AllPile

Version 7

User's Manual

Volume 1 and 2

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VOLUME 1

CHAPTER 1 INTRODUCTION

1.1 About AllPile

The program AllPile *for Windows* analyzes pile load capacity efficiently and accurately. AllPile can handle all types of piles: drilled shaft, driven pile, auger-cast pile, steel pipe pile, H-pile, timber pile, tapered pile, bell pile, shallow foundation, etc. You can define new pile types and input customized parameters based on local practices and experience. The program is capable of performing the following calculations:

- Lateral capacity and deflection
- Vertical capacity and settlement
- Group vertical and lateral analysis
- FHWA SHAFT program
- Static and cyclic conditions
- Negative and zero friction
- Shallow footing
- Tower foundation

The lateral calculation directly uses COM624S, which is the same method as FHWA's COM624P. It is comparable with Ensoft's Lpile®.[1] In our tests, AllPile provided the same results as COM624P[2] and Lpile. AllPile is compatible with all Windows operating systems, such as 98/NT/2000/ME/XP.

Lpile is a registered trademark of Ensoft, Inc. ***COM624P is a public-domain software downloadable free from the U.S. Federal Highways Administration web site.***

1.2 About the Manual

Volume 1:

- Describes how to install, activate, and start the program (Chapters 2 and 3).
- Describes each input and output parameters (Chapter 4 and 5).
- Describes customization of the program and how to set up calculation methods and parameters (Chapter 6).
- Provides typical examples for using the software (Chapter 7).

Volume 2:

Introduces the theory and methods of calculation used in the program (Users should be somewhat familiar with pile design theory) (Chapter 8).

1.3 About the Company

CivilTech Software employs engineers with experience in structural, geotechnical, and software engineering. CivilTech has developed a series of engineering programs that are efficient, easy to use, engineering-oriented, practical, and accurate. The CivilTech Software program series includes Shoring Suite Plus, LiquefyPro, AllPile, SuperLog, and lab testing programs. These programs are widely used in the U.S. and around the world. For more information, please visit our web site at www.civiltechsoftware.com.

CHAPTER 2 INSTALLATION AND ACTIVATION

2.1 Installation and Run

The program has two activation methods: USB key activation and code activation. Prior to activation, the program is in demo mode. In demo mode, some functions of the program is disabled. Please follow the installation and activation procedures below that correspond to your version of the software.

USB key:

If you have CivilTech USB key, the program is inside the key.

Introduction of USB key

- **Civiltech USB key** functions the same way as a USB flash drive, (or called memory sticks or jump drive), but with a special chipset inside. It has a memory of 128 MB, and USB 2.0 connectivity. The key is compatible with Windows 2000, Xp, or higher, but may not work with Windows 98 (You need to install USB driver for Win98).
- **Insert** the key into any USB port in your computer. If you do not have an extra USB port, you should buy a USB extension cord (about $10-$20)
- **Wait** until the small light on the back of the USB key stops flashing and stays red. This means that Windows has detected the USB key. A small panel may pop up that says "USB mass storage device found", you can either close this panel or click "OK".
- **Do not remove** the key while the light is blinking, as that will damage the key. You can remove the key only during the following situations:

  1. *Your computer is completely turned off, or*
  2. *You have safely ejected the key from the system. You can do this by going down to the Windows task bar, finding the icon that says "Unplug or Eject Hardware" (usually located at the bottom right-hand side of the screen) and clicking on that. It will then tell you when it is safe to remove the hardware.*

Running the Program within the Key.

- **No installation** is required.
- After you insert the key, use Windows Explorer (or click My Computer) to check the USB drive (on most computers, it is either

called D:, E:, or F:). You will find some files inside. There is a folder called "/Keep" inside. Do not change, remove, or delete this folder or the files inside, or else your key will become void.

- You will find a folder called "/AllPile7". Open this folder and find AllPile.exe. Double click this program to run AllPile from your key.
- You can also create a new folder, save and open your project files directly to and from your key. There should be enough room on the key for your files.
- The manual is also located in the key in the root directory. Double-click on the file to open it. You need Adobe PDF to read this file, which is downloadable free of charge from Adobe's website. (http://www.adobe.com)

Running the Program from your Hard Disk:

- You can also run the program from your hard disk; the program may run a little bit faster from your hard disk.
- There is a file called **al_setup.exe** in the root directory of the key. Double-click on the file to start installation.
- The installation process will help you to install the program on your local hard disk. Installation to network drive or disk is not recommended. The program may not work properly.
- The installation will create a shortcut on your desktop. Click the icon to start the program.
- You still need to plug the USB key into the USB port to run the program. It will automatically detect the USB key.
- The key activation status can be checked from Help manual under Activation.

No USB key:
If you received the program from email or from download…

Installation to Local Hard Disk:

The installation file is called **al_setup.exe.** Click it will start up the installation process automatically. The installation process will help you to install the program on your local hard disk and create a shortcut on your desktop. Installation to network drive or disk is not recommended. The program may not work properly.

Activation

- The activation panel will automatically appear. If it does not appear, you can go to Help/Activation to open it.
- The CPU number is shown on the panel. This is a unique number for your computer, which must be reported to CivilTech by email. The

email can be found on our web side: http://www.civiltechsoftware.com.

- An Activation Code will email back to you after we verify you have purchased the program.
- Input the Activation Code in the Activation Pane, and then close the program.
- Click the icon to start the program, which has full function now.

Download Manual from Internet

The most updated manual for AllPile can be downloaded from our Web site (www.civiltech.com/software/download.html). Click on **AllPile Manual** link to open the manual, (you must have Adobe Acrobat Reader to open the file). Then, save the PDF file onto your hard drive.

Quitting the Program

From the **File** menu, select [**Exit**] or Ctrl+X.

Input Firm and User Name

From the **Help** menu, select **Firm and User**. Once the panel pulls out, enter in your firm's name and the user's name. This information will be printed in the report.

About Program

From the **Help** menu, select **About**. This will provide you with the version of the program. Click anywhere on the screen to exit back to the program.

Note: The program is not compatible for networking. You cannot install the program on your network server and run it from workstations. The program is one copy per license, which can only be installed in one workstation.

CHAPTER 3 OVERVIEW

3.1 Program Outline

AllPile operations can be divided into three main steps (Figure 3-1).

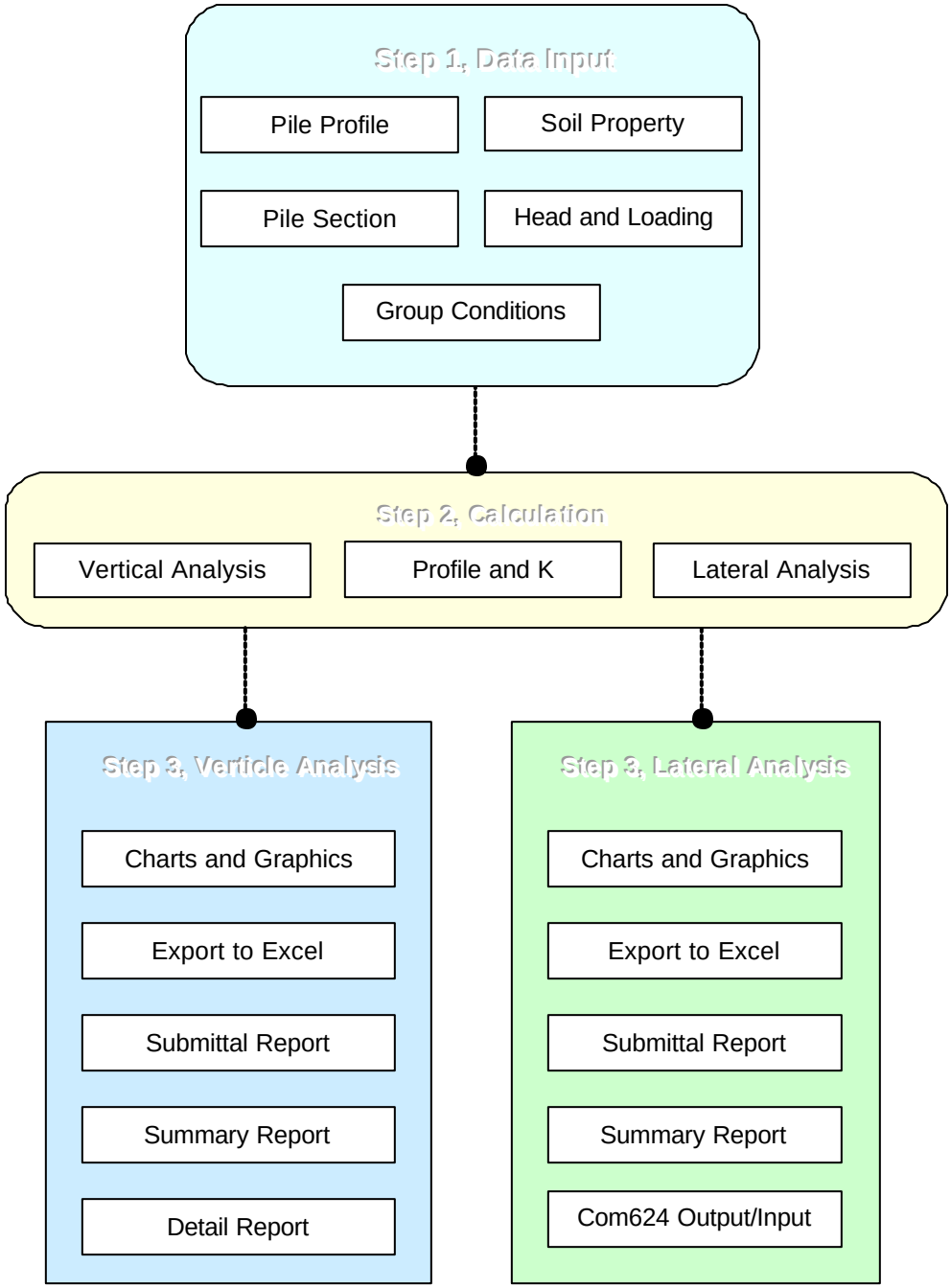


Figure 3-1. Program Flow

Step 1. **Input Data**	Enter information into the tabbed input pages (Figure 3-2). This step is described in detail in Chapter 4.
Step 2. **Execute Calculation**	Press either the **[Vertical Analysis]** button or the **[Lateral]** button after inputting all the required data. The **[Profile]** button provides the profile of the pile and soil information. The **[K]** button calculates the stiffness of pile.
Step 3. **View and Print Results**	After **Step 2**., select the reports and charts you want from the result panel. See Chapter 5 for details.

3.2 Program Interface

AllPile's program interface has three main components (Figure 3-2):

1. (Top) **Pull-down menus** of standard Windows type commands
2. (Second row) **Speed bar** with shortcut command buttons and samples.
3. **Input pages,** six tabs to open the desired data input page

The first two rows are described below. The input pages are described in detail in Chapter 4.

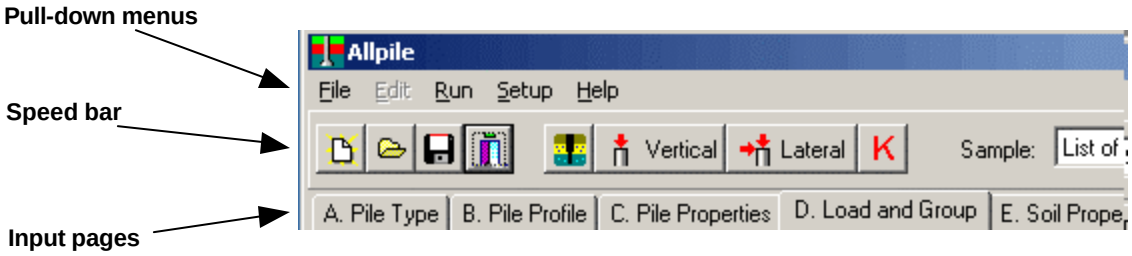


Figure 3-2. Main Components of Program Interface

3.3 Pull-Down Menus

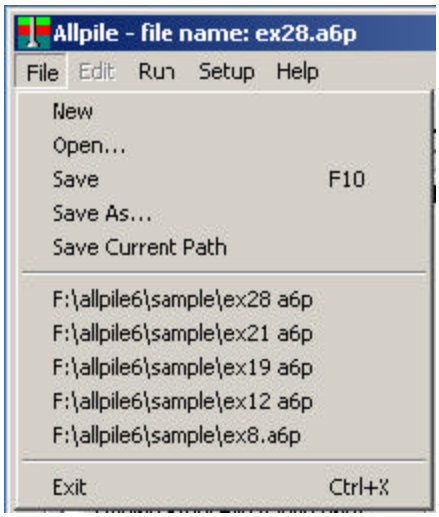


Figure 3-3. File Pull-Down Menu

***HINT:* You can use the Alt key plus the underlined letter to open the pull-down menu. For example, press Alt+F to pull down the File sub-menu.**

After the pull-down menu is open, you can type the underlined letter to select an option. For example, in the File submenu, press N to select New.

3.3.1 File

New	Create a new data file.
Open	Open an existing file. A dialog box with a list of files will open on the screen. Select the file you want and open or click on Cancel to return to program.
Save (F10)	Save the file you are working on (save your open files periodically to avoid losing data in case of a system crash). If the file is untitled, the program will automatically switch to the “Save as” command and ask you to provide a file name.
Save As	Save a new untitled file or change the file name or location of the file you are working with.
Save Current Path	Select this option to make the program "remember" the current path. When you open the program next time, it will automatically go to this path to find your data files.
Historical file list	Lists the five most recent files you used. You can click on any one of them to open the file instantly.

Exit	Exit the program. You will be prompted to save any open files.

3.3.2 Edit

The edit menu will be functional when the Pile Properties Table is active (Figure 4-4) or Soil Property Table is active (Figure 4-10).

Insert row	Insert a blank row in the table
Insert duplicate row	Insert a row with the same data as the row selected
Clear row	Clear (delete) the data in the selected row and create a blank row
Delete row	Delete the selected row from the table and shift next row up

***HINT:* Select a row by clicking any cell in the row. The selected cell will be highlighted in blue.**

3.3.3 Run

The **Run** menu gives options for executing the program's analyses. If you have not entered enough data to run the program, it will not execute.

Profile (F4)	Generate profile with information
Vertical Loading(F5)	Run vertical analysis only
Lateral Loading (F6)	Run vertical and lateral analyses
Stiffness, K (F7)	Run Stiffness analysis

3.3.4 Setup

The **Setup** menu allows you to enter the material properties for the piles and the properties of different pile types.

Open Setup	Open the Setup Options screen to set parameters related to pile properties
Close Setup	Close Setup Screen and return to program interface without saving changes
Save Setup	Save your changes in settings
Restore Saved Setup	Clear the screen and reload the previous saved setting
Restore Default Setup	Clear the screen and reload the default settings
Print Setup Data	Open Notepad to view and print the setup data. It is only enabled when you are in Setup Screen.

3.3.5 Help

Help/Manual (F1)	Open the help manual
Activation	Check status of USB key or Activation. You can activate program if not yet activated.
Firm and User	Input firm and user name
About	Display information about the version of your program.

3.4 Speed Bar

The speed bar provides seven short-cut buttons for certain commands and a quick pull down manual containing examples of pile designs. Figure 3-4 shows the buttons and their corresponding commands.

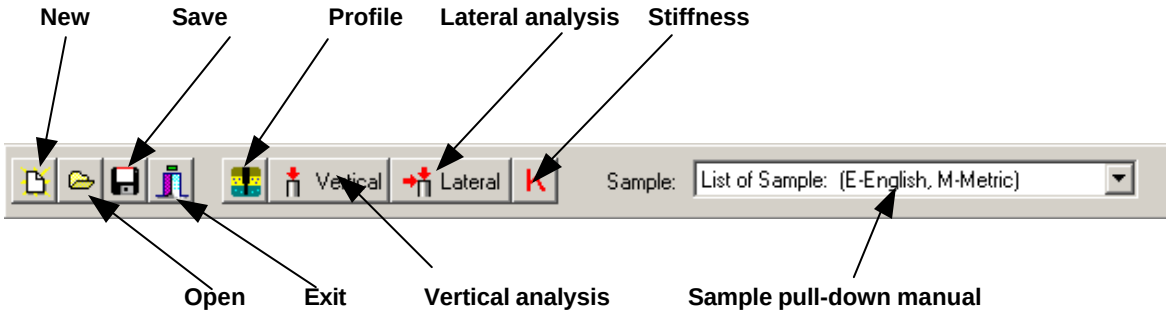


Figure 3-4. Speed Bar

3.5 Sample and Templates

The pull-down manual has thirty examples to illustrate how to use the program. These examples can also be used as templates, in which users can modify these examples and save it as a different file name. The original examples cannot be overwritten. The samples starting with E are in English units and M for metrics unit.

CHAPTER 4 DATA INPUT

4.1 Input Pages

The input pages of AllPile are categorized into six tabbed pages (see Figure 4-1). These pages and their relative input parameters are listed below:

A. Pile Type page	Input pile type and general information about the project
B. Pile Profile page	Input pile orientation and positioning
C. Pile Properties page	Input pile section data
D. Load and Group	Input pile head, load, and pile group conditions
E. l Properties page	Input subsurface conditions
F. Advanced page	Input analysis criteria

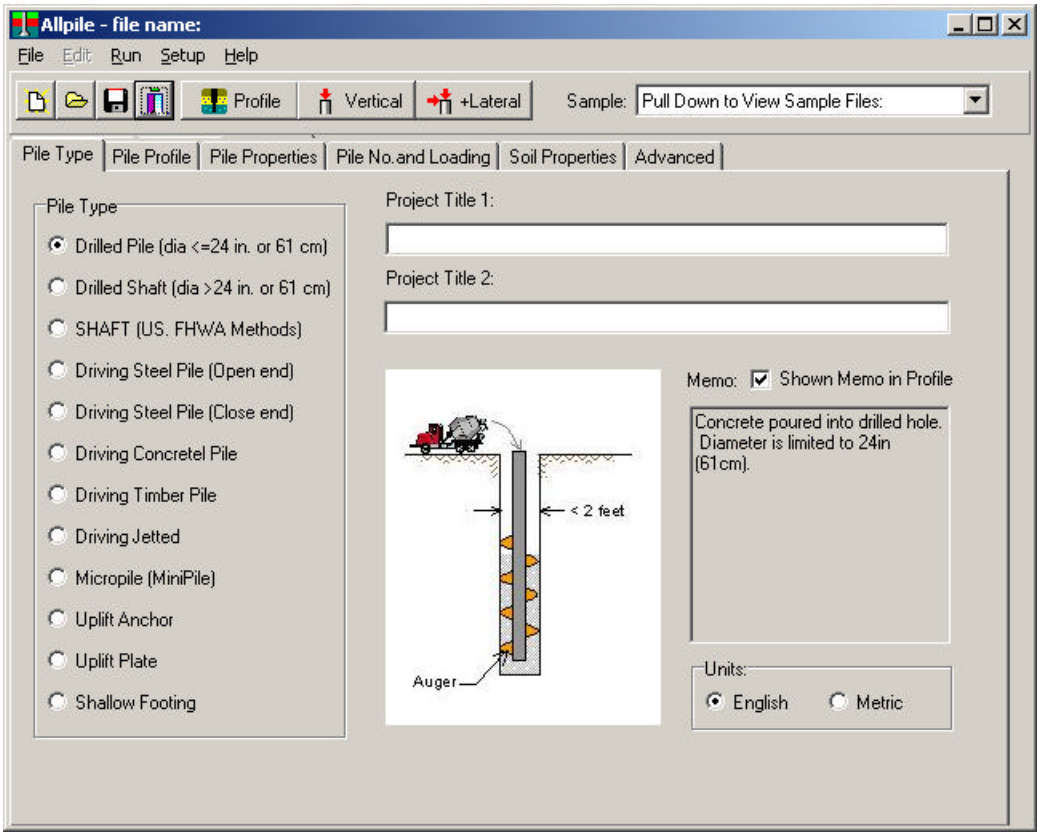


Figure 4-1. Pile Type Input Page

4.2 Pile Type Page

As shown in Figure 4-1, you can select the pile type that best suits your condition and design criteria. There are twelve different pile types to choose from the pile type list.

1. Drilled pile diameter less than or equal to 24 inches, such as auger cast
2. Drilled pile diameter is more than 24 inches, such as drilled shaft or pier
3. Shaft using US FHWA SHAFT methods of analysis
4. Driving steel pile with opened end, such as H-pile or open-end pipe. For plugged condition or friction inside of pile, refer to 4.4.4 of this chapter and Chapter 8, Section 8.7.
5. Driving steel pipe with closed end, including pipe with shoe on the tip
6. Driving concrete pile, such as pre-cased circular or square concrete pile
7. Driving timber pile, tapered pile with small tip and large top
8. Driving jetted pile, soils are jetted during driving
9. Micropile, is a pressure-grouted small-diameter pile, also called mini-pile.
10. Uplift anchor, frictionless steel bar with grouted ends (uplift only)
11. Uplift plate, frictionless steel bar with concrete or steel plates at the end (uplift only)
12. Shallow footing, spread footing for shallow foundations

NOTE: The parameters of each pile type can be customized in the Setup Screen (Chapter 6).

4.2.1 Project Titles

The project title and subtitle can be input in these two boxes. The text will appear in the report. The location and font can be customized in the Setup screen described in Chapter 6.

4.2.2 Comments

The Comments box is for additional comments or descriptions of the project. You can choose to include this message in the profile section of the report by checking the **Show Memo in Profile Box**.

4.2.3 Units

Select between English or Metric units to be used throughout the program. If you change the units after input of data, the data you have entered will automatically convert to the units specified. However, the data will not be exactly the same after some truncation during conversion.

4.3 Pile Profile Page

This page presents pile profile information as shown in Figure 4-2. The diagram on the left side reflects the information you input on the right side.

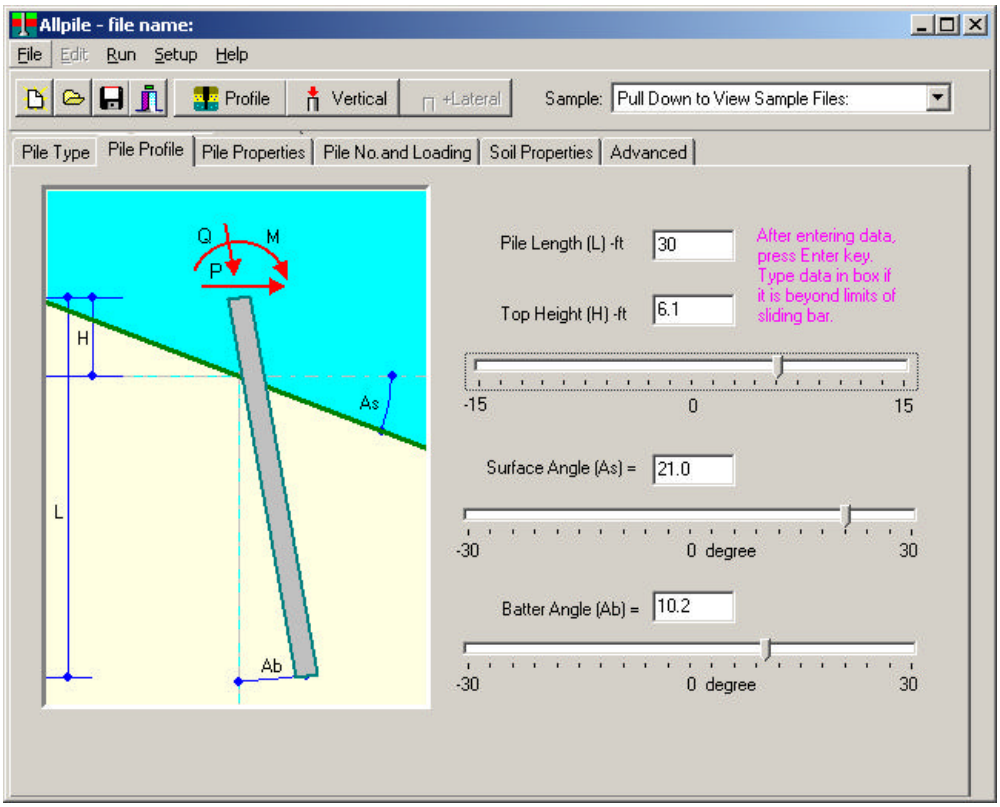


Figure 4-2. Pile Profile Input Page (H>0)

P is horizontal load at top of pile.

Q is vertical load at pile top. For batter pile, Q is axial load.

M is moment load at top of pile.

L is projected length of pile in vertical direction.

H is top height above ground *.

As is surface angle, limited up to 30 degree.

Ab is batter angle of pile, limited up to 30 degree.

HINT: You can enter pile data using either the interactive sliding bar or typing the numbers into the text boxes followed by **[Enter].** Changes will be reflected in the profile on the left immediately.

***** If H exceed the limits of sliding, you should type data directly in the text box.

1 Pile Length (L)

The total length of the pile, including above and below ground. Zp is called pile depth measured from pile top. Zs is called soil depth measured from ground surface. For better pile, L is projected length in vertical direction. The actual pile length will be longer than L (See Item 4 Batter Angle).

2. Top Height (H)

The distance from the top of the pile to the ground surface. A negative value indicates the pile is buried below the ground surface (see Figure 4-3). The sliding bar can also be used to select the desirable elevation.

H is the distance from top of pile to ground surface:

H > 0 Pile top above ground (Figure 4-2)

H = 0 Pile top at ground surface

H < 0 Pile top under ground (Figure 4-3)

For better pile, H is projected height in vertical direction. (See Item 4 Batter Angle).

3. Surface Angle (As)

If the ground surface is sloped, input the slope (in degrees) here. It is limited to 30 degree.

NOTE*:* Due to the limitations of the original COM624, the friction angle of any soils should be larger than the slope angle input here. Cohesive soil with zero or small friction angle in any layers cannot be associated with sloped ground surface.

4. Batter Angle (Ab)

If the pile is battered, input the batter angle here. It is limited to 30 degree.

The friction angle of any soils should be larger than the batter angle. For batter pile, L is projected length in vertical direction. The actual length is L/COS(Ab). The actual top height is H/COS(Ab).

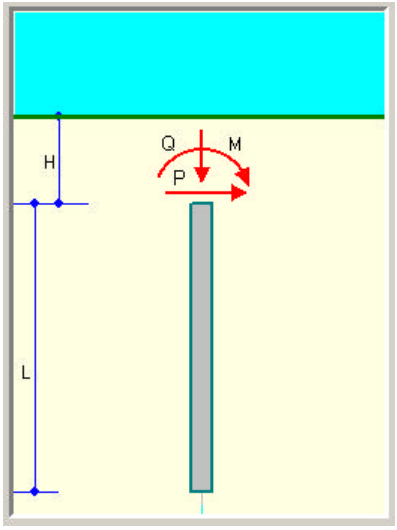


Figure 4-3. Pile Profile with H<0

4.4 Pile Properties Page

4.4.1 Pile Property Table

The table on the Pile Properties Page (Figure 4-4) allows you to choose the pile property. Ten different sections can be defined along the length of the pile. If the pile has a uniform section, you only need to input the first row. You should input all the data through the **Pile Section Screen** shown in Figure 4-5 by clicking on the buttons of the **Pile Property Table** Figure 4-4.

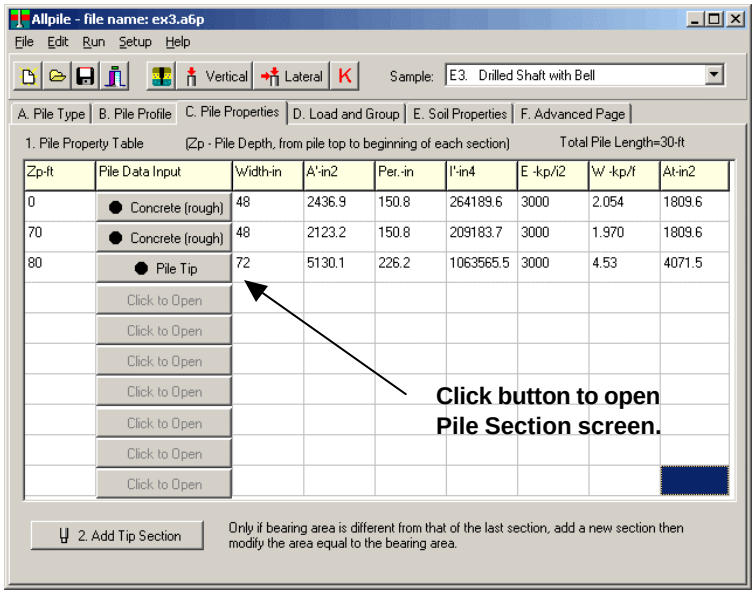


Figure 4-4. Pile Properties Page and Pile Property Table

Zp – Pile Depth	Input the distance from the top of the pile to the start of the following section having different pile properties (NOT from the ground surface). The first row is always zero.
Pile Data Input	Press the button in this column to select details from the Pile Section screen (Figure 4-5). You should input all the pile property data on the Pile Section screen instead of on the Pile Properties table.
Width	Width of the pile section, or the pile diameter for a circular pile.
A'	Effective area of the pile section.
Perimeter	Perimeter of the pile section.
Inertia*	Effective moment of inertia of the pile.
E	Elastic modules of outside materials.
W	Weight of the pile section for uplift calculation. It is per foot or meter.
At*	Total or Gross Area of the pile section.

* - See **4.4.3 Effective Area** and **Total Area** section in this chapter.

4.4.2 Add Tip Section

This button will add an optional tip section at the bottom of pile. The area is based on the outside perimeter of the pile. Users can modify the data, which is only for tip resistance calculation. If tip section is not added, then program assumes the tip section is the same as the last section, which uses effective area.

The tip section screen is different from the overall section screen as shown in Figure 4-5. A tip section uses total area, A, instead of the effective Area, A'. For more details, refer to "4.4.3 Effective Area and Total Area" section of this chapter. For tip section input, users can choice to input their own ultimate bearing pressure (capacity) or let the program generate its' own. If users define their own ultimate capacity, the program will directly use the value for analysis without modification in the calculation.

4.4.3 Pile Section Screen

The Pile Section screen is for inputting pile material and size for the particular section of the pile. Some of the fields in this window are the same as the fields shown on the Pile Property table, you can input or change these properties in either place.

Described below are seven general steps for inputting section properties. When you are done, press [**Apply**] button to save the data. If you press [**Cancel**], the data will not be saved and the Pile Property table (Figure 4-4) will not be changed. If you have selected Shallow foundation as the pile type, you will get the shallow foundation window for parameters input instead of the one below. Refer to Section 4.4.4.

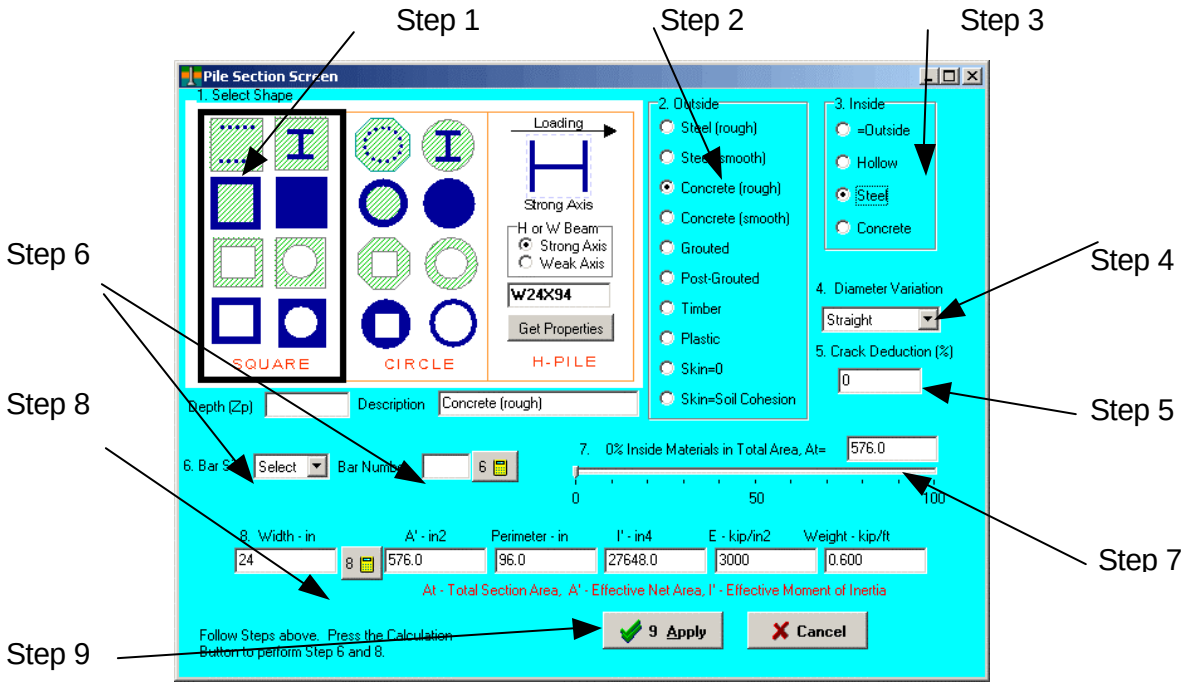


Figure 4-5. Pile Section Screen

Step 1 . Select Pile Shape

The shape of the pile can be square/rectangular, circular/octangular, or H-shaped. The internal configuration of the pile can be solid (one material), hollow (square or circular space inside), or different material on the skin than on the inside.

If you select H-pile, you can also input the pile designation, such as W24X94. Then select strong or weak axis (used for lateral analysis). Strong axis means the lateral load is acting in the same direction as the pile axis (X-X). Next, press [**Get Properties**] and the program will search the database and get the corresponding properties for the H-pile. If no match is found, the program will select the closest size pile or give a warning message.

Step 2. Select Outside Skin Materials

Select the outside skin material from the materials list. Skin material affects the result for vertical analysis. The parameter of each material can be modify in setup screen.

Steel-Rough	Specially treated rough surface
Steel-Smooth	Steel pipe or H-pile with normal surface
Concrete-Rough	Concrete cast directly against the soil such as auger-cast piles
Concrete-Smooth	Concrete cast in steel casing with smooth surface or pre-cast concrete pile
Grouted	Cement with high grouting pressure during installation such as tie-back anchor or micropile
Post-Grouted	Grouting twice or more with higher grouting pressure
Timber (Tapered)	Timber pile with large top and smaller tip (users should define the start depth and the start diameter, then the end depth and the end diameter)
Plastic	Pile with plastic surface
No-friction Steel	No friction, or frictionless part of pile, such as the unbound length of tieback anchor
S_f = Soil Cohesion	The ultimate side resistance equal to soil cohesion. There is no other modifications involved

Step 3. Select Inside Materials

The inside of the pile can be:

= Outside	The same material as the outside skin
Hollow	No material inside
Steel	Reinforcement bar in concrete
Concrete	Steel pipe filled with concrete

Plastic	Pile with plastic core

Step 4. Diameter Variation

Allows users to define the shape along the length of the pile. Choose from **straight**, **belled**, **tapered,** or **plate**.

Straight	For most pile with straight section
Belled	For belled pile. You need to input two sections to define a bell. Input the diameter where the bell starts and select the **[Belled]** feature. Input a large diameter at where the bell ends and select the **[Straight]** feature. (Refer to sample 3 & 4)
Tapered	For timber pile or any tapered pile. A tapered pile starts off with a large diameter at the top and a smaller diameter at the bottom of the pile. Select **[Tapered]** feature at the top of the pile with a larger diameter. Select **[Straight]** in the next section with a smaller diameter (Refer sample 12)
Plate	For steel or concrete uplift plate. Select **[Plate]** at the depth where the plate is to be located. (Refer to sample 17 & 18)

Step 5. Reduction Factors or Adhesion

If material of the pile is concrete, users can input reduction factor to reduce the moment of inertia due to cracking of the concrete (**30%** is typically used).

If metal is grouted or post-grouted section (Anchor or micro-pile), then adhesion can be inputted.

Step 6. Wall thickness or Bar number and size

If the section is pipe (Outside is steel and Inside is hollow), wall thickness can input here. If the outside material is concrete or grout, the program will allow you to input the **Bar Size** and **Bar Number**.

Bar Size	Based on ASTM standard reinforcement bars
Bar Number	Number of bars in the pile

After input in step 6, press  to run calculation and define Step 7.

Step 7. Percentage of Inside Materials of Total Area, and Total Area

If inside materials are different from outside materials, use the sliding bar to select the percentage of different material on the inside as a proportion of the total area of the section. 100% means the inside materials make up the entire pile section. The total area, At, is automatically calculated based on width of pile. But users can also input in step 7.

Step 8a. Width of Pile

Input width of pile section as follows:

Square section	Input side width
Circular section	Input diameter
Rectangular section	Input square root of (long side x short side)
Octangular section	Input average diameter
H-pile	Press [Get Properties] button to get data.

Step 8b. Effective Area, Perimeter, I, E, G

After inputting the pile section width, press to calculate the other parameters. These parameters are:

At	Total gross area, which is the area defined by the outside perimeter. Please refer to section 4.4.4 below and Chapter 8, Section 8.7
A'	Effective area, which is different from the total area (for H-Pile, the effective area is the steel section area)
Perimeter	Perimeter of section
I'	Effective moment of inertia
E	Elastic modulus
Weight	Weight of the section per unit length

Note: Pressing button will calculate the other parameters automatically based on width. You can also modify the data directly.

Step 9. Close Screen

If you are satisfied with your data, press **[Apply]** to close the screen and post the data to the Pile Property table (Figure 4-4). **[Cancel]** closes screen but does not save the data.

Hint:

If you already have data in Pile Property Table (Fig 4-4) and do not want data to be overwritten by Pile Section Screen (Fig 4-5), then you should click on [Cancel]

You also can modify the data in Pile Property Table (Fig 4-4) after close Pile Section Screen (Fig 4-5).

4.4.4 Effective Area and Total Area

For pile analysis, the effective area and total area is used according to the pile type. The effective area (A') defined by the section area, is commonly used

in pile shaft compression calculations, whereas, the total area (A) defined by the outside perimeter, is used for tip resistances calculations.

H-Pile (A > A'):

A = width x height

A'= is the steel net area

Concrete Pile with steel bar (A < A'):

A = section area of the pile

$$A' = A_{Concrete} + A_{Steel} \times \frac{E_{Steel}}{E_{Concrete}}$$

Steel Hollow Pipe Pile (A> A'):

A = Total outside circular area

A' = Net area of Steel

For open pipe piles, tip area is A',

For close pipe piles, tip area is A

Steel Pipe Pile Filled with Concrete (A>A'):

A = total outside circular area

$$A' = A_{seal} + A_{concrete} \times E_{concrete} / E_{steal}$$

The same relations can be used for the moment of Inertia (I) and (I').

For more information, please read Chapter 8, Section 8.7

4.4.5 Shallow Footing

If you have selected shallow footing as pile type, the pile section screen will be as shown in Figure 4-6.

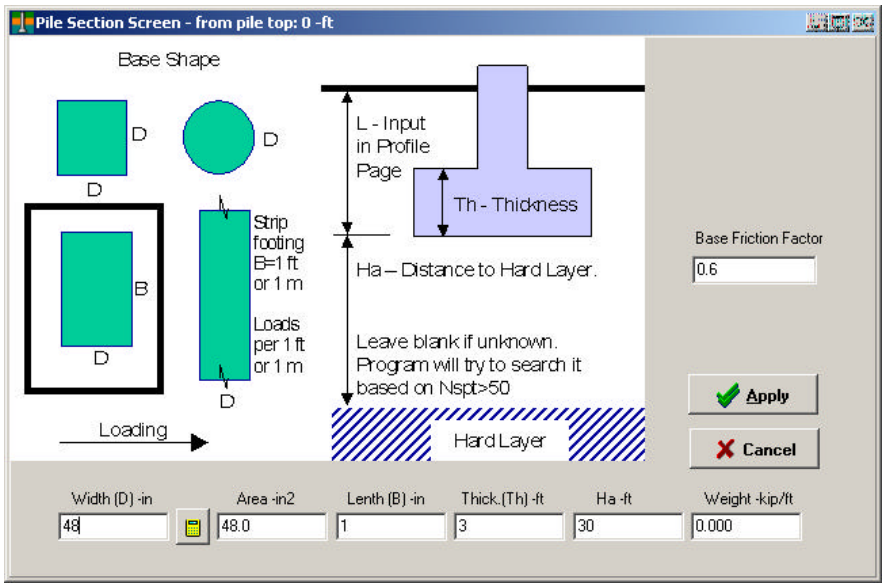


Figure 4-6. Shallow Foundation Screen

Listed below are the items to be inputted:

Depth of Footing (L)	This value is inputted in the pile profile page.
Shape	Select the shape of footing base. D is the width. B is the length. The lateral force act perpendicular to B. B can be larger or smaller than D. For strip footing, input B=1ft or 1 meter.
Thick (Th)	The thickness of the footing used to calculate its' weight
Distance to Hard Layer (Ha)	If a hard layer exists below the base of the footing within four times D, settlement will be significantly reduce. Users can leave this box blank or input **999** if Ha is at great depth or there is no hard layer. When this field is left blank, the program will automatically search for a hard layer. The program will consider a soil layer to be hard if the $N_{spt} > 50$.
Weight	Weight per unit depth (per foot or meter). Same as the weight in pile properties screen
Area	The total area of the base
Base Friction Factor	Factor required to calculate the friction against sliding at the base of the footing. Cast-in-place footing (rough): factor of 0.6 to 1 (typical value is 0.7) Pre-cast with small surface: factor of 0.3 to 0.6 (typical value 0.4 is used)

4.5 Load and Group

You can start off by selecting the pile configuration that most fits the analysis. Select **single pile**, **group pile** or **tower foundation** analysis (Figure 4-6) from the tabs on the left side of the panel.

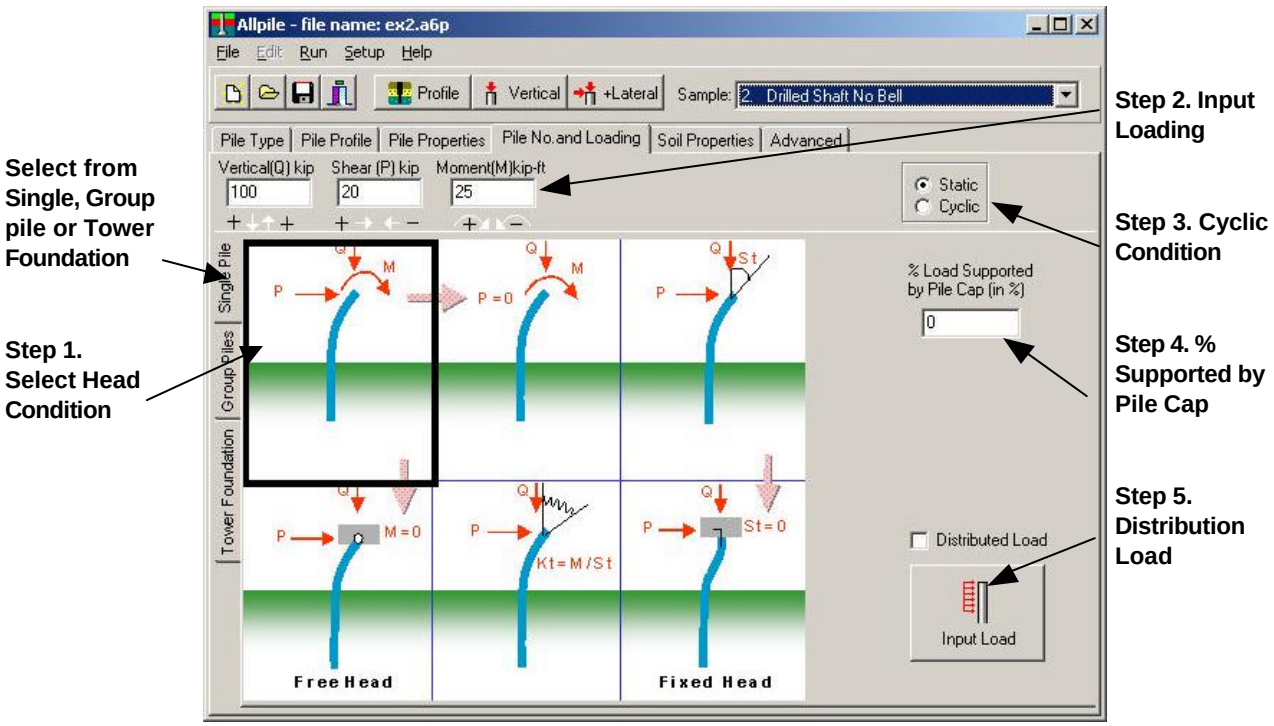


Figure 4-6. Group/Head/Load Page (Single Pile)

4.5.1 Single Pile

Click on the Single Pile tab if you want to perform analysis of one pile, then follow the steps below:

Step 1 . Head Conditions for Single Pile

Single Pile has six possible head conditions as shown in Figure 4-6, click on the condition that best suits your project. The conditions are described below:

1. **P, M** — The head of the pile can freely rotate under lateral shear load P and moment M.
2. **P, M=0** — This condition is a special case of condition 1 where moment M is zero. Only lateral shear load (P) is acting on the pile (commonly called free-head condition).

3.	**P=0, M**	Shear load is zero and only moment is acting on the pile top, a special case of condition 1.
4.	**P, St**	St is the top rotation in degrees. Input St to force the pile head to rotate to a certain degree.
5.	**P, St=0**	Commonly called fixed-head, there is no rotation in the pile head, since St=0. Moment will be generated at the pile head.
6.	**P, Kms**	Kms is head rotation stiffness in moment per unit slope (useful for some structural analyses). Input Kt along with P. If Kms=0, then it is the same as condition 2 above (P, M=0).

NOTE*:* All the conditions can be combined with vertical load (Q).

Step 2. Load Conditions for Single Pile

Based on the head conditions, there are many combinations of loads. The program automatically selects load combinations based on the head condition selected. Possible loads are:

Vertical load (Q) – Downward and uplift working load at pile top. *Input a negative value for uplift load*. The program will calculate both downward and uplift capacity in the vertical analysis. For batter pile, Q is axial load.

Shear load (P) – Lateral working load at pile top. Positive value of P is from left to right, and negative value is from right to left.

Moment (M) – Working moment on the pile head. A positive value if M is clockwise and a negative value if M is counterclockwise.

Slope (St) – The known slope angle at the pile head. Negative value is clockwise and positive value is counterclockwise (unit is deflection/length).

Stiffness (Kms or Kt) – The rotation stiffness Kms or Kt is the ratio of moment/slope (M/St). Negative value is clockwise and positive value is counterclockwise (unit is the same as M).

Step 3 Cyclic Conditions

Select **Static** or **Cyclic** shear load. If the load is cyclic, specify the number of cycles in the **No. of Cycles** box (between 2 and 500).

NOTE*:* The cyclic condition only applies to lateral analysis, not vertical.

Step 4 Percentage Load Supported by Pile Cap

You can adjust the amount of vertical load carried by the pile cap. For 0% load supported by the pile cap, the entire load is transfer to the pile therefore dissipated by the pile at greater depth. For 100% load supported, the entire load is supported by the pile cap.

Note: To be conservation using 0% is recommended.

Step 5 ***Distributed lateral loads***

To distribute load along the length of the pile press the [**Input Load**] button to open the panel shown in Figure 4-7. In the Distributed Load table, enter the following information:

Z	The starting point of the distributed load, z is the distance from the pile top.
Pq	Pq is distributed load along pile length at the z location.
B	B is the width of the pressure.

Note: To apply the distributed load, the check box above the [Input Load] button must be checked

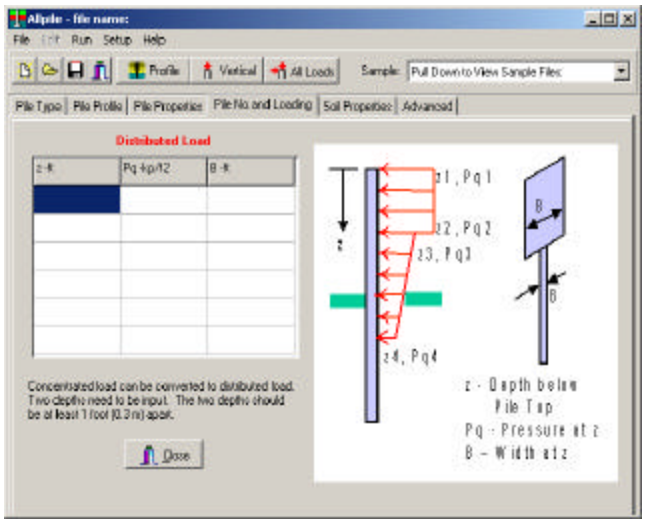


Figure 4-7. Distributed Load

The following examples illustrate how data are to be inputted in the table:

Example 1:

A signal post is 6ft wide and 8ft high above ground. A pile 1.2 ft in diameter supports it below ground. Wind pressure is 1.5 ksf. You can input z=0 ft, pq=1.5ksf, B=6 ft in the first row, and z=8 ft, Pq=0, and B=1.2ft in the second row.

Example 2:

If a lateral pressure load of 1 kip per square foot (1 ksf or 1 kip/ft^2) acting on a 2ft high pile shaft (dia = 1.5 ft), you can input z=2ft Pq=1ksf and B=1.5ft.

Example 3:

If a lateral load of 1kip per linear foot (1 kip/ft) is acting on the pile diameter (diameter = 1.5 feet),

4.5.2 Group Piles

Group analysis lets you select two head conditions under compressive, shear, moment, and torsion loading with unlimited number of piles. The analysis provides settlement, rotation, and lateral movement of the pile cap under these loadings. You can select the head condition that best fits your condition.

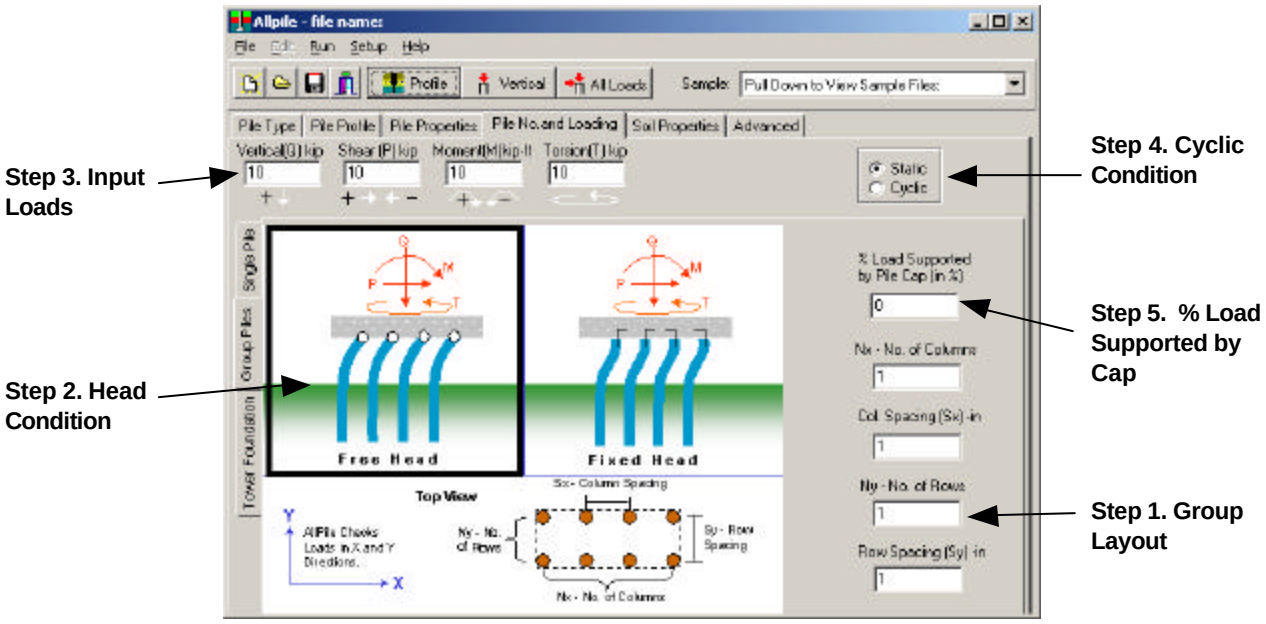


Figure 4-8. Pile No. & Loading Page

Step 1 *Group Pile Layout*

Assuming the lateral load (P) is acting in X direction, as shown in Figure 4-8, the following data are required for group configuration:

Number of Columns (Nx)	Input number of piles in X direction
Column Spacing (Sx)	Input pile spacing in X direction measured from center of piles
Number of Rows (Ny)	Input number of piles in Y direction (perpendicular to the page)
Row Spacing (Sy)	Input pile spacing in Y direction measured from center of piles

Step 2 *Head Conditions for Group Piles*

The piles within a group have two possible head conditions as shown on Figure 4-8.

1. Free Head	Referred to as **Free Head** condition. The top of each pile can freely rotate. Pin or hinge connections are assumed between pile cap and piles.
1. Fixed Head	Referred to as **Fix Head**, there is no rotation in the pile head. The pile and pile cap are fixed. Moment will be generated at the pile head.

Step 3 *Load Conditions for Group Piles*

Four load conditions apply to a set of group piles:

Vertical load (Q) – Downward and uplift working load at pile cap, equally distributed to all piles in the group. *Input a negative value for uplift load.*

Lateral load (P) – Lateral working load at pile cap. Positive value of P is from left to right, and negative value is from right to left. Load will be distributed to all piles in the group based on their lateral stiffness.

Moment (M) – Moment generated at the pile cap. Positive value of P is clockwise and a negative value is counterclockwise. There are no moments at the tip of each pile individually due to the fixation of head by the pile cap.

Torsion (T) – Torsion generated at the pile cap. Twisting of the pile cap due to external load.

Step 4 ***Cyclic Conditions***

Select **Static** or **Cyclic** shear load. **No. of Cycles** (between 2 and 500). Only for lateral analysis

Step 5 ***Percentage of Load Supported by Pile Cap***

You can adjust the amount of vertical load carried by the pile cap. For 0% load supported by the pile cap, the entire load is transfer to the pile therefore dissipated by the pile at greater depth. For 100% load supported, the pile cap supports the entire load.

Note: To be conservative using 0% is recommended.

4.5.3 Tower Foundation

Tower foundation analysis is similar to the other analyses, where you get to specify a head condition under compression, shear, moment, and torsion. It is assumed all piles have equal spacing in x and y direction. You can choose from fix head, free head or no pile cap. The users will also be asked to input the number of piles they want for the analysis (up to 4 piles).

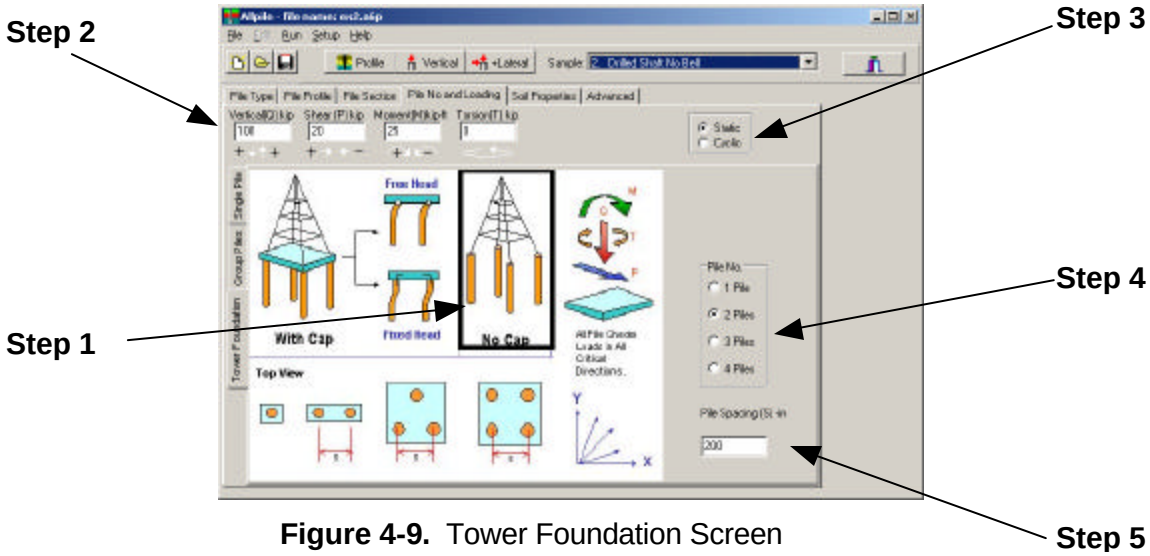


Figure 4-9. Tower Foundation Screen

Step 1 ***Select Head Condition***

Select from the three head condition as described below:

Free Head	Top of the pile can freely rotate. Pin or hinge connections are assumed between pile caps and piles.
Fixed Head	There are no rotation in the pile cap. Piles and pile cap are fixed. Moment will be generated at the pile head.
No Cap	There is no pile cap to connect each pile.

Step 2 ***Load Conditions for Group Piles***

Four load conditions apply to a set of group piles:

Vertical load (Q) – Downward and uplift working load at pile cap, equally distributed to all piles in the group. *Input a negative value for uplift load.*

Shear load (P) – Lateral working load at pile cap. Positive value of P is from left to right, and negative value is from right to left. Load will be distributed to all piles in the group based on their lateral stiffness.

Moment (M) – Moment generated at the pile cap. Positive value of P is clockwise and a negative value is counterclockwise. There are no moments at the tip of each pile individually due to the fixation of head by the pile cap.

Torsion (T) – Torsion generated at the pile cap. Twisting of the pile cap due to external load.

Step3 ***Cyclic Conditions***

Select **Static** or **Cyclic** shear load. **No. of Cycles** (between 2 and 500). This information is for lateral analyses only.

Step 4 ***Pile Number***

The total number of piles under a tower.

Step 5 ***Pile Spacing***

The spacing between piles are assumed to be equal. Spacing has to be input in inches or cm. It is assumed x and y direction have the same spacing.

4.6 Soil Property Page

The Soil Property page (Figure 4-10) allows you to input water and soil information in four easy steps.

4.6.1 Soil Property Table

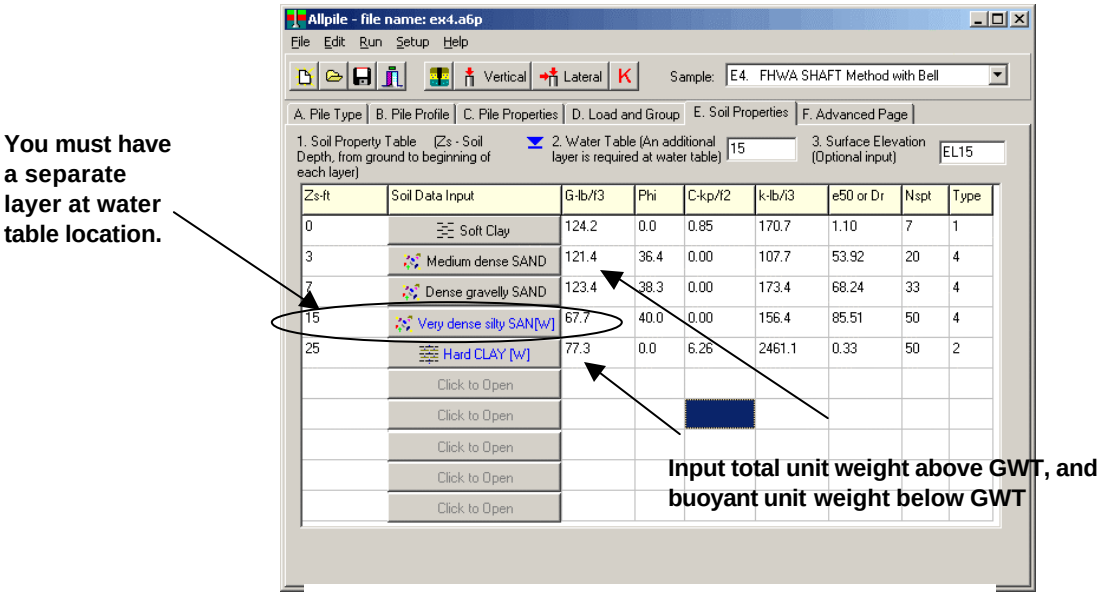


Figure 4-10. Soil Property Page

Step 1 ***Ground Water Table (GWT)***

First, users need to input depth of ground water table (GWT). The depth is the distance from ground surface to GWT. If the water table is deeper than the pile tip or at great depth, leave the box blank.

HINT: Input the water table depth before completing the Soil Property table. Leave the box blank if there is no water or water is at great depth.

Step 2 ***Soil Property Input***

You can input up to ten layers, if the GWT exist within a layer, you must break the layer into two layers at the water table location. The total unit weight should be use for soil above the GWT, but the buoyant unit weight should be used for soil below the GWT. **You should input all the data through the Soil Parameter screen shown in Fig. 4-11.**

Zs-Soil Depth Input the top depth of the soil layer. The top is the distance from ground surface to the top of the layer. The depth of the first row (layer) is zero. The top of the second layer is the bottom of the first layer. The top depth of the last layer is defined as the last row. The bottom depth of the last layer is undefined, assuming it extends to a great depth.

Soil Data Input Press the [Click to Open] button in the cell to open the Soil Parameter screen (see next section).

HINT: It is recommended to input all soil parameters to the Soil Parameters screen (Figure 4-11).

G	Unit weight of soil. If the soil is under the water table, buoyant weight must be input. (This is why it is necessary to divide a layer into two if the GWT sits within this layer.) Buoyant weight is the total unit weight of the soil minus the unit weight of the water. **HINT: Input total unit weight above GWT and buoyant weight below GWT.**
Phi	Friction angle of soil.
C	Cohesion of soil.
K	Modulus of Subgrade Reaction of soil (for lateral analysis only). If you only run vertical analysis, you don't have to input this value (Refer to Ch.8 for description).
e_{50} or Dr	If soil is silt, rock, or clay, e_{50} is strain at 50% deflection in p-y curve (only used for cohesive soil in lateral analysis) (Refer to Ch.8). If soil is sand, Dr is the relative density from 0 to 100 (%). It is for reference only and is not used in the analysis.
Nspt	Standard Penetration Test (SPT) value or N value is the number of blows to penetrate 12 inches in soil (304.8 mm) with a 140-lb (622.72 N) hammer dropping a distance of 30 inches (0.762 m).
Type	Number of Soil Type defined in **Soil Parameter screen**

HINT: for more detail on k and e_{50}, refer to Chapter 8, Lateral Analysis.

Step 3 Surface Elevation

It is optional to input a value in this field. If an elevation is inputted, the depth of the pile is shown on the left side and the elevation is shown on the right side of the chart.

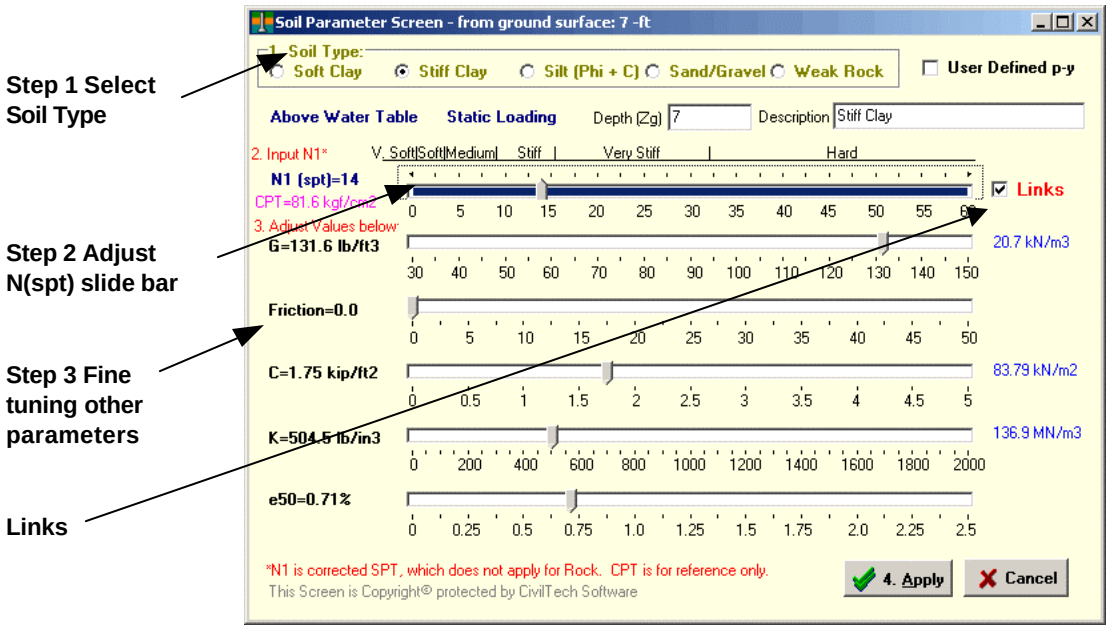


Figure 4-11. Soil Parameter Screen

4.6.2 Soil Parameter Screen

The Soil Parameter screen (Figure 4-11) is for inputting or modifying the soil parameters. The program provides correlation between N value (SPT value) and the other parameters (refer to Chapter 8 for details). You can move the N sliding bar to modify all the parameters or move each bar individually.

The following steps show how to use this screen.

Step 1 Select material: soft clay, stiff clay, silt, sand or rock (including concrete) and p-y input.

Step 2 Move the N bar to the desired value. If the **LINK** check box is checked the other bars will move correspondingly. If the box is unchecked, the other parameters will not be affected when moving the N(spt) slide bar.

Step 3 Fine tune the other sliding bars to get parameters that best suits your geology. Changes will not affect the other values if you alter the slide bars of other parameters other than N value.

Step 4 If you are finished with the input process, close the screen by clicking [**APPLY**]. The data will be display on the Soil Property table. (If you press [**Cancel**], the data will not be posted.)

NOTE:

- **The related properties selected from the N value are only recommendations. Users should use their engineering judgment to adjust the parameters.**
- **Users should input the water table first. The parameters related to N value are different above and below the water table.**

- **If the users have a known parameter (for example, C=500 psf), users can move N bar until the known parameter reaches its value (In the example, let C reach to 500).**

p-y Curve Input

You can customize the p-y curve for the soil type or use the system default p-y relation. From the Soil Parameter Screen, check the p-y input box on the upper right corner of the panel. Then click on **[Input p-y curve]**. The p-y input screen is shown in Figure 4-12. If you would like to modify the p-y curve from the previous layer, it can be copied by clicking on the **[Copy from previous row]** button. The values will be amplified if the users enter a multiplier in the **Copy Factor** field.

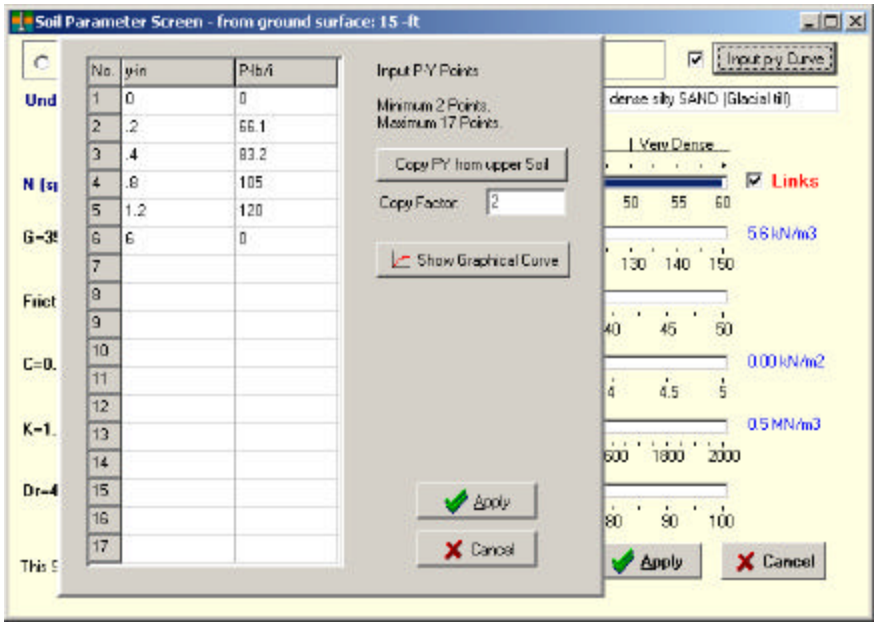


Figure 4-12. Users define p-y Input

After you are satisfied with the entry, clicking on **[Show Graphical Curve]** will give you the corresponding curve. Click **[Apply]** to accept the data inputted or click **[Cancel]** to exit screen without accepting changes.

NOTE:

The system will generate a p-y curve based on the k and e_{50} value selected on the soil parameter screen. Once the users input their preferred p-y curve values and the box is checked, the k and e_{50} will be ignored in the analysis. If p-y is inputted and the box is unchecked, the program uses the default p-y.

4.7 Advanced Page

This page allows users to assign analysis parameters. More details are outlined in the following sections.

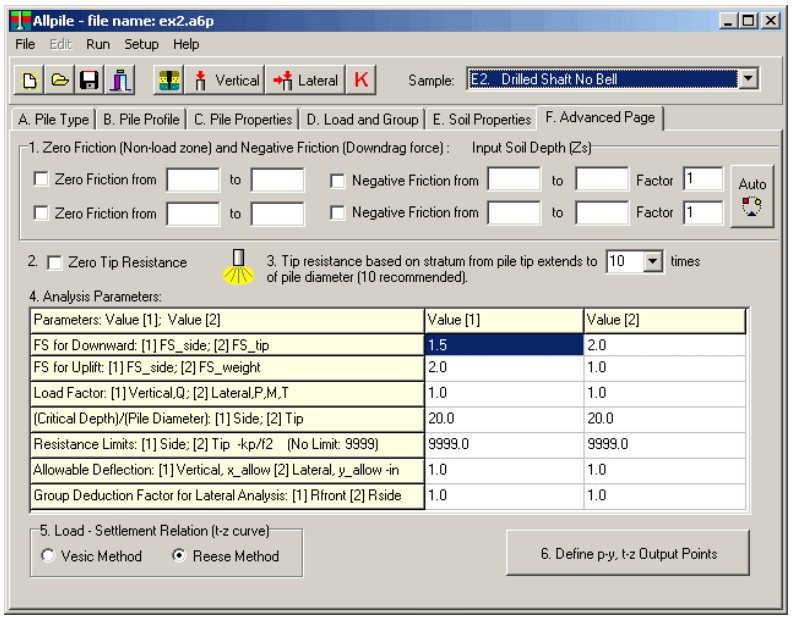


Figure 4-13. Advanced Page

4.7.1 Zero Resistance and Negative Resistance (Downdrag Force)

1a. Zero Resistance

The program handles zero resistance on the Advanced page (Figure 4-13). If a pile has a section that does not develop side resistance, this section has "zero resistance". For example, a free anchor length of tieback anchor and a smooth caisson section of micropile are considered as zero resistance zones. If a pile penetrates through a cave, the cave portion is considered as a zero resistance zone. Up to two zero resistance zones can be defined in each case. To specify the zone of zero resistance, you must enter the soil depth (Zs) of the zone measured from the top of the soil in (feet/meter). Zero resistance includes side and tip resistance.

***HINT:* You must check the check box to make the zone(s) be included in the calculation. See Chapter 8 for details.**

1b. Negative Resistance

If soils in the upper layers have significant settlement, the pile will experience downdrag force. This area is called negative resistance. The program handles

negative resistance on the Advanced page (Figure 4-13). Up to two negative resistance zones can be defined.

"Factor" is the effective factor, K_{neg}. It ranges from 0 to 1 depending on the impact of soil settlement on the pile shaft. If the factor equals 1, then the negative friction is equal to the friction in the downward capacity analysis. If the factor equals 0, then there is no friction between pile and soils. It is the same as zero friction. If the pile has a smooth surface and the soil has small settlement, K_{neg} is in the range of 0 to 0.3. If the pile has a rough surface and the soil has a large settlement, K_{neg} is 0.3 to 0.6.

HINTS:

1. **If K_{neg} = 0, there is no resistance between the pile and the soil, i.e., it is the same as zero resistance.**
2. **K_{neg} should be a positive value rather than using a negative value.**
3. **You must check the check box on the left side so that the calculation will take into account the negative resistance.**
4. **The negative resistance only applies to downward side resistance, not tip resistance. The induced downdrag force reduces the pile capacity in the analysis.**

1c. Auto determine Kneg

Users can click the button to let the program determine the K_{neg} value. Users need to input ground settlement at the top of negative zone. The settlement is calculated by the users based on surcharge loading on the ground surface. In Fig. 4.14, users need to calculate and input the ground settlement due to surcharge loading or water table changes. AllPile will calculate the pile settlement. If the ground settles more than pile, there is downdrag force and negative resistance. If there is less settlement, there is not downdrag force and negative resistance. AllPile will determine the neutral point internally and therefore, K_{neg} is cal ululated.

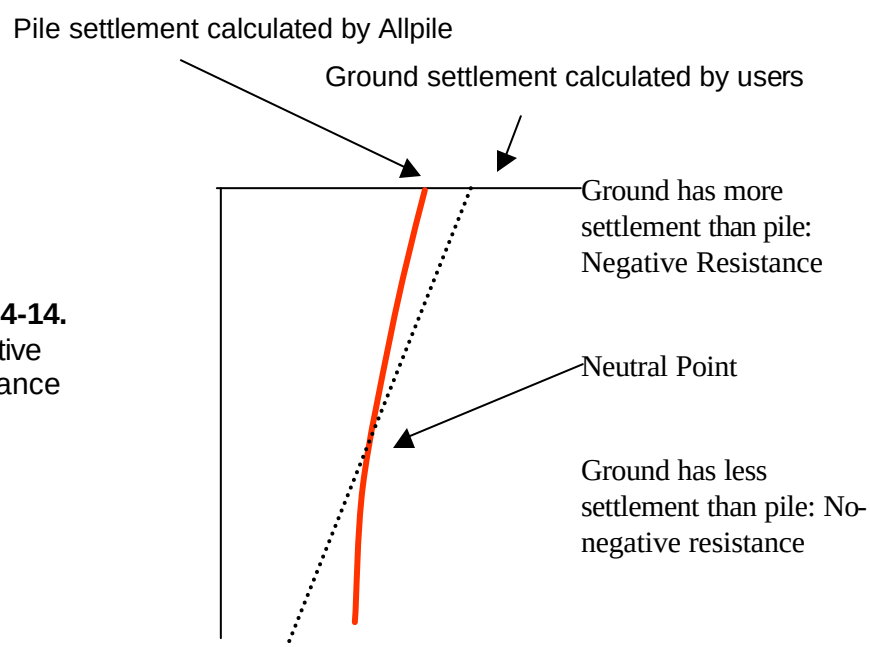


Figure 4-14. Negative Resistance

2. Zero Tip Resistance

If users do not want the tip resistance included in the vertical capacity, this box can be checked.

3. Define Tip Stratum

Tip resistance calculation is based on the soil properties at pile tip. There may be several very thin layers under the tip. If the stratum is not defined (as zero), the first layer below the tip will control the results. Users should define a stratum thick enough to include all the influence layers. 10 times pile diameter is recommended. This will provide more reasonable results and also smooth the pile capacity vs. pile length curve. For shallow footing, 4 times footing width is recommended. If a hard stratum is defined in footing property screen, the Tip Stratum is limited to the hard stratum.

4. Analysis Parameters

For advanced users they can customize analysis parameters listed below:

FS for Downward	The factor of safety for downward capacity, including side resistance and tip resistance.
FS for Uplift	The factor of safety for uplifting, including side resistance and the weight of the pile.
Load Factor	The factor that is multiplied into the vertical load and lateral load.
Critical Depth as Ratio of Diameter	The effect of overburden pressure increase with depth. The critical depth to which the pressure becomes constant is defined by the diameter of the pile. ***Note:*** A critical depth of 20D is recommended
Limit of Max Resistance	A limit can be applied to the side and tip resistance. ***Note:*** To apply no limits to these values enter "9999"
Allowable Deflection	The vertical settlement and lateral deflection limit. If any one of these values is exceeded, a warning message will be displayed.
Group Reduction Factor R_{side} and R_{front}	In lateral group analysis, pile lateral capacity is reduced by existence of a pile in front and a pile on side (based on spacing). Users can input factor in addition to program calculated Rside and Rfront.

Methods of Settlement Analysis

There are two methods for settlement analysis to choose from.

Vesic Method	Method based on Vesic's publication in 1977.
Reese Method	Method based on Reese and O'Neil publication in 1988.

Define p-y and t-z Output Depths

Sometimes users might require p-y and t-z curves to be plotted out. Since the curves are different at different depths, users can define the depths at which the curves are to be generated. If the table is left blank, the program will automatically generate curves at depths of equal intervals.

4.8 Units of Measure

Table 4-1 Units of Measure

Input Page of Program	Item	Symbol	English Unit	Metric Unit
Pile Profile	Pile length	L	feet (ft)	m
	Height (Pile top to ground)	H	feet (ft)	m
	Surface slope angle	As	degrees	Degrees
	Batter angle	Ab	degrees	Degrees
Pile Property	From pile top	Z	feet (ft)	m
	Width	D	inches (in)	cm
	Area of section	A	square inches (in^2)	cm^2
	Perimeter of section	P_i	in	cm
	Moment of inertia	I	in^4	cm^4
	Modulus of elasticity	E	kip/in^2	MN/m^2 (MPa)
	Weight of pile section	W_i	kip/ft	KN/m
Pile Number and Loading	Vertical Load	Q	Kip	KN
	Shear (Lateral Load)	P	kip	KN
	Moment	M	kip-ft	kN-m
	Torsion	T	kip-ft	kN-m
	Lateral Slope	St	in/in	cm/cm
	Stiffness	Kt	kip-ft/in/in	kN-m/cm/cm
Distribution Load	From pile tip	Z	Ft	M
	Pressure	P_q	kip/ft^2	kN/m^2 (kPa)
	Width	B	ft	M
Group Pile and Tower Foundation	% cap	Kcap	percent	percent
	Number of columns	Nx	--	--
	Column spacing	Sx	in	cm
	Number of rows	Ny	--	--
	Row spacing	Sy or S	in	cm
Soil Property	Water table depth from surface	GWT	ft	m
	Unit weight	G	lb/ft^3	kN/m^3
	Friction	Phi (ϕ)	degrees	degrees
	Cohesion	C	kip/ft^2	kN/m^2 (kPa)
	Modulus of subgrade reaction	k	lb/in^3	MN/m^3
	Soil strain or	E50	percent	Percent
	Relative density	Dr	percent	Percent
	SPT Value	Nspt	--	--

CHAPTER 5 RESULTS

5.1 Profile

The **Profile** function provides the pile profile and soil conditions (Figure 5-1). This report also presents soil parameters as well as foundation material properties input by users. The report can be printed for references.

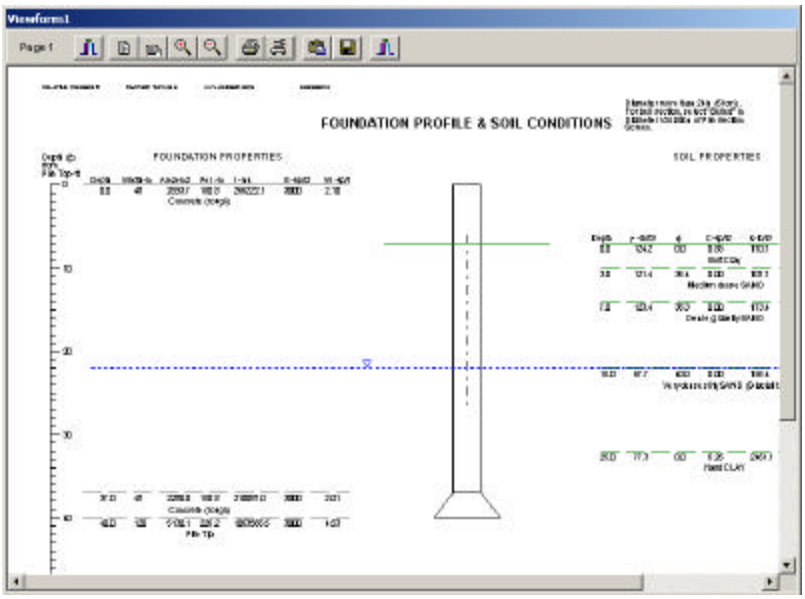


Figure 5-1. Profile Screen

5.2 Vertical Analysis Results

Clicking on **[Vertical Analysis]** will display a panel that allows you to choose the different types of result from the analysis. For this analysis all lateral load components are ignored and only vertical load is considered. Figure 5-2 shows the several choices available for vertical analysis.

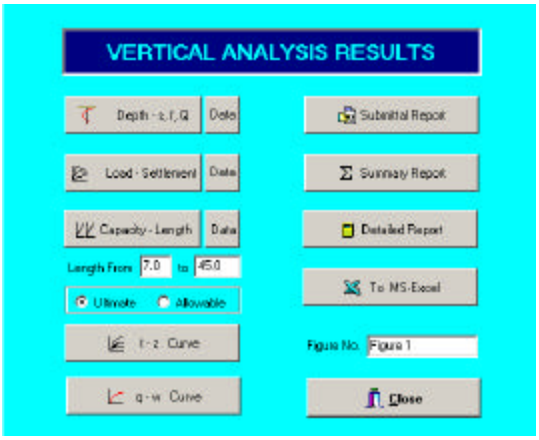


Figure 5-2. Vertical Analysis Results Panel

5.2.1 Depth (z) vs. s, f, Q

The program provides four diagrams in this report, as shown in Figure 5-3. Each diagram is explained below. (All the data is based on ultimate loading condition.)

V Stress (S) — Vertical stress (overburden stress) in the soil adjacent to the pile. The stress increases with depth (z) to a certain point and then becomes constant. This is because the overburden stress has a maximum limit. This limit can be modified on the Advanced page.

Skin Friction (f) — Upward and downward side resistances are the combination of friction and adhesion from soils.

Axial Force (Q) — Downward capacity and uplift are combined in one graph. The left portion of the graph defines the ultimate uplift capacity of the pile, whereas, the right side of the graph defines the ultimate downward (compression) capacity.

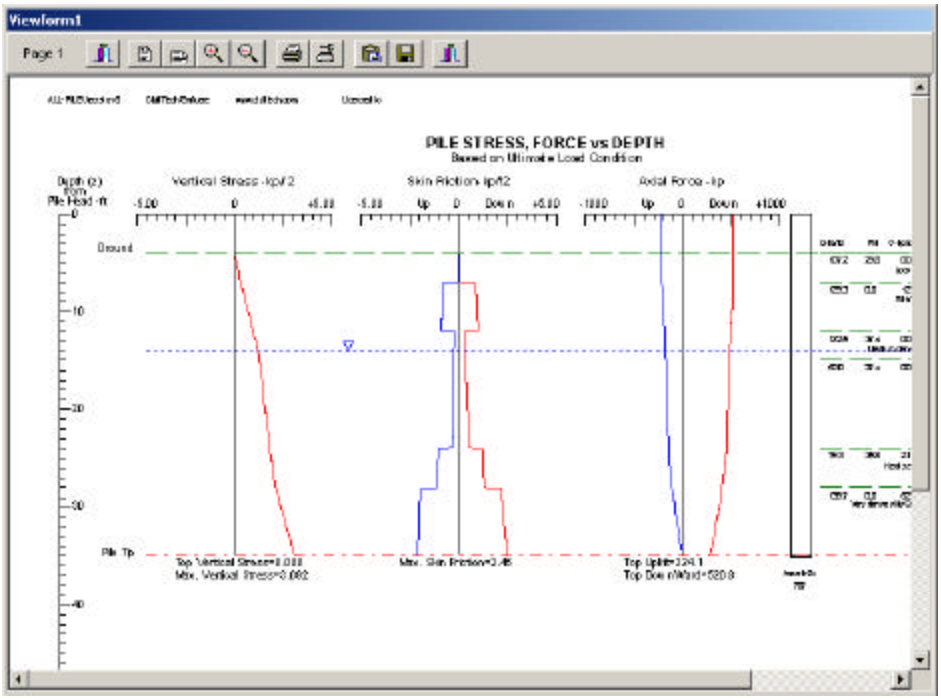


Figure 5-3. Depth vs. s, f, Q

5.2.2 Load vs. Settlement

By clicking on this button, you will get a graph of compression load vs. settlement of the pile/pile group. Three immediate settlement curves will be plotted. Settlement of the side is in blue, whereas, settlement of the tip is in red. Adding the two curves together will result in the total settlement, the black line on the graph. Note that the peak of side resistance is at a different location from peak of tip resistance.

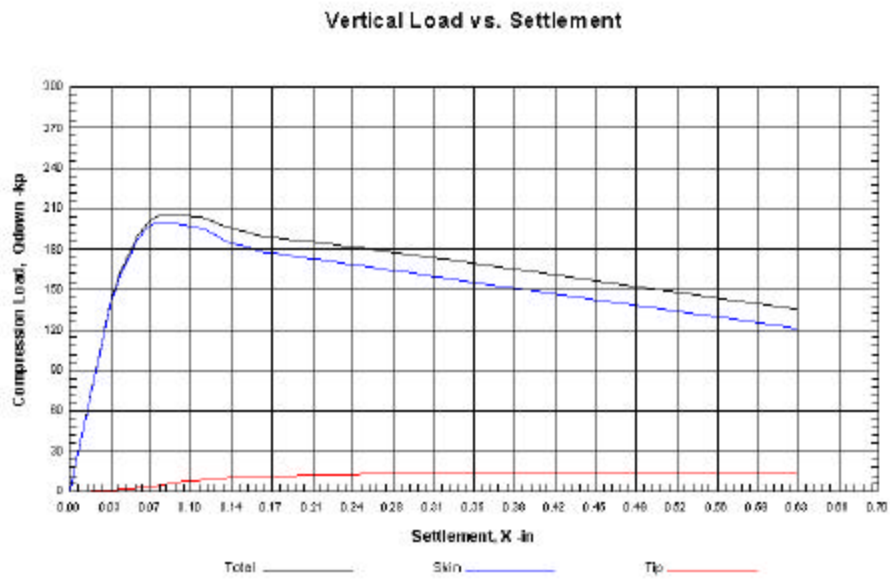


Figure 5-3. Vertical Load vs. Settlement Plot

5.2.3 Capacity vs. Length

Press the **[Capacity – Length]** button to get the two diagrams shown on Figure 5-4. One is the downward capacity (Q_d) versus pile length (L). The other is the uplift capacity (Q_u) versus pile length (L). The start and end lengths can be specified in the two boxes below the button. Users can also choose to generate graphs for ultimate capacity or allowable capacity by checking the corresponding box below the button. The Factor of Safety can be defined on the advanced page.

NOTE: This function only works for a single section pile. If the pile has more than one section, the resulted graph does not represent the actual condition.

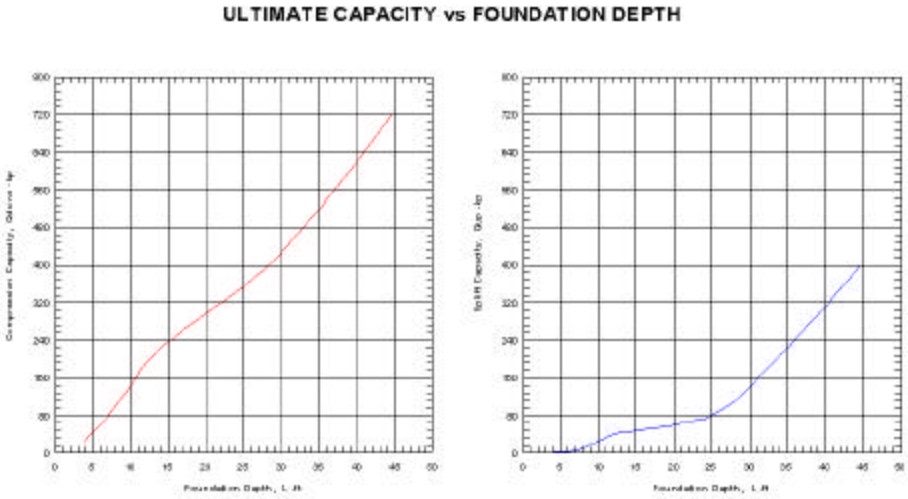


Figure 5-4. Capacity vs. Length

5.2.4 t-z Curve

When clicked on the **[t-z curve]** button, a t-z curve will be generated (Figure 5-5). This curve gives the skin friction along the depth of the pile. It is a function of relative movement between soil and pile. The t-z function can generate t-z curves at various depths. Users can define the depths at which these curves are to be generated on the **Advanced page**.

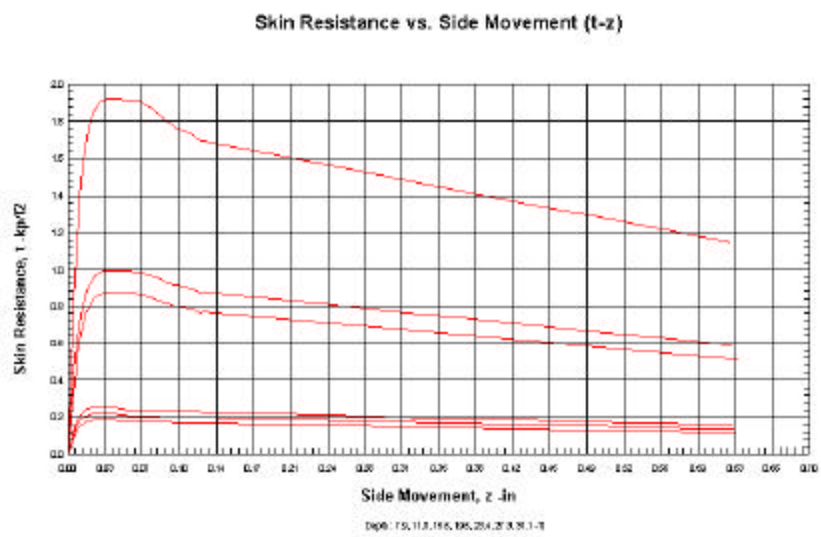


Figure 5-5. Skin Friction vs. Side Movement

5.2.5 q-w Curve

The q-w curve plots the tip settlement against the tip resistance. Figure 5-6 shows a plot of such curve.

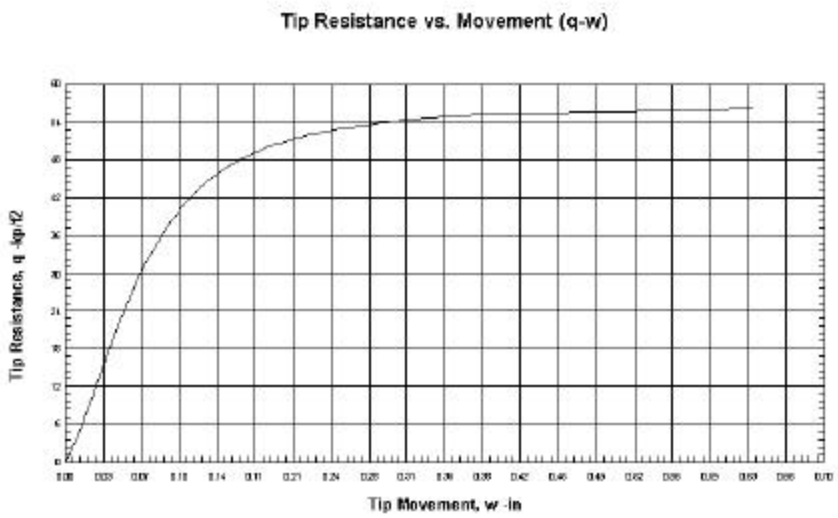


Figure 5-6. Tip Resistance vs. Tip Movement

5.2.6 Submittal Report

The formatted submittal report gives soil and pile physical parameters used in the analysis, as well as the calculated results for vertical analysis in an organized fashion. Presented here are the most important information required for pile design.

5.2.7 Summary Report

Summary report provides on unformatted summary of calculated results. The report is opened in Windows Notepad.

HINTS:

- **In the Notepad page, you can copy and paste data to other Windows programs, such as Word. The tabulated data are tab delimited, so they can be processed in Excel using Data/text to columns function. To export data directly to Excel, see "Exporting to Excel" below.**
- **If the report text is wrapped in Notepad, you can improve readability by selecting a smaller font by opening [Font] under the Format menu. We recommend using Courier New font size 8.**

5.2.8 Detail Report

The calculation report presents the details of the calculation so that the users can check the correctness of the calculation and also understand how it is done. It is viewed in Notepad or Wordpad (for larger files).

5.2.9 Exporting to Excel

If you have Microsoft Excel 97 or 2000 installed on your computer, clicking on this button will launch a pre-designed Excel file called "AllPile.xls". If your Excel program has an option called Virus Macro Protection, you will see a dialogue box when AllPile launches Excel. You should check the [**Enable Macros**] option to allow the operation to be continued.

After the Excel file is opened, on the first sheet (Data), there is a button called [**Update Vertical Data**]. Press this button to update data from AllPile. Then you can view graphics presented in the next few sheets. You can edit the graphics to customize your report, but do not change the structures and the settings of the Data sheet.

All the instructions are presented in the Excel file.

5.2.10 Figure Number

The figure number box allows you to input a figure/plate number or page number so that you can insert the graphic into your own report. The number you entered will be displayed on anyone of the above-mentioned report. The format of the report and the company name and logo can be modified in the Setup/Options screen (refer to Chapter 6 for detail).

5.3 Lateral Analysis Results

The lateral analysis results panel (Figure 5-7) provides several choices.

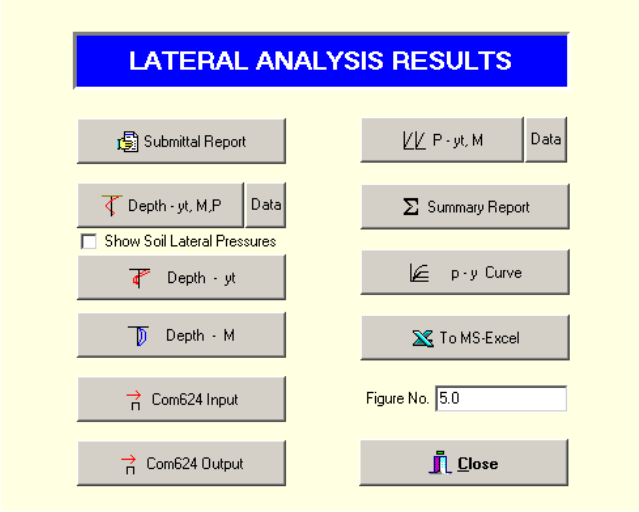


Figure 5-7. Lateral Analysis Results

5.3.1 Depth (z) vs. y_t, M, P and Pressures

The program provides 3 diagrams in the report, as shown in Figure 5-8.

Deflection (y_t)	Lateral deflection along the depth (z)
Moment (M)	Bending moment in the pile shaft
Shear (P)	Shear force in the pile shaft. It equals the lateral load applied at the pile head.
Soil Lateral Pressures	Lateral pressures between soils and pile. Users can check it with passive pressure of the soils.

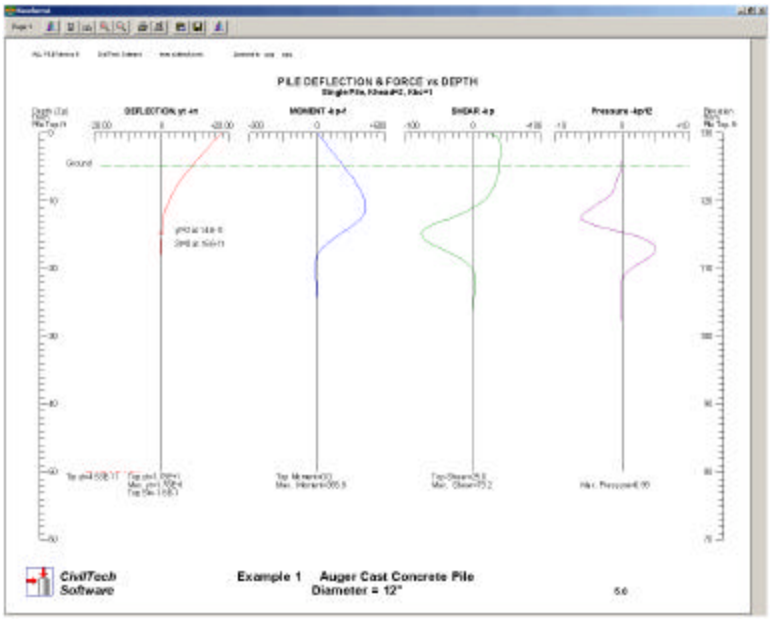


Figure 5-8. Depth vs. yt, M, P and Pressures

5.3.2 Load (P) - y_t, M

Click this button to get the two diagrams shown in Figure 5-9.

Lateral load (P) vs. head deflection (yt)	The diagram shows the pile head deflection under the lateral load at pile head.
Lateral load (P) vs. maximum moment (Mmax)	The diagram presents the maximum moment in the pile shaft under the lateral load at pile head.

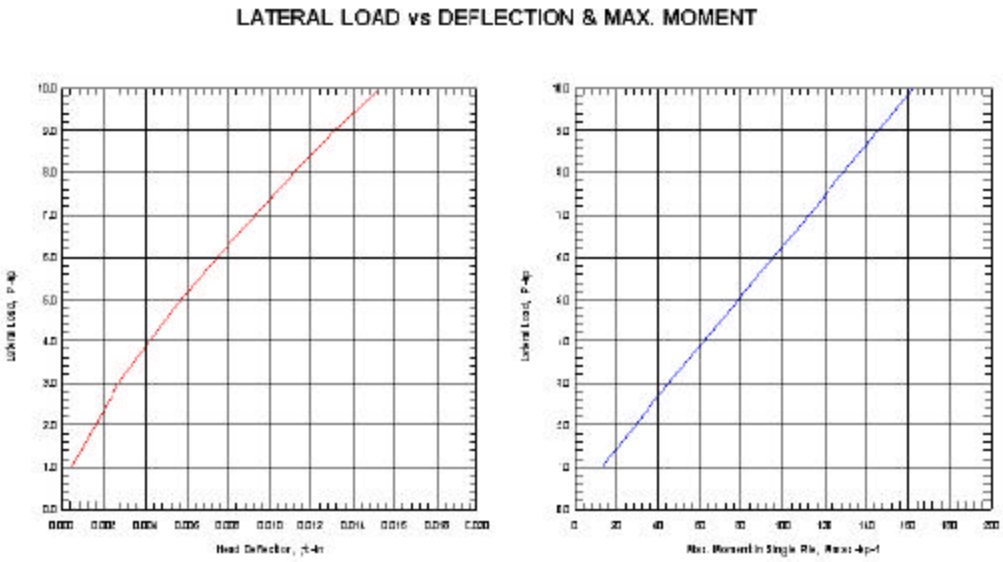


Figure 5-9. Lateral Load vs. Deflection & Moment

5.3.3 Depth vs. y_t

A series of deflection curves at increasing loading. The loading conditions of the different curves are presented on the table at the lower left corner of the report (Figure 5-10).

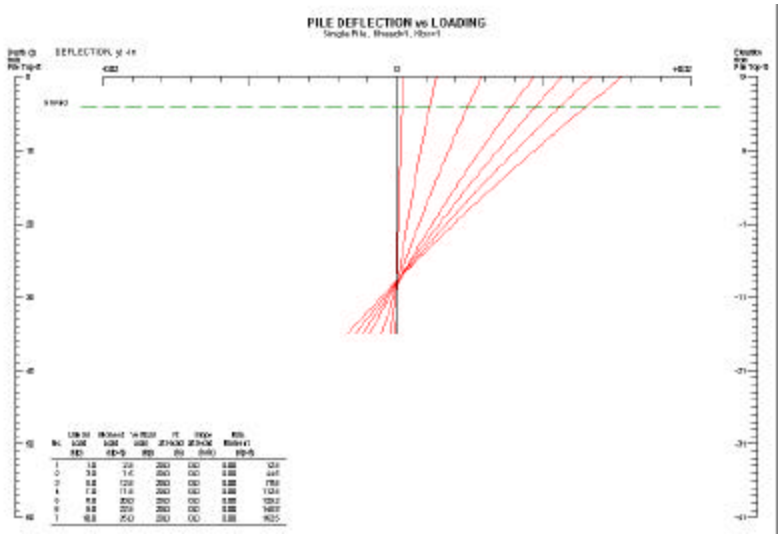


Figure 5-10. Depth vs. Deflection

5.3.4 Depth vs. M

A series of bending moment curves at increasing loading. Loading conditions are outlined in a chart at the lower left corner of the report (Figure 5-11).

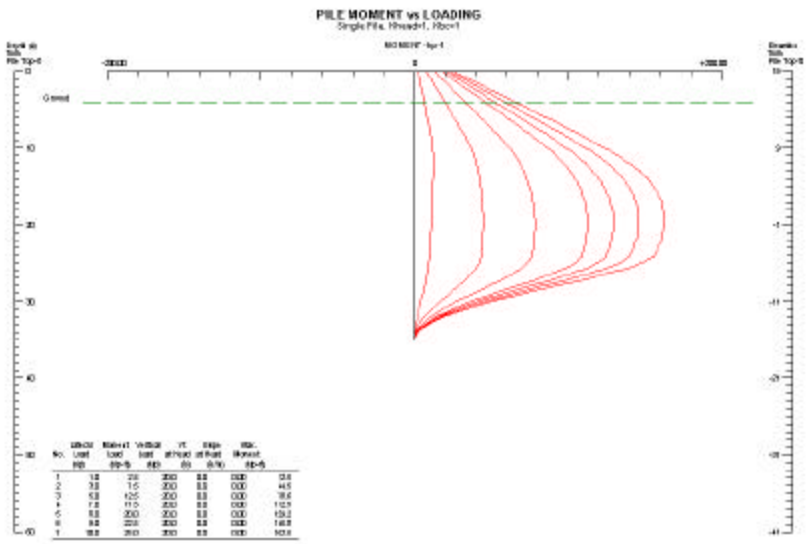


Figure 5-11. Depth vs. Moment

5.3.5 p-y Curve

A series of p-y curves at different depths. The depths are defined on the Advanced page.

5.3.6 Submittal Report

A report generated by the program that contains the most critical information for design. It extracts calculation results from Com624S Output and summarizes the information in this report.

5.3.7 Summary Report

Summary Report provides a summary of calculated results. The report is saved and opened in Windows Notepad. If the file is too large, Windows will automatically open the report in Wordpad instead of Notepad.

HINTS:

- **In the Notepad page, you can copy and paste data to other Windows programs, such as Word. However, the tabulated data are spacing delimited, so they are not suitable for Excel. To export data to Excel, see "Exporting to Excel" below.**
- **If the report text is wrapped in Notepad, you can improve readability by selecting a smaller font by opening [Set Font] under the Edit menu. We recommend using Courier new font size 8.**

5.3.8 Com624S Output/Input

The lateral analysis is performed by uses the revised version of Com624S program embedded in AllPile. You can view a typical Com624S output report

by pressing the button. You can also view the Com624S input file by pressing the Com624 Input button.

HINTS:

- **If the program encounters some errors and cannot produce results, you should review the Com624 output. You can also directly run Com624P using the input file by the program.**
- **Com624 program and example files can be downloaded from the AllPile Section in CivilTech's website.**

5.3.9 Exporting to Excel

If you have Microsoft Excel 97 or 2000 installed on your computer, clicking on this button will launch a pre-designed Excel file called "AllPile.xls". After the Excel file is opened, on the first sheet (Data) there is a button called [**Update Lateral Data**]. Press this button to update data from AllPile. You can view graphics presented on the next few sheets. You may edit the graphics, but do not change the structures or settings in the Data sheet. All instructions are presented in the Excel file.

5.3.10 Figure Number

The figure number box allows you to input a figure/plate number or page number so that you can insert the graphic into your own report. The format of the report and the company name and logo can be modified in the Setup/Options screen (refer to Chapter 6 for details).

5.4 Stiffness [K] Results

The stiffness analysis results panel (Figure 5-12) provides several choices. The results provide most stiffness for the analysis of upper structures. They are:

- Kqx - Secant Stiffness: Vertical load vs. Vertical movement (settlement)
- Kpy - Secant Stiffness: Lateral Shear vs. Lateral movement (deflection)
- Kps - Secant Stiffness: Lateral Shear vs. Slope (rotation). Clockwise is negative
- Kmy - Secant Stiffness: Moment vs. Lateral movement (deflection)
- Kms - Secant Stiffness: Moment vs. Slope (rotation). Clockwise is negative

The are also two pile head conditions to let users select:

- Free Head – The pile head is not restrained. The pile can free rotate. The stiffness will be lower.
- Fixed Head – The pile head is restrained by upper structure or pile cup. The pile cannot free rotate. The stiffness will be higher.

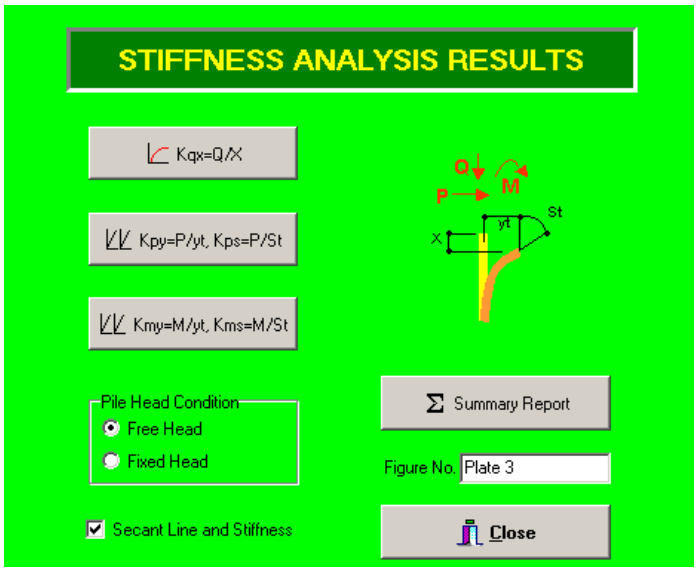


Figure 5-12. Stiffness Analysis Results

Summary Report provides a summary of calculated results. The report is saved and opened in Windows Notepad. If the file is too large, Windows will automatically open the report in Wordpad instead of Notepad.

5.5 Preview and Print Screen

The Preview and Print screen toolbar is shown below (Figure 5-13). The functions of all the buttons are described in the following text.

Figure 5-13. Preview Screen

The buttons are:

Close	Close Preview
Page Height	Zoom to the page height
Page Width	Zoom to the page width

Zoom In	Enlarge the image
Zoom Out	Reduce the image
Printer	Send to printer
Printer Setup	Set up printer
Clipboard	Copy the graphics to Windows Clipboard. Users can paste the graphics to any Windows program such as MS-Word, PowerPoint, and Excel.
Save	Save graphics to a Windows metafile, which can be opened or inserted by other drawing programs for editing.
Close	Close Preview

5.6 Errors and Troubleshooting

Report Layout

If the font, logo, and title are missing or misplaced in the report, most likely the setup file is damaged, or the setting parameters are out of range. You should open the Setup menu and restore to the manufacturer's settings. Please refer to chapter 6.

Vertical Analysis

The program will check most input for errors before calculation. Typical errors are:

- Total unit weight instead of buoyant unit weight under water table. Buoyant unit weight should be input under water table.
- No data in pile properties such as width, area, I, and E.
- No data in soil properties such as G, Phi, and C.
- Setup file is damaged, or the setting parameters are out of range. You should open the Setup menu and check the values.

Lateral Analysis

The program uses a pre-processor of COM624S to perform lateral analyses. The codes within the program have been re-written to solve most of the problems when initiating COM624 in the previous version of this program. The problems that are related to execution or limitations of COM624 are:

- No COM624 output file! - Com624 computation encountered an error and the program did not produce output file.
- Error in Com624 computation! No Depth-y_t data! - Com624 computation encountered an error and the program did not produce Depth-y_t.

- Error in Com624 computation! No p-y_t data! - Com624 computation encountered an error and the program did not produce p-y_t.

If any one of the above warnings is encountered, please check the data. Most of the cases are related to excessive calculated deflection, which exceeds the allowable y_t. This causes COM624 to terminate the calculations. The problem occurs when the pile is too flexible, soils are too soft, or load is too large.

- Pile too flexible – If the I and E of the pile section are too small, COM624 stops.
- Soils are too soft or loose – If Phi or K is too small for sandy soils and C or e50 is too small for cohesive soils, COM624 stops.
- Load is too large – If P, M, or y_t is too large, COM624 stops.
- Large surface slope angle or batter angle – If the surface or batter angle is larger than the soil friction angle, COM624 stops.
- Large H – If the distance between pile top and ground surface is too large, COM624 stops.

HINT: view the COM624 OUTPUT report to get the error message.

CHAPTER 6 SETUP

6.1 Setup Screen

The setup screen (Figure 6-1) can be accessed by selecting **[Open Setup]** from the **Setup** pull-down menu.

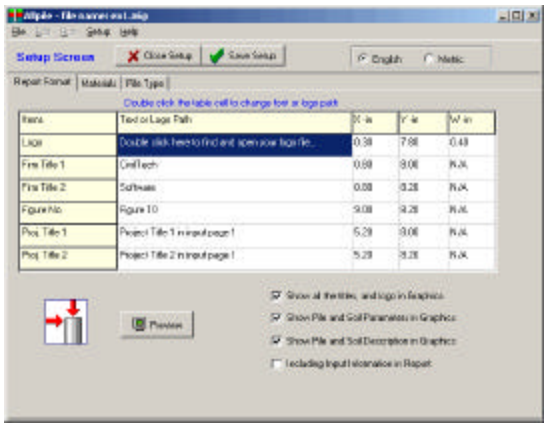


Figure 6-1. Setup Screen

The setting of the program is saved in the system. Users can choose to change these settings as they wish. After making the necessary changes to the setting, you could make this your default setting by clicking on **[Save Setup]**. If you make changes on the setup screen but would like to restore your default setting, click on **[Restore Saved Setup]** on the Setup pull-down menu. If you require to restore the manufacturers setting, click on **[Restore Default Setup]** on the Setup pull-down menu. After you are satisfied with the settings, you can return to the program by clicking on **[Close Setup]**.

6.2 Pull-Down Menu: Setup

Open Setup	Open setup screen.
Close Setup	Close the setup screen without saving the new settings.
Save Setup	Save the new settings and not close the screen
Restore Saved Setup	Restore the saved settings
Restore Default Setup	Restore the manufacturer settings
Print Setting	Summarize setting information in Notepad format which allows you to print

6.3 Speed Bar

The speed bar has two buttons:

Save Setup	Save the modified settings
Close Setup	Close the setup screen and return to the program

6.4 Tabbed Pages

The three tabbed pages are summarized below. Each page is described in detail in this chapter.

Report Format	Customize graphical output (reports)
Materials page	Configure pile materials
Pile Type	Configure pile type and method code

6.4.1 Report Format Page

You can customize the format of the output report by designating the position of each item. The location of each item are position based on coordinates, where (0,0) is located at the upper left corner of the page. Positive X is in the direction to the right, and positive Y is in the direction vertically downwards. The units of measurements are in inches or centimeters.

The items listed in the rows are as follows:

Logo	The logo shown in the report can be a bmp, gif, or jpeg file. Double click the row to specify the file path. The width of the logo can be changed on the right most column (W) in inches or centimeters.
Firm Title 1	Your company name is presented here. X and Y define the coordinates. Double click the row to select text font.
Firm Title 2	You may enter a company subtitle here. X and Y define the coordinates. Double click the row to select text font.
Figure Number	The page or figure number in the report. X and Y define the coordinates. Double click the row to select text font. The page number shown in the table is a dummy. The actual text in the report is from the Lateral Analysis Result or Vertical Analysis Result panel.
Project Title 1 & Project Title 2	This row specifies the location and font of the project title. X and Y define the coordinates. The text shown in the table is a dummy. The actual text in the report is from the Pile Type page.

Options:

Show all titles, and logos in Graphics	Turns on and off all the titles and logo in graphical report. It is useful for copying and pasting to other Windows programs.
Show Pile and Soil parameters in Graphics	Turns on and off all pile and soil parameters in Profile graphical report.
Show Pile and Soil Description in Graphics	Turns on and off all pile and soil descriptions in Profile graphical report.
Including Input Information in Report	The input data will be shown in the text Report

Preview:

Clicking on the [Preview] button will allow you to see the template of the graphical report.

6.4.2 Materials Page

This page sets the properties for the pile materials. The Materials Page (Figure 6-2) has two tables. The first table is the materials for the outside skin of the pile. The second table is inside materials of the pile.

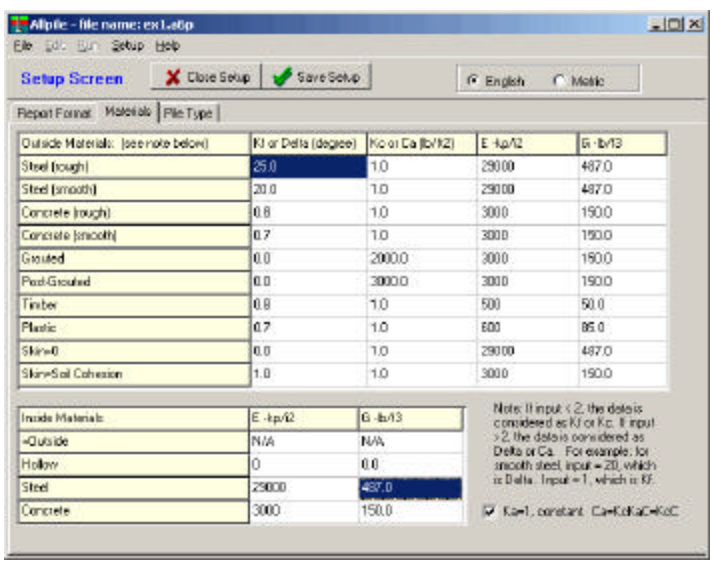


Figure 6-2. Materials Page

Each material in the table has four properties that can be customized:

Skin Friction	Defines the skin friction, δ, between granular soils and

Angle d or Faction K_f

the pile.

- If you input a value > 2, the program will recognize it as skin friction (δ)
- If you input a value ranging from 0.1 to 2, the program recognizes it as K_f. The program multiplies K_f by the soil internal friction, ϕ to get the skin friction, δ:
  $d = \mathbf{K_f} \times \phi$

  Where, K_f – friction factor (0.1 ~ 2)

NOTE: Internal friction, f, is the friction between granular soil particles. Skin friction, d, is the skin friction between soil and pile. d is not the same as f -- usually d is less than f.

Adhesion Ca or Factor Kc

Defines the adhesion, Ca, between cohesive soils and the pile.

If you input a value >2, the program recognizes it as adhesion, Ca.

If you input a factor (range 0.1 to 2), the program recognizes it as Kc. The program multiplies Kc by the soil cohesion, C, to get the adhesion, Ca:

Ca = Kc Ka×C

Where,

Ka – adhesion factor (0.1 ~ 2). Users define it.

Ka – adhesion ratio (0.1 ~ 1.5). Program defines it based on pile type and C (See Chapter 8).

Ka can be set to 1. It will bypass Ka calculation. This option is in a check box of this page.

NOTE: Cohesion, C, is the shear strength between cohesive soils. Adhesion, Ca, is the shear resistance between soil and pile. Ca is not equal to C. Usually Ca is less than C.

E Defines elastic modulus of pile materials.

G Specifies unit weight of pile materials.

The second table is the materials properties of the inside of the pile. For example, a steel pipe pile filled with concrete has outside materials = steel and inside materials = concrete. A concrete pile with steel bars has outside materials = concrete and inside materials = steel. The material properties can be customized:

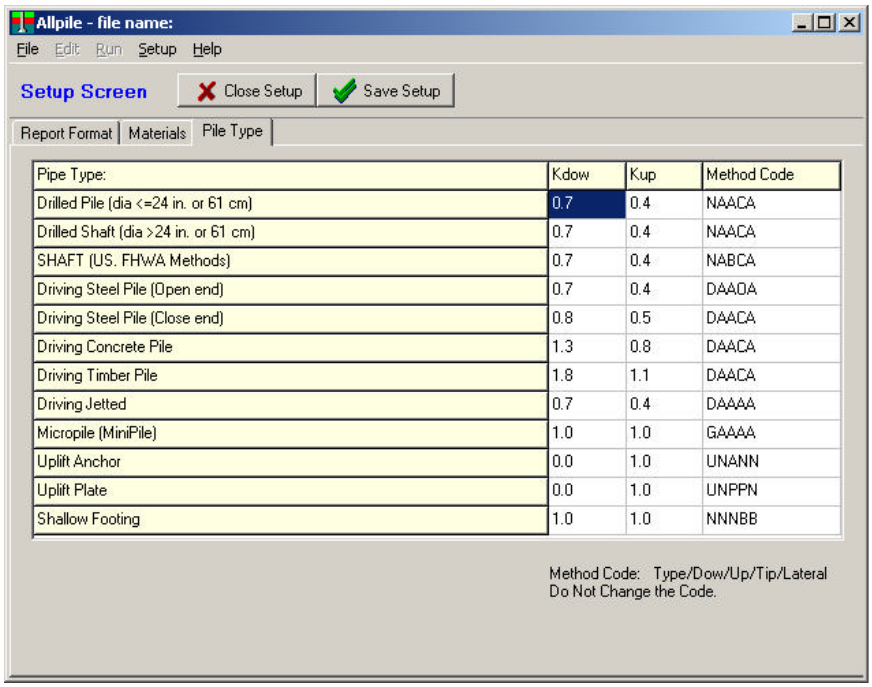
E Defines elastic modulus of inside pile materials.

G Specifies unit weight of inside pile materials.

Check Box for Ka=1: See explanation of Ca and Kc above.

6.4.3 Pile Type Page

The Pile Type page is shown in Figure 6-3. The table in this page defines the pile type and method code. The pile types listed in this table is the same list on the Pile Type input page (Figure 4-1).



Pipe Type:	Kdow	Kup	Method Code
Drilled Pile (dia <=24 in. or 61 cm)	0.7	0.4	NAACA
Drilled Shaft (dia >24 in. or 61 cm)	0.7	0.4	NAACA
SHAFT (US. FHWA Methods)	0.7	0.4	NABCA
Driving Steel Pile (Open end)	0.7	0.4	DAAOA
Driving Steel Pile (Close end)	0.8	0.5	DAACA
Driving Concrete Pile	1.3	0.8	DAACA
Driving Timber Pile	1.8	1.1	DAACA
Driving Jetted	0.7	0.4	DAAAA
Micropile (MiniPile)	1.0	1.0	GAAAA
Uplift Anchor	0.0	1.0	UNANN
Uplift Plate	0.0	1.0	UNPPN
Shallow Footing	1.0	1.0	NNNBB

Figure 6-3. Pile Type Setup Page

K_{down} The horizontal to vertical stress ratio for calculations of downward (compression) capacity. You can modify the factor based on your experience. See Chapter 8.

K_{down}=Vertical Stress/Horizontal Stress

Driven pile (displacement pile): K_{down}>=1

Drilled pile (no-displacement pile): K_{down}<1

K_{up} The horizontal to vertical stress ratio for calculations of uplift capacity. You can modify the factor based on your experience. See Chapter 8.

K_{up}=Vertical Stress/Horizontal Stress

Driven pile (displacement pile): K_{up}>=1

Drilled pile (no-displacement pile): K_{up}<1

Method Code This section is for the program's internal use. This should not be changed unless you are familiar with the code. A code including five letters to define the calculation method for each pile type. Each letter is explained below:

1st Pile installation method:

D – Driven pile (displacement pile)

N – Drilled pile (no-displacement pile)

2nd Downward calculation method:

A,B,C … - reserved for different methods

O – No calculation

3rd Uplift calculation method:

A,B,C … reserved for different methods

O – No calculation

4th Tip resistance calculation method:

A,B,C … reserved for different methods

O – No calculation

5th Lateral calculation method:

A – COM624S method

O – No calculation

CHAPTER 7 SAMPLES

7.1 Samples

Samples with different soil conditions and pile types are included in the program. These examples are intended to demonstrate the capabilities of the program and allow users to learn more about the input process and other key functions. The samples include:

1. Auger Cast Concrete Pile
2. Drilled Shaft No Bell
3. Drilled Shaft with Bell
4. FHWA SHAFT Method with Bell
5. Driving Steel Pipe, Close Ended
6. Driving Steel Pipe, Open Ended
7. Driving Steel H Pile, Open Ended
8. Driving Steel Pile in Sloped Ground
9. Driving Steel Pile with Battered Angle
10. Driving Concrete Pile with Battered Angle
11. Driving Concrete Pile with Stinger
12. Driving Timber Pile with Battered Angle
13. Driving Jetted Pile
14. Micropile with Pressure Grout
15. Uplift Anchor based on Soil Strength
16. Uplift Anchor based on Bound Strength
17. Uplift Plate in Shallow Mode
18. Uplift Plate in Deep Mode
19. Shallow Foundation
20. COM624 Sample 1, One Soil
21. COM624 Sample 2, Five Soils
22. COM624 Sample 3, in Butter Angle
23. COM624 Sample 4, P-Y Input
24. COM624 Sample 5, Sloped Ground
25. Group Steel Piles
26. Group Auger Cast Piles
27. Group Pre-cast Concrete Piles
28. Tower Mono-Pile
29. Tower with 3 Piles
30. Tower with 4 Piles

Please open the sample files stored in the program and run them to see the input and output data. The samples are in English units. For Metric (SI) units, open the sample then choose metric on the Pile Type page.

Volume 2

CHAPTER 8

CALCULATION THEORY

Detailed in this chapter:

- The theories behind the program
- The equations and methods that are use to perform the analyses.

CONTENTS for Chapter 8

CHAPTER 8 CALCULATION THEORY

8.1 GENERAL PILES

8.1.1 Vertical Analysis

This program uses procedures described in the *Foundations & Earth Structures, Design Manual 7.02,* published by Department of Navy, Naval Facilities Engineering Command.

8.1.1.1 Downward (Compression) Load Capacity Calculation

Ultimate downward capacity can be determined by the following equations:

$Q_{dw} = Q_{tip} + Q_{side}$

Where Q_{dw} = ultimate downward capacity

Q_{tip} = ultimate tip resistance

Q_{side} = ultimate side resistance

Ultimate tip resistance:

$Q_{tip} = A_{tip} \cdot q_{ult} = A_{tip} \cdot (N_q S_v + N_c)$

Where A_{tip} = area of pile tip

q_{ult}= ultimate end bearing pressure

S_v = vertical stress in soil (overburden pressure)

N_q = bearing factor for cohesionless soils. It is a function of friction shown in Table 8-1.

N_c = bearing factor for cohesive soils. It is a function of z/B (depth/width) shown in Table 8-2.

Table 8-1. Bearing Capacity Factor, N_q

f (Internal friction)	N_q (Displacement pile)	N_q (Non-Displacement pile)
26	11.0	5.6
28	15.2	7.6
30	21.0	10.3
31	24.6	12.1
32	29.1	14.2

33	34.5	16.9
34	41.3	20.3
35	49.9	24.6
36	60.9	30.1
37	75.0	37.1
38	93.0	46.1
39	116.1	57.7
40	145.4	72.3

Table 8-2. Bearing Capacity Factor, N_c

z/B (Depth/Width)	**N_c**
0	6.3
1	7.8
2	8.4
3	8.8
4	9
>4	9

Ultimate side resistance:

$$Q_{side} = \Sigma\ S_f P_i\ \Delta l = \Sigma\ (f_0 + C_a)\ P_i\ \Delta l$$

Where S_f = side resistance

f_0 = skin friction of cohesionless soil

C_a = adhesion of cohesive soil

P_i = Perimeter of pile section

Δl = segment of pile

Skin friction of cohesionless soil:

$$f_0 = S_h \tan(d) = K_{down} \cdot S_v \cdot \tan(d)$$

Where $K_{down} = \dfrac{S_h}{S_v}$ or $S_h = K_{down} \cdot S_v$

S_v = vertical stress in soil

S_h = horizontal stress in soil

K_{down} = ratio of S_h/S_v which is defined in the table of Setup.

d = skin friction between soil and pile. It is a function of pile skin materials. For steel pile, d = 20°-30°. For concrete pile, d = K_f ϕ. K_f is friction factor ranging from 0.1 to 1. K_f can be defined in the table of Setup.

Adhesion of cohesive soil:

$C_a = K_c \cdot K_a \cdot C$

Where C = shear strength of cohesive soil (cohesion)

K_c = adhesion factor ranging from 0.1 to 1, defined in the table of Setup.

K_a = Adhesion ratio, C_a/C, which is a function of C shown in Figure 8-1. If K_a =1, then calculation in Fig. 8-1 is bypassed.

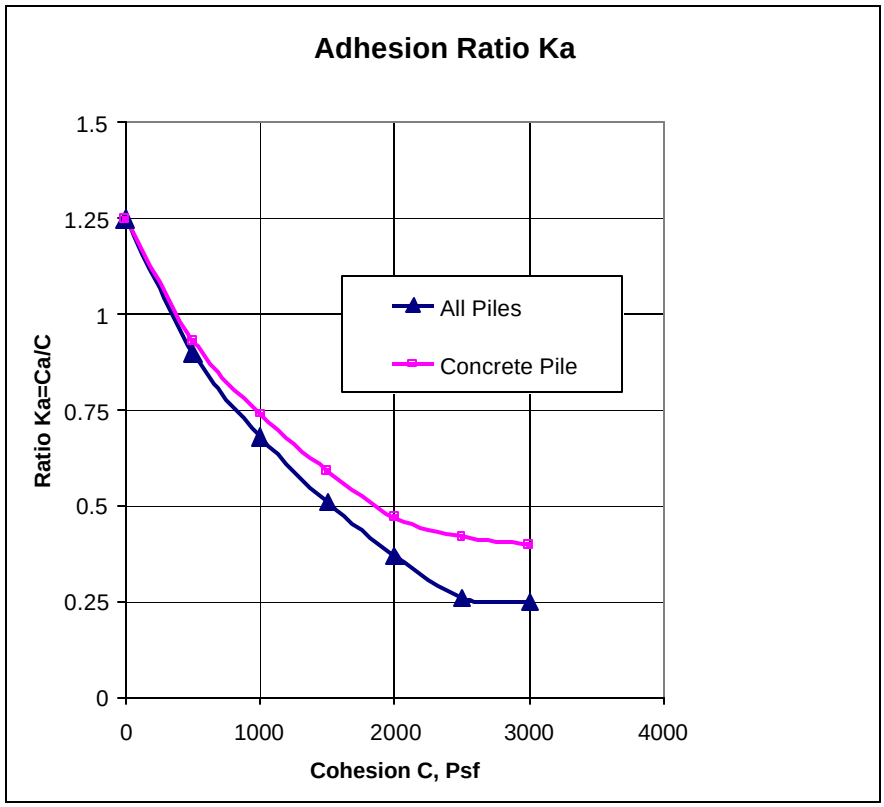


Figure 8-1. Adhesion Ratio, Ka

Limited Depth of side resistance and end bearing:

Experience and field evidence indicate that the side friction and end bearing increase with vertical stress S_v up to a limiting depth of embedment. Beyond this limiting depth (10D to 20D, B = Pile width), there is very little increase in side friction and end bearing. Penetration Ratio, PR, is used to define the limiting depth. PR = 20 is commonly used for both side friction and end bearing. The values can be changed on the Advanced page.

$PR_{tip} = (z/D)_{tip}$, Penetration ration for calculation of end bearing.

$PR_f = (z/D)_f$, Penetration ration for calculation of side friction.

Where z = depth

D = average pile width

The limitation of side friction and end bearing also can be expressed as absolute value for both cases. The values can be changed in the table of Advanced Page.

$q_{\_limit}$, Limit of end bearing pressure.

f_{0_limit}, Limit of sum of side friction and adhesion.

Allowable downward capacity can be determined by the following equation:

$$Q_{allw\_d} = \frac{Q_{tip}}{FS_{\_tip}} + \frac{Q_{side}}{FS_{\_side}}$$

Where Q_{tip} = ultimate tip resistance

Q_{side} = ultimate side resistance

$FS_{\_tip}$ = factor of safety for tip resistance, defined in the table of Advanced Page.

$FS_{\_side}$ = factor of safety for side resistance in downward direction, defined in Advanced Page.

8.1.1.2 Zero Side Resistance

In some cases, a portion of the pile does not have contact with soils. For example, soils have gaps, or the pile passes through an underground basement or tunnel. Side resistance cannot be developed in this portion. Therefore the concept of zero friction can be used. It includes both zero friction and zero adhesion. Two zero-resistance zones can be input in the program.

8.1.1.3 Zero Tip Resistance

In special conditions, users do not want to include the tip resistance in pile capacity. These conditions include peat or soft soils at pile tip. Or the pile tip has a very sharp point. Users can include the depth of the pile tip in the zero resistance zones. For example, if the pile tip is at a depth of 35 feet, users can set a zero resistance zone from 35 to 36 feet. The tip resistance will be zero in the calculation.

8.1.1.4 Negative Side Resistance

Piles installed through compressive soils can experience "downdrag" forces or negative resistance along the shaft, which results from downward movement (settlement) of adjacent soil. Negative resistance results primarily from consolidation of soft deposits caused by dewatering or fill placement. The downdrag force is the sum of negative friction and adhesion. It does not include tip resistance. It only effects downward capacity, not uplift capacity. Two zero- and two negative-resistance zones can be input in the program. If the same zone is defined as both a zero-resistance and negative-resistance zone, the program considers the zone as a zero-resistance area.

Downdrag Force from Negative Friction:

$$Q_{neg} = K_{neg} \cdot \Sigma\ (f_0)\ P_i\ \Delta l = K_{neg} \cdot \Sigma\ (S_f + C_a)\ P_i\ \Delta l$$

Where Q_{neg} = Downdrag force from negative side friction

K_{neg} = Negative side friction factor. It ranges from 0 to 1 depending on the impact of settlement of the soil to the pile shaft.

S_f = side resistance

f_0 = skin friction of cohesionless soil

C_a = adhesion of cohesive soil

Pi = Perimeter of pile section

Δl = segment of pile

8.1.1.5 Maximum Settlement Calculation at Ultimate Vertical Resistance

Based on Vesic's recommendation (1977), the settlement at the top of the pile consists of the following three components:

Settlement due to axial deformation of pile shaft, X_s

$$X_s = \Sigma(Q_{tip} + Q_{side})\frac{\Delta l}{A'E}$$

Where Q_{tip} = tip ultimate resistance

Q_{side} = side ultimate resistance

? l = pile segment

A' = effective pile cross sectional area

E = modulus of elasticity of the pile

The equation is different from what shown in DM-7. This equation uses numerical integration, which is more accurate then the empirical equation in DM-7.

Settlement of pile point caused by load transmitted at the point, X_{pp}

$$X_{pp} = \frac{C_p Q_t}{B q_{ult}}$$

Where C_p = empirical coefficient depending on soil type and method of construction. It is defined in Table 8-3 below.

B = pile diameter

q_{ult}= ultimate end bearing pressure

Table 8-3. Typical Value of C_p for Settlement Analysis

Soil Type	Driven Piles	Drilled Piles
Sand	0.03	0.135
Clay	0.025	0.045
Silt	0.04	0.105

Settlement of pile point caused by load transmitted along the pile shaft, X_{ps}

$$X_{ps} = \frac{C_s Q_s}{L_e q_{ult}}$$

Where L_e = embedded depth

q_{ult}= ultimate end bearing pressure

Q_s = side resistance

$$C_s = (0.93 + 0.16\sqrt{\frac{z}{B}})C_p$$

Where z/B = depth / pile width

(Note: NAVY DM-7 has typo mistake in the equation)

Total settlement of a single pile, X_{total}

$X_{total} = (X_s+X_{pp}+X_{ps})$

8.1.1.6 Relationship Between Settlement and Vertical Load

Vertical load and settlement relation can be developed from t-z (side load vs shift movement) and q-w (bearing load vs base settlement) curves. The t-z curve represents the relation between side resistance and relative movement within soil and shaft. The t-z curve can vary at different depth and in different soils. The q-w curve represents the relation between tip resistance and base movement of the shaft.

t-z and q-w Relation

Generally, t-z and q-w relations require a considerable amount of geotechnical data from field and laboratory tests, which are not always available for engineers. AllPile uses the following procedures to determine the amount of settlement:

1. First, calculate ultimate side resistance and ultimate tip resistance of shaft using the methods introduced in 8.1.1.5.
2. Find relationships between settlement and load transfer ratios (developed resistance against ultimate resistance) using the corresponding charts in Fig 8-2 – 8-5
3. Integrate both side and tip resistances, as well as elastic compression of shaft body, to obtain total vertical resistance as a function of settlement.
4. From the relationships between settlement and load transfer ratios, we can develop t-z and q-w curve.

Typical settlement against load transfer ratios are shown in Figures 8-2 through 8-5 proposed by Reese and O'Neal (1988). Figure 8-2 and 8-3 represent the side load transfer ratio for cohesive soils and cohesionless soils/gravel respectively. Figure 8-4 and 8-5 represent the end bearing load transfer ratio for cohesive soils and cohesiveless soils respectively.

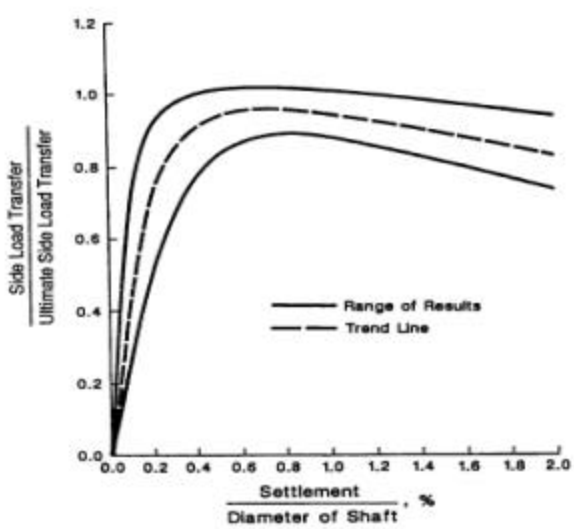


Figure 8-2.

Normalized load transfer relations for side resistance in cohesive soil (Reese and O'Neill, 1989)

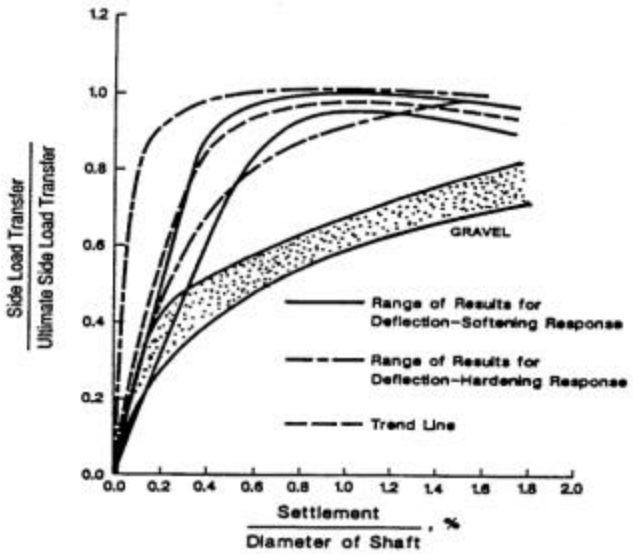


Figure 8-3 Normalized load transfer relations for side resistance in cohesionless soil (Reese and O'Neill, 1989)

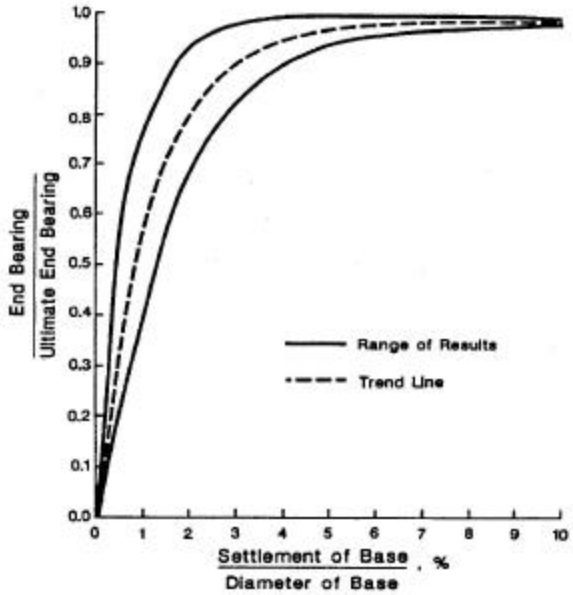


Figure 8-4. Normalized load transfer relations for base resistance in cohesive soil (Reese and O'Neill, 1989)

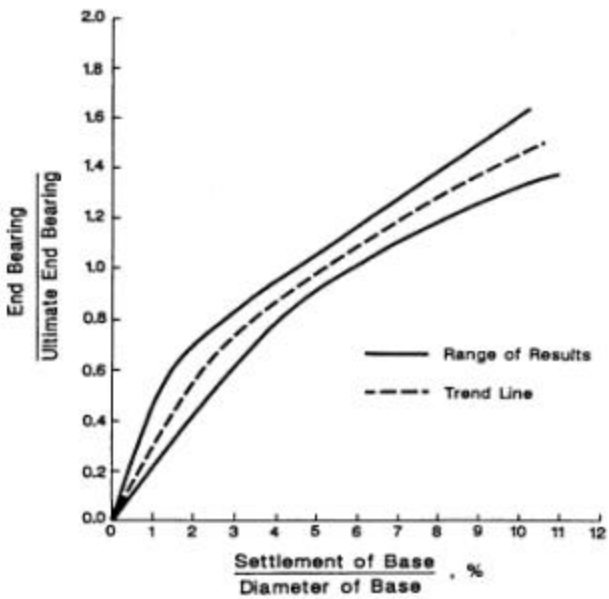


Figure 8-5. Normalized load transfer relations for base resistance in cohesionless soil (Reese and O'Neill, 1989)

Two Options for Settlement Analysis

In Advanced Page, AllPile provides two options for developing load-settlement relation.

Option 1:

The load transfer ratio is based on diameter of shaft (D_s) or base diameter of shaft (D_b) if it is different from the former, i.e. shafts with bell. This option is recommended for larger-size shafts.

Option 2:

The load transfer ratio is based on the calculated settlement from Vesic's method as described in Section 8.1.1.5. This option yields a closer match between settlement calculation of Vesic's method. It is recommended for smaller diameter piles.

Total, Side and Tip Resistance vs. Settlement

Figure 8-6 shows the vertical load is distributed in to side resistance and tip resistance. The chart from results of program shows that side resistance develops at small settlement, while tip resistance develops at large settlement. The ultimate value of the two cannot simply be added together. That is why tip resistance requires large Factor of Safety to get allowable capacity.

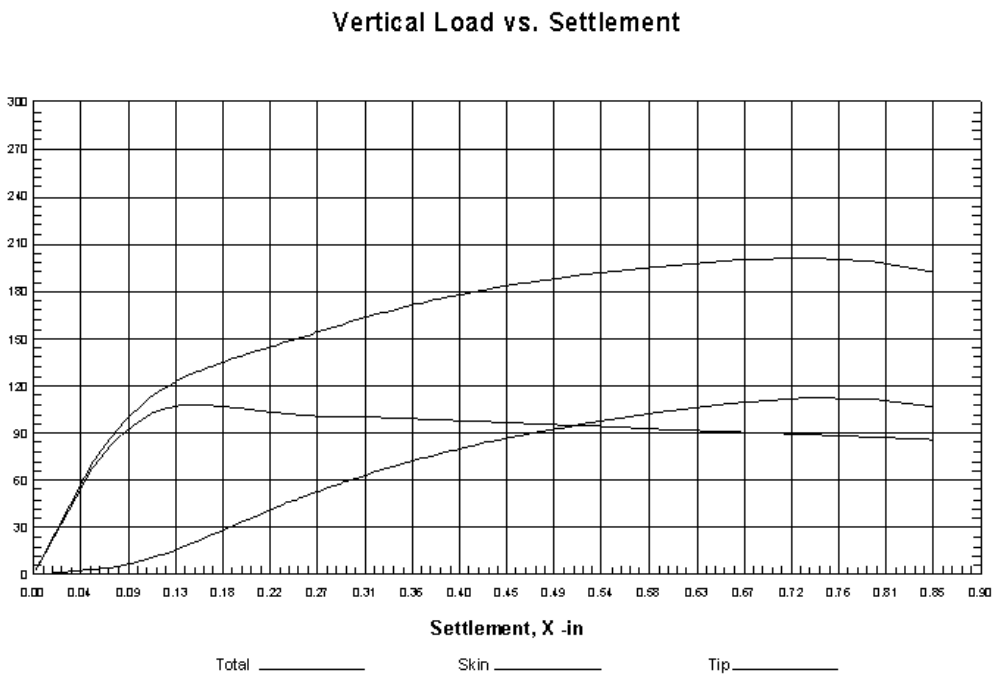


Figure 8-6. Total, Side and Tip Resistance vs. Settlement

Capacity at Allowable Settlement

AllPile provides two methods to determine Q_{allow}. One is defined by Factor of Safety presented in Section 8.1.1.1. The other method is defined by allowable settlement.

Calculate Q_{allow} based on allowable settlement. Depending on the amount of allowable settlement X_{allow}, then back-calculate Q_{allow} based on the relationship between X_{allow} and load. X_{allow} can be defined on Advanced Page.

8.1.1.7 Uplift Load Capacity Calculation

Ultimate uplift capacity can be determined by the following equations:

$$Q_{up} = Q_w + Q_{side}$$

Where Q_w = weight of pile

Q_{side} = ultimate side resistance

Q_w = ? W_i ?l

Where W_i = weight of pile section in unit length

?l = segment of pile

$Q_{side} = \Sigma\ S_f P_i \cdot \Delta l = \Sigma\ (f_0 + C_a)\ P_i\ \Delta l$

Where S_f = side resistance

f_0 = skin friction of cohesionless soil

C_a = adhesion of cohesive soil

Δl = segment of pile

P_i = Perimeter of pile section

$f_0 = K_{up} \cdot S_v$ tand

Where $K_{up} = \dfrac{S_h}{S_v}$ *or* $S_h = K_{up} \cdot S_v$

S_v = vertical stress in soil

S_h = horizontal stress in soil

K_{up} = ratio of S_h/S_v which is defined in the table of Setup

d = skin friction between soil and pile. It is function of pile side materials. For steel pile, d = 20°-30°. For concrete pile, d = K_f? . K_f is a friction factor ranging from 0.1 to 1. K_f can be defined in in the table of Setup.

$C_a = K_c \cdot K_a \cdot C$

Where C = shear strength of cohesive soil (cohesion)

K_c = adhesion factor ranging from 0.1 to 1, defined in the table of Setup.

K_a = Adhesion ratio, C_a/C, which is a function of C shown in Figure 8-1.

Allowable Uplift Capacity can be determined by following equations:

$$Q_{allw\_U} = \frac{Q_w}{FS_{\_w}} + \frac{Q_{side}}{FS_{\_up}}$$

Where Q_w = weight of pile

Q_{side} = ultimate side uplift resistance

$FS_{\_w}$ = factor of safety for pile weight, defined in the table of Advanced Page.

$FS_{\_up}$ = factor of safety for side resistance for uplift, defined in the table of Advanced Page.

8.1.1.8 Batter Shaft Capacities Calculation

The capacities of batter is from vertical capacities then adjusted by its batter angle:

$$Q_{batter} = \cos\alpha \cdot Q_{vertical}$$

Where α = Batter angle of shaft

Q = vertical capacities including downward and uplift

8.1.1.9 Group Vertical Analysis

In most cases, piles are used in groups as shown in Figure 8-7, to transmit the load to each pile. A pile cap is constructed over group piles. The analysis can be divided into four steps.

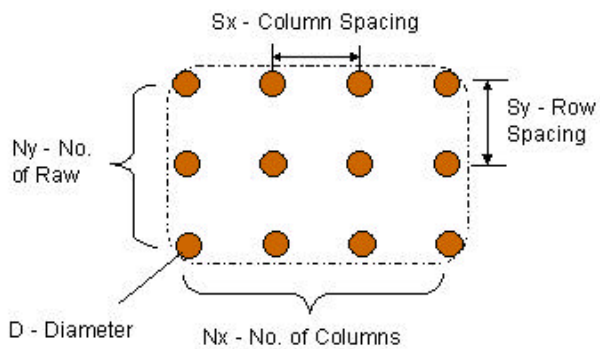


Figure 8-7 Group Pile for Vertical Analysis

Step 1. Calculate Capacity of Individual Pile, Q_{single}

$\mathbf{Q}_{single}$ can be calculated using the methods mentioned in above sections. $\mathbf{Q}_{single}$ includes side resistance and tip resistance.

Step 2. Calculate Capacity of a Pile Block, Q_{block}

$\mathbf{Q}_{block}$ is calculated using single pile method including side and tip resistance. The block has the following dimensions:

$$B_x = (n_x - 1) \cdot S_x + D$$

$B_y = (n_y - 1) \cdot S_y + D$

L is the same as the length of each individual pile

Step 3. Calculate the Group Efficiency, ?

$$h = \frac{Q_{block}}{nQ_{single}}$$

Where n = total number of pile. $n = n_x \cdot n_y$

$\mathbf{Q}_{\boldsymbol{single}}$ = capacity of individual pile

$\mathbf{Q}_{\boldsymbol{block}}$ = capacity of block pile

? = group efficiency

Step 4. Determine the Capacity of Group Pile, $\mathbf{Q}_{\boldsymbol{group}}$

If ? = 1, then $Q_{group} = n \cdot \mathbf{Q}_{\boldsymbol{single}}$

If ? < 1, then $Q_{group} = \mathbf{Q}_{\boldsymbol{block}}$

8.1.1.10 Settlement Analysis for Group Pile

Suggested by Vesic (1969), the settlement for group pile can be estimated

$$X_{group} = X_{single} \cdot \sqrt{\frac{B'}{D}}$$

based on settlement of a single pile (DM7-7.2-209):

Where B' = smallest dimension between B_x and B_y (see Step 2 above)

D = diameter of a single pile

8.1.2 Lateral Analysis

AllPile directly uses COM624S calculation methods for lateral analysis. For details on COM624, please refer to the FHWA publications, FHWA-SA-91-048, *COM624P – Laterally Loaded Pile Program for the Microcomputer, Version 2.0*, by Wang and Reese (1993). In that publication, Part I provides a User's Guide, Part II presents the theoretical background on which the program is based, and Part III deals with system maintenance. The appendices include useful guidelines for integrating COM624 analyses into the overall design process for laterally loaded deep foundations.

8.1.2.1 Lateral Deflection Calculation

Here is brief introduction to the program. COM624S uses the four nonlinear differential equations to perform the lateral analysis. They are:

$$EI\frac{d^4Y}{dZ^4} + Q\frac{d^2Y}{dZ^2} - R - P_q = 0 \qquad (1)$$

Where Q = axial compression load on the pile

Y = lateral deflection of pile at depth of Z

Z = depth from top of pile

R = soil reaction per unit length

E = modules of elasticity of pile

I = moment of inertia of the pile

P_q = distributed load along the length of pile

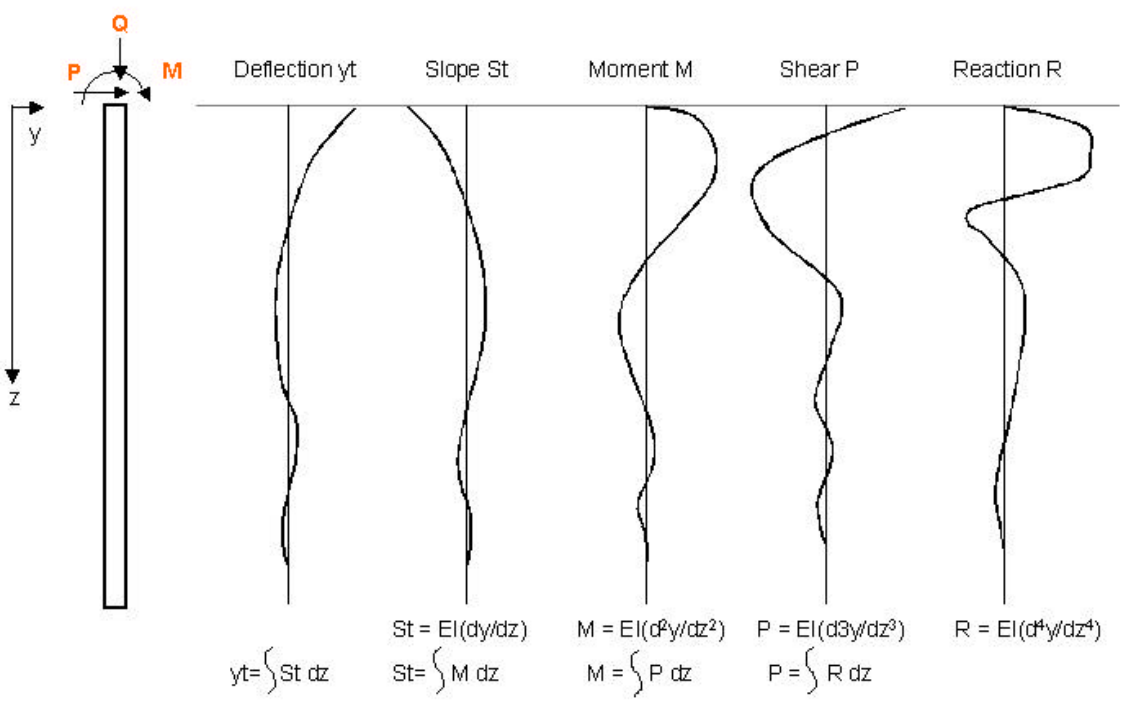
$$EI(\frac{d^3Y}{dZ}) + Q(\frac{dY}{dZ}) = P \qquad (2)$$

Where P = shear in the pile

Where M = bending moment of the pile

$$\frac{dY}{dZ} = S_t \qquad (4)$$

$$EI(\frac{d^2Y}{dZ^2}) = M \qquad (3)$$



The COM624S program solves the nonlinear differential equations representing the behavior of the pile-soil system to lateral (shear and moment) loading conditions in a finite difference formulation using Reese's p-y method of analysis. For each set of applied boundary loads the program performs an iterative solution which satisfies static equilibrium and achieves an acceptable compatibility between force and deflection (p and y) in every element.

Graphical presentations versus depth include the computed deflection, slope, moment, and shear in the pile, and soil reaction forces similar to those illustrated in Figure 8-8.

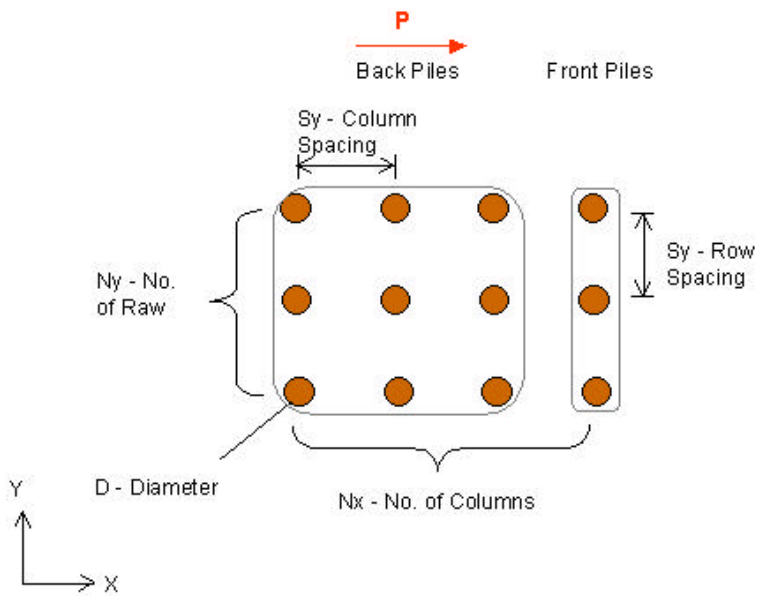


Figure 8-9 Group Pile for Lateral Analysis

8.1.2.2 Group Lateral Analysis

Typical group layout is shown in Fig. 8-9. Due to the group effect, the lateral capacity of individual piles cannot be fully developed. Deduction factors are applied to the soil reaction, and then lateral analysis is performed for individual piles.

Step 1. Calculate Deduction Factor R_{side} and R_{front}

Assuming the lateral load P is in X direction. Please note that R_{front} is not the same as R_{side}.

Table 8-4. Deduction Factor R_{front}

S_x	R_{front}
>8D	1
8D	1
6D	0.8

4D	0.5
3D	0.4
<3D	0.4

Table 8-5. Deduction Factor R_{side}

S_y	R_{side}
>3D	1
3D	1
2D	0.6
1D	0.3
<1D	0.3

Note: D = pile diameter Reference: *FHWA HI 97-013*

Step 2. Reducing Soil Lateral Resistance by Applying the Deduction Factors from Step 1

Combine the reduction factors and apply them to p-y curve for lateral analysis.

Step 3. Calculate P-yt (the Lateral Capacity and Deflection) of Each Individual Piles

Calculate the lateral capacity of each pile and get $P\text{-}Y_t$ curve for all piles.

Step 4. Get Lateral Capacity of group piles

After $P\text{-}Y_t$ curve for each pile is constructed. The P_{group} is the sum of P_{single} for individual piles at the same deflection under one pile cap.

P_{group} = **?** P_{single}

y_{group} = **y** $_{single}$

8.2 DRILLED SHAFT ANALYSES

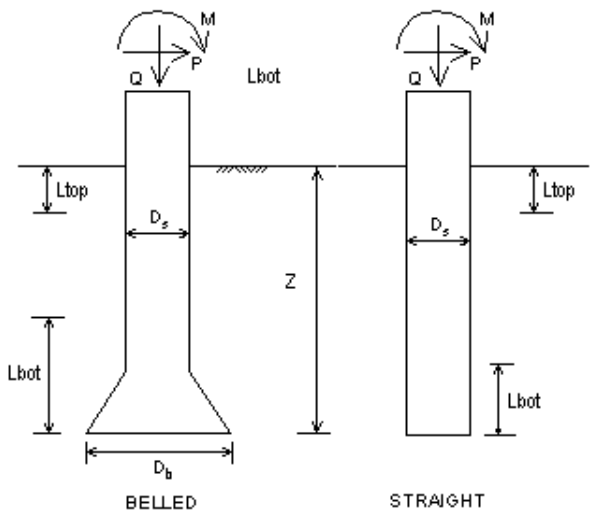


Figure 8-10. Drilled Shaft

Drilled shafts are normally used in deep foundation to transfer vertical load through weak soils to stronger soils or rocks at depth. Since it is often used to carry a relatively large vertical load over a good depth of soils, typical diameter of drilled shaft ranges from 4 ft (1.2 m) to 20 ft (6 m). In most cases, the aspect ratio of a drilled shaft, or its length divided by its diameter, should not exceed 30.

This program uses procedures described in the Drilled Shafts: Construction Procedures and Design Methods (FHWA-IF-99-025) published by FHWA in August 1999.

8.2.1 Vertical Analysis

8.2.1.1 Downward (Compression) Load Capacity Calculation

Ultimate downward capacity can be determined by the following equations:

$Q_{dw} = Q_{tip} + Q_{side}$

Where Q_{dw} = ultimate downward capacity

Q_{tip} = ultimate tip resistance

Q_{side} = ultimate side resistance

Ultimate tip resistance (Q_{tip}):

Base in cohesive soils [$S_u \leq 0.25$ MPa (5,200psf)]

$Q_{tip} = q_{ult} A_b$

Where q_{ult} = ultimate bearing pressure

A_b = base area

If Z (depth of base) $\geq 3D_b$ (diameter of base):

$q_{ult} = 9\ C$ [If C $\geq$ 96kPa (1tsf)]

or $q_{ult} = Nc^* \cdot C$ [If C < 96kPa (1tsf)]

Where C (or S_v) = undrained shear strength below base

N_c* = modified bearing capacity factor for cohesive soils. It can be assumed to be a function of S_u in UU triaxial compression as shown in Table 8-6.

Table 8-6. Modified Bearing Capacity Factor, N_c*

C (Undrained Shear Strength)	**N_c*** (Bearing Capacity Factor)
24kPa (500psf)	6.5
48kPa (1000psf)	8.0
96kPa (2000psf)	9.0

If Z (depth of base) ≥ $3D_b$ (diameter of base):

$$q_{ult} = \frac{2}{3} + \left[1 + \frac{Z}{6D_b}\right] N_c * \cdot S_u$$

<u>Base in cohesionless soils ($N_{SPT} \leq 50$)</u>

In English unit: q_{ult} (kPa) = 57.5 · N_{SPT}

In Metric unit: q_{ult} (tsf) = 0.6 · N_{SPT}

Where N_{SPT} = blow count per 0.3m or 1ft of penetration in the Standard Penetration Test

<u>Base in rocks [0.25MPa (2.5tsf) < C < 2.5MPa (25tsf)]</u>

If embedment in rock ≥ 1.5B (diameter of base):

$q_{ult} = 5 \cdot C = 2.5 \cdot q_u$

If embedment in rock < 1.5B (diameter of base):

$q_{ult} = 4 \cdot C = 2.0 \cdot q_u$

Where q_u = unconfined compressive strength below base

**Attention*: The two equations above were developed for drilled shafts sitting on or embedded in good quality bedrock with RQD close to 100%. If rock is jointed or fractured, please consult geotechnical engineer for correct procedures to calculate tip resistance.

Ultimate side resistance (Q_{side}):

$$Q_{side} = \Sigma\ f_0 \cdot \Delta l \cdot P_i$$

Where f_0 = skin friction

Δl = segment of pile

P_i = perimeter of pile

<u>Shaft in cohesive soils [$S_u \leq 0.25$ MPa (5,200psf)]</u>

$$f_0 = \alpha \cdot C$$

$\alpha = 0.55$ (for $S_u / P_a \leq 1.5$)

$$a = 0.55 - 0.1\left(\frac{S_u}{P_a} - 1.5\right)$$

(for $1.5 \leq S_u / P_a \leq 2.5$)

Where α = shear strength reduction factor

P_a = atmospheric pressure = 101kPa or 2.12ksf

<u>Shaft in cohesionless soils ($N_{SPT} \leq 50$)</u>

$$f_0 = \beta \cdot C$$

In sand:

$\beta = 1.5 - 0.245\ [Z(m)]^{0.5}$ [If $N_{SPT} \geq 15$]

<u>or</u> $\beta = N_{SPT} /15 \cdot \{1.5 - 0.245\ [Z(m)]^{0.5}\}$ [If $N_{SPT} \geq 15$]

Where β = empirical factor which varies with depth

S_v = effective vertical stress at depth Z

Z = depth where side resistance is calculated

<u>Attention</u>: - Z must be converted to meter before calculating β.

- Range of β: $0.25 \leq \beta \leq 1.2$

<u>Shaft in rocks [0.25MPa (2.5tsf) < C < 2.5MPa (25tsf)]</u>

$$f_0 = 0.65 \cdot P_a\left(\frac{q_u}{P_a}\right)^{0.5}$$

Where q_u = unconfined compressive strength at depth where side resistance is calculated

P_a = atmospheric pressure = 101kPa or 2.12ksf

Shaded area = A'_b

8.2.1.2 Uplift Load Capacity Calculation

Ultimate uplift capacity can be determined by the following equations:

$Q_{up} = Q_w + Q'_{side} + Q'_b$

Where Q_w = weight of pile

Q'_{side} = ultimate side resistance against uplift

Q'_b = ultimate bell resistance against uplift (Q'_b is only calculated for belled shafts in cohesive soils)

Q_w = ? W_i · ?l

Where W_i = weight of pile section in unit length

?l = segment of pile

$Q'_{side} = \Sigma\ k \cdot Q_{side}$

Where k = coefficient of uplift resistance

→ k = 1 (for cohesive soils)

→ k = 0.75 (for cohesionless soils)

→ k = 0.7 (for rocks)

Q_{side} = ultimate side resistance in compression in Section 8.2.1.1

*If a **belled** drilled shaft is used*

$Q'_b = N_u \cdot C \cdot A'_b$ (for cohesive soils only)

Where N_u = bearing capacity factor for uplift

= 3.5 Z/D_b <u>or</u> 9 (whichever is smaller)

Z = depth of drilled shaft

D_b = diameter of base/bell

C (or S_u) = undrained shear strength

A'_b = area of bell base - area of shaft body ("Donut" area)

<u>Attention</u>: Belled shaft is not recommended for cohesionless soil and is too difficult to be constructed in rock layer. Therefore, Q'_b will not be considered in those two types of earth material.

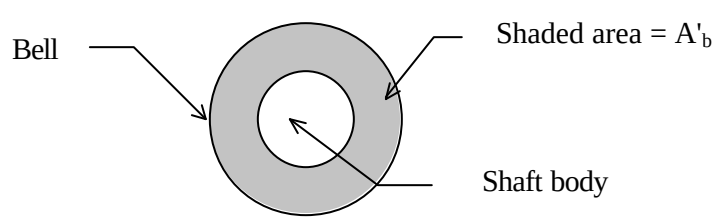


Figure 8-11 Top View of Donut

8.2.1.3 Exclusion Zones

According to the SHAFT manual, the exclusion zones do not contribute side resistance for drilled shaft as shown in Figure 8-10.

Exclusion zones in the calculation of ***Downward Capacity*** :

- For straight shafts: Top 5' and bottom one diameter of shaft
- For belled shafts: Top 5' belled section and one diameter of stem (D_s)

Exclusion zones in the calculation of ***Uplift Capacity*** :

- For straight shafts: Top 5'
- For belled shafts: Top 5', entire belled section and two diameter of stem (D_s) calculated from top of belled section

8.2.1.3 Group Vertical Analysis

In most cases, shafts are used in group as shown in Figure 7-10, to transfer the load to each shaft. A cap is constructed over group shafts. The analysis can be divided into four steps.

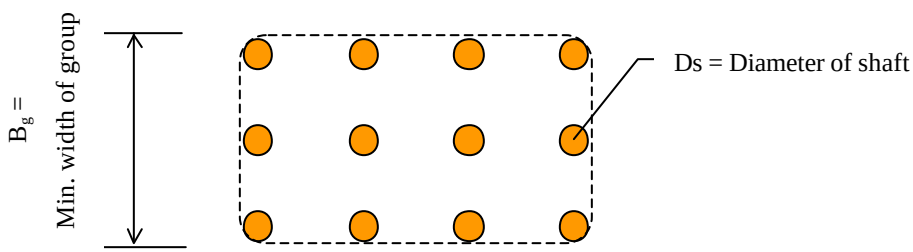


Figure 8-12 Group Shaft for **Vertical Analysis**

Step 1. Calculate Capacity of Individual Pile, Q_{single}

$\mathbf{Q}_{single}$ can be calculated using the methods mentioned in above sections. $\mathbf{Q}_{single}$ includes side resistance and tip resistance.

Step 2. Calculate Minimum (Shortest) Dimension of Shaft Block, B_g

$B_g = (N_x - 1) \cdot S_g + D_s$

Where N_x = number of shafts on the short side of the group

S_g = shaft spacing

D_s = diameter of drilled shaft

Step 3. Calculate the Group Efficiency, ?

$$h = \sqrt{\frac{B_g}{D_s}}$$

Where B_g = minimum width of shaft group

D_s = diameter of drilled shaft

Step 4. Determine the Capacity of Group Pile, Q_{group}

$Q_{group} = ? \cdot Q_{single}$

8.2.2 Lateral Analysis

Lateral analysis for drilled shafts at single or group conditions are identical to that for drilled or driven piles. User can refer to Section 8.1.2 for the theories and the calculation procedures used in lateral analysis.

8.3 SHALLOW FOOTING ANALYSES

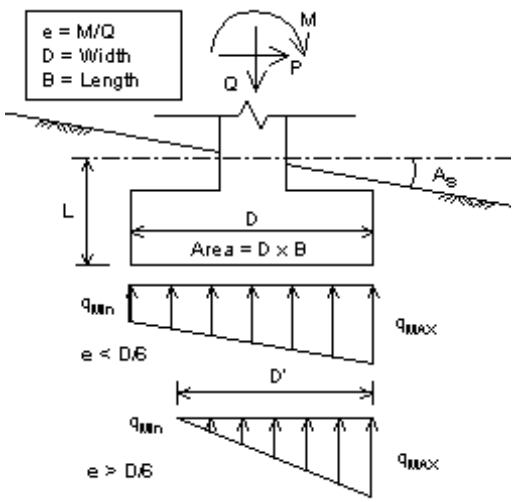


Figure 8-13. Shallow Footing

Shallow foundations are designed to transfer vertical load to soils at relatively shallow depths. Typical shallow foundations include spread footings, strip footings, and mats. The bearing capacity of shallow foundations is influenced by a number of factors, which will be covered in the next section. Shallow foundations are often subject to lateral loading or eccentricity. The stability of shallow foundations against eccentricity is controlled primarily by the ability to withstand overturning. *AllPile* uses procedures and recommendations given in *Principles of Foundation Engineering*, Brooks/Cole Engineering Division, Braja M. Das., 1984, as the primary references for shallow foundation analyses.

8.3.1 Vertical Analysis

8.3.1.1 Vertical (Compression) Load Capacity Calculation

Ultimate downward capacity (q_{ult}) can be determined by the following equation:

$$q_{ult} = c\, N_c\, s_c\, d_c\, i_c\, g_c + q\, N_q\, s_q\, d_q\, i_q\, g_q + 0.5\, \gamma\, D\, N_\gamma\, s_\gamma\, d_\gamma\, i_\gamma\, g_\gamma$$

Where c = cohesion

q = effective stress of soil at foundation base

γ = unit weight of soil

D = width or diameter of foundation

N = bearing capacity factors

s = shape factors

d = depth factors

i = load inclination factors

g = ground inclination factors

a.) Bearing Capacity Factors (N):

$$N_c = (N_q - 1)\cot f$$

$$N_q = \tan^2\left(45 + \frac{f}{2}\right)e^{p \tan f}$$

$$N_g = 2(N_q + 1)\tan f$$

b.) Shape Factor (s):

$$s_c = 1 + \left(\frac{Ds}{Dl}\right)\left(\frac{N_q}{N_c}\right)$$

$$s_q = 1 + \left(\frac{Ds}{Dl}\right)\tan f$$

$$s_g = 1 - 0.4\left(\frac{Ds}{Dl}\right)$$

Where, Ds = Sort side of Footing

Dl = Long side of footing

c.) Depth Factor (d):

For shallow foundations, in which embedment to footing width ratio (L/D) ≤ 1: L – Depth, D - Width

$$d_c = 1 + 0.4\left(\frac{L}{D}\right)$$

$$d_q = 1 + 2\tan f\,(1 - \sin f)^2\,\frac{L}{D}$$

$$d_g = 1$$

For deeper foundations, in which L/D > 1:

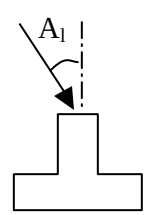
$$d_c = 1 + 0.4\tan^{-1}\left(\frac{L}{D}\right)$$

$$d_q = 1 + 2\tan f\,(1 - \sin f)^2\tan^{-1}\left(\frac{L}{D}\right)$$

$$d_g = 1$$

Where, $\tan^{-1}$ (L/D) is in radius

d.) Load Inclination Factor (i):



$$i_c = i_q = \left(1 - \frac{A_1}{90°}\right)^2$$

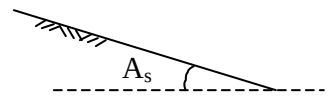
$$i_g = \left(1 - \frac{A_l}{f}\right)$$

Where, A_l is inclination of load in degree. $A_l = \tan^{-1}(P/Q)$ is in radius.

P = Shear Load, Q = Vertical Load

e.) Ground Inclination Factors (g) (Reference: *Foundation Design Principles & Practices*, Donald P. Conduto, p.176):

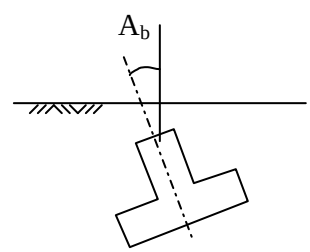
$$g_c = \left(1 - \frac{A_s}{147}\right)$$



$$g_c = g_g = (1 - 0.5 \tan A_s)^5$$

Where, A_s is angle of slope in degree.

f.) Battered Footing Reduction Factors (k_{bat}):



$$k_{bat} = \cos(A_b)$$

Where, A_b is angle of battered footing against vertical axis in degree.

*Attention: Unlike other factors, k_{bat} is not applied to the equation of ultimate downward capacity (q_u) directly. It will be put into the calculation when the <u>total</u> ultimate downward capacity (Q_u) is calculated. Detail about Q_u is given below.

Total ultimate downward capacity (Q_u) represents the total bearing capacity against compression over the area of footing base. It can be determined by the following equations:

Net Ultimate Bearing Capacity (q_{net}):

$$q_{net} = q_u - q$$

Where, q_u = ultimate bearing capacity

q = overburden soil pressure

Total Ultimate Bearing Capacity (Q_{ult}):

$$Q_{ult} = (q_{net} \times k_{bat})\ A$$

Where, k_{bat} = battered footing reduction factor

A = base area of footing

Allowable downward capacity (Q_{allow}) can be calculated by the following equation:

$$Q_{allow} = \frac{Q_{ult}}{F.S.}$$

8.3.2 Capacity for Combined Loading

8.3.2.1 Vertical (Compression) Load (Q) Only

If there is only a vertical load, *Q*, without any lateral loading, i.e. shear loads and bending moment, the Factor of Safety of the shallow foundation can be calculated using the equation below:

$$F.S. = \frac{Q_{ult}}{Q.}$$

Where, Q_{ult} = ultimate bearing capacity

Q = total vertical load

Users can also check the ratio between Q and the allowable bearing capacity, Q_{allow}, to see if the shallow foundation is considered stable. If $Q > Q_{allow}$, the foundation is insufficient.

8.3.2.2 Vertical Load With Moment (Q + M)

Typical lateral loads on the foundation include bending moment (M) and shear load (P) as illustrated in the next diagram. In this section, we will study the procedures used to determine footing capacity against the combination of vertical load and bending moment (Q+M).

Eccentricity (e) will be generated by the moment and vertical load (see Figure 8-12):

$$e = \frac{M}{Q}$$

a.) If **e** £ **D/6**, the pressure on the foundation can be determined by:

$$q_{\max} = \frac{Q}{DB} + \frac{6M}{D^2 B}$$

$$q_{\min} = \frac{Q}{DB} - \frac{6M}{D^2 B}$$

Where, D = width of foundation base in lateral load direction

B = length of foundation base in the other direction

Reaction pressure at the base of the foundation distributed in a trapezoid pattern across the full width (D) of the foundation.

b.) If **e** > **D/6**, then:

$$q_{\max} = \frac{4Q}{4B(D-2e)}$$

$$q_{\min} = 0$$

Reaction pressure at the base of the foundation is distributed in a triangular pattern across the effective width (D') of the foundation.

$$D' = D - 2e$$

Due to the distribution of reaction pressure, a new ultimate bearing capacity called, q_{ult}', has to be recalculated using the same procedures as mentioned in Section 8.3.1.1, but based on D' instead of D.

To calculate the Factor of Safety:

$$F.S. = \frac{q_{ult}'}{q_{\max}}$$

or

$$F.S. = \frac{Q_{ult}'}{Q}$$

Where, $Q_{ult}' = q_{ult}' \cdot D' \cdot B$

8.3.2.3 Vertical Load With Shear Load (Q + P)

The shear load (P) has two impacts to the shallow foundation calculation:

1. It generates load inclination – $A_l = \tan^{-1}(P/Q)$ – which affects vertical bearing capacity calculation (see Section 8.3.1.1).
2. Footing base sliding calculation becomes necessary. The sliding resistance (P_f) can be calculated by the following equation:

$$P_f = k_f (W + Q)$$

Where, k_f = base friction factor for cast-in-place foundation

k_f is close to $\tan\phi$ (ϕ = angle of internal friction)

k_f = 0.3-0.8 is recommended

W = weight of footing and the soil above

Factor of Safety against sliding can be calculated by:

$$F.S. = \frac{P_f}{P}$$

8.3.3 Settlement From Vertical Load

If only vertical load is applied to the shallow foundation, the elastic settlement (X_0) of the footing can be calculated using the equation below:

Where, q0 = pressure under working load

$$X_0 = \frac{Dsq_0}{E_s}(1 - m^2)a$$

$$q_0 = \frac{Q}{Area} \quad or \quad q_0 = \frac{q_u}{F.S.}$$

Ds – Short side of footing

Dl – Long side of footing

μ - Poisson ratio; μ = 0.3 is recommended for general soil conditions

E_s - Young's modulus

$E_s = 766N_{SPT}$ for cohesionless soils

$E_s = 375C$ for cohesive soils

Where, N_{SPT} = blow count over 12" of soil

C = undrained cohesion of soil

α = Settlement factor for flexible foundation, which is a function of Dl/Ds (footing shape ratio)

[Note 1] X_0 is the elastic settlement at the center of a footing. If there is soft clay underneath the footing, consolidation settlement, which is time-dependent, should be considered. *AllPile* does not include calculation of consolidation settlement as it is not within the scope of the program.

[Note 2] AllPile assumes that a hard layer of soil, i.e. rock or intermediate geomaterials (IGMs) is in great depth from the base of footing. If H_a, the distance between footing base and hard soil, is over 4 times the footing width (D), the actual elastic settlement will not change considerably.

If H_a is less than 4D, the elastic settlement can be calculated based on the following equation:

$$X_0' = X_0 \frac{H_a}{4D} \qquad (H_a < 4)$$

Where, X_0' = actual elastic settlement when Ha < 4D

X_0 = elastic settlement based on H_a > 4D

H_a = distance between bottom of footing and hard soil

If user does not define H_a, *AllPile* will automatically search for the closest hard soil stratum with $N_{SPT} \geq 50$ based on user's input in the *Soil Property* page.

8.3.4 Rotation From Moment

The maximum settlement and rotation for a footing under both vertical and lateral loads can be determined by the following procedures:

1. Calculate eccentricity and effective width (D') based on section 8.3.2.2.
2. Determine the ultimate capacity (Q'_{ult}) under moment and vertical load from Section 8.3.2.2
3. Determine the Factor of Safety under both moment and vertical load

$$F.S._1 = \frac{Q_{ult}}{Q}$$

4. Calculate the ultimate capacity under vertical load only (see Section

$$Q_{ult}(v)$$

8.3.2.1)

5. Get Q_{allow} (v) under vertical load only

$$Q_{allow}(v) = \frac{Q_{ult}(v)}{F.S._1}$$

6. Calculate X_0 under Q_{allow} (v) based on Section 8.3.3
7. Determine the maximum settlement and rotation using the equations below:

$$X_{\max} = X_0\left[1 + 2.31\left(\frac{e}{D}\right) - 22.61\left(\frac{e}{D}\right)^2 + 31.54\left(\frac{e}{D}\right)^3\right]$$

$$X_e = X_0\left[1 - 1.63\left(\frac{e}{D}\right) - 2.63\left(\frac{e}{D}\right)^2 + 5.83\left(\frac{e}{D}\right)^3\right]$$

$$R_t(Rotation) = \sin^{-1}\left[\frac{X_{\max} - X_e}{\frac{D}{2} - e}\right]$$

Where, X_{max} = settlement at edges of footing

X_e = settlement under point of vertical load (vertical load may not apply to center of footing)

e = eccentricity

R_t = Rotation of Footing

*Note: These equations are only valid if $e/D \leq 0.4$

8.4 UPLIFT PLATE

Uplift plates are commonly used as a ground anchors to stabilize structures that are subject to shear loads or moments. Due to its characteristics, uplift plate only provides uplift resistance against pull out, and has no bearing capacity. Uplift plate calculation can be divided into two modes:

- Shallow mode if L (= embedment) ≤ L_{cr}
- Deep mode if L > L_{cr}

Where ***L_{cr} = critical depth*** in uplift resistance calculation

For cohesionless soils, L_{cr} is defined in Figure 8-14; for cohesive soils, L_{cr} can be determined using the following equations:

$$L_{cr} = D\,(0.107\,C_u + 2.5)$$

$$L_{cr} \leq 7D$$

Where C_u = undrained cohesion in kPa

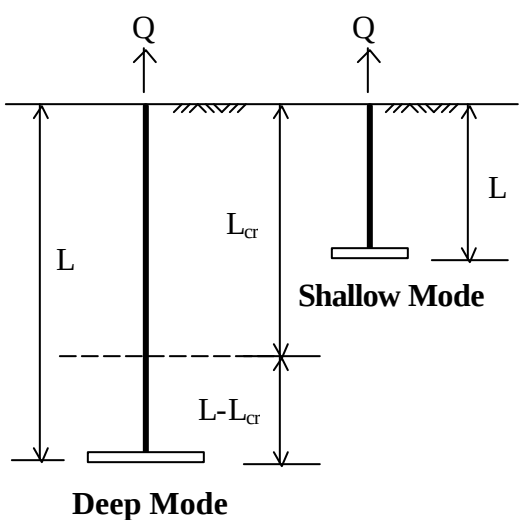


Figure 8-14 Critical Depth of Uplift Plates

8.4.1 Shallow Mode

For Cohesionless Soils

Uplift capacity (Q_{uplift}) can be determined by the following equation:

$$Q_{uplift} = B_q \cdot A \cdot gL + W$$

Where, A = area of plate

W = weight of plate

B_q = breakout factor

$$B_q = 2\left(\frac{L}{D}\right)K_u'\tan f\left[m\left(\frac{L}{D}\right)+1\right]+1$$

Where, D = width of plate

K_u' = uplift factor, equal to 0.9 in general

ϕ = internal angle of friction of soil

m = shape factor coefficient, a function of ϕ and is defined in figure 8-15

For Cohesive Soils

Uplift capacity (Q_{uplift}) can be determined by the following equation:

$$Q_{uplift} = (C_u \cdot B_c + gL)A + W$$

Where, B_c = breakout factor, can be determined using the Figure 7-14 on page 78

C_u = undrained cohesion in kPa

A = area of plate

W = weight of plate

8.4.2 Deep Mode

For Cohesionless Soils

Uplift capacity (Q_{uplift}) in deep mode can be determined by the following equation:

$$Q_{uplift} = Q'_{plate} + Q'_{skin}$$

Where, Q'_{plate} = uplift capacity calculated in shallow mode

Q'_{side} = side resistance developed in the portion of ($L - L_{cr}$)

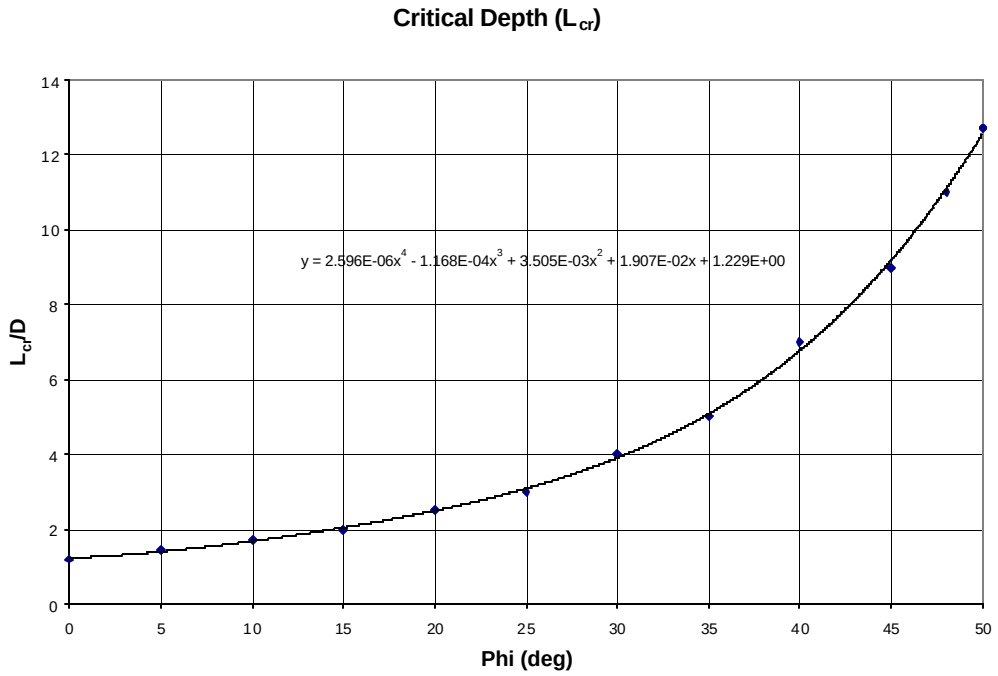


Figure 8-15 The relationship between critical depth (Lcr) and friction angle of soil (Phi)

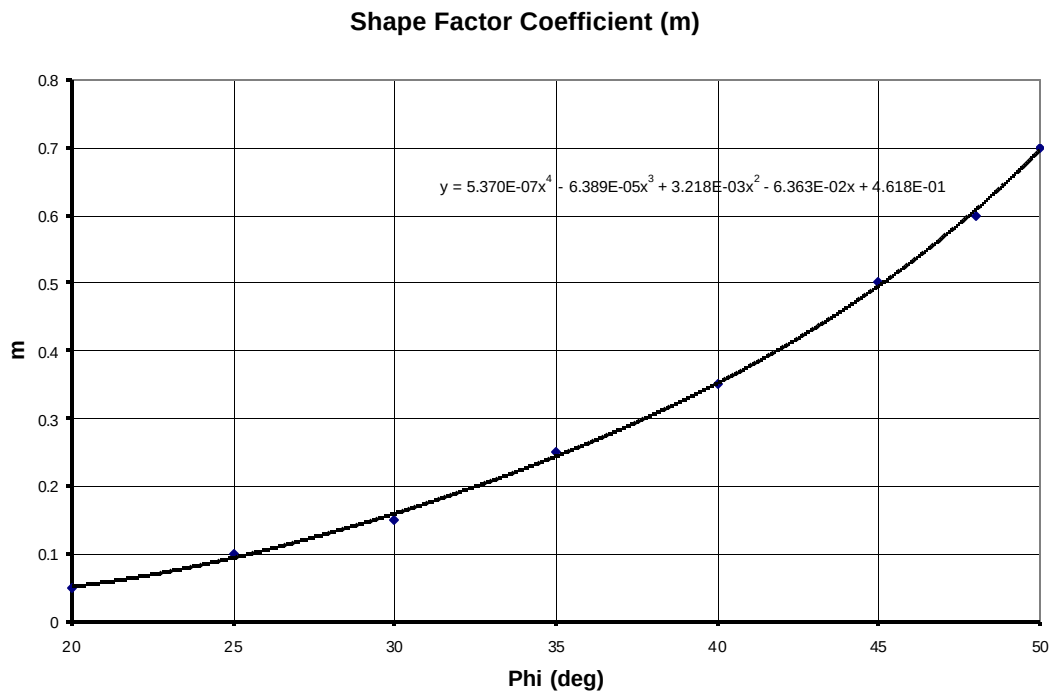


Figure 8-16 The relationship between shape factor coefficient (m) and friction angle of soil (Phi)

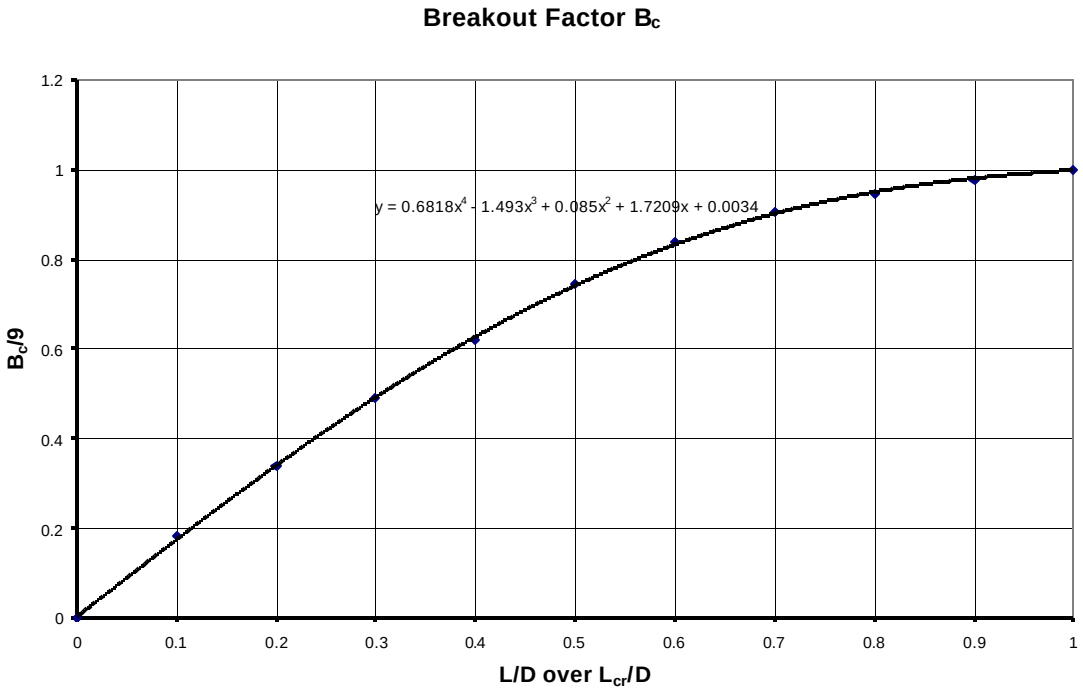


Figure 8-17 The relationship between breakout factor (Bc) and the ratio of embedment against

8.5 UPLIFT ANCHOR

Uplift anchors have the same function as uplift plates, though they use a completely different mechanism. Unlike uplift plates, which develop bearing capacity generated from its base plate against the soil mass on top of the plate to resist uplift forces, uplift anchors generates the majority of the uplift resistance through adhesion and friction along their grouted section. An uplift plate can be divided into two portions.

- The top section, formed by uncovered steel bar which extends from the ground surface to the top of the grout, is typically called Free Length (L_f). Friction developed in this section is neglected.
- The bottom section is the grouted portion of the uplift anchor with a diameter of D. The total side resistance generated in this section is based on the adhesion of the grout and the bonded length (L_b).

The amount of adhesion is developed on grout pressure. The higher the grout pressure, the higher the adhesion that can be achieved from the bonded length. Post-grout also helps to generate higher adhesion.

$$Q_{uplift} = pD \cdot L_b \cdot C_a$$

Where, L_b = bonded length

C_a = adhesion input by user

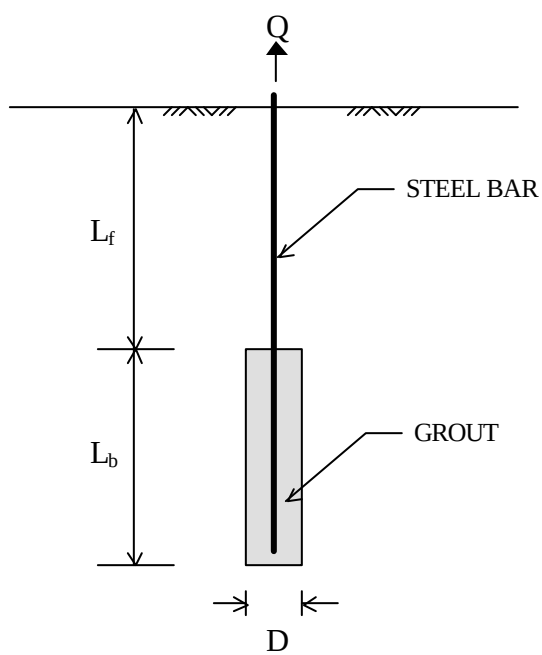


Figure 8.18 Uplift anchor

8.6 SOIL PARAMETERS AND CORRELATIONS

There are a number of references in the industry that present the correlations between soil parameters. The soil parameters function is useful if users only have a few parameters available and want to estimate the others to complete the calculation. However, one should bear in mind that these correlations are from various sources, references, and statistical results of different soil types under different conditions. The actual value may be different from the estimate given by the correlation. Users should make their own judgment based on local experience and local soil conditions and adjust the values accordingly.

Following are the references used to form the soil correlation in the program:

Table 8-6. General Soil Parameters for Sand

Compactness			Very Loose	Loose	Medium	Dense	Very Dense
	Symbol	Unit					
SPT*	N_{SPT}	--	0-4	4-10	10-30	30-50	>50
Relative Density	Dr	%	0-15	15-35	35-65	65-85	85-100
Friction	ϕ	Deg	<28	28-30	30-36	36-41	>42
Unit Weight							
Moist	γ	pcf	<100	95-125	110-130	110-140	>130
Submerged	γ	pcf	<60	55-65	60-70	65-85	>75

*SPT -- Standard Penetration Test
Reference: Steel Sheet Piling Design Manual, USS, 1975, p.12

Table 8-7. General Soil Parameters for Clay

Consistency			Very Soft	Soft	Medium	Stiff	Very Stiff	Hard
	Symbol	Unit						
SPT	N_{SPT}	--	0-2	2-4	4-8	8-16	16-32	>32
UCS*	q_u	pcf	0-500	500-1000	1000-2000	2000-4000	4000-8000	>8000
Shear Strength	C_u	psf	0-250	250-500	500-1000	1000-2000	2000-4000	>4000
Unit Weight								
Saturated	γ	pcf	<100	100-120	100-130	120-130	120-140	>130

*UCS -- Unconfined Compressive Strength
Reference: Steel Sheet Piling Design Manual, USS, 1975, p.12

k and e50:

There are two parameters that are particularly important for lateral pile analysis—Modulus of Subgrade Reaction (k) and Soil Strain (E_{50}). Modulus of subgrade reaction is used in the equation $Es = k\,x$ in COM624S analysis, where Es is the secant modulus on a p-y curve and x is the depth below ground surface. The value of k describes the increase in Es with depth. Please note that the k-value is not the same as the coefficient of vertical subgrade reaction used to calculate elastic settlements of shallow foundations. It is also different from the coefficient of lateral subgrade reaction used in **elastic** pile analysis. (For more detail and example, please refer to NAVY DM7, 2-235. COM624S uses nonlinear differential analysis.) On the other hand, the soil strain E_{50} parameter is only applicable for clay soil and is obtained by either lab testing or by correlation. The input value E_{50} represents the axial strain at which 50% of the undrained shear strength is developed in a compression test. The following two tables demonstrate the correlation of k and E_{50} with other soil parameters for different soil type:

Table 7-8. Modulus of Subgrade Reaction (k) vs N_{SPT} for Sand

Compactness			Loose	Medium	Dense
	Symbol	Unit			
SPT	N_{SPT}	--	4-10	10-30	30-50
MSR*					
(Dry)	k	kN/m^3	6790	24430	61000
		pci	25	90	225
(Saturated)	k	kN/m^3	5430	16300	33900
		pci	20	60	125

*MSR -- Modulus of Subgrade Reaction
Reference: Handbook on Design of Piles and Drilled Shafts Under lateral Load, US Department of Transportation, 1984, p.64

Table 7-8. Modulus of Subgrade Reaction (k) and Soil Strain (E_{50}) vs N_{SPT} for Clay

Consistency			Soft	Medium	Stiff	Very Stiff	Hard
	Symbol	Unit					
SPT	N_{SPT}	--	2-4	4-8	8-16	16-32	>32
Shear Strength	C_u	kPa	12-24	24-48	48-96	96-192	192-383
		psf	250-500	500-1000	1000-2000	2000-4000	>4000
MSR*							
Static Loading	k	kN/m^3	8140	27150	136000	271000	543000
		pci	30	100	500	1000	2000
Cyclic Loading	k	kN/m^3	--	--	54300	108500	217000
		pci	--	--	200	400	800
Soil Strain	E_{50}	%	2	1	0.7	0.5	0.4

Reference: Lateral Load Piles, Lymon C. Reese, p.97

8.7 Open End Pile with Plugged Condltions

For diving pile, users can select between open-end pile and close-end pile in Page A, Item 1.

- In open-end pile program uses effective area (A' - the area of steel tube) for tip resistance calculation.
- In close-end pile, program uses total gross area (At - the area base on outside diameter) for tip resistance calculation.

In both types, you always can add a tip section (Page C, Item 2), and then specify a tip area you want in following steps:
1. Select open-end pile or close-end pile in Page A, Item 1.
2. Create a tip section in Page C, Item 2.

Input a tip area (Here we call it as A_plug).

You need estimate A_plug based on soil type, local experience and knowledge of piles.
A_plug always falls between A and A'
If pile is fully plugged, use A_plug=At
If pile is not plugged, use A_plug=A'
The easy way is using A_plug=(A+A')/2
If it is more plug and more friction inside, A_plug close to At.
If it is less plug and less friction inside, A_plug close to A'.

The side resistance calculation outside pile is the same between two types of piles.

APPENDIX A SYMBOLS AND NOTATIONS

Symbol	Description	English	Metric
S_v	Vertical stress in soil (overburden pressure)	ksf	kN/m^2
S_h	Horizontal stress in soil	ksf	kN/m^2
q_{ult}	Ultimate end bearing	ksf	kN/m^2
$S_f = f_0 + C_a$	Side resistance, combination of skin friction and adhesion	ksf	kN/m^2
f_0	Skin friction from cohesionless soils (ultimate)	ksf	kN/m^2
C_a	Adhesion from cohesive soils (ultimate)	ksf	kN/m^2
FS_{work}	Factor of safety at working load condition	--	--
FS_{side}	FS for side resistance in downward calculation	--	--
FS_{up}	FS for side resistance in uplift calculation	--	--
FS_{tip}	FS for tip resistance in downward calculation	--	--
FS_{w}	FS for weight of pile in uplift calculation	--	--
Q_{tip}	Vertical tip resistance	kip	kN
Q_{up}	Uplift ultimate capacity	kip	kN
Q_{dw}	Downward (compression) ultimate capacity	kip	kN
Q_{neg}	Load from negative friction	kip	kN
Q_{work}	Vertical work load or design load applied to pile	kip	kN
Q_{allw_u}	Allowable uplift capacity	kip	kN
Q_{allw_d}	Allowable downward capacity	kip	kN
Q_{group}	Vertical capacity of group pile	kip	kN
Q_{single}	Vertical capacity of single pile	kip	kN
Q_{plate}	Vertical uplift capacity of plate or bell	kip	kN
dz or dl	Pile segment	ft	m
K_{bat}	Factor for battered pile	--	--
R_t	Base rotation	degree	degree
R, R_{side} or R_{front}	Group reduction factor	--	--
y_t or y	Lateral deflection	in	cm
x	Vertical settlement	in	cm
L_{cr}	Critical depth in uplift analysis	ft	m

APPENDIX B UNITS CONVERSIONS

English to Metric	Metric to English
1 ft = 0.3048 m	1 m = 3.281 ft
1 in = 2.54 cm = 25.4 mm	1 cm = 0.3937 in
1 lb = 4.448 N	1 mm = 0.03937 in
1 kip = 4.448 kN	1 N = 0.2248 lb
1lb/ft^2 = 47.88 N/m^2	1 kN = 224.8 lb = 0.2248 kip
1 kip/ft^2 = 47.88 kN/m^2 = 47.88 kPa	1 N/m^2 = 20.885 x 10^{-3} lb/ft^2
1lb/ft^3 = 0.1572 kN/m^3	1 kN/m^2 = 1 kPa = 20.885 lb/ft^2 = 20.885 x 10^{-3} kip/ft^2
1lb/in^3 = 271.43 kN/m^3	1 kN/m^3 = 6.361 lb/ft^3 = 0.003682 lb/in^3

Note: In some places of the program, “kp” is used instead “kip” due to limited spaces.