UPGRADE OF AXIALLY LOADED PILE-SOIL MODELING WITH THE IMPLEMENTATION OF LRFD DESIGN PROCEDURE

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DISCLAIMER

This report/user manual and the accompanying design software (WBUZPILE) were prepared for use by the Alabama Department of Transportation (ALDOT) technical staff. Neither the Alabama Department of Transportation nor the Principal Investigator warrants the manual, the software and results to be free of defects. All users are warned that they must have the technical training and experience to apply the information to their needs, and they must be responsible for the outcomes of such applications. Methods and techniques applicable to one locale or situation may not be suitable for others, and users are responsible for recognizing such deviations and for making appropriate adjustments. Some errors may exist in both the manual and software that may affect the results obtained. It is the user's responsibility to check results and to assure correctness and suitability of those results. This report and the accompanying design software do not constitute standard specifications, or regulations.

FORWARD

This report and the accompanying computer code (Software, WBUZPILE) describe the characterization and analysis of piles under axial loads. A combination of different formulas obtained from ALDOT long time experience along with fundamental equations of deep foundations are employed in this program to assess the axial capacity of driven piles. The report focuses on the entry of input data, interpretation of the output results and description of the employed soils and equations. In addition to sand and clay models developed by ALDOT, the report presents modeling formula for silt soils that include sandy silt and clayey silt and weathered rock (soft rock). The current program analysis allows the utilization of the LRFD approach that determines the geotechnical resistance factor based on the calibration by fitting as presented in Chapter 1. In addition to the use of varying values of safety factors and DL/LL, the program user can also use a default resistance factor of 0.71 which is based on a commonly used safety factor of 2 and DL/LL ratio of 2 as recommended by ALDOT.

The obtained results are presented numerically and graphically through the output data files and plotted graphs. Several warning messages are built in the program to avoid many of the common mistakes. It should be mentioned that the current version of the program WBUZPILE has the capability of directly uploading the input data files created earlier by the original program BUZPILE with no need for any modifications.

This report/user manual and related software have been developed by Dr. Mohamed Ashour, Mr. Amr Helal and Mr. Hamed Ardalan at the University of Alabama, Huntsville for the Alabama Department of Transportation (ALDOT) under the Research Project 930-769.

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CHAPTER 1

IMPLEMENTATION OF LRFD IN THE DESIGN OF DRIVEN PILES USING THE CALIBRATION BY FITTING

1.1 Introduction

In the Allowable Stress Design (ASD), the uncertainties or risks (errors and variations) in the calculations of loads and resistances are accounted for through one single factor of safety (FS). That factor of safety is applied to the sum of unfactored loads {Dead Load (DL), Live Load (LL), ….} to compare with the nominal resistance (R_n)

$$R_n \geq FS\ (DL + LL)$$

Unlike the ASD, the Load and Resistance Factored Design (LRFD) accounts for

1. the uncertainties associated with the estimated design load through the load factor (γ); and

2. the uncertainties associated with the estimated nominal geotechnical resistance (R_n) via the resistance factor, ϕ.

In the LRFD, the sources of uncertainties are separated to make it simpler and more rational to evaluate them (determine ϕ and γ) based on scientific methods (Abu-Hejleh et al. 2009).

The way the loads are combined in the LRFD for the strength limit and compared to resistances is significantly different from the ASD. Strength I is the most common and basic load group (no wind). The load factors (γ) for the same load type vary among the different strength groups (Strength I, II, III, IV, and V). The Strength I load factors are considered in the calibration of the geotechnical resistance factors, where the dominant loads are the Dead Load (DL, load factor 1.25) and Live Load (LL, load factor 1.75), with an average load factor of 1.4 (Abu-Hejleh et al.

2009). The load factors of the other load groups (Strength II, III, IV, and V) are selected to reflect the certainty and importance of these loads and to generate overall reliability with the loads close to that of the Strength I loads. Consequently, it is suggested the calibration of resistance factors using the Strength I Load Group be reasonable for use with other load groups.

There are two calibration methods to determine the LRFD resistance factor (ϕ).

1. The first method is the calibration by fitting with factors of safety of the allowable stress design (ASD) method to avoid unacceptable deviation from the past safe and satisfactory practices. With this approach, the LRFD geotechnical design results would be similar to those generated in the ASD method. This method is usually used to determine the resistance factors when a database or case histories are not available.

2. The second calibration method is to use the reliability analysis that would be considered when reliable/adequate number of load test data is available.

1.2 Calibration of Geotechnical Resistance Factor (ϕ) by Fitting to the ASD Factor of Safety (FS)

ALDOT uses in-house design method for the evaluation of the static axial capacity of driven piles based on the correlation between the SPT-N and soil properties to obtain pile tip and side ultimate resistance. With this approach, the LRFD geotechnical design results would be similar to those generated in the ASD method. This approach requires the Factor of safety (FS) of the ASD method and Strength I load factors with a load factor of 1.25 for Dead Loads (DL) and 1.75 for Live Loads (LL), as appeared in AASHTO LRFD 2010.

Fitting the geotechnical resistance factor (ϕ) with the ASD Factor of Safety (FS) is expressed as,

$$\phi = \frac{\gamma_{DL}(DL/LL) + \gamma_{LL}}{(DL/LL + 1)FS}$$

γ_{DL} = 1.25 and γ_{LL} = 1.75 where typical DL/LL ratio ranges between 1.5 to 3.

Table 1.1 Resistance factors fitting with different ASD factors of safety

DL/LL	Resistance Factor (ϕ)			
	FS = 1.5	FS = 2.0	FS = 2.5	FS = 3.0
1.5	0.97	0.73	0.58	0.48
2	0.94	0.71	0.57	0.47
2.5	0.93	0.70	0.56	0.46
3	0.92	0.69	0.55	0.46

Based on DL/LL ratio = 2 and desired Factor of Safety (FS = 2.0) as an example, the Geotechnical resistance Factor (ϕ) is calculated (0.71) and employed to obtain the Pile Factored Resistance. To facilitate the implementation of the LRFD, the computer program WBUZPILE internally employs a resistance factor (ϕ) of 0.71 as a default value in the program that has been determined based on the method of calibration by fitting to the ASD safety factor. However, the program allows the user to enter different values of DL/LL and FS to obtain different Geotechnical resistance Factor (ϕ).

CHAPTER 2

INPUT DATA

The user needs to enter the following data as shown in **Fig. 2-1**:

1. **Number of Soil Layers:**

   Enter the total number of soil layers in the soil profile with maximum of 15 layers. The program does not allow the user to enter more than 15 layers.

   Press Enter or *click Update Screen* to update the soil tables for the new soil layers.

2. **Elevation of Zero Depth (ft):**

   Enter the elevation of the ground surface (zero, positive or negative value).

3. **Table of Soil Profile and Properties:**

   a) Soil Type (Fig. 2-2):

   The program provides five different types of soil (sand, clay, weak rock, sandy silt, clay silt). Click the appropriate type of soils.

   Sand

   Clay

   Weathered Rock

   Sandy Silt: Use sandy silt for fine soil with plasticity index (PI) < 4

   Clayey Silt: Use clayey silt for fine soil with plasticity index $7 \geq (PI) \geq 4$

   b) Soil Description (Fig. 2-3):

   The user can type up to 30 characters for soil description.

   c) Depth to Bottom of Layer:

   Enter a positive value for the depth of the soil layer measured from the ground surface (Not the elevation of the ground surface)

   d) Blowcounts (N):

   Enter the Standard Penetration Test blowcounts per foot (N) after correcting N for the hammer efficiency of 60% (N_{60}) .

$$N = N_{60} = N_{field} \frac{Hammer\ Efficiency\ \%}{60\%}$$

- Use the mouse click or click Enter to move among the same soil table cells. Use the tab key to alternate between the soil and pile properties tables.

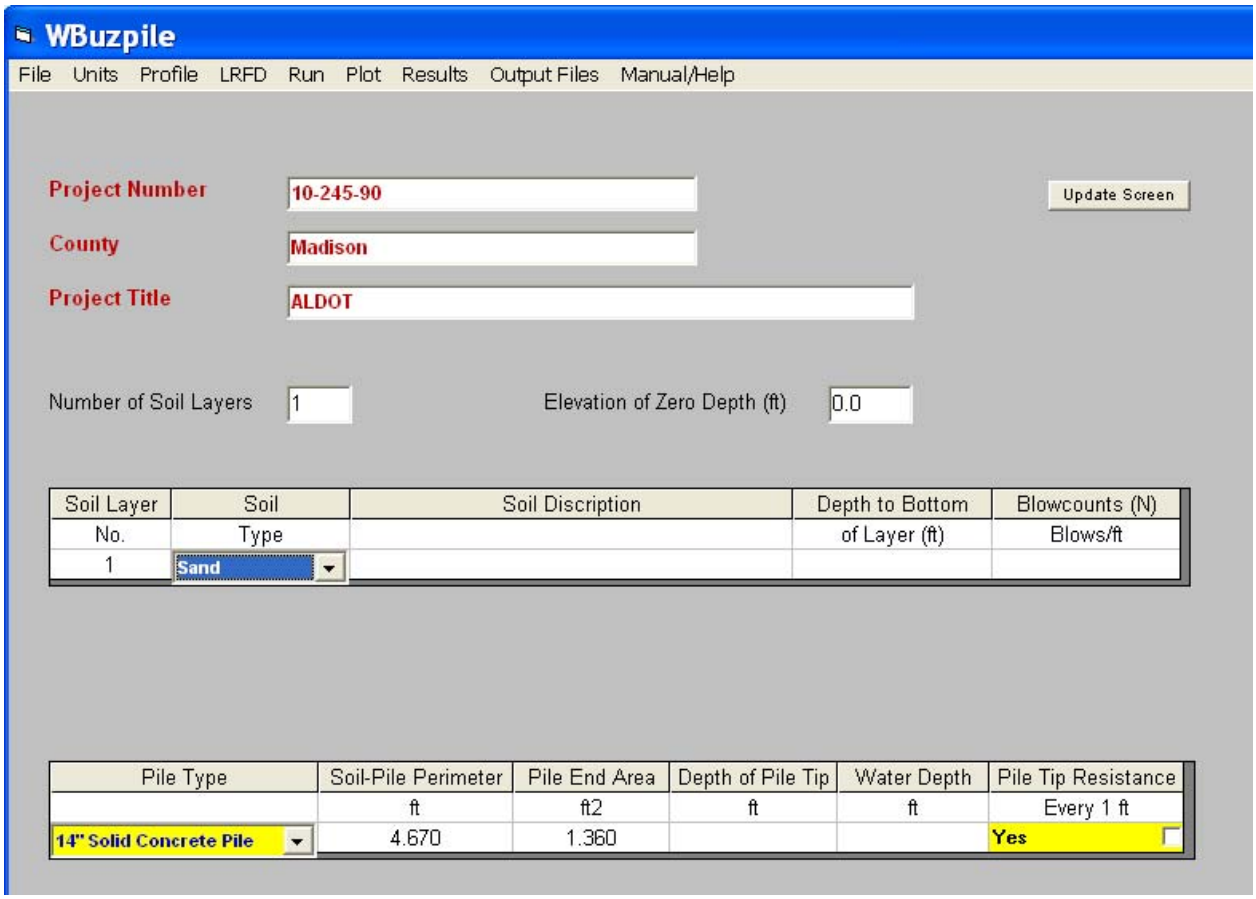


Fig. 2-1 Basic image for the software initial front page

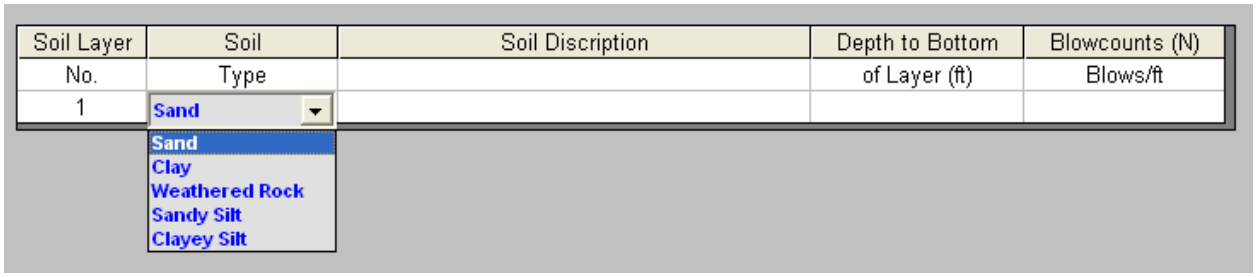


Fig. 2-2 The different types of soil employed in the software

Number of Soil Layers 11 Elevation of Zero Depth (ft) 90.0

Soil Layer No.	Soil Type	Soil Discription	Depth to Bottom of Layer (ft)	Blowcounts (N) Blows/ft
1	Sand	Loose Moist Sand	1.00	4
2	Sand	Medium Moist Sand	5.00	11
3	Sand	Loose Moist Sand	11.00	8
4	Sand	Medium Damp Silty Sand	15.00	21
5	Sand	Dense Sand	25.00	30

Fig. 2-3 Input soil profile and field data

4. Table of Pile Properties (Fig. 2-4):

a) Pile Type:

The user can choose the pile type from a drop-down menu that contains 11 different types of piles (most common type of piles used by ALDOT).

14" Solid Concrete Pile
16" Solid Concrete Pile
18" Solid Concrete Pile
20" Solid Concrete Pile
HP 10" x 42 Steel Pile
HP 12" x 53 Steel Pile
HP 14" x 73 Steel Pile
HP 14" x 89 Steel Pile
24" Hollow PSPT
30" Hollow PSPT
36" Hollow PSPT
New Steel Pile
New Concrete Pile

- By clicking the appropriate pile type, the following pile properties of the pile section will be uploaded,

Soil-Pile Perimeter: Pile perimeter in contact with soils that is used to determine the soil-pile frictional resistance along the pile side (shaft)

Pile End Area: Pile tip/base area used to calculate the pile tip bearing capacity (i.e. tip resistance)

- The user can also click "New Steel Pile" or "New Concrete Pile" option at the end of the Pile Type drop-down menu to enter new properties (Soil-Pile Perimeter and Pile End Area) for unregistered piles.

b) Depth of Pile Tip:

Enter the depth of the pile tip measured from the ground surface (i.e. the embedded length of the pile)

c) Water Depth:

Enter the depth of free water table (positive value) measured from the ground surface. If the water table is too deep, use a water depth value larger than the pile length.

d) Pile Tip Resistance:

- Check the pile tip resistance box every unit length to get the pile tip and side resistance every unit length (1 ft or 1 meter). This provides a profile for the pile side and tip resistance during the pile driving. Regardless of the value entered for the "Depth of Pile Tip", the embedded pile length (i.e. the analysis) continues down to the depth of the bottom of the last soil layer entered in the Soil Property Table.
- Uncheck the box of "Pile Tip Resistance every 1 ft" to get the pile capacity, pile tip resistance and side resistance just at the value assigned for the "Depth of Pile Tip" (not every unit length of the pile)

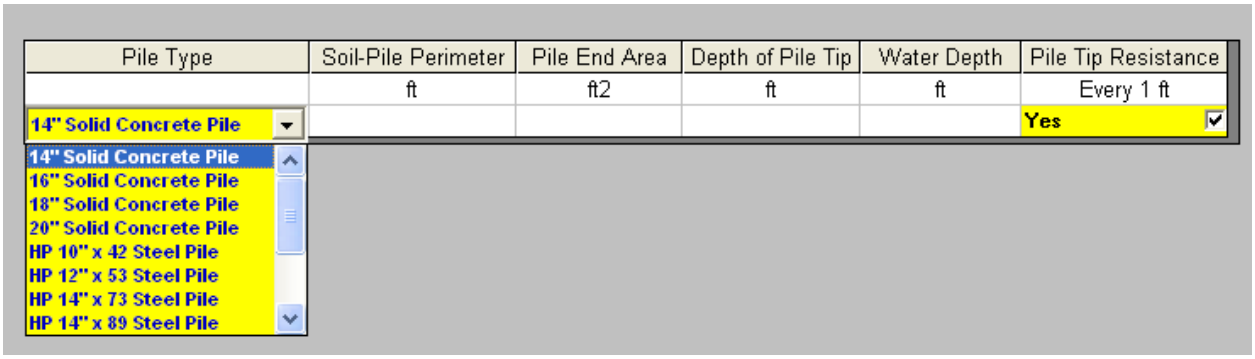


Fig. 2-4 Pile database in the software

5. Program Features for Input Data

a) Save Input Data File:

- Click *File* on the upper menu and then *Save As* to save the input data for the first time with a specific file name. The user can choose/create any folder to save the new file (**Fig. 2-5**). The name of the file will appear on the left upper corner of the program window. The program saves the input data file with an extension (*.INP)
- Click *File* and then *Save* to save the data input at anytime during the process of entering data. If the user clicks *Save* before the file yet has a name assigned, the Save As window will be opened.
- The user can upload any saved input data file that was created earlier by clicking *Open File* on the *File* menu (**Fig. 2-5**). A new window will be opened to list all saved input data file in that folder with extension (*.INP) (**Fig. 2-6**).
- Click *Exit* on *File* menu to close the program

b) Units:

The program has the capability to use Imperial and SI units with the input and output data. It can also convert the SI units to Imperial ones and vise versa by clicking the desired units (**Fig. 2-7**).

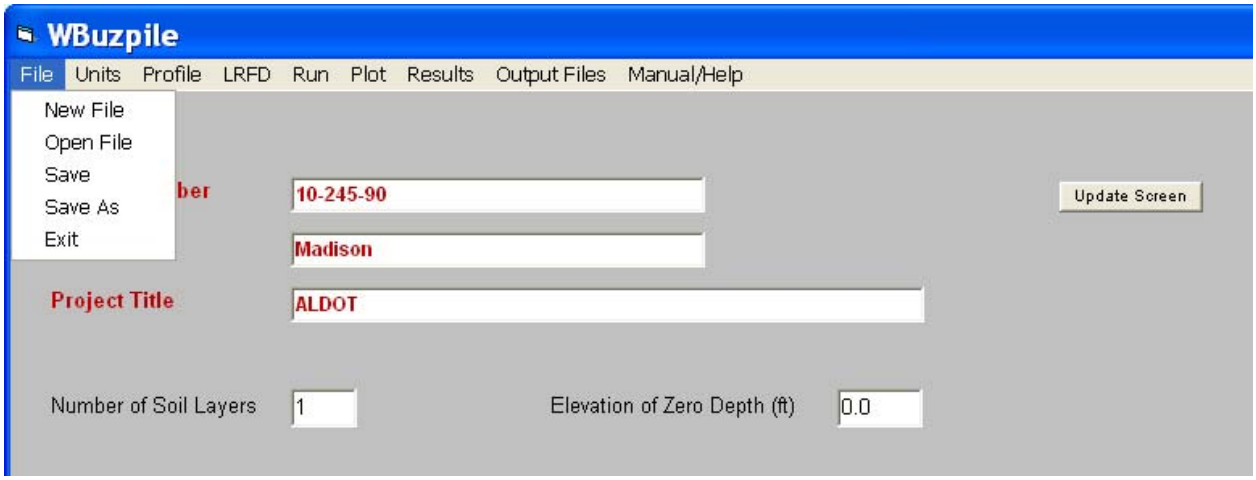


Fig. 2-5 Save and Open options in the software

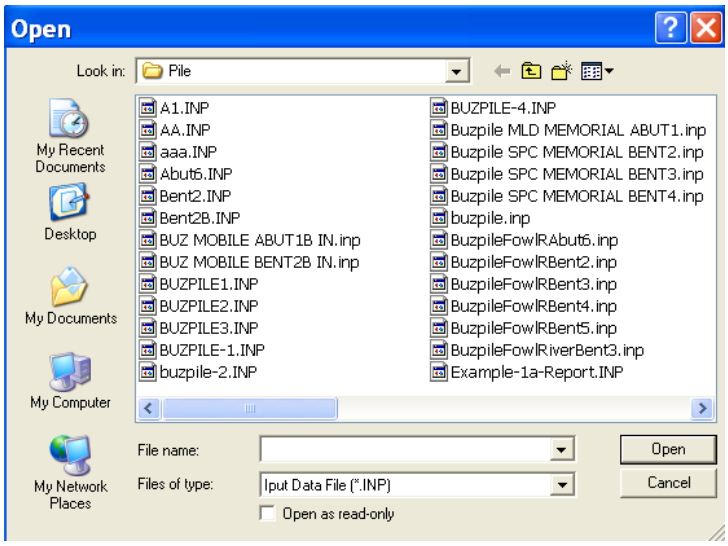


Fig.2-6 Open existing input data file

c) Profile:

Click *Profile* in the upper menu to plot the pile as embedded in the given soil layers. Plotted soil layers will be numbered from the top down listed in the Soil Property Table. The pile and values of soil layer depths below the ground surface will be plotted on the soil profile. As seen in **Fig. 2-8**, every soil type (sand, clay, -----) will have a distinctive color after selection. In addition to the table of soil properties, the user can plot the soil profile to locate any mistake in soil layer thicknesses.

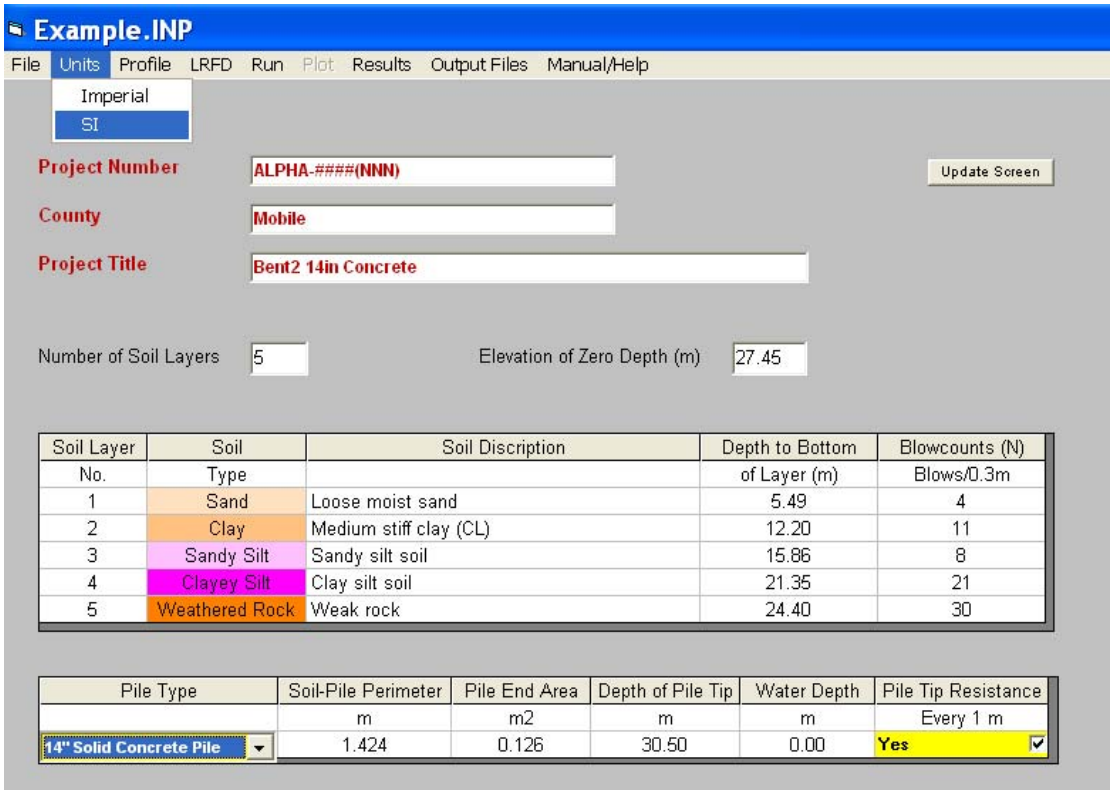


Fig. 2-7a Program flexibility of using SI units including unit conversion

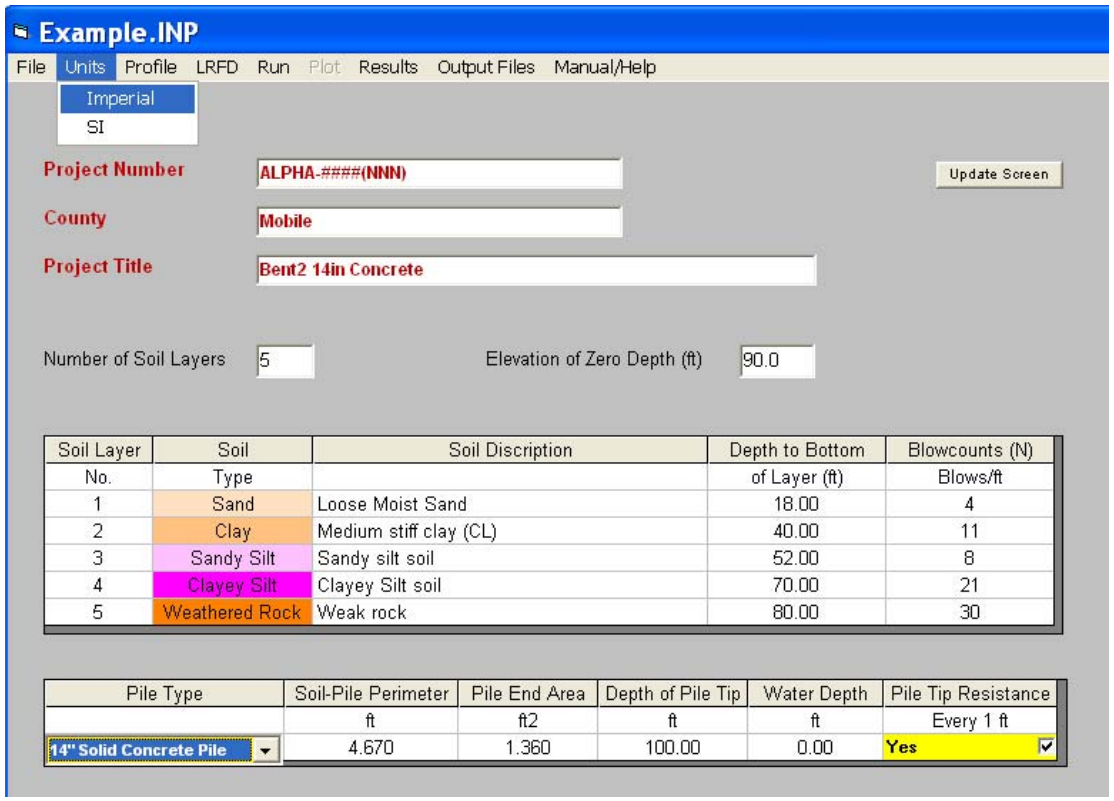


Fig. 2-7b Program flexibility of using Imperial units including unit conversion

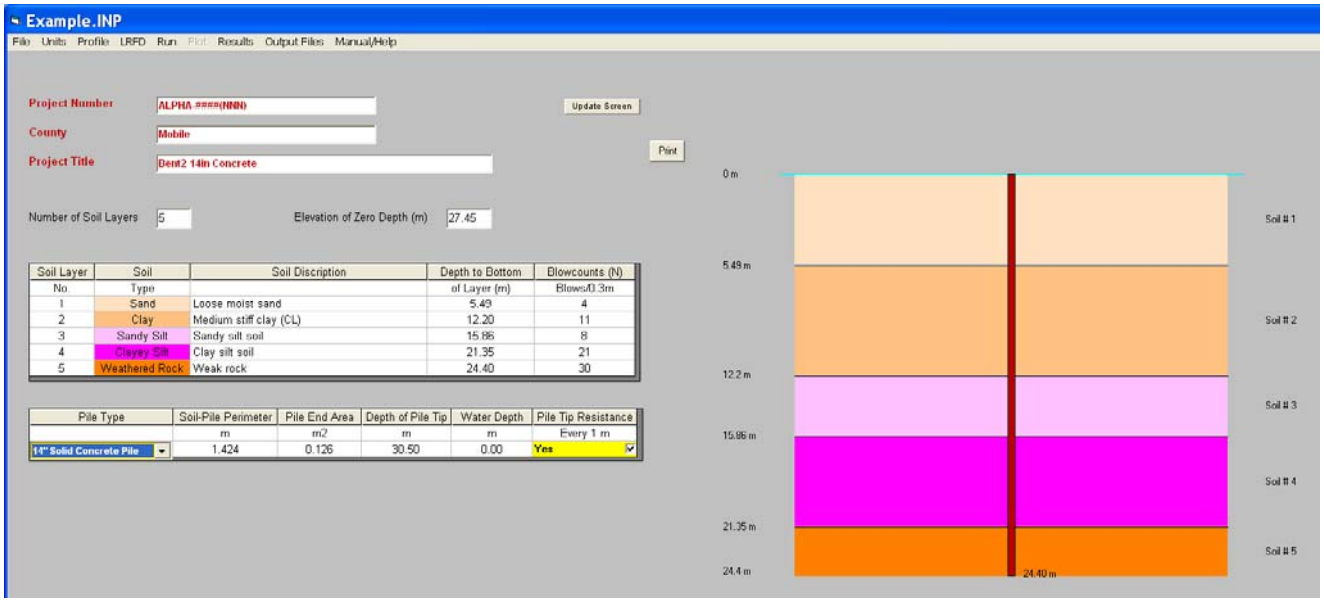


Fig. 2-8a Plot of input soil profile in SI units

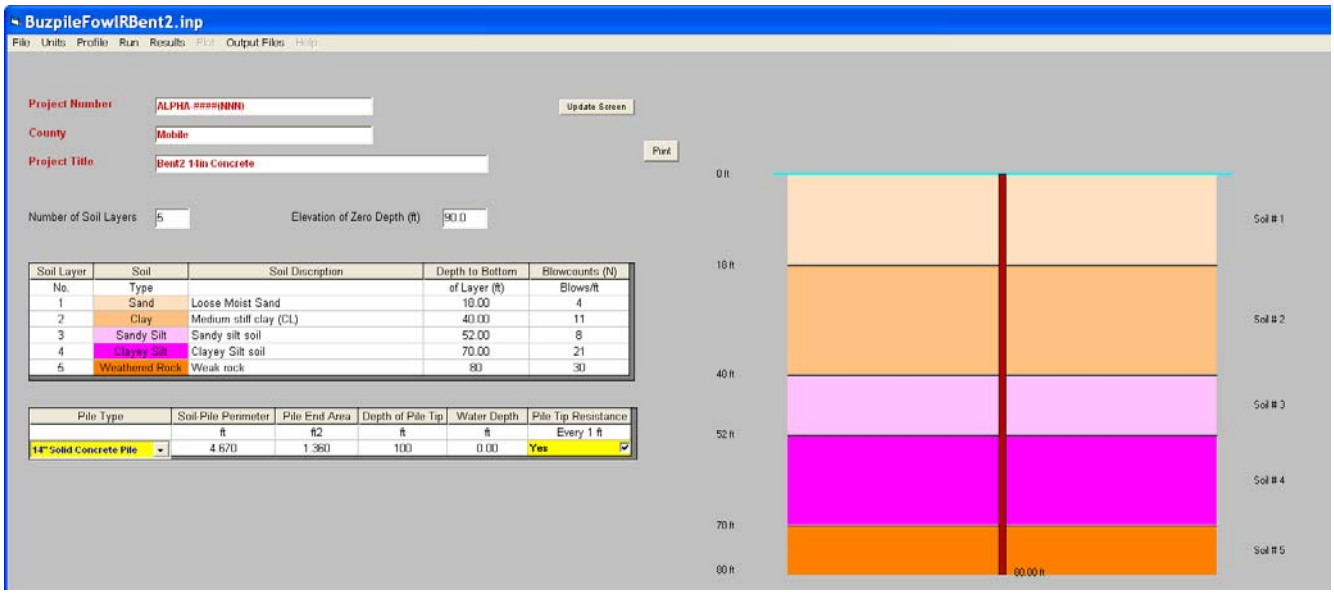


Fig. 2-8b Plot of input soil profile in Imperial units

d) LRFD:

Click *LRFD* in the upper menu to show the LRFD table parameters (**Fig. 2-9**) DL/LL and FS that was previously employed in the ASD method. The user can check the default option to use a geotechnical resistance factor (ϕ) of 0.71 as

explained in Chapter 1. The calculated ϕ will be shown on the load-depth plot after executing the program. The value of ϕ will be also printed in the output data file.

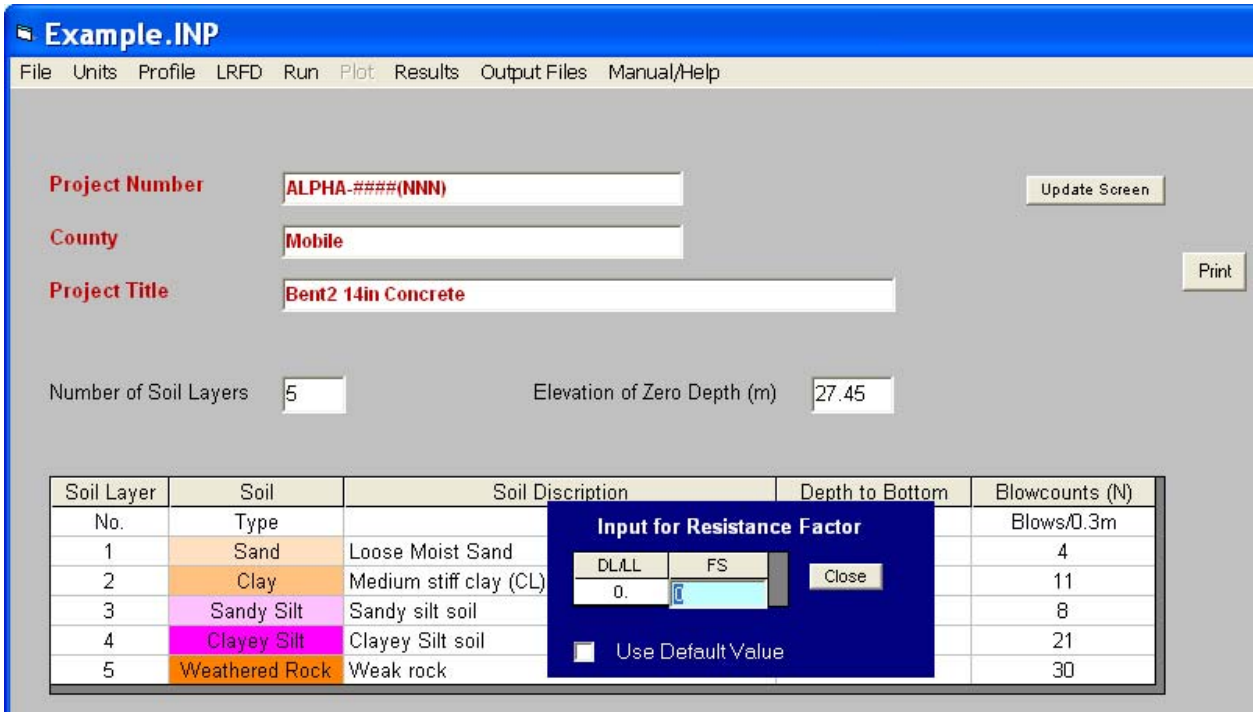


Fig. 2-9 LRFD parameters input to determine the geotechnical resistance factor (ϕ)

CHAPTER 3

OUTPUT DATA

1. **Run:**

   Click *Run* to execute the program. Once the calculation process is achieved, the table shown in **Fig. 3-1** will be visible. The values of

   Pile tip elevation (based on entered ground surface elevation);

   Pile tip embedment below ground surface;

   Pile tip ultimate resistance; and

   Pile side ultimate resistance

   will be displayed in the results table. This table is available when the "*Pile Tip Resistance Every Unit Length*" option is checked.

   If the "*Pile Tip Resistance Every Unit Length*" option is unchecked, just the pile tip and side resistance only for the case of assigned "*Depth of Pile Tip*" is displayed (**Fig. 3-2**).

2. **Plot:**

   As shown in **Figs. 3-3 and 3-4**, click *Plot* and choose either the *Ultimate Resistance* (pile side and tip resistance with no safety factors, **Fig. 3-3**) or *Factored Resistance* (using the LRFD resistance factored, ϕ = 0.71, **Fig. 3-4,** given in Chapter 1). Notice that the designer should use factored loads (DL and LL), as described in Chapter 1, to compare with the plotted factored resistance.

3. **Results:**

   Click *Results* Tab in the upper menu bar to get the input and output data formatted as shown in **Fig. 3-5**. The user can print out this file or create a pdf-file by clicking the *Print* command as shown in **Fig. 3-6**.

4. Output Files:

The input and output data is also saved in a file with the same name of the input data file with extension (*.out). Click *Output Files* tab on the upper menu bar to open the window shown in **Fig. 3-7**. The open windows display only the output data files with extension. By default, the output data files will be created in the same folder where the input data file is saved. However, the user can rename and relocate these files in any other folder.

The user can open the input and output data files with the program **Notepad** (automatically defined in the file windows) as shown in **Fig. 3-8**.

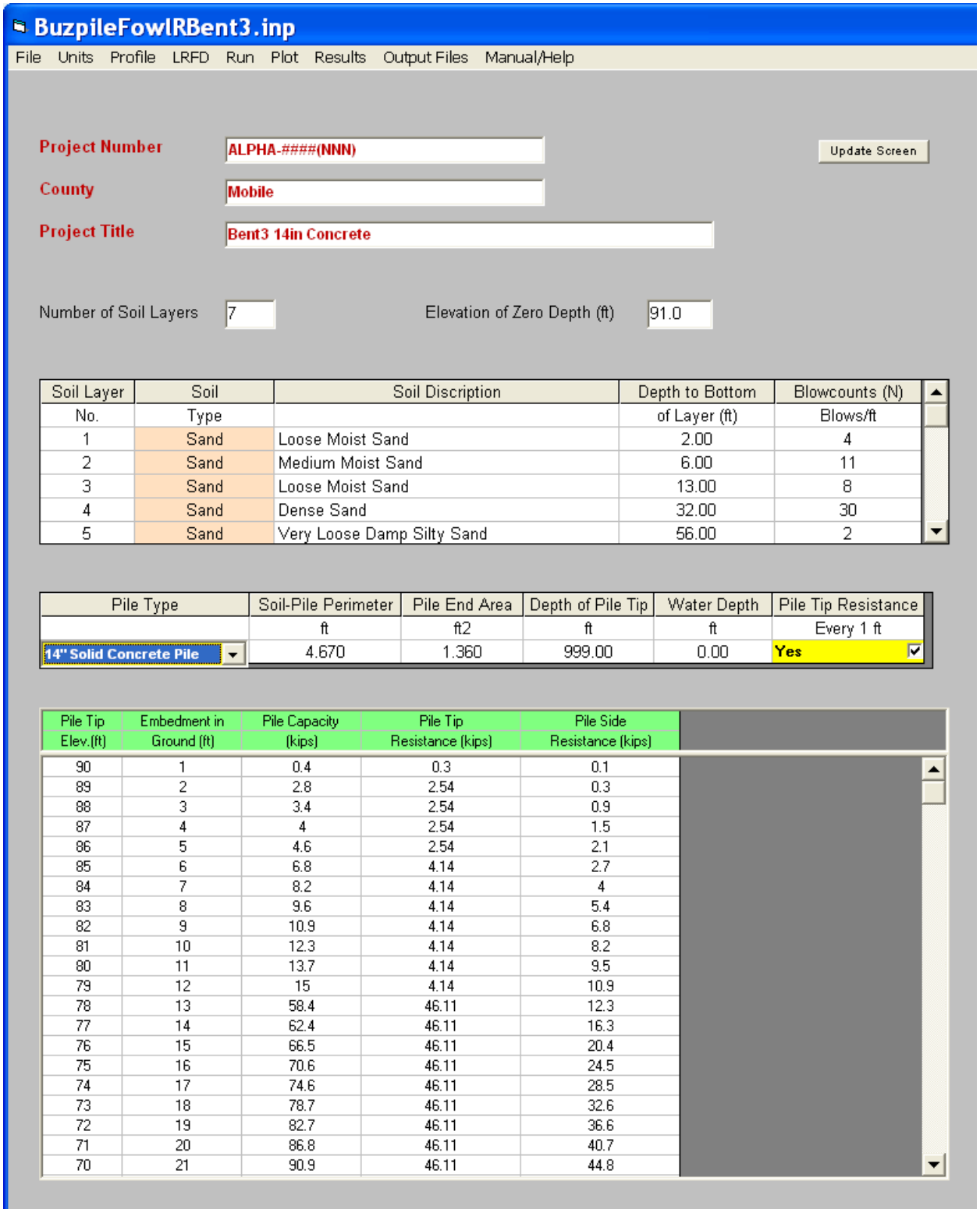


Fig. 3-1 Output data per one foot increment of pile driving after running the software

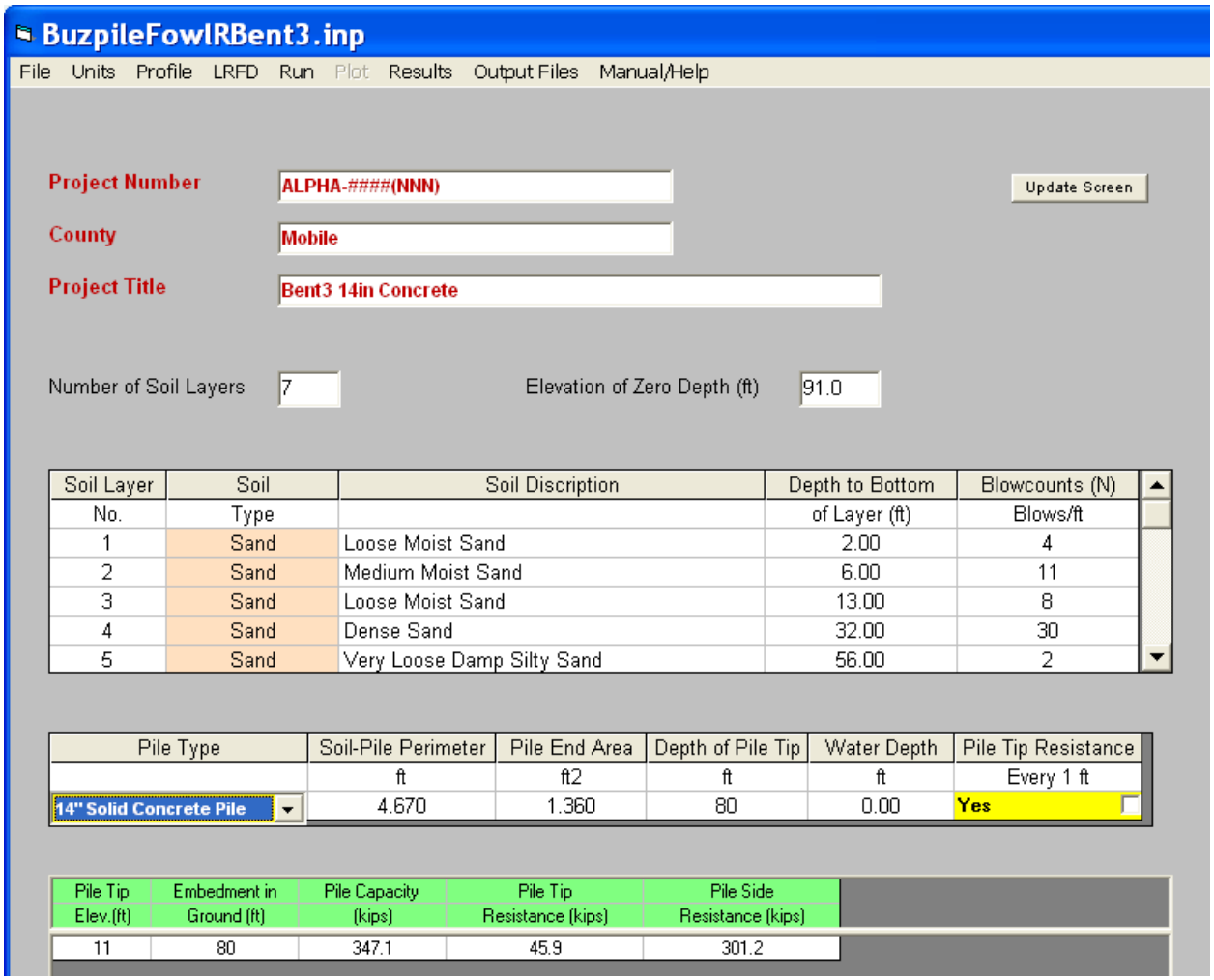


Fig. 3-2 Output data of pile capacity at specific driving depth

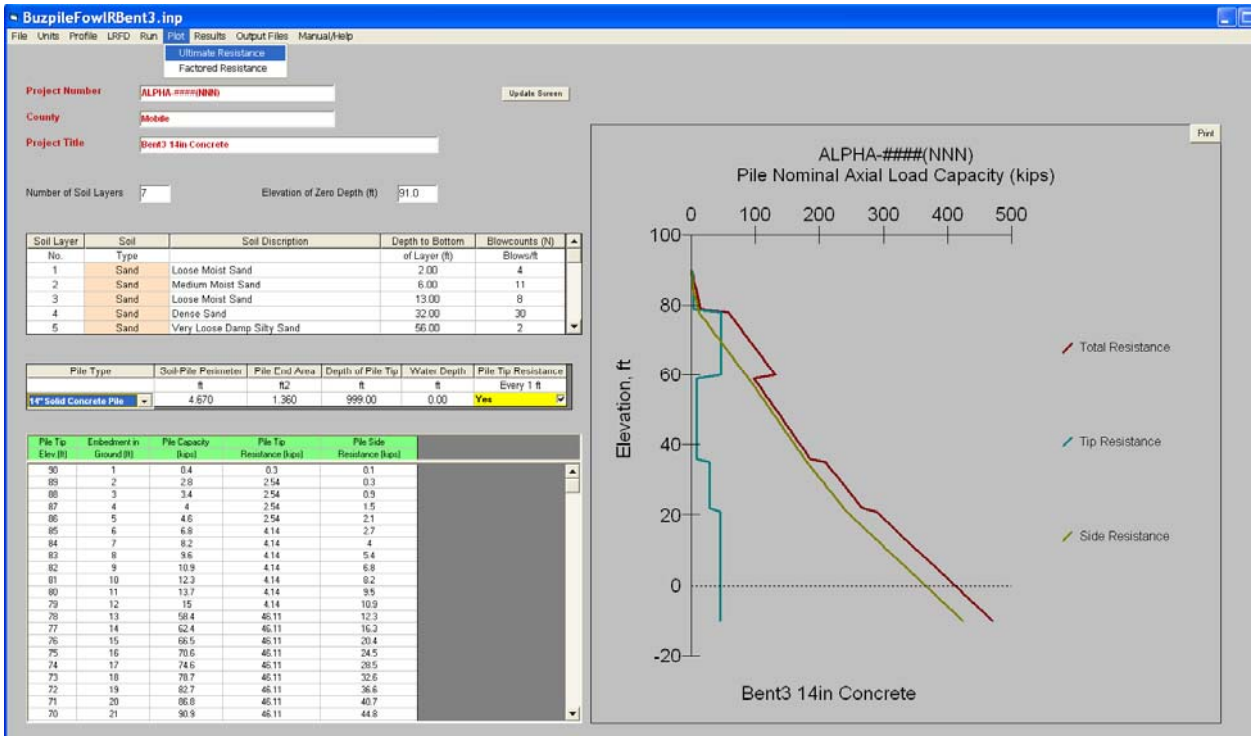


Fig. 3-3 Plot of the nominal axial load capacity (Diagram of pile tip/side resistance vs. depth)

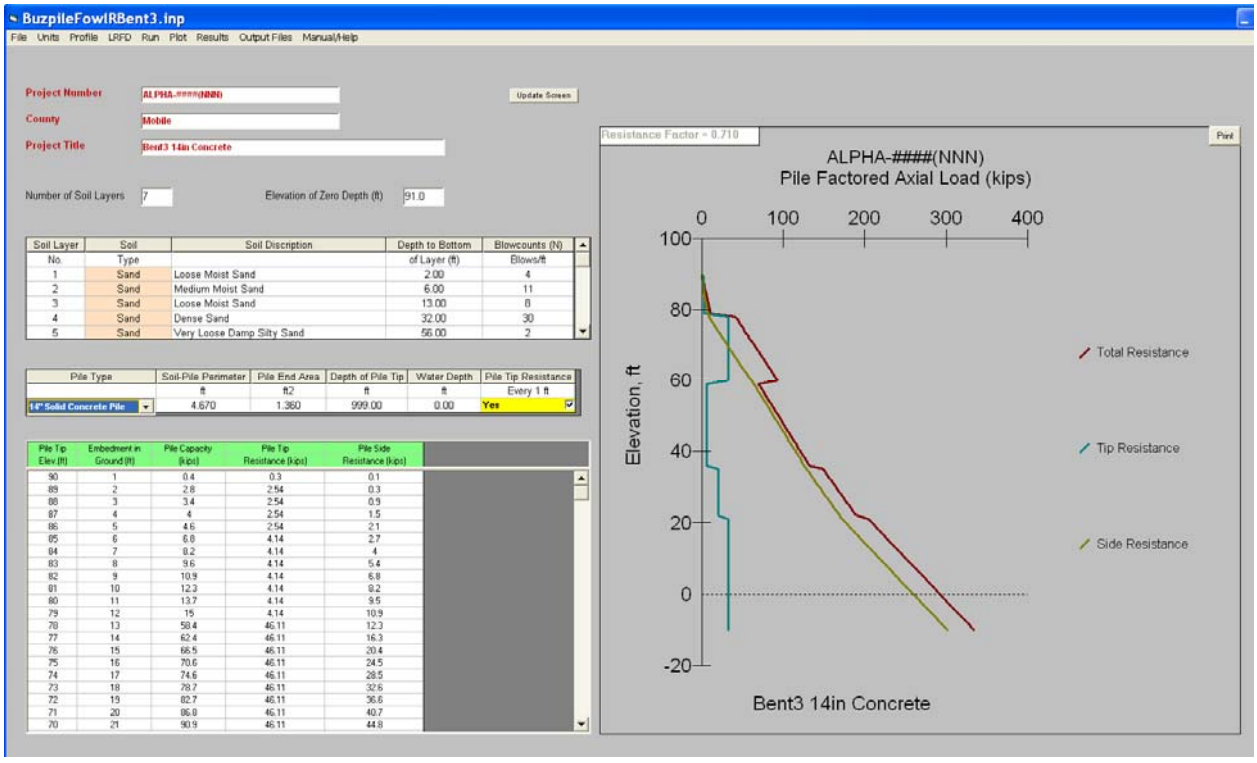


Fig. 3-4 Plot of the factored axial load capacity (Diagram of pile tip/side resistance vs. depth)

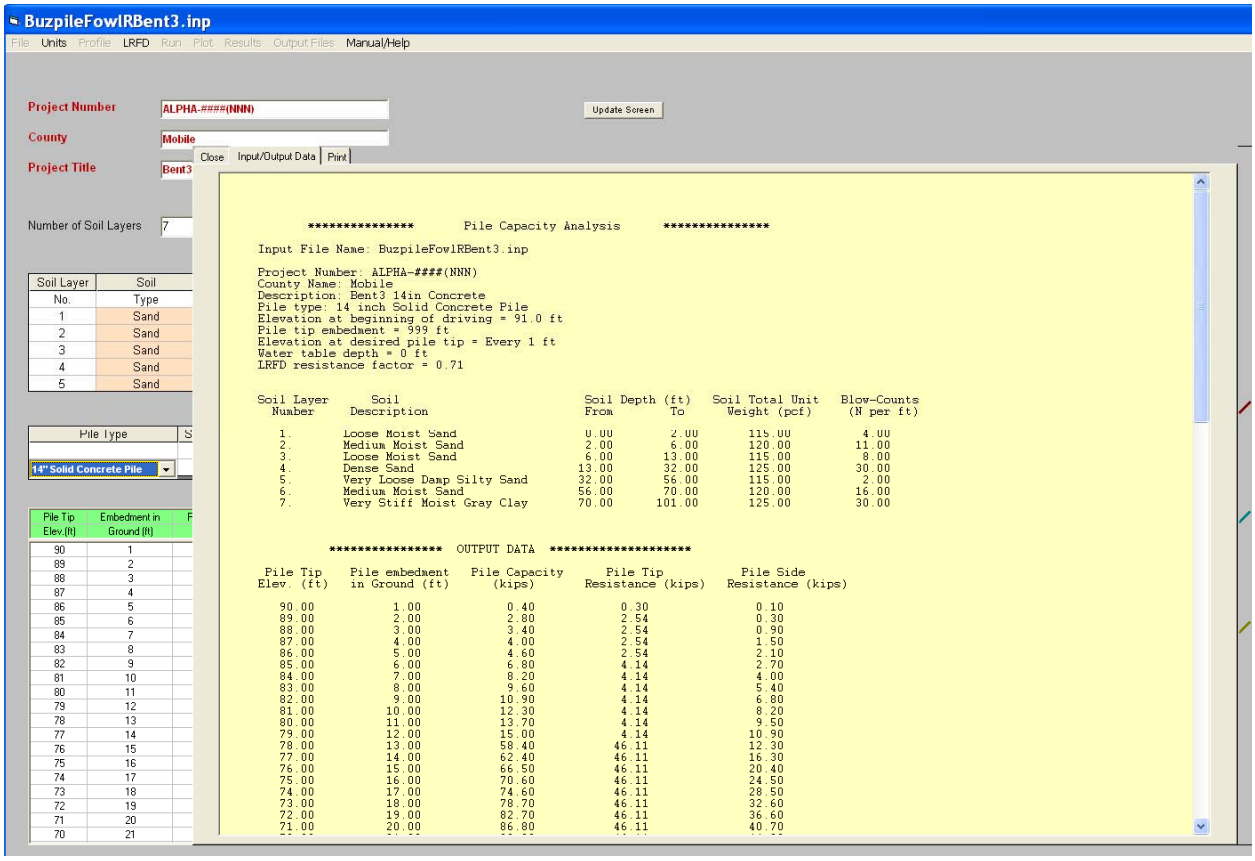


Fig. 3-5 Input/Output data (printable file)

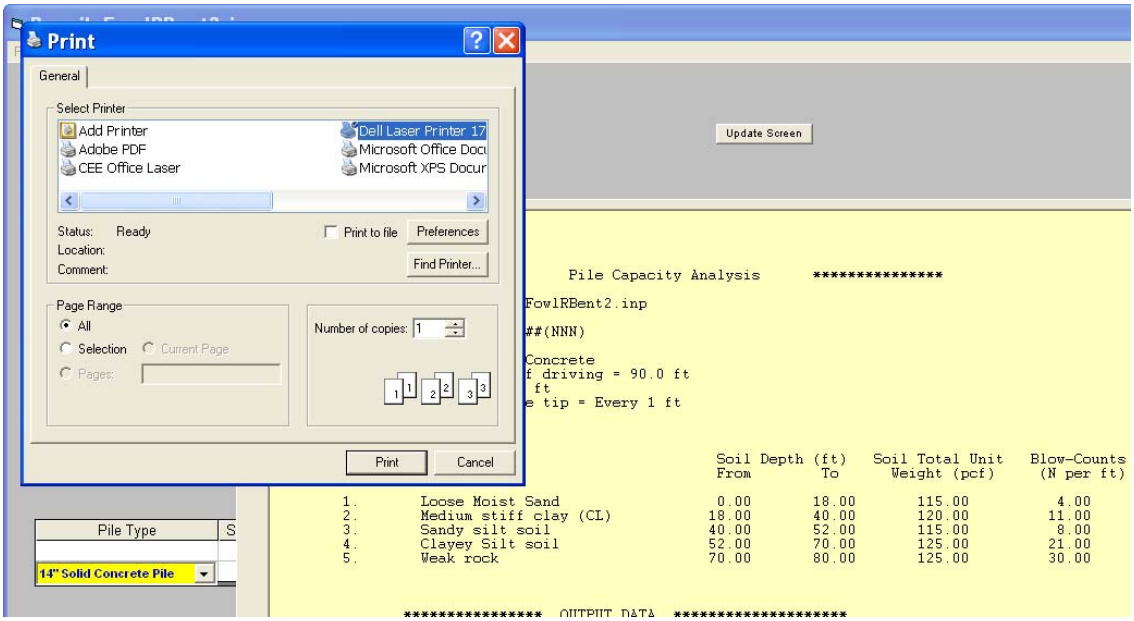


Fig. 3-6 Printing the Input/output data file as pdf-file

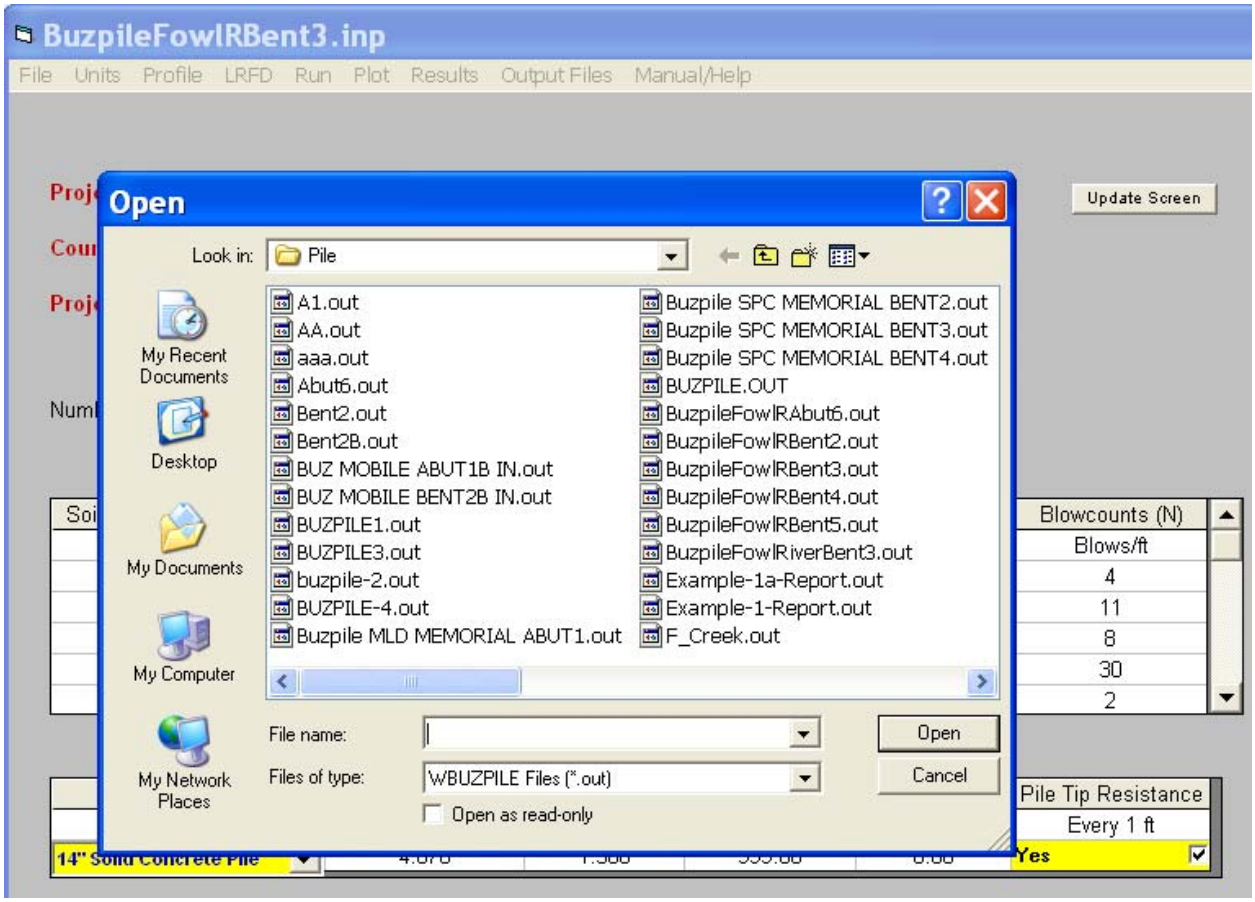
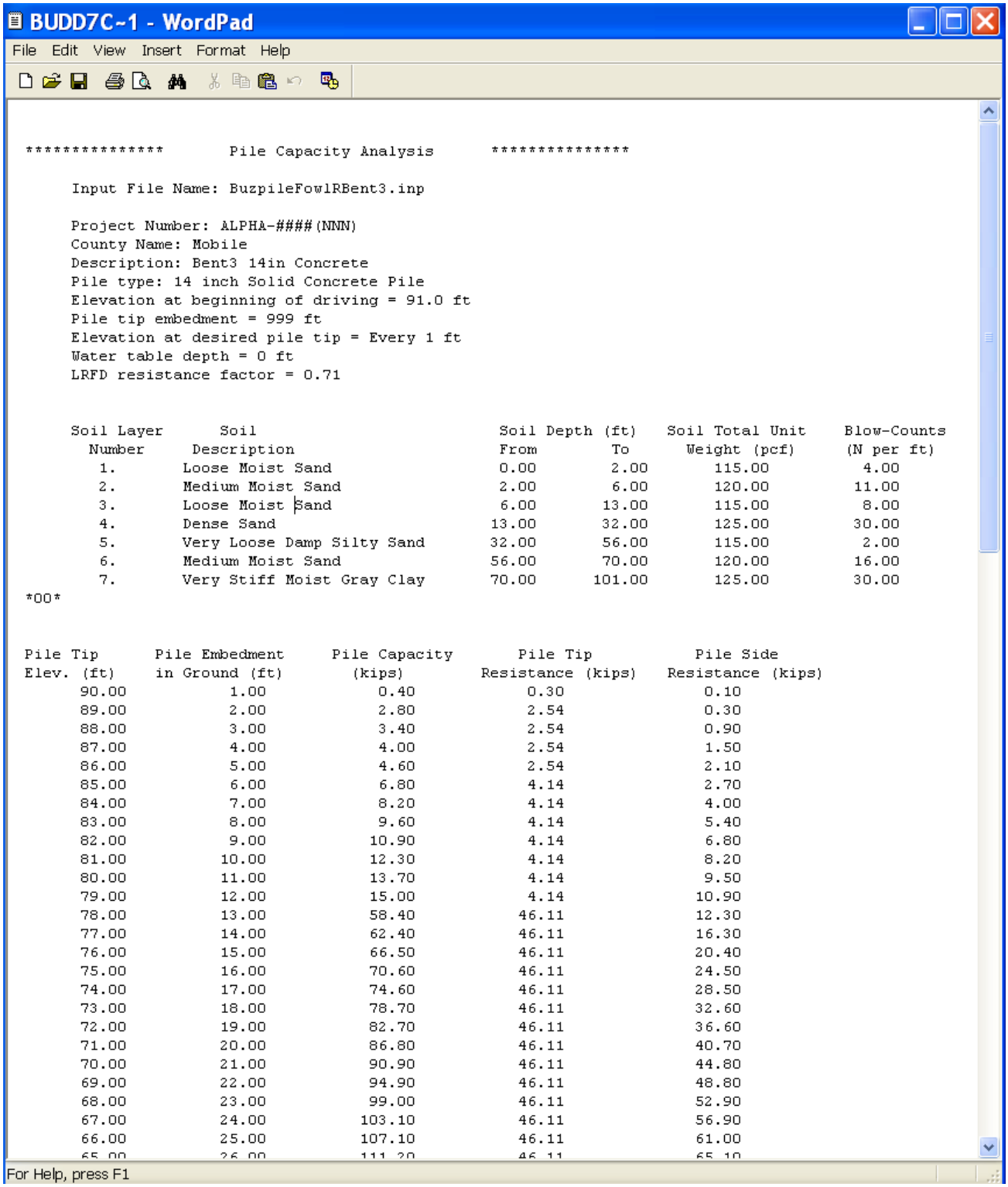


Fig. 3-7 Access to the output data as a text file



BUDD7C~1 - WordPad

File Edit View Insert Format Help

```
***************       Pile Capacity Analysis      ***************

     Input File Name: BuzpileFowlRBent3.inp

     Project Number: ALPHA-####(NNN)
     County Name: Mobile
     Description: Bent3 14in Concrete
     Pile type: 14 inch Solid Concrete Pile
     Elevation at beginning of driving = 91.0 ft
     Pile tip embedment = 999 ft
     Elevation at desired pile tip = Every 1 ft
     Water table depth = 0 ft
     LRFD resistance factor = 0.71


     Soil Layer      Soil                          Soil Depth (ft)    Soil Total Unit    Blow-Counts
       Number     Description                      From        To      Weight (pcf)      (N per ft)
         1.       Loose Moist Sand                0.00        2.00       115.00           4.00
         2.       Medium Moist Sand               2.00        6.00       120.00          11.00
         3.       Loose Moist Sand                6.00       13.00       115.00           8.00
         4.       Dense Sand                     13.00       32.00       125.00          30.00
         5.       Very Loose Damp Silty Sand     32.00       56.00       115.00           2.00
         6.       Medium Moist Sand              56.00       70.00       120.00          16.00
         7.       Very Stiff Moist Gray Clay     70.00      101.00       125.00          30.00
*00*


Pile Tip      Pile Embedment     Pile Capacity       Pile Tip          Pile Side
Elev. (ft)    in Ground (ft)       (kips)        Resistance (kips)   Resistance (kips)
      90.00          1.00            0.40            0.30               0.10
      89.00          2.00            2.80            2.54               0.30
      88.00          3.00            3.40            2.54               0.90
      87.00          4.00            4.00            2.54               1.50
      86.00          5.00            4.60            2.54               2.10
      85.00          6.00            6.80            4.14               2.70
      84.00          7.00            8.20            4.14               4.00
      83.00          8.00            9.60            4.14               5.40
      82.00          9.00           10.90            4.14               6.80
      81.00         10.00           12.30            4.14               8.20
      80.00         11.00           13.70            4.14               9.50
      79.00         12.00           15.00            4.14              10.90
      78.00         13.00           58.40           46.11              12.30
      77.00         14.00           62.40           46.11              16.30
      76.00         15.00           66.50           46.11              20.40
      75.00         16.00           70.60           46.11              24.50
      74.00         17.00           74.60           46.11              28.50
      73.00         18.00           78.70           46.11              32.60
      72.00         19.00           82.70           46.11              36.60
      71.00         20.00           86.80           46.11              40.70
      70.00         21.00           90.90           46.11              44.80
      69.00         22.00           94.90           46.11              48.80
      68.00         23.00           99.00           46.11              52.90
      67.00         24.00          103.10           46.11              56.90
      66.00         25.00          107.10           46.11              61.00
      65.00         26.00          111.20           46.11              65.10
```

For Help, press F1

Fig. 3-8 Input/output data file as opened with Notepad

CHAPTER 4

SOIL MODELING

4.1. Silt Model

Fine soil with low Plasticity Index (PI) less than 7 and considerable percentage of grain size finer than 0.075 mm can be treated as silt. The user can use D_{50} (grain size of 50% finer) as a measure to identify the type of soil.

- Soil is treated as sandy silt if 5 μm < D_{50} < 0.075 mm and PI < 4
- Soil is treated as clayey silt if 5 μm < D_{50} < 0.075 mm and 4 < PI < 7
- Soil is considered as clay if PI > 7

Using D_{50}, the correlation presented by Kulhawy and Mayne, 1990 (**Fig. 4-1**) is used to convert the SPT-N (where N = N_{60}) to the CPT bearing resistance (q_c). The atmospheric pressure is represented by p_a. The average values of the term $(q_c/p_a)/N$ are equal to 2.25 and 1.5 (in the program) for sandy silt and clayey silt soils, respectively.

As presented in the chart of Robertson and Kampanella, 1983 (**Fig. 4-2**), N values for sandy silt and clayey silt soil (corrected for hammer efficiency) are expected to be less than 8 and 6, respectively. If N is less than 6, soil type will be assumed to be silty clay as seen below.

The chart of soil classification based on CPT test results that were developed by Robertson and Kampanella, 1983 is utilized to determine the friction ratio (Rf) for sand silt and clayey silt soils (**Fig. 4-3**).

R_f (%) = [ln(q_c) – 2.58] / 0.742 sandy silt

R_f (%) = [ln(q_c) – 1.894] / 0.547 clayey silt

adhesion = R_f q_c

The failure to capture a positive value for the friction ratio (R_f) using the above soil classification (according to the user assigned soil type) results in the downgrade of the soil type to silty clay. Such an adjustment is undertaken internally in the program because of the conflict between the utilized SPT-N and the chosen type of silt.

R_f (%) = [ln(q_c) – 0.817] / 0.36 silty clay

The silt effective angle of internal friction is calculated using Caquot's relationship (Caquot and Kerisel 1948) that is formulated as follows,

Friction angle (φ) = [ln(q_c) + 1.386] / 0.184

Pile bearing resistance = q_c

Pile tip (base) resistance = q_c (Area of pile tip)

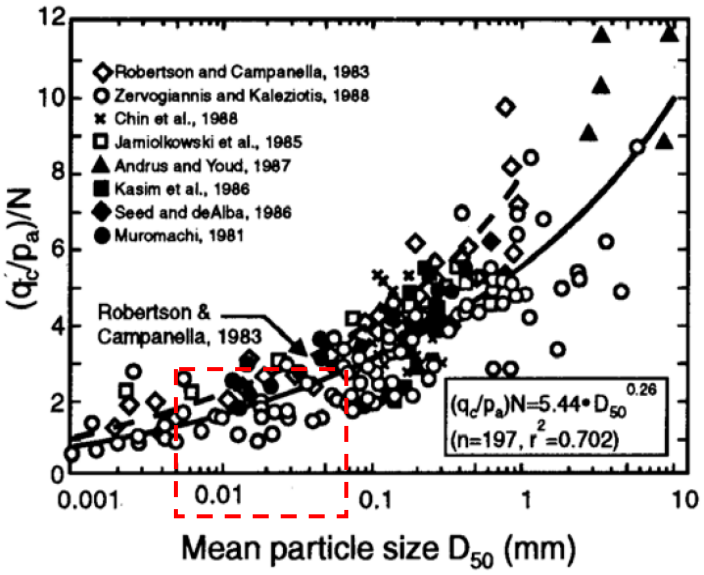


Fig. 4-1 CPT-SPT correlation with grain size (Kulhawy and Mayne, 1990)

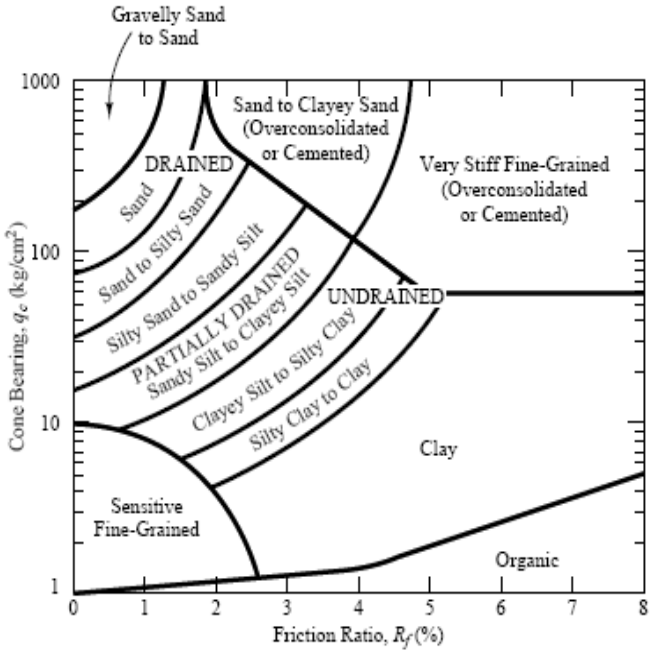


Fig. 4-2 Soil classification based on CPT test results
(Robertson and Kampanella, 1983)

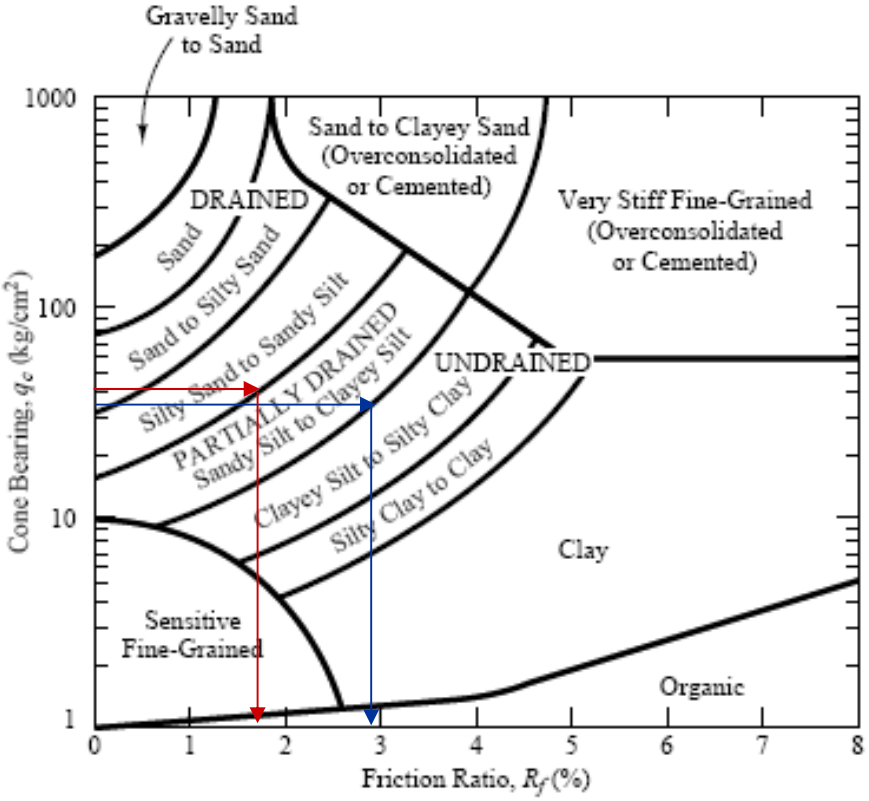


Fig. 4-3 The Use of soil classification based on CPT test results
(Robertson and Kampanella, 1983)

4.2 Current Sand and Clay Models

Sand and clay properties (unit weight, friction angle) are determined using SPT-N and an empirical equation proposed by ALDOT. The suggested empirical formula was developed based on field and test data assessed by ALDOT over several years of experience.

Sand

Friction angle (φ) = 27.9877 + 0.0951663 N + 0.0137846 N^2 - 0.000354596 N^3 + 0.00000290751 N^4

Bearing factor = 76103.3 - 11496.7 φ + 691.929 φ^2 - 20.7312 φ^3 + 0.309012 φ^4 – 0.00183079 φ^5

Clay

Cohesion (C) = 125 N (psf) if N < 100

Cohesion (C) = 0.375 * 144 N (psf) if N > 100

Bearing factor = 9 C (psf)

4.3 Weathered Rock

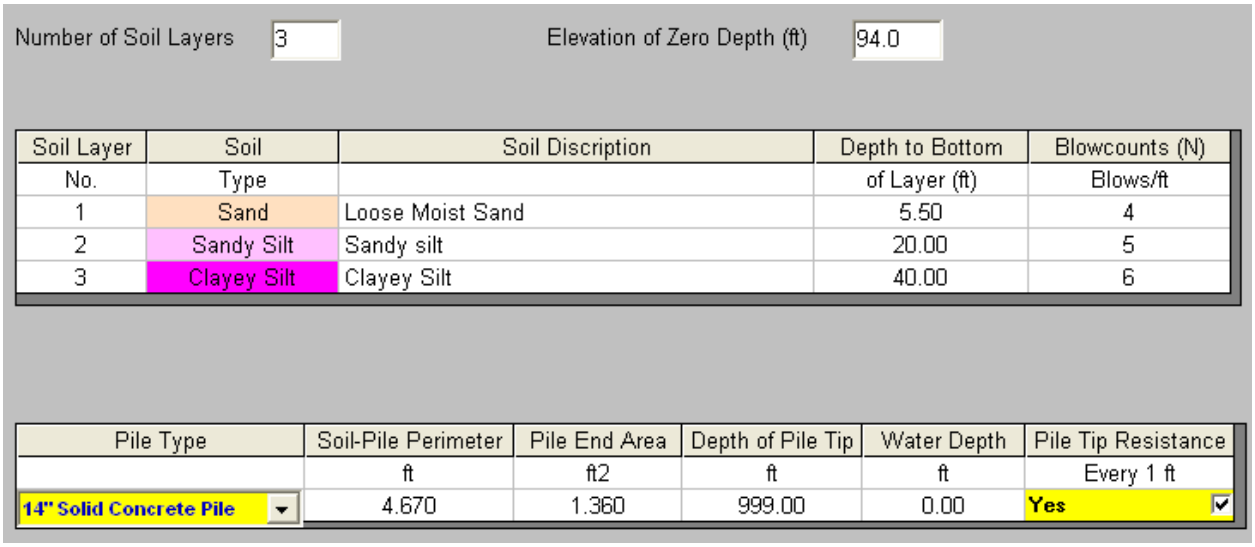
Bearing factor = 0.59 $(N_{60})^{0.8}$ $\overline{\sigma}_{vo}$ (psf) O'Neill and Reese (1999)

N_{60} = N corrected for the Hummer efficiency

$\overline{\sigma}_{vo}$ = effective stress at the pile tip

4.4 Example:

The following example shows the effect of assuming the sandy silt and clayey silt soils to be sand and clay, respectively, for the same number of blowcounts (N). Compared to the modified soil profile (**Fig 4-5**), the use of the actual soil classification (silty soils, **Fig. 4-4**) provides larger tip resistance and less side resistance which is realistic response with silt properties (**Fig. 4-6**).

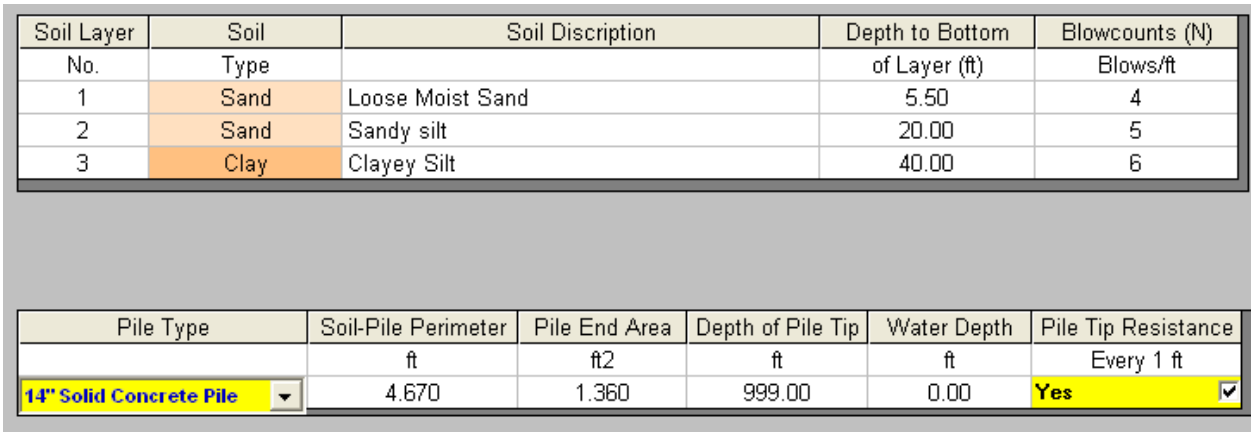


Number of Soil Layers: 3 — Elevation of Zero Depth (ft): 94.0

Soil Layer No.	Soil Type	Soil Discription	Depth to Bottom of Layer (ft)	Blowcounts (N) Blows/ft
1	Sand	Loose Moist Sand	5.50	4
2	Sandy Silt	Sandy silt	20.00	5
3	Clayey Silt	Clayey Silt	40.00	6

Pile Type	Soil-Pile Perimeter	Pile End Area	Depth of Pile Tip	Water Depth	Pile Tip Resistance
	ft	ft2	ft	ft	Every 1 ft
14" Solid Concrete Pile	4.670	1.360	999.00	0.00	Yes

Fig. 4-4 Example 1a using actual soil profile of silty soils



Soil Layer No.	Soil Type	Soil Discription	Depth to Bottom of Layer (ft)	Blowcounts (N) Blows/ft
1	Sand	Loose Moist Sand	5.50	4
2	Sand	Sandy silt	20.00	5
3	Clay	Clayey Silt	40.00	6

Pile Type	Soil-Pile Perimeter	Pile End Area	Depth of Pile Tip	Water Depth	Pile Tip Resistance
	ft	ft2	ft	ft	Every 1 ft
14" Solid Concrete Pile	4.670	1.360	999.00	0.00	Yes

Fig. 4-5 Example 1b using modified soil profile of sand and clay soils

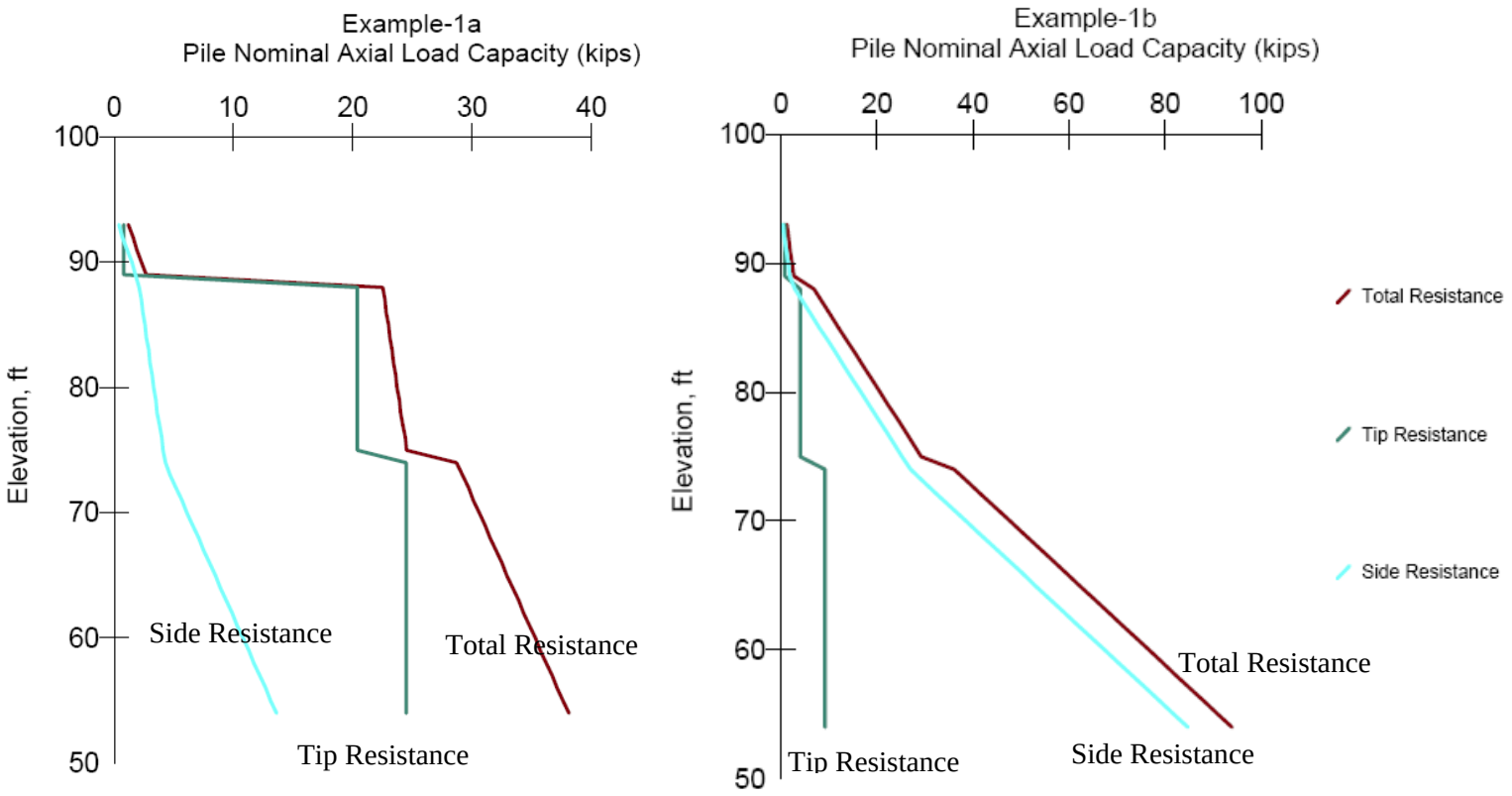


Fig. 4-6 Pile tip and side resistance along actual (**Fig. 4-4**) and modified (**Fig. 4-5**) soil profile

REFERENCES

Abu-Hejleh, N. M., DiMaggio, J. A., and Kramer, W. M. "Implementation of AASHTO LRFD geotechnical design specifications for structural foundations" PAPER 1, Overview of AASHTO LRFD, FHWA Resource Center, Olympia Fields, IL 60461

Caquot, A. and Kerisel, J. (1948). "Tables for the calculation of passive pressure, Active pressure and bearing capacity of foundations." Gauthier-Villars, paris.

Kulhawy, F.H. and Mayne, P.W. (1990). "Manual on estimating soil properties for foundation design." Rpt. EL-6800, Electric Power Res. Inst., Palo Alto, CA.

Robertson, P.K. and Campanella, R.G. (1983). "Interpretation of cone penetration tests." Canadian Geotechnical Journal Vol. 20, No. 4, pp. 718-745.