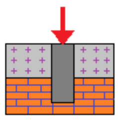

User Manual for PileROC

A Program for Rock Sockets under Axial Loading

By Innovative Geotechnics Pty Ltd

2017/7/5

Innovative Geotechnics

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Chapter 1. Introduction

PileROC is a program that predicts the load settlement curve at the pile head for the piles socketed into rock based on three commonly-used methods: (1) Fleming (1992)'s method; (2) Kulhawy and Carter (1992)'s method and (3) Load transfer method with using t-z and q-w curves. The program also computes the ultimate and factored pile capacities for a range of rock socket lengths.

It is a useful tool for rock socket design by geotechnical engineers. Some of the important features and benefits are summarised as follows:

- It is easy for the users to view the load settlement curve at the top of rock socket. Useful information such as axial pile capacity, ultimate end bearing resistance, ultimate total shaft resistance and settlement value are displayed on the same graph;
- The program plots the detailed analysis results such as ultimate and factored shaft resistance, end bearing resistance, total axial capacity along the socket length. The graphical presentation can be either printed or copied into word document for reporting purposes; and
- Lateral capacity checking of rock socket under lateral force and bending moment applied at the top can be carried out for different failure modes: (1) lateral bearing failure; (2) planar discontinuity controlled failure with specified dip angle of rock discontinuity and (3) planar discontinuity controlled failure with searching for critical dip angle of discontinuity. The adopted approach is based on the recommendations in Hong Kong Geoguide 1 (2nd Edition, 1993).

Chapter 2. Start the new file

When PileROC program is started, the following dialog (Figure 2-1) will firstly appear, which enables the user to choose (1) Start a new project or (2) Open an existing project.

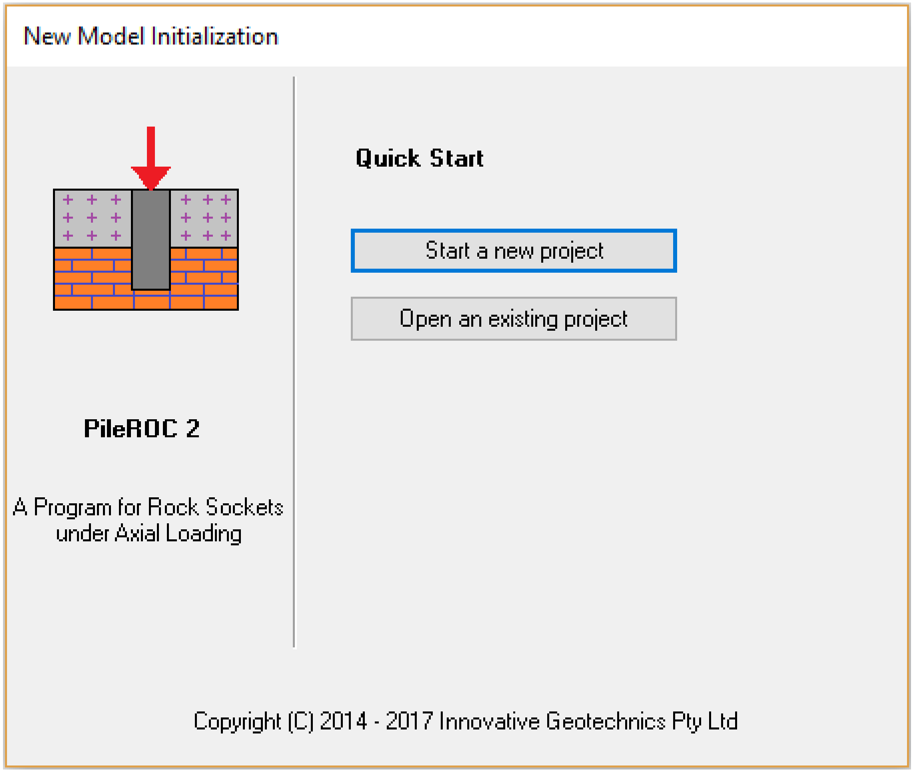


Figure 2-1 Project start dialog in PileROC

Once the option of "**Start a new project**" is selected, a default new project with two soil layers is automatically created. The default file name is "Newfile.ROC". The corresponding file path is shown on the top title bar of the program. The ground profile and general program interface is loaded and shown in Figure 2-2.

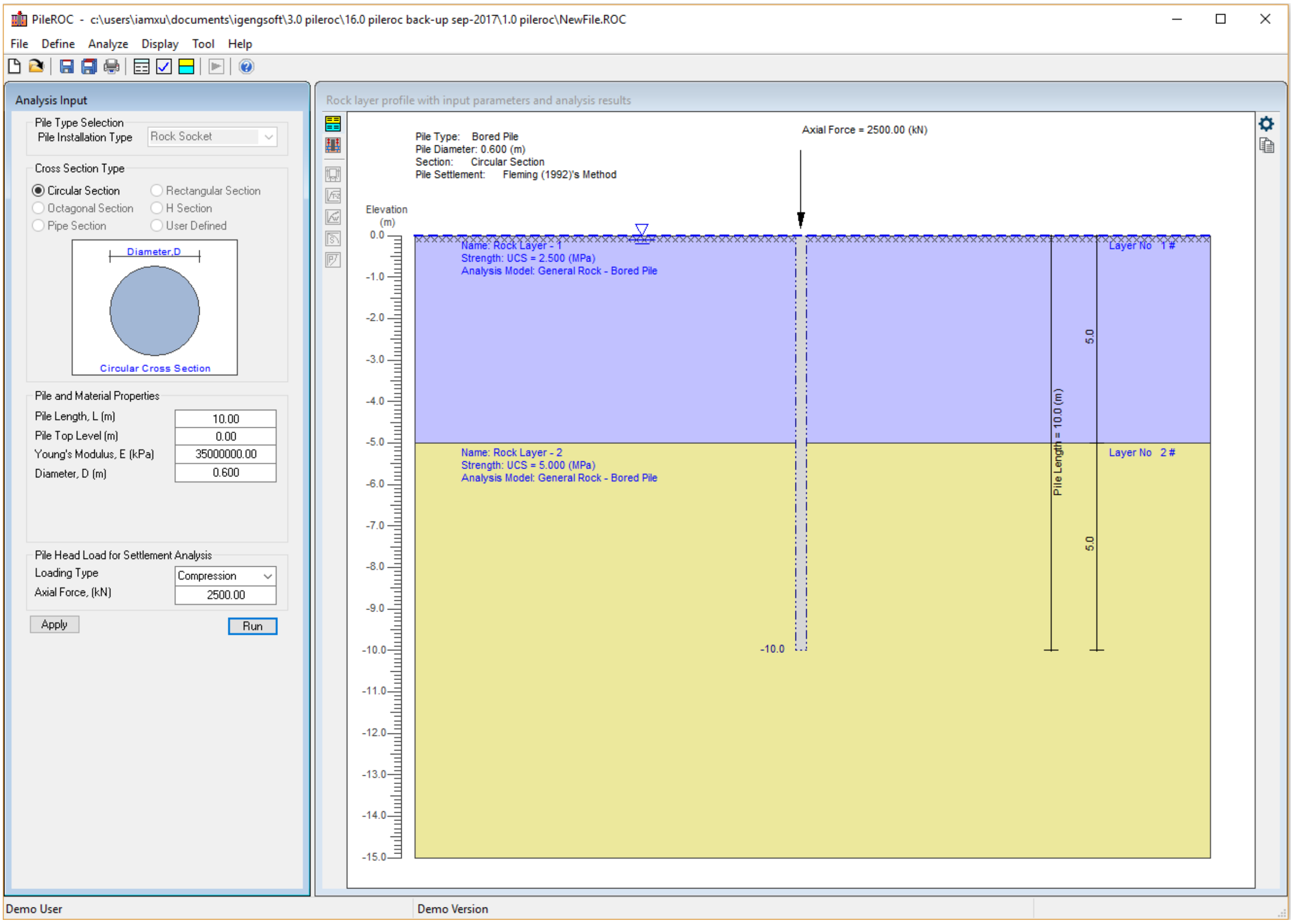


Figure 2-2 Default analysis file of PileROC

If "**Open an existing project**" button is clicked, then the file selection dialog will be invoked as shown in Figure 2-3 where the user will be able to open the existing PileROC analysis file with the file type of ROC.

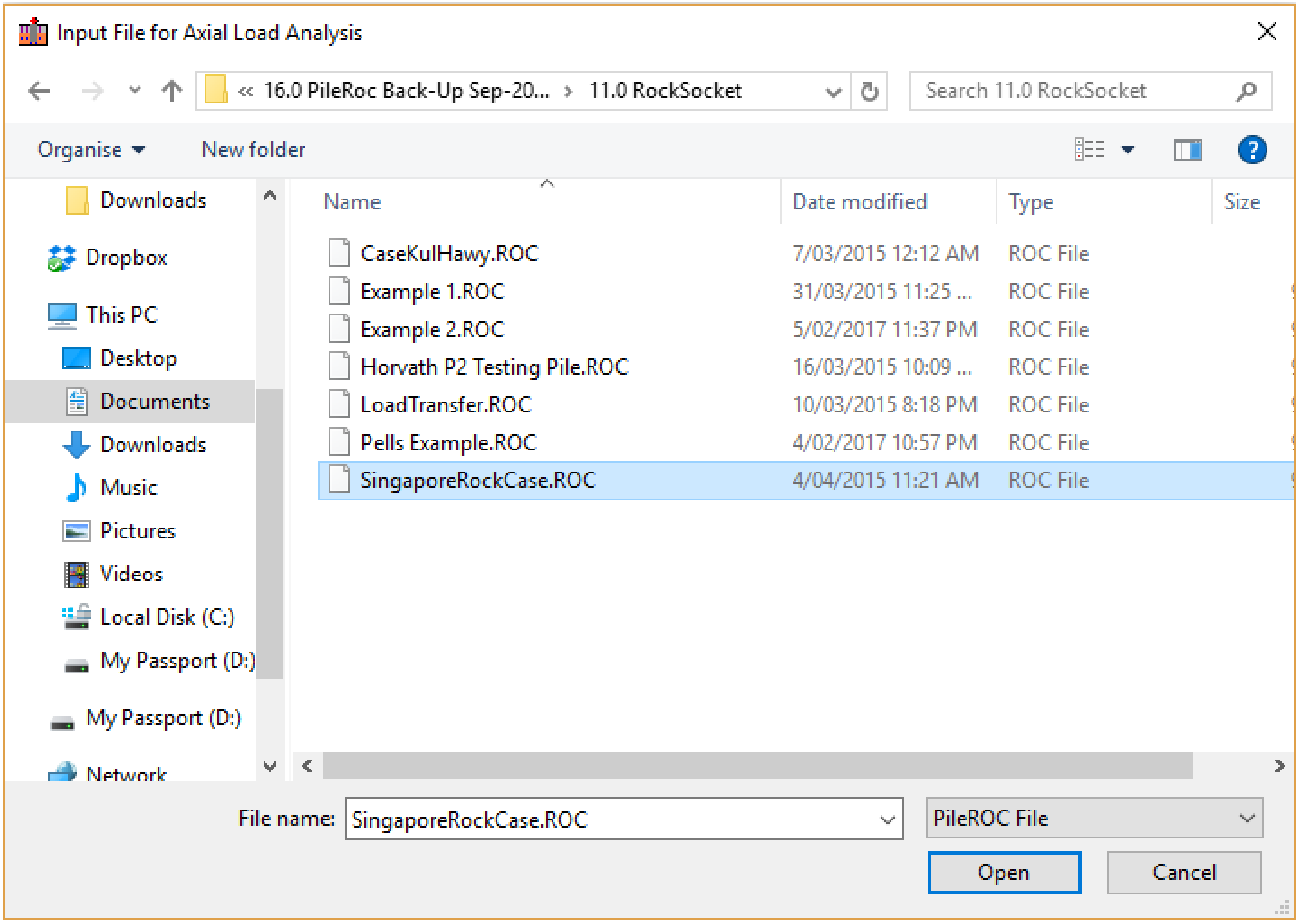


Figure 2-3 Analysis file selection dialog for PileROC

Chapter 3. Project Title Information Input

The project title information can be input by the users with clicking the "Title" icon from the toolbar or clicking "Project Title" menu item from the main "Define" menu of the program. Figure 3-1 shows the general layout of "Title" dialog. The following information can be input by the user for the project:

- Project Title;
- Job Number;
- Design Engineer;
- Client; and
- Description.

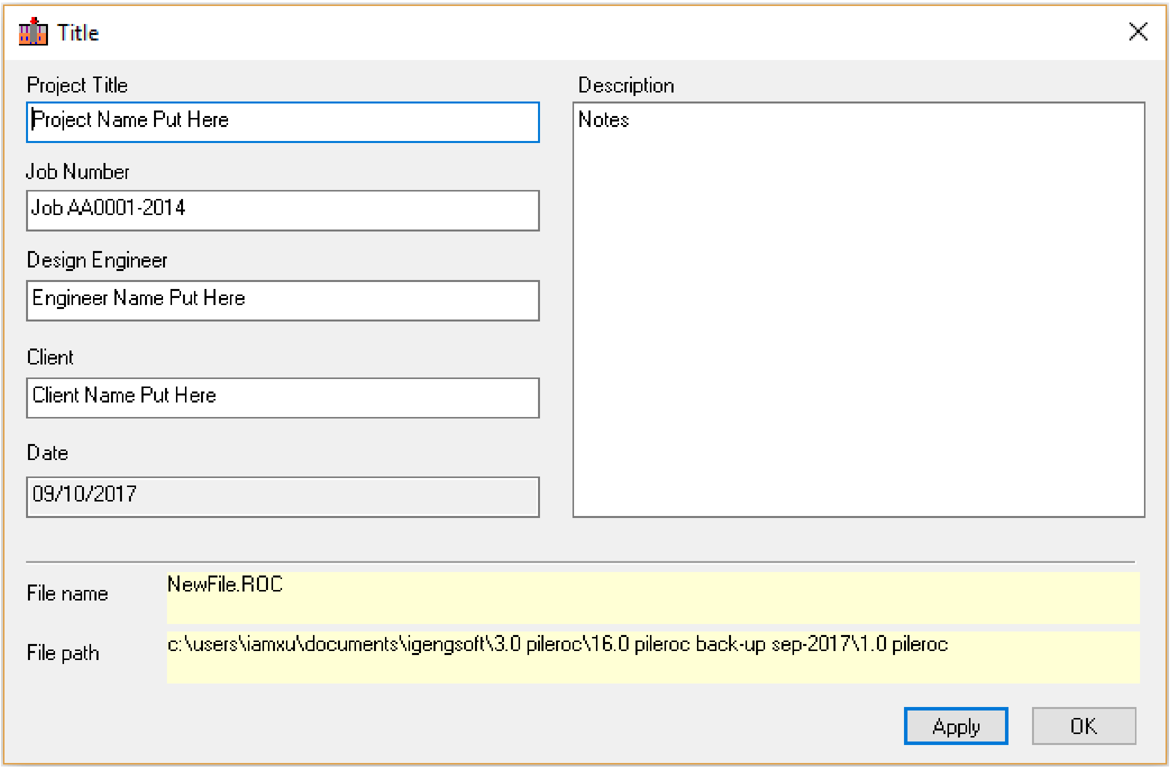


Figure 3-1 General layout of "Project Title" Dialog

The following items are created by the program for the user's reference and cannot be changed by the user from this dialog:

- Date – the creation date of the project file. The date will also be updated when the project file is changed and saved.
- File name – the full file name with the directory path; and

- File path – the directory path of the program.

Chapter 4. Analysis Option Input

Various analysis options can be input by the users with clicking the “Analysis Option” icon from the toolbar or clicking “Analysis Option” menu item from the main “Define” menu of the program. Figure 4-1 shows the general layout of “Analysis Option” dialog. This dialog provides the user with different analysis options as described below for two main groups: (1) Control Parameters; (2) Resistance factors for compression; (3) Resistance factor of tension; (4) Analysis methods for rock socket and (5) Units of Input and Analyses.

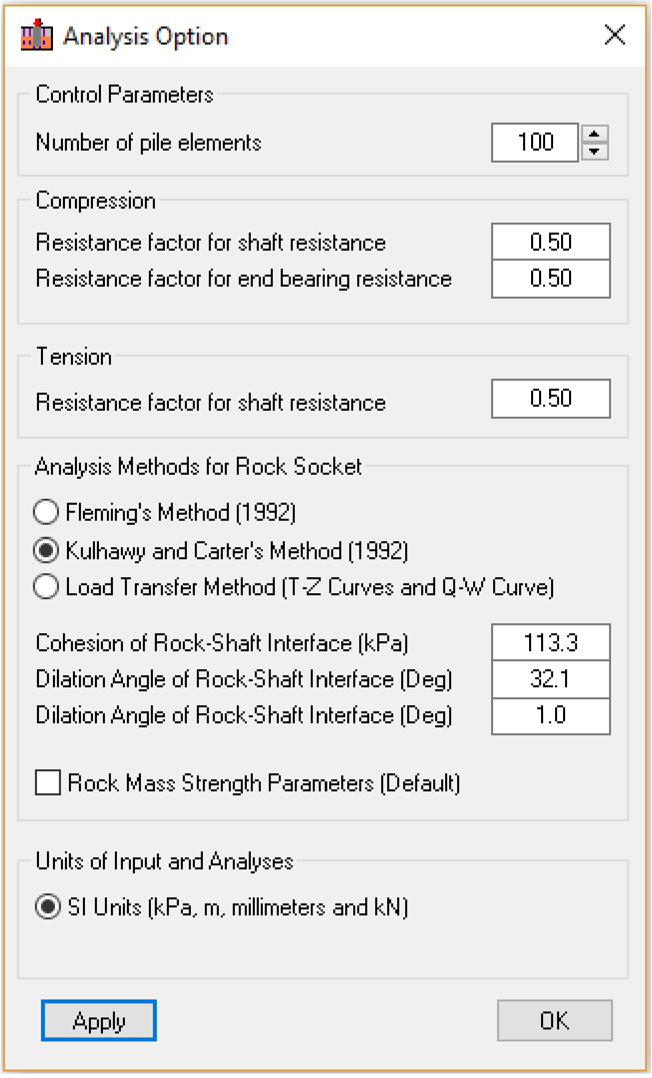


Figure 4-1 General Layout of Analysis Option Dialog for PileROC

"Control Parameters" group lists the main control parameters for the analysis:

- Number of pile elements: This is the number of pile elements used in the analysis. The pile length will be equally divided into elements with the specified number.

"Compression" group lists the main control parameters for the resistance factors adopted in the analysis for pile compression capacity:

- Resistance factor for shaft resistance: This is the resistance factor of the ultimate shaft resistance. It is usually less than 1.0 and similar to strength reduction factor or partial factor. It is mainly used to calculate the factor pile capacity in limit state design;

- Resistance factor for end bearing resistance. This is the resistance factor of the ultimate end bearing resistance. It is usually less than 1.0 and similar to strength reduction factor or partial factor. It is mainly used to calculate the factor pile capacity in limit state design;

"Analysis Methods for Rock Socket" group provides three different options for the design and analysis of rock socket:

- Fleming (1992)'s method. For this method, two additional parameters are required: Dimensionless Flexibility Factor Ms and Effective Length Coefficient Ke;
- Kulhawy and Carter (1992)'s method. Three additional parameters are required if this option is selected: Cohesion of Rock-Shaft Interface (c), Friction Angle of Rock-Shaft Interface (φ) and Dilation Angle of Rock-Shaft Interface (ψ); and
- Load transfer method. This method is adopted if multiple rock layers with different strength and stiffness properties are need to be considered.

More details for the rock socket analysis methods are enclosed in Appendix A.

"Units of Input and Analyses" group provides two unit options in the program.

- SI Units: This is to select SI Units in the program. It the default option in the program.
- English Units: This is to select English Units in the program. This option is currently not available.

Chapter 5. Pile Properties and Load Input

The inputs for the pile properties including different installation and cross section types can be accessed from the built-dialog at the left side on the main program interface as shown in the figure below.

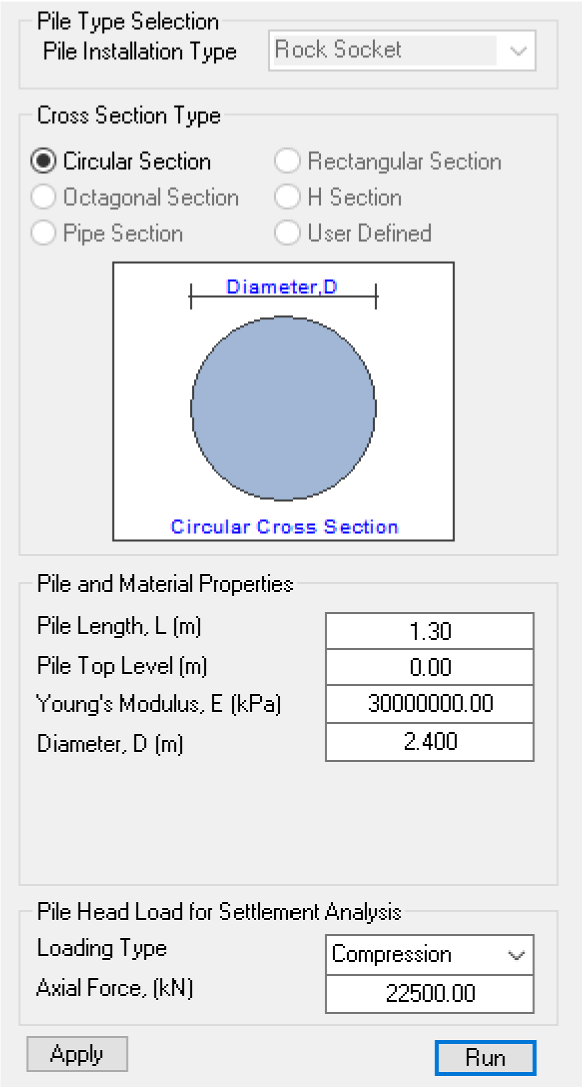


Figure 5-1 General Layout of Pile Type and Cross Section Dialog

The only section type which can be selected is 'Circular Section" option as shown in the figure above. Other options are disabled and cannot be selected by the user. Apart from the section type properties, the pile length, pile top level, Young's modulus of the pile material, loading type (compression or tension) and axial force at the pile head can be readily input by the users from this dialog.

Chapter 6. Rock Layers and Properties Input

PileROC offers an innovative and straightforward interactive way to create multiple rock layers with various relevant parameters in the program. Rock layer input dialog can be invoked through clicking "Rock Layers and Properties" item under "Define" menu or clicking "Rock Layers and Properties" icon from the toolbar.

In PileROC, Rock layers can be added, inserted or deleted through "Add", "Insert" and "Delete" buttons. The layer color also can be adjusted or updated by clicking "Color" button. In the current version, maximum 50 layers can be defined by the user. Layer name also can be defined by the user through text input.

The available material types from “Rock Layers and Properties” input dialog include: (1) Null material and (2) Rocks. For each material type, different analysis methods for ultimate shaft resistance and ultimate end bearing resistance can be selected through "Advanced" tab except for Null materials which are mainly used to model the pile cantilever (free length) section above or below water. In another word, free length or cantilever pile length is defined through adopting a soil layer with Null material properties at the ground surface. Once "Null Material" type is selected, the "Advanced" tab will be disabled.

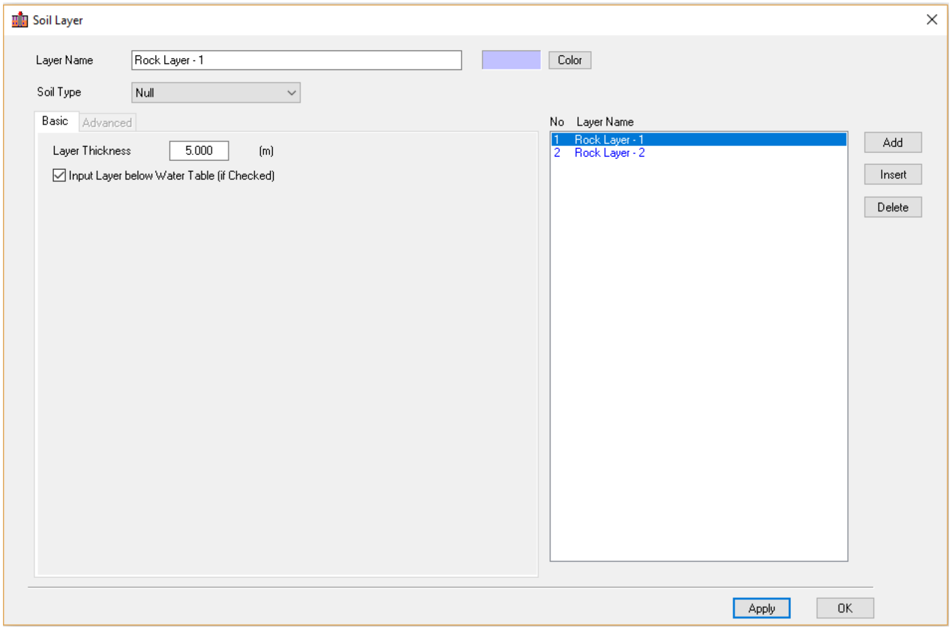


Figure 6-1 Rock Layers and Properties Input for the first layer with “Null” properties

Input of rock layers and properties mainly consists of two parts:

(1) Basic parameters on "Basic" Tab such as soil layer thickness, total unit weight, groundwater status (above or below ground water table) and unconfined compressive strength for rocks. The strength increment with the layer depth also can be specified through "Strength Parameters - Advanced" option. The strength increment is automatically set to zero if the default option is selected.

(2) Advanced parameters related to different pile capacity analysis approaches on "Advanced" Tab.

- Rock: General Rock Method; and
- User Defined Method.

Detailed descriptions about the different pile capacity analysis methods adopted by PileROC are presented in Appendix A.

For the rock layer with “Null” material type (Figure 6-1), the “Advanced” tab is disabled with grey colour and cannot be clicked. If the check box of “Input Layer below Water Table” is ticked, this means that the layer with “Null” material type is under the water table – cantilever or free length within the water. If the check box is unticked, the input layer thickness represents the cantilever or free length within the air.

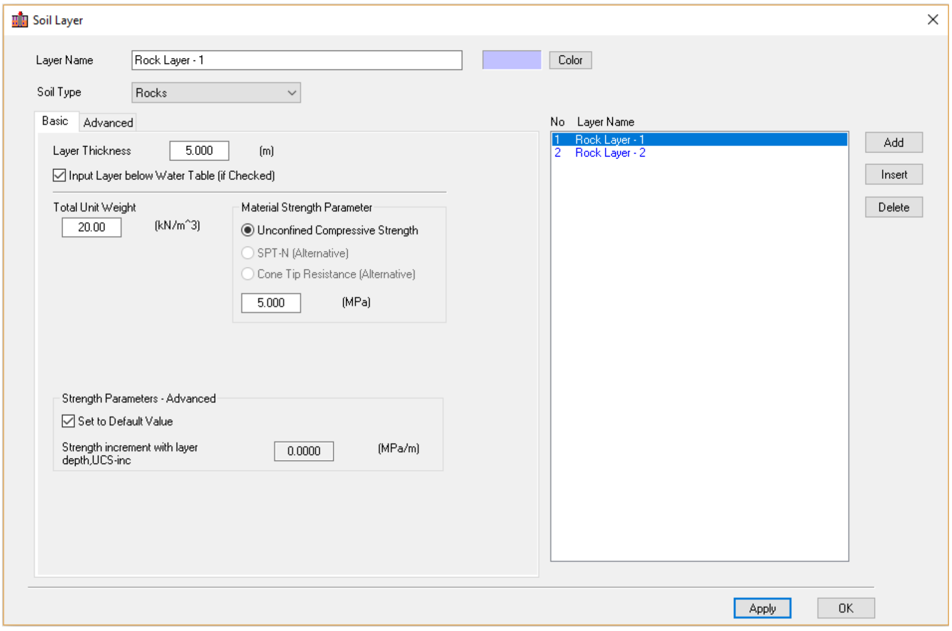


Figure 6-2 Soil Layers and Properties Input for the cohesive soils – Basic Parameters

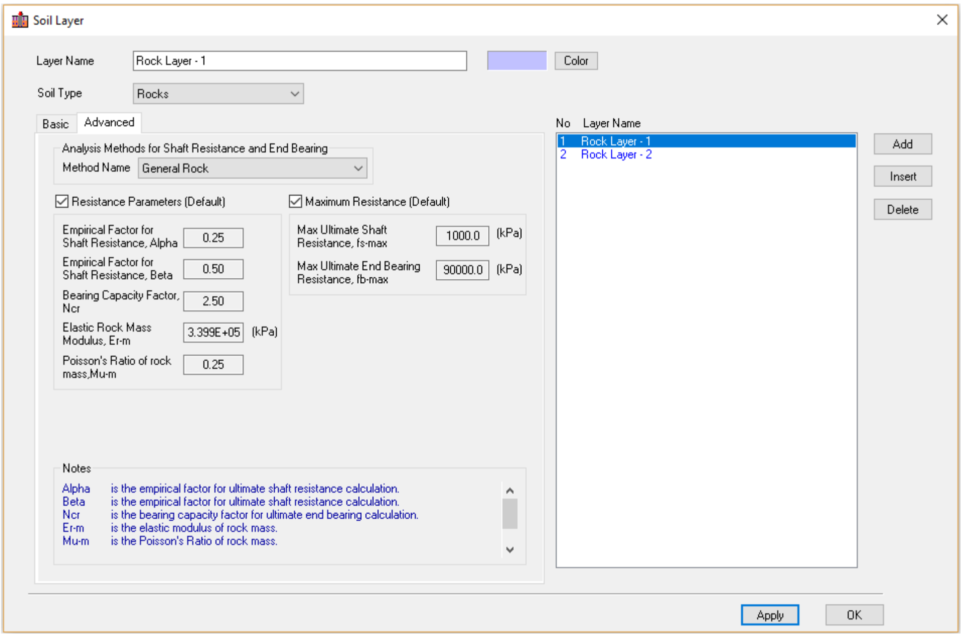


Figure 6-3 Soil Layers and Properties Input for the cohesive soils – Advanced Parameters

Figure 6-2 shows the rock layers and properties input for the basic parameters. Figure 6-3 shows a typical advanced parameter input dialog for the rocks.

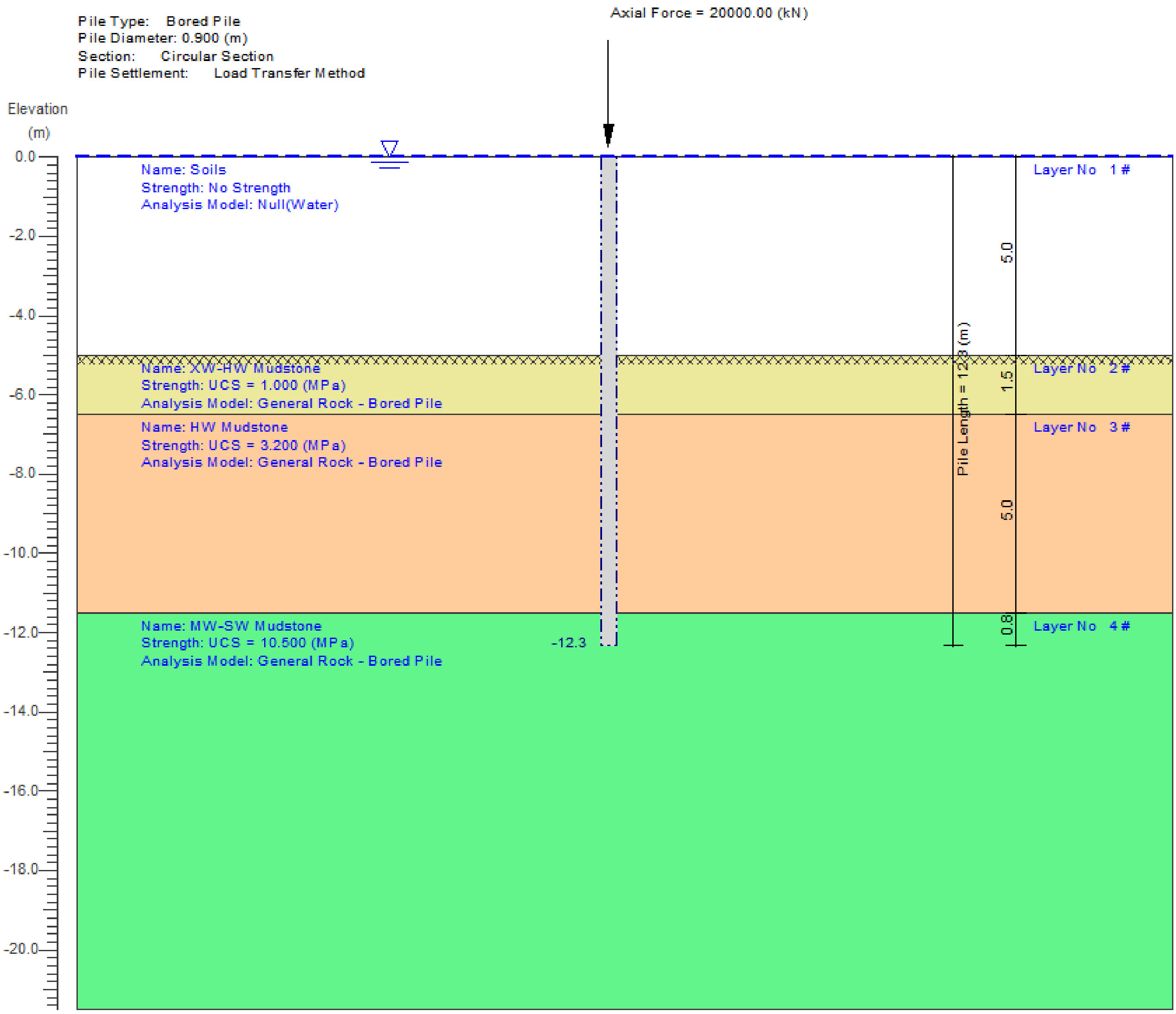


Figure 6-4 Copied ground profile graph from the "File" Menu

Clicking different layer within the layer list will display the corresponding basic parameter. The program will save the input parameters into the internal memory when the "OK" or "Apply" button at the bottom or "X" button at the top right corner is pressed. The ground profile will be automatically updated once the soil layer input is updated and saved. If "Copy Graph" item under the "File" menu is clicked or the "Copy to Clipboard" toolbar button on the right side of the program interface is pressed, then the input ground profile can be copied into the clipboard and then pasted into the report if required. A sample of the copied ground profile graph with the analysis results is shown in Figure 6-4.

The users can use "Display Option" dialog as shown in Figure 6-5 to select or deselect display items: (1) General input information and (2) Analysis results for the ground profile plot.

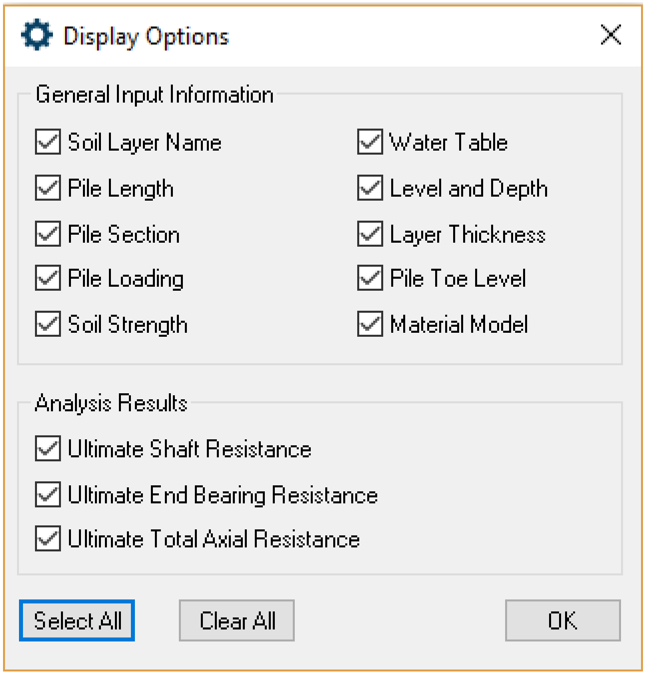
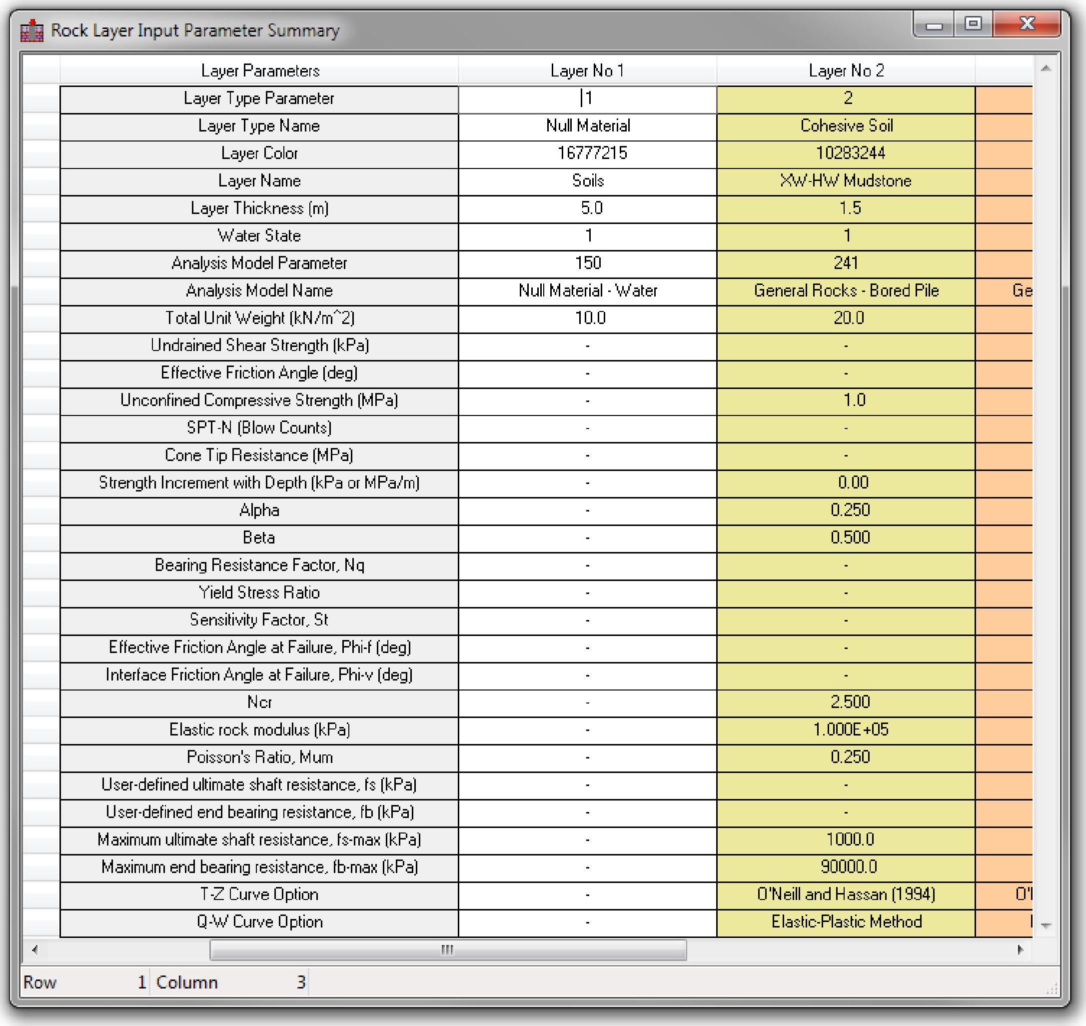


Figure 6-5 Display options for ground profile plot

Chapter 7. Reviewing Rock Layer Input Parameters

PileROC provides the user with the option of reviewing rock layer input parameters. Rock layer input summary dialog can be invoked through clicking "Rock Layer Input Summary" option under "Define" menu or "Rock Layer Input Summary" icon from the left toolbar. The invoked summary table is shown in Figure 7-1 which enables the user to review the detailed soil layer parameter inputs into the analysis and spot the input errors if any.


Rock Layer Input Parameter Summary

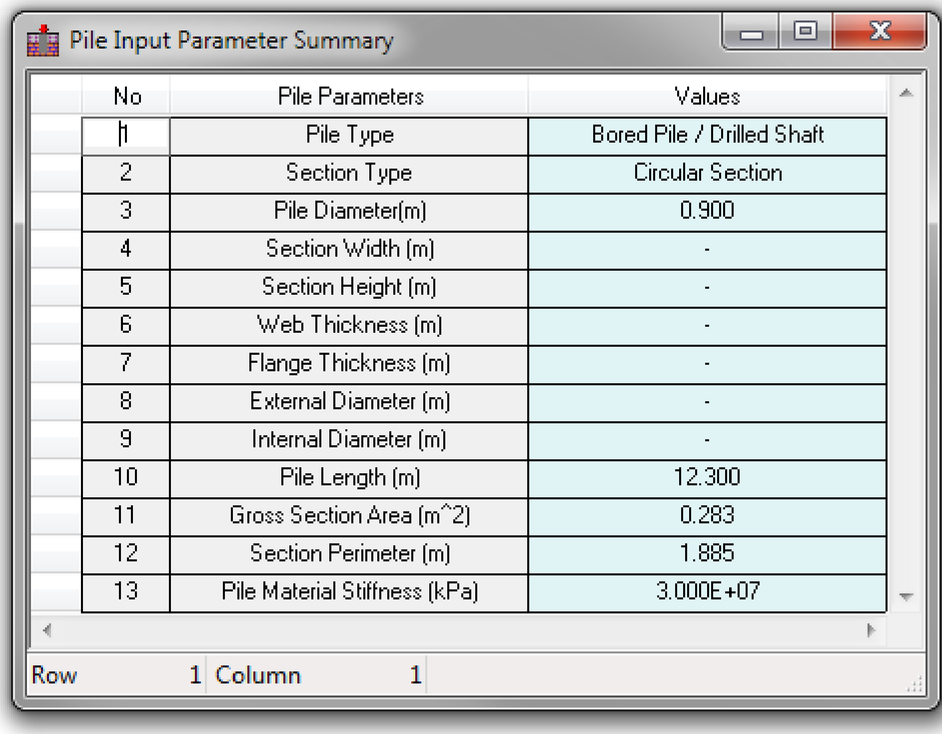
Layer Parameters	Layer No 1	Layer No 2	
Layer Type Parameter	1	2	
Layer Type Name	Null Material	Cohesive Soil	
Layer Color	16777215	10283244	
Layer Name	Soils	XW-HW Mudstone	
Layer Thickness (m)	5.0	1.5	
Water State	1	1	
Analysis Model Parameter	150	241	
Analysis Model Name	Null Material - Water	General Rocks - Bored Pile	Ge
Total Unit Weight (kN/m^2)	10.0	20.0	
Undrained Shear Strength (kPa)	-	-	
Effective Friction Angle (deg)	-	-	
Unconfined Compressive Strength (MPa)	-	1.0	
SPT-N (Blow Counts)	-	-	
Cone Tip Resistance (MPa)	-	-	
Strength Increment with Depth (kPa or MPa/m)	-	0.00	
Alpha	-	0.250	
Beta	-	0.500	
Bearing Resistance Factor, Nq	-	-	
Yield Stress Ratio	-	-	
Sensitivity Factor, St	-	-	
Effective Friction Angle at Failure, Phi-f (deg)	-	-	
Interface Friction Angle at Failure, Phi-v (deg)	-	-	
Ncr	-	2.500	
Elastic rock modulus (kPa)	-	1.000E+05	
Poisson's Ratio, Mum	-	0.250	
User-defined ultimate shaft resistance, fs (kPa)	-	-	
User-defined end bearing resistance, fb (kPa)	-	-	
Maximum ultimate shaft resistance, fs-max (kPa)	-	1000.0	
Maximum end bearing resistance, fb-max (kPa)	-	90000.0	
T-Z Curve Option	-	O'Neill and Hassan (1994)	O'I
Q-W Curve Option	-	Elastic-Plastic Method	I

Row 1 Column 3

Figure 7-1 Rock layer input summary table for an example

Chapter 8. Reviewing Pile Input Parameters

Similar to rock layer input parameters, pile input summary table can be opened through clicking "Pile Input Summary" option under "Define" menu or pressing "Pile Input Summary" from the left toolbar. It summaries the values of pile input parameters from the user. The dialog as shown in Figure 8-1 enables the users to review the input parameters related to the pile type, section type, section dimension, material stiffness, top connection conditions, bending stiffness and pile batter.



No	Pile Parameters	Values
1	Pile Type	Bored Pile / Drilled Shaft
2	Section Type	Circular Section
3	Pile Diameter(m)	0.900
4	Section Width (m)	-
5	Section Height (m)	-
6	Web Thickness (m)	-
7	Flange Thickness (m)	-
8	External Diameter (m)	-
9	Internal Diameter (m)	-
10	Pile Length (m)	12.300
11	Gross Section Area (m^2)	0.283
12	Section Perimeter (m)	1.885
13	Pile Material Stiffness (kPa)	3.000E+07

Figure 8-1 Pile input summary table for an example

Chapter 9. Run Analysis

Running the analysis file with the input parameters created from the previous steps can be invoked by clicking "Run Analysis" option under "Analyze" menu or clicking “Run Analysis” icon from the top toolbar. The invoked running message dialog as shown in Figure 9-1 details the analysis information and the analysis result status.

The warning messages if any will be displayed under the progress bar to show the likely cause of the problem. Clicking "OK" button will close the dialog and the user will be able to access the various analysis results if the analysis run is successful. Otherwise, the user will need to review the input file to find out why the analysis cannot be successfully completed.

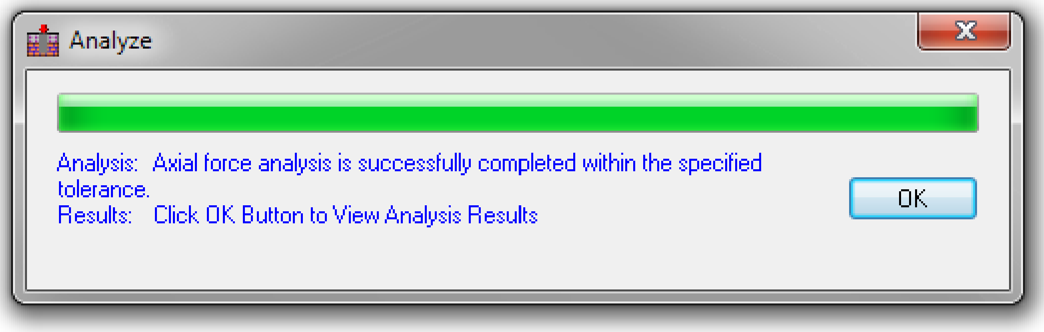


Figure 9-1 Run Analysis Message Box for an example

Chapter 10. Viewing Analysis Results

PileROC provides an easy way to access various detailed analysis results through "Analysis Results" Output Dialog as shown in Figure 10-1. The User can view almost all analysis results plotted against the pile length. Clicking the corresponding radio button enables the User to switch different analysis result plots conveniently. Rock layers with the specified layer colours and boundaries are also shown in the graph to help the user to know the relative position of the results to the rock layers.

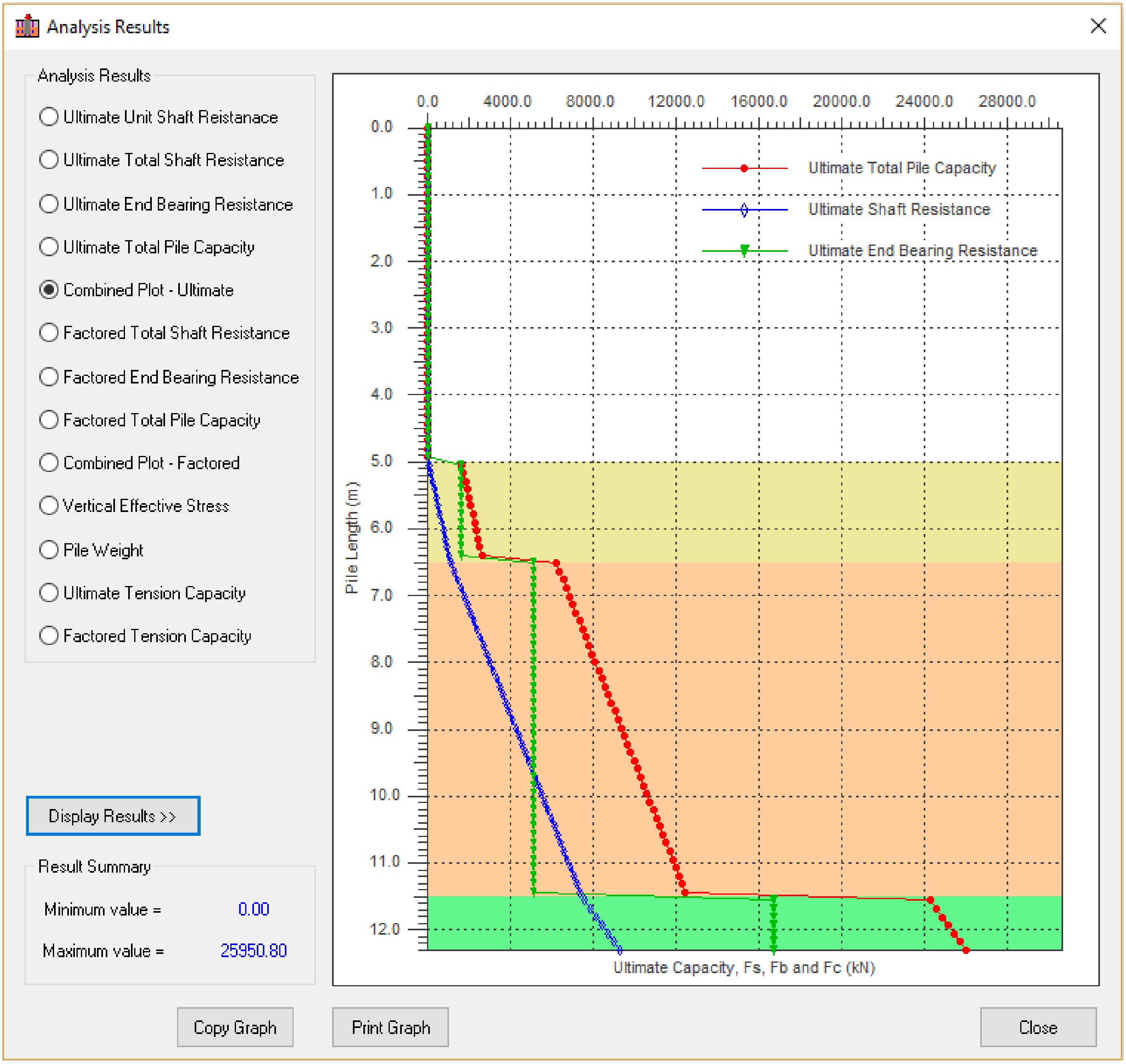


Figure 10-1 Analysis Results Dialog of PileROC

This “Analysis Results” Output Dialog can be invoked by clicking “Analysis Results” icon from the left toolbar and the analysis results which are available for viewing from this dialog include:

- Distribution of the ultimate unit shaft resistance with the pile length;
- Distribution of the ultimate total shaft resistance with the pile length;
- Distribution of the ultimate end bearing resistance with the pile length;
- Distribution of the ultimate total pile capacity (ultimate total shaft resistance plus ultimate end bearing resistance) with the pile length;
- Combined plot of the ultimate total shaft resistance, ultimate end bearing and ultimate total pile capacity against the pile length;
- Distribution of the factored total shaft resistance with the pile length;
- Distribution of the factored end bearing resistance with the pile length;
- Distribution of the factored total pile capacity (ultimate total shaft resistance plus ultimate end bearing resistance) with the pile length;
- Combined plot of the factored total shaft resistance, ultimate end bearing and ultimate total pile capacity against the pile length;
- Distribution of the effective vertical stress with the pile length;
- Distribution of the pile weight with the pile length;
- Distribution of the ultimate tension capacity; and
- Distribution of the factored tension capacity.

The above results can also be viewed by clicking the corresponding items under the “Display” menu. In addition to the plotting results, PileROC also provides the detailed analysis results in the excel-like table format if “Display Results” button is pressed. It is convenient for the user to go through each analysis result at different depths. The tabulated results can be also easily copied into the third-party software for further process if required.

PileROC also enables the user to copy or print the relevant results on the graph. This can be done by clicking “Copy Graph” or “Print Graph” on the bottom of the “Analysis Results” Dialog. The copied graph can be easily pasted into the third-party application for reporting purpose. A sample of the copied and pasted result graph is shown in Figure 10-2 for an example.

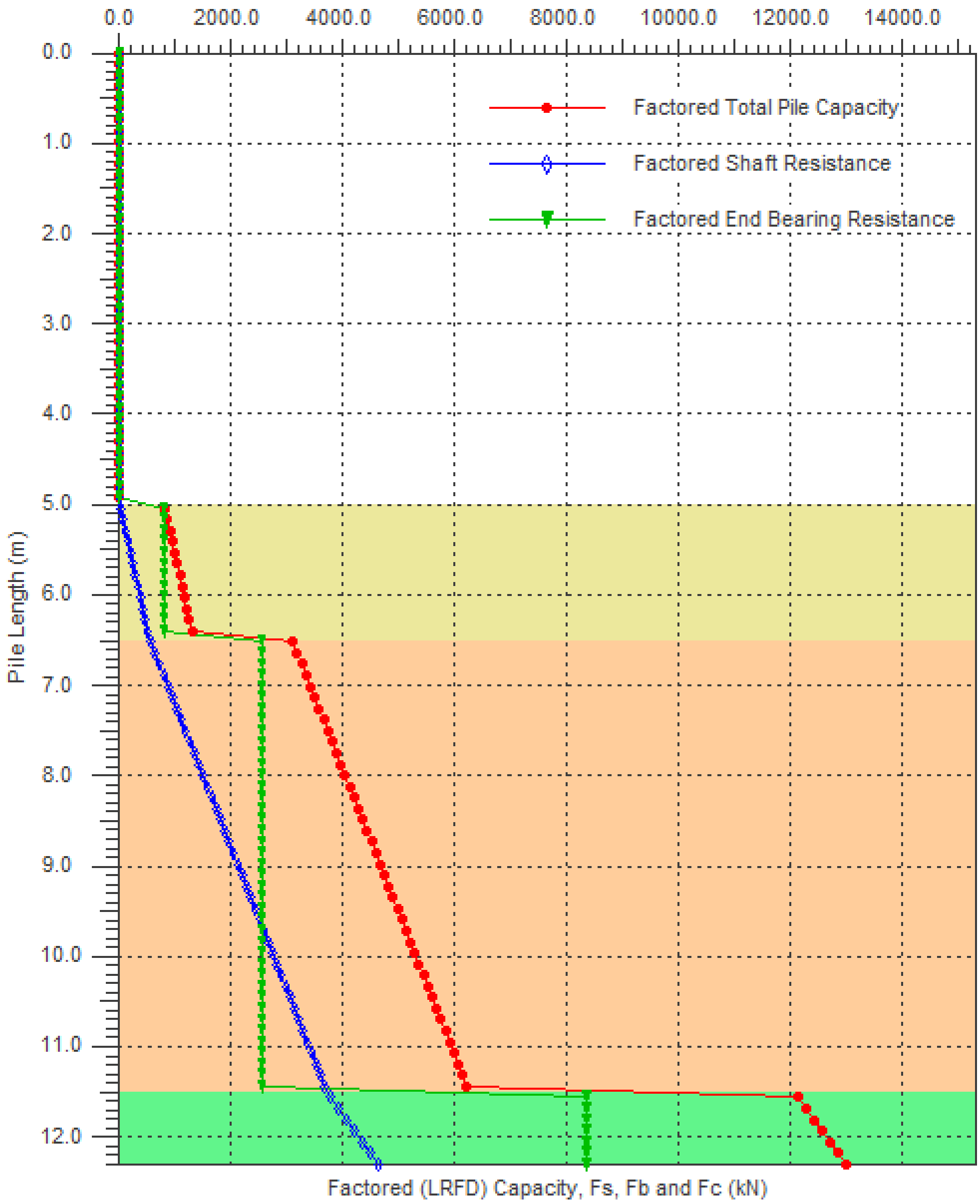


Figure 10-2 Copied result graph (combined Plot – Ultimate) for an example

Chapter 11. Viewing T-Z Curves

In PileROC, once the analysis is successfully completed with the option of Load Transfer Method for the rock socket analysis method, the user can access the various analysis results. The dialog for t-z curve plot can be invoked by clicking the "T-Z Curve Plot" option under "Display" menu or “T-Z Curve Plot” from the toolbar.

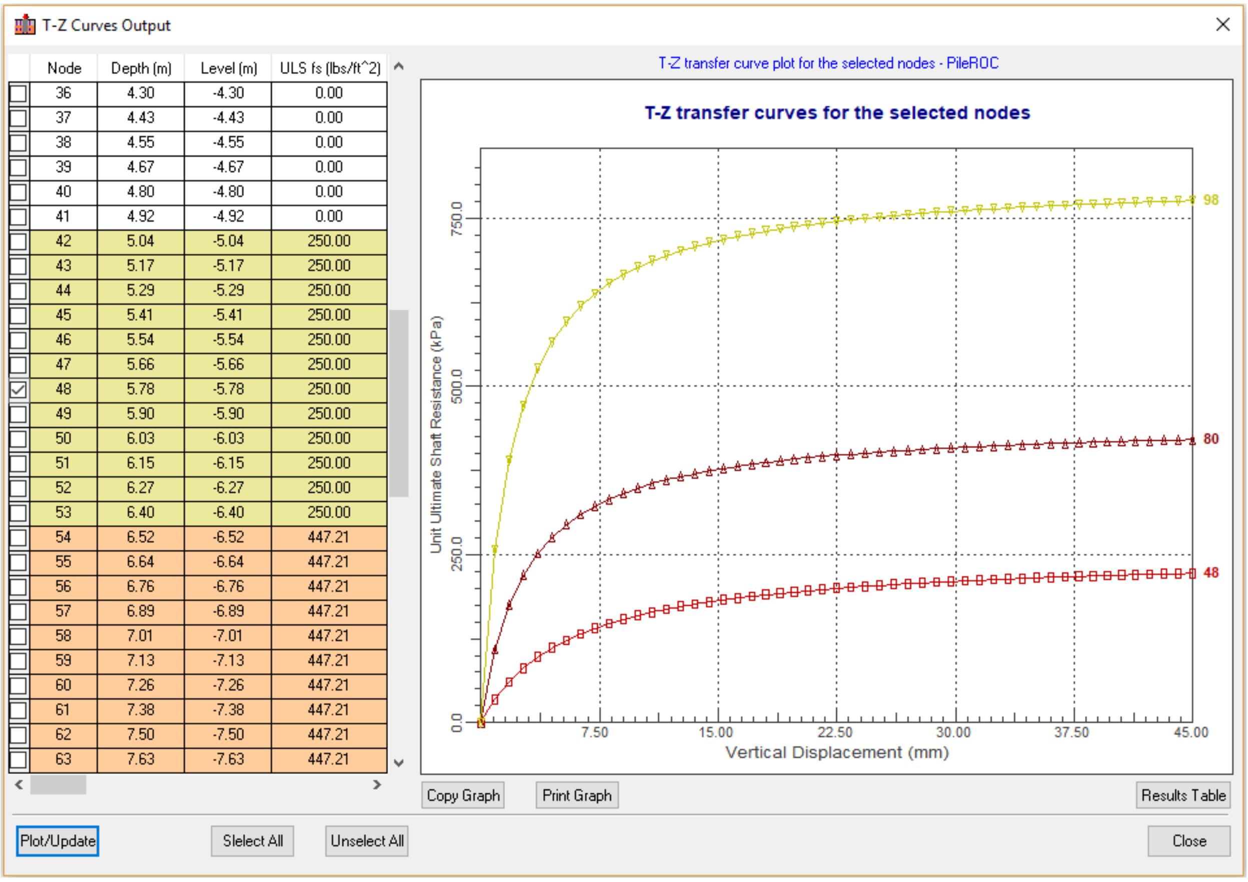


Figure 11-1 “T-Z Curve Plot” dialog for an example

T-Z curves for all the nodes can be selected and viewed by the user through T-Z Curve Plot Dialog as shown in Figure 11-1. Plot or update the T-Z curve plots can be done through the following steps:

- Step 1: Tick the check box for the pile node number where you want to view the results. Note that multiple node points can be selected;
- Step 2: Click the "**Plot/Update**" button at the bottom of the table to update the T-Z curve plots.

For each node point listed in the table, other relevant information such as Depth, Level, Ultimate Unit Shaft Resistance, and T-Z model type are also displayed for the user's information. The background colour of row in the table follows the colour of the soil layer.

If required, detailed T-Z curve results can be accessed through clicking the button of "Results Table" under the summary table. A new window with gird-type outlook as shown in Figure 11-2 will be invoked with "z" settlement (mm or inch) and "fs" mobilised shaft resistance (kPa or lbs/ft^2) for the selected node points along the pile length.

T-Z Curve Results Table

z (mm) for Node 48	fs (kPa) for Node 48	z (mm) for Node 80	fs (kPa) for Node 80	z (mm) for Node 98
0.00	0.00	0.00	0.00	0.00
0.90	34.48	0.90	108.93	0.90
1.80	60.61	1.80	175.18	1.80
2.70	81.08	2.70	219.74	2.70
3.60	97.56	3.60	251.75	3.60
4.50	111.11	4.50	275.87	4.50
5.40	122.45	5.40	294.68	5.40
6.30	132.08	6.30	309.78	6.30
7.20	140.35	7.20	322.15	7.20
8.10	147.54	8.10	332.48	8.10
9.00	153.85	9.00	341.24	9.00
9.90	159.42	9.90	348.75	9.90
10.80	164.38	10.80	355.27	10.80
11.70	168.83	11.70	360.98	11.70
12.60	172.84	12.60	366.02	12.60
13.50	176.47	13.50	370.50	13.50
14.40	179.78	14.40	374.52	14.40
15.30	182.80	15.30	378.13	15.30
16.20	185.57	16.20	381.41	16.20
17.10	188.12	17.10	384.38	17.10
18.00	190.48	18.00	387.10	18.00
18.90	192.66	18.90	389.60	18.90
19.80	194.69	19.80	391.89	19.80
20.70	196.58	20.70	394.01	20.70
21.60	198.35	21.60	395.97	21.60
22.50	200.00	22.50	397.80	22.50
23.40	201.55	23.40	399.49	23.40
24.30	203.01	24.30	401.08	24.30
25.20	204.38	25.20	402.56	25.20

Row 1 Column 1

Figure 11-2 Tabulated T-Z Curve results for an example

PileROC enables the user to copy or print the relevant results on the graph. This can be done by clicking “Copy Graph” or “Print Graph” on the bottom of the “Analysis Results” Dialog. The copied graph can be easily pasted into the third-party application for reporting purpose as shown in Figure 11-3.

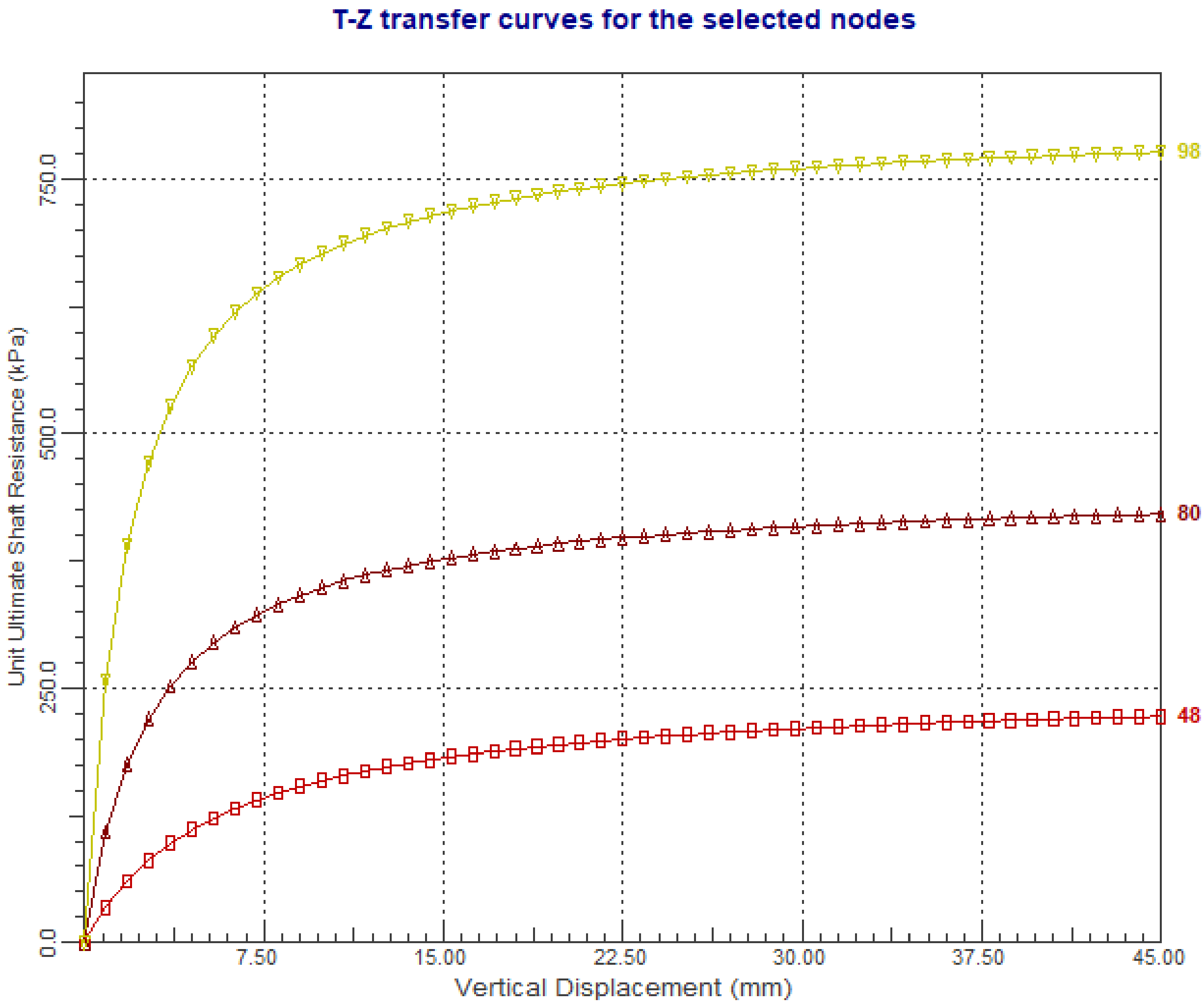


Figure 11-3 Copied T-Z curves graph for an example

Chapter 12. Viewing Q-W Curves

In addition to T-Z curves, the user also can access Q-W curve information once the analysis is successfully completed in PileROC. The dialog for Q-W curve plot can be invoked by clicking the "Q-W Curve Plot" option under "Display" menu or “Q-W Curve Plot” from the toolbar. The invoked “Load Deflection Curve for Pile Base” dialog is shown in Figure 12-1.

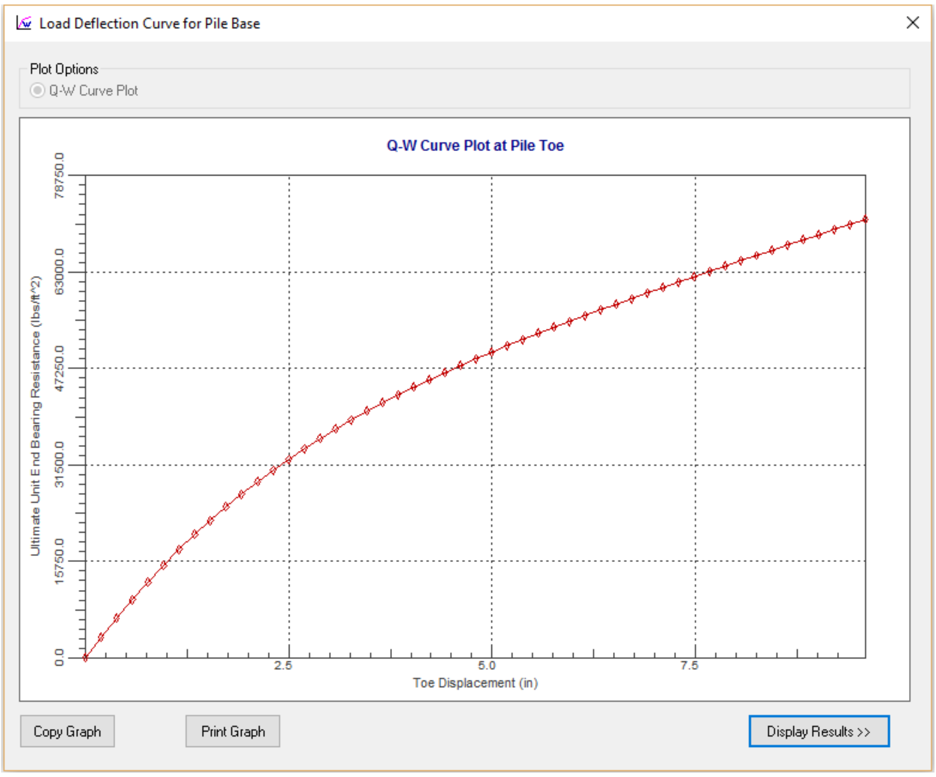


Figure 12-1 “Q-W Curve Plot” dialog for an example

The option of “Q-W Curve Plot” shows the relationship between the end bearing resistance and pile toe settlement. If required, the tabulated results as shown in Figure 12-2 for the load and deflection curves at the pile base will be presented in the Excel-like table format through clicking the button of "Display Results" under the graph.

Toe Displacement (in)	End Bearing (lbs/ft^2)
0.00	0.0
0.19	3345.5
0.38	6521.5
0.58	9536.3
0.77	12397.6
0.96	15113.2
1.15	17690.6
1.34	20137.0
1.54	22459.6
1.73	24665.2
1.92	26760.6
2.11	28752.1
2.30	30646.0
2.50	32448.5
2.69	34165.3
2.88	35802.1
3.07	37364.4
3.26	38857.4
3.46	40286.2
3.65	41655.6
3.84	42970.2
4.03	44234.5
4.22	45452.7
4.42	46628.9
4.61	47766.7
4.80	48870.0
4.99	49942.0

Figure 12-2 Tabulated Q-W Curve results for an example

PileROC also enables the user to copy or print the relevant results on the graph. This can be done by clicking “Copy Graph” or “Print Graph” on the bottom of the dialog. The copied graph can be easily pasted into the third-party application for reporting purpose. A sample of the copied and pasted result graph is shown in Figure 12-3.

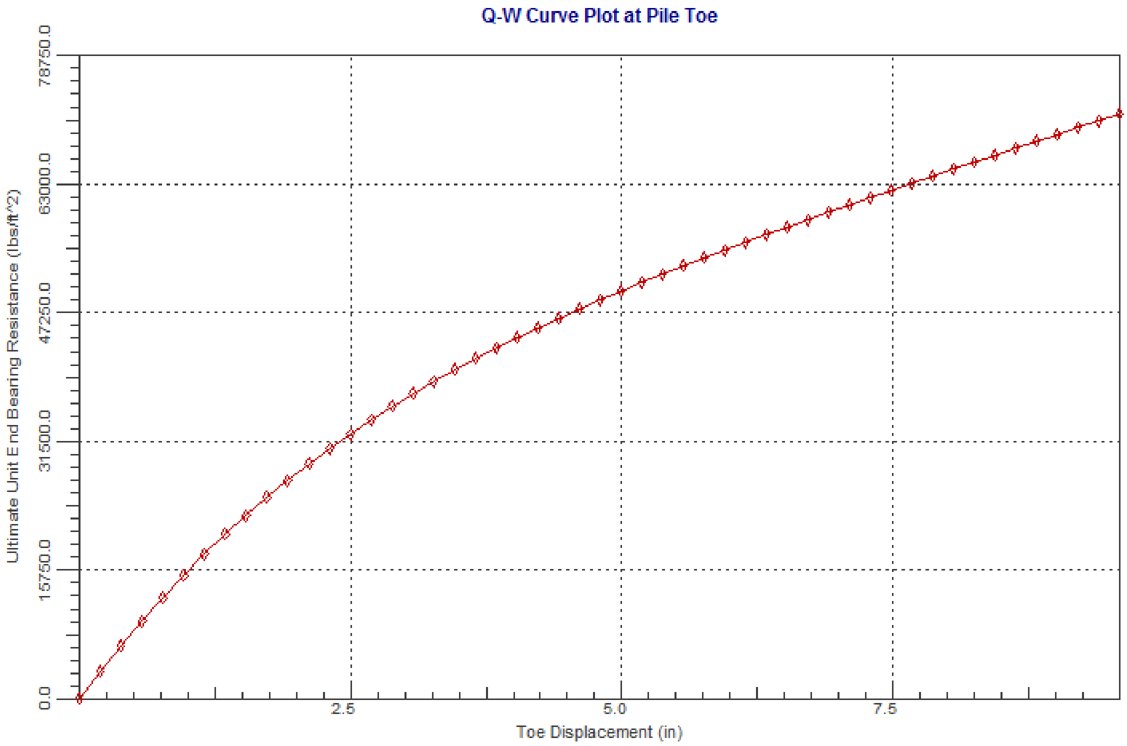
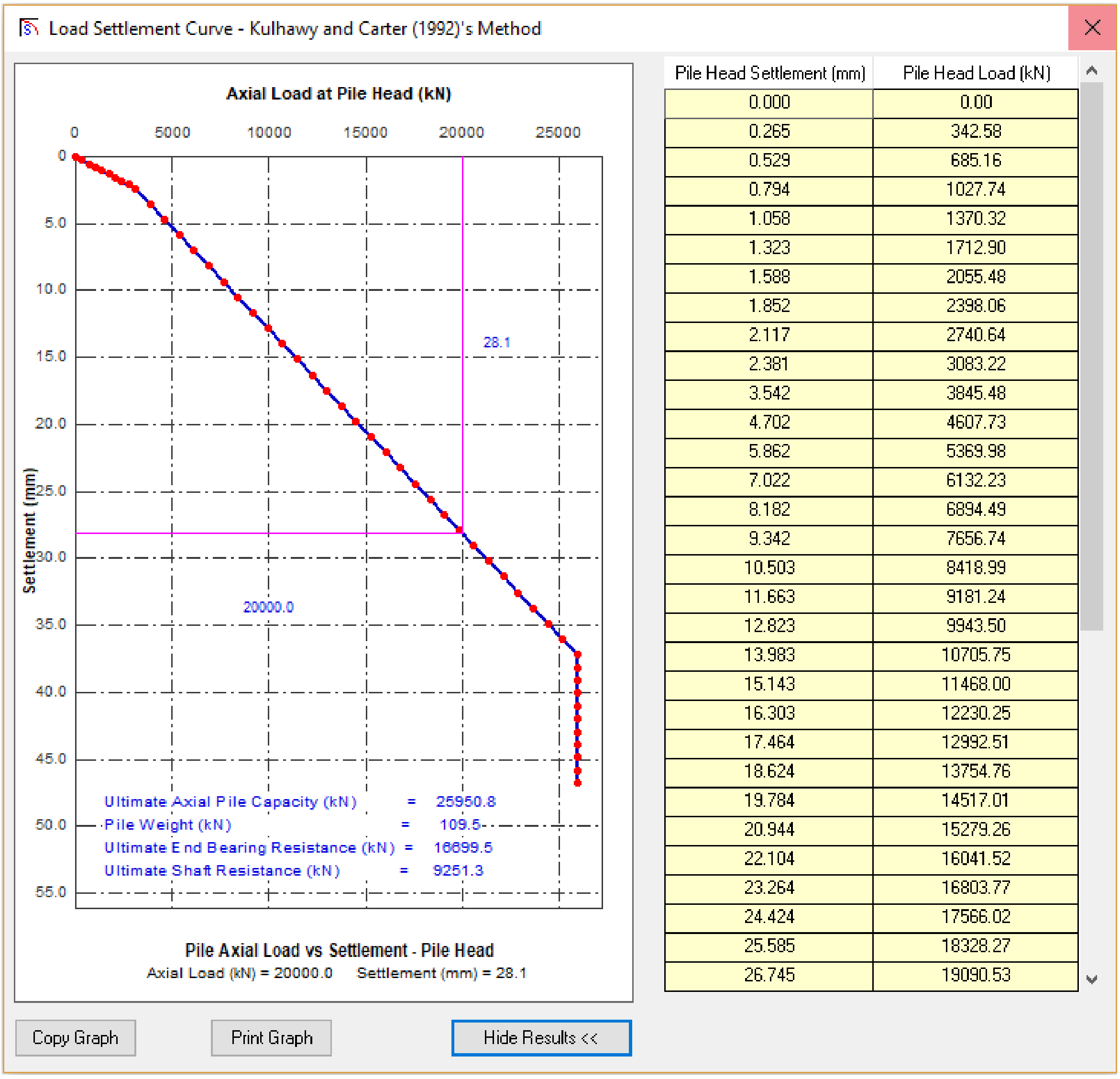


Figure 12-3 Copied Q-W Curve Plot for an example

Chapter 13. Pile Axial Load Settlement Curves

The dialog for pile settlement curve plot can be invoked by clicking the "Axial Load Settlement Curve" option under "Display" menu or “Axial Load Settlement Curve” icon from the toolbar. Figure 13-1 shows the “Axial Load Settlement Curve” dialog for an example.

Load-settlement curve is generated by the program for the specified axial loading at the pile head. Preliminary estimations on the ultimate shaft resistance, ultimate end bearing resistance and ultimate axial pile capacity are carried out by the program and the preliminary results are shown on the load-settlement curve graph. Since the load settlement curve covers a much wider settlement range in order to present a more complete picture, the pile head settlement corresponding to the input axial load is shown on the graph with the arrow pointing to the right axis. The arrow pointing to the bottom axis shows the input axial load at the pile head.



Pile Head Settlement (mm)	Pile Head Load (kN)
0.000	0.00
0.265	342.58
0.529	685.16
0.794	1027.74
1.058	1370.32
1.323	1712.90
1.588	2055.48
1.852	2398.06
2.117	2740.64
2.381	3083.22
3.542	3845.48
4.702	4607.73
5.862	5369.98
7.022	6132.23
8.182	6894.49
9.342	7656.74
10.503	8418.99
11.663	9181.24
12.823	9943.50
13.983	10705.75
15.143	11468.00
16.303	12230.25
17.464	12992.51
18.624	13754.76
19.784	14517.01
20.944	15279.26
22.104	16041.52
23.264	16803.77
24.424	17566.02
25.585	18328.27
26.745	19090.53

Figure 13-1 “Axial Load Settlement Curve” dialog for an example

If required, the tabulated results as shown in Figure 13-2 for the load and settlement curve at the pile head will be presented in the Excel-like table format through clicking the button of "Display Results" under the graph.

Pile Head Settlement (mm)	Pile Head Load (kN)
0.000	0.00
0.001	1.14
0.002	2.57
0.003	4.35
0.005	6.58
0.006	9.36
0.009	12.84
0.012	17.18
0.016	22.60
0.020	29.37
0.026	37.83
0.033	48.38
0.042	61.53
0.054	77.93
0.068	98.37
0.085	123.80
0.107	155.43
0.134	194.71
0.168	243.42
0.210	303.71
0.263	378.15
0.327	469.80
0.407	582.27
0.505	719.71
0.626	886.84
0.773	1088.90
0.953	1331.58
1.171	1620.84
1.434	1962.69
1.750	2362.97
2.128	2827.11

Figure 13-2 Tabulated axial load settlement curve results

PileROC also enables the user to copy or print the axial load settlement curve results on the graph. This can be done by clicking “Copy Graph” or “Print Graph” on the bottom of “Load Deflection Curve for Pile Head” dialog. The copied graph can be easily pasted into the third-party application for reporting purpose. A sample of the copied and pasted result graph is shown in Figure 13-3.

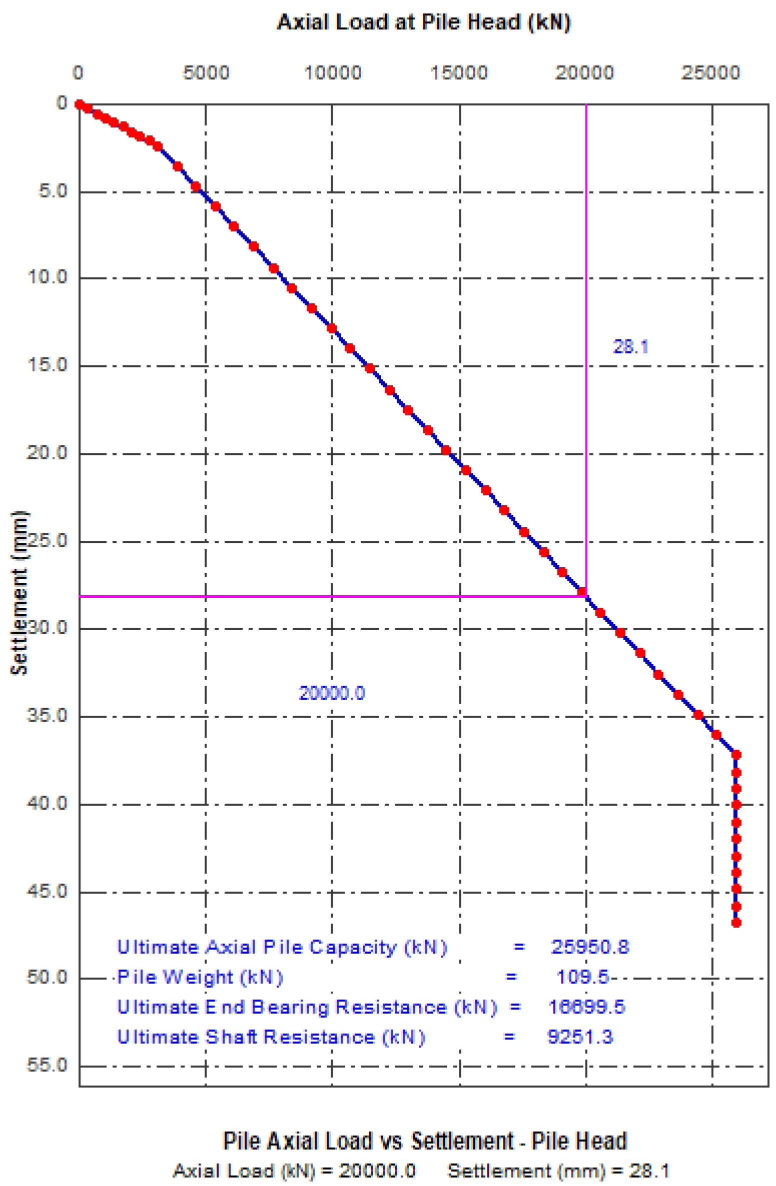


Figure 13-3 Copied axial load pile settlement curve – Kulhawy and Carter (1992)'s method

Chapter 14. Axial Load Transfer Curves

In addition to the axial load and settlement curve at the pile head, PileROC also provides with the user the distribution of axial load transfer along the pile shaft once the analysis is successfully completed. Note that this option is only available when Load Transfer Method is adopted for the rock socket analysis method. The dialog for the axial load transfer curve plot can be invoked by clicking the "Axial Load Distribution vs. Depth" option under "Display" menu or "Axial Load Distribution Curve Plot" from the toolbar.

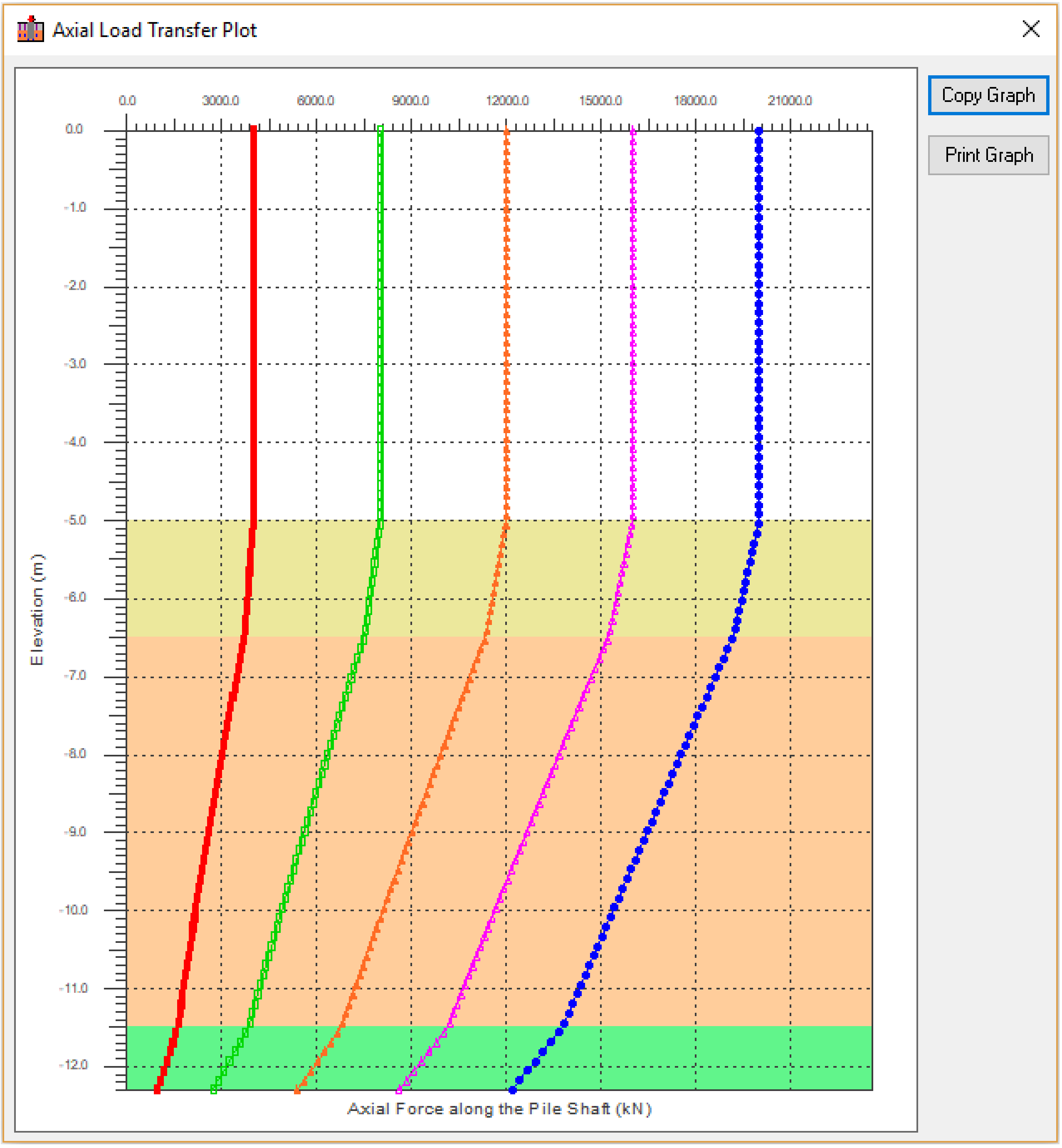


Figure 14-1 "Axial Load Transfer Curve" dialog for an example

Chapter 15. Short Pile Lateral Capacity Analysis

In additional to the estimation of axial capacity and settlement under the axial loading at the top of the rock socket, PileROC provides a simple and powerful tool to determine the capacity of the rock socket under later force and bending moment applied at the pile head in accordance with the methods recommended in Hong Kong Geoguide for (1) lateral bearing failure (Figures 52 and 53 of Hong Kong Geoguide); (2) planar discontinuity controlled failure with specified dip angle of discontinuity and (3) planar discontinuity controlled failure with searching for critical dip angle of discontinuity (Figure 54 of Hong Kong Geuoguide).

The dialog for rock socket lateral capacity analysis can be invoked by clicking the "SocketLAT" option under "Tool" menu from the toolbar. The invoked dialog is shown in Figure 15-1.

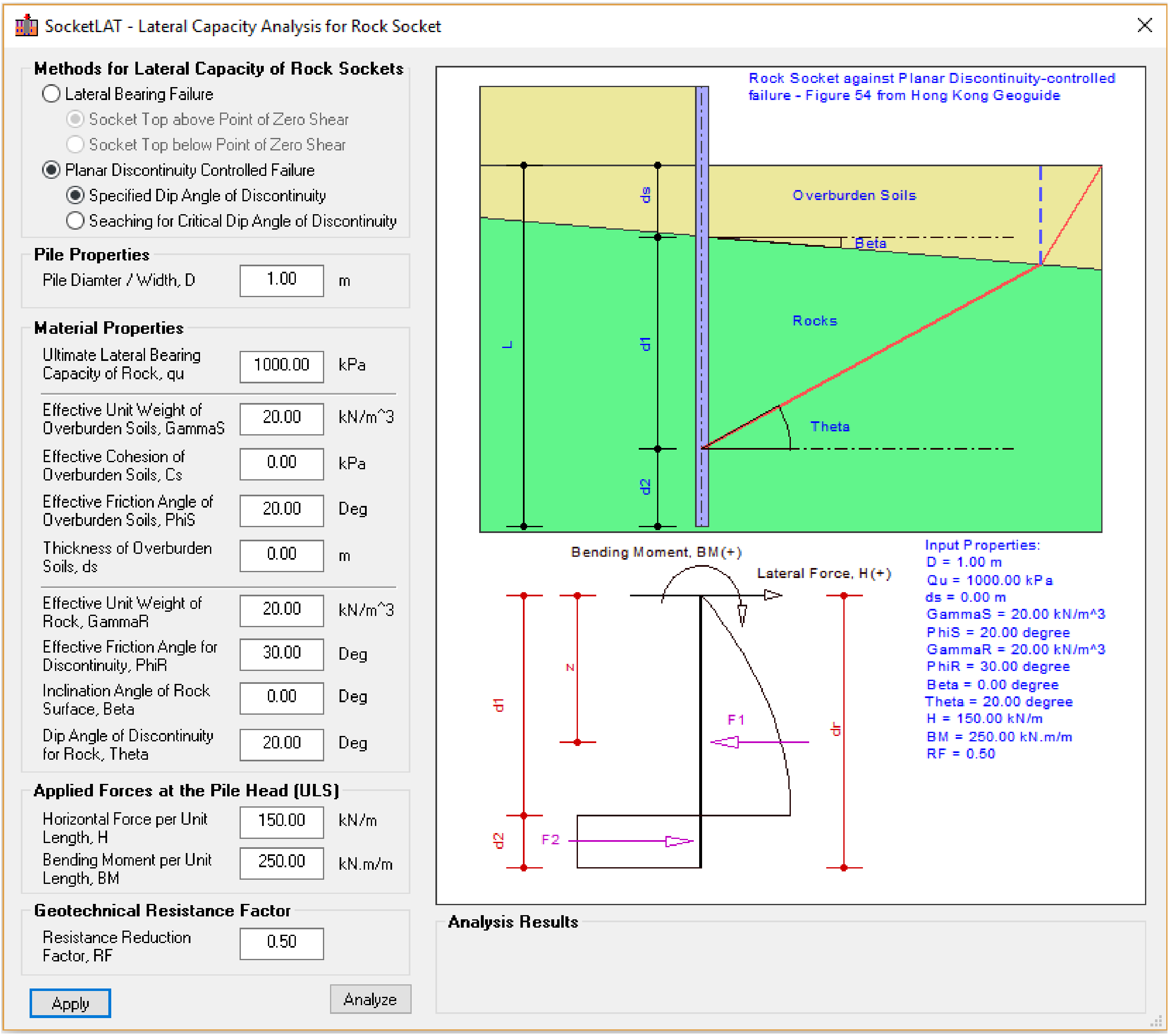
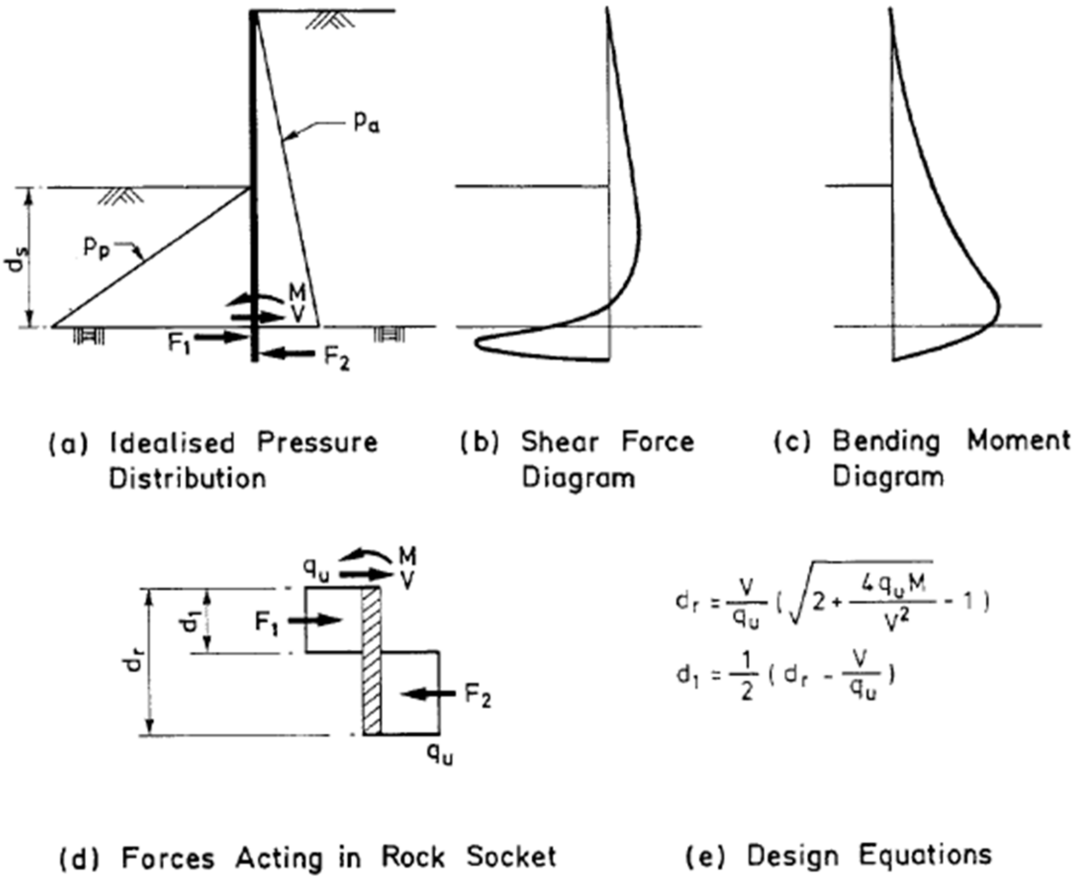


Figure 15-1 SocketLAT – Latera; Capacity Analysis for Rock Socket

The input parameters required for rock socket lateral capacity analysis are as follows:

- Pile Diameter;
- Unconfined lateral bearing capacity of rock, which can be conservative taken as one third of unconfined compressive strength of the rock as recommended in Hong Kong Guoguide;
- Effective Overburden Soil Unit Weight;
- Effective Rock Unit Weight;
- Effective cohesion for overburden soils;
- Effective friction angle for overburden soils;
- Thickness of overburden soils;
- Effective friction angle for discontinuity;
- Inclination of rock surface;
- Dip angle of discontinuity for rock;
- Applied Horizontal Force at the pile head, H. The applied force should be the factored force for ULS (Ultimate Limit State);
- Applied Bending Moment at the pile head, BM. The applied force should be the factored force for ULS (Ultimate Limit State); and
- Geotechnical Resistance Reduction Factor. Note that this factor is also defined as Geotechnical Strength Reduction Factor in some other Limit State Design Standards and is in general less than 1.0.

Clicking the button of “Analyze” will run the short pile lateral capacity analysis and the result summary will be displayed under “Analysis Results”. Graphical output is also presented on the right side of the dialog. Figures 15-2, 15-3 and 15-4 show the extracted relevant figures from Hong Kong Geoguide for the rock socket under lateral loading.



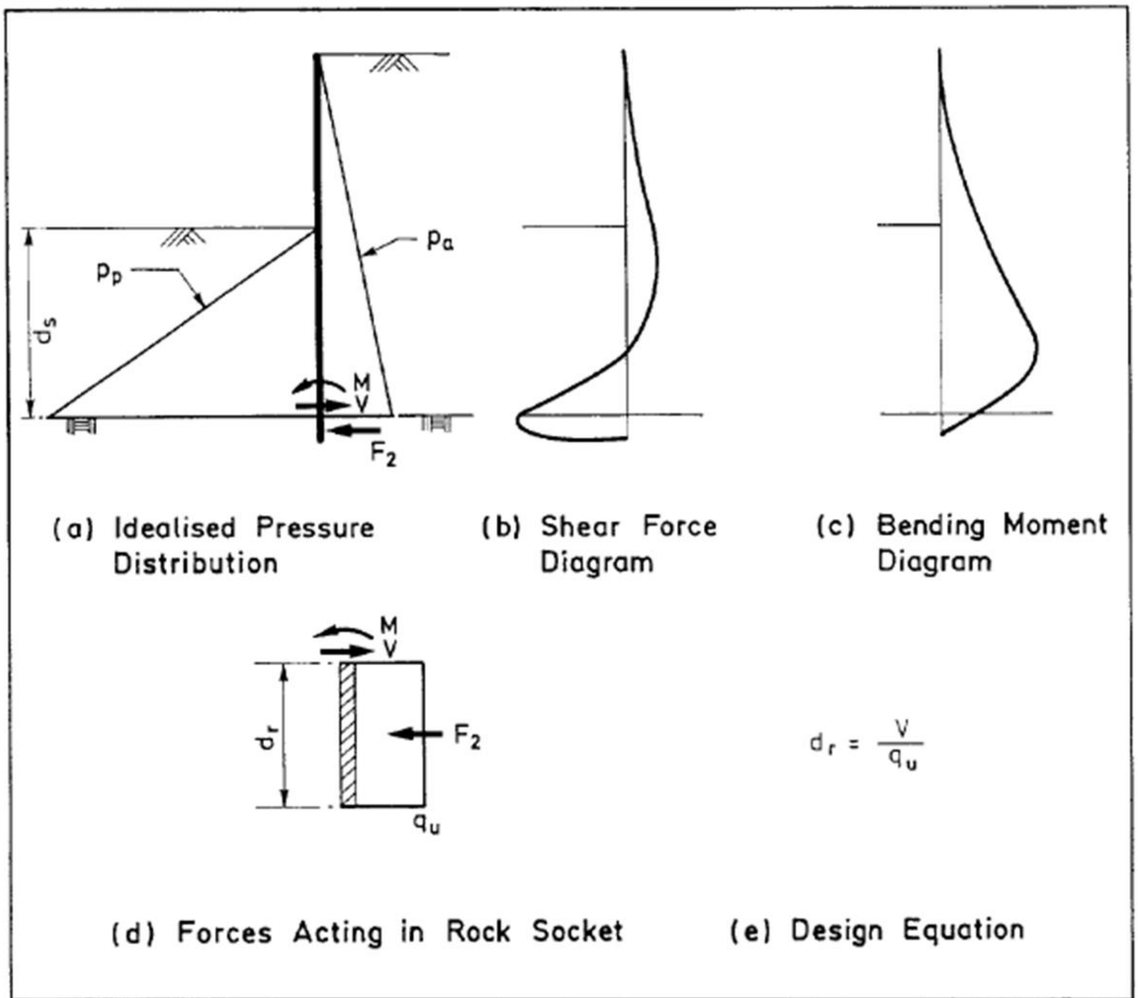
Legend :

F_1, F_2	Reactions in top and bottom portions of rock socket respectively
M, V	Bending moment and shear force respectively at the top of rock socket
q_u	Ultimate lateral bearing capacity of rock

Notes :
(1) Notes (1) to (3) of Figure 51 are also applicable.
(2) Where the depth of soil cover in the passive zone is large, the calculated d_1 value can be negative. For such cases, reference should be made to Figure 53.

Figure 52 - Design of Rock Socket Against Bearing Failure for the Case Where the Top of the Socket is Below the Point of Zero Shear

Figure 15-2 Hong Kong Geoguide Figure 52



Legend :

F_2	Reaction in the rock socket
M, V	Bending moment and shear force respectively at the top of rock rocket
q_u	Ultimate lateral bearing capacity of rock

Notes :

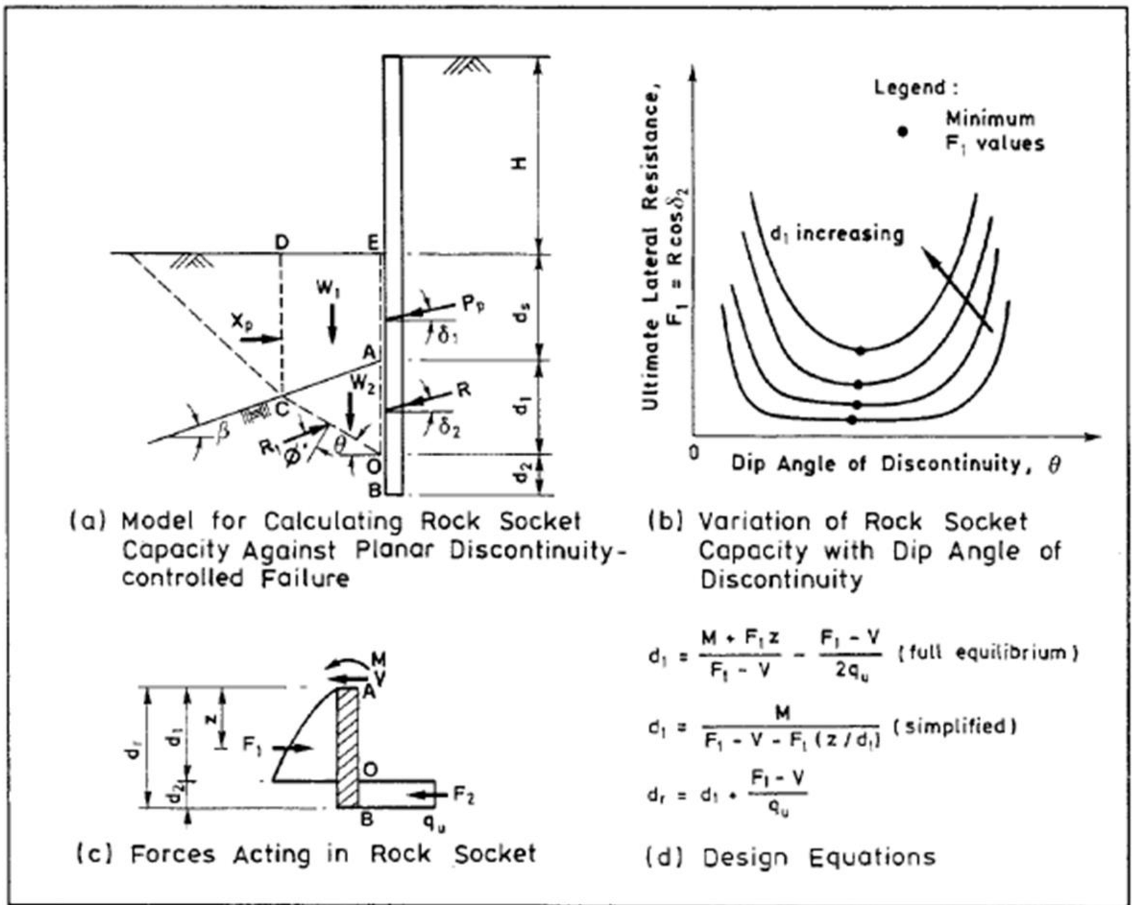
(1) For cantilevered sheet retaining walls, M, V, and F_2 should be calculated per unit width of the wall.

(2) For a wall composed of vertical members of width D at a spacing S, the values of M and V to be used in the above equations should be calculated based on active and passive earth pressures acting over a width equal to S. An exception to this is where S > 3D, in which case the contribution from the active and passive earth pressures below excavation level should be based on an effective width of 3D only. F_2 should always be based on a width equal to D, i.e. q_u should be multiplied by D.

(3) The possibility of excavation in front of the wall should be allowed for in evaluating passive resistance.

Figure 53 - Design of Rock Socket Against Bearing Failure for the Case Where $d_1 < 0$

Figure 15-3 Hong Kong Geoguide Figure 53



Legend :

F_1, F_2	Reactions at the top and bottom portions of the rock socket respectively
M, V	Bending moment and shear force respectively at the top of rock socket
P_p, X_p	Passive forces acting on the vertical boundaries AE and CD
R, R_1	Reactions acting on the presumed rock wedge
W_1, W_2	Weight of soil in ACDE and weight of rock in AOC respectively
δ_1, δ_2	Mobilised angles of wall friction in soil and in rock respectively
ϕ'	Angle of shearing resistance of the presumed discontinuity OC

Notes :

(1) If point A is below the point of zero shear, then the direction of V reverses.

(2) For cantilevered sheet retaining walls, M, V, F_1 and F_2 and R should be calculated per unit width of the wall.

(3) For a wall composed of vertical members of width D at a spacing S, the values of M and V to be used in the above equations should be calculated based on active and passive earth pressures acting over a width equal to S. An exception to this is where $S > 3D$, in which case the contribution from the earth pressures below excavation level should be based on an effective width of 3D only. The values of R, and hence F_1, may be based on a width equal to S. However, F_2 should always be based on a width equal to D only, i.e. q_u should be multiplied by D.

(4) The possibility of excavation in front of the wall should be allowed for in evaluating passive resistance.

(5) Where the depth of soil cover in the passive zone is large, the calculated d_1 value can be negative. For such cases, reference should be made to Figure 53.

Figure 54 - Design of Rock Socket Against Planar Discontinuity-controlled Failure

Figure 15-4 Hong Kong Geoguide Figure 54

APPENDICES

Appendix A. Fleming (1992)'s Method

The method proposed by Fleming (1992) is based on the hyperbolic relationship assumptions for both shaft and base load displacement responses. Elastic shortening of the pile is considered separately.

The relationship between the pile displacement Δ_s and shaft load P_s is:

$$\Delta_s = \frac{M_s D_s P_s}{U_s - P_s}$$

where D_s is the pile diameter, P_s is the shaft load, U_s is the ultimate total shaft resistance and M_s is the dimensionless flexibility factor ranging from 0.0001 to 0.004. Fleming (1992) suggested the value of approximately 0.0005 for soft rocks.

The hyperbolic relationship between the pile toe displacement Δ_B and pile base load $\mathrm{P_B}$ is:

$$\Delta_B = \frac{0.6 U_B P_B}{D_B E_B (U_B - P_B)}$$

where D_B is the pile diameter at the base, P_B is the pile toe load, U_B is the ultimate pile toe bearing resistance force and E_B is the Young's Modulus of the material at the pile toe. The total load at the pile head, P_T is calculated as:

$$P_T = P_B + P_S$$

The elastic shortening Δ_E of the pile is determined with using the following equation to the load up to the ultimate shaft load, U_S:

$$\Delta_E = \frac{4}{\pi} \frac{P_T (L_0 + K_E L_F)}{D_S^2 E_C}$$

For the greater load, the following equation is used to calculate the elastic shortening:

$$\Delta_E = \frac{4}{\pi} \frac{1}{D_S^2 E_C} [P_T (L_0 + L_F) - L_F U_S (1 - K_E)]$$

where E_C is the Young's modulus of the pile material, L_0 is pile free length where no friction resistance from the soils, L_F is length of the pile with friction load transfer and K_E is effective length coefficient ranging from 0.4 to 0.5.

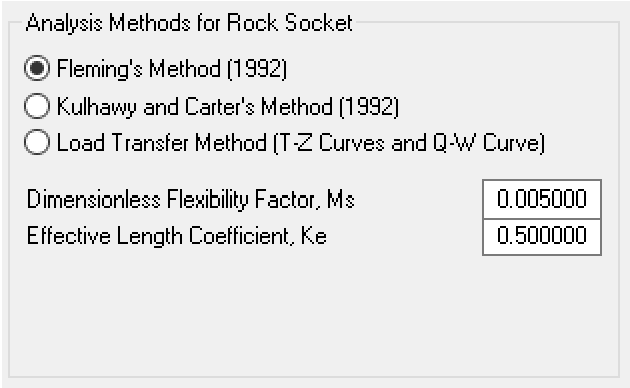


Figure A-1 Parameter input dialog for Fleming (1992)'s method

In PileROC, the parameter input for Fleming (1992)'s method is very straightforward. Only two parameters are required to be provided in the "Option" input dialog as shown in Figure A-1. The default dimensionless flexibility factor is 0.0005 and the default effective length coefficient is 0.5. The calculation procedures for the ultimate shaft resistance and ultimate end bearing resistance are detailed in Appendix C.

Appendix B. Kulhawy and Carter (1992)'s Method

The second method for the load settlement analysis of rock socket is based on the approach by Kulhawy and Carter (1992) which is based on approximate closed-form analyses. The behaviour of the piles socketed into rock is divided into the following steps as follows:

- The initial response of rock socket is assumed to be elastic and there is no slip along the pile shaft. The load settlement relationship is based on the theoretical equations from Randolph and Wroth (1978);
- The progressive slip between the pile and rock is ignored and only full slip is considered.

The following equation is used to calculate the pile settlement, W_C for the complete socket under compressive loading, Q_C at the linear stage:

$$\frac{G_r B W_c}{2Q_C} = \frac{1 + \left(\frac{4}{1-\upsilon_b}\right)\left(\frac{1}{\pi\lambda\xi}\right)\left(\frac{2D}{B}\right)\left(\frac{\tanh \mu D}{\mu D}\right)}{\left(\frac{4}{1-\upsilon_b}\right)\left(\frac{1}{\xi}\right) + \left(\frac{2\pi}{\zeta}\right)\left(\frac{2D}{B}\right)\left(\frac{\tanh \mu D}{\mu D}\right)}$$

Where

$$\zeta = \ln\left[\frac{5(1-\upsilon_r)D}{B}\right]$$

$$\lambda = E_c/G_r$$

$$G_r = \frac{E_r}{2(1+\upsilon_r)}$$

$$\xi = G_r/G_b$$

$$G_b = \frac{E_b}{2(1+\upsilon_b)}$$

The following equations are used to calculate the nonlinear pile settlement W_C for the complete socket under the compressive loading for the full slip condition:

$$W_C = F_3\left(\frac{Q_C}{\pi E_r B}\right) - F_4 B$$

$$a_1 = (1+\upsilon_r)\zeta + a_2$$

$$a_2 = \left[(1-\upsilon_r)\left(\frac{E_r}{E_c}\right) + (1+\upsilon_r)\right]\left(\frac{1}{2\tan\phi\tan\psi}\right)$$

$$a_3 = \left(\frac{\upsilon_c}{2\tan\psi}\right)\left(\frac{E_r}{E_c}\right)$$

$$\lambda_{1,2} = \frac{-\beta \pm (\beta^2 + 4\alpha)^{1/2}}{2\alpha}$$

$$F_3 = a_1(\lambda_1 BC_3 - \lambda_2 BC_4) - 4a_3$$

$$F_4 = \left[1 - a_1\left(\frac{\lambda_1 - \lambda_2}{D_4 - D_4}\right)B\right]a_2\left(\frac{c}{E_r}\right)$$

$$C_{3,4} = D_{3,4}/(D_4 - D_3)$$

$$D_{3,4} = \left[\pi(1 - \nu_b^2)\left(\frac{E_r}{E_b}\right) + 4a_3 + a_1\lambda_{2,1}B\right]exp[\lambda_{2,1}D]$$

In PileROC, the parameter input for Kulhawy and Carter (1992)'s method is very straightforward. Three additional rock strength parameters are required to be provided in the "Option" input dialog as shown in Figure B-1.

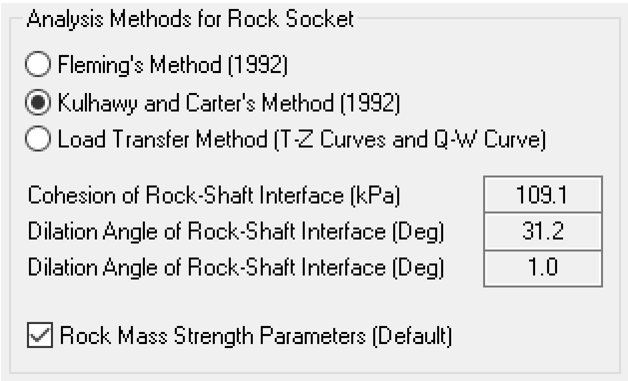


Figure B-1 Parameter input dialog for Kulhawy and Carter (1992)'s method

The default cohesion of rock-shaft interface, c, is calculated by the equation below:

$$\frac{c}{p_a} = 0.1\left(\frac{UCS}{p_a}\right)^2$$

The following equation is used to calculate the value of $\tan\phi\tan\psi$:

$$\tan\phi\tan\psi = 0.001\left(\frac{UCS}{p_a}\right)^{2/3}$$

The default dilation angle, ψ of rock-shaft interface is assumed to be 1 degree. The default friction angle,

ϕ of rock-shaft interface is then calculated by the equation above. Note that a value of zero cannot be input for the dilation angle of rock-shaft interface as this will cause equation breakdown. The calculation procedures for the ultimate shaft resistance and ultimate end bearing resistance are detailed in Appendix C.

Appendix C. Load Transfer Method

For general rock material in PileROC, the following equation are adopted to calculate the ultimate shaft resistance, f_s and ultimate end bearing resistance, f_b:

$$f_s = p_a \cdot \alpha \left(\frac{\sigma_c}{p_a}\right)^{\beta}$$

$$f_b = N_c \sigma_c$$

where α and β are empirical factors determined from the various load tests, σ_c is the unconfined compressive strength of intact rocks in the unit of MPa and N_c is the bearing capacity factor for the rock which is assumed to be 2.5 in PileROC. Kulhawy and Prakoso (2005) reviewed the database of the currently existing methods of predicting ultimate shaft resistance and suggested that β can be adopted as 0.5 for all practical purposes. As for the empirical factor, α, a default value of 0.63 is considered to be close to the lower bound to 90% of the published data for normal rock sockets in PileROC.

The following hyperbolic relationship for t-z curve as recommended by O'Neill and Hassan (1998) is adopted in the program to calculate the mobilised shaft resistance f_{s-mob} based on the pile settlement z:

$$f_{s-mob} = \frac{z}{\frac{2.5D}{E_m} + \frac{z}{f_s}}$$

where D is the pile diameter and E_m is the elastic modulus of the rock mass. The following relationship proposed by Rowe and Armitage (1984) is adopted to calculate the elastic modulus of the rock mass based on the unconfined compressive strength of rocks:

$$E_m = 215\sqrt{\sigma_c}$$

According to Pells (1999), for massive and intact rock, the load-displacement behaviour is linear up to bearing pressures of 2 to 4 times the UCS. For jointed rock mass, the load-displacement behaviour is linear up to 0.75 to 1.25 times the UCS. Baguelin (1982) suggested using the following equation for the linear load-displacement relationship for end bearing up to a specific maximum displacement at which the ultimate bearing resistance is mobilised:

$$\sigma_b = s_b \cdot \frac{4E_b}{\pi(1 - \upsilon_b^2)D}$$

in which E_b is elastic rock modulus at the pile toe; s_b is pile toe displacement; υ_b is Poisson's ratio (0.25 is adopted in the program); D is the pile diameter and σ_b is the mobilised end bearing pressure at the pile toe. This elastic-plastic relationship is adopted in PileROC.

The basic parameter input dialog for General Rock method for rocks (bored piles or drilled shafts) is shown in Figure C-1. The advanced parameter input dialog is shown in Figure C-2. T-z curve based on the method by by O'Neill and Hassan (1998) and q-w based on the recommendation from Baguelin (1982) are adopted.

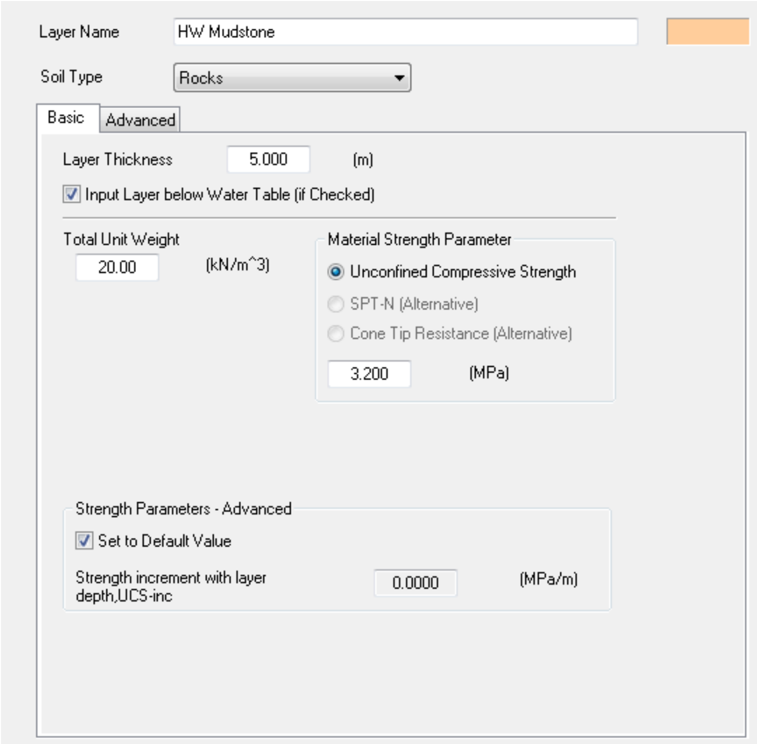


Figure C-1 Basic soil parameter input of General Rock Method

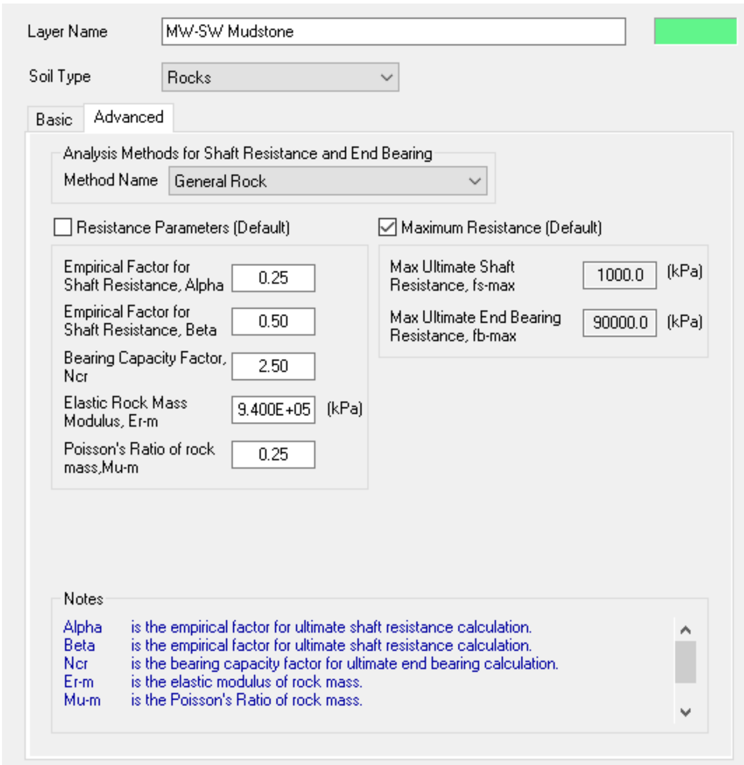


Figure C-2 Advanced soil parameter input of General Rock Method

Figure C-3 shows the advanced input parameter for the user defined method. Once this option is selected, the users only need to input the ultimate shaft resistance (fs), ultimate end bearing resistance (fb), rock mass elastic modulus (Er-m) and the Poisson's ratio for the rock mass (Mu-m).

For the User Defined Method, the basic soil parameter input dialog is the same as the previous method. Note that the input strength parameters on the basic soil parameter dialog will not be used to calculate the ultimate shaft resistance and end bearing resistance as those values are directly input into the program through the advanced soil parameter input dialog as show in Figure C-1. Slightly different from the user defined method for soils, two additional parameters will need to be provided for the rock: (1) Elastic modulus, Er-m and (2) Poisson's ratio, Mu-m as shown in the figure below.

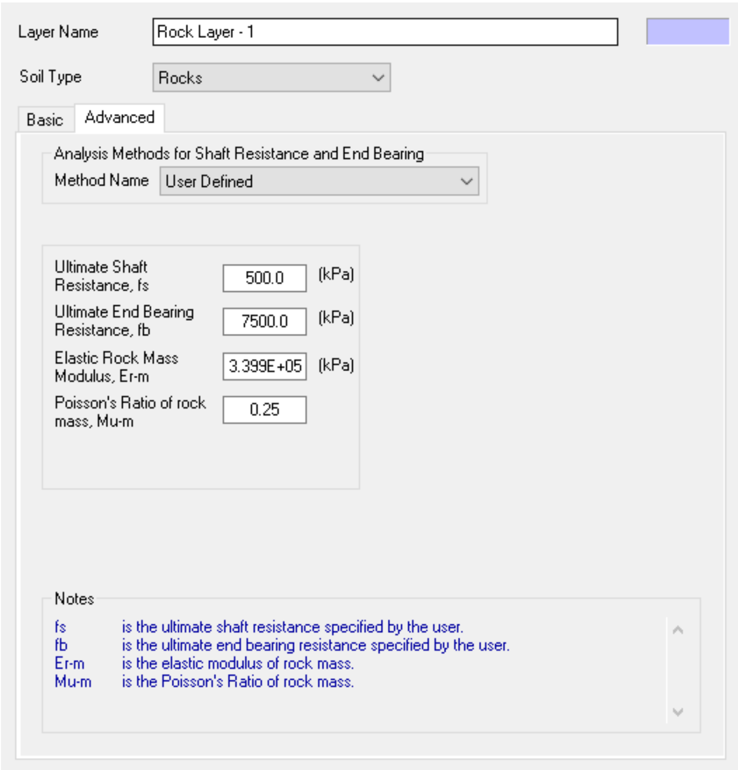


Figure C-3 Advanced soil parameter input of User Defined method

Appendix D. Examples

Example D.1 Bored Pile socketed into weak mudstone

This example involves a 900 mm diameter bored pile of 12.3 m long bored through 5 m thick overburden soils, 1.5 m thick XW-HW Mudstone (1 MPa for UCS), 5.0 m thick HW Mudstone (3.2 MPa for UCS) and socketed into MW-SW Mudstone (10.5 MPa for UCS) by 0.8 m. Compressive axial force applied at the pile head is 20 MN. Figure D.1-1 shows the ground profile with the pile length and loading conditions for this example.

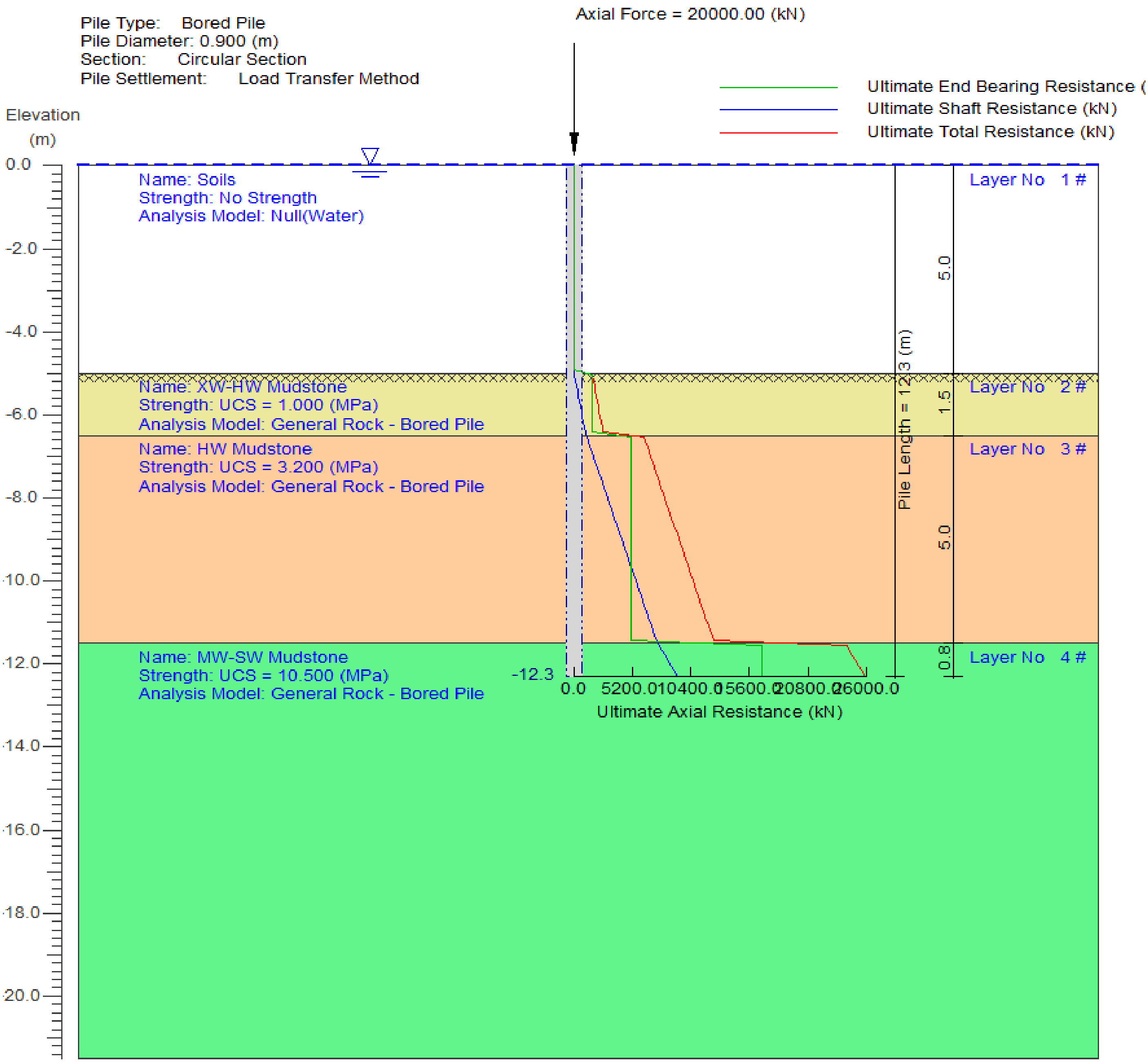


Figure D.1-1 Ground profile with the pile length and loading conditions for Example 1

Note that the portion of the pile within the soil layer is modelled with using a layer with "Null" material type in PileROC program since the contribution from the soils is ignored for rock socket design. If the cantilever portion is within the water, the user only needs to make sure that this special “Null” layer is under water table in the layer input. In this example, since the first 5 m portion is within the water, the first layer – which is the layer with “Null” material type under the water table. The water table is shown as a thicker blue line in the ground profile as shown in Figure D.1-1.

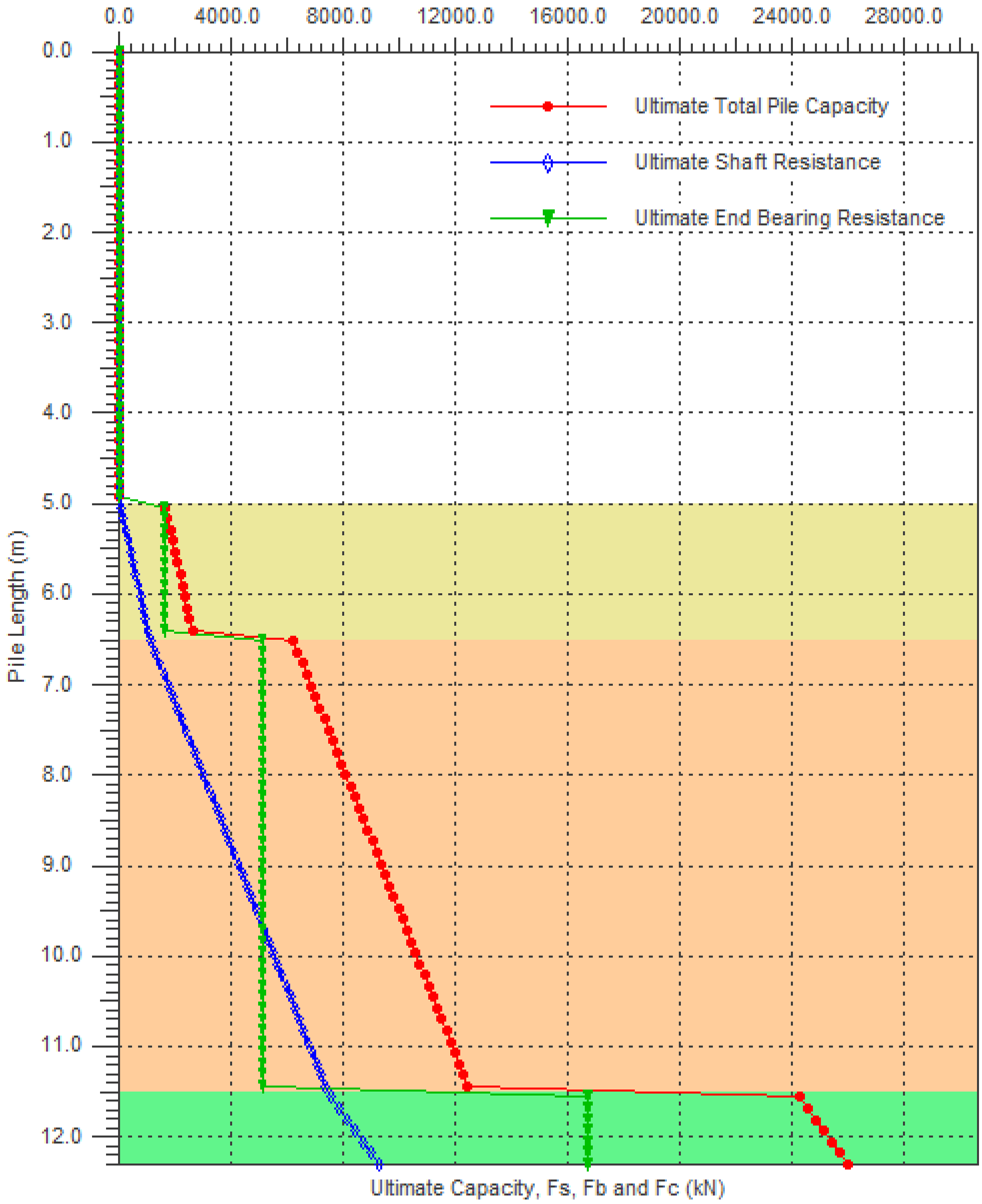


Figure D.1-2 Combined plot of the pile capacity results for Example 1

Figure D.1-2 shows the combined plot of the pile capacity results for Example 1 which includes the distribution of ultimate total shaft resistance, ultimate end bearing resistance and ultimate pile total capacity. Figure D.1-3 shows the pile axial load vs settlement relationship for this example.

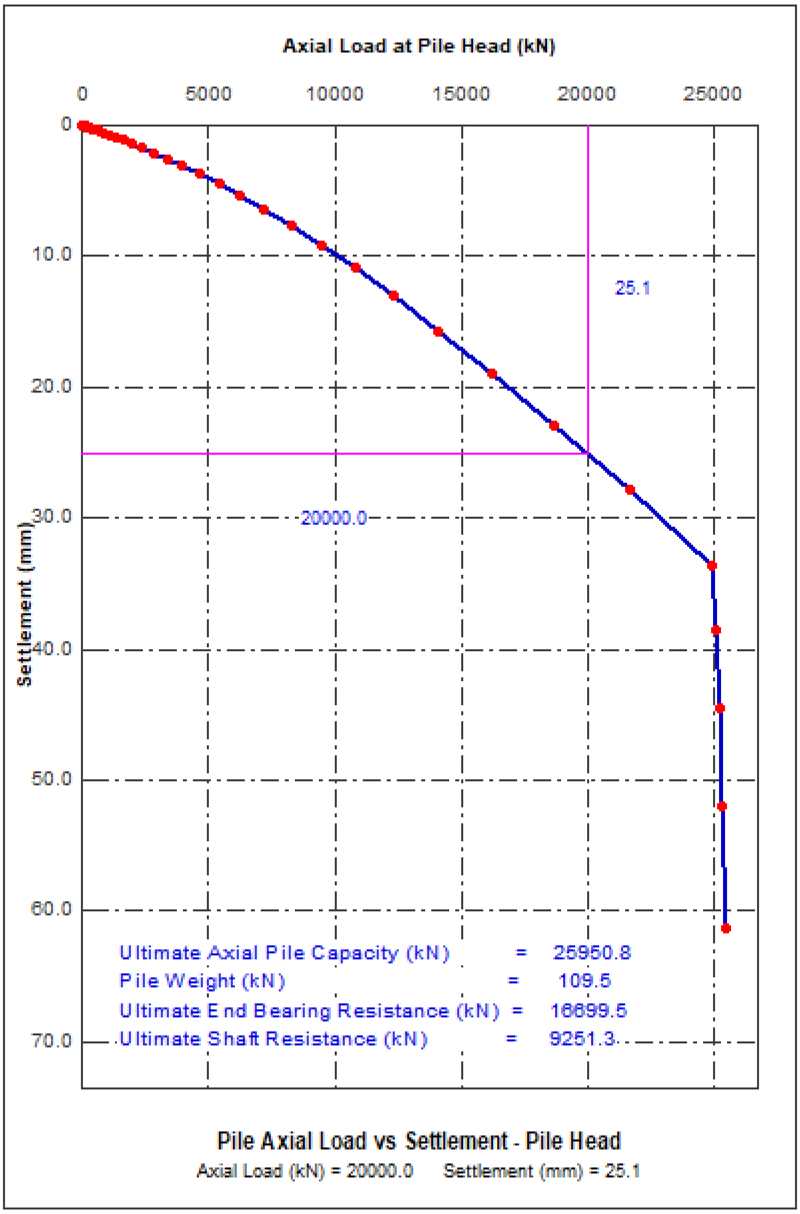


Figure D.1-3 Pile axial load and settlement relationship for Example 1

The results based on Fleming (1992)'s method and Kulhawy and Carter (1992)'s method are shown in Figures D.1-4 and D.1-5, respectively.

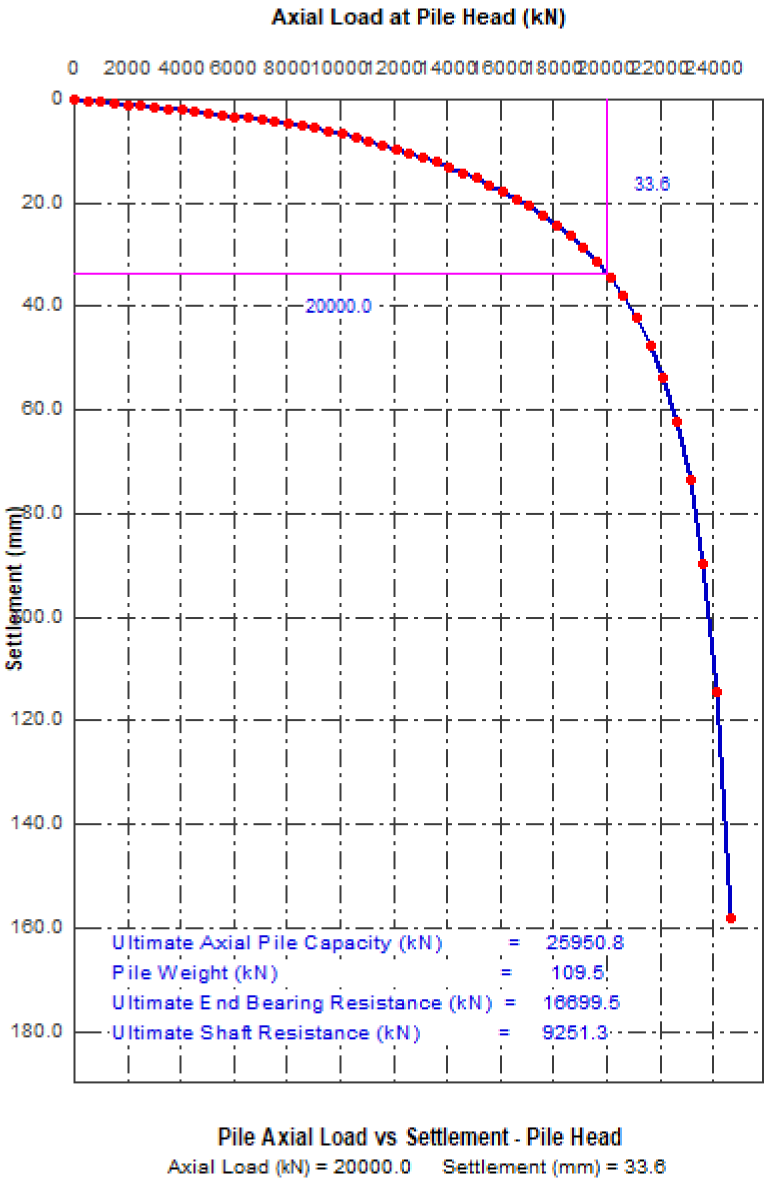


Figure D.1-3 Pile axial load and settlement relationship for Example 1 – Fleming (1992)'s Method

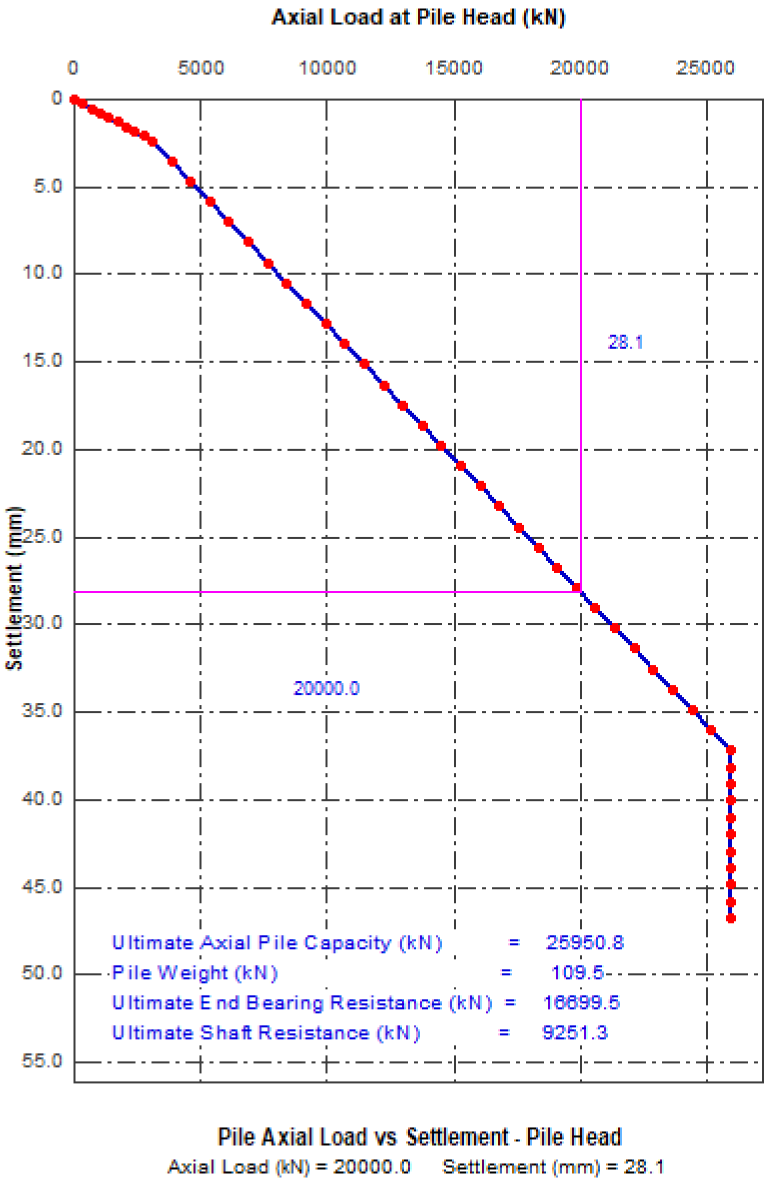


Figure D.1-4 Pile axial load and settlement relationship for Example 1- - Kulhawy and Carter (1992) Method

Example D.2 Bored pile socketed into strong rock – Hong Kong Case

This example involves a 1050 mm diameter bored pile of 35.6 m long bored through 33.6 m thick overburden soils and socketed into strong rock (30 MPa for UCS) by 2.0 m. Compressive axial force applied at the pile head is 26950 kN. Figure D.2-1 shows the ground profile with the pile length and loading conditions for this example.

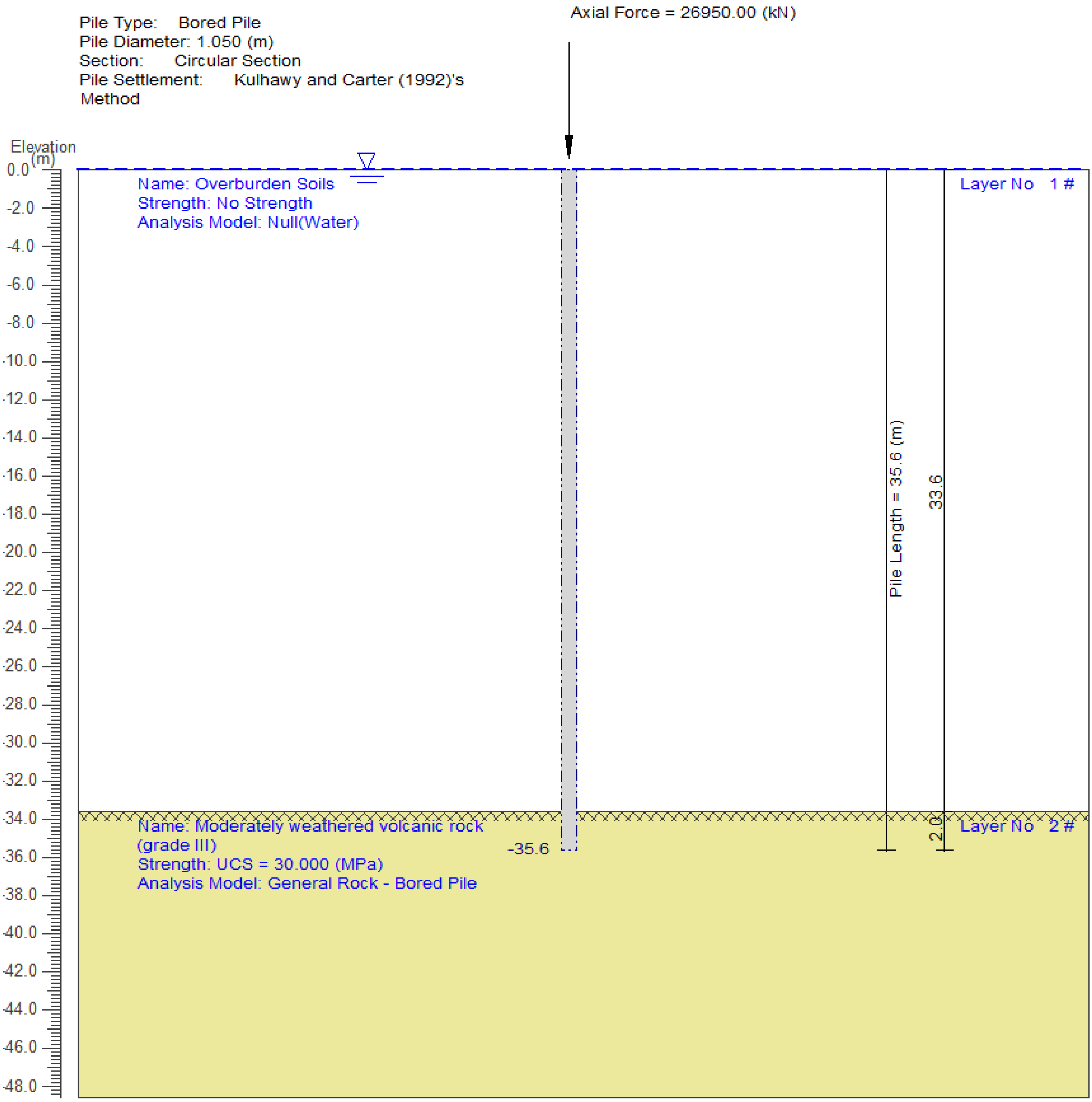


Figure D.2-1 Ground profile with the pile length and loading conditions for Example 2

Figure D.2-2 shows the pile axial load vs settlement relationship for this example for the option of load transfer method. The results based on Fleming (1992)'s method and Kulhawy and Carter (1992)'s method are shown in Figures D.2-3 and D.2-4, respectively.

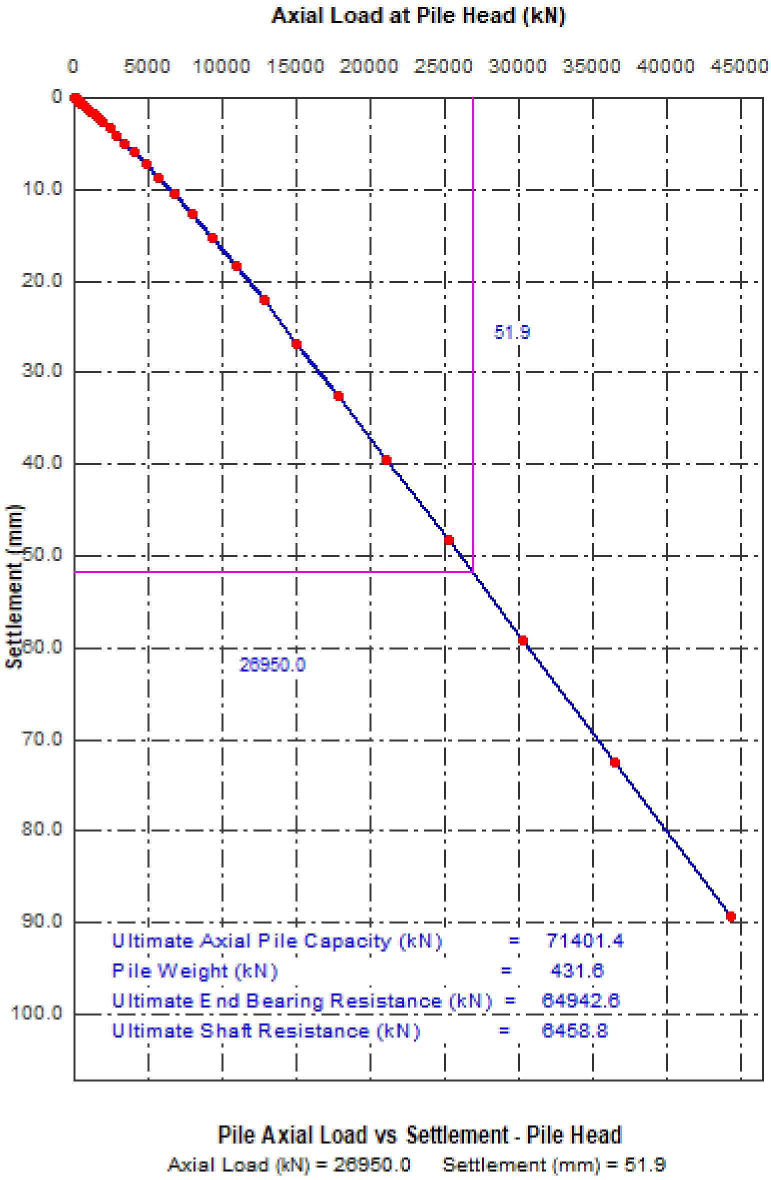


Figure D.2-2 Pile axial load and settlement relationship for Example 2 - Load Transfer Method

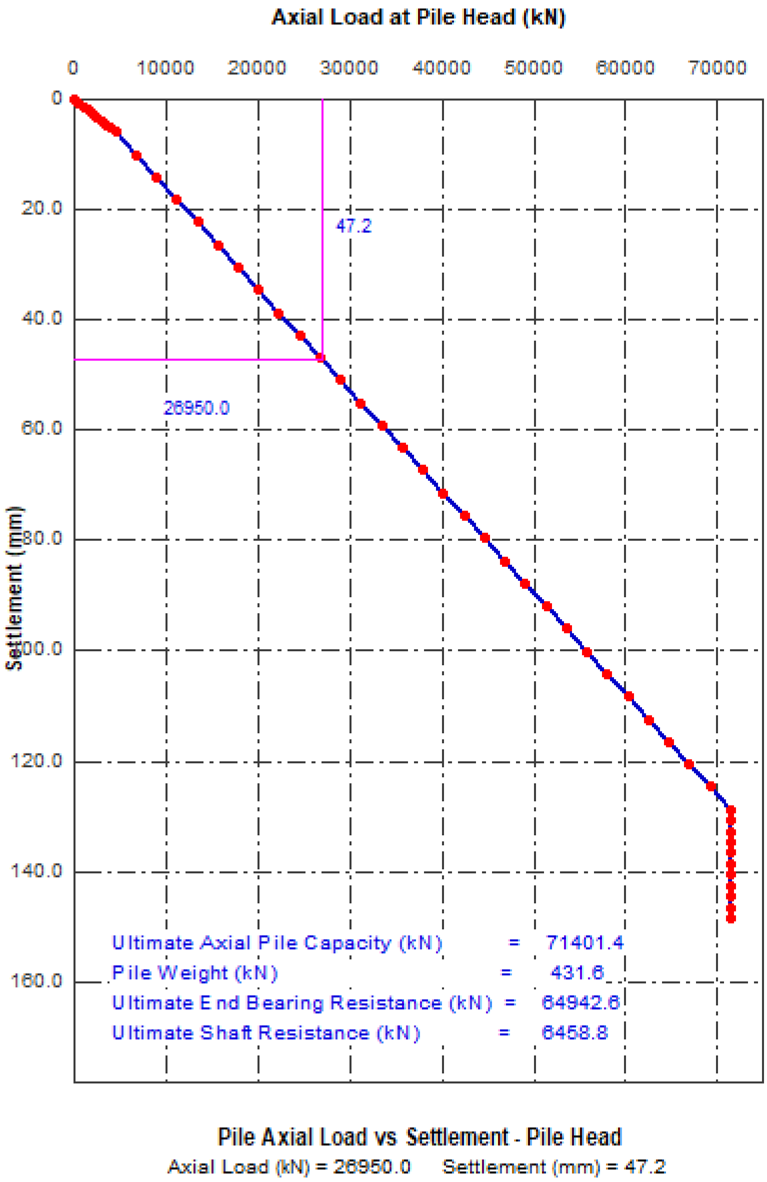


Figure D.2-3 Pile axial load and settlement relationship for Example 2 - Kulhawy and Carter (1992) Method

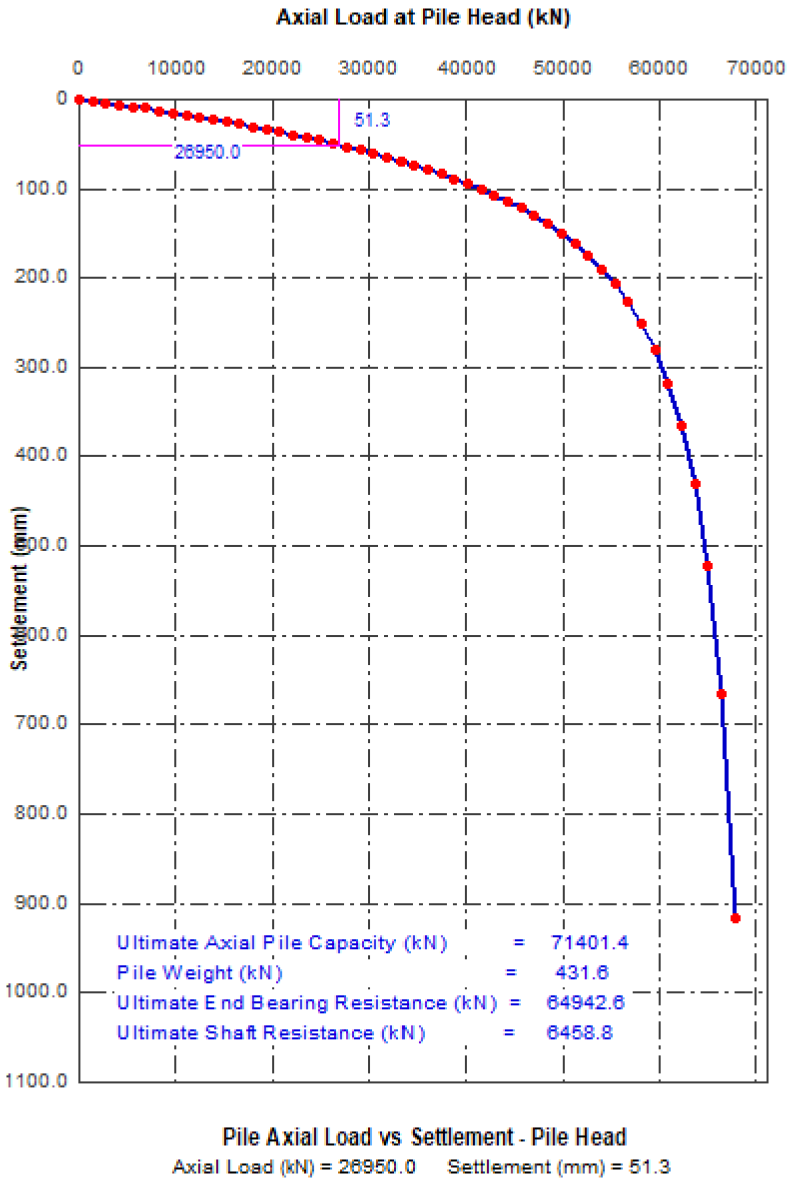


Figure D.2-4 Pile axial load and settlement relationship for Example 2 – Fleming (1992)'s Method

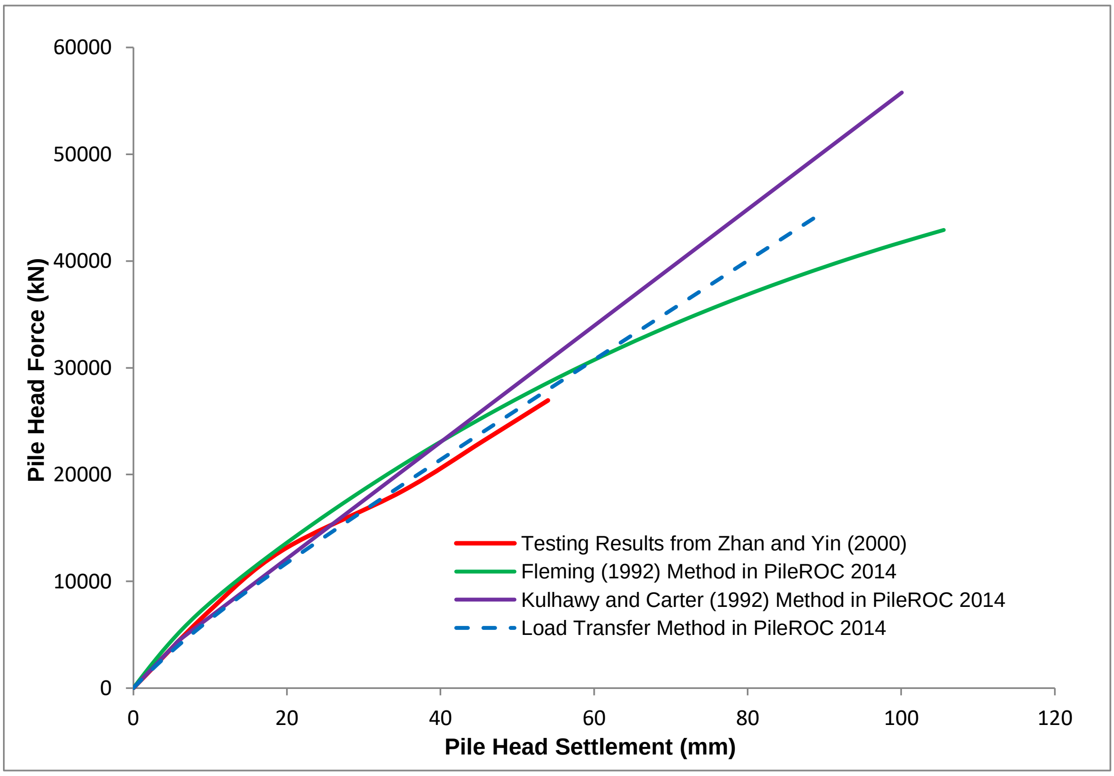


Figure D.2-5 Comparison results with the recorded testing values from Zhan and Yin (2000)

Zhan and Yin (2000) reported the value of the pile top settlement under the axial loading 26950 kN is 54 mm which compares well the analysis results from PileROC: 49.6 mm from Fleming (1992)'s method, 47.2 mm from Kulhawy and Carter (1992)'s method and 51.9 mm from the load transfer method. The comparison results among the resting results and the predictions from PileROC based on different methods are presented in Figure D.2-5. It can be seen that those results are reasonably close and it demonstrates the validity of PileROC program.

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