



The holistic workflow for  
the calculation of  
foundations

with SCIA & FRILO

# Table of contents

<b>Introduction</b>	<b>3</b>
<b>Step 1: How to size a pad foundation with help of SCIA</b>	<b>4</b>
Modelling	4
Definition of geometry and material	5
Definition of load cases and loads	6
Options for geotechnical verification	7
<b>Step 2: Transfer the foundation data to FRILO for further verification</b>	<b>8</b>
Manage the FRILO application FD+	8
<b>Step 3: Further foundation design options in FRILO FD+</b>	<b>9</b>
Modelling	9
Definition of geometry and material	10
Definition of load cases and loads	11
Options for geotechnical verification with FD+	12
Reinforced concrete design with FD+	14

# Introduction

Foundations form the stable base of a building. As a substructure, they have the essential task of safely transferring the vertical and horizontal loads of the superstructure into the ground. In order to fulfil its function, a foundation must be more robust and more resistant to vibration than the structure placed on top of it. For this reason, the correct and reliable verification of the structural safety and serviceability of foundations is essential in structural engineering.

Therefore, a smart interface between SCIA and FRILO has been developed to enable the holistic and complete verification of pad foundations. The two proven software solutions complement each other extraordinarily well, providing the structural engineer with an accurate and efficient solution for a common challenge in your daily work – foundation design.

SCIA Engineer is a FEM-based structural analysis software for designing an entire structure in 3D. Not only can you model complex structures with their foundations, but simplified geotechnical verifications can also be carried out. On the other hand, FRILO software is characterised by specialised solutions to calculate individual structural components quickly. The FRILO program FD+ allows for advanced geotechnical verification not available in the simplified checks in SCIA Engineer. In addition, FD+ can design the concrete reinforcement.

The interface between SCIA Engineer and FRILO FD+ reliably transfers the model geometry and resulting internal forces from the overall SCIA analysis to the more specialised FRILO component FD+. Then in FRILO FD+, the foundation reinforcement can be designed whilst finalising the necessary geotechnical verifications. Therefore, the time-consuming and error-prone manual entry of the internal forces is unnecessary.

This manual provides instructions for correctly modelling a pad foundation in SCIA Engineer. You will also learn how the data transfer occurs at the interface between the two software packages. Finally, you will also get an overview of the FRILO program FD+ verification possibilities.

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<sup>1</sup> Menges, Matthias (2018): Was genau ist eigentlich ein Fundament?, in: ABES, <https://abes-online.com/publikationen/ratgeber/was-ist-ein-fundament/> [18.02.2022].

# Step 1: How to size a pad foundation with the help of SCIA.

## Modelling.

Every workflow starts with the model you have created in SCIA Engineer. To be able to check a pad foundation, you must first define the column geometry, material and cross-section. Usually, if you create a nodal support, you can set up to six degrees of freedom to be free, rigid or flexible. However, in SCIA Engineer you can create a pad foundation by assigning the nodal supports to the type „Pad foundation“.

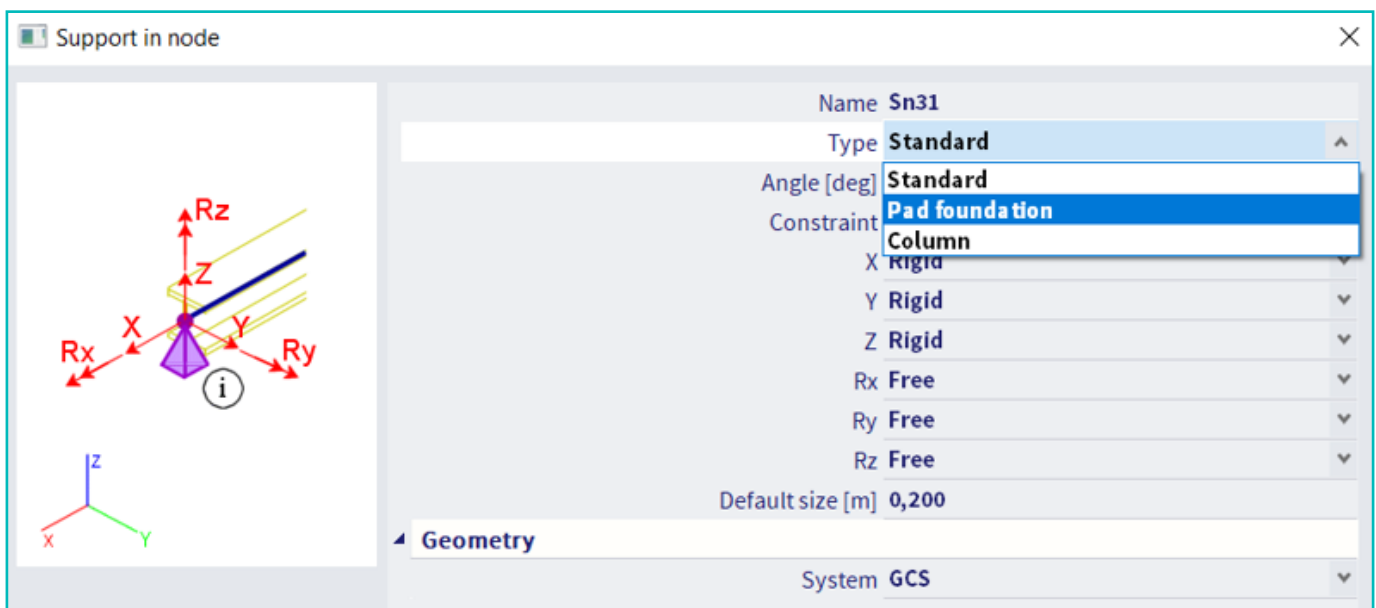


Figure 1: Conversion from a standard support to a pad foundation support.

# Definition of geometry and material.

When you define the geometry and material of a foundation in SCIA, you set the following properties:

- Foundation length, width and height
- Pocket Length, width and height (if any)
  - If the pocket height = ZERO, a single foundation without a pocket base is transferred to the FRILO program.
  - If the pocket height > ZERO, a pocket foundation is transferred to FD+
- Eccentricity in the x- and y-direction in case of eccentric column arrangements
- Foundation concrete grade

To derive the spring stiffness for the six degrees of freedom, you must also select a subsoil. You can define soil properties such as density  $\gamma$ , friction angle  $\varphi'$ , cohesion  $c$  and permissible base pressure resistance  $\sigma_d$ . SCIA Engineer then automatically calculates the spring stiffness values using the foundation dimensions and the soil parameters.

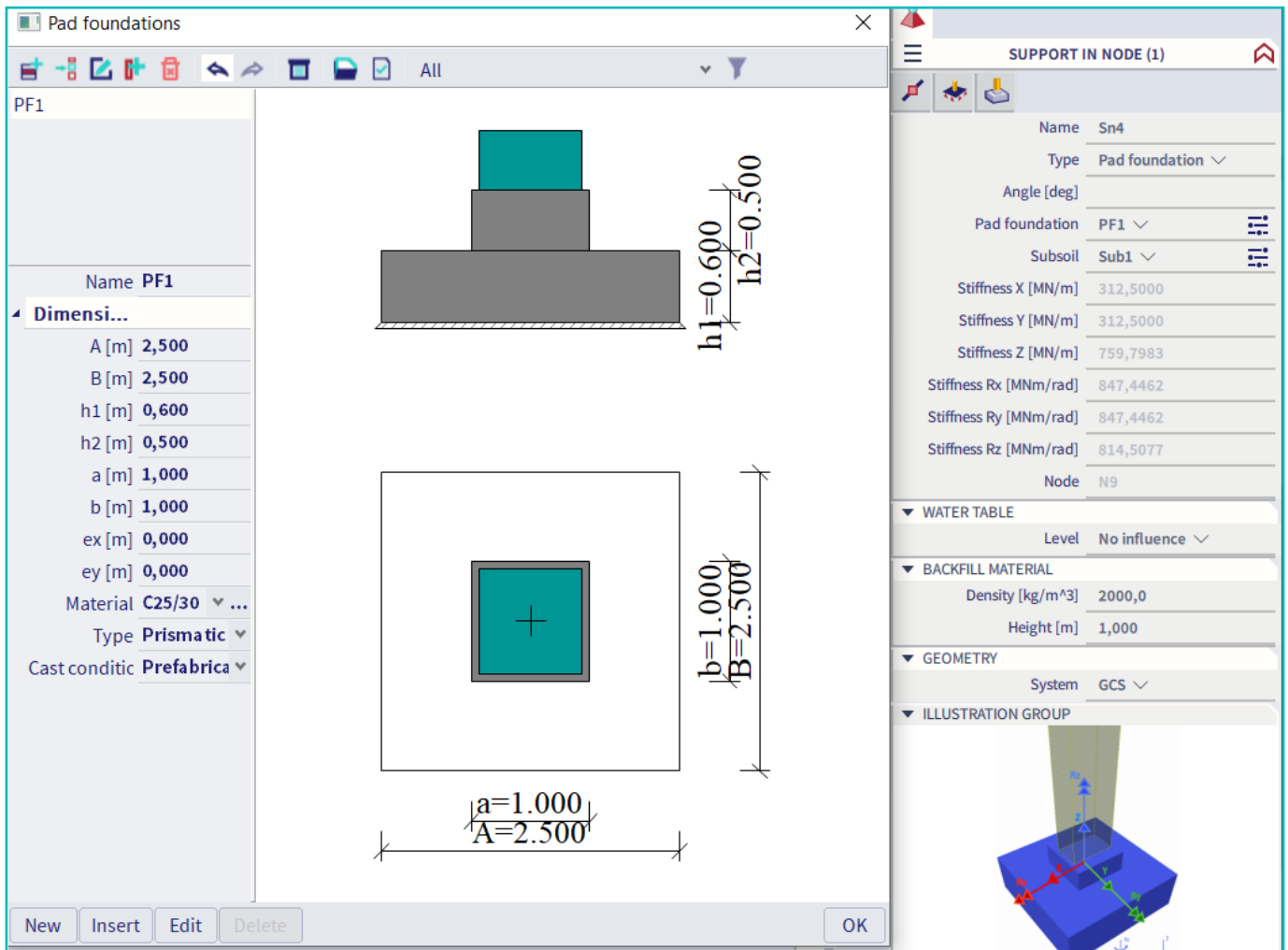


Figure 2: Pad foundation dimensions and the calculated stiffnesses for displacements and rotations.

# Definition of load cases and loads.

You can now model the loads in SCIA and create the limit states combinations for the appropriate design situations. User-defined load combinations or result classes can also be defined for more precise control. The following three load result types can be selected:

- Load case: results for an individual characteristic load case
- Load combination: results for a combination of load cases with appropriate factors
  - Ultimate limit state
  - Serviceability limit state - characteristic
  - Serviceability limit state - quasi-permanent
- Classes:
  - Arbitrarily definable result content
  - e.g. all characteristic load cases

Following the definition of the loads, the model can be calculated in SCIA. The load result type is exported when the foundation is later transferred from SCIA to FRILO.

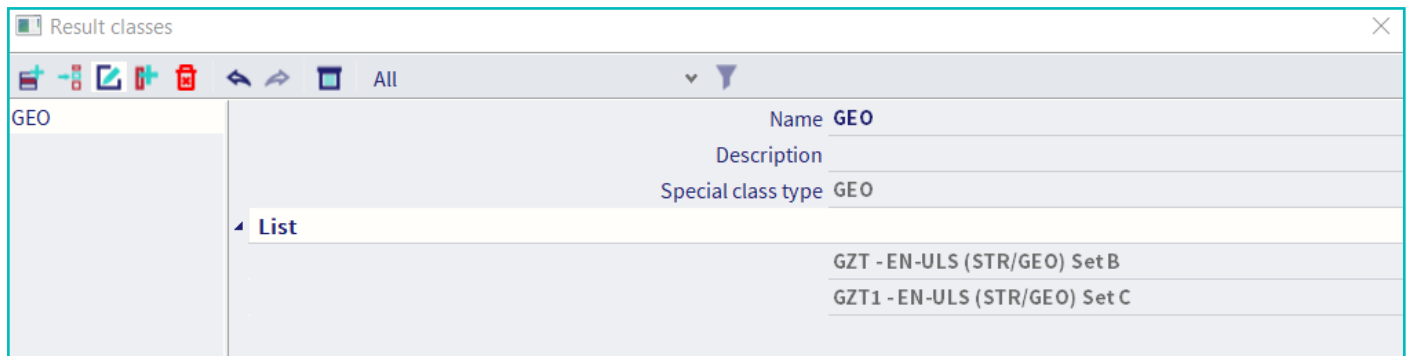


Figure 3: The dialogue shows the result classes in the ultimate limit state.

# Options for geotechnical verification

After the 3D structure has been calculated and the superstructure deformations and section sizes are available, you can now carry out the verifications of the pad foundation according to EC-EN 1997. SCIA Engineer performs the following verifications:

- Determination of the effective geometry (EN 1997-1 Annex D)
- Ground failure resistance (EN 1997-1, §6.5.2.1 and Annex D)
- Sliding resistance (EN1997-1, §6.5.3)
- Proof of max. eccentricity (overturning proof) (EN1997-1, §6.5.4)

The degree of utilisation of the verification is shown with a coloured arrow on the foundation. For example, a value of 0.4 means a verification value of 40%. The arrows are to be interpreted as follows:

- Green arrow: utilisation > 25%. The foundation is adequate. The utilisation of the foundation is economical.
- Grey arrow: utilisation < 25%. The foundation is adequate. The utilisation of the foundation is uneconomical. Material savings could still be made.
- Red arrow: utilisation > 100%. The foundation is not adequate.

Autodesign of the pad foundation

Autodesign

Maximal check:

Maximum unity check: 0.754

Next down    Next up

Search for optimal

Direction:

Parameter:

	Param.	Value [m]	Autodesign	Related to	Ratio	List	Step [m]	Min. [m]	Max. [m]
1	A	2,500	<input checked="" type="checkbox"/> Yes	No		No	0,100	0,100	4,000

Figure 4: If the degree of utilisation is not optimal, SCIA Engineer can redesign the dimensions.

# Step 2: Transfer the foundation data to FRILO for further verification.

## Manage the FRILO application FD+.

To control the FRILO program FD+, first call up the function „FRILO Foundation Input“ in SCIA Engineer found in the „Geotechnics“ input section. Using FRILO Foundation Input select the node(s) of the pad foundation(s). You can then run the „FRILO Foundation Check“ function and select the load results. FRILO FD+ will start automatically, and all the required data such as geometry, material and load results will be transferred automatically. So you can avoid the tedious and error-prone job of manually entering the values for numerous load combinations.

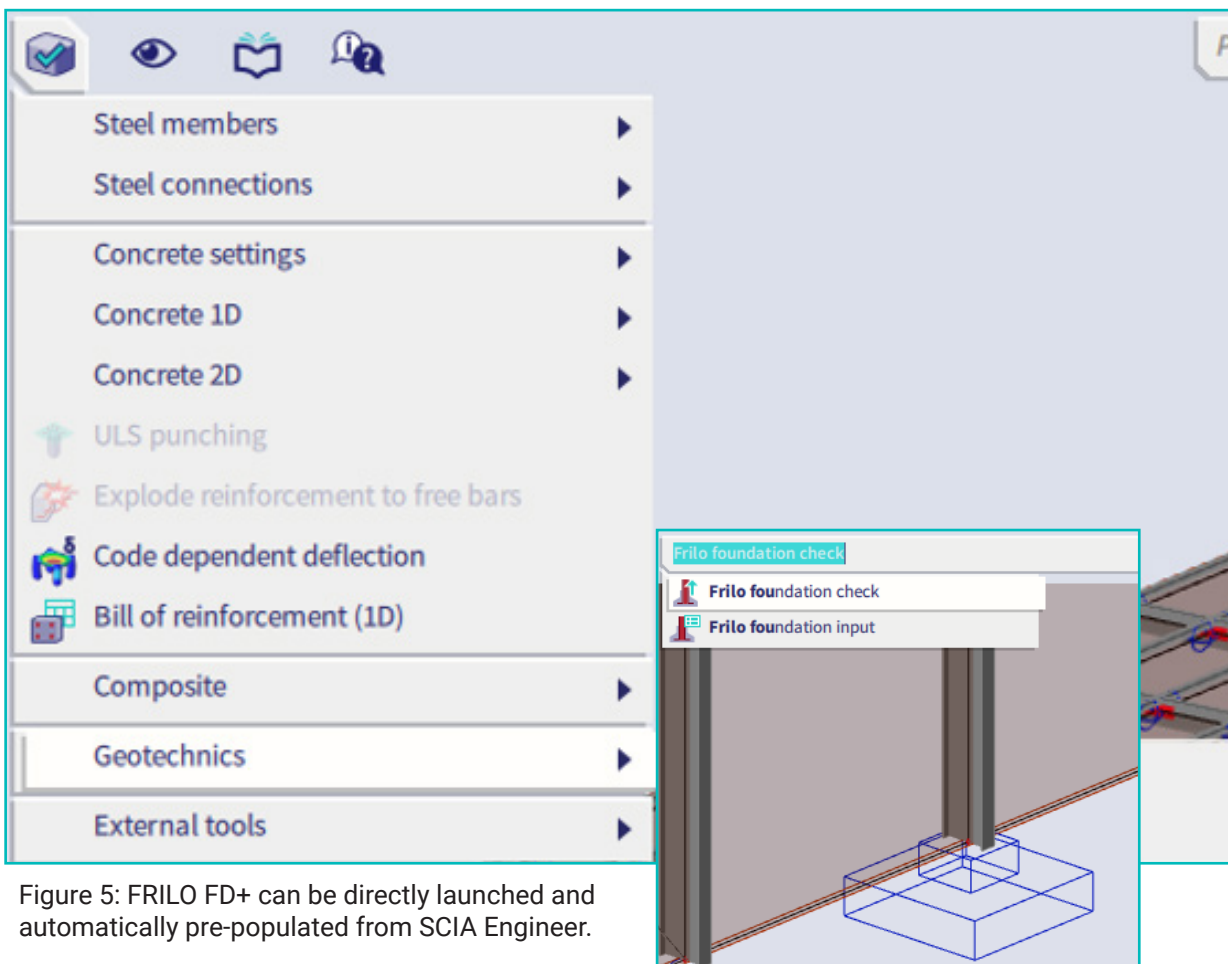


Figure 5: FRILO FD+ can be directly launched and automatically pre-populated from SCIA Engineer.



# Step 3: Further foundation design options in FRILO FD+.

## Modelling.

The FRILO program Foundation FD+ was designed to calculate individual pad foundations with and without pockets. Hence further foundation specifications and verifications can be made that exceed the design possibilities of SCIA Engineer.

If you have followed all the previously described steps, the foundation exported from SCIA Engineer can be calculated directly in FRILO FD+ without further intervention. The program recognises the imported foundation geometry, concrete grade and loads defined in SCIA. The imported loads will be interpreted as design loads by default. Transferring the design data directly from SCIA Engineer makes the foundation design process highly efficient.

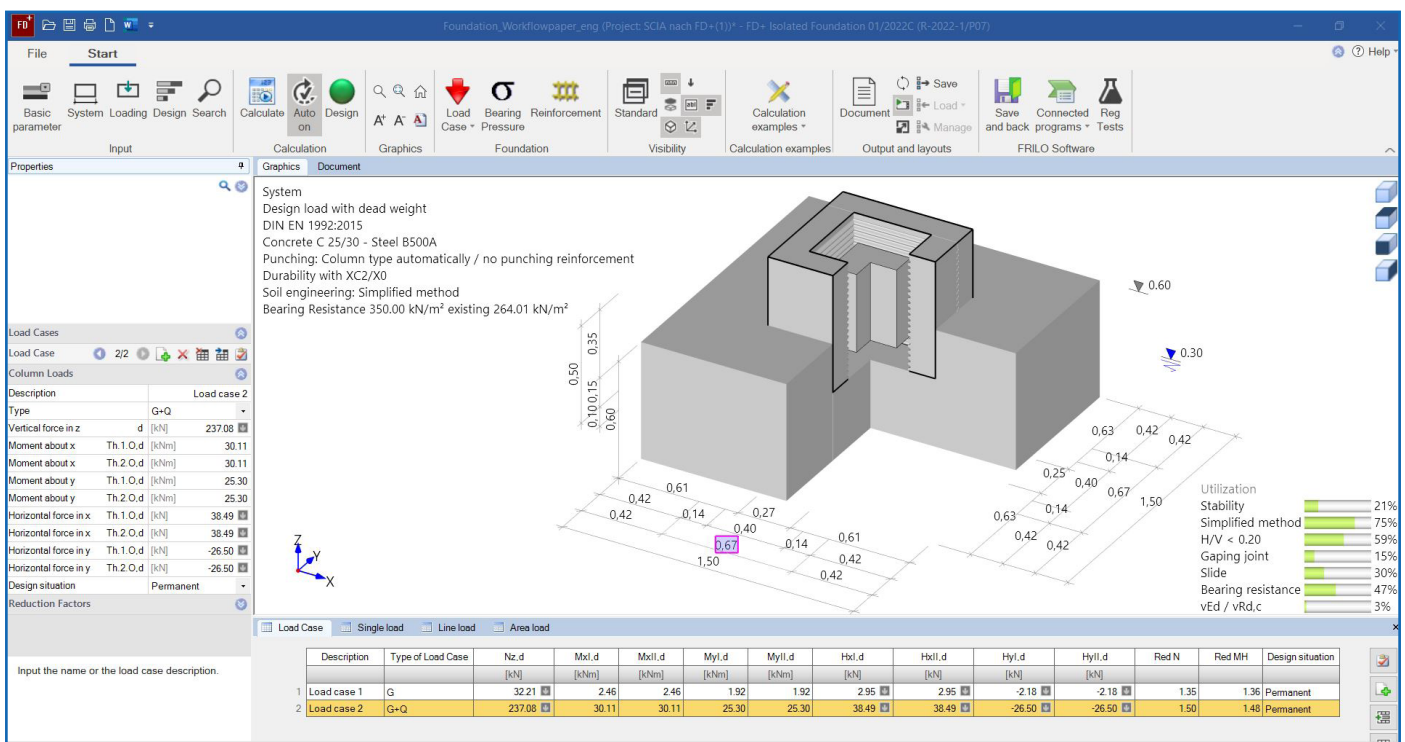


Figure 6: Standard view of the FD+ program interface after import from SCIA Engineer.

# Definition of geometry and material.

FD+ enables you to specify column embedment in the pocket, joint widths and surface properties. Specific information on steel grade, durability (exposure classes), and reinforcement spacing for the reinforced concrete design can also be specified. You can also model ground strata, groundwater level, and even sloping or rising ground levels.

The 'Soil layers' window displays a 3D model of a column with three soil layers. The column height is 2.00 m, with layers of 1.60 m, 1.00 m, and 2.00 m. A table below the model lists the soil parameters for each layer:

	$\gamma$ [kN/m <sup>3</sup> ]	$\gamma'$ [kN/m <sup>3</sup> ]	$\phi'$ [°]	$c'$ [kN/m <sup>2</sup> ]	$xU'$ [m]	others
1	18.00	18.00	33.0	10.00	1.60	Values
2	21.00	11.00	30.0	15.00	1.00	Values
3	23.00	13.00	37.5	0.00	2.00	Values

The 'Soil layer' dialog box is open, showing the following parameters:

Settlement analysis		
Procedure		direct specification
Compresses modulus $E^*$	[kN/m <sup>2</sup> ]	4946.00
Stiffness module $E_s$	[kN/m <sup>2</sup> ]	2473.00
Correction factor $x$		0.50
Settlement analysis: Consolidation		
Permeability factor $k$	[m/s]	1E-09
Both sides drained		<input type="checkbox"/>
Settlement analysis: Creep		
Creep coefficient $C\alpha'$		0.003
Void ratio $e_0$		0.7

Please select, whether you want the squeezed module  $E_m$  to be specified directly, or to be calculated from stiffness modulus and correction factor (from DIN 4019 T1).

Figure 7: Definition of a stratified ground with special parameters for settlement calculation.

# Definition of load cases and loads.

In FD+, an essential distinction should be made as to whether the applied loads are characteristic loads or partial safety factor design loads.

## Characteristic loads

A fully automated combination generation occurs for characteristic loads, including assigning the decisive combinations to the respective verification (as part of the limit state design philosophy).

## Design loads

Combination generation is deactivated for design loads, as each load case is interpreted as an independent design combination. For geotechnical verification, reduction factors are used to derive the characteristic loads.

After transferring from SCIA Engineer, you can also manually add loads to the foundation. These additional loads can be in the form of point (single), line or area loads.

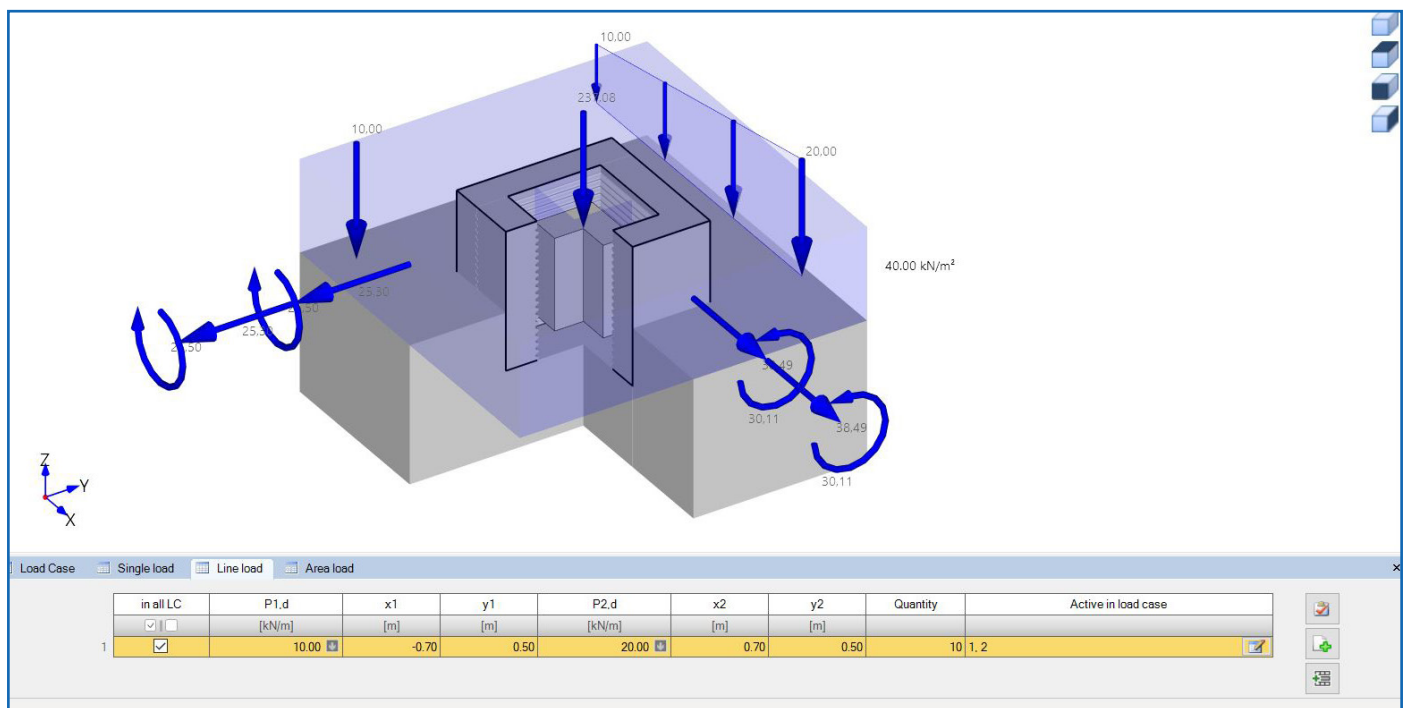


Figure 8: The possibilities of load definition in FRILo FD+ (column loads and additional loads).

# Options for geotechnical verification with FD+.

As already mentioned, you can perform a variety of geotechnical verifications in FD+. The following is an overview of the verification options offered by FD+:

## Ultimate limit state verification

- Loss of stability EQU
  - Overturning check
- Structural failure STR
  - Bending
  - Shear force
  - Punching shear
  - Pocket design
- Subsoil failure GEO
  - Sliding
  - Bearing
  - Ground failure
- Loss of stability due to buoyancy UPL
  - Verification of buoyancy if groundwater is present

## Serviceability limit state verification

- Rotational displacement
  - Verification of gaping (outside the middle third rule) over the 1st and 2nd core width
- Deformations/displacements
  - Settlement check
  - Tilt check

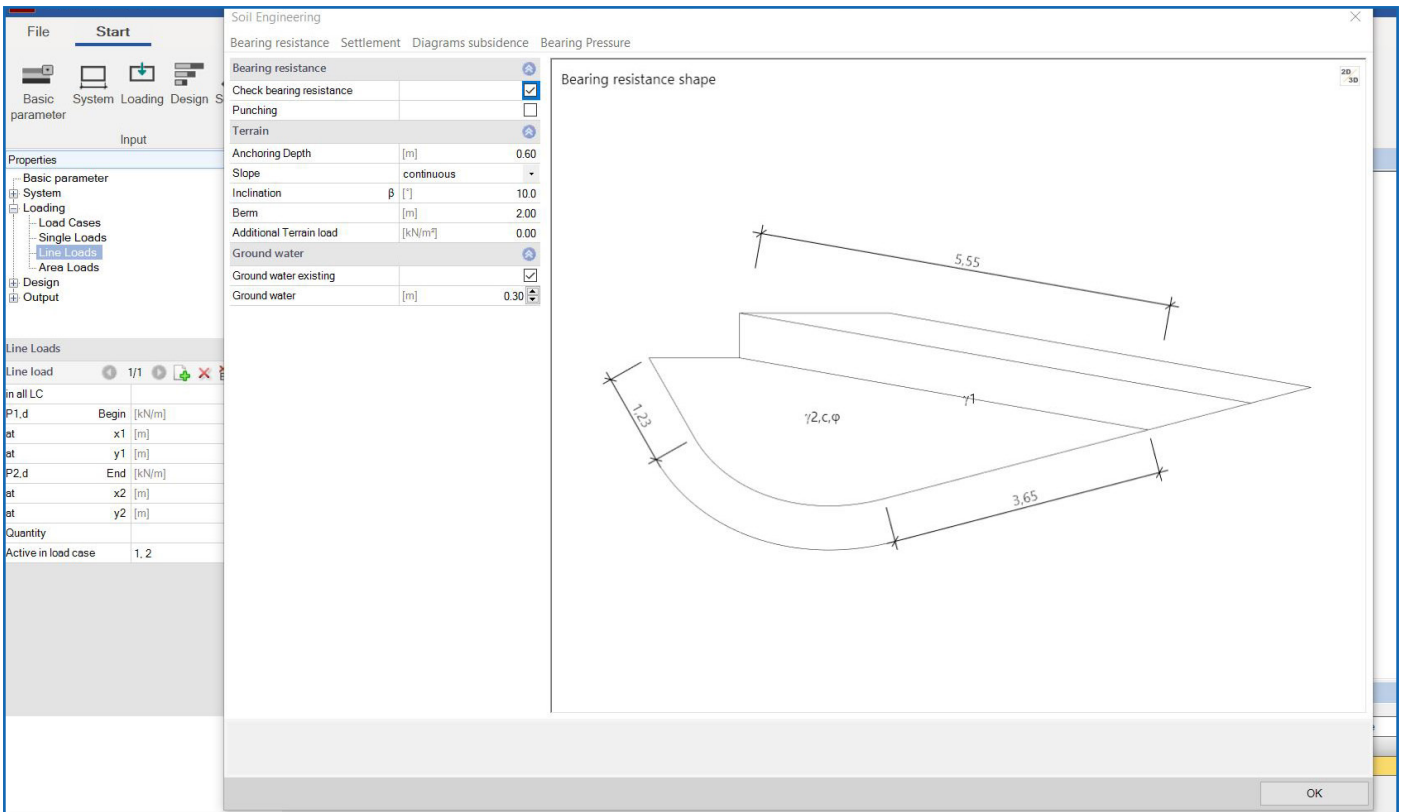


Figure 9: The formation of the base failure figure with sloped terrain in FD+.

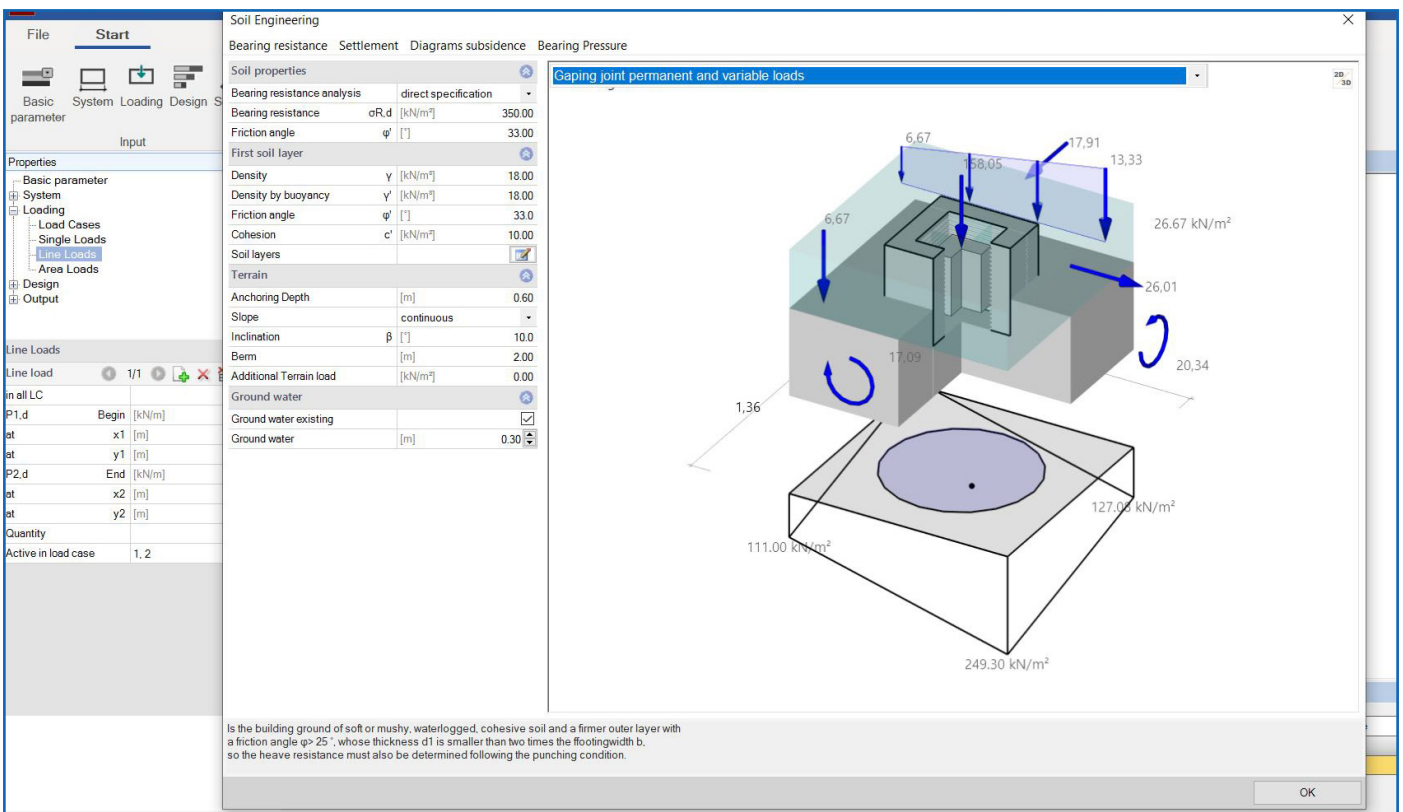


Figure 10: Bottom stress distribution with zero line, gapping joint and 2nd core width figure in FD+.

# Reinforced concrete design with FD+.

The structural design is carried out using the stress trapezoid method by calculating the bearing pressure distribution and, if necessary, taking into account the position of the zero stress line. The required reinforcement can be uniformly distributed in the foundation or concentrated under the column (e.g. according to booklet 240 DAfStb). This reinforcement arrangement can be output via a reinforcement drawing.

The punching shear design can be carried out using either longitudinal reinforcement only or by adding punching shear reinforcement. Outside the punching shear perimeter, a shear force check is carried out.

For pocket and embedded foundations, special framework models according to Leonhardt and Schlaich/Schäfer are implemented to design and reinforce the tension and compression struts in the base accordingly. Optionally, connection reinforcement can also be calculated.

Lap and anchorage lengths are calculated for all designed reinforcement quantities. All calculations can be output with clear reinforcement and distribution sketches.

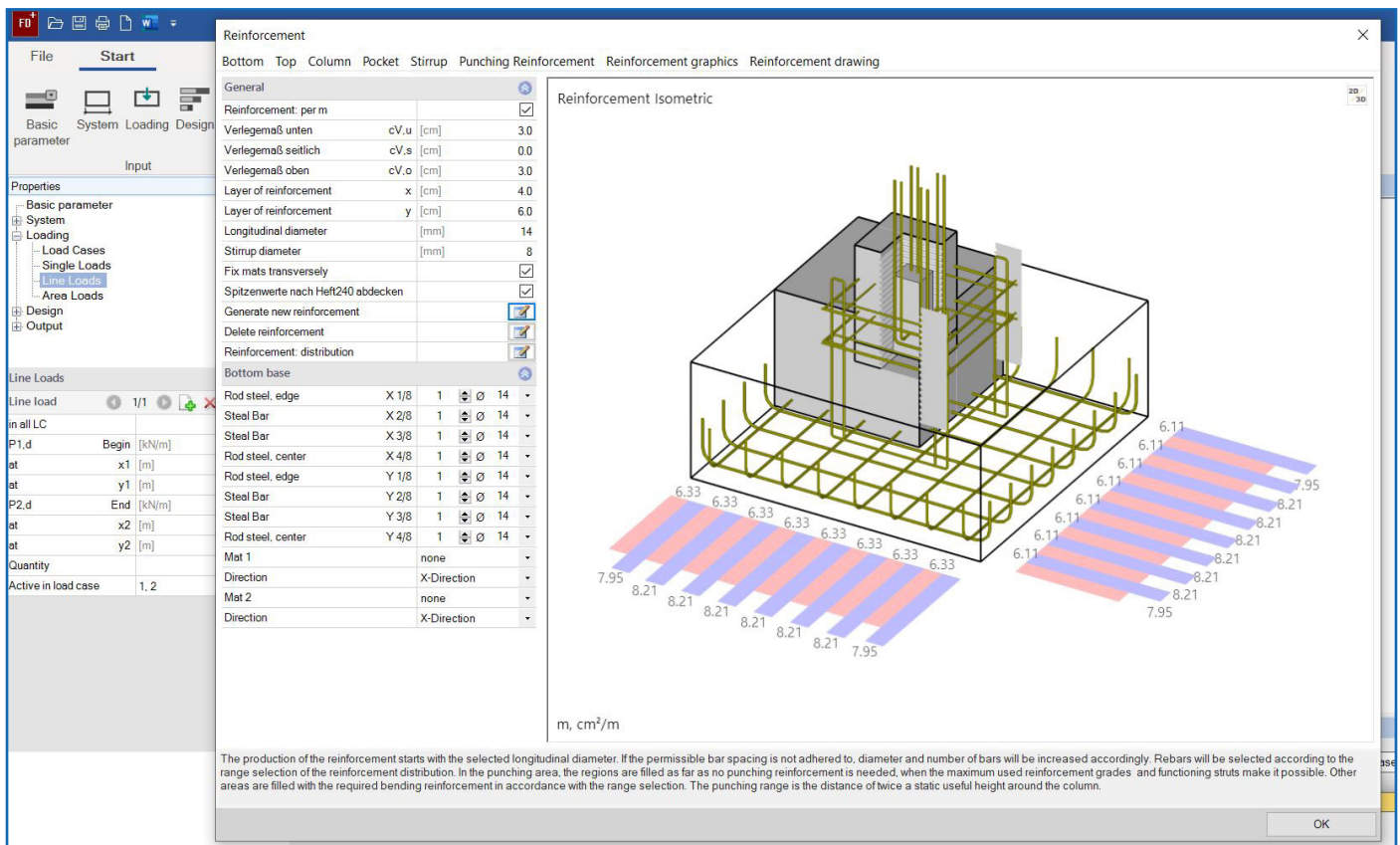


Figure 11: The reinforcement distribution in the sleeve and foundation.

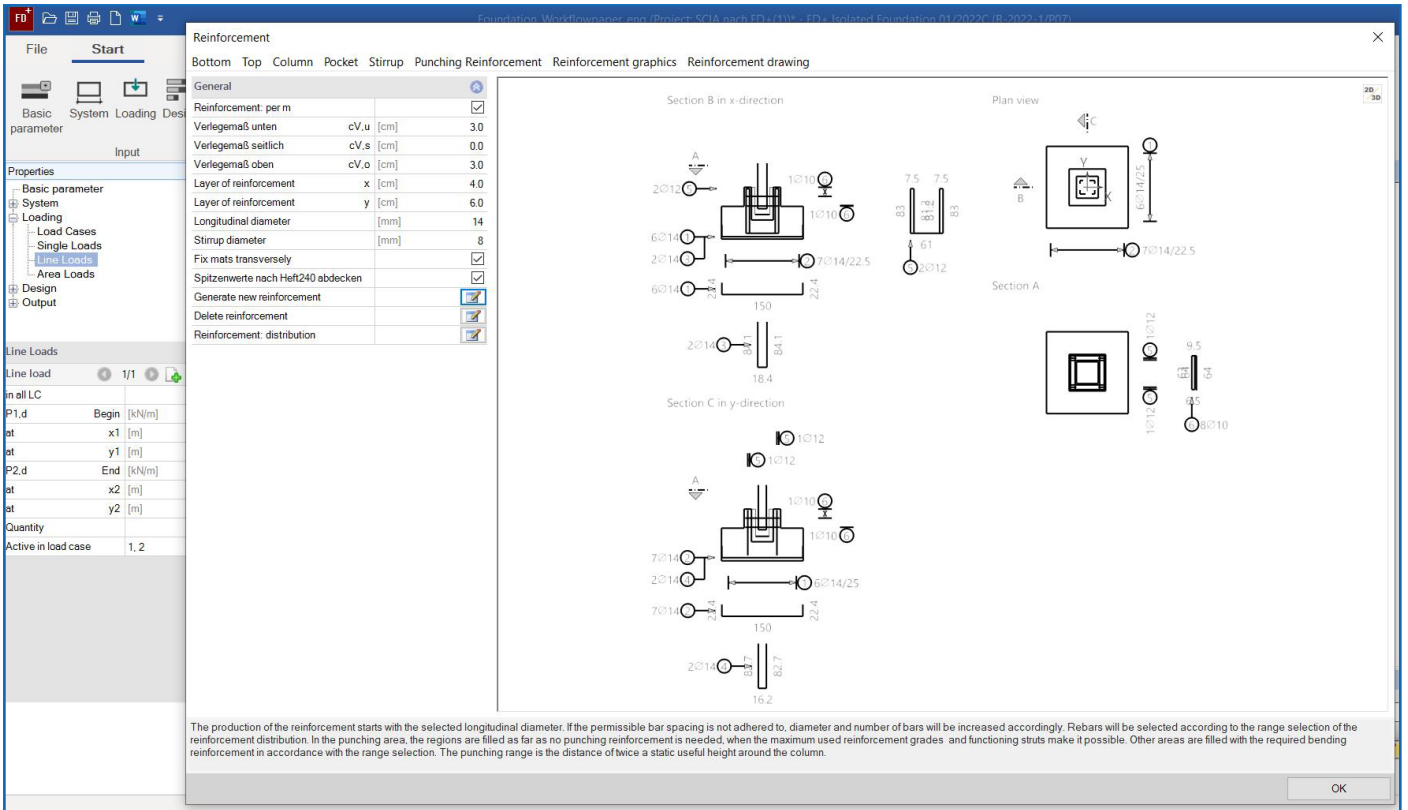


Figure 12: Representation of the total amount of reinforcement in a reinforcement sketch with different sections.

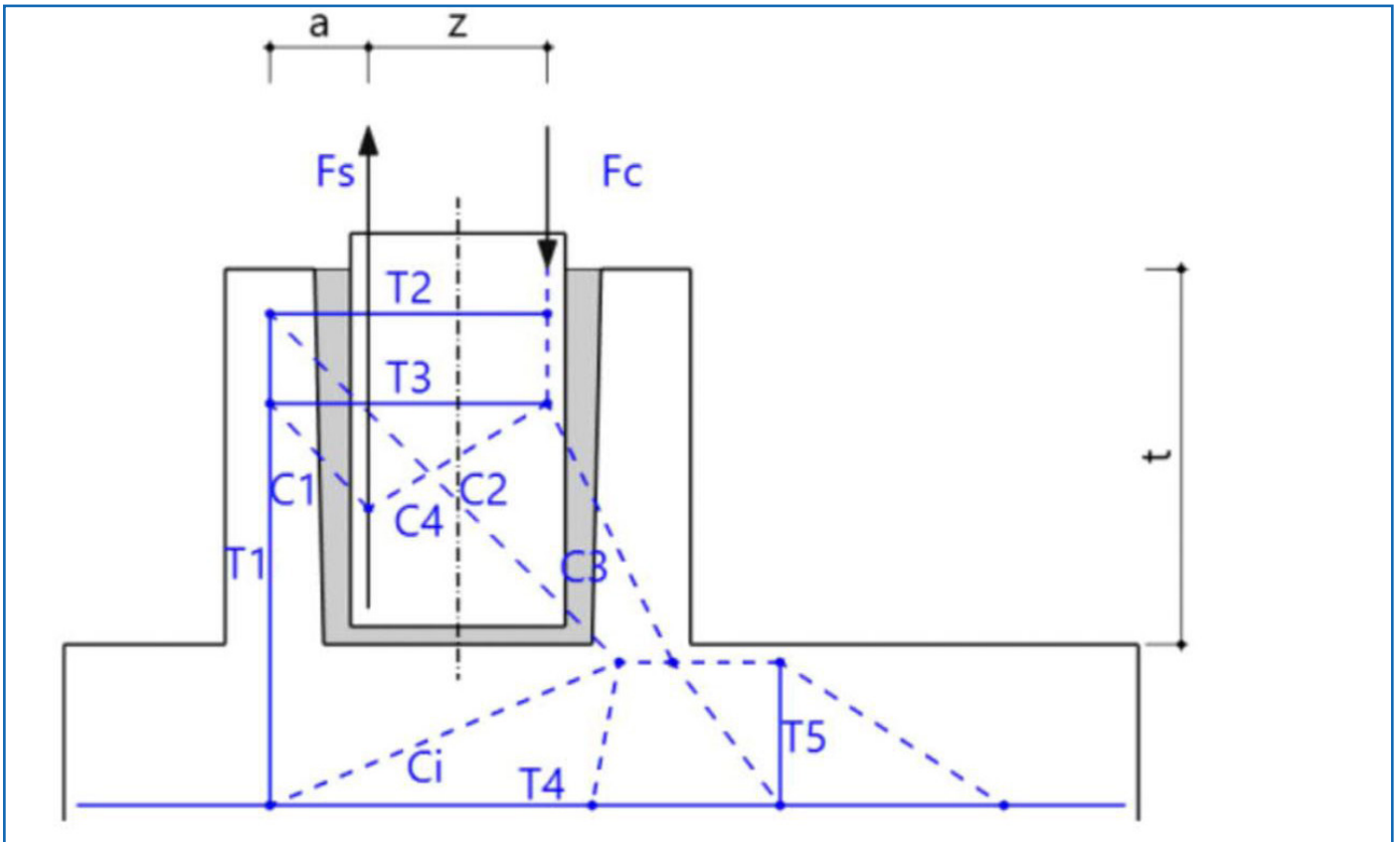


Figure 13: The framework model for designing the tension and compression struts in the sleeve.



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