Pile Foundation PFAHL+

Contents

Basic Documentation – Overview

In addition to the individual program manuals, you will find basic explanations on the operation of the programs on our homepage www.frilo.com in the Campus-download-section.

Application options

The new FRILO program PFAHL+ allows you to verify the internal and external load-bearing capacity of bored piles with rectangular and circular cross-sections.

Via interfaces to the proven FRILO programs Soil Settlement (SBR+) and Earth Pressure Calculation (EDB+), both the soil settlements in the pile environment and the lateral earth pressure acting on the piles can be taken into account. By comparing the pile settlements and the soil settlements along the pile skin surface, an action from negative skin friction up to the neutral point can be optionally applied.

The axial pile resistances, due to skin friction and end-bearing pressure, can optionally be determined either by evaluating static or dynamic pile test loads or based on empirical values given by the recommendations of the pile work group "EA-Pfähle" separately for the serviceability limit state (SLS) and the ultimate limit state (ULS). The recommendations on piles are published by the German Geotechnical Society DGGT. For a resulting tensile load in the pile, the axial pile resistances from skin friction are verified analogously. For tension piles, the verification of the safety against uplift (UPL) is optionally performed with the help of an attached soil prism.

In the verification of the external pile load-bearing capacity in the horizontal direction, the user-defined pile foundation is relocated to deeper soil layers until the resulting foundation stresses no longer exceed the maximum earth resistance stresses.

The design of the reinforced concrete cross-sections is performed on the basis of a non-linear calculation with consideration of second-order additional loads and the actual pile stiffnesses due to freely selectable reinforcement.

Available standards

- DIN EN 1997 / DIN EN 1992
- ÖNORM EN 1997 / ÖNORM EN 1992

Model

The user can define any number of horizontal soil layers and an aquifer.

The pile system can consist of a single pile or a group of piles with circular or rectangular cross-sections. The design is always performed for a single pile without giving consideration to any effect of the pile group. By defining a group of piles, the decisive lateral earth pressure acting on a single pile can be determined in accordance with the recommendations on piles. The user can optionally take a toe expansion for circular piles into account.

Loading and superposition

For the calculation of the soil settlements in the environment of the pile shaft, the user can define a surface load over a wide area.

Optionally, the self-weight of the piles can be included automatically.

The user can define the external loads acting on the piles either as vertical head loads, optionally also in connection with an eccentricity, or as horizontal head loads or also as head moments related to the main axes in the x- or y-direction in each case.

The number of load cases and their kind of action are freely selectable.

Automatic superposition of the load cases according to the applicable superposition rules is also integrated.

The application of variable loads and the number of decisive design load combinations can be controlled via the assignment of variable loads to alternative and concurrency groups.

Optionally, additional loading due to negative skin friction can be taken into account up to the neutral point if the soil settlements in the area of the pile skin surface are greater than the pile settlements. As a calculation approach, both a direct specification of the negative skin friction force and an automatic calculation (via interface to the Soil Settlement program SBR+) using pile and soil settlements are available for selection. In

this calculation, a distinction is always made between the two limit states ULS (Ultimate Limit State) and SLS (Serviceability Limit State).

Optionally, the user can define an action from lateral earth pressure acting on the piles in the x- or y-direction. When doing so, he/she can either take any user-defined load polygons into account or have the decisive lateral earth pressure automatically calculated from flow pressure or earth pressure via the interface to the Earth Pressure Calculation program EDB+.

Result options

The user can display all results as graphics or tables with a well-structured result list that is customizable in terms of scope and details. Especially the following results are put out:

- Comparison of pile settlement and soil settlement with representations of the neutral points in the serviceability and ultimate limit states for the derivation of negative skin friction.
- Mapping of the resistance settlement curve for the point-bearing pressure, the skin friction and the pile bearing capacity derived from empirical values or test loading.
- Design internal forces for compression and tension piles in the serviceability limit state (SLS) and the ultimate limit state (ULS).
- Mobilised foundation stresses, both in the direction of the main axes and as a resultant.
- Superposition of the foundation stresses with the earth resistance to represent the required stress limitation and the relocations of the foundation stresses to greater depth, if applicable.
- Deformation of the pile along the main axes in the serviceability limit state SLS.
- Representation of the selected and/or required reinforcement.

Planned extensions

In a subsequent version, additional pile systems (such as pre-fabricated driven piles, in-situ concrete piles, partial displacement piles, screw piles, displacement piles and micropiles) will be added. Most importantly, the empirical values for skin friction and point-bearing pressure given in the tables in section 5.4 of the recommendations on piles “EA-Pfähle” will be implemented for these systems, so that the decisive resistances can be automatically derived from the characteristic values of the undrained shear strength $c_{u,k}$ or the mean point-bearing resistance q_c of the pressure probe for each soil layer. For the design of the internal load-bearing capacity of these pile systems, a steel design feature will be implemented in addition.

Moreover, the evaluation of dynamic pile test loading will be implemented in addition to allow the derivation of the decisive pile resistances.

Also, the calculation of pile groups with consideration of the group effects is being planned in order to simulate the different load-bearing behaviour of the individual piles within a group. In this connection, a polygonal soil layer and topographical model will then also be available to consider different soil stratifications along individual piles within the group.

Interfaces to other programs

- Soil Settlement SBR+ (calculation of the decisive settlement in the pile environment to determine the negative skin friction)
- Earth Pressure Calculation EDB+ (calculation of the decisive lateral earth pressure and the earth resistances)
- Reinforced Concrete Column B5+ (calculation of the pile as a column on elastic foundation)
- Interface from GEO/PLT to Pfahl+: Piles below floor slabs can be modelled this way, loads from the floor slab can be passed on to the piles. When called from the building model, support springs are returned to the building model after the calculation.

Basis of calculation

The basis of calculation is described in the separate (german) document.

Data entry

General operating instructions

Wizard

The wizard is launched automatically when you start the program.
You can enter quickly the most important key figures of the structural system in the displayed window. These values can be edited subsequently in the input section or on the Graphical User Interface (GUI).
Self-defined items can be imported as templates. To save them as a template go to ▸ File ▸ Save as ▸ and select the option “Use as template”.

Graphical user interface GUI

See Definition options in the graphical user interface.

See also Graphical User Interface (GUI) in the Basic Operating Instructions-PLUS.

Interactive dimensional chains

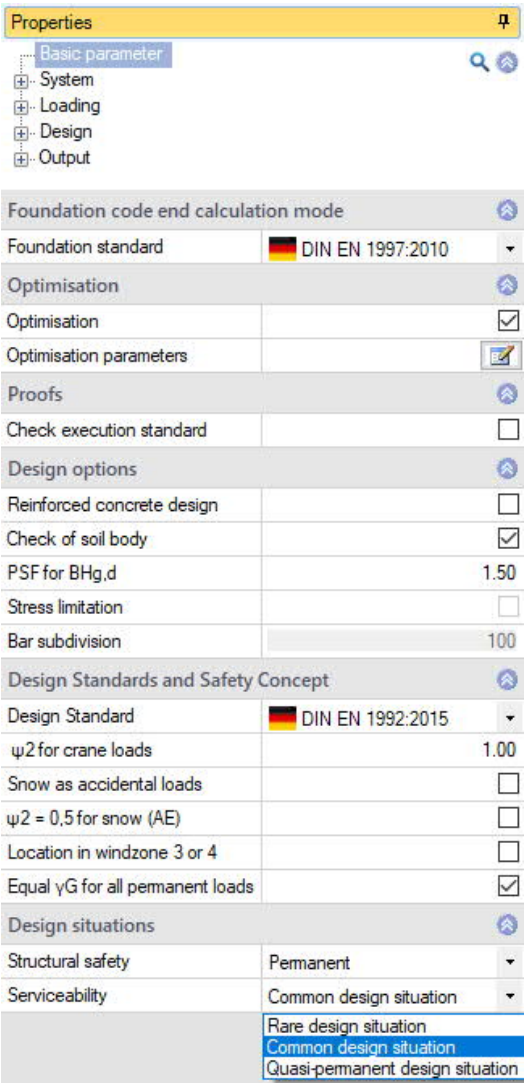
As in all Plus programs, the dimensional values are editable and can be changed directly in the graphical user interface.

Interactive texts

The texts displayed in the top left section of the GUI are interactive as in all PLUS programs and can be clicked on. This allows you to display dialogs in the GUI, which are otherwise only accessible via the menu on the left.
See also the Basic Operating Instructions-PLUS.

Basic parameters

Geotechnical Standards and calculation mode



Foundation standard — definition of the standard and its national annex.
- DIN EN 1997
- ÖNORM EN 1997

Optimisation

Optimisation — Check this option if the geometry of the pile is to be adjusted for the geotechnical verifications, if necessary.

Optimisation parameters — Click the edit button to display the dialog for the optimisation parameters. Here you define how the pile geometry is to be optimised:
Via the shaft length, the cross-section or both. Please note the information on the individual parameters displayed in the lower part of the window.

Proofs

Check execution standard — Check this option if the boundary conditions of the execution standard are to be checked.

Design options

Reinforced concrete design — check this option to perform a reinforced concrete design.

Check soil body — check this option if you want to perform a verification in the limit state UPLIFT for tension piles.

PSF for BHg,d — partial safety factor for the determination of the design value of the resulting soil resistance force.

Stress limitation — if you check this option, the soil stresses are limited automatically for the verification of laterally loaded piles. Currently, this option is only available for testing customers. The general activation of this option will come with the next release. Would you like to become a testing customer? If so, please contact our hotline.

Design Standard and Safety Concept

Design standard — select the load design standard the structural safety analysis is based on. If you use Eurocodes and specify the national version the associated National Annex is also referred to. Currently, the reinforced concrete based on DIN EN 1992, ÖNORM EN 1992 or BS EN 1992 is supported.

ψ2 for crane loads — combination coefficient ψ2 for crane loads (relation of the permanent portion to the total crane load).

Snow as accidental load — when you check this option, snow loads are considered as accidental action in addition to the common design situations.

Load factor for snow (A) — this factor is used to take the accidental snow load related to its characteristic value into account. You can freely specify it (check option, to enter the value) or have it automatically calculated by the program.

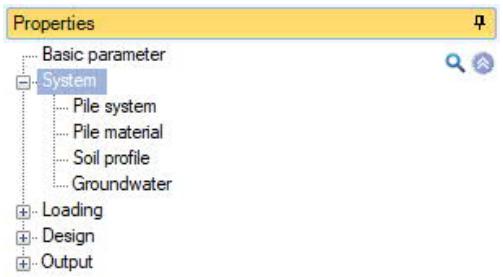
ψ2 = 0.5 for snow	check this option to increase the value of the combination coefficient ψ2 to 0.5 for snow action in the seismic design situation (AE). (See introductory decrees of the German federal states, e. g. Baden-Württemberg).
Located in wind zone	check this option, if the building is located in wind zone 3 or 4. In this case, 'snow' is not considered as an accompanying action to 'wind', which is the leading action.
Equal γG	if this option is checked, all permanent loads or load cases are applied together with the same partial safety factor (γG,sup or γG,inf), otherwise permanent loads are combined independently with their lower and upper partial safety factors.

Design situations

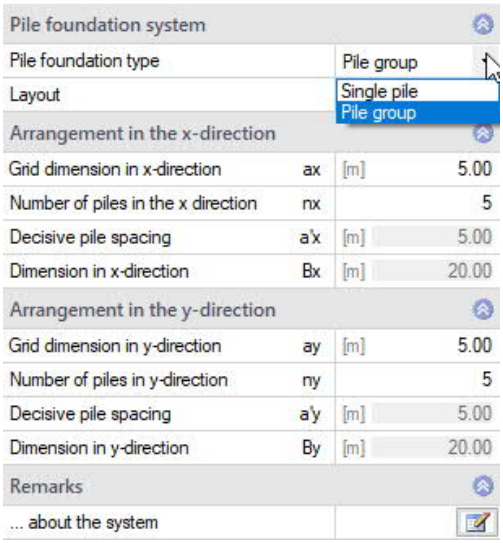
Structural safety	Selection of the design situation for the structural safety checks (permanent, transient).
Serviceability	Selection of the design situation for the serviceability checks (rare, common, quasi-permanent).

Structural system

Pile foundation system



Pile foundation type	select whether a single pile or a group of piles is used.
Attached soil body	when you enable the check of the soil body in the basic parameters, you can specify here the width of the attached soil body in the x- and y-direction for the uplift verification of an individual pile.



Group of piles

Layout	in a row or staggered (offset).

Arrangement in the x-direction or y-direction:

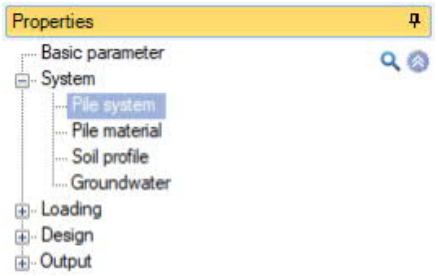
Grid dimension	mean spacing of the piles.
Number of piles	number of piles in the group per direction.

The decisive pile spacing and the dimensions are displayed as information.

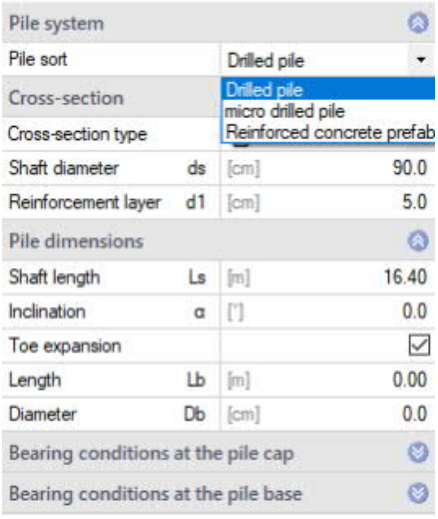
Remarks

You can optionally enter comments on the system that are subsequently included in the output.
See also Remarks Editor.

Pile system

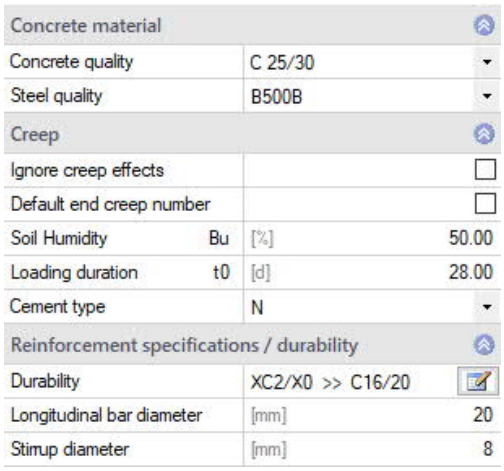


Type of pile (sort)	Selection of the type: drilled (bored) / micro drilled / reinforced concrete prefabricated.
Type of cross-section	the reinforced concrete pile can have a rectangular or circular cross-section.
Shaft diameter	diameter of the circular bored pile.
Width/height	dimensions of a rectangular pile cross-section.
Reinforcement layer	definition of the reinforcement layer in all directions by specifying the distance between the adjacent outer surface and the centre of gravity of the longitudinal reinforcement bars.
Shaft length	shaft length of the bored pile (without expanded bottom end).
Inclination	angle between member axis and vertical.
Toe expansion	check this option if the bored pile shall be installed with an expanded bottom at its toe (only available for circular cross-sections). Length: definition of the length of the toe expansion of a bored pile. Diameter: diameter of the toe expansion of a bored pile.
Bearing conditions	Discrete bearing condition for translation/rotation (rigid, 0 = free, > 0 elastically supported).



Pile material

Selection option for the concrete quality or the steel grade.



Creep

Ignore creep effects — this option disables the option (and the data-entry fields) for the inclusion of any creep effects.

Pre-set final creep factor — check the option to specify a user-defined factor. Otherwise, it is calculated automatically using ambient parameters. Default value for the final creep factor of concrete; increase factor applied to the final creep factor to account for non-linear creep Background information: The final creep factor as a material parameter is determined for a permanent load level of approx. 45 % of the compressive concrete strength. If the permanent load level is higher, an increased creep factor must be used in the calculation in accordance with EN 1992-1-1, 3.1.4. If the verification whether the inclusion of linear creep is permissible fails in a first calculation run, you can specify here the necessary increase factor as per EN 1992-1-1, 3.1.4 (4), Eq. 3.7.

Soil Humidity — relative humidity of the ambient air in per cent.

Loading duration — concrete age in days at the time when the load is applied.

Cement type — type of cement in accordance with EN 1992, N, R or S.

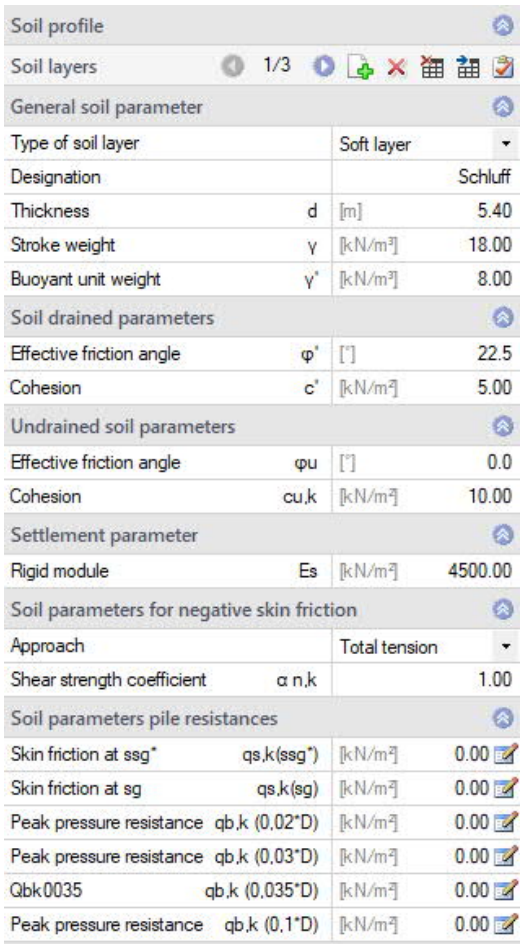
Reinforcement specifications /durability

Durability — accesses the durability dialog where you can define the parameters – see the document Durability - Creep Factor and Shrinkage Strain.pdf".

Bar/stirrup diameter — diameter of the longitudinal reinforcement bars or the stirrups. This diameter is used as a basic value when starting the calculation on the cross-section (exposure classes, reinforcement layer). The final diameter is determined when working through the reinforcement layout after the calculation.

Soil profile

You can define the soil layers directly in the left menu (see Basic Operating Instructions-PLUS – Data-entry via tables) or via a well-structured table. To access the table, click on the “Soil layers” tap below the GUI.



General soil parameters

Type of soil layer	the available options to define a soil layer are the following: - backfill, - soft layer or - base course (bearing layer).
Designation	designation of the soil layer.
Thickness	specification of the thickness of the soil layer.
Specific weight	specific weight γ of the soil.
Specific weight under buoyancy	specific weight γ' of the soil layer under buoyancy.

Parameters of the drained/undrained soil

Friction angle	characteristic value of the internal friction angle of the drained/undrained soil.
Cohesion	cohesion of cohesive soils in drained/undrained condition.

Settlement parameter

Stiffness modulus	stiffness modulus E_s of the selected soil layer.

Soil parameters for negative skin friction

Approach	you can select whether the characteristic values of the negative skin friction shall be specified by the user or be determined using the effective stress method or total stress method.
Shear strength coefficient	coefficient for the shear strength to calculate negative skin friction in accordance with the total stress method. The magnitude of the factor α ranges from 0.15 to 1.60, depending on the kind of soil and the type of pile. It is often set to α = 1 often as an approximation. This value is generally recommended for cohesive soils.

Soil parameters pile resistances

Skin friction	Characteristic value of skin friction.
Peak pressure resistance	Characteristic value of peak pressure resistance for 0.02*D/0.03*D/0.1*D.

Groundwater

Groundwater	when you check this option, groundwater is considered.
Groundwater level	depth of the groundwater level, measured from the ground top edge.

Loading

Select in the left menu under Loads whether self-weight should be included in the calculation or not.

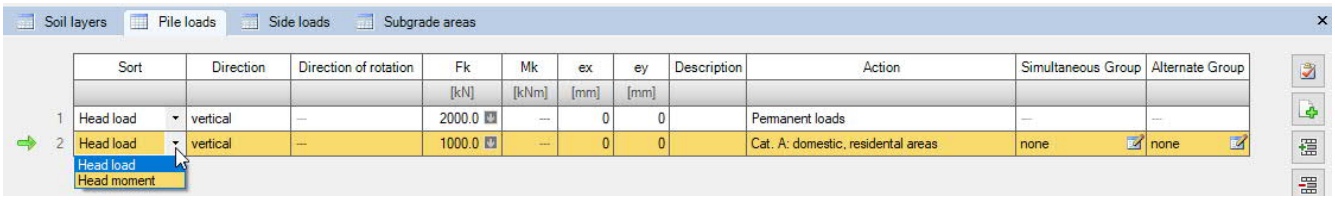
Surface load — specification of a permanent surface load applying to a large area. By clicking on the arrow icon you can access a load value compilation.

Remarks

You can optionally enter comments to the loads. These comments are included in the output.
See also Remarks Editor.

Pile loads

You can define pile loads in the left menu - see Data entry via tables in the Basic Operating Instructions-PLUS – or in a well-structured table accessible via the Pile loads tab below the GUI.



Type (Sort) — head load/head moment. Select whether the load is a force or a moment, the adjacent data-entry fields for the direction, the direction of rotation, the force F_k or the moment M_k are enabled accordingly.

Direction — direction of action of the force: vertical, in x-direction or y-direction.

Direction of rotation — direction of rotation of the moment: about the x-axis or the y-axis.

Force F_k — entry of the value of the force. By clicking on the arrow icon , you can access a Load Value Compilation.

Moment M_x/M_y — entry of the value of the moment.

Eccentricity e_x/e_y — definition of an eccentricity in the x-/y-direction for a vertical head load.

Description — optional brief description of the load.

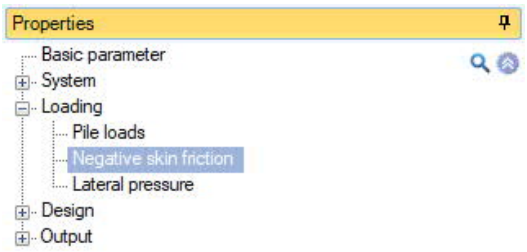
Action — selection of the action in accordance with EN 1990 Table A.1.1 or user-defined action.

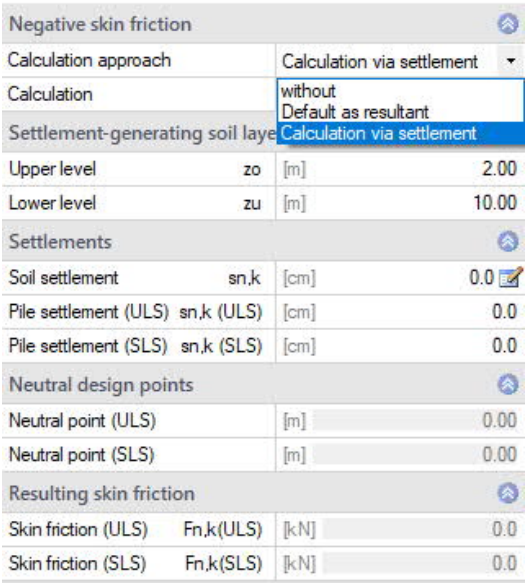
Simultaneous group — loads of a simultaneous group always act together.

Alternative group — loads of an alternative group always act individually and are not superimposed.

Note — *Simultaneous/Alternative Groups: Select "New group" to create a group with a consecutive number (Ccy 1, Ccy 2 etc.) You can also add descriptions to simultaneous or alternative groups, which are included in the output.*

Negative skin friction





Calculation approach
: selection whether negative skin friction should be included and in which way.

Pre-set as resultant
: characteristic value of the negative skin friction in
the ULS (Ultimate Limit State)
the SLS (Serviceability Limit State)

Calculation based on settlements

Calculation
: start the calculation of the negative skin friction based on the specified settlement parameters by activating this option.

Datum (upper/lower level)
: upper/lower datum of the soft layers relevant for settlement in relation to the ground top edge.

Soil settlement $s_{n,k}$
: $s_{n,k}$ is the settlement of the soil layers to the load-bearing subsoil to be expected due to a subsequent top load or backfill.
Using the edit button, you can optionally start the program Soil Settlement SBR+ to calculate the value and transfer it to the PFAHL+ program via "Save and return".

Pile settlement
: ULS: limit settlement of the pile in the ultimate limit state or calculated settlement in the ultimate limit state.
SLS: settlement to be expected in the serviceability limit state

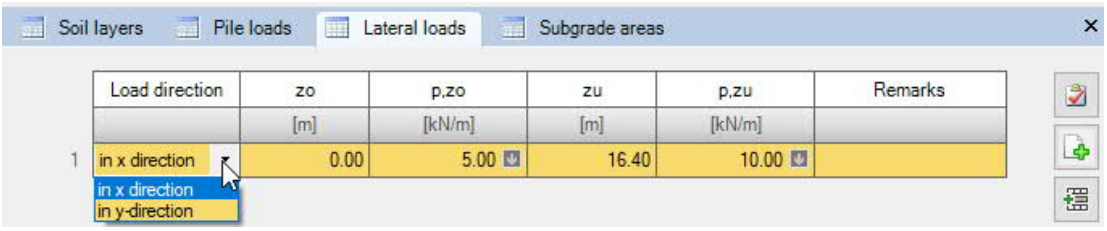
Neutral point
: indication of the position of the neutral point in the ultimate limit state (ULS)/serviceability limit state (SLS).

Skin friction
: indication of the resulting skin friction in the ultimate limit state (ULS)/serviceability limit state (SLS).

Lateral pressure

You can define pile loads in the left menu - see Data entry via tables in the Basic Operating Instructions-PLUS – or in a well-structured table accessible via the Pile loads tab below the GUI.

Determine lateral loads — optionally, you can launch the program Earth Pressure Calculation EDB+ to determine the lateral loads.



Load direction — direction of action of the lateral load: in the x- or y-direction.

Datum z_o/z_u — indicates the upper/lower datum for the upper/lower load value of the lateral load p, measured from the pile top.

Load value at p_{zo}/p_{zu} — Load value at the upper/lower datum.

By clicking on the arrow icon , you can access a Load Value Compilation.

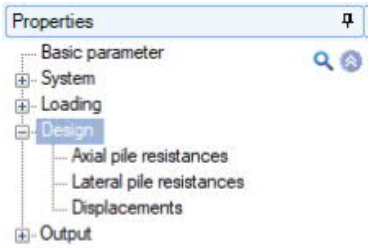
Remarks — you can add brief comments on the lateral loads.

Design

Design method

Nonlinear design

optionally, you can perform a cold design based on the general method as per EN 1992-1-1, 5.8.6. The method is based on a non-linear determination of the second-order internal forces with consideration of the non-linear material behaviour of concrete and reinforcing steel.



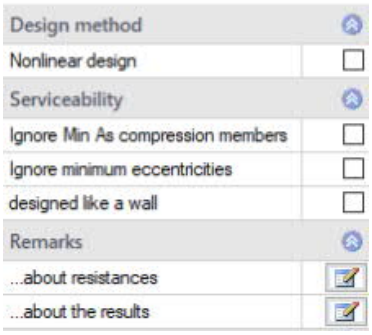
Serviceability

Ignore min. A_s compression members

checking this option disables the consideration of the minimum longitudinal reinforcement for compression members, which results in accordance with EN 1992-1-1, 9.5.2.

Ignore minimum eccentricities

checking this option disables the consideration of the minimum eccentricity with compression-loaded cross-sections, which results in accordance with EN 1992-1-1, 6.1 (4). In standard cases, the minimum eccentricities only have an effect in pile areas in which the moments from imperfections have a zero crossing.



Design as wall

enables the treatment of the pile as a wall. The design and reinforcement rules for walls are applied irrespective of the actual cross-sectional dimensions.

Remarks

You can optionally enter comments to be included in the output document behind the resistances/calculation results. See also Remarks Editor.

Axial pile resistances

Resistance of the pile to compression

Calculation approach

options for the determination of the pile's resistance to compression:
- Static trial loads,
- Dynamic test loads or
- Empirical values.

Specification/Evaluation

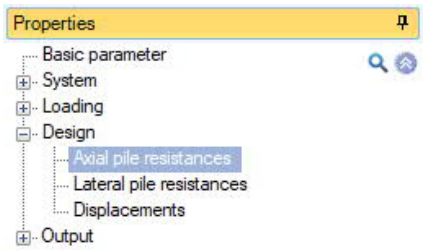
selection whether the pile pressure resistance is specified (pre-set) or calculated.

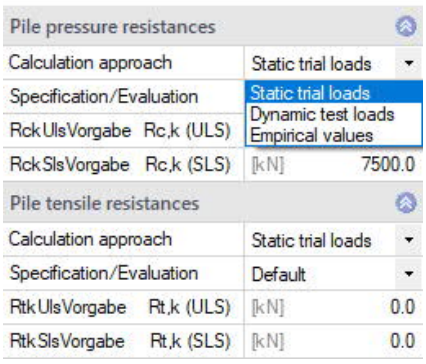
$R_{c,k}$ pre-set

user-defined characteristic values of the total pile resistance (compression), separately for the ultimate limit state ULS and the serviceability limit state SLS.

Pressure resistance $R_{c,k}$

characteristic compression resistance of the pile, separately for the ultimate limit state ULS and the serviceability limit state SLS, determined from a static pile test load or from empirical values, depending on the selected calculation approach.





Resistance of the pile to tension

Calculation approach	options for the determination of the pile's resistance to tension: - Static trial loads, or - Skin friction.
Specification/Evaluation	selection whether the pile tensile resistance is specified (pre-set) or calculated.
$R_{t,k}$ pre-set	user-defined characteristic values of the total pile resistance (tension), separately for the ultimate limit state ULS and the serviceability limit state SLS.
Tensile resistance $R_{t,k}$	characteristic tension resistance of the pile, separately for the ultimate limit state ULS and the serviceability limit state SLS, determined from a static pile test load.

Lateral pile resistances / subgrade areas

Calculation approach	calculation approach to determine the lateral resistances (subgrade reaction modulus method).
Subgrade reaction modulus method	click on the edit button  to start the determination of the subgrade areas based on the soil parameters (layer thicknesses).
Subgrade areas	indicates the calculated values of the upper datum $z_{o,i}$/lower datum $z_{u,i}$ and the pertaining length of the subgrade area l_i.
Subgrade reaction values	select the calculation approach. - Definition via stiffness modulus: $E_{s,k,i}$ characteristic value of the stiffness modulus. - Definition via subgrade reaction modulus: $D_{s,j}$ equivalent shaft diameter or relevant cross-section width. $k_{s,k,i}$ characteristic value of the subgrade reaction modulus.
Earth resistances	earth resistance at the upper/lower datum.
Spatial earth resistances	spatial earth resistance at the upper/lower datum.

Deformations (Displacements)

Permissible horizontal displacements	enter the permissible/resulting deformation of the pile head.
Limit of the vertical displacement	indicates the permissible limit settlement of the pile head in the serviceability limit state (SLS).

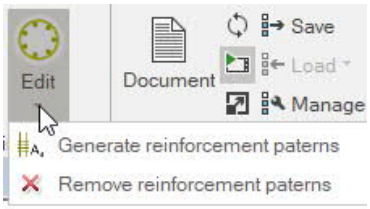
Reinforcement dialog (ribbon)

Reinforcement layout

The reinforcement layout can either be created automatically or defined manually.

Access via the button in the upper menu bar.

Note: *Click on the small arrow pointing downwards to access the options "Generate reinforcement patterns" and "Remove reinforcement patterns".*



Generate reinforcement patterns

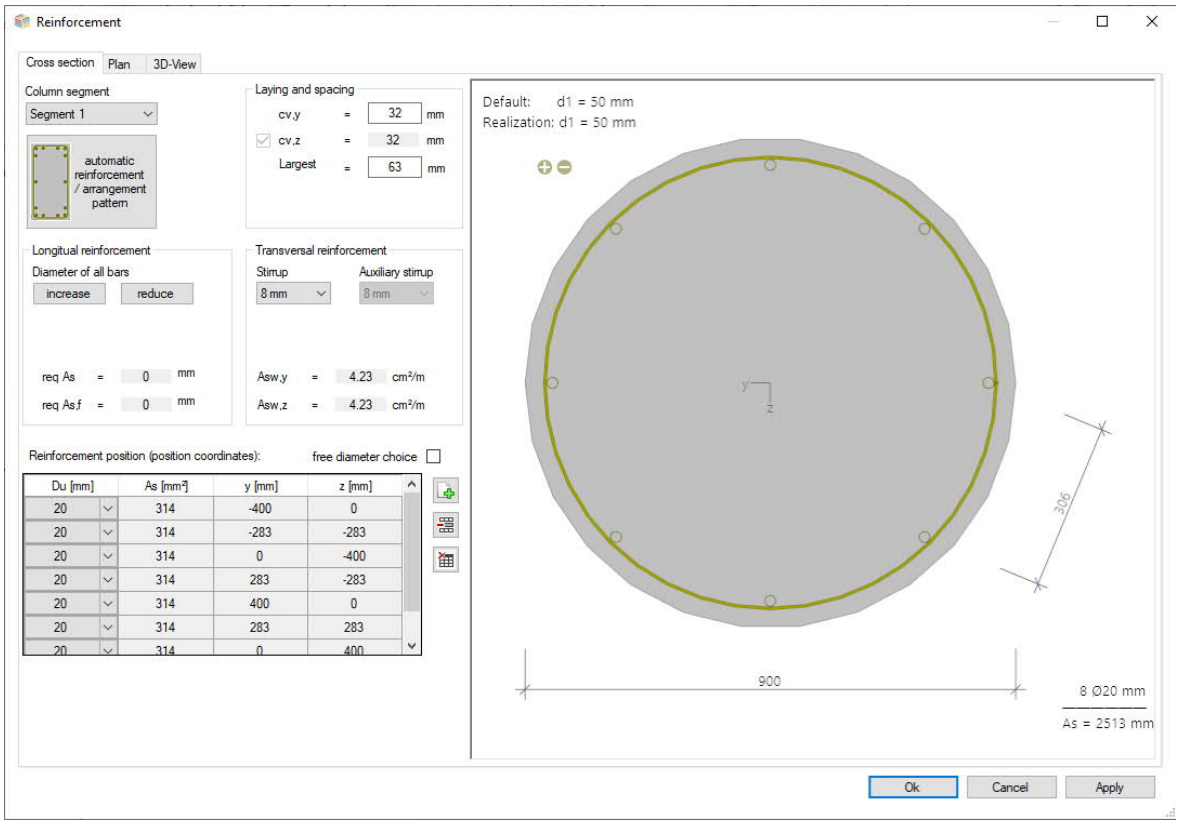
Automatically arranges the reinforcement for every single cross-section.

Remove reinforcement patterns

Removes all existing the reinforcement patterns.

Edit reinforcement layout

Click on the centre of the button to access the reinforcement layout dialog which allows you to create and edit reinforcement patterns.



Cross-section

Graphical view of the cross-section. Allows you to set reinforcement parameters such as the longitudinal and transverse reinforcement, the spacing/the position etc.

Column segment

For multi-part columns, select the column segment for which the reinforcement layout is to be created.

Automatic reinforcement laying/arrangement

Opens the dialog for selecting the reinforcement arrangement - the options available for selection are self-explanatory.

In the right dialog area, select the spacing, the diameters of the longitudinal bars and stirrups as well as the maximum grain.

Reinforcement layer

You can add or remove bars via the corresponding icons.

Interactive reinforcement GUI

The graphical user interface is interactive, i. e. you can add/remove bars or increase/reduce diameters using the +/- icons or the context menu (right mouse button).

Plan view

Graphical view from the side.

Compaction areas:

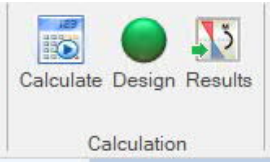
As per standard	controls the automatic determination of the compaction areas of the transverse reinforcement.
lv,top/bottom	length of the compaction areas of the transverse reinforcement at the upper/lower segment end.
Pre-set steel qty. Asw	pre-set value for the referenced cross-sectional area of the transverse reinforcement

3-D view

The right mouse button can be used to rotate and tilt the view.

Output

Scope of the output, calculation, results

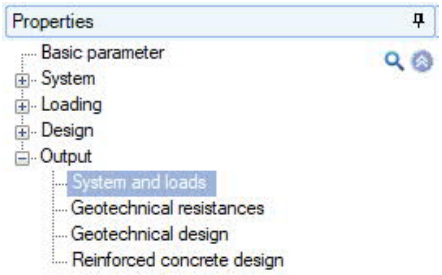


To start the output, click on the Calculate button.

After the calculation, the loading is displayed in the bottom right-hand corner of the GUI and provides a good overview of the economic efficiency of the structural system entered.

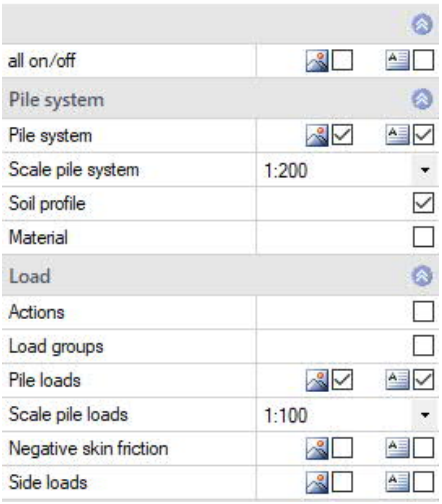
Results

Via the “Results” tab, you can display the different result graphs.



Output scope

By checking the desired options, you can determine the scope of data to be put out.



Output as a PDF document

Via the Document tab, you can display the document in PDF and print it.

See also Output and printing.pdf

Connected programs

You can launch the interfaced programs Soil Settlement SBR+, Earth Pressure Calculation EDB+ and Reinforced Concrete Column B5+.

Definition options in the graphical user interface

Use the right mouse button to display the context menu.

For data entry in the GUI in the PLUS programs, see also the Basic Operating Instructions PLUS.

For example, dimensions or load values can be directly clicked and changed in the GUI. Other data-entry options are accessible via the general context menu (right click on an empty area in the GUI) or via the context menu of the pile or via the interactive texts on top left. By clicking the +/- icon on bottom, you can add or remove a toe expansion.