Pile

Version 19.2

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Pile Oasys Geo Suite for Windows

This document has been created to provide a guide for the use of the software. It does not provide engineering advice, nor is it a substitute for the use of standard references. The user is deemed to be conversant with standard engineering terms and codes of practice. It is the users responsibility to validate the program for the proposed design use and to select suitable input data.

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1 About Pile

1.1 General Program Description

Pile Pile Load and Settlement

Pile is a program which calculates the vertical load carrying capacities and vertical settlements of a range of individual piles in a layered soil deposit. The theory is based on both conventional and new methods for drained (frictional) and undrained (cohesive) soils. Settlements are calculated for solid circular sections without under-ream.

1.2 Program Features

The main features of **Pile** are summarised below.

The user can perform either capacity analysis, settlement analysis, or both for a range of pile lengths and cross-sections.

Settlements are calculated for only solid circular cross-sections without under-ream.

The soil is specified in layers. Each layer is set to be drained (frictional) or undrained (cohesive) and appropriate strength parameters are specified. Maximum values can be set for ultimate soil/shaft friction stress and end bearing stress within each layer.

Levels may be specified as
- depth below ground level; or
- elevation above ordnance datum (OD).

Porewater pressures within the soil deposit can be set to hydrostatic or piezometric.

Pile capacities may be calculated for a range of pile lengths and a range of cross-section types such as circular, square and H-section. The circular and square cross-sections may be hollow or solid, whereas the H-section is only solid. Under-reams or enlarged bases may be specified.

Pile settlements may be calculated for a range of pile lengths and a range of solid circular cross-sections without under-ream.

There are two approaches available to calculate the capacity of the pile -
- working load approach; and
- limit-state approach.

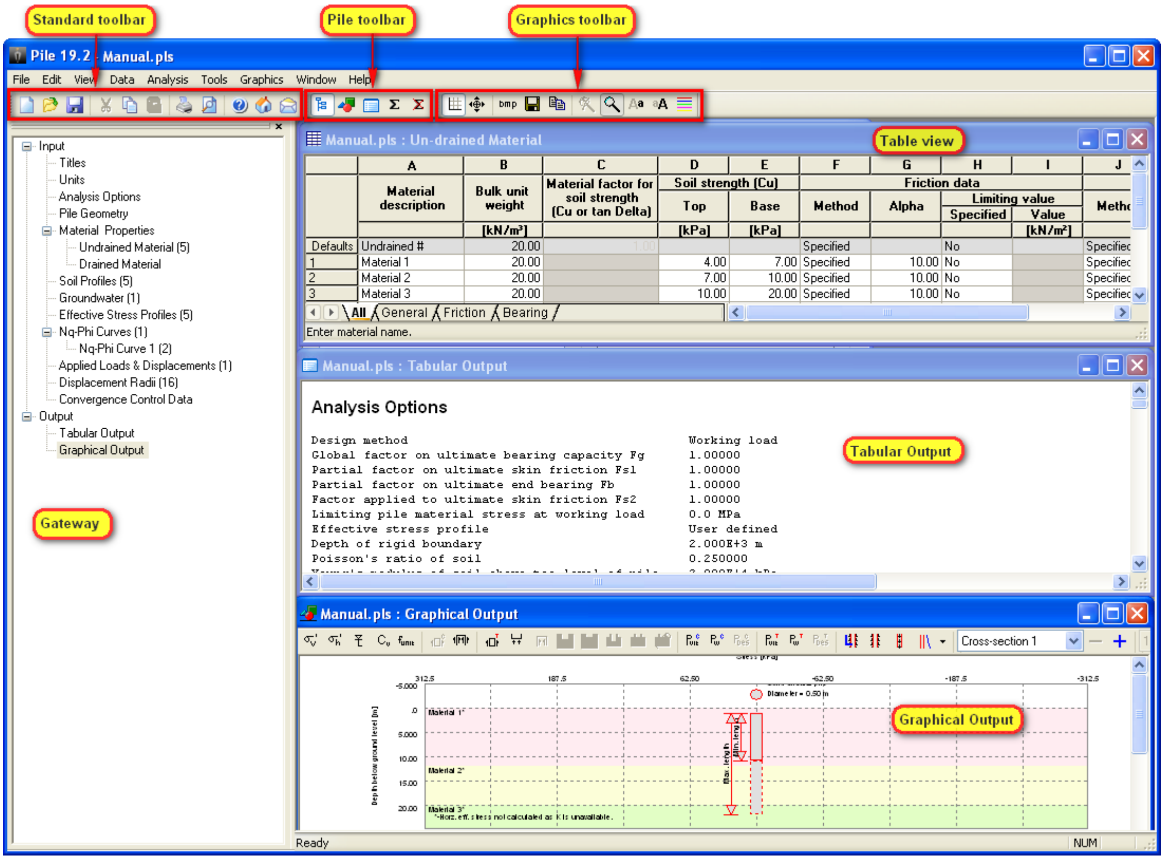
The graphical output depicts the variation of different pile capacities such as shaft resistance, end bearing, total bearing with pile depth and settlements of pile or soil. This may be exported in WMF format.

The text output contains the tabular representation of the input data and results. They may be exported to CSV format.

A legacy Pile and Pilset files may be read. Limiting shaft skin friction is now calculated from the material properties, so the reading of limiting shaft skin friction from legacy Pilset file is ignored.

1.3 Components of the User Interface

The principal components of Pile's user interface are the Gateway, Table Views, Graphical Output, Tabular Output, toolbars, menus and input dialogs. These are illustrated below.



1.3.1 Working with the Gateway

The Gateway gives access to all the data that is available for setting up a Pile model.

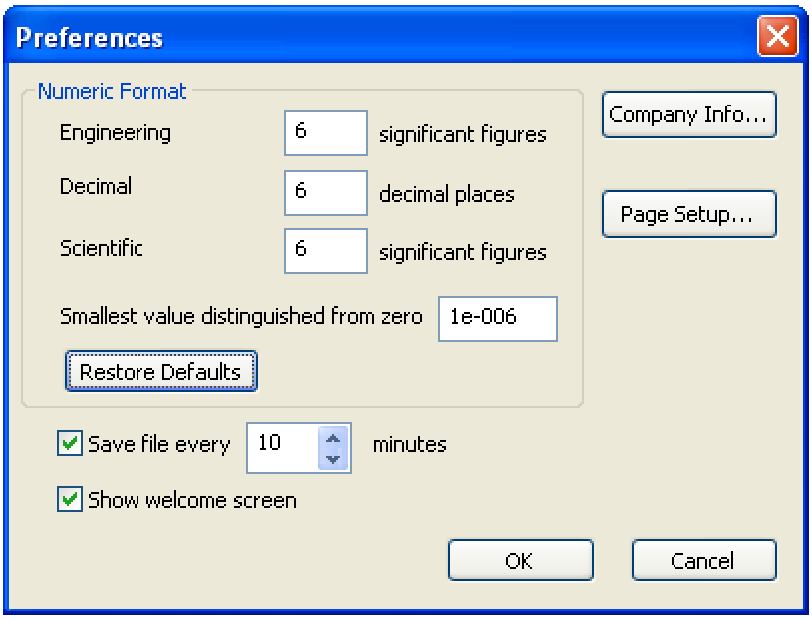
Top level categories can be expanded by clicking on the `+´ symbol beside the name or by double clicking on the name. Clicking on the `-´ symbol or double clicking on the name when expanded will close-up the item.

Double-clicking on an item will open the appropriate table view or dialog for data input. The greyed out items in the gateway are disabled.

1.3.2 Preferences

This dialog can be accessed by clicking Tools | Preferences. Preferences can be set whether a file is opened or not.

The Preferences dialog is accessible by choosing Tools | Preferences from the program's menu. It allows the modification of settings such as numeric format for output, show welcome screen, option for new model wizard, print parameters and company information. These choices are stored in the computer's registry and are therefore associated with the program rather than the data file. All data files will adopt the same choices.



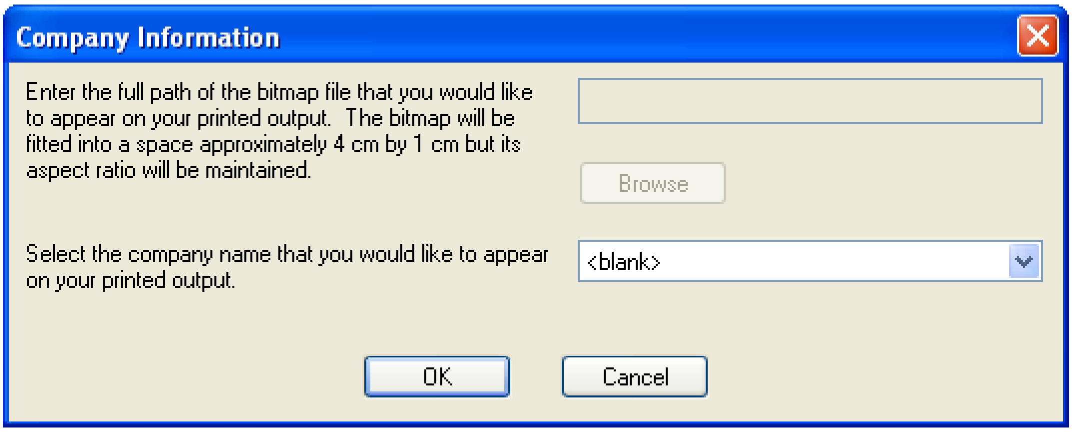
Numeric Format controls the output of numerical data in the Tabular Output. The Tabular Output presents input data and results in a variety of numeric formats, the format being selected to suit the data. Engineering, Decimal, and Scientific formats are supported. The numbers of significant figures or decimal places, and the smallest value distinguished from zero, may be set by the user.

Restore Defaults resets the Numeric Format specifications to program defaults.

A time interval may be set to save data files automatically. Automatic saving can be disabled by clearing the "**Save file every ...**" check box.

Show welcome screen enables or disables the display of the Welcome Screen. The Welcome Screen will appear on program start-up, and gives the option for the user to create a new file, to open an existing file by browsing, or to open a recently used file.

Company Info allows the user to change the company name and logo on the top of each page of print out. To add a bitmap enter the full path of the bitmap file. The bitmap will appear fitted into a space approximately 4cm by 1cm. The aspect ratio will be maintained. For Arup versions of the program the bitmap option is not available.



Page Setup opens the Page Setup dialog allowing the style of output for printed text and graphics to be selected.

If 'Calculation Sheet Layout´ is selected the page is formatted as a calculation sheet with details inserted in the page header.

If `Logo´ is selected the company logo is inserted in the top left corner of the page.

If `Border´ is selected this gives a border but no header information.

If `Clipped´ is selected the output is clipped leaving a space for the logo. This has no effect on text output.

1.4 Step by Step Guide

To perform capacity and settlement analysis of a pile follow the steps listed below. The data file should be saved at frequent intervals.

Item	**Description**
1	Begin a new data file by selecting "File | New" on the program menu.
2	Set the preferred units for data input and output in the Units dialog. The Units dialog is accessible by double-clicking "Units" in the Gateway, or via "Data | Units" on the program menu.
3	Choose analysis type, via the Analysis Options dialog, whether capacity or settlement or both. Choose effective stress profile, whether calculated or user-defined. Input for user-define effective stresses profile is explained in Item 8. Choose datum information, whether levels are entered as depths or elevations. Choose method for capacity analysis, whether working load or design resistance. and enter the factors for the selected method.

Specify the settlement data like young's modulus of soil above and below pile base, rigid boundary level, number of load increments and number of pile elements. This data input available for settlement analysis.

The Analysis Options dialog is accessible by double-clicking "Analysis Options" in the Gateway or via "Data | Analysis Options" on the program menu.

4 Specify type of pile, length and diameter of pile(s), via the Pile Geometry dialog. Follow the wizard for entering pile properties, pile lengths and pile cross-sections.

The Pile Geometry dialog is accessible by double-clicking "Pile Geometry" in the Gateway or via "Data | Pile Geometry" on the program menu.

5 Specify input data for material, undrained or drained.

5.1 Specify any undrained material data in the Undrained Material table view.

The Undrained Material table view is accessible by double-clicking "Material Properties | Undrained Material" in the Gateway or via "Data | Material Properties | Undrained Material" on the program menu.

5.2 Specify any drained material data in the Drained Material table view.

The Drained Material table view is accessible by double-clicking "Material Properties | Drained Material" in the Gateway or via "Data | Material Properties | Drained Material" on the program menu.

6 Specify soil layers in the Soil Profiles table view. At least on material should be defined to access this table view.

The Soil Profiles table view is accessible by double-clicking "Soil Profiles" in the Gateway or via "Soil Profiles" on the program menu.

7 Specify any hydrostatic or piezometric pressure in the Groundwater table view. This table view is accessible when capacity analysis is selected in Analysis Options dialog

The Groundwater table view is accessible by double-clicking "Groundwater" in the Gateway or via "Data | Groundwater" on the program menu.

8 Specify user-defined effective stress profile in the Effective Stress Profiles table view. At least on soil layer should be defined to access this table view.

The Effective Stress Profiles table view is accessible by double-clicking "Effective Stress Profiles" in the Gateway or via "Effective Stress Profiles" on the program menu.

9 Specify user-defined Nq-Phi curves in the Nq-Phi curves tabbed table view. This table view is accessible when capacity analysis is selected in Analysis Options dialog

The Nq-Phi curves tabbed table view is accessible by double-clicking "Nq-Phi curves" in the Gateway or via "Data | Nq-Phi curves" on the program menu.

10 Specify applied loads and prescribed displacements in the Applied Loads & Displacements table view. This table view is accessible when settlement analysis is selected in Analysis

Options dialog

The Applied Loads & Displacements table view is accessible by double-clicking "Applied Loads & Displacements" in the Gateway or via "Data | Applied Loads & Displacements" on the program menu.

11 Specify radius from the pile at which soil displacements are to be calculated in the Displacement Radii table view. This table view is accessible when settlement analysis is selected in Analysis Options dialog

The Displacement Radii table view is accessible by double-clicking "Displacement Radii" in the Gateway or via "Data | Displacement Radii" on the program menu.

12 Specify convergence control data in the Convergence Control Data dialog. This dialog is accessible when settlement analysis is selected in Analysis Options dialog

The convergence control data dialog is accessible by double-clicking "convergence control data" in the Gateway or via "Data | convergence control data" on the program menu.

13 Perform an analysis by clicking the Analyse button on the Pile toolbar, or via "Analysis | Analyse" on the program menu.

14 Pile performs a check on data for consistency. Correct any errors that are shown in the subsequent report of warnings and errors.

15 Inspect the results in the Tabular Output view and/or the Graphical Output.

These are accessible by double-clicking the "Output | Tabular Output", "Output | Graphical Output" in the Gateway, via "View | Tabular Output", "View | Graphical Output" on the program menu, or via the appropriate buttons on the Pile toolbar.

16 Adjust the data and re-analyse as necessary.

2 Method of Analysis

2.1 Capacity

The soil is split up into a number of layers, for which the user defines how skin friction and end bearing will be calculated.

The program will calculate bearing capacity at discrete elevations, either to provide a single bearing capacity at a single elevation specified by the user or to develop a bearing capacity versus depth profile over a specified range of elevations.

The calculation procedure will involve identifying a number of sub-layers within each specified soil layer corresponding to:

- depths at which capacity is to be assessed where these fall within a layer;
- depths at which capacity is to be assessed to allow a graph to be produced;
- changes in pile properties (i.e. under-reams);
- changes in groundwater/pore-pressure profile.

If there are n layers between the ground surface and the toe of the pile:

$$Q_{se} = \sum_{j=1}^{n} \Delta Q_{se}^{j}$$

where:

ΔQ_{se}^{j} = incremental external skin friction accumulated within a soil layer outside the pile

Within the layer:

$$\Delta Q_{se}^{j} = \Delta L_j P_e^j f_{se}^j$$

where:

ΔL_j = thickness of layer j
P_e^j = average external perimeter of outside the pile in contact with soil in layer j
f_{se}^j = average external skin friction in layer j outside the pile

Similarly:

$$\Delta Q_{si}^{j} = \Delta L_j P_i^j f_{si}^j$$

where:

ΔQ_{si}^{j} = incremental internal skin friction accumulated within a soil layer inside the pile
P_i^j = average internal perimeter of inside the pile in contact with soil in layer j
f_{si}^j = average internal skin friction in layer j inside the pile

2.1.1 Shaft Friction

Two basic methods are available, total stress and effective stress. The former is appropriate to clays and soft rocks and the latter to cohesion-less soils and clays for long term loading where the stress conditions are likely to change.

2.1.1.1 Total Stress Approach

The friction per unit area, f_s is given by:

$f_s = \alpha \, c_u$

where:

α = an adhesion factor

c_u = the average undrained shear strength in the layer

α may be specified by the user or may be calculated by specified API method.

API Method 1

The current API code recommends that for driven tubular steel piles:

$\alpha = 0.5\ \Psi^{-0.5}$, $\Psi < 1.0$

$\alpha = 0.5\ \Psi^{-0.25}$, $\Psi > 1.0$

$\Psi = c_u / \sigma_v'$

where:

σ_v' = vertical effective stress

Caution is required for cases where Ψ is greater than 3 or for long flexible piles (a program warning is generated).

API Method 2

Earlier editions of the API code advised that:

$\alpha = 1.0$, $c_u < 24$kPa

$\alpha = 0.5$, $c_u > 72$kPa

with linear interpolation between these values.

2.1.1.2 Effective Stress Approach

The friction per unit area, f_s is computed by the following two methods.

Beta Method

The Beta method relates friction directly to vertical effective stress, σ_v':

$f_s = \beta\sigma_v'$

Earth Pressure Method

More conventionally:

$f_s = \sigma_h'\tan(\delta)$

where:

σ_h' = average horizontal effective stress in layer
δ = soil/pile friction angle
σ_h' = either supplied by the user or calculated using:

$\sigma_h' = K\sigma_v'$

where:

K = earth pressure factor

2.1.1.3 Limiting Shaft Friction

Irrespective of the approach followed, the skin friction per unit area, f_s may be limited to a user-specified value.

If this value is set to zero, then the friction is assumed to increase continuously with depth.

2.1.1.4 Negative Skin Friction

Some layers may be defined as providing down-drag, in which case the cumulative capacity cannot contribute to the bearing capacity. The negative skin friction Q_{nsf} must be calculated separately to ensure that the factors of safety or partial load factors are applied correctly.

In all the bearing capacity calculations, negative skin friction is always calculated separately.

Cumulative skin friction is always exclusive of negative skin friction.

The negative skin friction is not taken into account when calculating the tension capacities, and for limit state design.

2.1.2 End Bearing

Two basic methods are available, **total stress** and **effective stress** based. The former is appropriate to clays and soft rocks and the latter to cohesion-less soils and clays for long term loading where the stress conditions are likely to change.

2.1.2.1 Total Stress Approach

In this approach, end bearing stress, q_b is given by:

$q_b = N_c c_u$

For solid piles N_c = 9 for embedment of over about 2D.

In the case of shallow embedment (< 2D), N_c is taken as zero and a warning to this effect is generated.

For hollow sections or H-piles, the pile wall acts more like a deep strip footing, therefore $N_c \approx 6$ is more appropriate.

2.1.2.2 Effective Stress Approach

In this approach, end bearing stress, q_b is given by:

$q_b = N_q \sigma_v'$

where:

σ_v' = The vertical effective stress at the base of the layer being considered

The following methods may be used to calculate N_q:

i) N_q specified

The value of N_q can be specified directly by the user.

ii) N_q calculated based on friction angle

The most commonly used method to assess N_q is that proposed by Berezantzev, as a function of drained friction angle ϕ'. The relationship can be defined explicitly or as a look-up table.

iii) N_q based on mean effective stress, relative density and friction angle

A more refined approach is given by Bolton (1984) taking into account dilatancy effects and the influence of stress level, particularly with heavily loaded piles.

This is an iterative approach based on the following expressions:

$I_R = I_D (10 - \ln p') - 1$

where:

I_R = corrected relative density (0 to 1)
I_D = original relative density (0 to 1)
p' = mean effective stress (kPa), calculated as:

$p' = (\sigma_v' + 2\sigma_h')/3$

$\phi' = \phi_{cv}' + 3I_R$ (degrees)

where:

ϕ_{cv}' = critical state angle of friction (degrees)

$p' \approx (\sqrt{N_q})*\sigma_v'$

N_q is estimated using the Berezantzev method

To start the process it is suggested that N_q is first estimated using ϕ_{cv}'.

iv) N_q calculated based on friction angle, depth ratio (depth/width) and friction angle corresponding to the soil of overburden

This approach is given by Berezantzev et al (1961), wherein the bearing capacity is calculated from:

$q_b = A_k \gamma B + B_k \alpha_T \gamma_D D$

where:

A_k,B_k are coefficients depending upon ϕ, and are read from the ϕ - A_k and ϕ - B_k graphs respectively
α_T is a function of D/B and ϕ_D
ϕ_D and γ_D pertain to the soil of overburden

The value of N_q is then calculated from the resulting bearing capacity.

2.1.2.3 Limiting End Bearing

Irrespective of the approach followed, the end bearing stress q_b may be limited to a user-specified value.

If this value is set to zero, then the end bearing stress is assumed to increase continuously with depth.

2.1.3 Bearing Capacity

The following capacities are calculated by the program.

Solid piles:
- Ultimate Capacity
- Allowable Capacity
- Design Capacity

Hollow piles:
- Plugged Capacity
- Unplugged Capacity (fixed and changing internal soil level)
- Ultimate capacity
- Allowable capacity
- Design Capacity

Solid piles

The total bearing capacity of solid piles is:

$Q = Q_{se} + Q_b$

where:

Q_{se} = cumulative skin (or shaft) friction
Q_b = end bearing

For piles in tension $Q_b = 0$

Hollow piles

The total bearing capacity of hollow piles is the lesser of:

$Q_{plugged} = Q_{bp} + Q_{bw} + Q_{se}$ and

$Q_{unplugged} = Q_{bw} + Q_{se} + Q_{si}$

where:

Q_{si} = cumulative internal skin friction (kN)
Q_{se} = cumulative external skin friction (kN)
Q_{bp} = end bearing acting over the soil plug area (kN)
Q_{bw} = end bearing acting over the pile wall area (kN)

For piles in tension $Q_{bw} = Q_{bp} = Q_{si} = 0$

2.1.3.1 Ultimate Capacity

Solid Piles

The ultimate bearing capacity, Q of solid piles is:

$Q = Q_{se} + Q_b - Q_{nsf}$

where:

Q_{se} = cumulative skin (or shaft) friction
Q_b = end bearing
Q_{nsf} = negative skin friction

For piles in tension $Q_b = Q_{nsf} = 0$

Hollow piles

The ultimate bearing capacity, Q of hollow piles is given by:

$Q = \text{Minimum}(Q_{plugged}, Q_{unplugged,case1}, Q_{unplugged,case2})$

where:

$Q_{plugged}$ is the plugged capacity of the hollow pile
$Q_{unplugged,case1}$ is the unplugged capacity for case 1
$Q_{unplugged,case2}$ is the unplugged capacity for case 2

The above quantities are described below.

2.1.3.2 Plugged Capacity

The plugged capacity of hollow piles is given by:

$$Q_{plugged} = Q_{bp} + Q_{bw} + Q_{se} - Q_{nsf,Ext}$$

where:

Q_{se} = cumulative external skin friction exclusive of negative skin friction (kN)
Q_{bp} = end bearing acting over the soil plug area (kN)
Q_{bw} = end bearing acting over the pile wall area (kN)
$Q_{nsf,Ext}$ = external negative skin friction

For piles in tension, $Q_{bp} = Q_{bw} = Q_{nsf,Ext} = 0$

2.1.3.3 Unplugged Capacity

The unplugged capacity of hollow piles is given by:

$$Q_{unplugged} = Q_{bw} + Q_{se} + Q_{si} - Q_{nsf,Ext} - Q_{nsf,Int}$$

where:

Q_{si} = cumulative internal skin friction exclusive of negative skin friction (kN)
Q_{se} = The cumulative external skin friction exclusive of negative skin friction (kN)
Q_{bw} = end bearing acting over the pile wall area (kN)
$Q_{nsf,Ext}$ = external negative skin friction
$Q_{nsf,Int}$ = internal negative skin friction

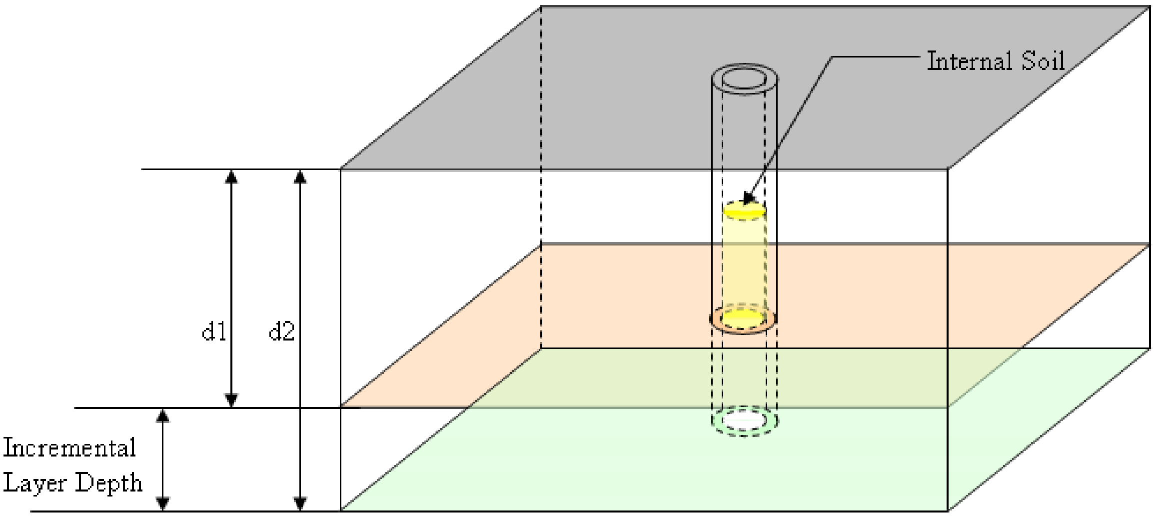
When driving hollow piles (or H-piles) it may not be possible to mobilise the full theoretical internal friction; this may be too great to allow the plug end bearing force to push the soil up inside the pile (typically in clay soils). In this situation the pile becomes plugged and the level of soil inside is lower than that outside. If the end bearing later increases within a deeper layer, the accumulated internal friction will be fully mobilised again and more material will be pushed up inside the pile. However the internal capacity will be less than if the plug level is at the ground surface.

Thus, there are two cases for calculation of unplugged capacity as described below.

- Case 1: Internal soil level is the same as external soil level, where in the internal skin friction is calculated assuming as internal soil profile similar to the external soil profile.Thus, the external and internal friction in this case will be in the ratio of external perimeter to internal perimeter of the pile.

- Case 2: Internal soil level changes with the driven pile depth. In this case, calculations are made at each depth increment to ensure that soil is pushed inside the pile only if the entire skin friction has been mobilised, as follows.

Consider two pile embedment depths d1 and d2 such that d1 < d2.



Assume that the **incremental layer does not contribute to negative skin friction**

If

$$Q_{si,d1} - Q_{nsf,Int,d1} + Q_{si,inc} < Q_{bp,d2}$$

then

$$Q_{si,d2} = Q_{si,d1} + Q_{si,inc}$$

else

$$Q_{si,d2} = Q_{si,d1}$$

where:

$Q_{si,d1}$ = internal skin friction at a pile embedment depth d1

$Q_{si,d2}$ = internal skin friction at a pile embedment depth d2

$Q_{nsf,Int,d1}$ = cumulative internal negative skin friction accumulated over depth d1

$Q_{si,inc}$ = incremental internal skin friction between depths d1 and d2

$Q_{bp,d2}$ = bearing capacity at depth d2 over the plug area alone - excluding the wall area

However, if the **incremental layer contributes to negative skin friction**

If

$Q_{si,d1}$ - $Q_{nsf,Int,d1}$ - $Q_{si,inc} < Q_{bp,d2}$

then

$Q_{nsf,Int,d2}$ = $Q_{nsf,Int,d1}$ + $Q_{si,inc}$

where:

$Q_{si,d1}$ = internal skin friction at a pile embedment depth d1
$Q_{si,d2}$ = internal skin friction at a pile embedment depth d2
$Q_{nsf,Int,d1}$ = cumulative internal negative skin friction accumulated over depth d1
$Q_{nsf,Int,d2}$ = cumulative internal negative skin friction accumulated over depth d2
$Q_{si,inc}$ = incremental internal skin friction between depths d1 and d2
$Q_{bp,d2}$ = bearing capacity at depth d2 over the plug area alone - excluding the wall area

Note:

- The **reported** unplugged capacity from case 2 will be the **minimum of the capacities from case 1 and case 2;**
- For piles in tension, Q_{bw} = $Q_{nsf,Ext}$ = $Q_{nsf,Int}$ = 0.

2.1.3.4 Allowable Capacity - Working Load Approach

Traditionally, global factors of safety are applied to the ultimate end bearing capacity and the skin friction to take into account uncertainties in soil properties, loads, installation method and the calculation method and also to limit settlement.

Solid Piles

The factored load is termed the allowable or working load. For solid piles, this is defined as the lesser of:

$P_d = (Q_s + Q_b)/F_g - Q_{nsf}$

$P_d = Q_s / F_{s1} + Q_b / F_b - Q_{nsf}$

$P_d = Q_s / F_{s2}$

$P_d = (f_{allowable})*(A_p)$

where:

Q_s = skin friction (excluding negative skin friction)
Q_{nsf} = negative skin friction
Q_b = end bearing capacity of the solid pile
A_p = cross-section area of pile
$f_{allowable}$ = allowable stress in pile at working load

F_g = global factor applied to the calculated ultimate bearing capacity
F_{s1} = partial factor applied to the ultimate skin friction component
F_b = partial factor applied to the ultimate end bearing component
F_{s2} = factor applied to the ultimate skin friction component

In tension, Q_b and Q_{nsf} are both zero, and the four criteria reduce to:

$P_d = Q_s/F_g$

$P_d = Q_s /F_{s1}$

$P_d = Q_s /F_{s2}$

$P_d = (f_{allowable})*(A_p)$

Hollow piles

For hollow piles however, we have the following criteria to consider, owing to the plugged condition of the pile:

$P_d = (Q_{se} + Q_{si} + Q_b)/F_g - Q_{nsf,e} - Q_{nsf,i}$

$P_d = (Q_{se} + Q_{si} + Q_b)/F_g - Q_{nsf,e} - Q_{nsf,i,autoplugging}$

$P_d = (Q_{se}+ Q_b+ Q_{plug})/F_g - Q_{nsf,e}$

$P_d= (Q_{se} + Q_{si}) /F_{s1} + Q_b /F_b - Q_{nsf,e} - Q_{nsf,i}$

$P_d= (Q_{se} + Q_{si}) /F_{s1} + Q_b /F_b - Q_{nsf,e} - Q_{nsf,i,autoplugging}$

$P_d = (Q_{se}) /F_{s1} + (Q_b+ Q_{plug})/F_b - Q_{nsf,e}$

$P_d= (Q_{se}) /F_{s2}$

$P_d= (f_{allowable})*(A_p)$

where:

Q_{se} = external skin friction (excluding negative skin friction)
Q_{si} = internal skin friction (excluding negative skin friction)
$Q_{nsf,e}$ = external negative skin friction
$Q_{nsf,i}$ = internal negative skin friction - in this case, the top of internal soil at the same level as ground level
$Q_{nsf,i,autoplugging}$= internal negative skin friction - in this case, internal soil level changes with driven pile depth
Q_b = end bearing capacity of the hollow pile (over the wall area)

Q_{plug} = bearing capacity of the plugged portion of the hollow pile (excluding wall area)
A_p = cross-section area of pile
$f_{allowable}$ = allowable stress in pile at working load
F_g = global factor applied to the calculated ultimate bearing capacity
F_{s1} = partial factor applied to the ultimate skin friction component
F_b = partial factor applied to the ultimate end bearing component
F_{s2} = factor applied to the ultimate skin friction component

In tension, Q_b, Q_{plug}, $Q_{nsf,e}$ and $Q_{nsf,i}$ are all zero, and there are just four criteria.

$P_d = Q_s/F_g$

$P_d = Q_s/F_{s1}$

$P_d = Q_s/F_{s2}$

$P_d = (f_{allowable})*(A_p)$

2.1.3.5 Design Resistance - Limit State Approach

In limit state codes it is usual to assess the ultimate limit state (ULS) for one or more combinations of factored applied loads and material properties. Additional factors may be applied relating to the pile type and calculation method.

In EC7 terms the design action, based on factored loads, is compared with the design bearing resistance calculated using factored soil parameters and other related factors. Different factors are used, appropriate to one or more load cases. Other codes use a similar approach. Using EC7 notation, although the approach is applicable to other codes, the design bearing resistance is:

$R_d = R_{sd} + R_{bd}$

where:

R_{bd} = design base resistance
R_{sd} = design shaft resistance

These are determined using:

$R_{bd} = R_{bk}/\gamma_b$
$R_{sd} = R_{sk}/\gamma_s$

where:

R_{bk} = characteristic base resistance
R_{sk} = characteristic shaft resistance
γ_b and γ_s = base and shaft resistance factors respectively

For solid piles the above definitions are straight forward. However, for hollow piles in compression, there are three conditions to be considered:

Unplugged condition - (internal soil level remains at ground level)

- R_{bk} is obtained by calculating bearing capacity only over the wall area.
- R_{sk} is obtained by adding the contributions of external skin friction and internal skin friction, assuming the internal soil level remains at ground level.

Unplugged condition - (internal soil level changes with driven pile depth)

- R_{bk} is obtained by calculating bearing capacity only over the wall area.
- R_{sk} is obtained by adding the contributions of external skin friction and internal skin friction, with the internal soil level not necessarily at ground level.

Plugged condition

- R_{bk} is obtained by calculating bearing capacity only over the **wall area, and the plug area.**
- R_{sk} is obtained by considering only the external skin friction.

The design resistance is the **minimum** of the above calculated resistances.

For hollow piles in tension, again the definition is straight forward with R_{bk} = 0.

Depending on the load case under consideration, the characteristic resistances may or may not be determined using partial material factors. However, **presently, partial material factors are always applied when "Design Resistance" option is chosen**.

When calculating pile capacity it is important to note that the calculated bearing resistance is neither an allowable working load or an ultimate capacity, and must be compared with the appropriately factored combination of applied loads, dependent on the design case being assessed.

The **negative skin friction** is treated as an "action" and is **not included** in the calculation of design resistance.

2.1.4 Solution Algorithm

1. divide the soil into required number of layers, based on:
   - soil profile;
   - effective stress profiles/ groundwater profiles;
   - depth of the pile (single or range);
   - changes in the pile properties (eg. under-ream);

2. calculate the vertical stress profile and vertical effective stress profile (if not specified);

3. compute the skin friction and end bearing (if necessary) of each layer. (as described below);

4. compute the cumulative positive skin friction and negative skin friction taking into account layers which contribute to negative skin friction;

5. compute the end bearing capacity of the pile;

6. compute the working load or the design resistance of the pile, based on the user's choice;

7. store the values obtained in steps 5 and 6, in order to plot the variation of the above quantities with depth.

2.1.4.1 Skin Friction Computation

If total stress:

1. get the profile of c_u across the layer;
2. get the profile of α across the layer (get user-specified value or from API methods 1 or 2);
3. get the profile of f_{se} and f_{si} (if necessary) across the layer, taking into account the limiting skin friction in the layer;
4. get the average value of f_{se} and f_{si} for the layer;
5. get the perimeter of the pile in the layer (both external and internal);
6. compute external and internal skin friction provide by the layer;

Else if effective stress:

1. get the profile of f_s based on the method selected:

   If β method:

   a. get the user-specified value β;

   b. get the profile of f_s from σ_v' profile using the relation:
   $f_s = \beta * \sigma_v'$

   Else If earth pressure method

   a. get the profile of σ_h' (User-specified or using the value of earth pressure coefficient K, supplied by the user viz. $\sigma_h' = K\sigma_v'$);

   b. get the profile of f_s using the relation, $f_s = \sigma_h' \tan(\delta)$, where δ is the friction angle between the pile and soil;

2. get the average value of f_{se} and f_{si} for the layer;
3. get the perimeter P of the pile layer (both external and internal);
4. compute external and internal skin friction provided by the layer.

2.1.4.2 End Bearing Computation

1. get the profile of bearing pressure, q_b:

If total stress:

a. get the profile of undrained cohesion, c_u across the layer;

b. get value of N_c (User-specified or calculated) based on embedment depth;

c. get the profile of bearing pressure from $q_b = N_c c_u$;

Else If effective stress:

a. get the profile of σ_v' across the layer(either calculated or user-specified);

b. get the value of N_q – either form user, or Berezantzev Method or Bolton method;

c. get the bearing pressure, q_b from $q_b = N_q \sigma_v$';

2. get the cross section area of the pile base, pile wall, and soil plug as appropriate;

3. compute end bearing capacity of the pile.

2.1.4.2.1 Berezantzev method

The following steps are implemented in the Nq calculation algorithm when the user selects "Berezantzev method" in Effective stress table.

i) Berezantzev Ak Bk Curves

These curves are derived from Berezantzev et al (1961).

This calculation algorithm is performed when the user selects standard "Berezantzev Ak Bk Curves" option in the Nq-Phi curve field of the Effective stress table.

1. get the user-specified value of drained friction angle ϕ';

2. get the user-specified value of friction angle ϕ_D corresponding to the soil of overburden;

3. from the given ϕ' value interpolate/extrapolate the value of coefficients A_k and B_k from the ϕ' - A_k and ϕ' - B_k graphs respectively;

4. the values of A_k and B_k in the program are calculated by the polynomial equations generated for the data points that are read from the graph;

5. in digitising the curve, the lower bound values have been read;

6. the generated polynomial equations for A_k and B_k are given below:

$$Ak = 0.00261719 \times \left(\phi'\right)^4 - 0.300278 \times \left(\phi'\right)^3 + 13.0706 \times \left(\phi'\right)^2 - 253.216 \times (\phi) + 1837.45$$

$$Bk = 0.0033242 \times \left(\phi'\right)^4 - 0.363837 \times \left(\phi'\right)^3 + 15.1495 \times \left(\phi'\right)^2 - 280.875 \times (\phi) + 1955.20$$

7. from the given ϕ', ϕ_D and depth ratio (depth/width), calculate the value of α_T which is given by the following equation:

$$\alpha_T = 1 - \frac{2 \times f\left(\phi_D\right)}{s\left(\phi'\right)} \times \left[1 + \frac{H\left(\frac{D}{B}\right)}{g\left(\phi_D\right)}\left(1 - P\left(\phi_D\right)\right)\right]$$

where:

$$\lambda = 2 \times \tan \phi_D \times \tan\left(\frac{\pi}{4} + \frac{\phi_D}{2}\right)$$

$$f\left(\phi_D\right) = \frac{\tan\left(\phi_D\right) \times \tan\left(\frac{\pi}{4} - \frac{\phi_D}{2}\right)}{\lambda - 1}$$

$$s\left(\phi'\right) = \left[1 - \left(\frac{\ell_0}{R}\right)^{-2}\right]$$

$$g\left(\phi_D\right) = (2 - \lambda) \times \tan\left(\frac{\pi}{4} - \frac{\phi_D}{2}\right)$$

$$\ell_0 = R \times \left[1 + \frac{\left(\sqrt{2} \times e^{\left(\frac{\pi}{2} - \frac{\phi}{2}\right) \times \tan\frac{\phi}{2}} \right)}{\sin\left(\frac{\pi}{4} - \frac{\phi'}{2} \right)} \right]$$

$$H\left(\frac{D}{B}, \phi'\right) = \frac{1}{2 \times \left(\frac{D}{B}\right)} \times \left[1 + \frac{\left(\sqrt{2} \times e^{\left(\frac{\pi}{2} - \frac{\phi}{2}\right) \times \tan\frac{\phi}{2}} \right)}{\sin\left(\frac{\pi}{4} - \frac{\phi'}{2} \right)} \right]$$

$$P\left(\phi_D, \phi', \frac{D}{B}\right) = \left\{ 1 + \left(\frac{1}{H\left(\frac{D}{B}\right)} \times \tan\left(\frac{\pi}{4} - \frac{\phi_D}{2} \right) \right) \right\}^{2-\lambda}$$

where:

R = radius of the pile
D = depth of the pile
B = diameter of the pile

8. finally calculate the value of q_b .

$$q_b = A_k \gamma B + B_k \alpha_T \gamma_D D$$

ii) User-defined Nq-Phi curve

This calculation algorithm is performed when the user selects any user-defined Nq-Phi curve in the Nq-Phi curve field of the Effective stress table.

1. get the user-specified value of drained friction angle ϕ';

2. get the value of Nq based on user-specified equation or user-specified look-up table.

2.1.4.2.2 Bolton method

This is a more refined approach is given by Bolton (1984), taking into account dilatancy effects and the influence of stress level, particularly with heavily loaded piles.

It involves the following steps:

1. get the user specified values of ϕ_{cv}' and I_R;

   where:

   I_R = corrected relative density (0 to 1).

2. get the value of $\phi' = \phi_{cv'} + 3I_R$;

3. get the value of N_q using the Berezantzev method;

4. get the value of mean effective stress p', using the relation $p' \approx \sqrt{(N_q \sigma_v')}$;

5. get the value of I_R using the relation $I_R = I_D$ (10 - ln p') -1,

   where:

   I_R = corrected relative density (0 to 1),

   I_D = original relative density (0 to 1).

6. get the value of $\phi' = \phi_{cv}' + 3I_R$;

7. get the value of N_q using the Berezantzev method;

8. if difference between the new value of N_q and value of N_q from step 3 is within tolerance, stop the iteration, else repeat the steps 4 to 8.

2.2 Settlement

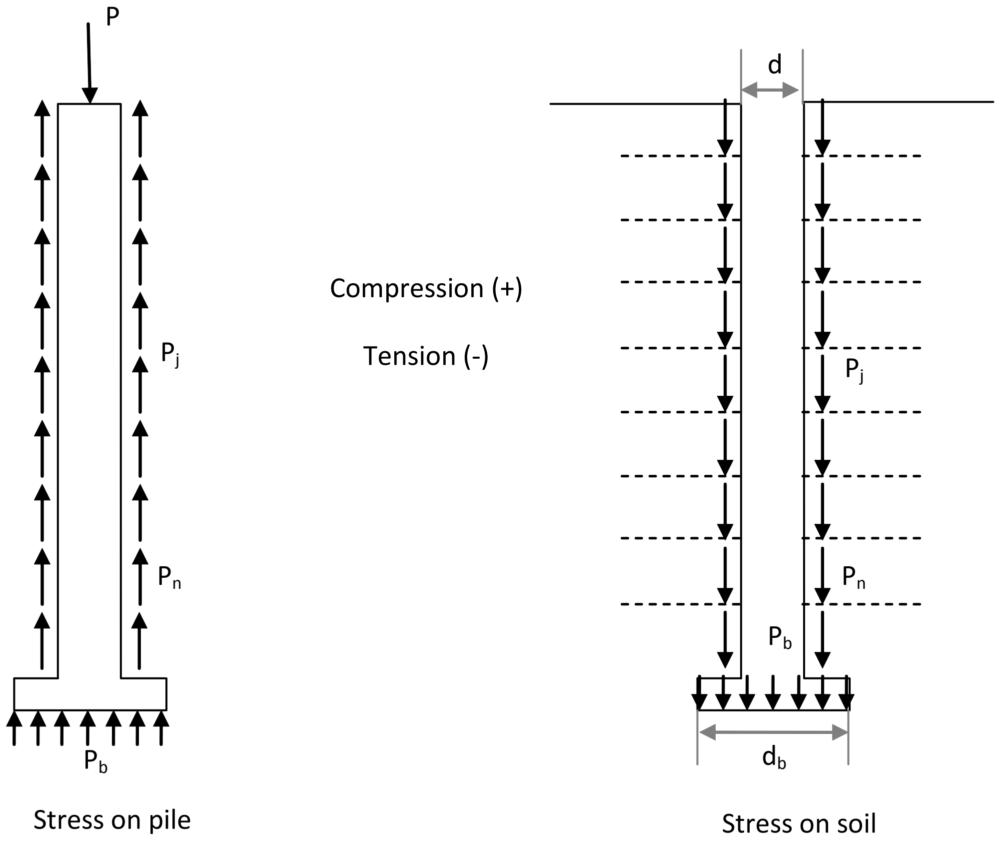
Settlement analysis calculates the settlement of a range of piles with different lengths and cross-sections and of the surrounding soil. Pile soil slip is modelled, together with the effects of soil heave inducing tension, or settlement causing compression and negative skin friction.

2.2.1 Theory of Analysis

Settlement calculation is based on theoretical analyses of the settlement of single compressible piles which are based on linear elastic theory. The analysis uses the integral method adopted by Mattes and Poulos, and is explained briefly below.

Limiting shaft skin friction is calculated from the material properties.

Soil Displacements



Stresses acting on Pile and Adjacent Soil

The soil displacements adjacent to the pile can be expressed by:

$$\{\rho^s\} = \frac{d}{E^s}[I^s]\{p\}$$

where:

$\{\rho^S\}$ = soil displacement vector

$$\{\rho^s\} = \begin{Bmatrix} \rho_1^s \\ \rho_2^s \\ \rho_3^s \\ \vdots \\ \vdots \\ \rho_n^s \\ \rho_b^s \end{Bmatrix}$$

$\{p^S\}$ = shaft skin friction vector

$$\{p^s\} = \begin{Bmatrix} p_1 \\ p_2 \\ p_3 \\ \vdots \\ \vdots \\ p_n \\ p_b \end{Bmatrix}$$

E^S = soil Young's modulus

n = number of nodes on pile shaft

$[l^S]$ = soil displacement factor matrix

$$[l^s] = \begin{bmatrix} l_{11} & l_{12} & \cdots & \cdots & l_{1n} & l_{1b}\dfrac{d_b}{d} \\ l_{21} & l_{22} & \cdots & \cdots & l_{2n} & l_{2b}\dfrac{d_b}{d} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ l_{n1} & l_{n2} & \cdots & \cdots & l_{nn} & l_{nb}\dfrac{d_b}{d} \\ l_{b1} & l_{b2} & \cdots & \cdots & l_{bn} & l_{bb}\dfrac{d_b}{d} \end{bmatrix}$$

in which d = diameter of pile shaft
d_b = diameter of pile base

where superscript s and subscript b denote soil and pile base respectively.

the elements in $[l^S]$ are derived using integrations of Mindlin's equations.

The equation can be rewritten in the form of soil stiffness:

$$\{p\} = \frac{E^s}{d}[l^s]^{-1}\{\rho^s\}$$

Pile Displacements

The pile shaft stresses at nodes can be expressed by:

$$\{p\} = \frac{d}{4\delta^2}E^p R_A[l^p]\{\rho^p\} + \{Y\}$$

where:

superscript p denotes pile

$\{\rho^P\}$ = pile displacement vector

$$\{\rho^p\} = \begin{Bmatrix} \rho_1^p \\ \rho_2^p \\ \rho_3^p \\ \vdots \\ \vdots \\ \rho_n^p \\ \rho_b^p \end{Bmatrix}$$

δ = length of pile element

E^p = pile Young's Modulus

$$R_A = \frac{A}{1/_4 \pi d^2}$$

A = pile section area

$[l^p]$ = pile action matrix

$$[l^p] = \begin{bmatrix} -1 & 1 & 0 & 0 & \dots & \dots & \dots & 0 \\ 1 & -2 & 1 & 0 & \dots & \dots & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & -2 & 1 \\ 0 & 0 & 0 & 0 & -0.2 & 2 & -5 & 3.2 \\ 0 & 0 & 0 & 0 & 0 & -1.33f & 12f & -10.67f \end{bmatrix}$$

in which:

$$f = \frac{\delta}{dR_A}$$

$\{Y\}$ = applied stress vector

$$\{Y\} = \frac{1}{\pi d \delta} \begin{Bmatrix} F_1 \\ F_2 \\ F_3 \\ \vdots \\ \vdots \\ F_n \\ F_b \end{Bmatrix}$$

in which:

F = applied force at node down the pile

The elements in $[l^p]$ are obtained using the finite difference method.

Displacement Compatibility

When elastic conditions at the pile-soil interface are maintained, the displacements of adjacent points along the interface are equal.

$$\{\rho^s\} = \{\rho^p\} = \{\rho\}$$

$$\left|\frac{E^s}{d}[l^s]^{-1} - \frac{d}{4\delta^2}E^p R_A[l^p]\right|\{\rho\} = \{Y\}$$

The pile displacements are then calculated and shaft skin frictions are calculated based on the computed pile displacements.

Effect of Rigid Boundary

The elements of $[l^s]$ apply only for the soil having an infinite depth, i.e. a floating pile. To allow for the effect of a rigid boundary on the pile displacement the mirror-image approximation suggested by D'Appolonia and Romulaldi was introduced. The elements in $[l^s]$ are then corrected to $(l_{ij} - l'_{ij})$

where:

l_{ij} = vertical displacement factor for i due to shear stress on element j

l'_{ij} = vertical displacement factor for i due to shear stress on imaginary element j'

Pile-Soil Slip

Displacement compatibility requires that no slip occurs at the pile-soil interface. However, real soils have a finite shear strength, thus slip or local yield will occur when the shaft skin friction reaches the limiting value. Thus the elastic analysis as previously described is modified to take account of the possible slip.

For any loading stage, first the displacements are solved on the assumption that all elements are elastic. From these displacements the shear stresses are calculated and are then compared with the specified limiting stresses. At an element, say element i, if the computed skin friction p_i exceeds the limiting value T_i the extra displacement caused by the out-of-balance force is calculated and is added to the previous elastic solution. The shear stresses are then calculated again based on the modified displacements. The above procedure is repeated until all the computed shear stresses do not exceed the appropriate limiting shear stresses.

Downward drag (or gap between pile base and soil) correction

If there is a gap between pile base and the soil then Pile ignores the force due to end-bearing and iterates until the force equilibrium and displacement compatibility is achieved.

Correction of Soil Stiffness

To allow for the two different soil stiffness above and below the pile toe, an approximate treatment is included in the program.
The elements of the flexibility matrix $\{\delta\}$ consist of two components:

$$\delta_{ii} = \delta_{bi}(E_b) + (\delta_{ii} - \delta_{bi})(E_s)$$

where:

$\delta_{bi}(E_b)$ = displacement at the pile toe in the soil with E_b due to a unit load at element i

$(\delta_{ii} - \delta_{bi})(E_s)$ = relative displacement between i and b in the soil with E_s due to a unit load at element i;

$$\delta_{ij} = \delta_{ji}(E_s) \times F_{ij} = \delta_{ij}$$

where F_{ij} is the smaller of:

$$\frac{\delta_{ii}}{\delta_{ii}(E_s)} \; and \; \frac{\delta_{jj}}{\delta_{jj}(E_s)}$$

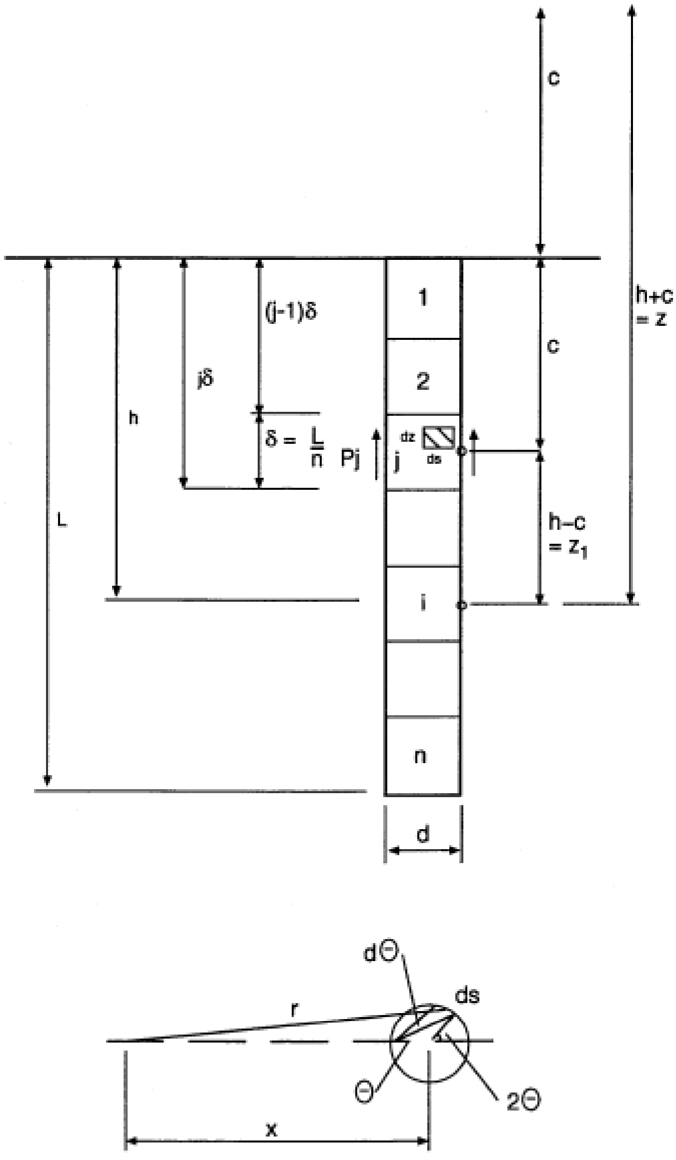
in which:

$\delta_{ii}(E_s)$ = displacement at element i in a soil with E_s due to a unit load at element i

$\delta_{jj}(E_s)$ = displacement at element j in a soil with E_s due to a unit load at element j

2.2.2 Integration of Mindlin's equations

Displacement of Point i due to Stress on Element j



Geometry of Single Pile

For a general point i, the value of l_{ij} is

$$l_{ij} = 2 \int_{(j-1)\delta}^{j\delta} \int_{0}^{\pi/2} l^{\rho} \, d\theta \, dc$$

where:

I^p = influence factor for vertical displacement due to a vertical point load

From Mindlin's equation, I^p is given by:

$$I^p = \frac{(1+\vartheta)}{8\pi(1-\vartheta)}\left\{\frac{z_1}{R_1^3} + \frac{(3-4\vartheta)}{R_1} + \frac{(5-12\vartheta+8\vartheta^2)}{R_2} + \frac{[(3-4\vartheta)z^2 - 2cz + 2c^2]}{R_2^3} + \frac{[6cz^2(z-c)]}{R_2^5}\right\}$$

where:

$z = h + c$

$z_1 = h - c$

$$R_1^2 = \frac{d^2}{4} + x^2 + dx\,cos2\theta + z_1^2$$

$$R_2^2 = \frac{d^2}{4} + x^2 + dx\,cos2\theta + z^2$$

The integral with respect to c is given by:

$$I^p dc = \frac{(1+\vartheta)}{8\pi(1-\vartheta)}\left\{\frac{z_1}{D_1} - 4(1-\vartheta)\ln(z_1 + D_1) + 8(1-2\vartheta+\vartheta^2)\ln(z+D) + \frac{[2h^2z/r^2 - 4h - (3-4\vartheta)z]}{D} + \frac{2(hr^2 - h^2z^3/r^2)}{D}\right\}$$

where:

$$D_1 = \sqrt{(r^2 + z_1^2)}$$

$$D = \sqrt{(r^2 + z^2)}$$

and the limits of integration are:

z_1 from $h - (j-1)d$ to $h - jd$

z from $h + (j-1)d$ to $h + jd$

The integration with respect to θ is evaluated by numerical means.

Displacement of Base Centre due to Stress on Element j

$$l_{bj} = \pi \int_{(j-1)\delta}^{j\delta} l^p \, dc$$

the integral with respect to c is

$$l^p dc = \frac{(1+\vartheta)}{8\pi(1-\vartheta)}\{\frac{z_1}{D_1} - 4(1-\vartheta)\ln(z_1 + D_1) + 8(1 - 2\vartheta + \vartheta^2)\ln(z + D) + \frac{[2h^2 z/r^2 - 4h - (3 - 4\vartheta)z]}{D} + \frac{2(hr^2 - h^2 z^3/r^2)}{D}\}$$

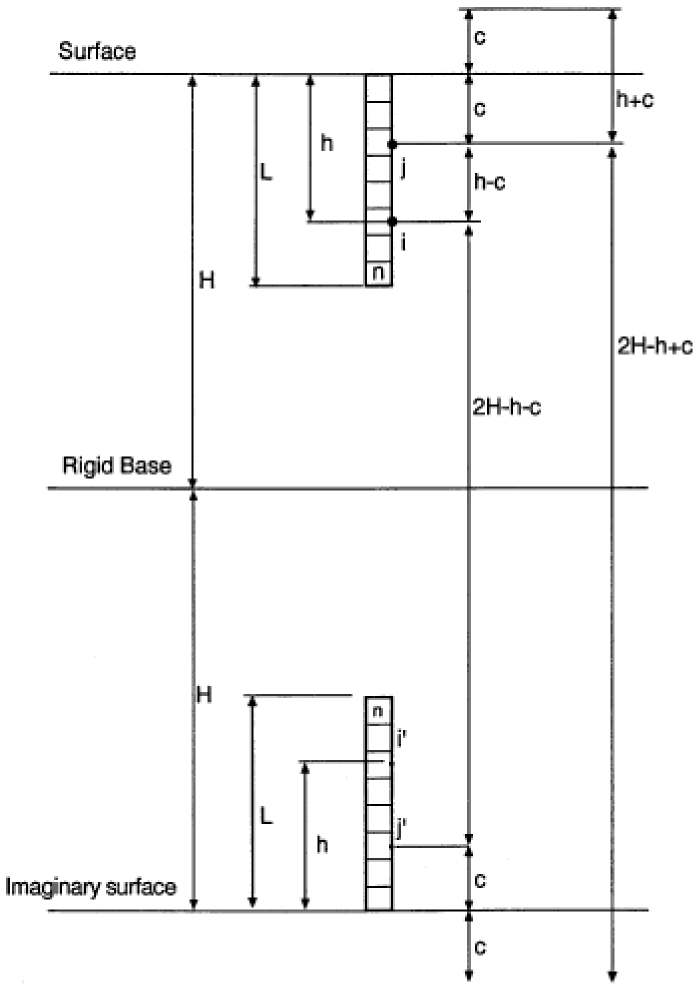
where:

$$h = L$$

$$D^2 = z^2 + \frac{d^2}{4}$$

$$D_1^2 = z_1^2 + \frac{d^2}{4}$$

Displacement of Base due to the Base itself



Geometry of Integration Over Pile Base Area

$$l_{bb} = \frac{\pi^2}{2d}\int_0^{d_b/2} l^p\, r dr$$

with:

$c \quad = L$

$R_1 \quad = r$

$R_2^2 = 4c^2 + r^2$

$z_1 = 0$

therefore:

$$l_{bb} = \frac{\pi(1+\vartheta)}{16(1-\vartheta)d}\{(3-4\vartheta)\frac{d_b}{2} + (5-12\vartheta+8\vartheta^2)(R-z) + \frac{(5-8\vartheta)}{2}z^2\left(\frac{1}{z}-\frac{1}{R}\right) + \frac{z}{2} - \frac{z^4}{2R^3}\}$$

where:

$$R = \sqrt{\left(z^2 + \frac{d_b^2}{4}\right)}$$

$$z = 2L$$

Displacement of Point i due to the Base

$$l_{jb} = \frac{1}{d}\int_0^{2\pi}\int_0^{d_b/2} l^{\rho}\, r dr\, d\theta$$

with:

$$c = L$$

$$R_1^2 = z_1^2 + x^2 + r^2 - 2rx\cos\theta$$

$$R_2^2 = z^2 + x^2 + r^2 - 2rx\cos\theta$$

$$z = z_1 + 2c$$

the integration with respect to *r* is:

$$\begin{aligned} l^{\rho} r\, dr = \frac{(1+\vartheta)}{8\pi(1-\vartheta)} & \left\{\frac{z_1^2(rA-R_0^2)}{(R_0^2-A^2)\sqrt{x_0}} + (3+4\vartheta)\left[\sqrt{x_0} + A\ln\left(r-A+\sqrt{x_0}\right)\right]\right. \\ & + (5-12\vartheta+8\vartheta^2)\left[\sqrt{x_1} + A\ln\left(r-A+\sqrt{x_1}\right)\right] \\ & + \left[(3-4z^2) - 2cz + 2c^2\right]\frac{(rA-R_1^2)}{(R_1^2-A^2)\sqrt{x_1}} \\ & \left. + 2cz^2(z-c)\left[\frac{(rA-R_1^2)}{(R_1^2-A^2)\sqrt[3]{x_1}} + \frac{2A(r-A)}{(R_1^2-A^2)^2\sqrt{x_1}}\right]\right\} \end{aligned}$$

where:

$$R_0^2 = z_1^2 + x^2$$

$$A = x\cos\theta$$

$$x_0 = r^2 - 2Ar + R_0^2$$

$$R_1^2 = z^2 + x^2$$

$$x_1 = r^2 - 2Ar + R_1^2$$

$$z = z_1 + 2c$$

$$c = L$$

The limit of integration is from 0 to $d_b/2$. The integration with respect to θ is evaluated by numerical means.

It is assumed that the influence of the pile base on the displacement of i is negligible, hence

$$I_{ib} = 0$$

Mirror-Image Method

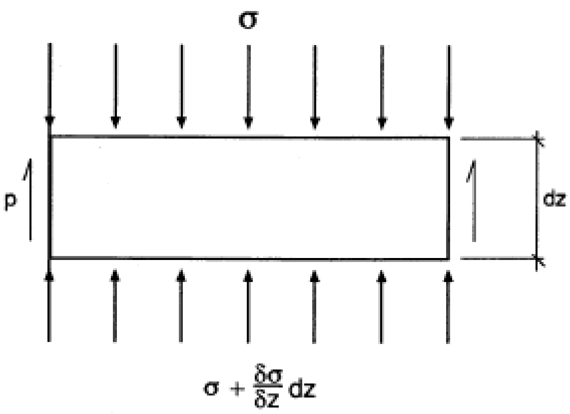
The element l_{ij}' is similar to l_{ij}, but with

$z = 2H - h + c$ and

$z_1 = 2H - h - c$

2.2.3 Pile Stiffness Matrix

In calculating the displacement of the pile itself, only axial compression of the pile is considered.



Consider the vertical equilibrium of a small element of the pile.

An equilibrium equation can be derived as:

$$\frac{\delta\sigma}{\delta z} = -\frac{p\pi d}{A} = -\frac{4p}{R_A d}$$

The axial strain of the element is approximately:

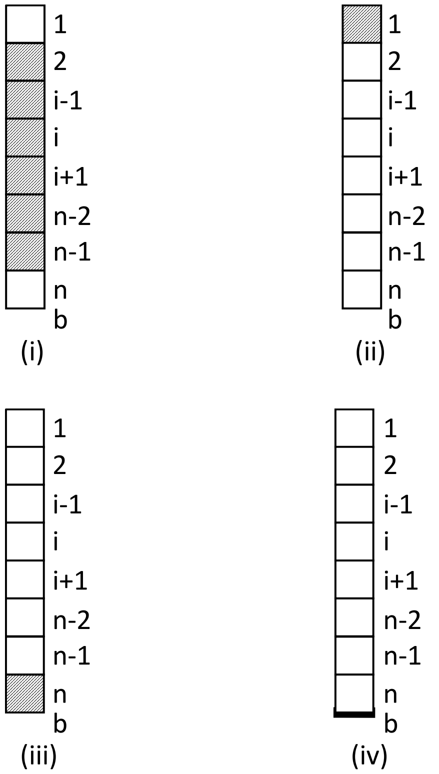
$$\frac{\delta\rho}{\delta z} = -\frac{\sigma}{E^p}$$

therefore:

$$\frac{\delta^2\rho}{\delta z^2} = \frac{4p}{d}\frac{1}{E^p R_A}$$

This is solved by using finite difference method which may be approximately expressed by Taylor Expansion.

Difference Formulations



(i) For 2 ≤ i ≤ n-1

$$\rho_{i-1} = \rho_i - \delta\rho_i' + {}^1\!/_2\,\delta^2\rho_i''$$

$$\rho_{i+1} = \rho_i + \delta\rho_i' + {}^1\!/_2\,\delta^2\rho_i''$$

$$\rho_i'' = \frac{\rho_{i-1} - 2\rho_i + \rho_{i+1}}{\delta^2}$$

therefore:

$$p_i = \frac{d}{4} E^p R_A \frac{(\rho_{i-1} - 2\rho_i + \rho_{i+1})}{\delta^2}$$

(ii) For i = 1

$$\sigma = \frac{F_1}{A}$$

$$\frac{\delta\rho}{\delta z} = -\frac{\delta}{E^p} = -\frac{F_1}{AE^p}$$

$$\rho_1' = \rho_1 - \delta\rho_i'$$

$$\rho_1' = \frac{\rho_1 - \rho_1'}{\delta} = -\frac{F_1}{AE^p}$$

$$\rho_1' = \rho_1 + \frac{F_1\delta}{AE^p}$$

$$p_1 = \frac{d}{4} E^p R_A \frac{(-\rho_1 + \rho_2)}{\delta^2} + \frac{F_1}{\pi d \delta}$$

(iii) For i = n

$$\rho_b = \rho_n + {}^1/_2\,\delta\rho_n' + \frac{\delta^2}{8}\rho_n''$$

$$\rho_{n-2} = \rho_n + 2\delta\rho_n' + 4\delta^2\rho_n''$$

so:

$$16\rho_b - \rho_{n-2} - 15\rho_n = 10\delta\rho_n'$$

$$\rho_{n-1} = \rho_n - \delta\rho_n' + {}^1/_2\,\delta^2\rho_n''$$

or:

$$\rho_n' = \frac{1}{\delta}(\rho_n - \rho_{n-1} + {}^1/_2\,\delta^2\rho_n'')$$

so:

$$16\rho_b - \rho_{n-2} - 15\rho_n = 10(\rho_n - \rho_{n-1} + {}^1/_2\,\delta^2\rho_n'')$$

$$\rho_n'' = \frac{1}{\delta^2}(-0.2\rho_{n-2} + 2\rho_{n-1} - 5\rho_n + 3.2\rho_b)$$

therefore:

$$\rho_n = \frac{d}{4}\frac{E^p R_A}{\delta^2}(-0.2\rho_{n-2} + 2\rho_{n-1} - 5\rho_n + 3.2\rho_b)$$

(iv) For pile base:

$$\rho_n = \rho_b - {}^1/_2\,\delta\rho_b' + \frac{\delta^2}{8}\rho_b''$$

$$\rho_{n-1} = \rho_b - \frac{3}{2}\delta\rho_b' + \frac{9}{8}\delta^2\rho_b''$$

so:

$$\rho_b' = \frac{\rho_{n-1} - 9\rho_n + 8\rho_b}{3\delta} = \frac{-p_b}{E^p}$$

therefore:

$$p_b = \frac{d}{4}\frac{E^p R_A}{\delta^2}\frac{\delta}{dR_A}(-\frac{4}{3}\rho_{n-1} + 12\rho_n - \frac{32}{3}\rho_b)$$

$$p_b = \frac{d}{4}\frac{E^p R_A}{\delta^2}(-\frac{4}{3}f\rho_{n-1} + 12f\rho_n - \frac{32}{3}f\rho_b)$$

where:

$$R_A = \frac{A}{{}^1/_4\,\pi d^2}$$

$$f = \frac{\delta}{dR_A}$$

Pile Stiffness

The pile stiffness matrix is given by:

$$\frac{d}{4}\frac{E^p R_A}{\delta^2}\begin{bmatrix} -1 & 1 & 0 & 0 & \dots & \dots & \dots & 0 \\ 1 & -2 & 1 & 0 & \dots & \dots & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & -2 & 1 \\ 0 & 0 & 0 & 0 & -0.2 & 2 & -5 & 3.2 \\ 0 & 0 & 0 & 0 & 0 & -1.33f & 12f & -10.67f \end{bmatrix}$$

3 Input Data

3.1 Assembling Data

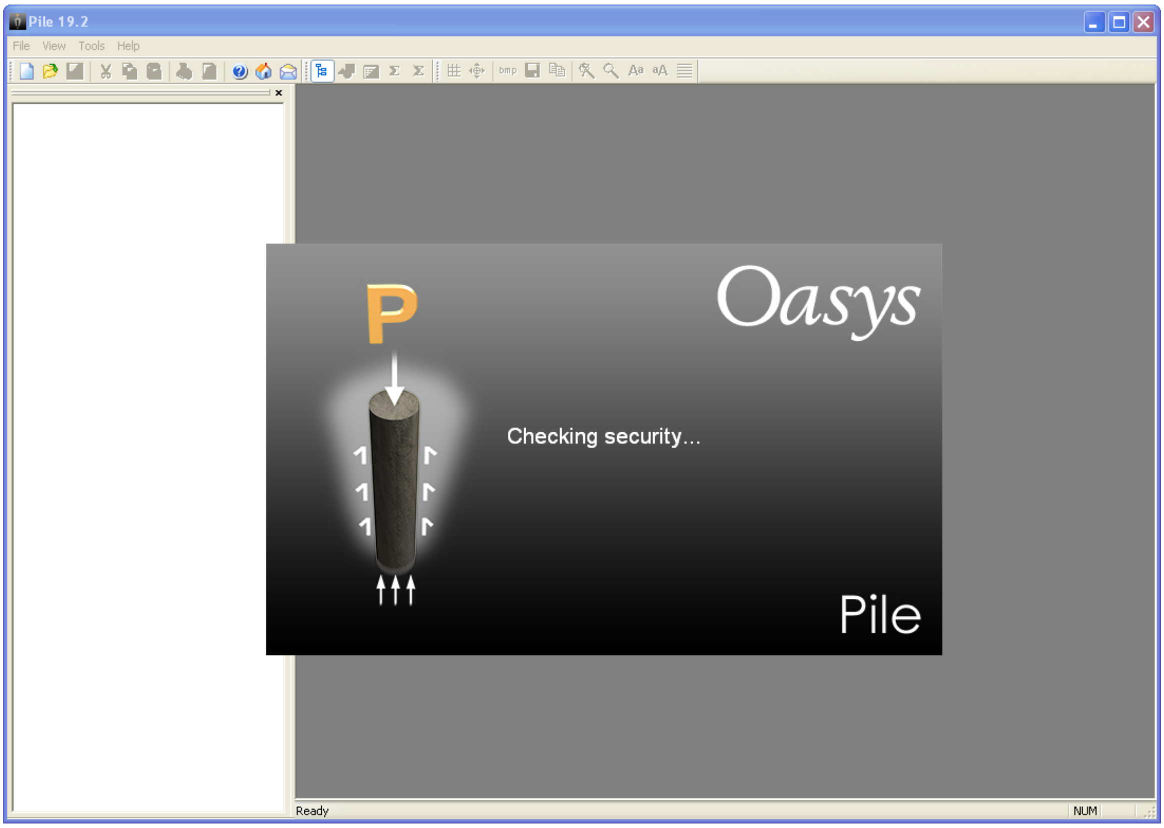
Details of the following should be gathered:

- the drained/undrained parameters of the different soil materials at the proposed site;
- ground water data - phreatic surface location and piezometric pressure distribution elevations if needed;
- soil layer levels;
- geometry of the pile and cross-section information, and depth of the pile.

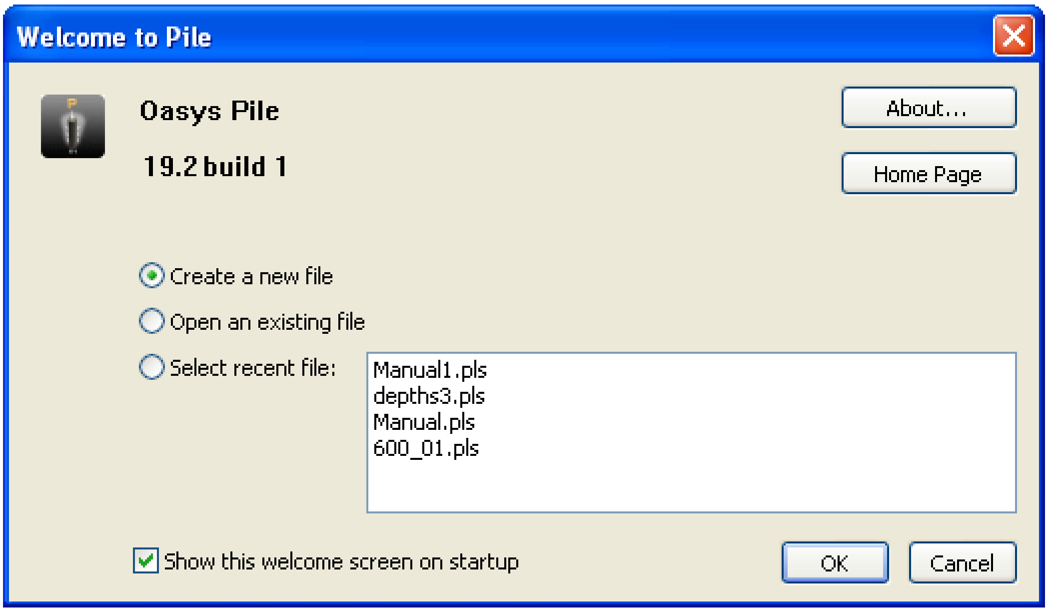
3.2 Opening the Program

The following provides details of all the information required to run the **Pile** program.

On selection of the **Pile** program the main screen will open.



To start a new project file select "Create a new file" option on the opening screen.



If the "Show this welcome screen on startup" option is unchecked then this dialog will not be displayed on startup. In that case a new data file may be created by clicking

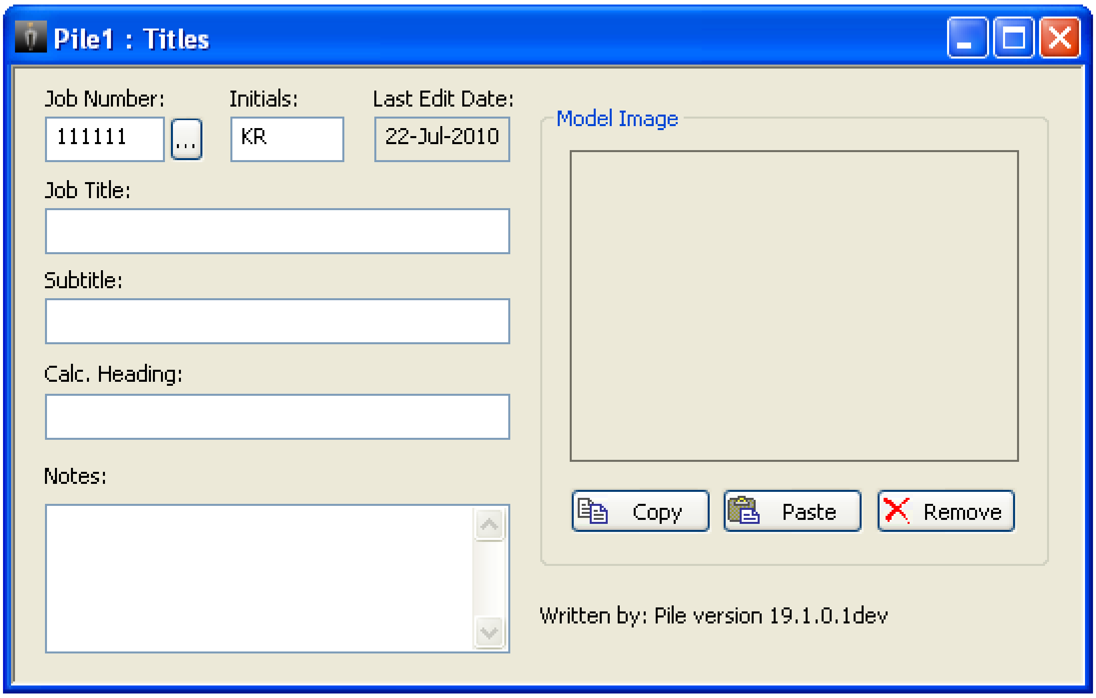
File | New on main menu or the corresponding icon  on toolbar.

This will open a new Titles window and allow you to proceed.

To display Welcome to Pile at startup, check "Show welcome screen" in Preferences dialog. Preference dialog can be accessed via Tools | Preferences.

It is possible to open more than one data file at any one time. The file name is therefore displayed in the title bar at the top of each child window.

It is possible to open legacy Pile and Pilset files in this version. (In this version limiting shaft skin friction is calculated from the material properties, so reading of limiting shaft skin friction from a Pilset file is ignored.)



3.2.1 Intranet link and emails

To view the latest information regarding the **Pile** program or to contact the support team click on the internet  or  support team buttons on the Start screen or select them from the standard toolbar.

The list below gives information that should be gathered and action that should be taken before contacting the support team.

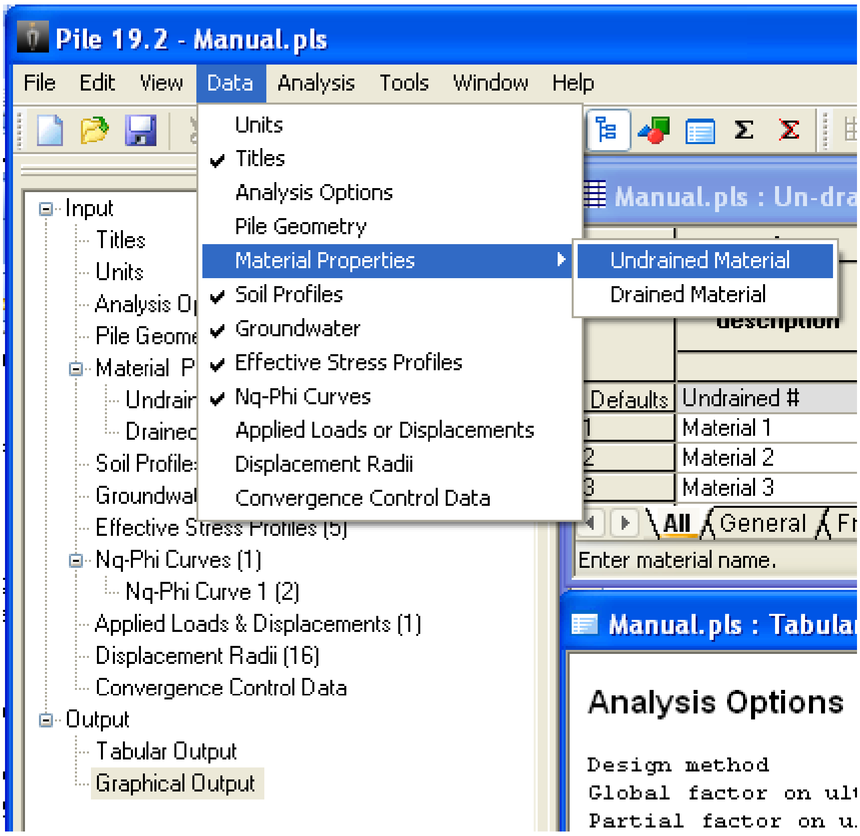
- Version of **Pile** (see top bar of program or Help | About **Pile**);
- Specification of machine being used;
- Type of operating system;
- Pre-check all input data;
- Access help file for information;
- Check web site for current information;
- Should a program malfunction be specified then attempt to repeat and record the process prior to informing the team.

The web site aims to remain up to date with all data regarding the program and available versions. Should any malfunctions persist then the work-around or fix will be posted on the web site.

The input file can be emailed to the support team by choosing the 'Help | Email' from the program menu

3.3 Data Input

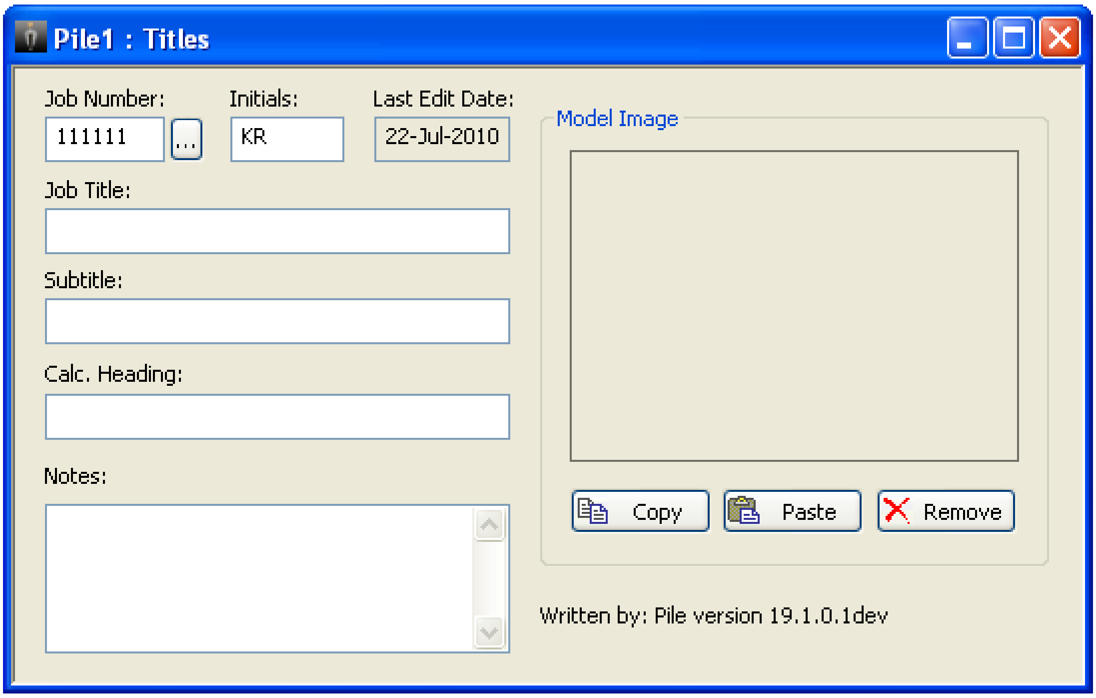
Data is input via options that are available via the Data menu, or via the Gateway.



For options other than "Units and Preferences" and "Analysis Options" a check mark is placed against the option once data has been entered.

3.3.1 Titles

The first window to appear, for entry of data into **Pile**, is the Titles window.



This window allows entry of identification data for each program file. The following fields are available.

Job Number allows entry of an identifying job number. By clicking the drop-down button, the user can access the job numbers previously used.

Initials for entry of the users initials.

Date this field is set by the program at the date the file is saved.

Job Title allows a single line for entry of the job title.

Subtitle allows a single line of additional job or calculation information.

Calculation Heading allows a single line for the main calculation heading.

The titles are reproduced in the title block at the head of all printed information for the calculations. The fields should therefore be used to provide as many details as possible to identify the individual calculation runs.

Notes allow the entry of a detailed description of the calculation. This can be reproduced at the start of the data output by selection of notes using File | Print Selection.

3.3.1.1 Titles window - Bitmaps

The box in the right of the Titles window can be used to display a picture beside the file titles.

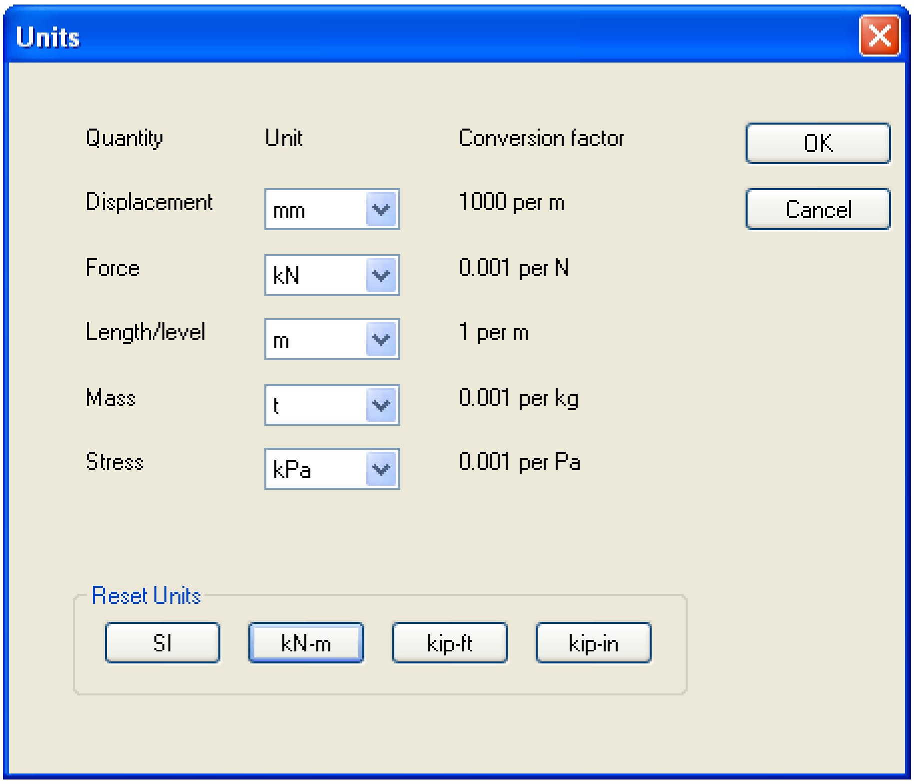
To add a picture, place an image on to the clipboard. This must be in a RGB (Red / Green / Blue) Bitmap format. Select the "Paste Bitmap" button to place the image in the box.

The image is purely for use as a prompt on the screen and can not be copied into the output data. Care should be taken not to copy large bitmaps, which can dramatically increase the size of the file.

To remove a bitmap select the button "Remove Bitmap".

3.3.2 Units

The Units dialog is accessible via the Gateway, or by choosing Data | Units from the program's menu. It allows the user to specify the units for entering the data and reporting the results of the calculations. These choices are stored in, and therefore associated with, the data file.



Default options are the Système Internationale (SI) units - kN and m. The drop down menus provide alternative units with their respective conversion factors to metric.

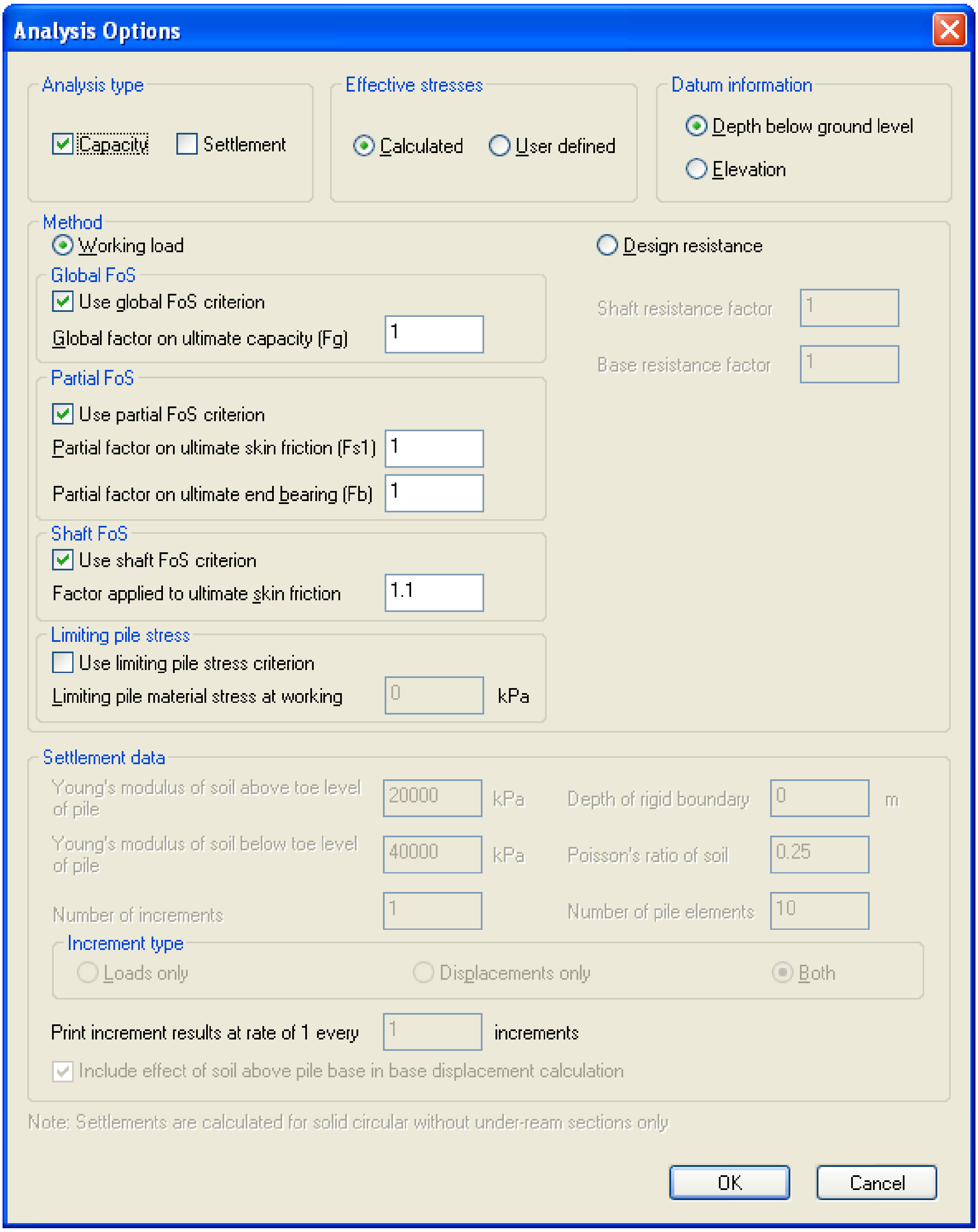
Standard sets of units may be set by selecting any of the buttons: SI, kN-m, kip-ft kip-in.

Once the correct units have been selected click 'OK' to continue.

SI units have been used as the default standard throughout this document.

3.3.3 Analysis Options

The following general data is entered to define the outline of the problem and type of analysis to be carried out.



Analysis type

Type of analysis can be selected - either Capacity or Settlement or both. If only Capacity analysis is selected then the data input for Settlement will be disabled, and vise versa.

Effective Stresses

The user can select either of the following options,

Calculated - the effective stresses in the soil layers are calculated by the program.

User-defined - the user specifies the effective stress profiles (both vertical stress profile and horizontal stress profile) to be used by the program in calculating the pile capacity.

Datum Information

There are two choices for datum.

- Depth below Ground Level

- Elevation (above Ordnance Datum).

Method

This data is required for Capacity calculation. There are two options available:

- **Working Load**

The following factors of safety must be specified.

Global factor on ultimate capacity

Partial factor on ultimate skin friction

Partial factor on end bearing

Factor applied to ultimate skin friction

In working load option, the user should select select at least one of the following combinations:

- global factor of safety on total bearing capacity

- partial factors of safety on shaft skin friction and end bearing

- factor of safety on shaft skin friction only

The user may also include the limiting pile stress criterion if needed.

The program calculates the minimum capacity from all the selected combinations and prints it as the allowable capacity.

- **Design Resistance**

The following factors must be specified.

Shaft resistance factor

Base resistance factor

For information about the design resistance approach and working load approach, refer the topics Limit State Approach and Working Load Approach.

Limiting Pile Material Stress at Working Load the value of the maximum allowable stress in the pile material. This represents only for the "Working Stress" approach.

Settlement data

Settlement data is enabled when settlement analysis is selected.

Young's Modulus of soil above toe level of pile and Young's Modulus of soil below toe level of pile are average value representing the soil stiffness above and below the pile toe respectively.

Include effect of soil above pile base in base displacement calculation

For calculation of stiffness at the base node user can Include/exclude effect of soil above pile base.

Number of pile elements - the pile is divided into the number of elements and Pile Stiffness is calculated for each element.

Number of increments - the load is applied in a number of equal increments, and

Increment type - i.e. whether load alone is incremented, or applied displacement alone is incremented, or both of them are incremented.

Increasing the increments helps to reduce any incompatibilities between relative displacements at the pile-soil interface, and the mobilized skin friction.

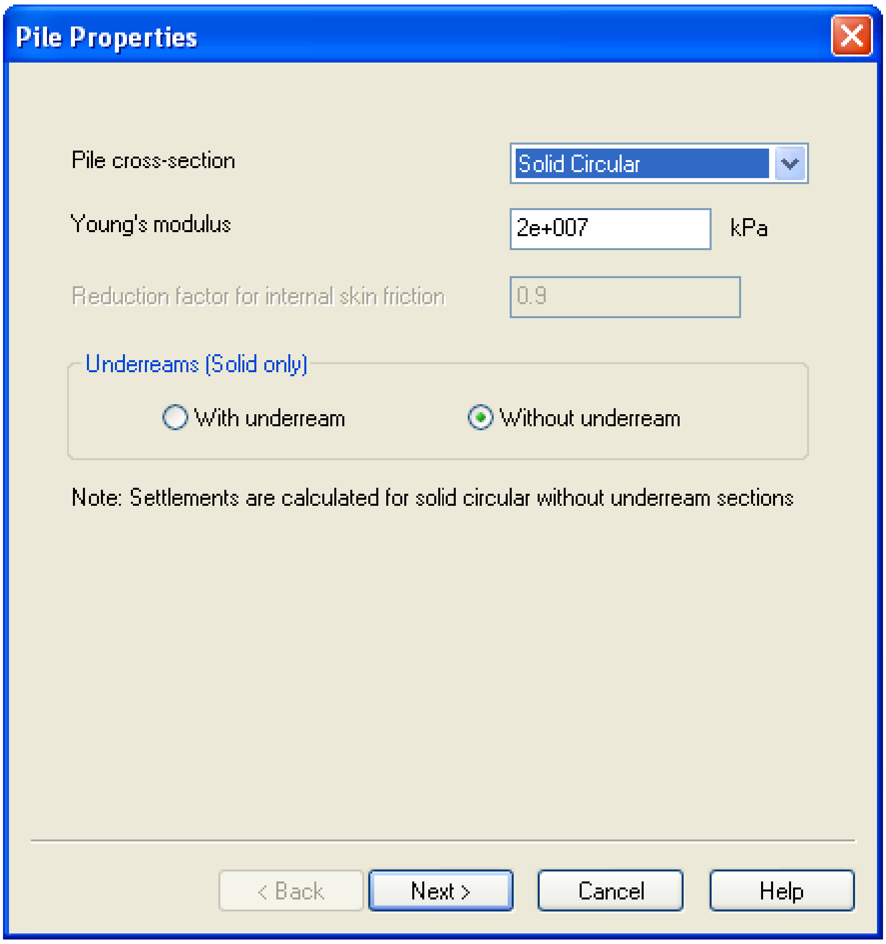
The user may also specify the rate at which the results from various increments need to be printed, i.e one in every 10 increments etc. Irrespective of the frequency specified, the program always prints the last increment.

3.3.4 Pile Geometry

Pile Geometry contains information regarding the type of pile, the length of the pile, cross-section and under-ream dimensions.

3.3.4.1 Pile Properties

The **Pile Properties** dialog presents the following input data.



Pile cross-section

Different types of cross-sections available are Solid Circular, Hollow Circular, Solid Square, Hollow Square and H-Pile.

Settlements are calculated for solid circular without under-ream sections only. If as other cross-section type is selected, an error message will popup at the time of analysis.

Young's modulus

This is used in the settlement calculation.

Under-reams (Solid only)

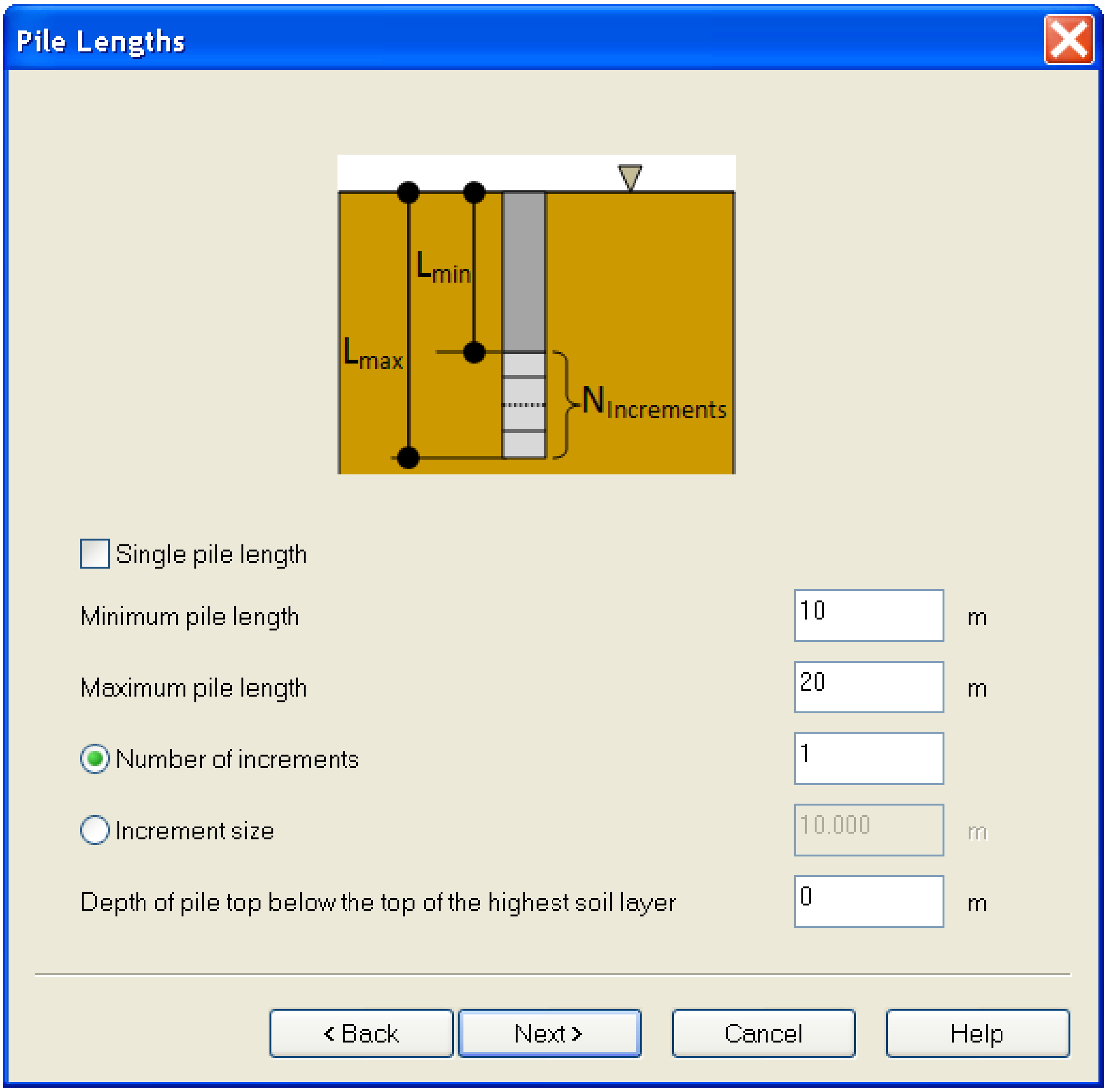
This option is available only if the user selects "Solid" pile type.

Reduction Factor for Internal Skin Friction

This factor is used in calculating the internal skin friction.

3.3.4.2 Pile Lengths

The **Pile Lengths** dialog presents the following input data.



Single pile length - If checked then capacity and settlements are calculated for one pile length only.

Minimum Pile Length - the minimum pile length for which the pile capacity to be calculated.

Maximum Pile Length - the maximum pile length for which the pile capacity to be calculated.

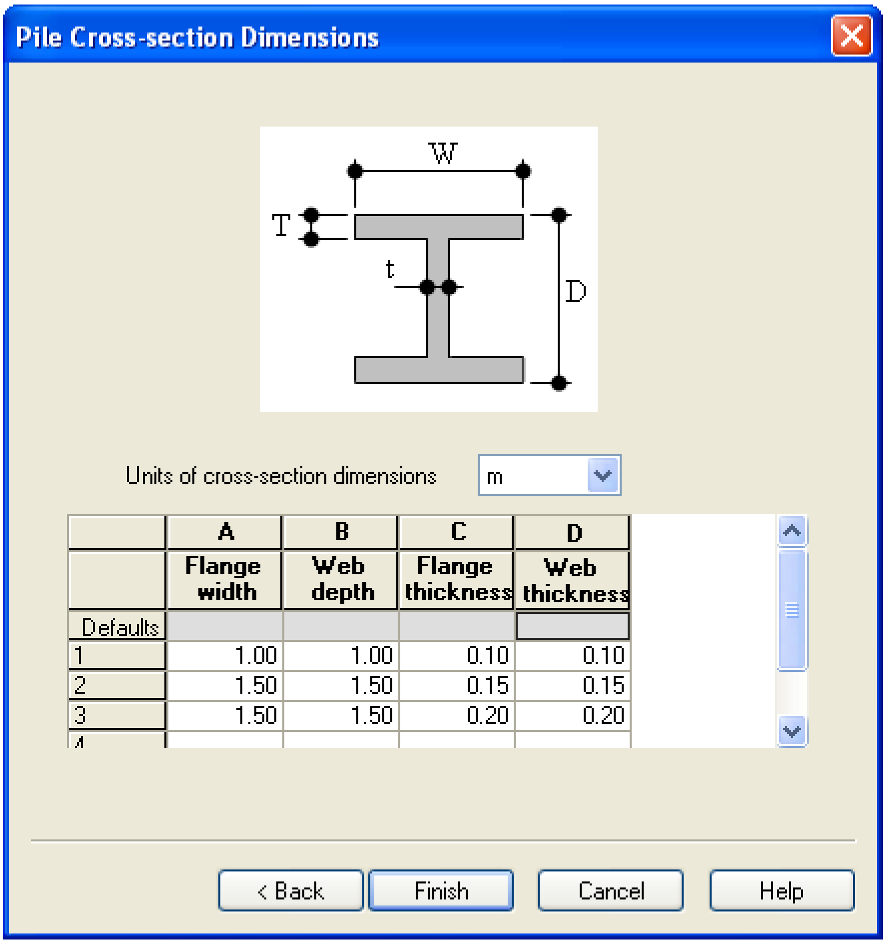
Number of Increments - the number of increments between the minimum and maximum pile depth for which the pile capacity to be calculated.

Quantities like skin friction, plugged capacity etc. do not vary linearly with depth. The accuracy of such calculations can be improved by choosing a sufficient number of increments.

Depth of pile top below the top of the highest soil layer - is the difference in height between the highest soil layer and the top of the pile. If this value is positive, it is used to represent basement piles. If this value is negative, it is used to represent general and local scour if the water table is above ground level.

3.3.4.3 Pile Cross-section Dimensions

The **Pile Cross-section Dimensions** dialog presents the following input data.



The user can choose to enter multiple cross sections - one per row of the table.

Circular cross-section

- Shaft Diameter outside;
- Shaft Wall Thickness (for hollow piles only);
- Wall Thickness at Base (for hollow piles only).

Square cross-section

- External Side Width;

- Shaft Wall Thickness (for hollow piles only);
- Wall Thickness at Base (for hollow piles only).

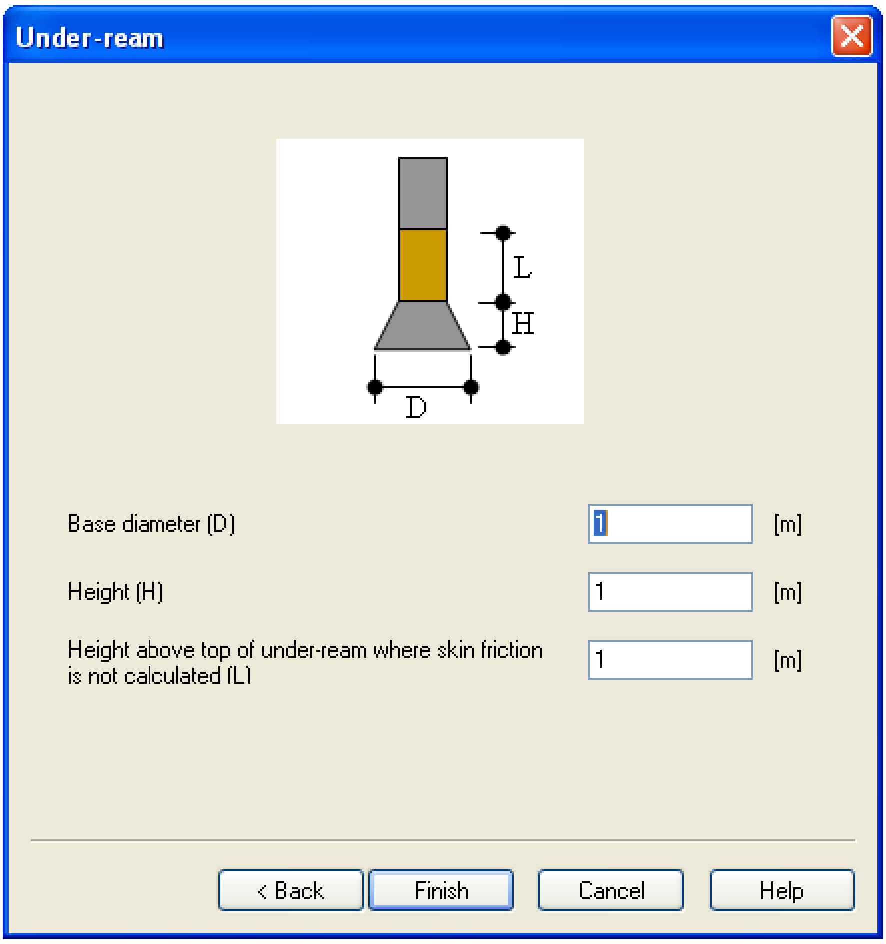
H-Pile

- Depth along Web;
- Width along Flanges;
- Average Web Thickness;
- Average Flange Thickness.

Units of cross-section dimensions - specifies the required units for entering cross-section data in this dialog.

3.3.4.4 Under-ream

The **Under-ream** dialog presents the following input data.



- Base diameter;

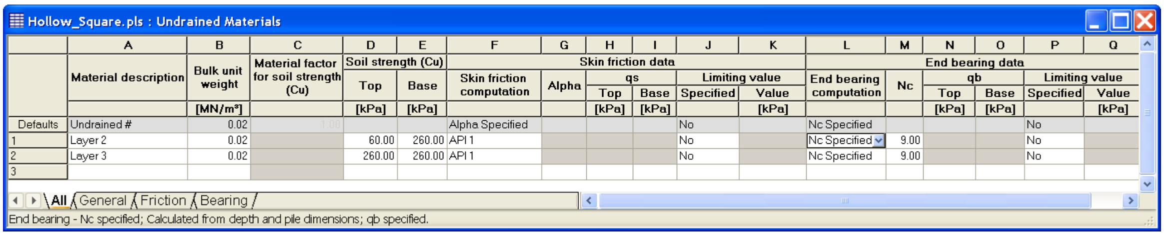
- Height of the under-ream;
- Height above top of under-ream where skin friction is neglected.

3.3.5 Material Properties

The **Material Properties** dialog presents the following input data.

3.3.5.1 Undrained Material

Each record in the **Undrained Material** table consists of the following items.



Material description - brief descriptions for the material types can be entered here.

Bulk unit weight - bulk unit weight of the soil layer.

Material factor for soil strength - this factor that needs to be applied to cohesive strength or friction angle depending on type of material.

When the user selects "Working load" method in the "Analysis options", the "Material factor for soil strength" field is greyed out completely. This is active only when the "Design resistance" method is chosen in the "Analysis options".

Soil strength(C_u)

Top - undrained shear strength of the total stress material at the top of the layer.

Bottom - undrained shear strength of the total stress material at the top of the layer.

When the bottom most layer in the model is assigned a "Total stress" material, the cohesion with in the layer is assumed to be constant with value of cohesion specified at the top of the layer - "C_u-Top". The cohesion at the bottom of layer, "C_u-Bottom" is ignored in this case.

The following fields relate to **Friction data**

Method - method of calculating Alpha, the adhesion factor. This is one of API method 1, API method 2, or user-specified value of Alpha.

Alpha - adhesion factor, if specified by user.

Limiting value

Specified - select 'Yes' to specify limiting value.

Value - friction value is limited to this value.

When the limiting value of the frictional shear stress is entered as zero, the maximum allowable frictional shear stress between the pile and the material is assumed to be infinite.

The following fields are related to **End bearing**

Method - method of calculating N_c, the bearing capacity factor. This is one of user-specified or calculated.

N_c - value of bearing capacity factor, if specified by the user.

Limiting value

Specified - select 'Yes' to specify limiting value.

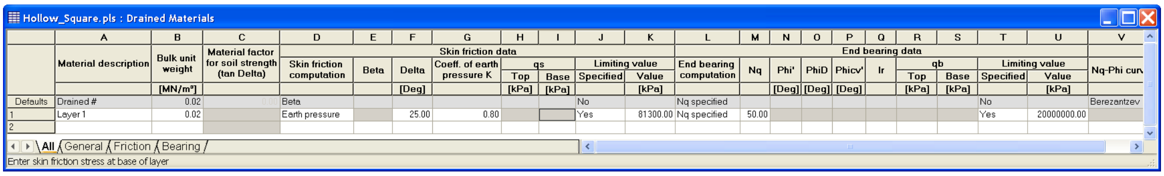
Value - bearing value is limited to this value.

When the limiting value of the end bearing stress is entered as zero, the maximum allowable end bearing stress for the given material is assumed to be infinite.

For information about the methods used to evaluate pile capacities using the total stress approach please refer to the topics: Shaft friction - Total stress approach and End bearing - Total stress approach.

3.3.5.2 Drained Material

Each record in the **Drained Material** table consists of the following items


Hollow_Square.pls : Drained Materials

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
				Skin friction data								End bearing data										
	Material description	Bulk unit weight	Material factor for soil strength (tan Delta)	Skin friction computation	Beta	Delta	Coeff. of earth pressure K	qs		Limiting value		End bearing computation	Nq	Phi'	PhiD	Phicv'	Ir	qb		Limiting value		Nq-Phi curv
								Top	Base	Specified	Value							Top	Base	Specified	Value	
		[MN/m³]				[Deg]		[kPa]	[kPa]		[kPa]			[Deg]	[Deg]	[Deg]		[kPa]	[kPa]		[kPa]	
Defaults	Drained #	0.02	0.00	Beta						No		Nq specified								No		Berezantzev
1	Layer 1	0.02		Earth pressure		25.00	0.80			Yes	81300.00	Nq specified	50.00							Yes	20000000.00	
2																						

All / General / Friction / Bearing

Enter skin friction stress at base of layer

Material description - brief descriptions for each of the material types can be entered here.

Bulk unit weight - bulk unit weight of the soil layer.

Material factor for soil strength - material factor that needs to be applied to cohesive strength or friction angle depending on type of material.

When the user selects "Working load" method in the Analysis options, the "Material factor for soil strength" field is greyed out completely. This is active only when the "Design resistance" method is chosen in the Analysis options.

The following fields relate to **Friction data**

Skin friction computation method - either Beta Method or Earth Pressure Method.

Beta - value of beta.

Delta - friction angle.

Coefficient of earth pressure K - is used to calculate horizontal effective stress from vertical effective stress.

This filed is enabled when "Effective stresses" in Analysis options is selected as calculated.

Limiting value

Specified - select 'Yes' to specify limiting value.

Value - friction value is limited to this value.

When the limiting value of the frictional shear stress is entered as zero, the maximum allowable frictional shear stress between the pile and the material is assumed to be infinite.

The following fields relate to **End bearing**

Nq computation method - either of user-specified, Bolton or Berezantzev.

Nq - value of bearing capacity factor Nq.

Phi' - value of effective friction angle for the soil profile.

PhiD- value of angle of internal friction corresponding to the soil of overburden.

Phicv' - value of critical state angle of friction.

Ir - value of the corrected relative density (0 to 1).

Limiting value

Specified - select 'Yes' to specify limiting value.

Value - bearing value is limited to this value.

When the limiting value of the end bearing stress is entered as zero, the maximum allowable end bearing stress for the given material is assumed to be infinite.

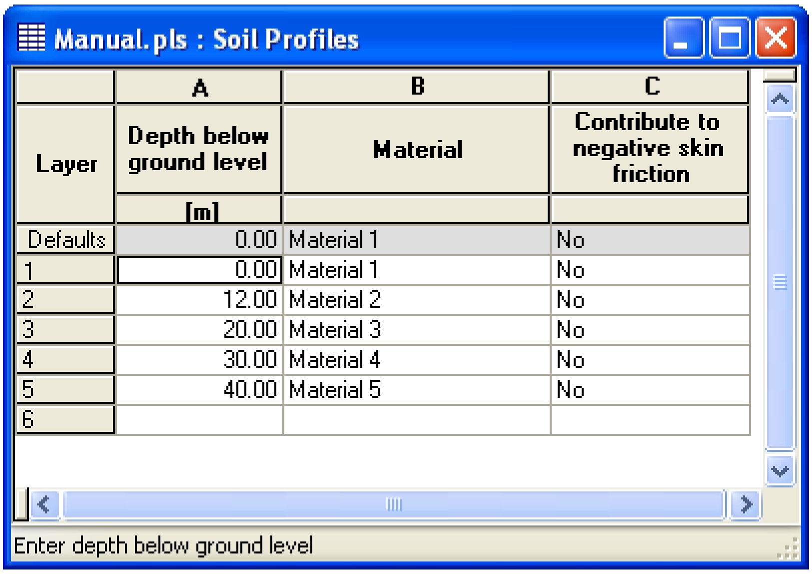
Nq-Phi Curve - used for calculating the value of Nq from friction angle, Phi.

This option becomes available for Berezantzev and Bolton methods. "Berezantzev Ak Bk Curves" or user-defined Nq-Phi curves may be selected.

For information about the methods used to evaluate pile capacities using the effective stress approach refer to the topics: Shaft friction - Effective stress approach and End bearing - Effective stress approach.

3.3.6 Soil Profiles

Each record in the **Soil Profiles** table consists of the following items.



	A	B	C
Layer	Depth below ground level [m]	Material	Contribute to negative skin friction
Defaults	0.00	Material 1	No
1	0.00	Material 1	No
2	12.00	Material 2	No
3	20.00	Material 3	No
4	30.00	Material 4	No
5	40.00	Material 5	No
6			

Level at Top/ Depth below ground level - level of the top of each layer according to the datum chosen

The levels must be entered in decreasing order if datum information is elevation in Analysis options dialog.

The depths must be entered in increasing order if datum information is depths in Analysis options dialog.

Material - the soil material that is present in the layer.

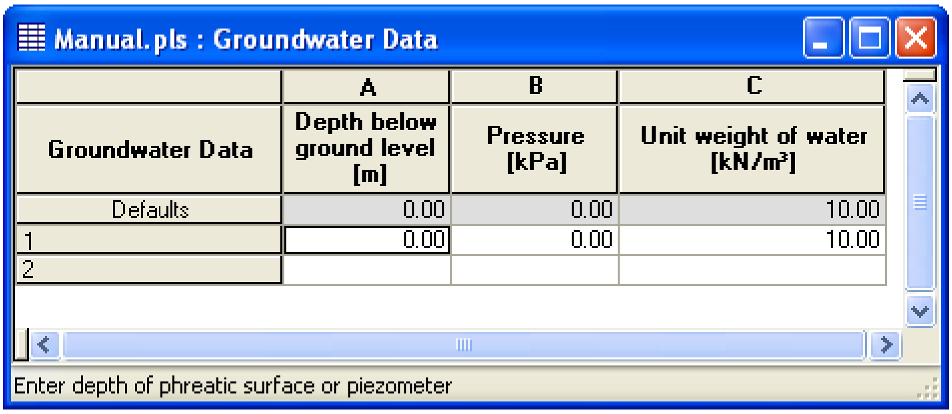
Contribute to Negative Skin Friction - whether the layer contributes to negative skin friction.

This was material specific in earlier versions of Pile, it is now layer specific.

3.3.7 Groundwater

A single groundwater profile is entered to surround the pile. This can be hydrostatic or piezometric.

Each record in the **Groundwater** table consists of the following items.



Level/ Depth below ground level - level/depth at which the pressure is the specified.

Pressure - pressure at the level/depth when a piezometric profile is entered.

Unit weight of water - the value of unit weight of water. The entry in the first record alone is available for input.

This first line of the table allows a single value for the unit weight of water to be added. On subsequent lines, levels/depths and pressures can be entered to create a piezometric profile. Interpolation between the points is linear and the water profile beneath the lowest point is assumed to be hydrostatic.

If only one data point is entered the program will also assume a hydrostatic groundwater distribution.

For hydrostatic distributions the water pressure (u) is calculated from:

$u = z_w \gamma_w$

where:

z_w = depth below water table level

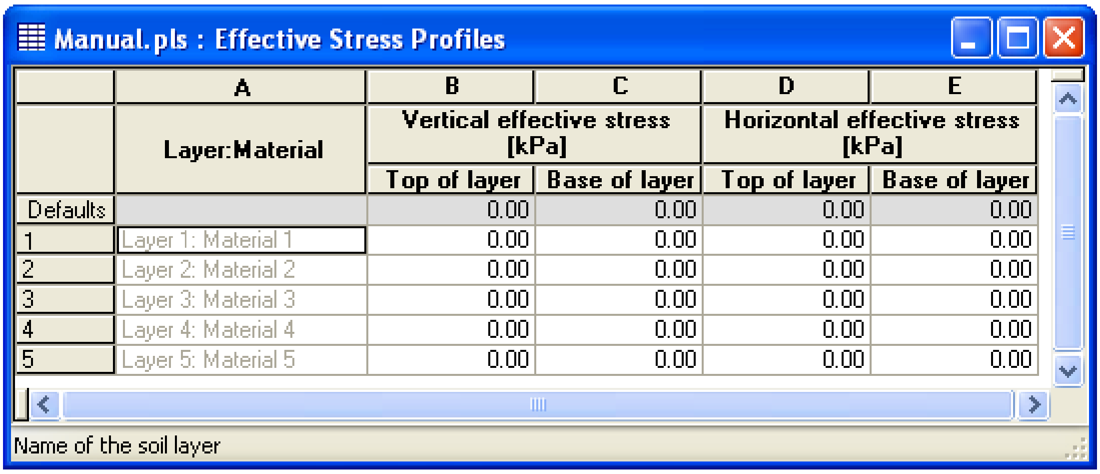
γ_w = specified unit weight of water

Thus a partial hydrostatic condition can be modelled by specifying a value of γ_w less than $10 kN/m^3$.

For piezometric profiles the level/depth and pressure at each known point must be entered. If more than one data point is entered, the program will assume that the points represent piezometers, and the ground water pressure will be interpolated vertically between the specified points. Below the lowest point, groundwater pressure will be assumed to extend hydrostatically.

3.3.8 Effective Stress Profiles

Each record in the **Effective Stress Profiles** table consists of the following items.


Manual.pls : Effective Stress Profiles

	A	B	C	D	E
	Layer:Material	Vertical effective stress [kPa]		Horizontal effective stress [kPa]	
		Top of layer	Base of layer	Top of layer	Base of layer
Defaults		0.00	0.00	0.00	0.00
1	Layer 1: Material 1	0.00	0.00	0.00	0.00
2	Layer 2: Material 2	0.00	0.00	0.00	0.00
3	Layer 3: Material 3	0.00	0.00	0.00	0.00
4	Layer 4: Material 4	0.00	0.00	0.00	0.00
5	Layer 5: Material 5	0.00	0.00	0.00	0.00

Name of the soil layer

Layer:Material - the soil material that is present in the layer.

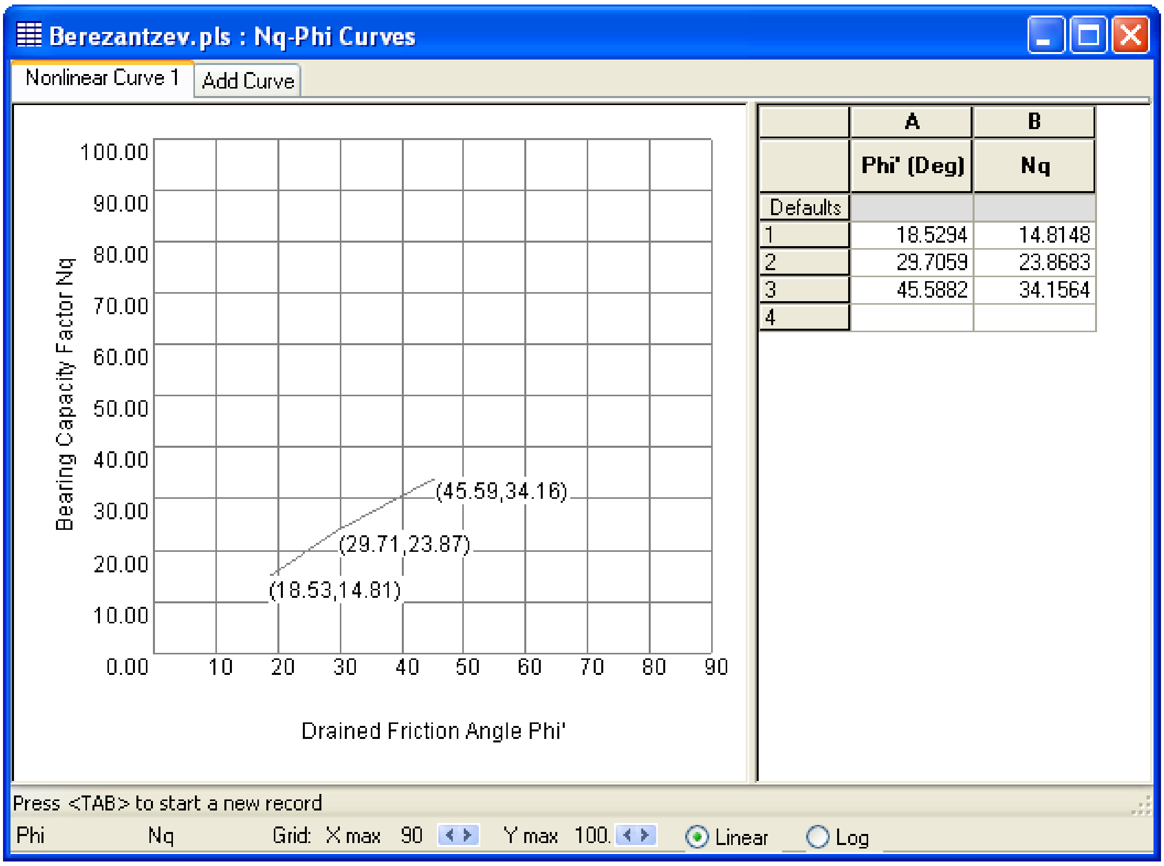
Vertical effective stress - user-defined vertical effective stress profile is entered here.

Horizontal effective stress - user-defined horizontal effective stress profile is entered here.

The vertical and horizontal effective stresses at any intermediate level are linearly interpolated between top and bottom of layer.

3.3.9 Nq-Phi Curves

Each record in the **Nq-Phi** table consists of the following items.



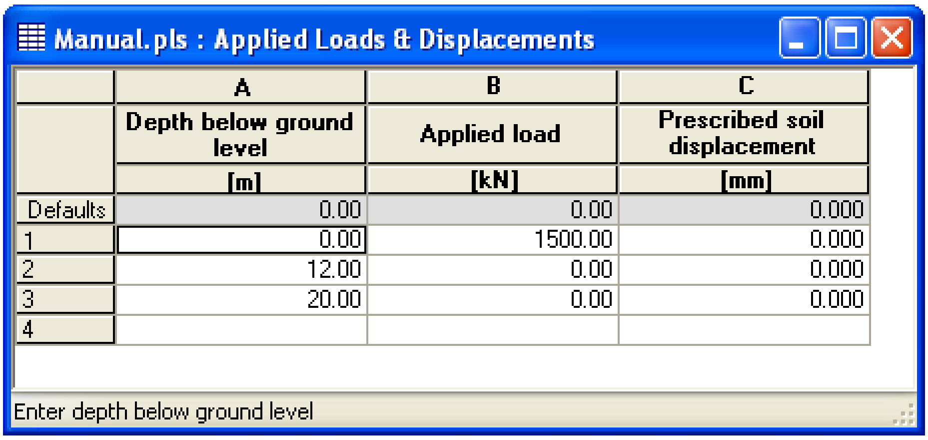
Phi' - the effective friction angle.

N_q - the value of bearing capacity factor at the given friction angle.

This table is used by the Berezantzev (1961) and Bolton (1984) methods for calculating N_q.

3.3.10 Applied Loads & Displacements

Each record in the **Applied Loads & Displacements** table consists of the following items.



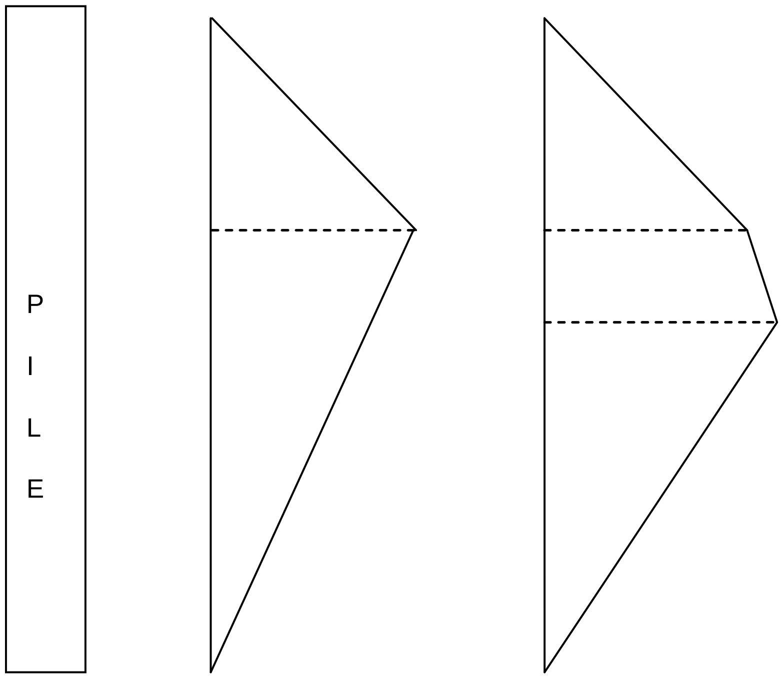
Level/ Depth below ground level - level/depth at which the pressure is the specified.

Applied load - downward positive and upward negative.

Prescribed soil displacement - heave is defined as negative displacement and settlement as positive displacement. i.e soil moving upward negative and downward positive.

The data are specified at appropriate levels down the pile. The data can be entered in any order, the program internally arranges levels and interpolates between the levels to determine the values of prescribed soil displacement at each node down the pile. It assumes zero displacement at top and bottom of pile if not entered.

Interpolation of prescribed displacement down the pile:

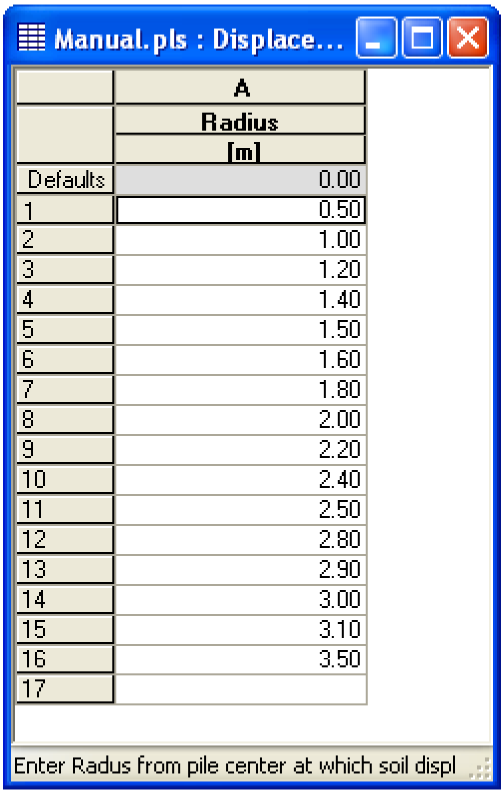


Single data is entered for prescribed displacement

Multiple data is entered for prescribed displacement

3.3.11 Displacement Radii

Each record in the **Displacement Radii** table consists of the following items.


Manual.pls : Displace...

	A Radius [m]
Defaults	0.00
1	0.50
2	1.00
3	1.20
4	1.40
5	1.50
6	1.60
7	1.80
8	2.00
9	2.20
10	2.40
11	2.50
12	2.80
13	2.90
14	3.00
15	3.10
16	3.50
17	

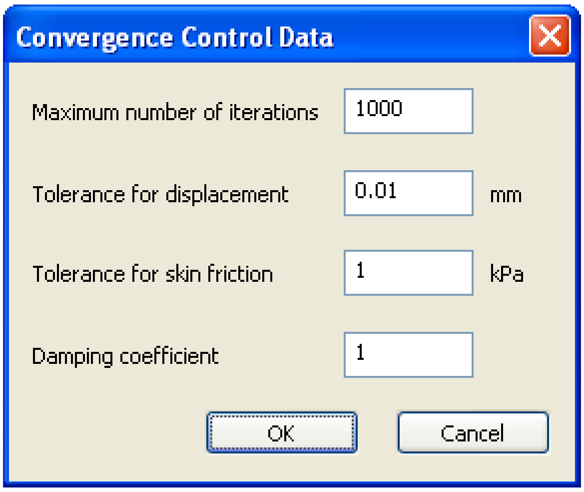
Enter Radus from pile center at which soil displ

Radius - enter the radius from the pile at which soil displacements are to be calculated.

If displacement radius entered is less then the shaft/base radius, the displacements are calculated at the interface of pile and soil. (i.e. at the radius of shaft/base)

3.3.12 Convergence Control Data

The **Convergence Control Data** dialog presents the following input data.



Tolerance for displacement - the maximum change of displacement between successive iterations. The absolute error will be considerably larger (typically by a factor of 100).

Tolerance for skin friction - the maximum error in the shaft skin friction (ie. how much the skin friction exceeds the limiting value). This is an absolute value.

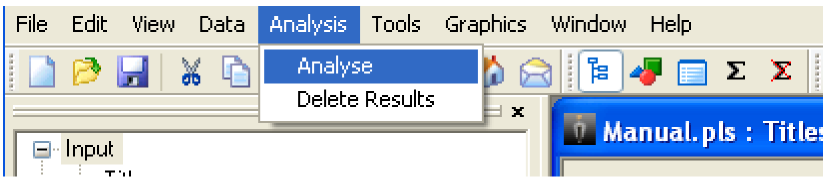
Damping coefficient - can be enhanced if convergence is slow.

If instability is apparent it may possibly be solved by reducing this coefficient.

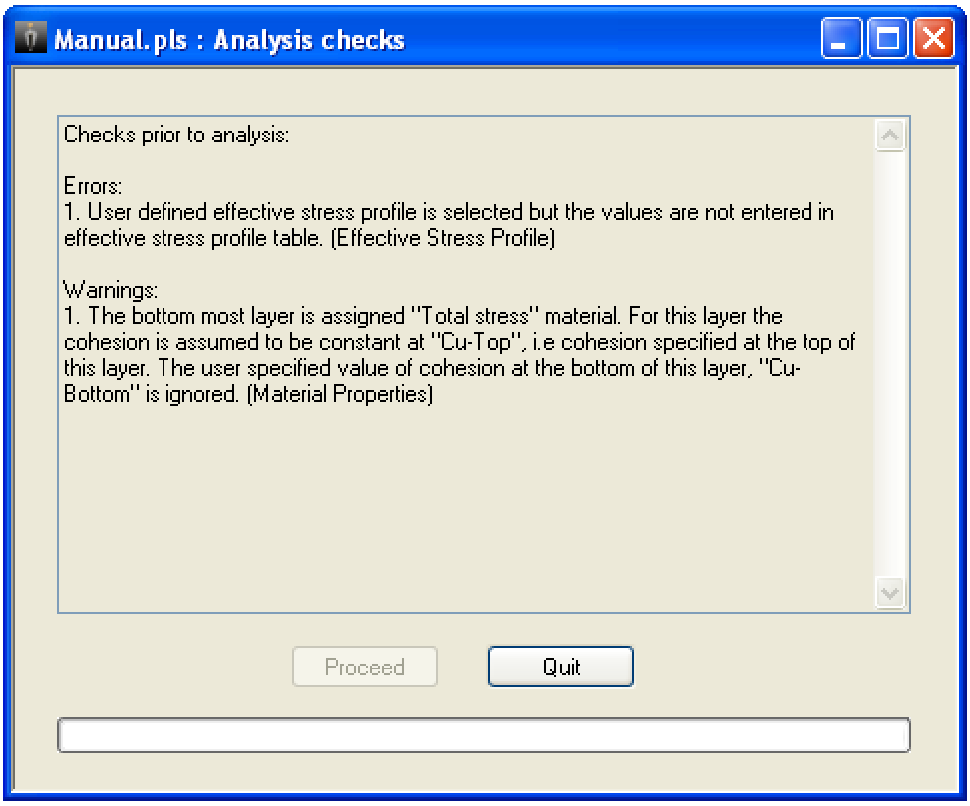
4 Output

4.1 Analysis and Data Checking

The data can be analysed via Analysis | Analyse from the program menu or the analysis button  on the analysis toolbar.

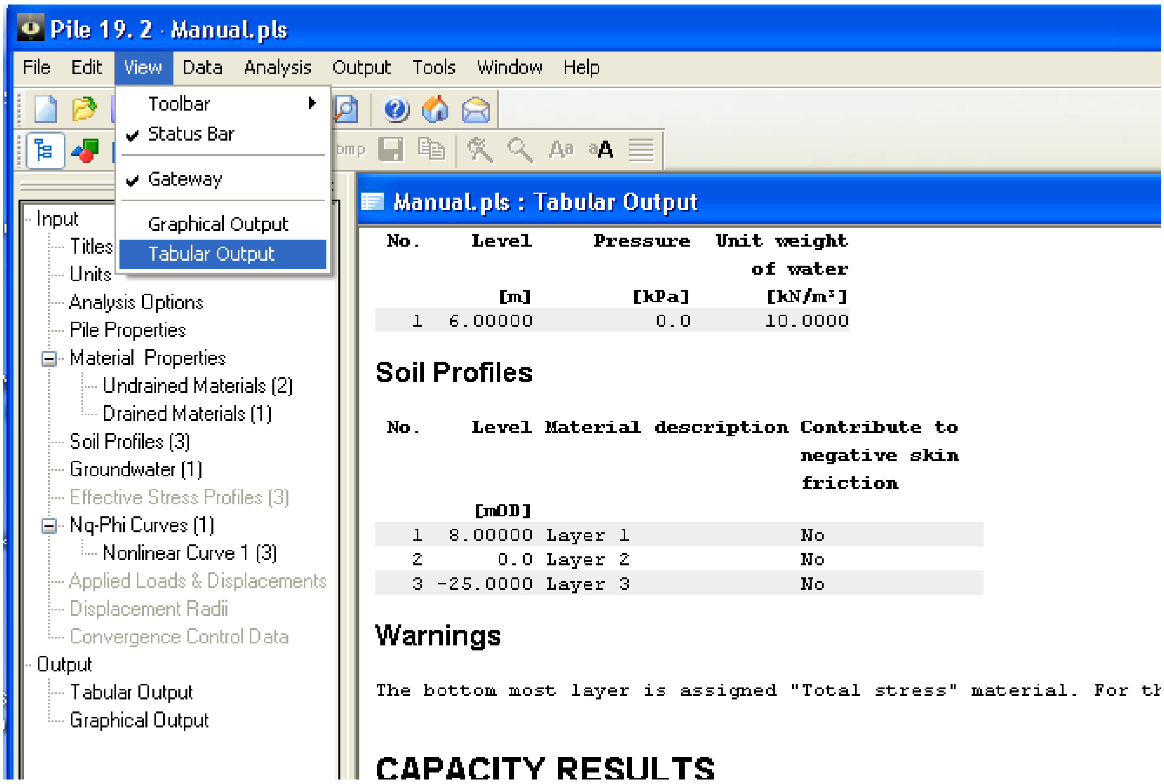


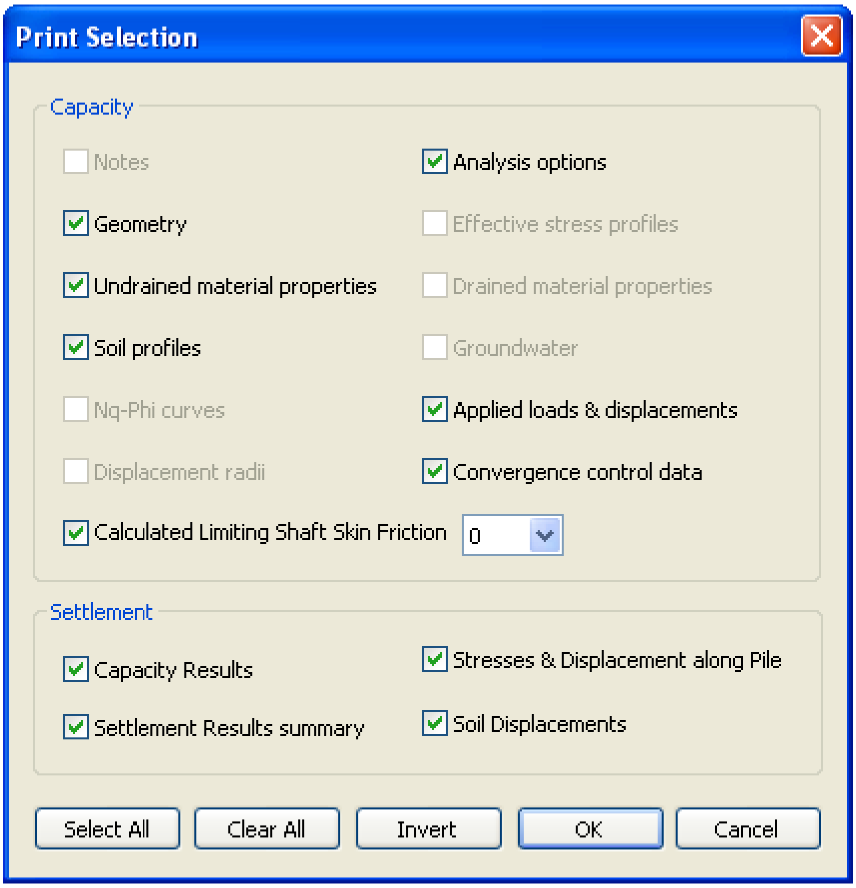
Prior to analysing the data, the program performs various checks and gives warnings/errors if the data is not consistent. Warnings do not prevent an analysis. Errors do and must be corrected before an analysis may proceed.


Manual.pls : Analysis checks
Checks prior to analysis:
Errors:
1. User defined effective stress profile is selected but the values are not entered in effective stress profile table. (Effective Stress Profile)
Warnings:
1. The bottom most layer is assigned "Total stress" material. For this layer the cohesion is assumed to be constant at "Cu-Top", i.e cohesion specified at the top of this layer. The user specified value of cohesion at the bottom of this layer, "Cu-Bottom" is ignored. (Material Properties)
Proceed
Quit

4.2 Tabular Output

Tabulated output is accessible from the View menu, the Gateway or the Pile toolbar. This output may include input data, and results if an analysis has been performed.





The results are provided in a tabular form, containing the levels corresponding to the depth(s) of the pile and the various load capacities at the given level.

The pile limiting shaft skin friction, shaft skin friction, pile stress, pile and soil displacement at the given level are tabulated for each pile length and each cross-section and for each load increment.

The number of outputs of calculated limiting shaft skin friction with in a layer can be selected in the Print Selection dialog.

The analysis warnings also be viewed in the results.

Manual.pls : Tabular Output

Cross-section 1 results:

Results - Compression

Level [mOD]	Pile length [m]	Ultimate base capacity (Q_b) [kN]	Cumulative external Friction (Q_s) [kN]	Negative skin friction (Q_{nsf}) [kN]	Ultimate capacity [kN]	Allowable capacity [kN]	Limiting criterion #
3.0000	5.0000	989.60	144.15	0.0	1133.8	288.30	3
2.0000	6.0000	1131.0	196.89	0.0	1327.9	393.78	3
1.0000	7.0000	1272.3	256.66	0.0	1529.0	513.32	3
0.0	8.0000	1413.7	323.46	0.0	1737.2	646.92	3
0.0	8.0000	152.68	323.46	0.0	476.14	190.46	1
-1.0000	9.0000	173.04	377.75	0.0	550.79	220.31	1
-2.0000	10.000	193.40	438.82	0.0	632.22	252.89	1
-3.0000	11.000	213.75	506.68	0.0	720.43	288.17	1
-4.0000	12.000	234.11	581.32	0.0	815.43	326.17	1
-5.0000	13.000	254.47	662.75	0.0	917.22	366.89	1
-6.0000	14.000	274.83	750.97	0.0	1025.8	410.32	1
-7.0000	15.000	295.18	845.97	0.0	1141.2	456.46	1
-8.0000	16.000	315.54	947.76	0.0	1263.3	505.32	1
-9.0000	17.000	335.90	1056.3	0.0	1392.2	556.89	1
-10.000	18.000	356.26	1171.7	0.0	1527.9	611.18	1
-11.000	19.000	376.61	1293.8	0.0	1670.5	668.18	1
-12.000	20.000	396.97	1422.8	0.0	1819.7	727.90	1
-13.000	21.000	417.33	1558.5	0.0	1975.8	790.33	1
-14.000	22.000	437.69	1701.0	0.0	2138.7	855.47	1
-15.000	23.000	458.04	1850.3	0.0	2308.3	923.33	1
-16.000	24.000	478.40	2006.3	0.0	2484.8	993.90	1
-17.000	25.000	498.76	2169.2	0.0	2668.0	1067.2	1

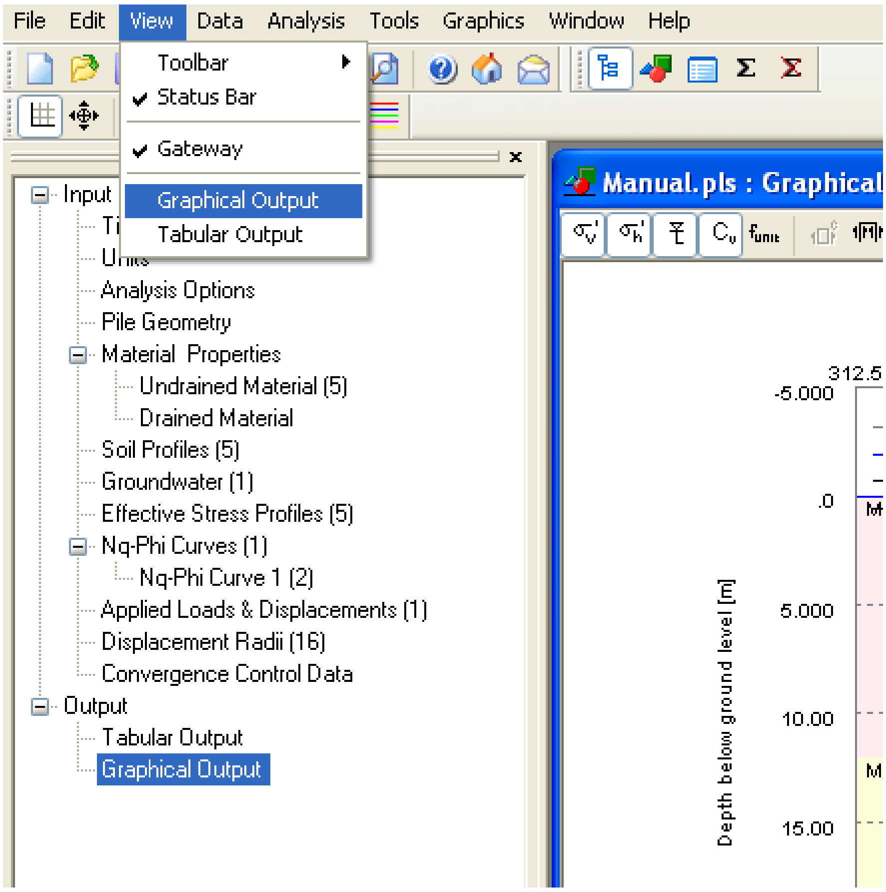
The lists of tabulated output can be highlighted and then copied to the clipboard and pasted into most Microsoft Windows type applications e.g. Microsoft Word or Excel. The output can also be directly exported to various text or HTML formats by choosing 'File | Export' from the program menu.

Sign convention are as follows:

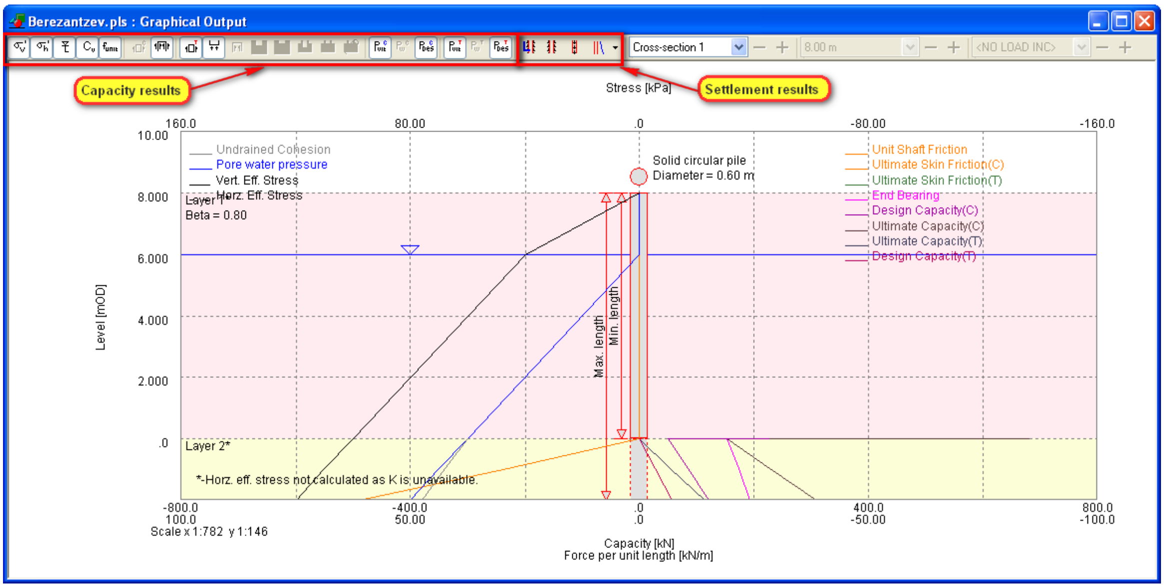
- Displacements - negative movement is upwards (eg. soil heave), and positive is downwards (eg. pile or soil settlements);
- Applied load - downward positive and upward negative;
- Pile stress - compression positive and tension negative;
- Base pressure - downwards positive and upward negative.

4.3 Graphical Output

Graphical output of data and results is accessed via the View menu, the Gateway or the Pile toolbar.

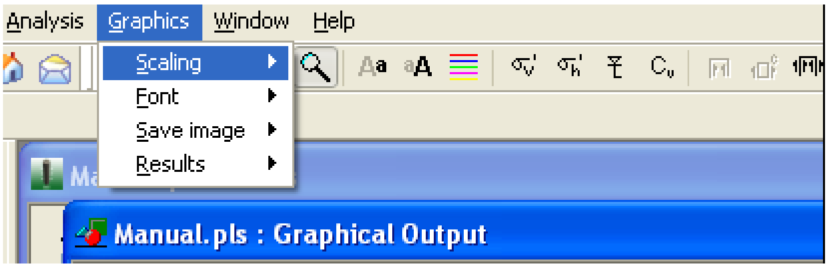


The graphical representation of the soil layers, the pile and the cross-section of the pile is shown here.



Introduction to Graphics menu

When the graphical output view is open the graphics menu shows the following options.



Graphical toolbar buttons

 **Axis** - provides a reference grid behind the drawing.

 **Set Scale** - this allows the user to toggle between the default 'best fit' scale, the closest available engineering scale. e.g. 1:200, 1:250, 1:500, 1:1000, 1:1250, 1:2500, or exact scaling. The same options are available via the View menu "Set exact scale" command.

 **Save Metafile** - this save icon allows the image to be saved in the format of a Windows Metafile. This retains the viewed scale. The metafile can be imported into other programs such as word processors, spreadsheets and drawing packages.

 **Zoom Facility** - select an area to 'zoom in' to by using the mouse to click on a point on the drawing and then dragging the box outwards to select the area to be viewed. The program will automatically scale the new view. The original area can be restored by clicking on the 'restore zoom' icon as shown here.

 **Smaller/Larger font -** allows adjustment of the font sizes on the graphical output view.

 **Edit colours -** allows line and fill colours to be edited.

Axis - provides a reference grid behind the drawing.

Save BMP - allows the file to be saved in the format of bitmap.

Copy - allows to copy the graphical view to be copied to clip board.

Capacity

Vertical effective stress - toggles the vertical effective stress plot.

Horizontal effective stress - toggles the horizontal effective stress plot.

Pore water pressure - toggles the pore water pressure plot.

Undrained cohesion - toggles the undrained cohesion plot.

Unit shaft friction - toggles the unit shaft friction plot.

External skin friction compression - toggles the external skin friction compression plot.

Total skin friction compression - toggles the total skin friction compression plot.

Total skin friction tension - toggles the total skin friction tension plot.

End bearing capacity - toggles the end bearing capacity plot.

Internal skin friction - toggles the internal skin friction plot.

Wall end bearing - toggles the wall end bearing plot.

Plugged end bearing - toggles the plugged end bearing plot.

Plugged capacity - toggles the plugged capacity plot.

Unplugged capacity - toggles the unplugged capacity plot.

Unplugged capacity - auto plugged - toggles the unplugged capacity - auto plugged plot.

Ultimate load compression - toggles the ultimate load compression plot.

Working load compression - toggles the working load compression plot.

Design load compression - toggles the design load compression plot.

Ultimate load tension - toggles the ultimate load tension plot.

Working load tension - toggles the working load tension plot.

Design load tension - toggles the design load tension plot.

Settlement

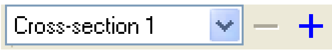
Limiting Shaft Skin Friction - toggles the limiting shaft skin friction plot.

 **Axis -** provides a reference grid behind the drawing.

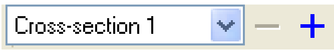
 **Shaft Skin Friction -** toggles the shaft skin friction plot.

 Pile Stress - toggles the pile stress plot.

 **Pile/Soil Displacement -** toggles the displacements for pile or soil.

Capacity results can be viewed for a selected cross-section 

.

Settlement results can be viewed for a selected cross-section 

and selected pile length 

and selected load/applied displacement increments 

(if load increments exist) .

When the user makes the appropriate selection, the corresponding plot is shown.

The plot can be exported in WMF format.

5 List of References

5.1 References

Berezantzev V G, Khristoforov V S and Golubkov V N (1961). Load bearing capacity and deformation of piled foundations. Proceedings of the 5th International Conference on Soil Mechanics and Foundation Engineering. pp. 11-15.

Mattes N S and Poulos H G (1969). Settlement of Single Compressible Pile. Journal of the Soil Mechanics and Foundation Division, Proceedings of ASCE, Volume 95, No. SM1, January 1969, pp. 189-206.

Poulos H G and Mattes N S (1968). The Settlement Behaviour of Single Axially Loaded Incompressible Piles and Piers. Geotechnique, Volume 18, pp. 351-371.

Poulos H G and Mattes N S (1969). The Behaviour of Axially Loaded End-bearing Piles. Geotechnique, Volume 19, No. 2, pp. 285-300.

Poulos H G and Davis E H (1980). Pile Foundation Analysis and Design Chapter 5. Series in Geotechnical Engineering, T. W. Lambe and R. V. Whitman (eds), John Wiley and Sons.

D'Appolonia, E. and Romualdi, J.P. (1963). Load Transfer in End Bearing Steel HPiles, Journal of the Geotechnical Engineering Division, ASCE, Vol. 89.

6 Manual Example

6.1 General

The data input and results for the **Pile** manual example are available in the 'Samples' sub-folder of the program installation folder. The example has been created to show the data input for all aspects of the program and does not seek to provide any indication of engineering advice.

This example can be used by new users to practice data entry and get used to the details of the program.

7 Brief Technical Description

7.1 Pile

Pile is a program which calculates the vertical load carrying capacities and vertical settlements of a range of individual piles in a layered soil deposit. The theory is based on both conventional and new methods for drained (frictional) and undrained (cohesive) soils. Currently the settlements are calculated for solid circular sections without under-ream. Other type of cross-sections will be implemented in later version.

The main features of **Pile** are summarised below:

The user can perform either capacity analysis, settlement analysis, or both for a range of pile lengths and cross-sections.

Settlements are calculated for only solid circular cross-sections without under-ream.

The soil is specified in layers. Each layer is set to be drained (frictional) or undrained (cohesive) and appropriate strength parameters are specified. Maximum values can be set for ultimate soil/shaft friction stress and end bearing stress within each layer.

Levels may be specified as depth below ground level or elevation above ordnance datum (OD).

Porewater pressures within the soil deposit can be set to hydrostatic or piezometric.

Pile capacities may be calculated for a range of pile lengths and a range of cross-section types such as circular, square and H-section. The circular and square cross-sections may be hollow or solid, whereas the H-section is only solid. Under-reams or enlarged bases may be specified.

Pile settlements may be calculated for a range of pile lengths and a range of solid circular cross-sections without under-ream.

There are two approaches available to calculate the capacity of the pile - working load approach and limit-state approach.

The graphical output depicts the variation of different pile capacities such as shaft resistance, end bearing, total bearing with pile depth and settlements of pile or soil. This may be exported in WMF format.

The text output contains the tabular representation of the input data and results. They may be exported to CSV format.

A legacy Pile and Pilset files may be read. Limiting shaft skin friction is calculated from the material properties, so the reading of limiting shaft skin friction from legacy Pilset file is ignored. results in CSV format.

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