



SCIA  
BY ALLPLAN



\ SCIA ENGINEER  
TOPIC TRAINING  
Foundations

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## Introduction

This course will explain the principles of the use of Foundations and Subsoil in SCIA Engineer. Most of the modules necessary for these calculations are included in the **Concept Edition**.

For some options a Concept Edition is not sufficient. These specific required modules are included in an **Expert Edition** or even some **extra modules** are necessary.

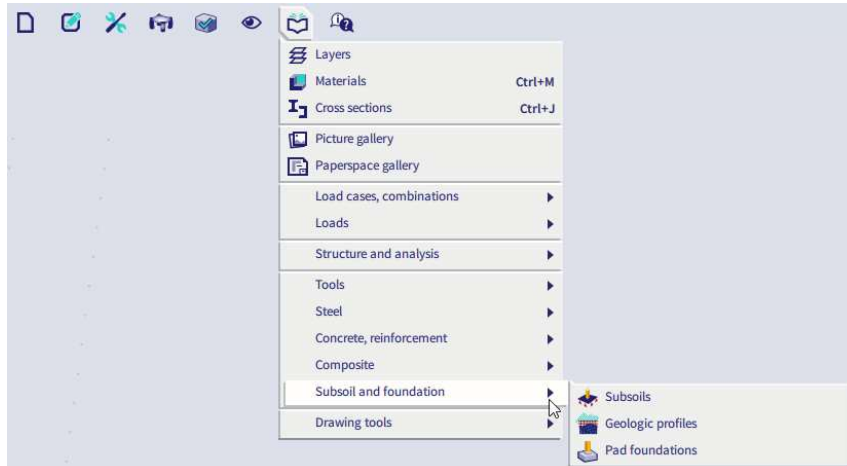
The methods discussed in this manual are based on Eurocode 7. **EN 1997-1** is intended to be applied to the geotechnical aspects of the design of buildings and civil engineering works. It is concerned with the requirements for strength, stability, serviceability and durability of structures.

### List of necessary modules:

- |                             |  |
|-----------------------------|--|
| • senfd.01.en (esafd.02.01) | Pad Foundations EC (Part of Concept Edition) |
| • sens.04 (esas.06)         | Soil interaction (Part of Expert Edition)    |
| • esas.08                   | Soil (Part of basic module sens.00)          |

## Chapter 1: Subsoil

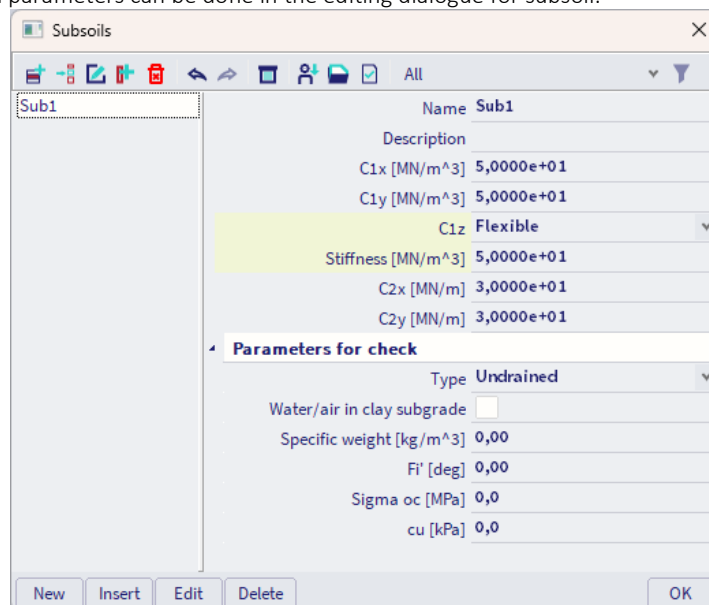
In SCIA Engineer the "under-foundation" soil is called subsoil and can be defined via Main menu > Libraries > Subsoil and foundation.



It is not necessary to activate any functionalities in SCIA Engineer 25.0. In older versions of the software it could be necessary to activate the functionality 'Subsoil' in the project settings.

### 1.1. Subsoil Parameters

The definition of subsoil parameters can be done in the editing dialogue for subsoil.



The constants C1 and C2 for directions X, Y, Z are parameters representing the subsoil properties.

**Note:** usually C2x is considered equal to C2y and C1x equal to C1y.

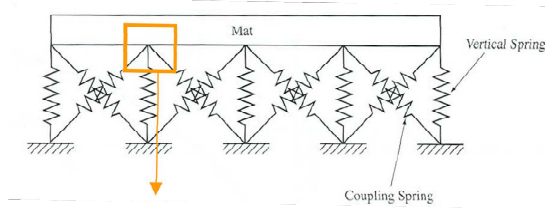
#### 1.1.1. Parameters for check

These data are used only for the stability check of a foundation block:

- Type soil type: Undrained or Drained
- Specific weight soil density
- Fi' ( $\phi'$ ) value of the angle of the shearing resistance in terms of effective stress
- Sigma oc ( $\sigma_{oc}$ ) admissible ground stress (optional)
- Cu value of the undrained shear strength

## 1.2. Elastic foundation

In SCIA Engineer the soil can be modelled as an elastic foundation where the soil under a plate (2D member) is represented by springs.

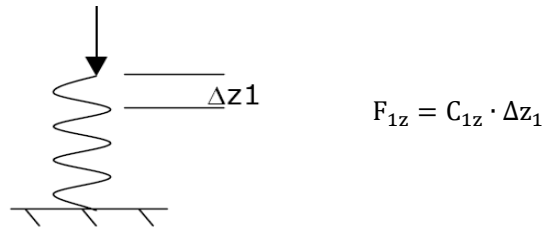


The subsoil parameters  $C_1$  and  $C_2$  represent the stiffnesses of these springs.

### Winkler Model

The Winkler method is the most common and simple method. This model is based on a uniform settlement of the plate. A load  $F_{1z}$  will give a certain deformation  $\Delta z_1$  so the subsoil parameter  $C_{1z}$  can be determined.

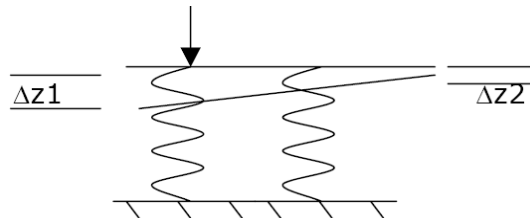
The parameters  $C_{1x}$ ,  $C_{1y}$  and  $C_{1z}$  will represent a linear stiffness.



The horizontal subsoil parameters  $C_{1x}$  and  $C_{1y}$  indicate the friction between the plate and the ground. In literature more information can be retrieved for the calculation of these parameters. For normal soils (no rock, peat ...) a guide value of 10% of the vertical stiffness  $C_{1z}$  may be taken.

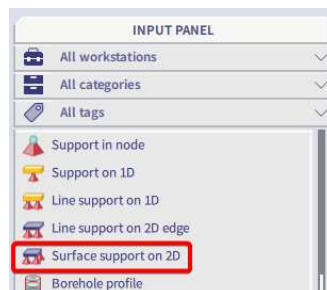
### Pasternak Model

The Winkler model can be extended with the Pasternak model ( $C_2$  constants). 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.

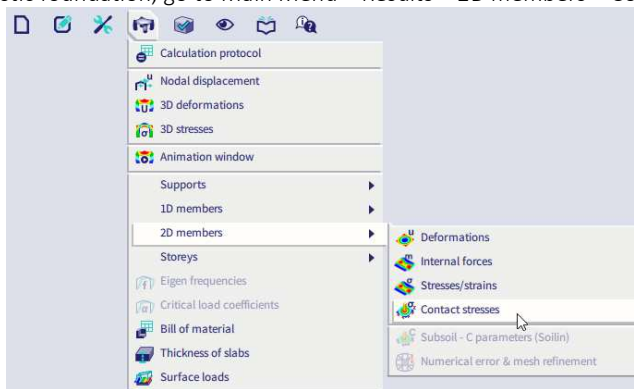


The calculation of those parameters is not easy, but it could be done by the module Soilin of SCIA Engineer. If Soilin is not being used in SCIA Engineer, it is recommended to have zero values for these  $C_2$  parameters.

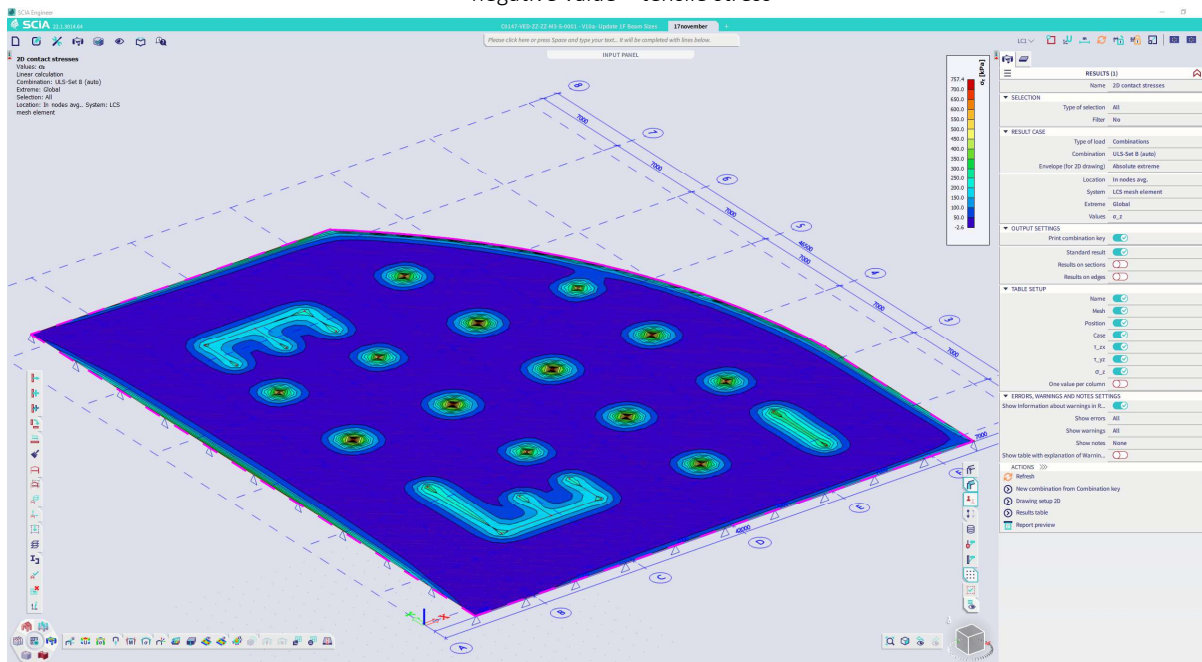
After modelling a 2D member, you can add an elastic foundation with the function 'surface support' which you can find in the input panel.



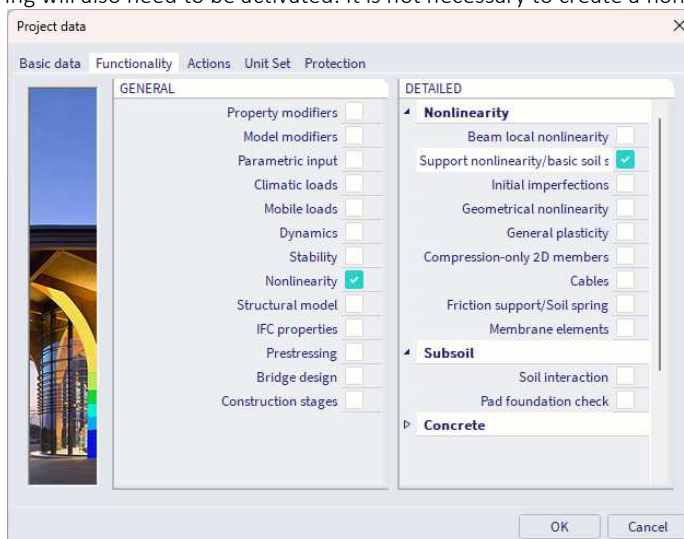
To see the results of the elastic foundation, go to Main Menu > Results > 2D members > Contact stresses.



**Note:** Convention for the soil stresses is: - positive value = compressive stress  
- negative value = tensile stress



To eliminate the tension in the subsoil, you have to perform a nonlinear analysis. The functionality 'support nonlinearity/basic soil spring' will also need to be activated. It is not necessary to create a nonlinear function.



## Chapter 2: Pad foundations

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  $V_d$ , horizontal design loading  $H_d$  and effective geometry of the pad are determined.

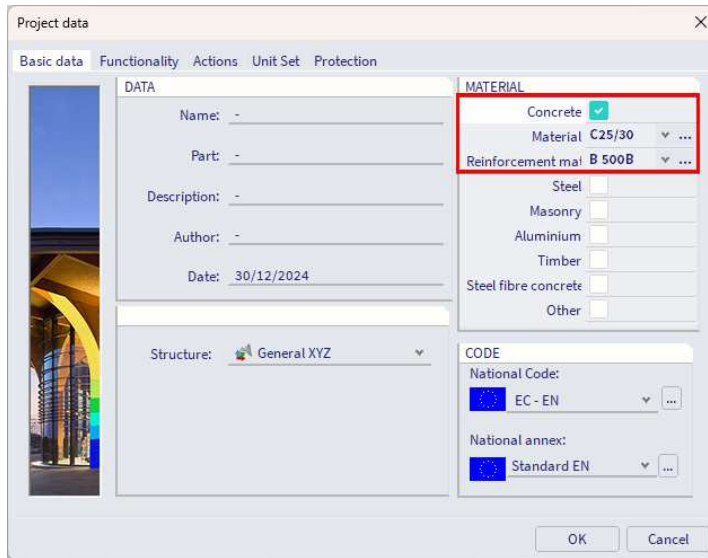
Based on this effective geometry, the different checks are executed.

The above steps are explained in detail in the following paragraphs.

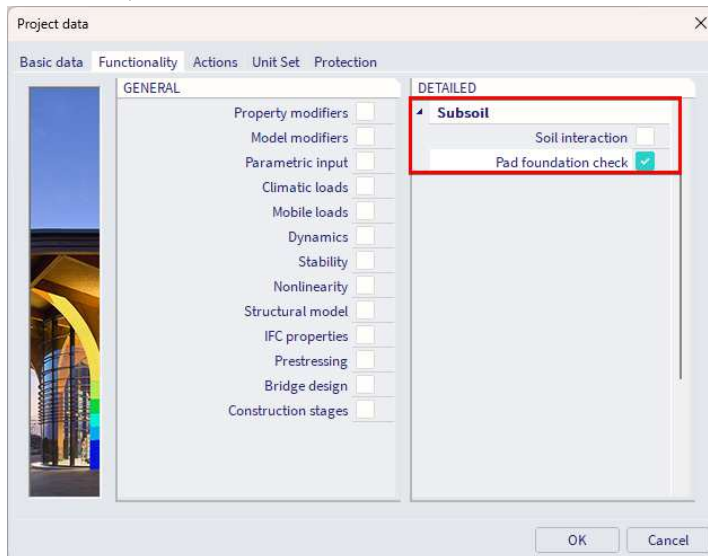
### 2.1. Requirements

In order to design a foundation pad, the following functionalities should be enabled in the Project Data dialogue:

- Material Concrete



- Functionality 'Pad foundation check'

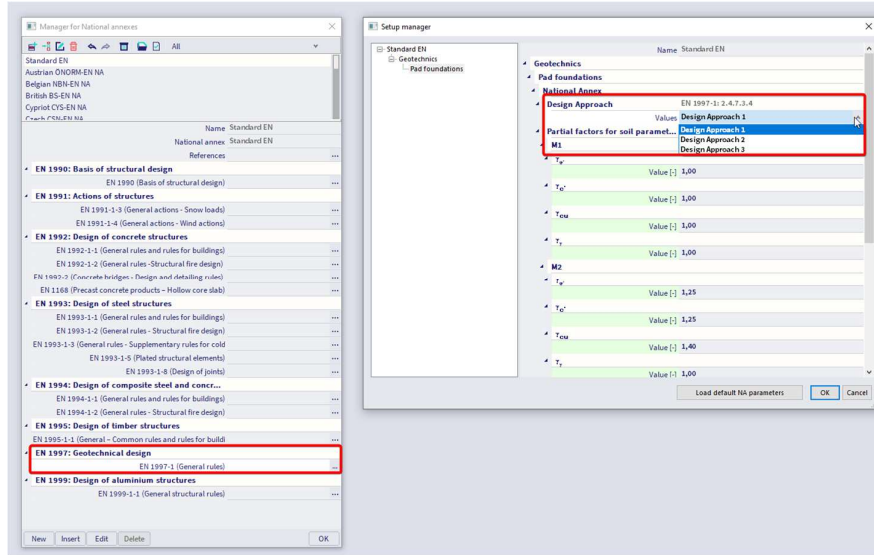




## 2.2. Design approaches

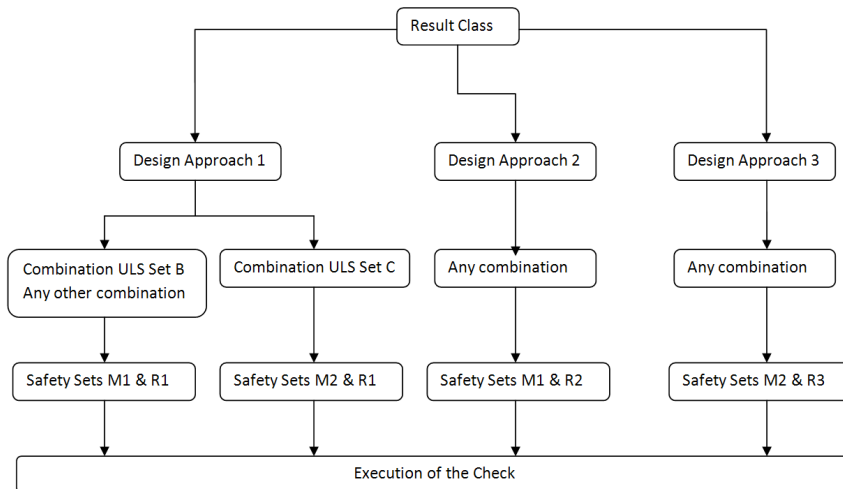
The Pad Foundation check is executed for a Result Class.

The manner in which the design effects of actions and resistances are applied shall be determined using one of three Design Approaches. The design approach can be set in the annex setup:



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:

1) Partial factors on actions or the effects of actions (Set A1-A2)

- $\gamma_G$ : on permanent unfavourable or favourable actions
- $\gamma_Q$ : on variable unfavourable or favourable actions

**Table A.3 - Partial factors on actions ( $\gamma_E$ ) or the effects of actions ( $\gamma_E$ )**

Action		Symbol	Set	
			A1	A2
Permanent	Unfavourable	$\gamma_G$	1,35	1,0
	Favourable		1,0	1,0
Variable	Unfavourable	$\gamma_Q$	1,5	1,3
	Favourable		0	0

2) Partial factors for soil parameters (Set M1-M2)

- $\gamma_\phi$ : on the tangent of the angle of shearing resistance
- $\gamma_c$ : on effective cohesion
- $\gamma_{cu}$ : on undrained shear strength
- $\gamma_{qu}$ : on unconfined strength
- $\gamma_\gamma$ : on weight density

**Table A.4 - Partial factors for soil parameters ( $\gamma_M$ )**

Soil parameter	Symbol	Set	
		M1	M2
Angle of shearing resistance <sup>a</sup>	$\gamma_\phi$	1,0	1,25
Effective cohesion	$\gamma_c$	1,0	1,25
Undrained shear strength	$\gamma_{cu}$	1,0	1,4
Unconfined strength	$\gamma_{qu}$	1,0	1,4
Weight density	$\gamma_\gamma$	1,0	1,0

<sup>a</sup> This factor is applied to  $\tan \phi'$

3) Partial resistance factors for pad foundations (Set R1-R3)

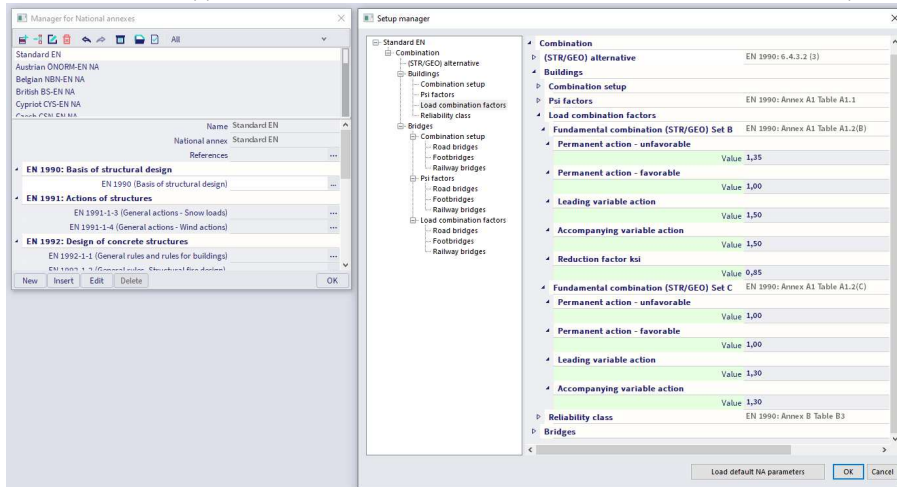
- $\gamma_{R,v}$ : on bearing resistance
- $\gamma_{R,h}$ : on sliding resistance

**Table A.5 - Partial resistance factors ( $\gamma_R$ ) for spread foundations**

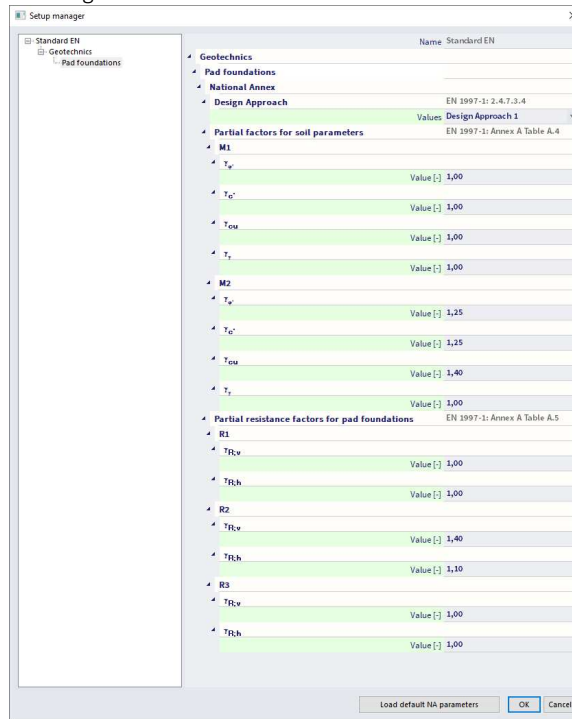
Resistance	Symbol	Set		
		R1	R2	R3
Bearing	$\gamma_{R,v}$	1,0	1,4	1,0
Sliding	$\gamma_{R,h}$	1,0	1,1	1,0

The partial safety factors for the combinations are defined in the Manager for National Annexes. It can be opened from the Project settings dialogue.

Available are factors for Set B of the EN-ULS (STR/GEO) combination defined in EN 1990. In addition, for Geotechnical analysis, also Set C needs to be supported. Also these factors are available in the Combination Setup:



Also the partial factors for soil parameters and the partial resistance factors for pad foundations which are defined in EN 1997 are implemented in the manager for National Annexes.



In order to perform a Pad Foundation check, you have to define 2 types of combinations:

- EN-ULS (STR/GEO) Set B
- EN-ULS (STR/GEO) Set C

After the calculation, a new class **GEO** will be generated automatically which contains all combinations of these 2 types.

**Note:** The Result Class may off course also contain load cases or non-linear combinations. These are seen as ‘Any combination’ for the check.

### 2.3. Ground properties

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

$$\phi'_{d} = \text{atan} \left[ \frac{\tan(\phi')}{\gamma_{\phi'}} \right]$$

$$c'_{d} = \frac{c'}{\gamma_{c'}}$$

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

$$\gamma'_{d} = \frac{\gamma'}{\gamma_{\gamma}}$$

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

With:

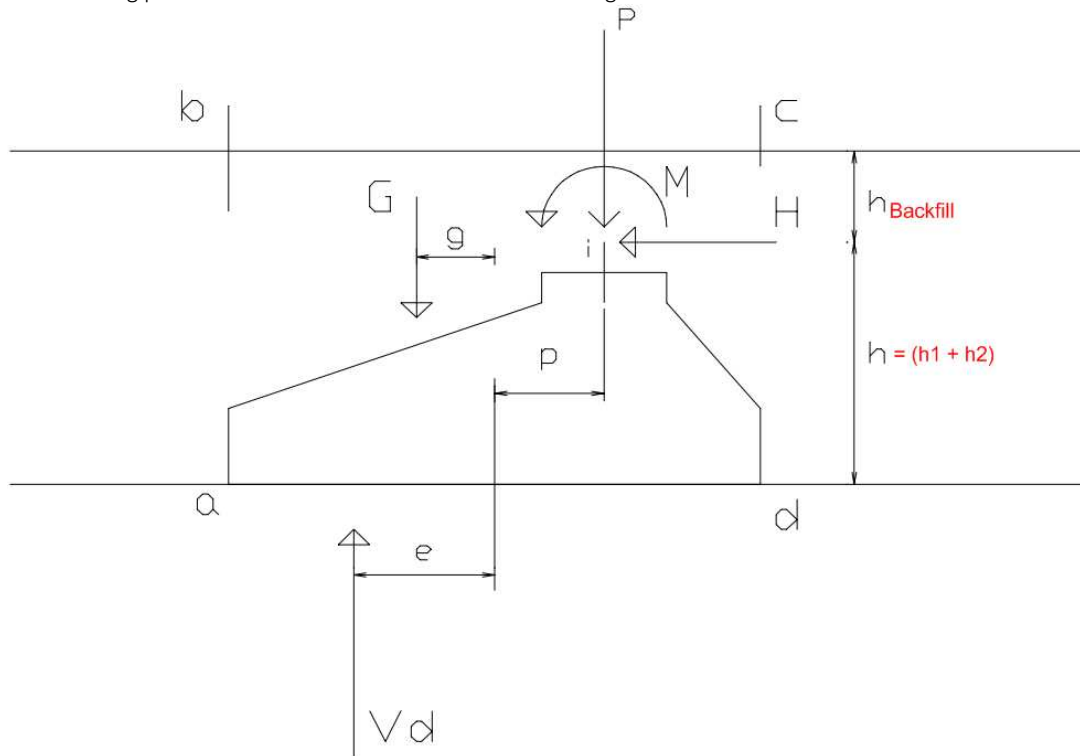
- $\phi'$  read from Subsoil Library
- $c'_{d}$  read from Subsoil Library
- $c_u$  read from Subsoil Library
- $\gamma'$  specific weight read from Library
- $\gamma_{\phi'}$  read from National Annex Setup
- $\gamma_{c'}$  read from National Annex Setup
- $\gamma_{cu}$  read from National Annex Setup
- $\gamma_{\gamma}$  read from National Annex Setup
- $\gamma_{\text{Backfill}}$  weight read from Pad foundation input Data

$\gamma_G$ : 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.  $\gamma_G$ . In case a combination does not have a permanent load case,  $\gamma_G$  is taken as 1,00.

## 2.4. Properties of the Pad Foundation

### 2.4.1. 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  $R_z$  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  $e_x$  and  $e_y$  from the Pad Foundation library
- $H$  horizontal  $R_x$  or  $R_y$  reaction of the support
- $h = (h_1 + h_2)$   
Load application point of the horizontal load  $H$  referenced to the foundation base  
With  $h_1$  and  $h_2$  read from the Pad Foundation Library
- $M$  moment  $M_x$  or  $M_y$  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  $V_d$  referenced to the center point of the foundation base

### Eccentricity $e$

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,  $G_{\text{Block}}$

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

no influence	$\gamma_{\text{Block}}$
at foundation base	$\gamma_{\text{Block}}$
at ground level	$(\gamma_{\text{Block}} - \gamma_w)$
- The Water Density  $\gamma_w$  is taken as **9,81 kN/m<sup>3</sup>**

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

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

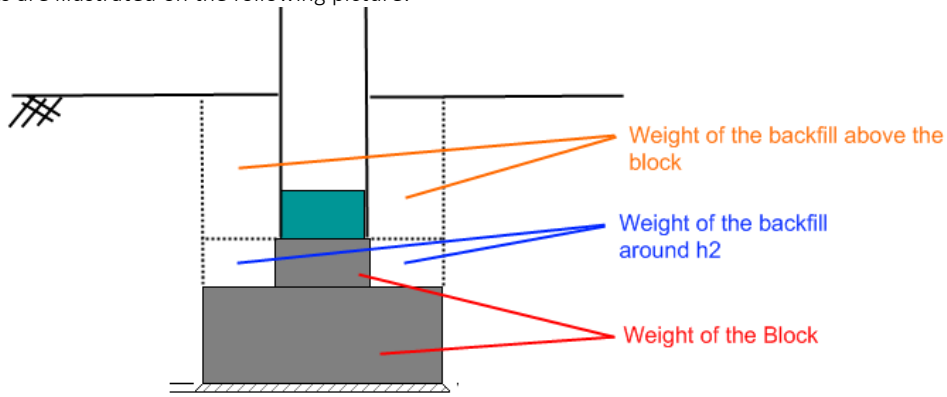
no influence	$\gamma_{\text{Backfill,d}}$
at foundation base	$\gamma_{\text{Backfill,d}}$
at ground level	$(\gamma_{\text{Backfill,d}} - \gamma_w)$
- The Water Density  $\gamma_w$  is taken as **9,81 kN/m<sup>3</sup>**

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

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

**Note:** 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  $\gamma_G$  the safety factor of the permanent loading for the combination under consideration, as defined in “Ground properties”.

### Distances $g_x$ & $g_y$

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

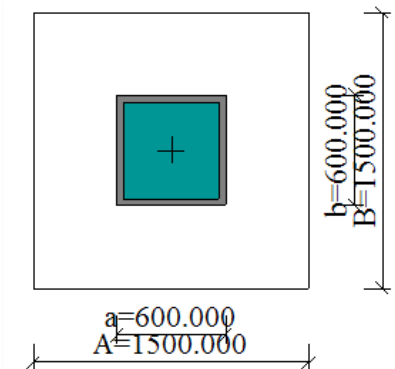
### Effective geometry

As a final step, using the eccentricities  $e_x$  and  $e_y$ , the effective geometry of the foundation base is calculated as follows:

$$L_1 = A - 2 * |e_x|$$

$$L_2 = B - 2 * |e_y|$$

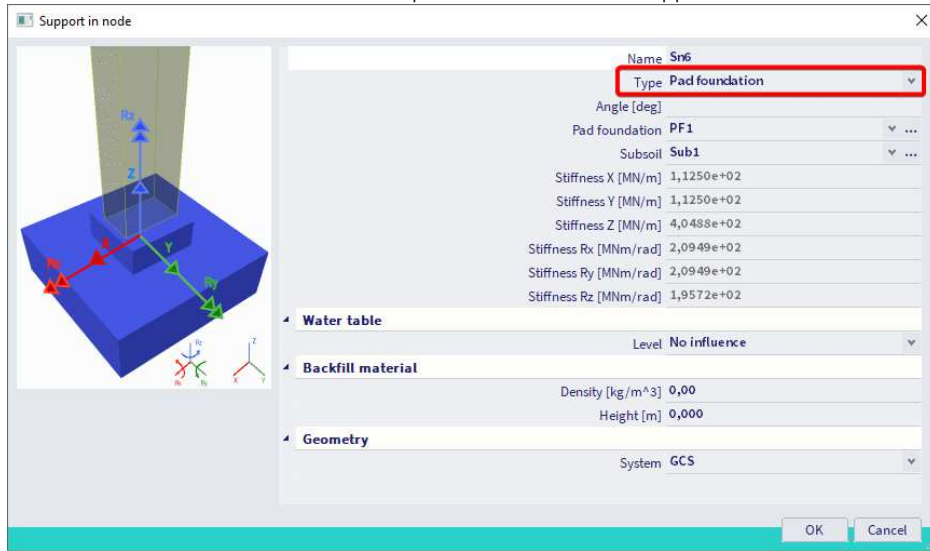
With  $A$  and  $B$  read from the Pad Foundation library:



- $B' = \min (L_1 ; L_2)$
- $L' = \max (L_1 ; L_2)$
- $A' = B' * L'$

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

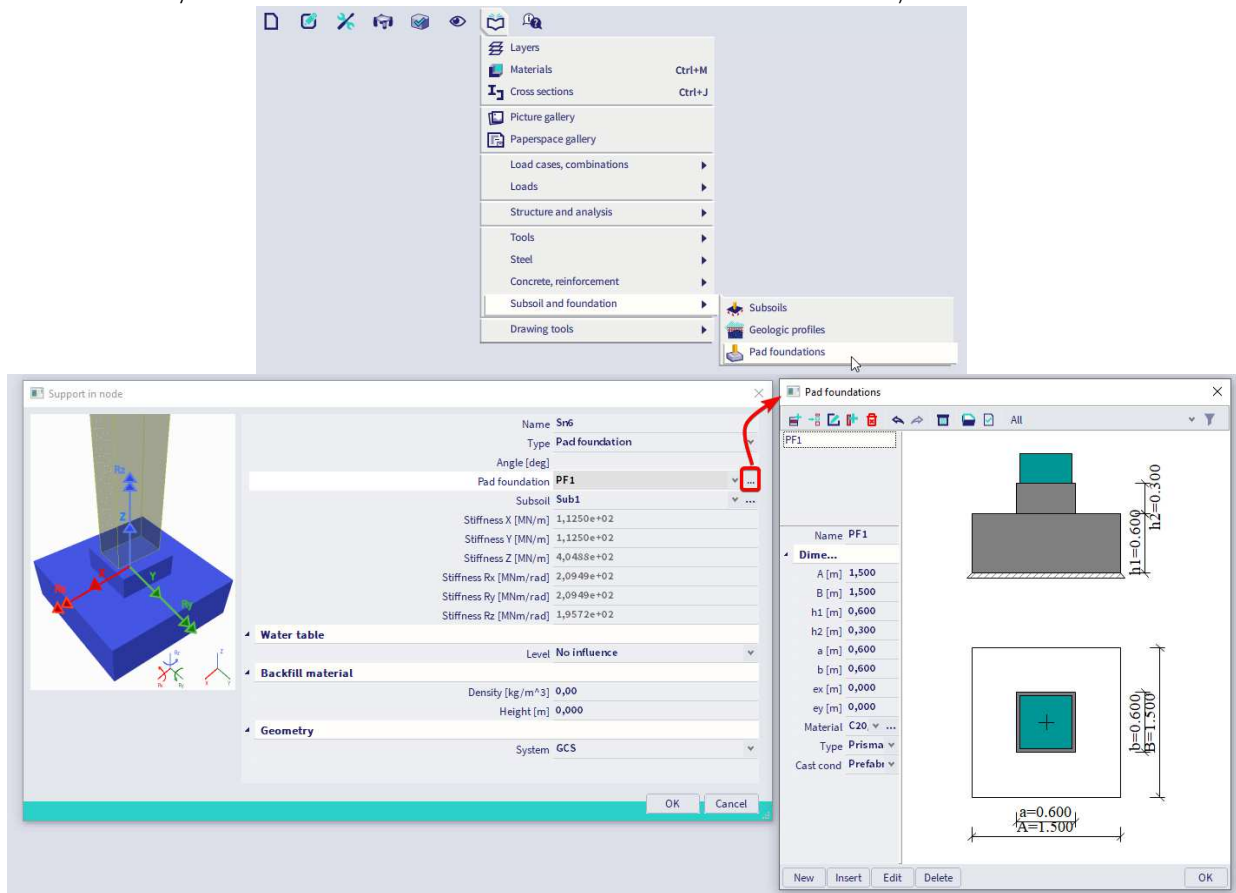
The option “Pad foundation” can be chosen in the Properties window of the supports:



Here it is possible to input the influence of the water table and the properties of the backfill material. Also the type of the subsoil can be chosen under “Subsoil”.

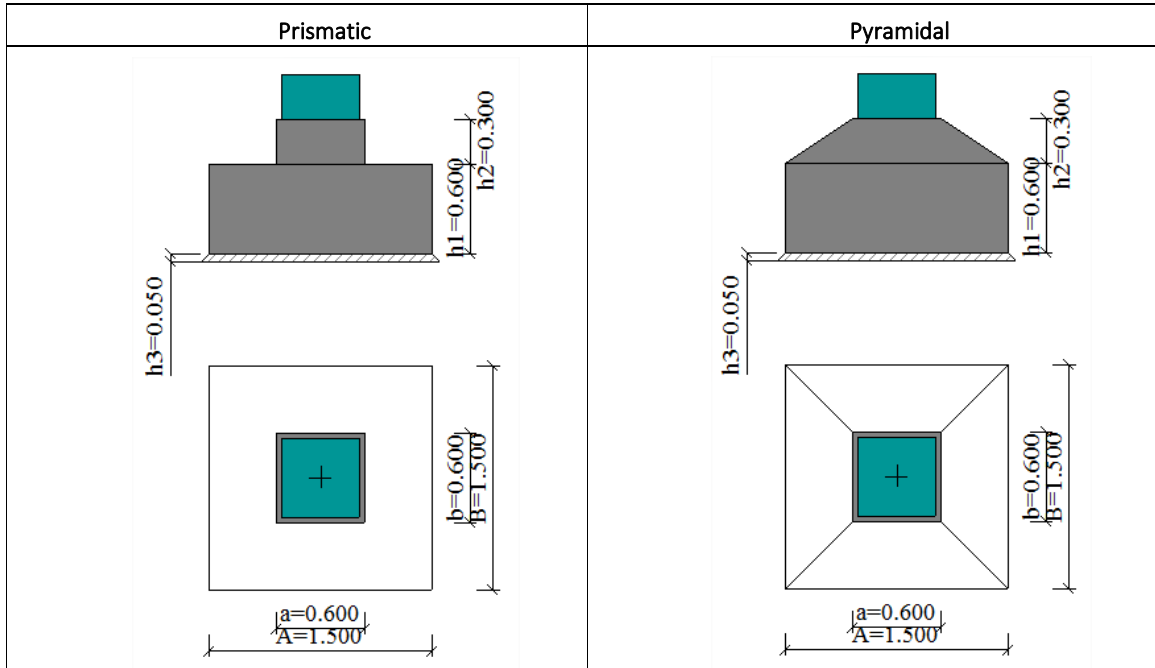
The given stiffnesses of the Pad Foundation are automatically calculated by the program by the formulas that you can find in Annex 1.

The dimensions of the pad foundations can be inputted at the option “Pad foundation” (or you can open the Pad foundation library via Main Menu > Libraries > Subsoil and foundation > Pad foundations):



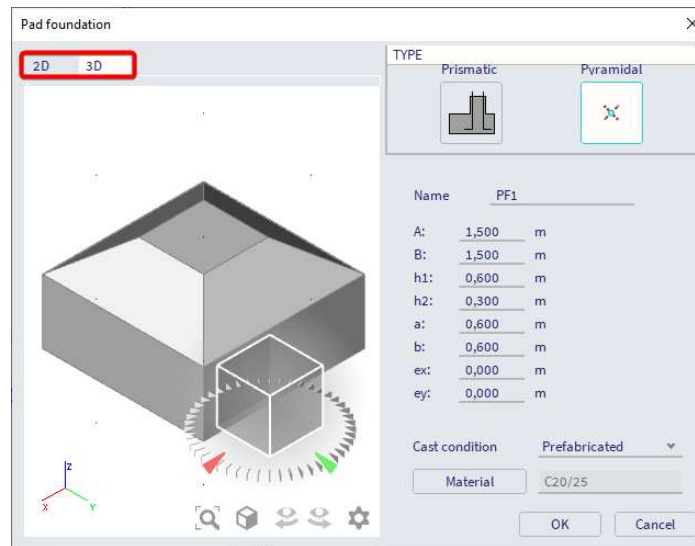


You can choose from two variant shapes of pad foundations:



When clicking 'Edit' the pad foundation can be displayed in 2D or 3D mode:

- The 2D mode shows side view, plan view and dimension lines for all input values.
- The 3D mode allows you to have a good visualisation of the defined foundation block



## 2.5. Pad foundation checks

In general three separate checks are executed:

- Bearing check
- Sliding check
- Eccentricity check

In a special case, instead of the three above checks, a so called Uplift Check is executed.

For Design Approach 1 the class for which the check is executed needs to contain at least one combination of each of the following types:

- EN-ULS (STR/GEO) Set B
- EN-ULS (STR/GEO) Set C

In case the class for which you wish to execute the check does not comply with this requirement, the check is not executed and a warning is shown instead.

For Design Approach 2 & 3 there is no requirement for the content of the class.

### 2.5.1. Bearing check

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

$$V_d \leq R_d$$

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

In case you 'know' the soil capacity, for example from a geotechnical report,  $R_d$  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  $R_x$  as defined in "General"

$H_y$  Horizontal support reaction  $R_y$  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

$$= (h_1 + h_2 + h_{backfill}) * \gamma_{Backfill,d}$$

With:

$h_1$  &  $h_2$  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:

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

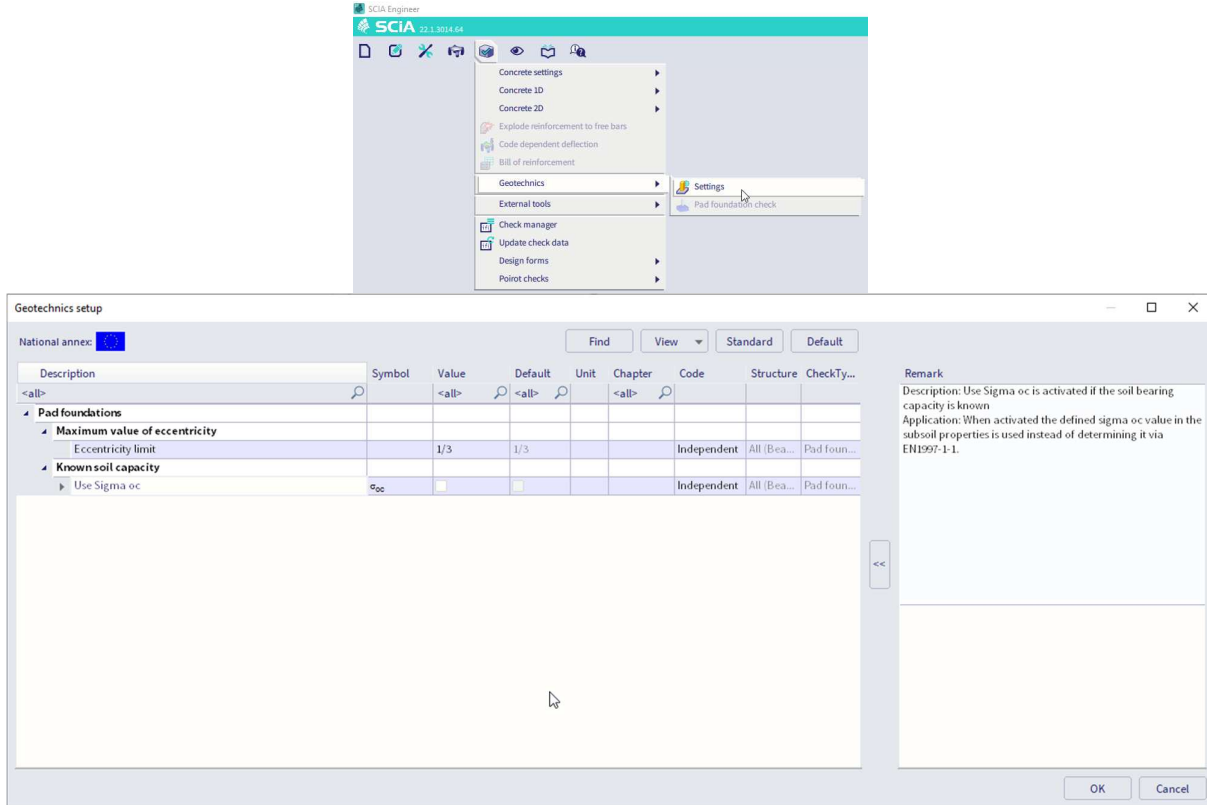
$c'_d$	As specified in the National Annex Setup
$N_c$	Bearing resistance factor $= (N_q - 1) * \cot(\varphi'_d)$
$N_q$	Bearing resistance factor $= e^{\pi * \tan(\varphi'_d)} * \tan^2(45 + \frac{\varphi'_d}{2})$
$N_\gamma$	Bearing resistance factor $= 2 * (N_q - 1) * \tan(\varphi'_d)$
$b_c$	Inclination 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: $b_q = 1,00$
$b_\gamma$	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, $s_q = 1 + (\frac{B'}{L'}) * \sin(\varphi'_d)$
$s_\gamma$	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 $H_d$ $= \left[ 1 - \frac{H_d}{V_d + A' * c'_d * \cot(\varphi'_d)} \right]^m$
$i_\gamma$	Inclination of the load, caused by horizontal load $H_d$ $= \left[ 1 - \frac{H_d}{V_d + A' * c'_d * \cot(\varphi'_d)} \right]^{m+1}$
$m$	$= m_L * \cos^2(\theta) + m_B * \sin^2(\theta)$
$m_L$	$= \frac{[2 + (\frac{L'}{B'})]}{[1 + (\frac{L'}{B'})]}$

$m_B$	$= \frac{\left[2 + \left(\frac{B'}{L'}\right)\right]}{\left[1 + \left(\frac{B'}{L'}\right)\right]}$						
$\theta$	Angle of the horizontal load $H_d$ with the direction $L'$						
$\varnothing'_d$	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 $R_x$						
$H_y$	Horizontal support reaction $R_y$						
$V_d$	Vertical reaction as specified in "General"						
$q'_d$	Effective overburden at the foundation base $=(h_1 + h_2 + h_{\text{backfill}}) * \gamma'_t$ With: h1 & h2 read from the Pad Foundation Library h <sub>backfill</sub> read from the Pad Foundation input $\gamma'_t$ is depending on the water level as follows: <table> <tr> <td>No influence</td> <td><math>\gamma_{\text{Backfill},d}</math></td> </tr> <tr> <td>at foundation base</td> <td><math>\gamma_{\text{Backfill},d}</math></td> </tr> <tr> <td>at ground level</td> <td><math>(\gamma_{\text{Backfill},d} - \gamma_w)</math></td> </tr> </table> $\gamma_{\text{Backfill},d}$ as defined in Ground properties $\gamma_w$ is taken as <b>9,81 kN/m<sup>3</sup></b>	No influence	$\gamma_{\text{Backfill},d}$	at foundation base	$\gamma_{\text{Backfill},d}$	at ground level	$(\gamma_{\text{Backfill},d} - \gamma_w)$
No influence	$\gamma_{\text{Backfill},d}$						
at foundation base	$\gamma_{\text{Backfill},d}$						
at ground level	$(\gamma_{\text{Backfill},d} - \gamma_w)$						
$\gamma'_d$	Effective weight density of the soil below the foundation level depending on the water level as follows: <table> <tr> <td>No influence</td> <td><math>\gamma'_d</math></td> </tr> <tr> <td>at foundation base</td> <td><math>(\gamma'_d - \gamma_w)</math></td> </tr> <tr> <td>at ground level</td> <td><math>(\gamma'_d - \gamma_w)</math></td> </tr> </table> $\gamma'_d$ as defined in Ground properties $\gamma_w$ is taken as <b>9,81 kN/m<sup>3</sup></b>	No influence	$\gamma'_d$	at foundation base	$(\gamma'_d - \gamma_w)$	at ground level	$(\gamma'_d - \gamma_w)$
No influence	$\gamma'_d$						
at foundation base	$(\gamma'_d - \gamma_w)$						
at ground level	$(\gamma'_d - \gamma_w)$						
$\gamma_{R,v}$	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. You can find the setup via Main Menu > Design > Geotechnics > Settings.



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

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

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

## 2.5.2. 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 **R<sub>d</sub>** depends on the fact if the soil condition is drained or undrained.

The value **R<sub>p,d</sub>** 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 **R<sub>d</sub>** 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"
$\delta_d$	Design friction angle at the foundation base Dependent on the <b>Cast condition</b> specified in the Pad Foundation Library:
	Prefabricated $\frac{2}{3} * \varphi'_d$
	In situ $\varphi'_d$
$\varphi'_d$	As specified in Ground properties
$\gamma_{R,h}$	Resistance factor read from the National Annex Setup

### 2.5.3. 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.*

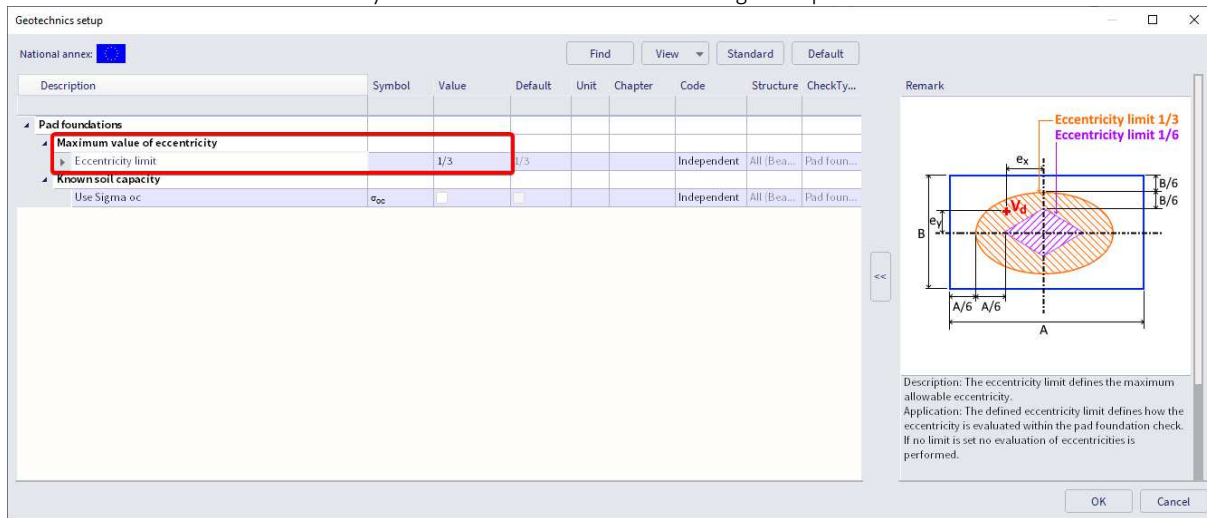
*Such precautions include:*

- 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.

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

This can be 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:

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

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

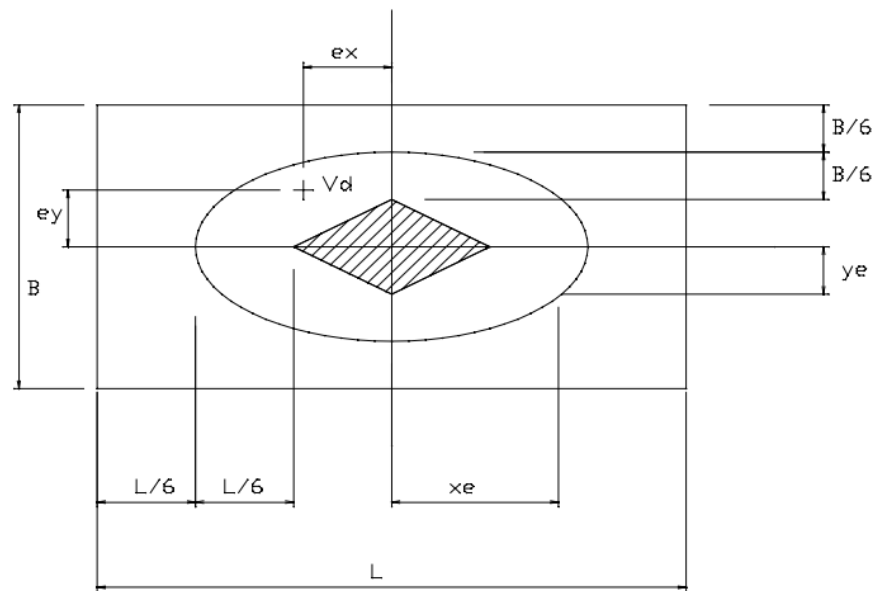
The eccentricity check of **1/3** takes into account that the pad foundation will not lose contact with the ground over more than half its width under the service loads.

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

#### 2.5.4. 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**:

$$|P| \leq G_d$$

- $P$  vertical  $R_z$  reaction as specified in "General"
- $G_d$  weight of the foundation and any backfill as specified in "General"

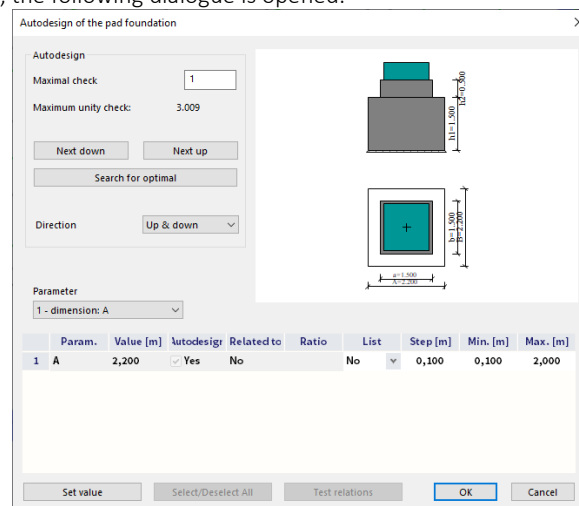
## 2.6. Pad foundation Autodesign

Autodesign of a concrete pad foundation is located in the actions window of geotechnics: Main Menu > Design > Geotechnics > Pad foundation check.

The autodesign can run after the calculation. The filter will be automatically switched to Pad foundation when choosing Autodesign.



When starting the Autodesign, the following dialogue is opened:



You can choose which parameter has to be considered in the Autodesign. When you select the 'Advanced autodesign' multiple dimensions can be selected to be Autodesigned.

Next step is to click 'Search for optimal' to find the optimal dimensions of the selected pad foundation. This means that the maximum unity check has to be smaller than 1.

After clicking 'OK', the pad foundation is automatically replaced with the new designed one.

## Chapter 3: Foundation strips

A linear support may be defined in the form of a foundation strip. The supporting is then specified by the properties and dimensions of the strip together with the properties of the soil below the footing surface.

### 3.1. Definition

Insert a line support on beam and choose as Type the Foundation strip.

Name	S1b1
Type	Foundation strip
Subsoil	sub1
Width b [m]	1,000
Height h [m]	1,000
Stiffness X [MN/m <sup>2</sup> ]	3,5000e+00
Stiffness Y [MN/m <sup>2</sup> ]	3,5000e+00
Stiffness Z [MN/m <sup>2</sup> ]	3,5000e+01
Stiffness Rx [MNm/m/rad]	2,9167e+00
<b>Geometry</b>	
System	LCS
Extent	full
Coord. definition	Rela
Position x1	0,000
Position x2	1,000
Origin	From start

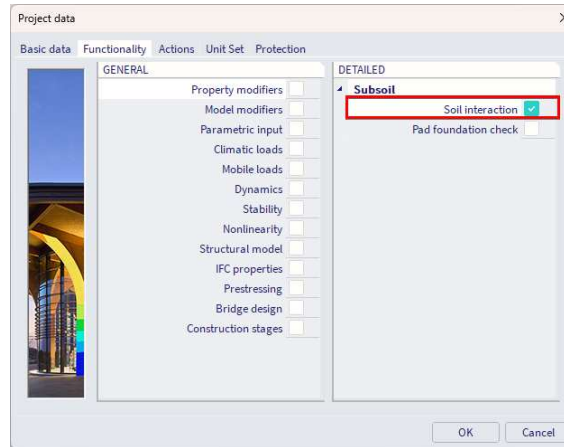
The stiffness of the foundation strip is defined by its width, height and the subsoil.

## Chapter 4: Geologic profiles, Geologic areas and Boreholes

The 3D model with defined subsoil and geologic profiles displays the subsoil surface. This surface defines the area where soil properties between boreholes is inter- and extrapolated.

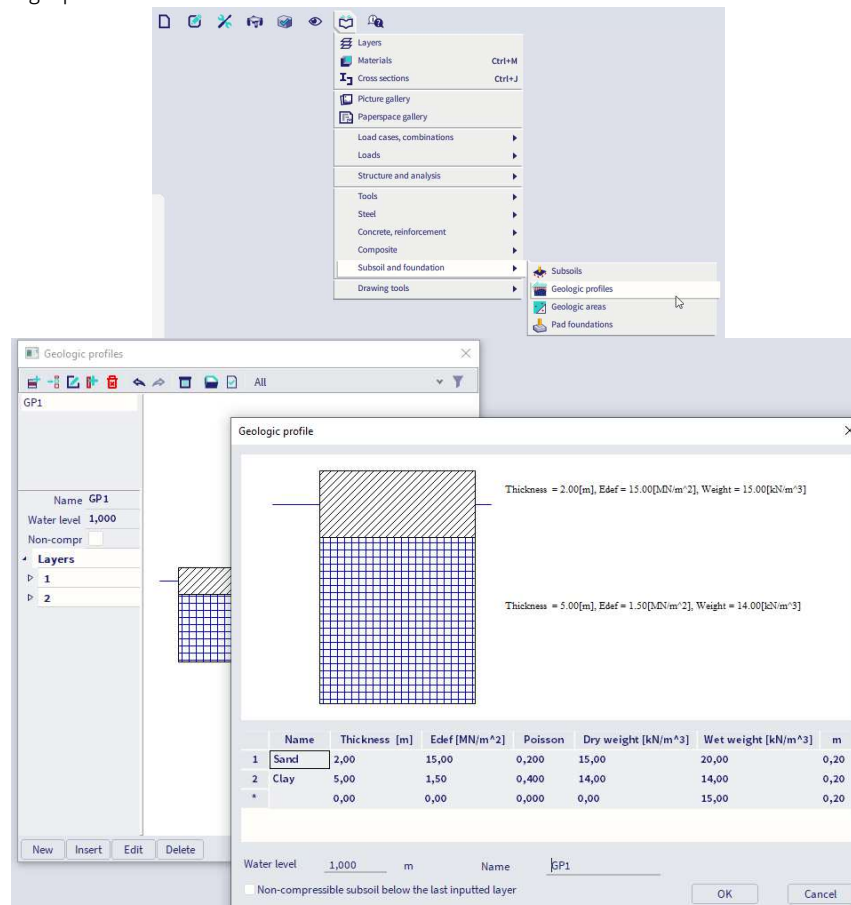
Boreholes together with geologic profiles provide the program information relating to the composition of the foundation soil. Both data are necessary to calculate the interaction between the structure and the soil below it.

To insert geologic profiles, geologic areas and boreholes in SCIA Engineer, you have to check the functionality 'Soil interaction'.



### 4.1. Geologic profile

You can define a new geologic profile in the Geologic profile manager via Main menu > Libraries > Subsoil and foundation > Geologic profiles



#### 4.1.1. General geologic profile parameters

- Water level Defines the level of underground water  
The water level influences the parameters of the soil
- Name Specifies the name of the geologic profile
- Not compressible subsoil If ON, the program applies coefficient of depth reduction  $k_2$  in compliance with CSN 001, art. 80.  
Numerically it means that the damping of stress component  $s_z$  in the half-space is slowed down. All components of elastic-half-space-stress-tensor are calculated in this reduced depth. It is just an approximate calculation, not an exact solution of the elastic layer. The difference is however negligible in comparison with other inaccuracies.

#### 4.1.2. Layer-related parameters

- Name Name of the layer
- Thickness Thickness of the layer
- Edef Module of deformation (see Annex 2)  
For geotechnical categories 1 and 2 the indicative value from e.g. CSN 73 1001 can be used, for category 3 a survey should be carried out to provide the value
- Poisson Coefficient of transverse deformation (range: 0 – 0.5)  
An indicative value or experimentally found value can be used
- Dry weight Specific soil weight for dry soil, normally within the range from 18 to 23 kN/m<sup>3</sup>
- Wet weight Specific soil weight for wet soil
- m Structural strength coefficient  
Dimensionless value in the formula for settlement according to CSN 73 1001

$$s = \sum_{i=1}^n \frac{\sigma_{z,i} - m_i \sigma_{or,i}}{E_{oed,i}} h_i$$

Table 10 in the standard states indicative values for various soils in the range from 0.1 to 0.5. For category 3 it is advisable to consult the engineer who carried out the survey of the locality in question  
For other codes (other than CSN) this coefficient is equal to 0.2

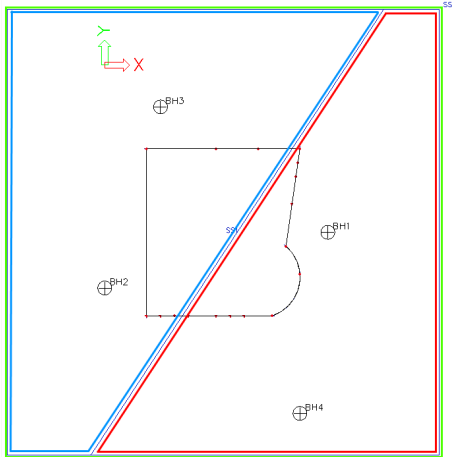
To edit the content of the table, it is possible to copy and paste the content from the clipboard.

**Note:** The geologic profile must be defined up to such a depth where the effective stress is still active, otherwise the program does not have enough information.

## 4.2. Geologic area

The basic surface polygon has been divided to the separate areas which are inter- and extrapolated, but the first area does not affect the next one. Different number of layers in the geologic profile may be used in different areas. For example: 5 layers in all boreholes in area 1 and 8 layers in all boreholes in area 2.

The line between 2 geologic areas is a geologic fault.



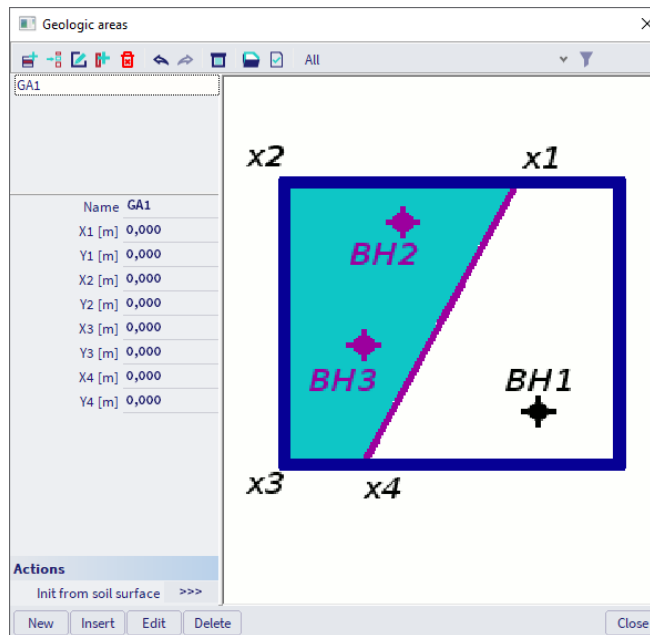
Green: basic outline of the subsoil surface

Red (right side): geologic area 1

Blue (left side): geologic area 2

Red-Blue line: geologic fault

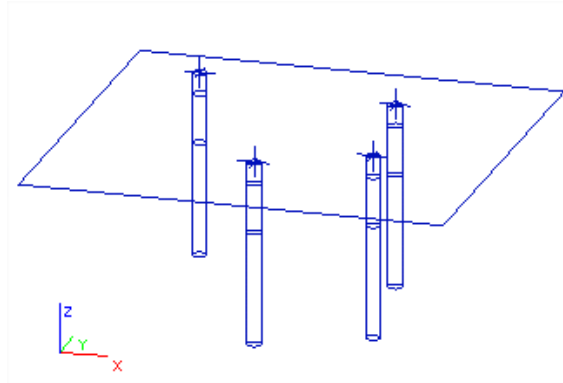
A new geologic area can be defined in the Geologic area library which contains the geometry (4 points) and can be opened via Main menu > Libraries > Subsoil and foundation > Geologic areas



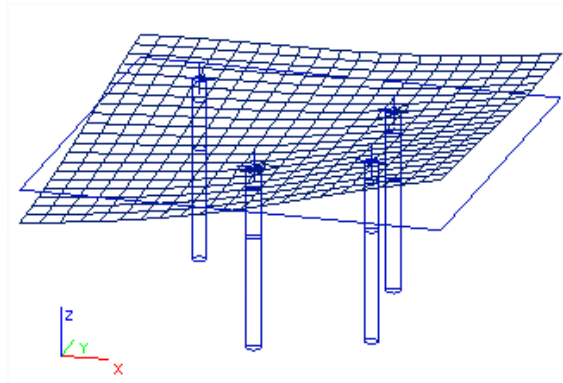
### 4.3. Boreholes

A borehole is fully defined by the (i) corresponding geologic profile, (ii) location and (iii) altitude. Usually a set of boreholes will be defined and thus they can be used to calculate and display the surface of the land in their surroundings. This surface can be used for impressive presentations of projects. The surface itself is not taken into account during the calculation.

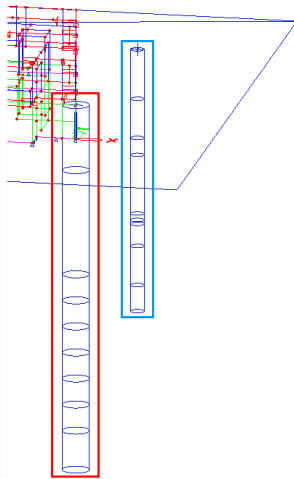
The following picture shows an example of defined boreholes. The rectangle represents the patch of land over which the soil properties can be inter- and extrapolated.



Next picture shows the calculated surface.



There is a possibility to use the borehole as a sand-gravel pile (holes in soil filled by sand and gravel). The sand-gravel pile consists from the geologic profile and a geometry which defines its outline. The sand-gravel pile outline has the same behavior as a geologic fault. You can define a borehole with soil layers of this pile and activate the checkbox "sand-gravel pile. After that you can multicopy this borehole to real positions of piles and in the analysis these "pile boreholes" are taken into account as local piles under the foundation slab. Moreover you must define one standard borehole with layers of soil between piles. It must be combined with soilin calculation.

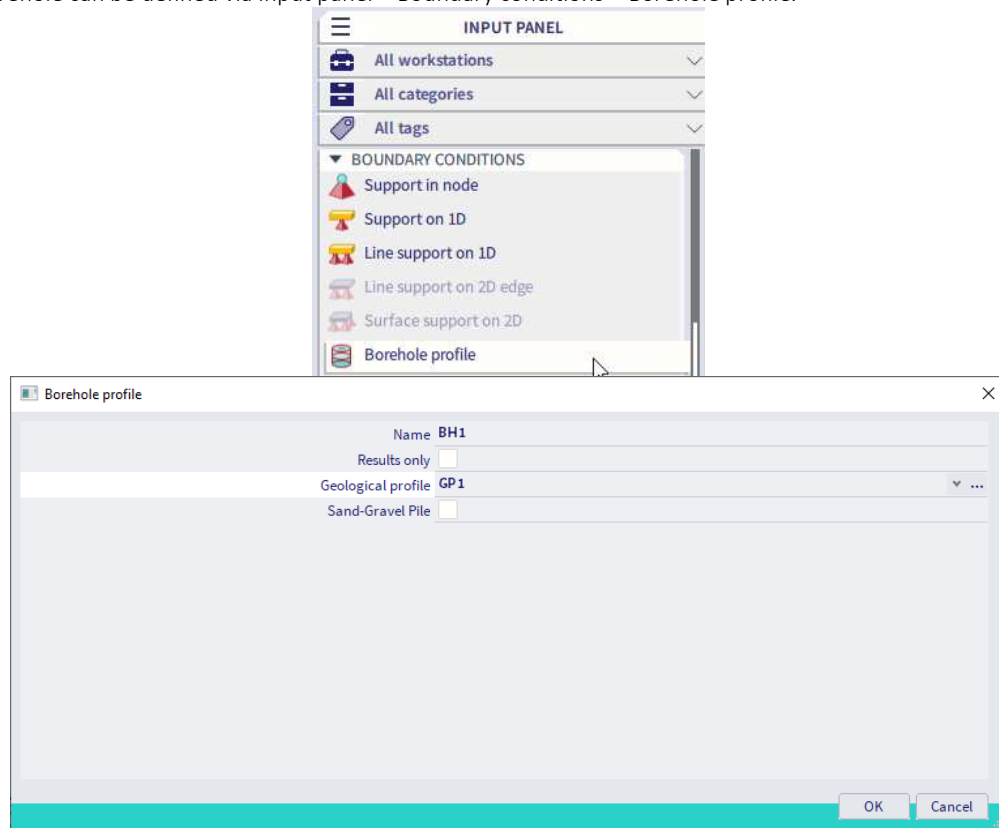


Red (left side): sand-gravel pile with diameter 1m

Blue (right side): standard borehole

Both are displayed inside the subsoil surface outline

A new borehole can be defined via Input panel > Boundary conditions > Borehole profile.



#### 4.3.1. Borehole parameters

- Name Identifies the borehole profile
- Coord X, Y, Z Coordinates of the inserting point of the borehole
- Results only When the calculation is performed, you can obtain a table of settlement. The values of settlement are calculated in places where boreholes are located. The borehole itself (the corresponding geologic profile) is also used as an input value for the calculation of interaction between the structure and the soil  
However, it is possible to exclude some boreholes from the input data and use them only as the location for the calculation of results – settlement  
If this parameter is ON, the geologic profile defined in the borehole is ignored, the conditions in this place are interpolated from surrounding boreholes, but final settlement is calculated in this location
- Geologic profile Specifies the geologic profile corresponding to the location of the borehole
- Sand-gravel pile Defines if the borehole is used as a sand-gravel pile
- Radius Specifies the radius of sand-gravel pile

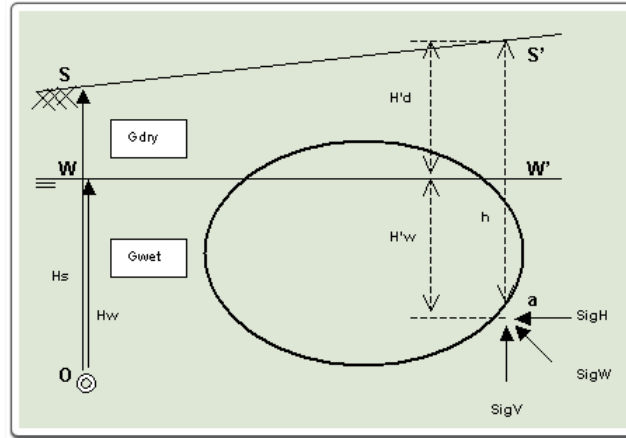
**Note:** After some modification (especially modification of the position) of the borehole, it may be necessary to refresh the surface.



#### 4.4. Soil pressure and water pressure

Several types of load (point force, line load and surface load) can be defined as what is called "soil pressure" or "water pressure ". Both loads are quite related and will be explained together.

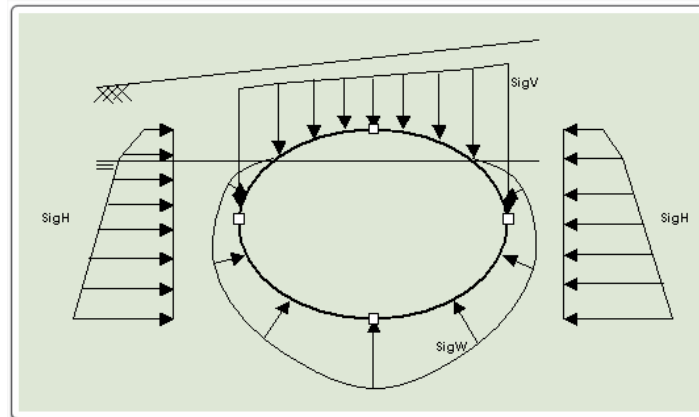
Both load types appear only if a structure is located underground. Depending on the surrounding soil, level of underground water and depth below the surface, the program automatically calculates the soil pressure and water pressure.



In depth h (point a), the intensities of the generated loads are:

SigV,a	If a is located above water level: $(h \leq H'd)$ , then $(h * Gdry)$ If a is located below water level: $(h > H'd)$ , then $(H'd * Gdry + H'w * Gwet)$ It works ONLY in the negative direction of global Z-axis!
SigH,a	$SigH,a = SigV,a * k0$
SigW,a	If a is located above water level: $(h \leq H'd)$ , then $(0)$ If a is located below water level: $(h > H'd)$ , then $(H'w * Gwater)$

This would lead to a distributed load as in the image below:



Water and soil loads can be inputted for the following load cases:

- action type = "permanent" and load type = "standard",
- action type = "variable" and load type = "static".

The procedure to input soil / water pressure:

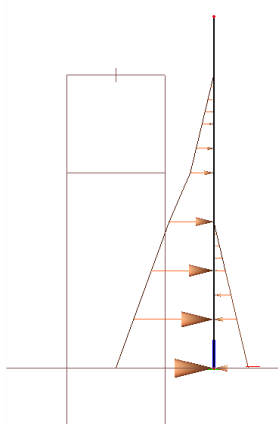
1. Open the Input panel
2. Start the required load type (point, line, surface).
3. Adjust the parameters - see below.
4. Confirm with [OK].
5. Apply the load on required entities.

## 4.5. Soil/Water load parameters

In addition to common parameters for point, line and surface loads, this load type requires the input of following data:

- Type Must be set to Soil pressure or Water pressure
- Distribution Only for line load  
The line load may be uniform or trapezoidal
- Acting area Only for point load  
Defines the acting area for the load
- Acting width Only for line load  
Defines the acting width for the load
- Coefficient Only for soil pressure  
This coefficient must be defined for horizontal soil pressure. It specifies the ration between vertical and horizontal soil pressure (i.e. for vertical pressure it should be equal to 1)
- Borehole profile Borehole profile

The soil / water pressure is displayed as shown in the picture below.



Both are generated (orange) loads. The generated soil pressure (left part) reaches just to the top of the borehole (that was used as the reference borehole). The generated water pressure (right part) is defined only below the level of underground water. So if the whole model is above the water level, no pressure is generated at all.

**The calculation considers these generated loads.**

## Chapter 5: Soilin

The analysis of foundation structures is challenged by the problem of modeling of the part of the foundation that is in contact with subsoil. The best solution is to use a 2D model of the subsoil that properly represents the deformation properties of the whole under-foundation massif by means of a surface model. The properties of such model are expressed by what is called interaction parameters marked C. These parameters are assigned directly to structure elements that are in contact with the subsoil and they influence the stiffness matrix.

The parameters of the interaction between the foundation and the subsoil depends on the distribution and loading level, or the contact stress between the structure surface and the surrounding subsoil, on the geometry of the footing surface and on mechanical properties of the soil.

Calculation module Soilin takes account of all the mentioned dependencies.

As the C parameters influence the contact stress and vice versa – the distribution of the contact stress has impact on the settlement of the footing surface and thus the C parameters, it is necessary to use an iterative solution.

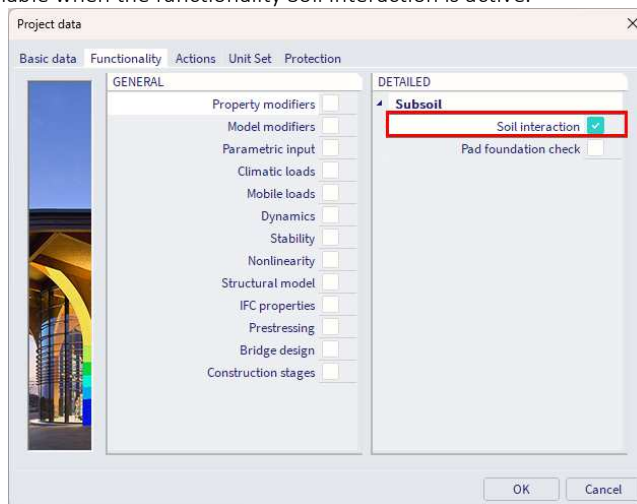
The results from the soilin iteration are the C-parameters C1z, C2x and C2y. The parameters C1x and C1y are always defined by the user.

- C1z - resistance of environment against wP (mm) [C1z in MN/m<sup>3</sup>]
- C2x - resistance of environment against wP/xP (mm/m) [C2x in MN/m]
- C2y - resistance of environment against wP/yP (mm/m) [C2y in MN/m]
- C1x - resistance of environment against uP (mm) [C1x in MN/m<sup>3</sup>]
- C1y - resistance of environment against vP (mm) [C1y in MN/m<sup>3</sup>]

**Note:** Usually, C2x is considered equal to C2y and C1x equal to C1y, because the calculation is done by so called isotropic variant of the calculation of C2 parameter.

### 5.1. Soilin calculation

The soilin calculation is available when the functionality Soil interaction is active.



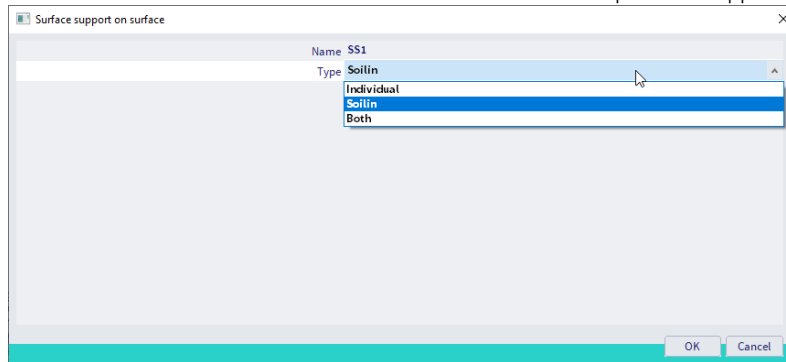
The Soil interaction is available only for Plate XY and General XYZ structure types.

### 5.1.1. Subsoil in the 3D model

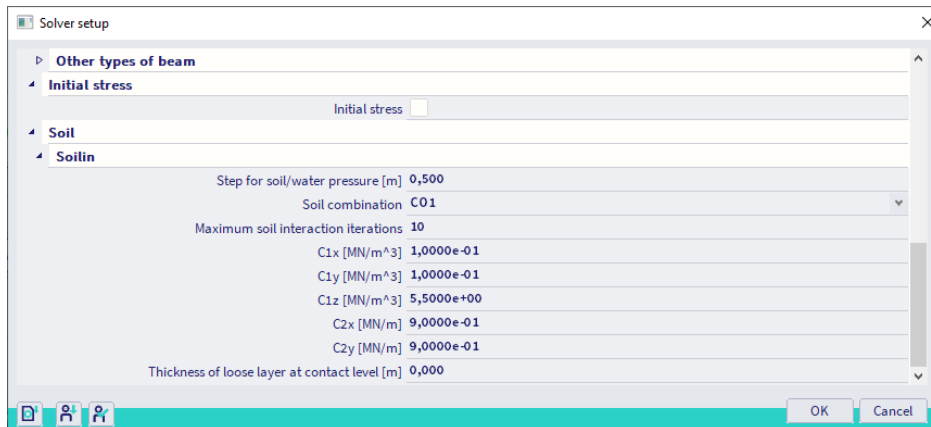
The subsoil in the 3D window is defined as a soil surface and a soil borehole. The geologic profile is defined for each soil borehole. The position and the composition of the geologic profiles provide information about the subsoil. The level of the foundation base is considered on the bottom surface of the plate. The eccentricities are also taken into account.

#### Surface support

The interaction between the structure and subsoil is calculated if the structure is put on a support of "Soilin" type.



- Name Specifies the name of the support
- Type Defines the type of support
  - **Individual**  
A particular subsoil type is assigned to the slab.  
The subsoil is defined by means of C parameters. These user-defined C parameters are used for the calculation (e.g. contact stress of the foundation surface)
  - **Soilin**  
For such a support, the interaction of the structure with the foundation subsoil is carried out by means of the Soilin module.  
All initial values of C parameters are defined in the Solver setup.

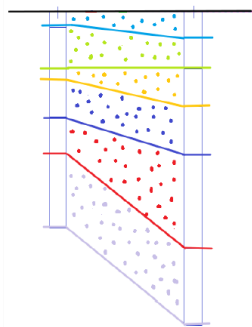


Parameters C1z, C2x, C2y are calculated by Soilin module, C1x and C1y are taken from the solver setup.

- **Both**  
Both of the above mentioned types are combined on the same slab.  
The user defines which C parameters will be user-defined and which ones will be calculated by the Soilin module. The parameters C1z, C2x and/or C2y that are set in the subsoil-property dialogue as zero will be calculated by the Soilin module. Non-zero parameters will be taken as they are inputted in the Subsoil. Parameters C1x and C1y are always defined by the user.

## Layers approximation

When more borehole profiles are used in the project then it must fulfil one important condition – the same number of layers. This is required because of the soilin approximation.



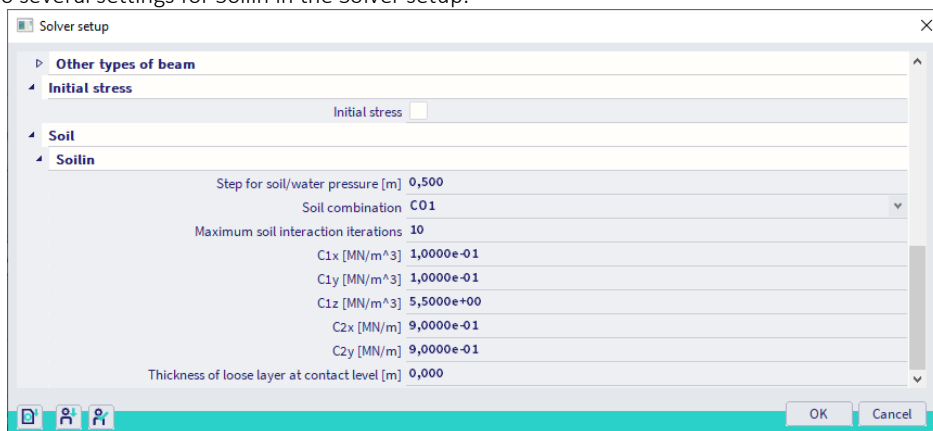
If there is some layer missing in one borehole, then it can be substituted by a layer with minimum thickness – e.g. 1 mm so the soilin has appropriate number of layers for approximation

### 5.1.2. Settings

There are some parameters that are required in a project in order to do a Soilin calculation:

- Project with at least one borehole with predefined geologic profile
- Structure with surface support type Soilin or Both
- Load
- Combination type Linear (ULS or SLS)

There are also several settings for Soilin in the Solver setup:



**Soil combination:** linear combination which is used for the soilin calculation. Even though it is not an exact solution, for practical reasons the C parameters are not calculated separately for each load case or each load case combination. The user must specify one particular reference combination that is used to calculate the C parameters. The calculated C parameters are then applied in all remaining defined load cases and combinations.

**Max soil interaction step:** number of iteration cycles (when the program stops iterations if there are still no proper C parameters calculated, in case those results diverge), the max. limit is 99 steps.

**C1x, C1y:** parameters defined by the user.

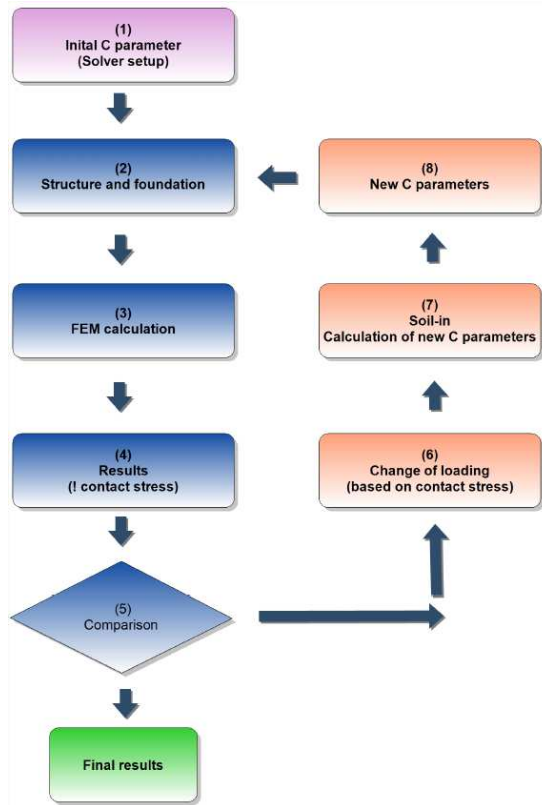
**C1z, C2x, C2y:** initial values for soilin (if the support type is Soilin).

### 5.1.3. Soilin iterative cycle

The values from the top structure and the foundation are calculated by FEM. The values are used as the source data for the soilin.

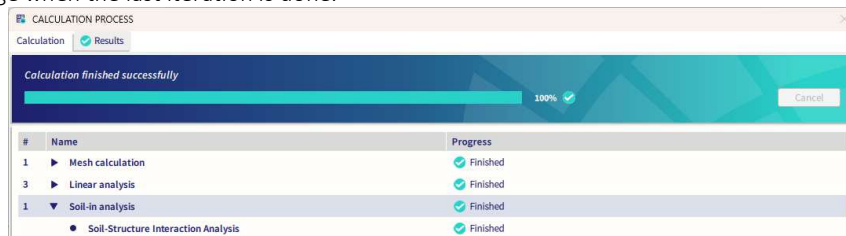
The iterative process is finished when the contact stress  $\sigma_z$  and displacement  $u_z$  does not change significantly in the two subsequent iterations. The special quadratic norms are evaluated in the each iteration cycle to find out if this condition is fulfilled.

Diagram of the iterative cycle:



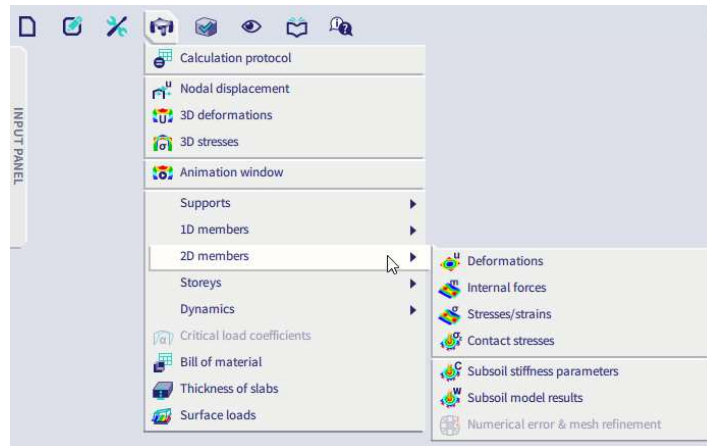
- 1) The values are taken from the solver setup, predefined by the user.
- 2) Data from the structure and its foundation.
- 3) FEM calculation – important results for soilin contact stress  $\sigma_z$  and displacement  $u_z$ .
- 4) The results of  $i$  iteration.
- 5) Comparison of the contact stress  $\sigma_z$  and  $u_z$  – it is based on the quadratic norms, when it does not change significantly, then the calculation is done and SCIA Engineer displays results.
- 6) 1<sup>st</sup> step of soilin – the contact stress is recalculated to the new loading.
- 7) 2<sup>nd</sup> step of soilin – the C parameters are recalculated, new loading is taken from the previous step.
- 8) 3<sup>rd</sup> step of soilin – final C parameters from soilin - the new input data.
- 9) New C parameters are used for the next FEM calculation.

There is a message when the last iteration is done.



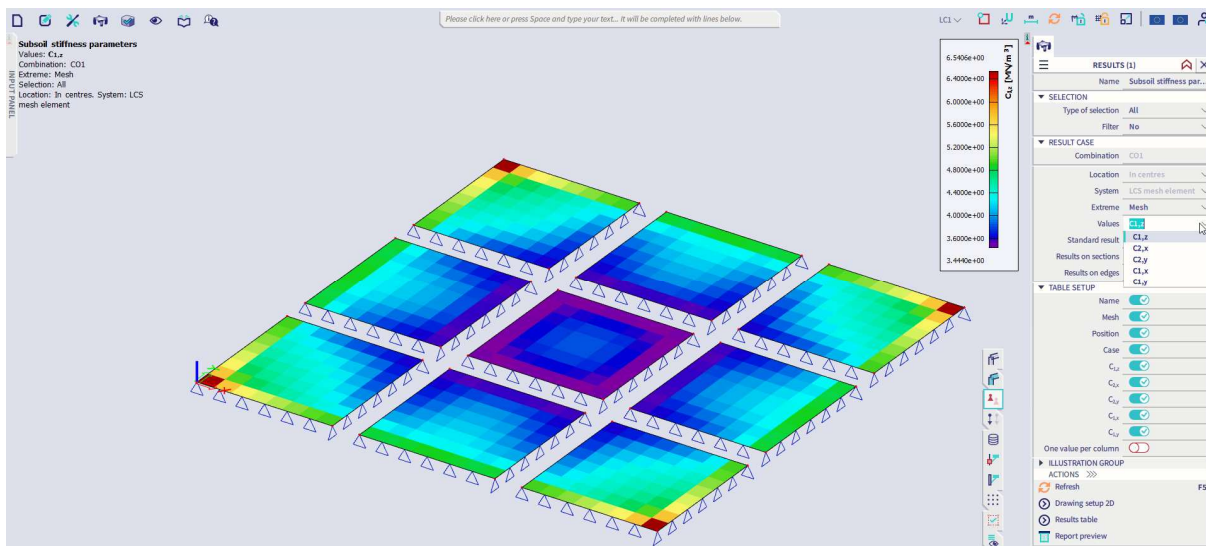
## 5.2. Results of soilin

Via Main menu > Results > 2D members results for the subsoil can be checked



### 5.2.1. Subsoil stiffness parameters

The C parameters are calculated for the mesh on the 2D member. It is displayed by the colour planes. The results can be displayed for each C parameter.

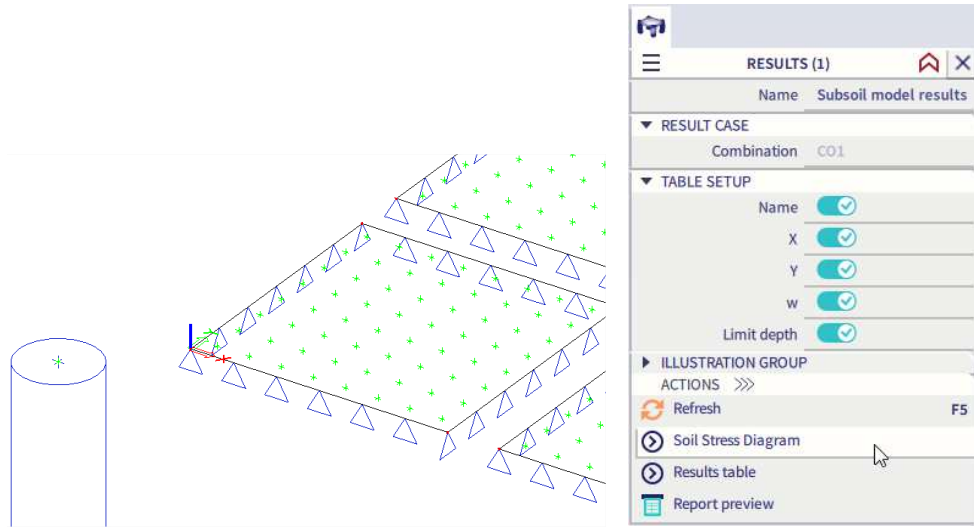


## 5.2.2. Subsoil model results

### Soil stress diagram

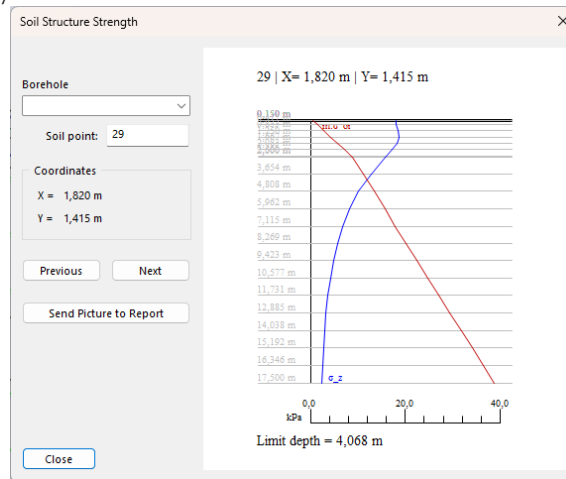
The settlement is calculated for each mesh element (in its centre of gravity) and for each borehole inserting point. The checkbox Results only exclude a borehole inserting point from the input data. It means that the point is used for the calculation of settlement but the geologic profile is not taken into account for the layers approximation.

The points for the settlement calculation are shown when selecting Soil Stress Diagram



Green vertices displayed on the plate are centres of elements from the 2D mesh, outside the plate are inserting points from boreholes.

The vertical axial components of stress and the structure strength (consequently the depth of the deformed subsoil zone) can be displayed for all points from the 2D mesh and for the inserting points of the boreholes. You just select the point and the diagram is displayed.



- **Previous** displays the Soil Structure Strength for the previous node
- **Next** displays the Soil Structure Strength for the next node
- **Borehole** displays the Soil Structure Strength for the selected borehole inserting point
- **Soil point** node number
- **m\*Sigma,or** original soil stress
- **Sigma,z** overstress



The Soilin module calculates two stresses: the overstress  $\Sigma_{z,z}$  and the original soil stress  $\Sigma_{z,or}$ . According to theory, settlement will occur if  $\Sigma_{z,z} > m * \Sigma_{z,or}$ .

The m-value is code dependent: (i) for the CSN code it can vary, for EC & DIN it is fixed at 0,2. It practically means that settlement occurs in case the overstress is bigger than 20% of the original soil stress.

The picture shows these two lines:  $\Sigma_{z,z}$  in blue and  $m * \Sigma_{z,or}$  in red. The program is looking for the intersection of the two lines: all layers above have  $\Sigma_{z,z} > m * \Sigma_{z,or}$  and settlement occurs in them and all the layers below have  $\Sigma_{z,z} < m * \Sigma_{z,or}$ , which means that no settlement is there. The depth at which the lines intersect is called the "limit depth"

In case you have not input a sufficient geological profile i.e. not deep enough, the intersection point cannot be determined. It means that the calculated settlement will be too small since there are still deeper layers which will also be compressed and will thus settle. Therefore, the program gives a warning that the geology is "Insufficient".

## Settlement table

The table is displayed via Report Preview. This preview table contains values w for each node.

The settlement w is different from displacement  $u_z$  of the foundation plate because w is calculated without stiffness of the structure and from the penultimate iteration. Therefore it is useful to watch values w only outside the foundation (see chapter additional plates to check the settlement around the surface support).

REPORT PREVIEW

Subsoil model results

Combination: CO1

Subsoil model results

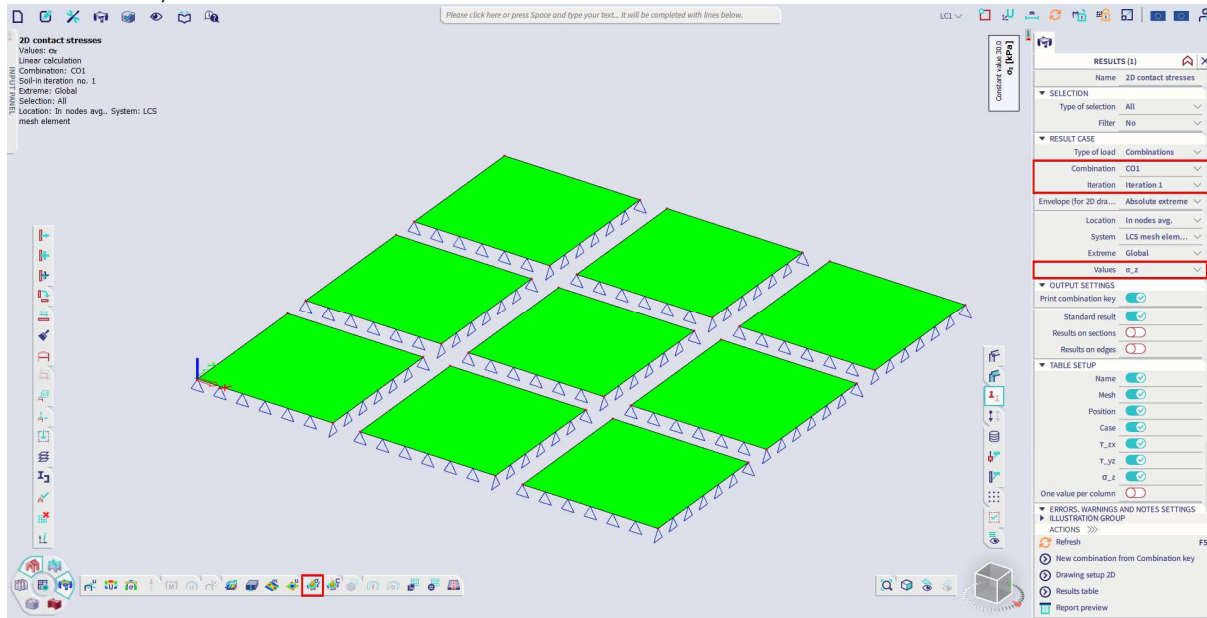
Name	X [m]	Y [m]	w [mm]	Limit depth [m]
1	0,202	0,202	3,0	2,457
2	0,607	0,202	4,0	2,804
3	1,011	0,202	4,5	3,089
4	1,415	0,202	4,8	3,285
5	1,820	0,202	4,9	3,426
6	2,224	0,202	5,0	3,527
7	2,629	0,202	4,8	3,604
8	3,033	0,202	4,3	3,671
9	0,202	0,607	4,0	2,804
10	0,607	0,607	5,3	3,181

## Results for each iteration cycle

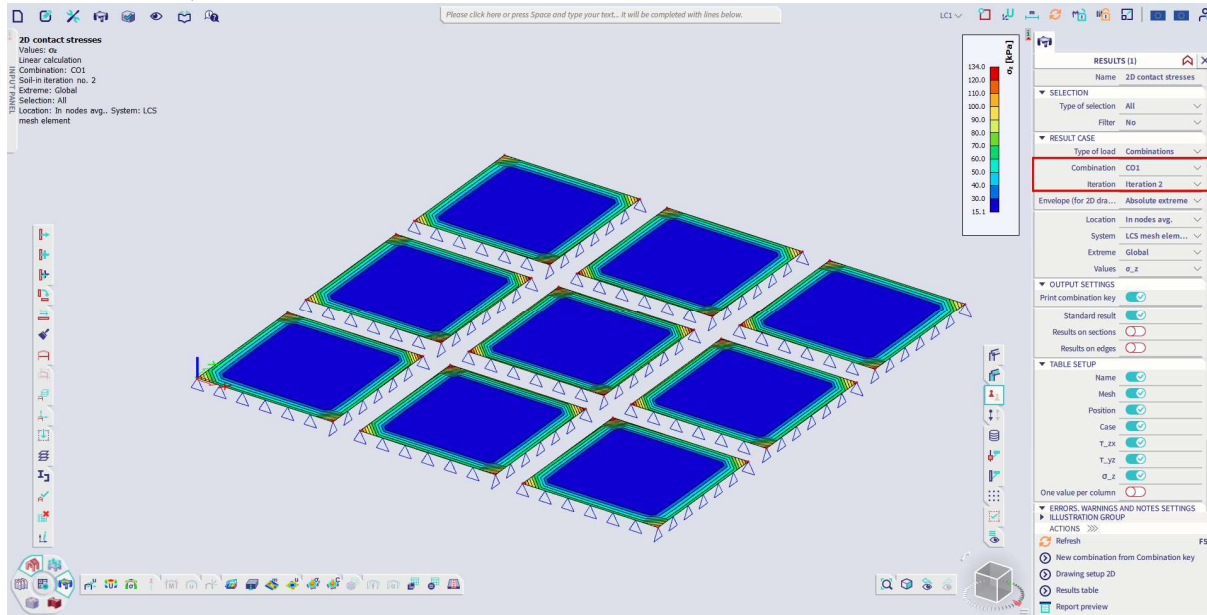
When the soilin does not finish its iteration process in a standard way, the calculation ends after the predefined number of cycles (the solver setup). You can display the contact stresses on the plate for each cycle separately so you are able to find the problem.

The calculated contact stresses for each iteration cycle can be found in the 2D contact stresses result.

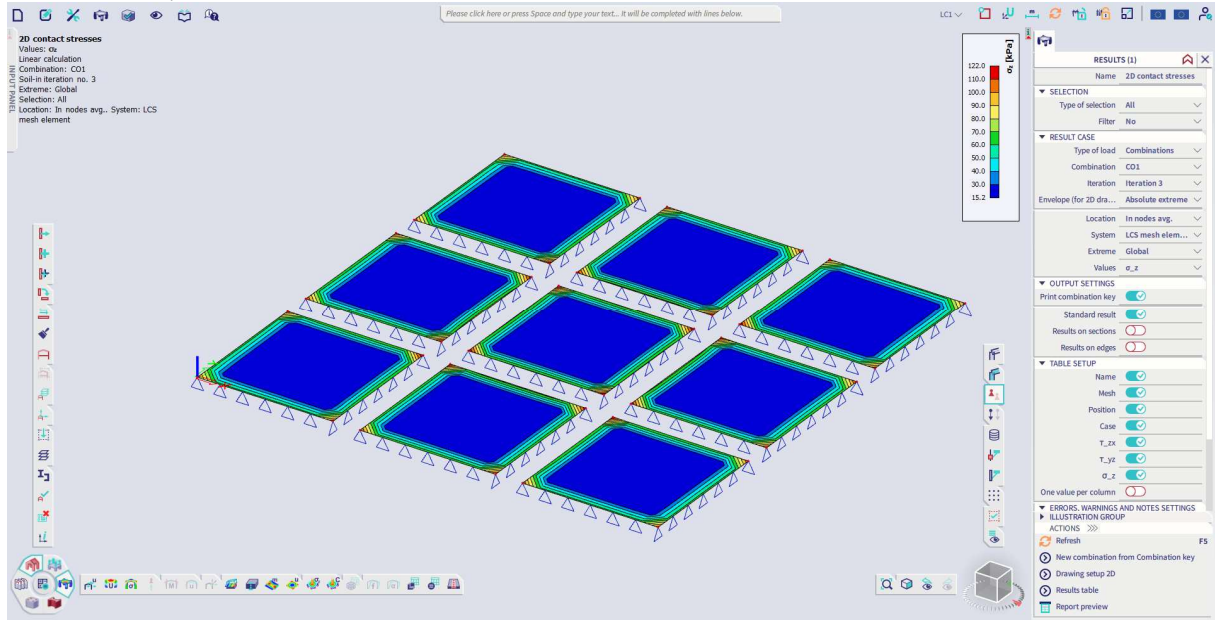
### First iteration cycle:



### Second iteration cycle:



Third iteration cycle:

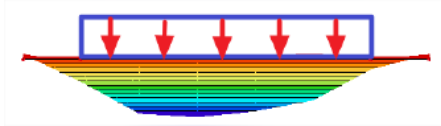


### 5.2.3. Additional plates

Soilin is a tool which calculates C parameters of the subsoil under the surface support. Using additional plates around the support provides more realistic results.

About C parameters:

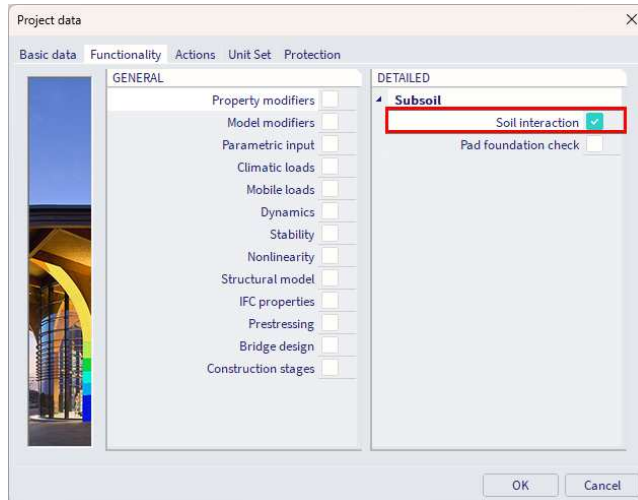
1. C parameters are parameters of interaction, so their value depends on the structure, load, stiffness and subsoil. Change in any of those parts causes different C parameters.
2. The whole plate is supported vertically by the soil stiffness – parameter  $C_1$  (Winkler) and also in the shear direction – parameter  $C_2$  (Pasternak).
3. The plate edges are more supported by the  $C_2$  parameters because it is affected by neglecting.
4. The area around the support is affected by the shear stiffness of the soil and the decrease basin is created.



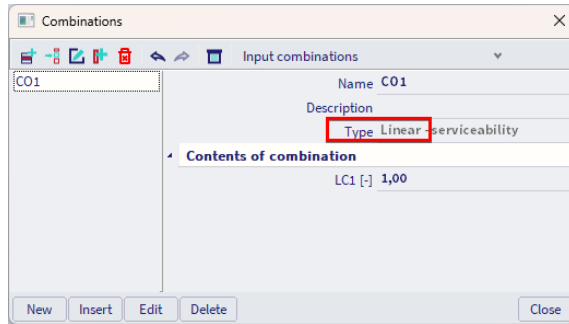
5. The decrease basin can be substituted by spring supports around the plate – this is done automatically in SCIA Engineer when user does not add plates around.
6. When user uses the plates around the support, the springs are not added and the C parameters are calculated for the whole area.

### Settings for soilin calculation

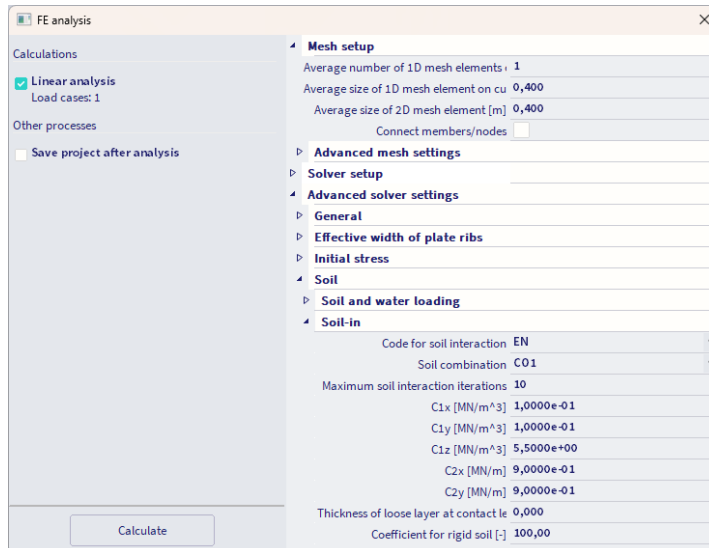
1. The functionality Soil iteration must be checked.



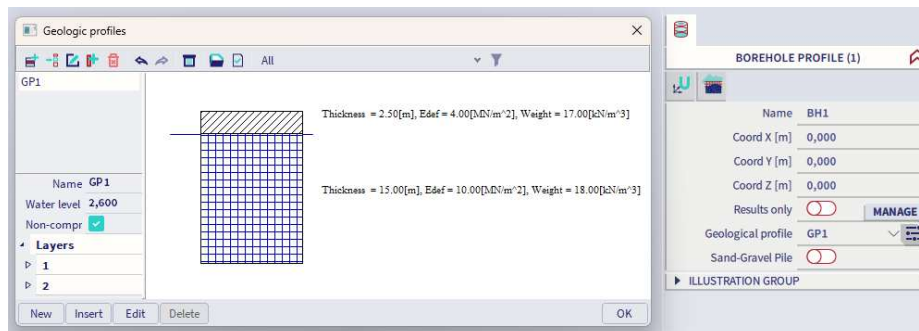
- One combination must be linear - this combination is used for soilin calculation.



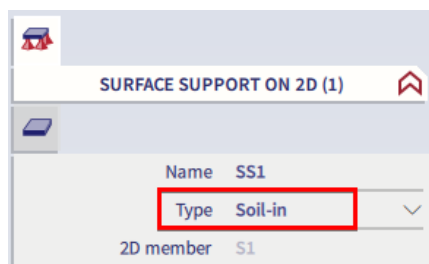
- This linear combination must be selected in Solver setup to run soilin with it.



- The project must contain a borehole with geologic profile.

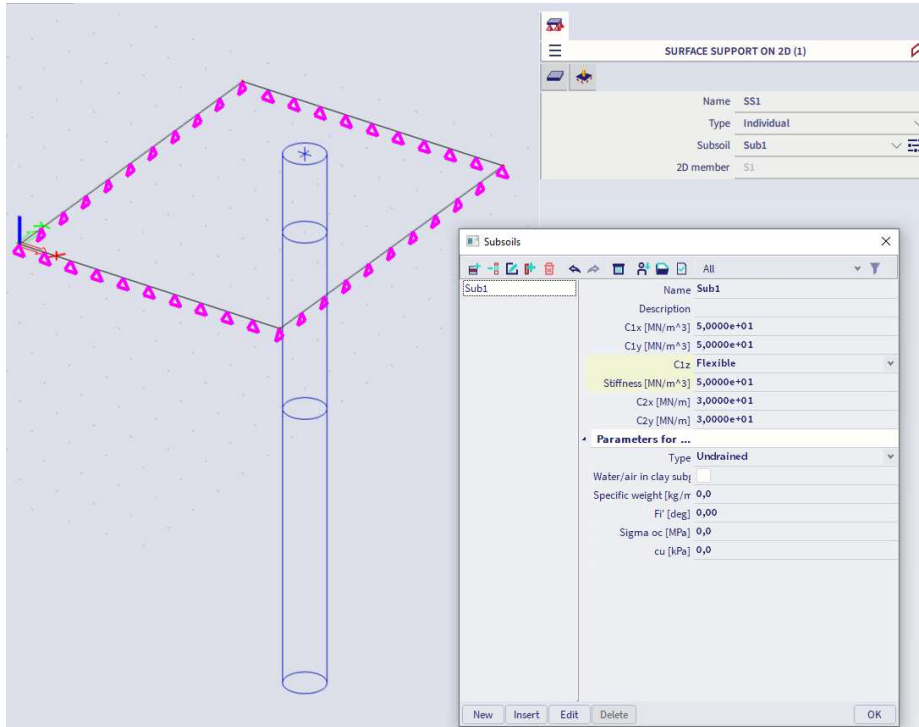


- The project must contain a surface support type soilin.

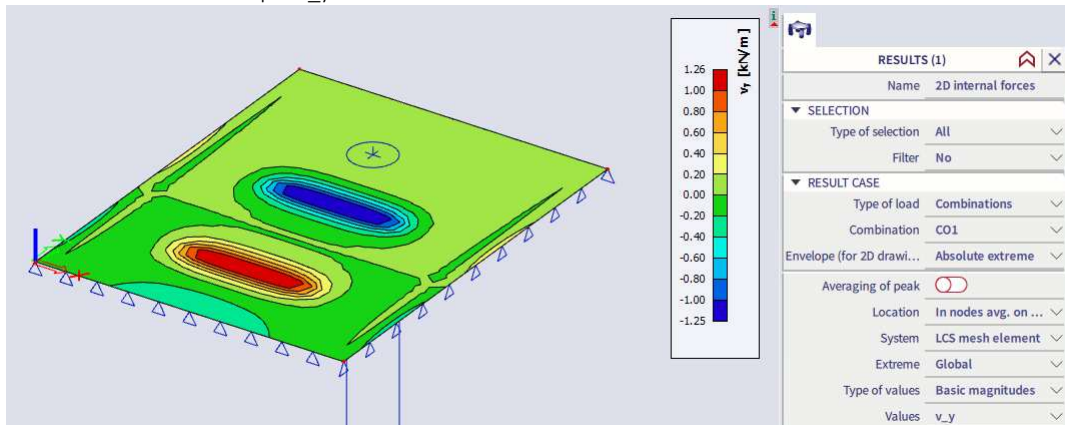


## How to calculate the plate without soilin

1. Open the project “soilin\_start.esa”.
2. There is one plate with the surface support type Individual. This type of the support has constant parameters C1 and C2.

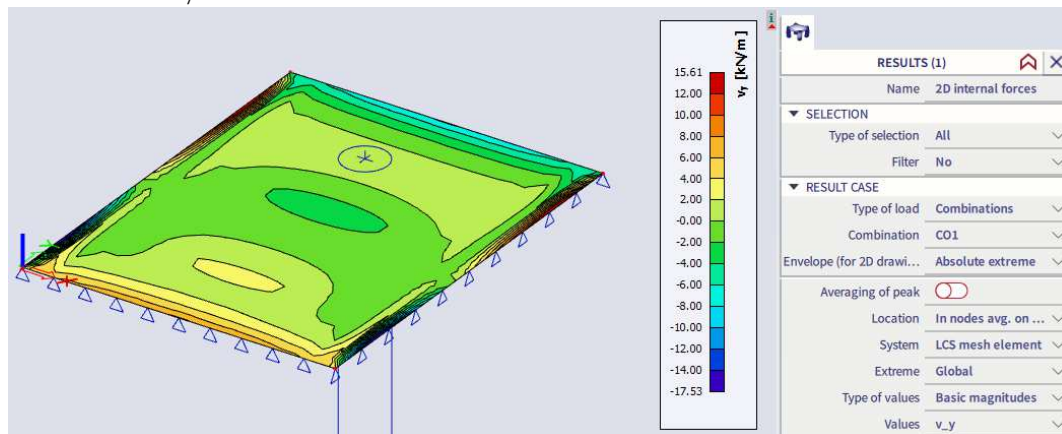


3. Run the linear calculation with the default settings.
4. Display the results for internal forces. There are no results for C parameters.
5. Internal forces - for example  $v_y$ :

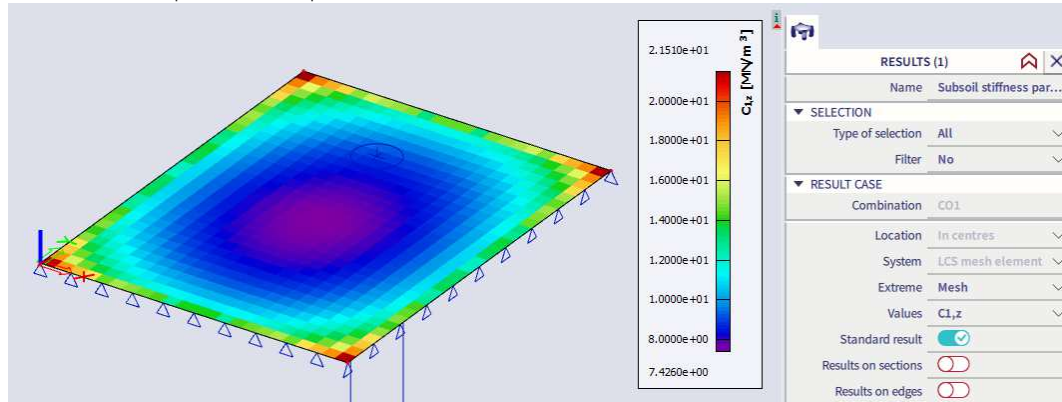


## How to calculate the plate with soilin

1. Change the support type to Soil-in.
2. Run the linear calculation again.
3. Go to the service Results. Display the results for internal forces and soilin for combination CO1.
4. Internal forces -  $v_y$ :



5. Subsoil stiffness parameters - parameter C1z:



6. Subsoil model results (see the Report preview with the table for the settlement):

### Subsoil model results

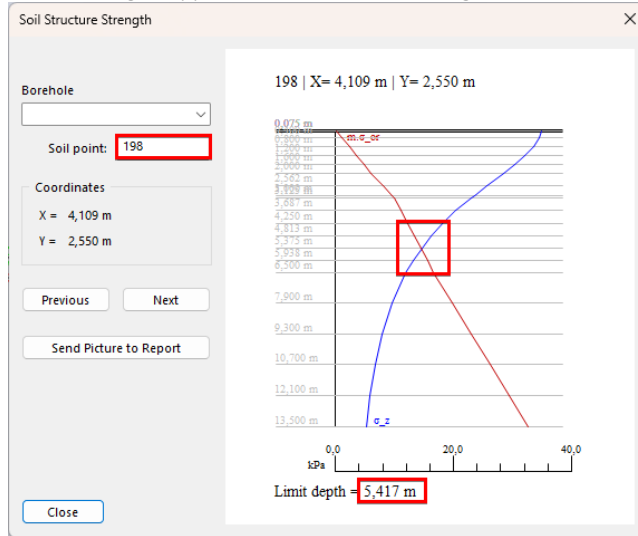
Combination: CO1

#### Subsoil model results

Name	X [m]	Y [m]	w [mm]	Limit depth [m]
1	0,152	0,150	0,8	2,515
2	0,457	0,150	1,1	2,759
3	0,761	0,150	1,2	2,954
4	1,065	0,150	1,4	3,169
5	1,370	0,150	1,5	3,363
6	1,674	0,150	1,5	3,526
7	1,978	0,150	1,6	3,661
8	2,283	0,150	1,7	3,770
9	2,587	0,150	1,7	3,851
10	2,891	0,150	1,7	3,907
11	3,196	0,150	1,7	3,939
12	3,500	0,150	1,7	3,952

7. Subsoil model results - use the action button "Soil Stress Diagram" and select one green vertex (e.g. SP198)

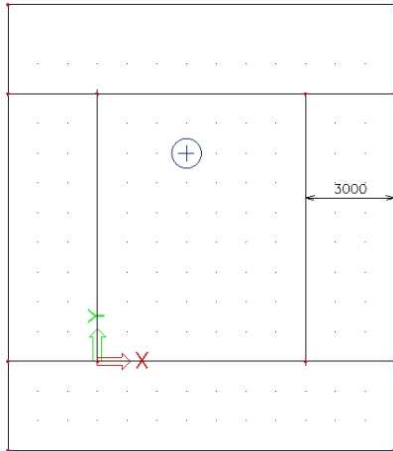
- A new dialogue appears - there is a stress diagram for the selected mesh element:



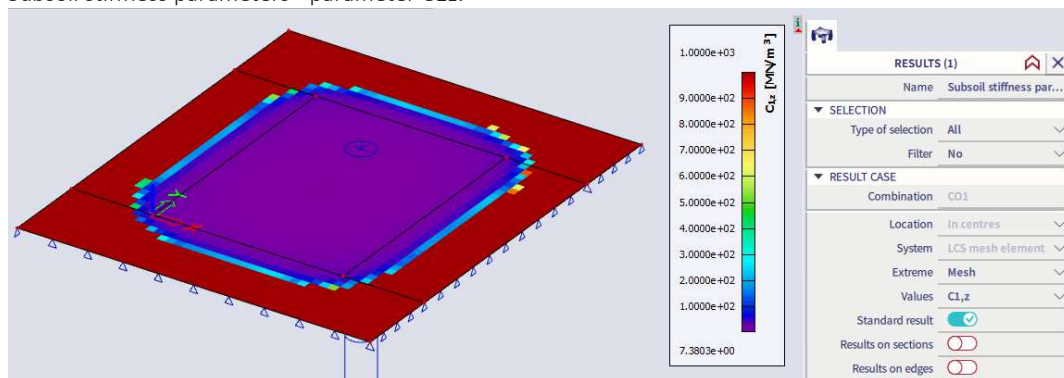
The edges of the plate are supported by springs automatically.

### How to create the additional plates

- Use the same project.
- Create a new plate.
- Set the thickness of the plate to 1mm.
- Create 4 plates around the surface support according to the picture. The width from the original plate is 3 m.



- Add the surface support type Soil-in on those plates.
- Run the linear calculation with the same settings again.
- Go to the service Results. Display the results for soilin.
- Subsoil stiffness parameters - parameter C1z:





9. Subsoil model results (see the Report preview with the table for settlement):

### Subsoil model results

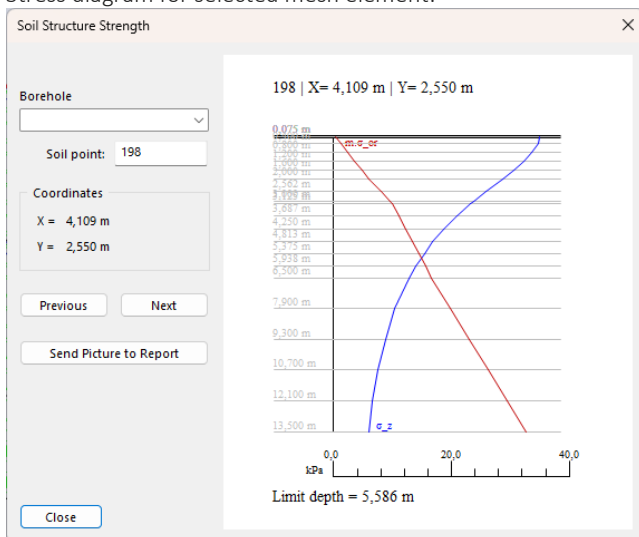
Combination: CO1

#### Subsoil model results

Name	X [m]	Y [m]	w [mm]	Limit depth [m]
1	0,152	0,150	0,6	2,569
2	0,457	0,150	0,8	2,815
3	0,761	0,150	1,0	3,032
4	1,065	0,150	1,2	3,291
5	1,370	0,150	1,4	3,502
6	1,674	0,150	1,5	3,672
7	1,978	0,150	1,6	3,814
8	2,283	0,150	1,7	3,926
9	2,587	0,150	1,7	4,011
10	2,891	0,150	1,8	4,069
11	3,196	0,150	1,8	4,105
12	3,500	0,150	1,8	4,117
13	3,804	0,150	1,8	4,105

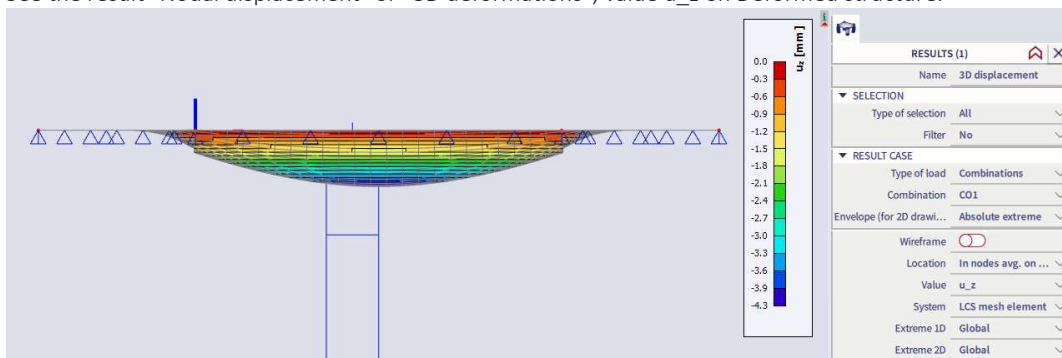
10. Subsoil model results - use the action button "Soil Stress Diagram" and select one green vertex (e.g. SP198).

11. Stress diagram for selected mesh element:



12. The interesting results are deformations.

13. See the result "Nodal displacement" or "3D deformations", value  $u_z$  on Deformed structure:

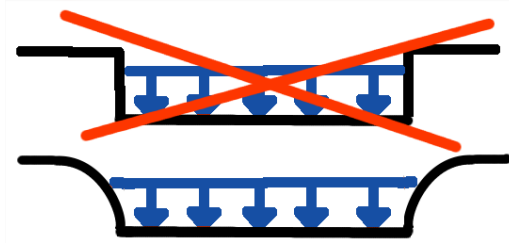


The deformed structure shows the decrease basin.

### 5.3. Advanced tips

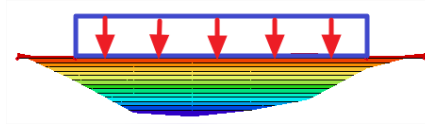
#### 5.3.1. The effect of the subsoil outside the structure

The nearest subsoil around the loaded structure is also affected by its settlement. The better realistic picture how it works in the reality is displayed below.

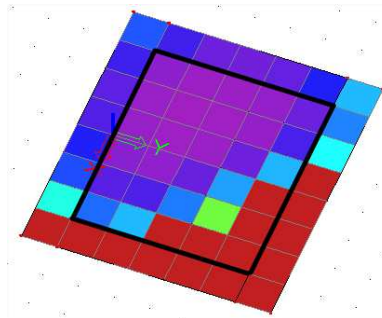


Calculation of the nearest surrounding of the structure is a specific use case. It is recommended to add one more plate to the structure for this purpose – additional subsoil element. The new plate should be inserted with the minimum thickness (e.g. 0,01 mm) and placed next to the foundation. In some cases of larger structures with more complex geometry, the required thickness of this plate might be 10 mm, or even 50 mm in order to achieve convergence of the solver.

The C parameters for this affected subsoil around the structure are calculated this way also. The deformed subsoil calculated by the SCIA Engineer:



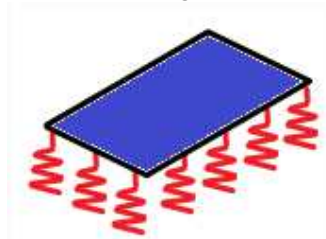
Calculated stiffness parameters:



The structure is marked by the black rectangle and around this is one more plate - surrounding plate – with thickness 0,001 mm.

#### 5.3.2. Automatic calculation of the edge supports

When you don't use any subsoil elements then the program will eliminate the neglect of the subsoil on edges by an automatic inserting of vertical supports on the foundation edges.



The calculation of those supports is based on already known C parameters. The program tries to support the plate in the same way as it should be supported by the subsoil itself. This leads to approximate model where the sum of reaction is contact stress with reactions in those nodes.

This solution can be sometimes undesirable – e.g. if there is a second foundation near by the calculated one or there is some other support under or near the foundation edge.

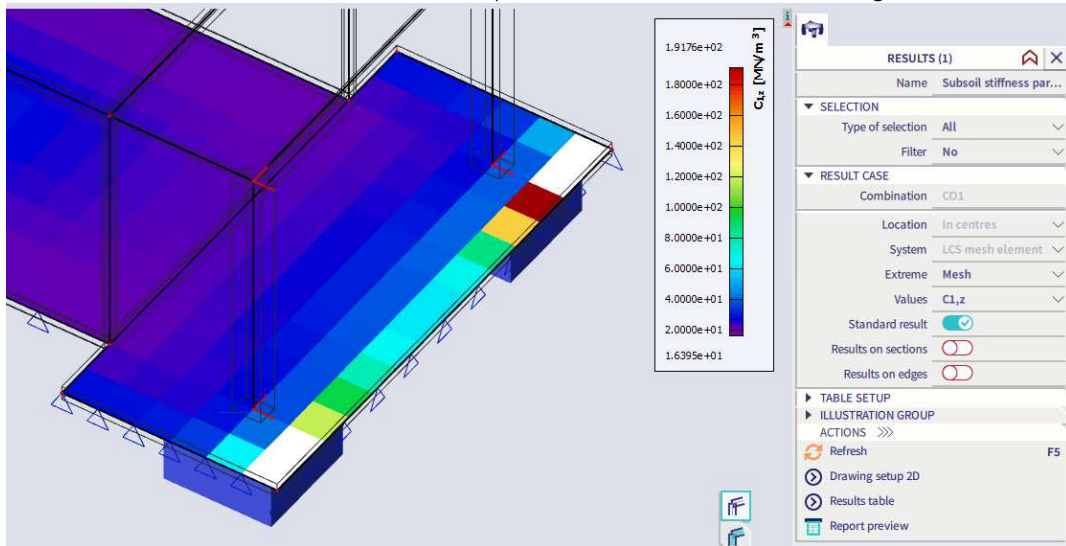
This automatic input can be avoided manually. User can insert a spring with a small stiffness on the plate edges and then the system won't use automatic input of vertical supports. This could be the additional subsoil elements.

### 5.3.3. Pad foundation and soilin

Pad foundation is not connected with the soilin calculation.

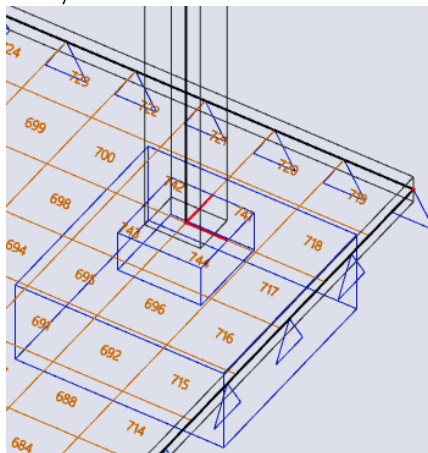
How to use soilin for the pad foundation check:

1. Create an additional structure to calculate the C parameters in the nearest surrounding:

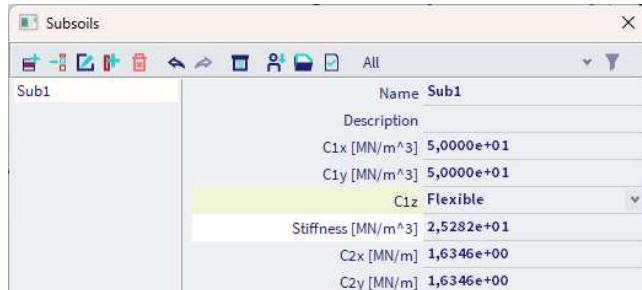
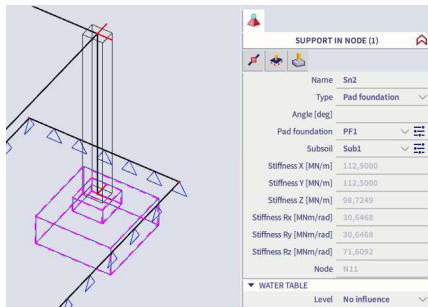


Calculated C parameters on the surrounding plate → C parameters for the pad foundation

2. Calculated C parameters can be used in the Subsoil library. Put the values from the table to the Subsoil library.



Mesh	C1,z [MN/m3]	C2,x [MN/m]	C2,y [MN/m]	C1,x [MN/m3]	C1,y [MN/m3]
Element: 739	2,6573e+01	1,4569e+00	1,4569e+00	1,0000e-01	1,0000e-01
Element: 740	3,9688e+01	1,3206e+00	1,3206e+00	1,0000e-01	1,0000e-01
Element: 741	3,7022e+01	1,3129e+00	1,3129e+00	1,0000e-01	1,0000e-01
Element: 742	2,6180e+01	1,4615e+00	1,4615e+00	1,0000e-01	1,0000e-01
Element: 743	2,5282e+01	1,6346e+00	1,6346e+00	1,0000e-01	1,0000e-01
Element: 744	3,6956e+01	1,4683e+00	1,4683e+00	1,0000e-01	1,0000e-01



3. Run the linear calculation again.
4. Check the pad foundation in a standard way.

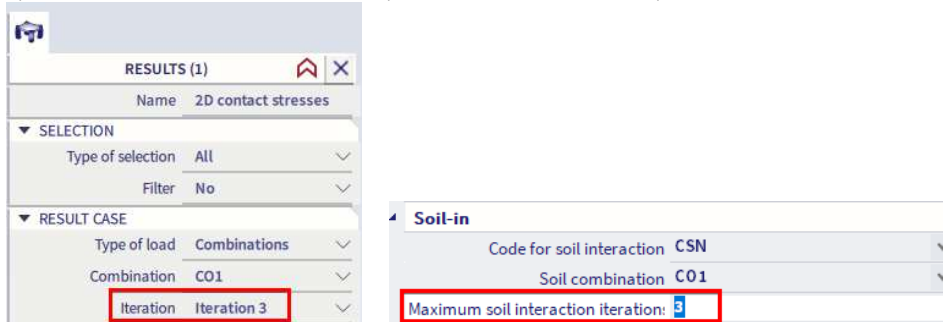
### 5.3.4. What if the model is correct but the iteration is not finished

Sometimes the model is correct but some circumstances may cause unfinished iterative process. The results in cycles don't lead to one set of C parameters but on the contrary, the results are more and more different.

This can be caused by some tensions in the foundation plate, specific foundation members and similar problems.

How to solve those problems:

1. It is necessary to check the model. It must be correct – the mesh elements are not triangular, the element's Z axis is upward, the foundation plate must be under the soil surface and so on.
2. Check the iteration cycles in the result of 2D contact stresses, Type of loads – Combinations. First few iteration cycles will be probably quite OK and after some time the results become messy. Find one cycle (between those correct ones) where the results seem to be close to the reality – e.g. 3rd cycle. Use this value in the solver setup for number of iteration cycles.

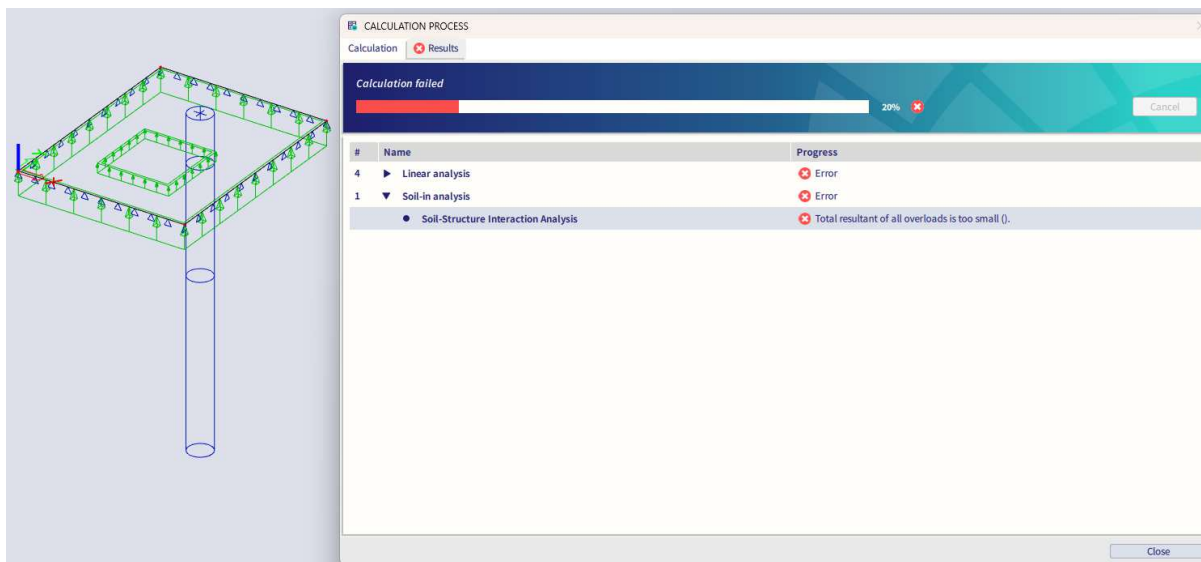


3. Start the linear calculation again, it will be finished after the 3<sup>rd</sup> iteration cycle with results most closest to the reality. The correct cycle is between 2<sup>nd</sup> and 5<sup>th</sup> cycle in most cases.

### 5.3.5. What if the load is wrongly inserted?

When the plate is not in compression, then soilin cannot be calculated properly.

There could be an error message about wrong total resultant: "Total resultant of all overloads is too small"

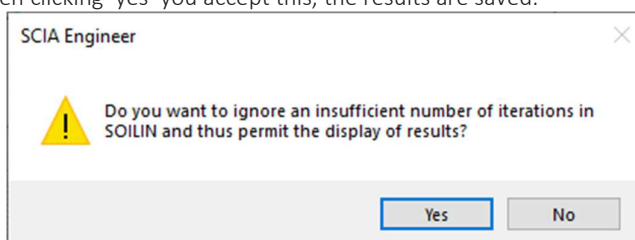


This may happen when loads are from the bottom to the top as shown in the example above, or when there is some change in local LCS of the plate.

### 5.3.6. What if the symmetrical structure gives non-symmetrical results?

This may happen when additional subsoil elements are not added around the structure.

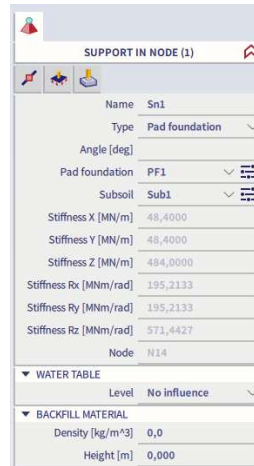
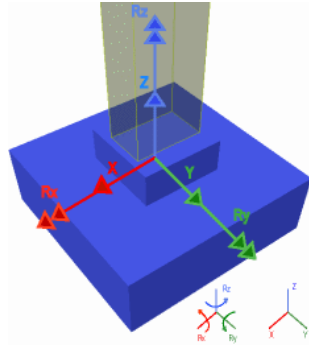
Also when the soilin didn't find the correct result and calculation is stopped too soon (for example when solver setup defines only few soilin cycles). When the amount of iterations set in the solver setup is insufficient, the following message will be shown: "do you want to ignore an insufficient number of iterations in SOILIN and thus permit the display of results?". When clicking 'yes' you accept this, the results are saved.



## Annex 1: Pad Foundation Stiffness

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

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



Stiffness	Formula
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	$B^3 \cdot \frac{A \cdot C1z + 2 \cdot \sqrt{C1z \cdot C2x}}{12} + \frac{A \cdot B^2 \cdot \sqrt{C1z \cdot C2x}}{2} + \frac{B^2 \cdot C2x}{2} + A \cdot B \cdot C2x$
Stiffness Ry	$A^3 \cdot \frac{B \cdot C1z + 2 \cdot \sqrt{C1z \cdot C2x}}{12} + \frac{B \cdot A^2 \cdot \sqrt{C1z \cdot C2x}}{2} + \frac{A^2 \cdot C2x}{2} + B \cdot A \cdot C2x$
Stiffness Rz	$C1y \cdot lx + C1x \cdot ly + \frac{h1 \cdot A^3 \cdot C1z}{6} + \frac{h1 \cdot B^3 \cdot C1z}{6} + \frac{2 \cdot \sqrt{C1z \cdot C2x} \cdot A^2 \cdot h1}{4}$ $+ \frac{2 \cdot \sqrt{C1z \cdot C2x} \cdot B^2 \cdot h1}{4} + \frac{C2x \cdot A^2}{2} + \frac{C2x \cdot B^2}{2}$

Parameters	
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
lx	$\frac{A \cdot B^3}{12}$
ly	$\frac{B \cdot A^3}{12}$

## Annex 2: Recommended geotechnical data

All geological layers of a subsoil are represented by their 3D geotechnical properties defined according National Standards. The exactness of these input data depends firstly on the geotechnical category of foundation problem, defined in EC7. Shortly: the 1<sup>st</sup> and 2<sup>nd</sup> category pertains to common buildings founded on common subsoil, previous as well as definitive design, without extraordinary complications. The 3<sup>rd</sup> category includes very important buildings in complicate foundation conditions whose geotechnical properties must be investigated in situ in any case separately with sufficient number of deep test pits or other secure methods. Nonlinear and time dependent behaviour must be taken into account which means an iterative Soilin procedure respecting the increase and decrease of overload.

Such an exacting analysis presents only a few percent of the common design practice. Therefore, a recommendation of certain mean European values for the first calculations using Soilin can be useful.

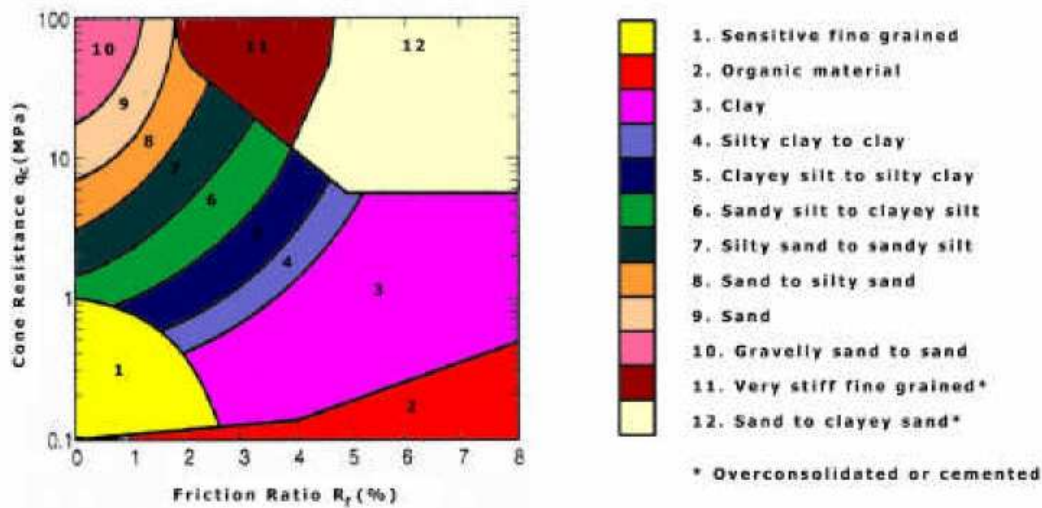
### Robertson

Where a building will be established, we need to know the soil profile. A deep knowledge of the ground under the base of the foundation is important as the layers below the base determine the bearing capacity. In order to gain an insight into the ground profile, many properties such as the thickness and composition must be known. We can derive these data from a geotechnical atlas or experiences, but we will mainly derive it from in situ soil research or laboratory tests.

In order to be able to identify a ground, the existence of a ground classification is necessary. For the interpretation of the CPT data, there exist several methods of identification. For example the method according to Robertson is a well known method for electric CPT's and it appears to give the most reliable results in Belgium.

In the following diagram, the cone resistance and friction ratio are used to determine a soil type, wherein the friction ratio is the ratio between the frictional resistance and the cone resistance.

$$R_f = \frac{f_s}{q_c}$$



An identification of the ground means that we now know the soil characteristics at any depth. In tables, you can read these characteristics (angle of friction, cohesion, E-modulus ...) by soil type. Finding of this E-modulus is necessary for the determination of the constant C. We attempt rather to distract the E-modulus from CPT results via soil identification since an additional ground investigation involves an additional cost.

In SCIA Engineer it is necessary to insert the parameter Edef. As said before, it is best to enter a value which is defined directly by a geologist from a real geologic profile. If this is not available, you must use standard values (each country has its own standards for classification of soils). For every soil, there is a range for value Edef (the smaller values are on the safe side).

**Table 1. Recommended values for Fine – Grained Soil**

No	Short Soil Name	Quantity	Consistency			
			soft	stiff	rigid	hard
F1	gravel clay	$E_0$ (MPa)	5-15	10-20	12-30	needs to be investigated separately
	$\gamma = 19 \text{ kNm}^{-3}$	$c_u$ (kPa)	40	70	70-80	
	$v = 0.35$	$\phi_u$ (deg)	0	0	10-15	
F2	gravel clay loam	$E_0$ (MPa)	4-8	7-15	10-25	
	$\gamma = 19.5 \text{ kNm}^{-3}$	$c_u$ (kPa)	30	60	60-70	
	$v = 0.35$	$\phi_u$ (deg)	0	0	10-15	
F3	sand clay	$E_0$ (MPa)	3-6	5-8	8-15	
	$\gamma = 18 \text{ kNm}^{-3}$	$c_u$ (kPa)	30	60	60-70	
	$v = 0.35$	$\phi_u$ (deg)	0	0	10-15	
F4	sand clay loam	$E_0$ (MPa)	2.5-4	4-6	5-12	
	$\gamma = 18.5 \text{ kNm}^{-3}$	$c_u$ (kPa)	30	50	70-80	
	$v = 0.35$	$\phi_u$ (deg)	0	0	5-14	
F5	clay	$E_0$ (MPa)	1.5-3	3-5	5-10	10-20
	$\gamma = 20 \text{ kNm}^{-3}$	$c_u$ (kPa)	30	60	70-80	80-200
	$v = 0.40$	$\phi_u$ (deg)	0	0	5-14	0-20
F6	clay loam	$E_0$ (MPa)	1-3	3-5	5-10	10-20
	$\gamma = 21 \text{ kNm}^{-3}$	$c_u$ (kPa)	25	50	80-90	80-170
	$v = 0.40$	$\phi_u$ (deg)	0	0	0-12	0-18
F7	plastic clay	$E_0$ (MPa)	1.5-3	3-6	6-12	10-20
	$\gamma = 21 \text{ kNm}^{-3}$	$c_u$ (kPa)	25	50	80-90	80-170
	$v = 0.40$	$\phi_u$ (deg)	0	0	0-12	0-18
F8	high plastic	$E_0$ (MPa)	1-2	2-4	4-8	8-15
	$\gamma = 19.5 \text{ kNm}^{-3}$	$c_u$ (kPa)	20	40	80-90	80-150
	$v = 0.35$	$\phi_u$ (deg)	0	0	0-10	0-16

$c_u, \phi_u$  =, undrained cohesion and internal friction angle for the 1st limit state (soil collapse)

$E_0 = E_{def}$  = average secante deformation modulus at common pressure level



**m** (soil structure strength factor):

F1 – F8 at  $E_0 = 1 - 4$ :  $m = 0.1$   
 F1 – F8 at  $E_0 = 4 - 30$ :d  $m = 0.2$ , except of:  
 F5 and F7 at  $E_0 = 1 - 10$ :  $m = 0.5$  (maximum)

$(\gamma - 10) \text{ kNm}^{-3}$  specific eigenweight below water level

**Table 1a.** Recommended values for Fine – Grained Soil

The first estimation (without any geotechnical investigation) of the result order may be done at the following mean values:

Fine-Grained Soil No.	$E_0$ [MPa]	$\nu$ [1]	$\gamma$ [ $\text{kNm}^{-3}$ ]	$m$ [1]
F1 – 4 soft/stiff	3 – 20	0.35	18 – 20	0.2
average	10	0.35	19	0.2
F1 – 4 rigid	5 – 30	0.35	18 - 20	0.2
average	15	0.35	19	0.2
F5 – 8 soft/stiff <sup>*)</sup>	1 – 6	0.4	20 – 21	0.1
average	3	0.4	20.5	0.1
F5 – 8 rigid	4 – 12	0.4	20 – 21	– 0.2
average	8	0.4	20.5	0.15
F5 – 8 hard	8 – 20	0.4	20 – 21	0.2
average	15	0.4	20.5	0.2

<sup>\*)</sup> Mould types ML, MI, MH, MV over the water level if the water never will rise and the soil remain dry:  $m = 0.5$ .

**Table 2** Recommended Values for Sands (S1 to S5) and Gravels (G1 to G5)

No.	Short Soil Name	$\gamma$ ( $\text{kNm}^{-3}$ )	$\nu$ (1)	$E_0$ (MPa)	$c_{er}$ (kPa)	$\varphi_{er}$ (deg)
S1	course sand	20.0	0.28	30-100	0	34-42
S2	sand	18.5	0.28	15-50	0	32-37
S3	fine sand	17.5	0.30	15-25	0	28-33
S4	clayer sand	18.0	0.30	5-15	0-10	28-30
S5	loam mouldign sand	18.5	0.35	4-12	4-12	26-28

G1	well granulated gravel	21.0	0.20	250-500	0	36-44
G2	poorly granulated gravel	20.0	0.20	100-250	0	33-41
G3	gravel with fine soil	19.0	0.25	80-100	0	30-38
G4	clayey gravel	19.0	0.30	60-80	0-8	30-35
G5	loam moulding gravel	19.5	0.30	40-60	2-10	28-32

$c_{ef}, \varphi_{ef} \dots$  effective (drained) cohesion and internal friction angle for the 1<sup>st</sup> st limit state (soil collapse)

**m** (soil structure strength factor):

S1, S2, G1, G2 .....  $m = 0.2$  to  $0.3$

S3 – 5, G3 – 5 .....  $m = 0.3$

**Table 2a** Mean values for the first estimation on a common subsoil

Subsoil	$E_0$ (MPa)	$\nu$ (1)	$\gamma$ (kNm <sup>-3</sup> )	<b>m</b> (1)
Sand	5 – 40	0.3	17.5 – 20.0	– 0.3
average	20	0.3	18.5	0.25
Gravel	50 - 200	0.2– 0.3	19.0 – 21.0	0.3
average	100	0.25	20.0	0.3

**Table 3** Recommended values for some rocks in subsoil

Rock	$E_0$ (MPa)	$\nu$ (1)	$\gamma$ (kNm <sup>-3</sup> )	<b>m</b> (1)
R1, 2, 4, 5 (II.)	20-25000	0.1-0.3	18-31	0.1
R3	15-10000	0.1-0.35	18.5-26	0.2
R4, 5 (IX.)	20-3000	0.2-0.3	18-31	0.3
R6	10-300	0.25-0.4	21-26	0.4

Remark: Withered rocks as subsoil layers are of small efficient  $E_0$  values up to 100 – 300 MPa. Sound rock is usually assumed as an undeformable deepest layer with  $E_0$  substantially larger than the other layers without influence on surface settlement. See also Tab. 4.

**Table 4.** Subsoils ordered by their soil structure strength factor  $m$ 

No.	EC7 sort	$E_0$ (MPa)	$\nu$ (I)	$\gamma$ (kNm <sup>-3</sup> )	$m$ (I)
I.	F1-F8	1-4	0.35-0.42	18-21	0.1
II.	R1, 2, 4, 5	20-25000	0.10-0.30	18-31	0.1
III.	F1-F8	4-30	0.35-0.42	18-21	0.2
IV.	S1, 2; G1, 2, R3	15-10000	0.10-0.35	18.5-26	0.2
V.	S1, 2	15-100	0.28	18.5-20	0.3
VI.	G1, 2	100-500	0.20	20-21	0.3
VII.	S3, 4, 5	4-25	0.30-0.35	17.5-18.5	0.3
VIII.	G3, 4, 5	40-100	0.25-0.30	19-19.5	0.3
IX.	R4, 5	20-3000	0.20-0.30	18-31	0.3
X.	R6	10-300	0.25-0.40	21-26	0.4
XI.	F5 (ML, MI) F7 (MH, MV)	1-10	0.40	20-21	0.5
I- XI.	Below the water level			$\gamma - 10$	

I. Fine – grained soils F1 – F8 easily compressible without previous compactness improvement, soft to stiff,  $E_0 = 1 - 4$  MPa. Subsoil till this time not overloaded, loose scattering, fillers.

II. Rocks R1 – R2. Unchanged sediments R4 from the 2nd and 3rd geological epoch, most of R5.

III. All fine – grained soils with exception of I., X., XI.

IV. Sand and gravel S1 – 2, G1 – 2 below the water level and rocks R3.

V. Sand S1 – 2 over the water level.

VI. Gravel G1 – 2 over the water level.

VII. Fine, clayer and loam moulding sands S3 – S5 with substantial clay content.

VIII. Clayey and loam moulding gravel with substantial fine soil content G3 – G5.

IX. Rocks R4 – R5 with exception of II.

X. Rocks R6 (eluvium).

XI. Dry clay mould F5 (ML, MI), F7 (MH, MV) permanently over the water level.