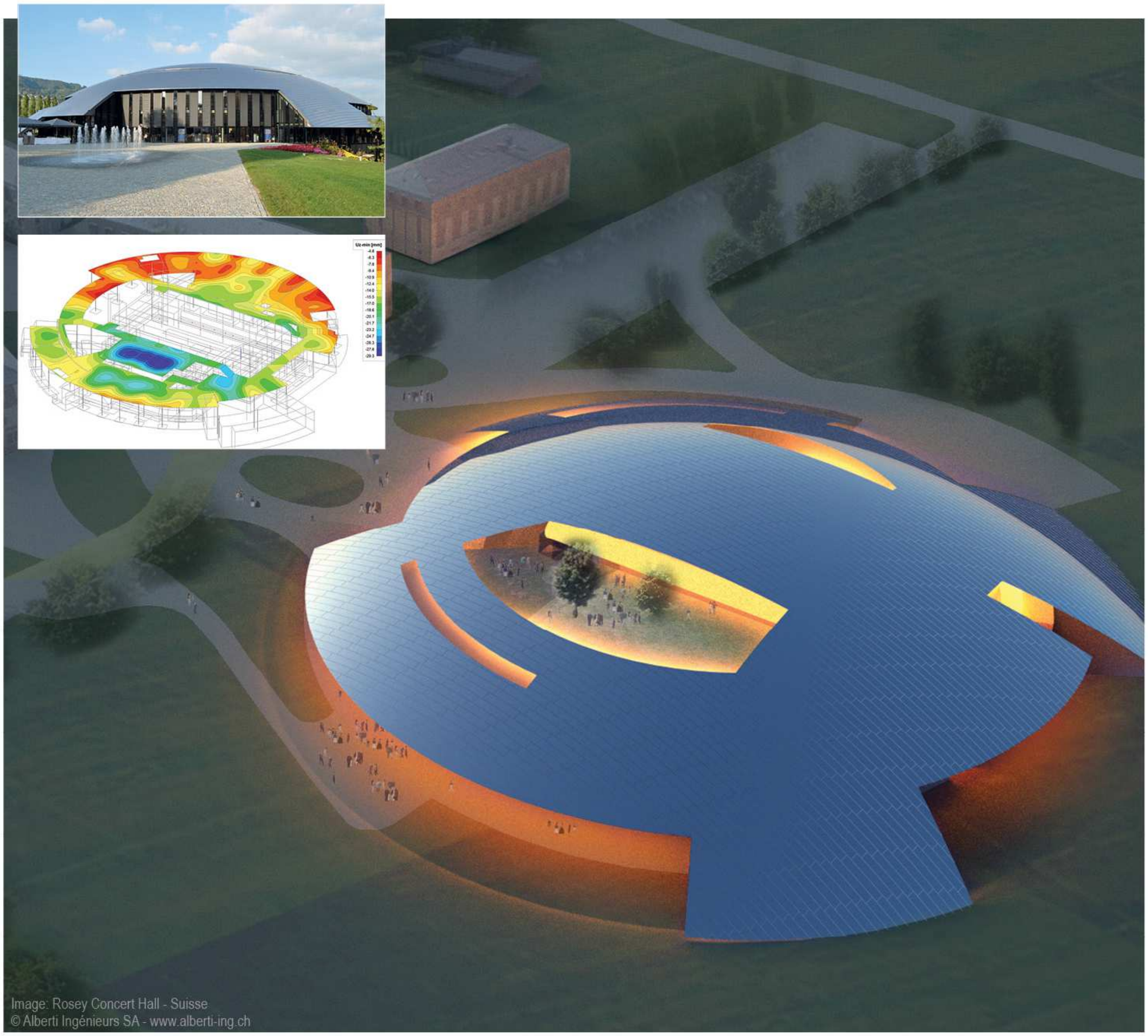
SCIA ENGINEER



Eurocode Training

EN 1997 in SCIA Engineer

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Introduction

Edition

This course will explain the non linear and stability calculations in SCIA Engineer. Most of the modules necessary for this calculation are included in the **Professional edition**.
For some options a concept edition is sufficient or for other options an expert edition or an extra module is required. This will always be indicated in the corresponding paragraph.

Overview

The Structural Eurocode program comprises the following standards generally consisting of a number of Parts:

EN 1990	Eurocode:	Basis of structural design
EN 1991	Eurocode 1:	Action on structures
EN 1992	Eurocode 2:	Design of concrete structures
EN 1993	Eurocode 3:	Design of steel structures
EN 1994	Eurocode 4:	Design of composite steel and concrete structures
EN 1995	Eurocode 5:	Design of timber structures
EN 1996	Eurocode 6:	Design of masonry structures
EN 1997	Eurocode 7:	Geotechnical design
EN 1998	Eurocode 8:	Design of structures for earthquake resistance
EN 1999	Eurocode 9:	Design of aluminium structures

EN 1997-1 is intended to be applied to the geotechnical aspects of the design of buildings and civil engineering works. It is concerned with the requirements for strength, stability, serviceability and durability of structures.

Eurocode 7 consists of two parts:

EN 1997-1:	Geotechnical design – Part 1: General Rules
EN 1997-2:	Geotechnical design – Part 2: Ground investigation and testing

EN 1997-1 is supplemented by **EN 1997-2** that provides requirements for the performance and evaluation of field and laboratory testing.

In this manual only EN 1997-1 is discussed.

National annex for EN 1997-1
This standard gives alternative procedures and recommended values with notes indicating where national choices may have to be made. Therefore the National Standard implementing EN 1997-1 should have a National annex containing all Nationally Determined Parameters to be used for the design of buildings and civil engineering works to be constructed in the relevant country.

National choice is allowed in EN 1997-1 through:

- 2.1(8)P
- 2.4.6.1(4)P
- 2.4.6.2(2)P
- 2.4.7.1(2)P
- 2.4.7.1(3)
- 2.4.7.2(2)P

- 2.4.7.3.2(3)P
- 2.4.7.3.3(2)P
- 2.4.7.3.4.1(1)P
- 2.4.7.4(3)P
- 2.4.7.5(2)P
- 2.4.8(2)
- 2.4.9(1)P
- 2.5(1)
- 7.6.2.2(8)P
- 7.6.2.2(14)P
- 7.6.2.3(4)P
- 7.6.2.3(5)P
- 7.6.2.3(8)
- 7.6.2.4(4)P
- 7.6.3.2(2)P
- 7.6.3.2(5)P
- 7.6.3.3(3)P
- 7.6.3.3(4)P
- 7.6.3.3(6)
- 8.5.2(2)P
- 8.5.2(3)
- 8.6(4)
- 11.5.1(1)P

And the following clauses in annex A:
- A.2
- A.3.1
- A.3.2
- A.3.3.1
- A.3.3.2
- A.3.3.3
- A.3.3.4
- A.3.3.5
- A.3.3.6
- A.4
- A.5

2. Basis of geotechnical design

Ground properties

With the correct Design Approach, the design values for the soil properties are determined:

$$\varphi'_d = \text{atan}\left[\frac{\tan(\varphi')}{\gamma_{\varphi'}}\right]$$

With: φ' read from Subsoil Library

$\gamma_{\varphi'}$ read from National Annex Setup

$$c'_d = \frac{c'}{\gamma_{c'}}$$

With: c' read from Subsoil Library

$\gamma_{c'}$ read from National Annex Setup

$$c_{ud} = \frac{c_u}{\gamma_{cu}}$$

With: c_u read from Subsoil Library

γ_{cu} read from National Annex Setup

$$\gamma'_d = \frac{\gamma'}{\gamma_\gamma}$$

With: γ' specific weight read from Library

γ_γ read from National Annex Setup

$$\gamma_{Backfill,d} = \frac{\gamma_{Backfill}}{\gamma_\gamma}$$

With: $\gamma_{Backfill}$ weight read from Pad foundation input Data

γ_γ read from National Annex Setup

γ_G A final safety factor which needs to be determined concerns the safety factor for the weight of the pad foundation and the backfill material. This safety factor is taken as the safety factor for the first permanent load case for the combination under consideration i.e. γ_G.

In case a combination does not have a permanent load case, γ_G is taken as 1,00.

Ultimate Limit State

(EN 1997-1 §2.4.7)
Where relevant, it shall be verified that the following limit states are not exceeded:

- Loss of equilibrium of the structure or the ground **(EQU)**
- Internal failure or excessive deformation of the structure or structural elements in which the strength of structural materials is significant in providing resistance **(STR)**
- Failure or excessive deformation of the ground, in which the strength of soil or rock is significant in providing resistance **(GEO)**
- Loss of equilibrium of the structure or the ground due to uplift by water pressure or other vertical actions **(UPL)**
- Hydraulic heave, internal erosion and piping in the ground caused by hydraulic gradients **(HYD)**

Limit state **GEO** is often critical to the sizing of structural elements involved in foundations or retaining structures and sometimes to the strength of structural elements.

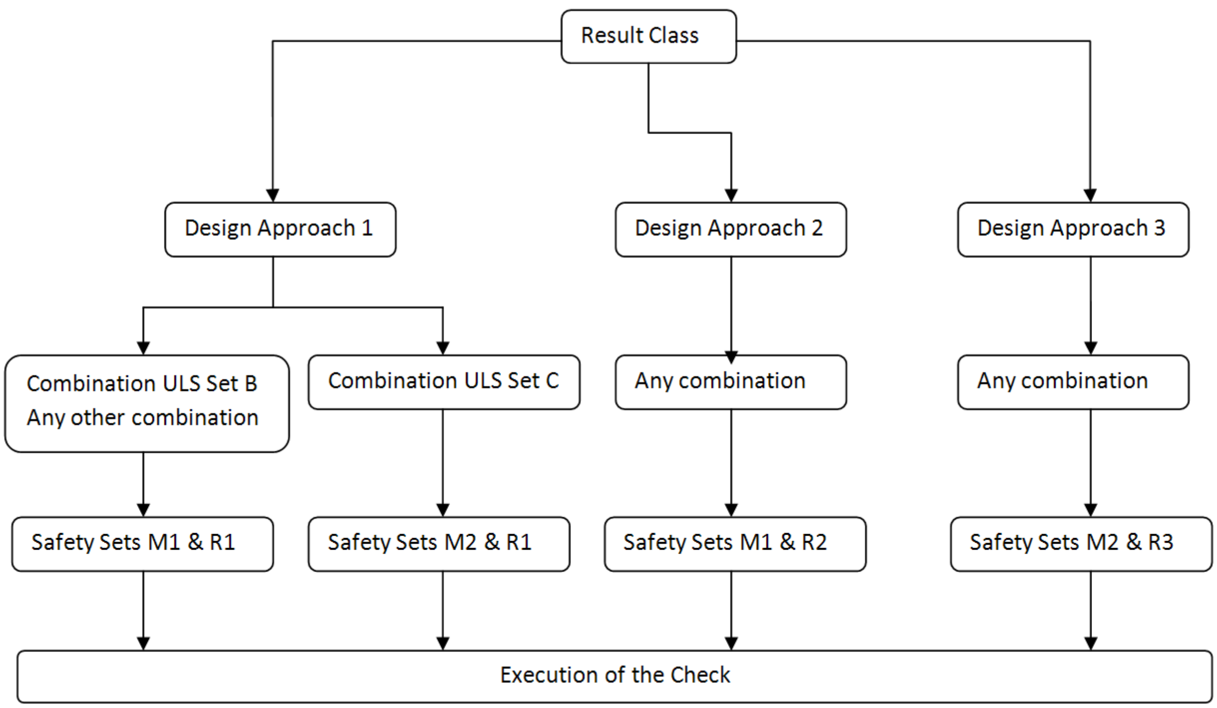
Design Approaches

(EN 1997-1 §2.4.7)

The manner in which the design effects of actions and resistances are applied shall be determined using one of three Design Approaches:

Depending on the **Design Approach** set in the National Annex Setup, the sets of safety factors are read from the setup as follows:

Design Approach 1	Combination 1: A1 "+" M1 "+" R1 Combination 2: A2 "+" M2 "+" R1
Design Approach 2	Combination: A1 "+" M1 "+" R2
Design Approach 3	Combination: (A1* or A2**) "+" M2 "+" R3 * On structural actions ** On geotechnical actions



- For **Design Approach 1** the safety sets depend on the combination type.
  For combinations of type **EN-ULS (STR/GEO) Set B** sets **M1** & **R1** are used.

  For combinations of type **EN-ULS (STR/GEO) Set C** sets **M2** & **R1** are used.
  For any other combination sets **M1** & **R1** are used.
- For **Design Approach 2**, in all cases sets **M1** & **R2** are used.
- For **Design Approach 3**, in all cases sets **M2** & **R3** are used.

The safety factors corresponding with a certain design approach can be found in the Annex A of EN 1997-1:

Partial factors on actions or the effects on actions – Set A1-A2

The Partial factors on actions or the effects of actions:

γ_G: on permanent unfavourable or favourable actions

γ_Q: on variable unfavourable or favourable actions

Table A.3 - Partial factors on actions (γ_F) or the effects of actions (γ_E)

Action		Symbol	Set	
			A1	*A2*
Permanent	Unfavourable	γ_G	1,35	1,0
	Favourable		1,0	1,0
Variable	Unfavourable	γ_Q	1,5	1,3
	Favourable		0	0

Partial factors for soil parameters – Set M1-M2

Partial factors on soil parameters (γ_M) shall be applied:

$\gamma_{\phi'}$: on the tangent of the angle of shearing resistance

$\gamma_{c'}$: on effective cohesion

γ_{cu}: on undrained shear strength

γ_{qu}: on unconfined strength

γ_γ: on weight density

Table A.4 - Partial factors for soil parameters(γ_M)

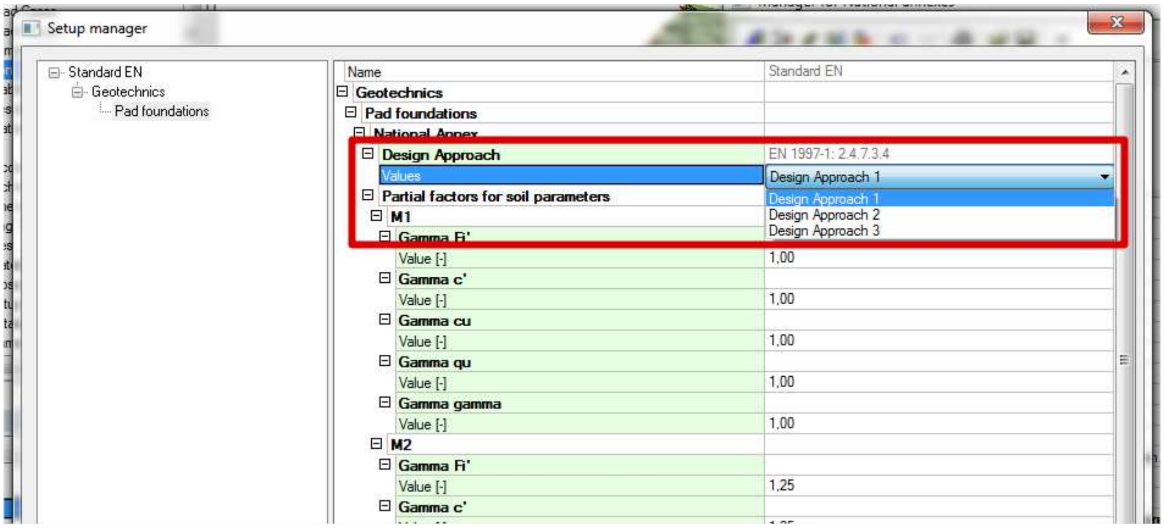
Soil parameter	Symbol	Set	
		M1	*M2*
Angle of shearing resistance[a]	$\gamma_{\varphi'}$	1,0	1,25
Effective cohesion	$\gamma_{c'}$	1,0	1,25
Undrained shear strength	γ_{cu}	1,0	1,4
Unconfined strength	γ_{qu}	1,0	1,4
Weight density	γ_γ	1,0	1,0
[a] This factor is applied to tan φ'			

Partial resistance factors – Set R1-R3

In annex A.3.3 of EN 1997-1 several options for set R1, R2 and R3 are given, depending on the type of ground resistance

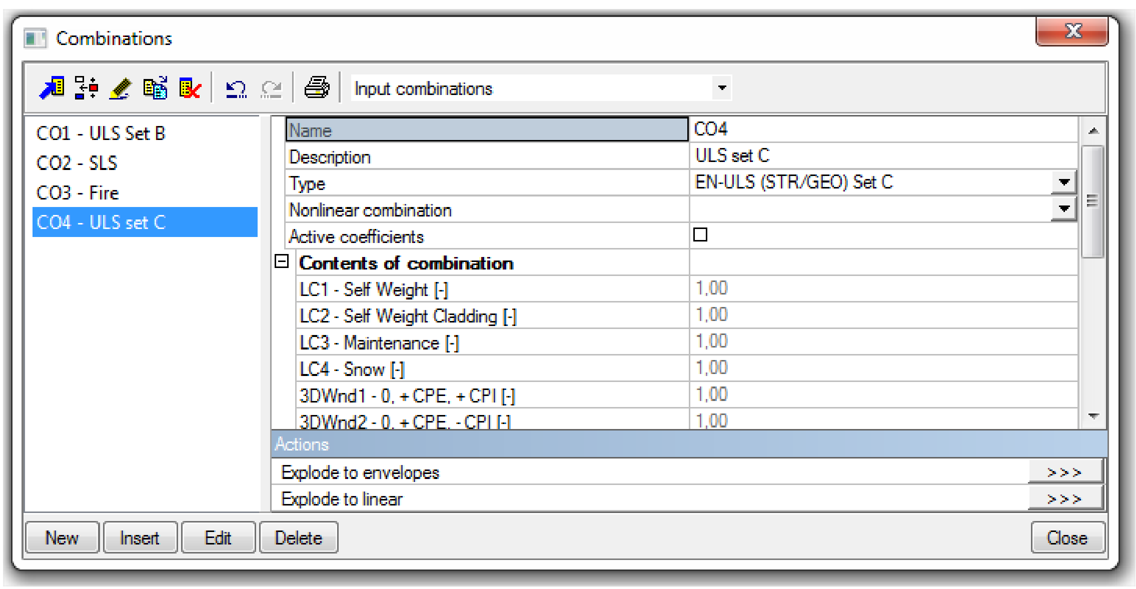
Design approaches in SCIA Engineer

In SCIA Engineer the choice for the Design Approach can be done in the National Annex parameters of EN 1997-1-1:

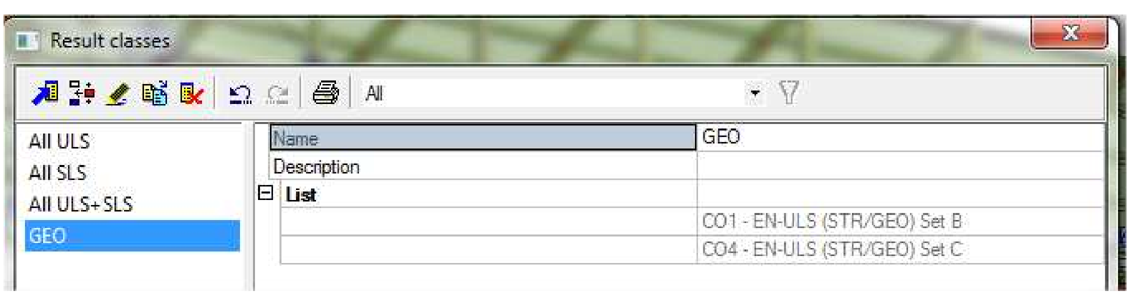


Also all tabulated factors can be adapted here.

Afterwards the correct design approach will be taken into account when using a “EN-ULS (STR/GEO) Set C” Combination.



When starting the calculation, SCIA Engineer will make a class “GEO” automatically:



6. Spread foundations

General

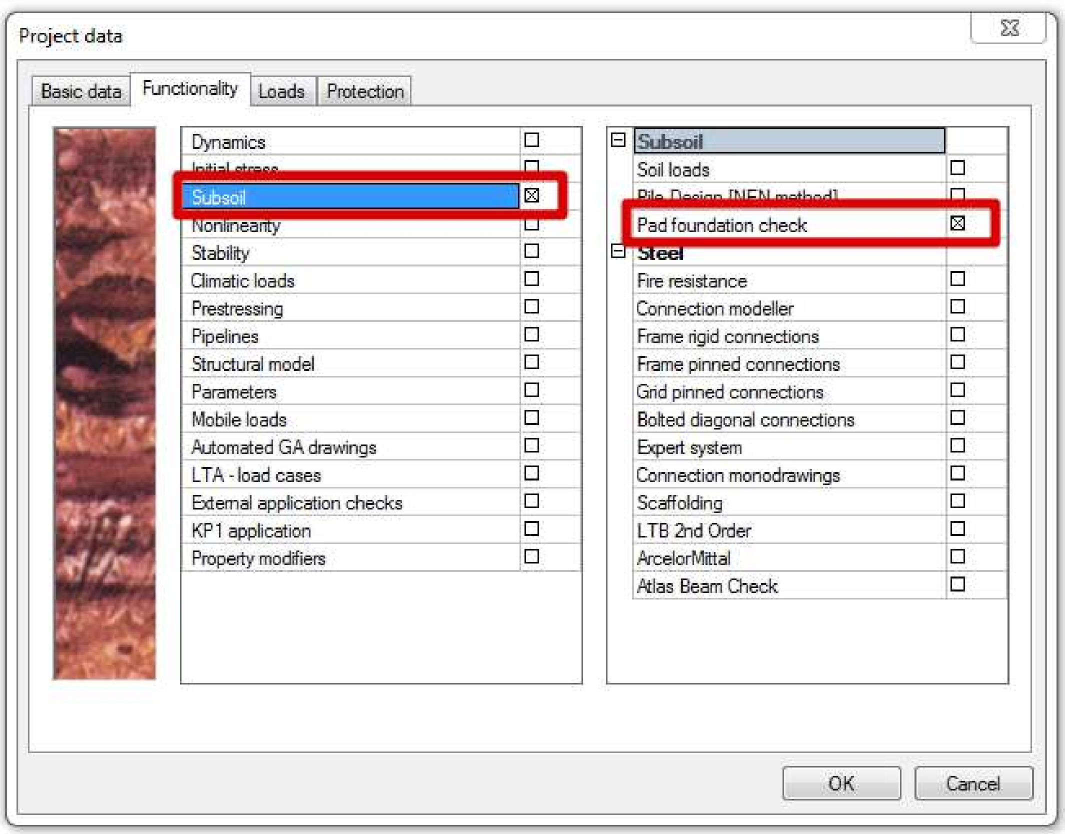
The provisions of section 6 of EN 1997-1 apply to spread foundations including pads, strips and rafts.

In SCIA Engineer the option “pad foundations” has been inputted following EN 1997-1.

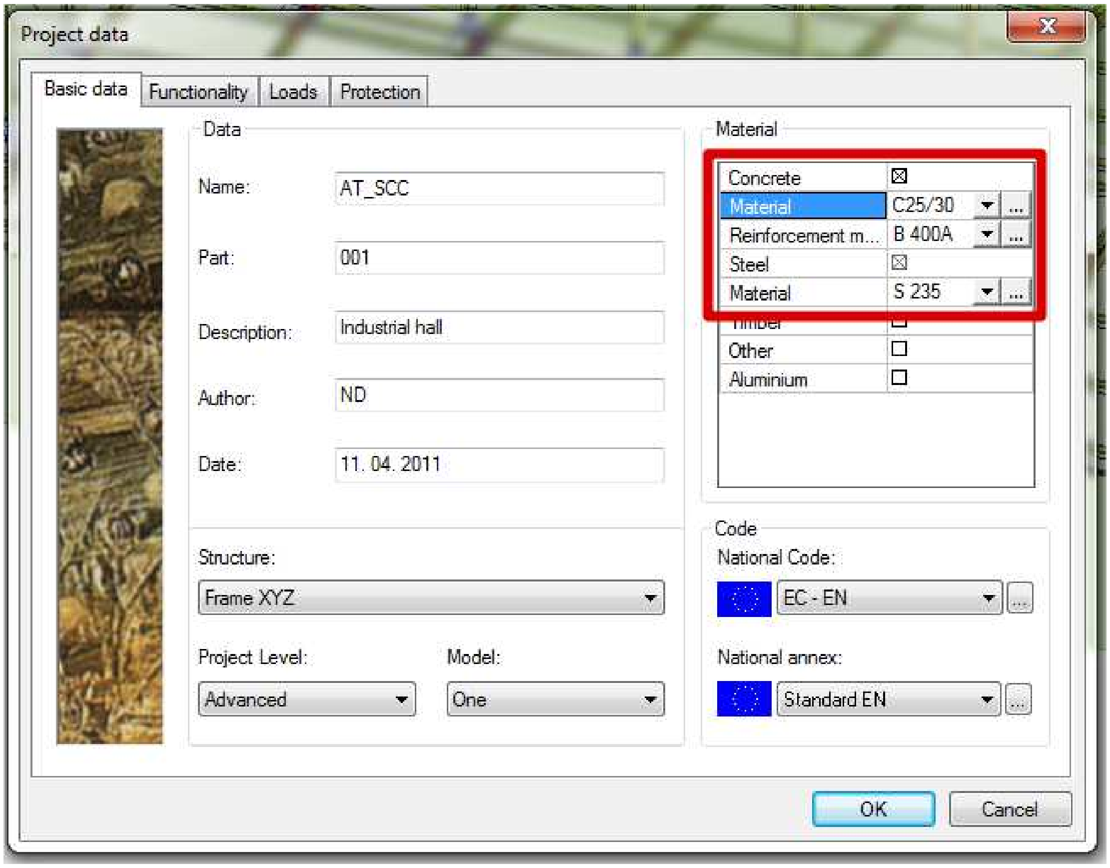
The following limit states shall be considered in this chapter:

- Loss of overall stability
- bearing resistance failure, punching failure, squeezing
- failure by sliding
- combined failure in the ground and in the structure
- structural failure due to foundation movement
- excessive settlements
- excessive heave due to swelling, frost and other causes
- unacceptable vibrations

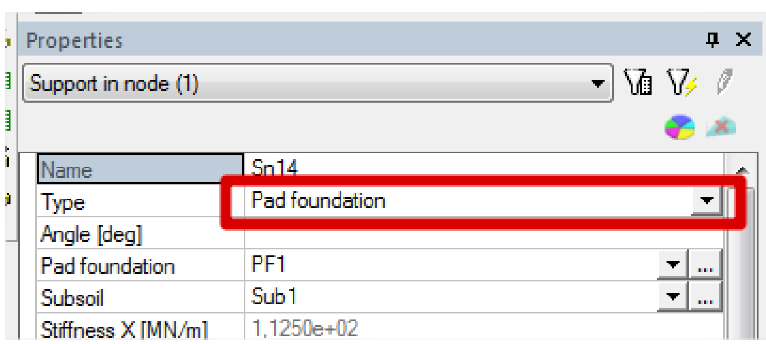
To use the pad foundation check in SCIA Engineer, the functionalities “Subsoil” and “Pad foundation check” should be activated:



Remark: Make sure that also the material “Concrete” has been activated; otherwise it is not possible to input a pad foundation!



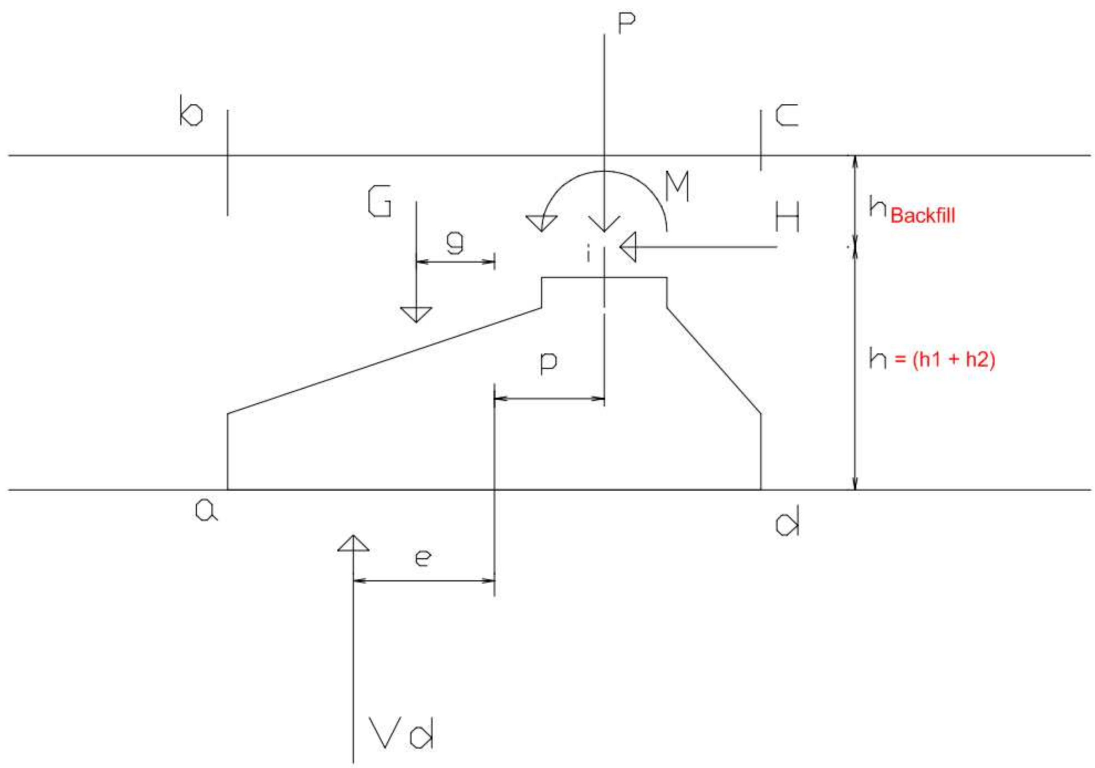
And afterwards the option "Pad foundation" can be chosen in the Properties window of the supports:



Properties of the Pad Foundation

Determination of Effective Geometry

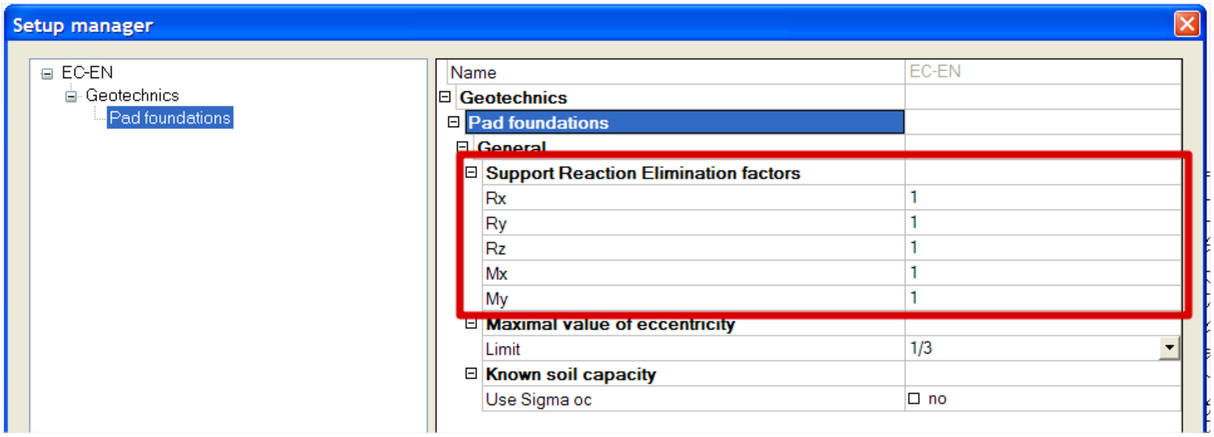
The next step in the check concerns the determination of the effective geometry of the pad foundation. The following picture illustrates the different actions working on the foundation.



In this picture the following notations are used:

G	Weight of the foundation and of any backfill material inside the area of abcd.
g	Load application point for load **G** referenced to the center point of the foundation base
P	Vertical **Rz** reaction of the support
p	Load application point for load **P** referenced to the center point of the foundation base.
	This is read as the load eccentricities ex and ey from the Pad Foundation library.
H	Horizontal **Rx** or **Ry** reaction of the support
h	=(h1 + h2)
	Load application point of the horizontal load H referenced to the foundation base.
	With h1 and h2 read from the Pad Foundation Library.
M	Moment **Mx** or **My** reaction of the support
V_d	= G + P
	Ultimate load vertical to the foundation base including the weight of the foundation and any backfill material.
e	Load application point for load $\mathbf{V_d}$ referenced to the center point of the foundation base

In SCIA Engineer **Support Reaction Elimination factors** can be defined in the Geotechnics setup.



These factors can be used in case the user for example models only a pad foundation and omits other foundation elements like a ring beam. The user can then specify that for example only 50% of a reaction should be used to design the pad foundation since the other 50% goes into the ring beam.

The eccentricity **e** is calculated as follows:

$$e = \frac{M + G * g + H * h - P * p}{V_d}$$

For a **general 3D case** this formula is written as:

$$e_x = \frac{M_y + G * g_x + H_x * h - P * p_x}{V_d}$$

$$e_y = \frac{M_x + G * g_y + H_y * h - P * p_y}{V_d}$$

Weight G

The weight G consists of three parts:

1) The weight of the foundation block, $\mathbf{G_{Block}}$

- This depends on the shape of the block (prismatic or pyramidal), dimensions and also the density γ_{Block} of the block material.
- The density of the block depends on the **Water table level**.

No influence	γ_{Block}
at foundation base	γ_{Block}
at ground level	$(\gamma_{Block} - \gamma_W)$

- The Water Density γ_W is taken as **9,81 kN/m³**

2) The weight of the backfill around h2, $\mathbf{G_{Backfill,Around}}$

- This depends on the shape of the block (prismatic or pyramidal), dimensions and also the density of the backfill material.
- The backfill density $\gamma_{Backfill,d}$ is specified in Ground properties
- The density of the backfill depends on the **Water table level**.

No influence	$\gamma_{Backfill,d}$

at foundation base $\gamma_{Backfill,d}$

at ground level $(\gamma_{Backfill,d} - \gamma_W)$

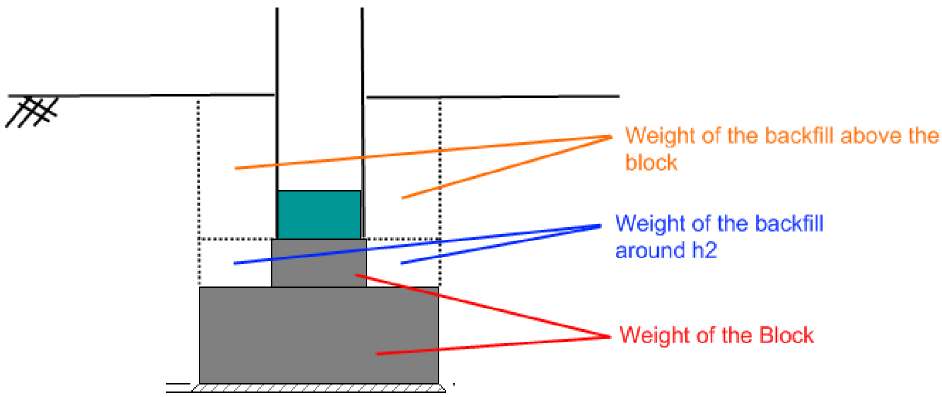
- The Water Density γ_W is taken as **9,81 kN/m³**

3) The weight of the backfill above the foundation block, $\mathbf{G_{Backfill,Above}}$

- This depends on the height and density of the backfill as specified in the input of the Pad Foundation.

In SCIA Engineer it is also possible to input a **negative height for the backfill material**. A negative value is used to indicate that the soil is lower than the top of the foundation block.

The three parts are illustrated on the following picture:



The design value of the total weight G can then be calculated as follows:
$G_d = \gamma_G * [G_{Block} + G_{Backfill,Around} + G_{Backfill,Above}]$

With γ_G the safety factor of the permanent loading for the combination under consideration, as defined in "Ground properties".
γ_G is a safety factor which needs to be determined concerns the safety factor for the weight of the pad foundation and the backfill material. This safety factor is taken as the safety factor for the first permanent load case for the combination under consideration i.e. γ_G. In case a combination does not have a permanent load case, γ_G is taken as 1,00.

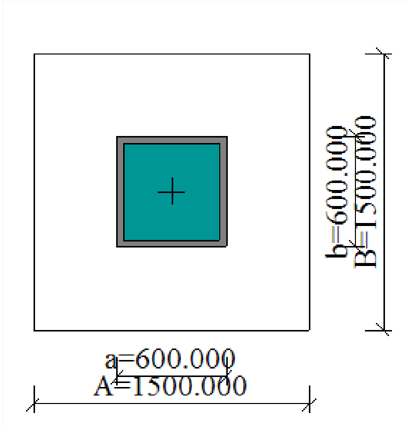
Distances gx & gy

Using the weight and the volume, the center of gravity of the block and backfill are determined. The distances gx and gy are then calculated from this centroid to the center point of the foundation base.

Effective Geometry

As a final step, using the eccentricities ex and ey the effective geometry of the foundation base is calculated as follows:

L1 = A – 2 * |ex|
L2 = B – 2 * |ey|
With A & B read from the Pad Foundation library:

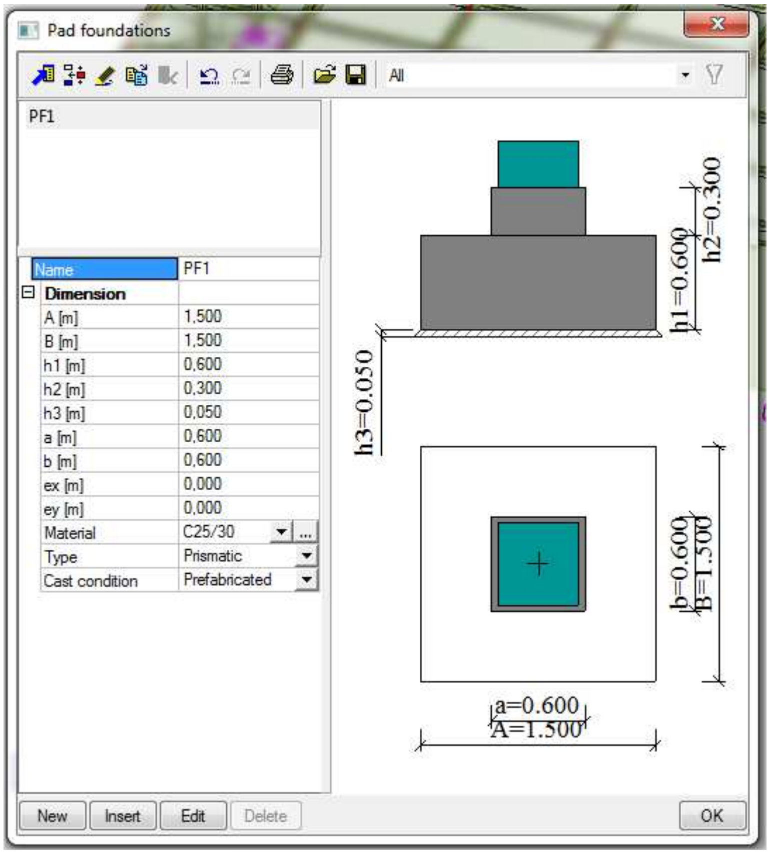


B' = min (L1 ; L2)
L' = max (L1 ; L2)
A' = B' * L'

In case SCIA Engineer will find a value B'< 0 or L'< 0, the geometry is incorrect and the check is not executed and a warning is given on the output.

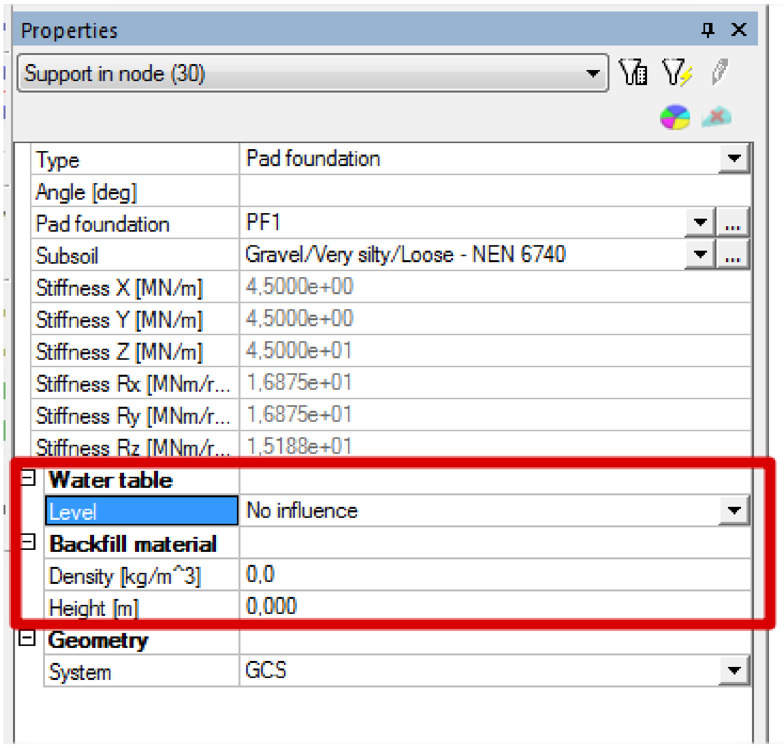
In SCIA Engineer

The dimensions of the pad foundations can be inputted in the properties window of the support, at "Pad foundation":

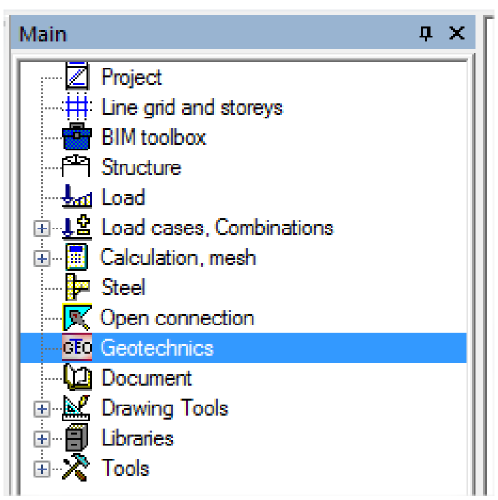


And the type of the subsoil under "Subsoil".

Afterwards it is also possible to input here the influence of the water table and the properties of the backfill material:



The checks can be found in the menu “Geotechnics”:



When performing this Pad foundation stability check, first the general properties of the pad foundation are shown here:

Pad foundation check

Linear calculation, Extreme : Global
Selection : All
Class : GEO
Pad foundation check

EN 1997-1 Stability check

Sn4/N9	CO4/1	4,64

....::Input & Loading::...

Design data

Design approach	1 (Combination 2)
Partial factor sets	M2 "+" R1
Gamma Fi'	1,25
Gamma c'	1,25
Gamma cu	1,40
Gamma qu	1,40
Gamma gamma	1,00
Gamma R;v	1,00
Gamma R;h	1,00

Pad foundation data

Name	PF1
Material	C25/30
Type	Prismatic
Cast condition	Prefabricated

Pad foundation geometry

A [m]	B [m]	h1 [m]	h2 [m]	h3 [m]	a [m]	b [m]	ex [m]	ey [m]
2,200	2,200	1,500	0,500	0,050	1,500	1,500	0,000	0,000

Subsoil data

Name	Gravel/Very silty/Stiff	
Type	Drained	
Density	2000,0	kg/m^3
Fi'	35,00	deg
Sigma oc	0,0	MPa
c'	0,0	MPa
cu	0,0	MPa

Backfill material

Density	0,0	kg/m^3
Height	0,000	m

Water table

Level	No influence

Loading

Reaction		Elimination factor	Loading		
Rx	-75,70	1,00	Hx	-75,70	kN
Ry	0,07	1,00	Hy	0,07	kN
Rz	117,12	1,00	P	117,12	kN
Mx	-0,33	1,00	Mx	-0,33	kNm
My	-103,56	1,00	My	-103,56	kNm

....::ULS Stability Check::...

Determination of Effective Geometry
According to EN 1997-1 Annex D

Table of values		
Weight of backfill material	0,00	kN
Weight of pad foundation	209,63	kN
Partial safety factor	1,00	
Design weight of pad foundation and backfill G	209,63	kN
qx	0,000	m
qy	0,000	m
px	0,000	m
py	0,000	m
h	2,000	m
Design value of the vertical load Vd	326,74	kN
Design value of the horizontal load Hd	75,70	kN
Eccentricity ex	-0,780	m
Eccentricity ey	-0,001	m
Effective foundation width B'	0,639	m
Effective foundation length L'	2,199	m
Effective foundation area A'	1,406	m^2

And afterwards the Ultimate limit state checks will be displayed (see further).

Ultimate limit state

(EN 1997-1 §6.5)

In this chapter the different steps of the Pad Foundation Checks are specified.

First of all, the required safety and resistance factors need to be determined depending on the chosen Design Approach.

Using these safety factors, the vertical design loading $\mathbf{V_d}$, horizontal design loading $\mathbf{H_d}$ and effective geometry of the pad are determined.

Based on this effective geometry the different checks are executed.
The above steps are detailed in the following paragraphs.

Bearing Check

The Bearing check is executed according to **EN 1997-1 art. 6.5.2** and **Annex D** [Ref.1]

$$V_d \leq R_d$$

The Bearing resistance $\mathbf{R_d}$ depends on the fact if the soil condition is drained or undrained.

In case the user ‘knows’ the soil capacity, for example from a geotechnical report, $\mathbf{R_d}$ can be read directly from the input data instead of calculated.

Undrained Bearing Resistance

The formulas in this paragraph are used in case the **Type** field in the Subsoil Library is set to **Undrained**.

The design value of the undrained bearing resistance is calculated as follows:

$$R_d = \frac{[(\pi + 2) * c_{ud} * b_c * s_c * i_c + q] * A'}{\gamma_{R,v}}$$

c_{ud} As specified in the National Annex Setup

b_c Inclination of the foundation base

In SCIA Engineer, the foundation base is always horizontal, thus: b_c = 1,00

s_c Shape of the foundation

In SCIA Engineer the foundation block has a rectangular shape, $s_c = 1 + 0{,}2 * \frac{B'}{L'}$

i_c Inclination of the load, caused by horizontal load H_d

$$= \frac{1}{2}\left[1 + \sqrt{1 - \frac{H_d}{A' * c_{ud}}}\right]$$

and $H_d \leq A' * c_{ud}$

in case $H_d > A' * c_{ud}$ the value of **i_c** is set to **0,5**

H_d Resulting horizontal load

$$= \sqrt{H_x^2 + H_y^2}$$

H_x Horizontal support reaction Rx as defined in “General”

H_y Horizontal support reaction Ry as defined in “General”

B’ Effective width as defined in “General”

L’ Effective length as defined in “General”

A’ Effective area as defined in “General”

q Overburden at the foundation base [Ref.5]

$=(h1 + h2 + h_{backfill}) * \gamma_{Backfill,d}$

With:

h1 & h2 read from the Pad Foundation Library

$h_{backfill}$ read from the Pad Foundation input

$\gamma_{Backfill,d}$ as defined in ground properties

$\gamma_{R,v}$ Resistance factor read from the National Annex Setup

Drained Bearing Resistance

The formulas in this paragraph are used in case the **Type** field in the Subsoil Library is set to **Drained**.

The design value of the drained bearing resistance is calculated as follows:

$$R_d = \frac{\left[c'_d * N_c * b_c * s_c * i_c + q'_d * N_q * b_q * s_q * i_q + 0{,}5 * \gamma'_d * B' * N_\gamma * b_\gamma * s_\gamma * i_\gamma\right] * A'}{\gamma_{R,v}}$$

c_d’ As specified in the National Annex Setup

N_c Bearing resistance factor

$$= (N_q - 1) * \cot(\varphi'_d)$$

N_q Bearing resistance factor

$$= e^{\pi * \tan(\varphi'_d)} * \tan^2\left(45 + \frac{\varphi'_d}{2}\right)$$

N_γ Bearing resistance factor

$$= 2 * (N_q - 1) * \tan(\varphi'_d)$$

b_c Inclination of the foundation base

In SCIA Engineer, the foundation base is always horizontal, thus: $b_c = 1{,}00$

b_q Inclination of the foundation base

In SCIA Engineer, the foundation base is always horizontal, thus: $b_q = 1{,}00$

b_γ Inclination of the foundation base

In SCIA Engineer, the foundation base is always horizontal, thus: $b_\gamma = 1{,}00$

s_c Shape of the foundation

In SCIA Engineer the foundation block has a rectangular shape,

$s_c = \frac{s_q * N_q - 1}{N_q - 1}$

s_q Shape of the foundation

In SCIA Engineer the foundation block has a rectangular shape,

$s_q = 1 + \left(\frac{B'}{L'}\right) * \sin(\varphi'_d)$

s_γ Shape of the foundation

In SCIA Engineer the foundation block has a rectangular shape, $s_\gamma = 1 - 0{,}3 * \frac{B'}{L'}$

i_c Inclination of the load, caused by horizontal load H_d

$$= i_q - \frac{(1 - i_q)}{N_c * \tan(\varphi'_d)}$$

i_q Inclination of the load, caused by horizontal load H_d

$$= \left[1 - \frac{H_d}{V_d + A' * c'_d * cot(\varphi'_d)}\right]^m$$

i_γ Inclination of the load, caused by horizontal load H_d

$$= \left[1 - \frac{H_d}{V_d + A' * c'_d * cot(\varphi'_d)}\right]^{m+1}$$

m $= m_L * \cos^2(\theta) + m_B * \sin^2(\theta)$

m_L

$$= \frac{\left[2 + \left(\frac{L'}{B'}\right)\right]}{\left[1 + \left(\frac{L'}{B'}\right)\right]}$$

m_B

$$= \frac{\left[2 + \left(\frac{B'}{L'}\right)\right]}{\left[1 + \left(\frac{B'}{L'}\right)\right]}$$

θ Angle of the horizontal load H_d with the direction L'

φ'_d As specified in the Ground properties

B' Effective width as defined in general

L' Effective length as defined in general

A' Effective area as defined in General

H_d Resulting horizontal load

$$= \sqrt{H_x^2 + H_y^2}$$

H_x Horizontal support reaction Rx

H_y Horizontal support reaction Ry

V_d Vertical reaction as specified in “General”

q'_d Effective overburden at the foundation base [Ref.5]

=(h1 + h2 + $h_{backfill}$)* γ'_t

With:

h1 & h2 read from the Pad Foundation Library

$h_{backfill}$ read from the Pad Foundation input

γ'_t is depending on the water level as follows:

No influence	$\gamma_{Backfill,d}$
at foundation base	$\gamma_{Backfill,d}$
at ground level	$(\gamma_{Backfill,d} - \gamma_W)$

$\gamma_{Backfill,d}$ as defined in Ground properties

γ_W is taken as **9,81 kN/m³**

γ'_d Effective weight density of the soil below the foundation level depending on the water level as follows:

No influence	γ'_d
at foundation base	$(\gamma'_d - \gamma_W)$
at ground level	$(\gamma'_d - \gamma_W)$

γ'_d as defined in Ground properties

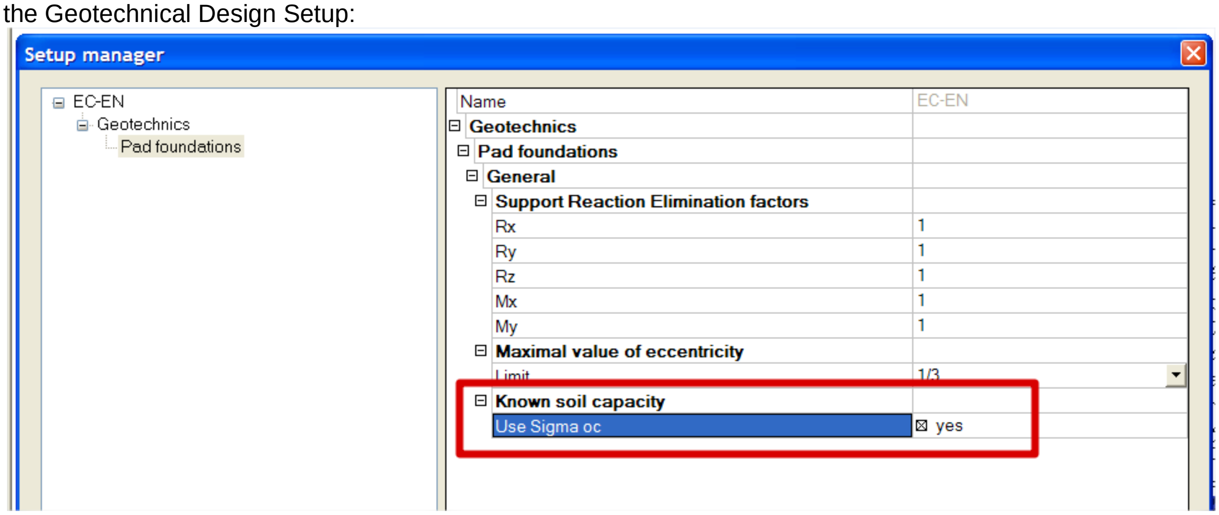
γ_W is taken as **9,81 kN/m³**

$\gamma_{R,v}$ Resistance factor read from the National Annex Setup

Known Soil Capacity Bearing Resistance

In case the Soil capacity is known, this value can be used directly instead of using the EN 1997-1 bearing resistance calculation outlined above.

This procedure is applied in case the checkbox **Known soil capacity, use Sigma oc** is activated in the Geotechnical Design Setup:



The design value of the bearing resistance is calculated as follows:

$$R_d = A' * \sigma_{od}$$

A'	Effective area as defined in "general
σ_{od}	Design value of the admissible soil capacity, taken as $\boldsymbol{\sigma_{oc}}$
σ_{oc}	Read from the Subsoil Library

Bearing check in SCIA Engineer

Bearing Resistance Check
According to EN 1997-1 article 6.5.2.1 and Annex D

Table of values		
Bearing resistance factor Nq	16,92	
Bearing resistance factor Nc	28,42	
Bearing resistance factor N gamma	17,84	
Pad foundation base inclination factor bq	1,00	
Pad foundation base inclination factor bc	1,00	
Pad foundation base inclination factor bgamma	1,00	
Shape factor sq	1,14	
Shape factor sc	1,15	
Shape factor sgamma	0,91	
Angle theta	89,95	deg
Exponent mB	1,77	
Exponent mL	1,23	
Exponent m	1,77	
Load inclination factor iq	0,63	
Load inclination factor ic	0,62	
Load inclination factor i gamma	0,48	
Effective backfill density	0,0	kN/m^3
Design effective overburden q'	0,00	kN/m^2
Effective subsoil density	20,0	kN/m^3
Design bearing resistance Rd	70,45	kN
Unity check (6.1)	4,64	

So in this example the unity check for the Bearing resistance is not okay.

Sliding Check

The Sliding check is executed according to **EN 1997-1 art. 6.5.3** [Ref.1]

$$H_d \leq R_d + R_{p,d}$$

The Sliding resistance $\mathbf{R_d}$ depends on the fact if the soil condition is drained or undrained.

The value $\mathbf{R_{p,d}}$ specifies the positive effect of the earth pressure at the side of the foundation.

Since this effect cannot be relied upon, this value is taken as zero in SCIA Engineer.

The sliding resistance is dependent on the condition of the subsoil.

a) - In case the **Type** field in the Subsoil Library is set to **Undrained**.

$$R_d = \frac{A' * c_{ud}}{\gamma_{R,h}}$$

c_{ud}	As defined in Ground properties
A'	Effective area as defined in "General"
$\gamma_{R,h}$	Resistance factor read from the National Annex Setup

- In case the checkbox **Water/air in clay subgrade** in the Subsoil Library is activated, it means that it is possible for water or air to reach the interface between a foundation and an undrained clay subgrade. Following EN 1997-1 § 6.5.3(12), the value of $\mathbf{R_d}$ is limited as follows:

$$R_d \leq 0{,}4 * V_d$$

V_d	Vertical reaction as defined in "General"

b) In case the **Type** field in the Subsoil Library is set to **Drained**.

$$R_d = \frac{V_d * \tan(\delta_d)}{\gamma_{R,h}}$$

V_d	Vertical reaction as defined in "General"	
δ_d	Design friction angle at the foundation base	
	Dependent on the **Cast condition** specified in the Pad Foundation Library:	
	Prefabricated	$\frac{2}{3} * \varphi'_d$
	In situ	φ'_d
φ'_d	As specified in Ground properties	
$\gamma_{R,h}$	Resistance factor read from the National Annex Setup	

Sliding check in SCIA Engineer

Sliding Resistance Check
According to EN 1997-1 article 6.5.3

Table of values		
Design friction angle delta	19,50	deg
Design earth pressure resistance Rpd	0,00	kN
Design shear resistance Rd	115,73	kN
Unity check (6.2)	0,65	

So in this example the unity check for the Sliding resistance is okay.

Eccentricity check

EN 1997-1 art. 6.5.4 specifies that special precautions are required for loads with large eccentricities:

Special precautions shall be taken where the eccentricity of loading exceeds 1/3 of the width of a rectangular footing or 0,6 of the radius of a circular footing.
Such precautions include:

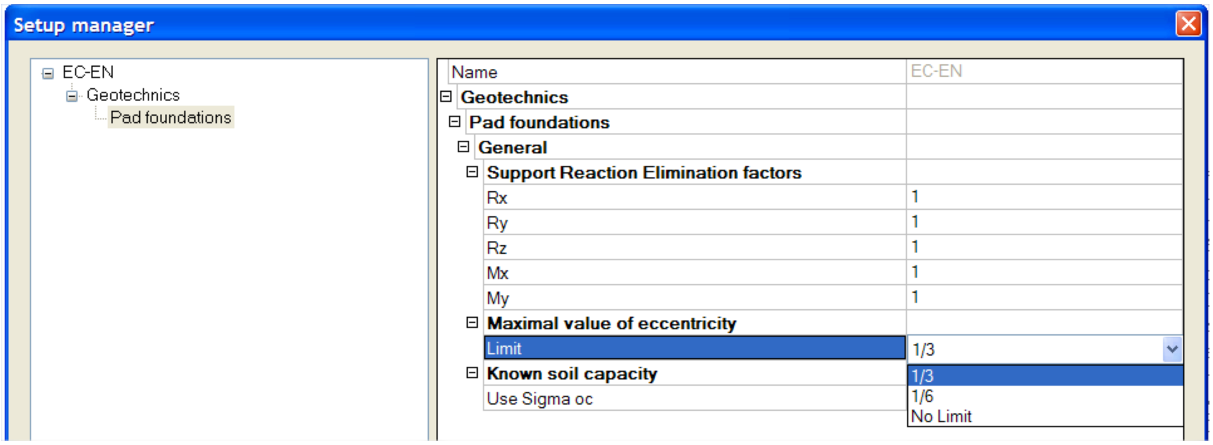
- *careful review of the design values of actions in accordance with 2.4.2*
- *designing the location of the foundation edge by taking into account the magnitude of construction tolerances.*

According to [Ref.2] pp96:

*It is common practice (**although not required by EN 1997-1**) to put some limit on the eccentricity under characteristic values of actions.*

According to [Ref.3] this is done by checking if the design load is within a critical ellipse or critical diamond.
More specifically the eccentricity of the load should not exceed **1/3** or **1/6** of the width.

The maximal value of the eccentricity is defined in the Geotechnical Design Setup:



Based on the maximal value an eccentricity check is executed as follows according to [Ref.3].

a) In case the maximal eccentricity is set to **1/3**

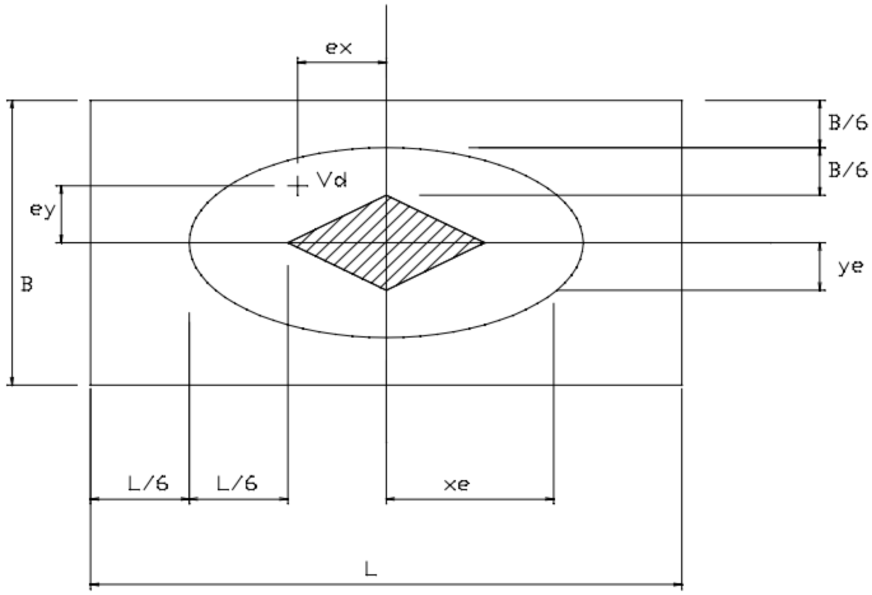
$$\left(\frac{e_x}{A}\right)^2 + \left(\frac{e_y}{B}\right)^2 \leq \frac{1}{9}$$

The eccentricity check of **1/3** take into account that the pad foundation will not lose contact with the ground over more than half its width under the service loads.

b) In case the maximal eccentricity is set to **1/6**

$$\frac{e_x}{A} + \frac{e_y}{B} \leq \frac{1}{6}$$

e_x	As specified in “General”
e_y	As specified in “General”
A	Read from Pad Foundation Library
B	Read from Pad Foundation Library



The eccentricity check of **1/6** take into account that the whole pad foundation is under pressure. The foundation will not lose contact with the ground over the whole area.

c) In case the maximal eccentricity is set to **No limit**
In this case there is no limit i.e. any eccentricity is allowed. The unity check is then set to **0,00**.

Following the EN 1997-1 it is not required to put limits on the eccentricity calculation

Excentricity check in SCIA Engineer

Check of Maximal Eccentricity
According to EN 1997-1 article 6.5.4 &
Bautabellen fur Ingenieure, 13. Auflage, Werner Verlag, 1998

Table of values	
Maximal value of eccentricity	1/3
Unity check	1,13

So in this example the unity check for the maximum excentricity is not okay.

Uplift Check

In case the vertical design loading V_d is negative, it implies that the pad foundation is in tension and may thus be 'uplifted' from the ground.
The uplift check is written out as follows and is **executed instead of the Bearing, Sliding and Eccentricity checks**:

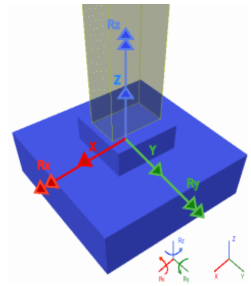
$$|P| \leq G_d$$

P: The vertical **Rz** reaction as specified in "General"
G_d The weight of the foundation and any backfill as specified in "General"

Pad Foundation Stiffness calculation in SCIA Engineer

This chapter specifies the calculation of the stiffness coefficients of a pad foundation.

In the stiffness calculation has been assumed that C2x = C2y.



Stiffness X $A \cdot B \cdot C1x$

Stiffness Y $A \cdot B \cdot C1y$

Stiffness Z $A \cdot B \cdot C1z + 2 \cdot (A + B) \cdot \sqrt{C1z \cdot C2x} + 2C2x$

Stiffness Rx $B^3 \cdot \frac{A \cdot C1z + 2 \cdot \sqrt{C1z \cdot C2x}}{6} + \frac{A \cdot B^2 \cdot \sqrt{C1z \cdot C2x}}{2} + \frac{B^2 \cdot C2x}{2} + A \cdot B \cdot C2x$

Stiffness Ry $A^3 \cdot \frac{B \cdot C1z + 2 \cdot \sqrt{C1z \cdot C2x}}{6} + \frac{B \cdot A^2 \cdot \sqrt{C1z \cdot C2x}}{2} + \frac{A^2 \cdot C2x}{2} + B \cdot A \cdot C2x$

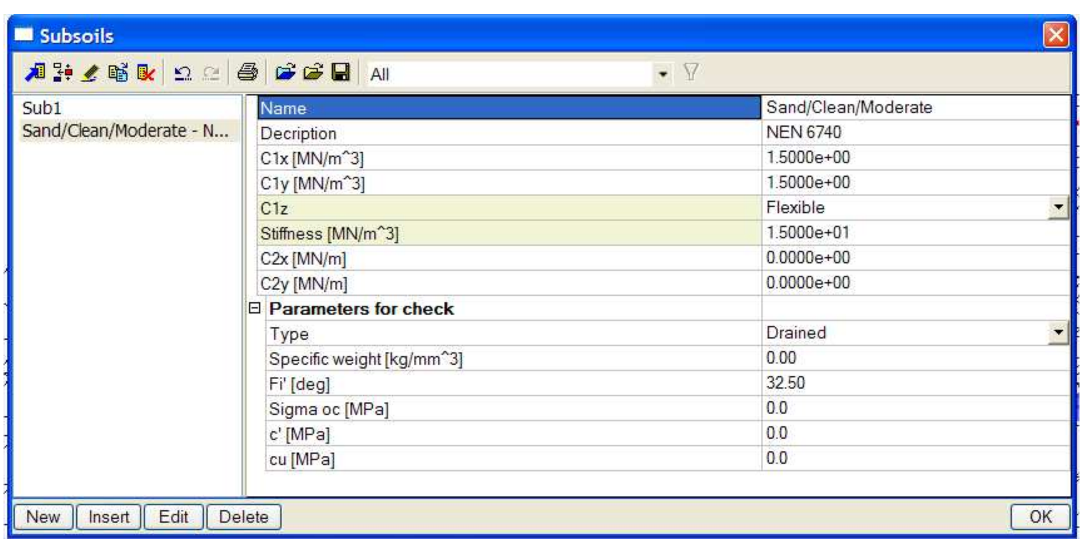
Stiffness Rz
$$C1y \cdot Ix + C1x \cdot Iy + \frac{h1 \cdot A^3 \cdot C1z}{6} + \frac{h1 \cdot B^3 \cdot C1z}{6} + \frac{2 \cdot \sqrt{C1z \cdot C2x} \cdot A^2 \cdot h1}{4} + \frac{2 \cdot \sqrt{C1z \cdot C2x} \cdot B^2 \cdot h1}{4} + \frac{C2x \cdot A^2}{2} + \frac{C2x \cdot B^2}{2}$$

With:

A	Dimension read from Pad Foundation library
B	Dimension read from Pad Foundation library
C1x	Soil stiffness read from Subsoil Library
C1y	Soil stiffness read from Subsoil Library
C1z	Soil stiffness read from Subsoil Library
C2x	Soil stiffness read from Subsoil Library

Ix $\frac{A \cdot B^3}{12}$

Iy $\frac{B \cdot A^3}{12}$

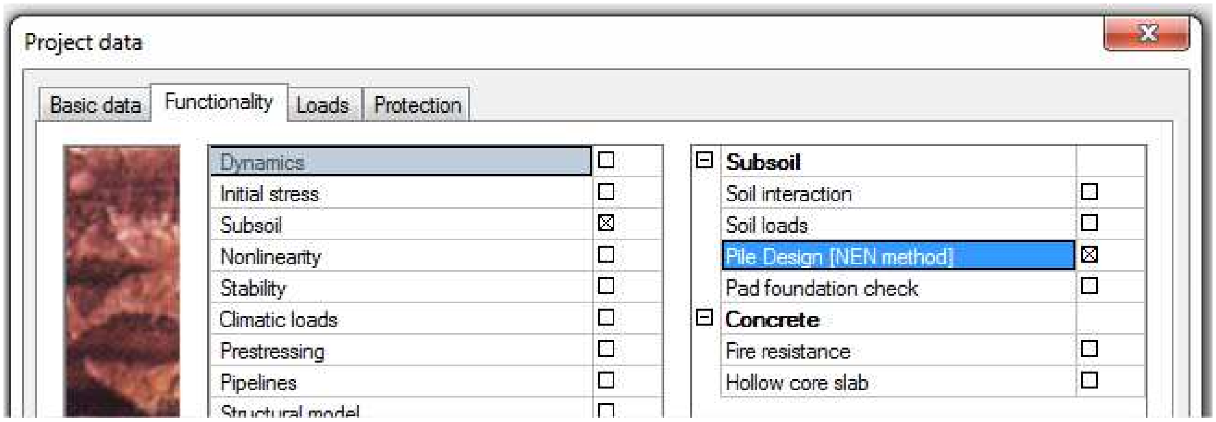


7. Pile foundations in SCIA Engineer – NEN method

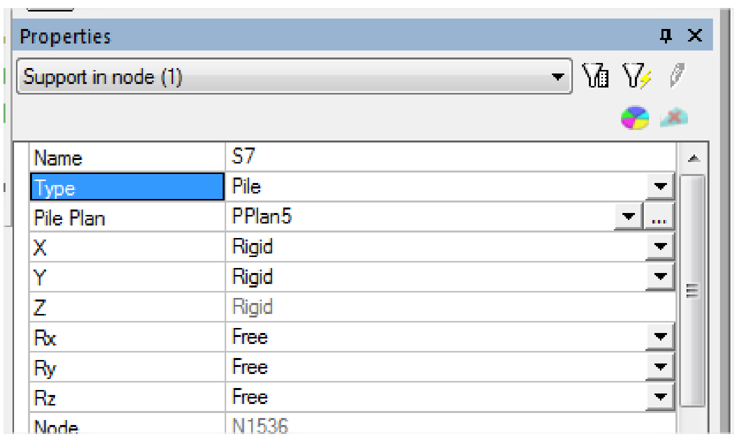
Pile foundations are programmed in SCIA Engineer following the EN 1997-1, with the Dutch National Annex. For the moment this check does only exist for the Dutch National annex and not yet for the other countries.

Functionality in SCIA Engineer

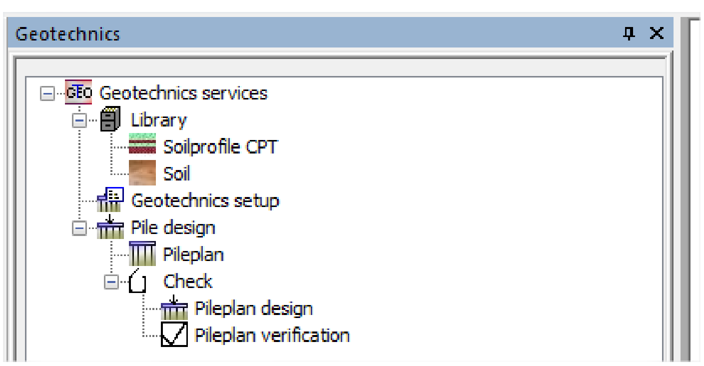
Pile design [NEN Method] functionality is added under the subsoil category.



When this functionality has been activated, the Type of the support can be changed to "Pile":



A New service "Geotechnics" has been introduced in SCIA Engineer. This service is common for Pile design and Pad Foundation. This service is available only if the Pile design functionality is selected.

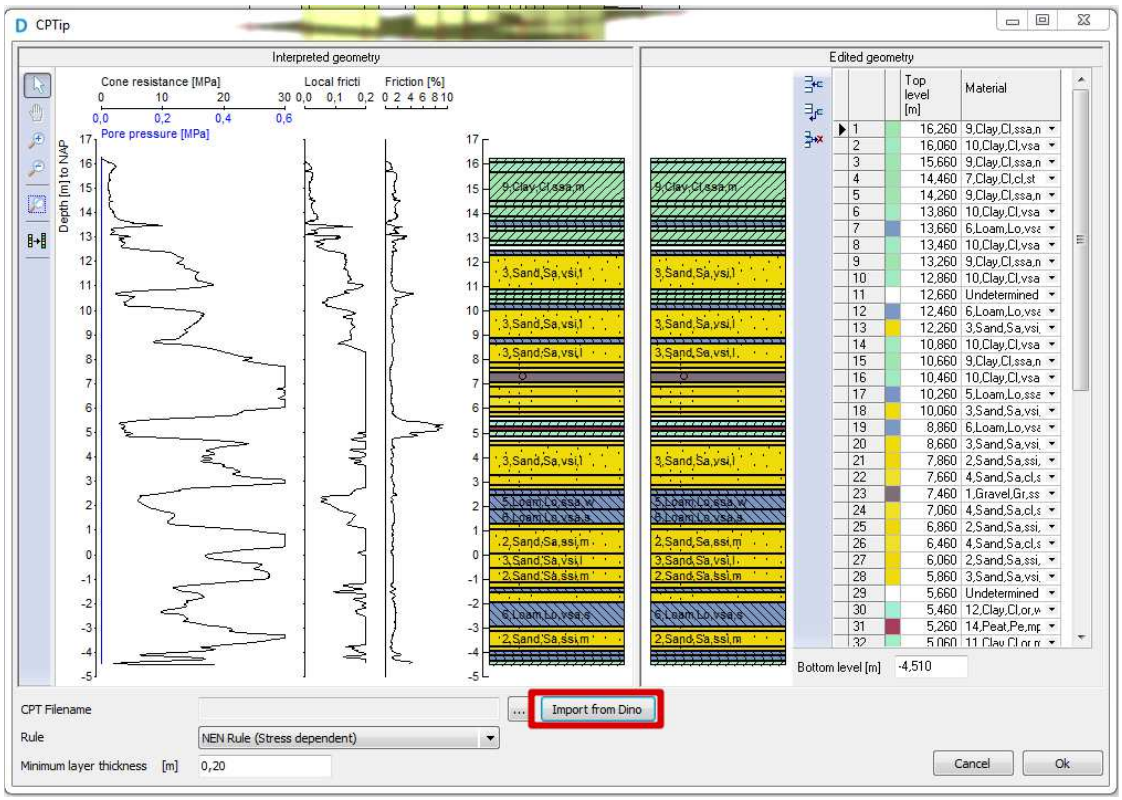


Geotechnics in SCIA Engineer

Soil Profile CPT

The soil profile CPT is a library in SCIA Engineer which enables the user to generate the soil profiles from CPT data. The generated soil profiles are used in Pile plan design /verification.
The CPT dialog will be as shown below.

The user has to select the GEF file using the [...] button. The program also allows the user to get the gef file from the link “Import from Dino”.

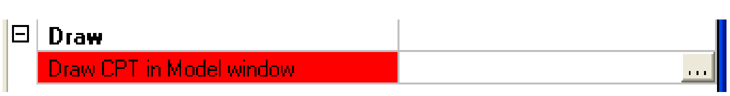


The program generates the soil profile from the CPT data. In this dialog, two soil profiles are drawn. The left profile is the result of the interpretation from the CPT data with the CPT data drawn to the left of it and the other profile is the edited geometry.

The interpretation is based on the NEN rule (Stress Dependent) which is based on table 1 of NEN 6740. The default min layer thickness is 0.5m.
The program allows the user to edit the interpreted soil profile. The interpreted soil profile consists of only the soils which are defined by the NEN model (see also next chapter). The user can edit the interpreted geometry of the soil profile with the user defined soils. The soils used by NEN are made available in the database of the soil library and the user will be able to define the new soils.

The interpreted geometry can be retrieved at any time by using the option “Copy interpreted geometry to edited geometry. [icon].

The edited geometry (or soil profile) will be used as an input for the pile plan design/verification. After generating the soil profile, a library object (CPT) has been added into the Soil profile CPT library. The CPT object is represented graphically in the 3D model as a borehole object in SCIA Engineer. The user has to use the “Draw CPT in Model window” option to draw the CPT in the model, with other words to make it visible on the graphical screen.



The XY coordinates are defined by the user and the top level is the test level. The test level has been read from the CPT data.

Insertion point	
X [m]	10.000
Y [m]	10.000
Z [m]	-0.850

The user has to specify the additional data of the soil profile which are required during the design/verification.

Additional data	
Phreatic level [m]	0.000
Overconsolidation ratio of bearing layer	1
Top of positive skin friction zone [m]	-1.000
Bottom of negative skin friction zone ...	-0.850
Expected ground level settlement [m]	0.110

The default values are specified in the properties. The values for Top of positive skin friction zone and bottom of negative skin friction zone will be entered by the user.

Phreatic level — The level between the dry soil and the wet soil

OCR — The value of **Overconsolidation ratio** of bearing layer determines whether the maximum pile tip resistance to be reduced due to Overconsolidation or not. Overconsolidation is normally caused by loads which were applied to the bearing layer over a long period of time. The range and effect of OCR on Pile tip resistance are

OCR<=2 – No effect on Pile tip resistance

2< OCR < 4 – Maximum Pile tip resistance is reduced by 33%

OCR > 4 – Maximum Pile tip resistance is reduced by 50%

Explanation OCR:

Consolidation *is a process by which soils decrease in volume. According to Karl Terzaghi* ***consolidation is any process which involves decrease in water content of a saturated soil without replacement of water by air.*** *In general it is the process in which reduction in volume takes place by expulsion of water under long term static loads. It occurs when stress is applied to a soil that causes the soil particles to pack together more tightly, therefore reducing its bulk volume. When this occurs in a soil that is saturated with water, water will be squeezed out of the soil. The magnitude of consolidation can be predicted by many different methods. In the Classical Method, developed by Karl von Terzaghi, soils are tested with an oedometer test to determine their compression index. This can be used to predict the amount of consolidation.*

When stress is removed from a consolidated soil, the soil will rebound, regaining some of the volume it had lost in the consolidation process. If the stress is reapplied, the soil will consolidate again along a recompression curve, defined by the recompression index. ***The soil which had its load removed is considered to be overconsolidated.*** *This is the case for soils which have previously had glaciers on them. The highest stress that it has been subjected to is termed the preconsolidation stress. The over consolidation ratio or* ***OCR*** *is defined as the* ***highest stress experienced divided by the current stress****. A soil which is currently experiencing its highest stress is said to be normally consolidated and to have an OCR of one. A soil could be considered underconsolidated immediately after a new load is applied but before the excess pore water pressure has had time to dissipate.*

Top of Positive Skin Friction Zone	Top of Positive skin friction zone The bottom of the zone coincides with the pile tip level. For a prefabricated pile with widened tip, the top of the zone may never be placed above the widening. The program checks and corrects for this automatically.
Bottom of Negative Skin Friction Zone	Bottom of Negative skin friction zone The top of the zone coincides with the surface or excavation level. The calculation of negative skin friction depends on whether piles are to be considered as single or group. When Piles are within 5m, the piles form a pile group, if not they are considered as single piles.
Expected Ground Level settlement	Expected ground level settlement The expected ground level settlement determines how the negative skin friction has to be incorporated in the calculations. If the expected settlement is 0.02m, negative skin friction is negligible and will not be considered. For the values ranging from 0.02m to 0.10m, the effect of negative skin friction is directly incorporated into the calculated pile settlement by adding half of the expected ground level settlement to the total pile settlement. For values >0.10m, the maximum forces due to negative skin friction are calculated. These forces are then used to determine the negative skin friction on the pile settlement.

CPT Data

The gef file contains the relevant CPT data. The data include the Level, qc, friction, water pressure and friction number. The availability of the above properties is dependent on the gef file. The program identifies the input data and will generate the soil profile based on the input data and the interpretation rule.

Import from Dino: This option allows the user to import the gef files from the map. The available CPT's in the region will be shown to the user and the user will select the CPT. The program will generate the soil profile for the selected CPT.

NEN Rule (Stress dependent)

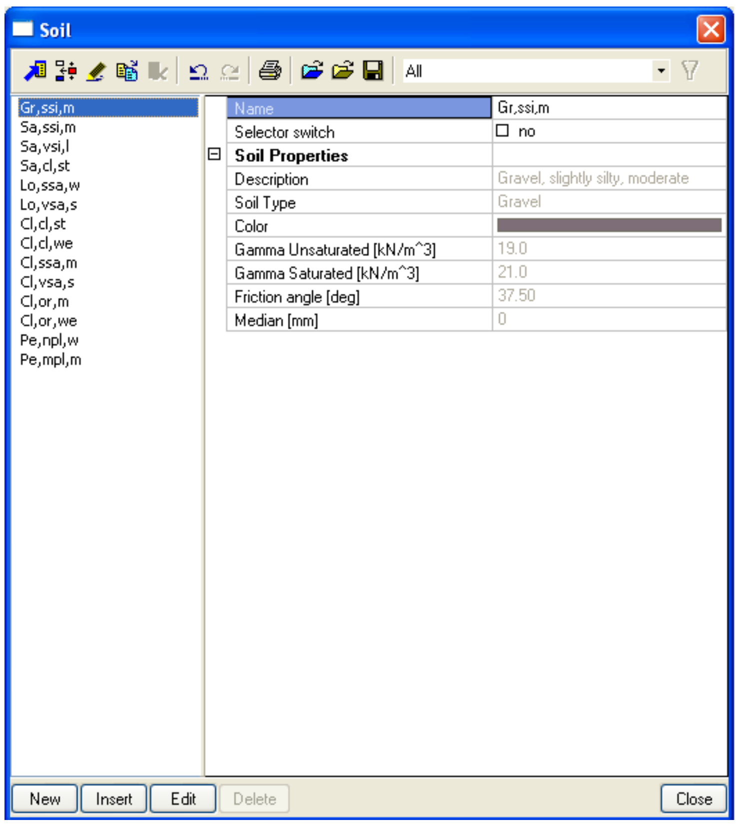
The NEN rule (stress dependent) is considered to be a more common and is used for interpretation of the soil profile. This rule uses 14 different areas and is based on the Dutch standard NEN 6740. Each area describes certain soil types by defining the relationship between CPT resistance and friction ratio. The friction ratio is defined as the shear resistance as a percentage of the cone resistance. The soils used by the NEN rule and its properties are defined in a soil library. The soil types used by NEN rule are:

Gravel, slightly silty, moderate	Sand, clean, stiff
Sand, slightly silty, moderate	Sand, very silty, loose
Loam, very sandy, stiff	Loam, slightly sandy, weak
Clay, very sandy, stiff	Clay, slightly sandy, moderate
Clay, clean, stiff	Clay, clean, weak
Clay, organ, moderate	Clay, organ, weak
Peat, moderately preloaded, moderate	Peat, not preloaded, weak.

Soil library

Soil library is a new standard library in SCIA Engineer. This library is added under the subsoil node. The soil materials and its properties are specified in this library. The database of soils used by the NEN model is created in a db4 file and will be loaded automatically.

The program also enables the user to define the new soils. The user defined soils will be used to edit the interpreted geometry of the soil profile.



Description	Description of the Soil
Soil type	The soils can be any of the following types: Gravel, Sand, Loam, Clay, Peat Note: this type must be selected in order to perform a correct calculation.
Gamma unsaturated	Dry unit weight of the soil
Gamma saturated	Saturated unit weight of the soil
Friction angle	Angle of internal friction for the soil – The value must be between 0 - 90 degrees

Median — This property applies to soil type's sand and gravel.

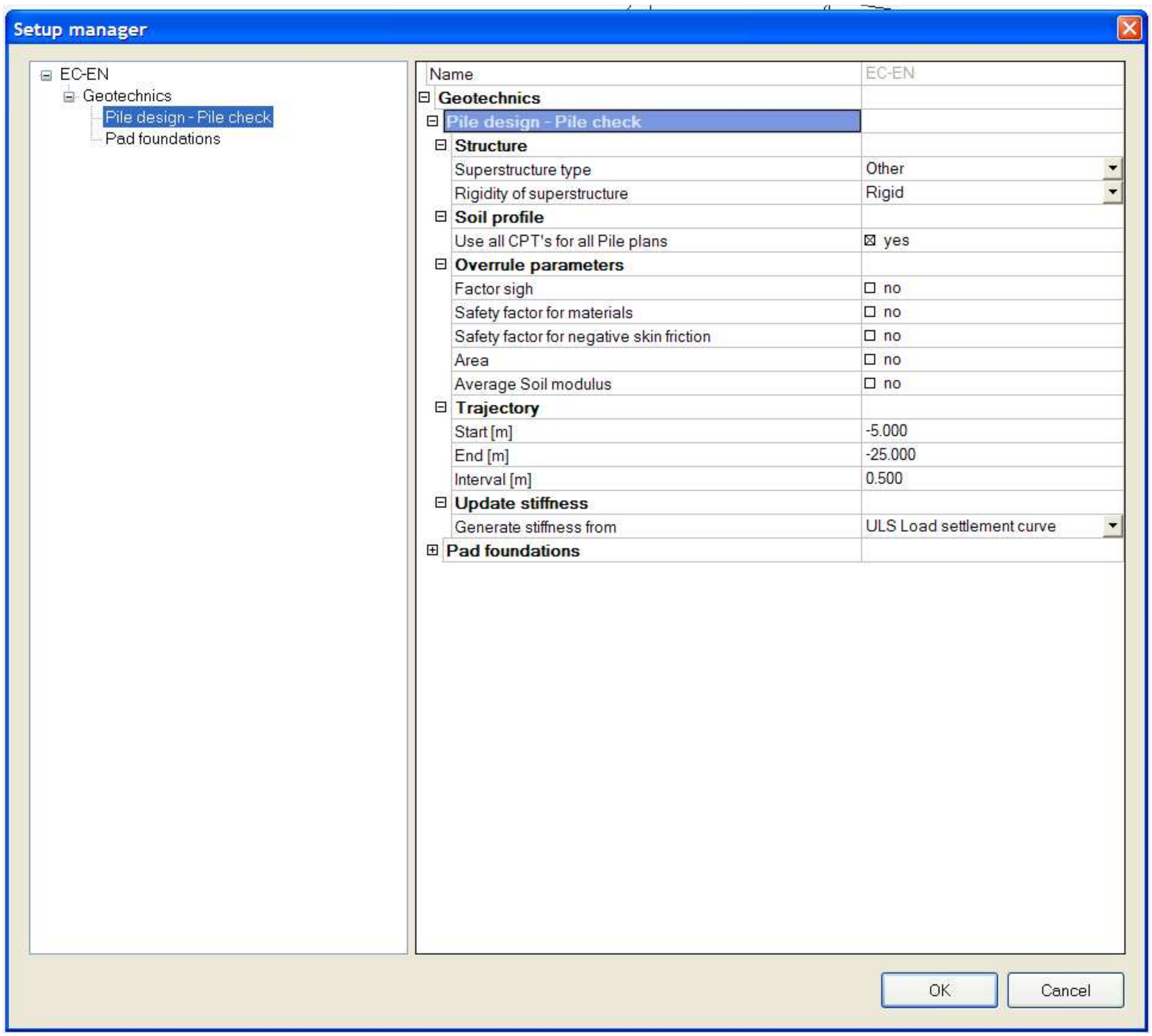
The size of median will influence the value of α_S which is used to determine the positive skin friction.

For sand with median >0.6mm, the values of α_S will be reduced by 25%.

For gravel with median >2mm α_S will be reduced by 50%.

Geotechnics setup

A New setup for "Geotechnics" has been introduced in SCIA Engineer. This setup is common for Pile design and Pad Foundation.



The parameters described in the setup are required for the Pile plan design/verification.

Superstructure type — The type of structure "House" and "Other" can be selected from the drop down list.

Based on the type of structure, the requirements for both the limit states and the number of CPTs are carried out.

Rigidity of Superstructure — The superstructure can be specified either Rigid or non-rigid.

	This parameter influences the calculation. The ξ (sigh factor) also depends on the rigidity of the structure.
Use all CPTs for all pile plans	If this option is selected all the soil profiles will be automatically associated to all the Pile plans. If the user wishes to manually associate the CPTs to pile plans this option must be unchecked.
Overrule parameters	The parameters listed under this can be overruled, If not the parameters would be determined according to the standard or calculated. The user has to make sure that the overruling of parameters is allowable.
Factor ξ	This factor depends on the number of CPTs and the number of piles under rigid super structure. The factor is derived from table 1 of NEN 6743.
γ_{mb}	Safety factor for materials – Derived from table 3 in NEN 6740
$\gamma_{f;nk}$	Safety factor for negative skin friction – Derived from NEN 6740 11.5.1
Area	The influence area per pile, to be used in the calculation of negative skin friction for pile groups. If this option is not overruled, the program calculates the influence area. This is done by calculating the average pile distance within the pile group (D_{avg}). Area = D_{avg}*D_{avg}.
Average Soil Modulus	The value of the average soil modulus is calculated according to NEN 6743-1:2006, art 6.3.2 (i.e. mean modulus of elasticity of the soil beneath the level of 4D under the pile point).
Trajectory	The trajectory is specified by start and end limit above/below the reference level. The interval of trajectory determines the number of calculations to be performed. The top and bottom limits of the trajectory must meet the following requirements. The start trajectory must be at least 5*dmin below the lowest surface level, excavation level and pile head level. (dmin- smallest cross section dimension of the pile) The end trajectory must be at least 4*Deq above the deepest level of the shallow CPT. Deq – Equivalent diameter. The interval has to be chosen in such a way that the maximum number calculations should not exceed 151.

In below the factors as given in the NEN-EN 1997-1:2005/NB:2008:

Factor ξ

EN 1997-1: A.3.3.3:
For verifications of structural (STR) and geotechnical (GEO) limit states, the following correlation factors ξ shall be applied to derive the characteristic resistance of axially loaded piles:

ξ 1 on the mean values of the measured resistances in static load tests

ξ 2 on the minimum value of the measured resistances in static load tests ξ 3 on the mean values of the calculated resistances from ground test results

ξ 4 on the minimum value of the calculated resistances from ground test results

ξ 5 on the mean values of the measured resistances in dynamic load tests

ξ 6 on the minimum value of the measured resistances in dynamic load tests.

NEN-EN 1997-1:2005/NB:2008**:**

Tabel A.9a — Correlatiefactoren ξ voor de bepaling van karakteristieke waarden uit statische paalbelastingsproeven (*n* is het aantal beproefde palen) voor een niet-stijf bouwwerk

ξ voor *n* =	**1**	**2**	**3**	**4**	**5**	**7**	**10**
ξ_1	1,39	1,32	1,30	1,28	1,28	1,27	1,25
ξ_2	1,39	1,32	1,30	1,03	1,03	1,01	1,00

Tabel A.9b — Correlatiefactoren ξ voor de bepaling van karakteristieke waarden uit statische paalbelastingsproeven (*n* is het aantal beproefde palen) voor een stijf bouwwerk

ξ voor *n* =	**1**	**2**	**3**	**4**	**5**	**7**	**10**
ξ_1 [a]	1,26	1,20	1,18	1,17	1,17	1,15	1,14
ξ_2 [a]	1,26	0,96	0,94	0,93	0,93	0,92	0,91

[a] De factor 1,1 volgens NEN-EN 1997-1, 7.6.2.2 (9) is al verwerkt in de factoren van tabel A.9b.

Tabel A.10a — Correlatiefactoren ξ voor de bepaling van karakteristieke waarden uit de resultaten van grondproeven (*n* is het aantal proeven) voor een niet-stijf bouwwerk

ξ voor *n* =	**1**	**2**	**3**	**4**	**5**	**7**	**10**
ξ_3	1,39	1,32	1,30	1,28	1,28	1,27	1,25
ξ_4	1,39	1,32	1,30	1,03	1,03	1,01	1,00

Tabel A.10b — Correlatiefactoren ξ voor de bepaling van karakteristieke waarden uit de resultaten van grondproeven (*n* is het aantal proeven) voor een stijf bouwwerk

ξ voor *n* =	**1**	**2**	**3**	**4**	**5**	**7**	**10**
ξ_3 [a]	1,26	1,20	1,18	1,17	1,17	1,15	1,14
ξ_4 [a]	1,26	0,96	0,94	0,93	0,93	0,92	0,91

[a] De factor 1,1 volgens NEN-EN 1997-1, 7.6.2.3 (7) is al verwerkt in de factoren van tabel A.10b.

EN 1997-1: §A.3.3.3:

Table A.11 - Correlation factors ξ to derive characteristic values from dynamic impact tests[a, b, c, d, e] (n - number of tested piles)

ξ for n =	≥ 2	≥ 5	≥ 10	≥ 15	≥ 20
ξ_5	1,60	1,50	1,45	1,42	1,40
ξ_6	1,50	1,35	1,30	1,25	1,25

[a] The ξ-values in the table are valid for dynamic impact tests.

[b] The ξ-values may be multiplied with a model factor of 0,85 when using dynamic impact tests with signal matching.

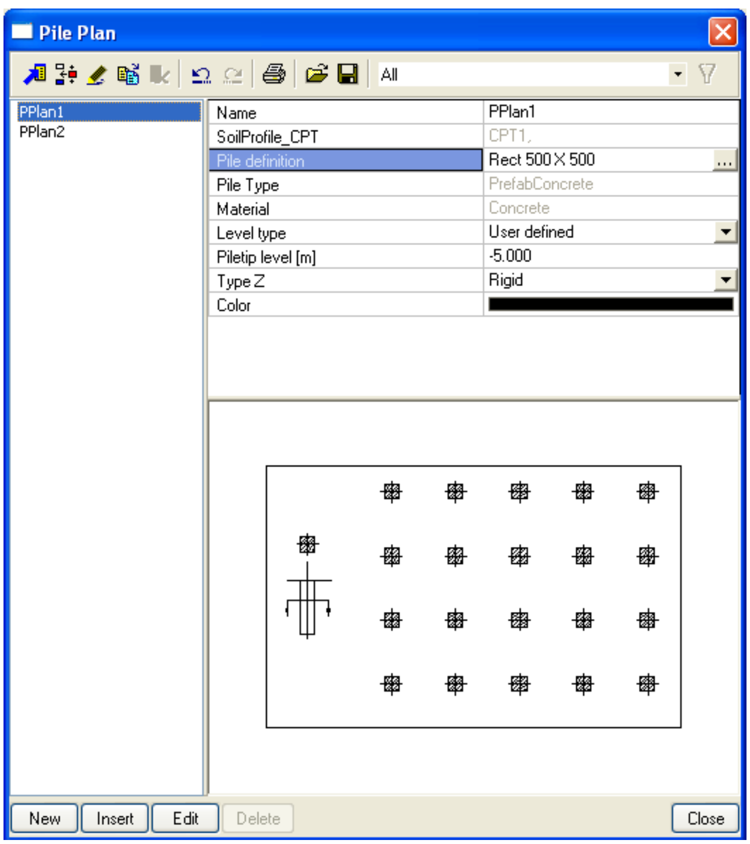
[c] The ξ- values should be multiplied with a model factor of 1,10 when using a pile driving formula with measurement of the quasi-elastic pile head displacement during the impact.

[d] The ξ -values shall be multiplied with a model factor of 1,20 when using a pile driving formula without measurement of the quasi-elastic pile head displacement during the impact.

[e] If different piles exist in the foundation, groups of similar piles should be considered separately when selecting the number n of test piles.

Pile Plan

In SCIA Engineer the Pile plan library has been inputted. The piles are defined in the library and are associated to the supports.

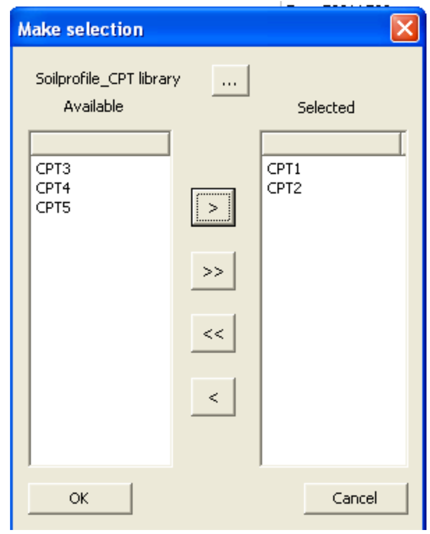


Soil profile CPT

The soil profile generated from the CPT data must be associated with the Pile plan. At least one soil profile is to be associated with every pile plan. The design/verification of piles could be performed based on the soil profile.

In the Geotechnics setup page, if the option "Use all the CPTs for all Pile plans" is checked, all the soil profiles will be directly associated with all the pile plans.

If the user wishes to associate the soil profiles manually, this option must be unchecked. The standard selection tool with the list of available CPTs is displayed in the left and the associated CPTs are displayed in the right window. There is also a link to the soil profile CPT library in the selection dialog.

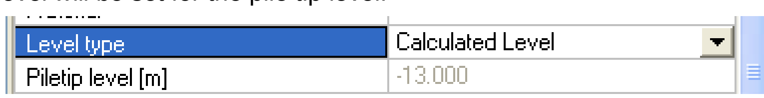


Pile Definition

The properties of the pile and the relevant parameters are defined in a special dialog. This dialog is opened through the button ... . This dialog is language independent. All the parameters are only in English. All parameters for this dialog are given in the next paragraph.

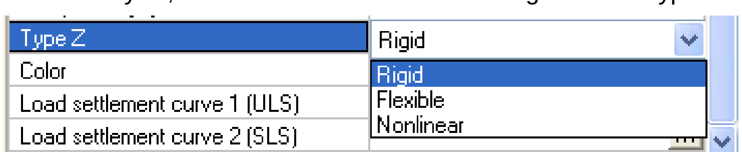
Pile tip Level

When we define /create the pile plan, the level type will be user defined and the user has to specify the pile tip level. After the pile design has been performed the level type is automatically set to calculated level and the calculated pile tip level will be set for the pile tip level.

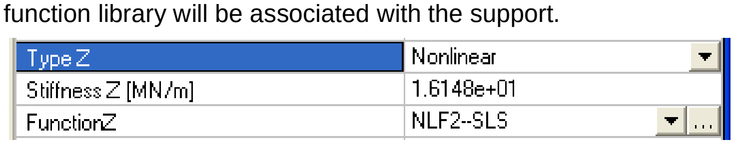


Type Z

The stiffness type for the supports in the Z direction has to be specified. For Linear analysis, the user has to choose either rigid/flexible type.



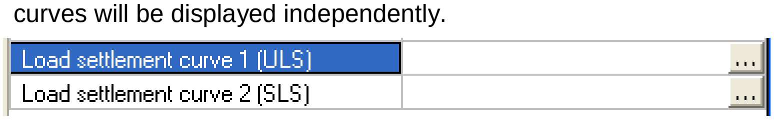
If Non-linear functionality is selected, in addition to Rigid/Flexible, the non-linear option will also be available. If this option is selected, the Non-linear function library will be associated with the support.

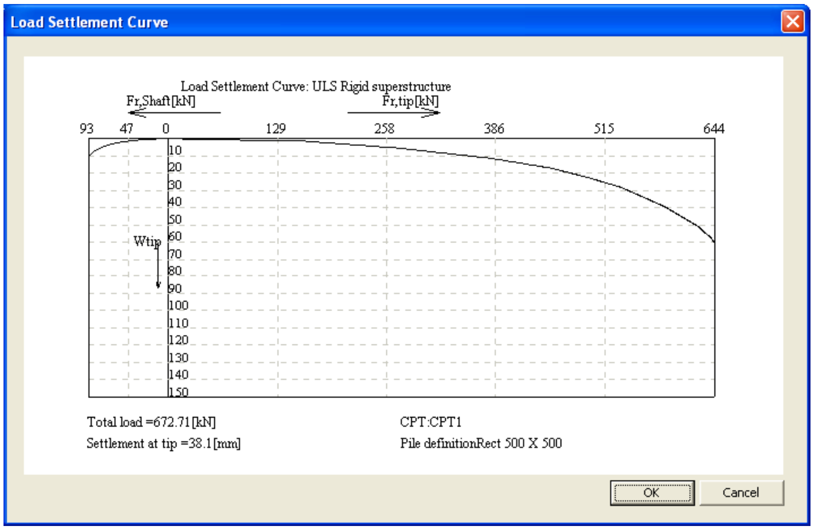


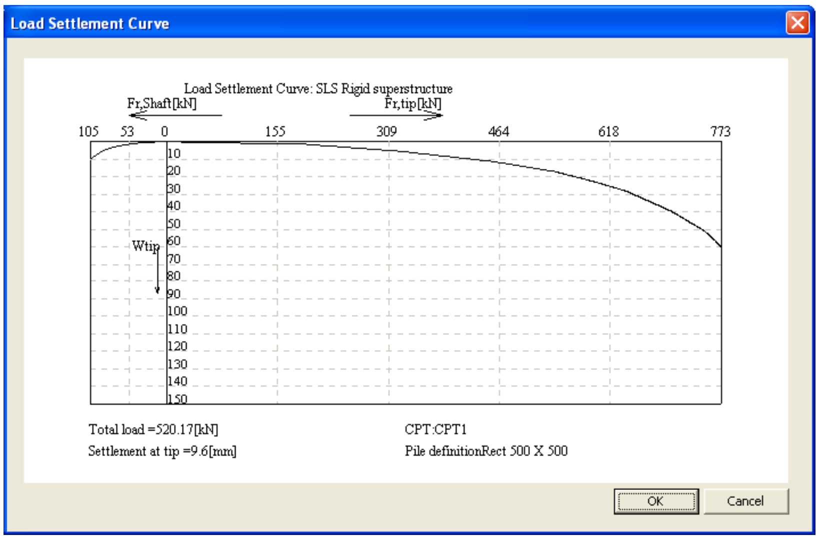
Load Settlement curves

The Load settlement curves are the result of Pile verification. After Pile verification, these load settlement curves will be included in the pile plan library.

The ... buttons will enable the user to view the LS curves. The ULS and SLS curves will be displayed independently.

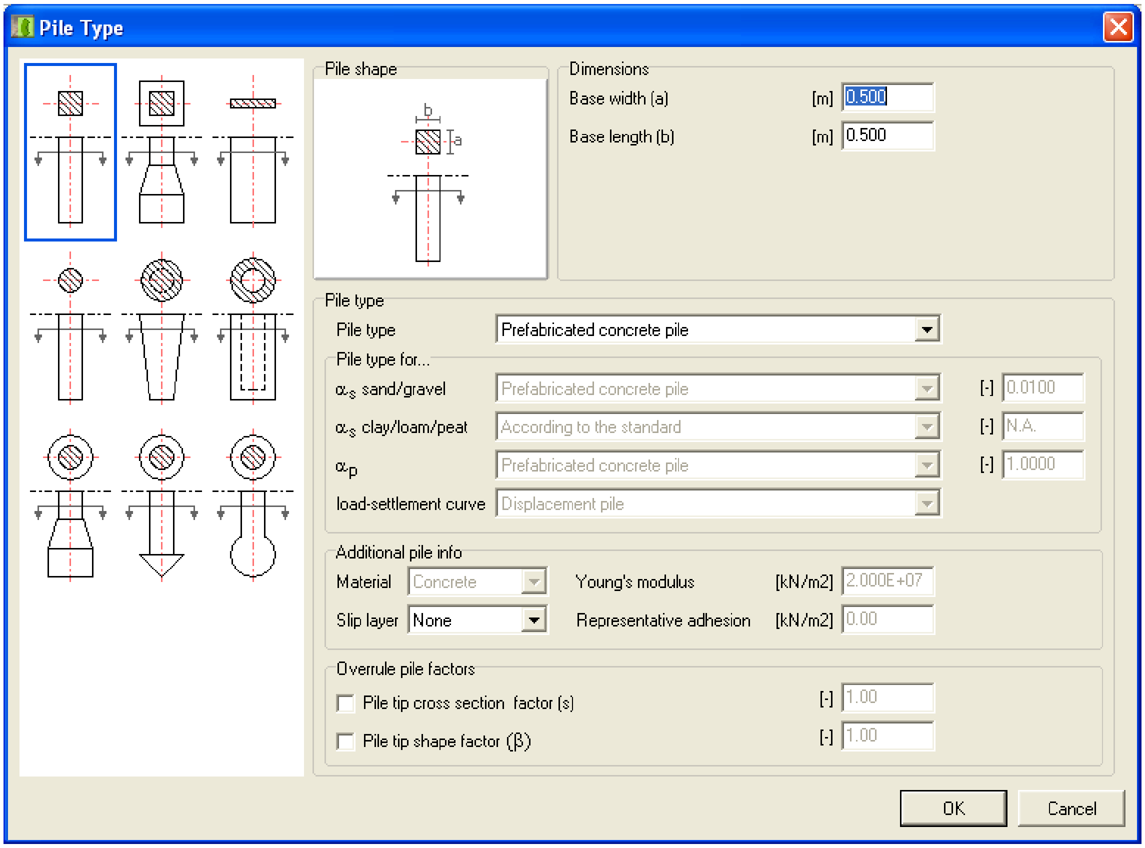






Pile definition

This dialog can be found through the button ... after "Pile definition" in the Pile plan dialog.



Shape of Pile The user can specify the shape of pile by selecting one of the shapes represented graphically on the left part of the dialog. The selected shape will be displayed in the Pile shape dialog.

Dimensions Based on the shape of pile, the user has to specify the dimensions for the Pile. The dimensions have to be specified in “m”, “m/m” or “mm”.

Rect Pile	Base width and base length of the Pile
Rect Pile with enl base	Width, length and height of base & width and length of shaft
Steel Section	Base width and base length of the Pile
Round pile	Diameter of Pile
Round tapered pile	Diameter at tip and increase in diameter
Round hollow pile	Internal and external diameter of pile
Round enlarged base	Diameter and height of base and Pile diameter
Round lost tip	Diameter and height of base and Pile diameter
Round driven base	Diameter and height of base and Pile diameter

Pile type The program will display the predefined pile types that can be selected for the chosen pile shape in the dropdown list.

The user has to select the type of pile from the list. If the predefined type is selected, the corresponding pile data are filled automatically and these data cannot be edited. Selection of User defined type will allow the user to enter all the data manually.

α_s α_s is the pile factor for the **shaft friction**.

For cohesive soils, the value for this factor is according to NEN 6743-1:2006 and depends on the soil material.

For non-cohesive soils (sand, gravel) the value for α_s depends on the pile type. Hence it can be specified by selecting one of the predefined pile types from the dropdown box. As a result the actual value for as will be displayed in the current value box. If User defined is selected as the subtype, only the parameter value is entered and the relation of the subtype with the pile type no longer applies. It has the following consequences:

The value entered for α_s, valid for sand and gravel layers, will NOT be adjusted for any instance of coarse grain (NEN 6743-1:2006 Table 3) The exception for the determination of the pile tip shape factor ß cannot be met because it is impossible to determine that a cast-in place pile with a regained steel driving tube is applied (NEN 6743-1:2006 5.4.2.2.3).

The check on dL (length of positive skin friction zone) when a weighted tip is applied cannot be performed because it cannot be determined that a pre-fabricated pile is used (NEN 6743-1:2006 5.4.2).

For cohesive soils (clay, peat, loam) the factor according to the standard is depth-dependent and thus has no single value. As a result the current value box displays N.A. (Not Applicable) as the value can not be shown. If User defined is selected as the subtype, only the parameter value is entered. That value can and will be displayed as current value.

α_p — α_p is the pile factor for the **pile point**.

As α_s for sand/gravel, α_p depends on the pile type for its value. Therefore it can be specified by selecting one of the standard pile types from the combo box. As a result the actual value for α_p will be displayed in the current value box. Select User defined to specify any other value for $\alpha_{p.}$ If User defined is selected for α_p, the pile factor for the pile point, then the exception for ‘continuous flight auger’ piles cannot be taken into account for the reduction of qc-values when determining qc;III;mean. The reason for this is that it cannot be determined if a continuous flight auger pile is used (NEN 6743-1:2006 5.4.2.2.1).

LS Curve — Load-Settlement curves NEN 6743-1:2006 Figures 6 and 7 contain only lines for three subtypes

- Displacement pile
- Continuous flight auger pile
- Bored pile

Material — The material of the user defined pile is selected.

Young’s modulus — The corresponding elasticity modulus is provided automatically for concrete, steel and timber and cannot be edited. If the material "User defined" is selected then the Young’s modulus must also be specified.

Slip layer — The slip layer for the pile has been specified.

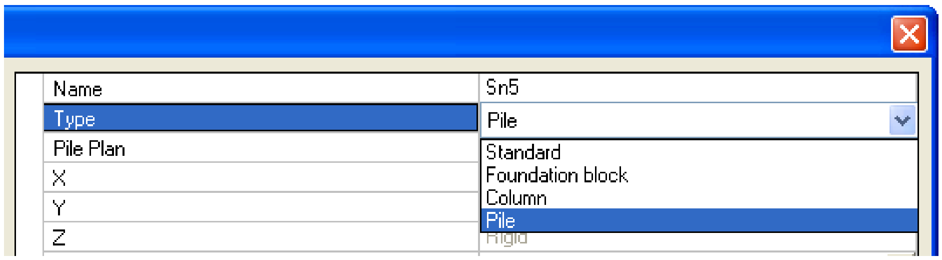
Representative Adhesion — The corresponding representative adhesion is provided automatically and cannot be edited, unless the value User defined is selected, in which case the required Representative adhesion should be input.

New nodal support

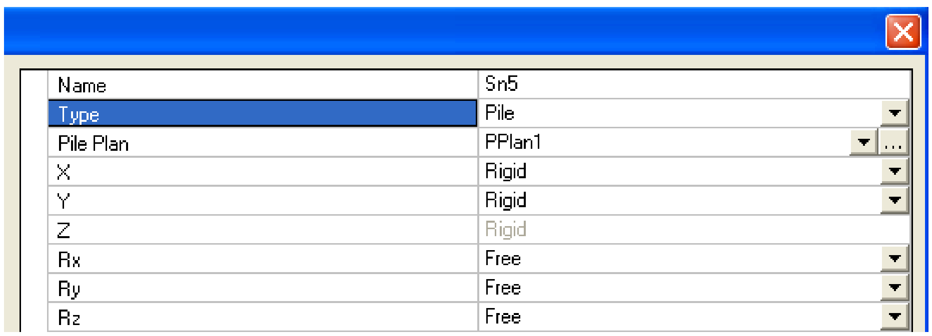
A new nodal support type “Pile” has been added into the standard support. The pile plan library is associated to the “Pile” support.

The standard properties of the support are defined. The type **Z** is directly read from the pile plan library and will be used by all the supports during the analysis. The supports are grouped by the pile plan.

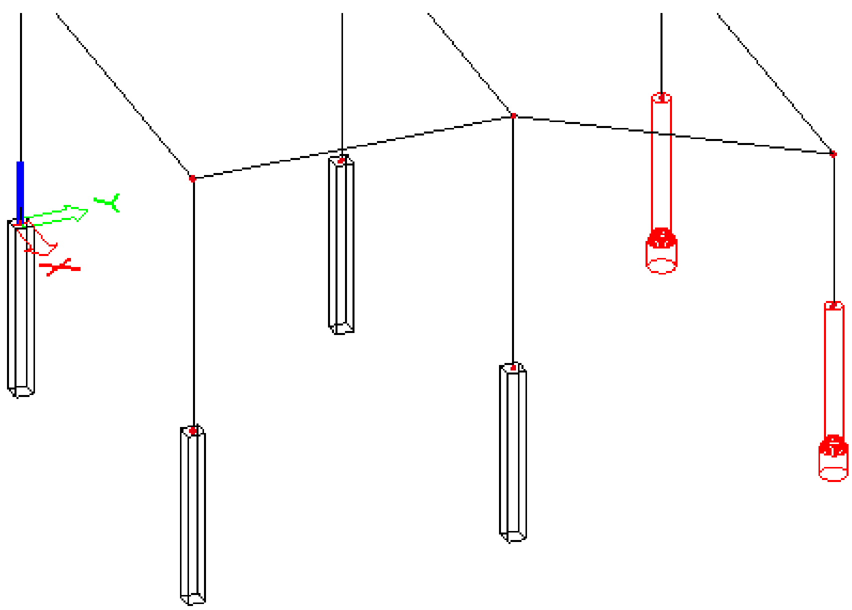
By default, the value of **X** & **Y** will be set to “Free” and the user may change only these two values. The support can have any condition.
By default the support is a hinge i.e. **X**, **Y** and **Z** are fixed, **Rx**, **Ry** and **Rz** are free.
In case the reaction in the Z-direction is negative i.e. the pile is in tension, no check is executed for the pile and a warning is displayed.



The properties of the support are:



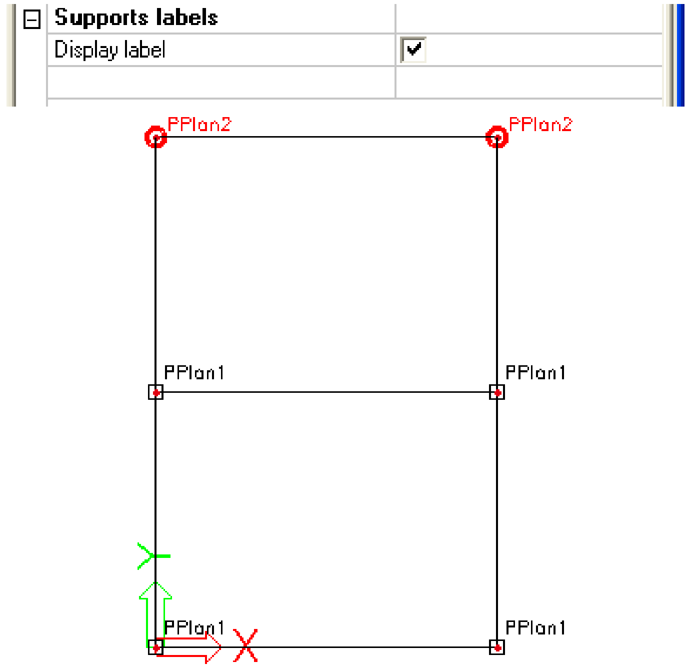
The supports are represented in the Model as shown below



The colour of the Pile is from the Pile plan library. The colour of piles is controlled by the view flag parameters under the tab “Model”

The option “colour by pile plan” is by default checked and if the user wishes to see all the piles represented by colour of supports, the user has to uncheck this option.

The display of pile labels for the supports is also controlled by the view parameters.



Check – Pile plan design

Properties in SCIA Engineer

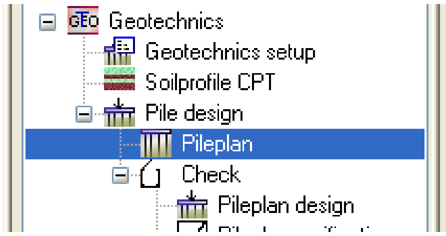
This option enables the user to calculate the pile tip level. The design/ verification of bearing piles are performed based on the guidelines given by NEN 6740 and NEN 6743.
In SCIA Engineer this option is available in the case that **NEN or EC-EN** is selected as code.

The design is performed only for bearing piles which are subjected to static or quasi static loads that cause compressive forces in the piles. The calculation of pile forces and pile displacements are based on cone penetration test. Any possibility of tension in piles and horizontal displacements of piles and/or pile plans are not taken into account.

In Pile Design (preliminary design), a single pile is always assumed and the calculations performed are based on a single pile for ULS. Any possible pile plan is disregarded when using the Pile design option.

Hence a non-rigid superstructure is assumed and pile group effects are not considered and these limitations are explicitly mentioned in the results/ document of SCIA Engineer.

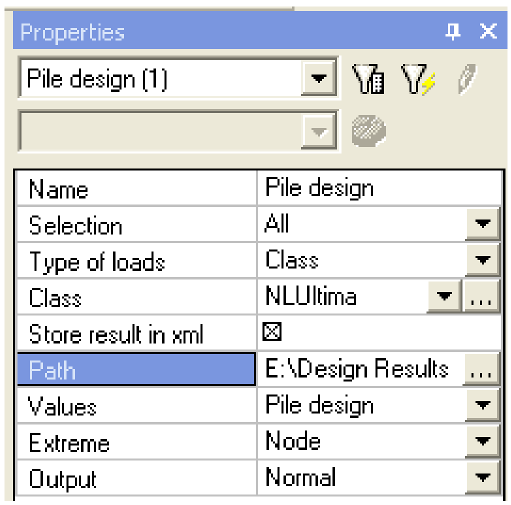
The program evaluates **the pile tip level where the net bearing capacity of the pile is equal to or more than the maximum load on the pile**. After performing the analysis, the pile plan design command will be enabled in the “Geotechnics” service:



The following are the Prerequisites for performing the Pile plan design:

- Model of the analysed structure must be properly defined.
- The reactions of the supports must be known.

The procedure used for performing the design is analogous to the procedure for evaluation of results. In the tree menu of service Geotechnics, select the command Pile plan design. Once the command is selected, the appropriate parameters are listed in the Property window.



Selection

The user may perform the design either on all pile plans or only selected pile plans. The selection of pile plans is carried in a unique manner:

The user may select any pile and all the piles belonging to the selected pile plan will be internally selected. The pile which is subjected to maximum vertical reaction [among the selected class] will be identified and the design will be performed for this load. The calculated level will be applied to all the piles of the selected pile plan.

If the selection is “All”, the pile subjected to maximum vertical reaction is identified in each pile plan and the design will be performed for each pile plan based on the worst pile.

Load type Class

Pile plan design will be performed **only for the result classes** which have the ultimate combinations defined. The filtering will be done automatically by the program and only the result classes which have the ULS combinations will be made available. If no result class is defined by the user and only the combinations are defined, the program automatically creates a result class with ULS combination.

The design will be performed for the selected pile plans. The calculation will be done after the user presses the Refresh button and the results will be displayed in the preview window.

Store result

This check box will allow the user to store the input and output xml files which are used for Pile design/verification by the program. This will enable the user to enhance the pile design in MFoundation as this will offer the possibility to create a project using this xml file.

Path

The user has to select the folder in which the input and output xml of the pile plans are to be stored.

The name of the file will be automatically set by the program - Name of Pile plan and the result class. Eg Name of Pile plan is Pplan1 and the result class name is ULS result class, then the name of xml file will be pplan1ulsin.xml and pplan1ulsout.xml.

Calculation process

First, for every CPT, the **maximum bearing capacity ($R_{c;k}$)** for a single pile is determined as the **sum of the maximum bearing capacity of the pile tip ($R_{b;k}$) and the maximum shaft friction force ($R_{s;k}$)**. The following factor applies to the maximum shaft friction force:

EN 1997-1, §7.6.2.2 (12): $R_{c;k} = R_{b;k} + R_{s;k}$

The execution factor is not a fixed value here and is dependent on the soil type of the layer, as well as on the depth of the relevant layer. For each layer, the program calculates the generated pile shaft friction in that layer after defining the correct value of α_s for the relevant layer. Aggregation of the pile shaft friction calculated per layer in this way for the layers affected by pile shaft friction produces the eventual value of the maximum pile shaft friction.

Determining the circumference of the pile segment for which the maximum shaft friction force is calculated as follows. If it involves a non-constant circumference, as is the case with tapered wooden piles and piles with a reinforced tip, for example, the standard (NEN 6743, art. 5.4) does not actually provide a solution. In that case, the program calculates the mean circumference of the relevant pile segment.

Skin Friction zones

The essential requirements to calculate the positive and negative shaft friction resistance are specified in NEN 6743.

For the **positive skin friction zone**, the bottom of that zone coincides with the pile tip level, and for a prefabricated pile with a widened base, the top of that zone may never be above the widening (NEN 6743 art. 5.4).

For the **negative skin friction zone**, the top of this zone coincides with the ground level or excavation level.

In order to satisfy these requirements in the bearing piles model, the skin friction zones are defined as mentioned below:

- The bottom of the positive skin friction zone automatically coincides with the pile tip level and therefore does not have to be entered.
- The top of the positive skin friction zone is specified by the user as a level relative to the reference level
- The top of the negative skin friction zone automatically coincides with the ground level or excavation level and therefore does not have to be entered.

- The bottom of the negative skin friction zone is specified by the user as a level relative to the reference level.

Pile plan design

The required pile tip level is calculated in a user-defined pile tip trajectory. This trajectory is defined by means of start and end limit (Defined in the Geotechnics setup page). The interval of trajectory determines the number of calculations to be performed. When defining the trajectory the user need not to adjust the levels of positive and negative skin friction. If needed, these levels are automatically adjusted for each calculation step.

The value Rz is only considered for the design. **The horizontal forces/ any possible rotations are not considered for the design**. The maximum load (from Rz) on the support is determined from all the piles of selected pile plan. This load will be used for calculation of the pile tip level. This value is used as a stopping criterion for the calculation.

As the level is detected by the program where the calculated net bearing capacity equals or more than the maximum load the calculation is stopped and the program will display the calculated capacity at this level.

If within the trajectory **no level is found** where the net bearing capacity meets the maximum load, the program returns the **pile tip level as "zero" and a warning "The required bearing capacity is not met within the trajectory, Hence the level can not be calculated"**.

If all the piles in the pile plan are subjected to **tension**, the program will not perform the design and hence the pile tip level will not be calculated and a warning will be issued "All the piles in the pile group are subjected to tension. The design could not be performed for tension piles". The user defined level will be used by the program.

If one or more piles in the pile plan are subjected to tension, the maximum load will be determined from the other piles which are not subjected to tension. The design has been performed for this maximum load and a warning is issued "There are one or more piles in the pile plan subjected to tension"

The pile tip level calculated by the program is updated in the pile plan library and the supports of all the piles in the pile plan will be updated with this calculated level.

The drawing of piles in the 3D model will also get updated. The results can be viewed in the preview window and in the document.

Any changes made in the Geotechnics setup /soil profile / soil will not affect the analysis results but affects the pile design results. In such case, the user has to perform the pile plan design in order to get the new results.

If there is any change in the model/load (i.e.) if the analysis results become invalid, the pile plan design results are also not valid. In such case, the pile tip is automatically set as user defined level. The user has to perform the analysis and the design in order to get the new results.

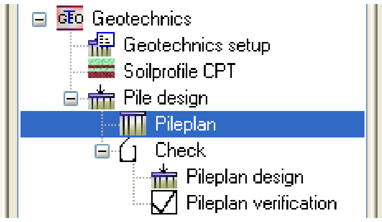
Check – Pile plan verification

Properties in SCIA Engineer

The verification of bearing piles is performed based on the guidelines given by NEN 6740 and NEN 6743. This option is limited to NEN and EC-EN standards.
The verification is performed only for bearing piles which are subjected to static or quasi static loads that cause compressive forces in the piles. The calculation of pile forces and pile displacements are

based on cone penetration test. Any possibility of tension in piles and horizontal displacements of piles and/or pile plans are not taken into account.

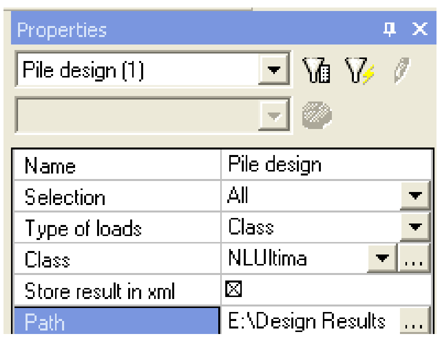
The entire pile plan is considered during verification and the group effects are considered. The program results the Load-settlement curve from ULS and SLS.
This option carries out all required calculations such as bearing capacity, settlement and negative skin friction. After performing the analysis, the pile plan verification command will be enabled in the “Geotechnics” service.



The following are the Prerequisites for performing the Pile plan design:

- Model of the analysed structure must be properly defined
- The reactions of the supports must be known.
- The Pile tip Level(s) must have been set or calculated.

The procedure used for performing the verification is analogous to the procedure for evaluation of results. In the tree menu of service Geotechnics, select the command Pile plan verification. Once the command is selected, the appropriate parameters are listed in the Property window.



Selection The user may perform the verification either on all pile plans or only selected pile plans. The selection of pile plans is carried in a unique manner. The user may select any one pile and all the piles belong to the selected pile plan will be internally selected and the verification will be performed together for all the piles of the pile plan.

Load type Pile plan verification will be performed only for the result classes.

Class Pile plan verification will be performed only for the result classes which have the ULS and SLS combinations defined. The filtering will be done automatically by the program and only the result classes which have the **ULS & SLS combinations** will be made available. If no result class is defined by the user and only the combinations are defined, the program automatically creates a result class with ULS + SLS combination.

The verification will be performed for the selected pile plans. The calculation will be done after the user presses the Refresh button. The results will be displayed in the preview window.

To perform the verification, the design loads (ULS & SLS) on all the piles of the pile plan are considered. The result of this calculation is the Load settlement curve and the settlement at tip.

Store result This check box will allow the user to store the input and output xml files which are used for Pile design / verification by the program. This will enable the user to enhance the pile design in MFoundation as this will offer the possibility to create a project using this xml file.

Path The user has to select the folder in which the input and output xml of the pile plans are to be stored.

The name of the file will be automatically set by the program - Name of Pile plan and the result class. Eg Name of Pile plan is Pplan1 and the result class name is ULSSLS result class, then the name of xml file will be pplan1ulsslsin.xml and pplan1ulsslsout.xml.

Calculation process

First, for every CPT, the **maximum bearing capacity ($R_{c;k}$)** for a single pile is determined: see also previous paragraph.

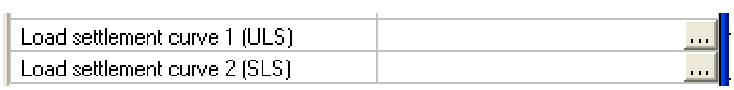
Secondly, the **maximum bearing capacity of the foundation** is determined. Here, the number of piles, the number of CPTs and whether the structure may be considered as rigid or not (NEN 6743, art. 5.2.2) play a role.

In case of a **rigid structure**, regardless of the number of CPTs, the program calculates the maximum bearing capacity of the foundation based on the average bearing capacity of a single pile, multiplied by the total number of piles, since the foundation element contains all of the piles.

In case of a **non-rigid structure**, determination of the maximum bearing capacity of the foundation depends on the number of CPTs. If there are more than three CPTs, the definition is again based on the average bearing capacity of a single pile, whereas if there are three CPTs or less, the minimum bearing capacity of a single pile is used. In this case, the bearing capacity of a single pile is not multiplied by the total number of piles because the foundation element consists of a single pile.

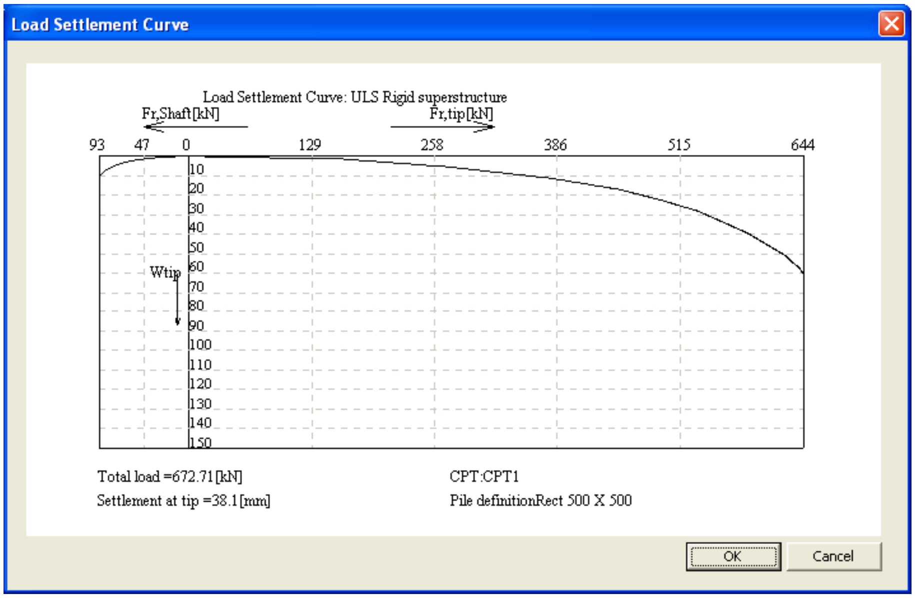
Pile verification results:

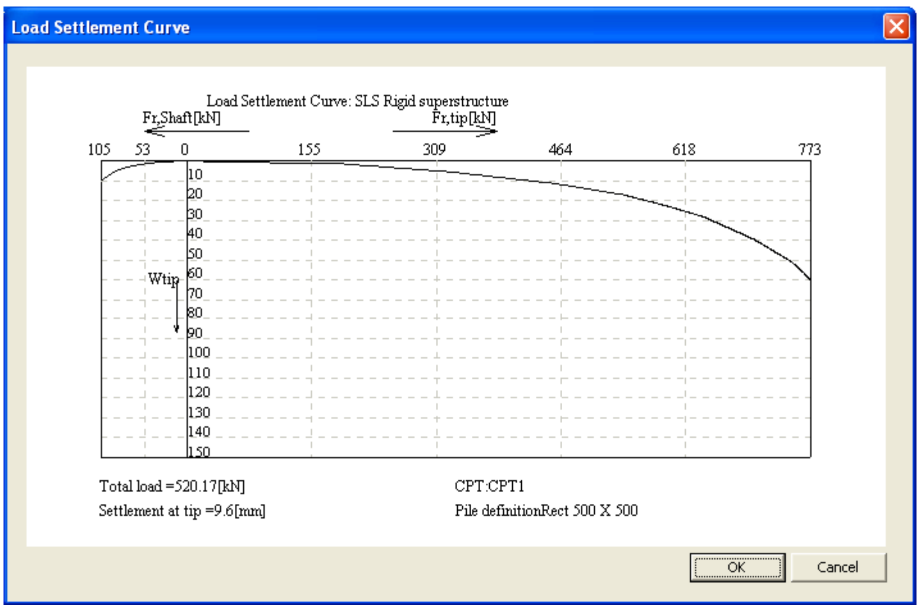
The results can be viewed in the preview window and the document. The load –settlement curves are updated in the pile plan library.



Load settlement curves:

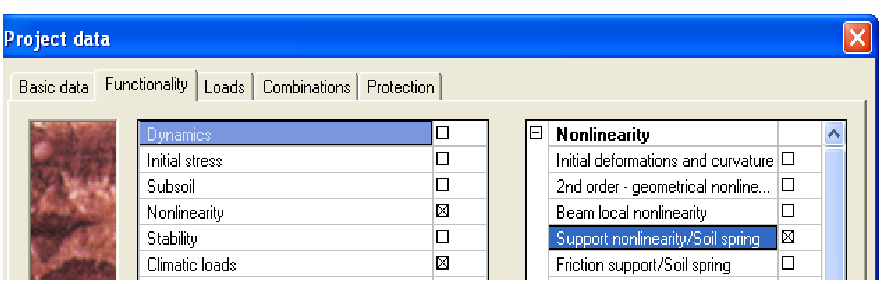
If the problem fully meets all the verification requirements, both the load settlement curves will be generated. If not the curves may not be generated and warning is issued.



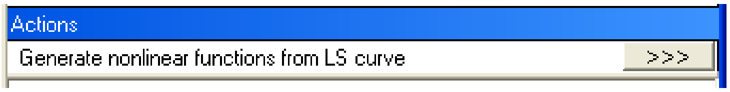


Non Linear Functions

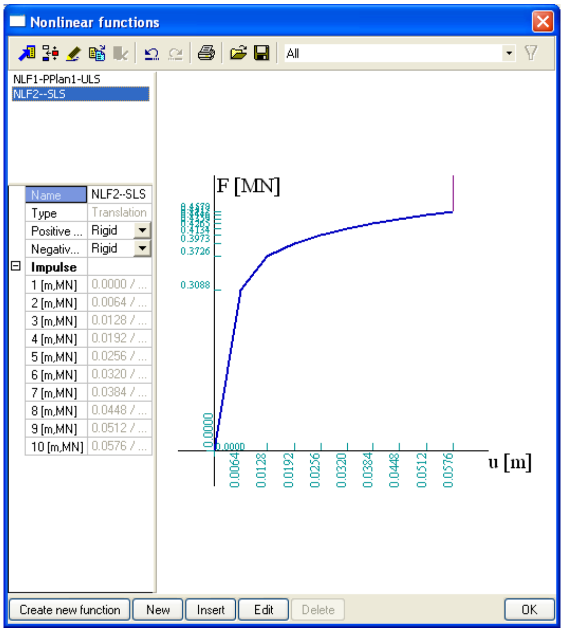
If support non-linearity functionality is selected, a new action button will be enabled in the Pile plan library after the pile verification.



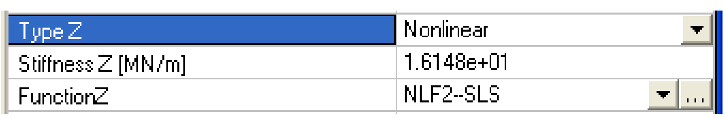
After pile verification, the program will enable the user to generate Non linear functions from load settlement curves using an action button. The generated functions can be associated to the supports [type Z].



This action button will generate the two non-linear functions each from ULS Load settlement curve and SLS Load settlement curve.



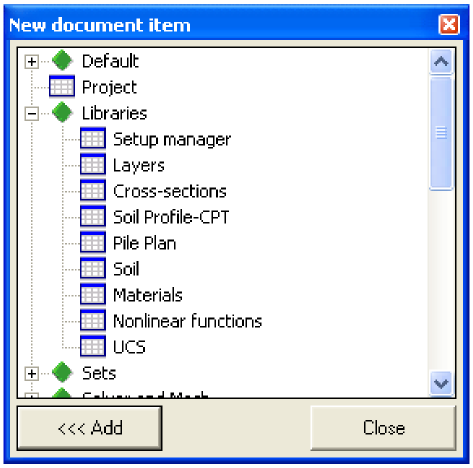
If the type Z is set as Nonlinear, the program will set the default function from SLS. The stiffness value is also proposed for the function.The stiffness of the pile is taken as the secant defined by zero point and the point in the middle of the curve.



Recalculating the entire structure using these non-linear functions will improve the overall results, itself leading to 'new' loads on the piles. With these loads, the process of pile-design, verification and calculation of the entire structure can be repeated to optimize the total design.

Output tables

All the output tables of Pile design are made available in the standard document service of SCIA Engineer. The output tables include the libraries (soil, Soil profile, Pile plan) and the design/verification results.



Soil profile-CPT

Input data

1. Soil Profile-CPT

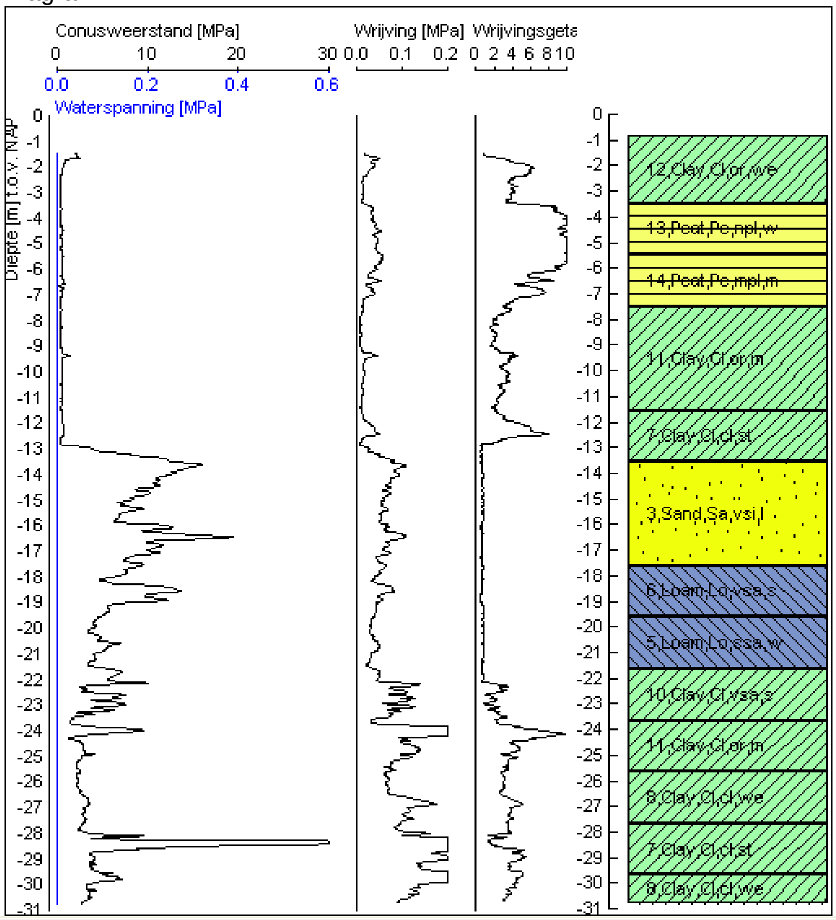
Name	CPT1
Profile Type	CPT Import
Interpretation tool	Interpretation tool
Minimum layer thickness [m]	2
Phreatic level [m]	0
Overconsolidation ratio of bearing layer	1
Top of positive skin friction zone [m]	-1
Bottom of negative skin friction zone [m]	-0.85
Expected ground level settlement [m]	0.11

Profile Data

1. Soil Profile-CPT

Top level [m]	Soil name	Description
-0.85	Cl,or,we	Clay, organ, weak
-3.475	Pe,npl,w	Peat, not preloaded, weak
-5.495	Pe,mpl,m	Peat, mod preloaded, moderate
-7.515	Cl,or,m	Clay, organ, moderate
-11.552	Cl,cl,st	Clay, clean, stiff
-13.57	Sa,vsi,l	Sand, very silty, loose
-17.604	Lo,vsa,s	Loam, very sandy, stiff
-19.619	Lo,ssa,w	Loam,slightly sandy weak
-21.633	Cl,vsa,s	Clay, very sandy, stiff
-23.646	Cl,or,m	Clay, organ, moderate
-25.657	Cl,cl,we	Clay, clean, weak
-27.666	Cl,cl,st	Clay, clean, stiff
-29.672	Cl,cl,we	Clay, clean, weak

Profile Diagram



Soil

The soils used in the soil profile are filtered and displayed along with the properties.

2. Soil

Name	Description	Soil Type	Gamma Unsaturated [kN/m3]	Gamma Saturated [kN/m3]	Friction angle [deg]	Median [mm]
Gr,ssi,m	Gravel, slightly silty, moderate	Gravel	19.00	21.00	37.50	0.20
Sa,ssi,m	Sand, slightly silty, moderate	Sand	19.00	21.00	32.50	0.20
Sa,vsi,l	Sand, very silty, loose	Sand	19.00	21.00	30.00	0.20
Sa,cl,st	Sand, clean, stiff	Sand	20.00	22.00	40.00	0.20
Lo,ssa,w	Loam,slightly sandy weak	Loam	20.00	20.00	30.00	0.20
Lo,vsa,s	Loam, very sandy, stiff	Loam	20.00	20.00	35.00	0.20
Cl,cl,st	Clay, clean, stiff	Clay	20.00	20.00	25.00	0.20
Cl,cl,we	Clay, clean, weak	Clay	17.00	17.00	17.50	0.20
Cl,ssa,m	Clay, slightly sandy, moderate	Clay	20.00	20.00	22.50	0.20
Cl,vsa,s	Clay, very sandy, stiff	Clay	20.00	20.00	32.50	0.20
Cl,or,m	Clay, organ, moderate	Clay	16.00	16.00	15.00	0.20
Cl,or,we	Clay, organ, weak	Clay	15.00	15.00	15.00	0.20
Pe,npl,w	Peat, not preloaded, weak	Peat	12.00	12.00	15.00	0.20
Pe,mpl,m	Peat, mod preloaded, moderate	Peat	13.00	13.00	15.00	0.20

Pile plan

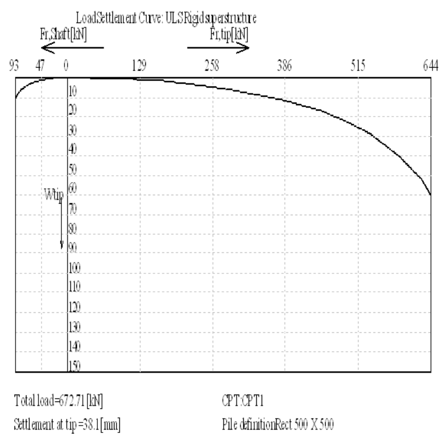
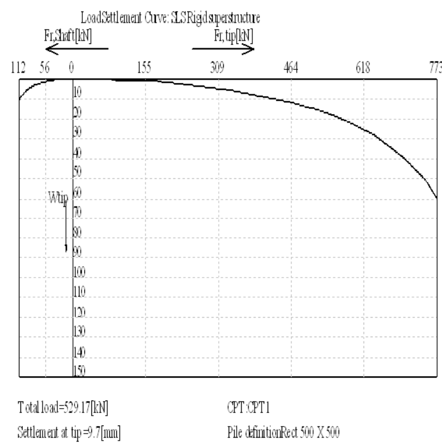
Pile data

1. Pile Plan

Name	SoilProfile_CPT	Pile definition	Pile Type	Material	Level type	Piletip level [m]
PPlan1	CPT1,	Rect 500 X 500	PrefabConcrete	Concrete	Calculated Level	-13.000

Load settlement curves

Pile plan design

Name	PictureULS	PictureSLS
PPlan1		

Linear calculation, Extreme : Node
Selection : All
Class : All ULS
Note1: The design/verification is performed only for bearing piles which are subjected to static or quasi static loads that cause compressive forces in the piles. The calculation of pile forces and pile displacements are based on cone penetration test. Any possibility of tension in piles and horizontal displacements of piles and/or pile plans are not taken into account.
Note2: In Pile Design (preliminary design), a single pile is always assumed and the calculations performed are based on a single pile for ULS. Any possible pile plan is disregarded when using the Pile design option. Hence a non-rigid superstructure is assumed and pile group effects are not considered.
Pile Design check

Pile Design check

Type Name	Pile plan id	Case	Nodes	Pile plan name	Pile tip level [m]	Net bearing capacity at advised level [kN]	Rz [kN]
Pile design	PPlan1	NC1	N1,N3,N5,N7,	Rect 500 X 580	-10	365	272.01

Pile plan verification

Linear calculation
Selection : All
Class : All ULS+SLS
Note1: The design/verification is performed only for bearing piles which are subjected to static or quasi static loads that cause compressive forces in the piles. The calculation of pile forces and pile displacements are based on cone penetration test. Any possibility of tension in piles and horizontal displacements of piles and/or pile plans are not taken into account.

ULS							
Type Name	**Pile plan id**	**Case**	**CPT**	**Total load [kN]**	**Pile plan name**	**Pile tip level [m]**	**Settlement at tip-Wtip [mm]**
Pile verification	PPlan1	NC1	CPT1	272.01	Rect 500 X 580	-10.00	7.70

SLS							
Type Name	**Pile plan id**	**Case**	**CPT**	**Total load [kN]**	**Pile plan name**	**Pile tip level [m]**	**Settlement at tip-Wtip [mm]**
Pile verification	PPlan1	NC1	CPT1	206.68	Rect 500 X 580	-10.00	2.20

Limitations for Pile Design in SCIA Engineer

In pile design (NEN method) functionality some limitations are applied. This functionality is based on the guidelines given by Dutch standards **NEN 674**0 and **NEN 6743**.

Functionality Soil profile

This functionality is made available only for the EC-EN and NEN standards.

The soil profiles could be generated only using a valid CPT data and the CPT data should only be in gef (Geotechnical exchange format) file. No other format is supported.

The user interface for the generation of soil profile does support only “English language”. Other languages are not supported in this special dialog.

The position of CPT (soil profiles) can be defined only in the user coordinates systems (UCS). The GPS coordinates of the project can not defined and hence the GPS co-ordinates of CPT can not be used.

Interpretation Tool

The interpretation tool used for generating the soil profile is “NEN rule (Stress Dependent)”. Any tool other than NEN can not be defined or used.

The soil types defined by the NEN rule alone are used by the interpretation tool and the user defined soils are not used. The user can edit the interpreted soil profile with the user defined soils.

Pile plan

The special dialog for definition of Pile plan does support only “English”. All the parameters required by this dialog are based on NEN.

Design/verification

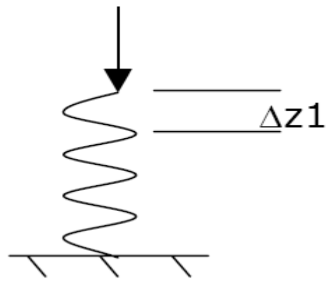
The design/verification is performed only for bearing piles which are subjected to static or quasi static loads that cause compressive forces in the piles. The calculation of pile forces and pile displacements are based on cone penetration test. Any possibility of tension in piles and horizontal displacements of piles and/or pile plans are not taken into account.

In Pile Design, a single pile is always assumed and the calculations performed are based on a single pile for ULS. Any possible pile plan is disregarded when using the Pile design option. Hence a non-rigid superstructure is assumed and pile group effects are not considered.

Soilin - Settlements

This option is an extra option, available in SCIA Engineer.
In SCIA Engineer the stiffness of the soil is calculated with C1 and C2 parameters, as shown below in the figures:

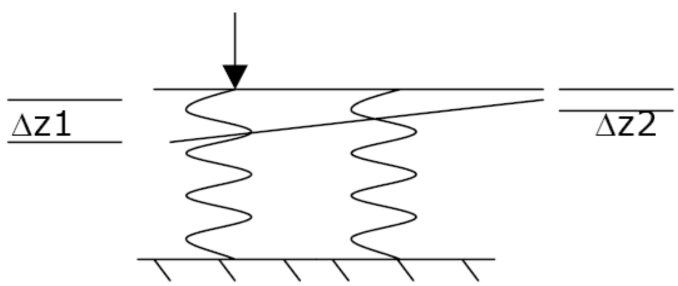
The parameter C_{1X}, C_{1y} and C_{1z} will represent a linear stiffness;



$$F_{1z} = C_{1z} \cdot \Delta z_1$$

This is the Winkler Model (or also called “Heavy Liquid model”).

This model can be extended with the Pasternak model (2 constants model). The springs between the points of the soil are now connected with this value. So a point load in a certain point, will also give a deformation a bit further in the X and Y direction.



The calculation of those parameters is not easy, but it could be done by the module Soilin of SCIA Engineer.

The principle has not been implemented in SCIA Engineer following the Eurocode and so this is not explained further in this course.

References

[1]	EN 1997-1 *Eurocode 7: Geotechnical design – Part 1: General rules* CEN, 2004.
[2]	Frank R., Baudoin C., Driscoll R., Kavvadas M., Krebs Ovesen N., Orr T., Schuppener B., *Designer's Guide to EN 1997-1 Eurocode 7: Geotechnical design – Part 1: General rules*, Thomas Telford, 2004.
[3]	Schneider K.-J., Bautabellen für Ingenieure, 13. Auflage, Werner Verlag, 1998.
[4]	EN 1990, *Eurocode – Basis of Structural Design*, CEN, 2002.
[5]	Lambe T., Whitman R., *Soil Mechanics*, MIT, John Wiley & Sons, Inc, 1969.
[6]	EN 1997-1:2004/AC:2009 Correction Sheet *Eurocode 7: Geotechnical design – Part 1: General rules* CEN, 2009.
[7]	Pad_Foundation_Theory_enu SCIA
[8]	NEN-EN 1997-1/NB *National Annex to NEN-EN 1997-1: Eurocode 7: Geotechnical design – Part 1: General rules* 2008