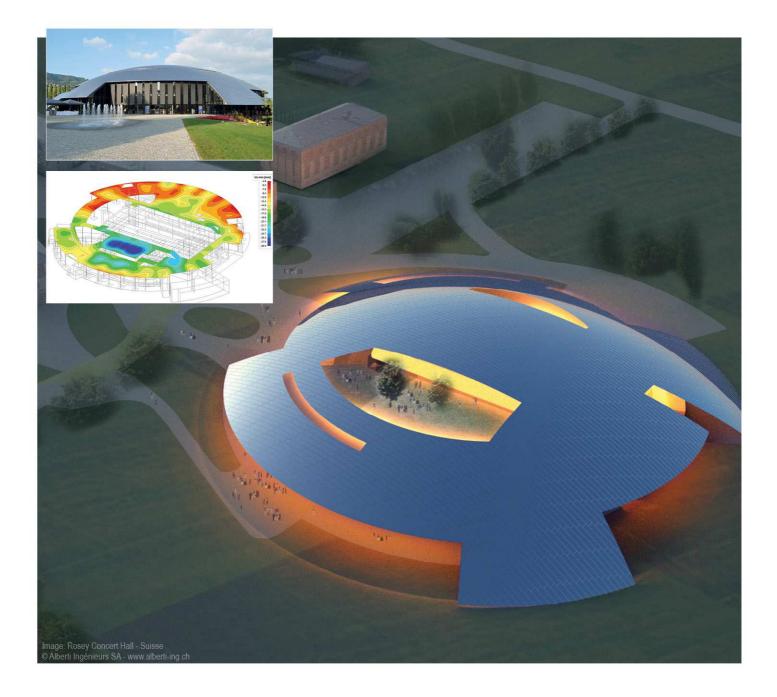
SCIAENGINEER



Advanced Concept Training Reinforced concrete (EN 1992) – 1D members

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Calculation Types
Axial compression only
Uni-axial bending

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Introduction

1D concrete design is available in the Concept Edition of SCIA Engineer.

Both beam and column design are part of the module esacd.01.01 (1D concrete design for EN1992). Practical reinforcement on 1D members is part of the module esacdt.01. Both modules are part of the Concept Edition of SCIA Engineer.

All topics that will be treated in this training document about basic concrete calculation for 1D members are available in the modules described above.

For 2D members and advanced concrete calculations reference is made to the respective training documents.

Materials

Verification by the partial factor method

Design values (art. 2.4.2)

Partial factors for materials (art. 2.4.2.4)

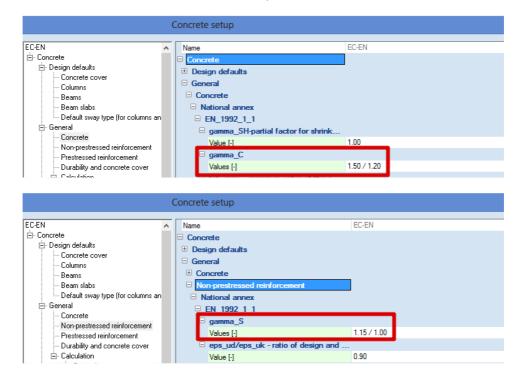
Partial factors for materials for ultimate limit states, γ_c and γ_s should be used.

The recommended values of γ_c and γ_s for 'persistent & transient' and 'accidental, design situations are given in the following table. These are not valid for fire design for which reference should be made to EN 1992-1-2.

For fatigue verification the partial factors for persistent design situations given in this table are recommended for the values of $\gamma_{c,fat}$ and $\gamma_{s,fat}$.

Design situations	$\gamma_{\rm C}$ for concrete	$\gamma_{\rm S}$ for reinforcing steel	$\gamma_{\rm S}$ for prestressing steel
Persistent & Transient	1,5	1,15	1,15
Accidental	1,2	1,0	1,0

These values can also be found in the concrete setup:



All factors related to the code are shown in green on the screen. By default, the values of the chosen code are taken.

The values for partial factors for materials for serviceability limit state verification should be taken as those given in the particular clauses of this Eurocode.

The recommended values of γ_c and γ_s in the serviceability limit state for situations not covered by particular clauses of this Eurocode is 1,0.

Lower values of γ_c and γ_s may be used if justified by measures reducing the uncertainty in the calculated resistance.

Concrete

The following clauses give principles and rules for normal and high strength concrete.

Strength (art 3.1.2)

The compressive strength of concrete is denoted by concrete strength classes which relate to the characteristic (5%) cylinder strength f_{ck} , or the cube strength $f_{ck,cube}$.

The strength classes in this code are based on the characteristic cylinder strength f_{ck} determined at 28 days with a maximum value of C_{max} .

The recommended value of C_{max} is C90/105.

	Concrete setup	
ECEN Design defaults Concrete cover Concrete cover Columns Deams	General Concrete National annex EN_1992_1_1 gamma_SH-partial factor for shrinkage action	1
- 2D structures and beam slabs	Value [-]	1.00
Punching	🗆 gamma_C	
Default sway type (for columns an General Concrete Non-prestressed reinforcement	Values [-] Gck_max - maximum value of the characteristic cylinder strengt Value [MPa]	1.50 / 1.20 90.00

In certain situations (e.g. prestressing) it may be appropriate to assess the compressive strength for concrete before or after 28 days, on the basis of test specimens stored under other conditions than prescribed in EN 12390.

All values can also be found in the material library of SCIA Engineer:

	Materials			
A 😳 🖋 🖉	1 <u>오</u> 오 종 중 중 🔒 M	• 🕅		
C12/15	Name	C50/60		
C16/20	Code independent			
C20/25	Material type	Concrete		
C25/30 C30/37	Thermal expansion [m/mK]	0.00		
C35/45	Unit mass [kg/m^3]	2500.0		
C40/50	Time dependency of unit mass	None.		
C45/55	E modulus [MPa]	3.7300e+04		
C50/60	Poisson coeff.	0.2		
C55/67 C60/75	Independent G modulus			
C70/85	G modulus (MPa)	1.5542e+04		
C80/95	Log. decrement	0.2		
C90/105	Colour			
B 400A	Specific heat [J/gK]	6.0000e-01		
B 500A	Temperature dependency of specific heat	None		
B 600A B 400B	Themal conductivity [W/mK]	4.5000e+01		
B 500B	Temperature dependency of thermal conductivity	None *		
B 600B	Order in code	9		
B 400C	EN 1992-1-1			
B 500C	Characteristic compressive cylinder strength fck(28) [MPa]	50.00		
B 600C C12/15(EN1992-2)	Calculated depended values	V	Measured values	
C16/20(EN1992-2)	Mean compressive strength fcm(28) [MPa]	58.00	Measured values Measured values of mean compressive strength (influence of ageing)	
C20/25(EN1992-2)	fcm(28) - fck(28) [MPa]	8.00		
C25/30(EN1992-2)	Mean tensile strength fctm(28) [MPa]	4.10	Measured values I	7.0
C30/37(EN1992-2)	fctk 0.05(28) [MPa]	2.90	Age of concrete [day]	
C35/45(EN1992-2)	fctk 0,95(28) [MPa]	5.30	Mean value of compressive cylinder strength [MPa]	44.12
C40/50(EN1992-2) C45/55(EN1992-2)	Design compressive strength - persistent (fcd = fck / gamma c_p) [MPa]	33.33	Emod, sec [MPa]	34342.2
C50/60(EN1992-2)	Design compressive strength - accidental (fcd = fck / gamma c_a) [MPa]	41.67	Measured values II	
C55/67(EN1992-2)	Strain at reaching maximum strength eps c2 [1e-4]	20.0	Age of concrete [day]	28.0
C60/75(EN1992-2)	Ultimate strain eps cu2 [1e-4]	35.0	Mean value of compressive cylinder strength [MPa]	50.00
C70/85(EN1992-2)	Strain at reaching maximum strength eps c3 [1e-4]	17.5	Emod, sec [MPa]	35654.4
C80/95(EN1992-2) C90/105(EN1992-2)	Ultimate strain eps cu3 [1e-4]	35.0	Measured values III	
C30/103(EN1332-2)	Stone diameter (dg) [mm]	32	Age of concrete [day]	0.0
	Cement class	N (normal hardening - CEM 32,5 R, CEM 42,5 N)	Mean value of compressive cylinder strength [MPa]	0.00
	Cement type - for BS and French NA only	CEMI	Emod, sec [MPa]	0.00
	Type of aggregate	Quartzite	Standard deviation [MPa]	4.9
	Measured values		Characteristic compressive cylinder strength (28) (Fck) [MPa]	42.0
	Measured values of mean compressive strength (influence of ageing)		Graph	
	Stress-strain diagram			
	Type of diagram	Bi-linear stress-strain diagram		
	Picture of Stress-strain diagram	100 CONTRACT CONTRACTOR		
New Insert Edit	Delete	Close		
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It may be required to specify the concrete compressive strength, $f_{ck}(t)$, at time *t* for a number of stages (e.g. demoulding, transfer of prestress), where:

$$f_{ck}(t) = f_{cm}(t) - 8 (MPa) \quad \text{for } 3 < t < 28 \text{ days}$$

$$f_{ck}(t) = f_{ck} \quad \text{for } t \ge 28 \text{ days}$$

The compressive strength of concrete at an age *t* depends on the type of cement, temperature and curing conditions. For a mean temperature of 20°C and curing in accordance with EN 12390 the compressive strength of concrete at various ages $f_{cm}(t)$ may be estimated from:

$$f_{cm}(t) = \beta_{cc}(t) f_{cm}$$
(3.1)

with
$$\beta_{cc}(t) = e^{\left\{s \left[1 - \left(\frac{28}{t}\right)^2\right]\right\}}$$
 (3.2)

R)

where:

f _{cm} (t)	is the mean concrete compressive strength at an age of t days
f _{cm}	is the mean compressive strength at 28 days according to Table 3.1
$\beta_{cc}(t)$	is a coefficient which depends on the age of the concrete t
t	is the age of the concrete in days
S	is a coefficient which depends on the type of cement:
	= 0,20 for cement of strength Classes CEM 42,5 R, CEM 52,5 N and CEM 52,5 R (Class I
	= 0,25 for cement of strength Classes CEM 32,5 R, CEM 42,5 N (Class N)
	= 0,38 for cement of strength Classes CEM 32,5 N (Class S)

The type of cement can be chosen in the material library:

	Materials		
l 🤮 🗶 👬 🖬 🖡	(🗠 🗠 🚔 🖨 🖨 🔚 Concrete	• 9	
2/15	Name	C30/37	
6/20	Code independent		
0/25	Material type	Concrete	
5/30	Thermal expansion [m/mK]	0.00	
0/37 5/45	Unit mass [kg/m^3]	2500.0	
0/50	Time dependency of unit mass	None	*
5/55	E modulus (MPa)	3.2800e+04	
0/60	Poisson coeff.	0.2	
5/67	Independent G modulus		
0/75	G modulus [MPa]	1.3667e+04	
0/85 0/95	Log. decrement	0.2	
0/95 0/105	Colour		
2/15(EN1992-2)	Specific heat [J/gK]	6.0000e-01	
5/20(EN1992-2)	Temperature dependency of specific heat	None	*
0/25(EN1992-2)	Thermal conductivity [W/mK]	4.5000e+01	
5/30(EN1992-2)	Temperature dependency of thermal conductivity	None	*
0/37(EN1992-2) 5/45(EN1992-2)	Order in code	5	
0/50(EN1992-2)	□ FN 1992-1-1		
5/55(EN1992-2)	Characteristic compressive cylinder strength fck(28) [MPa]	30.00	
0/60(EN1992-2)	Calculated depended values		
5/67(EN1992-2)	Mean compressive strength fcm(28) [MPa]	38.00	
0/75(EN1992-2)	fcm(28) - fck(28) [MPa]	8.00	
0/85(EN1992-2) 0/95(EN1992-2)	Mean tensile strength fctm(28) [MPa]	2.90	
0/105(EN1992-2)	fctk 0,05(28) [MPa]	2.00	
	fctk 0,95(28) [MPa]	3 80	
	Design compressive strength - persistent (fcd = fck / gamma c p) [MPa]	(CO)	
	Design compressive strength - accidental (fcd = fck / gamma c_a) [MPa]	20.0	
	Strain at reaching maximum strength eps c2 [1e-4]	35.0	
	Ultimate strain eps cu2 [1e-4]	5.200	
	Strain at reaching maximum strength eps c3 [1e-4]	17.5	
	Ultimate strain eps cu3 [1e-4]	35.0	
	Stone diameter (dg) [mm]	32	
	Cement class	N (normal hardening - CEM 32,5 R, CEM 42,5 N)	
	Cement type - for BS and French NA only	S (slow hardening - CEM 32,5 N) N (normal hardening - CEM 32,5 R, CEM 42,5 N)	
	Measured values	R (rapidl hardening - CEM 42,5 R, CEM 52,5 N, CEM 52,5 R)	
	Measured values of mean compressive strength (influence of ageing)		
	Stress-strain diagram		
	Type of diagram	Bi-linear stress-strain diagram	
	Picture of Stress-strain diagram		

The tensile strength refers to the highest stress reached under concentric tensile loading.

The characteristic strengths for f_{ck} and the corresponding mechanical characteristics necessary for design, are given in Table 3.1:

					Streng	jth cla	sses	for co	Strength classes for concrete						Analytical relation / Explanation
f _{ak} (MPa)	12	16	20	25	30	35	40	45	50	55	60	70	80	90	
f _{ck abe} (MPa)	15	20	25	8	37	45	8	<mark>55</mark>	8	67	75	85	<mark>9</mark> 5	105	
f _{am} (MPa)	20	24	28	33	8	43	48	53	<mark>58</mark>	63	68	78	88	<u>98</u>	$f_{\rm cm} = f_{\rm cirt} + 8(\rm MPa)$
f _{etm} (MPa)	1,6	1,9	2,2	2,6	2,9	3,2	3,5	3,8	4,1	4,2	4,4	4,6	4 ,8	5,0	$f_{cim}=0.30 \times f_{ck}^{(23)} \le CS0/60$ $f_{cim}=2,12 \cdot \ln(1+(f_{cm}/10))$ > C50/60
f _{dk, 0,05} (MPa)	1,1	1,3	1,5	1,8	2,0	2,2	2,5	2,7	2,9	3,0	3,1	3,2	3,4	3,5	$f_{ck,0,05} = 0.7 \times f_{clm}$ 5% fractile
f _{ck.095} (MPa)	2,0	2,5	2,9	3,3	3,8	4,2	4,6	4,9	5,3	5,5	5,7	6,0	6,3	6,6	f _{c4:0,06} = 1,3×f _{cim} 95% fractile
E _{cm} (GPa)	27	29	30	31	33	34	35	36	37	38	39	41	42	44	$E_{\rm cm} = 22[(f_{\rm cm})'10]^{0.3}$ ($f_{\rm cm}$ in MPa)
Ect (%00)	1,8	1,9	2,0	2,1	2,2	2,25	2,3	2,4	2,45	2,5	2,6	2.7	2,8	2,8	s ce Figure 3.2 ₆₅₁ (⁹ / ₅₀) = 0.7 f _{em} ^{0,31} < 2.8
East (%0)					3,5					3,2	3,0	2,8	2,8	2,8	see Figure 3.2 for f _{6k} ≥ 50 Mpa _{6.44} ⁰ (m)=2.8+271(98-f _{cm})/1001 ⁴
E.a. (%0)					2,0					2.2	2,3	2,4	2,5	2,6	see Figure 3.3 for f _{6k} ≥ 50 Mpa _{6⊲} (^{0,0,0)=2,0+0,085(f_{0k}-50)⁰⁵⁸}
Eu2 (%0)					3,5					3,1	2,9	2,7	2,6	2,6	see Figure 3.3 for f _{4s} ≥ 50 Mpa ε _{out} (th ₀₀)=2,6+35[(90-f ₆)/100] ⁴
u					2.0					1,75	1,6	1,45	1,4	1,4	for f _o ≥ 50 Mpa <i>n</i> =1,4+23,4[(90- <i>f_a</i>)/100] [‡]
E (%0)					1,75				oo	1,8	1,9	2,0	2,2	2,3	see Figure 3.4 for f ₄ ≥ 50 Mpa € ₅₃ (¹) ₀₀)=1,75+0,55[(f ₅ ,-50)/40]
Ea13 (%o)					3,5					3,1	2,9	2,7	2,6	2,6	see Figure 3.4 for <i>f_s</i> ≥ 50 Mpa <i>ε</i> _{co6} (? ₁₀)=2,6+35[(90-f ₆)/100] ⁴

Table 3.1	Strength and	deformation	characteristics for	or concrete
-----------	--------------	-------------	---------------------	-------------

Design compressive and tensile strengths (art 3.1.6)

1) The value of the design compressive strength is defined as

$$f_{cd} = \alpha_{cc} f_{ck} / \gamma_C \tag{3.15}$$

where:

- $\gamma_{\rm C}$ is the partial safety factor for concrete.
- α_{cc} is the coefficient taking account of long term effects on the compressive strength and of unfavourable effects resulting from the way the load is applied.

The value of α_{cc} should lie between 0,8 and 1,0. The recommended value is 1,0.^[1]

2) The value of the design tensile strength, f_{ctd} , is defined as

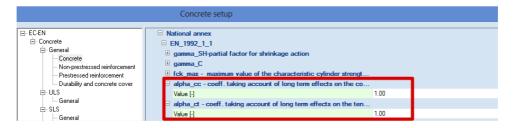
$$f_{ctd} = \alpha_{ct} f_{ctk,0,05} / \gamma_C \tag{3.16}$$

where:

- γ_{C} is the partial safety factor for concrete.
- α_{ct} is a coefficient taking account of long term effects on the tensile strength and of unfavourable effects, resulting from the way the load is applied.

The recommended value of α_{ct} is 1,0.

The values of the coefficients taking account of long term effects can be found in the concrete setup:



If the concrete strength is determined at an age t > 28 days the values α_{cc} and α_{ct} should be reduced by a factor k_{t} .

The recommended value of k_t is 0,85.

^[1] Remark: the Belgian National Annex recommends the use of the value 0,85.

Elastic deformation (art 3.1.3)

The elastic deformations of concrete largely depend on its composition (especially the aggregates). The values given in this Standard should be regarded as indicative for general applications. However, they should be specifically assessed if the structure is likely to be sensitive to deviations from these general values.

The modulus of elasticity of a concrete is controlled by the moduli of elasticity of its components. Approximate values for the modulus of elasticity E_{cm} , secant value between $\sigma_c = 0$ and $0.4f_{cm}$, for concretes with quartzite aggregates, are given in Table 3.1.

For limestone and sandstone aggregates the value should be reduced by 10% and 30% respectively. For basalt aggregates the value should be increased by 20%.

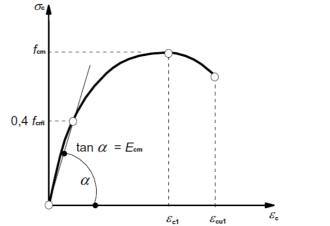


Figure 3.2: Schematic representation of the stress-strain relation for structural analysis (the use $0,4f_{cm}$ for the definition of E_{cm} is approximate).

Variation of the modulus of elasticity with time can be estimated by:

$$E_{cm}(t) = (f_{cm}(t) / f_{cm})^{0.3} E_{cm}$$
(3.5)

where $E_{cm}(t)$ and $f_{cm}(t)$ are the values at an age of *t* days and E_{cm} and f_{cm} are the values determined at an age of 28 days. The relation between $f_{cm}(t)$ and f_{cm} follows from Expression (3.1).

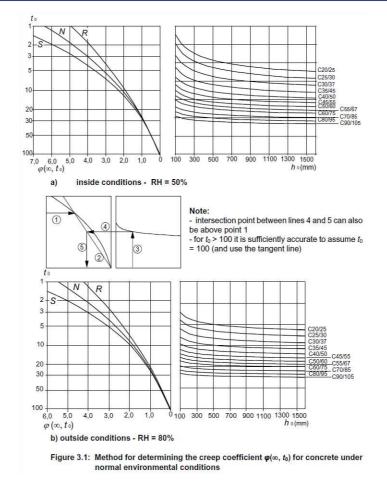
Poisson's ratio may be taken equal to 0,2 for uncracked concrete and 0 for cracked concrete.

Creep and shrinkage (art 3.1.4)

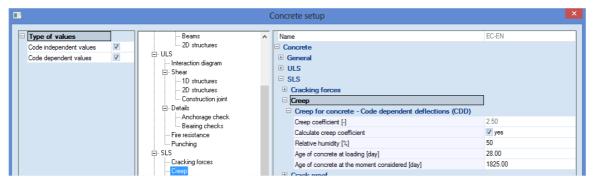
Creep and shrinkage of the concrete depend on the ambient humidity, the dimensions of the element and the composition of the concrete. Creep is also influenced by the maturity of the concrete when the load is first applied and depends on the duration and magnitude of the loading.

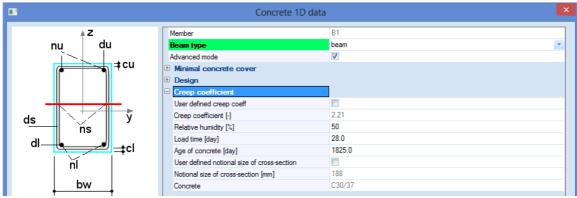
The creep coefficient, $\varphi(t, t_0)$ is related to E_c , the tangent modulus, which may be taken as 1,05 E_{cm} .

Where great accuracy is not required, a value found from a figure (Figure 3.1) may be considered as the creep coefficient, provided that the concrete is not subjected to a compressive stress greater than 0,45 *f*ck (t_0) at an age t_0 , the age of concrete at the time of loading.



All these parameters can be inputted in the setup for concrete or in the beam concrete data:





The creep deformation of concrete $\varepsilon_{cc}(\infty, t_0)$ at time $t = \infty$ for a constant compressive stress σ_c applied at the concrete age t_0 , is given by:

$$\varepsilon_{cc}(\infty, t_0) = \varphi(\infty, t_0) \cdot (\sigma_c / E_c)$$
(3.6)

Stress-strain relations for the design of cross-sections (art 3.1.7)

For the design of cross-sections, the following stress-strain relationship may be used:

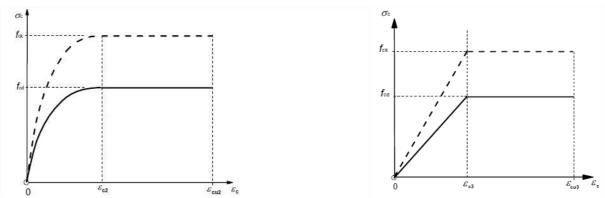


Figure 3.3: Parabola-rectangle diagram for concrete under compression. Figure 3.4: Bi-linear stress-strain relation.

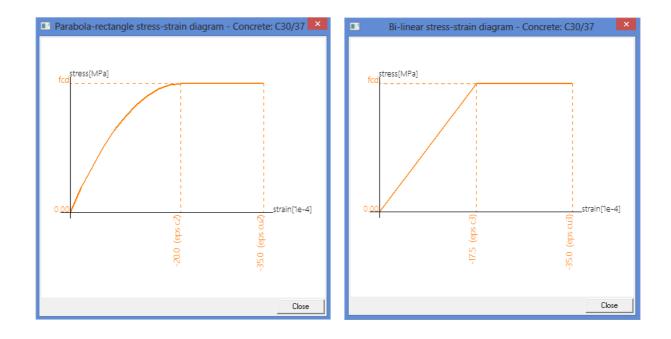
ϵ_{c2}	is the strain at reaching the maximum strength in the parabola-rectangle diagram
ϵ_{cu2}	is the ultimate strain in the parabola-rectangle diagram

E _{c3}	is the strain at reaching	the maximum	strength in the	bi-linear diagram
-00	J			

 ϵ_{cu3} is the ultimate strain in the bi-linear diagram

The user can choose in the material library which one of the diagrams should be used for the calculation:

Stress-strain diagram	
Type of diagram	Bi-linear stress-strain diagram
	Bi-linear stress-strain diagram
	Parabola-rectangle stress-strain diagram



Reinforcing steel

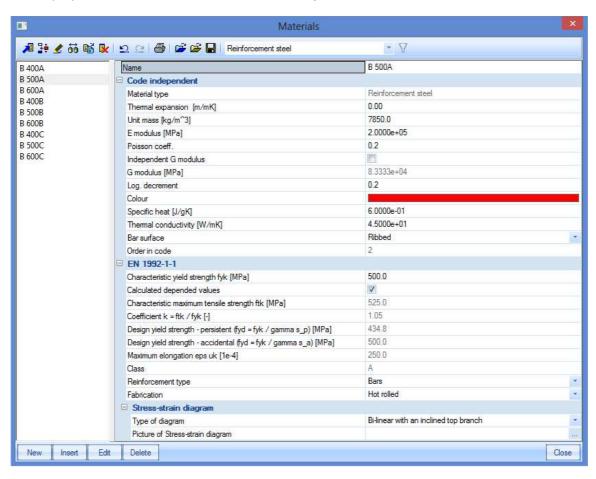
The following clauses give principles and rules for reinforcement which is in the form of bars, de-coiled rods, welded fabric and lattice girders. They do not apply to specially coated bars.

Properties (art 3.2.2)

The behaviour of reinforcing steel is specified by the following properties:

- yield strength (f_{yk} or $f_{0,2k}$)
- maximum actual yield strength (fy,max)
- tensile strength (f_t)
- ductility (ε_{uk} and f_t/f_{yk})
- bendability
- bond characteristics (f_R)
- section sizes and tolerances
- fatigue strength
- weldability
- shear and weld strength for welded fabric and lattice girders

The steel properties can be found in the material library:



The mean value of density may be assumed to be 7850 kg/m³. The design value of the modulus of elasticity E_s may be assumed to be 200 GPa.

This Eurocode applies to ribbed and weldable reinforcement, including fabric.

The application rules for design and detailing in this Eurocode are valid for a specified yield strength range, $f_{yk} = 400$ to 600 MPa.

Table C.1 gives the properties of reinforcement suitable for use with this Eurocode:

Table C.1: Properties of reinforcement

Product form	Bars and de-coiled rods		Wire Fabrics			Requirement or quantile value (%)	
Class	А	в	с	A	В	с	-
Characteristic yield strength f_{yk} or $f_{0,2k}$ (MPa)			400	to 600			5,0
Minimum value of $k = (f_{t}/f_{y})_{k}$	≥1,05	≥1,08	≥1,15 <1,35	≥1,05	≥1,08	≥1,15 <1,35	10,0
Characteristic strain at maximum force, \mathcal{E}_{uk} (%)	≥2,5	≥5,0	≥7,5	≥2,5	≥5,0	≥7,5	10,0
Bendability	Bei	nd/Rebend	d test		5		
Shear strength				0,3 A f	_{/k} (A is area	a of wire)	Minimum
Maximum Nominal deviation from bar size (mm) nominal mass ≤ 8 (individual bar > 8 or wire) (%)	9			6,0 4,5			5,0

Design assumptions (art 3.2.7)

For normal design, either of the following assumptions may be made:

- B1) an inclined top branch with a strain limit of ε_{ud} and a maximum stress of kf_{yk} / γ_s at ε_{uk} , where $k = (f_l/f_y)_k$.
- B2) a horizontal top branch without the need to check the strain limit.

The recommended value of ε_{ud} is 0,9 ε_{uk} . The value of $(f_t/f_y)_k$ is given in Table C.1.

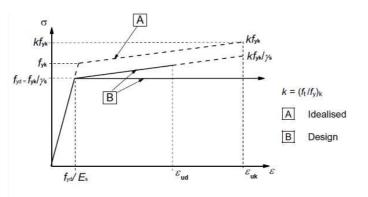
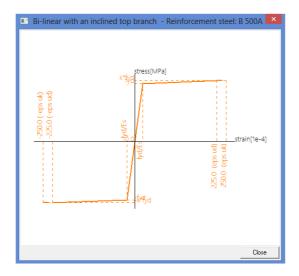
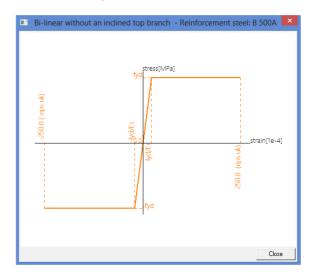


Figure 3.8: Idealised and design stress-strain diagrams for reinforcing steel (for tension and compression)

In the material library the user can choose between the two assumptions:





Durability and cover to reinforcement

Environmental conditions (art 4.2)

Exposure conditions are chemical and physical conditions to which the structure is exposed in addition to the mechanical actions.

Environmental conditions are classified according to Table 4.1:

Table 4.1: Exposure classes related to environmental conditions in accordance with EN 206-1 Class Description of the environment Informative examples where exposure classes designation may occur 1 No risk of corrosion or attack For concrete without reinforcement or X0 embedded metal: all exposures except where there is freeze/thaw, abrasion or chemical attack For concrete with reinforcement or embedded metal: very dry Concrete inside buildings with very low air humidity 2 Corrosion induced by carbonation Concrete inside buildings with low air humidity Dry or permanently wet XC1 Concrete permanently submerged in water XC2 Wet, rarely dry Concrete surfaces subject to long-term water contact Many foundations XC3 Moderate humidity Concrete inside buildings with moderate or high air humidity External concrete sheltered from rain XC4 Cyclic wet and dry Concrete surfaces subject to water contact, not within exposure class XC2 3 Corrosion induced by chlorides XD1 Moderate humidity Concrete surfaces exposed to airborne chlorides XD2 Wet, rarely dry Swimming pools Concrete components exposed to industrial waters containing chlorides XD3 Cyclic wet and dry Parts of bridges exposed to spray containing chlorides Pavements Car park slabs 4 Corrosion induced by chlorides from sea water Exposed to airborne salt but not in direct Structures near to or on the coast XS1 contact with sea water XS2 Permanently submerged Parts of marine structures XS3 Tidal, splash and spray zones Parts of marine structures 5. Freeze/Thaw Attack XF1 Moderate water saturation, without de-icing Vertical concrete surfaces exposed to rain and freezing agent XF2 Vertical concrete surfaces of road structures Moderate water saturation, with de-icing agent exposed to freezing and airborne de-icing agents XF3 High water saturation, without de-icing agents Horizontal concrete surfaces exposed to rain and freezing XF4 High water saturation with de-icing agents or Road and bridge decks exposed to de-icing agents sea water Concrete surfaces exposed to direct spray containing de-icing agents and freezing Splash zone of marine structures exposed to freezing 6. Chemical attack XA1 Slightly aggressive chemical environment Natural soils and ground water according to EN 206-1, Table 2 Moderately aggressive chemical environment XA2 Natural soils and ground water according to EN 206-1, Table 2 XA3 Highly aggressive chemical environment Natural soils and ground water according to EN 206-1, Table 2

In the concrete setup the user can choose the desired exposure class. All items in blue can be overwritten in the data concrete on a member.

Type of values	EC-EN	Name		EC-EN		
Design default 🔍	È Concrete	Concrete				
Drawing settings	 Design defaults Concrete cover 	Design defaults				
	Columns	Concrete cover				
	Beams Beam slabs	Use min concrete con Design working life [y		50		
	Default sway type (for columns and		earsj	XC3		
	Reinforcement and reinforcement desig			None		
	- Input of reinforcement	Type of concrete		In-situ concrete		
	Anchorage of stirrups	Special geometric qu	ality control	📰 no		
	- Anchorage of longitudinal reinfo			Normal surface		
	Prestressing pre-tensioned	Special concrete qua	ity control	m no		
≰Z	Member		B1		^	
. 7			D1			
nu d	U Beam type		beam		*	
	Advanced mode		V			
		Minimal concrete cover				
1990 B	Input for sides					
	Structural class		S4			
	Exposure class		XC3			
ds	V Abrasion class		None			
ns ns	Type of concrete		In-situ concrete		*	
	0.0000000000000000000000000000000000000	control				
10563	Special geometric	Contract				
dl_	trype of concrete		Normal		*	
dl_			Normal C30/37		*	
10563	Type of concrete	surface			<u> </u>	
dl_	Type of concrete Concrete	surface g) [mm]	C30/37		-	
	Type of concrete Concrete Stone diameter (d	surface g) [mm]	C30/37 32		-	
	Type of concrete Concrete Stone diameter (d Special concrete	surface g) [mm]	C30/37 32		-	
	Type of concrete Concrete Stone diameter (d Special concrete cmin,dur [mm]	surface (g) [mm] quality control	C30/37 32 25		•	
	Type of concrete Concrete Stone diameter (d Special concrete cmin,dur [mm] Delta;cdur [mm]	surface (g) [mm] quality control f Delta;cdur	C30/37 32 25		•	
	Type of concrete Concrete Stone diameter (d Special concrete cmin,dur [mm] Delta;cdur [mm]	surface (g) [mm] quality control f Delta;cdur na [mm]	C30/37 32 25 0		-	

Methods of verification (art 4.4)

Concrete cover (art 4.4.1)

General (art 4.4.1.1)

The concrete cover is the distance between the surface of the reinforcement closest to the nearest concrete surface (including links and stirrups and surface reinforcement where relevant) and the nearest concrete surface.

The nominal cover shall be specified on the drawings. It is defined as a minimum cover, c_{min} , plus an allowance in design for deviation, Δc_{dev} :

$$C_{nom} = C_{min} + \Delta C_{dev}$$

(4.1)

Minimum cover, c_{min} (art 4.4.1.2)

Minimum concrete cover, c_{\min} , shall be provided in order to ensure:

- the safe transmission of bond forces
- the protection of the steel against corrosion (durability)
- an adequate fire resistance

The greater value for c_{\min} satisfying the requirements for both bond and environmental conditions shall be used:

$$c_{\min} = \max \left\{ c_{\min,b}; c_{\min,dur} + \Delta c_{dur,\gamma} - \Delta c_{dur,st} - \Delta c_{dur,add}; 10 \text{ mm} \right\}$$
(4.2)

where:

C _{min,b}	minimum cover due to bond requirement
C min,dur	minimum cover due to environmental conditions
$\Delta c_{dur,\gamma}$	additive safety element
$\Delta c_{dur,st}$	reduction of minimum cover for use of stainless steel
$\Delta C_{dur,add}$	reduction of minimum cover for use of additional protection

The recommended value of $\Delta c_{dur,y}$, $\Delta c_{dur,st}$ and $\Delta c_{dur,add}$, without further specification, is 0 mm.

- In order to transmit bond forces safely and to ensure adequate compaction of the concrete, the minimum cover should not be less than $c_{\min,b}$ given in table 4.2.

Table 4.2: Minimum cover, cmin,b, requirements with regard to bond

Arrangement of bars	Minimum cover c _{min,b} *
Separated	Diameter of bar
Bundled	Equivalent diameter (dn)(see 8.9.1)

- The minimum cover values for reinforcement and prestressing tendons in normal weight concrete taking account of the exposure classes and the structural classes is given by *c*_{min,dur}.

The recommended Structural Class (design working life of 50 years) is S4 for the indicative concrete strengths (given in Annex E of EN 1992-1-1). The recommended minimum Structural Class is S1.

The recommended modifications to the structural class is given in Table 4.3N:

Structural Class								
Criterion	Exposure	Class accor	ding to Table	e 4.1			10C	
Citterion	X0	X0 XC1 XC2/XC3 XC			XD1	XD2 / XS1 XD3 / XS2 / XS		
Design Working Life of 100 years	increase class by 2	increase class by 2	increase class by 2	increase class by 2	increase class by 2	increase class by 2	increase class by 2	
Strength Class 1) 2)	≥ C30/37 reduce class by 1	≥ C30/37 reduce class by 1	≥ C35/45 reduce class by 1	≥ C40/50 reduce class by 1	≥ C40/50 reduce class by 1	≥ C40/50 reduce class by 1	≥ C45/55 reduce class b 1	
Member with slab geometry (position of reinforcement not affected by construction process)	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class b 1	
Special Quality Control of the concrete	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class b 1	
production ensured		5						
design working life		ined in the	Concrete set			100 50		
design working life	Can be def	ined in the	Concrete set			EC-EN		
design working life	EC-EN Concrete - Design defaul - Concrete - Columns - Beams slat	ts cover	Concrete set Concrete Design def Concrete Use min con Design work Exposure da	up oults cover cover corete cover ang life (years) ass		EC-EN		
design working life	EC-EN Design defaul Concrete Cournese Columns Beams slat Default so General Concrete	ts cover 15	Concrete setu Concrete Concrete Concrete Use min con Design work	aults cover cover ing life (years) ass ss		♥ 50 50 100		

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The recommended values of $c_{\min,dur}$ are given in Table 4.4N (reinforcing steel):

Table 4.4N: Values of minimum cover, c_{min,dur}, requirements with regard to durability for reinforcement steel in accordance with EN 10080.

Environmental Requirement for c _{min,dur} (mm)										
Structural	Exposure Class according to Table 4.1									
Class	X0	XC1	XD1/XS1	XD2/XS2	XD3 / XS3					
S1	10	10	10	15	20	25	30			
S2	10	10	15	20	25	30	35			
S3	10	10	20	25	30	35	40			
S4	10	15	25	30	35	40	45			
S5	15	20	30	35	40	45	50			
S6	20	25	35	40	45	50	55			

The concrete cover should be increased by the additive safety element Δc_{dur.y}.

Where stainless steel is used or where other special measures have been taken, the minimum cover may be reduced by $\Delta c_{dur,st}$. For such situations the effects on all relevant material properties should be considered, including bond.

For concrete with additional protection (e.g. coating) the minimum cover may be reduced by $\Delta c_{dur.add}$.

For concrete abrasion special attention should be given on the aggregate. Optionally concrete abrasion may be allowed for by increasing the concrete cover (sacrificial layer). In that case, the minimum cover c_{\min} should be increased by k_1 for Abrasion Class XM1, by k_2 for XM2 and by k_3 for XM3.

Abrasion Class XM1 means a moderate abrasion like for members of industrial sites frequented by vehicles with air tyres. Abrasion Class XM2 means a heavy abrasion like for members of industrial sites frequented by fork lifts with air or solid rubber tyres. Abrasion Class XM3 means an extreme abrasion like for members industrial sites frequented by fork lifts with elastomer or steel tyres or track vehicles.

The recommended values of k_1 , k_2 and k_3 are respectively: 5 mm, 10 mm and 15 mm.

The abrasion class and the values of k_1 , k_2 and k_3 can be inputted in the concrete setup:

Concrete setup							
EC-EN	Concrete cover						
E- Concrete	Use min concrete cover						
Design defaults	Design working life [years]	50 👻					
Concrete cover	Exposure class	XC3 -					
Columns	Abrasion class	None					
Beams		the second se					
Beam slabs	Type of concrete	None XM1					
Default sway type (for columns an	Special geometric quality control	XM2					
⊡ General	Type of concrete surface	XM3					
- Non-prestressed reinforcement	Special concrete quality control	no					
	± Columns						
- Durability and concrete cover	t Beams						
	Beam slabs						
General							
Columns	Default sway type (for columns and beams only)						
Beams	General						
⊡- ULS	Concrete Non-prestressed reinforcement						
General							
Fire resistance	Prestressed reinforcement						
Interaction diagram	Durability and concrete cover						
🖻 Shear	National annex						
- 1D structures	□ Clause 4.4.1.2(5)						
Construction joint							
🖻 Details	Formula	Tables 4.3N, 4.4N, 4.5N					
Anchorage check	delta_cdur,gamma - additive safety element for concrete cover 4						
Bearing checks	Value [mm]	0.0					
Fire resistance	delta_cdur.st - reduction of minimum concrete cover for use of st						
⊟- SLS	Value [mm]	0.0					
Cracking forces	delta cdur,add - reduction of minimum concrete cover for use of						
General	Value [mm]	0.0					
Prestressing		0.0					
Creep	k_XM - values of abrasion for classes XM 1,2,3 4.4.1.2(13)						
Crack proof	Values [mm]	5.0 / 10.0 / 15.0					

Allowance in design for deviation (art 4.4.1.3)

To calculate the nominal cover, c_{nom} , an addition to the minimum cover shall be made in design to allow for the deviation (Δc_{dev}). The required minimum cover shall be increased by the absolute value of the accepted negative deviation.

The recommended value of Δc_{dev} is 10 mm.

In certain situations, the accepted deviation and hence allowance, Δc_{dev} , may be reduced.

The recommended values are:

- where fabrication is subjected to a quality assurance system, in which the monitoring includes measurements of the concrete cover, the allowance in design for deviation Δc_{dev} may be reduced:

 $10 mm \ge \Delta c_{dev} \ge 5 mm$

 where it can be assured that a very accurate measurement device is used for monitoring and non conforming members are rejected (e.g. precast elements), the allowance in design for deviation Δc_{dev} may be reduced:

 $10 mm \ge \Delta c_{dev} \ge 0 mm$

Also these values can be found in the concrete setup:

			1112-725	
EC-EN	^	Use min concrete cover	8	
🖻 Concrete		Design working life [years]	50	
⊟- Design defaults		Exposure class	XC3	
Concrete cover Columns		Abrasion class	None	
Beams		Type of concrete	In-situ concrete	
Beam slabs		Special geometric quality control	V yes	
Default sway type (for columns a	in 📗	Type of concrete surface	Normal surface	
🖨 General		Special concrete quality control	no	
Concrete		Columns		
Non-prestressed reinforcement		E Beams		
 Prestressed reinforcement Durability and concrete cover 		Beam slabs		
E Calculation		Default sway type (for columns and beams only)		
General	33	General General		
Columns				
Beams		E Concrete		
🖕 ULS		Non-prestressed reinforcement		
General		Prestressed reinforcement		
Fire resistance		Durability and concrete cover		
Interaction diagram		National annex		
E Shear — 1D structures		Clause 4.4.1.2(5)		
Construction joint		Formula	Tables 4.3N, 4.4N, 4.5N	
		delta_cdur,gamma - additive safety element for concret		
Anchorage check		Value [mm]	0.0	
Bearing checks		delta cdur,st - reduction of minimum concrete cover for		
Fire resistance		Value [mm]	0.0	
🛱 SLS		delta cdur,add - reduction of minimum concrete cover f		
Cracking forces		Value [mm]	0.0	
General		and the second	1242	
- Prestressing		k_XM - values of abrasion for classes XM 1,2,3 4.4.1.2(
Creep Crack proof		Values [mm]	5.0 / 10.0 / 15.0	
Code Dependent Deflections		delta_cdev - value of deviation for concrete cover 4.4	THE REPORT OF A DECISION OF A DECISIONO OF A	
Allowable stress		Values [mm]	5.0 / 10.0 / 5.0	

Analysis models

Eurocode

Structural models for overall analysis (art 5.3.1)

The elements of a structure are classified, by consideration of their nature and function, as beams, columns, slabs, walls, plates, arches, shells etc. Rules are provided for the analysis of the commoner of these elements and of structures consisting of combinations of these elements.

For buildings the following provisions are applicable:

- 1) A beam is a member for which the span is not less than 3 times the overall section depth. Otherwise it should be considered as a deep beam.
- 2) A slab is a member for which the minimum panel dimension is not less than 5 times the overall slab thickness.
- 3) A slab subjected to dominantly uniformly distributed loads may be considered to be one way spanning if either:
 - it possesses two free (unsupported) and sensibly parallel edges.
 - it is the central part of a sensibly rectangular slab supported on four edges with a ratio of the longer to shorter span greater than 2.
- 4) Ribbed or waffle slabs need not be treated as discrete elements for the purposes of analysis, provided that the flange or structural topping and transverse ribs have sufficient torsional stiffness.

This may be assumed provided that:

- the rib spacing does not exceed 1500 mm
- the depth of the rib below the flange does not exceed 4 times its width.
- the depth of the flange is at least 1/10 of the clear distance between ribs or 50 mm, whichever is the greater.
- transverse ribs are provided at a clear spacing not exceeding 10 times the overall depth of the slab.

The minimum flange thickness of 50 mm may be reduced to 40 mm where permanent blocks are incorporated between the ribs.

5) A column is a member for which the section depth does not exceed 4 times its width and the height is at least 3 times the section depth. Otherwise it should be considered as a wall.

SCIA Engineer

Assignment of analysis model

In SCIA Engineer several types of analysis models are available. It is up to the user to decide which model should be used for which element.

For 1D members, there is the choice between Beam, Beam slab and Column calculation. Each element has a property 'Type' assigned to it, to determine which type of calculation will be used:

Properties	4 ×			
Member (1)	🖃 Va V/ 🖉			
	😤 🙈			
Name	B1			
Туре	beam (80) 🔹			
Analysis model	general (0)			
CrossSection	beam (80) column (100)			
Alpha [deg]	gable column (70)			
Member syste	secondary column (60) rafter (90)			
ey [mm]	purlin (0)			
ez [mm]	roof bracing (0) wall bracing (0)			
LCS	girt (0)			
LCS Rotation	truss chord (95) truss diagonal (90)			
FEM type	beam slab (99)			

The Beam calculation is used for the Types 'General', 'Beam, 'Rafter', 'Purlin', 'Roof bracing', 'Wall bracing', 'Girt', 'Truss chord' and 'Truss diagonal'.

The Beam slab calculation is used only for the Type 'Beam slab'. For this type, by default no shear reinforcement is added (unless necessary in case of a slab thickness of 200 mm or more, as defined in the Concrete Setup for slabs). As diameter for the longitudinal reinforcement, the default diameter for 2D structures – and not for beams! – is taken from the Concrete Setup.

The Column calculation is used for the Types 'Column', 'Gable column' and 'Secondary column'.

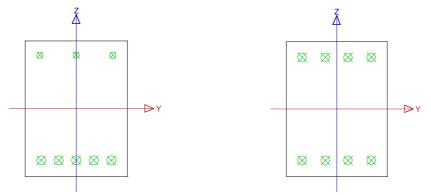
Be careful when Member data are added to an element, via Concrete menu > 1D member > Member data. Also there, the user has the choice for the 3 different analysis models, by means of the option Beam type:

≜Z .	Member	B1	^
nų du	Beam type	beam	
	Advanced mode	beam column	
t cu	Minimal concrete cover	beam slab	
	Input for sides		
	Structural class	S3	
	Exposure class	XC3	Ψ.
ds y	Abrasion class	None	-
	Type of concrete	In-situ concrete	-
	Special geometric control		
	Type of concrete surface	Normal	-
	Concrete	C30/37	
	Stone diameter (dg) [mm]	32	
bw	Actions		
I I	Load default values		>>>
	Concrete Setup		>>>

These Member data *overwrite* both the element properties and the default settings in the Concrete Setup.

Difference between Beam and Column analysis model

The most important difference between Beam and Column calculation is the difference in reinforcement area per direction. A beam has an upper reinforcement area that differs from the lower reinforcement area. A column always has the same reinforcement configuration for the parallel sides, per direction.



These configurations are obvious, and caused by the difference in dominant internal forces per calculation type. For a Beam calculation the bending moment is dominant, while for a Column calculation the axial compression force + bending moments (if present).

So in fact, when the axial pressure on a beam is too high, the user should choose to calculate the element as a column. In the Concrete Setup an option is available to help the user determine whether the Beam calculation type is valid or not. Go to Setup > Concrete solver > General > Calculation > Tab Beams:

	Concrete setup				
EC-EN Concrete G-General Calculation General Columns Beams	Name Concrete General Calculation General Columns	EC-EN			
	Beams Calculate compression reinforcement Include normal force to calculation Check compression of member NEd <x*ac*fcd;x =="" [-]="" at="" force="" force<="" moment="" reduce="" reduction="" shear="" supports="" th=""><th>yes yes ves 0.10 no no In the face (support/column)</th></x*ac*fcd;x>	yes yes ves 0.10 no no In the face (support/column)			

This option 'Check compression of member' will check how important the contribution of the axial compression force is:

If the axial compression load N_{ed} < 0,1*A_c*f_{cd}, warning 60 will appear after reinforcement design:

'The member is not considered to be in compression', which means the type 'Beam' is the right choice.

- If the axial compression load Ned > 0,1*Ac*fcd, **warning 61** will appear after reinforcement design:

'The member is considered to be in compression', which means the beam has to be modelled as type 'Column'.

Example

		7			-			-
								Π
Column					E			
3					2			a di la calcularia di l
		1	·					
	1							
1	628/W 300	628/W 270			59/W 61 59/W 61			59/W 61 59/W 61
	∕ A							

Design As EN 1992-1-1

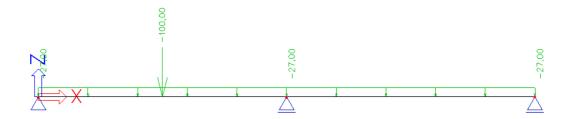
-												
Linear cal Selection Load case	: All es : LC1											
Main upp	er reinfor	cement f	or selecte	ed beams								
Member	d _x Cas [m]	e N _d [kN]	M _{yd} [kNm] [r	x _u d mm][mm]	A _{s,reg} [mm ²]	Reinf.[no .]	W/E					
Beam	0.000 LC1	-100.00	0.00	0 247	59 1x	20.0(314)	61					
Beamslab	0.000 LC1	-100.00	0.00	0 265	59 10	.0-300(59)	61					
Main lowe		Cement fo	Nd [kN]	ed beams	J d n] [mm]	A _{s, reg} [mm ⁻]	Reinf.[no.]	W/E				
Beam	0.000	LC1	-100.00	0.00	0 247	59	1x20.0(314)	61				
Beamslab	0.000	LC1	-100.00	0.00	0 265	59	10.0-300(59)	61				
Main rein	forcemen	t for sele	cted colu	imns								
Member	d _x [m]	Case	N _d [kN]	M _{yd} [kNm]	M _{zd} [kNm]	Calc. typ	De Interaction check [%]	Ratio y/z [%]	A _{s,reg} [mm ²]	Reinf _{req}	Reinf _{tot}	W/E
Column	0.000	LC1	-100.00	12.95	12.95	В	47 < 100	50/50	1257	4(4/4)x20.0	4x20.0(1257)	270

Beam design

Description of used example

The example that will be used to explain reinforcement calculation in a beam is called 'beam.esa'.

The beam reinforcement calculation is explained by means of the following two span beam:



The length of the total beam is 10 m and it has a dimension of 500x300mm.

The inputted loads are:

- 1) BG1: self weight
- 2) BG2: permanent load
 - o Line load: -27 kN/m
 - Point load: -100 kN at position x = 0.25
- 3) BG3: variable load
 - o Line load: -15 kN/m
 - Point load: -150 kN at position x = 0

1_Recalculated internal forces

Reinforcement calculation in SCIA Engineer is based on recalculated internal forces. The pure internal forces calculated by the mechanical FEM calculation are transformed according to code regulation into 'recalculated internal forces' to design the reinforcement.

These recalculated internal forces can be viewed in the concrete menu of SCIA Engineer.

Shifting of moment line (art 9.2.1.3)

The first transformation of internal forces is the shifting of moment line.

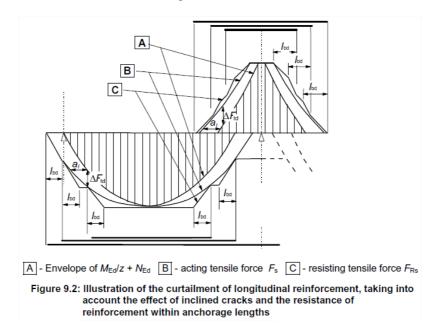
Sufficient reinforcement should be provided at all sections to resist the envelope of the acting tensile force, including the effect of inclined cracks in webs and flanges.

For members with shear reinforcement the additional tensile force, ΔF_{td} , should be calculated. For members without shear reinforcement, ΔF_{td} may be estimated by shifting the moment curve a distance $a_l = d$. This "shift rule" may also be used as an alternative for members with shear reinforcement, where:

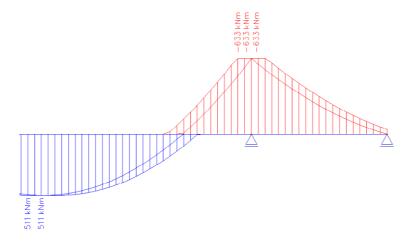
(9.2)

$$a_l = z (\cot \theta - \cot \alpha)/2$$

The additional tensile force is illustrated in Figure 9.2:



In SCIA Engineer the user can review the recalculated internal forces. In the concrete menu it is possible to view the internal forces and recalculated internal forces. In the figure below the difference is clearly visible:



The shifted moment line is automatically taken into account for recalculated internal forces and by this also for calculation of longitudinal reinforcement. It cannot be found in the setup.

(The picture is taken from another example on which the difference is shown between My and My,_{recalc}. Note that the value does not change since no moment capping at supports is taken into account.)

Moment capping at supports (art 5.3.2.2 (4))

Another typical case of recalculated internal forces is the moment capping at supports.

Regardless of the method of analysis used, where a beam or slab is continuous over a support which may be considered to provide no restraint to rotation (e.g. over walls), the design support moment, calculated on the basis of a span equal to the centre-to-centre distance between supports, may be reduced by an amount ΔM_{Ed} as follows:

$$\Delta M_{Ed} = F_{Ed,sup} t / 8$$

(5.9)

where:

F_{Ed,sup} is the design support reaction t is the width of the support

In SCIA Engineer this moment capping is only taken into account if it is activated in the concrete setup:

Beams	
Calculate compression reinforcement	V yes
Include normal force to calculation	V yes
Check compression of member	no
NEd < x*Ac*fcd: x = [-]	0.00
Moment reduction at supports	V yes
Shear force reduction at supports	V yes
Reduce shear force	In the face (support/column)

In SCIA Engineer the width t used for the moment capping at supports can be set in the properties of that support:

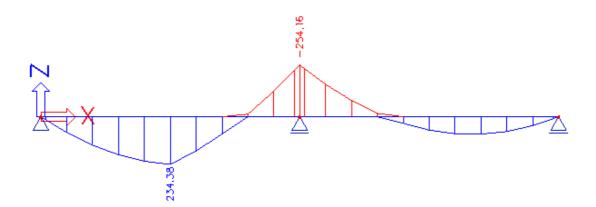
Properties			ą×
Support in node (1)	🔁 Va	V/ 🖉
			8
Name	Sn2		
Туре	Standard		.
Angle [deg]			
Constraint	Sliding		
x	Free		
Z	Rigid		
By	Free		.
Default size [m]	0.200		
Node	K2		
Geometry			
System	GCS		Ψ.

If the support is provided by a column then of course the program will take the width of the column as t.

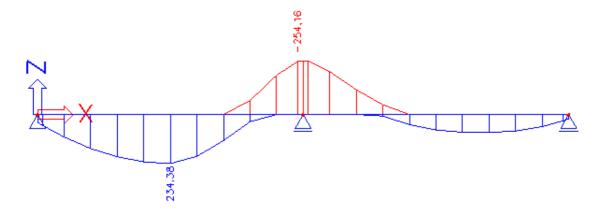
The reduction of moment by moment capping at supports is illustrated for our example below:

- t = 0.2 m
- F_{Ed,sup} = 477.5 kN
- $\Delta M_{Ed} = 477.5*0.2 / 8 = 11.94 \text{ kNm}$

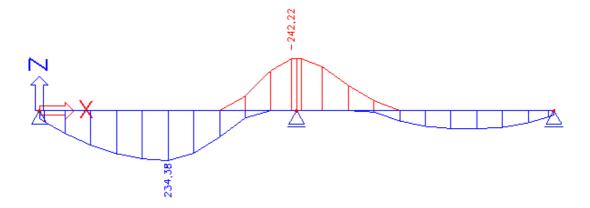
The original moment My at the support was 254.16 kNm.



The recalculated moment clearly shows the shifting of the moment line



With moment capping at support taken into account the recalculated moment is 242.22 kNm.



Shear force capping at supports (art 6.2.1 (8))

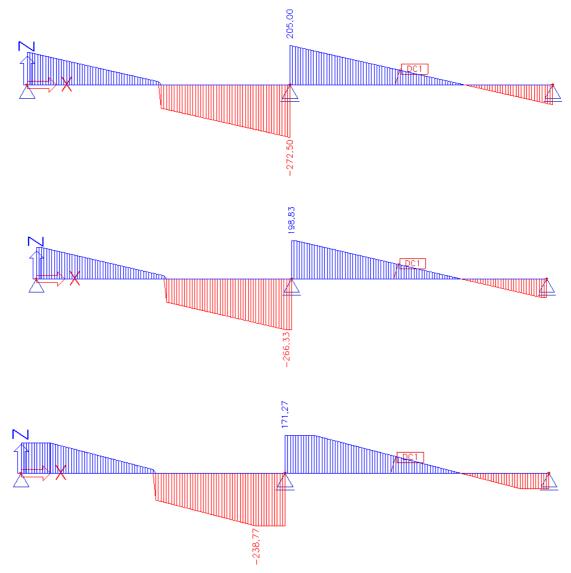
For members subject to predominantly uniformly distributed loading, the design shear force need not to be checked at a distance less than d from the face of the support. Any shear reinforcement required should continue to the support. In addition it should be verified that the shear at the support does not exceed $V_{Rd,max}$.

In SCIA Engineer it is possible to choose between at the face of the support or at a distance d from the face of the support:

E Beams	
Calculate compression reinforcement	V yes
Include normal force to calculation	V yes
Check compression of member	no 📃
NEd < x*Ac*fcd; x = [-]	0.00
Moment reduction at supports	V ves
Shear force reduction at supports	V yes
Reduce shear force	In the face (support/column)
ULS d.c	In the face (support/column) In the face (support/column)+ effective height of the beam

In the figures below it is clear that the shear force is kept constant over the support.

The first figure displays original V_z , the second shows the capping at the face, and the third shows the capping at effective depth from the face:



Other calculation settings

For the calculation of theoretical reinforcement some other settings can still be made in the setup:

Beams	
Calculate compression reinforcement	V yes
Include normal force to calculation	V yes
Check compression of member	no
NEd < x*Ac*fcd; x = [·]	0.10
Moment reduction at supports	no
Shear force reduction at supports	ino no
Reduce shear force	In the face (support/column)

1) Calculate compression reinforcement : default is ON

By de-activating this option, compression reinforcement will never be calculated and can thus lead to undesignabilities or uneconomical high amounts of tension reinforcement.

2) Include normal force to calculation: default is ON

By de-activating this option, normal force will be neglected (if there is any).

3) Check compression of member:

If this is on, the value of normal force will be checked.

This check can be interesting for two reasons.

- If it is a compression force with an absolute value higher than 0,1·Ag·fc', then this should be calculated as a column. The beam has to be modelled as type 'column'.
- If the absolute value normal force is lower than 0,1·Ag fc', then the structure can be assumed as primarily subject to bending. In zones primarily subject to bending redistribution of bending moments is allowed. This redistribution is a new feature of SCIA Engineer 2010.

2_Theoretical reinforcement

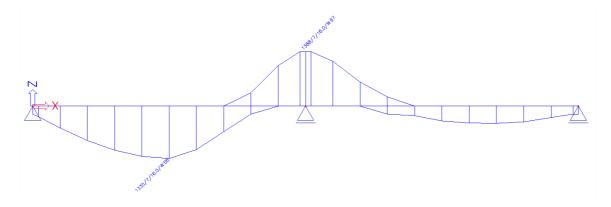
Calculation of longitudinal reinforcement As

The longitudinal reinforcement calculation is based on My, recalc represented in the previous chapter.

The only thing left to be set in the concrete setup is the default diameter and material quality:

- Material quality is set to B 500A.
- The default diameter is set to 16mm.

The following results are obtained with these settings:



Design As EN 1992-1-1

Linear calculation, Extreme : Member Selection : All Combinations : ULS Main upper reinforcement for selected beams

Member	d _x [m]	Case	N _d [kN]	M _{yd} [kNm]	x _u [mm]	d [mm]	b _{tor} [mm]	A _{s,b} [mm²]	A _{s,t} [mm ²]	A _{s,reg} [mm²]	Reinf.[no.]	W/E
S1	4.900	ULS/1	0.00	-242.22	136	449	300	1388	0	1388	7x16.0(1407)	67
Main Laura				d la a a sa a								

main lower	reinforcement for	selected beams	

Member	d _x [m]	Case	N _d [kN]	M _{yd} [kNm]	x _u [mm]	d [mm]	b _{tor} [mm]	A _{s,t} [mm²]	A _{s,reg} [mm ²]	Reinf.[no.]	W/E
S1	2.500	ULS/1	0.00	234.38	131	449	300	0	1335	7x16.0(1407)	68

Detailing reinforcement for selected member

Member	d _x [m]	Case	T _{Ed} [kNm]	A _k [mm²]	u _k [mm]	A _{s,tors} [mm ²]	A _{s,det} [mm ²]	Reinf.[no.]	W/E
S1	2.500	ULS/1	0.00	78804	1192	0	0	2x8.0(101)	78
S1	4.900	ULS/1	0.00	78804	1192	0	0	2x8.0(101)	78

Explanation of warnings and errors

The bar distance for the upper reinforcement is too small. 67 The bar distance for the lower reinforcement is too small. 68 78

The reinforcement was designed according to detailing provisions.

d: lever arm of reinforcement.

 $d = h - cover - \Phi_{stirrup} - \Phi_{longitudinal beam} / 2 = 500 - 35 - 8 - 16/2 = 449 mm$

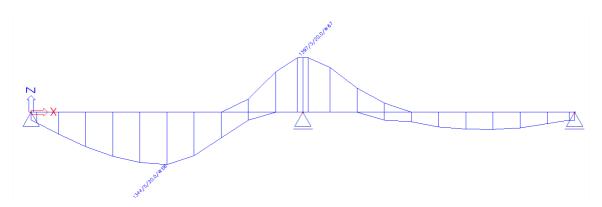
(the cover is defined by the environmental class and is 35 mm for XC3)

The only internal force working on this beam is M_{yd} . N_d and T_d are zero.

For detailing reinforcement (the reinforcement in the side of the beam), the theoretically required is zero because there is no torsion on this beam (the 2x8 refers to the stirrups).

The warnings 67 and 68 are typical warnings that appear when the chosen diameter is too small. It means that with this diameter too many bars are needed resulting in a bar distance which is too small. This gives an indication that it is better to choose a bigger default diameter.

If default diameter is set to 20mm, the following results are obtained:



Design As EN 1992-1-1

Linear calculation, Extreme : Member Selection : All Combinations : ULS Main upper reinforcement for selected beams

		-												
Member	d _x	Case	N _d	M _{yd}	X _u	d	b _{tor}		s,b	A _{s,t}	A _{s,req}	Re	einf.[no.]	W/E
	[m]		[kN]	[kNm]	[mm]	[mm]	[mm]	լ լո	nm²]	[mm ²]	[mm ²]			
S1	4.900	ULS/1	0.00	-242.22	137	447	30	00	1397	(0 1397	5x20	0.0(1571)	67
Main lower	reinforc	ement fo	r selecteo	d beams										
Member	d,	Case	N _d	M _{vd}	X	d	b _{tor}	A	s.t	A _{s,req}	Reinf.[no	0.]	W/E	
	[m]		[kŇ]	[kNm]	[mm]	[mm]	[mm]		m²]	[mm ²]	-	_		
S1	2.500	ULS/1	0.00	234.38	132	447	30	0	0	1344	5x20.0(15	71)	68	
Detailing re	einforcen	nent for s	elected r	nember										
Member	d _x [m]	Case	T _{Ed} [kNm]	A _k [mm ²]	u _k [mn		tors	A _{s,det} mm ²]	Reir	nf.[no.]	W/E			
S1	2.500	ULS/1	0.0			176	0	0	2x8.0	0(101)	78			
S1	4.900	ULS/1	0.0	0 7643	6 11	176	0	0	2x8.0	0(101)	78			
Explanatio	on of wa	rnings a	nd error	S										
67 Th	e bar dis	tance for	the upper	reinforcen	nent is to	o small.								
68 Th	e bar dis	tance for	the lower	reinforcem	nent is to	o small.								
78 Th	o roinforo	ar distance for the lower reinforcement is too small. einforcement was designed according to detailing provisions.												

If you take a close look at these results, you can see that also the value for A_{s,req} has changed.

This is because the lever arm d has decreased:

d = h -cover - $\Phi_{\text{stirrup}} - \Phi_{\text{longitudinal beam}}/2 = 500 - 35 - 8 - 20/2 = 447 \text{ mm}$

As you can see, the default diameter has also a slight effect on the amount of reinforcement that is required, because of the changed lever arm.

We will now input a basic reinforcement and calculate then the additional reinforcement which is needed.

As basic reinforcement we will use 2 bars of 20mm on the upper and lower side of the beam. Basic reinforcement can be inserted in the beam by use of member data.

(Note that concrete data can also be used without setting a number of bars. In that case concrete data are used to change the default diameter for the bar to which these data are assigned. It is obvious that the member data have higher priority than the general setup.)

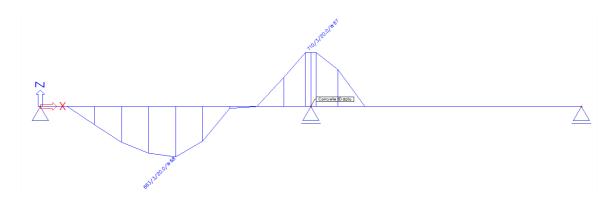
≜ Z	E Design		
nu du	Material	B 500A 💌	
i~	🕀 Upper		
a ‡cu	Number of bars (nu)	2	
	Diameter (du) [mm]	20.0	*
	Type of cover	use minimal cover	*
	Concrete cover (cu) [mm]	35	
ý y	🕀 Lower		
ns	Number of bars (nl)	2	
	Diameter (dl) [mm]	20.0	
station states and states an	Type of cover	use minimal cover	*
n	Concrete cover (cl) [mm]	35	
1986-961 An	Way of calculation As,min	According to formula 9.1N (9.2.1.1)	*
bw	🕀 Stimups		
	Material	B 500A	22
	Basic distance (ss) [mm]	300	*
	Diameter (ds) [mm]	8.0	-
	Actions		
	Load default values		>>>
	Concrete Setup		>>>

To take the user reinforcement into account, the following setting has to be on (default it is on):

			Concrete setup		K			
tandard EN		Nan E Co	ne oncrete	Standard EN]			
Control Careeral Calculation General Columns Columns Columns Construction diagram Shear Construction joint Starting Construction joint Starting Construction joint Starting Starting		= 0	General □ Calculation					
		E	General Number of iteration steps	100				
			Precision of iteration [%] Limit value for checks [-]	1 1.00	-			
			User defined and end sections only Concrete area weakened by reinforcement bars	no no	-			
			Concrete area weakened by prestressed reinforcement For design calculations of 1D members, consider longitudinal user reinforcement.	no V yes	1			
			Calculation of effective depth Check torsion	Automatic 💌	1			
Cracking forces			Check shear of construction joint Calculation of additional force caused by shear and torsion	The state of the s				

The additional required reinforcement equals the total reinforcement minus the basic user reinforcement.

The result is shown below:



Design As EN 1992-1-1

Member	d _x [m]	Case	N _d [kN]	M _{yd} [kNm]	x _u [mm]	d [mm]	A _{s,b} [mm ²]	A _{s,t} [mm ²]	A _{s,req} [mm ²]	A _{s,user} [mm ²]	Reinf.[no.]	W/E
S1	4.900	ULS/1	0.00	-242.22	91	447	710	0	710	628	3x20.0+2x20.0(1571)	67
Main Iowei	ain lower reinforcement for selected beams											
Member	d _x [m]	Case	N _d [kN]	M _{yd} [kNm]	x _u [mm]	d [mm]	A _{s,b} [mm ²]	A _{s,t} [mm ²]	A _{s,req} [mm ²]	A _{s,user} [mm ²]	Reinf.[no.]	W/E
S1	2.500	ULS/1	0.00	234.38	89	447	663	0	663	628	3x20.0+2x20.0(1571)	68
Detailing r	einforcen	nent for s	elected m	ember								
Member	d _x [m]	Case	T _{Ed} [kNm]	A _k [mm ²]	u _k [mm]	A _{s,t}	n²] [mi	_{det} Rei n ²]	nf.[no.]	W/E		
wember	լող					70	0	0 (0)		004		
S1	2.500	ULS/1	0.00	7643	6 11	/6	0	0 (0)		221		

As you can see graphically, we will only need additional reinforcement at the upper face over the support and at the lower face in the field of the beam.

We can input this additional reinforcement by means of practical reinforcement. The manual input of practical reinforcement will be described in chapter 3.

Calculation of shear reinforcement Ass

Design As EN 1992-1-1

Selection Combination	Linear calculation, Extreme : Member Selection : All Combinations : ULS Shear reinforcement for selected members										
Member	Memberd_xCase V_{Ed} b_wd $V_{Rd,c}$ $V_{Rd,max}$ A_{ss}Reinf.[no.]										
	[m] [KŇ] [mm] [KN] [KŇ] [mm ² /m]										
S1	4.900	ULS/1	-266.33	300	447	83.40	627.56	1278	2x8.0-79		

V_{Ed}	= design shear force	resulting from	external loading

V_{Rd.c} = design shear resistance of the member without shear reinforcement

- = design value of the shear force which can be sustained by the yielding shear $V_{Rd,s}$ reinforcement
- V_{Rd,max} = design value of the maximum shear force which can be sustained by the member, limited by crushing of the compression struts

In general we can have three cases:

- V _{Ed} > V _{Rd,max}	Concrete strut failure
- $V_{Ed} \leq V_{Rd,c}$	Shear force carried by concrete. No shear reinforcement necessary (minimum shear reinforcement according to detailing provisions)
- $V_{Ed} > V_{Rd,c}$ and $V_{Ed} < V_{Rd,max}$	Shear reinforcement necessary in order that: $V_{Ed} \le V_{Rd}$

Members NOT requiring design shear reinforcement: VEd < VRd,c (art 6.2.2)

$$V_{Rd,c} = [C_{Rd,c} k(100 \rho_1 f_{ck})^{1/3} + k_1 \sigma_{cp}] b_w d$$
(6.2.a)

with a minimum of

$$V_{Rd,c} = (v_{min} + k_1 \sigma_{cp}) b_w d \tag{6.2.b}$$

where:

 $\begin{array}{ll} f_{ck} & = characteristic \mbox{ concrete compressive strength [MPa]} \\ k & = size \mbox{ factor: } k = 1 + \sqrt{(200/d)} \leq 2,0 \mbox{ (with d in mm)} \\ \rho_l & = longitudinal \mbox{ reinforcement ratio: } \rho_l = A_{sl}/b_w d \leq 0,02 \\ b_w & = \mbox{ smallest web width of the cross-section in the tensile area [mm]} \\ \sigma_{cp} & = \mbox{ concrete compressive stress due to loading: } \sigma_{cp} = N_{Ed}/A_c < 0,2 \mbox{ f}_{cd} \mbox{ [MPa]} \\ d & = \mbox{ effective height of cross section} \end{array}$

The recommended value for $C_{Rd,c}$ is 0,18/ γ_c , that for k_1 is 0,15 and that for v_{min} is given by expression:

$$V_{min} = 0,035 \ k^{3/2}. \ f_{ck}^{1/2} \tag{6.3N}$$

The shear force
$$V_{Ed}$$
, calculated without reduction by β , should always satisfy the condition:

$$V_{Ed} \le 0.5 \ b_w \ d \ v \ f_{cd} \tag{6.5}$$

where v is a strength reduction factor for concrete cracked in shear.

The recommended value for v follows from:

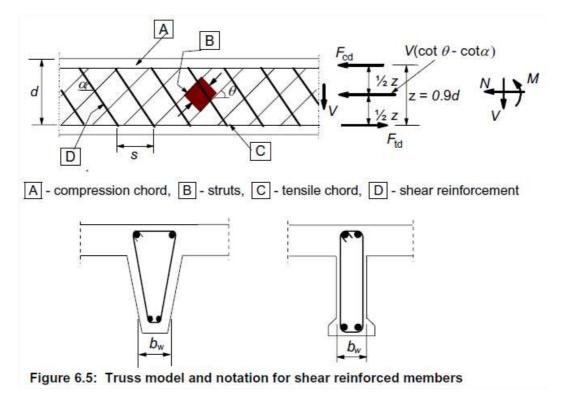
$$V = 0.6 \left[1 - \frac{f_{Ck}}{250} \right]$$
(6.6N)

In SCIA Engineer, it is possible to input the following parameters:

Concrete setup								
	_							
EC-EN	^	Name	EC-EN					
E Concrete		Concrete						
🚍 Design defaults		Design defaults						
Concrete cover		+ General						
Columns								
Beams								
- 2D structures and beam slabs		General General						
- Punching								
Default sway type (for columns an		theta 0=1/x - basic value of inclination 5.2(5)						
🚊 General								
Concrete		Iambda_lim 5.8.3.1(1)						
Non-prestressed reinforcement		Type of simplified method for analysis second order effect						
- Prestressed reinforcement		□ C_Rd,c						
- Durability and concrete cover		Value [-]	0.18					
⊟- Calculation		k1_shear - coeff. for calculation Vrd,c 6.2.2(1)						
General		Value [-]	0.15					
Columns		v_min - coeff. for calculation Vrd,c for shear 6.2.2(1)						
Beams		Formula	Formula					
2D structures								
Ė∾ ULS		ni - strength reduction factor for concrete cracked in shear 6.2.2(6)						
General		Formula	Formula					

(Note that the green values are according to EN code)

Members requiring design shear reinforcement: VEd > VRd,c (art 6.2.3)



The design of members with shear reinforcement is based on a truss model:

The angle θ should be limited.

The recommended limits of $\cot \theta$ are given:

$$1 \le \cot \theta \le 2,5$$

(6.7N)

The angle θ can be inserted in SCIA Engineer:

Concrete setup						
EC-EN	^	Name	EC-EN			
- Concrete	-		EG EN			
E- Concrete		Concrete				
E- General E- Calculation General		General				
		Interaction diagram				
Columns						
Beams		Shear				
⊡- ULS		1D structures				
Interaction diagram		Distance with full resistance from outside stirrup (multiple of stirrup distance) [-]	0.50			
⊟ Shear		Angle between the concrete compression strut and beam axis m				
		Type of input theta	Angle			
		⊡ Web				
Anchorage check		theta [deg]	40.00			
Bearing checks		cot (theta)	1.192			
- Fire resistance		Compression flange				
🚍 - SLS			0.00			
 Cracking forces 		theta [deg]				
Creep		cot (theta)	1.192			
Crack proof		Tension flange				
Code Dependent Deflections		theta [deg]	0.00			
Allowable stress		cot (theta)	1.192			
Calculation						

For members with vertical shear reinforcement, the shear resistance V_{Rd} is the smaller value of:

$$V_{Rd,s} = \frac{A_{SW}}{s} z f_{ywd} \cot \theta$$
(6.8)

and

 $V_{Rd,max} = \alpha_{cw} b_w z v_1 f_{cd} / (\cot \theta + \tan \theta)$ (6.9)

where:

 $\begin{array}{lll} A_{sw} & = cross-sectional area of the shear reinforcement \\ s & = spacing of the stirrups \\ f_{ywd} & = design \ yield \ strength \ of \ the \ shear \ reinforcement \\ v_1 & = strength \ reduction \ factor \ for \ concrete \ cracked \ in \ shear \\ \alpha_{cw} & = coefficient \ taking \ account \ of \ the \ state \ of \ the \ stress \ in \ the \ compression \ chord \end{array}$

The recommended value of v_1 is v (see Expression 6.6N)

If the design stress of the shear reinforcement is below 80% of the characteristic yield stress f_{yk} , v_1 may be taken as:

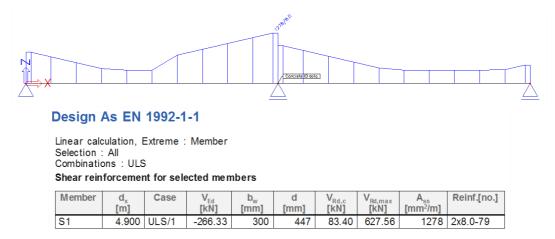
$V_1 = 0,6$	for $f_{ck} \leq 60 MPa$	(6.10.aN)
$V_1 = 0.9 - f_{ck}/200 > 0.5$	for $f_{ck} \ge 60 MPa$	(6.10.bN)

The recommended value of α_{cw} is 1 for non-prestressed structures.

These code related parameters can be found in the setup:

	Concrete setup
EC:EN Concrete Concrete cover Columns Beams Beams Beams Beam slabs Default svey tope (for columns an	v_min - coeff. for calculation Vrd.c for shear 6.2.2(1) in - strength reduction factor for concrete cracked in shear 6.2.2(6) k - Coefficient for calculation of longitudinal shear stress resisted by theta_min - min. angle between the concrete compression strut an Value (deg) theta_max - max. angle between the concrete compression strut a Value (deg) theta_max - max. angle between the concrete compression strut a Value (deg) theta_max - max. angle between the concrete compression strut a Value (deg) theta_max - max.angle between the concrete compression strut a Value (deg) theta_max - max.angle between the concrete compression strut a Value (deg) theta_max - max.angle between the concrete compression strut a
General Concrete Non-prestressed reinforcement Prestressed reinforcement	theta_min_c - Minimal angle between the concrete compression st theta_min_t - Minimal angle between the concrete compression st theta_max_f - Maximal angle between the concrete compression s
□ Durability and concrete cover □- Calculation □ General □ Columns □ Beams	Imi_la - strength reduction factor for concrete cracked in shear (fc Value [-] 0.60 Imi_lb - strength reduction factor for concrete cracked in shear (fc Formula Formula
⊡- ULS General	Alpha_cw (non-prestressed structures) Value [-] 1.00

If we come back to our example in SCIA Engineer, we find the following A_{ss} for the whole beam:



In the middle of the span you can see that there is everywhere a minimum of 335mm². This is because we defined earlier in the concrete data that there is a two section stirrup of 8mm every 300mm. The maximum value of 1278mm² corresponds to a two section stirrup of 8mm every 79mm.

3_Practical reinforcement

We will now pass on to the level of practical reinforcement. This will allow us to specify the reinforcement locally over the beam.

In the theoretical reinforcement design, we have calculated where we needed additional reinforcement. This will allow us to manually input the practical reinforcement.

In chapter 5 we will see that also automatic input of practical reinforcement is possible.

We will start by converting the user defined reinforcement into practical reinforcement:



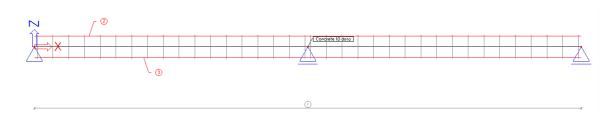
We can first select a stirrup shape:

•	Stirrup shape manager	×
🏓 🤮 🏒 📸 🔛 🖸	. 🗠 🖨 🖻 🔒	
StirrupR1 ^ StirrupR2		
Name Stimup R1 Description Stimups t Number of 1 Diameter [m 8.0 Number of 2		
New Insert Edit	Delete	ок

Image: construction of bass Image: construction of bass Collision New reinforcement parameters Number of bass Image: construction of bass Collision Simups Eddt stimups Simups Eddt stimups Simups Collision Collision		Member S1, Zone from 0.	500 m to 4.000 m(0.050 - 0.400))	×
3 1 3 1 1		2	1	L1-S1E2	<u> </u>
3 1 3 1 1 Postion number 3 Material B 500A • Diameter [mm] 20.0 Number of bars 2 Area [mm^22] 628 Layer type Uniform • Cover type Surface to s • Cover (mm] 0.0 Left bar Before the b • New reinforcement New reinforcement parameters Number of bars 2 Diameter [mm] 8.0 Stirup name S1 Edge index 4 Stirups Diameter [mm] Stirup name S1 Edge index 4 Stirups Diameter [mm] Stirup name S1 Edit stirups Diameter [mm] Stirup name S1 Edit stirups Draw dimensions Texts scale 0.5 Diameter [mm] S0 Stirup name S1 Edit stirups Draw dimensions Texts scale 0.5 Redraw S1				Delete	Delete all
3 1 Material B 500A * Diameter [mm] 20.0 Number of bars 2 4 Add bars to corners New layer Number of bars Add bars to corners Simup name Stirup name S1 Edge index 4 Stirups Edit stirups Edit stirups Draw dimensions Edge index 4 Stirup name S1 Stirups Edit stirups Edit storer Draw dimensions Edge index 0.5 Bars positions 0.5				Name	L2-S1E4 ^
Longitunidal reinforcement Add bars to corners New reinforcement parameters Number of bars Type of beam New reinforcement layers area New layer Number of bars 2 Analysis model Automatic design New layer Number of bars 2 Image: Simup name Simup name Simup name Bars positions Collision of bars 2 Image: Simup name Simup name Simup name Collision of bars 2 Image: Simup name Simup name Simup name Simup name Edge index 4 Image: Simup name Simup name Simup name Simup name Simup name Simup name Simup name Simup name Simup name Simup name Edit cover Save to template Disameter Redraw Simup		2	1	Position number	
Longitunidal reinforcement Add bars to corners New reinforcement parameters Number of bars Type of beam Number of bars 2 Add bars to corners Number of bars 2 Bars positions Collision of bars 2 Collision of bars 2 Eddt cover Stirrup name S1 Eddt stirrups Edge index 4 V		3	1		
Longituridal reinforcement Add bars to corners New reinforcement parameters Number of bars Type of beam New layer Number of bars Image: Collision of bars Image: Collision of bars Bars positions Collision of bars Image: Collision of bars Image: Collision of bars Collision of bars Image: Collision of bars Image: Collision of bars Image: Collision of bars Collision of bars Image: Collision of bars Image: Collision of bars Image: Collision of bars Collision of bars Image: Collision of bars Image: Collision of bars Image: Collision of bars Collision of bars Image: Collision of bars Image: Collision of bars Image: Collision of bars Image: Collision of bars Collision of bars Image: Collision of bars Image: Collision of bars Image: Collision of bars Image: Collision of bars Collision of bars Image: Collision of bars Image: Collision of bars Image: Collision of bars Image: Collision of bars Collision of bars Image: Collision of bars Collision of bars Image: Collision of bars Image: Collision of bars Image: Collisi					
Layer type Uniform Layer type Uniform Cover type Surface to s Right bar Before the b Stimup name S1 Stimup name S1 Stimup name S1 Edge index 4 Very to beam Stimups Edit stimups Diameter (mm) Stimup name S1 Edit cover Save to template					
Longitunidal reinforcement New reinforcement parameters New layer Number of bars Add bars to corners Stirrup name Bars positions Collision Collision Collision © Between existing bars Stirrups Eddt cover Save to template					
Longitunidal reinforcement Add bars to corners New reinforcement parameters Number of bars Type of beam Cover [m] 0.0 Longitunidal reinforcement Add bars to corners New reinforcement parameters Type of beam Edge index 4 ✓ New layer Number of bars 2 ✓ Edge index 4 ✓ Bars positions Collision of bars 2 ✓ Edit stirups Edit stirups Edit stirups Edge index 4 ✓ ✓ Edit stirups 1257 mm^22 Stirup name 51 ✓ Edit stirups Draw dimensions Edge index 4 ✓ Ficture properties Draw dimensions Edit cover Save to template Redraw Image: Stirup					
Longitunidal reinforcement New reinforcement parameters New layer Number of bars Add bars to corners Stirup name Stirup name S1 Diameter (mm) 8.0 Stirups Stirups Edge index 4 Vew layer S1 Diameter (mm) 8.0 Stirups Stirups Edge index 4 Vew layer S1 Diameter (mm) 8.0 Stirups Stirups Edit stirups Diameter (mm) Edge index 4 Vew layer S1 Edit stirups Diameter (mm) Edit cover Save to template					
Longitunidal reinforcement New reinforcement parameters New layer Number of bars 2 Add bars to corners Number of bars 2 Diameter (mm) 8.0 Bars positions Edge index 4 Collision of bars 2 Between existing bars Stirrups Edit stirrups Edit cover Save to template					
Longitunidal reinforcement New reinforcement parameters New layer Number of bars 2 Add bars to corners Diameter (mm) 8.0 Bars positions Edge index 4 Collision for bars 2 Between existing bars Stirrups Edit stirrups Edit cover Save to template					
Longitunidal reinforcement New reinforcement parameters Type of beam Analysis model Automatic design New layer Number of bars 2 Image: Collision of bars 2 Add bars to corners Diameter (mm) 8.0 Image: Collision of bars 2 Bars positions Edge index 4 Image: Collision of bars 2 Image: Collision of bars 1257 mm^22 All layers 1257 mm^2 Image: Collision of bars				-	
Longitunidal reinforcement New reinforcement parameters Type of beam Analysis model Automatic design New layer Number of bars 2 Image: Collision of bars Image: Collision of bars <td></td> <td>4</td> <td></td> <td></td> <td></td>		4			
Longitunidal reinforcement New reinforcement parameters New layer Number of bars 2 Add bars to corners Diameter (mm) 8.0 Stirrup name S1 Edit stirrups Edge index 4 Edit stirrups Collision Fetween existing bars Edit cover				Edge index	4 🗸 🗸
Longitunidal reinforcement New reinforcement parameters New layer Number of bars 2 Add bars to corners Diameter (mm) 8.0 Stirrup name 51 Edge index 4 Edit cover Draw dimensions Edit cover Save to template				Analysis model	Automatic design
New layer Number of bars 2 Image: Collision Number of bars 2 Image: Collision Selected layers Selected layers Selected layers Selected layers fc28 mm^22 Add bars to corners Diameter (mm) 8.0 Image: Collision Stirrups All layers 1257 mm^22 Bars positions Edge index 4 Image: Collision Edit stirrups Edit cover Draw dimensions Collision Fetween existing bars Fetween existing bars Save to template Redraw	- Longitunidal reinforcement	New reinforcement parameters	Type of beam	- Reinforcement la	yers area
Add bars to corners Diameter [mm] 8.0 Image: star in the star	New Javer	Number of bars 2		Selected layers	628 mm^2
Bars positions Stirup name Stirup Collision © Between existing bars Stirup save to template				All layers	, 1257 mm^2
Bars positions Edge index 4 Edit stirrups Collision of bars Collision © Between existing bars Edit cover	Add bars to comers		Stimups	-	1
Bars positions Edge index 4 Edit stimups Collision of bars Edit cover Edit cover Collision © Between existing bars Save to template			· · · · · · · · · · · · · · · · · · ·		
Collision of bars Edit cover Collision Image: Between existing bars	Bars positions	Edge index 4			
Collision © Between existing bars Save to template	Collision of bars			P	
C Move layer OK Cancel	Collision	 Between existing bars 	Save to template	n	
		C Move layer		OK	Cancel

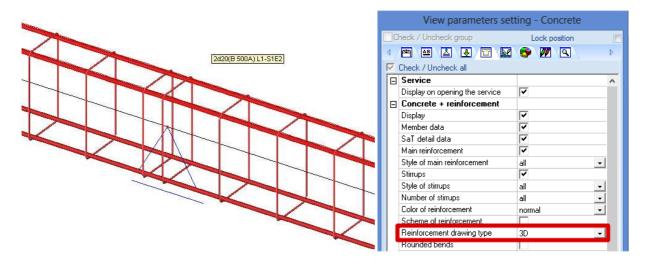
Then the configuration of longitudinal reinforcement is shown:

The practical reinforcement is shown graphically on the screen:



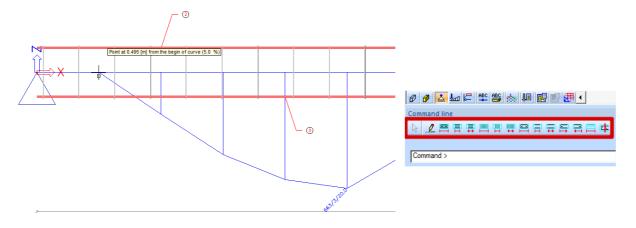
By selecting this reinforcement it is always possible to change this through the property window.

Through view parameter settings a 3D representation of the reinforcement can be obtained:



To input locally extra practical reinforcement, we take back the results for additional reinforcement.

On this picture we can precisely define where the extra practical reinforcement needs to be putted:



To add a new layer of longitudinal reinforcement the following screen will pop up. Here can be set on which face extra reinforcement needs to be added:

2 Filter All L1:51E2 L2:51E4 L3:51E4 3 1
Name L3-S1E4 A
Position number 4
3 Material B 500A •
Diameter [mm] 20.0
Number of bars 3
Area [mm^2] 942
Layer type No comer 💌
Cover type Surface to s •
Cover [mm] 0.0
Stimup name S1 💌
Edge index 4
24 Detailing no
Torsion
Analysis model Automatic design
Longitunidal reinforcement New reinforcement parameters Type of beam Reinforcement layers area
New layer Number of bars 3 💌 beams and ribs 💌 Selected layers 942 mm ²
Add bars to corners Diameter [mm] 20.0 All layers 2199 mm ²
Stirrups Picture properties
- The second sec
Bars positions
Collision of bars Redraw
Collision C Between existing bars Save to template
OK Cancel

For reasons of simplicity we will add 3 bars of 20mm that are still needed over the whole area where extra reinforcement is required. This can of course be done more detailed.

The same procedure will be repeated for the upper reinforcement over the support.

After adding the extra longitudinal reinforcement, we can verify if this is enough through verifying if still additional reinforcement is required or not.

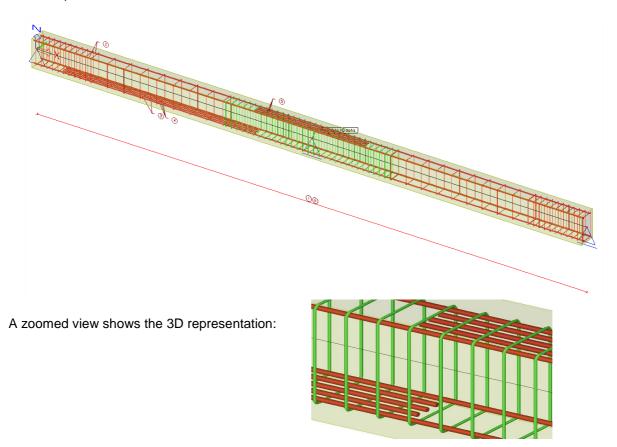
Also the shear reinforcement needs to be increased in the zones over the support. This can be done by increasing the diameter of the stirrups or by decreasing the distance between the stirrups.

Different stirrup zones can be created:

Stirrups zones	×
2x 10d8.0-0.100 2x9d8.0-0.300 2x31d10.0-0.100 2x10d8.0-0.277 0.05050 0.050 2.500 0.005 0.005 0.004 2.500 2cre 1 Minimum stirup reinforcement Zone Length [m] Diameter [mm] Distance [m] Real distance [m] Type By user Distance to begin [m]	Text scale 1
Zone 3 Zone 4 3 3.000 10.000 0.1 0.100 single yes × 0.005 Zone 5	yes 0.000
Additional stirup reinforcement	
Input type Numbers Diameter [mm] Distance [m] Tota	tal distance [m] Type
New zone Delete zone New part Delete part	OK Cancel

To check if there is enough shear reinforcement, a capacity check needs to be performed. This will be explained in the next chapter.

The total practical reinforcement of the beam is shown below:



4_Checks

There are some typical checks that can be performed on a beam with practical reinforcement.

The following checks are implemented in SCIA Engineer:

- **capacity check**: checks the interaction of internal forces
- response check: checks the maximal strains based on the stress/strain diagram
- detailing provisions: checks if detailing provisions described in EN chapter 8 and 9 are met
- crack control: checks if maximum crack width is not exceed, according to EN chapter 7.3
- **deflections check**: checks if the long term deflections don't exceed max values (described in chapter CDD)

The capacity and response check should be okay if no additional reinforcement is required.

However these checks give interesting information on the efficiency of reinforcement. For instance if in a section only 50% of reinforcement is used, then we can conclude that here less reinforcement would have been sufficient.

The detailing provisions check and the crack control check are extra checks that are not accounted in the reinforcement design. If these checks are not okay then the practical reinforcement needs to be changed.

We will explain the checks one by one on our example.

We can start from the esafile: 'beam_practical reinforcement.esa'

Capacity check

We will start by controlling if there is enough shear force reinforcement by asking the report for Vzu:

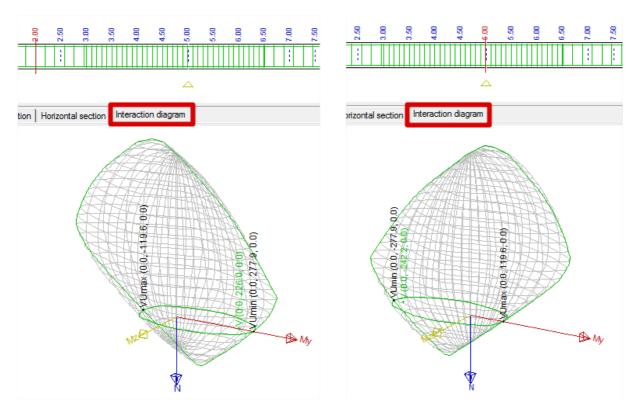
Check c	heck capacity EN 1992-1-1										
inear calculation, Extreme : Member Selection : All Sombinations : ULS											
Check of s	hear for se	elected m	embers								
Member	d _x [m]	Case	Method	V _{Ed} [kN]	stirr dist [mm]	diam. [mm]	A _{ss} [mm²/m]	V _{Rd,c} [kN]	V _{Rd,s} [kN]	Check _{calc}	Check
					transv dist [mm]			V _{Rd,max} [kN]	V _{Rd} [kN]	Check _{lim} [-]	W/E
S1	3.000	ULS/1	formula 6.2a.b) EN1992-1-1	-149.16	300	8.0	335	87.78	69.54	2.14	NOT OK
					218			624.75	69.54	1.00	678
S1	7.000	ULS/1	formula 6.2a.b) EN1992-1-1	81.66	277	8.0	363	64.68	75.35	1.08	NOT OK
					218			624.75	75.35	1.00	678

As expected the unity check is higher than one, so this is not okay.

We will increase shear force reinforcement also in the middle zones to solve this problem.

This is done in the new file 'beam_practical reinforcement2.esa'.

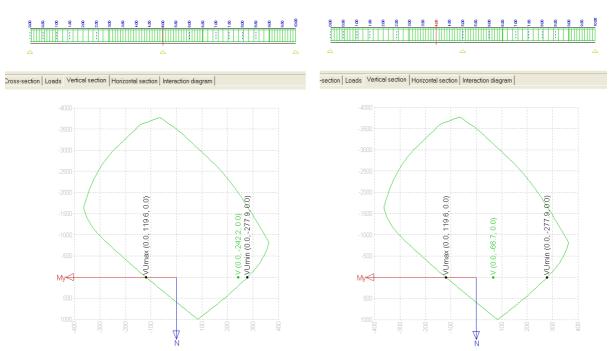
It is also possible to do a single check in a specific section of the beam. This gives very detailed information on the interaction diagram as shown below:



Note the positive moment My in the middle of the span and the negative moment My over the support. (make sure you set the extreme to My+ and My- respectively if you look at these interaction diagrams)

Since Mz and N are zero in this case we could better look at the vertical section of the interaction diagram.

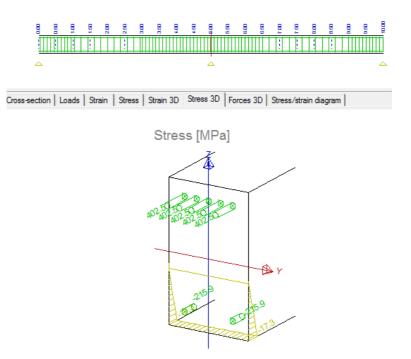
If we compare the results at x = 5m (over support) and at x = 4m (1m next to support), we can see that at x = 4m we could have succeeded easily with less reinforcement:



Response check

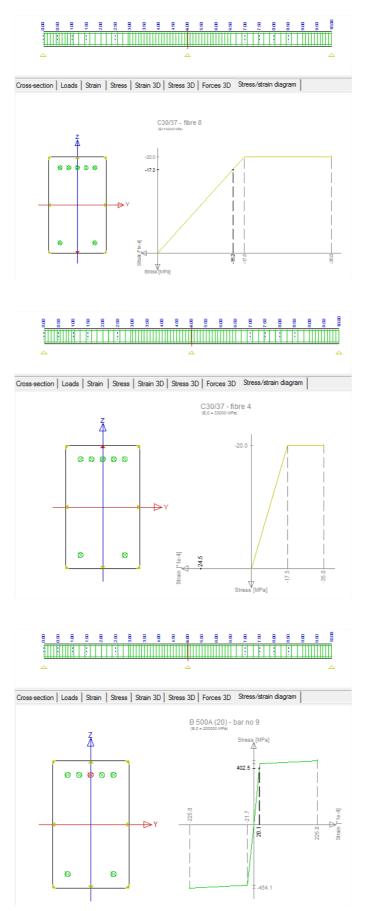
The response check is related to the stress strain diagram and checks if maximal strains are not exceeded. As mentioned above, this check is satisfied if no additional reinforcement was required.

The single check over the support is shown:



It is clear from this picture that the upper side is in tension and that the concrete does not work in tension. All tension has to be taken by the upper reinforcement bars.

The stress/strain diagrams are shown below for the lower and upper fibre of concrete and for the upper reinforcement bar:



Detailing provisions check

The check of detailing provisions checks the detailing provisions activated in the concrete setup.

Since the EN requires checking these detailing provisions, it is advised to activate them all (note that default they are all activated):

	Concrete setup	
Standard EN Concrete General Prestessed reinforcement General Slabs Warnings and errors	 Min. bar distance - factor k1 Value [-] Min. bar distance - faktor k2, dg+ 8.2(2) Value [mn] Minimum mandrel diameter for bends, hooks and loops Min. bar distance - distance 8.2(2) [m] Columns Beams Setting of checks Min. percentage of longitudinal reinforcement Max. percentage of longitudinal reinforcement Additional moment above support Max. bar distance of shear reinforcement Max. ratio (percentage) of shear reinforcement Max. longitudinal spacing of shear reinforcement (shear) Max. Iongitudinal spacing of shear reinforcement (shear) Max. transverse spacing of shear reinforcement (shear) 	1.00 5 0.02 V yes V yes
	Max. longitudinal spacing of shear reinforcement (shear) Max. longitudinal spacing of shear reinforcement (torsion) Max. transverse spacing of shear reinforcement	 ✓ yes ✓ yes
	Max. percentage of longitudinal reinforcement Value [%] Beta_1 Max. bar distance 9.2.3(4) [m] Beam as stab Shear reinforcement	4.00 0.35
	Min. ratio (percentage) of shear reinforcement Value [-] Max. long. spacing of the legs Value [-]	0.08

The check of detailing provisions of longitudinal reinforcement is shown below:

Detailing provisions EN 1992-1-1

Linear calculation, Extreme : Member Selection : All Combinations : ULS Detailing provisions of longitudinal reinforcement for selected members

Member	d _x [m]	Case	µ _{lc,min} /µ _{l,min} [-]	µ _{l,max} /µ _{lc,max} [-]	s _{lc,min} /s _{l,min}	s _{l,max} /s _{lc,max}	Check _{calc} [-]	Check _{lim} [-]	Check	W/E
S1	0.497	ULS/1	0.13	0.37	1.48	0.51	1.48	1.00	NOT OK	868

Explanation of warnings and errors

868 Minimum surface to surface spacing of longitudinal reinforcement is not satisfactory.

The problem in this example is that the surface to surface spacing of longitudinal reinforcement is less than the minimum.

Spacing of bars (art 8.2)

The clear distance (horizontal and vertical) between individual parallel bars or horizontal layers of parallel bars should be not less than the maximum of k_1 . bar diameter, ($d_g + k_2 mm$) or 20 mm where d_g is the maximum size of aggregate (d_g can be set in the material properties).

The recommended values of k_1 and k_2 are respectively 1 and 5 mm.

A possible solution would be to replace the 5 bars of 20 mm by a smaller amount of bigger bars.

(7.8)

Crack control check

The unity check for crack control in SCIA Engineer is the biggest of three checks:

- crack width (w > w_{lim})
- minimum reinforcement area (Asprov > Asmin)
- maximum bar diameter and distances (it is sufficient that either the distances or the diameters satisfy)

Calculation of crack widths (art 7.3.4)

The crack width, w_k , may be calculated from:

$$W_k = S_{r,max} \left(\varepsilon_{sm} - \varepsilon_{cm} \right)$$

where

- s_{r.max} = maximum crack spacing
- ϵ_{sm} = mean strain in the reinforcement under the relevant combination of loads

 ϵ_{cm} = mean strain in the concrete between cracks

Limiting calculated crack (art 7.3.1(5))

A limiting calculated crack width, w_{max} , taking into account the proposed function and nature of the structure and the costs of limiting cracking, should be established.

The recommended values of w_{max} for relevant exposure classes are given in following table:

Exposure Class	Reinforced members and prestressed members with unbonded tendons	Prestressed members with bonded tendons				
	Quasi-permanent load combination	Frequent load combination				
X0, XC1	0,4 ¹	0,2				
XC2, XC3, XC4		0,2 ²				
XD1, XD2, XS1, XS2, XS3	0,3	Decompression				
 Note 1: For X0, XC1 exposure classes, crack width has no influence on durability and this limit is set to guarantee acceptable appearance. In the absence of appearance conditions this limit may be relaxed. Note 2: For these exposure classes, in addition, decompression should be checked under the quasi-permanent combination of loads. 						

Table 7.1N	Recommended values of w _{max} (mm)
------------	---

The allowable crack width can be set in the setup:

SLS	
Cracking forces	
😑 General	
National annex	
k3_crack - coefficient for calculation maximal final crack spacing	n
Value [-]	3.40
k4_crack - coefficient for calculation maximal final crack space	n
Value [-]	0.42
w_max - for non-prestressed structure 7.3.1(5)	
Values [mm]	0.4 / 0.3 / 0.3

For environmental class XC3, w_{lim} equals 0.3 mm:

Crack proof EN 1992-1-1

```
Linear calculation, Extreme : Global
Selection : All
Combinations : SLS
Crack width calculation for selected members
```

Member	d _x [m]	Case	N [kN]	M _y [kNm]	σ _s [MPa]	s _{r,max} [mm]	w [mm]	Check _{calc} [-]	Check
			N _r [kN]	M _{yr} [kNm]	f _{ct,eff} [MPa]	ε _{sm} -ε _{cm} [1e-4]	w _{lim} [mm]	Check _{lim} [-]	
S1	8.500	SLS/1	0.00	63.43	244.7	375	0.275	0.92	OK
			0.00	39.61	2.90	7.3	0.300	1.00	
S1	5.000	SLS/1	0.00	-188.27	300.0	232	0.289	0.96	OK
			0.00	-43.22	2.90	12.4	0.300	1.00	

Minimum reinforcement area (art 7.3.2)

The required minimum areas of reinforcement may be calculated as follows:

$$A_{s,min}\sigma_s = k_c \ k \ f_{ct,eff}A_{ct}$$

where:

$A_{s,min}$	= minimum area of reinforcing steel within the tensile zone
A _{ct}	= area of concrete within tensile zone
σ_{s}	= absolute value of the maximum stress permitted in the reinforcement immediately after
	formation of the crack
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
k	= coefficient which allows for the effect of non-uniform self-equilibrating stresses, which lead
	to a reduction of restraint forces
k.	= coefficient which takes account of stress distribution within the section immediately prior to

(7.1)

k_c = coefficient which takes account of stress distribution within the section immediately prior to cracking and of the change of the lever arm

The check of minimum reinforcement can be shown in SCIA Engineer:

Crack proof EN 1992-1-1

Linear calculation, Extreme : Global Selection : All Combinations : SLS Minimum reinforcement for selected members

Member	d _x [m]	Case	k _c [-]	h [mm]	σ [MPa]	A _{s,min} [mm²]	Check _{calc} [-]	Check
			k [-]	h* [mm]	f _{ct,eff} [MPa]	A _{s,prov} (P) [mm ²]	Check _{lim} [-]	
S1	0.500	SLS/1	0.40	500	213.2	351	0.22	OK
			0.86	500	2.90	1571	1.00	

Control of cracking without direct calculation (art 7.3.3)

Where the minimum reinforcement is provided, crack widths are unlikely to be excessive for cracks caused mainly by loading; either the provisions of Table 7.2N OR the provisions of Table 7.3N are complied with:

Table 7.2N Maximum bar diameters ϕ_s for crack control¹

Steel stress ²	Maximum bar size [mm]								
[MPa]	$w_{k} = 0,4 \text{ mm}$	$w_{k} = 0,3 \text{ mm}$	w _k = 0,2 mm						
160	40	32	25						
200	32	25	16						
240	20	16	12						
280	16	12	8						
320	12	10	6						
360	10	8	5						
400	8	6	4						
450	6	5	-						

Notes: 1. The values in the table are based on the following assumptions:

c = 25mm; $f_{ct,eff} = 2,9$ MPa; $h_{cr} = 0,5$; (h-d) = 0,1h; $k_1 = 0,8$; $k_2 = 0,5$; $k_c = 0,4$; k = 1,0; $k_t = 0,4$ and k' = 1,0

2. Under the relevant combinations of actions

Table 7.3N Maximum bar spacing for crack control¹

Steel stress ²	Maximum bar spacing [mm]								
[MPa]	w _k =0,4 mm	w _k =0,3 mm	w _k =0,2 mm						
160	300	300	200						
200	300	250	150						
240	250	200	100						
280	200	150	50						
320	150	100							
360	100	50	. · · ·						

For Notes see Table 7.2N

We can also see the maximum bar spacing and maximum diameters:

Crack proof EN 1992-1-1

Linear calculation, Extreme : Global Selection : All Combinations : SLS Maximum bar spacing for selected members

Member	d _x [m]	Case	N [kN]	M _y [kNm]	σ [MPa]	s _{max} [mm]	s _{prov} (P) [mm]	Check _{calc}	Check
			N _r [kN]	M _{yr} [kNm]				Check _{iim} [-]	
S1	8.500	SLS/1	0.00	63.43	244.7	194	180	0.93	OK
			0.00	39.61				1.00	

Maximum diameters for selected members

Member	d _x [m]	Case	N _r [kN] N _r [kN]	M _{yr} [kNm] M _{yr} [kNm]	σ [MPa]	φ՝ [mm]	Φ _s [mm]	Φ _{prov} (P) [mm]	Check _{calc} [-] Check _{lim} [-]	Check	W/E
S1	5.000	SLS/1	0.00 0.00	-43.22 -43.22	300.0	11.0	10.0	20.0	2.00 1.00	NOT OK	669

Note that **only one of these two conditions should be satisfied**. In this case the maximum bar spacing is not exceeded, so also this third check is passed.

Since all three conditions are satisfied, we can conclude that our example passes the crack control.

5_Automatic member reinforcement design (AMRD)

In chapter two of the chapter beam calculation, the theoretical design of reinforcement was explained. In chapter three, practical reinforcement was inserted manually, based on the amount of required reinforcement. In chapter four, a response check and capacity check was performed.

This procedure is collected in the option 'Automatic reinforcement design'. Automatic reinforcement design takes into account:

- capacity check
- response check
- detailing provisions: minimum and maximum percentage and maximum bar distances.

The method of AMRD is explained by means of the same example explained in '1_description' of used example. Open this example 'beam.esa'.

First of all, we have a look at the theoretical design. It's always recommended to do this before you perform an AMRD. On that way you have an idea of the amount of reinforcement and the possible minimum diameter.

For example: a basic diameter of 10 mm and quality B 600C is taken in the setup of concrete. The following output is obtained:

Design As EN 1992-1-1

Linear calculation, Extreme : Member Selection : All Combinations : ULS Main upper reinforcement for selected beams

Member	d _x [m]	Case	N _d [kN]	M _{yd} [kNm]	x _u [mm]	d [mm]	b _{tor} [mm]		s,b m²]	A _{s,t} [mm ²]	A _{s,req} [mm ²]	Re	inf.[no.]	W/E
S1	4.900	ULS/1	0.00	-242.22	135			_	1148		0 1148	15x1	0.0(1178)	67
Main lowe	r reinforc	ement fo	r selecte	dbeams							1			
Member	d _x [m]	Case	N _d [kN]	M _{yd} [kNm]	x _u [mm]	d [mm]	b _{tor} [mm]		s,t n²]	A _{s,req} [mm ²]	Reinf.[n	10.]	W/E	
S1	2.500	ULS/1	0.00	234.38	130	452	300		0	1105	15x10.0(1	178)	68	
Detailing r Member	einforcen d _x [m]	Case	elected r T _{Ed}	A _k	u _k] [mn		tors Asm ²] [m	,det m 2]	Reir	nf.[no.]	W/E			
S1	2.500	ULS/1	0.0	0 824	16 12	216	0	0	2x8.0	0(101)	78			
S1	4.900	ULS/1	0.0	0 824 ⁻	16 12	216	0	0	2x8.0	0(101)	78			
	e bar dis	tance for	the upper	reinforcer										

78 The reinforcement was designed according to detailing provisions.

It is obvious that this diameter cannot be used for a design because of the bar distances. So, we increase the diameter in the setup to 16 mm:

Design As EN 1992-1-1

Linear calculation, Extreme : Member Selection : All Combinations : ULS Main upper reinforcement for selected beams

Member	d _x [m]	Case	N _d [kN]	M _{yd} [kNm]	x _u [mm]	d [mm]	b _{tor} [mm]	A _{s,b} [mm²]	A _{s,t} [mm²]	A _{s,req} [mm ²]	Reinf.[no.]	W/E
S1	4.900	ULS/1	0.00	-242.22	136	449	300	1159	0	1159	6x16.0(1206)	67
Main lowe	Main lower reinforcement for selected beams											

Member	d _x [m]	Case	N _d [kN]	M _{yd} [kNm]	x _u [mm]	d [mm]	b _{tor} [mm]	A _{s,t} [mm²]	A _{s,req} [mm ²]	Reinf.[no.]	W/E
S1	2.500	ULS/1	0.00	234.38	131	449	300	0	1115	6x16.0(1206)	68

Detailing reinforcement for selected member

Member	d _x [m]	Case	T _{Ed} [kNm]	A _k [mm ²]	u _k [mm]	A _{s,tors} [mm ²]	A _{s,det} [mm ²]	Reinf.[no.]	W/E
S1	2.500	ULS/1	0.00	78804	1192	0	0	2x8.0(101)	78
S1	4.900	ULS/1	0.00	78804	1192	0	0	2x8.0(101)	78

Explanation of warnings and errors

Γ	67	The bar distance for the upper reinforcement is too small.
	68	The bar distance for the lower reinforcement is too small.
	78	The reinforcement was designed according to detailing provisions.

Also, in this case, the bar distance is too small. However, for an automatic design, one layer can contain a mix of diameters. So, we keep the diameter of 16 mm as minimum.

Now, we can do an automatic reinforcement design. The non-prestressed reinforcement is designed in the selected beam. Both longitudinal and stirrups are designed.

There are 3 manners to do this:

- By means of the setup
- By means of the member data
- By means of a reinforcement template

The 3 options will be explained.

AMRD by means of the setup

Project: AMRD01.esa

First of all, the minimum diameter has to be determined in the setup. This was done in the previous step:

itandard EN	Name	Standard EN
∃ Concrete	Concrete	
⊡ Design defaults	Design defaults	
Concrete cover Columns	Concrete cover	
Beams	Columns	
Beam slabs	Beams	
Default sway type (for columns and b	Longitudinal reinforcement]
Reinforcement and reinforcement design	Upper	-
Input of reinforcement □- Hooks	Diameter [mm]	16.0
Anchorage of stirrups	E Lower	
Anchorage of longitudinal reinforc	Diameter [mm]	16.0
Prestressing pre-tensioned	Stirrups	
Prestressing post-tensioned	Diameter [mm]	8.0

After this, some settings of the AMRD can be adapted in the setup of concrete:

Lieneral	Reinforcement and reinforcement design		
Prestressing	Input of reinforcement		
Creep	+ Hooks		
Crack proof			
Code Dependent Deflections	Automatic reinforcement design		
⊨ Allowable stress	General		
Stress limitation during tensioning	Maximal exploitation of cross-section [%]	90	
SLS stress limitation Calculation	Longitudinal reinforcement		
Detailing provisions	Minimal length of bars [m]	0.50	
Common detailing provisions	Check min. number of longitudinal bars above supports	Ves	
Columns	Minimal number of longitudinal bars above supports [%]	30	
Beams	Try to reduce length of bars	V yes	
⊡- Fire resistance General	Minimal number of reduced bars in a reinf. layer	2	
Columns	Maximal number of bigger diameter than the default diameter	2	
Beams	Do not use "Neighboring" diameters	no no	
Slabs	Stirrups		
Reinforcement and reinforcement des	Minimal center-to-center distance for stimups [mm]	50.0	
Input of reinforcement	Minimal reduction length	By length	
 Hooks Anchorage of stirrups 	Minimal length of one stirrup part [mm]	1000.0	
Anchorage of longitudinal rein	Minimal number of stimups in one stimup part	5	
Automatic reinforcement design	Step for reduction [mm]	50.0	
- Prestressing pre-tensioned	Try to create symmetrical part of stirrups	no 📃	

Explanation of the AMRD-parameters

General

Maximum exploitation of cross-section [%]

Specifies the maximal utilization of the cross-section in the automatically reinforced beam. The value may be between 1 and 100%.

Longitudinal reinforcement

Minimal length of bars [m]

Defines the minimal length of bars automatically inserted into the reinforced beam. The algorithm tries to shorten the reinforcement bars if possible so that they do not extent along the whole length of the beam. The shortened bar cannot be shorter than the value of this parameter.

Check min. number of longitudinal bars above supports

If ON, the number of reinforcement bars above supports is checked and compared to the values specified below.

Minimal number of longitudinal bars above supports [%]

Defines the minimal required amount of reinforcement bars above supports.

Try to reduce length of bars

If OFF, the program uses only bars that extent along the whole length of the beam. If ON, some bars may be shortened if the unity check is satisfied without them.

Minimal number of reduced bars a in reinforcement layer

Imagine a simply supported beam. There must be 6 bars in the middle of the span. Only 5 bars are required in a section that is closer to the support. And only 4 bars are necessary in another section that is still closer to the support. And so on. So in general, you could shorten the bars one by one. This may be sometimes impractical as it would lead to a large number of different bars.

The value in this parameter defines the minimal number of bars that may be shortened at the same time. The default value is 2. It means that, in our example, you would have 6 bars in the middle, there still will be 6 bars in the section where 5 is sufficient, and only farther towards the support the number will be reduced to 4 bars. And so on.

Maximal number of bigger diameter than the default diameter

Defines how many different (bigger) diameters of the reinforcement can be used for the optimization. Let us assume that the default diameter specified in the Design default tab is 10mm.

If this parameter is set to 2, the program can use diameters 10, 12 (i.e. +1 item in the manufacturing program) and 14 (i.e.+2 item in the manufacturing program) for the design.

Do not use "Neighboring" bars

Some standards recommend that "neighboring" profiles from the manufacturing program should not be used in one beam (in order to avoid unintentional interchange of the profiles).

Let us assume that the default diameter specified in the Design default tab is 10mm. Further assume that Maximal number of bigger diameters than the default is set to 2.

If this option is ON, the following bars can be inserted into the beam: (i) either 10mm, (ii) or 12mm, (iii) or 14mm, (iv) or 10mm and 14mm can be combined together. 10mm and 12mm are not permitted to be combined in one beam.

Stirrups

Minimal center-to-center distance for stirrups [mm]

Specifies the minimal distance between stirrups measured from the centre of a bar to the centre of an adjacent bar.

Minimal reduction length

Defines the minimum reduction length. It may be defined by means of length or number of stirrups in the part. See the next two parameters.

Minimal length of one stirrup part [mm]

Defines the length of one part of the beam where stirrups are distributed uniformly. This parameter ensures than a situation the distance between two adjacent stirrups is different for every two adjacent stirrups.

Minimal number of stirrups in one stirrup part

Analogous to the parameter above.

Step for reduction [mm]

Defines the step for the reduction of the distance between two adjacent stirrups. This insures that the distance between stirrups is always a "rounded" number – e.g. 200mm, then 250mm, then 300mm, etc. (and not e.g. 200, 246mm, 298mm, etc.).

Try to create symmetrical part of stirrups

This parameter may enforce that the stirrup part are symmetrical along the length of the beam.

To see the influence of the diameter, we change the maximal number of bigger diameters than the default diameter into 0:

Longitudinal reinforcement	
Minimal length of bars [m]	0.50
Check min. number of longitudinal bars above supports	📝 yes
Minimal number of longitudinal bars above supports [%]	30
Try to reduce length of bars	V yes
Minimal number of reduced bars in a reinf, laver	2
Maximal number of bigger diameter than the default diameter	0
Do not use "Neighboring" diameters	E no

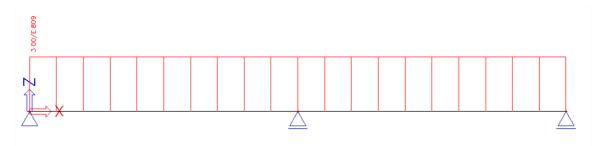
Now, we can perform a Reinforcement design.

Go to Automatic member reinforcement design > Reinforcement design.

🚊 🐨 Automatic member reinforcement design
📲 🖥 Member data
🔤 🖬 Reinforcement design

And select combination ULS.

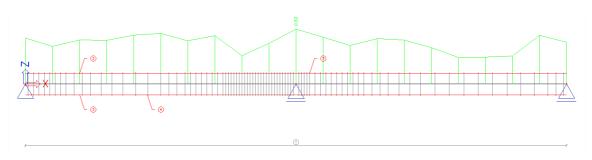
After refreshing, the following result is obtained:

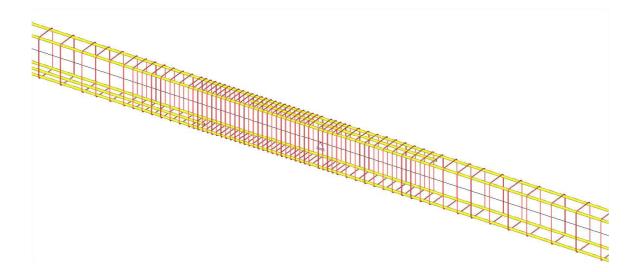


SCIA Engineer could not find a solution. This was expected, because we stated that only the diameter 16 could be used. The bar distances will be too small.

So, we go back to the concrete setup and change the Maximal number of bigger diameters than the default diameter into 3. So 16, 18, 20 and 25 mm can be used.

Now, after refreshing, the amount of reinforcement is:



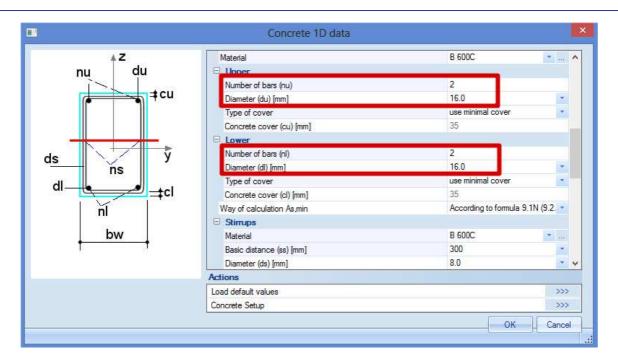


AMRD by means of the concrete data

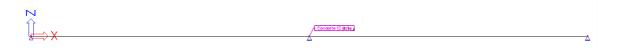
Project: AMRD02.esa

In the first step, Member data are inputted on the beam. So go to Member data in the concrete menu and select the beam.

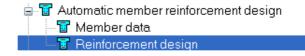
Next, some basic reinforcement is chosen, namely 2 bars of diameter 16 mm at the upper and lower side:



<u>Remark:</u> it is not obligated to insert a number of bars, it is also possible to insert only a basic diameter.



Next, select Automatic member reinforcement design > Reinforcement design.

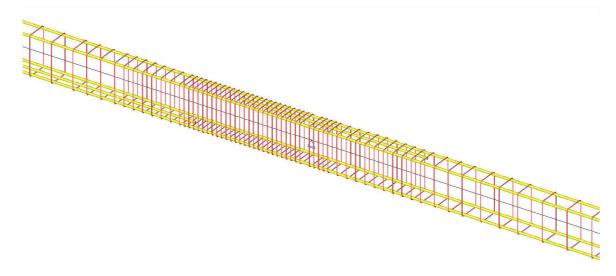


And select combination ULS.

Now, the basic reinforcement of the member data will be used because they overwrite the diameters given in the Concrete Setup:



This results in the following reinforcement configuration:



As expected, we will get the same result as in the previous example: a diameter of 16 mm is implemented but we may use also diameter 18 mm, 20 mm and 25 mm.

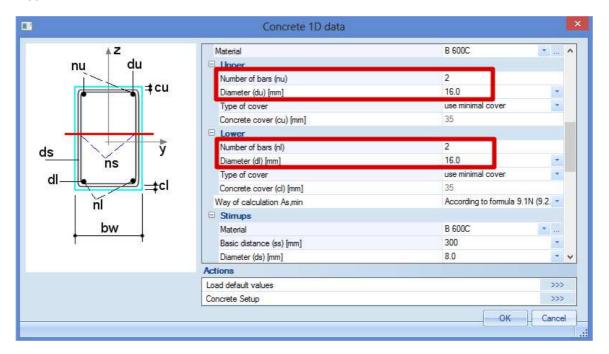
AMRD by means of a reinforcement template

Project: AMRD03.esa

A last option to do an AMRD design is according to a reinforcement template. This can be determined in the AMRD data.

Here you can choose if you use the diameters of the Concrete Setup (AMRD01.esa) or if you use the diameters defined in the Member data (AMRD02.esa).

Suppose that we use the same member data as in the previous example: 2 bars of diameter 16mm at the upper side and 2 bars of diameter 16mm at the lower side:

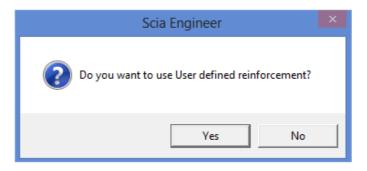


In the second step, the member data of the Automatic member reinforcement design can be inputted.

Select Automatic member reinforcement design > Member data:



The following question arises:

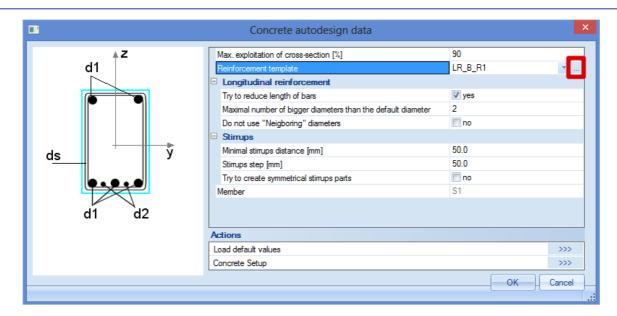


Confirm this by clicking "Yes".

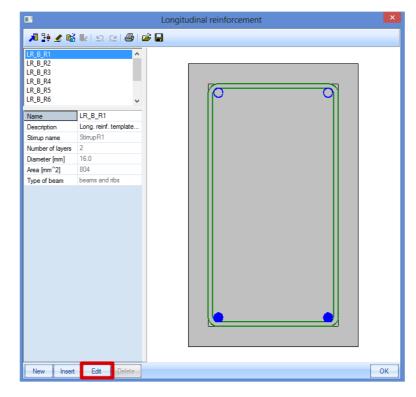
Then, the dialog box of the stirrup shape manager opens, where you can choose a stirrup template:

			Stirr	irrup shape manager	×
🔎 💱 🏒	: 🖬	k 🖸 🤅	2141		
StirrupR1 StirrupR2 StirrupR3 StirrupR4 StirrupR5 StirrupR6			~		
Name		Stirrup R1			
Description		Stirrups tem	plate for		
Number of st	timups	1			
Diameter [mr	m]	8.0			
Number of c	uts	2			
New	Insert	Edit	Delete		K

Click OK to see the autodesign member data:



Here you can click on the button behind Reinforcement template to see the templates for the longitudinal reinforcement:



In that case, the selected template LR_B_R1 is used as basic reinforcement. Click on the button 'Edit' to see the reinforcement parameters.

Create the following configuration: Upper: 2 bars

Lower: 2 bars Middle left/right: 1 bar at each side

	Longitudin	al reinforcement		×
	2		Filter All L1-S1E4 L2-S1E2 L3-S1E3 L4-S1E1	T
			Delete	Delete all
			Name	L2-S1E2
			Position number	2
	3	1	Diameter [mm]	16.0
	I IP II		Number of bars	2
			Area [mm ²]	402
			Layer type	Uniform 💌
			Cover type	Surface to s 💌
			Cover [mm]	0.0
			Left bar	Before the b 💌
			Right bar	Before the b 💌
			Stimup name	S1 💌
	4		Edge index	2 🔹
			Detailing	🗖 no 🗸 🗸
			Analysis model	Automatic design
- Longitunidal reinforcement	New reinforcement parameters	Type of beam	Reinforcement la	yers area
New layer	Number of bars 1 -	beams and ribs 🔹	Selected layers	402 mm^2
Add bars to corners	Diameter [mm] 16.0 V		All layers	1206 mm^2
	Stirrup name S1 💌	Stirrups	Picture properties	
	Edge index 2	Edit stirrups	🔲 Draw dimens	
Bars positions	Luge muex 2	· · · · · · · · · · · · · · · · · · ·	Texts scale	0.5 ÷
Collision of bars			Be	edraw
Collision	Between existing bars			
	C Move layer		OK.	Cancel

Select the tab Automatic design:

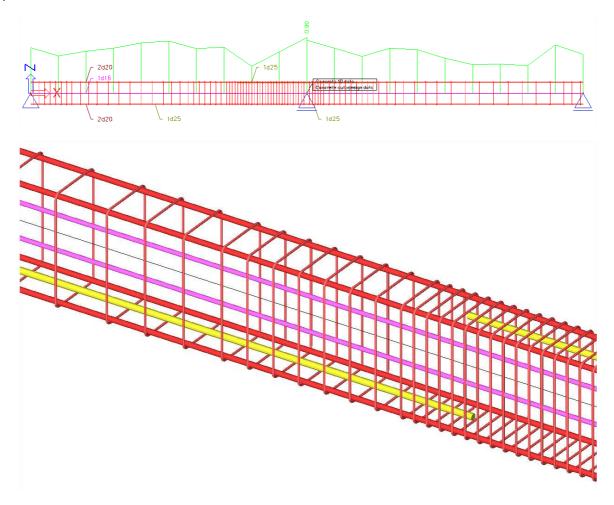
Longitudinal reinforcement		×
	Filter All	
	Analysis model A	utomatic design

Note that this option is checked for the upper and lower bars. The bars in the middle are not taken into account for the automatic design. This means that the upper and lower bars will be used to vary during the design process.



For example, the first configuration that will be verified is the configuration of the template. Suppose that this gives a capacity check higher than 1. So, new bars are added or diameters are changed (only 3 diameter higher regarding the member data!) to satisfy the check.

The two flank bars however are not taken into account in the automatic reinforcement design. This means that they are included for the checks, but their diameter or number will not vary during the process.



Column Design

Calculation Types

For column design, there are 3 types of calculation:

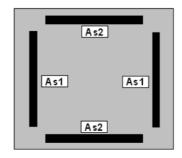
- Axial compression only
- Uni-axial bending
- Bi-axial bending

When taking a closer look at the column calculation, 2 different approaches can be distinguished:

- For the 'Axial compression only' and 'Uni-axial bending' calculation, SCIA Engineer uses the same computing heart as for beams.
- For 'Bi-axial bending' calculations, SCIA Engineer uses a combination of the computing heart for beams and the so-called interaction formulas.

Furthermore, the uni-axial bending calculation always has as result a 1-directional reinforcement configuration, with the same number of reinforcement bars at parallel sides.

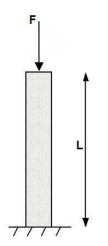
The bi-axial bending calculation has as result a 2-directional reinforcement configuration. The number of bars may differ per direction, but is always the same for parallel sides:



The uni-axial bending calculation is a relatively simple calculation type, while the bi-axial bending calculation requires an iterative process.

Keep this in mind as the reason why the uni-axial bending calculation will go a lot faster.

Axial compression only



No reinforcement required: N_{Ed} < N_{Rd}

Example: open the example 'Axial force - uni ax bending.esa'

Geometry Column cross-section: RECT 350x350 mm² Height: 4,5 m Concrete grade: C45/55

Concrete Setup

Item General: Calculation > Tab Columns: 'Buckling data' are not taken into account (only 1st order moments are considered).

Ξ (Calculation	
+	General	
-	Columns	
	Advanced setting	no
	Only comer design	no no
	Determine governing cross-section beforehand	V yes
	Use buckling data	no
	Optimize the number of bars in c-s for biaxial calculation	V yes

Item Detailing provisions: not taken into account, to view the pure results (according to the Eurocode, always a minimum reinforcement percentage has to be added).

D	etailing provisions	
± (Common detailing provisions	
	Columns	
-	Setting of checks	
	Min. percentage of longitudinal reinforcement	no no
	Max. percentage of longitudinal reinforcement	no
	Min. bar diameter of longitudinal reinforcement	no no
	Max. bar distance of longitudinal reinforcement	no no
	Min. number of long.bars in circular column	no
	Max. longitudinal spacing of transverse reinforcement	no no
	Max. transverse spacing of tranverse reinforcement	no no
	Min. bar diameter of transverse reinforcement	no no

Loads

BG1: Permanent load > F = 1100 kN

BG2: Variable load > F = 1000 kN

This means the column is loaded with a single compression force.

Combination according to the Eurocode: ULS Combination = 1,35 * BG1 + 1,50 * BG2Design normal force N_d = 1,35 * 1100 + 1,50 * 1000 = 2985 kN

Bar diameter

The bar diameter is taken from the Concrete Setup > Design defaults > Tab Columns, or from Member data if applied (member data always overwrite the Concrete Setup data, for the specific member they are assigned to).

Design defaults		
Concrete cover		
Use min concrete cover		
Design working life [years]	50	
Exposure class	XC3	-
Abrasion class	None	*
Type of concrete	In-situ concrete	*
Special geometric quality control	no 📃 no	
Type of concrete surface	Normal surface	*
Special concrete quality control	no 📃 no	
Columns		
Longitudinal reinforcement		
Diameter [mm]	20.0	
Stimups		
Diameter [mm]	8.0	

By default, the diameter for the main column reinforcement is put to 20 mm. Based on this diameter and the exposure class (by default XC3), the concrete cover is calculated. This information is necessary to be able to calculate the lever arm of the reinforcement bars.

Results

Go to Concrete menu > Member design - Design, ask the value for A_s for member B1, and click the action button [Refresh]. The value 0 appears on the screen, followed by warning 77.

Select now the option 'Print explanation of errors and warnings' in the Properties menu, and click the action [Preview]. The following screen will appear:

Design As EN 1992-1-1

Linear calculation, Extreme : Member Selection : B1 Combinations : ULS Main reinforcement for selected columns

Member	d _x [m]	Case	N _d [kN]	M _{yd} [kNm]	M _{zd} [kNm]	Calc. type	A _{s,req} [mm ²]	W/E
B1	0.000	ULS/1	-2985.00	0.00	0.00	N/A	0	77

Explanation of warnings and errors

77 The calculation of the main reinforcement is done and the theoretical reinforcement is zero.

No theoretical reinforcement is required.

<u>Remark:</u> this result is obtained only because **all of the detailing provisions are deselected** in the Concrete Setup!

Check of reinforcement $N_{Rd} = f_{cd} \cdot \alpha \cdot A_c$ $= 30 \cdot 0.85 \cdot 350^2 / 1000 = 3124 \text{ kN}$

Since N_{Rd} = 3124 kN > N_d = 2985 kN, indeed no theoretical reinforcement is required.

Reinforcement required: N_{Ed} > N_{Rd}

For this example the same configuration as above is used, only the permanent point load is increased to 2000 kN.

Loads BG1: Permanent load > F = 2000 kN BG2: Variable load > F = 1000 kN

Combination according to the Eurocode: ULS Combination = $1,35 \times BG1 + 1,50 \times BG2$ Design normal force N_d = $1,35 \times 2000 + 1,50 \times 1000 = 4200$ kN

Results

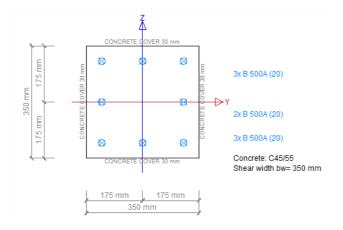
Remark that SCIA Engineer shows on the screen the reinforcement per direction. The total reinforcement area is in fact $750 + 750 = 1500 \text{ mm}^2$.

Design As EN 1992-1-1

Linear calculation, Extreme : Member Selection : B2 Combinations : ULS Main reinforcement for selected columns

Member	d _x [m]	Case	N _d [kN]	M _{yd} [kNm]	M _{zd} [kNm]	Calc. type	Ratio y/z [%]	A _{s,req} [mm²]	Reinf _{req}	Reinf _{tot}
B2	0.000	ULS/1	-4200.00	0.00	0.00	N/A	50/50	1500	8(6/6)x20.0	8x20.0(2513)

When going to Concrete menu > Member design - Design, the user has the choice for the action Single Check at the bottom of the Properties menu. There the proposed configuration can be found:

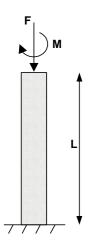


Explanation of the number of reinforcement bars

In the previous example, the configuration of required reinforcement bars was noted as 8(6/6), which stands for "6 bars in the y direction (3 bars per side //y), 6 bars in the z direction (3 bars per side //z)".

This is a simple representation of the bar configuration, so the user can easily understand how the bars should be inputted.

Uni-axial bending



For uni-axial bending, 2 types of calculation are supported: the (sum) and the (max) calculation.

Uni-axial bending calculation (sum)

Principle

The reinforcement is designed separately around both axes, and the final area of reinforcement is the sum of reinforcement for both directions:

- Asy is designed for forces N_{Ed} and M_{Ed,y}
- Asz is designed for forces N_{Ed} and M_{Ed,z}
- As = Asy+Asz

This calculation often gives uneconomic solutions for the reinforcement. This is the reason another calculation type has been implemented, uni-axial bending calculation (max), which may be used in most situations.

See paragraph Calculation methods: Overview – Automatic design, to understand how it is determined which calculation may be used.

Uni-axial bending calculation (max)

Principle

The reinforcement is designed only around the axis with the bigger bending moment:

- If $M_{Ed,v} > M_{Ed,z} \rightarrow As = Asy is designed for forces N_{Ed} and M_{Ed,v}$
- If $M_{Ed,z} > M_{Ed,y} \rightarrow As = Asz$ is designed for forces N_{Ed} and $M_{Ed,z}$

Example

Example: open the example 'Axial force - uni ax bending.esa'

Geometry Column cross-section: RECT 350x350mm² Height: 4,5 m Concrete grade: C45/55

Concrete Setup

Item General: Calculation > Tab Columns: 'Buckling data' are not taken into account (only 1st order moments are considered).

	Calculation	
Ŧ	General	
	Columns	
	Advanced setting	no
	Only comer design	no
	Determine governing cross-section beforehand	V yes
	Use buckling data	no
	Optimize the number of bars in c-s for biaxial calculation	V yes

Item Detailing provisions: not taken into account, to view the pure results.

la De	Detailing provisions				
🗄 C(ommon detailing provisions				
	olumns				
Ξ.	Setting of checks				
1	Min. percentage of longitudinal reinforcement	no			
1	Max. percentage of longitudinal reinforcement	no no			
1	Min. bar diameter of longitudinal reinforcement	no			
1	Max. bar distance of longitudinal reinforcement	no no			
1	Min. number of long.bars in circular column	no no			
1	Max. longitudinal spacing of transverse reinforcement	no			
1	Max. transverse spacing of tranverse reinforcement	no			
1	Min. bar diameter of transverse reinforcement	no no			

Loads

BG1: Permanent load > F = 500 kN; M_y = 100 kNm BG2: Variable load > F = 1000 kN; M_y = 100 kNm

Combination according to the Eurocode: ULS Combination = 1,35 * BG1 + 1,50 * BG2 Design normal force N_d = 1,35 * 500 + 1,50 * 1000 = 2175 kN Design moment M_{vd} = 1,35 * 100 + 1,50 * 100 = 285 kNm

Results

Go to Concrete menu > Member design - Design, ask the value for As, and click the action buttons [Refresh] and [Preview]. The numerical results of the calculation are as follows:

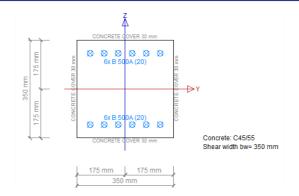
Design As EN 1992-1-1

Linear calculation, Extreme : Member Selection : B3 Combinations : ULS Main reinforcement for selected columns

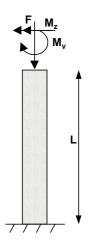
Member	d _x [m]	Case	N _d [kN]	M _{yd} [kNm]	M _{zd} [kNm]	Calc. type	Ratio y/z [%]	A _{s,req} [mm ²]	Reinf _{req}	Reinf _{tot}	W/E
B3	0.000	ULS/1	-2175.00	-285.00	0.00	Um	100/0	3160	12(12/4)x20.0	12x20.0(3770)	134

Remark the calculation type: Um (Uni-axial bending (max)). Remark that ratio y/z is 100/0: all of the reinforcement works in 1 direction.

When going to the Concrete menu > Member design - Design, the user has the choice for the action Single Check at the bottom of the Properties menu. There the proposed configuration can be found:



Bi-axial bending



Bi-axial bending (art 5.8.9)

To decide if a bi-axial bending calculation is required, the following conditions should be checked:

No further check is necessary if the slenderness ratios satisfy the following two conditions:

$$\lambda_{y}/\lambda_{z} \le 2 \text{ and } \lambda_{z}/\lambda_{y} \le 2 \tag{5.38a}$$

and if the relative eccentricities e_v/h and e_z/b satisfy one of the following conditions:

$$\frac{e_{y}/h_{eq}}{e_{z}/b_{eq}} \le 0.2 \text{ or } \frac{e_{z}/b_{eq}}{e_{y}/h_{eq}} \le 0.2$$
(5.38b)

where:

b, h are the width and depth of the section

b, if the decide which and depth of the section $b_{eq} = i_y \sqrt{12}$ and $h_{eq} = i_z \sqrt{12}$ for an equivalent rectangular section λ_y , λ_z are the slenderness ratios l_0/i with respect to y- and z-axis respectively i_y , i_z are the radii of gyration with respect to y- and z-axis respectively $e_z = M_{Edy} / N_{Ed}$; eccentricity along z-axis $e_y = M_{Edz} / N_{Ed}$; eccentricity along y-axis M_{Edy} is the design moment about y-axis, including second order moment (if required) M_{Edz} is the design moment about z-axis, including second order moment (if required) N_{Ed} is the design value of axial load in the respective load combination

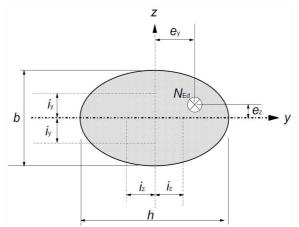


Figure 5.8. Definition of eccentricities ey and ez.

If the conditions of expression (5.38a) and (5.38b) are **NOT** fulfilled, bi-axial bending should be taken into account including the 2nd order effects in each direction (unless they may be ignored). In the absence of an accurate cross-section design for bi-axial bending, the following simplified criterion may be used:

$$\left(\frac{M_{Edz}}{M_{Rdz}}\right)^a + \left(\frac{M_{Edy}}{M_{Rdy}}\right)^a \le 1,0$$
(5.39)

where:

 $N_{\rm Ed}$

is the design moment around the respective axis, including a 2nd order moment (if required) M_{Edz/y} is the moment resistance in the respective direction $M_{\rm Rdz/y}$ is the exponent; Α

for circular and elliptical cross sections: a = 2 for rectangular cross sections:

$N_{\rm Ed}/N_{\rm Rd}$	0,1	0,7	1,0	
a =	1,0	1,5	2,0	

with linear interpolation for intermediate values

is the design value of axial force

= $A_c f_{cd}$ + $A_s f_{yd}$, the design axial resistance of the section $N_{\rm Rd}$ where:

 $A_{\rm c}$ is the gross area of the concrete section

A_s is the area of longitudinal reinforcement

The criterion described by Expression 5.39 - which is known as the interaction formula - is also implemented in SCIA Engineer as basis for the bi-axial bending calculation. Only the notation 'a' for the exponent (= safety factor) of the interaction formula has been replaced by an 'x'.

See Concrete Setup > General: Calculation > Tab Columns:

	Concrete setup		
Standard EN	Name	Standard EN	
Concrete General Calculation General Columns Beams	Concrete General Calculation General Columns		
🖻 - ULS	Advanced setting	V yes	
Interaction diagram Shear To structures Construction joint Co	Only comer design Determine governing cross-section beforehand Use buckling data Optimize the number of bars in c-s for biaxial calculation User estimate of reinf, ratio for design of reinforcement [%] Take into account eccentricity according to chapter 6.1.4 Calculation Method Type of calculation method Biaxial bending ratio for automatic determination [%] Design reinforcement using (biaxial and only corner design Area of reinforcement type	Real area of reinforcement bar	
⊢ Allowable stress	Delta area of reinforcement [mm^2]	10	
Calculation Detailing provisions Common detailing provisions Columns	Bi-axial bending Input type x = [-]	Automatic 1.40	
- Beams	Ratio y/z		
⊡- Fire resistance General Columns	Ratio type Ratio y/z [-]	Automatic 0.50	*
Beams	Limit stress ratio y/z [-]	4.00	

By default the safety factor is calculated automatically by SCIA Engineer, according to the requirements of the Eurocode mentioned in the previous paragraph.

Also, the notation for M_{Rdy} and M_{Rdz} has been replaced by M_{uy} and M_{uz} in SCIA Engineer. These are the ultimate moments, the moments that can be carried by the concrete + the present reinforcement bars.

Iteration process for bi-axial bending calculation

The increment routine for the number of bars, as implemented in SCIA Engineer, is as follows:

Start situation:

One reinforcement bar in each corner.

The diameter of the reinforcement bars is taken from the Concrete Setup, or from Member data.

Check of interaction formula:

SCIA Engineer determines the values for M_{yu} and M_{zu} for the present reinforcement layout, and calculates the interaction formula.

If the value is less than 1, the calculation is stopped.

```
Increment step 1:
```

For the 'weakest' direction, 1 bar per side is added.

Check of interaction formula:

SCIA Engineer determines the new values for M_{yu} and M_{zu} and recalculates the interaction formula.

If the value is less than 1, the calculation is stopped.

Calculation of moment ratios:

For each one of the design moments (M_{yd} and M_{zd}), SCIA Engineer determines the normal stress in the exterior fibre by dividing the design moment by the resistance moment W for that direction. This means that $\sigma_y = M_{yd} / W_y$ and $\sigma_z = M_{zd} / W_z$.

Based on these σ 's, the ratio of the moments can be determined per direction: $r_y = \sigma_y / (\sigma_z + \sigma_y)$ and $r_z = \sigma_z / (\sigma_z + \sigma_y)$ Increment step 2 to ...:

According to the values for r_v and r_z the reinforcement is now increased per direction:

- For the 'strongest' direction, 1 bar per side is added.
- For the 'weakest' direction, the new number of bars in the 'strongest' direction (n) is taken and multiplied by 1/r. The value of n*1/r is rounded off to integer even values.

Check of interaction formula – after each increment step:

SCIA Engineer determines the new values for M_{vu} and M_{zu} and recalculates the interaction formula.

If the value is less than 1, the calculation is stopped. If this is not the case, increment step 2 is repeated until the interaction check does satisfy.

Iteration process – Example

The iteration process used by SCIA Engineer can be simulated by means of an example where each time the values for the loads are increased.

Remark that the ratio between the design moments stays the same while the values are increased.

Example: open the example 'Bi axial bending.esa'

Geometry Column cross-section: RECT 350x350mm² Height: 4,5 m Concrete grade: C25/30 Elastic resistance moments: $W_v = 1/6 \cdot 350^3 = 7,15 \cdot 10^6 \text{ [mm}^3\text{]} = W_z$

Concrete Setup

Item General: Calculation > Tab Columns: 'Buckling data' are not taken into account (only 1st order moments are considered).

Item General: Calculation > Tab Columns: 'Optimize the number of bars in cross-section for bi-axial calculation' is deselected.

□ Calculation	
General	
Columns	
Advanced setting	🔲 no
Only comer design	🔲 no
Determine governing cross-section beforehand	V yes
Use buckling data	🔲 no
Optimize the number of bars in c-s for biaxial calculation	🔲 no

Item Detailing provisions: All of the provisions are deselected (to have a look at the pure results).

Detailing provisions	
Common detailing provisions Columns	
Setting of checks	
Min. percentage of longitudinal reinforcement	no 📰
Max. percentage of longitudinal reinforcement	no
Min. bar diameter of longitudinal reinforcement	no
Max. bar distance of longitudinal reinforcement	no
Min. number of long bars in circular column	no
Max. longitudinal spacing of transverse reinforcement	no
Max. transverse spacing of tranverse reinforcement	no
Min. bar diameter of transverse reinforcement	in no

Loads Final load configuration: $N_d = 1050,00 \text{ kN}$

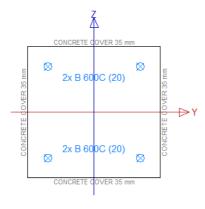
$$M_{yd} = 128,45 \text{ kNm}$$

 $M_{zd} = 216,25 \text{ kNm}$

Start situation:

The start situation is always one reinforcement bar per corner. The bar diameter is taken from the Concrete Setup, or from Member data (if applied).

Simulation: Column B1



 N_d = 1050,00 kN M_{yd} = 51,23 kNm M_{zd} = 86,25 kNm

Reinforcement configuration: (4/4) – This configuration can be found when going to Concrete menu > Member design - Design, and choose the action Single Check for column B1 at the bottom of the Properties menu.

Check of interaction formula: M_{yu} = M_{zu} = 148,4 kNm

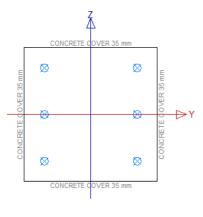
These values can be found when going to Concrete menu > Member design - Design, and choose the action Single Check for column B1 at the bottom of the Properties menu. On the tabs 'Vertical section $M_{y'}$ (where $M_{dz} = 0$ kNm) & 'Vertical section $M_{z'}$ (where $M_{dy} = 0$ kNm), these specific sections from the interaction diagram are shown and the ultimate values M_{yu} and M_{zu} are indicated to it.

Interaction formula: $(128,45/148,4)^{1,4} + (216,25/148,4)^{1,4} = 2,51 > 1$

Increment step 1:

For the 'weakest' direction, // z, 1 bar per side is added.

Simulation: Column B2



 $N_d = 1050,0 \text{ kN}$

M_{yd} = 63,11 kNm $M_{zd} = 106,25 \text{ kNm}$

Reinforcement configuration: (4/6)

Check of interaction formula: $M_{yu} = 150,3 \text{ kNm}$ $M_{zu} = 182,9 \text{ kNm}$

Interaction formula: $(128,45/150,3)^{1,4} + (216,25/182,9)^{1,4} = 2,07 > 1$

Calculation of moment ratios:

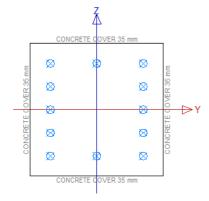
 $r_y = 128,45 / 344,70 = 0,37$ and $r_z = 216,25 / 344,70 = 0,63$

The values for M_{dy} and M_{dz} are taken from the final load configuration.

Increment step 2 - 3 - 4:

For the 'strongest' direction, // y, 1 bar per side is added.
For the 'weakest' direction, the new number of bars in the 'strongest' direction (n) is taken and multiplied by $1/r_z$ (= 1/0,63 = 1,59). The value of n^*1/r_z is rounded off to integer even values.

Simulation: Column B3

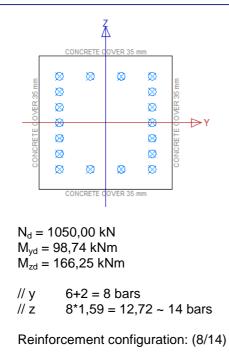


 $N_{d} = 1050,00 \text{ kN}$ $M_{vd} = 86,86 \text{ kNm}$ $M_{zd} = 146,25 \text{ kNm}$

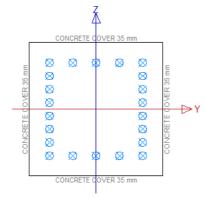
// y 4+2 = 6 bars // z 6*1,59 = 9,54 ~ 10 bars

Reinforcement configuration: (6/10)

Simulation: Column B4



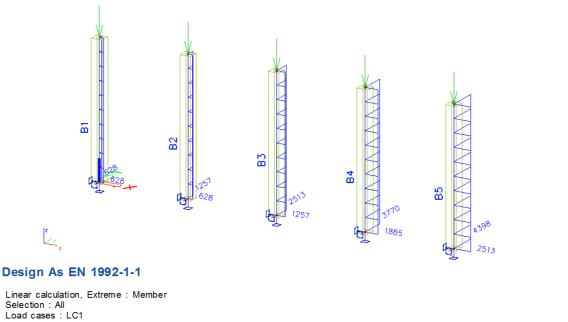
Simulation: Column B5



// y 8+2 = 10 bars // z 10*1,59 = 15,90 ~ 16 bars

Reinforcement configuration: (10/16)

The detailed results can be found in the Concrete menu > Member design - Design section, when you ask the value for As,total req and open the action Preview at the bottom of the Properties menu:



Main reinforcement for selected columns

Member	d _x [m]	Case	N _d [kN]	M _{yd} [k Nm]	M _{zd} [k Nm]	Calc. type	Interaction check [%]	Ratio y/z [%]	A _{s,req} [mm²]	Reinf _{req}	Reinf _{tot}
B1	0.000	LC1	-1050.00	-51.23	-86.25	В	81 < 100	50/50	1257	4(4/4)x20.0	4x20.0(1257)
B2	0.000	LC1	-1050.00	-63.11	-106.25	в	89 < 100	33/67	1885	6(4/6)x20.0	6x20.0(1885)
B3	0.000	LC1	-1050.00	-86.86	-146.25	в	88 < 100	33/67	3770	12(6/10)x20.0	12x20.0(3770)
B4	0.000	LC1	-1050.00	-98.74	-166.25	В	75 < 100	33/67	5655	18(8/14)x20.0	18x20.0(5655)
B5	0.000	LC1	-1050.00	-128.45	-216.25	В	86 < 100	36/64	6912	22(10/16)x20.0	22x20.0(6912)

For the final load configuration, represented by column B5, the interaction check is 86% < 100%. As the requirement for the interaction check is met, the iteration process is stopped and the solution for the reinforcement configuration is (10/16).

Optimization

There might be a more optimal solution, with an interaction check even closer to 100%. A specific option has been implemented to make SCIA Engineer look for such a solution:

Go to Concrete Setup > General: Calculation > Tab Columns and activate the option 'Optimize the number of bars in cross-section for bi-axial calculation':

Concrete setup							
Standard EN Concrete General Calculation Columns	^	Name Concrete General Calculation General	Standard EN				
→ Beams → Interaction diagram → Shear → 1D structures → Construction joint → Details		Columns Advanced setting Only comer design Determine governing cross-section beforehand Use buckling data Optimize the number of bars in c-s for biaxial calculation	no no Vyes no Vyes				

Return now to Member design - Design, and open the Preview again:

Design As EN 1992-1-1

Linear calculation, Extreme : Member Selection : B5 Load cases : LC1 Main reinforcement for selected columns Reinf_{req} M_{yd} [kNm] M_{zd} [kNm] A_{s,reg} [mm²] Reinf_{tot} Member d Case N, Calc. Interaction Ratio [kN] y/z [%] [m] type check [%] B5 0.000 LC1 -1050.00 -128.45 -216.25 B 94 < 100 40/60 6283 20(10/14)x20.0 20x20.0(6283)

We can conclude that indeed a more optimal solution is found, where the reinforcement configuration is only (10/14) instead of (10/16), and the interaction check is now 94% instead of 86%.

Calculation methods: Overview – Automatic design

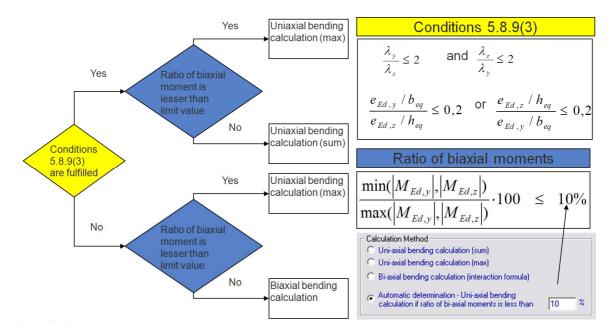
Concrete Setup > General: Calculation > Tab Column:

After selecting the option 'Advanced setting', the option Calculation Method becomes available. The user can enforce now 1 of the 3 calculation methods, if desired. By default the option is put to 'Automatic determination'. In that case, SCIA Engineer automatically determines which type of calculation fits best for each column in the structure:

	Concrete setup	
- Standard EN	 ▲ Calculation ★ General ■ Columns 	
General Columns Beams ULS Interaction diagram	Advanced setting Only comer design Determine governing cross-section beforehand Use buckling data	V yes no V yes no
G Shear G Shear Construction joint G Details	Optimize the number of bars in c-s for biaxial calculation User estimate of reinf. ratio for design of reinforcement [%] Take into account eccentricity according to chapter 6.1.4 Calculation Method	Im no 2 I ves
Anchorage check Bearing checks Fire resistance SLS Cracking forces	Type of calculation method Biaxial bending ratio for automatic determination [½] Design reinforcement using (biaxial and only corner design) Area of reinforcement type	Automatic determination Uni-axial bending calculation (sum) Uni-axial bending calculation (max) Bi-axial bending calculation (interaction formula) Automatic determination

- First is checked if the conditions according to EC art 5.8.9(3) are fulfilled.
- Secondly, a ratio check of the bending moments in the different directions is carried out. The check value of 10% forms (by default) the boundary between uni-axial and bi-axial bending calculation.

The Automatic determination in SCIA Engineer can be summarized in a flow chart as follows:



Circular columns

SCIA Engineer is able to calculate reinforcement not only for rectangular but also for circular columns. The calculation method for circular columns is the simplest one, because the required number of reinforcement bars is spread equally along the face of the column.

Example

Example: open the example 'Circular column.esa'

Geometry Column cross-section: CIRC diameter 400mm Height: 4,5 m Concrete grade: C45/55

Concrete Setup

Item General: Calculation > Tab Columns: 'Buckling data' are not taken into account (only 1st order moments are considered).

Concrete setup							
Standard EN	Name Concrete General Calculation General Columns	Standard EN					
	Advanced setting Only comer design Determine governing cross-section beforehand Use buckling data	no no Vyes no					

Loads

Load	configuration:
------	----------------

 $N_d = 2175,00 \text{ kN}$ $M_{yd} = 142,50 \text{ kNm}$ $M_{zd} = 0 \text{ kNm}$

Results

Go to Concrete menu > Member design - Design, and open the action Preview at the bottom of the Properties menu:

Design As EN 1992-1-1

Linear calculation, Extreme : Member Selection : All Class : Alle UGT Main reinforcement for selected columns

Member	d _x [m]	Case	N _d [kN]	M _{yd} [kNm]	M _{zd} [kNm]	Calc. type	A _{s,reg} [mm ²]	Reinf _{req}	Reinf _{tot}
B1	0.000	CO1/1	-2175	-143	0	С	1571	5x20.0	5x20.0(1571)

Calculation type = C (Circular column)

As, req = 1571 mm², which equals exactly 5 bars of \emptyset 20mm (5*314mm²).

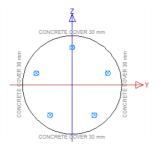
The bar diameter is taken from the Concrete Setup > Design defaults > Tab Columns, or from Member data if applied. The bar diameter is set to 20mm in the concrete setup.

Remark that SCIA Engineer uses the real area of the bars to calculate the required reinforcement area.

The minimum number of bars in a circular column is also taken from the Concrete Setup > Detailing provisions. This is '4' by default, according to EC art 9.5.2(4).

Concrete setup						
Standard EN	^	Vame		Standard EN		
🖻 Concrete		Concrete				
🚍 General		General				
⊟ Calculation		ULS				
General		SLS				
Columns						
l Beams ⊟ ULS		Allowable stress				
Interaction diagram		Detailing provisions				
- Interaction diagram		Common detailing provision	IS			
1D structures		Columns				
- Construction joint		Setting of checks				
⊡- Details		Min. percentage of longitudinal	reinforcement	V yes		
Anchorage check		Max. percentage of longitudinal	l reinforcement	V yes		
Bearing checks		Min. bar diameter of longitudina	l reinforcement	V yes		
Fire resistance		Max. bar distance of longitudina	al reinforcement	🚺 yes		
⊡- SLS		Min. number of long.bars in circ	ular column	V yes		
- Creep		Max. longitudinal spacing of tra	nsverse reinforcement	V yes		
Crack proof		Max, transverse spacing of tran	verse reinforcement	V yes		
Code Dependent Deflections		Min, bar diameter of transverse	reinforcement	ves		
Allowable stress		Longitudinal reinforcement	t .			
Calculation		Max, bar distance 9.2.3(4) [m]		0.35		
Detailing provisions		Min. number of bars in circular of	column 9 5 2(4) [-]	4.00		
Common detailing provisions Columns		Transverse reinforcement		1.00		
Beams				0.75		
Eire resistance		Max. transverse spacing of the				
General		Max. transverse spacing of the		0.600		
Columns		Min. bar diameter of transverse	reinforcement [mm,-]	6.0 / 0.25		

When going to Concrete menu > Member design - Design > action Single Check, the proposed configuration can be found:



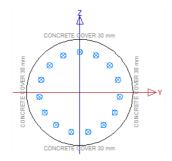
When the value for the variable point load is increased to 1250 kN, and for the variable moment to 100 kNm (so that N_d = 2550,00 kN; M_{yd} = 217,50 kNm; M_{zd} = 0 kNm), the results are as follows:

Design As EN 1992-1-1

Linear calculation, Extreme : Member Selection : All Class : Alle UGT Main reinforcement for selected columns

Member	d _x [m]	Case	N _d [kN]	M _{yd} [kNm]	M _{zd} [kNm]	Calc. type	A _{s,reg} [mm ²]	Reinf _{req}	Reinf _{tot}
B1	0.000	CO1/1	-2550	-218	0	С	4712	15x20.0	15x20.0(4712)

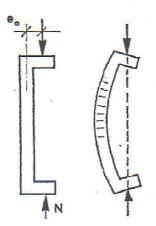
The corresponding bar configuration is the following:



2nd order calculation

2nd order effects:

- Caused by structural deformations
- Important for walls, columns, piles, ...



Eurocode

According to the Eurocode, 2nd order effects have to be taken into account in each direction, unless they may be ignored according to *art 5.8.2 (6)* or *art 5.8.3*.

General (art 5.8.2 (6))

Second order effects may be ignored if they are less than 10 % of the corresponding first order effects.

Simplified criteria for second order effects (art 5.8.3)

Slenderness criterion for isolated members (art 5.8.3.1)

As an alternative to 5.8.2 (6), second order effects may be ignored if the slenderness λ is below a certain value λ_{lim} .

The recommended value for λ_{lim} follows from:

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

where:

А = 1 / (1+0,2 φ_{ef}) (if φ_{ef} is not known, A = 0,7 may be used) В $=\sqrt{1+2\omega}$ (if ω is not known, B = 1,1 may be used) = $1,7 - r_m$ (if r_m is not known, C = 0,7 may be used) С effective creep ratio; see 5.8.4; ϕ_{ef} = $A_s f_{yd} / (A_c f_{cd})$; mechanical reinforcement ratio; (1) is the total area of longitudinal reinforcement As = N_{Ed} / ($A_c f_{cd}$); relative normal force n $= M_{01}/M_{02}$; moment ratio ľm M_{01}, M_{02} are the first order end moments, $|M_{02}| \ge |M_{01}|$

In cases with biaxial bending, the slenderness criterion may be checked separately for each direction. Depending on the outcome of this check, second order effects (a) may be ignored in both directions, (b) should be taken into account in one direction, or (c) should be taken into account in both directions.

Slenderness and effective length of isolated members (art 5.8.3.2)

The slenderness ratio λ is defined as follows:

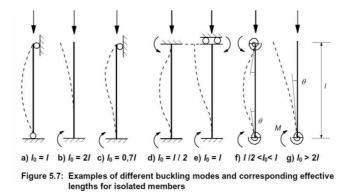
$$\lambda = l_0 / i \tag{5.14}$$

where:

i

- I₀ is the effective length
 - is the radius of gyration of the uncracked concrete section

Examples of effective length for isolated members with constant cross section are given:



Geometric imperfections (art 5.2)

The effect of geometric imperfections always has to be taken into account: both in a 1st and 2nd order calculation.

For isolated members, the effect of imperfections may be taken into account in two alternative ways:

a) as an eccentricity, *e_i*, given by:

$$\mathbf{e}_i = \theta_i \, l_0 \, / \, 2$$

where I_0 is the effective length.

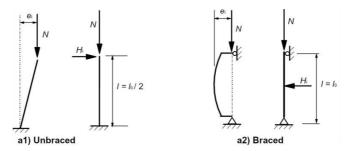
For walls and isolated columns in braced systems, $e_i = I_0/400$ may always be used as a simplification, corresponding to $\alpha_h = 1$.

b) as a transverse force, H_{i} , in the position that gives the maximum moment:

-	for unbraced members:	
	$H_{i} = \theta_{i} N$	(5.3a)
-	for braced members:	

$$H_i = 2 \theta_i N$$

where N is the axial load.



(5.2)

(5.3b)

According to EC art 5.8.9 (2), imperfections need to be taken into account only in the direction where they will have the most unfavourable effect.

Method based on nominal curvature (art 5.8.8)

Several methods are described by the Eurocode to take into account 2nd order effects. The one implemented in SCIA Engineer is the method based on the nominal curvature.

In fact this is an approximation of a genuine 2nd order calculation: only 1st order moments are calculated, and then increased by 2nd order moments which are calculated based on the 1st order internal forces.

General (art 5.8.8.1)

This method is primarily suitable for isolated members with constant normal force and a defined effective length l_0 . The method gives a nominal 2^{nd} order moment based on a deflection, which in turn is based on the effective length and an estimated maximum curvature.

The resulting design moment is used for the design of cross sections with respect to bending moments and axial force.

Bending moments (art 5.8.8.2)

The design moment is:

$$M_{\rm Ed} = M_{\rm 0Ed} + M_2 \tag{5.31}$$

where:

 M_{0Ed} is the 1st order moment, including the effect of imperfections, see (1) M_2 is the nominal 2nd order moment, see (2)

The maximum value of M_{Ed} is given by the distributions of M_{0Ed} and M_2 ; the latter may be taken as parabolic or sinusoidal over the effective length.

(1) Differing first order end moments M_{01} and M_{02} may be replaced by an equivalent first order end moment M_{0e} :

$$M_{0e} = 0.6 \ M_{02} + 0.4 \ M_{01} \ge 0.4 \ M_{02} \tag{5.32}$$

 M_{01} and M_{02} should have the same sign if they give tension on the same side, otherwise opposite signs. Furthermore, $|M_{02}| \ge |M_{01}|$.

(2) The nominal second order moment M_2 is:

$$M_2 = N_{Ed} * e_2 \tag{5.33}$$

where:

- N_{Ed} is the design value of axial force
- e_2 is the deflection = (1/r) I_0^2/c
- 1/r is the curvature
- I_o is the effective length
- c is a factor depending on the curvature distribution

For constant cross section, $c = 10 \ (\approx \pi^2)$ is normally used. If the first order moment is constant, a lower value should be considered (8 is a lower limit, corresponding to constant total moment).

Curvature (art 5.8.8.3)

The curvature 1/r can be calculated as follows for members with constant symmetrical cross sections (incl. reinforcement):

$$1/r = K_r K_{\omega} 1/r_0$$
(5.34)

where:

K_r is a correction factor depending on axial load

 K_{ϕ} is a factor for taking account of creep

 $1/r_0 = \epsilon_{yd} / (0,45 d)$

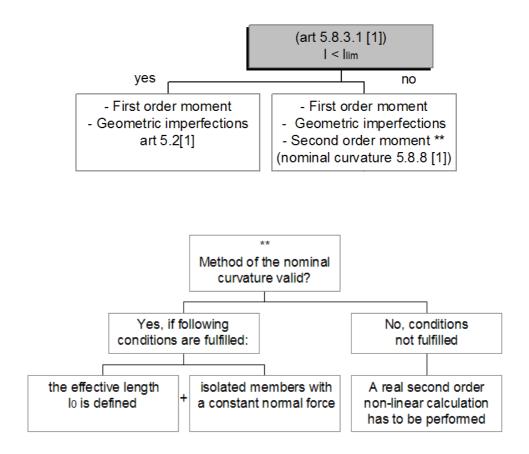
 $\varepsilon_{yd} = f_{yd} / E_s$

d is the effective depth

Overview

All of this can be summarized as follows:

- 1) Check if $\lambda < \lambda_{\text{lim}}$.
- If 2nd order effects have to be taken into account: Check if the method based on the nominal curvature is valid, so a nominal 2nd order calculation can be carried out. If not, a real non-linear 2nd order calculation has to be performed.



SCIA Engineer

Slenderness

If $\lambda > \lambda_{lim}$, 2nd order effects have to be taken into account. The values for λ and λ_{lim} , and the corresponding check, can be found in the Concrete menu > Concrete slenderness.

Concrete 🛛 🕂 🗙		
	Name	Standard EN
E Design defaults	Concrete	
	Design defaults	
E 1D member	General	
Member buckling data		
Member data	General	
Concrete slenderness	□ EN_1992_2	
⊕ 🖞 Redes (without As)	theta_0=1/x - basic value of inclination 5.2(105)	
🗄 🚡 Automatic member reinforcement d	Value [-]	200.00
	theta_0=1/x - basic value of inclination 5.2(5)	
Internal forces	Value I-1	200.00
Member design - Design	Iambda_lim 5.8.3.1(1)	
H Member check	Formula	Formula
SaT_Details	Type of simplified method for analysis second order effect	
New free bars - New free bar	Formula	Method based on nominal curvature (5.8.8)
E New nee bars - New nee bar		

Buckling data

In the Concrete Setup > General: Calculation > Tab columns, the option 'Use buckling data' can be found. By default this option is activated:

Concrete setup							
Standard EN	^	Name Concrete General Calculation	Standard EN				
<mark>Columns</mark> Beams 2D structures		General Columns Advanced setting] no				
⊡ ULS Interaction diagram ⊡ Shear 1D structures		Only comer design Determine governing cross-section beforehand Use buckling data	no no V yes				
- 2D structures		Optimize the number of bars in c-s for biaxial calculation	V yes				

It is important to know that:

- When this option is not activated, only the 1st order bending moments are taken into account.
- When this option is activated, also the moments caused by geometrical imperfections and the nominal 2nd order moments are taken into account. This means the eccentricities e_i and e₂ have to be calculated supplementary, and in this way the problem of buckling is also taken care of (e₂ depends of the buckling length I₀):

$$e_1 = \frac{M_d}{N_d}$$
$$e_i = \frac{\theta_i \cdot l_0}{2}$$
$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

(Where M_d, N_d are the values from 1st order calculation.)

Note that if no second order moment is required according to art 5.8.3.1, only the moment caused by geometrical imperfections is taken into account and not the second order moment.

Effective length

The effective length (= buckling length) is calculated by default by SCIA Engineer. <u>Attention:</u> this is only valid for simple structures!

In Concrete Setup > Design defaults, can be found that for buckling around the local y axis (Y-Y) and for buckling around the local z axis (Z-Z), the structure is by default considered as 'sway':

Concrete setup							
Concrete Design defaults Concrete cover Columns Beams 20 structures and beam slabs Punching Default sway type (for columns and Concrete Non-prestressed reinforcement	Name Concrete Design defaults Concrete cover Columns Beams 2D structures and beam slabs Punching Default sway type (for columns and beams only)	Standard EN					
Prestressed reinforcement	y-y	V yes					
Durability and concrete cover	2-2	V yes					

Of course, the user can assign specific buckling data to each member separately. To do so, select a member and click in the Properties menu on the [...] button behind 'Buckling and relative lengths'. Here you can choose to input your own buckling factor (beta) or length (I).

Properties	џ
Member (1)	🔁 Va V/ 🖉
	8 1
Name	B1
Туре	column (100) 🔹
Analysis model	Standard 🔹
CrossSection	CS1 - RECT (350; 3 💌
Alpha [deg]	0.00
Member system-line at	centre 🔹
ey [mm]	0
ez [mm]	0
LCS	standard 🔹
LCS Rotation [deg]	0.00
FEM type	standard 🗸 🗸
Buckling and relative lengths	Default 🔹
Layer	Layer1

The effective length based on these buckling data is required to calculate e_2 and the corresponding moment M_2 .

Recalculated internal forces

In the Concrete menu > Internal forces, the following results can be asked for:

- The values for Mx, My, Mz, which are the 1st order design moments.
- The values for Mx,recalc, My,recalc, Mz,recalc, which are the recalculated design moments where the moments caused by geometrical imperfections and the nominal 2^{nd} order moments are taken into account ($M_{Ed} = M_{0Ed} + M_2$).

Reinforcement design

In the Concrete menu > Member design - Design, the values for As,req are calculated based on the recalculated design values of the internal forces (My,recalc and Mz,recalc).

Example

Example: open the example '2nd order.esa'

Geometry Column cross-section: RECT 350x350mm² Height: 4,5 m Concrete grade: C45/55

Concrete Setup All of the default values are kept.

Loads Load configuration: $N_d = 405,00 \text{ kN}$ $M_{yd} = 40,50 \text{ kNm}$ $M_{zd} = 0 \text{ kNm}$

Buckling data

Note that the option 'buckling data' is by default activated. This means that for reinforcement design automatically the geometrical imperfections are taken into account.

Since geometrical imperfections are taken into account, no extra buckling check is required.

The calculation of geometrical imperfections is based on the buckling length I₀.

To view or edit the basic settings for calculation of buckling length I_0 , the user can access the buckling properties of a member through the Properties > Buckling and relative lengths:

Properties			×	Buckling dat	a 🧕
Member (1)	I 🖬 🖸	7	0	1 🤮 🖌 🖬 🗼 🗠 😂 💕	Number of parts - 1
		8	4	Name	BC1
Name	B1		^	Number of parts	1
Туре	column (100)	+		Member(s) material	Concrete
Analysis model	Standard	*			
CrossSection	CS1 - RECT (350; 35	÷:			
Alpha [deg]	0.00				
Member system-line at	centre	*			
ey [mm]	0			УУ	ZZ
ez [mm]	0				
LCS	standard	÷			
LCS Rotation [deg]	0.00			5 8 18	•
FEM type	standard	*			
Buckling and relative lengths	BC1	÷			
Layer	Layer1		~		
Actions				1 K	
Buckling data		>>	>		
Buckling coefficient		>>	>		
Graphical input of system length	1.	>>	>		
Table edit geometry		>>	>	New Insert Edit Delete	Close

Slenderness criterion

Check if second order calculation is required following art 5.8.3.1:

Concrete slenderness

Concrete s Linear calc Selection : Load cases	ulation, Extrem All	me : No									
Member	CS Name	Part	Sway _y	l _y [m]	β _γ [-]	l _{o,y} [m]	i _y [mm]	λ _y [-]	λ _{iim,y} [-]	Check _{calc} [-]	Check
			Sway _z	l _z [m]	β _z [-]	l _{o,z} [m]	i _z [mm]	λ _z [-]	λ _{lim,z} [-]	Check _{lim} [-]	
B1	CS1	1	Yes	4.500	2.00	9.011	101	89.18	46.55	1.92	Not OK
			Yes	4.500	2.00	9.011	101	89.18	46.55	1.00	

Since λ is greater than λ_{lim} , a second order calculation will be required.

Note that the program automatically takes into account a second order moment if required. So this check is just extra information for the user.

Internal forces Basic:

Internal forces

Member	d _x [m]	Case	N [kN]	M _y [kNm]	M _z [kNm]	N _{rec} [kN]	M _{y rec} [kNm]	M _{z rec} [kNm]
B1	0.000	ULS/1	-405.00	-40.50	0.00	-405.00	-114.85	8.60

Recalculated internal forces taking into account geometrical and second order imperfection (both are automatically calculated based on I_0 if of course the option 'buckling data' is not manually de-activated):

Results of recalculated bending moment My,recal

Member	d _x [m]	Case	Type of check	N [kN]	M _y [kNm]	M _{y,recal} [kNm]	M _{0Ed,y} [kNm]	M _{2,y} [kNm]	e _{tot,z} [mm]	e _{0,z} [mm]	e _{2,z} [mm]	e _{i,z} [mm]
B1	0.000	ULS/1	Design ULS	-405.00	-40.50	-114.85	-49.10	-65.75	-284	-121	-162	-21

Results of recalculated bending moment Mz,recal

Member	d _x [m]	Case	Type of check	N [kN]	M _z [kNm]	M _{z, recal} [kNm]	M _{0Ed,z} [kNm]	e _{tot,y} [mm]	e _{0,y} [mm]	e _{i,y} [mm]
B1	0.000	ULS/1	Design ULS	-405.00	0.00	8.60	8.60	21	21	21

Results

The results for the reinforcement design are shown below:

Main reinforcement for selected columns

Member	d _x [m]	Case	N _d [kN]	M _{yd} [kNm]	M _{zd} [kNm]	Calc. type	Ratio y/z [%]	A _{s,reg} [mm ²]	Reinf _{req}	Reinf _{tot}	W/E
B1	0.000	ULS/1	-405.00	114.85	8.60	Um	100/0	918	4(4/4)x20.0	4x20.0(1257)	270

Note that uniaxial bending (max) is the calculation type because the ratio of biaxial moment is lesser than the limit value of 10%.

Concrete Setup: Overview

Concrete Setup > General: Calculation > Tab Columns:

Columns	
Advanced setting	I yes
Only comer design	no
Determine governing cross-section beforehand	Basic setting
Use buckling data	V yes
Optimize the number of bars in c-s for biaxial calculation	V yes
User estimate of reinf. ratio for design of reinforcement [%]	2
Take into account eccentricity according to chapter 6.1.4	V yes
Calculation Method	
Type of calculation method	Automatic determination
Biaxial bending ratio for automatic determination [%]	10
Design reinforcement using (biaxial and only corner design)	
Area of reinforcement type	Real area of reinforcement bar Advanced settin
Delta area of reinforcement [mm^2]	10
Bi-axial bending	
Input type	Automatic 🔹
x = [·]	1.40
□ Ratio y/z	
Ratio type	Automatic 👻
Ratio y/z [-]	0.50
Limit stress ratio y/z [-]	4.00

Basic Settings

Only corner design

This is a special type of calculation, where the reinforcement is designed only in the corners of the cross-section with an internal angle of 90°. It is an iterative calculation, where the number of bars stays the same, but the diameter or area of reinforcement is increased until the configuration satisfies the ULS checks.

The way of increasing the diameter depends on the setting of the option 'Design reinforcement by using real area / delta area' (discussed further in this paragraph):

The position of the corner bars is calculated in both cases from parameters (such as concrete cover) defined in the Concrete Setup or in the Member data, and the position is not changed during the iteration calculation.

Only the basic concrete sections are supported for this calculation (see Libraries > Cross-sections > group Concrete: rectangular, I -, T-, L-sections). The number of bars depends on the shape of the cross-section:

Section	Rectangular section	I section	T section	L section with lower flange	L section with upper flange	
ns	4	8	6	5	5	
Shape	0 0		6 0 6 0	6 0 6 6		

Determine governing cross-section beforehand

When this option is on, the design of the reinforcement is only carried out in the foot and head of the column. When this option is off, the design is carried out in all intermediate sections as well, which may be time consuming and brings no profit in terms of accuracy.

The subsequent check of the designed reinforcement is in both cases performed in all sections.

<u>Remark</u>: the option 'Determine governing cross-section beforehand' is not taken into account in the action Single Check!

Use buckling data

When this option is off, only the 1st order bending moments are taken into account. When this option is on, also the moments caused by geometrical imperfections and the nominal 2^{nd} order moments are taken into account. This means the eccentricities e_i and e_2 have to be calculated supplementary, and in this way the problem of buckling is also taken care of (e_2 depends of the buckling length I_0).

In fact it is an approximation (described by the Eurocode) of a genuine 2nd order calculation: only 1st order moments are calculated, and then increased by 2nd order moments which are calculated based on the 1st order moments.

Optimize the number of bars in cross-section for biaxial calculation

If this option is on, the number of bars in the cross-section is optimised to achieve the minimum number of bars with the cross-section still passing the ULS checks.

This option only has influence on the reinforcement of members where a bi-axial calculation is performed. In fact, SCIA Engineer looks for the solution where the value for the interaction formula is as close to 1 as possible.

Advanced Settings

These are only available when the option 'Advanced setting' is selected.

User estimate of reinforcement ratio for design of reinforcement [%]

This estimated value for the reinforcement ratio is used to calculate the nominal curvature 1/r according to *EC art 5.8.8.3*, where the value for As has to be filled in. The value for As is then taken as the 'reinforcement ratio * Ac'. Since the nominal curvature is only needed for the calculation of second order effects, this ratio is only calculated for members with "Buckling data" on.

The default value for the ratio is 2%. If the "percentage of additional (required) reinforcement is less than 80% of user estimate ratio", then SCIA Engineer gives warning 270. If the "percentage of additional (required) reinforcement is greater than 120% of user estimate ratio", then SCIA Engineer gives warning 271.

Take into account eccentricity according to chapter 6.1.4

If this option is on, the first order eccentricity including imperfections (e_0) in both directions has to be the maximum of (h/30; 20 mm), where h is the depth of the section.

This option is implemented according to the EC art 6.1(4).

Calculation method

The user has the choice between 3 calculation methods: Uni-axial bending calculation (sum) or (max) and Bi-axial bending calculation.

By default the option 'Automatic determination' is selected; SCIA Engineer follows a certain flow chart to determine which calculation is best suited (See paragraph Bending – Overview for the flow chart).

Design reinforcement by using real area / delta area

The choice made here is only taken into account for bi-axial bending calculation and corner design only, which are both iterative calculations. It defines the way in which the required reinforcement area is increased in each iteration step.

Real area of reinforcement bar

For bi-axial bending calculation

If this option is on, the value for As,req is calculated based on the real sectional area of an individual reinforcement bar. This means that the value for As,req is always a multiple of the area of the used reinforcement bar:

Design As EN 1992-1-1

Linear calculation, Extreme : Member Selection : B5

Load cases : LC1

Main reini	orcemen	LIOI Sele	cied colum	115							
Member	d _x [m]	Case	N _d [kN]	M _{yd} [kNm]	M _{zd} [k Nm]	Calc. type	Interaction check [%]	Ratio y/z [%]	A _{s,reg} [mm ²]	Reinf_{req}	Reinf _{tot}
B5	0.000	LC1	-1050.00	-128.45	-216.25	В	94 < 100	40/60	6283	20(10/14)x20.0	20x20.0(6283)

For corner design only

The diameter of the corner bars is increased in each iteration step according to a list of basic diameters, which is for the Eurocode: 5-6-8-10-12-14-16-20-25-28-32-40 mm. As initial value for the bar diameter, the default value from the Concrete Setup or from the Member data (if applied) is taken. If the last diameter from the list doesn't satisfy yet, the calculation is ended with error 508.

Delta area of reinforcement

For bi-axial bending calculation

If this option is on, the value for As, req is calculated based on the user defined delta area. This means that the value for As, req is always a multiple of the value inputted by the user:

Design As EN 1992-1-1

Linear calculation, Extreme : Member Selection : B5 Load cases : LC1 Main reinforcement for selected columns Reinf_{req} M. Reinf_{tot} Member Cas e M Calc. Interaction Ratio N A_{s,req} [mm²] d [kŇ] [kNm] [kNm] [m] check y/z type ŕ%1 [%] -1050.00 -128.45 B5 0.000 LC1 -216.25 86 < 100 37/63 6240 22(10/16)x20.0 22x20.0(6912)

In this case a value for delta area of 20mm² has been inputted:

Design reinforcement using (biaxial and only come							
Area of reinforcement type	Delta area of reinforcement						
Delta area of reinforcement [mm^2]	20						

For corner design only

The value for delta area represents the increasing area per reinforcement bar in each iteration step. The 'real' diameter of reinforcement bars ds_i after each iteration step i is calculated according to the formula below and is rounded up to an integer:

$$ds_i = \sqrt{\frac{4 \cdot \Delta A \cdot i}{\pi}}$$

Bi-axial bending - Safety factor

The value for the safety factor x used in the interaction formula can be determined automatically or by user input.

When the option 'Automatic' is chosen, SCIA Engineer calculates the factor x by means of the following rules from the Eurocode:

x = 2 for circular and elliptical cross-sections

x = the value 'a' according to the following table for rectangular cross-sections (with linear interpolation for intermediate values)

$N_{\rm Ed}/N_{\rm Rd}$	0,1	0,7	1,0
a =	1,0	1,5	2,0

Bi-axial bending - Ratio y/z

Automatic

SCIA Engineer calculates the ratio y/z automatically, after the design has been done.

Manual

The user can impose a ratio y/z, so the reinforcement configuration will be adapted to meet this requirement.

From user reinforcement

The ratio of the reinforcement in y and z direction is calculated from existing user reinforcement:

ratio
$$\frac{y}{z} = \frac{(\frac{n_y}{n_y + n_z})}{(\frac{n_z}{n_y + n_z})}$$

where: n_y = number of bars in the y direction n_z = number of bars in the z direction

If no user reinforcement is defined, then the ratio y/z = Automatic.

If the user reinforcement is unsymmetrical about y or z axis, then error 879 will appear: "The calculation is not supported because of unsymmetrical user reinforcement".

Bi-axial bending – Limit stress ratio y/z

This is the limit value for the ratio y/z of additional (or required) reinforcement for a bi-axial bending calculation.

The default value for (ratio y/z)_{lim} is 4. If ratio y/z > (ratio <math>y/z)_{lim} or ratio y/z < 1/(ratio <math>y/z)_{lim}, then warning 245 will appear: "An unusual design situation is encountered: the stress ratio y/z exceeds the preset limit or the required reinforcement is hardly acceptable."

This is due to too many bars in 1 direction, and the solution is to:

- use a different Calculation Method
- use a different Ratio y/z
- switch on the option 'Optimize the number of bars' (best solution)

Theoretical background

An extended manual that also contains some theoretical background can be found through the help menu of SCIA Engineer: