2009

WVDOH PSSLOPE MANUAL

West Virginia Department of Transportation

West Virginia Division of Highways

Engineering Division

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DISCLAIMER

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CHAPTER 1 - SLOPE STABILITY

A. PRELIMINARY STEPS

1. **Prepare the Cross-section**: Before the data can be entered into the program, a cross section should be prepared. Use a reasonable number of straight line segments that will represent the cross section. You can ignore some survey points if a single line segment is very close to two or more surveyed line segments, but do not over simplify. Accurate surveyed cross sections are important since the slope geometry is used to back calculate the soil parameters on the failure plane.

   Each location where your line segments intersect, or end, is called a point and each line segment is called a line. Use lines to show the ground surface, different soil zones, and water table surface. Plot the core boring soil and rock layers on the cross section and determine the different soil boundaries. Number each line from left to right starting at the top boundary (see Figure 1). Do not number water surface boundary at this time.

   Determine and record on the cross section the coordinates x, y (offsets and elevations) for the endpoints of all line segments, including those for the water surface, if any (Figure 1). Notice all boundaries have the same beginning and ending edges. Extend the water surface to the same beginning and ending edges. No vertical or overhanging boundaries are allowed. The program always sets the starting point for the graph at x, y = 0, 0. Consequently, when preparing the cross section, adjust the values of the coordinates so that the lower left starting point is at least x, y = (10, 10) to allow room for the slip plane below the lowest surface. Also, if the actual elevations are used, the program will plot the actual distance from zero, producing an impracticably small graph (e.g., if the lower left starting point on Figure 1 was imputed at the actual elevation 510-feet, the graph would be scaled to fit the screen in such a manner that it would be hard to see the geometry shown below).

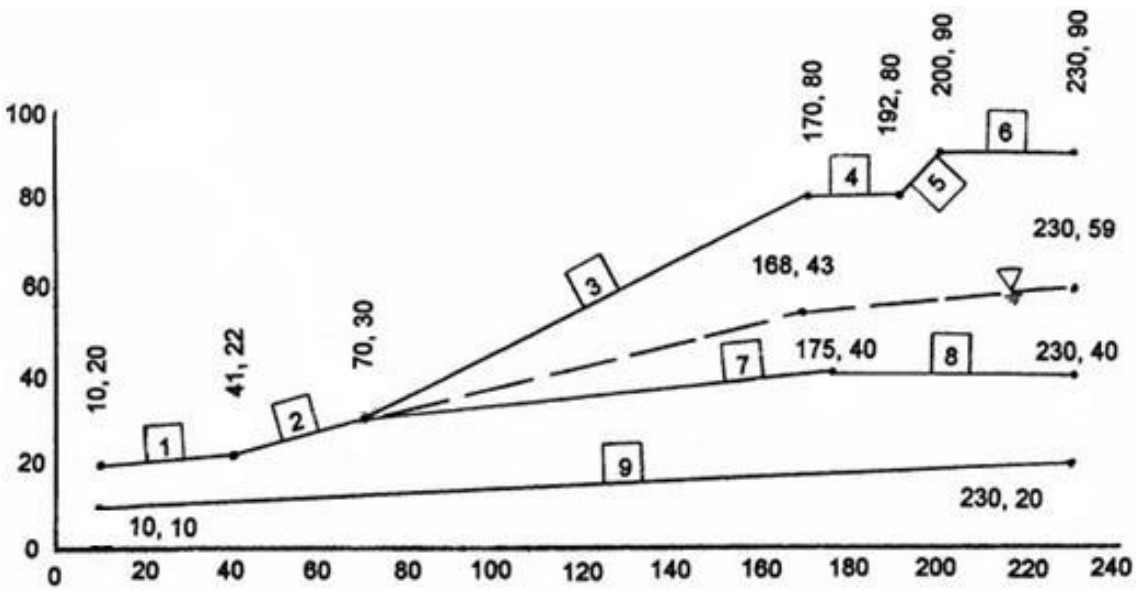


Figure 1: Flagged Lines and Point Coordinates. Notice that the water surface is not flagged.

2. **Prepare the Soils Data**: Number the soil (rock) zones on the cross section and record the properties of the soil in each zone (Figure 2). The soil below each line is imputed into the program as will be discussed later. The average Standard Penetration Test (SPT) N-values can be used by the program to estimate the undisturbed soil parameters for each layer. Unit weight, saturated unit weight, residual friction angle, peak friction angle, disturbed cohesion, and undisturbed cohesion can be estimated based on the soil type or from laboratory testing. The Rock Mass Rating (RMR) can be used to estimate rock properties. Selecting soil parameters, using RMR and N-values will be discussed later.

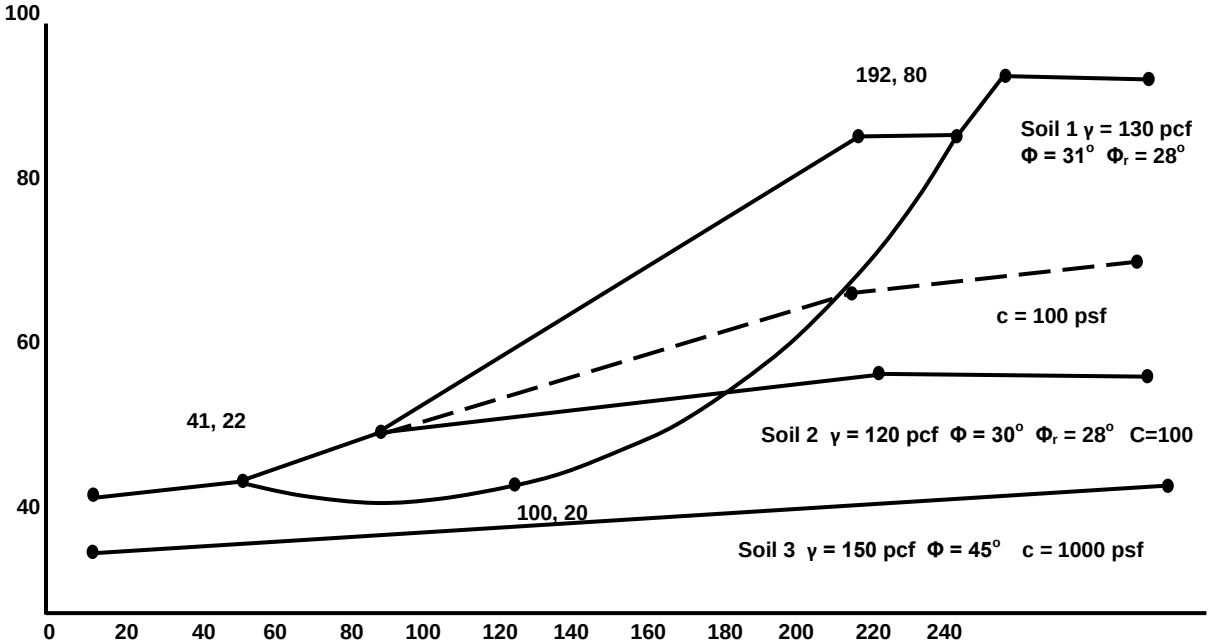


Figure 2: Cross Section Showing Typical Required Data.

3. **Select Coordinates for the Failure Surface**: Use the scarp and toe plus any other information, such as a boring, to determine or estimate the failure surface location. The program uses a circular failure surface. Use a CAD program or a compass and graph paper (this may require taping a piece of paper to your cross section) to find three points of the arc that fits the predicted failure surface (see the three points on Figure 2). Alternatively, if a range for the initiation point near the toe and ending point near the scarp is entered, the program will search for the worst failure surface out of the ten worst failure surfaces in the selected range. Make sure your circle does not intersect the ground surface in more than two points or an error message will be generated. You may have to slightly change some points, or lines, on the cross section to correct this problem.

B. INPUT

When entering data, refer to Figure 3 (Input Table)

1. Enter a title.

2. Enter a number for Number of Soil Types; this must be greater than zero, except when the Simple Wedge Analysis is used, then the number of soils should be 2 (See page 22).

3. Change the SPT Hammer Efficiency if the hammer used has a different efficiency than the standard 60% for rope and cathead hammer. The program internally adjusts the SPT blow-counts to the standard (N60) to determine the soil properties needed for soil-pile analysis. If an Auto Hammer is used, input the efficiency to 80% (if the efficiency of the Auto Hammer is unknown).

4. Click the Update Screen button to generate the required rows for the number soils entered. After making changes to a table/section, and prior to selecting another table/section, or running the analysis, the screen must be updated).

5. Select the Soil Type. There are four choices to choose from: three soils types and one rock. When selecting Soil Type, it is important to understand how the program uses each type of soil in the calculations.

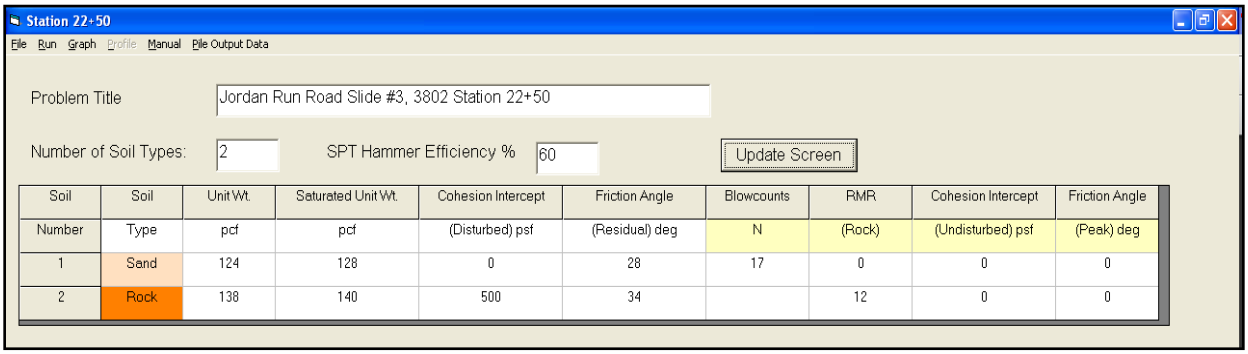
    a. **Sand**: This soil type has zero cohesion and has only friction; therefore the program ignores any values entered input in the Cohesion Intercept undisturbed column. This soil would be recognized as fairly clean sand with not enough binder soil to stick together.
    b. **Clay**: This soil type has zero friction and has only cohesion; therefore the program ignores any values entered Friction Angle peak column. This soil would be classified as clay with only a trace of sand of silt, and can be rolled into a thin thread between the fingers.
    c. **C-Phi**: This soil type is the typical soil found in West Virginia and contains both friction and cohesion soil properties. This selection will use both soil properties in the calculation. This soil should be selected unless it can be determined the soil is either a pure sand, or pure clay.
    d. **Rock**: Used for bedrock of all types, including an intermediate geomaterial (IGM) of extremely weathered rock.

6. Input the disturbed cohesion intercept and friction angle. Cohesive Intercept Disturbed and Friction Angle Residual represent the soil strength parameters along the failure surface. These values are used in the slope stability analysis.

7. The last four columns of the soil properties, Blowcounts, RMR (rock mass rating), Cohesion Intercept, Friction Angle, represent the data needed for the soil-pile analysis. These represent the soil strength parameters above and below the failure surface and are considered as undisturbed.

8. The program defaults to the columns labeled Blowcounts and RMR, when running the soil-pile analysis. If values are entered into the Blowcounts (N Value), or RMR columns, the program ignores any value entered in the last two columns, Cohesion Intercept and Friction Angle.

9. Use the enter key, or the mouse, to move from one cell to the next, when entering data.



Soil Number	Soil Type	Unit Wt. pcf	Saturated Unit Wt. pcf	Cohesion Intercept (Disturbed) psf	Friction Angle (Residual) deg	Blowcounts N	RMR (Rock)	Cohesion Intercept (Undisturbed) psf	Friction Angle (Peak) deg
1	Sand	124	128	0	28	17	0	0	0
2	Rock	138	140	500	34		12	0	0

Figure 3: Soil Input Table

C. BOUNDARIES

1. There are three methods of analysis used in this program for analyzing the slope stability as follows:

   a. Existing Failure Surface
   b. Potential Failure Surface
   c. Simple Wedge Analysis

   The input of the boundary layers is the same for the first two methods above. Before inputting the soil layer boundaries and selecting a method for analysis it is important to understand the difference in each method. The first two methods, **Existing** and **Potential** Failure Surface, both require a detailed input of boundaries, soil profile, water surface and slip plane. The third method, **Simple Wedge Analysis**, which will be discussed later in detail, requires only the width of the wedge, height of wedge, depth of water table and depth to bedrock. No surface, soil, or water boundaries are input into the boundary tables for the simple wedge analysis (see page 22).

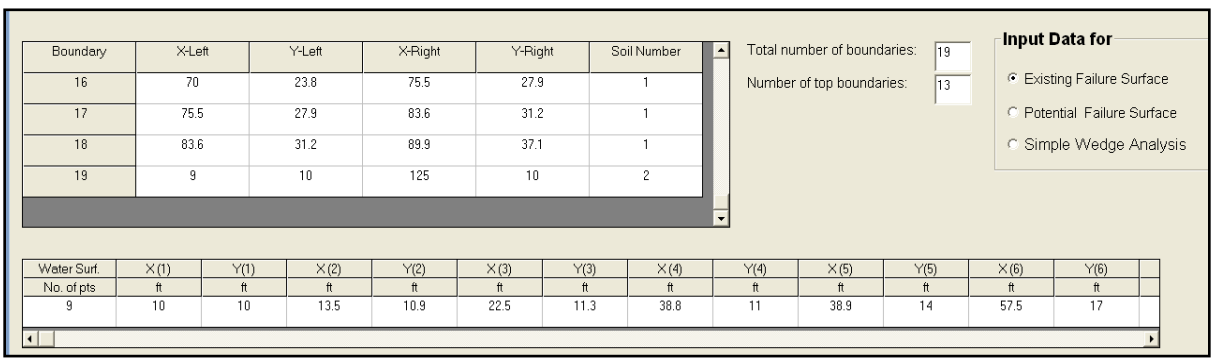
   This section covers only the first of the three methods. When inputting the data into this section, refer to Figure 4.

2. Input the Total number of boundaries and the Number of top boundaries and click Update Screen. Referring to Figure 1, the number of top boundaries is 6 and the total number of boundaries is 9.

3. Input the boundary line segments <u>starting from the left and top most boundary</u> and working to the right and down through the layers. Input lines using the x and y coordinate for the start and end of each line segment. Notice that the <u>ending coordinates are repeated as the starting coordinates</u> for the next line segment.

4. When entering the line segments, it is required to define which soil type underlies which line segment by giving the soil a number corresponding to the soil type. This Soil Number is input in the same row as the line segment for which it underlies.

5. It is important to accurately estimate where the water surface was at the time of failure. Enter the number of water surface points that make up the total number of line segments. Do not forget the last ending point. For example, 9 line segments will require 10 points. Enter the x and y coordinates that make up the line segments. The program only accepts one water surface.



Boundary	X-Left	Y-Left	X-Right	Y-Right	Soil Number
16	70	23.8	75.5	27.9	1
17	75.5	27.9	83.6	31.2	1
18	83.6	31.2	89.9	37.1	1
19	9	10	125	10	2

Total number of boundaries: 19

Number of top boundaries: 13

Input Data for

- (•) Existing Failure Surface
- ( ) Potential Failure Surface
- ( ) Simple Wedge Analysis

Water Surf.	X(1)	Y(1)	X(2)	Y(2)	X(3)	Y(3)	X(4)	Y(4)	X(5)	Y(5)	X(6)	Y(6)
No. of pts	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft
9	10	10	13.5	10.9	22.5	11.3	38.8	11	38.9	14	57.5	17

Figure 4: Input Table for Boundary Line and Water Surface Segments

6. It is possible to enter the data for either/both Existing Failure Surface or Potential Failure Surface, on the same file and switch back and forth between the two methods. However, <u>if at any time the Simple Wedge Analysis button is selected all soil boundaries will be deleted and lost from the program</u>. Switching back to one of the other methods will require that the boundary data be re-entered. Therefore, it is recommended that the user <u>save the file after inputting the boundary data and prior to switching methods of analysis</u>.

   It is a good practice to adopt a naming convention for naming files that identifies not only the name of the slide, but also the analysis method used. For instance, if a file contains information for a slide referred to as Pendleton slide and uses the existing failure surface method of analysis, then a good name for the file is Pendleton_efs. Using such a naming method will make it easier to differentiate among files that use different analysis methods for the same slide.

D. RUNNING STABILITY ANALYSIS:

1. **<u>Existing Failure Surface</u>**: This method requires inputting the slip surface, utilizing a three point method. The failure surface is determined from the slope geometry, by the scarp, by the toe, and by the depth to slip plane as indicated from the borings. This requires the x and y coordinates for the starting, ending, and middle points be entered in a table (see Figure 5) that opens when the Existing Failure Surface button is selected. The slope geometry and the failure surface can be viewed by selecting the Plot Failure Surface button. This option is useful to determine if adjustments are needed to the failure surface or boundaries.

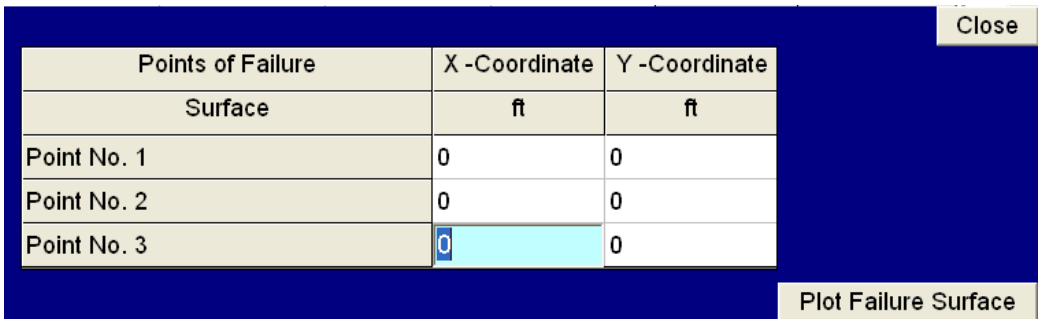


Figure 5: Existing Failure Surface Input Box

If the table is closed without inputting data, the program will generate the warning box shown in Figure 6. Ignore this warning; it is just indicating there is no data to plot.

Figure 6: Warning Box

2. **<u>Potential Failure Surface</u>**: This method requires entering the slip surface by inputting the Leftmost Initiation Point, Rightmost Initiation Point, Left Termination Limit, Right Termination Limit and the Min. Elevation of Surface Development (Figure 7). The table will open when the 2nd button is selected (Figure 4). This method is used when the exact failure surface is unknown or when searching for the most critical slip surface. It is also used when just analyzing a slope for stability, which has not failed. It is common to conduct a preliminary search for the critical slip surface first. It is usually found that most of the slip surfaces occur within a defined range. It is possible after the first run to more precisely define the search limits or force the critical surface to a predetermined location.

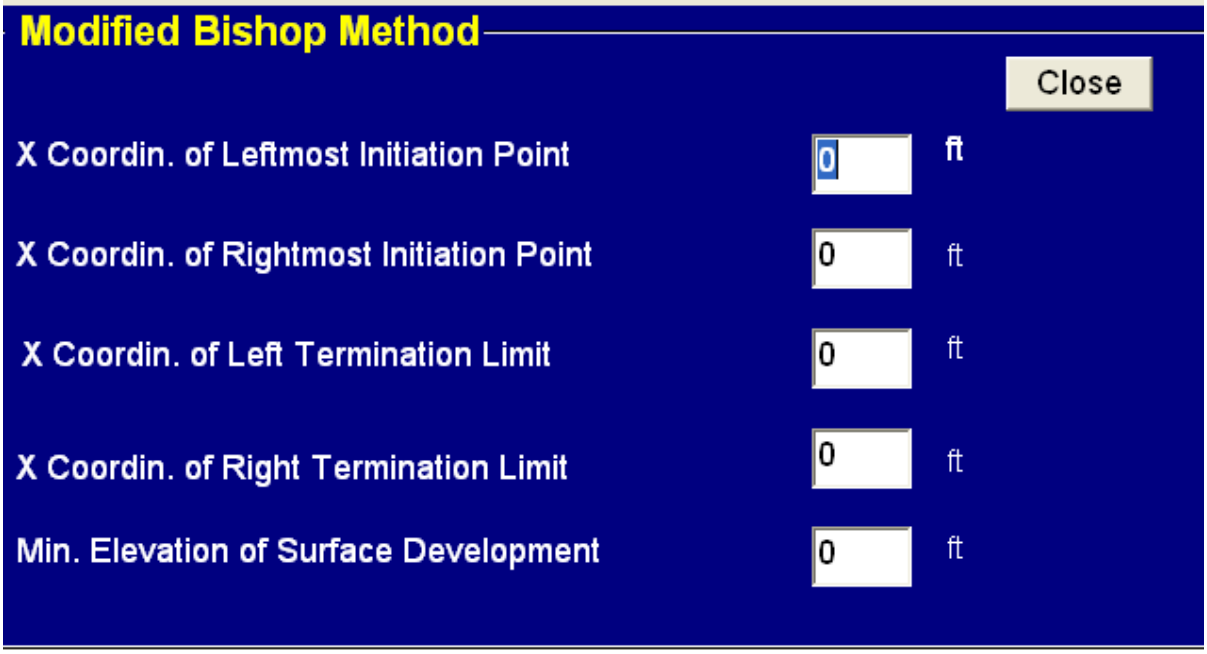


Figure 7: Potential Failure Surface Input Box

3. **Modified Bishop Method**: The method used in the program is the Modified Bishop Method, which is simulates a circular failure surfaces. When the factor of safety of a slide is 0.99, or for practical purposes 1.0, failure has occurred. (It is commonly observed that failures can occur with a factor of safety of 1.10 using this method – more on factors of safety will be discussed later.) Other methods are available that simulate sliding block failures which may be more accurate for the type of failure, but it is believed that the Bishop method is within the accuracy of estimating soil parameters and provides adequate results for pile wall design.

4. **The Goal for the Initial Stability**: The goal of the initial analysis is to establish the soil parameters (strength parameters and water surface) to obtain a factor of safety of 1.0. In this form of back-analysis, the soil parameter values do not have to be exact, just *reasonably correct*. If you are running the program for an existing slide, the factor of safety should be 1.0. If 1.0 factor of safety is not reached, adjust the strength parameters, the water table data, or both until a 1.0 is reached. Do not waste time making the slide factor of safety exactly 1.0, if the factor of safety rounds to 1.0 (i.e., is 0.96 to 1.04; use two decimal places only). Use soil parameters and water surface in subsequent stability analyses to evaluate the pile wall design (discussed later).

   We seek the best method to correct the slide. The best method may be the least expensive, the fastest, the easiest, or even the most aesthetic, depending on the circumstances. Albeit the programs best attribute is that of a pile wall design, using the stability analysis section of the program does allow for other designs, such as a buttress, modifying the slope or relocating the road.

5. **Run the Stability Analysis**: At the top in the menu, select **Run, Slope Stability**. The following note will appear if all inputs were input correctly (Figure 8).

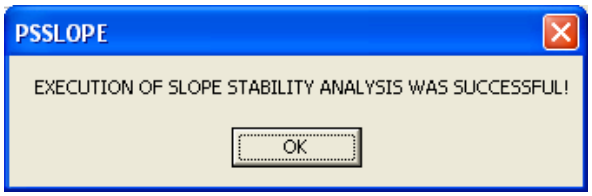


Figure 8: Notification Message of Successful Stability Analysis

6. **Common Input Errors**:
   a. Coordinates' value error (Figure 11).

      i. Mismatched line segments: Either the beginning or ending x or y coordinate in a line segment does not match the previous or next line segment corresponding coordinate
      ii. Total number of boundaries and top boundaries do not correspond to profile. When listing boundaries, PSSlope expects top boundaries to be listed first. So if N is the total number of top boundaries, then the X-Left of the first N boundaries must match the X-Right of the boundary listed before it. This error can also indicate that the total number of top boundaries has been listed incorrectly.

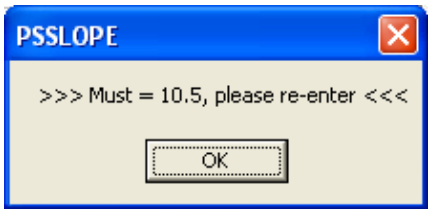


Figure 11: Error Message

   b. Number of top boundaries exceeding total number of boundaries (Figure 12).

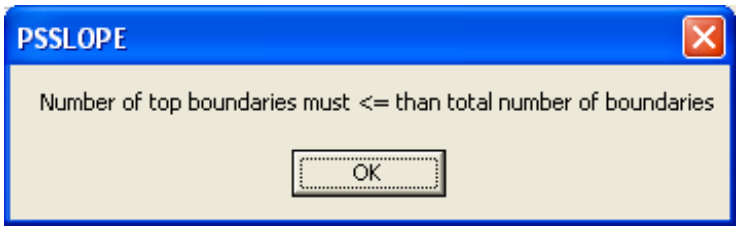


Figure 12: Error Message

   c. Total number of boundaries exceeds the actual boundaries in the table (Figure 13). The program is expecting a value on the next line and to match the previous x value.

Figure 13: Error Message

d. Execution of program failure (Figure 14); This message can appear for a couple of reasons:
   i. Failure surface does not intersect the surface at two points or intersects in more than two points, For example, the failure surface jumps across a ditch.
   ii. A negative number(s) was input.

Figure 14: Error Message

e. The Run-time error '#' (Figure 15)

   i. This is a common system error message that often results because the programmer did not anticipate that the user would enter a value outside of the expected range. In the PSSlope program, entering a value of zero for the slip plane strength parameters is one way to generate this error. Because PSSlope does not handle system error messages, generating one of these will cause the program to crash.

   ii. If this message is encountered please note the error message and contact the central office. The file (.stm) will need to be saved and sent to the office to correct the program.

Figure 15: Run-time error

f. PSSlope will display a warning or error message for the first input error it encounters in the program. The error message most likely points directly to the problem or it can

indicate an error caused by an incorrect input in some other location. Check inputs carefully before making corrections. It is important to remember that the program will allow as many corrections to a section as needed, but the Update Screen must be selected prior to selecting another section for corrections or running an analysis.

7. **Viewing Results:** The program offers two methods to view the profile of the input parameters prior to running the stability analysis (this function is not available in the Simple Wedge Analysis). This function can be used to check the soil, water table and failure surfaces, and make adjustments prior to running the analysis (Figure 17).

   a. In the Existing Failure Surface press the Plot Failure Surface button (Figure 16). This button is not available in the Potential Failure Surface.

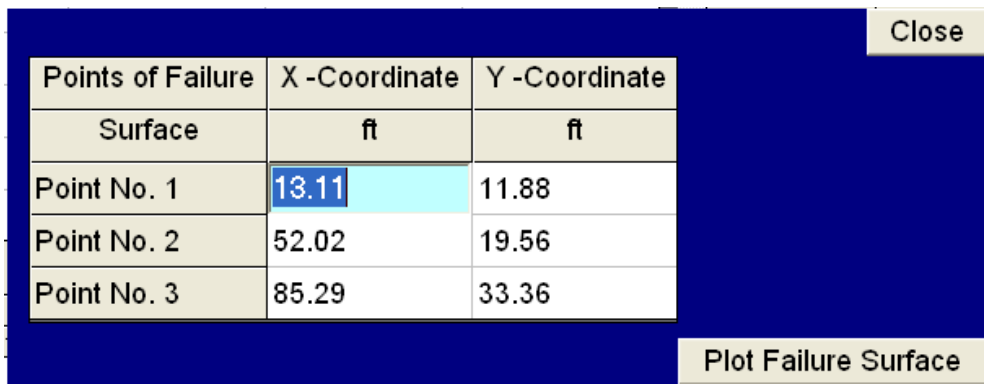


Figure 16: Plotting Failure Surface

A small sketch of the surface, water and slip plane boundaries will be generated (Figure 17).

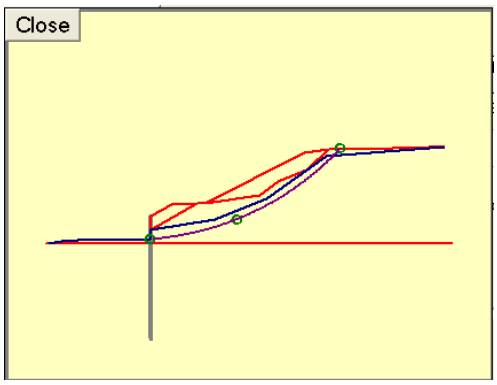


Figure 17: Preview

   b. To view the preview sketch (Figure 17), select Profile on the main menu bar at the top of the screen (Figure 18).

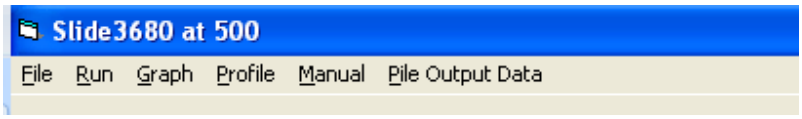


Figure 18: Profile on Main Menu Bar

c. Once the stability analysis has run successfully, the user has the option to view a graph of the geometry and failure surface(s), Figure 19. The graph displays the date and time, factor-of-safety (F.S.), water table, soil layers and slide name. If the mouse pointer is moved over the graph the x and y coordinates are displayed on the lower border of the graph. <u>Please note that the order of the coordinates are reversed, y and x.</u>

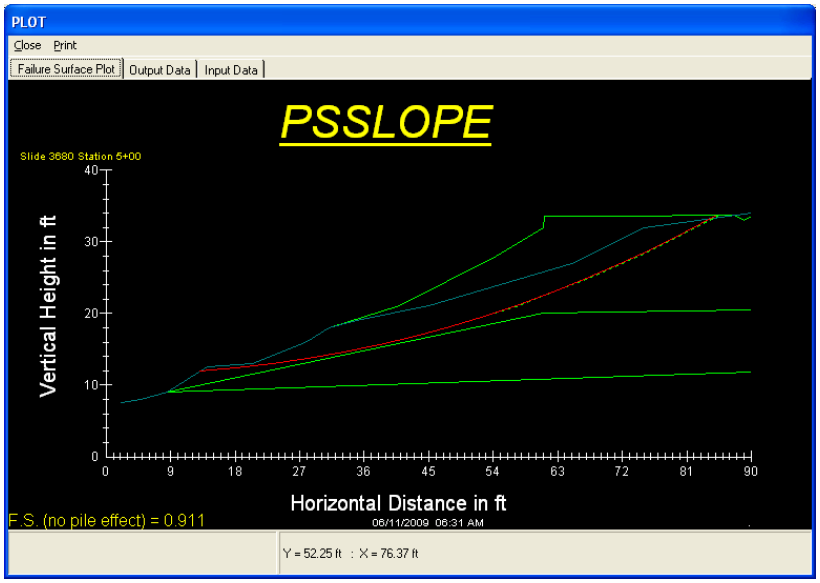


Figure 19: Stability Graph/Plot

In addition to the information displayed on the graph, other information can be printed or viewed on the additional two tabs:

i. Output Data: A couple of pages long, containing.
   1. All the input data
   2. Failure surface
   3. Circle center coordinates and radius
   4. Data on forces along the slices
   5. Cannot be edited in this form

ii. Input Data
   1. All the input data in plain text form
   2. Can be edit, but not advisable

iii. Print
   1. Plot/Graph
      a. Monochrome
      b. Color (uses a lot of ink)
   2. Output data

8. **Including the Pile Wall:** Once a F.S. of 1.0 has been reached by back calculating the soil strength parameters and the user is confident in the modeling of the slip, it is recommended to adjust the soil layers to include the pile wall and correction. Often the installation of a pile wall requires rebuilding the road to include a 4 to 6-foot shoulder, and possibly a guardrail. This added weight could result in a greater driving force on the wall and should be modeled. When modeling the wall it is important to note that the piling cannot be input as a vertical line. Offset the top by 0.1-feet, uphill (remember that there must be soil under the line and not air, so don't offset in the wrong direction). Remove any slide material below the piling that will be removed for construction and/or road clearing. This will be dependent upon the situation. The main objective is to model the correction geometry as accurate as possible, eliminating any resisting forces and adding any additional driving forces. Run the analysis and ignore any change to the F.S. as a result of these changes.

CHAPTER 2 – PILE SIZING AND ANALYSIS

A. Pile Data Input

1. Select from the drop down menu the appropriate pile (Figure 20), the most common H and W sizes, for compact (Mp) and noncompact (My) piles are listed. Compact piles utilize the plastic moment and noncompact piles use the yield moment.

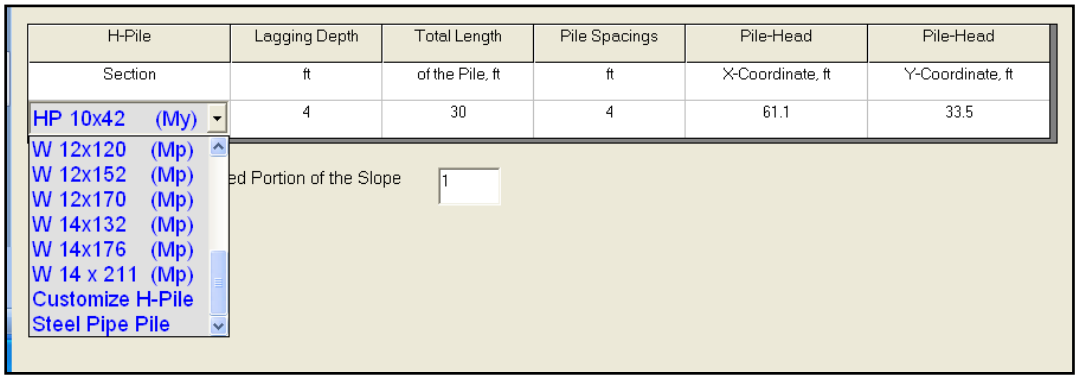


Figure 20: Pile Input Table

Another option is to enter a custom pile size (Figure 21); some inputs can be obtained directly from the "Manual of Steel Construction" or any other official source. Others will have to be calculated as outlined below.

a. Flange Width: Column Width (b_f), from manual
b. Depth: Column Depth (d), from manual
c. EI: Modulus of Elasticity of Steel (E=29,000,000 psi) x Moment of Inertia (I), in the strong axis, (Elastic Properties column, Axis x-x, column I)
d. Unfactored Moment: 50,000 psi x S, in the strong direction (S=section modulus, (Elastic Properties column, Axis x-x, column S); or if $b_f/2t_f$ column under compact section criteria is less than 9.15 Z^x (plastic Modulus) can be used.

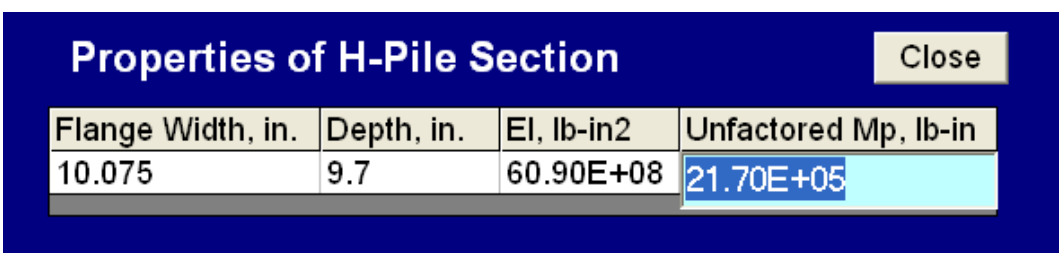


Figure 21: Custom H-Pile Input

Note that this input window is not limited to just H-Pile sections, other shapes can be used. Selection of the proper pile size will come with experience and will only need minor adjustment to achieve the proper performance and deflection. A good practice is to select a pile size a little larger than anticipated, and run the program to determine the smallest size needed. Selecting a pile size that is too small results in an error

message (see Figure 22) that the pile failed under the moment and produces no quantifying results in which to gauge how much larger the pile needs to be.

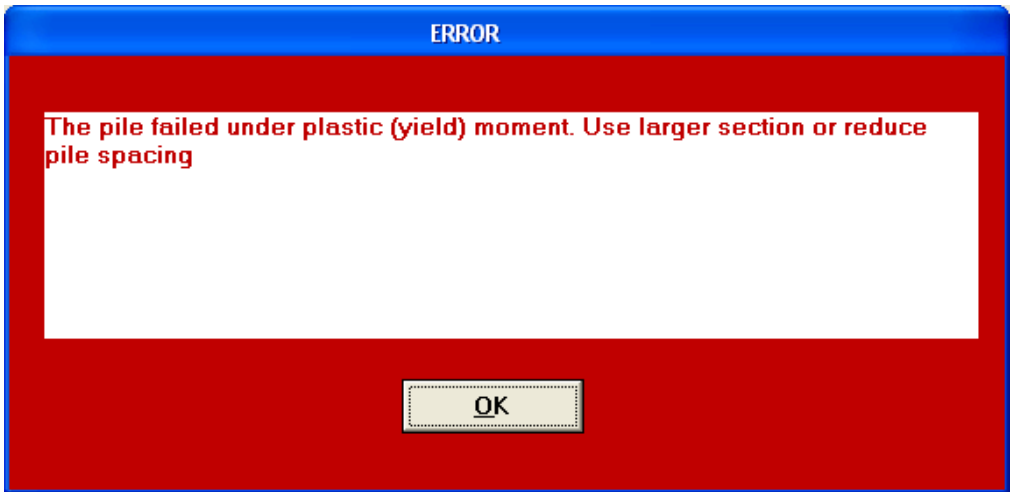


Figure 22: Pile Failure Warning Message.

2. Enter the desired **Lagging Depth**; keep in mind that the slope on the downhill side may continue to move. A good practice is to embed the lagging 2-feet into the ground. The lagging cannot be extended beyond the failure surface.

3. Enter the estimated **Total Length** of the pile in feet. A good practice is to embed the pile 10-feet into bedrock. Although this is not always possible or practical.

4. Enter the **Pile Spacing**, the standard spacing is 4-feet center-to-center of piles. This can be adjusted as the situation dictates.

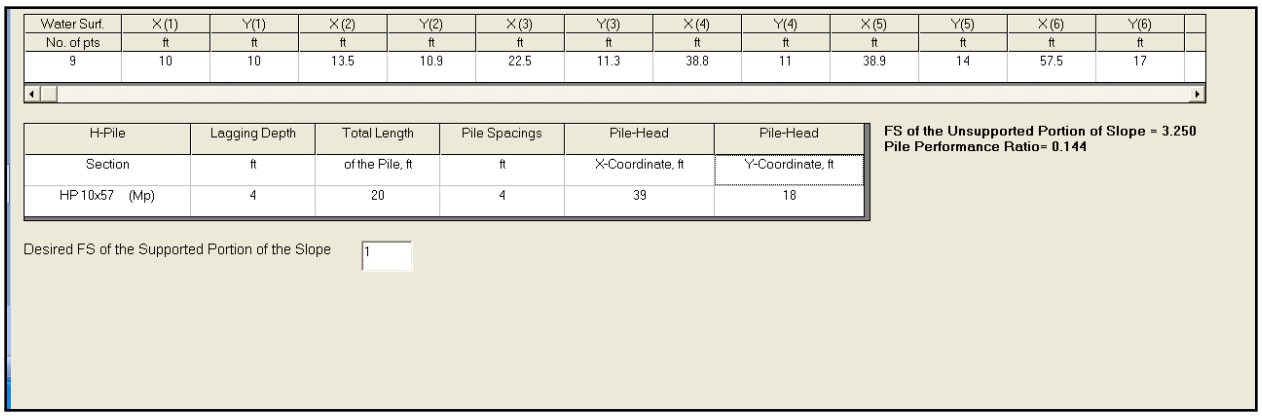
5. Enter the **Pile Head** x and y coordinate. This must be the same coordinates as the top of the pile that was entered into the boundary input table.

6. Select the desired **FS**, for the initial analysis, use FS of 1.0.

B. RUNNING PILE ANALYSIS

1. It is important to remember that the Slope Stability must be run prior to running the Slope with Piles, ***EVERY TIME*** a change is made. If a change is made to ***ANY*** input data, then the slope stability must be run again. So it is recommended as a practice to run the Slope Stability and then run the Slope with Piles, every time. To run the program, select Run the Slope with Piles.

2. Once the program has successfully run, pile performance information will be displayed on the main page, and the user has the option of viewing several files, and graphs. The Factor of Safety and Pile Performance Ratio will be displayed at the far lower right of the main page (Figure 23).



Water Surf.	X(1)	Y(1)	X(2)	Y(2)	X(3)	Y(3)	X(4)	Y(4)	X(5)	Y(5)	X(6)	Y(6)
No. of pts	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft
9	10	10	13.5	10.9	22.5	11.3	38.8	11	38.9	14	57.5	17

H-Pile	Lagging Depth	Total Length	Pile Spacings	Pile-Head	Pile-Head
Section	ft	of the Pile, ft	ft	X-Coordinate, ft	Y-Coordinate, ft
HP 10x57 (Mp)	4	20	4	39	18

FS of the Unsupported Portion of Slope = 3.250
Pile Performance Ratio= 0.144

Desired FS of the Supported Portion of the Slope 1

Figure 23: Pile Analysis Output

a. **FS of the Unsupported Portion of Slope**: This is the FS for the portion of the slide that is downhill from the pile wall, which is not supported by the pile wall. By stabilizing the upper portion of the slide, the driving force could be reduced or even eliminated, thereby stabilizing the lower portion. This information is of concern if there is something downhill of the slide that may be in jeopardy such as structures, another road, railroad, and etcetera.

b. **Pile Performance Ratio**: This is a percent of the factored pile strength that is being used. This information can be utilized several ways. When sizing the pile up or down, this percent can help in determining how much to adjust the pile size. It is important to remember that the final correction requires a factor of safety of 1.3 for general slides and 1.5 around structures (per AASHTO LRFD Bridge Design Specifications). The higher FS will use a greater percent of the pile strength. Also, if the pile is not long enough and rotates over (fence post), the performance ratio <u>will be low</u>. This number should always be used in conjunction with the deflection as discussed below.

3. **Graphing Results**: From the main menu select Graph, and then select Pile Response from the drop-down menu. The pile response is analyzed utilizing four separate graphs: Deflection, Moment, Shear Force and Line Load. On the graph there is a tab for Graphic Control, this has no function with the program. Although it is still active and can be used to modify the overall look of the graph, it will tend to produce a graph that is not as usable. Once the graph has been manipulated with this function, it is not possible to return to the original graph. Do not fear, closing the program and restarting the program will restore the graph to the default.

   a. **Deflection**: This graph displays the deflection of the pile, in feet, along the y axis. Deflection is most critical when analyzed at a factor of safety of 1.0 (Figure 24). The amount of deflection that is allowed is dependent on the situation. As a practice 4 inches is the maximum deflection for rural roads, 2.0 for major roads. Road type, slope steepness, shoulder width, and if a guardrail will be installed, all have a major impact on the maximum allowable deflection. If the shoulder is going to be paved up to the wall, less deflection is desirable. In addition to deflection, this graph indicates if the length of the pile is adequate. It is important

to get two points crossing the zero line to get fixity, using the final factor of safety of 1.3.

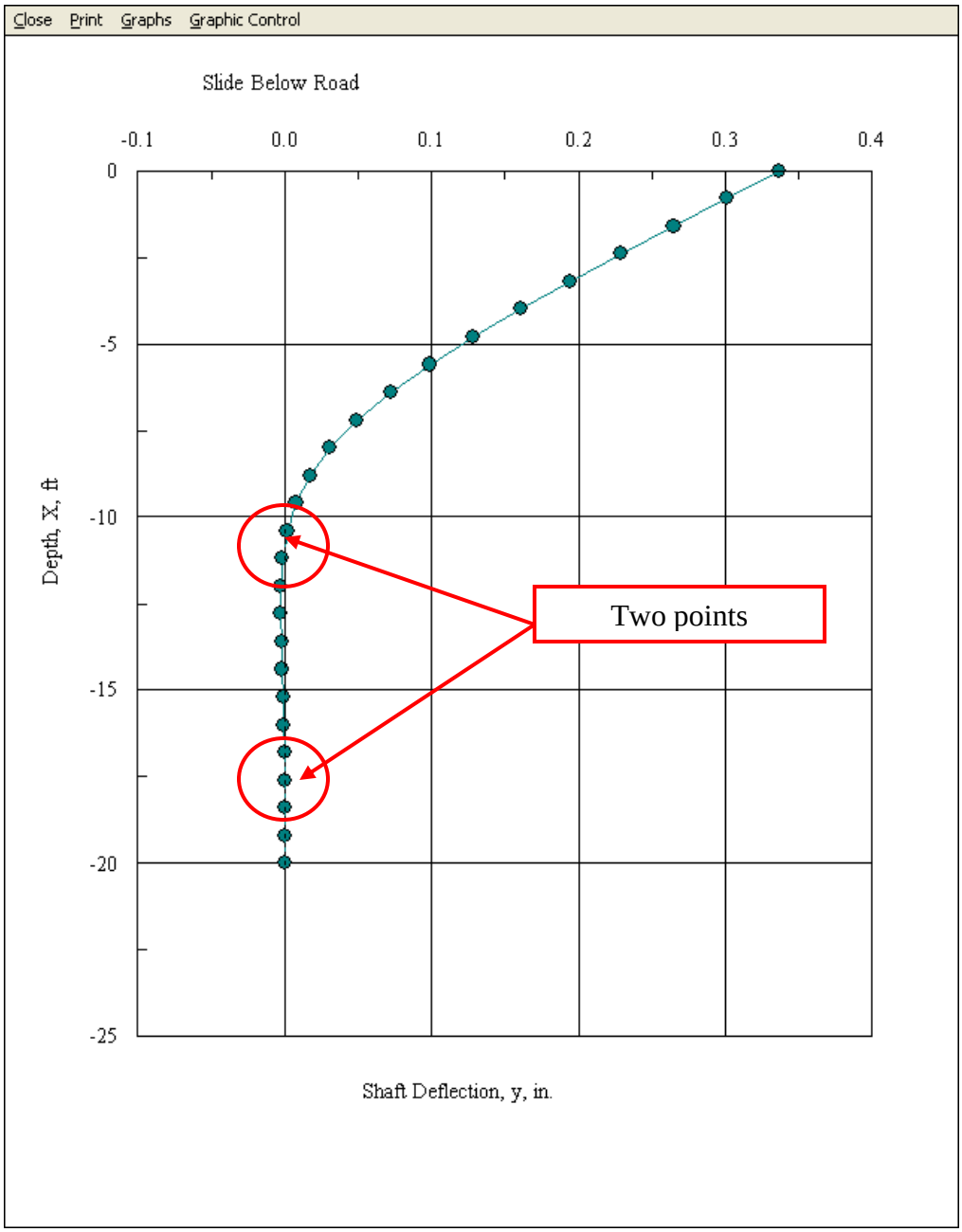


Figure 24: Deflection Graph

b. Bending Moment: The location and magnitude of the bending moment can be visualized (Figure 25). As a check, the moment in the flexure formula (moment/section modulus = fiber stress) can be used, to determine what section modulus to use if a different shape is desired.

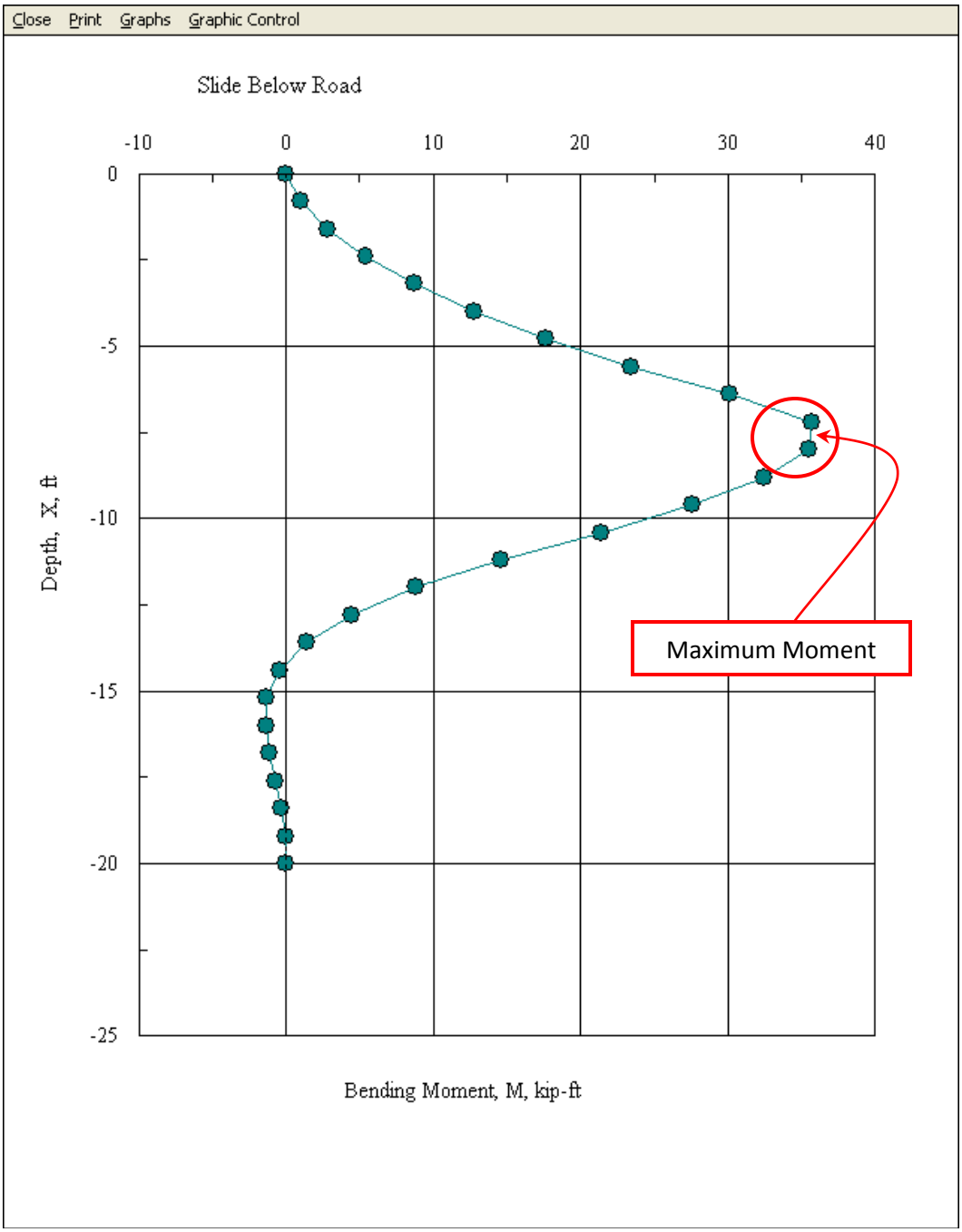


Figure 25: Bending Moment

c. **Shear Force**: The shear is built up within the pile by the slipping mass then shed into the more resistive layer below the slip surface. Shear is usually not a critical design state for steel piles (Figure 26).

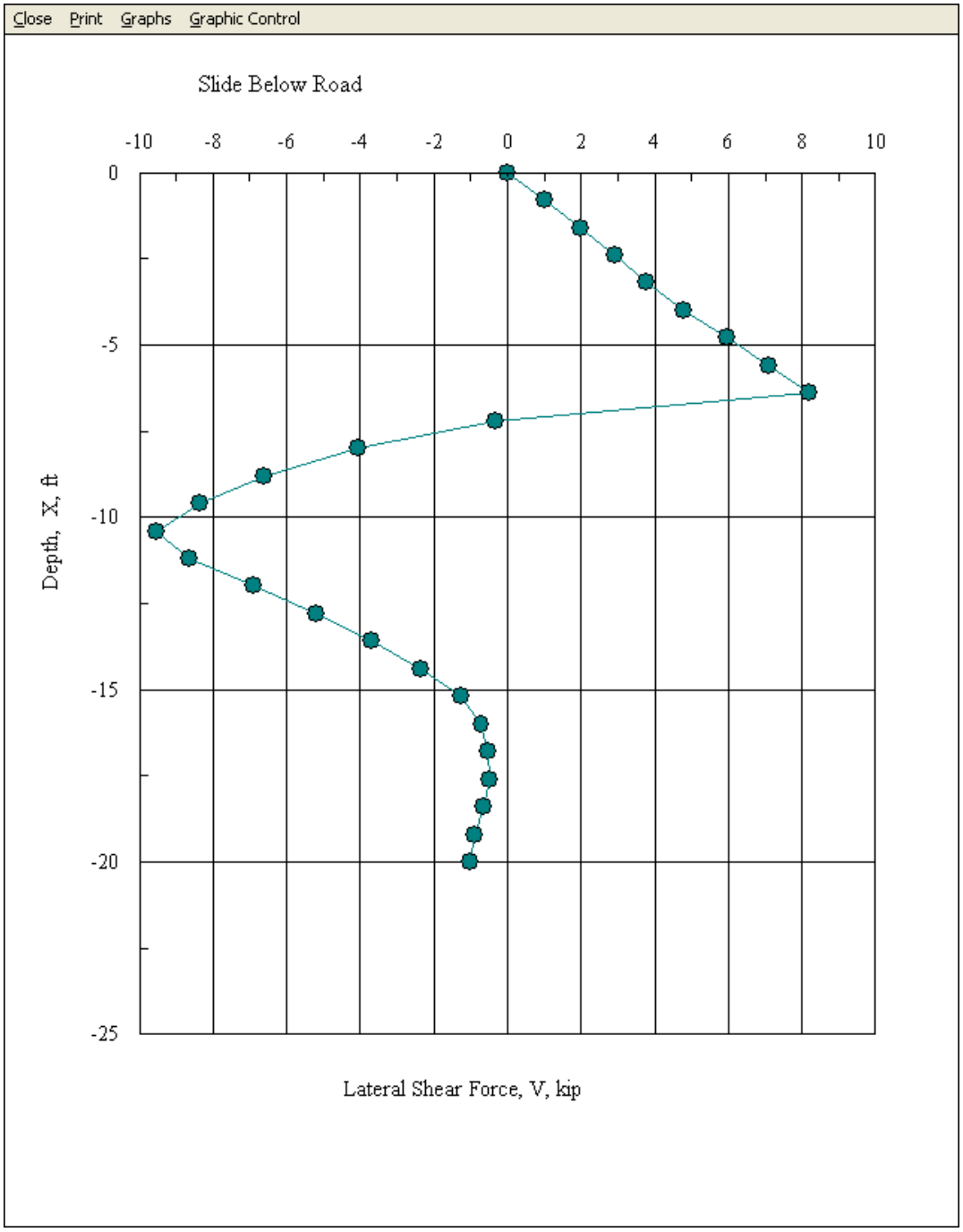


Figure 26: Shear Force

d. Line Load: The line load is the load per vertical inch of the pile that the soil or rock sees. To convert this load to stress, divide the force by the flange width. This is used to check the spike at the rock line to determine if the pressure exceeds the unconfined compressive strength of the rock mass (Figure 27).

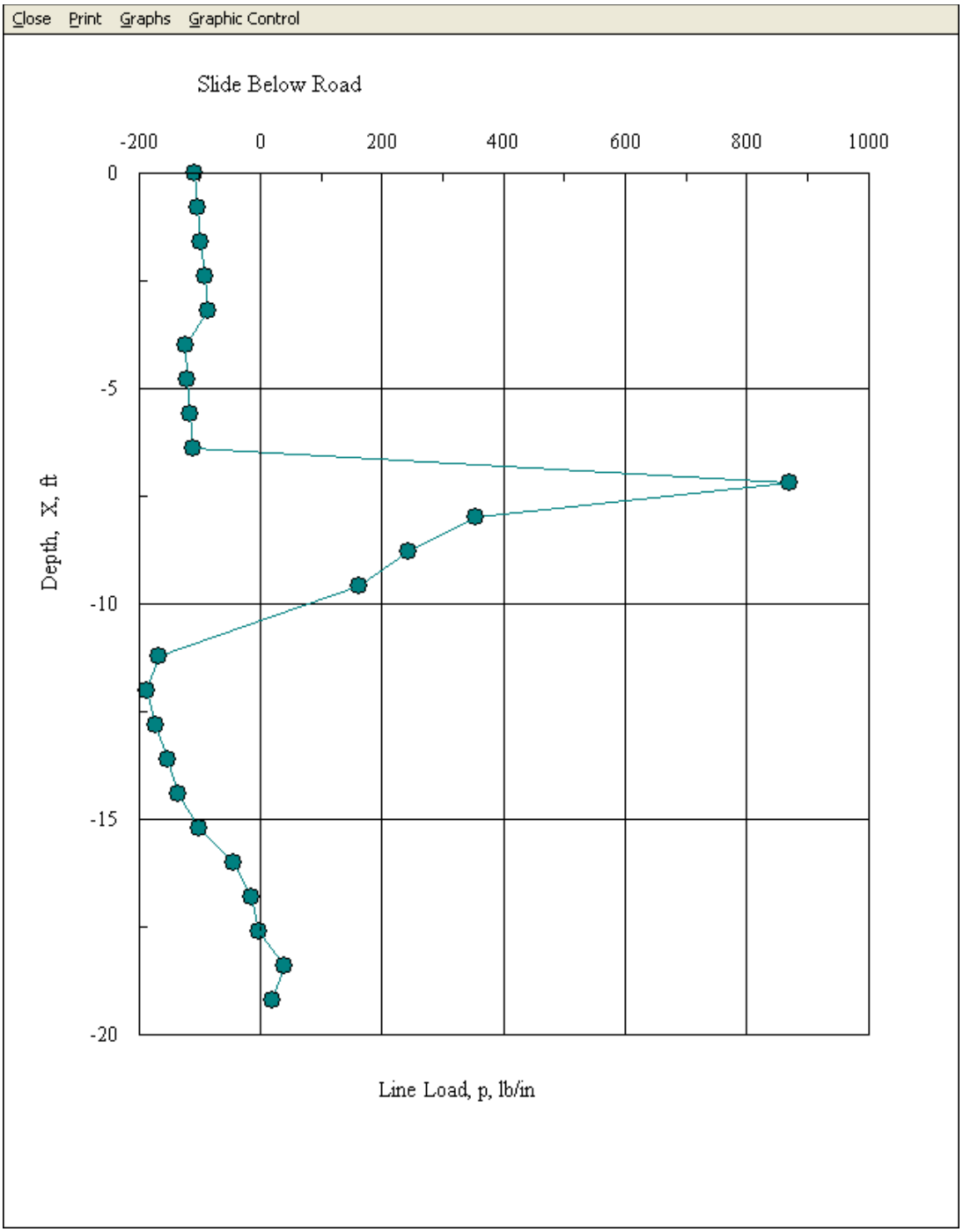


Figure 27: Line Load

4. **Pile Size**: Once the required pile size has been determined by checking the pile performance at a FS of 1.0 and 1.3, save the file, and print any files required.

5. In addition to graphs and plots the program generates two text files, Figure 28, 29 and 30. These files are output files generated and used as input files to parts of the program. Care should be taken when examining these files, as changes will corrupt the original results. However, if needed the user can obtain the exact deflection, location, and depth of the maximum moment from these files, although, as with most things in Geotechnical Engineering, this level of accuracy is not really needed.

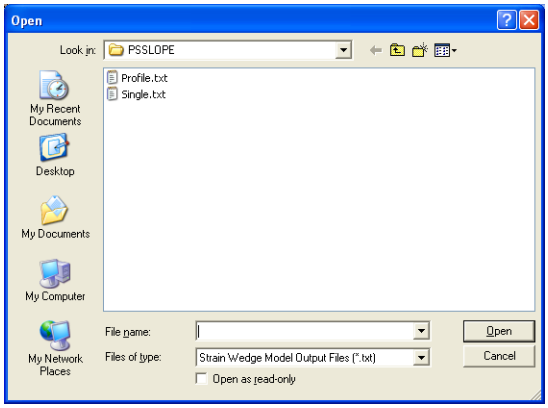
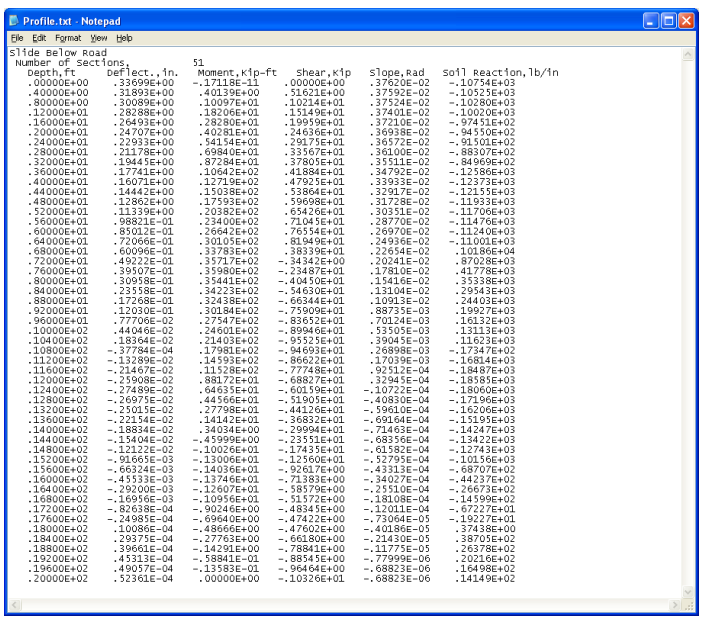
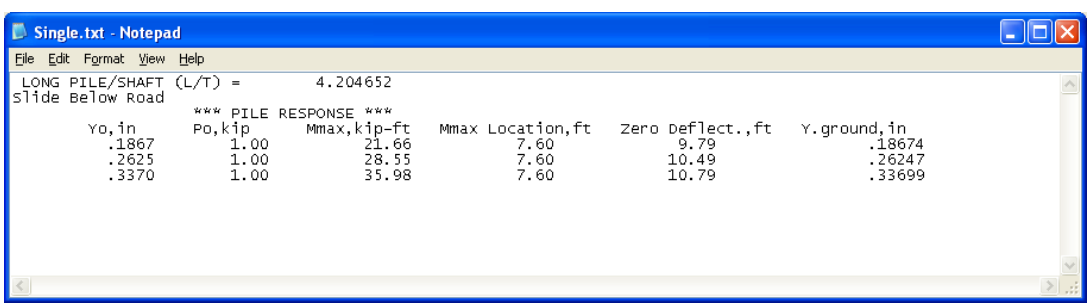


Figure 28: Output Text Files




```
Slide Below Road
 Number of Sections,          51
   Depth,ft     Deflect.,in.   Moment,kip-ft   Shear,kip   Slope,Rad   Soil Reaction,lb/in
  .00000E+00    .33699E+00   -.17118E-11    .00000E+00   .37620E-02   -.10754E+03
  .40000E+00    .31893E+00    .40139E+00    .51621E+00   .37592E-02   -.10525E+03
  .80000E+00    .30089E+00    .10097E+01    .10214E+01   .37524E-02   -.10280E+03
  .12000E+01    .28288E+00    .18206E+01    .15149E+01   .37401E-02   -.10020E+03
  .16000E+01    .26493E+00    .28280E+01    .19959E+01   .37210E-02   -.97451E+02
  .20000E+01    .24707E+00    .40281E+01    .24636E+01   .36938E-02   -.94550E+02
  .24000E+01    .22933E+00    .54154E+01    .29175E+01   .36572E-02   -.91501E+02
  .28000E+01    .21178E+00    .69840E+01    .33567E+01   .36100E-02   -.88307E+02
  .32000E+01    .19445E+00    .87284E+01    .37805E+01   .35511E-02   -.84969E+02
  .36000E+01    .17741E+00    .10642E+02    .41884E+01   .34792E-02   -.12586E+03
  .40000E+01    .16071E+00    .12719E+02    .47925E+01   .33933E-02   -.12373E+03
  .44000E+01    .14442E+00    .15038E+02    .53864E+01   .32917E-02   -.12155E+03
  .48000E+01    .12862E+00    .17593E+02    .59698E+01   .31728E-02   -.11933E+03
  .52000E+01    .11339E+00    .20382E+02    .65426E+01   .30351E-02   -.11706E+03
  .56000E+01    .98821E-01    .23400E+02    .71045E+01   .28770E-02   -.11476E+03
  .60000E+01    .85012E-01    .26642E+02    .76554E+01   .26970E-02   -.11240E+03
  .64000E+01    .72066E-01    .30105E+02    .81949E+01   .24936E-02   -.11001E+03
  .68000E+01    .60096E-01    .33783E+02    .38339E+01   .22654E-02    .10186E+04
  .72000E+01    .49222E-01    .35717E+02   -.34342E+00   .20241E-02    .87028E+03
  .76000E+01    .39507E-01    .35980E+02   -.23487E+01   .17810E-02    .41778E+03
  .80000E+01    .30958E-01    .35441E+02   -.40450E+01   .15416E-02    .35338E+03
  .84000E+01    .23558E-01    .34223E+02   -.54630E+01   .13104E-02    .29543E+03
  .88000E+01    .17268E-01    .32438E+02   -.66344E+01   .10913E-02    .24403E+03
  .92000E+01    .12030E-01    .30184E+02   -.75909E+01   .88735E-03    .19927E+03
  .96000E+01    .77706E-02    .27547E+02   -.83652E+01   .70124E-03    .16132E+03
  .10000E+02    .44046E-02    .24601E+02   -.89946E+01   .53505E-03    .13113E+03
  .10400E+02    .18364E-02    .21403E+02   -.95525E+01   .39045E-03    .11623E+03
  .10800E+02   -.37784E-04    .17981E+02   -.94693E+01   .26898E-03   -.17347E+02
  .11200E+02   -.13289E-02    .14593E+02   -.86622E+01   .17039E-03   -.16814E+03
  .11600E+02   -.21467E-02    .11528E+02   -.77748E+01   .92512E-04   -.18487E+03
  .12000E+02   -.25908E-02    .88172E+01   -.68827E+01   .32945E-04   -.18585E+03
  .12400E+02   -.27489E-02    .64635E+01   -.60159E+01  -.10722E-04   -.18060E+03
  .12800E+02   -.26975E-02    .44566E+01   -.51905E+01  -.40830E-04   -.17196E+03
  .13200E+02   -.25015E-02    .27798E+01   -.44126E+01  -.59610E-04   -.16206E+03
  .13600E+02   -.22154E-02    .14142E+01   -.36832E+01  -.69164E-04   -.15195E+03
  .14000E+02   -.18834E-02    .34034E+00   -.29994E+01  -.71463E-04   -.14247E+03
  .14400E+02   -.15404E-02   -.45999E+00   -.23551E+01  -.68356E-04   -.13422E+03
  .14800E+02   -.12122E-02   -.10026E+01   -.17435E+01  -.61582E-04   -.12743E+03
  .15200E+02   -.91665E-03   -.13006E+01   -.12560E+01  -.52795E-04   -.10156E+03
  .15600E+02   -.66324E-03   -.14036E+01   -.92617E+00   -.43313E-04   -.68707E+02
  .16000E+02   -.45533E-03   -.13746E+01   -.71383E+00   -.34027E-04   -.44237E+02
  .16400E+02   -.29200E-03   -.12607E+01   -.58579E+00   -.25510E-04   -.26673E+02
  .16800E+02   -.16956E-03   -.10956E+01   -.51572E+00   -.18108E-04   -.14599E+02
  .17200E+02   -.82638E-04   -.90246E+00   -.48345E+00   -.12011E-04   -.67227E+01
  .17600E+02   -.24985E-04   -.69640E+00   -.47422E+00   -.73064E-05   -.19227E+01
  .18000E+02    .10086E-04   -.48666E+00   -.47602E+00   -.40186E-05    .37438E+00
  .18400E+02    .29375E-04   -.27763E+00   -.66180E+00   -.21430E-05    .38705E+02
  .18800E+02    .39661E-04   -.14291E+00   -.78841E+00   -.11775E-05    .26378E+02
  .19200E+02    .45313E-04   -.58841E-01   -.88545E+00   -.77999E-06    .20216E+02
  .19600E+02    .49057E-04   -.13583E-01   -.96464E+00   -.68823E-06    .16498E+02
  .20000E+02    .52361E-04    .00000E+00   -.10326E+01   -.68823E-06    .14149E+02
```

Figure 29: Profile Text File of data presented in the pile graphs




```
 LONG PILE/SHAFT (L/T) =        4.204652
Slide Below Road
                    *** PILE RESPONSE ***
        Yo,in       Po,kip      Mmax,kip-ft   Mmax Location,ft   Zero Deflect.,ft   Y.ground,in
         .1867        1.00          21.66            7.60              9.79              .18674
         .2625        1.00          28.55            7.60             10.49              .26247
         .3370        1.00          35.98            7.60             10.79              .33699
```

Figure 30: Output data indicating whether the pile is stiff, intermediate or flexible

C. SIMPLE WEDGE PROGRAM

1. **<u>Simple Wedge Analysis</u>**: This method of analysis is, as the name implies, a very simple method to model the slip as a simple wedge of soil applying a driving force to the pile. The program requires inputs as follows: the wedge geometry, depth to water table, and depth to bedrock (Figure 45), as well as two soils types, lagging depth, pile length, pile spacing and pile size. The second soil is assumed to be the bedrock, regardless of the strength parameters entered.

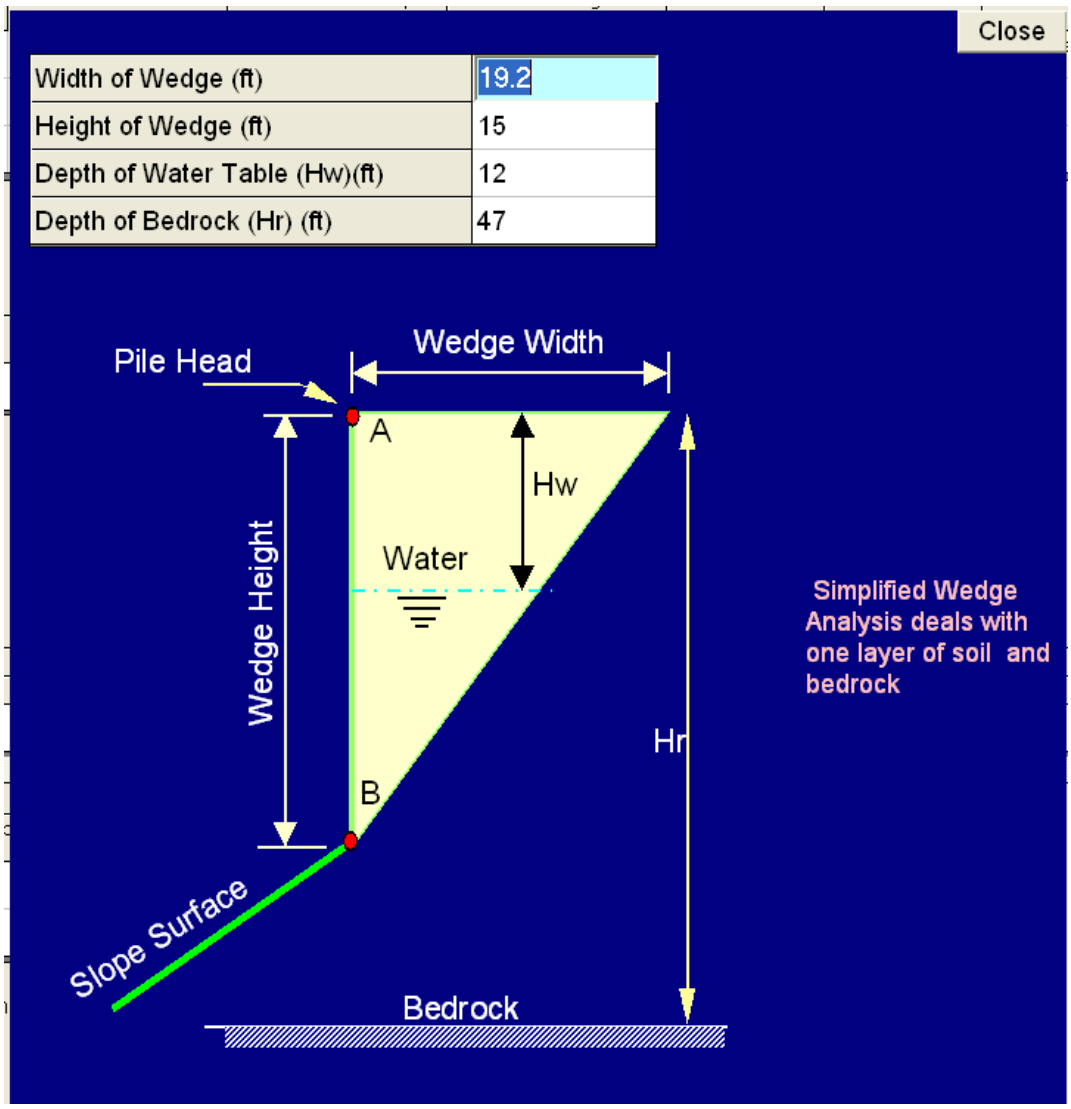


Figure 45: Simple Wedge Input

a. **Soil Input** - Enter the two soils as follows: one soil for the slip surface and surrounding area, and another to embed the pile into. Both soils can have the

exact undisturbed and disturbed strength parameters, or they can be two entirely different soils/rock. The main point is the program requires two soils. The Total number of boundaries, Number of top boundaries, boundary coordinates and water table surface need not be entered.

b. **Width of Wedge**: Next select the Simple Wedge Analysis button and enter the data the Width of the Wedge. This is the horizontal distance from the top of the pile to the last break in the road. Adding extra width to the wedge will reduce the driving force and is not advised. Caution is recommended when using this analysis method and the results can readily be checked as discussed later.

c. **Pile Height**: Enter the Height of Wedge (ft); this is the vertical distance from the top of the pile to the suspected slip surface.

d. **Depth of Water Table**: Input the estimated Depth of Water Table (Hw) (ft).

e. **Depth of Bedrock**: Enter the Depth of Bedrock (Hr) (ft), this is the second soil listed in Figure 1. The second soil does not necessarily have to be Rock or even a different soil type. If for example, the core borings show the same type of soil deeper then the estimated pile length, enter the second soil having the same strength properties as the first soil.

f. **Pile Data**: Enter the Pile size, Lagging Depth, Total Length and Pile Spacing.

g. **FS**: Enter the desired factor of safety. The program should be run with the FS of 1.0, and 1.3 or 1.5 as discussed on Page 17, "Running Pile Analysis"

2. **Running the Program**: On the main menu tool bar select run, then Slope with Piles. It is the only option.

3. **Viewing the Results**: The program only allows for the viewing of the pile response.

4. **Pile Performance**: The pile performance is analyzed by viewing the available graphs and the Pile Performance Ratio, see page 18.

CHAPTER 3 – EXAMPLE PROBLEMS

A. Learning By Example

1. The following example problem is provided to show the user how to design a pile wall as a corrective measure. The user is encouraged to adjust the soil, rock, and water table parameters (layering and soil properties) to produce a variety of results. The user is also highly encouraged to experiment with the different slope stability methods. An effort has been made to explain all steps in the analysis and design.

2. The program has been made as user friendly as practical; this includes trying to trap common errors that the user may make. However, not all of these errors can be anticipated, and error messages may arise that are incomprehensible to the average user.

B. A Note on Factors of Safety

1. **Service Limit State**: In the analysis, only a factor of safety of 1.0 is used to determine an acceptable deflection. If a higher FS is used, the deflection becomes meaningless since the pile/soil should be in equilibrium when deflection is assessed.

2. **Strength Limit State**: The factor of safety used by WVDOH for the design of ordinary soil slopes (cuts and embankments) is 1.25 for Allowable Stress Design and 1.30 for Load Factor Design. Many designs have been developed by the WVDOH Engineering Division in the last few years with factors of safety 1.25. The lowest FS in the strength limit state is 1.1. This should only be used for extreme event limit states, such as end of construction or rapid draw-down. A factor of safety of 1.1 is considered at the edge of failure due to the accuracy of the method.

3. **Factor of Safety**: The use of reduced factors of safety for slide corrections requires judgment based on experience. Sliding cause's a reduction of soil strength from peak to residual, so strength can be lost between the times of design and construction. Further, ground water conditions can become worse than those existing at the time of original failure. Use good judgment or, if you lack experience, use a factor of safety of 1.3. With experience, factors of safety of 1.25 can be used, based on local experience.

C. A Note on Failure Surfaces

1. **Failure Circle**: The failure circle must intersect the ground surface at two points (the end points of the circular arc). Otherwise an error message will appear. If the slide has a steep scarp or slope above the upper limit of the slip plane, the circle may intersect the ground surface *again* (for the third time). Hence, some superfluous lines above the slip plane must be eliminated. However, if a new circle is run to check the corrective design, *the eliminated lines may have to be added.*

2. On rare occasions, a circle through the toe of the slope can intersect a line below (for the third time) to give an error. It is good to check your circles before you run the program.

3. The maximum vertical depth of a slide rarely exceeds ¼ of the slope length of the slide; the maximum failure surface depth is always less than 0.3 times the length and averages about 0.17 times the length. These criteria do not apply to new embankments over soft, deep clay foundations.

D. Important Design Considerations

1. **Driving Forces**: The driving force to be resisted depends on the location of corrective measures within the slide and the slope configuration within the slide. For example, a piling correction near the top of the slide may only have to hold the top of the slide, not the entire slide. However, if we must fill on top of the slide (e.g., to rebuild the road surface), we need a piling wall (with lagging) to hold the top of the slide PLUS the new fill. We need to perform a new stability analysis on the slide and fill to obtain the force the piling must resist. To accomplish this, the soil surface profile will need to be modified to model the correction. So prior planning when selecting and entering the x and y coordinates makes possible the remodeling of the correction, much easier and becomes a simple matter of entering new line segments at the end of the input table or change the value of a few points.

2. **Resisting Forces**:

   a. **Soil Strength**: Soil strength is defined by the parameters of the internal friction angle (phiϕ) and the cohesion intercept (c). Each type of soil will, in general, have different values for ϕ and c. Furthermore, the same soil within and surrounding a slide mass will typically have different strengths.

   b. Where to use different strength parameters? Use ϕ_r along the slip plane (disturbed) during the original analysis. Within the slide mass and below the slip plane (undisturbed), use peak values. Do not choose strength parameters over conservatively; this will require the ground water to be modeled higher to get the slide to fail.

   c. Ground Water: The pore water force (U) values reduce the effective normal forces, thereby reducing resisting forces. The exact U values are rarely known since this requires extensive and usually long term piezometric water level measurements. Even when such measurements are made, they may not reflect values at the time of failure. One of following three ground water conditions is normally encountered during corrective design.

      1. Ground water approximately known or partially known: Seepage is sometimes visible on the ground surface so that the uppermost elevation where the water emerges from the ground can be measured. On some of these occasions, the

water level at the time of failure will be at the ground surface for the full length of the slide, even though there is no visual evidence. Borings above the visible seepage may also show indications of the ground water level (when practical, have observation well installed). These conditions allow an approximate ground water level to be plotted on the design cross section. If only partial information is available, i.e., only visible surface seepage or only an indication of the water level in a boring, the water level must be estimated from this information. The estimated water level may be adjusted later if results of the stability analysis indicate that such adjustment is necessary.

2. Ground water unknown, but soil strength is known: Sometimes no reliable indications of ground water are available. If soil strength parameters are available, either from test results, N-Values, or from estimates, a stability analysis without ground water can be performed. Use a rough water level to estimate a trial water surface. Adjust the water surface to get F.S. =1.0. If strength parameters were estimated and water levels appear to be too high or too low, you can adjust the strength parameters (usually just ϕ_r with c = 0) so that the water level looks reasonable. Be careful adjusting the soil strength too much as piezometric levels can be above the ground surface when artesian pressures are encountered and at least some groundwater will be present.

3. Ground water and soil strength unknown: Emergency situations arise where corrective measures must be based solely on site observations. Surface soils are visible and surface indications of ground water may be visible, but strength parameters and water levels are quite problematic. Guesstimate strength parameters and water levels based on your observations, and run a stability analysis. Adjust the assumed values to obtain a 1.0 factor of safety. Design the correction using these values to estimate conditions outside the slide area. For example, if the ϕ_r is 23 degrees and use ϕ = 27 degrees and c = 100 psf for the soil under the slide. Adjust the embedment depth during piling installation if the soil under the slide is significantly different or if bedrock is encountered.

E. Example Problem

1. The number of soils used in the analysis will depend upon the information available. It is often easy to determine the number of soil zones from boring logs. For this example the soil parameters were derived from field observations and core borings they are depicted in Figures 31 and 32. The core boring indicated three main soil layers and a depth to water, at the time of coring.

Core Boring Results				
Soil Type	**Blow Count (N)**	**Consistency**	**Moisture Content**	**Weathering**
Silty Clay	10	Stiff	Slightly Moist	
Sandy Clay	6	Med Stiff	Moist	
Sandstone	NA	Hard	Dry	Slightly Weathered

Figure 31: Core Boring Table

Estimated Soil Strength Properties							
Soil #	Soil Type	Unit Weight	Saturated Unit Weight	Cohesion Intercept Disturbed	Friction Angle Residual	Cohesion Intercept Undisturbed	F Friction Angle Peak
1	C-Phi	124	126	0	23	50	31
2	C-Phi	120	124	0	26	100	28
3	Rock	145	146	10000	36	10000	36

Figure 32: Soil Strength Parameters Table

2. Input the soil data in the program from Figure 31 and 32.

3. Determining the soil boundary coordinates is best accomplished through the use of a CAD program. Often the coordinates are derived from a professional survey, but if time is a limiting factor, the user can, with the aid of an assistant, produce a simple plan view and cross section, by utilizing a surveyors tape and Abney Level. In this example the soil boundaries and water surface coordinates have been determined and plotted on Figure 33 and entered into the Figure 35.

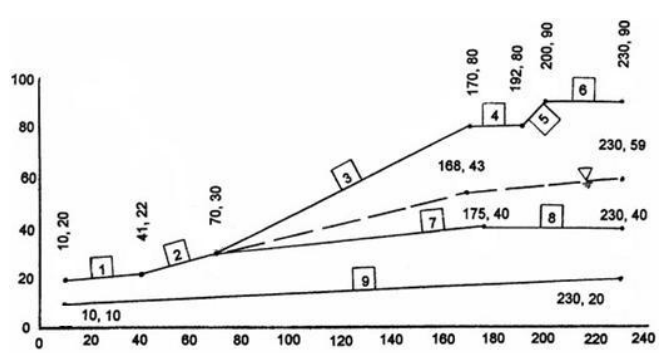


Figure 33: Surface Boundaries Coordinates

4. The soil types and corresponding soil number have been annotated on Figure 34.

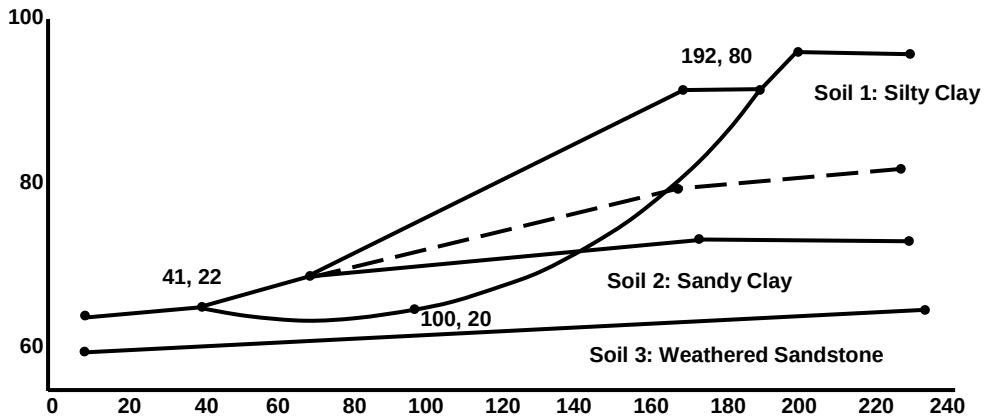


Figure 34: Soil Types

5. Input the Total Number of Boundaries, Number of Top Boundaries, and the soil layer boundary coordinates from the coordinate table shown in Figure 35.

SOIL SURFACE COORDINATES					
Total Number of Boundaries = **9**			Total of Top Boundaries = **6**		
Boundary	**X-Left**	**Y-Left**	**X-Right**	**Y-Right**	**Soil Num**
1	10	20	41	22	1
2	41	22	70	30	1
3	70	30	170	80	1
4	170	80	192	80	1
5	192	80	200	90	1
6	200	90	230	90	1
7	70	30	175	40	2
8	175	40	230	40	2
9	10	10	230	20	3

WATER SURFACE COORDINATES										
No. of Pts	X(1)	Y(1)	X(2)	Y(2)	X(3)	Y(3)	X(4)	Y(4)	X(5)	Y(5)
5	10	20	41	22	70	30	168	52	230	59

Figure 35: Soil and Water Surface Coordinate Table

6. Input the Water Surface coordinates from Figure 35.

7. Input the Existing Failure Surface from Figure 34, utilizing the 3 points.

8. Plot the failure surface; recall there are two methods for checking the failure surface. Adjust inputs as required, correcting any errors.
9. After making any necessary adjustments, run the Slope Stability analysis.

10. View the Graph of the Slope Stability analysis and check the factor of safety. The goal is to adjust the parameters to achieve a factor of safety of 1.0. At this point the graph should look similar to Figure 36.

    In this example the initial input of soil parameters were estimated low to produce a F.S. of less than 1.0, for demonstration purposes.

11. Adjust the soil parameters as required to obtain a F.S. of 1.0, rounded. The Cohesion Intercept and Friction Angle have the greatest effect. However, disturbed soil has little to no cohesion, so it is highly recommended to input 0 for cohesion. The friction angle is determined by the type of soil. Try adjusting the friction angle and unit weight of the soil that is affected by the failure surface.

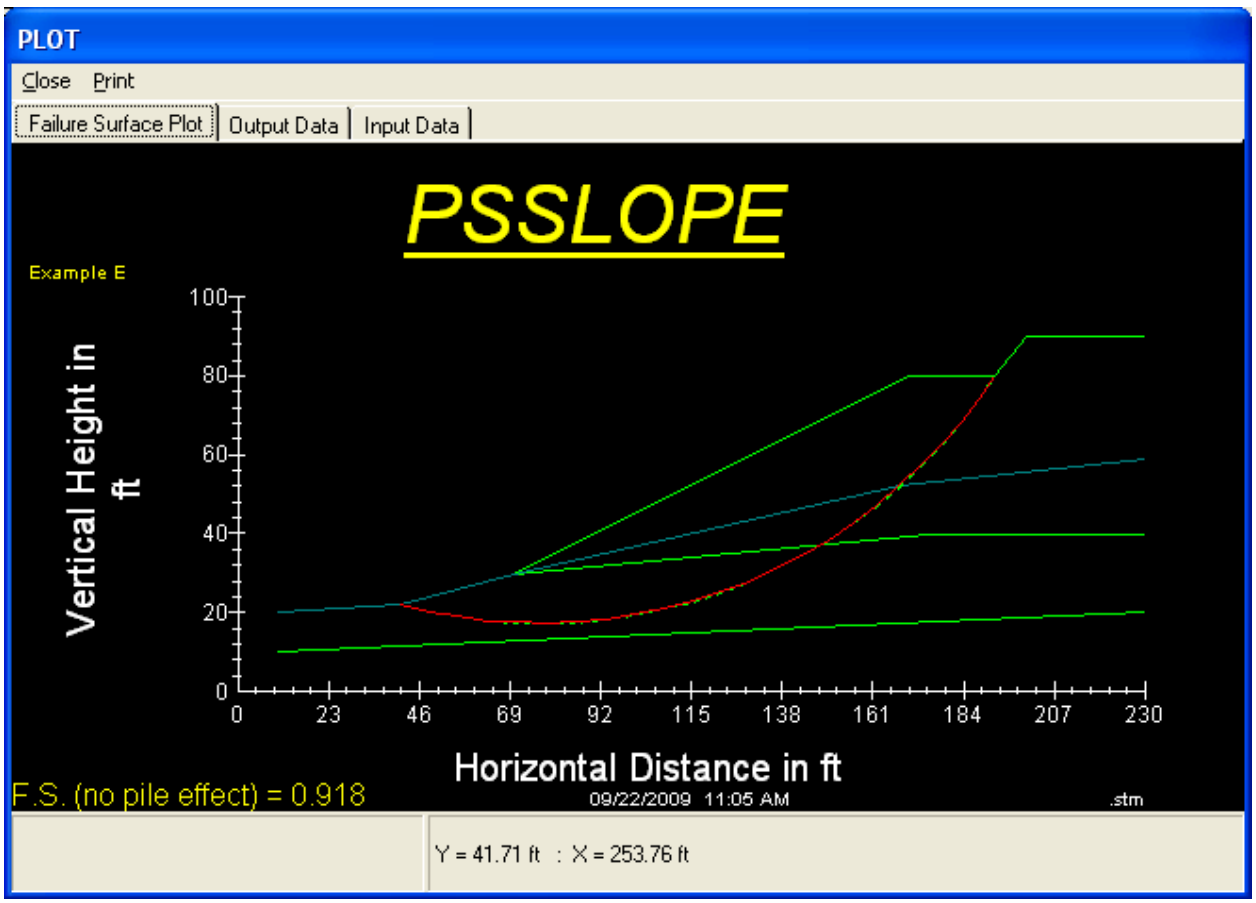


Figure 36: Slope Stability Analysis Graph

    Adjust each item one at a time and check the graph, until proficiency is gained at predicting the desired results.

12. The inputs in Figure 37 will give the desired results of a F.S. of 1.0, rounded. Enter the inputs from the table below if a F.S. has not been achieved or the user inputs differ greatly from those listed in the table. Having similar inputs will be important to obtaining similar pile size for the rest of the exercise.

Soil Strength Properties							
Soil #	Soil Type	Unit Weight	Saturated Unit Weight	Cohesion Intercept Disturbed	Friction Angle Residual	Cohesion Intercept Undisturbed	Friction Angle Peak
1	C-Phi	126	128	0	24	50	31
2	C-Phi	124	126	0	28	100	28
3	Rock	145	146	10000	36	10000	36

Figure 37: Inputs that Produce 1.0 Factor of Safety in Example Problem.

The output graph should look similar to the graph in Figure 38.

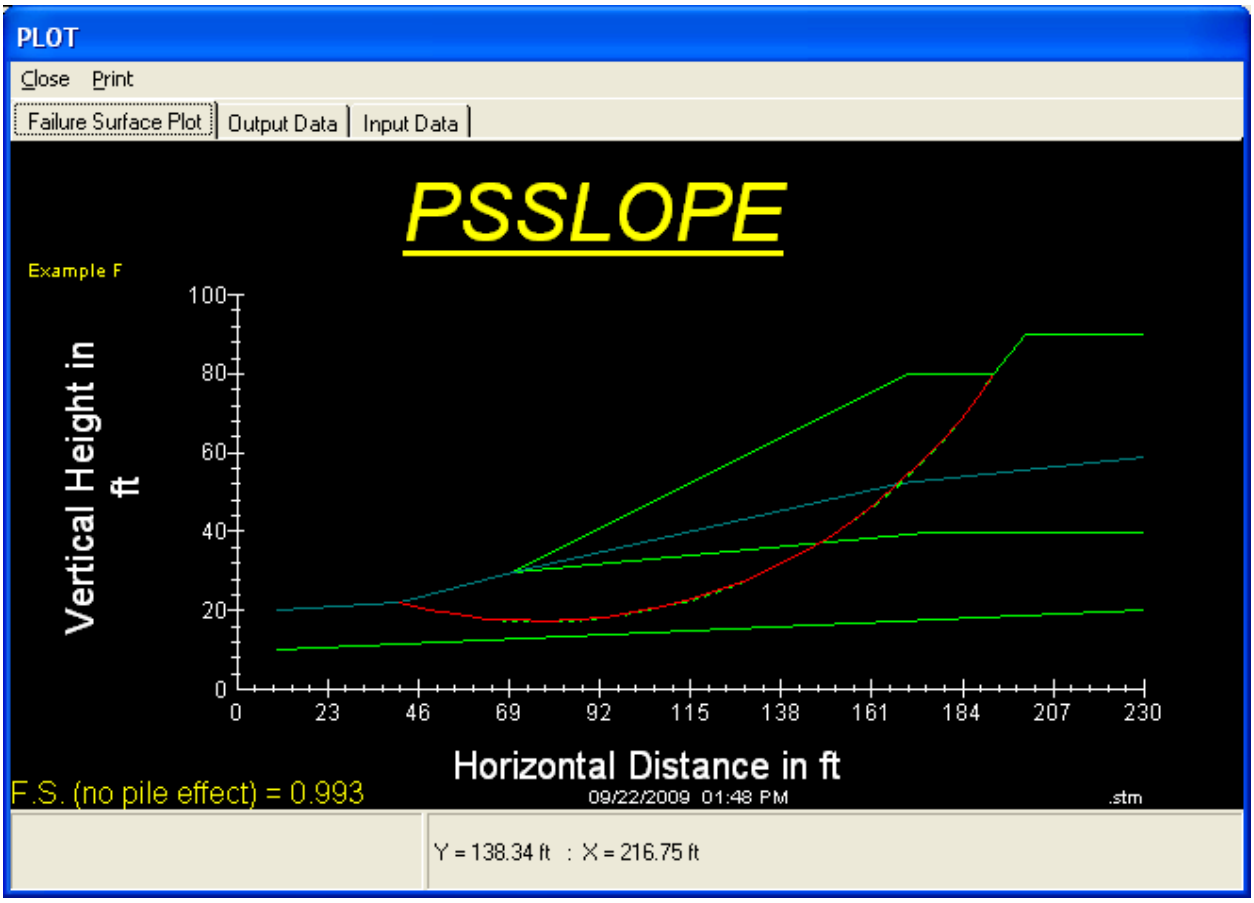


Figure 38: Stability Analysis Graph

13. Once the soil parameters have been adjusted to produce a factor of safety of 1.0 (rounded), input the soil boundary coordinates (Figure 39) to model the pile wall correction. Only the cells highlighted in yellow have been changed. Do not make adjustments to the disturbed soil strength parameters at this time. It is important to remember that the pile wall head needs to be battered slightly, for modeling purpose only. This adjustment will raise the soil boundary up, causing the slip surface to terminate below the surface. Adjust the slip surface to account for the extra soil (Figure 39).

SOIL SURFACE COORDINATES					
Total Number of Boundaries = **9**			Total of Top Boundaries = **6**		
Boundary	**X-Left**	**Y-Left**	**X-Right**	**Y-Right**	**Soil Num**
1	10	20	41	22	1
2	41	22	70	30	1
3	70	30	170	80	1
4	170	80	181.5	80	1
5	181.5	80	182	90	1
6	182	90	230	90	1
7	70	30	175	40	2
8	175	40	230	40	2
9	10	10	230	20	3
Slip Surface Adjustment		Point 3	X= 200	Y=90	

Figure 39: Soil Surface Coordinates for pile wall correction

14. Run the stability analysis for the slope and view the graph (Figure 40) for any errors. Ignore the factor of safety.

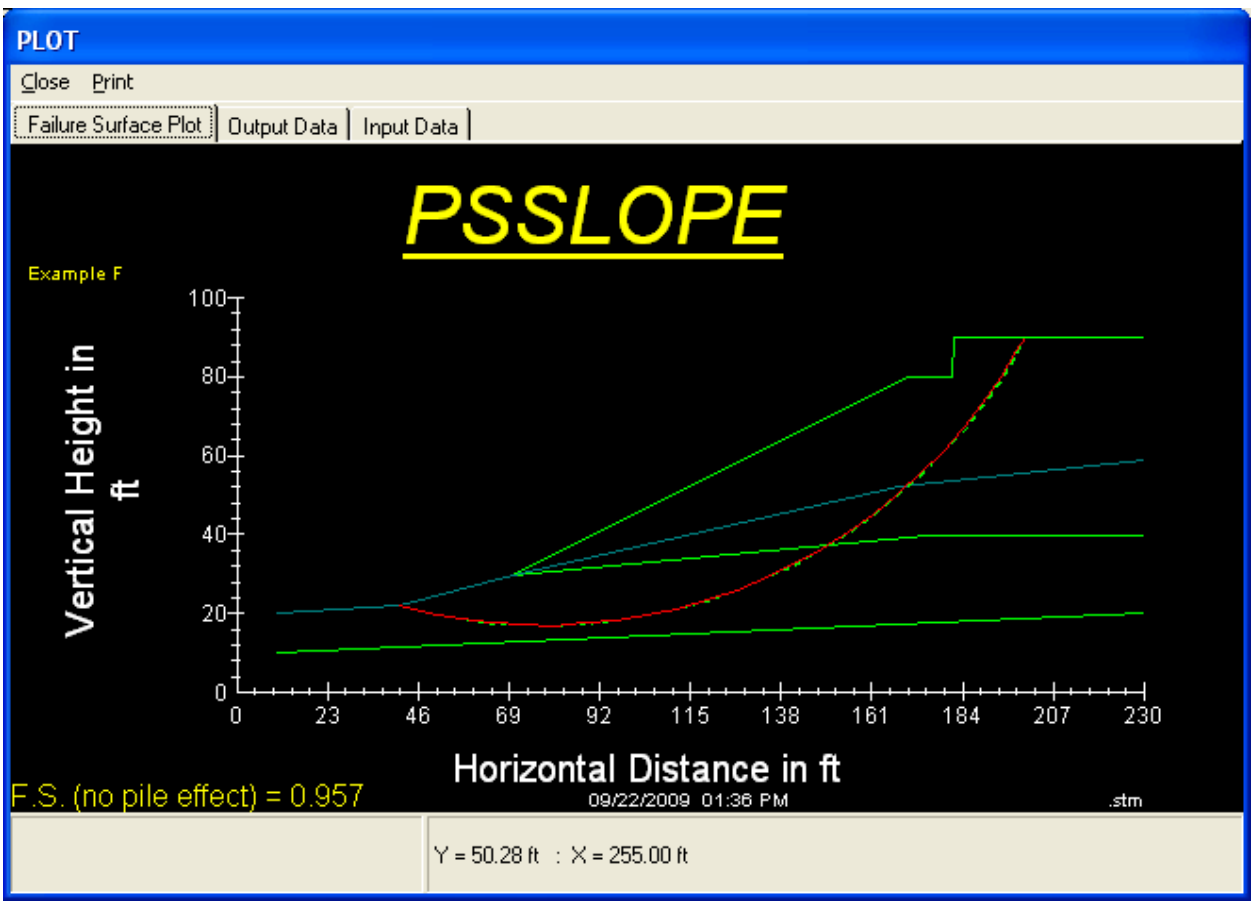


Figure 40: Slope Stability Graph

15. Input the undisturbed soil strength parameters from Figure 37, if not already accomplished.

16. Input the Pile analysis information from Figure 41 and run the Stability with Pile. It is a good practice to size the pile larger than the anticipated size. However for demonstration purpose the initial input will be smaller than the required size. The initial analysis should be done with the Desired FS of the Supported Portion of the Slope set to 1.0.

H-Pile	Lagging Depth	Total Length	Pile Spacings	Pile-Head	Pile-Head
Section	ft	of the Pile, ft	ft	X-Coordinate, ft	Y-Coordinate, ft
HP 8x36 (Mp)	6	20	4	182	90

Desired FS of the Supported Portion of the Slope 1

Figure 41: Pile Inputs

17. Because the pile is not long enough to penetrate beyond the failure surface, the program displays the warning shown below in Figure 42.

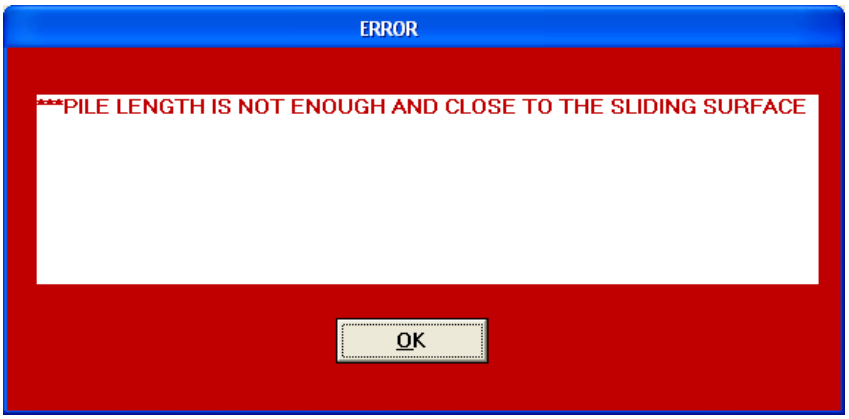


Figure 42 Pile Length Error Box

After clicking OK, another message will be displayed that says to "check data for a zero value" (Figure 43). Click the ok button; this is normal because the short pile length caused a division by zero error.

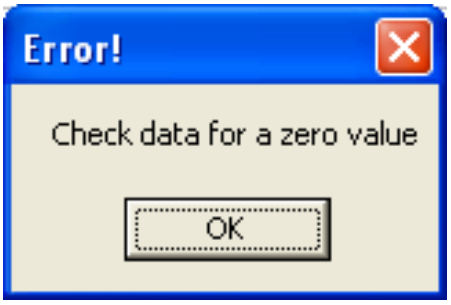


Figure 43: Error Message

18. Check the stability graph and note that the pile wall is now present on the graph, but was not used in the calculations of the slope stability.

19. Now close the graph and adjust the pile length to 30 feet, and run the slope stability and slope with piles programs again. This time a different warning message is displayed as shown in Figure 44 below. This message indicates that the pile penetrates the failure surface, but not deeply enough to be stable. This can be seen by checking the slope stability graph and noticing that the pile just barely penetrates the failure surface.

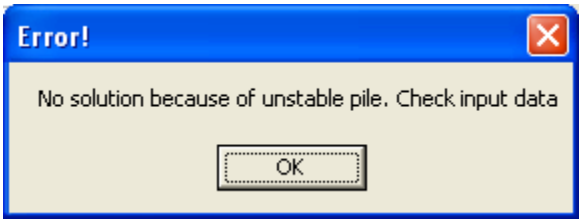


Figure 44: No solution because of unstable pile

20. Now set the pile length to 40 feet and run the slope stability and slope with piles programs again. This time, a warning will be displayed that the pile failed under plastic moment (Figure 45). This warning indicates that the piles are too small and that either larger sections should be used or the pile spacing should be reduced.

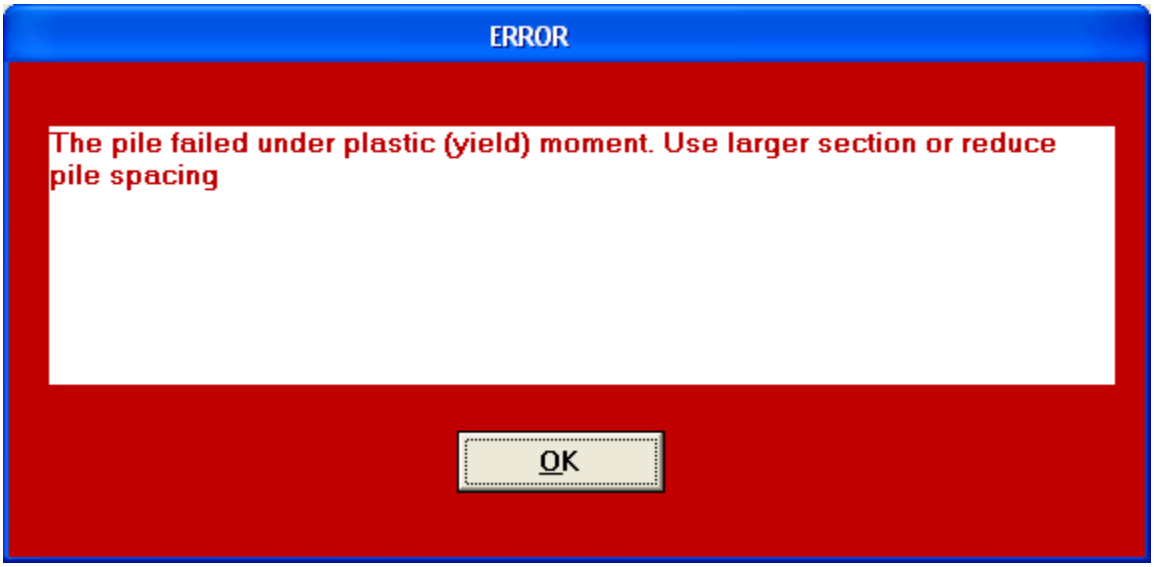


Figure 45: Pile Failure due to Plastic Moment Warning

21. Through trial and error, run the slope stability and slope with piles program using increasing pile sizes until a size is found that does not fail. In this example, the smallest pile size that does not fail should be HP 12x84. The Pile Performance Ratio and FS of the Unsupported Portion of Slope are also now displayed to the left of the input table.

22. Open the Graph drop-down menu and view the pile response graph (Figure 46).

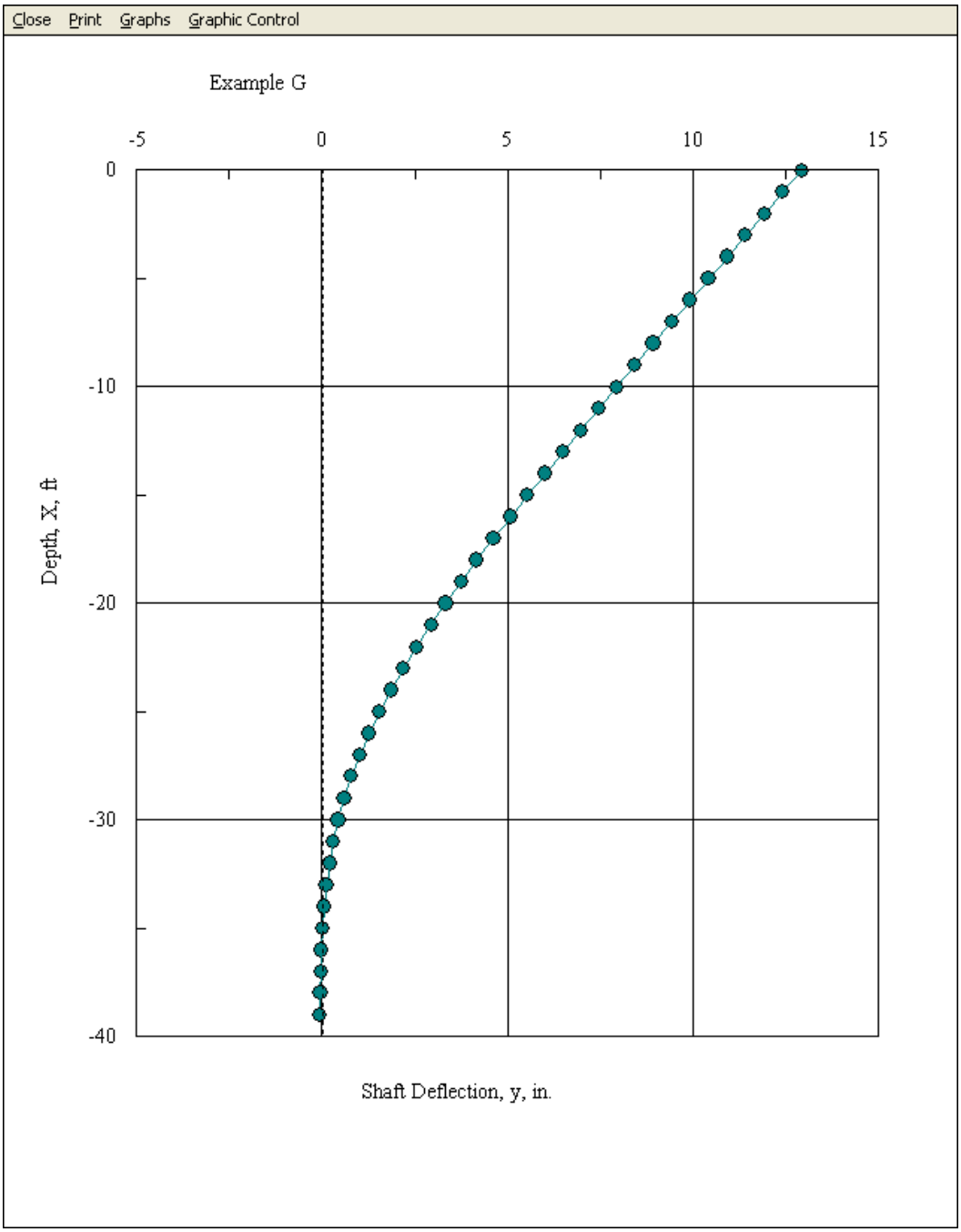


Figure 46: Fence Posting

23. Fence posting can indicate that the pile is too short. Enter a new pile length of 45 feet and re-run the program.

24. Open the pile response graph (Figure 47) and notice that the pile has two points on the zero line (nodes); this indicates that under these conditions the pile has

fixity and that its length is long enough. The deflection is almost 13 inches; this is excessive for a FS of 1.0.

a. The desired deflection is less than 4 inches for rural roads.
b. For major roads, the desired deflection is less than 2 inches.

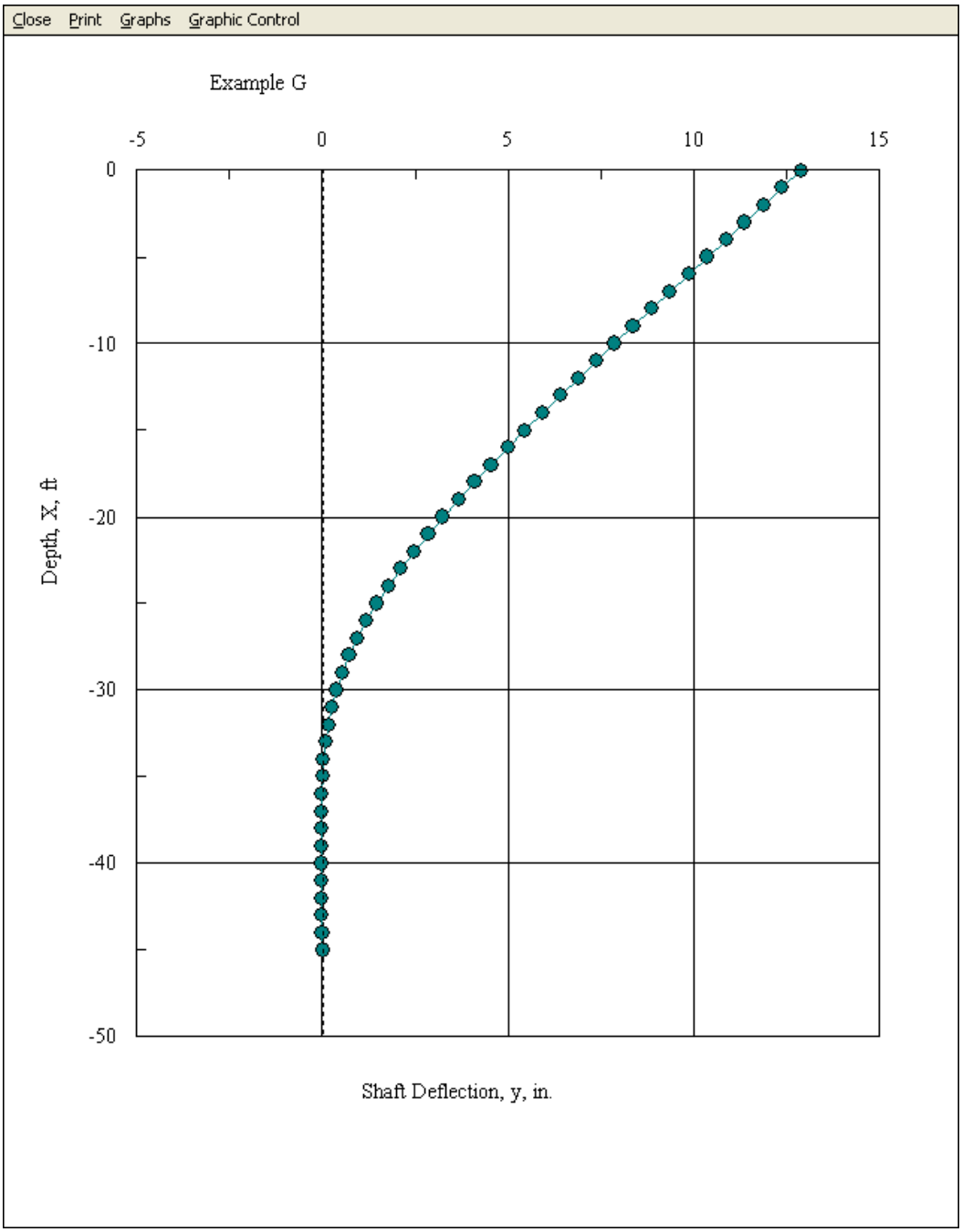


Figure 47: Graph of Pile Deflection

25. A deflection of 13 inches is not acceptable, so the pile size must be increased so that the deflection meets the specified standard. In this example, a pile size of W 14x176 meets the deflection criteria for rural roads of being less than 4 inches.

26. Notice that the graph shows that the pile is slightly fence posting again (Figure 48). Extend the length of the pile to 50 feet and run the analysis once more.

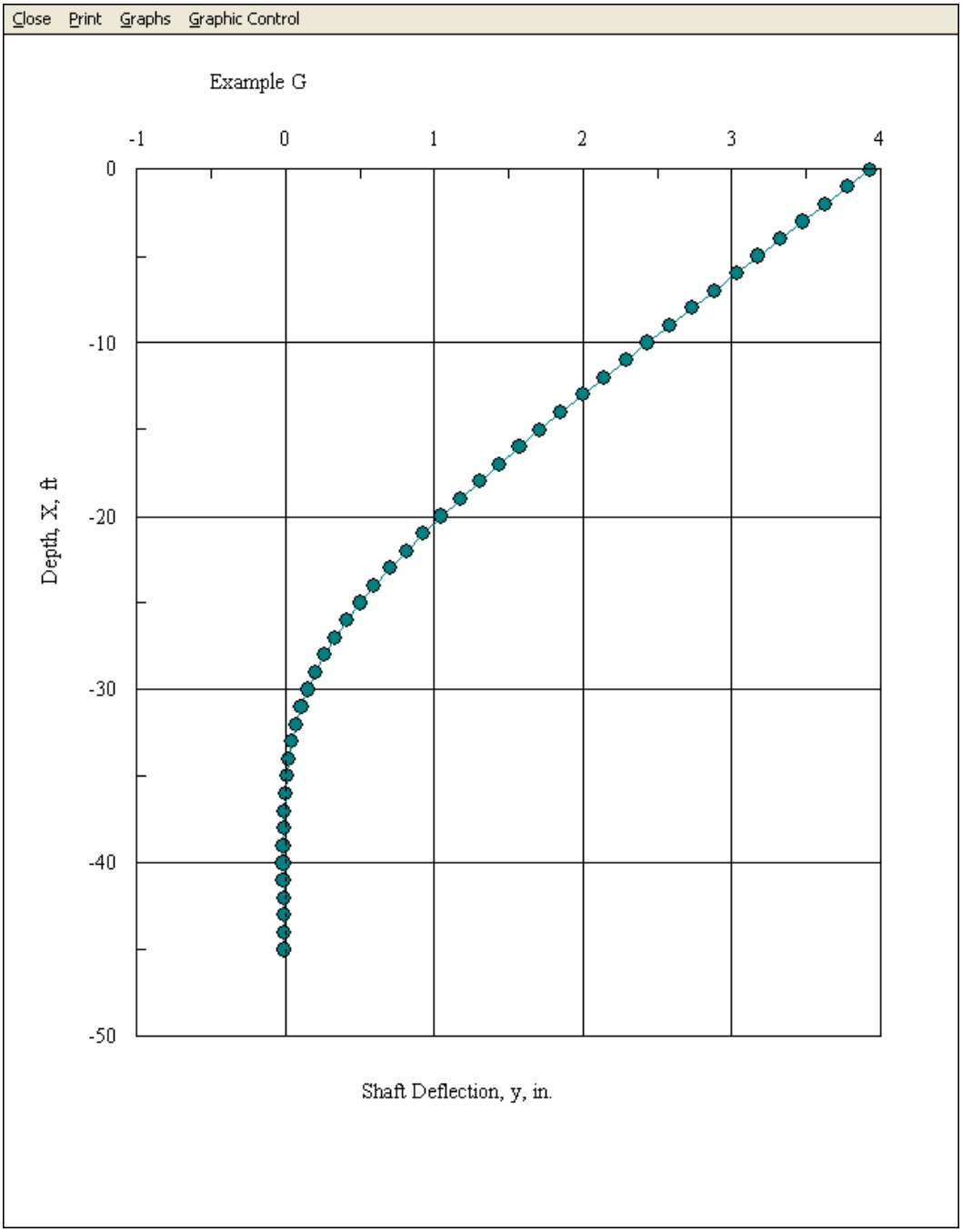


Figure 48: Fence Posting Deflection

27. With a pile size of W 14x176, this example has the following results:
    a. The deflection is less than 4 inches.
    b. The performance ratio is 28%.

28. Increase the FS to 1.3 and run the program.
    a. The pile performance is 46%.
    b. The pile deflection is not critical at a FS of 1.3; however the pile does still need to have two points which cross the zero line (nodes) in order for the pile to be considered stable (fixity) in the strength limit state.

29. The FS of the Unsupported Portion of Slope is 1.03. With this FS, it is anticipated the slope below the pile will continue to move. Therefore, place the lagging deep enough to account for the loss of material. If structure and/or road are below the slip, then the unsupported portion of the slope may need to be addressed.

F. Error and Warning Messages

1. General input error (Figure 49): This could be caused by several reasons
    a. Soil strength parameter missing: C-Phi requires both cohesion and a friction angle. However the program will accept a zero for cohesion, but not a zero friction angle.
    b. Other inputs could cause this problem if a zero is placed in the cell.

Figure 49: General input error

2. Boundary Input Warning (Figure 50): This box is generated for a couple of errors.
    a. A coordinate in a surface boundary does not correspond to a previously entered coordinate (i.e. X-Left does not match X-Right of the previous boundary) OR.
    b. Total number of boundaries and top boundaries do not match the input of boundary data: The number of top boundaries is too great.

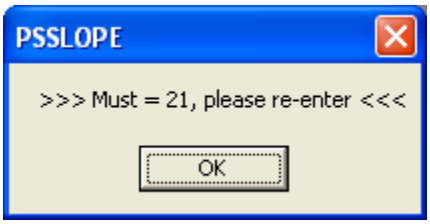


Figure 50: Input Warning

3. Make sure that the total number of boundaries has been entered and is greater than zero.

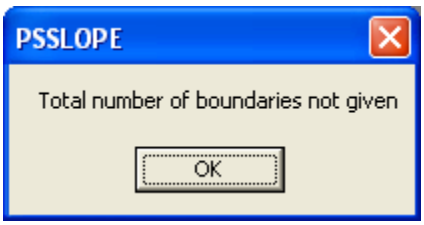


Figure 51: Total number of Boundaries Warning

4. Top Boundary Warning (Figure 52): This message is self explanatory.

Figure 52: Top Boundary Warning

5. Water Surface Points Warning (Figure 53):
    a. The number points listed exceed the number of points entered.

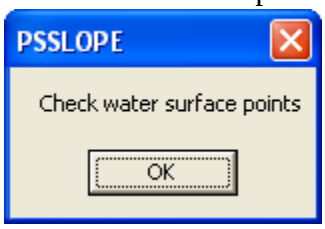


Figure 53: Water Surface Points Warning

6. Failure Surface Point Coordinates Warning (Figure 54):
    a. This error can difficult at times to locate
    b. Recheck all three points against CAD file.
    c. Common errors include, but not limited to
        i. Intersecting surface boundary more than twice
        ii. Not crossing surface boundary twice.

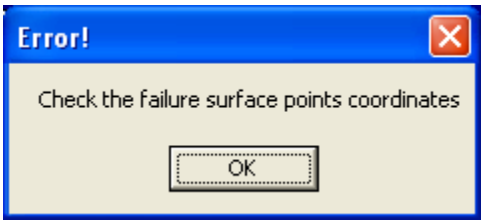


Figure 54: Slip Surface Coordinates Error

7. Number of Top Boundaries (Figure 55): This message is self explanatory.
    a. The number of boundaries on the top surface exceeds the total number of boundaries
    b. Check the number of total boundaries and
    c. Check the number of top boundaries.

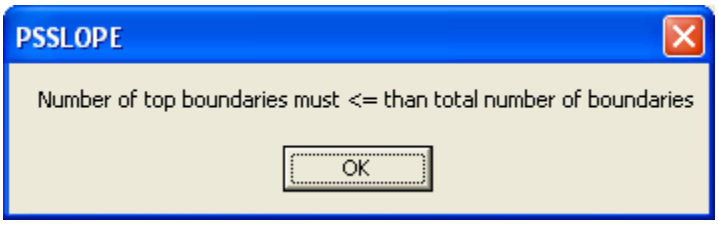


Figure 55: Number of Boundaries Warning

8. Surface Boundary Error (Figure 56): This message can occur for a couple of reasons.
    a. The right coordinate exceed the left coordinate.
    b. The Total number of boundaries exceeds the actual coordinates.
    c. The program is expecting coordinates on the last line.

Figure 56: Surface Boundary Error

9. General Stability Program Run Failure (Figure 57): This message can appear for a couple of reasons:
    a. Failure surface does not intersect the surface at two points or intersect in more than two points.
    b. A Negative number exist in the data.
        i. Negative numbers are not allowed

Figure 57: Stability Analysis Program Failure to Run

10. This error is generated if the value entered for a Boundary's Soil Number is less than or equal to zero.

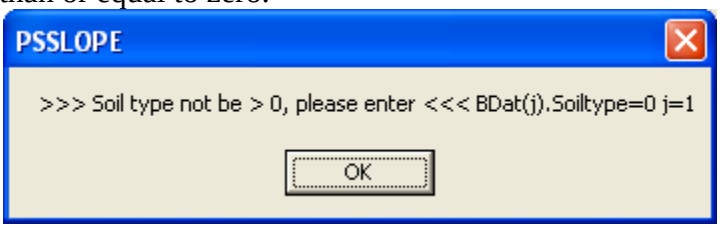


Figure 58: Invalid Soil Number

11. Lagging Depth Warning (Figure 59): This message is self explanatory.
    a. Lagging is set to deep, extends to or beyond the failure surface.

Figure 59: Lagging Depth Warning

12. Pile Spacing Error (Figure 60): This message is self explanatory.

a. Enter a value for pile spacing (whole number).

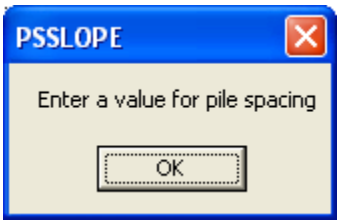


Figure 60: Pile Spacing Value Error

13. Concave Failure Surface Warning (Figure 61): This message is self explanatory.
    a. Check all three points for error
        i. Error is most likely is with the middle point.

Figure 61: Concave Failure Surface

14. Slope Stability Warning (Figure 62): This message is self explanatory.
    a. The pile location needs to be moved, or
    b. The soil strength parameters need to be adjusted, or
    c. Water surface needs to be adjusted, or
    d. All of the above.

Figure 62: Stable Slope

15. No Solution
    a. A possible cause of this error can be a negative number in the Lagging Depth column. Check all pile related inputs.

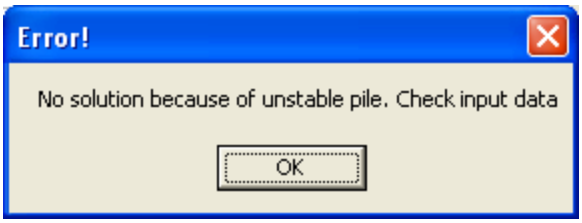


Figure 63: No solution warning

16. Run Time Error (Figure 64): General input error.
    a. Run-time error number is the specific input and programming error.
    b. They can occur from a large list of problems.
        i. Input error (such as a zero friction angle) not anticipated in the programming
        ii. Programming errors.
    c. They are difficult to diagnose
    d. Close program, restart program and rerun file.
        i. Sometimes a reboot of the computer is required.
    e. Check all input data
    f. Start another file and reenter the data
        i. The file may have become corrupted.
    g. Contact Head Office
    h. Write down the error and send email to Head Office.

Figure 64: Run-time error

17. Pile to Soil Interaction Error (Figure 65): Soil strength is too low to accommodate the forces applied by the pile wall. The soil is yielding and flowing around the pile.
    a. Check soil parameters and adjust as necessary OR
    b. Adjust pile spacing to allow the soil wedge to interact with piles.

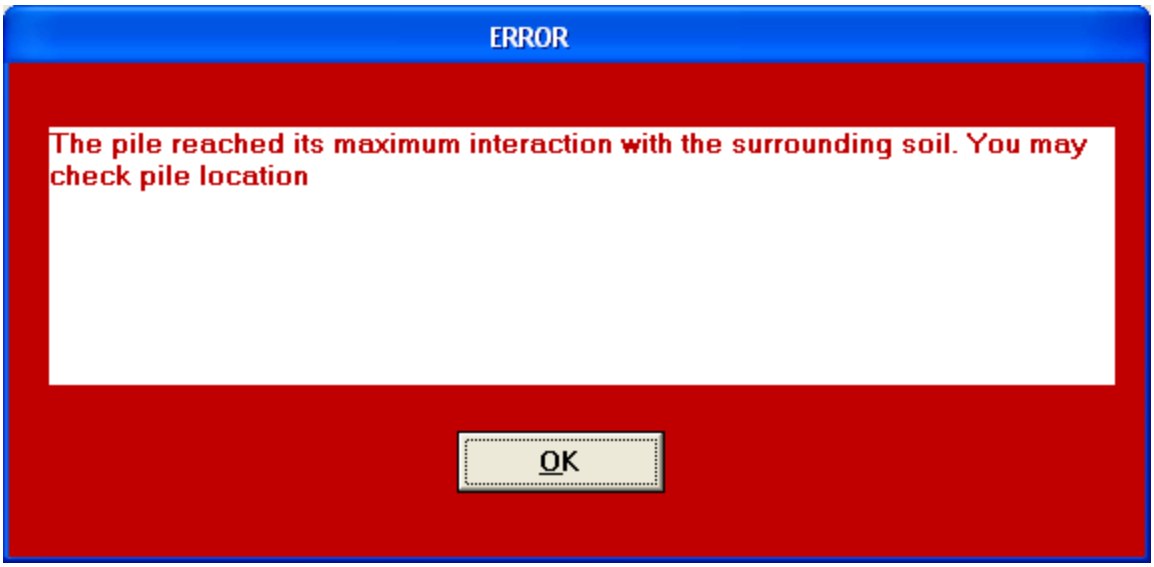


Figure 65: Pile to Soil Interaction

18. Pile Length Error (Figure 66): Tip of pile is not fixed in the soil below.
    a. Check pile length or
    b. Check failure surface.

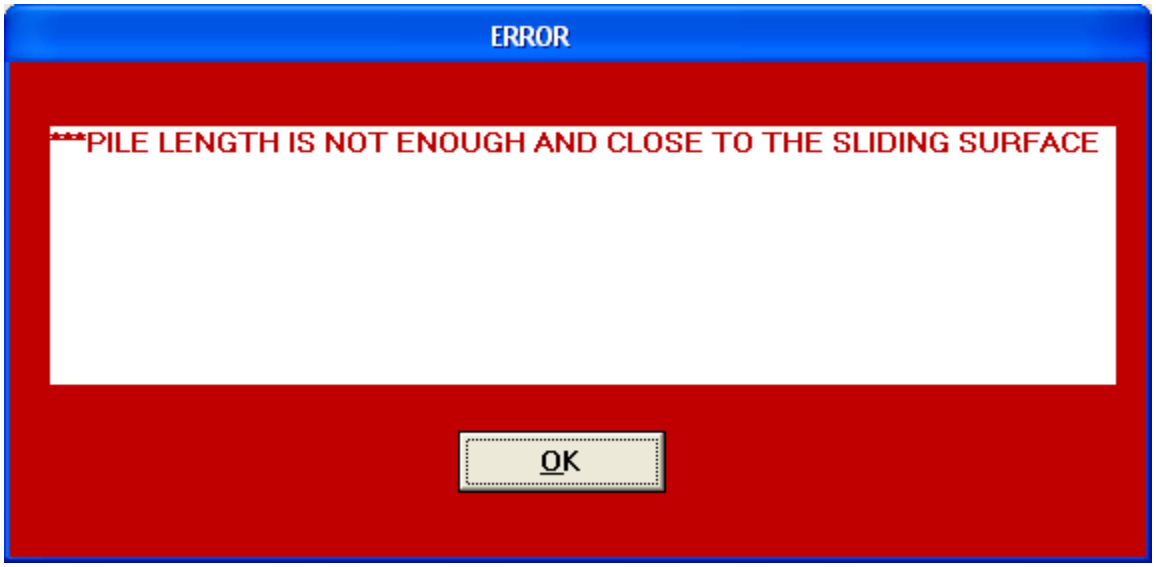


Figure 66: Pile Length

19. Pile Failure (Figure 67): The pile has failed due to excessive forces for the selected pile size.
    a. Select a larger pile size OR
    b. Reduce pile spacing OR
    c. Recheck stability analysis and failure surface for errors.

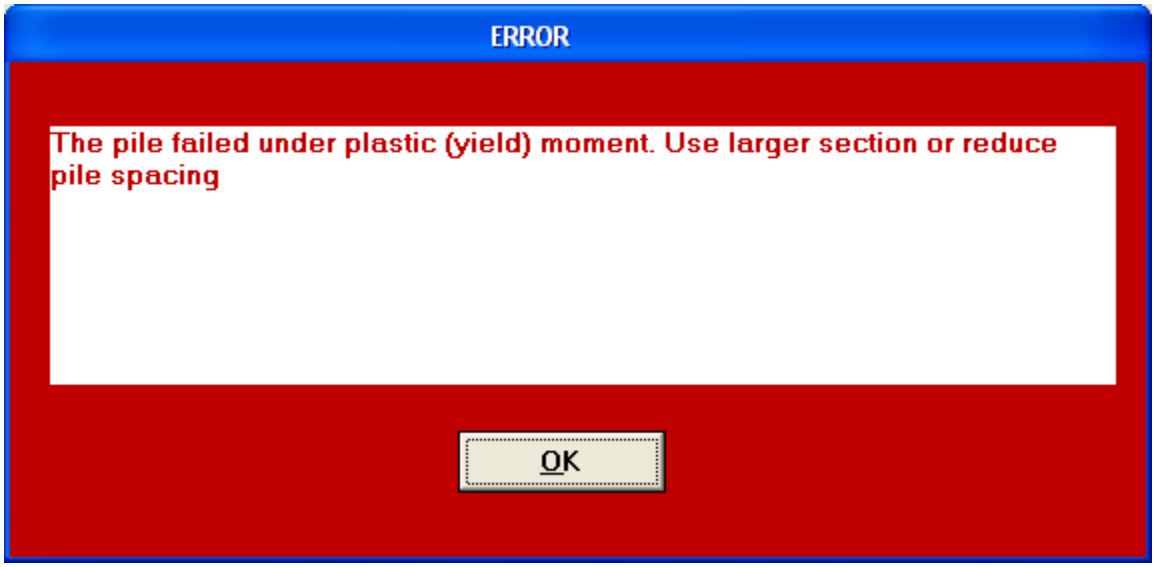


Figure 67: Pile Failure