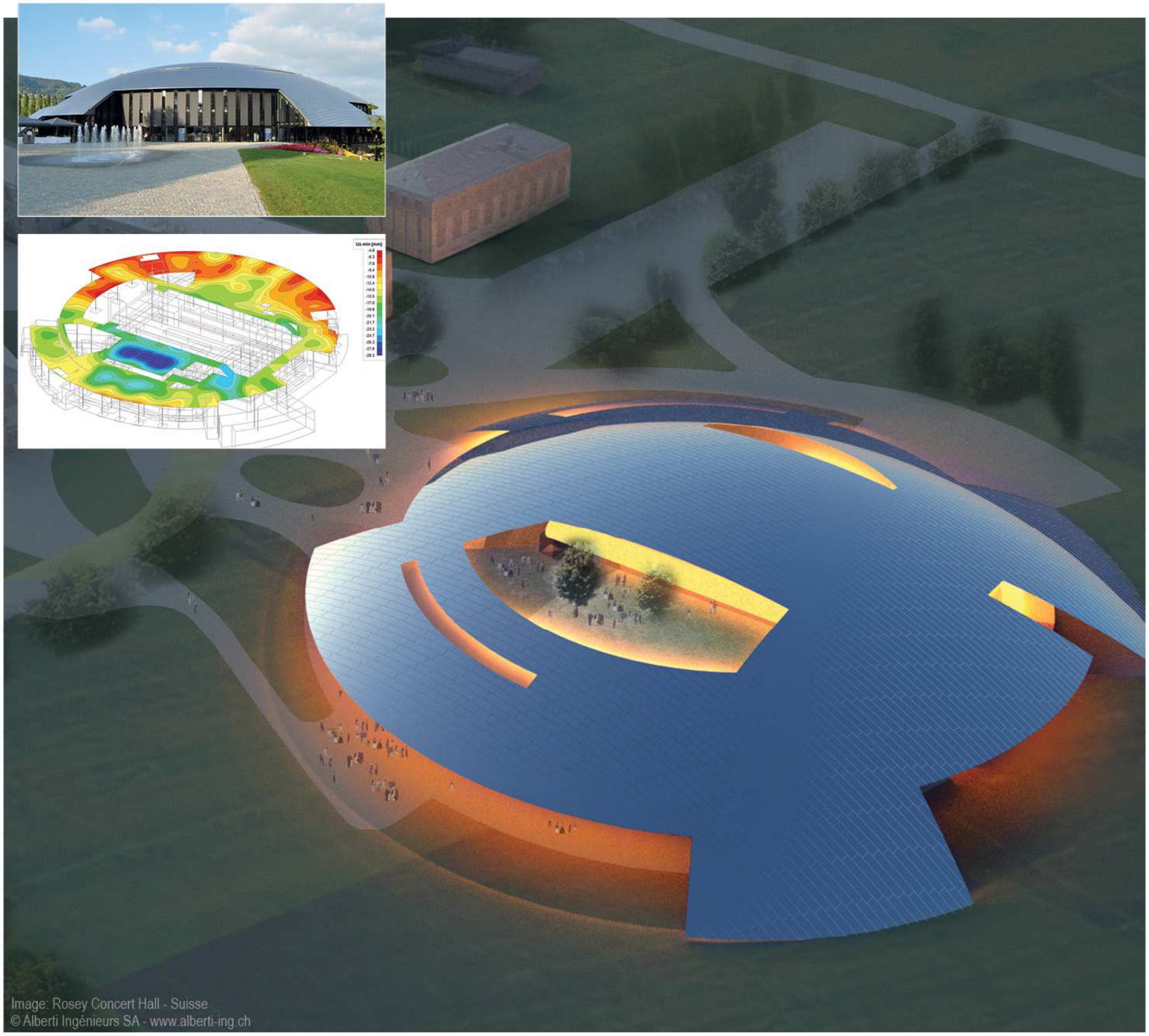
SCIA ENGINEER



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Topic Training

New Concrete

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Introduction

SCIA Engineer 15 brings a completely new solution for 1D concrete members. New technologies of the Open design, powered by our SCIA Design Forms platform, have allowed for a complete revision of the design and checking of reinforced concrete 1D members. This allows us the use of all well known features of this platform such as very nice and detailed layouts of calculation, using equations in output etc. Beside this, we offer more - rearrangement of the service tree, new concrete setup and member data and a couple of new checks. The described solution works for all kind of shapes of non-prestressed cross-section (e.g. with holes) subjected to all types of loading (e.g. biaxial shear combined with torsion). Generally this new module provides the following advantages:

- **high performance** - design and checks run very fast using a parallel process providing results in a very small calculation time
- **transparency** - detailed output enables to verify each intermediate steps of check using formulas with values and proper units; assisting in dealing with EN 1992-1-1
- **dynamic figures** - drawing of stress-strain state of cross-section, reinforcement pattern or interaction diagram
- **smart settings** - new revised global and member settings, including 'quick search' function
- **general solution**
- supporting interaction of all internal forces (N, M_y, M_z, V_y, V_z, T)
- supporting arbitrary cross-section shapes including openings & arbitrary reinforcement positions
- revised and updated generic functions for design & checking of reinforced concrete columns & beams
- **code compliance** - supporting compliance with EN 1992-1-1:2004/AC:2010-11, corrigendum including National Annexes (currently 18 NA´s)

The revised design and checks functions are developed within the *SCIA Design Forms* environment. This platform is linked as post-processor to SCIA Engineer. The new reporting style makes use of its advantages regarding the presentation of results. Next to text and tabular output, also formulas, code references, dynamic images and diagrams are included to increase the insight in the calculation!

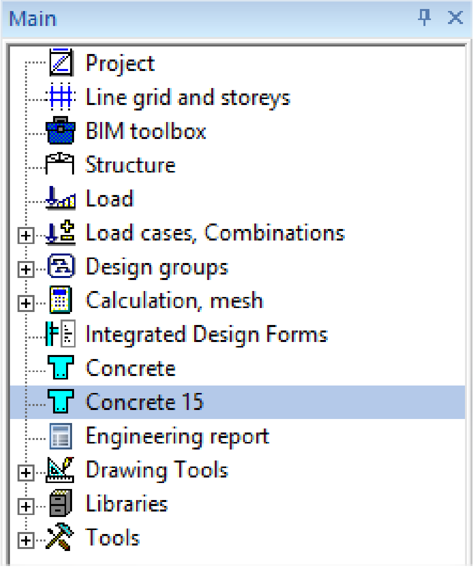
The *Concrete Toolbox* is the new 'calculation heart', used by SCIA Design Forms. It contains a set of code-independent functions for the design and checking of reinforced concrete members. It makes use of advanced generic algorithms, however in full compliance with e.g. the Eurocode assumptions. This means they are valid for arbitrary cross-section shapes and reinforcement positions. They also support the interaction of any mixture of internal forces (N, M_y, M_z, V_y, V_z, T).

There are also some limitations. New concrete checks do not support the following items:

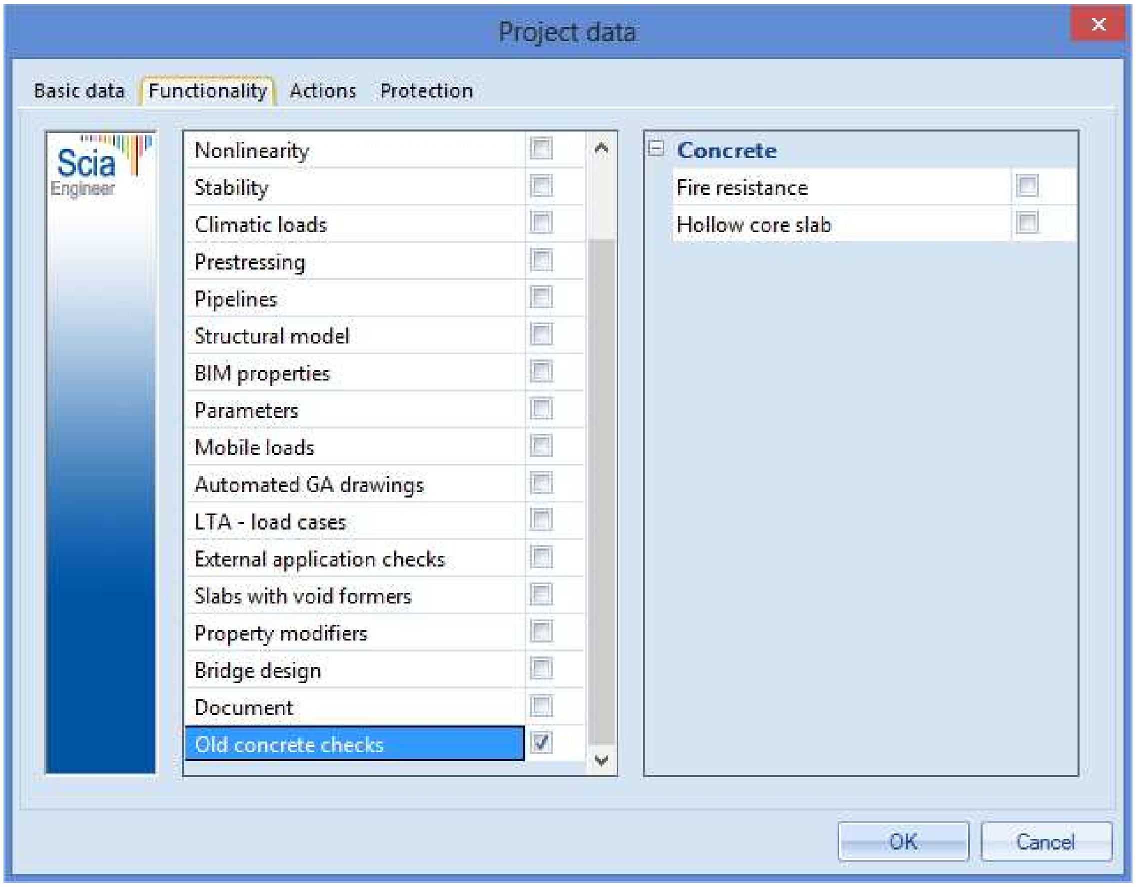
- numerical cross-section
- cross-section with more components
- phased cross-section
- member or cross-section with different material than concrete material – composite cross-section
- different reinforcement materials in one section

Concrete in SCIA Engineer 15

The new version of the Concrete module is placed in a completely different part of the main program tree. This module is situated in the new command '**Concrete 15'** in the tree.



Nevertheless, the existing old solution for concrete design and check is still available. The functionality of existing concrete checks is activated in Project data - Functionality - Old concrete checks.

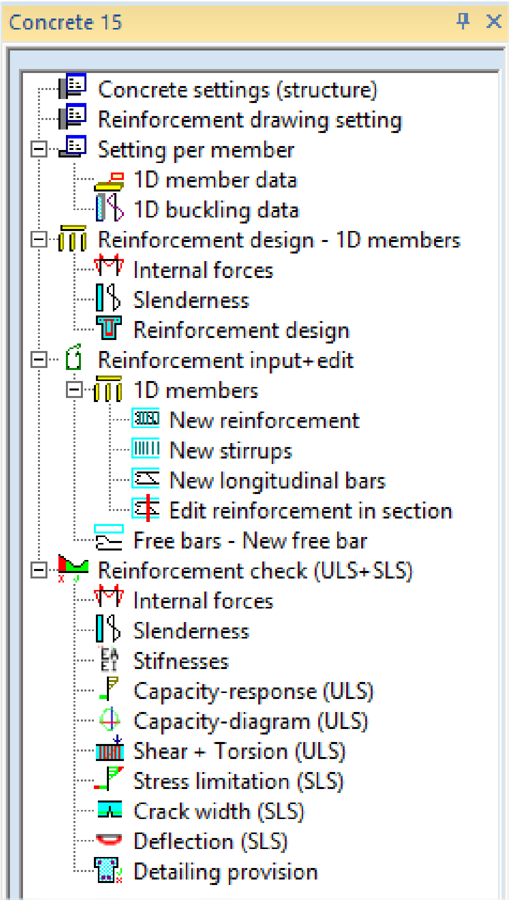


- ☐ Nonlinearity
- ☐ Stability
- ☐ Climatic loads
- ☐ Prestressing
- ☐ Pipelines
- ☐ Structural model
- ☐ BIM properties
- ☐ Parameters
- ☐ Mobile loads
- ☐ Automated GA drawings
- ☐ LTA - load cases
- ☐ External application checks
- ☐ Slabs with void formers
- ☐ Property modifiers
- ☐ Bridge design
- ☐ Document
- ☑ Old concrete checks

Concrete

- ☐ Fire resistance
- ☐ Hollow core slab

When we go into the concrete tree we can also see a completely different arrangement of the tree. The concrete tree is split into four parts:



Concrete 15

- Concrete settings (structure)
- Reinforcement drawing setting
- Setting per member
  - 1D member data
  - 1D buckling data
- Reinforcement design - 1D members
  - Internal forces
  - Slenderness
  - Reinforcement design
- Reinforcement input+edit
  - 1D members
    - New reinforcement
    - New stirrups
    - New longitudinal bars
    - Edit reinforcement in section
  - Free bars - New free bar
- Reinforcement check (ULS+SLS)
  - Internal forces
  - Slenderness
  - Stifnesses
  - Capacity-response (ULS)
  - Capacity-diagram (ULS)
  - Shear + Torsion (ULS)
  - Stress limitation (SLS)
  - Crack width (SLS)
  - Deflection (SLS)
  - Detailing provision

- **Settings - global and local settings**
  - Concrete settings (structure)
  - Reinforcement drawing settings
  - Settings per member
    - 1D member data
    - 1D buckling data
- **Reinforcement design - 1D members**
  - Internal forces
  - Slenderness
  - Reinforcement design - design of longitudinal and shear reinforcement
- **Input of real reinforcement**
- **Checks**
  - Internal forces
  - Slenderness
  - Stiffnesses
  - Capacity - response (ULS)
  - Capacity - diagram (ULS)
  - Shear + Torsion (ULS)
  - Stress limitation (SLS)
  - Crack width (SLS)
  - Deflection (SLS)
  - Detailing provisions

Each part will be explained more in detail in the following chapters.

Settings

Concrete settings (structure)

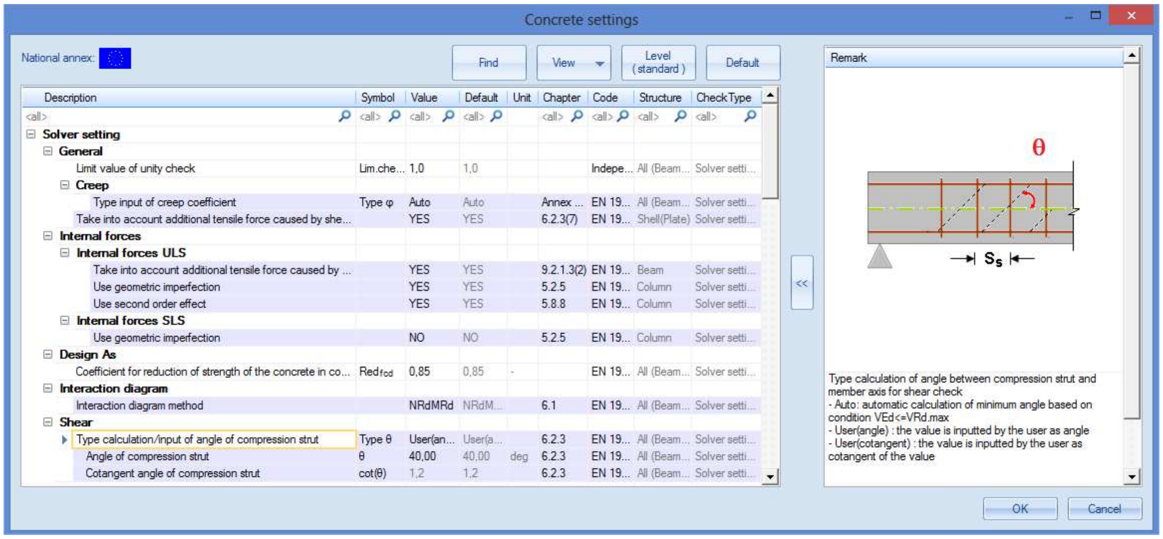
There is a brand new Concrete settings (structure) setup for concrete members, which contains all needed settings coming from the code or calculation routines. The global settings located in Concrete settings (structure) are by default valid for all members in the project, unless they are overwritten by Settings per member - 1D member data. A lot of input parameters and calculation settings are collected here, reflecting the complexity of the Eurocode.

In Annex 3, the available settings are described more in detail.

Concrete settings dialogue

This dialogue is split into two main parts. The left part contains the values themselves and the right side includes an explanatory figure with a description of the value. Additionally there are several buttons for searching, filtering, mode selection and default settings.

The Concrete settings dialogue is presented as a kind of table with 9 columns (description, symbol, value, default, unit, chapter, code, structure and check type). Each column has enabled the possibility for searching. The user can easily start typing in the first row of a column and see the intermediate output of the search.

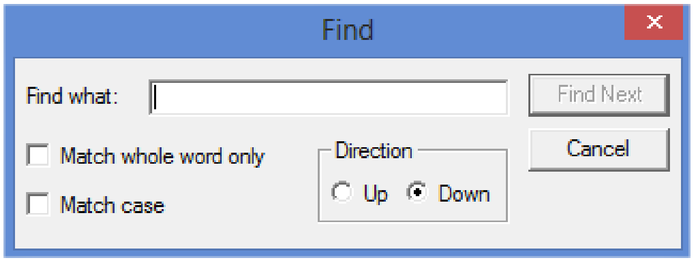


Description	Symbol	Value	Default	Unit	Chapter	Code	Structure	Check Type
<all>	<all>	<all>	<all>		<all>	<all>	<all>	<all>
Solver setting								
General								
Limit value of unity check	Lim.che...	1,0	1,0			Indepe...	All (Beam...	Solver setti...
Creep								
Type input of creep coefficient	Type φ	Auto	Auto		Annex ...	EN 19...	All (Beam...	Solver setti...
Take into account additional tensile force caused by she...		YES	YES		6.2.3(7)	EN 19...	Shell(Plate)	Solver setti...
Internal forces								
Internal forces ULS								
Take into account additional tensile force caused by ...		YES	YES		9.2.1.3(2)	EN 19...	Beam	Solver setti...
Use geometric imperfection		YES	YES		5.2.5	EN 19...	Column	Solver setti...
Use second order effect		YES	YES		5.8.8	EN 19...	Column	Solver setti...
Internal forces SLS								
Use geometric imperfection		NO	NO		5.2.5	EN 19...	Column	Solver setti...
Design As								
Coefficient for reduction of strength of the concrete in co...	Red_{fcd}	0,85	0,85	-		EN 19...	All (Beam...	Solver setti...
Interaction diagram								
Interaction diagram method		NRdMRd	NRdM...		6.1	EN 19...	All (Beam...	Solver setti...
Shear								
Type calculation/input of angle of compression strut	Type θ	User(an...	User(a...		6.2.3	EN 19...	All (Beam...	Solver setti...
Angle of compression strut	θ	40,00	40,00	deg	6.2.3	EN 19...	All (Beam...	Solver setti...
Cotangent angle of compression strut	cot(θ)	1,2	1,2		6.2.3	EN 19...	All (Beam...	Solver setti...

Type calculation of angle between compression strut and member axis for shear check
- Auto: automatic calculation of minimum angle based on condition VEd<=VRd.max
- User(angle) : the value is inputted by the user as angle
- User(cotangent) : the value is inputted by the user as cotangent of the value

Find

There is also a 'Find' function, where the user can insert a search term. It brings some kind of filtering of items in the setup. This function enables the search of the defined value anywhere in the Concrete setting dialogue.



Find what:

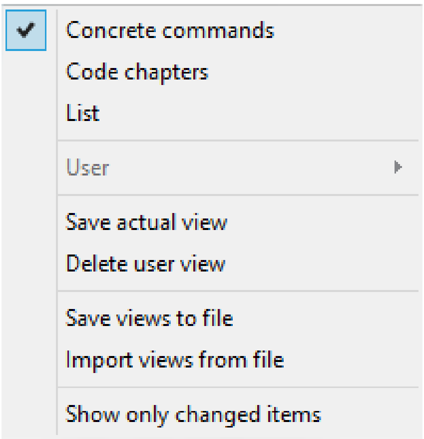
☐ Match whole word only

☐ Match case

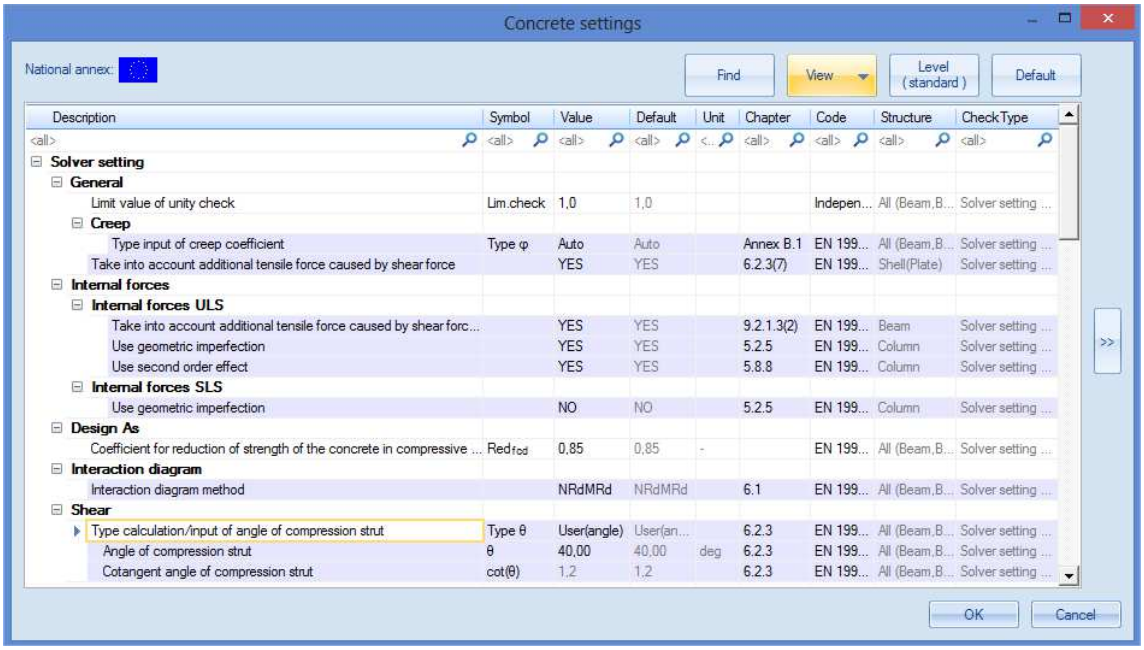
Direction: ○ Up ● Down

View

Furthermore, a very useful new option is the possibility of switching the type of view of items of the setup - concrete commands view, code chapter view or list view.

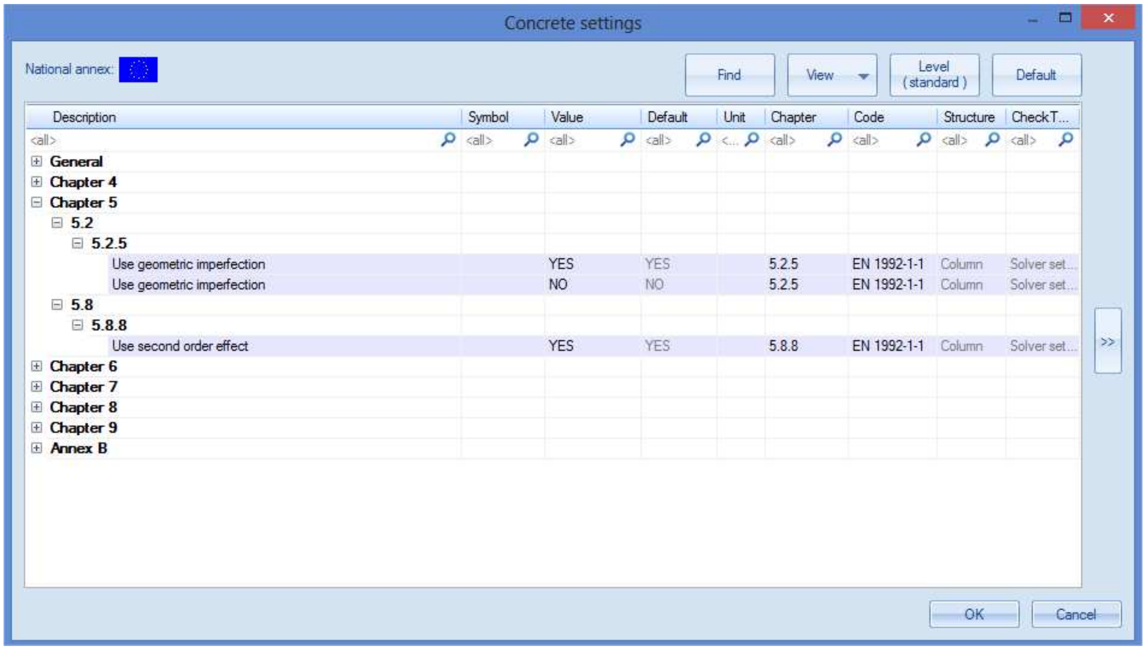


The first view is according to the commands (Concrete commands view) used for design and check.



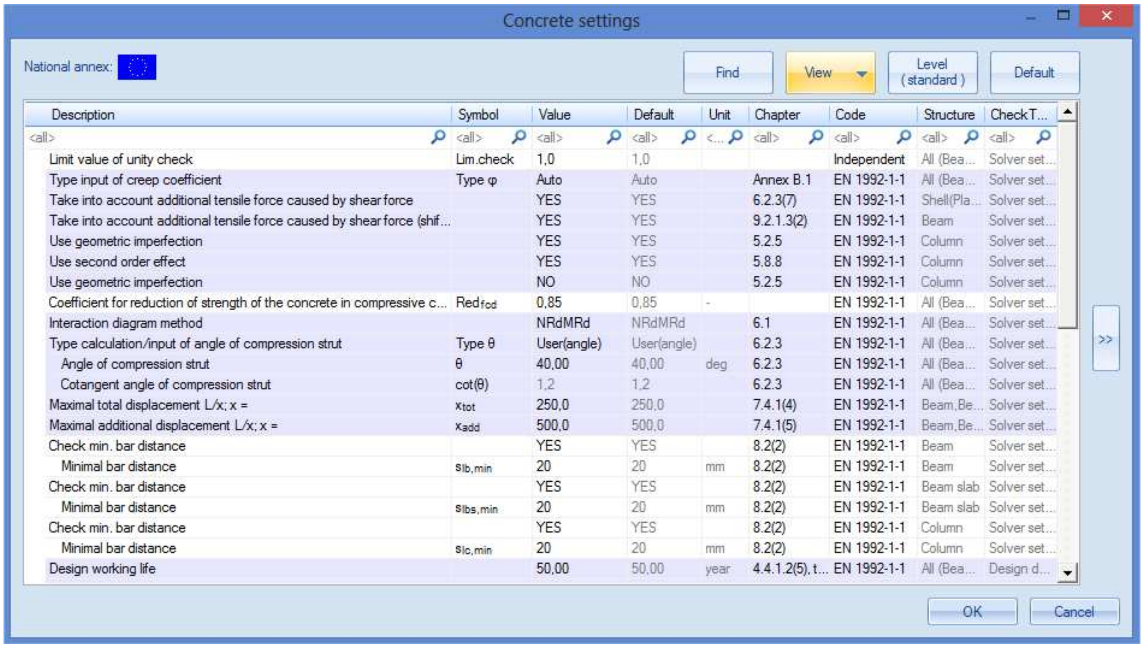
Description	Symbol	Value	Default	Unit	Chapter	Code	Structure	CheckType
<all>	<all>	<all>	<all>	<...	<all>	<all>	<all>	<all>
Solver setting								
General								
Limit value of unity check	Lim.check	1,0	1,0			Indepen...	All (Beam,B...	Solver setting ...
Creep								
Type input of creep coefficient	Type φ	Auto	Auto		Annex B.1	EN 199...	All (Beam,B...	Solver setting ...
Take into account additional tensile force caused by shear force		YES	YES		6.2.3(7)	EN 199...	Shell(Plate)	Solver setting ...
Internal forces								
Internal forces ULS								
Take into account additional tensile force caused by shear forc...		YES	YES		9.2.1.3(2)	EN 199...	Beam	Solver setting ...
Use geometric imperfection		YES	YES		5.2.5	EN 199...	Column	Solver setting ...
Use second order effect		YES	YES		5.8.8	EN 199...	Column	Solver setting ...
Internal forces SLS								
Use geometric imperfection		NO	NO		5.2.5	EN 199...	Column	Solver setting ...
Design As								
Coefficient for reduction of strength of the concrete in compressive ...	Red_{fcd}	0,85	0,85	-		EN 199...	All (Beam,B...	Solver setting ...
Interaction diagram								
Interaction diagram method		NRdMRd	NRdMRd		6.1	EN 199...	All (Beam,B...	Solver setting ...
Shear								
Type calculation/input of angle of compression strut	Type θ	User(angle)	User(an...		6.2.3	EN 199...	All (Beam,B...	Solver setting ...
Angle of compression strut	θ	40,00	40,00	deg	6.2.3	EN 199...	All (Beam,B...	Solver setting ...
Cotangent angle of compression strut	cot(θ)	1,2	1,2		6.2.3	EN 199...	All (Beam,B...	Solver setting ...

Another view is based on numbering of form design code as mentioned on the following figure.



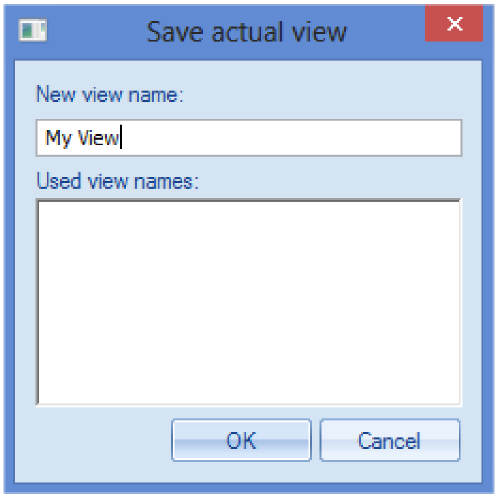
Description	Symbol	Value	Default	Unit	Chapter	Code	Structure	CheckT...
<all>	<all>	<all>	<all>	<...	<all>	<all>	<all>	<all>
⊞ **General**								
⊞ **Chapter 4**								
⊟ **Chapter 5**								
⊟ **5.2**								
⊟ **5.2.5**								
Use geometric imperfection		YES	YES		5.2.5	EN 1992-1-1	Column	Solver set...
Use geometric imperfection		NO	NO		5.2.5	EN 1992-1-1	Column	Solver set...
⊟ **5.8**								
⊟ **5.8.8**								
Use second order effect		YES	YES		5.8.8	EN 1992-1-1	Column	Solver set...
⊞ **Chapter 6**								
⊞ **Chapter 7**								
⊞ **Chapter 8**								
⊞ **Chapter 9**								
⊞ **Annex B**								

The last predefined view is the List view where all items are listed and could be alphabetically sorted.



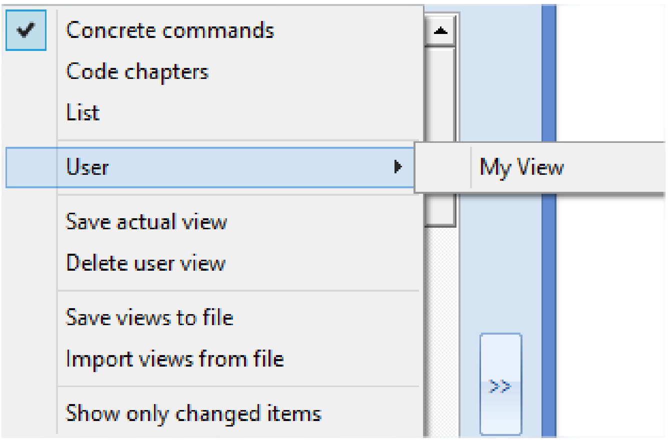
Description	Symbol	Value	Default	Unit	Chapter	Code	Structure	CheckT...
<all>	<all>	<all>	<all>	<...	<all>	<all>	<all>	<all>
Limit value of unity check	Lim.check	1,0	1,0			Independent	All (Bea...	Solver set...
Type input of creep coefficient	Type φ	Auto	Auto		Annex B.1	EN 1992-1-1	All (Bea...	Solver set...
Take into account additional tensile force caused by shear force		YES	YES		6.2.3(7)	EN 1992-1-1	Shell(Pla...	Solver set...
Take into account additional tensile force caused by shear force (shif...		YES	YES		9.2.1.3(2)	EN 1992-1-1	Beam	Solver set...
Use geometric imperfection		YES	YES		5.2.5	EN 1992-1-1	Column	Solver set...
Use second order effect		YES	YES		5.8.8	EN 1992-1-1	Column	Solver set...
Use geometric imperfection		NO	NO		5.2.5	EN 1992-1-1	Column	Solver set...
Coefficient for reduction of strength of the concrete in compressive c...	Red_{fcd}	0,85	0,85	-		EN 1992-1-1	All (Bea...	Solver set...
Interaction diagram method		NRdMRd	NRdMRd		6.1	EN 1992-1-1	All (Bea...	Solver set...
Type calculation/input of angle of compression strut	Type θ	User(angle)	User(angle)		6.2.3	EN 1992-1-1	All (Bea...	Solver set...
Angle of compression strut	θ	40,00	40,00	deg	6.2.3	EN 1992-1-1	All (Bea...	Solver set...
Cotangent angle of compression strut	cot(θ)	1,2	1,2		6.2.3	EN 1992-1-1	All (Bea...	Solver set...
Maximal total displacement L/x; x =	x_{tot}	250,0	250,0		7.4.1(4)	EN 1992-1-1	Beam,Be...	Solver set...
Maximal additional displacement L/x; x =	x_{add}	500,0	500,0		7.4.1(5)	EN 1992-1-1	Beam,Be...	Solver set...
Check min. bar distance		YES	YES		8.2(2)	EN 1992-1-1	Beam	Solver set...
Minimal bar distance	$s_{lb,min}$	20	20	mm	8.2(2)	EN 1992-1-1	Beam	Solver set...
Check min. bar distance		YES	YES		8.2(2)	EN 1992-1-1	Beam slab	Solver set...
Minimal bar distance	$s_{lbs,min}$	20	20	mm	8.2(2)	EN 1992-1-1	Beam slab	Solver set...
Check min. bar distance		YES	YES		8.2(2)	EN 1992-1-1	Column	Solver set...
Minimal bar distance	$s_{lc,min}$	20	20	mm	8.2(2)	EN 1992-1-1	Column	Solver set...
Design working life		50,00	50,00	year	4.4.1.2(5), t...	EN 1992-1-1	All (Bea...	Design d...

Additionally, the user has also the possibility to create his own view based on filtered items and use them for some quick changes afterwards. The user defined view can be created using **Save actual view** where the new view name can be written.



My View

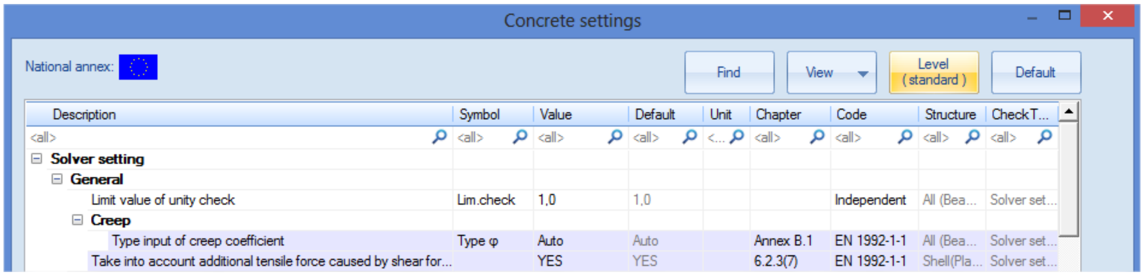
Afterwards, this view is possible to select in User item. It is possible to save or import this user view from the file using **Save views into file**, and **Import views from file**.



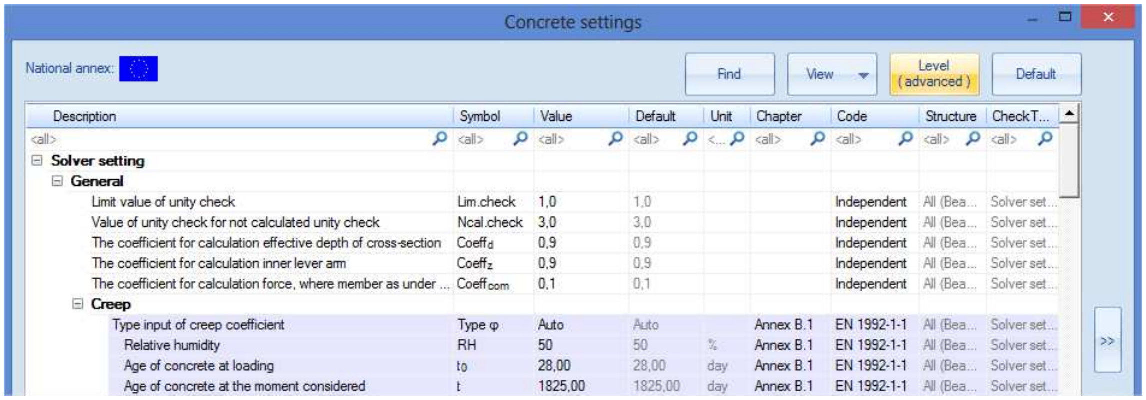
Finally, there is a possibility to see only changed items using **Show only changed items** in the settings, and not the defaults.

Filters

The user can choose between a **Standard** or **Advanced** level, which filters the amount of data.



Description	Symbol	Value	Default	Unit	Chapter	Code	Structure	CheckT...
<all>	<all>	<all>	<all>	<...	<all>	<all>	<all>	<all>
⊟ **Solver setting**								
⊟ **General**								
Limit value of unity check	Lim.check	1,0	1,0			Independent	All (Bea...	Solver set...
⊟ **Creep**								
Type input of creep coefficient	Type φ	Auto	Auto		Annex B.1	EN 1992-1-1	All (Bea...	Solver set...
Take into account additional tensile force caused by shear for...		YES	YES		6.2.3(7)	EN 1992-1-1	Shell(Pla...	Solver set...



Description	Symbol	Value	Default	Unit	Chapter	Code	Structure	CheckT...
<all>	<all>	<all>	<all>	<...	<all>	<all>	<all>	<all>
⊟ **Solver setting**								
⊟ **General**								
Limit value of unity check	Lim.check	1,0	1,0			Independent	All (Bea...	Solver set...
Value of unity check for not calculated unity check	Ncal.check	3,0	3,0			Independent	All (Bea...	Solver set...
The coefficient for calculation effective depth of cross-section	Coeff_d	0,9	0,9			Independent	All (Bea...	Solver set...
The coefficient for calculation inner lever arm	Coeff_z	0,9	0,9			Independent	All (Bea...	Solver set...
The coefficient for calculation force, where member as under ...	Coeff_{com}	0,1	0,1			Independent	All (Bea...	Solver set...
⊟ **Creep**								
Type input of creep coefficient	Type φ	Auto	Auto		Annex B.1	EN 1992-1-1	All (Bea...	Solver set...
Relative humidity	RH	50	50	%	Annex B.1	EN 1992-1-1	All (Bea...	Solver set...
Age of concrete at loading	t_0	28,00	28,00	day	Annex B.1	EN 1992-1-1	All (Bea...	Solver set...
Age of concrete at the moment considered	t	1825,00	1825,00	day	Annex B.1	EN 1992-1-1	All (Bea...	Solver set...

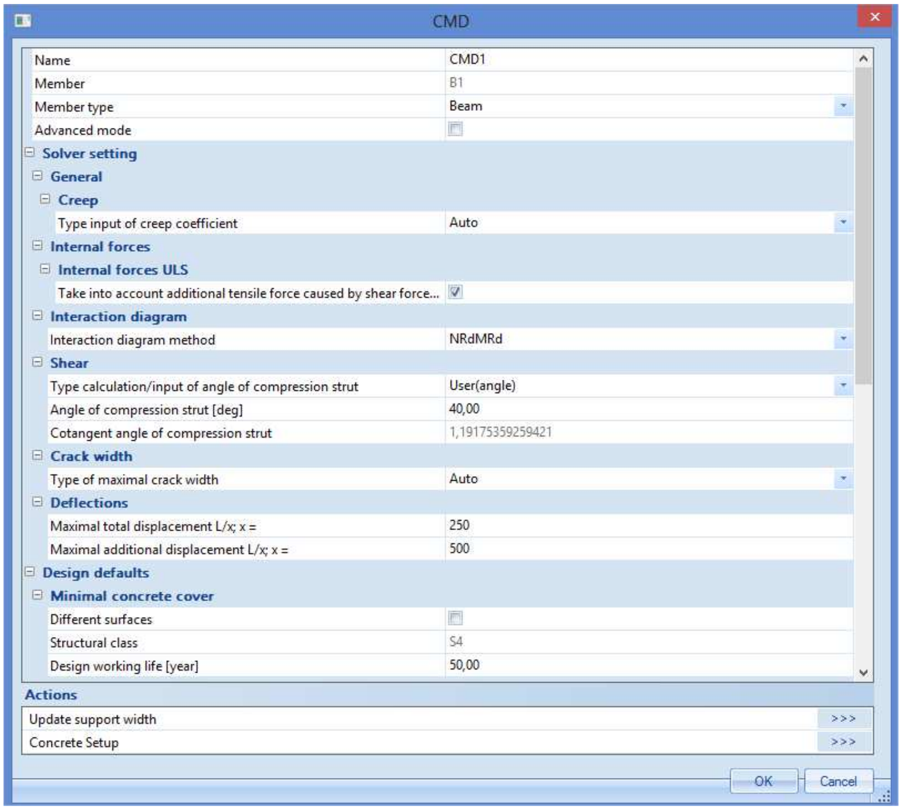
Default

Finally, when the user wants go back to the predefined values it is possible to press the button **Default** and all settings are restored.

Setting per member

1D member data

These settings overwrite the global settings for a specific member. Member data can easily be copy-pasted to similar members. There is a differentiation based on type of member (beam, column, beam slab). As in the case of the concrete settings, member data has also been restyled. Local settings contains about the same input parameters and calculation settings as the global settings in the setup. Moreover, the user can set his/her own value of limit deflection and limit width of crack, define more environmental classes than just one as in the previous version.



Name	CMD1
Member	B1
Member type	Beam
Advanced mode	☐
⊟ **Solver setting**	
⊟ **General**	
⊟ **Creep**	
Type input of creep coefficient	Auto
⊟ **Internal forces**	
⊟ **Internal forces ULS**	
Take into account additional tensile force caused by shear force...	☑
⊟ **Interaction diagram**	
Interaction diagram method	NRdMRd
⊟ **Shear**	
Type calculation/input of angle of compression strut	User(angle)
Angle of compression strut [deg]	40,00
Cotangent angle of compression strut	1,19175359259421
⊟ **Crack width**	
Type of maximal crack width	Auto
⊟ **Deflections**	
Maximal total displacement L/x; x =	250
Maximal additional displacement L/x; x =	500
⊟ **Design defaults**	
⊟ **Minimal concrete cover**	
Different surfaces	☐
Structural class	S4
Design working life [year]	50,00

Actions

Update support width	>>>
Concrete Setup	>>>

Properties of 1D Member data

1D Member data are arranged similarly as Concrete settings (structure). Generally, there are the following items.

- Name – name of the member data
- Member - name of the associated member
- Member type - generally member data can be set for Beam, Columns and Beam Slab differently.
- Advanced mode - some items are visible only in advanced mode
- Solver settings
- Design defaults

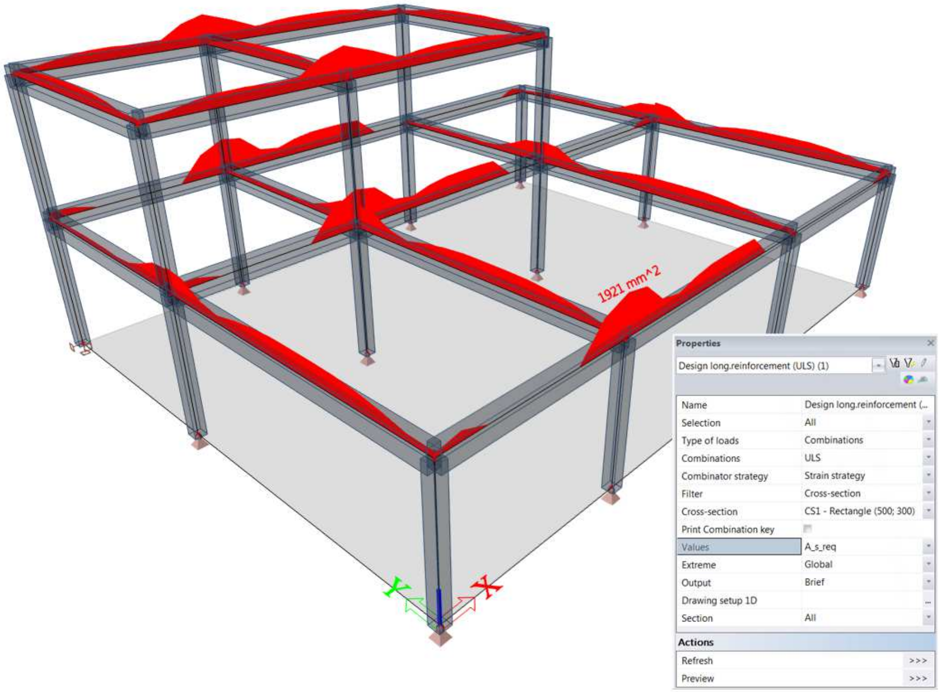
The available settings for the Solver settings and Design Defaults are described in Annex 1.

Reinforcement design

First you get an overview of the input data for the design:

- Internal forces, displaying the characteristic and design values.
    - For member type 'column', the design values of the bending moments include the 2nd order bending moments (if required) and the moments due to geometric imperfections.
    - For member type 'beam', the design values of the bending moments include the shifting of the moment line - to take the additional tensile force due to shear into account.
- Slenderness calculation (for member type 'column'), determining if 2nd order effects need be taken into account.

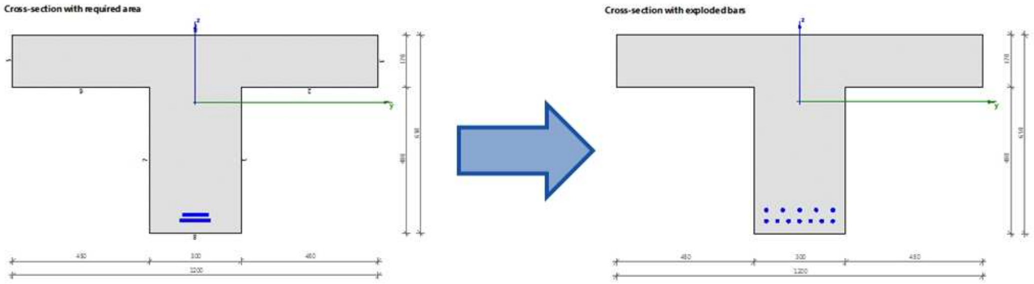
The design of longitudinal reinforcement to resist N, My and Mz is done according to the Ultimate Limit State requirements. Design method is selected based on type of member (beam x column) and according to the acting load. There is not any limit for type of cross-section (formerly for columns rectangle and column) nor for load type (formerly for beams - My OR Mz).



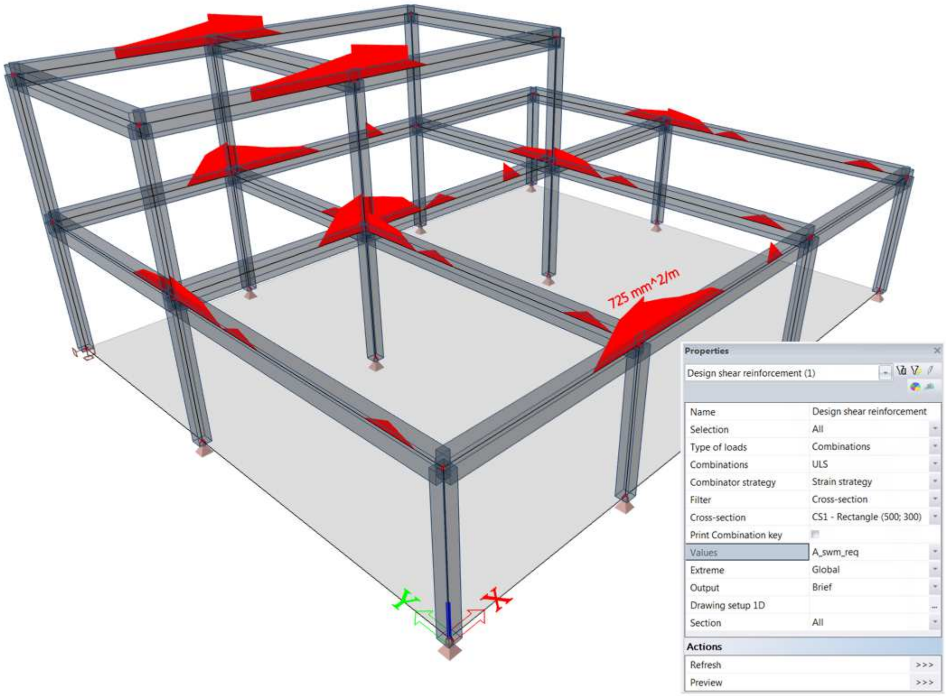
Design long.reinforcement (ULS) (1)

Name	Design long.reinforcement (...
Selection	All
Type of loads	Combinations
Combinations	ULS
Combinator strategy	Strain strategy
Filter	Cross-section
Cross-section	CS1 - Rectangle (500; 300)
Print Combination key	☐
Values	A_s_req
Extreme	Global
Output	Brief
Drawing setup 1D	
Section	All

In case the required area of reinforcement exceeds the available space on one layer, more layers (with adapted lever arm) are automatically generated. Designed reinforcement is automatically recalculated to real bars afterwards.



The design of shear reinforcement to resist Vy and Vz is done according to the ULS requirements. Formerly, there was possibility to design shear reinforcement just for Vy or Vz.



Design shear reinforcement (1)

Name	Design shear reinforcement
Selection	All
Type of loads	Combinations
Combinations	ULS
Combinator strategy	Strain strategy
Filter	Cross-section
Cross-section	CS1 - Rectangle (500; 300)
Print Combination key	☐
Values	A_swm_req
Extreme	Global
Output	Brief
Drawing setup 1D	
Section	All

Refresh >>>
Preview >>>

Internal forces

The internal forces, which are used for design and checks of concrete members, can be different as the internal forces calculated from FEM analysis. The differences may be caused by:

- for compression member (column)
  - taken into account eccentricities caused by imperfections
  - taken into account second order eccentricity
- for beams and beams as slab
  - taken into account additional tensile forces caused by shear and torsion (shifting of bending moments)

The following preconditions are used for the calculation:

- The shifting of bending moments is taken into account only for beams and beams as slab and in both directions
- The second order effect and geometrical imperfection are calculated only for column in compression
- Cross-section with one polygon and one material is taken into account for calculation second order effect and imperfection in version SEN 15
- The material of all reinforcement bars have to be same in SEN 15

Parameters which influence the calculation

Coefficient for calculation of effective depth of cross-section

Coefficient for calculation of effective depth of cross-section can be set and loaded from the concrete settings (Advanced level). The default value is 0.9. If the value cannot be calculated from the plane of deformation, this value will be calculated by a simplified formula:

$$d = Coeff_d \cdot h$$

Coefficient for calculation of lever arm

Coefficient for calculation of inner lever arm can be set and loaded from the concrete settings (Advanced level). The default value is 0.9. If the value cannot be calculated from the plane of deformation, this value will be calculated by a simplified formula:

$$z = Coeff_z \cdot d$$

Angle between concrete compression strut and beam axis

Angle between concrete compression strut and beam axis perpendicular to the shear force can be calculated automatically or inputted by the user in SEN depending on parameter Type calculation/input angle of compression strut. This parameter can be changed in Concrete setting (if 1D concrete member data is not defined) or in 1D concrete member data. There are the following options:

- Auto - angle of compression strut is calculated automatically as minimal value between qmin and qmax to condition according to equation 6.29 in EN 1992-1-1

$$\frac{T_{Ed}}{T_{Rd,max}} + \frac{V_{Ed}}{V_{Rd,max}} \leq 1$$

- User(angle) - angle of compression strut be input directly by the user as an angle. If the inputted value is outside of the interval qmin and qmax , the minimal or maximum value is taken into account for calculation
- User(cotangent) - angle of compression strut be input directly by the user as cotangent of the angle. If the inputted value is outside of the interval qmin and qmax , the minimal or maximum value is taken into account for calculation.

Minimal and maximal angle of compression strut is a parameter of national annex and can be edited in the Manager of national annex.

Angle of shear reinforcement

There are differences in using the angle of shear reinforcement in calculation between design of reinforcement and check.

- Design - angle of shear force for member = Beam, can be set directly in Concrete setting (if 1D concrete member data is not defined) or in 1D concrete member data. For member = Column, the angle of shear reinforcement is always 90 degrees and cannot be changed.
- Check - angle of stirrups is loaded from inputted shear reinforcement. It is only possible to input shear reinforcement with an angle of 90 degrees in SEN 15.

Type of member can be defined in properties of member via parameter Type or directly in 1D concrete member data

Use equivalent first order value

This setting allows to the user to set, if equivalent bending moment according to 5.8.8.2(2) in EN 1992-1-1 will be taken into account for the calculation of first order eccentricity. This setting can be done in Concrete setting for Advanced mode. The code EN 1992-1-1 recommends the use of equivalent first order moments, therefore this value is set to Yes by default.

Coefficient for calculation of force at which member is in compression

Coefficient for calculation of forces, when member is in compression, can be set and loaded from concrete settings (Advanced level). Default value is 0.1. This coefficient is used for determination, if member is in compression, which is necessary for calculation second order effect, imperfection and minimal eccentricity. Member is in compression, if condition below satisfies:

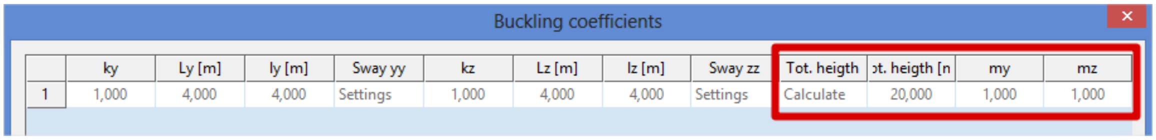
$$N_{Ed} > -Coeff_{com} \cdot f_{cd} \cdot A_c$$

Isolated member

Check box for determination if the member is an isolated member or not. Default setting is the automatic determination by the program and the member is isolated, if the member is not linked the others members. This setting can be changed in **1D concrete member data** for Member type = **Column** (Advanced mode). This setting is used for calculation length of the member for calculation of geometrical imperfection, clause 5.2(6) in EN 1992-1-1.

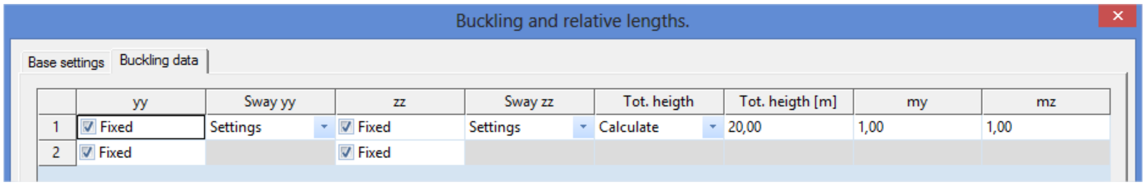
Buckling data

The detailed description of inputting buckling data and the way of calculating buckling data are described in Topic Training – Buckling lengths. There is described the general functionality, but for concrete members there are additional parameters for definition of buckling data.



	ky	Ly [m]	ly [m]	Sway yy	kz	Lz [m]	lz [m]	Sway zz	Tot. heigth	ot. heigth [n	my	mz
1	1,000	4,000	4,000	Settings	1,000	4,000	4,000	Settings	Calculate	20,000	1,000	1,000

These additional data are important for calculation of eccentricities caused by imperfection (see clause 5.2(5) in EN 1992-1-1) and they can be defined in tab-sheet **Buckling data** in dialogue **Buckling and relative lengths** (member properties > parameter Buckling and relative length > button Edit).



	yy	Sway yy	zz	Sway zz	Tot. heigth	Tot. heigth [m]	my	mz
1	☑ Fixed	Settings	☑ Fixed	Settings	Calculate	20,00	1,00	1,00
2	☑ Fixed		☑ Fixed					

There are following additional data:

- Combo box **Tot. height** – this combo allows to set type of calculation of total height of building or length of the isolated columns. There are two items in the combo box:
    - **Calculate** – the tot height. will be calculated automatically as sum of lengths of all the members in the buckling system
    - **User** – the value can be inputted directly by the user. The input value will be taken into account if **Calculate = User**
- edit box **Tot. height** – this edit box allows to input total height of building or length of the isolated columns directly by the user. The input value will be taken into account if item **User** is set in combo box **Tot. Height**

- edit box **my** - is the number of vertical members contributing to the total effect of the imperfection perpendicular to y axis of LCS. It means that the value is used for recalculation of bending moment around y axis. Only one value can be set for all columns in a buckling system
- edit box **mz** - is the number of vertical members contributing to the total effect of the imperfection perpendicular to z axis of LCS. It means that the value is used for recalculation of bending moment around z axis. Only one value can be set for all columns in a buckling system

The important parameter for calculation of buckling data is the type of structure (braced or unbraced). The global type of structure can be set in Concrete Setting (Design defaults > Default sway type). For example, the structures is braced perpendicular to y axis of GCS, if parameter Sway around y axis = NO (it means that the structure is not prone to sway perpendicular to y axis).

Use geometric imperfection

This setting allows the user to set, if geometrical imperfection will be taken into account of ULS or SLS. This setting can be done in Concrete settings (if 1D concrete member data is not defined) or directly in 1D concrete member data for Member type = Column.

The imperfection shall be taken into account in ultimate limit states and need not to be considered for serviceability limit states, see clause 5.2(2P) and 5.2(3) in EN 1992-1-1, therefore default setting in SEN is:

- ULS - use geometric imperfection = Yes , it means geometric imperfection will be taken into account
- SLS - use geometric imperfection = No , it means geometric imperfection will not be taken into account

Use minimum eccentricity

User can set if minimum first order eccentricity, calculated according to clause 6.1(4) in EN 1992-1, will be taken into account in the calculation of first order eccentricity including geometrical imperfection for ULS. This setting can be done in Concrete settings (if 1D concrete member data is not defined) or directly in 1D concrete member data for Member type = Column by using **Advanced mode/level.**

Use second order effect

This setting allows the user to set if second order effect will be taken into account. This setting can be done in Concrete settings (if 1D concrete member data is not defined) or directly in 1D concrete member data for Member type = Column.

If check box **Use second order effect** = Yes, then the second order effect will be taken into account, if conditions below are satisfied:

- the combination for ULS is used
- Member type = Column and it in case, that column is in compression
- calculated slenderness is greater than limit slenderness

Design defaults

Design defaults is a special group of properties where the user can define the basic parameters (diameter of longitudinal and shear reinforcement, type of value of concrete cover...) for design of longitudinal and shear reinforcement. This setting can be done in Concrete settings (if 1D concrete member data is not defined) or directly in 1D concrete member data.

Determination of unfavourable direction

This setting allows the user to set in which direction the second order moment and the geometrical imperfection will be taken into account. This setting can be done in Concrete settings (if 1D concrete member data is not defined) or directly in 1D concrete member data for Member type = Column in case of Advanced mode/level.

Shifting of bending moments

Additional tensile forces caused by shear and torsion is taken into account in SEN15 by using a simplified calculation based on shifting of bending moments according to clause 9.2.1.3(2). Shifting of bending moment is calculated only for beams and beams as slab.

Distance for shifting is calculated around for both axes dependent on type of member

- for beams
  $a = z \cdot (\cot(\theta) - \cot(\alpha)) / 2$
- for beams as slab
  $a = d$

Automatic calculation of angle between the concrete compression strut and beam axis is calculated by simplified method for shifting with the following simplifications:

- *shear of member for calculation value $V_{Rd.max}$ is calculated as minimum width of cross-section at whole cross-section perpendicular to direction of shear forces*
- *value A_k and u_k for calculation of $T_{Rd.max}$ is calculated for effective rectangular cross-section, which has the same cross-sectional area and same perimeter as inputted cross-section*

Determination whether member is in compression

The second order effect, minimal eccentricity and geometrical imperfection are taken into account only for member = Column, which is in compression. Column is in compression if conditions below are satisfied:

$$N_{Ed} > -Coeff_{com} \cdot f_{cd} \cdot A_c$$

First order bending moments with imperfection

The calculation of first order moment is calculated only for Member type = Column and in the case that column is in compression it runs according to the following procedure:

- first order eccentricity without effect of imperfection is calculated,
- eccentricity caused by imperfection is calculated,
- first order eccentricity including effect of imperfection is calculated.

Calculation of first order eccentricity without effect of imperfection

There are two options for calculating first order moments and eccentricity in SEN depending on the check box **Use equivalent first order value**.

- the equivalent first order bending moments are taken into account. It means, that bending moments will be the same at the whole length of the member. This option is used if check box **Use equivalent first order value = Yes** in Concrete settings (if 1D concrete member data is not defined) or in 1D concrete member data

  $$e_{oy} = \frac{M_{oez}}{N_{Ed}},\ e_{oz} = \frac{M_{oey}}{N_{Ed}}$$

- the first order eccentricity is calculated from bending moments in the current section. It follows, that bending moments in each section can be different. This option is used if check box **Use equivalent first order value = No** in Concrete settings (if 1D concrete member data is not defined) or in 1D concrete member data

  $$e_{oy} = \frac{M_z}{N_{Ed}},\ e_{oz} = \frac{M_y}{N_{Ed}}$$

The 1st order equivalent moment is calculated according to clause 5.8.8.2 (2) in EN 1992-1-1

$M_{0,ey}$ = max (0,6*$M_{02,y}$ +0,4*$M_{01,y}$; 0,4* $M_{02,y}$)

$M_{0,ez}$ = max (0,6*$M_{02,z}$ +0,4*$M_{01,z}$; 0,4*$M_{02,z}$)

where

- $M_{01y(z)}$ is the first end bending moments around y(z) axis of LCS with lesser absolute value as the second end bending moment. |M01y(z)| < |M02y(z)| The same values are used for the calculation of limit slenderness

- $M_{02y(z)}$ is the second end bending moments around y(z) axis of LCS with greater absolute value as the first end bending moment. |M02y(z)| ≥ |M01y(z)| The same values are used for the calculation of limit slenderness

The user (real) reinforcement defined via REDES and free bars are not taken into account for calculation effective depth of cross-section for design reinforcement to column (Type of check = Design ULS in service Internal forces)

Calculation of eccentricity due to imperfection

The imperfection in SEN is represented by an inclination according to clause 5.2(5) in EN 1992-1-1. The imperfection shall be taken into account in ultimate limit states and need not to be considered for serviceability limit states, see clause 5.2(2P) and 5.2(3) in EN 1992-1-1. The user can set independently if the imperfection will be taken into account for ULS or SLS.

The inclination is calculated around both axis (axis y and z) of LCS according to formula:

$$\theta_{i,y(z)} = \theta_0 \cdot \alpha_h \cdot \alpha_{m,y(z)}$$

where

- θ_0 is the basic value of inclination. The value is a National parameter; it means that this value can be different for each country. The value can be set in the **Manager for national annex > EN 1992-1-1 > General > ULS > General > Theta_0**
- α_h is the reduction factor for the length of a column or the height of a structure. The value is calculated according to formula

$$\alpha_h = \frac{2}{\sqrt{l}}; \quad \frac{2}{3} \le \alpha_h \le 1$$

- $\alpha_{m,y(z)}$ is the reduction factor for the number of members calculated according to formula

$$\alpha_{m,y(z)} = \sqrt{0{,}5\left(1+\frac{1}{m_{y(z)}}\right)}$$

- l is the length of a column or the height of a structure depending on, if the member is isolated or not
    - isolated member l = L, where L is the length of the member
    - not isolated member l = H, where H is the total height of the building (buckling system). This height can be defined in Buckling data
- $m_y(m_z)$ is the number of vertical members contributing to the total effect of the imperfection perpendicular to y(z) of LCS. It means, that this value is used for recalculation of the bending moment around y(z) axis of LCS. These value can be defined in Buckling data

The effect of imperfection for an isolated column and for a structure is always taken into account as an eccentricity according to clause 5.2(7a) in EN 1992-1-1.

$$e_{i,y} = \frac{\theta_{i,z} \cdot l_{0,z}}{2}; \quad e_{i,z} = \frac{\theta_{i,y} \cdot l_{0,y}}{2}$$

The direction (sign) of the value of eccentricity caused by imperfection has to be the same as the direction (sign) of first order eccentricity.

Minimum first order eccentricity

The minimum first order eccentricity is calculated according to clause 6.1(4) in EN 1992-1-1.

$$e_{0,min,y} = \max\left(\frac{b}{30}, 20mm\right), e_{0,min,z} = \max\left(\frac{h}{30}, 20mm\right)$$

The minimum eccentricity is taken into account, if check box **Use minimum value of eccentricity = Yes**

The direction (sign) of minimum first order eccentricity has to be same as direction (sign) of first order eccentricity

Calculation of first order eccentricity including effect of imperfection

First order eccentricity including effect of imperfection is calculated according to the formula below

$$e_{oEd,y(z)} = e_{0,y(z)} + e_{i,y(z)} > e_{0,min,y(z)}$$

After calculation of the first order eccentricity including the effect of imperfection, the 1st order moment, including the effect of imperfections around y (z) axis of LCS is calculated:

$$M_{0Ed,y(z)} = N_{Ed} * e_{oEd,z(y)}$$

Calculation of second order effects

The EN 1992-1-1 defines several methods for the analysis of second order effects with axial load (general method, simplified method based on nominal stiffness, simplified method based on nominal curvature...). SEN allows making the analysis of the second order effect by using the following methods:

- General method - equilibrium and resistance is verified in the deformed state, deformations are calculated taking into account the relevant effects of cracking, non-linear material properties and creep, see clause 5.8.2(2) in EN 1992-1-1,
- Simplified method based on nominal curvature according to EN 1992-1-1, clause 5.8.8

The second order effect by the simplified method is taken into account:

- for the ultimate limit state
- only for Member type = Column and it in case that the column is in compression
- check box Use second order effect in switched ON
- calculated slenderness is greater than limit slenderness

Calculation of second order moment

Nominal second order moment is calculated according to clause 5.8.8.2(3) in EN 1992-1-1

$$M_{2,y(z)} = N_{Ed} * e_{2,z(y)}$$

The second order eccentricities are calculated according to formulas below

$I_{z(y)} > I_{z(y),lim}$	Use second order effect	Second order eccentricity
YES	YES	$e_{2y(z)} = \frac{(1/r)_{z(y)} \cdot l_{0z(y)}^{2}}{c_{z(y)}}$
YES	NO	$e_{2y(z)} = 0$
NO	YES	
NO	NO	

The direction (sign) of final value of second order eccentricity has to be same as direction (sign) of first order eccentricity

Calculation of curvature

The curvature for the calculation of second order eccentricity is calculated according to clause 5.8.8.3 in EN 1992-1-1.

$$(1/r)_{y(z)} = K_r * K_{f,y(z)} * (1/r0)_{y(z)}$$

It follows that the calculation of curvature depends on many parameters and factors, but the most important are the following:

- relative normal force
- mechanical ratio of reinforcement
- effective creep ratio
- slenderness of the column
- effective depth of cross-section
- basic value of curvature

Coefficient Beta

Slenderness of the column for calculation of factor $K_{f,y(z)}$ is taken into account by parameter ($\beta_{y(z)}$) , which is calculated according to formula:

$$\beta_{y(z)} = 0,35 + f_{ck}/200 - \lambda_{y(z)}/150$$

Effective depth of cross-section

Effective depth of cross-section is used for the calculation of basic value of curvature and it is calculated according to clause 5.8.8.3(2) in EN 1992-1-1. The EN 1992-1-1 is not giving rules where the reinforcement is not symmetrical, but according to *“Designers’ guide to EN 1992-2 Eurocode 2: Design of concrete structures”* the following rules are used for the calculation of effective depth:

- for symmetrical reinforcement and in case if all reinforcement is not concentrated on opposite sides, but part of it is distributed parallel

  $$d_y = 0,5 \cdot b + i_{sy}, \quad d_z = 0,5 \cdot h + i_{sz}$$

- for other cases (design of reinforcement)

  $$d_y = b - a_s, \quad d_z = h - a_s$$

- for other cases (check) - the effective depth is calculated from plane of equlibrium or by simplified calculation, if this value cannot be calculated from this plane

The calculation of the radius of gyration of the total reinforcement and distance of centre of tensile reinforcement from tensile edge depends on the shape of the cross-section and, if the internal forces are calculated for design of reinforcement or for checks. It means that this value can be different for design of reinforcement and for checks.

The user (real) reinforcement defined via REDES and free bars are not taken into account for calculation of effective depth of cross-section for design reinforcement of a column

Design of reinforcement for rectangular section

Total area of reinforcement

$$A_s = \mu_s . A_c$$

Calculation of ratio of reinforcement in y and z direction

$$ratio\_y = \frac{\sigma_y}{\sigma_y + \sigma_z}, \quad ratio\_z = \frac{\sigma_z}{\sigma_y + \sigma_z}$$

if σ_y= 0 MPa and σ_z=0, then $ratio_y$= $ratio_z$=0.5

Calculation area of reinforcement in direction of y(z) axis of LCS

$$A_{s,y(z)} = ratio_{y(z)} * A_s$$

Distance of centre of tensile reinforcement from tensile

$$a_s = c_{nom} + d_{ss} + 0,5 \cdot d_{sm}$$

Position of reinforcement from centroid of concrete cross-section in direction of y (z)

$$z_{sy} = 0,5 \cdot b - a_s, z_{sz} = 0,5 \cdot h - a_s$$

Second moment of reinforcement area

$$I_{s,y} = A_{s,y} \cdot \left(z_{s,z}\right)^2 + \frac{1}{3} \cdot A_{s,z} \cdot \left(z_{s,z}\right)^2$$

$$I_{s,z} = A_{s,z} \cdot \left(z_{s,y}\right)^2 + \frac{1}{3} \cdot A_{s,y} \cdot \left(z_{s,y}\right)^2$$

Radius of gyration of the total reinforcement area

$$i_{s,y(z)} = \sqrt{\frac{I_{s,z(y)}}{A_s}}$$

Design of reinforcement for circular section

Total area of reinforcement

$A_s = \mu_s . A_c$

Distance of centre of tensile reinforcement from tensile

$$a_s = c_{nom} + d_{ss} + 0,5 \cdot d_{sm}$$

Position of reinforcement from centroid of concrete cross-section in direction of y (z)

$$z_s = 0,5 \cdot D - a_s$$

Second moment of reinforcement area

$$I_{s,y} = I_{s,z} = \frac{A_s}{2} \cdot \left(\left(\frac{A_s}{4 \cdot \pi \cdot z_s} \right)^2 + {z_s}^2 \right)$$

Radius of gyration of the total reinforcement area

$$i_{s,y(z)} = \sqrt{\frac{I_{s,z(y)}}{A_s}}$$

Design of reinforcement for other cross-sections

Total area of reinforcement

$A_s = \mu_s . A_c$

Area of reinforcement in each edge

$A_{si} = A_s / n_{edge}$

Distance of centre of tensile reinforcement from tensile

$$a_s - c_{nom} + d_{ss} + 0,5 \cdot d_{sm}$$

Position of reinforcement from centroid of concrete cross-section in direction of y (z)

$$z_{sy(z)i} = dist_{y(z)i} - a_s$$

Second moment of reinforcement area

$$I_{sy(z)} - \sum_{i=1}^{n_{edge}} \Lambda_{si} \; z_{sz(y)_i}{}^2$$

Radius of gyration of the total reinforcement area

$$i_{s,y(z)} = \sqrt{\frac{I_{s,z(y)}}{A_s}}$$

Checks for all type of cross-sections

Total area of reinforcement

$$A_s = \sum_{i=1}^{n_s} A_{1,s}$$

Second moment of reinforcement area

$$I_{s,y(z)} = \sum_{i=1}^{n_s} A_{1,s_i} \cdot \left(z_{s,z(y)_i}\right)^2$$

Radius of gyration of the total reinforcement area

$$i_{s,y(z)} = \sqrt{\frac{I_{s,z(y)}}{A_s}}$$

Basic value of curvature

There is a rule for the calculation of basic curvature only for symmetrical cross-section with symmetrical reinforcement. in EN 1992-1-1, where the formula below should be used:

$$(1/r_o)_{y(z)} = \frac{\varepsilon_{yd}}{0,45 \cdot d_{z(y)}}$$

For unsymmetrical cross-section with unsymmetrical reinforcement according to recommendation of *“Designers’ guide to EN 1992-2 Eurocode 2: Design of concrete structures”* the following formula should be used

$$(1/r_o)_{y(z)} = \frac{\varepsilon_{yd} + \varepsilon_{cu}}{d_{z(y)}}$$

Calculation of unfavourable direction

The minimum eccentricity, geometrical imperfection and first order moments including imperfection are calculated in both directions. The second order effect depends on the comparison of slenderness and limit slenderness and can be calculated too in both directions. The column will deflect under the action of the first-order moments and the accidental moment. It proposes that the second order moments will occur in the direction where the deflection, due to first-order moment as a proportion of the effective length of the column, is greatest. It is assumed, though this is not stated in the code, that the accidental moment and second-order moments will only occur in one direction and not in both directions at once. Therefore it is possible in SEN, to define the unfavourable direction; it means the direction in which the second order moment and geometrical imperfection will be taken into account.

There are 3 possibilities:

- **Auto** - the direction for the calculation of second order effect and geometrical imperfection is determined automatically according to conditions 5.38a and 5.38b in EN 1992-1-1

  The uniaxial calculation for automatic determination is taken into account; if conditions below are satisfied, otherwise biaxial calculation will be used.

  $$\left(\frac{\lambda_y}{\lambda_z} \leq 2\right) \text{ and } \left(\frac{\lambda_y}{\lambda_z} \leq 2\right) \text{ and } \left(\frac{(e_{0Edz}+e_{2z})/h_{eq}}{(e_{0Edy}+e_{2y})/b_{eq}} \leq 0.2\right) \text{ or } \left(\frac{(e_{0Edy}+e_{2y})}{(e_{0Edz}+e_{2z})} \leq 0.2\right)$$

- **Uniaxial** - second order effect and geometrical imperfection is taken into account only in one direction (more unfavourable direction). In case that the more unfavourable direction cannot be assigned (accidental bending moments, effective length and css properties are the same in both direction), the second order effect and geometrical imperfection will be taken into account in both directions.

- **Biaxial** - second order effect and geometrical imperfection is always taken into account in both directions.

There are no rules for the determination of unfavourable direction in EN 1992-1-1, therefore in SEN is used the procedure described in *“Designers’ guide to EN 1992-1-1 and EN 1992-1-2: Eurocode 2: Design of concrete structures, General rules for buildings and structural fire design”*, where the unfavourable direction is determined according to the equation below:

$$\eta_y = \frac{\left|N_{Ed} \cdot e_{0Edz} \cdot \lambda_y\right|}{h_{eq}}$$

$$\eta_z = \frac{\left|N_{Ed} \cdot e_{0Edy} \cdot \lambda_z\right|}{b_{eq}}$$

ηy > ηz - unfavourable direction is around y axis
ηy < ηz - unfavourable direction is around z axis
ηy = ηz - both directions are taken into account

Slenderness

Slenderness and limit slenderness of a column should be checked before the design or check of the members. Using the second order effect in the calculation depends on the check of slenderness, because if the check of slenderness is greater than the limit slenderness, the second order effect has to be taken into account for the column calculation.

Conditions	Calculation of second order effect
$\lambda_y > \lambda_{limy}$ or $\lambda_z > \lambda_{limz}$	YES
$\lambda_y \leq \lambda_{limy}$ and $\lambda_z \leq \lambda_{limz}$	NO

The slenderness and limit slenderness is calculated according to clause 5.8.3.1 and 5.8.3.2 in EN 1992-1-1. The following preconditions are used for calculation:

- The slenderness is calculated for beams and columns and for general load (N+My+Mz)
- The limit slenderness is calculated only if the axial forces is smaller than zero (N < 0 kN)
- Cross-section with one polygon and one material is taken into account in version SEN 15
- The material of all reinforcement bars has to be same in SEN 15

Buckling data

The detailed description of inputting buckling data and the way of calculating buckling data are described in Topic Training – Buckling lengths. There is described the general functionality, but for the calculation of slenderness and limit slenderness the following properties are important:

- properties for the calculation of effective length of the member around y and z axis
- if the member is braced (Sway = NO) or unbraced (Sway = YES) around y and z axis

*The important parameter for calculation of buckling data is type of structure (braced or unbraced). The global type of the structure can be set in Concrete Settings **(Design defaults > Default sway type)**. For example, the structure is braced perpendicular to y axis of GCS, if parameter **Sway around y axis = NO** (it means the structure is not prone to sway perpendicular to y axis).*

Creep coefficient

This value can be set in the **Concrete settings** by using **Advanced level** or in **1D member data** (advanced mode is ON), if it is defined. The creep coefficient can be calculated automatically by using the input of ages of concrete and relative humidity (see annex B.1 in EN 1992-1-1), if the **Type input of creep coefficient = Auto.** If the **Type input of creep coefficient = User value,** the creep coefficient can be inputted directly by the user.

Estimation of ratio of longitudinal reinforcement

There are some values in the design of reinforcement, which are dependent on the area of reinforcement, for example:

- mechanical reinforcement ratio (μ) in the calculation of limit slenderness (clause 5.8.3.1(1) in EN 1992-1-1)
- mechanical reinforcement ratio (μ) in the calculation of second order eccentricity (clause 5.8.8.3(3) in EN 1992-1-1)
- radius of gyration of the total reinforcement area (i_s) in the calculation of second order eccentricity (clause 5.8.8.3(2) in EN 1992-1-1)
- calculation of the exponent of interaction formula x in the biaxial bending calculation (clause 5.8.9.(4) in EN 1992-1-1)

These values should be calculated before the design of reinforcement, but before the design we do not know the area of reinforcement. It follows that for calculation of this value:

- area of reinforcement will be neglected,
- iterative calculation will be used,
- area of reinforcement will be estimated.

The third solution is implemented in SEN via the parameter Estimation ratio of longitudinal reinforcement for recalculation internal forces, where the user can set the ratio of reinforcement, which will be used for calculation of the values above. This value can be set in the **Concrete settings** by using **Advanced level** or in **1D member data** (advanced mode is ON), if it is defined. Total area of reinforcement is calculated according to formula:

$$A_s = \mu_s . A_c$$

Calculation of slenderness

The slenderness (slenderness ratio) is calculated according to clause 5.8.3.2(1) in EN 1992-1-1.

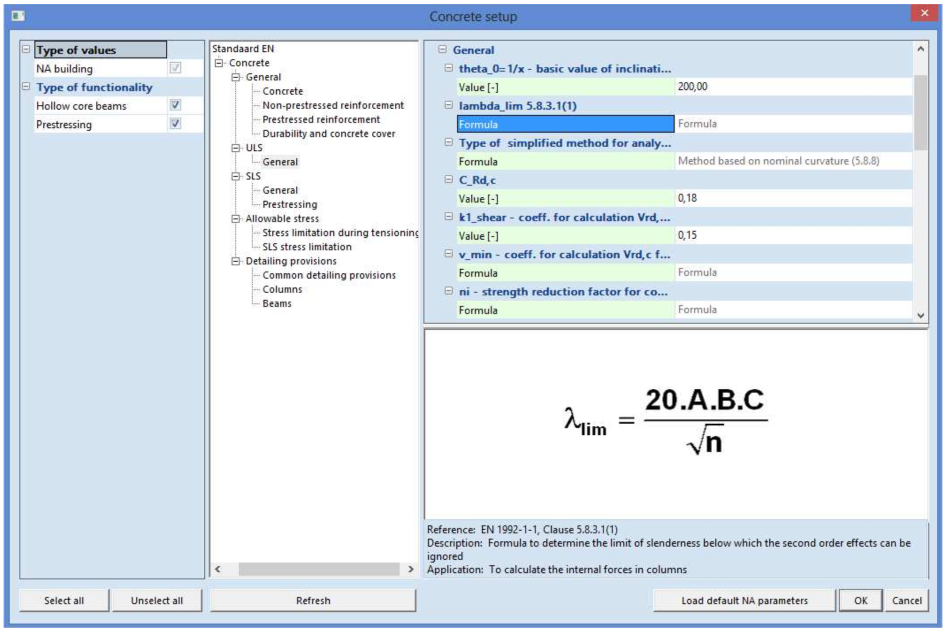
$$\lambda_{y(z)} = \frac{l_{0,y(z)}}{i_{c,y(z)}}$$

The simplified values and formulas for calculation of effective length for isolated columns, braced and unbraced frames are described in clauses 5.8.3.2(2-4) in EN 1992-1-1

The slenderness is calculated in each section, it follows that for an arbitrary member and member with a haunch, the slenderness can be different along the length of the member

Calculation of limit slenderness

The limit slenderness is calculated according to clause 5.8.3.1(1) in EN 1992-1-1. The limit slenderness and the slenderness are always checked separately for each direction according to 5.8.3.1(2) in EN 1992-1-1. The formula for the calculation of limit slenderness in EN 1992-1-1 is a national parameter, it means, that a different formula, method or value can be used in some countries, see concrete setup (**Manager for national annex > EN 1992-1-1 > General > ULS > General > lambda_lim**)



General

theta_0=1/x - basic value of inclinati...	
Value [-]	200,00
lambda_lim 5.8.3.1(1)	
Formula	Formula
Type of simplified method for analy...	
Formula	Method based on nominal curvature (5.8.8)
C_Rd,c	
Value [-]	0,18
k1_shear - coeff. for calculation Vrd,...	
Value [-]	0,15
v_min - coeff. for calculation Vrd,c f...	
Formula	Formula
ni - strength reduction factor for co...	
Formula	Formula

$$\lambda_{\text{lim}} = \frac{20.A.B.C}{\sqrt{n}}$$

Reference: EN 1992-1-1, Clause 5.8.3.1(1)
Description: Formula to determine the limit of slenderness below which the second order effects can be ignored
Application: To calculate the internal forces in columns

There are changes in the calculation of limit slenderness for some national annex, see the table below:

National annex	**Calculation of limit slenderness**
Standard EN 1992-1-1	λ_lim = (20*A*B*C)⁄√n
DIN EN 1992-1-1 NA	λ_lim = 25 ... for |n| ≥ 0,41 λ_lim = 16⁄√n ... for |n| < 0,41
CSN 1992-1-1 NA STN 1992-1-1 NA	λ_lim = (20*A*B*C)⁄√n ≤ 75

The limit slenderness calculated according to standard EN 1992-1-1 depends on:

- effective creep ratio φ_{eff} (coefficient A),
- mechanical reinforcement ratio w (coefficient B),
- shape (ratio) of bending moment r_m (coefficient C),
- relative normal force n.

The limit slenderness is not calculated if normal force (relative normal force) is compressive.

The limit slenderness is calculated in each section, it follows that for an arbitrary member or a member with a haunch, the normal force is not uniform at the length of the member or the reinforcement is not constant at the length, the limit slenderness can be different along the length of the member.

Effective creep ratio

In SCIA Engineer, for the calculation of limit slenderness the creep ratio is used loaded from the concrete settings (if member data is not defined) or concrete member data. It means that if the user wants to take into account the effective creep ratio according to clause 5.8.4 in EN 1992-1-1, the value of this creep ratio has to be directly inputted in the concrete settings or the concrete member data. Otherwise, the final creep ratio will be taken into account.

The coefficient A is calculated according to formula:

A = 1/1+0,2•φ.

Mechanical reinforcement ratio

Check

The mechanical reinforcement ratio depends on total area of longitudinal reinforcement. For checks, the total area of reinforcement is calculated from inputted reinforcement via REDES or Free bars. The mechanical reinforcement can be different at the whole length of the column and in each section of the member and it is calculated according to formula below:

$$\varpi = \frac{\Sigma(A_{si} \cdot f_{ydi})}{A_c \cdot f_{cd}}$$

The coefficient B is calculated according to formula:

B = √(1+2·ω)

Design

The mechanical reinforcement ratio depends on total area of longitudinal reinforcement. For design of reinforcement, total area of reinforcement is calculated from estimation ratio loaded from Concrete settings (if concrete member data is not defined) or concrete member data. The mechanical reinforcement ratio is the same at the whole length of the column and it is calculated according to formula:

$$\omega = \mu_s \cdot \frac{f_{yd}}{f_{cd}}$$

The coefficient B is calculated according to formula:

$$B = \sqrt{(1+2 \cdot \omega)}$$

Shape of bending moment

Shape of bending moment is expressed by the ratio of first order end bending moments without the influence of imperfection around the selected local axis. The ratio of these moments (value r_m) depends on the type of member and on the shape of shear force.

- if type of member is unbraced around local axis (sway = YES), then $r_m = 1,0$
- if type of member is braced around local axis (sway = NO) and first order moments arise only from or predominantly due to imperfections or transverse loading (maximum bending moment along the member is not at the beginning or at the end of the member), then $r_m = 1,0$
- otherwise, value r_m is calculated according to formula

$$r_{m.y(z)} = M_{01y(z)} / M_{02y(z)} \quad \left|M_{02y(z)}\right| \geq \left|M_{01y(z)}\right|$$

where

- $M_{01y(z)}$ is first end bending moment around y(z) axis of LCS with lesser absolute value as second end bending moment. $| M_{01y(z)} | < | M_{02y(z)} |$ The same values are used for the calculation of limit slenderness.
- $M_{02y(z)}$ is second end bending moment around y(z) axis of LCS with greater absolute value as first end bending moment. $| M_{02y(z)} | \geq | M_{01y(z)} |$ The same values are used for the calculation of limit slenderness.
- $r_{m.y(z)}$ is ratio of bending moment around y(z) axis of LCS which is used for the calculation of limit slenderness around y(z) axis of LCS.

The coefficient C is calculated according to formula:

$$C_{y(z)} = 1{,}7 - r_{m.y(z)}$$

Relative normal force

Relative normal force is calculated according to formula

$$n = N_{Ed} / A_c \bullet f_{cd}$$

If normal force is not uniform at length of column or part of the column (for arbitrary member and member with haunch), the maximum value of normal force at length of column or part of the column will be taken into account.

Reinforcement design – theory

SEN 15 allows to design reinforcement for a general cross-section which is loaded by general forces (N, My,Mz,Vy,Vz, Mx) . It is possible to design:

- statically required longitudinal reinforcement
- longitudinal reinforcement including detailing provisions
- statically required shear reinforcement
- shear reinforcement including detailing provisions
- torsional longitudinal reinforcement

The following preconditions are used for calculation:

- additional tensile forces caused by shear is taken into account by shifting of bending moments, see clause 9.2.1.3(2)in EN 1992-1-1,
- cross-section with one polygon and one material is taken into account,
- practical (user defined) reinforcement is not taken into account.

Parameters

Design defaults

Design defaults is a special group of properties where the user can define the basic parameters (diameter of longitudinal and shear reinforcement, type of value of concrete cover...) for design of longitudinal and shear reinforcement. This setting can be done in Concrete settings (if 1D concrete member data is not defined) or directly in 1D concrete member data.

Three types of 1D members with different design defaults parameter are supported in SEN 15:

- Beam - member predominantly loaded by bending moments, for which longitudinal and shear reinforcement can be designed. There are the following parameters:
    - Longitudinal reinforcement
        - diameter of upper/lower reinforcement
        - type of cover of upper and lower reinforcement (auto or user defined value)
        - type of cover of side reinforcement (upper, lower or user defined value)
        - material of longitudinal reinforcement (only in 1D concrete data)
    - Stirrups
        - diameter of stirrups
        - number of cuts (number of shear links)
        - angle of shear reinforcement
        - material of shear reinforcement (only in 1D concrete data)
        - basic (user defined stirrup) – the user can define user value of area of shear reinforcement per meter with some angle and material of this reinforcement
- Beam as slab - member predominantly loaded by bending moments for which shear reinforcement is not designed (for example cut of 2D member). There are the following parameters:
    - Longitudinal reinforcement
        - diameter of upper/lower reinforcement
        - type of cover of upper and lower reinforcement (auto or user defined value)
        - type of cover of side reinforcement (upper, lower or user define value)

        - material of longitudinal reinforcement (only in 1D concrete data)

- Column - member predominantly in compression for which longitudinal and shear reinforcement can be designed. There are the following parameters:
    - Longitudinal reinforcement
        - diameter of upper/lower reinforcement
        - type of cover of upper and lower reinforcement (auto or user defined value)
        - type of cover of side reinforcement (upper, lower or user define value)
        - material of longitudinal reinforcement (only in 1D concrete data)
    - Stirrups
        - diameter of stirrups
        - number of cuts (number of shear links)
        - material of shear reinforcement (only in 1D concrete data)

Design defaults in concrete settings:

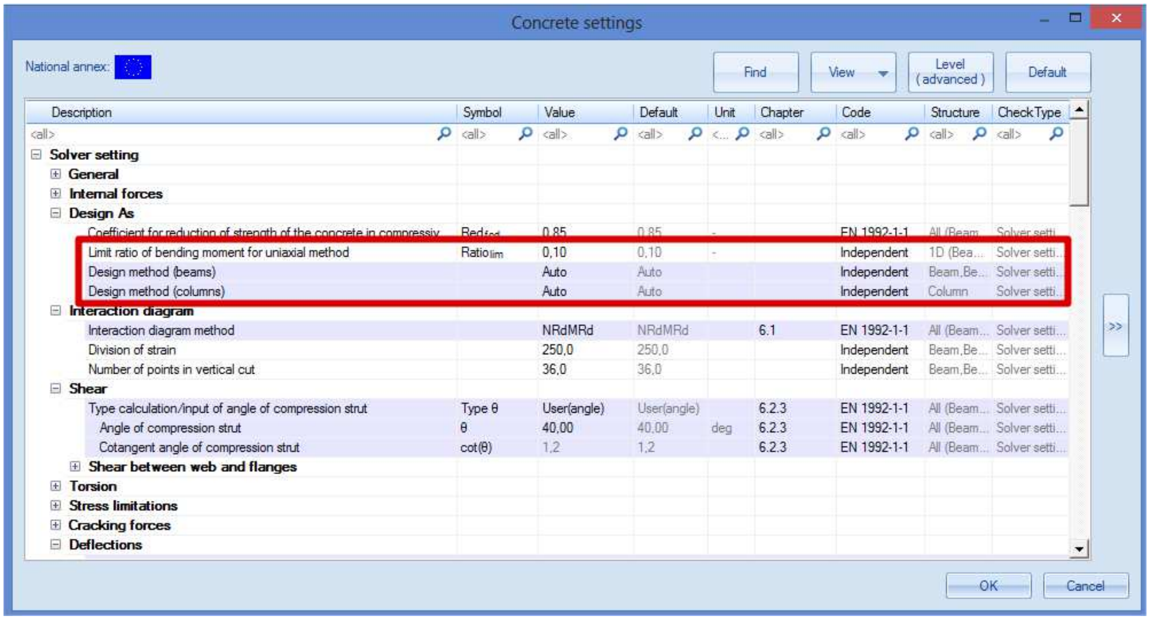
- there is a possibility to define design defaults for all types of 1D member (beam, column, beam slab)
- it is not possible to input/edit the material of longitudinal and shear reinforcement in this setting, but material is loaded from project data and it is the same for all type of members

Design defaults in 1D concrete member data

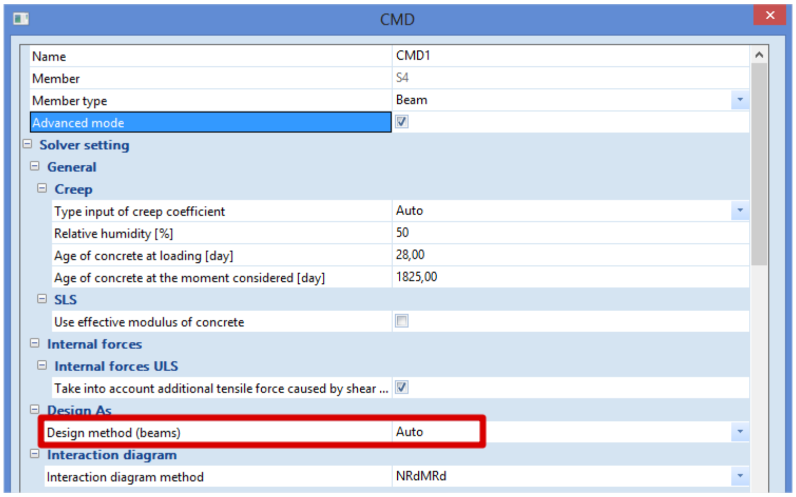
- only design defaults of selected type of member can be edited in this setting
- material of shear and longitudinal reinforcement can be edited directly in the concrete member data

Design method

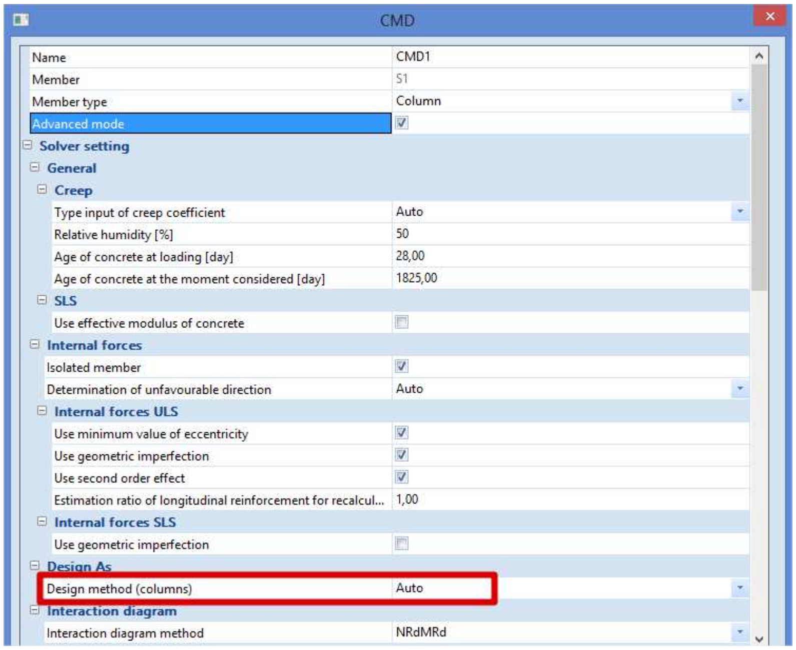
The user can set the type of method for design of reinforcement for columns and beams This setting can be done in Concrete settings (if 1D concrete member data is not defined) or directly in 1D concrete member data for Member type = Column or beams by using **Advanced mode/level.**



Description	Symbol	Value	Default	Unit	Chapter	Code	Structure	Check Type
<all>	<all>	<all>	<all>	<...	<all>	<all>	<all>	<all>
Solver setting								
General								
Internal forces								
Design As								
Coefficient for reduction of strength of the concrete in compressiv	Red_{fcd}	0,85	0,85	-		EN 1992-1-1	All (Beam...	Solver setti...
Limit ratio of bending moment for uniaxial method	$Ratio_{lim}$	0,10	0,10	-		Independent	1D (Bea...	Solver setti...
Design method (beams)		Auto	Auto			Independent	Beam,Be...	Solver setti...
Design method (columns)		Auto	Auto			Independent	Column	Solver setti...
Interaction diagram								
Interaction diagram method		NRdMRd	NRdMRd		6.1	EN 1992-1-1	All (Beam...	Solver setti...
Division of strain		250,0	250,0			Independent	Beam,Be...	Solver setti...
Number of points in vertical cut		36,0	36,0			Independent	Beam,Be...	Solver setti...
Shear								
Type calculation/input of angle of compression strut	Type θ	User(angle)	User(angle)		6.2.3	EN 1992-1-1	All (Beam...	Solver setti...
Angle of compression strut	θ	40,00	40,00	deg	6.2.3	EN 1992-1-1	All (Beam...	Solver setti...
Cotangent angle of compression strut	cot(θ)	1,2	1,2		6.2.3	EN 1992-1-1	All (Beam...	Solver setti...
Shear between web and flanges								
Torsion								
Stress limitations								
Cracking forces								
Deflections								



Name	CMD1
Member	S4
Member type	Beam
Advanced mode	☑
Solver setting	
General	
Creep	
Type input of creep coefficient	Auto
Relative humidity [%]	50
Age of concrete at loading [day]	28,00
Age of concrete at the moment considered [day]	1825,00
SLS	
Use effective modulus of concrete	☐
Internal forces	
Internal forces ULS	
Take into account additional tensile force caused by shear ...	☑
Design As	
Design method (beams)	Auto
Interaction diagram	
Interaction diagram method	NRdMRd



Name	CMD1
Member	S1
Member type	Column
Advanced mode	☑
Solver setting	
General	
Creep	
Type input of creep coefficient	Auto
Relative humidity [%]	50
Age of concrete at loading [day]	28,00
Age of concrete at the moment considered [day]	1825,00
SLS	
Use effective modulus of concrete	☐
Internal forces	
Isolated member	☑
Determination of unfavourable direction	Auto
Internal forces ULS	
Use minimum value of eccentricity	☑
Use geometric imperfection	☑
Use second order effect	☑
Estimation ratio of longitudinal reinforcement for recalcul...	1,00
Internal forces SLS	
Use geometric imperfection	☐
Design As	
Design method (columns)	Auto
Interaction diagram	
Interaction diagram method	NRdMRd

Four types of methods for design statically required reinforcement are supported for beams and columns:

- auto
- uniaxial around y
- uniaxial around z
- biaxial

Uniaxial method around y axis is always used for type of member = beam as slab.

Biaxial method independently on selected method is always used for circular and oval columns.

Limit ratio of bending moments for uniaxial method

The automatic method for design of reinforcement is based on the ratio of bending moments around y and z axis and on the value of limit ratio of bending moments for using uniaxial method. This limit value can be set and loaded from concrete setting (Advanced level). Default value is 0.1. It follows, if ratio of maximal bending moments around y and z axis for all combinations in current section is lesser than limit ratio of bending moments, uniaxial method is used for design, otherwise biaxial method is used.

Design of longitudinal reinforcement

The design of statically required reinforcement is based on the calculation equilibrium. This method uses an iteration routine to calculate equilibrium based on the internal forces, the cross-section, material properties and position of reinforcement. Generally, this iterative method works for the interaction of the normal force (N) with uni-axial or bi-axial bending moments (My + Mz).

There are the following assumptions:

- Plane sections remain plane.
- Strain in bonded reinforcement, whether in tension or compression, is the same as the strain in the concrete at the same level
- Tensile strength of the concrete is ignored.
- The stresses in the concrete in compression are given by the design stress–strain relationships (bilinear or parabola-rectangular stress-strain diagram)
- The stresses in the reinforcing steel are given by the design stress–strain relationships (bilinear with or without inclined horizontal branch stress-strain diagram)

Four methods are supported in SEN 15 for design of reinforcement for beams and columns:

- uni-axial around y axis
- uni-axial around z axis
- biaxial
- auto

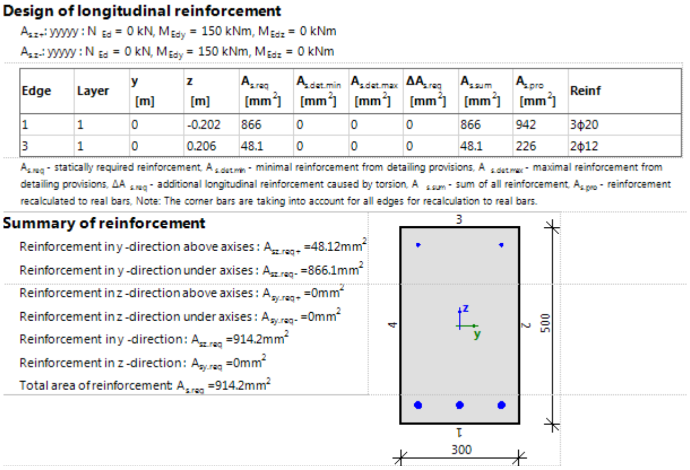
Uniaxial method around y axis is always used for type of member = beam as slab.

Biaxial method independently on selected method is always used for circular and oval columns.

Designed required area is for a better overview and graphical presentation recalculated to the directions of axis's of LCS of the cross-section (member).

Except of statically required longitudinal reinforcement ($A_{s.req}$), the program calculates also the provided longitudinal reinforcement ($A_{s.prov}$). It is the statically required longitudinal reinforcement area recalculated to real bars, where:

- diameter of longitudinal reinforcement is taken into account (cross-sectional area of bars with input diameter)
- minimal number of bars per edge is 2
- number of bars is rounded to whole number
- corner bars are taking into account for all edges (half of a bar is taken into account for one edge, and half of a bar for second edge)



Design of longitudinal reinforcement

$A_{s.z+}$: yyyy : N_{Ed} = 0 kN, M_{Edy} = 150 kNm, M_{Edz} = 0 kNm

$A_{s.z-}$: yyyy : N_{Ed} = 0 kN, M_{Edy} = 150 kNm, M_{Edz} = 0 kNm

Edge	Layer	y [m]	z [m]	$A_{s.req}$ [mm^2]	$A_{s.det.min}$ [mm^2]	$A_{s.det.max}$ [mm^2]	$\Delta A_{s.req}$ [mm^2]	$A_{s.sum}$ [mm^2]	$A_{s.pro}$ [mm^2]	Reinf
1	1	0	-0.202	866	0	0	0	866	942	3ϕ20
3	1	0	0.206	48.1	0	0	0	48.1	226	2ϕ12

$A_{s.req}$ - statically required reinforcement, $A_{s.det.min}$ - minimal reinforcement from detailing provisions, $A_{s.det.max}$ - maximal reinforcement from detailing provisions, $\Delta A_{s.req}$ - additional longitudinal reinforcement caused by torsion, $A_{s.sum}$ - sum of all reinforcement, $A_{s.pro}$ - reinforcement recalculated to real bars. Note: The corner bars are taking into account for all edges for recalculation to real bars.

Summary of reinforcement

Reinforcement in y -direction above axises : $A_{sz.req+}$ =48.12mm^2

Reinforcement in y -direction under axises : $A_{sz.req-}$ =866.1mm^2

Reinforcement in z -direction above axises : $A_{sy.req+}$ =0mm^2

Reinforcement in z -direction under axises : $A_{sy.req-}$ =0mm^2

Reinforcement in y -direction: $A_{sz.req}$ =914.2mm^2

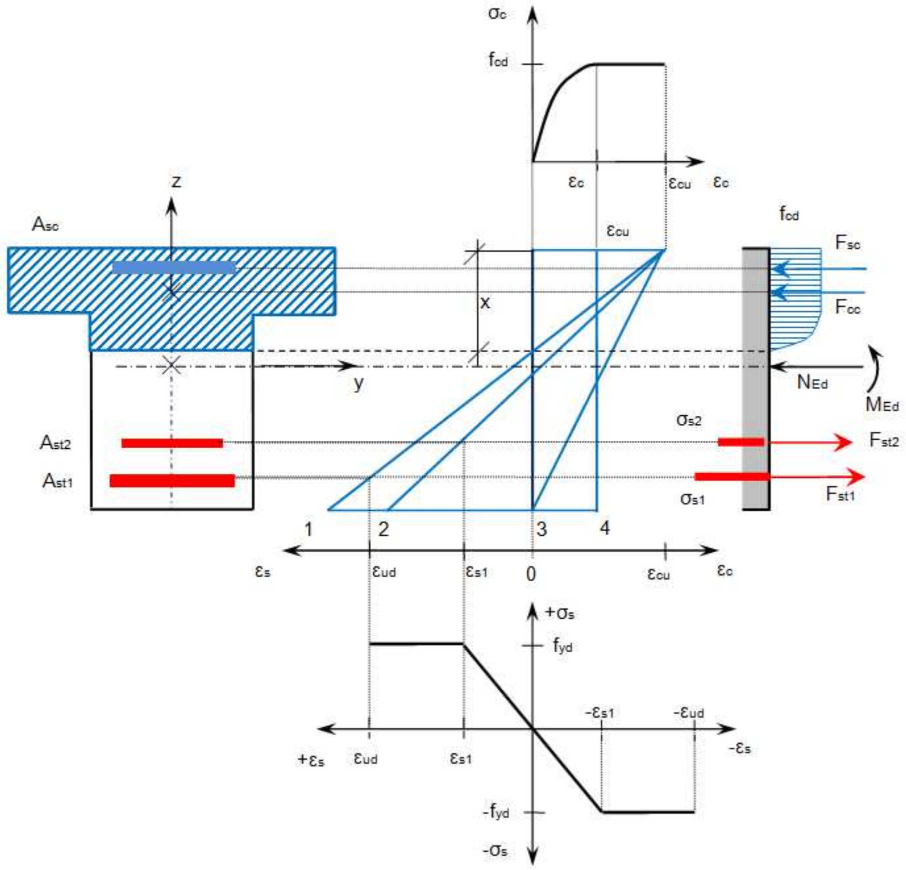
Reinforcement in z -direction: $A_{sy.req}$ =0mm^2

Total area of reinforcement: $A_{s.req}$ =914.2mm^2

Uniaxial method for design

This method allows designing the reinforcement only for normal force (N_{Ed}) and one bending moment (M_{Ed}). In case, that the cross-section is loaded by bending moments around both axes, one bending moment is ignored:

- for method **uniaxial around y**, the bending moment M_{Edz} is ignored, it follows that the reinforcement is designed only for normal forces N_{Ed} and bending moment M_{Edy}
- for method **uniaxial around z**, the bending moment M_{Edy} is ignored, it follows that the reinforcement is designed only for normal forces N_{Ed} and bending moment M_{Edz}



The results of uniaxal method depend on type of member:

- for beams and beam as slab
  - reinforcement is designed only at one or two edges (if compressive reinforcement is required or cross-section is loaded only by normal force)
  - the reinforcement can be unsymmetrical
  - the reinforcement can be designed in more layers
- for columns
  - reinforcement is designed always at two edges and the reinforcement is symmetrical
  - reinforcement is designed always at one layer

The position of reinforcement is calculated from parameters defined in Design defaults.

Calculation position of reinforcement

The position of reinforcement is calculated from parameters, which are defined in Concrete settings > Design defaults. The position of reinforcement is always in the middle of the edge, which is created by offset of current cross-section in distance as. This distance and diameter of reinforcement can be different for each edge and it is calculated in dependence on type of member according to formulas:

- beam

$$a_{s,lj} = c_{nom,l} + d_{ss} + 0.5 \cdot d_{s,l} + (s_{\min} + d_{s,l}) \cdot (j - 1)$$

$$a_{s,uj} = c_{nom,u} + d_{ss} + 0.5 \cdot d_{s,u} + (s_{\min} + d_{s,u}) \cdot (j - 1)$$

$$a_{s,sj} = c_{nom,s} + d_{ss} + 0.5 \cdot d_{s,s} + (s_{\min} + d_{s,s}) \cdot (j - 1)$$

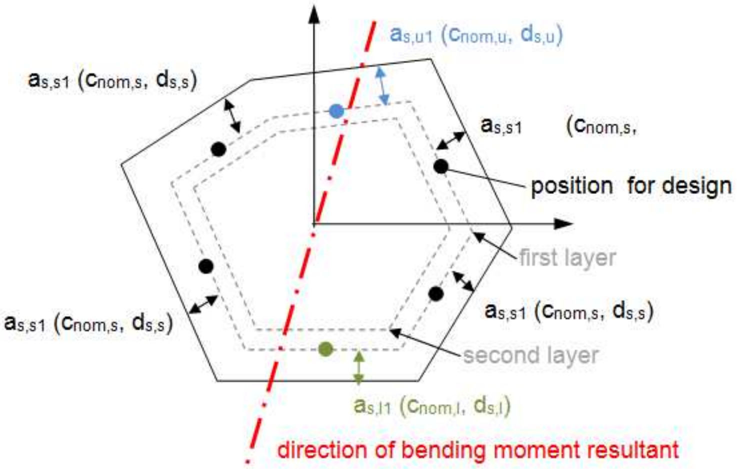
- beam as slab

$$a_{s,lj} = c_{nom,l} + 0.5 \cdot d_{s,l} + (s_{\min} + d_{s,l}) \cdot (j - 1)$$

$$a_{s.uj} = c_{nom.u} + 0.5 \cdot d_{s.u} + (s_{\min} + d_{s.u}) \cdot (j - 1)$$

- column

$$a_s = c_{nom} + d_{ss} + 0.5 \cdot d_s$$



The edge, for which the parameter of upper reinforcement is used, is the edge above axis which is crossed by the line in direction of bending moment resultant for dangerous combination, which causes the biggest linear stress in the cross-section.

The edge, for which the parameter of lower reinforcement is used, is the edge under axis which is crossed by the line in direction of bending moment resultant for dangerous combination, which causes the biggest linear stress in the cross-section.

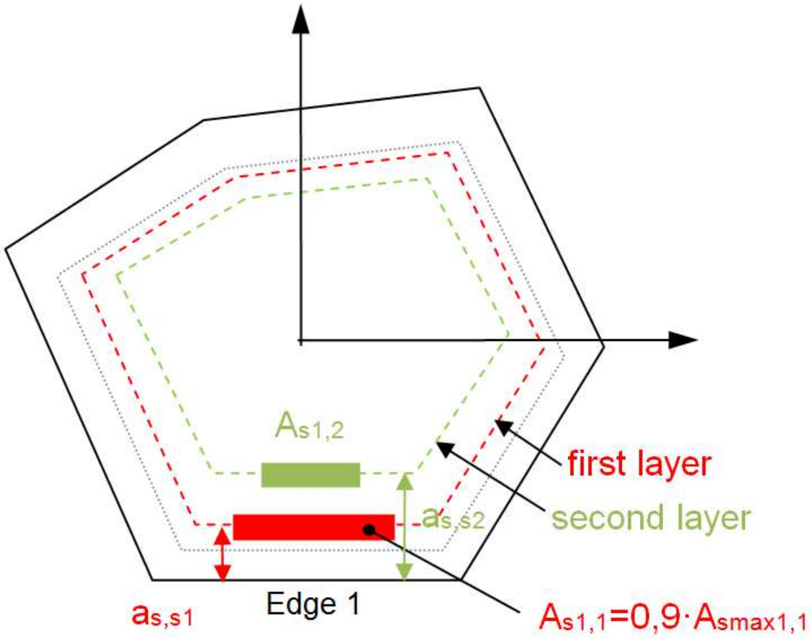
Design for several layers

The program is able to design reinforcement for more layers. It is an iterative calculation, where the following procedure is used:

- the reinforcement is designed at the first layer for the selected method
- designed area at each edge is checked with maximum area of reinforcement (area of reinforcement calculated from minimum surface to surface distance of bars), which can be placed along the edge
- if designed area at some edge is bigger than maximum area, then new design for the next layer is done where:

- the area of reinforcement $A_{s,max}$ is inputted to the previous layer
- the position of reinforcement for the next layer is calculated
- design with new positions of reinforcement is run with taking into account reinforcement from the previous layer

Maximal number of layers which is taken into account is 5 in SEN 15. The program finishes with some error, when maximum number of layer (n_{max} = 5) is inefficient.

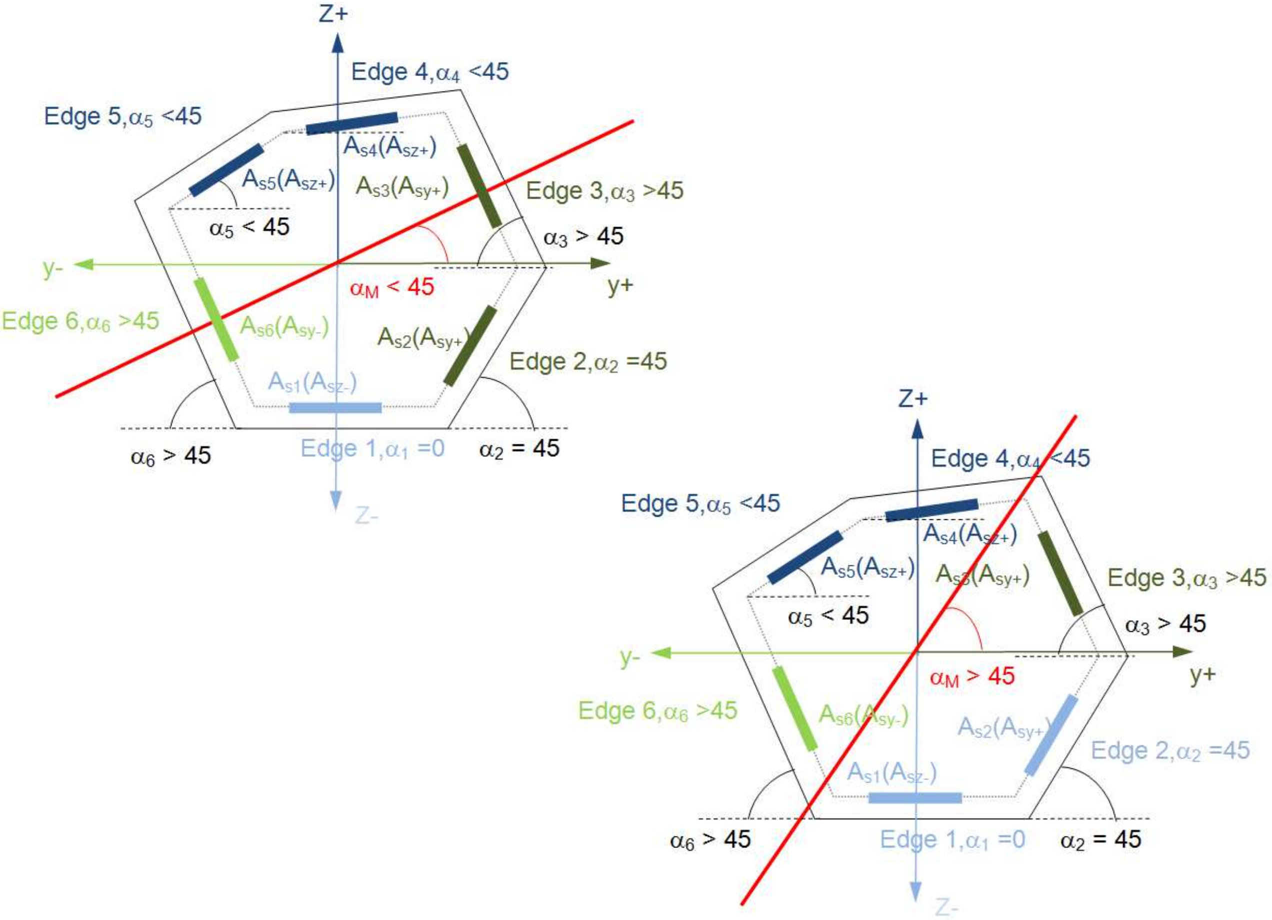


Design for more layers is supported only for beams and beams as slab.

Recalculation reinforcement to directions

Longitudinal reinforcement can be designed to more edges of a cross-section and for a general cross-section. Designed required area is for a better overview and a graphical presentation recalculated to directions of axes of LCS of the cross-section (member). The recalculated area of reinforcement depends on the angle of the edge from y-axis and the angle of bending moment resultant from y-axis. It follows, that 4 areas of reinforcement can be presented in graphical and numerical output:

$A_{sz.req+}$	required area of reinforcement (mostly designed for bending moment M_y) placed on edges above axis y with angle of edges lesser than 45 degree from y- axis. The edges with angle 45 degree and above axis y are assigned to this direction if direction of bending moment resultant (α_M) is lesser or equal than 45 degree.
$A_{sz.req-}$	required area of reinforcement (mostly designed for bending moment M_y) placed on edges under axis y with angle of edges lesser than 45 degree from y- axis.The edges with angle 45 degree and under axis y are assigned to this direction if direction of bending moment resultant (α_M) is lesser or equal than 45 degree.
$A_{sy.req+}$	required area of reinforcement (mostly designed for bending moment M_z) placed on edges above axis z with angle of edges greater than 45 degree from y- axis.The edges with angle 45 degree and above axis z are assigned to this direction if direction of bending moment resultant (α_M) is greater than 45 degree.
$A_{sy.req-}$	required area of reinforcement (mostly designed for bending moment M_z) placed on edges under axis z with angle of edges greater than 45 degree from y- axis. The edges with angle 45 degree and under axis z are assigned to this direction if direction of bending moment resultant (α_M) is greater than 45 degree.



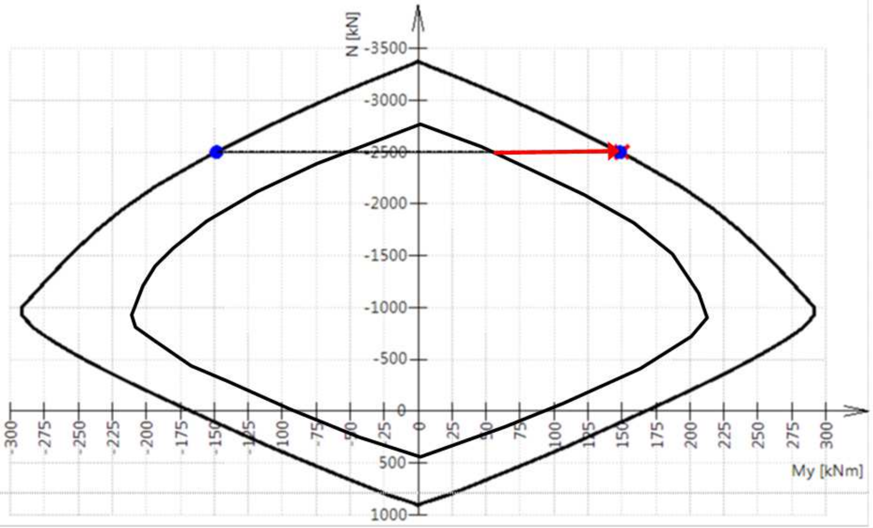
Biaxial method for design

This method allows designing the reinforcement for normal force (N_{Ed}) and biaxial bending moments. This method is based on interaction formula, equation 5.39 in EN 1992-1-1.

$$\left(\frac{M_{Edz}}{M_{Rdz}}\right)^a + \left(\frac{M_{Edy}}{M_{Rdy}}\right)^a \leq 1{,}0$$

Procedure of calculation:

- program designs initial area of reinforcement according to linear stress on the edges of the cross-section
- program increases area of reinforcement, generates interaction diagram around y and z axes and checks interaction formula in iterative calculation, till interaction formula is not satisfied
- if interaction formula is fulfilled, then program checks plane of deformation and increases area of reinforcement , if the plane of deformation is not found



The results of biaxial method depend on type of member:

- for beam and beam as slab
  - the reinforcement can be unsymmetrical
  - exponent of interaction formula is 1
  - the reinforcement can be designed in more layers
- for column
  - reinforcement is symmetrical, if the cross-section is symmetrical
  - exponent of interaction formula depends on shape of cross-section
  - reinforcement is designed always at one layer

Automatic method for design

There is a possibility to use the automatic method for design. The program automatically selects the uniaxial or biaxial method according to the values of bending moments around y and z axis. It follows:

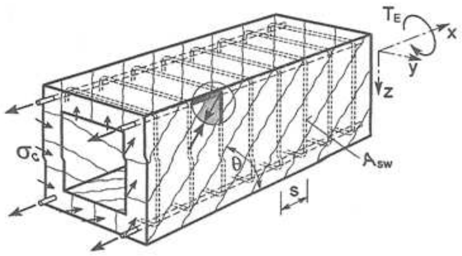
- uniaxial method is used if

$$Ratio = \frac{\min\left(\left|M_{Edy,max}\right|, \left|M_{Edz,max}\right|\right)}{\max\left(\left|M_{Edy,max}\right|, \left|M_{Edz,max}\right|\right)} \leq Ratio_{lim}$$

- biaxial method is used in other cases

Different method for design of reinforcement can be used in each section along the member in dependence on values of bending moments around y and z axis from all combinations

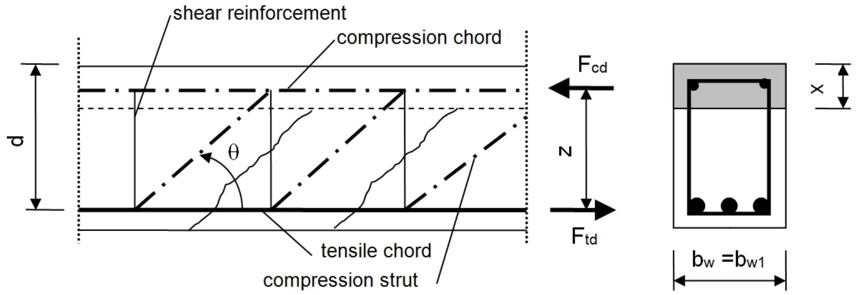
Design of shear reinforcement



Design of shear reinforcement includes:

- design for biaxial shear force
- design for torsion
- design for interaction shear force and torsion

Design is provided according to clause 6.1 -6.3 in EN 1992-1-1. Design reinforcement for shear and torsion is commonly based on the theory of the concrete truss-model too. In this theory a virtual truss-model is imagined in a concrete beam. This truss-model has a set of vertical (or slightly diagonal), horizontal and diagonal members. The vertical bars are considered to be the stirrups; the horizontal bars are the main reinforcement and the diagonal bars are the concrete struts.



There are the following assumptions:

- The shear forces in both directions are taken into account and design of shear reinforcement is done for resultant of shear forces
- The parameters of plane of equilibrium (value d, z and h) are recalculated to the direction of shear force resultant
- The design shear resistance of the member without shear reinforcement ($V_{Rd,c}$) is calculated according to clause 6.2.2(1) in EN 1992-1-1, if section is cracked in flexure, otherwise clause 12.6.3 in EN 1992-1-1 is used
- Design value of maximum shear force will be calculated according to clause 6.2.2(6) ($V_{Ed,max}$) and 6.2.3 (3,4) ($V_{Rd,max}$) in EN 1992-1-1
- Design value of shear resistance is calculated according to 6.2.3 (3,4) ($V_{Rd,s}$) in EN 1992-1-1
- The number of shear links is loaded directly from Design defaults from concrete settings or concrete data
- The angle of compression strut can be calculated automatically or defined by the user
- The torsional cracking moment ($T_{Rd,c}$) is calculated according to clause 6.3.2(5) in EN 1992-1-1
- Design value of maximum of torsional resistance moment ($T_{Rd,max}$) is calculated according to clause 6.3.2(4) in EN 1992-1-1
- The angle of stirrups for design of shear reinforcement for torsion has to be perpendicular
- There are 5 possibilities for calculation of thin-walled closed section

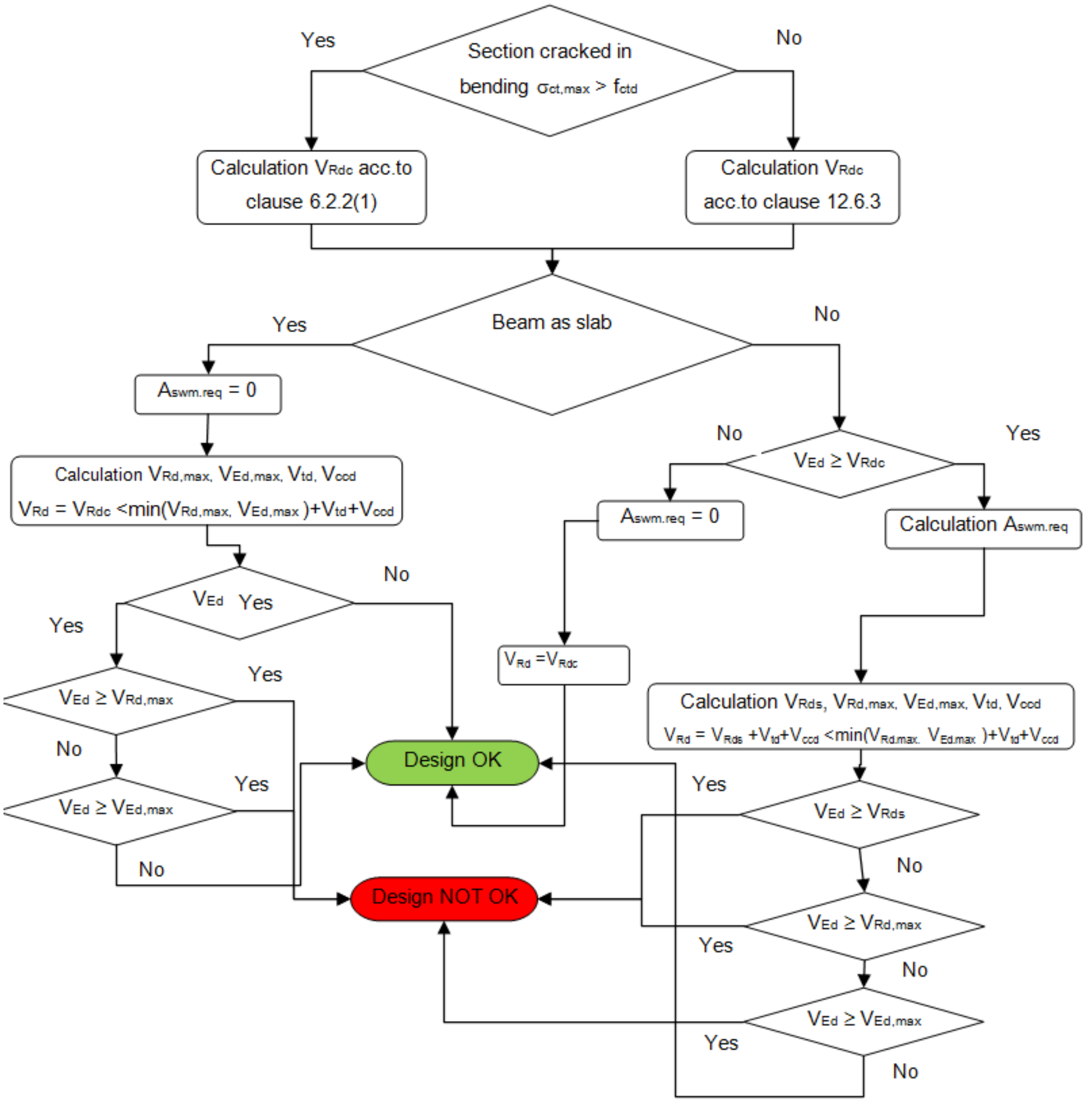
With the following limitations

- Cross-section with one polygon and one material is taken into account in version SEN 15
- The user (practical) reinforcement is not taken into account
- Design should be done only in case, that the angle between gradient of the strain plane and the resultant of shear forces is not greater than 15 degrees
- Inclined compression chord or inclined tensile chord are not taken into account
- The widths of cross-section for shear checks (value b_w and b_{w1}) are calculated automatically. There is no possibility for definition of user value in SEN 15

Except of statically required shear reinforcement per meter ($A_{swm.req}$), the program calculates provided shear reinforcement ($A_{swm.prov}$). It is statically required shear reinforcement, where the spacing of the stirrups in longitudinal direction is rounded to 25 mm.

Design shear reinforcement for shear forces

As was mentioned above, there exists the general concept of “strut-and-tie” model for the prediction of shear effects in concrete. In this model, the top compression and bottom tensile members represent the compressive concrete and tensile reinforcement, respectively. The procedure for design can be represented by the diagram below:



The formulas which are used for the calculation of each component of this model are the following.

Generally, there are two possibilities for the calculation of shear capacity of concrete dependently on existence of cracked in bending:

Shear concrete capacity in region cracked in bending – formula 6.2.a, b in EN 1992-1-1

$$V_{Rd,c} = \left[C_{Rd,c} \cdot k \cdot (100 \cdot \rho_l \cdot f_{ck})^{1/3} + k_1 \cdot \sigma_{cp} \right] \cdot b_w \cdot d$$

$$V_{Rd,c,\min} = (v_{\min} + k_1 \cdot \sigma_{cp}) \cdot b_w \cdot d$$

Shear concrete capacity in region uncracked in bending – clause 12.6.3(3) in EN 1992-1-1

$$V_{Rd,c} = \frac{f_{cvd} \cdot A_{cc}}{k_{12.6.3}}$$

Additionally, there is calculated the maximal shear force ($V_{Ed,max}$) without reduction by b for member where load is applied in the upper side of the member (see formula 6.5 in EN 1992-1-1).

$$V_{Ed.max} - 0.5 \quad b_{w1} \quad d \quad v \quad f_{cd}$$

Maximal capacity of concrete compressive strut ($V_{Rd,max}$) is determined according to formula 6.9 in EN 1992-1-1, because as has been mentioned before, the angle of stirrups (θ) is always perpendicular to the member axis.

$$V_{Rd,max} = \frac{\alpha_{cw} \cdot b_{w1} \cdot z \cdot v_1 \cdot f_{cd}}{\cot(\theta) + \tan(\theta)}$$

Statically required cross-sectional area of the shear reinforcement per meter is calculated from the formula 6.13 in EN 1992-1-1

$$A_{swm.req} = \frac{A_{sw.req}}{s_{l.req}} = \frac{V_{Ed}}{z \cdot f_{ywd} \cdot (\cot(\theta) + \cot(\alpha)) \cdot \sin(\alpha)}$$

Design value of shear force sustained by shear reinforcement ($V_{Rd,s}$) is calculated according to formula 6.13 in EN 1992-1-1

$$V_{Rd,s} = \frac{A_{sw}}{s} \cdot z \cdot f_{ywd} \cdot (\cot(\theta) + \cot(\alpha)) \cdot \sin(\alpha)$$

Design value of shear force sustained by shear reinforcement ($V_{Rd,s}$) is calculated according to formula 6.13 in EN 1992-1-1

$$V_{Rd,s} = \frac{A_{sw}}{s} \cdot z \cdot f_{ywd} \cdot (\cot(\theta) + \cot(\alpha)) \cdot \sin(\alpha)$$

Final design value of shear force (V_{Rd}) carried by the member is calculated based on the following formulas depending on type of member and area of shear reinforcement.

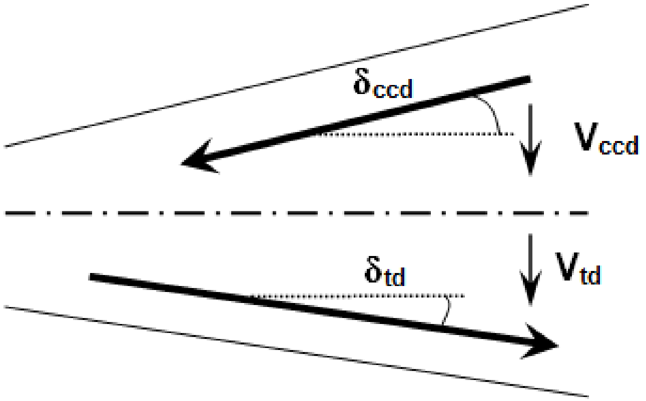
- for beam as slab and for other member with only detailing stirrups ($A_{swm.req} = 0$)

  $$V_{Rd} = V_{Rd.c} \le \min(V_{Rd.max}, V_{Ed.max}) + V_{td} + V_{ccd}$$

- for other cases

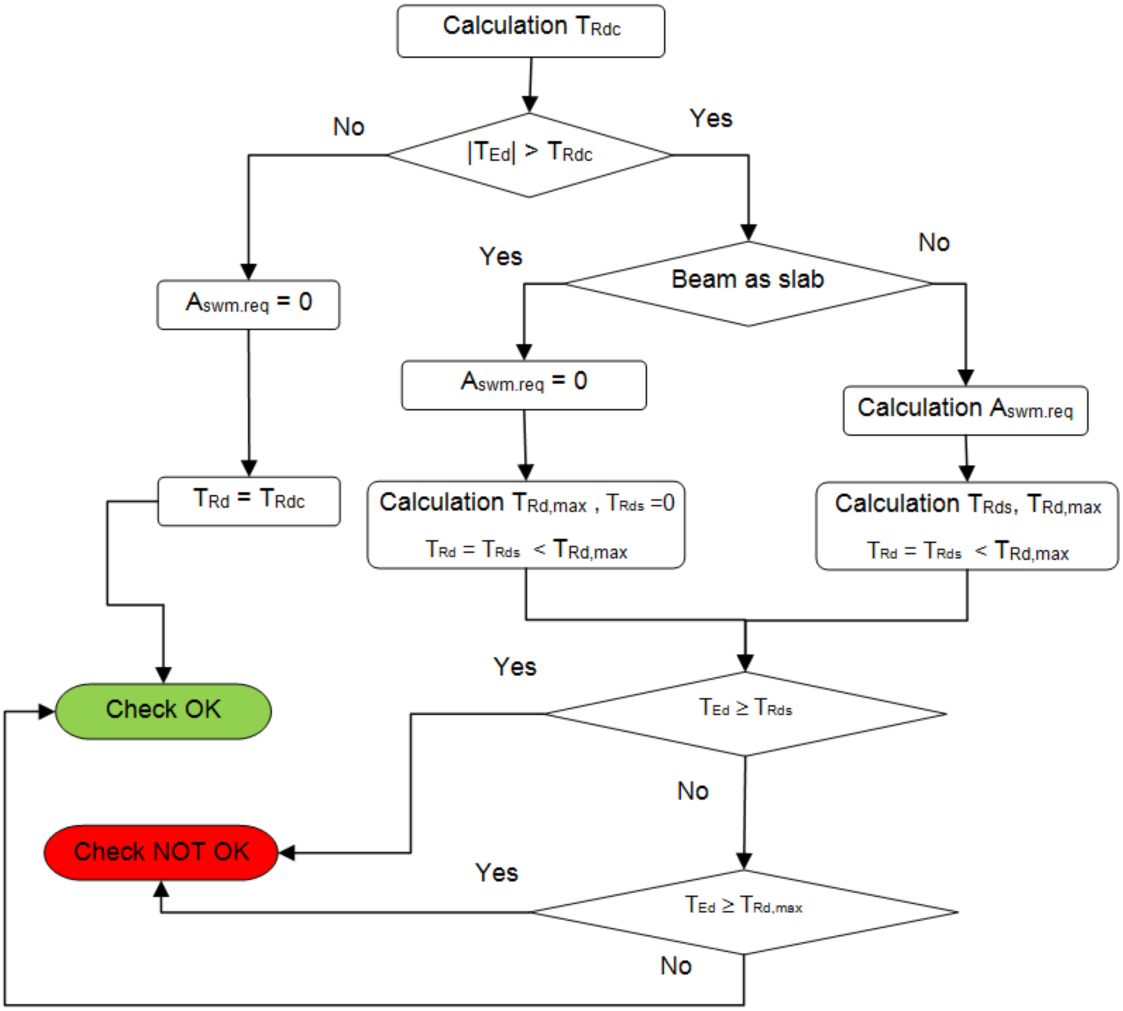
  $$V_{Rd} = V_{Rd,s} + V_{td} + V_{ccd} \le \text{mir}(V_{Rd.max}, V_{Ed,max}) + V_{td} + V_{ccd}$$

For a member with inclined chords the additional forces have to be taken into account for the shear check according to clause 6.2.1(1). The calculation is prepared for taking into account also inclined chords. Nevertheless the calculation itself is not implemented yet. The partial components are explained in the following figure.



Design shear reinforcement for torsion

As was mentioned above, there exists a general concept of the “strut-and-tie” model for the prediction of torsion effects in concrete. In this model, the top compression and bottom tensile members represent the compressive concrete and tensile reinforcement, respectively. The procedure for the design can be represented by the diagram below:



The formulas which are used for the calculation of each component of this model are the following.

Torsional cracking moment is calculated according to equation 6.26 in EN 1992-1-1, provided that the stress caused by the torsional moment is equal to the design axial tensile strength of concrete (value f_{ctd}). It follows:

$$T_{Rdc} = 2 \cdot f_{ctd} \cdot t_{ef} \cdot A_k$$

Maximum of torsional resistance moment ($T_{Rd,max}$) is determined according to formula 6.30 in EN 1992-1-1.

$$T_{Rd.max} = 2 \cdot v \cdot \alpha_{cw} \cdot f_{cd} \cdot A_k \cdot t_{ef} \cdot \cos(\theta) \cdot \sin(\theta)$$

Statically required cross-sectional area of the shear reinforcement per meter is calculated according to the formula below:

$$A_{swm.req} = \frac{A_{swt.req}}{s_{l.req}} = \frac{|T_{Ed}|}{2 \cdot A_k \cdot f_{ywd} \cdot \cot(\theta)}$$

Design torsional resistance moment of torsional reinforcement ($T_{Rd,st}$) is calculated according to the formula below

$$T_{Rd.st} = 2 \cdot A_k \cdot \left(\frac{A_{swt}}{s_t}\right) \cdot f_{ywd} \cdot \cot(\theta)$$

Final design value of torsional moment (T_{Rd}) carried by the member is calculated based on the following formulas:

- for member without or with only detailing stirrups for torsion ($A_{swm.req} = 0$)

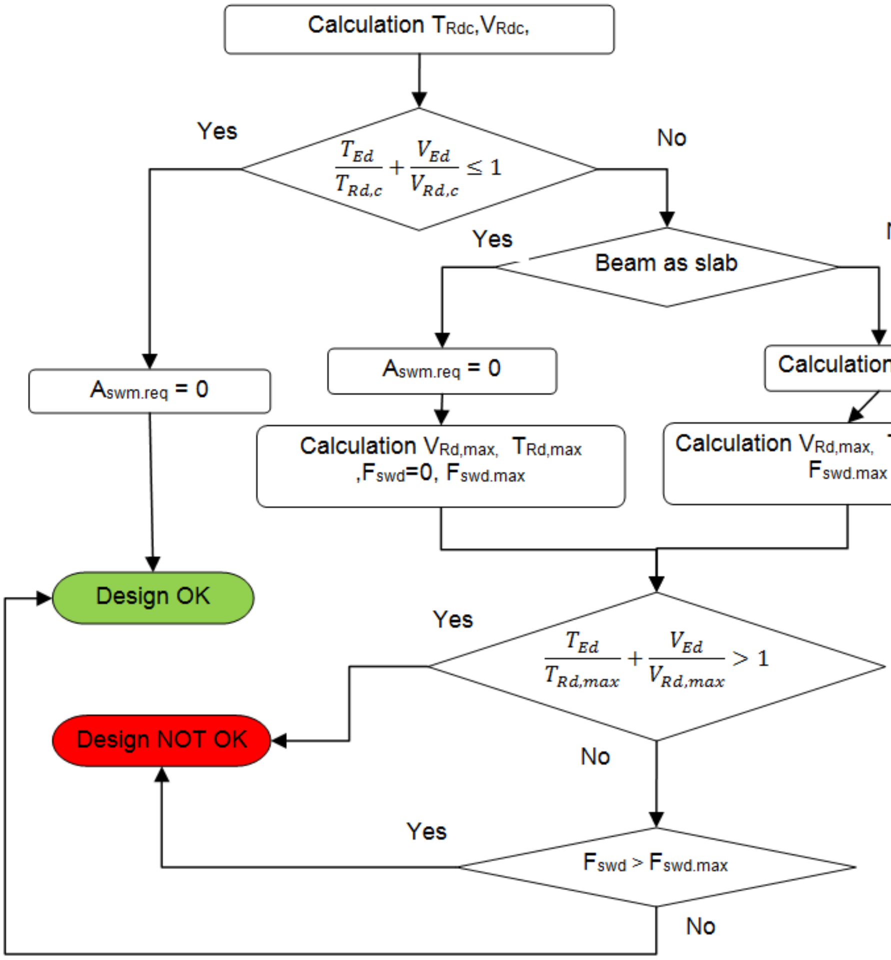
  $T_{Rd} = T_{Rd,c} \leq T_{Rd.max}$

- for other cases

  $T_{Rd} = T_{Rd,s} \leq T_{Rd.max}$

Design shear reinforcement for interaction shear and torsion

As was mentioned above, there exists a general concept of the “strut-and-tie” model for the prediction of shear and torsional effects in concrete. The procedure for design of shear reinforcement for interaction shear and torsion can be represented by the diagram below:



Only minimum reinforcement is required, provided that the following condition (equation 6.31 in EN 1992-1-1) is satisfied:

$$\frac{T_{Ed}}{T_{Rd,c}} + \frac{V_{Ed}}{V_{Rd,c}} \leq 1$$

The maximum resistance of a member subjected to torsion and shear is limited by the capacity of the concrete struts. In order not to exceed this resistance the following condition (equation 6.29 in EN 1992-1-1) should be satisfied:

$$\frac{T_{Ed}}{T_{Rd,max}} + \frac{V_{Ed}}{V_{Rd,max}} \leq 1$$

Statically required cross-sectional area of the shear reinforcement per meter is calculated according to formulas

$$A_{swm1,req} = \frac{A_{sw,req}}{s_{l,req}} = \frac{V_{Ed}}{z \cdot f_{ywd} \cdot (\cot(\theta) + \cot(\alpha)) \cdot \sin(\alpha)}$$

$$A_{swm2,req} = \frac{A_{swt,req}}{s_{l,req}} = \frac{\frac{|T_{Ed}|}{2 \cdot A_k} + \frac{V_{Ed}}{n_s \cdot z}}{f_{ywd} \cdot \cot(\theta)}$$

$$A_{swm,req} = \max(A_{swm1,req}, A_{swm2req})$$

The force in shear reinforcement caused by shear and torsion effect can be calculated according to formula

$$F_{swd} = \left(\frac{T_{Ed}}{2 \cdot A_k} + \frac{V_{Ed}}{n_s \cdot z}\right) \cdot \frac{s_t}{\cot(\theta)}$$

The maximum force which, can be carried by shear reinforcement is given by formula:

$$F_{swd,max} = A_{swt} \cdot f_{ywd}$$

Torsional longitudinal reinforcement

Additional tensile forces caused by torsion are calculated from the equation 6.28 in EN 1992-1-1:

$$F_{sdt} = \frac{|T_{Ed}|}{2 \cdot A_k} \cdot u_k \cdot \cot(\theta)$$

The required cross-sectional area of the longitudinal reinforcement for torsion is calculated in the case, when sum of design axial forces (N_{Ed}) and Additional tensile forces caused by torsion (F_{sdt}) is tensile (bigger than 0). This area is calculated by using the biaxial method for design, with following preconditions:

- reinforcement is designed only for pure tension
- longitudinal reinforcement is equally distributed on each edge of the cross-section

In a simplified way said, the longitudinal reinforcement for torsion is designed according to the formula below:

$$\Delta A_s = \frac{F_{sdt}}{\sigma_{sd}}$$

Additional tensile forces caused by shear forces is taken into account in the design of statically required reinforcement by shifting of the bending moments.

Practical reinforcement

As in the past, a practical reinforcement layout can be defined for each 1D concrete member. Longitudinal bars, stirrups and free-form bars are available for manual input by the user. Additionally, also anchorage types may be chosen and their properties may be manipulated by the user.

This practical reinforcement layout forms the basis for several ULS and SLS checks of reinforced concrete members.

The input of practical reinforcement is explained more in detail in the Advanced Concept Training – 1D concrete members.

Check

Stiffness

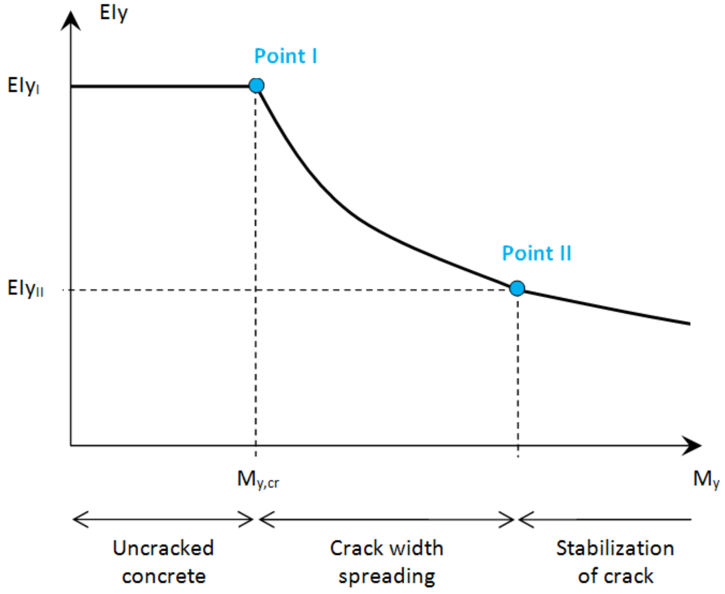
The behaviour of reinforced concrete is not linear-elastic, even with loads within working stress limits, and it is therefore necessary to adjust either E or I depending on the magnitude of the applied load. In addition concrete is subject to significant long term strains due to creep and shrinkage, which will affect the curvature and stiffness of a reinforced concrete structure. This chapter describes how the curvature and stiffness of a reinforced concrete section is calculated.

Stiffness presentation command is used for the presentation of the calculated stiffness. The procedure for calculation of stiffness is based on the requirements mentioned in chapter 7.4.3 from EN 1992-1-1. Generally, two states of cross-section are considered:

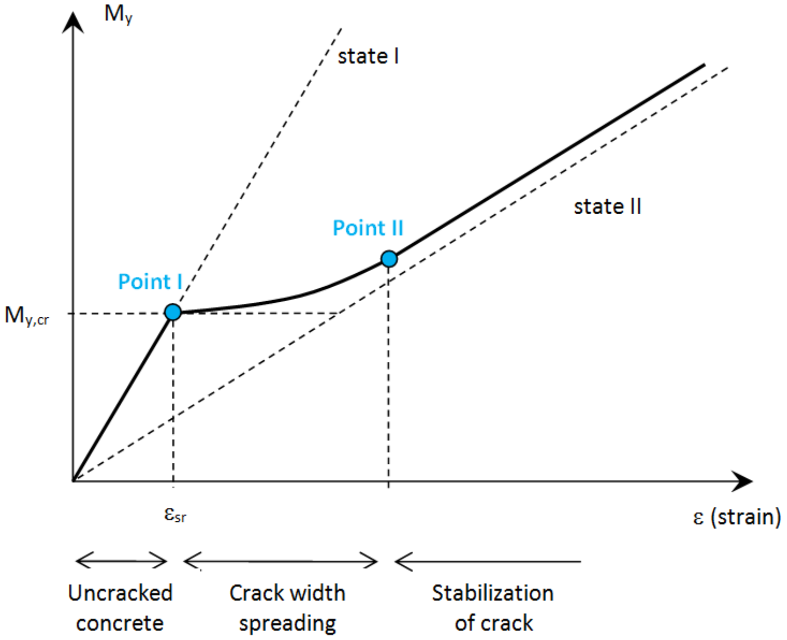
I. **uncracked cross-section** - which is loaded below the level when tensile strength of concrete is reached, here the cross-section with tensile strength is used

II. **fully cracked cross-section** - which is loaded above the level when tensile strength of concrete is reached, here the cross-section without tensile strength is used

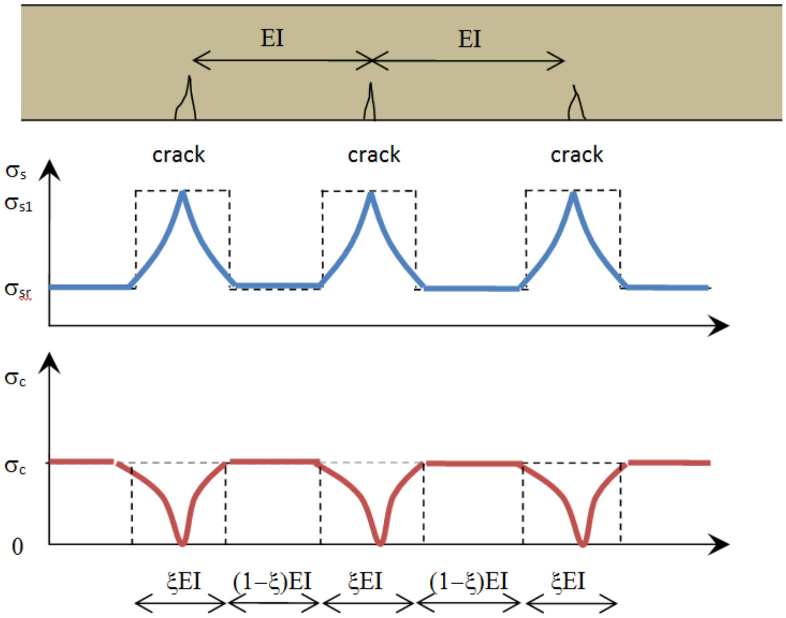
The stiffness is decreased when the load achieves the cracking moment ($M_{y,cr}$). The dependency of stiffness on the cracking moment is visible from the following figure. The curve is not linear due to tensile stiffening which is partly higher when the cross-section is completely without tensile strength.



The behaviour of the reinforced cross-section can also be expressed in term of moment and strain (deformation) diagram. The final value of stiffness is calculated using the interpolation formula between state (I) deformation for uncracked concrete section (x=0) and state (II) deformation for fully cracked concrete section (no tension carries) (x=1) dependently on the ratio of stress in reinforcement from cracking load and acting load. The dependency of cracking moment on strain in the concrete is visible from the following figure.

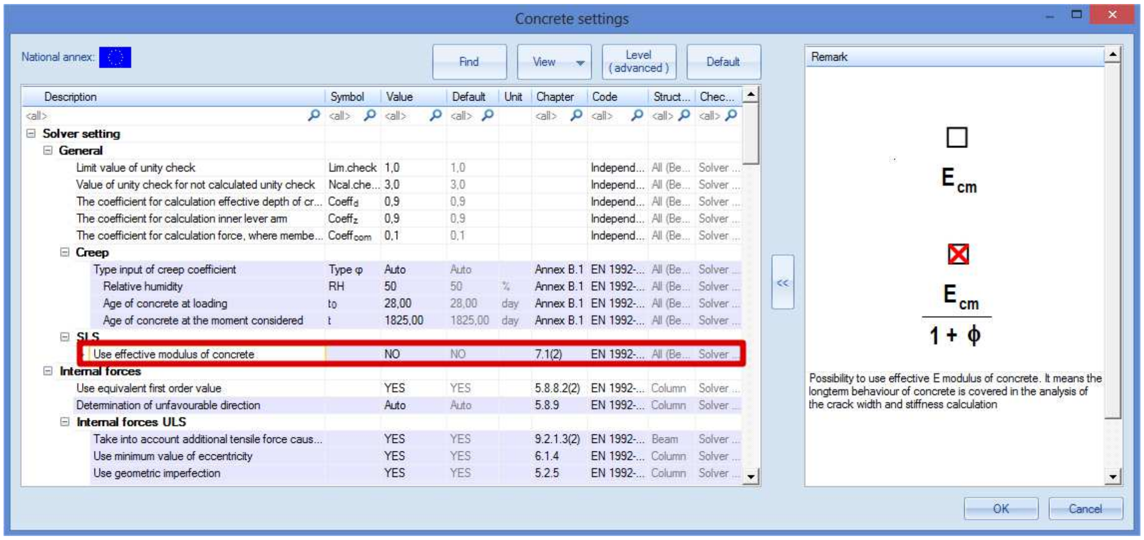


The distribution of the reinforcement stress in crack and between cracks can be graphically expressed on the following figure. Reinforcement stress is higher in cracks and concrete stress is zero in cracks. The final value of stiffness is dependent on the tension stiffening of concrete in cracks based on the distribution coefficient.



The plane of the equilibrium is calculated for a particular state of the cross-section using the method described in chapter "Theoretical background" . There are used different stress-strain diagrams towards the Capacity-response (ULS). Stress-strain diagrams based on the serviceability limit state are used for finding of the plain of the equilibrium. Generally, this command uses the iterative method for the interaction of the normal force (N) with uni-axial or bi-axial bending moments ($M_y + M_z$). Additionally, there is a possibility to calculate short-term or long-term stiffness which is applied via a modified stress-strain diagram.

SCIA Engineer is able to calculate short-term or long-term stiffness. This type depends on setting in Global settings - Solver settings - General - SLS - Use effective modulus of elasticity.



Description	Symbol	Value	Default	Unit	Chapter	Code	Struct...	Chec...
<all>	<all>	<all>	<all>		<all>	<all>	<all>	<all>
Solver setting								
General								
Limit value of unity check	Lim.check	1,0	1,0			Independ...	All (Be...	Solver ...
Value of unity check for not calculated unity check	Ncal.che...	3,0	3,0			Independ...	All (Be...	Solver ...
The coefficient for calculation effective depth of cr...	$Coeff_d$	0,9	0,9			Independ...	All (Be...	Solver ...
The coefficient for calculation inner lever arm	$Coeff_z$	0,9	0,9			Independ...	All (Be...	Solver ...
The coefficient for calculation force, where membe...	$Coeff_{com}$	0,1	0,1			Independ...	All (Be...	Solver ...
Creep								
Type input of creep coefficient	Type φ	Auto	Auto		Annex B.1	EN 1992-...	All (Be...	Solver ...
Relative humidity	RH	50	50	%	Annex B.1	EN 1992-...	All (Be...	Solver ...
Age of concrete at loading	t_0	28,00	28,00	day	Annex B.1	EN 1992-...	All (Be...	Solver ...
Age of concrete at the moment considered	t	1825,00	1825,00	day	Annex B.1	EN 1992-...	All (Be...	Solver ...
SLS								
Use effective modulus of concrete		NO	NO		7.1(2)	EN 1992-...	All (Be...	Solver ...
Internal forces								
Use equivalent first order value		YES	YES		5.8.8.2(2)	EN 1992-...	Column	Solver ...
Determination of unfavourable direction		Auto	Auto		5.8.9	EN 1992-...	Column	Solver ...
Internal forces ULS								
Take into account additional tensile force caus...		YES	YES		9.2.1.3(2)	EN 1992-...	Beam	Solver ...
Use minimum value of eccentricity		YES	YES		6.1.4	EN 1992-...	Column	Solver ...
Use geometric imperfection		YES	YES		5.2.5	EN 1992-...	Column	Solver ...

☐ E_{cm}

☒ $\dfrac{E_{cm}}{1+\phi}$

Possibility to use effective E modulus of concrete. It means the longterm behaviour of concrete is covered in the analysis of the crack width and stiffness calculation

Theory

The calculation procedure can be described in the following steps:

1) Calculation of uncracked cross-section
The cross-section characteristics for the uncracked cross-section (using linear stress-strain diagram with tensile branch for concrete and reinforcement) are calculated. This state is signed with bottom index I.

Cross-section characteristics

Type of component	t_y [m]	t_z [m]	A [m^2]	I_y [m^4]	I_z [m^4]	x_i [m]	A_{st} [m^2]	A_{sc} [m^2]	A_s [m^2]
Linear	0	0	0.354	$664 \cdot 10^{-6}$	0.164	0.075	-	-	-
Uncracked	0	$-8 \cdot 10^{-3}$	0.418	$805 \cdot 10^{-6}$	0.198	0.08	$2.21 \cdot 10^{-3}$	0	$2.21 \cdot 10^{-3}$
Cracked	0	0.015	0.205	$449 \cdot 10^{-6}$	0.0994	0.06	$2.21 \cdot 10^{-3}$	0	$2.21 \cdot 10^{-3}$

2) Calculation of tensile concrete strength used for crack appearance
Stiffness and deflections are dependent significantly on the effective concrete strength which governs the cracking moment. Value of strength determines if crack appears or not. The resultant value is the effective tensile concrete strength σ_{cr} which can be f_{ctm} or $f_{ctm,fl}$. Additionally, there is a possibility to set the tensile strength to 0MPa.

3) Verification of crack appearance
At first crack appearance is verified for the characteristic load combination in accordance to chapter 7.1(2) - maximal tensile stress in concrete fibre is compared with effective concrete tensile strength $f_{ct,eff}$. The calculation of maximal tensile stress in the concrete fibre is performed on the cross-section with SLS linear diagram of concrete with tensile branch and the reinforcement is taken into account with linear diagram. As a conclusion, two cases can appear:

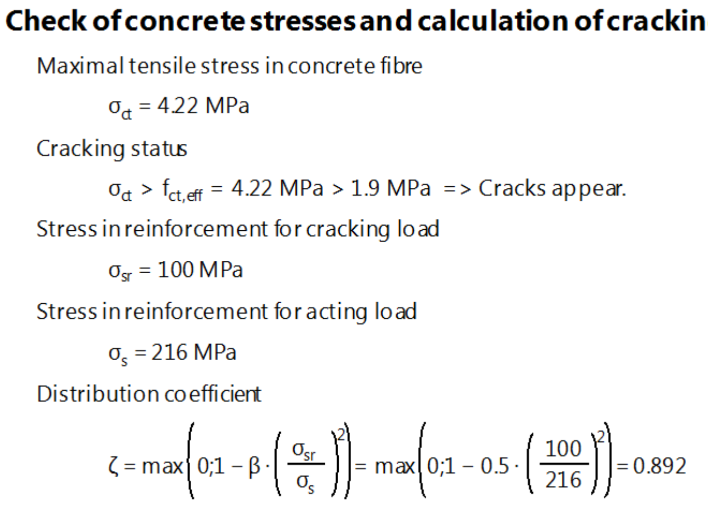
1) $s_{ct} \leq \sigma_{cr}$ - no crack appears; the cross-section is considered as uncracked and SLS linear diagram with tension is used for another step of the calculation.
2) $s_{ct} > \sigma_{cr}$ - crack appears; the cross-section is considered as cracked; the cross-section is recalculated using SLS linear diagram without tension.

When the cracks appear then the following steps are done.

4) Calculation of cracking internal forces
The cracking internal forces are calculated based on the uncracked CSS characteristics and tensile concrete strength. Afterwards, these cracking forces are used for calculation of stress in reinforcement (σ_{sr}).

5) Calculation of distribution coefficient
Before the distribution coefficient is calculated, the reinforcement stress for acting load (σ_s) and for cracking load (σ_{sr}) has to be known. There is a coefficient β which is determined according to the duration of the load:

- β = 1,0 - for short-term load
- β = 0,5 - for long-term load (based on using Use effective modulus of concrete = true)



Check of concrete stresses and calculation of cracking forces

Maximal tensile stress in concrete fibre

$\sigma_{ct} = 4.22$ MPa

Cracking status

$\sigma_{ct} > f_{ct,eff} = 4.22$ MPa > 1.9 MPa => Cracks appear.

Stress in reinforcement for cracking load

$\sigma_{sr} = 100$ MPa

Stress in reinforcement for acting load

$\sigma_s = 216$ MPa

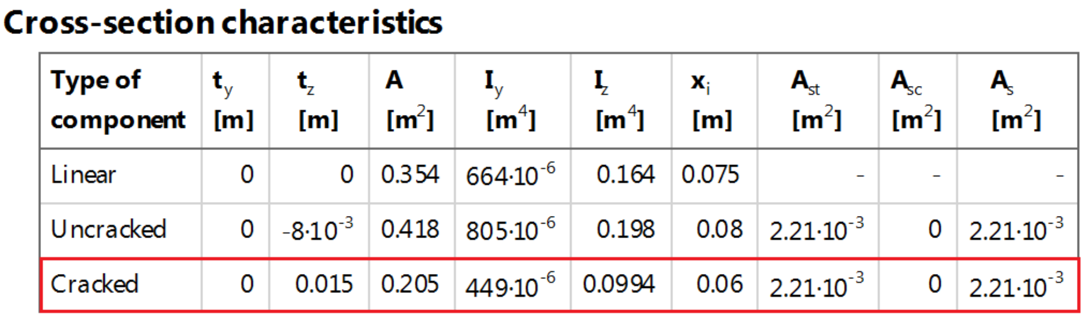
Distribution coefficient

$$\zeta = \max\left(0;1 - \beta \cdot \left(\frac{\sigma_{sr}}{\sigma_s}\right)^2\right) = \max\left(0;1 - 0.5 \cdot \left(\frac{100}{216}\right)^2\right) = 0.892$$

The distribution coefficient (in fact coefficient of tension stiffening) is calculated based on the type of load (β) and also on the ratio of reinforcement stress for cracking and acting load

$$x = 1\text{-}\beta \bullet (\sigma_{sr}/\sigma_s)^2$$

6) Calculation of fully cracked cross-section
The cross-section characteristics for full cracked cross-section (using linear stress-strain diagram without tensile branch for concrete and reinforcement) are calculated. This state is signed with bottom index II.



Cross-section characteristics

Type of component	t_y [m]	t_z [m]	A [m^2]	I_y [m^4]	I_z [m^4]	x_i [m]	A_{st} [m^2]	A_{sc} [m^2]	A_s [m^2]
Linear	0	0	0.354	$664 \cdot 10^{-6}$	0.164	0.075	-	-	-
Uncracked	0	$-8 \cdot 10^{-3}$	0.418	$805 \cdot 10^{-6}$	0.198	0.08	$2.21 \cdot 10^{-3}$	0	$2.21 \cdot 10^{-3}$
Cracked	0	0.015	0.205	$449 \cdot 10^{-6}$	0.0994	0.06	$2.21 \cdot 10^{-3}$	0	$2.21 \cdot 10^{-3}$

7) Calculation of resultant values of stiffnesses and curvatures
When the steps above are calculated then resultant values of stiffnesses can be calculated using the interpolation formula respecting uncracked state (I) and fully cracked state (II).

Calculation of the resultant bending stiffness:

$$EI_y = \frac{1}{\frac{\zeta}{EI_{y,II}} + \frac{1-\zeta}{EI_{y,I}}}$$

axial stiffness:

$$EA = \frac{1}{\frac{\zeta}{EA_{II}} + \frac{1-\zeta}{EA_{I}}}$$

and curvatures:

$$\frac{1}{r_y} = \zeta \cdot \frac{1}{r_{y,II}} + (1-\zeta) \cdot \frac{1}{r_{y,I}}$$

Capacity - response (ULS)

The Capacity - response is based on the calculation of strain and stress in a particular component (concrete fibre, reinforcement bar) and comparison with limited values with respect of EN 1992-1-1 requirements. Based on the internal forces, concrete cross-section and defined reinforcement by the user, SCIA Engineer is able to calculate the response of a member or a single cross-section. This method uses an iteration routine to calculate equilibrium based on the internal forces, the cross-section, material properties and reinforcement layout. However, this method does not calculate extremes (capacities of cross-section) like the interaction diagram, but calculates the state of equilibrium for that section (response). The calculation also includes depth of compression zones (d), curvatures in each axis (ε_x,ε_y and ε_z), stresses, strains and forces in particular components. Generally, this iterative method works for the interaction of the normal force (N) with uni-axial or bi-axial bending moments ($M_y + M_z$).

There are the following assumptions:

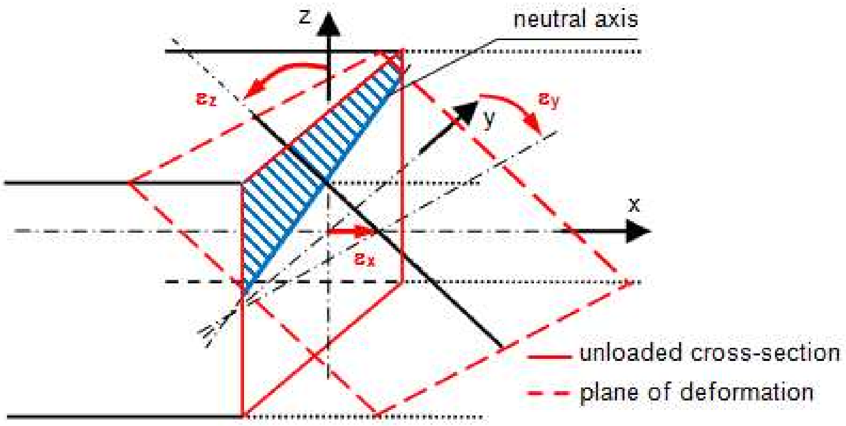
- Strain and stress diagram defined in material properties will be used
  - Concrete – bilinear or parabola-rectangular stress-strain diagram
  - Reinforcement – bilinear with or without inclined horizontal branch stress-strain diagram
- Tensile stress in concrete is not considered
- Standard REDES reinforcement is considered

With the following limitations

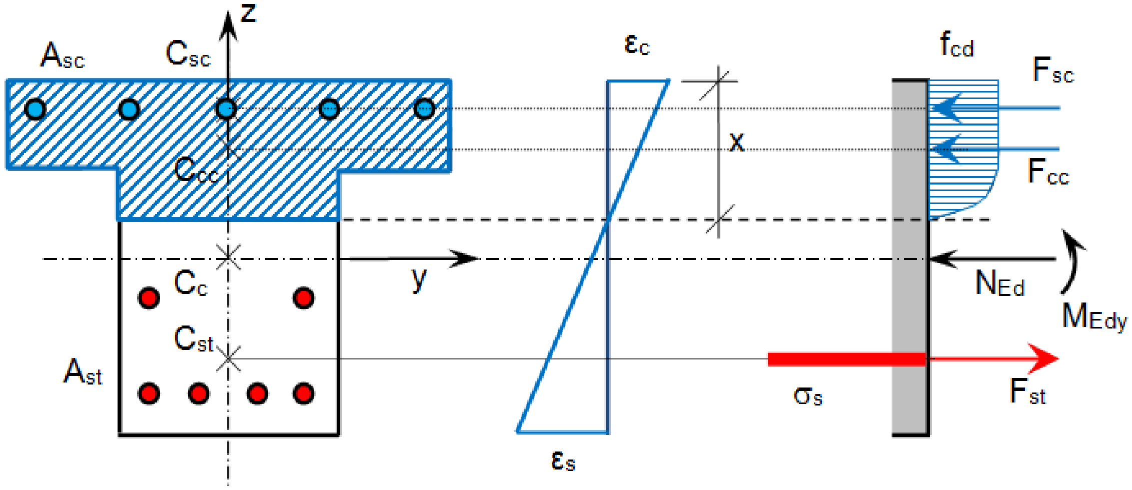
- The area of longitudinal reinforcement is not subtracted from concrete area in the first step

Theoretical background

Imagine a diagram representing the strain in a reinforced concrete cross-section. Generally, the cross-section can be non-symmetric to y or z axis and loaded with a combination of N, M_y and M_z. Then the vector of strain consists of three nonzero values $\varepsilon = \{\varepsilon_x; \varepsilon_y, \varepsilon_z\}$. This vector determines the so called plane of deformation.



Corresponding plane of strain for plane of equilibrium in one plane bending only (M_y) is shown in following figure. Nevertheless, the distribution of the stress in compression part depends on type of stress-strain diagram of concrete. When bilinear diagram is used then the distribution is constant or linear constant. In case of parabola-rectangular diagram the stress distribution is constant or linear-parabola.



The previous figure shows a non specific case, but let us imagines an ultimate state. Under the ultimate state, we understand a case, where either concrete or steel is strained to a limit value. We can draw some cases in a similar diagram. The basic assumptions of this limit strain method show the following figure. Generally, four limit strain states can occur. The numbering (1-4) in the following figure represents particular state types of the cross-section. The state (1) corresponds to the optimal failure when ultimate compressive strain in concrete (ε_{cu}) and ultimate tensile strain in reinforcement (ε_{ud}) are reached. In case of state (2), the ultimate limit strain in concrete is assumed within considering the strain in prestressing at the beginning of plastic branch (ε_s). The state (3) expresses the starting of the concrete crushing. Finally, the state (4) represents the reaching of ultimate compressive strain for an axially loaded member decreased due to brittle failure effect.

The following checks are performed:

- Check of compressive concrete

$\frac{\varepsilon_{cc}}{\varepsilon_{cc,lim}}$ verification of strains

$\frac{\sigma_{cc}}{\sigma_{cc,lim}}$ verification of stresses

- Check of compressive reinforcement

$$\frac{\varepsilon_{sc}}{\varepsilon_{sc,lim}}$$

verification of strains

$$\frac{\sigma_{sc}}{\sigma_{sc,lim}}$$

verification of stresses

- Check of tensile reinforcement

$$\frac{\varepsilon_{st}}{\varepsilon_{st,lim}}$$

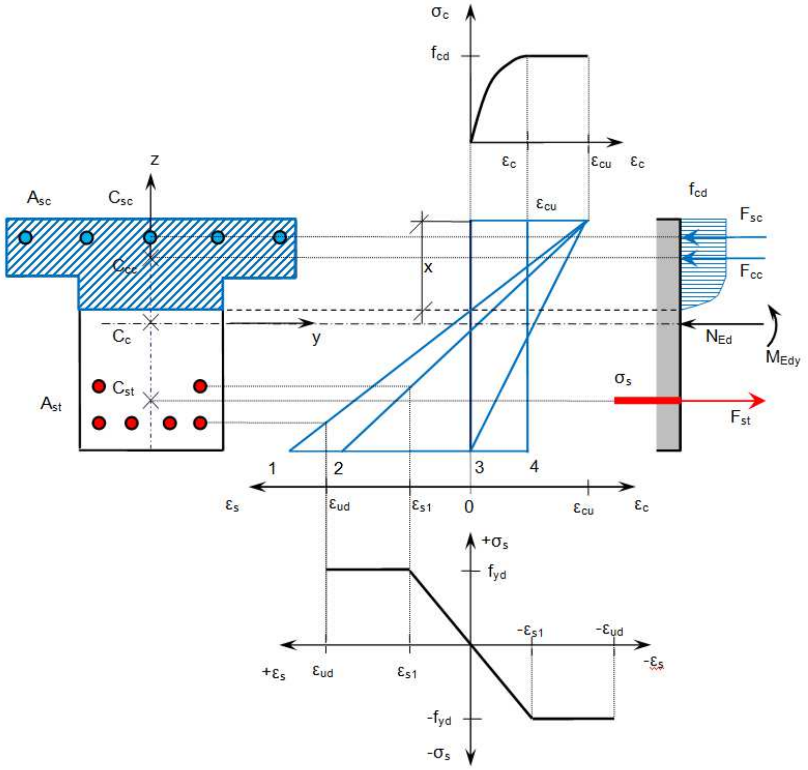
verification of strains

$$\frac{\sigma_{st}}{\sigma_{st,lim}}$$

verification of stresses

Unity check is maximum from all partial unity checks. It means

$$Unity\ check\ = max\left(\frac{\varepsilon_{cc}}{\varepsilon_{cc,lim}};\frac{\sigma_{cc}}{\sigma_{cc,lim}};\frac{\varepsilon_{sc}}{\varepsilon_{sc,lim}};\frac{\sigma_{sc}}{\sigma_{sc,lim}};\frac{\varepsilon_{st}}{\varepsilon_{st,lim}};\frac{\sigma_{st}}{\sigma_{st,lim}}\right)$$



Effective depth of cross-section

The effective depth of cross-section is usually defined as the distance between the most compressive fibre of concrete to the centre of gravity of tensile reinforcement. In SEN, the effective depth of cross-section is defined as the distance between the most compressive fibre of concrete to the position of resultant of forces in tensile reinforcement. In relation of bending loading in SEN is calculated the perpendicular projection of this distance to the straight line perpendicular to the neutral axis (slope line plane of equilibrium), called d_{rec}.

There are some exceptional cases, when effective depth is not calculated from plane of equilibrium:

- The most compressive fibre cannot be determined (the whole cross-section is in tension)
- Resultant of forces in tensile reinforcement cannot be determined (whole section is in compression)
- Equilibrium is not found
- Distance between the most compressive fibre and Resultant of forces in tensile reinforcement is lesser than 0,5×h

In this cases, the effective depth is calculated according to formula

$$d = d_{rec} = Coef_d \times h_l$$

If there are most compressive concrete fibres with the same value of compressive stress, the fibre which is the nearest to the straight line in the direction of the resultant of bending moment and crossing the centre of gravity of cross-section, is taken into account for the calculation of effective depth .

Inner lever arm

Inner lever arm in EN 1992-1-1, clause 6.2.3 (3) is defined as the distance of forces in tensile and compression chord, it follows that it is the distance of position of resultant of tensile force (tensile reinforcement) and position of resultant of compressive force (compressive reinforcement and compressive concrete). For a better overview, there is calculated the perpendicular projection inner lever am to a straight line perpendicular to the neutral axis (slope line plane of equilibrium), called z_{rec}.

Except of the value of inner lever arm, there is calculated only a part of inner lever arm:

- part of inner lever arm (distance from centre of tensile force to centre of gravity of cross-section) – value z+ or projection of this value to a straight line perpendicular to neutral axis – value z_{rec+}
- is part of inner lever arm (distance from centre of compressive force to centre of gravity of cross-section) – value z- or projection of this value to a straight line perpendicular to neutral axis – value z_{rec-}

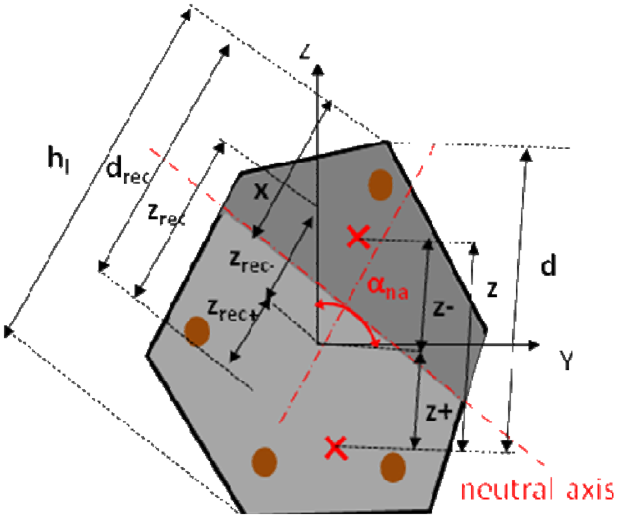
There are some exceptional cases, when inner lever arm is not calculated from plane of equilibrium:

- The most compressive fibre cannot be determined (the whole cross-section is in tension)
- Resultant of forces in tensile reinforcement cannot be determined (whole section is in compression)
- equilibrium is not found

In this cases, the inner lever arm and parts of inner lever arm is calculated according to formula

$$z = z_{rec} = Coef_z \times d$$

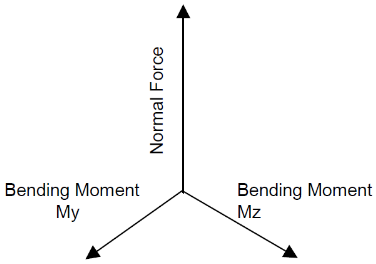
$$z+ = z_{rec+} = z- = z_{rec-} = 0.5 \times z$$



Capacity - diagram (ULS)

Capacity - diagram service uses creation of interaction diagram which is a graph illustrating the capacity of the concrete member to resist a set of combinations of axial force and bending moment. Dependent on the load, the position of the neutral axis is changed and this leads to obtaining different values of compressive and tensile areas in concrete members. Therefore this concludes to a different capacity calculated from the strain distribution.

The Capacity - diagram calculates the extreme allowable interaction between the normal force N and bending moments M_y and M_z. In theory this diagram is a 3D-diagram, but SCIA Engineer allows the user to obtain horizontal and vertical sections. The axis of the diagram has an axis for the normal force N, the bending moment M_y and the bending moment M_z.



There are the following assumptions:

- Strain and stress diagram defined in material properties will be used
    - Concrete – bilinear or parabola-rectangular stress-strain diagram
    - Reinforcement – bilinear with or without inclined horizontal branch stress-strain diagram
- Tensile stress in concrete is not considered
- Standard REDES reinforcement is considered
- Capacity of plain concrete is also calculated by interaction diagram using proper coefficient $a_{cc,pl}$ according to chapter 12.6.3(1) from EN 1992-1-1

With the following limitations

- The area of longitudinal reinforcement is not subtracted from concrete area in the first step

Theoretical background

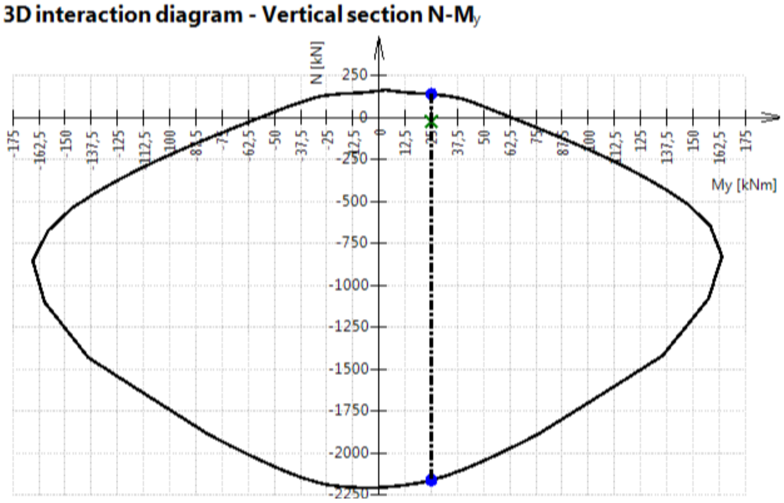
First the section is in pure compression, then it will be over-reinforced until it reaches the point where it is balanced designed. After the point of balanced design the section will reach pure bending, then be under-reinforced and finally be in pure tension

Generally the interaction diagram is used to find the capacities for the checked cross-section. The searching of capacities depends on used method for finding intersection with interaction diagram. This method can be the following:

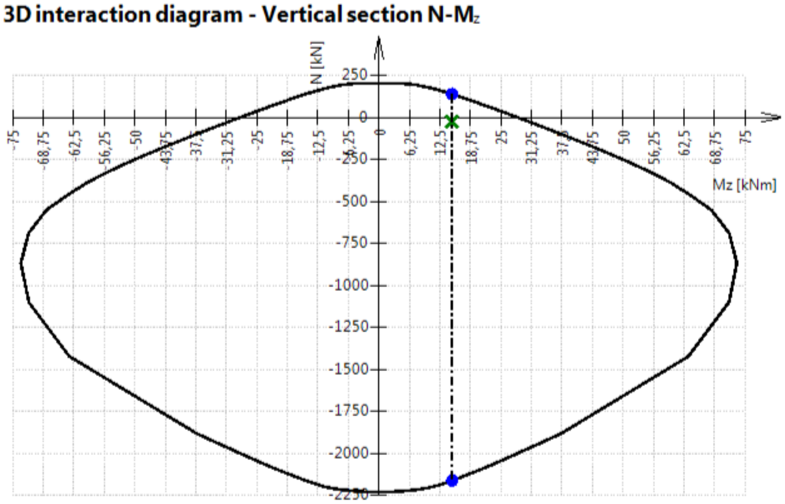
- **NRd** - the bending moment My and Mz are constant and the intersections are searched in the vertical direction
- **MRd** - the normal force N is constant and the intersections are searched in horizontal direction
- **NRdMRd** - the used eccentricity is constant and the intersections are searched in direction of constant eccentricity
- **MRdy** - the bending moment around z axis and normal force are constant and the intersections are searched in horizontal direction in plane N-My
- **MRdz** - the bending moment around y axis and normal force are constant and the intersections are searched in vertical direction in plane N-Mz

See the examples of interaction diagram sections for particular method type:

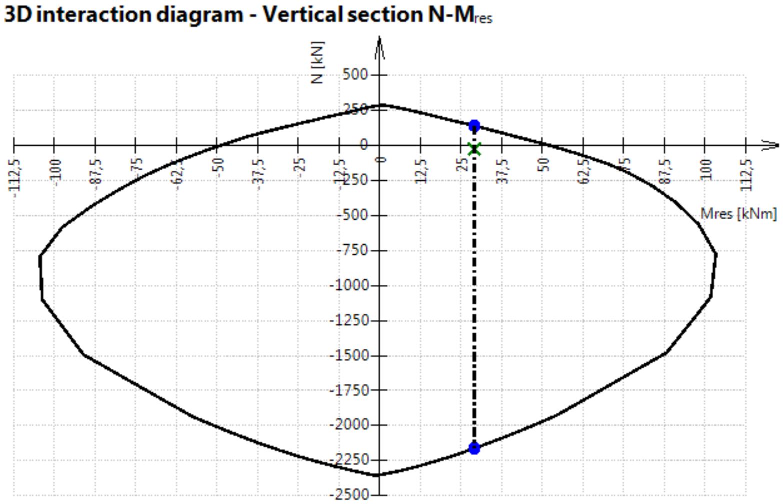
Method NRd: (My and Mz are constant)



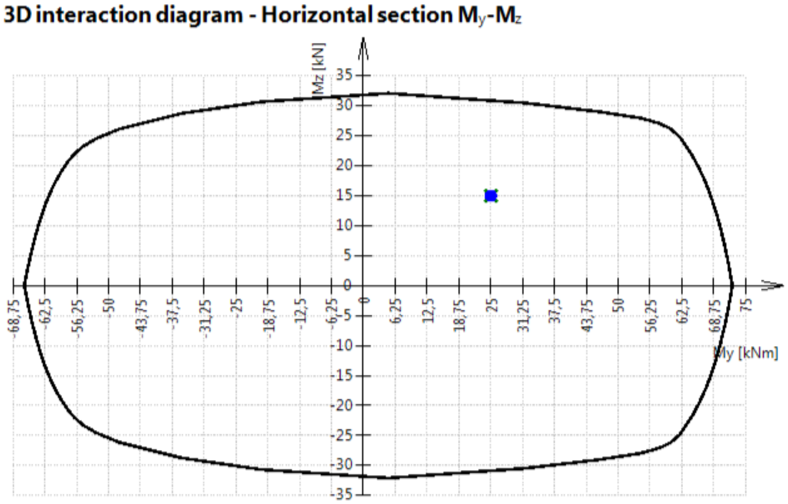
3D interaction diagram - Vertical section N-M_y



3D interaction diagram - Vertical section N-M_z

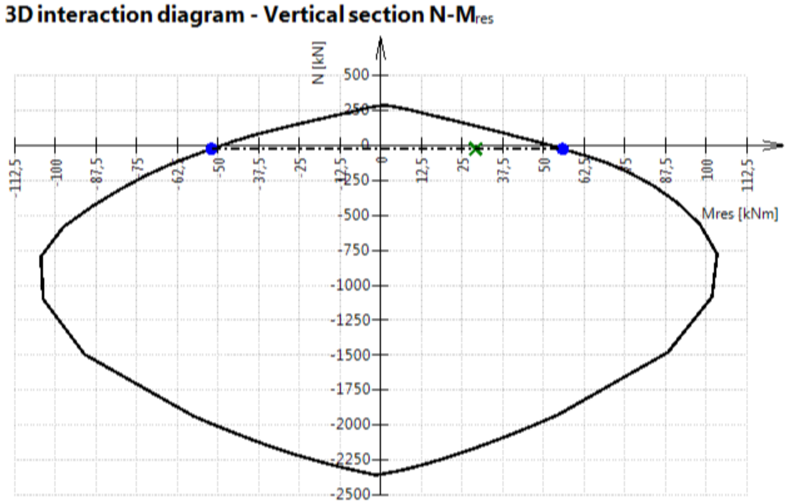


3D interaction diagram - Vertical section N-M_{res}

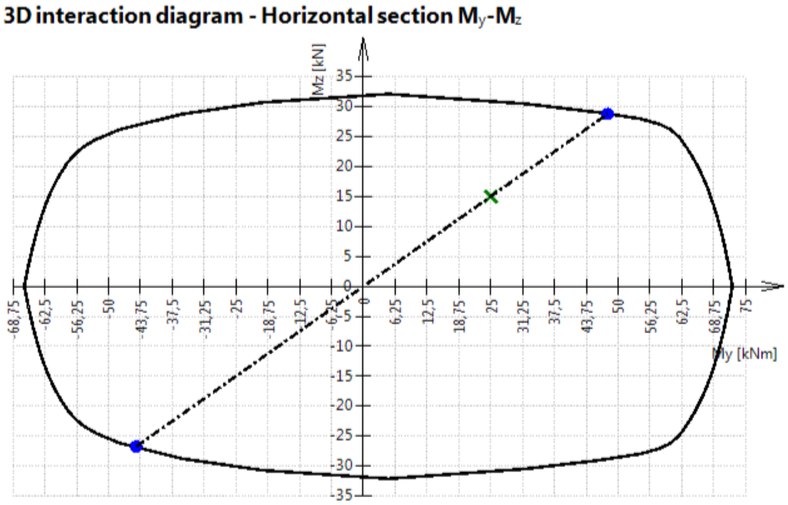


3D interaction diagram - Horizontal section M_y-M_z

Method MRd: (N is constant)

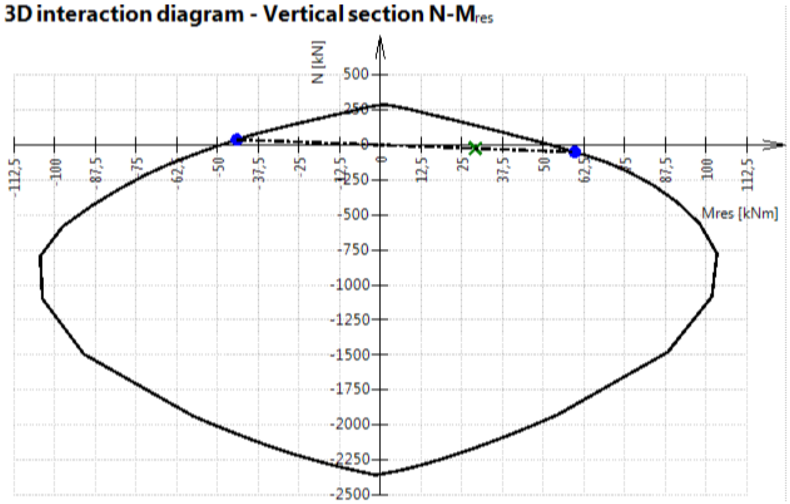


3D interaction diagram - Vertical section N-M_{res}

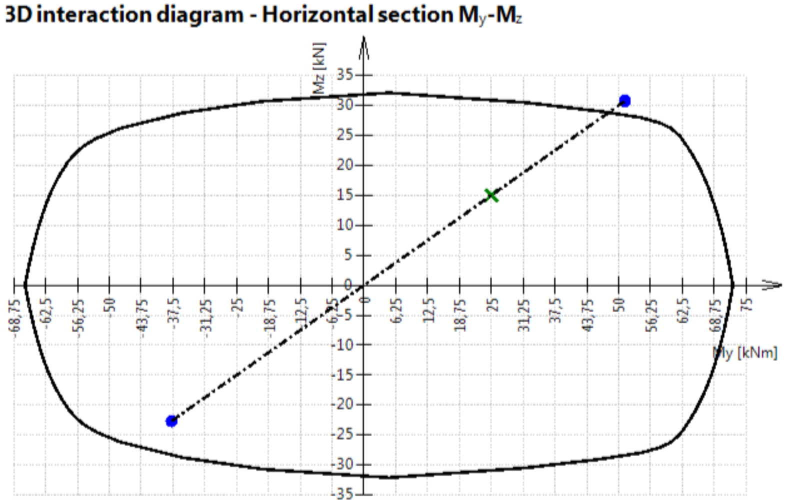


3D interaction diagram - Horizontal section M_y-M_z

Method NRdMRd: (eccentricity = constant)

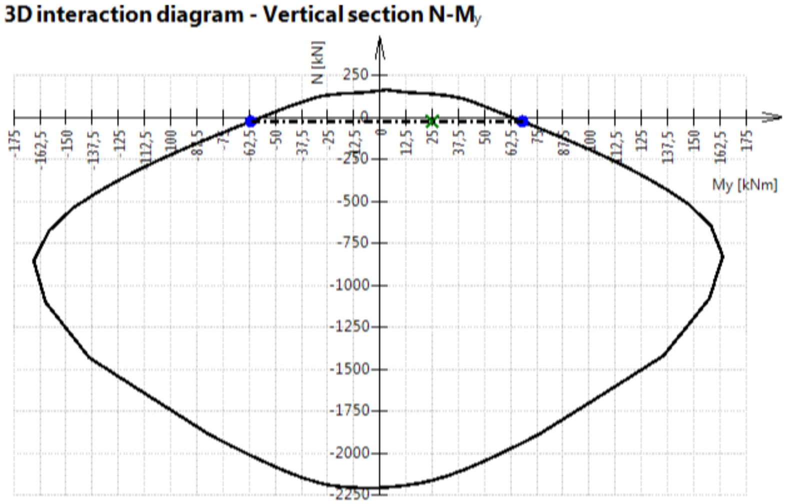


3D interaction diagram - Vertical section N-M_{res}

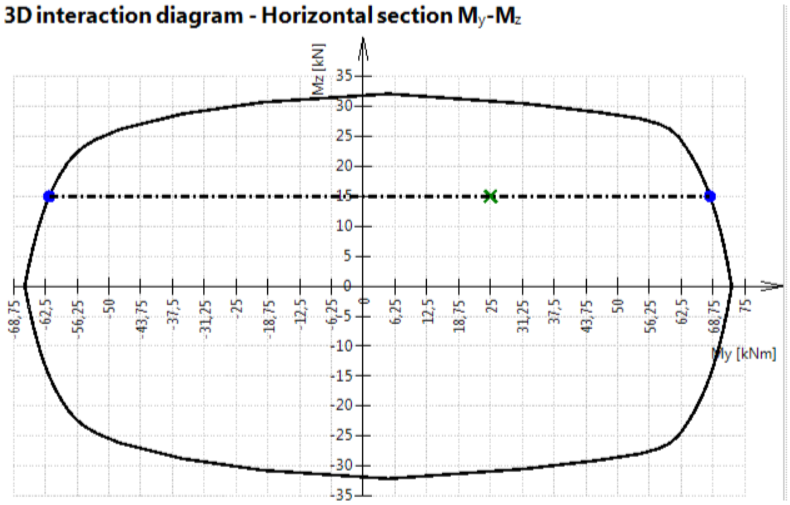


3D interaction diagram - Horizontal section M_y-M_z

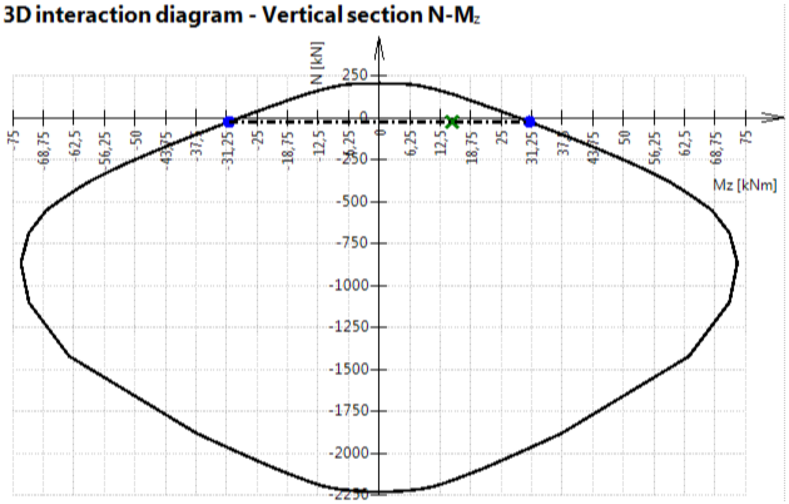
Method MRdy: (Mz and N are constant)

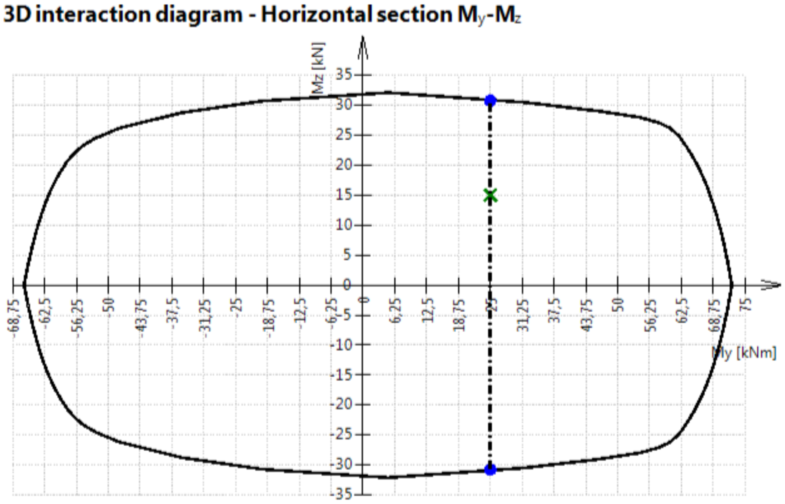


3D interaction diagram - Vertical section N-M_y



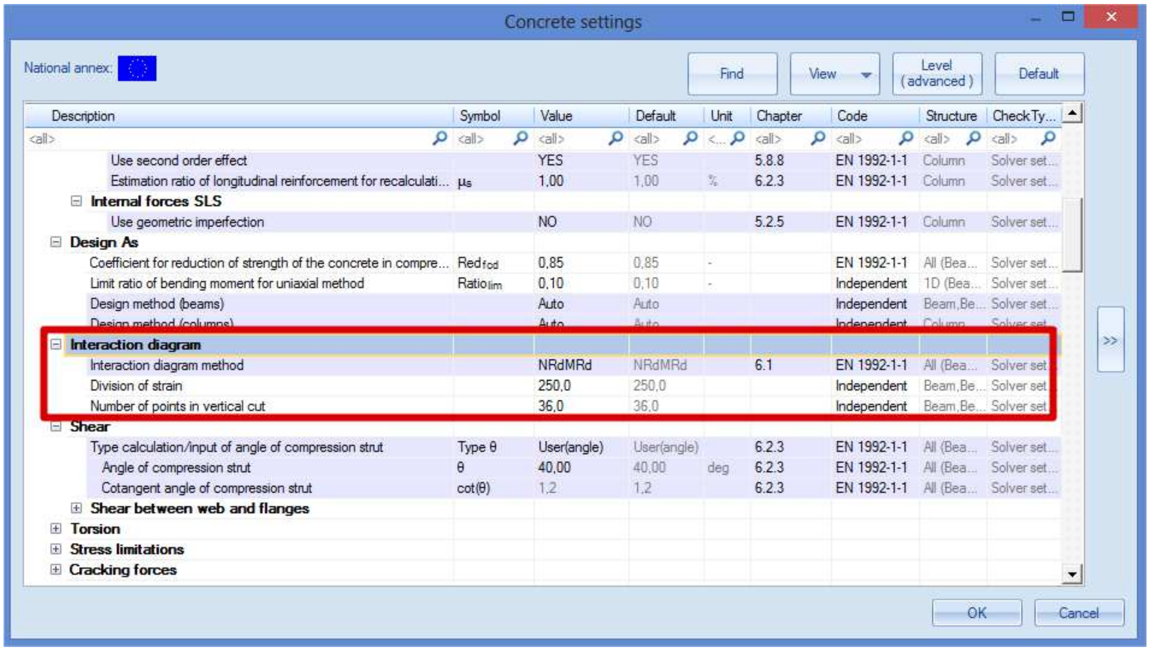
Method MRdz: (My and N are constant)





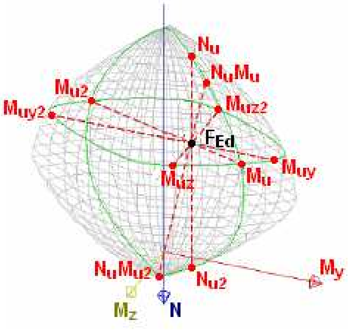
Setup

There are several parameters which affect the generation of the horizontal and vertical cuts of interaction diagrams. These values are stored in Concrete settings (structure). The parameters for interaction diagram are the following:



Concrete settings

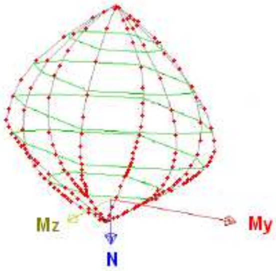
Description	Symbol	Value	Default	Unit	Chapter	Code	Structure	CheckTy...
<all>	<all>	<all>	<all>	<...	<all>	<all>	<all>	<all>
Use second order effect		YES	YES		5.8.8	EN 1992-1-1	Column	Solver set...
Estimation ratio of longitudinal reinforcement for recalculati...	μs	1,00	1,00	%	6.2.3	EN 1992-1-1	Column	Solver set...
⊟ **Internal forces SLS**								
Use geometric imperfection		NO	NO		5.2.5	EN 1992-1-1	Column	Solver set...
⊟ **Design As**								
Coefficient for reduction of strength of the concrete in compre...	Red_{fcd}	0,85	0,85	-		EN 1992-1-1	All (Bea...	Solver set...
Limit ratio of bending moment for uniaxial method	$Ratio_{lim}$	0,10	0,10	-		Independent	1D (Bea...	Solver set...
Design method (beams)		Auto	Auto			Independent	Beam,Be...	Solver set...
Design method (columns)		Auto	Auto			Independent	Column	Solver set...
⊟ **Interaction diagram**								
Interaction diagram method		NRdMRd	NRdMRd		6.1	EN 1992-1-1	All (Bea...	Solver set
Division of strain		250,0	250,0			Independent	Beam,Be...	Solver set
Number of points in vertical cut		36,0	36,0			Independent	Beam,Be...	Solver set
⊟ **Shear**								
Type calculation/input of angle of compression strut	Type θ	User(angle)	User(angle)		6.2.3	EN 1992-1-1	All (Bea...	Solver set...
Angle of compression strut	θ	40,00	40,00	deg	6.2.3	EN 1992-1-1	All (Bea...	Solver set...
Cotangent angle of compression strut	cot(θ)	1,2	1,2		6.2.3	EN 1992-1-1	All (Bea...	Solver set...
⊞ **Shear between web and flanges**								
⊞ **Torsion**								
⊞ **Stress limitations**								
⊞ **Cracking forces**								



Interaction diagram method - this option enables to select appropriate interaction diagram method. The following approaches can be applied:

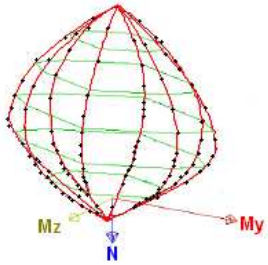
- NRd – assuming Md is constant
- MRd – assuming Nd is constant
- NRdMRd – assuming eccentricity is constant
- MRdy – assuming Mdz is constant
- MRdz – assuming Mdy is constant

Default value is NRdMRd.



Division of strain - this option explains the precision of calculation of diagram point during generation of vertical cuts. The value means how many times the strain plane is readjusted from the position of section under full compression to the position of section under full tension. The value influences the accuracy and the speed of calculation

Default value = 250, with limits <0;10000>.



Number of points in vertical cuts - number of direction (number of "branches") in which interaction diagram is calculated during generation of interaction diagram.

Default value = 36, with limits <0;10000>.

Shear + torsion (ULS)

Check of Interaction shear and torsion consist three checks:

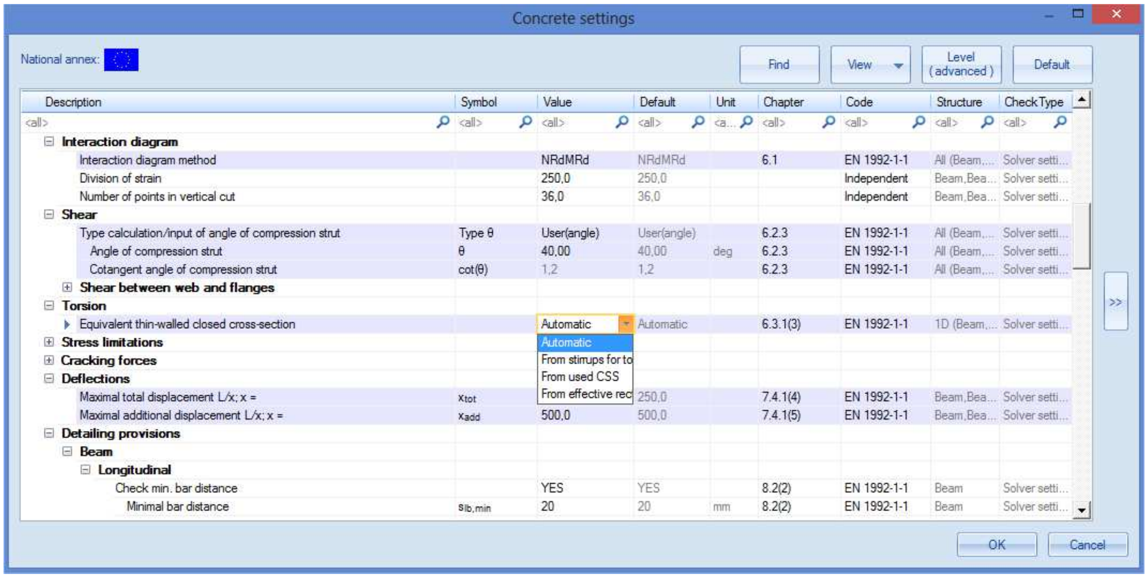
- check shear
- check torsion
- check interaction of shear and torsion

The all check area is calculated according to clause 6.1 -6.3 in EN 1992-1-1. The following preconditions are used for calculation:

- The checks are calculated for beams and columns and for general load (N+My+Mz)
- Cross-section with one polygon and one material is taken into account in version SEN 15
- The material of all reinforcement bars and stirrups have to be the same in SEN 15
- The checks should be used only in case, that the angle between gradient of the strain plane and the resultant of shear forces is not greater, than 15 degrees

Equivalent thin-walled closed cross-section

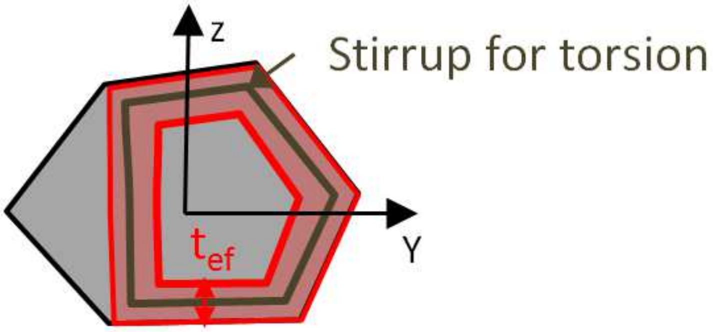
Equivalent thin-walled cross-section can be calculated by 4(5) possibilities in SEN depending on parameter **Equivalent thin-walled cross-section**. This parameter can be changed in Concrete settings (if 1D concrete member data is not defined) or in 1D concrete member data for Advanced mode/ level.



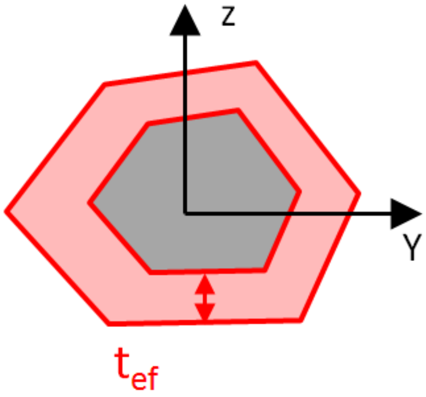
Description	Symbol	Value	Default	Unit	Chapter	Code	Structure	Check Type
<all>	<all>	<all>	<all>	<a...	<all>	<all>	<all>	<all>
Interaction diagram								
Interaction diagram method		NRdMRd	NRdMRd		6.1	EN 1992-1-1	All (Beam,...	Solver setti...
Division of strain		250,0	250,0			Independent	Beam,Bea...	Solver setti...
Number of points in vertical cut		36,0	36,0			Independent	Beam,Bea...	Solver setti...
Shear								
Type calculation/input of angle of compression strut	Type θ	User(angle)	User(angle)		6.2.3	EN 1992-1-1	All (Beam,...	Solver setti...
Angle of compression strut	θ	40,00	40,00	deg	6.2.3	EN 1992-1-1	All (Beam,...	Solver setti...
Cotangent angle of compression strut	cot(θ)	1,2	1,2		6.2.3	EN 1992-1-1	All (Beam,...	Solver setti...
Shear between web and flanges								
Torsion								
Equivalent thin-walled closed cross-section		Automatic Automatic From stirrups for to From used CSS From effective rec	Automatic		6.3.1(3)	EN 1992-1-1	1D (Beam,...	Solver setti...
Stress limitations								
Cracking forces								
Deflections								
Maximal total displacement L/x; x =	x_{tot}		250,0		7.4.1(4)	EN 1992-1-1	Beam,Bea...	Solver setti...
Maximal additional displacement L/x; x =	x_{add}	500,0	500,0		7.4.1(5)	EN 1992-1-1	Beam,Bea...	Solver setti...
Detailing provisions								
Beam								
Longitudinal								
Check min. bar distance		YES	YES		8.2(2)	EN 1992-1-1	Beam	Solver setti...
Minimal bar distance	$s_{lb,min}$	20	20	mm	8.2(2)	EN 1992-1-1	Beam	Solver setti...

There are the following options:

- **Automatic** - the program calculates equivalent thin-walled cross-section according one method below. It means that the program tries to create an equivalent thin-walled cross-section from stirrup for torsion at first, and if this method is not successful, the program uses a method based on the shape of cross-section or. This is the default setting.
- **From stirrups for torsion** - program tries to create equivalent thin-walled cross-section around stirrup, which check box Torsion = ON for. If equivalent thin-walled cross-section was not successful created or stirrup for torsion is not defined, program finishes with some warning/error. This method is not supported for design of shear reinforcement, because user (practical) reinforcement is not taken into account and therefore for design method From used Css - is used, if this method is selected.



- **From used Css** - program tries to create equivalent thin-walled cross-section from current cross-section by offsetting value t_{ef}. If equivalent thin-walled cross-section was not successful created the program finishes with some warning/error.

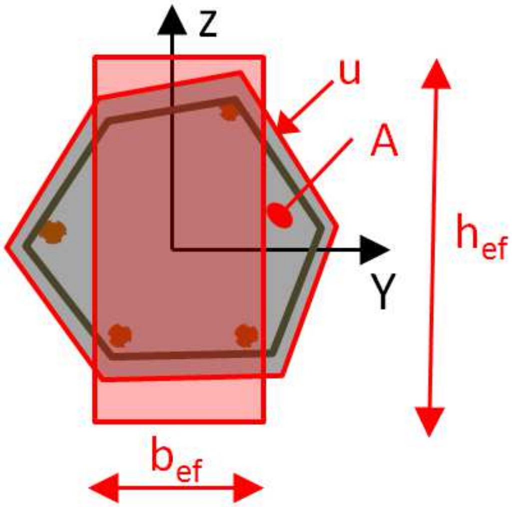


- **From effective rectangular Css** - program tries to create equivalent thin-walled cross-section as rectangular concrete cross-section to perimeter and area of target and source cross-section were the same . It follows, that effective rectangular cross-section with the following dimension will be created:

$$h_{ef} = \frac{\left(u + \sqrt{u^2 - 16 \cdot A}\right)}{4}$$

$$b_{ef} = A / h_{ef}$$

If equivalent thin-walled cross-section was not successful created program finishes with some warning/error.



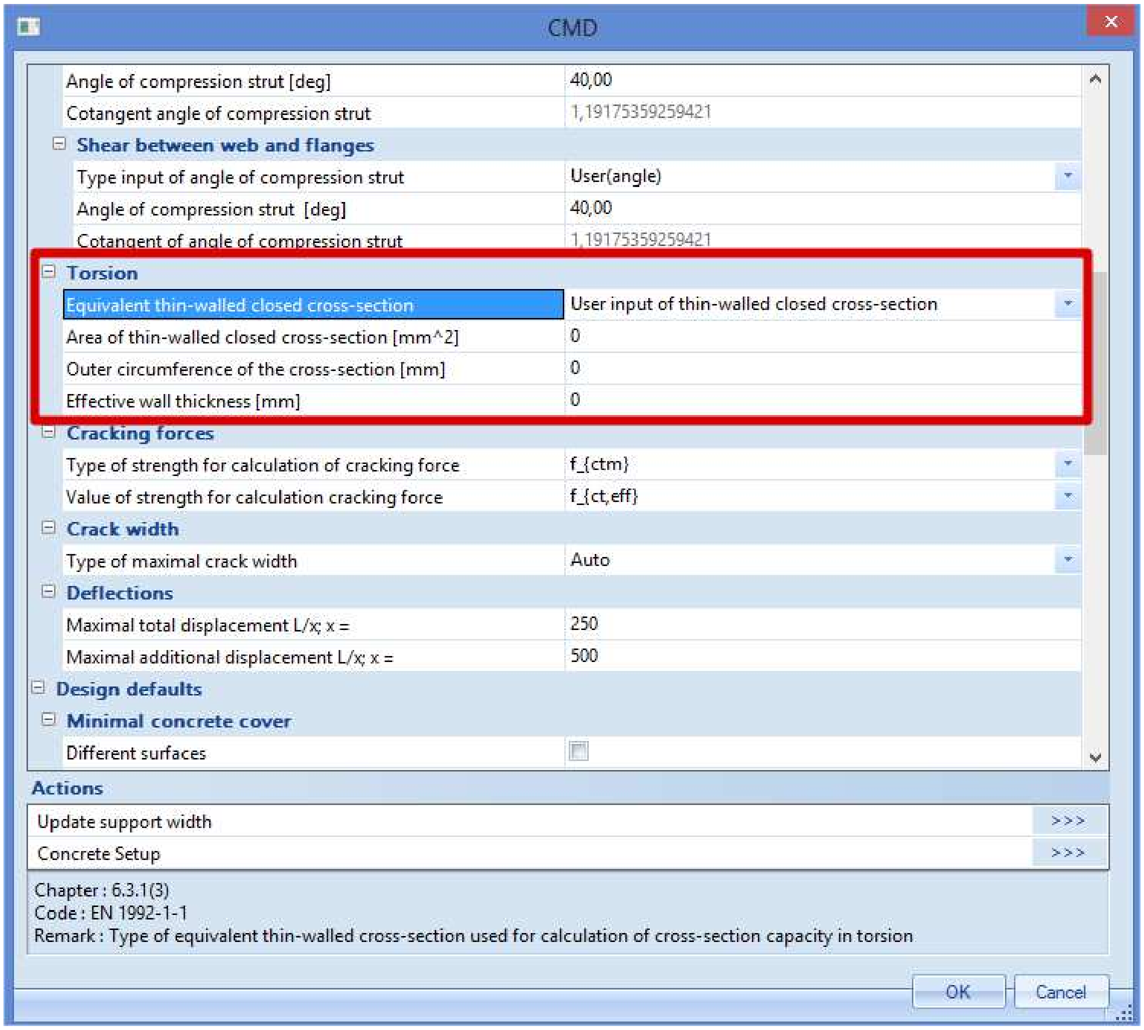
- **User input** - equivalent thin-walled cross-section can be defined directly by the user, it means, that the user has to define following properties:
    - area of thin-walled cross-section ($A_{k,user}$)
    - outer circumference of thin-walled cross-section ($u_{k,user}$)
    - effective wall thickness ($t_{ef,user}$)

This method is available only in 1D concrete member data. If the member is not prismatic (arbitrary member or member with haunches), equivalent thin walled cross-section is recalculated to each section of the member according to the formulas below:

$$A_{ki} = A_i \cdot \frac{A_{k,user}}{A_m}$$

$$u_{ki} = u_i \cdot \frac{u_{k,user}}{u_m}$$

$$t_{efi} = \frac{A_i}{u_i} \cdot \frac{u_m}{A_m} \cdot t_{ef,user}$$



Angle of compression strut [deg]	40,00
Cotangent angle of compression strut	1,19175359259421
Shear between web and flanges	
Type input of angle of compression strut	User(angle)
Angle of compression strut [deg]	40,00
Cotangent of angle of compression strut	1,19175359259421
Torsion	
Equivalent thin-walled closed cross-section	User input of thin-walled closed cross-section
Area of thin-walled closed cross-section [mm^2]	0
Outer circumference of the cross-section [mm]	0
Effective wall thickness [mm]	0
Cracking forces	
Type of strength for calculation of cracking force	f_{ctm}
Value of strength for calculation cracking force	f_{ct,eff}
Crack width	
Type of maximal crack width	Auto
Deflections	
Maximal total displacement L/x; x =	250
Maximal additional displacement L/x; x =	500
Design defaults	
Minimal concrete cover	
Different surfaces	☐

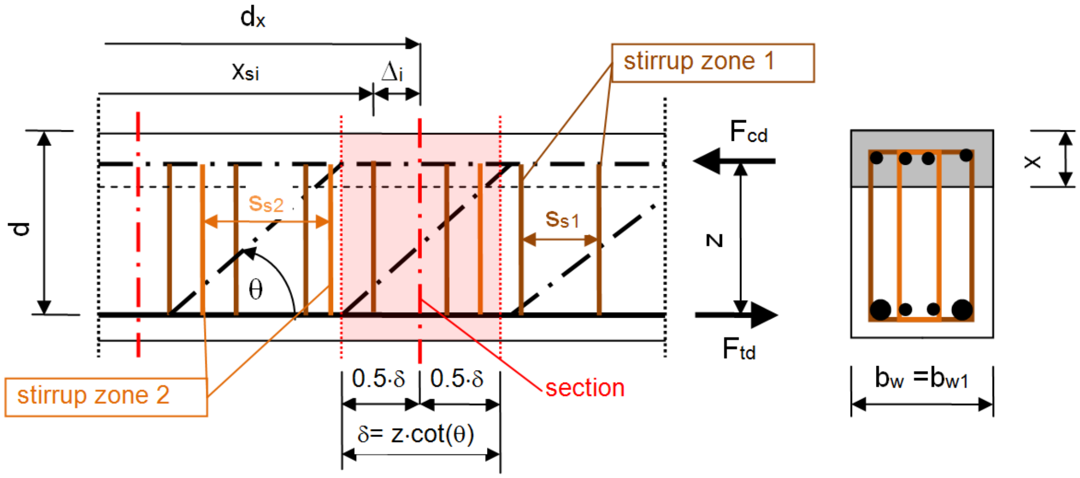
Chapter : 6.3.1(3)
Code : EN 1992-1-1
Remark : Type of equivalent thin-walled cross-section used for calculation of cross-section capacity in torsion

Shear reinforcement

Determination stirrups around section

The stirrups around the section are taking into account on a length corresponding to the horizontal projection of the length of compression strut (the width of concrete strut), which can be calculated according to formula:

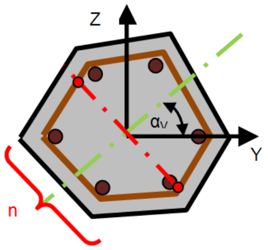
$$\delta = z \cdot \cot(\theta)$$



Calculation number of stirrup links (number of cuts)

The way for calculating the number of stirrup links can be inputted in the properties of the stirrup layer and there are two possibilities for calculating the number of stirrup links in SEN:

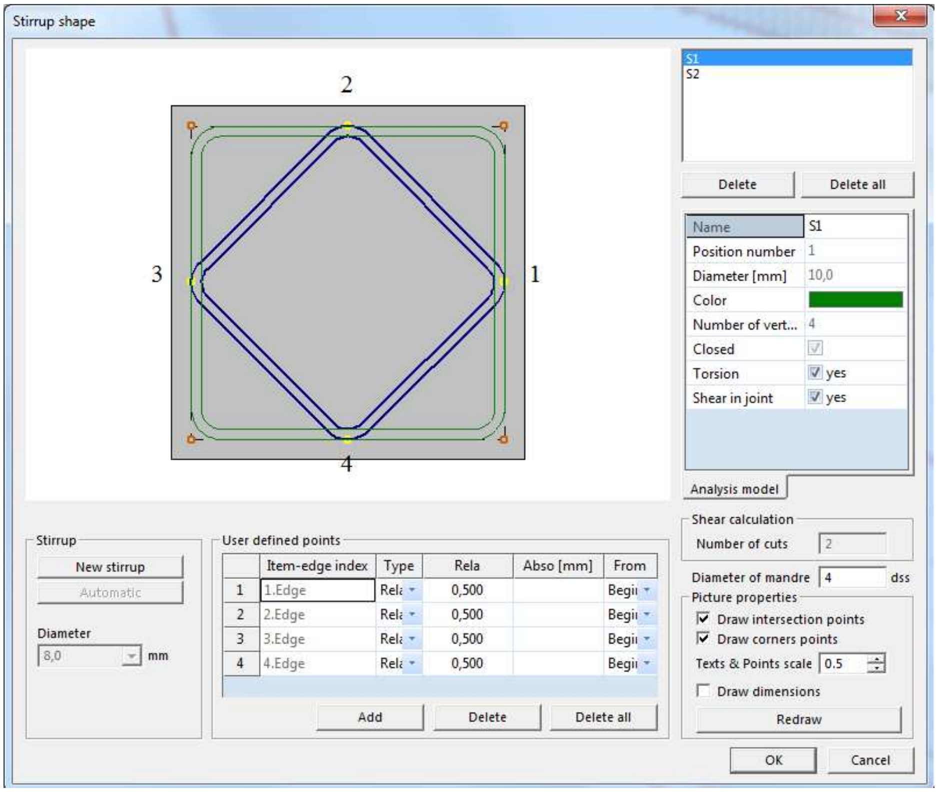
- **Automatic calculation** – the number of links is calculated as a number of intersections of stirrup with a straight line perpendicular to the direction of shear force resultant, where this line is crossing the centre of polygon



- **User input** – the number of links is inputted directly by the user

Stirrup for torsion

There is taken into account for torsional check only the stirrup, where check box **Torsion = ON** for. This check box can be switched ON/OFF in the dialogue Stirrup shape (action button Edit stirrup shape in properties of Stirrup or in library of stirrups).



Name	S1
Position number	1
Diameter [mm]	10,0
Color	🟩
Number of vert...	4
Closed	☑
Torsion	☑ yes
Shear in joint	☑ yes

Stirrup

Diameter 8,0 mm

User defined points

	Item-edge index	Type	Rela	Abso [mm]	From
1	1.Edge	Rela	0,500		Begi
2	2.Edge	Rela	0,500		Begi
3	3.Edge	Rela	0,500		Begi
4	4.Edge	Rela	0,500		Begi

Shear calculation

Number of cuts 2

Diameter of mandre 4 dss

Picture properties

☑ Draw intersection points

☑ Draw corners points

Texts & Points scale 0.5

☐ Draw dimensions

Calculation of average characteristics of shear reinforcement

As was mentioned there is a possibility to define more stirrup zones (more stirrups) around a section with different properties, therefore it is necessary to calculate average characteristics. The average characteristics are calculated from stirrups within the calculated interval, and in this calculation distance of stirrups from the section (value D) is taken into account. It means that the stirrup, which is nearer to the section, has bigger influence on average values than the stirrup with a bigger distance.

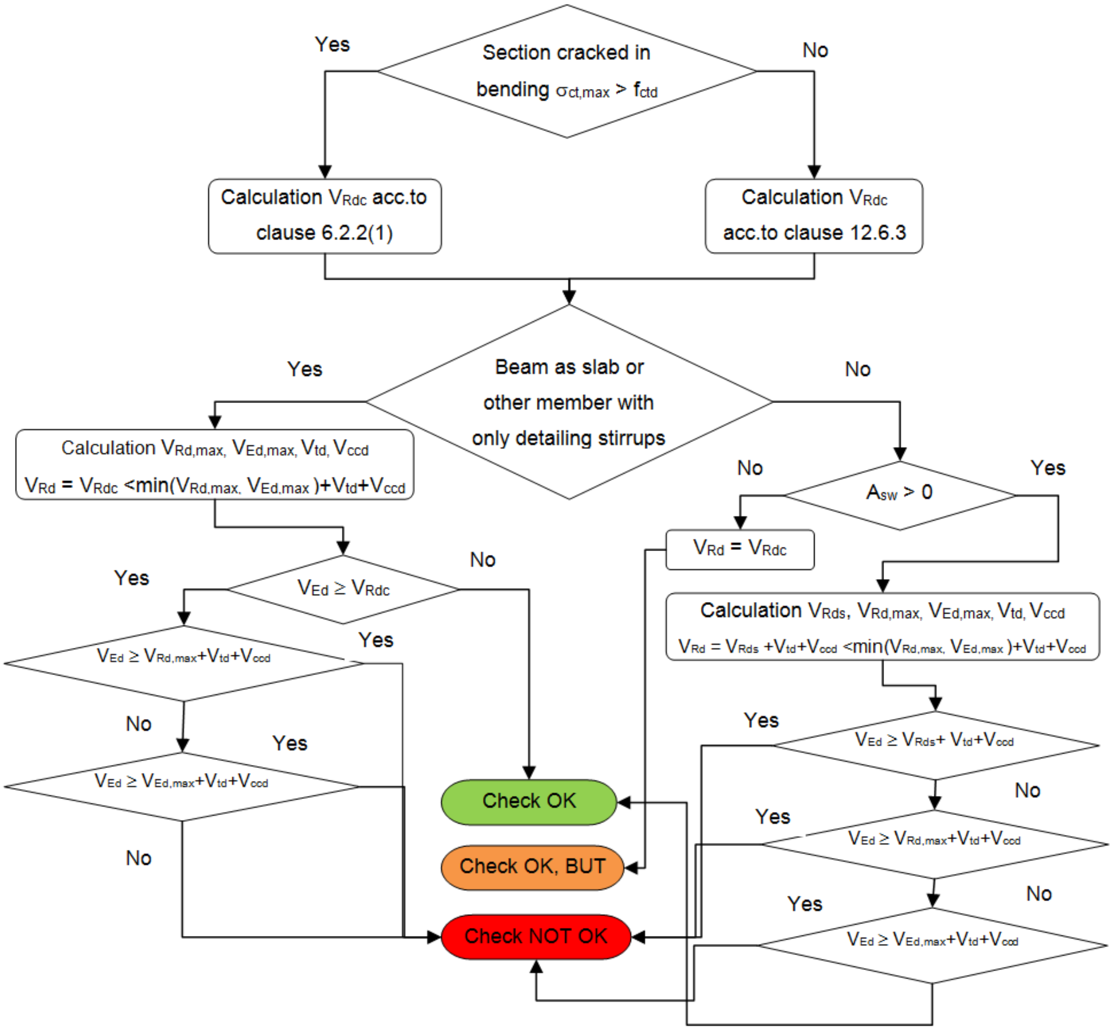
Calculation of characteristic of shear reinforcement

The shear reinforcement in SEN can be inputted via REDES (stirrup zone) and via Free bars. There is a possibility to input more stirrup zones and more free bars (stirrups) to a member with different parameters. Therefore it is very important to set the region for taking into account stirrups around the section and to calculate average characteristics of shear reinforcement for the shear check.

Shear check

Calculation procedure

As was mentioned above, there exists a general concept of the "strut-and-tie" model for the prediction of shear effects in concrete. In this model, the top compression and bottom tensile members represent the compressive concrete and tensile reinforcement, respectively. The horizontal members are connected by the compressive virtual struts and reinforcement tensile ties. The axial forces in tensile ties should be transmitted by the shear reinforcement. Consequently, the maximal force in concrete struts ($V_{Rd,max}$) and shear force retained by the shear resistance ($V_{Rd,s}$) have to be compared with acting shear force (V_{Ed}). The procedure for check can be represented by the diagram below:



The formulas which are used for the calculation of each component of this model are the following. Generally, there are two possibilities for the calculation of shear capacity of concrete dependently on existence of cracked in bending:

Shear concrete capacity in region cracked in bending - formula 6.2.a,b in EN 1992-1-1

$$V_{Rd,c} = \left[C_{Rd,c} \cdot k \cdot (100 \cdot \rho_l \cdot f_{ck})^{1/3} + k_1 \cdot \sigma_{cp} \right] \cdot b_w \cdot d$$

$$V_{Rd,c,\min} = (v_{\min} + k_1 \cdot \sigma_{cp}) \cdot b_w \cdot d$$

Shear concrete capacity in region uncracked in bending – clause 12.6.3(3) in EN 1992-1-1

$$V_{Rd,c} = \frac{f_{cvd} \cdot A_{cc}}{k_{12.6.3}}$$

Additionally, there is calculated maximal shear force ($V_{Ed,max}$)) without reduction by β for member where load is applied in the upper side of the member (see formula 6.5 in EN 1992-1-1).

$$V_{Ed.max} = 0.5 \cdot b_{w1} \cdot d \cdot v \cdot f_{cd}$$

Maximal capacity of concrete compressive strut ($V_{Rd,max}$) is determined according to formula 6.9 in EN 1992-1-1, because as has been mentioned before, the angle of stirrups (θ) is always perpendicular to member axis.

$$V_{Rd,max} = \frac{\alpha_{cw} \cdot b_{w1} \cdot z \cdot v_1 \cdot f_{cd}}{\cot(\theta) + \tan(\theta)}$$

Design value of shear force sustained by shear reinforcement ($V_{Rd,s}$) is calculated according to formula 6.13 in EN 1992-1-1

$$V_{Rd,s} = \frac{A_{sw}}{s} \cdot z \cdot f_{ywd} \cdot (\cot(\theta) + \cot(\alpha)) \cdot \sin(\alpha)$$

Final design value of shear force (V_{Rd}) carried by member is calculated based on the following formulas depending on type of member and area of shear reinforcement.

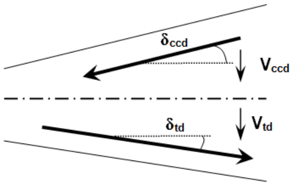
- for beam as slab and for other member with only detailing stirrups (Asw =0)

$$V_{Rd} = V_{Rd,c} \leq \min(V_{Rd,max}, V_{Ed,max}) + V_{td} + V_{ccd}$$

- for other cases

$$V_{Rd} = V_{Rd,s} + V_{td} + V_{ccd} \leq \min(V_{Rd,max}, V_{Ed,max}) + V_{td} + V_{ccd}$$

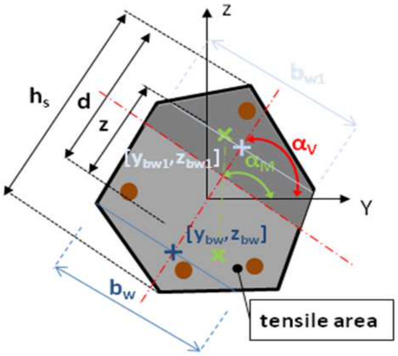
For members with inclined chords the additional forces have to be taken into account for shear check according to clause 6.2.1(1). The calculation is prepared for taking into account also inclined chords. Nevertheless the calculation itself is not implemented yet. The partial components are explained in the following figure.



Width for cross-section

There are calculated two widths for shear check

- **value b_w** – this value is calculated as the smallest width of the cross-section in tensile area of cross-section perpendicular to direction of resultant shear force. This value is used for the calculation of shear resistance of concrete (V_{Rdc}) according to clause 6.2.2(1)
- **value b_{w1}** – this value is calculated as minimum width of cross-section between tension and compression chord perpendicular to direction of shear force. This value is used for calculation
  - design value of maximum shear force $V_{Ed,max}$ (calculation without reduction β), clause 6.2.2(6)
  - design value of maximum shear force limited by crushing of the compression struts ($V_{Rd,max}$), clause 6.2.3(3,4)
  - design value of shear force carried by shear reinforcement (V_{Rds}), clause 6.2.3(3,4)



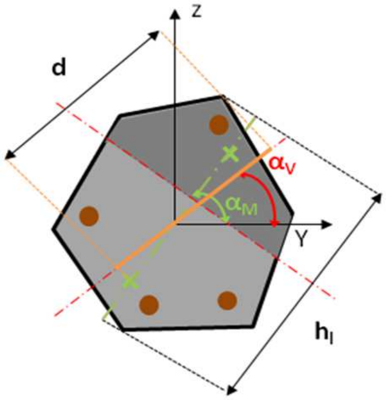
Effective depth of cross-section

The effective depth of cross-section is usually defined as the distance of the most compressive fibre of concrete to centre of gravity of tensile reinforcement. In SEN, the effective depth of a cross-section is defined as the distance of the most compressive fibre of concrete to the position of resultant of forces in tensile reinforcement. There is calculated in SEN the perpendicular projection which is the distance of a straight line perpendicular to the neutral axis (slope line plane of equilibrium), called d_{rec}. The problem is how to calculate this distance if difference between direction of resultant of bending moment and resultant of shear force is markedly. In this case the effective depth for shear is calculated than perpendicular projection this distance calculated from bending load to direction of shear force resultant. There are some exceptional cases, when effective depth is not calculated from plane of equilibrium:

- the most compressive fibre cannot be determined (the whole cross-section is in tension)
- resultant of force in tensile reinforcement cannot be determined (whole section is in compression)
- equilibrium is not found

In this case, the effective depth is calculated according to formula:

$$d = Coeff_d \cdot h_l \cdot \cos(|\alpha_V - \alpha_M|)$$



Inner lever arm

Inner lever arm in EN 1992-1-1, clause 6.2.3 (3) is defined as the distance of forces in tensile and compression chord, it follows that it is the distance of position resultant of tensile force (tensile reinforcement) and position resultant of compressive force (compressive reinforcement and compressive concrete). Since in EN code it is not defined, how to calculate inner lever arm, if difference between direction of resultant of bending moment and resultant of shear force is markedly. Therefore in SEN is used the same principle as for calculation effective depth, it mean that inner lever arm is calculated as projection to direction of shear force resultant. There are some exceptional cases, when inner lever arm is not calculated from plane of equilibrium:

- the most compressive fibre cannot be determined (the whole cross-section is in tension)
- resultant of forces in tensile reinforcement cannot be determined (whole section is in compression)
- equilibrium is not found

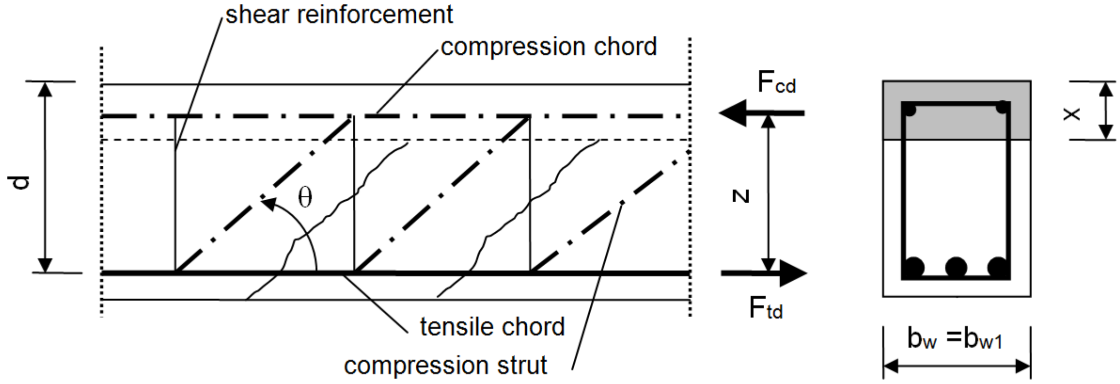
In this case, the inner lever arm is calculated according to formula:

$$z = Coeff_z \cdot d$$

The EN code gives these values to relation with bending load, but there is a problem to calculate these values, if difference between direction of resultant of bending moments and resultant of shear forces is markedly. In this case the code EN does not give any recommendation. Therefore in SEN, if the angle between resultant of bending moments and resultant of shear forces is greater than 15 degrees, the program gives this warning and in this case the more sophisticated method (for example biaxial shear method) should be used.

Shear check

The shear check is commonly based on the theory of the concrete truss-model. In this theory a virtual truss-model is imagined in a concrete beam. This truss-model has a set of vertical (or slightly diagonal), horizontal and diagonal members. The vertical bars are considered to be the stirrups; the horizontal bars are the main reinforcement and the diagonal bars are the concrete struts. The check of biaxial shear is calculated according to preconditions in clause 6.2 in EN 1992-1-1.



There are the following assumptions:

- The shear forces in both direction are taken into account and shear check is done for resultant of shear force
- The parameters of plane of equilibrium (value d, z and h) are recalculated to direction of resultant shear force
- The design shear resistance of the member without shear reinforcement ($V_{Rd,c}$) is calculated according to clause 6.2.2(1) in EN 1992-1-1, if section is cracked in flexure, otherwise clause 12.6.3 in EN 1992-1-1 is used
- Design value of maximum shear force will be calculated according to clause 6.2.2(6) ($V_{Ed,max}$) and 6.2.3 (3,4) ($V_{Rd,max}$) in EN 1992-1-1
- Design value of shear resistance is calculated according to 6.2.3 (3,4) ($V_{Rd,s}$) in EN 1992-1-1
- The number of shear links can be calculated automatically or defined by the user (in properties of stirrup zone)
- The angle of compression strut can be calculated automatically or defined by the user
- The angle of stirrups for check is always perpendicular to member axis

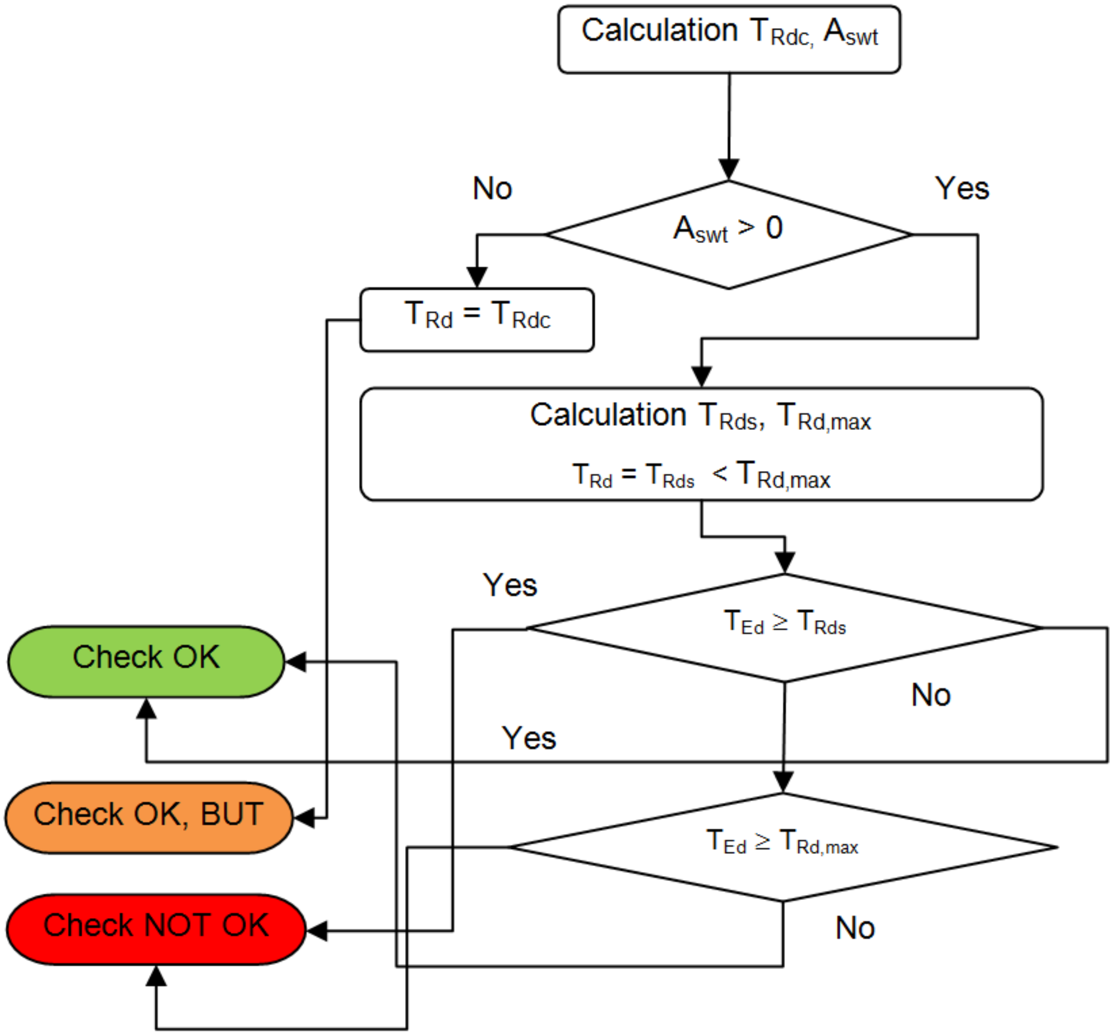
With the following limitations

- Inclined compression chord or inclined tensile chord are not taken into account
- The widths of cross-section for shear checks (value b_w and b_{w1}) are calculated automatically. There is no possibility for definition of user value in SEN 15
- Free bars reinforcement is not taken into account
- The area of longitudinal reinforcement is not subtracted from concrete area

Torsion check

Calculation procedure

As was mentioned above, there exists a general concept of “strut-and-tie” model for the prediction of torsional effects in concrete. In this model, the top compression and bottom tensile members represent the compressive concrete and tensile reinforcement, respectively. The horizontal members are connected by the compressive virtual struts and reinforcement tensile ties. Consequently, the maximum of torsional resistance moment carried by concrete strut ($T_{Rd,max}$) and torsional moment retained by the torsional resistance ($T_{Rd,s}$) have to be compared with acting torsional moment (T_{Ed}). The procedure for check can be represented by the diagram below:



The formulas which are used for the calculation of each component of this model are the following.

Torsional cracking moment is calculated according to equation 6.26 in EN 1992-1-1, provided that the stress caused by torsional moment is equal to design axial tensile strength of concrete (value f_{ctd}). It follows:

$$T_{Rdc} = 2 \cdot f_{ctd} \cdot t_{ef} \cdot A_k$$

Maximum of torsional resistance moment ($T_{Rd,max}$) is determined according to formula 6.30 in EN 1992-1-1.

$$T_{Rd.max} = 2 \cdot \nu \cdot \alpha_{cw} \cdot f_{cd} \cdot A_k \cdot t_{ef} \cdot \cos(\theta) \cdot \sin(\theta)$$

Design torsional resistance moment of torsional reinforcement ($T_{Rd,st}$) is calculated according to formula below

$$T_{Rdst} = 2 \cdot A_k \cdot \left(\frac{A_{swt}}{s_t}\right) \cdot f_{ywd} \cdot \cot(\theta)$$

Final design value of torsional moment (T_{Rd}) carried by the member is calculated based on the following formulas

- for member without or with only detailing stirrups for torsion ($A_{swt} = 0$)

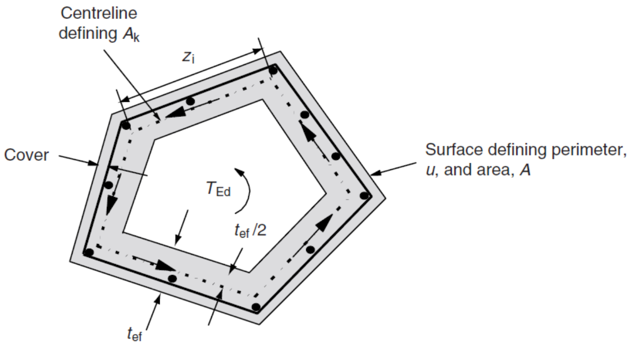
  $$T_{Rd} = T_{Rd,c} \leq T_{Rd.max}$$

- for other cases

  $$T_{Rd} = T_{Rd,s} \leq T_{Rd.max}$$

Calculation basic characteristics

The torsional resistance of sections is calculated on the basis of a thin-walled closed section, even if the section is actually solid. For solid members, the section is idealized as a thin-walled section. There are several options for generation of thin -walled cross-section in SEN.



The effective wall thickness is calculated according to clause 6.3.2(1) in EN 1992-1-1

$$t_{ef} = \frac{A}{u} > 2 \cdot a_{sl}$$

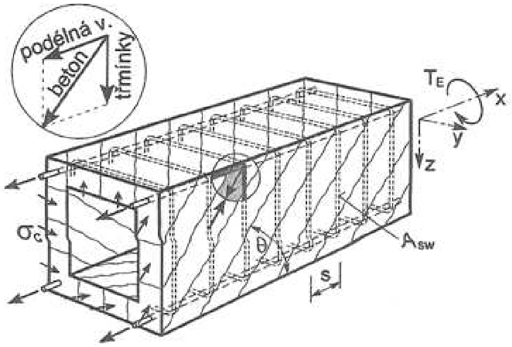
The important parameters for check of torsion calculated from the centre line of the effective thin-walled cross-section are:

- the area enclosed by the centre-lines of the thin-walled cross-section, including inner hollow areas (value A_k)
- the circumference of the centre line thin-walled cross-section (u_k)

Torsion check

In normal building structures, torsion generally arises as a secondary effect, and specific calculations are not necessary. Torsional cracking is generally adequately controlled by reinforcement provided to resist shear. Even, when torsion occurs, it rarely controls the basic sizing of the members, and torsion check is often a check calculation after the members have been checked for flexure. In some cases, the loading that causes the maximum torsional moment may not be same that induces the maximum flexural effect. In some cases, reinforcement provided for flexure and the other forces may prove adequate to resist torsion.

The torsion check is commonly based on the theory of the concrete truss-model too. In this theory, a virtual truss-model is imagined in a concrete beam. This truss-model has a set of vertical (or slightly diagonal), horizontal and diagonal members. The vertical bars are considered to be the stirrups; the horizontal bars are the main reinforcement and the diagonal bars are the concrete struts.



There are the following assumptions:

- The parameters of plane of equilibrium (value d, z and h) are recalculated to direction of resultant shear force
- The torsional cracking moment ($T_{Rd,c}$) is calculated according to clause 6.3.2(5) in EN 1992-1-1
- Design value of maximum of torsional resistance moment ($T_{Rd,max}$)is calculated according to clause 6.3.2(4) in EN 1992-1-1
- The angle of compression strut can be calculated automatically or defined by user
- The angle of stirrups for check is always perpendicular to member axis.
- There are 5 possibilities for the calculation of thin-walled closed section

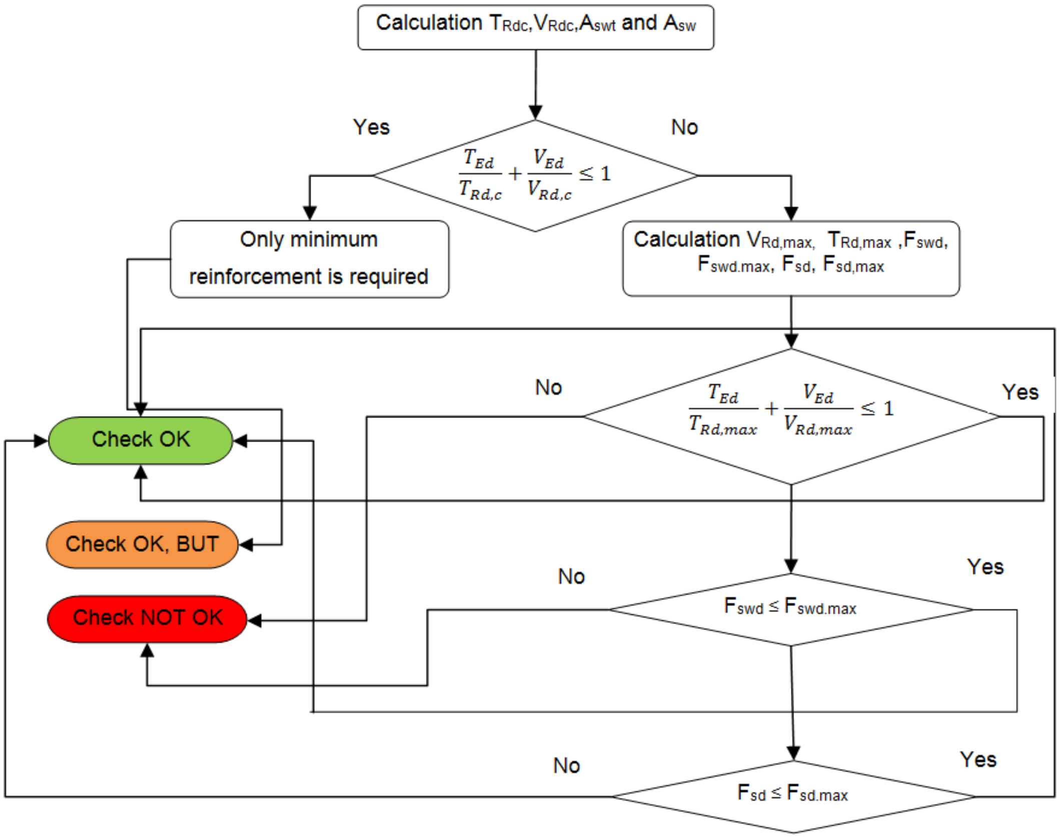
With the following limitations

- Only one stirrup can be taken into account for torsion check
- Free bars reinforcement is not taken into account
- The area of longitudinal reinforcement is not subtracted from concrete area.

Check interaction shear and torsion

Calculation procedure

As was mentioned above, there exists a general concept of “strut-and-tie” model for the prediction of shear and torsional effects in concrete. In this model, the top compression and bottom tensile members represent the compressive concrete and tensile reinforcement, respectively. The horizontal members are connected by the compressive virtual struts and reinforcement tensile ties. The procedure for check interaction of shear and torsion can be represented by the diagram below:



Only minimum reinforcement is required (provided that the following condition (equation 6.31 in EN 1992-1-1 is satisfied):

$$\frac{T_{Ed}}{T_{Rd,c}} + \frac{V_{Ed}}{V_{Rd,c}} \leq 1$$

The maximum resistance of a member subjected to torsion and shear is limited by the capacity of the concrete struts. In order not to exceed this resistance the following condition (equation 6.29 in EN 1992-1-1) should be satisfied:

$$\frac{T_{Ed}}{T_{Rd,max}} + \frac{V_{Ed}}{V_{Rd,max}} \leq 1$$

The force in shear reinforcement caused by shear and torsion effect can be calculated according to formula

$$F_{swd} = \left(\frac{T_{Ed}}{2 \cdot A_k} + \frac{V_{Ed}}{n_s \cdot z}\right) \cdot \frac{s_t}{\cot(\theta)}$$

The maximum force which, can be carried by shear reinforcement is given by formula:

$$F_{swd,max} = A_{swt} \cdot f_{ywd}$$

The additional tensile force in longitudinal reinforcement caused by shear and torsion is calculated according to formula:

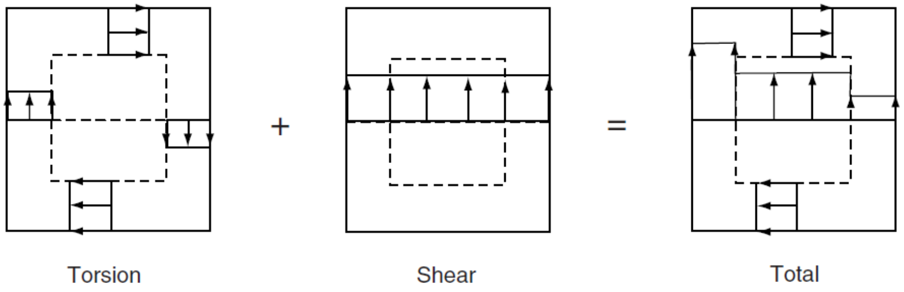
$$F_{sd} = \left(\frac{T_{Ed}}{2 \cdot A_k} \cdot u_k + V_{Ed}\right) \cdot \cot(\theta)$$

The maximum force which, can be carried by longitudinal reinforcement is given by formula:

$$F_{sd,max} = A_{sl.tor} \cdot f_{yd}$$

Check interaction shear and torsion

The interaction of shear and torsion has to be taken into account, if the member is loaded by shear and torsion effect. The shear and torsion checks are commonly based on the theory of the concrete truss-model.



There are the following assumptions:

- The special assumptions for shear check are described in "Shear check".
- Assumptions for check torsion are described in "Torsion check"
- Only minimum reinforcement is required provided that condition clause 6.3.2(5) in EN 1992-1-1 is satisfied
- The maximum resistance of a member subjected to torsion and shear is limited by the capacity of the concrete struts. In order not to exceed this resistance the condition in clause 6.3.2(4) in EN 1992-1-1 should be satisfied

With the following limitations

- Inclined compression chord or inclined tensile chord are not taken into account
- The widths of cross-section for shear checks (value b_w and b_{w1}) are calculated automatically. There is no possibility for definition of user value in SEN 15
- only one stirrup can be taken into account for torsion check
- Free bars reinforcement is not taken into account
- The area of longitudinal reinforcement is not subtracted from concrete area.

Stress limitations (SLS)

Stress limitation (SLS) check is based on the calculation of stresses in a particular component (concrete fibre, reinforcement bar) and the comparison with limited values with respect of EN 1992-1-1 requirements. Based on the internal forces, concrete cross-section and defined reinforcement by the user, SCIA Engineer is able to calculate the plain of equilibrium of a member or a single cross-section and find the actual value of stresses in each component.

Generally, stress limitation is from the point of the serviceability limit state is based on the verification of the following states:

- **compressive stress in concrete** - the high value of compressive stress in concrete could lead to appearance of longitudinal cracks, spreading of micro-cracks in concrete and higher values of creep (mainly non linear). This effect can lead to a state where the structure is unusable.
- **tensile stress in reinforcement** - stress in reinforcement is verified due to limitation of unacceptable strain existence and thus appearance of cracks in concrete.

The method described in chapter "Theoretical background" is used for determination of the plane of the equilibrium. There are used different stress-strain diagram towards the Capacity-response (ULS).

Stress-strain diagram based on the serviceability limit state are used for finding of the plain of the equilibrium. This check provides the calculation of the stresses in particular components for each state of cross-section.

Generally, this check uses the iterative method for the interaction of the normal force (N) with uni-axial or bi-axial bending moments (M_y + M_z). Additionally, there is A possibility to calculate stresses for short-term or long-term stiffness which is applied via modified stress-strain diagram.

There are the following assumptions:

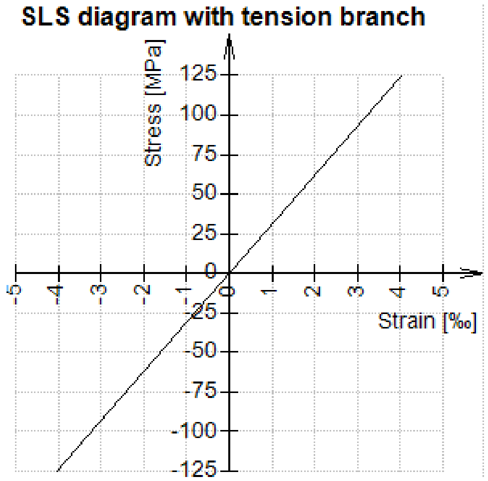
- Strain and stress diagram defined in properties of material will be used
    - Concrete – linear stress-strain diagram dependent on:
        - type of E-modulus - short-term (E_c) or long-term ($E_{c,eff}$) E-modulus for preparation of stress-strain diagram
        - cracking of the cross-section
            - un-cracked cross-section - stress-strain diagram with tensile concrete is considered
            - cracked cross-section - stress-strain diagram without tensile concrete is considered
    - Reinforcement – linear stress-strain diagram with tensile branch
- Standard REDES reinforcement is considered

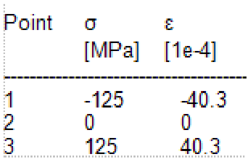
With the following limitations

- The area of longitudinal reinforcement is not subtracted from concrete area in the first step

As an example the preparation of the stress-strain diagram for C25/30 (f_{ck} = 25MPa, E_c = 31GPa) is visible from the following figures.

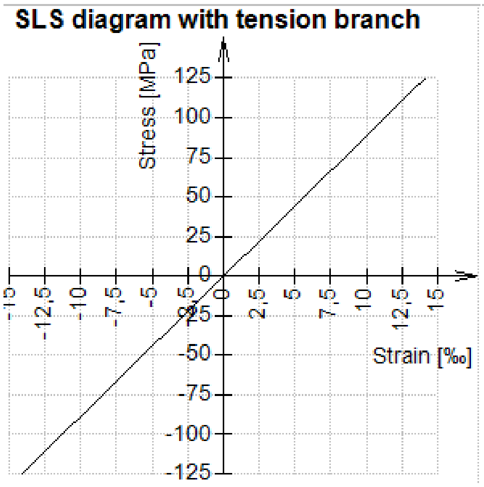
Concrete SLS short-term uncracked





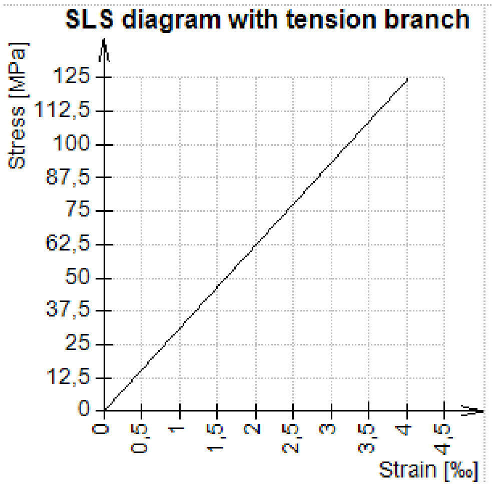
Point	σ [MPa]	ε [1e-4]
1	-125	-40.3
2	0	0
3	125	40.3

Concrete SLS long-term uncracked



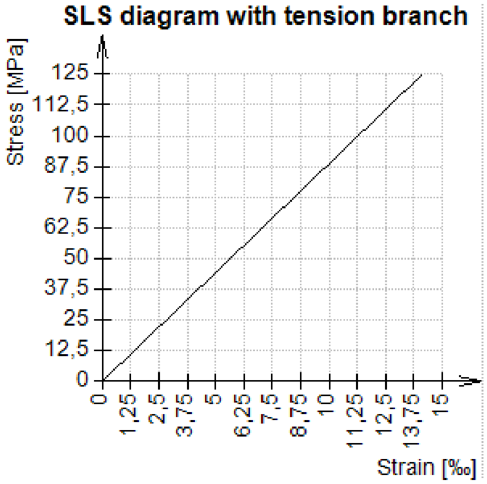
Point	σ [MPa]	ε [1e-4]
1	-125	-141
2	0	0
3	125	141

Concrete SLS short-term cracked



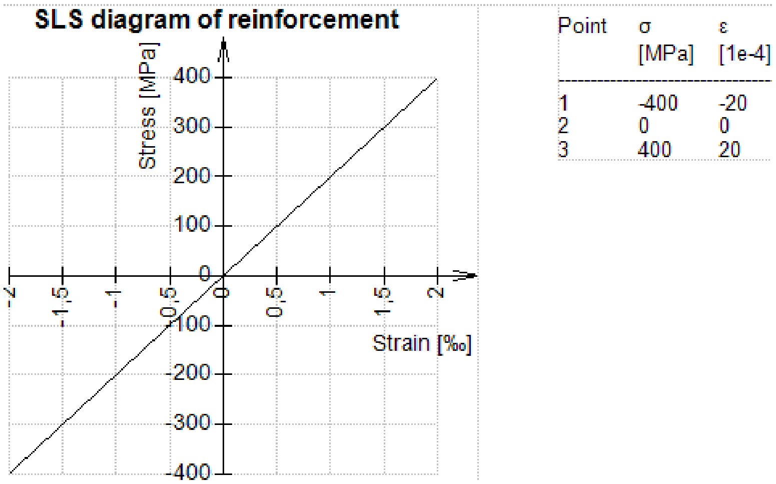
Point	σ [MPa]	ε [1e-4]
1	-125	-40.3
2	0	0

Concrete SLS long-term cracked



Point	σ [MPa]	ε [1e-4]
1	-125	-141
2	0	0

As an example for the reinforcement material the stress-strain diagram for B400 C (f_{yk} = 400MPa, E_s = 200GPa) is visible from the following figure.



Point	σ [MPa]	ε [1e-4]
1	-400	-20
2	0	0
3	400	20

Theoretical background

The calculation procedure can be described in the following steps:

Verification of crack appearance

At first crack appearance is verified for characteristic load combination in accordance to chapter 7.1(2) - maximal tensile stress in concrete fibre is compared with effective concrete tensile strength $f_{ct,eff}$. The calculation of maximal tensile stress in concrete fibre is performed on cross-section with SLS linear diagram of concrete with tensile branch and the reinforcement is taken into account with linear diagram. As a conclusion, two cases can appear:

1) **$\sigma_{ct} \leq \sigma_{cr}$ - no crack appears**; the cross-section is considered as uncracked and SLS linear diagram with tension is used for other steps of the calculation.
2) **$\sigma_{ct} > \sigma_{cr}$ - crack appears**; the cross-section is considered as cracked; the cross-section is recalculated using SLS linear diagram without tension.

Verification of stress in component

Calculation of stresses in component based on the combination. There are compared three different cases

1) **verification of concrete stress under characteristic load according to chapter 7.2(2)**

   this verification is calculated against to longitudinal cracks in concrete and it is provided only for exposure classes XD, XF and XS. Generally, maximal compressive concrete stress $\sigma_{c,char}$ has to be lesser than maximal allowed compressive concrete strength for characteristic combination $\sigma_{c,char,lim} = k_1 \times f_{ck}$. It can be expressed as follows:

   $$\sigma_{c,char,lim} \leq k_1 \times f_{ck}$$

   where k_1 is NA parameter, standard value is k_1= 0,6.

2) **verification of concrete stress under quasi-permanent load according to chapter 7.2(3)**

   this verification is calculated against to considering of linear creep only. When the condition is not fulfilled then non-linear creep calculation should be considered. Generally, maximal compressive concrete stress $\sigma_{c,qp}$ has to be lesser than maximal allowed compressive concrete strength for quasi-permanent combination $\sigma_{c,qp,lim} = k_2 \times f_{ck}$. It can be expressed as follows:

   $$\sigma_{c,qp,lim} \leq k_2 \times f_{ck}$$

   where k_2 is NA parameter, standard value is k_2 = 0,45.

3) **verification of reinforcement stress under characteristic load according to chapter 7.2(5)**

this verification is calculated against to considering of unacceptable cracks and deformation in the concrete. Generally, maximal reinforcement tensile stress $\sigma_{s,char}$ has to be lesser than maximal allowed reinforcement tensile strength for characteristic combination $\sigma_{s,char,lim} = k_3 \times f_{yk}$. It can be expressed as follows:

$$\sigma_{s,char,lim} \leq k_3 \times f_{yk}$$

where k_3 is NA parameter, standard value is $k_3 = 0,8$.

Additionally, when the stress in reinforcement is caused by an imposed deformation then the maximal strength is increased to $k_4 \times f_{yk}$, where k_4 is NA parameter, standard value is $k_4 = 1,0$.

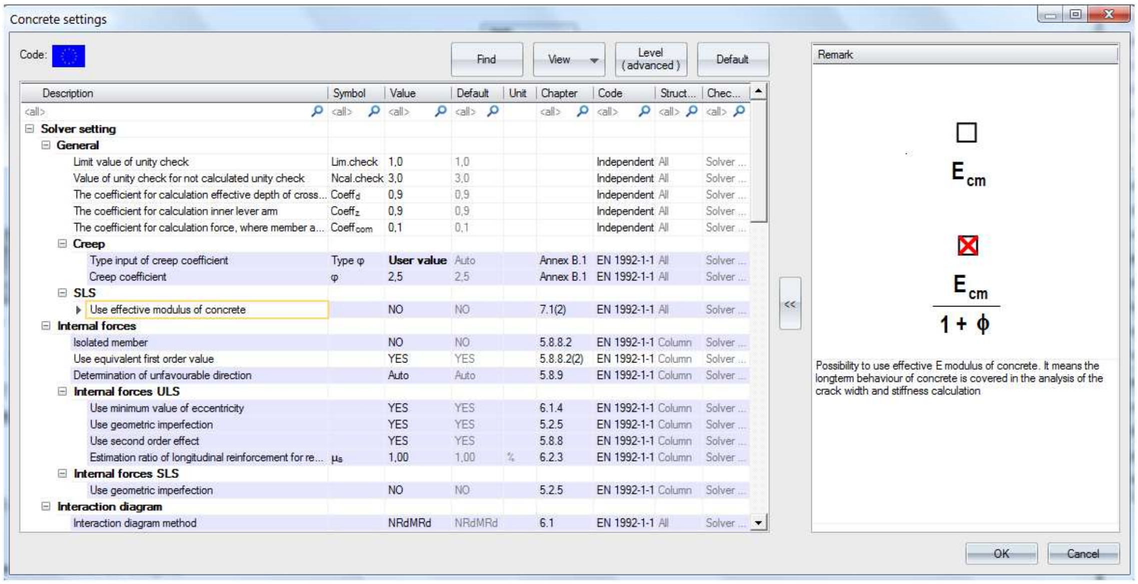
Unity check is maximum from all partial unity checks. It means

$$\text{Unity check} = \max(\sigma_{c,char}/\sigma_{c,char,lim};\sigma_{c,qp}/\sigma_{c,qp,lim};\sigma_{s,char}/\sigma_{s,char,lim})$$

The procedure above can be done for short-term or long-term state. It means stress-strain diagram including or not effective modulus of elasticity can be used. Effective E modulus of elasticity is based on the creep coefficient and it is calculated as follows:

$$E_{c,eff} = E_{cm} / (1+ f)$$

The including of long-term behaviour into the calculation is possible to set in Global settings - Solver settings - General - SLS - Use effective modulus of elasticity.



Description	Symbol	Value	Default	Unit	Chapter	Code	Struct...	Chec...
<all>	<all>	<all>	<all>		<all>	<all>	<all>	<all>
Solver setting								
General								
Limit value of unity check	Lim.check	1,0	1,0			Independent	All	Solver ...
Value of unity check for not calculated unity check	Ncal.check	3,0	3,0			Independent	All	Solver ...
The coefficient for calculation effective depth of cross...	$Coeff_d$	0,9	0,9			Independent	All	Solver ...
The coefficient for calculation inner lever arm	$Coeff_z$	0,9	0,9			Independent	All	Solver ...
The coefficient for calculation force, where member a...	$Coeff_{com}$	0,1	0,1			Independent	All	Solver ...
Creep								
Type input of creep coefficient	Type φ	**User value**	Auto		Annex B.1	EN 1992-1-1	All	Solver ...
Creep coefficient	φ	2,5	2,5		Annex B.1	EN 1992-1-1	All	Solver ...
SLS								
Use effective modulus of concrete		NO	NO		7.1(2)	EN 1992-1-1	All	Solver ...
Internal forces								
Isolated member		NO	NO		5.8.8.2	EN 1992-1-1	Column	Solver ...
Use equivalent first order value		YES	YES		5.8.8.2(2)	EN 1992-1-1	Column	Solver ...
Determination of unfavourable direction		Auto	Auto		5.8.9	EN 1992-1-1	Column	Solver ...
Internal forces ULS								
Use minimum value of eccentricity		YES	YES		6.1.4	EN 1992-1-1	Column	Solver ...
Use geometric imperfection		YES	YES		5.2.5	EN 1992-1-1	Column	Solver ...
Use second order effect		YES	YES		5.8.8	EN 1992-1-1	Column	Solver ...
Estimation ratio of longitudinal reinforcement for re...	μ_s	1,00	1,00	%	6.2.3	EN 1992-1-1	Column	Solver ...
Internal forces SLS								
Use geometric imperfection		NO	NO		5.2.5	EN 1992-1-1	Column	Solver ...
Interaction diagram								
Interaction diagram method		NRdMRd	NRdMRd		6.1	EN 1992-1-1	All	Solver ...

☐ E_{cm}

☒ $\frac{E_{cm}}{1 + \phi}$

Possibility to use effective E modulus of concrete. It means the longterm behaviour of concrete is covered in the analysis of the crack width and stiffness calculation

SCIA Engineer is not able to use characteristic or quasi-permanent combination together in one step. Therefore the same forces are used for crack appearance and final stress values.

Load cases are considered as standard load used for the stress limitation check

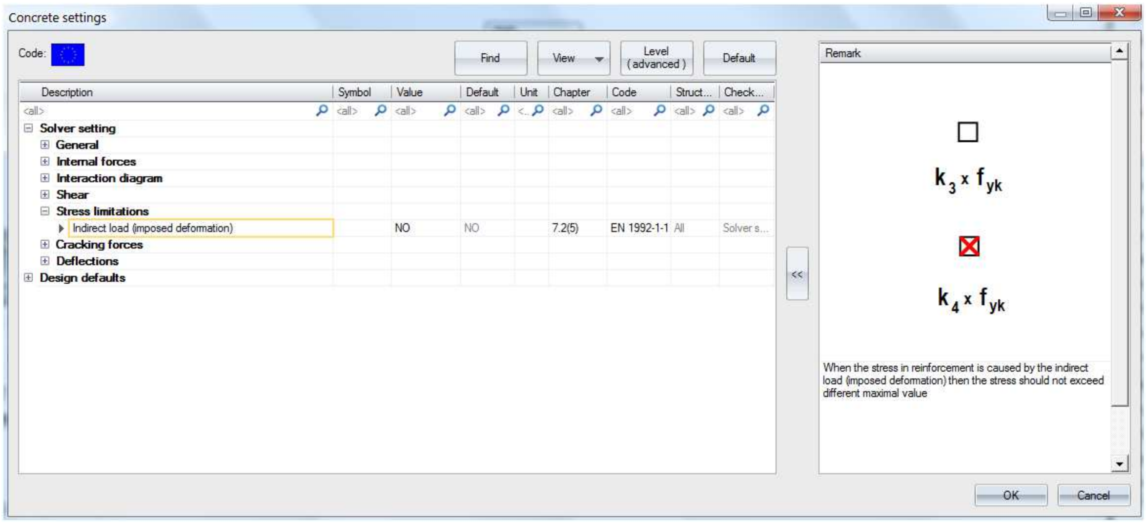
Setup

The following items have impact on the calculation of stress limitation check.

Imposed load

Additionally, when the stress in the reinforcement is caused by an imposed deformation then the maximal strength is increased to $k_4 \times f_{yk}$, where k_4 is a NA parameter, standard value is $k_4 = 1,0$.

The option for imposed deformation is available in Global settings-Solver settings - Stress limitations - Indirect load (imposed deformation).



Description	Symbol	Value	Default	Unit	Chapter	Code	Struct...	Check...
Solver setting								
General								
Internal forces								
Interaction diagram								
Shear								
Stress limitations								
Indirect load (imposed deformation)		NO	NO		7.2(5)	EN 1992-1-1	All	Solver s...
Cracking forces								
Deflections								
Design defaults								

☐ $k_3 \times f_{yk}$

☒ $k_4 \times f_{yk}$

When the stress in reinforcement is caused by the indirect load (imposed deformation) then the stress should not exceed different maximal value

Value of strength for calculation of cracking forces

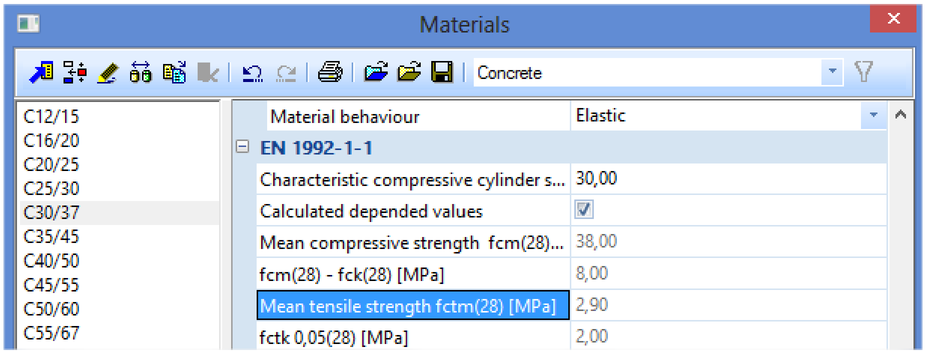
This value can be set in **Concrete settings** by using **Advanced level** or in **1D member data** (advanced mode is ON), if it is defined. If normal concrete stress on un-cracked section at the most tensioned fibre of concrete cross-section is greater than this value, the crack width will be occurred and will be calculated. There are two possibilities:

0 MPa	crack width is calculated if there is some tension in cross-section
$f_{ct,eff}$	crack width is calculated only in case, that normal concrete stress on un-cracked section at the most tensioned fibre of concrete cross-section is greater than the mean value of the tensile strength of the concrete effective at the time

Type of strength for calculation of cracking forces

This value can be set in **Concrete settings** by using **Advanced level** or in **1D member data** (advanced mode is ON).There are two possibilities:

f_{ctm}	mean tensile strength of concrete in time 28 days is taken into account, see picture below
$f_{ctm,fl}$	mean flexural tensile strength (EN 1992-1-1,clause 3.1.8(1)) is taken into account. This value should be used if restrained deformations such as shrinkage or temperature movements are taking into account for calculation crack width



C12/15
C16/20
C20/25
C25/30
C30/37
C35/45
C40/50
C45/55
C50/60
C55/67

Material behaviour	Elastic
EN 1992-1-1	
Characteristic compressive cylinder s...	30,00
Calculated depended values	☑
Mean compressive strength fcm(28)...	38,00
fcm(28) - fck(28) [MPa]	8,00
Mean tensile strength fctm(28) [MPa]	2,90
fctk 0,05(28) [MPa]	2,00

The value presented in material properties of concrete (picture above) is mean tensile strength of concrete in time 28 days. If cracking is expected earlier than 28 days, it is necessary to input value $f_{ctm(t)}$ in this time to material properties (EN 1992-1-1,clause 3.1.2(9))

Use of effective modulus of concrete

This value can be set in **Concrete settings** by using **Advanced level** or in **1D member data** (advanced mode is ON). If this check box is ON, then effective module of elasticity is taken into account.

Check width (SLS)

The crack width is calculated according to clause 7.3.4 in EN 1992-1-1. The following preconditions are used for calculation:

- The crack width is calculated for beams and columns and for general load (N+My+Mz)
- Cross-section with one polygon and one material is taken into account in version SEN 15
- The material of all reinforcement bars have to be same in SEN 15
- Normal stress on un-cracked section at the most tensioned fibre for determination if crack occurred or not (check of normal stresses), should be calculated for characteristic combination of the load according to EN 1992-1-1, clause 7.2(2). There is made simplification in SEN 15 that this normal stress is calculated for the same type of combination as is used for the calculation of crack width (load/combination/class inputted in service Crack control)

Value of strength for calculation of cracking forces

This value can be set in **Concrete setting**s by using **Advanced level** or in **1D member data** (advanced mode is ON), if it is defined. If normal concrete stress on un-cracked section at the most tensioned fibre of concrete cross-section is greater than this value, the crack will occur and the crack width will be calculated. There are two possibilities:

0 MPa	crack width is calculated if there is some tension in cross-section
$f_{ct,eff}$	crack width is calculated only in case, that normal concrete stress on un-cracked section at the most tensioned fibre of concrete cross-section is greater the mean value of the tensile strength of the concrete effective at the time

Check of normal stresses (occurring of crack width)

Before calculation of crack width the normal concrete stresses on un-cracked section at the most tensioned fibre has to be checked. If condition below is satisfied, the crack width does not occur and the crack width is not calculated

$$\sigma_{ct} \leq \sigma_{cr}$$

It is possible to present cracking forces (N_{cr}, M_{cry}, M_{crz}) in numerical output. These cracking forces are forces which are caused by reaching of value $f_{c,teff}$ (occurring of crack width in cross-section) in the most tensioned fibre of concrete cross-section in direction of first or second principal stress. For calculation of this cracking forces is used condition, that eccentricity of inputted forces and cracking forces has to be the same.

Type of strength for calculation of cracking forces

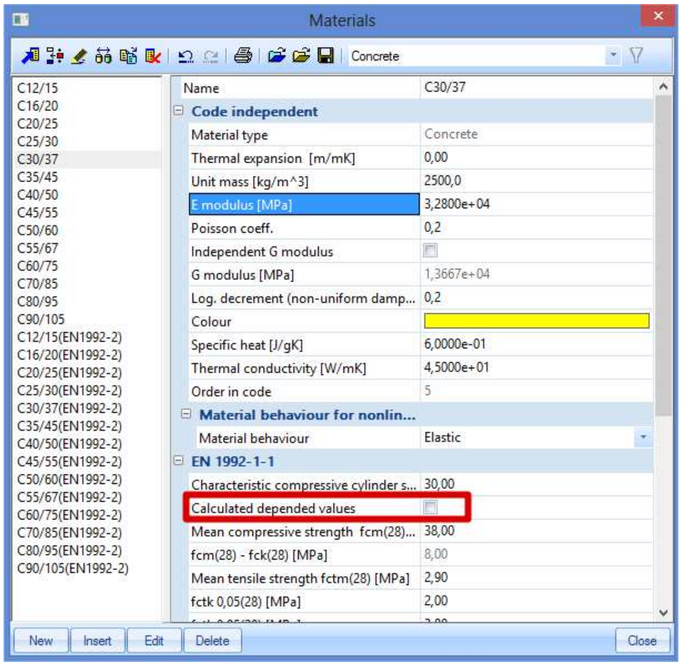
This value can be set in **Concrete settings** by using **Advanced level** or in **1D member data** (advanced mode is ON).There are two possibilities:

f_{ctm}	mean tensile strength of concrete in time 28 days is taken into account
$f_{ctm,fl}$	mean flexural tensile strength (EN 1992-1-1,clause 3.1.8(1)) is taken into account. This value should be used if restrained deformations such as shrinkage or temperature movements are taking into account for calculation of crack width

Use of effective modulus of concrete

This value can be set in **Concrete settings** by using **Advanced level** or in **1D member data** (advanced mode is ON). If this check box is ON, then effective module of elasticity is taken into account.

EN 1992-1-1 does not give instructions, how creep under varying load should be taken into account for calculation of the crack width. The creep can be generally taken into account by assuming that effective module of elasticity (EN 1992-1-1, clause 5.8.7(2)) for calculation modular ratio ($E_s/E_{c,eff} \approx 15$). A Lower value of modular ratio (greater value of module of elasticity of concrete than effective) may be used where less than 50 % of the stresses arise from quasi-permanent load. The different value of modulus of elasticity can be inputted directly in material properties, see picture below, but this change has influence to FEM analysis too.



Name	C30/37
Code independent	
Material type	Concrete
Thermal expansion [m/mK]	0,00
Unit mass [kg/m^3]	2500,0
E modulus [MPa]	3,2800e+04
Poisson coeff.	0,2
Independent G modulus	☐
G modulus [MPa]	1,3667e+04
Log. decrement (non-uniform damp...	0,2
Colour	🟨
Specific heat [J/gK]	6,0000e-01
Thermal conductivity [W/mK]	4,5000e+01
Order in code	5
Material behaviour for nonlin...	
Material behaviour	Elastic
EN 1992-1-1	
Characteristic compressive cylinder s...	30,00
Calculated depended values	☐
Mean compressive strength fcm(28)...	38,00
fcm(28) - fck(28) [MPa]	8,00
Mean tensile strength fctm(28) [MPa]	2,90
fctk 0,05(28) [MPa]	2,00

Type of maximal crack width

This value can be set only in 1D member data (advanced mode is ON) and there are two options

Auto	Maximal (limit value) of crack width will be calculated according to EN 1992-1-1 (Table 7.1N)
User	user defined value will be taken into account for this member

Calculation of mean strain in the reinforcement and concrete

Difference between mean strain in the reinforcement and the mean strain in concrete between the cracks is calculated according to EN 1992-1-1, formula 7.9

$$\left(\varepsilon_{sm} - \varepsilon_{cm}\right) = \max\left[\frac{\sigma_s - k_t \cdot \frac{f_{ct,eff}}{\rho_{p,eff}} \cdot \left(1 + \alpha_e \cdot \rho_{p,eff}\right)}{E_s}; 0.6 \cdot \frac{\sigma_s}{E_s}\right]$$

From the formula above follows, that difference between mean strain in the reinforcement and concrete mainly depends on:

- strain (stress) in the most tensioned reinforcement,
- effect of tension stiffening.

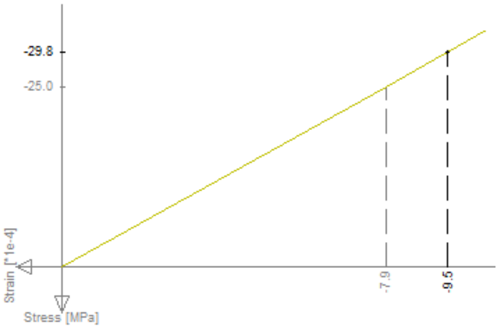
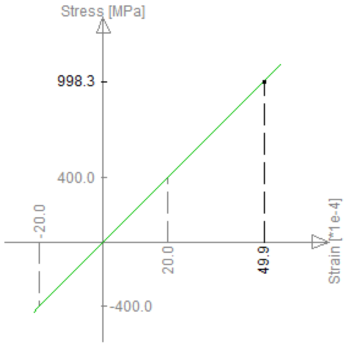
Strain in the most tensioned reinforcement

Strain in the most tensioned reinforcement is calculated according to formula below:

$$\varepsilon_s = \frac{\sigma_s}{E_s}$$

There are used following preconditions in SEN:

- The section is loaded by load/combination/class selected in service crack control
- Transformed section is used
- Plane section remains plane after loading (deformation) too
- Tensile strength of concrete is not taken into account (cracked section)
- ideal bond between concrete and reinforcement is taken into account, it means change strain of reinforcement ε_s and concrete fibre ε_c in the same position is the same
- The linear strain-stress diagram of concrete and reinforcement with infinite branch is used, it means, that distribution of stress is linear and depends on change of strain (Hooke's law)

Linear stress-strain diagram of concrete	**Linear stress-strain diagram of reinforcement**
	

Effect of tension stiffening

The tension stiffening effect represents the capacity of the intact concrete between neighbouring cracks to a limited amount of tensile forces. The reason for this effect is bond slip between the reinforcement and the neighbouring concrete. The decreasing of stress in reinforcement due to tension stiffening can be calculated according to formula:

$$\Delta\sigma_s = k_t \cdot \frac{f_{ct,eff}}{\rho_{p,eff}} \cdot \left(1 + \alpha_e \cdot \rho_{p,eff}\right)$$

Calculation of maximum crack spacing

Maximum crack spacing is calculated according to EN 1992-1-1, clause 7.3.4(3)

$$s_{r,max} = 1.3 \cdot (h - x) \leftarrow if\, s_s > 5\left(c + 0.5 \cdot d_s\right)\ or\ \rho_{p,eff} = 0$$

$$s_{r,max} = \min\left[k_3 \cdot c + \frac{k_1 \cdot k_2 \cdot k_4 \cdot d_s}{\rho_{p,eff}};\ 1.3 \cdot (h - x)\right]\ otherwise$$

Calculation of crack width

The crack width is calculated according to EN 1992-1-1, formula 7.8.

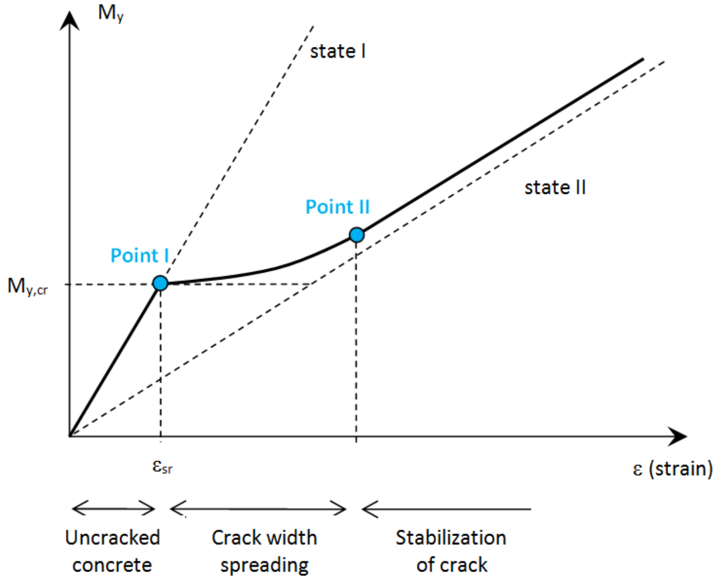
$$w = s_{r,max} \bullet (\varepsilon_{sm} - \varepsilon_{cm})$$

Deflections (SLS)

The calculation of deflection is done according to chapter 7.3.4 from EN 1992-1-1. The verification of deflections should be performed due to the following reasons:

- Unacceptable deflection should not affect proper function of the structure or aesthetic - limit for total deflection
- To avoid damage to partitions and finishes due to increments in deflection following their construction - limit for additional deflection

The behaviour of the reinforced cross-section for deflection needs is the same as used for the stiffness calculation and can be also expressed in term of moment and strain (deformation) diagram. The final value of stiffness is calculated using interpolation formula between state (I) deformation for uncracked concrete section (x = 0) and state (II) deformation for fully cracked concrete section (no tension carries) (x = 1) dependently on the ratio of stress in reinforcement from cracking load and acting load. The dependency of cracking moment on strain in concrete is visible from the following figure. The value of deformation is then recalculated from the stiffness and acting load.



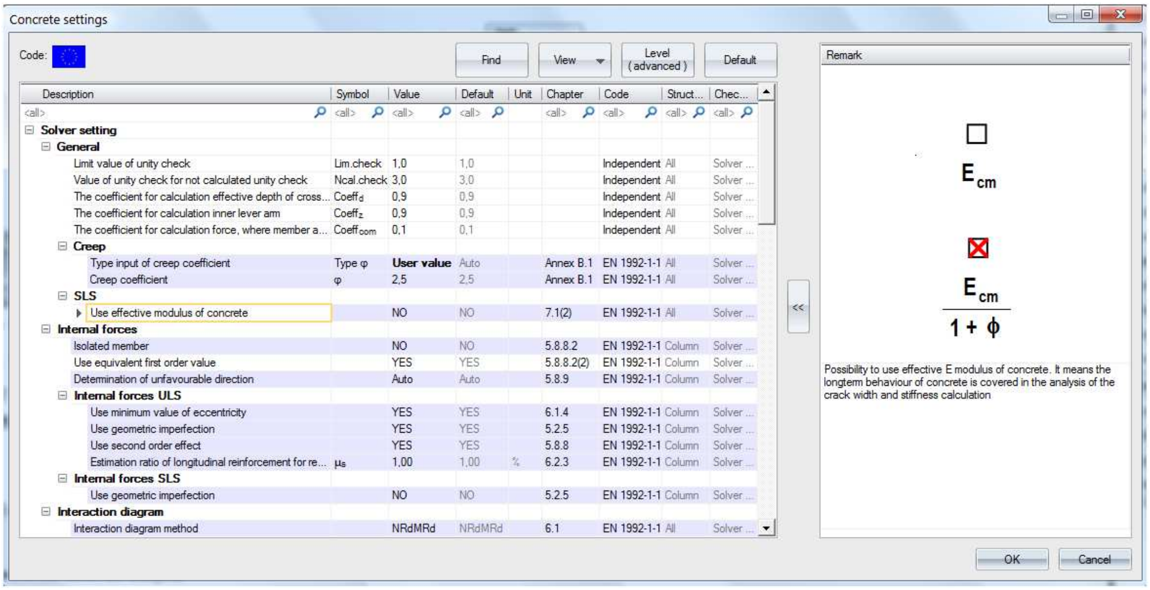
Generally, there are three main effects which affect the values of deformation.

Effect of load
In concrete structures, deflections increase with time under sustained load. The greater part of the deflection normally occurs under sustained loads. Therefore, long-term deflections are calculated under a best estimate of the sustained load during the lifetime of the structure. The design load for calculating long-term deflections is the permanent load

Effect of cracking
Effect of concrete cracking is an irreversible process. Therefore, it is necessary to calculate long-term deflections using an effective tensile concrete strength which corresponds to the worst cracking during the lifetime of the structure.

Effect of creep
In fact creep is the continuous deformation of a member under sustained load. The creep effect is covered in the calculation via effective modulus of elasticity which is calculated using the creep coefficient.

SCIA Engineer is able to calculate short-term or long-term stiffness. This type depends on setting in Global settings - Solver settings - General - SLS - Use effective modulus of elasticity.



Concrete settings

Code:

Description	Symbol	Value	Default	Unit	Chapter	Code	Struct...	Chec...
<all>	<all>	<all>	<all>		<all>	<all>	<all>	<all>
⊟ **Solver setting**								
⊟ **General**								
Limit value of unity check	Lim.check	1,0	1,0			Independent	All	Solver ...
Value of unity check for not calculated unity check	Ncal.check	3,0	3,0			Independent	All	Solver ...
The coefficient for calculation effective depth of cross...	$Coeff_d$	0,9	0,9			Independent	All	Solver ...
The coefficient for calculation inner lever arm	$Coeff_z$	0,9	0,9			Independent	All	Solver ...
The coefficient for calculation force, where member a...	$Coeff_{com}$	0,1	0,1			Independent	All	Solver ...
⊟ **Creep**								
Type input of creep coefficient	Type φ	**User value**	Auto		Annex B.1	EN 1992-1-1	All	Solver ...
Creep coefficient	φ	2,5	2,5		Annex B.1	EN 1992-1-1	All	Solver ...
⊟ **SLS**								
▸ Use effective modulus of concrete		NO	NO		7.1(2)	EN 1992-1-1	All	Solver ...
⊟ **Internal forces**								
Isolated member		NO	NO		5.8.8.2	EN 1992-1-1	Column	Solver ...
Use equivalent first order value		YES	YES		5.8.8.2(2)	EN 1992-1-1	Column	Solver ...
Determination of unfavourable direction		Auto	Auto		5.8.9	EN 1992-1-1	Column	Solver ...
⊟ **Internal forces ULS**								
Use minimum value of eccentricity		YES	YES		6.1.4	EN 1992-1-1	Column	Solver ...
Use geometric imperfection		YES	YES		5.2.5	EN 1992-1-1	Column	Solver ...
Use second order effect		YES	YES		5.8.8	EN 1992-1-1	Column	Solver ...
Estimation ratio of longitudinal reinforcement for re...	μ_s	1,00	1,00	%	6.2.3	EN 1992-1-1	Column	Solver ...
⊟ **Internal forces SLS**								
Use geometric imperfection		NO	NO		5.2.5	EN 1992-1-1	Column	Solver ...
⊟ **Interaction diagram**								
Interaction diagram method		NRdMRd	NRdMRd		6.1	EN 1992-1-1	All	Solver ...

Remark

☐ E_{cm}

☒ $\dfrac{E_{cm}}{1+\phi}$

Possibility to use effective E modulus of concrete. It means the longterm behaviour of concrete is covered in the analysis of the crack width and stiffness calculation

There are the following assumptions:

- check is performed on linear/envelope or code combination (it is not necessary to defined concrete combinations)
- check is done for selected members (Current CDD runs for whole structure)

There are the following limitations:

- Deformation caused by shrinkage is not automatically taken into account in version SCIA Engineer 15.
- Verification based on limiting span / depth ratio according to 7.4.2 is not implemented.
- The check is done only on user defined reinforcement (check using theoretical designed reinforcement is not supported).
- **The calculation of deflection depends on the internal forces used for the reduced stiffness. Therefore the check of deflection does not work for case where the internal forces are equal to zero but deflection are not zero. Typically for cantilever structure of member with free overhang. Here the results cannot be considered.**

Theory

As mentioned in EN 1992-1-1 chapter 7.4.1(3) calculated deformations should not exceed those that can be accommodated by other connected elements such as partitions, glazing, cladding, services or finishes. In some cases limitation may be required to ensure the proper functioning of machinery or apparatus supported by the structure, or to avoid pounding on flat roofs.

Generally two main situations are required to be checked:

- **Total deflection** - The appearance and general utility of the structure could be impaired when the calculated sag of a beam, slab or cantilever subjected to quasi-permanent loads exceeds span/250. The sag is assessed relative to the supports. Pre-camber may be used to compensate for some or all of the deflection but any upward deflection incorporated in the form-work should not generally exceed span/250
- **Additional deflection** - Deflections that could damage adjacent parts of the structure should be limited. For the deflection after construction, span/500 is normally an appropriate limit for quasi-permanent loads. Other limits may be considered, depending on the sensitivity of adjacent parts.

The calculation procedure used in new Deflection check can be described in the following steps:

1) Calculation of short-term stiffness - short-term stiffness is calculated using 28 days E modulus for acting load

2) Calculation of long-term stiffness - long-term stiffness is calculated using effective E modulus based on creep coefficient for acting load.

Unfortunately, for time being there is not a possibility to distinguish between short-term and long-term part of the load in combination. Therefore some precondition has been established for determination of long-term part of the load. Long-term part of the load (LongTermPercentage) is estimated based on the type of combination for check. There are three main SLS combinations:

1) SLS characteristics - LongTermPercentage = 70%
2) SLS frequent - LongTermPercentage = 85%
3) SLS quasi-permanent- LongTermPercentage = 100%

3) Calculation of ratios - stiffness ratios are used as simplified method for the calculation of particular deflections (see below). These values are calculated for each state according to 1 and 2 point above. Generally, the values are ratios of linear stiffness of concrete component only divided by resultant stiffness taking cracks into account.

$$\text{ratio} = \text{Stiffness}_{\text{lin}} / \text{Stiffness}_{\text{res}}$$

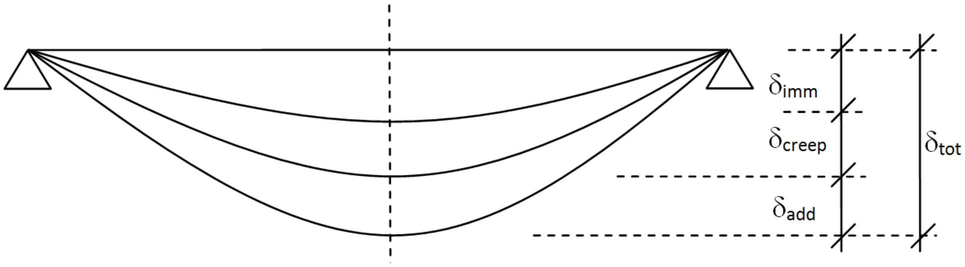
For example:

$$\text{ratio}_{\text{uz}} = EI_{z,\text{lin}} / EI_{z,\text{res}}$$

4) Calculation of particular component - Several particular components are needed from the calculation of total and additional deflection.

As was mentioned before, the short- and long-term stiffnesses are calculated using a so-called creep factor. This creep-factor is dependent on the relative humidity, outline of the cross-section, reinforcement percentage, concrete class, etc. This factor is used to divide the short-term stiffness and obtain the long-term stiffness, Thus by taken the concrete stiffness for short- and long-term and the representative compression strength the program calculates the stress and strain diagram.

Generally, the components calculated below can be graphically presented on the following figure:



Linear (elastic) deflection - is the sum of short-term and long-term elastic deflection

$$\delta_{\text{lin}} = \delta_{\text{lin,s}} + \delta_{\text{lin,l}}$$

Immediate deflection - to calculate the immediate deformation, the deformation of the permanent load is calculated using the short-term stress and strain diagram. Additionally by subtracting the immediate deformation from the total deformation, the program calculates the additional deformation.

$$\delta_{\text{imm}} = \delta_{\text{lin,l}} {}^{x} \text{ ratio }_{s}$$

Short-term deflection - is the multiplication of short-term elastic deflection and short-term ratio

$$\delta_{s} = \delta_{\text{lin,s}} {}^{x} \text{ ratio }_{s}$$

Long-term deflection + creep - is the multiplication of long-term elastic deflection and long-term ratio

$$\delta_{l,creep} = \delta_{lin,l} \times \text{ratio}_{l}$$

Creep deflection - is calculated based on short and long term ratios

$$\delta_{creep} = \delta_{lin,l} \times (\text{ratio}_{l} - \text{ratio}_{s})$$

Long-term deflection - is the difference between deflection caused by long-term + creep and creep parts of deflection

$$\delta_{l} = \delta_{l,creep} - \delta_{creep}$$

Additional deflection - is the difference between sum of short-term and long-term with creep towards immediate deflection

$$\delta_{add} = \delta_{s} + \delta_{l,creep} - \delta_{imm}$$

Total deflection - is the sum of short-term and long-term + creep deflection

$$\delta_{tot} = \delta_{s} + \delta_{l,creep}$$

5) Check of deflections - as was reported at the beginning of this chapter two deflections are required to be checked. At first the limit values has to be calculated for particular direction of deflections. These values are:

a) limit for total deflection

$$\delta_{tot,lim} = L / 250$$

b) limit for additional deflection

$$\delta_{add,lim} = L / 500$$

In formulas above, there is mentioned L value. This value corresponds to buckling length multiplied by β factor of the member in particular direction.

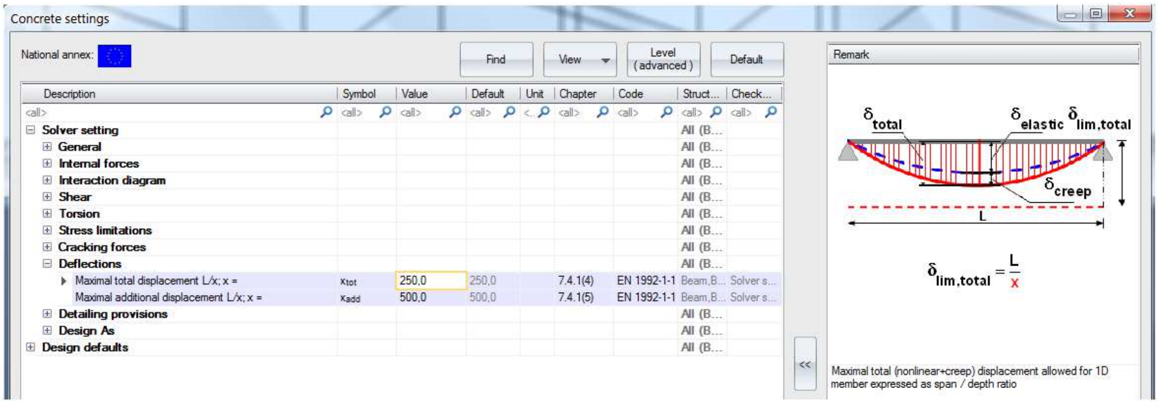
Finally the unity check can be calculated as follows:

$$\text{Unity check} = \max(\delta_{tot}/\delta_{tot,lim};\delta_{add}/\delta_{add,lim})$$

Setup

The following items have impact on the calculation of deflection check. Both are store in Concrete settings (structure) - Global settings - Solver settings - Deflections

Maximal total displacement
Maximal total displacement expresses ad L/x. Default value is 250. The limit is taken according to chapter 7.4.1(4) from EN 1992-1-1.



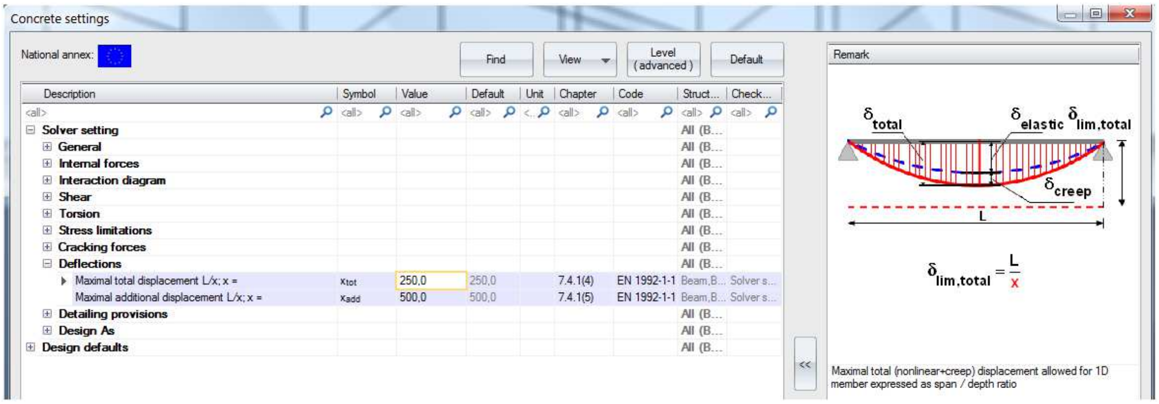
Description	Symbol	Value	Default	Unit	Chapter	Code	Struct...	Check...
<all>	<all>	<all>	<all>	<...	<all>	<all>	<all>	<all>
Solver setting							All (B...	
General							All (B...	
Internal forces							All (B...	
Interaction diagram							All (B...	
Shear							All (B...	
Torsion							All (B...	
Stress limitations							All (B...	
Cracking forces							All (B...	
Deflections							All (B...	
Maximal total displacement L/x; x =	x_{tot}	250,0	250,0		7.4.1(4)	EN 1992-1-1	Beam,B...	Solver s...
Maximal additional displacement L/x; x =	x_{add}	500,0	500,0		7.4.1(5)	EN 1992-1-1	Beam,B...	Solver s...
Detailing provisions							All (B...	
Design As							All (B...	
Design defaults							All (B...	

$$\delta_{lim,total} = \frac{L}{x}$$

Maximal total (nonlinear+creep) displacement allowed for 1D member expressed as span / depth ratio

Maximal additional displacement

Maximal additional displacement expresses ad L/x. Default value is 500. The limit is taken according to chapter 7.4.1(5) from EN 1992-1-1.

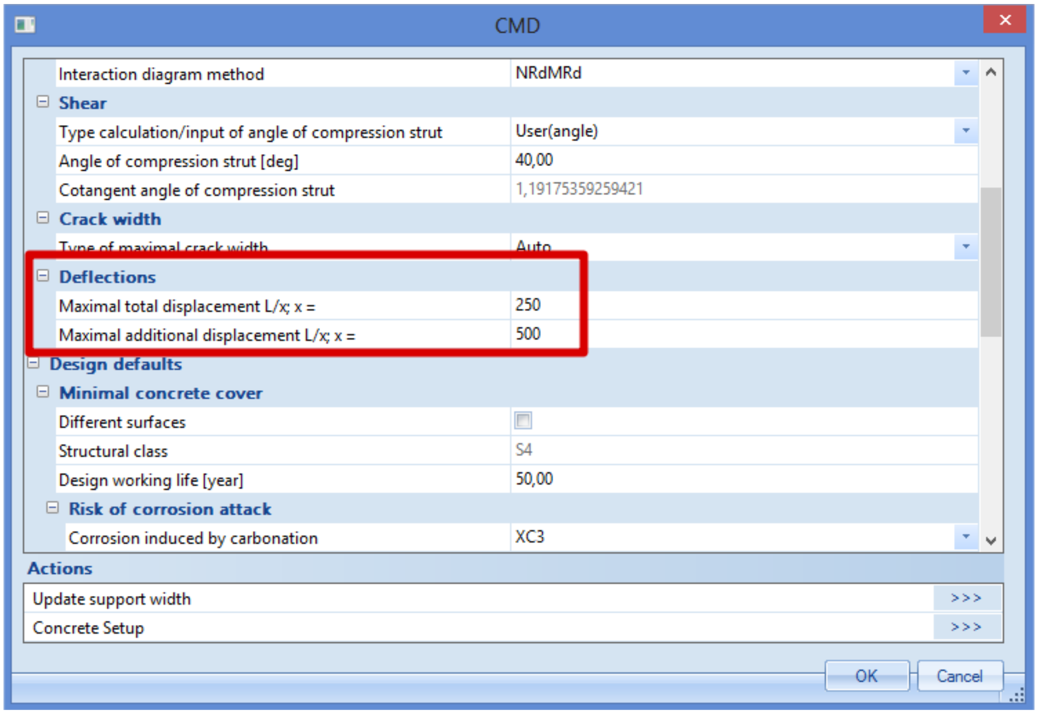


Description	Symbol	Value	Default	Unit	Chapter	Code	Struct...	Check...
<all>	<all>	<all>	<all>	<...	<all>	<all>	<all>	<all>
Solver setting							All (B...	
General							All (B...	
Internal forces							All (B...	
Interaction diagram							All (B...	
Shear							All (B...	
Torsion							All (B...	
Stress limitations							All (B...	
Cracking forces							All (B...	
Deflections							All (B...	
Maximal total displacement L/x; x =	x_{tot}	250,0	250,0		7.4.1(4)	EN 1992-1-1	Beam,B...	Solver s...
Maximal additional displacement L/x; x =	x_{add}	500,0	500,0		7.4.1(5)	EN 1992-1-1	Beam,B...	Solver s...
Detailing provisions							All (B...	
Design As							All (B...	
Design defaults							All (B...	

$$\delta_{lim,total} = \frac{L}{x}$$

Maximal total (nonlinear+creep) displacement allowed for 1D member expressed as span / depth ratio

Additionally, both values above can be modified using Concrete member data per each member.



Interaction diagram method	NRdMRd
Shear	
Type calculation/input of angle of compression strut	User(angle)
Angle of compression strut [deg]	40,00
Cotangent angle of compression strut	1,19175359259421
Crack width	
Type of maximal crack width	Auto
Deflections	
Maximal total displacement L/x; x =	250
Maximal additional displacement L/x; x =	500
Design defaults	
Minimal concrete cover	
Different surfaces	☐
Structural class	S4
Design working life [year]	50,00
Risk of corrosion attack	
Corrosion induced by carbonation	XC3

Update support width

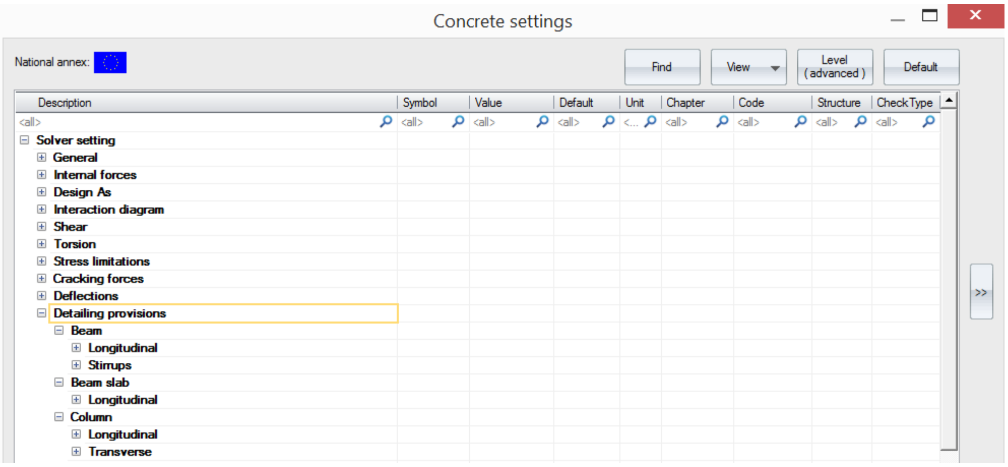
Concrete Setup

Detailing provisions

Requirements for detailing provisions of reinforced concrete members are another step of proper design respecting safety, serviceability and durability of structure.

Generally SCIA Engineer distinguishes three main types of member within theirs detailing provisions:

- Beam - verification of longitudinal and shear reinforcement
- Column - verification of main and transverse reinforcement
- Beam slab - verification of longitudinal reinforcement only



Following table shows which checks of detailing provisions are performed for a particular member type:

Member type	longitudinal (main)	shear (transverse)
Beam	8.2(2) - Minimal clear spacing of bars 9.2.1.1(1) - Minimal area of longitudinal reinforcement 9.2.1.1(3) - Maximal area of longitudinal reinforcement 9.2.3(4) - Maximal centre-to-centre bar distance based on torsion Code-Independent - Maximal clear spacing	6.2.3(3) - Maximal percentage of shear reinforcement 9.2.2(5) - Minimal percentage of shear reinforcement 9.2.2(6) - Maximal longitudinal spacing of stirrups (shear) 9.2.2(8) - Maximal transverse spacing of stirrups (shear) 9.2.3(3) - Maximal longitudinal spacing of stirrups (torsion)
Column	8.2(2) - Minimal clear spacing of bars 9.5.2(1) - Minimal bar diameter of longitudinal reinforcement 9.5.2(2) - Minimal area of longitudinal reinforcement 9.5.2(3) - Maximal area of longitudinal reinforcement 9.5.2(4) - Minimal number of longitudinal reinforcement bars	9.2.3(3) - Maximal longitudinal spacing of stirrups (torsion) 9.5.3(1) - Minimal diameter of transverse reinforcement 9.5.3(3) - Maximal longitudinal spacing of transverse reinforcement
Beam Slab	8.2(2) - Minimal clear spacing of bars 9.3.1.1(3) - Maximal bar distance of longitudinal reinforcement	-

There are the following assumptions and limitations:

- Stirrups can be defined with perpendicular direction to axis of the member (α = 90°).
- Shear bents are not able to define, therefore check of detailing provisions for them is not supported
- Each check of detailing provisions includes differences per national annex, if those exist.

Minimal clear spacing of bars 8.2(2)

The main principles which are checked are mainly satisfying minimal distances between bars which should be arranged in such a way that concrete can be placed and compacted satisfactorily so that adequate bond will develop between the bars and concrete.

The procedure of calculation is running for each distance between bars and verification of the minimal distance among them towards the limited value from the code. The distances are evaluated as the minimal clear distance for all member types mentioned before (beam, column and beam slab). Check looks as follows.

Calculation of minimal clear distance between longitudinal bar as:

$$s_{s\text{-}s,min}.$$

Furthermore minimal allowed clear distance between bars from all bars in cross-section is calculated according to chapter 8.2(2) as

$$s_{s\text{-}s,min,lim} = \max\,(k_1 \bullet \phi; d_g + k_2; s_{lb,min})$$

where:

- k_1 and k_2 are coefficients defined in NA. For standard Eurocode $k_1 = 1$ and $k_2 = 5$.
- ϕ is diameter of maximal longitudinal reinforcement
- d_g - maximal stone diameter in concrete mixture
- $s_{lb,min}$ is minimal clear distance defined as fixed value in chapter 8.2(2)

Finally unity check is calculated as follows:

$$UC_{8.2(2)} = s_{s\text{-}s,min,lim} / s_{s\text{-}s,min}.$$

Maximal percentage of shear reinforcement (6.2.3(3))

The maximal percentage of shear reinforcement should not exceed minimal value defined in 6.2.3(3) formula 6.12. Check looks as follows. Calculation of percentage of shear reinforcement from defined reinforcement is done according to formula 9.4.

$$\rho_w = A_{sw} / (s\,.b_w.\sin(\alpha))$$

Furthermore maximal allowed percentage of shear reinforcement is calculated as follows (see formula 6.12).

$$\rho_{w,max} = 0{,}5.\alpha_{cw}.\nu f_{cd} / f_{yd}$$

Finally unity check is calculated as follows:

$$UC_{6.2.3(3)} = \rho_w / \rho_{w,max}.$$

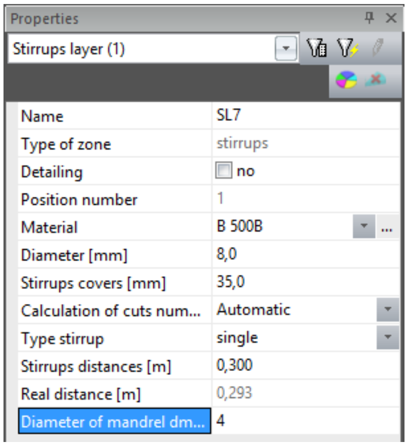
Minimal mandrel diameter (8.3(2))

The mandrel diameter should not exceed minimal value defined in 8.3(2). Check looks as follows. Calculation of minimal defined mandrel diameter of stirrups:

$$\phi_m = Coeff_{\phi m} .\phi_s$$

where

- $Coeff_{\phi m}$- value defined in Stirrup layer - Diameter of mandrel



Name	SL7
Type of zone	stirrups
Detailing	☐ no
Position number	1
Material	B 500B
Diameter [mm]	8,0
Stirrups covers [mm]	35,0
Calculation of cuts num...	Automatic
Type stirrup	single
Stirrups distances [m]	0,300
Real distance [m]	0,293
Diameter of mandrel dm...	4

- ϕ_s- diameter of defined stirrup

Furthermore minimal allowed mandrel diameter of stirrup is determined as follows from table 8.1N

$$\text{for } \phi_s \leq 16mm;\ \phi_{m,min} = 4.\ .\phi_s$$
$$\text{for } \phi_s > 16mm;\ \phi_{m,min} = 7.\ .\phi_s$$

Finally unity check is calculated as follows:

$$UC_{8.3(2)} = \phi_m/\phi_{m,min}.$$

Minimal reinforcement area 9.2.1.1(1)

The area of tensile longitudinal reinforcement has to be limited by minimal value $A_{s,min}$ calculated as follows.

$$A_{s,min} = \max(Coeff_{As,min,2}\bullet f_{ctm}\bullet b_t\bullet d\ /\ f_{yk};\ Coeff_{As,min,1}\bullet b_t\bullet d)$$

Calculation of tensile area of reinforcement in considered cross-section A_{st}.
Finally unity check is calculated as follows:

$$UC_{9.2.1.1(1)} = A_{s,min} / A_{s,t}.$$

Maximal area of reinforcement 9.2.1.1(3)

The maximal area of longitudinal reinforcement $A_{s,max}$ should not exceed the values described in 9.2.1.1(3) and is calculated as follows.

$$A_{s,max} = 0{,}04 \bullet A_c$$

Calculation of longitudinal reinforcement area in considered cross-section A_s.
Finally unity check is calculated as follows:

$$UC_{9.2.1.1(3)} = A_s / A_{s,max}.$$

Minimal percentage of shear reinforcement (9.2.2(5))

The minimal percentage of shear reinforcement should not exceed minimal value defined in 9.2.2(5). Check looks as follows. Calculation of percentage of shear reinforcement from defined reinforcement is done according to formula 9.4.

$$\rho_w = A_{sw} / (s .b_w.\sin(\alpha))$$

Furthermore minimal allowed percentage of shear reinforcement is calculated as follows (see formula 9.5N).

$$\rho_{w,min} = 0{,}08.\sqrt{f_{ck}} / f_{yk}$$

Finally unity check is calculated as follows:

$$UC_{9.2.2(5)} = \rho_{w,min} / \rho_w.$$

Maximal longitudinal spacing of stirrups based on shear (9.2.2(6))

The maximal longitudinal spacing between stirrups links should not exceed maximal value defined in 9.2.2(6). Check looks as follows. Calculation of maximal defined longitudinal distance of stirrups s_l.

Furthermore maximal allowed longitudinal distance between stirrups is calculated as follows

$$s_{l,max} = 0{,}75 \bullet d \bullet (1+\cot g\ (\alpha))$$

Finally unity check is calculated as follows:

$$UC_{9.2.2(6)} = s_l / s_{l,max}.$$

Maximal longitudinal spacing of stirrups based on shear (9.2.3(3))

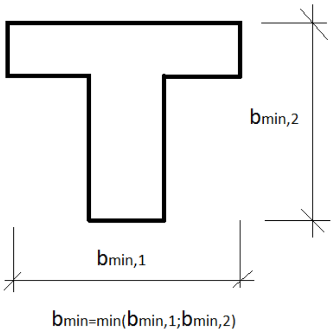
The maximal longitudinal spacing between stirrups links based on torsion requirements should not exceed maximal value defined in 9.2.3(3). Check looks as follows. Calculation of maximal defined longitudinal distance of stirrups s_l.

Furthermore maximal allowed longitudinal distance between stirrups based on torsion requirements is calculated as follows

$$s_{l,tor,max} = \min\ (u_k/8;\ s_l;\ b_{min})$$

where:

- u_k - perimeter of effective are for torsion
- b_{min} - minimal dimension of cross-section determined for rewritten rectangular cross-section



Finally unity check is calculated as follows:

$$UC_{9.2.3(3)} = s_l / s_{l,tor,max}.$$

Maximal centre-to-centre bar distance based on torsion (9.2.3(4))

The procedure of calculation is running for each distance between bars and verification of the maximal distance among them towards the limited value from the code. The distances are evaluated as the maximal centre-to centre distance. Check looks as follows.

Calculation of maximal centre-to-centre bar distance between longitudinal bar as:

$s_{c\text{-}c,max}$.

Furthermore minimal allowed centre-to-centre distance between bars from all bars in cross-section is determined according to chapter 9.2.3(4) as

$s_{c\text{-}c,max,lim} = 350mm$

Finally unity check is calculated as follows:

$UC_{9.2.3(4)} = s_{c\text{-}c,max} / s_{c\text{-}c,max,lim}$.

Maximal clear spacing of bars (Code independent)

The procedure of calculation is running for each distance between bars and verification of the maximal distance among them towards the limited value from the user point of view. The distances are evaluated as the maximal clear distance for all member types mentioned before (beam, column and beam slab). Check looks as follows.

Calculation of maximal clear distance between longitudinal bars as:

$s_{s\text{-}s,max}$.

Furthermore maximal allowed clear distance between bars from all bars in cross-section is defined by user in Concrete settings (structure)

$s_{s\text{-}s,max,lim}$

Finally unity check is calculated as follows:

$UC_{max\_bar\_distance(user)} = s_{s\text{-}s,max} / s_{s\text{-}s,max,lim}$.

Unity check calculation

Finally, the unity check is calculated dependently on member type and settings in Concrete settings. Three basic cases are distinguished:

- **Beam**

  $UC = max (UC_{8.2(2)}; UC_{8.3(2)}; UC_{6.2.3(3)}; UC_{9.2.1.1(1)}; UC_{9.2.1.1(3)}; UC_{9.2.2(5)}; UC_{9.2.2(6)}; UC_{9.2.2(8)}; UC_{9.2.3(3)}; UC_{9.2.3(4)}; UC_{max\_bar\_distance(user)})$
- **Beam slab**

  $UC = max (UC_{8.2(2)}; UC_{8.3(2)}; UC_{9.2.1.1(1)}; UC_{9.2.1.1(3)}; UC_{9.3.1.1(3)})$
- **Columns**

  $UC = max (UC_{8.2(2)}; UC_{8.3(2)}; UC_{9.5.2(1)}; UC_{9.5.2(2)}; UC_{9.5.2(3)}; UC_{9.5.2(4)}; UC_{9.5.3(1)}; UC_{9.5.3(3)}; UC_{max\_bar\_distance(user)})$

Output values

There are presented the following output values:

- **Unity check** - unity check of detailing provisions
- **Unity check long** - unity check of detailing provisions for longitudinal reinforcement
- **Unity check shear** - unity check of detailing provisions for shear reinforcement

Minimal bar diameter of longitudinal reinforcement 9.5.2(1)

The diameter of longitudinal reinforcement in a column should not exceed the minimal value defined in 9.5.2(1). Check looks as follows. Calculation of used minimal diameters of longitudinal reinforcement in column $\phi_{l,min}$.

Furthermore minimal allowed diameter of longitudinal reinforcement is determined as follows

$$\phi_{l,min,col} = 8 \text{ mm}$$

Finally unity check is calculated as follows:

$$UC_{9.5.2(1)} = \phi_{l,min,col} / \phi_{l,min}$$

Minimal area of longitudinal reinforcement 9.5.2(2)

The total area of longitudinal reinforcement in a column should not exceed the minimal value defined in 9.5.2(2). Check looks as follows. Calculation of total area of longitudinal reinforcement in column A_s.

Furthermore minimal allowed area of longitudinal reinforcement is calculated as follows

$$A_{s,min} = \max(0{,}1.|N_{Ed}| / f_{yd}; 0{,}002.A_c)$$

Finally unity check is calculated as follows:

$$UC_{9.5.2(2)} = A_{s,min} / A_s.$$

Maximal area of longitudinal reinforcement 9.5.2(3)

The total area of longitudinal reinforcement in a column should not exceed the maximal value defined in 9.5.2(3). Check looks as follows. Calculation of total area of longitudinal reinforcement in column A_s.

Furthermore maximal allowed area of longitudinal reinforcement is calculated as follows

$$A_{s,max} = 0{,}04.A_c$$

Finally unity check is calculated as follows:

$$UC_{9.5.2(3)} = A_s / A_{s,max}.$$

Minimal number of bars in circular column 9.5.2(4)

The minimal number of longitudinal bars in a circular column should not exceed the minimal value defined in 9.5.2(4). Check looks as follows. Calculation of used number of longitudinal bars in column n_{bars}.

Furthermore minimal allowed number of bars in column is determined as follows

$$n_{bars,min,col.} = 4$$

Finally unity check is calculated as follows:

$UC_{9.5.2(4)} = n_{bars,min,col}. / n_{bars}.$

Minimal bar diameter of transverse reinforcement 9.5.3(1)

The diameter of transverse reinforcement in a column should not exceed the minimal value defined in 9.5.3(1). Check looks as follows. Calculation of used minimal diameters of transverse reinforcement in column $\phi_{s,min}$.

Furthermore minimal allowed diameter of transverse reinforcement is determined as follows

$\phi_{s,min,lim} = \max (6mm; 0,25.\phi_{l,max})$

Finally unity check is calculated as follows:

$UC_{9.5.3(1)} = \phi_{s,min,lim}/\phi_{s,min}$

Maximal longitudinal spacing of stirrups (9.5.3(3))

The maximal longitudinal spacing between stirrups links should not exceed the maximal value defined in 9.5.3(3). Check looks as follows. Calculation of maximal defined longitudinal distance of stirrups s_l.

Furthermore maximal allowed longitudinal distance between stirrups is calculated as follows

$s_{clt,max} = \min (20.\phi_{l,min}; \min(b,h); 400mm)$

where:

- $\phi_{l,min}$ - minimal diameter of longitudinal bars
- b,h -dimensions of columns

Finally unity check is calculated as follows:

$UC_{9.5.3(3)} = s_l / s_{clt,max}.$

Maximal centre-to-centre bar distance (9.3.1.1(3))

The procedure of calculation is running for each distance between bars and verification of the maximal distance among them towards the limited value from the code. The distances are evaluated as the maximal centre-to centre distance. Check looks as follows.

Calculation of maximal centre-to-centre bar distance between longitudinal bars as:

$s_{max,slab}.$

Furthermore minimal allowed centre-to-centre distance between bars from all bars in cross-section is determined according to chapter 9.3.1.1(3) as

$s_{max,slab,lim} = \max (3.h; 400mm).$

Finally unity check is calculated as follows:

$UC_{9.3.1.1(3)} = s_{max,slab}. / s_{max,slab,lim}$

The check is performed only for principal reinforcement

Annex 1: List of parameters

<table>
<tr><td>$(1/r)_{y(z)}$</td><td>curvature around y(z) axis of LCS (perpendicular to y(z) axis of LCS)</td></tr>
<tr><td>$(1/r0)_{y(z)}$</td><td>basic value of curvature around y(z) axis of LCS.</td></tr>
<tr><td>A</td><td>area of particular cross-section type</td></tr>
<tr><td>a</td><td>exponent of interaction formula

for column with circular cross-section a = 2
for column with rectangular cross-section , the value is calculated from the table below by interpolation
<table>
<tr><td>N_{Ed}/N_{Rd}</td><td>0,1</td><td>0,7</td><td>1,0</td></tr>
<tr><td>$a =$</td><td>1,0</td><td>1,5</td><td>2,0</td></tr>
</table>
for other cases a = 1
</td></tr>
<tr><td>A_{1si}</td><td>cross-sectional area of i-th bar of reinforcement</td></tr>
<tr><td>A_c</td><td>area of concrete cross section</td></tr>
<tr><td>$A_{c,eff}$</td><td>effective area of concrete in tension surrounding the reinforcement. This is area of reinforcement bounded by line, which is in distance $h_{c,eff}$ from the most tensioned fibre of concrete in the direction of bending moment resultant</td></tr>
<tr><td>A_{cc}</td><td>compressed concrete area for uncracked cross-section</td></tr>
<tr><td>A_i</td><td>cross-sectional area of concrete cross-section in i-th section</td></tr>
<tr><td>A_k</td><td>area enclosed by the centre-lines of the thin-walled closed cross-section, including inner hollow areas</td></tr>
<tr><td>$A_{k,user}$</td><td>user input area of thin-walled cross-section</td></tr>
<tr><td>A_m</td><td>cross-sectional area of concrete cross-section in the middle of the member</td></tr>
<tr><td>A_s</td><td>area of total reinforcement for particular cross-section type</td></tr>
<tr><td>$A_{s,eff}$</td><td>area of non-prestressed reinforcement within effective area of concrete in tension</td></tr>
<tr><td>A_{sc}</td><td>area of compressive reinforcement for particular cross-section type</td></tr>
<tr><td>A_{si}</td><td>cross-sectional area of i-th reinforcement in the cross-section of current section inputted via REDES or Free bars</td></tr>
<tr><td>a_{sl}</td><td>minimal distance between edge and centre of the longitudinal reinforcement</td></tr>
<tr><td>A_{sl}</td><td>statically required tensile area of reinforcement</td></tr>
<tr><td>$A_{sl,tor}$</td><td>area of longitudinal reinforcement bars, which are inside stirrup for torsion</td></tr>
<tr><td>A_{st}</td><td>area of tensile reinforcement for particular cross-section type</td></tr>
<tr><td>A_{sw}</td><td>cross-sectional area of the shear reinforcement calculated from inputted parameters in design defaults
$A_{sw} = n_s \cdot 0,25 \cdot \pi \cdot d_{ss}^2$</td></tr>
<tr><td>$A_{swm.req}$</td><td>statically required cross-sectional area of the shear reinforcement per meter</td></tr>
<tr><td>A_{swt}</td><td>cross-sectional area of the torsional reinforcement calculated from inputted parameters in design defaults
$A_{sw} = 0,25 \cdot \pi \cdot d_{ss}^2$</td></tr>
<tr><td>$a_{sy(z)}$</td><td>distance of centre of tensile reinforcement from tensile edge of cross-section</td></tr>
<tr><td>b</td><td>dimension of cross-section in centre of gravity in direction of y axis of LCS</td></tr>
<tr><td>b_{eq}</td><td>width of equivalent rectangular section, see clause 5.8.9(3) in EN 1992-1-1
$b_{eq} = i_{cy} \cdot \sqrt{12}$</td></tr>
<tr><td>b_t</td><td>mean width of cross-section in tensile zone of cross-section</td></tr>
<tr><td>b_w</td><td>smallest width of the cross-section in tensile area of cross-section perpendicular to direction of resultant shear force</td></tr>
</table>

b_{w1}	minimum width of cross-section between tension and compression chord perpendicular to direction of shear force
c	cover of the most tensioned reinforcement calculated in direction of resultant of bending moments
c_{nom}	nominal concrete cover
$c_{nom,l}$	concrete cover at lower surface for beam or beam as slab
$c_{nom,s}$	concrete cover for side reinforcement for beams (for edge which is not at lower or upper surface). This value depends on parameter Type of cover of side reinforcement.
$c_{nom,u}$	concrete cover at upper surface for beam or beam as slab
$Coeff_{com}$	coefficient for calculation force for determination if member is in compression or not
$Coeff_d$	coefficient for calculation effective depth of cross-section loaded from Concrete setup (if effective depth of cross-section is not possible to calculate from plane of equilibrium). Default value is 0,9.
$Coeff_z$	coefficient for calculation inner lever arm of cross-section loaded from Concrete setup (if inner lever arm of cross-section is not possible to calculate from plane of equilibrium). Default value is 0,9.
$C_{Rd,c}$	coefficient for calculation $V_{Rd,c}$ loaded from Manager for National annexes
$c_{y(z)}$	factor depending on the curvature distribution around y(z) axis of LCS according to clause 5.8.8.2(4) in EN 1992-1-1. • for constant first order bending moment (non zero) at whole length of the column and in case that equivalent bending moment is taken into account, value 8 is used • otherwise value 10 is used
d	effective depth of cross-section, calculated in direction in which inner lever arm of cross-section is calculated in $d = Coeff_d \cdot h(b)$
D	diameter of circular cross-section
$dist_{y(z)}$	distance from the middle of the i-th edge to centre of gravity of cross-section in direction of y(z) axis of LCS
d_s	• diameter of longitudinal reinforcement for columns, the value is the same for all edges • diameter of bars of the most tensioned layer of reinforcement. If bars with different diameter are inside of the effective area of concrete, the equivalent diameter according to equation 7.12 in EN 1992-1-1 is taken into account
$d_{s,l}$	diameter of longitudinal reinforcement at lower surface for beam or beam as slab
$d_{s,s}$	diameter of longitudinal reinforcement for side reinforcement for beams. In SEN 15, this value is the same as the diameter of longitudinal reinforcement at lower surface
$d_{s,u}$	diameter of longitudinal reinforcement at upper surface for beam or beam as slab
d_{sm}	diameter of longitudinal main reinforcement of the column
d_{ss}	diameter of stirrups (transverse reinforcement) loaded from Concrete settings or Concrete data for beam or column
$d_{y(z)}$	effective depth of cross-section in direction of y(z) axis of LCS
$e_{0,min,y(z)}$	minimum first order eccentricity in direction of y(z) axis of LCS
$e_{0,y(z)}$	first order eccentricity in direction of y(z) axis of LCS
$e_{0e,y(z)}$	first order equivalent eccentricity in direction of y(z) axis of LCS
$e_{0Edy(z)}$	first order eccentricity including the effect of imperfection in direction of y(z) axis of LCS
$e_{2y(z)}$	second order eccentricity in direction of y(z) axis of LCS
EA	axial stiffness of the cross-section

$e_{i,y(z)}$	eccentricity caused by imperfection in direction of y(z) axis of LCS
EI_y	bending stiffness around (y) axis of the cross-section
EI_z	bending stiffness around (z) axis of the cross-section
E_s	design value of modulus of elasticity of the most tensioned reinforcement member. The quality of reinforcement can be inputted in Project data or in 1D concrete member data, if concrete member data is inputted
E_{si}	design value of modulus of elasticity of i-th reinforcement in the cross-section inputted via REDES or Free bars inputted via REDES or Free bars
f_{cd}	design value of concrete compressive strength
f_{ck}	characteristic value of concrete compressive strength
f_{ctd}	design axial tensile strength of concrete
f_{ctm}	mean tensile strength of concrete
$f_{ct,eff}$	mean value of the tensile strength of the concrete effective at the time when the cracks may first be expected to occur. The value can be set by "Type of strength for calculation of cracking forces"
f_{cvd}	concrete design strength in shear and compression, see equations 12.5 and 12.6 in EN 1992-1-1 $f_{cvd} = \sqrt{f_{ctd}^2 + \sigma_{ccp} \cdot f_{ctd}} \qquad \sigma_{ccp} \le \sigma_{c,\lim}$ $f_{cvd} = \sqrt{f_{ctd}^2 + \sigma_{ccp} \cdot f_{ctd} - \left(\frac{\sigma_{ccp} - \sigma_{c,\lim}}{2}\right)^2} \qquad \sigma_{ccp} > \sigma_{c,\lim}$
f_{yd}	design yield strength of reinforcement. The quality of reinforcement can be inputted in Project data (if concrete member data is not defined) or in concrete member data
f_{ydi}	design yield strength of i-th reinforcement in the cross-section inputted via REDES or Free bars inputted via REDES or Free bars
f_{ywd}	design yield strength of the shear reinforcement $f_{ywd} = 0,8 \cdot f_{ywk} \qquad \sigma_{swd} \le 0,8 \cdot f_{ywk}$
f_{ywk}	characteristic yield strength of the shear reinforcement
h	dimension of cross-section in centre of gravity in direction of z axis of LCS
$h_{c,eff}$	depth of effective area of concrete in tension surrounding the reinforcement. $h_{c,eff} = \min\left[2.5 \cdot \left(h - d\right); \frac{h-x}{3}; 0.5 \cdot h\right] \leftarrow if x \le h$ $h_{c,eff} = \min[2.5 \cdot (h - d); 0.5 \cdot h] \leftarrow if x > h$
h_{eq}	height of equivalent rectangular section, see clause 5.8.9(3) in EN 1992-1-1 $h_{eq} = i_{cz} \cdot \sqrt{12}$
h_l	height of cross-section perpendicular to neutral axis
$i_{cy(z)}$	radius of gyration of the concrete cross-section in direction of y(z) axis of LCS
$i_{sy(z)}$	radius of gyration of the total reinforcement area in direction of y(z) axis of LCS
I_y	moment of inertia for particular cross-section type around (y) direction
I_z	moment of inertia for particular cross-section type around (z) direction
j	layer of reinforcement
k	coefficient of effective height of cross-section $k = 1 + \sqrt{\frac{200}{d}} \le 2$
k_1	coefficient for calculation of $V_{Rd,c}$ loaded from Manager for National annexes
k_1	coefficient which takes into account the bond properties of the bonded reinforcement • k1 = 0,8 for high bond bars (in SEN bar surface = ribbed) • k1 = 1,6 for bars with an effectively plain surface e.g. prestressing tendons (in SEN bar surface = smooth)

	The bar surface can be defined in material properties of the reinforcement
$k_{2,i+}$	coefficient which takes account of the distribution of strain - k_2 = 0.5 for pure bending - k_2 = 1.0 for pure tension - $k_2 = (\varepsilon_1 + \varepsilon_2)/2 \bullet \varepsilon_1$
k_3	coefficient of calculation loaded from national annex setting (Manager of national annex > code EN 1992-1-1 > SLS)
k_4	coefficient of calculation loaded from national annex setting (Manager of national annex > code EN 1992-1-1 > SLS)
K_r	correction factor depending on axial load, see clause 5.8.8.3 (3) in EN 1992-1-1. This factor depends on relative normal force (n) and mechanical ratio of reinforcement (ω). The formula below can be used for symmetrical cross-section and symmetrical reinforcement. For unsymmetrical cross-section and reinforcement a simplification is used and value K_r = 1 $K_r = \frac{1+\omega-n}{1+\omega-0{,}4}$
k_t	factor dependent on duration of the load. The following values should be used according to code EN 1992-1-1, chapter 7.3.4(2). - kt = 0,6 for short term loading - kt = 0,4 for long term loading The value of k_t in SEN depends on type of modulus of concrete. If check box "Use of effective modulus of concrete" is ON, the value 0.4 is used, otherwise value 0.6 is used
$K_{\varphi,y(z)}$	factor for taking into account of creep around y(z) axis of LCS , see clause 5.8.8.3 (4) in EN 1992-1-1. This factor depends on the effective creep ratio (φ_{ef}) and factor ($\beta_{y(z)}$) depending on slenderness $K_{\varphi,y(z)} = 1 + \beta_{y(z)} \cdot \varphi_{ef} \geq 1$
$l_{0,y(z)}$	effective length of the member (column) around y(z) axis of LCS (perpendicular to y (z) axis of LCS), which can be defined via Buckling data
$l_{y(z)}$	slenderness ratio around y(z) axis of LCS
$l_{y(z),lim}$	limit slenderness ratio around y(z) axis of LCS
$M_{0e,y(z)}$	1st order equivalent moment around y(z) axis of LCS
M_{Edy}	design value of bending moment (M_y)
$M_{Edy.max}$	maximal design moment around y axis from all combinations in current section
M_{Edz}	design value of bending moment (M_z)
$M_{Edz.max}$	maximal design moment around z axis from all combinations in current section
M_{Rdy}	design moment resistance around y-axis, it means intersection of interaction diagram and line parallel with M_y axis across the point with coordinates [N_{Ed},M_{Edy},0]
M_{Rdy-}	bending moment (M_y) resistance (minimal negative values)
M_{Rdy+}	bending moment (M_y) resistance (maximal positive values)
M_{Rdz}	design moment resistance around z-axis, it means intersection of interaction diagram and line parallel with M_z axis across the point with coordinates [N_{Ed},0,M_{Edz}]
M_{Rdz-}	bending moment (M_z) resistance (minimal negative values)
M_{Rdz+}	bending moment (M_z) resistance (maximal positive values)
$M_{y(z)}$	1st order moment around y(z) axis of LCS
N_{Ed}	design value of normal force
n_{edge}	number of edges of cross-section

$\mathbf{N_{Rd}}$	design axial resistance $N_{Rd} = A_c \cdot (f_{cd} + \mu_s \cdot f_{yd})$
$\mathbf{N_{Rd-}}$	normal force resistance (minimal negative values)
$\mathbf{N_{Rd+}}$	normal force resistance (maximal positive values)
$\mathbf{n_s}$	number of cuts (shear links) loaded from Concrete settings or Concrete data
$\mathbf{Ratio_{lim}}$	limit ratio of bending moments for uniaxial method loaded from Concrete settings
$\mathbf{s}$	spacing of the stirrups calculated as average area from all stirrups within calculated interval
$\mathbf{s_{r,max}}$	maximum crack spacing
$\mathbf{s_s}$	centre to centre spacing between bars of reinforcement of the most tensioned layer of reinforcement perpendicular to direction of bending moments resultant
$\mathbf{s_t}$	spacing of the stirrups calculated as average area from all stirrups for torsion within calculated interval
$\mathbf{s_{l.req}}$	the spacing of the stirrups in longitudinal direction, $s_{l.req} = \frac{A_{swt}}{A_{swm.req}} \quad if \ A_{swm2.req} > A_{swm1req}$ $s_{l.req} - \frac{A_{sw}}{A_{swm.req}} \quad \text{otherwise}$
$\mathbf{s_{min}}$	minimal surface-to-surface distance of reinforcement between two layers
$\mathbf{T_{Ed}}$	design torsional moment
$\mathbf{t_{ef}}$	effective wall thickness
$\mathbf{t_{ef,user}}$	user input effective wall thickness
$\mathbf{T_{Rd,c}}$	design value of torsional cracking moment
$\mathbf{T_{Rd,max}}$	maximum of design torsional resistance moment
$\mathbf{T_{Rd,st}}$	design torsional resistance moment of torsional reinforcement
$\mathbf{t_y}$	distance from centre of gravity of particular cross-section type to centre of gravity of concrete cross-section in (y) direction
$\mathbf{t_z}$	distance from centre of gravity of particular cross-section type to centre of gravity of concrete cross-section in (z) direction
$\mathbf{u}$	the outer circumference of the source cross-section
$\mathbf{u_i}$	outer circumference of concrete cross-section in i-th section
$\mathbf{u_k}$	circumference of the area enclosed by the centre-lines of the thin-walled closed cross-section
$\mathbf{u_{k,user}}$	user input outer circumference of thin-walled cross-section
$\mathbf{u_m}$	outer circumference of concrete cross-section in the middle of the member
$\mathbf{u_{tot}}$	center to center distance between the outer reinforcement bars in the same layer
$\mathbf{V_{ccd}}$	design value of the shear component of the force in the compression area, in the case of an inclined compression chord
$\mathbf{V_{Ed}}$	design resultant of shear force $V_{Ed} = \sqrt{V_{Ed,y}^2 + V_{Ed,z}^2}$
$\mathbf{V_{Ed,max}}$	maximum value of shear force resultant calculated without reduction by coefficient b , see clause 6.2.2(6) in EN 1992-1-1
$\mathbf{V_{Ed,y(z)}}$	shear force in direction of y(z)-axis of LCS
$\mathbf{V_{Rd,c}}$	design shear resistance of the member without shear reinforcement
$\mathbf{V_{Rd,c,min}}$	minimal value of design shear resistance of the member without shear reinforcement
$\mathbf{V_{Rd,max}}$	design value of the maximum shear force which can be sustained by the member, limited by crushing of the compression struts

$V_{Rd,s}$	design value of the shear force which can be sustained by the yielding shear reinforcement.
V_{td}	design value of the shear component of the force in the tensile reinforcement, in the case of an inclined tensile chord
$W_{c,y(z)}$	section modulus of concrete cross-section around y(z) axis of LCS $W_{c,y} = \frac{1}{6} \cdot (b) \cdot (h)^2$ $W_{c,z} = \frac{1}{6} \cdot (h) \cdot (b)^2$
x	depth of neutral axis (compressive zone for particular cross-section type)
z	inner lever arm of cross-section recalculated to direction of shear forces resultant $z = Coeff_z \cdot Coeff_d \cdot h(b)$
$z_{s,y(z)i}$	position of i-th bar of reinforcement from centre of gravity of cross-section in direction of y(z) axis of LCS
α	angle between shear reinforcement and the beam axis perpendicular to the shear force, loaded from Concrete settings or Concrete data. The angle for columns is 90 degrees.
α_{cw}	coefficient taking into account state of the stress in the compression chord, see note 3 in clause 6.2.3(3) in EN 1992-1-1. The value 1 is always taken into account for non - prestressed structures
α_e	ratio of design value of modulus of elasticity of the most tensioned reinforcement and modulus elasticity of the concrete $\alpha_e = \frac{E_s}{E_c}$
α_M	angle of slope line plane of equilibrium
α_V	angle between direction of shear resultant and y-axis of cross-section
$\delta_{add,lim,y}$	limit additional deflection in (y) direction
$\delta_{add,lim,z}$	limit additional deflection in (z) direction
$\delta_{add,y}$	additional deflection in (y) direction
$\delta_{add,z}$	additional deflection in (z) direction
$\delta_{tot,lim,y}$	limit total deflection in (y) direction
$\delta_{tot,lim,z}$	limit total deflection in (z) direction
$\delta_{tot,y}$	total deflection in (y) direction
$\delta_{tot,z}$	total deflection in (z) direction
ε_1	the greater tensile strain at the boundaries (edges) of the cross-section. The strain is calculated for uncracked section with taking into account conditions in chapter 4.6.1.1 and the value of strain is zero for edge in compression
ε_2	the lesser tensile strain at the boundaries (edges) of the cross-section. The strain is calculated for uncracked section with taking into account conditions in chapter 4.6.1.1 and the value of strain is zero for edge in compression
ε_{cc}	maximal value of compressive strain of concrete
ε_{cm}	mean strain in concrete between the cracks
ε_{cu}	ultimate compressive strain in the concrete
ε_{sc}	maximal value of compressive strain of reinforcement
ε_{sm}	mean strain in the reinforcement
ε_{st}	maximal value of tensile strain of reinforcement
ε_{yd}	strain in reinforcement at reaching design yield strength of reinforcement • for design of reinforcement strain in reinforcement at reaching design yield strength of reinforcement is calculated from default material properties defined in dialogue Project data according to formula:

	$\varepsilon_{yd} = \frac{f_{yd}}{E_s}$ • for checks strain in reinforcement at reaching design yield strength of reinforcement is calculated from material properties of inputted reinforcement via REDES or Free bars according to formula: $\varepsilon_{yd} = max\left(\frac{f_{ydi}}{E_{si}}\right)$
θ	angle between concrete compression strut and beam axis perpendicular to the shear force
$\theta_{i,y(z)}$	inclination around y(z) axis of LCS (perpendicular to y (z) axis of LCS)
μ_s	estimation ratio of longitudinal reinforcement loaded from Concrete settings (if concrete member data is not defined) or concrete member data or from recalculation of internal forces for design
v	strength reduction factor for concrete cracked in shear loaded from Manager for National annexes, see equation 6.6N in EN 1992-1-1
v_1	strength reduction factor for concrete cracked in shear loaded from Manager for National annexes, see note 1 and 2 in clause 6.2.3(3) in EN 1992-1-1. $v_1 = v \quad \sigma_{swd} > 0,8 \cdot f_{ywk}$ $v_1 = 0,6 \quad \sigma_{swd} \leq 0,8 \cdot f_{ywk}$ and $f_{ck} \leq 60MPa$ $v_1 = 0,9 - \frac{f_{ck}}{200} > 0,5 \quad \sigma_{swd} \leq 0,8 \cdot f_{ywk}$ and $f_{ck} > 60MPa$
v_{min}	coefficient of minimum value of shear resistance of the member without shear reinforcement loaded from Manager for National annexes,see equation 6.3N in EN 1992-1-1
ρ_l	ratio of tensile reinforcement $\rho_l = \frac{A_{sl}}{b_w \cdot d} \leq 0,02$
$\rho_{p,eff}$	ratio of reinforcement within effective area of concrete in tension. This ratio is calculated only for non-prestressed reinforcement (prestressed reinforcement is not taken into account for check crack width) according to formula: $\rho_{p,eff} = \frac{A_{s,eff}}{A_{c,eff}}$
$\sigma_{c,lim}$	limit value of stress caused by axial force, see equation 12.7 in EN 1992-1-1 $\sigma_{c.lim} = f_{cd} - 2 \cdot \sqrt{f_{ctd} \cdot (f_{ctd} + f_{cd})}$
σ_{cc}	maximal value of compressive stress of concrete
σ_{ccp}	normal (axial) stress of uncracked cross-section $\sigma_{ccp} = \frac{N_{Ed}}{A_{cc}}$
σ_{cp}	stress caused by axial force ($N_{Ed} > 0$ for compression) $\sigma_{cp} = \frac{N_{Ed}}{A_c} \leq 0,2 \cdot f_{cd}$
σ_{cr}	value of strength for determination if crack width will be calculated or not
σ_{ct}	normal concrete stress on un-cracked section at the most tensioned fibre of concrete cross-section
$\sigma_{ct,max}$	maximal tensile strength in uncracked cross-section
σ_s	stress in the most tensioned reinforcement
σ_{sc}	maximal value of compressive stress of reinforcement
σ_{sd}	design value of stress in longitudinal reinforcement
σ_{st}	maximal value of tensile stress of reinforcement

σ_{swd}	design stress of the shear reinforcement $\sigma_{swd} = \frac{V_{Ed} \cdot s}{z \cdot (\cot(\theta) + \cot(\alpha)) \cdot \sin(\alpha)}$
$\sigma_{y(z)}$	bending stress in concrete calculated for uncracked concrete cross-section according to formula: $\sigma_{y(z)} = \frac{M_{0Ed,y(z)}}{W_{c,y(z)}}$
φ	creep ratio loaded from concrete settings (if concrete member data is not defined on column) or concrete member data

Annex 2: National Annexes

Chapter 2.4.2.4 - Partial safety factor for concrete (γ_c) and reinforcement (γ_s) for permanent, transient and accidental design situation

There are the following differences in particular NA.

National annex	*Permanent and transient*		*Accidental*	
	γ_c	γ_s	γ_c	γ_s
Standard NA	1,5	1,15	1,2	1,0
Polish PN-NA	1,40	1,15	1,2	1,0
German DIN NA	1,5	1,15	1,3	1,0

Chapter 3.1.6 (1)(2)- Coefficients taken into account longterm effects on compressive (α_{cc}) and tensile (α_{ct}) strength according to EN1992-1-1

There are the following differences in particular NA.

National annex	α_{cc}	α_{ct}
Standard NA	1,0	1,00
German DIN-NA	0,85	0,85
Finnish SFS – EN NA	0,85	1,00
Belgian NBN – NA	0,85	1,00
Greek ELOT – EN NA	0,85	1,00
British BS – EN NA and Irish – EN NA	0,85 for compression in flexure and for axial loading 1,0 for other cases	1,00

Chapter 3.2.7(2) - Ratio of design and characteristic strain limit

There are the following differences in particular NA.

National annex	*Coeff*ε_{ud}	ε_{ud}
Standard NA	0,90	-
German DIN-NA	-	$250\ 1^{-4}$
Belgian NBN NA	0,80	-
Finnish SFS – EN NA	-	$100\ 1^{-4}$

The same national annexes are used for capacity-diagram. There are the following additional NA parameters related to plain or lightly reinforced concrete cross-sections.

Chapter 12.3.1(1) - Coefficients taken into account longterm effects on compressive ($\alpha_{cc,pl}$) and tensile ($\alpha_{ct,pl}$) strength of plain or lightly reinforced concrete according to EN1992-1-1

There are the following differences in particular NA.

National annex	$\alpha_{cc,pl}$	$\alpha_{ct,pl}$
Standard NA	0,80	0,80
Finnish SFS – EN NA	0,80	0,60
Irish – EN NA	0,80	0,60
Swedish	1,00	0,50
Singaporean	0,60	0,80

Chapter 7.2(2) - Coefficients used for calculation of allowable concrete stress under characteristic combination in case of longitudinal crack appears according to EN1992-1-1

There are the following differences in particular NA.

National annex	k_1
Standard NA	0,6
Polish PN – EN NA	1,0
Belgian NBN– EN NA	0,5 (XD,XF and XS) 0,6 other exposure classes

Chapter 7.2(3) - Coefficients used for calculation of allowable concrete stress under quasi-permanen combination in case of linear creep can be considered according to EN1992-1-1

There are the following differences in particular NA.

National annex	k_2
Standard NA	0,45

Chapter 7.2(5) - Coefficients used for calculation of allowable stress under characteristic combination in case of unacceptable cracking or deformation appears according to EN1992-1-1

There are the following differences in particular NA.

National annex	k_3	k_4
Standard NA	0,8	1,0
Dutch NEN – EN NA	0,0	0,0
Finnish SFS -EN NA	0,6	0,8
Swedish SS - EN NA	1,0	1,0

Clause 8.2.(2) - Coefficients used for National annex parameters

There are the following differences in particular NA.

National annex	k_1	k_2
Standard NA	1,0	5,0
Czech ČSN – EN NA	1,5	5,0
Slovak STN – EN NA	1,5	5,0
German DIN-EN NA	1,0	0,0 for $d_g \leq$ 16mm 5,0 for $d_g >$ 16mm
Austrian ONORM-EN NA	1,0	0,0 for one reinforcement layer 10,0 for more reinforcement layers
Finnish SFS-EN NA	1,0	3,0

Clause 9.2.1.1(1) - Minimal tensile reinforcement for National annex

There are the following differences in particular NA.

National annex	formula 9.1N	formula 9.1N
Standard NA	$Coeff_{As,min,2} \bullet f_{ctm} \bullet b_t \bullet d / f_{yk}$	$Coeff_{As,min,1} \bullet b_t \bullet d$
German DIN-EN NA	Not used	Not used
Dutch NEN-EN NA	$Coeff_{As,min,2} \bullet f_{ctm} \bullet b_t \bullet d / f_{yk}$ *	$Coeff_{As,min,1} \bullet b_t \bullet d$ *

German NA does not give the limit for minimal tensile are of longitudinal reinforcement. In this case unity check is =0

** The procedure for Dutch NEN-NA gives another rule. The values from table above are marked as $A_{s,min,1}$. Additionally necessary area from ULS ($A_{s,req}$) is calculated as $A_{s,min,2}$ = 1,25 * $A_{s,req}$. Finally, the minimal allowed value of longitudinal reinforcement is: $A_{s,min}$ = max ($A_{s,min,1}$; $A_{s,min,2}$).*

Clause 9.2.1.1(3) - Maximal area of reinforcement for National annex
There are the following differences in particular NA.

National annex	formula
Standard NA	0,04 $\cdot A_c$
German DIN-EN NA	0,08 $\cdot A_c$
Finnish SFS-EN NA	Not limited
Swedish SS-EN NA	Not limited
Slovenian SIST-EN NA	Not limited

The verification for SFS, SS and SIST NA is not done at all and unity check is set to $UC_{9.2.1.1(3)} = 0$

Clause 9.2.2.(5) - Minimal percentage of shear reinforcement for National annex
There are the following differences in particular NA.

National annex	formula9.5N
Standard NA	$0{,}08.\sqrt{f_{ck}} / f_{yk}$
German DIN-EN NA	$0{,}16.f_{ctm} / f_{yk}$
Austrian ONORM-EN NA	$0{,}15.f_{ctm} / f_{yd}$

Clause 9.2.2.(6) - Maximal longitudinal spacing of stirrups for National annex
There are the following differences in particular NA.

National annex	formula
Standard NA	0,75•d•(1+cotg (α))
Austrian ONORM-EN NA	max(0,75•d•(1+cotg (α)); 250mm)
Czech ČSN-EN NA	max(0,75•d•(1+cotg (α)); 400mm)
French NF-EN NA	for h ≤ 250mm • $s_{l,max}$= 0,9•d for h > 250mm • $s_{l,max}$= max(0,75•d•(1+cotg (α))
German DIN-EN NA	for $V_{Ed} \leq 0{,}3 \cdot V_{Rd,max}$ • for $f_{ck} \leq$ 50MPa ---->$s_{l,max}$= max(0,7•h;300mm) • for $f_{ck}>$ 50MPa ---->$s_{l,max}$= max(0,7•h;200mm) • for $V_{Ed} < V_{Rd,c}$; h<200mm and beam o $s_{l,max}$= 200mm for $0{,}3 \cdot V_{Rd,max} < V_{Ed} \leq 0{,}6 \cdot V_{Rd,max}$ • for $f_{ck} \leq$ 50MPa ---->$s_{l,max}$= max(0,5•h;300mm) • for $f_{ck}>$ 50MPa ---->$s_{l,max}$= max(0,5•h;200mm) for $V_{Ed} > 0{,}6 \cdot V_{Rd,max}$ • $s_{l,max}$= max(0,25•h;200mm)
Slovak STN-EN NA	max(0,75•d•(1+cotg (α)); 400mm)

Clause 9.5.2(1) - minimal bar diameter of longitudinal reinforcement for National annex

There are the following differences in particular NA.

National annex	formula
Standard NA	8mm
Austrian ONORM-EN NA	12mm for min(b,h) ≥ 200mm 10mm for other cases
Belgian NBN-EN NA	12mm
British BS-EN NA	12mm
Czech ČSN-EN NA	12mm for min(b,h) ≥ 200mm 10mm for other cases
German DIN-EN NA	12mm
Irish IS-EN NA	12mm
Polish PN-EN NA	6mm
Singaporean SS-EN NA	12mm
Slovak STN-EN	10mm
Slovenian SIST-EN NA	12mm

Clause 9.5.2(2) - minimal area of longitudinal reinforcement for National annex

There are the following differences in particular NA.

National annex	formula
Standard NA	$\max(0,1.\|N_{Ed}\| / f_{yd}; 0,002.A_c)$
Austrian ONORM-EN NA	$\max(0,13.\|N_{Ed}\| / f_{yd}; 0,0026.A_c)$
German DIN-EN NA	$0,15.\|N_{Ed}\| / f_{yd}$
Slovenian SIST-EN NA	$\max(0,1.\|N_{Ed}\| / f_{yd}; 0,003.A_c)$
Swedish SS-EN NA	$0,002.A_c$

Clause 9.5.2(3) - maximal area of longitudinal reinforcement for National annex

There are the following differences in particular NA.

National annex	formula
Standard NA	$0,04.A_c$
German DIN-EN NA	$0,09.A_c$
Austrian ONORM-EN NA	$0,04.A_c$ for in-situ concrete members $0,09.A_c$ for prefabricated concrete members
Finnish SFS-EN NA	$0,06.A_c$
Swedish SS-EN NA	not used

Clause 9.5.3(3) - Maximal longitudinal spacing of stirrups for National annex

There are the following differences in particular NA.

National annex	formula
Standard NA	$\min(20.\phi_{l,min}; \min(b,h); 400mm)$
Austrian ONORM-EN NA	$\min(12.\phi_{l,min}; \min(b,h); 250mm)$
Czech ČSN-EN NA	$\min(15.\phi_{l,min}; \min(b,h); 300mm)$
Finnish SFS-EN NA	$\min(15.\phi_{l,min}; \min(b,h); 400mm)$
German DIN-EN NA	$\min(12.\phi_{l,min}; \min(b,h); 300mm)$
Luxembourgian LU-EN NA	$\min(15.\phi_{l,min}; \min(b,h); 400mm)$
Slovak STN-EN NA	$\min(15.\phi_{l,min}; \min(b,h); 300mm)$
Slovenian SIST-EN NA	$\min(12.\phi_{l,min}; \min(b,h); 300mm)$

Clause 9.3.1.1(3) - maximal centre-to-centre bar distance for National annex

There are the following differences in particular NA.

National annex	**formula**
Standard NA	max (3.h; 400mm)
Austrian ONORM-EN NA	max (1,5.h; 250mm)
Belgian NBN-EN NA	max (2,5.h; 400mm)
Czech ČSN-EN NA	max (2.h; 300mm)
German DIN-EN NA	150mm for h ≤ 150mm h for (150mm<h<250mm) 150mm for h ≥ 250mm
Luxembourgian LU-EN NA	max (2,5.h; 400mm)
Slovak STN-EN NA	max (2.h; 300mm)

Annex 3: Concrete settings – Values

Generally, the items in the Concrete settings are split into two main groups:

- Solver settings
- Design defaults

Solver settings

General

Limit value of unity check

Description	Limit value of unity check when the check is still OK
Default	Edit box , default = 1,0
Code	-
Level	Standard
Figure	-

Value of unity check for not calculated unity checks

Description	Value of unity check which is presented when the unity check is not possible to calculate due to some errors during calculation
Default	Edit box; default = 3,0
Code	-
Level	Advanced
Figure	-

The coefficient for calculation effective depth of cross-section

Description	The coefficient for calculation of effective depth of cross-section from depth of cross-section, if effective depth of cross-section is not possible to calculate from plane of equilibrium (tensile reinforcement or compressive concrete fibre was not found)
Default	Edit box; default $Coeff_d$ = 0,9
Code	-
Level	Advanced
Figure	$d = Coeff_d \cdot h$

The coefficient for calculation of inner lever arm

Description	The coefficient for calculation of inner lever arm from effective depth of cross-section, if effective inner lever arm is not possible to calculate from plane of equilibrium (tensile reinforcement or compressive concrete fibre was not found)
Default	Edit box $Coeff_z = 0,9$
Code	-
Level	Advanced
Figure	$z = Coeff_z \cdot d$

The coefficient for calculation force, where member as under compression

Description	The coefficient for calculation force, where member is considered as under compression. If N_{Ed} <= N_{com} => member is under compression
Default	Edit box $Coeff_{com} = 0,1$
Code	-
Level	Advanced
Figure	$N_{Ed} \leq Coeff_{com} \cdot A_c \cdot f_{cd}$

Creep

Type input of creep coefficient

Description	Type of calculation creep coefficient: - user value - creep coefficient inputted directly by the user - auto - creep coefficient is calculated automatically by the program
Default	Combo box ; $Type_{\phi}$ = Auto / User input; default = Auto
Code	Annex B.1
Level	Standard
Figure	-

Relative humidity

Description	Relative humidity of ambient environment
Default	Edit box; RH = 50%
Code	Annex B.1
Level	Advanced
Figure	-

Age of concrete at loading

Description	Age of concrete at loading of the member
Default	Edit box; t_0 = 28days
Code	Annex B.1
Level	Advanced
Figure	-

Age of concrete at the moment considered

Description	Age of concrete at the moment considered. It means, time, which creep coefficient is calculated for.
Default	Edit box; t = 1825days
Code	Annex B.1
Level	Advanced
Figure	-

SLS

Use effective modulus of concrete

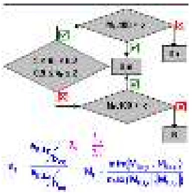
Description	Possibility to use effective E modulus of concrete. It means the long-term behaviour of concrete is covered in the analysis of the crack width, stress limitations and stiffness calculation.
Default	Check box, default NO
Code	7.1(2)
Level	Advanced
Figure	 ☐ E_{cm} ☒ $\frac{E_{cm}}{1+\phi}$

Internal forces

Use equivalent first order value

Description	The first order moment is taken into account as equivalent first order moment, if this parameter is ON.
Default	Check box , default True
Code	5.8.8.2(2)
Level	Advanced
Figure	$M_{0e} = 0,6 \cdot M_{02} + 0,4 \cdot M_{01} \geq M_{02}$

Determination of unfavourable direction

Description	Determination of the direction for calculation of second order effect and geometrical imperfection effect and geometrical imperfection according to conditions 5.38a a 5.38b - Auto: automatic calculation of direction for taking into account second order effect and geometrical imperfection according to conditions 5.38a a 5.38b - Uniaxial: second order effect and geometrical imperfection is taken into account only in one (more unfavourable) direction - Biaxial: second order effect and geometrical imperfection is always taken into account in both directions
Default	Combo box Auto / uniaxial / biaxial; default Auto
Code	5.8.9
Level	Advanced
Figure	

Internal forces ULS

Take into account additional tensile force caused by shear force

Description	If the check box is ON , the additional tensile force caused by shear force is taken into account by using shift rules
Default	Check box default True
Code	9.2.1.3(2)
Level	Standard
Figure	-

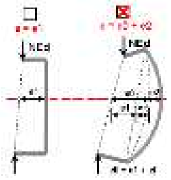
Use minimum value of eccentricity

Description	The minimum value of eccentricity is taken into account for calculation of first order eccentricity, if this parameter is ON.
Default	Check box default True
Code	6.1.4
Level	Advanced
Figure	☐ $e_t = e_1 + e_i$ ☒ $e_t = \max\left[(e_1 + e_i); \frac{h}{30}; 20mm\right]$

Use geometric imperfection

Description	The geometric imperfection is taken into account for calculation of first order eccentricity, if this parameter is ON.
Default	Check box, default True
Code	5.2.5
Level	Standard
Figure	-

Use second order effect

Description	The second order effect is taken into account, if slenderness is greater than limit slenderness and this parameter is ON.
Default	Check box, default True
Code	5.8.8
Level	Standard
Figure	

Estimation of longitudinal reinforcement for recalculation internal forces

Description	Estimation of ratio of longitudinal reinforcement for calculation mechanical reinforcement ratio in design of reinforcement. Mechanical ratio is calculated for calculation limit slenderness (chapter 5.8.3.1(1) and second order effect - method based on nominal curvature (formula 5.36)
Default	Edit box; default μ_s = 1 %
Code	6.2.3
Level	Advanced
Figure	-

Internal forces SLS

Use geometric imperfection

Description	The geometric imperfection is taken into account for calculation of first order eccentricity, if this parameter is ON.
Default	Check box, default True
Code	5.2.5
Level	Standard
Figure	-

Design As

Coefficient for reduction of strength of the concrete in compressive concrete

Description	Coefficient for reduction of strength of the concrete in compressive concrete which is used for calculation design value of resistance of concrete compressive strut $n_{Rd} = A_{cc} \cdot Red_{fcd} \cdot f_{cd}$
Default	Edit box, default Red_{fcd} = 0,85
Code	-
Level	Advanced
Figure	-

Limit ratio of bending moment for uni axial method

Description	Limit ratio of bending moments for using uniaxial design method. If ratio of bending moments is lesser than limit ratio, uniaxial design method is used and smaller value of bending moment and shear force is neglected. $Ratio_{uni} = \min(M_{Edy}/M_{Edz}) / \max(M_{Edy}/M_{Edz})$
Default	Edit box, $Ratio_{lim} = 0{,}1$
Code	-
Level	Standard
Figure	-

Design method (beams)

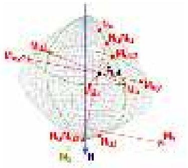
Description	Method for design of longitudinal reinforcement for beams and beam slabs
Default	Combo box; Auto / Uniaxial around y / Uniaxial around z / Biaxial; Default Auto
Code	-
Level	Advanced
Figure	-

Design method (columns)

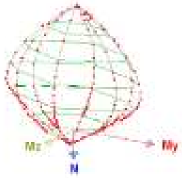
Description	Method for design of longitudinal reinforcement for columns
Default	Combo box; Auto / Uniaxial around y / Uniaxial around z / Biaxial; Default Auto
Code	-
Level	Advanced
Figure	-

Interaction diagram

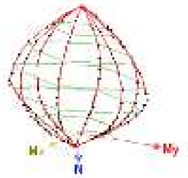
Interaction diagram method

Description	Possibility to set method for evaluation of results using interaction diagram: - NRd - assuming M_{Ed} is constant - MRd - assuming N_{Ed} is constant - NRdMrd - - assuming eccentricity is constant - Mrdy - assuming M_{Edz} is constant - Mrdz - assuming M_{Edy} is constant
Default	Combobox NRd / MRd / NRdMrd / Mrdy / Mrdz, default NRdMRd
Code	6.1
Level	Standard
Figure	

Division of strain

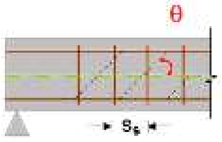
Description	Calculation precision for one of the diagram “branches” during generation of interaction diagram. The value means how many times the strain plane is readjusted from the position of section under full compression to the position of section under full tension
Default	Edit box; 200
Code	-
Level	Advanced
Figure	

Number of points in vertical cut

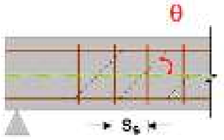
Description	Number of directions in which the interaction diagram is calculated (number of “branches”) during generation of interaction diagram
Default	Edit box; 36
Code	-
Level	Advanced
Figure	

Shear

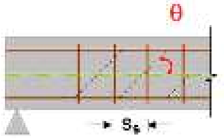
Type calculation / input of angle of compression strut

Description	Type of calculation of angle between compression strut and member axis for shear check - Auto: automatic calculation of minimum angle based on condition $V_{Ed}<=V_{Rd.max}$ - User(angle) : the value is inputted by the user as angle - User(cotangent) : the value is inputted by the user as cotangent of the value
Default	Combo box, Auto / User (angle) / User (cotangent); default User (angle)
Code	6.2.3
Level	Standard
Figure	

Angle of compression strut

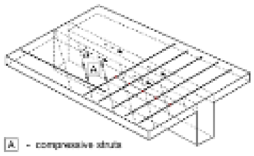
Description	Angle between compression strut and member axis for shear check; editable only if type of calculation of compression strut angle is User (angle)
Default	Edit box, θ = 40deg
Code	6.2.3
Level	Standard
Figure	

Cotangent angle of compression strut

Description	Cotangent angle between compression strut and member axis for shear check; editable only if type of calculation of compression strut angle is User (cotangent)
Default	Edit box, cot θ =1,2
Code	6.2.3
Level	Standard
Figure	

Shear between web and flange

Type calculation / input of angle of compression strut

Description	Input type for angle between compression strut and member axis for longitudinal shear check - User(angle): the value is inputted by the user as angle - User(cotangent): the value is inputted by the user as cotangent of the value
Default	Combo box, User (angle) / User (cotangent); default User (angle)
Code	6.2.4(4)
Level	Advanced
Figure	

Angle of compression strut

Description	Angle between compression strut and member axis for longitudinal shear check; editable only if type of calculation of compression strut angle is User (angle)
Default	Edit box, θ_f = 40deg
Code	6.2.4(4)
Level	Advanced
Figure	-

Cotangent angle of compression strut

Description	Cotangent of the angle between compression strut and member axis for longitudinal shear check; editable only if type of calculation of compression strut angle is User (cotangent)
Default	Edit box, cot θ_f =1,2
Code	6.2.4(4)
Level	Advanced
Figure	-

Torsion

Equivalent thin walled cross-section

Description	Type of equivalent thin-walled cross-section used for calculation of cross-section capacity in torsion
Default	Combo box; Automatic / From stirrups from torsion / From effective CSS / From effective rectangular CSS; default Automatic
Code	6.3.1(3)
Level	Advanced
Figure	-

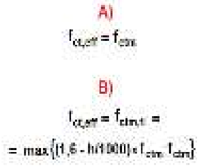
Stress limitation

Indirect load

Description	When the stress in reinforcement is caused by the indirect load (imposed deformation) then the stress should not exceed different maximal value
Default	Check box, default NO
Code	7.2(5)
Level	Advanced
Figure	

Cracking forces

Type of strength for calculation of cracking forces

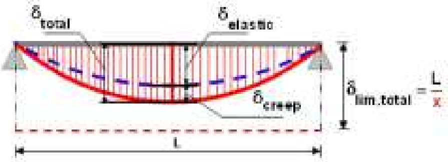
Description	Type of tensile strength of concrete used for calculation of cracking forces in SLS checks (stresses and deflections). It is possible to select between f_{ctm} (Table 3.1) and $f_{ctm,fl}$ (Clause 3.1.8).
Default	Combobox f_{ctm} / $f_{ctm,fl}$ (default f_{ctm})
Code	7.1(2)
Level	Advanced
Figure	

Value of strength for calculation of cracking forces

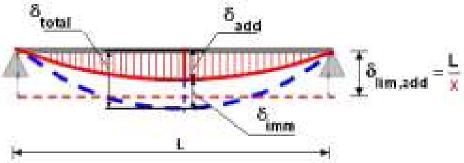
Description	Value of strength of concrete used for calculation of cracking forces in SLS checks (stresses and deflections). It is possible to select between a) 0MPa - first crack appears when tensile stress is reached in concrete cross-section b) f_{cteff} - first crack is appears when effective tensile strength is reached in cross-section
Default	Combo box 0MPa/ $f_{ctm,eff}$ (default $f_{ct,eff}$)
Code	7.1(2)
Level	Advanced
Figure	-

Deflection

Maximal total displacement L/x; x =

Description	Maximal total (nonlinear + creep) displacement allowed for 1D member expressed as span / depth ratio
Default	Edit box; x_{tot} = 250
Code	7.4.1(4)
Level	Standard
Figure	

Maximal additional displacement L/x; x =

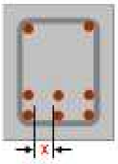
Description	Maximal additional (total - immediate) displacement allowed for 1D member expressed as span / depth ratio
Default	Edit box; x_{add} = 500
Code	7.4.1(5)
Level	Standard
Figure	

Detailing provisions

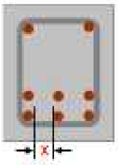
Beam

Longitudinal reinforcement

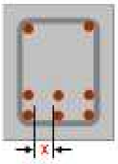
Check min. bar distance

Description	Setting if minimal clear bar distance of longitudinal reinforcement for beam is checked or not.
Default	Checkbox YES
Code	8.2(2)
Figure	

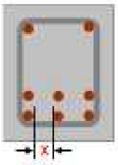
Minimal bar distance

Description	Additional limit for minimal clear bar distance of longitudinal reinforcement for beam
Default	Edit box $s_{lb,min}$ = 20mm
Code	8.2(2)
Figure	

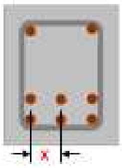
Check max. bar distance

Description	Setting if maximal clear bar distance of longitudinal reinforcement for beam is checked or not.
Default	Checkbox NO
Code	Code-independent
Figure	

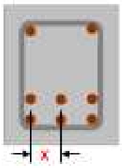
Maximal bar distance

Description	Additional limit for maximal clear bar distance of longitudinal reinforcement for beam
Default	Edit box $s_{lb,max}$ = 350mm; this item is visible only if check box above is set ON
Code	Code-independent
Figure	

Check max. bar distance (torsion)

Description	Setting if maximal centre-to-centre bar distance of longitudinal reinforcement for beam based on torsion requirement is checked or not. This value is checked if torsional moment exists in cross-section only.
Default	Checkbox YES
Code	9.2.3(4)
Figure	

Maximal bar distance (torsion)

Description	Maximal centre-to-centre bar distance of longitudinal reinforcement for beam based on torsion requirement. This value is checked if torsional moment exists in cross-section only.
Default	Edit box $s_{lbt,max}$ = 350mm; this item is visible only if check box above is set ON
Code	9.2.3(4)
Figure	

Check min. reinforcement area

Description	Setting if minimal reinforcement area of longitudinal reinforcement for beam is checked or not.
Default	Checkbox YES
Code	9.2.1.1(1)
Figure	☐ $A_s = A_s$ ☒ $A_s = \max(A_{s,min}, A_s)$

Check min. reinforcement area for secondary member

Description	Setting if minimal reinforcement area of longitudinal reinforcement for secondary beam is checked or not. Settings for secondary member is defined in Concrete member data
Default	Checkbox YES
Code	9.2.1.1(1)
Figure	-

Check max. reinforcement area

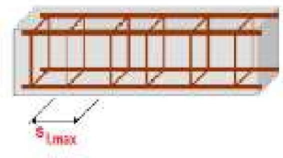
Description	Setting if maximal reinforcement area of longitudinal reinforcement for beam is checked or not.
Default	Checkbox YES
Code	9.2.1.1(3)
Figure	☐ $A_s = A_s$ ☒ $A_s = \min(A_{s,max}, A_s)$

Stirrups

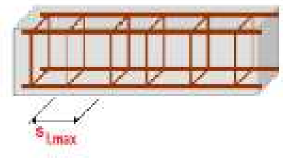
Check min. mandrel diameter

Description	Setting if minimal mandrel diameter of stirrups for beam is checked or not
Default	Checkbox NO
Code	8.3(2)
Figure	-

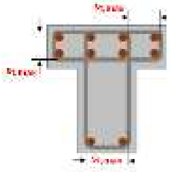
Check max. longitudinal spacing (shear)

Description	Setting if maximal longitudinal spacing of stirrups based on shear requirements is checked or not.
Default	Checkbox YES
Code	9.2.2(6)
Figure	

Check max. longitudinal spacing (torsion)

Description	Setting if maximal longitudinal spacing of stirrups based on torsion requirements is checked or not.
Default	Checkbox YES
Code	9.2.3(3)
Figure	

Check max. transverse spacing (shear)

Description	Setting if maximal transverse spacing of stirrups based on shear requirements is checked or not.
Default	Checkbox YES
Code	9.2.2(8)
Figure	

Check min. percentage of stirrups

Description	Setting if minimal percentage of stirrups for beam is checked or not.
Default	Checkbox YES
Code	9.2.2(5)
Figure	-

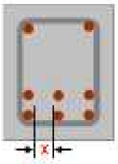
Check max. percentage of stirrups

Description	Setting if maximal percentage of stirrups for beam is checked or not.
Default	Checkbox YES
Code	6.2.3(3)
Figure	-

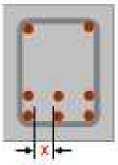
Beam Slab

Longitudinal

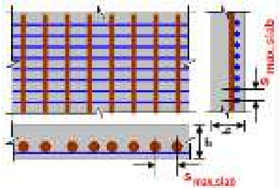
Check min. bar distance

Description	Setting if minimal clear bar distance of longitudinal reinforcement for beam slab is checked or not.
Default	Checkbox YES
Code	8.2(2)
Figure	

Minimal bar distance

Description	Additional limit for minimal clear bar distance of longitudinal reinforcement for beam slab
Default	Edit box $s_{lb,min}$ = 20mm
Code	8.2(2)
Figure	

Check max. bar distance

Description	Setting if maximal centre-to-centre bar distance of longitudinal reinforcement for beam slab is checked or not. Only principal reinforcement is checked
Default	Checkbox YES
Code	9.3.1.1(3)
Figure	

Check min. reinforcement area

Description	Setting if minimal reinforcement area of longitudinal reinforcement for beam slab is checked or not.
Default	Checkbox YES
Code	9.3.1.1(1)
Figure	☐ $A_s = A_s$ ☒ $A_s = \max(A_{s,min}, A_s)$

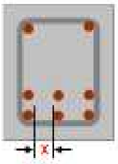
Check max. reinforcement area

Description	Setting if maximal reinforcement area of longitudinal reinforcement for beam slab is checked or not.
Default	Checkbox YES
Code	9.3.1.1(1)
Figure	☐ $A_s = A_s$ ☒ $A_s = \min (A_{s,max} , A_s)$

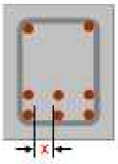
Column

Main

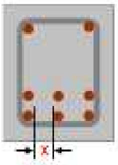
Check min. bar distance

Description	Setting if minimal clear bar distance of longitudinal reinforcement for column is checked or not.
Default	Checkbox YES
Code	8.2(2)
Figure	

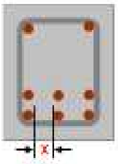
Minimal bar distance

Description	Additional limit for minimal clear bar distance of longitudinal reinforcement for column
Default	Edit box $s_{lc,min}$ = 20mm
Code	8.2(2)
Figure	

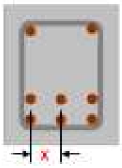
Check max. bar distance

Description	Setting if maximal clear bar distance of longitudinal reinforcement for column is checked or not.
Default	Checkbox NO
Code	Code-independent
Figure	

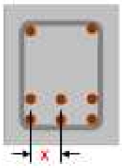
Maximal bar distance

Description	Additional limit for maximal clear bar distance of longitudinal reinforcement for column
Default	Edit box $s_{lc,max}$ = 350mm; this item is visible only if check box above is set ON
Code	Code-independent
Figure	

Check max. bar distance (torsion)

Description	Setting if maximal centre-to-centre bar distance of longitudinal reinforcement for column based on torsion requirement is checked or not. This value is checked if torsional moment exists in cross-section only.
Default	Checkbox YES
Code	9.2.3(4)
Figure	

Maximal bar distance (torsion)

Description	Maximal centre-to-centre bar distance of longitudinal reinforcement for column based on torsion requirement. This value is checked if torsional moment exists in cross-section only.
Default	Edit box $s_{lct,max}$ = 350mm; this item is visible only if check box above is set ON
Code	9.2.3(4)
Figure	

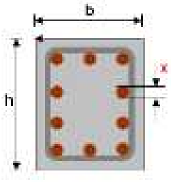
Check min. reinforcement area

Description	Setting if minimal reinforcement area of longitudinal reinforcement for column is checked or not.
Default	Checkbox YES
Code	9.5.2(2)
Figure	☐ $A_s = A_s$ ☒ $A_s = \max(A_{s,min}, A_s)$

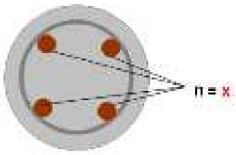
Check max. reinforcement area

Description	Setting if maximal reinforcement area of longitudinal reinforcement for column is checked or not.
Default	Checkbox YES
Code	9.5.2(3)
Figure	☐ $A_s = A_s$ ☒ $A_s = \min(A_{s,max}, A_s)$

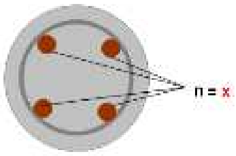
Check min. bar diameter

Description	Setting if minimal bar diameter of longitudinal reinforcement for column is checked or not.
Default	Checkbox YES
Code	9.5.2(1)
Figure	

Check min. number of bars in circular column

Description	Setting if minimal number of bars in circular column is checked or not.
Default	Checkbox YES
Code	9.5.2(4)
Figure	

Min. number of bars in circular column

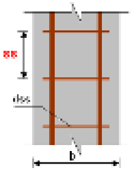
Description	Minimal number of bars in circular column is checked or not. This item is viable if the item above is set YES
Default	Edit box; $n_{lc,min}$ = 4 bars
Code	9.5.2(4)
Figure	

Transverse

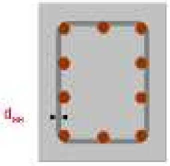
Check min. mandrel diameter

Description	Setting if minimal mandrel diameter of stirrups for column is checked or not
Default	Checkbox NO
Code	8.3(2)
Figure	-

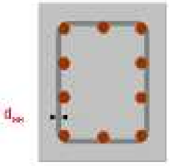
Check max. longitudinal spacing

Description	Setting if maximal longitudinal spacing of stirrups is checked or not.
Default	Checkbox YES
Code	9.5.3(3)
Figure	

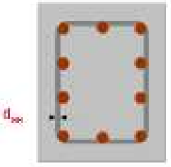
Check min. bar diameter

Description	Setting if minimal diameter of longitudinal bar in column is checked or not.
Default	Checkbox YES
Code	9.5.3(1)
Figure	

Min bar diameter

Description	User defined minimal diameter of longitudinal bar in column; visible if checkbox above is YES
Default	Edit box; $d_{sc,min}$ = 6mm
Code	9.5.3(1)
Figure	

Min bar diameter

Description	User defined minimal diameter of longitudinal bar in column as multiplication factor of maximal diameter of longitudinal reinforcement; visible if checkbox above is YES
Default	Edit box; x d_{sc} = 25%
Code	9.5.3(1)
Figure	

Design defaults

Minimal concrete cover

Design working life

Description	Design working life is information used for determination of minimal concrete cover
Default	Edit box , default =50 years
Code	4.4.1.2(5), table 4.3N
Level	Standard
Figure	-
Member	1D member (Beam / Column / Beam Slab)

Risk of corrosion attack

Corrosion induced by carbonation

Description	Exposure class caused by carbonation is used for determination of minimal concrete cover in Table 4.4N
Default	Combo box;None / X0 /XC1 / XC2 / XC3 / XC4; default =XC3
Code	4.4.1.2(5), table 4.3N
Level	Standard
Figure	-
Member	1D member (Beam / Column / Beam Slab)

Corrosion induced by chlorides

Description	Exposure class caused by chlorides is used for determination of minimal concrete cover in Table 4.4N
Default	Combo box; None / XD1 / XD2 / XD3; default =None
Code	4.4.1.2(5), table 4.3N
Level	Standard
Figure	-
Member	1D member (Beam / Column / Beam Slab)

Corrosion induced by chlorides from sea water

Description	Exposure class caused by chlorides from sea water is used for determination of minimal concrete cover in Table 4.4N
Default	Combo box; None / XS1 / XS2 / XS3; default =None
Code	4.4.1.2(5), table 4.3N
Level	Standard
Figure	-
Member	1D member (Beam / Column / Beam Slab)

Freeze / thaw attack

Description	Additional Exposure class caused by freezing or thawing
Default	Combo box; None / XF1 / XF2 / XF3; default =None
Code	4.4.1.2(12)
Level	Standard
Figure	-
Member	1D member (Beam / Column / Beam Slab)

Chemical attack

Description	Additional Exposure class caused by chemical attack
Default	Combo box; None / XA1 / XA2 / XA3; default =None
Code	4.4.1.2(12)
Level	Standard
Figure	-
Member	1D member (Beam / Column / Beam Slab)

Risk of abrasion attack

Description	Additional Exposure class caused by abrasion attack
Default	Combo box; None / XM1 / XM2 / XM3; default =None
Code	4.4.1.2(13)
Level	Advanced
Figure	-
Member	1D member (Beam / Column / Beam Slab)

Possibility of special control

Risk of casting on atypical surface

Description	To take into account additional deviation to nominal concrete cover caused by casting on atypical surface
Default	Combo box; Standard / Against prepared ground / Again soil / Uneven surface default = Standard
Code	4.4.1.3(4)
Level	Advanced
Figure	-
Member	1D member (Beam / Column / Beam Slab)

Concrete characteristic

Type of concrete

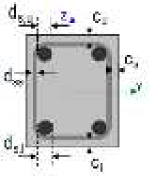
Description	To take into account additional deviation to nominal concrete cover caused by production type
Default	Combo box; In-situ / Prefabricated ; default = In-situ
Code	4.4.1.3(1P, 3)
Level	Advanced
Figure	-
Member	1D member (Beam / Column / Beam Slab)

Beam

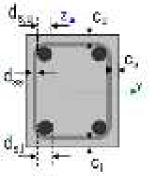
Longitudinal

Upper

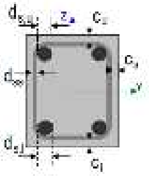
Diameter of upper reinforcement

Description	Information about diameter of upper reinforcement
Default	Edit box; default $d_{s,u}$ = 16mm
Code	-
Level	Standard
Figure	
Member	Beam

Type of cover of upper reinforcement

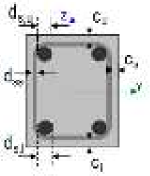
Description	Information about type of cover of upper reinforcement
Default	Combo box; Auto / User; default = Auto
Code	4.4.1
Level	Standard
Figure	
Member	Beam

User defined concrete cover of upper reinforcement

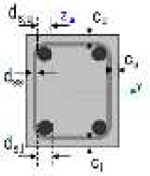
Description	Possibility to define concrete cover of upper reinforcement; this item is visible only if the item above is set to User
Default	Edit box; cu = 30mm
Code	4.4.1
Level	Standard
Figure	
Member	Beam

Lower

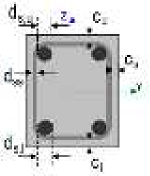
Diameter of lower reinforcement

Description	Information about diameter of lower reinforcement
Default	Edit box; default $d_{s,l}$ = 16mm
Code	-
Level	Standard
Figure	
Member	Beam

Type of cover of lower reinforcement

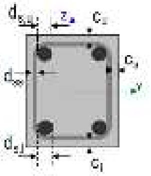
Description	Information about type of cover of lower reinforcement
Default	Combo box; Auto / User; default = Auto
Code	4.4.1
Level	Standard
Figure	
Member	Beam

User defined concrete cover of lower reinforcement

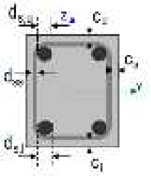
Description	Possibility to define concrete cover of lower reinforcement; this item is visible only if the item above is set to User
Default	Edit box; cl = 30mm
Code	4.4.1
Level	Standard
Figure	
Member	Beam

Side

Type of cover of side reinforcement

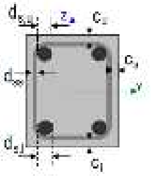
Description	Information about type of cover of side reinforcement
Default	Combo box; Auto / User; default = Auto
Code	4.4.1
Level	Standard
Figure	
Member	Beam

User defined concrete cover of side reinforcement

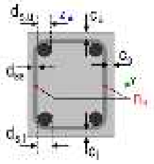
Description	Possibility to define concrete cover of side reinforcement; this item is visible only if the item above is set to User
Default	Edit box; cs = 30mm
Code	4.4.1
Level	Standard
Figure	
Member	Beam

Stirrups

Diameter of stirrups

Description	Information about diameter of stirrups
Default	Edit box; d_{ss} = 8mm
Code	-
Level	Standard
Figure	
Member	Beam

Number of cuts

Description	Information about number of cuts for shear reinforcement
Default	Edit box; $n_s = 2$
Code	-
Level	Standard
Figure	
Member	Beam

Angle

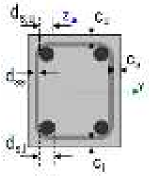
Description	Angle between shear reinforcement and the beam axis perpendicular to the shear force
Default	Edit box; $\alpha = 90deg$
Code	-
Level	Standard
Figure	-
Member	Beam

Beam slab

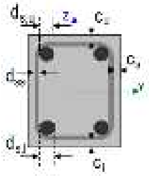
Longitudinal

Upper

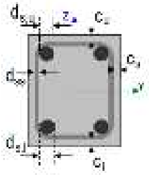
Diameter of upper reinforcement

Description	Information about diameter of upper reinforcement
Default	Edit box; default $d_{s,u} = 16mm$
Code	-
Level	Standard
Figure	
Member	Beam slab

Type of cover of upper reinforcement

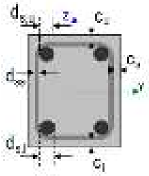
Description	Information about type of cover of upper reinforcement
Default	Combo box; Auto / User; default = Auto
Code	4.4.1
Level	Standard
Figure	
Member	Beam slab

User defined concrete cover of upper reinforcement

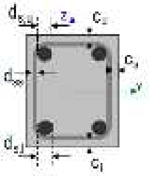
Description	Possibility to define concrete cover of upper reinforcement; this item is visible only if the item above is set to User
Default	Edit box; cu = 30mm
Code	4.4.1
Level	Standard
Figure	
Member	Beam slab

Lower

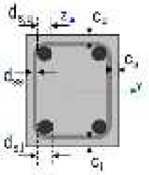
Diameter of lower reinforcement

Description	Information about diameter of lower reinforcement
Default	Edit box; default $d_{s,l}$ = 16mm
Code	-
Level	Standard
Figure	
Member	Beam slab

Type of cover of lower reinforcement

Description	Information about type of cover of lower reinforcement
Default	Combo box; Auto / User; default = Auto
Code	4.4.1
Level	Standard
Figure	
Member	Beam slab

User defined concrete cover of lower reinforcement

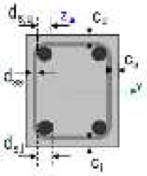
Description	Possibility to define concrete cover of lower reinforcement; this item is visible only if the item above is set to User
Default	Edit box; cl = 30mm
Code	4.4.1
Level	Standard
Figure	
Member	Beam slab

Column

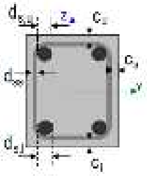
Longitudinal

Main

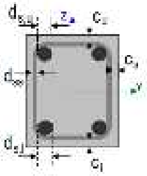
Diameter of main reinforcement

Description	Information about diameter of main reinforcement
Default	Edit box; default $d_{s,m}$ = 16mm
Code	-
Level	Standard
Figure	
Member	Column

Type of cover of main reinforcement

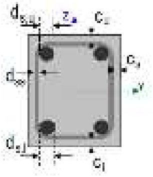
Description	Information about type of cover of main reinforcement
Default	Combo box; Auto / User; default = Auto
Code	4.4.1
Level	Standard
Figure	
Member	Column

User defined concrete cover of main reinforcement

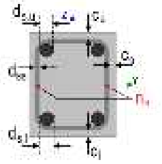
Description	Possibility to define concrete cover of main reinforcement; this item is visible only if the item above is set to User
Default	Edit box; cm = 30mm
Code	4.4.1
Level	Standard
Figure	
Member	Column

Stirrups

Diameter of stirrups

Description	Information about diameter of stirrups
Default	Edit box; d_{ss} = 8mm
Code	-
Level	Standard
Figure	
Member	Column

Number of cuts

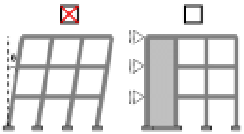
Description	Information about number of cuts for shear reinforcement
Default	Edit box; n_s = 2
Code	-
Level	Standard
Figure	
Member	Column

Angle

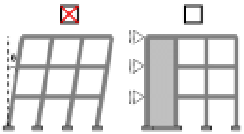
Description	Angle between shear reinforcement and the beam axis perpendicular to the shear force
Default	Edit box; α = 90deg
Code	-
Level	Standard
Figure	-
Member	Column

Default sway type

Sway around y axis

Description	Yes indicates, that the members are prone to sway (unbraced) around y axis of LCS of the member. This setting is used in calculation of slenderness and internal forces 1D, if in Buckling data or Buckling data library if possibility “Setting” is selected.
Default	Check box ; Default True
Code	-
Level	Standard
Figure	
Member	1D member (Beam / Column / Beam Slab)

Sway around z axis

Description	Yes indicates, that the members are prone to sway (unbraced) around z axis of LCS of the member. This setting is used in calculation of slenderness and internal forces 1D, if in Buckling data or Buckling data library if possibility “Setting” is selected.
Default	Check box ; Default True
Code	-
Level	Standard
Figure	
Member	1D member (Beam / Column / Beam Slab)