

The Unified Method of Piled Foundation Analysis by Means of UniPile

Bengt H. Fellenius, May 2026

1. Introduction

Piled foundation designs are mostly routine, involving single piles or small groups of piles bearing in competent soil below overlying compressible and weak soil layers, the design being directed toward ensuring safe bearing. According to conventional practice, when analysis or test results show bearing to be adequate, foundation settlement due to the applied loads is expected to be minimal. However, where the piled foundation could be affected by downdrag caused by general area subsidence due to groundwater lowering or by stress increase from fills and adjacent loads, additional settlement might occur. The designing engineer must then perform detailed force and settlement analysis and determine the pile interaction with the soil for the loading specifics. The analysis requires incorporating aspects of immediate and long-term force transfer, stress-shear movement response, and pile interaction. The effort can be quite complex and time-consuming. However, the UniPile software saves a user hours of effort to produce the analysis results and finding and addressing all issues of a case, be the issues straight-forward or complex.

The multitude of issues involved in a piled foundation design are addressed in the UniPile6 extensive software manual comprising almost 50 pages. The manual can be downloaded for review and reference from within the software. A first-time user might find the wealth of information daunting and become lost in all options offered. The following aims to smoothen that first experience by showing three basic steps:

- A case addressing the most commonly used options in UniPile for single piles, i.e., loading-test simulation, force distribution, and settlement,
- Display of input for various pile types, and
- Applying the Unified Method of Piled Foundation Analysis for pile groups.

2. Soil Parameters and Input

The example addresses a 30 m (100 ft) embedment 356 mm (14 in) diameter prestressed pile; a test pile considered for a project involving piles with an assigned sustained (dead) load of 800 kN (180 kips) and a transient (live) load of 200 kN (45 kips).

The groundwater table lies at a depth of 1.0 m (3.3 ft) and the pore pressure distribution is hydrostatic. The soil data include CPT sounding records and SPT N-indices. In preparing the site for construction, an about 1.0 m (3.3 ft) thick fill was placed across the site, but no fill was placed over the 20 x 36 m (66 ft x 118 ft) building footprint.

The 60 m thick soil profile is summarized in Table 1. The compressibility is expressed in Janbu modulus numbers (m and m_r). The Janbu method and modulus numbers may be unfamiliar to some. To avoid confusion, UniPile, provides three alternative methods with automatic conversion between them: Janbu m , E -modulus, or $C_c e_0$. Note, for the $C_c e_0$ -method to work, the soil void ratio, e_0 , must be input. (If only the water content, w_n , is known, UniPile will assist in calculating the void ratio as well as the soil density. See the Manual, Page 17/47).

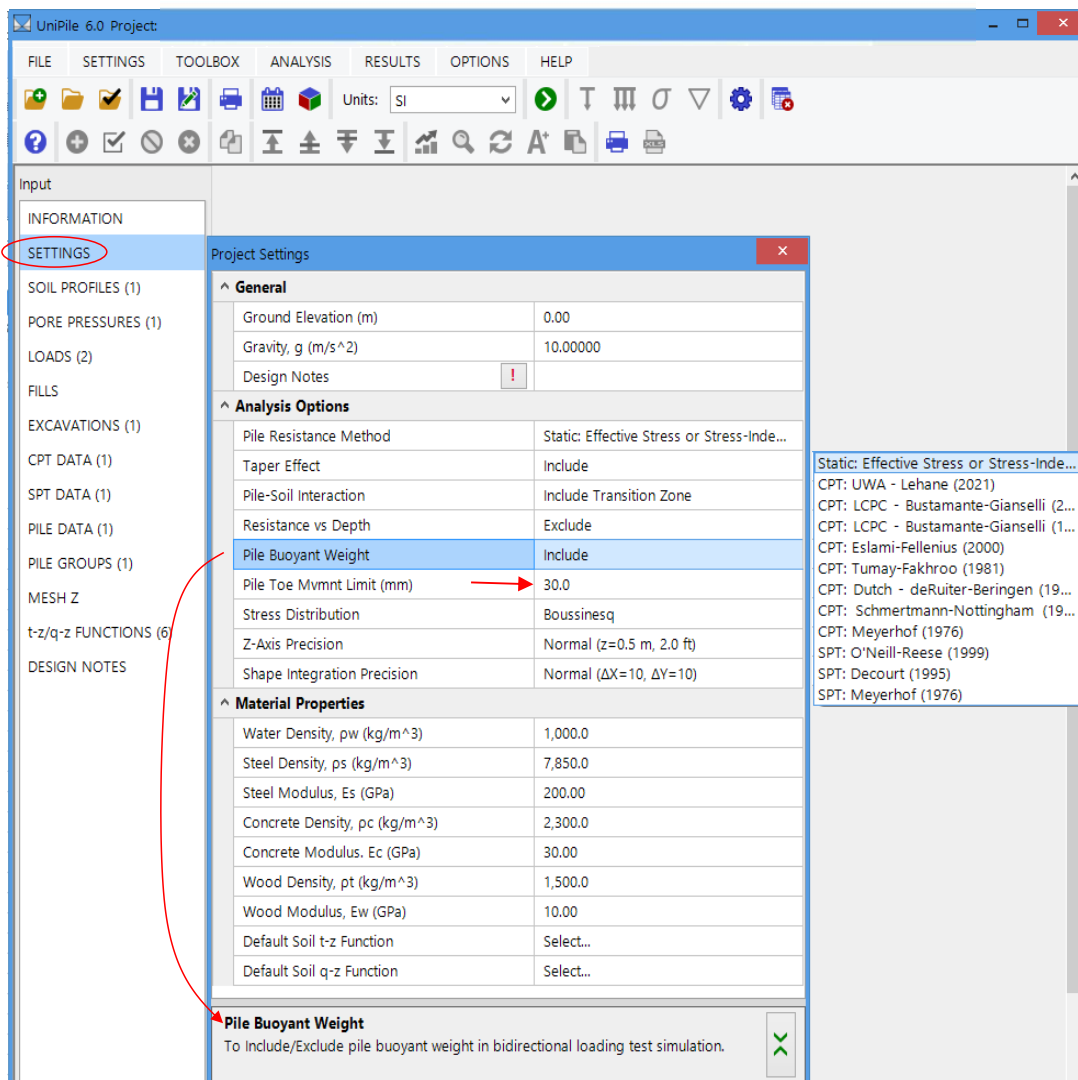
Table 1. Soil Profile

Layer	Type	Thickness	Density, ρ	Janbu, m ,	m_r	j	$\Delta\sigma'$
1	Clay	25 m (80 ft)	1,800 kg/m ³ (112 pcf)	20	100	0	5 (kPa)
2	Sand	10 m (30 ft)	2,000 kg/m ³ (125 pcf)		400	1	
3	Clay	25 m (80 ft)	1,800 kg/m ³ (119 pcf)	30	300	0	20 (kPa)

The foregoing three paragraphs summarize the design principles. I believe that most engineers would consider the data to indicate a routine piled foundation design. That is, provided they are confidently familiar with the geology of the site and with the past performances of piled foundations constructed by the local contractors. But, not if they, as often in the past, only care about the drag force introduced by the site fill (then, adding it as equal to the sustained load, no doubt), because, in the past, that's all they were expected to do. However, these days, downdrag, not drag force, is the main issue. Moreover, be the required analysis a case of routine design or not, it still requires analysis and the UniPile software is a time-saving approach to establish all the analysis calculation results necessary to decide whether or not the indicated design is suitable.

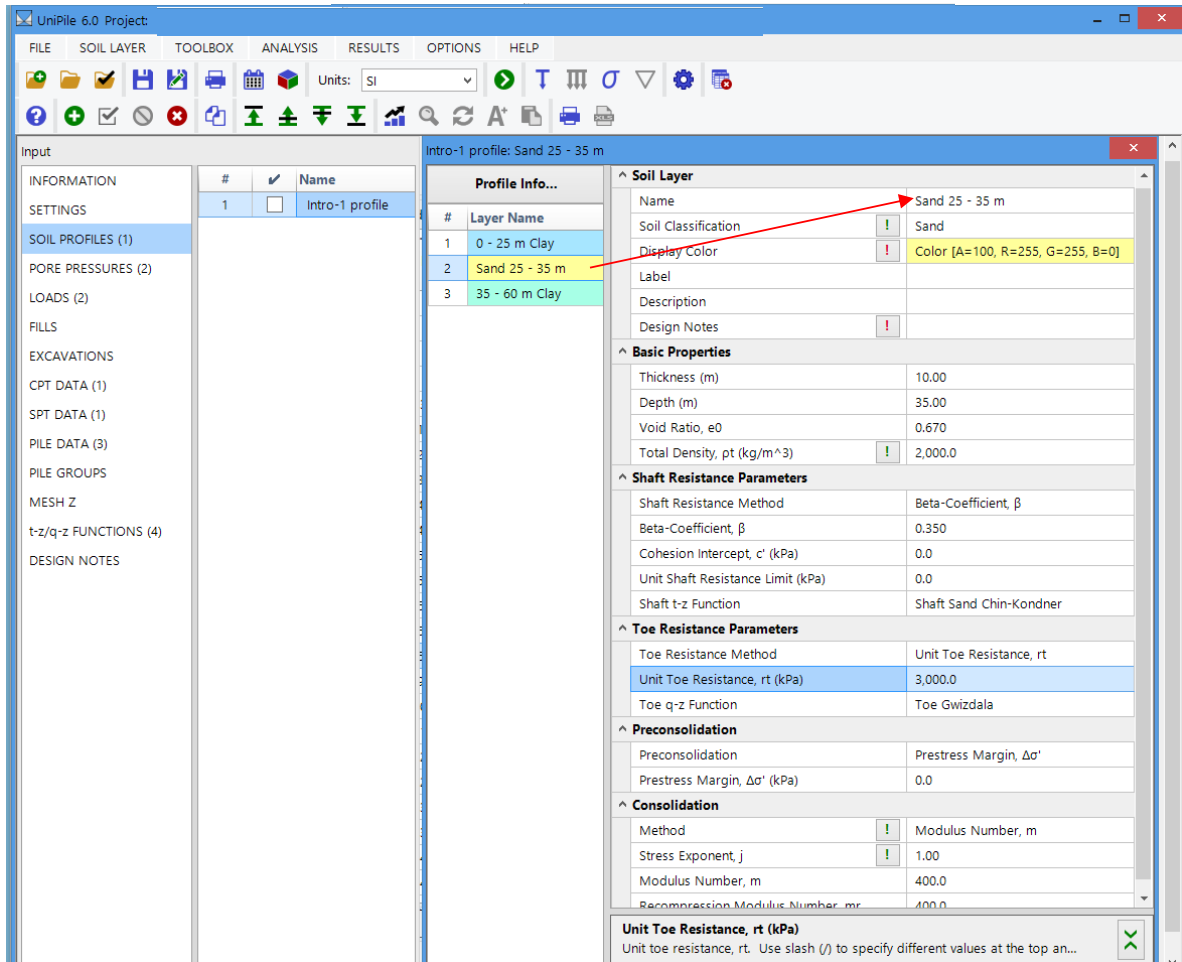
The UniPile6 software opens with a display of the tool bar and input options (Figure 1). The first option on the input list is "INFORMATION" which is for adding specific case and project information to the file. It has no effect on the analysis. The "SETTINGS" option (displayed) presents defaults for the analysis. Notice that each input line has an explanation box at the bottom of the screen. For the example, the UniPile defaults are accepted, as they likely would be for most cases. For reasons of limiting output, perhaps, the input limit on pile-toe penetration would be one most often changed. The first listed Analysis Option: "Pile Resistance Method" shows analysis alternatives listed to the right in the figure: "Effective Stress (β) or Stress-independent" (α -method), eight CPT-methods, and three SPT-methods. For "Pile-Sol Interaction" always choose the option to "Include Transition Zone".

Fig. 1 Main input screen with *SETTINGS*



The "SOIL PROFILE (1)" is a key input screen (Figure 2). The example includes only one soil profile. However, UniPile can accept several different soil profiles. The "(1)" refers to the number of separate profiles input separated by location coordinates. The screen includes all the input data for the example mentioned in the three paragraphs of Section 2. The three little squares with a red explanation mark (!) are (1) for adding design notes, (2) for calculation of void ratio and for finding soil density from water content, and (3) for converting between Janbu modulus number and conventional $C_c e_0$ approach. See the Manual, Page 17/47.

Fig. 2 Main input screen with SOIL PROFILE



The additional soil input needed for the Unified Method comprises pile resistance parameters. For both shaft and toe resistances, the input is not by an ultimate value, but by a target value applicable to a specific movement between pile and soil. Shaft resistance can be expressed as a ratio to effective stress, i.e., the β -method; the effective stress distribution is calculated by UniPile. (The β -coefficient can optionally be combined with a cohesion intercept, c'). Alternatively, the shaft resistance can be expressed as a stress-independent value, r_s , i.e., by the α -method. The latter is suitable for estimating the shaft resistance for a pile cored into bedrock, where, depending of the bedrock characteristics, the shaft resistance is usually not a function of effective stress. Moreover, sometimes you know neither the soil densities, the depth to the groundwater table nor the pore pressure distribution. Then, analysis using the stress-independent method is necessary.

The toe resistance can, similarly, be input as target stress, r_t , or as an N_t -coefficient. The N_t -coefficient expresses toe resistance as a ratio to the effective overburden stress at the pile toe.

3. Comments on input of β or r_s and r_t resistance and t-z/q-z functions

Many are used to regard the β , r_s , and r_t as parameters representing ultimate resistances, that is, resistances at infinite movement. Actually, those who are used to work only with ultimate resistance may not even think of movement in this context! The fact is, however, that every resistance value is coupled to a movement. Of course, in a plastic soil, after a brief initial movement, say, about 5 mm (a commonly chosen "target movement"), the resistance is constant—practically—and stays the same for all continued movement. But many soils, in fact most soils, are not plastic but strain hardening; soft sensitive clays are even often strain-softening. For strain-hardening, the mobilized resistance increases with increasing movement; very rapidly at first, then, at a diminishing rate. Therefore, a user who knows what resistance to input must also know what movement between the pile and the soil which would generate that resistance. Indeed, most geotechnical engineers, who have a feel for what shear resistance or toe resistance to expect, do also, when asked, have a feel for what movement that resistance would be mobilized—at least within a range.

So, for every soil layer, the user inputs a target shaft resistance (β or r_s) estimated to develop for an, also estimated, specific movement, δ , the "target movement". The latter information is input at "t-z/q-z FUNCTIONS" (Second option up from the bottom of the main list on the left side (Figure 2). (If you are uncertain of what these are, you should download my Red Book from www.fellenius.net and read through Chapter 7). The functions are resistance-movement relations called t-z (shaft) and q-z (toe) functions and their shape is determined by a "function coefficient". The t-z/q-z function input curve, will always pass through the Target Point, expressed by the target movement and the target β or r_s and r_t input.

In summary, the input of a Target Pair of resistance and movement coupled with the estimated shape function (for each soil layer) enables UniPile to calculate and report a pile-head load-movement result and force distributions for different applied loads. The input of the compressibility parameters enables UniPile to calculate and report pile and soil settlement.

The shape to input of the force-movement response of both shaft and toe resistance depend on the geologic origin of the soil, densities and many other aspects. Figure 3 shows three typical examples for shaft and toe response, respectively. Both graphs show an ordinate axis in units of % of the input resistance plotted versus the relative movement (here, in mm) between the pile and the soil. (Perhaps it would make sense to plot the pile-toe movement in percent of pile diameter. However, normalizing shaft movement to pile diameter makes little sense and using the same abscissa format for shaft and toe avoids confusion). The open red circles indicate the Target Movement for the 100 % Target Resistance. Both graphs show three function curves. Graph (1) in 3A represents a plastic soil response with the shaft resistance more or less constant.

Fig. 3 t-z and q-z curves

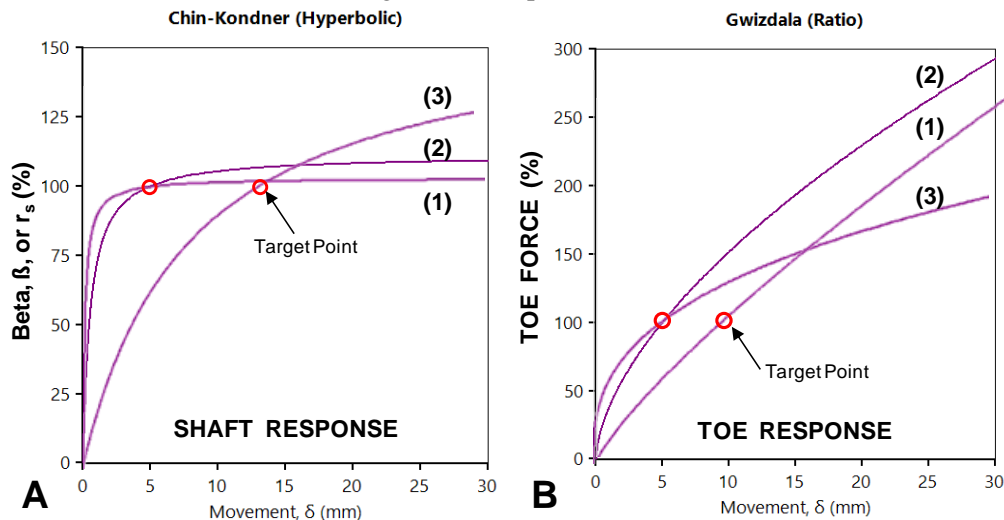


Figure 3A shows the same Target Movement (5 mm) for Curves (1) and (2) and Curve (3) shows 13 mm. In Figure 3B, Curves (2) and (3) have the same 5 mm Target Movement and Curve (1) has a 10-mm movement. In principle, a Target Point (Target Pair of resistance and movement) can be for any position on the curve. For example, if the unit shaft resistance that produced a 16.5 mm movement is known along with the shear-movement development, then, that unit shaft resistance value and the 16.5 mm movement can equally well be used as the Target pair for the analysis as long as the Point lies on the same curve (determined by the function coefficient). However, it is convenient to organize one's experience and expectation to a common movement value, say, 5 mm.

You are a geotechnical engineer with experience in path response and design of piled foundations. If someone would tell you that a particular pile will have a specific shaft resistance and a certain toe resistance, and move no more than a definite value, you can normally tell whether that movement is likely to be about right or under- or overestimated. That is, you do have a feel for what resistance and movement to expect of a specific pile. UniPile lets you rationalize that 'feel' and determine actual numbers and graphs that will serve you well to accept or improve on your estimation. When you still feel unsure about the result, and, therefore, perform a static loading test to gain confidence, using UniPile to back-calculate the loading test results will provide you with calibrated information that you can use to determine the response of a longer or shorter, larger or smaller diameter pile. After a couple of those analyses, your ability to 'feel' will be considerably enhanced.

4. Input of resistance (β or r_s and r_t) and t - z / q - z functions

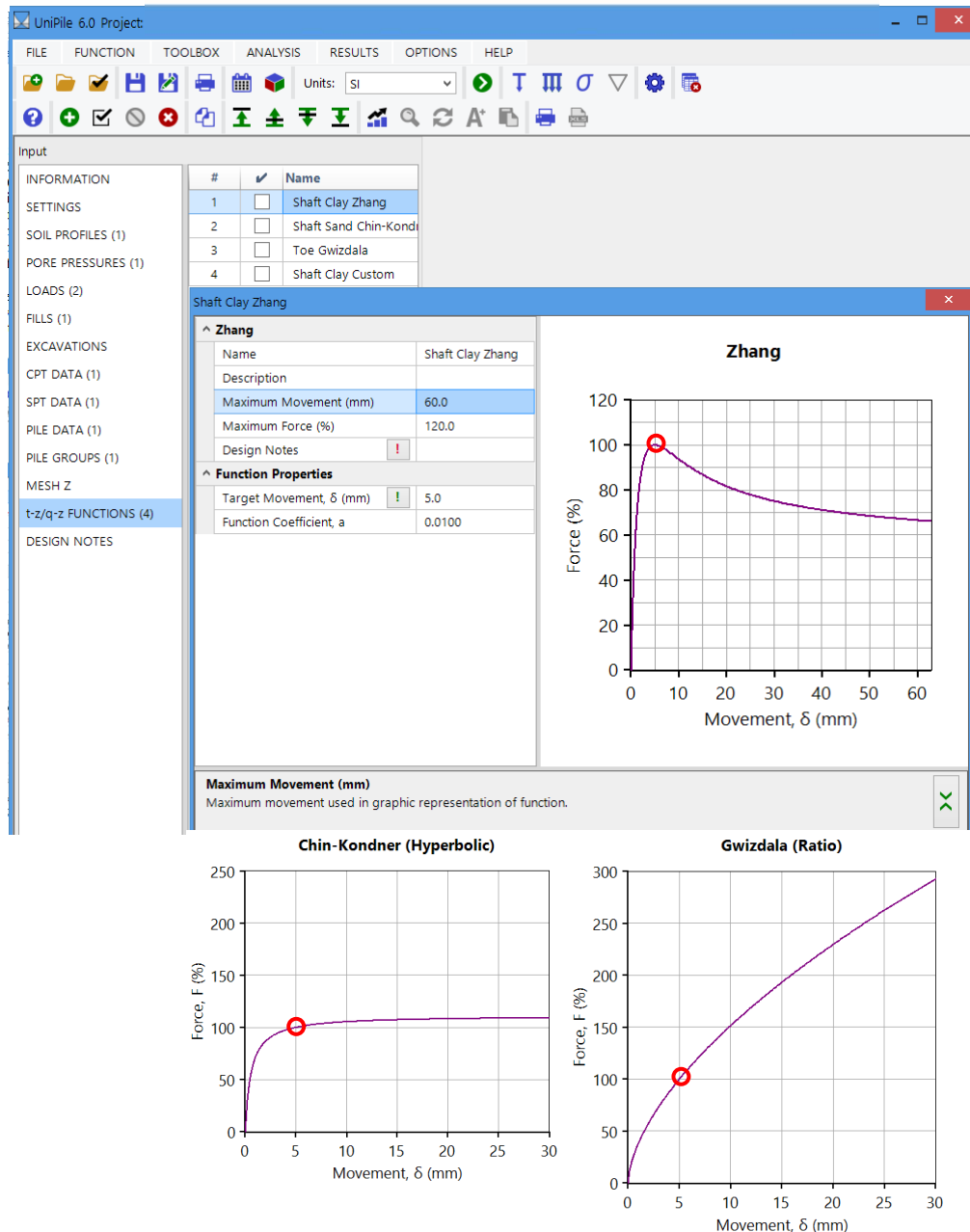
Both shaft and toe resistances depend on the stress-movement response expressed by t - z / q - z functions. UniPile offers several different t - z / q - z functions for the user to choose between. To complete the pile-resistance input for the example, go to " t - z / q - z FUNCTIONS" (Figure 4). The t - z / q - z input shown in the figure comprises the following functions: a strain-softening t - z function for the upper clay layer (Zhang, function coefficient, $a = 0.0010$), an almost plastic hyperbolic function for the sand (Chin-Kondner, function coefficient, $C1 = 0.009000$), and a toe-response strain-hardening q - z function (Gwizdala, function coefficient, $\theta = 0.600$). A Gwizdala function is normally the most appropriate toe function. No function is input for the lower clay, as the pile toe terminates in the sand layer. For details on t - z / q - z functions, see Chapter 8 in my Red Book.

The target values (β -coefficients and unit toe resistance, r_t) input are here assumed paired with being mobilized at 5 mm movement. For some other case, other target movements may be considered more suitable. The user has full freedom to select the target input pairs of the soil layers or depth ranges along with the shape of the function as governed by the input function coefficient.

The next key input of data necessary for the analysis is "*PORE PRESSURES*". UniPile considers two conditions: The "*Initial*", which is assumed to be the conditions for end-of-construction or for those of a static loading test before construction and "*Final*", which is assumed to be for the long-term conditions. If the pore pressure distribution would not change, i.e., "*Final*" is same as "*Initial*", then, only "*Initial*" needs to be input, which applies here.

The example includes a change of effective stress due to load (1.0 m thick fill) placed on the ground surface across the entire site. This is input at option "*LOADS*" (Figure 5). The subject example assumes that all fill is placed simultaneously with the pile driving and, therefore, the piles will be affected by all the settlement introduced by the fill load. Of course, in a real case, some fill, if not all, is placed before start of construction (discussed later). If the time for consolidation is an issue, settlement calculations can be performed in UniSettle5, which software is able to import a soil profile directly from a UniPile file and establish the effect of time on the settlement distribution.

Fig. 4 Main input screen with t - z curve



Fill can also be input under the option "*FILL*". Then, the effect of shaft resistance along the length of the pile in the fill in the fill zone will be included in the analysis. UniPile will treat the pile response in the fill similar to that in a soil layer and requires input of similar soil particulars. The option was not used for the example, as the piles were installed where there was no fill.

The next key input is that of the pile types: "*PILE DATA*" (Figure 6). The Intro-1 Case comprises only one Pile Data set numbered "(1)". UniPile can accept several such sets. The piles can be placed at different locations identified by pile the pile coordinates. Intro-1 Case includes the pile placed at three locations: Pile #1 in the footprint center and Pile #2 at a corner of the excavation and Pile #3 "away" from the excavation. UniPile references each pile to the soil profile nearest it, as determined by the location coordinates of the pile and the soil profile. (Section 5 illustrates the input of various pile types).

Fig. 5 Main input screen with *LOADS*

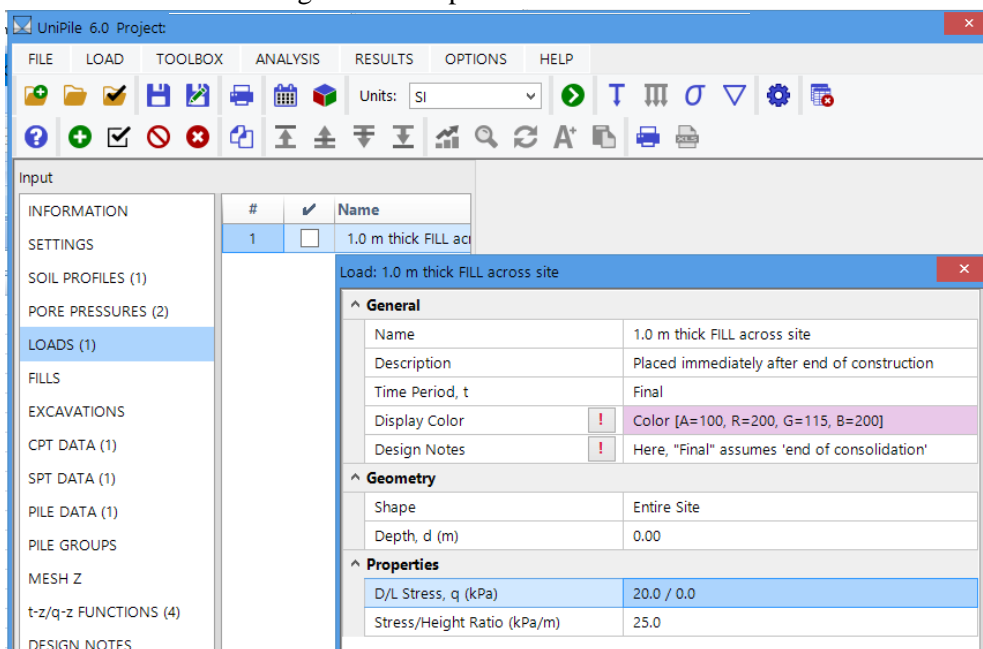
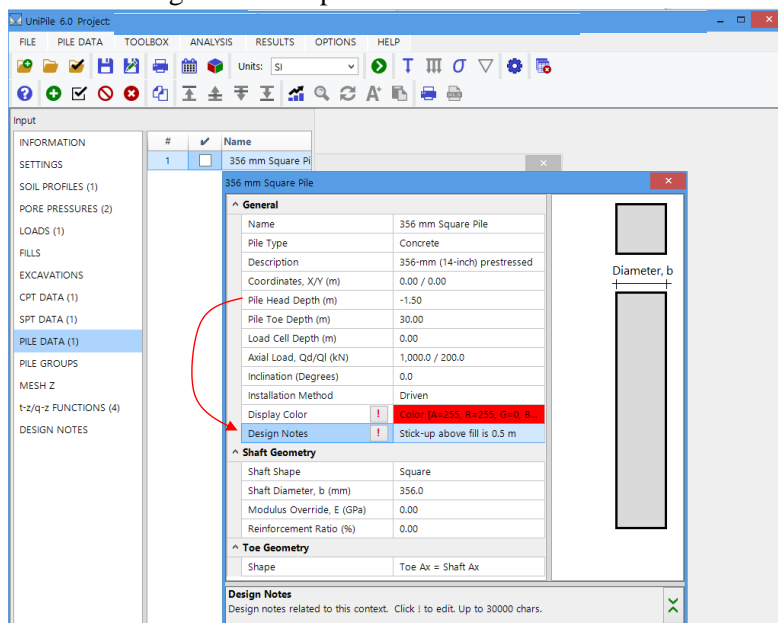


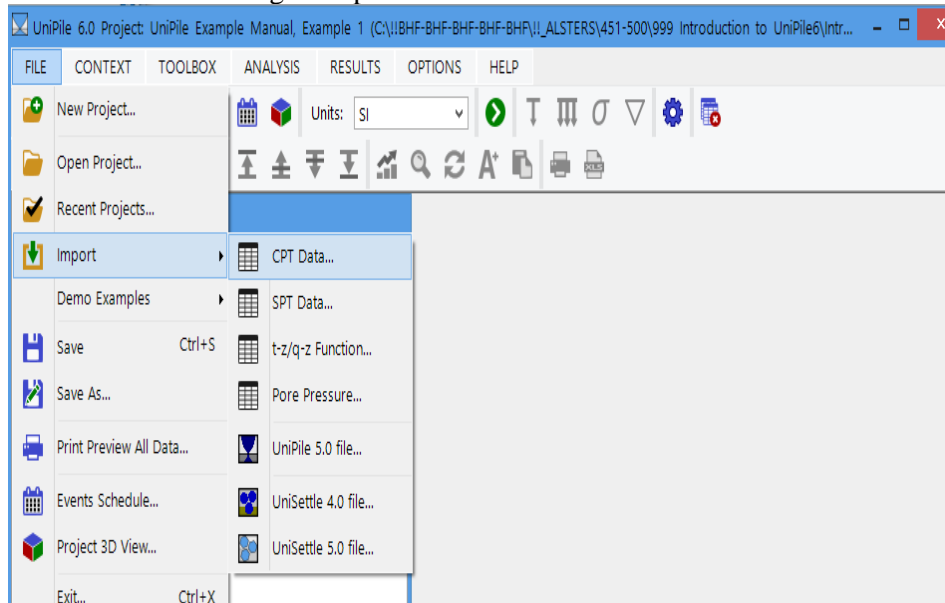
Fig. 6 Main input screen with *PILE DATA*



UniPile can address piles of all shapes and combine the amount of steel and concrete making up the pile, e.g., a steel-pipe pile. If the pipe pile is concrete-filled, UniPile calculates the combined E-modulus of the pile from the *SETTINGS* input of E-modulus of steel and concrete and area of steel (wall and reinforcement) and E-modulus. As the concrete in a pipe pile is confined, strictly, the concrete E-modulus to use should be the confined modulus, which is larger than that in a plain concrete pile. Therefore, the *SETTINGS* E-modulus may appear too small. However, adjusting the *SETTINGS* input is impractical when the case file includes piles of different type. The Pile Data option includes the input for "*Modulus Override*", which for each individual pile lets UniPile use an "override" value for the average E-modulus of the pile cross section as calculated from area-weighted moduli of steel and concrete. Similarly for a drilled-shaft with a reinforcement cage.

The last input is the CPT and SPT records. If the records are available in a text file, the input is achieved by clicking on the first word in the tool bar: "FILE" followed by "Import" and choosing desired CPT-file (Figure 6), then applying appropriate formatting options. The files are already loaded into the Intro-1 example. Click on CPT (1) and SPT (1) on the Input Option list and the graphs will appear. To produce classification results, choose "SETTINGS/Pile Resistance Method (CPT or SPT)", and click on the F10 function key. UniPile will analyze and interpret the CPT records for soil classification by three different methods. (The CPT file can be exported to a *.csv-format file by selecting each in turn from the input list menu and then clicking on the green "XLS" Excel symbol, (📄), on the far right on the toolbar). As calculation of pile compression and settlement using ultimate resistance is not representative for actual pile response, direct output based on the CPT-methods is not reliable. The user is better served by looking at the output from the CPT/SPT methods as merely a guide toward choosing the β and r_s input for the *Effective Stress or Stress-Independent*" approach. In my opinion, CPT and SPT records are not directly useful for a calculation of pile resistance, but, the output may be useful for assistance in choosing the Target Input of shaft and toe resistances.

Fig. 6 Import of CPTU and SPT records



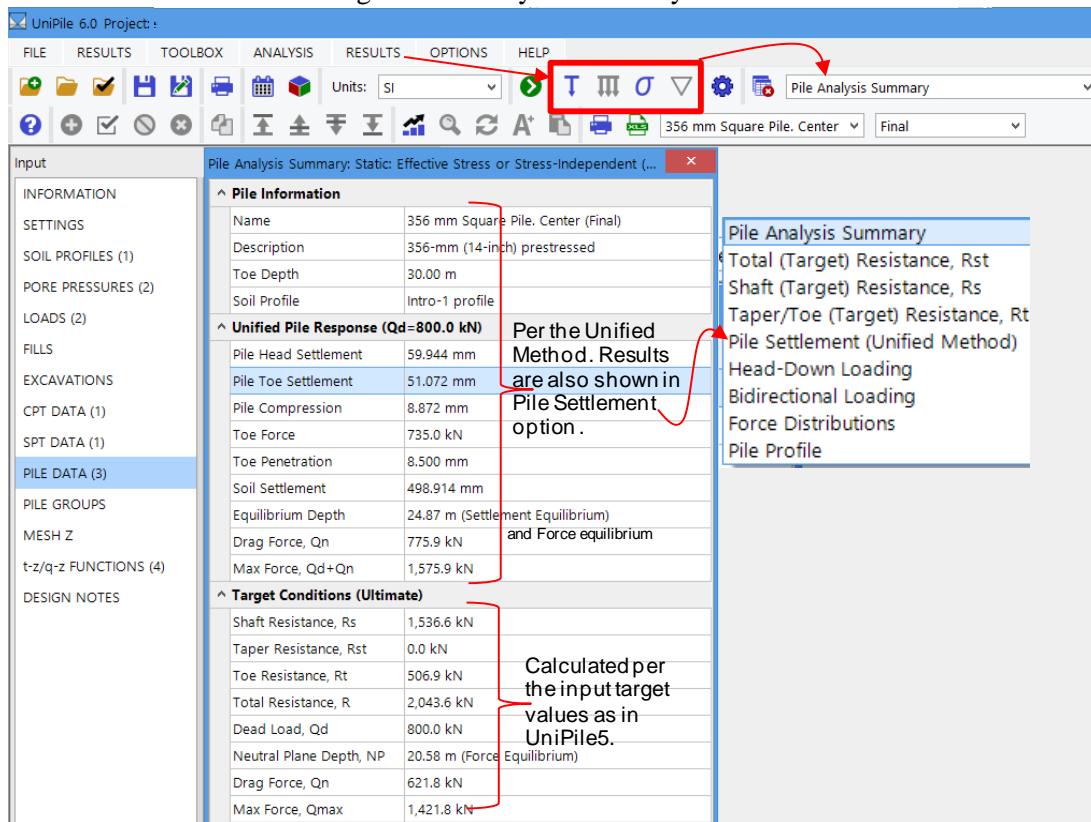
4. Analysis and Calculation Results

Once all input is made, the file is ready for analysis calculation. The step to initiate the analysis is to click on the F7 Function key or the green circle with the white "▶". UniPile will execute all pile analysis alternatives simultaneously. The output options are listed in the box at the far right on the toolbar (Figure 7).

(The output options listed in Figure 7 under "Pile Profile" will list all pertinent parameters for the piles employed in the analysis).

The single-pile results calculated by UniPile are displayed by default. For results pertaining the pile groups and CPT or SPT analysis, the "RESULTS" option needs to be engaged. For single-pile analysis, the first display option is "Pile Analysis Summary", displaying a screen showing "Information" and "Unified Pile Response" (Figure 7: results per the Unified Method for the sustained load, Q_d). The values shown under "Target Conditions" are calculated per the same approach as the previous software version, UniPile Version 5. The graphic display of this option (📊) is the same as that of the output option "Pile Settlement (Unified Method)".

Fig. 7 Pile Analysis Summary results



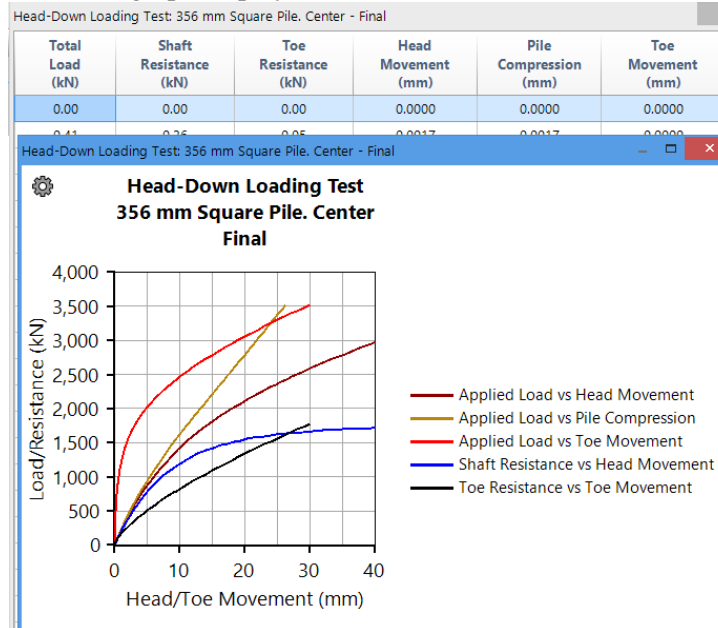
The next three output options of the "Pile Analysis Summary" are "Total (Target) Resistance, Rst", "Shaft (Target) Resistance, Rs", and "Taper/Toe (Target) Resistance, Rt" and they can best be characterized as output per the previous version, UniPile5. They are helpful to show the difference between the former version, UniPile5, and the current version of the Unified Method, UniPile6. They also provide sometimes useful table columns of soil stress distribution.

The fifth output option, the "Loading Test", is normally looked at first. UniPile offers both the option of a head-down test and a bidirectional test (the depth to the bidirectional cell is input under Pile Data for each pile). For the subject example, the user can ponder the suitability of the 1,000-kN sustained plus transient load in relation to the curves, notably the "Applied load vs. Head Movement" curve. By adjusting the UniPile Target Input in a trial-and-error procedure, the UniPile input can be fitted (calibrated) to make the output results fit the actual results of the loading test. Figure 8 shows the UniPile output (to enhance resolution, the t-z/q-z inputs was slightly changed from the information in Figure 4).

Often, the static loading test has been carried out during a pre-construction condition before fills, excavations, and GW changes have impacted the site. The "Initial" would represent the conditions applicable to a pre-design test and the "Final" would represent the conditions applicable to the project design. Adjust UniPile input to provide output that simulates the actual loading test results obtained for "Initial" conditions. Then shift to "Final" conditions to determine the actual long-term conditions for the piled foundation of the project.

To adjust the graph scales and select curves of the output graphs, click on the cog wheel. Notice that every output table can be exported to an Excel file for more detailed evaluation. For this, click on the green "Excel" square ("📄") on the tool bar. Similarly, all graphs can be copied to a clip-file for pasting in a Word file or and Excel file. For this, click on the tool-bar copy-symbol left of the Excel square ("📄").

Fig. 8 Table and graph display of results of a head-down static loading test



As mentioned, assessing the load-movement results is normally the first output to address be it from an analysis of a test or from theoretical calculations—and it is often the only result addressed. So, is the example pile good for 1,000 kN? Of course it is, the 1,000 kN load planned for the example case is smaller than a "capacity" determined from the calculated load-movement response divided or multiplied by every conceivable "safety factor" or "resistance factor", respectively. It is just a matter of defining the "capacity" right. The Offset Limit, Maximum Curvature, pile-head or pile-toe movement smaller than 5 or 10% of pile diameter (head or toe), load that resulted in a 10 or 30 mm toe movement, the 80-% criterion, Chin extrapolation, Mazurkiewics Limit, etc., just to name a few of the dozens actually employed by the profession.

The primary output for a piled foundation design is provided by the output option "Pile Settlement (Unified Method)". Figure 9 shows the output tables for Pile #1 at "Final" condition (printed at 1.5-m output precision to fit the entire length of the pile to the screen). Figure 10 shows the output graphs (explanatory text is added to the UniPile output graphs). Note, table and figure can be exported for use in a formal report by ("🖨️"). The calculation are made assuming each the pile to act as a single pile unaffected by any adjacent pile.

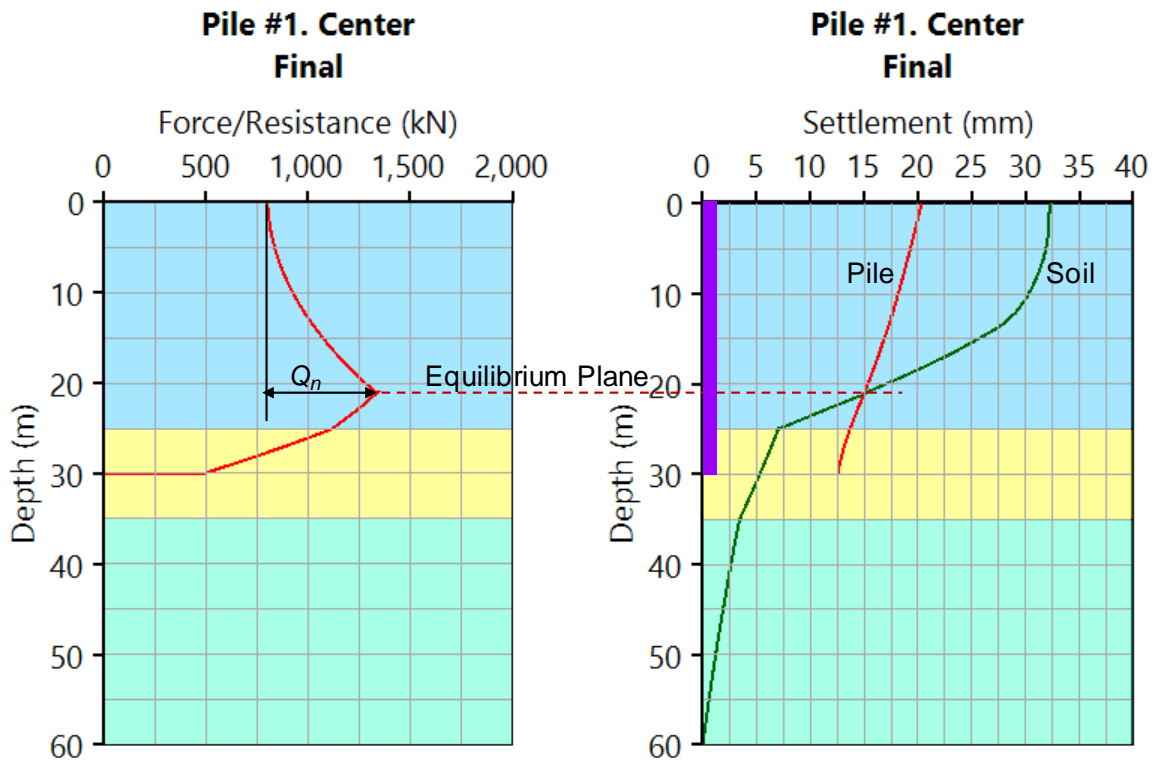
The long-term settlement of the pile due to the 800 kN load and the fill will amount to about 20 mm, which includes the compression of the pile due to placing the 800 kN load on the pile and the subsequent settlement due to the fill. (Note, there is no need to input a settlement distribution from an assumed settlement profile, or one obtained from calculation by means of separate software for each pile location. The calculated settlement of the soil next to the pile is 32 mm. The settlement calculation is built into UniPile and it addresses the actual location and conditions of every particular pile analyzed). Shifting the output option to "Initial" will show the calculated pile settlement at end of construction (before any soil settlement has developed): amounting to about 5 mm comprising pile compression and pile-toe movement of the pile-toe force.

So, the pile is "good" from a settlement point of view. Whatever the definition that would be favored for "capacity", it too will surely be "good". That is, when a pile is "good" from assessment of settlement, it is normally also "good" for "capacity". In contrast, that a pile "capacity" is "good" does not mean that settlement would be "good", too.

Fig. 9 Output tables of force and settlement distributions

Depth (m)	Elevation (m)	Initial Stress, σ' (kPa)	Final Stress, σ' (kPa)	Soil S_c (mm)	Pile Force (kN)	Pile EA (MN)	Pile δH (mm)	Pile S (mm)	Soil-Pile ΔS (mm)
Layer 1: 0 - 25 m Clay									
0.00	0.00	0.0	0.0	32.196	800.0	3,802.1	7.821	20.336	-11.860
1.00	-1.00	18.0	18.0	32.194	802.1	3,802.1	7.610	20.126	-12.068
1.50	-1.50	22.0	22.0	32.189	804.5	3,802.1	7.505	20.020	-12.169
3.00	-3.00	34.0	34.2	32.128	814.6	3,802.1	7.187	19.703	-12.425
4.50	-4.50	46.0	46.7	31.966	829.2	3,802.1	6.866	19.382	-12.584
6.00	-6.00	58.0	59.4	31.673	848.5	3,802.1	6.539	19.055	-12.618
7.50	-7.50	70.0	72.4	31.242	872.8	3,802.1	6.204	18.720	-12.522
9.00	-9.00	82.0	85.4	30.684	902.1	3,802.1	5.860	18.376	-12.309
10.50	-10.50	94.0	98.6	30.020	936.6	3,802.1	5.504	18.020	-12.000
12.00	-12.00	106.0	111.7	29.077	976.5	3,802.1	5.134	17.650	-11.427
13.50	-13.50	118.0	124.8	27.628	1,021.8	3,802.1	4.749	17.265	-10.363
15.00	-15.00	130.0	137.9	25.695	1,072.6	3,802.1	4.346	16.862	-8.833
16.50	-16.50	142.0	150.8	23.396	1,129.0	3,802.1	3.923	16.439	-6.957
18.00	-18.00	154.0	163.7	20.825	1,191.1	3,802.1	3.477	15.993	-4.832
19.50	-19.50	166.0	176.6	18.056	1,258.9	3,802.1	3.008	15.523	-2.533
21.00	-21.00	178.0	189.3	15.149	1,332.5	3,802.1	2.511	15.027	-0.122
21.07	-21.07	178.6	190.0	15.001	1,336.5	3,802.1	2.485	15.001	0.000
22.50	-22.50	190.0	202.0	12.147	1,261.0	3,802.1	1.984	14.499	2.352
24.00	-24.00	202.0	214.6	9.086	1,175.7	3,802.1	1.486	14.002	4.915
25.00	-25.00	210.0	223.0	7.027	1,115.7	3,802.1	1.177	13.693	6.666
Layer 2: Sand 25 - 35 m									
25.00	-25.00	210.0	223.0	7.026	1,115.6	3,802.1	1.177	13.692	6.667
25.50	-25.50	215.0	228.2	6.862	1,057.2	3,802.1	1.030	13.546	6.684
27.00	-27.00	230.0	243.7	6.358	874.2	3,802.1	0.613	13.129	6.771
28.50	-28.50	245.0	259.2	5.835	679.8	3,802.1	0.268	12.784	6.949
30.00	-30.00	260.0	274.6	5.296	474.0	3,802.1	0.000	12.516	7.219

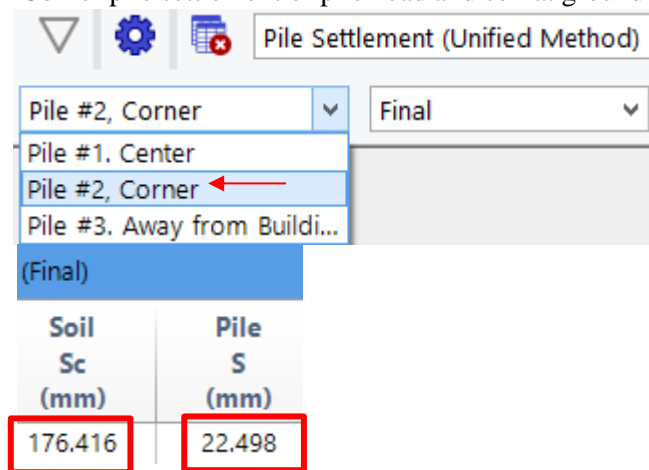
Fig. 10 Output graphs for the Unified Method applied to a single pile



UniPile also reports the force that Tim Siegel, of Dan Brown and Associates, so aptly calls the "the Bogey Man": the drag force developing due to the subsiding soil. Pile #1 will have a drag force of about 500 kN and the pile will have to accommodate a maximum force of about 1,300 kN. That will be perfect. The drag force will stiffen up the pile response to the 200 kN transient load. As to the drag force, it is only of concern for the axial structural strength of the pile: (1) Output option "Pile Profile" shows that the pile area is 0.1267 m² and this multiplied with a 50-MPa concrete strength results in about 6,000-kN structural strength. (2) The 30-GPa modulus times the 0.1267 m² area, gives EA = 3.8 GN. Thus, the maximum force of 1,300 kN at the Equilibrium Plane will result in a strain of about 400 µε, which is much below the strain that could damage the pile structurally.

Pile #1 is located in the middle of the 20 x 36 m building footprint. The conditions at the footprint sides and corners are different and, therefore, the pile response may differ, too. The output for the corner pile, Pile #2, shows that the calculated settlement for the pile will almost 25 mm (Figure 11), only a few millimetre more than that for Pile #1 in the building center. Both the total and differential settlements of the building supported on the piled foundations will be small. However, UniPile shows that the soil settlement next to the foundations will be almost 200 mm, indicating that the designer needs to make sure that the connection of the building utilities can accommodate this difference. Note, this important information is obtained within seconds after desiring it.

Fig. 11 Corner pile settlement of pile head and soil at ground surface



Some piled foundations contain a large number of piles, and the pile can be single or be in small groups, or even a single wide pile group. The combined total pile load will be transformed to the pile-toe level and the settlement analysis needs to estimate the settlement of the soil layer below the pile-toe level for the average so-imposed stress. See Section 6.

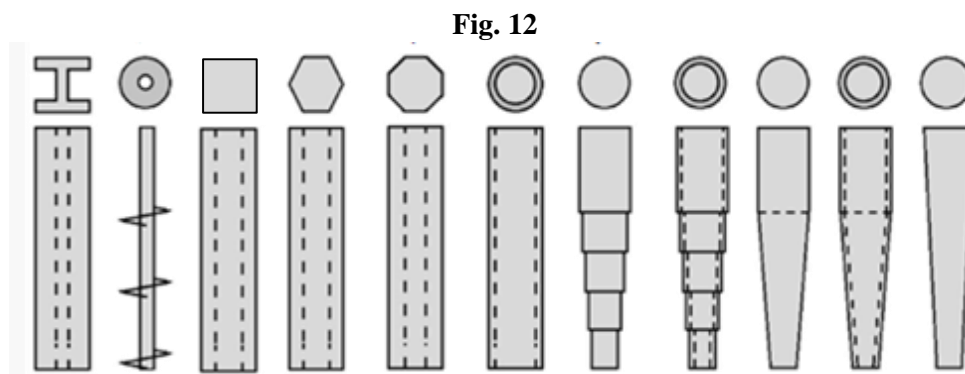
The foregoing example addresses a non-complex design. UniPile can equally well address complex issues, such as incorporating several areas loaded by piled foundations or by footings, or by fills and unloading due to excavations at a site. The analysis results will show the difference in response of perimeter and interior piles in wide group, compare the responses of piles of different size and types, and much more. A user having gone through this example will have no problem in advancing to a complex case.

UniPile makes no difference whether the effective stress parameter, β , or the stress-independent, r_s parameters are input, provided that they are matched. The results tables in "Total (Target) Resistance, R_{st} ", will show a conversion from β to r_s . For example, Pile #3, the β at 0 and 25 m depth was input as 0.20. Converted to stress-independent values for these depths, the " r_s " becomes 4 and 46 kPa, respectively. If the input would be changed to "Unit shaft Resistance, r_s " and the input be "4.0/46.0", the Pile #3 calculation results would be

unchanged. The results for the three piles would, of course, be slightly different because effective stress is ignored. However, the difference would be too small to have any practical consequence for the example case. Now, consider an excavation for a storey or two. I have seen several such cases in practice where ignoring the effective stress difference due to an excavation for basements was sufficiently significant for the structure to suffer distress. One case resulted in a very expensive lawsuit. The designer, who was sued, claimed that using a shear strength value proven by a static loading test without recognizing that the later basement excavation had reduced the effective stress was acceptable level of engineering. The judge disagreed.

5. Input of Pile Types

Piles come in all shapes and materials, and they are installed by driving or pushing, or by pouring concrete into drilled holes. They are straight or tapered and the pile toes have often a shape that differs from the pile shaft. UniPile can handle all pile types and offers several easy template input forms for input of the geometry of the pile and modulus of the pile material (Figure 12). UniPile can provide the response of an inclined pile, which involves adjusting to the larger surface area per unit length. The input is the angle to the vertical in degrees.



Manual Page 25 of 47

5.1 The steel-pipe pile

Steel-pipe piles are amongst the most common piles, for example, the 14-inch, 3/8 inch wall (356 mm, 9.5 mm) steel pipe installed to 30 m depth and "concrete-filled" after the installation. Figure 13 shows the input for this pile. If not concrete-filled, the input is "Empty". An open-toe pipe pile may be partially or completely filled with soil, i.e., have a plug. If the pipe does not move with the plug, then, there is toe resistance, if the plug moves (actually, it is the pile that moves), then, there is inside shaft resistance, which could be modeled by increasing the input shaft resistance; the β or the r_s , along appropriate pile length up from the pile toe). The concrete may be considered confined, which means that the E-modulus would be larger than the E in the *SETTINGS* input. The *Modulus Override* refers to the combined modulus ($E_{comb.} = E_{steel} A_{steel} = E_{concrete} A_{concrete}$) and not to the separate pile moduli input to Settings. The latter is shown in the calculation results, the *Pile Profile*. To indicate a change of the concrete E-modulus by inputting an *Override*, the input value has to reflect the combined modulus.

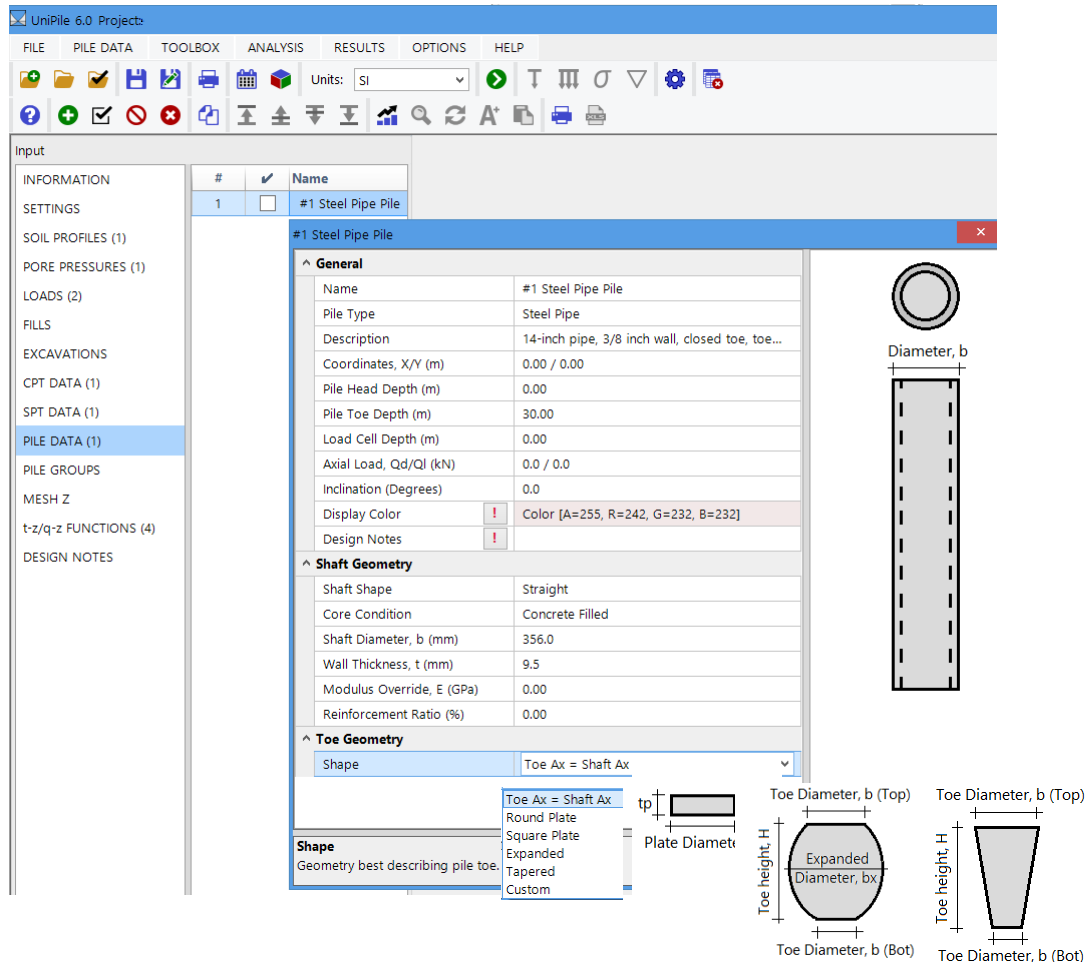
If the pile is concrete-filled, UniPile will calculate toe resistance for the pile response to an applied load across the entire pile-toe cross section. If not, only for the pipe area (the pipe wall) per the soil input for the pile toe. Whether "Empty" or not, the pile-toe can be open or closed condition. If closed, then, the options are: "Round Plate", "Expanded", "Tapered" and "Custom" (the "Square Plate" is for square cross section piles addressed later). The "Load Cell" input is for the depth to a bidirectional cell.

5.2 The steel H-pile

Next to illustrate (Figure 14) is a 12-inch steel H-pile, 12HP102 (\approx 310HP110). The point of importance is the option of having UniPile calculate the shaft resistance as acting along the entire pile surface, the "H", or along the circumference, the "rectangle" (or "square").

Moreover, with equal toe and shaft cross sections, " $Toe Ax = Shaft Ax$ ", UniPile calculates toe resistance only on the steel for an "Empty" pile and for the entire cross section for a "Concrete-filled" or a pile with a toe plate.

Fig. 13 Steel pipe pile



5.3 The bored or drilled, precast pile

A drilled-shaft, Pile #3, is usually a straight shaft pile with either "No Casing" or "Permanent Casing". If marked as the latter, the thickness of the casing wall is a needed input. Like the steel-pipe pile, it can have a toe with a plate, or an expanded or tapered toe.

The precast concrete pile, Pile #4, comes in all shapes (Figure 15). The *Round*, *Square*, *Rectangular*, *Hexagonal*, *Octagonal* differ by the shape of the cross section. The *Cylindrical* is for input of a cylinder pile, a PHC Pile, which is a pile made of concrete (prestressed) with a central hole of width about half the pile diameter. If *concrete-filled*, the input becomes similar to that of the *Round Pile*. For all concrete piles, the input of *Modulus Override* should be considered. For examples, the E-modulus of a PHC pile is normally much larger than that for concrete input under *SETTINGS*.

Fig. 14 Steel H-pile

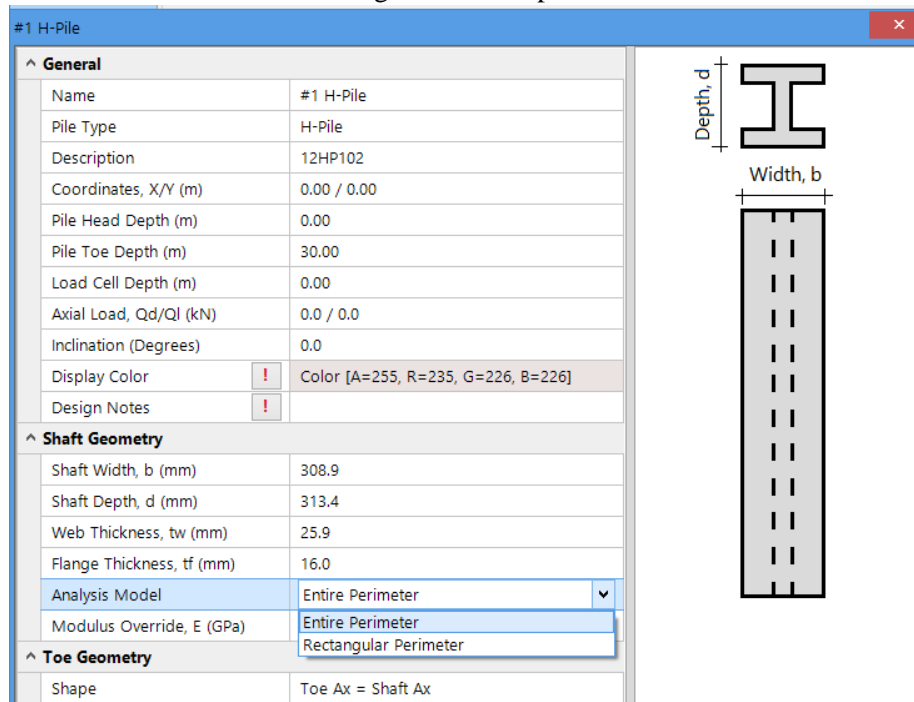
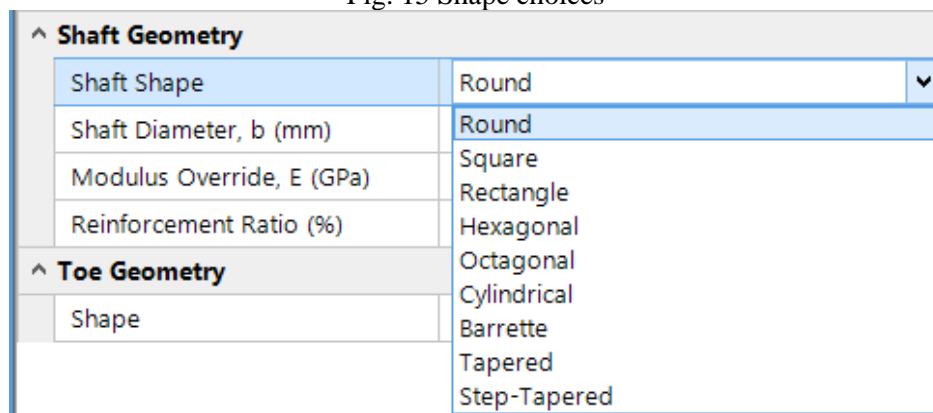


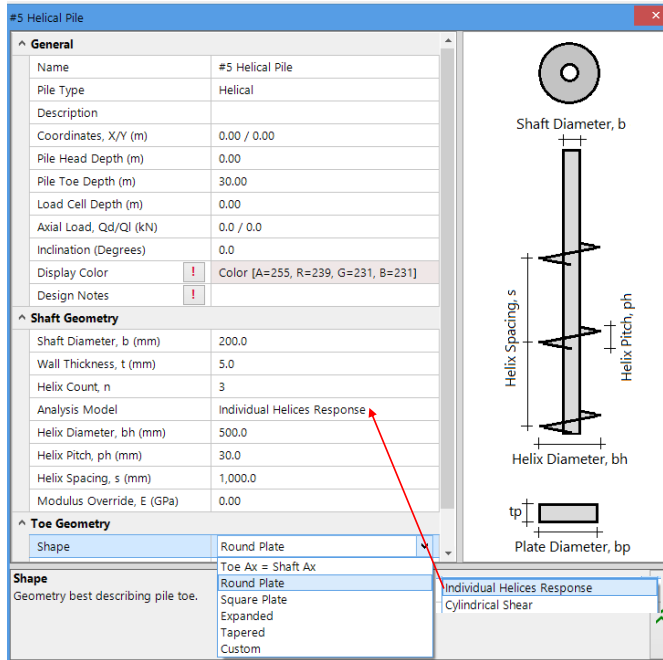
Fig. 15 Shape choices



5.4 The helical pile

The helical pile, Pile #5, comprises a round (usually) or square centered bar equipped with helices. The latter enable the pile to be screwed down to a desired depth, The helices also provide pile bearing. Figure 16 shows the input for the pile. The input requires the user to indicate if the individual helices bear on the soil or if the pile bearing is from shaft resistance along shaft of the soil cylinder encompassing the pile. In case of the former, UniPile considers shaft resistance along the central pipe (minimal contribution) and bearing at the helices, each calculated as an intermediate pile toe (the soil input must indicate toe resistance and q-z function for the particular layer). In case of the pile acting as a uniform cylinder, UniPile calculates the pile as a uniform pile with a diameter equal to the helix width and a E-modulus equal toe the E-modulus weighted to the areas of steel and soil. For toe resistance, the input needs to indicate whether the pile toe is open or closed.

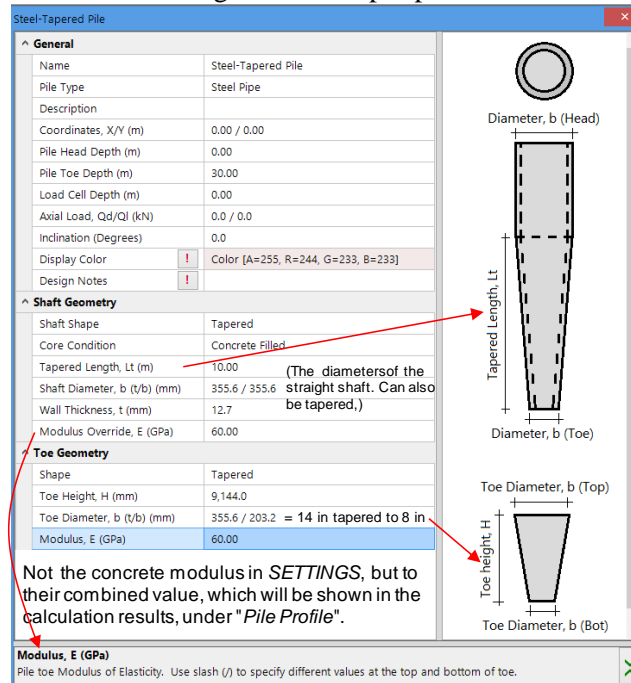
Fig. 16 Helical pile



5.5 The steel-taper pile

(Figure 17) shows the input for a steel-taper pile, Pile #6, comprises an upper length of straight pipe-pile and a lower tapered length. It is either "Empty" or "Concrete-filled". If no change is made to the *SETTINGS* E, the *Modulus Override* refers to the combined modulus ($E_{comb.} = E_{steel} A_{steel} = E_{concrete} A_{concrete}$) (and not to one of the pile moduli in *SETTINGS*, but to their combined value, which is only shown in the calculation results, the "Pile Profile". Then, whatever override value is input, it will also be applied to the straight part of the tapered pile, although it does change with depth. However, as this only affects the pile compression, the effect on the accuracy of results is minor).

Fig. 17 Steel-taper pile



6. The Unified Method applied to Pile Groups

The example includes two major simplifications. First, the piles are assumed installed in one single event and the pile loads were assumed applied simultaneously with placing the fill. That is, pile compression and long-term soil settlement were assumed to start simultaneously and second, all piles are single and there is no pile interaction. In reality, the piles are installed over a significant length of time and the fill may be fully or partially placed before the piles are installed. Therefore, the calculated settlement due to construction and long term settlement is larger than the true, and the error due to the first simplification is on the safe side. The error due to the second simplification, that of ignoring the fact that the piles interact is much larger. The group effect will cause considerable settlement. However, this settlement occurs while the building is constructed gradually increasing the loads applied to the piles. The associated pile compression and, in particular, the compression of the soils underneath the pile-toe level, i.e., under the building footprint, is commonly ignored.

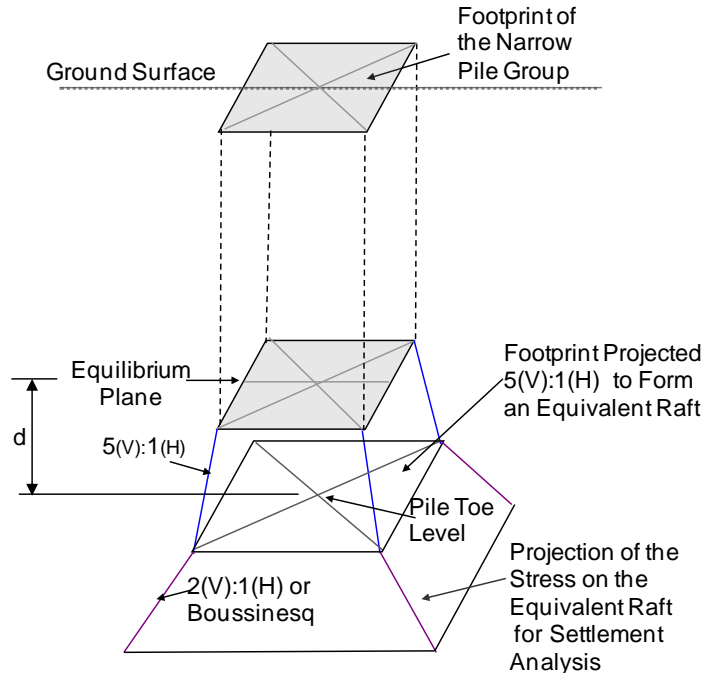
Simply speaking, a pile group is a piled foundation involving two or more piles joined in a common cap, raft, or mat. The axial effect of interaction between the individual piles in the group is less consequential for the piled foundation design than the group effect involving the transfer of the applied loads to the soil layer below the pile-toe level (introducing settlement calculated by the equivalent raft concept). However, a group comprising, say, 36 piles in a square configuration of 6 by 6 piles or group in a rectangular configuration of 3 by 12 piles would respond quite differently to load. In fact, the response of the pile group depends on whether the group is narrow or wide as defined by the number of piles in a row. The shape of the group (the number of piles in the column) is irrelevant. A narrow pile group has four or fewer piles in a row and all will respond much like single piles. A wide pile group has five or more pile in a row. The distinction based on four piles per row is not absolute. A four-pile group at minimal spacing would act like a wide group and the response of a group of five widely spaced piles would trend to act more like a narrow group.

6.1 The Narrow Group

All piles in a narrow group respond as equally loaded single piles. A narrow-group analysis addresses the settlement of the group below the pile-toe level by combining the effect of the applied loads. The response can be simplified by distributing the applied loads to an equivalent raft starting at the Equivalent Plane (EP) and, from there, projecting it to an equivalent raft at the pile toe expanded by 5(V):1 (H) from the EP. The resulting stress on the equivalent raft is input to a settlement calculation of the raft with stress distributed according to the 2:1-method or per Boussinesq distribution as illustrated in [Figure 18](#). This settlement is assumed to be equal for all piles in the narrow group. The final settlement of the piled foundation is the sum of the settlement of the equivalent raft, and the separately calculated pile-toe moment and pile compression.

The settlement calculation is straight forward. Just run the single-pile analysis and determine the depth to the EP. Then, add 40 % of the distance between the EP and the pile-toe level to the width and length of the pile group footprint to form an equivalent raft at the pile-toe level, input that raft at "*LOAD*" at the pile-toe depth, convert the applied load on the piles to average stress on the equivalent raft, and let UniPile calculate the settlement. Actually, for routine cases, there is no need for this, UniPile includes this option under "*PILE GROUPS*" and several narrow groups can be input. [Figure 19](#) shows the input for a narrow group at the center of the site comprising 20 piles at 3b spacing.

Fig. 18 Principle of settlement analysis for the narrow pile group



Copy of Fig. 7.26 in the Red Book

Fig. 19 Input for a narrow pile group

Narrow Pile Group	
General	
Name	Narrow Pile Group
Description	
Type	Small Pile Group (Rigid)
Applicable Pile	Pile #1. Center
Display Color	Color [A=100, R=245, G=233, B=233]
Design Notes	
Pile Group Geometry	
No. Piles in Group, n	20
Breadth, B (m)	3.55
Length, L (m)	4.75
Equilibrium Depth Overwrite (m)	0.00

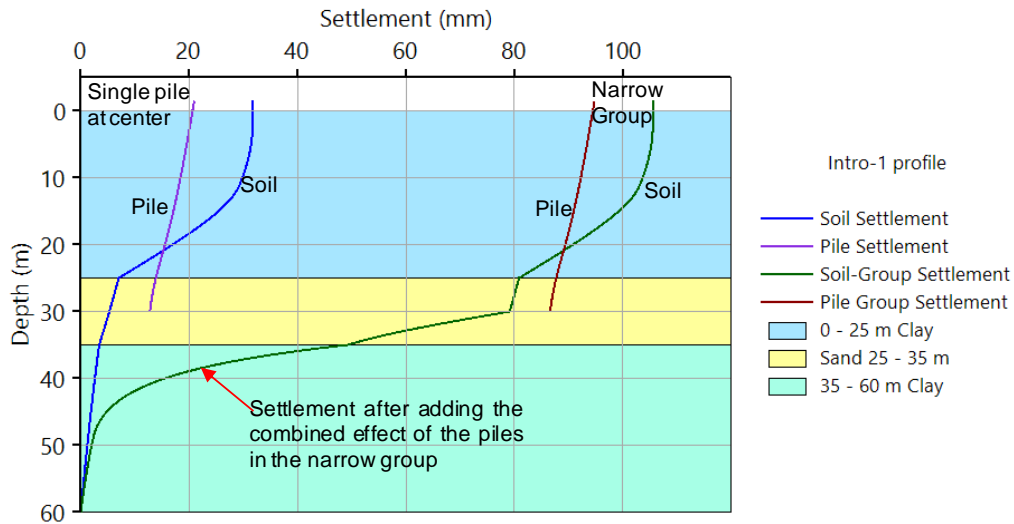
Design Notes

CLEAR COPY CLOSE

E.P. at 21 m: 3.55 x 4.75 m.
 Added width = 3.6 m. Toe: 7.2 x 8.4 m;
 Raft area = 60 m²
 20 piles at 800 kN ==> q = 260 kPa.

The analysis output for the narrow group is shown in Figure 20 indicating that the actual settlement of the Center Pile of the example is not about 20 mm but, rather, about 95 mm. However, the 75-mm below the pile-toe level will occur during the construction, as will a good deal of the pile compression for the applied load. (A UniPile run for initial condition will show the pile-toe movement and compression for the applied load. A run for final conditions will add the effect of the downdrag. Simple subtraction will extract that value). These additional calculations of narrow group settlement are of little practical concern. However, UniPile can perform them and, in some other cases, the calculation results might well have consequential interest.

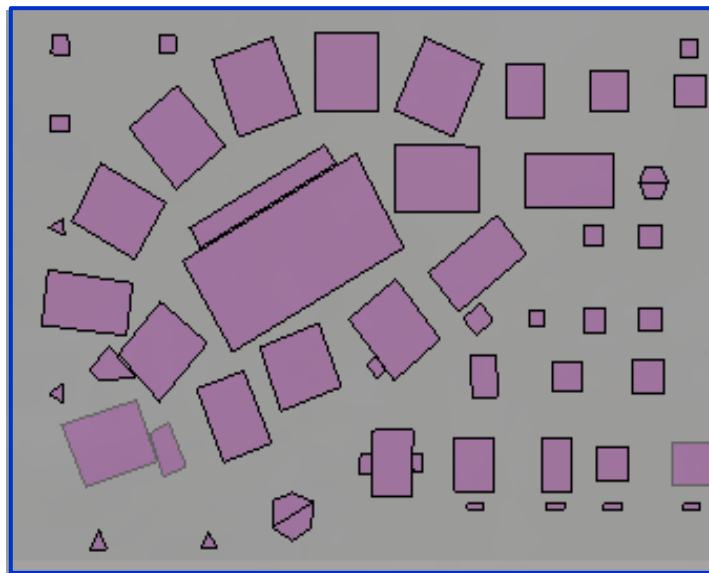
Fig. 20 Output of narrow group analysis compared to results of a single pile analysis



Note, the narrow group analysis in UniPile assumes that the various groups are far enough apart not to have overlapping stress with each other or with any single pile near the groups. When this is the case, it is better to forego the "GROUPS" option and, instead input every group, as "LOADS" (loaded areas of pile group footprint shapes at the pile-toe level). One might even include single piles with the 40% widening of the pile diameter. UniPile will calculate the force and settlement distribution for every pile input under "PILE DATA". (The latter output does not apply to interior piles in a wide pile group as addressed in Section 6.2).

The Manzana 40 West Tower in Santa Cruz, Bolivia is an example of a piled foundation, comprising single piles, small groups of 2 or 3 piles, several narrow groups, and close to a dozen wide groups containing about 50 piles. Figure 21 shows the layout in plan of the tower foundation, as input to UniPile. The design considered the interaction between the piles and pile groups aiming for a final differential settlement after end of construction to be smaller than 10 mm verified in calculation output for piles located across the site.

Fig. 21 Plan view of the piled foundations of the Manzana 40 West Tower



6.2 The Wide Group

The wide group response is slightly more complex than that of the narrow group because only the perimeter piles in a wide group respond similarly to a single pile. The interior piles will have no shaft resistance (and no drag force or downdrag). For details, see Chapter 7 in my Red Book. The settlement of the soil beneath the pile-toe level can be calculated similarly to that of the narrow group. However, because there is no EP, the 5(v):1 (H) spreading does not apply, the equivalent raft at the pile toe has the same dimension as the piled foundation footprint. The same comments as for the narrow group apply; i.e., the pile group settlement and much of the pile compression and pile-toe movement will occur during the construction, whereas long-term and downdrag settlements develop after the construction end.

The interior piles and the soil will have equal strain, that is, no shear develops between the pile and the soil other than at close to the upper and lower boundaries of the pile group. This means that the load applied to an interior pile will be distributed downward with no decrease due to shaft resistance and no increase due to negative skin friction, but for a boundary zone above the pile-toe. (The results for Pile #1 shown in [Figure 10](#) are calculated for the pile as a single pile away from other piles, which is why it experiences shaft resistance and drag force). Within the pile-toe boundary zone, the interior pile-toe force will cause the pile toe to penetrate into the soil and the soil between the interior piles will be similarly pushed upward generating shaft resistance that correspondingly reduces the pile-toe force.

There is another difference: the response of an equivalent raft at the pile-toe level for a narrow group can reasonably be assumed similar to that of the piled foundation raft, usually rigid. However, the response of the equivalent raft at the pile-toe level of a wide group is always flexible. That means that the pile-toe movement of interior piles will not be equal and the calculation of the equivalent raft settlement for individual piles must indicate the location (the coordinates) of the specific pile considered. For a flexible pile cap, the pile head loads will be unaffected. However, if the pile cap is rigid, the applied loads will differ between the piles. There will be a balance of pile deformation comprising the compression of the pile for the load applied to the pile, the pile-toe movement, and the settlement at the pile toe for the equivalent raft. Therefore, pile-toe force and pile-toe movement of the interior piles will not be equal. Because the perimeter piles are affected by shaft resistance, their response will be stiffer and they will attract larger load. The center piles, where the soil movement below the pile-toe level is the largest will attract the smallest load. If the site experiences general subsidence, as in the example case, the added compression due to the drag force will turn around the stiffness response of the perimeter piles and, the applied load will actually be smaller for the perimeter piles than the nearest interior piles, developing as the soil settles and the drag force increases. This has been shown in actual full-scale long-term monitoring and illustrated in numerical analysis (quoted in the Red Book). UniPile can calculate this response qualitatively. Just run a series of trial-and-error calculations in UniPile for piles at different locations with input of different applied load aiming for equal settlement of the pile cap. Alternatively, the response can be modeled in a numerical analysis. Note, however, that a numerical analysis invariably assumes elastic-plastic shaft and toe response, which is rarely true for shaft resistance and almost never for toe resistance. UniPile simulations can apply realistic shaft and toe responses, t-z/q-z functions.

To repeat, the largest movement difference between the piles will be between the perimeter piles and the interior piles. If there is downdrag, the perimeter piles in group with a rigid pile cap will take on smaller loads from the pile cap (and interior piles will have to take on more). If there is no downdrag, a perimeter pile, having shaft resistance, will take on more load than an interior pile.

Assume that the example would involve a 20 x 36 m wide pile group comprising 18 x 34 piles = 612 piles at an about 3 b spacing over a 720 m² footprint. This would result in a 680 kPa average stress. For this input of an equivalent draft at pile-toe level, UniPile would report a settlement distribution ranging from 130 mm at the footprint center through 130 mm at the corners and about 150 mm at the mid-length of the sides (to obtain this, simply input a pile at each of the locations). As mentioned, this occurs during the construction and these settlements are usually disregarded in the piled foundation design. However, they may be of consequence for the response of walls and floors of the actual building as it is being constructed along with associated pile compression and pile-toe movement as the loads are applied.

The perimeter piles will respond as single piles. Figure 22 shows the force and settlement distributions of a perimeter pile calculated free-headed and single. The analysis included development during both the construction and the long-term. The combined effect of downdrag and pile compression for the 800-kN applied load resulted in a 25-mm pile-head settlement. The EP developed at 22.5 m depth. The pile-toe movement was 16 mm and the pile-toe force was 570 kN. The axial maximum force in the pile was 1,380 kN, well below any structural concern.

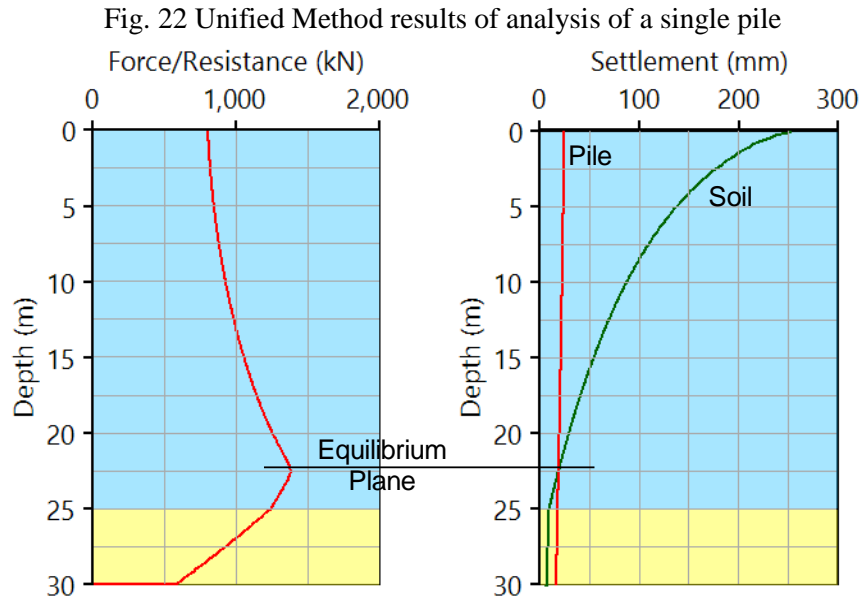
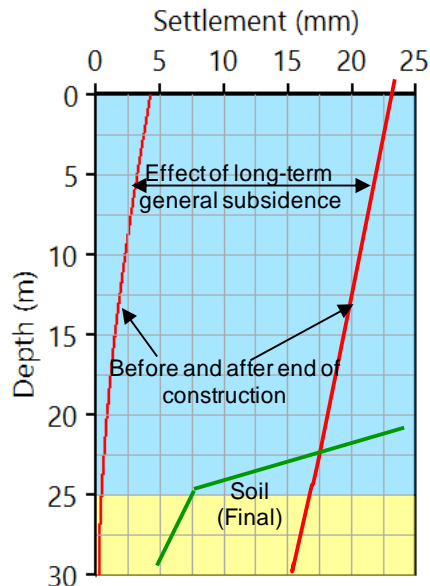


Figure 23 shows the settlement distributions of the perimeter pile at the end of construction after placing the fill supplemented with the results from Figure 22, the difference between the curves shows the long-term effect of the fill.

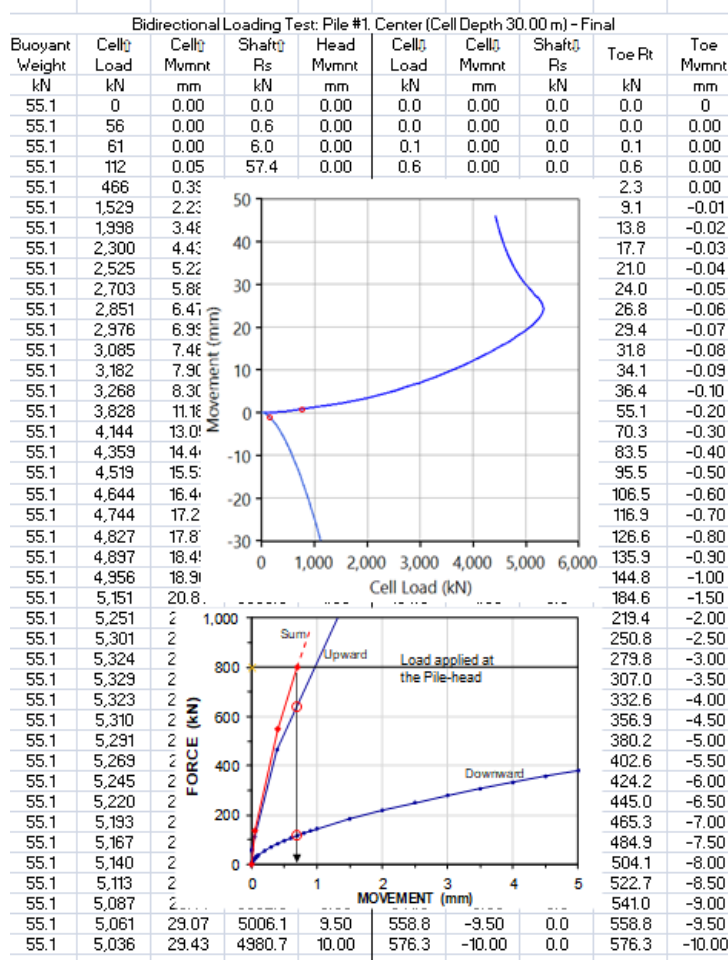
Fig. 23 Long-term effect after end of construction



The most interesting part of the analysis of the wide group is the analysis of the interior piles. As mentioned, this can be modeled in a bidirectional test. The only new input is placing the directional cell at the pile-toe level and simulating a BD test. For interior piles in a wide group, when the upward and downward cell movements are equal for any applied sustained load. The movement is the pile-toe movement for the interior piles. The compression of the pile is equal to the applied load multiplied by the pile length and divided by the EA-parameter ($\Delta L = QL/EA$), adjusted, as needed, by the fact that that nearest the pile toe, the force is reduced by the shaft resistance immediately above the pile-toe level. For details, see the Red Book, Section 7.18 and in particular, Clause 17.18.3 and Figures 7.36 and 7.37.

Figure 24 shows the UniPile output for the pile-toe response calculated by modeling a bidirectional test with the BD-cell placed at the pile toe. The calculation results show that, because the toe resistance is so small compared to the shaft resistance, the upward and downward movements will be very small. The upper add-in graph is produced by UniPile and the lower graph is plotted from the output table. Both graphs show that the pile-toe force is very small. The EA = 3.8 GN for the 30 m long pile shows the compression for the 800-kN load to be about 6 mm.

Fig. 24 Bidirectional test output and toe movement of interior piles



The table (Figure 24) shows that, if instead of 800 kN, the applied load would be the 2,300 kN (unrealistically large), the pile-toe upward and downward movements would have been 3.5 mm (upward force about 2,000 kN and downward force about 300 kN).

The calculations show that, for a flexible raft, the settlement difference between the interior piles and perimeter piles of the example will be about 20 mm. For a rigid pile raft that resists differential settlement, much of the load assigned to the 100 perimeter piles will be transferred to the 512 interior piles.

7. Summary

Sections 1 - 4 intend to introduce the basic approach to pursuing analysis of a single pile with the aid of UniPile6. Section 5 displays the most common pile types, unknown to many, such as helical piles and tapered piles. The software is rich and has many various novel options that initially might cause the software appear confusing. I thought it would be useful to ease the introduction by leading the beginning user through the first exposure.

Some prefer to use ultimate resistance values, i.e., stress-independent (α -method), which is fine, unless the effective stress conditions change due to excavations or fills. Then, effective stress analysis (β -method) is more reliable. If a user desires to calculate or simulate the load movement results of a head down test, the user needs to input the resistance movement conditions so-called $t-z/q-z$ functions, which might be new to many. The intent is to guide a new UniPile user into toward load-movement analysis. Input of soil compressibility and calculating settlement as a part of the analysis may also be novel to some. The example aims to serve as introduction to analysis and modeling a head-down loading test and the distribution of axial force and settlement per the Unified Method.

Once the basics are mastered, it is straight-forward to add several different piles, soil profiles, and/or fills and excavations. The main output is the results of distribution of axial force and settlement according to the principles of the Unified Method for the various alternative inputs and the simulation of a static loading test.

Section 6 advances beyond the basic approach for single piles widening the analysis to incorporating the effect of pile groups. When the project includes groups of piles, whether small or large, narrow or wide groups, UniPile6 can calculate the stress due to the increase of stress below the pile-toe level group. The analysis will show the load-movement result of perimeter piles and interior piles, which will be different for a site where there is no downdrag as opposed to where there is as well as for a rigid as opposed to a flexible pile raft.

All output graphs that can be adjusted as to scale and proportions and exported. All tables, input as well as output, can be exported and used for results compilation in combined graphs and data from outside UniPile. The veracity of all calculations can be verified from the output tables using separate "hand-calculations".

8. Disclosure

The Unified Method originated in the early 1980s and I pursued calculations by means of pen and paper and a slide rule. Then came the first spreadsheet program, Visicalc, which toward the end of the decade was replaced by Lotus123. In about 1990, Pierre Goudreault produced the first UniPile version, then, a DOS-based program. We formed UniSoft and started to market UniPile and Pierre kept updating it into a tremendously useful software for piled foundation analysis and design, gradually incorporating additional insight into the Unified Method. About two decades ago, I left the company and I have since then had no business association with UnisoftGS. However, I kept in close contact with Pierre and have had much pleasure from commenting and discussing his continued development of the program, now UniPile6—but no financial involvement or benefit.

I have a personal reason for putting this introduction together. I want to see the geotechnical practice in regard to piled foundation directed to design not from the aspect of "capacity" of a single pile, but in considering interaction between with load and movement and between single piles and small and large groups of piles, in short, foundation settlement. UniPile is the tool for this. I cannot see how geotechnical engineers engaged in deep foundation analysis and design can properly pursue their work without this tool.