DeepFND – HelixPile User's & Theory Manual

DeepFND – Deep Foundations Design Software

HelixPile – Helical Pile Design Software

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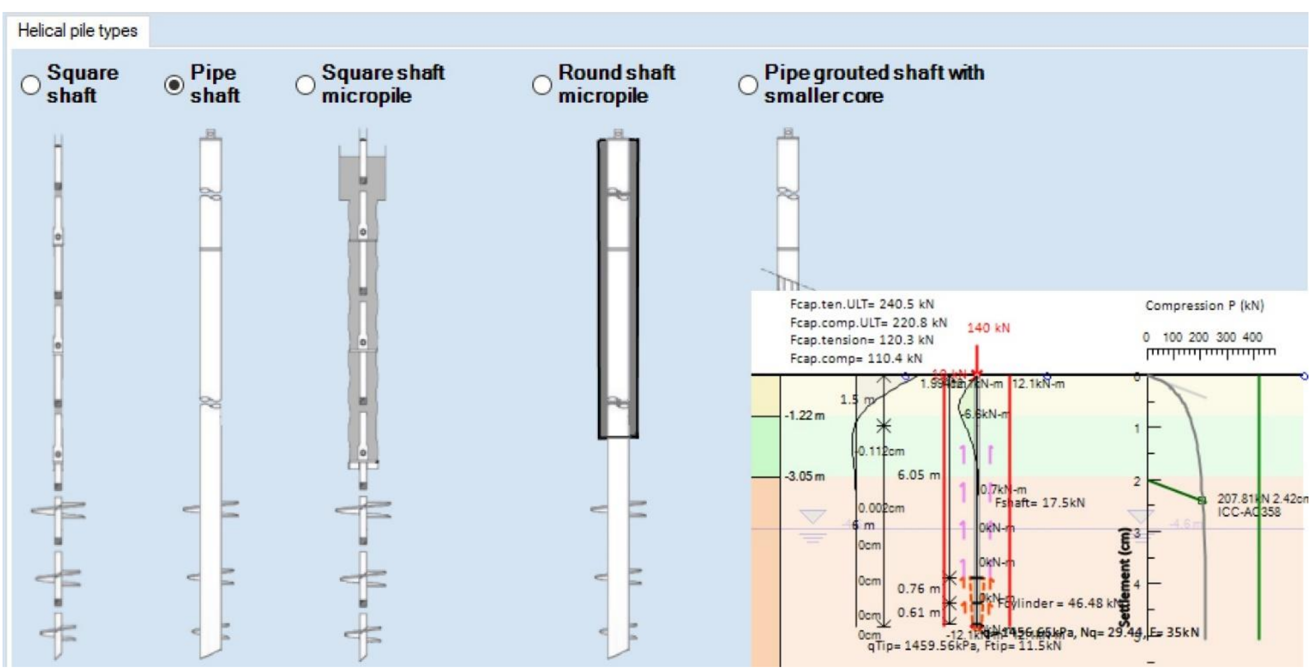

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INTRODUCTION

This user's manual provides reference guide for engineers and contractors in the use of the DeepFND and HelixPile software programs. The document details how different parameters and settings can be controlled within the program, how to simulate different conditions, and how to analyze and evaluate software results.

The software programs DeepFND and HelixPile use the exact same interactive interface, and they include the same functions. The software programs are almost identical, with the only difference being the available pile types each software can handle:

DeepFND can perform vertical and lateral pile analysis, structural and geotechnical design of any pile type (helical and non-helical). The non-helical piles can be installed by any method (drilled, driven, caissons, CFA piles, drilled-in-displacement piles) and they can be timber, reinforced concrete or steel piles. In DeepFND, we can change the pile section with depth and simulate cases like belled pile tips. Helical piles can be pipes, square solid or square hollow pile sections with any helix configuration. The helical piles can be grouted, and we can also use casings on the top of the piles.

HelixPile can perform vertical and lateral pile analysis, structural and geotechnical design of helical piles. The HelixPile software is identical to the helical pile component of DeepFND.

The pile design procedure with the use of our software programs can be summarized as follows:

A. Define the soil properties and stratigraphy (manually or with the use of CPT or SPT logs).

B. Define the vertical and lateral loads on the pile head.

C. Define the pile type and pile structural section.

D. Define analysis options (vertical and lateral analysis methods, torque estimation profiles, surface settlements criteria).

E. Run the analysis – Evaluate the results – Optimize the model.

F. Export reports in PDF or MS Word format.

The following sections present in detail all different software options for the creation and analysis of any pile model with helical or non-helical piles. Both programs offer capabilities to model pile groups and pile supported rafts.

PART A: GENERAL INFORMATION – SOFTWARE USE

INFORMATION – SOFTWARE INTERFACE, FUNCTIONS AND DIALOGS

The following sections provide useful information about the software versions and capabilities, system requirements, license activation and transfer, as well as general an introduction to the software interface, main tabs and toolbar functions. The contents of all software, main and secondary, dialogs are also discussed.

SECTION 1: INTRODUCTION TO DeepFND and HelixPile

1.1 About DeepFND (Deep Foundation Engineering Program)

DeepFND is a user friendly, modern and powerful software program for the design of deep foundations. DeepFND allows us to handle an unlimited number of stage conditions and soil profiles. DeepFND incorporates the latest recommendations and allows us to easily view the controlling design conditions. DeepFND can perform analysis of single piles, pile groups, and pile rafts (additional optional modules Pile Groups and Pile Rafts are required).

DeepFND can perform vertical and lateral pile analysis of any pile type (reinforced concrete, steel beams (pipes-channel sections-H beams), composite sections, timber (wood) piles, belled type piles, helical piles and more). It implements widely accepted recommendations about different pile installation methods (drilled, driven, micropiles, CFA piles, drilled-in-displacement piles).

1.2 About HelixPile (Helical Piles Design Engineering Program)

HelixPile is a user friendly, powerful software program for the design of helical piles. HelixPile can perform vertical and lateral pile analysis of all helical pile types (pipes, square solid and square hollow sections) with unlimited number of helix configurations. The software can also perform pile settlement analysis and it can calculate the installation torque. HelixPile can perform analysis of single piles and of pile groups and pile rafts (additional optional modules Pile Groups and Pile Rafts are required).

HelixPile and DeepFND software programs are identical, with the only difference being the available pile types. In the rest of the document, we will use the name of DeepFND. The same features and procedures apply for HelixPile.

1.3 Software Compatibility & Installation

DeepFND is compatible with Windows (OS) XP, Vista,7 8 and 10. A minimum of 380 Mb must be available on your hard disk. However, Windows 10 computers with 64bits are generally recommended. Some 32-bit computers with very old operating systems have demonstrated issues in running parts of the lateral analysis.

1.4 Support & Technical Assistance

Support and technical assistance for DeepFND is offered through our web sites at:
www.deepexcavation.com and **www.deepex.com**

Please send us any question at: **support@deepexcavation.com**

1.5 DeepFND Training, Examples and Projects

You can find extensive examples and videos on our official websites (**www.deepexcavation.com** and **www.deepex.com**).

For examples and training videos, please visit:

https://www.deepexcavation.com/post/deepfnd-helixpile-software-training-materials

https://www.deepexcavation.com/deepfnd-examples-training-videos

Software training/online presentations:

We can always arrange a free online presentation (up to one hour), where we can present the main features and capabilities of our software. Extensive training (online or on spot) can be arranged upon request. The cost of the full training course can be defined according to your needs. To arrange a presentation and for additional information, please contact:

sales@deepexcavation.com

1.6 End User License Agreement

Deep Excavation makes every effort to ensure quality and accuracy of computations performed by Steel Connect. However, the end user (you) assumes full responsibility for the applicability of the results to actual projects as described in the License Agreement that follows. If you decide to use *DeepFND 1.0* you agree to abide by the terms and conditions described in the License Agreement.

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1.6 Software Basic Version and Additional Optional Modules

Both DeepFND and HelixPile are available in different versions to match your project needs, with functionality expanding from single pile design to full pile group and pile raft analysis. In DeepFND, additional optional modules can further extend capabilities.

Basic Version

In the Basic version of **DeepFND**, users can perform full axial and lateral design for a single pile of any type. This includes non-helical piles such as concrete, steel, timber, and stone columns, as well as helical piles. The software performs both structural and geotechnical design checks, settlement analysis, and—when working with helical piles—installation torque estimation.

The Basic version of **HelixPile** provides the same analysis and design capabilities but is limited exclusively to helical piles. Both programs allow engineers to create and manage multiple design scenarios within a single file. Each scenario can represent different soil profiles, pile sections, loading conditions, or analysis assumptions, making it easy to evaluate a range of conditions within one project.

Pile Groups and Pile Rafts Version

For engineers who need to design beyond a single pile, both programs offer a **Pile Groups and Pile Rafts** version. In **DeepFND**, this version expands the basic capabilities to include the design of pile groups of any arrangement and pile raft foundations where a raft slab and supporting piles work together. Pile–soil interaction is modeled using PY springs, allowing accurate simulation of both vertical and lateral response.

HelixPile also offers a Groups and Rafts version with the same capabilities but limited to helical piles. In both programs, pile groups and rafts can be configured in any shape, and the model can account for the combined effect of piles and the supporting soil beneath the raft.

Optional Modules (DeepFND Only)

While HelixPile is limited to its two main versions, **DeepFND** can be extended with two optional modules. The **3D FEM Analysis Module** enables advanced three-dimensional finite element modeling of pile–soil interaction for single piles, pile groups, and pile rafts. This allows for more detailed simulations and visualization of complex geotechnical behavior.

The **Pile Cap Design Checks Module** adds the ability to perform full structural design checks of pile caps in accordance with supported international design codes. These checks help ensure that pile caps meet both geotechnical and structural requirements, giving engineers additional confidence in their designs.

SECTION 2: DeepFND Interface and Main Tabs

2.1 Using DeepFND

DeepFND is a user-friendly software program and includes powerful features and versatile options. In DeepFND we can work with many design sections of pile analysis conditions. In a sense, a design section is a design scenario. This way, multiple conditions can be examined simultaneously. The main interface is shown in Figure 2.1.1. The general philosophy in creating a model in DeepFND is:

1) Specify the global coordinates.
2) Specify the soil types and properties.
3) Specify the layers and stratigraphy.
4) Create a generalized water table.
5) Specify the pile properties (installation method, depth, x-coordinate, pile section).
6) Specify different stages.
7) Specify DeepFND analysis methods, combinations and standards.
8) Analyze the project.
9) Optimize the model.
10) Create and analyze the pile cap or pile raft (if required)

The main tabs that appear on the top of the program have the following functions:

1. General: This tab includes the DeepFND wizard, general information about the project, model limits, general settings, soil properties, Pile and pile sections properties, pile loads, stage options and water behavior options.

2. Properties: This tab contains various information about Borings, CPT and SPT records and structural materials.

3. Analysis: This tab contains provides options for single pile Analysis methods, shaft resistance, factors on cohesion and cylinder method.

5. Design: In this tab we can define structural or load combination code options as well as change several structural and geotechnical safety factors.

6. Settlement: In this tab we can choose to perform settlement analysis, define the settlement parameters and edit the pile settlement acceptance criteria. In addition, actual axial load test records can be defined for comparison or calibration against pile settlement estimates.

7. Lateral: In this tab we can define the lateral pile analysis assumptions, methods and options, as well as any lateral load test records.

8. <u>Pile Caps:</u> In this tab we can select to create a pile cap (or pile raft) and review results after the analysis.

9. <u>Results:</u> In this tab we can select to present individual pile results directly to the screen after the analysis is performed.

10. <u>Report:</u> In this tab we can select options for generating output reports, or viewing calculation progress files.

11. <u>View:</u> In this tab we can modify various view options or generate a top view of the model.

12. <u>Help:</u> This tab provides links to help and terms of use.

13. <u>Dynamic:</u> This tab contains the LEM seismic options, the dynamic analysis settings, the dynamic earthquake analysis options, and the post processing options.

14. <u>Torque:</u> In this tab we can select to estimate the required installation torque for helical piles or define the installation torque profile we wish to use on the model. The Torque tab is available only in HelixPile software, and in DeepFND when the pile type is changed to helical pile (the additional helical piles module of DeepFND is required).

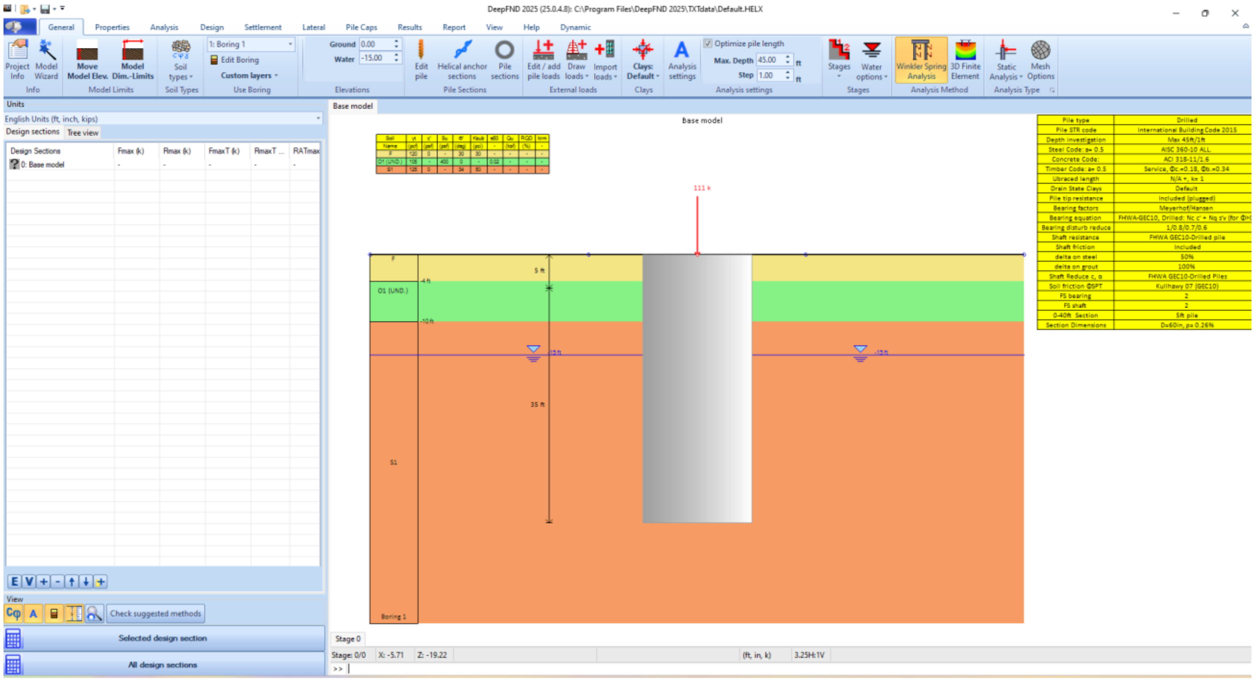


Figure 2.1.1: General DeepFND 2020 Interface.

2.2.1 Toolbar Functions, Design Section List, and Project Tree View

The following section provides a detailed list of all toolbar functions. The first tab group to encounter contains the following options:

Start button 

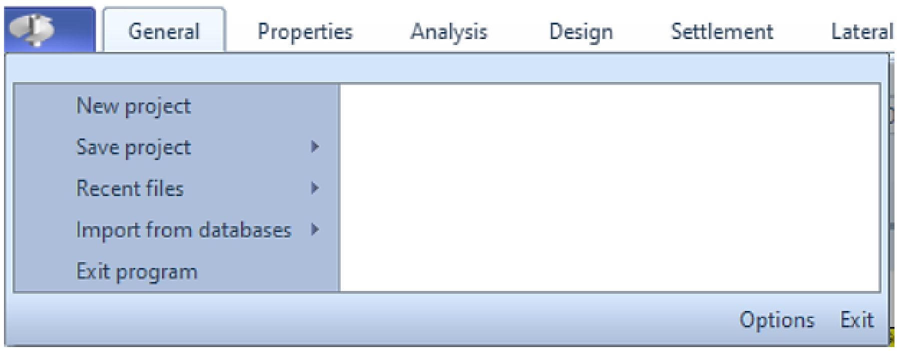
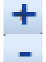


Figure 2.2.1: Main button.

This window provides the following options:

- Create a new project
- Save a project (save as)
- See and choose to open recent files
- Exit the program
- On the left side of the program, right under the design section list, a horizontal toolbar is available for viewing or modifying available design sections (Figure 2.2.2):

Tool	Description
	Edit the name of the selected design section
	Generate a new view of the current design section
	Add a new design section
	Delete design section
	Move design section up on the list
	Move design section down on the list
	Add a new design section (empty – including only stage 0)

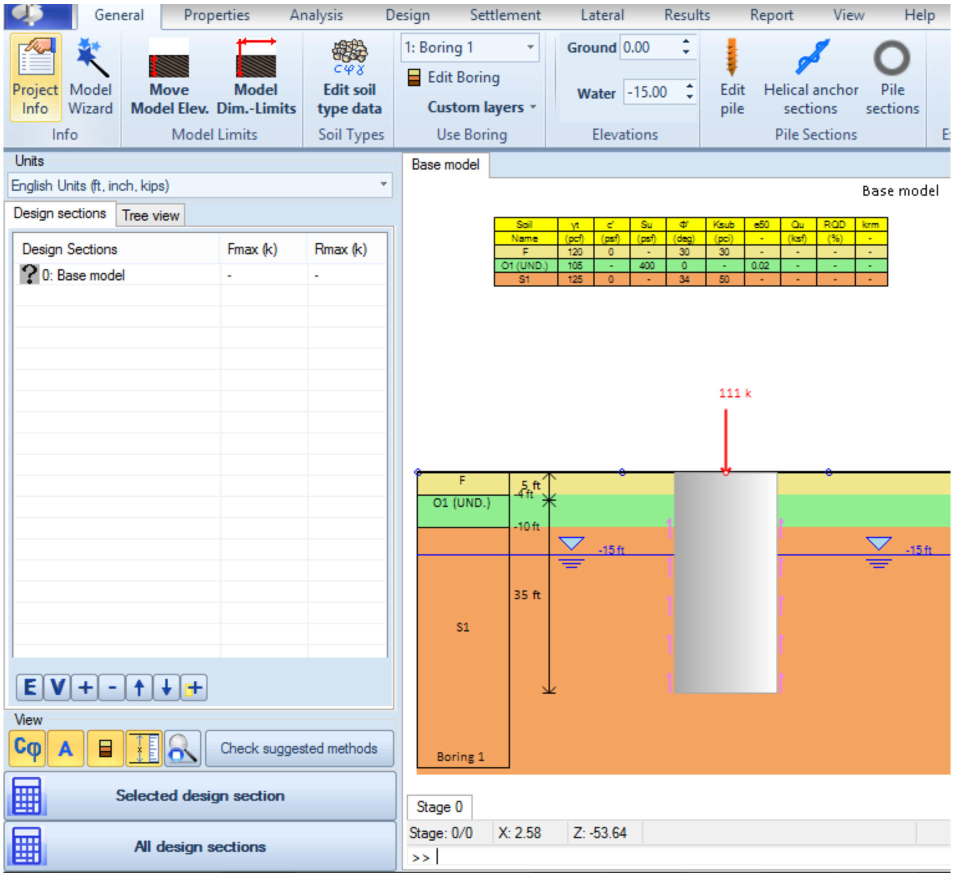


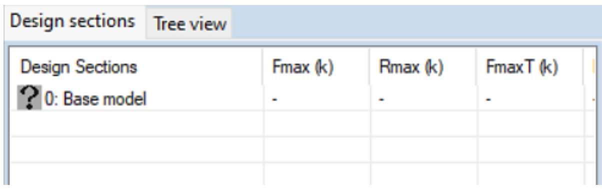
Figure 2.2.2: Design section toolbar.

On the bottom left program corner, a toolbar with two buttons instructs the software to start performing calculations.

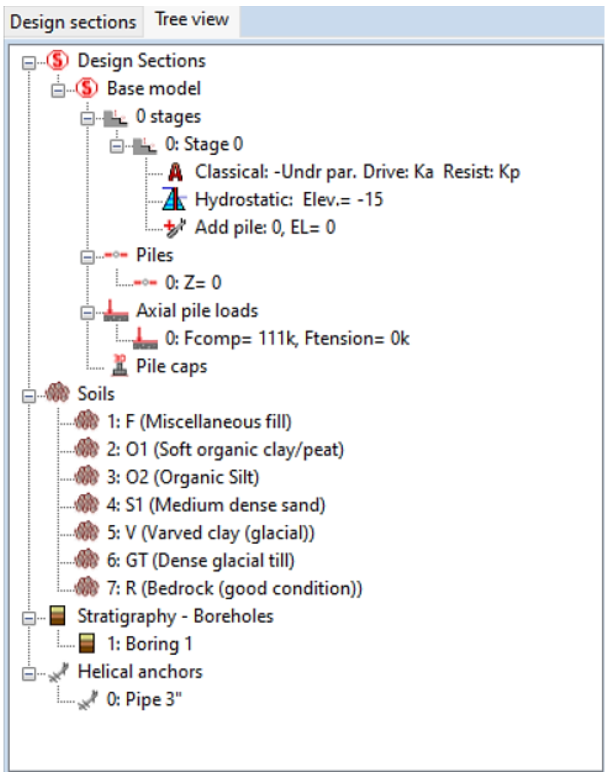
Figure 2.2.3: Calculate tools.

Tool	Description
	Calculate the selected design section
	Calculate all design sections

DeepFND offers features that include multiple design sections and a tree-style project view. The tree view enables the user to quickly access vital project data, as well as visualize crucial project settings. The next table briefly describes the functionality of the Pile list, Design Section List, and Tree View items.



Selects current design section, shows available design sections.



Shows available design sections

Pile loads (right click to add or erase)
Piles (right click to add or erase)

Available soil types (by clicking the user can select which soil's properties to modify)
Available boreholes (by clicking the user can select which borehole's properties to modify)
Helical anchors (by clicking the user can select to change the properties of the piles)

2.3 General menu

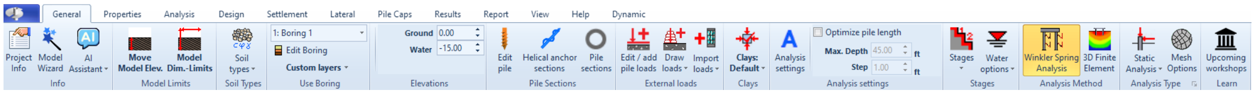
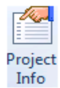


Figure 2.3.1: DeepFND 2017: General tab.

- **Project Info:** by pressing the 

button, we can modify the project, file, company and engineer name.

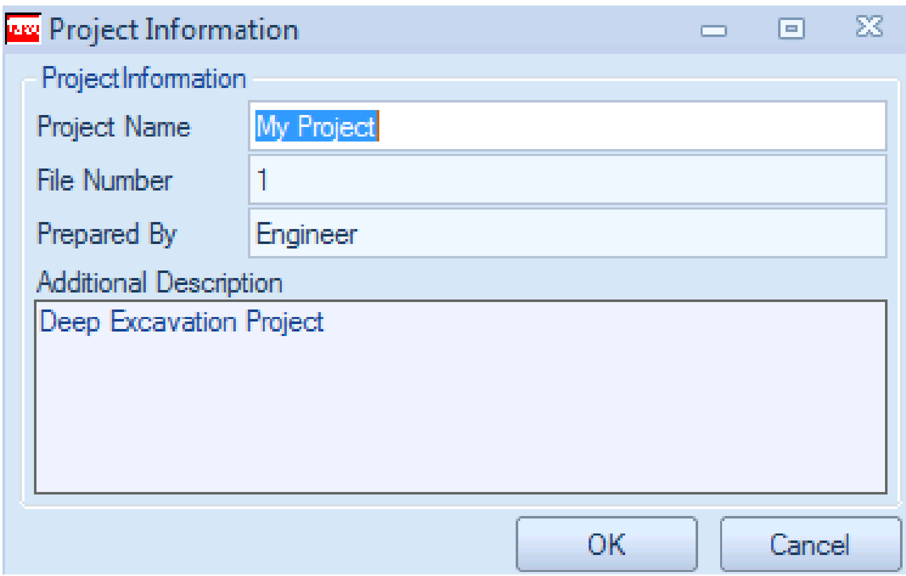
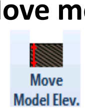


Figure 2.3.2: Project information dialog.

- **Model Wizard:** by pressing the 

button, the DeepFND wizard dialog appears. In this dialog we can fast create a pile model, define project and analysis parameters and perform the analysis. **Section 4.2 includes more information regarding the model wizard**.

- **Move model elevation:** In DeepFND we can design projects using actual elevations. By pressing the 

button, we can modify the model elevation by entering a new top of pile elevation.

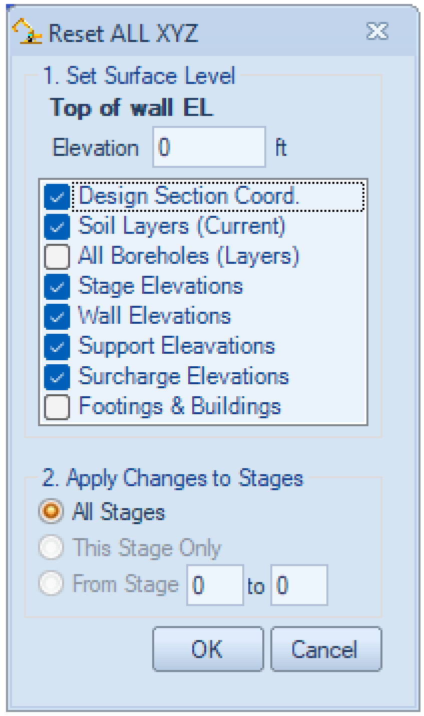
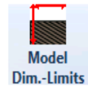


Figure 2.3.3: Model Elevation dialog.

The user can choose the objects to be affected by the change in elevation. These are:

The design section coordinates
The soil layers elevation (of current borehole)
All the soil layer elevations of all boreholes
Elevations of all stages
Elevations of walls
Elevations of all supports
Elevations of all surcharges
Elevations of all footings and buildings

The top of the pile is used as the point of reference for changing elevations.

- **Model Dimension - Limits:** by pressing the 

button, we can change the Design Section name and the Model Limits to create a nice view of the model.

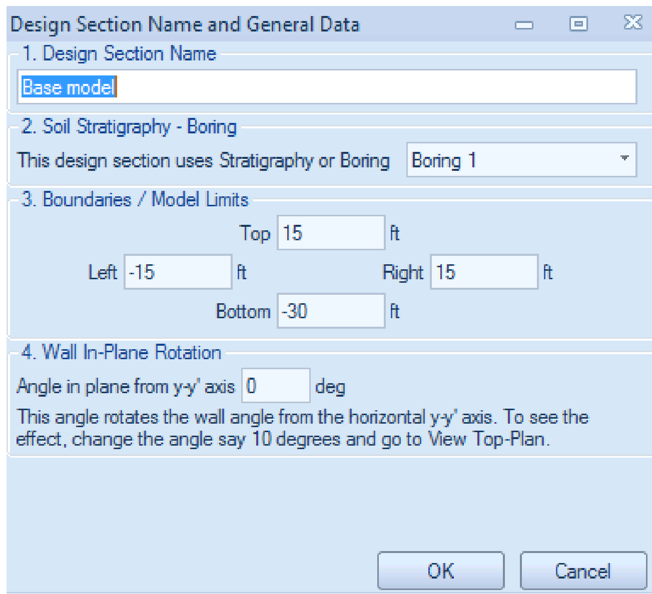


Figure 2.3.4: Design Section Name and General Data dialog.

This dialog includes the following options:
The design section name.
The model limits. Here we can define the top, bottom, left and right limits of the model. These are absolute coordinates.
Angle in plane from y-y' axis.

- **Edit soil type data:** by pressing the 

button, the soil properties form appears. In this form we can add, delete, or modify available soils by changing their type, the general properties like unit weights, strength parameters and permeability, modify the elastoplastic parameters and modify the bond resistance for tiebacks. A soil can be used in a boring more than one time. A number of estimation tools that help the user estimate values are also included. **Section 3.3 includes all the options that are available in this form**.

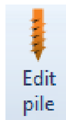
- **Borings (Soil layers):** by pressing the 

button, the soil layer dialog appears. In this dialog we can edit the borings available for use in the project. In each boring the user can add soil layers. To do this, we can type the new soil layer's elevation, choose the soil type from the list of soil types and define the new layers OCR and Ko. In addition, by clicking on Edit button, we can modify the selected soil's properties **(see section 3.4).** The coordinates X and Y refer to the plan location of the boring and do not affect analysis results.

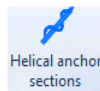
- Custom Layers: By pressing the 

button, we can choose to use the custom layer mode of DeepFND or choose to reset custom layers from boring. In the custom layer mode, we can define non-horizontal soil layers.

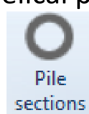
- Elevations: Change the general ground elevation and define the water table.

- Edit pile data: By pressing the 

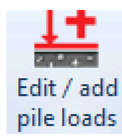
button, we can edit the properties of the pile. **Properties on this form are described in section 3.5**.

- Edit helical anchor sections: By pressing the 

button we can edit the structural and geotechnical properties of the helical anchor sections. **Properties on this form are described in section 3.6**. This feature is available if helical piles are enabled (separate purchase in DeepFND).

- Edit pile section data: By pressing the 

button, we can edit the properties of regular type pile sections. **Properties on this form are described in section 3.7**.

- External pile loads: by pressing the 

button, we can add, remove and edit the properties of all external loads applied on the pile head of single piles. **Properties on this form are described in section 3.9**.

- Clays: Here we can define the Clay behavior at each stage by choosing from available options:

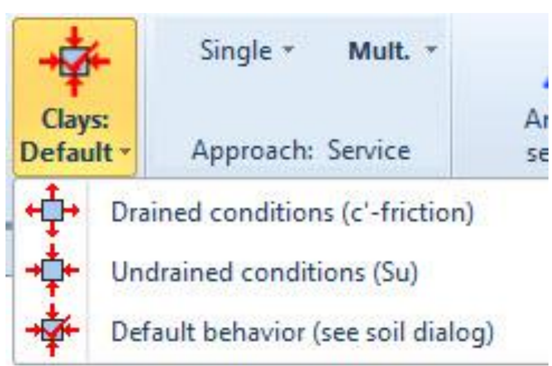
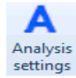


Figure 2.3.5: Clay behavior options.

- **Analysis Settings:** By pressing the  button, we can define the different analysis settings. **Properties on this form are described in section 3.14**.

- Pile Length Optimization:

<u>**Defined Pile Length**</u>
By having the "Optimize pile length" option unselected, HelixPile will use the user-specified pile depth for the analysis, it will calculate the shaft resistances and the end bearing capacities (axial tension and compression) and will present these results.

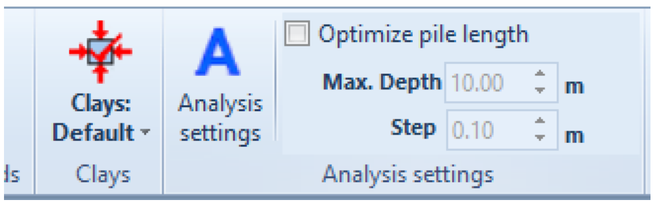


Figure 2.3.6: Unselected pile length optimization option.

<u>**Optimizing Pile Length**</u>
By having the "Optimize pile length" option selected, the software will start increasing the pile depth using the defined "Step" length, calculating the bearing capacities in each step. As soon as the calculated axial tension and compression capacities are enough to cover the applied maximum tension and compression load on the pile head respectively, the analysis will stop. The software will return as a result the calculated depth and capacities.

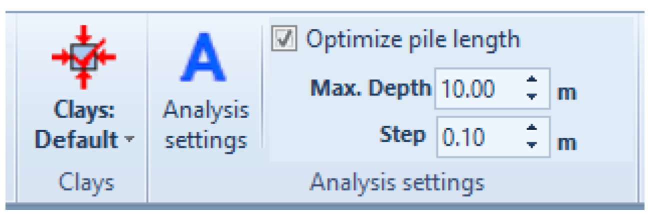
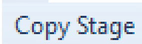


Figure 2.3.7: Selected pile length optimization option.

If the maximum defined depth is reached, the analysis will stop, returning the calculated capacities for this depth.

- Stages: In this area we can add, delete, insert or copy a construction stage.

Icon	**Description**
	Add a new construction stage
	Deletes the current construction stage
	Insert a construction stage after the current stage
	Copy selected construction stage
	Paste construction stage

- By clicking on the  button, the Ground water table dialog shows up.

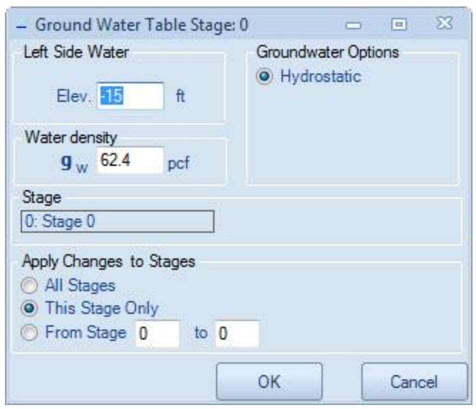


Figure 2.3.8: Ground water table.

The following table presents the options that are included in the ground water table dialog.

Define the general water elevation

Define the water density γ_w

-Analysis methods

Select the analysis method: Wincker Springs Analysis and 3D Finite Element

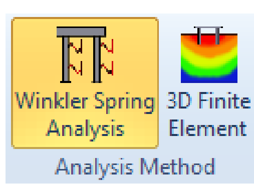
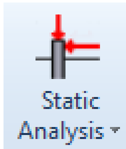


Figure 2.3.9: Analysis methods.

-Analysis style

The button 

allows to choose between static analysis, Pushover analysis, and Dynamic analysis.

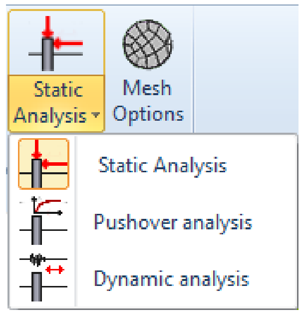


Figure 2.3.10: Analysis style.

-Mesh options

The button 

leads to the mesh options, to define the refinement.

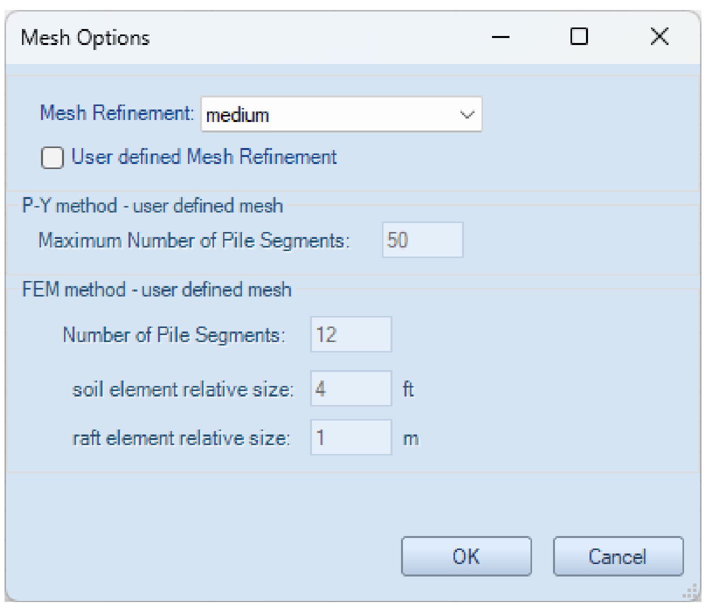


Figure 2.3.11: Mesh options.

-Upcoming workshops

The button 

leads to a tab containing information about upcoming workshops, in our webpage.

2.4 Properties menu

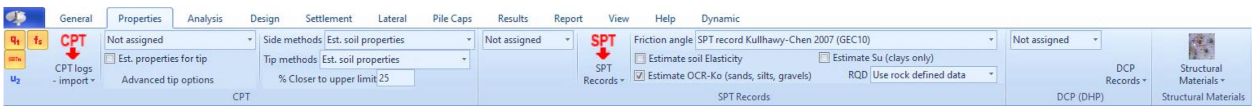


Figure 2.4.1: The Properties tab menu.

CPT logs: by pressing the arrow next to the 

button, we can import and process CPT logs into the current software file. CPT records can be used within DeepFND, with the program being able to export soil properties by processing CPT logs. **Properties on this form are described in section 3.11**.

SPT logs: by pressing the arrow next to the 

button, we can import and process SPT records into the current software file. SPT records can be used within DeepFND, with the program being able to estimate the ultimate bearing capacity from SPT's (if the SPT option is selected in the Analysis dialog). **Properties on this form are described in section 3.11**.

Structural materials: In this area we can edit the structural material properties for all material types (steel, concrete and timber). **Properties on this form are described in section 3.12**.

2.5 Analysis menu

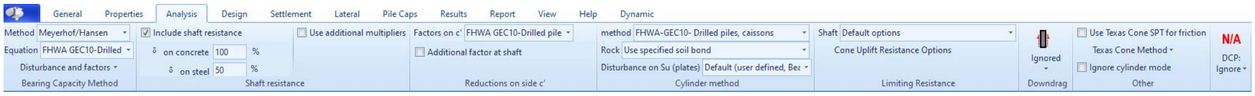


Figure 2.5.1: The Analysis tab menu.

In the Analysis tab we can define the bearing capacity method, the shaft resistance, the reduction factors on cohesion c' and the cylinder method that will be used in the model.

Bearing capacity method: We can choose from the following methods:
Vesic 1974
Meyerhoff/Hansen
SPT values (user must assign an SPT record)
CPT log (user must assign a CPT log and method)
The following methods are available:

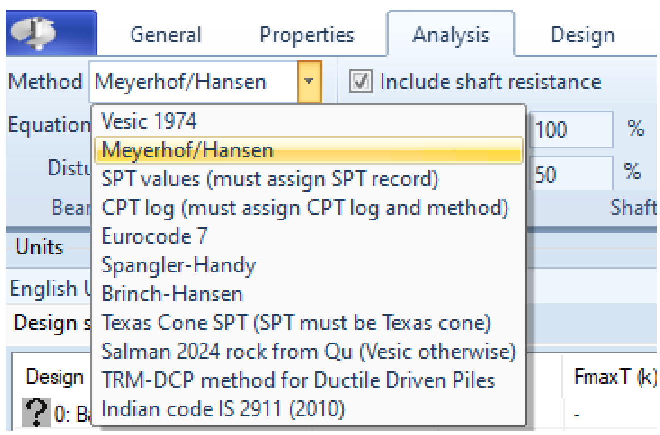


Figure 2.5.2: The Bearing Capacity Equations.

The following methods are available:

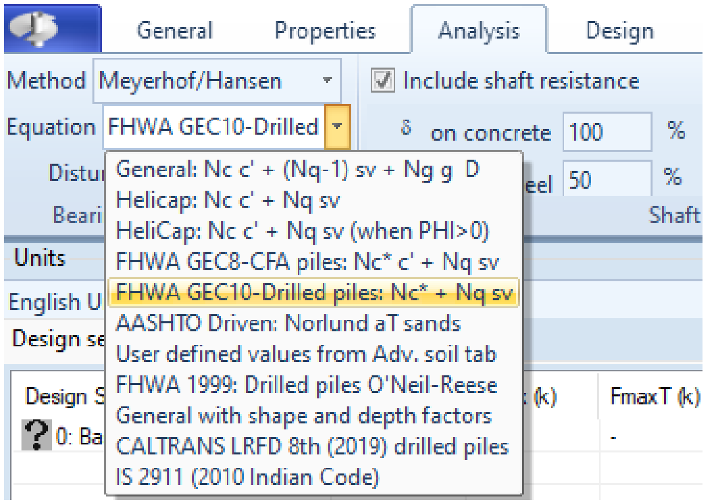


Figure 2.5.3: The Bearing Capacity Methods.

Disturbance effects on the bearing resistance can be changed by pressing the Edit button (Figure 2.5.4). In this dialog we can define disturbance factors for bearing and elastic response. Different factors can be defined for compression and tension. Disturbance factors should be selected with caution, and can be affected by factors such as soil type, installation speed, etc.

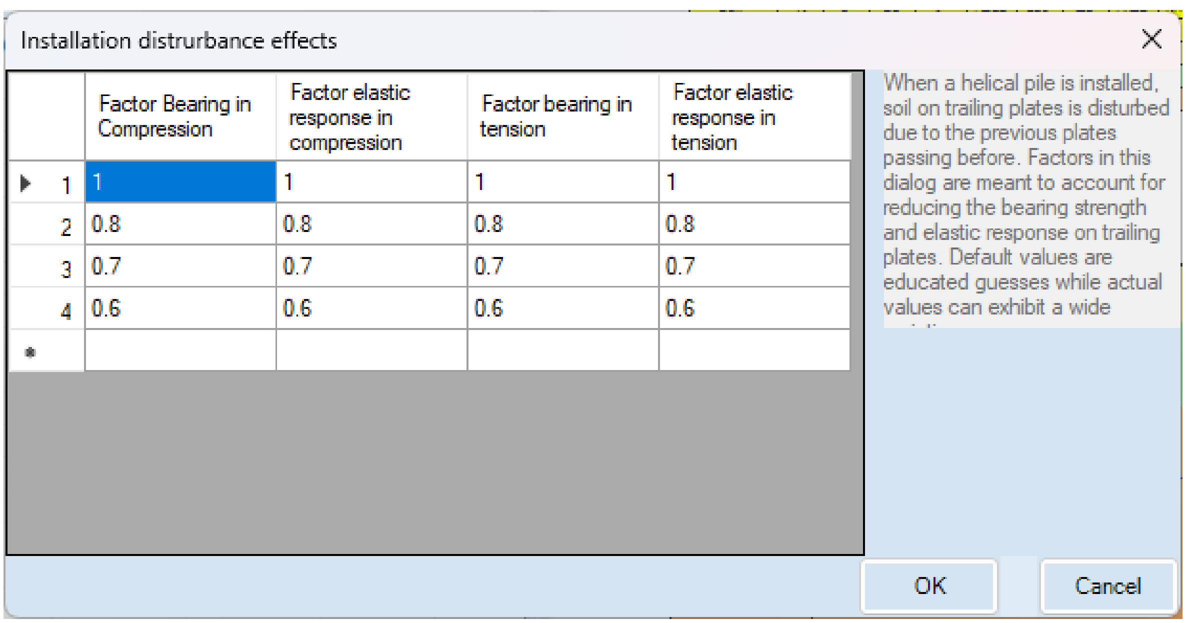


Figure 2.5.4: The Installation Disturbance Effects dialog.

Shaft resistance: Shaft resistance can be considered in the model. We can then define the ratio of interface friction for concrete and on steel vs. the assumed effective soil friction angle. For regular piles this option should be always selected.

Reduction on side c': Provides options for calculating the side adhesion from c' or Su. A single additional factor can also be used on the shaft. In helical piles the additional factor is used on the pile segment above the upper plate. The following options are available:

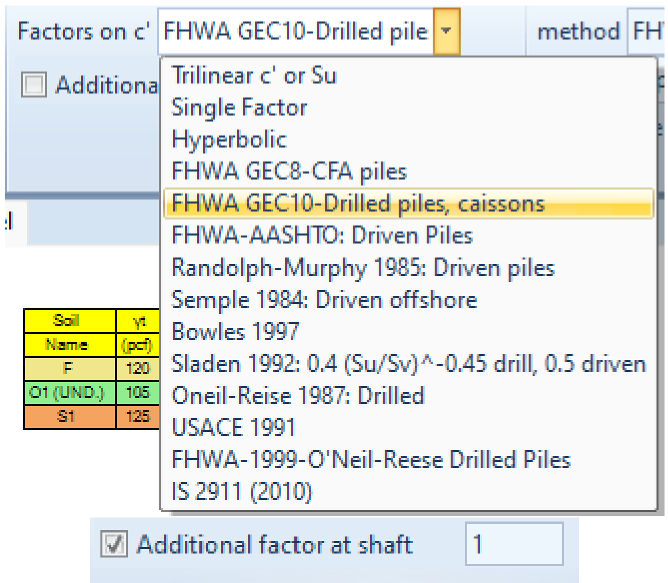


Figure 2.5.5: The available options for c' or Su factors.

Cylinder method: These options control the cylindrical failure and lateral K pressure methods for regular piles. Figures 2.5.6 and 2.5.8 present the available methods and rock options.

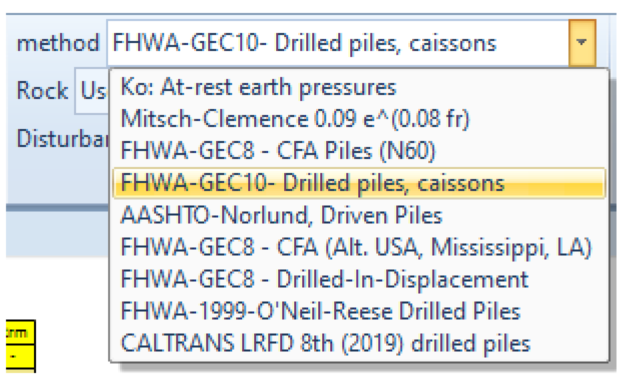


Figure 2.5.6: The cylinder method options.

Additional options are available for the side resistance in rocks. The following options are available:

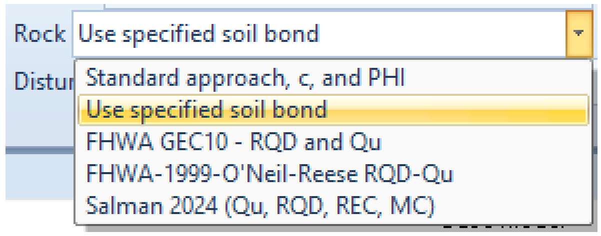


Figure 2.5.7: Rock options.

2.6 Design menu

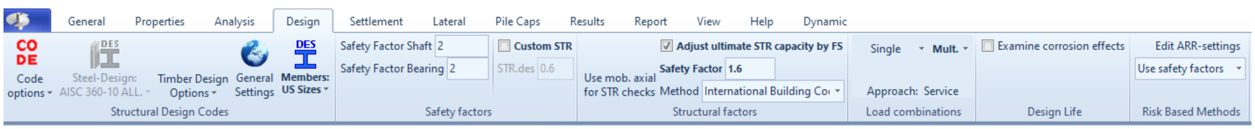


Figure 2.6.1: The Design tab menu.

Code options: By clicking on the  button, we can define which structural code's settings to apply in analysis. These code settings control structural codes and other options.

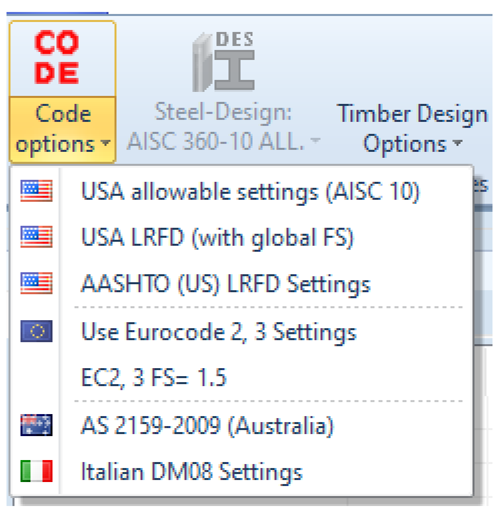


Figure 2.6.2: Code options.

The following options are available:

Use Eurocode 2, 3 settings	Apply Eurocode settings to the design
Use US allowable settings	Apply US allowable settings to the design
Use US LRFD settings	Apply US LRFD settings to the design
Use AASHTO (US) LRFD settings	Apply AASHTO LRFD settings to the design
Use AS 2159-2009 (Australia)	Apply AS 2159-2009 settings to the design
Italian DM08 Settings	Apply Italian DM08 settings to the design

By pressing on the CODE button, the Structural code options dialog appears. In this dialog we can define different code options for concrete and steel design. The following options are available:

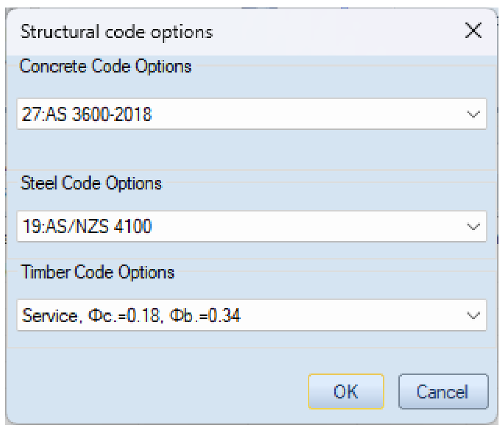


Figure 2.6.3: Structural code options.

DeepFND: Concrete Codes	DeepFND: Steel Codes	DeepFND: Timber Codes
ACI 318-11	ASD 1989 (Allowable)	Service – a=0.36
Eurocode 2 2004 (General)	LRFD 13th Edition 2005	AASHTO LRFD 6th Edition
Eurocode 2 – National Annexes	NTC 2008	
	ANSI/AISC 360-2010	
Eurocode 8 – National Annexes	AISC 360-2010 Allowable	
	ANSI/AISC 360-2016	
AS 3600-2018 (Australia, New Zealand	AISC 360-2016 Allowable	
	Eurocode 3 2005 (General)	
CN (China)	Eurocode 3 2005 – National Annexes	
	BS 5950-1 2000 (Britain)	
	AS/NZS 4100	
	CN (China)	

Safety factors: Here we can define several safety factors to be used in the design. We can define the Shaft FS, the bearing capacity FS, as well as a custom structural FS.

Structural factors: Here we can define a safety factor in order to define the ultimate structural capacity. We can also select the analysis method. The following options are available:
International Building Code 2015
AASHTO LRFD 6th
NYC Building Code 2014

Load combinations: Here we can choose the load combinations from Standards, choosing from the options below.

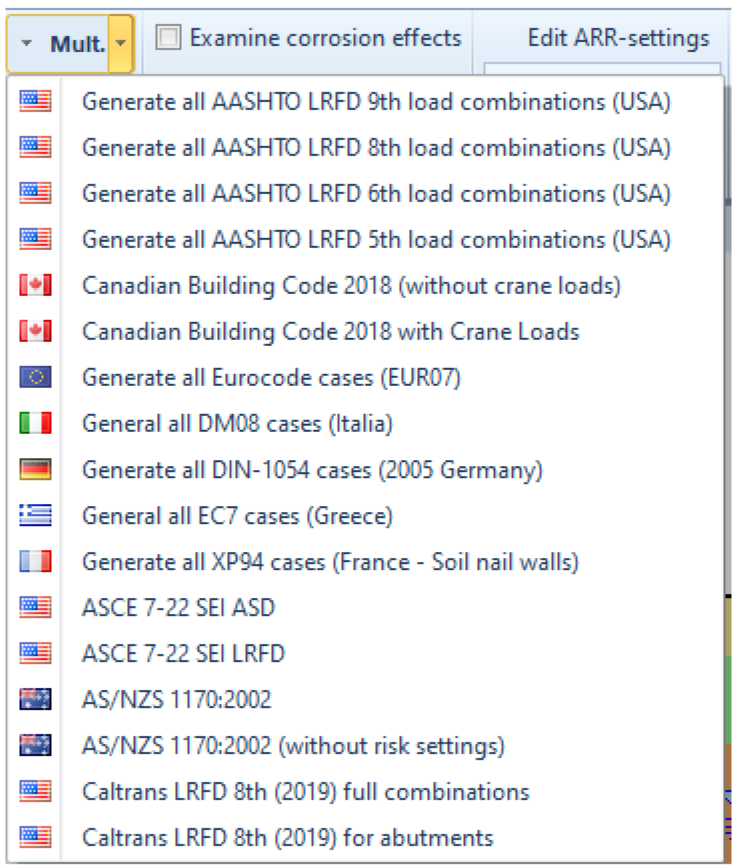


Figure 2.6.4: Load combinations available in DeepFND.

Design life: Here we can choose to examine corrosion effects. I so, we should define the design time (years) and the method. The available options are:
ICC Method AC355
AASHTO 2004
AS 2159-2009

Risk based methods: Used to define the safety factors for bearing and for shaft resistance.

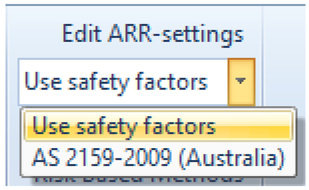


Figure 2.6.5: Edit ARR-settings.

2.7 Settlement menu

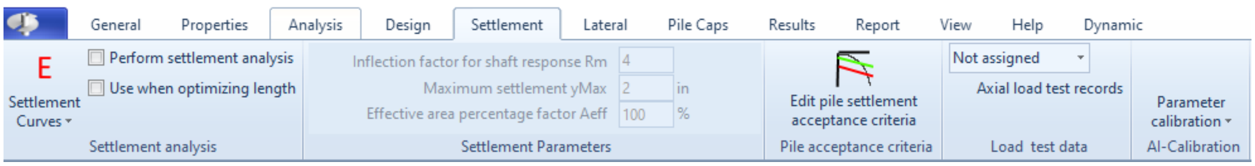
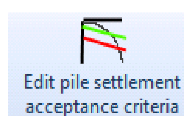


Figure 2.7.1: The Settlement tab menu.

Settlement Analysis: Here we can choose to perform a settlement analysis. If we choose to do so, the following options are available:
Option to calculate design capacity from PY response
Option to include corrosion effects in PY response
Settlement Parameters: Here we can define the settlement analysis parameters. The following parameters are available:
Installation factor for shaft response Rm
Maximum settlement yMax
Effective area percentage factor Aeff

Pile acceptance criteria: By pressing on the 

button, the pile acceptance criteria dialog appears (Figure 2.7.2).

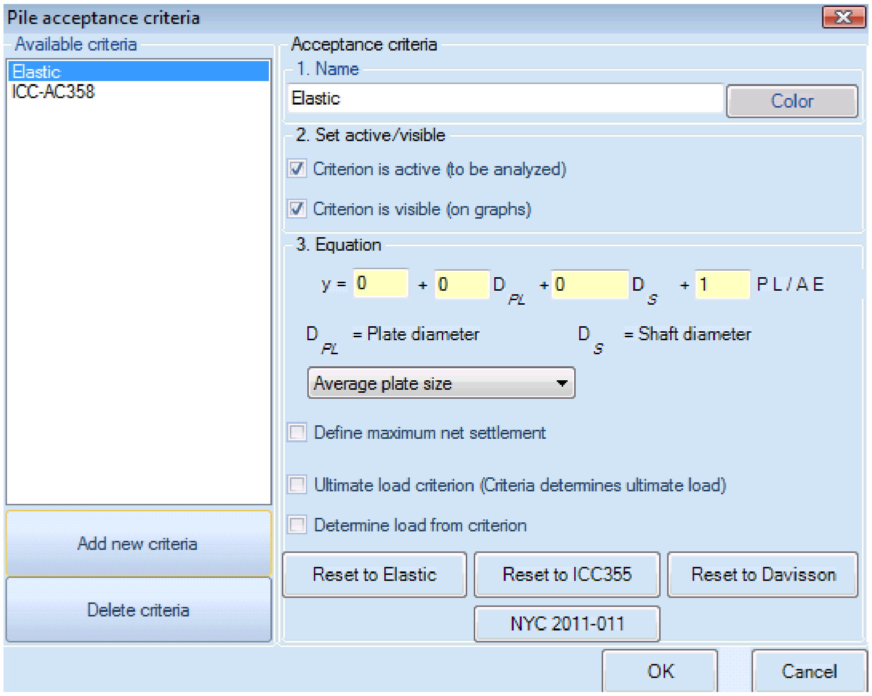


Figure 2.7.2: The pile acceptance criteria dialog.

In this dialog we can modify the following data:

Add or delete criteria, modify existing criteria
Option that the criterion is active and will be used in the analysis
Option that the criterion is visible and will be presented on the graphs
Modify the criterion equation parameters
Option to define maximum net settlement
Option to use ultimate load criterion
Option to determine load from criterion
Option to use a predefined criterion (options: Elastic, ICC355, Davisson, NYC 2011-011)

Load Test Data: In this area we can define the axial load test records (if available). We should press on the Axial load test records button. This opens the Axial Pile Load Test Records dialog (Figure 2.7.3).

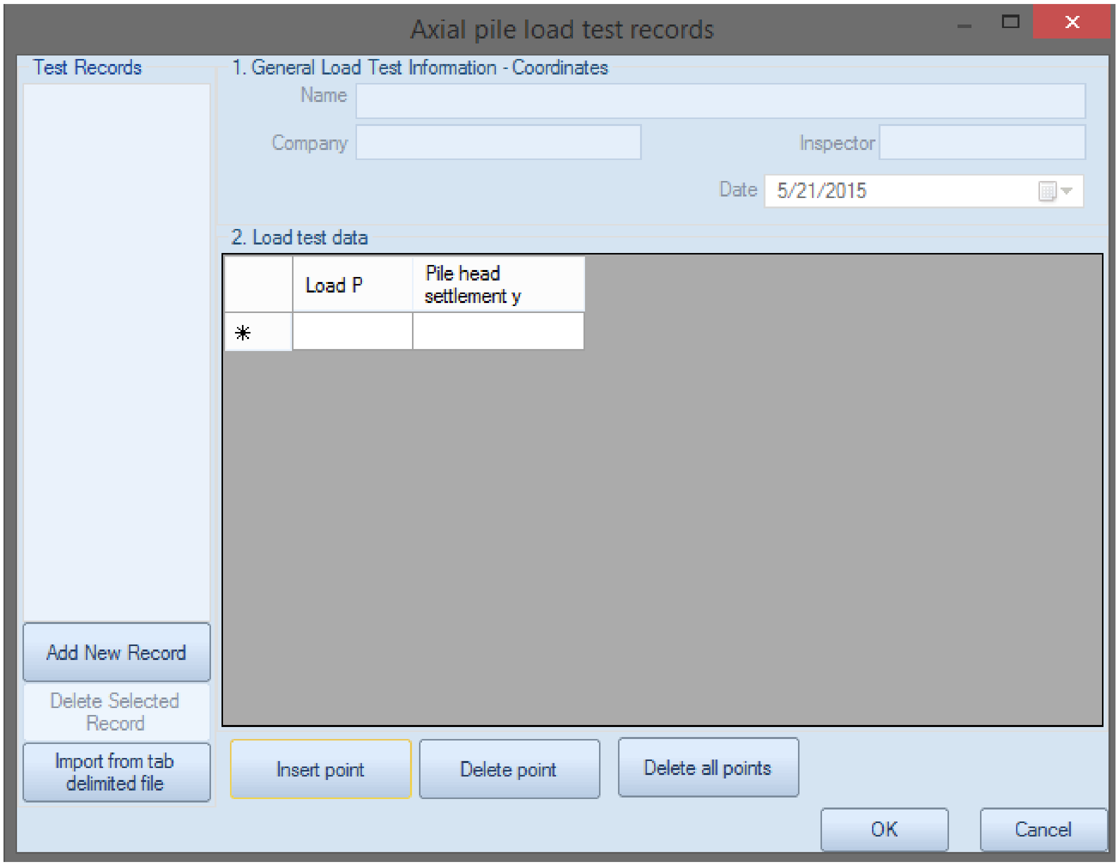


Figure 2.7.3: The axial pile load test records dialog.

In this dialog we can modify the following data:

Add or delete load test record
Option to add a pile load test record from a tab delimited file
Edit the pile load test name
Edit the pile load test company
Edit the pile load test inspector
Edit the pile load test date
Options to insert or delete points from pile test
Define load P and respective pile head settlement y

Parameter calibration: The parameter calibration allows to adapt soil parameters from SPT and CPT to the models to match load tests.

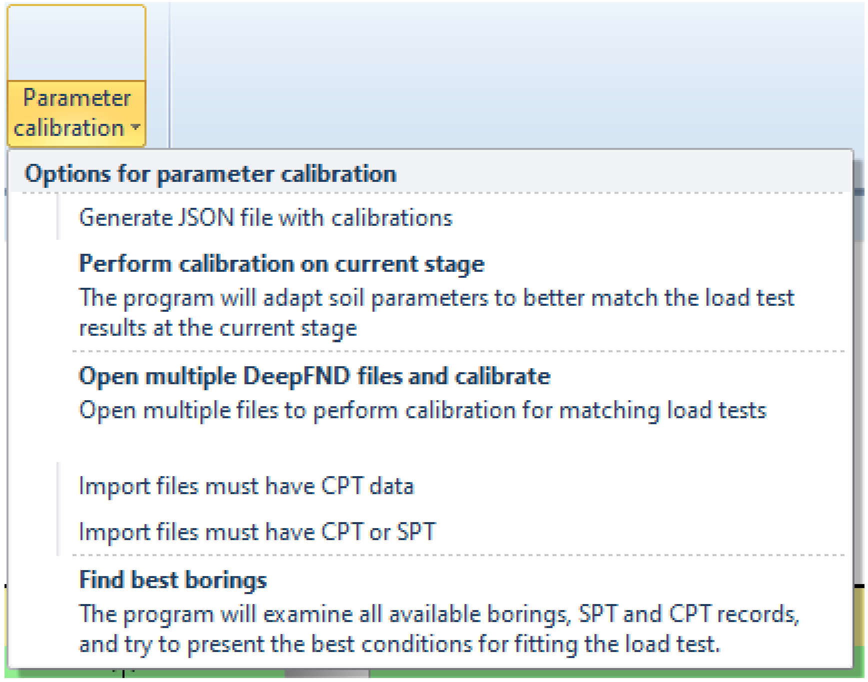


Figure 2.7.4: Parameter calibration.

2.8 Lateral menu

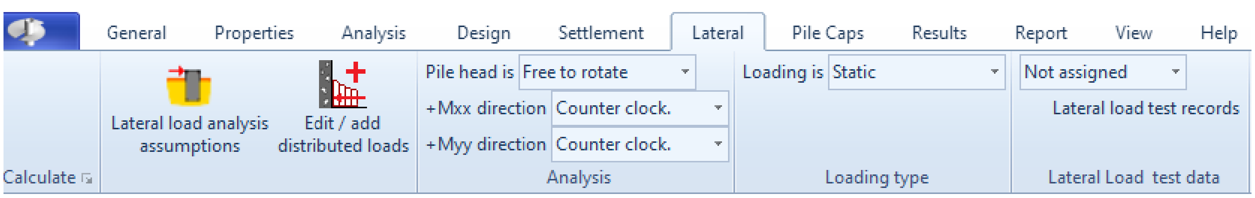
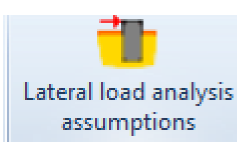


Figure 2.8.1: The Lateral tab menu.

In this tab we can define the lateral pile analysis parameters. The following options are available:

By pressing on the 

button, the Lateral pile analysis settings dialog appears (Figure 2.8.2).

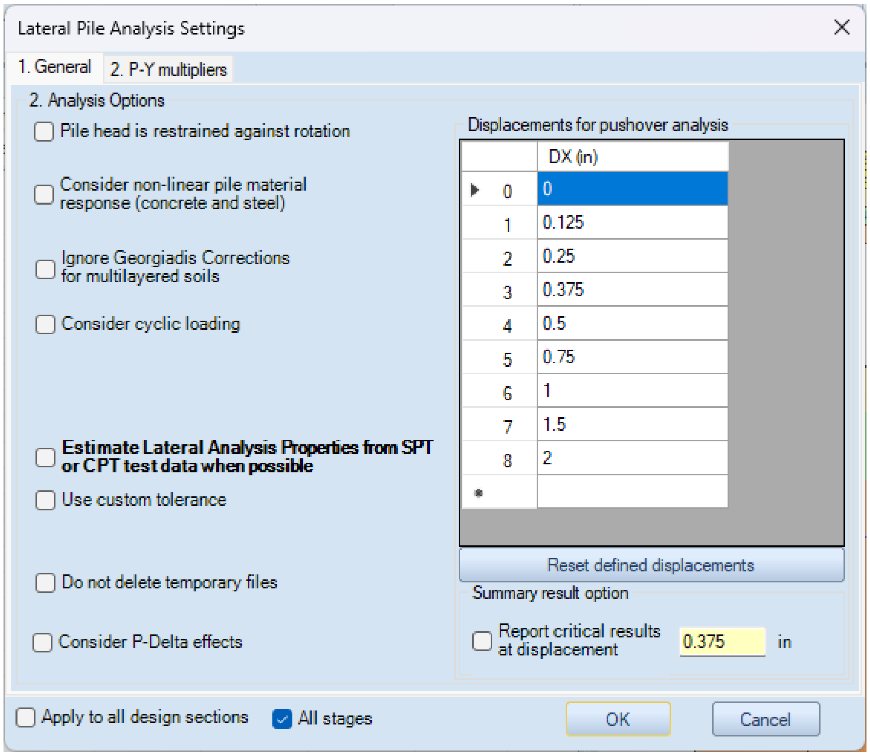


Figure 2.8.2: The Lateral pile analysis settings dialog.

In this dialog we can modify the following parameters:

Analysis mode: Here we can choose between:

- Analysis for defined lateral loads (from load menu)

- Pushover analysis (define displacements)

When the second option is selected, we can define the displacements for pushover analysis in the same dialog. In addition, we can define the displacement at which we should report the critical results.

- Option that the pile head is restrained against rotation
- Option to consider non-linear pile material response (concrete and steel)
- Option to Consider cyclic loading (when selected we can define the number of cycles)
- Option to estimate Lateral Analysis Properties from SPT or CPT test data when possible.
- Option to apply changes to all design sections and all stages.

By pressing on the 

button, Trapezoidal loads dialog appears (Figure 2.8.2).

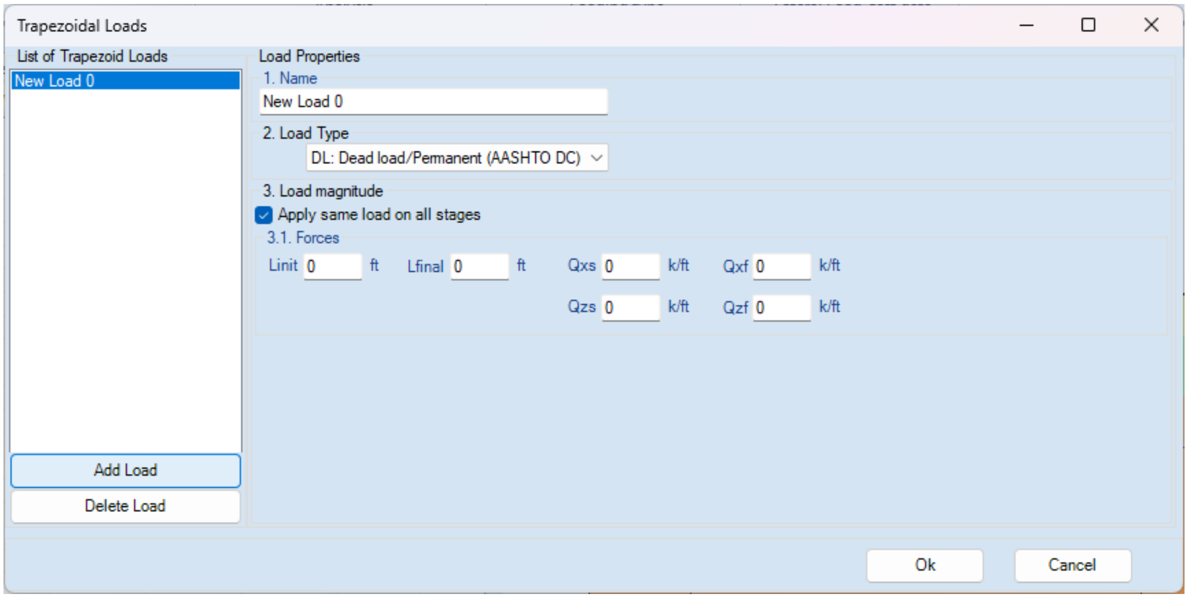


Figure 2.8.2: The Trapezoidal loads dialog.

Properties on this form are described in section 3.9.

Analysis: Here we can define the analysis type (Lateral load defined / Pushover analysis) and the pile head condition (Free to rotate / Fixed against rotation).

Loading: Here we can define the loading type (Static / Cyclic)

Lateral Load Test Data: In this area we can define the lateral load test records (if available). We should press on the Lateral load test records button. This opens the Lateral Pile Load Test Records dialog (Figure 2.8.3).

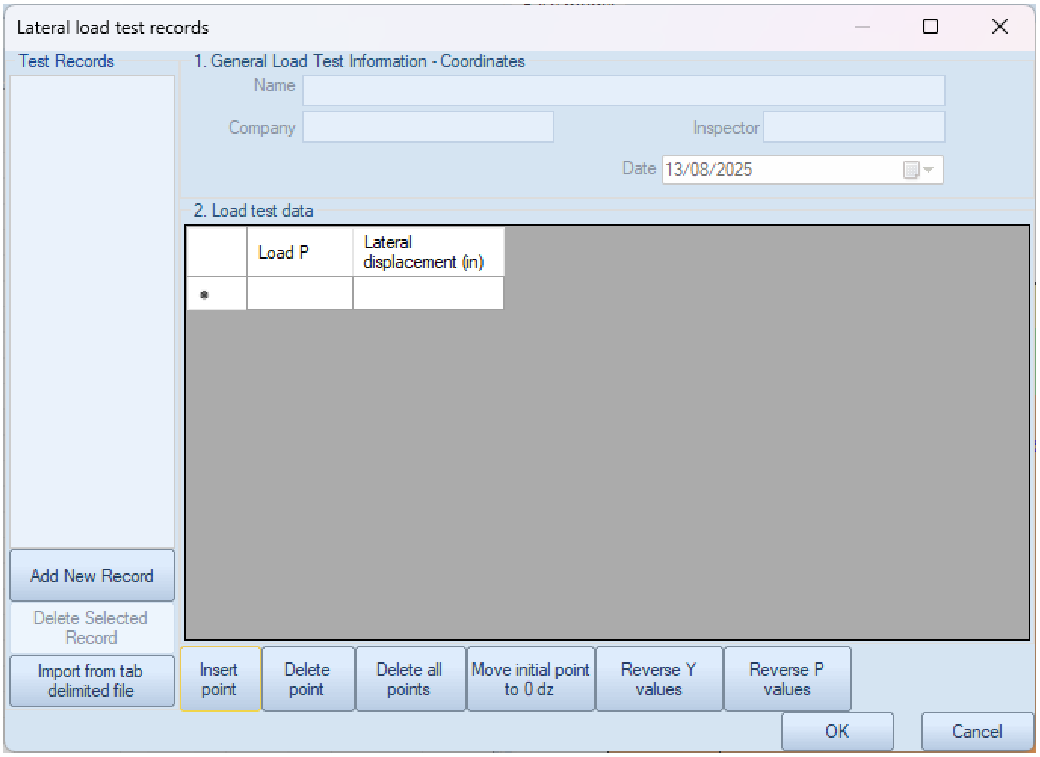


Figure 2.8.3: The lateral pile load test records dialog.

In this dialog we can modify the following data:

Add or delete load test record
Option to add a pile load test record from a tab delimited file
Edit the pile load test name
Edit the pile load test company
Edit the pile load test inspector
Edit the pile load test date
Options to insert or delete points from pile test
Define load P and respective pile head settlement y

2.9 Pile Caps menu

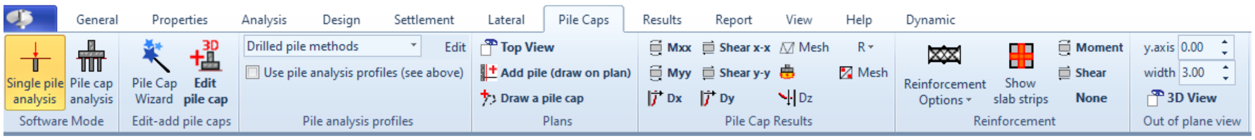


Figure 2.9.1: The Pile Caps tab menu.

This tab contains the tools to create, edit and view the results of pile caps supported by pile groups.

Analysis Type: Here we can select to perform a single pile analysis, or analyze a pile cap.

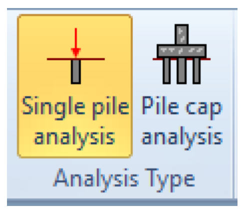
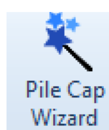
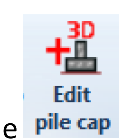


Figure 2.9.2: Option to analyze a single pile or a pile cap.

Pile Cap Wizard: By pressing the 

button, the pile cap wizard dialog appears. The wizard dialog allows as to quickly create a pile cap, defining the pile cap shape, loading, dimensions and number or piles. The pile cap and all piles are generated and presented on the model area automatically. **Properties on this form are described in section 6.1**.

Edit Pile Cap: By pressing the 

button, the 3D Footing Pile Cap dialog appears. In this dialog we can review and edit all pile cap items and properties. **Properties on this form are described in section 3.8**.

Pile Analysis Profiles: In this area we can select a pile installation profile. The default option is always the one selected in the Single pile that we used to model all piles on the pile cap. We can change the installation method on each pile independently, or we can define the same profile for all piles from the menu.

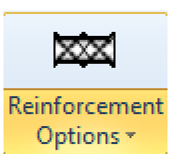
Plans: In this area we can select to see the top (plan) view. While on plan view, we can use the tools in order to add new piles on the model area or draw a custom pile cap. **The use of these tools is explained further in sections 6.3 and 6.4.**

Pile Cap Results: This area includes tools that can show different calculated results on the pile cap plan view model**. The results are presented in section 6.5**. The following options are available:

Option	Description
Mxx	Show the moments produced on the pile caps along the x-axis
Myy	Show the moments produced on the pile caps along the y-axis
Shear x-x	Show the shear forces produced on the pile caps along the x-axis
Shear y-y	Show the shear forces produced on the pile caps along the y-axis
Dx	Show the pile cap displacements along the x-axis
Dy	Show the pile cap displacements along the y-axis
Axial	Show the axial forces distributed in the pile cap
Mesh	Show the calculated mesh displacement on the pile cap
Dz	Show the pile cap settlements
	Show the soil stresses distribution on the pile cap

Out of plain view: In this area we can define the model width area, as well as, define the out-of-plain position (y-axis coordinate) to be displayed on the 2D model area. We can also select to generate the 3D View of the created pile cap with all the piles.

Reinforcement: This option allows to view, optimize rebars, and punching capacity as well as show slab strips.

The button 

leads to the options presented in Figure 2.9.3.

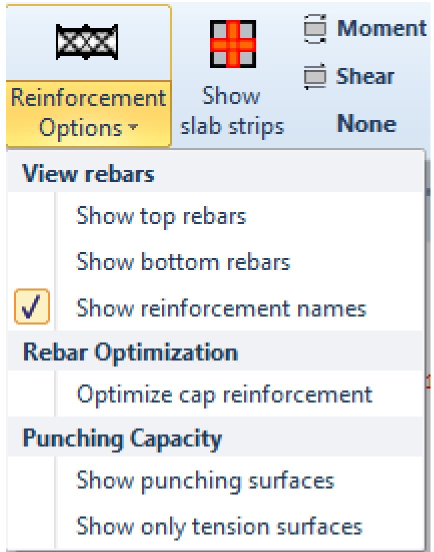


Figure 2.9.3: Reinforcement options.

Seismic loads: In this area we can select to include seismic loads on the model and define the seismic accelerations on each direction (3D).

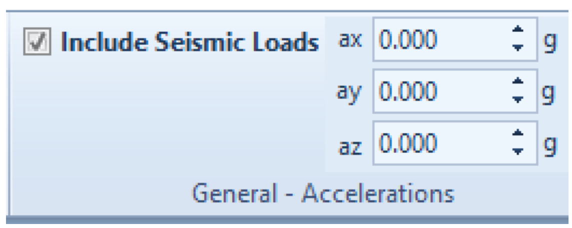


Figure 2.9.4: Option to include seismic loads and define seismic accelerations.

2.10 Results menu

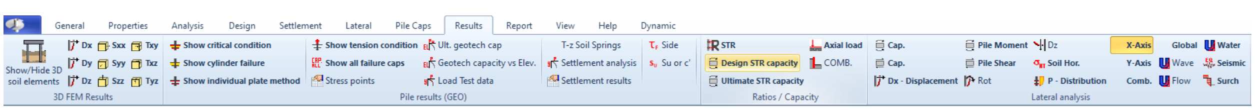


Figure 2.10.1: The Results tab menu.

This tab contains a list of results that can be either viewed on the 2D model or presented in diagrams or tables. Results can be presented when the analysis has been completed. The following options are available:

Option	Description
Show critical condition	Show the critical condition results on screen (most critical between cylinder and individual plate failure modes)
Show cylinder failure	Show the cylinder failure results
Show individual plate method	Show the individual plate results
Show tension condition	Show the results for tension condition
Show all failure caps	Show the geotechnical capacities of both cylinder and individual plate modes
Stress points	Show several results for points along the pile in table
Ult. geotech cap	Show the ultimate geotechnical capacity vs. elevation
Geotech capacity vs Elev.	Show the geotechnical capacity vs. elevation
Settlement analysis	Show the axial load vs. pile head settlement graph
Settlement results	Show the axial load vs. pile settlement diagram in a detailed graph and values in table format
Load Test data	Show the axial load test data on screen (if defined)
T-z Soil Springs	Show the Vertical T-z pile response for individual springs
T_F Side	Show the side pile shear stresses along pile
S_U Su or c'	Show the Su or c' values used along pile (undrained shear strength or effective cohesion)
STR	Show the structural stress ratio
Design STR capacity	Show the design structural capacity
Ultimate STR capacity	Show the ultimate structural capacity
Axial load	Show the Axial load on the pile at the current stage
Option	**Description**
Pile Moment	Show the calculated pile bending moments
Cap.	Show the pile moment capacity when moment is displayed
Pile Shear	Show the calculated pile shear forces
σ_{HT} Soil Hor.	Show the effective horizontal soil pressure on pile

Dx - Displacement	Show the horizontal pile displacement for current stage
P - Distribution	Show Axial load distribution along pile

The button 

allows to hide/show the soil elements in 3D models.

2.11 Report menu

From the Report tab we can control options for viewing reports in pdf or word formats as well as see summary tables of all calculations.

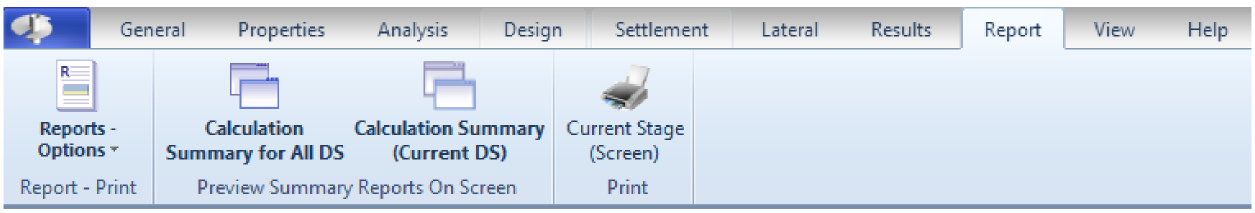


Figure 2.11.1: The Reports tab menu.

Option to create a report – **see section 3.13.**
Option to show the calculations summary table for all design sections – **see section 4.3.**
Option to show the calculations summary table for the current section – **see section 4.3.**
Option to print the current screen

2.12 View menu

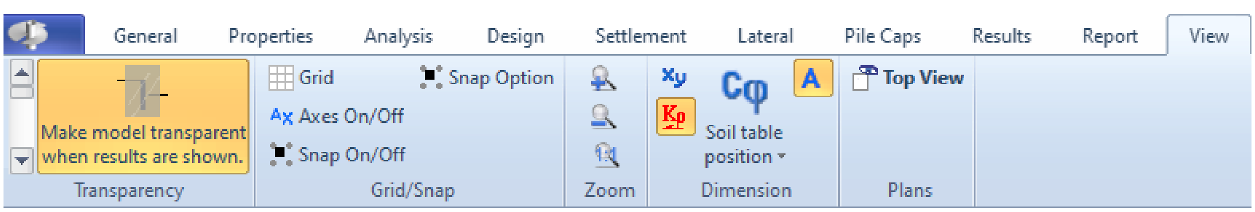
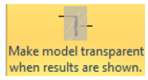
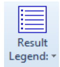


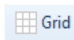
Figure 2.12.1: The View tab menu.

Transparency: By pressing the 

button we can make the model transparent when results are shown. The transparency can be adjusted from the vertical bar.

Result legend: By pressing the 

button we can turn the result legend on or off.

Grid/snap: By pressing the 

button we can change the view options of the snap and axis or show a grid.
Zoom: These icons can be used in order to zoom in/out the model area or create a 1:1 view of the model.

Soil Table Position: This drop-down can change the position of the soil properties table in the model area:

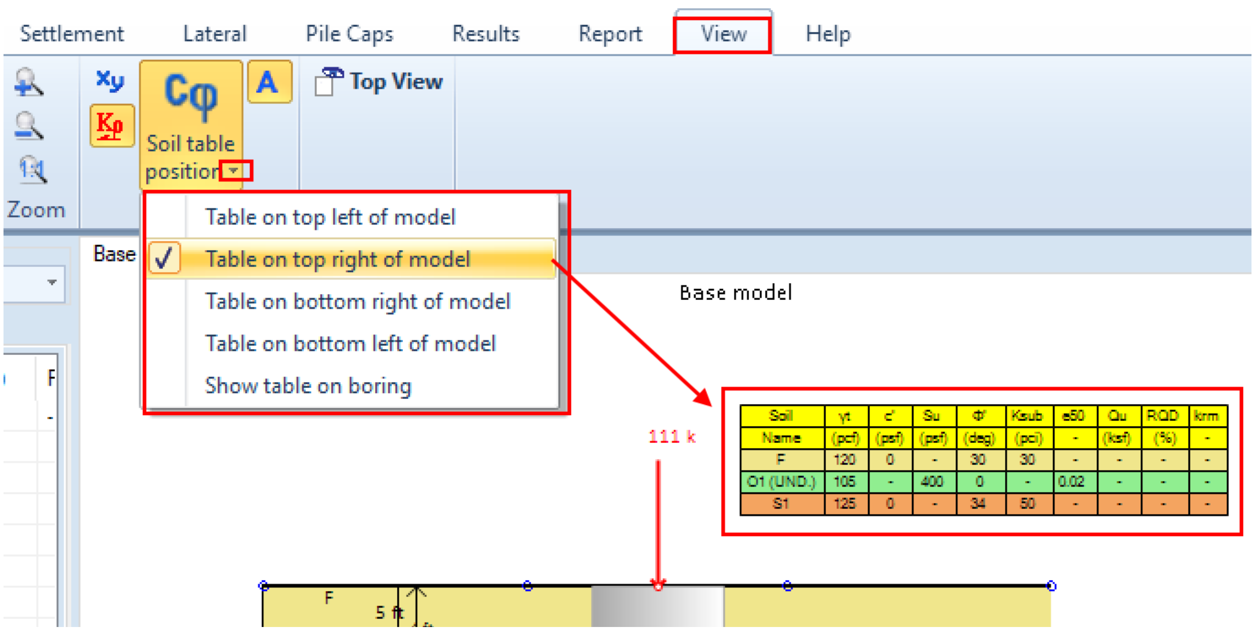


Figure 2.12.2: Edit the soil properties table position.

2.13 Help menu

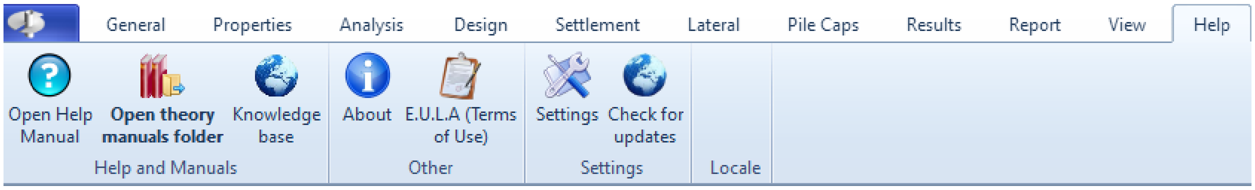
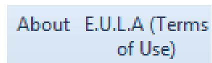


Figure 2.13.1: The Help tab menu.

About and terms of use: By pressing the  button, the user can read the terms of use of DeepFND.

Settings: by pressing the  button, the Default Settings dialog appears.

General tab: In this tab we can define the default units, company and engineer name and the Auto save directory.

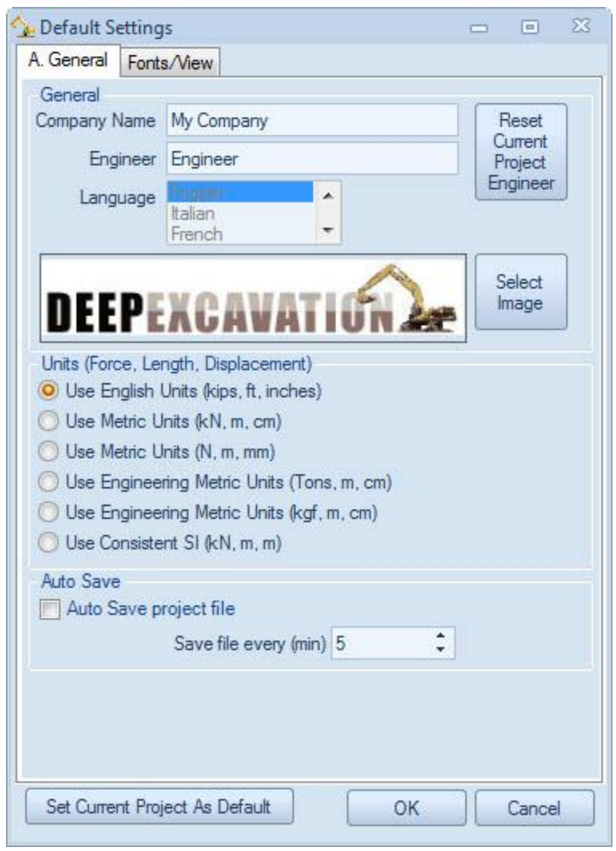


Figure 2.13.2: Settings – General Tab.

Fonts/View tab: In this tab we can define the fonts and some other viewing options.

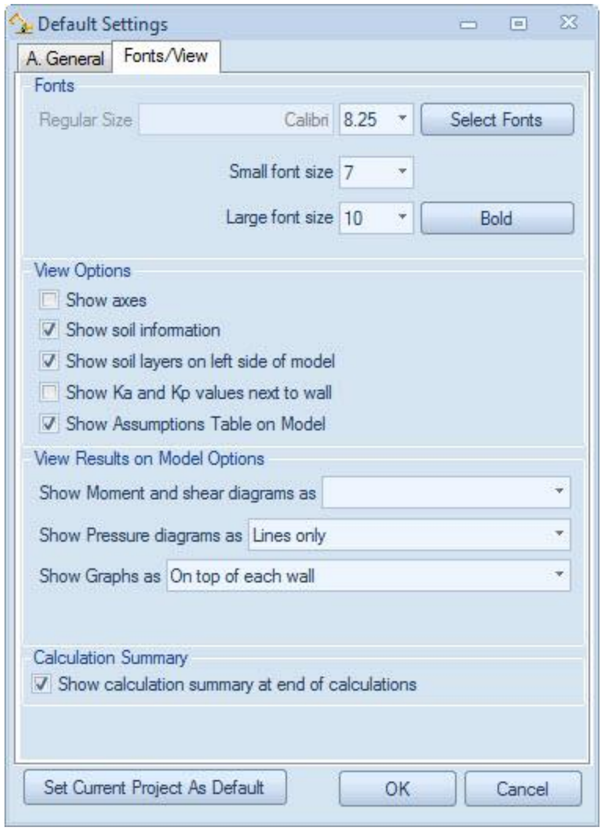


Figure 2.13.3: Settings – Fonts/View Tab.

Available view options are:
Show axes.
Show soil information.
Show soil layers on left side of model.
Show Ka and Kp values next to the wall.
Show assumptions table on model.

2.14 Dynamic

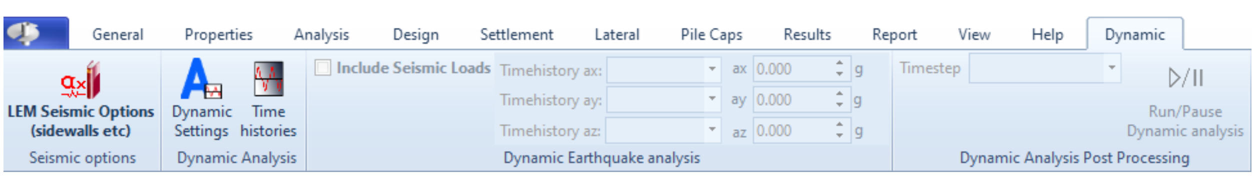
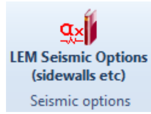


Figure 2.14.1: The Dynamic tab menu.

Seismic options: This option 

allows to set the seismic effect settings.

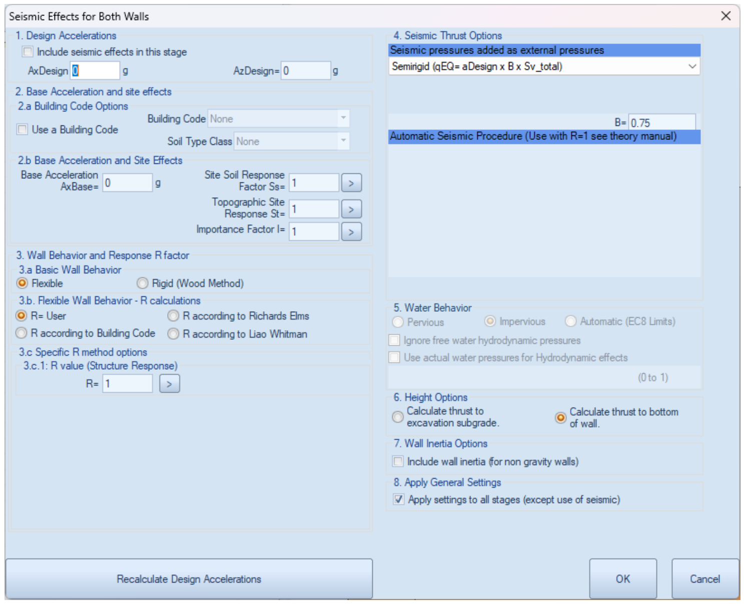


Figure 2.14.2: Seismic effects options.

Dynamic settings: By pressing the 

button, we can review and edit the software default implemented profiles. We can also add new profiles and define the factors manually.

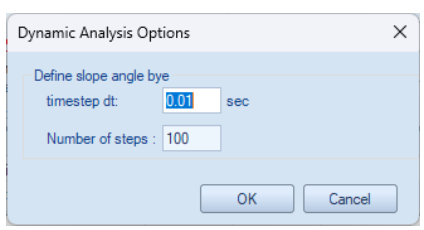


Figure 2.14.3: Dynamic analysis options.

Time histories: This button 

provides the time history records; time/Multiplier coefficient.

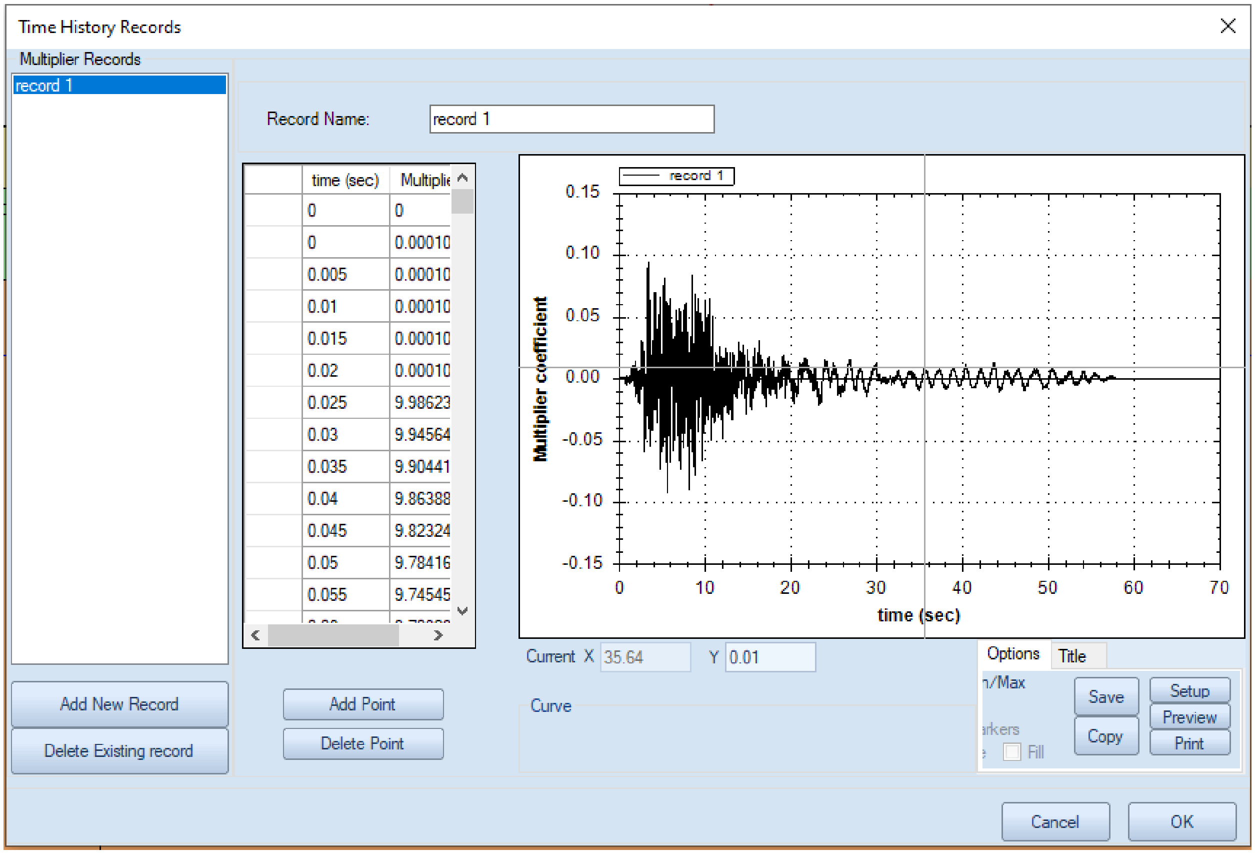


Figure 2.14.4: Time history records.

2.15 Edit Default Software Settings

In order to change the software default settings, we have to start the software as administrator, open the Settings dialog from the Help tab and press to set the current project as default.

IMPORTANT: Changing the default software parameters is an important procedure and we have to be very careful. By setting a project as default, we actually select the project that will be loaded each time we open the software. It is highly recommended that any settings changes should be applied in a clear model with no modifications to soil properties, stratigraphies, construction stages etc., else these settings will be saved as default as well.

The following procedure should be followed:

A. With the software closed, we should take the mouse over the software icon in the PC Desktop and RIGHT-CLICK on it.

B. From the menu that appears, we have to select to run the software as administrator.

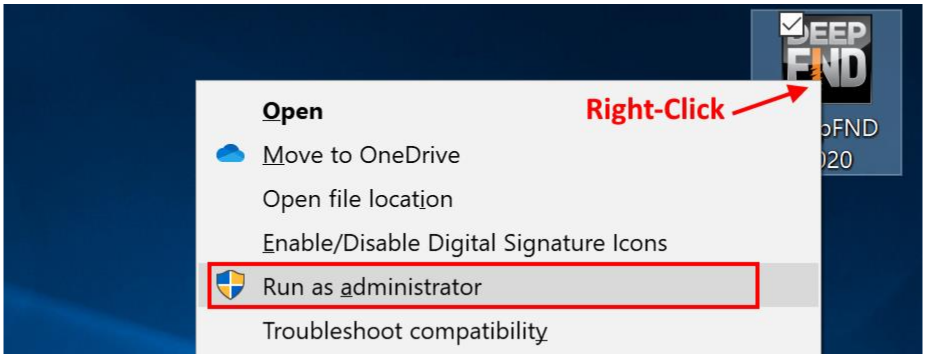


Figure 2.15.1: Option to open DeepFND as administrator.

C. In the Help tab of DeepFND, we can select the option Settings. In the dialog that appears, we can define all initial software settings (unit system, language, company and engineer name, font sizes, structural codes and more). We can also change the company logo, which appears in the DeepFND reports. The logo should be in jpg format, with dimensions 300x52 pixels. After changing all parameters, we can select to set the project as default.

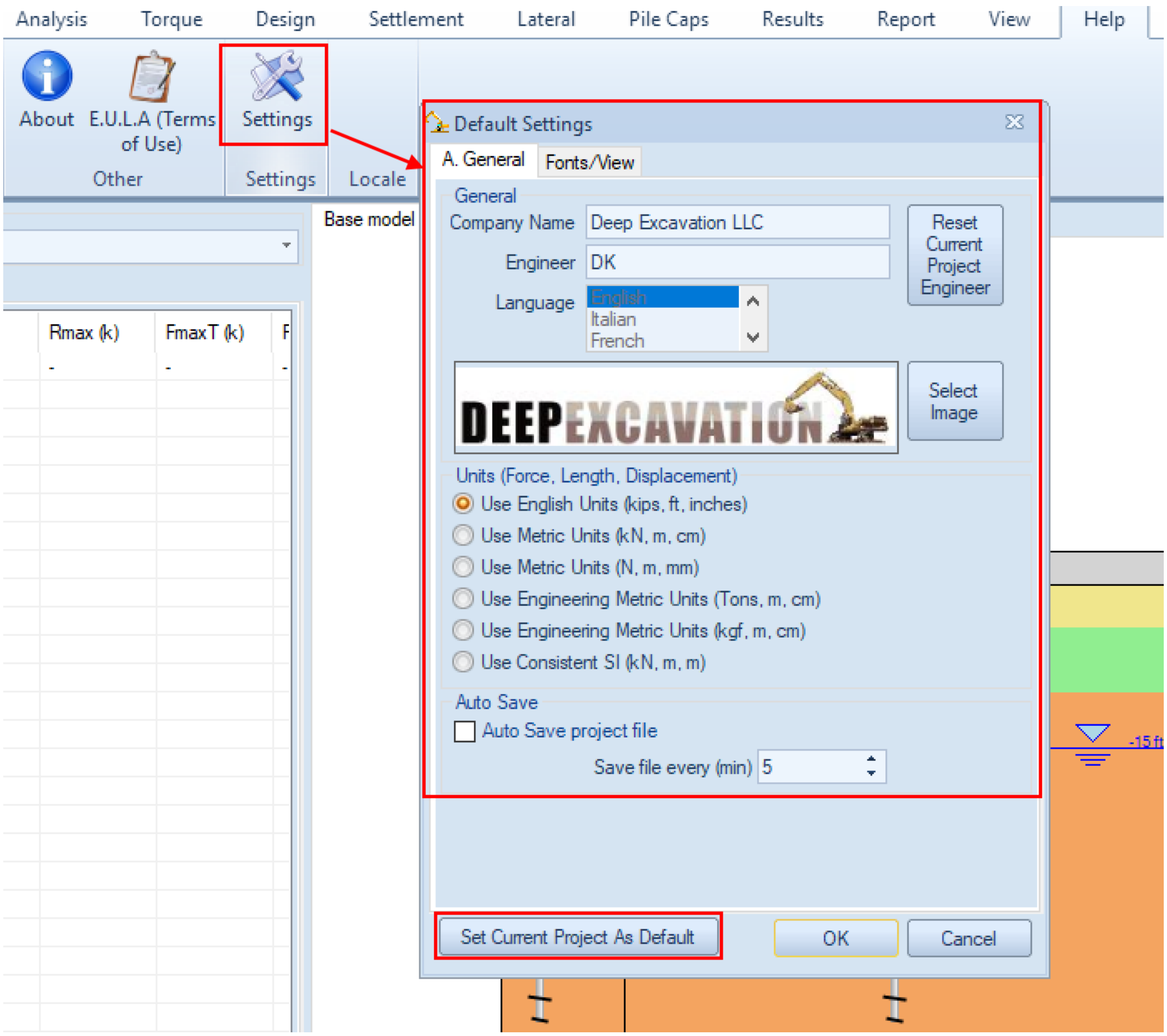


Figure 2.15.2: Change settings and set project as default.

SECTION 3: MAIN SOFTWARE DIALOGS – USE OF THE SOFTWARE

3.1 Define Model Elevation and Dimensions

In DeepFND, we can define the actual model surface elevation. All the current items elevation coordinates (ground surface and soil layer points, water table, support locations etc.) will change according to this selection.

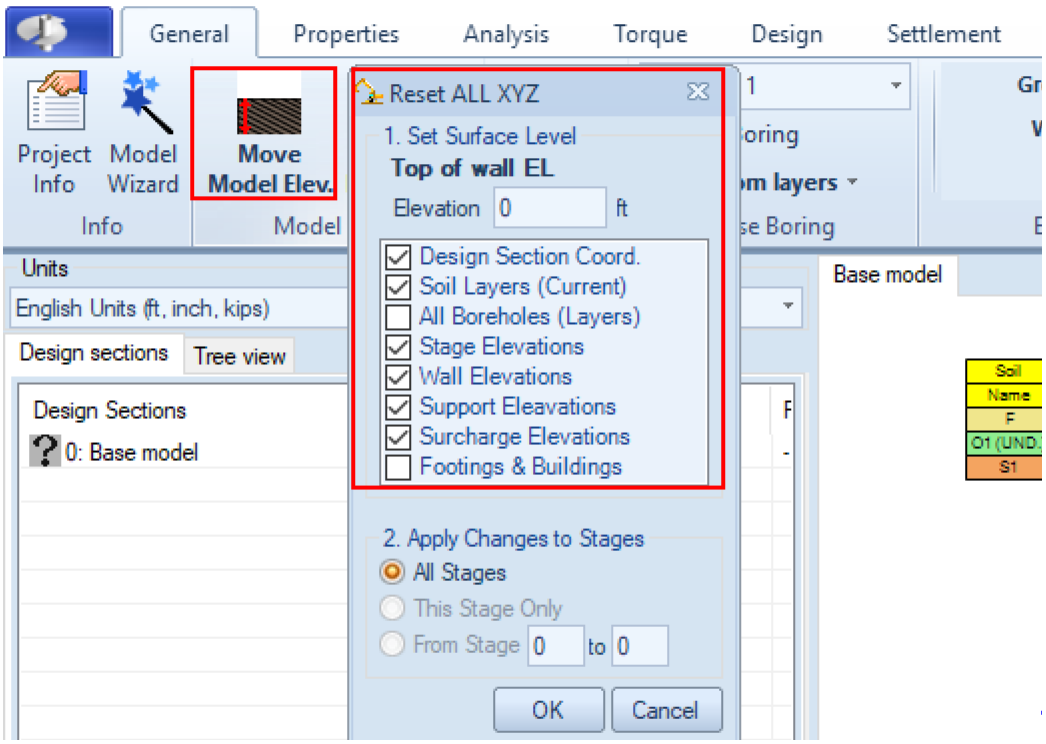


Figure 3.1.1: Edit general elevation options.

Our general recommendation is to always use actual elevations for project design, and define the general elevation in the beginning, before any other operation.

The option "All Boreholes (Layers) in the dialog is by default unselected. This is to avoid changing the reference elevation in or boreholes (if several borings are created in the project file), and keep the change effect in the boring that is currently selected. We can of course choose to pass the change to all borings at the same tie if needed. The same applies to the Footings and Buildings elevations (if they are currently installed before the general elevation change).

Also, in the General tab of the software, we can select the option Move model Dim-Limits. In the dialog that appears (Figure 3.1.2) we can define the design section name and the model boundaries (top, bottom, left and right).

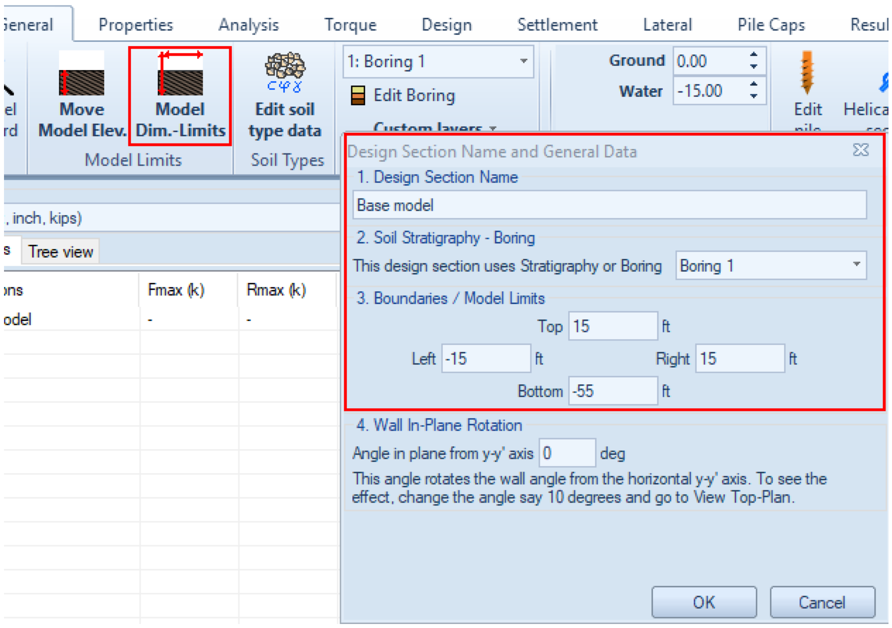


Figure 3.1.2: Design section options and limits

3.2 Define Project information

I the Project Information dialog (Figure 3.2.1), we can specify the Project Name, file number (or job number) and the name of the engineer preparing the analysis.

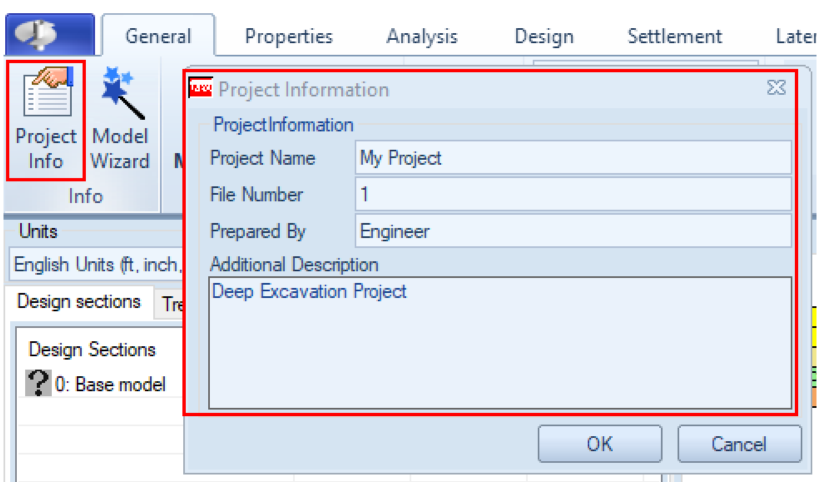


Figure 3.2.1: Project information dialog.

3.3 Define Soil Properties

One of the first actions to create a project in DeepFND software is to review the geotechnical report and create a list of soils with their soil properties. These soils can be later used to define the actual stratigraphy of the project area.

By pressing the Edit soil type data button of the General tab of DeepFND, the Soil Types dialog appears. Here we can use the options on the left side of the dialog to create as many soil types as needed (Figure 3.3.1), access them one by one and define their properties.

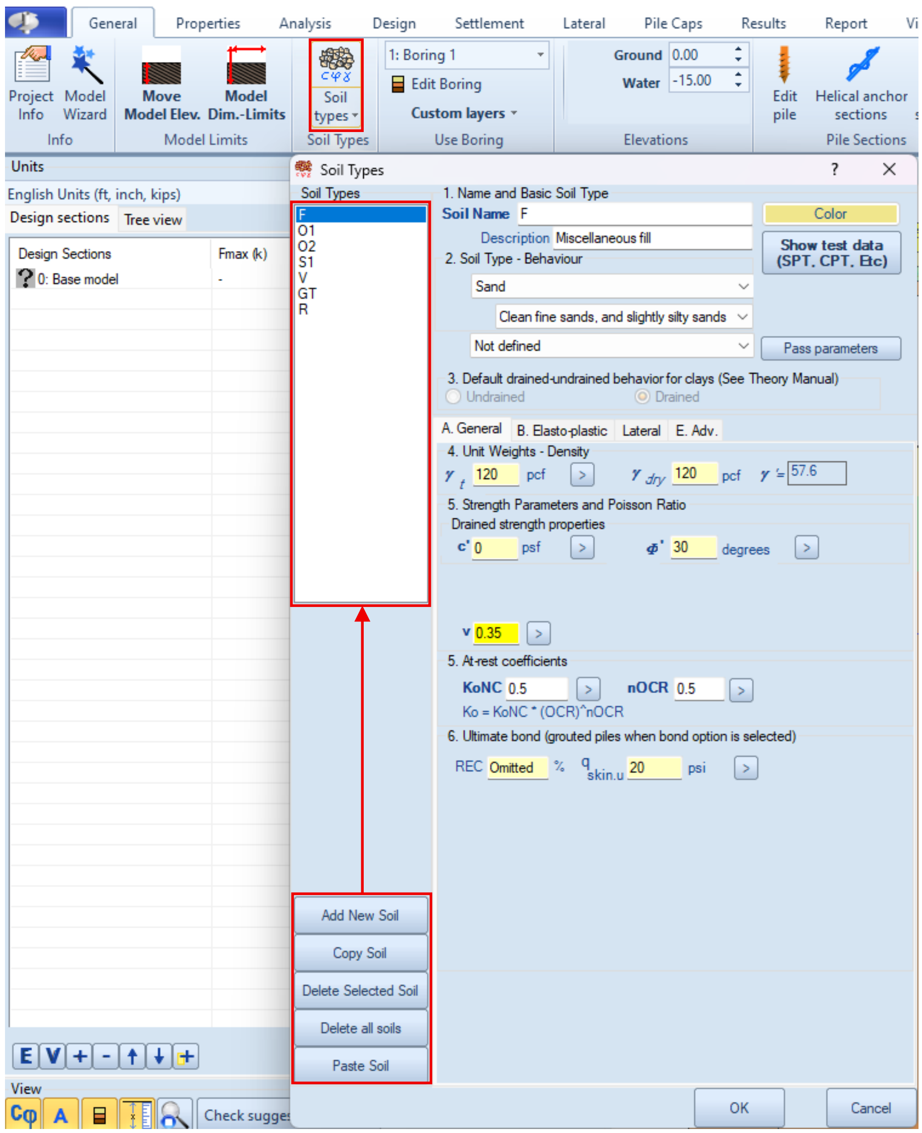


Figure 3.3.1: Open soil types of dialog and edit list of soils.

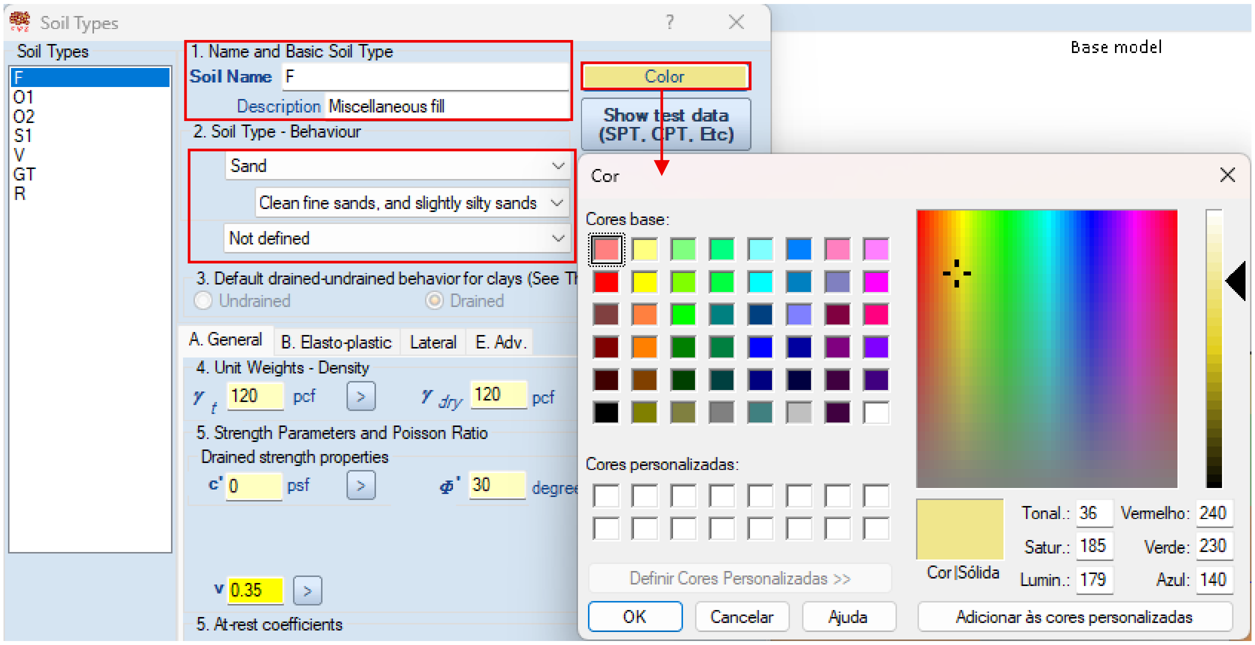


Figure 3.3.2: Define name, color and soil type of each soil.

Depending on the soil type of each soil (Sand, Clay, Silt, Gravel, Intermediate geo-material or Rock), we must define the general soil properties. Several properties can be defined for each soil (Poisson's ratio, permeability, At-rest Earth Coefficients etc.).

For frictional soils (sands, silts, etc.) we must define the unit weights, the cohesion and the friction angle (Figure 3.2.3). For clays, we also must define the default clay behavior (drained or undrained). Based on this selection, we have either to define the drained shear strength of the clay and the friction angle (drained condition), or the undrained shear strength of the clay Su.

When we wish to use concrete or grouted steel piles, we should also define the q skin value for each soil. This is the ultimate bond resistance between each soil and the concrete grout.

Our general recommendation is to review the geotechnical report carefully and always consult the person who conducted the report about the proper soil types and properties. The use of undrained clay behavior should be avoided for clays that are located above the water table, since it is unlikely to be fully saturated, thus working as an undrained clay.

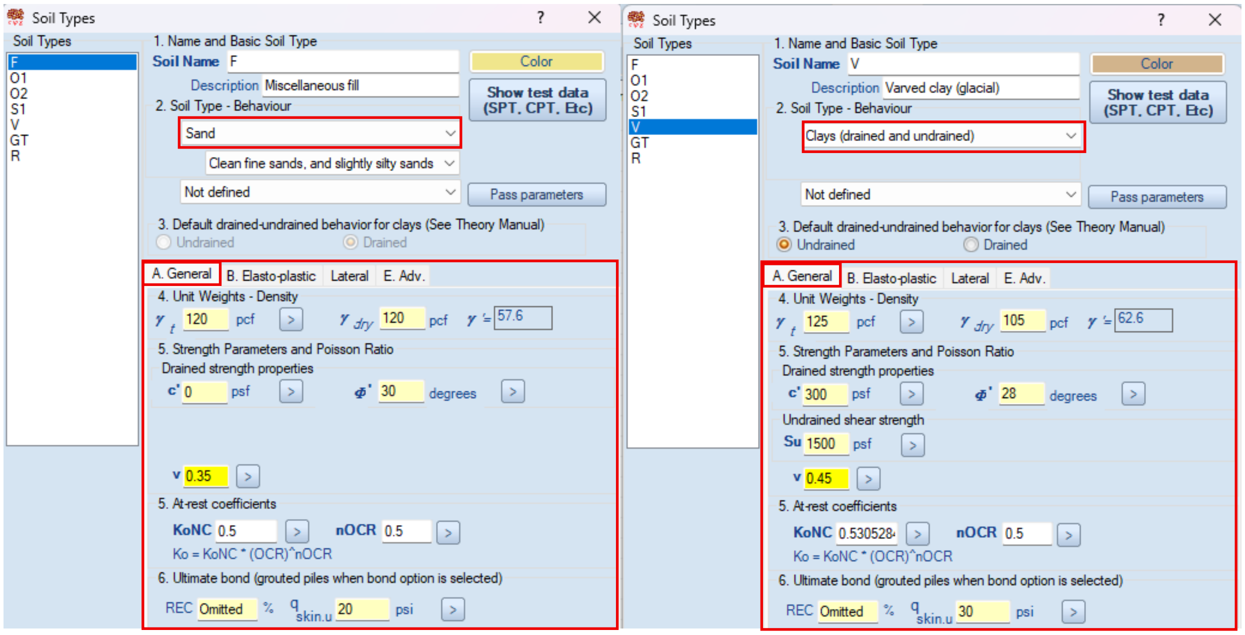


Figure 3.3.3: General soil properties – Sands and Clays.

The General soil properties are summarized in the following table:

Symbol	Description
γ_t	Total unit weight of soil (used below the water table)
γ_{dry}	Dry unit weight of soil (used above the water table)
c'	Effective soil cohesion
Su	Undrained shear strength (used for clays when undrained modeling is selected). In the non-linear analysis this is used as an upper limit strength
v	Poisson's ratio (used for loads calculated with theory of elasticity)
ϕ'	Effective soil friction angle
KoNC	Coefficient of at-rest lateral earth pressures for normally consolidated conditions
nOCR	Exponent for calculating Ko with Ko=KoNC*[(OCR)^(nOCR)]
$q_{skin,\,u}$	Ultimate bond resistance (when bond option is selected)

In addition, there is the option that Rock joints are open filled with gouge. Also, when a Rock soil is selected, user can define the value of RQD and the bearing capacity for rocks.

In the Elastoplactic tab of the dialog (Figure 3.3.4) we can define the soil model for each soil in the list. The available options are Elastoplastic, Exponential (hyperbolic) and Exponential with a linear creep.

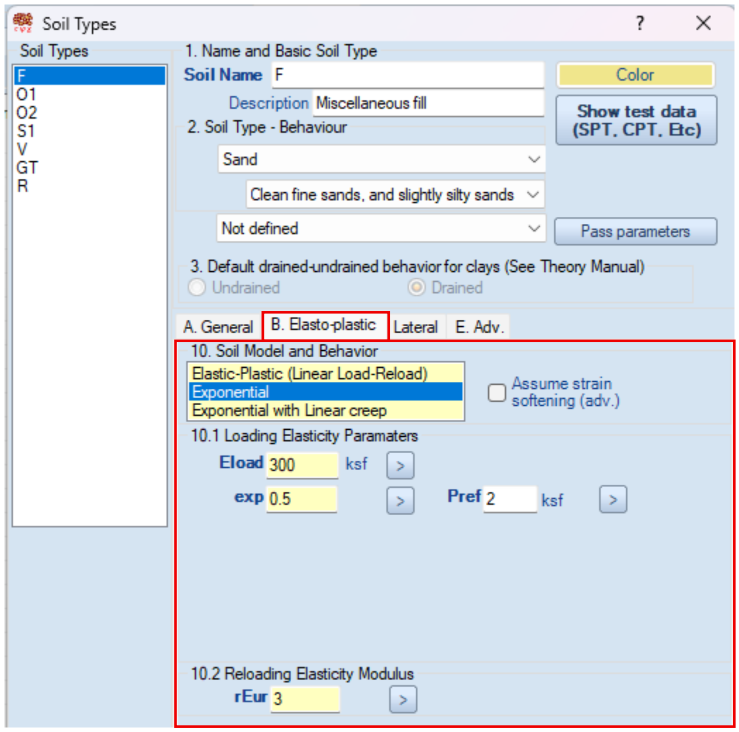


Figure 3.3.4: Soil Model options.

The soil model parameters are summarized in the following table:

Symbol	Description for elasticity parameter
Eload	Loading modulus of elasticity
exp	Exponent for exponential soil model
Pref	Reference stress for hyperbolic soil model (2 ksf or 100 kPa typical)
rF	Factor that determines when linear creep behavior kicks in (0.5 to 0.9) when exponential with linear creep model is selected.
erF	Ratio of ultimate failure strain to strain where exponential behavior ends for exponential soil model with linear creep
rEur	Ratio of reloading elasticity modulus

Ratio Eside/Eload for loads.

In the Lateral tab we can define the lateral pressure parameters of each soil (subgrade reaction modulus for sands, e50 value for clays, Krm value for rocks). These properties are used for the lateral analysis of the foundation piles. The following options are available:

- Lateral options for Sand soil layers:
    - Models for Sand: Sand API / Sand Reese
    - PY Model data: Specify the subgrade reaction modulus, k
- Lateral options for Silt soil layers:
    - PY Model data: Specify the subgrade reaction modulus, k
- Lateral options for Clay soil layers:
    - Models for Clay: Stiff clay with no free water / Stiff clay with free water / Soft clay
    - PY model: Specify strain at 50% of failure, e50
- Lateral options for Rock soil layers:
    - Model for Rock: Weak rock
    - PY model: Specify Unconfined compressive strength of Rock, qu
- Specify Rock Quality Designation, RQD (%)
- Specify Weak rock constant for Reese PY model, Krm (between 0.0005 and 0.00005, controls the overall stiffness)

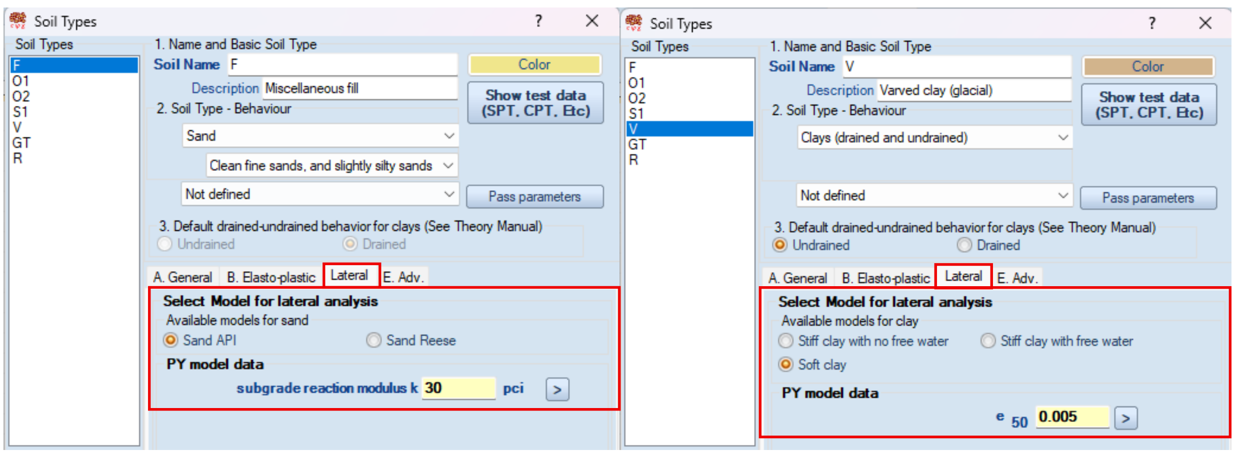


Figure 3.3.5: Lateral parameters for sands and clays.

In tab E. Advance, there is the option to include soil in parameter variation for Eurocode 7 type codes. It is recommended to keep this option selected. In addition, here the user can define a USER defined ultimate bearing pressure. This will be used only if the respective User pressure method is used in the analysis tab. Finally, in the advanced tab, user can select that the Su values can be calculated from an initial defined value, modified with the vertical effective stress multiplied with a user defined constant.

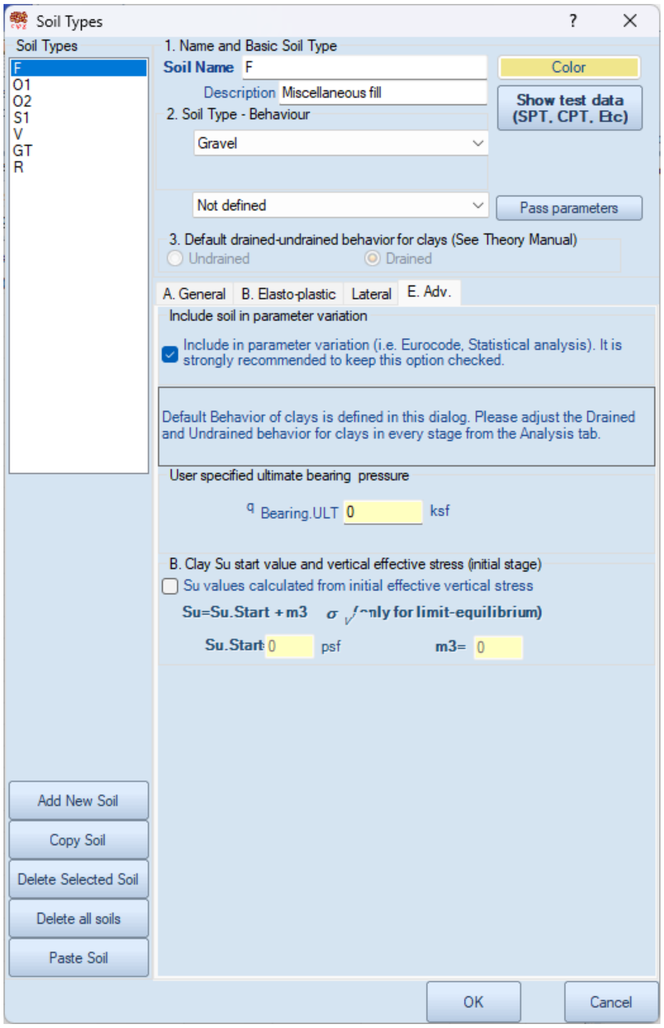


Figure 3.3.6: Advanced options tab.

The soil properties in DeepFND can be defined using the following methods:

A. **Manually defined by the user** based on the geotechnical report, previous projects and the designer experience.

B. **Use of the DeepFND SPT Estimator tool**. When we press the Show test data button, we can access the DeepFND SPT Estimator., where we can define the NSPT value for the specific soil in the NSPT bar. The software can estimate the soil properties from the NSPT. Choosing the option "Elasticity modulus", the elasticity parameters of the soil can also be estimated.

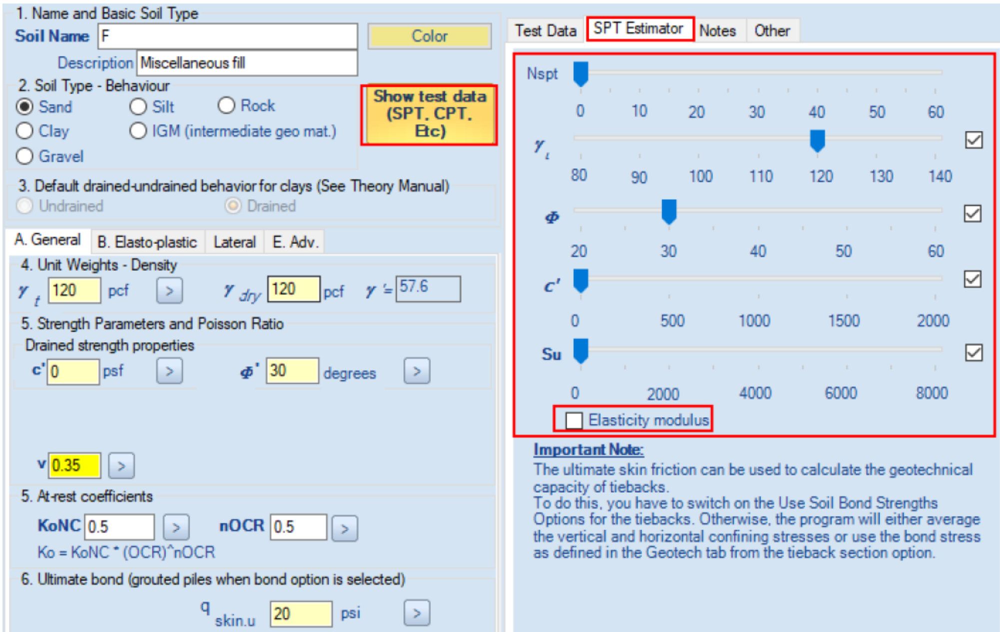


Figure 3.3.7: SPT Estimator in DeepFND.

C. **Use of the partial estimation tools, existing next to almost every value** (small arrows). Some of these arrows will offer specific values based on soil types, and some others will propose scientific methods for the calculation of the specific value. In this case, we will have to define one on more test results in the Test Data tab (data for standard penetration tests, cone penetrometer tests, pressuremeter tests etc.).

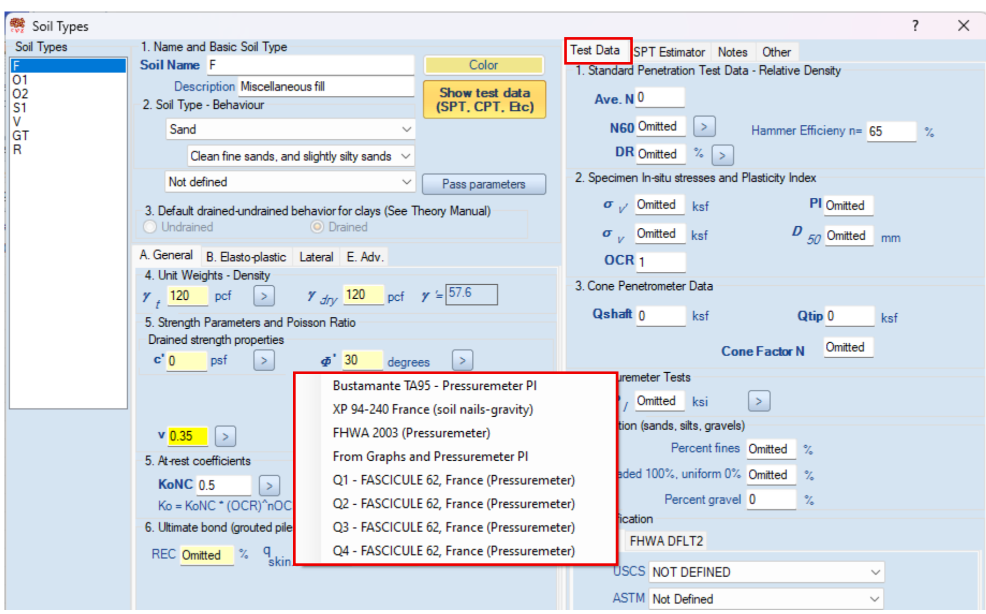


Figure 3.3.8: Local soil property estimation tools in DeepFND.

3.4 Define Soil Layers - Stratigraphy

In any DeepFND project file we can define unlimited number of borings, to simulate all different boreholes as described in the geotechnical report. If needed, we can assign a different boring in each design section from the drop-down in the General tab of DeepFND.

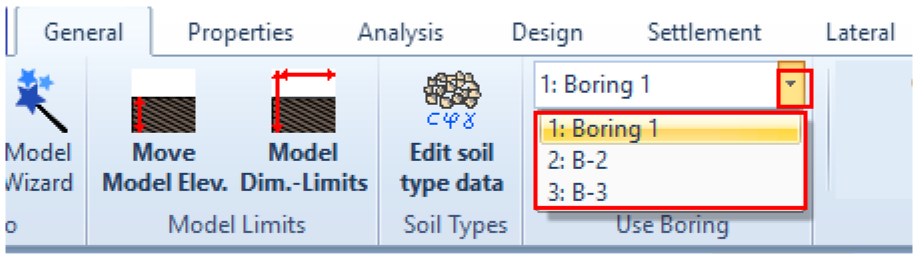


Figure 3.4.1: Assign a boring to the selected design section.

When we select the option Edit Boring in the General tab of DeepFND, the Edit Soil Layers dialog appears. There we can select to add new borings in the project database. We can access each one of them and define the stratigraphy by defining top of the soil layer elevation and select a soil type below the specified elevation from the list of soils, for each soil layer (Figure 3.4.2). We can repeat soil types in different depths.

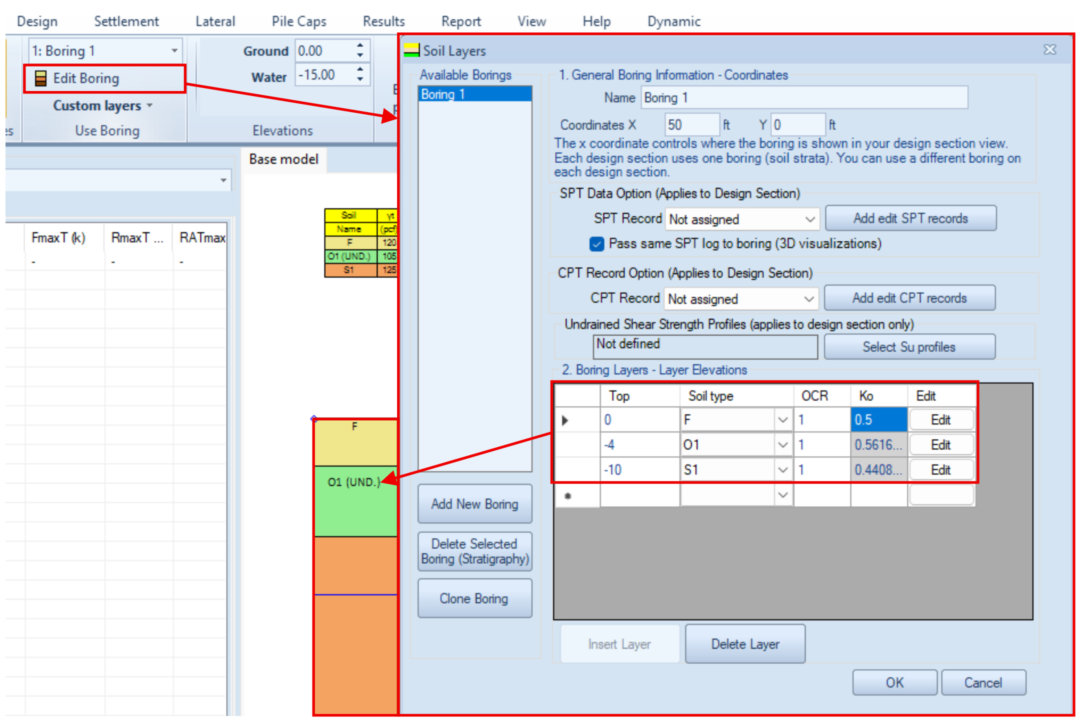


Figure 3.4.2: Define soil layers in DeepFND.

3.5 Define Pile Properties

DeepFND can be used for the design of helical and non-helical piles. On the other hand, HelixPile can design only helical piles. This section presents the Edit pile dialog properties in each case. This dialog appears by double-clicking on the pile in the model area.

Edit Pile Properties – Helical Piles (DeepFND and HelixPile)

By double-clicking on the pile in the model area, we can define the general pile properties. In the dialog that appears, we can define the top of the pile elevation, the pile installation angle and the pile depth. If the shaft is grouted, we can also define the grout diameter.

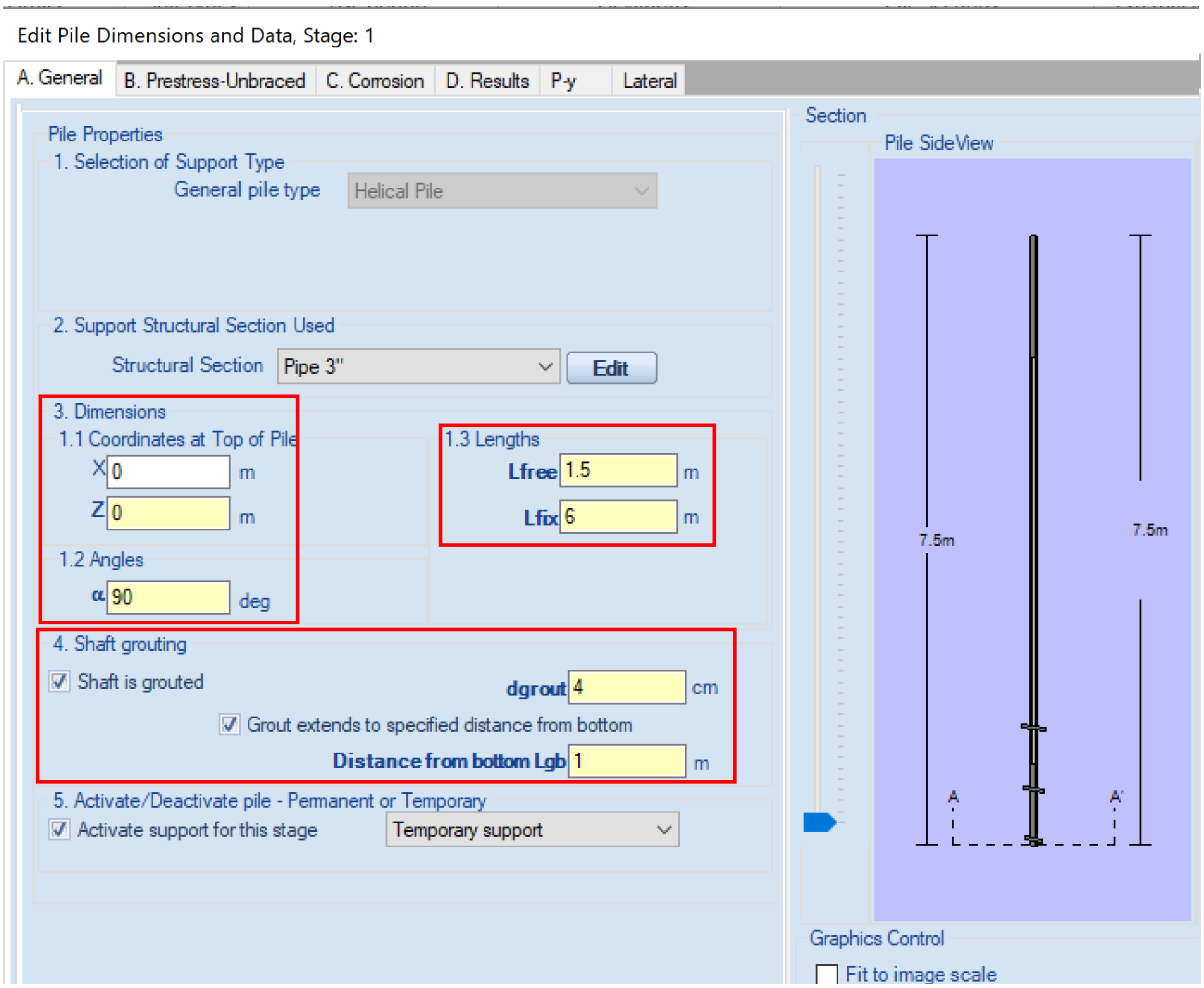


Figure 3.5.1: Defined general pile properties.

By pressing the button "Edit", we can update the helical pile section database (see section 3.6).

Edit Pile Properties – Non-Helical Piles (DeepFND Only)

By double-clicking on the pile in the model area, we can define the general pile properties. In the "Edit Pile Dimensions and Data" dialog that appears (see Figure 3.5), we can define the following options:

Pile Type (Helical or Non-Helical pile)

Free length (where adhesion or side resistance is ignored).

Installation angle (90 deg = vertical pile)

Installation method (option available for non-helical piles only). The following options are available:

- Drilled piles
- Driven piles
- Caisson piles
- Micropiles
- CFA (Continuous Flight Auger) piles
- Drilled-In-Displacement piles

Structural section and pile length. User can define the depth of each pile segment and select a structural section. The structural sections list can be updated by pressing the "Edit" button next to each pile section segment.

By selecting to Edit the structural section, we can update the non-helical pile sections database (see section 3.7).

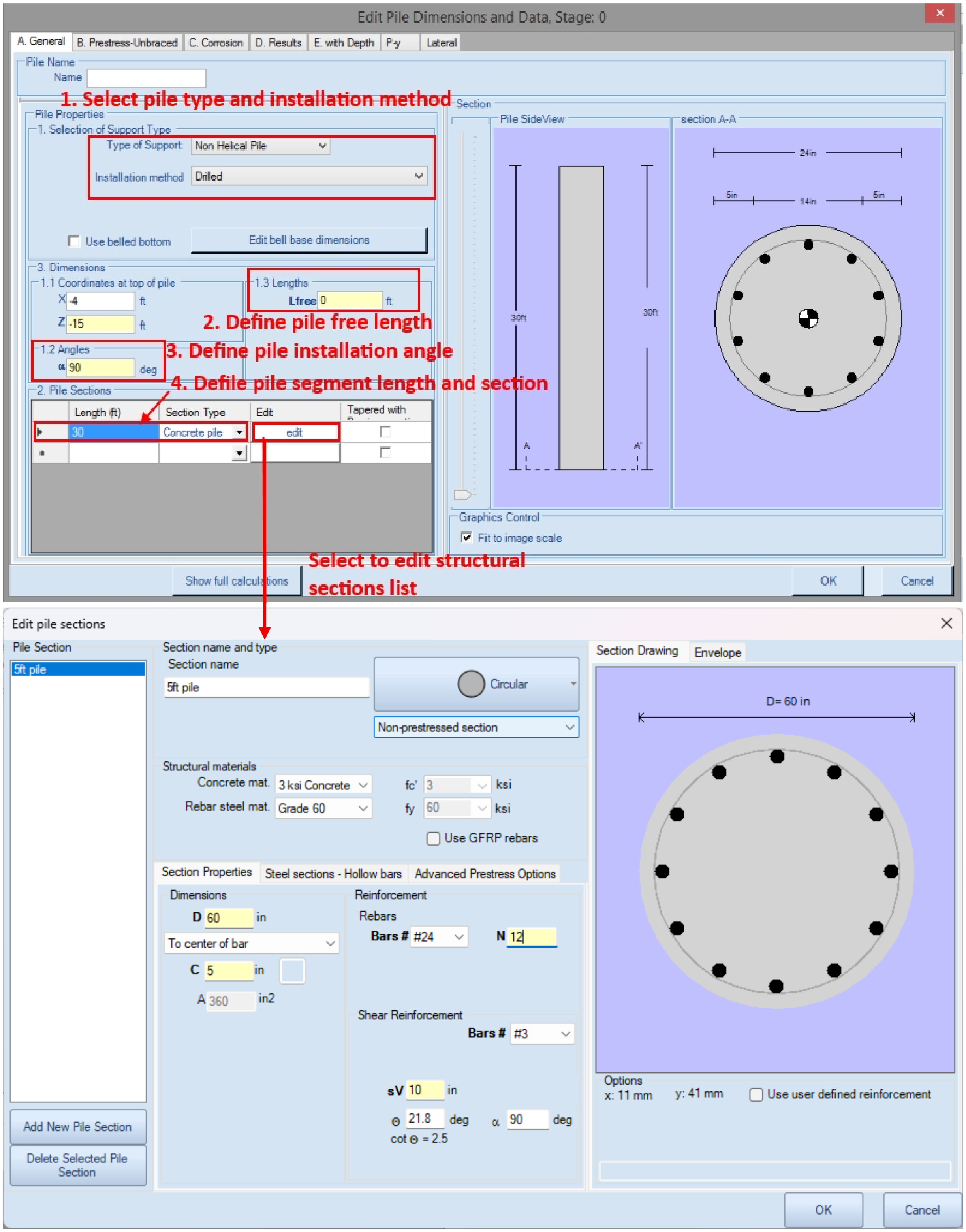


Figure 3.5.2: Define pile type and structural section.

3.6 Edit Helical Pile Sections (DeepFND and HelixPile)

By selecting the button "Edit" in the Edit pile dimensions and data dialog (see Figure 3.5.1 above), the Helical Anchor Sections dialog appears. In this dialog we can create a list of tieback sections. We can access each tieback section independently and modify it, defining the anchor structural section type, the material and dimensions, the helix configurations and the parameters for the geotechnical capacity calculations.

In the Helical Anchors dialog, we can select an anchor from the existing database of anchors or add some sections to the database. All the created anchors can be accessed and modified independently. In the General tab, we can define the pipe diameter, thickness and material, the torsional pipe capacity and the helix configuration (number of helixes, diameter and thickness of each helix, helix spacing).

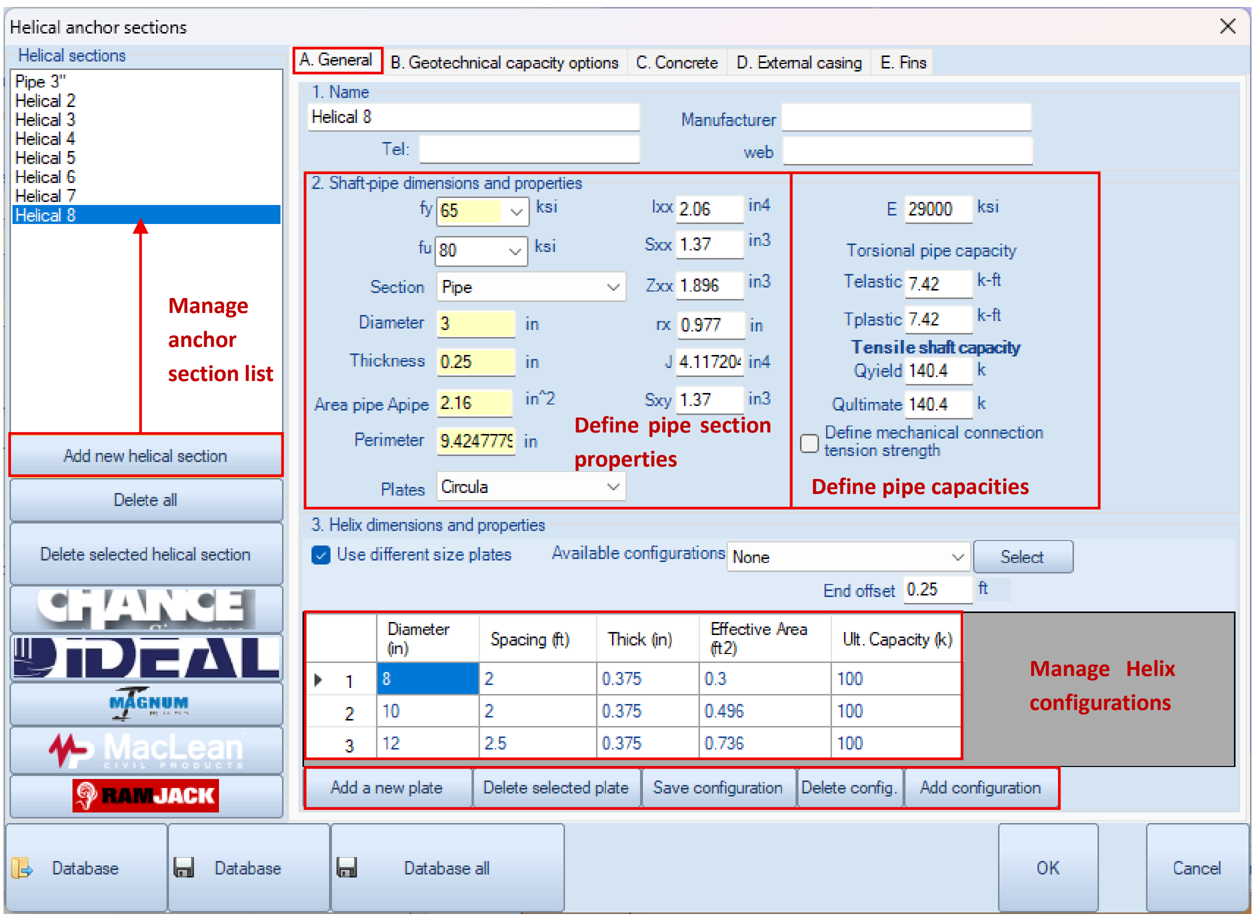


Figure 3.6.1: Define helical anchor section properties.

DeepFND has already helical sections from Chance, Ideal, Magnum, MacLean and Ramjack incorporated (Figure 3.6.1). The following parameters can be defined in this tab:

Symbol/Option	**Description**
Fy	Tensile Yield Strength of anchor
Fu	Tensile Ultimate Strength of anchor
Diameter	Anchor diameter
Thickness	Anchor thickness
Ixx	Moment of inertia
Sxx	Elastic section modulus
Zxx	Plastic section modulus
Telastic	Torsional elastic pipe capacity
Tplastic	Torsional plastic pipe capacity
E	Modulus of elasticity
Apipe	Area of the pipe of the anchor
Qyield	Tensile yield shaft capacity
Qultimate	Tensile ultimate shaft capacity
Helix diameter	The diameter of the helical plate
Helix spacing	The spacing between the helical plates
Helix thickness	The thickness of the helical plate
Effective helix area	The effective area of the helical plate
Helix pitch	The helical plate inclination
Qhelix	Ultimate tension capacity for one helical plate

In HelixPile we can define an unlimited number of helix configurations. When defining the plate diameter, thickness and pile capacity, we can press on the button "Add configuration" and the configuration is added in the local pile database.

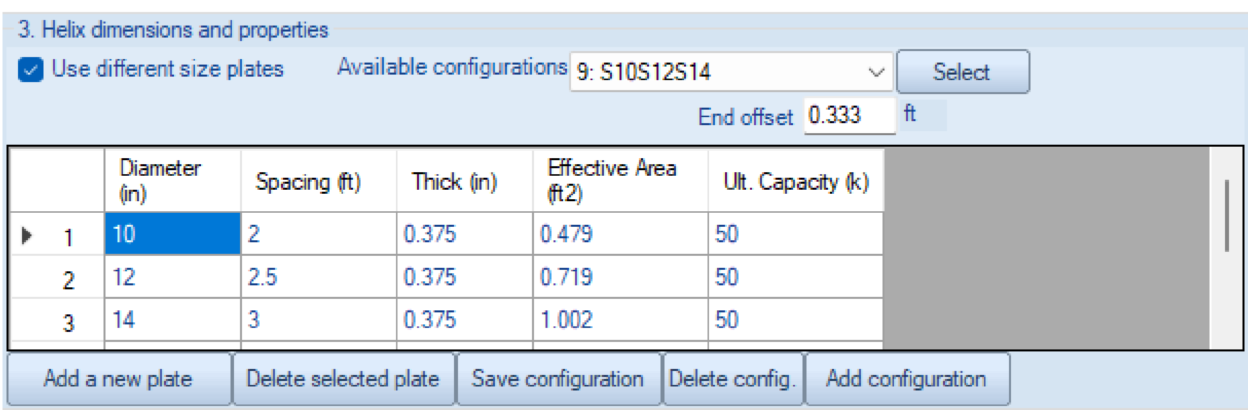


Figure 3.6.2: Edit helix configurations.

In the Geotechnical capacity options tab, we can select and define the parameters for the pullout capacity method.

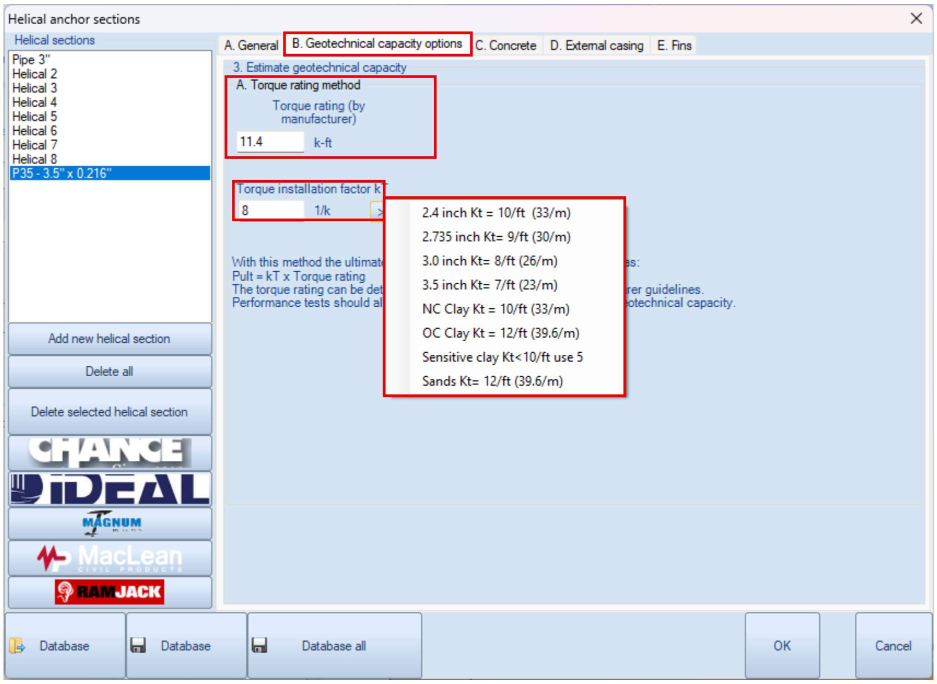


Figure 3.6.3: Helical anchor geotechnical capacity options.

An external casing can be defined as shown in Figure 3.6.4.

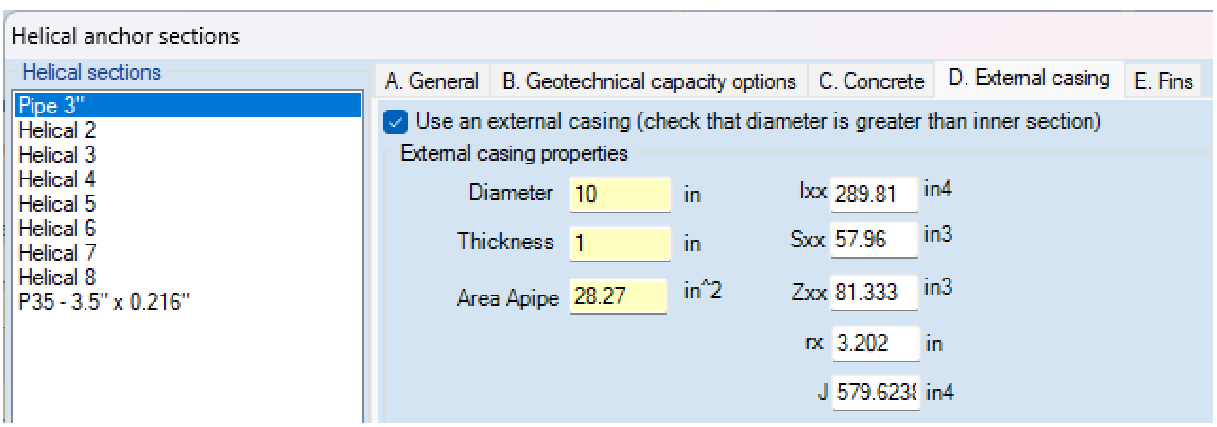


Figure 3.6.4. External casing options.

3.7 Edit Non-Helical Pile Sections (DeepFND Only)

From the Pile Sections dialog, we can create a list with pile sections that we can use along the pile. We can add several pile sections to the list on the left side of the dialog, access each added section and edit them independently, by defining the pile section type, dimensions and reinforcement.

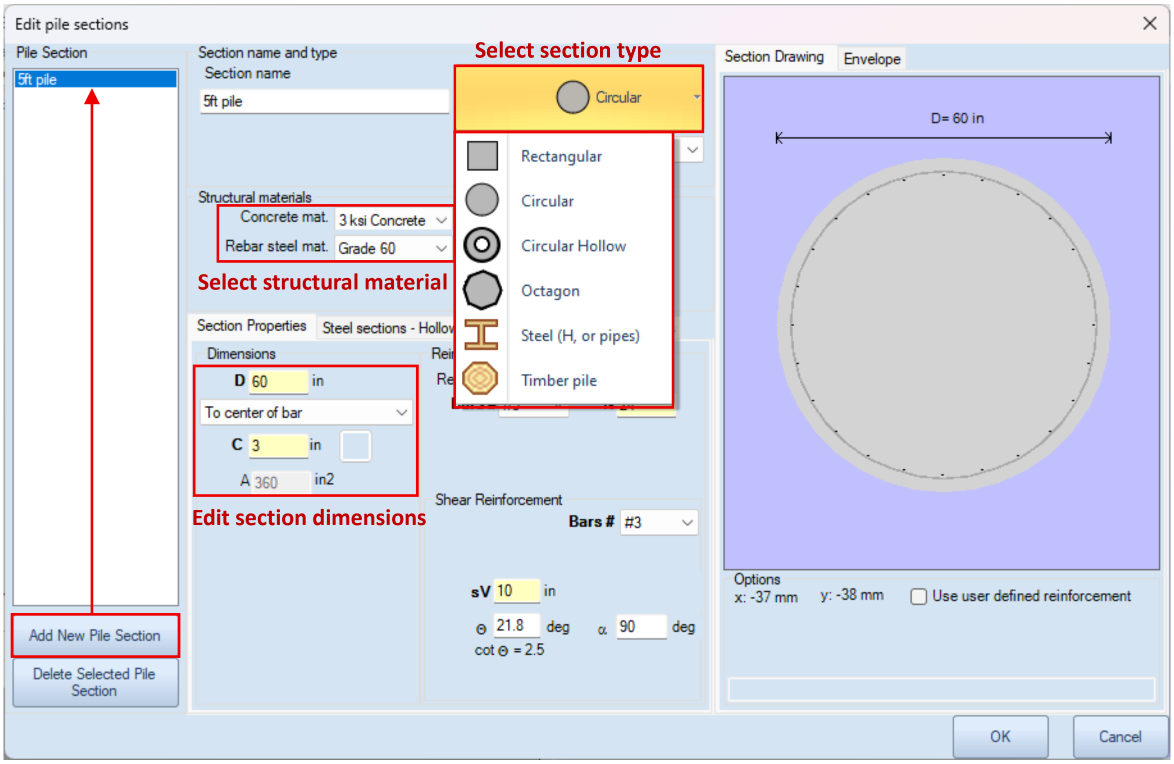


Figure 3.7.1: Edit non-helical pile sections.

In DeepFND we can select each pile section to be rectangular, circular, circular hollow, octagon, steel beam or timber pile.

For reinforced concrete sections, user can define the rebar size and number of bars. For steel sections (pipes, H piles, channel sections), user can select the steel section from the software implemented databases.

Finally, we can create composite sections (i.e. use both rebars and steel beams).

If we wish to change the pile section along the pile depth, we simply need to create here multiple pile sections and then use them in different depths along the pile (section 3.5 – Figure 3.5.2).

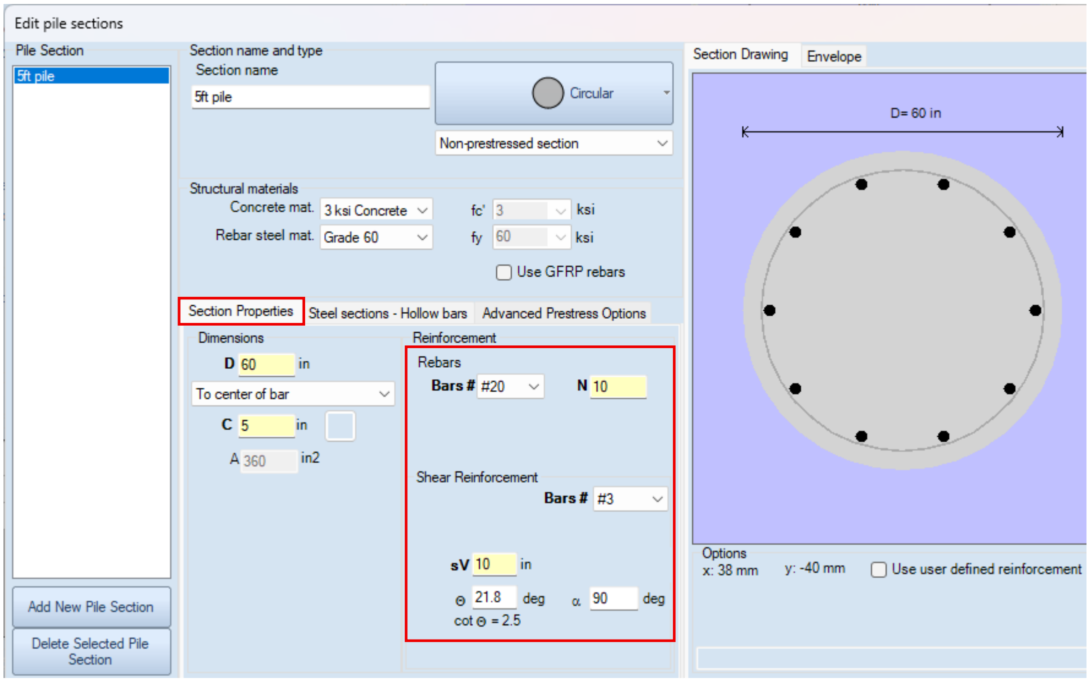


Figure 3.7.2: Edit reinforced concrete section reinforcement.

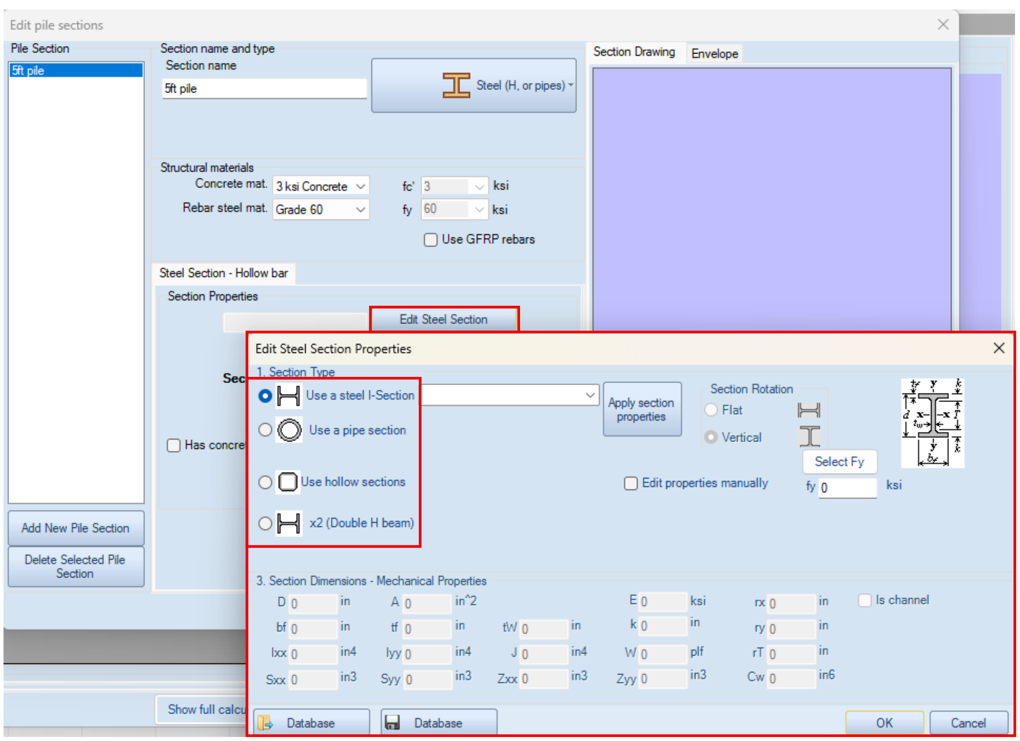


Figure 3.7.3: Edit steel section reinforcement.

3.8: Edit Pile Caps

After a pile cap is generated (see section 6.1), we can access it and edit the pile cap properties (dimensions, loading, pile properties). To access the Edit Pile Cap dialog, we can double-click on the pile cap in the model area or select the option "Edit Pile Cap" in the Pile Caps tab of DeepFND.

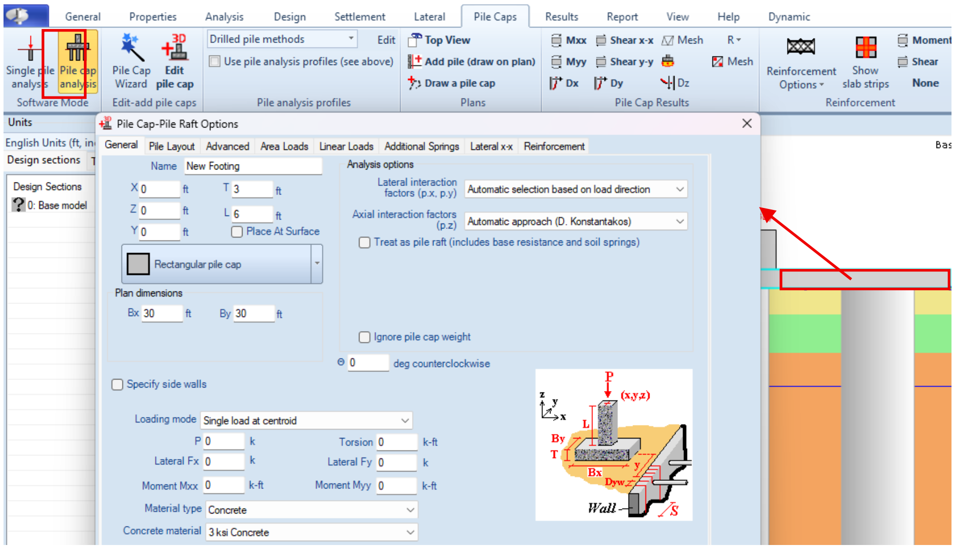


Figure 3.8.1: Access the Edit Pile Caps dialog.

In the **General tab** of this dialog, we can define the pile cap shape, dimensions and loading mode. We can also set the lateral and axial interaction factors.

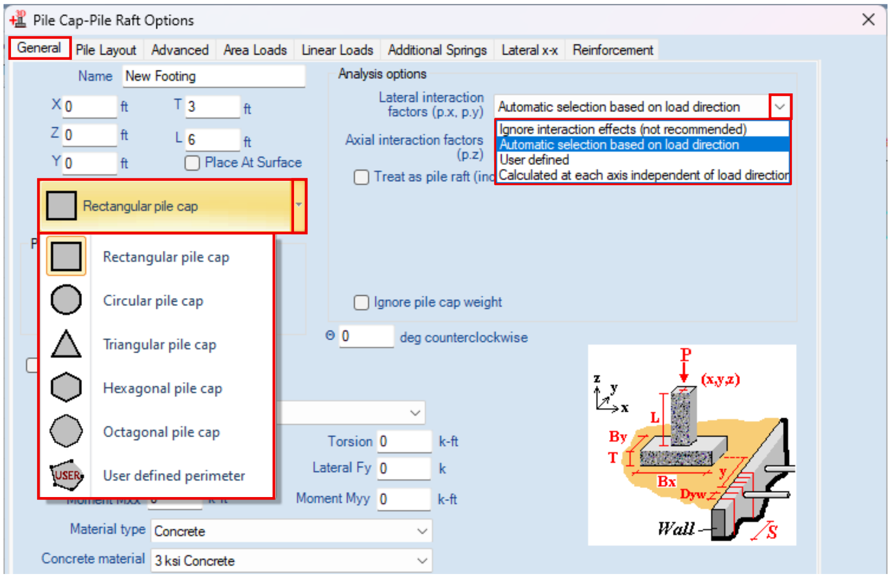


Figure 3.8.2: Define the Pile Cap shape and interaction factors.

In this tab we can select to treat the pile cap as a pile raft, taking into consideration the combined effect of the soil below the raft (the additional module Pile Rafts is required for this option). We can also select whether to include or ignore the cap weight in the calculations. If the pile cap supports a footing, we can define the footing dimensions and loading.

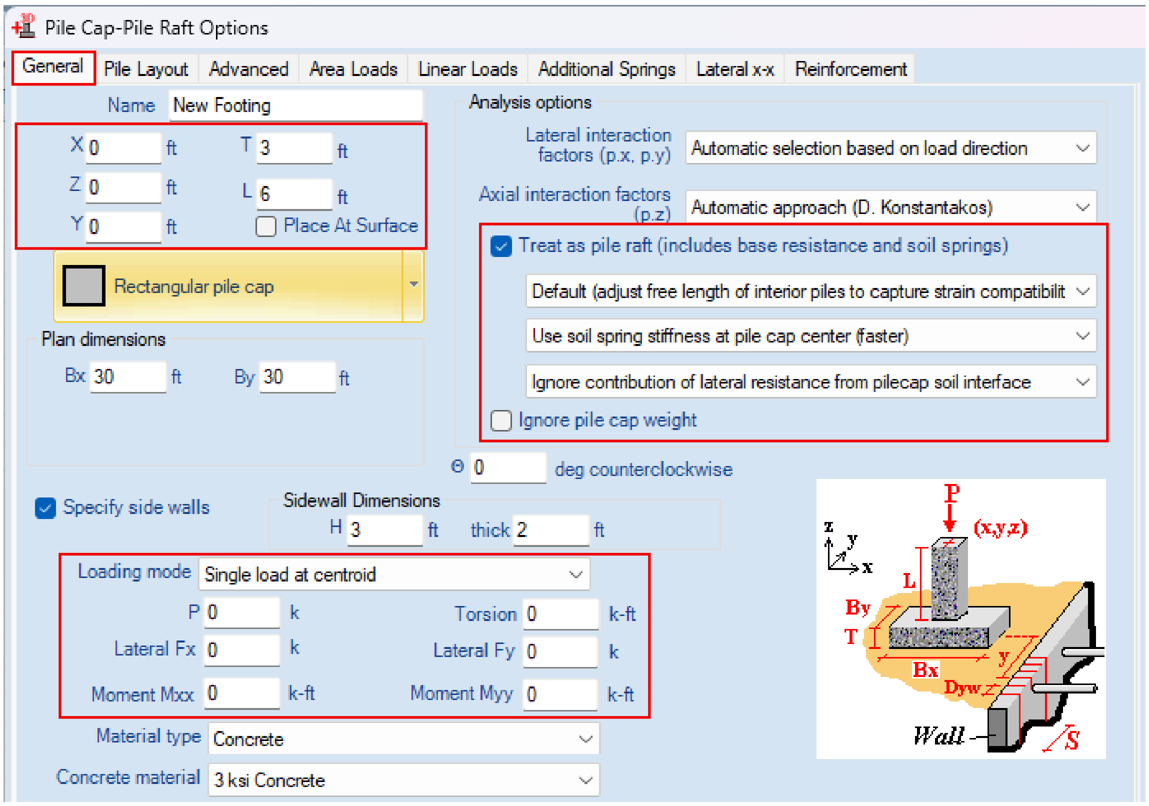


Figure 3.8.3: Footing properties, pile weight and option to treat Pile Cap as a Pile Raft.

Finally, we can select either to include a single load at the cap centroid or use multiple loads. The latter option allows us to define multiple external point loads, applied on different positions on the pile cap. This also allows us to use the software staging to define different load magnitudes on different stages, applying the maximum compression and tension load. Additional area loads and linear loads can be used in both cases.

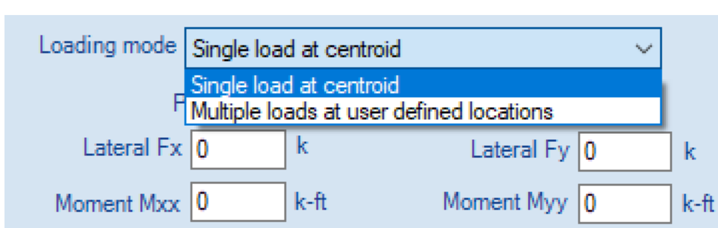


Figure 3.8.4: Loading modes.

In the **Piles Layout tab** of this dialog, we can add new piles on the pile cap and define the pile positions and structural sections.

By selecting to Edit the section of each pile, the Edit Pile dialog appears (see section 3.5).

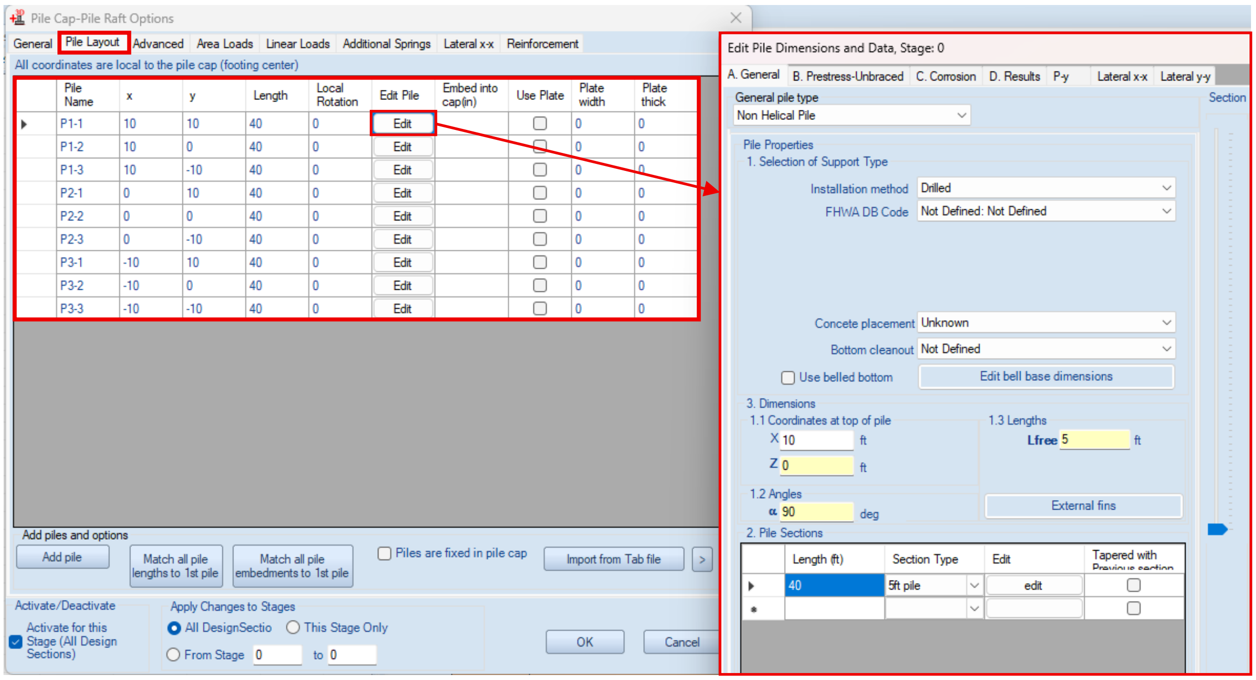


Figure 3.8.5: Pile Caps – Edit pile properties.

In the **Advanced tab** of this dialog we can select if the footing will be treated as a point load or not. It the footing is not considered a point load, we can define some footing area intervals, within which the footing load will be handled as a point load.

In the **Point Loads, Area Loads and Linear Loads tabs** of this dialog we can define multiple loads that can be defined on the pile cap. These options are presented in **section 3.10**.

3.9: Define External Loads on the Single Piles

<u>Add Loading Stages</u>

In DeepFND (or HelixPile), we can select to add new stages below the model area. When we select to add a stage in HelixPile, a new stage is added as an exact copy of the last stage. This new stage can be modified independently.

The stages can be used as loading stages: user can define different loads on the pile head for each stage.

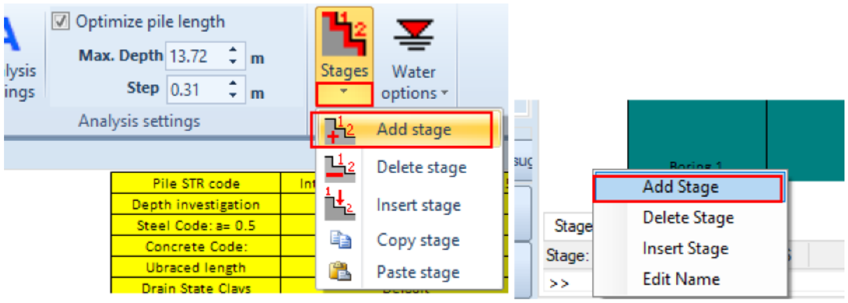


Figure 3.9.1: Manage stages in general tab and below the model area

Define Loads on Pile Head

By double-clicking on the load on the model area, the Loads on pile dialog appears. In this dialog, we can define a list of loads and define the vertical and lateral load magnitude for each construction stage.

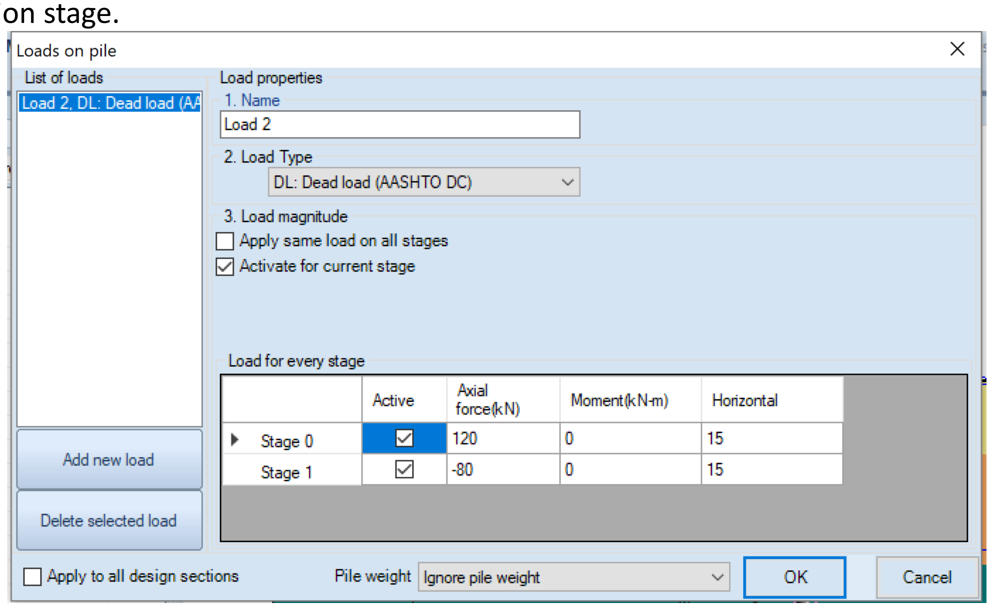


Figure 3.9.2: Loads on Pile dialog.

For Axial loads:
Use a positive value (+) for compression loads.
Use a negative value (-) for tension loads.

For each load, we can define the load category. All defined loads are summed and applied on the pile head as a total.

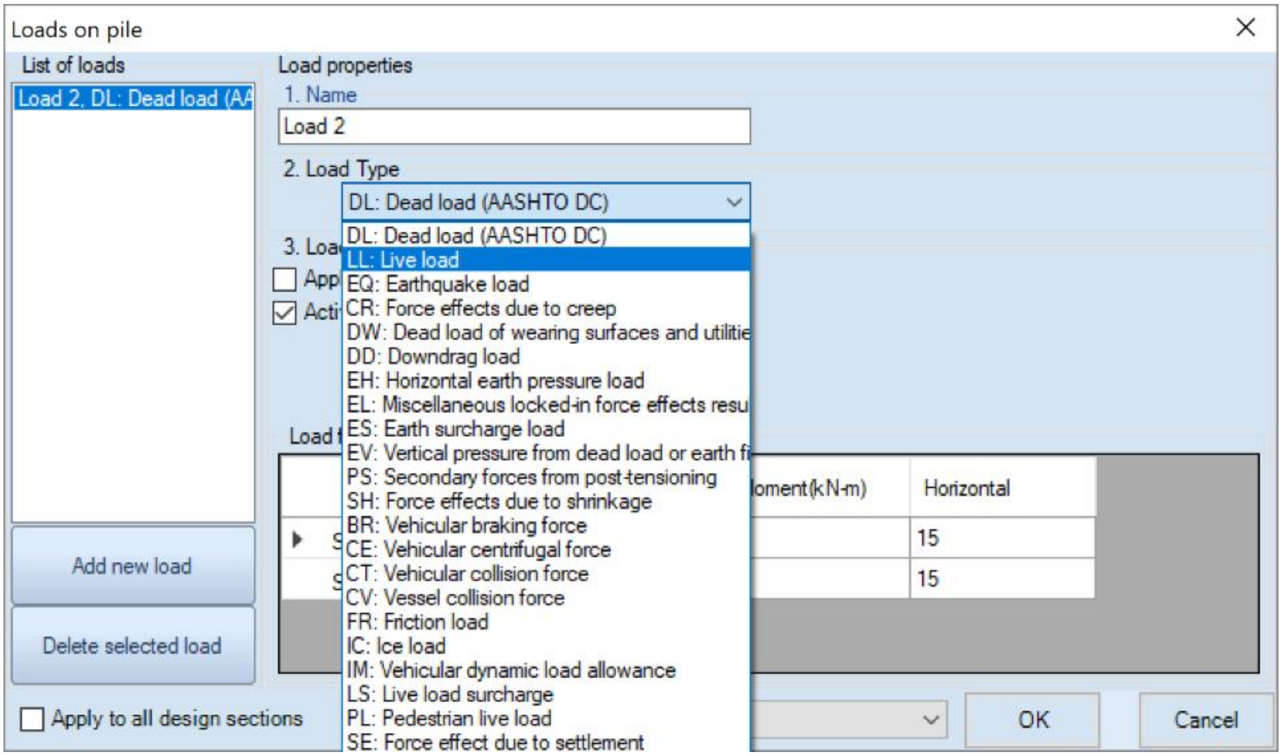


Figure 3.9.3: Define load category.

We can choose among the following options:

DL	Dead load (AASHTO DC)
LL	Live load
EQ	Earthquake load
CR	Force effects due to creep
DW	Dead load of wearing surfaces and utilities
DD	Downdrag load
EH	Horizontal earth pressure load
EL	Miscellaneous locked-in force effect results
ES	Earth surcharge load
EV	Vertical pressure from dead load of earth fill
PS	Secondary forces from post-tensioning
SH	Force effects due to shrinkage
BR	Vehicular braking force
CE	Vehicular centrifugal force
CT	Vehicular collision force
CV	Vessel collision force
FR	Friction load
IC	Ice load
IM	Vehicular dynamic load allowance
LS	Live load surcharge

PL	Pedestrian live load
SE	Force effect due to settlement
TG	Force effect due to temperature gradient
TU	Force effect due to uniform temperature
WA	Water load and stream pressure
WL	Wind on live load
WS	Wind load on structure

Choose to apply the same load to all construction stages or vary the load magnitude in each stage. Define the load magnitude.
For non-helical piles, there are options to consider the pile self-weight, either for tension, or for all load conditions.

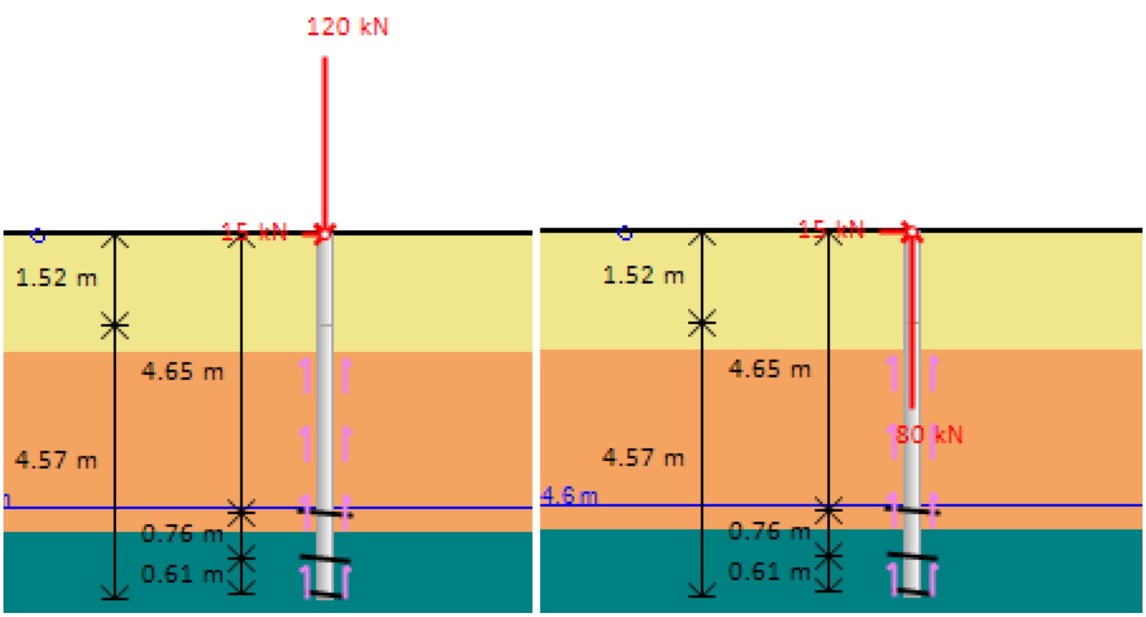
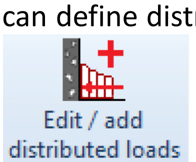


Figure 3.9.4: Defined load in each stage.

Define Distributed Loads

We can define distributed loads along the pile in the Lateral tab of the software. By pressing on the 

button, the Trapezoidal loads dialog appears (Figure 3.9.5). In this dialog we can create a list of loads, and for each one of them we can define:

- The Load Type (same options as described for the linear loads above).

- The initial and final load application depth (Linil and Lfinal)
- The start and end magnitudes of the horizontal load components (Qxs and Qxf)
- The start and end magnitudes of the vertical load components (Qzs and Qzf)

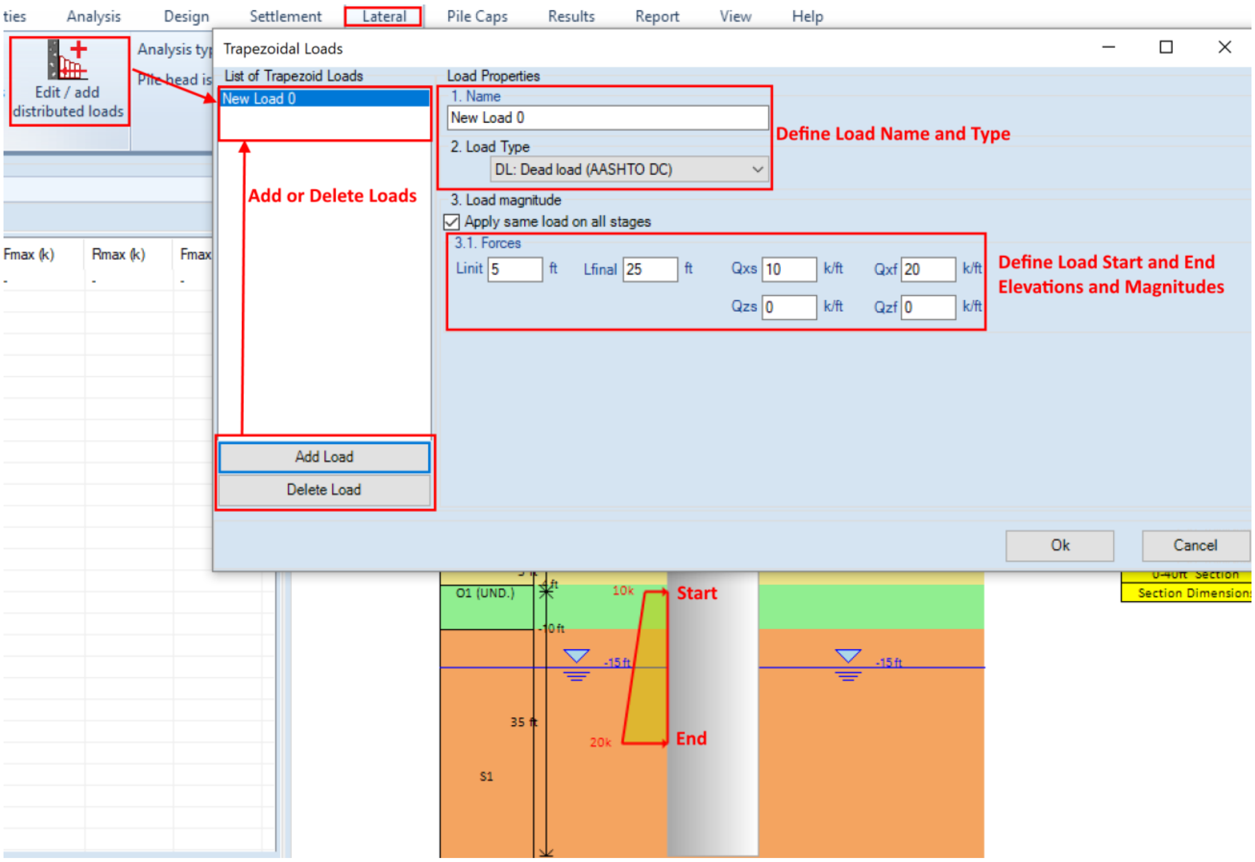


Figure 3.9.5: A Distributed load applied on the pile.

3.10 Define loads on pile cap

In the Edit Pile Cap dialog of DeepFND we can select either to include a single load at the cap centroid or use multiple loads (see section 3.8). In this dialog we can define either the footing load magnitude (applied on the cap centroid), or we can define a series of point loads, linear loads and area loads.

Single Point Load at Centroid

The load magnitudes (vertical load and lateral loads and moments on each direction x and y) can be defined in the General tab of the Edit Pile Cap dialog:

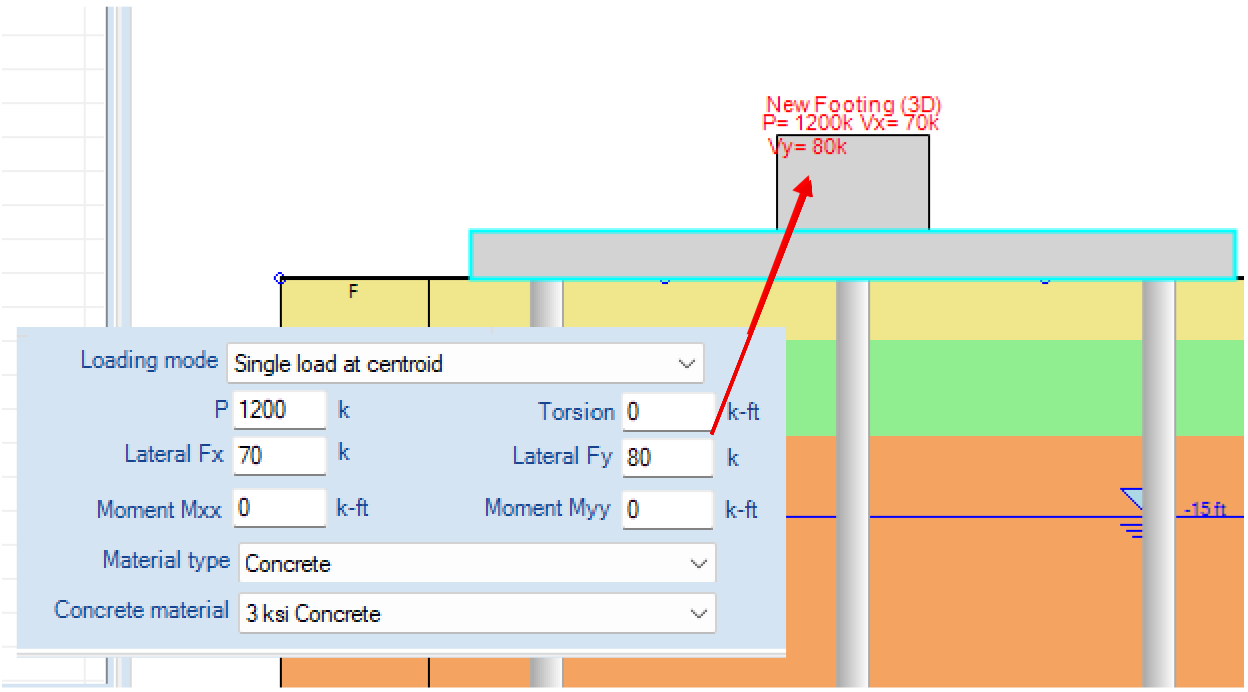


Figure 3.10.1: Define Footing Loads (applied on cap centroid).

Area Loads

In the Area Loads tab of the Edit Pile Cap dialog, we can select to add new area loads on the pile cap. For each load we can define the exact area coordinates and magnitude.

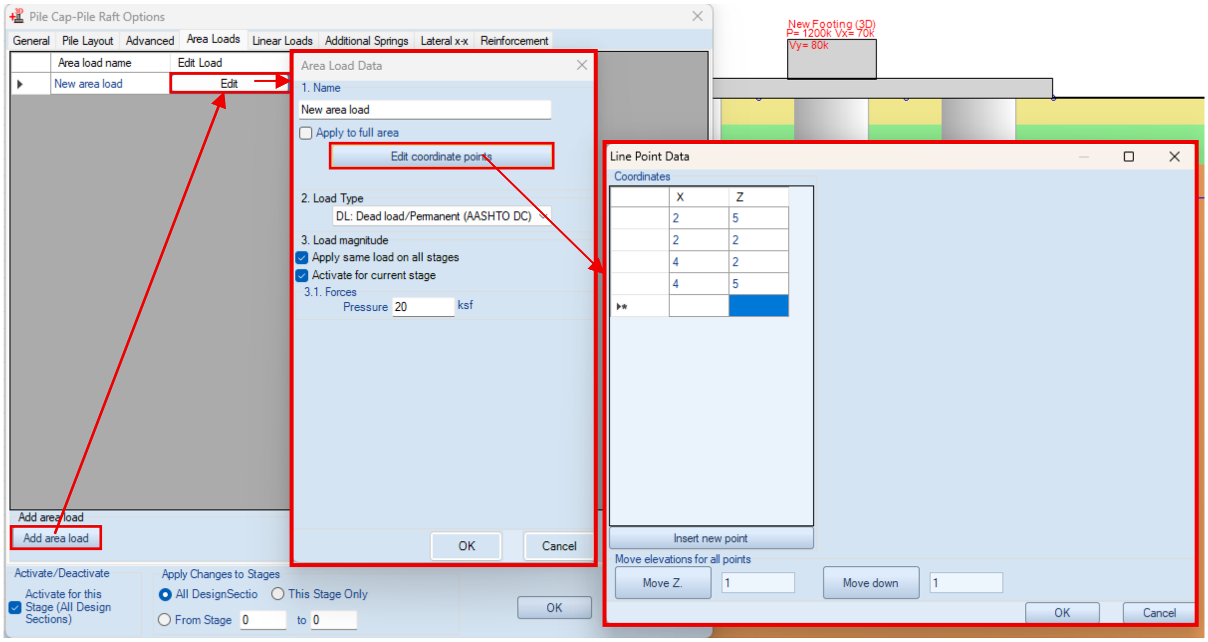


Figure 3.10.2: Add an area load and edit the load properties.

Linear Loads

In the Linear Loads tab of the Edit Pile Cap dialog, we can select to add new linear loads on the pile cap. For each load we can define the exact start and end point coordinates and magnitude.

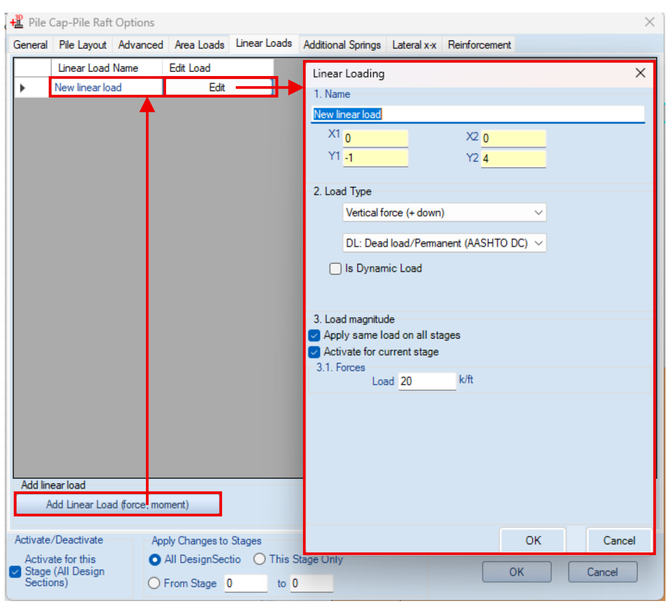


Figure 3.10.3: Add a linear load and edit the load properties.

3.11: Data Entry: CPT Logs and SPT Records

CPT logs: by pressing the arrow next to the  button in the properties tab of DeepFND, we can see the dialog of figure 3.11.1. CPT records can be used within DeepFND, with the program being able to export soil properties by processing CPT logs.

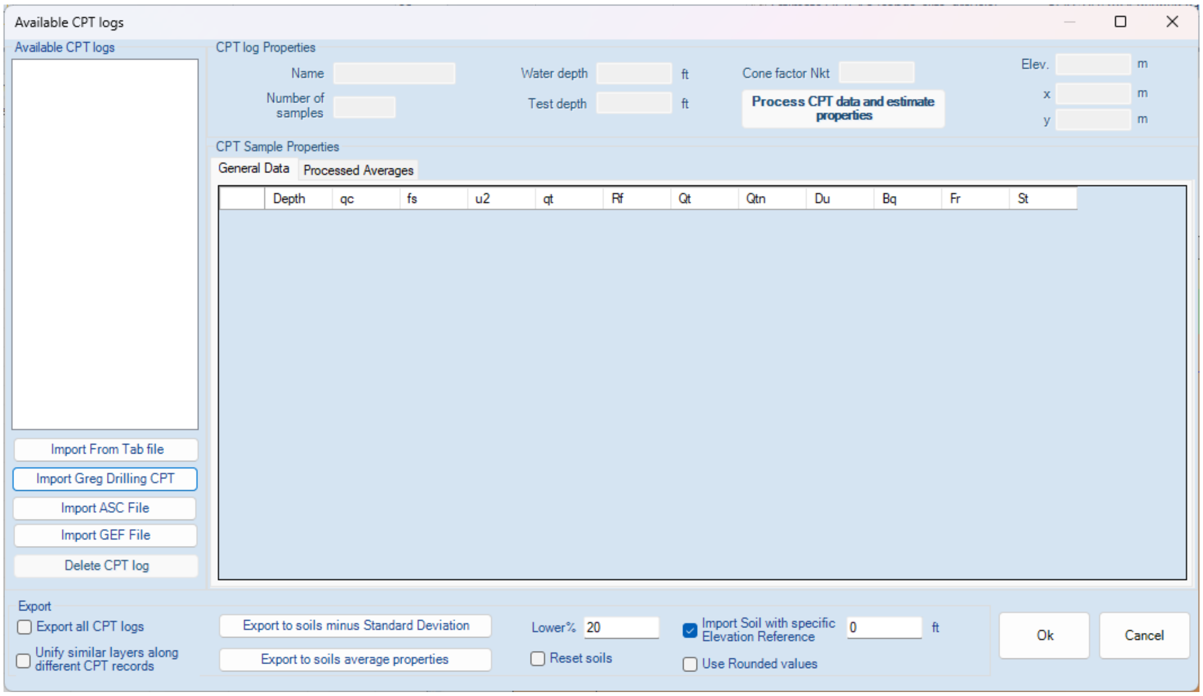


Figure 3.11.1: Available CPT records options.

The following options are also available in the properties tab of DeepFND, related to the CPT logs:

 Shows CPT tip resistance on model (CPT log must be applied)

 Sleeve friction (CPT log must be applied)

 Standard soil description for CPT tests according to Robertson (CPT log must be applied)

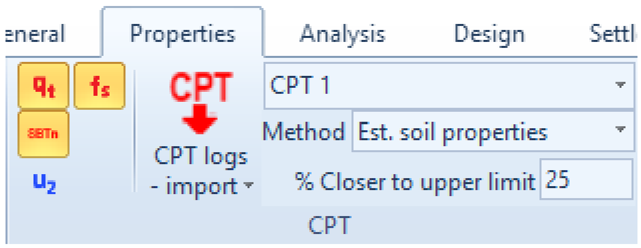
 Water pressure (CPT log must be applied)

Once a CPT raw record is imported, enter the depth to the water table and select the option "Process CPT data and estimate all properties".

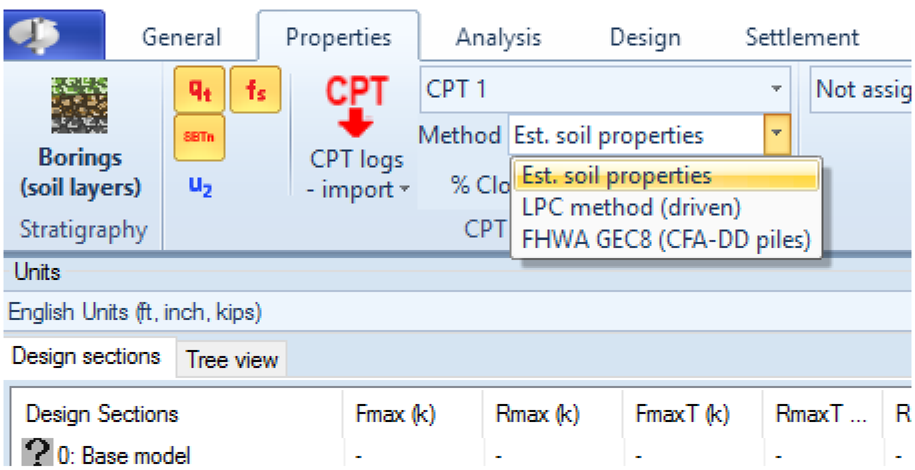
You can also import raw data from a tab delimited file. In such a case you need to label the first two rows as such:

Depth ft	fs tsf	u ksf	qc tsf
0.164	0.107	3.744	127.3683
0.328	0.296	-0.031	147.8371
0.492	0.480	-0.003	129.2297

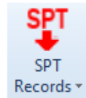
The units can be changed to m, KPa, MPa, psi. Then once imported, the CPT log will need to be assigned to the design section.



When a CPT log is assigned, the program offers option on how CPT data is used:



In the standard option, the program estimates soil properties and the uses the other methods for determining the side resistance along the pile. Otherwise, a method can be selected that correlates CPT tip resistance to the side shear (LPC, FHWA, etc.). These options also control the pile bearing resistance when CPT is selected as the method in the Analysis tab.

SPT logs: by pressing the arrow next to the 

button in the properties tab od DeepFND, we can see the options of Figure 3.11.2. By pressing on the button, the dialog of figure 2.4.5 appears. SPT records can be used within DeepFND, with the program being able to estimate the ultimate bearing capacity from SPT's (if the SPT option is selected in the Analysis dialog).

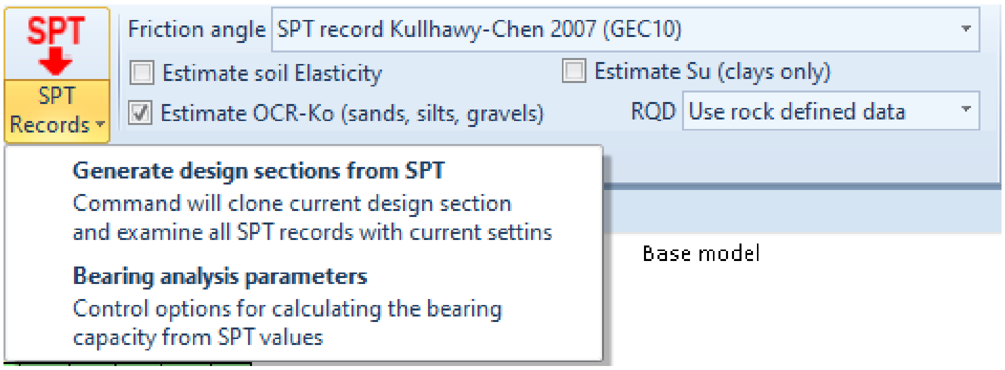


Figure 3.11.2: Available SPT records options.

Here we can choose to:
- ***Generate design sections from SPT***: If one or more SPT records are defined, the program can replicate the current design section and assign an SPT log to each design section. In such a case, it is important that a separate boring (soil layers) are prescribed so that the stratigraphy matches the available SPT record on each design section.

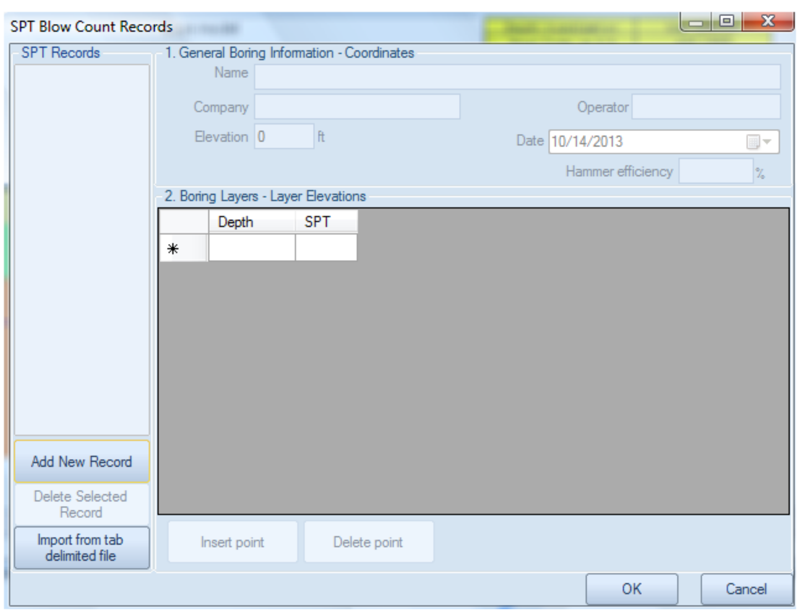


Figure 3.11.3: SPT records options dialog.

- ***Bearing analysis parameters (Figure 3.11.4):*** Bearing analysis parameters are used to define the ultimate bearing pressure from SPT blow counts. Factors should represent the low range of estimates. The ultimate bearing pressure is typically defined as:
Qult = SPT x factor x ⍰

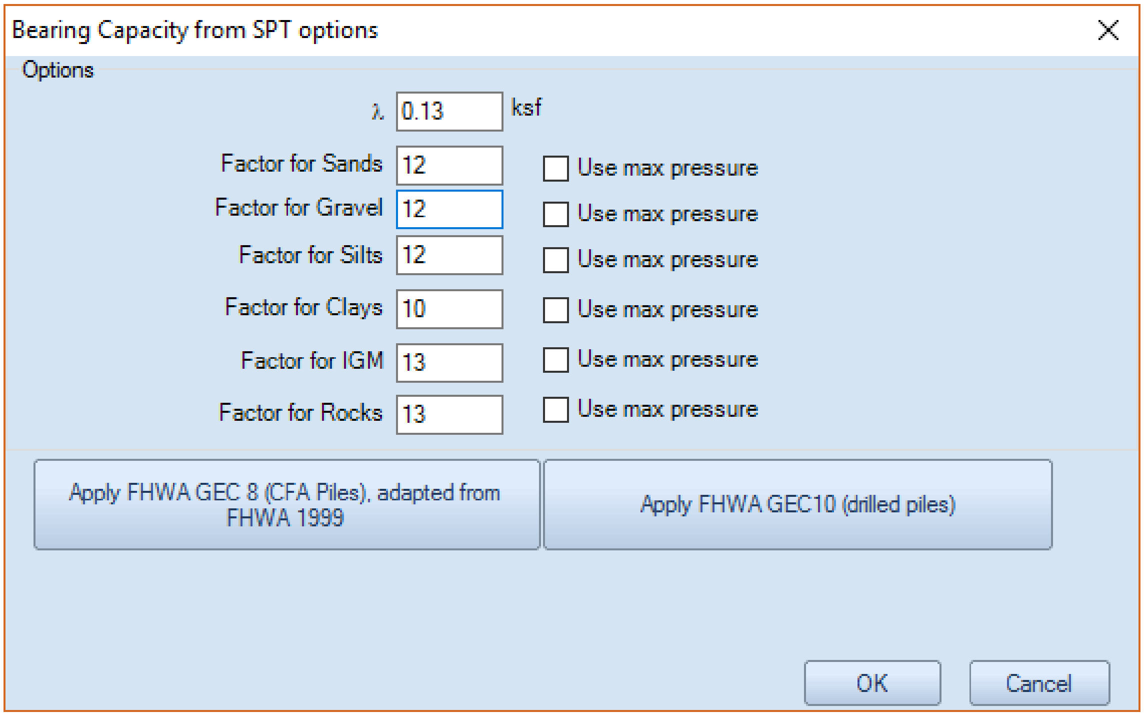


Figure 3.11.4: The bearing capacity from SPT options dialog.

In this dialog we can define the following factors:
- λ = 0.13 ksf (default value according to Perko)
- Factor for sand type soils
- Factor for silt type soils
- Factor for clay type soils
- Factor for IGM (intermediate geomaterials)
- Factor for rock

Default values have been mostly based on a limited range of data available from FHWA GEC 8 (CFA piles) and FHWA GEC 10 (drilled piles). Different standards can also be applied according to FHWA GEC8, GEC10, which also provide upper limits on bearing pressure.

The following options are also available in the properties tab of DeepFND, related to the SPT logs:

Friction angle:
- Value defined in the soil type defined properties
- SPT record Kullhawy-Chen 2007 (GEC10)
- SPT record (triaxial compression friction)
- SPT record (Perko)

Option to estimate soil elasticity
Option to estimate Su (clays only)
Option to estimate OCR-Ko (sands, silts, gravels)
Options for RQD
- Rock defined data
- Low values from SPT record
-Exact value from SPT record

3.12: Edit Structural Materials

In the Properties tab of DeepFND, we can select to edit the structural materials used in all structural sections. We can select to edit the default steel, concrete and timber (wood) materials, or add new materials in the software database and define the material properties manually.

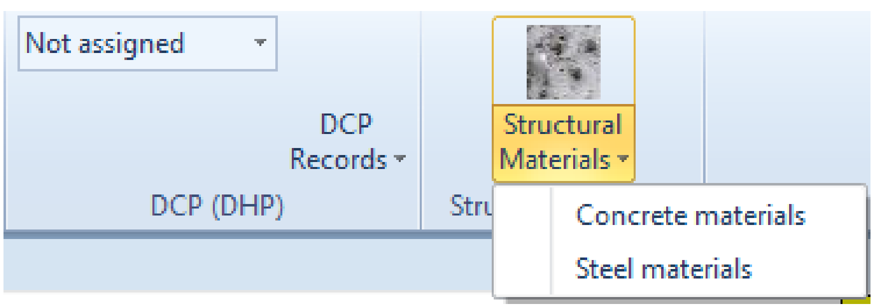


Figure 3.12.1: Structural material options.

Edit steel properties: By pressing the Steel Materials we can edit the structural steel properties. We can import already available materials from the "Import standard steel materials" box.

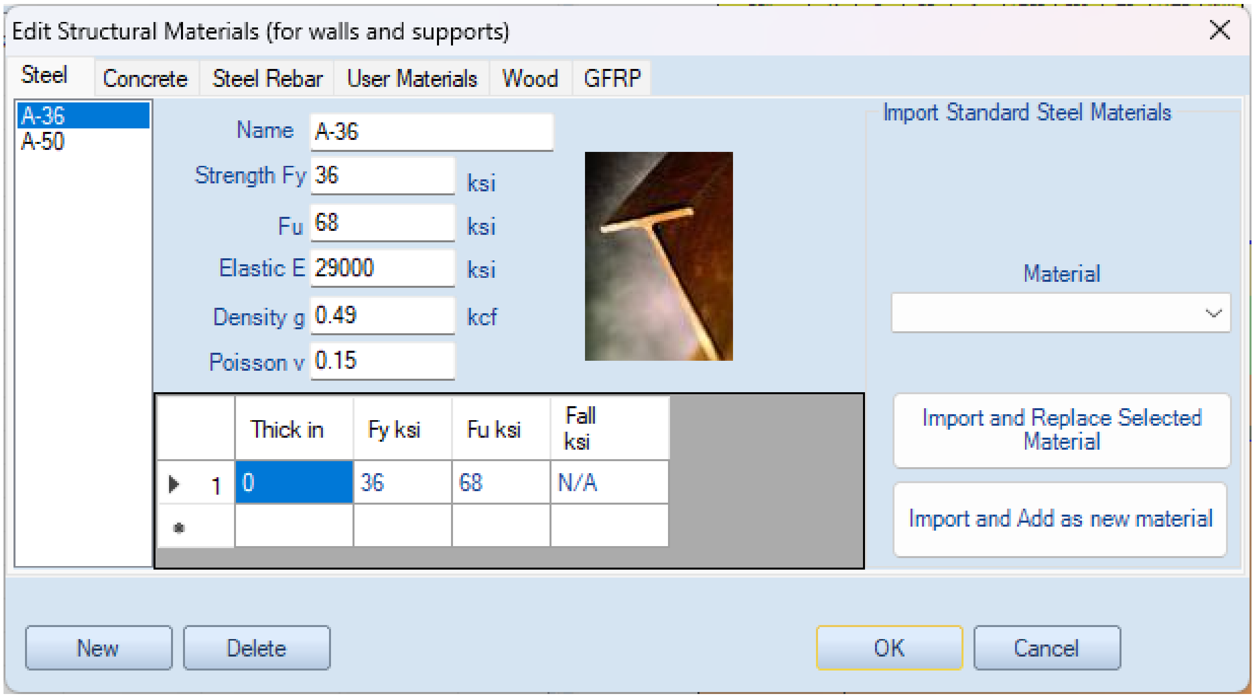


Figure 3.12.2: Edit structural steel properties dialog.

In this form we can define the following properties:

- The steel name
- The yield strength Fy
- The ultimate strength Fu
- The modulus of elasticity E
- The density g
- The steel material used
- Import and replace selected material
- Import and add as a new material

Edit concrete properties: By pressing the Concrete Materials we can edit the concrete properties. We can import already available materials from the "Import standard concrete materials" box.

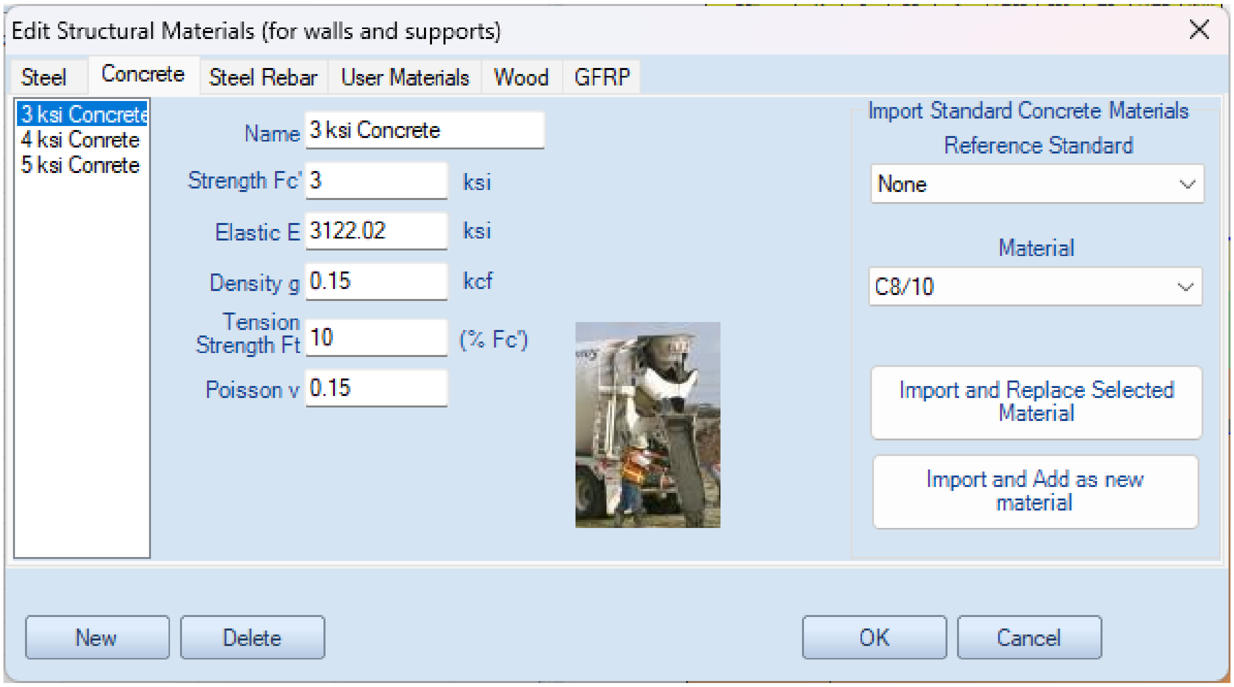


Figure 3.12.3: Edit concrete properties dialog.

In this form we can define the following properties:

The steel name
The concrete strength Fc
The tension strength Ft (% of compressive strength)
The modulus of elasticity E
The density g
The standard concrete material reference standard
The concrete material
Import and replace selected material
Import and add as a new material

Wood: In DeepFND this tab controls material properties for timber piles. Some standard timber materials are predefined.

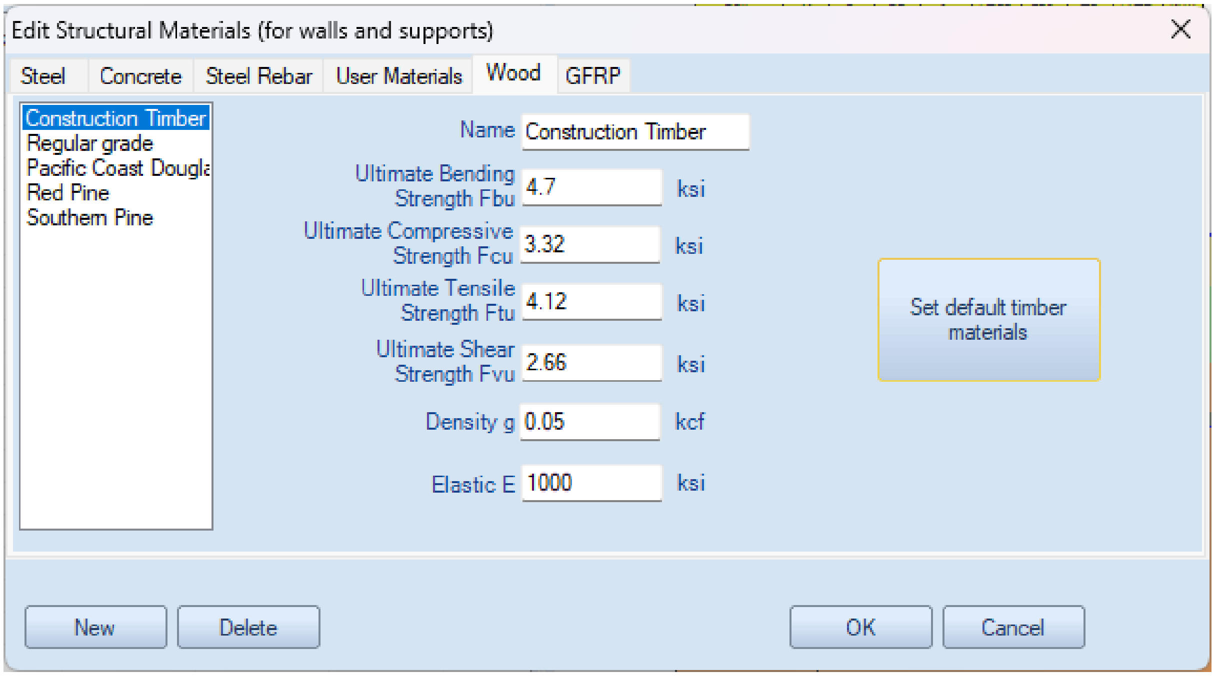


Figure 3.12.4: Edit timber (wood) properties dialog.

In this form we can define the following properties:

The material name
The ultimate bending strength Fbu
The ultimate tensile strength Ftu
The ultimate shear strength Fvu
The density g
The modulus of elasticity E

3.13: Report Options - Printed Reports

Once a project is analyzed, full analysis reports can be generated by selecting the Reports – Options option at the Report tab. By selecting this, we can modify the included output sections.

On the left side of the dialog, we can select which design sections and stages will be included in the current report.

From the Available Report Sections area, we can select the results and options that shall be included. We can also drag and drop these items at the Report Format area. Next, the user can select to see a preview of the report and export it in a word or PDF format.
]

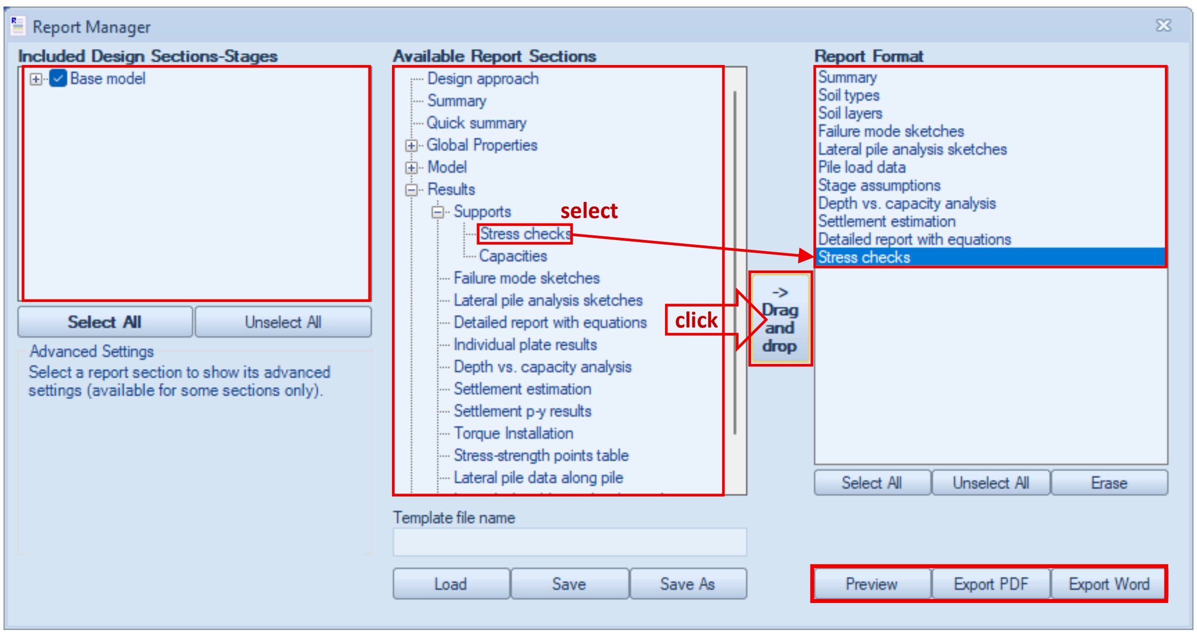
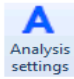


Figure 3.13.1: Report manager.

The generated report includes all the requested sections, presenting soil properties tables, calculated capacities, calculated lateral pile analysis results (moments and displacement diagrams) and it also presents the equations and calculation procedure for the vertical pile design.

3.14: Define Analysis Settings

By pressing the 

button in the General tab of the software, the Analysis Settings dialog appears (Figure 3.14.1). In this dialog we can several settings for the pile capacity calculations.

- General tab

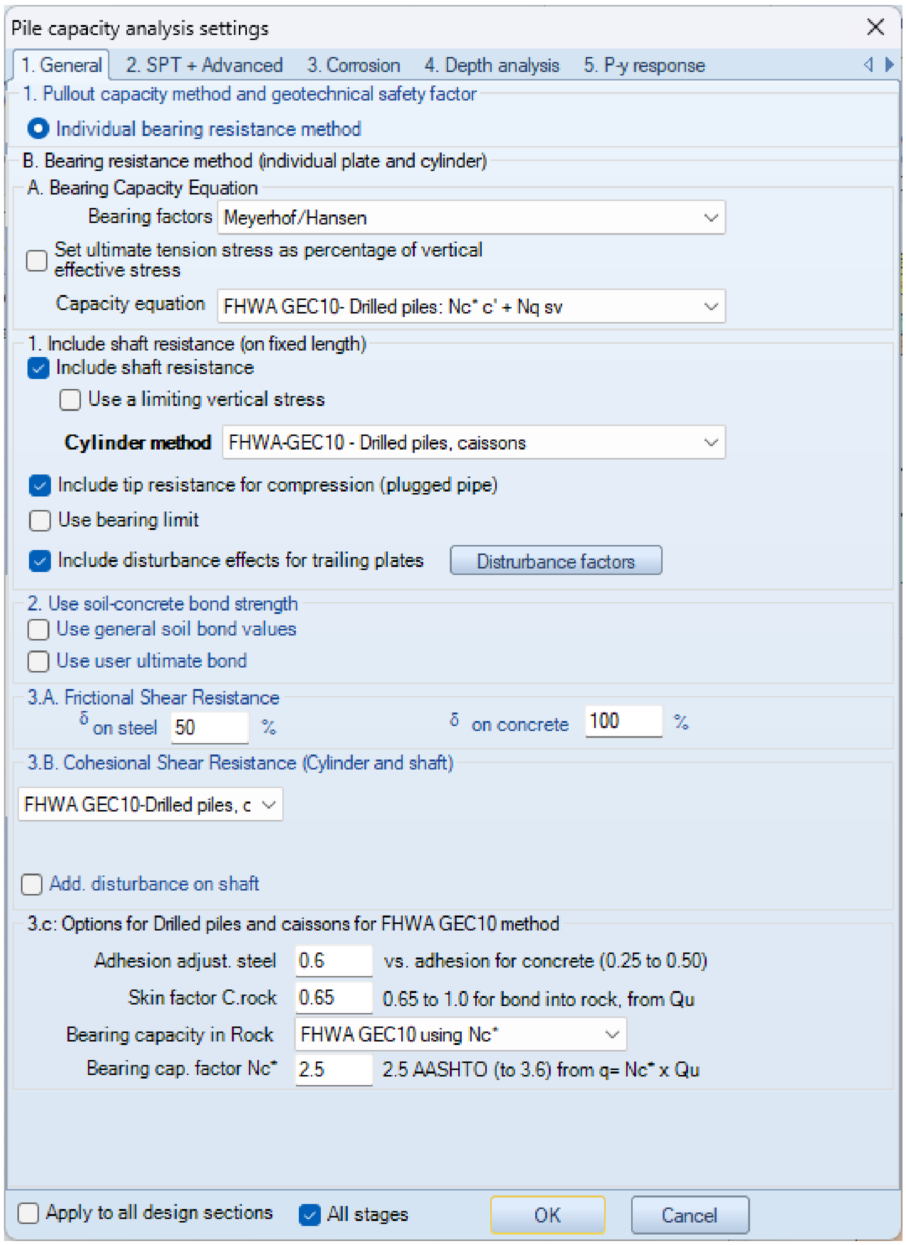


Figure3.14.1: Analysis Settings-General tab.

In this tab we can define the following options:

- Pullout capacity method and geotechnical safety factor.

- Bearing capacity equation and factors. DeepFND provides the following options:
  - Bearing factors:
    - Vesic 1974
    - Meyerhof/Hansen
    - SPT values
    - CPT Methods
  - Capacity equation: The following options are available for the capacity equations:
    - General Equation
    - Helicap Equation
    - Customized Helicap Equation
    - FHWA GEC08 CFA piles
    - FHWA GEC10 Drilled piles
    - AASHTO Driven piles: Norland aT Sands
    - User defined values from Advanced tab of soil properties dialog
- Option to include shaft resistance
- Option to use a limiting vertical stress

- **Cylinder method:** Controls the lateral earth pressure coefficients next to the pile. For helical piles this influences the cylindrical shear mode when multiple plates are used. DeepFND provides the following options:
  - Ko: At-rest earth pressures
  - Mitsch-Clemence
  - FHWA GEC08 CFA piles (N60)
  - FHWA GEC10 Drilled piles, caissons
  - AASHTO Norland, Driven piles
  - FHWA GEC08 CFA (Alt. USA, Mississippi, Louisiana)
  - FHWA GEC08 Drilled-in-Displacement piles
- Option to include tip resistance for compression.
- Option to use bearing limit
- Option to include disturbance effects for trailing plates. By pressing the button, the installation disturbance effects dialog appears:

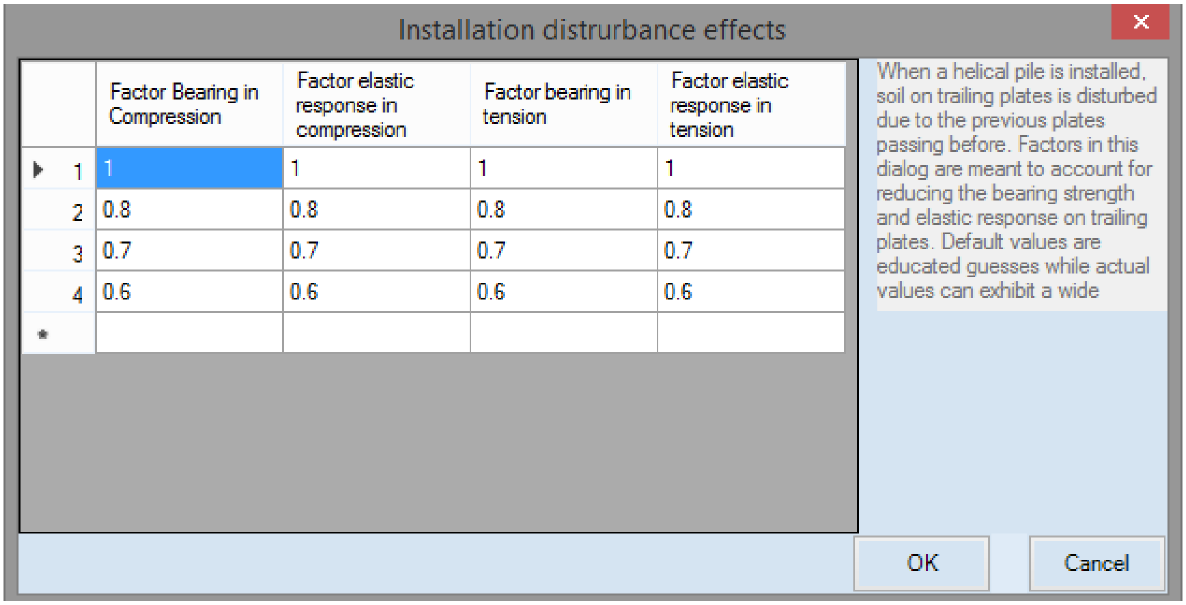


Figure 3.14.2: The installation disturbance effects dialog.

- Option to use soil-concrete bond strength. DeepFND provides the following options:
  - Use general soil bond values
  - Use user ultimate bond
- Definition of frictional shear between soil and steel or concrete
- Define how the cohesion shear resistance is calculated
- Options for Drilled piles and caissons for FHWA GEC10 method
- Adhesion for steel vs. adhesion for concrete
- Skin factor C for Rock soils
- Bearing capacity in Rock
- Bearing capacity factor Nc*

- SPT+Advanced tab: Here we can define:

- The structural allowable stress factor
- The fixed body and free length colors for the helical piles
- Option to estimate strength from the selected SPT test (when an SPT test is used)
- Option to estimate modulus of Elasticity for the soil from the selected SPT test (when an SPT test is used)
- Option to estimate undrained shear strengths for clays (Su) from the selected SPT test (when an SPT test is used)
- Option to estimate OCR and Ko according to Kullhawy and Chen 2007 (sands, silts, gravels)

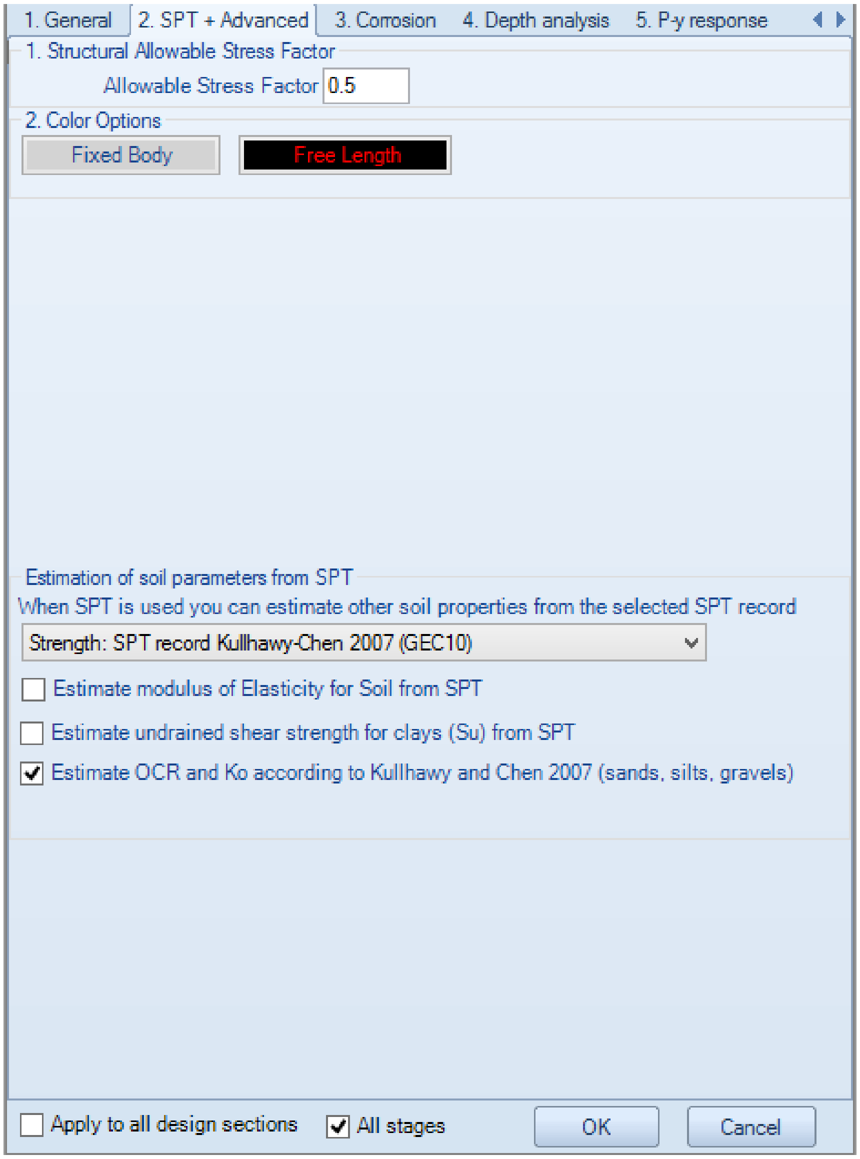


Figure 3.14.3: Helical capacity analysis settings-SPT+Advanced tab.

- Corrosion tab: During the life of a helical pile various environmental or site factors can contribute to loss of section (corrosion). Corrosion options are only applicable to helical piles at this time. DeepFND offers some basic methods for estimating steel section loss in reasonably moderately to low corrosive environments. Such methods are very approximate, and a more detailed analysis might be required in highly corrosive environments:

- Specify the design time for the pile.
- Choose the analysis method. We can choose to use the ICC Method AC355 or the AASHTO 2004 Method.

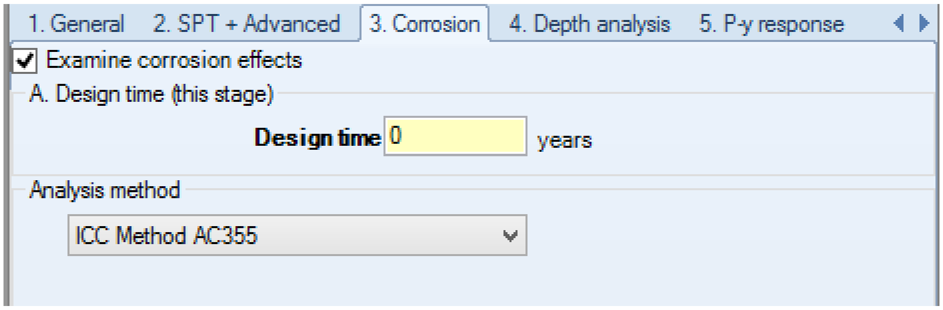


Figure 3.14.4: Helical capacity analysis settings-Corrosion tab.

- Depth analysis: Here we can:
Investigate pile capacity for a range of depths: With this option the program will iterate pile lengths and determine the optimum pile length for matching tension and compression capacity. If a depth analysis is performed, then the maximum depth and the depth step should be defined.

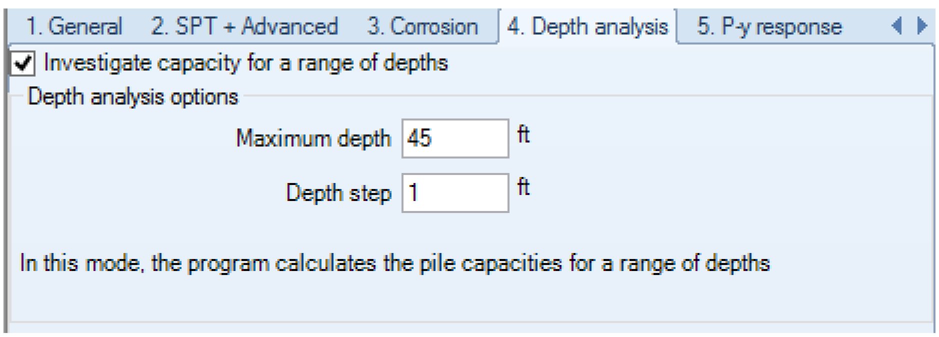


Figure 3.14.5: Helical capacity analysis settings-Corrosion tab.

P-Y response: The P-y response refers to the axial load-settlement pile behavior. DeepFND incorporates a methodology for estimating pile settlement behavior that accounts for non-linear response. The following options are available:

Perform settlement analysis: With this option, the program estimates the pile settlement behavior (in compression only with current version).

Calculate design capacity from PY response: With this option, DeepFND examines all available pile acceptance criteria to determine the allowable axial load.

Include corrosion effects in PY response: DeepFND can examine the axial pile response by including or ignoring cross-sectional area losses due to corrosion.

Inflection factor for shaft response, Rm: The inflection factor represents the ratio of the radius where shear displacements go to zero over the shaft radius. Values from 2 to 4 are considered typical. A greater value increased calculated displacements at the same load.

Advance non-linear exponent for shaft, mS*:* mS represents an additional exponent factor for modelling shaft behavior. A factor of 1 would render the shaft soil spring response to exponential. Please see theoretical section on PY-response.

Maximum settlement, yMax: Represents the maximum settlement that the settlement analysis will consider.

Effective area percentage factor, Aeff: Very often the full steel section area is not fully effective due to a variety of reasons. This number represents the effectiveness of the steel section. If a pile is filled with grout, the grout area is not affected by this factor.

Pile settlement acceptance criteria: DeepFND offers the ability to define pile acceptance criteria (typical criteria). Pile settlement criteria can be used for estimating the ultimate capacity (and possibly the allowable load) based on acceptable displacements.

Pile acceptance criteria can generally be defined by an equation of the following form:
$y = a + b_{pl}\, D_{pl} + b_s\, D_s + m\, PL / A\, E$
Where:
a = Initial displacement at zero load
b_{pl} = Dimensionless factor for plate diameter
D_{pl} = Considered plate diameter (bottom, average, maximum)
b_s = Dimensionless factor for shaft diameter
D_s = Helical pile shaft diameter
m = Dimensionless factor on elastic pile response (typically 1)
PL / A E = Elastic pile response P= load, L= total pile length, A= area cross-section, E= modulus of elasticity

By pressing the 

button, the Pile acceptance criteria dialog appears:

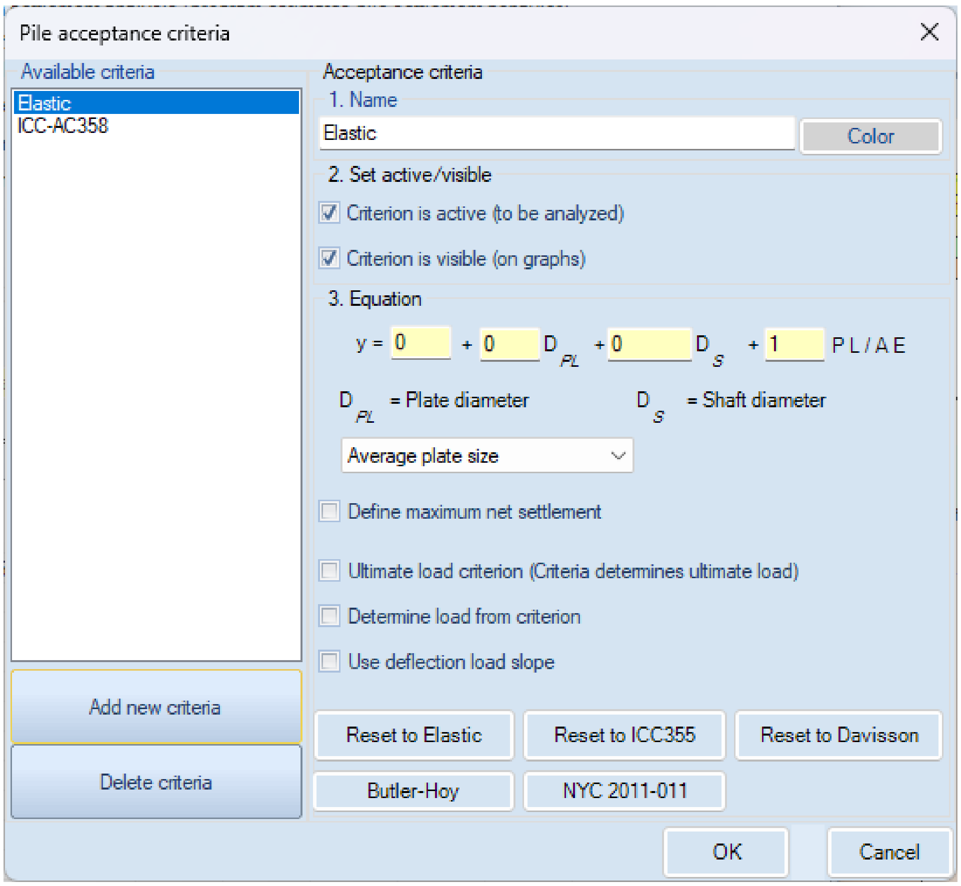


Figure 3.14. 6: The pile acceptance criteria dialog.

This dialog provides the following options:
- ***Criterion is active (to be analyzed):*** Option to activate the criterion
- ***Criterion is visible (on graphs):*** Option to make the criterion visible on graphs.
- Plate size to be considered: Option to use average plate size, base plate size or maximum plate size.
- ***Define maximum net settlement***
- ***Ultimate load criterion (criteria determine ultimate load):*** This option should be selected if the criterion is used to define the ultimate load (i.e. Davisson is an ultimate load criterion).
- ***Determine load from criterion:*** Select option if criterion is examined in determining the allowable load.
- ***Reset to Elastic:*** Resets the current criterion to the full elastic pile response
- ***Reset to ICC355:*** Resets the current criterion to ICC355 specifications
- ***Reset to Davisson:*** Resets the current criterion to Davisson (1974).
- ***Reset to NYC 2011-011:*** Resets the current criterion to NYC 2011-011.

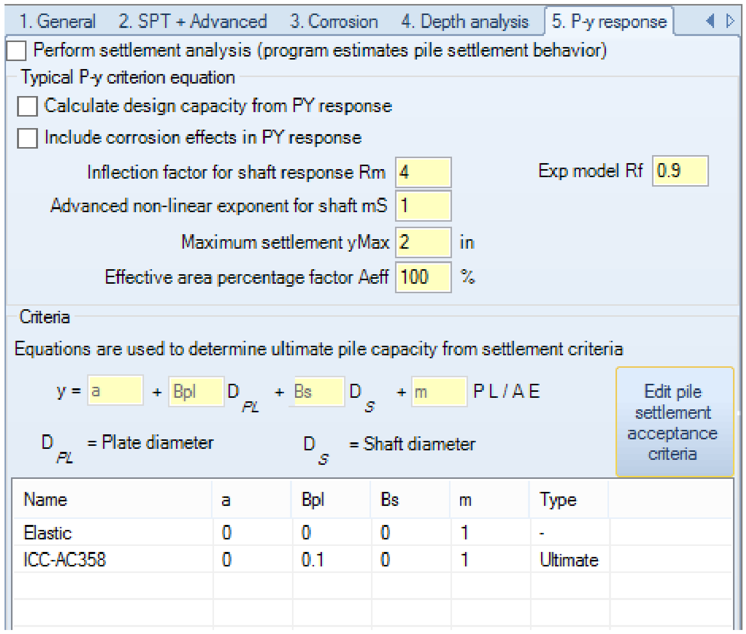


Figure 3.14. 7: Helical capacity analysis settings-Corrosion tab.

PART B: SINGLE PILES – DESIGN AND ANALYSIS

MODEL CREATION – ANALYSIS SETTINGS – RESULTS - EXAMPLES

The following sections provide useful information about the use of the software for the design of single piles. We examine the procedures to create a model, define the analysis and perform the model optimization using the calculated results. A series of examples present the use of the software in the design of different pile types.

SECTION 4: SINGLE PILES – MODELS AND ANALYSIS

4.1 Creating a Model Manually and Define Analysis Settings

The following procedure should be followed in order to create any model manually:

A. Define soil properties

Our first action while working in any DeepFND project is to review the geotechnical report, summarize the described soils and simulate all these soils in the Edit Soils dialog of the software.

We can create an unlimited number of soils and define the soil types and soil properties either manually, or with the use of the soil properties optimization tools. **This procedure is summarized in section 3.3**.

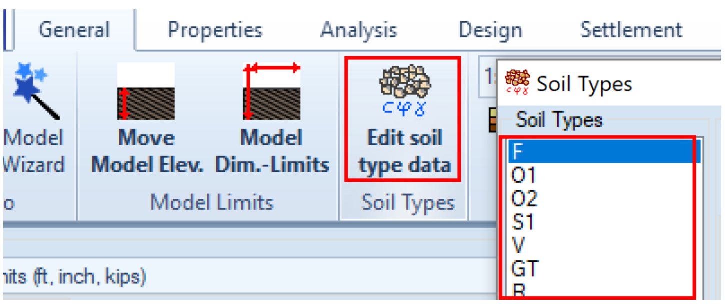


Figure 4.1.1: Model – Step 1 – Define soil properties.

B. Define project stratigraphy

In DeepFND, we can use an unlimited number of borings in any software file. The stratigraphies can be defined in the Edit Borings dialog, **as summarized in section 3.4**.

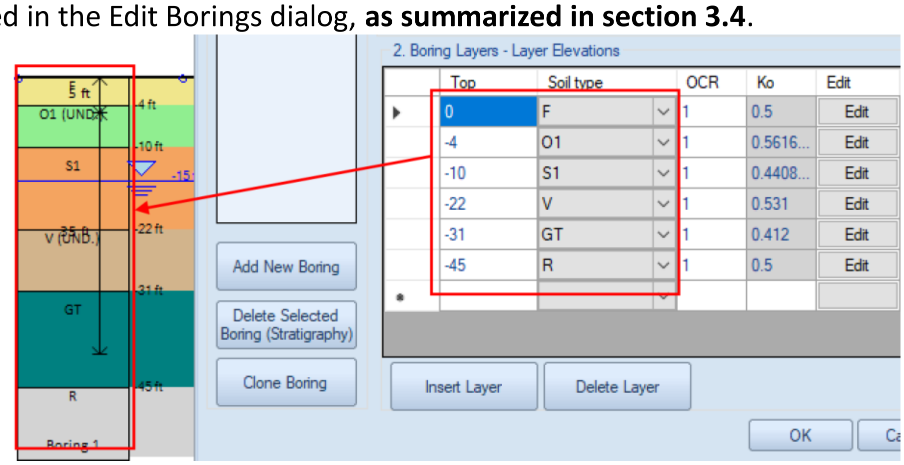


Figure 4.1.2: Model – Step 2 – Define Boring - Stratigraphy.

C. Define external loads on the pile

In DeepFND we can add several stages in any model, either by using the options in the General tab of the software, or by right-clicking on an existing stage below the model area (i.e. Stage 0). These options are summarized in Figure 4.1.3.

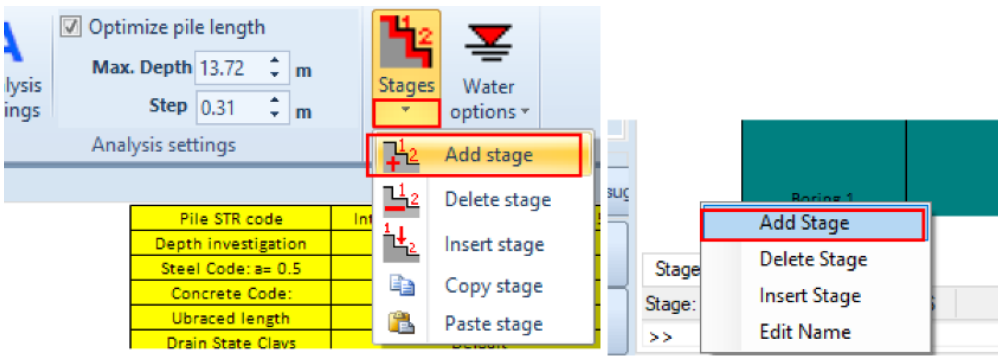


Figure 4.1.3: Options to add Stages.

The stages can be used in order to define different loading magnitudes and load combinations (i.e. use one stage to define the maximum compression load and one stage for the maximum tension load).

Several vertical and lateral loads can be defined on the pile head, as well as, along the pile, **as summarized in section 3.9**.

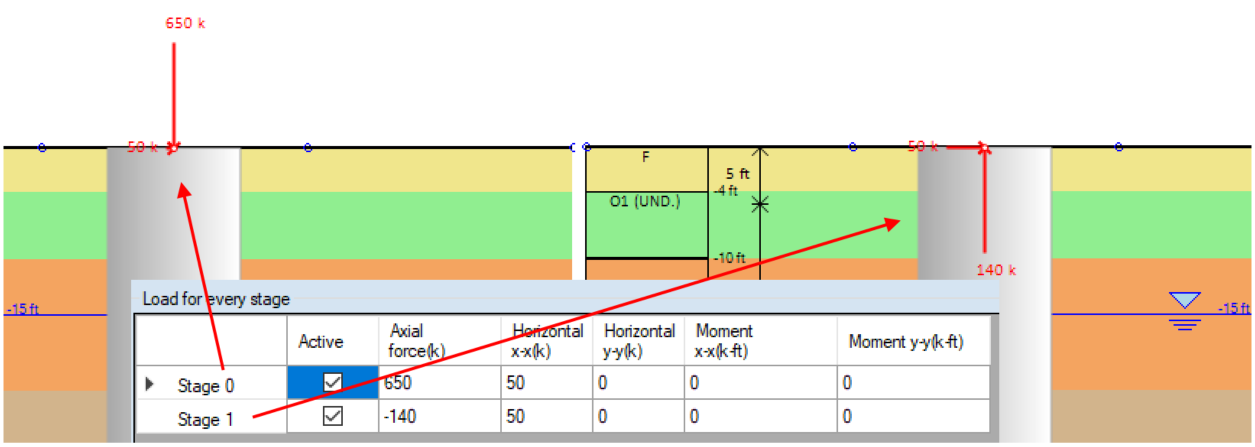


Figure 4.1.4: Loads in different stages.

D. Define pile type and pile section

We should double-click on the pile in the model area and define the pile position, inclination, length and pile structural section. The use of the Edit Piles dialog **is presented in section 3.5**.

The pile types in DeepFND can be helical (**see section 3.6**) and non-helical (**see section 3.7**). HelixPile can design only helical piles.

E. Select to perform settlement analysis

In the Settlement tab of DeepFND (or HelixPile), we can select the option to perform settlement analysis. In the same tab we can select to define pile acceptance criteria, either by selecting one of the existing, or by defining the parameters manually.

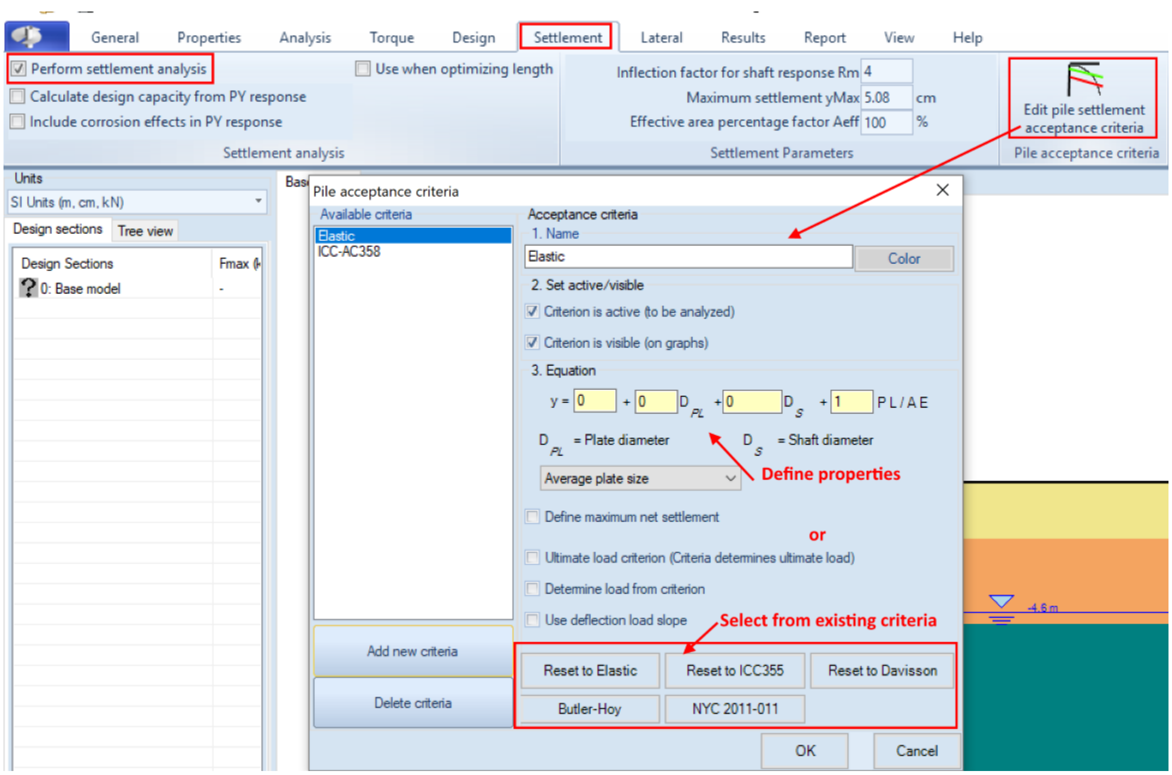


Figure 4.1.5: Perform settlement analysis and define pile criteria.

F. Select to Estimate Torque and define installation Torque profile

In the Torque tab of DeepFND (or HelixPile), we can select to define the torque profiles. In the dialog that appears we can edit the torque profiles list by adding new profiles and define the properties (pile diameter and torque installation factor). From the drop down in the Torque tab, we can select to assign a Torque profile to the model. We have to make sure that the pile diameter is covered by the existing Torque profiles.

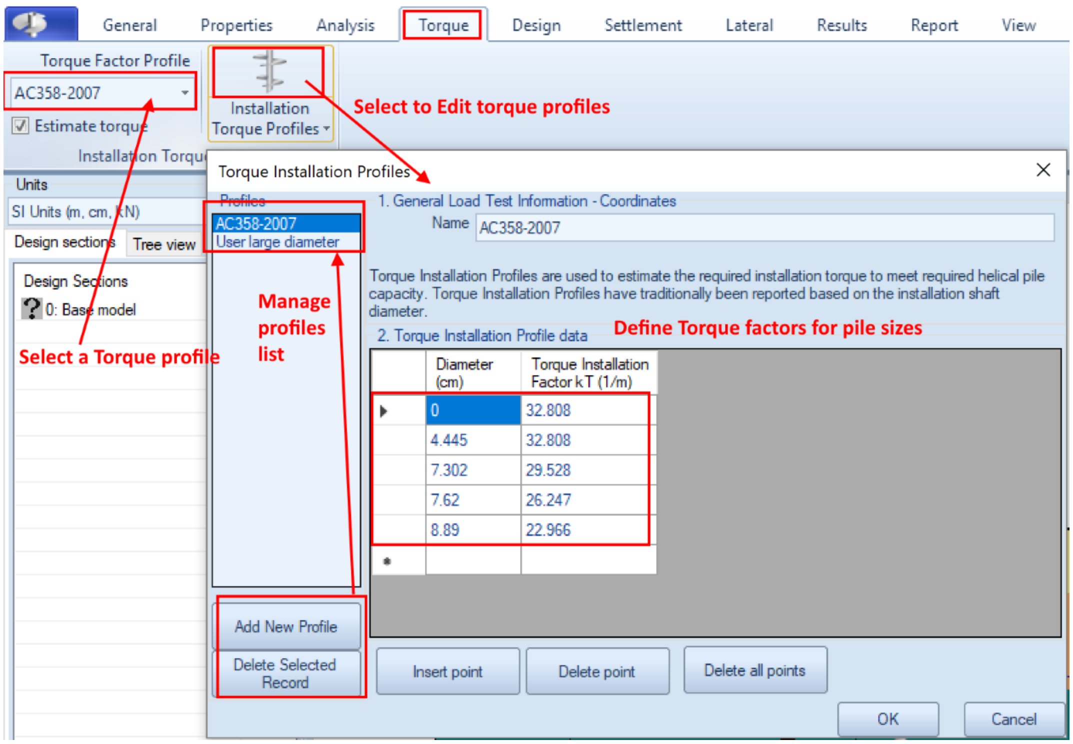


Figure 4.1.6: Define and select installation torque profiles.

G. Define Bearing Capacity Safety Factors (DeepFND and HelixPile)

In the Design tab of DeepFND (or HelixPile), we can define the applied bearing capacity, shaft resistance and structural capacity factors. HelixPile calculated the ultimate capacities and divides them with the defined factors, comparing the applied loads with the factored design capacities.

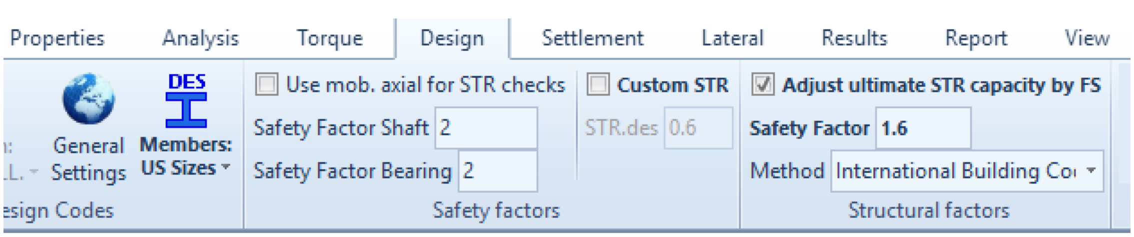


Figure 4.1.7: Structural and geotechnical factors.

H. Define Lateral Pile Analysis Parameters

In the Lateral tab of DeepFND (see section 2.8) we can select the lateral pile analysis method (use defined lateral loads or perform a pushover analysis). In the same tab we can edit the lateral analysis options and define lateral load tests.

I. Define Pile Length Optimization Options

In the General tab of DeepFND (or HelixPile), we can select if we wish to analyze the specified pile length and calculate the pile capacities, or if we wish to optimize the pile length.

Defined Pile Length

By having the "Optimize pile length" option unselected, HelixPile will use the user-specified pile depth for the analysis, it will calculate the shaft resistances and the end bearing capacities (axial tension and compression) and will present these results.

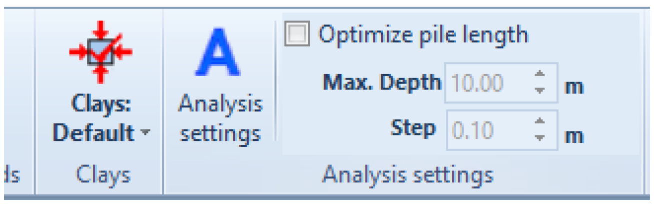


Figure 4.1: Unselected pile length optimization option.

Optimizing Pile Length

By having the "Optimize pile length" option selected, the software will start increasing the pile depth using the defined "Step" length, calculating the bearing capacities in each step. As soon as the calculated axial tension and compression capacities are enough to cover the applied maximum tension and compression load on the pile head respectively, the analysis will stop. The software will return as a result the calculated depth and capacities.

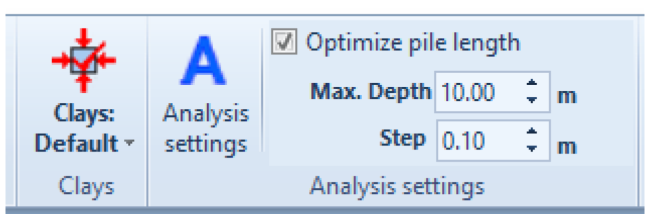
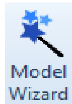


Figure 4.2: Selected pile length optimization option.

If the maximum defined depth is reached, the analysis will stop, returning the calculated capacities for this depth.

4.2 Create a Model with the Model Wizard

By pressing on the 

button in the General tab of DeepFND. The Wizard dialog appears. In this dialog we can define all project properties in order to create a model really fast.

Pile length tab (Figure 4.2.1)

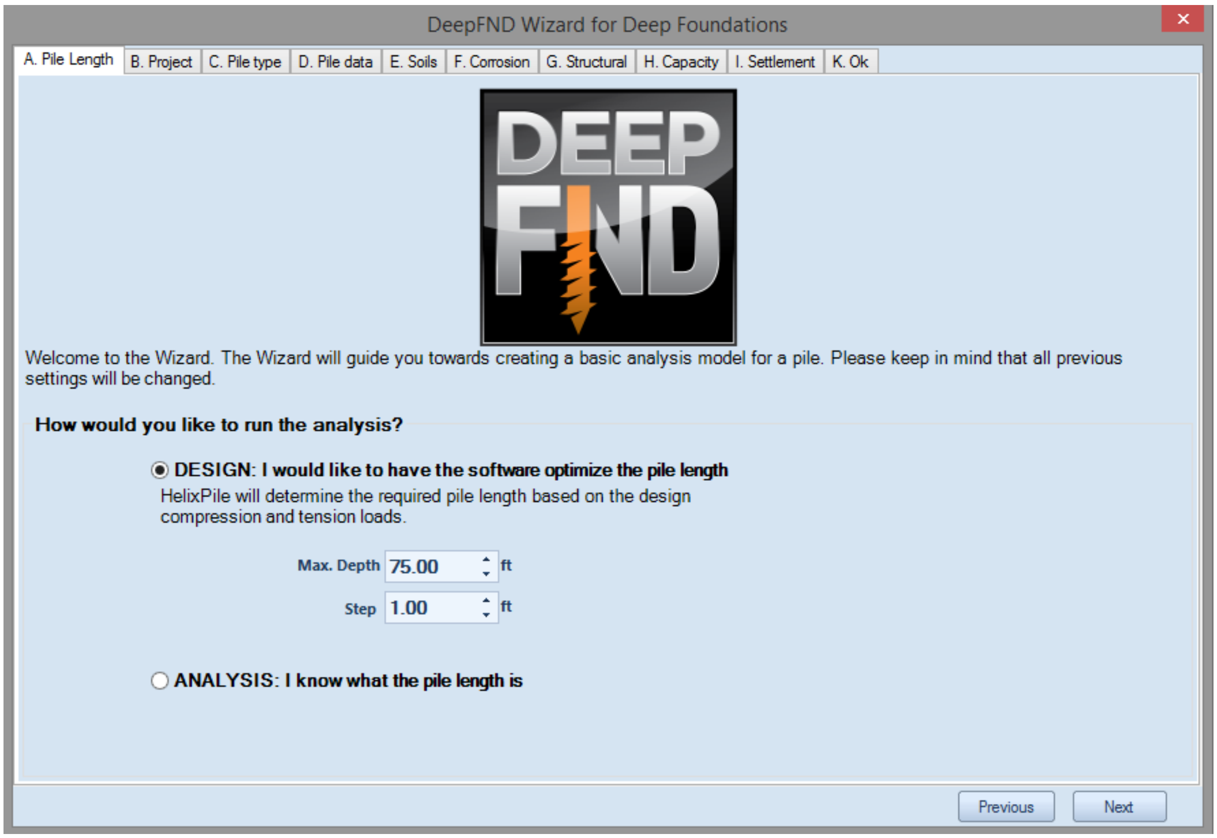


Figure 4.2.1: DeepFND Wizard – Pile length tab

In this tab we can select the program mode. DeepFND offers two options:

- Design mode: Using this mode, DeepFND optimizes the pile length, determining the required length based on the design tension and compression loads. We have to define the maximum depth and the step with which the software will perform the calculations.
- Analysis mode: Using this mode, we define the pile length and DeepFND calculates the bearing capacity of the pile.

Project tab

In this tab we can define the project name, file number, name of engineer and we can add a description.

Pile type tab (Figure 4.2.2)

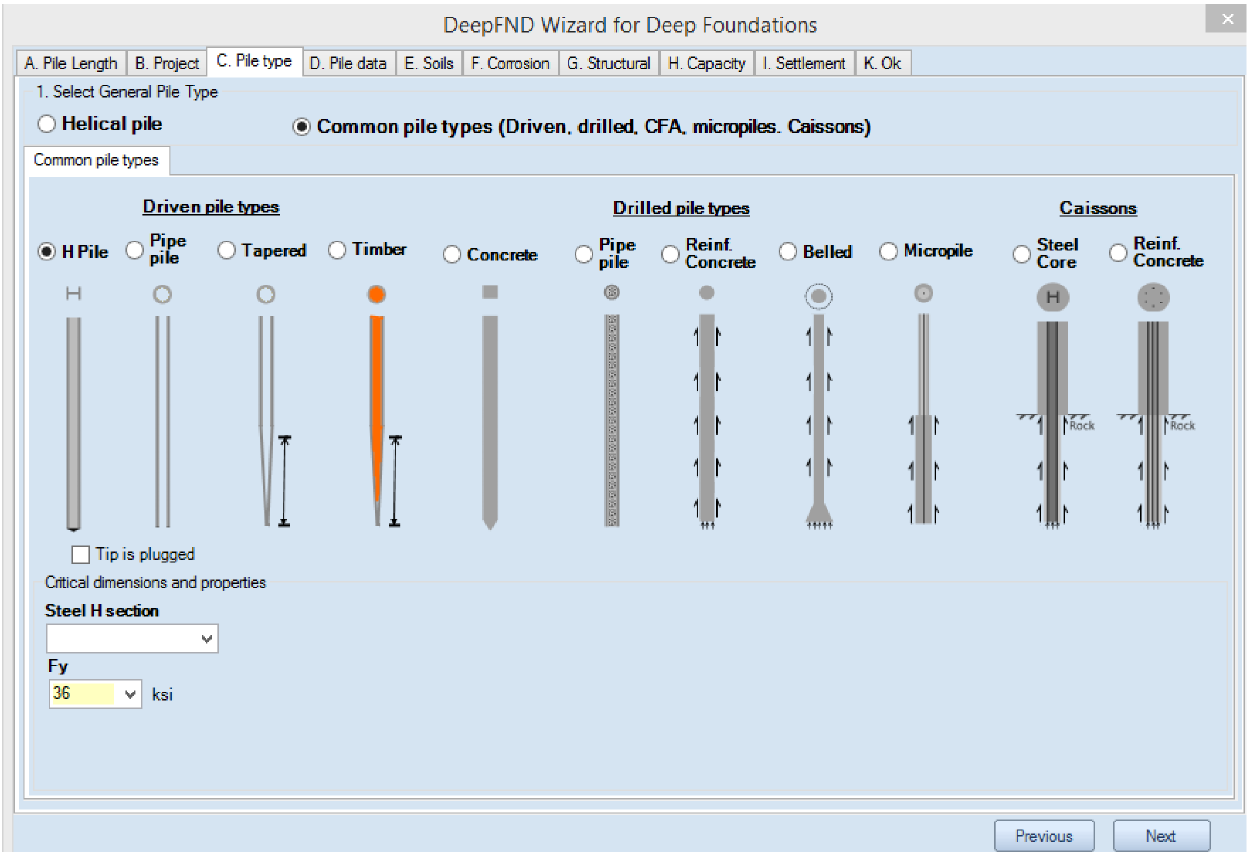


Figure 4.2.2: DeepFND Wizard – Pile type tab

In this tab we can select the pile type. DeepFND offers the following options:
Use an H pile
Use a pipe shaft pile
Use a tapered pile
Use a timber pile
Use a square-section concrete pile
Use a circular-section concrete pile
Use a circular-section reinforced concrete pile
Use a Belled concrete pile
Use a Micropile
Use a Steel core caisson
Use a reinforced concrete caisson

In case we select a steel core section pile, we can select the steel beam section from the software implemented databases.

Pile data tab (Figure 4.2.3)

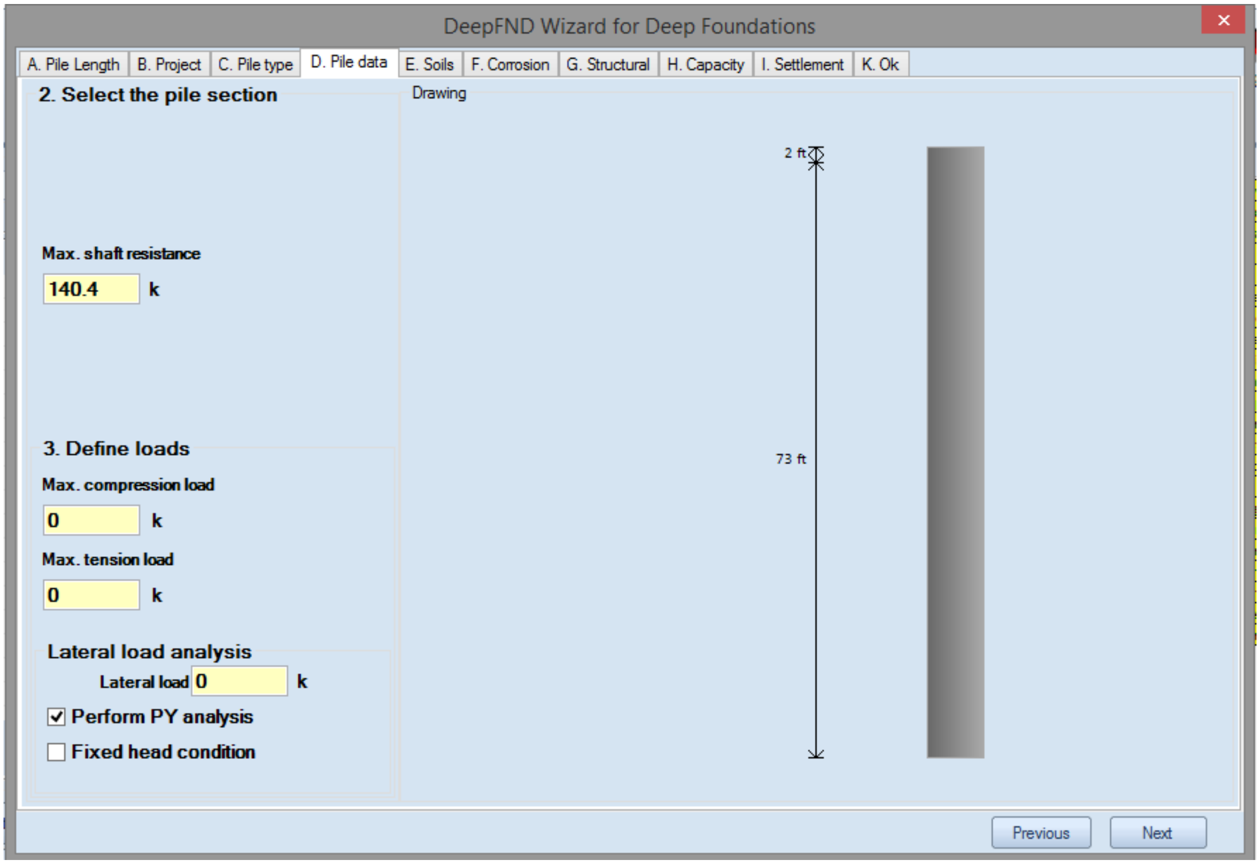


Figure 4.2.3: DeepFND Wizard – Pile data tab

In this tab we can modify the pile properties. DeepFND offers the following options:
Select a pile section from the software list
Manually edit the pile section (opens the pile section dialog, see Section 3.6)
Import a section from DeepFND database. DeepFND has adopted pile sections from Magnum, Ramjack and Chance.
Define the maximum shaft resistance (usually this parameter is defined from the selected pile section)
Define maximum compression and tension load
Define lateral load
Option to perform PY analysis
Option to define fixed pile head condition

Soils tab (Figure 4.2.4)

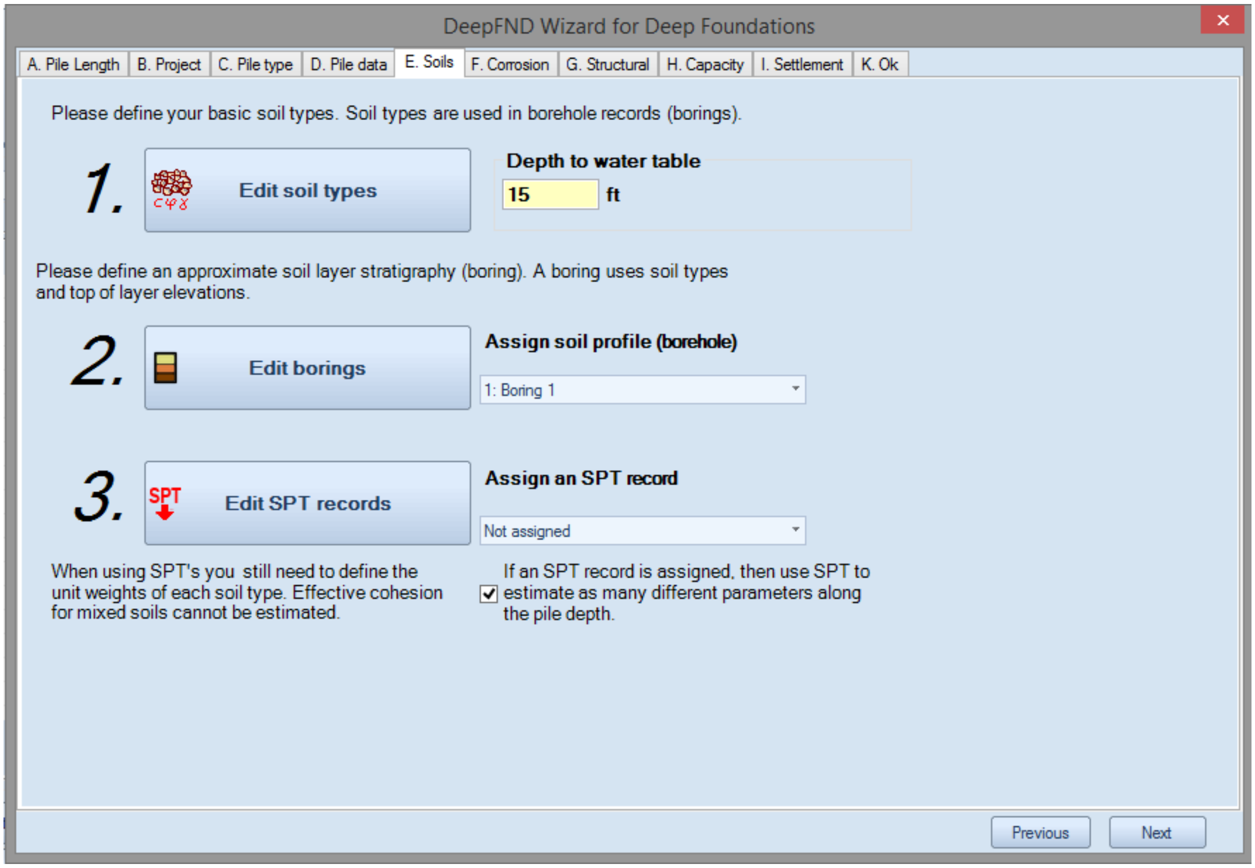


Figure 4.2.4: DeepFND Wizard – Soils tab

In this tab we can modify the soil properties. DeepFND offers the following options:
Edit soil types (opens the soil data dialog, see Section 3.3)
Edit borings (opens the Borings - Stratigraphy dialog, see Section 3.4)
Edit SPT records (opens the SPT records dialog, see Section 2.4)
Define the depth to the water table

Corrosion tab (Figure 4.2.5)

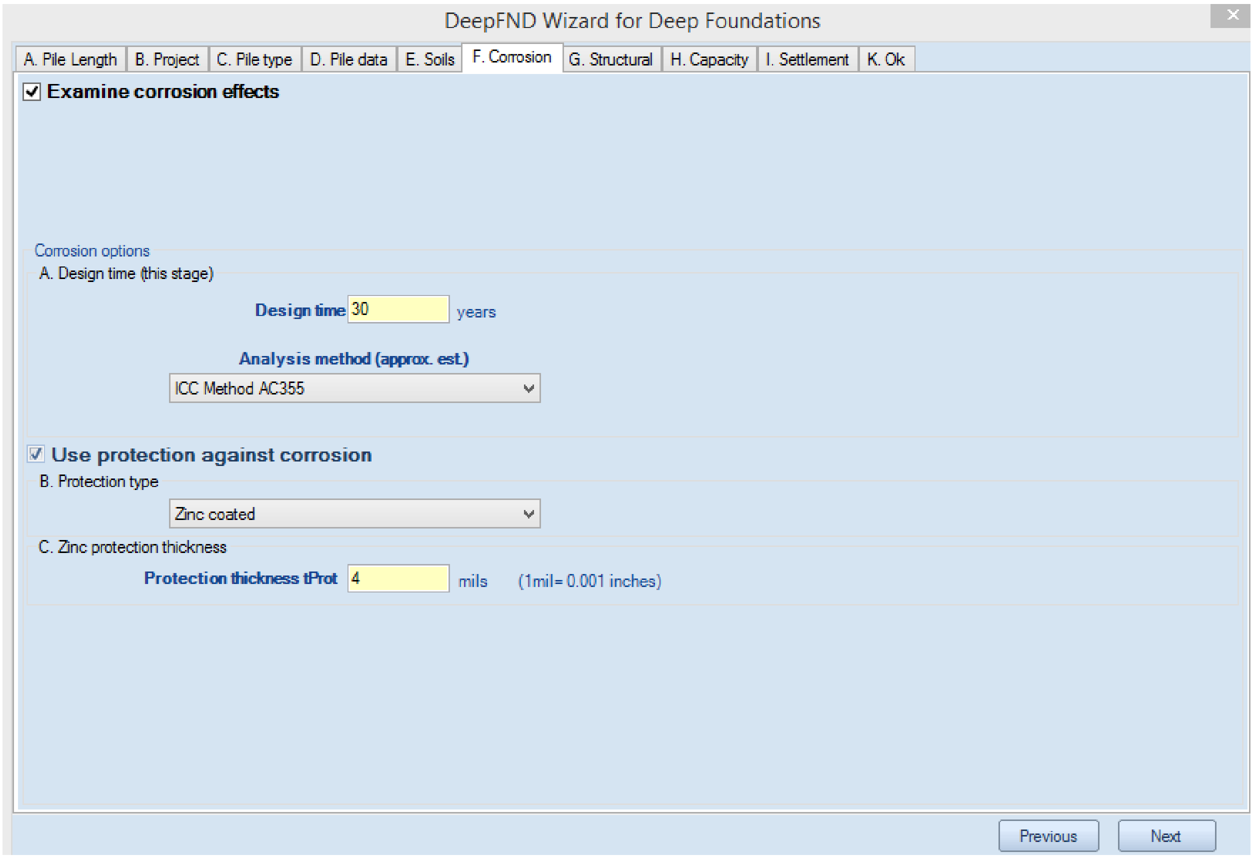


Figure 4.2.56: DeepFND Wizard – Corrosion tab

In this tab we can modify the design time and the protection against corrosion. DeepFND offers the following options:

Define design time

Select the analysis method (Provided methods: ICC Method AC355 and AASHTO 2004)

Option to use protection against corrosion

Define the protection type (Provided options: Zinc coated, Bare steel, Powder coated steel)

In case we select to use Zinc coated protection, we can define the protection thickness

Structural tab (Figure 4.2.6)

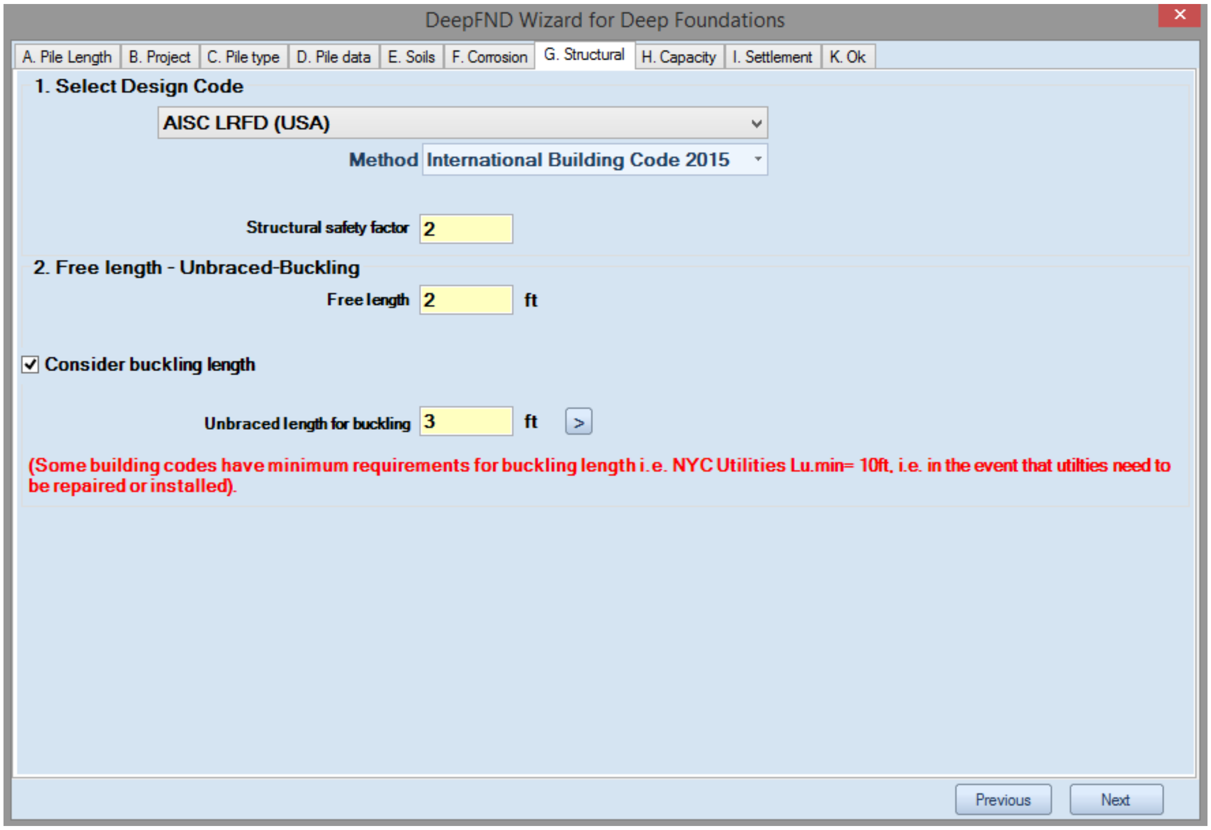


Figure 4.2.6: DeepFND Wizard – Structural tab

In this tab we can modify the structural analysis method, the unbraced length and the buckling length. DeepFND offers the following options:

Select structural design code (Provided options: AISC Allowable Stress Design (USA) and AISC LRFD (USA))

Select the design method (Provided options: International Building Code 2015, AASHTO LRFD 6th and NYC Building Code 2014)

Define the structural safety factor

Define the pile free length

Option to consider buckling

Define the unbraced length for buckling. For this parameter, DeepFND provides an estimation table with common values

Capacity tab (Figure 4.2.7)

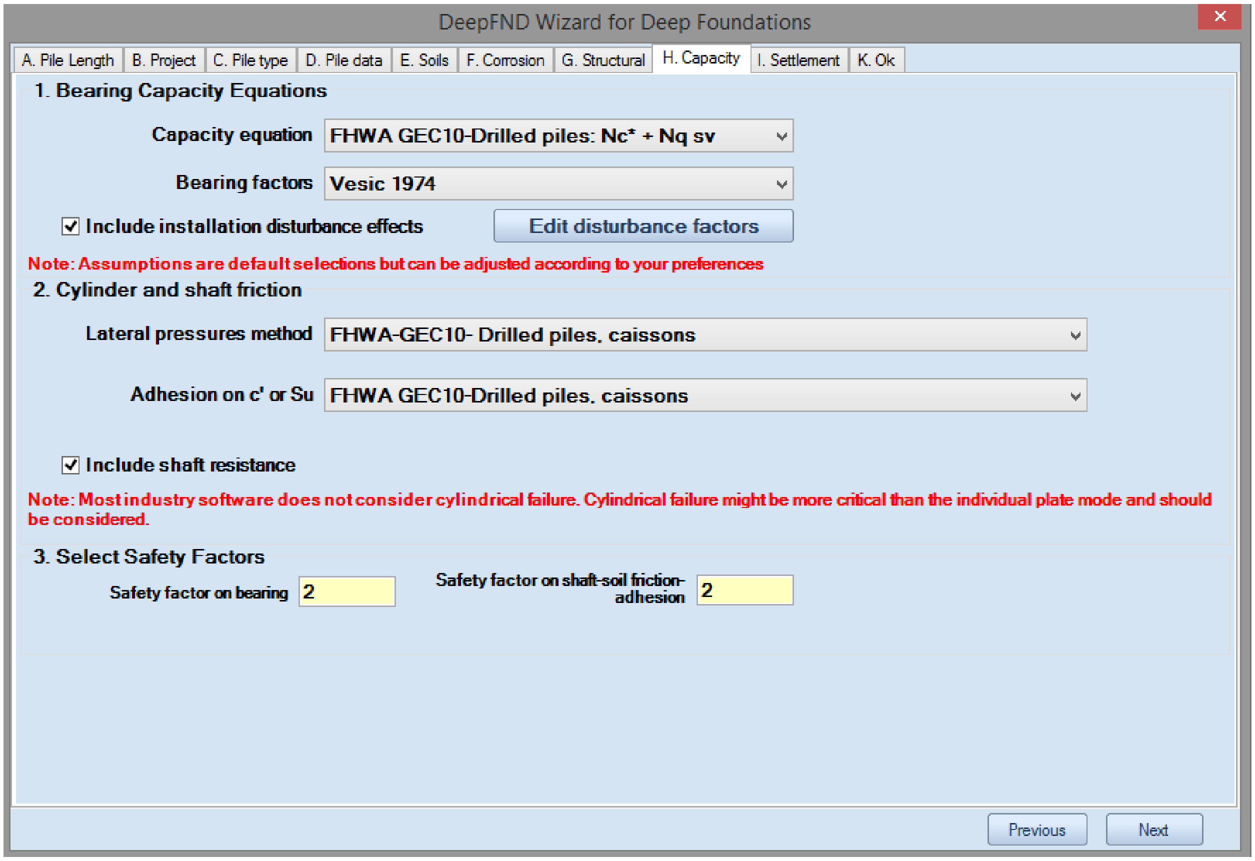


Figure 4.2.7: DeepFND Wizard – Capacity tab

In this tab we can modify the capacity equations and define some basic safety factors. DeepFND offers the following options:
Select a capacity equation
Define the bearing factors (Provided options: Vesic 1974, Hansen/Meyerhof)
Option to include installation disturbance effects (see Section 2.3 – Analysis settings)
Define the lateral pressures method (Provided options: see section 2.5)
Define adhesion on c' or Su (Provided options: see section 2.5)
Option to include shaft resistance
Define safety factors for bearing and shaft-soil friction-adhesion

Settlement tab (Figure 4.2.8)

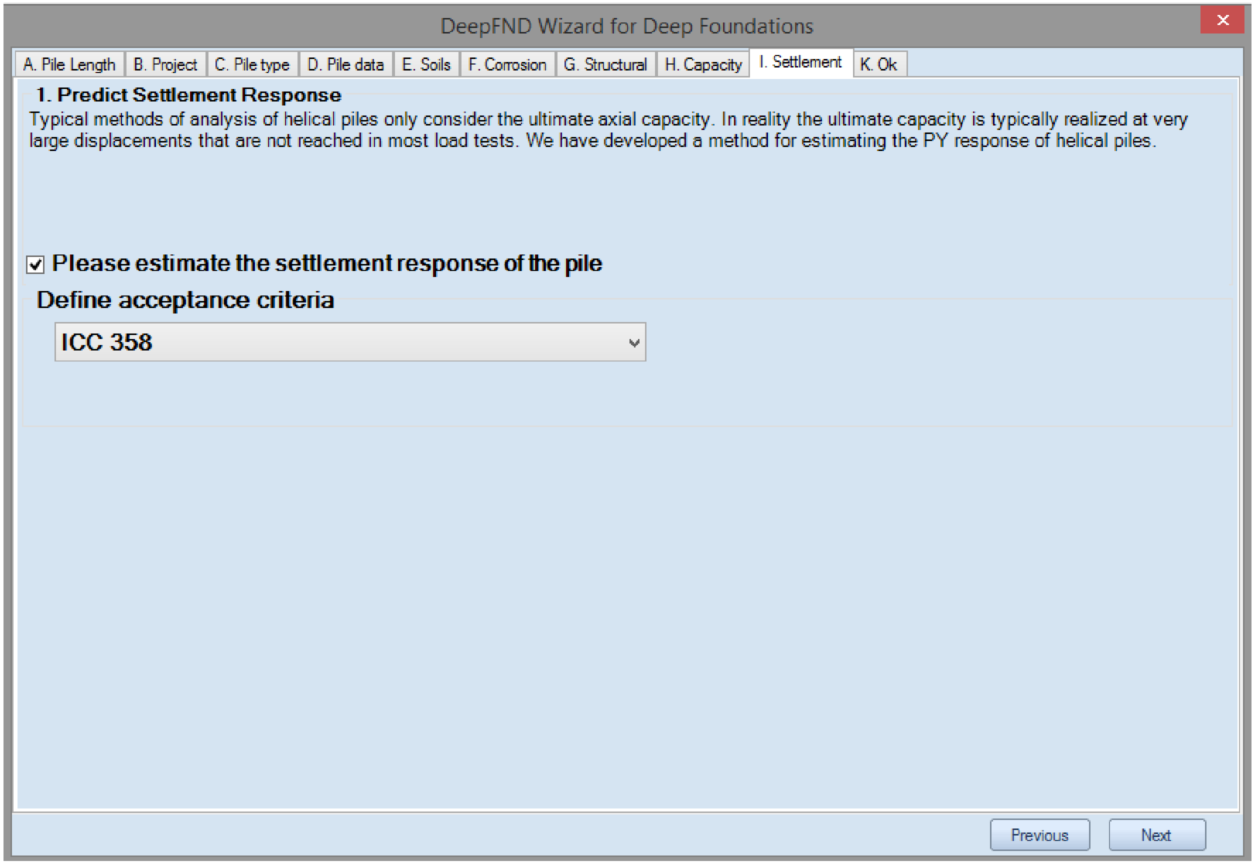


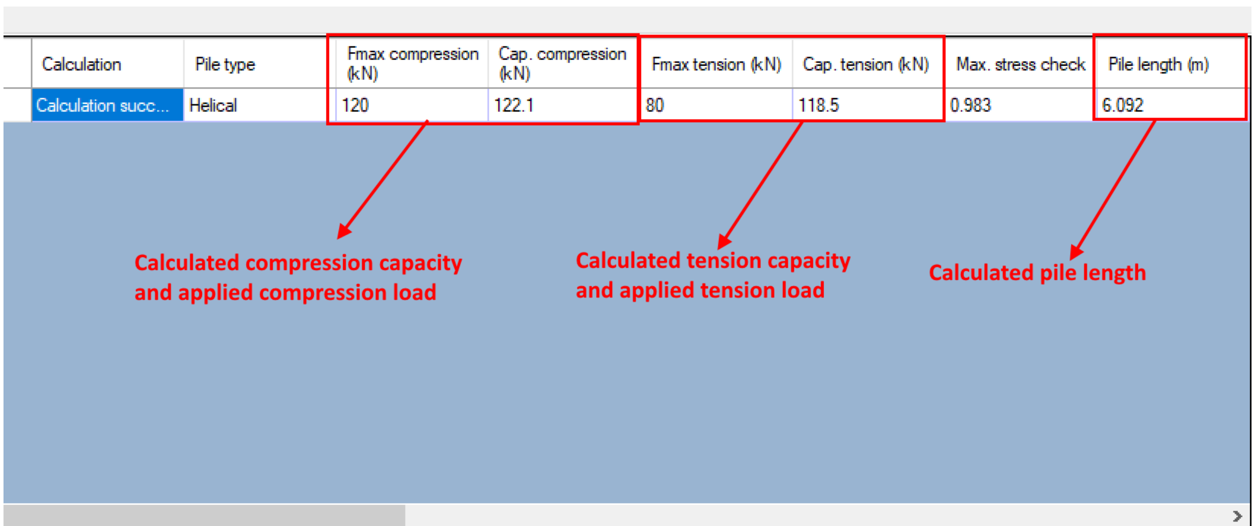
Figure 4.2.8: DeepFND Wizard – Settlement tab

In this tab we can modify the pile settlement response parameters. DeepFND offers the following options:
Option to estimate the settlement response of the pile
Define the acceptance criteria (Provided options: ICC 358, Davisson, NYC 2011-011). ICC 358 is only applicable for helical piles.

4.3 Review Analysis Results

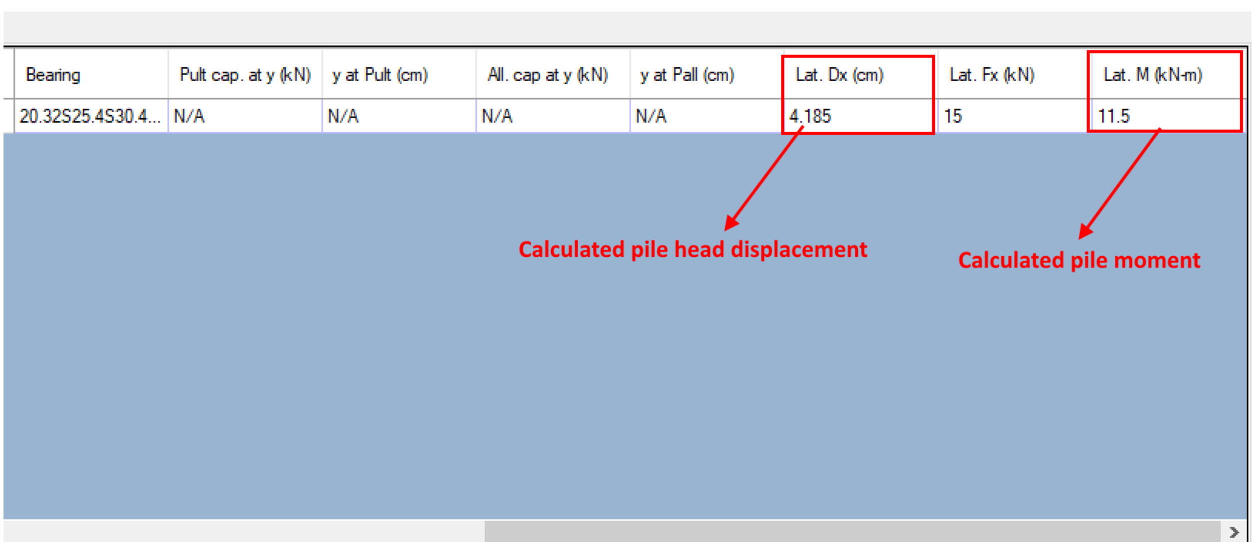
<u>Review Summary Table Results</u>

After the analysis is completed, we can review the results in the Analysis and Checking summary table that appears. This table presents the calculated compression and tension capacities, the estimated pile length and the lateral pile analysis results (lateral pile head displacement and moment).



Calculation	Pile type	Fmax compression (kN)	Cap. compression (kN)	Fmax tension (kN)	Cap. tension (kN)	Max. stress check	Pile length (m)
Calculation succ...	Helical	120	122.1	80	118.5	0.983	6.092

Figure 4.3.1: Analysis table results: Axial pile analysis.



Bearing	Pult cap. at y (kN)	y at Pult (cm)	All. cap at y (kN)	y at Pall (cm)	Lat. Dx (cm)	Lat. Fx (kN)	Lat. M (kN-m)
20.32S25.4S30.4...	N/A	N/A	N/A	N/A	4.185	15	11.5

Figure 4.3.2: Analysis table results: Lateral pile analysis.

Review Results on the Model Area

Once a project is analyzed, results can be viewed on screen by selecting one or more of the options provided below:

Show the structural ration on screen.
Show the critical condition results on screen (most critical between cylinder and individual plate failure modes).
Show the cylinder failure results on screen
Show the individual plate results on screen
Show the results for tension condition on screen
Show all failure capacities on screen
Show stress points in table
Show ultimate geotechnical capacity on screen
Show the geotechnical capacity vs. elevation on screen
Show the PY settlement analysis response on screen
Show the PY results in table
Show the load test data on the model screen
Show installation torque diagram on screen
Show torque capacity on screen
Show torque table results

DeepFND and HelixPile can graphically represent results for all analyzed design sections and stages. The following figures show some typical on-screen output diagrams and results. Output results can be visible only if the given problem has been analyzed. Feel free to explore the functionality of these toolbars.

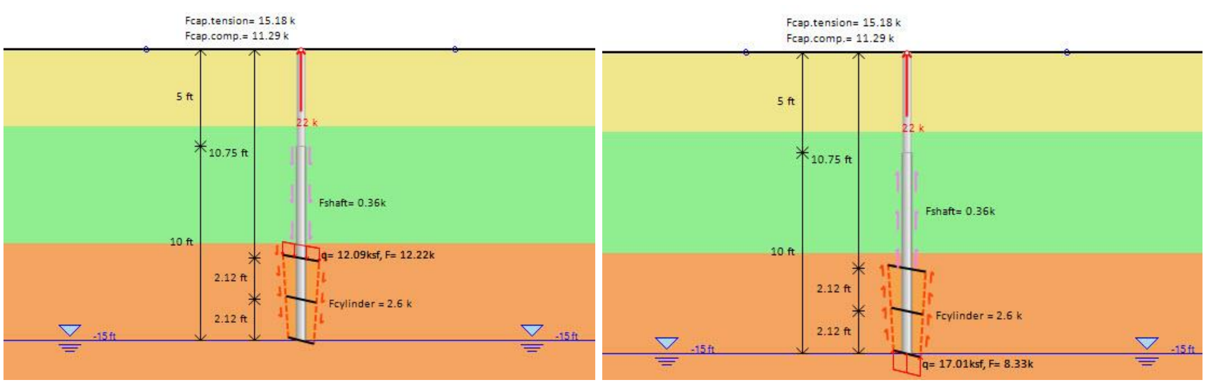


Figure 5.3: Helical Piles: Critical condition results and Cylinder failure results.

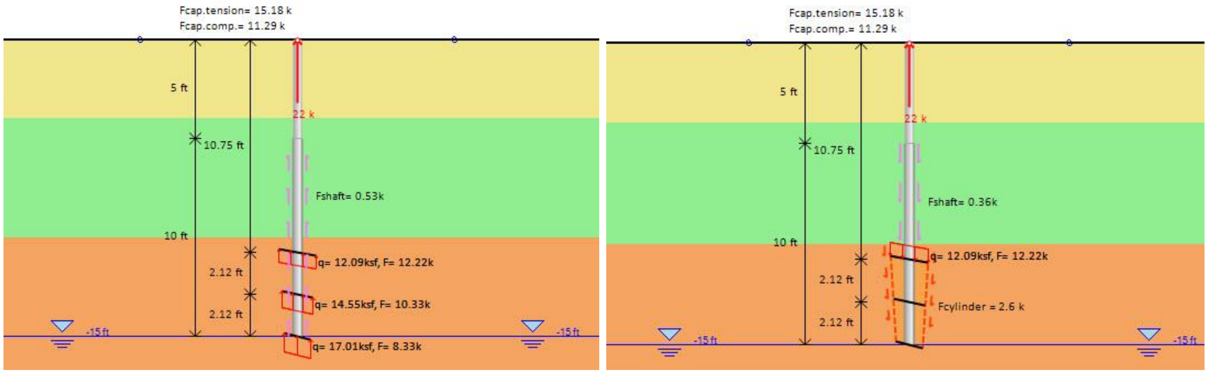


Figure 5.4: Helical piles: Individual plate method and Tension condition.

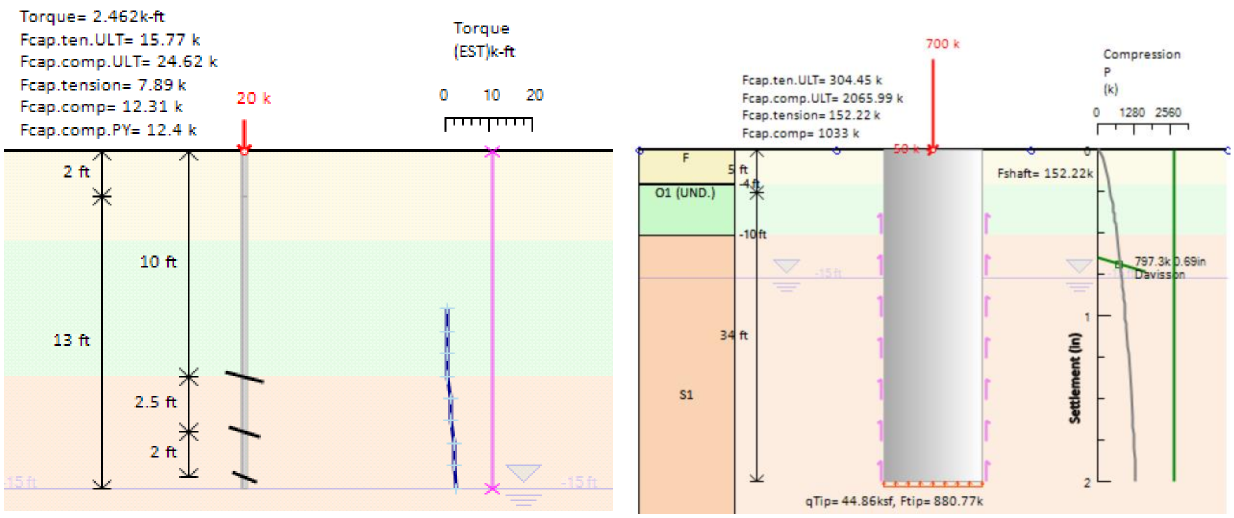


Figure 5.5: Installation torque diagram - Load/Settlement diagram.

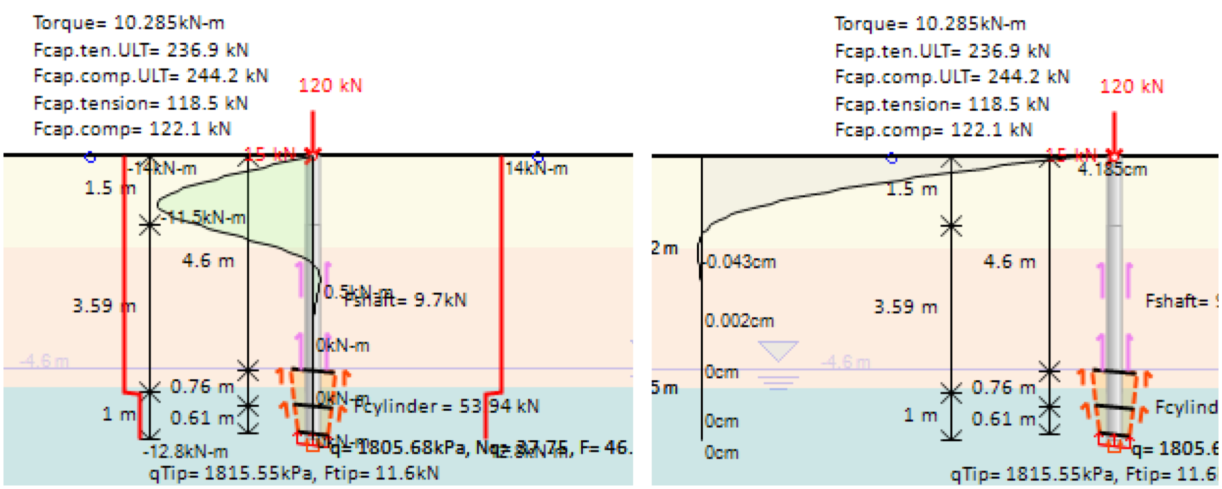


Figure 5.6: Pile Moment and Pile Displacements diagrams.

SECTION 5: SINGLE PILES - EXAMPLES

5.1 Example 1: Design of a Drilled Reinforced Concrete Pile

A. Project description

In this example we will design a drilled reinforced concrete foundation pile. The Figure below presents the project model. Tables 1 and 2 present the soil properties and the stratigraphy respectively. Table 3 presents the external loads applied on the pile head. Table 4 presents the pile section properties that we are going to use. The general ground surface is at El. 0ft and the general water table is at El. -15 ft.

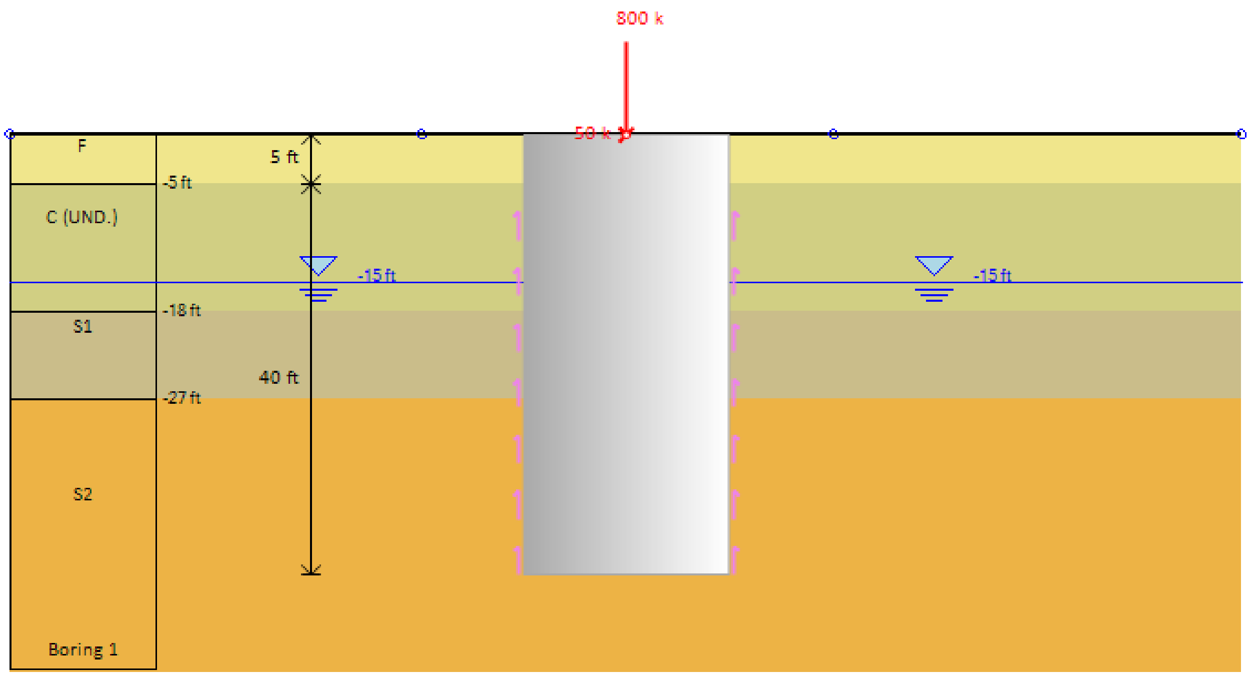


Figure 5.1.1: Driled RC Pile Example - Project model.

Table 5.1.1: Soil properties.

Soil Layer	Soil Type	General properties						Lateral properties		
		φ' (deg)	C'/Su (psf)	γ (pcf)	$γ_{dry}$ (pcf)	E_{LOAD} (ksf)	E_{RELOAD} (ksf)	k (pci)	e50	Krm
F	Fill	25	0	120	120	300	900	60	-	-
C	Clay (Undrained)	-	1300	116	116	400	1200	-	0.005	-
S1	Sand	32	0	130	130	600	1800	60	-	-
S2	Sand	34	10	135	135	900	2700	90	-	-

Table 5.1.2: Stratigraphy.

Soil Layer	Elevation (ft)	OCR	Ko
F	-0	1	0.577
C	-5	1	0.515
S1	-18	1	0.47
S2	-27	1	0.441

Table 5.1.3: External loads.

Stage	Axial Load (kips)	Moment (k-ft)	Lateral Load (kips)
Stage 0 (Compression)	800	0	50
Stage 1 (Tension)	-180	0	50

Table 5.1.4: Pile parameters.

Pile Type	Drilled Reinforced Concrete
Pile Width	5ft
Longitudinal Reinforcement	24 bars #5
Steel Grade	Grade 60
Concrete Grade	3 ksi

B. Modeling with DeepFND

In DeepFND software, we should define initially the soil properties of all soils according to the geotechnical report, the model stratigraphy, the pile head loads and the pile initial depth and structural section.

Define soil properties:
From the General tab of DeepFND we can select the option "Edit Soil Type Data". In the dialog that appears, we can modify the existing soils database or add new soils, and then for each one of them, we have to define the general soil properties, the soil model and the lateral soil properties. The soil parameters can be defined manually, or with the use of the software SPT estimator or local parameter estimation tools.

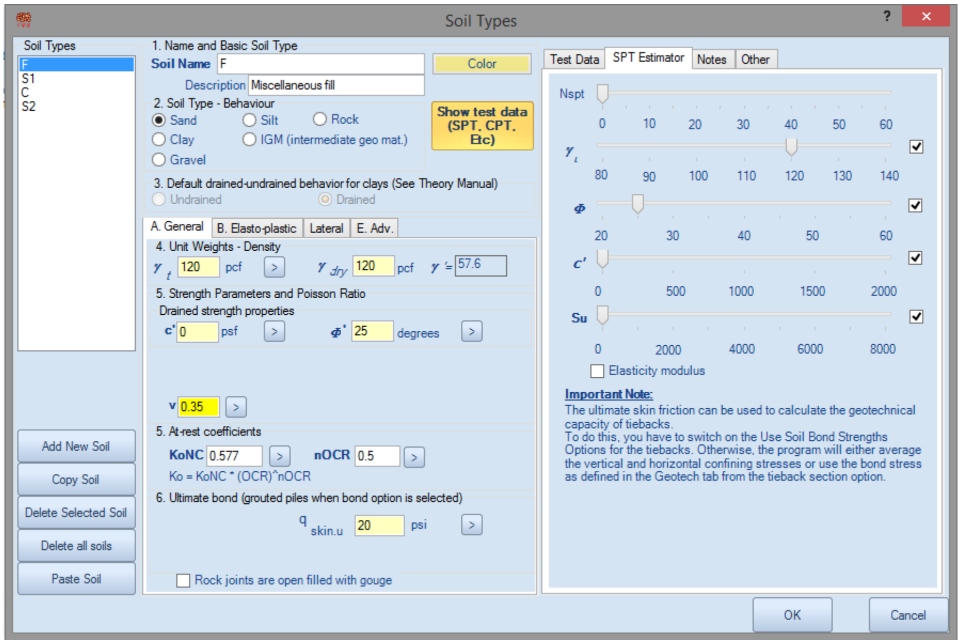


Figure 5.1.2: Edit Soil Type Data Dialog.

Define stratigraphy:

From the General tab of DeepFND we can select the option "Edit Boring". In the dialog that appears, we can define the top of the soil layer elevation and the soil type for each soil layer.

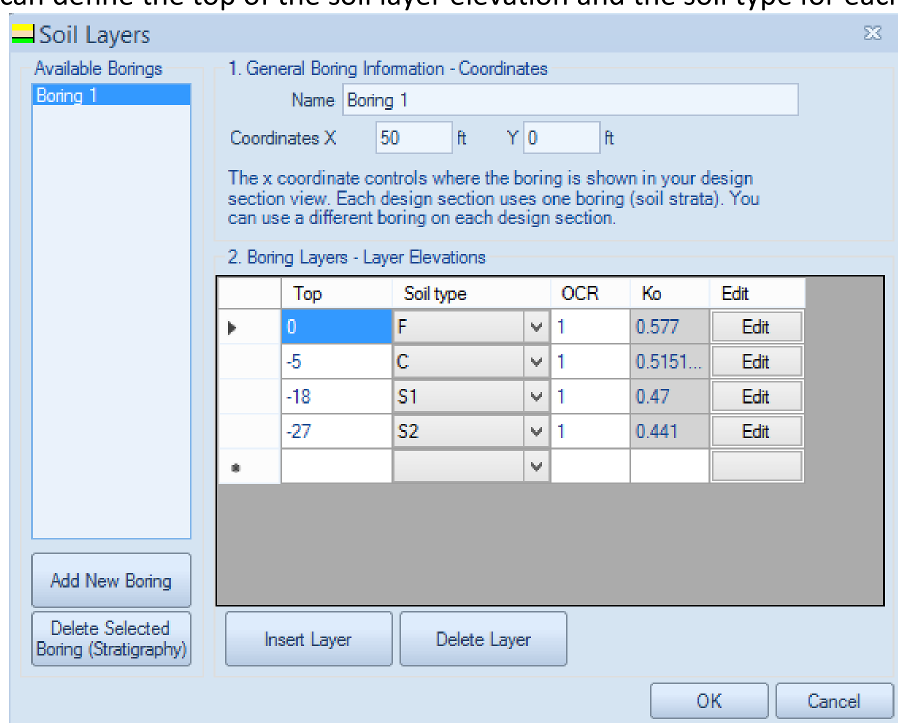


Figure 5.1.3: Edit Soil Layers Dialog.

Define external loads on pile head:

In any model in DeepFND we can add several stages. In our deep foundation software these can work as loading stages, so in each stage we can define a different load (load type, magnitude etc.). In this example, we will use Stage 0 to define our maximum compression load, and Stage 1 to define our maximum tension load on the pile head.

First, we right-click on the Stage 0-tab right below the model area and we select to Add Stage (so Stage 1 is added):

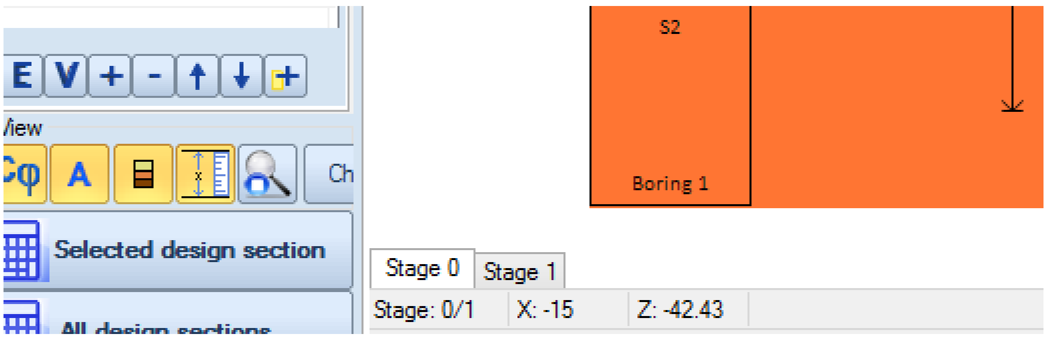


Figure5.1.4: Stages in DeepFND.

After we create the stages, we double-click on the load in the model area. In the dialog that appears, we can add several loads in the list and define the load type and the magnitude of each load, in each stage. The summary of all loads will be applied on the pile head. If we apply a design standard (i.e. AASHTO LRFD), the loads will be factored depending on the load type (dead, live, wind, ice, vehicular etc.).

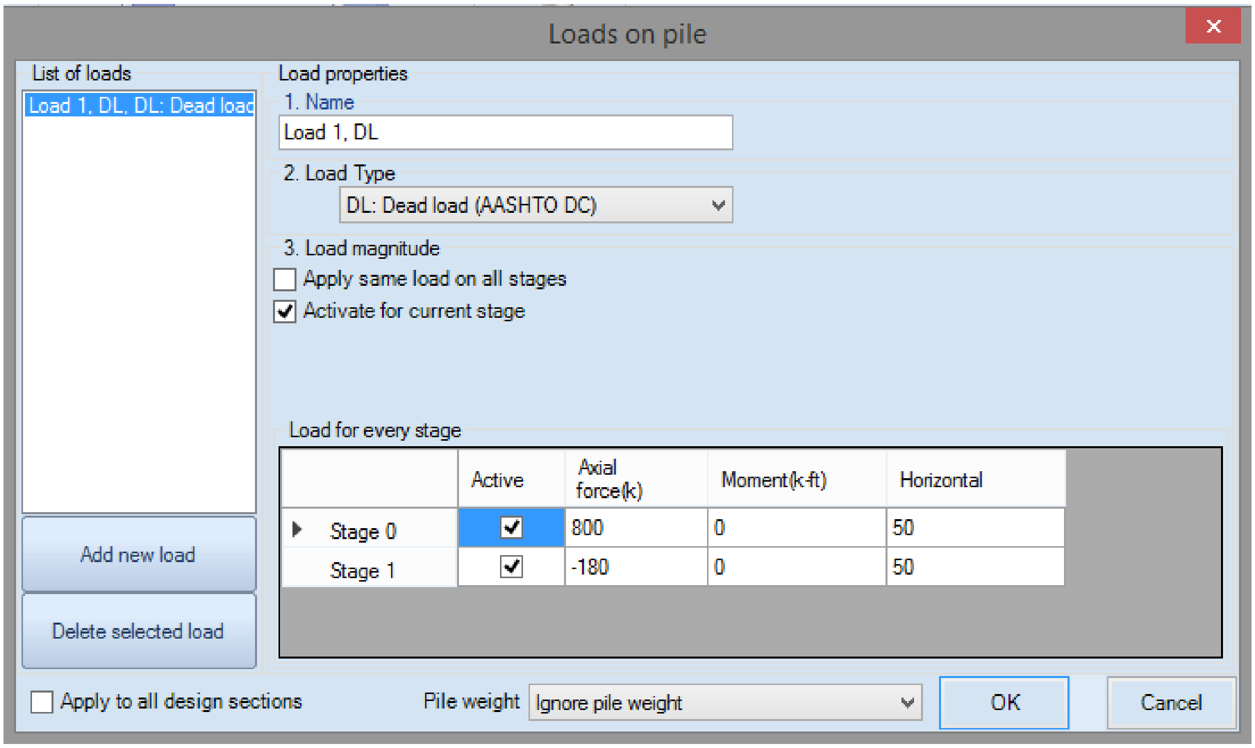


Figure 5.1.5: Define loads on pile head.

<u>Define pile section and initial length:</u>

In DeepFND we have to define the pile type, installation method, structural section and original depth. Later, based on the analyses results, we can choose to optimize the pile section and the pile embedment. The required pile length can also be calculated by the software. We have to double-click on the pile and define the pile parameters in the dialog that appears. By pressing "Edit" on this dialog, we can define the pile type and the pile structural section.

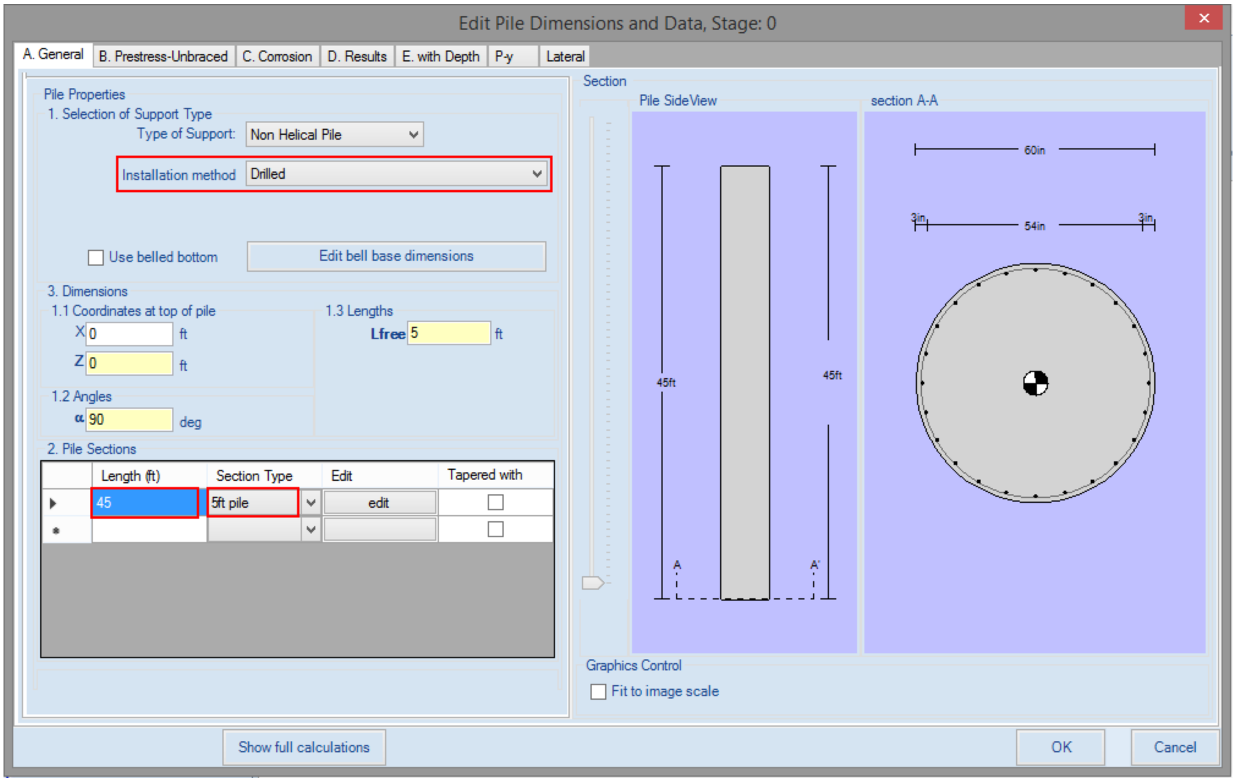


Figure5.1.6: Define pile dimensions and data dialog.

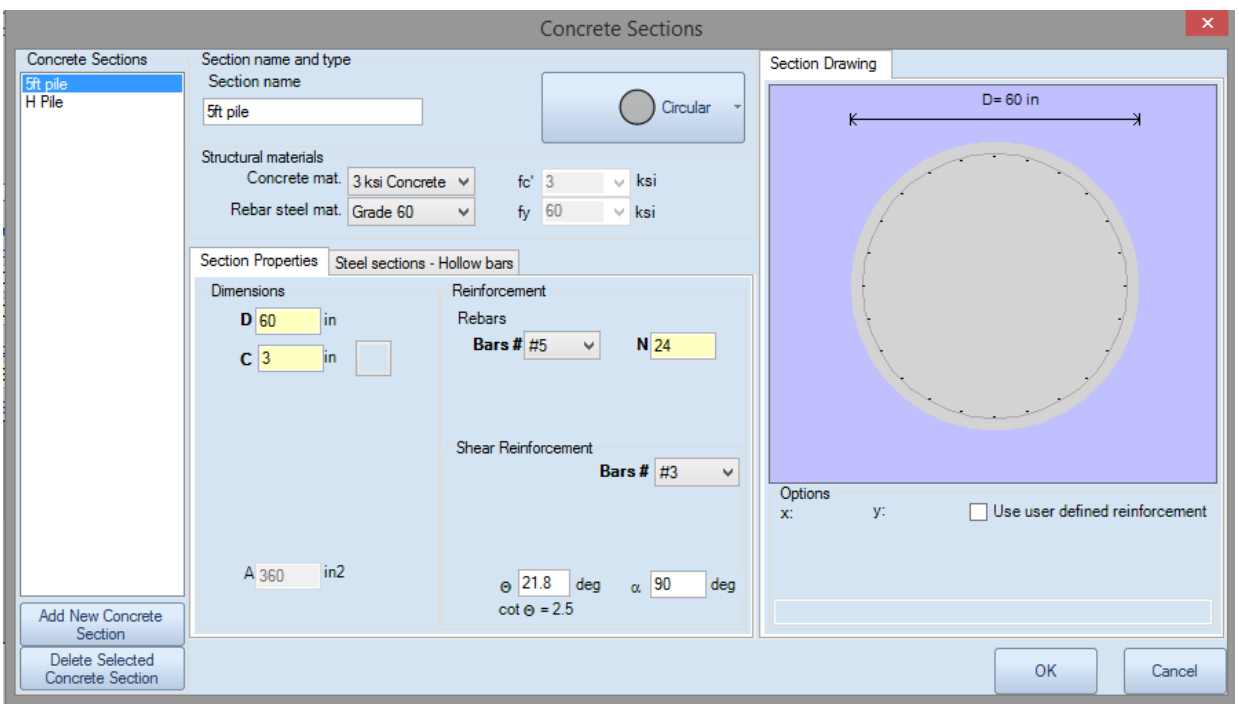


Figure 5.1.7: Select the pile type and choose to edit the steel section.

C. Define Analysis Options

After we create the model in DeepFND, we have to define several analysis parameters.

Pile length automatic optimization:

In the general tab of DeepFND we can select to optimize the pile length. In this case, we need to define the maximum pile depth and the step. The software will use the step to calculate the pile tensional and compressional capacity in several depths and compare them with the applied tension and compression loads respectively. It will stop the analysis when both capacities exceed the applied loads and return as a result the pile depth, the calculated capacities and the pile structural results (moment, shear, displacement etc.). If the software reaches the maximum depth and fails to find a suitable solution, it will stop the analysis and return as a result the calculated capacities etc. of the maximum depth.

If we leave this option unselected, the software will use the pile depth we manually specified for the analysis and return all analysis results.

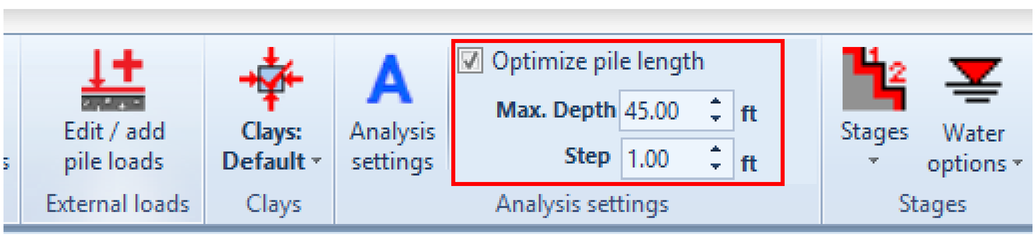


Figure 5.1.8: Option to optimize pile length in the General tab.

Analysis equations and settings:

In the Analysis tab of DeepFND, all analysis parameters are automatically defined according to the pile type (helical or non-helical) and the pile installation method (drilled, driven, caisson, micporile etc.).

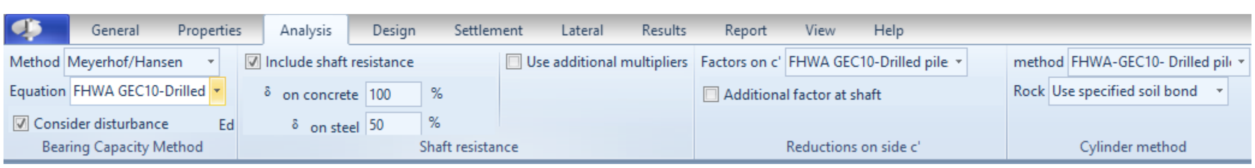


Figure 5.1.9: Analysis settings automatically selected.

Design standards and Safety factors:

In the Design tab we can define the structural codes and the safety factors applied on the bearing, shaft and structural capacities. Alternatively, we can select a load combination of a specific geotechnical design standard (we will not use one in the current example).

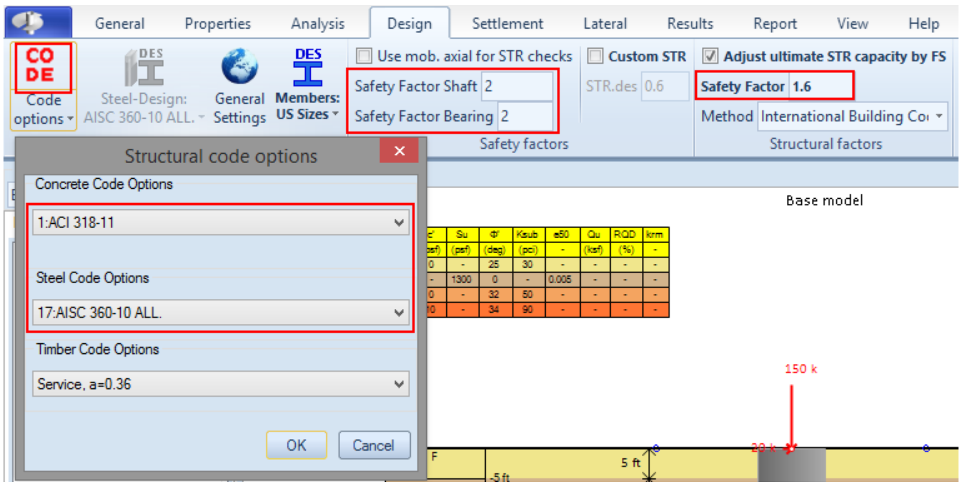


Figure 5.1.10: Define structural codes and structural/geotechnical safety factors.

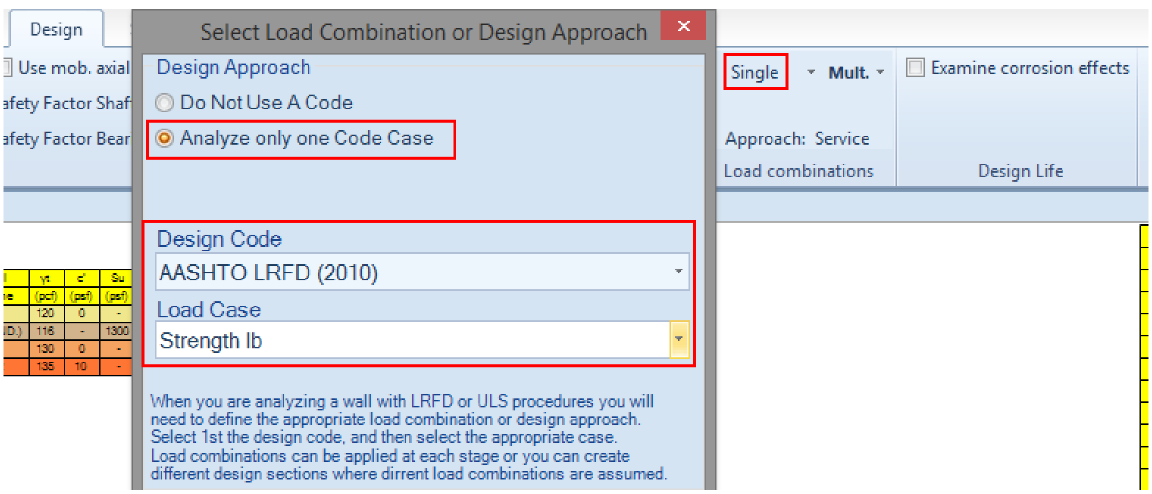


Figure 5.1.11: Option to assign a design standard load combination.

Settlement analysis options:

In the Settlement tab we can select the option to perform settlement analysis. Also, there, we can define pile settlement acceptance criteria.

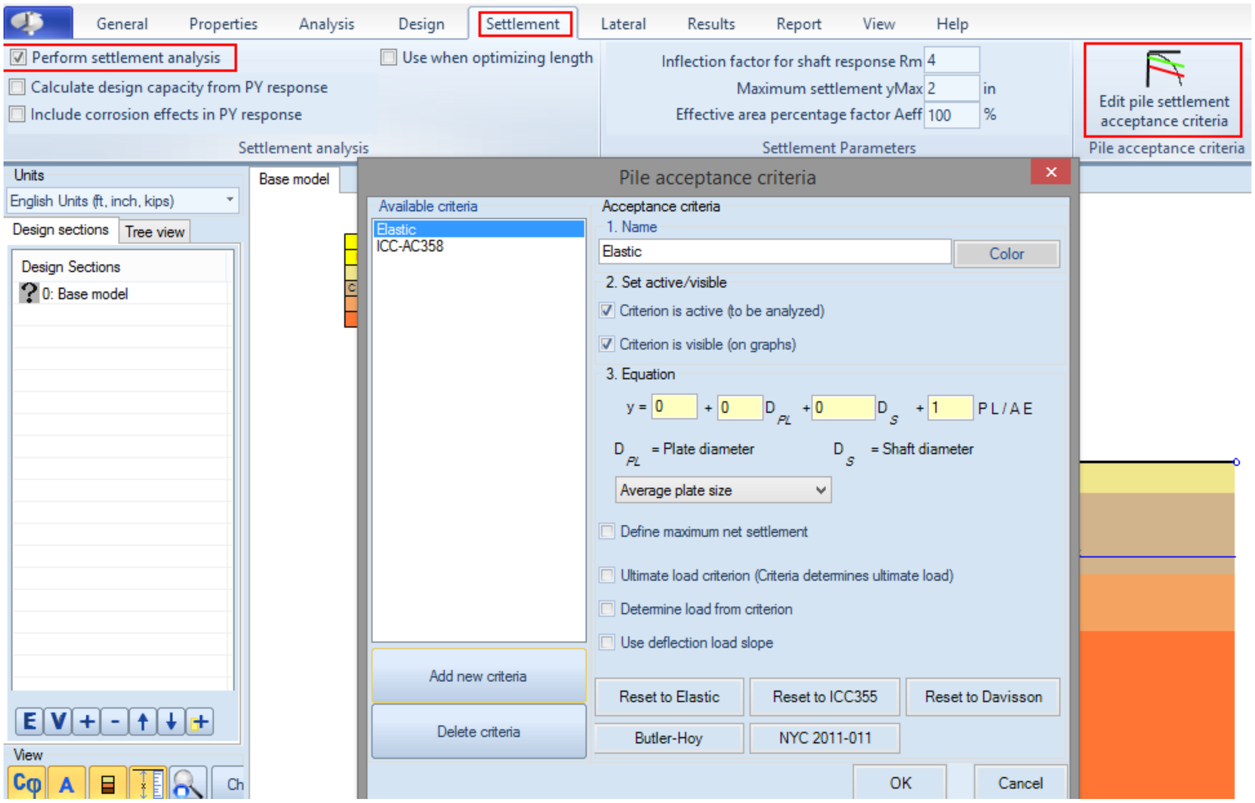


Figure 5.1.12: Option to perform settlement analysis and pile acceptance criteria.

Lateral pile analysis options:

In the Lateral tab we can select the lateral pile analysis method. The available options are either to calculate pile moment, shear and displacement for the defined lateral loads, or perform a pushover analysis and report the required load to achieve a specific displacement.

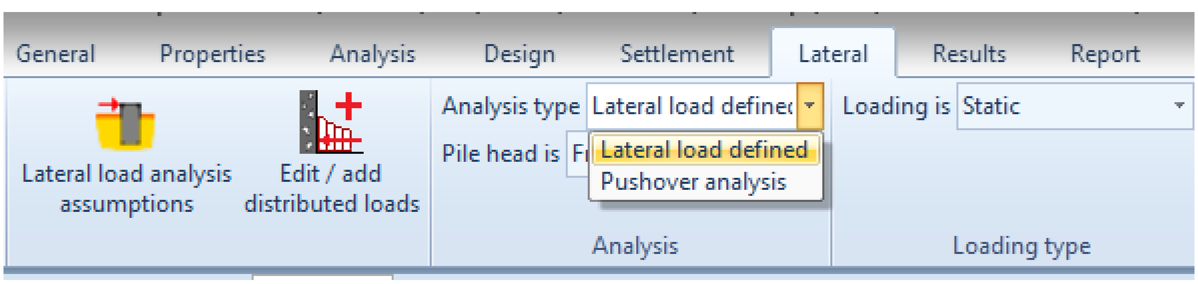


Figure 5.1.13: Lateral load options.

D. Analysis and Results

Since the model is ready, we can choose to calculate the design section. After the analysis is succeeded, the Summary table appears. The table below includes the calculated compression and tension capacities, the optimized pile depth, the lateral pile results and more. With red we can see some values that are critical. In this case, we can see that at least one stress check is above the limit "1". We can locate the issue by closing the summary table and reviewing the results graphically on the model area for every stage. In this case, the structural capacity and moment capacity on the pile in Stage 1 (tension stage) are not enough to cover the combination of the tension and lateral load applied on the pile head. In this case we need to somehow increase the pile capacity (increase number or size of rebars, concrete grade, pile diameter etc.).

Table 5.1.5: Analysis and Checking Summary table.

Extended Summary

	Calculation	Pile type	Fmax compression (k)	Cap. compression (k)	Fmax tension (k)	Cap. tension (k)	Max. stress check	Pile length (ft)	Pile OD (in)	Bearing
Base model	Calculation succ...	Drilled	800	1129.1	180	186.8	1.449	37	60	Atip= 19.63 ft2

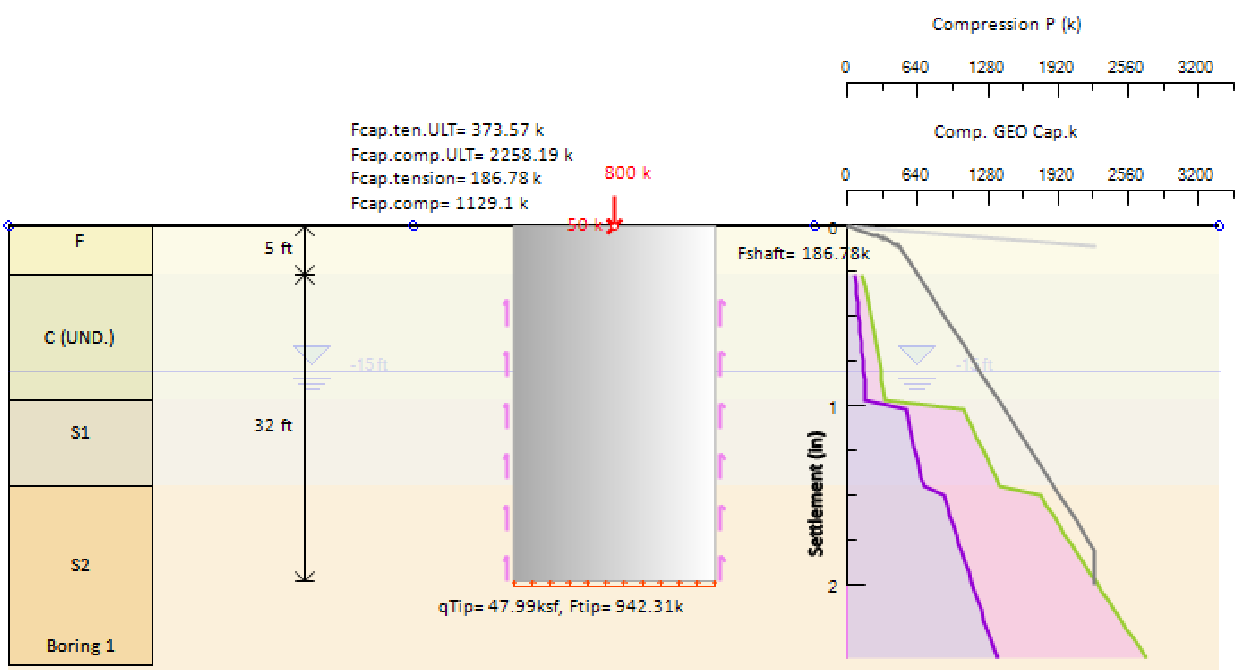


Figure 5.1.14: Pile geotechnical capacities and settlement.

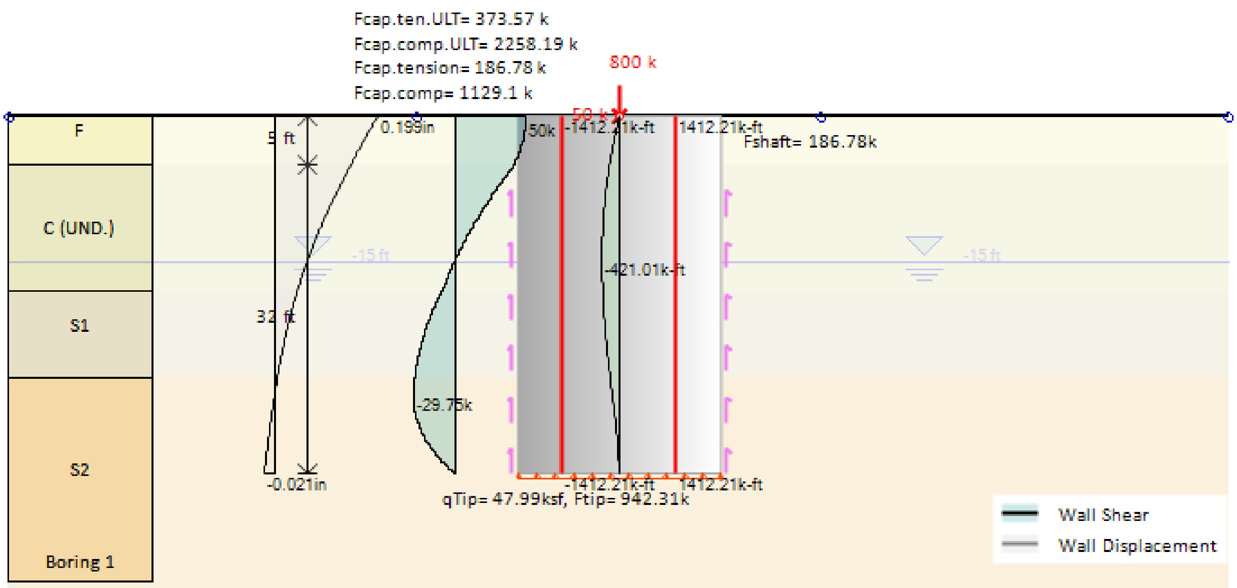


Figure 5.1.15: Pile displacement, shear and moment diagrams – Stage 0.

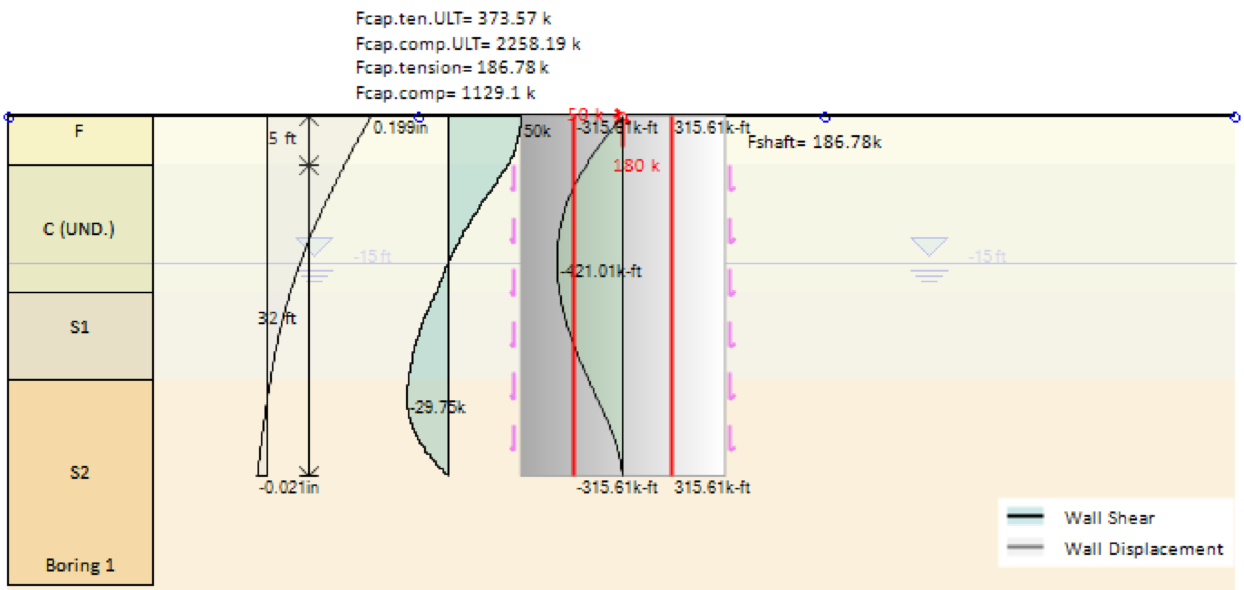


Figure 5.1.16: Pile displacement, shear and moment diagrams – Stage 1.

5.2 Example 2: Design of a Helical Pile

In this example we will design a helical foundation pile. The Figure below presents the project model. Tables 1 and 2 present the soil properties and the stratigraphy respectively. Table 3 presents the external loads applied on the pile head. Table 4 presents the pile section properties that we are going to use. The general ground surface is at El. 0ft and the general water table is at El. -15 ft.

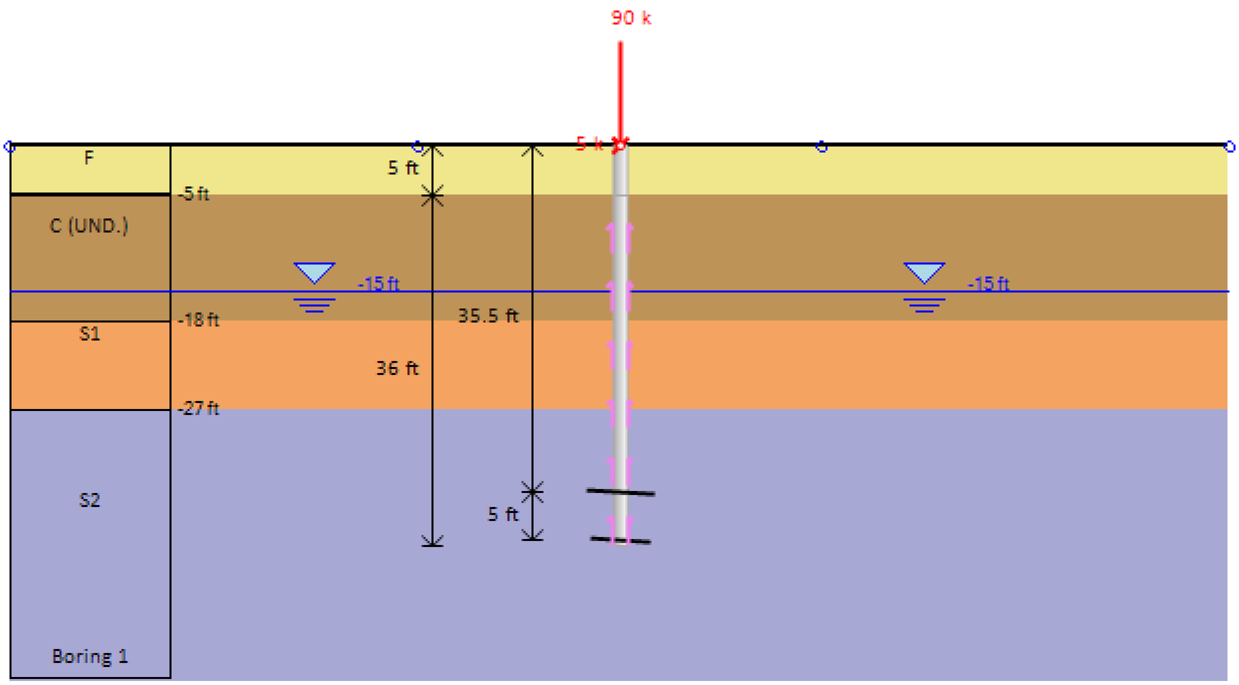


Figure 5.2.1: Helical Pile Example - Project model.

Table 5.2.1: Soil properties.

Soil Layer	Soil Type	General properties						Lateral properties		
		φ' (deg)	C'/Su (psf)	γ (pcf)	γ_{dry} (pcf)	E_{LOAD} (ksf)	E_{RELOAD} (ksf)	k (pci)	e50	Krm
F	Fill	25	0	120	120	300	900	60	-	-
C	Clay (Undrained)	-	1300	116	116	400	1200	-	0.005	-
S1	Sand	32	0	130	130	600	1800	60	-	-
S2	Sand	34	10	135	135	900	2700	90	-	-

Table 5.2.2: Stratigraphy.

Soil Layer	Elevation (ft)	OCR	Ko
F	-0	1	0.577
C	-5	1	0.515
S1	-18	1	0.47
S2	-27	1	0.441

Table 5.2.3: External loads.

Stage	Axial Load (kips)	Moment (k-ft)	Lateral Load (kips)
Stage 0 (Compression)	90	0	5
Stage 1 (Tension)	-70	0	5

Table 5.2.4: Pile parameters.

Pile Type	Helical Pile
Pipe Width	4 in
Pipe Thickness	0.5 in
Number of Helixes	2
First Helix Diameter	18 in
Tip Offset	0.5 ft
First Plate Thickness	0.375 in
First Plate Ult. Capacity	100 kips
Second Helix Diameter	20 in
Plate Spacing	5 ft
Second Plate Thickness	0.375 in
Second Plate Ult. Capacity	100 kips

B. Modeling with DeepFND/HelixPile

Our software programs DeepFND and HelixPile are identical. They share the same user-friendly interactive interface, and they include the same analysis options. The only difference is that DeepFND can do the lateral and vertical design of all pile types (helical and non-helical). On the other hand, HelixPile includes only helical pile sections. This example was created using the Helical Pile component of the DeepFND software, but the exact same options should be followed to create the model in HelixPile.

In DeepFND software, we should define initially the soil properties of all soils according to the geotechnical report, the model stratigraphy, the pile head loads and the pile initial depth and structural section.

Define soil properties:

From the General tab of DeepFND we can select the option "Edit Soil Type Data". In the dialog that appears, we can modify the existing soils database or add new soils, and then for each one of them, we have to define the general soil properties, the soil model and the lateral soil properties. The soil parameters can be defined manually, or with the use of the software SPT estimator or local parameter estimation tools.

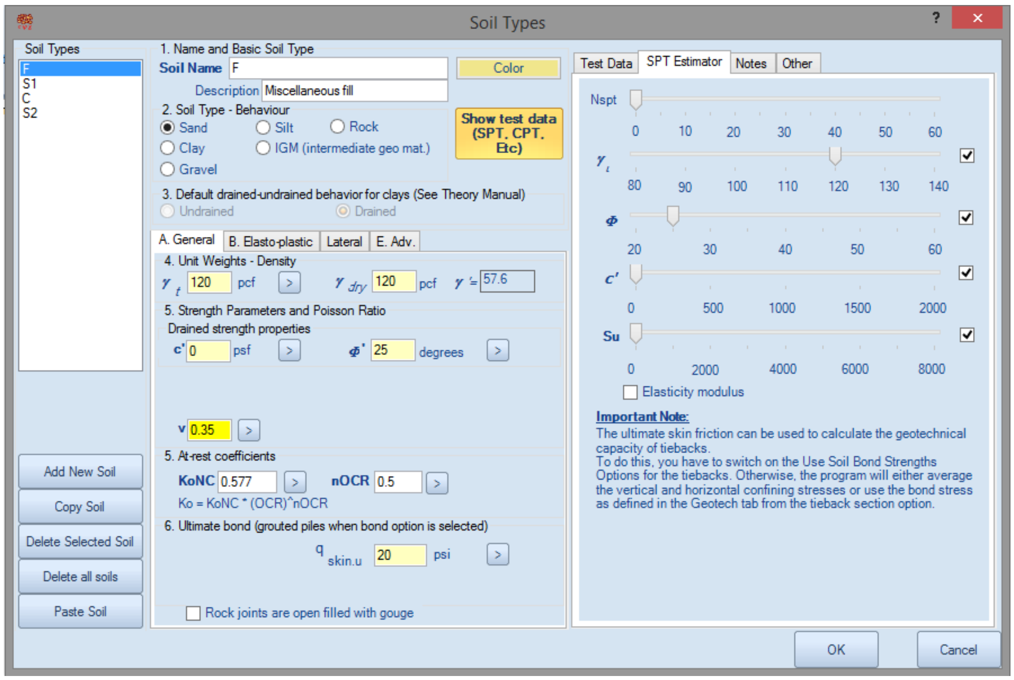


Figure 5.2.2: Edit Soil Type Data Dialog.

Define stratigraphy:

From the General tab of DeepFND we can select the option "Edit Boring". In the dialog that appears, we can define the top of the soil layer elevation and the soil type for each soil layer.

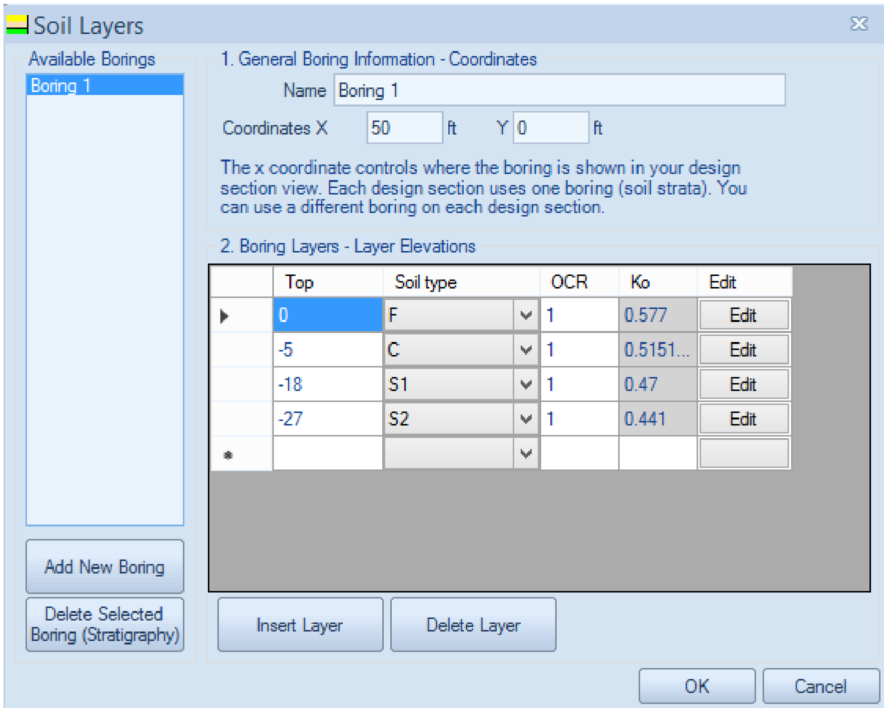


Figure 5.2.3: Edit Soil Layers Dialog.

__**Define external loads on pile head:**__

In any model in DeepFND we can add several stages. In our deep foundation software these can work as loading stages, so in each stage we can define a different load (load type, magnitude etc.). In this example, we will use Stage 0 to define our maximum compression load, and Stage 1 to define our maximum tension load on the pile head.

First of all, we right-click on the tab Stage 0 right below the model area and we select to Add Stage (so Stage 1 is added):

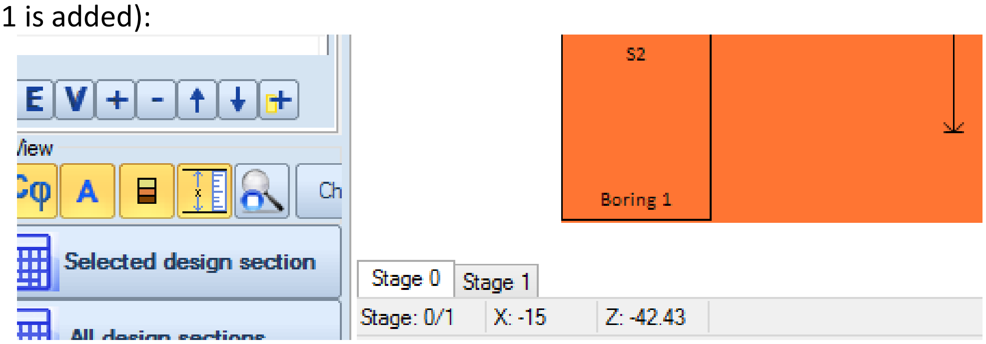


Figure 5.2.4: Stages in DeepFND.

After we create the stages, we double-click on the load in the model area. In the dialog that appears, we can add several loads in the list and define the load type and the magnitude of each load, in each stage. The summary of all loads will be applied on the pile head. If we apply a design standard (i.e. AASHTO LRFD), the loads will be factored depending on the load type (dead, live, wind, ice, vehicular etc.).

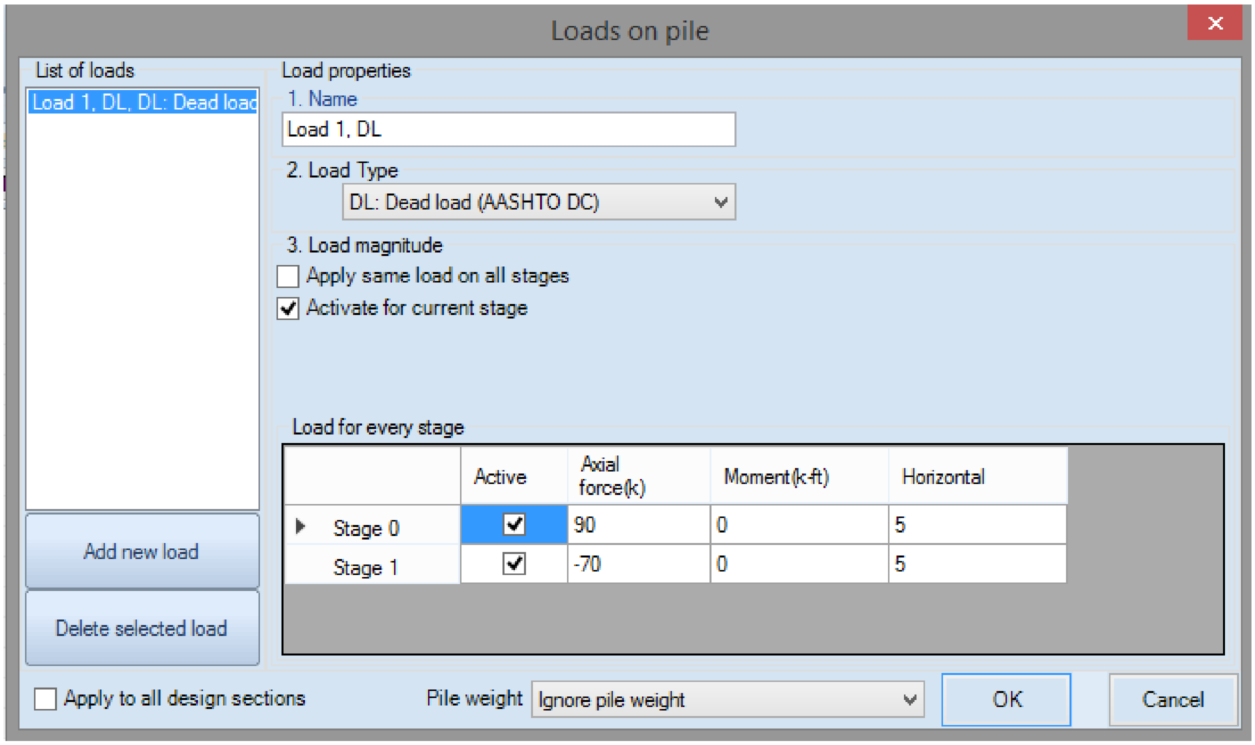


Figure 5.2.5: Define loads on pile head.

<u>Define pile section and initial length:</u>

In DeepFND we have to define the pile type, structural section (pipe dimensions and helix configurations) and original depth. Later, based on the analyses results, we can choose to optimize the pile section and the pile embedment. The required pile length can also be calculated by the software. We have to double-click on the pile and define the pile parameters in the dialog that appears. By pressing "Edit" on this dialog, we can define the pile type and the pile structural section.

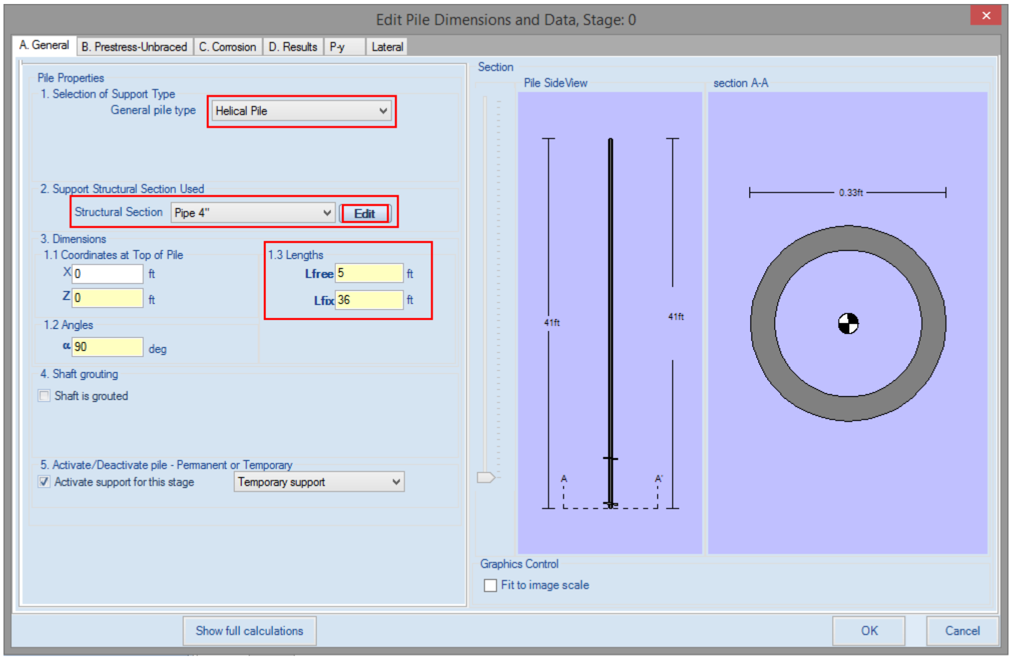


Figure 5.2.6: Define pile dimensions and data dialog.

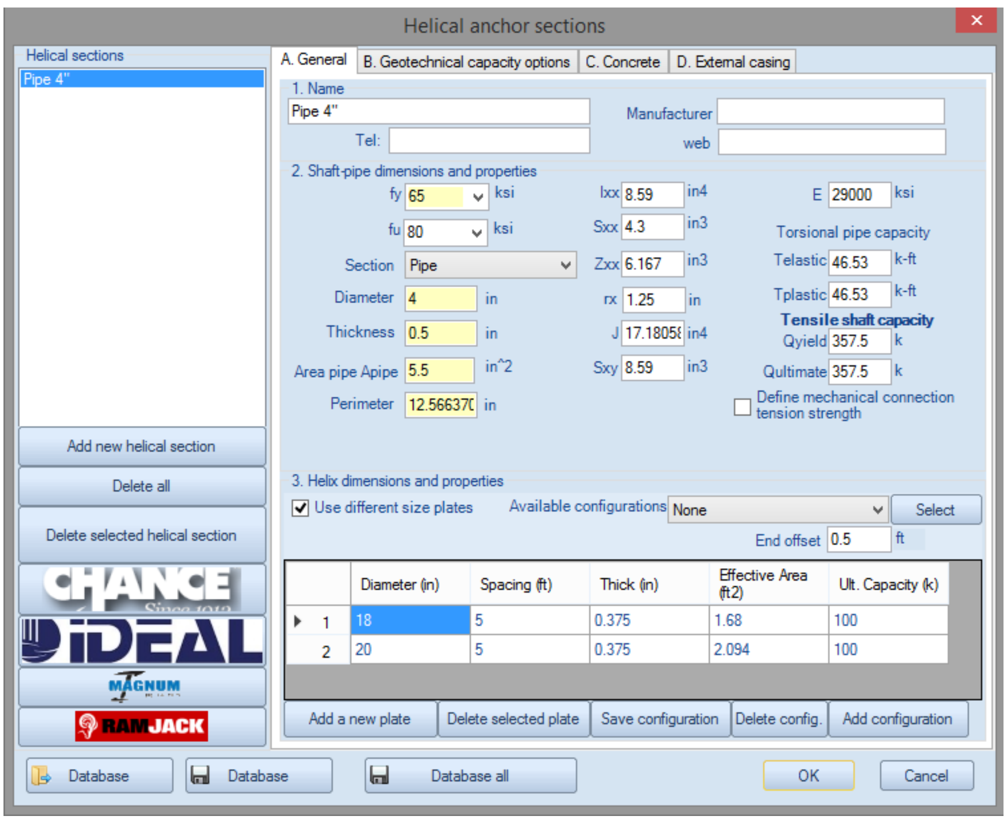


Figure 5.2.7: Define pipe size and helix configurations.

C. Define Analysis Options

After we create the model in DeepFND, we have to define several analysis parameters.

<u>Pile length automatic optimization:</u>

In the general tab of DeepFND we can select to optimize the pile length. In this case, we need to define the maximum pile depth and the step. The software will use the step to calculate the pile tensional and compressional capacity in several depths and compare them with the applied tension and compression loads respectively. It will stop the analysis when both capacities exceed the applied loads and return as a result the pile depth, the calculated capacities and the pile structural results (moment, shear, displacement etc.). If the software reaches the maximum depth and fails to find a suitable solution, it will stop the analysis and return as a result the calculated capacities etc. of the maximum depth.

If we leave this option unselected, the software will use the pile depth we manually specified for the analysis and return all analysis results.

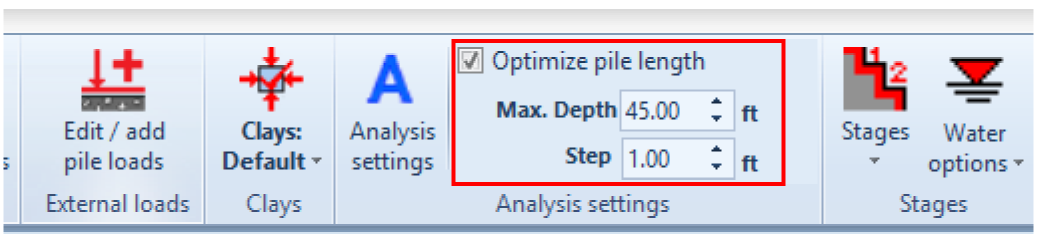


Figure 5.2.8: Option to optimize pile length in the General tab.

<u>Analysis equations and settings:</u>

In the Analysis tab of DeepFND, all analysis parameters are automatically defined according to the pile type (helical or non-helical) and the pile installation method (drilled, driven, caisson, micporile etc.).

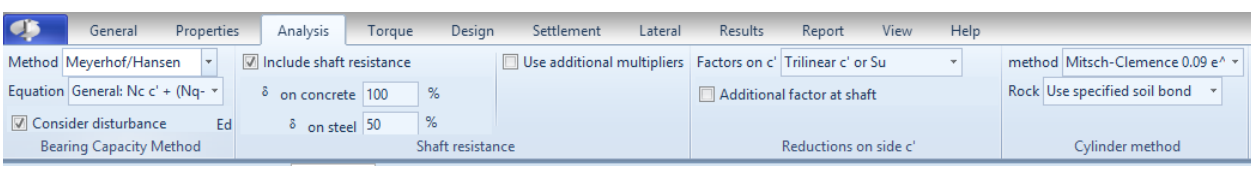


Figure 5.2.9: Analysis settings, automatically selected.

Design standards and Safety factors:

In the Design tab we can define the structural codes and the safety factors applied on the bearing, shaft and structural capacities. Alternatively, we can select a load combination of a specific geotechnical design standard (we will not use one in the current example).

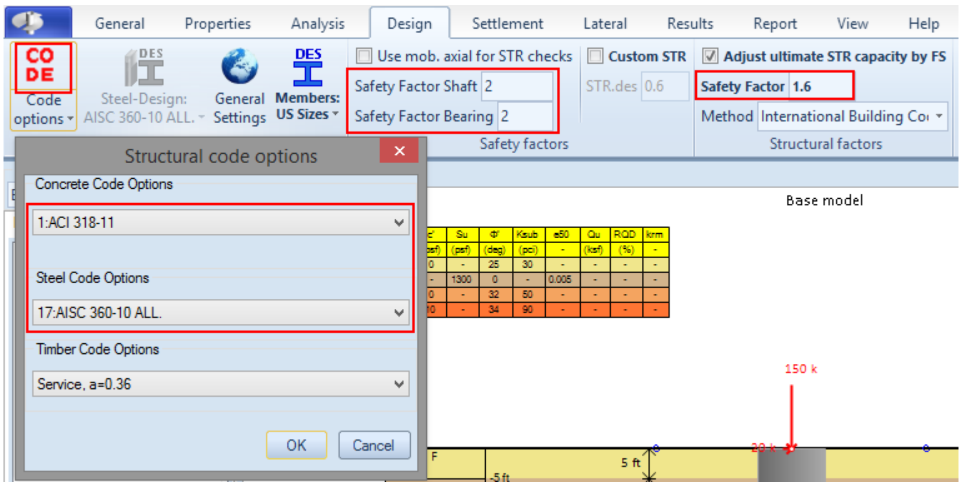


Figure 5.2.10: Define structural codes and structural/geotechnical safety factors.

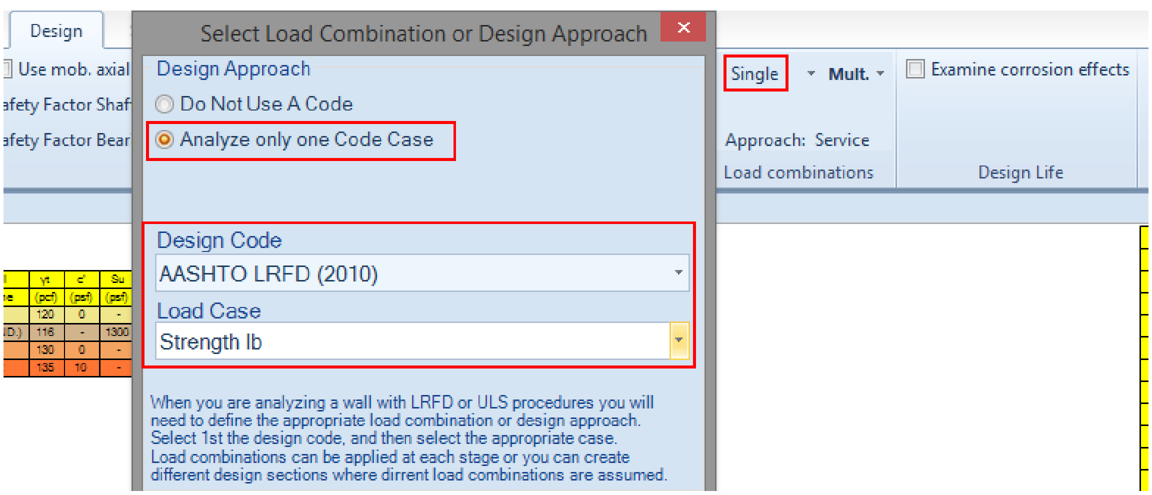


Figure 5.2.11: Option to assign a design standard load combination.

Settlement analysis options:

In the Settlement tab we can select the option to perform settlement analysis. Also, there, we can define pile settlement acceptance criteria.

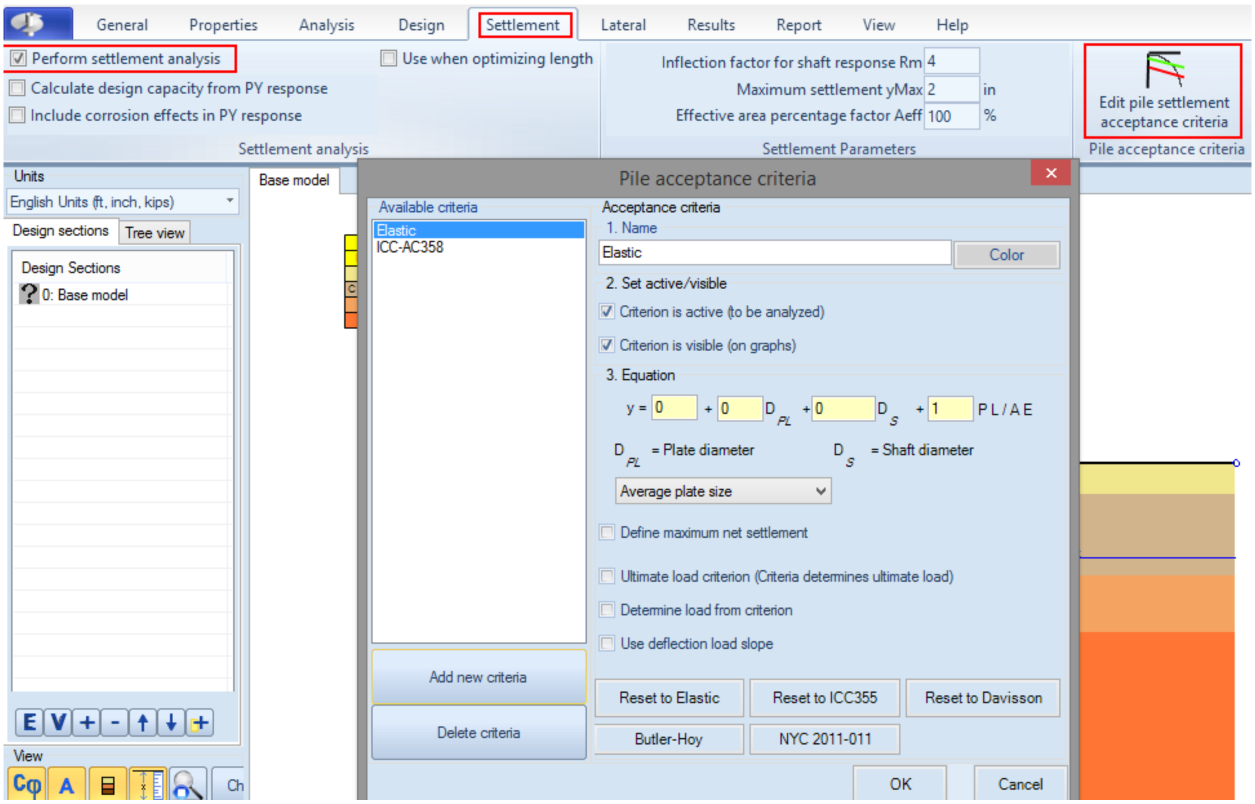


Figure 5.2.12: Option to perform settlement analysis and pile acceptance criteria.

Lateral pile analysis options:

In the Lateral tab we can select the lateral pile analysis method. The available options are either to calculate pile moment, shear and displacement for the defined lateral loads, or perform a pushover analysis and report the required load to achieve a specific displacement.

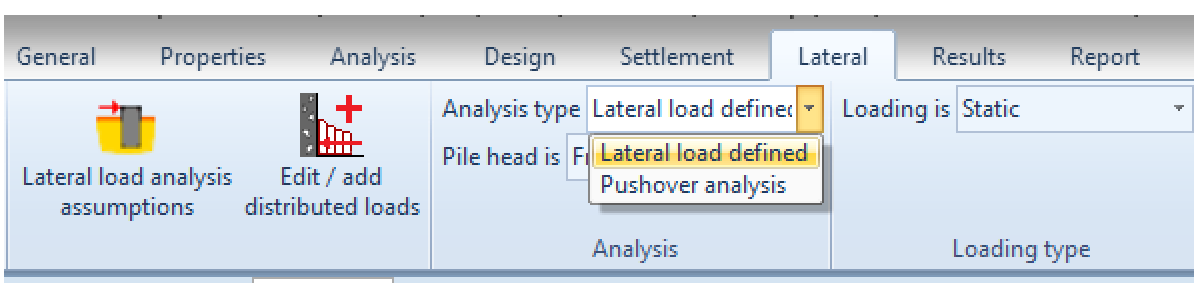


Figure 5.2.13: Lateral load options.

Torque options:

In the Torque tab of DeepFND, we can either select one of the existing Torque factor profiles, or we can define new profiles:

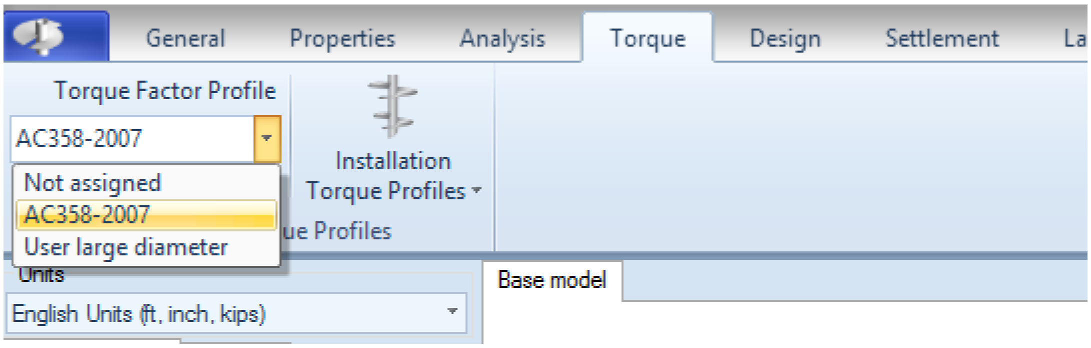


Figure 5.2.14: Torque profiles.

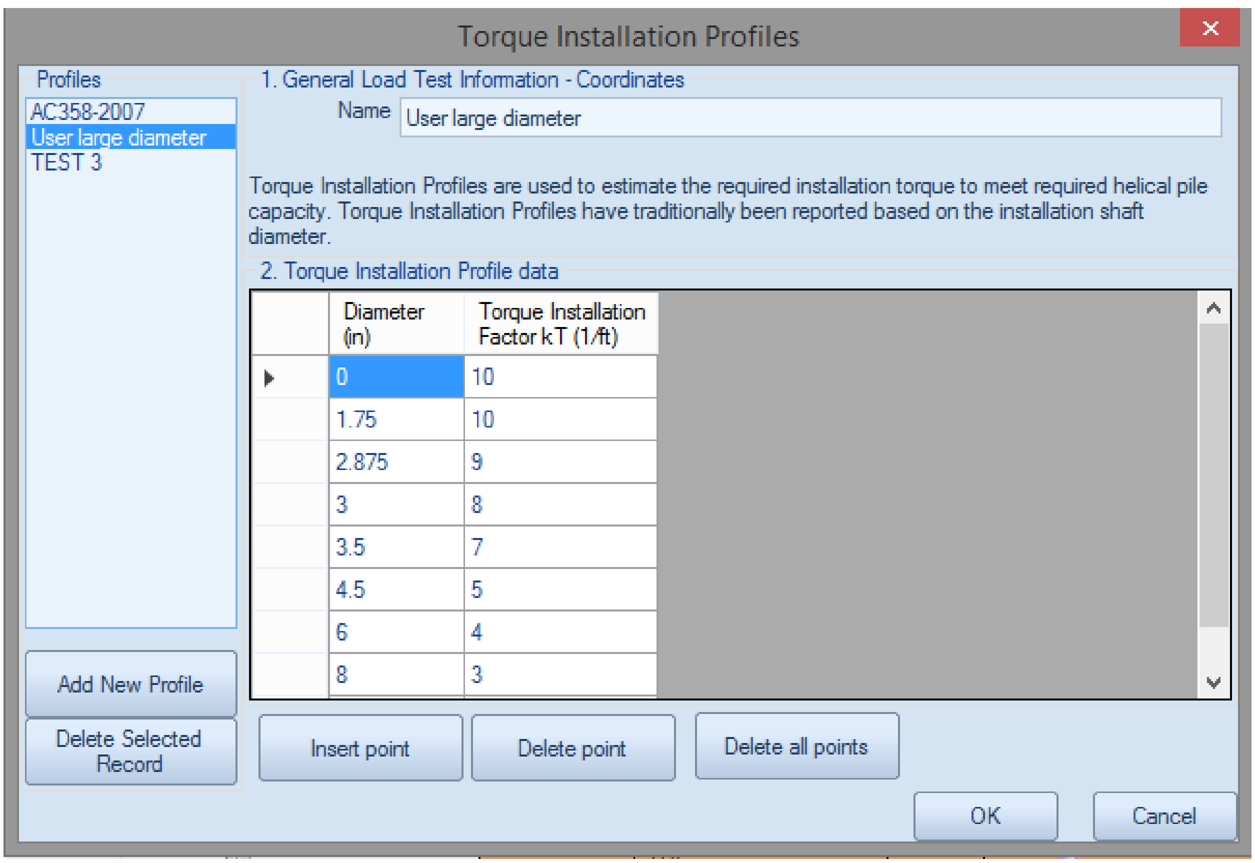


Figure 5.2.15: Edit torque profile factors.

D. Analysis and Results

Since the model is ready, we can choose to calculate the design section. After the analysis is succeeded, the Summary table appears. The table below includes the calculated compression and tension capacities, the optimized pile depth, the lateral pile results and more. With red we can see some values that are critical. In this case, we can see that at least one stress check is above the limit "1". We can locate the issue by closing the summary table and reviewing the results graphically on the model area for every stage. In this case, the pile structural capacity and moment capacity are not enough to cover the combination of the tension and lateral load applied on the pile head. In this case we need to somehow increase the pile capacity (increase pipe section or use an external casing on the top of the pile).

Table 5.2.5: Analysis and Checking Summary table.

Extended Summary

	Calculation	Pile type	Fmax compression (k)	Cap. compression (k)	Fmax tension (k)	Cap. tension (k)	Max. stress check	Pile length (ft)	Pile OD (in)	Bearing
Base model	Calculation succ...	Helical	90	91.4	70	84.6	1.182	31.5	4	18S20S

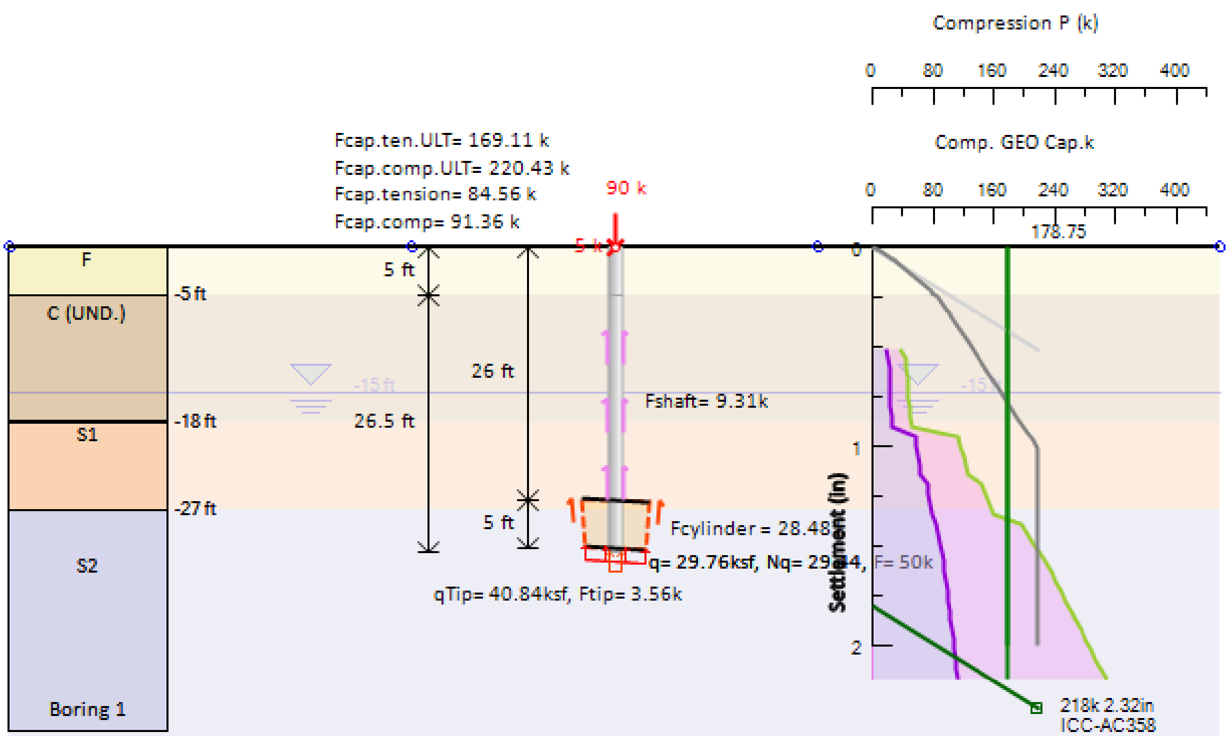


Figure 5.2.16: Pile bearing capacity (cylinder method) and settlement.

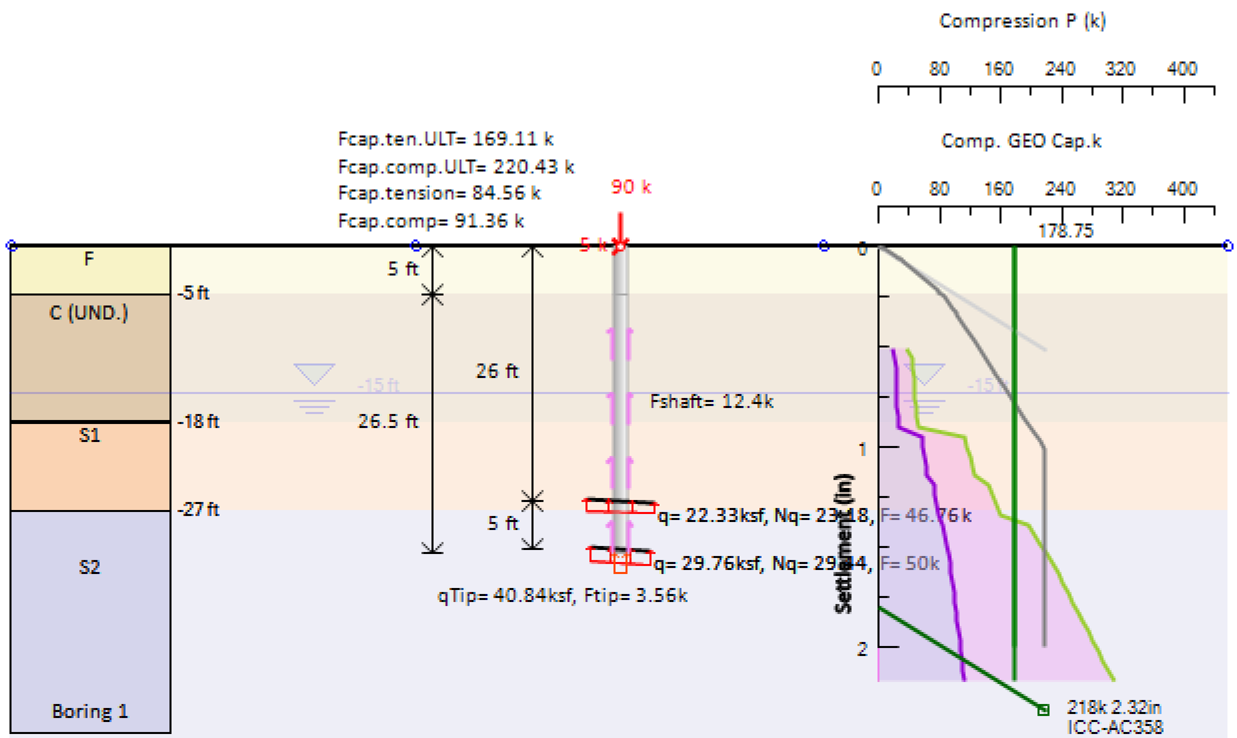


Figure 5.2.17: Pile bearing capacity (individual plate method) and settlement.

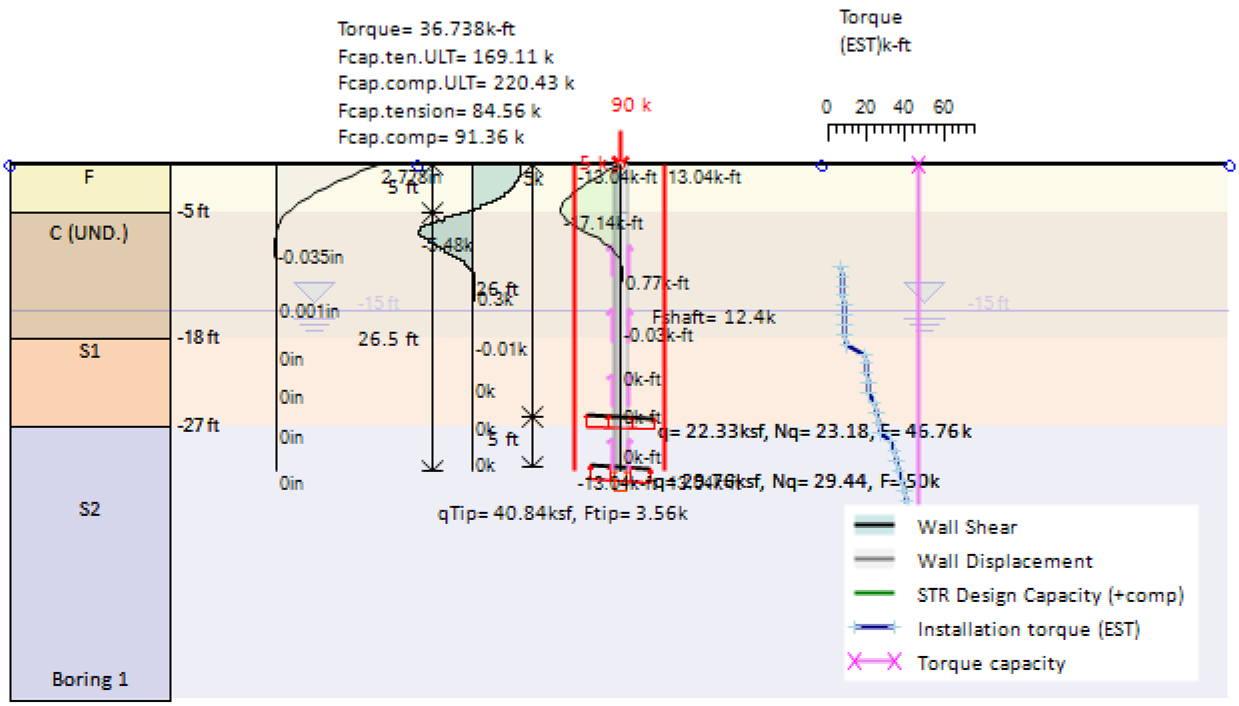


Figure 5.2.18: Pile displacement, shear and moment diagrams, and estimated torque.

PART C: PILE GROUPS AND PILE RAFTS

MODEL CREATION – ANALYSIS SETTINGS – RESULTS

The following section provides useful information about the use of the software for the design of pile groups and pile rafts. We examine the procedures to create a model, define the analysis settings and perform the model optimization using the calculated results. We present how to effectively use the tools of the software in order to create any pile cap shape.

SECTION 6: PILE GROUPS – MODELS AND ANALYSIS

6.1 Creating a Pile Cap Model Automatically

DeepFND (and HelixPile) can design pile caps supported by pile groups. The pile caps can be of any shape and the piles can be of any structural section.

When we wish to perform a pile cap design, it is recommended to analyze first the single piles. This way we can examine the pile settlements and the torque capacity of the piles, since these parameters are not examined in the pile cap mode. By analyzing a single pile first, we can also do an initial pile depth optimization, since the automatic optimization does not work in Pile Cap mode.

The following steps should be followed for the creation of a pile cap model:

A. Define the soil properties and Stratigraphy

These procedures are summarized in **sections 3.3 and 3.4**.

B. Define the single pile type and structural section

We should access the single pile on the model area and define the pile type (see section 3.5) and the pile section (see **sections 3.6 and 3.7** for helical and non-helical piles respectively).

All the piles generated in the pile cap will use the same pile type and section, as defined in the single pile. After the pila cap generation, we can access and modify each pile section, position and inclination independently.

C. Analyze and optimize the single pile (optional)

The analysis and optimization of the single pile is recommended in order to achieve an efficient solution. We could define the loads on the pile head, define the analysis settings and perform the analysis as described in **section 4.1**.

D. Create the pile cap with the use of the Pile Cap Wizard

In the Pile Caps tab of DeepFND we can select to open the Pile Cap wizard. In the wizard, we can define the basic pile cap shape, geometry, piles layout and loading.

Define pile shape and dimensions:

The pile cap generated by the wizard can be rectangular, circular or triangular. Further options are available in the Edit Pile Cap dialog (appears when the cap is generated). We can also define the pile cap dimensions, center coordinates, thickness and elevation.

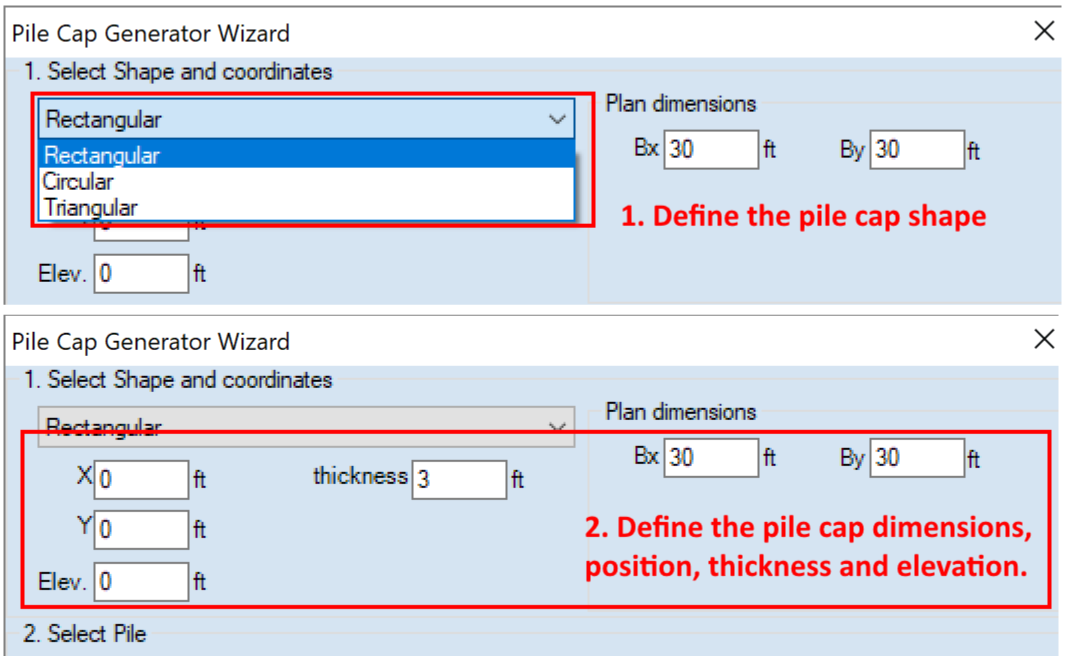


Figure 6.1.1: Pile Cap Wizard: Define cap shape and dimensions.

Define piles layout:

In the Wizard dialog we can define the piles layout. We can set the number of piles on each direction and the pile spacing.

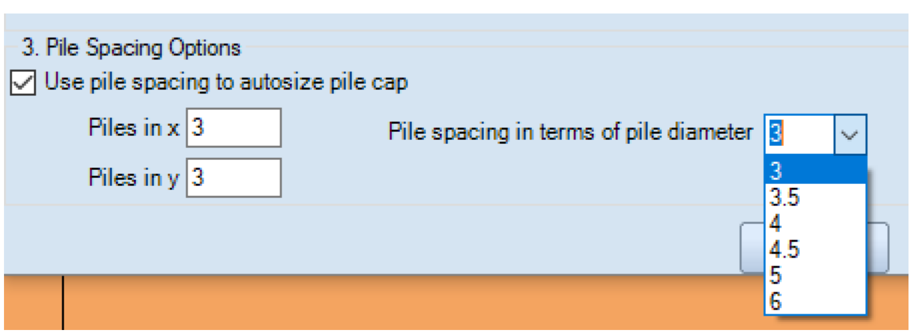


Figure 6.1.2: Pile Cap Wizard: Define piles layout.

E. Edit the pila cap parameters (shape – loading – analysis options)

When we close the Wizard, the Edit Pile Cap dialog appears automatically. The same dialog can be accessed any time by double-clicking on the pile cap in the model area.

In this dialog we can readjust the pile shape and dimensions, choosing from a big variety of pile shapes (rectangular, circular, triangular, hexagonal, octagonal, random shape). We can also define the analysis settings and we can access and modify the position and structural section of every generated pile. All these options are presented in **section 3.8**.

Finally, in the Edit Pile Caps dialog we can define additional area and linear loads on the pile cap, as well as, we can define if there will be a single point load on the cap centroid or if we will use several point loads on user-defined locations. All the load options are presented in **section 3.10**.

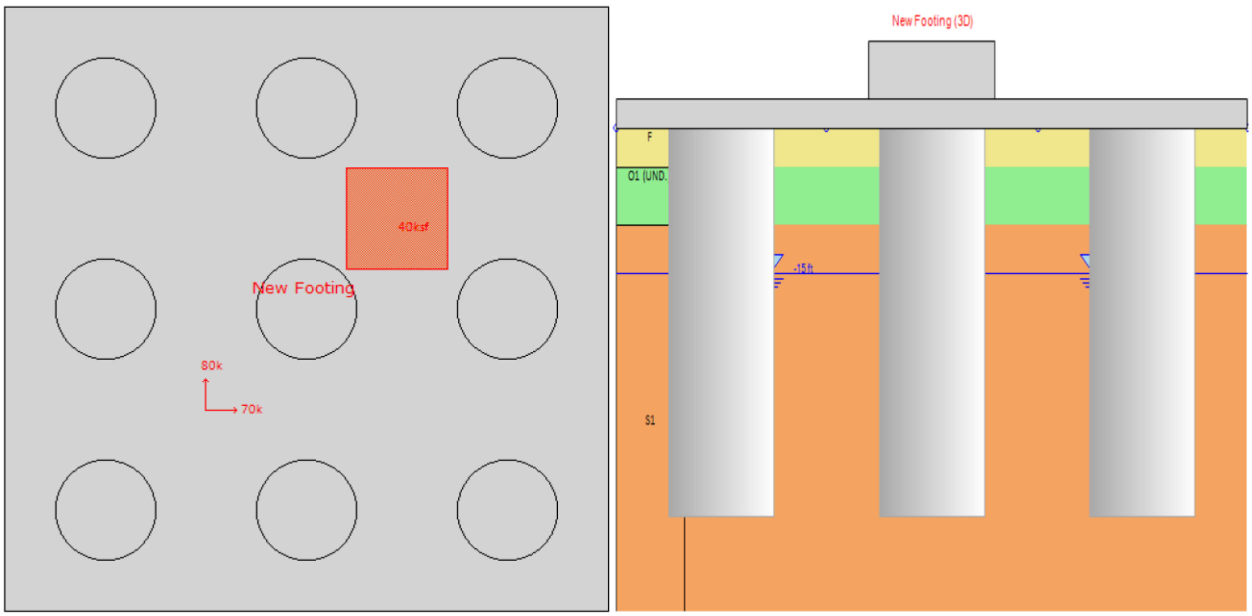


Figure 6.1.3: Generated pile cap – Top and side view.

6.2 Editing the Created Model

In DeepFND we can edit all items in the model area. After the model is generated, we see the side view of the model.

Define presented Y axis on the model area

The DeepFND 2D model area presents actually a cut section of the model along the X- Axis. With the middle pile placed by default at X=0, unless otherwise defined in the Edit Pile Caps dialog. From the Pile Caps tab of the software, we can select the Y coordinate that is presented, so we can access and review the 2D section of all piles.

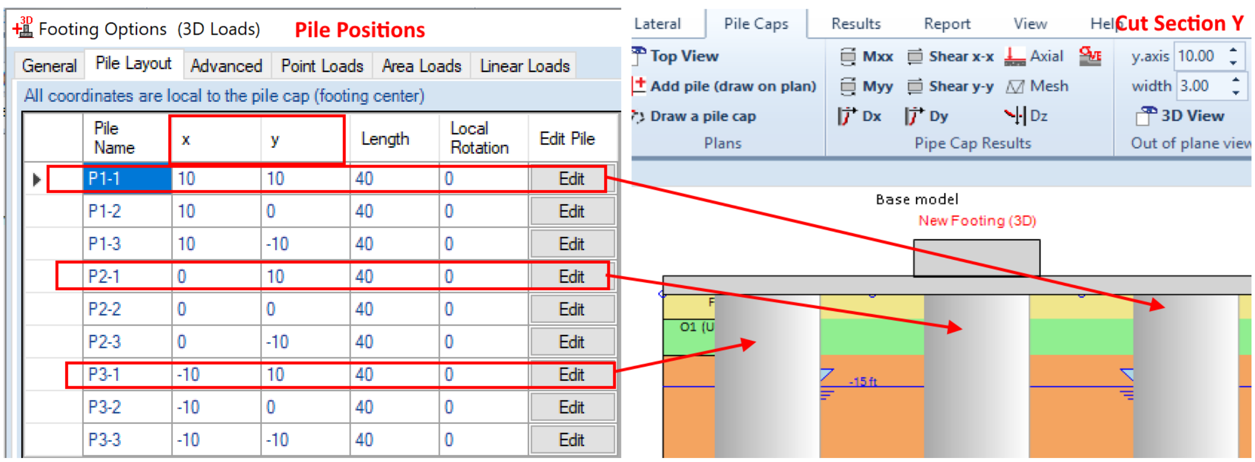


Figure 6.2.1: Pile positions and cut section Y-axis.

Review the model top view

In the Pile Caps tab of DeepFND, we can select to open the Top View of the pile group, that presents the pile cap, the loading positions from, above and the created piles.

From the Top View tab in the model area, we can access and modify each pile independently. We can also right click on the pile cap and select to Activate/Deactivate the cap in the selected construction stages, and we can also select to Edit the pile cap.

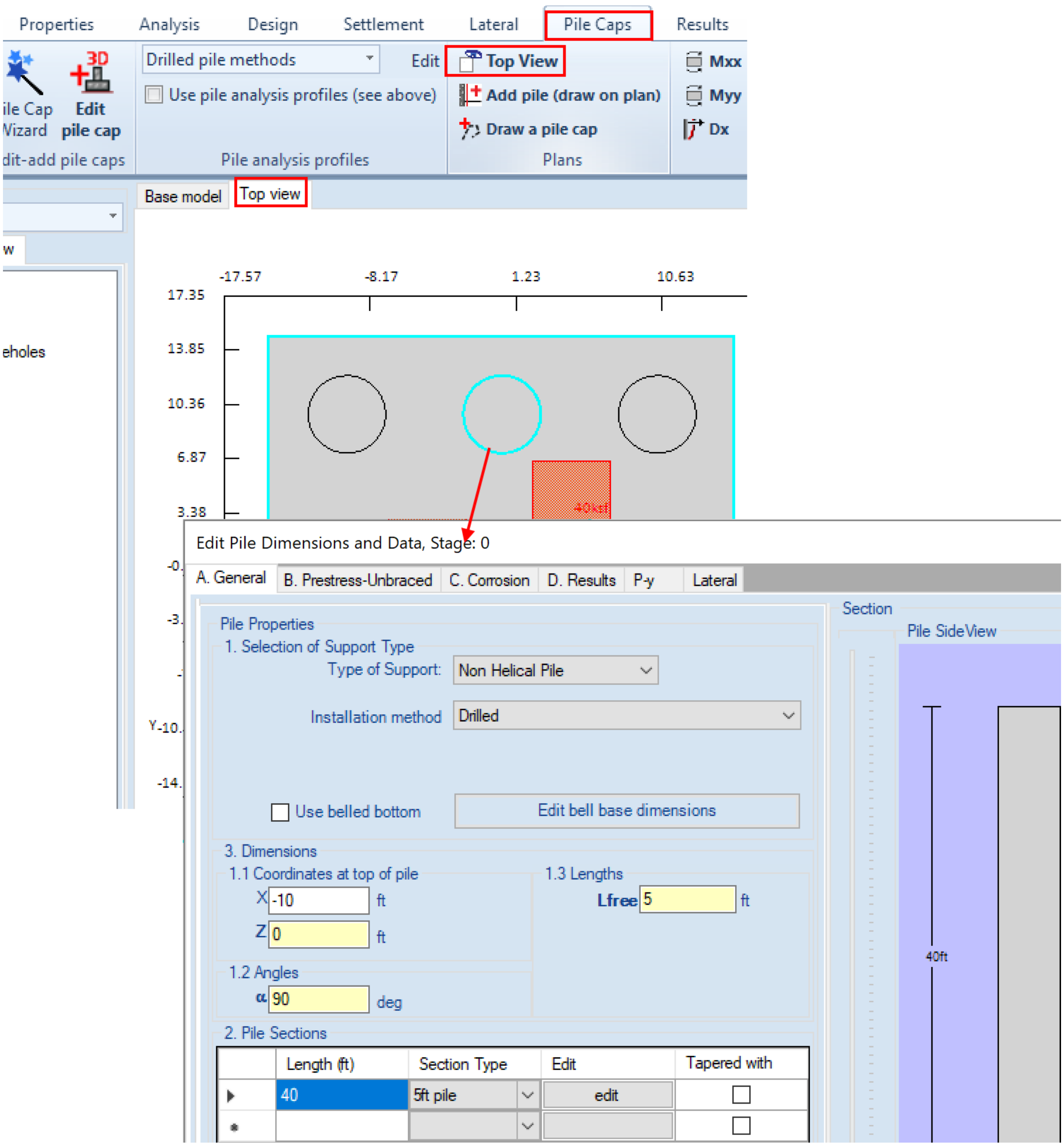


Figure 6.2.2: Open top view and access piles.

Review the 3D view

In the Pile Caps tab of DeepFND, we can select to open the 3D View of the pile cap. The 3D model opens in a separate tab in the model area and it can be accessed and manipulated with the mouse. We can move and rotate the model with the mouse buttons. We can zoom in and out the model with the mouse roller button.

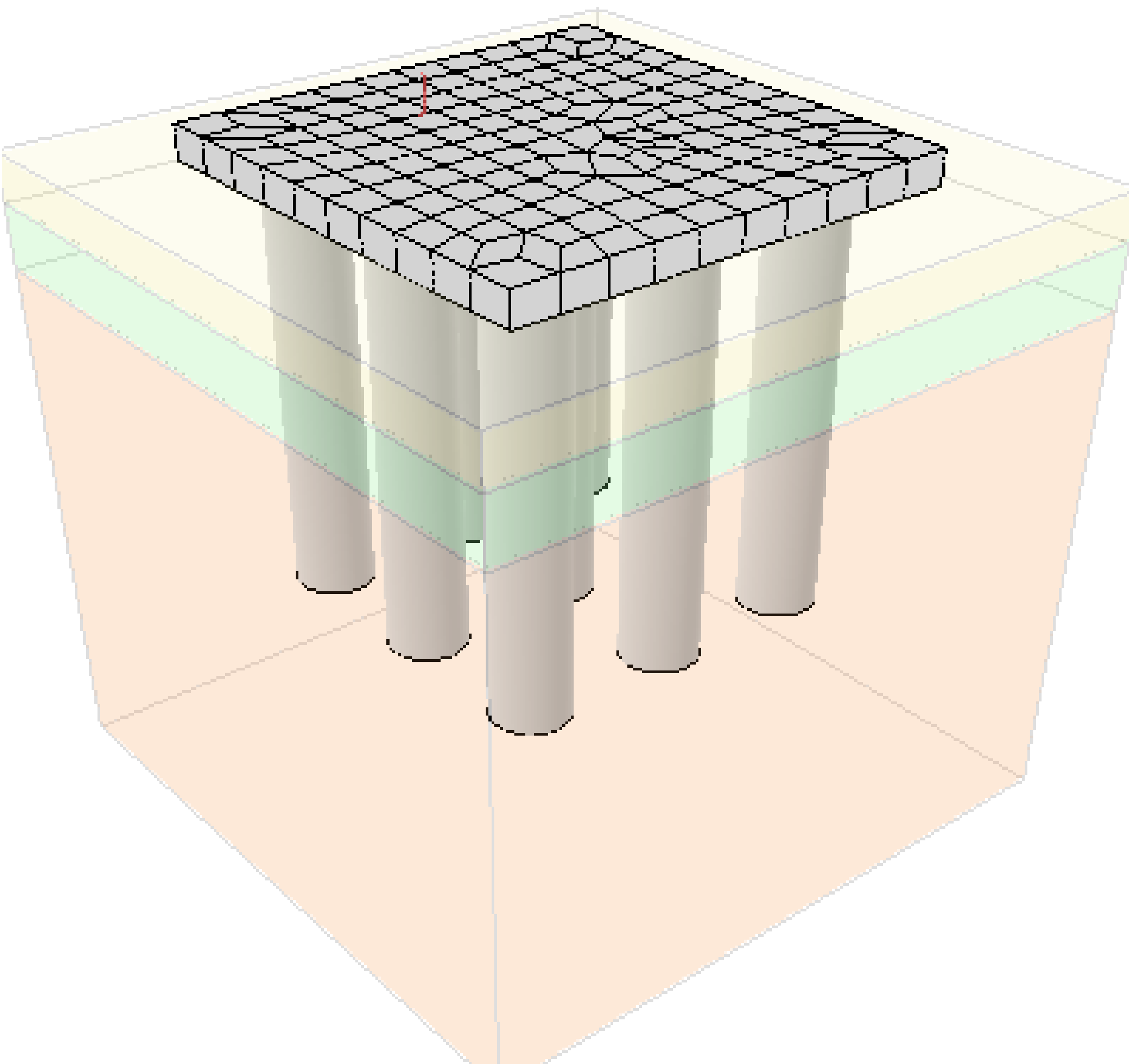


Figure 6.2.3: Pile cap 3D view.

6.3 Creating a Custom Shape Pile Cap Manually

In the Pile Caps tab of the software, we can select the option Pile Cap Analysis. This will change the software mode and virtually delete the single pile. We can access the Top View tab, where we see the project area, along with the project global X and Y axis.

While on Top view, we can select the tool "Draw a pile cap" from the Pile Caps tab of the software. Ce can click on several points on the model area, defining the pile cap shape. After we click on the first point we actually added (so a closed shape is created), a table will appear, presenting all created points coordinates. We can edit these coordinates defining the pile cap points exact positions.

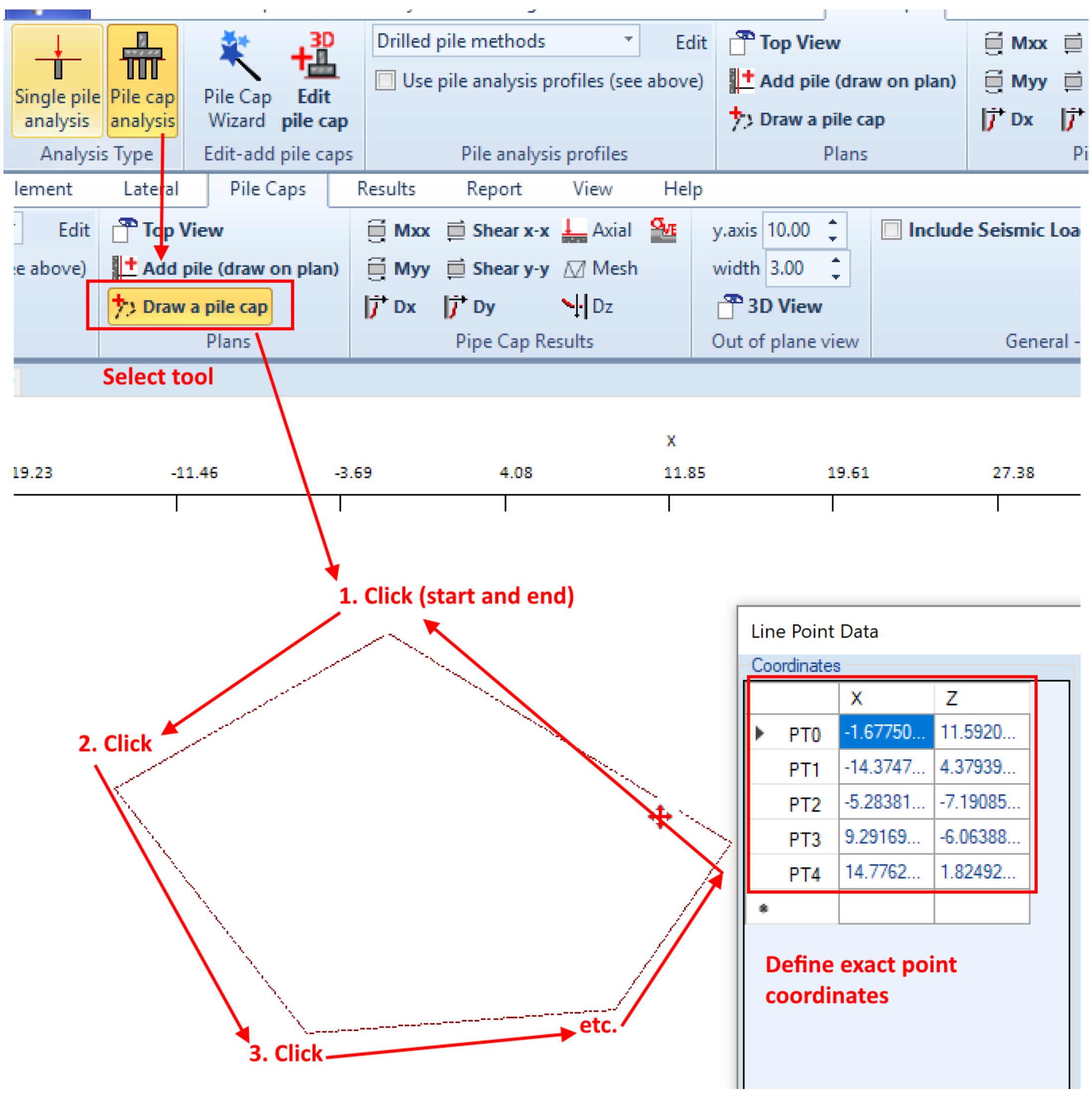


Figure 6.3.1: Procedure to add a custom shape pile cap.

6.4 Adding New Piles Graphically

Both in custom pile caps, and in normal shape caps generated with the wizard, we can select to add new piles on the model area graphically, using the "Add pile" tool from the general tab of the software.

We need to select the tool and right-click on the pile cap in the Top View tab of the model area, close to the points we need to add the piles. After adding the last pile, we should press the "Escape" button from the keyboard, so the Add Pile tool is deactivated.

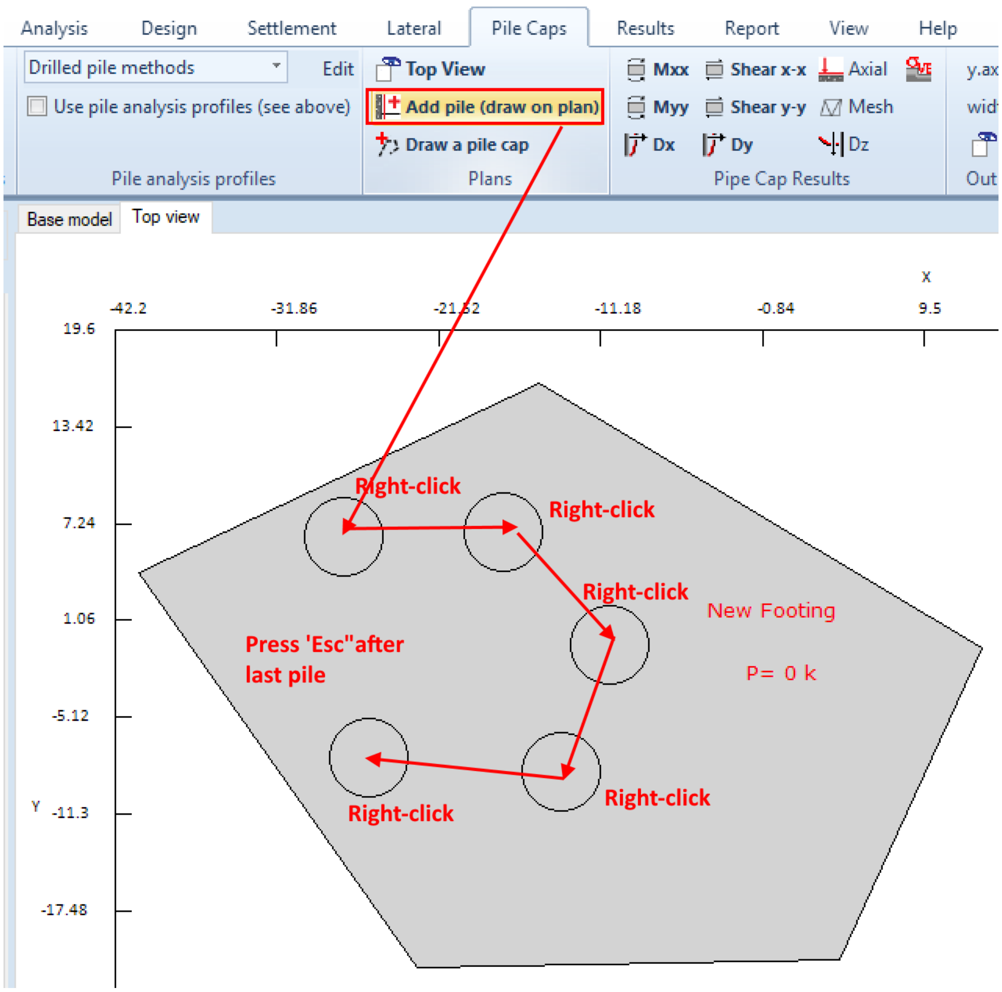


Figure 6.4.1: Procedure to add piles graphically.

In the Edit Pile Caps dialog we can set the exact pile positions (X – Y coordinates) and structural sections (see **section 3.8**).

6.5 Review Pile Cap and Pile Group Results

Review Summary Table Results

After the analysis is completed, we can review the results in the Analysis and Checking summary table that appears. This table presents the calculated compression and tension loads and capacities, and the lateral pile analysis results (lateral pile head displacement and moment) for the most critical pile.

Calculated tension and compression loads and capacities

Calculation	Pile type	Fmax compression (k)	Cap. compression (k)	Fmax tension (k)	Cap. tension (k)
Calculation succ...	Pile cap, pile:P1-...	195	164.6	0	180.7

Figure 6.5.1: Analysis table results: Axial pile analysis.

Calculated Lateral Load, Displacement and Moment

y at Pult (in)	All. cap at y (k)	y at Pall (in)	Lat. Dx (in)	Lat. Fx (k)	Lat. M (k-ft)
N/A	N/A	N/A	1.026	4.51	11.18

Figure 6.5.2: Analysis table results: Lateral pile analysis.

Review Results on the Model Area – Pile Cap

Once a project is analyzed, pile cap results can be viewed on screen in the Top View tab of the model area.

We can select to review the pile cap moments, shear stresses and displacements on each axis (X and Y-direction). We can also review the calculated pile cap settlements, stresses, axial forces and mesh displacements.

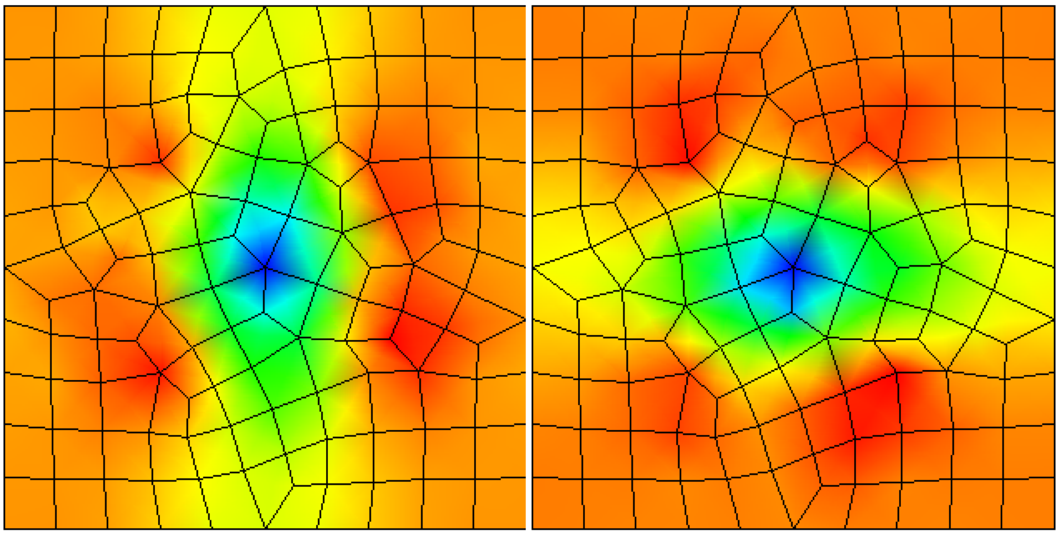


Figure 6.5.3: Pile Cap Results – X and Y-direction moments.

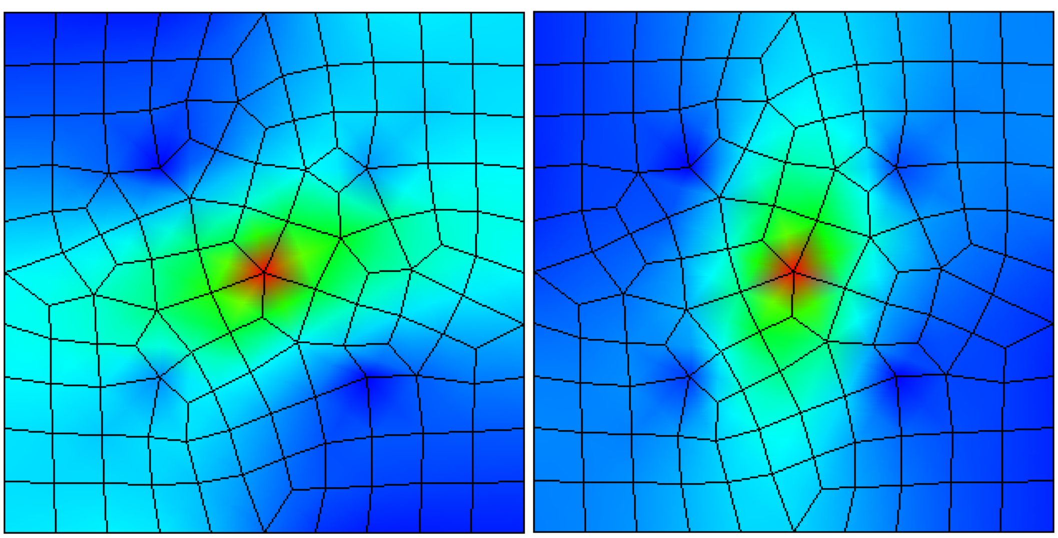


Figure 6.5.4: Pile Cap Results – X and Y-direction displacements.

Review Results on the Model Area - Piles

After the analysis is performed, we can review several results on the 2D model area for each axis (X and Y-direction).

We can select to review the calculated bearing capacities, as well as, the calculated moment, shear, axial and displacement diagrams for each pile. The Y-Axis position in the Pile Caps tab allows us to access and review all piles (see **section 6.2**). The 2D pile results can be accessed from the Results tab of the software.

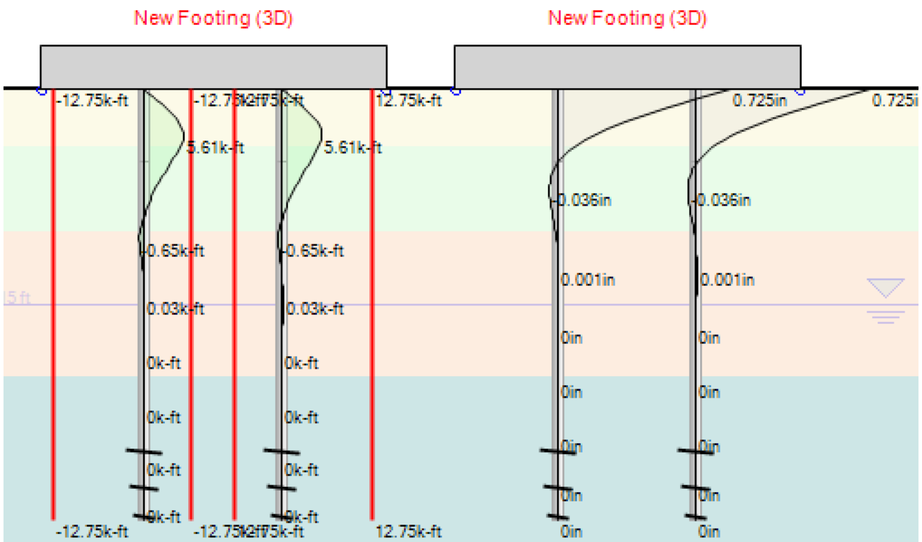


Figure 6.5.5: Pile Results – Moment and displacement diagrams – X-Axis.

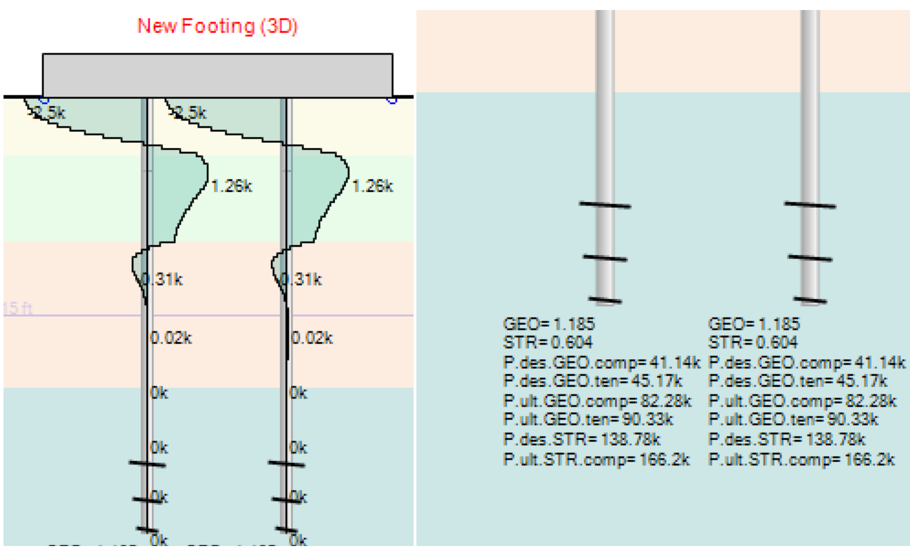


Figure 6.5.6: Pile Results – Shear diagrams and calculated bearing capacities.

Review Results on the Model Area – 3D Model

The 3D View can be accessed from the Pile Cap tab of the software (see **section 6.2**). After the analysis is performed, the pile cap and pile results can be displayed on the 3D model as well.

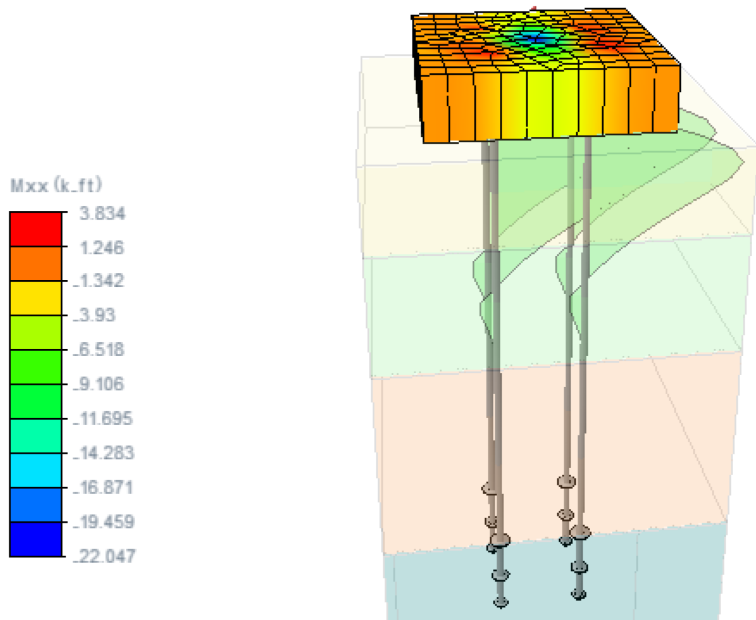


Figure 6.5.7: 3D Results – Pile moment diagrams and Pile cap moments (X-axis).

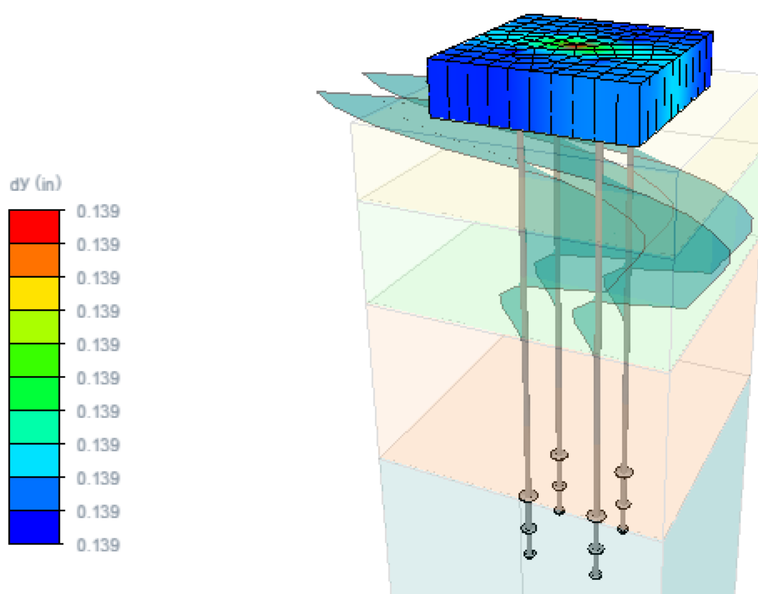


Figure 6.5.8: 3D Results – Pile displacement diagrams and Pile cap displacements (Y-axis).

PART D: THEORETICAL BACKGROUND

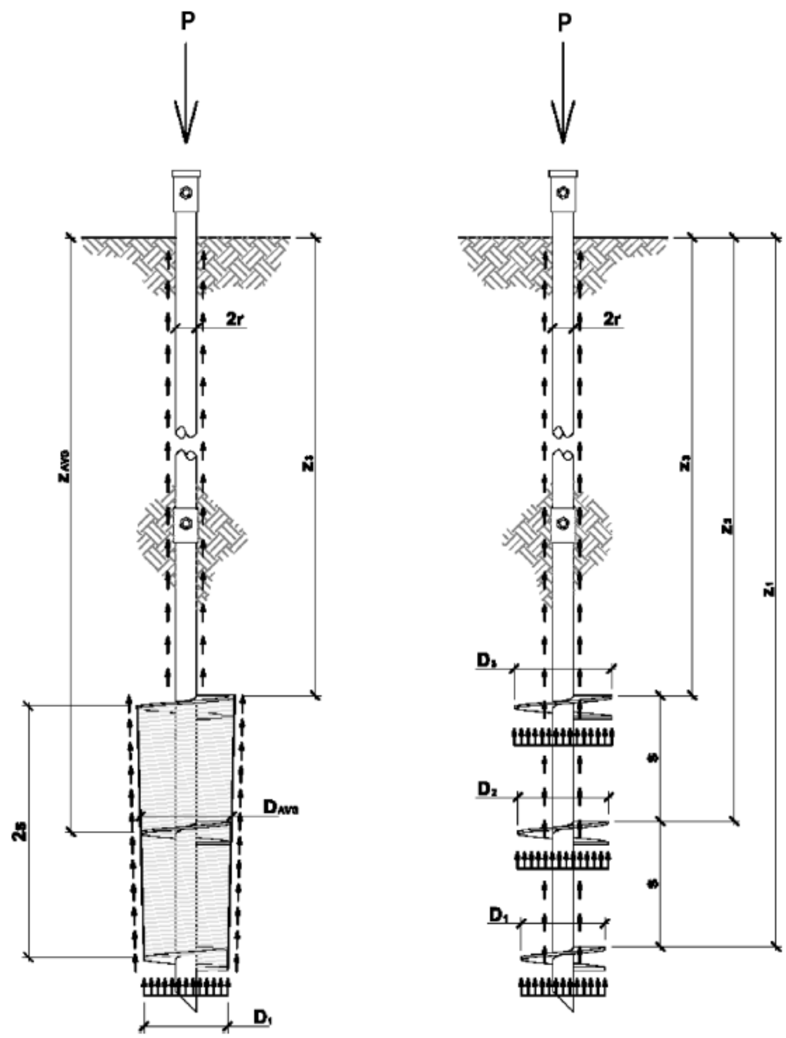
METHODS AND EQUATIONS

The following sections provide useful information about the methods and equations utilized in DeepFND and HelixPile software programs for the design of Helical and Non-Helical Piles.

SECTION 7: THEORETICAL BACKGROUND FOR HELICAL PILES

7.1 Theoretical background

Helical piles derive their capacity from bearing and side resistance. In general, two geotechnical modes are recognized for helical pile failure: a) Individual plate failure mode, and b) cylinder failure mode, as illustrated in the following figure. If the helix spacing is large enough, then each helix will act independently, and the individual bearing capacity failure will control at each plate (provided that the plates has enough structural capacity). On the other hand, if the helical plates are spaced close enough then the capacity will be controlled by the bottom plate bearing failure and side resistance along the cylinder bound by the helical plates (for compression).



Cylinder method **Individual plate,**

Figure7.1.1: Helical pile theoretical failure modes.

The general bearing capacity equation used within the software is:
qult=c Nc+Nq-1 σ'+ 0.5 γ D Nγ
Where:

- c = Effective cohesion or undrained shear strength
- D = Helical plate diameter
- γ = Soil unit weight
- σ'= Effective vertical stress

The bearing capacity factor N_q according to Vesic 1974 is calculated as
N_q=0.5 (12 ϕ) $^{\phi/54}$
The bearing capacity factor N_γ according to Vesic 1974 is calculated as
N_γ=(N_q-1) tan (1.4 ϕ)
Where φ is the effective friction angle in degrees.
For Meyerhoff/Hansen the bearing capacity equation is defined as:
N_q= $e^{\pi\ \tan(\varphi)}$ tan(π4+φ2)2
For fine-grained soils where φ= 0 degrees, Hansen and Vesic equations yield N_c equal to 10. However, Skempton (1951) showed both theoretically and experimentally that N_c approaches a constant value of 9 for deep foundations. Most practitioners used Skempton's result for the φ= 0 degrees condition. Under this condition, the second and third terms in bearing capacity equation go to zero because N_q= 1 and N_γ= 0. For this reason, the program assumes a conservative value of N_c = 9 even when the friction angle is greater than 0.

However, use of general bearing capacity equation would result in the calculated ultimate bearing pressure increasing without bound as q increases steadily with depth. In many cases this leads to an overprediction of bearing capacity. It has been proposed that the bearing pressure at the base of a deep foundation reaches a maximum limit at some critical depth (Meyerhof, 1951, 1976). The critical depth has been established for straight shaft piles based on a number of load tests. However, previously published critical depths for other types of deep foundations may not apply to helical piles.

Perko (2009) concluded that in summary, the ultimate bearing pressure for helical piles in coarse-grain soils may be computed using traditional bearing capacity theory by replacing the effective overburden stress, q' with the product of soil unit weight, γ, and two times the average helix diameter, Davg. Within the analysis settings dialog, one can select the Use Bearing Limit option as q= f x γ (N_q -1). Here the default f=2 value is proposed, but this can be changed according to user preference.

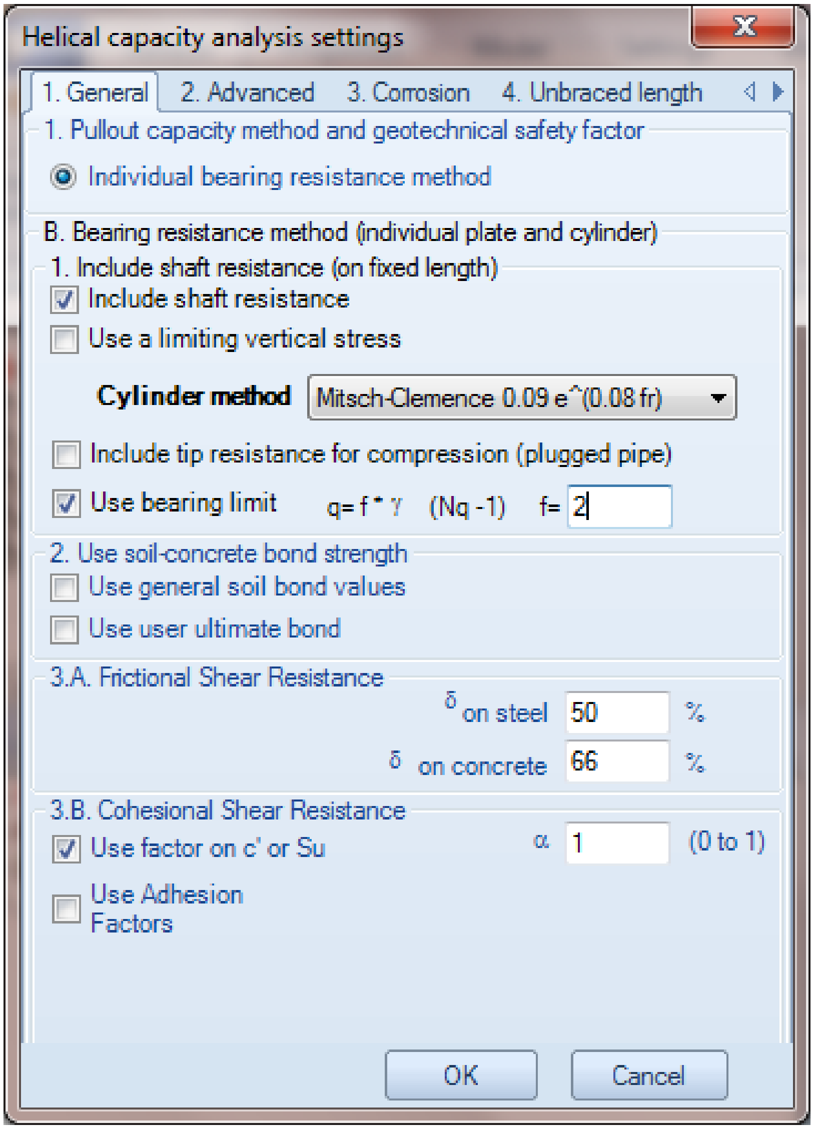


Figure 7.1.2: Analysis settings for limiting bearing pressure

7.2: Shaft side resistance

While in general shaft side resistance is ignored, in some occasions it might be desirable to incorporate shaft resistance within the calculations. In DeepFND there are two methods of calculating shaft resistance a) Effective stress approach, and b) soil bond values. If the option Use general soil bond values is not selected, then the program will use an effective stress approach for calculating shaft side resistance.

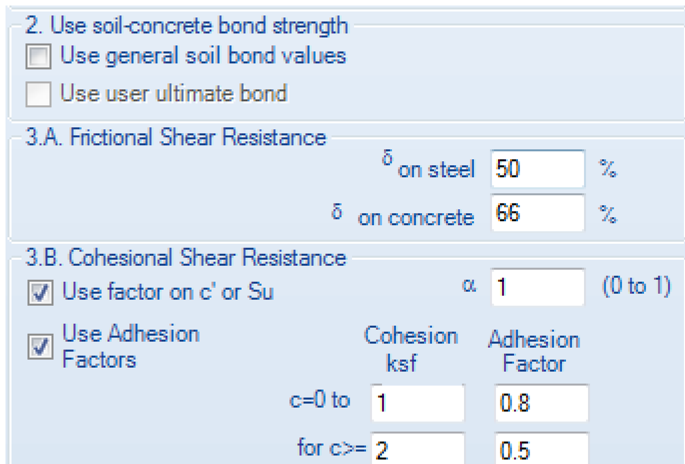


Figure 7.2.1: Shaft resistance options in analysis settings dialog

a) General soil bond values: Side resistance is calculated from the bond resistance values in the soils type dialog. This condition would be more appropriate for grouted shafts or pressure grouted shafts where the external shaft is encased in concrete.

b) Effective stress approach: In the effective stress approach, the program calculates the average effective vertical and lateral stress along the shaft. Shaft resistance is then determined from:

$\tau=\tan(\delta\ \varphi)\ \sigma'^{ave}+\alpha\ m\ c'$

Where:

δ = Ratio of shaft to soil friction. Default δ_{steel} value is used. If the helical pile is grouted, program will use $\delta_{concrete}$. Please note that the initial percentages are general estimates and that they should be adjusted if site conditions differ.

ϕ = Effective soil friction angle

σ'_{ave} = Average normal soil stress along the shaft

α = Overall adhesion factor for cohesive component of side stress

c'= Effective cohesion or undrained shear strength for clays in undrained state.

m= Optional factor applied on cohesive side stress that reduces adhesion with tri-linear approach. In figure 5.2, for c<= 1 ksf then m= 0.8, for c>=2ksf m= 0.5 while the program performs a linear interpolation for intermediate values. The initially assumed limits are obtained from experience and general references, but should be adjusted if soil-adhesion behavior differs.

7.3 Cylinder strength method

DeepFND also examines cylinder strength to determine which axial loading condition is more critical. The program subdivides the space between plates into a number of nodes where the side shear strength on the cylinder is integrated from a side resistance of:

$\tau = \tan\varphi\ \sigma'_{ave} + c'$

Where:

δ = Ratio of shaft to soil friction. Default δ_{steel} value is used. If the helical pile is grouted, program will use $\delta_{concrete}$. Please note that the initial percentages are general estimates and that they should be adjusted if site conditions differ.

ϕ = Effective soil friction angle

σ'_{ave} = Average normal soil stress along the shaft

If the plate sizes are different, then the program calculates and includes both the cylinder angle (from the pile axis) as well as the effective diameter along the virtual cylinder. The angle inclination of the cylinder in respect to the pile axis should make little difference in most cases. The side cohesion factors in 5.2 are also applied in the cylinder method.

7.4 Installation disturbance factors

As a helical pile is installed and helical plates cut through insitu soils, the very process of individual helical plates passing through disturbs the original soil. As a result, it has been observed that trailing plates do not experience their full bearing capacity potential. Such installation disturbance factors are applied both to the bearing capacity of each individual bearing plate as well as the elastic (or non-linear) soil response. Disturbance factors can be affected by many factors, including pile size (shaft, shape), installation speed, and original soil conditions. Stiffer clays have been observed to experience a greater reduction in strength as a result of helical pile installation. Default installation disturbance are estimates based on engineering judgment and may have to be adjusted on each analysis.

5.5 Structural capacity calculations

Initially the design structural capacity of the pile is calculated as:

$P_{des} = \alpha \cdot P_y$

Where: P_{des} = Design axial capacity

P_y = Yield strength of shaft

α = Design stress factor (for allowable design typically taken as 0.5)

α is controlled from the Analysis settings dialog, tab B. Its value is automatically updated when a new structural code is selected from the Design tab.

The program also considers the structural capacity according to the selected structural code standards. This affects the compressive structural capacity when buckling is considered. DeepFND determines which loading condition is controlling in each stage, and reports the respective structural capacity.

The unbraced length below the surface has to be defined by the user depending on soil conditions for each helical pile. The program subsequently tries to determine if the pile sticks out of the ground and incorporate this length into the effective unbraced height. Last, the effective unbraced length is calculated by multiplying by the unbraced length factor k which accounts for the end conditions of the beam. The initially assumed value is assumed as 1 (for a pinned beam at both ends), while typical values can range from 0.65 to 2 depending on the assumed fixity conditions.

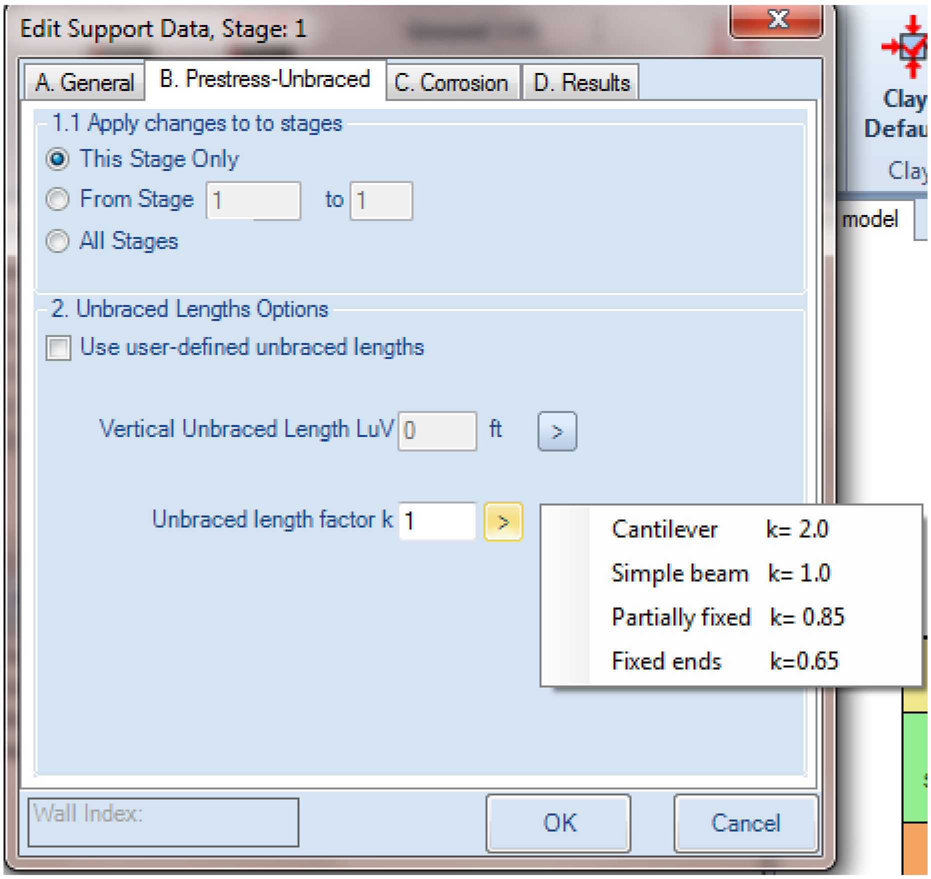
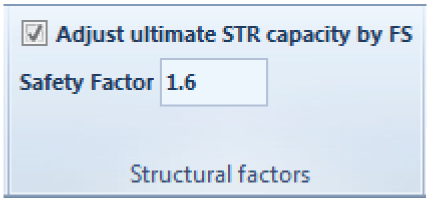


Figure 7.4.1: Unbraced length factor with standard recommendations

7.5 Structural Safety Factors

When ultimate structural codes such as AISC LRFD editions are employed, then a designer might have to consider additional safety factors applied to the structural analysis. This will also depend on whether external pile loads are factored or not. For example, if external pile loads are not factored and AISC LRFD is used, then it might be prudent to use a safety factor of 1.6 or greater to factor services loads for the buckling structural analysis according to building code standards. These settings are initially automatically set when a building code is selected but can be adjusted from the design tab as shown in Figure 7.5.1. When an overall safety factor is used, the assumptions table will also show that a safety factor is applied by the name of the structural code.



Steel Code: a= 0.585	LRFD 3rd Edition 2003/ FS= 1.6
Ubraced length	N/A +, k= 1

Figure 7.5.1: Using a safety factor on loads for ultimate structural codes such as AISC LRFD

7.6 Helical pile settlement estimation procedure

Helical pile capacity is almost always defined from the actual settlement response due to applied loading. It is well known that the ultimate bearing capacity of individual plates is mobilized at settlements that tend to be unacceptable for typical structures. It has also been observed that maximum theoretical bearing pressure limits have rarely been mobilized in most axial pile load tests. DeepFND incorporates a new settlement, based, methodology for estimating the axial response of a helical pile. As Perlow (2013) has outlined, a helical pile settlement response is typically divided into the following components:
End bearing plate soil response
Cylinder shaft response
Shaft friction response
Elastic response of helical pile itself

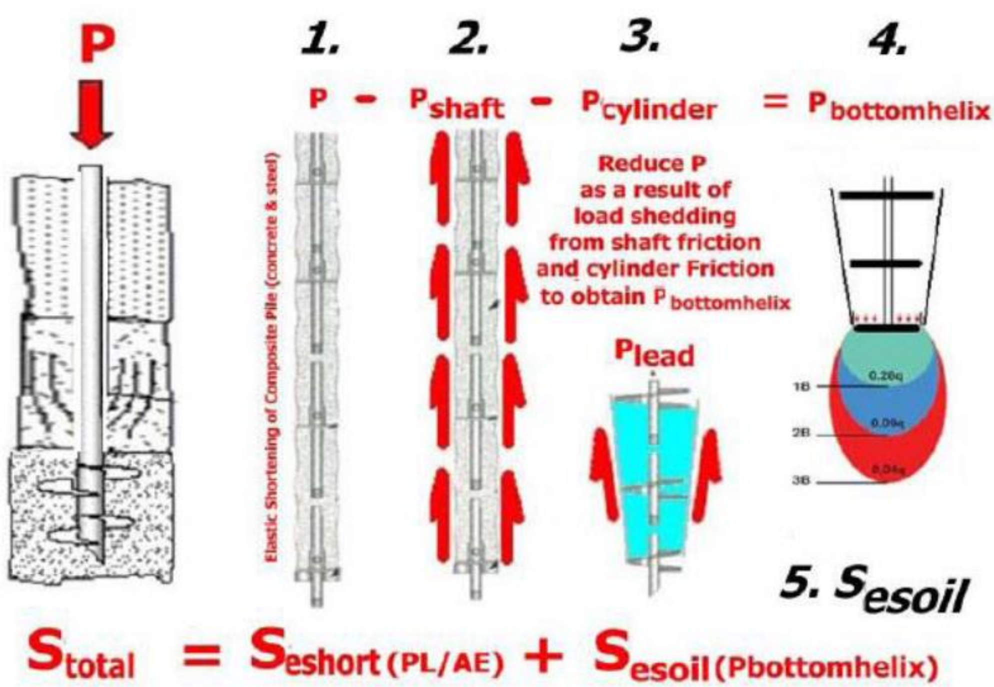


Figure 7.6.1: Idealized helical pile settlement response

In case the individual plate mode is critical, then the response of each individual plate, and the shaft between the plates is considered.

DeepFND estimates the PY response by discretizing the soil continuum into vertical soil spring elements for the shaft, cylinder, and plates. Hyperbolic soil response is ideally captured by employing the Exponential soil model. Fleming (1992) presented a procedure for estimating axial pile response. For rigid piles the shaft vertical soil response can be represented as:

$$\Delta_S = \frac{M_S\ D_S\, U_S\, P_S}{U_S - P_S} \quad \text{Eq. 7.6.1}$$

Where:

M_S = Shaft factor

D_S = Shaft diameter (or cylinder diameter)

U_S = Ultimate shaft resistance

P_S = Applied shaft traction

M_S is in fact the tangent slope at the origin of the hyperbolic function representing shaft friction (Randolph 1992).

To capture more complex soil response the equation has been expanded to include an exponent:

$$\Delta_S = M_S\ D_S\, U_S\, \left(\frac{P_S}{U_S - P_S}\right)^m \quad \text{Eq. 7.6.2}$$

According to Randolph and Wroth (1978, 1982) M_s can be replaced by:

$$M_S = \frac{\ln(r_m/r_p)\ \tau_S}{2\,G} \quad \text{Eq. 7.6.3}$$

Where r_m is the radius at which soil deflections become vanishing small, r_p is the pile radius, τ_s is the shear stress at the pile surface, and G is the soil shear modulus:

$G=E/2(+v)$ Eq. 7.6.4

According to theory of elasticity the settlement under the center of a circular footing can be computed as:

$$\Delta_P = \frac{\pi}{4}\ \frac{q_a}{E_B}\ D_{PL}\,(1 - v^2)f \quad \text{Eq. 7.6.5}$$

Where:

q_a = Applied stress on footing (average)

E_B = Modulus of elasticity of bearing soils

D_{PL} = Circular footing diameter (in this case, helical plate diameter)

f = 0.85 Shape factor

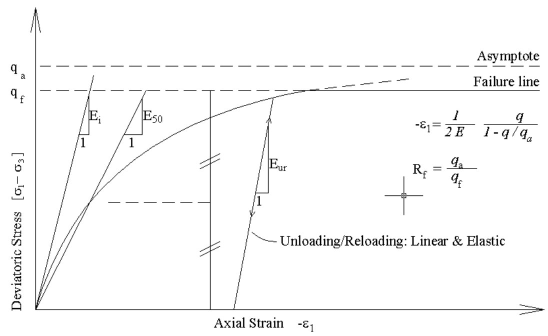
The settlement response equation though is expressed in a linear form. To capture non-linear behavior, it is important to use a non-linear soil model (such as the exponential soil model). Such work has previously been reported by Kodner & Zelasko 1963, and Schanz, Vermeer, and Bonnier 2000.

$$\varepsilon_1 = \frac{q_a}{2\,E_{50}} \frac{\sigma_1 - \sigma_3}{q_a - (\sigma_1 - \sigma_3)} \quad \text{For } q<q_f \qquad \text{Eq. 7.6.7}$$

Where:

$q_a = q_f R_f$ Eq. 7.6.8

A suitable value for R_f is often 0.9 assumed.



With the hardening soil model, the soil modulus at 50% strain is calculated at each point as:

$E_{50} = E_{50ref} (\sigma_V' / p_{ref})^m$ Eq. 7.6.9

Since the axial capacity of a helical pile is a primarily vertical loading scenario, the following simplified assumptions can be made:

$q_f = q_{ult} + \sigma_V'$ Eq. 7.6.10

Where q_{ult} is the ultimate bearing capacity of the helical plate (or other bearing element).

$\sigma 1$ can be taken as the applied load on the plate plus the vertical effective stress due to soil and water.

Combining equations 7.6.7 through 7.6.10 appears to produce a reasonable and rational simplified procedure for estimating non-linear base response. By constructing the strain-stress relationship, the secant elastic modulus at each level of strain can be computed and this value is progressively used in Equation 7.6.5.

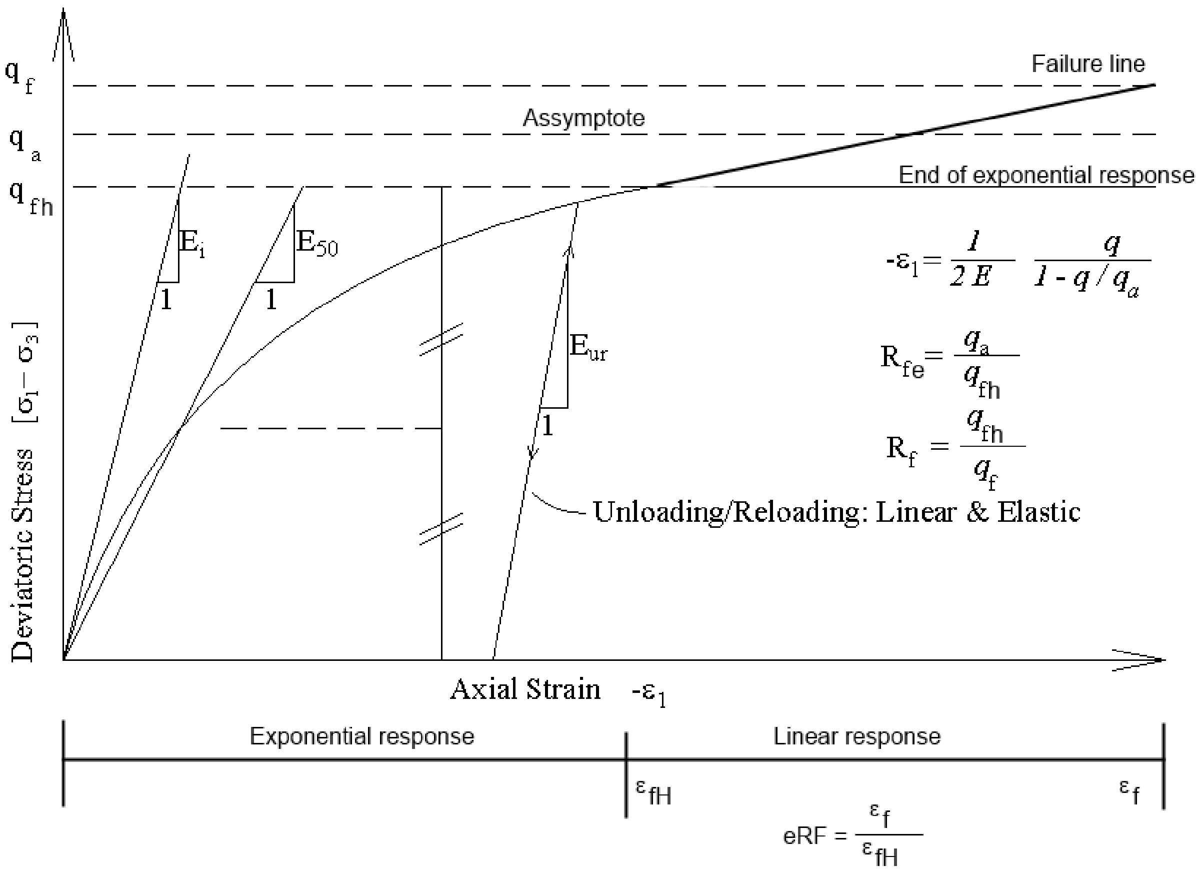
DeepFND considers a linear structural shaft response. When pile couplings have imperfections or buckling is observed the effective structural pile section area might be smaller than the full cross-sectional area.

It is recommended that the exponential elasticity model is used for most soils to accurately capture a more realistic bearing plate response.

The settlement response in DeepFND does not consider more complex behavior including downdrag or time related consolidation effects. It is generally best if predictions made with the software are always accompanied by axial load tests to verify pile response. It should also be kept in mind that actual pile response will be affected by soil variability and pile installation, which can exhibit significant variation even within the same site.

7.7 Exponential soil model with linear creep

Many times, some soils exhibit a linear response after a certain stress level has been exceeded. To cover such cases, we have expanded the exponential soil model to include a linear portion after the exponential response is exceeded.



SECTION 8: THEORETICAL BACKGROUND FOR REGULAR PILE TYPES

8.1 Introduction

In order to properly estimate the axial pile capacity different methods will have to be adopted. Amongst other factors, such methods may depend on the pile installation method as well as on different soil or rock type properties. DeepFND offers a number of well accepted methods for estimating the geotechnical axial pile capacity. Most methods are either based on AASHTO, FHWA, or Eurocode 7 type recommendations. All methods should be used by experienced professionals who understand their limitations. DeepFND also gives direct options for overriding many of these settings with user defined options.

8.2. A Driven Pile Recommendations

For driven piles, DeepFND has incorporated Norlund's method as outlined in AASHTO Bridge design specifications (2012 and on). The program will automatically classify the pile as tapered, steel monotube, or step tapered, depending on the selected pile geometry. A series of verification examples with DeepFND are presented in the following sections.
For adhesion, the program uses Tomlinson's method (Tomlinson 1979). The program interpolates for values of D/d between 10 and 40.

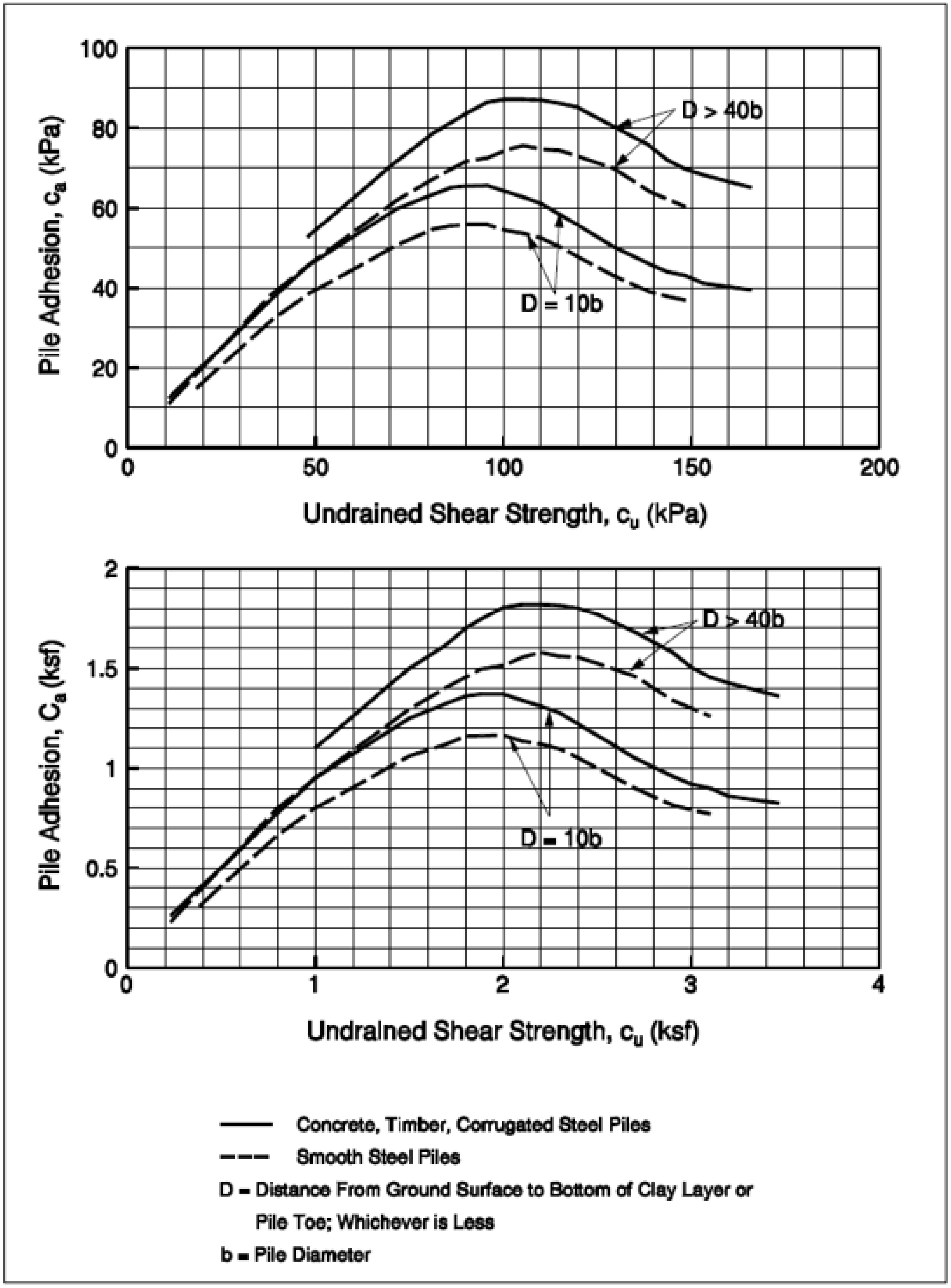


Figure 8.2.1.A: Adhesion Values for Piles in Cohesive Soils (after Tomlinson, 1979)

Figure 8.2.1.B Nordlund/Thurman Method Verification

The following report includes the software DeepFND verification of the geotechnical capacity calculation of driven installed piles in cohesionless soils through the Nordlund/Thurman Method as presented in AASHTO LFRD 2012 [1].

Example 8.2.1. Timber driven pile ω=0

The assembly of the example 1 along with the pile and soil layer properties are illustrated in Figure 8.2.1.1, 8.2.1.2a and 8.2.1.2b respectively.

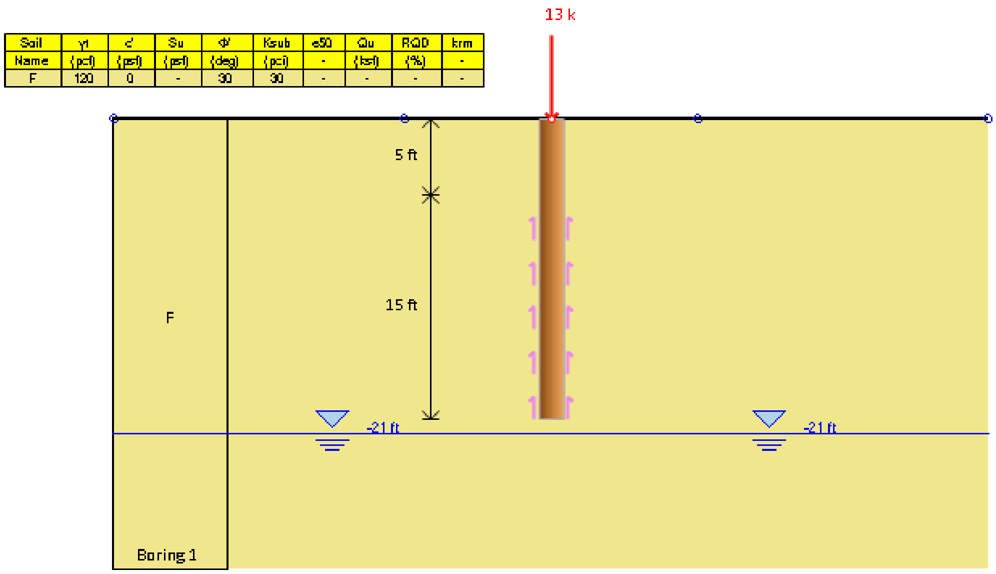


Figure 8.2.1.1: Assembly of pile foundation example 1.

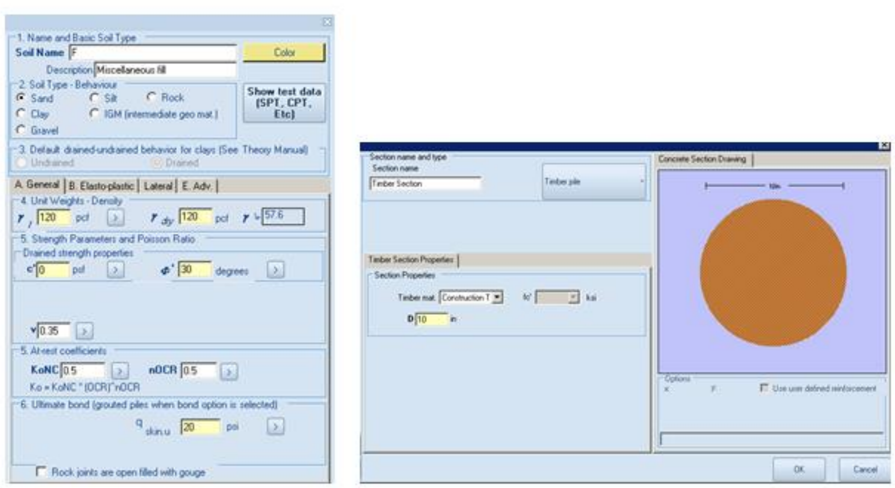


Figure 8.2.1.2: Properties of a) cohesionless soil layer b) the circular timber section

The calculation of the nominal unit side resistance is accomplished according to the AASHTO LRFD [1] guidelines, section 10.7.3.8.6f, through equation (1).

$$q_s = K_\delta \cdot C_F \cdot \sigma' \frac{\sin(\delta+\omega)}{\delta+\omega)} \qquad (1)$$

The value of the coefficient of lateral earth pressure at mid-point of soil layer K_δ=0.998 is calculated through the use of figure 8.2.1.3a. The effective Volume displaced is equal to V_{eff}=0.56 ft^3/ft while ω=0°. The δ/φ_f =0.55 ratio is calculated from figure 8.2.1.3b according to Veff value and the curve "*b*" corresponding to timber piles.

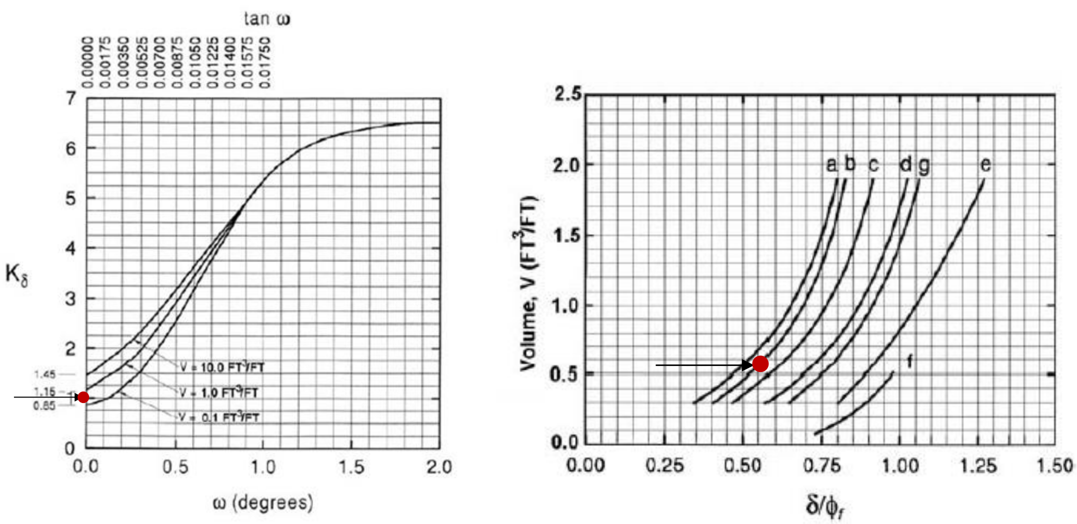


Figure 8.2.1.3a) selection of K_δ value b) selection of δ/ϕ_f value

The value of the correction factor C_f =0.789 is calculated through the use of figure 4 according to the previously selected δ/φ_f value and the soil friction angle ϕ=30°.

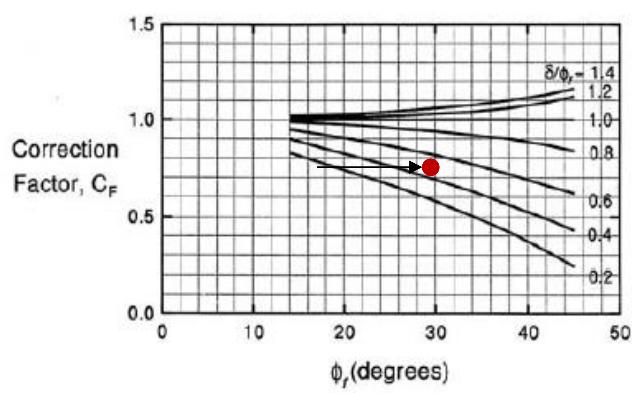


Figure 8.2.1.4: selection of C_f correction factor value.

The calculation of the nominal side stress is accomplished according to equation (1) for the different depths along the pile foundation according to the meshing discretization provided by DeepFND in the stress point results menu. The calculation results along with the nominal side stress provided by DeepFND are illustrated in a tabulated form in Table 8.2.1.

Table 8.2.1: tabulated results nominal shear stress calculation

Depth(ft)	σv'	Li	δ/f	Cf	Kδ	ω	δ	Analytical qs	**qs (DeepFND)**
-5	0.6	0.25	0.53	0.76	1.008	0	15.9	0.125925	0.127
-5.25	0.63	0.25	0.53	0.76	1.008	0	15.9	0.132221	0.133
-5.5	0.66	0.25	0.53	0.76	1.008	0	15.9	0.138517	0.14
-5.75	0.69	0.25	0.53	0.76	1.008	0	15.9	0.144814	0.146
-6	0.72	0.25	0.53	0.76	1.008	0	15.9	0.15111	0.152
-6.25	0.75	0.25	0.53	0.76	1.008	0	15.9	0.157406	0.159
-6.5	0.78	0.25	0.53	0.76	1.008	0	15.9	0.163702	0.165
-6.75	0.81	0.25	0.53	0.76	1.008	0	15.9	0.169998	0.171
-7	0.84	0.25	0.53	0.76	1.008	0	15.9	0.176295	0.178
-7.25	0.87	0.25	0.53	0.76	1.008	0	15.9	0.182591	0.184
-7.5	0.9	0.25	0.53	0.76	1.008	0	15.9	0.188887	0.19
-7.75	0.93	0.25	0.53	0.76	1.008	0	15.9	0.195183	0.197
-8	0.96	0.25	0.53	0.76	1.008	0	15.9	0.20148	0.203
-8.25	0.99	0.25	0.53	0.76	1.008	0	15.9	0.207776	0.209
-8.5	1.02	0.25	0.53	0.76	1.008	0	15.9	0.214072	0.216
-8.75	1.05	0.25	0.53	0.76	1.008	0	15.9	0.220368	0.222
-9	1.08	0.25	0.53	0.76	1.008	0	15.9	0.226665	0.228
-9.25	1.11	0.25	0.53	0.76	1.008	0	15.9	0.232961	0.235
-9.5	1.14	0.25	0.53	0.76	1.008	0	15.9	0.239257	0.241
-9.75	1.17	0.25	0.53	0.76	1.008	0	15.9	0.245553	0.247
-10	1.2	0.25	0.53	0.76	1.008	0	15.9	0.25185	0.254
-10.25	1.23	0.25	0.53	0.76	1.008	0	15.9	0.258146	0.26
-10.5	1.26	0.25	0.53	0.76	1.008	0	15.9	0.264442	0.266
-10.75	1.29	0.25	0.53	0.76	1.008	0	15.9	0.270738	0.273
-11	1.32	0.25	0.53	0.76	1.008	0	15.9	0.277035	0.279
-11.25	1.35	0.25	0.53	0.76	1.008	0	15.9	0.283331	0.285
-11.5	1.38	0.25	0.53	0.76	1.008	0	15.9	0.289627	0.292
-11.75	1.41	0.25	0.53	0.76	1.008	0	15.9	0.295923	0.298
-12	1.44	0.25	0.53	0.76	1.008	0	15.9	0.30222	0.304
-12.25	1.47	0.25	0.53	0.76	1.008	0	15.9	0.308516	0.311
-12.5	1.5	0.25	0.53	0.76	1.008	0	15.9	0.314812	0.317
-12.75	1.53	0.25	0.53	0.76	1.008	0	15.9	0.321108	0.323
-13	1.56	0.25	0.53	0.76	1.008	0	15.9	0.327404	0.33
-13.25	1.59	0.25	0.53	0.76	1.008	0	15.9	0.333701	0.336
-13.5	1.62	0.25	0.53	0.76	1.008	0	15.9	0.339997	0.343
-13.75	1.65	0.25	0.53	0.76	1.008	0	15.9	0.346293	0.349
-14	1.68	0.25	0.53	0.76	1.008	0	15.9	0.352589	0.355
-14.25	1.71	0.25	0.53	0.76	1.008	0	15.9	0.358886	0.362
-14.5	1.74	0.25	0.53	0.76	1.008	0	15.9	0.365182	0.368
-14.75	1.77	0.25	0.53	0.76	1.008	0	15.9	0.371478	0.374
-15	1.8	0.25	0.53	0.76	1.008	0	15.9	0.377774	0.381
-15.25	1.83	0.25	0.53	0.76	1.008	0	15.9	0.384071	0.387
-15.5	1.86	0.25	0.53	0.76	1.008	0	15.9	0.390367	0.393
-15.75	1.89	0.25	0.53	0.76	1.008	0	15.9	0.396663	0.4
-16	1.92	0.25	0.53	0.76	1.008	0	15.9	0.402959	0.406
-16.25	1.95	0.25	0.53	0.76	1.008	0	15.9	0.409256	0.412
-16.5	1.98	0.25	0.53	0.76	1.008	0	15.9	0.415552	0.419
-16.75	2.01	0.25	0.53	0.76	1.008	0	15.9	0.421848	0.425
-17	2.04	0.25	0.53	0.76	1.008	0	15.9	0.428144	0.431
-17.25	2.07	0.25	0.53	0.76	1.008	0	15.9	0.434441	0.438
-17.5	2.1	0.25	0.53	0.76	1.008	0	15.9	0.440737	0.444
-17.75	2.13	0.25	0.53	0.76	1.008	0	15.9	0.447033	0.45
-18	2.16	0.25	0.53	0.76	1.008	0	15.9	0.453329	0.457
-18.25	2.19	0.25	0.53	0.76	1.008	0	15.9	0.459626	0.463
-18.5	2.22	0.25	0.53	0.76	1.008	0	15.9	0.465922	0.469
-18.75	2.25	0.25	0.53	0.76	1.008	0	15.9	0.472218	0.476
-19	2.28	0.25	0.53	0.76	1.008	0	15.9	0.478514	0.482
-19.25	2.31	0.25	0.53	0.76	1.008	0	15.9	0.484811	0.488
-19.5	2.34	0.25	0.53	0.76	1.008	0	15.9	0.491107	0.495
-19.75	2.37	0.25	0.53	0.76	1.008	0	15.9	0.497403	0.501
-20	2.4	-20	0.53	0.76	1.008	0	15.9	0.503699	0.507

Both the nominal side stress derived directly from the guidelines of [1] along with the nominal side stress results produced by DeepFND are illustrated relatively to the depth of the pile in Figure 8.2.1.5.

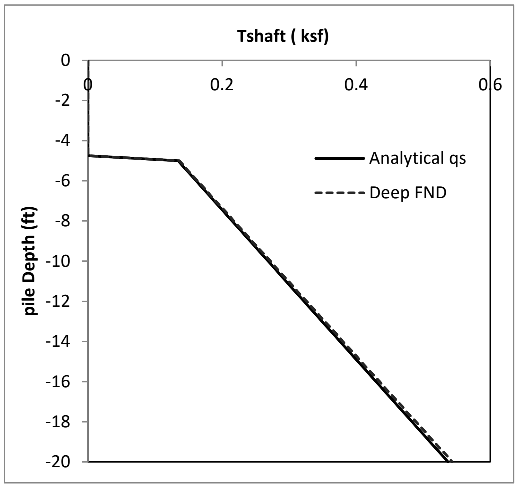


Figure 8.2.1.5: Comparison of the nominal side stress for both the analytical approach and DeepFND.

Example 8.2.2. Non-Prismatic timber section pile ω=1

The assembly of the example 2 along with the pile and soil layer properties are illustrated in Figures 8.2.2.1, 8.2.2.2a, 8.2.2.2b, and 8.2.2.2c.

Soil	γt	c'	Su	Φ'	Ksub	e50	Qu	RQD	krm
Name	(pcf)	(psf)	(psf)	(deg)	(pci)	-	(ksf)	(%)	-
F	120	0	-	30	30	-	-	-	-

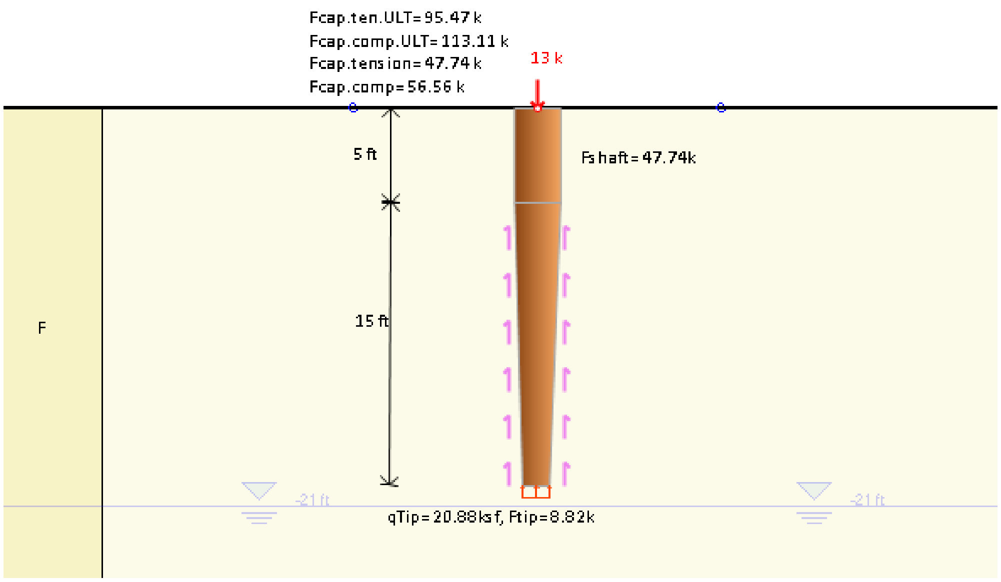
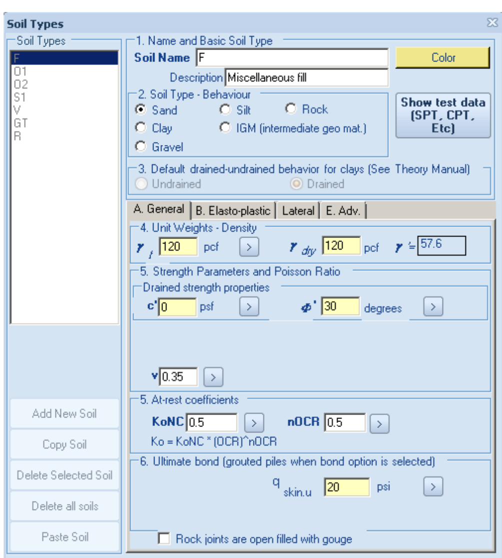
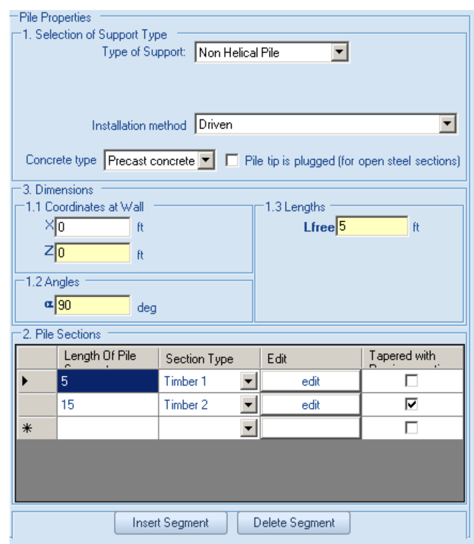


Figure 8.2.2.1: Assembly of pile foundation example 2





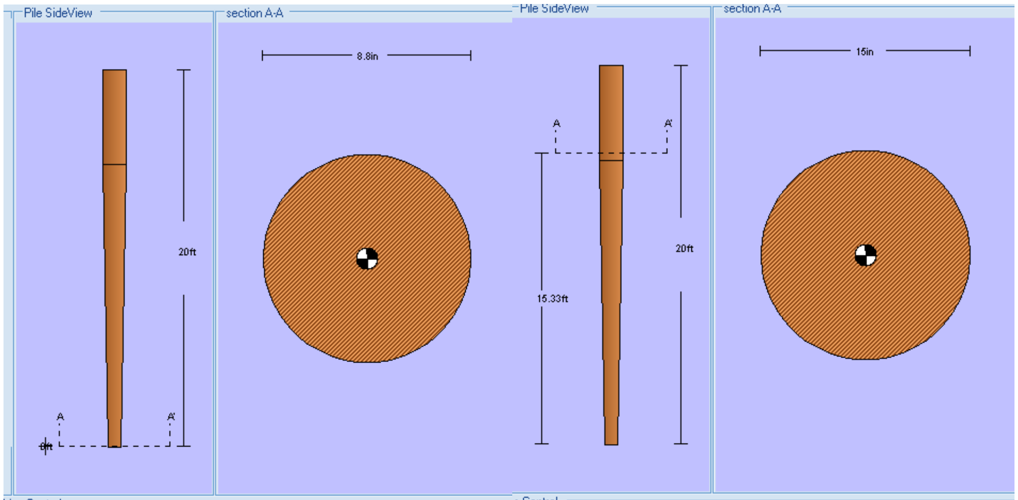


Figure 8.2.2.2: a) properties of cohesionless soil layer b) section components and general properties of pile c) properties of the circular timber section at a bottom and on the prismatic component of the timber pile.

The calculation of the nominal unit side resistance is accomplished according to the AASHTO LRFD [1] guidelines, section 10.7.3.8.6f, through equation (1).

$$q_s = K_\delta \cdot C_F \cdot \sigma' \frac{\sin(\delta + \omega)}{\delta + \omega)} \qquad (1)$$

The value of the coefficient of lateral earth pressure coefficient K_δ is calculated through the use of figure 8.2.2.3a for each depth along the pile foundation according to the meshing discretization. The effective Volume displaced is decreasing along the depth while ω=1°. The δ/φ_f ratio is calculated from figure 8.2.2.3b according to Veff value at each depth and the curve "*b*" corresponding to timber piles. The value of the correction factor C_f is calculated through the use of figure 4 according to the previously selected δ/φ_f value and the soil friction angle φ=30°.

The calculation of the nominal side stress is accomplished according to equation (1) for the different depths along the pile foundation according to the meshing discretization provided by DeepFND in the stress point results menu. The calculation results along with the nominal side stress provided by DeepFND are illustrated in a tabulated form in Table 8.2.2.

Table 8.2.2: tabulated results nominal shear stress calculation

Li	**V.pile**	σv'	Li	δ/f	Cf	Kδ	ω	δ	Analytical qs	**qs (DeepFND)**
-5.0	1.2	0.6	0.3	0.7	0.9	1.2	0.0	21.9	0.2	0.2
-5.3	1.2	0.6	0.3	0.7	0.9	5.3	1.0	21.9	1.2	1.2
-5.5	1.2	0.7	0.3	0.7	0.9	5.3	1.0	21.8	1.2	1.2
-5.8	1.2	0.7	0.3	0.7	0.9	5.3	1.0	21.6	1.3	1.3
-6.0	1.2	0.7	0.3	0.7	0.9	5.3	1.0	21.5	1.3	1.3
-6.3	1.1	0.8	0.3	0.7	0.9	5.3	1.0	21.4	1.4	1.4
-6.5	1.1	0.8	0.3	0.7	0.9	5.3	1.0	21.2	1.4	1.4
-6.8	1.1	0.8	0.3	0.7	0.9	5.3	1.0	21.1	1.4	1.4
-7.0	1.1	0.8	0.3	0.7	0.9	5.3	1.0	21.0	1.5	1.5
-7.3	1.1	0.9	0.3	0.7	0.9	5.3	1.0	20.8	1.5	1.5
-7.5	1.1	0.9	0.3	0.7	0.9	5.3	1.0	20.7	1.6	1.6
-7.8	1.0	0.9	0.3	0.7	0.9	5.3	1.0	20.6	1.6	1.6
-8.0	1.0	1.0	0.3	0.7	0.9	5.3	1.0	20.4	1.6	1.7
-8.3	1.0	1.0	0.3	0.7	0.9	5.3	1.0	20.3	1.7	1.7
-8.5	1.0	1.0	0.3	0.7	0.9	5.3	1.0	20.2	1.7	1.7
-8.8	1.0	1.1	0.3	0.7	0.9	5.3	1.0	20.0	1.8	1.8
-9.0	1.0	1.1	0.3	0.7	0.9	5.3	1.0	19.9	1.8	1.8
-9.3	1.0	1.1	0.3	0.7	0.9	5.3	1.0	19.8	1.8	1.8
-9.5	0.9	1.1	0.3	0.7	0.9	5.3	1.0	19.7	1.9	1.9
-9.8	0.9	1.2	0.3	0.7	0.9	5.3	1.0	19.5	1.9	1.9
-10.0	0.9	1.2	0.3	0.6	0.9	5.3	1.0	19.4	1.9	1.9
-10.3	0.9	1.2	0.3	0.6	0.9	5.3	1.0	19.3	2.0	2.0
-10.5	0.9	1.3	0.3	0.6	0.9	5.3	1.0	19.1	2.0	2.0
-10.8	0.9	1.3	0.3	0.6	0.9	5.3	1.0	19.0	2.0	2.0
-11.0	0.9	1.3	0.3	0.6	0.9	5.3	1.0	18.9	2.1	2.0
-11.3	0.8	1.4	0.3	0.6	0.9	5.3	1.0	18.7	2.1	2.1
-11.5	0.8	1.4	0.3	0.6	0.9	5.3	1.0	18.6	2.1	2.1
-11.8	0.8	1.4	0.3	0.6	0.9	5.3	1.0	18.5	2.2	2.1
-12.0	0.8	1.4	0.3	0.6	0.9	5.3	1.0	18.3	2.2	2.2
-12.3	0.8	1.5	0.3	0.6	0.9	5.3	1.0	18.2	2.2	2.2
-12.5	0.8	1.5	0.3	0.6	0.9	5.3	1.0	18.1	2.2	2.2
-12.8	0.8	1.5	0.3	0.6	0.9	5.3	1.0	17.9	2.3	2.2
-13.0	0.7	1.6	0.3	0.6	0.9	5.3	1.0	17.8	2.3	2.3
-13.3	0.7	1.6	0.3	0.6	0.9	5.3	1.0	17.7	2.3	2.3
-13.5	0.7	1.6	0.3	0.6	0.9	5.3	1.0	17.5	2.3	2.3
-13.8	0.7	1.7	0.3	0.6	0.9	5.3	1.0	17.4	2.4	2.3
-14.0	0.7	1.7	0.3	0.6	0.9	5.3	1.0	17.3	2.4	2.3
-14.3	0.7	1.7	0.3	0.6	0.9	5.3	1.0	17.1	2.4	2.4
-14.5	0.7	1.7	0.3	0.6	0.9	5.3	1.0	17.0	2.4	2.4
-14.8	0.7	1.8	0.3	0.6	0.9	5.3	1.0	16.9	2.5	2.4
-15.0	0.6	1.8	0.3	0.6	0.8	5.3	1.0	16.7	2.5	2.4
-15.3	0.6	1.8	0.3	0.6	0.8	5.3	1.0	16.6	2.5	2.5
-15.5	0.6	1.9	0.3	0.5	0.8	5.3	1.0	16.5	2.5	2.5
-15.8	0.6	1.9	0.3	0.5	0.8	5.3	1.0	16.3	2.5	2.5
-16.0	0.6	1.9	0.3	0.5	0.8	5.3	1.0	16.2	2.6	2.5
-16.3	0.6	2.0	0.3	0.5	0.8	5.3	1.0	16.1	2.6	2.5
-16.5	0.6	2.0	0.3	0.5	0.8	5.3	1.0	16.0	2.6	2.6
-16.8	0.6	2.0	0.3	0.5	0.8	5.3	1.0	15.8	2.6	2.6
-17.0	0.5	2.0	0.3	0.5	0.8	5.3	1.0	15.7	2.6	2.6
-17.3	0.5	2.1	0.3	0.5	0.8	5.3	1.0	15.6	2.6	2.6
-17.5	0.5	2.1	0.3	0.5	0.8	5.3	1.0	15.4	2.6	2.6
-17.8	0.5	2.1	0.3	0.5	0.8	5.3	1.0	15.3	2.7	2.6
-18.0	0.5	2.2	0.3	0.5	0.8	5.3	1.0	15.2	2.7	2.7
-18.3	0.5	2.2	0.3	0.5	0.8	5.3	1.0	15.0	2.7	2.7
-18.5	0.5	2.2	0.3	0.5	0.8	5.3	1.0	14.9	2.7	2.7
-18.8	0.5	2.3	0.3	0.5	0.8	5.3	1.0	14.8	2.7	2.7
-19.0	0.5	2.3	0.3	0.5	0.8	5.3	1.0	14.6	2.7	2.7
-19.3	0.5	2.3	0.3	0.5	0.8	5.3	1.0	14.5	2.7	2.7
-19.5	0.4	2.3	0.3	0.5	0.8	5.3	1.0	14.4	2.7	2.7
-19.8	0.4	2.4	0.3	0.5	0.8	5.3	1.0	14.2	2.7	2.7
-20.0	0.4	2.4	0.1	0.5	0.8	5.3	1.0	14.1	2.8	2.8

Both the nominal side stress derived directly from the guidelines of [1] along with the nominal side stress results produced by DeepFND are illustrated relatively to the depth of the pile in figure 8.2.2.3.

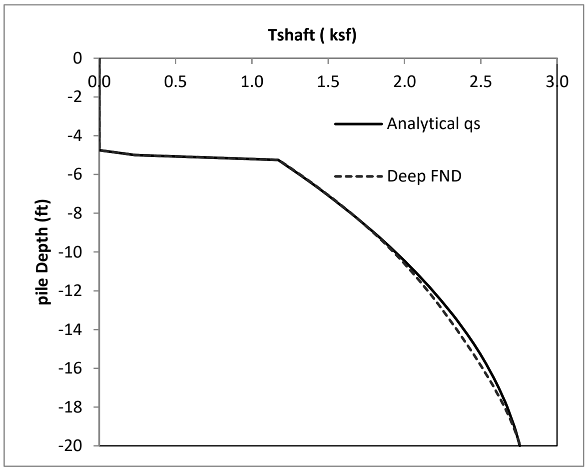


Figure 8.2.2.3: Comparison of the nominal side stress for both the analytical approach and DeepFND

Example 8.2.3. Steel pipe driven pile ω=0.98º

The assembly of the example 1 along with the pile and soil layer properties are illustrated in Figures 8.2.3.1, 8.2.3.2a and 8.2.3.2b respectively.

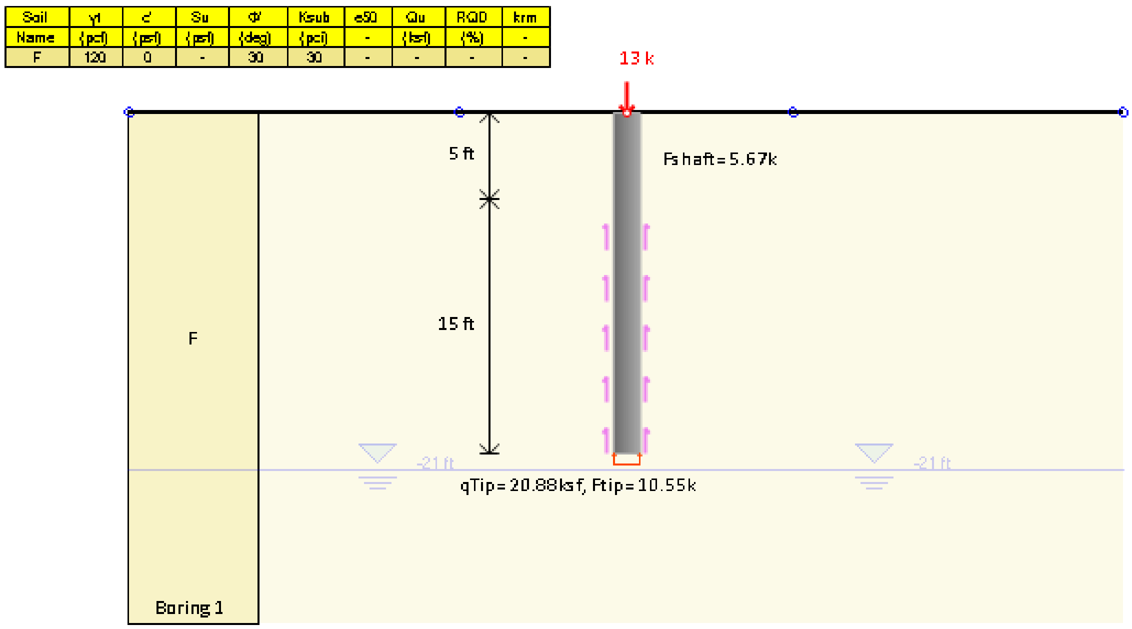
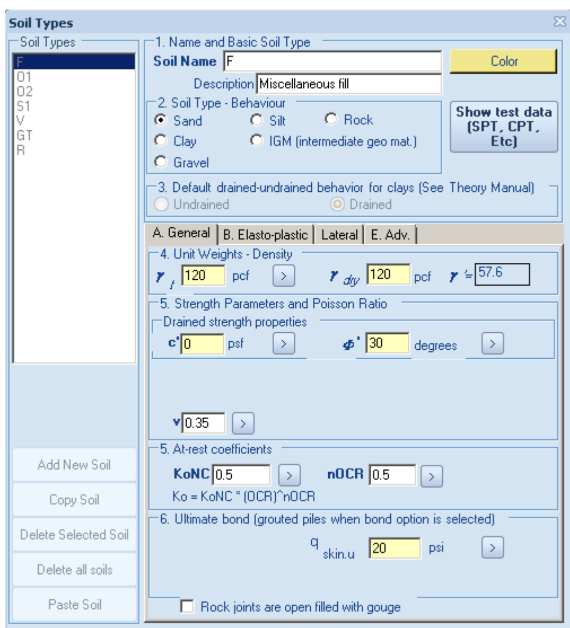


Figure 8.2.3.1: Assembly of pile foundation example 1



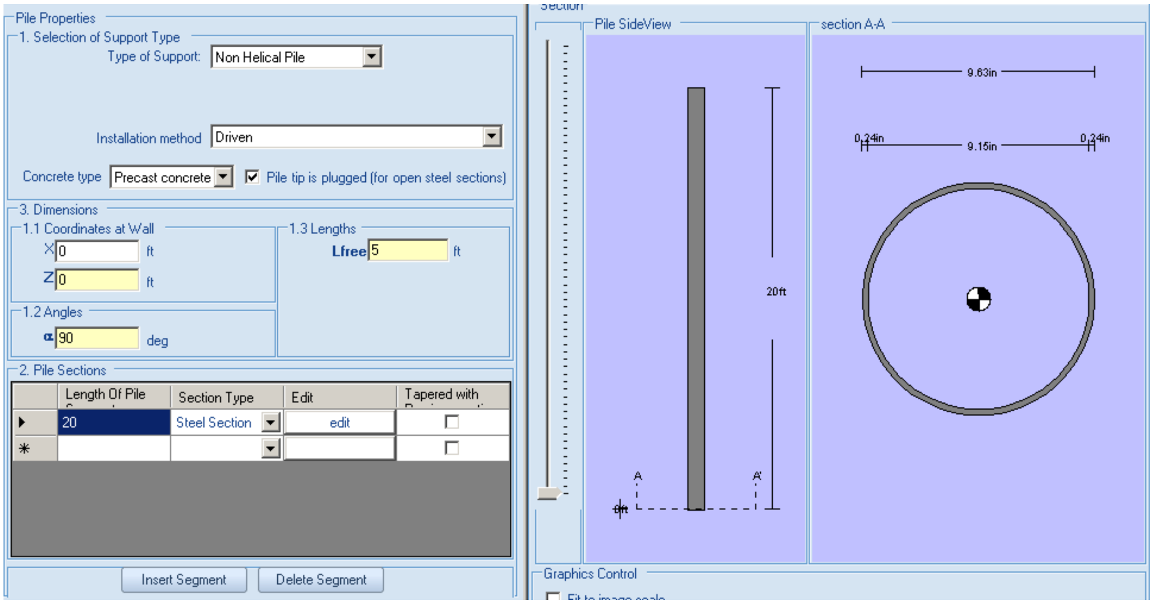


Figure 8.2.3.2: a) properties of cohesionless soil layer b) properties of the steel pipe section

The calculation of the nominal unit side resistance is accomplished according to the AASHTO LRFD [1] guidelines, section 10.7.3.8.6f, through equation (1).

$$q_s = K_\delta \cdot C_F \cdot \sigma' \frac{\sin(\delta + \omega)}{\delta + \omega)} \qquad (1)$$

The value of the coefficient of lateral earth pressure at mid-point of soil layer K_δ=0.995 is calculated through the use of figure 6.2.3.3a. The effective Volume displaced is equal to V_{eff}=0.505 ft^3/ft while ω=0°. the δ/φ_f =0.465 ratio is calculated from figure 8.2.3.3b according to Veff value and the curve "*a*" corresponding to closed pipe or non-tapered portion of monotube piles.

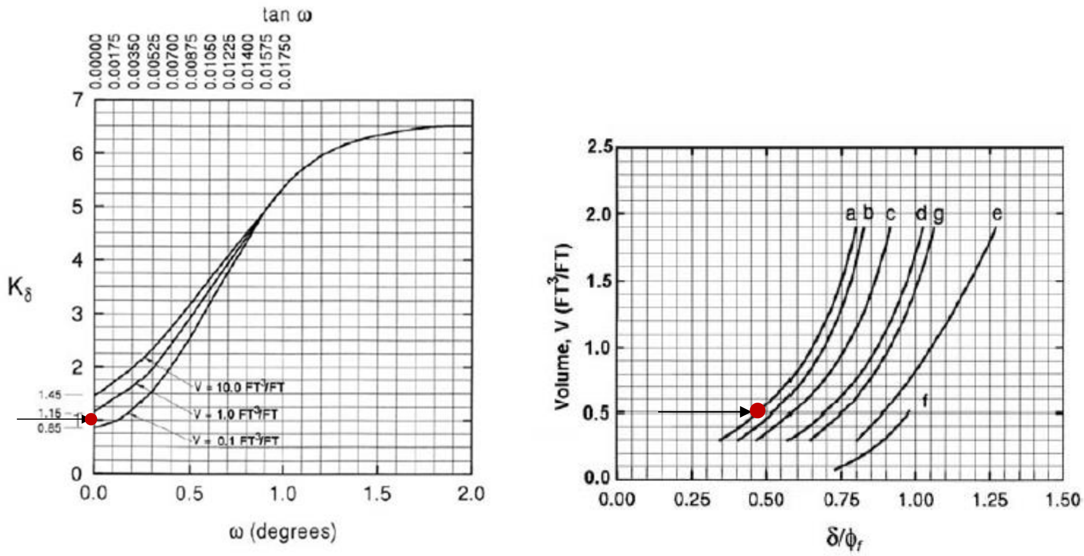


Figure 8.2.3a) selection of K_δ value b) selection of δ/ϕ_f value

The value of the correction factor C_f =0.72 is calculated through the use of figure 12 according to the previously selected δ/φ_f value and the soil friction angle ϕ=30°.

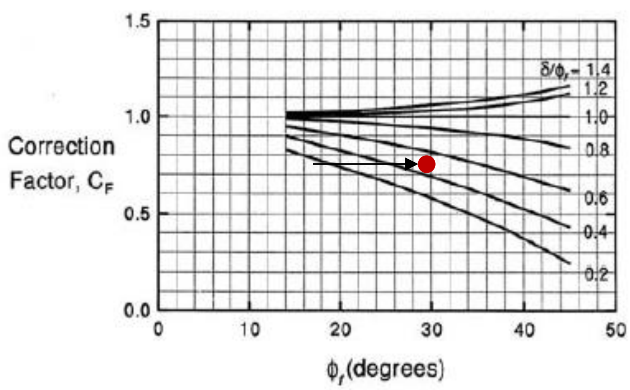


Figure 8.2.4: selection of C_f correction factor value

The calculation of the nominal side stress is accomplished according to equation (1) for the different depths along the pile foundation according to the meshing discretization provided by DeepFND in the stress point results menu. The calculation results along with the nominal side stress provided by DeepFND are illustrated in a tabulated form in Table 8.2.3.

Table 8.2.3: tabulated results nominal shear stress calculation

	σv'	Li	δ/f	Cf	Kδ	ω	δ	Analytical qs	qs (DeepFND)
-5	0.6	0.25	0.465	0.72	0.995	0	13.95	0.104	0.104
-5.25	0.63	0.25	0.465	0.72	0.995	0	13.95	0.109	0.109
-5.5	0.66	0.25	0.465	0.72	0.995	0	13.95	0.114	0.114
-5.75	0.69	0.25	0.465	0.72	0.995	0	13.95	0.119	0.119
-6	0.72	0.25	0.465	0.72	0.995	0	13.95	0.124	0.125
-6.25	0.75	0.25	0.465	0.72	0.995	0	13.95	0.130	0.13
-6.5	0.78	0.25	0.465	0.72	0.995	0	13.95	0.135	0.135
-6.75	0.81	0.25	0.465	0.72	0.995	0	13.95	0.140	0.14
-7	0.84	0.25	0.465	0.72	0.995	0	13.95	0.145	0.145
-7.25	0.87	0.25	0.465	0.72	0.995	0	13.95	0.150	0.151
-7.5	0.9	0.25	0.465	0.72	0.995	0	13.95	0.155	0.156
-7.75	0.93	0.25	0.465	0.72	0.995	0	13.95	0.161	0.161
-8	0.96	0.25	0.465	0.72	0.995	0	13.95	0.166	0.166
-8.25	0.99	0.25	0.465	0.72	0.995	0	13.95	0.171	0.171
-8.5	1.02	0.25	0.465	0.72	0.995	0	13.95	0.176	0.177
-8.75	1.05	0.25	0.465	0.72	0.995	0	13.95	0.181	0.182
-9	1.08	0.25	0.465	0.72	0.995	0	13.95	0.187	0.187
-9.25	1.11	0.25	0.465	0.72	0.995	0	13.95	0.192	0.192
-9.5	1.14	0.25	0.465	0.72	0.995	0	13.95	0.197	0.197
-9.75	1.17	0.25	0.465	0.72	0.995	0	13.95	0.202	0.203
-10	1.2	0.25	0.465	0.72	0.995	0	13.95	0.207	0.208
-10.25	1.23	0.25	0.465	0.72	0.995	0	13.95	0.212	0.213
-10.5	1.26	0.25	0.465	0.72	0.995	0	13.95	0.218	0.218
-10.75	1.29	0.25	0.465	0.72	0.995	0	13.95	0.223	0.223
-11	1.32	0.25	0.465	0.72	0.995	0	13.95	0.228	0.228
-11.25	1.35	0.25	0.465	0.72	0.995	0	13.95	0.233	0.234
-11.5	1.38	0.25	0.465	0.72	0.995	0	13.95	0.238	0.239
-11.75	1.41	0.25	0.465	0.72	0.995	0	13.95	0.244	0.244
-12	1.44	0.25	0.465	0.72	0.995	0	13.95	0.249	0.249
-12.25	1.47	0.25	0.465	0.72	0.995	0	13.95	0.254	0.254
-12.5	1.5	0.25	0.465	0.72	0.995	0	13.95	0.259	0.26
-12.75	1.53	0.25	0.465	0.72	0.995	0	13.95	0.264	0.265
-13	1.56	0.25	0.465	0.72	0.995	0	13.95	0.269	0.27
-13.25	1.59	0.25	0.465	0.72	0.995	0	13.95	0.275	0.275
-13.5	1.62	0.25	0.465	0.72	0.995	0	13.95	0.280	0.28
-13.75	1.65	0.25	0.465	0.72	0.995	0	13.95	0.285	0.286
-14	1.68	0.25	0.465	0.72	0.995	0	13.95	0.290	0.291
-14.25	1.71	0.25	0.465	0.72	0.995	0	13.95	0.295	0.296
-14.5	1.74	0.25	0.465	0.72	0.995	0	13.95	0.301	0.301
-14.75	1.77	0.25	0.465	0.72	0.995	0	13.95	0.306	0.306
-15	1.8	0.25	0.465	0.72	0.995	0	13.95	0.311	0.312
-15.25	1.83	0.25	0.465	0.72	0.995	0	13.95	0.316	0.317
-15.5	1.86	0.25	0.465	0.72	0.995	0	13.95	0.321	0.322
-15.75	1.89	0.25	0.465	0.72	0.995	0	13.95	0.326	0.327
-16	1.92	0.25	0.465	0.72	0.995	0	13.95	0.332	0.332
-16.25	1.95	0.25	0.465	0.72	0.995	0	13.95	0.337	0.338
-16.5	1.98	0.25	0.465	0.72	0.995	0	13.95	0.342	0.343
-16.75	2.01	0.25	0.465	0.72	0.995	0	13.95	0.347	0.348
-17	2.04	0.25	0.465	0.72	0.995	0	13.95	0.352	0.353
-17.25	2.07	0.25	0.465	0.72	0.995	0	13.95	0.358	0.358
-17.5	2.1	0.25	0.465	0.72	0.995	0	13.95	0.363	0.363
-17.75	2.13	0.25	0.465	0.72	0.995	0	13.95	0.368	0.369
-18	2.16	0.25	0.465	0.72	0.995	0	13.95	0.373	0.374
-18.25	2.19	0.25	0.465	0.72	0.995	0	13.95	0.378	0.379
-18.5	2.22	0.25	0.465	0.72	0.995	0	13.95	0.383	0.384
-18.75	2.25	0.25	0.465	0.72	0.995	0	13.95	0.389	0.389
-19	2.28	0.25	0.465	0.72	0.995	0	13.95	0.394	0.395
-19.25	2.31	0.25	0.465	0.72	0.995	0	13.95	0.399	0.4
-19.5	2.34	0.25	0.465	0.72	0.995	0	13.95	0.404	0.405
-19.75	2.37	0.25	0.465	0.72	0.995	0	13.95	0.409	0.41
-20	2.4	-20	0.465	0.72	0.995	0	13.95	0.414	0.415

Both the nominal side stress derived directly from the guidelines of [1] along with the nominal side stress results produced by DeepFND are illustrated relatively to the depth of the pile in Figure 8.2.5.

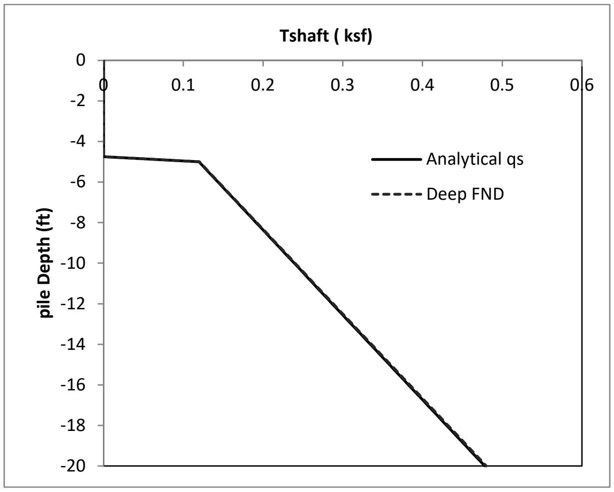


Figure 8.2.5: Comparison of the nominal side stress for both the analytical approach and DeepFND

Example 8.2.4. Non-Prismatic steel pipe section pile ω=0.541°

The assembly of the example 2 along with the pile and soil layer properties are illustrated in Figures 8.2.4.1, 8.2.4.2a, 8.2.4.2b, and 8.2.4.2c.

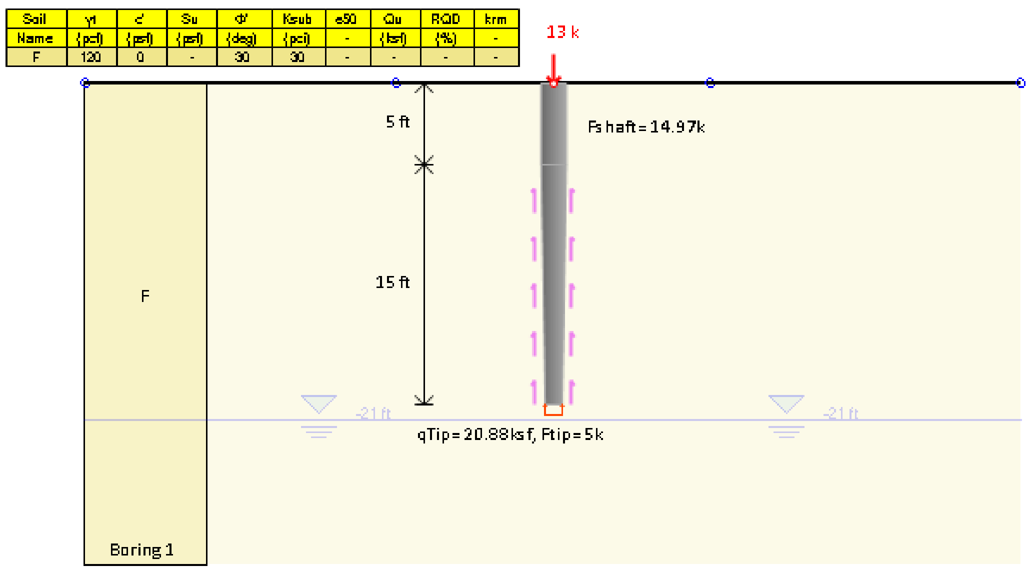
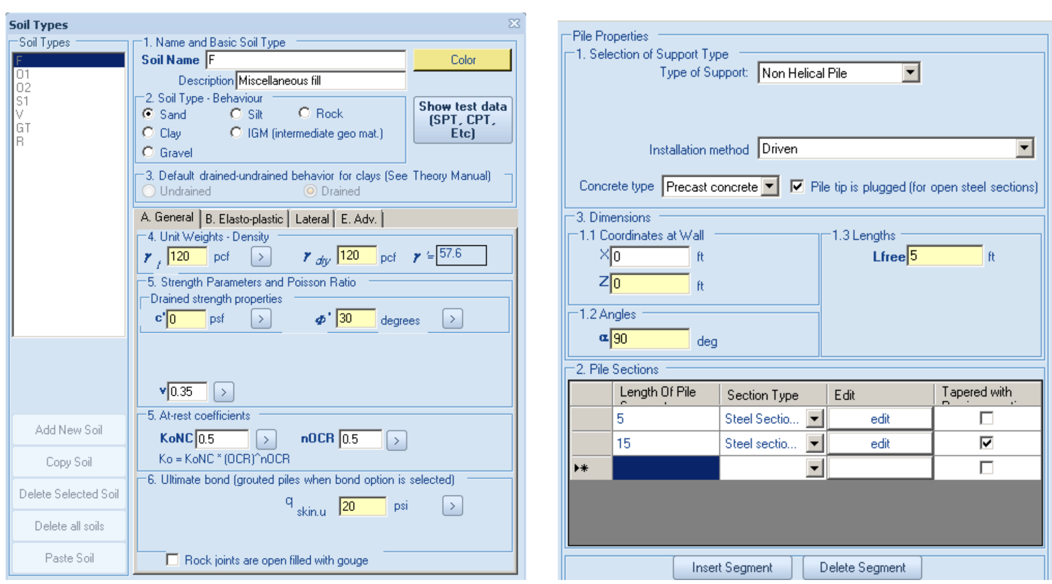


Figure 8.2.4.1: Assembly of pile foundation example 2



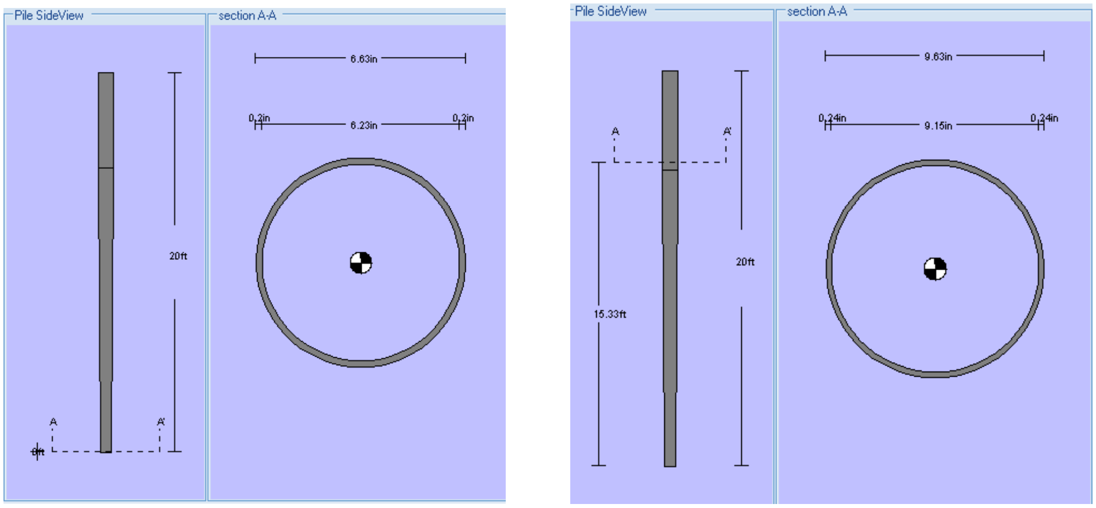


Figure 8.2.4.2: a) properties of cohesionless soil layer b) section components and general properties of pile c) properties of the steel pipe section at a bottom and on the prismatic component of the pipe pile

The calculation of the nominal unit side resistance is accomplished according to the AASHTO LRFD [1] guidelines, section 10.7.3.8.6f, through equation (1).

$$q_s = K_\delta \cdot C_F \cdot \sigma' \frac{\sin(\delta + \omega)}{\delta + \omega)} \qquad (1)$$

The value of the coefficient of lateral earth pressure coefficient K_δ is calculated through the use of Figure 8.2.4.3a for each depth along the pile foundation according to the meshing discretization. The effective Volume displaced is decreasing along the depth while ω=1°. The δ/φ_f ratio is calculated from Figure 8.2.4.3b according to Veff value at each depth and the curve "*a*" corresponding to non-tapered steel piles and curve "g" for the tapered steel pipe section of the pile. The value of the correction factor C_f is calculated through the use of Figure 8.2.4.4 according to the previously selected δ/φ_f value and the soil friction angle ϕ=30°.

The calculation of the nominal side stress is accomplished according to equation (1) for the different depths along the pile foundation according to the meshing discretization provided by DeepFND in the stress point results menu. The calculation results along with the nominal side stress provided by DeepFND are illustrated in a tabulated form in Table 8.2.4.

Table 8.2.4: tabulated results nominal shear stress calculation

Li	**V.pile**	σv'	Li	δ/f	Cf	Kδ	ω	δ	Analytical qs	**qs (DeepFND)**
-5.00	0.51	0.60	0.25	0.47	0.72	0.995	0.00	13.95	0.10	0.11
-5.25	0.50	0.63	0.25	0.76	0.9	2.46	0.54	22.80	0.55	0.58
-5.50	0.49	0.66	0.25	0.76	0.90	2.46	0.54	22.74	0.58	0.60
-5.75	0.49	0.69	0.25	0.76	0.90	2.46	0.54	22.69	0.60	0.63
-6.00	0.48	0.72	0.25	0.75	0.90	2.46	0.54	22.63	0.63	0.65
-6.25	0.48	0.75	0.25	0.75	0.90	2.46	0.54	22.58	0.65	0.67
-6.50	0.47	0.78	0.25	0.75	0.90	2.46	0.54	22.52	0.67	0.70
-6.75	0.47	0.81	0.25	0.75	0.89	2.46	0.54	22.46	0.70	0.72
-7.00	0.46	0.84	0.25	0.75	0.89	2.46	0.54	22.41	0.72	0.74
-7.25	0.46	0.87	0.25	0.75	0.89	2.46	0.54	22.35	0.74	0.76
-7.50	0.45	0.90	0.25	0.74	0.89	2.46	0.54	22.30	0.77	0.79
-7.75	0.45	0.93	0.25	0.74	0.89	2.46	0.54	22.24	0.79	0.81
-8.00	0.44	0.96	0.25	0.74	0.89	2.46	0.54	22.18	0.81	0.83
-8.25	0.44	0.99	0.25	0.74	0.89	2.46	0.54	22.13	0.83	0.85
-8.50	0.43	1.02	0.25	0.74	0.89	2.46	0.54	22.07	0.86	0.87
-8.75	0.43	1.05	0.25	0.73	0.89	2.46	0.54	22.02	0.88	0.89
-9.00	0.42	1.08	0.25	0.73	0.89	2.46	0.54	21.96	0.90	0.91
-9.25	0.42	1.11	0.25	0.73	0.88	2.46	0.54	21.91	0.92	0.93
-9.50	0.42	1.14	0.25	0.73	0.88	2.46	0.54	21.85	0.94	0.95
-9.75	0.41	1.17	0.25	0.73	0.88	2.46	0.54	21.79	0.97	0.97
-10.00	0.41	1.20	0.25	0.72	0.88	2.46	0.54	21.74	0.99	0.99
-10.25	0.40	1.23	0.25	0.72	0.88	2.46	0.54	21.68	1.01	1.01
-10.50	0.40	1.26	0.25	0.72	0.88	2.46	0.54	21.63	1.03	1.03
-10.75	0.39	1.29	0.25	0.72	0.88	2.46	0.54	21.57	1.05	1.05
-11.00	0.39	1.32	0.25	0.72	0.88	2.46	0.54	21.51	1.07	1.07
-11.25	0.38	1.35	0.25	0.72	0.88	2.46	0.54	21.46	1.09	1.09
-11.50	0.38	1.38	0.25	0.71	0.88	2.46	0.54	21.40	1.11	1.10
-11.75	0.37	1.41	0.25	0.71	0.88	2.46	0.54	21.35	1.13	1.12
-12.00	0.37	1.44	0.25	0.71	0.87	2.46	0.54	21.29	1.15	1.14
-12.25	0.36	1.47	0.25	0.71	0.87	2.46	0.54	21.23	1.17	1.16
-12.50	0.36	1.50	0.25	0.71	0.87	2.46	0.54	21.18	1.19	1.17
-12.75	0.36	1.53	0.25	0.70	0.87	2.46	0.54	21.12	1.21	1.19
-13.00	0.35	1.56	0.25	0.70	0.87	2.46	0.54	21.07	1.23	1.21
-13.25	0.35	1.59	0.25	0.70	0.87	2.46	0.54	21.01	1.25	1.22
-13.50	0.34	1.62	0.25	0.70	0.87	2.46	0.54	20.95	1.27	1.24
-13.75	0.34	1.65	0.25	0.70	0.87	2.46	0.54	20.90	1.29	1.25
-14.00	0.33	1.68	0.25	0.69	0.87	2.46	0.54	20.84	1.31	1.27
-14.25	0.33	1.71	0.25	0.69	0.87	2.46	0.54	20.79	1.33	1.28
-14.50	0.33	1.74	0.25	0.69	0.87	2.46	0.54	20.73	1.35	1.30
-14.75	0.32	1.77	0.25	0.69	0.87	2.46	0.54	20.67	1.36	1.31
-15.00	0.32	1.80	0.25	0.69	0.86	2.46	0.54	20.62	1.38	1.33
-15.25	0.31	1.83	0.25	0.69	0.86	2.46	0.54	20.56	1.40	1.34
-15.50	0.31	1.86	0.25	0.68	0.86	2.46	0.54	20.51	1.42	1.36
-15.75	0.30	1.89	0.25	0.68	0.86	2.46	0.54	20.45	1.44	1.37
-16.00	0.30	1.92	0.25	0.68	0.86	2.46	0.54	20.39	1.45	1.38
-16.25	0.30	1.95	0.25	0.68	0.86	2.46	0.54	20.34	1.47	1.41
-16.50	0.29	1.98	0.25	0.68	0.86	2.46	0.54	20.28	1.49	1.43
-16.75	0.29	2.01	0.25	0.67	0.86	2.46	0.54	20.23	1.51	1.45
-17.00	0.28	2.04	0.25	0.67	0.86	2.46	0.54	20.17	1.52	1.47
-17.25	0.28	2.07	0.25	0.67	0.86	2.46	0.54	20.12	1.54	1.49
-17.50	0.28	2.10	0.25	0.67	0.86	2.46	0.54	20.06	1.56	1.51
-17.75	0.27	2.13	0.25	0.67	0.86	2.46	0.54	20.00	1.57	1.53
-18.00	0.27	2.16	0.25	0.66	0.86	2.46	0.54	19.95	1.59	1.55
-18.25	0.27	2.19	0.25	0.66	0.85	2.46	0.54	19.89	1.61	1.57
-18.50	0.26	2.22	0.25	0.66	0.85	2.46	0.54	19.84	1.62	1.59
-18.75	0.26	2.25	0.25	0.66	0.85	2.46	0.54	19.78	1.64	1.61
-19.00	0.25	2.28	0.25	0.66	0.85	2.46	0.54	19.72	1.66	1.63
-19.25	0.25	2.31	0.25	0.66	0.85	2.46	0.54	19.67	1.67	1.65
-19.50	0.25	2.34	0.25	0.65	0.85	2.46	0.54	19.61	1.69	1.67
-19.75	0.24	2.37	0.25	0.65	0.85	2.46	0.54	19.56	1.70	1.69
-20.00	0.24	2.40	0.13	0.65	0.85	2.46	0.54	19.50	1.72	1.71

Both the nominal side stress derived directly from the guidelines of [1] along with the nominal side stress results produced by DeepFND are illustrated relatively to the depth of the pile in Figure 8.2.4.5.

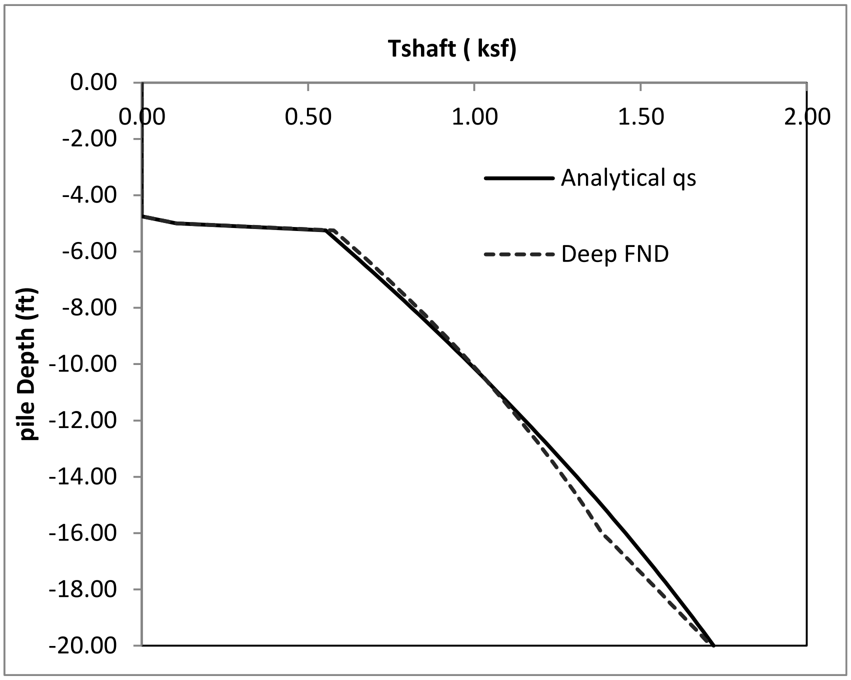


Figure 8.2.4.6: Comparison of the nominal side stress for both the analytical approach and DeepFND

8.3 FHWA Methods for Drilled Piles

For drilled piles DeepFND incorporates recommendations suggested by FHWA GEC10 (FHWA-NHI-10-016, May 2010).

FHWA GEC10 recommends using Mayne and Kulhawy, 1982, for estimating lateral pressure coefficients on piles:

$$K_o = (1 - \sin \phi')\ OCR^{\sin \phi'} \leq K_p \qquad 13\text{-}8$$

$$OCR = \frac{\sigma'_p}{\sigma'_v} \qquad 13\text{-}9$$

The above values are to be limited by the Rankine Kp value for horizontal ground conditions.

The maximum past pressure may be estimated from SPT according to Mayne 2007:

$$\frac{\sigma'_p}{p_a} \approx 0.47 (N_{60})^m$$

Where m= 0.6 for clean quarzitic z ands and m=0.8 for silty sands to sandy silts (e.g. Piedmont residual soils). For gravelly soils Kulhawy and Chen (2007) suggested the following equation:

$$\frac{\sigma'_p}{p_a} = 0.15 N_{60}$$

For the beta method, this can result in the following equation:

$$\beta \approx (1 - \sin\phi') \left(\frac{\sigma'_p}{\sigma'_v}\right)^{\sin\phi'} \tan\phi' \qquad \leq K_p \tan\phi'$$

For bearing resistance, Reese and O'Neil (1989) recommended the following equation for routine design:

$$q_{BN}\ (tsf) = 0.60\ N_{60} \qquad \leq 30\ tsf$$

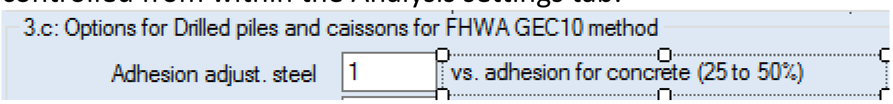
For cohesive soils, FHWA recommends ignoring adhesion over the top 5 ft of the pile. Thereafter, using the alpha method:

$$\alpha = 0.55 \text{ along remaining portions of the shaft for } \frac{s_u}{p_a} \leq 1.5$$

$$\alpha = 0.55 - 0.1\left(\frac{s_u}{p_a} - 1.5\right) \text{ along remaining portions of the shaft for } 1.5 \leq \frac{s_u}{p_a} \leq 2.5$$

p_a = atmospheric pressure in the same units as s_u (2,116 psf or 14.7 psi in U.S. customary units).

For steel portions FHWA GEC10 recommends an additional 50 o 75% reduction. This reduction is controlled from within the Analysis settings tab:



This reduction may also be applied for cased portion of caissons and micropiles.

The bearing resistance in clays can be calculated as:

$$q_{BN} = N^*_c\, s_u$$

TABLE 13-2 BEARING CAPACITY FACTOR N*C

Undrained shear strength, s_u (lb/ft^2)	$I_r \approx \dfrac{E_u}{3s_u}$	N^*_c
500	50	6.5
1,000	150	8.0
2,000	250 - 300	9.0

E_u = Undrained Young's Modulus

For side resistance in Rock, FHWA recommends:

$$\frac{f_{SN}}{p_a} = C\sqrt{\frac{q_u}{p_a}}$$

$$\frac{f_{SN}}{p_a} = 0.65\,\alpha_E\sqrt{\frac{q_u}{p_a}}$$

Where the side resistance reduction factor is determined from the following table:

TABLE 13-3 SIDE RESISTANCE REDUCTION FACTOR FOR ROCK

RQD (%)	Joint Modification Factor, φ	
	Closed joints	Open or gouge-filled joints
100	1.00	0.85
70	0.85	0.55
50	0.60	0.55
30	0.50	0.50
20	0.45	0.45

The base resistance in rock is defined from:

$$q_{BN} = N^*_{cr}\, q_u$$

The standard recommended value for N*cr is 2.5 where qu is the sole parameter used for design, although the mean value was reported as 3.56 with a COV of 61.0%.

For cohesive IGM (Fine-Grained Sedimentary Rock):

$$f_{SN} = \alpha \varphi q_u$$

Where:

q_u = compressive strength of intact rock,
φ = a correction factor to account for the degree of jointing, and
α = empirical factor given in Figure 13-9.

Where:

$$\sigma_n = 0.65\, \gamma_c\, z_i^*$$

Z^*_1 is the fluid pressure of the concrete at a middle of a layer, with the depth z limited to 40ft.

$$\alpha = \alpha_{Figure13-8} \frac{\tan\phi_{rc}}{\tan 30^{\circ}} \quad 13\text{-}27$$

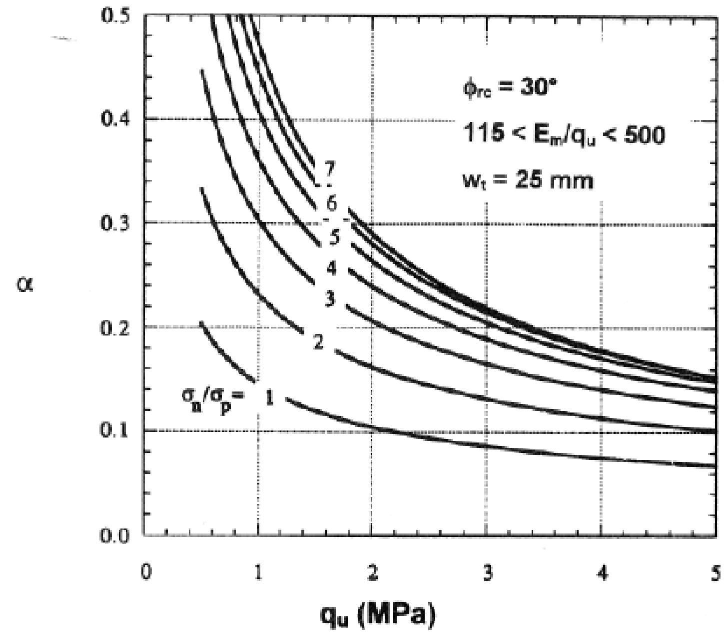


Figure 13-9 Factor α for Cohesive IGM (O'Neill et al. 1996) (25 mm = 1 inch; 1 MPa = 20.9 ksf)

8.4 FHWA methods for CFA and Drilled-In-Displacement piles

For pile adhesion FHWA recommends using the tri-linear relationship from FHWA 1999, similar to the one outline before for drilled piles. End bearing in clays is also treated in a similar way with FHWA GEC10:

$$N_c^* = 9$$

for 200 kPa (2 tsf) $\leq S_u \leq$ 250 kPa (2.6 tsf), and $L \geq 3D$, or

$$N_c^* = \frac{4}{3}\left[\ln I_r + 1\right] \qquad \text{(Equation 5.9)}$$

for $S_u <$ 200 kPa (2 tsf), and $L \geq 3D$.

where L is the pile embedment length below top of grade, and I_r is the rigidity index.

Note that values of S_u greater than 250 kPa (2.6 tsf) are treated as intermediate geo-materials in accordance with O'Neill and Reese (1999). The rigidity index (I_r) is calculated as follows:

$$I_r = \frac{E_S}{3S_u} \qquad \text{(Equation 5.10)}$$

The alternative methods for side-shear estimates using the undrained shear strength can also be used. The method by Coleman and Acrement (2002) was derived from pile load tests conducted in mixed soil conditions of mostly alluvial and loessial deposits and interbedded sands and clays in Mississippi and Louisiana:

$$f_S = \alpha\, S_u \qquad \text{(Equation 5.12)}$$

$$\alpha = \frac{56.2}{S_u} \quad (S_u \text{ in kPa}) \qquad \text{(Equation 5.13a)}$$

$$\alpha = \frac{0.56}{S_u} \quad (S_u \text{ in tsf}) \qquad \text{(Equation 5.13b)}$$

For the TXDOT 1971 method, a single adhesion factor of 0.7 can be applied with a maximum value of 1.25 tsf (to be manually controlled by the user).

For cohesionless soil, FHWA 1999 recommends:

$$f_s = K\,\sigma_v'\tan\phi \quad \le \quad 200\text{ kPa }(2.0\text{ tsf}) \qquad \text{(Equation 5.17)}$$

Where K is the lateral earth pressure coefficient, σ'_v is the vertical effective stress, and ϕ is the soil drained angle of internal friction. The β factor is defined as:

$$\beta = K\tan\phi \qquad \text{(Equation 5.18)}$$

and is limited to $0.25 \le \beta \le 1.2$. The β factor for a pile segment is estimated as:

$$\beta = 1.5 - 0.135\cdot Z^{0.5} \qquad \text{for } N \ge 15 \text{ bpf} \qquad \text{(Equation 5.19a)}$$

$$\beta = \frac{N}{15}\left(1.5 - 0.135\,Z^{0.5}\right) \qquad \text{for } N < 15 \text{ bpf} \qquad \text{(Equation 5.19b)}$$

where Z is the depth (in feet) from the ground surface to the middle of a given soil layer or pile segment.

In the FHWA 1999 method, the ultimate unit end-bearing resistance (q_p) is estimated as:

$$q_p\text{ (tsf)} = 0.6N_{60} \qquad \text{for } 0 \le N_{60} \le 75 \qquad \text{(Equation 5.20a)}$$

$$q_p = 4.3\text{ MPa [45 tsf]} \qquad \text{for } N_{60} > 75 \qquad \text{(Equation 5.20b)}$$

For the alternative method by Coleman and Acrement (2002), using SPT values:

$$f_s = \beta\,\sigma_v \le 200\text{ kPa }(2.0\text{ tsf}) \qquad \text{(Equation 5.21)}$$

The values of β are computed as follows:

$$\beta = 2.27\,Z_m^{-0.67} \qquad \text{(for silty soils)} \qquad \text{(Equation 5.22)}$$

$$\beta = 10.72\,Z_m^{-1.3} \qquad \text{(for sandy soils)} \qquad \text{(Equation 5.23)}$$

Where Z_m is the depth (in meters) from the ground surface to the middle of a given soil layer or pile segment. The values of β are limited to $0.2 \le \beta \le 2.5$.

For other SPT methods:

$$f_S \text{ (tsf)} = 0.05\ N + W_S \qquad \text{for } N \leq 50 \qquad \text{(Equation 5.29)}$$

where the correlation constant (W_s) and limiting ultimate unit side-shear (f_s) are as follows:

- $W_s = 0$, and $f_s \leq 0.16$ MPa (1.7 tsf) for uniform, rounded materials having up to 40% fines.
- $W_s = 0.05$ MPa (0.5 tsf) and $f_s \leq 0.21$ MPa (2.2 tsf) for well-graded angular materials having up to 10% fines.
- For soil conditions with material properties falling between the provided ranges, a linear interpolation between the limiting values should be made.

For tip resistance:

$$q_p = 0.4\ q_c + W_T < 19 \text{ MPa (200 tsf)} \qquad \text{(Equation 5.30)}$$

$$q_p \text{ (MPa or tsf)} = 0.19\ N_{60} + W_T \qquad \text{for } N_{60} \leq 50 \qquad \text{(Equation 5.31)}$$

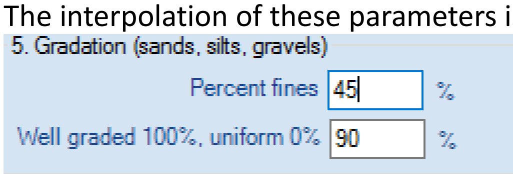
where the constant (W_T) is as follows:

$W_T = 0$, for $q_p \leq$ 7.2 MPa (75 tsf) and uniform, rounded materials having up to 40% fines.

$W_T = 1.34$ MPa (14 tsf), for $q_p \leq 8.62$ MPa (89 tsf) and well-graded angular materials having up to 10% fines.

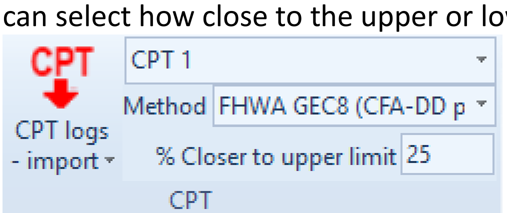
For soil conditions with material properties falling between the ranges provided above, a linear interpolation between the limiting values should be made.

The interpolation of these parameters is controlled from user input in the soils tab:

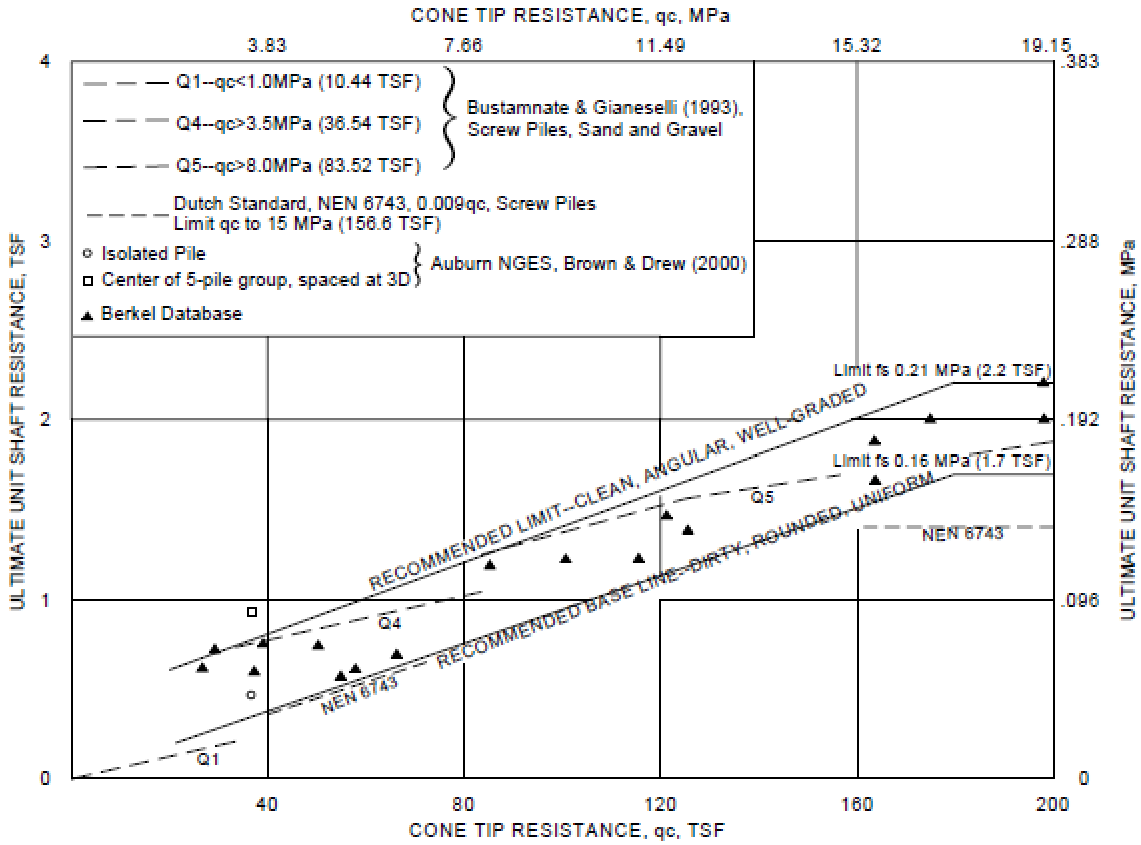


This previous interpolation should be treated as approximate.

For CPT test data methods, DeepFND can utilize the recommended methods. The user though can select how close to the upper or lower limit the estimation should be from:

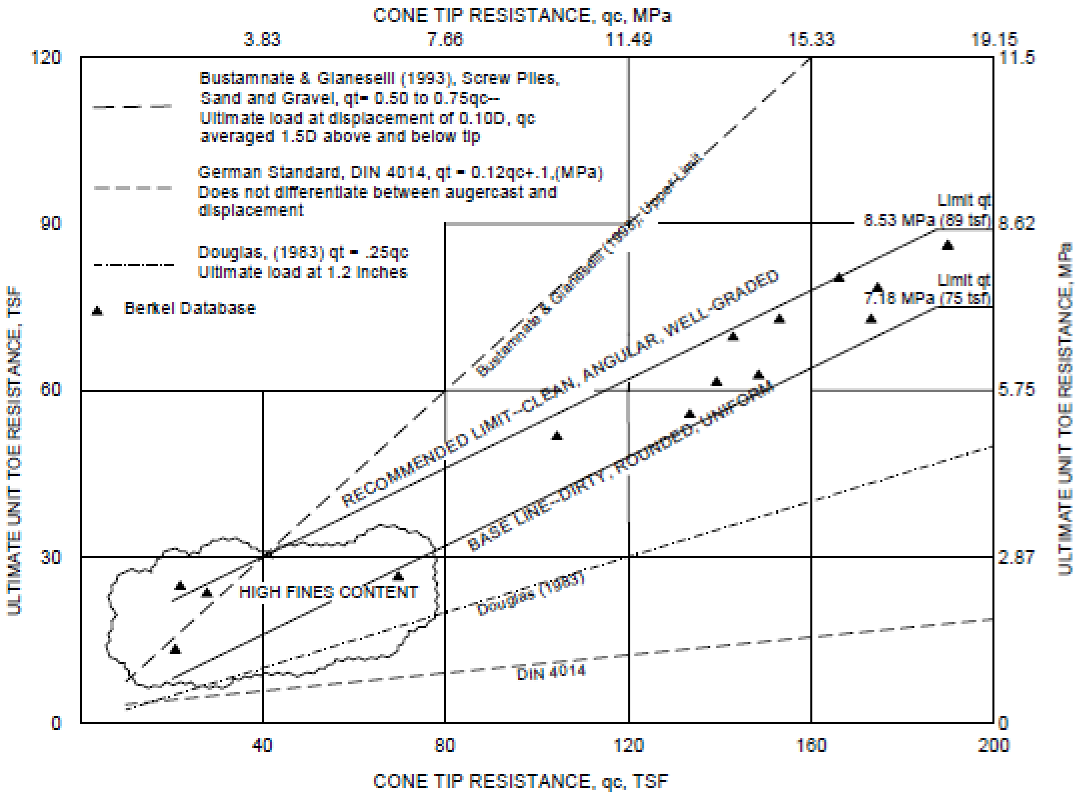


The default value is 25% above the lower recommended limit, 100% will produce the upper limit for both the shaft and the bearing resistance.



(a) Correlated to CPT Testing

Figure 8.4.1: Ultimate Unit Side-Shear Resistance for Drilled Displacement Piles for NeSmith (2002) Method



(a) Correlated to CPT Testing

Figure 8.4.2: Ultimate Unit End-Bearing Resistance for Drilled Displacement Piles for NeSmith (2002) Method

8.5 Axial structural capacity with building codes

Axial pile capacity can be calculated using predefined building code standards. Currently DeepFND incorporates IBC and NYC building code standards. For the NYC building code:

TABLE 1808.8
ALLOWABLE STRESSES FOR MATERIALS USED IN PILES

MATERIAL TYPE AND CONDITION	MAXIMUM ALLOWABLE STRESS[a]
1. Concrete or grout in compression[b]	
Cast-in-place with a permanent casing in accordance with Section 1810.5.2	$0.4\,f'_c$
Cast-in-place in a pipe, tube, other permanent casing or rock	$0.33\,f'_c$
Cast-in-place without a permanent casing	$0.3\,f'_c$
Precast nonprestressed	$0.33\,f'_c$
Precast prestressed	$0.33\,f'_c - 0.27\,f_{pc}$
2. Nonprestressed reinforcement in compression	$0.4\,f_y \leq 30{,}000$ psi
3. Structural steel in compression	
Cores within concrete-filled pipes or tubes	$0.5\,F_y \leq 32{,}000$ psi
Pipes, tubes or H-piles, where justified in accordance with Section 1808.2.10	$0.5\,F_y \leq 32{,}000$ psi
Pipes or tubes for micropiles	$0.4\,F_y \leq 32{,}000$ psi
Other pipes, tubes or H-piles	$0.35\,F_y \leq 16{,}000$ psi
Helical piles	$0.6F_y \leq 0.5F_u$
4. Nonprestressed reinforcement in tension	
Within micropiles or caissons less than 14 inches in diameter	$0.6\,f_y$
Other conditions	$0.5\,f_y \leq 24{,}000$ psi
5. Structural steel in tension	
Structural steel cores in caisson piles,	$0.5\,F_y \leq 32{,}000$ psi
Pipes, tubes or H-piles, where justified in accordance with Section 1808.2.10	$0.5\,F_y \leq 32{,}000$ psi
Other pipes, tubes or H-piles	$0.35\,F_y \leq 16{,}000$ psi
Helical piles	$0.6\,F_y \leq 0.5F_u$
6. Timber	See Section 1809.5.4

For SI: 1 pound per square inch = 6.895 kPa.

a. f'_c is the specified compressive strength of the concrete or grout; f_{pc} is the compressive stress on the gross concrete section due to effective prestress forces only; f_y is the specified yield strength of reinforcement; F_y is the specified minimum yield stress of structural steel; F_u is the specified minimum tensile stress of structural steel.

b. The stresses specified apply to the gross cross-sectional area within the concrete surface. Where a temporary or permanent casing is used, the inside face of the casing shall be considered the concrete surface.

For IBC:

TABLE 1810.3.2.6 ALLOWABLE STRESSES FOR MATERIALS USED IN DEEP FOUNDATION ELEMENTS

MATERIAL TYPE AND CONDITION	MAXIMUM ALLOWABLE STRESS[a]
1. Concrete or grout in compression[b]	
Cast-in-place with a permanent casing in accordance with Section 1810.3.2.7	$0.4 f'_c$
Cast-in-place in a pipe, tube, other permanent casing or rock	$0.33 f'_c$
Cast-in-place without a permanent casing	$0.3 f'_c$
Precast nonprestressed	$0.33 f'_c$
Precast prestressed	$0.33 f'_c - 0.27 f_{pc}$
2. Nonprestressed reinforcement in compression	$0.4 f_y \le 30{,}000$ psi
3. Steel in compression	
Cores within concrete-filled pipes or tubes	$0.5 F_y \le 32{,}000$ psi
Pipes, tubes or H-piles, where justified in accordance with Section 1810.3.2.8	$0.5 F_y \le 32{,}000$ psi
Pipes or tubes for micropiles	$0.4 F_y \le 32{,}000$ psi
Other pipes, tubes or H-piles	$0.35 F_y \le 16{,}000$ psi
Helical piles	$0.6 F_y \le 0.5 F_u$
4. Nonprestressed reinforcement in tension	
Within micropiles	$0.6 f_y$
Other conditions	$0.5 f_y \le 24{,}000$ psi
5. Steel in tension	
Pipes, tubes or H-piles, where justified in accordance with Section 1810.3.2.8	$0.5 F_y \le 32{,}000$ psi
Other pipes, tubes or H-piles	$0.35 F_y \le 16{,}000$ psi
Helical piles	$0.6 F_y \le 0.5 F_u$
6. Timber	In accordance with the ANSI/AWC NDS

a. f'_c is the specified compressive strength of the concrete or grout; f_{pc} is the compressive stress on the gross concrete section due to effective prestress forces only; f_y is the specified yield strength of reinforcement; F_y is the specified minimum yield stress of steel; F_u is the specified minimum tensile stress of structural steel.

b. The stresses specified apply to the gross cross-sectional area within the concrete surface. Where a temporary or permanent casing is used, the inside face of the casing shall be considered the concrete surface.

Alternatively, structural capacity is determined by the concrete, steel, or timber design code that is utilized assuming an appropriate safety factor.

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