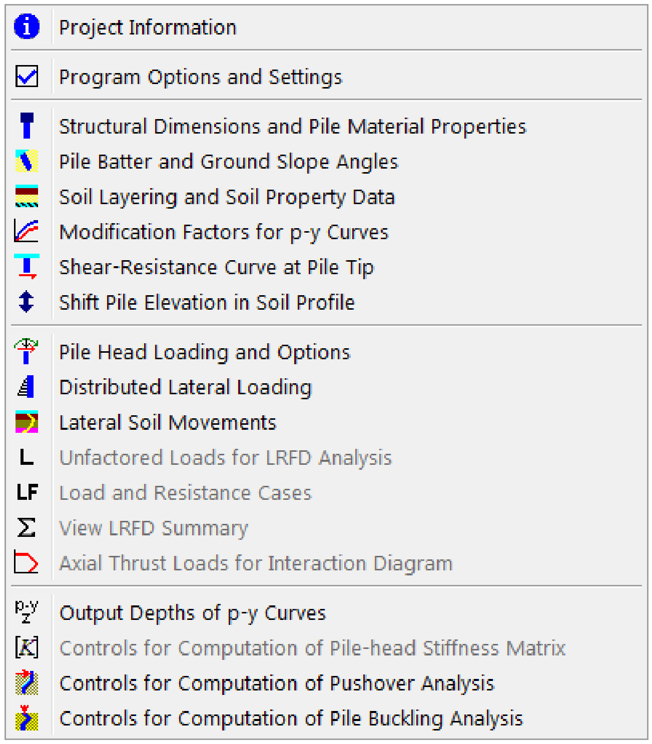


Figure 3-1 Data Menu

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

3-2 Speed Buttons for Data Entry

The button bar contains a set of buttons to open the dialogs for the entry and manipulation of data. The buttons for data entry for conventional analysis are shown in Figure 3-2, for Computation of *EI* only are shown in Figure 3-3, and for LRFD Analysis are shown in Figure 3-4.

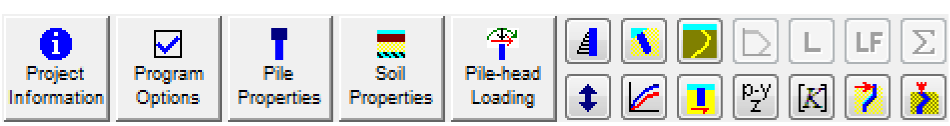


Figure 3-2 Buttons for Data Entry and Manipulation for Conventional Analysis

Figure 3-3 Buttons for Data Entry and Manipulation for Computation of Nonlinear *EI* Only

Figure 3-4 Buttons for Data Entry and Manipulation for LRFD Analysis

3-3 Project Information Dialog

The Project Information dialog, shown in Figure 3-5, 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.

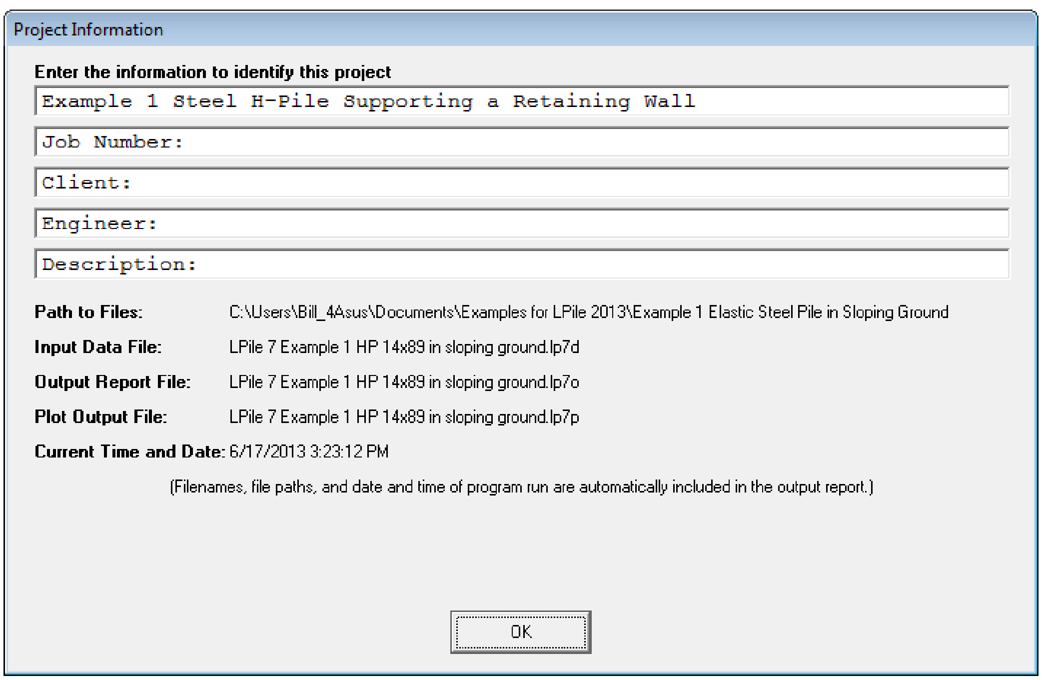


Figure 3-5 Example of Project Information Input Dialog

3-4 Program Options and Settings Dialog

Almost all program options have been consolidated into a single input dialog box. Two options not included in this dialog are the option to enter distributed lateral loading for conventional analysis and the option to compute top deflection versus pile length for individual load cases for conventional analysis.

The Program Options and Settings dialog is used by the user to select options and settings for each set of data being analyzed by LPile. This input dialog provides options that are 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.

3-4-1 Computational Options

There are twelve computational options displayed in the upper left corner of the Program Options and Settings dialog shown in Figure 3-6. These options are:

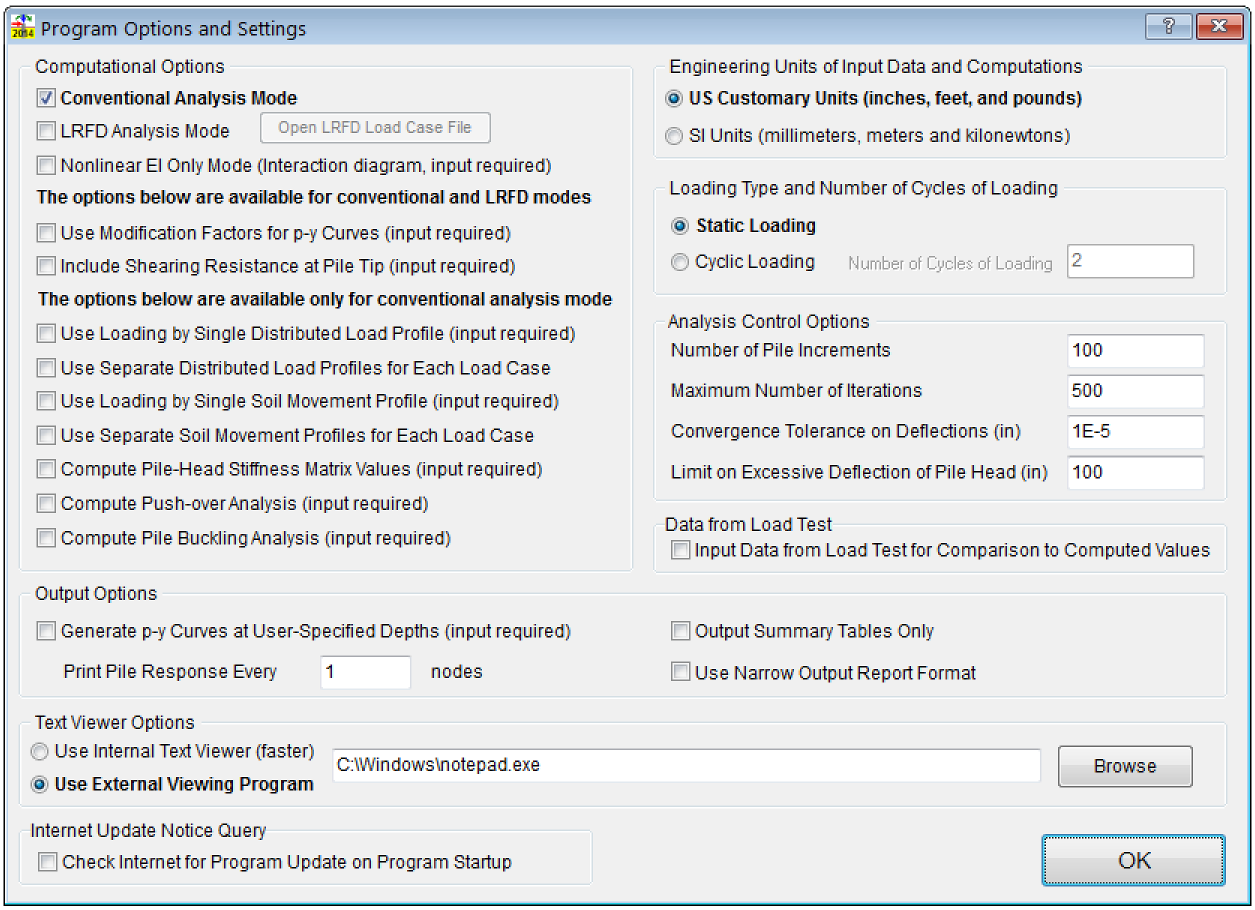


Figure 3-6 Program Options and Settings Dialog

These options are:

☑ Use Conventional Analysis
If checked, LPile permits input of up to 100 load cases for various pile-head loading and displacement conditions. When conventional analysis is selected, the additional options for distributed lateral loading and loading by soil movement, computation of pile head stiffness, push-over analysis, and pile buckling analysis become active.

- ☑ Use 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. Optionally, the LRFD case load combinations may be either read from or saved to an external file (with the file type of *lrfd*) or may be entered by the user.
- ☑ Compute Nonlinear *EI* Only
  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.

- ☑ Include Modification Factors for Group Action: Activates *p-y* Modification Factors for Group Action under the Data Menu.
- ☑ Include Shearing Resistance at Pile Tip: Activates Shear Resistance Curve at Pile-Tip under the Data Menu.

The following options become active only when using conventional analysis.

- ☑ Use loading by single distributed lateral loading profile
- ☑ Use separate distributed loading profiles per load case
- ☑ Use loading by single soil movement profile.
- ☑ Use separate soil movement profiles per load case.
- ☑ 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 Controls for Computation of Stiffness Matrix dialog discussed in Section 3-12-4.
- ☑ Compute pushover analysis
  If this option is selected, LPile computes the pushover analysis according to the controls set by the use in the Controls for Pushover Analysis dialog discussed in Section 3-12-5.
- ☑ 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 Controls for Pile Buckling analysis discussed in Section 3-12-6.

3-4-2 Engineering Units of Input Data and Computations

Here the user can specify either US Customary System (USCS) units using pounds, inches, and feet or 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.

3-4-3 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, the limit on excessive deflection of the pile head, and the number of pile increments.

3-4-3-1 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.

Often the user may opt to use an odd number of increments to obtain computed results at specific rounded valued of depth. For example, a user may opt to use 140 increments to obtain results for every 0.5 feet of depth for a 70-ft-long pile.

3-4-3-2 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.

Table 3-2 Recommended Ranges for Maximum Number of Iterations

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

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.

3-4-3-3 Convergence Tolerance

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 cautious when using values larger the 0.0001 inches or 2.54×10^{-6} meters.

3-4-3-4 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 wished 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.*

3-4-4 Loading Type and Number of Cycles of Loading

The user can specify either static or cyclic loading in the option group for Loading Type and Number of Cycles of Loading. Selection of type of loading is important when analyzing piles under lateral forces. Further information on the influence of loading type is included in the *Technical Manual.*

In general, cyclic loading 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 cyclic loads considered in LPile. When cyclic loading 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 for the *p-y* curves, as described in the *Technical Manual*.

Dynamic loading from earthquakes can be analyzed by LPile if equivalent pseudo-static loads are input. Pseudo-static loads are sized in a manner that results in computed moments and deflections that 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 use of the DynaN, DynaPile, or DynaMat programs from Ensoft or some other program for performing dynamic response analyses.

3-4-5 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.

3-4-5-1 Generate *p-y* Curves at User-Specified Depths

Checking activates the feature to output *p-y* curves at the depths specified by the user. 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.

3-4-5-2 Print Summary Tables Only

Checking this option activates the printing of summary tables only for computations of pile bending stiffness and pile response.

3-4-5-3 Printing Increment

The user may also 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 Only Print Summary Tables option. A value of 1 prints the values at every node; 2 prints values at every other nodes, etc. Note that the printing increment is used only for the generation of the output report, but not for the generation of output graphs.

3-4-5-4 Use Narrow Output Report Format

This option controls the printed width of the output reports, 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.

3-4-6 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. The selected text editor will be used for View Input Text File, View Processor Run Notes, View Output Text File, and Text Viewer under the Computation Menu.

3-4-7 Input of Data from Load Testing

It is possible to enter and save load test data input into LPile and to display the load test data along with the results computed by LPile on the graphs of pile-head shear force versus pile-head deflection and bending moment versus depth. The ability to enter and save load test data is enabled by checking this option.

3-4-8 Internet Update Notice Query

Checking the *Show Internet Update Notice Query on Program Startup* restores the automatic display of this query dialog if this option has been turned off.

3-5 Structural Dimensions and Material Properties

3-5-1 General Description of Input

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

Use of the features to evaluate ultimate moment capacity and nonlinear bending stiffness is essential when analyzing the behavior of drilled shafts under lateral loading.

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.

3-5-2 Section Type and Shape

The tab page for Section Type and Shape is shown in Figure 3-7. There are 14 general types of sections and a pile may have up to 20 different sections of different section types. The default section type is an elastic (non-yielding) section. All other section types have either specified or computed structural moment capacities and will have non-linear moment-curvature relationships.

The dialog box shown in Figure 3-7 is for an H-pile defined as an elastic section, after definition of the structural shape. Once the section shape and dimensions have been properly defined, a scale drawing of the section or section profile is displayed, as shown below.

The user should note the tab pages shown in the input dialog. For an elastic section, only two tabs are shown. For other types of sections, the number of tab pages shown will depend on the types of materials used in the section type selected.

The light yellow memo shown below the tab pages gives a general description of the section type and may provide special guidance in its use and construction.

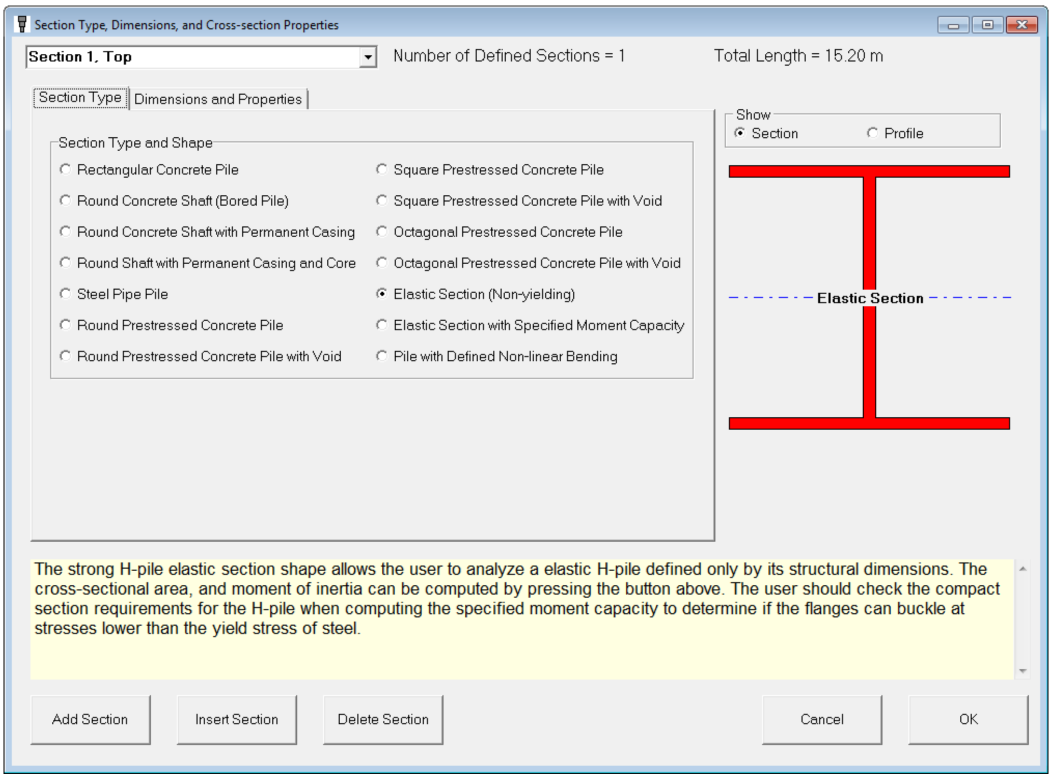


Figure 3-7 Pile Section, Section Type Tab

3-5-3 Warning and Design Error Messages

LPile provides warning messages and advice for design for several of the structural types. The purpose for these warning messages is to alert the user either to design geometries that may be difficult to construct and to alert the user if inappropriate design parameters have been specified by the user. A short discussion of several types of the warning messages follows.

3-5-3-1 Spacing of Reinforcement

Warning and design error 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 fluid concrete to flow around the bars.

3-5-3-2 Percentage of Reinforcement

Design error 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. Warning messages will be displayed if the percentage of axial reinforcement is between 0.5 and 0.95 percent. The lower limits for axial reinforcement are 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. deep in long shafts), the minimum steel percentage can be less than 1 percent. Section 10.9.1 of ACI 318 states that the minimum area of longitudinal stress 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 10.8.4 of ACI 318 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.

3-5-3-3 Level of Prestressing After Losses

LPile is capable of computing the level of prestress after losses for prestressed sections. LPile will display design error 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.

3-5-4 Elastic Sections

Elastic sections require input for the section length in feet or meters, section shape (rectangular, circular, pipe, strong or weak H-pile, or embedded circular pole), sectional dimensions in inches or millimeters at the top and bottom of the section, and the modulus of elasticity in psi or kPa for the full section.

Six cross-sectional shapes are available for elastic sections. These shapes are:

- Rectangular shape defined by the width and depth of section at top and bottom of section.
- Circular shape without void defined by diameter at top and bottom of section.
- Pipe shape defined by outer diameter and wall thickness at top and bottom of section.
- Strong H-pile shape (web perpendicular to neutral axis).
- Weak H-pile shape (web aligned with neutral axis).
- Embedded pile defined by diameter of drilled hole and bending properties of the embedded pole.

The rectangular, circular and pipe sections may be tapered with depth. The H-pile sections and embedded pole sections cannot be tapered with depth.

In the case of tapered sections, the section dimensions at top and bottom of section are check 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 from the cross-sectional dimensions interpolated with depth and the input 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.

In the case of 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 pile has a shear strength that is more than ten times the shear strength of the surrounding soil profile.

The purpose of the input 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.

The elastic sections are the only type of section that does not 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 3-12-5.

3-5-5 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 specified moment capacity. 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.

The rectangular, circular and pipe sections may be tapered with depth. The H-pile sections and embedded pole sections cannot be tapered with depth.

In the case of tapered sections, the section dimensions at top and bottom of section are check 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 from the cross-sectional dimensions interpolated with depth and the input 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.

In the case of tapered elastic sections with specified moment capacity, the assumption is made that the yield stress of the pile material is uniform over the length of the section. The yield stress of the pile material is computed from the specified moment capacity at the top of the section and is used to compute the plastic moment capacity along the length of the section.

3-5-6 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 the length, width, and depth of section; the compressive strength of concrete; and the number, positions, yield stress, and modulus of elasticity of the reinforcing steel bars. The tab pages for this data are shown in Figure 3-8 through Figure 3-10.

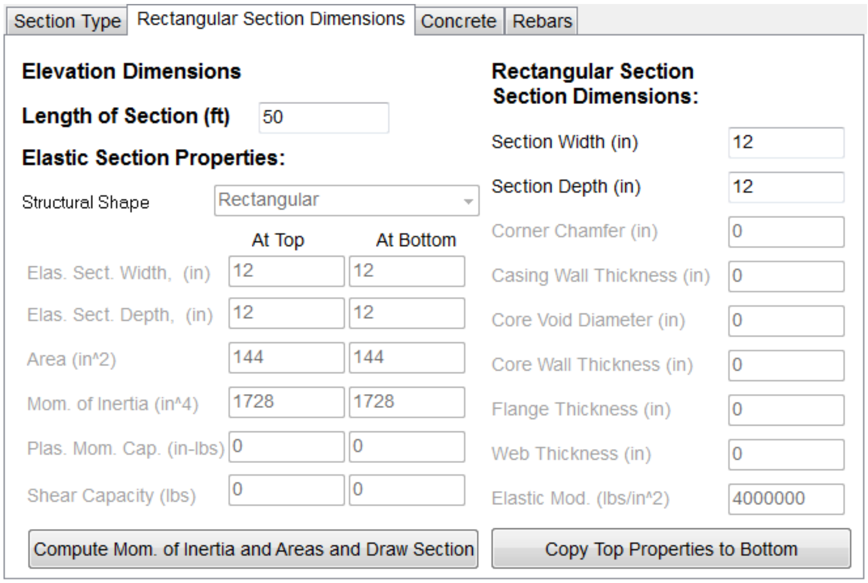


Figure 3-8 Dimensions Tab Page for Rectangular Concrete Section

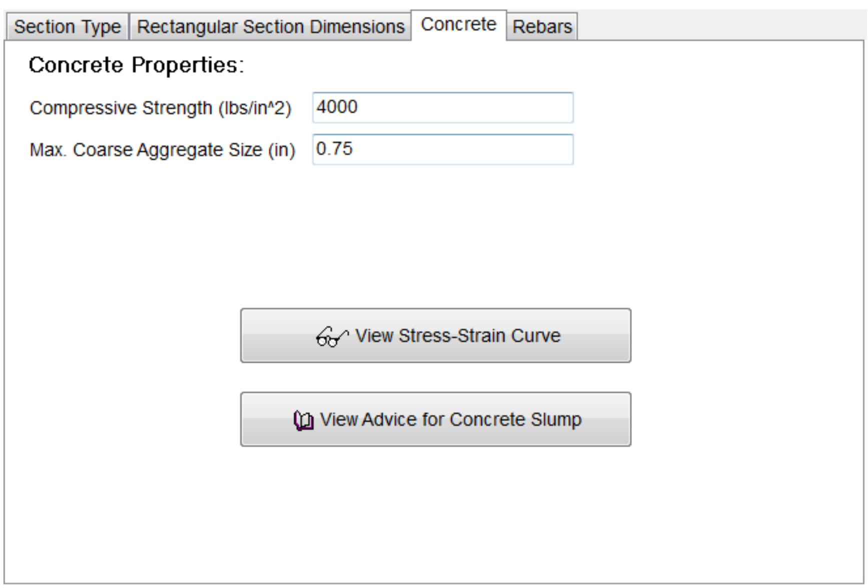


Figure 3-9 Concrete Tab Page for Rectangular Concrete Section

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 rebar layout table is shown in Figure 3-11. Once the position and size of reinforcing steel has been entered, LPile will display a scale drawing of the section as shown in Figure 3-12.

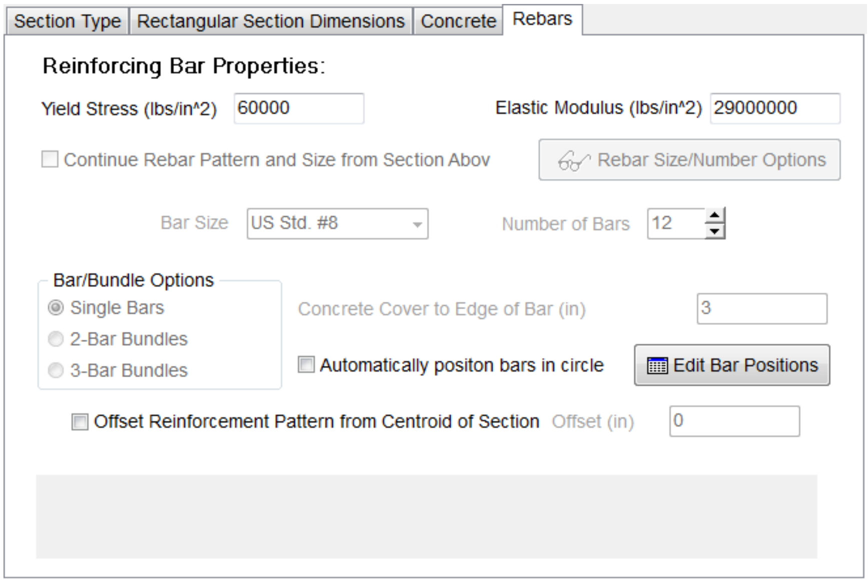


Figure 3-10 Rebars Tab Page for Rectangular Concrete Section

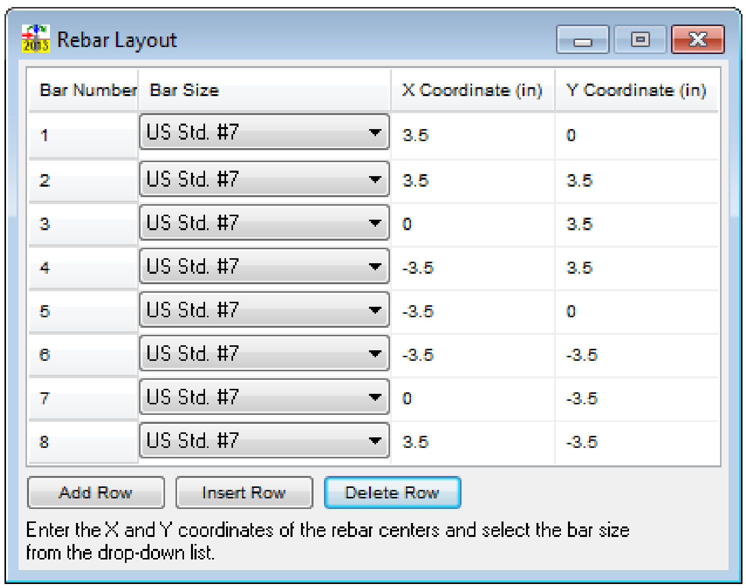


Figure 3-11 Rebar Layout Table for Rectangular Concrete Section

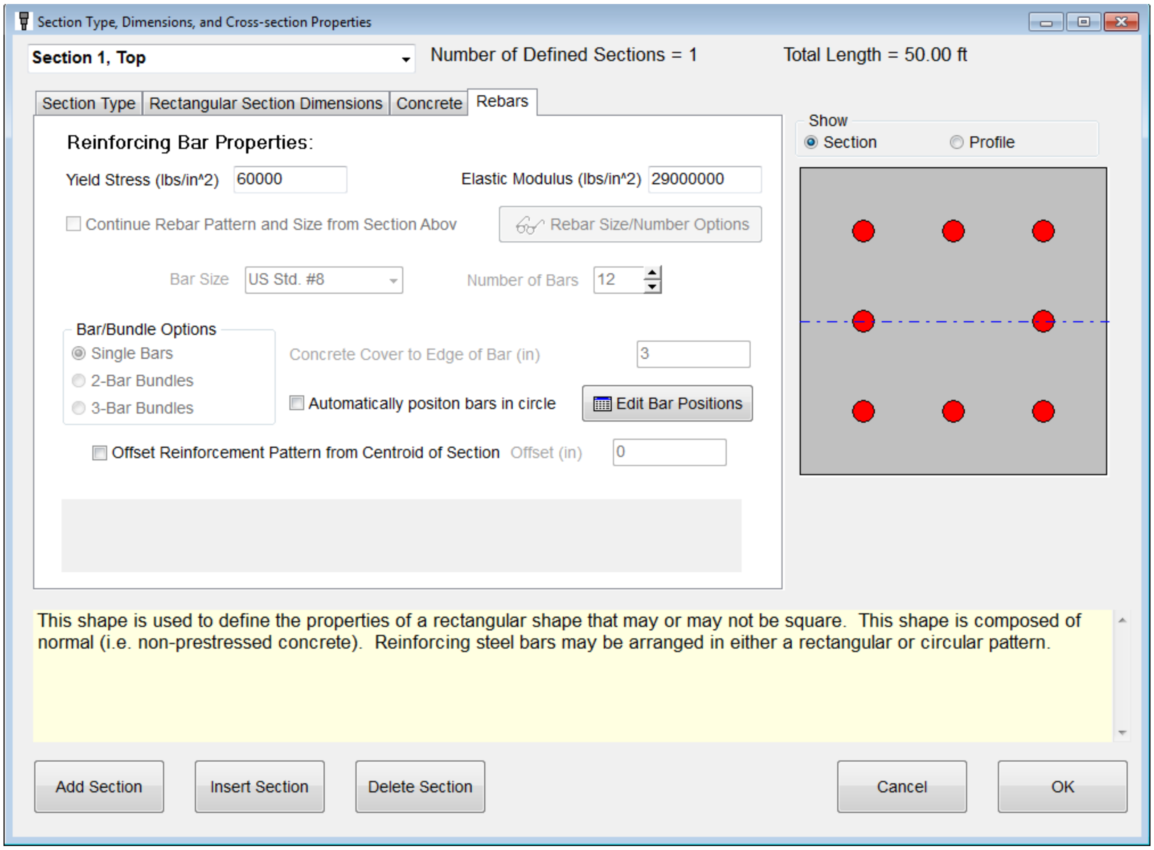


Figure 3-12 Section Type, Dimensions, and Cross-section Properties Dialog for Rectangular Concrete Section Showing Rebar Layout After Definition

3-5-7 Round Concrete Shafts (Bored Piles)

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 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 3-13 is an example of the Section Type page 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 shows the shaft dimensions. All data entry cells for which input is not required are disabled. In the case of a round concrete shaft, the only required dimensions are the section length in feet or meters and diameter in inches or millimeters.

The Concrete tab page, shown before in Figure 3-9, shows the compressive strength of concrete and the maximum size of coarse aggregate. 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.

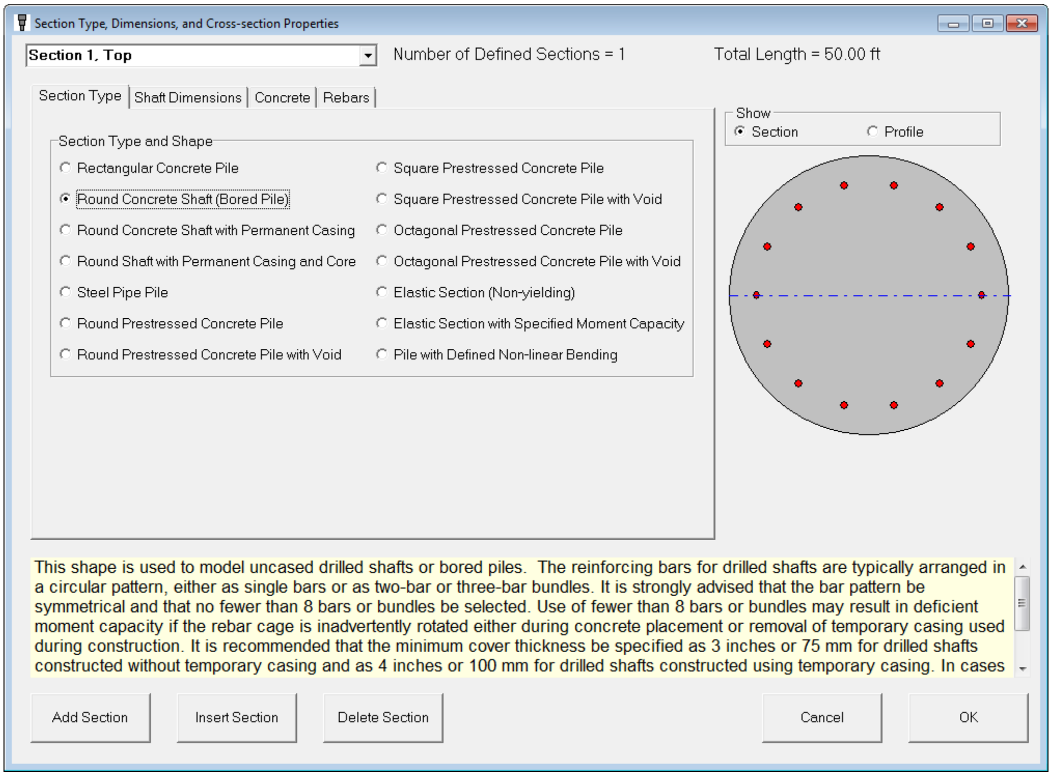


Figure 3-13 Tab Sheet for Selection of Section Type Showing Current Cross-section

The layout of reinforcement is defined 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 3-14. The drawing of the cross-section automatically updates to indicate any changes in the geometric properties of the reinforcing bars.

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 third of the dialog shown above. 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.

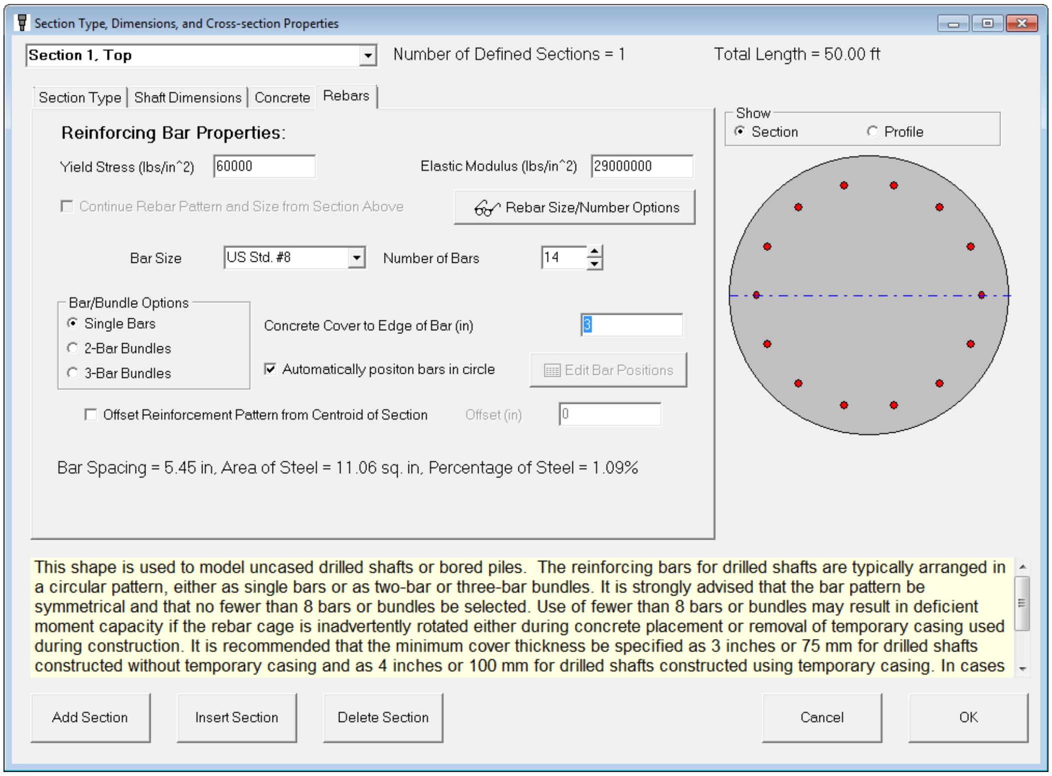


Figure 3-14 Tab Sheet for Reinforcing Bar Properties

3-5-8 Round Concrete Shaft with Permanent Casing

The properties of round concrete drilled shafts 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 Dimensions tab page, shown in Figure 3-15 shows the dimensions for the outer diameter and wall thickness of the permanent casing. The drawing of the cross-section will automatically update to show any changes in the shaft geometric properties for casing or reinforcing bars.

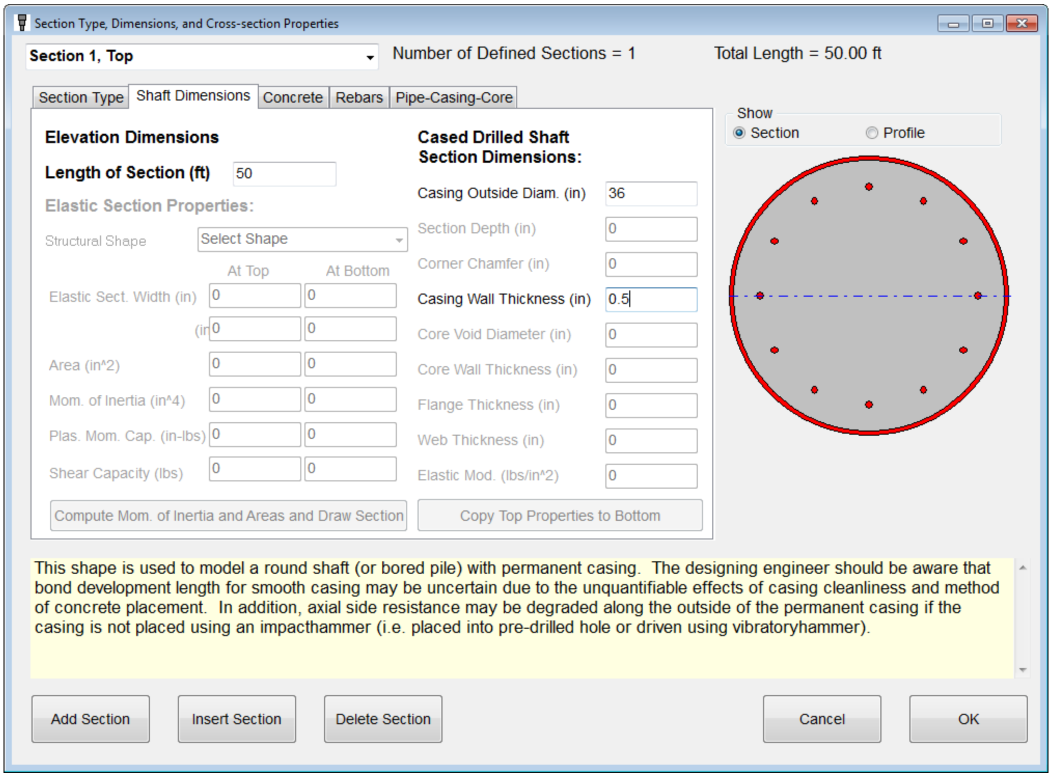


Figure 3-15 Tab Sheet for Shaft Dimensions for Drilled Shaft with Permanent Casing

The tab page for reinforcement is similar to that used for drilled shafts, except that the label for the entry cell for concrete cover has be modified to indicate that the cover dimension is measured inside the permanent casing as shown in Figure 3-16.

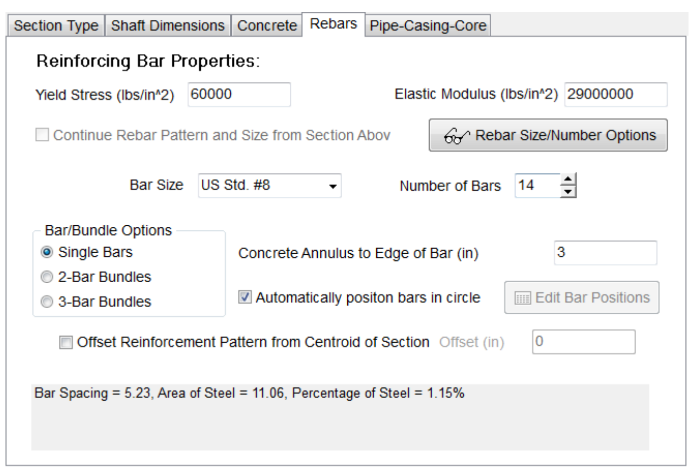


Figure 3-16 Tab Sheet for Rebars for Drilled Shaft with Permanent Casing

The tab page for casing material properties, shown in Figure 3-17, 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.

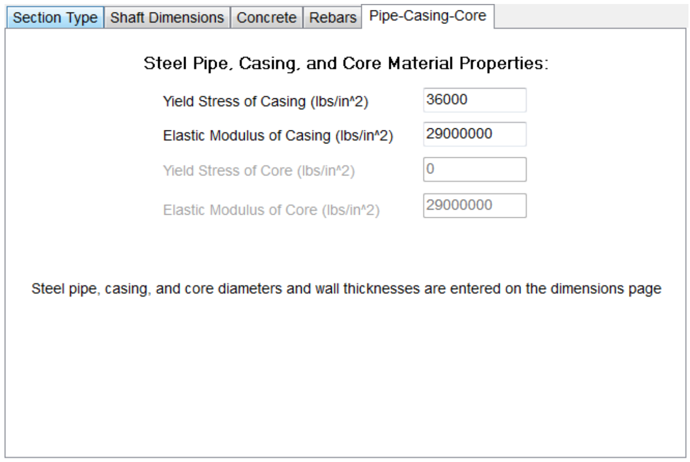


Figure 3-17 Tab Sheet for Casing Material Properties for Drilled Shaft with Permanent Casing

3-5-9 Round Concrete Shaft with Permanent Casing and Core

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 and core;
- the yield stress and modulus of elasticity of the casing and core;
- the number, positions, yield stress, and modulus of elasticity of the reinforcing steel bars; and
- the compressive strength of concrete.

In addition, the user may specify if the core is filled with concrete by checking the box on the casing and core materials tab page.

The Shaft Dimensions tab page for a drilled shaft with casing and core 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 values of the casing and 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. This is done by entering a set of core diameter and wall thickness that has a moment of inertia equal to that for the structural steel insert.

The values entered for the wall thickness values of the casing and 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. This is done by entering a set of core diameter and wall thickness that has a moment of inertia equal to that for the structural steel insert.

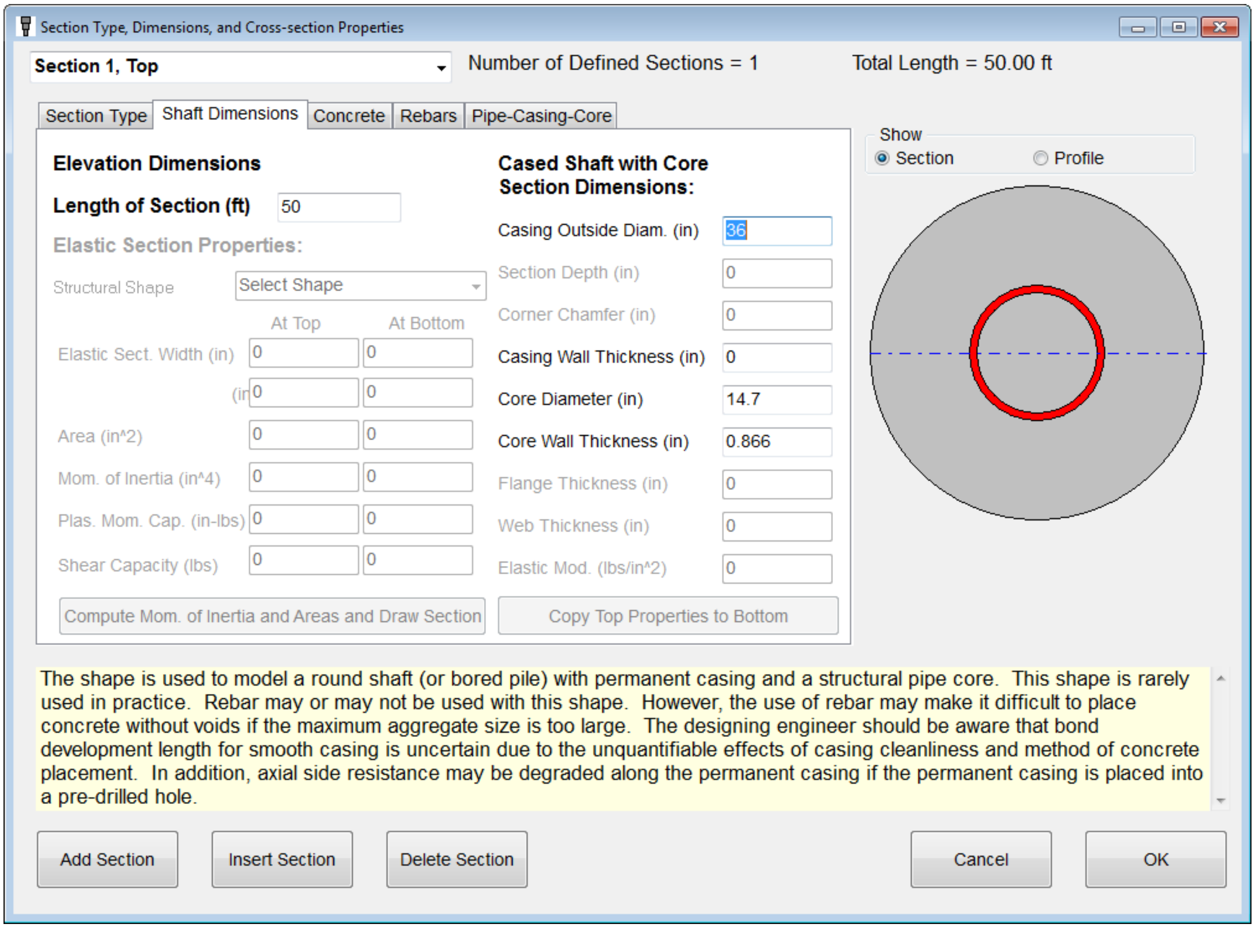


Figure 3-18 Tab Sheet forShaft Dimensions of Drilled Shaft with Casing and Core

An example of the computation of an equivalent wall thickness is as follows. Suppose that a 14x89 H-pile is being used as a structural insert. The flange width is 14.7 inches and the moment of inertia is 904 in^4. The equivalent wall thickness of a pipe section of the same width and moment of inertia is

$$t = \frac{d_o - \sqrt[4]{d_o^4 - \dfrac{64I}{\pi}}}{2} = \frac{14.7 - \sqrt[4]{14.7^4 - \dfrac{(64)(904)}{\pi}}}{2} = 0.866\text{ in.}$$

The moment of inertia will be computed as a check on the computation for *t*. A check computation yields a result of 903.90 in^4, which is acceptable because a closer match would have required more significant digits for *t*.

The tab page for material properties of the casing and core 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.

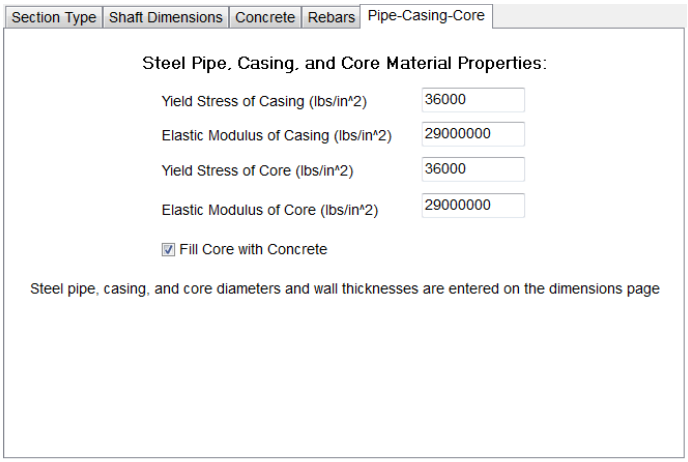


Figure 3-19 Tab Sheet for Casing and Core Material Properties

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.

It is not necessary to include reinforcing bars when modeling a section with a structural insert. To omit the bars, enter zero for the number of bars.

3-5-10 Steel Pipe Pile

The properties of steel pipe piles are defined by the length, outside diameter, and wall thickness of the pile section as shown in Figure 3-20. The material properties are the yield stress and modulus of elasticity as shown in Figure 3-21.

The computed curve of moment versus curvature for a 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).

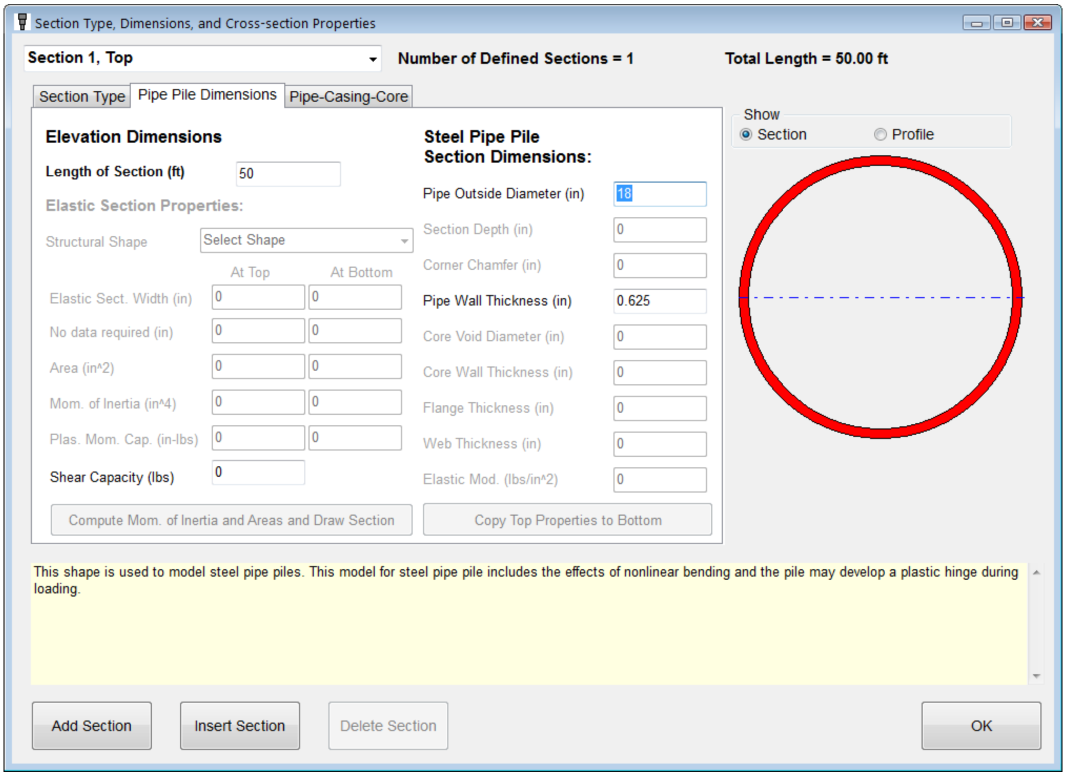


Figure 3-20 Dimensions Tab Page for Steel Pipe Piles

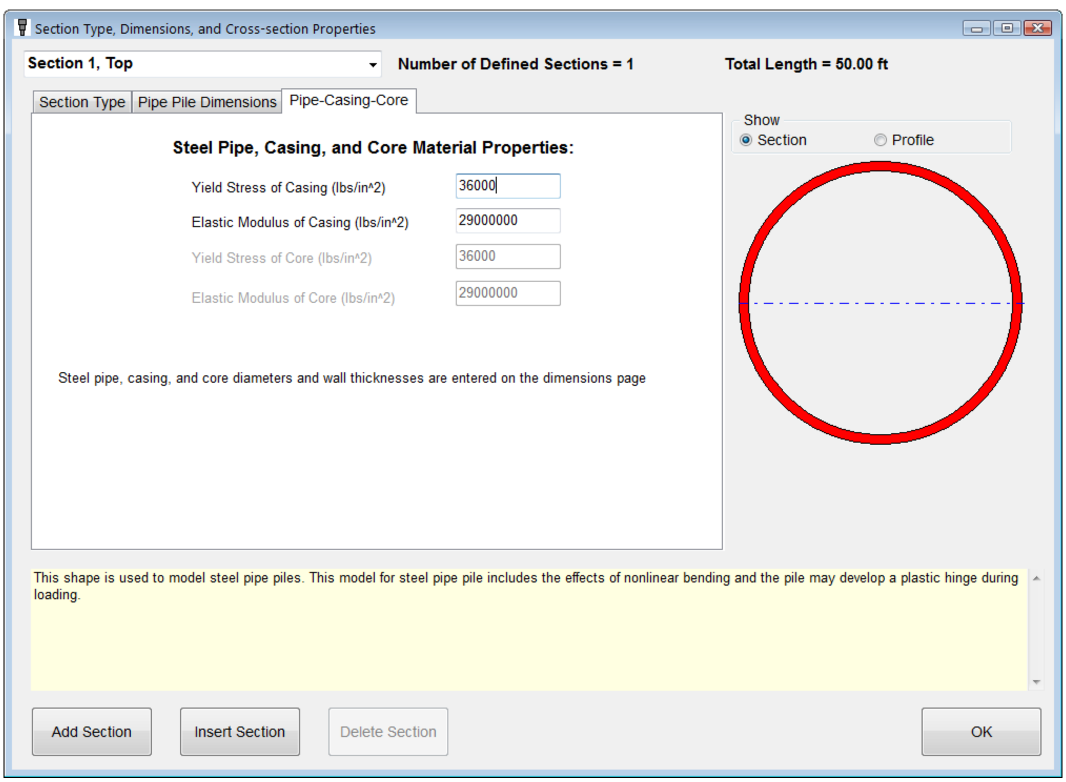
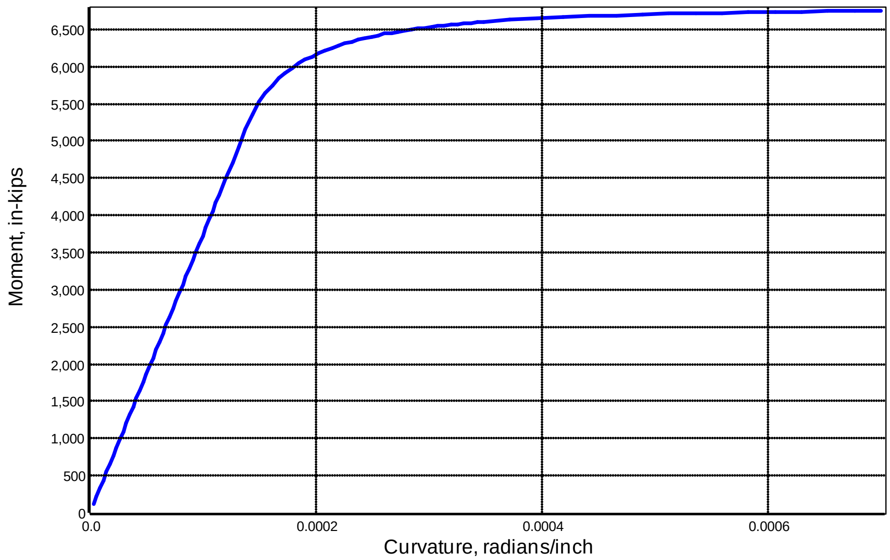
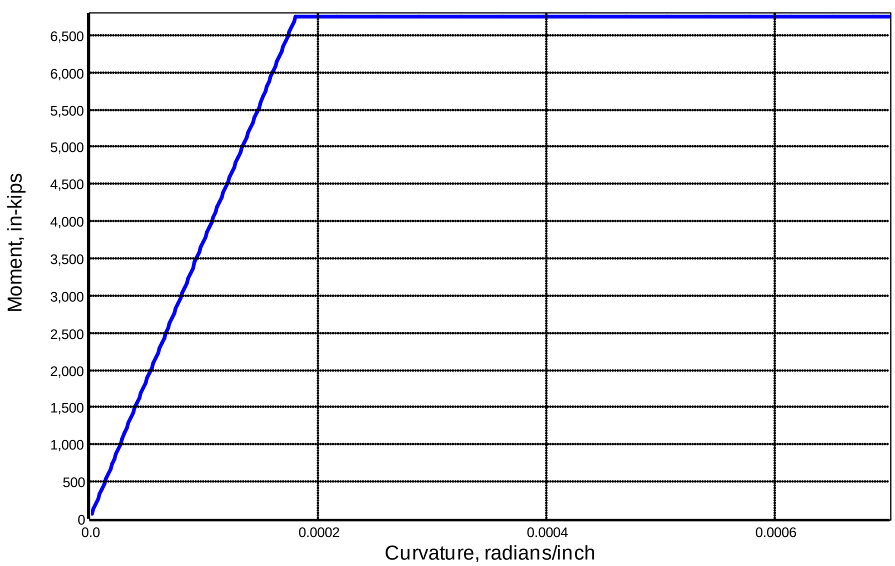


Figure 3-21 Pipe-Casing-Core Properties Tab Page for Steel Pipe Pile



(a)



(b)

Figure 3-22 Comparison of Moment vs. Curvature for (a) Steel Pipe Pile and (b) Elastic-Plastic Pipe Pile with Similar Properties

3-5-11 Round Prestressed Concrete Pile

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.

The usual procedure for the LPile user is to enter the pile dimensions, compressive strength of concrete, the 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 3-23. 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.

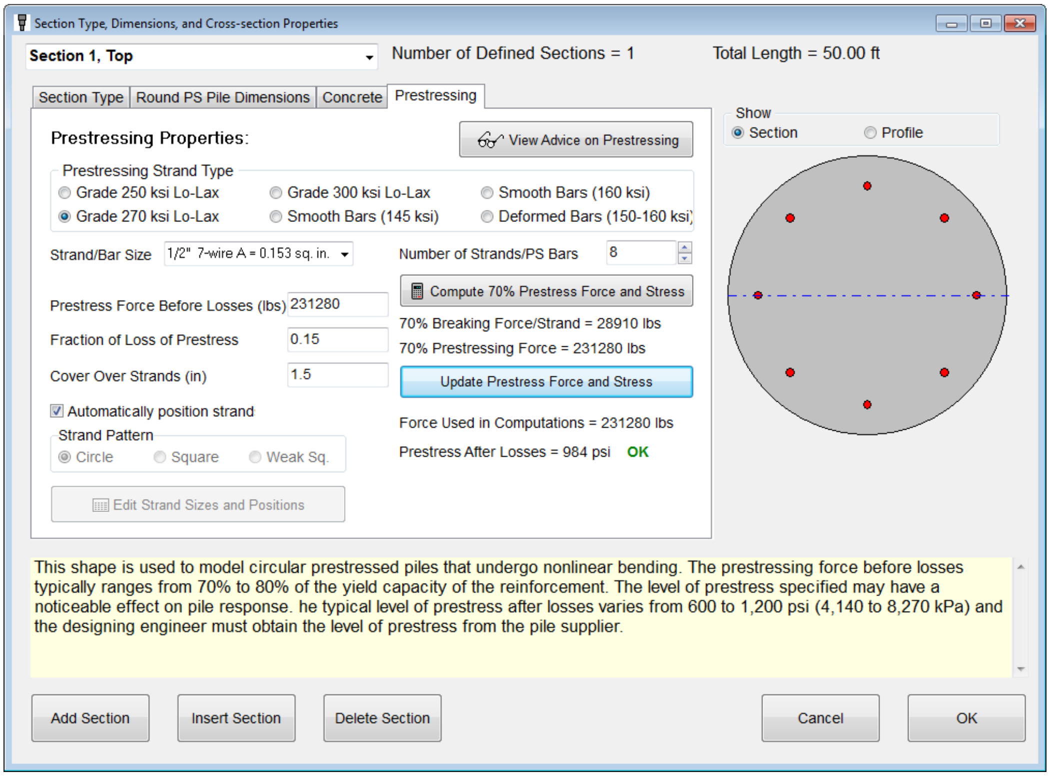


Figure 3-23 Prestressing Tab Page Common to All Prestressed Pile Types

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 what the fraction of loss of prestress is, provided the initial prestressing forces before losses is 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.

3-5-12 Round Prestressed Concrete Pile with Void

The properties of round prestressed concrete piles with void are defined by the length and diameter of the pile, the diameter of the hollow core void, the compressive strength of concrete, and the prestressing reinforcement and loss of prestress.

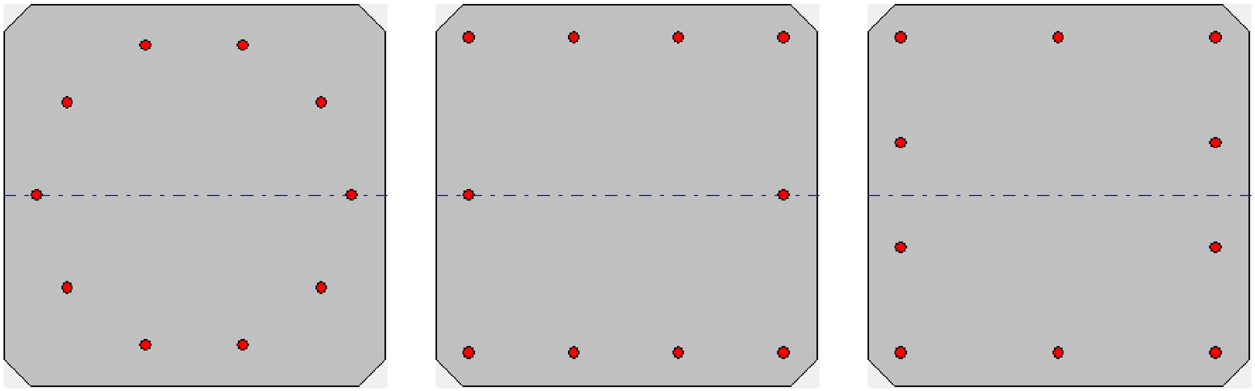
The input for the round prestressed concrete pile with void is the same as for the round prestressed pile without void, with the exception of the entry of the diameter of the core void. Please refer to the discussion in Section 3-5-11 for information about the computation of prestress after losses.

3-5-13 Square Prestressed Concrete Pile

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.

The input for the square prestressed concrete pile is the largely same as for the round prestressed pile without void, with the exception of the entry of the dimensions for the pile width and corner chamfer. Please refer to the discussion in Section 3-5-11 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 3-24. 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 3-24 Automatic Prestressing Arrangements for Square Prestressed Piles

3-5-14 Square Prestressed Concrete Pile with Void

The properties of square prestressed concrete piles with void are defined by the length and width of the pile, the size of the corner chamfer, the diameter of the hollow core void, the compressive strength of concrete, and the prestressing reinforcement and loss of prestress.

The input for the square prestressed concrete pile with void is the largely same as for the round prestressed pile with void, with the exception of the entry of the dimensions for the pile width and corner chamfer. Please refer to the discussion in Section 3-5-11 for information about the computation of prestress after losses and to Section 3-5-13 for information about automatic prestressing strand arrangements.

3-5-15 Octagonal Prestressed Concrete Pile

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 pile except that the size of the corner chamfer is defined internally to produce the octagonal shape.

3-5-16 Octagonal Prestressed Concrete Pile with Void

The properties of octagonal prestressed concrete piles with void are defined by the length and width of the pile, the diameter of the hollow core void, 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 pile with void except that the size of the corner chamfer is defined internally to produce the octagonal shape.

3-5-17 Pile with Defined Nonlinear Bending

The properties of piles with nonlinear bending are defined by the length and width of the pile and the defined 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 3-25. 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 3-26.

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 3-26 to open the input tables shown in Figure 3-27.

. 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.

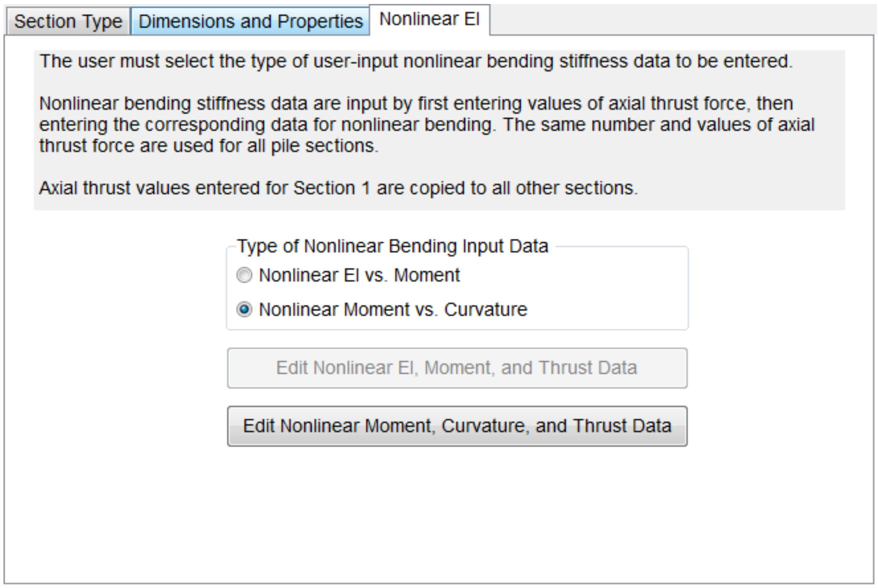


Figure 3-25 Nonlinear *EI* Tab Page

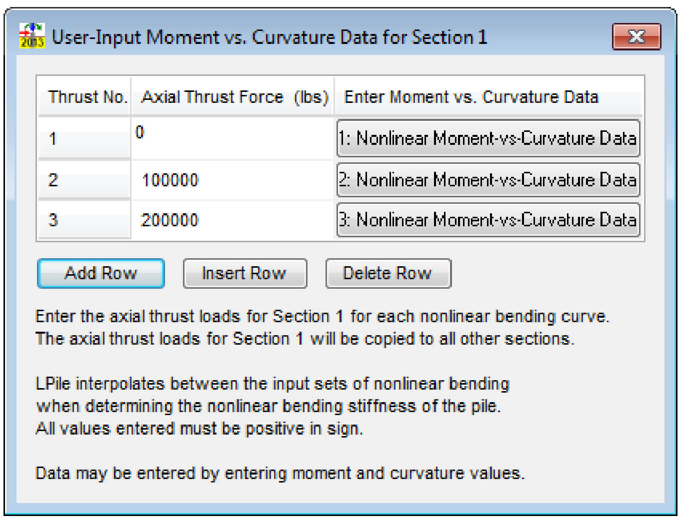
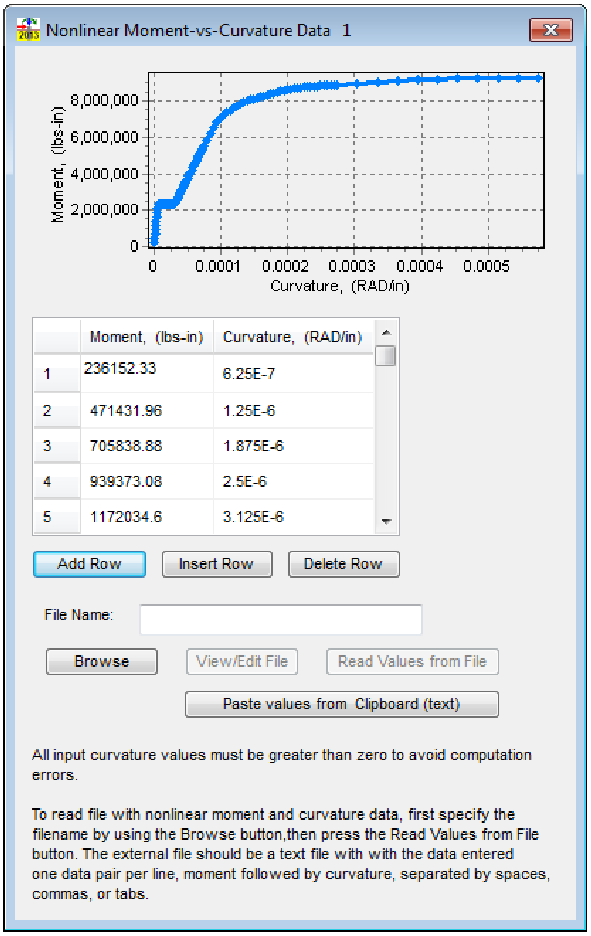
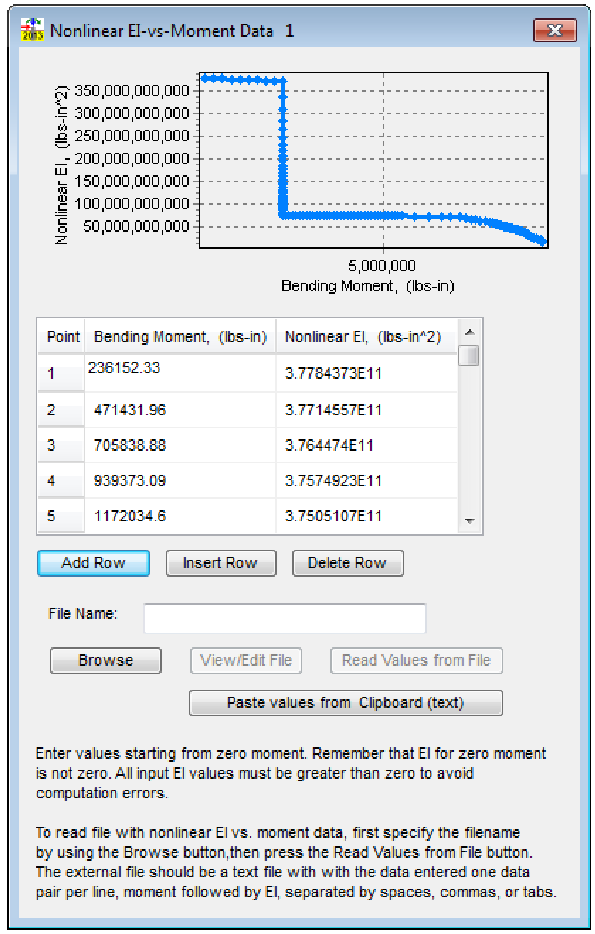


Figure 3-26 Table for Entering Axial Thrust Forces for Nonlinear Bending Data



(a)



(b)

Figure 3-27 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 located 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.

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 Lateral Load Transfer Relationships

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 3-6-1.

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 3-7

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 3-8.

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 3-9

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 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 is included in LPile to assist in this task and is discussed in Section 3-10.

3-6-1 Soil Layering and *p-y* Curve Models

This dialog for 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 3-28.

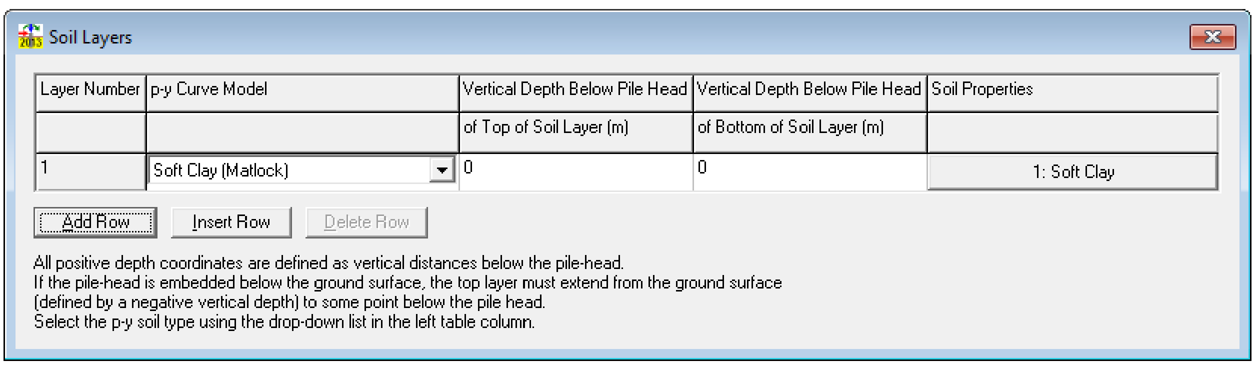


Figure 3-28 Dialog for Definition of Soil Layering and Soil Properties

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.

p-y Curve Model: There are 14 internal types of soils plus user-input *p-y* curves that can be specified in LPile using the dropdown box, plus user-input *p-y* curves. These types are:

1. Soft Clay (Matlock)
2. Stiff Clay with Free Water (Reese)
3. Stiff Clay without Free Water (Reese)

4. Modified Stiff Clay without Free Water
5. Sand (Reese)
6. API Sand (O'Neill)
7. Liquefied Sand (Rollins)
8. Weak Rock (Reese)
9. Strong Rock (Vuggy Limestone)
10. Piedmont Residual
11. Silt (cemented c-ϕ)
12. Loess
13. Elastic Subgrade
14. User-input *p-y* curves
15. API soft clay with *J*
16. Massive rock.

Top of Soil Layer Below Pile Head: Values for the top of the soil layer are entered relative to the origin of the depth coordinates. The origin of depth coordinates is the pile head, which is the point of application of boundary conditions and corresponding loads.

A positive value for the Top 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 for 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 line.

Bottom of Soil Layer Below Pile Head: 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:

3-6-1-1 Comments on *p-y* Curve Models

The following comments are made above 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.

The *p-y* curve for silt (cemented c-ϕ soil) was not based on a load-testing program on full-sized piles. Consequently, reliable recommendations for k and ε_{50} cannot be made for this model. However, if it is possible to perform a lateral load test in the field, it may be possible to fit these parameters to a site-specific load test to calibrate the model. In such cases, the performance of the model may be significantly improved.

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*.

3-6-1-2 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 linearly interpolate 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.
- *k Value for Soil Layers:* 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.
- *Undrained Shear Strength:* 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.
- *Internal Friction (degrees):* Values of the angle of internal friction ϕ for sands and/or silts at each soil depth are entered in degrees.
- *Strain Factor E50:* Values of ε_{50} strain at 50% of the maximum stress. The strain factor ε_{50} for clays and/or silts 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.*

Initial Mass Modulus for Weak Rock: The initial mass modulus for weak rock should be entered for this value. 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 the uniaxial compressive strength of weak 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 are flagged in the output file and a warning dialog box is displayed. However, the analysis is performed normally.

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 k_{rm}**:** 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 3-29 as an example.

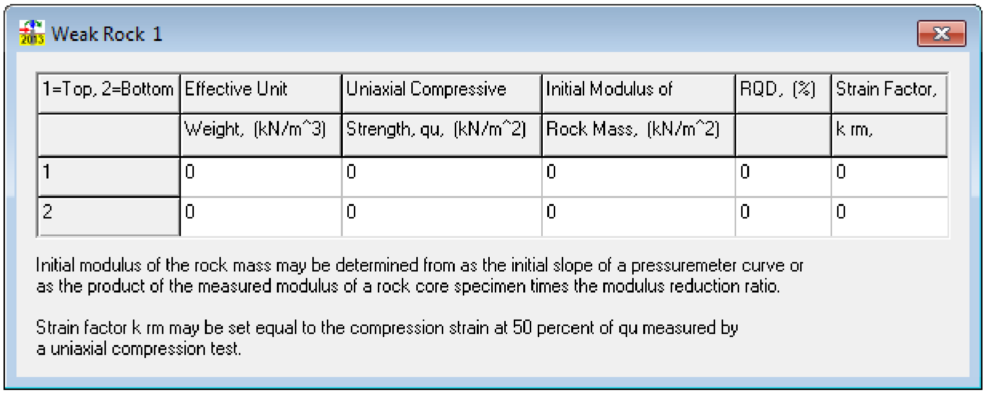


Figure 3-29 Dialog for Properties of Weak Rock

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, m_i, 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, 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 3-30 as an example.

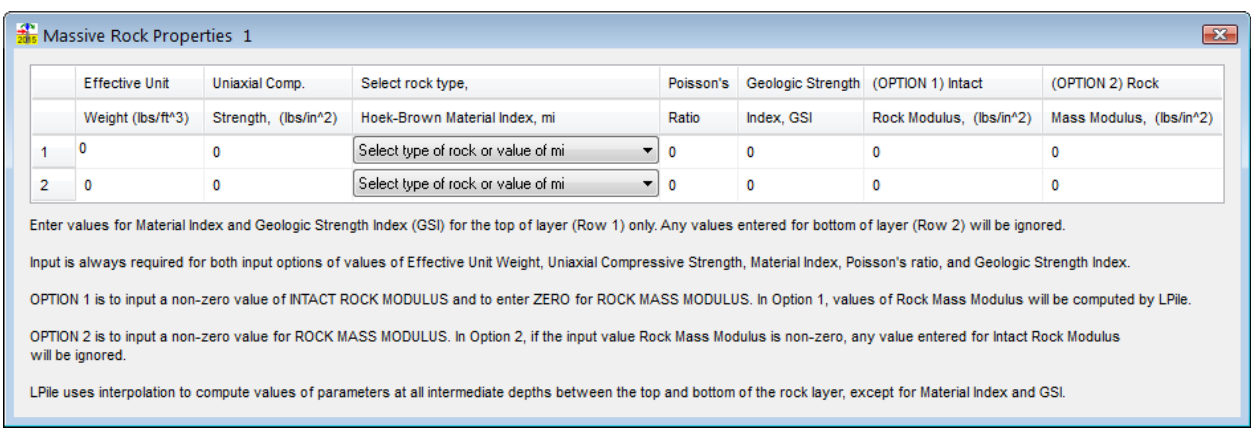


Figure 3-30 Dialog for Properties of Massive Rock

3-6-2 User Input p-y Curves

Data for user-input *p-y* curves are input using two linked dialog boxes. The first dialog box 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.

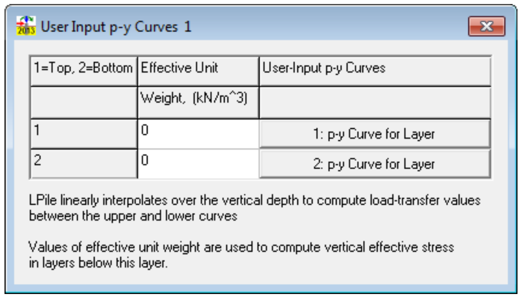


Figure 3-31 Dialog for Effective Unit Weights of User-input *p-y* Curves

The second input dialog box 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 by paste the data into the table via the Windows clipboard, or read an external text data file. The 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 3-32.

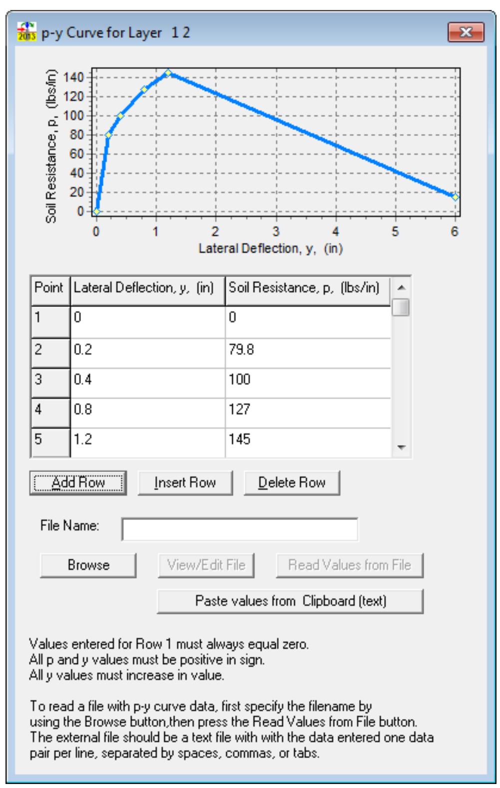


Figure 3-32 Dialog for User-input *p-y* Curve Values

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, the user needs to select *User Input p-y Curves* under the *p-y* Curve Soil Model column in the *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 upper and lower curves by clicking on the corresponding *External 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:

1. *Lateral Deflection: y*-values of lateral movement must be entered in units of length. As a reference, a review of the theory of "Soil Response" is included in Part II, Chapter 3 of the *Technical Manual*.
2. *Soil Resistance: 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 "Soil Response" is included in Part II, Chapter 3 of the *Technical Manual*.

3-7 Pile Batter and Ground Slope

The user specifies the ground slope and batter angles using the Ground Slope and Batter dialog shown in Figure 3-33. The 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.

- *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 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 slope angle. The lateral capacity provided by soils in a negative slope is thus increased.
- *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.

3-8 *p-y* Modification Factors

This 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 a report of internally-generated *p-y* curves, 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 3-34.

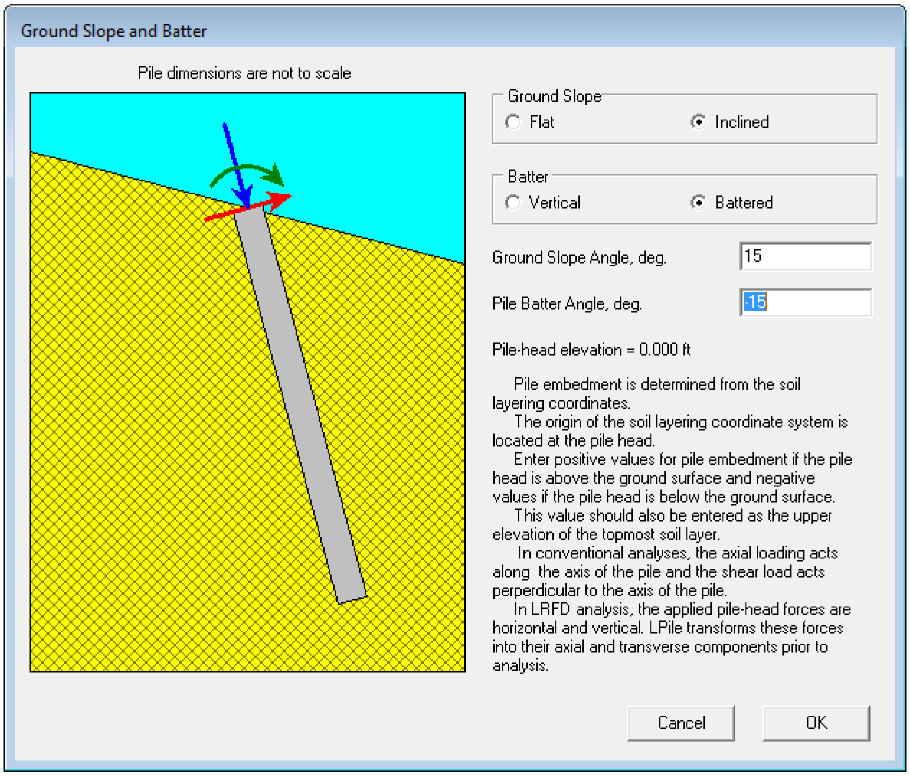
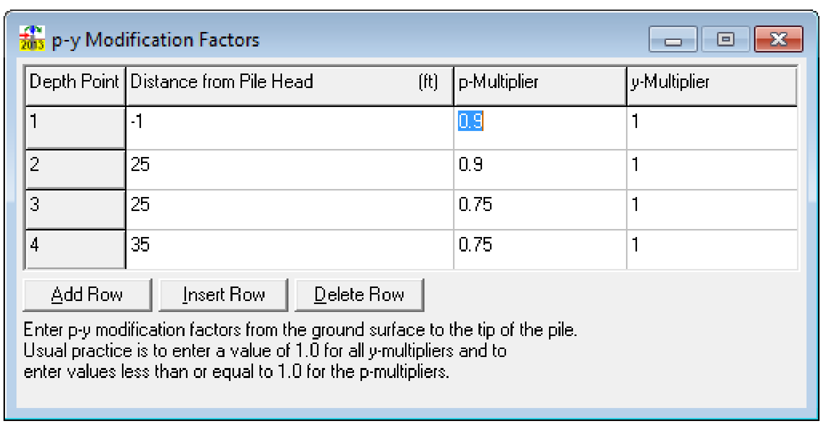


Figure 3-33 Dialog for Definition of Pile Batter and Slope of Ground Surface



Depth Point	Distance from Pile Head (ft)	p-Multiplier	y-Multiplier
1	-1	0.9	1
2	25	0.9	1
3	25	0.75	1
4	35	0.75	1

Figure 3-34 Dialog for *p*-Multipliers and *y*-Multipliers versus Depth Below Pile Head

Distance from Pile Head: These values represent the depths where modification factor 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.

3-9 Tip Shear-Resistance

This input 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 3-35.

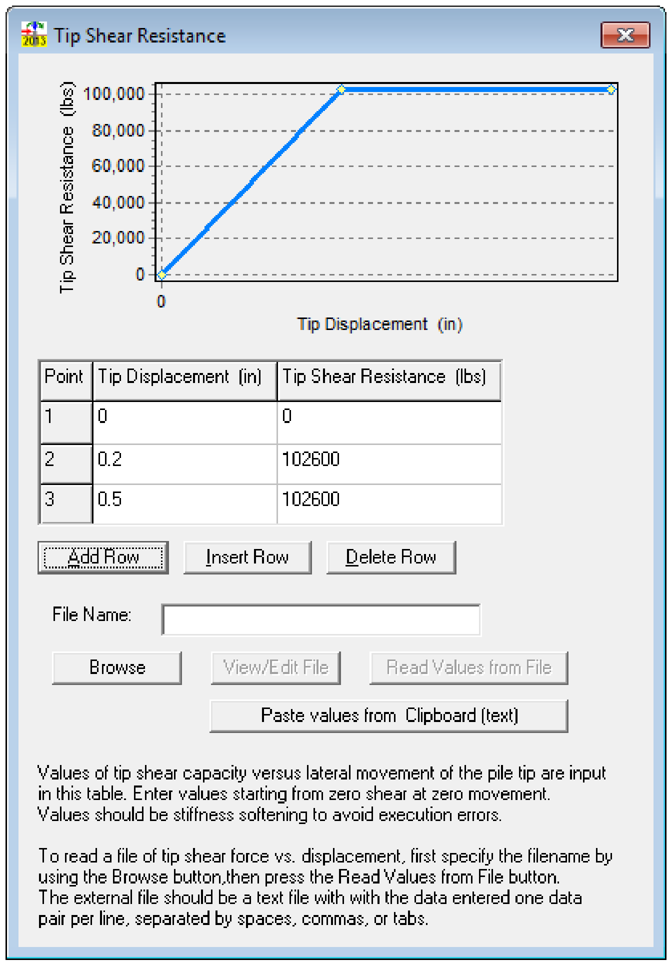


Figure 3-35 Dialog for Tip Shear Resistance versus Lateral Tip Displacement

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 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 tip shear curve.

3-10 Shift Pile or Soil Elevations

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 command under the Data Menu.

An example of the Shift Pile Elevation input dialog is shown in Figure 3-36. 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).

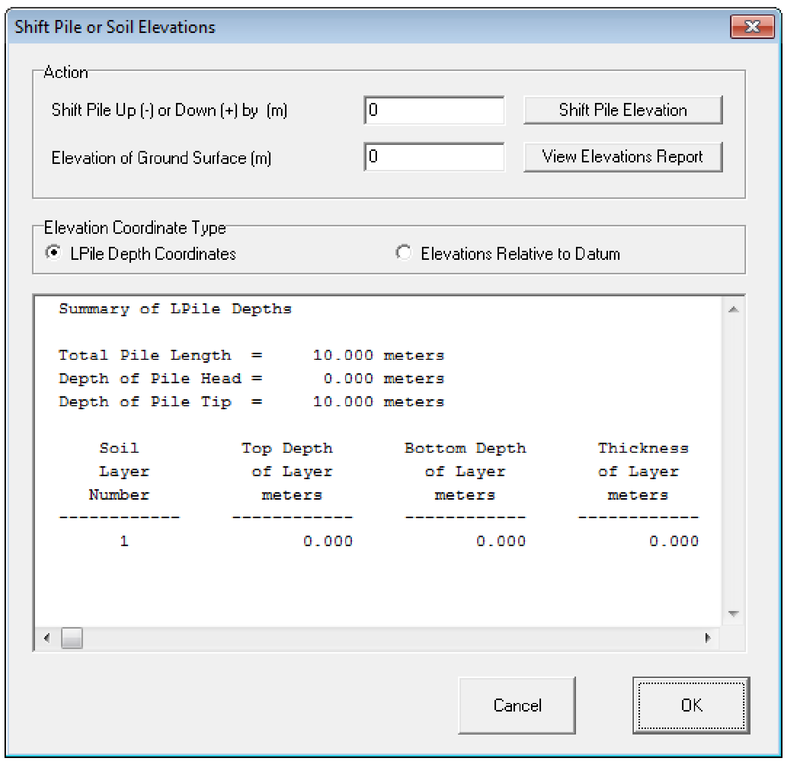


Figure 3-36 Dialog for Shifting of Pile Elevation Relative to Input Soil Profile Showing a Pile Head at the Top of the Soil Profile

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 3-37 shows that the top of the first layer has been moved to −2 meters, but that the thicknesses of the layers are unchanged.

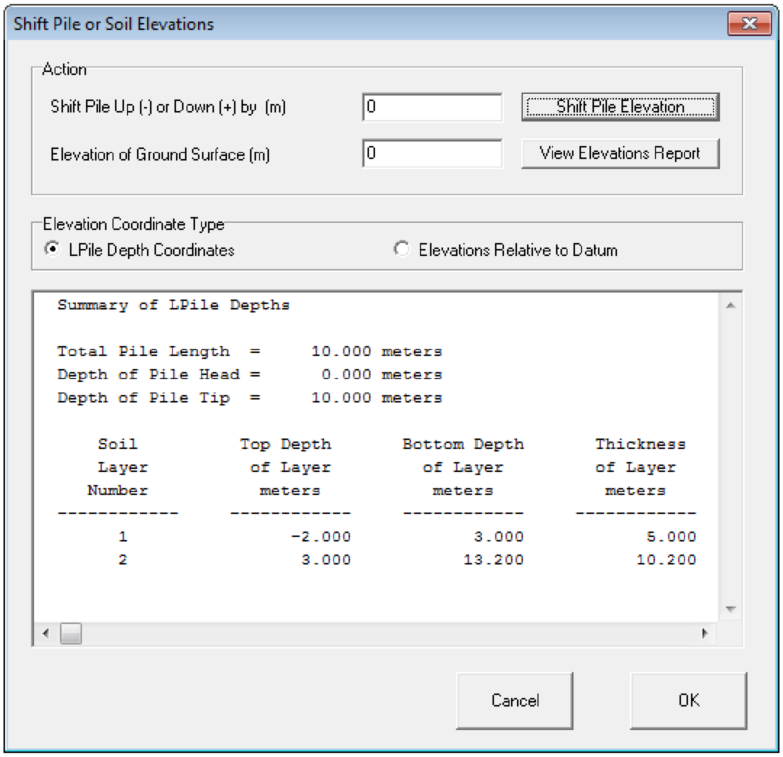


Figure 3-37 Dialog for Shifting of Pile Elevation Relative to Input Soil Profile After Shifting a Pile Head To Be Below the Ground Surface

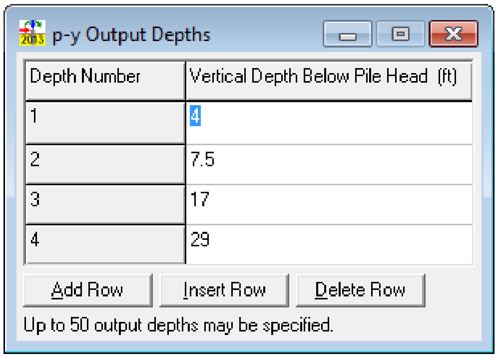
If the user wishes to compare the depths of the soil layer profile to elevation data, the user enters a value for the elevation of the ground surface and presses the View Elevations Report button. The Shift Pile or Soil Elevations dialog can display the report in two formats that are selected by pressing 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.

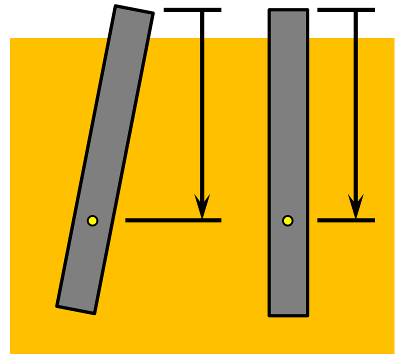
3-11 Input of Output Depths for *p-y* Curves

The user may generate and plot *p*-*y* curves at user-specified depths. These curves are not used in the analysis, as LPile computes exact values of *p* for every corresponding value of *y* for every node along the length of the pile. Many of the various parameters needed to compute the output *p*-*y* curves are output in the output report file from LPile.

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 output by the program.

An example of the input dialog for *p*-*y* Output Depths is shown in Figure 3-38. It should be noted that the depth is the vertical depth below the pile head, not the depth along the axis of the pile.





(a) (b)

Figure 3-38 Output Depths of *p-y* Curves Below Pile Head, (a) Dialog for *p-y* Curve Output Depths, (b) Measurement of Vertical Depths

3-12 Conventional Loading Analysis

The conventional loading analysis is the same type of analysis used in all versions of LPile older than Version 6. 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.

3-12-1 Pile-head Loading and Options

The Pile-head Loading and Options dialog shown in Figure 3-39 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. In addition, the user may specify the computation of pile top deflection versus pile length for any of the specified load cases. In general, user should restrict use of this option 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.

3-12-1-1 Pile-Head Loading Types

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 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.

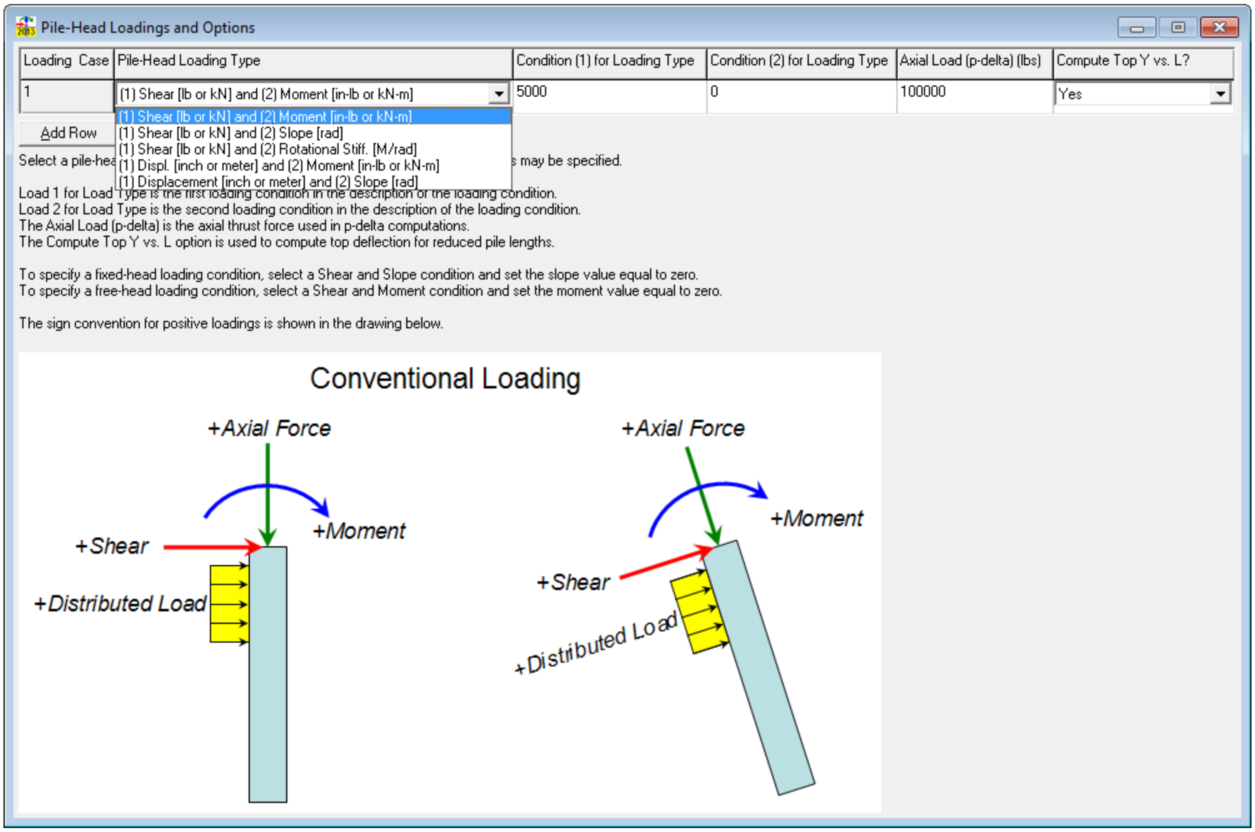


Figure 3-39 Dialog for Definition of Conventional Pile-head Loading

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.

3-12-1-2 Condition 1

This value is the first load in the loading type description; shear force for the first three loading type conditions and displacement for the last two loading type conditions.

3-12-1-3 Condition 2

This value is the second load in the loading type description.

3-12-1-4 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).

3-12-1-5 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 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 of the displacement-moment or displacement-slope pile-head conditions is specified.

3-12-2 Distributed Lateral Loading

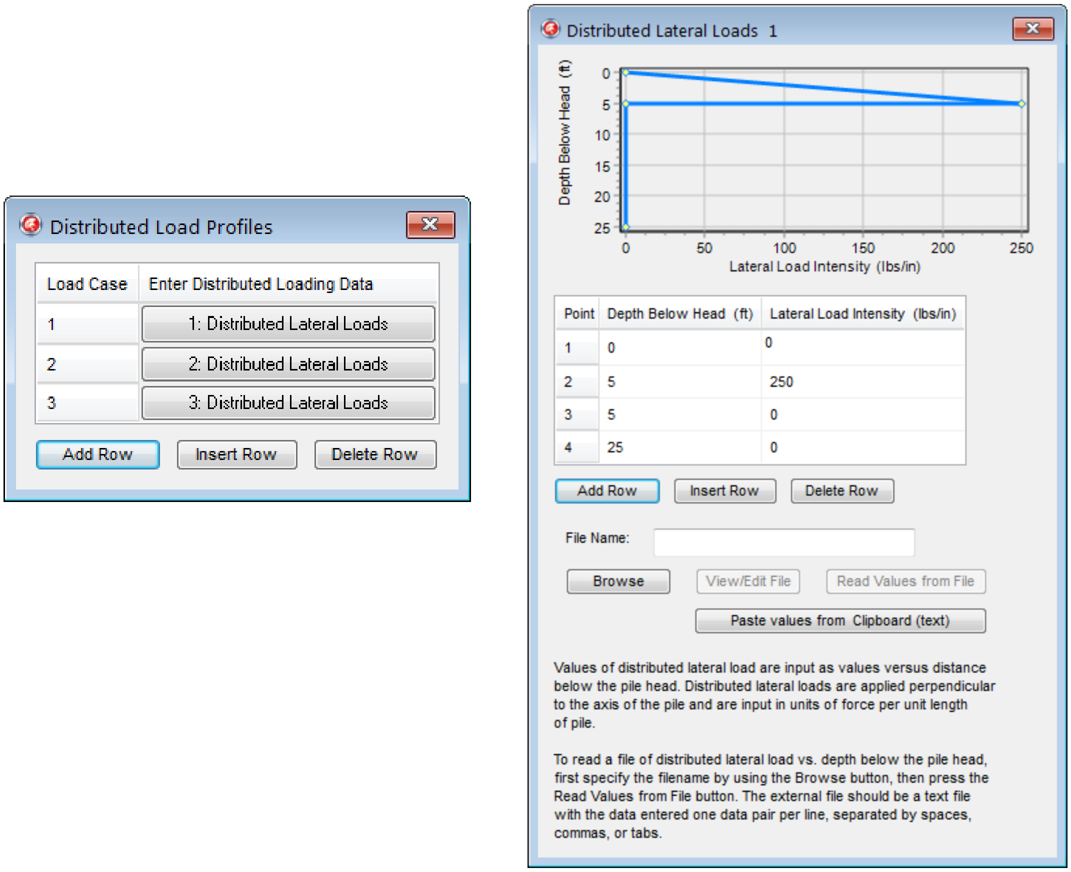
The data entry for distributed lateral loading for conventional analysis is controlled either using a single input dialog if a single distributed load profile is used for all conventional loading cases or using two linked input dialogs if distributed loading profiles are defined independently for the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

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 3-40.

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 3-41. 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 3-40 Dialogs for Multiple Distributed Lateral Loads for Conventional Loading, (a) 3 Load Cases, (b) Distributed Load Profile Data for Load Case 1

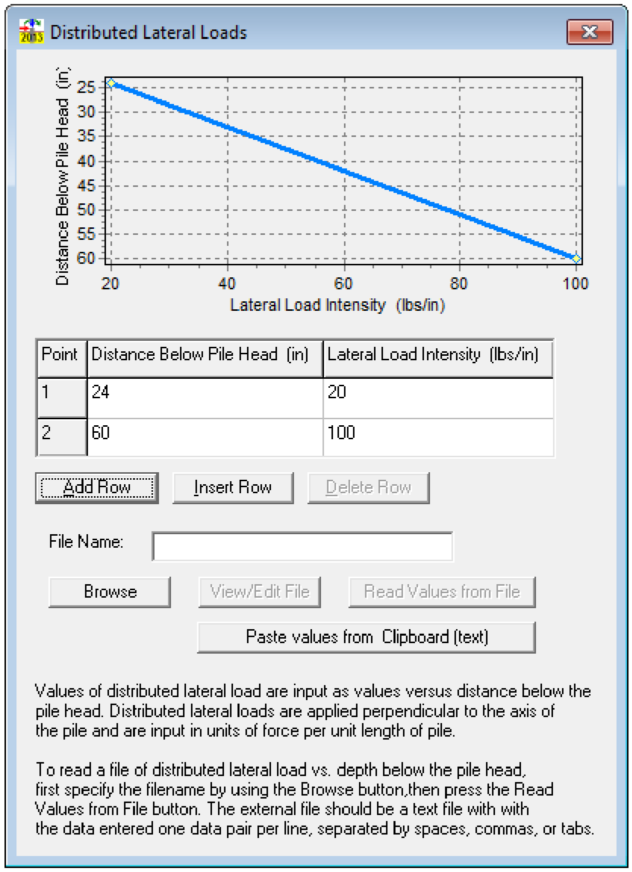


Figure 3-41 Dialog of Values of Distributed Lateral Loads versus Depth

3-12-2-1 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 use 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 spaced 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 3-42). When LPile computes the equivalent nodal point loads for this example, one-third of the applied force result is a applied at the nodal point above the point of load application and the remain two-thirds is applied at the closest node.

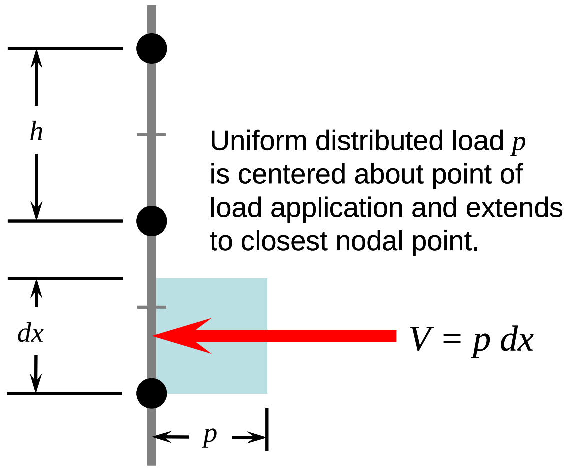


Figure 3-42 Recommendation for Modeling of Lateral Force Applied Below the Pile Head

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.

3-12-2-2 Modeling of Moments Below Pile Head

There are more restrictions in modeling in the case of modeling concentrated moments in the pile. It is only possible to apply a concentrated moment about a nodal point, not any arbitrary location. 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 3-43 illustrates the principle of applying equal and opposite equivalent forces to model a concentrated moment in the pile.

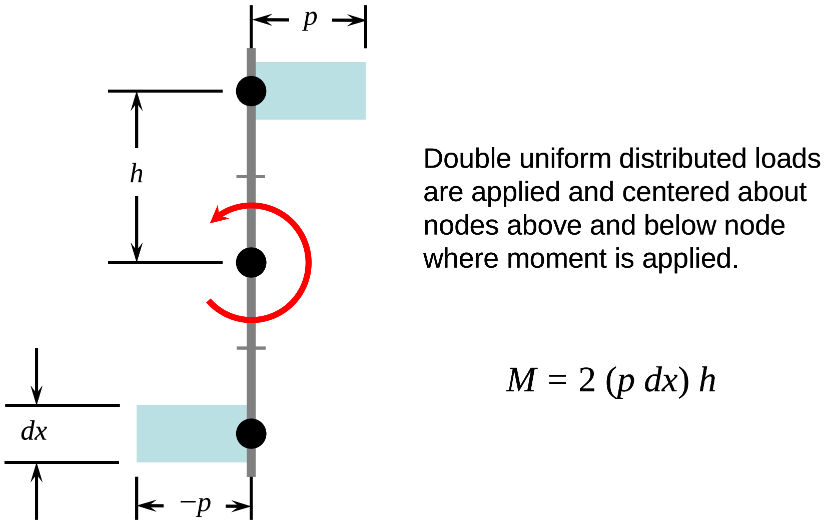


Figure 3-43 Recommendation for Modeling of Moment Applied Below the Pile Head

3-12-3 Loading by Lateral Soil Movements

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. A maximum of 50 entries is allowed for definition of the soil movement profile in an analysis.

The input dialog for soil movements versus depth is shown in Figure 3-44. 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 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 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 of as the applied loads.

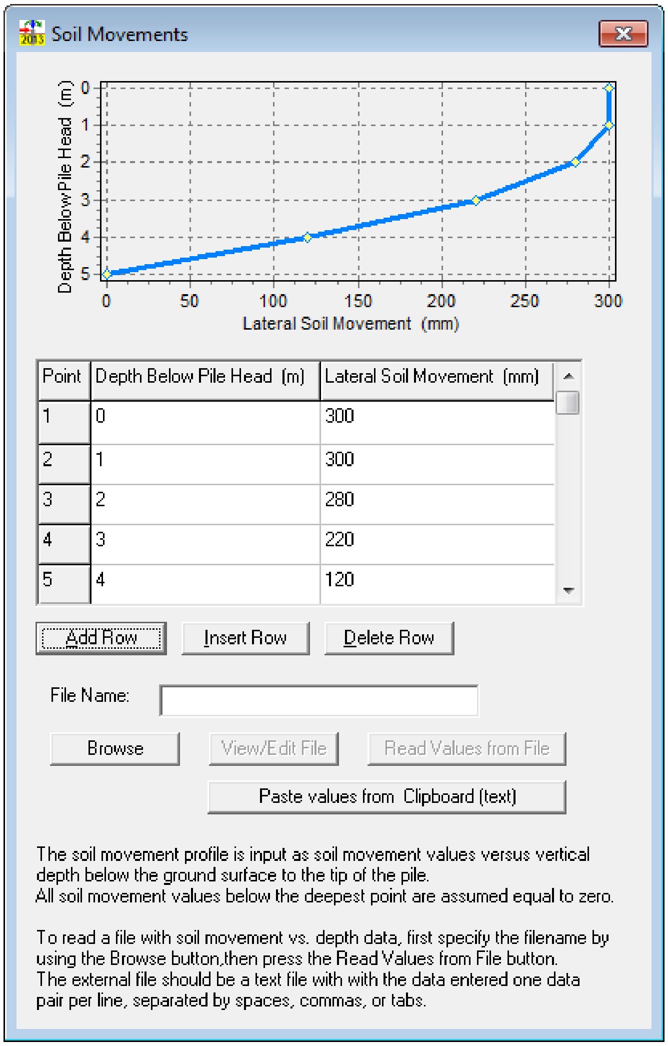


Figure 3-44 Dialog for Input of Soil Movements versus Depth Below Pile Head

3-12-4 Computation of Pile-head Stiffness Matrix Components

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.

The dialog for Controls for Computation of Stiffness Matrix is shown in Figure 3-45.

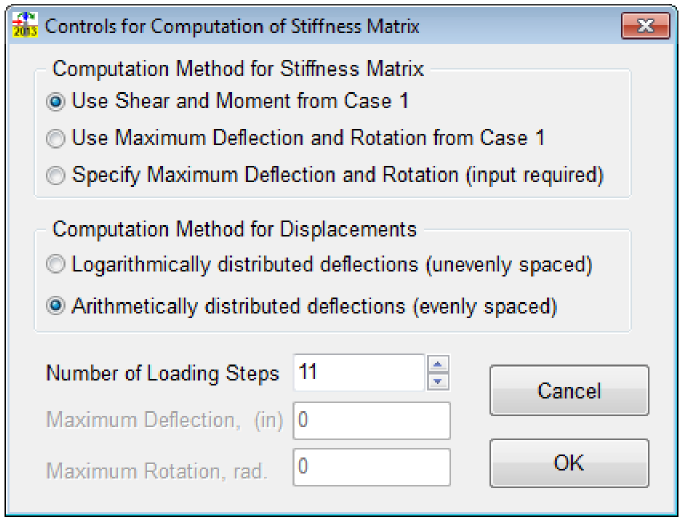


Figure 3-45 Dialog for Controls for Computation of Stiffness Matrix

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

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

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

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

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

3-12-5 Pushover Analysis

The program feature for pushover analysis has options for different pile-head fixity options and the setting of 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.

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 used in the pushover analysis must be entered in the dialog. If the pile being analyzed is not an elastic pile, the user should make sure that the axial thrust force entered matches one 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.

The pushover analysis feature is enabled by checking the appropriate check box in the Program Options and Settings dialog box (see Figure 3-6 on page 24). The dialog for Controls for Pushover Analysis is opened by selecting from the Data Menu or by pressing the button on the button bar of the main program Window. The dialog for Controls for Pushover Analysis is presented in Figure 3-46.

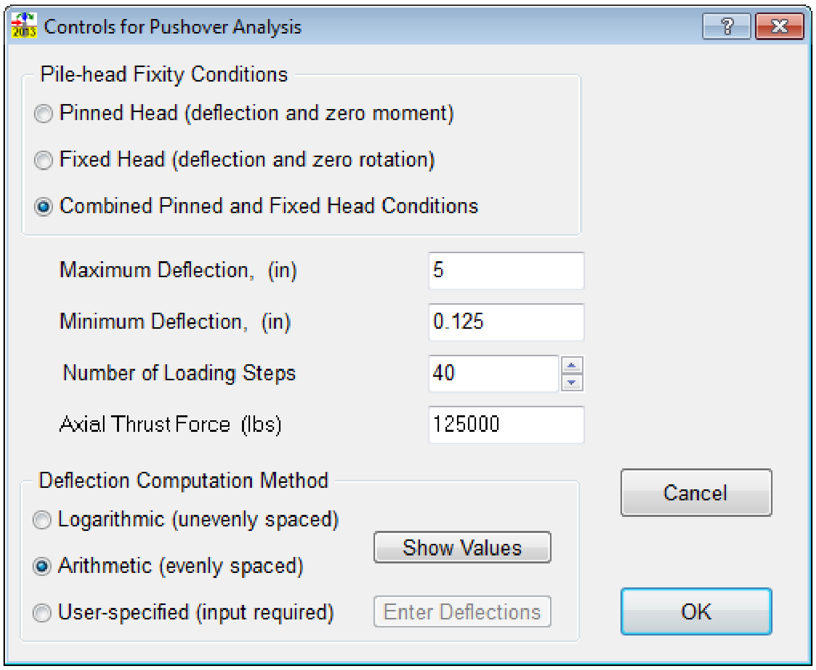


Figure 3-46 Dialog for Controls for Pushover Analysis

Some typical results from a pushover analysis are presented in the following two figures. Figure 3-47 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 3-48 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.

Often is 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 3-47 and Figure 3-48.

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 head.

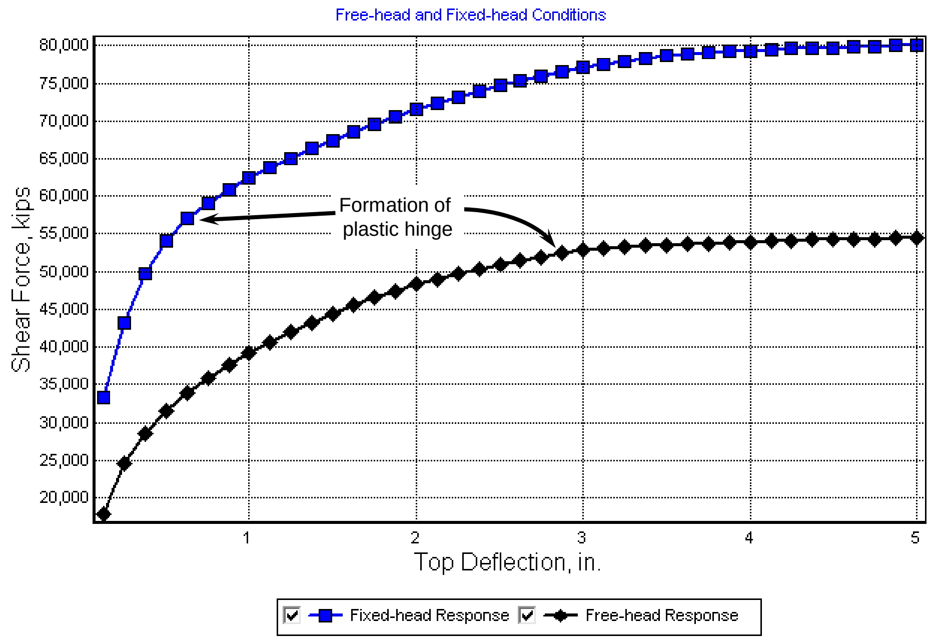


Figure 3-47 Pile-head Shear Force versus Displacement from Pushover Analysis

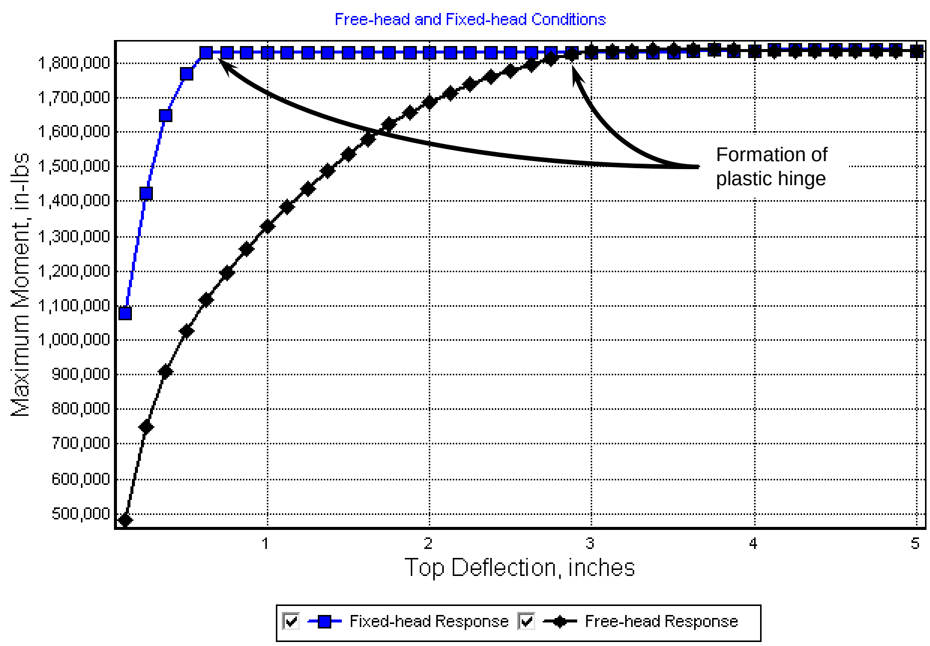


Figure 3-48 Maximum Moment in Pile versus Displacement from Pushover Analysis

3-12-6 Pile Buckling Analysis

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. The dialog for the Controls for Pile Buckling Analysis is shown in Figure 3-49.

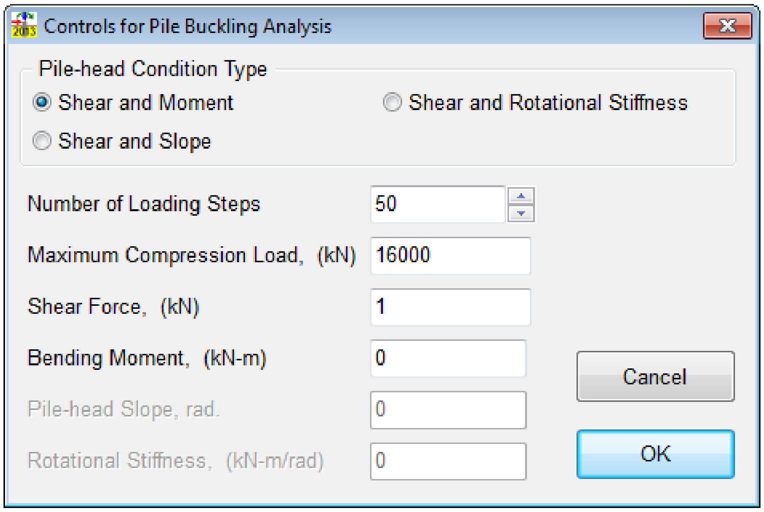


Figure 3-49 Dialog for Controls for Pile Buckling Analysis

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 3-50. In this figure, P is the axial thrust force and y_0 is the pile-head deflection for the case of zero axial load. These results are then redrawn with every deflection value shifted to the left by an amount equal to y_0, as shown in Figure 3-51.

The form of the hyperbolic curve to be fitted is

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

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

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

The computed results are then redrawn as in Figure 3-52 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

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

LPile can graph the computed results, the fitted curve, and the estimated pile buckling capacity. A typical graph is shown in Figure 3-53.

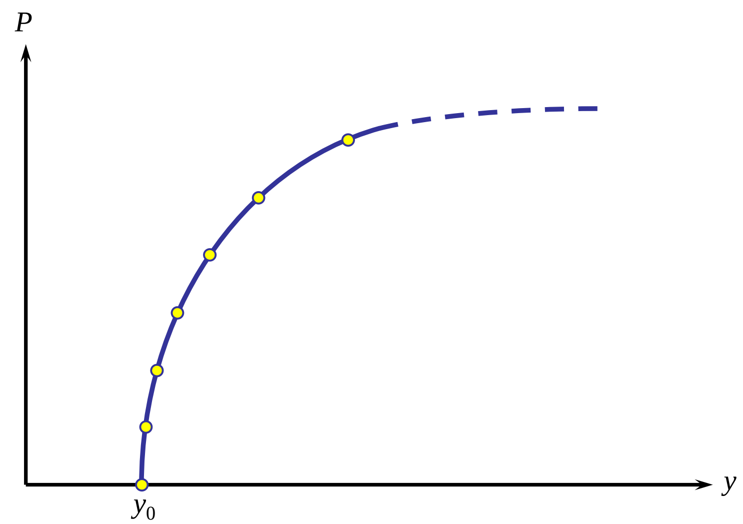


Figure 3-50 Typical Results for a Pile Buckling Analysis

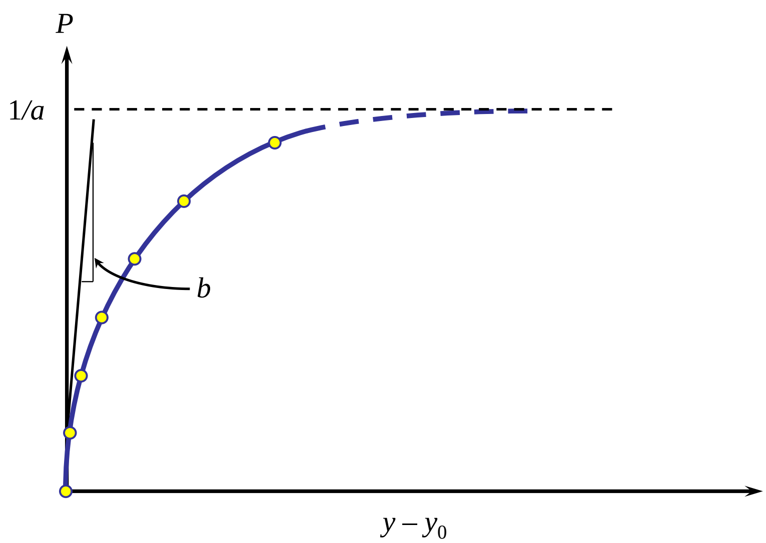


Figure 3-51 Computed Pile Buckling Result Shifted to the Left

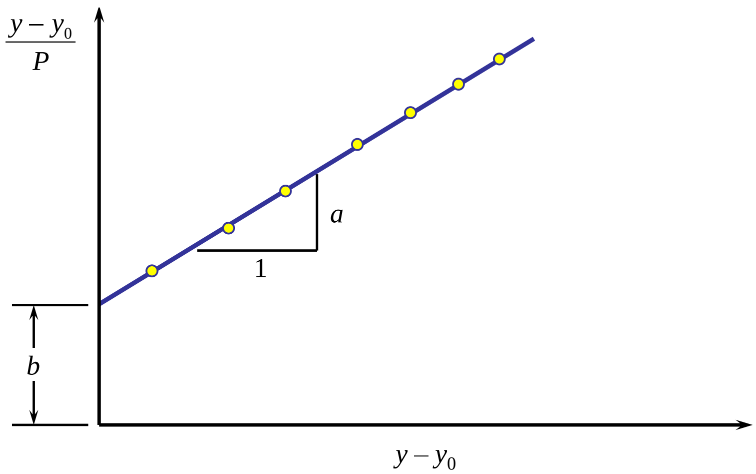


Figure 3-52 Redrawn Pile Buckling Results Used for Curve Fitting

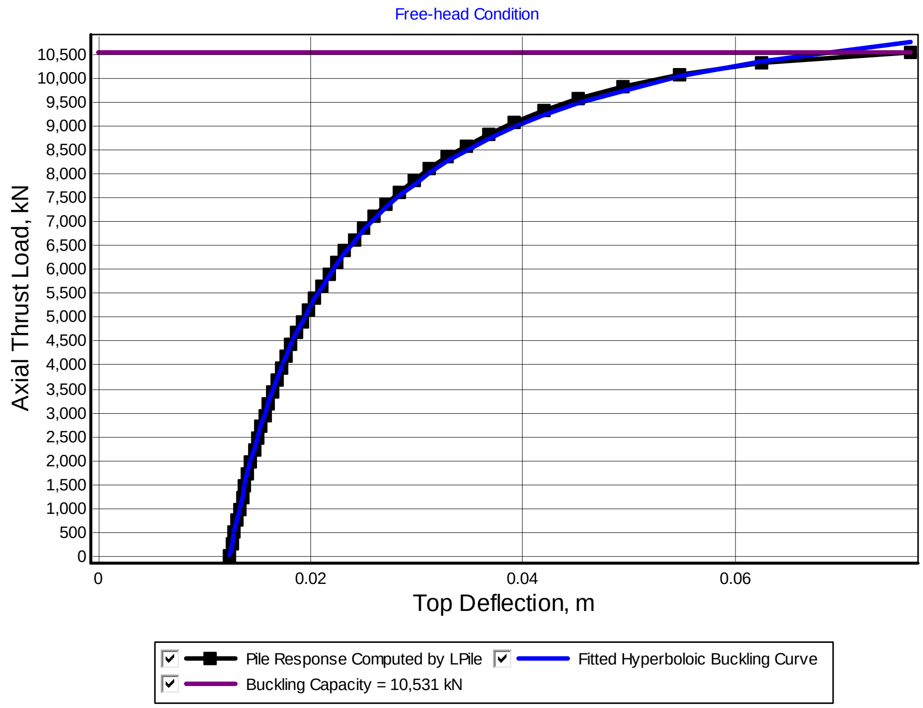


Figure 3-53 Results from Pile Buckling Analysis

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 3-53.

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 3-54.

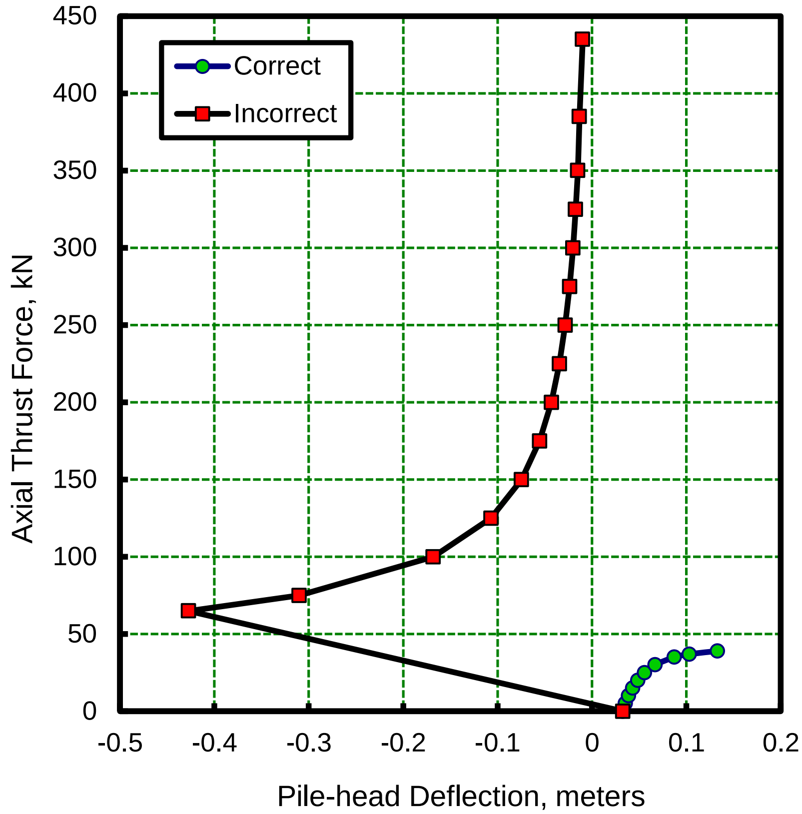


Figure 3-54 Example of Correct (green symbols) and Incorrect (red symbols) Pile Buckling Analyses

3-13 Input of Load Testing Data

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.

3-13-1 Controls for Input of Load Test Data

Entry of load test data is controlled using the dialog box shown in Figure 3-55. The basic data entered are the pile-head shear versus displacement data. Optionally, the user may also 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.

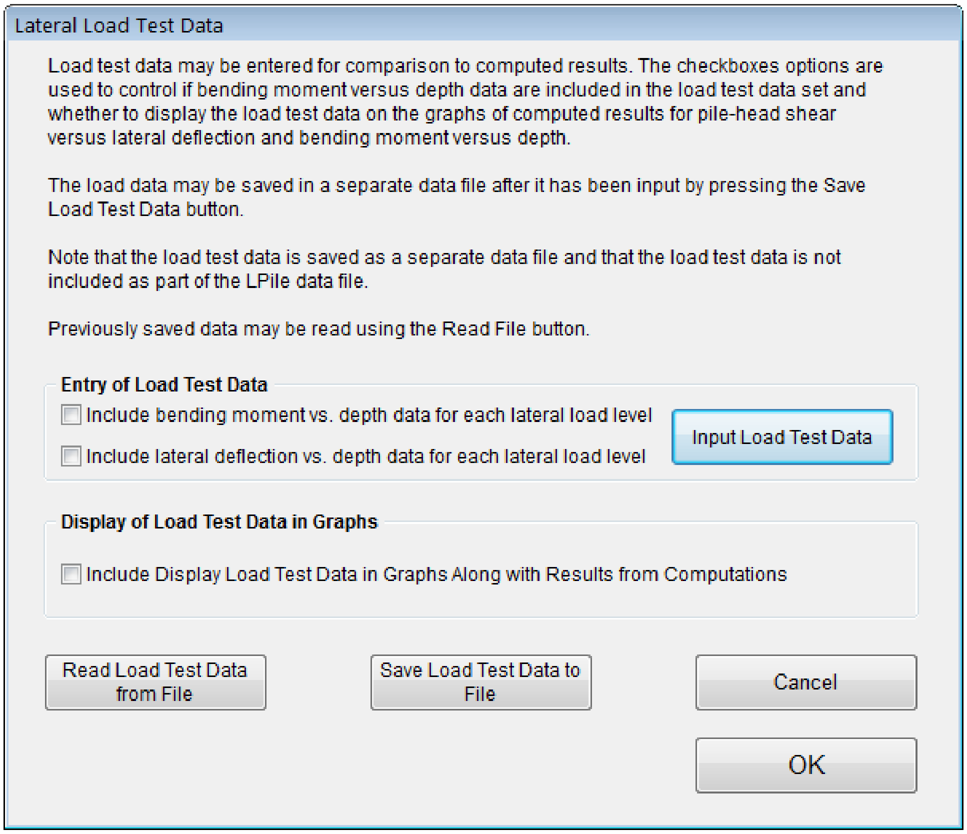


Figure 3-55 Dialog for Control of Input and Saving of Load Testing Data

3-13-2 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 3-56. 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 3-55, 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.

3-13-3 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 3-55 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 3-57. 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 3-58.

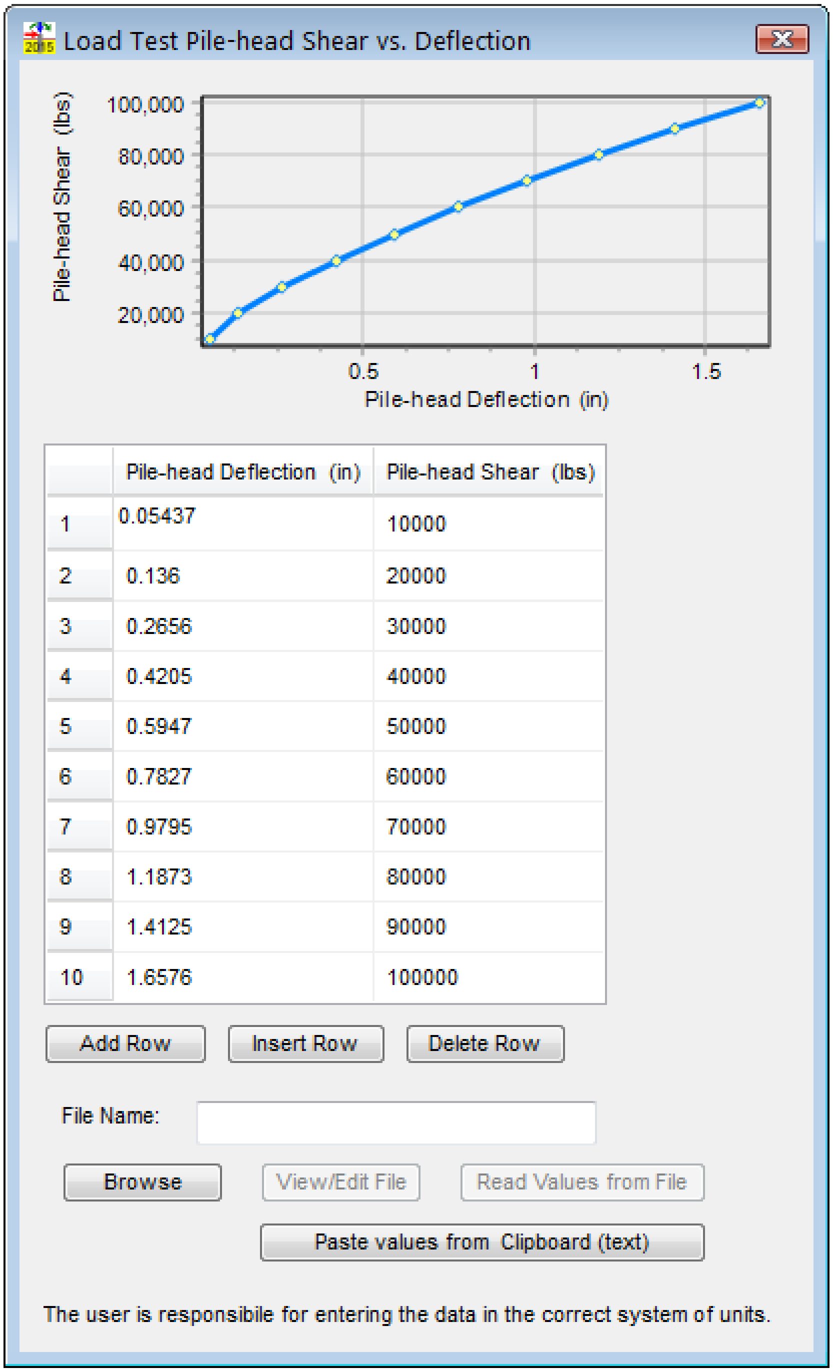


Figure 3-56 Dialog for Input of Pile-head Shear Force versus Lateral Deformation from Load Testing, if input of Bending Moment and/or Lateral Movement versus Depth is not specified.

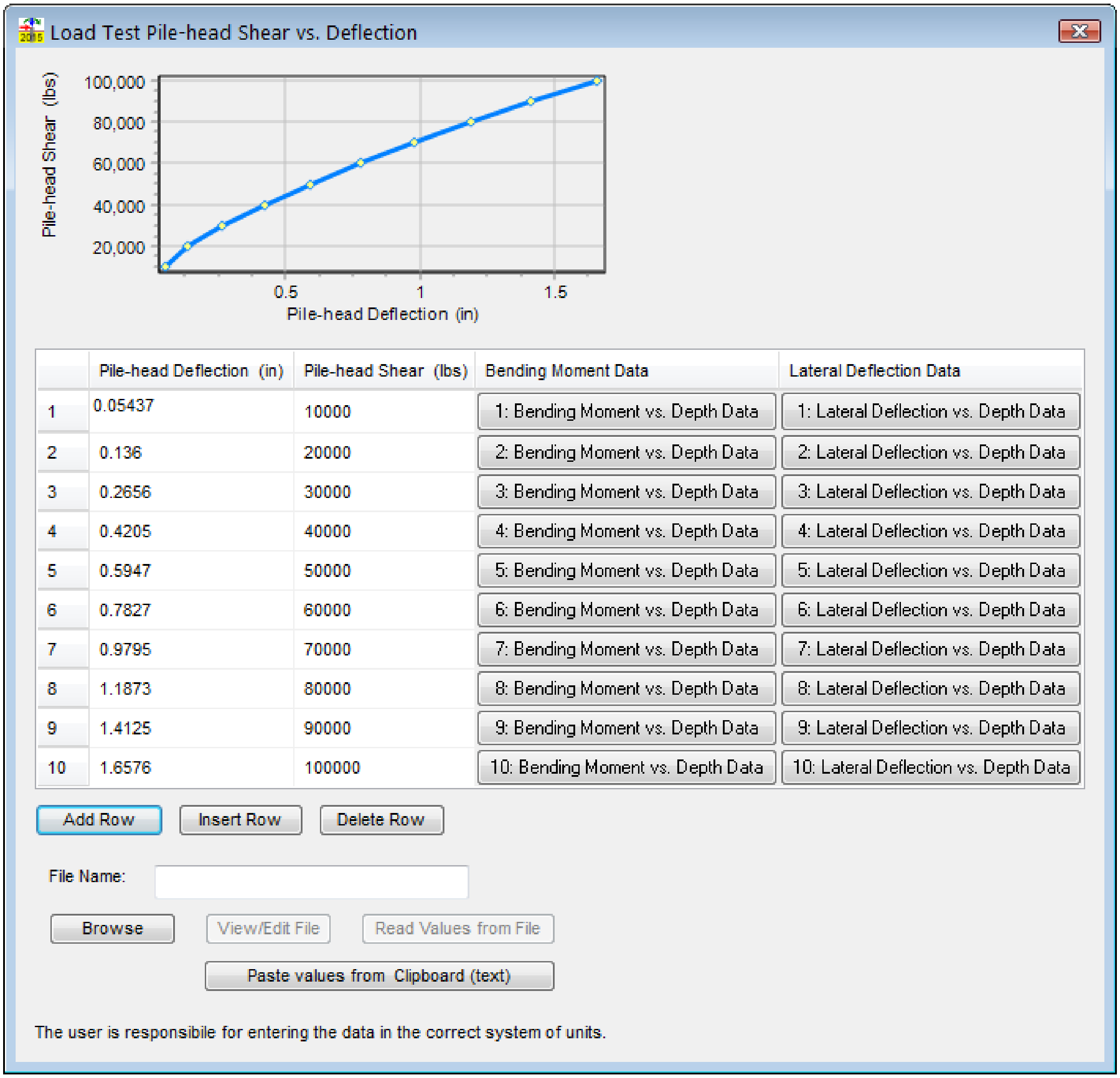
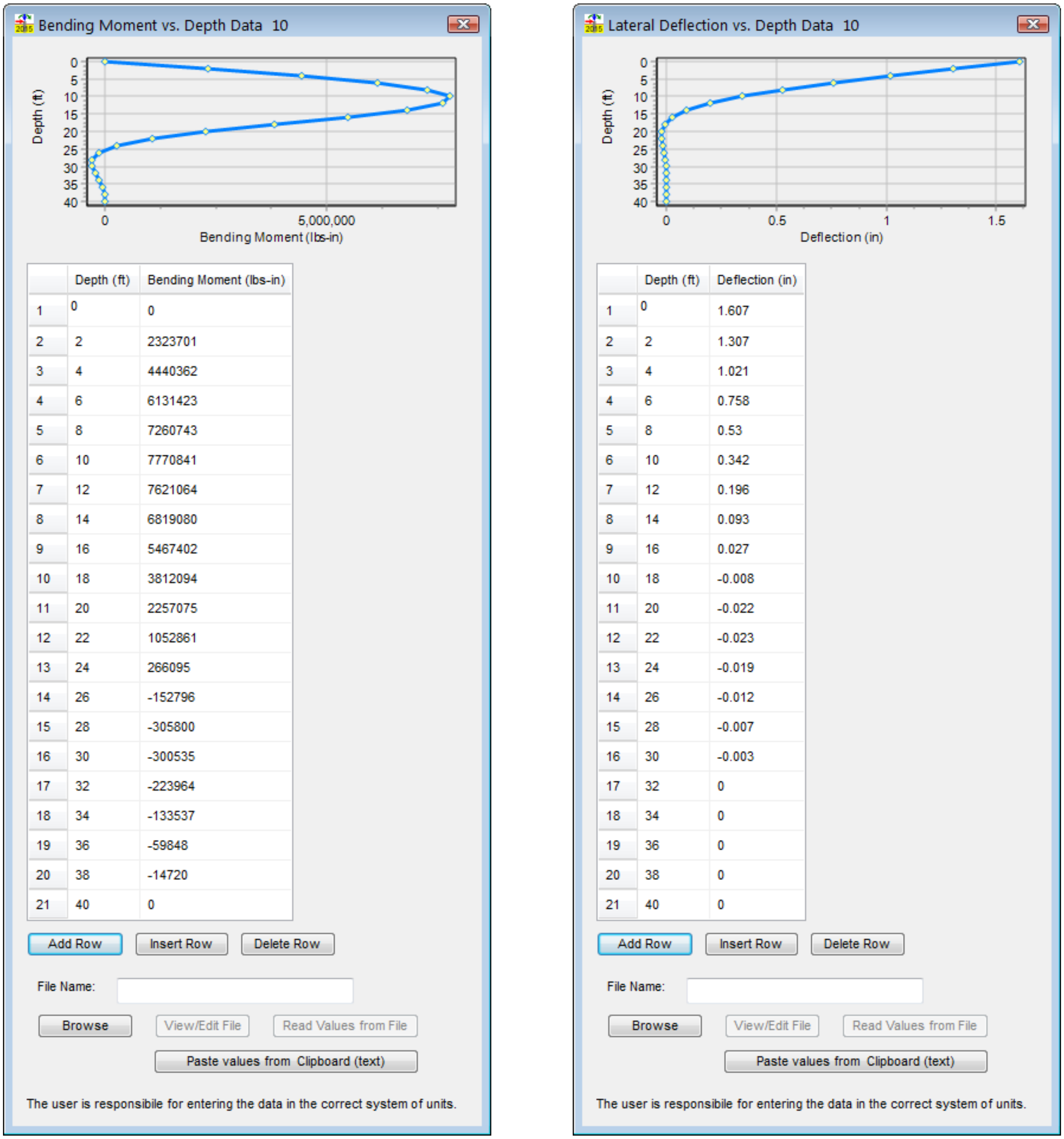


Figure 3-57 Dialog for Input of Pile-head Shear Force versus Lateral Deformation from Load Testing, if input of Bending Moment and Lateral Deflection versus Depth are specified.



	Depth (ft)	Bending Moment (lbs-in)
1	0	0
2	2	2323701
3	4	4440362
4	6	6131423
5	8	7260743
6	10	7770841
7	12	7621064
8	14	6819080
9	16	5467402
10	18	3812094
11	20	2257075
12	22	1052861
13	24	266095
14	26	-152796
15	28	-305800
16	30	-300535
17	32	-223964
18	34	-133537
19	36	-59848
20	38	-14720
21	40	0

	Depth (ft)	Deflection (in)
1	0	1.607
2	2	1.307
3	4	1.021
4	6	0.758
5	8	0.53
6	10	0.342
7	12	0.196
8	14	0.093
9	16	0.027
10	18	-0.008
11	20	-0.022
12	22	-0.023
13	24	-0.019
14	26	-0.012
15	28	-0.007
16	30	-0.003
17	32	0
18	34	0
19	36	0
20	38	0
21	40	0

Figure 3-58 Dialogs for Input of Bending Moment and Lateral Deflection versus Depth from Load Testing.

3-14 Load and Resistance Factor Design

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.

3-14-1 Unfactored Loads

The input dialog for unfactored loads shown in Figure 3-59 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.

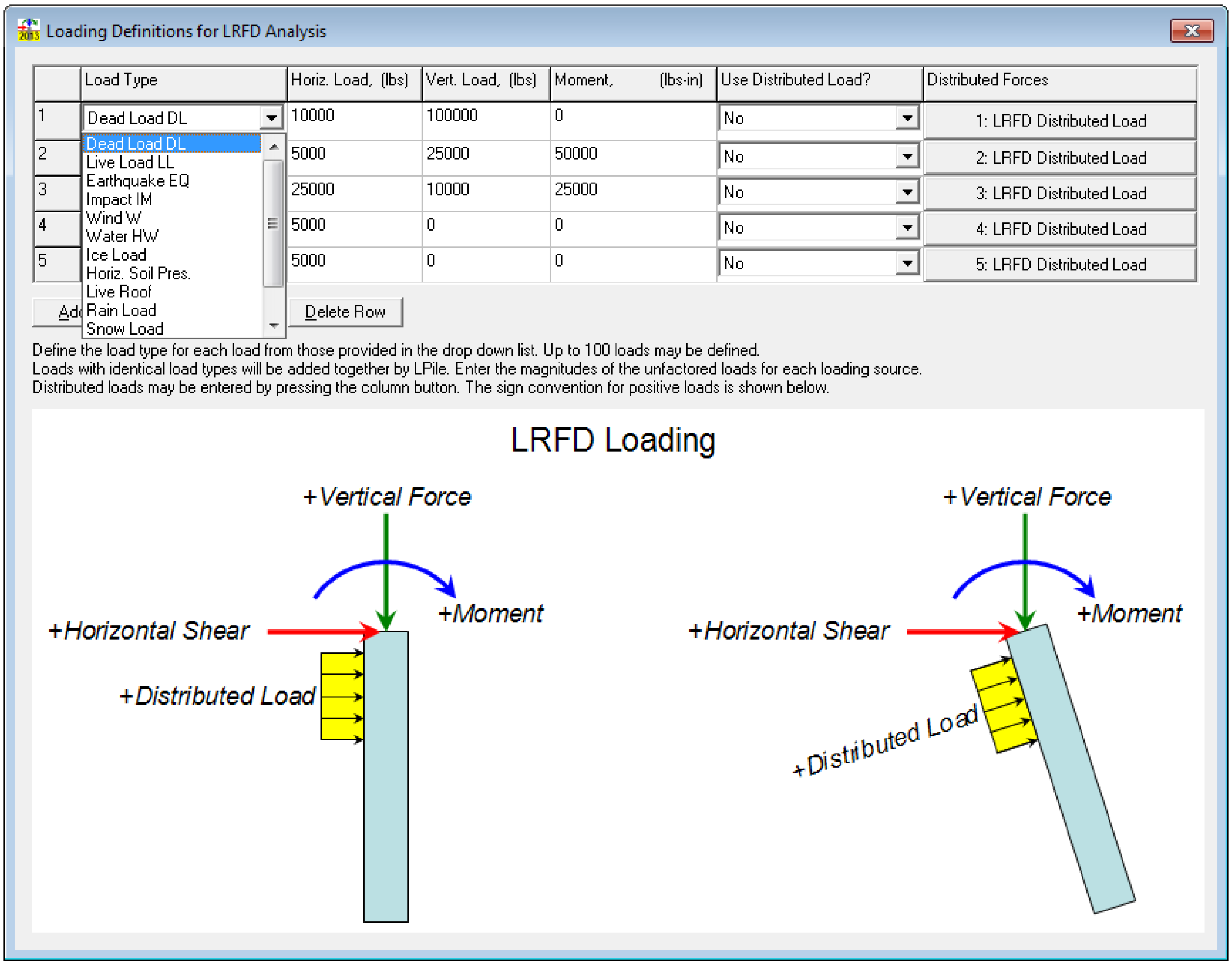


Figure 3-59 Dialog for Definition of Unfactored Pile-head Loadings for LRFD Analysis

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

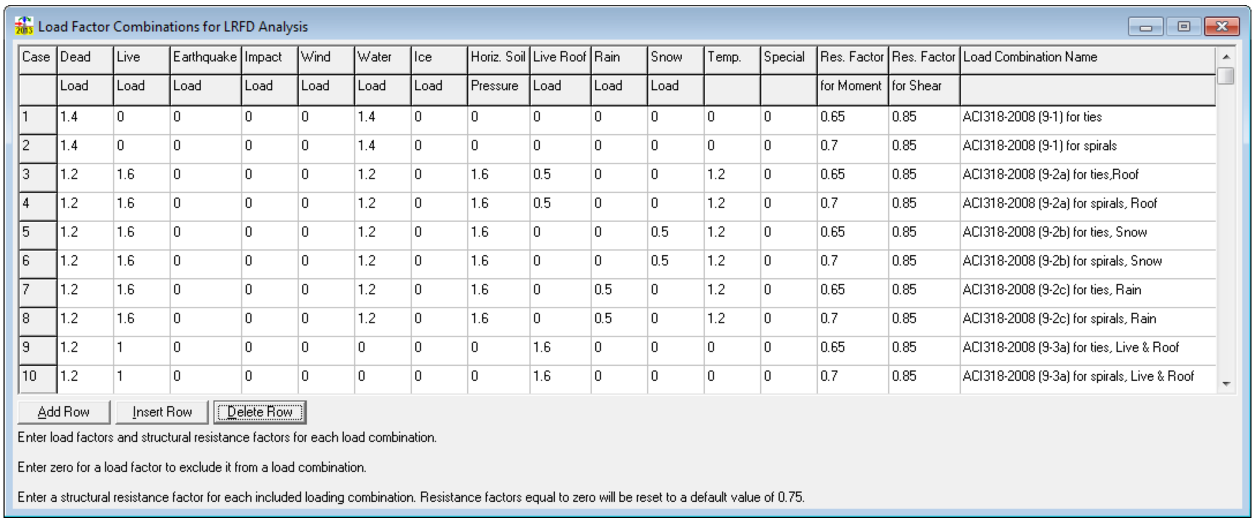
- Dead load
- Live load
- Earthquake
- Impact
- Wind
- Water
- Ice
- Horizontal Soil Pressure

- 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 3-41 on page 62 is displayed.

3-14-2 Load Cases and Resistance Factors

The user controls the definition of load cases either by reading the LRFD load case data file from the Program Options and Settings dialog box or by entering the specific load case in the dialog shown in Figure 3-60. 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.



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 3-60 Dialog for LRFD Load Combinations and Structural Resistance Factors

The current version of LPile does not compute structural shear capacity, but allows the user to input a value of shear capacity for each pile section. So, 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.

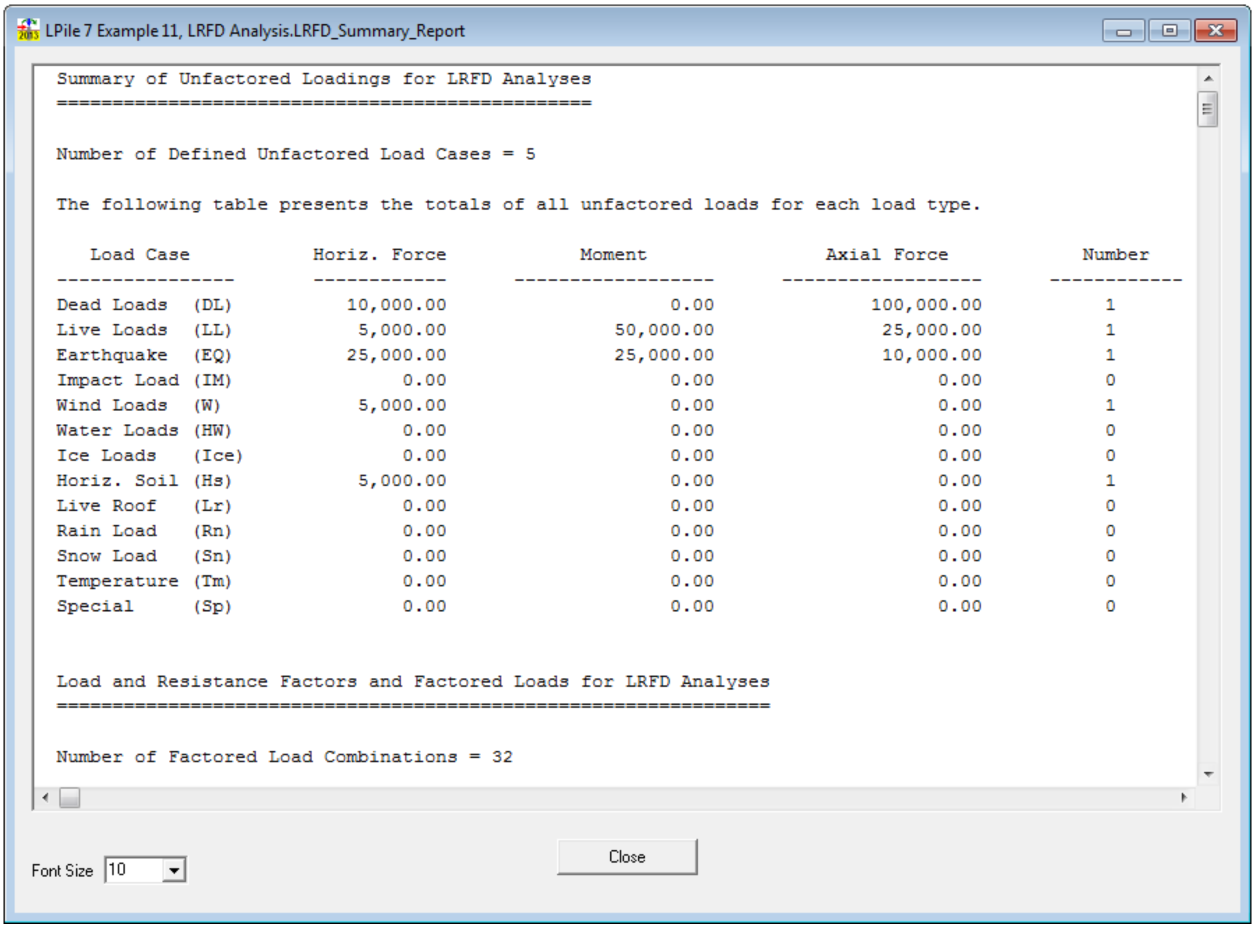
In the case of pile sections defined as elastic-plastic piles with tapered dimensions, the value of shear capacity at each pile nodal point is computed by interpolation between the values at the top and bottom of the section and the developed shear force is compared to the shear capacity at every nodal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

3-14-3 Summary of Factored Load Cases

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 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 filename of the data file with the file extension of *LRFD_Summary_Report*. An example of the summary report is shown in Figure 3-61.


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 3-61 Summary Report of Computed Factored Load Combinations for LRFD Analysis

3-15 Computation of Nonlinear *EI* Only

3-15-1 Axial Thrust Loads for Interaction Diagram

If the user selects the program option to Compute Nonlinear *EI* Only, 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. An example of the input dialog for entering axial thrust force values is shown in Figure 3-62.

Example 5, discussed in Section 6-5, demonstrates how to compute nonlinear *EI* only and how to produce both unfactored and factored interaction diagrams. Note that factored interaction diagrams can only be produced using the Presentation Charts utility discussed in Section 4-9.

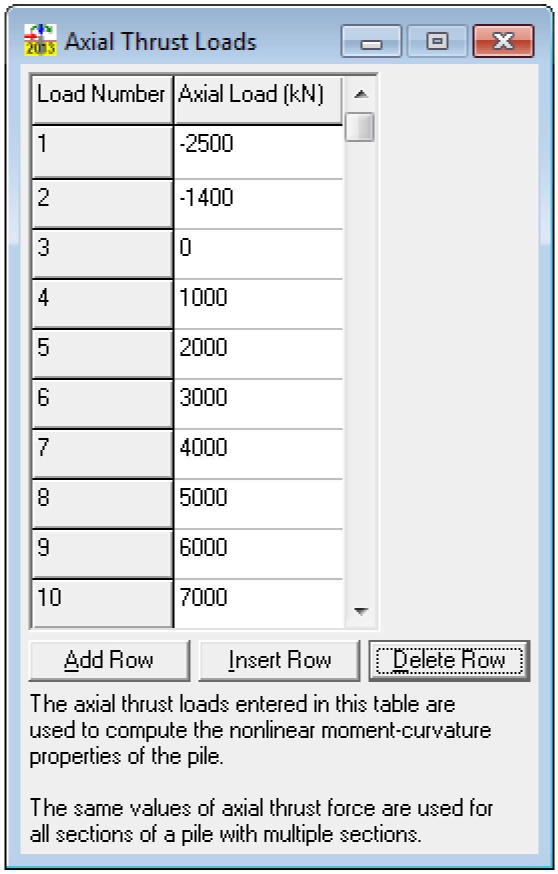


Figure 3-62 Dialog for Axial Thrust Forces for Computation of Interaction Diagram

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 graphing options 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.

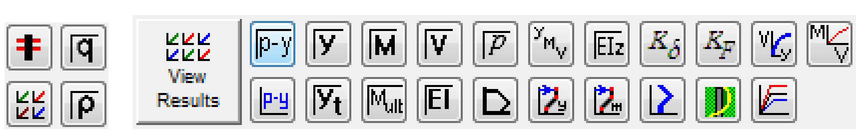


Figure 4-1 Speed Buttons for Graphics

4-5 Graphics Menu

The 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.

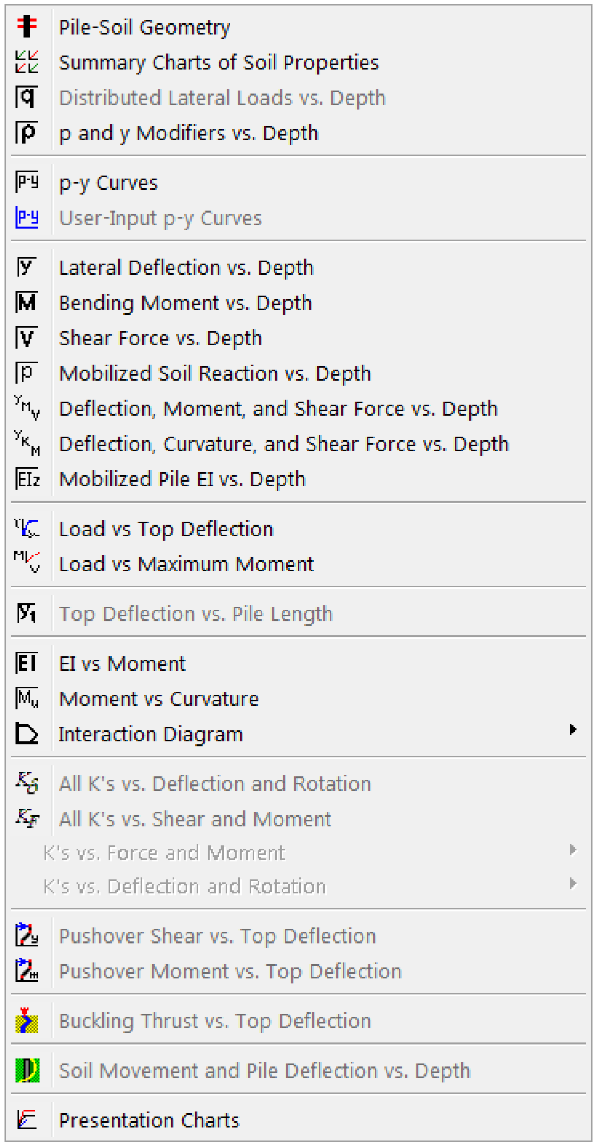


Figure 4-2 Graphics Menu

4-6 Plot Menu

The Plot Menu is visible only when a fast graphic is being displayed. The Plot Menu is shown below.

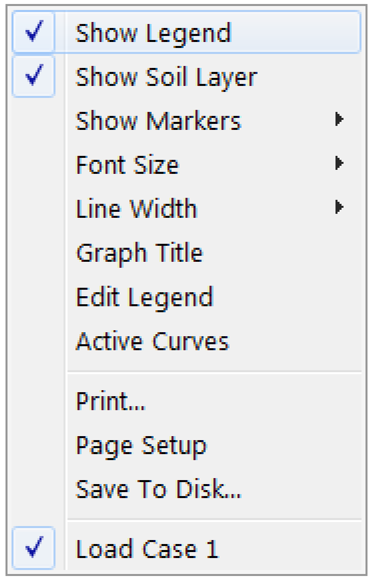


Figure 4-3 Plot Drop-Down Menu

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 of pile response versus depth. The soil profile is not shown on other types of graphs

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 Presentation Charts utility is used to save the 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 View Pile-Soil Geometry

This Graphics Menu command 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 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 4-4.

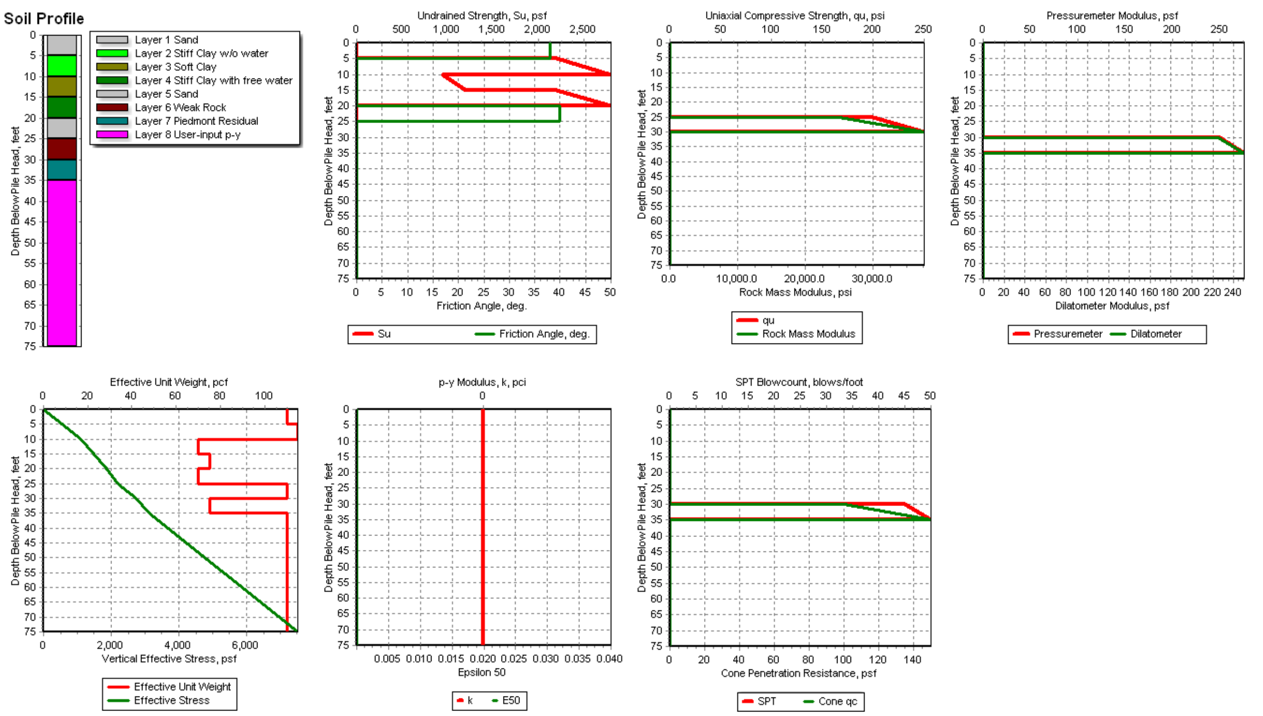


Figure 4-4 Example of Summary Graphs of Soil Properties

4-7-3 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.

4-7-4 Distributed Lateral Loads vs. Depth

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 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.

4-8 Graphics of Computational Results

4-8-1 View Results

The View Results button displays summary charts of the principal results from the last computation. The type and number of charts displayed in the View Results window depends on the Program Options selected for the computation. 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 4-5.

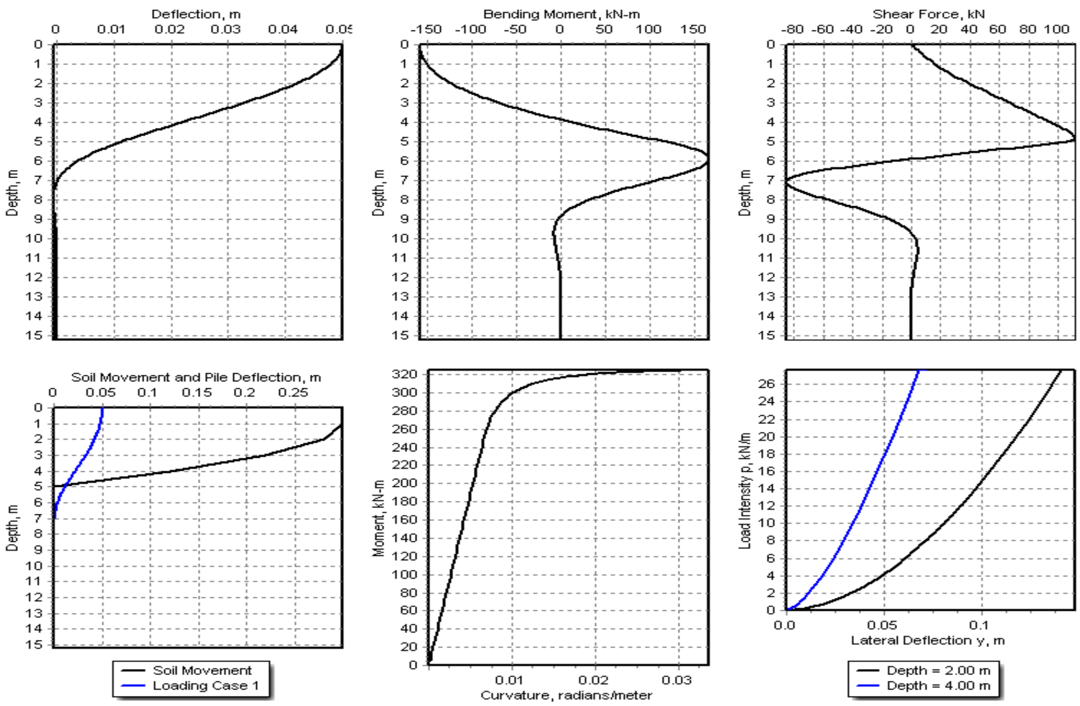


Figure 4-5 Example of View Results Window

4-8-2 *p-y* Curves at User-specified Depths

LPile is capable of generating graphs of internally generated *p-y* curves at user-specified depths located between the lower of the ground surface or top of pile and the pile tip. This graphics command is enabled if the user asked the program to print *p-y* curves for verification purposes by checking in the Program Options and Settings dialog (see Section 3-4-4 for further information). When specified, the graphics dialog will show the *p-y* curves for all specified depths. If no *p-y* curves were output, this Graphics command will not be enabled (grayed out).

4-8-3 Lateral Deflection versus Depth

This Graphics Menu command displays a graph 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.

4-8-4 Bending Moment versus Depth

This Graphics Menu command displays a graph bending moment 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.

4-8-5 Shear Force versus Depth

This Graphics Menu command displays a graph of shear force 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.

4-8-6 Mobilized Soil Reaction versus Depth

This Graphics Menu command displays a graph of soil reaction 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 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.

4-8-7 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.

4-8-8 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.

4-8-9 Mobilized Pile *EI* versus Depth

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

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 Graphics command to display a graph of curve of applied lateral load versus pile-top deflection.

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 Graphics command to display a graph of applied lateral load versus maximum bending moment along the pile length.

4-8-12 Top Deflection versus Pile Length

This Graphics Menu command is enabled if the user selects Generate Pile Length versus Top Deflection option for a load case for conventional loading. The user may select this Graphics command to display a graph of pile length versus pile-head deflection for the load cases evaluated with this option.

4-8-13 Moment versus Curvature

This Graphics Menu command is enabled whenever the nonlinear bending is evaluated for a pile section. The user may select this Graphics command to display a graph of bending moment versus curvature. 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.

4-8-14 *EI* versus Moment

This Graphics Menu command is enabled whenever the nonlinear bending is evaluated for a pile section. The user may select this Graphics command to display a graph of bending stiffness 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 Interaction Diagram

This Graphics Menu command is enabled if the user selected to perform a section analysis and inputs several axial thrust load cases for the analysis. The user may select this Graphics command to display an unfactored interaction diagram (ultimate bending moment versus axial load) of the modeled cross section. These curves are helpful to find the ultimate bending moment for several axial load cases in 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 loads defined by the pile-head loading conditions.

4-8-16 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.

4-8-17 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.

4-8-18 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 4-6.

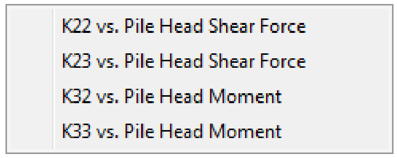


Figure 4-6 Sub-menu for Pile-head Stiffnesses versus Pile-head Force and Moment

4-8-18-1 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 3-12-4 for more information about the feature for computing pile-head stiffnesses.

4-8-18-2 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 3-12-4 for more information about the feature for computing pile-head stiffnesses.

4-8-18-3 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 3-12-4 for more information about the feature for computing pile-head stiffnesses.

4-8-18-4 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 3-12-4 for more information about the feature for computing pile-head stiffnesses.

4-8-19 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 4-7.

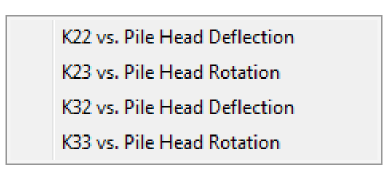


Figure 4-7 Submenu for Pile-head Stiffnesses versus Deflection and Rotation

4-8-19-1 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.

4-8-19-2 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.

4-8-19-3 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.

4-8-19-4 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.

4-8-20 Pushover Shear Force versus Top Deflection

This Graphics Menu command is available only if the Pushover Analysis option was selected. This graph may contain either one or two curves depending on the pile-head fixity condition selected in the Controls for 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.

4-8-21 Pushover Moment versus Top Deflection

This Graphics Menu command is available only if the Pushover Analysis feature was activated. This graph may contain either one or two curves depending on the pile-head fixity condition selected in the Controls for 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.

4-8-22 Pile Buckling Thrust versus Top Deflection

This Graphics Menu command is available only in the Pile Buckling Analysis feature was activated. 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 3-53.

4-8-23 Deflection and Soil Movement versus Depth

This Graphics Menu command displays a combined chart of lateral pile deflection and input 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.

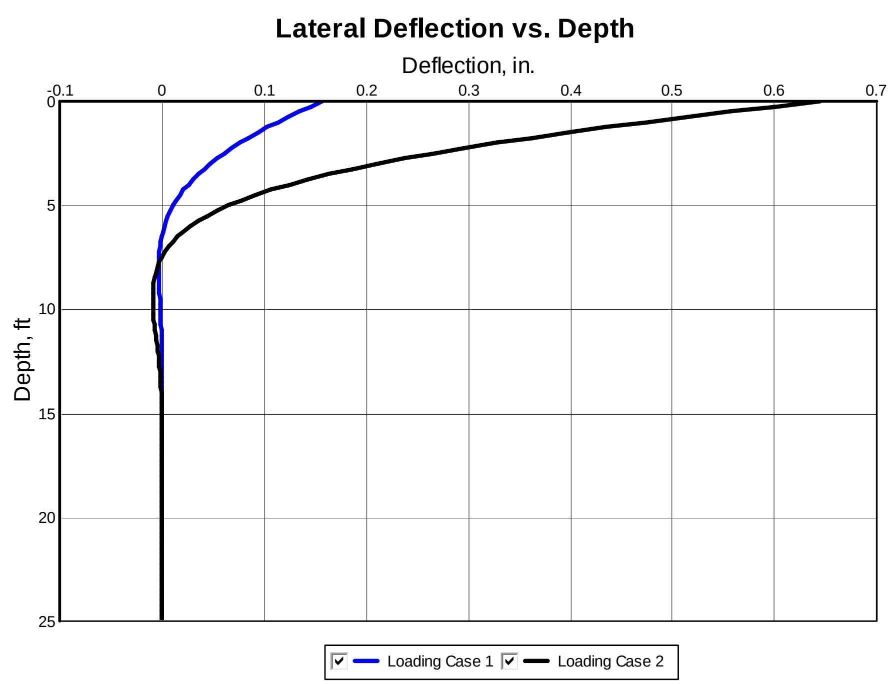
4-9-3 Creating Graphs for Reports

The following procedure has been found to be useful to prepare graphics for reports that are uniform in format.

1. Create an empty table to contain each graph. This table should contain one cell for the graph that is formatted with fixed dimensions to be the standard size for the report graph. Cell borders and title blocks to contain graph title information and company logos can also be included and be formatted to the desired dimensions and styles.
2. Save the empty table as a separate file for re-use later.
3. Copy the empty table for each required graph.
4. Fill in the cells with the necessary title blocks and company logos.

5. Create the graphs using the Presentation Graphics utility in LPile, applying a presentation chart template to assure uniformity in appearance.
6. Click the button to Edit or Print Chart.
7. Modify the graph as desired (this may not be required if a presentation chart template is being applied.
8. Click the Export tab on the top tab row.
9. Select “as Metafile” and check the box for Enhanced
10. Click the Copy button to copy the graph to the Windows Clipboard.
11. Switch back to the word processing program and position the cursor in the cell for the graph.
12. Paste the graph into the cell. The size of the graph may need to be resized to fit the table cell.

An example of a report graph prepared using the procedure above is shown in Figure 4-8.



Insert Title for Figure Here		
ENSOFT, INC. Insert Company Logo	Insert Project Title Block Here	Insert Figure Numbering Here

Figure 4-8 Example of Table for a Report Graph

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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.

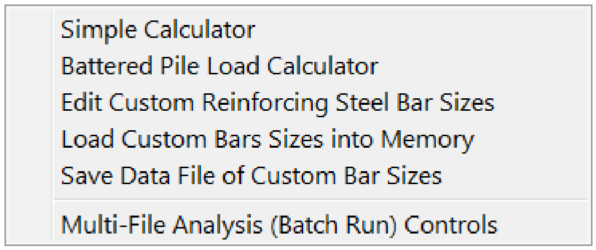

Figure 5-1 Tools Menu

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.

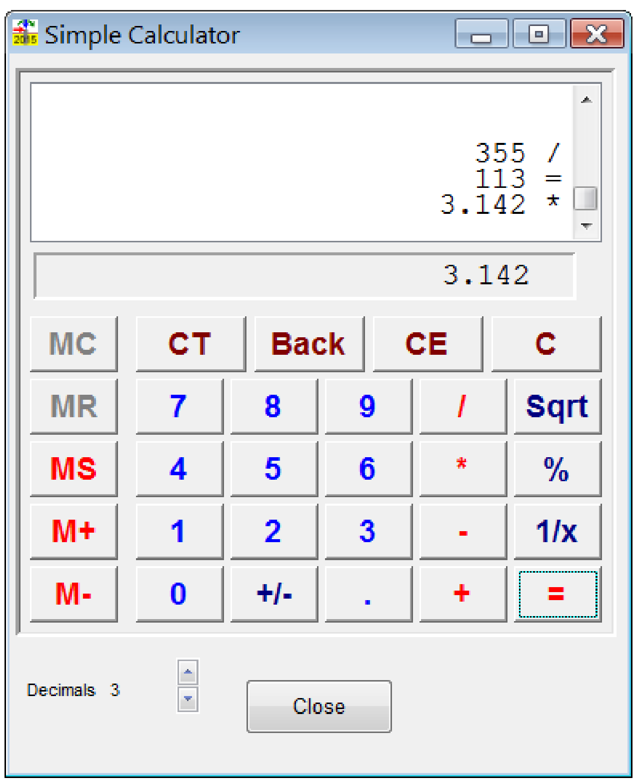

Figure 5-2 Simple Calculator

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

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

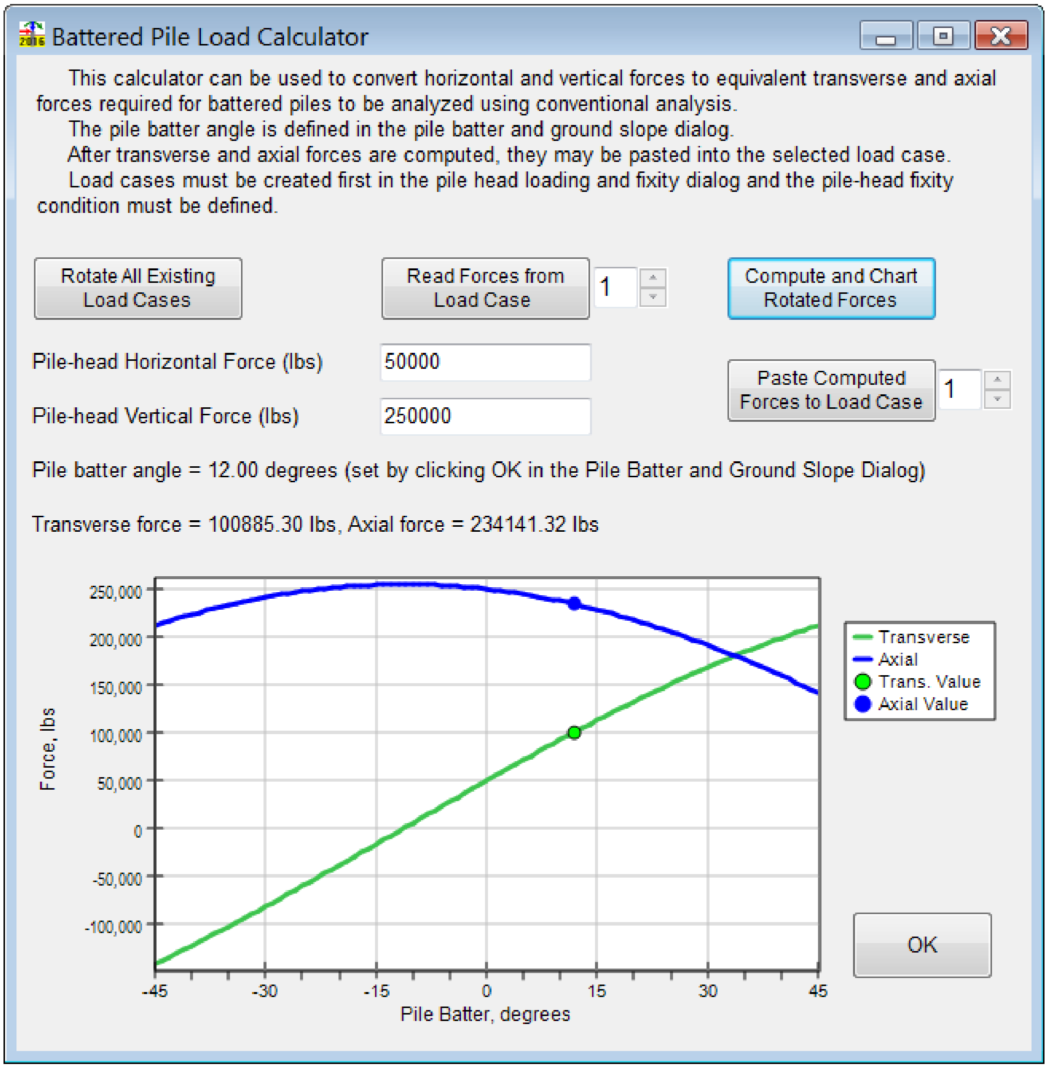

Figure 5-3 Battered Load Calculator

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.

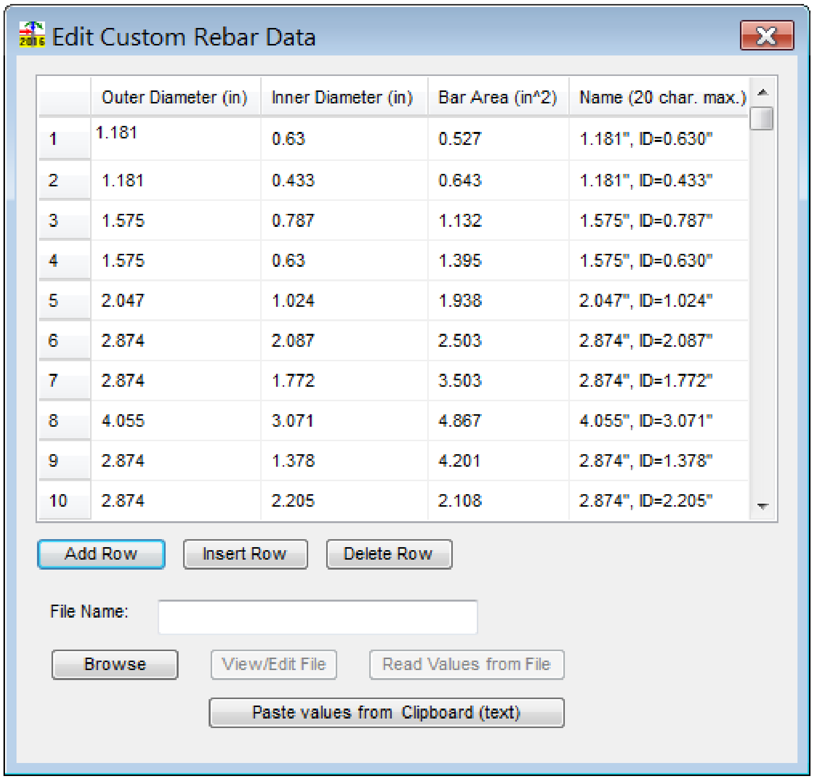

Figure 5-4 Dialog for Editing of Custom Rebar Data

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.

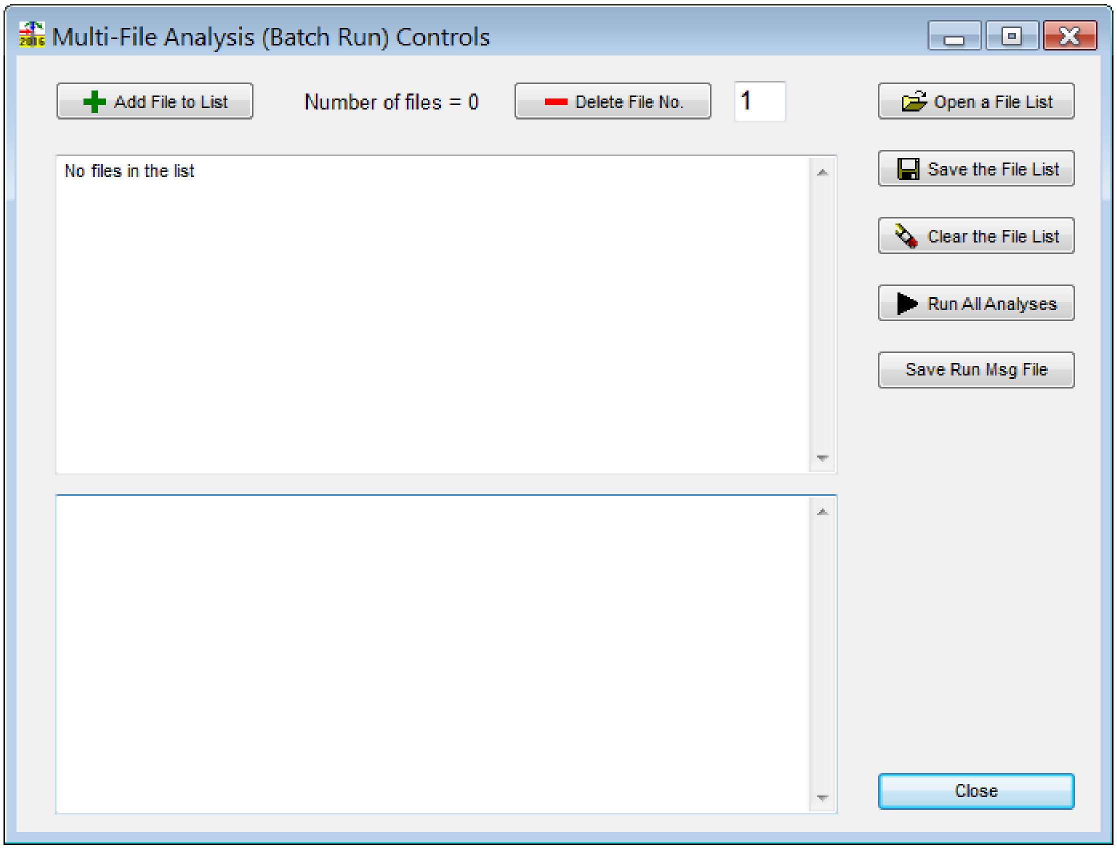

Figure 5-5 Dialog for Multi-File Analysis Controls

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.

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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 Lpile2013-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 Example 1 is

C:\Ensoft\Lpile2013-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 – Steel pile supporting a retaining wall. Among other aspects, this problem uses sample applications of the following program features:

- 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 – Bored pile supporting a retaining wall. This example includes the following program features:

- 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. Includes the following program features:

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

Example 4 – Buckling of a pile column. This example includes the following program features:

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

Example 5 – Ultimate bending moment for bored piles. Includes the following program features:

- 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 *y* 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

6-1 Example 1 – Steel Pile in Sloping Ground

The general description and geometrical configuration of Example 1 is shown in 5-1. 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 particular 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 the retaining wall so that no rotation of the top of the pile will occur. This assumption is not strictly true, but research is yet 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 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.

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, which is thought to be unlikely for most retaining walls.

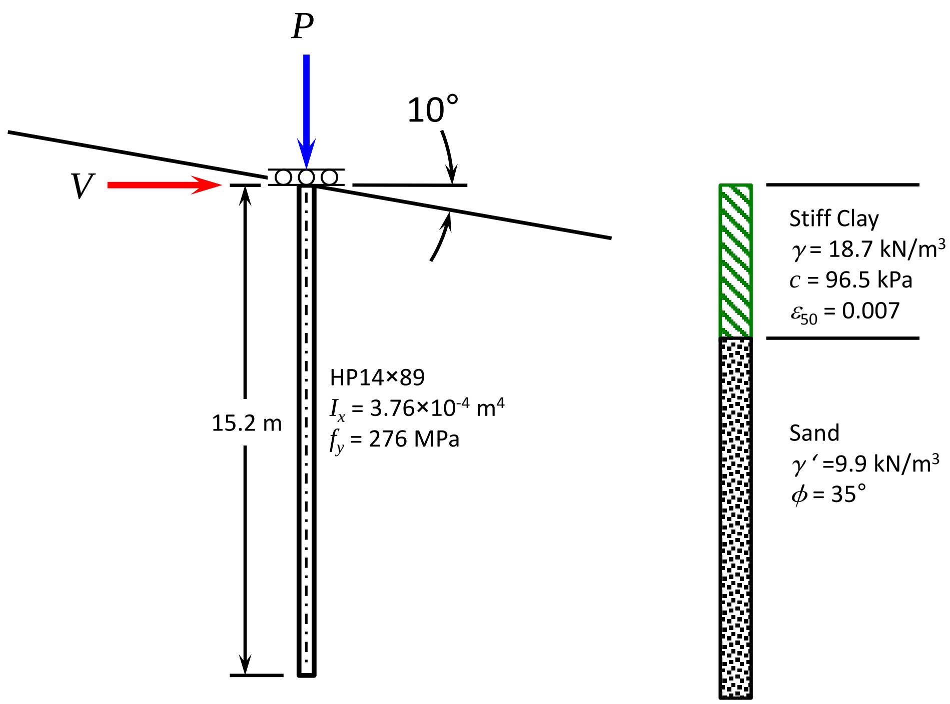

Figure 6-1 General Description of Example 1

The pile section type selected for the analysis is the 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.).

The first 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, the actual width of 373 mm (14.686 in.) may be entered. 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.

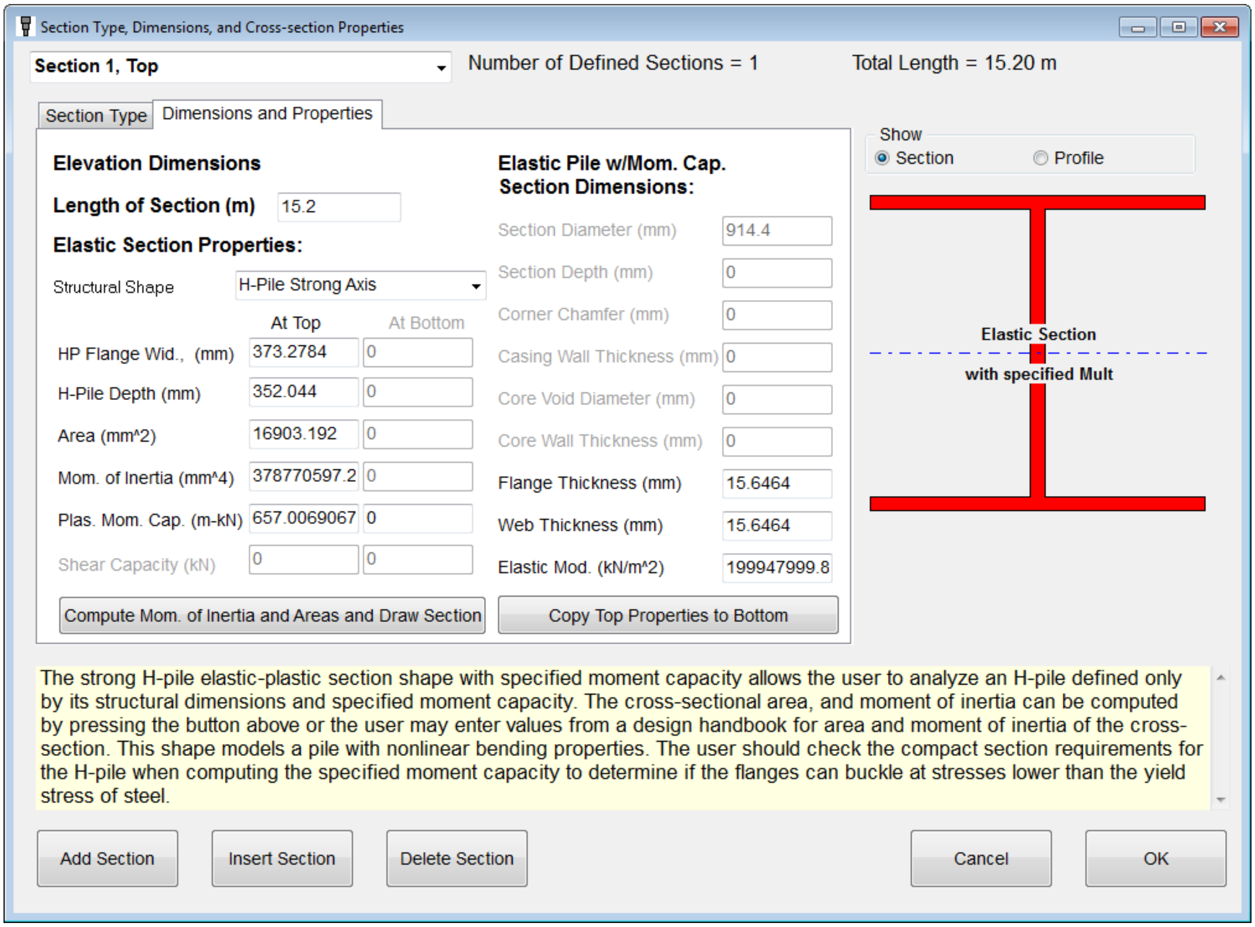

Figure 6-2 Dimensions and Properties Entered for Example 1

The user should understand how the values entered for Dimensions and 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 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:

$$M_p = F_y\, Z$$
$$M_p = (276)\left(2.39 \times 10^{-3}\right)$$
$$M_p = 0.660\ \text{MN-m}$$
$$M_p = 660\ \text{kN-m}$$

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 from a retaining wall 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 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.

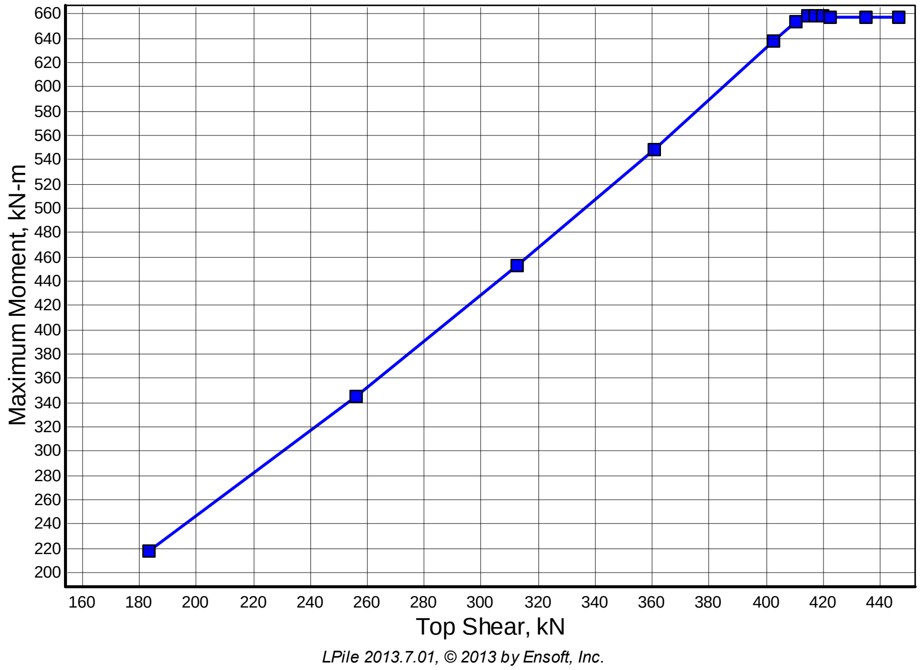

Figure 6-3 Generated Curve of Lateral Load versus Maximum Moment for Example 1.

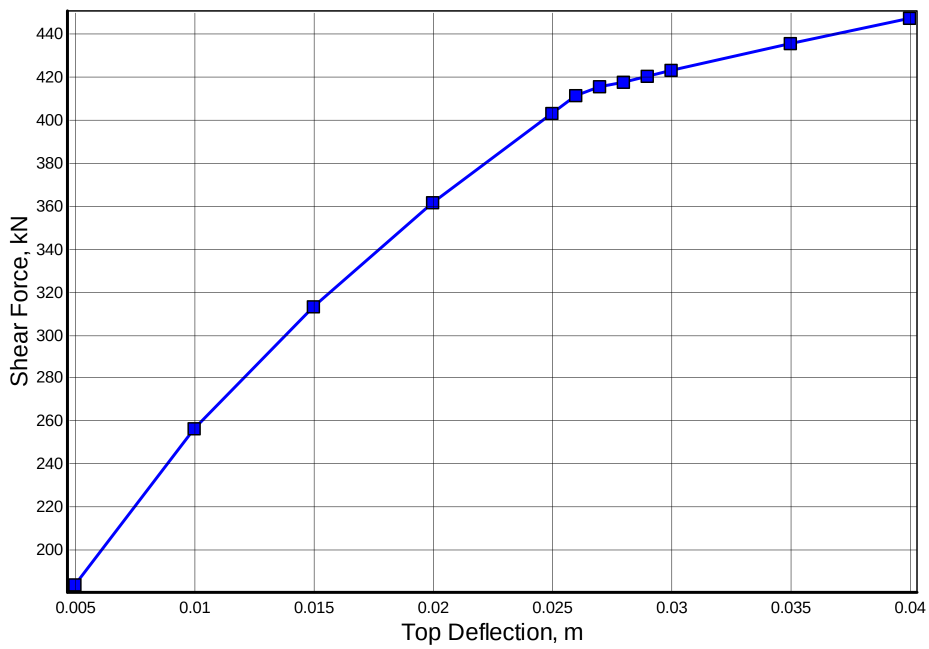

Figure 6-4 Generated Curve of Lateral Load versus Top Deflection for Example 1.

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).

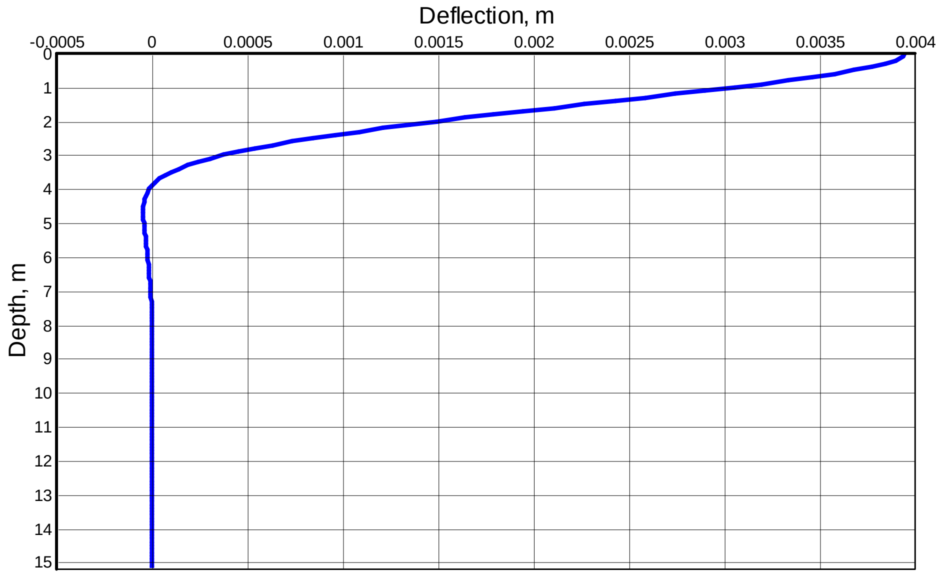

Figure 6-5 Curve of Deflection versus Depth for Example 1, Second Analysis

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.lp9d*. These files are found in the Examples folder with the program. The filename extensions for the files are shown in Table 2-1. 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.lp9d*. The input and output files are not shown here due to their length.

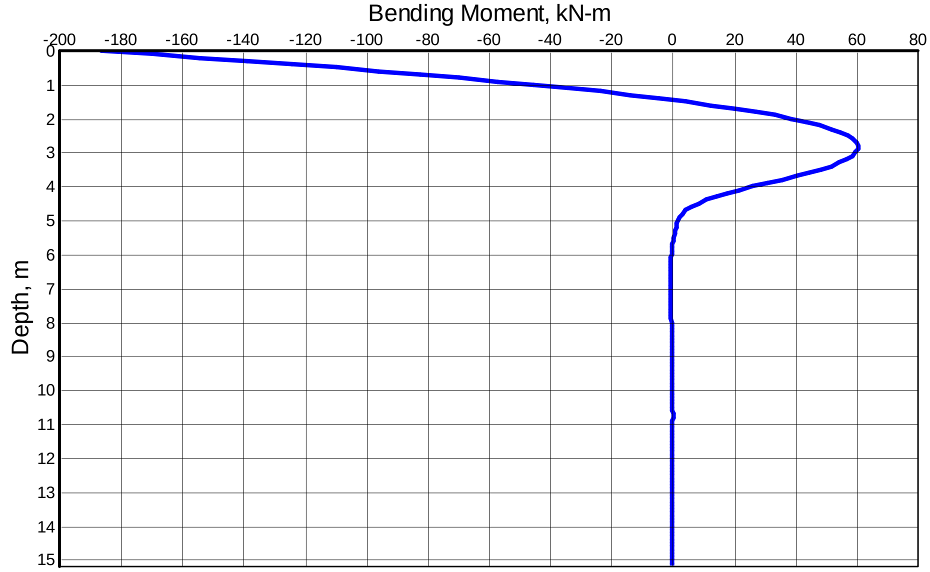

Figure 6-6 Bending Moment versus Depth for Example 1, Second Analysis

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 Program 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. 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 report and use these values to set the upper and lower values of axial thrust for the second analysis.

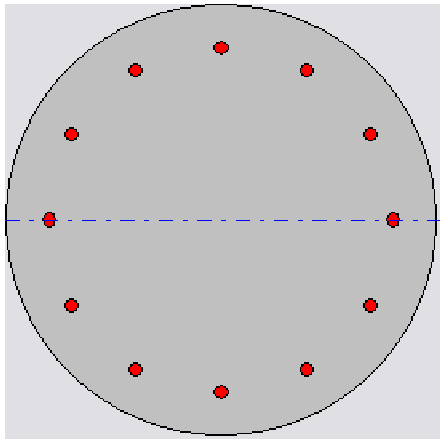

Figure 6-7 Cross-section of Drilled Shaft for Example 2.

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.

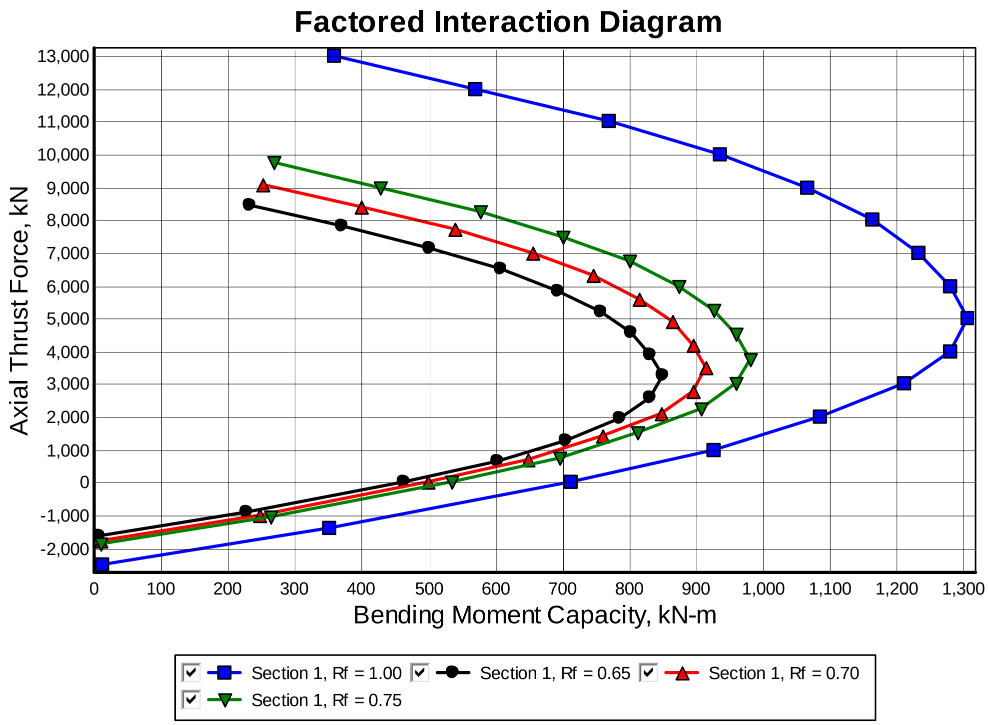

Figure 6-8 Factored Interaction Diagram for Example 2a.

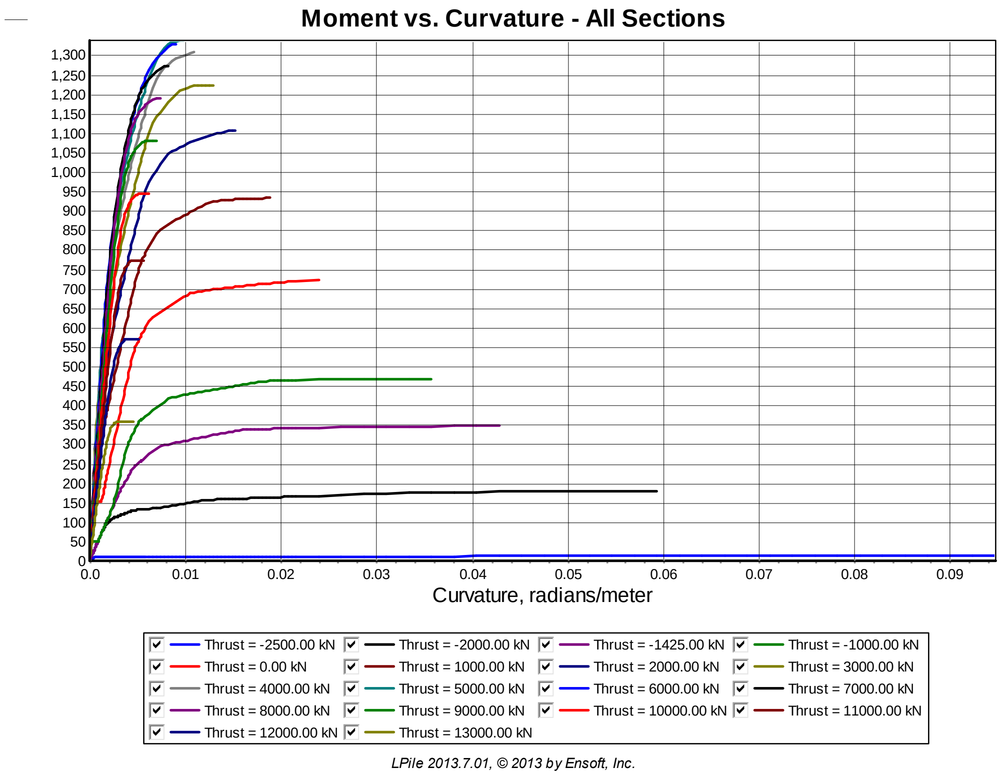

Figure 6-9 Moment-Curvature Diagram for Example 2a.

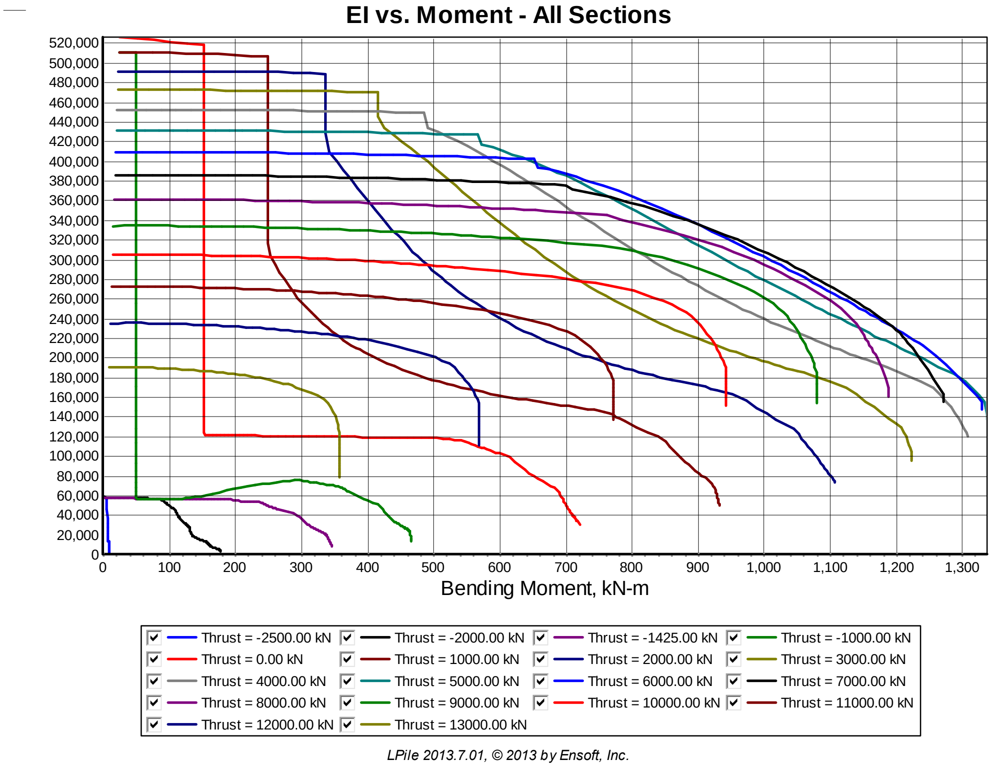

Figure 6-10 Bending Stiffness versus Bending Moment for Example 2a.

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. The 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 top deflection versus pile length for free and fixed-head conditions is shown in Figure 6-14.

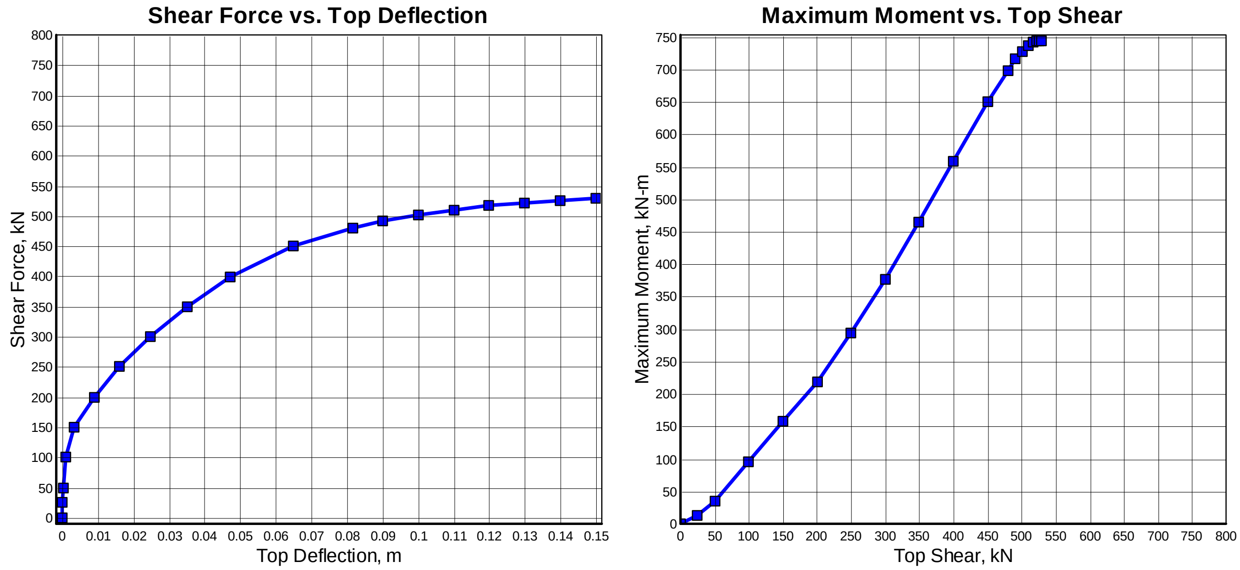

Figure 6-11 Shear Force versus Top Deflection and Maximum Bending Moment versus Top Shear Load for Free-head Conditions in Example 2b.

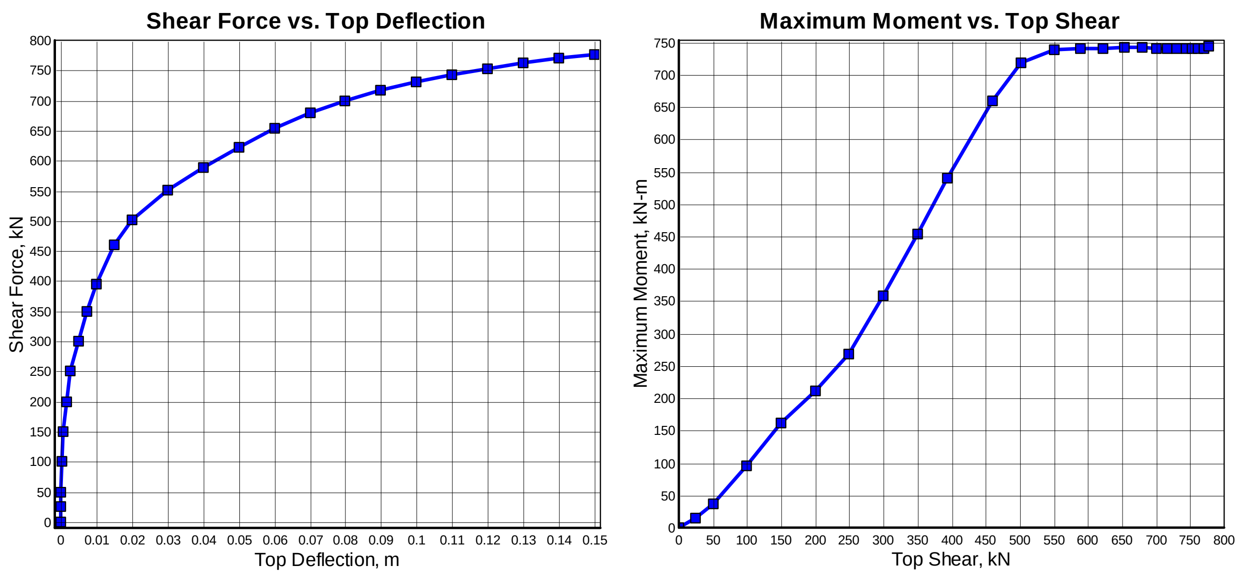

Figure 6-12 Shear Force versus Top Deflection and Maximum Bending Moment versus Top Shear Load for Fixed-head Conditions in Example 2c.

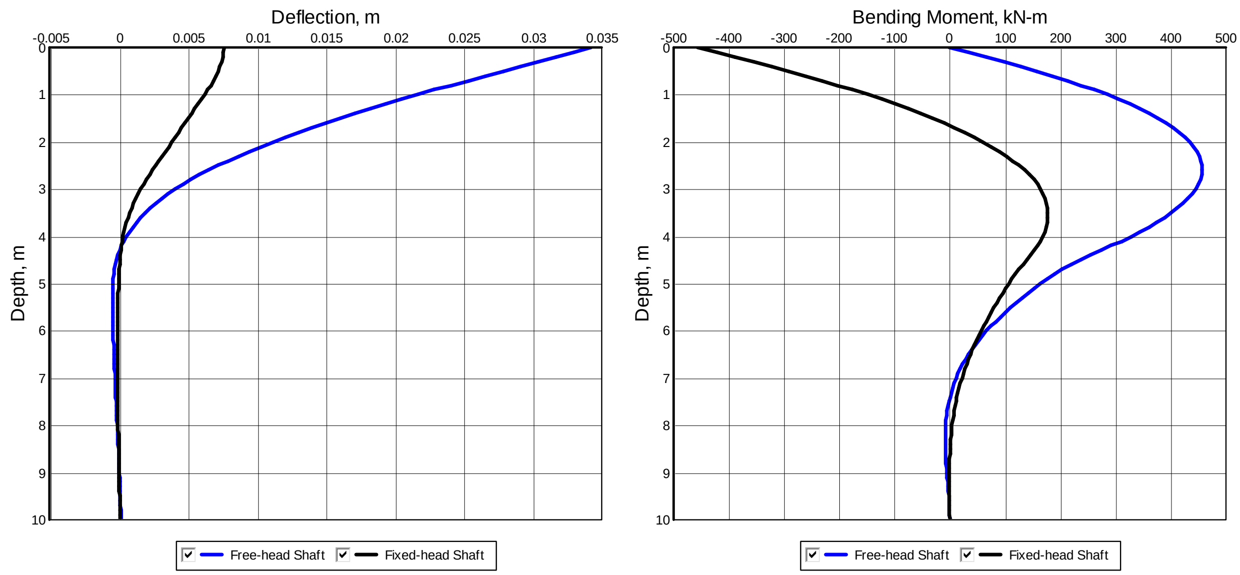

Figure 6-13 Results for Free-head and Fixed-head Loading Conditions for Example 2d

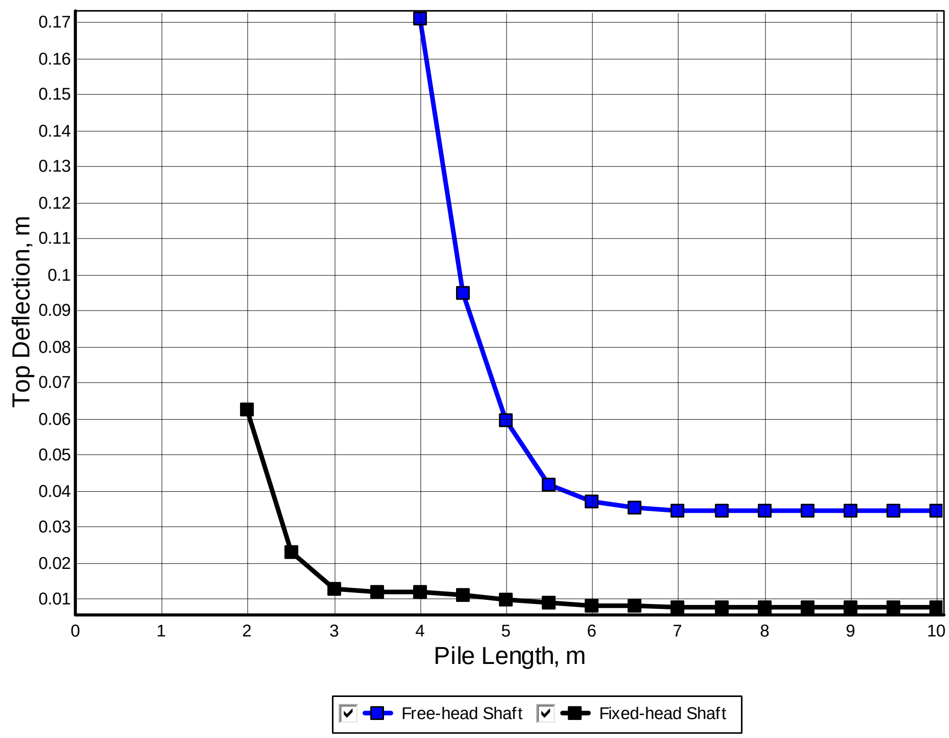

Figure 6-14 Top Deflection versus Pile Length for Example 2d

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.

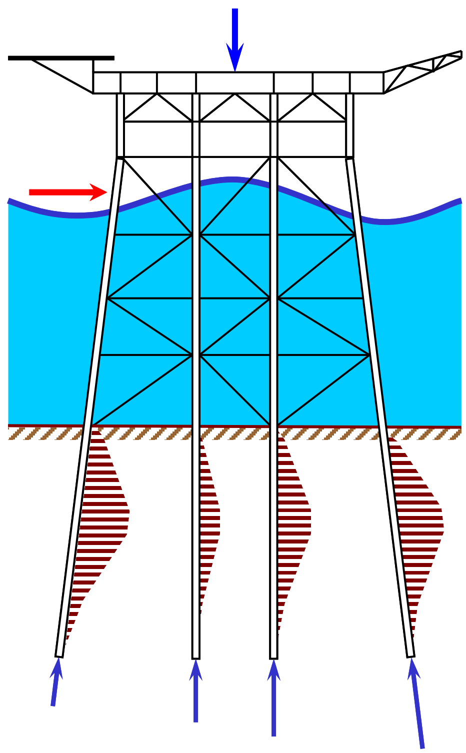

Figure 6-15 Idealized View of an Offshore Platform Subjected to Wave Loading, Example 3

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.

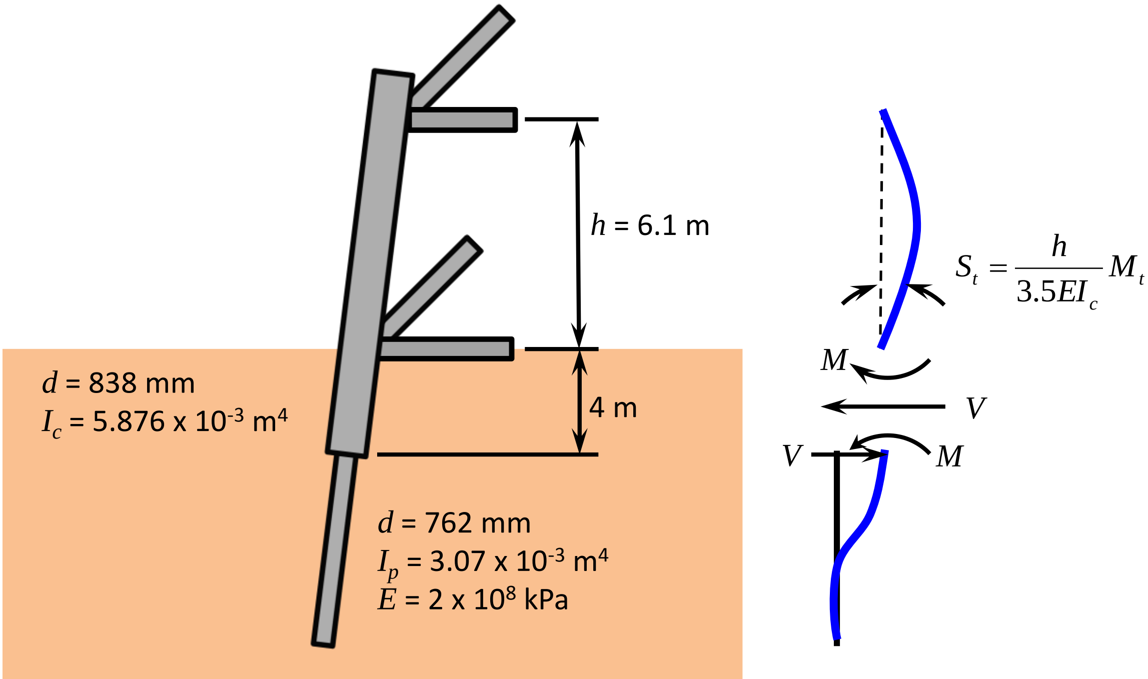

Figure 6-16 Superstructure and Pile Details, Example 3

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.

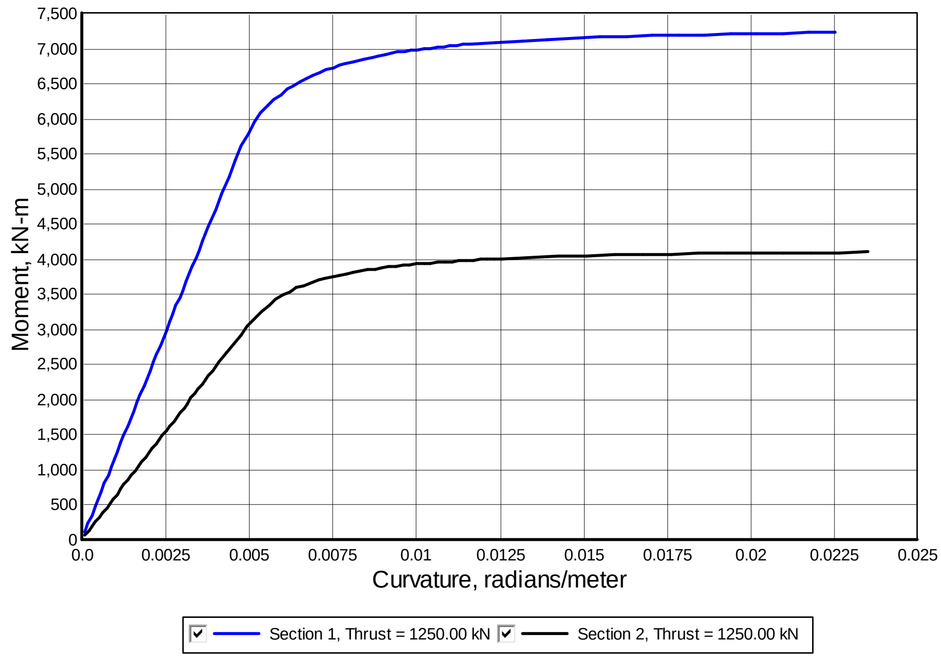

Figure 6-17 Moment versus Curvature, Example 3

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.

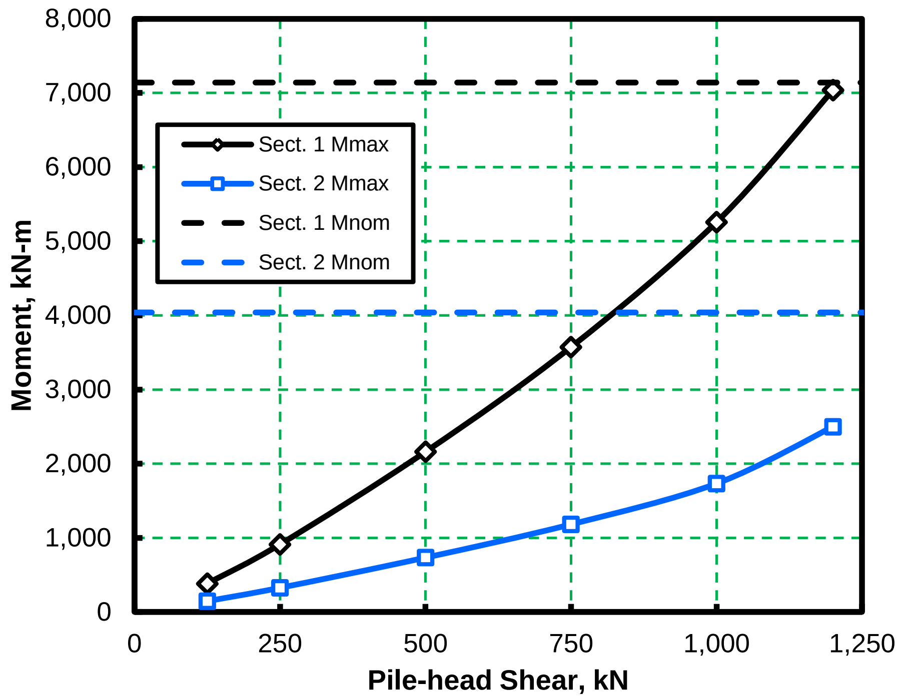

Figure 6-18 Results of Initial Computation with *p-y* Curves, Example 3

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.

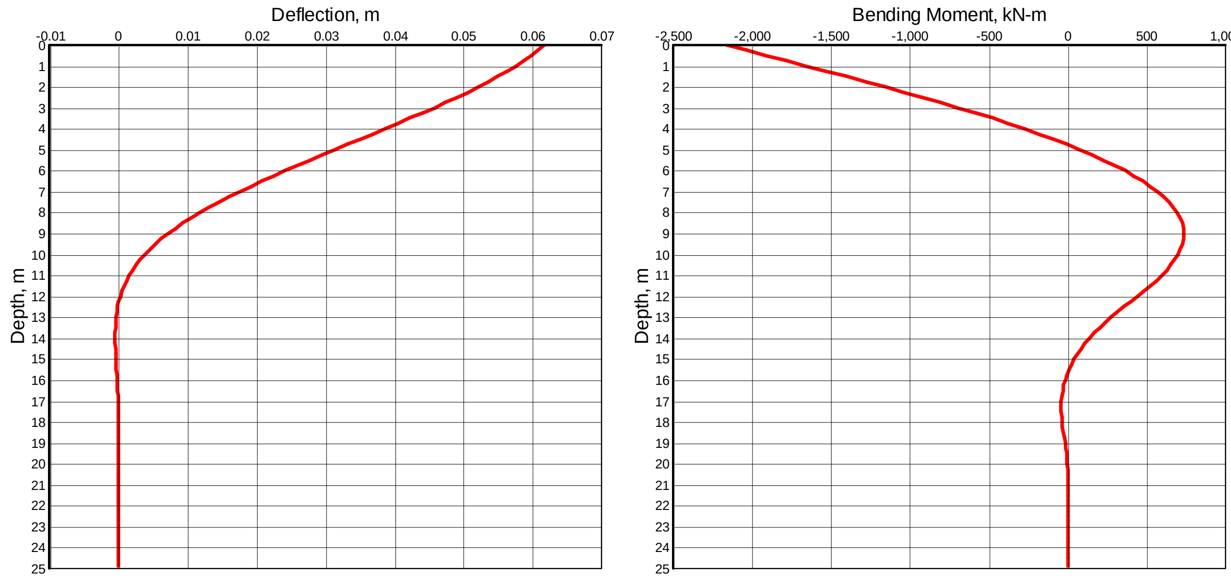

Figure 6-19 Pile Deflection and Bending Moment versus Depth for V_{top} = 500 kN, Example 3

6-4 Example 4 - Buckling of a Pile-Column

One analytical feature of LPile is an automatic analysis for 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.

In this example, the lateral load at the pile head is 44.5 kN (10 kips) and the loading was static. The lateral load and the axial load are applied at the top of the pile, which was 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 the bending moment capacity of the pile is fully mobilized.

The example pile is an elastic steel pipe, 610 mm (24 in.) in outside diameter, and with a wall thickness of 22.2 millimeters (0.875 inch). The *EI* is 354,312 kN-m^2 (1.235×10^{11} lb-in^2). The length is 15.2 meters (50 feet). Had the portion of the pile above the groundline been greater than 2.54 m (8.33 ft), the buckling load that was found would have been much less than the computed value.

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.

The results from the pile buckling analysis are shown in Figure 6-20. Note that this figure was drawn for this manual and was not generated by 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).

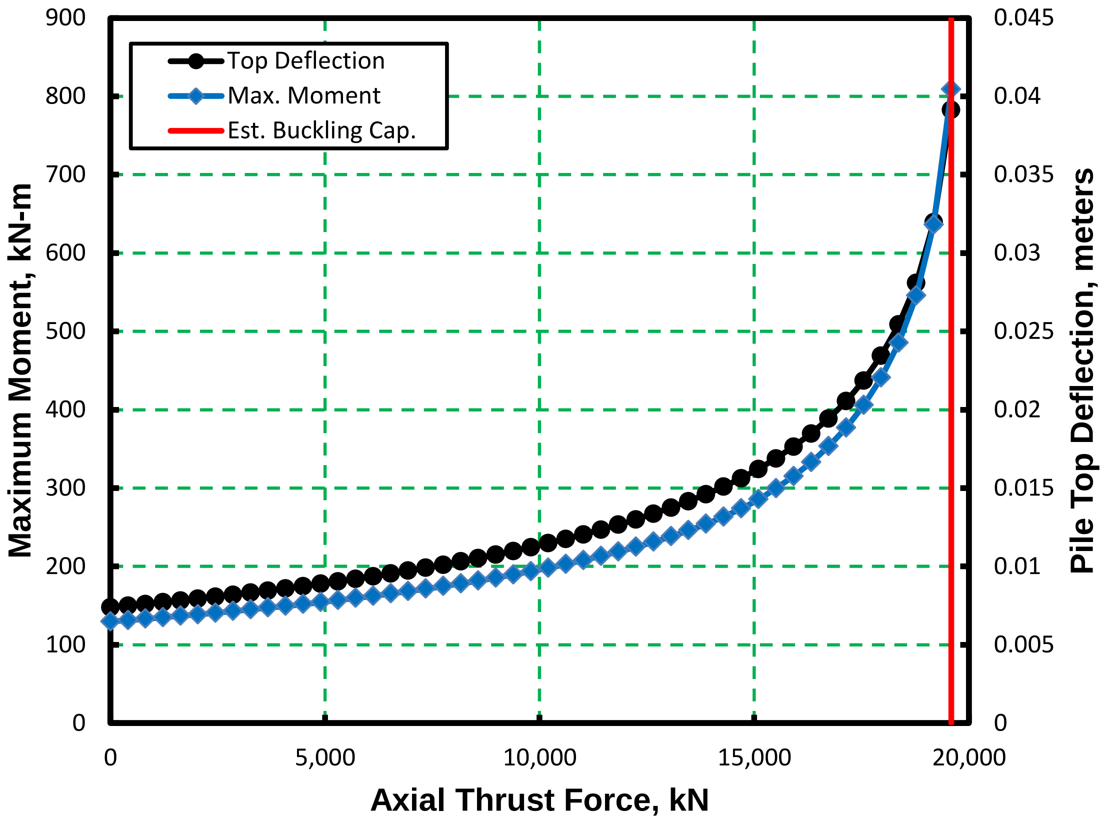

Figure 6-20 Pile-head Deflection and Maximum Bending Moment versus Axial Thrust Loading

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 3-12-6. A graph of the pile buckling analysis results generated by LPile for Example 4 is shown in Figure 6-21.

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.

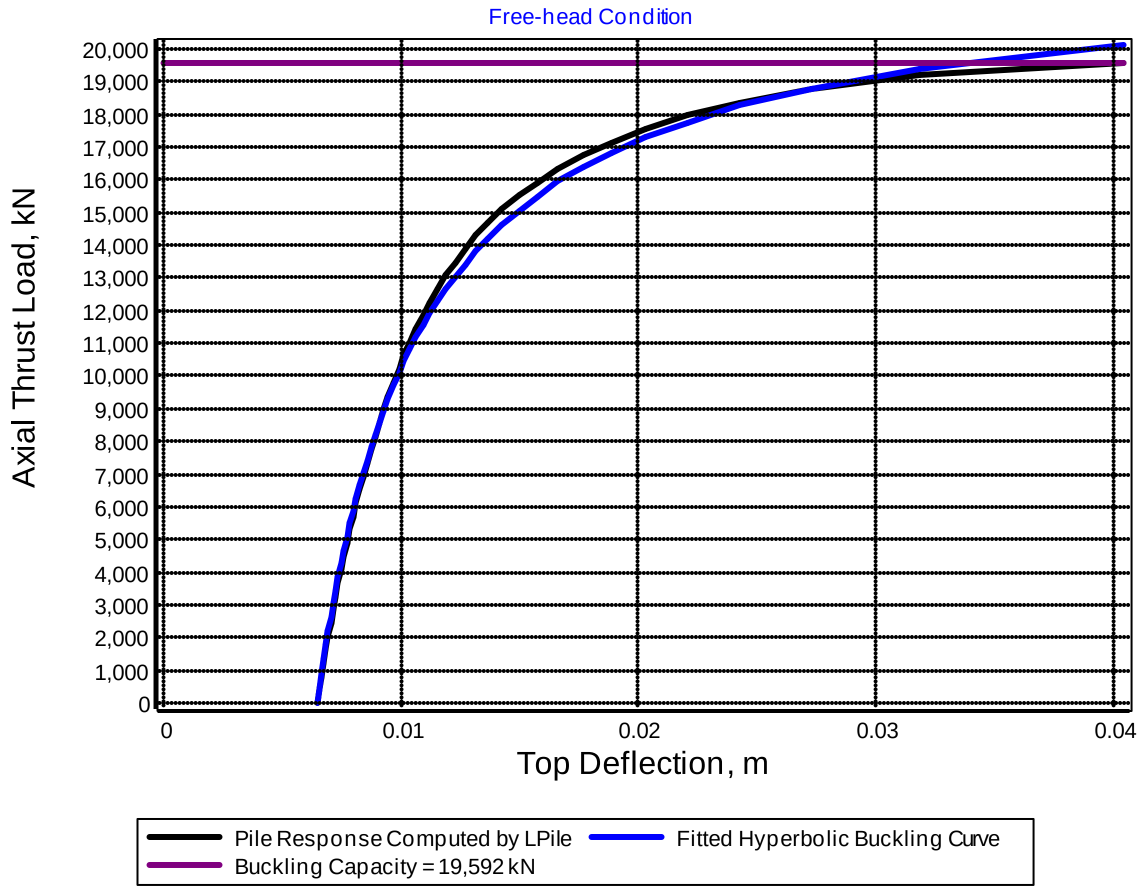

Figure 6-21 Results from LPile Solution for Buckling Analysis, Example 4

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 6-22. 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.

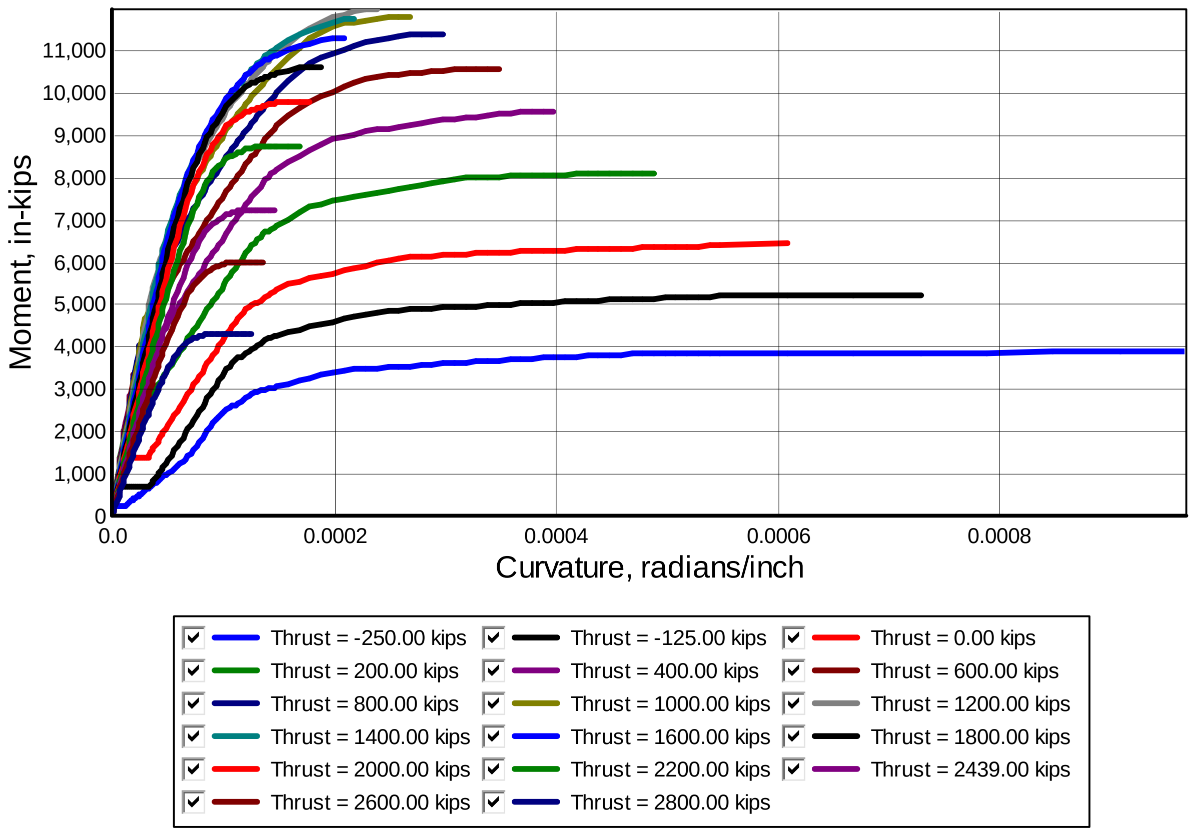

Figure 6-22 Moment versus Curvature for Example 5

Curves of bending stiffness versus bending moment are shown in Figure 6-23. 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 6-24. Note that this graph was produced using the presentation graph utility in order to show the factored curves.

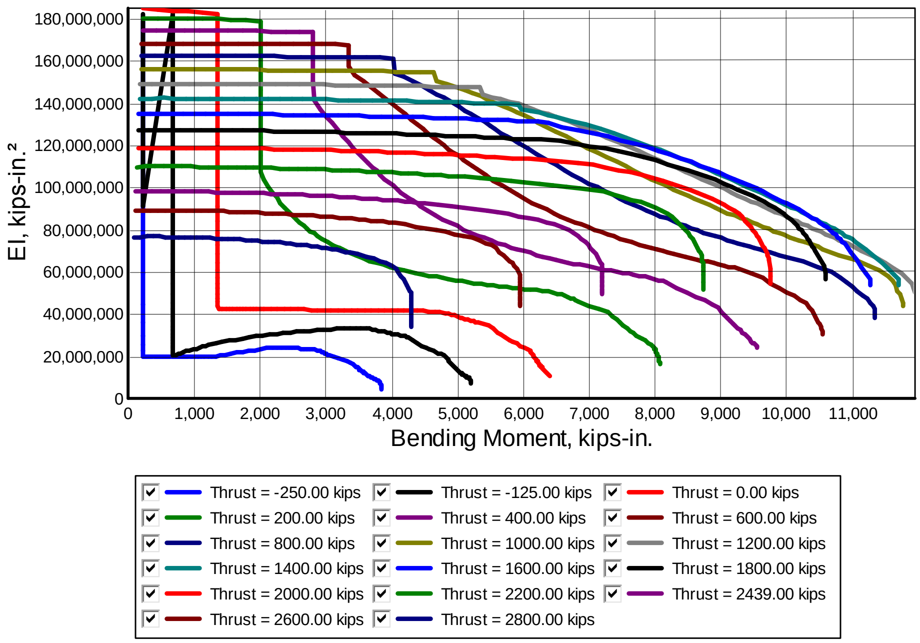

Figure 6-23 Bending Stiffness versus Bending Moment, Example 5

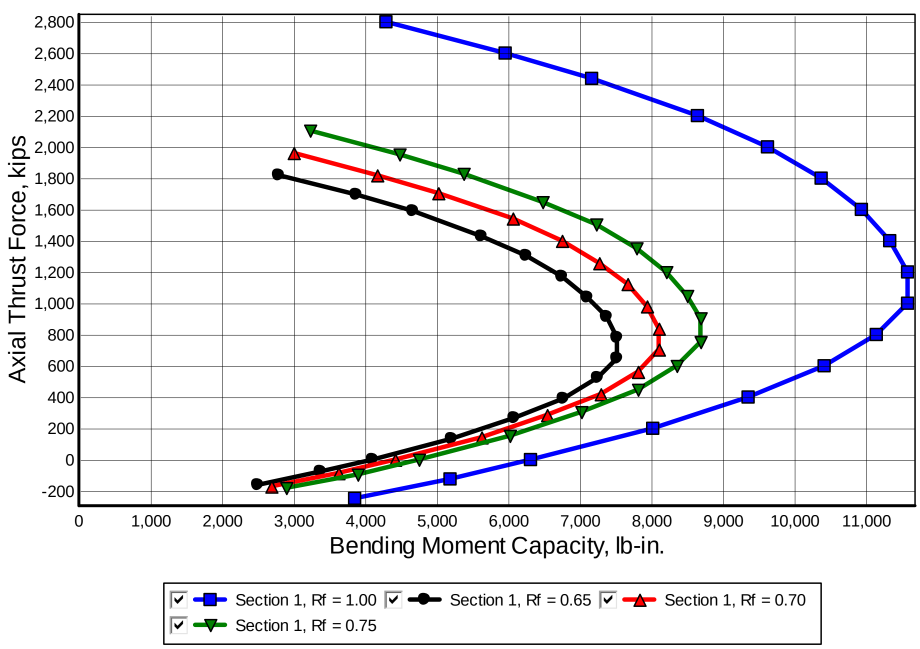

Figure 6-24 Factored Interaction Diagram of Reinforced-concrete Pile, Example 5

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 6-25 and versus forces in Figure 6-26.

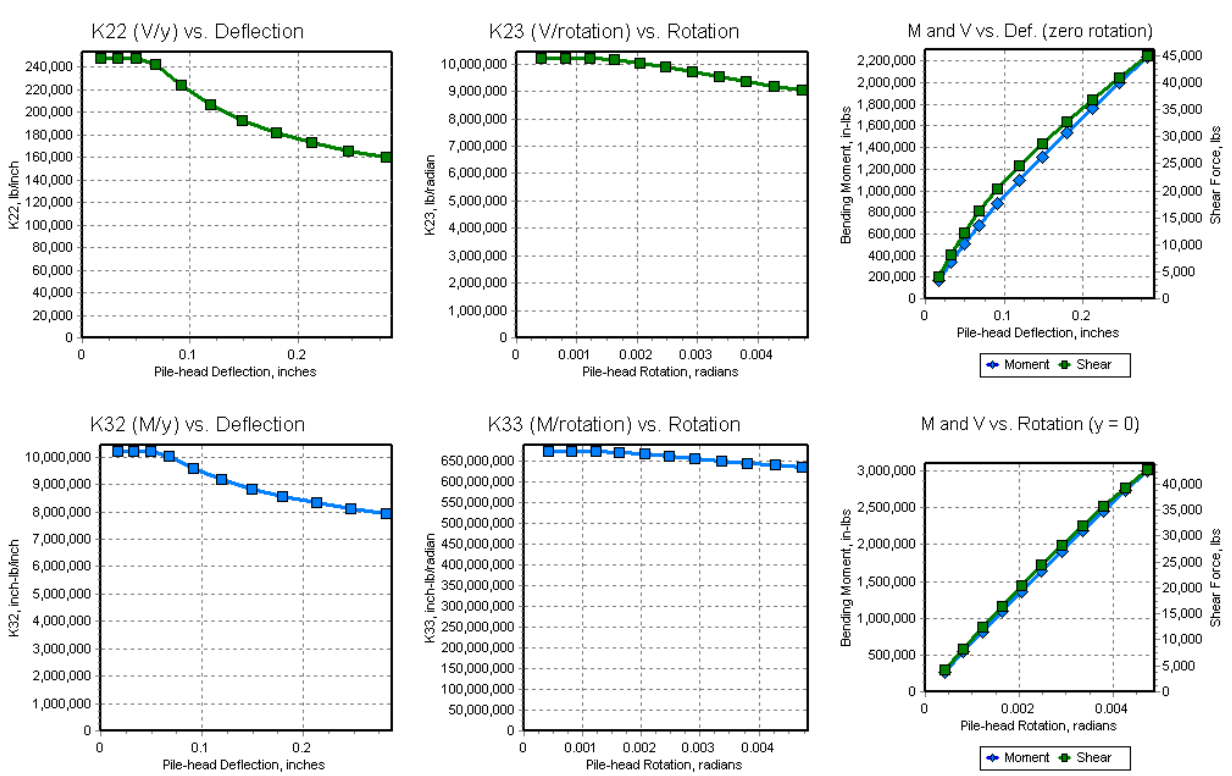

Figure 6-25 Stiffness Matrix Components versus Displacement and Rotation, Example 6

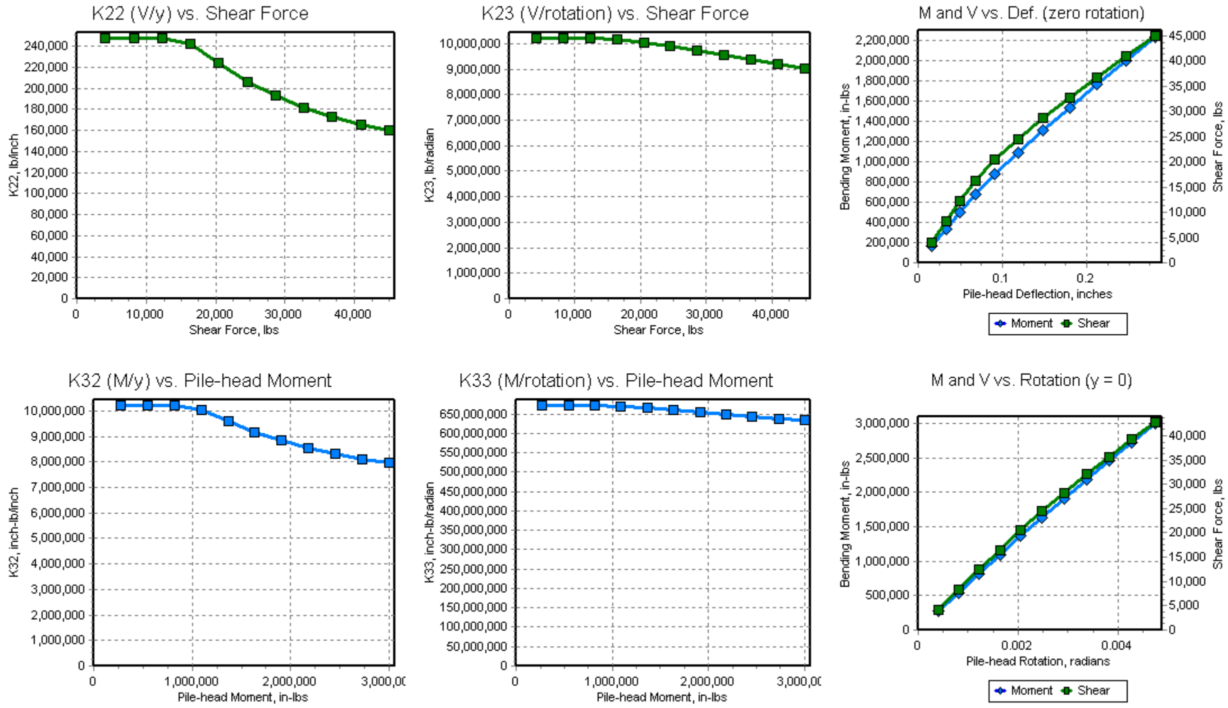

Figure 6-26 Stiffness Matrix Components versus Force and Moment, Example 6

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 6-27 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 6-28 will be entered for this problem. The program interpolates linearly between points on a *p-y* curve and between depths of *p-y* curves.

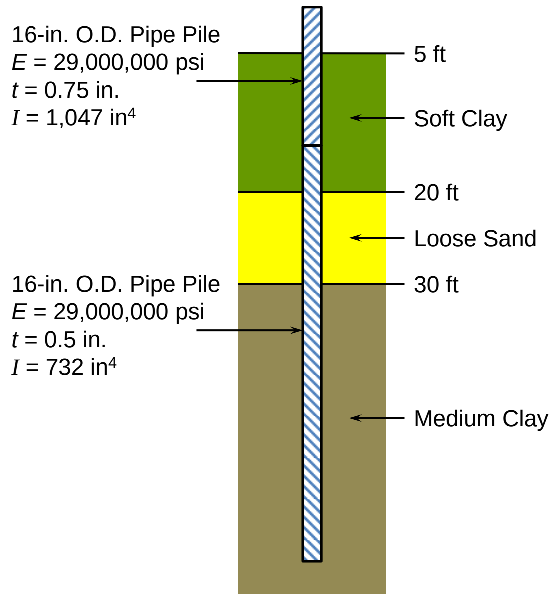

Figure 6-27 Pile and soil details for Example 7

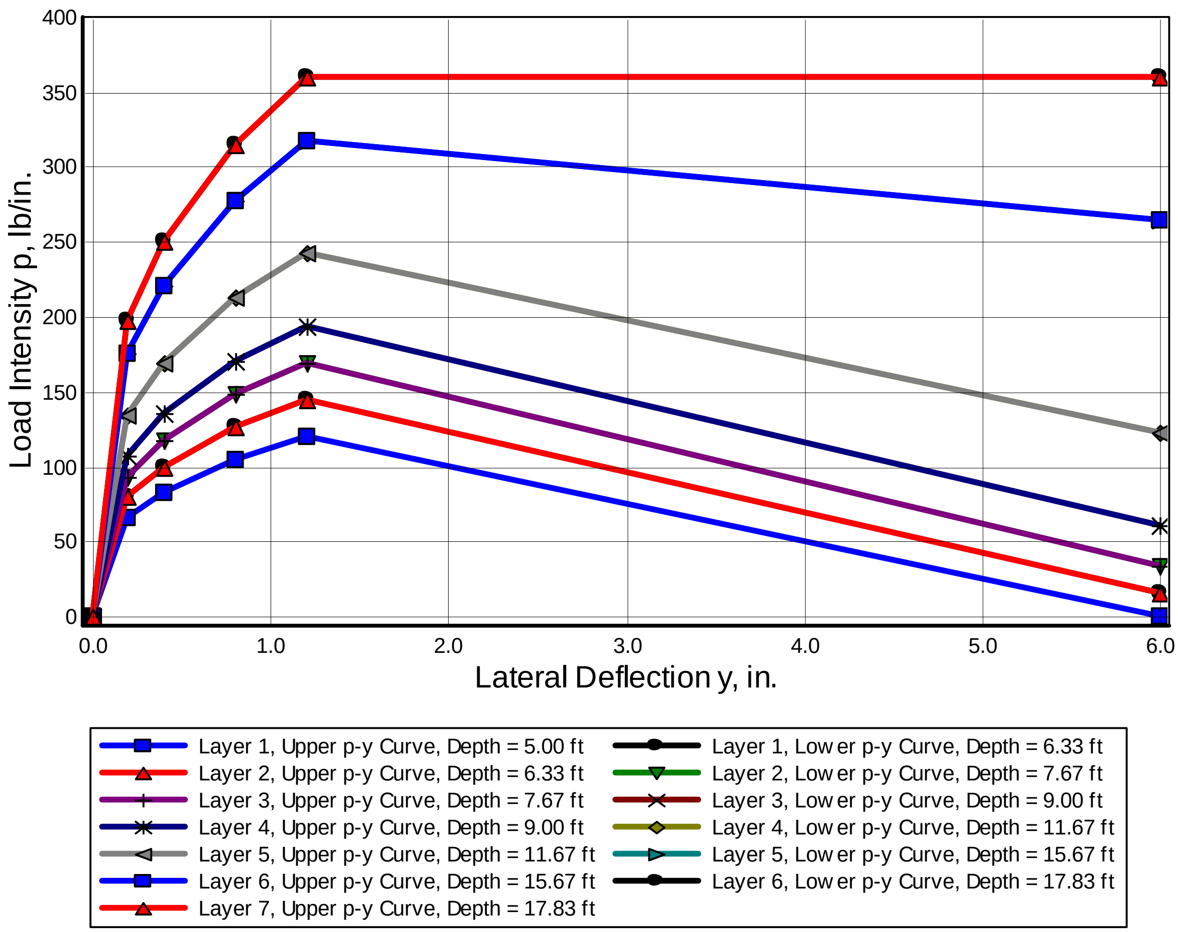

Figure 6-28 User-input *p-y* Curves for Example 7 (Lower curve for Layer 7 not shown)

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 Young's modulus for concrete was measured during a cylinder test and a representative value of 3,200 psi (22 MPa) was selected. 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 6-29. 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.

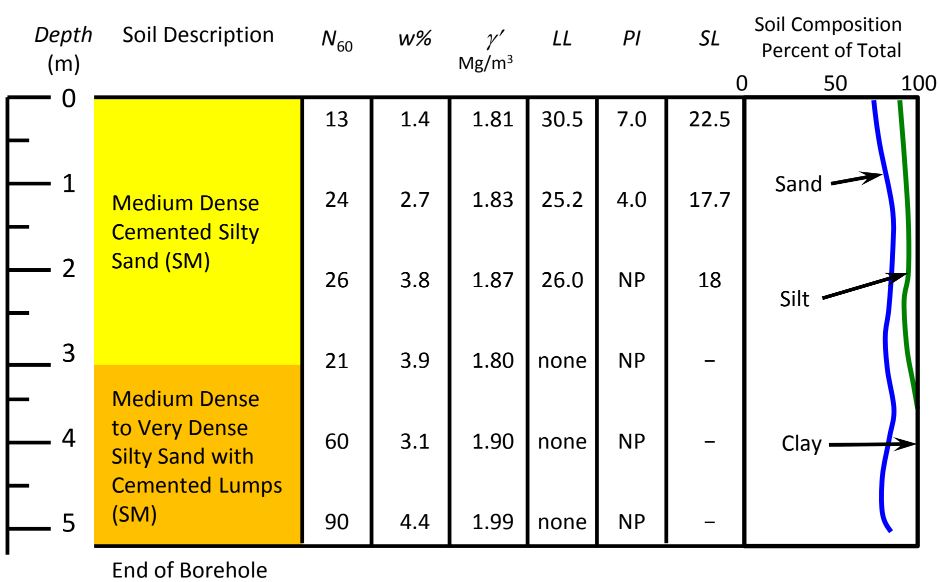

Figure 6-29 Soil details for Example 8

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 6-30. A comparison between measured and predicted behavior for bending moment versus depth is shown in Figure 6-31.

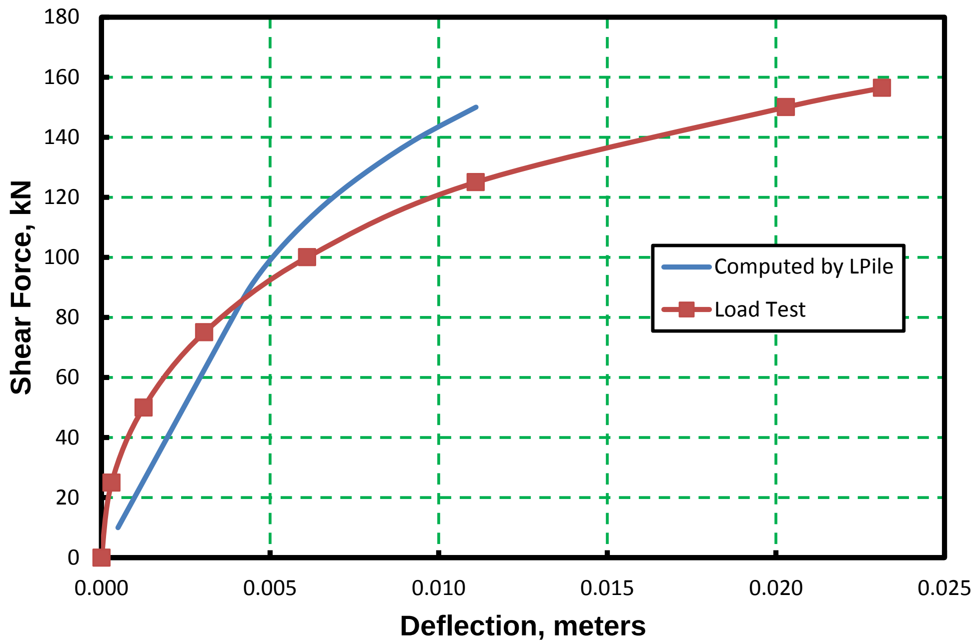

Figure 6-30 Comparison between Measured and Predicted Pile-head Load versus Deflection Curves for the 5-m Pile of Example 8

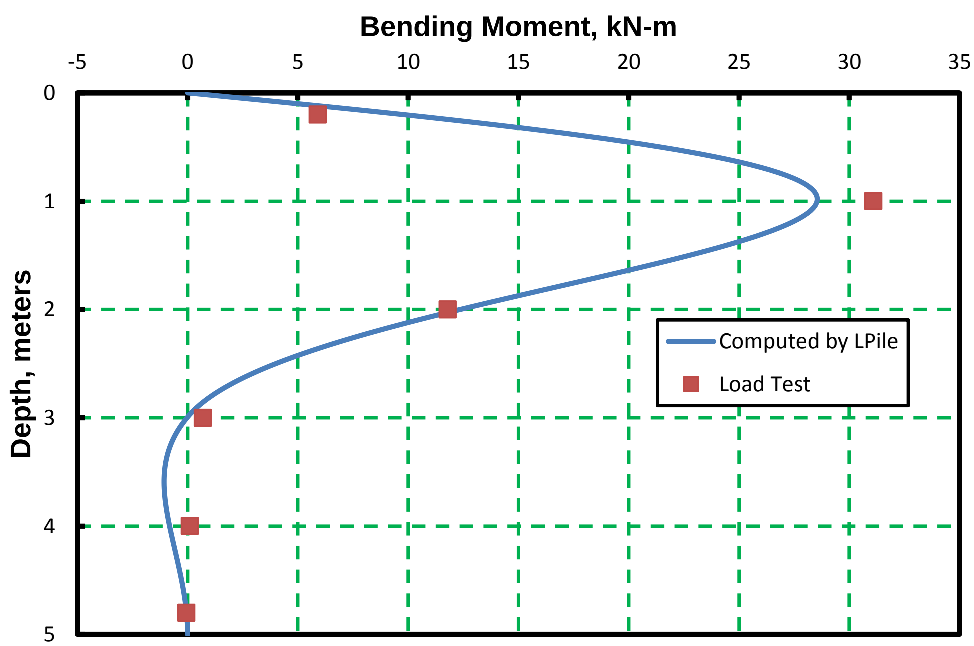

Figure 6-31 Comparison between Measured and Computed Bending Moment versus Depth for the 5-m Pile of Example 8

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 6-32.

The soil stratigraphy is composed of three different layers of sand, soft clay, and stiff clay. The soil properties are also shown in Figure 6-32. In addition, there is a water-bearing sand layer at a depth of 60 feet not shown in the figure.

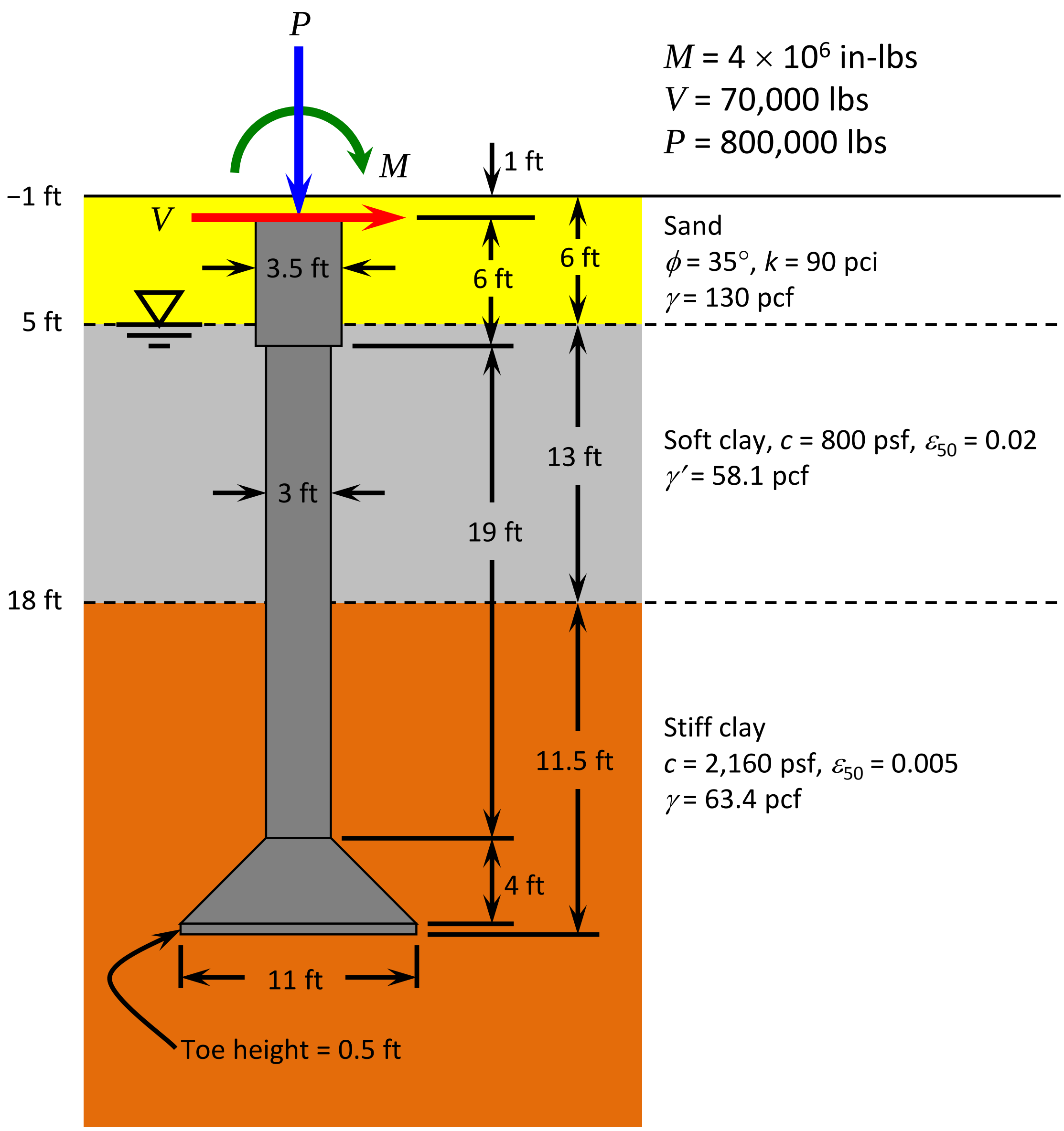

Figure 6-32 Shaft Geometry and Soil Properties for Example 9

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 6-33. 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 6-34.

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 6-35 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.

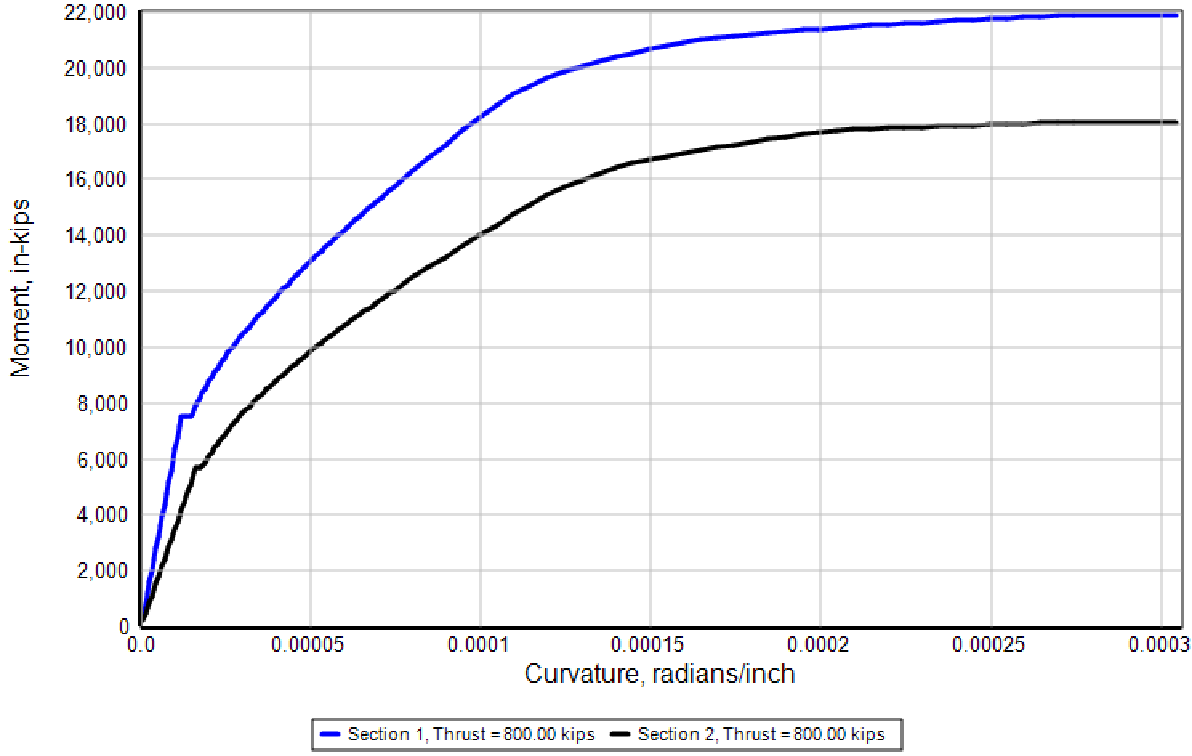

Figure 6-33 Moment versus Curvature for Sections 1 and 2, Example 9

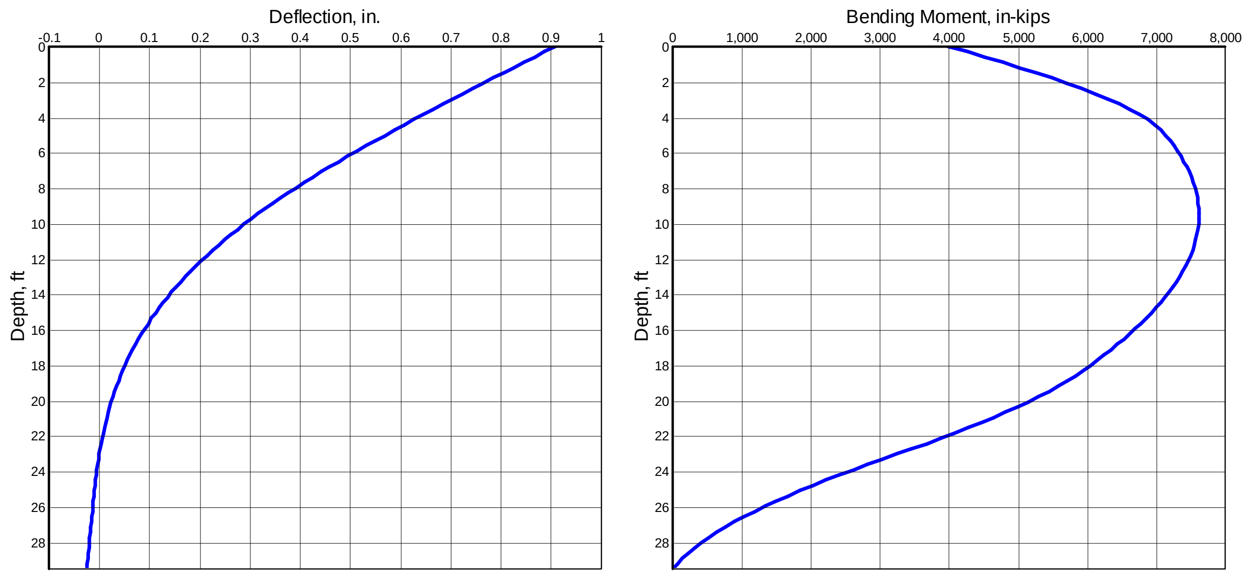

Figure 6-34 Lateral Deflection and Bending Moment versus Depth, Example 9

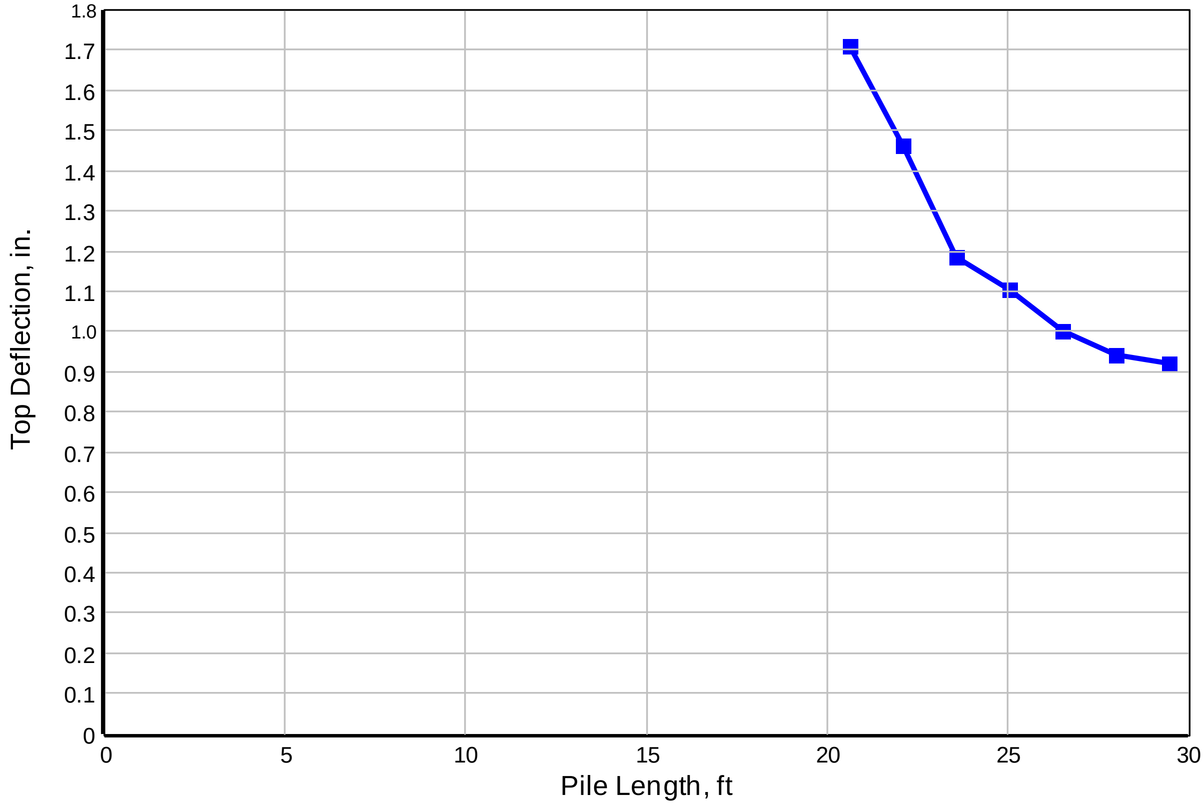

Figure 6-35 Top Deflection versus Pile Length, Example 9

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 6-36. 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.

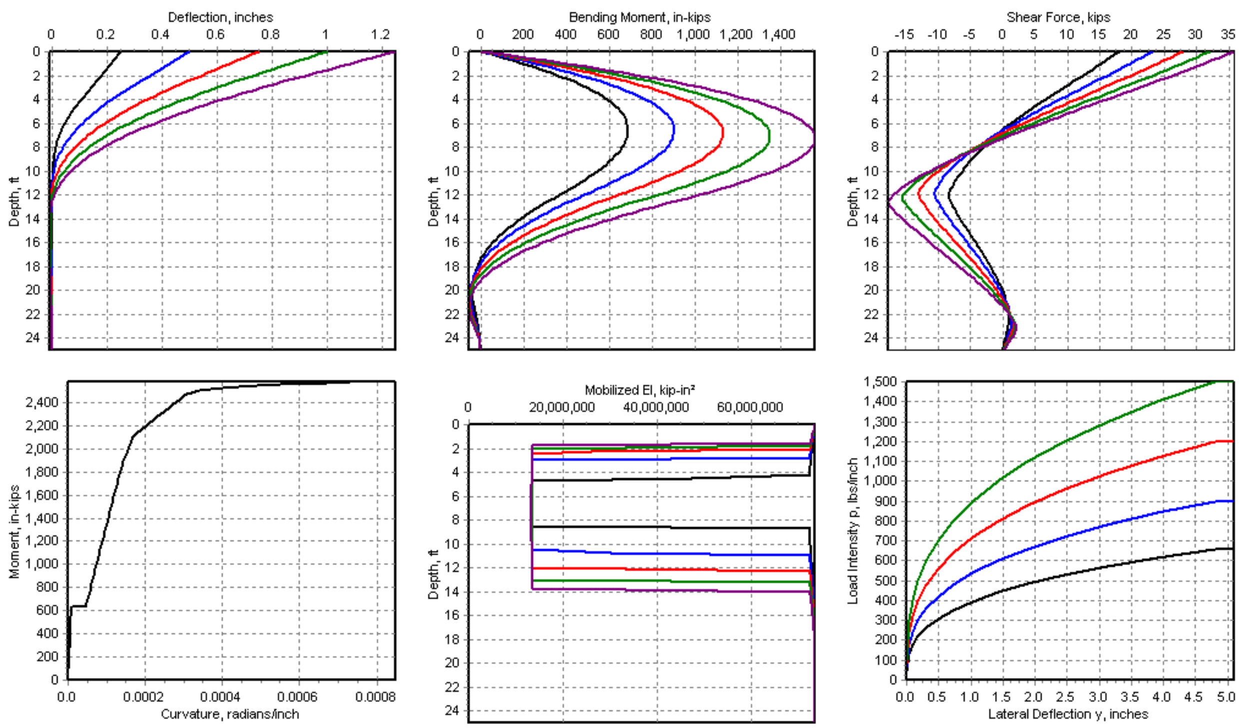

Figure 6-36 Summary Plots of Results for Example 10

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 3-14.

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 6-37.

```
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 6-37 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 6-38.

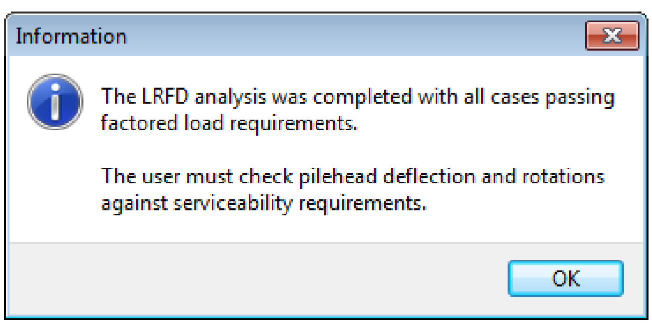

Figure 6-38 Message for Successful LRFD Analysis for Example 11

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 6-39 and the lateral spread profile versus depth is shown in Figure 6-40.

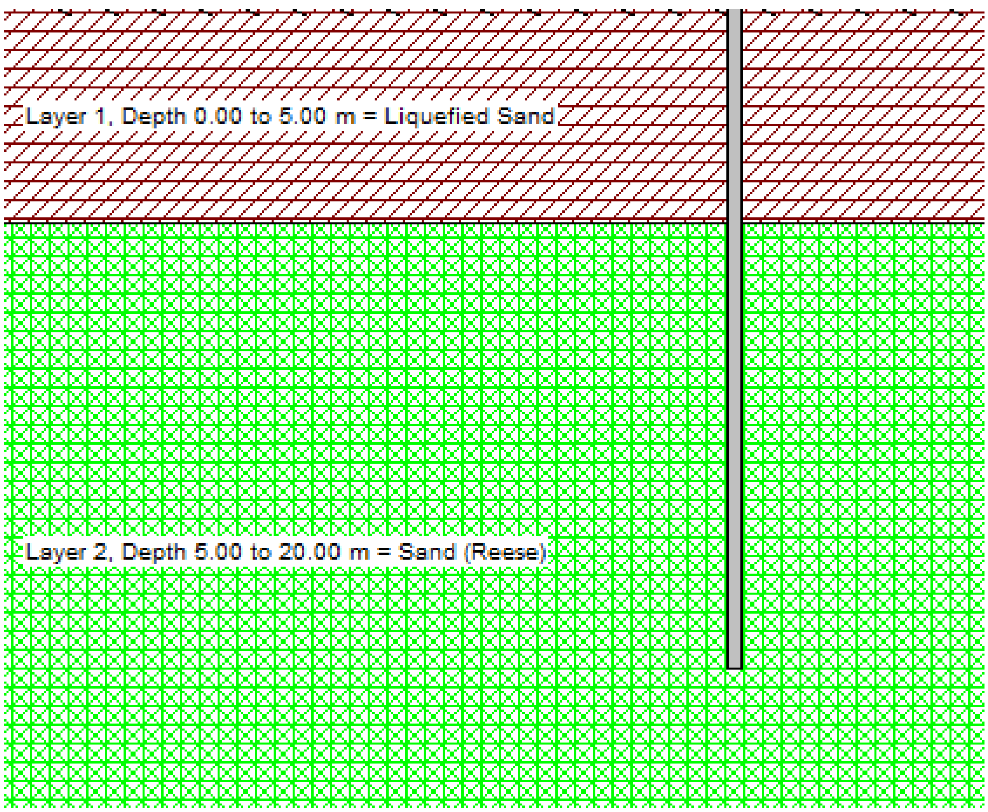

Figure 6-39 Pile and Soil Profile for Example 12

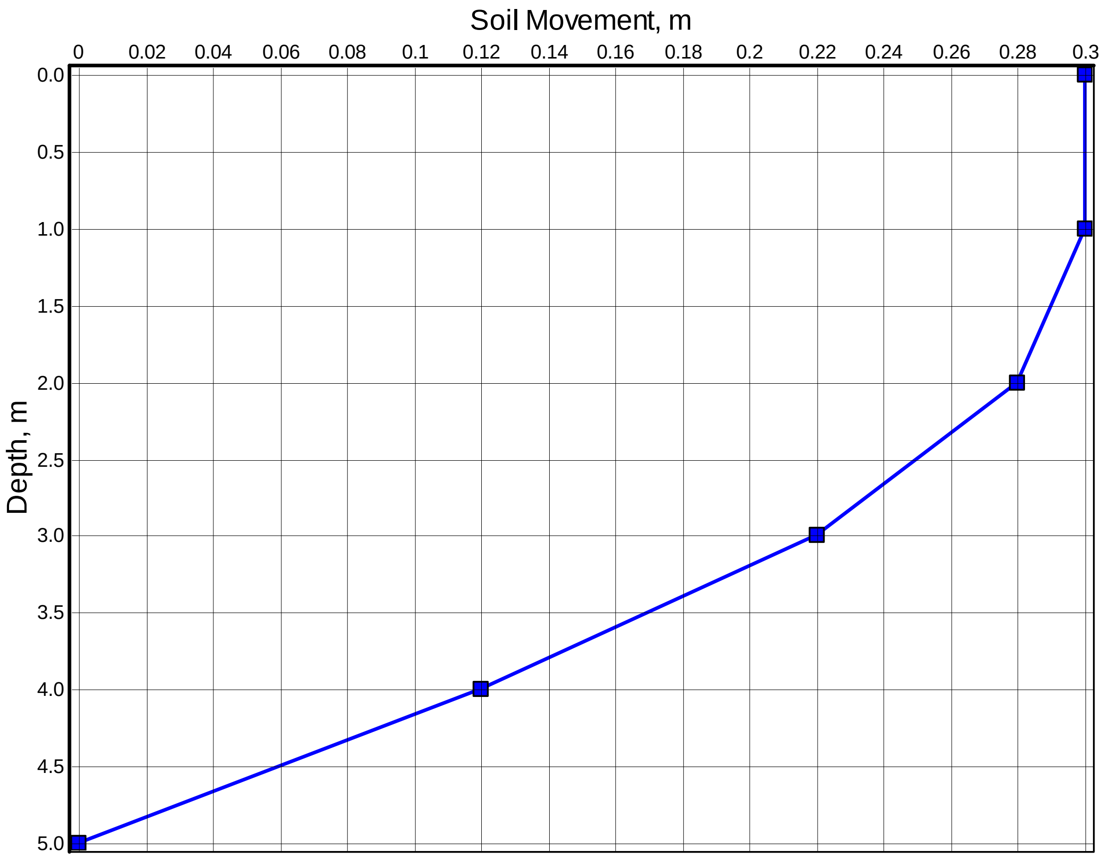

Figure 6-40 Lateral Spread Profile versus Depth for Example 12

The summary graphs of the analysis are shown in Figure 6-41. 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.

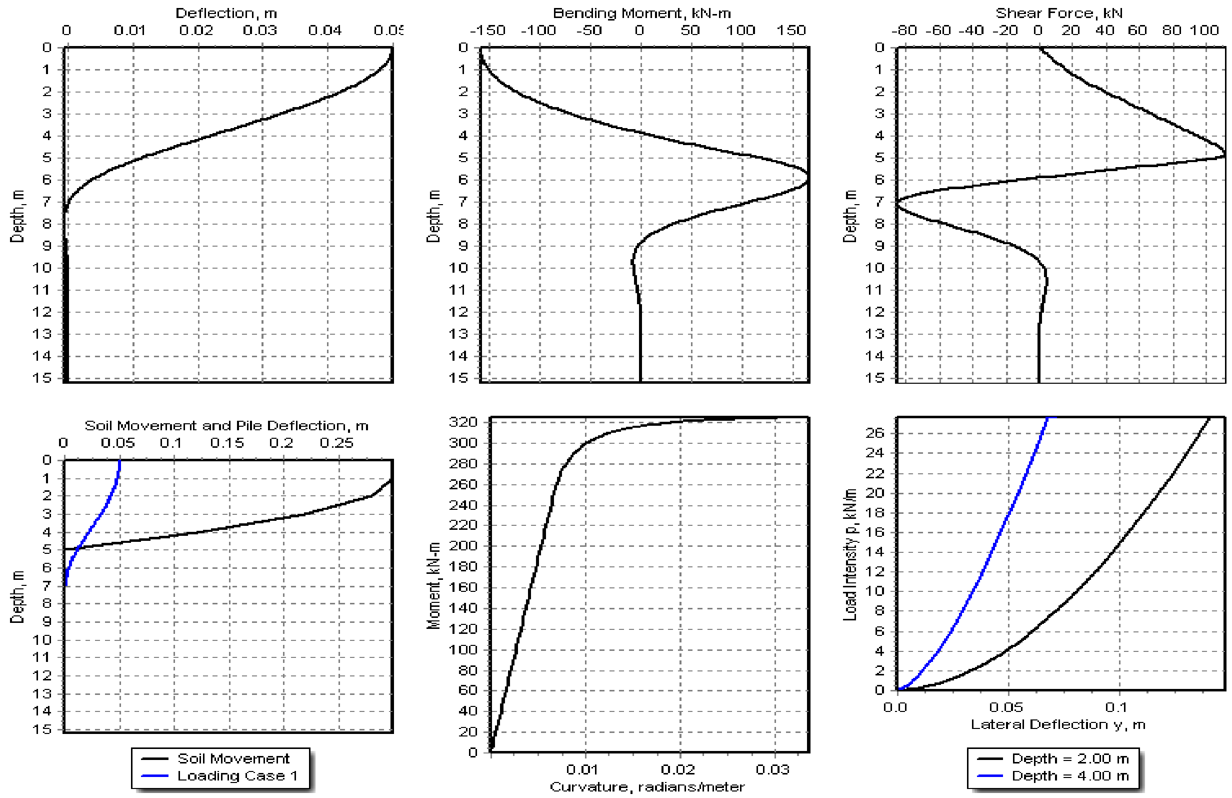

Figure 6-41 Summary Graphs for Example 12

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 6-42.

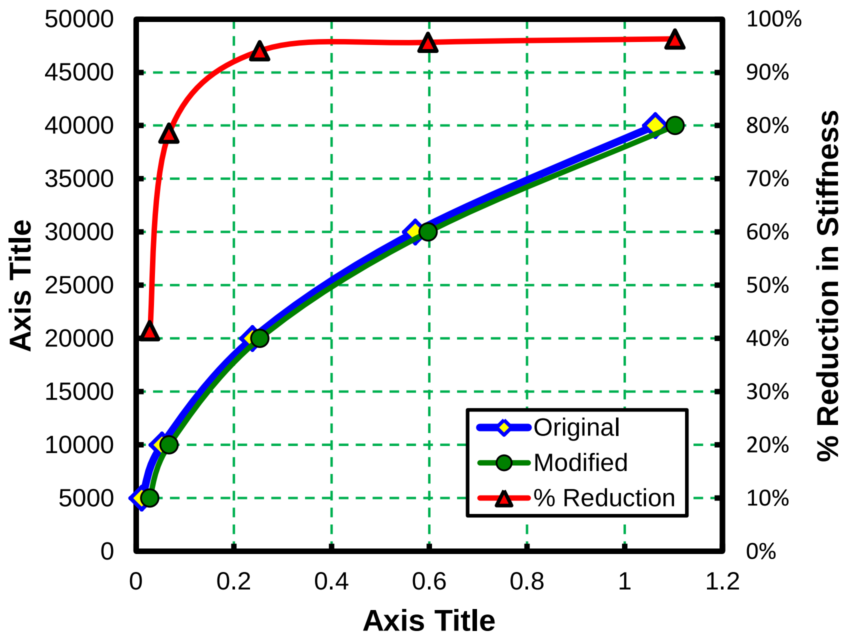

Figure 6-42 Pile-head Load versus Deflection Curves Using Original and Modified *p-y* Curves for Stiff Clay without Free Water and Percentage Reduction in Stiffness for Example 13

The curves of pile top deflection versus pile length are shown in Figure 6-43.

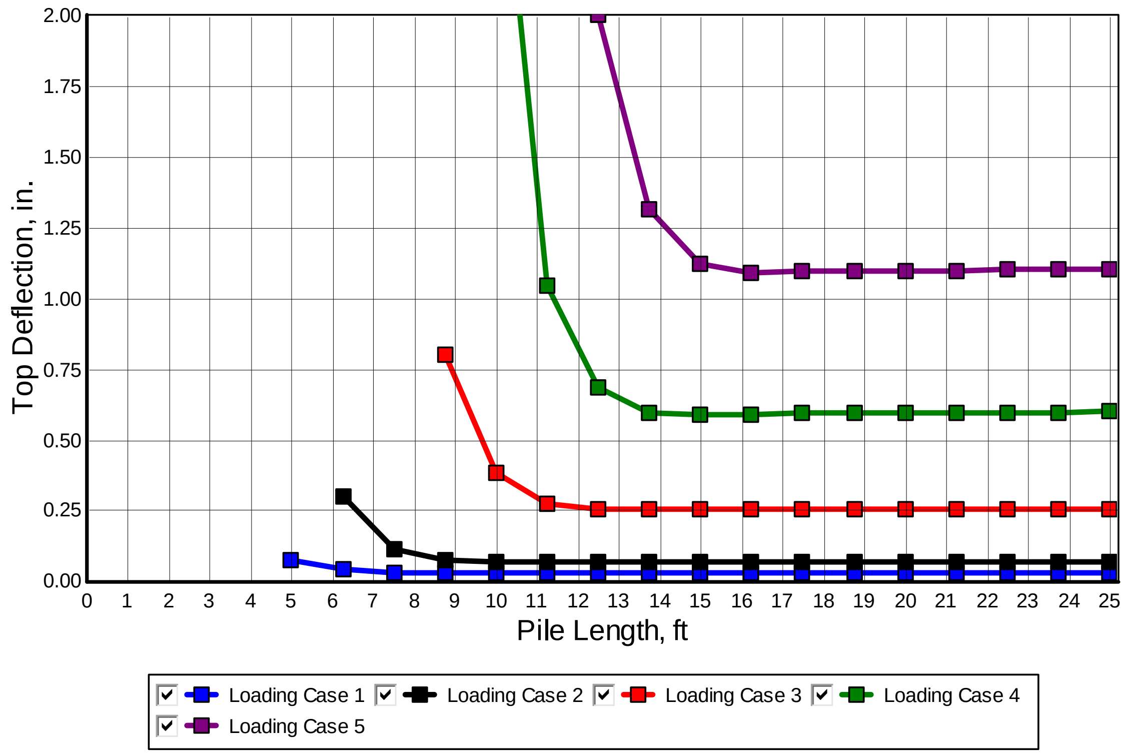

Figure 6-43 Curves of Pile Top Deflection versus Pile Length for Example 13

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 6-44.

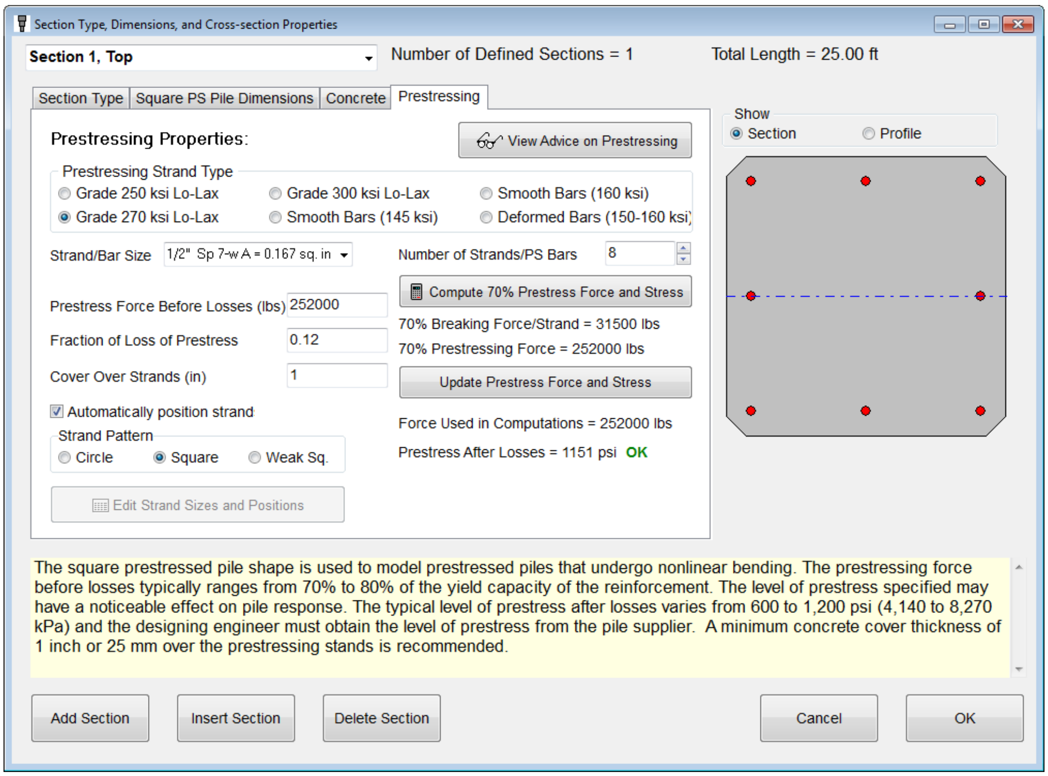

Figure 6-44 Reinforcement Details for Prestressed Concrete Pile of Example 14

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 6-45 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.

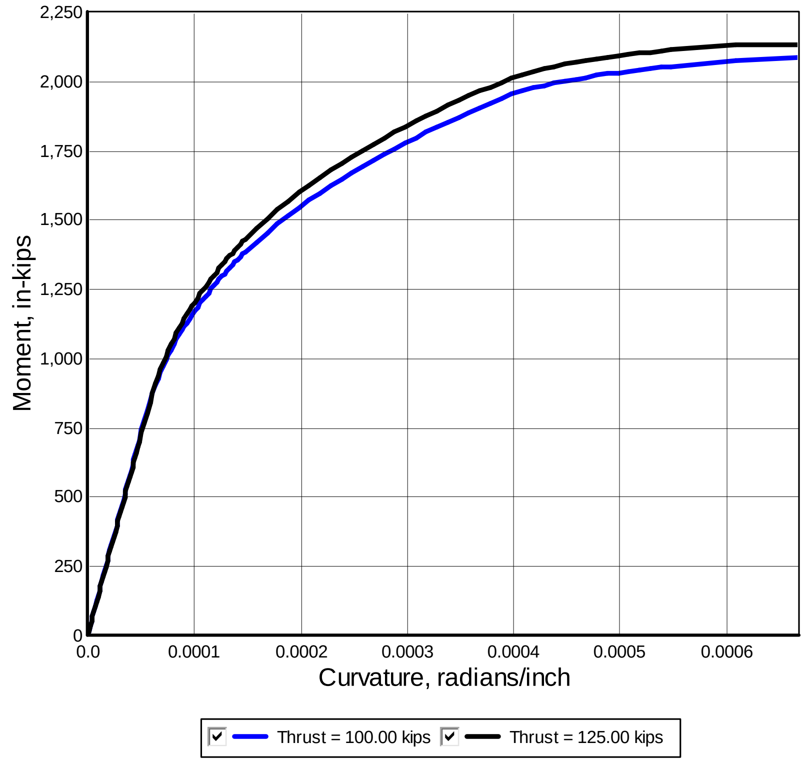

Figure 6-45 Moment versus Curvature of Prestressed Pile for Example 14

The results of the pushover analysis are shown in the two graphs of Figure 6-46. These graphs shown the results for both fixed-head and free-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 2.75 inches and a shear load of 56,300 lbs. Other information gained from these graphs is maximum lateral capacity is approximately 85,000 lbs for fixed-head conditions and is 58,400 lbs for free-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.

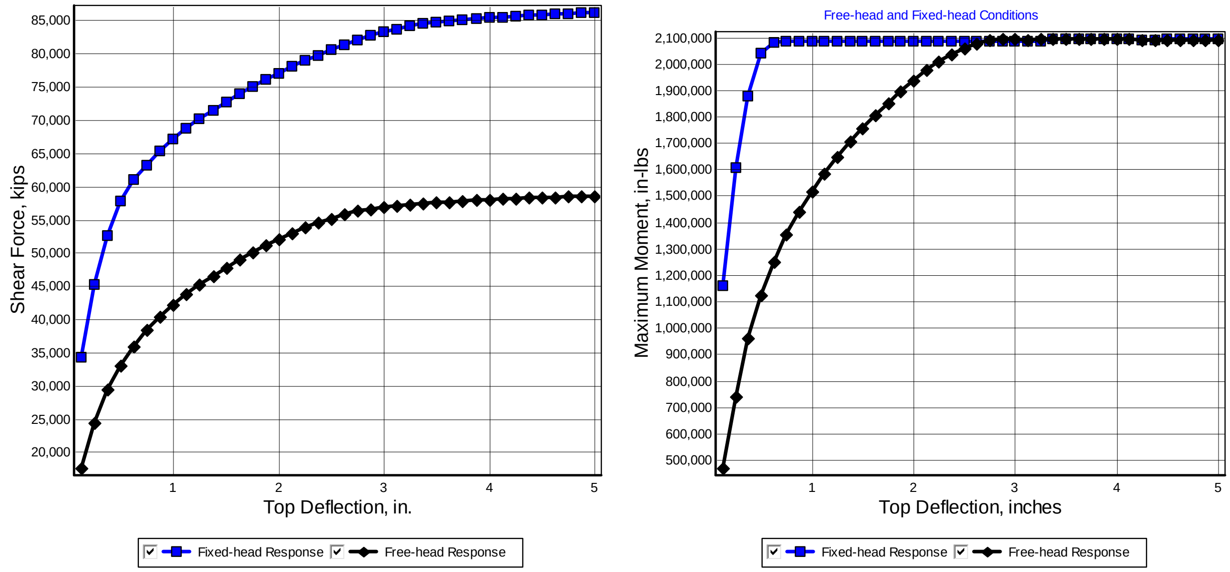

Figure 6-46 Results of Pushover Analysis of Prestressed Concrete Pile of Example 14

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 6-47. 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.

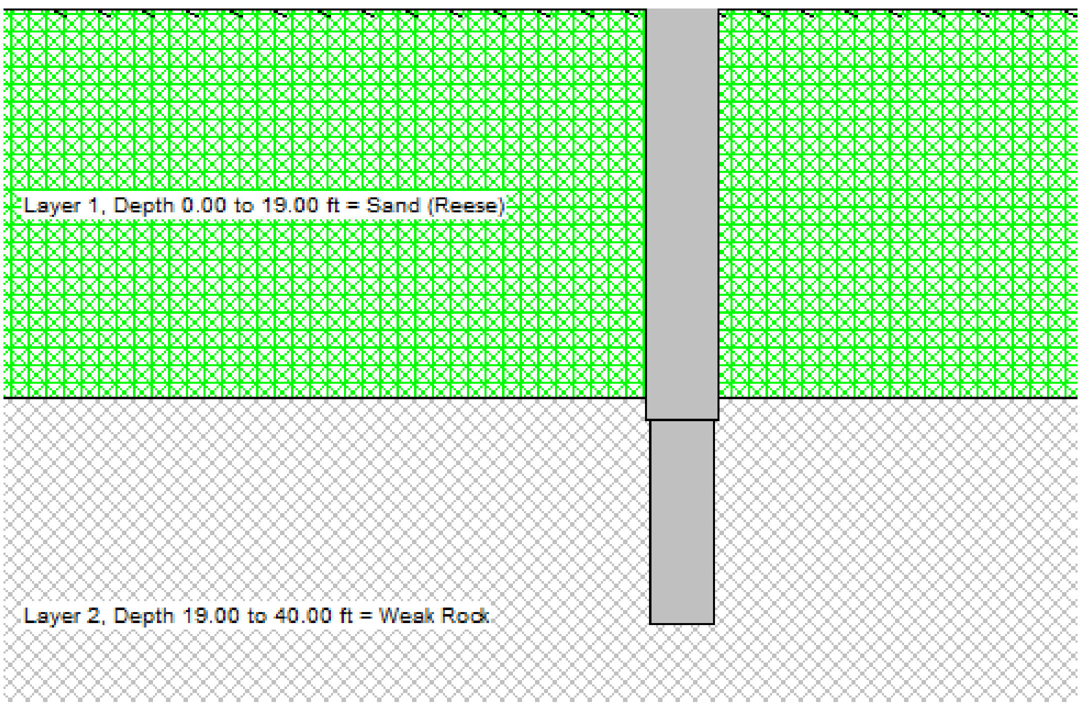

Figure 6-47 Pile and Soil Profile for Example 17

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 6-48. 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.

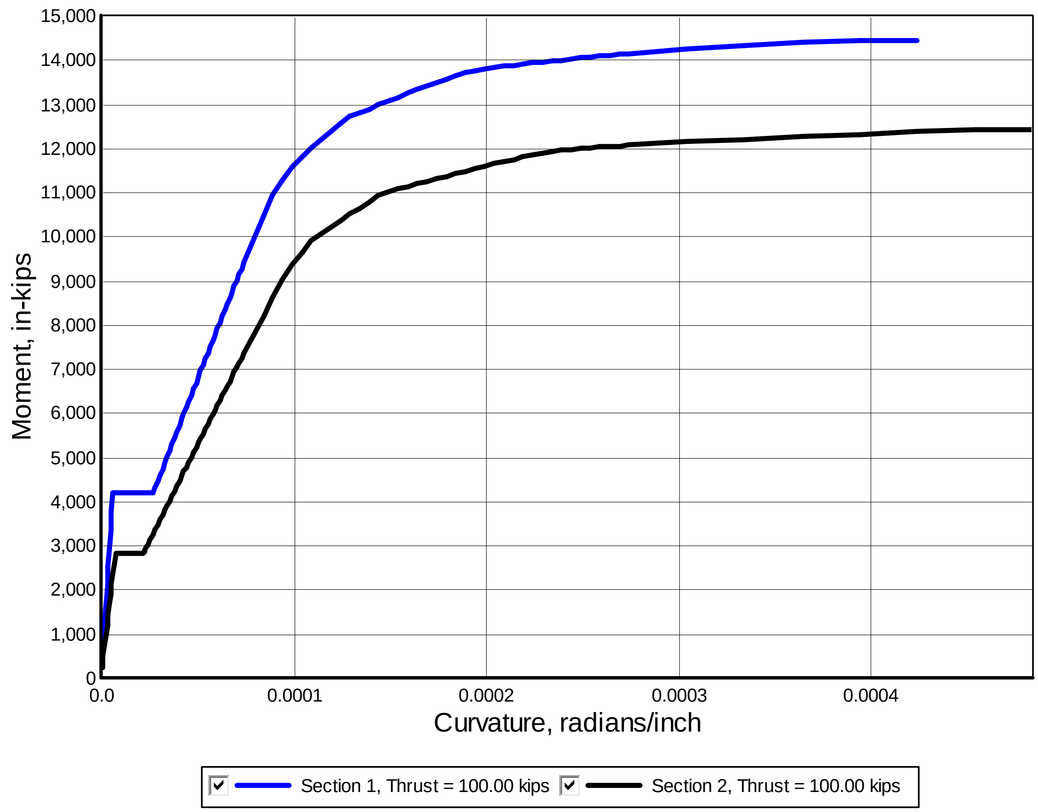

Figure 6-48 Moment versus Curvature for Dual Section Drilled Shaft of Example 17

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 6-49.

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 6-50.

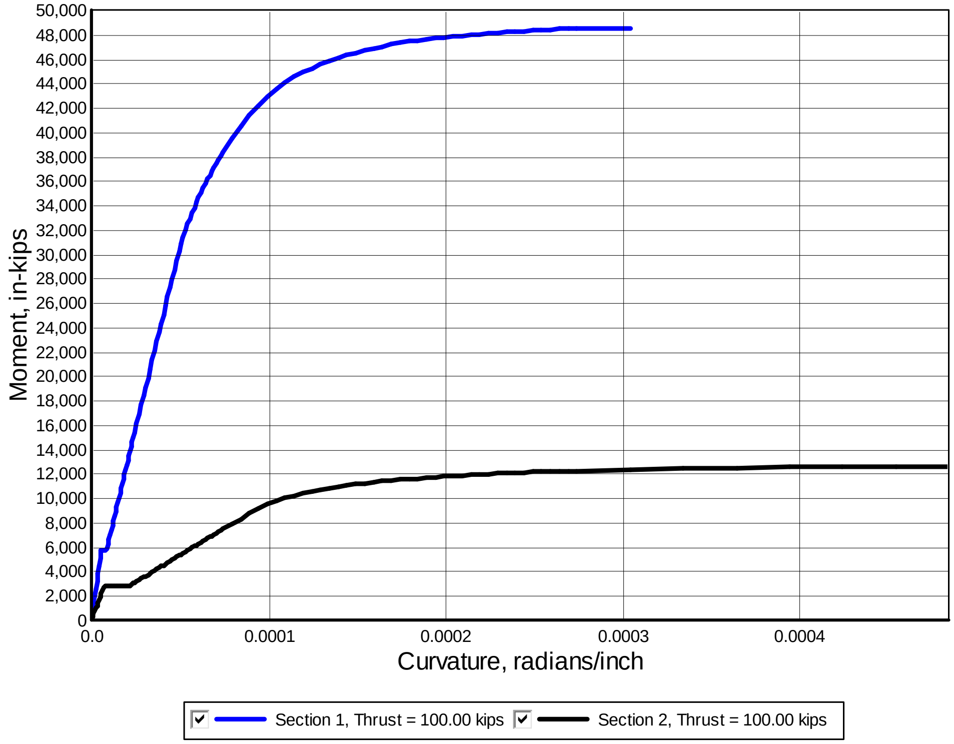

Figure 6-49 Moment versus Curvature for Dual Section Drilled Shaft with Permanent Casing of Example 18

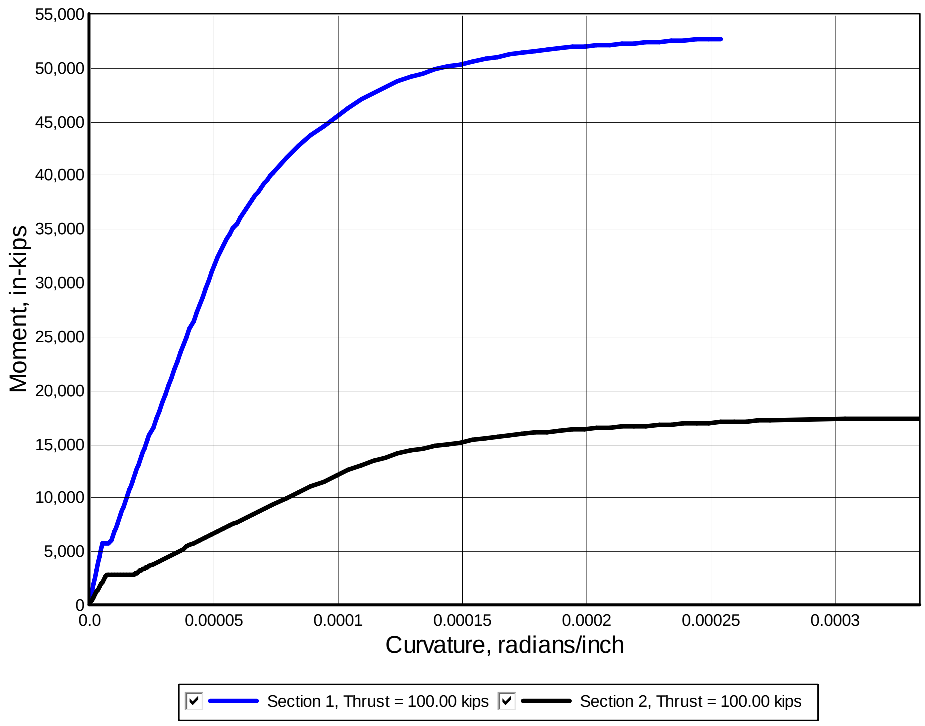

Figure 6-50 Moment versus Curvature for Dual Section Drilled Shaft with Permanent Casing and Core of Example 19

6-20 Example 20 – Analysis of Embedded Pole

This example is provided as an example of the embedded pole option. Embedded poles are commonly used in the electrical utility industry. The typical utility pole in the United States is embedded to a depth of 10 percent of the overall pole length, plus 2 feet. Thus, the embedded pole of Example 20 has an overall length of 40 feet and an embedment of 6 feet. The pile and soil profile for this example is shown in Figure 6-51.

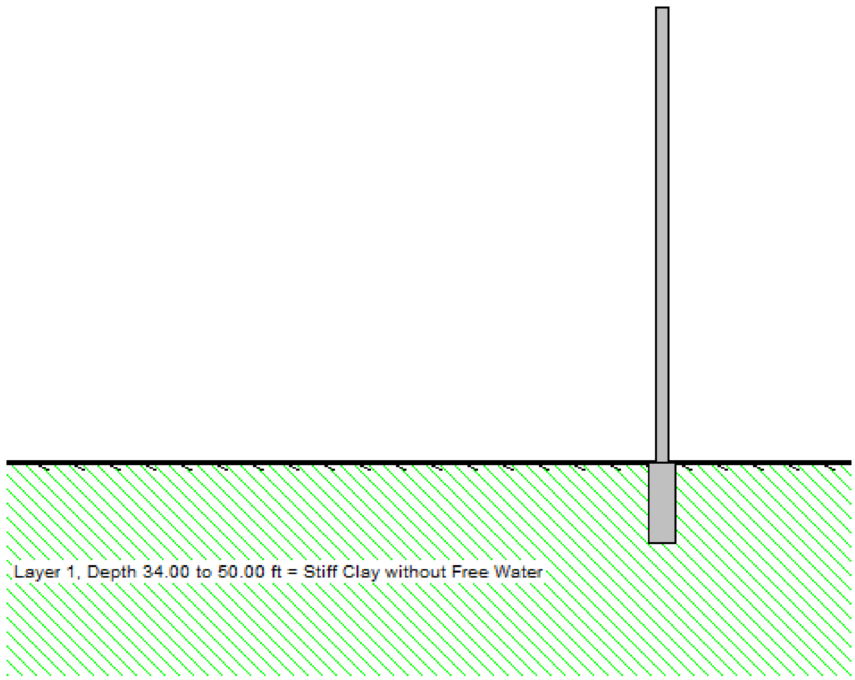

Figure 6-51 Pile and Soil Profile for Embedded Pole of Example 20

The output computed using LPile for this problem is conservative because there are load-transfer mechanisms between the foundation and soil that not included in the LPile analysis. These mechanisms are any vertical shear stresses developed along the sides of the pile and any shear that might develop at the tip of the pole.

In practice, the computation of these additional load-transfer mechanisms present some difficulties because of uncertainties related to how the poles are constructed. In some applications, an oversize hole is drilled, the pole is inserted on one side of the hole, and backfill is compacted in the open void on one side of the pole. In other applications, the pole is placed in the center of an oversized hole and a cemented-stabilized, flowable fill is placed in the annular space around the pole.

The loading on the pole is representative of a 100-mph wind loading on the pile and transformer mounted on top of the pole (the transformer is not shown in the above figure). The wind load is equivalent to a uniform pressure of 40 psf acting over the projected area of the pole and transformer. The weight of the transformer is in pile-head loading for the pole. The computed pile-head deflection is 3.14 inches and the ground line deflection is 0.0127 inches.

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.

Table 6-1 Dimensions, Cross-sectional Area, and Bending Stiffness of Tapered Pile

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}

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 value shown for a depth of 5 feet, where the difference is due to the limited output precision of LPile. The internal value computed by LPile is identical.

Table 6-2 Interpolated Dimensional Properties, Cross-sectional Area, Moment of Inertia, Bending Moment of Tapered Pile Computed by LPile

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	9101.64
5	15	7.5	22.777	599.308	1,004,361	13886.16	13886.00
10	14	7.0	21.206	483.756	341,233	6352.39	6352.39
15	13	6.5	19.635	384.109	-28,547	2010.97	2010.97
20	12	6.0	18.064	299.188	-12,814	1917.72	1917.72
25	11	5.5	16.493	227.815	1,395	1852.60	1852.60
30	10	5.0	14.923	168.812	0	2010.38	2010.38

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 6-52.

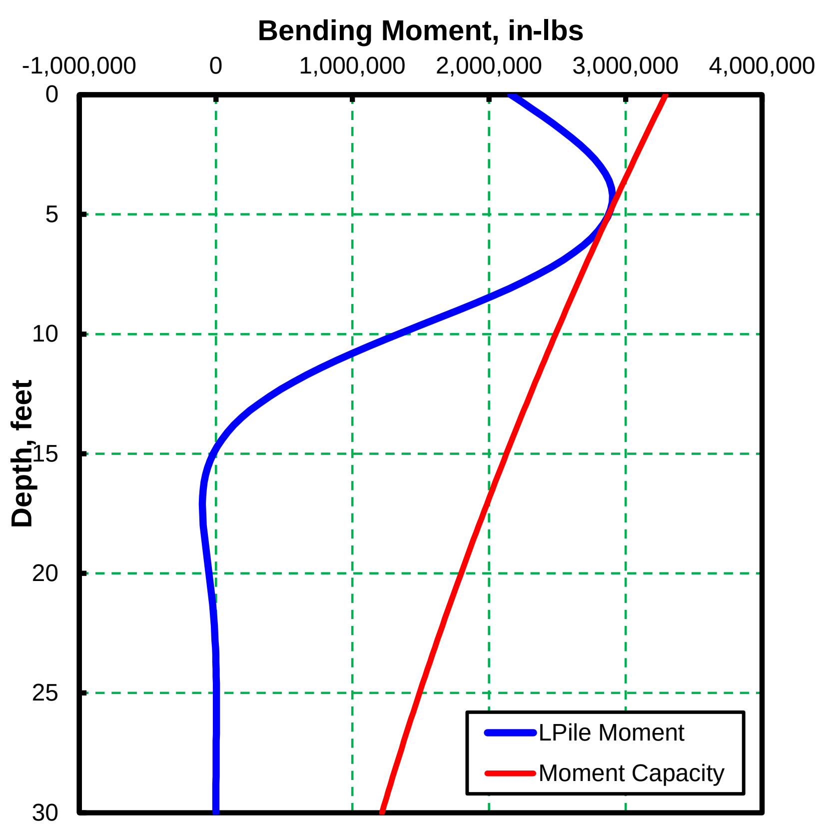

Figure 6-52 Bending Moment and Plastic Moment Capacity versus Depth for Example 22

A close examination of Figure 6-52 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 6-53.

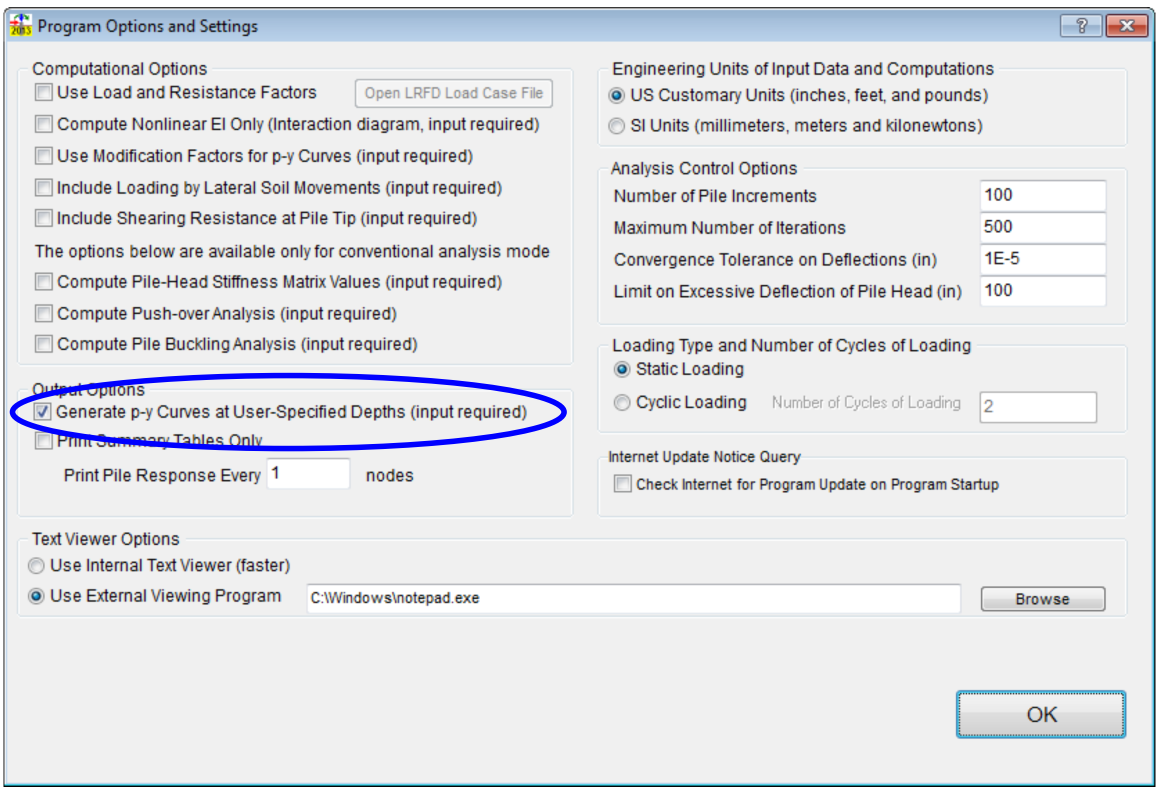

Figure 6-53 Program and Setting Dialog Showing Check for Generation of *p-y* Curves

The pile and soil profile for Example 23 is shown in Figure 6-54. 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 6-55.

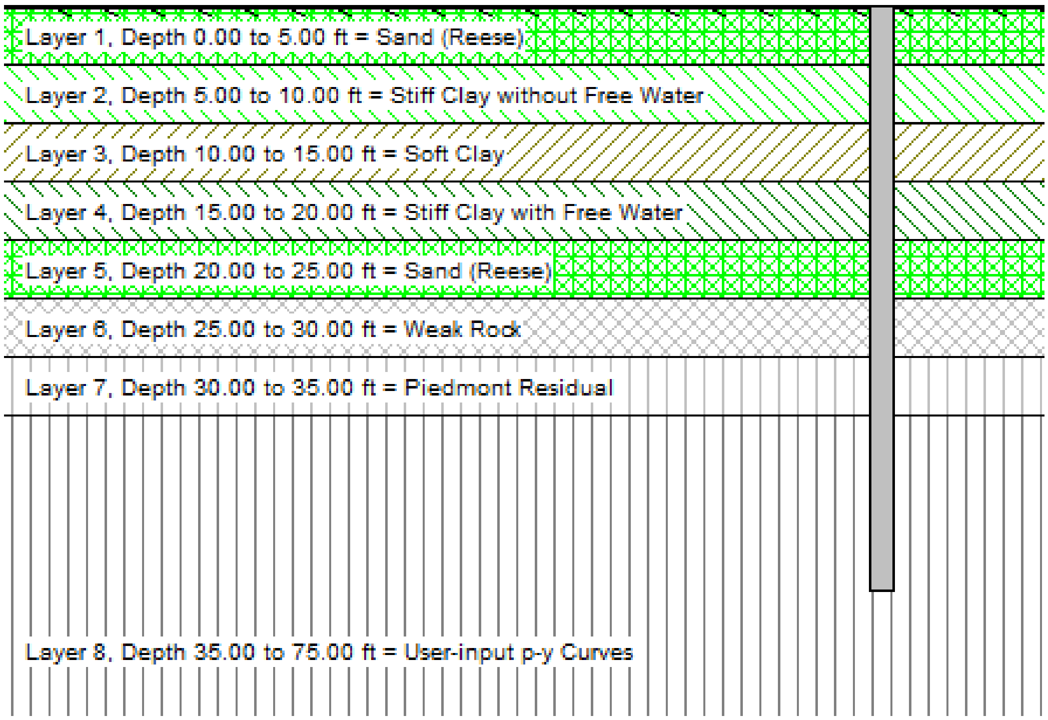

Figure 6-54 Pile and Soil Profile for Example 23

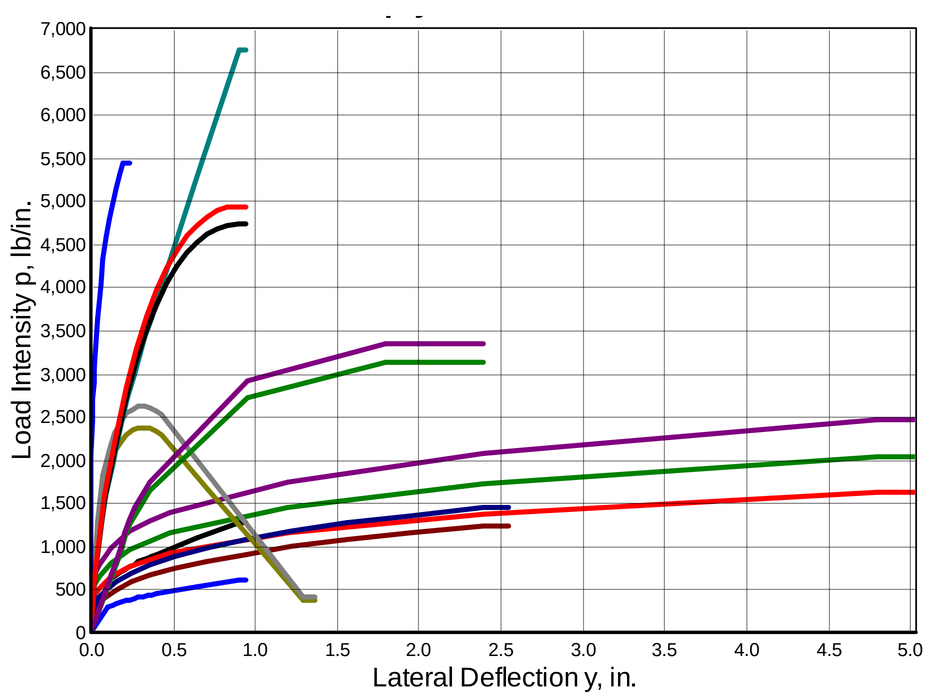

Figure 6-55 Standard Output of 17-point *p-y* Curves for Example 23

Figure 6-56 is the same as Figure 6-55 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 6-56 are composed of 17 points and the curves are interpolated with depth at 40 and 49 feet below the pile head.

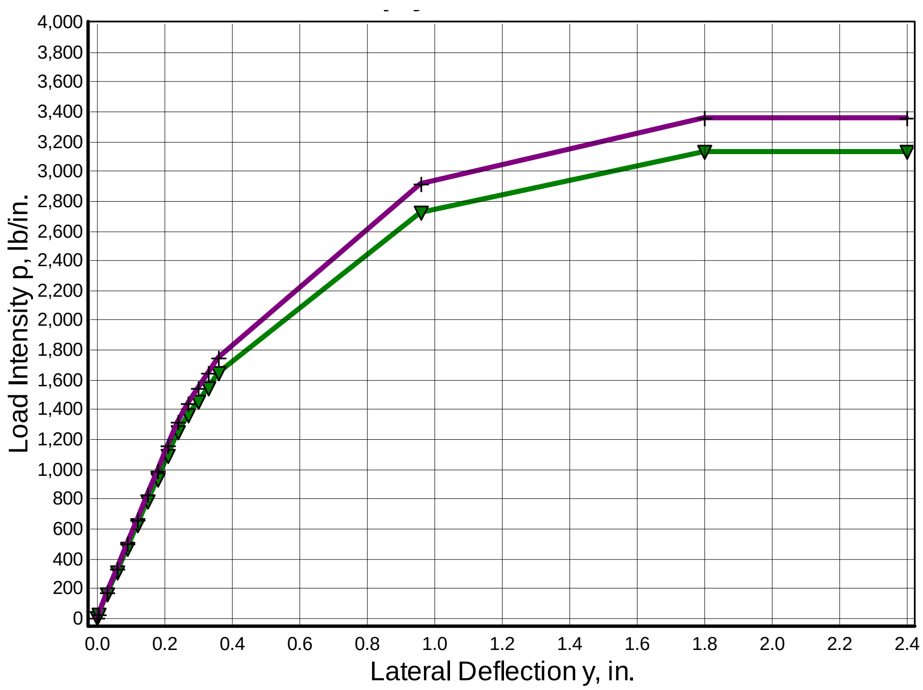

Figure 6-56 User-input *p-y* Curves Interpolated with Depth Using 17 Points for Example 23

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 6-57.

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.

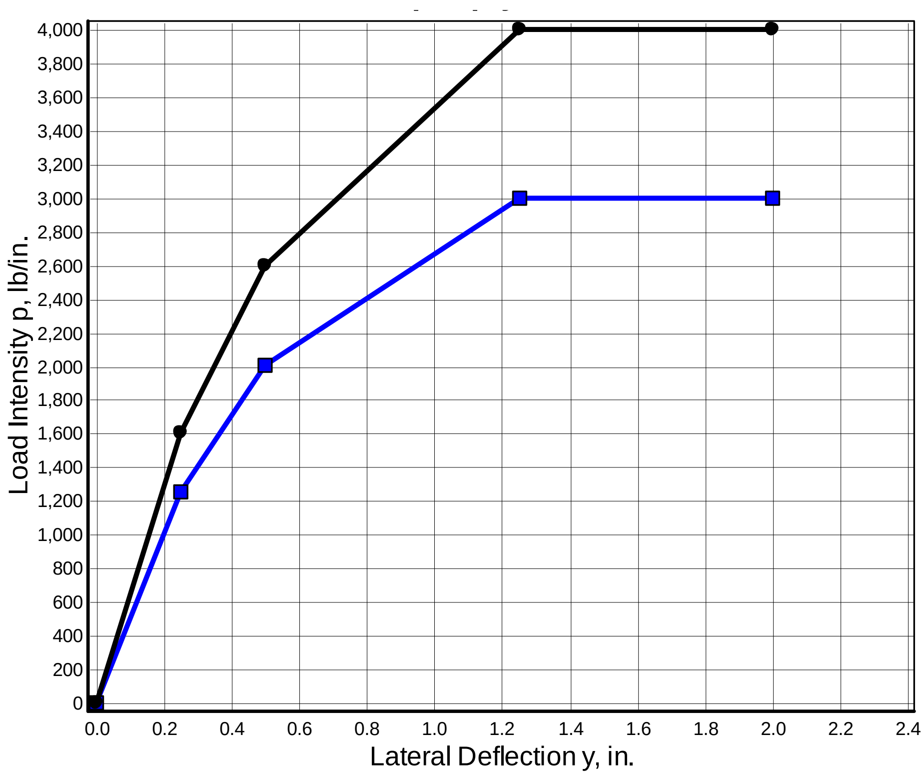

Figure 6-57 Output of User-input *p-y* Curves with Five Points for Example 23

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 6-58. 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 6-59. 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 6-60.

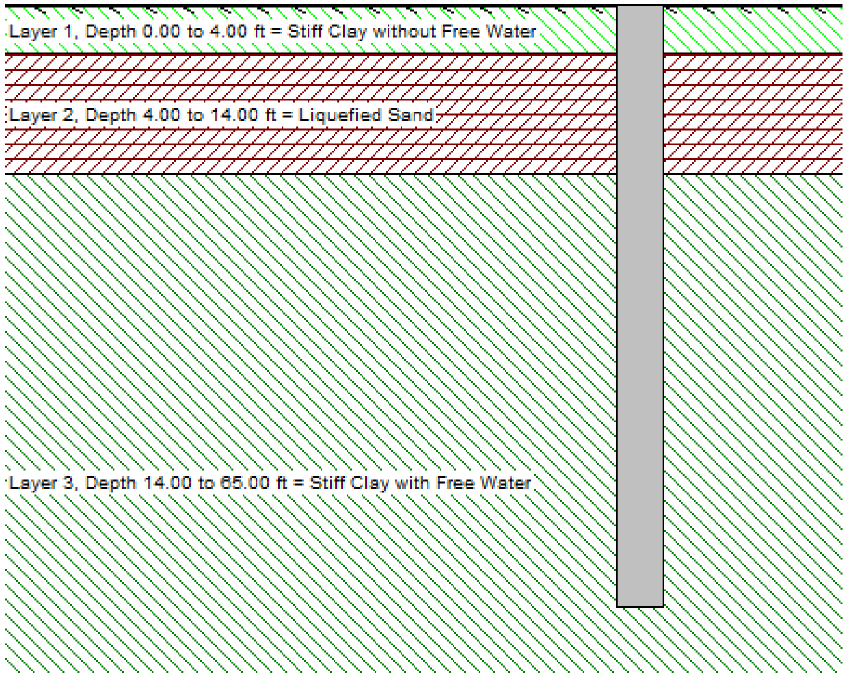

Figure 6-58 Pile and Soil Profile for Example 24

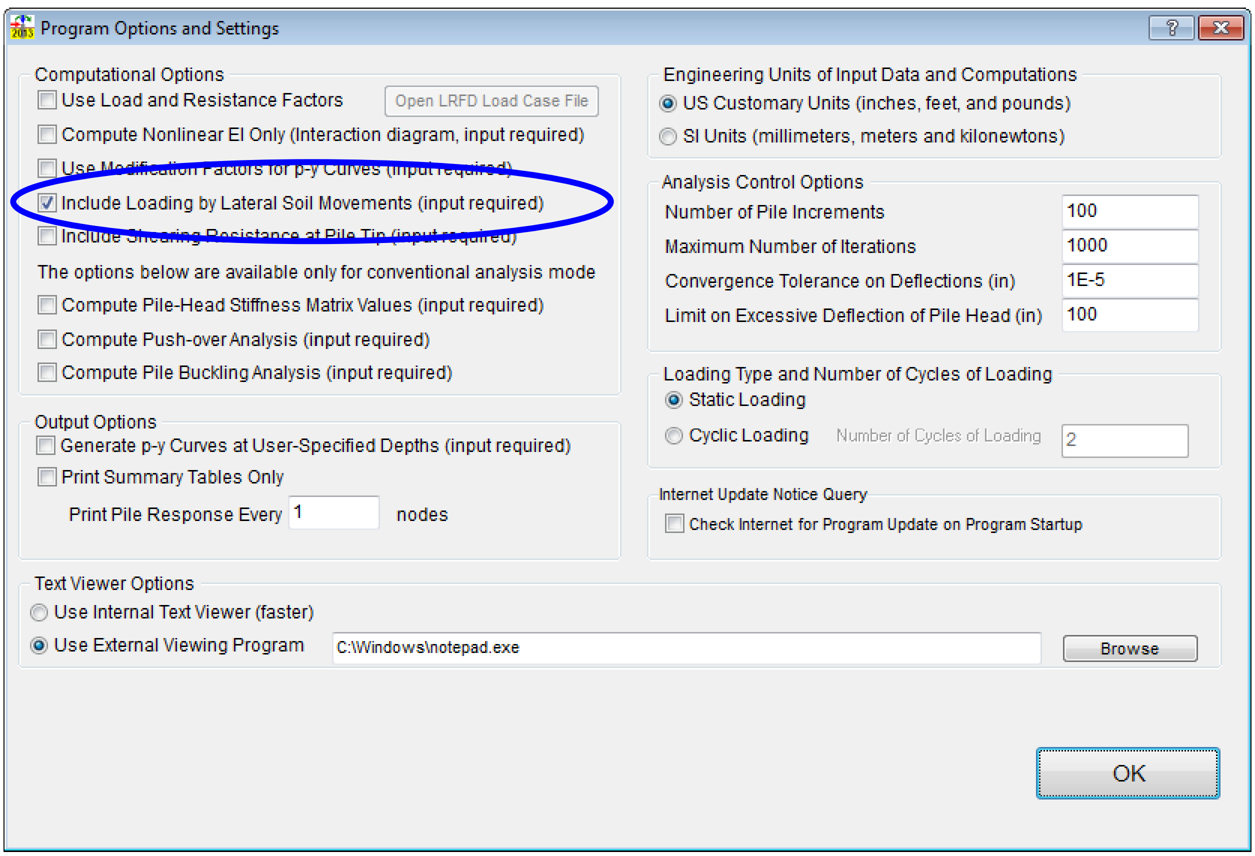

Figure 6-59 Program and Setting Dialog Showing Check for Inclusion of Loadings by Lateral Soil Movements

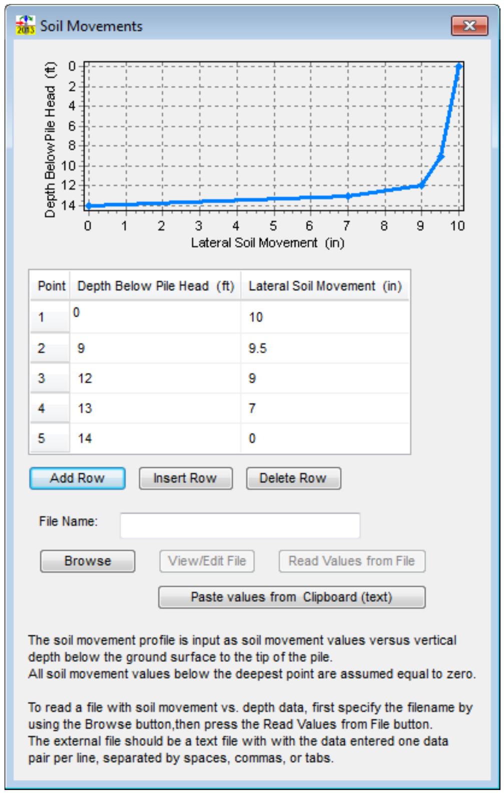

Figure 6-60 Input Dialog for Lateral Soil Movements versus Depth for Example 24

The results of the analysis with loading by soil movements are shown in Figure 6-61. 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.

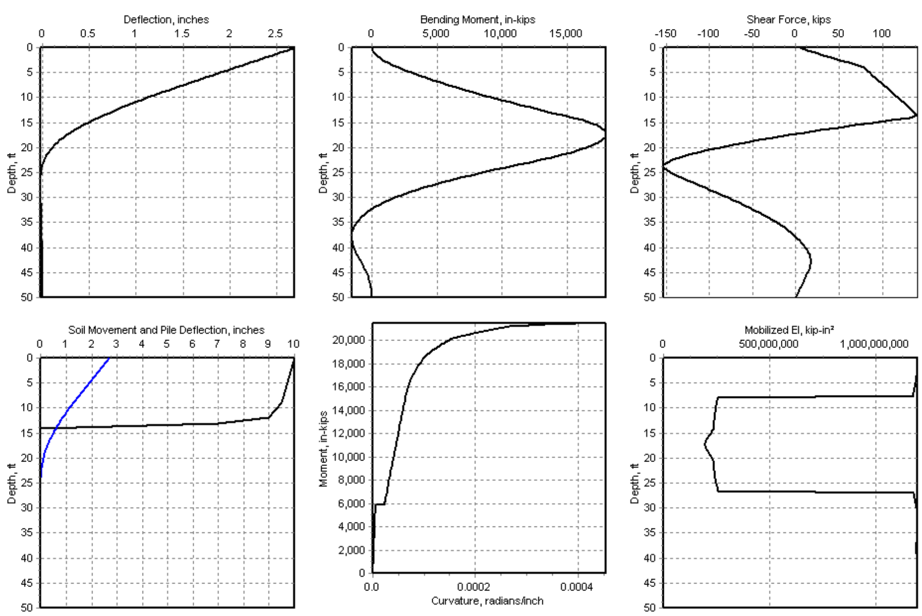

Figure 6-61 Results of Analysis for Example 24

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

See Section 7-3-7 for the discussion of this example.

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 6-62. 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 300 inches 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.

In this problem, 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 pile-head shear force, V_{top}, is 8,859.8755 lbs and the ground line deflection, y_{GL}, is 0.14478516 inches (these numbers were retrieved from the plot output file in order to obtain the maximum number of significant digits).

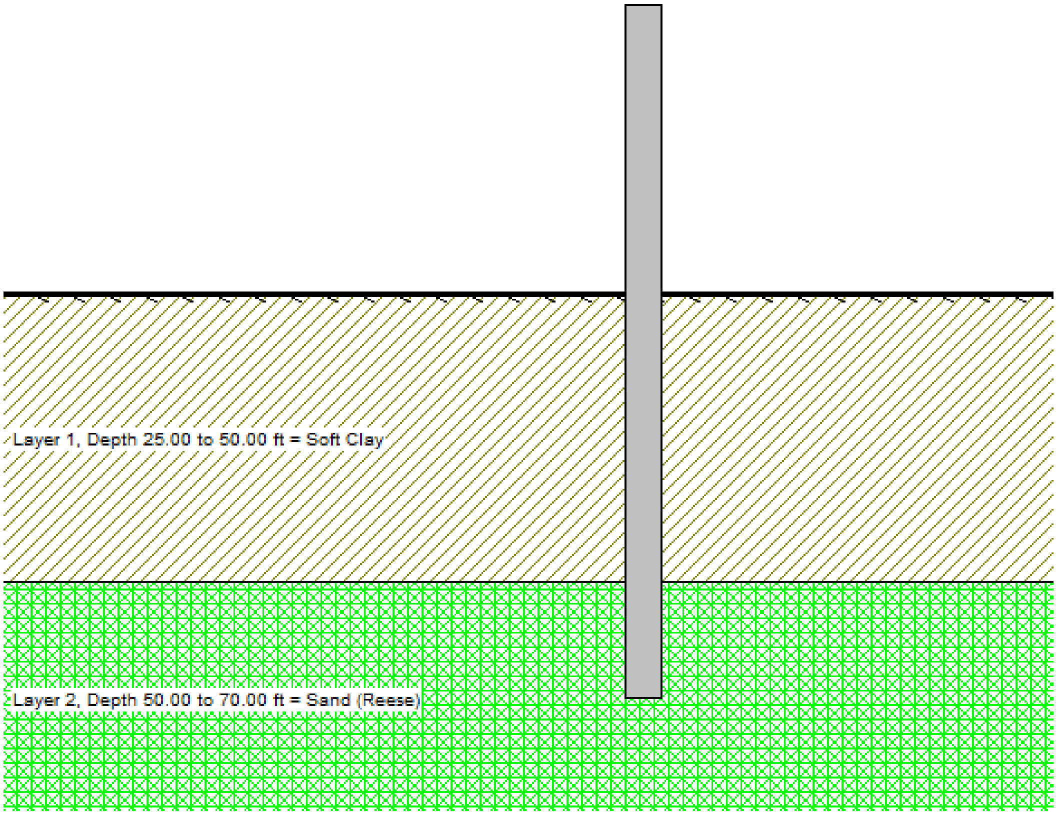

Figure 6-62 Pile and Soil Profile for Verification of *P-Delta* Effect

The moment at the ground line, M_V, from the pile-head shear force is

$$M_V = V_{top} L_e = (8{,}859.8755 \text{ lb})(300 \text{ in.}) = 2{,}657{,}962.65 \text{ in-lbs}$$

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.

$$M_P = P(y_{top} - y_{GL}) = 100{,}000. \text{ lbs}(1.0 \text{ in.} - 0.14478516 \text{ in.}) = 85{,}521.484 \text{ in-lbs}$$

The total moment at the ground line due to the shear force and eccentric axial load is

$$M_{total} = M_V + M_P = 2{,}743{,}484.134 \text{ in-lbs}$$

The computed moment by LPile at the ground line is 2,743,484.100 in-lbs.

The error in the computed moment is −0.034 in-lbs. This is an error of 1.24×10^{-6} percent.

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Chapter 7 Validation

7-1 Introduction

Two approaches are used to validate the computations of the computer program. Firstly, case studies are shown that give the comparison of maximum bending moments from experiment and from computation. Secondly, suggestions are made for checking the output to ensure that the equations of mechanics are satisfied.

7-2 Case Histories

The engineering literature contains a number of papers that present the results of load tests of piles under lateral load; however, in only a small number of these paper present values of bending moment measured by instrumentation along the length of the pile. The case studies presented herein are concerned with these latter cases because the failure of a pile is frequently due to the development of a plastic hinge.

A list of case histories where bending moment was measured is presented in Table 7-1. The table shows the location of the experiment, the reference citation, a general description of the soil and the position of the water table, the computed lateral load at a load factor of 2.5, and the kind and size of pile. For each of the cases, a preliminary computation was made, using the analytical methods presented herein, to find the lateral load P_{ult} that would cause the maximum bending moment to occur. The next step was to find the experimental bending moment and the computed bending moment at the load of $P_{ult}/2.5$. The reason for the comparison at the reduced loading is that the load actually applied to the pile would be reduced by a factor of safety and a value of 2.5 is reasonable.

Table 7-1 Comparison of Bending Moments and Deflections from Computer Analyses and Experimental Case Histories

Case	M_{max}, kN-m	$P_{t,fail}$, kN	$P_{t,serv}$, kN	$y_{t,comp}$, mm	$y_{t,exp}$, mm	M_{comp}, kN-m	M_{exp}, kN-m	Factor of Safety
Bagnolet 2	204	138	76.7	9.6	9.6	104	95	2.15
Bagnolet 3	204	130	72.2	9.4	9.5	105	112	1.82
Houston Static	2030	950	432	20.2	26	702	600	3.38
Houston Cyclic	2030	900	409	26	34	742	642	3.16
Japan	55.9	50	28	22	28	19.6	21.9	2.55
Lake Austin Static	231	145	81	35	35	110	106	2.18
Lake Austin Cyclic	231	113	63	22	46	79	110	2.10
Sabine Static	231	99	55	49	36	103	96	2.41
Sabine Cyclic	231	72	40	27	41	68	82	2.82
Manor Static	1757	693	385	11	9.7	760	715	2.46
Manor Cyclic	1757	543	302	13.1	10.2	710	610	2.88
Mustang Island Static	640	324	180	16	16	305	305	2.10
Mustang Island Cyclic	640	295	164	15	15	320	320	2.00
Garston	15900	4520	2055	33	40	6600	7500	2.12
Los Angeles	4400	1779	809	21	22	1640	1890	2.33
San Francisco	17740	8670	3940	2	3	7030	6640	2.67

A comparison of maximum bending moments from computations and from experiment is presented in Figure 7-1. As it may be seen in the figure, the agreement is excellent over three orders of magnitude. However, it is important to indicate that some of the experiments were used to develop the criteria for the response of soils under lateral loading that are used in the analyses.

Nevertheless, the validity of those experiments cannot be questioned as reflecting the behavior of piles under lateral loading, particularly where the loading was cyclic.

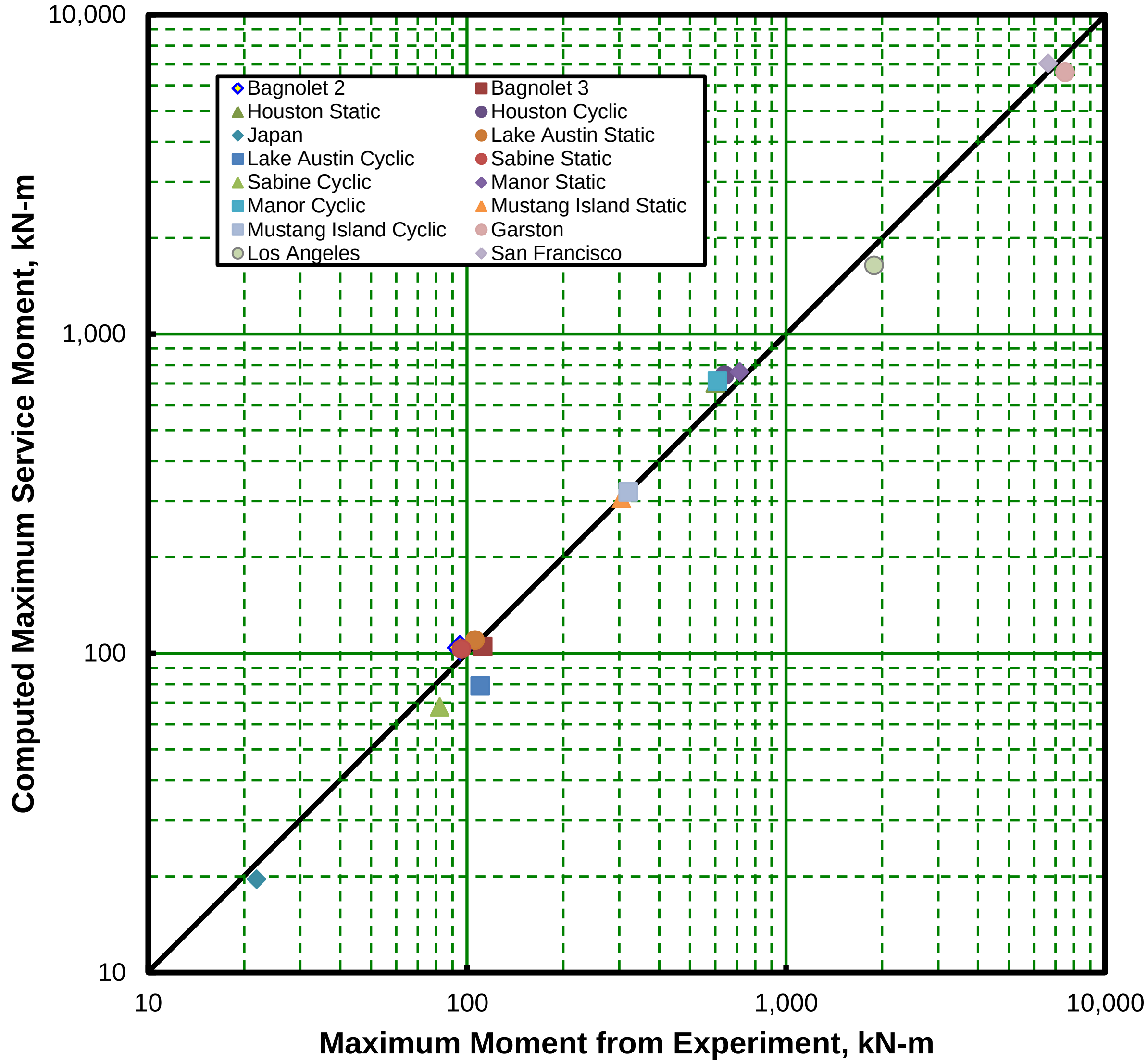


Figure 7-1 Comparison of Maximum Bending Moments from Computations and from Experimental Case Histories

A comparison of experimental and computed pile-head deflection values at service load levels is presented in Figure 7-2. The agreement is fair for this comparison, but with fewer tests showing larger computed values as smaller computed values. The worst agreement is for the cyclic test at Lake Austin. Except for that test, the differences probably would not lead to difficulties.

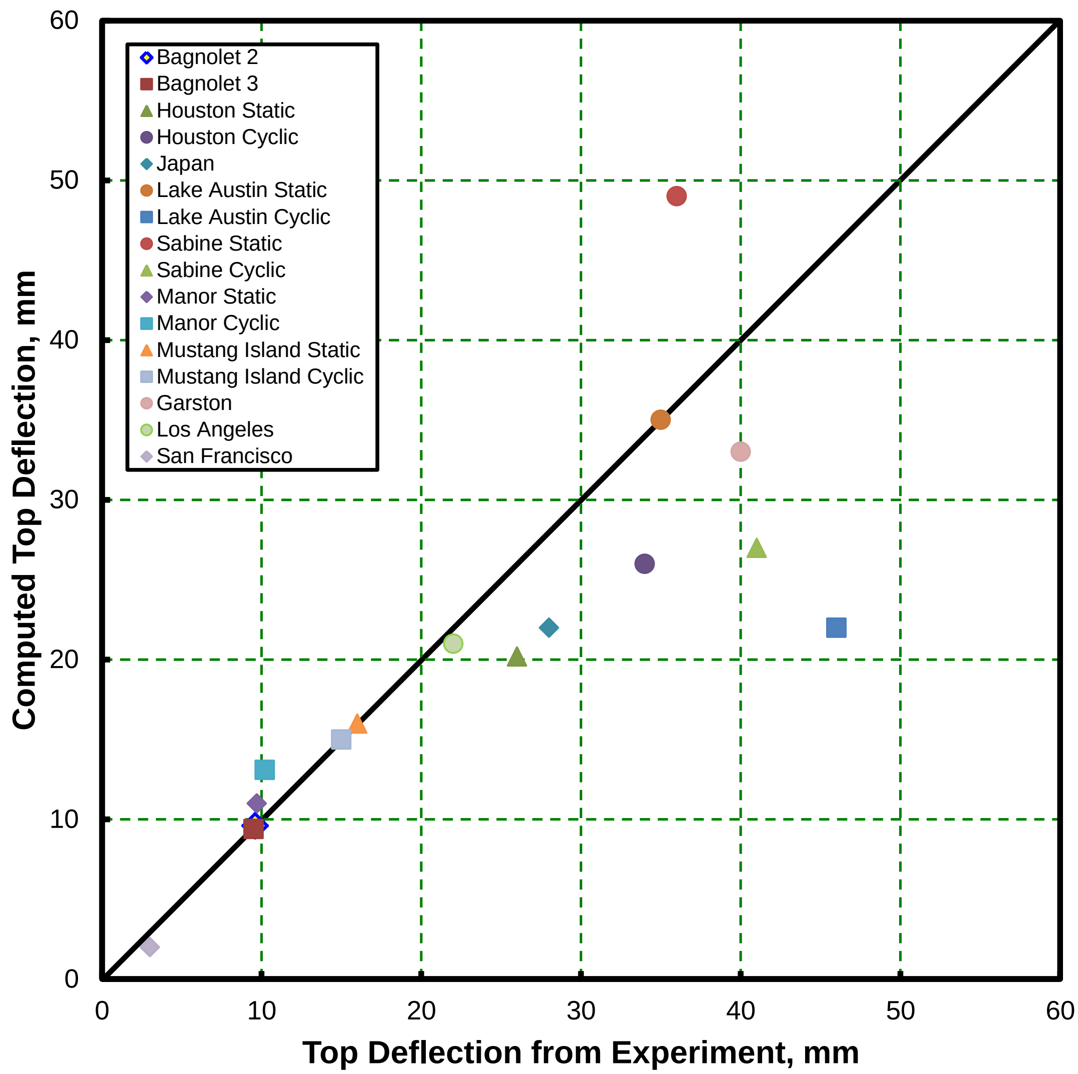


Figure 7-2 Comparison of Experimental and Computed Pile-head Deflections at Service Load

7-3 Verification of Accuracy of Solution

The best policy for a user of a computer program is to assume that the output is in error unless a check is made. There are many stories about engineers accepting computer output as valid only to learn later, perhaps after some kind of failure, that the output was in error. One kind of check that is valid is that the user has made many solutions with the computer and has a good idea of what the output should be. Other kinds of checks that can be made are shown in the following paragraphs.

7-3-1 Solution of Example Problems

A number of example problems have been solved using LPile and the results are included in Chapter 5 of the *LPile User's Manual*. The user should code some of the example problems on occasion to see if identical results, or nearly identical, are obtained.

Another example problem was analyzed and the results are shown in the following pages. The output from this example problem will be checked to illustrate some of the procedures employed for verification.

7-3-2 Numerical Precision Employed in Internal Computations

All real values are programmed as IEEE 64-bit reals, ranging in magnitude from 5.0×10^{-324} to 1.7×10^{308}, with a mantissa of 16 significant figures. This numerical precision was chosen because the difference-equation method requires that a relatively large number of significant figures be employed in order to avoid significant round-off errors.

7-3-3 Selection of Convergence Tolerance and Length of Increment

The convergence tolerance is a number that is input to control the accuracy of the solution. The values of deflection for successive iterations are retained in memory and the differences at corresponding depths are computed. All of the differences must be less than the convergence tolerance to end the iterative computations. The convergence tolerance used in most of the example problems of Chapter 5 of the *LPile User's Manual*, and in the study of this Chapter, was 1×10^{-5} in. (2.54×10^{-7} m), which is the default value provided by the computer program.

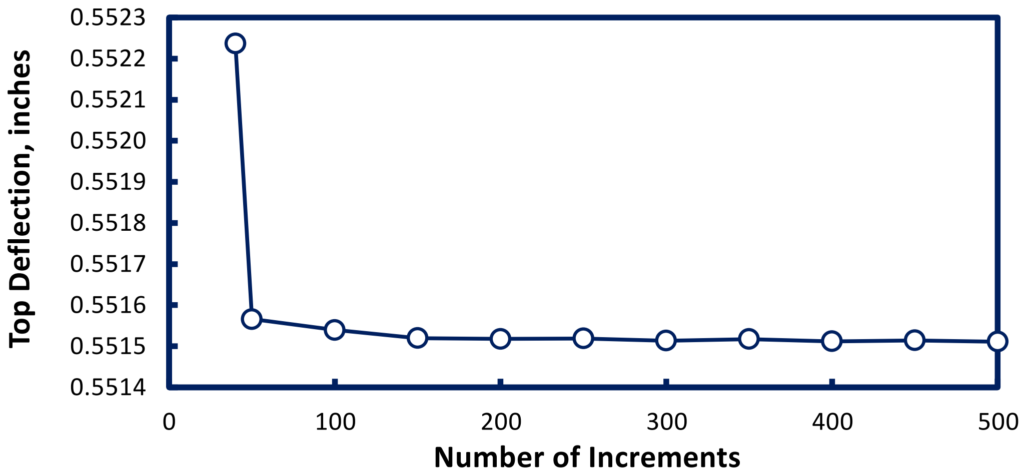
The user has control over the convergence tolerance, but the default value appears to be a good selection for the majority of problems. If a significantly larger value had been selected, inaccurate computations could have resulted; had a significantly smaller value been selected, the number of iterations would be increased and, in fact, a very small value could prevent the achievement of convergence. Verification of accuracy in the solution of the difference equations has been demonstrated and results agree closely with those from the closed-form solution. In addition, the exercise presented below demonstrates to a certain extent that accurate solutions are being obtained. Convergence is usually obtained with 30 or fewer iterations when the pile is in the elastic range, which does not require much time on most computers.

The user must select the length of the increments into which the pile is divided by specifying the number of pile increments. The total length of the pile is the embedded length plus the portion of the pile extending above the ground surface. In cases where the pile being analyzed is extremely long, such as an oil well conductor, one may decide to shorten the length of the modeled pile to where there are just a few points of zero deflection. The behavior of the upper portion of the pile is unaffected as the length is reduced to the point where there are at least two or three points of zero deflection. The number of points of zero deflection is listed on the output for convenience.

A possible exception to shortening the pile to facilitate the computations may occur if the lower portion of the pile is embedded in rock or very strong soil. In such a case, small deflection could generate large values of soil resistance that in turn could influence the behavior of the upper portion of the pile.

With the length of the pile adjusted so that there is no exceptionally long portion at the bottom where the computed pile deflection is oscillating about the axis with extremely small deflections and soil resistances, the user may wish to make a few runs with the pile subdivided into various numbers of increments. Such a study was done for the example shown in this chapter. Figure 7-3 shows a plot of the computed values of groundline deflection and maximum bending moment as a function of the number of increments into which the pile is subdivided.

These values become virtually constant with the pile subdivided into 50 increments or more. Errors are introduced if the number of increments is 40 or less.



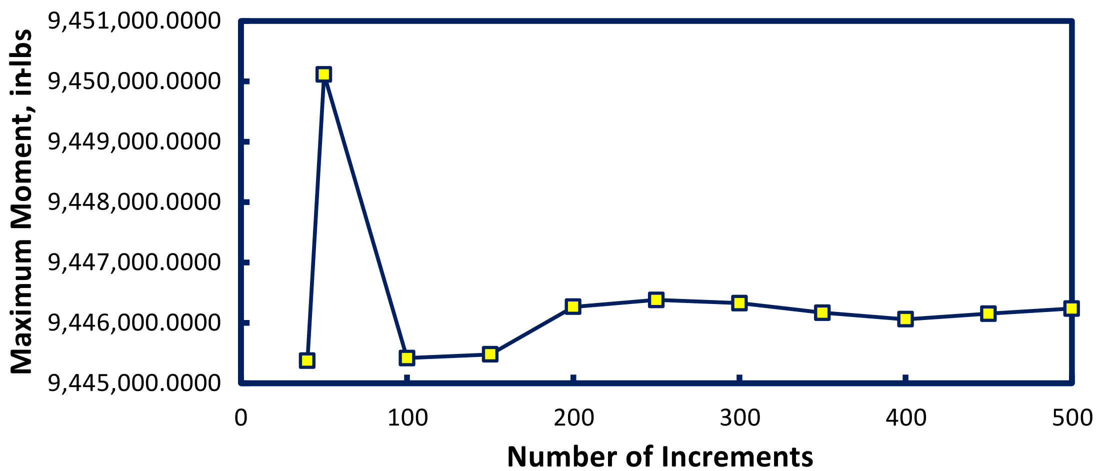


Figure 7-3 Influence of Number of Increments on Computed Values of Pile-head Deflection and Maximum Bending Moment

Errors would have been introduced if solutions had been made for large numbers of increments, at some point beyond 500. The computed deflections at successive increments would have been so close to each other that differences would have disappeared and round-off errors would have been introduced. The number of increments at which such errors are introduced will depend, of course, on the number of significant figures employed in the computations of the particular computer being used. The computer used for the examples presented herein, with the computer program using double-precision arithmetic, employs 8 bytes of storage for a number, which translates into a word length of approximately 16 decimal digits.

For the particular problem that was solved, the pile length was 12.7 m (42 ft) and the diameter was 0.914 meters (36 inches).

The increment length at which good results apparently were obtained was 0.25 m (10 in.) (equal to 50 increments) which is about one-third or one-fourth of the pile diameter. However, it is not only the pile diameter, but also the relative stiffness of the pile compared to the stiffness of the soil that controls the results.

7-3-4 Check of Soil Resistance

A drilled shaft, with a length of 12.7 m and a diameter of 0.9144 m, was constructed in sand with an angle of internal friction of 35 degrees and a unit weight of 18.7 kN/m^3. The top of the pile is unrestrained, a lateral load of 445 kN is applied, and the loading is static.

A *p-y* curve was printed for a depth of 1.524 meters. Initially, it will be assumed that the curve is correct. The computed deflection at a depth of 1.524 m is reported as 0.007032m (0.28 in.) and the soil reaction is 204.6997 kN/m. The linear interpretation of the *p-y* curve that is reported for the depth of 1.524 m is

$$p = 204.1049 \text{ kN/m}$$

The close agreement in the tabulated and computed values of soil resistance is reassuring. Some difference would have been expected between the two values of p because the computer uses the equations for the *p-y* relationship and the check was done by linear interpolation.

The next step is to ascertain that the *p-y* values that are printed are consistent with the equations that are given in the *Technical Manual*. As noted in the computer output, the loading is static, the soil is sand with an angle of internal friction of 35 degrees, and a unit weight of 18.7 kN/m^3. The pile has a diameter of 0.9144 m and the initial modulus of subgrade reaction of 24,400 kN/m^3.

Computations of the ultimate resistance, using the equations in the *Technical Manual* for response of the near-surface soils, yields 217.2 kN/m for p_u and for the soils at depth p_u is 1,398.1 kN/m. The former value controls. The deflection at y_u is equal to 3b/80 and is 0.0343 m. The value of p_u is computed by multiplying 217.2 by the value of A_s (equal to 1.67, found from Figure 3-25, of the *Technical Manual*) and becomes 362 kN/m (2,069 lbs/in.). These values confirm the last four values in the output for p shown in the computer listing.

The value of y_m is b/60 and is 0.0152 meter. The value of p_m is found from $B_s\, p_s$ and is found to be 260 kN/m (reading a value of B_s = 1.20 from Figure 3-26 of the *Technical Manual*). This value confirms another point on the computer output. By referring to the curves giving the characteristic shape of the *p-y* curves for sand, it can be seen that two significant points on the *p-y* curve have been confirmed. Other points can be checked, but it will be assumed here that those points are also correct.

7-3-5 Check of Equilibrium

The values of soil resistance that are listed in the computer output were plotted as a function of depth along the pile, and the plot is shown in Figure 7-4. The squares were counted and the forces that were computed from the area under the curve are shown in the figure. The following check was made of the summation of the forces in the horizontal direction.

$$\sum F_h = 445 - 657 + 227 - 15 = 0$$

The forces are in equilibrium, which is quite fortuitous in view of the lack of precision in the procedure for numerical integration.

The next step is to make a check of the position of the point of the maximum moment. As shown in Figure 7-4, the curve of soil resistance was integrated numerically and the position of zero shear force (where the area under the soil-resistance curve is 445 kN) was at approximately 2.8 m from the top of the pile. The output in the appendix shows that the depth to zero shear force is between 2.71 m and 2.88 m, which confirm the results of the numerical integration.

To obtain a rough check of the value of the maximum moment, the centroid of the area under the curve equal to 445 kN is assumed to be approximately 1.8 m from the top of the pile or 1.0 m from the point of maximum moment; thus, the following equation can be written:

$$M_{max} = (445)(2.8) - (445)(1.0)$$

$$M_{max} = 806 \text{ kN-m}$$

The tabulated value of the maximum moment is 711kN-m, and the rough check shown above is considered acceptable.

The next step in verifying the mechanics is to make an approximate solution for the deflection. Several assumptions are made, as will be seen. Figure 7-4 shows that zero deflection occurs at depths of approximately 4.9 m and 10.9 m (where the soil resistance is zero), so the assumption is made that a zero slope exists in the deflection curve at midway between these two points, or at a depth of 7.9 meters. The deflection at the top of the pile can be computed by taking moments of the *M/EI* diagram about the top and down to the point of zero slope.

In order to simplify the computations, a further assumption is made that concentrated loads can be used to obtain the moment diagram instead of the distributed loads. Referring to Figure 7-4, the concentrated loads to be used in the analysis are a pile-head shear load of 445 kN, a resisting load of 657 kN at approximately 2.2 m from the top of the pile, and a resisting load of 165 kN at approximately 6.8 m from the top of the pile. The following equation results:

$$\begin{aligned} y_t &= \frac{1}{734{,}000}\left\{445\frac{(7.9)^3}{3} - 657\frac{(5.7)^2}{2}\left[2.2 + \frac{(2)(5.7)}{3}\right] + 165\frac{(1.1)^2}{2}\left(6.8 + \frac{(2)(1.1)}{3}\right)\right\} \\ &= \frac{1}{734{,}000}\left(73{,}134 - 64{,}038 + 742\right) \\ &= 0.0134\,\text{m} = 0.053\,\text{in.} \end{aligned}$$

The analysis found y_t to be 0.0134 meters (0.52 inch). The agreement is close, in view of the assumptions that were made.

This computation completes the checking of the mechanics of the output from a computer run. While the results are not fully definitive, there is ample reason to trust the coding if a proper selection is made of a computer, the number of increments for a particular run, and the value of the tolerance used for concluding the iterations.

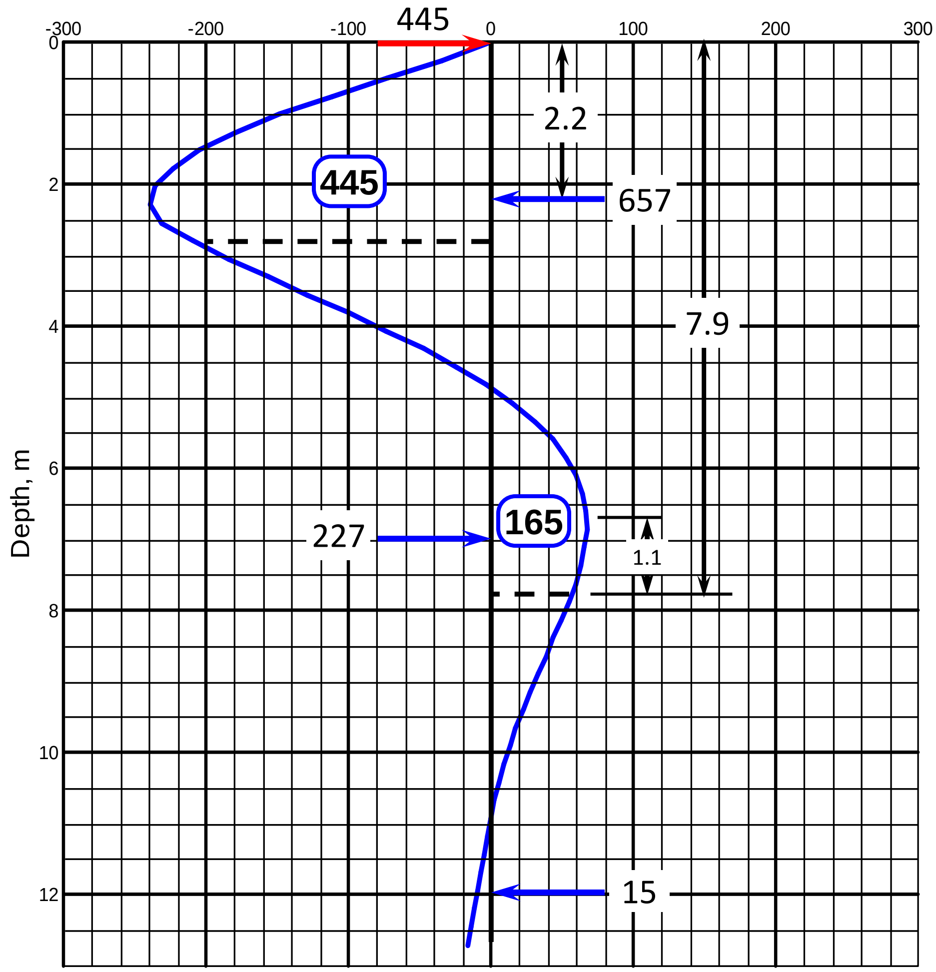


Figure 7-4 Plot of Mobilized Soil Resistance versus Depth

7-3-6 Use of Non-Dimensional Curves

Another type of verification can be made by using the *p-y* curves as tabulated by the computer. These curves should be checked by the engineer to be sure that they are accurate. Then nondimensional curves can be employed to solve the problem. These curves are presented by Matlock and Reese (1962) and in Reese (1984).

7-3-7 Use of 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

$$y = \frac{e^{-\beta x}}{2EI\beta^2}\left[\frac{V_t}{\beta}\cos\beta x + M_t\left(\cos\beta x - \sin\beta x\right)\right]$$

$$M = e^{-\beta x}\left[\frac{V_t}{\beta}\sin\beta x + M_t\left(\sin\beta x + \cos\beta x\right)\right]$$

$$V = e^{-\beta x}\left[V_t\left(\cos\beta x - \sin\beta x\right) - 2M_t\beta\sin\beta x\right]$$

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

The data file for this verification is provided as Example 25.

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 7-5 through Figure 7-7, 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.

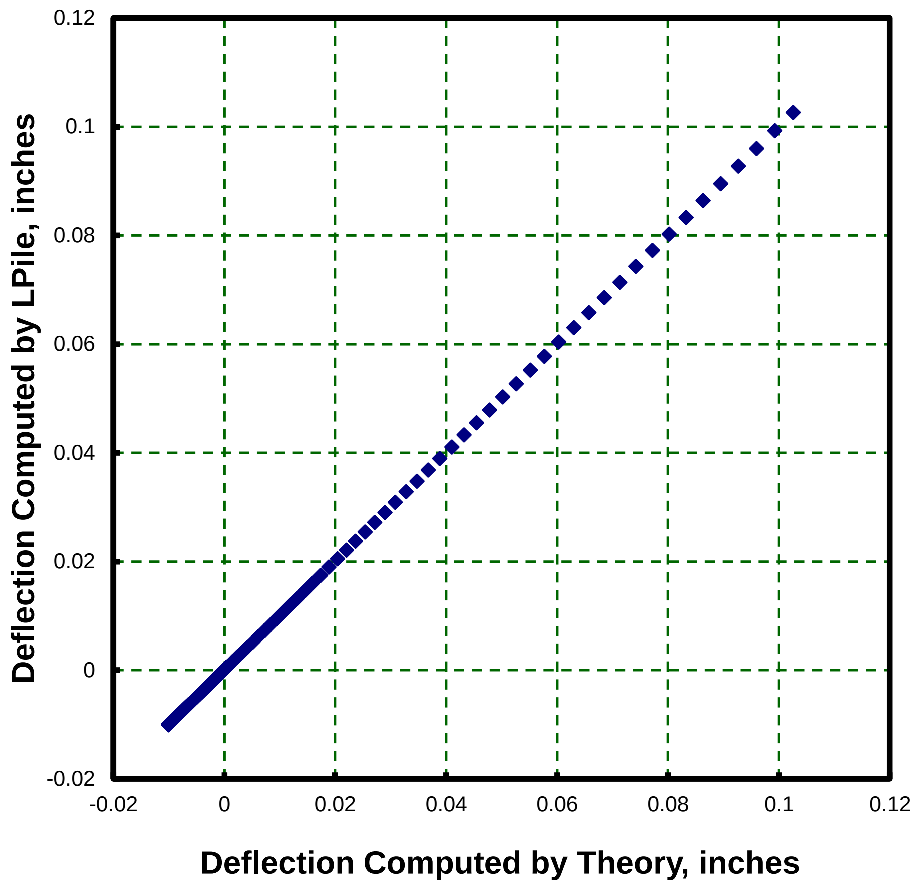


Figure 7-5 Verification of Pile Deflections

7-3-8 Concluding Comments on Verification

The discussion above presents some procedures that can be used for verifying the accuracy of the output from the computer. The point cannot be made too strongly that the engineer should make verification a priority in working with LPile.

The user, if desired, may easily perform some of the elementary computations shown in this chapter.

With regard to the static equilibrium of the lateral force on a single pile, the values of soil resistance can be computed and plotted along the length of the pile. With the lateral loads at the top of the pile, a check on the equilibrium of lateral forces can be made. A satisfactory check has been made by estimation; a more comprehensive check can be made by use of numerical integration of the distributed loads. The program will also conduct such checks internally to ensure the force equilibrium.

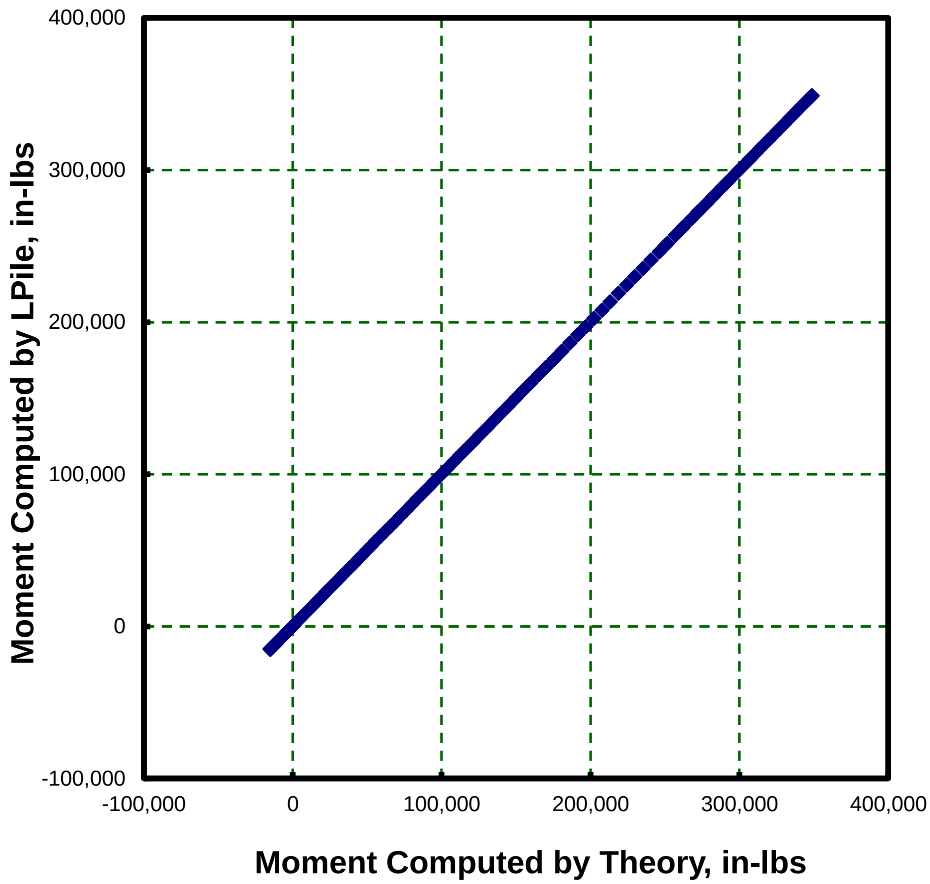


Figure 7-6 Verification of Bending Moments

The final internal check relates to the computed movement of the system. The first step is to refer to the computer output to confirm that the distributed load (soil resistance) and the distributed deflections along the length of the pile are consistent with the *p-y* curves that were input. If equations were used to compute the values of *p* and *y*, it is necessary to interpret the equations at a sufficient number of points to shown that the soil criteria for lateral load was followed. The second step with respect to lateral load is to employ the diagram is Step 1 and to use principles of mechanics to ascertain that the deflection of the individual piles was computed correctly.

While employing the steps shown above have confirmed the internal functioning of LPile, the application of the program to results of field experiments is useful. The book by Reese and Van Impe (2011) presents a discussion of the development of the methods used in LPile and applies the methods to several cases.

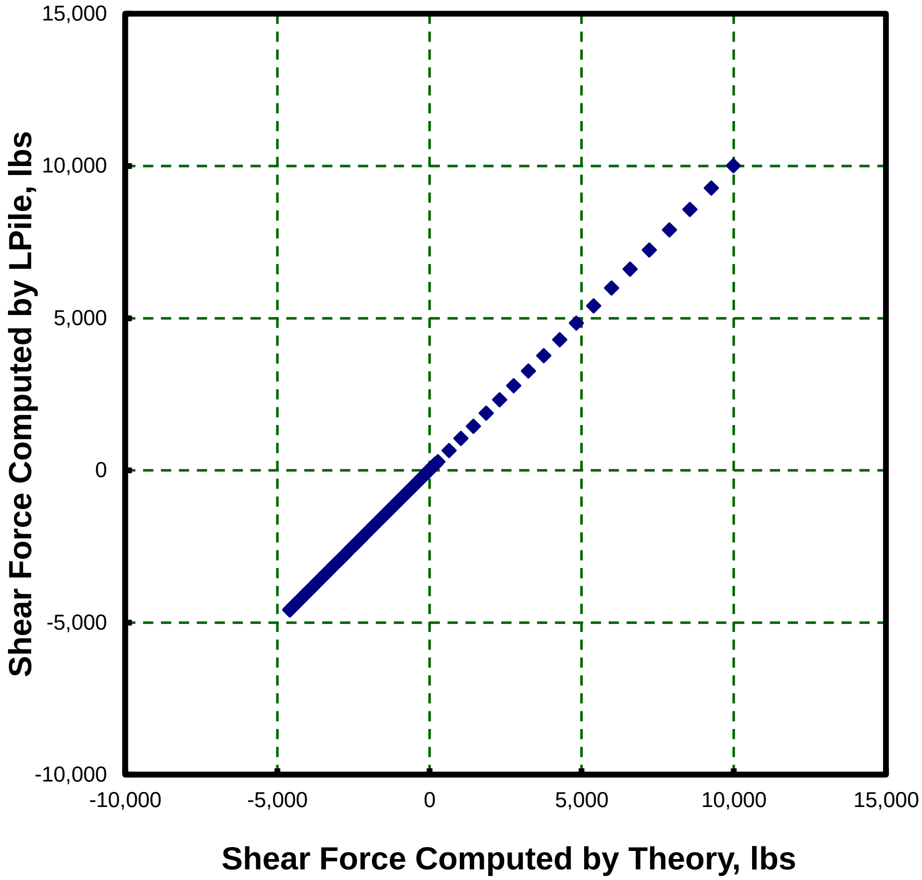


Figure 7-7 Verification of Shear Forces

Chapter 8
Line-by-Line Guide for Input

The input file for LPile Format Version 8 is an ASCII text file. The data file is updated with the latest data contained in the data editing dialogs of LPile immediately before every analysis is made. The computation functions in LPile begin by reading the input data file.

The general format is a series of key words that denote the start of a section of data. The key words may be entered in any order, but the order of input in each section must follow a specific sequence.

The content of the input data file is designed to be easily understandable by the user.

8-1 Key Words for Input Data File

The following table lists the key words that define sections of data. The key words may be entered in any order.

Table 8-1 Key Words for Definition of Input Data

Input Command Word	Data Type Defined by Key Word
LPILEP8	Input file format version number
TITLE	Title lines for data file (five lines)
OPTIONS	Program and analysis options
SECTIONS	Pile section and material properties
AXIAL THRUST LOADS	Axial thrust loads used in nonlinear moment-curvature computations
SOIL LAYERS	Soil profile dimension and soil properties used for *p-y* curve computations
TIP SHEAR	Tip shear versus lateral tip movement data
PILE BATTER AND SLOPE	Pile batter and slope data
LRFD LOADS	Unfactored loads for LRFD analysis
LRFD FACTORS AND CASES	Load and resistance factors and load combination data
LOADING	Pile-head boundary conditions and loading data for conventional analysis
SOIL MOVEMENTS	Soil movement versus depth data
GROUP EFFECT FACTORS	Group effect factors (p and y-multiplier) data
P-Y OUTPUT DEPTHS	Output depths for reported *p-y* curves
FOUNDATION STIFFNESS	Control data for computation of foundation stiffness
PILE PUSHOVER ANALYSIS DATA	Control data for computation of pile pushover analysis
PILE BUCKLING ANALYSIS DATA	Control data for computation of pile buckling analysis
END	Terminates reading of input data

8-2 TITLE Command

The TITLE keyword indicated that the following five lines of text are entered for the problem title. Entering fewer or more than five lines of text will result in an execution error and input of data is ended.

By default, the following lines of text are predefined in LPile, but may be changed to anything that the user wishes to enter. The default lines are:

Project Name:

Job Number:

Client:

Engineer:

Description:

8-3 OPTIONS Command

The OPTIONS keyword begins the definition of program options selected by the user. Some options are either Yes or No options and the other options require numerical input. The order of the options must be in the following sequence.

Table 8-2 Program Options and Settings

Options Keyword (without spaces)	Defines Option for	Permissible Values
Units	Engineering units	USCS, SI
UseLRFD	Perform LRFD analysis	YES, NO
ComputeKmatrix	Compute pile-head stiffness matrix component values	YES, NO
UseTipShear	Use tip shear resistance curve	YES, NO
UseDistributedLoading	Include loading by distributed lateral loading	ALL, ONE, NO To enter multiple distributed load profiles for every load case enter “ALL.” To enter a single distributed lateral load profile to apply to all load cases enter “ONE.” To omit distributed lateral loading enter “NO.”
UseSoilMovement	Include loading by soil movements	ALL, ONE, NO To enter multiple soil movement profiles for every load case enter “ALL.” To enter a single soil movement profile to apply to all load cases enter “ONE.”

Options Keyword (without spaces)	Defines Option for	Permissible Values
		To omit soil movements enter "NO."
UsePYModifiers	Use *p-y* modifiers for group action	YES, NO
ComputeEIOnly	Compute nonlinear moment-curvature values and nominal moments capacity only	YES, NO
Loading	Number of cycles of loading	If for static loading enter: "STATIC", followed by 5 spaces, then "1" If for cyclic loading enter: "CYCLIC", followed by number of cycles of loading, 5000 = maximum
IterationsLimit	Maximum number of iterations for numerical solution	500 = default value, 1,000 = maximum value
ConvergenceTolerance	Convergence tolerance for numerical solution	1.0×10^{-5} inches = default value
NumberPileIncrements	Number of pile increments for numerical solution	100 = default, 40 = minimum, 500 = maximum
PrintSummaryOnly	Print summary tables only	YES, NO
PrintIncrement	Printing increment for pile response	1 = default value
PrintPYCurves	Report *p-y* curves at user-specified depths	YES, NO
ComputeInteration	Compute interaction diagram only	YES, NO
ComputePushover	Compute pushover analysis	YES, NO
ComputePileBuckling	Compute pile buckling analysis	YES, NO

8-4 SECTIONS Command

The SECTIONS keyword begins the definition of structural properties of the pile to be analyzed. The order of the input data must be in the following sequence. The input data consists of one or more numbers followed by an optional comment. Data written by LPile will be followed by a comment that describes the input data and the engineering units of the data.

Table 8-3 Pile Section Data

SECTIONS Line Number	Input Value
1 Total Number of Sections	1 = minimum, 10 = maximum
2 Section number	1 = top section, sections number consecutively from top to bottom of pile

SECTIONS Line Number	Input Value
3 Section Type	0 = rectangular, 1 = drilled shaft, 2 = drilled shaft with casing, 3 = drilled shaft with casing and core filled with concrete, -3 = drilled shaft with casing and void core 4 = steel pipe 5 = circular solid prestressed pile, 6 = circular hollow prestressed pile 7 = square solid prestressed pile, 8 = square hollow prestressed pile, 9 = octagonal solid prestressed pile, 10= octagonal hollow prestressed pile, 11 = elastic pile, 12 = elastic-plastic pile 13 = pile with user-defined nonlinear bending properties in terms of *EI* and moment values -13 = pile with user-defined nonlinear bending properties in terms of moment and curvature values

Follow by section dimensions for specific Section Type

Table 8-4 Properties for Rectangular Sections

Properties for rectangular sections	Lines 3.0
3.0.1 Section dimension	Length of section, ft or m
3.0.2 Shear capacity	Shear capacity of section, lbs or kN
3.0.3 Section dimension	Section depth, inches or mm
3.0.4 Section dimension	Section width inches or mm

Follow with concrete properties (Lines 4) and rebar properties (Lines 5) to complete section data.

Table 8-5 Properties for Drilled Shafts

Properties for Drilled Shaft Sections	Lines 3.1
3.1.1 Section dimension	Length of section, ft or m
3.1.2 Shear capacity	Shear capacity of section, lbs or kN
3.1.3 Section dimension	Section diameter, inches or mm
3.1.4 Section dimension	Section width inches or mm

Follow with concrete properties (Lines 4) and rebar properties (Lines 5) to complete section data.

Table 8-6 Properties of Drilled Shafts with Casing

Properties of Drilled Shafts with Casing	Lines 3.2
3.2.1 Section dimension	Length of section, ft or m,
3.2.2 Shear capacity	Shear capacity of section, lbs or kN
3.2.3 Section dimension	Section diameter, inches or mm
3.2.4 Section dimension	Casing wall thickness, inches or mm
3.2.5 Casing property	Yield stress of casing, psi or kPa
3.2.6 Casing property	Young's modulus of casing, psi or kPa

Follow with concrete properties (Lines 4) and rebar properties (Lines 5) to complete section data.

Table 8-7 Properties of Drilled Shafts with Casing and Core

Properties for Drilled Shafts with Casing and Core	Lines 3.3
3.3.1 Section dimension	Length of section, ft or m,
3.3.2 Shear capacity	Shear capacity of section, lbs or kN
3.3.3 Section dimension	Section diameter, inches or mm
3.3.4 Section dimension	Casing wall thickness, inches or mm
3.3.5 Casing property	Yield stress of casing, psi or kPa
3.3.6 Casing property	Young's modulus of casing, psi or kPa
Properties for Drilled Shafts with Casing and Core	Lines 3.3
3.3.7 Core property	Core diameter, inches or mm
3.3.7 Core property	Core wall thickness, inches or mm
3.3.8 Core property	Yield stress of core, psi or kPa
3.3.9 Core property	Young's modulus of core, psi or kPa

Follow with concrete properties (Lines 4) and rebar properties (Lines 5) to complete section data.

Table 8-8 Properties for Steel Pipe Piles

Properties for Steel Pipe Piles	Lines 3.4
3.4.1 Section dimension	Length of section, ft or m
3.4.2 Shear capacity	Shear capacity of section, lbs or kN
3.4.3 Pipe pile property	Core diameter, inches or mm
3.4.4 Pipe pile property	Core wall thickness, inches or mm
3.4.5 Pipe pile property	Yield stress of core, psi or kPa
3.4.6 Pipe pile property	Young's modulus of core, psi or kPa

This completes the definition of section properties for steel pipe sections.

Table 8-9 Properties for Circular Solid Prestressed Piles

Properties for Circular Solid Prestressed Piles	Lines 3.5
3.5.1 Section dimension	Length of section, ft or m
3.5.2 Shear capacity	Shear capacity of section, lbs or kN
3.5.3 Section dimension	Section diameter, inches or mm

Follow with concrete properties (Lines 4) and prestressing strand properties (Lines 6) to complete section data.

Table 8-10 Properties for Circular Hollow Prestressed Piles

Properties for Circular Hollow Prestressed Piles	Lines 3.6
3.6.1 Section dimension	Length of section, ft or m
3.6.2 Shear capacity	Shear capacity of section, lbs or kN
3.6.3 Section dimension	Section diameter, inches or mm
3.6.4 Section core diameter	Core void diameter, inches or mm

Follow with concrete properties (Lines 4) and prestressing strand properties (Lines 6) to complete section data.

Table 8-11 Properties for Square Solid Prestressed Piles

Properties for Square Solid Prestressed Piles	Lines 3.7
3.7.1 Section dimension	Length of section, ft or m
3.7.2 Shear capacity	Shear capacity of section, lbs or kN
3.7.3 Section dimension	Section diameter, inches or mm
3.7.4 Section chamfer	Corner chamfer, inches or mm

Follow with concrete properties (Lines 4) and prestressing strand properties (Lines 6) to complete section data.

Table 8-12 Properties for Square Hollow Prestressed Piles

Properties for Square Hollow Prestressed Piles	Lines 3.8
3.8.1 Section dimension	Length of section, ft or m
3.8.2 Shear capacity	Shear capacity of section, lbs or kN
3.8.3 Section dimension	Section diameter, inches or mm
3.8.4 Section core diameter	Core void diameter, inches or mm
3.8.5 Section chamfer	Corner chamfer, inches or mm

Follow with concrete properties (Lines 4) and prestressing strand properties (Lines 6) to complete section data.

Table 8-13 Properties for Octagonal Solid Prestressed Piles

Properties for Octagonal Solid Prestressed Piles	Lines 3.9
3.9.1 Section dimension	Length of section, ft or m
3.9.2 Section dimension	Section diameter, inches or mm

Follow with concrete properties (Lines 4) and prestressing strand properties (Lines 6) to complete section data.

Table 8-14 Properties for Square Hollow Prestressed Piles

Properties for Square Hollow Prestressed Piles	Lines 3.10
3.10.1 Section dimension	Length of section, ft or m
3.10.2 Shear capacity	Shear capacity of section, lbs or kN
3.10.3 Section dimension	Section diameter, inches or mm
3.10.4 Section core diameter	Core void diameter, inches or mm

Follow with concrete properties (Lines 4) and prestressing strand properties (Lines 6) to complete section data.

Table 8-15 Properties for Elastic Piles

Properties for Elastic Piles	Lines 3.11
3.11.1 Section dimension	Length of section, ft or m
3.11.2 Geometric shape code	Enter: 1 = rectangular, follow by Lines 3.11.3.1 2 = circular solid, follow by Lines 3.11.3.2 3 = pipe , follow by Lines 3.11.3.3 4 = strong H-pile, follow by Lines 3.11.3.4 5 = weak H-pile, follow by Lines 3.11.3.5 6 = embedded pole, follow by Lines 3.11.3.6

Properties of elastic rectangular sections	Lines 3.11.3.1
3.11.3.1.1 Section property	Young's modulus, psi or kPa
3.11.3.1.2 Section dimension	Width at top, inches or mm
3.11.3.1.3 Section dimension	Width at bottom, inches or mm
3.11.3.1.4 Section dimension	Depth at top, inches or mm
3.11.3.1.5 Section dimension	Depth at bottom, inches or mm
3.11.3.1.6 Section dimension	Area at top, sq. inches or sq. mm
3.11.3.1.7 Section dimension	Area at bottom, sq. inches or sq. mm
3.11.3.1.8 Section property	Moment of inertia at top, $in.^4$ or mm^4
3.11.3.1.9 Section property	Moment of inertia at bottom, $in.^4$ or mm^4

Properties of elastic circular sections	Lines 3.11.3.2
3.11.3.2.1 Section property	Young's modulus, psi or kPa
3.11.3.2.2 Section dimension	Width at top, inches or mm
3.11.3.2.3 Section dimension	Width at bottom, inches or mm
3.11.3.2.4 Section dimension	Area at top, sq. inches or sq. mm
3.11.3.2.5 Section dimension	Area at bottom, sq. inches or sq. mm
3.11.3.2.6 Section property	Moment of inertia at top, in.^{4} or mm^4
3.11.3.2.7 Section property	Moment of inertia at bottom, in.^{4} or mm^4

Properties of elastic pipe sections	Lines 3.11.3.3
3.11.3.3.1 Section property	Young's modulus, psi or kPa
3.11.3.3.2 Section dimension	Width at top, inches or mm
3.11.3.3.3 Section dimension	Width at bottom, inches or mm
3.11.3.3.4 Section dimension	Wall thickness at top, inches or mm
3.11.3.3.5 Section dimension	Wall thickness at bottom, inches or mm
3.11.3.3.6 Section dimension	Area at top, sq. inches or sq. mm
3.11.3.3.7 Section dimension	Area at bottom, sq. inches or sq. mm
3.11.3.3.8 Section property	Moment of inertia at top, in.^{4} or mm^4
3.11.3.3.9 Section property	Moment of inertia at bottom, in.^{4} or mm^4

Properties of strong H-pile sections	Lines 3.11.3.4
3.11.3.4.1 Section property	Young's modulus, psi or kPa
3.11.3.4.2 Section dimension	H section flange width, inches or mm
3.11.3.4.3 Section dimension	H section depth, inches or mm
3.11.3.4.4 Section dimension	H section flange thickness, inches or mm
3.11.3.4.5 Section dimension	H section web thickness, inches or mm
3.11.3.4.6 Section dimension	H section area, sq. inches or sq. mm
3.11.3.4.7 Section dimension	H section moment of inertia, in.^{4} or mm^4

Properties of weak H-pile sections	Lines 3.11.3.5
3.11.3.5.1 Section property	Young's modulus, psi or kPa
3.11.3.5.2 Section dimension	H section flange width, inches or mm
3.11.3.5.3 Section dimension	H section depth, inches or mm
3.11.3.5.4 Section dimension	H section flange thickness, inches or mm
3.11.3.5.5 Section dimension	H section web thickness, inches or mm
3.11.3.5.6 Section dimension	H section area, sq. inches or sq. mm
3.11.3.5.7 Section property	H section moment of inertia, in.^{4} or mm^4

Properties of elastic embedded pole	Lines 3.11.3.6
3.11.3.6.1 Section property	Young's modulus, psi or kPa
3.11.3.6.2 Section dimension	Pole width at top, inches or mm
3.11.3.6.3 Section dimension	Pole width at bottom, inches or mm
3.11.3.6.4 Section dimension	Pole area at top, sq. inches or sq. mm

Properties of elastic embedded pole	Lines 3.11.3.6
3.11.3.6.5 Section dimension	Pole area at bottom, sq. inches or sq. mm
3.11.3.6.6 Section property	Pole moment of inertia at top, $in.^4$ or mm^4
3.11.3.6.7 Section property	Pole moment of inertia at bottom, $in.^4$ or mm^4
3.11.3.6.8 Section dimension	Drilled hole diameter, inches or mm

Table 8-16 Properties for Elastic Piles with Specified Moment Capacity

Properties for Elastic Piles with Specified Moment Capacity	Lines 3.11
3.11.1 Section dimension	Length of section, ft or m
3.11.2 Shear capacity at top of section	Shear capacity of section, lbs or kN
3.11.3 Shear capacity at bottom of section	Shear capacity of section, lbs or kN
3.11.4 Geometric shape code	Enter: 1 = rectangular, follow by Lines 3.11.3.1 2 = circular solid, follow by Lines 3.11.3.2 3 = pipe , follow by Lines 3.11.3.3 4 = strong H-pile, follow by Lines 3.11.3.4 5 = weak H-pile, follow by Lines 3.11.3.5 6 = embedded pole, follow by Lines 3.11.3.6

Properties of elastic rectangular sections with specified moment capacity	Lines 3.11.4.1
3.11.4.1.1 Section property	Young's modulus, psi or kPa
3.11.4.1.2 Section dimension	Width at top, inches or mm
3.11.4.1.3 Section dimension	Width at bottom, inches or mm
3.11.4.1.4 Section dimension	Depth at top, inches or mm
3.11.4.1.5 Section dimension	Depth at bottom, inches or mm
3.11.4.1.6 Section dimension	Area at top, sq. inches or sq. mm
3.11.4.1.7 Section dimension	Area at bottom, sq. inches or sq. mm
3.11.4.1.8 Section property	Moment of inertia at top, $in.^4$ or mm^4
3.11.4.1.9 Section property	Moment of inertia at bottom, $in.^4$ or mm^4

Properties of elastic circular sections with specified moment capacity	Lines 3.11.4.2
3.11.4.2.1 Section property	Young's modulus, psi or kPa
3.11.4.2.2 Section dimension	Width at top, inches or mm
3.11.4.2.3 Section dimension	Width at bottom, inches or mm
3.11.4.2.4 Section dimension	Area at top, sq. inches or sq. mm
3.11.4.2.5 Section dimension	Area at bottom, sq. inches or sq. mm
3.11.4.2.6 Section property	Moment of inertia at top, $in.^4$ or mm^4
3.11.4.2.7 Section property	Moment of inertia at bottom, $in.^4$ or mm^4

Properties of elastic pipe sections with specified moment capacity	Lines 3.11.4.3
3.11.4.3.1 Section property	Young’s modulus, psi or kPa
3.11.4.3.2 Section dimension	Width at top, inches or mm
3.11.4.3.3 Section dimension	Width at bottom, inches or mm
3.11.4.3.4 Section dimension	Wall thickness at top, inches or mm
3.11.4.3.5 Section dimension	Wall thickness at bottom, inches or mm
3.11.4.3.6 Section dimension	Area at top, sq. inches or sq. mm
3.11.4.3.7 Section dimension	Area at bottom, sq. inches or sq. mm
3.11.4.3.8 Section property	Moment of inertia at top, $in.^4$ or mm^4
3.11.4.3.9 Section property	Moment of inertia at bottom, $in.^4$ or mm^4

Properties of strong H-pile sections with specified moment capacity	Lines 3.11.4.4
3.11.4.4.1 Section property	Young’s modulus, psi or kPa
3.11.4.4.2 Section dimension	H section flange width, inches or mm
3.11.4.4.3 Section dimension	H section depth, inches or mm
3.11.4.4.4 Section dimension	H section flange thickness, inches or mm
3.11.4.4.5 Section dimension	H section web thickness, inches or mm
3.11.4.4.6 Section dimension	H section area, sq. inches or sq. mm
3.11.4.4.7 Section property	H section moment of inertia, $in.^4$ or mm^4

Properties of weak H-pile sections with specified moment capacity	Lines 3.11.4.5
3.11.4.5.1 Section property	Young’s modulus, psi or kPa
3.11.4.5.2 Section dimension	H section flange width, inches or mm
3.11.4.5.3 Section dimension	H section depth, inches or mm
3.11.4.5.4 Section dimension	H section flange thickness, inches or mm
3.11.4.5.5 Section dimension	H section web thickness, inches or mm
3.11.4.5.6 Section dimension	H section area, sq. inches or sq. mm
3.11.4.5.7 Section property	H section moment of inertia, $in.^4$ or mm^4

Properties of elastic embedded pole with specified moment capacity	Lines 3.11.4.6
3.11.4.6.1 Section property	Young’s modulus, psi or kPa
3.11.4.6.2 Section dimension	Pole width at top, inches or mm
3.11.4.6.3 Section dimension	Pole width at bottom, inches or mm
3.11.4.6.4 Section dimension	Pole area at top, sq. inches or sq. mm
3.11.4.6.5 Section dimension	Pole area at bottom, sq. inches or sq. mm
3.11.4.6.6 Section property	Pole moment of inertia at top, $in.^4$ or mm^4
3.11.4.6.7 Section property	Pole moment of inertia at bottom, $in.^4$ or mm^4
3.11.4.6.8 Section dimension	Drilled hole diameter, inches or mm

Table 8-17 Properties for Piles with Nonlinear Bending Properties

Properties for Piles with Nonlinear Bending Properties	Lines 3.13
3.13.1 Section dimension	Length of section, ft or m
3.13.2 Shear capacity	Shear capacity of section, lbs or kN
3.13.3 Section dimension	Section diameter, inches or mm
3.13.4.1 Number of axial thrusts	Minimum = 1, maximum = 100
Repeat Lines 3.13.4.1.1 through 3.13.4.1.2.2 for every axial thrust value	
3.13.4.1.1 Axial thrust force	Axial thrust force in lbs or kN
3.13.4.1.2 Number of input *M-EI* values for Section or Number of input moment and curvature values for Section	Minimum = 2, maximum = 150
Repeat the following two lines for each input point	
3.13.4.1.2.1 Moment	Bending moment in in-lbs or kN-m
3.13.4.1.2.2 Bending Stiffness *EI* or Bending Curvature	Bending stiffness in lb-in^2 or kN-m^2, or bending curvature in rad/in or rad/m

Table 8-18 Concrete Properties

Concrete Properties	Lines
1 Compressive strength of concrete	psi or kPa
2 Maximum coarse aggregate size	in. or mm
3 Concrete tensile strength option	"Use default concrete tensile strength" (provided for future program option to utilize non-default value)
4 Concrete stress-strain curve option	"Use internal stress-strain curve for concrete" (provided for future program option to utilize user-defined stress-strain curve for concrete)

Table 8-19 Reinforcing Steel Properties

Reinforcing Steel Properties	Lines
1 Rebar option	Rebar number options: For no rebar enter: "No rebar" If not Section 1 and rebar data same as above section, enter: "Rebar Arrangement Same As Section Above" If Section 1 or rebar not same as above section enter: "Rebar Arrangement Same As Section Above"
2 Rebar pattern option	If rebar in circular pattern, enter: "Rebar in circle", and follow by Lines 3.1 through 3.7. If rebar in noncircular pattern, enter: "Rebar in noncircular pattern", and follow by

Reinforcing Steel Properties	Lines
	Lines 4.1 through 4.4.6
3.1 Circular pattern data	Yield stress of bars, psi or kPa
3.2 Circular pattern data	Young's modulus of bars, psi or kPa
3.2 Circular pattern data	Number of bars or bundles; Maximum = 300 for single bars, Maximum = 150 for 2-bar bundles, or Maximum = 100 for 3-bar bundles
3.3 Circular pattern data	Number of bars in bundle, 1 to 3
3.4 Circular pattern data	Bar diameter, inches or mm
3.5 Circular pattern data	Bar area, sq. in. or sq. mm
3.6 Circular pattern data	Rebar clear cover, inches or mm
3.7 Circular pattern data	Rebar circle offset from centroid of section, inches or mm
4.1 Non-circular pattern data	Yield stress of bars, psi or kPa
4.2 Non-circular pattern data	Young's modulus of bars, psi or kPa
4.3 Non-circular pattern data	Number of bars, Repeat line 5.4.4.1 through 5.4.4.6 for all bars in noncircular arrangement
4.4.1 Non-circular pattern bar data	Bar identification number
4.4.2 Non-circular pattern bar data	Bar size index number
4.4.3 Non-circular pattern bar data	Bar diameter, inches or mm
4.4.4 Non-circular pattern bar data	Bar area, sq. in. or sq. mm
4.4.5 Non-circular pattern bar data	Bar X-coordinate
4.4.6 Non-circular pattern bar data	Bar Y-coordinate

Table 8-20 Prestressing Strand Properties

Prestressing Strand Properties	Lines
1 Strand arrangement option	If strands in arranged pattern, enter: "Autoposition strands", and follow by Lines 2.1 through 2.7. If strands in non-arranged pattern, enter: "Manually-positioned strands", and follow by Lines 3.1 through 3.6.4.
2.1 Auto-arranged strand property	Strand family type, enter 1 for Grade 250 Lo-lax strands, 2 for Grade 270 Lo-lax strands, 3 for Grade 300 strands, 4 for Grade 145 smooth bars, 5 for Grade 160 smooth bars, 6 for deformed bars
2.2 Auto-arranged strand property	Stand size index number
2.3 Auto-arranged strand property	Number of strands
2.4 Auto-arranged strand property	Prestressing force, lbs or kN
2.5 Auto-arranged strand property	Fraction of prestress loss, decimal
2.6 Auto-arranged strand property	Strand clear cover, inches or mm

Prestressing Strand Properties	Lines
2.7 Auto-arranged strand property	Strand pattern type, enter 0 for circle, 1 for square, 2 for weak square
3.1 Manually-arranged strand property	Strand family type, enter 1 for Grade 250 Lo-lax strands, 2 for Grade 270 Lo-lax strands, 3 for Grade 300 strands, 4 for Grade 145 smooth bars, 5 for Grade 160 smooth bars, 6 for deformed bars
3.2 Manually-arranged strand property	Stand size index number
3.3 Manually-arranged strand property	Number of strands,
3.4 Manually-arranged strand property	Prestressing force, lbs or kN
3.5 Manually-arranged strand property	Fraction of prestress loss, decimal
Repeat Lines 3.6.1 through 3.6.4 for all strands	
3.6.1 Individual strand property	Strand identification number
3.6.2 Individual strand property	Strand size index
3.6.3 Individual strand property	Strand X-coordinate
3.6.4 Individual strand property	Strand Y-coordinate

8-5 SOIL LAYERS Command

Table 8-21 Soil Layer Properties

Soil Layer Properties	Lines
1 Number of soil Layers	Minimum = 1, maximum = 40
Repeat following lines for each soil layer	

Soil Layer Properties	Lines
2(1) Soil type index.	Enter 1 = soft clay, follow by lines 3.1 2 = API soft clay with *J*, follow by lines 3.2 3 = stiff clay with free water, follow by lines 3.3 4 = stiff clay without free water, follow by lines 3.4 5 = stiff clay without free, with *k* , follow by lines 3.5 6 = Reese sand, follow by lines 3.6 7 = API sand, follow by lines 3.7 8 = Liquefied sand, follow by lines 3.8 9 = Liquefied sand hybrid model, follow by line 3.9 10 = Reese weak rock, follow by lines 3.10 11 = vuggy limestone (strong rock) , follow by lines 3.11 12 = Piedmont residual soil, follow by lines 3.12 13 = massive rock, follow by lines 3.13 14 = loess, follow by lines 3.14 15 = silt (cemented c-ϕ soil) , follow by lines 3.15 16 = elastic subgrade, follow by lines 3.16 17 = user-input *p*-*y* curves, follow by lines 3.17
2(2) Depth of top of soil layer	Depth of top of soil layer below pile head, ft or m
2(3) Depth of bottom of soil layer	Depth of bottom of soil layer below pile head, ft or m

Table 8-22 Properties for Soft Clay

3.1 Properties for soft clay (3 values per line)	
3.1.1(1) Effective unit weight at top of layer	Effective unit weight in pcf or kN/m^3
3.1.1(2) Undrained shear strength at top of layer	Shear strength in psf or kPa
3.1.1(3) Strain factor E50 at top of layer	Strain factor ε_{50} (dimensionless), enter 0 for internal default value
3.1.2(1) Effective unit weight at bottom of layer	Effective unit weight in pcf or kN/m^3
3.1.2(2) Undrained shear strength at bottom of layer	Shear strength in psf or kPa
3.1.2(3) Strain factor E50 at bottom of layer	Strain factor ε_{50} (dimensionless), enter 0 for internal default value

Table 8-23 Properties for API Soft Clay

3.2 Properties for API soft clay with *J*	
3.2.1(1) Effective unit weight at top of layer	Effective unit weight in pcf or kN/m^3
3.2.1(2) Undrained shear strength at top of layer	Shear strength in psf or kPa
3.2.1(3) Strain factor E50 at top of layer	Strain factor ε_{50} (dimensionless), enter 0 for internal default value
3.2.1(4) Parameter *J* at top of layer	dimensionless
3.2.2(1) Effective unit weight at bottom of layer	Effective unit weight in pcf or kN/m^3
3.2.2(2) Undrained shear strength at bottom of layer	Shear strength in psf or kPa
3.2.2(3) Strain factor E50 at bottom of layer	Strain factor ε_{50} (dimensionless), enter 0 for internal default value
3.2.1(4) Parameter *J* at bottom of layer	dimensionless

Table 8-24 Properties for Stiff Clay with Free Water

3.3 Properties for stiff clay with free water (4 values per line)	
3.3.1(1) Effective unit weight at top of layer	Effective unit weight in pcf or kN/m^3
3.3.1(2) Undrained shear strength at top of layer	Shear strength in psf or kPa
3.3.1(3) Strain factor E50 at top of layer	Strain factor ε_{50} (dimensionless), enter 0 for internal default value
3.3.1(4) *p*-*y* modulus *k* at top of layer	*k* in lbs/in^3 or kN/m^3, enter 0 for internal default value
3.3.2(1) Effective unit weight at bottom of layer	Effective unit weight in pcf or kN/m^3
3.3.2(2) Undrained shear strength at bottom of layer	Shear strength in psf or kPa
3.3.2(3) Strain factor E50 at bottom of layer	Strain factor ε_{50} (dimensionless), enter 0 for internal default value
3.3.1(4) *p*-*y* modulus *k* at bottom of layer	*k* in lbs/in^3 or kN/m^3, enter 0 for internal default value

Table 8-25 Properties for Stiff Clay without Free Water

3.4 Properties for stiff clay without free water (3 values per line)	
3.4.1(1) Effective unit weight at top of layer	Effective unit weight in pcf or kN/m^3
3.4.1(2) Undrained shear strength at top of layer	Shear strength in psf or kPa
3.4.1(3) Strain factor E50 at top of layer	Strain factor ε_{50} (dimensionless), enter 0 for internal default value
3.4.2(1) Effective unit weight at bottom of layer	Effective unit weight in pcf or kN/m^3
3.4.2(2) Undrained shear strength at bottom	Shear strength in psf or kPa

3.4 Properties for stiff clay without free water (3 values per line)	
of layer	
3.4.2(3) Strain factor E50 at bottom of layer	Strain factor ε_{50} (dimensionless), enter 0 for internal default value

Table 8-26 Properties for Stiff Clay with Free Water Using *k*

3.5 Properties for stiff clay without free water using *k* (4 values per line)	
3.5.1(1) Effective unit weight at top of layer	Effective unit weight in pcf or kN/m^3
3.5.1(2) Undrained shear strength at top of layer	Shear strength in psf or kPa
3.5.1(3) Strain factor E50 at top of layer	Strain factor ε_{50} (dimensionless), enter 0 for internal default value
3.5.1(4) *p-y* modulus *k* at top of layer	*k* in lbs/in^3 or kN/m^3, enter 0 for internal default value
3.5.2(1) Effective unit weight at bottom of layer	Effective unit weight in pcf or kN/m^3
3.5.2(2) Undrained shear strength at bottom of layer	Shear strength in psf or kPa
3.5.2(3) Strain factor E50 at bottom of layer	Strain factor ε_{50} (dimensionless), enter 0 for internal default value
3.5.2(4) *p-y* modulus *k* at bottom of layer	*k* in lbs/in^3 or kN/m^3, enter 0 for internal default value

Table 8-27 Properties for Sand

3.6 Properties for Reese sand (3 values per line)	
3.6.1(1) Effective unit weight at top of layer	Effective unit weight in pcf or kN/m^3
3.6.1(2) Friction angle at top of layer	Friction angle in degrees
3.6.1(3) *p-y* modulus *k* at top of layer	*k* in lbs/in^3 or kN/m^3, enter 0 for internal default value
3.6.2(1) Effective unit weight at bottom of layer	Effective unit weight in pcf or kN/m^3
3.6.2(2) Friction angle at bottom of layer	Friction angle in degrees
3.6.2(3) *p-y* modulus *k* at bottom of layer	*k* in lbs/in^3 or kN/m^3, enter 0 for internal default value

Table 8-28 Properties for API Sand

3.7 Properties for API sand (3 values per line)	
3.7.1(1) Effective unit weight at top of layer	Effective unit weight in pcf or kN/m^3
3.7.1(2) Friction angle at top of layer	Friction angle in degrees
3.7.1(3) *p-y* modulus *k* at top of layer	*k* in lbs/in^3 or kN/m^3, enter 0 for internal default value
3.7.2(1) Effective unit weight at top of layer	Effective unit weight in pcf or kN/m^3
3.7.2(2) Friction angle at bottom of layer	Friction angle in degrees
3.7.2(3) *p-y* modulus *k* at bottom of layer	*k* in lbs/in^3 or kN/m^3, enter 0 for internal

3.7 Properties for API sand (3 values per line)	
	default value

Table 8-29 Properties for Liquefied Sand

3.8 Properties for liquefied sand (1 value per line)	
3.8.1 Effective unit weight at top of layer	Effective unit weight in pcf or kN/m^3
3.8.2 Effective unit weight at bottom of layer	Effective unit weight in pcf or kN/m^3

Table 8-30 Properties for Liquefied Sand Hybrid Model

3.9 Properties for liquefied sand hybrid model (4 values per line)	
Option 1 is to enter values for effective unit weight and SPT blowcount and zeros for residual strength and ε_{50}. Option 2 is to enter non-zero values for effective unit weight and for residual strength and ε_{50}.	
3.9.1(1) Effective unit weight at top of layer	Effective unit weight in pcf or kN/m^3
3.9.1(2) SPT blowcount at top of layer	SPT $(N_1)_{60\text{-cs}}$ blows/ft or blows/0.3 m
3.9.1(3) Residual strength at top of layer	S_r in psf or kPa
3.9.1(4) ε_{50} at top of layer	ε_{50}
3.9.2(1) Effective unit weight at bottom of layer	Effective unit weight in pcf or kN/m^3
3.9.2(2) SPT blowcount at bottom of layer	SPT $(N_1)_{60\text{-cs}}$ blows/ft or blows/0.3 m
3.9.2(3) Residual strength at bottom of layer	S_r in psf or kPa
3.9.2(4) ε_{50} at bottom of layer	ε_{50}

Table 8-31 Properties for Weak Rock

3.10 Properties for weak rock (5 values per line)	
3.10.1(1) Effective unit weight at top of layer	Effective unit weight in pcf or kN/m^3
3.10.1(2) Uniaxial compressive strength q_u at top of layer	Uniaxial compressive strength in psi or kPa
3.10.1(3) Initial rock mass modulus at top of layer	E_{mass} in psi or kPa
3.10.1(4) RQD at top of layer	RQD in percent
3.10.1(5) Parameter k_{rm} at top of layer	k in lbs/in^3 or kN/m^3, enter 0 for internal default value
3.10.2(1) Effective unit weight at bottom of layer	Effective unit weight in pcf or kN/m^3
3.10.2(2) Uniaxial compressive strength q_u at bottom of layer	Uniaxial compressive strength in psi or kPa
3.10.2(3) Initial rock mass modulus at bottom of layer	E_{mass} in psi or kPa
3.10.2(4) RQD at bottom of layer	RQD in percent
3.10.2(5) Parameter k_{rm} at bottom of layer	k in lbs/in^3 or kN/m^3, enter 0 for internal default value

Table 8-32 Properties for Vuggy Limestone

3.11 Properties for vuggy limestone (2 values per line)	
3.11.1(1) Effective unit weight at top of layer	Effective unit weight in pcf or kN/m^3
3.11.1(2) Uniaxial compressive strength q_u at top of layer	Uniaxial compressive strength in psi or kPa
3.11.2(1) Effective unit weight at bottom of layer	Effective unit weight in pcf or kN/m^3
3.11.2(2) Uniaxial compressive strength q_u at bottom of layer	Uniaxial compressive strength in psi or kPa

Table 8-33 Properties for Piedmont Residual Soil

3.12 Properties for Piedmont residual soil (6 values per line)	
3.12.1(1) Effective unit weight at top of layer	Effective unit weight in pcf or kN/m^3
3.12.1(2) Test type index	Enter 1 for SPT, 2 for cone penetrometer, 3 for dilatometer, or 4 for pressuremeter modulus
3.12.1(3) SPT blowcount at top of layer	Blows/foot or blows/ 0.3 m
3.12.1(4) Cone tip resistance at top of layer	q_{tip} in psi or kPa
3.12.1(5) Dilatometer modulus at top of layer	psi or kPa
3.12.1(6) Pressuremeter modulus at top of layer	psi or kPa
3.12.2(1) Effective unit weight at bottom of layer	Effective unit weight in pcf or kN/m^3
3.12.2(2) Test type index (a value must be entered but is ignored for bottom of layer)	Enter 1 for SPT, 2 for cone penetrometer, 3 for dilatometer, or 4 for pressuremeter modulus
3.12.2(3) SPT blowcount at bottom of layer	Blows/foot or blows/ 0.3 m
3.12.2(4) Cone tip resistance at bottom of layer	q_{tip} in psi or kPa
3.12.2(5) Dilatometer modulus at bottom of layer	psi or kPa
3.12.2(6) Pressuremeter modulus at bottom of layer	psi or kPa

Table 8-34 Properties for Massive Rock

3.13 Properties for massive rock	
3.13.1(1) Effective unit weight at top of layer	Effective unit weight in pcf or kN/m^3
3.13.1(2) Uniaxial compressive strength of intact rock at top of layer	Uniaxial compressive strength of intact rock in psi or kPa
3.13.1(3) Material index for layer	Hoek-Brown material index m_i
3.13.1(4) Poisson's ratio for layer	Poisson's ratio ν
3.13.1(5) GSI for layer	Geologic Strength Index

Option 1 is to input a non-zero value for modulus of intact rock and a value of zero for modulus of rock mass to have LPile compute the modulus for rock mass internally. Option 2 is to input a non-zero value for the modulus of rock mass.	
3.13.1(6) Modulus of intact rock for layer	Modulus of intact rock in psi or kPa
3.13.1(7) Modulus of rock mass for layer	Modulus of rock mass in psi or kPa
3.13.2(1) Effective unit weight at bottom of layer	Effective unit weight in pcf or kN/m^3
3.13.2(2) Uniaxial compressive strength of intact rock at bottom of layer	Uniaxial compressive strength of intact rock in psi or kPa
3.13.2(3) Material index for layer	Hoek-Brown material index m_i
3.13.2(4) Poisson's ratio for layer	Poisson's ratio ν
3.13.2(5) GSI for layer	Geologic Strength Index
3.13.2(6) Modulus of intact rock for layer	Modulus of intact rock in psi or kPa
3.13.2(7) Modulus of rock mass for layer	Modulus of rock mass in psi or kPa

Table 8-35 Properties for Loess

3.14 Properties for loess, (2 values per line)	
3.14.1(1) Effective unit weight at top of layer	Effective unit weight in pcf or kN/m^3
3.14.1(2) Cone tip resistance at top of layer	q_{tip} in psi or kPa
3.14.2(1) Effective unit weight at bottom of layer	Effective unit weight in pcf or kN/m^3
3.14.2(2) Cone tip resistance at bottom of layer	q_{tip} in psi or kPa

Table 8-36 Properties for Cemented Silt

3.15 Properties for cemented silt c-ϕ soil (5 values per line)	
3.15.1(1) Effective unit weight at top of layer	Effective unit weight in pcf or kN/m^3
3.15.1(2) Undrained shear strength at top of layer	Shear strength in psf or kPa
3.15.1(3) Friction angle at top of layer	Friction angle in degrees
3.15.1(4) Strain factor E50 at top of layer	Strain factor ε_{50} (dimensionless), enter 0 for internal default value
3.15.1(5) *p-y* modulus *k* at top of layer	*k* in lbs/in^3 or kN/m^3, enter 0 for internal default value
3.15.2(1) Effective unit weight at bottom of layer	Effective unit weight in pcf or kN/m^3
3.15.2(2) Undrained shear strength at bottom of layer	Shear strength in psf or kPa
3.15.2(3) Friction angle at bottom of layer	Friction angle in degrees
3.15.2(4) Strain factor E50 at bottom of layer	Strain factor ε_{50} (dimensionless), enter 0 for internal default value
3.15.2(5) *p-y* modulus *k* at bottom of layer	*k* in lbs/in^3 or kN/m^3, enter 0 for internal default value

Table 8-37 Properties for Elastic Subgrade

3.16 Properties for elastic subgrade (2 values per line)	
3.16.1(1) Effective unit weight at top of layer	Effective unit weight in pcf or kN/m^3
3.16.1(2) Elastic subgrade modulus at top of layer	pci or kN/m^3
3.16.2(1) Effective unit weight at bottom of layer	Effective unit weight in pcf or kN/m^3
3.16.2(2) Elastic subgrade modulus at bottom of layer	pci or kN/m^3

Table 8-38 Properties for User-Input *p-y* Curves

3.17 Properties for User-Input *p-y* Curves (2 values per line)	
3.17.1(1) Effective unit weight at top of layer	Effective unit weight in pcf or kN/m^3
3.17.1(2) Number of input *p-y* points for curve at top of layer	Number of points
Repeat Line 3.17.2 for each point on curve	
3.17.2(1) *y* value for curve at top of layer	inches or meters
3.17.2(2) *p* value for curve at top of layer	lbs/inch or kN/m
3.17.3(1) Effective unit weight at bottom of layer	Effective unit weight in pcf or kN/m^3
3.17.3(2) Number of input *p-y* points for curve at bottom of layer	Number of points
Repeat Line 3.17.4 for each point on curve	
3.17.4(1) *y* value for curve at bottom of layer	inches or meters
3.17.4(2) *p* value for curve at bottom of layer	lbs/inch or kN/m

8-6 PILE BATTER AND SLOPE Command

Table 8-39 Pile Batter and Ground Slope Properties

Pile Batter and Slope Properties	Lines
1 Ground slope	degrees
2 Pile batter	degrees

8-7 TIP SHEAR Command

Table 8-40 Tip Shear Curve Properties

Tip Shear Properties	Lines
1 Number of points	integer
Repeat Line 2 for all tip shear points	
2(1) Point number	Maximum coarse aggregate size, in. or mm
2(2) y value	Inches or meters
2(3) tip shear value	lbs or kN

8-8 GROUP EFFECT FACTORS Command

Table 8-41 Group Effect Properties

Group Effect Properties	Lines
1 Number of points	integer
Repeat Line 2 for all points	
2(1) Point number	integer
2(2) Depth below pile head	ft or meters
2(3) *p*-multiplier	Dimensionless
2(4) *y*-multiplier	Dimensionless

8-9 LRFD LOADS Command

Table 8-42 LRFD Load Properties

LRFD Load Properties	Lines
1 Number of LRFD unfactored loads	integer
Repeat line 2 and .3 for every load	
2(1)	Load number (starting with 1)
2(2) Load type index	Enter: 1 for dead load 2 for live load 3 for earthquake load 4 for impact load 5 for wind load 6 for water load 7 for ice load 8 for horizontal soil pressure 9 for live roof load 10 for rain load 11 for snow load 12 for temperature load 13 for special load
2(3) Horizontal shear force	lbs or kN
2(4) Moment	in-lbs or kN-m
2(5) Vertical load force	lbs or kN
2(6) Number of distributed lateral load points	integer
Repeat line 12.3 for each distributed lateral load point for this unfactored load	
3.(1) Point number	integer
3(2) Depth below pile head	in or meters
3(3) Lateral load intensity	lbs/in or kN/m

8-10 LRFD FACTORS AND CASES Command

Table 8-43 LRFD Load Factors and Loading Case Properties

Concrete Properties	Lines
1 Number of load combinations	Minimum = 1, maximum = 100
Repeat line 2 for every load combination	
2(1) dead load factor	Dimensionless
2(2) live load factor	Dimensionless
2(3) earthquake load factor	Dimensionless
2(4) impact load factor	Dimensionless
2(5) wind load factor	Dimensionless
2(6) water load factor	Dimensionless
2(7) ice load factor	Dimensionless
2(8) horizontal soil pressure load factor	Dimensionless
2(9) live roof load factor	Dimensionless
2(10) rain load factor	Dimensionless
2(11) snow load factor	Dimensionless
2(12) temperature load factor	Dimensionless
2(13) special load factor	Dimensionless
2(14) resistance factor for moment	Dimensionless
2(15) resistance factor for shear	Dimensionless
2(16) Name of load combination	Text

8-11 LOADING Command

Table 8-44 Conventional Loading Properties

Conventional Loading Properties	Lines
1 Number of load cases	Integer
Repeat Line 2 for all load cases	
2(1) Load number	Integer
2(2) Pile-head condition	Enter: 1 for shear and moment, 2 for shear and slope, 3 for shear and rotational stiffness, 4 for displacement and moment, 5 for displacement and slope
2(3) Pile-head condition 1	Enter shear force for conditions 1, 2, or 3 in lbs or kN Enter displacement for conditions 4 or 5 in inches or meters
2(4) Pile-head condition 2	Enter moment for condition 1 or 4 in in-lbs or kN-m Enter slope for condition 2 in radians Enter rotational stiffness for condition 3 in in-

Conventional Loading Properties	Lines
	lbs/rad. or kN-m/rad. Enter slope for condition 4 in radians
2(5) Axial thrust load	Lbs or kN
2(6) Toggle for computation of top deflection versus pile length for this load condition	Enter 0 for no, 1 for yes
If UseDistributedLoading NO has been input under OPTIONS, omit lines 3 and 4. If UseDistributedLoading ONE has been input under OPTIONS, enter lines 3 and 4once. If UseDistributedLoading ALL has been input under OPTIONS, enter lines 3 and 4 for every load case	
3 Number of distributed lateral loading points	Enter 0 for no distributed lateral loading, Enter number of loading points to enter distributed lateral loading data
Repeat Line 4 for all distributed lateral loading points	
4(1) Load point number	dimensionless
4(2) Depth below pile head	Feet or meters
4(3) Distributed lateral loading intensity	lbs/inch or kN/m

8-12 P-Y OUTPUT DEPTHS Command

Table 8-45 *p-y* Output Depth Properties

p-y Output Depth Properties	Lines
1 Number of output depths	integer
Repeat Line 2 for all depths	
2 Depth of output *p-y* curve	ft or meters

8-13 SOIL MOVEMENTS Command

Table 8-46 Soil Movement Properties

Soil Movement Properties	Lines
1 Number of soil movement points	integer
Repeat Line 2 for all depths	
3 Depth below pile head	ft or meters
4 Lateral soil movement	inches or millimeters

8-14 AXIAL THRUST LOADS Command

Table 8-47 Axial Thrust Loads for *EI* Computations Only

Axial Thrust Properties	Lines
1 Number of axial thrust values	Compressive strength of concrete, psi or kPa
Repeat Line 2 for all axial thrust values	
2 Thrust load number, axial thrust	Two values per line (thrust number, thrust value)

8-15 FOUNDATION STIFFNESS Command

Table 8-48 Foundation Stiffness Computations

Controls for Computation of Foundation Stiffness Computations	Lines
1 Computation method	Integer 1 = Use force and moment from Load Case 1 2 = Use pile-head deflection and rotation from Load Case 1 3 = Use specified values of pile-head deflection and rotation
2 Number of points to compute	Integer
3 Point distribution method	Integer, 0 = logarithmic distribution, 1 = arithmetic distribution
If computation method = 2, enter values for pile-head deflection and rotation	
4 Pile-head deflection	Inches or meters
5 Pile-head rotation	Radians

8-16 PILE PUSHOVER ANALYSIS DATA Command

Table 8-49 Pushover Analysis Computations

Controls for Pile Pushover Analysis Computations	Lines
1 Computation method	Integer 0 = pinned head 1 = fixed head 2 = pinned and fixed head
2 Point distribution method	Integer, 0 = logarithmic distribution, 1 = arithmetic distribution 2 = user-specified displacements
If point distribution method = 0 or 1, enter Lines 3, 4, and 5	
3 Number of points to compute	Integer
4 Maximum pile-head deflection	Inches or meters
5 Minimum pile-head deflection	Inches or meters
If point distribution method = 2, enter Lines 6 and 7	
6 Number of user-specified displacements	Integer
Repeat Line 7 for every user-specified pushover displacement	
7 User-specified pushover displacement	Inches or meters
8 Axial thrust force	Lbs or kN

8-17 PILE BUCKLING ANALYSIS DATA Command

Table 8-50 Pile Buckling Analysis Data

Pile Buckling Analysis Data	Lines
1 Pile-head fixity condition	0 = shear and moment 1 = shear and slope 2 = shear and rotational stiffness
2 Number of loading steps	Integer, maximum 50
3 Pile-head shear	Lbs or kN
4 Pile-head moment	In-lbs or kN-m
5 Pile-head rotational stiffness	In-lbs/radians or kN-m/radians
6 Maximum axial compression load	Lbs or kN

8-18 LRFD Data File

The LRFD data file is used to store load and resistance factors in a format that also defines load case combinations and load case names. The purpose of this data file is to eliminate the need to input data that may be common to many analyses.

The LRFD data file is a plain text (ASCII) file. The LRFD data file is read from the Program Options and Settings dialog (see Section 3-4 on page 23 for more information about the Program Options and Settings dialog). Any edited set of LRFD load and resistance factors and load combinations may be saved as an LRFD file from the File Menu. It is suggested that the user use the editing features of LPile to create any LRFD data file.

The file extension for the LRFD data file is *lrfd*.

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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."

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.

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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]

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.

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[1] Note, the warning message number is not displayed by LPile

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.