

SHAFT v2026 – User's Manual

**A Program for the Study
of Drilled Shafts & CFA Piles
under Axial Loads**

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CHAPTER 1. Introduction

1.1 General Description

It is beyond the scope of this document to discuss methods of construction, but it is certainly appropriate to emphasize the importance and influence of these methods. While past failures of drilled shafts to perform properly under axial loading have been relatively rare, the difficulties that have been reported, almost without exception, have been related to errors in construction. Therefore, the user of the SHAFT software is urged to give careful attention to the preparation of construction specifications and to the performance of field inspection by qualified personnel to ensure that good construction is achieved.

At the present time it is well established that drilled shafts can carry a substantial portion of their load in skin friction or side resistance. Much of the data from field tests of instrumented drilled shafts show that the initial loads are sustained almost completely by skin friction. Usually, at a relatively small downward movement, the full resistance in skin friction is mobilized and the remaining load is carried in end bearing. At the ultimate load, a sizeable portion may be carried in end bearing but at a significant amount of downward movement of the drilled shaft. In some instances, there is some reduction in the load carried in side resistance as the downward movement is continued, due probably to the reduction in shear strength of the soil along the sides of the shaft. Thus, the designer must take into account the amount of downward movement and the resulting influence on load transfer when both end bearing and skin friction are being counted on.

As noted above, tests of instrumented drilled shafts have allowed the load that was transferred to the soil in skin friction (side resistance) to be measured and correlations have been developed between the skin friction and soil properties. The scatter in the correlation is relatively small where excellent methods of construction were employed. However, there are several reasons to use caution in making designs that depend strongly on skin friction: the number of instrumented tests is relatively small, there are some types of soil where tests have not been performed, and the load transfer in skin friction is influenced strongly by construction procedures. Therefore, designs that make use of skin friction must be made with care or field load tests must be made to prove the design or to obtain revised design parameters.

SHAFT is a special-purpose program based on rational procedures for analyzing a drilled shaft and continuous flight auger piles under axial loading. The program computes settlement of the top and base of the shaft as a function of axial loading, along with the distribution of axial load along the length of the shaft.

1.2 History of Development

1.2.1 SHAFT1 (1987)

With the advent of wide-spread availability of personal computers, the founder of ENSOFT, Inc., had a vision to improve the engineering capability for analysis and design of deep foundations by providing useful and practical software tools. The development of SHAFT1 was completed under the direction of Dr. Lymon C. Reese and was first commercially distributed in 1987. While based on an earlier mainframe program, SHAFT1 was developed to use an interactive input method in DOS.

1.2.2 SHAFT, Version 2 (1989)

Version 2 of SHAFT was released in 1989. This version incorporated the improved methods of analysis developed by Reese and O'Neill (1988). In addition, a new menu-based DOS interface was introduced.

1.2.3 SHAFT 3.0 for Windows (1995)

The success of Windows 3.1 from Microsoft, Inc., as the dominant platform for personal computers pushed software development to adopt a standard, graphical-user interface. This version of SHAFT utilized Windows-based pre-and post-processors, while retaining the original computation engine from Version 2.

1.2.4 SHAFT 4.0 for Windows (1998)

SHAFT 4.0 was a complete recoding of both the pre-and post-processing programs running under Windows 95/NT and the computation engine. The graphical-user interface was coded to provide a more intuitive process for data input and to enhance the graphical capabilities.

In addition, in the technical side, Version 4 includes new capabilities to analyze drilled shafts in intermediate geomaterials, such as gravel and soft rock. Version 4 was capable of automatically computing capacities for shaft subjected to uplift forces.

1.2.5 SHAFT 5.0 for Windows (2001)

This version of SHAFT has been improved over the previous version in that the computational methods have been updated to conform to the recommendations by the Federal Highway Administration (FHWA, 1999). In addition, the graphical output features have been updated to allow the user to plot both the ultimate and service load cases for the shaft. SHAFT 5.0 also included an updated help file that contained information on all areas of the program where the user is asked to input information, as well as information on program output.

1.2.6 SHAFT 6.0 for Windows (2007)

SHAFT Version 6.0 added new soil criteria for computing the axial capacity of drilled shafts in strata of gravelly sand and gravel based on the studies by Rollins et al (2005). Another new feature in Version 6.0 is to allow the user to include both side friction and tip resistance for drilled shafts in strong rock (for comparative purposes). The load-versus-settlement curve at the top of drilled shafts in soils had become important for structural engineers in specifying the stiffness of the foundations. The new version of SHAFT allowed users to compare the upper-bound, lower-bound, and trend (averaged) curves together for engineering assessment. The user may specify the increment length, such as 1 ft, 2 ft, 1 m, or 2 m, for printing the output. SHAFT Version 6.0 also generates t - z curves for each soil layer and saved the data in an external file. The graphics allow the user to present the soil profile along the predicted pile capacity as a function of depth.

1.2.7 SHAFT 2012 (v7)

The SHAFT program used the year number in the version sequence starting in 2012. The major improvement in v2012 was to provide options for specifying the reduction factors on side friction and tip resistance for each soil/rock layer if the user selects the LRFD method for design. The option for the conventional Allowable Stress Design (ASD) method through specifying factors of safety is still available in SHAFT 2012. The program allows the user to change the line width and font sizes in the generated plots. In addition, the v2012 release introduced compatibility to Windows 8. The program text book was updated and released in separate User's and Technical Manuals, both improved plus released electronically in protected PDF format.

1.2.8 SHAFT 2017 (v8)

A number of major improvements were implemented in SHAFT v2017 (equivalent to SHAFT v8 when using the old release numbering).

1.2.8.1 Computational Changes

1. New option to generate curves of load settlement with pile penetration.
2. New option to generate design curves (capacity vs penetration/diameter) for specified settlements.
3. New option to estimate side friction using Kulhawy and Chen Method for Sand.
4. Expanded computations of side resistances for sand based on SPT blow counts (when provided).

1.2.8.2 Interface Changes

5. Added a new option to display elevations instead of depth for vertical axes in all applicable plots.
6. This release also includes a change in the data format for the input data files (now using the extension “sf8d” for the new input-data files). An input-data converter is introduced to read older data files and make them compatible to the new format.
7. Updated interface and speed buttons.
8. New prints of t - z curves and Q - w curves as text in file extension “sf8z”. Depending on the model type, the new t - z curves may correspond to maximum shaft length, initial shaft diameter and for averaged values. Depending on the model type, the new Q - w curves may correspond to maximum shaft length, various shaft diameter and for averaged values.
9. Added a new 3D view window where users can choose to see the soil layers, depths and load transfers with depth for the modeled shaft.

1.2.8.3 File Handling Changes

10. The File > Open dialog box has been updated with more user-friendly features for navigation.
11. Any of the output graphics from the new SHAFT program can be exported to a pre-formatted spreadsheet with multiple descriptive tabs.
12. t - z and Q - w curves outputted by the program or at depths required by the user can now be exported to text or pre-formatted spreadsheet. Depending on the model type, the new t - z curves may correspond to maximum shaft length, initial shaft diameter and for averaged values. Depending on the model type, the new Q - w curves may correspond to maximum shaft length, various shaft diameter and for averaged values.

1.2.9 SHAFT 2023 (v9)

The most important improvements implemented in SHAFT v2023 (equivalent to SHAFT v9 when using the old release numbering) are included in the list below.

1. Introduced computational methods for estimating the axial capacity of continuous flight auger (CFA) piles. CFA pile capacity is estimated using recommended methods for Clay and Sand:
- Reese & O'Neill Method (Using Undrained Shear Strength or SPE Values)

- Coleman and Arcement (2002) Method (Using CPT or SPT Values)
- Laboratoire Des Ponts et Chaussées (LPC) method (Using CPT Values)
- 2. Expanded the Sand (FHWA) criteria by adding recommendations from GEC-10 using the values from Over Consolidation Ratio.
- 3. Added the Brown et al (2018) GEC-10 criteria for FHWA Clay & Shale to the existing FHWA criteria from Reese & O'Neill (1988). Users now have the option to select entries of undrained cohesion based on three different laboratory tests: unconfined compression (UC) test, unconsolidated undrained (UU) triaxial compression, and consolidated isotropically undrained triaxial compression (CIUC).
- 4. Improved the scaling and presentation of plots in models with negative elevations (instead of depths).
- 5. All changes to plot/graphics (titles, legends, etc) done by the user are now associated and saved with the SHAFT model.
- 6. Users are now able to open the new v2023 Technical Manual in standard PDF file format.
- 7. Minor changes were also made throughout the program interface to improve data input and output displays.

1.2.10 SHAFT 2026 (v10)

New features and enhancements in SHAFT v2026 are as follows:

1. Allows for the new input of **User-Defined Soil Layer** (under **Data > Soil Layer Data > Soil Type**) so users can enter specific values of Unit Side Friction, Unit End Bearing and Total Unit Weight plus select the base shape of $t-z$ and $Q-w$ curves of their preference (either **Clay** or **Sand**). This feature is very useful for a site where an internally-instrumented test pile of smaller diameter (to reduce test costs) provided unit skin friction for several layers, plus unit end bearing for the layer at the tip. Using this input, SHAFT can easily estimate the axial response (capacity and movements) of production piles with different diameters than the test pile.
2. New computation results and graphs of estimated axial load distribution and axial displacement distribution versus pile penetration (**Graphics > Load Distribution** and **Graphics > Axial Displacement Distribution**).
3. New feature to evaluate if group reduction factors would be applicable when the modeled pile is in close spacing with others nearby. Under **Data > Evaluate Pile Group Effects** users can now quickly evaluate the group effects for piles on a Rectangular, Circular or General plan layout. For each layout, results are quickly computed and displayed under **Graphics > Combined Plot Single Pile Factor**, where users can check the applicable reduction factor for each pile depth (and the influence/contribution that was originated from side resistance and end bearing).
4. Users can now evaluate any swelling layer of **Clay** by entering negative **Alpha** values in the soil properties, so as to see the effects on pile capacity and penetration.
5. New feature to evaluate **DownDrag** for any specified depths of soil in a pile model (under **Data > Evaluate Down Drag**). The effects from **DownDrag** can be visualized in resulting graphs of Unit Skin Friction, Ultimate Skin Friction, Total Capacity and Axial Load vs Settlement.

6. Users can now select to **Generate a Formatted Report** in Microsoft Word format (under **Computation** menu). The user may select to include in the formatted report several tables to echo print the user's model data and also several different output tables and graphs.
7. Many improvements are also made to operational features and smaller technical additions, such as:
 - The **Computation > View Shaft Elevation** is now displayed on the background when opening existing SHAFT models.
 - Added new features to the **Plot** dialog when observing any **Graphics** results, so users can select to **Copy data to clipboard** and paste into a spreadsheet (or other software) all the X and Y data of the selected plot for further editing.
 - The new **Plot** dialog also allows to **Copy as image to clipboard** so the image can be pasted into other software to incorporate into a presentation or for further editing.
 - User-selected depths for printing of internally-generated t-z curves have been increased to 100 (upgraded from 50 in previous version).
 - Improved status bar, now displaying license status and position of cursor in **Computation > View Shaft Elevation** screen and in all **Graphics** plots.
 - Added **Data > Control Options** for Program Startup so users can **Check for Program Update on Startup** and/or **Check on Maintenance/Subscription Date on Startup**.
8. For models with any **Rock** layers (particularly **Decomposed Rock**) this version improves the procedure to estimate rock socket length in order to estimate better the load settlement curves.
9. A new request for 'username' entry is provided when the program first starts after a fresh software installation. This 'username' can be edited at any time in the '**Help > User Information**' menu. The user can enter any line of information to personalize the individual installation of the APILE software, thus identifying the person that ran the analyses.
10. Introduction and management of optional Cloud Subscription Licensing along with Single Sign On (SSO) feature for licenses with large corporations (Enterprise Level Remote Subscription Licenses) to ease the login and licensing process for their unlimited number of users.
11. Released new Technical and User's Manuals.

1.3 Organization of SHAFT Manuals

The documentation provided with the computer program SHAFT consists of two volumes. The User's Manual contains full documentation about the operation of the program on personal computers. The User's Manual covers the areas of installation, preparation of input data, program execution, view of computational results, and example applications. The distribution of the User's Manual is made via standard & unprotected Adobe® PDF file format.

The Technical Manual provides information about the theories of load-transfer and settlement of drilled shafts in different types of soil/rock strata. The Technical Manual includes other helpful references related to concepts utilized in program SHAFT. ENSOFT holds a copyright of the Technical Manual so it is distributed in protected form that can only be opened by licensed users of the SHAFT program.

Both Manuals are installed with the SHAFT program and accessible via any one of the following three methods: i) from the Windows Start Menu, ii) from the Ensoft tile in Windows 10, 8 and 8.1, or iii) from the Help menu within the SHAFT program.

1.4 Typographical Conventions

To orient the user to different program features, certain terms are set in typefaces that distinguish them from the body text. The following formatting conventions are used throughout the manuals:

- Commands that are typed directly on the keyboard: “Enter” ; “F1” ; “Esc”
- Commands with keys simultaneously pressed in the keyboard: “Alt+F” ; “Ctrl+O”
- Menu items and other text displayed on the screen are in sans serif:
From the File menu choose Open
- File names and names of directories and folder and icon names are in italics:
Open the example file *example1.sf10d*
- Internet and electronic mail addresses are underlined:
Send email to support@ensoftinc.com

1.5 Contents of the SHAFT Package

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

- One USB Key, similar to Figure 1.1. This is a gray (new version) or black (old version) colored USB-based hardware security key (dongle), with a plastic tag indicating its unique serial number, licensed site (office name and location) and name of licensed software. Each USB Key is programmed with the purchased Ensoft Software. The USB Key for a single-user license can be used on any computer when plugged directly into a working USB port of the computer in use (it cannot be shared over a network). The USB Key for a local network license is plugged on a License Server.
- One USB Memory Stick, similar to Figure 1.2. This is a standard memory stick with either silver (new version) or white (old version) flip casing. This memory stick contains installation programs for all Ensoft Software that were available at the time of shipment. Manuals are installed with each software in electronic form using protected PDF files. The USB Memory Sticks may be discarded or reformatted for other uses. Latest updates of all Ensoft Software are always available at www.ensoftinc.com/downloads



a. New Gray Metal Casing



b. Old Black Plastic Casing

Figure 1.1 Sample USB Key for Ensoft Software.



Figure 1.2 Sample USB Memory Stick.

In the optional Cloud Subscription Licensing of SHAFT v2026 there is no longer any need for a shipment of USB Key or USB Memory Stick since users can download the software and are assigned with the proper authorization that is checked when with access to the internet.

1.6 Default Installation Directories

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

1.6.1 Directory for Main Program Files

Program files are installed by default in the following directory:

Root Drive:\Program Files\Ensoft\Shaft2026

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

c:\Program Files\Ensoft\Shaft2026

Main program files are the following:

winsh2026.exe is the main Windows-program module (executable/application),

SHAFT2026_DLL.dll is the program engine for direct computations,

User's and Technical Manuals are also included in the main installation directory.

1.6.2 Directory for Example Files

Several modeling examples with input files (files with name/extension of the type *filename.sh9d*) are installed on a separate folder that defaults to:

Root Drive:\Ensoft\Shaft2026-Examples

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

c:\Ensoft\Shaft2026-Examples

1.7 Hardware Requirements

To use this software, the user needs the following minimum hardware configuration:

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

1.8 Technical Support

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

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

1.8.1 Preferred Methods of Software Support

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

- Electronic mail to: support@ensoftinc.com
- Fax to: (512) 244-6067
- Telephone call to: (512) 244-6464, extension 2

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

- full software version/release/update (obtained from the Help > About dialog),
- a description of the user's problem or concern,
- attach a copy of the input-data file that is associated with the issue/concern (files with name/extension of the type *filename.sf10d*), and
- name and telephone number of the contact person and of the licensed user (or name and office location of the licensed company site and/or serial number of the USB Key).

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

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

1.8.2 Upgrade Verification and Internet Site

Starting from SHAFT v2012 the software provides options for the user to check the most recent maintenance release through an internet connection by selecting **Help > Check for Updates** from within the software. This command starts the default internet browser and will display the user's maintenance expiration date, the user's software release number and the most recent release number that is available for downloading.

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

1.8.3 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. There are small price increases with time after expiration. The pricing policy for renewing a program maintenance that has not expired can be found on the Ensoft website at https://www.ensoftinc.com/order_form

1.8.4 Changes of Support Policy

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

CHAPTER 2. Installation and Getting Started

2.1 Installation Procedures

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

Users with standard single-user licenses can check the following link to a PDF with Installation Notes: https://www.ensoftinc.com/doc/Ensoft_Single-User_License_Installation_Booklet.pdf

Users with local network licenses can check the following link to a PDF with Network Installation Notes: https://www.ensoftinc.com/doc/Ensoft_Network_License_Installation_Booklet.pdf

2.1.1 Installation of Single-User Version

This version of SHAFT has been tested to be compatible with the following versions of the Microsoft Windows® operating systems: 2000, XP, Vista, and Windows 7 and 8, 8.1, 10 and 11 in 32 and 64-bit releases.

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

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

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

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

6. Select **Single-User License** in Figure 2.3 then click **Next**. For network installations please contact Ensoft support (support@ensoftinc.com).
7. The user will be provided with an option to select a drive and directory for the installation of example files (see Figure 2.4). Default installation directory is the following:

(Root Drive):\Ensoft\Shaft2026-Examples

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

(Root Drive):\Program Files\Ensoft\Shaft2026

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

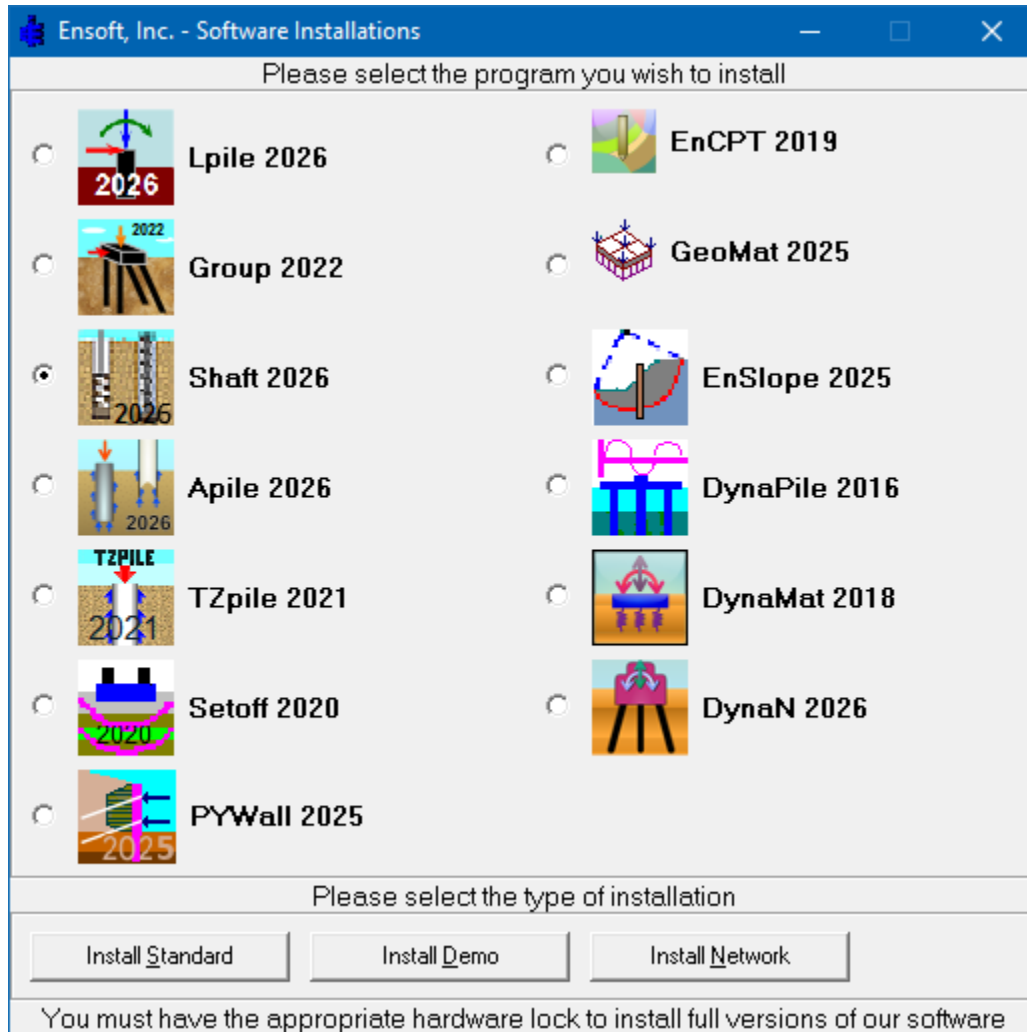


Figure 2.1 Main installation screen for ENSOFT software (may change with time)

9. During the installation the user will be asked to set the file extension association for opening SHAFT v2026 input data files (see Figure 2.6). If the user agrees (leaves the default check mark) then double clicking (or running) any input data file with extensions of the type *filename.sf10d* will start the installed SHAFT v2026 software.
10. The user will be prompted to confirm the shortcut directory name that will be created in the Windows Start Menu (See Figure 2.7). The default is *Start Menu/Programs/Ensoft/Shaft2026*. Windows 11, 10 and 8 will automatically create an Ensoft tile with the same shortcuts.

After the installation is finished, it is usually not necessary to reboot Windows for the program to run. The user may run the program by selecting Shaft v2026 from the standard links installed in the Microsoft Windows® Start Menu: Start Menu > All Programs > Ensoft > Shaft2026



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

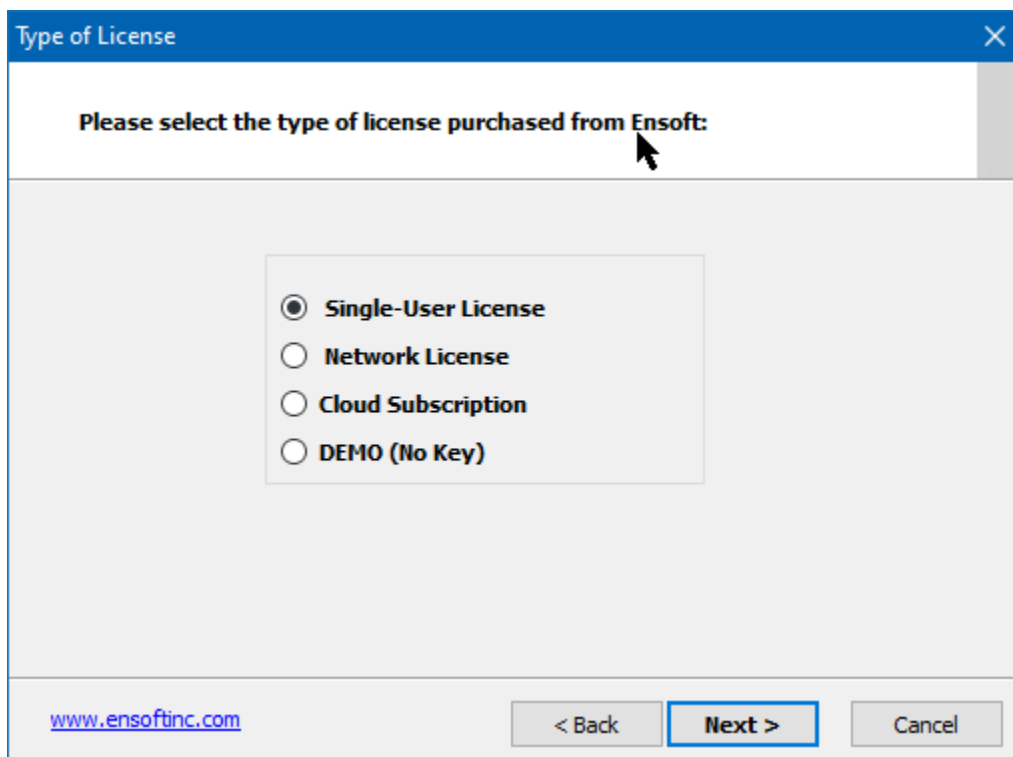


Figure 2.3 Selection of Single-User License (may change with time)

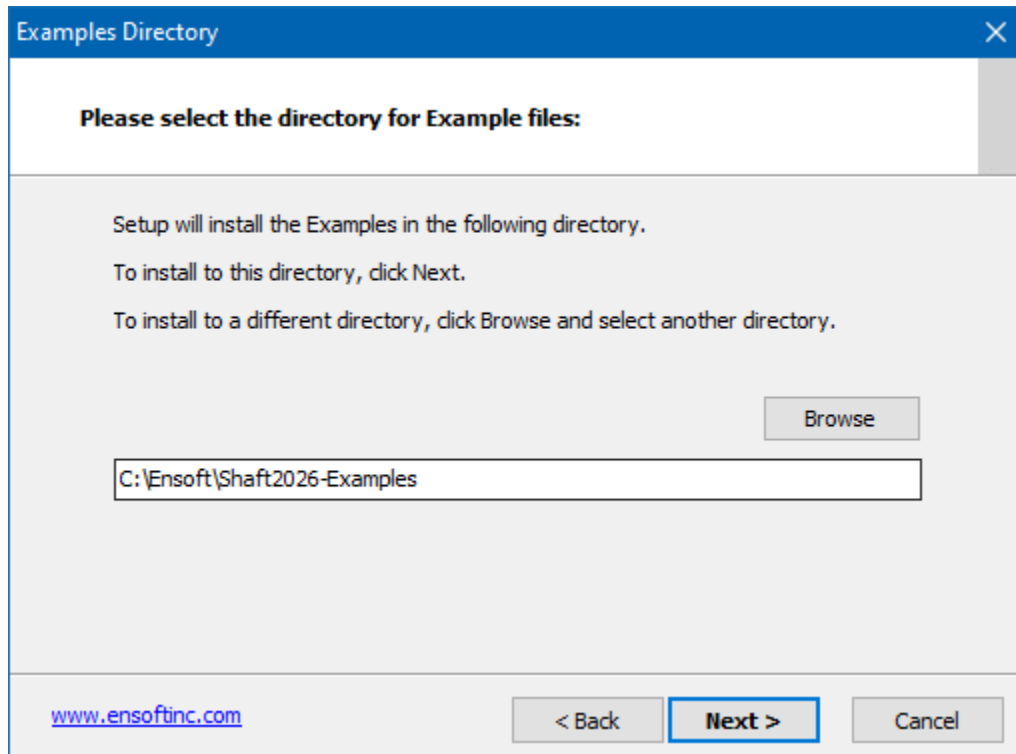


Figure 2.4 Default Installation Directory for Example Files (may change with time)

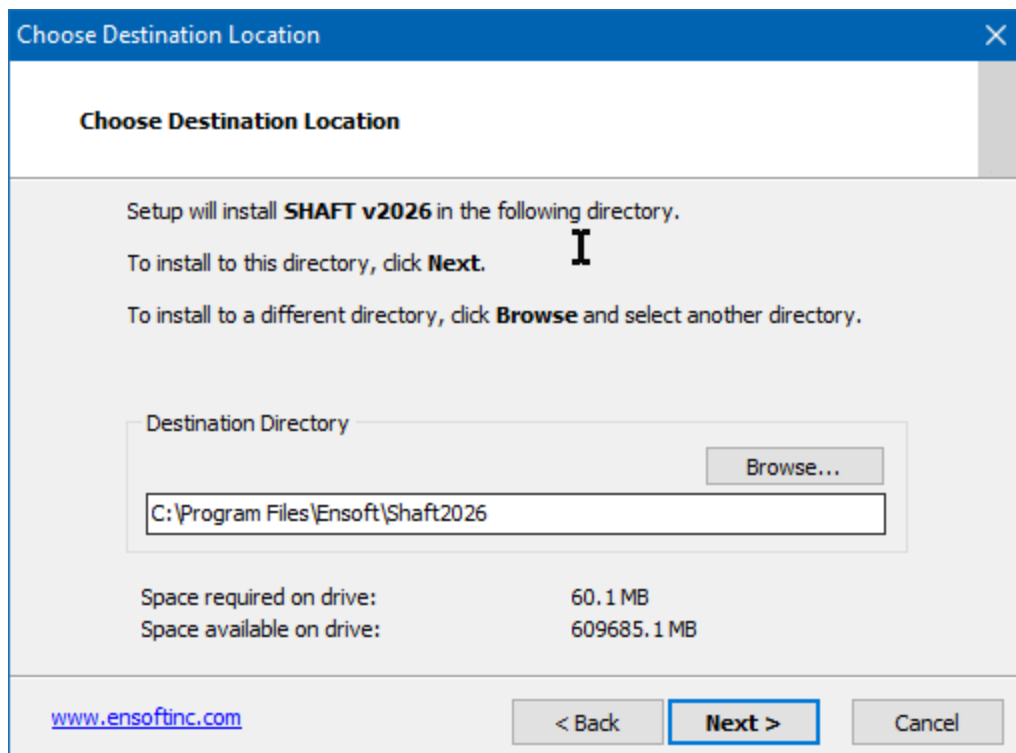


Figure 2.5 Default Installation Directory for Program Files (may change with time)

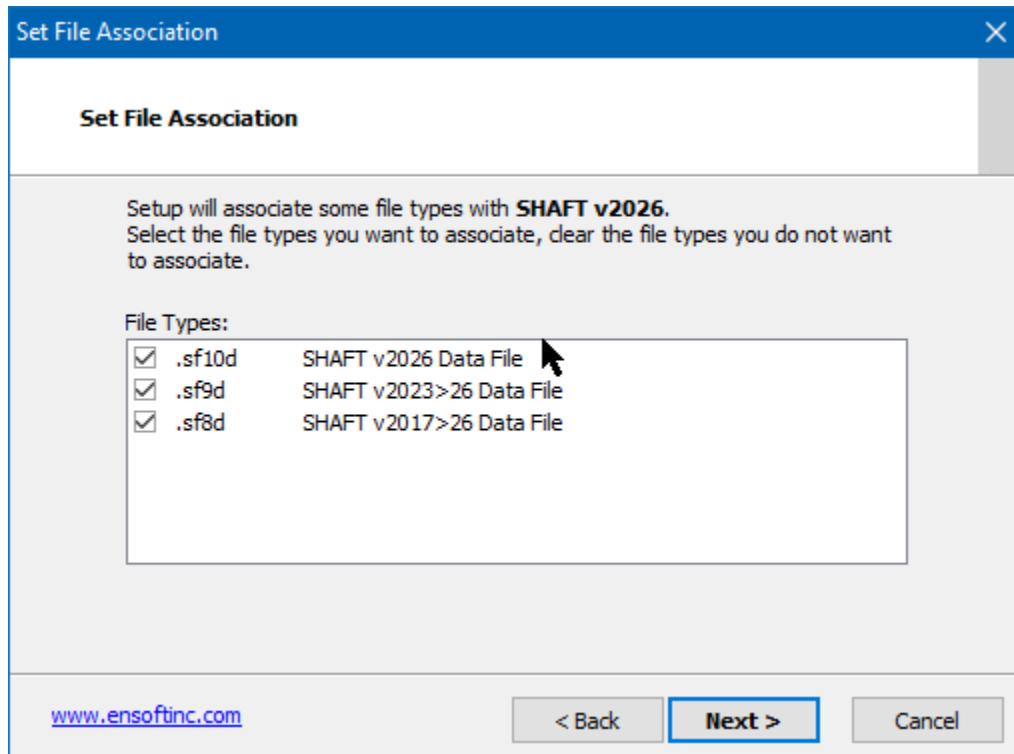


Figure 2.6 File Extension Association for Shaft Data Files (may change with time)

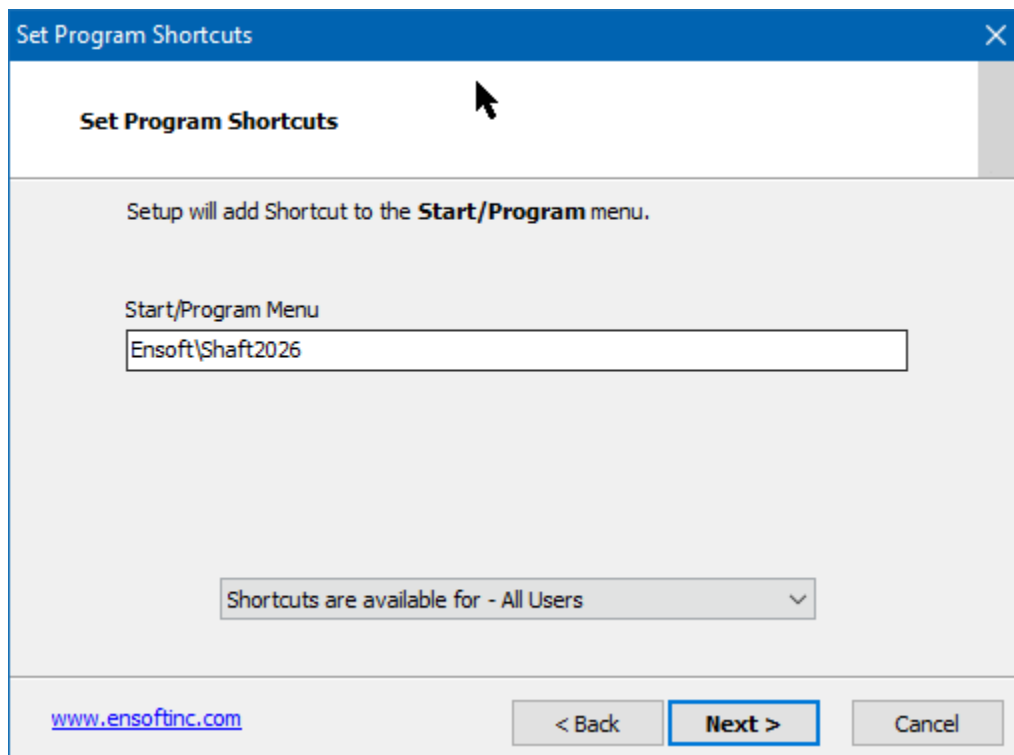


Figure 2.7 Default Shortcut Folder in Windows Start Menu (may change with time)

2.1.2 Installation of Cloud Subscription Version

The latest Ensoft Software updates are compatible with all recent versions of the Microsoft Windows® operating system, including 11, 10. The following guidelines are recommended for the installation of cloud licenses.

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

<https://www.ensoftinc.com/downloads>

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

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

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

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

3. Select **Cloud Subscription** in Figure 2.3 then click **Next**. For single-user installations see Section 2.1.1. For network installations see Section 2.1.3.
4. Ensoft currently offers three types of **Cloud Subscription Licenses**: Personal, Office and Enterprise. The most common selection is **Personal/Office** since the **Enterprise** is only for very large customers (see Figure 2.8).
5. The user will be provided with an option to select a drive and directory for the installation of example files (see Figure 2.4). Default installation directory is the following:

(Root Drive):\Ensoft\Shaft2026-Examples

6. The user will also be asked to select a drive and directory for the installation of the software (see Figure 2.5). Default installation directory (varies according to the Windows release where it is installed) is one of the following:

(Root Drive):\Program Files\Ensoft\Shaft 2026

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

6. During installation the user will be asked to set the file extension association for opening SHAFT v2026 input data files (see Figure 2.6). If the user agrees (leaves the default check mark) then double clicking (or running) any input data file with extensions of the type *filename.sf10d* will start the installed SHAFT v2026 software.
7. The user will be prompted to confirm the shortcut directory name that will be created in the Windows **Start Menu** (See Figure 2.7). The default is *Start Menu/Programs/Ensoft/Shaft2026*. Windows 11, 10 will automatically create an **Ensoft** tile with the same shortcuts.
8. After copying files, the installer may check if the user's Windows OS has the necessary Microsoft Visual C++ drivers. If those are not found the user will be prompted to install (Figure 2.9) and must agree to terms and select the **Install** button. If the drivers are present, the user will be prompted with Figure 2.10 where you can simply select the **Close** button.

After the installation is finished, it is usually not necessary to reboot Windows for the program to run. The user may run the program by selecting **Shaft v2026** from the standard links installed in the Microsoft Windows® Start Menu: **Start Menu > All Programs > Ensoft > Shaft2026**

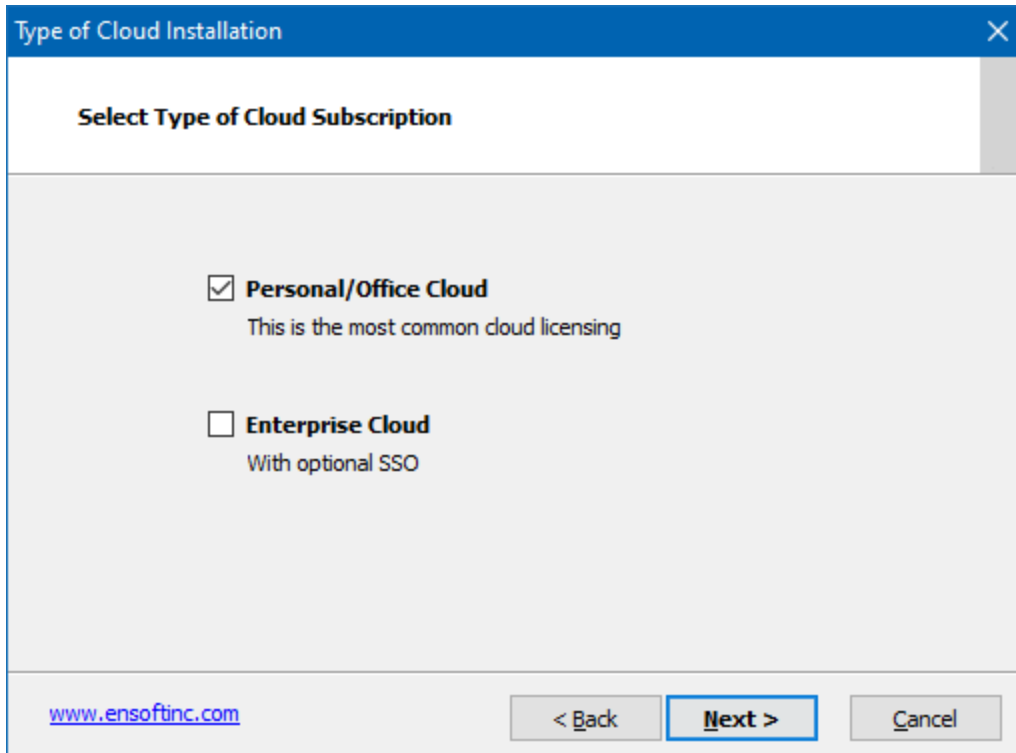


Figure 2.8 Selection of Type of Cloud Subscription (may change with time)

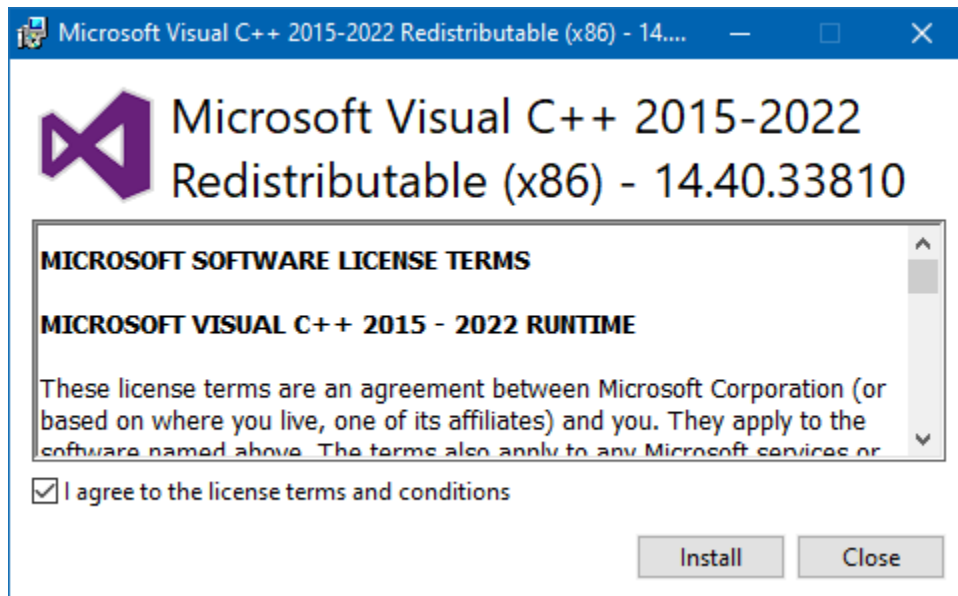


Figure 2.9 Consent for Installation of Microsoft Visual++ Drivers

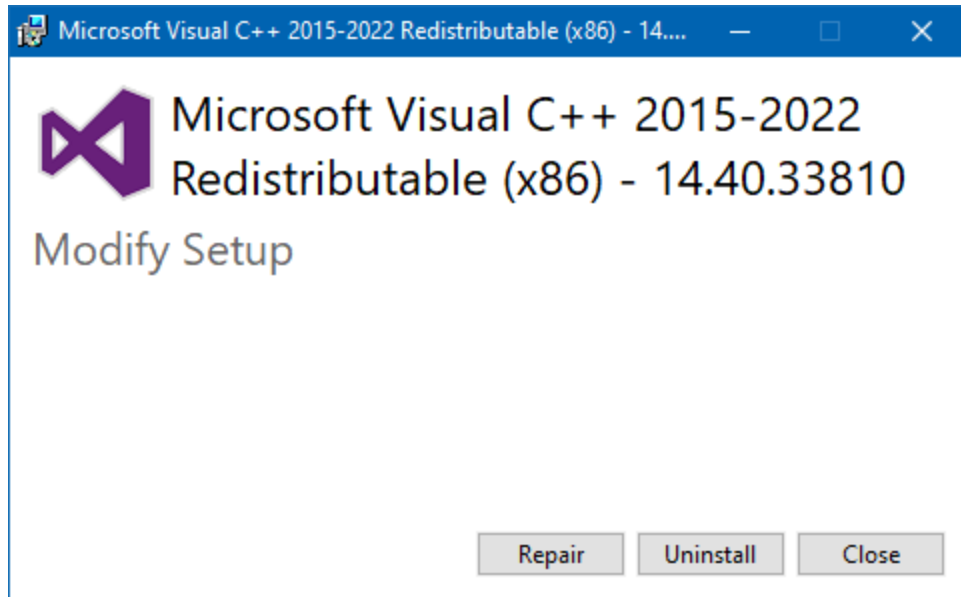


Figure 2.10 Found Installed Microsoft Visual++ Drivers

2.1.3 Introduction of Network Version

Special network licenses and Net USB Key (network hardware key) are available for users that desire to operate SHAFT on a Windows network. The network version is limited to users within a limited range of IP addresses that are employed at a named licensed office site.

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

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

2.1.3.1 Installation of Network Version

Installers of network licenses should refer to a separate booklet with installation instructions for the Network version of this product. The document can be downloaded from the Ensoft web site (http://www.ensoftinc.com/updates/Ensoft_Network_Installation_Notes.pdf) or can be requested via email to support@ensoftinc.com

2.1.3.2 Silent Installations on Client Computers

For installation of network licenses on local client computers there is an option for command-based installations that are completely silent (performed without other user input). Instructions for silent installations on client computers can be downloaded from the Ensoft web site using the following link:

<http://www.ensoftinc.com/updates/Silent Install on Client Computers.pdf>

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

2.1.4 Backup of Original Software

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

2.1.5 Software Updates on the Internet

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

2.2 Getting Started

A general diagram showing the menu choices and operational flow chart of program SHAFT is presented in Figure 2.11. The following paragraphs provide a short description of the operational features of SHAFT and should quickly enable the user to get started with the program.

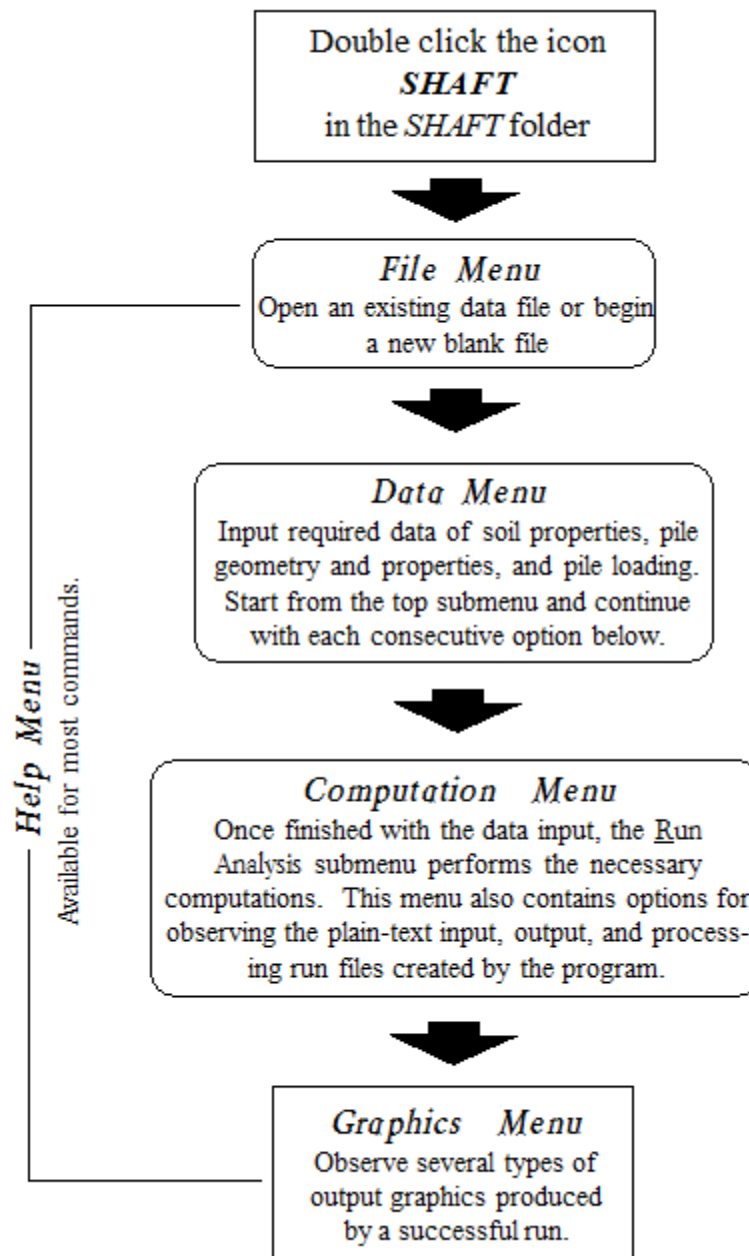


Figure 2.11 Sample organization and operational flow chart for SHAFT

2.2.1 Starting the Program

In the very first start of the program, after a fresh installation, the user will be asked to personalize the installed copy of SHAFT (Figure 2.12). This dialog allows the user to enter any name to distinguish the software installation. The selected name will be included at the beginning of all output files that are generated by this particular installation of SHAFT. The selected name can be changed any time afterwards from the Help > User Information menu.

In any software start after the first, the program displays a blank screen containing the following top-menu choices: File, Data, Computation, Graphics, Window, and Help along with a variety of speed buttons (Figure 2.13). If the user starts the software from an existing model (using Windows OS file extension association), the software opens with a background display of main graphical features of the working model.

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

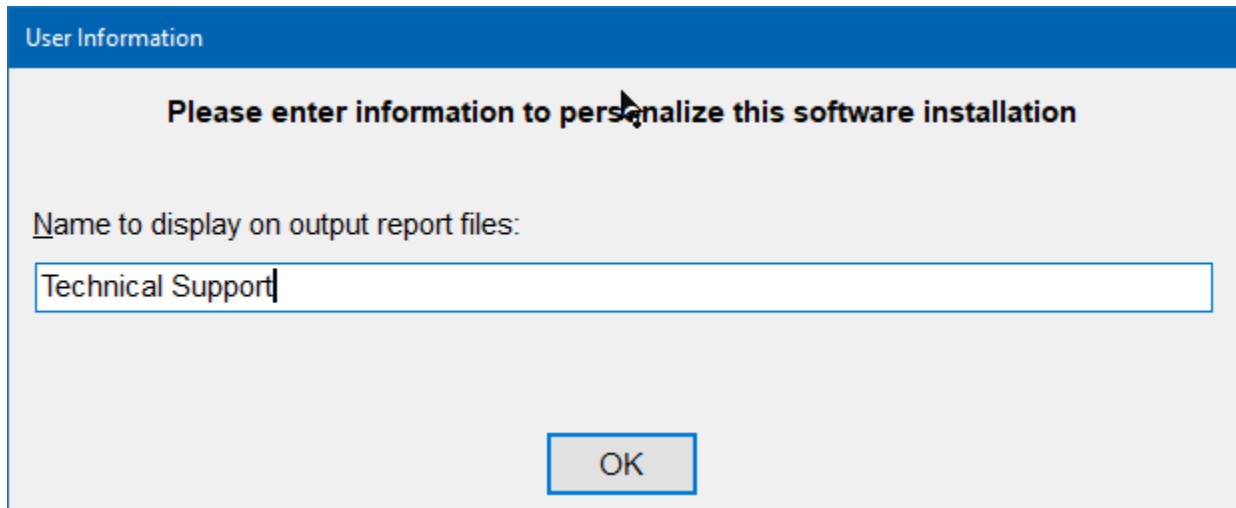


Figure 2.12 User Information on Initial Program Start (after a fresh installation).

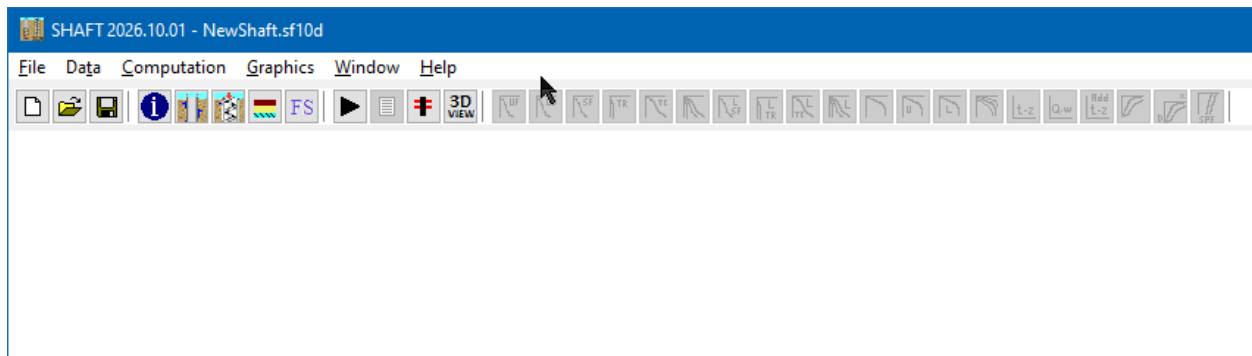


Figure 2.13 Blank Screen on Subsequent Program Starts.

2.2.2 File Management

The File menu option contains five submenus, as shown in Figure 2.14; they are:

- **New** to create a new data file.
- **Open...** to open an existing data file.
- **Save** to save input data under the current file name.
- **Save As...** to save input data under a different file name.
- **Exit** to exit program SHAFT.

A history list of up to the last ten recently-opened data files is located between the **Save As** and the **Exit** options. This list varies on each user's computer and allows for easy access to recent data files.

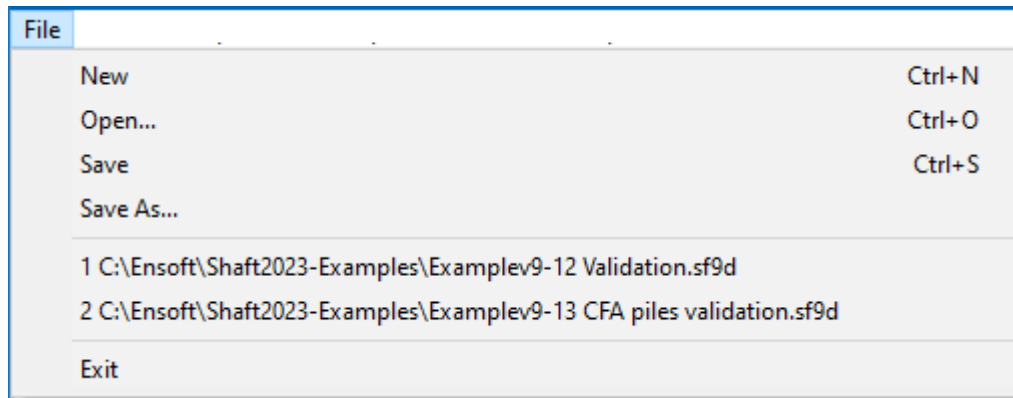


Figure 2.14 Sample File Menu

Several additional files are created in every new SHAFT run. A general description of these files is presented in Table 2.1. Every run of SHAFT thus generates four text files in the same drive and directory where the input-data file was saved or opened. The output-data file may be opened with standard text editors or word-processing programs.

File Name Extension	Usage Description	File Format	Example Files
*.sf10d	Input-data file	Binary	example1.sf10d example2.sf10d
*.sf10o	Output-data file	Text file	example1.sf10o example2.sf10o
*.sf10p	Plot-data file	Text file	example1.sf10p example2.sf10p
*.sf10r	Processor-data file	Text file	example1.sf10r example2.sf10r

Table 2.1 Files created in SHAFT runs

2.2.3 Data Input of Application Problem

The **Data** menu contains several choices of submenus, as shown in Figure 2.15. The choices are listed below, along with a general description of their use.

Title to enter a single line of text with a general description for the project.

Unitsthis option allows the user to select either **English Units** (using pounds, feet, and inches) or **SI Units** (using kiloNewtons and meters) or any other consistent set of units of force and length. English units are enabled, as a default, for all new data files. The user may change the system of units as many times as desired and values that were previously inputted will be automatically converted by the program.

Design Method (ASD or LRFD)users may select the Allowable Stress Design (ASD) or the Load and Resistance Factor Design (LRFD) for the model.

Drilled Shaft/CFA Pile Properties.....to describe dimensions, and material properties of a drilled shaft or for a continuous flight auger (CFA) pile.

Soil Layer Datathis is used to define the type and depth of each soil/rock layer and to enter the associated mechanical properties for each soil/rock layer.

Factor of Safety (Allowable Stress Design)...here the user enters the factor of safety that will be used during computations with ASD method (menu is disabled for LRFD method).

Computation Methods ..this submenu is used to select the analysis for a specific shaft length or for a specific design load.

Water Table....this is used to specify the depth of the water table. The depth of water table is referenced from the ground surface or finished grade.

Evaluate Multiple Shaft Lengths(optional entry) users can choose to evaluate multiple shaft penetrations in one single model to see a graphical representation of pile capacities for various lengths (this menu is disabled if the user selects ASD/LRFD Design Charts).

ASD/LRFD Design Charts(optional entry) these are design aids for either ASD or LRFD methods, containing pile capacity charts for user-specified pile-head settlements for various pile diameters and/or pile penetrations (this menu is disabled if the user selects Evaluate Multiple Shaft Lengths).

Evaluate Down Drag.....(optional entry) users can evaluate the effects of downdrag forces acting along any length of the pile. In models with multiple shaft diameters, the Downdrag effect will only be evaluated for the initial/first pile diameter.

Evaluate Group Effects...(optional entry) in this dialog box, the user can evaluate if any group reduction factors would be applicable when the modeled pile is in close spacing with others nearby. In models with multiple shaft diameters, the Group effects will only be evaluated for the initial/first pile diameter.

Control Options.....(optional entry) includes various optional control parameters that users may choose for certain analyses. Available options in this menu include choosing elevation instead of depth measurements, printing of t-z curves at specified depths, analytical option for end bearing in sands and text editor.

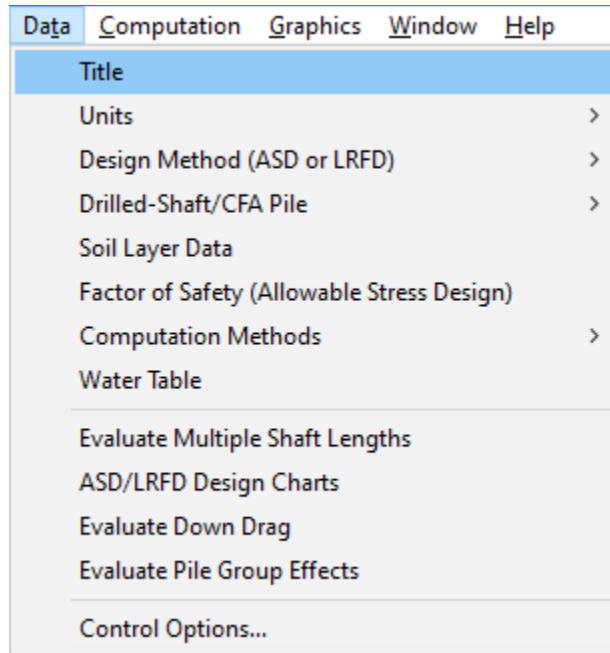


Figure 2.15 Sample Data Menu

2.2.4 Computation Options

The **Computation** menu is provided to run the analytical computations after all data are entered and saved. After the computation is executed successfully this menu also provides options for the reviews of plain-text input data, notes produced during computation, and output data. It also provides selections for the graphical observation of the modeled pile and soil layers. Submenu choices, shown in Figure 2.16, are briefly described below.

Run Analysis this is chosen to run the analytical computations. This option should be selected after all data have been entered and saved.

View Processor-Run Notes.....in this selection the chosen **Text Editor** (selected under **Data > Control Options**) is used to observe, format, and/or print the notes provided during processing. This selection only becomes available after a computational run. The user is encouraged to read the processor-run notes if the model is not running successfully. The processor-run notes may provide the user with some additional information about possible causes of the problem.

View Output Text..... the chosen **Text Editor** (selected under **Data > Control Options**) is used here to observe, format, and/or print the analytical-output data. This selection only becomes available after a successful run has been made. Certain output files may be too large for the Microsoft Notepad editor, so other text editors would have to be used (Microsoft Word Pad should be able to open most text files).

View Shaft Elevation.....here users can see a simple graphical representation of the elevation of the modeled shaft and the location of the specified soil layers.

3D View.....this selection allows the modeler to see a more descriptive graphical representation of the shaft elevation, soil layers, depths and also charts of load transfers (available only after a

successful run). When in 3D View users have access to the Show 3D View menu that allows for the various display options.

Generate Report in MS-Word.....this selection allows users to export input and output information of the SHAFT model along with optional output charts into a Microsoft Word file that is pre-formatted for report presentations.

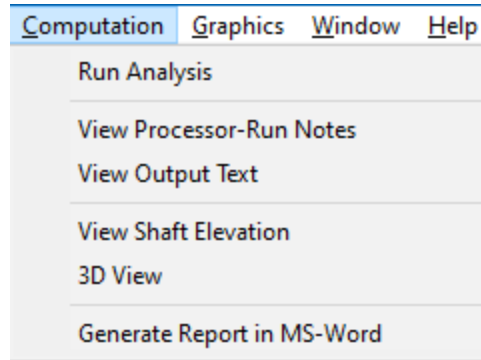


Figure 2.16 Sample Computation Menu

2.2.5 Graphics

The Graphics menu is used to observe plots of output data after a successful program run. Options for the observation of output curves under this menu are only enabled after a successful run has been made. Even after performing successful runs, some selections may be disabled since the output data depends on specifications provided in the input file of each program run. Submenu choices, shown in Figure 2.17, are briefly described below.

Unit Skin Friction vs. Depthprovides a plot of the unit skin on the modeled shaft versus depth.

Unit End Bearing vs. Depth.... provides a plot of unit tip resistance on the modeled shaft versus depth.

Ultimate Skin Friction vs. Depth.....provides a plot of ultimate skin friction on the modeled shaft versus depth.

Ultimate Tip Resistance vs. Depth.... provides a plot of ultimate end bearing on the modeled shaft versus depth.

Ultimate Total Capacity vs. Depth.... provides a plot of the ultimate total capacity (skin friction + tip resistance) of the modeled shaft versus depth.

Combined Plots vs. Depth.... provides a plot of ultimate skin friction, ultimate tip resistance, and the ultimate total capacity versus depth all combined on the same plot. If a model uses multiple shaft lengths the combined plot is only provided for the initial length. If a model uses multiple shaft diameters the combined plot is only provided for the initial diameter.

ASD/LRFD Skin Friction vs. Depth.... provides a plot of skin friction on the modeled shaft versus depth with the specified factor of safety (ASD) or the specified resistance factors (LRFD).

ASD/LRFD Tip Resistance vs. Depth.... provides a plot of top resistance of the modeled shaft versus depth with the specified factor of safety (ASD) or the specified resistance factors (LRFD).

ASD/LRFD Total Capacity vs. Depth.... provides a plot of the total capacity (skin friction + tip resistance) of the modeled shaft versus depth with the specified factor of safety (ASD) or the specified resistance factors (LRFD).

Combined Plots vs. Depth.... provides a plot of skin friction, tip resistance, and the total capacity versus depth on the same plot all with the specified factor of safety (ASD) or the specified resistance factors (LRFD). If a model uses multiple shaft lengths the combined plot is only provided for the initial length. If a model uses multiple shaft diameters the combined plot is only provided for the initial diameter.

Axial Load vs. Settlement (Averaged).... provides a plot of the axial loads versus settlement at the shaft head based on the averaged trend.

Axial Load vs. Settlement (Upper Bound)... provides a plot of the axial loads versus settlement at the shaft head based on the upper-bound data.

Axial Load vs. Settlement (Lower Bound).... provides a plot of the axial loads versus settlement at the shaft head based on the lower-bound data.

Combined Plots of Load vs. Settlement.... provides a plot of the axial loads versus settlement curves at the shaft head based on the upper-bound, lower-bound, and averaged trend data. If a model uses multiple shaft lengths the combined plot is only provided for the initial length. If a model uses multiple shaft diameters the combined plot is only provided for the initial diameter.

t-z Curves.... provides a plot of the load-transfer curves in side resistance that are printed for approximately four depths on each soil layer that was defined in the model. The plotted *t-z* curves correspond to the averaged trend and also for the initial shaft diameter (if the model uses multiple shaft diameters).

Q-w Curves.... provides a plot of the load-transfer curves in end bearing that are printed for each shaft diameter (if the model uses multiple shaft diameters). The plotted *Q-w* curves correspond to the averaged trend.

Additional t-z Curves.... optional plot of the load-transfer curves in side resistance that are printed for user-defined depths (in **Data > Control Options > Print Additional t-z Curves**). The plotted *t-z* curves correspond to the averaged trend and also for the initial shaft diameter (if the model uses multiple shaft diameters).

Load Distribution.... provides a plot of the distribution of total axial capacity versus depth.

Axial Displacement Distribution.... provides a plot of the distribution of total axial displacement versus depth.

Design Chart (xx movement).... plots of design charts for each user-defined (xx) movements. These plots are only available in models using **Data > ASD/LRFD Design Charts**.

Combined Plot Single Pile Factor.... plots of group factors versus pile depth when comparing a single pile to the block failure of a group of piles. These plots are only available in models using Data > Evaluate Pile Groups Effects.

Exports Plots to Excel.... allows the user to export some (or all) of the above plots to an excel file. Each plot will be exported to two sheets, one contains the data and the second the chart.

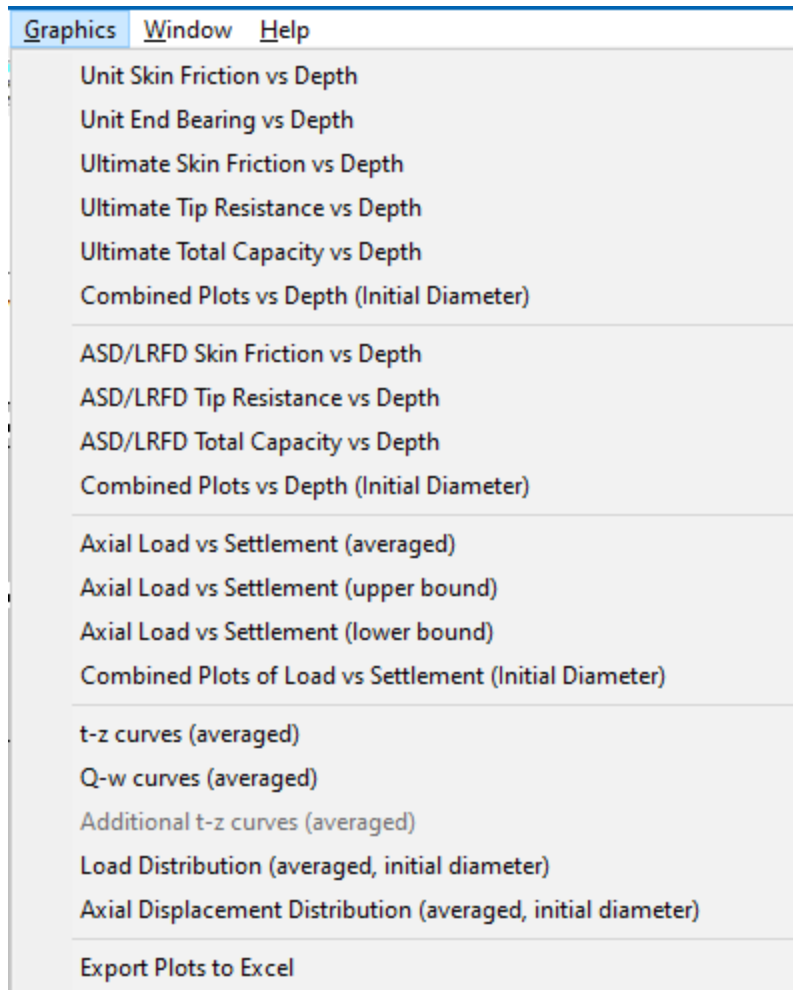


Figure 2.17 Sample Graphics Menu

2.2.6 Arrangement of Windows

The Window menu provides two standard functions for organizing open- screen windows and/or minimized screen-window icons. Submenu options, shown in Figure 2.18, are briefly described below.

Cascade.....this option organizes all open-windowed menus so that all become visible with their tops cascading from the top left portion of the screen.

Arrange Icons.this option organizes the icons of all minimized windowed menus so that all become visible and aligned at the bottom portion of the screen.

Other entries under the Windows menu are names of any open windows or plot file, that the user may select to navigate between open windows.

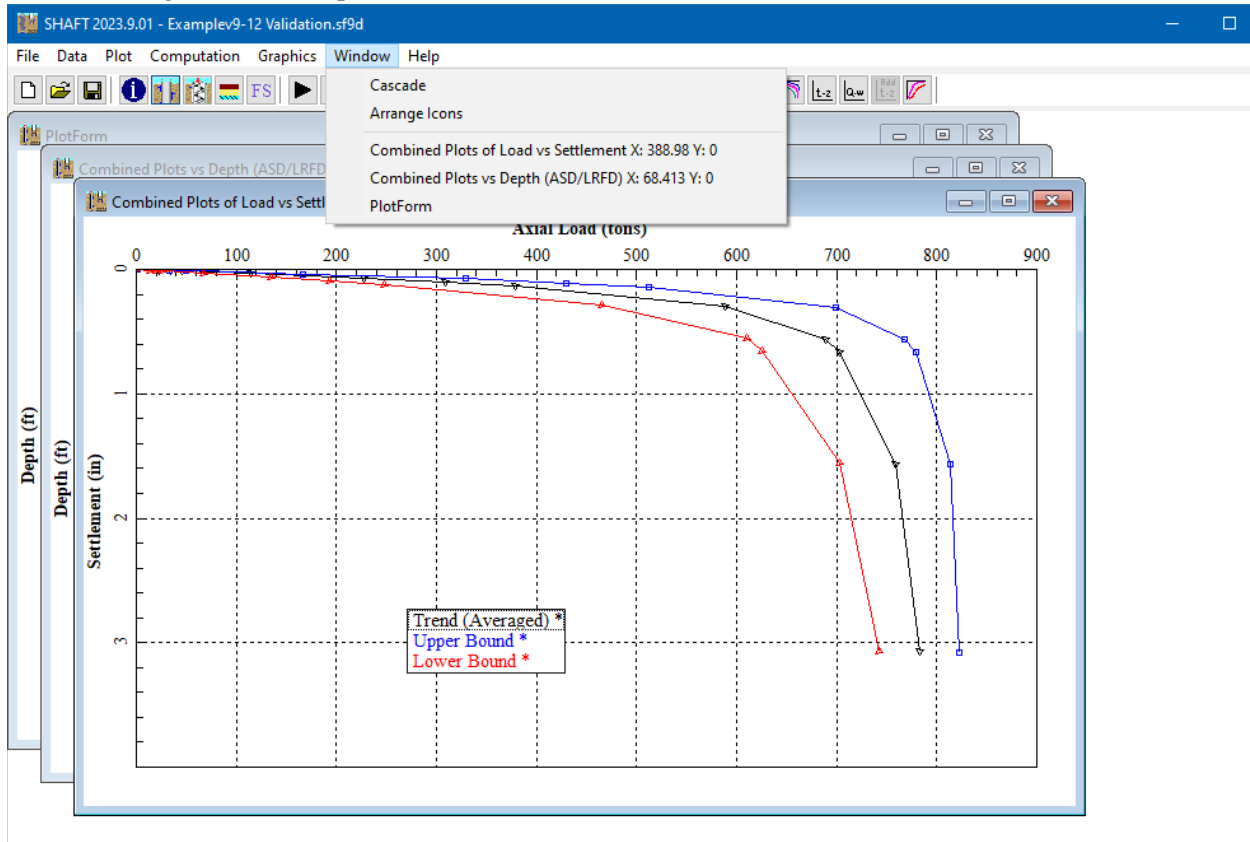


Figure 2.18 Window Menu

2.2.7 Help Menu

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

Options in the **Help** menu, shown in Figure 2.19, are briefly described below.

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

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

User Information this is used to personalize the individual installation of SHAFT. A screen capture of this dialog was previously shown in Figure 2.12. The user specified entry in this dialog will be included at the beginning of all output files that are generated by this particular installation of SHAFT.

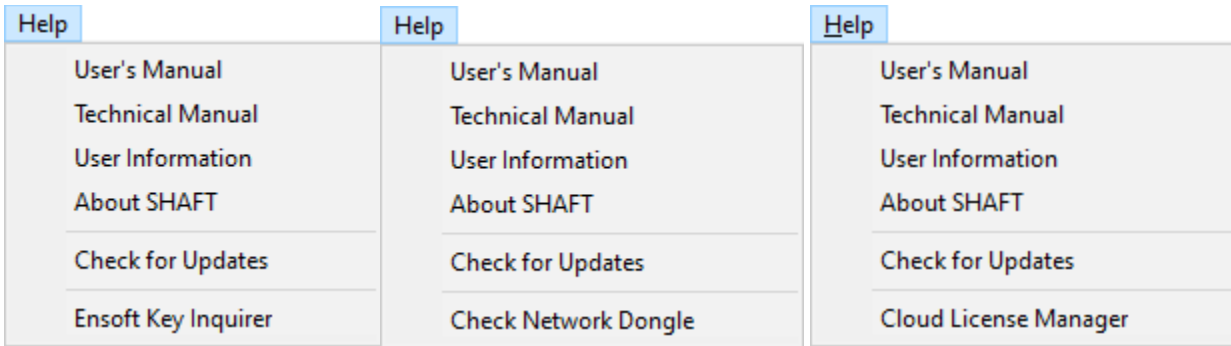
Aboutthis command provides a dialog describing the program version, date, and methods for accessing technical support. Other information about the program licensing and maintenance expiration date, program version, and program release date are also shown. Examples of the **Help > About** dialog for two different licensing options are shown in Figure 2.20.

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

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

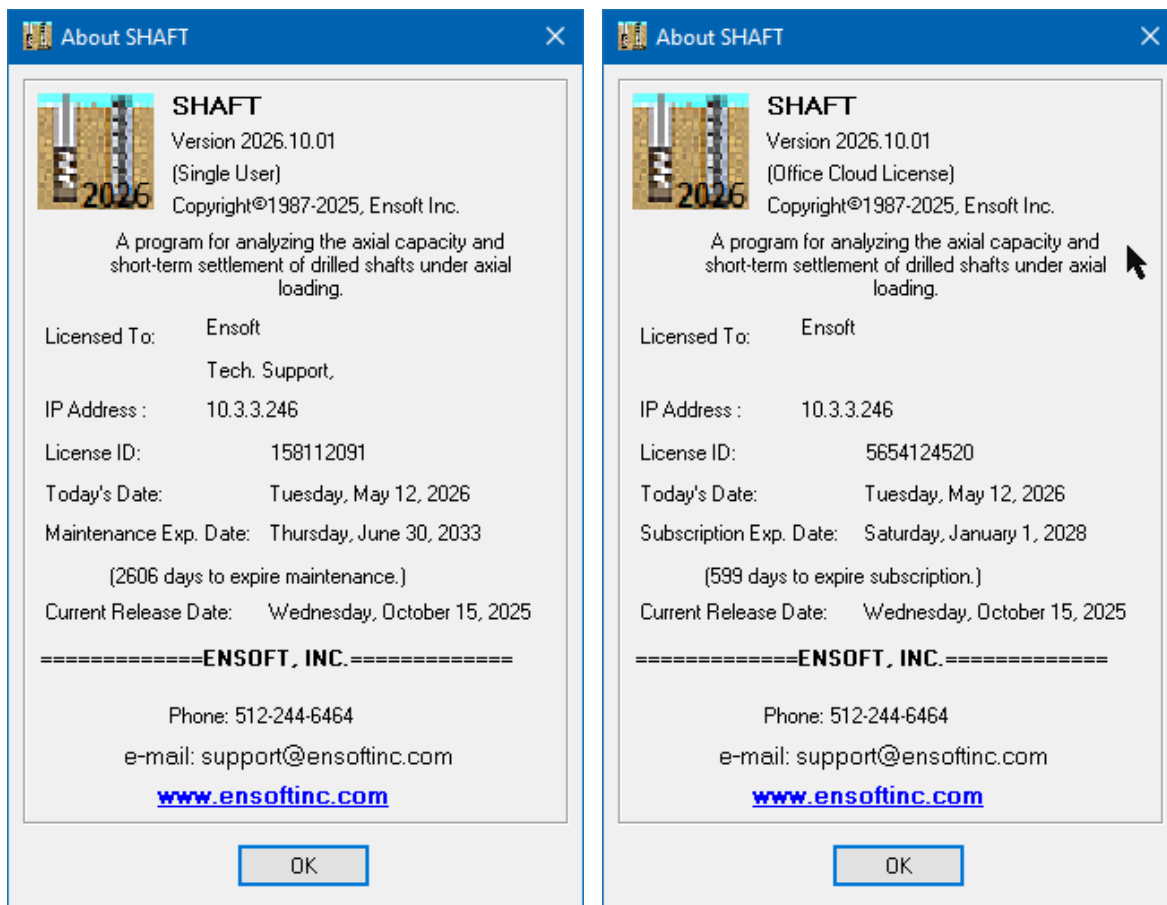
Check Network Dongle. this choice is only available in client computers of local network licenses (not available in single-user licenses or cloud licenses). This function calls the utility that is used to check the licensing and to troubleshoot communications with the License Server. This utility is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

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



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

Figure 2.19 Help Menu



- a. Single-User License b. Cloud Subscription License

Figure 2.20 Examples of About SHAFT Dialog

CHAPTER 3. References for Data Input

3.1 File Menu

This menu contains selections related to the management of input-data files and to exit the program. Input-data files created for SHAFT are provided with a standard file-name extension in the form of **filename*.sf10d* (where **filename** represents any Windows-allowable file name). All input data files are standard text files and may be edited with any text editor or word-processing program.

3.1.1 File > New



Once the program is started, default values are used for certain operating parameters and a blank input-data file is created. Selecting **New** under the **File** menu resets all SHAFT variables to either default or blank values, as appropriate. This option should be selected when a new data file is desired to be created from a blank form. This menu option may also be accessed with the Ctrl+N keyboard combination.

3.1.2 File > Open



This is used to open a file that has been previously prepared and saved to disk. The **File > Open** window dialog, shown in Figure 3.1, is used to search for an existing input-data file. By default, the file is initially searched in the directory where SHAFT was installed. After initial usage the program will default to the last directory where a data file has been successfully opened. Standard windows-navigation procedures may be used to locate the name and directory of the desired project file. This menu option may be accessed with the Ctrl+O keyboard combination.

Every analytical run of SHAFT produces several additional files (previously described in Table 2.1 of this manual). The name of the input-data file indicates the names of all related files produced by a successful program run (output, graphics, and processor text files). All the additional program files will be created in the same directory as the input file. Input-data files that are partially completed may be saved and later opened for completion, run, and observation of results.

Opening partially-completed SHAFT input files or invalid data files may produce an information window reporting that an “invalid or incomplete” file is being opened. The user should click the OK button and all partial-input data that was previously prepared should become available.

The program allows users to read input-data files created for the previous SHAFT 2023, 2017, 2012 or 6.0 versions by selecting the drop-down arrow at the bottom right corner of the **File > Open** dialog window (Figure 3.1). The program will automatically convert the older input files to the latest version of SHAFT when the user saves the file.

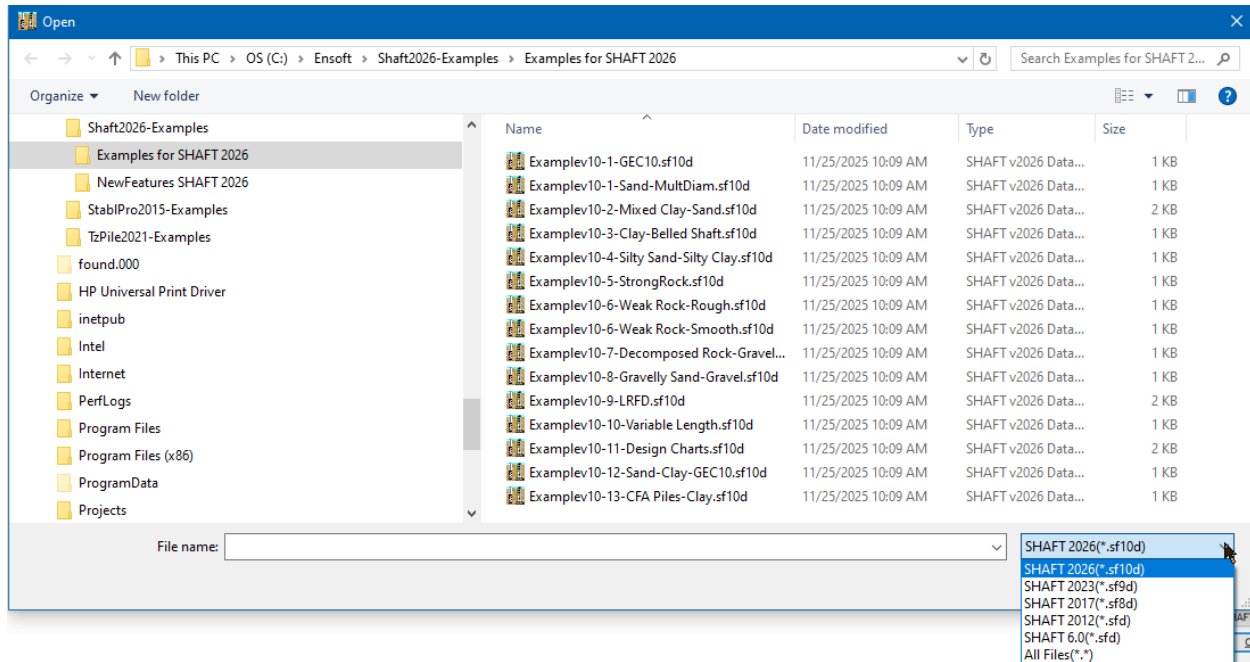


Figure 3.1 Sample File > Open Dialog Screen

3.1.3 File > Save



This selection is used to save input data under the current file name. With this method of storing data to disk, any input data that was previously saved with the same file name is replaced with the current parameters. Input-data files should be saved every time before proceeding with runs for analytical computation. This menu option may also be accessed with the Ctrl+S keyboard combination.

3.1.4 File > Save As

This selection allows the user to save any opened or new input data file under a different file name and/or different directory. Any input data file saved under an existing file name will replace the contents of the existing file.

3.1.5 File > Exit

This is selected to exit SHAFT. Any input-data file that was modified and not yet saved to disk will produce a confirmation window before exiting the program.

3.2 Data Menu

The input of specific parameters for an application is controlled under selections contained within this menu (shown in Figure 3.2). It is recommended that the user choose each submenu and enter parameters in a consecutive manner starting from the top of this menu.

Selecting or clicking any of the submenu choices contained in the Data menu produces various types of windows. As a reminder of standard commands of Microsoft Windows®, open windows may be closed by all or some of the following methods:

- clicking the OK button (if available), or
- clicking the X-box on the upper-right corner of the window, or
- double-clicking the SHAFT icon on the upper-left corner of the window, or
- clicking once on the SHAFT icon on the upper-left corner of the window and then choosing Close.

Open windows may optionally be left open on the screen. The selection of other menu options will then produce new windows on top of those that were left open.

Many sub-windows of the Data menu will show an Add Row, Insert Row and/or Delete Row buttons. The Add Row button always adds new rows at the end after all existing rows. The Insert Row button always inserts a new row right after an existing row highlighted by the mouse. Clicking on the Delete Row button deletes the row where the cursor is located.

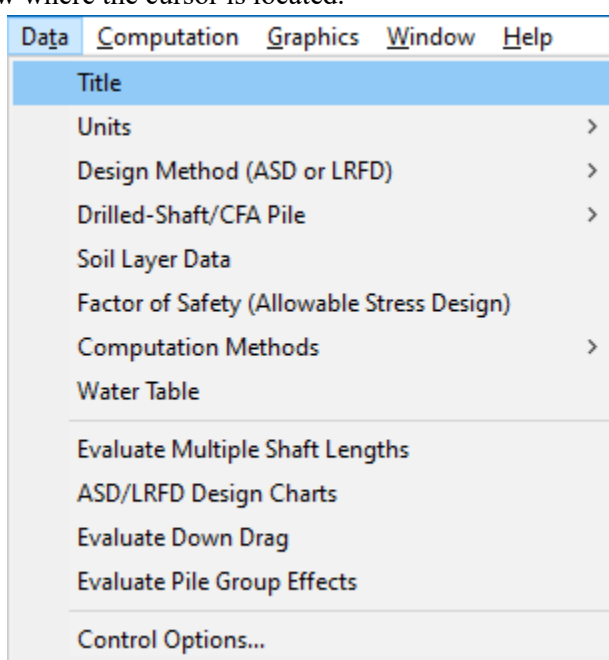


Figure 3.2 Sample Data Menu

3.2.1 Numeric Data Entries

Cells that require numeric data may accept entries of mathematical expressions in addition to simple numeric entries. Entering a mathematical expression works similarly to normal numeric data. The user types the expression that represents the data and presses the Return key to calculate the entered expression and to display the numeric result in the same cell.

Table 3.1 below shows the list of supported operations and constants. The order of operations follows the order in the list of Table 3.1. Note that implicit multiplication (i.e. $2(4+6)$) is not supported (instead, use $2*(4+6)$ for the previous example).

OPERATORS	
Symbol	Description
()	Parenthesis (may be nested)

^	Exponentiation
*	Multiplication
/	Division
+	Addition
-	Subtraction
-	Negation (same as subtraction)
CONSTANTS	
Symbol	Value
PI (or pi)	3.1415927
e (or E)	2.7182818

Table 3.1 Supported mathematical operations and constants

The two constants that are currently supported are PI and e. Implicit multiplications using constants is not supported (use 2*e instead of 2e). Negation of the constants PI or e is not allowed. For instance, instead of entering -PI the user must enter - (PI).

Scientific notation (i.e. 1.65e8 or 1.65e-8) may be used to input very large or very small numbers. After an expression is calculated, very large or very small numbers will be displayed using scientific notation.

3.2.2 Data > Units

This selection provides the user with a choice of specifying input data in English Units, and S.I. Units (international units). In general, the following specific units of measurements will be used throughout the program:

Units	Length	Force	Modulus
English	foot (ft)	pounds (lbs)	psi
International	meters (m),	kilo Newtons (kN)	kPa

The user should always check the unit specification, which is affixed to each variable, for data input. For instance, *psi* instead of *psf* is used for the elastic modulus of materials.

The user may change from one system of units to the other as many times as desired. The program will automatically convert all the appropriate input that was already specified by the user before the time of selection of a different system of units. Small conversion errors may appear if multiple changes of units are performed. The user must always check that input data have been converted appropriately.

3.2.3 Data > Design Method (ASD or LRFD)

This submenu option allows the user to select either the Allowable Stress Design (ASD) method or the Load and Resistance Factor Design (LRFD) method as shown in Figure 3.3. In the United States, many engineers use a combination of the ASD method for geotechnical analysis of the foundation and the LRFD method for analysis of the foundation as a structural member.

The ASD method is also known as the factor of safety method. The ASD method is most often used by foundation engineers and is usually referenced as the *global* approach. The engineer will consider all of the factors at hand, including such things as the quality of the subsurface investigation, the statistical nature of the loading, and the expected competence of the contractor, and an overall factor of safety is selected for individual piles and for the group of piles.

The LRFD method originated in structural engineering and is usually termed as the *component* approach. The LRFD method was accepted formally in 1994 by the American Association of State Highway and Transportation Officials (AASHTO) as a standard.

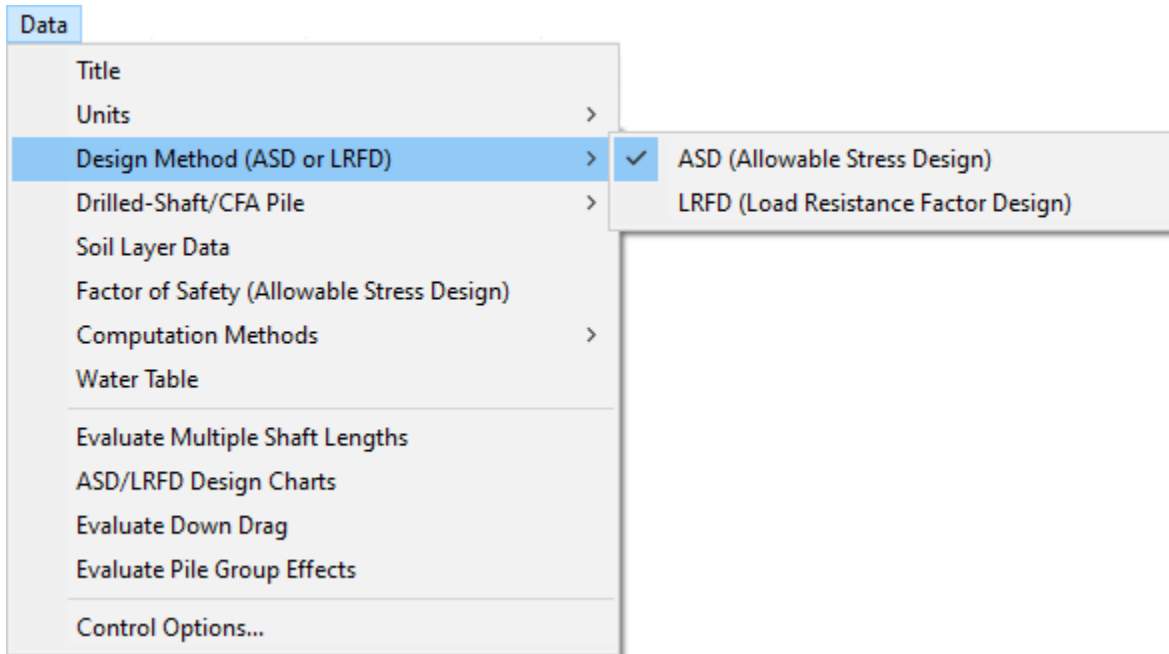


Figure 3.3 Data Menu > Design Method (ASD or LRFD)

3.2.4 Data > Title



This selection activates the window shown in Figure 3.4, where the user can enter a line of text containing a general description for the application problem. Any combination of characters may be entered in the text box in order to describe a particular application. The user input will be restrained automatically once the maximum length of text is reached. This is done to prevent the user from going beyond the maximum permissible length of characters allowed for the title line.

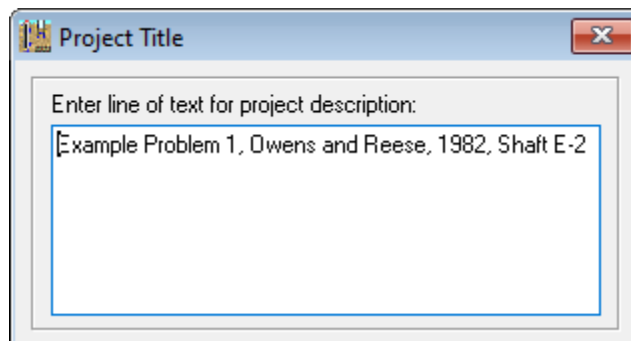
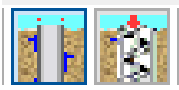


Figure 3.4 Sample Data > Title

3.2.5 Data > Drilled-Shaft Properties



In this menu, shown in Figure 3.5, the user is provided with the option to select either a Drilled Shaft (also known as ‘bored pile’ or ‘augered cast in place pile’) or a CFA Pile (also known as ‘continuous flight auger’ pile). Depending on the user’s selection, the program will display the screens shown in Figure 3.6 (Drilled-Shaft Properties) or Figure 3.7 (CFA Pile Properties).

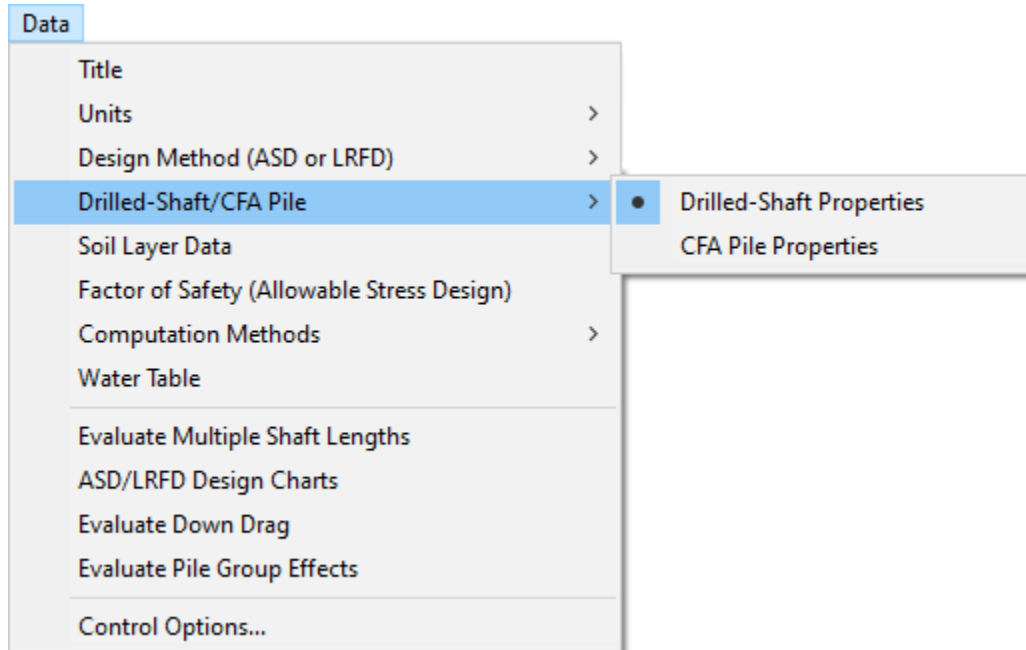
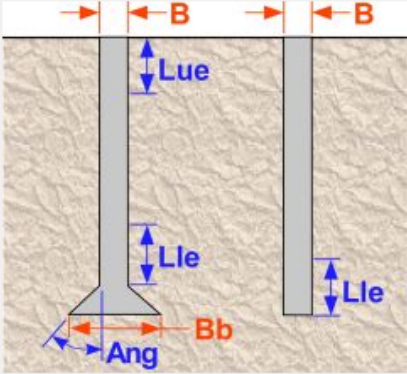


Figure 3.5 Data Menu > Drilled-Shaft/CFA Pile Properties



Minimum Shaft Diameter, B, to be Considered (ft)	3
Maximum Shaft Diameter, B, to be Considered (ft) (Enter 0 if same as minimum)	6
Ratio of Base Diameter to Shaft Diameter, Bb/B (Enter 0 for straight shaft)	0
Angle of Bell with Respect to Vertical, Ang (deg) (Enter 0 for straight shaft)	0
Length of Upper Exclusion Zone without Skin Friction, Lue (ft)	0
Length of Bottom Portion of Shaft without Skin Friction, Lle (ft)	0
Modulus of Elasticity of Drilled Shaft (lbs/in ²)	3500000

Shaft diameter, B, is automatically incremented in 6-inch or 0.15 m increments between the specified minimum and maximum diameters.

* This default increment can be changed while using Design Charts.

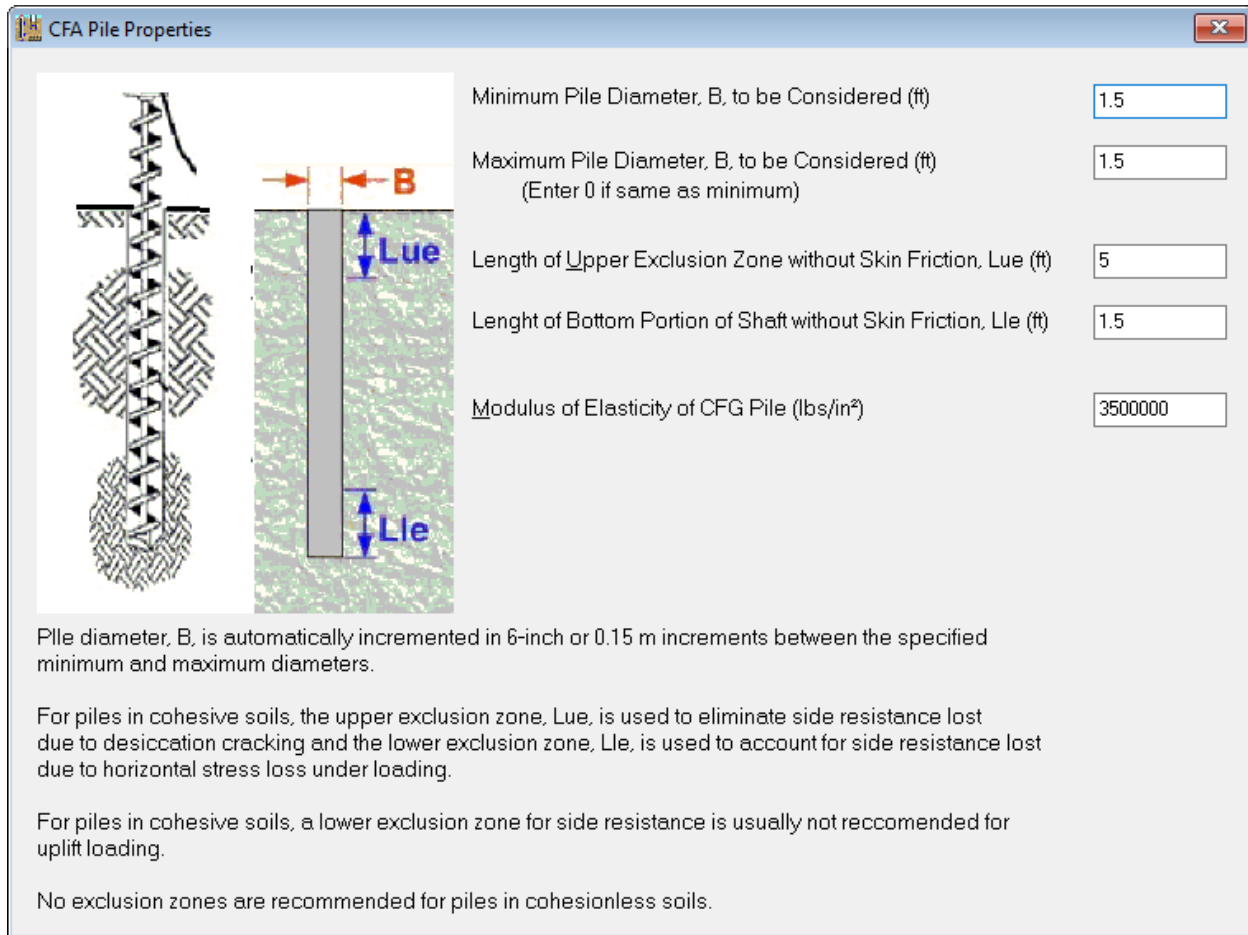
For shafts in cohesive soils, the upper exclusion zone, Lue, is used to eliminate side resistance lost due to desiccation cracking and the lower exclusion zone, Lle, is used to account for side resistance lost due to horizontal stress loss under loading.

For shafts in cohesive soils, a lower exclusion zone for side resistance is usually not recommended for uplift loading.

No exclusion zones are recommended for shafts in cohesionless soils.

Bells should not be specified for shafts in cohesionless soils or rock.

Figure 3.6 Sample Drilled-Shaft Properties



CFA Pile Properties

Minimum Pile Diameter, B, to be Considered (ft)

Maximum Pile Diameter, B, to be Considered (ft)
(Enter 0 if same as minimum)

Length of Upper Exclusion Zone without Skin Friction, Lue (ft)

Length of Bottom Portion of Shaft without Skin Friction, Lle (ft)

Modulus of Elasticity of CFG Pile (lbs/in²)

Pile diameter, B, is automatically incremented in 6-inch or 0.15 m increments between the specified minimum and maximum diameters.

For piles in cohesive soils, the upper exclusion zone, Lue, is used to eliminate side resistance lost due to desiccation cracking and the lower exclusion zone, Lle, is used to account for side resistance lost due to horizontal stress loss under loading.

For piles in cohesive soils, a lower exclusion zone for side resistance is usually not recommended for uplift loading.

No exclusion zones are recommended for piles in cohesionless soils.

Figure 3.7 Sample CFA Pile Properties

The various input parameters that are needed under entries in the Data > Drilled-Shaft/CFA Pile Properties menu option are listed below.

Minimum Shaft Diameter

This is the minimum (or initial) diameter to be considered in the computations. The English unit for this variable is “ft”, while “meter” is for the SI unit.

Maximum Shaft Diameter

This is the largest diameter to be considered in the computations. The English unit for this variable is “ft”, while “meter” is for the SI unit.

The program will compute the axial capacity of drilled shafts starting with the minimum diameter and then add 0.5 ft (0.15 m) to the diameter for each consecutive run until the diameter reaches the largest (maximum) specified. This default increment of diameter can be changed in Data > ASD/LRFD Design Charts for models that use such analytical method.

If the user only wants to run with the initial diameter, the variable for the largest diameter should be left as zero (or same as the minimum diameter).

In models where there is one or more layers of rock along with defined Minimum and Maximum shaft diameters the program will use the defined ratio of (rock socket diameter/shaft diameter) for all analyzed cases of increased shaft diameter (up to the Maximum defined).

Ratio of Base Diameter to Shaft Diameter

To define a belled shaft the user should enter the ratio of the base diameter to the stem diameter. The program will calculate the dimension of the bell accordingly. For a straight shaft, the value for this variable should be left as zero.

Belled shafts are not used in cohesionless soils (sand, gravel) or rock.

For belled shafts in uplift, the program computes side resistance of a column with a diameter equal to that at the base of the bell (Bb).

Angle of Bell with Respect to Vertical

For a belled shaft, the user should enter the angle (in degrees) from the vertical line to the slope of the bell (always smaller than 90 degrees). The program will calculate the dimension of the bell accordingly. For a straight shaft, the value for this variable should be left as zero.

Belled shafts are not used in cohesionless soils (sand, gravel) or rock.

Length of Upper Exclusion Zone without Skin Friction

This number (always positive) represents the section length on the top of the shaft that is declared as noncontributing to side resistance.

This upper exclusion zone is not recommended in cohesionless soils.

The English unit for this variable is “ft” while “meter” is for the SI unit.

Length of Bottom Portion of Shaft without Skin Friction

This number (always positive) represents the section length at the bottom of the shaft that is declared noncontributing to side resistance. For a belled shaft, this length is taken above the beginning of the bell.

This lower exclusion zone is not recommended in cohesionless soils. For shafts in cohesive soils, this lower exclusion zone is not recommended for uplift loading.

The English unit for this variable is “ft” while “meter” is for the SI unit.

Modulus of Elasticity of Drilled Shaft

Modulus of Elasticity of CFG Pile

This number (always positive) represents the modulus of elasticity of the drilled shaft or CFA pile. The user may enter in this variable the elastic modulus of the composite section or simply use the elastic modulus of the concrete. The English unit for this variable is “psi” while “kPa” is for the SI unit.

3.2.6 Data > Soil Layer Data



This submenu allows the user to specify the different types of soil/rock and material properties to be used for the computations. Illustrations of the Soil Layer Data window for example applications are shown in Figure 3.8 and Figure 3.9.

A general description for the data needed under each column in the Data > Soil Layer Data submenu option is listed below.

Soil Layers

Layers Definition

Layer	Soil Type	Depth at Bottom *	Max. Side Friction **	Max. End Bearing **
		of each layer (ft)	(lb/ft ²)	(lb/ft ²)
Edit Layer 1	clay (FHWA Spec.)	10	6400	0
Edit Layer 2	sand (FHWA Spec.)	20	4000	0
Edit Layer 3	clay (FHWA Spec.)	80	6400	0
Edit Layer 4	clay (FHWA Spec.)	100	6400	0

☒ Confirm Deletion

Notes:

* Bottom of last layer must be deeper than the shaft bottom plus two pile diameters.
 ** If entries are left as zero, the program assumes no limits in side friction and end bearings computed by the program
 ** Use a very small number (e.g. 0.001) for layers where load transfer should be ignored.

Figure 3.8 Sample Data > Soil Layer Data dialog box for ASD Method

Soil Layers

Layers Definition

Layer	Soil Type	Depth at Bottom *	Max. Side Friction **	Max. End Bearing **	LRFD Res. Factor	LRFD Res. Factor
		of each layer (ft)	(lb/ft ²)	(lb/ft ²)	(Side Friction)	(End Bearing)
Edit Layer 1	sand (FHWA Spec.)	25	0	0	0.55	0.5
Edit Layer 2	sand (FHWA Spec.)	65	0	0	0.55	0.5
Edit Layer 3	sand (FHWA Spec.)	85	0	0	0.55	0.5
Edit Layer 4	clay (FHWA Spec.)	100	0	0	0.45	0.5
Edit Layer 5	sand (FHWA Spec.)	110	0	0	0.55	0.5

☒ Confirm Deletion

Notes:

* Bottom of last layer must be deeper than the shaft bottom plus two pile diameters.
 ** If entries are left as zero, the program assumes no limits in side friction and end bearings computed by the program
 ** Use a very small number (e.g. 0.001) for layers where load transfer should be ignored.

Figure 3.9 Sample Data > Soil Layer Data dialog box for LRFD Method

Layer

This column includes **Edit Layer x** buttons where x is a sequential number that is automatically and sequentially provided to each soil layer. This number is computed by the program as new rows of soil layers are added. The maximum number of soil layers that may be used in a model is limited to 40.

Clicking on each **Edit Layer x** button allows the user to specify soil or rock properties that correspond to the defined soil layer. A sub-window will pop on the screen when each **Edit Layer x** button is selected. The program requires different input parameters for each type of soil and rock. Therefore, the data column in the sub-window that appears varies with the selection made by the user in the **Soil Type** drop-down list. A detailed description of the parameters needed for each soil and rock type is described in Section 3.2.7.

Soil Type

This column includes drop-down buttons that are used to select the type of each soil layer. There are currently nine internal types of soils that may be specified for program SHAFT. The user specifies the desired soil type using a drop-down list with the following choices:

Code Number	Internal Soil Type
1	Sand (FHWA)
2	Clay (FHWA)
3	Shale (Aurora and Reese)
4	Strong Rock (FHWA, $q_u > 1000$ psi, either Side Friction or Tip Resist.)
5	Decomposed Rock/Gravel (FHWA)
6	Weak Rock (FHWA)
7	Strong Rock (Side Friction + Tip Resistance)
8	Gravelly Sand (Rollins et al)
9	Gravel (Rollins et al)
12	User-Defined Soil Layer

In models using the new CFA Piles, the recommended criteria is limited to the following two soil types:

Code Number	Internal Soil Type
10	Sand (for CFA Piles)
11	Clay (for CFA Piles)
12	User-Defined Soil Layer

For strong rock, FHWA recommends to use either side friction or tip resistance but not both, as described in the Technical Manual. However, in some cases the user may want to observe the shaft capacity that includes the side friction and tip resistance together. Such evaluation may be done by selecting Soil Type 7. The user must consider good engineering judgment when selecting such option.

Depth at Bottom of Each Layer

Values for the bottom of each soil layer are entered with respect to an origin of coordinates set at the ground surface. As a minimum, the bottom of the last soil layer must be two pile diameters deeper than the depth of the modeled shaft.

Max. Side Friction

In this entry the user may specify the maximum value of skin-friction transfer that is permissible for a given stratum. If the user enters a value for the maximum-permissible skin friction, the program will compare its

internally-computed value with the maximum that is here provided by the user and the program will use the smaller of these two for the final computation.

If the user does not want to add any restriction on the computed value, simply enter 0 to suppress this option and always use the internally-computed values. The output text will list 'No Limit' in the line labeled MAXIMUM LOAD TRANSFER FOR SOIL in any layer where the user entered zero.

A very small value (eg. 0.001 psf) may be entered if the user wants to ignore any load transfer in side friction for the selected layer.

Max. End Bearing

In this entry the user may specify the maximum value of transfer in end bearing that is permissible for a given stratum. If the user enters a value for the maximum-permissible end bearing, the program will compare the internally-computed value with the maximum that is here provided by the user and the program will use the smaller of these two for the final computation. If the user does not want to add any restriction on the computed value, simply enter 0 to suppress this option and always use the internally-computed values. A very small value (eg. 0.001 psf) may be entered if the user wants to ignore any load transfer in end bearing for the selected layer.

LRFD Resistance Factor (Side Friction)

If the user selects the LRFD design method, a data column for entering the LRFD resistance factor on side friction is added onto the input table as shown in Figure 3.9. In this entry the user may specify the resistance factor on skin-friction transfer that is permissible for a given stratum. Enter 1.0 for no reductions on the computed values of side friction.

LRFD Resistance Factor (End Bearing)

If the user selects the LRFD design method, a data column for entering the LRFD resistance factor on tip resistance is added onto the input table as shown in Figure 3.9. In this entry the user may specify the resistance factor on the tip resistance that is permissible for a given stratum. Enter 1.0 for no reductions on the computed values of end bearing.

3.2.7 Data > Soil Layer Data > Edit Layer x

As mentioned earlier, the **Edit Layer x** button allows the user to define soil and/or rock properties for the selected strata. A new dialog box is provided when the **Edit Layer x** button is clicked. The program requires different input parameters for each type of soil and rock. Required entries vary according to the selection that is made by the user in the **Soil Type** drop-down list.

In general, the **Edit Layer x** provides entry fields for the top of the layer and the bottom of the layer. The user may enter different parameters for the top and the bottom of each layer. The program will interpolate linearly the data for any point between those two depths. The following sections provide a general description regarding input data for each soil type.

After each successful model run, users are encouraged to double check their entries and the calculated values in the output text (**Computation > View Output Text**).

3.2.7.1 Sand Layers

A sample dialog screen for Sand (FHWA) layers is shown in Figure 3.10. The inputs for sand layers are explained below.

Side Friction Procedure

Three computational methods are offered for load transfers in side resistance on cohesionless soils. The selection of a method changes the required input below to display only information that is applicable to the selected method.

Ko Methodthis is also known as the “Fundamental Method,” and was presented by Kulhawy (1991), Mayne and Harris (1993), Chen and Kulhawy (2002), Kulhawy and Chen (2007), and evaluates separately the values of K and δ which are then combined to determine β .

Beta Method ..this is also known as the “Depth-Dependent β Method” and this is the basis of the equations given in the first version of the FHWA Drilled Shaft Manual (O’Neill and Reese, 1999) as well as the AASHTO LRFD Bridge Design Specifications (2007). This method requires the input of the **Beta Value** which is described further below.

Chen and Kulhawy (FHWA, GEC 10) Method This is basically the **Ko Method** described earlier but with the ability to define the parameter m (the exponent for computation of preconsolidation stress). See more information about this method in the Technical Manual and further below while describing the **Preconsolidation Stress Exponent (m)**.

Data for Layer 1

Sand

Sand (FHWA Spec.)

Side Friction Procedure

☐ Ko Method
 ☐ Beta Method
 ☒ Chen and Kulhawy Method (FHWA, GEC 10)

	Values at Top of Layer	Values at Bottom of Layer
1. Total Unit Weight (lbs/ft ³)	115	115
2. Coefficient of Lateral Earth Pressure, K_o	0	0
3. Beta Value (°)	0	0
4. Preconsolidation Stress Exponent (m)	0.8	0.8
5. Blow Counts from SPT	11	11
6. OCR Value (***)	0	0
7. Friction Angle (****) (Deg)	0	0

Copy Values From Top To Bottom

Notes:

(**) Recommended values for m: 0.6 for clean quartzitic sands and 0.8 for silty sands to sandy silts.

(***) Program will overwrite OCR value if m and Blow Counts are defined

(****) Program will estimate friction angle based on blow counts if it is left as zero.

Close

Figure 3.10 Sample soil data for sand (FHWA) layers

Total Unit Weight

This column entry corresponds to values of total unit weight (submerged weight is calculated based on the separate **Data > Water Table** entry for depth of water table). Values for the top and bottom of the sand layer are entered in standard units of force per unit volume (either lb/ft³ or kN/m³). The SHAFT program will interpolate linearly between the values provided for the top and the bottom of each layer.

K_o (Coefficient of Lateral Earth Pressure)

This is only enabled in models where the user selects **Ko Method** for **Side Friction Procedure** as defined at the beginning of this section.

This input reflects values of the lateral earth pressure coefficient for the top and bottom of the sand layer. Values for K_o depend on the relative density of the sand and the process by which the sand deposits were formed. For general reference, if the sand deposits did not receive any artificial compaction, values of K_o range from about 0.40 for loose to 0.50 for dense sand. Artificial compaction or tamping may increase K_o

values to 0.80. The SHAFT program will interpolate linearly between the values provided for the top and the bottom of each layer.

Beta Value

This is only enabled in models where the user selects **Beta Method** for **Side Friction Procedure** as defined at the beginning of this section.

The **Beta Value** is an empirical parameter that takes into account the lateral earth pressure coefficient and the effective-friction angle at the interface between the concrete of the shaft and the soil. The parameter thus takes into account the fact that the stress at the interface due to the fluid pressure of the concrete may be greater than that from the soil itself. Many factors that modify the lateral stress at the soil-concrete interface can be taken into account with the **Beta** value. For instance, factors may include the use of drilling fluid, use of casing or a dry excavation during the construction process, and the type of slump used in the concrete.

If the input for **Beta** is left as zero, the computer program automatically generates **Beta** values at each foot of penetration in the sand layer (or at each 0.3 meters if SI units are used). Internally, the SHAFT program uses the method specified in the FHWA Drilled Shaft Manual (O'Neill and Reese, 1999) as well as the current AASHTO LRFD Bridge Design Specifications (2007)

This method (O'Neill and Reese, 1999) is covered in the Technical Manual of this product. The method uses a formula that assumes a drilled shaft construction with a concrete slump of 6 in. or higher. The method also assumes that drilling slurry, if employed, should be such that it would not cause a weak layer of bentonite to develop at the wall of the excavation. The following formula is used internally to compute **Beta** values:

$$\text{For } N \geq 15 \dots \beta = 1.5 - 0.135 z^{0.5}$$

$$\text{For } N < 15 \dots \beta = (N/15) (1.5 - 0.135 z^{0.5})$$

Where

β = empirical value, limited to $1.2 \geq \beta \geq 0.25$

z = depth belowground surface, in units of ft.

N = uncorrected blow counts from the SPT test.

Optionally the user may input his own value of **Beta** for the top and bottom of the layer. The SHAFT program will interpolate linearly between the values provided for the top and the bottom of each layer.

Preconsolidation Stress Exponent (m)

This is only enabled in models where the user selects **Chen and Kulhawy Method** for **Side Friction Procedure** as defined at the beginning of this section. This is basically the **Ko Method** described earlier but with the ability to define the parameter m (the exponent for computation of preconsolidation stress) in the following equation:

$$K_o = (1 - \sin \phi') OCR^{\sin \phi'} \leq K_p \quad (3.1)$$

$$OCR = \frac{\sigma'_p}{\sigma'_v} \quad (3.2)$$

$$\frac{\sigma'_p}{P_a} \approx 0.47(N_{60})^m \quad (3.3)$$

where

σ'_p = effective vertical preconsolidation stress. K_o is limited to an upper bound value equal to the Rankine coefficient of passive earth pressure, K_p . A variety of methods have been proposed for evaluation of either K_o or σ'_p by correlations with in-situ test measurements.

P_a = atmospheric pressure in the same units as σ'_p (for example, 2,116 psf).

The value of m is usually 0.6 for clean quartzitic sands and 0.8 for silty sands to sandy silts. The user may input different values of m for the top and bottom of the layer. The SHAFT program will interpolate linearly between the values provided for the top and the bottom of each layer.

If the Preconsolidation Stress Exponent (m) and the OCR Value are missing (left as zero), the SHAFT program will assume that $OCR = 1$ in Equation (3.1).

If the Preconsolidation Stress Exponent (m) is missing (left as zero) but the user enters the OCR Value (must be equal or higher than one), the SHAFT program will use the user-specified OCR Value in Equation (3.1).

Blow Counts from SPT

This column entry corresponds to the number of blow counts obtained at the top and bottom of the sand layer while performing a Standard Penetration Test (SPT test). The user may optionally input Blow Counts obtained from SPT tests in cases where the values of Friction Angle and K_o are not readily available. When the user provides a value different than zero for Friction Angle and K_o , the values for Blow Counts are not used in the computations and may be left as zero.

Blow Counts for the Fundamental Method (K_o and GEC10) are normally entries of N_{60} while for the Depth-Dependent Method (Beta Method) it is to the user's judgement. However, using entries of SPT-N (raw) may be more applicable since the Depth Dependent Method is much older and at the time there may have not been much distinction.

For friction transfers (transfers in side resistance) when Friction Angle is left as zero the computer program converts internally between the provided values of Blow Counts from SPT tests to equivalent values of Friction Angle using Table 3.2 (for further reference see the Technical Manual for comments of side resistance in sand layers).

For transfers in end bearing, when a Friction Angle is provided (different than zero) the computer program uses the Quiros and Reese (1977) recommendations for loose sand, medium-dense sand and very dense

sand based on ranges of ϕ angles (for further reference see the Technical Manual for comments of end bearing in sand layers).

When the user provides values of **Blow Counts** (different than zero) the computer program uses those for computations of end bearing following equations and limits specified in the Technical Manual (comments of end bearing in sand layers).

OCR Value

This is only enabled in models where the user selects **Chen and Kulhawy Method for Side Friction Procedure** as defined at the beginning of this section.

This entry defines the value for Overconsolidation Ratio (OCR) that will be used for Equation (3.1):

- If the user has entries (different than zero) for both, **Preconsolidation Stress Exponent (m)** and **Blow Counts** from SPT, SHAFT will estimate the **OCR Value** based on Equations (3.2) and (3.3).
- If the **Preconsolidation Stress Exponent (m)** and the **OCR Value** are missing (left as zero), the SHAFT program will assume that $OCR = 1$ in Equation (3.1).
- If the **Preconsolidation Stress Exponent (m)** is missing (left as zero) but the user enters the **OCR Value** (must be equal or higher than one), the SHAFT program will use the user-specified **OCR Value** in Equation (3.1).
- Any entry for **OCR Value** smaller than one will be ignored and replaced with $OCR = 1$.

Friction Angle

This column entry corresponds to values of the internal angle of friction (also known as friction or ϕ angle) for the top and bottom of the sand layer. The values of **Friction Angle** are entered in standard units of degrees.

For the **Ko Method**:

- If both **Friction Angle** and **Blow Counts** are defined by the user then the program will use the inputted **Friction Angle** for estimation of transfers in side resistance and the program will use the inputted **Blow Counts** for estimation of transfers in end bearing.
- If the user only enters **Blow Counts** (**Friction Angle** left as zero) then the program will estimate the **Friction Angle** based on **Blow Counts** (see Table 3.2) to estimate transfers in side resistance and will use the inputted **Blow Counts** for estimation of transfers in end bearing. The program will print the computed **Friction Angle** in the soil properties section on the output text file.
- If the user only enters **Friction Angle** (**Blow Counts** left as zero) then the program will use the inputted **Friction Angle** for estimation of transfers in side resistance and the program will also use the inputted **Friction Angle** for estimation of transfers in end bearing.
- Values for **Ko** must always be entered (different than zero) for this method. If the user wants to ignore **Ko** then use a different method or enter a very small value for **Ko**.

For the **Chen and Kulhawy Method**:

- If both **Friction Angle** and **Blow Counts** are defined by the user then the program will use both, the inputted **Friction Angle** and **Blow Counts** for estimation of transfers in side resistance and the program will use the inputted **Blow Counts** for estimation of transfers in end bearing.
- If the user only enters **Blow Counts** (**Friction Angle** left as zero) then the program will estimate the **Friction Angle** based on **Blow Counts** (see Table 3.2) to estimate transfers in side resistance and will use the inputted **Blow Counts** for estimation of transfers in end bearing. The program will print the computed **Friction Angle** in the soil properties section on the output text file.
- If the user only enters **Friction Angle** (**Blow Counts** left as zero) then the program will use the inputted **Friction Angle** for estimation of transfers in side resistance and the program will also use the inputted **Friction Angle** for estimation of transfers in end bearing.

For the **Beta Method**:

- If both **Friction Angle** and **Blow Counts** are defined by the user then the program will use the inputted **Beta Value** for estimation of transfers in side resistance and the program will use the inputted **Blow Counts** for estimation of transfers in end bearing.
- If the user only enters **Blow Counts** (**Friction Angle** left as zero) then the program will use the inputted **Beta Value** to estimate transfers in side resistance and will use the inputted **Blow Counts** for estimation of transfers in end bearing.
- If the user only enters **Friction Angle** (**Blow Counts** left as zero) then the program will use the inputted **Beta Value** for estimation of transfers in side resistance and the program will estimate the **Friction Angle** based on **Blow Counts** (see Table 3.2) for estimation of transfers in end bearing.
- If the **Beta Value** is missing (left as zero) then the program will estimate the **Beta Value** based on Eq. 3.5 and others (Section 3.1.1) of the SHAFT Technical Manual. The program will print the computed **Beta Value** in the soil properties section on the output text file.

According to the FHWA manuals, for concrete cast in place against soil, as in a drilled shaft, the interface is assumed to be rough and the interface friction angle (δ or ϕ_c) can be equal to the internal friction angle of the soil (ie., $\delta = \phi'$). This is how the SHAFT program considers within internal computations with Sand layers.

N (SPT) blows/ft	Overburden Stress, lb/in ²		
	0	20	40
	Values of ϕ , degrees		
0	0		
2	32		
4	34		
6	36	30	
10	38	32	31
15	42	34	32
20	45	36	34
25		37	35
30		39	36
35		40	36
40		41	37
45		42	38
50		44	39
55		45	39
60			40
65			41
70			42
75			42
80			43
85			44
90			44

Table 3.2 Relationship between N and ϕ (after Gibbs and Holtz, 1957)

3.2.7.2 Clay and Shale Layers

A sample dialog screen for layers of Clay (FHWA) or Shale (Reese & Aurora) is shown in Figure 3.11. The required inputs are explained below.

Method

Two computational methods are offered for load transfers on cohesive soils. The selection of a method changes the required input below to display only information that is applicable to the selected method.

FHWA Method this entry follows equations given in the first version of the FHWA Drilled Shaft Manual (O'Neill and Reese, 1999). This method requires the input of the Alpha Factor which is described further below.

FHWA, GEC 10 Method this entry follows the criteria added in the Brown et al (2018) GEC-10 publication for FHWA.

Total Unit Weight

This entry corresponds to values of total unit weight (submerged weight is calculated based on separate entry for depth of water table). Values for the top and bottom of the layer are entered in standard units of force per unit volume (either lb/ft³ or kN/m³). The SHAFT program will interpolate linearly between the values provided for the top and the bottom of each layer.

Cohesion

These entries are for values of the unconfined-undrained shear strength at the top and bottom of the clay layer. Ordinarily, these values are taken as one half of the compression strength of samples obtained from unconsolidated-undrained triaxial tests.

The SHAFT program will interpolate linearly between the values provided for the top and the bottom of each layer.

Type of Test

This entry is only available for the FHWA GEC 10 (Brown et al 2018) method. It incorporates corrections based on the type of laboratory test that was used to obtain the **Cohesion** value. It allows for the following three types of tests: Consolidated Isotropically Undrained triaxial Compression (CIUC), Unconfined Compression (UC) test, and Unconsolidated Undrained (UU) triaxial compression. The CIUC triaxial test is listed on top since it is considered more reliable than UC and UU tests. See Brown et al (2018) for further reference.

Blow Counts from SPT (Optional)

This entry is only available for the FHWA 1999 (O'Neill & Reese) method. This column entry corresponds to the number of blow counts obtained at the top and bottom of the clay layer from the performance of a Standard Penetration Test (SPT test). The user may optionally input **Blow Counts** obtained from SPT tests in cases where the values of undrained shear strength (**Cohesion**) are not readily available. When the user provides a value different than zero for the **Cohesion**, the values for **Blow Counts** are not used in the computations and may be left as zero.

The option to input values of **Blow Counts** instead of **Cohesion** (undrained shear strength) should be selected only when it is desirable to make a rough computation of the load-carrying capacity of a drilled shaft. The computer program converts internally between the provided values of blow counts from SPT tests to equivalent values of undrained shear strength by using the following equations (specified in the Technical Manual):

$$c_u = N_{SPT} / 10, \text{ for } c_u \text{ in units of tons/ft}^2.$$

$$c_u = N_{SPT} / 0.1, \text{ for } c_u \text{ in units of kPa.}$$

Where:

c_u = unconsolidated-undrained shear strength of the clay.

N_{SPT} = average number of blow counts (blows per foot) from the Standard Penetration Test.

Data for Layer 1

Clay (FHWA Spec.)

Method

☐ FHWA O'Neil_Reese (1999) ☒ FHWA GEC 10, Brown et al (2018)

	Values at Top of Layer	Values at Bottom of Layer
1. Total Unit Weight (lbs/ft ³)	125	125
2. Undrained Cohesion (lbs/ft ²)	0	0
3. Type of Test	CIUC	CIUC
4. Blow Counts from SPT (*)	UC	0
5. Alpha Factor (**)	0.55	0.55
6. Bearing Capacity Coefficient, Nc (**)	0	0

Copy Values From Top To Bottom

Notes:

(*) Only for approximate computations
Program will ignore blow count value if cohesion is defined

(**) Program will generate internally the value if it is left as zero

Close

Figure 3.11 Sample soil data for clay (FHWA) and shale layers

Alpha Factor

This entry is only available for the FHWA 1999 (O'Neill & Reese) method. This is an empirical factor that varies with depth and takes into account the construction procedures of the drilled shaft. The amount of research that has been performed to date is still insufficient to allow for a precise prediction of the Alpha Factor as a function of depth.

If the user leaves the default values of zero, the program will automatically compute values of Alpha Factor according to recommendations from literature (O'Neill and Reese, 1999; and O'Neill and Hassan, 1994). It is evident, actually, from the results of the load tests of instrumented drilled shafts that α is not a constant, but that it varies with the magnitude of undrained shear strength (which usually varies with depth). The SHAFT program follows the FHWA manual, where O'Neill and Reese (1999) recommend the following formulations for variations of alpha values

$$\alpha = 0.55 \text{ for } \frac{c_u}{p_a} \leq 0.55$$

(3.4)

and

$$\alpha = 0.55 - 0.1 \left(\frac{c_u}{p_a} - 1.5 \right) \quad \text{for} \quad 1.5 \leq \frac{c_u}{p_a} \leq 2.5$$

(3.5)

where

p_a = atmospheric pressure (14.7 psi, 2116 psf or 101.3 kPa).

In Equation (3.4) the value of α is 0.55 for up to $c_u/p_a = 1.5$ (which corresponds to c_u of about 1.5 tsf). If c_u is very low, it is possible that α may be greater than 0.55, but higher values should not be taken unless proven by load test. From $c_u/p_a = 1.5$ the values of α reduces linearly to 0.4 when $c_u/p_a = 3$. It is considered that a cohesive geomaterial is no longer a cohesive soil when c_u/p_a exceeds 2.5. Drilled shafts in such geomaterials should be designed according the cohesive intermediate geomaterial (Cohesive IGMs) criteria covered in Section 3.2.7.4. However, data from load tests on hard clays and weak clay shales in the South and Southwest of the United States have indicated that α remains at about 0.40 in such geomaterials up to $c_u/p_a = 5$. The cohesive soil method can be used in such geomaterials if the α factors are confirmed by load tests. Evidence has shown that values of α are the same for loadings in compression or tension. For further reference see the Technical Manual for comments of side resistance in clay layers.

The values suggested for α in Equations (3.4) and (3.5) that are internally computed by the SHAFT program are by no means certain and mainly correspond to undrained loading of drilled shafts in cohesive soil. The user should input his/her own values of **Alpha Factor** if site-specific data is available from loading tests. It is obvious that better estimates of values can be obtained from loading tests on drilled shafts that are constructed in situ with the same techniques and procedures that are planned for the production shafts.

The **Alpha Factor** for the GEC10 Method is computed internally according to the formulations referenced in the Technical Manual. The values that were estimated by the program are provided with a (*) in the output text file (Computation > View Output Text) for the top and bottom of each applicable soil layer.

Any **Clay** layer where the user enters negative values of **Alpha** is considered as a swelling soil so the user can evaluate the effects on pile capacity and penetration.

Bearing Capacity Coefficient, N_c

This column corresponds to the value of bearing capacity coefficient to be used in the computations of end bearing for clay. A value of 7.0 is suggested for the bearing capacity factor, **N_c** , for shafts built by the slurry-displacement method. This value can be increased to 8.0 when shafts are constructed by the casing or in the dry method. The SHAFT program will interpolate linearly between the values provided for the top and the bottom of each layer.

3.2.7.3 Strong Rock

A sample dialog screen for layers of Strong Rock (FHWA) is shown in Figure 3.12. The required inputs are explained below.

Total Unit Weight

This entry corresponds to values of total unit weight (submerged weight is calculated based on separate entry for depth of water table). Values for the top and bottom of the layer are entered in standard units of force per unit volume (either lb/ft³ or kN/m³). The SHAFT program will interpolate linearly between the values provided for the top and the bottom of each layer.

Rock Compressive Strength

This column corresponds to the values of uniaxial compressive strength of rock as taken from core samples (not intact or mass). The strong rock criterion requires that the unconfined compressive strength of rock is at least 144,000 psf (6,900 kPa). The SHAFT program takes into consideration the smaller value between the compressive strengths of concrete and rock to compute the capacity in side resistance. Values are entered in units of stress (force per unit area, either lb/ft² or kPa=kN/m²).

Concrete Compressive Strength

This column corresponds to the values of unconfined compressive strength (cylinder test) of concrete. The program takes into consideration the smaller value between the compressive strengths of concrete and rock to compute the capacity in side resistance. Values are entered in units of force per unit area (either lb/ft² or kPa = kN/m²).

Discontinuity Spacing

The spacing of discontinuities is taken into account to compute the bearing capacity of the rock. The formula is valid for a rock mass with spacing of discontinuities larger than 12 in. (305 mm). Engineering judgment is required for shorter spacing. Values are entered in units of length (either ft or m).

Discontinuity Thickness

The thickness of discontinuities is taken into account to compute the bearing capacity of the rock. The formula is valid for a rock mass with thickness of discontinuities smaller than 0.2 in. (5 mm). Engineering judgment is required for larger thickness. Values are entered in units of length (either ft or m).

Socket Diameter

The diameter of the rock socket is taken into account to compute the bearing capacity of the rock. Values are entered in units of length (either ft or m).

In models where there is one or more layers of rock along with defined Minimum and Maximum shaft diameters (under Data > Drilled-Shaft Properties) the program will use the defined ratio of (Socket Diameter/Minimum Shaft Diameter) for all analyzed cases of increased shaft diameter (up to the Maximum defined).

	Values at Top of Layer	Values at Bottom of Layer
1. Total Unit Weight (lbs/ft ³)	130	130
2. Rock Compressive Strength (lbs/ft ²)	1152000	1152000
3. Concrete Compressive Strength (lbs/ft ²)	1152000	1152000
4. Discontinuity Spacing (ft)	7	7
5. Discontinuity Thickness (ft)	0.0001	0.0001
6. Socket Diameter (ft)	3.5	3.5
7. Elastic Modulus (lbs/in ²)	2000000	2000000
8. RQD, %	100	100

Copy Values From Top To Bottom

Close

Figure 3.12 Sample soil data for layers of strong rock

Elastic Modulus

This column corresponds to the value of Young's modulus of the intact rock. The computer program internally modifies the value of the elastic modulus of the intact rock according to the RQD values that are placed in the last input data for strong rock. The objective is to obtain values for the modulus of the in-situ rock that take into account the number of joints and their spacing. If values of the modulus of elasticity for the rock are available from in-situ tests, the test values should be used along with an input of 100 in the RQD column (to avoid modifications of the in-situ rock modulus). Values are entered in standard units of force per unit area (either lb/ft² or kPa=kN/m²).

RQD

This column corresponds to the values of "rock quality designation" or RQD obtained from in-situ soil tests. According to the RQD value, the modulus of the intact rock is modified to account for joints in the rock. The adjustments are performed internally by the computer program using formulations in the

Technical Manual. Please read previous entry for Elastic Modulus for other information regarding entries of RQD.

3.2.7.4 Decomposed Rock/Gravel Layers

A sample dialog screen for layers of Decomposed Rock/Gravel (FHWA) is shown in Figure 3.13. The required inputs are explained below.

Total Unit Weight

This column entry corresponds to values of total unit weight (submerged weight is calculated based on separate entry for depth of water table). Values for the top and bottom of the layer are entered in standard units of force per unit volume (either lb/ft³ or kN/m³).

Blow Counts from SPT

This column entry corresponds to the number of blow counts obtained at the top and bottom of the layer while performing a Standard Penetration Test (SPT test). The user should preferably input the value of N₆₀, which is the SPT blow counts, in blows per foot (or blows per 300 mm) for the condition in which the energy transferred to the top of the drive string is 60% of the drop energy of the SPT hammer.

Poisson's Ratio

The Poisson ratio of the decomposed rock (gravel or decomposed geomaterial) at the top and bottom of the layer. This value can be approximated as 0.3 to 0.4 for drained loading in gravel, unless more specific values are available for the site. This value is only used in the computations of load versus settlement for this type of soil/rock criteria.

Young's Modulus

This column represents Young's Modulus of Elasticity of the material at the top and at the bottom of the socket in the gravel/decomposed rock layer. These values are only used in the computations of load versus settlement for this type of soil.

If the user leaves the default values of zero for Young's Modulus, the program will automatically compute values at the top and bottom of the layer based on the values of Blow Counts inputted earlier. The program computes the modulus of elasticity of the rock based on equations presented in the Technical Manual. The values of Young's Modulus that are computed and used by the program are printed in the output text file (Section 4.2.3).

Socket Diameter

The diameter of the socket in the gravel/decomposed rock may be specified to be different than at other layers. The values on this column are only used in the computation of load versus settlement. Values are entered in standard units of length (either ft or m).

In models where there is one or more layers of rock along with defined Minimum and Maximum shaft diameters (under Data > Drilled-Shaft Properties) the program will use the defined ratio of (Socket Diameter/Minimum Shaft Diameter) for all analyzed cases of increased shaft diameter (up to the Maximum defined).

Data for Layer 2

Decomp. Rock

Decomposed Rock/Gravel (FHWA Spec.)

	Values at Top of Layer	Values at Bottom of Layer
1. Total Unit Weight (kN/m ³)	21	21
2. Blow Counts from SPT	75	75
3. Poisson Ratio	0.4	0.4
4. Young Modulus (*) (kN/m ²)	0	0
5. Socket Diameter (m)	0.915	0.915
6. K/Ko factor (*)	0	0
7. Delta/Phi factor (*)	0	0

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(*) Program will generate internally the value if it is left as zero

Close

Figure 3.13 Sample soil data for decomposed rock/gravel layers

K/Ko factor

This is a dimensionless factor to account for type of construction. Chen and Kulhawy (1994) suggested this factor equal to 0.67 when using slurry construction, equal to 0.83 when using casing w/out slurry and equal to 1.0 for dry excavation.

Delta/Phi factor

This is a dimensionless factor to account for the effects of: i) disturbance of the soil on the side of the borehole during excavation, ii) borehole roughness, and iii) existence of residual mudcake. This is usually 1.0 since the sand is sheared to very large strains during the drilling process (particularly when used with the recommended K/Ko factor in previous input).

3.2.7.5 Weak Rock

A sample dialog screen for layers of Weak Rock (FHWA) is shown in Figure 3.14. The required inputs are explained below.

Data for Layer 2

Weak Rock

Weak Rock (FHWA Spec.)

	Values at Top of Layer	Values at Bottom of Layer
1. Total Unit Weight (kN/m ³)	20.4	20.4
2. Interface Condition Index (*)	1	1
3. Rock Compressive Strength (kN/m ²)	2400	
4. Concrete Slump (m)	0.175	0.175
5. Interface Friction Angle (Deg)	30	30
6. Socket Diameter (m)	0.61	0.61
7. Elastic Modulus of Rock Core (kN/m ²)	275790	275790
8. RQD, %	100	100

Notes:
 (*) Interface Condition Index
 1 - Rough Surface w/closed joints
 2 - Smooth Surface w/closed joints
 3 - Rough Surface w/open joints
 4 - Smooth Surface w/open joints

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Close

Figure 3.14 Sample soil data for weak rock layers

Total Unit Weight

This entry corresponds to values of total unit weight (submerged weight is calculated based on separate entry for depth of water table). Values for the top and bottom of the layer are entered in standard units of force per unit volume (either lb/ft³ or kN/m³). The SHAFT program will interpolate linearly between the values provided for the top and the bottom of each layer.

Interface Condition

This column input is related to the condition of the borehole after drilling. Weak rocks behave quite differently if the borehole is either rough or smooth after drilling. The user must select only one of the four

available options for the top and bottom of the layer of weak rock: (1) Rough Surface w/closed joints, (2) Smooth Surface w/closed joints, (3) Rough Surface w/open joints, or (4) Smooth Surface w/ open joints.

In general, if the user selects to use a **Rough Surface** option, one of the following conditions should be present:

- The construction specifications should require that the drilling contractor roughen the borehole by cutting circular grooves of approximately 50 mm. (2 in.) height into the sides of the borehole. Each circular groove should penetrate at least 25 mm (1 in.) into the borehole walls over the full 360 degrees around the holes. The circular grooves should have vertical spacing no greater than 0.3 m (1 ft).
- The designer must be otherwise convinced that the drilling will produce a roughness pattern generally equivalent to the specification recommended above (circular grooves), without leaving any soft, soil-like material (or “smears”) on the wall of the borehole.

It is recommended to consider a **Smooth Surface** option if none of the conditions specified earlier can be achieved. In addition, if there is a possibility that the borehole is drilled using a drilling slurry, unless circular grooves are cut into the weak rock and verified by callipering, the user should assume a **Smooth Surface** condition.

Joints are considered closed if they contain no voids or soft material in the joint. Likewise a joint is considered open if the joint contains voids or soft material.

Rock Compressive Strength

This column corresponds to the values of q_u , the uniaxial compressive strength of rock. Whenever possible, the weak rock cores should be consolidated to the mean effective stress in the ground and then subjected to undrained loading to establish the value for q_u . The validity of this solution is for soft rocks with $0.5 < q_u < 5.0$ MPa ($73 < q_u < 725$ psi). The method also assumes that high-quality samples, such as those obtained using triple-walled, core barrels, have been recovered. Values are entered in standard units of force per unit area (either lb/ft² or kPa = kN/m²).

Concrete Slump

This column represents the value for the slump of the concrete that will be used in the weak-rock socket. This is provided in units of length (in or m). The user would normally use the same concrete slump at the top and bottom of the layer. The fluidity of the concrete (as measured by the concrete slump) along with the depth of concrete are used as an indication of the pressures that the concrete will exert against the borehole walls.

The internal formulas used in the computer program are only valid for the following conditions:

- the concrete slump must be between 125 to 225 mm (5 in to 9 in),
- the rate of placement of concrete in the borehole should exceed 12 m/hour (40 ft per hour, or about 8 in. per minute), and
- the ratio of the maximum size of the coarse aggregate to the borehole diameter should be less than 0.02.

Interface Friction Angle

This column represents the value for ϕ_{rc} in degrees. The parameter ϕ_{rc} represents the angle of internal friction of the weak rock at the interface with the concrete. A value for ϕ_{rc} that is considered typical of most clay-shales and mudstones in the United States is $\phi_{rc} = 30$ degrees. This is a value that was measured at a test site in clay-shale.

Socket Diameter

This column represents the value for D , the diameter of the rock socket, in units of length (ft or m). The value of socket diameter is used in the computation of settlement. The SHAFT program thus uses only the value specified at the bottom of the layer.

The computations of settlement are only considered accurate for drilled shafts satisfying the following conditions:

- $2 < L/D < 20$, where L is the length of the socket in weak rock and D the socket diameter, and
- $D > 0.5$ m (or $D > 20$ in.).

In models where there is one or more layers of rock along with defined Minimum and Maximum shaft diameters (under Data > Drilled-Shaft Properties) the program will use the defined ratio of (Socket Diameter/Minimum Shaft Diameter) for all analyzed cases of increased shaft diameter (up to the Maximum defined).

Elastic Modulus of Rock Core

This column represents the value for E_i , Young's elastic modulus of elasticity of intact rock cores at the top and bottom of the socket. The parameter must be provided in units of stress (force per unit area, either lb/ft² or kPa=kN/m²).

RQD

This column corresponds to the values of "rock quality designation" or RQD obtained from in-situ soil tests at the top and bottom of the socket. Internally, the computer program uses the RQD to modify the modulus of elasticity of the rock, E_i , to obtain the mass modulus of elasticity, E_m , based on the values of Table 7.1 in the Technical Manual. Linear interpolation is used for intermediate values.

E_m can be estimated from the ratios in the referenced table based on the RQD of the weak rock (IGM) cores. In cases in which the RQD of the cores is less than 50 percent, it is advisable to make direct measurements of E_m in situ through plate loading tests, borehole jack tests, large-scale pressure meter tests, or by back-calculating E_m from drilled shaft loading tests, since the correlations in the referenced table become less accurate with decreasing RQD.

3.2.7.6 Strong Rock Including Side Friction plus End Bearing

The same data format described for Strong Rock in Section 3.2.7.3 is applicable to this soil option. As described in the Technical Manual, in strong rock FHWA recommends to use either side friction or tip resistance only, but not both. However, this soil option becomes convenient for cases where the user desires to observe the calculated capacity that includes the side friction and tip resistance together. The user should use a good engineering judgment when considering this option.

3.2.7.7 Gravelly Sand and Gravel Layers

A sample window for gravelly sand layers or gravel layers is shown in Figure 3.15. The required properties for these soils are explained below.

Data for Layer 2

Gravelly Sand (Rollins et al)

	Values at Top of Layer	Values at Bottom of Layer
1. Total Unit Weight (lbs/ft ³)	130	130
2. Blow Counts from SPT	40	50
3. Beta Value	0	0

Copy Values From Top To Bottom

Close

Figure 3.15 Sample soil data for gravelly sand and gravel layers

Total Unit Weight

This column entry corresponds to values of total unit weight (submerged weight is calculated based on separate entry for depth of water table). Values for the top and bottom of the layer are entered in standard units of force per unit volume (either lb/ft³ or kN/m³).

Blow Counts from SPT

This column entry corresponds to the number of blow counts obtained at the top and bottom of the layer while performing a Standard Penetration Test (SPT test). It should be noted that the Blow Counts should be greater than 25 for usage of either criteria of gravelly sand or gravel (soils with Blow Counts less than 25 would be modeled better using the Sand criteria). User-inputted values of Blow Counts are used to calculate End Bearing following Table 3.2 in the Technical Manual.

Beta Value (Optional)

The **Beta** value is an empirical parameter that takes into account the lateral earth pressure coefficient and the effective-friction angle at the interface between the concrete of the shaft and the soil. The parameter thus takes into account the fact that the stress at the interface due to the fluid pressure of the concrete may be greater than that from the soil itself. Many factors that modify the lateral stress at the soil-concrete interface can be taken into account with the **Beta** value. For instance, other factors may include the use of drilling fluid, use of casing or a dry excavation during the construction process, and the type of slump used in the concrete.

If the input for **Beta** is left as zero, the computer program automatically generates **Beta** values at each foot of penetration in the layer (or at each 0.3 meters if SI units are used). Internally, the SHAFT program uses the equations recommended by Rollins et al (2005) for the **Beta** value, which is covered in the Technical Manual.

Optionally the user may input his own value of **Beta** for the top and bottom of the layer. The SHAFT program will interpolate linearly between the values provided for the top and the bottom of each layer.

3.2.7.8 Sand Layers for CFA Piles

A sample dialog screen of **Sand for CFA Piles** is shown in Figure 3.16.

Three computational methods are offered and the selection of a method changes the required input below to display only information that is applicable to the selected method.

Coleman and Arcement.... this method is a modification of the FHWA (1999) β method for side resistance and is based on multiple CFA pile tests analyzed by Coleman and Arcement (2002). It is a recommended alternative for CFA piles in GEC 8 (2007) from FHWA. End bearing is calculated using the FHWA (1999) with SPT values.

European LPC.... this is a method using results from cone penetrometer tests (CPT) and also a recommended alternative for CFA piles in GEC 8 (2007) from FHWA. It is based on publications from Bustamante and Gianceselli (1981, 1982) for the Laboratoire Des Ponts et Chaussées (LPC).

FHWA O'Neill & Reese.... this is also known as the “depth-dependent β method” and this is the basis of the equations given in the first version of the FHWA Drilled Shaft Manual (O'Neill and Reese, 1999) as well as the AASHTO LRFD Bridge Design Specifications (2007). This method requires the input of the **Beta Value** which is described further below.

Data for Layer 1

Sand CFA

Sand for CFA Piles

Method

☒ Coleman and Arcement ☐ European LPC ☐ FHWA O'Neill & Reese (1999)

	Values at Top of Layer	Values at Bottom of Layer
1. Total Unit Weight (lbs/ft ³)	120	120
2. Blow Counts from SPT	30	30
3. Soil Type	Sand	Sand
4. CPT Qc (lbs/ft ²)	0	0
5. Beta Value (°)	0	0
6. Friction Angle (°) (Deg)	0	0

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Close

Figure 3.16 Sample soil data of Sand for CFA Piles

Total Unit Weight

This column entry corresponds to values of total unit weight (submerged weight is calculated based on the separate **Data > Water Table** entry for depth of water table). Values for the top and bottom of the sand layer are entered in standard units of force per unit volume (either lb/ft³ or kN/m³). The SHAFT program will interpolate linearly between the values provided for the top and the bottom of each layer.

Blow Counts from SPT

This column entry corresponds to the number of blow counts obtained at the top and bottom of the sand layer while performing a Standard Penetration Test (SPT test). Values of **Blow Counts** are used for computations of end bearing following equations and limits specified in the Technical Manual (comments of end bearing in sand layers). This entry is not enabled nor used in the European LPC method.

Soil Type

This entry is only required for the Coleman and Arcement method. The user can select the use of Sandy Soils or Silty Soils to define the characteristics of the load transfer in side resistance for this criteria.

CPT Q_c

This entry is only required for the European LPC method. The entry represents the cone bearing resistance, q_c , obtained from standard penetrometer tests (CPT). It is entered in standard units of pressure (either lb/ft² or kN/m²). The method provides a formulation for computations of load transfers in side resistance and in end bearing based on this entry for sand layers.

Beta Value

This entry is only enabled in the FHWA O'Neill & Reese method. The reference for this entry was defined previously in Section 3.2.7.1 of this manual.

Friction Angle

This entry is only enabled in the FHWA O'Neill & Reese method. This column entry corresponds to values of the internal angle of friction (also known as friction or ϕ angle) for the top and bottom of the sand layer. The values of Friction Angle are entered in standard units of degrees. The reference for this entry was defined previously in Section 3.2.7.1 of this manual.

3.2.7.9 Clay Layers for CFA Piles

A sample dialog screen of Clay for CFA Piles is shown in Figure 3.16.

Three computational methods are offered and the selection of a method changes the required input below to display only information that is applicable to the selected method.

Coleman and Arcement.... this method is a modification of the FHWA (1999) α method for side resistance and is based on multiple CFA pile tests analyzed by Coleman and Arcement (2002). It is a recommended alternative for CFA piles in GEC 8 (2007) from FHWA. End bearing is calculated using the FHWA (1999) with N_c values.

European LPC.... this is a method using results from cone penetrometer tests (CPT) and also a recommended alternative for CFA piles in GEC 8 (2007) from FHWA. It is based on publications from Bustamante and Gianceselli (1981, 1982) for the Laboratoire Des Ponts et Chaussées (LPC).

FHWA O'Neill & Reese.... this entry follows equations given in the first version of the FHWA Drilled Shaft Manual (O'Neill and Reese, 1999) as well as the AASHTO LRFD Bridge Design Specifications (2007). This method requires the input of the Alpha Factor which is described further below.

Data for Layer 2

Clay CFA

Clay for CFA Piles

Method

☐ Coleman and Arcement ☐ European LPC ☒ FHWA O'Neill & Reese (1999)

	Values at Top of Layer	Values at Bottom of Layer
1. Total Unit Weight (lbs/ft ³)	125	125
2. Undrained Cohesion (lbs/ft ²)	3200	3200
3. Bearing Capacity Coefficient, N _c	9	9
4. CPT Q _c (lbs/ft ²)	0	0
5. Blow Counts from SPT (*)	0	0
6. Alpha Factor (**)	0.55	0.55

Copy Values From Top To Bottom

Notes:

(*) Only for approximate computations
Program will ignore blow count value if cohesion is defined

(**) Program will generate internally the value if it is left as zero

Close

Figure 3.17 Sample soil data of Clay for CFA Piles

Total Unit Weight

This entry corresponds to values of total unit weight (submerged weight is calculated based on the separate **Data > Water Table** entry for depth of water table). Values for the top and bottom of the sand layer are entered in standard units of force per unit volume (either lb/ft³ or kN/m³). The SHAFT program will interpolate linearly between the values provided for the top and the bottom of each layer.

Undrained Cohesion

This is not required for the European LPC method but are necessary input for the other two methods. These entries represent values for the unconfined-undrained shear strength at the top and bottom of the clay layer. Ordinarily, these values are taken as one half of the compression strength of samples obtained from unconsolidated-unconfined triaxial tests.

The SHAFT program will interpolate linearly between the values provided for the top and the bottom of each layer.

Bearing Capacity Coefficient, N_c

This is not required for the European LPC method but are necessary input for the other two methods. These entries are for values of bearing capacity coefficient to be used in the computations of end bearing for clay.

Values for the bearing capacity factor, N_c , can be correlated to undrained cohesion (c_u) and undrained Young's modulus (E_s) for the soil just below the pile tip (O'Neill & Reese, FHWA, 1999). For ease of reference, some suggested relationships are provided in Table 3.3 below (O'Neill & Reese, FHWA, 1999). Check relevant sections in Chapter 9 of the SHAFT Technical Manual for further reference.

Undrained Cohesion C_u	Rigidity Index I_r	Bearing Coefficient N_c
25 kPa (520 psf)	50	6.5
50 kPa (1050 psf)	150	8.0
100 kPa (2100 psf)	250	8.7
200 kPa (4200 psf)	300	8.9
>200 kPa (>4200 psf)		9
>250 kPa (>5200 psf)		<i>Use different criteria (IGM)</i>

Table 3.3 Relationships for Cohesive Soils for FHWA 1999 Method

CPT Q_c

This entry is only required for the European LPC method. The entry represents the cone bearing resistance, q_c , obtained from standard penetrometer tests (CPT). It is entered in standard units of pressure (either lb/ft² or kN/m²). The European LPC method provides a formulation for computations of load transfers in side resistance and in end bearing based on this entry for sand layers.

Blow Counts from SPT (Optional)

This entry is only available for the FHWA O'Neill & Reese method. SPT is not recommended in cohesive soils so these entries should only be used as approximation when Undrained Cohesion is not available. The reference for this entry was defined previously in Section 3.2.7.1 of this manual.

Alpha Factor

This entry is only enabled in the FHWA O'Neill & Reese method. This is an empirical factor that varies with depth and takes into account the construction procedures of the CFA pile. The reference for this entry was defined previously in Section 3.2.7.1 of this manual.

3.2.7.10 User Defined Soil Layer

A sample dialog window for the selection of User Defined Soil Layer is shown in Figure 3.18. This selection is useful for sites where the user knows the unit transfers for each layer but needs to compute the estimated capacity and response for piles of various diameters and penetrations.

Soil model to estimate t-z and q-w curves

The user has to select the shape of the response curve that is applicable to the layer, either Clay or Sand, so the program can compute the response curve based on the unit friction/end bearing and pile diameter. Computations are made according to the corresponding criteria and as defined in the Technical Manual.

Data for Layer 1

User Defined

User Defined Layer

Soil model to estimate t-z and q-w curves

☒ Sand ☐ Clay

	Values at Top of Layer	Values at Bottom of Layer
1. Total Unit Weight (lbs/ft ³)	115	115
2. Unit Side Friction (lbs/ft ²)	150	300
3. Unit End Bearing (lbs/ft ²)	200	600

Copy Values From Top To Bottom

Close

Figure 3.18 Sample soil data of User Defined Soil Layer

Total Unit Weight

This entry corresponds to values of total unit weight (submerged weight is calculated based on the separate Data > Water Table entry for depth of water table). Values for the top and bottom of the sand layer are

entered in standard units of force per unit volume (either lb/ft³ or kN/m³). The SHAFT program will interpolate linearly between the values provided for the top and the bottom of each layer.

Unit Side Friction

The user should enter the unit skin friction that is applicable to the top and bottom of each layer. Values are entered in standard units of force per unit area (either lb/ft² or kN/m²). The SHAFT program will interpolate linearly between the values provided for the top and the bottom of each layer.

Unit End Bearing

The user should enter the unit tip resistance that is applicable to the top and bottom of each layer. Values are entered in standard units of force per unit area (either lb/ft² or kN/m²). The SHAFT program will interpolate linearly between the values provided for the top and the bottom of each layer.

3.2.8 Data > Factor of Safety (Allowable Stress Design)

This is only enabled in models where the user selects Data > Design Method > ASD (Allowable Stress Design).

This submenu allows the user to specify the factor of safety that will be used during internal computations (Figure 3.19) for the ASD method. The user may enter a global factor of safety for the total ultimate capacity, or merely apply a factor of safety to the ultimate tip resistance. Despite the factor of safety that is specified by the user, the computer program will provide full printouts of the unfactored ultimate skin friction and ultimate tip resistance for reference.

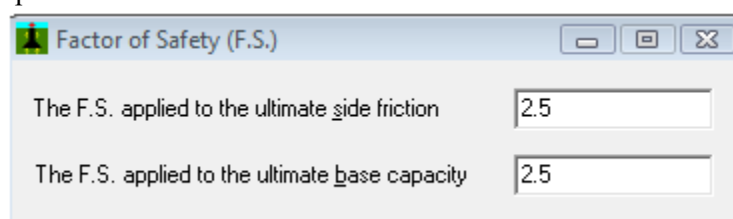


Figure 3.19 Sample screen of Data > Factor of Safety (ASD Method)

3.2.9 Data > Computation Methods

The user has the option to run the analysis by specifying either a desired depth or design load. As shown in Figure 3.20, the Computation Methods under the Data menu provides the user the following options:

- Specify the shaft length
- Specify the design load

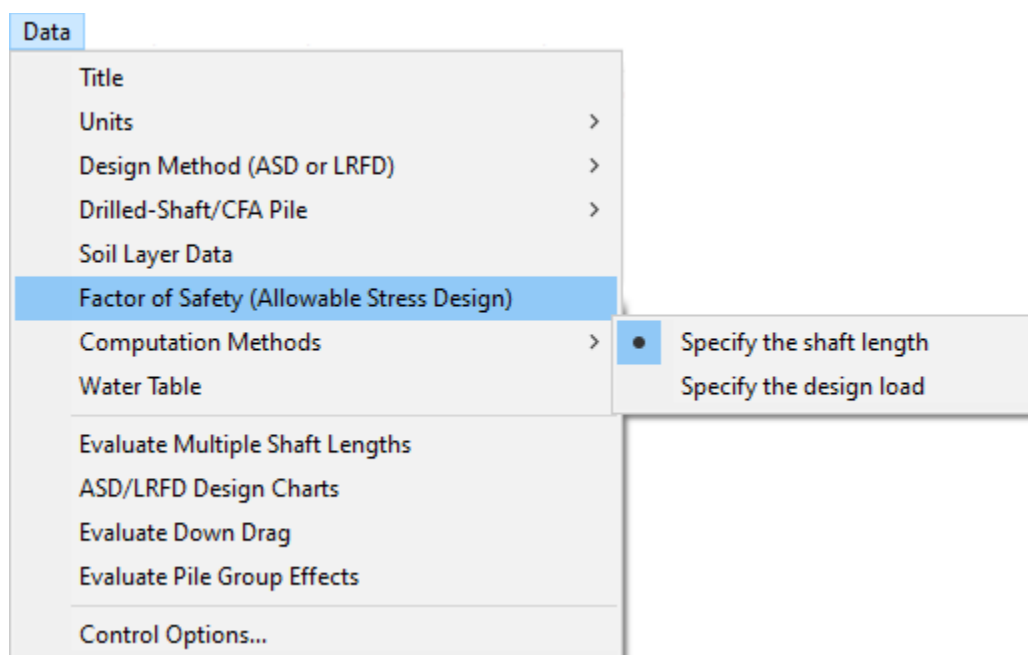


Figure 3.20 Data > Computation Methods Menu

If the user selects to **Specify the shaft length**, the dialog box in Figure 3.21 will appear for the user to enter the proposed shaft length. Similarly, if the user selects to specify the design load, the dialog box in Figure 3.22 will appear for the user to enter the proposed design load.

In both cases, as seen in Figure 3.21 and Figure 3.22, the user should also specify the **Type of Loading** by selecting one of the following options:

- **Compression.** When the loads are in compression, the SHAFT program adds the contributions from side friction and end bearing. Please notice that the weight of the shaft is not taken into account during computations of pile capacity for compressive loads.
- **Uplift.** For loads in tension, the program takes into account the contributions from side friction and weight of the shaft. The user may also reduce the side-friction contribution to uplift loads by specifying a reduction factor smaller than 1.

The depth specified for the bottom layer must be at least two diameters deeper than the specified-shaft length. The program uses the averaged-soil properties within two diameter below the shaft tip for computations of end bearing. In general, users are recommended to specify the shaft length.

The program uses 150 lb/ft³ to compute the concrete weight in tension. In most cases, the weight of concrete is ignored in compression due to the small differences that exist between the weight of the displaced soil and the concrete.

Figure 3.21 Sample entries under Data > Computation Methods > Specify the shaft length

Figure 3.22 Sample entries under Data > Computation Methods > Specify the design load

3.2.10 Data > Water Table

This submenu, shown in Figure 3.23, allows the user to specify the depth of the water table. If this entry is left at the default value of zero then the SHAFT program will consider that the water table is located at the ground surface. The water-table depth is referenced from the ground surface.

Figure 3.23 Data > Water Table Dialog Screen

3.2.11 Data > Evaluate Multiple Shaft Lengths

This optional selection is used to calculate the axial response of multiple shaft penetrations (lengths). The user can enter any Maximum shaft length but the program will stop at approximately 2.5 pile diameters above the depth of the bottom soil layer. The Minimum shaft length can be left as zero and the program will default to a minimum length that is 70% of the maximum. The minimum length must also be at least

6 pile diameters plus any exclusion zones entered in the model. The Shaft length increment may also be left as zero so the program will use the default of 3 ft (or 1 m).

This selection is not available in models where the user chooses the separate option of Data > ASD/LRFD Design Charts. A sample of this dialog box is shown in Figure 3.24.

Multiple Shaft Lengths

☒ Evaluate Shaft Lengths (for Specified Diameter)

Maximum shaft length (ft)

Minimum shaft length (ft)

Shaft length increment (ft)

* Should be at least 6 diameters plus any exclusion zone defined.
- default: 70% maximum shaft length

* A maximum of 100 increments will be considered.
- default: 3 ft or 1 m

Figure 3.24 Sample Data > Evaluate Multiple Shaft Lengths

3.2.12 Data > ASD/LRFD Design Charts

This optional selection is used to calculate and display curves of axial capacity versus depth for user-specified pile-head settlements. These curves are similar to the Chart 2 specified in guidelines prepared by the Intermodal Transportation Division, Arizona Department of Transportation (ADOT) on December 1, 2010. This selection is not available in models where the user chooses the separate option of Data > ASD/LRFD Design Charts. A sample of this dialog box is shown in Figure 3.25. This optional selection is also not available (disabled) for any model containing a rock layer.

The user may enter any Maximum shaft length but the program will stop at approximately 2.5 pile diameters above the depth of the bottom soil layer. The Minimum shaft length can be left as zero and the program will default to a minimum length that is 70% of the specified maximum. The minimum length must be at least 6 pile diameters plus any exclusion zones entered in the model. The Shaft length increment may also be left as zero so the program will use the default of 3 ft (or 1 m). The Defined Settlements are specified by the user as needed for the top of shaft and entered in units of in or mm.

LRFD Design Charts

☒ Compute LRFD Design Charts

Shaft Length/Diameter Variation

Maximum shaft length (ft)

Minimum shaft length (ft) * Should be at least 6 diameters plus any exclusion zone defined. - default: 30% maximum shaft length

Shaft length increment (ft) * A maximum of 100 increments will be considered. - default: 3 ft or 1 m

Shaft diameter increment (ft) * A maximum of 20 increments will be considered. - default: 0.5 ft or .15 m

Defined Settlements

N	Settlement (in)
1	0.1
2	0.25
3	0.5
4	0.75
5	1
6	1.2
7	1.4
8	2

Number of Points

Figure 3.25 Sample Data > ASD/LRFD Design Charts

3.2.13 Data > Evaluate Down Drag

This optional selection is used to evaluate the effects of downdrag forces from soils along any length of the modeled pile. A sample of this dialog box is shown in Figure 3.26. The user can specify the **Initial downdrag depth** and the **Final downdrag depth** for the soils that should be considered with negative skin friction. If the **Final downdrag depth** is left as zero, the program will assume only one depth (**Initial downdrag depth**) for the downdrag effects (thus use only one finite increment of pile at the defined single depth). Input of **Downdrag depth increment** establishes the number of intermediate computations between initial depth and final depth. In models with multiple shaft diameters, the **Downdrag** effect will only be evaluated for the initial/first pile diameter.

Downdrag Analysis

☒ Evaluate Downdrag (for Initial Diameter)

Initial downdrag depth (m)

Final downdrag depth (m)

Leave as zero if only one downdrag depth is analyzed

Downdrag depth increment (m)

* A maximum of 100 increments will be considered.
- default: 3 ft or 1 m

Figure 3.26 Sample Data > Evaluate Down Drag

3.2.14 Data > Evaluate Pile Group Effects

This optional selection is used to evaluate if group reduction factors would be applicable when the modeled pile is in close spacing with others nearby. A sample of this dialog box is shown in Figure 3.27. A comparison is made of the nominal resistance of the block/group of piles with respect to the sum of the individual shaft resistances. For models with sand layers, an additional comparison is made using the AASHTO 2017 group efficiencies for drilled shafts tipping in cohesionless soils (which is based on pile spacing rather than resistances).

The user can specify the **Rectangular**, **Circular** or **General** pile layouts and provide the referenced dimensions. For the **General** layout, the entry of Minimum pile spacing in pile group, S , is the minimum center-to-center distance between any two piles in the group.

In models with multiple shaft diameters, the Group effects will only be evaluated for the initial/first pile diameter.

The estimated group factors will be provided in the **Graphics > Combined Plot Single Pile Factor**. Where the user can review the estimated reduction factor for Skin Friction, Tip Resistance and for the combined Total Capacity at various pile depths.

Pile Group Effects

☒ Evaluate Pile Group Effects (for Initial Diameter)

Pile Group Layout
☐ Rectangular ☒ Circular ☐ General

Total number of piles in pile group

Radius from center of single pile at perimeter (ft)

Single pile diameter, B (ft)

Minimum pile spacing in pile group, S (ft)

Minimum pile spacing/diameter ratio (S/B)

Equivalent diameter of pile group, B1 (ft)

Equivalent area of pile group (ft²)

Net area of pile group (ft²)

Equivalent perimeter of pile group (ft)

Figure 3.27 Sample Data > Evaluate Pile Group Effects

3.2.15 Data > Control Options...

The windows dialog screen that comes up under this menu option is shown in Figure 3.28. The various entries are described as follows:

Output Increment

This numeric entry describes the increments of shaft length for which the SHAFT program will provide tabular output of its computational results. The output increment should be entered in standard units of length (either ft or m).

Plot Options

This entry allows users to change the numeric values displayed in the vertical axis of output plots. Users can change from the standard “Depth” (with zero value at ground/mudline) values to “Elevation” values, which will start from the value entered in this entry (for top of shaft, ground/mudline) and decrease downward along the shaft. If a negative value is entered here then the resulting elevations will all be negative until reaching the shaft tip. A positive values will decrease and become negative (if the shaft is sufficiently long).

The analysis must be completed (Computation > Run Analysis) in order to display the desired elevation values in the resulting graphs.

Please notice that this is only a change in the numeric values of output plots, it does not change the Depth that is used for entering input data.

Printing Additional t-z Curves

Users may select to print out the internally-generated t - z curve (load-transfer curve in side resistance) at any depth along the modeled shaft. The resulting output text file (Computation > Edit Output Text) will contain the additional t - z curves that correspond to the averaged, upper-bound and lower-bound trend lines. These curves correspond only to the initial shaft diameter (if the model defines multiple shaft diameters). The plotted additional t - z curves (Graphics > Additional t-z Curves) correspond to the averaged trend and also for the initial shaft diameter (if the model defines multiple shaft diameters).

Please notice that t - z curves are only available for soils and shale. The concepts of load-vs-deformation for sockets in intermediate geomaterials and rock are explained in notes on the accompanying Technical Manual and do not separate deformation curves for side resistance and end bearing.

In models where soils and shale are on top of rock the t - z curves for soils and shale are not taken into account. The load-vs-deformation in those models are based on elastic deformation for the length of shaft in soils/shale plus the overall deformation from the socket in the underlying rock.

End Bearing in Sands

This dialog box is only applicable for models that have a layer of Sand, Gravel or Gravelly Sand at the tip of the shaft. For those cases the SHAFT program computes end bearing based on recommendations from Quiros and Reese (1977) that considers a linear variation of q_b from zero at ground surface to maximum values (shown in Tables 3.2 and 8.1 of the Technical Manual) at a penetration of 10 pile diameters.

In Gravelly Sand and Gravel, this assumption of linear interpolation from zero at ground surface may be too conservative so designers may choose to use values from Table 3.2 of the Technical Manual according to their input and variations of N_{SPT} (Blow Counts) values from ground surface. For this option the user would select the radio button to “Use maximum values at any depth” and enter appropriate values of N_{SPT} (Blow Counts) in the applicable Data > Soil Layer Data screens.

Text Editor

The user should input in this box the complete path and command line for the preferred-text editor or word processor that will be used to examine and print the input, output, and the processor run notes files created by the SHAFT program.

As a default, the command line `c:\windows\notepad.exe` is used to operate a standard text editor. Microsoft Notepad is included with the Microsoft Windows operating system. However, the path to the directory where *notepad.exe* is installed varies in different versions of the Microsoft Windows operating system.

There may be some instances when the output files are too large for Notepad and a different text editor or word processor should be used. In those cases it is suggested to use Microsoft WordPad (`c:\windows\wordpad.exe`).

Startup Options

Selecting to Check for Program Update on Startup will open the default web browser and perform a check to see if the user is running the latest version+update of SHAFT when the program is next started. This can also be checked in the Help > Check for Updates menu.

Selecting to Check on Maintenance/Subscription Date on Startup will open the default web browser and perform a check to report the current maintenance or subscription expiration date of SHAFT when the program is next started. This can also be checked in the Help > About SHAFT menu.

Control Options

Printing Options

Output Increment (ft)

Plot Options

☐ Use Elevation instead of Depth for Label of Vertical Axis

Elevation for Top of Shaft (ft)

Note: Labels will be updated after analysis is completed.

Printing Additional t-z Curves

☐ Print Internally-Generated t-z Curves for Verification Edit Depths

End Bearing in Sands

☒ Use linear interpolation from zero at ground to maximum values at 10 pile diameters.

☐ Use maximum values at any depth

Text Editor Options

Text Editor: Browse...

Startup Options

☐ Check for Program Update on Startup

☐ Check on Maintenance/Subscription Date on Startup

Close

Figure 3.28 Entries under Data > Control Options...

3.3 Help Menu

This menu provides access to manuals that are installed with SHAFT: User’s Manual and Technical Manual. All manuals are copyrighted and also protected against modifications or copying of its content. These manuals are distributed in standard PDF files and should be available for any PDF reader that is installed in the user’s computer. For reference, the original Adobe Reader program is freely distributed by Adobe Systems Inc. at www.adobe.com

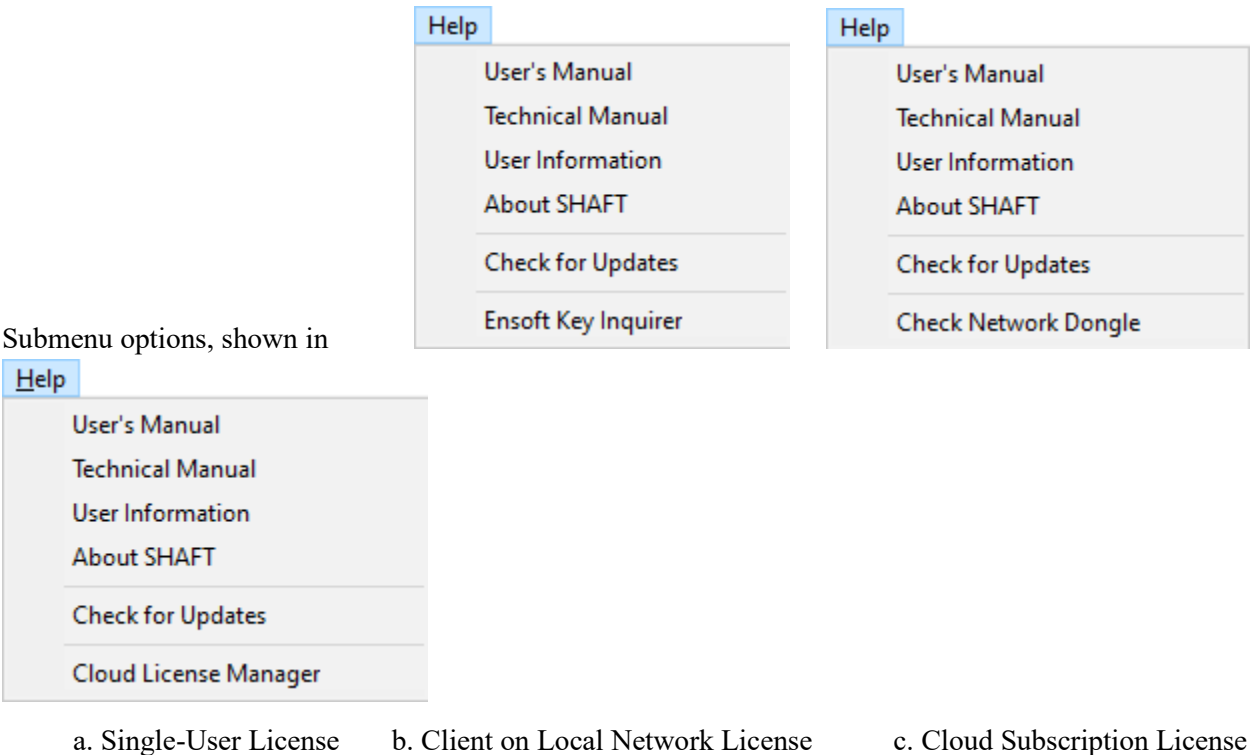


Figure 3.29, are briefly described below. The menu may be accessed at any time while in SHAFT.

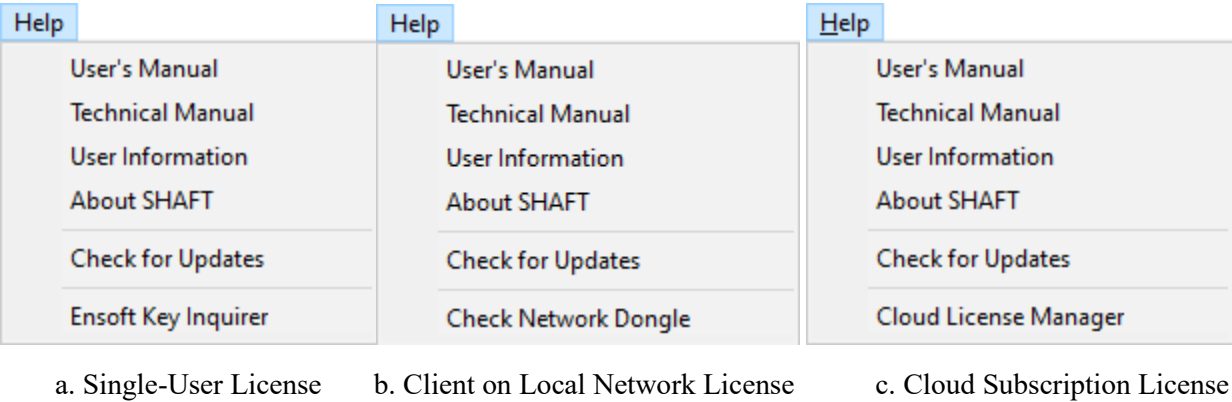


Figure 3.29 Help Menu

3.3.1 User's Manual

The Help > User's Manual calls the default PDF-file reader that is installed in the user's computer and opens the PDF file of the SHAFT User's Manual. The User's Manual for SHAFT is contained in the *Shaft 2023 Users Manual.pdf* file that is installed with the program.

3.3.2 Technical Manual

The Help > Technical Manual calls the default PDF-file reader that is installed in the user's computer and opens the PDF file of the SHAFT Technical Manual. The Technical Manual for SHAFT is contained in the *Shaft 2023 Technical Manual.pdf* file that is installed with the program.

3.3.3 User Information

This entry is used to personalize the individual installation of SHAFT. A screen capture of this dialog was previously shown in Figure 2.12. The user specified entry in this dialog will be included at the beginning of all output files that are generated by this particular installation of SHAFT. This entry can be changed/modified as necessary.

3.3.4 About ...

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.

3.3.5 Check for Updates

The Help > Check for Updates submenu will start up the default Internet browser and report the user of the current program version and maintenance expiration date as well as any new update that is available for downloading from Ensoft's website (www.ensoftinc.com). Users shall be able to download, install and run, in full mode and without the intervention from Ensoft, any SHAFT program release/update that was made prior to their maintenance expiration date. Notice that some anti-virus programs may require the user to grant permission to SHAFT to open the Internet browser program.

3.3.6 Ensoft Key Inquirer

This entry is only available on single-user installations of the software product (it is not available for users running a network version of the product). This utility is used to check for licensing information on the USB Key that is connected to a working USB port of the computer in use. It provides information such as serial number, maintenance expiration date, etc. This utility is also necessary for a remote update and renewal of the license for this product. This utility is installed in the selected installation directory with the following filename: *ensoft_key_inquirer_v7.exe* (may change with time).

3.3.7 Check Network Dongle

This entry is only available on client computers of network versions of the software product (it is not available for users running a single-user version of the product). This utility helps to check the licensing and to troubleshoot communications with a license manager (or software server). This utility is very useful in case of problems in clients while trying to run the licensed software. This utility is installed in the

selected installation directory with the following filename: *CheckNetworkDongle_ipv_512.exe* (may change with time).

3.3.8 Cloud License Manager

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

CHAPTER 4. References for Program Execution and Output Reviews

4.1 Introduction

CHAPTER 4 presents choices related to execution of the program and includes methods of addressing run-time errors. This Chapter also includes suggestions for reviewing input, output, and processor text files. The final section of this Chapter includes descriptions about all the output curves that may be observed in graphical form. The commands covered in this chapter are contained in the top menu, under the Computation and the Graphics titles.

4.2 Computation Menu

This menu is selected to execute the program using the parameters that were saved in the input-data file. Within the options contained under this menu, shown in Figure 4.1, there are commands that facilitate the reviews of the text files produced for storing input data, output results, and processor notes. In addition, the user may select an option to observe a graphical representation of the side view of the modeled pile and soil layers. Detailed description of the submenu options contained under the Computation menu are explained in the following topics.

4.2.1 Computation > Run Analysis

This command executes the analytical portion of program SHAFT. **The user should remember to save the input data under a user-specified name before executing the analytical module.** When saving data to disk, SHAFT will automatically add an extension of the type **.sf10d* to the name of the input data file.

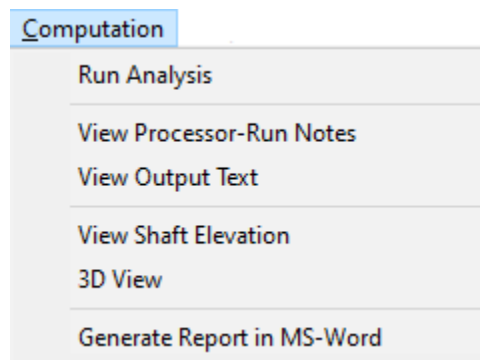


Figure 4.1 Commands in the Computation Menu.

When the execution process is finished, the active command is returned to the main SHAFT program with a screen indicating that computations are completed. The user should always check the output text file (Computation > View Output Text) for any error or warning messages that were produced during computations.

At the beginning of the computational run the analytical module will read the saved input data. If an input-data format is incorrect during reading, the analytical module will stop immediately and, in many cases, display an error message. A status report may also be saved in a file with the same name as the input but with the extension **.sf10r*. This status-report file may be accessed by selecting Computation > View Processor-Run Notes.

The analytical module automatically creates an output text file with the same name as the input but with the extension **.sf10o*. This file may be accessed by selecting **Computation > View Output Text**. Once a successful run is produced the user may proceed to the next items for observation of results.

4.2.2 Computation > View Processor Run Notes

This command is used to view a text file with processor run notes that is automatically produced during each analytical run. This file contains notes produced during the processing of input data.

Observation of the notes produced during a processor run may become helpful to debug a data file that did not produce a successful run. A successful run usually produces a file of processor-run notes containing similar lines of text as those in Figure 4.2.

This submenu automatically invokes the word processor or text editor specified under **Data > Control Options...** The default setting is to use the utility program named *notepad.exe* provided by Microsoft Windows®.

Files containing processor-run notes are automatically saved to disk with the same file name as the input-data file but with the extension **.sf10r*. Use of the Microsoft Notepad® for editing the processor-run notes for Example Problem 1 is shown in Figure 4.2.

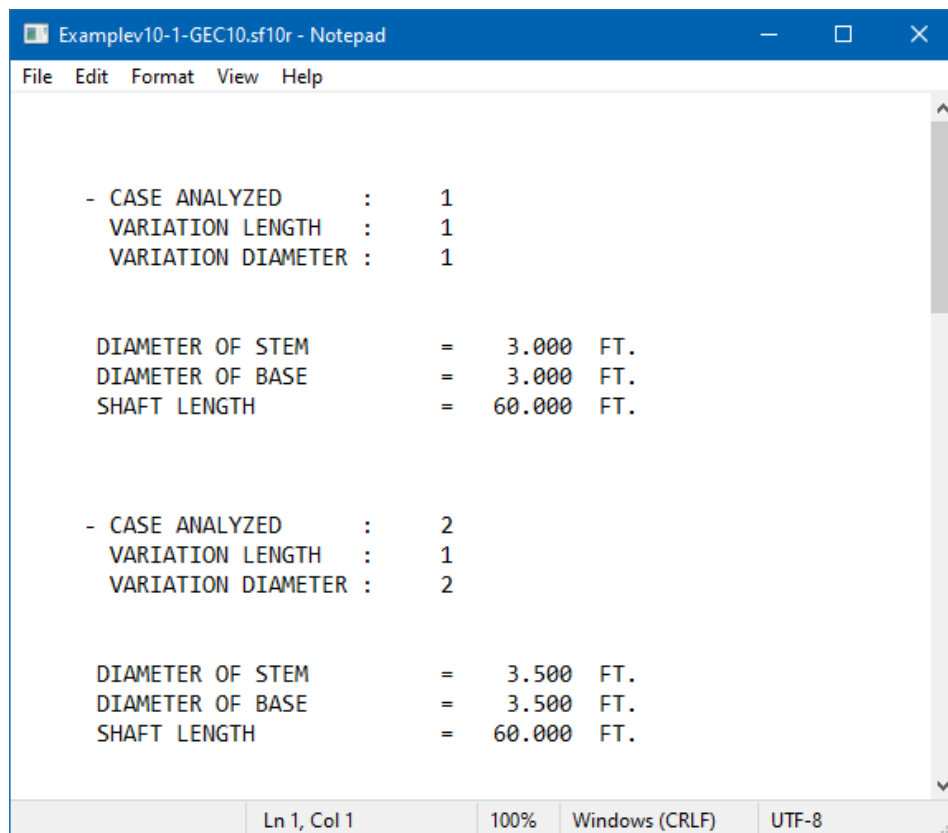


Figure 4.2 Sample Microsoft Notepad © session of processor-run notes for Example Problem 1.

4.2.3 Computation > View Output Text

This selection is used to edit the output-text file that is automatically produced during each successful analytical run. This command becomes active after new data files have been saved to disk and successfully executed, or when opening previously-executed input-data files.

The submenu automatically invokes the word processor or text editor that was previously specified under **Data > Control Options...** The default setting is to use the utility program named *notepad.exe* provided by Microsoft Windows®.

Output files are automatically saved to disk with the same file name as the input-data file but with the extension **.sf10o*. Use of Microsoft Notepad® for editing the output file for Example Problem 1 is shown in Figure 4.3.

```

Example10-1-GEC10.sf10o - Notepad
File Edit Format View Help
=====

          SHAFT Version 2026.10.01

          License ID : 158112091
          License Type : (Single User)

    VERTICALLY LOADED DRILLED SHAFT ANALYSIS
          © 1987-2025 by Ensoft, Inc.
          All Rights Reserved

    This software is licensed for exclusive use by:
          Ensoft
          Tech. Support

=====

This model was prepared by:
Technical Support

Path to file locations      : C:\Ensoft\Shaft2026-Examples\Examples for SHAFT 2026\
Name of input data file    : Example10-1-GEC10.sf10
Name of output file       : Example10-1-GEC10.sf10
Name of plot output file  : Example10-1-GEC10.sf10
Name of runtime file      : Example10-1-GEC10.sf10

-----
                    Time and Date of Analysis
-----

          Date: May 21, 2026      Time: 11:23:05

Example Problem 1, Owens and Reese, 1982, Shaft E-2

Ln 1, Col 1      100%  Windows (CRLF)  ANSI

```

Figure 4.3 Sample use of Microsoft Notepad © for editing the output-text file of Example Problem 1.

4.2.4 Computation > View Shaft Elevation

The **Computation > View Shaft Elevation** command provides a graphical screen that displays an elevation view of the drilled shaft and soil layers along with their various depths. This command becomes active after entries under **Drilled-Shaft Properties** and **Soil Layer Data** have been entered in the **Data** menu, or when opening previously-executed input-data files. A sample graphics of the **Computation > View Shaft Elevation** command option is shown in Figure 4.4.

Any extension of the drilled shaft above ground surface is only provided for graphical purposes and has no implication in the resulting computations (the shaft is only modeled starting from ground surface). The vertical position of the cursor in the screen will display an approximate indication of the depth (from ground surface to the cursor position).

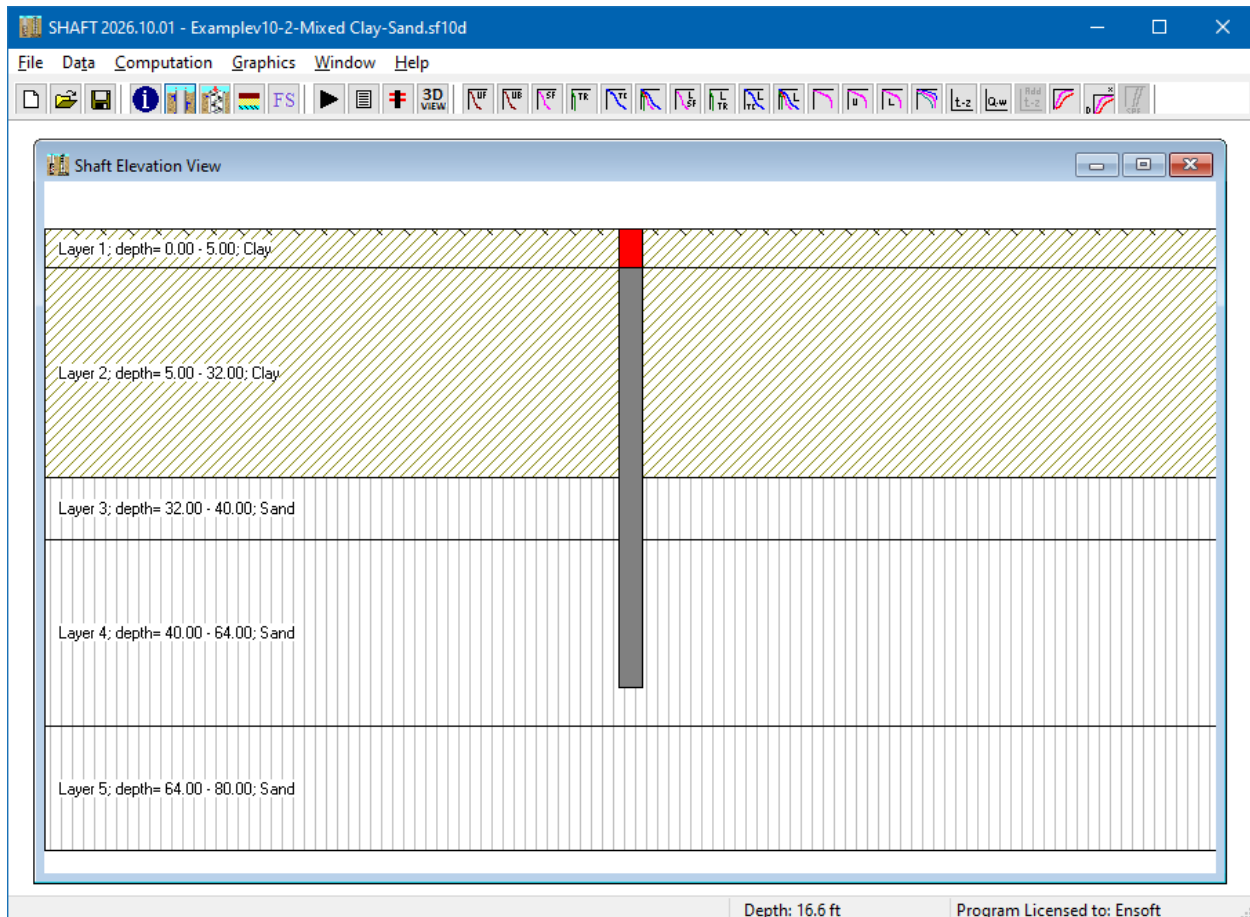


Figure 4.4 Sample **Computation > View Shaft Elevation** command.

4.2.5 Computation > 3D View

The **Computation > 3D View** command selection provides a graphical screen of the modeled shaft. This command becomes active after entries under **Drilled-Shaft Properties** and **Soil Layer Data** have been entered in the **Data** menu, or when opening previously-executed input-data files. A sample graphics of the **Computation > 3D View** command option is shown in Figure 4.5.

The selection of **Computation > 3D View** introduces a new top menu labeled **Show 3D View** (see Figure 4.6) and several new speed buttons (see Figure 4.7).

4.2.6 Show 3D View Menu

This menu becomes available when selecting the **Computation > 3D View** command. Within this menu there are several control features for the displayed 3D graph (see Figure 4.6). The following menu options are self-explanatory on/off features for the displayed graph: **Shaft**, **Water Level**, **Soil Layers**, **Layer Labels**, **Layer Depths** and **Global Axes**.

The **Show 3D View > Combined Plots** (see Figure 4.8) introduces a graphical display of load transfers (either Ultimate or ASD/LRFD) in **Skin Friction**, **Tip Resistance** and **Total Capacity** with pile depth. This may be useful to see the influence of specific soil layers in the axial load transfers. The user may also select one graph at a time to automatically display the maximum values on the 3D screen.

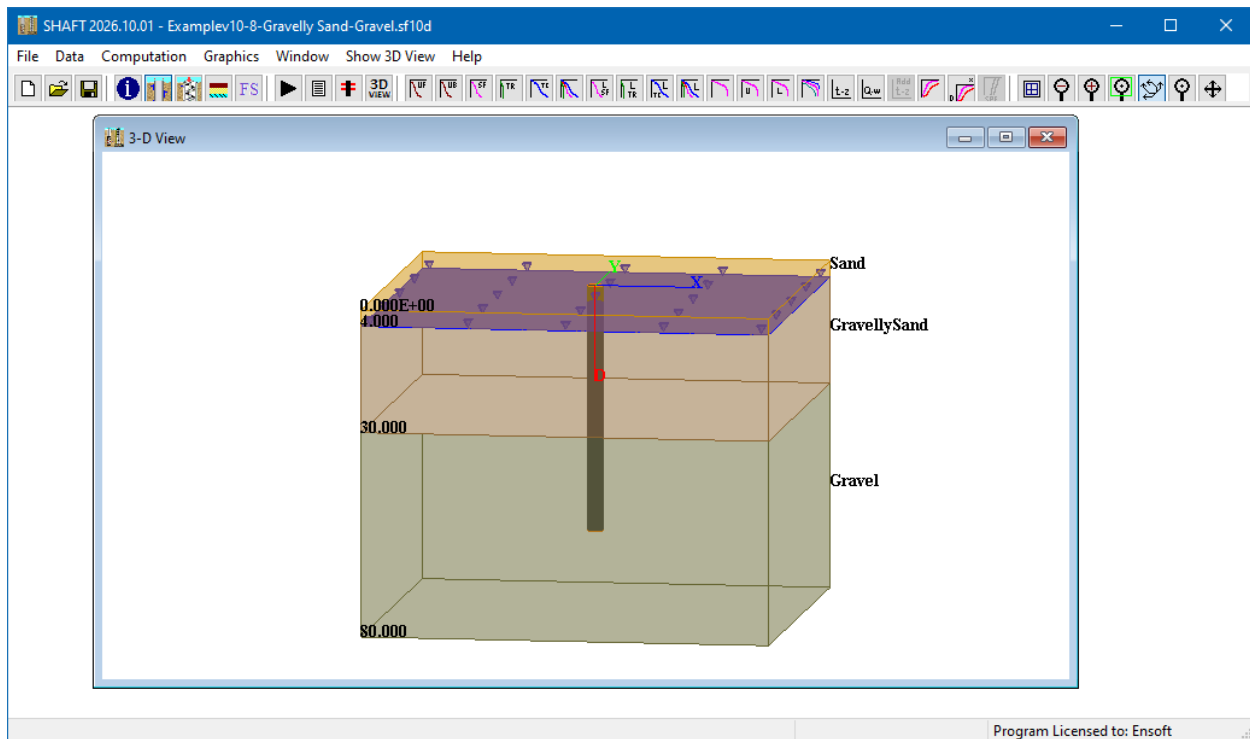


Figure 4.5 Sample **Computation > 3D View** command option.

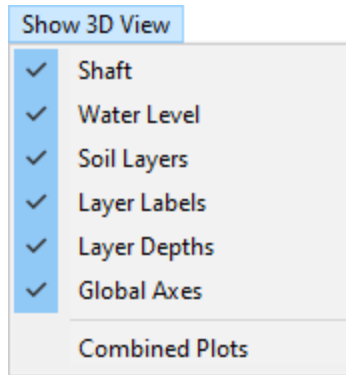


Figure 4.6 Show 3D View menu for Computation > 3D View command option.

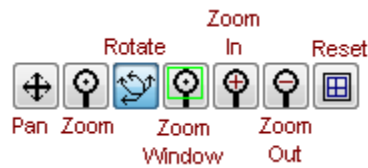


Figure 4.7 Speed buttons for Computation > 3D View command option.

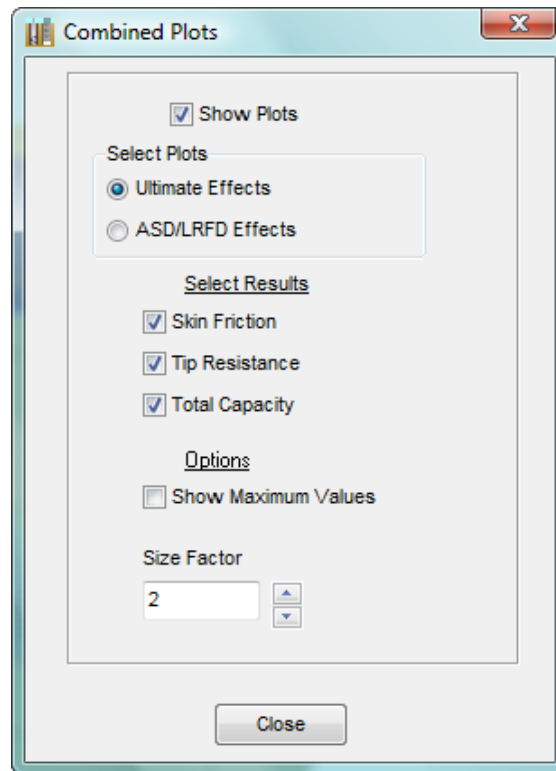


Figure 4.8 Show 3D View > Combined Plots Dialog Screen.

4.3 Graphics Menu

This menu is selected to observe the different graphical representations of the program results contained in the output file. Sample submenu options contained under this menu are shown in Figure 4.9. Not all of the graphics may be enabled for observation, active curves depend on specifications contained in the input.

All of the graphical representation of output data that may be produced by the program are contained in the following commands of the Graphics menu:

Unit Skin Friction vs Depth
Unit Tip Resistance vs Depth
Ultimate Skin Friction vs Depth
Ultimate Tip Resistance vs Depth
Ultimate Total Capacity vs Depth
Combined Plots vs Depth (Initial Diameter)
ASD/LRFD Skin Friction vs Depth
ASD/LRFD Tip Resistance vs Depth
ASD/LRFD Total Capacity vs Depth
Combined Plots vs Depth (Initial Diameter)
Axial Load vs Settlement (averaged)
Axial Load vs Settlement (upper bound)
Axial Load vs Settlement (lower bound)
Combined Plots of Load vs Settlement (Initial Diameter)
t-z Curves (averaged, initial diameter)
Q-w Curves (averaged)
Additional t-z Curves (averaged, initial diameter)
Load Distribution (averaged, initial diameter)
Axial Displacement Distribution (averaged, initial diameter)
Design Charts (xx movement)
Combined Plot Single Pile Factor
Export Plots to Excel

The observation of any of the above-listed curves will activate the graphics mode of SHAFT. Several changes occur during use of the graphics mode: new mouse commands are enabled and a new top-menu option (Plot) becomes available.

The background data from any observed Graphics plot can be easily copied and pasted into any spreadsheet for further observations using the Plot > Copy data to clipboard menu command.

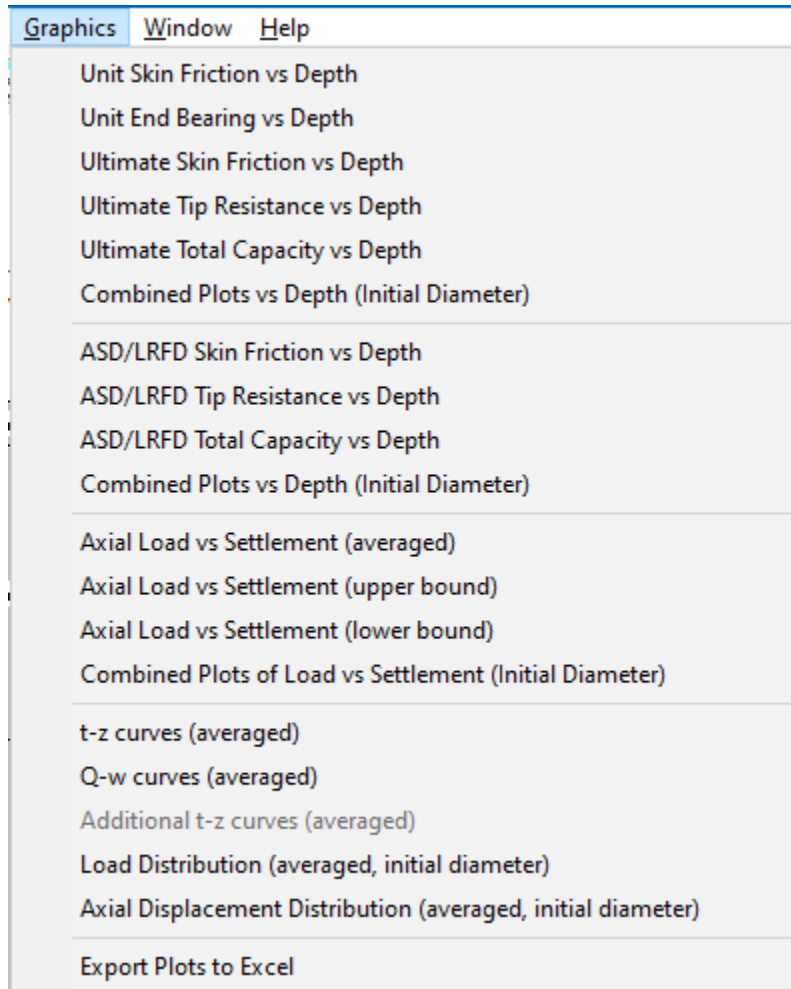


Figure 4.9 Sample Graphics Menu.

4.3.1 Mouse Commands in the Graphics Mode

Table 4.1 describes mouse commands that become enabled automatically during all graphical observations of output curves.

Event	Description
Mouse Left Click	Zooms in on the graphics at the clicked position (up to five zoom levels)
Mouse Right Click	Zooms out from the graphics
Mouse Double Click on Legend	Turns the selected curve on/off at every click

Table 4.1 Mouse commands in the graphics mode

4.3.2 Graphics > Unit Skin Friction vs Depth

This selection provides a curve(s) of the unit skin friction (unit side resistance) versus depth for the modeled-drilled shaft. This curve is automatically generated in all analytical runs of a drilled shaft. The data value at each depth represents the unit skin friction resistance of the soil in units of force per unit side frictional area of pile. A single curve is presented if the model involves only one shaft diameter. Several curves are provided when the model involves multiple pile diameters.

A sample screen of the Graphics > Unit Skin Friction vs Depth command option is shown in Figure 4.10. In models with Data > Evaluate Down Drag, the values of Unit Skin Friction will be negative for the lengths with Downdrag.

In models with uplift, the values of skin friction represented in the graphics have been modified by the reduction factor that was specified for uplift loads (under Data > Computations Method).

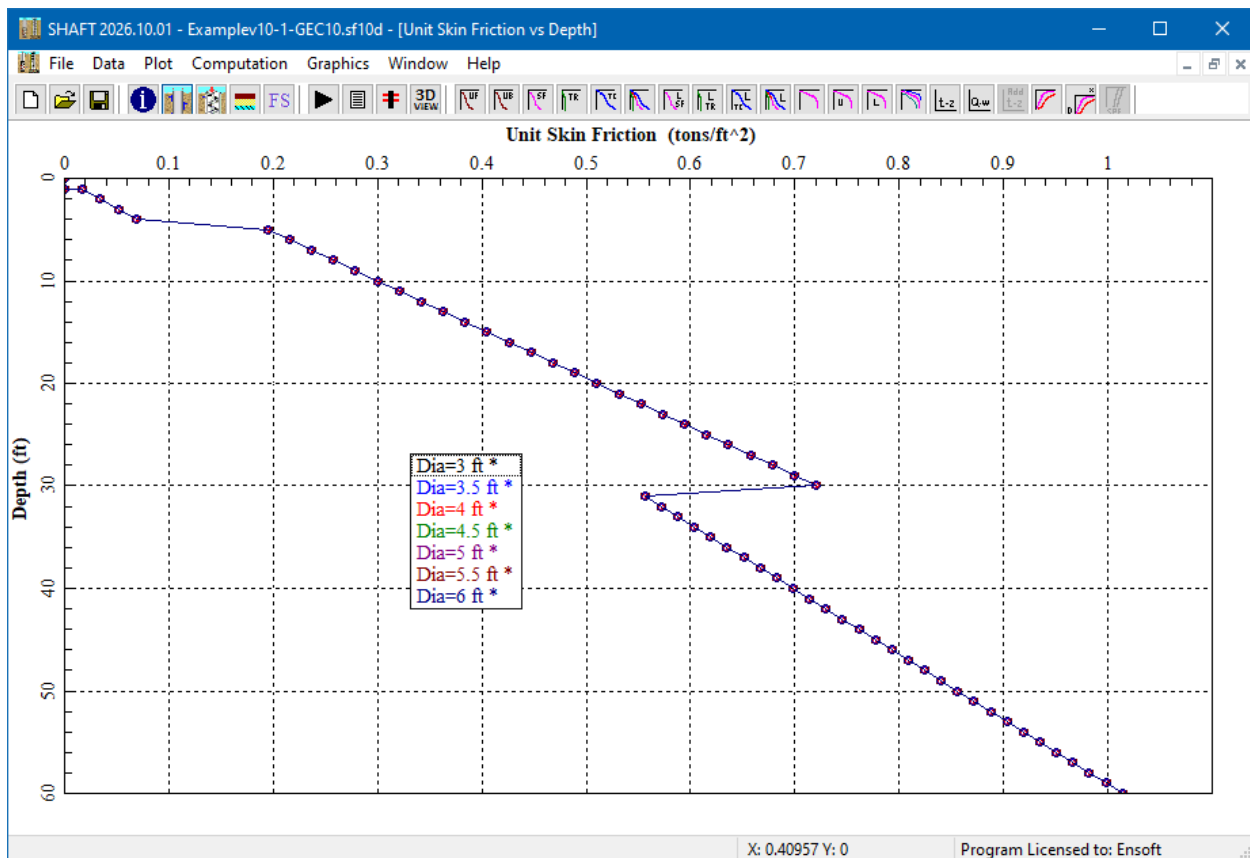


Figure 4.10 Unit Skin Friction vs Depth for Example Problem 1.

4.3.3 Graphics > Unit End Bearing vs Depth

This selection provides a curve(s) of the unit end bearing (unit tip resistance) versus depth for the modeled-drilled shaft. This curve is automatically generated in all analytical runs of a drilled shaft. The data value at each depth represents the unit end bearing of the soil in units of force per unit cross sectional area of the pile.

A single curve is presented if the model involves only one shaft diameter. Several curves (different lengths) are provided when the model involves multiple pile diameters. A sample screen of the Graphics > Unit End Bearing vs Depth command option is shown in Figure 4.11.

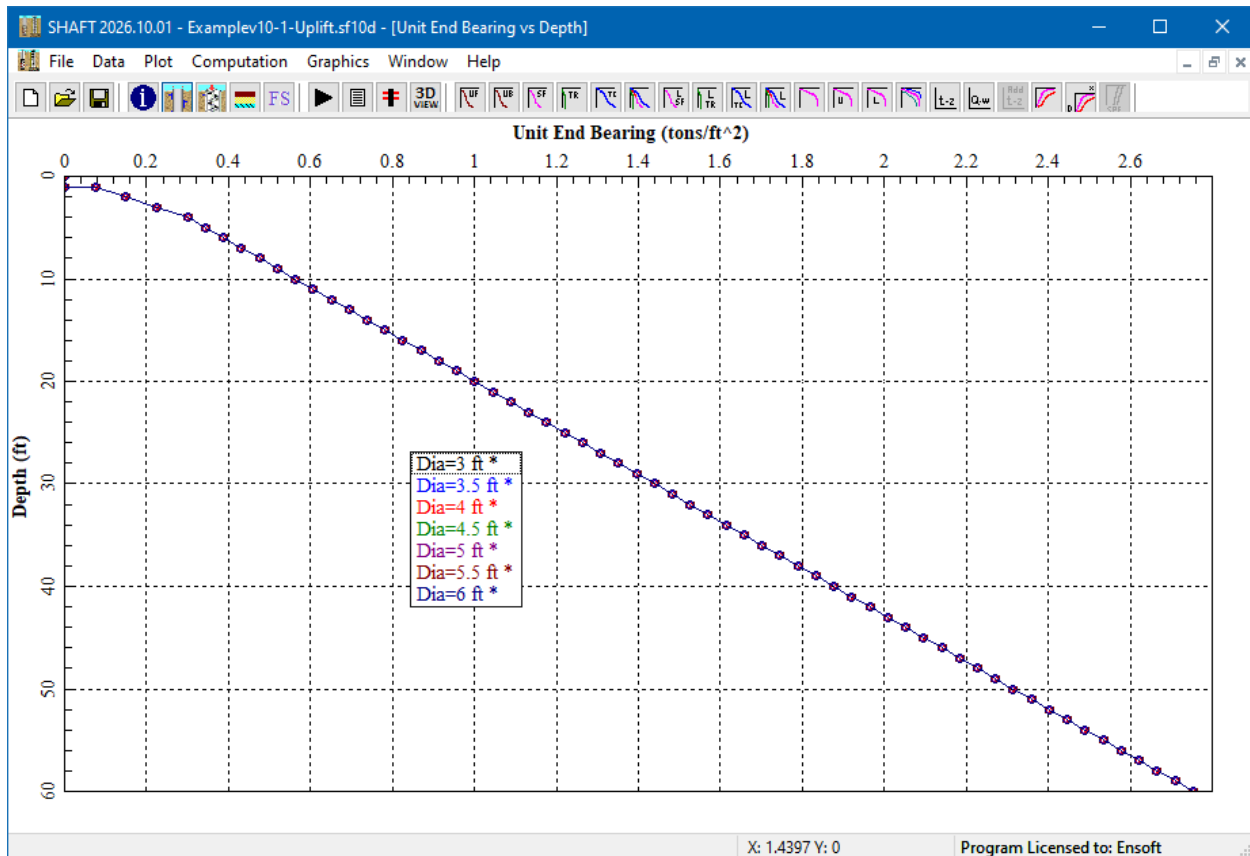


Figure 4.11 Unit End Bearing vs Depth for Example Problem 1.

4.3.4 Graphics > Ultimate Skin Friction vs Depth

This selection provides a curve(s) of the ultimate skin friction (side resistance) versus depth for the modeled-drilled shaft. This curve is automatically generated in all analytical runs of a drilled shaft. The data value at each depth represents the unfactored, total friction (ultimate values) from the ground surface to the specified depth. A single curve is presented if the model involves only one shaft diameter. Several curves are provided when the model involves multiple pile diameters.

A sample screen of the Graphics > Ultimate Skin Friction vs Depth command option is shown in Figure 4.12. In cases of uplift, the values of skin friction represented in the graphics have been modified by the reduction factor that was specified for uplift loads (under Data > Computations Method). The values of skin friction, although reduced for uplift, are still ultimate and do not take into account the specified load factors.

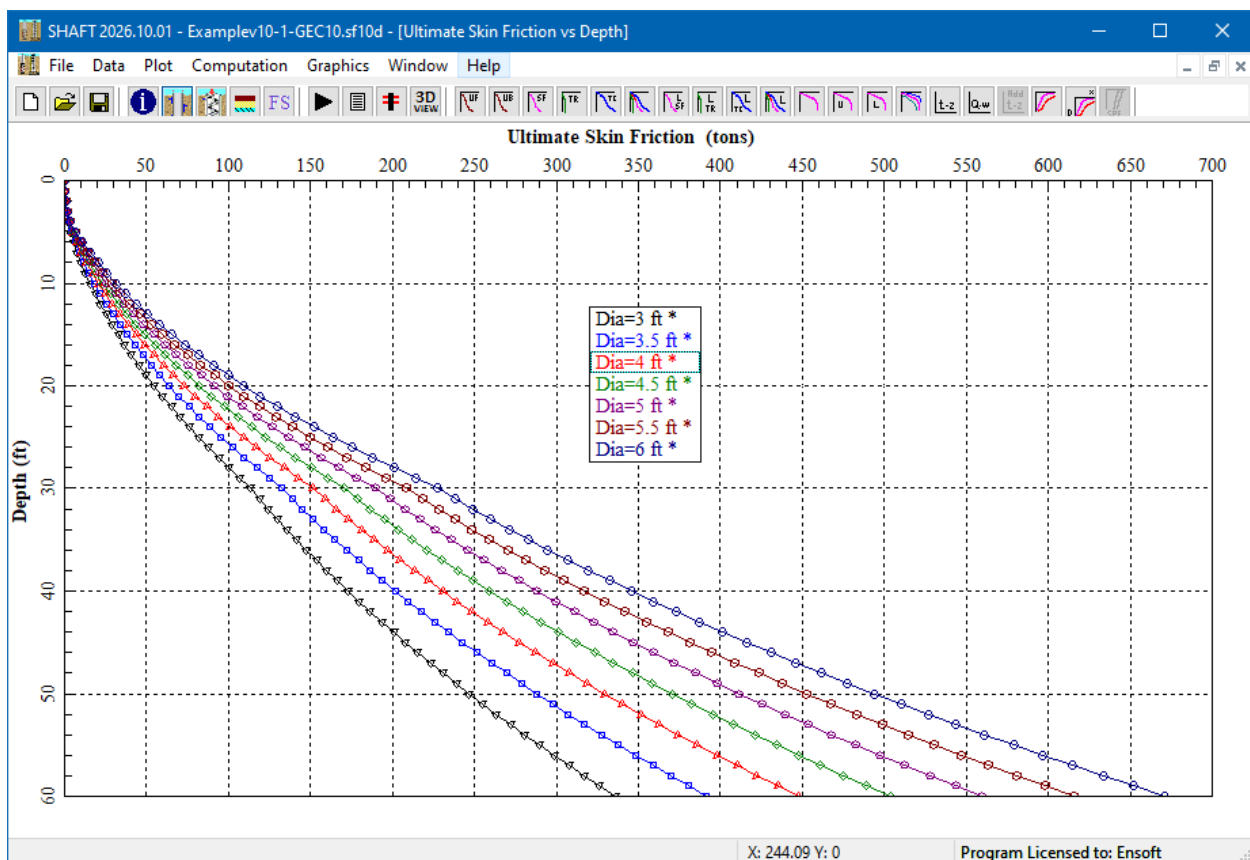


Figure 4.12 Ultimate Skin Friction vs Depth command option for Example Problem 1.

4.3.5 Graphics > Ultimate Tip Resistance vs Depth

This selection provides a curve(s) of the ultimate tip resistance versus depth for the modeled-drilled shaft. The data value at each depth represents the unfactored, tip resistance (ultimate values) developed at that depth. A single curve is presented if the model involves only one shaft diameter. Several curves are provided when the model involves multiple pile diameters.

A sample graphics screen of the Graphics > Ultimate Tip Resistance vs Depth command option is shown in Figure 4.13. The curve of Tip Resistance vs Depth is disabled (not applicable) for models with uplift loads.

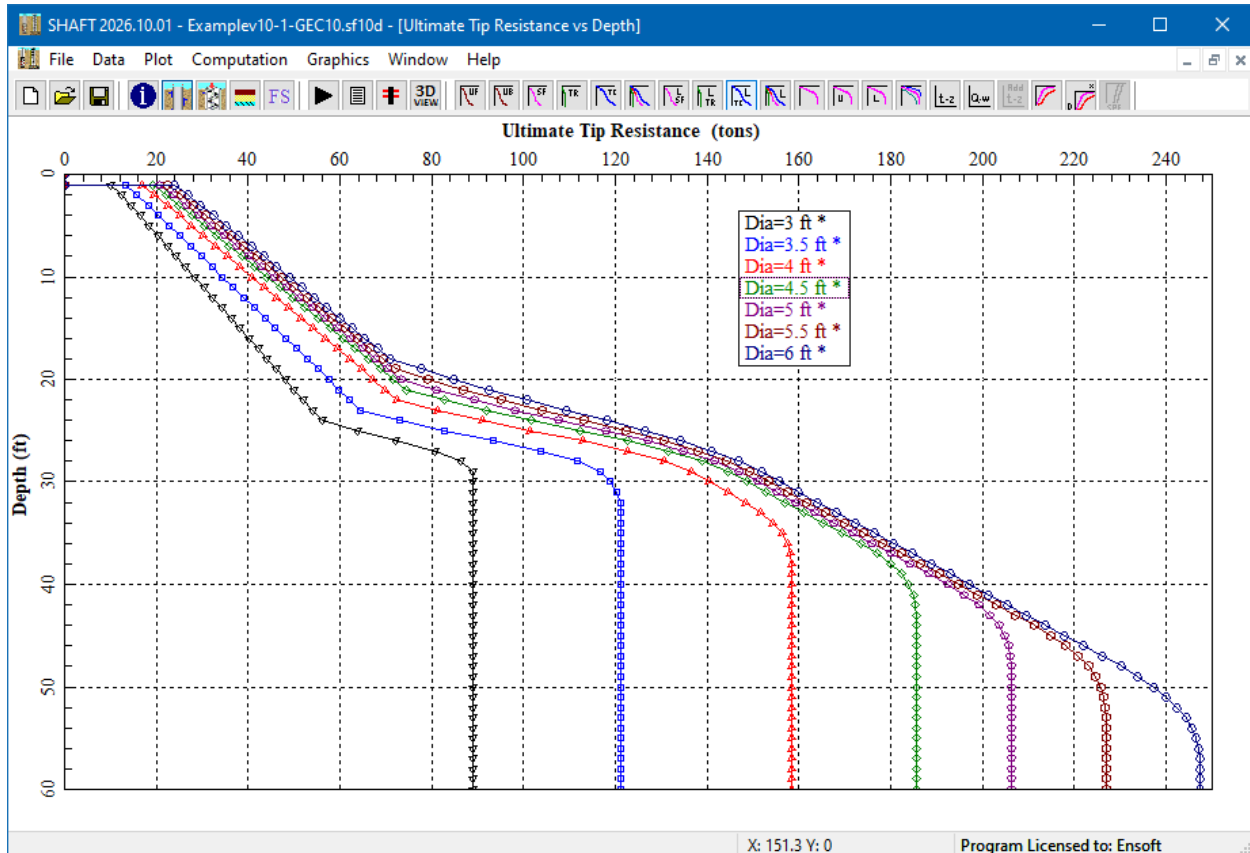


Figure 4.13 Ultimate Tip Resistance vs Depth command option for Example Problem 1.

4.3.6 Graphics > Ultimate Total Capacity vs Depth

This selection provides a graphical representation of the curve(s) of the ultimate total capacity versus depth for the modeled-drilled shaft. This curve is automatically generated in all analytical runs of an axially-loaded drilled shaft. The data value at each depth represents the unfactored, total capacity (ultimate loads) from the ground surface down to that depth. A sample graphics screen of the Graphics > Ultimate Total Capacity vs Depth command option is shown in Figure 4.14.

Values of total capacity are equal to skin friction plus tip resistance for compressive loads. Total capacity is equal to skin friction plus shaft weight for uplift loads. For uplift loads, the displayed values have been modified according to the reduction factor that the user has previously specified (under the Data > Computations Method). The values of Ultimate Total Capacity, although reduced for uplift (if selected), are still ultimate and do not take into account the specified factors of safety.

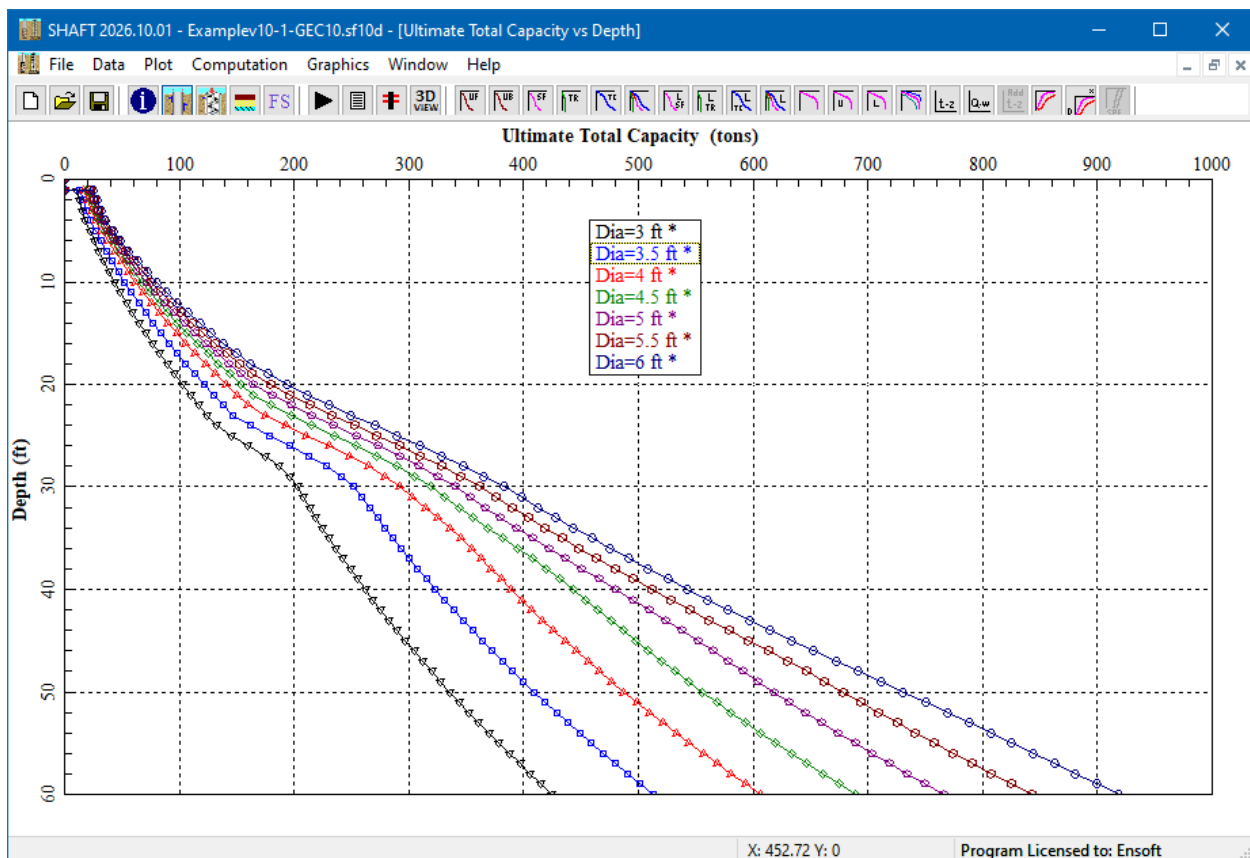


Figure 4.14 Ultimate Total Capacity vs Depth for Example Problem 1.

4.3.7 Graphics > Combined Plots vs Depth (ultimate)

This selection provides a graphical representation of the curves of ultimate skin friction, ultimate tip resistance, and ultimate total capacity versus depth for the modeled-drilled shaft all combined on the same plot. These curves are automatically generated in all analytical runs of an axially-loaded drilled shaft. The data value at each depth represents the unfactored, total capacity (ultimate loads) from the ground surface down to that depth. A sample graphics screen of the Graphics > Combined Plots vs Depth command option is shown in Figure 4.19.

Values of total capacity are equal to skin friction plus tip resistance for compressive loads. Total capacity is equal to skin friction plus shaft weight for uplift loads. For uplift loads, the displayed values have been modified according to the reduction factor that the user has previously specified (under the Data > Computations Method). The capacity values, although reduced for uplift (if selected), are still ultimate and do not take into account the specified factors of safety. In models evaluating multiple shaft diameters, the combined plots are only for the drilled shaft with the initial diameter (smallest).

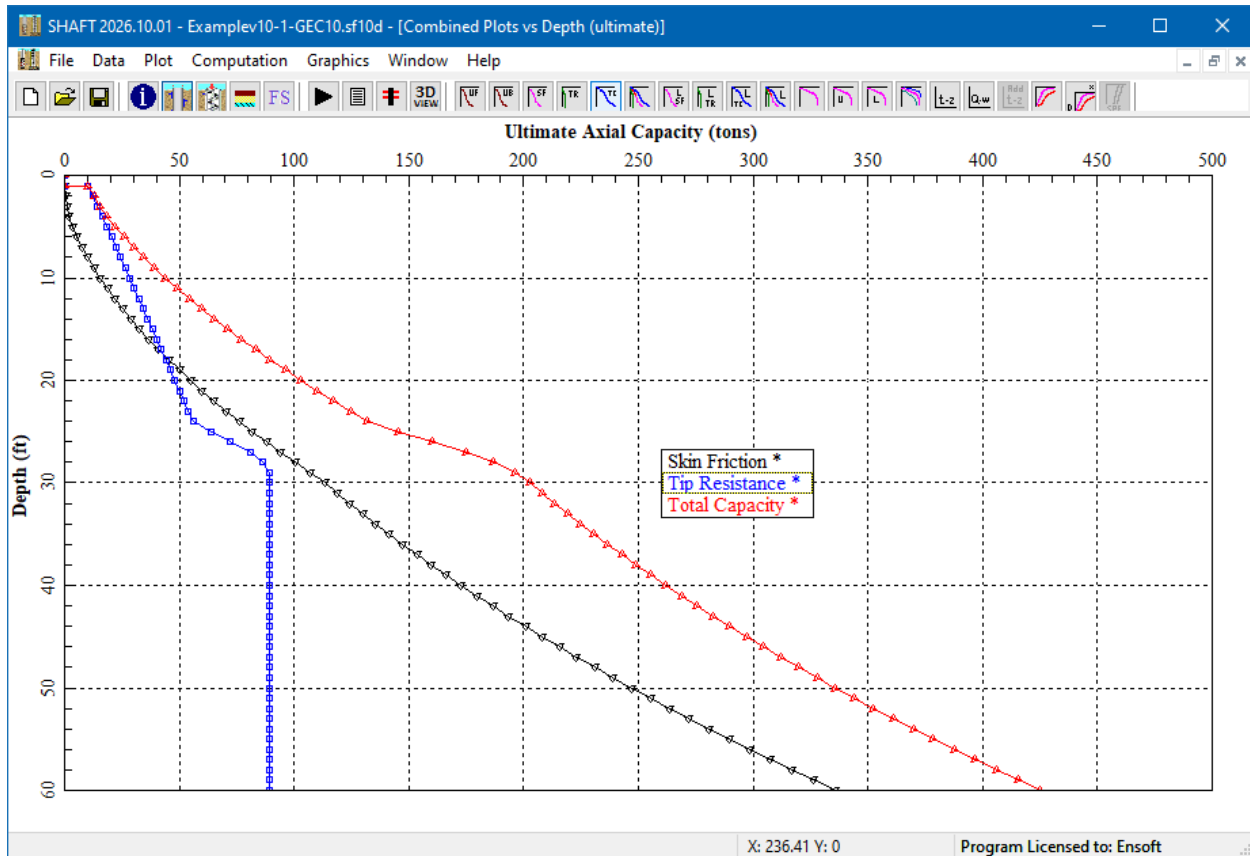


Figure 4.15 Combined Plots vs Depth (Ultimate) for Example Problem 1.

4.3.8 Graphics > ASD/LRFD Skin Friction vs Depth

The user may select this command to observe a graphical representation of the curve of skin friction (side resistance) versus depth for the modeled-drilled shaft. This curve is automatically generated in all analytical runs of a drilled shaft. The data value at each depth represents the factored, total friction from the ground surface down to that depth. In ASD analyses the curve uses the factor of safety that the user specified for ultimate side friction under the **Data > Factor of Safety** menu. In LRFD analyses the curve uses the resistance factors for Side Friction of each soil layer that the users specified under the **Data > Soil Layer Data** menu.

A sample graphics screen of the ASD/LRFD Skin Friction vs Depth command option is shown in Figure 4.16. In cases of uplift, the values of skin friction represented in the graphics have been modified by the reduction factor that was specified for uplift loads.

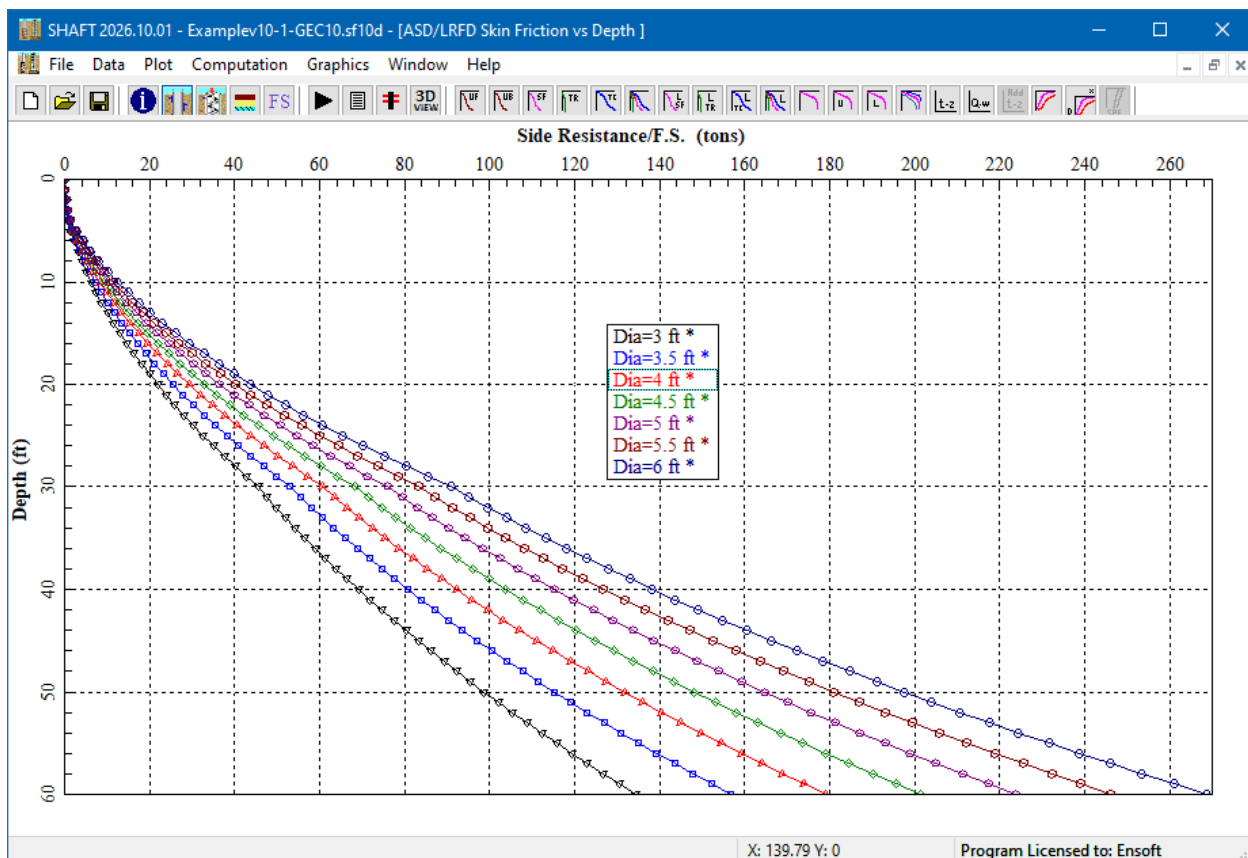


Figure 4.16 Skin Friction vs. Depth (w/F.S.) for Example Problem 1.

4.3.9 ASD/LRFD Graphics > Tip Resistance vs Depth

This command option is selected to observe a graphical representation of the curve of tip resistance versus depth for the modeled pile. This curve is automatically generated in all analytical runs of a drilled shaft, except for cases with uplift loads. In ASD analyses the curve uses the factor of safety for ultimate base capacity that the user specified under the **Data > Factor of Safety** menu. In LRFD analyses the curve uses the resistance factors for End Bearing of each soil layer that the users specified under the **Data > Soil Layer Data** menu.

The data value at each depth represents the factored, tip resistance developed at that depth. A sample graphics screen of the ASD/LRFD Tip Resistance vs Depth command option is shown in Figure 4.17. The curve of Tip Resistance vs Depth is disabled for uplift loads.

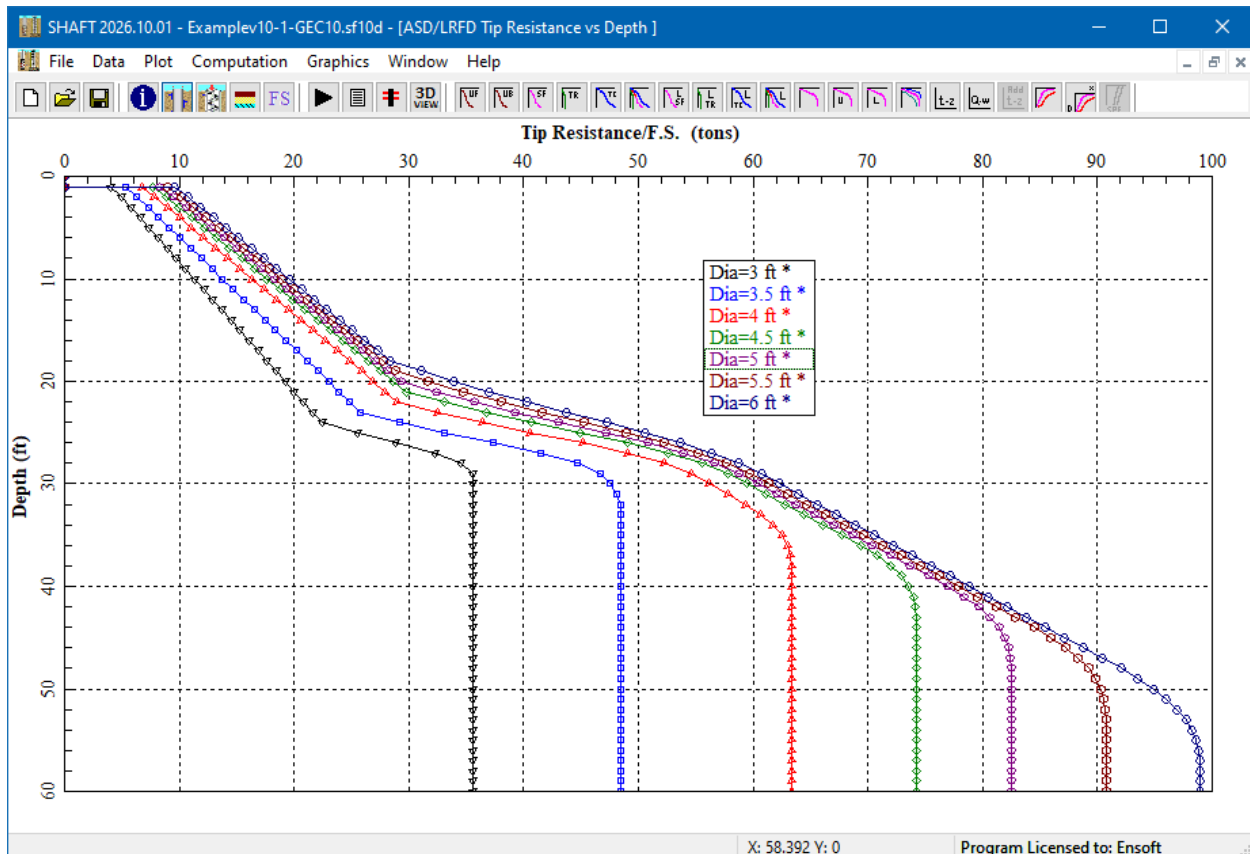


Figure 4.17 Tip Resistance vs Depth (w/F.S.) for Example Problem 1.

4.3.10 ASD/LRFD Graphics > Total Capacity vs Depth

This selection provides a graphical representation of the curve of total capacity versus depth for the modeled-drilled shaft. This curve is automatically generated in all analytical runs of an axially-loaded drilled shaft. The data value at each depth represents the factored, total capacity from the ground surface down to that depth. A sample graphics screen of the ASD/LRFD Total Capacity vs Depth command option is shown in Figure 4.18.

Values of total capacity are equal to skin friction plus tip resistance for compressive loads. Total capacity is equal to skin friction plus shaft weight for uplift loads. For uplift loads, the values have been modified according to the reduction factor that the user has previously specified under the **Data > Computations Method** menu. In ASD analyses the curve uses the factor of safety for ultimate base capacity and for ultimate side friction that the user specified under the **Data > Factor of Safety** menu. In LRFD analyses the curve uses the resistance factors for End Bearing and Side Friction of each soil layer that the users specified under the **Data > Soil Layer Data** menu.

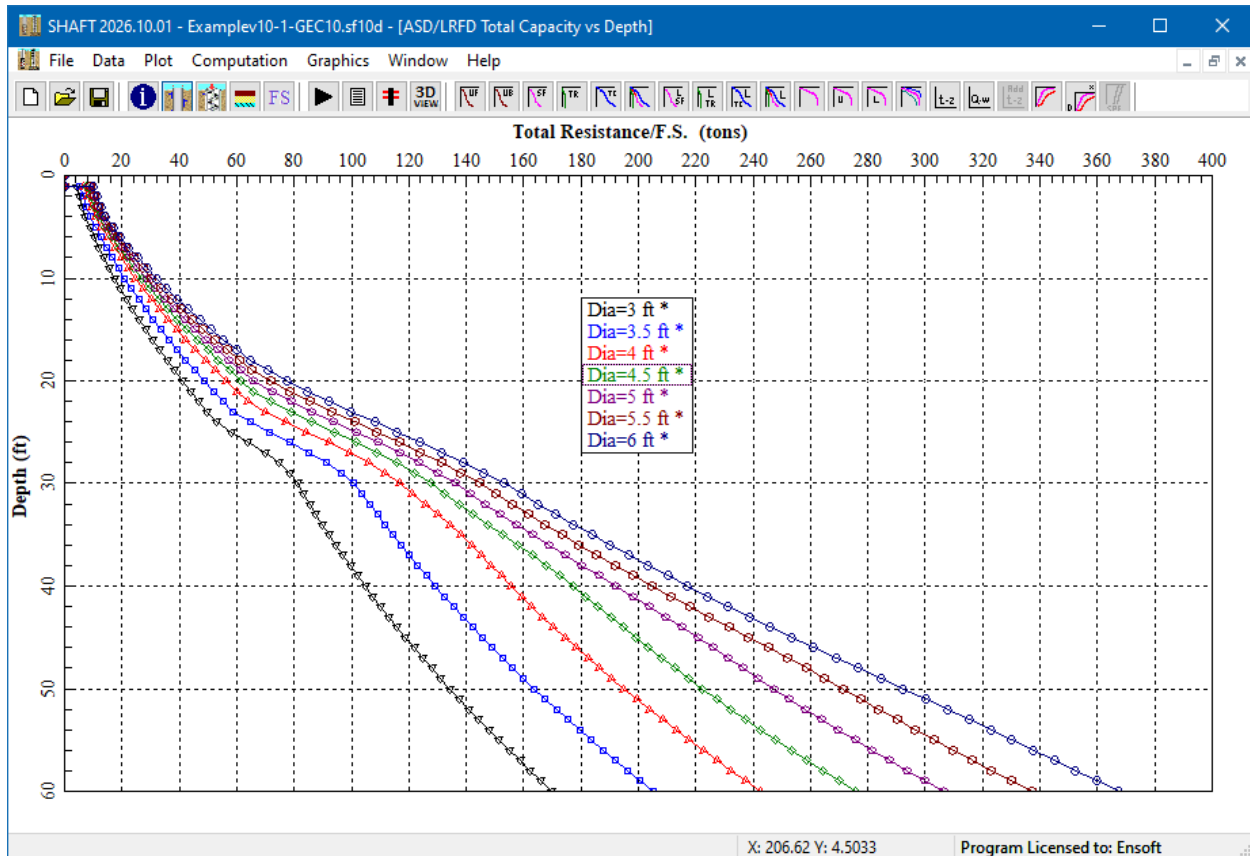


Figure 4.18 Total Capacity vs Depth (w/F.S.) for Example Problem 1.

4.3.11 Graphics > Combined Plots vs Depth (ASD/LRFD)

The user may select this command option to observe a graphical representation of the curves of skin friction, tip resistance, and total capacity, all with a factor of safety applied, versus depth for the modeled-drilled shaft on the same plot. This curve is automatically generated in all analytical runs of a drilled shaft.

A sample graphics screen of the Combined Plots vs Depth (ASD/LRFD) command option is shown in Figure 4.19. In ASD analyses the curve uses the factor of safety for ultimate base capacity and for ultimate side friction that the user specified under the **Data > Factor of Safety** menu. In LRFD analyses the curve uses the resistance factors for End Bearing and Side Friction of each soil layer that the users specified under the **Data > Soil Layer Data** menu. In models evaluating multiple shaft diameters, the combined plots are only for the drilled shaft with the initial diameter (smallest).

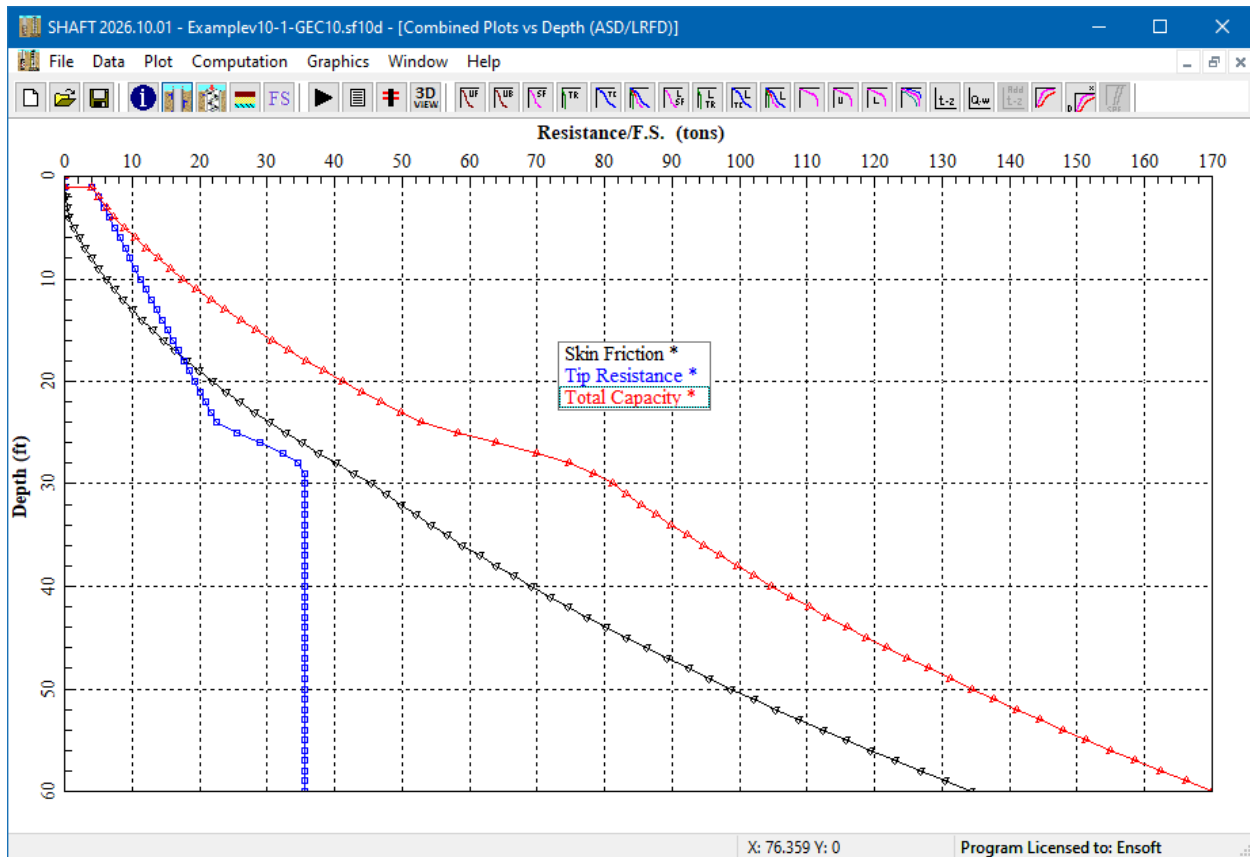


Figure 4.19 Combined Plots vs Depth (w/F.S.) for Example Problem 1.

4.3.12 Graphics > Axial Load vs Settlement (Averaged)

This selection provides a graphical representation of the curves of axial load versus settlement for the modeled drilled shaft based on the trend (averaged) curves shown in the FHWA manual. This curve is automatically generated in all analytical runs of a drilled shaft. A sample graphics screen of the Axial Load vs Settlement (Averaged) command option is shown in Figure 4.20.



Figure 4.20 Axial Load vs Settlement (averaged) for Example Problem 1.

4.3.13 Graphics > Axial Load vs Settlement (Upper Bound)

This selection provides a graphical representation of the curves of axial load versus settlement for the modeled drilled shaft based on the upper-bound curves shown in the FHWA manual. This curve is automatically generated in all analytical runs of a drilled shaft. A sample graphics screen of the command option is shown in Figure 4.21.

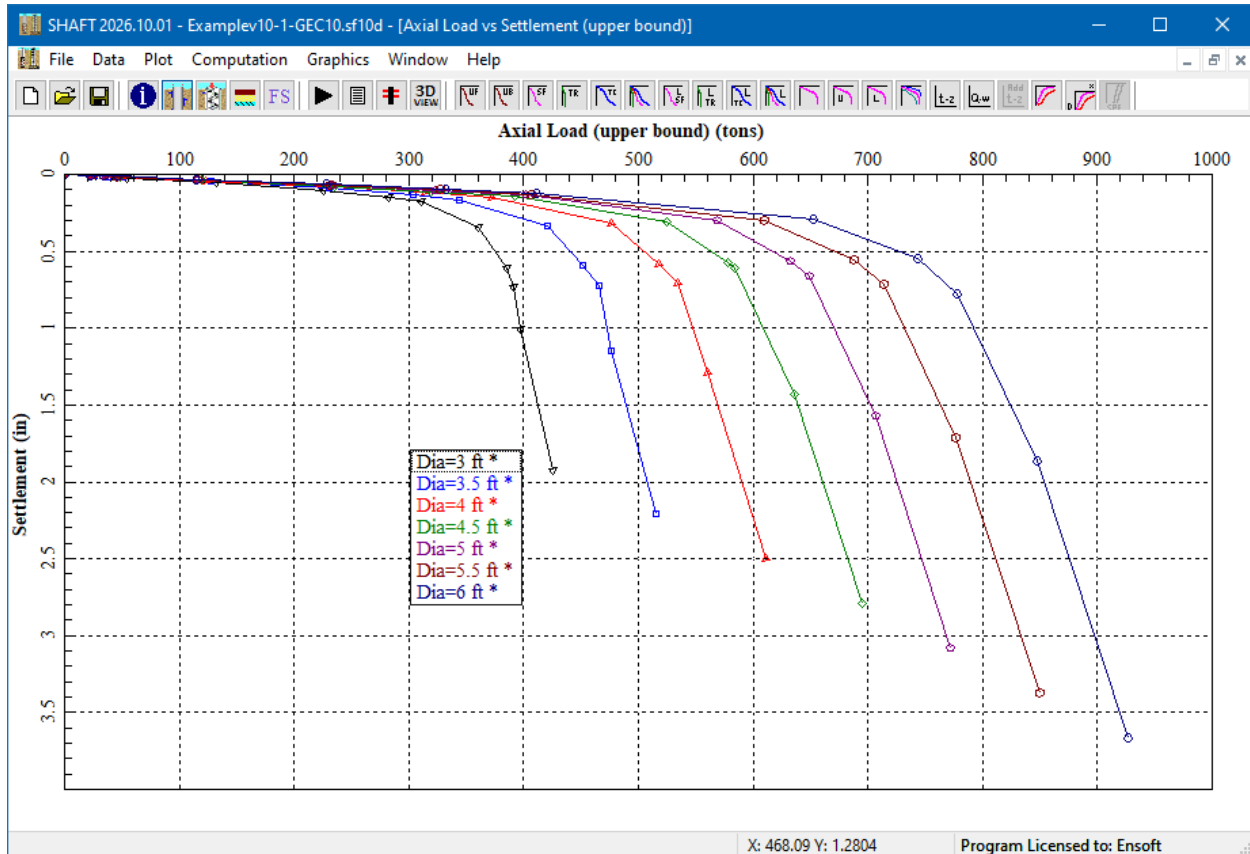


Figure 4.21 Axial Load vs Settlement (upper bound) for Example Problem 1.

4.3.14 Graphics > Axial Load vs Settlement (Lower Bound)

This selection provides a graphical representation of the curves of axial load versus settlement for the modeled drilled shaft based on the lower-bound curves shown in the FHWA manual. This curve is automatically generated in all analytical runs of a drilled shaft. A sample graphics screen of the Axial Load vs Settlement (Lower Bound) command option is shown in Figure 4.22.

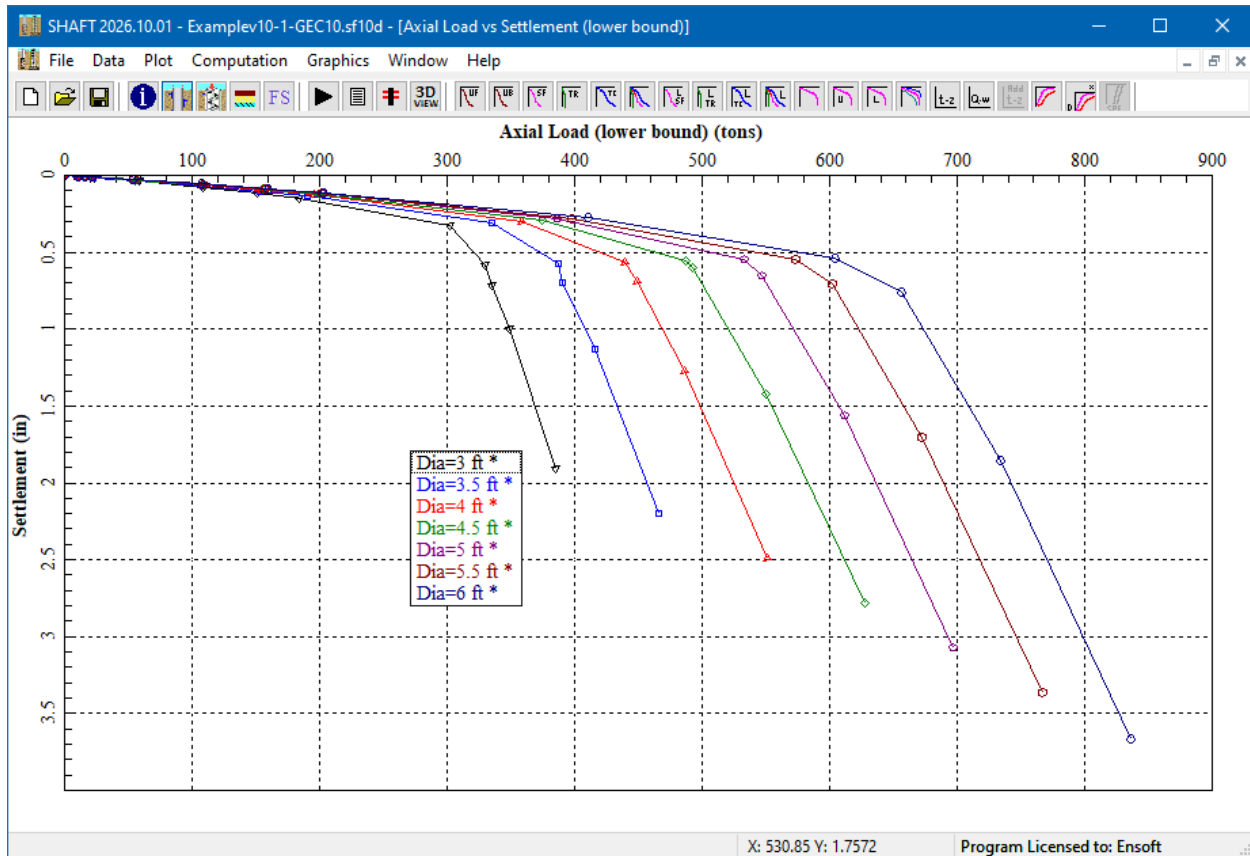


Figure 4.22 Axial Load vs Settlement (lower bound) for Example Problem 1.

4.3.15 Graphics > Combined Plots of Load vs Settlement

The user may select this command option to observe a graphical representation of the curves of axial load versus settlement for the modeled drilled shaft based on the trend (averaged), upper-bound, and lower-bound curves shown in the FHWA manual. These combined plots provide the user with some comparison between each condition. For the analysis using multiple diameters, this graphics will only display the combined plots for the drilled shaft with the initial diameter (smallest). A sample graphics screen of the Combined Plots of Load vs Settlement is shown in Figure 4.23.

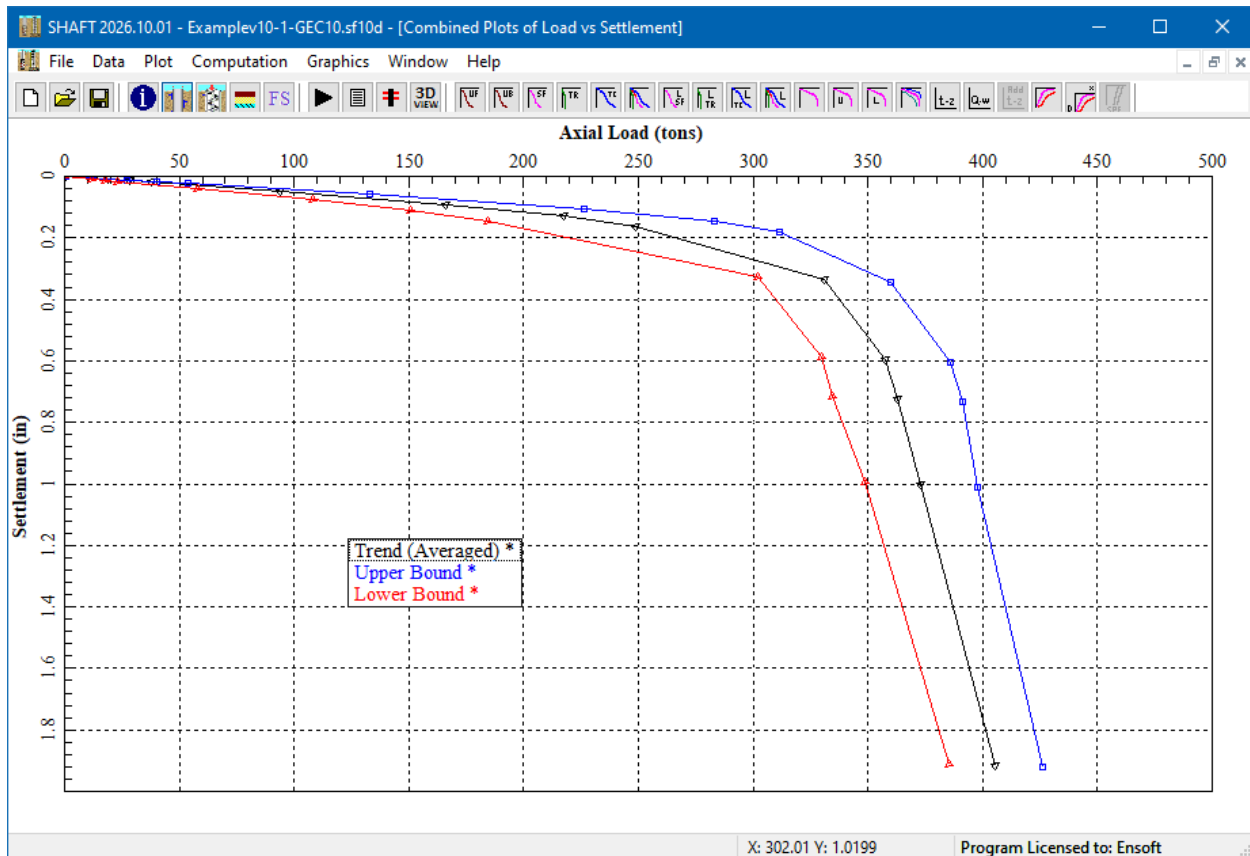


Figure 4.23 Combined Axial Load vs Settlement Curves for Example Problem 1.

4.3.16 Graphics > t-z curves

This command displays a selection of t - z curves that were generated by the SHAFT program for each soil layer. Five curves are normally displayed for each soil layer, the t - z curves are for near the top and bottom of each layer plus three intermediate depths. For internal computations the SHAFT program generates t - z curves at every finite increment but the printout for display is only for the five selected depths. For analyses using multiple diameters, the displayed t - z curves are only for the drilled shaft with the initial diameter (smallest). Also, these t - z curves correspond to the trend (averaged) curves shown in the FHWA manual. A sample graphics screen of the t - z curves is shown in Figure 4.24.

Please notice that t - z curves are only available for soils and shale. The concepts of load-vs-deformation for sockets in intermediate geomaterials (IGM) and rock are explained in notes on the accompanying Technical Manual and do not separate deformation curves for side resistance and end bearing.

In models where soils and shale are on top of IGM/rock the t - z curves for soils and shale are not taken into account. The load-vs-deformation in those models are based on elastic deformation for the length of shaft through the soils/shale layer(s) plus the overall deformation from the socket in the underlying IGM/rock.

In models where a layer of IGM or rock is placed between layers of soils and shale the models of load-vs-deformation for IGM/rock are not taken into account. The load-vs-deformation in those models are based on the elastic deformation for the length of shaft through the IGM/rock plus the t - z curves for the layers of soils/shale.

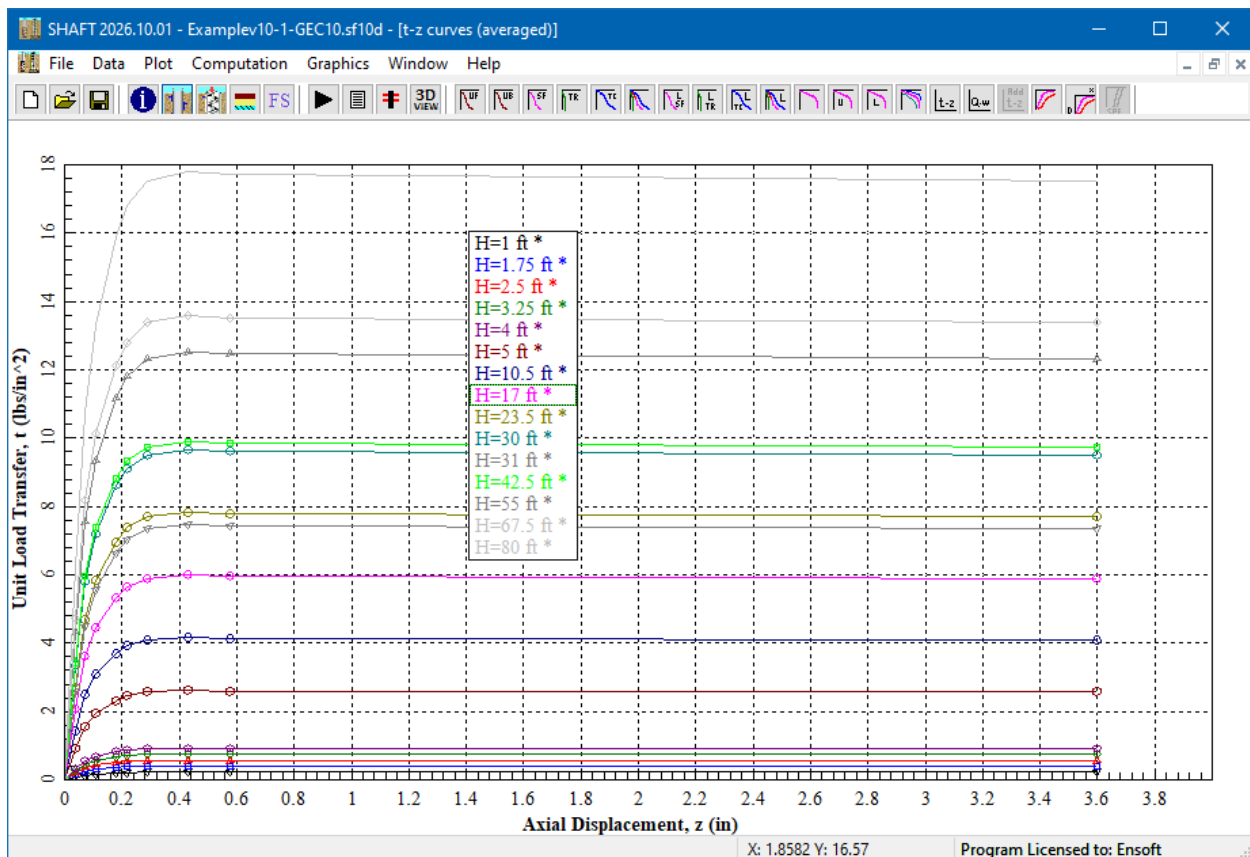


Figure 4.24 t - z curves for Example Problem 1.

4.3.17 Graphics > Q-w curves

This command displays the Q - w curves that were generated by the SHAFT program for the analyzed model. The program will display more than one Q - w curve in models that specify multiple shaft diameters. Also, these Q - w curves correspond to the trend (averaged) curves shown in the FHWA manual. A sample graphics screen of the Q - w curves is shown in Figure 4.25.

Please notice that Q - w curves are only available for soils and shale. The concepts of load-vs-deformation for sockets in intermediate geomaterials and rock are explained in notes on the accompanying Technical Manual and do not separate deformation curves for side resistance and end bearing.

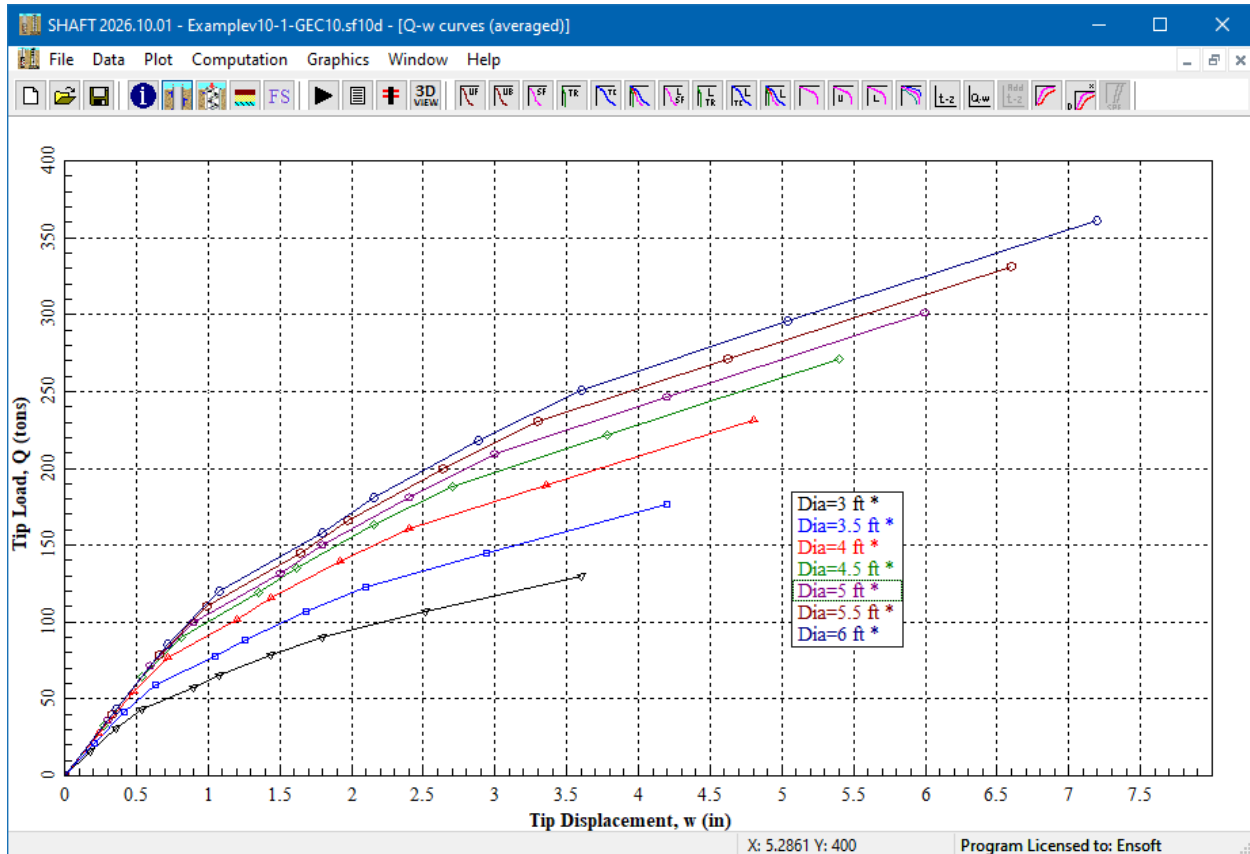


Figure 4.25 Q-w curves for Example Problem 1.

4.3.18 Graphics > Additional t-z curves

This menu option is only available in models where users selected to print additional t - z curves (under Data > Control Options > Print Internally-Generated t - z Curves for Verification). The command displays the t - z curves that were used by the SHAFT program for the user-specified soil depths.

For analyses using multiple shaft diameters, the displayed t - z curves are only for the drilled shaft with the initial diameter (smallest). Also, these t - z curves correspond to the trend (averaged) curves shown in the FHWA manual. A sample graphics screen of the Additional t - z curves is shown in Figure 4.26.

Please notice that t - z curves are only available for soils and shale. The concepts of load-vs-deformation for sockets in intermediate geomaterials (IGM) and rock are explained in notes on the accompanying Technical Manual and do not separate deformation curves for side resistance and end bearing.

In models where soils and shale are on top of IGM/rock the t - z curves for soils and shale are not taken into account. The load-vs-deformation in those models are based on elastic deformation for the length of shaft through the soils/shale layer(s) plus the overall deformation from the socket in the underlying IGM/rock.

In models where a layer of IGM or rock is placed between layers of soils and shale the models of load-vs-deformation for IGM/rock are not taken into account. The load-vs-deformation in those models are based on the elastic deformation for the length of shaft through the IGM/rock plus the t - z curves for the layers of soils/shale.

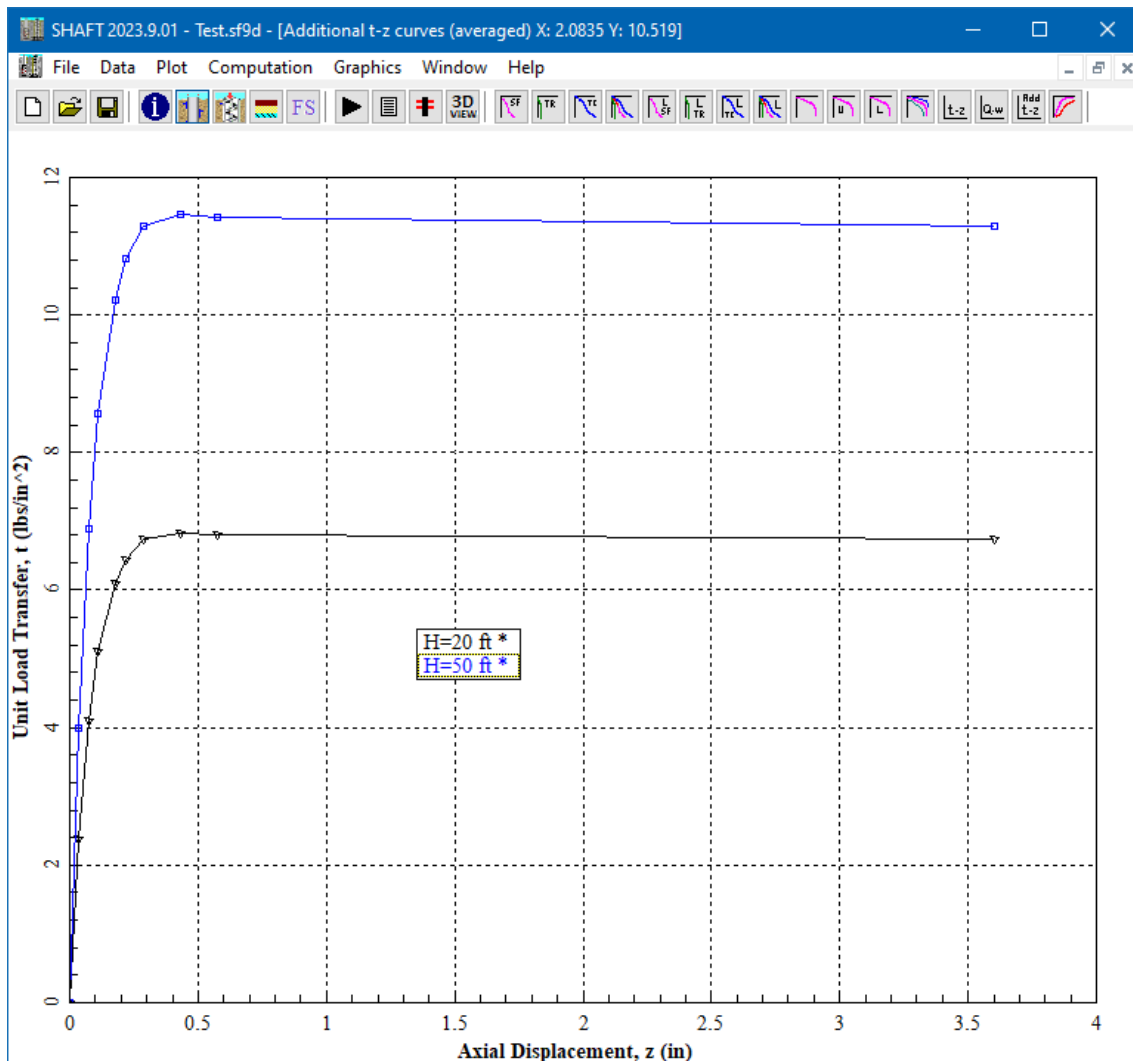


Figure 4.26 Sample plot for additional t - z curves.

4.3.19 Graphics >Load Distribution

This menu selection is used to observe a graphical representation of the distributions of axial loads versus depth for the modeled pile. From this plot the user can identify the side friction contributed by each soil layer as well as the resistances in end bearing for each top load and pile penetration.

For models using multiple diameters, the displayed Load Distribution curves are only for the drilled shaft with the initial diameter (smallest). Also, these curves correspond to the trend (averaged) curves shown in the FHWA manual.

A sample graphics screen of the Load Distribution (Total Capacity versus Depth) for Example Problem 11 is shown in Figure 4.29. In this example plot, the side display of soil layers was also selected (Plot > Show Soil Layer).

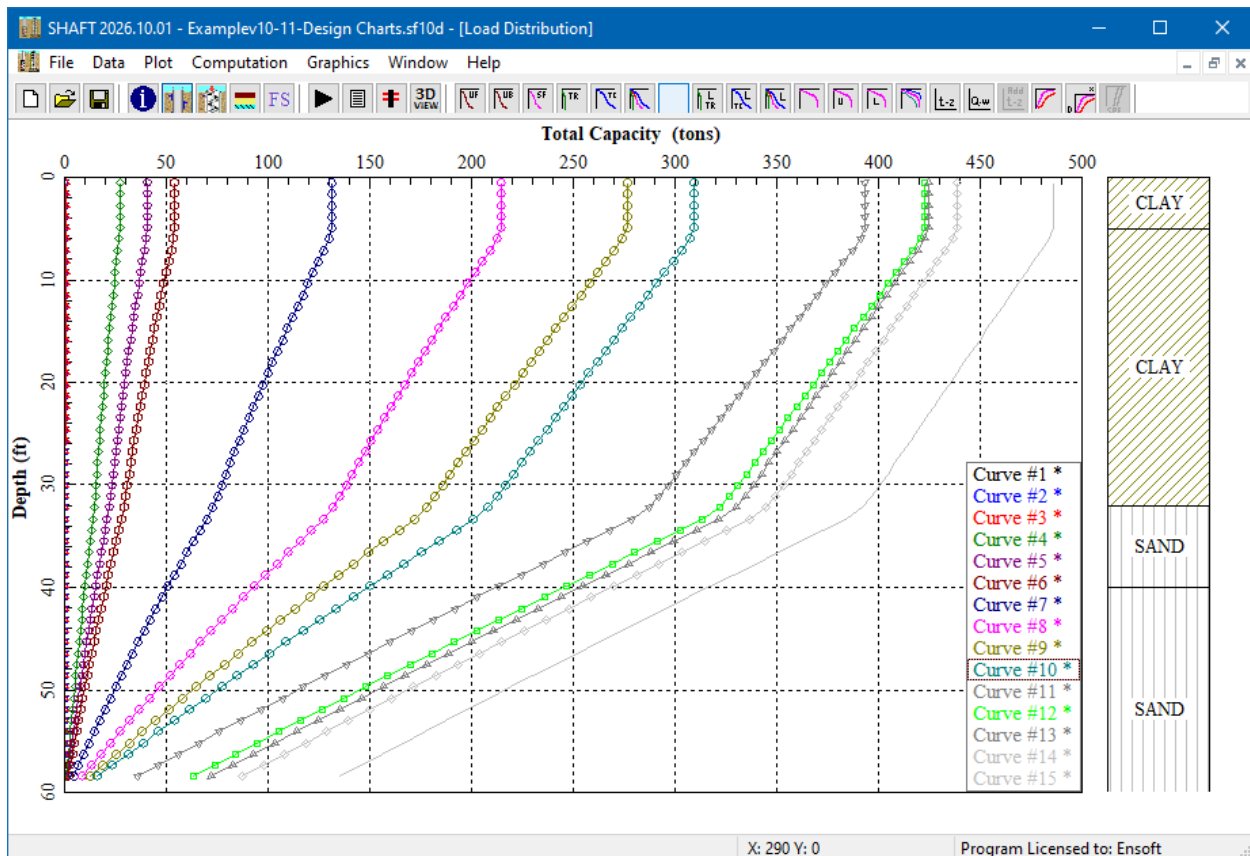


Figure 4.27 Load Distribution for Example Problem 11.

4.3.20 Graphics >Axial Displacement Distribution

This menu selection is used to observe a graphical representation of the distributions of axial displacements versus depth for the modeled pile. From this plot the user can identify the axial movements that are necessary to develop side friction and those for end bearing for each top load and pile penetration.

For models using multiple diameters, the displayed Axial Displacement Distribution curves are only for the drilled shaft with the initial diameter (smallest). Also, these curves correspond to the trend (averaged) curves shown in the FHWA manual.

A sample graphics screen of the Axial Displacement Distribution for Example Problem 11 is shown in Figure 4.29. In this example plot, the side display of soil layers was also selected (Plot > Show Soil Layer).

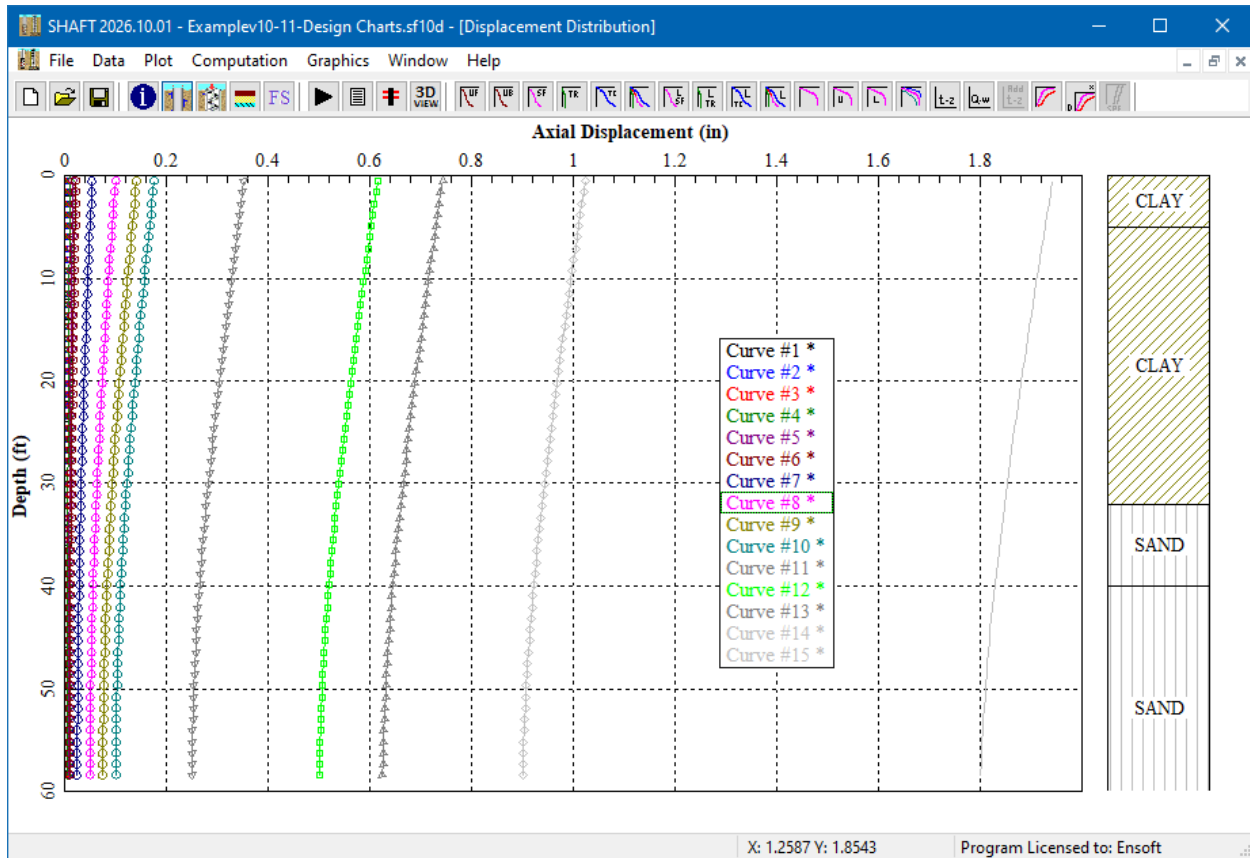


Figure 4.28 Axial Displacement Distribution for Example Problem 11.

4.3.21 Graphics > Design Chart (xx movement)

This menu option is only available in models where users selected to plot ASD/LRFD Design Charts (under the Data menu). The command displays the curves of axial capacity versus depth for the user-specified settlements. Also, these t - z curves correspond to the trend (averaged) curves shown in the FHWA manual. A sample graphics screen of the Design Chart (0.1-in movement) for Example Problem 11 is shown in Figure 4.29.

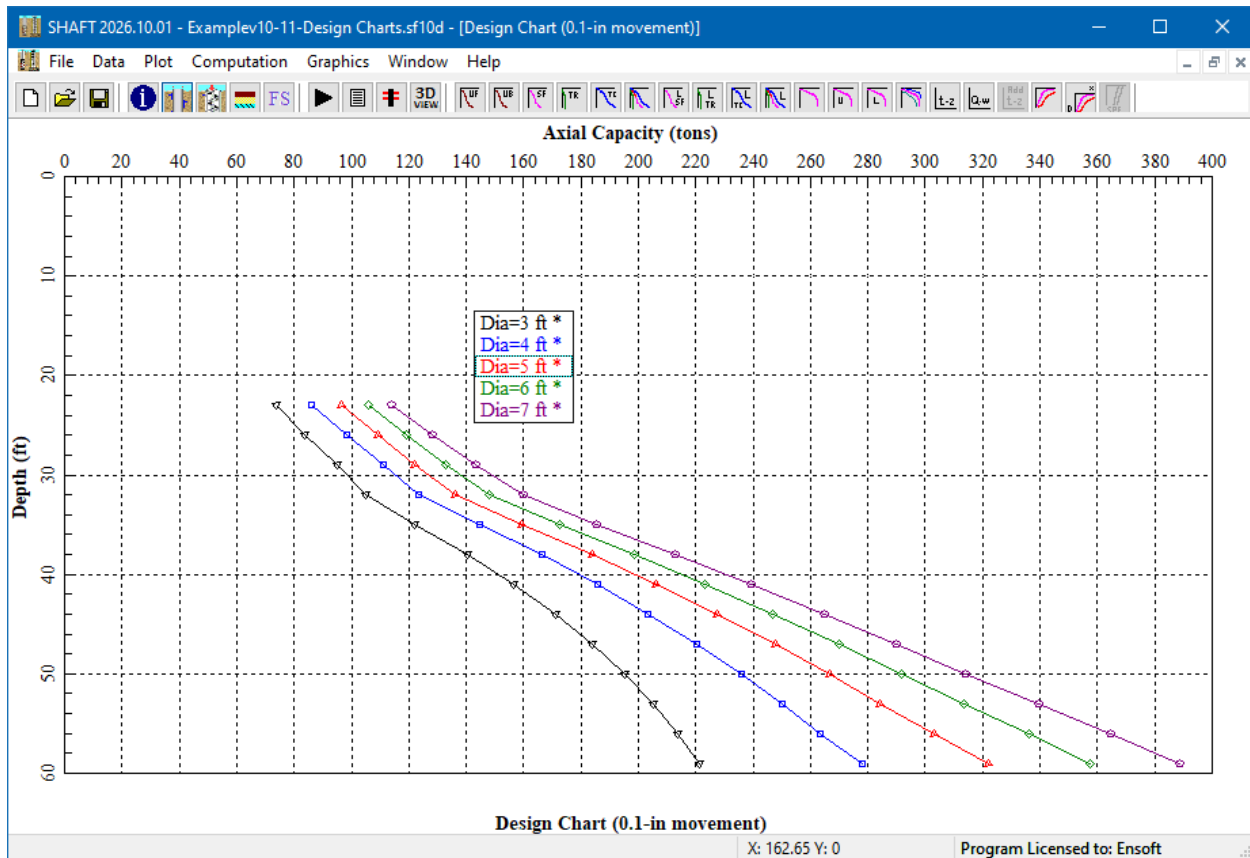


Figure 4.29 Design Chart (0.1-in movement) for Example Problem 11.

4.3.22 Graphics > Export Plots to Excel

This command is selected to export some (or all) of the output plots to a pre-formatted spreadsheet file for Microsoft Excel©. Each check-marked plot will be exported to two spreadsheet tabs, one contains the data points and the second the plotted chart. A sample graphics screen of the Graphics > Export Plots to Excel dialog box is shown in Figure 4.30.

Options contained in this dialog box are explained below.

Add Markers in Plots

Adds markers for all the points in each plotted graph.

Select All

Marks all available plots for export to an Excel file.

Unselect All

Unselect all available plots so none will be exported.

Generate Excel File

After clicking this button, the Microsoft Excel software will be started (only if available in the computer in use). The user must wait until all the data has been exported to the file. User must save the generated excel file before closing.

Close Window

Click this button to close the Export to Excel dialog box.

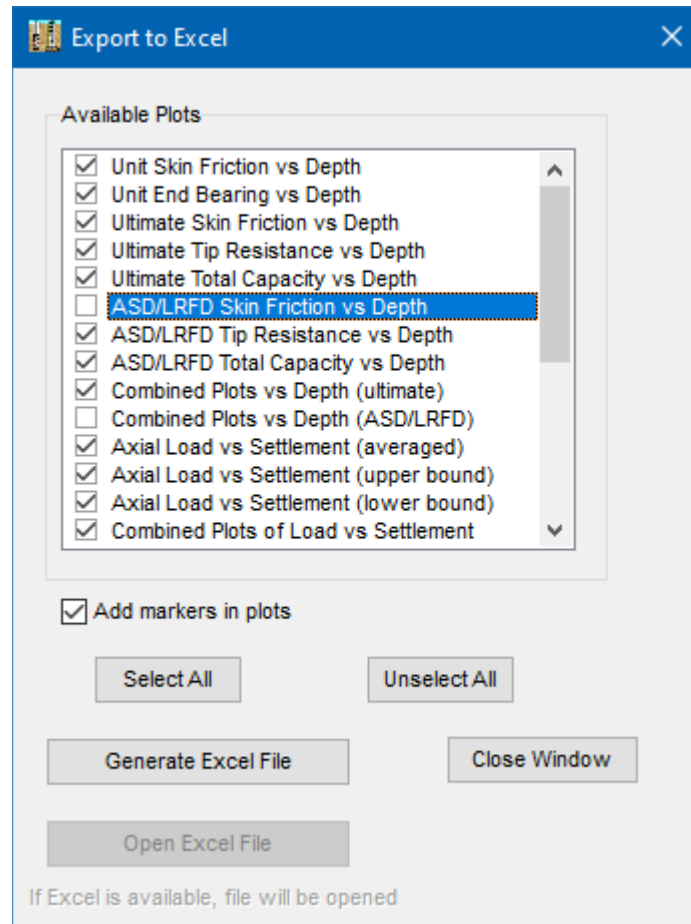


Figure 4.30 Sample Export Plots to Excel dialog box.

4.4 Plot Menu

This menu command only appears in the top-menu bar while in the graphics mode (when observing any output graphics). Command options contained in this menu, shown in Figure 4.31, are explained below. Notice that none of the parameters selected in this menu command are not saved with the output file and must be changed each time the file is opened.

Show Legend

This activates or deactivates the floating legend included in the graphics mode. The legend box can be moved with click-and-drag operations of the mouse to any position in the graphics screen. Despite its location in the screen, the legend is always located at the right-bottom corner on the printouts.

Show Soil Layers

Click this menu-item to activate or deactivate a soil profile plotted at the right side of the graphics. This option is not available in some plots (where not applicable).

Show Markers

This menu provides the option to activate or deactivate the markers for each point of all the curves displayed in the active screen of the graphics mode. By default, the program automatically plots at every foot of penetration, or every 30 cm when using metric units. The user may optionally select to show markers every 1, 2, 3, 5, or 10 increments of unit. The type of markers used in each curve is automatically selected by the program. Once activated, the markers are enabled for all visible curves of the active graphics screen.

Font Sizes

This menu provides the option to enlarge the default size of fonts used in plots. The user may optionally select to enlarge the font by 1.5, 2, 2.5, 3, or 4 times of the default size.

Line Width

This menu provides the option to enlarge the default width of lines used in plots. The user may optionally select to enlarge the width by 2, 4, 6, or 10 times of the default width.

Graph Title

The user may optionally add a title to the active graphics using this command. However, the parameters selected here are not saved with the output file and must be changed each time the file is opened.

Edit Legend

The user may change the text of the legend in the active graphics using this command. However, the modified names are not saved with the output file and must be changed each time the file is opened.

Print...

This command is used to produce a hard copy of the active graphics screen. The Print dialog box includes a drop-down menu that allows the user to select any of the installed Windows printers, allows for change of printer properties, and allows the selection of the total number of copies to be printed. The printed graphics is sized according to the margins that the user specifies in the Plot > Page Setup menu.

Page Setup

The user can here specify the printed size of the active-graphics screen. The size of the plot is based on the specified margins and selection of paper orientation. The parameters selected here are not saved with the output file and must be changed each time that the graphics is plotted.

Active Graphs...

This command is used to activate or de-activate the graphs that are displayed on the screen.

Save to Disk...

This command is used to save the active-graphics screen to disk. The format of the saved file is as *bmp* graphics (bitmap file), which is the internal-file format used in Microsoft Windows®.

Copy data to clipboard

The background data from any observed Graphics plot can be easily copied and pasted into any spreadsheet for further observations using the Plot > Copy data to clipboard menu command.

Copy as image to clipboard

Any observed Graphics plot can be easily copied and pasted in a graphics file format into any external document (Microsoft Word or PowerPoint or other) using the Plot > Copy as image to clipboard menu command.

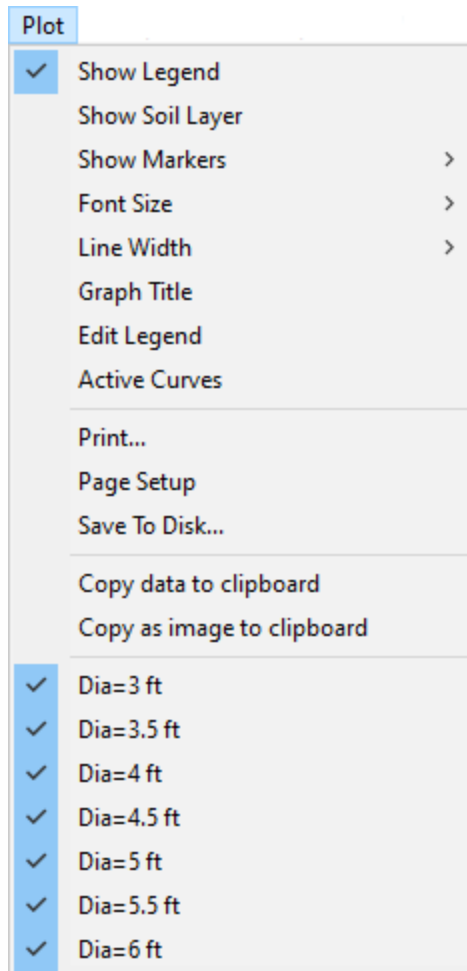


Figure 4.31 Sample Plot Menu.

CHAPTER 5. Example Problems

5.1 Introduction

This chapter presents several example problems studied using the computer program SHAFT. In order to ensure accuracy from the computer results, some examples have been compared with results from hand calculations. The step-by-step hand calculations in this chapter are carried out based on the procedures described in the Technical Manual. The user can have confidence in their results if hand calculations are performed for comparison. The studies in this chapter also provide additional guidance for the method of analyses of axially loaded piles with SHAFT.

Several problems are provided herein as examples of different applications that may be solved using our computer program SHAFT. Each example focuses on a particular computational feature of the program. Input files for each example are automatically copied to the SHAFT data directory during installation (*Root Drive\Ensoft\Shaft2026-Examples*).

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

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

Example 1 Drilled shaft in sand

- varying pile diameter from 3 ft to 6 ft (in 0.5-ft increments),
- method for sand (user-specified values),
- inputted values of blow counts, N_{SPT} , from Standard Penetration Tests for sand properties.

Example 2 Drilled shaft in layers of clay and sand

- top two layers of clay,
- ignored side resistance on top 5 ft,
- internally-generated values of N_c ,
- bottom three layers of sand, and
- method for sand (using internally-generated values).

Example 3 Belled shaft in clay

- two layers of clay,
- variable c_u on top layer of clay,
- small bell at bottom,
- ignored side resistance at top 5 ft, and
- ignored side resistance at bottom one diameter over bell.

Example 4 Belled shaft in silty sand/clay

- three layers of clay,
- one intermediate layer of sand,
- method for sand (user-specified values),

- large bell at bottom,
- ignored side resistance at top 5 ft, and
- ignored side resistance at bottom one diameter over bell.

Example 5 Drilled shaft in strong rock

- top layer of clay, and
- bottom is dolomite rock (strong rock).

Example 6 Drilled shaft in weak rock

- top layer of sand,
- bottom is a weak rock, and
- example with metric units.

Example 7 Drilled shaft in gravel (decomposed rock)

- top layer of sand with neglected skin friction,
- two bottom layers of decomposed rock,
- internally generated elastic modulus of decomposed rock based on blow counts (N_{SPT}), and
- example with metric units.

Example 8 Drilled shaft in gravelly sand and gravel

- top layer of sand,
- two bottom layers of gravelly sand and gravel strata,
- internally generated Beta values for gravel based on blow counts (N_{SPT}), and
- example with English units.

Example 9 Model using the LRFD method

- top layer of clay,
- bottom layer with sand,
- separate resistance factors used for side resistance and end bearing for each soil layer.

Example 10 Model using Multiple Shaft Lengths

- same shaft (3-ft OD) and soils (sand) as Example 1,
- study of load-vs-settlement for multiple shaft lengths from 42-ft to 60-ft.

Example 11 Model using Design Charts

- same soils (clay/sand) as Example 2,
- checked response for shaft diameters from 3-ft OD to 7-ft OD and multiple lengths from 24-ft to 60-ft.

5.2 Example Problem 1 – Sand

This is an example of a shaft drilled into sand. The example has been studied in the referenced literature of Reese and O'Neill, 1988. The example is also modeled after load tests in sand, Owens and Reese, 1982.

5.2.1 Soil Profile

The soil profile is shown in Figure 5.1. The water table is at a depth of 4 ft below the ground surface.

5.2.2 Soil Properties

N-values (blow counts per foot) from the Standard Penetration Test are included in Figure 5.1.

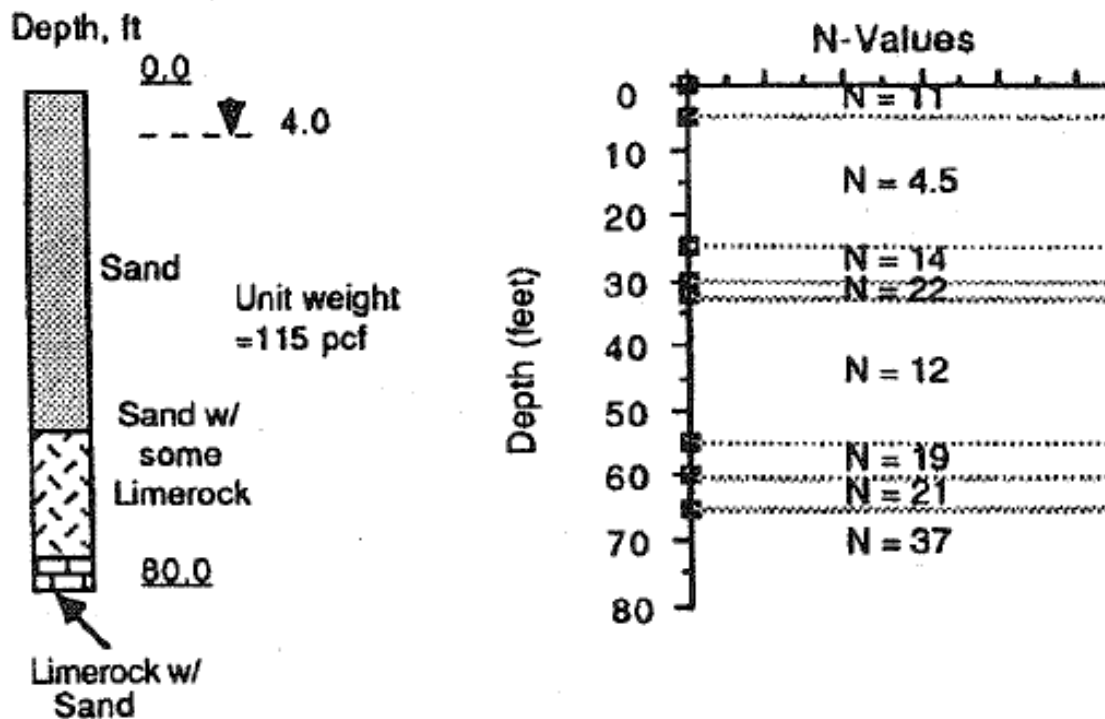


Figure 5.1 General soil description of Example Problem 1.

5.2.3 Construction

High-quality construction is assumed. The contractor will have all the required equipment in good order and experienced personnel will be on the job.

5.2.4 Loadings

The working-axial load is 170 tons, lateral load is negligible, and no downdrag is expected.

5.2.5 Factor of Safety

It is assumed that a load test has been performed nearby but considering the possible variation in the soil properties over the site and other factors, an overall factor of safety of 2.5 is selected. The diameter will be

sufficiently small so that reduced-end bearing will not be required. Consequently, the global factor of safety can be applied to both components of resistance.

5.2.6 Ultimate Load

The ultimate-axial load is thus established as $2.5 \times 170 = 425$ tons, since a global factor of safety (of 2.5) is used.

5.2.7 Geometry of the Drilled Shaft

A straight drilled shaft is selected with a diameter of 3.0 ft and a penetration of 60 feet.

5.2.8 Hand Computations

Side Resistance

Computations are performed assuming a total-unit weight of sand equal to 115 pcf. The hand computations are as follows:

Depth Interval	ΔA	Avg. Effective Stress	β	ΔQ_s
ft	ft ²	Tsf		Tons
0-4	37.7	0.115	0.8	3.5
4-30	245.0	0.572	0.8	112.1
30-60	282.7	1.308	0.6	221.9

$$Q_s = 337.5$$

Base Resistance

Computations for base resistance are performed using the soil at the base of the shaft.

At the 60-ft tip penetration:

$$N_{SPT} = 21$$

$$q_B = (0.6)(21) = 12.6 \text{ tsf}$$

$$A_B = 7.07 \text{ ft}^2$$

$$Q_B = (7.07)(12.6) = 89.1 \text{ tons}$$

Total Resistance

$$Q_U = 337.5 + 89.1 = 427 \text{ tons} \approx Q_T = 425 \text{ tons (OK)}.$$

5.2.9 Comparison of Results

Table 5.1 contains a comparison of the results obtained from hand computations against those from computer run in SHAFT (3-ft diameter).

Category	Manual Calculations (tons)	Computer Analysis (tons)	Deviation
Side Resistance	337.5	335.7	0.1%
Tip Resistance	89.1	89.1	0%
Total Capacity	427	426.7	0%

Table 5.1 Comparison of results for Example Problem 1

5.2.10 Input and Output Data Files for Example 1

Users can read Section 2.1.1 (7) of this manual for reference on the location of placement of the input and output data files for the example files installed with this program. The default installation directory is the following: (Root Drive) *c:\Ensoft\Shaft2026-Examples*. The input data files for all examples presented in this manual are installed automatically with the program.

Input-data filenames for Example 1 are the following:

Examplev10-1-GEC10.sf10d

Examplev10-1-Sand-MultDiam.sf10d

The output-data filenames for Example 1 are the following:

Examplev10-1-GEC10.sf10o

Examplev10-1-Sand-MultDiam.sf10o

5.2.11 Graphical Results of Computer Analysis

Each of the resulting plots of skin friction, tip resistance, and total capacity versus depth (w/F.S.) provided by the computer program contains seven curves, as may be seen in Figure 5.2, Figure 5.3 and Figure 5.4 respectively. These curves correspond to six increments in drilled shaft diameter, since the data input specified 6 ft as the largest and 3 ft as the smallest diameters for consideration. The program automatically computed results for the smallest diameter and for each 0.5-ft increase in diameter up to the largest specified by the user.

Results of combined plots versus depth, shown in Figure 5.5, only contains the curves of skin friction, tip resistance, and total capacity versus depth for the initial shaft diameter.

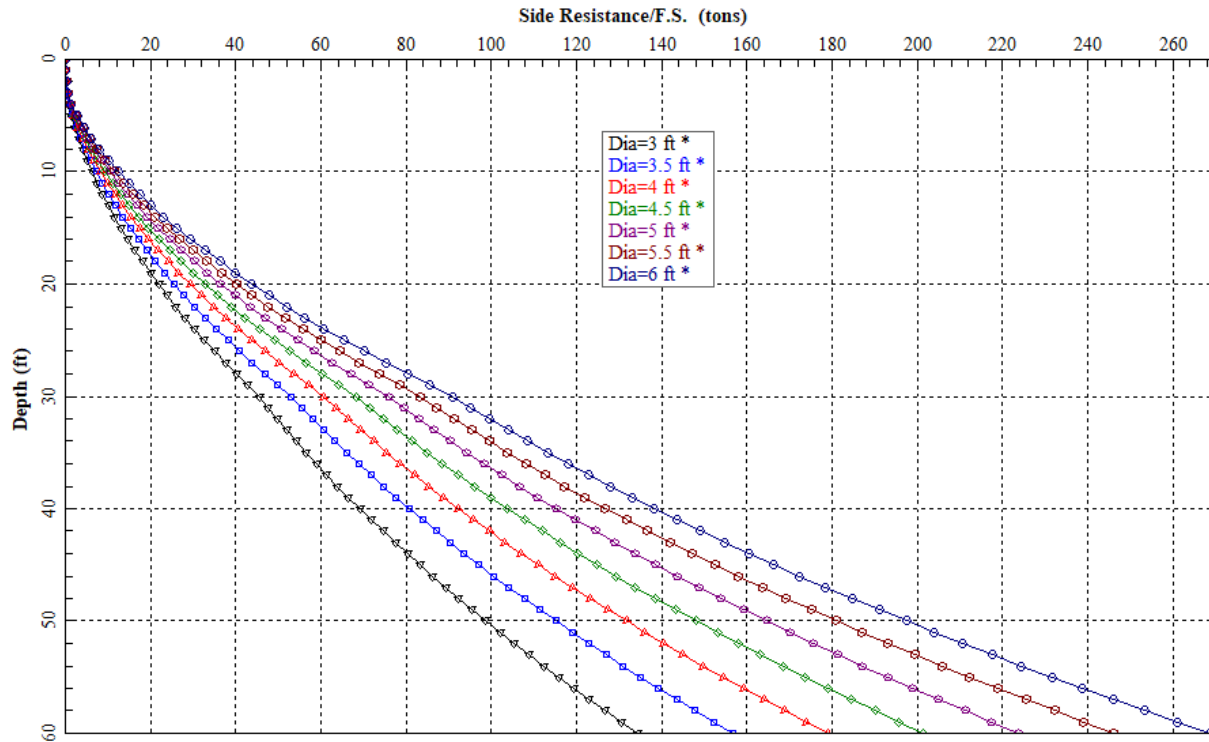


Figure 5.2 Curve of Skin Friction vs Depth (w/F.S.) for Example Problem 1.

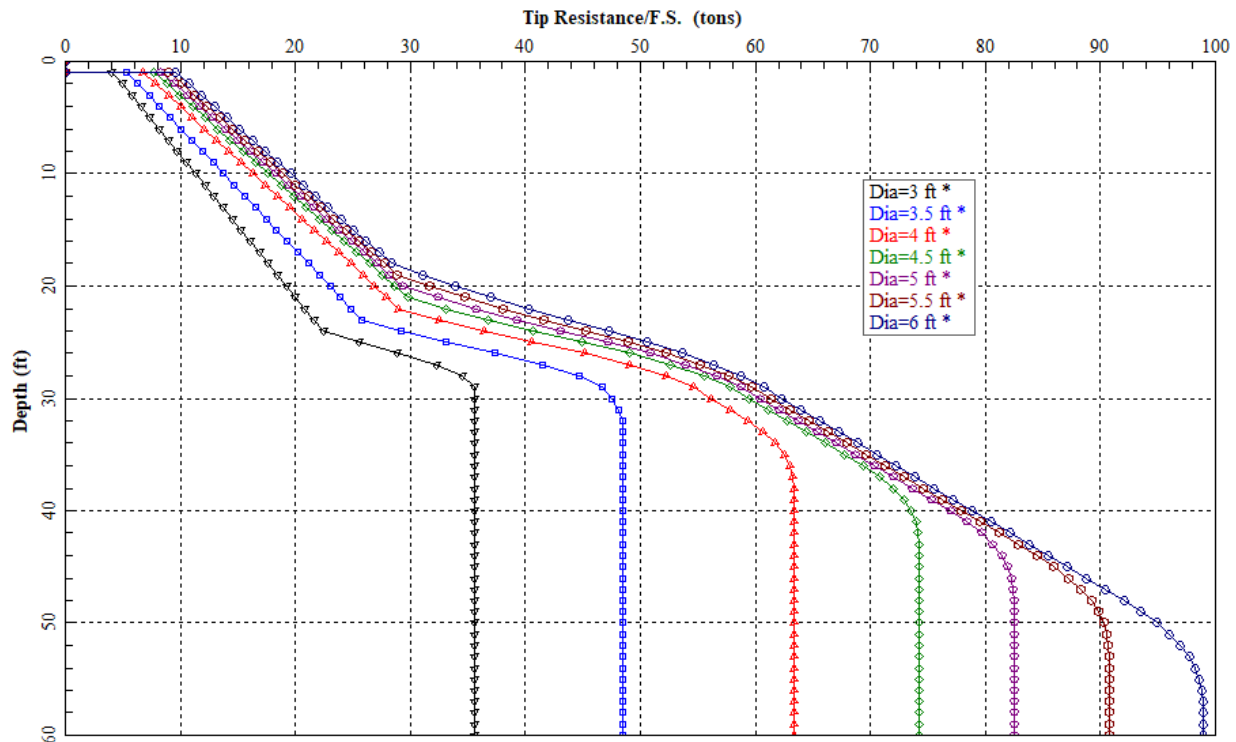


Figure 5.3 Curve of Tip Resistance vs Depth (w/F.S.) for Example Problem 1.

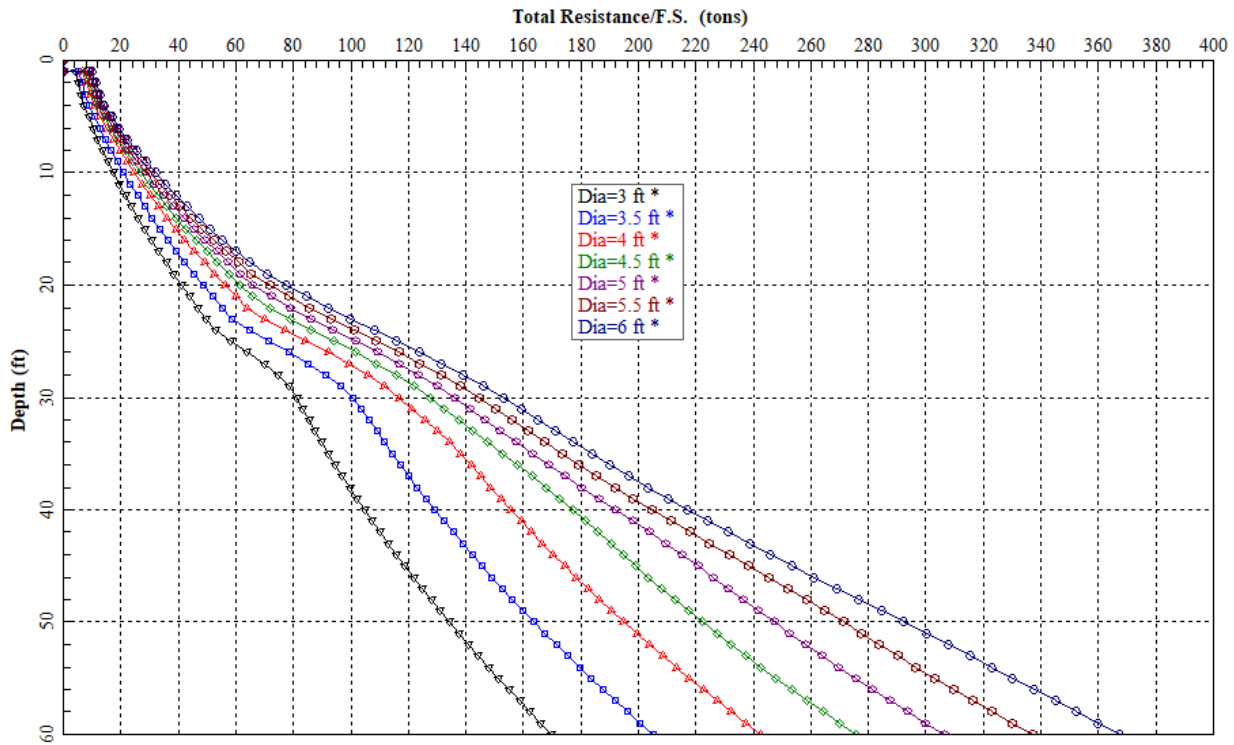


Figure 5.4 Curve of Total Capacity vs Depth (w/F.S.) for Example Problem 1.

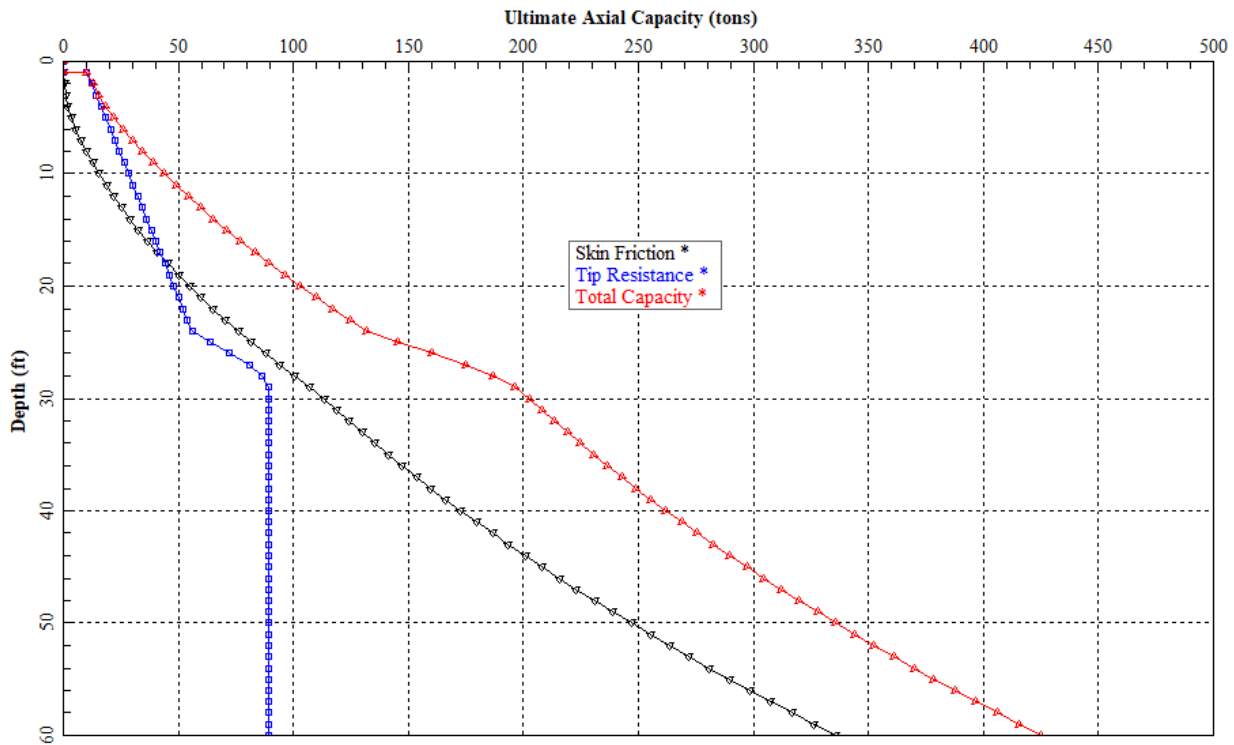


Figure 5.5 Curve of Combined Plots vs Depth (w/F.S.) for Example Problem 1.

5.3 Example Problem 2 – Mixed Clay/Sand

This is an example of a shaft drilled into a soil of a mixed profile with layers of clay and sand. The example is modeled after load tests performed and reported by Touma and Reese, 1972, at the G1 site.

5.3.1 Soil Profile

The soil profile is shown in Figure 5.6. The water table is at a depth of 17 ft below the ground surface.

5.3.2 Soil Properties

Values of undrained shear strength obtained from laboratory tests and N-values (blow counts per foot) from the Standard Penetration Test are included in Figure 5.6. Top 5 ft of clay is assumed with no strength for transfers in side resistance (unit weight is considered).

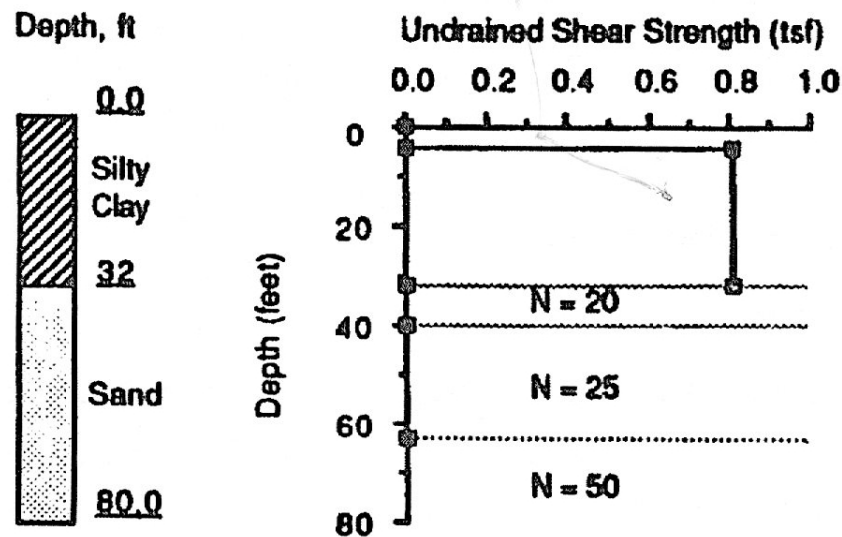


Figure 5.6 General soil description of Example Problem 2.

5.3.3 Construction

High-quality construction, good specifications, and excellent inspection are assumed.

5.3.4 Loadings

Working axial load is 150 tons, no downdrag is expected, and lateral loading is negligible. The depth to the zone of seasonal moisture change is judged to be about 10 feet.

5.3.5 Factor of Safety

Soil conditions across the site are variable, and the foundation is for a major and complex structure. An overall factor of safety of 3.0 was selected.

5.3.6 Ultimate Load

Using the factor of safety of 3, the ultimate axial load is computed to be 450 Tons.

5.3.7 Geometry of the Drilled Shaft

A straight shaft is selected with a diameter of 3.0 ft and a penetration of 59 feet.

5.3.8 Hand Computations

Side Resistance

Computations are performed assuming a total unit weight of clay equal to 125 pcf and total unit weight of sand equal to 115 pcf. For ease of hand computations, an average value of β was selected for the sand layer. However, the computer program has been instructed to generate internally the values of β and to interpolate linearly with depth. The hand computations are as follows:

Soil Type	Depth Interval ft.	ΔA ft ²	Avg. effective stress tsf	α_z or β	ΔQ_s tons
Clay	0-5	---	(cased)	0	0
Clay	5-32	207.3	0.81	0.55	116.7
Sand	32.59	254.5	1.887	0.6	288.1

$$Q_s = 404.8$$

Base Resistance

Computations for base resistance are performed using the soil at the base of the shaft.

At the 59-ft location:

$$N_{SPT} = 25.$$

$$q_B = (0.6)(25) = 15.0 \text{ tsf}$$

$$A_B = 7.07 \text{ ft}^2$$

$$Q_B = (7.07)(15.0) = 106.0 \text{ tons}$$

Total Resistance

$$Q_U = 404.8 + 106.0 = 510 \text{ tons} > Q_T = 450 \text{ tons (OK)}.$$

5.3.9 Comparison of Results

Table 5.2 contains a comparison of the results obtained from hand computations against those from computer run in SHAFT.

Category	Manual Calculations (tons)	Computer Analysis (tons)	Deviation
Side Resistance	405	391 ^(a)	-3.4%
Tip Resistance	106	129 ^(b)	21.7%
Total Capacity	510	519	1.8%

^(a) Values of β were generated at the top and bottom of each sand layer and were interpolated linearly by the computer program.

^(b) The computer program takes into account soil properties of two diameters below the bottom of the drilled shaft so it is higher due to the influence of the bottom sand layer.

Table 5.2 Comparison of results for Example Problem 2

5.3.10 Input and Output Data Files for Example 1

Users can read Section 2.1.1 (7) of this manual for reference on the location of placement of the input and output data files for the example files installed with this program. The default installation directory is the following: (Root Drive) *c:\Ensoft\Shaft2026-Examples*. The input data files for all examples presented in this manual are installed automatically with the program.

The input-data filename for Example 2 is the following:

Example10-2-Mixed Clay-Sand.sf10d

The output-data filename for Example 2 is the following:

Example10-2-Mixed Clay-Sand.sf10o

5.3.11 Graphical Results of Computer Analysis

Resulting plots of ultimate skin friction, ultimate tip resistance, and ultimate total capacity versus depth provided by the computer program may be observed in Figure 5.7, Figure 5.8 and Figure 5.9 respectively. Results of axial load versus short-term settlement are included in Figure 5.10.

To introduce another program feature, Figure 5.11 shows a graphical display of the shaft and soil layers along with a plot of ultimate load transfers in side resistance. This type of graph may help to display the importance of each soil layer for various load transfers selected in the Show 3D View > Combined Plots menu.

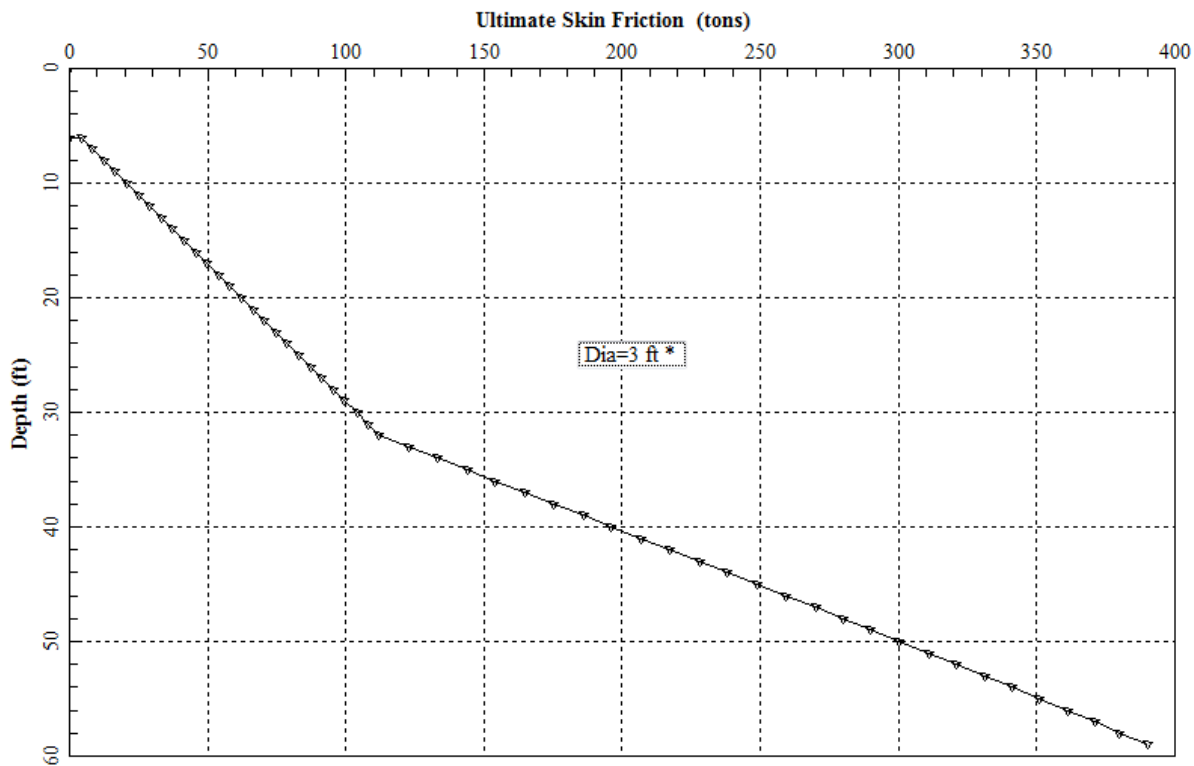


Figure 5.7 Curve of Ultimate Skin Friction vs Depth for Example Problem 2.

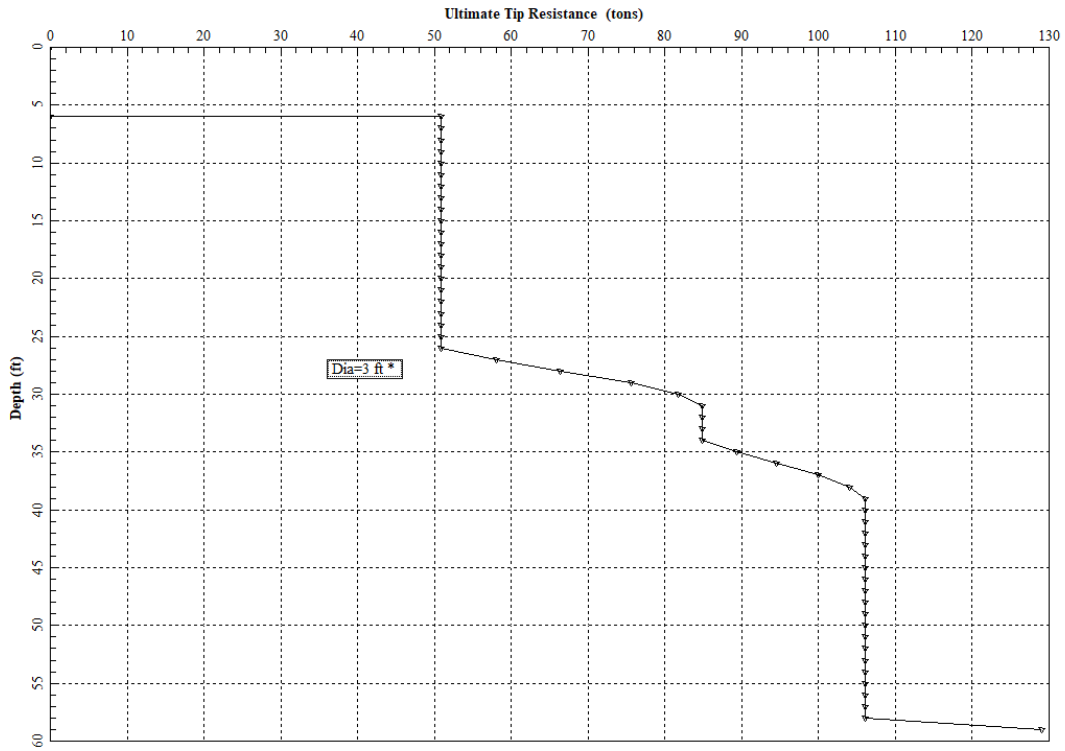


Figure 5.8 Curve of Ultimate Tip Resistance vs Depth for Example Problem 2.

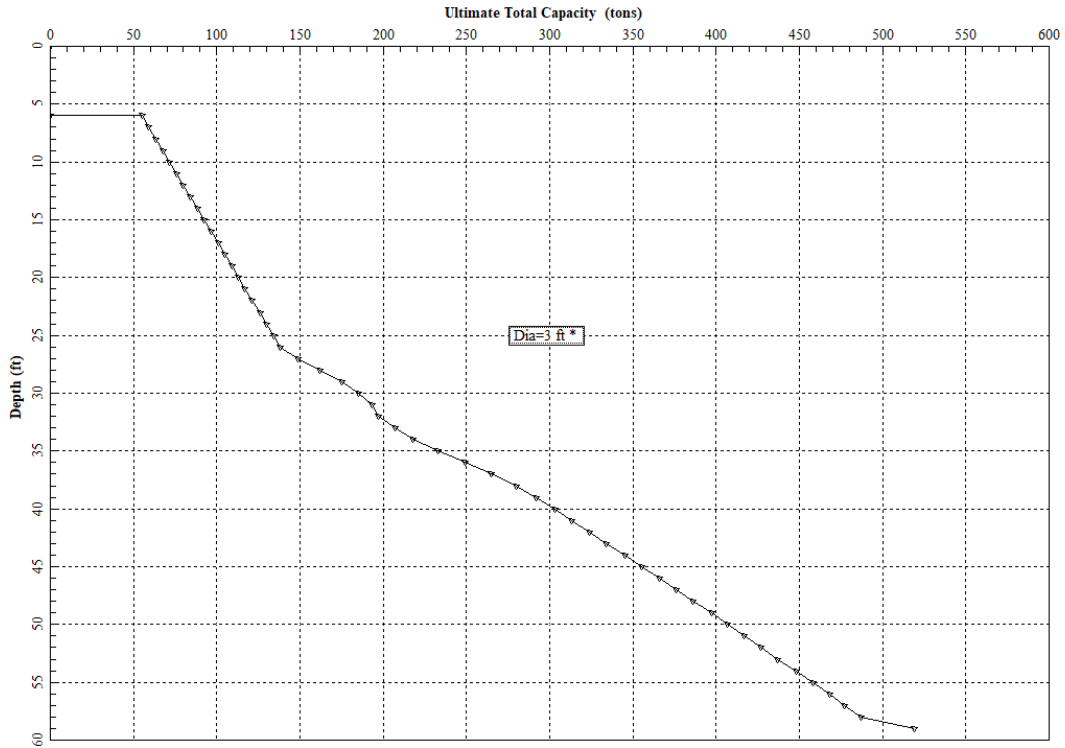


Figure 5.9 Curve of Ultimate Total Capacity vs Depth for Example Problem 2.

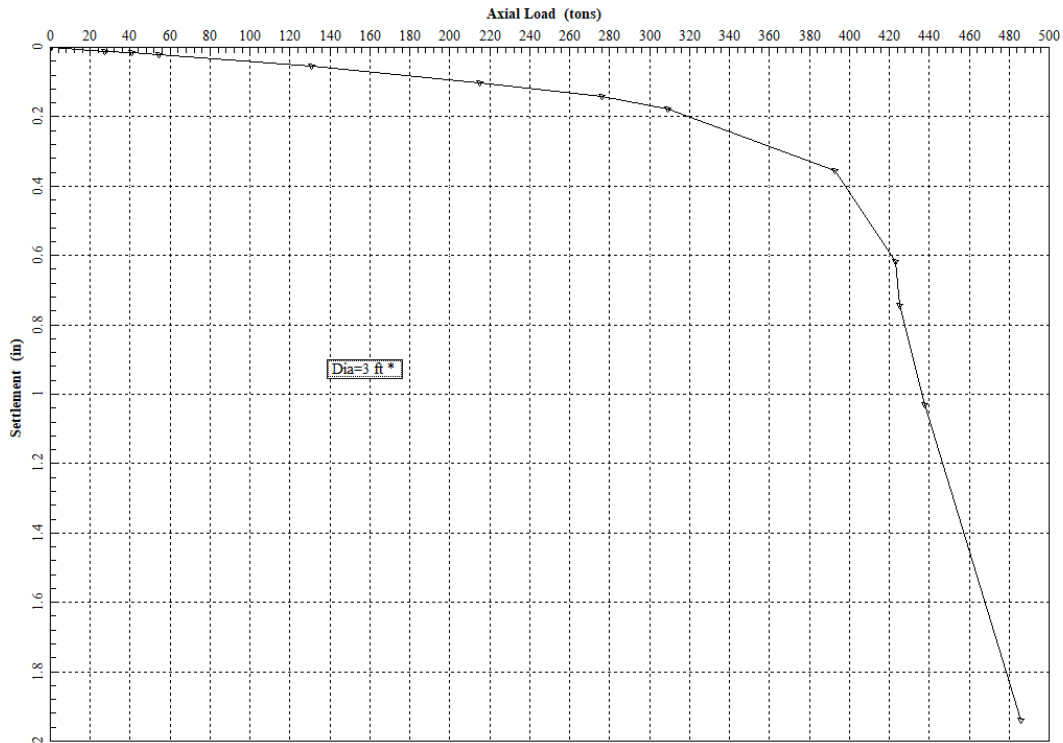


Figure 5.10 Curve of Axial Load vs Settlement (averaged) for Example Problem 2.

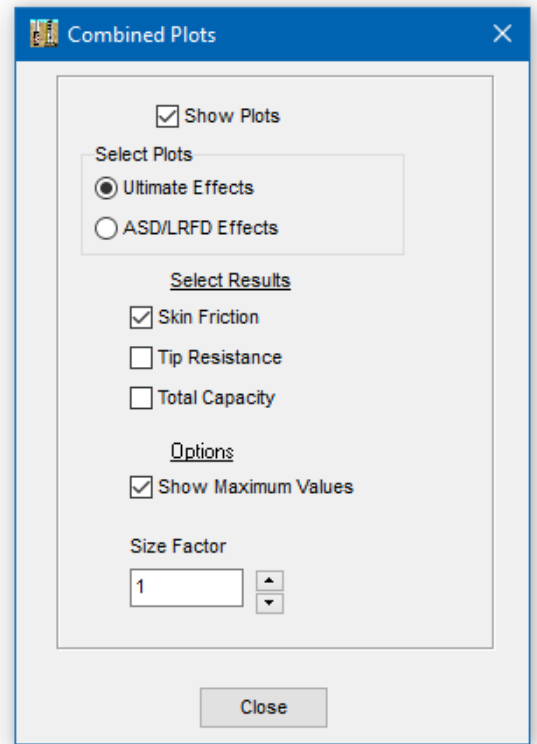
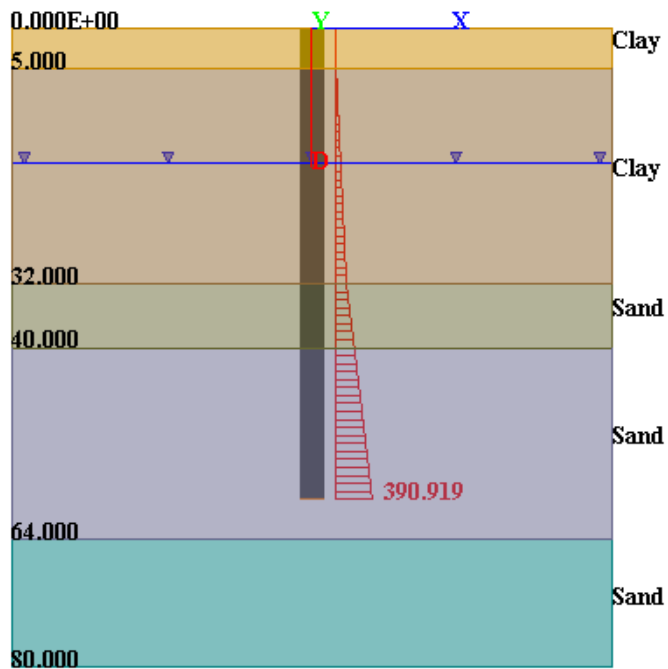


Figure 5.11 Graphical plot of ultimate skin friction with depth for Example Problem 2.

5.4 Example Problem 3 – Clay

This is an example of a shaft drilled into clay and with a small bell at the tip. The example is modeled after load tests performed and reported by Whitaker and Cooke, 1966, Pile A.

5.4.1 Soil Profile

The soil profile is shown in Figure 5.12. The clay is overconsolidated. The depth to the water table was not given and is not needed in capacity calculations (with cohesive soil). However, the water table should be obtained for construction considerations.

5.4.2 Soil Properties

Values of undrained shear strength obtained from laboratory tests are included in Figure 5.12.

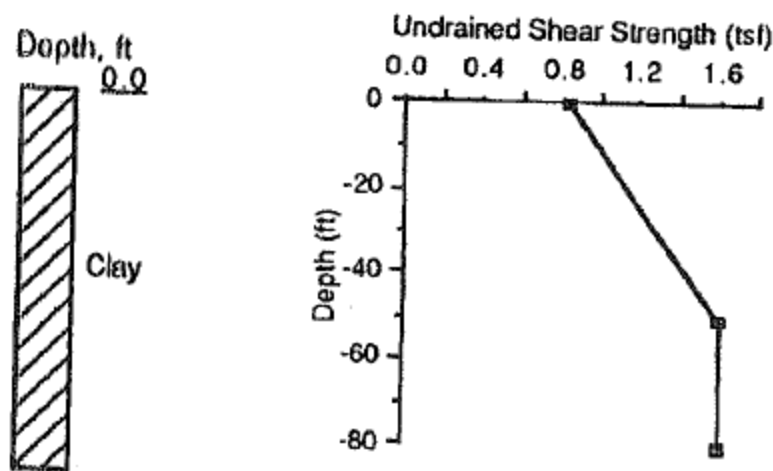


Figure 5.12 General soil description of Example Problem 3.

5.4.3 Construction

High-quality construction, good specifications, and excellent inspection are assumed.

5.4.4 Loadings

Working axial load is 230 tons, no downdrag is expected, expansive clay is not a problem, and lateral loading is negligible. The depth to the zone of seasonal moisture change is judged to be about 10 feet.

5.4.5 Factor of Safety

It is assumed that a load test has been performed in the area, that the design parameters have been proven, and that the soil conditions across the site are relatively uniform; therefore, an overall factor of safety of 2.0 was selected.

5.4.6 Ultimate Load

Using a factor of safety of 2, the ultimate axial load was computed to be 460 tons.

5.4.7 Geometry of the Drilled Shaft

An under-reamed shaft was selected to penetrate a total of 40 ft into the clay. The height of the bell is 4.0 ft, making the length of the straight-sided portion 36.0 feet. The diameter of the straight-sided portion of the shaft is 2.58 ft and the diameter of the bell is 5.5 feet. Since 5.5 ft (66 in) is less than 75 in, reduced end bearing need not be considered. A rotated graphical representation of this model using the Computation > 3D View feature along with displayed soil layers and depths is shown in Figure 5.13.

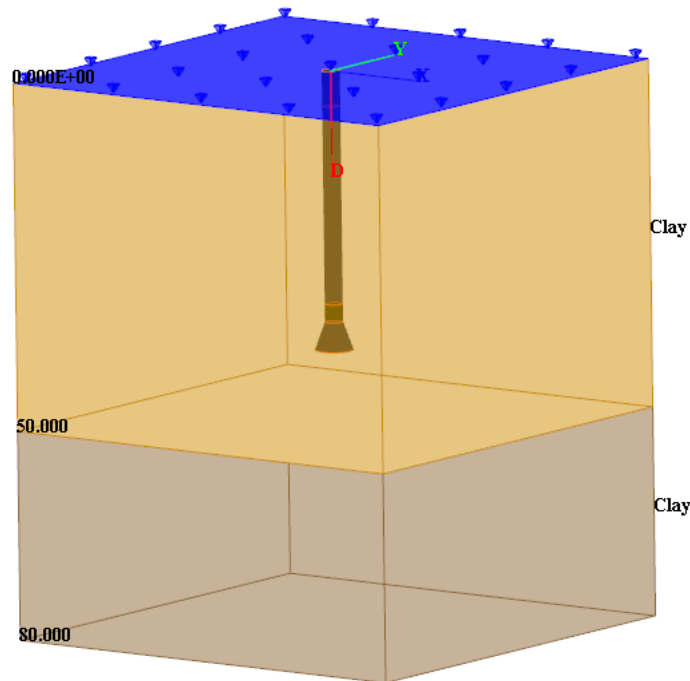


Figure 5.13 3D View of Example Problem 3.

5.4.8 Hand Computations

Side Resistance

For ease of hand computations, it is assumed a constant value of A_z equal to 0.55 and an average c_u of 2,280 psf. However, the computer program interpolates linearly the top and bottom values of c_u with depth. The hand computations are as follows:

Depth interval ft.	ΔA ft ²	Avg. effective stress, tsf	α_z	ΔQ_s tons
0-5			0	0
5-33.4	230.2	1.14	0.55	144.3
33.4-40			0	0

$$Q_s = 144.3$$

Base Resistance

The average undrained shear strength over one base diameter below the base is 1.48 tsf and the area of the base is 23.76 ft².

$$q_B = (1.48)(9) = 13.32 \text{ tsf}$$

$$A_B = 23.76 \text{ ft}^2$$

$$Q_B = (13.32) (23.76) = 316.5 \text{ tons}$$

Total Resistance

$$Q_U = 144.3 + 316.5 = 461 \text{ tons} \approx Q_T = 460 \text{ tons (OK)}.$$

5.4.9 Comparison of Results

Table 5.3 contains a comparison of the results obtained from hand computations against those from computer run in SHAFT.

Category	Manual Calculations (tons)	Computer Analysis (tons)	Deviation
Side Resistance	144	139*	-3.5%
Tip Resistance	317	330	-4.1%
Total Capacity	461	469	1.7%

*values of c_u at the top and bottom of the clay layer were interpolated linearly by the computer program

Table 5.3 Comparison of results for Example Problem 3

5.4.10 Input and Output Data Files for Example 1

Users can read Section 2.1.1 (7) of this manual for reference on the location of placement of the input and output data files for the example files installed with this program. The default installation directory is the following: (Root Drive) *c:\Ensoft\Shaft2026-Examples*. The input data files for all examples presented in this manual are installed automatically with the program.

The input-data filename for Example 3 is the following:

Example10-3-Clay-Belled Shaft.sf10d

The output-data filename for Example 3 is the following:

Example10-3-Clay-Belled Shaft.sf10o

5.4.11 Graphical Results of Computer Analysis

The resulting plot of combined ultimate axial capacities versus depth provided by the computer program may be observed in Figure 5.14. Results of axial load versus short-term settlement are included in Figure 5.15.

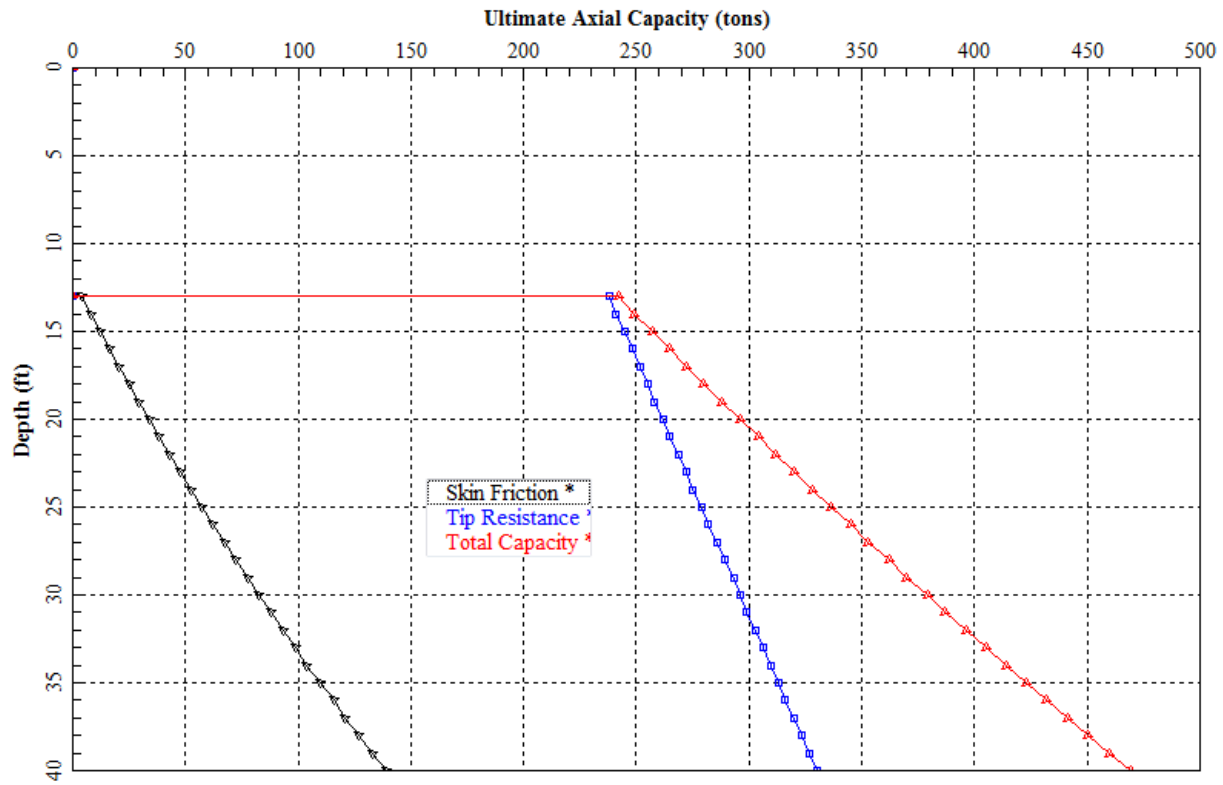


Figure 5.14 Curve of Combined Plots vs Depth (ultimate) for Example Problem 3.

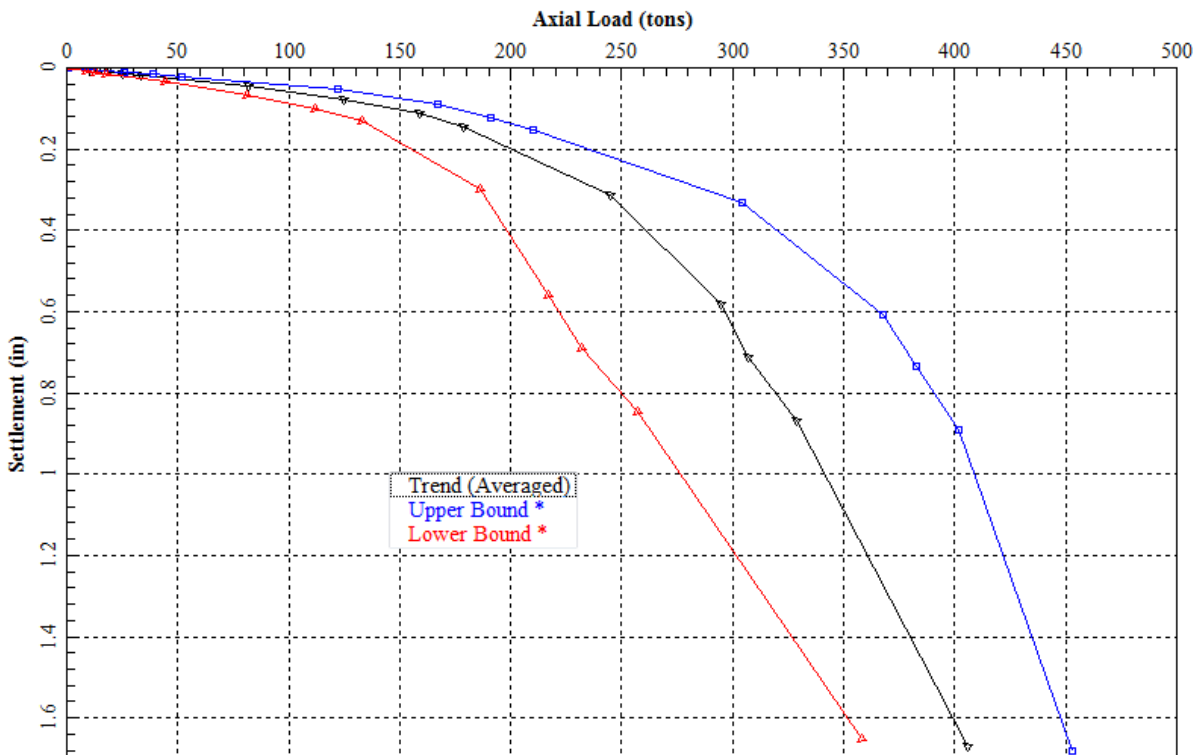


Figure 5.15 Curve of Axial Load vs Settlement (combined) for Example Problem 3.

5.5 Example Problem 4 – Belled, Silty Sand & Silty Clay

This is an example of a drilled shaft with an enlarged base (belled tip) into layers of silty sand and sandy clay.

5.5.1 Soil Profile

The soil profile is shown in Figure 5.16. The water table is at a depth of 10 ft during part of the year. The depth of seasonal moisture change is 5 feet (ignored for transfers in side resistance).

5.5.2 Soil Properties

Values of undrained shear strength obtained from laboratory tests and the N-values from the Standard Penetration Test are included in Figure 5.16. The N value for the interbedded silt and fine sand is 18.

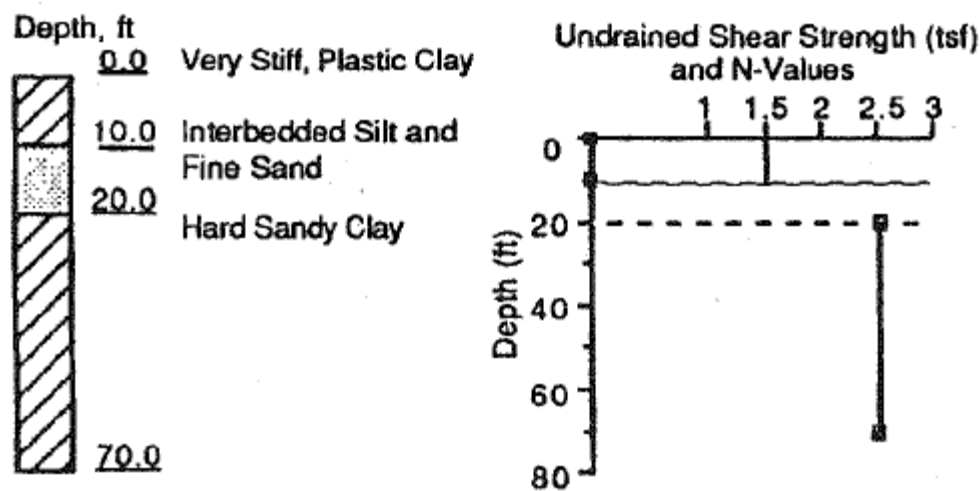


Figure 5.16 General soil description of Example Problem 4.

5.5.3 Construction

Advantage is to be taken of the strong bearing material below the sand, and a large bell will be installed. High-quality construction (including elimination of water from the bell), good specifications, and excellent inspection are assumed. Slurry and casing will be employed to a depth of 24 feet.

5.5.4 Loading

The working axial load is 640 tons, distributed as 500 tons dead load and 140 tons live load. No downdrag is expected, no lateral loading is to be considered and effects of expansive clays near the surface are to be considered in a separate analysis.

5.5.5 Factor of Safety

No load test has been conducted but soil conditions are consistent across the site and are familiar to the designer. A global factor of safety of 2.5 is selected.

5.5.6 Geometry of the Drilled Shaft

A belled shaft with a 12-ft-diameter bell cut at 45 degrees at a depth of 40 feet is initially designed. The shaft is also designed with a 4-ft diameter straight portion.

5.5.7 Hand Computations

Side Resistance

For ease of hand computations, average values of α_z and β were selected for the clay and sand layers. In this model, the computer program has been instructed to use internally the same constant values of α_z and β that are used in the hand computations. The hand computations are as follows:

Soil Type	Depth interval ft.	ΔA ft ²	Avg. effective stress, tsf	α_z or β	ΔQ_s tons
Clay	0-5	62.8	1.5	0	0
Clay	5-10	62.8	1.5	0.55	51.8
Sand/silt	10-20	125.7	0.744	0.80	74.8
Clay	20-32	150.8	2.5	0.55	207.4
Clay	32-40	-	-	0	0

$$Q_s = 334.0$$

Base Resistance

Computations for base resistance are performed using the soil at the base of the shaft.

$$N_c = 6.0 [1 + 0.2(40/12)] = 10.0 > 9; \text{ use } 9.$$

$$q_b = 9(2.5) = 22.5 \text{ tsf}$$

$$a = 0.0071 + 0.0021 (40/12) = 0.0141$$

$$b = 0.45(5)^{0.5} = 1.01$$

$$F_r = 2.5/[0.0141(144) + 2.5 (1.01)] = 0.55$$

$$q_{br} = 0.55 (22.5) = 12.4 \text{ tsf}$$

$$A_B = (p/4) (12^2) = 113.1 \text{ ft}^2$$

$$Q_B = 12.4(113.1) = 1402 \text{ tons.}$$

Total Resistance

$$Q_T = 334 + 1402 = 1736 \text{ tons.}$$

Check Structural Capacity of Bell

The ultimate load applied to the base of the bell, using dead load factor of 1.4 and live load factor of 1.7, is as follows:

$$Q_u = 1.4 (500) + 1.7 (140) - 334 = 604 \text{ tons.}$$

It is predicted that the ultimate structural capacity of a 45 degree bell with a 3:1 slope is 15 ksf. A concrete strength reduction factor of 0.85 is applied to this value; however no other factors are applied.

The ultimate structural capacity, using a material factor of 0.85 is thus the following:

$$Q_u = (15/2)(0.85)(113.1) = 721.0 \text{ tons.}$$

Ultimate Load Capacity

(a) based on the global F.S. = $1736/2.5 = 694.4$ tons > 604 tons

(b) based on the structural capacity of the bell and F.S. of 2.5 on side resistance: $334/2.5 + 721.0 = 854.6$ tons >> 604 tons

∴ OK both ways, structural capacity of bell does not control.

5.5.8 Comparison of Results

Table 6.4 contains a comparison of the results obtained from hand computations against those from computer run in SHAFT.

Category	Manual Calculations (tons)	Computer Analysis (tons)	Deviation
Side Resistance	334	334	0%
Tip Resistance	1402	1361	-2.9%
Total Capacity	1736	1695	-2.4%

Table 5.4 Comparison of results for Example Problem 4

5.5.9 Input and Output Data Files for Example 1

Users can read Section 2.1.1 (7) of this manual for reference on the location of placement of the input and output data files for the example files installed with this program. The default installation directory is the following: (Root Drive) *c:\Ensoft\Shaft2026-Examples*. The input data files for all examples presented in this manual are installed automatically with the program.

The input-data filename for Example 4 is the following:

Examplev10-4-Silty Sand-Silty Clay.sf10d

The output-data filename for Example 4 is the following:

Examplev10-4-Silty Sand-Silty Clay.sf10o

5.5.10 Graphical Results of Computer Analysis

The resulting plots of ultimate skin friction and ultimate tip resistance versus depth provided by the computer program may be observed in Figure 5.17 and Figure 5.18. Note that the load-transfer curve of skin friction versus depth in Figure 5.17 starts from about the 14-ft depth. This is because the program was instructed to ignore skin friction at the top 5 ft and at the bottom 4 ft (one shaft diameter). In addition, the program automatically ignores transfers in skin friction for the height of the bell, which is an additional 4 ft.

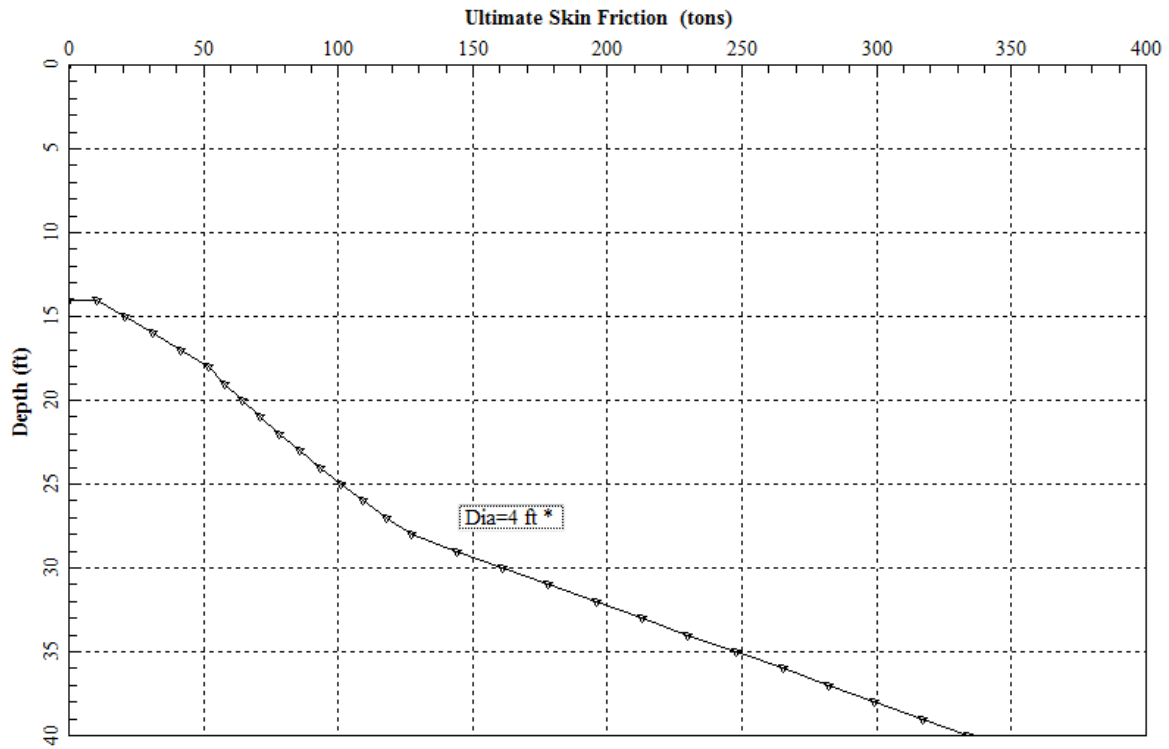


Figure 5.17 Curve of Ultimate Skin Friction vs Depth for Example Problem 4.

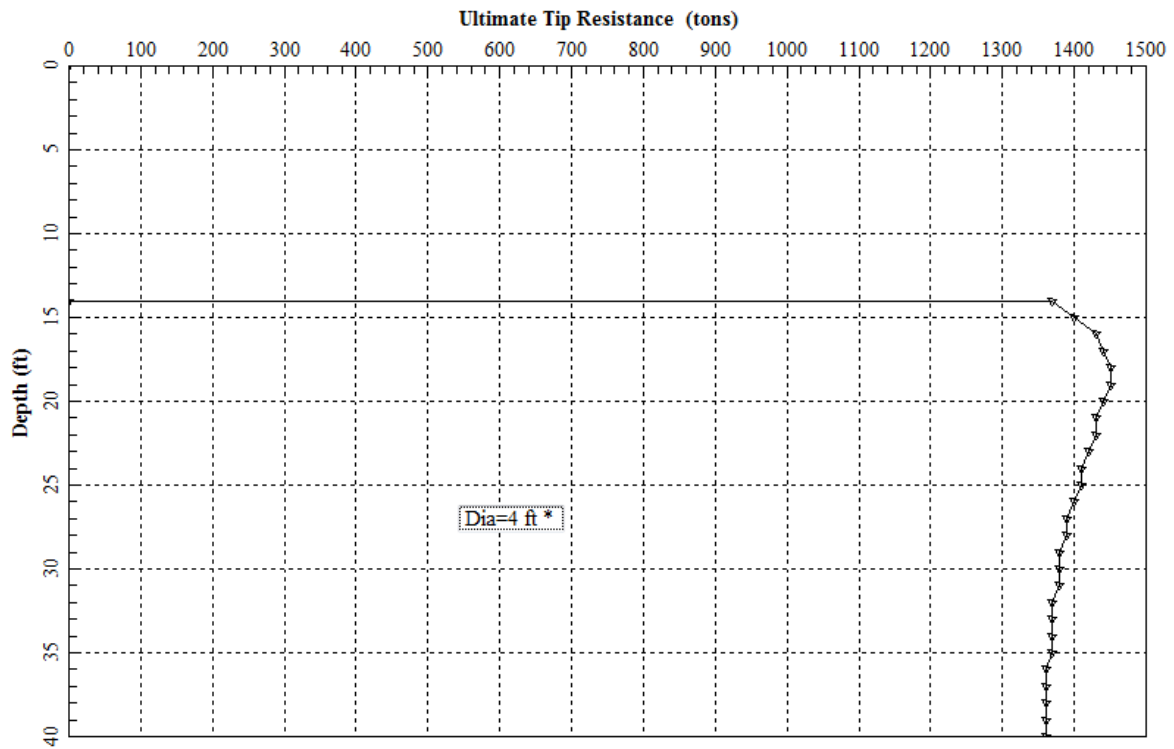


Figure 5.18 Curve of Ultimate Tip Resistance vs Depth for Example Problem 4.

5.6 Example Problem 5 – Strong Rock

This is an example of a drilled shaft into strong rock.

5.6.1 Soil Profile

The soil profile is shown in Figure 5.19. Only a small amount of water was encountered at the site during the geotechnical investigation.

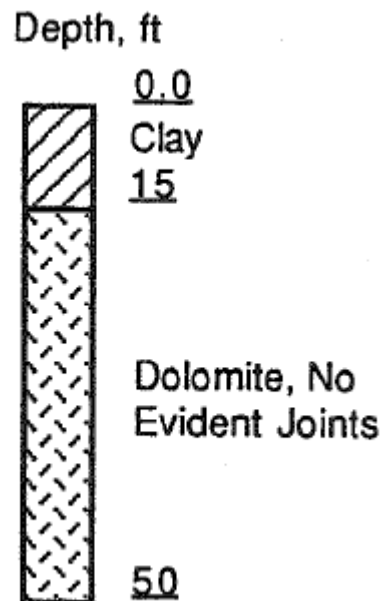


Figure 5.19 General soil description of Example Problem 5.

5.6.2 Soil Properties

The dolomite rock found at the site has a compressive strength of 8,000 psi and the RQD was 100 percent. The Young's modulus of the intact rock was estimated as 2.0×10^6 psi and the modulus of the rock mass was identical to this value. Assume the spacing of discontinuities is about 7 ft and that the thickness of the discontinuities is negligible.

5.6.3 Construction

The excavation can be made dry. A socket can be drilled into the strong rock and inspected carefully before concrete is poured.

5.6.4 Loading

The lateral load is negligible. The working axial load is 300 tons. No downdrag or uplift is expected.

5.6.5 Factor of Safety

An overall factor of safety of 3.0 is selected.

5.6.6 Geometry of the Drilled Shaft

A diameter of 3.5 ft is selected, and a socket of 3.5 ft into the dolomite is specified.

5.6.7 Hand Computations

Assuming all load is transferred in end bearing and using the method proposed by the Canadian Geotechnical Society (1978):

$$q_a = K_{sp} q_u$$

$$K_{sp} = \frac{3 + c_s / B_b}{10\sqrt{1 + 300\delta / c_s}} = 0.5$$

$$q_a = (0.5) (8000) = 4,000 \text{ psi}$$

$$Q_B = (4,000) (\pi/4) (42)^2 = 5.54 \times 10^6 \text{ lb} = 2,771 \text{ tons}$$

The value of end bearing includes a factor of safety of 3.

5.6.8 Comparison of Results

Table 5.5 contains a comparison of the results obtained from hand computations against those from computer run in SHAFT.

Category	Manual Calculations (tons)	Computer Analysis (tons)	Deviation
Side Resistance	----	90*	----
Tip Resistance	2771	2765**	-0.2%
Total Capacity	----	2795	----

* Transfer in side friction is computed by the program for the upper clay layer

** Computer output is reduced by factor of 3 implied in hand computations

Table 5.5 Comparison of results for Example Problem 5

5.6.9 Input and Output Data Files for Example 5

Users can read Section 2.1.1 (7) of this manual for reference on the location of placement of the input and output data files for the example files installed with this program. The default installation directory is the following: (Root Drive) *c:\Ensoft\Shaft2026-Examples*. The input data files for all examples presented in this manual are installed automatically with the program.

The input-data filename for Example 5 is the following:

Example10-5-StrongRock.sf10d

The output-data filename for Example 5 is the following:

Example10-5-StrongRock.sf10o

5.6.10 Graphical Results of Computer Analysis

The resulting plots of ultimate total capacity versus depth provided by the computer program may be observed in Figure 5.20 (for example of program features, this plot was created from the **Computation >**

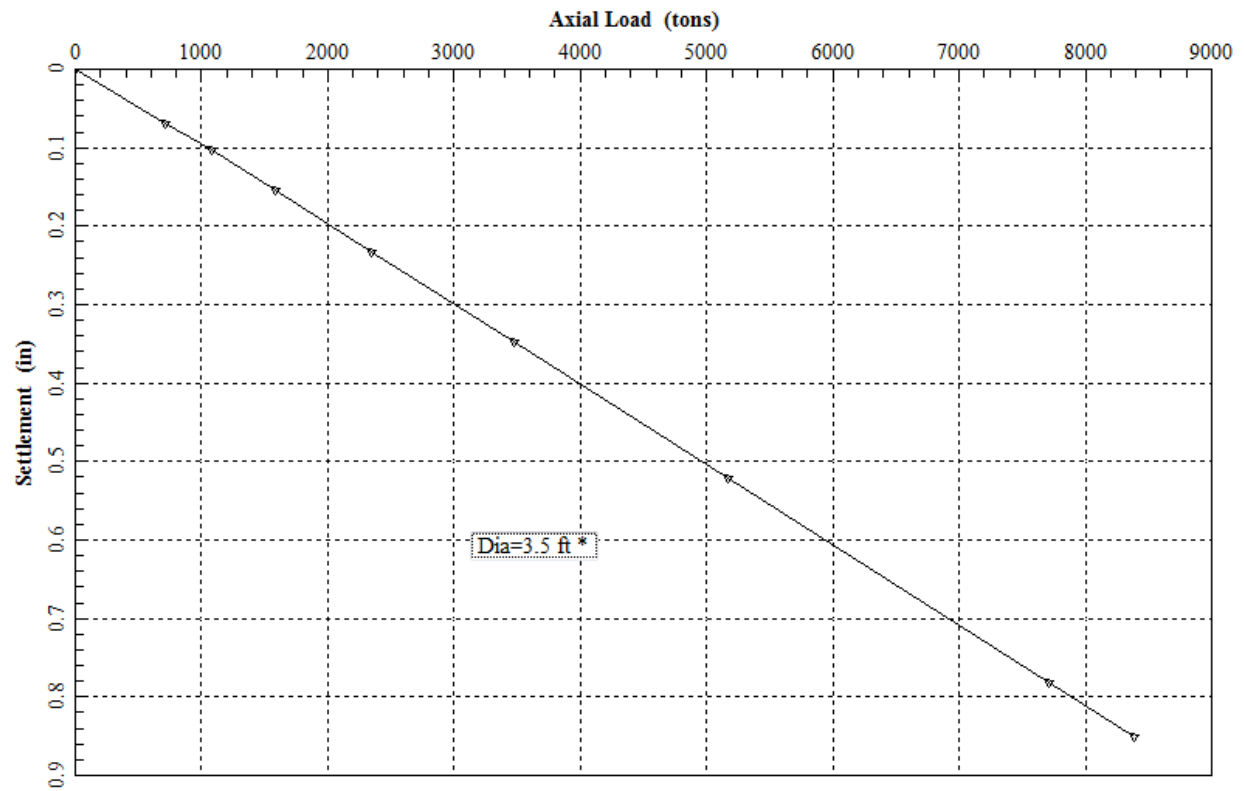


Figure 5.21 Curve of Axial Load vs Settlement for Example Problem 5.

5.7 Example Problem 6 – Weak Rock

This is an example of a drilled shaft in weak rock.

5.7.1 Description of the Problem – Rough Socket

Consider the shaft and soil profile shown in Figure 5.22. The user is asked to compute the load-settlement relation for the socket, and to estimate the ultimate resistance at a settlement of $w_t = 25\text{mm}$. The socket is assumed to be rough. The RQD for the sample is 100%.

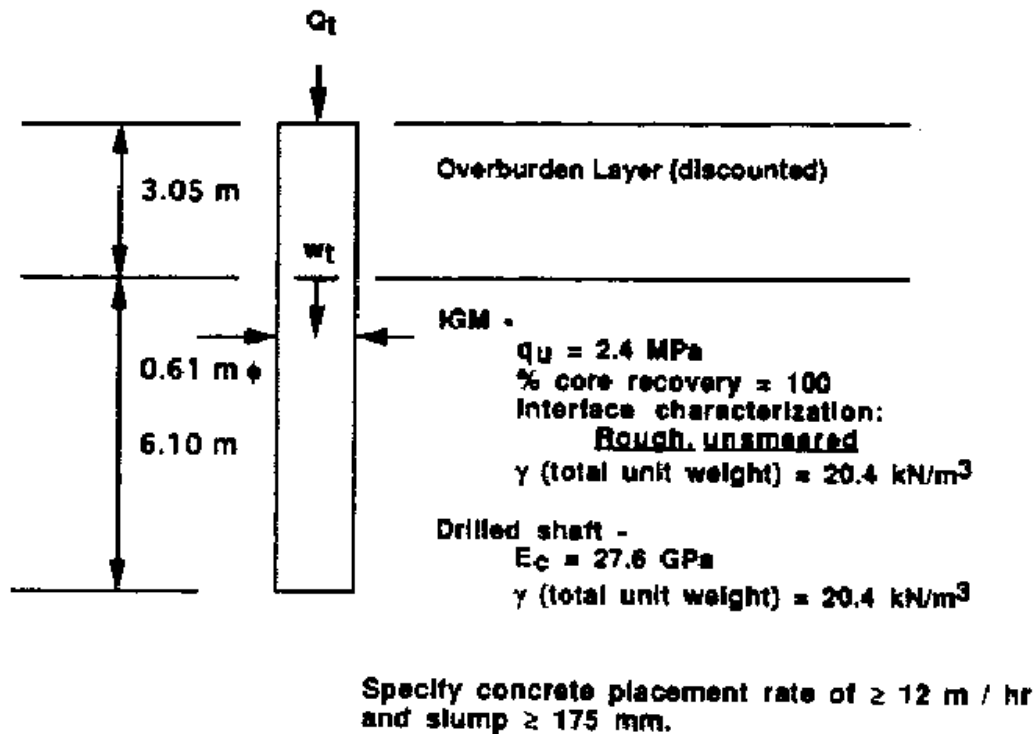


Figure 5.22 General pile and soil description for Example Problem 6.

5.7.2 Hand Computations – Rough Socket

1. Since the core recovery and RQD are high, assume that: $E_m = 115 q_u$. Note that $E_c/E_m = 100\%$.
2. $f_{aa} = f_a = 2.4/2 = 1.2$ MPa, or 1200 kPa (Technical Manual, Eq. 7-3).
3. $z_c = 6.1$ m (depth from top of concrete to middle of socket). Considering concrete placement specifications:
 $\sigma_n = 0.92 \gamma_c z_c$ from figure 3.15, or
 $\sigma_n = 0.92(20.4)(6.1) = 115$ kPa $= 1.14 \sigma_p$
4. $n = 115$ kPa / 2400 kPa = 0.048 (Technical Manual, Eq. 7-7).
5. $L/D = 6.1 / 0.61 = 10$.
6. $\Omega = 1.14 (10)^{0.5} - 0.05 [(10)^{0.5} - 1] \log 100 - 0.44 = 2.94$ (Technical Manual, Eq. 7-12)
7. $\Gamma = 0.37 (10)^{0.5} - 0.15 [(10)^{0.5} - 1] \log 100 + 0.13$, or
 $\Gamma = 0.651$ (Technical Manual, Eq. 7-13)
8. $\Theta_f = \{[115 (2400) 2.94] / [3.14 (6100 \text{ mm})(0.651) 1200]\} w_i$

- $\Theta_f = 0.0542w_t$ (Technical Manual, Eq. 7-10).
9. $K_f = 0.048 + (0.0542w_t - 0.048)(1 - 0.048)/(0.0542w_t - 0.096 + 1)$
 $K_f = 0.048 + (0.0542w_t - 0.048)(0.952)/(0.0542w_t + 0.904)$ (Technical Manual, Eq. 7-11).
10. At the end of the elastic stage, $\Theta_f = n$ (implied by Technical Manual, Eq. 7-8). Therefore,
 $w_{te} = \frac{n}{\Theta} = \frac{0.048}{0.0542} = 0.88\text{mm},$
 where w_{te} signifies w_t at the end of the elastic stage. (Note that elastic response occurs only up to a very small settlement in this example.)
11. $q_b = \Lambda w_t^{0.67}$ (Technical Manual, Eqs. 7-14 and 7-15)
 $q_b = \{[(115)(2400)(10/11)]\} \left\{ \frac{[200(10^{0.5} - 2.94)(11)]}{[3.14(6100).651]} \right\}^{0.67} w_t^{0.67}$
 $q_b = 383.7 w_t^{0.67} \text{ (kPa). Note that } \Lambda = 383.7.$
12. $\pi DL = 11.7\text{m}^2; \pi D^2/4 = 0.2922\text{m}^2$
13. Compute Q_t corresponding to w_{te} , signified by Q_{te} :
 $Q_{te} = 11.7(0.0542)(0.88)(1200) + (0.2922)(383.7)(0.88)^{0.67}$
 $Q_{te} = 670 + 103 = 773 \text{ kN}$ (Technical Manual, Eq. 7-8).
 Note that at this point, 670 kN is transferred to the weak rock in side resistance and 103 kN is transferred in base resistance. (Q_{te}, w_{te}) is a point on the load-settlement curve, and a straight line can be drawn from ($Q_t = 0, w_t = 0$) to this point.
14. Compute the values of Q_t for selected values of w_t on the nonlinear portion of the load-settlement curve. Numerical evaluations are made in the following table.

(1) w_t (mm)	(2) Θ_f $= 0.0542w_t$	(3) K_f (Step 9)	(4) Q_s $= \pi DL K_f f_{aa}$ (kN)	(5) q_b $= \Lambda w_t^{0.67}$ (kPa)	(6) Q_b $= (\frac{\pi D^2}{4}) q_b$ (kN)	(7) Q_t (kN) $= (4) + (6)$
5	0.271	0.229	3210	1128	330	3540
10	0.542	0.373	5232	1795	524	5756
15	0.813	0.472	6621	2355	688	7309
25	1.355	0.599	8402	3316	969	9371

Note that:

$$q_b(\text{at } w_t = 25\text{mm}) = 3.32 \text{ MPa} = 1.38 q_u < q_{\max} = 2.5q_u$$

Which is OK for definition of ultimate resistance. Based on base resistance, working load should be limited to $q_b = q_u$ or w_t should be limited to about 12 mm at working load. Note also that the compressive stress in the shaft at $w_t = 15 \text{ mm}$ is 25,000 kPa (7309 kN/cross-sectional area), which may be approaching the structural failure load in the drilled shaft.

15. The numerical values from steps 13 and 14 are graphed in Figure 5.23. Also shown in Figure 5.23 is the case with smooth socket for the same problem. Hand computations for the case of smooth socket are included in the next section.

The physical significance of the parameters Θ_f and K_f is evident from the numerical solution. Θ_f is a proportionality constant for elastic resistance for side shear, and K_f is a proportionality parameter for actual side shear, including elastic, plastic and interface slip effects.

5.7.3 Description of the Problem – Smooth Socket

Consider the same example as before (shaft and soil profile shown in Figure 5.22). The rock socket is now assumed to be smooth. Estimate that $\phi_{rc} = 30$ degrees. The user is asked to compute the load-settlement relation for the socket, and to estimate the ultimate resistance at a settlement of $w_t = 25$ mm.

5.7.4 Hand Computations – Smooth Socket

1. $f_a = f_{aa} = \alpha q_u$
2. Referring to Technical Manual, Figure 7-1, for $\frac{\sigma_n}{\sigma_p} = 1.14$, and $q_u = 2.4$ MPa, we have $\alpha = 0.12$.
3. $f_a = f_{aa} = 0.12(2400) = 288$ kPa
4. $q_u / \sigma_p = 2400 / 101.3 = 24$, and $E_m / \sigma_n = 115 (2.4) (1000) / 115 = 2400$
5. From Technical Manual, Figure 7-2, $n = 0.11$.
6. $\Omega = 2.94$ (unchanged); $\Gamma = 0.651$ (unchanged)
7. $\Theta_f = \{[115 (2400) 2.94] / [3.14 (6100 \text{ mm})(0.651) 288]\} w_t$
 $\Theta_f = 0.226 w_t$ (Technical Manual, Eq. 7-10).
8. $K_f = 0.11 + [(0.226 w_t - 0.11)(1 - 0.11)] / [0.226 w_t - 2(0.11) + 1]$;
 $K_f = 0.11 + (0.226 w_t - 0.11)(0.89) / (0.226 w_t + 0.78)$.
9. At $\Theta_f = n$, $w_{te} = 0.11 / 0.226 = 0.487$ mm.
10. $q_b = 383.7 (w_t)^{0.67}$, where w_t is in mm. and q_b in kPa. From Technical Manual, Eqs. 7-14 and 7-15 (unchanged).
11. $Q_{te} = 11.7 (0.226) (0.487) (288) + (0.2922) (383.7) (0.487)^{0.67}$;
 $Q_{te} = 371 + 103 = 474$ kN (Technical Manual, Eq. 7-8).
12. $Q_{te} = 474$ kN, $w_{te} = 0.487$ mm is the point at the end of the linear portion of the load settlement curve.
13. Compute the values of Q_t for selected values of w_t on the nonlinear portion of the load-settlement curve. Numerical evaluations are made in the table below.

(1) w_t (mm)	(2) Θ_f $= 0.0542 w_t$	(3) K_f (Step 9)	(4) $Q_s =$ $\pi D L K_f f_{aa}$ (kN)	(5) $q_b =$ $\Lambda w_t^{0.67}$ (kPa)	(6) $Q_b =$ $(\pi D^2 / 4) q_b$ (kN)	(7) Q_t (kN) = (4) + (6)
5	1.13	0.585	1971	1128	330	2301
10	2.26	0.739	2490	1795	524	3014
15	3.39	0.810	2729	2355	688	3417
25	5.65	0.877	2955	3316	969	3924

14. The numerical values for smooth socket are graphed in Figure 5.23 in comparison with the values from rough socket to illustrate the effect of borehole roughness in this problem. Note again that $q_b < 2.5 q_u$

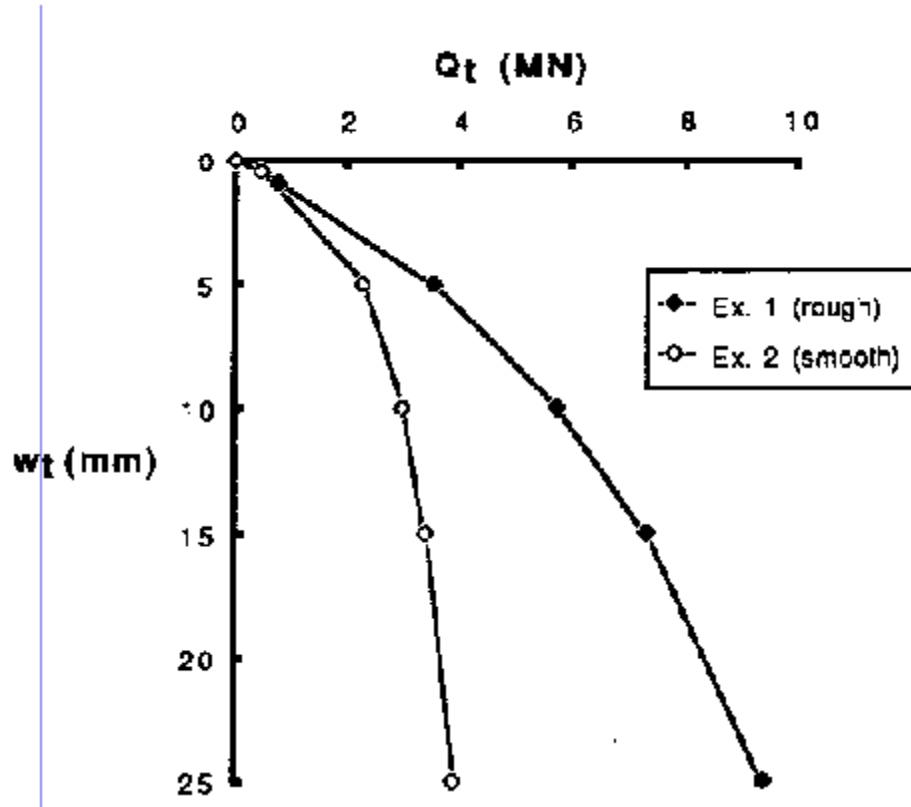


Figure 5.23 Curves of Axial Load vs Settlement for Example Problem 6 (rough and smooth sockets). Obtained from hand computations (O'Neill et al., 1975)

5.7.5 Input and Output Data Files for Example 6

Users can read Section 2.1.1 (7) of this manual for reference on the location of placement of the input and output data files for the example files installed with this program. The default installation directory is the following: (Root Drive) *c:\Ensoft\Shaft2026-Examples*. The input data files for all examples presented in this manual are installed automatically with the program.

The input-data filenames for Example 6 are the following:

Example10-6-Weak Rock-Rough.sf10d

Example10-6-Weak Rock-Smooth.sf10d

The output-data filenames for Example 6 are the following:

Example10-6-Weak Rock-Rough.sf10o

Example10-6-Weak Rock-Smooth.sf10o

5.7.6 Graphical Results of Computer Analysis

The resulting plots of axial load versus settlement provided by the computer program for the cases of a rough socket with closed joints and a smooth socket with closed joints may be observed in Figure 5.24 and Figure 5.25 respectively.

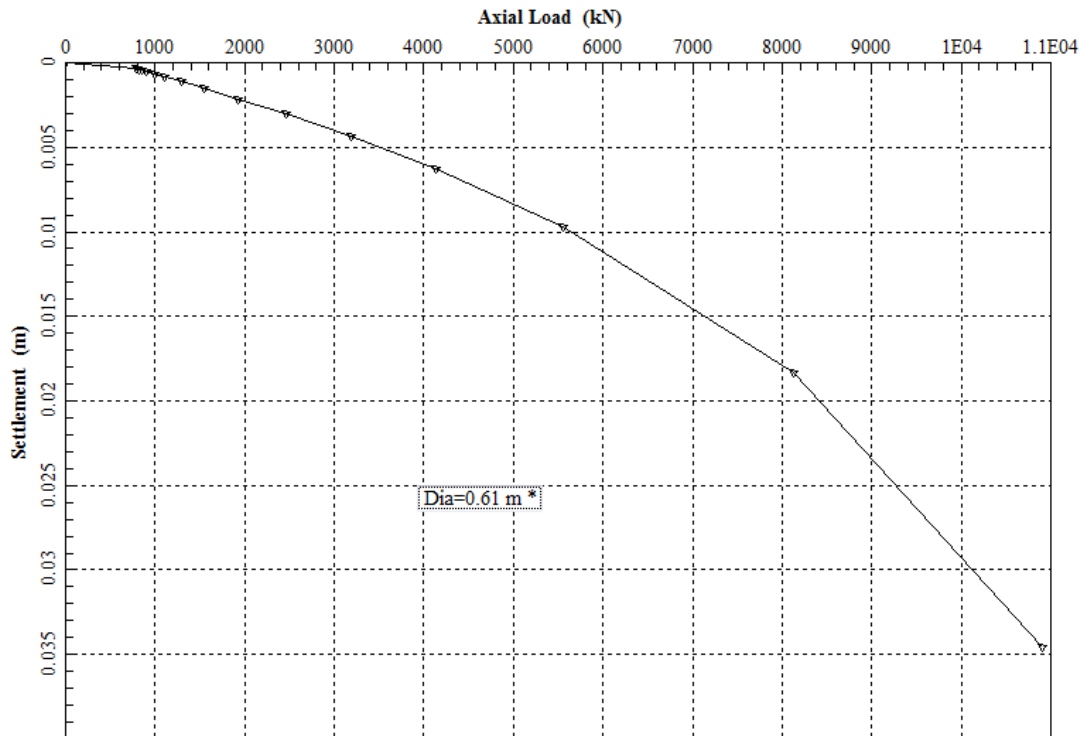


Figure 5.24 Curve of Axial Load vs Settlement for Example Problem 6 using rough socket with closed joints.

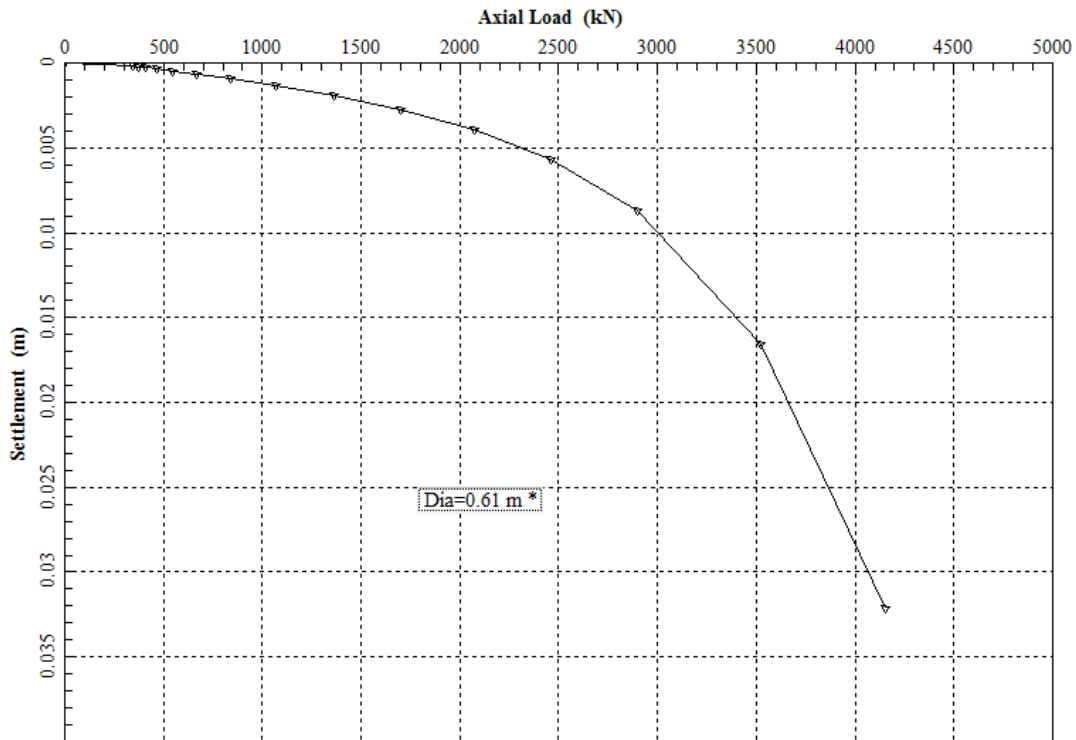


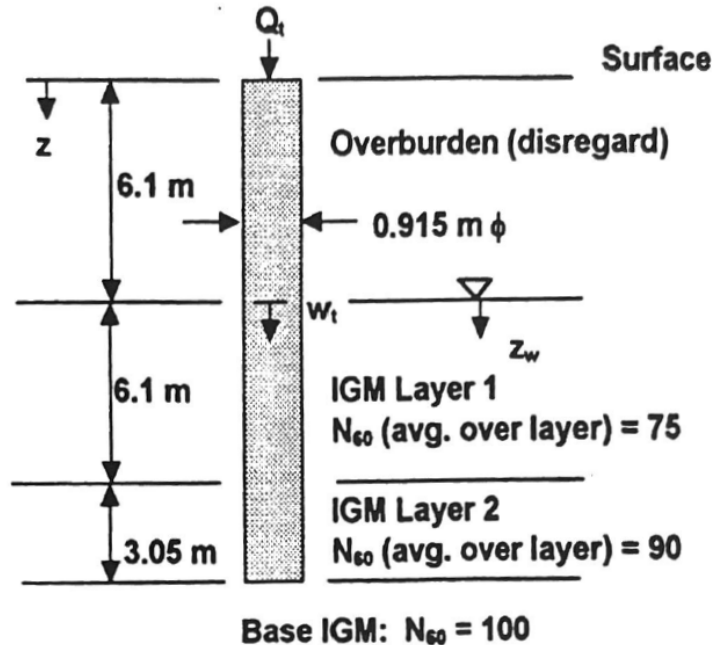
Figure 5.25 Curve of Axial Load vs Settlement for Example Problem 6 using smooth socket with closed joints.

5.8 Example Problem 7 – Decomposed Rock/Gravel

This is an example of a drilled shaft in decomposed rock/gravel. This example was obtained from the O'Neill and Reese (1999) FHWA Drilled Shaft Manual, Example C-4 (Settlement of a drilled shaft in granular IGM).

5.8.1 Description of the Problem

Consider the shaft and soil profile shown in Figure 5.26. The user is asked to compute the load-settlement relation and to estimate the ultimate resistance.



$$E_c = 27.6 \text{ GPa} \quad \gamma = 21.0 \text{ kN/m}^3 \quad \gamma_w = 9.81 \text{ kN/m}^3 \quad \nu(\text{IGM}) = 0.4 \text{ (estimated)}$$

Anticipate drilling with slurry with good construction controls.

Figure 5.26 General pile and soil description for Example Problem 7.

5.8.2 Hand Computations

- $q_{\max}(\text{base}) = 9.33 (0.23)(230)(8.79)^{0.80}$
 $q_{\max}(\text{base}) = 2806 \text{ kPa}$, (Technical Manual, Eqs. 6-6 and 6-7)
- Assessment of moduli:

$$E_s(\text{layer 1}) = 22(101)75^{0.82}$$

$$E_s(\text{layer 1}) = 76,600 \text{ kPa} \quad (\text{Technical Manual, Eq. 6-9}).$$

$$E_s(\text{layer 2}) = E_{sL} = 22(101)90^{0.82}$$

$$E_s(\text{layer 2}) = 89,000 \text{ kPa} \quad (\text{Technical Manual, Eq. 6-9}).$$

$$E_{sm}(\text{avg.}) = [6.1(76,000) + 3.05(89,000)]/9.15$$

$$E_{sm}(\text{avg.}) = 80,700 \text{ kPa}.$$

$$E_{sL} = 22(101)100^{0.82}$$

$$E_{sL} = 97,000 \text{ kPa} \quad (\text{Technical Manual, Eq. 6-9}).$$

$$E_b = \frac{E_{SL}}{2.5} = 38,800 \text{ kPa}.$$

The numerical computation for load-transfer factors is included in Table 5.6.

Layer	N_{60} (B per 0.3 m)	σ'_p (kPa) (B.59)	σ'_v (middle of layer) (kPa)	OCR (B.60)	σ'_v/p_a	ϕ' (deg.) (B.61)	K_o (B.51)	f_{max} (kPa) (B.62)
1	75	1515	162	9.35	1.60	50.0	1.30	162
2	90	1818	213	8.54	2.11	49.8	1.21	197
Base	100	2020	230	8.78	-	-	-	-

Note: f_{max} was computed using $0.75\phi'$ as the angle of wall friction since slurry is likely used in the construction.

Table 5.6 Numerical computation of load-transfer factors for Example Problem 7

$$\frac{L}{D} = \frac{15.25}{0.915} = 16.7$$

$$\lambda = 2(1 + 0.4) [27,600,000] = 868; x = 2.5 \text{ (by convention).}$$

$$\zeta\zeta = \ln\{[0.25 + (2.5(80,700/89,000)(1 - 0.4) - 0.25)2.5]33.3\}$$

$$\zeta\zeta = 4.61.$$

$$\mu L = 2[2/(4.61)(868)]^{0.5} (16.7) = 0.747$$

3. Compute the influence coefficient, I , according to Technical Manual, Eq. 6-10:

$$I = 4(1 + 0.4) \frac{1 + \frac{8 \tanh 0.747}{\pi(868)(1 - 0.4)(2.5)(0.747)} 16.7}{\frac{4}{(1 - 0.4)(2.5)} + \frac{4\pi \frac{80,700}{89,000} \tanh 0.747}{4.61(0.747)} 16.7}$$

$$= 0.19$$

4. $Q_{s \max} = \pi(0.915) [6.1 (162) + 3.05 (197)]$

5. $Q_{s \max} = 4568 \text{ kN}$ (Technical Manual, Eq. 6-11, segmentally)

6. $Q_{t1} = \frac{4568 \text{ kN}}{1 - \frac{0.191}{2.5 \cosh(0.747)[(1 - 0.4)(1 + 0.4)]}} = 4807 \text{ kN}$ (Technical Manual, Eq. 6-12).

7. $w_{t1} = \frac{Q_{t1} I}{DE_{SL}} = 4807 (0.19) / 89000(0.915) = 11.2 \text{ mm}$ (Technical Manual, Eq. 6-8).

8. $\Delta w_b = (6413 - 4807)[0.6(1.4)] / [97,000/2.5)(0.915)]$
 $\Delta w_b = 38.0 \text{ mm}$ (Technical Manual, Eq. 6-14).

9. $w_{t2} = 38.0 + 11.2$
 $w_{t2} = 49.2 \text{ mm at } Q_{tmax} = 6413 \text{ kN}.$
10. The numerical values obtained from hand computations for Q_t versus w_t , are plotted in Figure 5.27

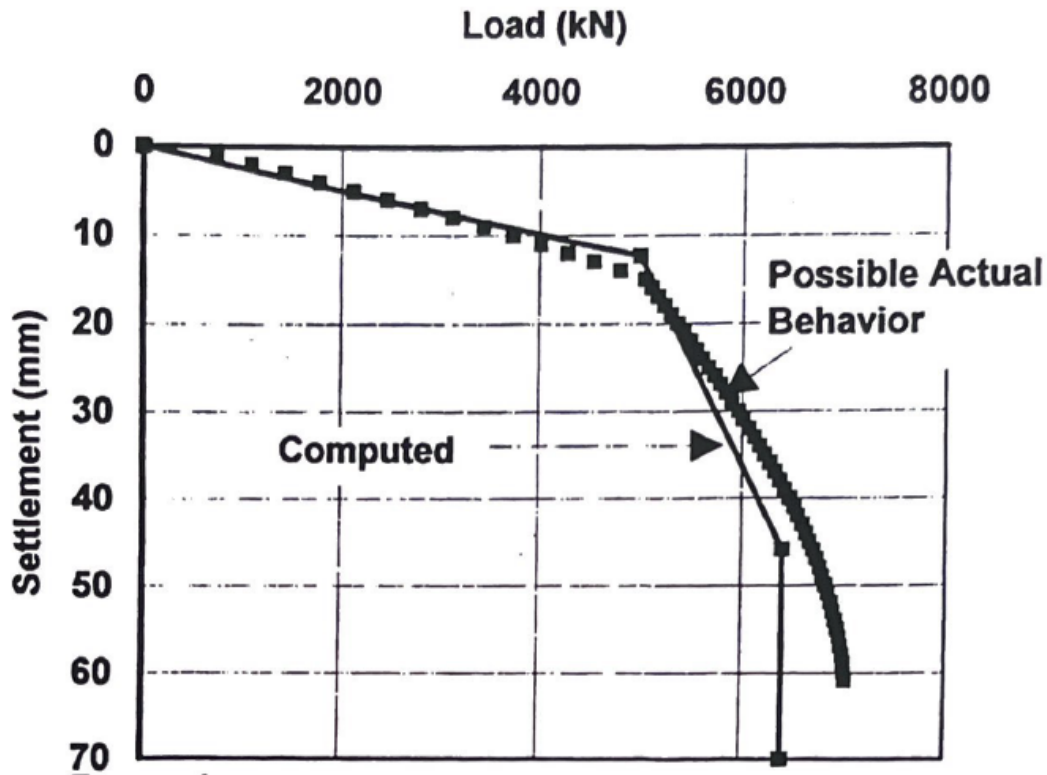


Figure 5.27 Curves of Axial Load vs Settlement for Example Problem 7. Obtained from hand computations (O'Neill and Reese, 1999).

5.8.3 Comparison of Results

Note: the computer solution divides each soil layer into several increments while the hand computations assume only one increment per layer.

Table 5.7 contains a comparison of the results obtained from hand computations against those from computer run in SHAFT.

Parameter	Manual Calculations	Computer Analysis	Deviation
Side Resistance (kN)	4568	4362	4.5%
Total Capacity (kN)	6413	6531	-1.8%
Q_{t1} (kN)	4807	5140	-6.9%
w_{t1} (movement, mm)	(11.2)	(12.3)	-9.8%
w_{t2} (movement, mm)	(49.2)	(45.1)	8.3%

Note: the computer solution divides each soil layer into several increments while the hand computations assume only one increment per layer.

Table 5.7 Comparison of results for Example Problem 7

5.8.4 Input and Output Data Files for Example 7

Users can read Section 2.1.1 (7) of this manual for reference on the location of placement of the input and output data files for the example files installed with this program. The default installation directory is the following: (Root Drive) *c:\Ensoft\Shaft2026-Examples*. The input data files for all examples presented in this manual are installed automatically with the program.

The input-data filename for Example 7 is the following:

Example10-7-Decomposed Rock-Gravel.sf10d

The output-data filename for Example 7 is the following:

Example10-7-Decomposed Rock-Gravel.sf10o

5.8.5 Graphical Results of Computer Analysis

The resulting plots of axial load versus settlement provided by the computer program may be observed in Figure 5.28.

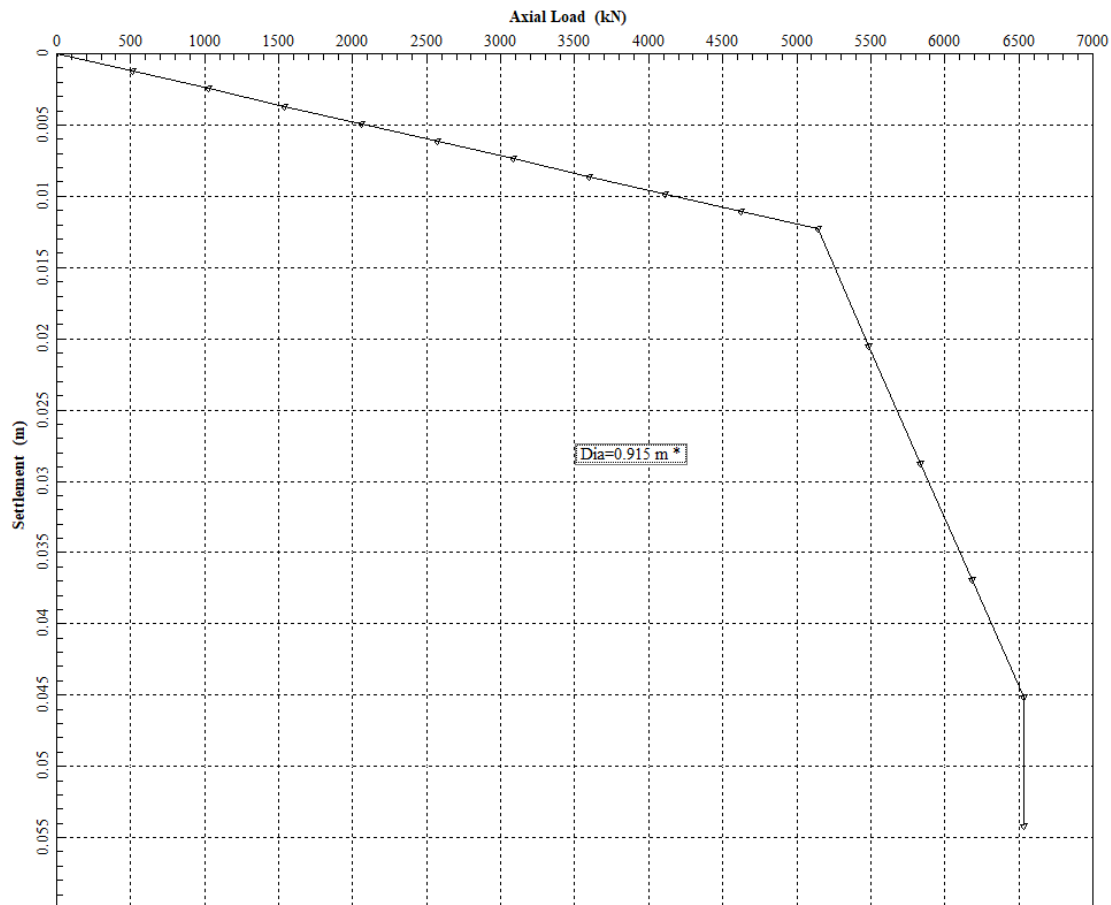


Figure 5.28 Curve of Axial Load vs Settlement for Example Problem 7.

5.9 Example Problem 8 – Gravelly Sand & Gravel

This is an example of a shaft drilled installed in gravelly sand and gravel strata. The example used the values recommended by Rollins et al (2005) for computing the side friction in gravelly sand and gravel. The blow counts (SPT-N) in gravelly layers have to be greater than 25 in order to use the recommended criteria for gravelly soils.

5.9.1 Soil Profile

The soil profile is shown in Figure 5.29. The water table is at a depth of 4 ft below the ground surface.

5.9.2 Soil Properties

N-values (blow counts per foot) from the Standard Penetration Test are included in Figure 5.29.

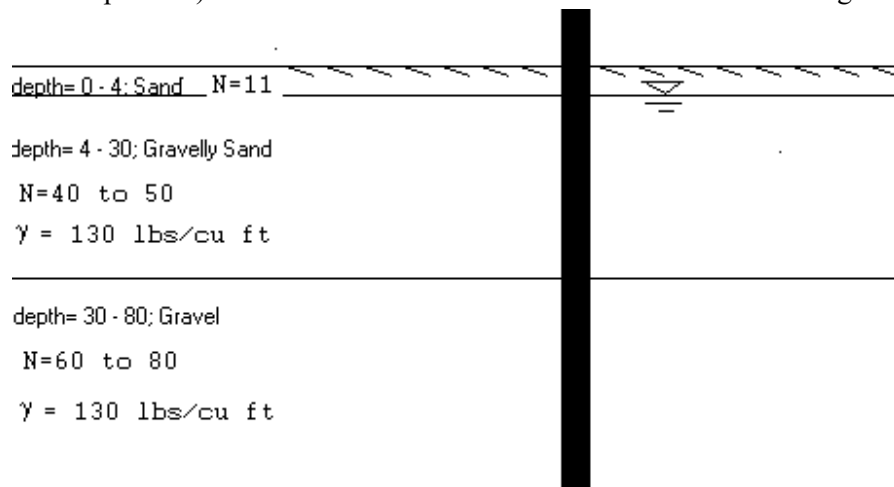


Figure 5.29 General soil description of Example Problem

5.9.3 Construction

High-quality construction is assumed. For gravelly soils, the contractor may start with the slurry method with a good control of slurry quality. In some case the contractor may experience a loss of the slurry in the hole. The contractor needs to be very careful to avoid the hole cave-in or collapse during operation in gravelly strata. The contractor may need to use the casing method if the slurry method cannot work for a particular condition. The contractor will have all the required equipment in good order and experienced personnel will be on the job for drilling holes in gravelly soils.

5.9.4 Input and Output Data Files for Example 8

Users can read Section 2.1.1 (7) of this manual for reference on the location of placement of the input and output data files for the example files installed with this program. The default installation directory is the following: (Root Drive) *c:\Ensoft\Shaft2026-Examples*. The input data files for all examples presented in this manual are installed automatically with the program.

The input-data filename for Example 8 is the following:

Example10-8-Gravelly Sand-Gravel.sf10d

The output-data filename for Example 8 is the following:

Example10-8-Gravelly Sand-Gravel.sf10o

5.9.5 Graphical Results of Computer Analysis

The results of skin friction, tip resistance, and total capacity versus depth provided by the computer program were plotted together in Figure 5.30. Figure 5.31 includes a plot of axial load versus settlement. As expected, the full capacity can be fully mobilized at settlement of 0.6 inches.

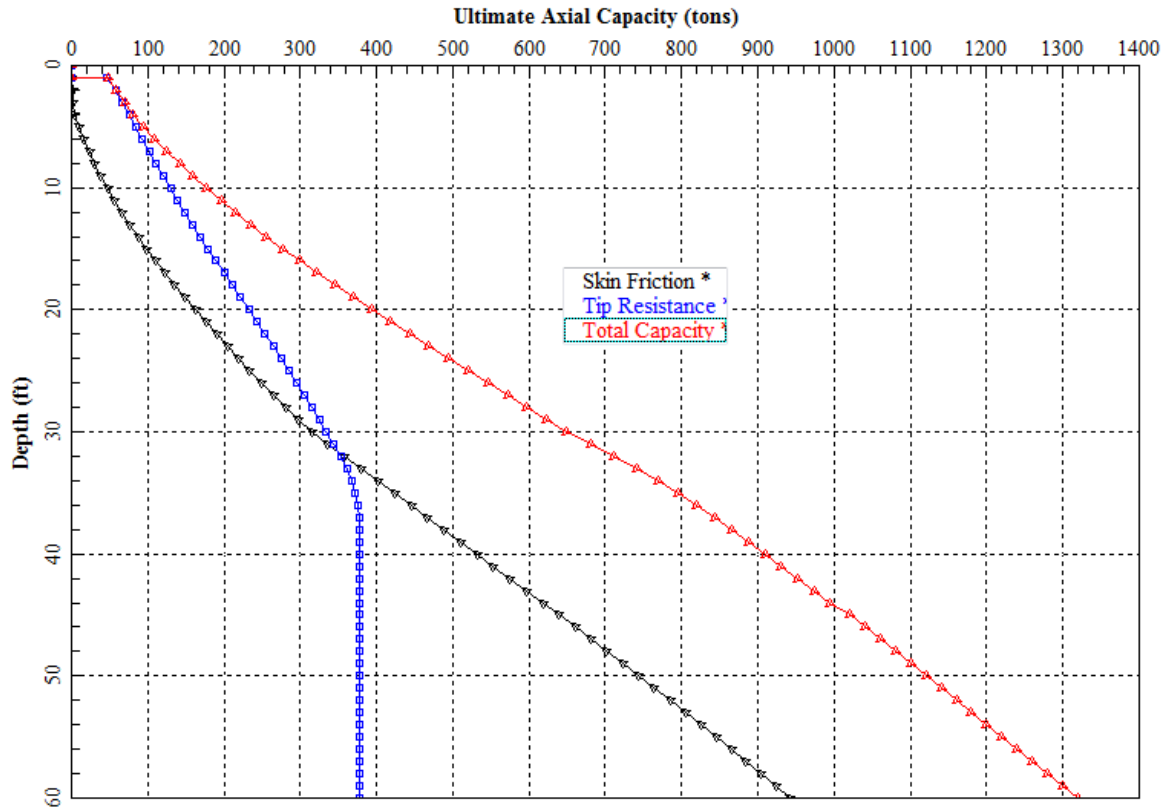


Figure 5.30 Curve of Ultimate Total Capacity vs Depth for Example Problem 8.

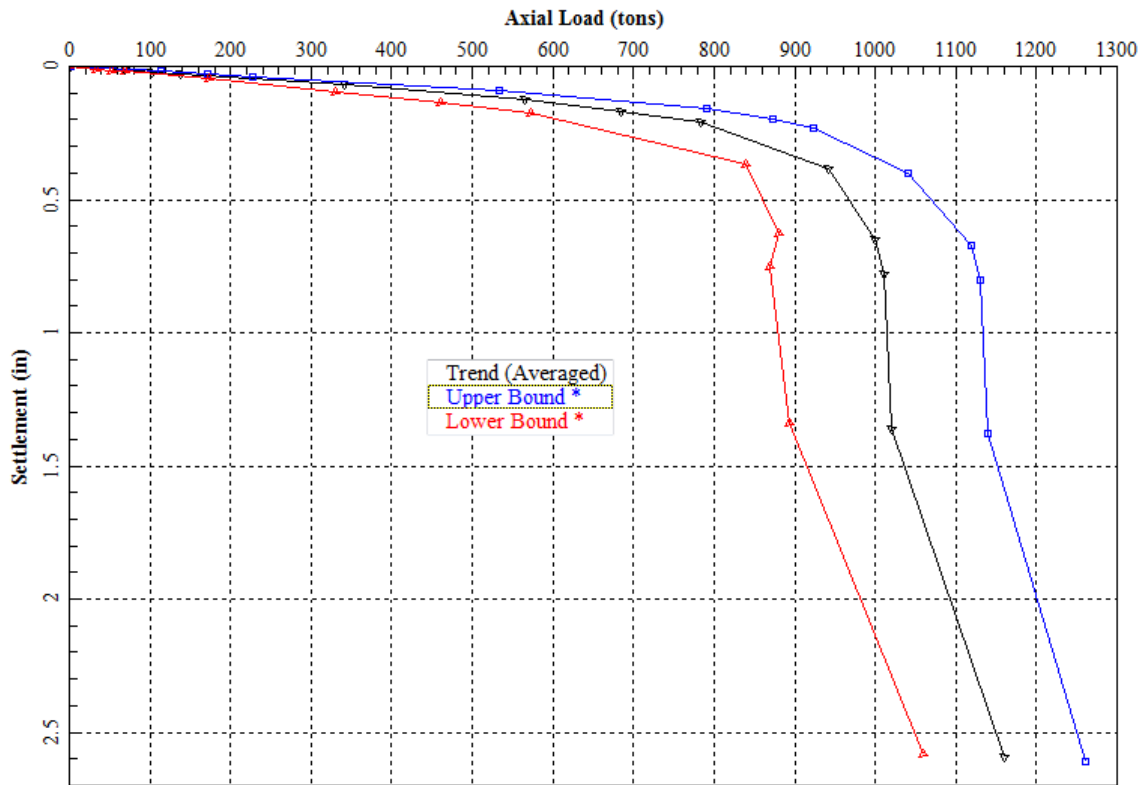


Figure 5.31 Curve of Axial Load vs Settlement for Example Problem 8.

5.10 Example Problem 9 – LRFD

An example is presented in Appendix A of the NHI Drilled Shaft Manual (2010) to illustrate design of drilled shafts as foundations for a proposed replacement bridge. This case study is included in Example 9 for demonstrating the accuracy and convenience of using SHAFT in design of drilled shafts under axial loads based on the LRFD design procedures. The proposed shaft is 8-ft in diameter and the total length (penetration) below the original grade (without scouring) is 192 ft.

The factored axial, lateral, and moment forces at the foundation level were derived through a separate comprehensive structural modeling based on the LRFD design requirement. The summary of factored loads on the proposed drilled shaft at the existing mudline is presented in Table 5.8.

Limit State	Max Axial Compression (kips)	Min Axial Compression (kips)	Lateral, Longitudinal (kips)	Lateral, Transverse (kips)	Longitudinal Moment (kip-ft)	Transverse Moment (kip-ft)
Strength I	3,390	2,673	37.0	9.6	1,687	222
Service I	2,835	1,836	54.7	34.6	2,647	317
Extreme Event I	2,823	2,810	144.5	290.5	7,776	3,212

Table 5.8 Summary of factored loads for Example Problem 9.

5.10.1 Soil Profile

A generalized subsurface profile along the alignment of the bridge is shown in Figure 5.32. Soils subdivided into general strata with identified layer thickness (Table 5.9) can be used in analysis. The water table is at the existing ground surface. Based on hydrologic studies at this location a scour depth of 38 ft is recommended for the design flood (100 year flood).

Geomaterial Layer No.	Elevation, Top of Layer (ft)	Elevation, Bottom of Layer (ft)	Thickness (ft)	Depth Interval (ft), from Mudline	Geomaterial Type		
					Subsurface Stratum	Cohesionless soil	Cohesive Soil
1	-29	-54	25	0 - 25	C	✓	
2	-54	-94	40	25 - 65	C	✓	
3	-94	-114	20	65 to 85	D	✓	
4	-114	-129	15	85 to 100	D		✓
5	-129	-139	10	100 to 110	D	✓	
6	-139	-219.5	80.5	110 to 190.5	D and E		✓
7	-219.5	-241.5	22	190.5 to 212.5	F	✓	
8	-241.5	-249	7.5	212.5 to 220	F		✓

220

Table 5.9 Summary of subsurface profile for Example Problem 9

5.10.2 Soil Properties

Soil properties for use in analysis including unit weight, internal friction angle (sand layers), undrained shear strength (clay layers), and others can be found in Figure 5.32. Corrected N-value, $(N_1)_{60}$, for the sand layer at the tip of the drilled shaft is 41.

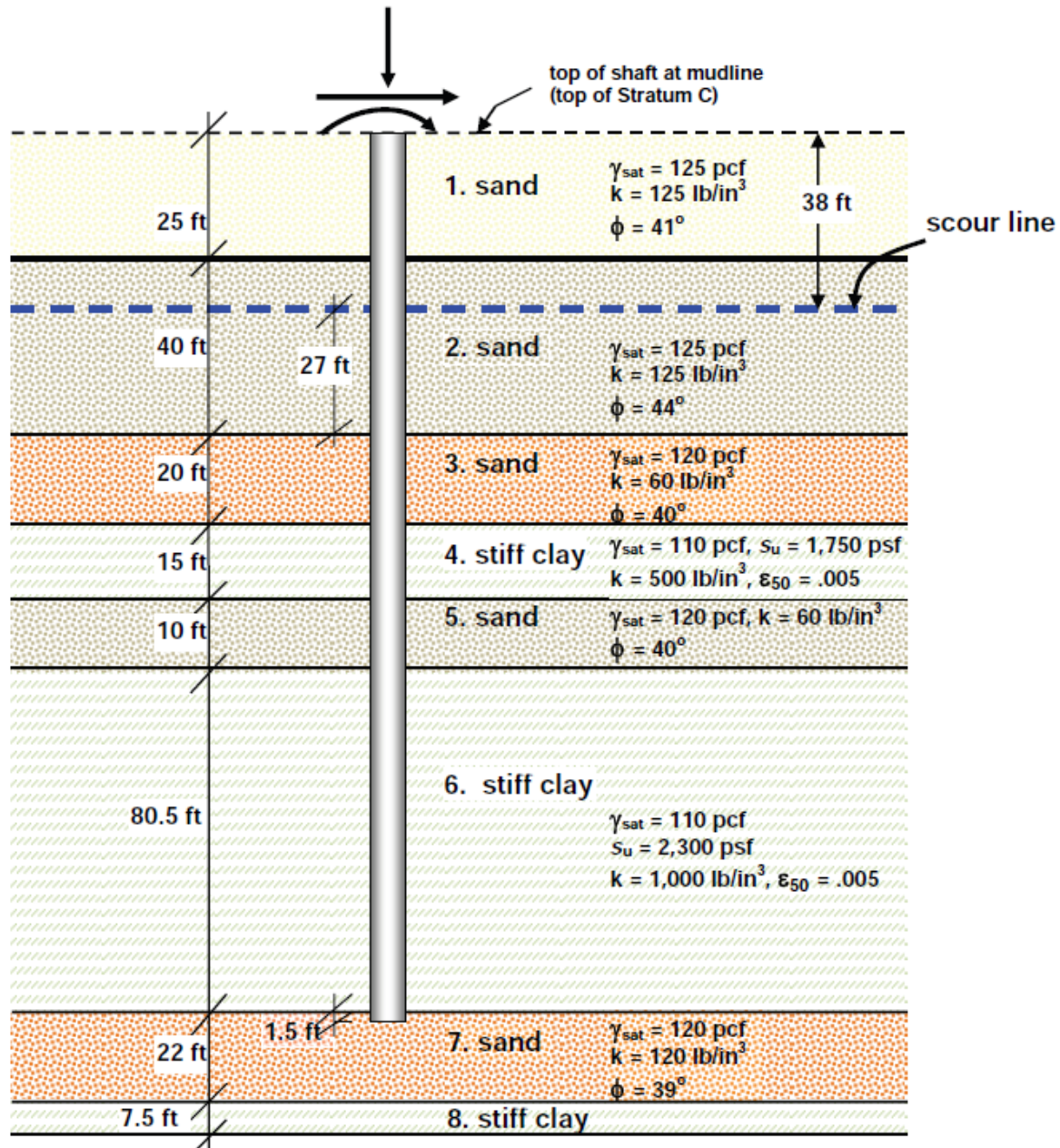


Figure 5.32 General soil description of Example Problem 9

5.10.3 Hand Computations

Calculations of nominal side and base resistance were carried out using a spreadsheet tool. Table 5.10 shows the calculation results for the Strength I limit state of this example. The table is divided into three areas: (A) side resistance in cohesionless soil layers; (B) side resistance in cohesive soil layers, and (C) base resistance.

A. Side Resistance, Cohesionless Soil Layers							
Geomaterial Layer No.	Thickness, ft (after scour)	Average ϕ	Existing Ground: Mean Vertical Effective Stress, σ'_v (psf)	After Scour: Mean Vertical Effective Stress, σ'_v (psf)	Mean N-value (N_{60})	σ_p (psf) = $0.47(N_{60})^m$	
1	0	41	783	0	17	5,444	
2	27	44	2,817	845	75	13,263	
3	20	40	4,645	2,266	30	7,654	
5	10	40	6,223	3,844	36	8,539	
7	1.5	39	10,645	8,266	41	9,232	
Geomaterial Layer No.	OCR	$K = K_o$	$\beta = K \tan \phi$	Nominal Unit Side Resistance, $f_{SN} = \beta \sigma'_v$	Layer Nominal Side Resistance, R_{SN} (lb)	Side Resistance Factor, ϕ_s	Layer Factored Side Resistance, $\phi_s R_{SN}$ (lb)
1	7.0	1.23	1.07	0	0	NA	0
2	15.7	2.07	2.00	1,687	1,144,899	0.55	629,695
3	3.4	0.78	0.66	1,485	746,583	0.55	410,621
5	2.2	0.60	0.50	1,925	483,692	0.55	266,031
7	1.1	0.37	0.30	2,481	93,544	0.55	51,449
				$\Sigma =$	2,468,718	$\Sigma =$	1,357,795
B. Side Resistance, Cohesive Soil Layers							
Geomaterial Layer No.	Thickness (ft)	Average Undrained Shear Strength (psf)	Coefficient α	Nominal Unit Side Resistance, $f_{SN} = \alpha c_u$	Layer Nominal Side Resistance, R_{SN} (lb)	Side Resistance Factor, ϕ_s	Layer Factored Side Resistance, $\phi_s R_{SN}$ (lb)
4	15	1,750	0.55	963	362,854	0.45	163,284
6	80.5	2,300	0.55	1,265	2,559,330	0.45	1,151,698
				$\Sigma =$	2,922,184	$\Sigma =$	1,314,983
C. Base Resistance, Layer 7, Cohesionless Soil							
Geomaterial Layer No.	Mean N-value for 2-Diameters Below Tip	Nominal Unit Base Resistance = $0.6 N_{60}$ (tsf)	Nominal Base Resistance, R_{BN} (lb)	Base Resistance Factor, ϕ_B	Factored Base Resistance, $\phi_B R_{BN}$ (lb)		
7	41	24.6	2,473,062	0.50	1,236,531		
Summation of Factored Resistances =				3,909 kips			

Table 5.10 Calculations for Axial Compressive Resistance and Strength I Limit State for Example Problem 9.

Computations for base resistance are performed using the soil at the base of the shaft.

At the depth of 192 ft:

$$N_{SPT} = 41$$

$$q_B = (0.6)(41) = 24.6 \text{ tsf}$$

$$A_B = 50.27 \text{ ft}^2$$

$$Q_B = (50.27)(24.6) = 1,236.6 \text{ tons} = 2,474 \text{ kips}$$

Total Nominal Resistance

$$Q_U = 2469 + 2922 + 2474 = 7865 \text{ kips}$$

5.10.4 Comparison of Results

Table 5.11 contains a comparison of the results obtained from hand computations against those from computer run in SHAFT.

Category	Manual Calculations (kips)	Computer Analysis (kips)	Deviation
Factored Side Resistance	2673	2643	-1.1%
Factored Tip Resistance	1237	1237	0%
Factored Total Capacity	3910	3880	-0.8%

Table 5.11 Comparison of results for Example Problem 9

5.10.5 Input and Output Data Files for Example 9

Users can read Section 2.1.1 (7) of this manual for reference on the location of placement of the input and output data files for the example files installed with this program. The default installation directory is the following: (Root Drive) *c:\Ensoft\Shaft2026-Examples*. The input data files for all examples presented in this manual are installed automatically with the program.

The input-data filename for Example 9 is the following:

Example10-9-LRFD.sf10d

The output-data filename for Example 9 is the following:

Example10-9-LRFD.sf10o

5.10.6 Graphical Results of Computer Analysis

The results of skin friction, tip resistance, and total capacity versus depth provided by the computer program were plotted together in Figure 5.33. Figure 5.34 includes a plot of axial load versus settlement. As expected, the full capacity can be fully mobilized at settlement of 0.6 inches.

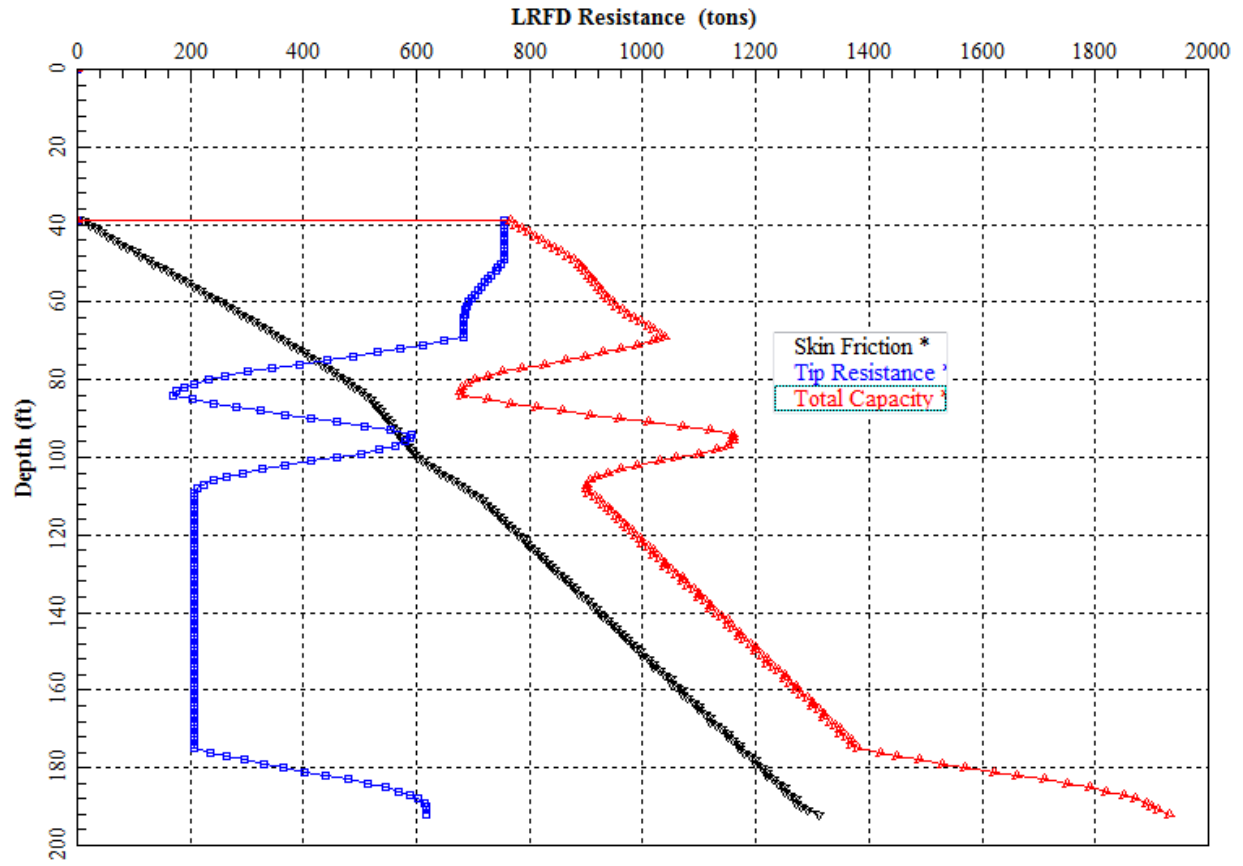


Figure 5.33 Curves of LRFD Geotechnical Capacity vs Depth for Example Problem 9.

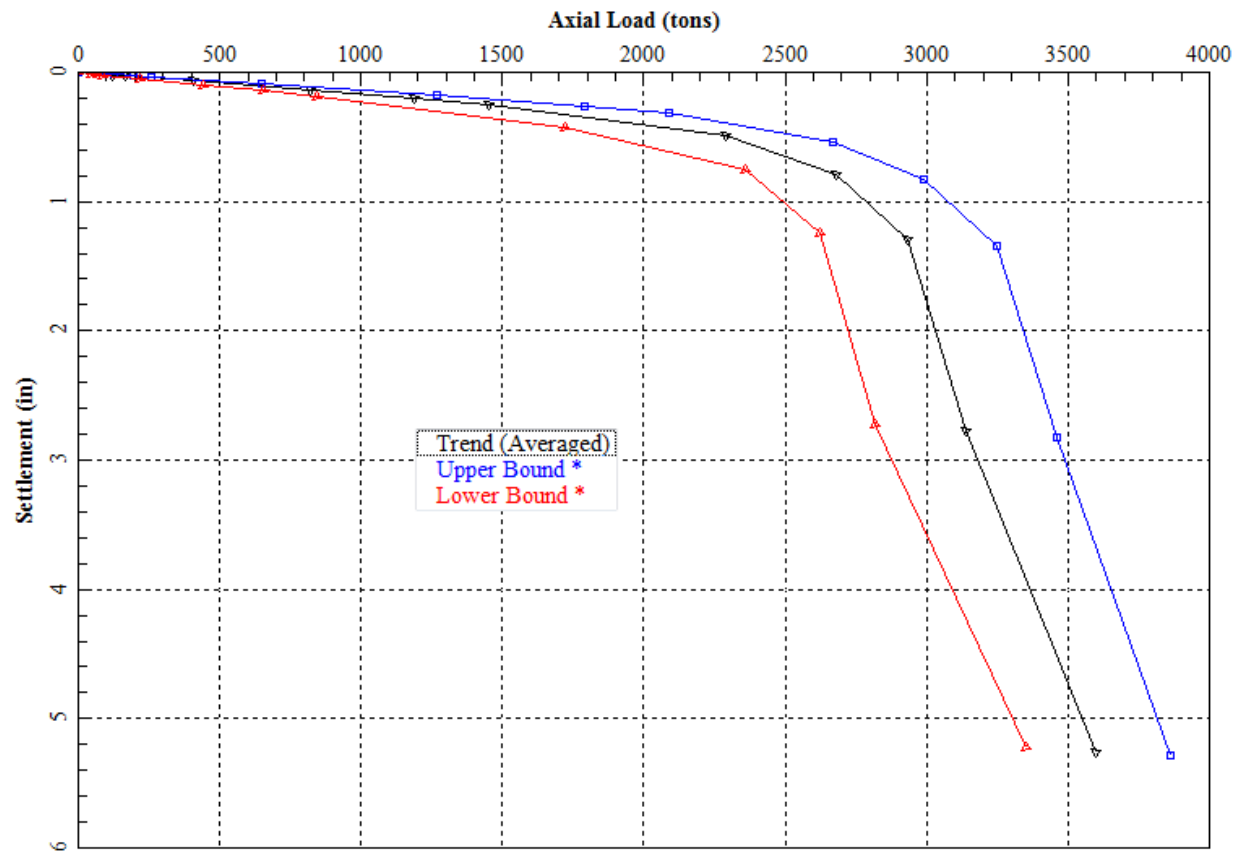


Figure 5.34 Curve of Axial Load vs Settlement for Example Problem 9.

5.11 Example Problem 10 – Multiple Shaft Lengths

This example is provided to investigate the SHAFT feature of multiple automatic computations with varying shaft penetrations. For simplicity, this model uses the same shaft and soil example that were previously defined in Example Problem 1 of this manual (see Section 5.2).

5.11.1 Soil and Shaft Properties

The background information on soil strata, loads and shaft geometry are the same as those in Section 5.2 of this manual. For a combined view of the graphs of load-vs-settlement for multiple shaft lengths the original Example Problem 1 model was modified with the selection of Data > Evaluate Multiple Shaft Lengths with the information in Figure 5.35.

Figure 5.35 Data > Evaluate Multiple Shaft Lengths for Example Problem 10.

The specified parameters Figure 5.35 indicate to start with the maximum shaft length of 60 ft and calculate axial responses with 3-ft shorter penetrations to a final 42 ft shaft length (70% of the maximum).

5.11.2 Input and Output Data Files for Example 10

Users can read Section 2.1.1 (7) of this manual for reference on the location of placement of the input and output data files for the example files installed with this program. The default installation directory is the following: (Root Drive) *c:\Ensoft\Shaft2026-Examples*. The input data files for all examples presented in this manual are installed automatically with the program.

The input-data filename for Example 10 is the following:

Example10-10-Variable Length.sf10d

The output-data filename for Example 10 is the following:

Example10-10-Variable Length.sf10o

5.11.3 Graphical Results of Computer Analysis

The interesting result plot in this example is obtained from the Graphics > Axial Load vs Settlement (averaged) menu that is shown in Figure 5.36. The resulting graph is helpful for a designer that is trying to determine the optimum length for a shaft of a defined diameter.

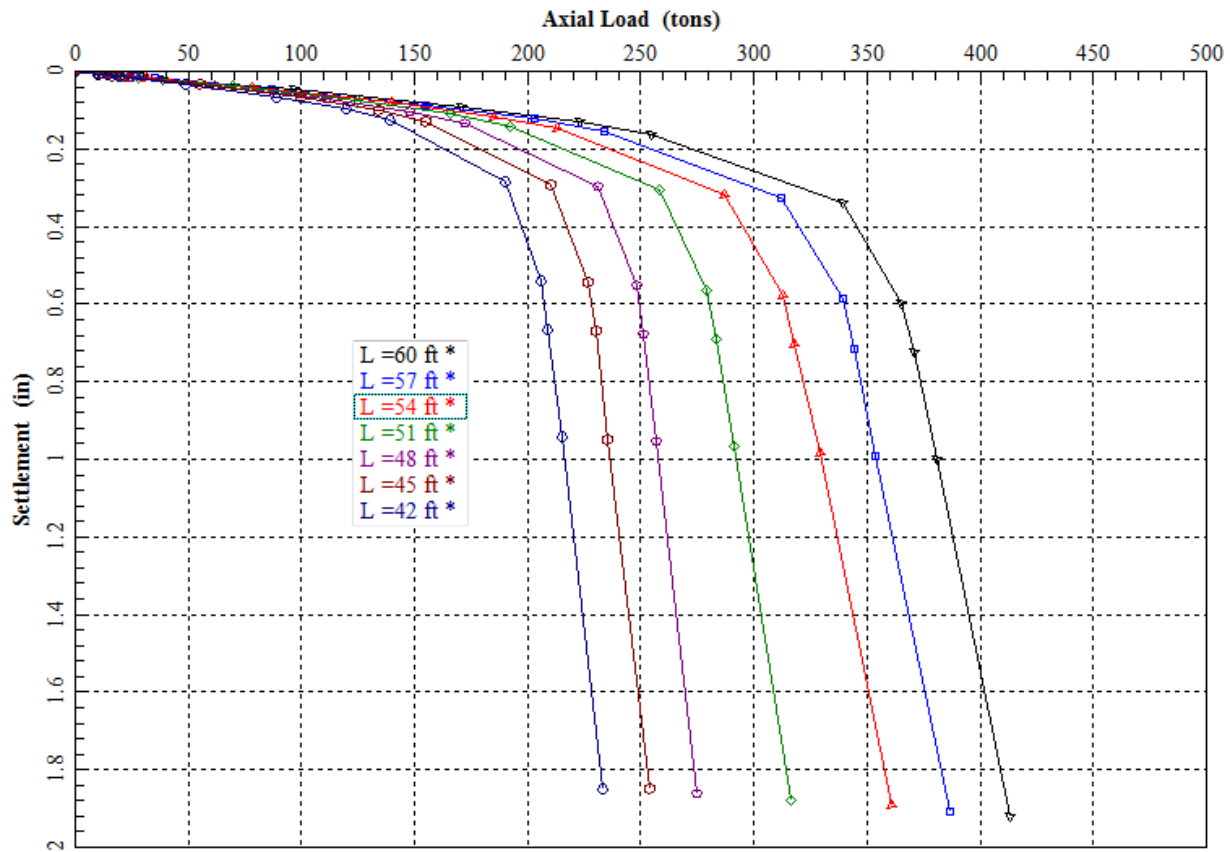


Figure 5.36 Axial Load vs Settlement (averaged) for Example Problem 10.

5.12 Example Problem 11 – Use of Design Charts

This example is provided to investigate the SHAFT feature of ASD/LRFD Design Charts that provide responses for multiple shaft diameters as well as varying shaft penetrations. For simplicity, this model uses the same shaft and soil example that were previously defined in Example Problem 2 of this manual (see Section 5.3).

5.12.1 Soil and Shaft Properties

The background information on soil strata, loads and shaft geometry are the same as those in Section 5.3 of this manual. For the generation of the Design Charts, the original Example Problem 2 model was modified with the selection of **Data > ASD/LRFD Design Charts** with the information in Figure 5.37.

LRFD Design Charts

☒ Compute LRFD Design Charts

Shaft Length/Diameter Variation

Maximum shaft length (ft)

Minimum shaft length (ft) * Should be at least 6 diameters plus any exclusion zone defined. - default: 30% maximum shaft length

Shaft length increment (ft) * A maximum of 100 increments will be considered. - default: 3 ft or 1 m

Shaft diameter increment (ft) * A maximum of 20 increments will be considered. - default: 0.5 ft or .15 m

Defined Settlements

N	Settlement (in)
1	0.1
2	0.25
3	0.5
4	0.75
5	1
6	1.2
7	1.4
8	2

Number of Points

Figure 5.37 Data > ASD/LRFD Design Charts for Example Problem 11.

The specified parameters Figure 5.37 indicate to start with the maximum shaft length of 60 ft and calculate axial responses with 3-ft shorter penetrations to a final 24-ft shaft length (controlled by the minimum limitation of 6-3 ft pile diameters plus 5-ft length of exclusion zones). Default increments of 3-ft are used

in shaft length and 1-ft increments specified for shaft diameters. The user may define any pile-head movements (settlements), the ones in the example were chosen at random.

The variations of shaft diameters are specified under **Data > Drilled-Shaft Properties** where the it is defined to use a minimum of 3-ft OD and maximum of 7-ft OD. The default increase of 6-in increments in shaft diameters is replaced by the value specified in the **ASD/LRFD Design Charts** menu.

5.12.2 Input and Output Data Files for Example 11

Users can read Section 2.1.1 (7) of this manual for reference on the location of placement of the input and output data files for the example files installed with this program. The default installation directory is the following: *(Root Drive) c:\Ensoft\Shaft2026-Examples*. The input data files for all examples presented in this manual are installed automatically with the program.

The input-data filename for Example 11 is the following:

Example10-11-Design Charts.sf10d

The output-data filename for Example 11 is the following:

Example10-11-Design Charts.sf10o

5.12.3 Graphical Results of Computer Analysis

The interesting results in this example are obtained from the **Graphics > Design Chart (xx movement)** plots. One sample plot for 0.5-in movement at the top of shaft is shown in Figure 5.38. The graph is helpful for a designer that is trying to determine the optimum diameter and length for a defined axial capacity.

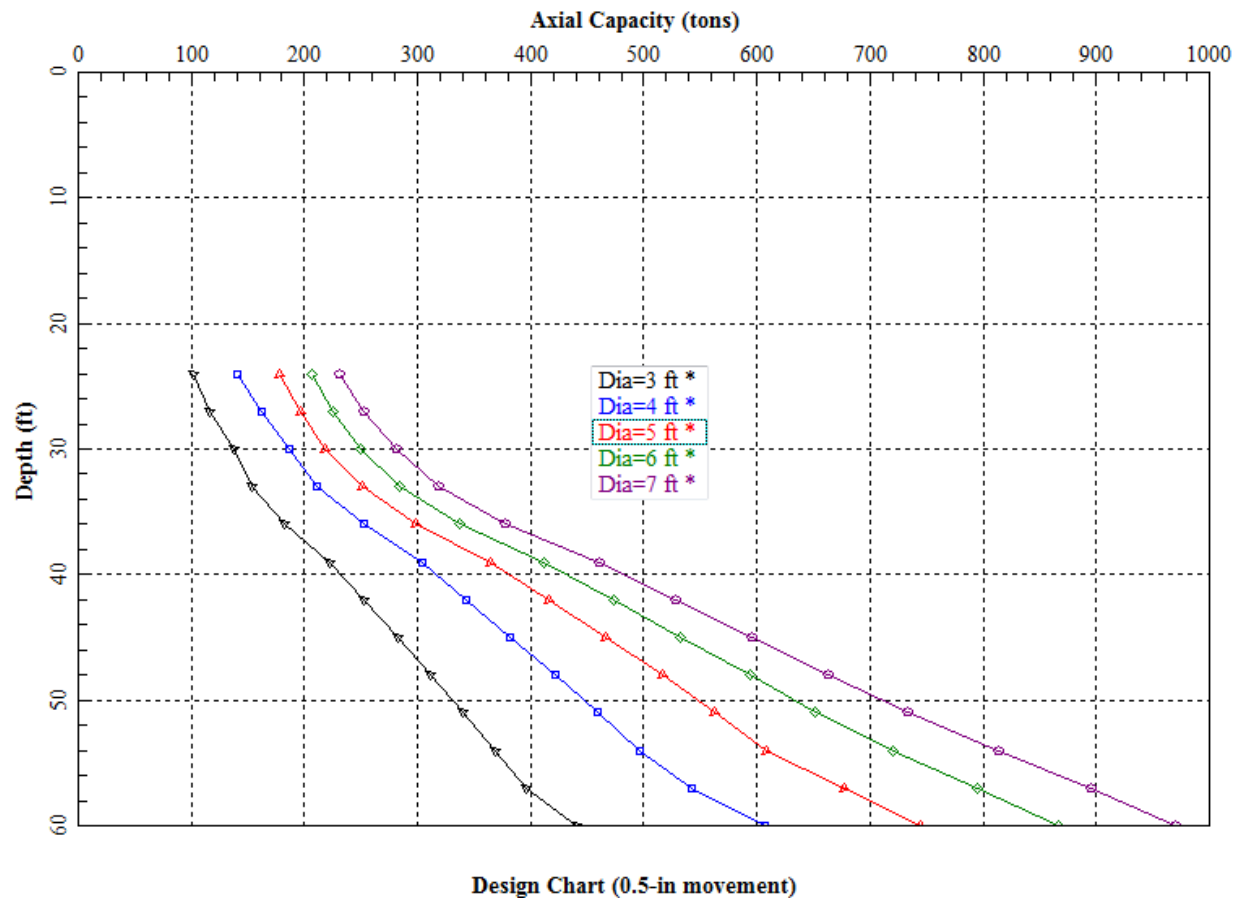


Figure 5.38 Design Chart for 0.5-in Movement for Example Problem 11.

List of Technical References

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