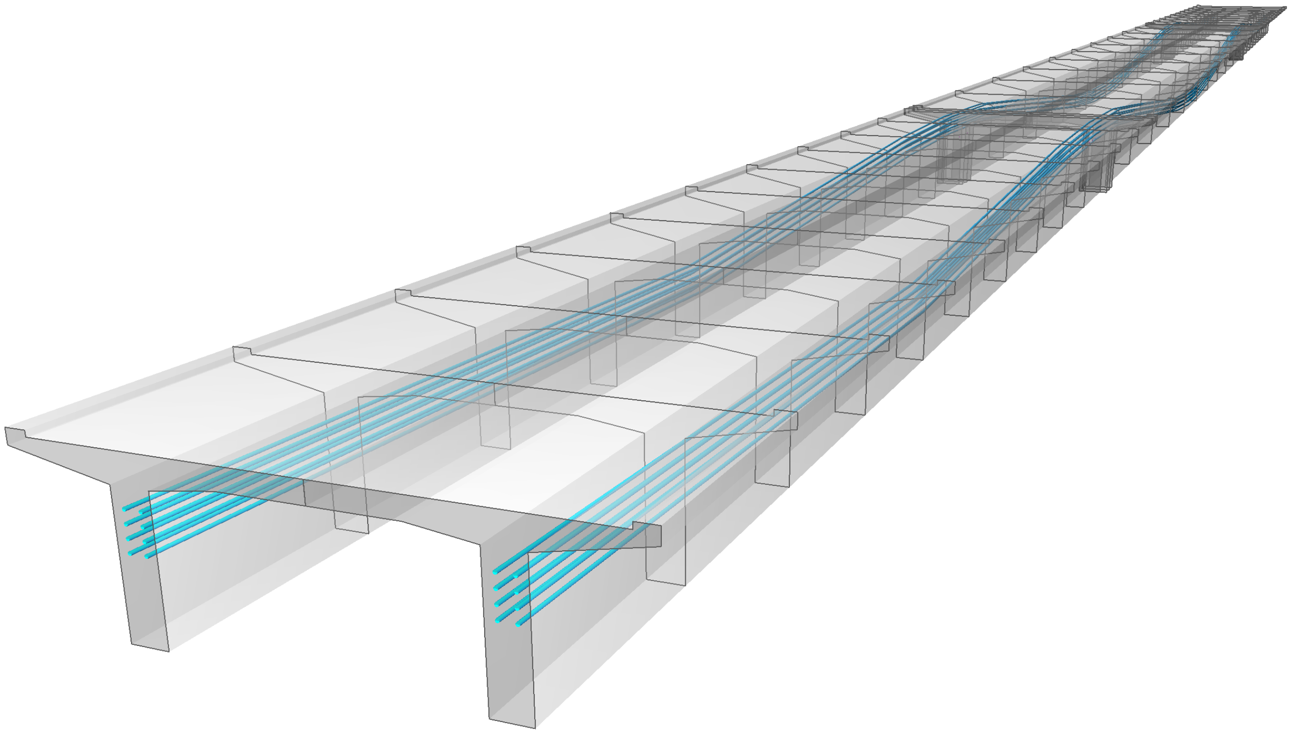
Reinforced and Prestressed Concrete Design according to SIA 262



InfoGraph
Software für die Tragwerksplanung

Title image: Structural model of a prestressed three-span bridge

Contents

SIA 262 Design

Basics

The reinforced concrete and prestressed concrete design according to SIA 262:2017 is applicable for both building and bridge structures. Permitted structure models include beam, area and solid constructions. Prestressed structures can only be checked in the FEM module.

Differing components can be combined in a structure model:

- Non-prestressed components
- Prestressed components with subsequent bond
- Prestressed components without bond
- Components with external prestressing
- Mixed-construction components

The design is carried out after the static calculation. To do so, you need to assign the calculated load cases to the actions in accordance with SIA 260. The program will take into account the preset safety factors and combination coefficients for the desired design situations to automatically calculate the decisive design internal forces for either the entire system or a group of selected elements.

The actions and check selection dialogs can be opened from the analysis settings. Detailed check specifications and reinforcement data must be entered during section definition.

The checks are limited to elements with materials *SC12/15* to *SC50/60*, *SLC12/13* to *SLC50/55* and *SCX*.

For beams and design objects, all checks are carried out at the polygon or composite section. For general notes on using design objects, refer to the relevant chapter of the manual.

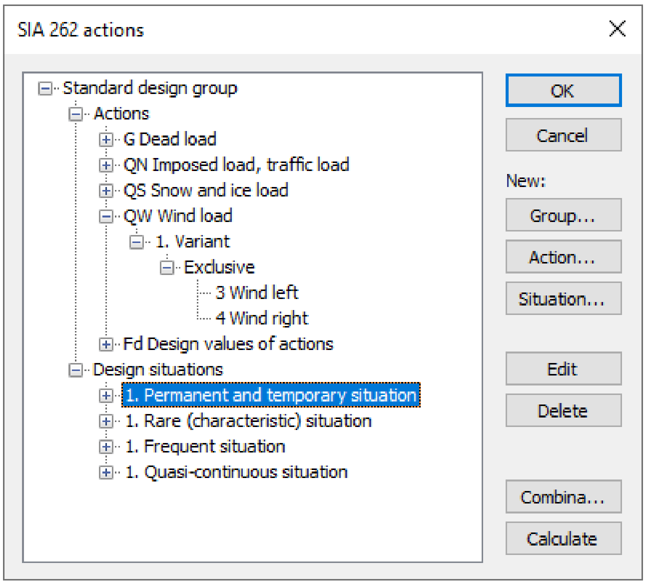
In the *SIA 262 Design* folder of the database you can also perform a single design for user-defined polygon sections or composite sections.

Input

Actions and Design Situations

The design values of the load are calculated based on the internal forces of the individual load cases and load case combinations. For this the existing load cases and load case combinations must be assigned to actions. This results in the desired design situations.

The following dialog is opened from the database or the *Settings* in the *Analysis* menu.



Action...

Open the dialog for entering new actions:

- Permanent actions (G, GE, GH)
- Prestressing (P)
- Creep and shrinkage, relaxation (CSR1, CSR2)
  These actions are only available if a P action has been defined. In the combinations they are treated, along with P, as a single action.
- Variable actions (QN, QS, QW, QT, QH, QD)
- Accidental actions (A)
- Actions due to earthquakes (AE)
- Design values of actions (Fd)
  The assigned load cases should contain a design-relevant set of loads with partial safety factors and combination coefficients such as for example a load group to take into account nonlinear effects. The selected load cases are combined exclusively.
- Cyclic fatigue actions (Qfat)

Group...

Open the dialog for entering a new design group. According to e.g. standard SIA 261, Chapter 8.3.3, certain components (sections) may be designed with reduced imposed loads. Therefore, variable actions (Q) and design situations can be changed here.

Situation...

Open the dialog for entering new design situations. Situations must be classified as either a construction stage or a final state in order to control the checking process. For prestressed concrete structures with subsequent bond, you can specify that the tendons are still ungrouted.

Edit

Open the Edit dialog for the selected action or situation.

Delete

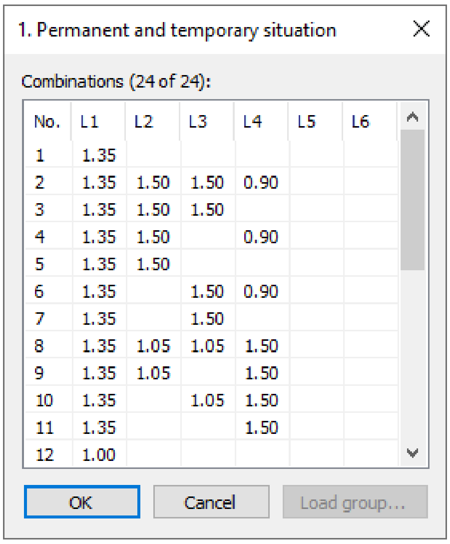
Delete the selected action or situation.

Combinations...

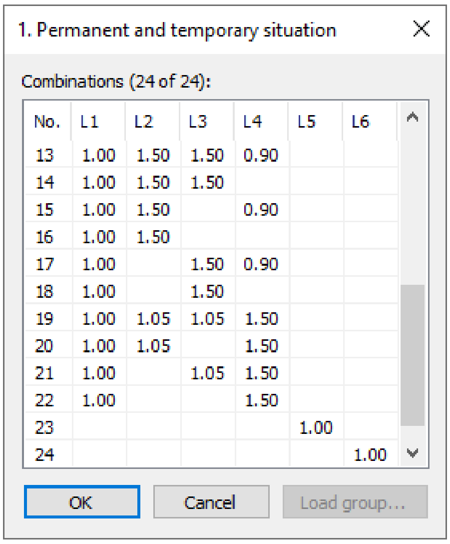
Opens a dialog that contains the first 999,999 load case variants to be combined for the selected design situation and includes an option to create load groups for selected variants. These variants can be used for second-order theory analysis or nonlinear analysis.

The following example shows the total variants of the *permanent and temporary situation* according to Eq. (6.10) to be examined with the load cases (L1...L6) involved and their weighting factors.

Actions	Load cases	γ_{sup}	γ_{inf}	ψ_0
Dead load	1	1.35	1.0	-
Imposed load, traffic load	2, 3 (inclusive)	1.5	0	0.7
Wind load	4	1.5	0	0.6
F_d Design values of actions	5, 6	1.0	1.0	-



No.	L1	L2	L3	L4	L5	L6
1	1.35					
2	1.35	1.50	1.50	0.90		
3	1.35	1.50	1.50			
4	1.35	1.50		0.90		
5	1.35	1.50				
6	1.35		1.50	0.90		
7	1.35		1.50			
8	1.35	1.05	1.05	1.50		
9	1.35	1.05		1.50		
10	1.35		1.05	1.50		
11	1.35			1.50		
12	1.00					



No.	L1	L2	L3	L4	L5	L6
13	1.00	1.50	1.50	0.90		
14	1.00	1.50	1.50			
15	1.00	1.50		0.90		
16	1.00	1.50				
17	1.00		1.50	0.90		
18	1.00		1.50			
19	1.00	1.05	1.05	1.50		
20	1.00	1.05		1.50		
21	1.00		1.05	1.50		
22	1.00			1.50		
23					1.00	
24						1.00

Calculate

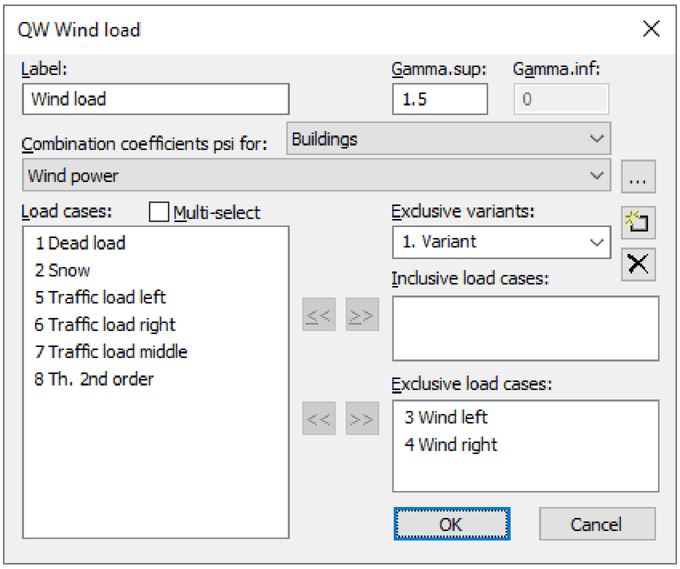
Calculate the defined design situations. Once calculated, the extremal results (internal forces, support reactions) can be accessed for all combinations in the database. This allows you to evaluate the results without having to open the checking module. Each time you open the checking module, all results will be automatically recalculated using the currently valid actions and then stored in the database for the elements to be checked.

The following table demonstrates how the situations are used in the various checks. The numbers refer to the SIA 262 chapters.

Situation	Ultimate limit state	Chapter	Serviceability limit state	Chapter
Permanent and temp. Accidental Earthquake	Longitudinal reinf. Lateral reinf. Torsional reinf.	4.3.2 4.3.3 4.3.5		
Characteristic (rare)			Prevention of brittle failure	4.4.2
Frequent			Crack width limitation	4.4.2
Quasi-continuous			Concrete compr. stress Crack width limitation	3.1.2.6.3 4.1.5.2.4 4.4.2
Fatigue	Fatigue reinf. steel Fatigue prestr. steel Fatigue concrete	4.3.8 4.3.8 4.3.8		

Definition of an Action

The illustration below shows an example of the dialog field for entering variable actions. The dialog fields for the other action types have a similar appearance.



Label

User-defined label for the action.

Gamma.sup, **Gamma.inf**

Partial safety factors γ_{sup} and γ_{inf}.

Combination coefficients psi for:

Input fields for selecting the combination coefficients for variable actions. The ... button allows you to view and modify the selected combination coefficients ψ_0, ψ_1 and ψ_2.

Load cases

List of the possible load cases or load case combinations. Select items by highlighting them and clicking the >> button or use drag & drop.

Multi-select

Load cases and combinations can be added to the actions more than once.

Exclusive variants

Variable actions may consist of multiple exclusive variants that are mutually exclusive. The variants themselves contain both inclusive and exclusive parts. You can add or delete action variants by clicking the or buttons.

Inclusive load cases

Selected load cases and combinations that can have a simultaneous effect.

Exclusive load cases

Selected load cases and combinations that are mutually exclusive.

Prestressing loss from relaxation of prestressing steel

The prestressing loss is defined as a constant percentage reduction of prestress.

CS as constant reduction of prestress

As an alternative to defining load cases, you can allow for the effect of creep and shrinkage (CS) by defining a constant percentage reduction of prestress.

Internal prestressing

Selected load cases that describe internal prestressing. The reactions of the individual load cases are added up.

External prestressing

Selected load cases that describe external prestressing. The reactions of the individual load cases are added up.

Partial Safety Factors

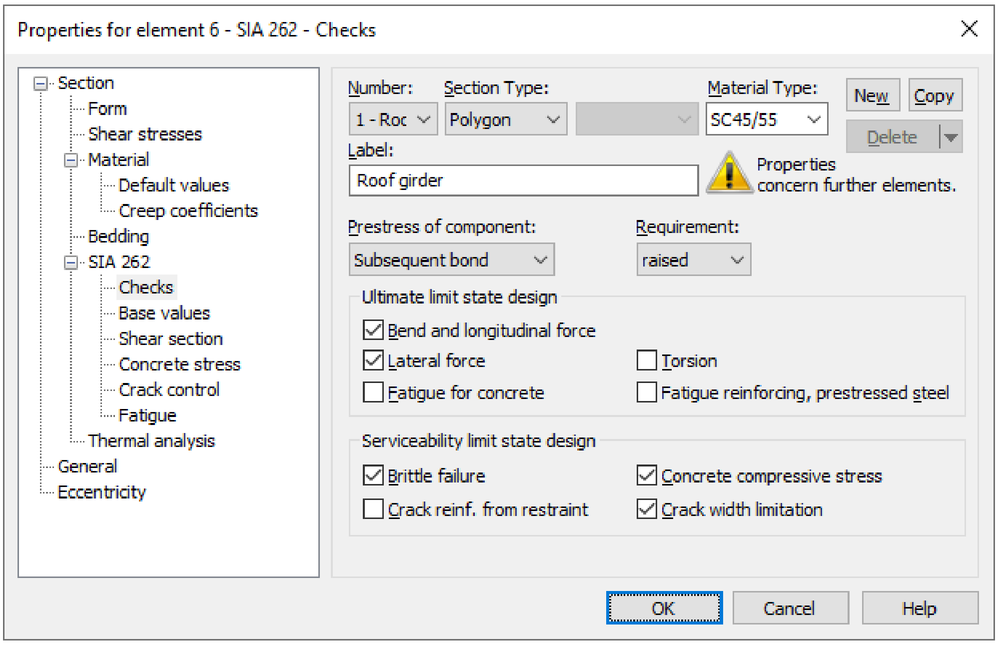
The partial safety factors for actions are determined by the definition of actions in accordance with SIA 260, Table 1, and can be modified if necessary. The partial safety factors of the construction materials are preset with the values specified by SIA 262, Section 2.3.2.5.

Section Input

The section inputs contain all of the specific settings made for checks in the ultimate limit and serviceability states. In addition to these specifications, the selected material properties and the properties of the reinforcing steel are also relevant for the design. An overview of the design specifications can be accessed in the *SIA 262 Design* section of the database.

Checks

The following dialog is used to define which ultimate limit state and serviceability checks are available for the section. For composite sections, the selection is limited to the load-bearing capacity checks. The analysis settings allow to override this selection for the entire structure.



Prestress of component

The type of prestressing can be selected for each section separately:

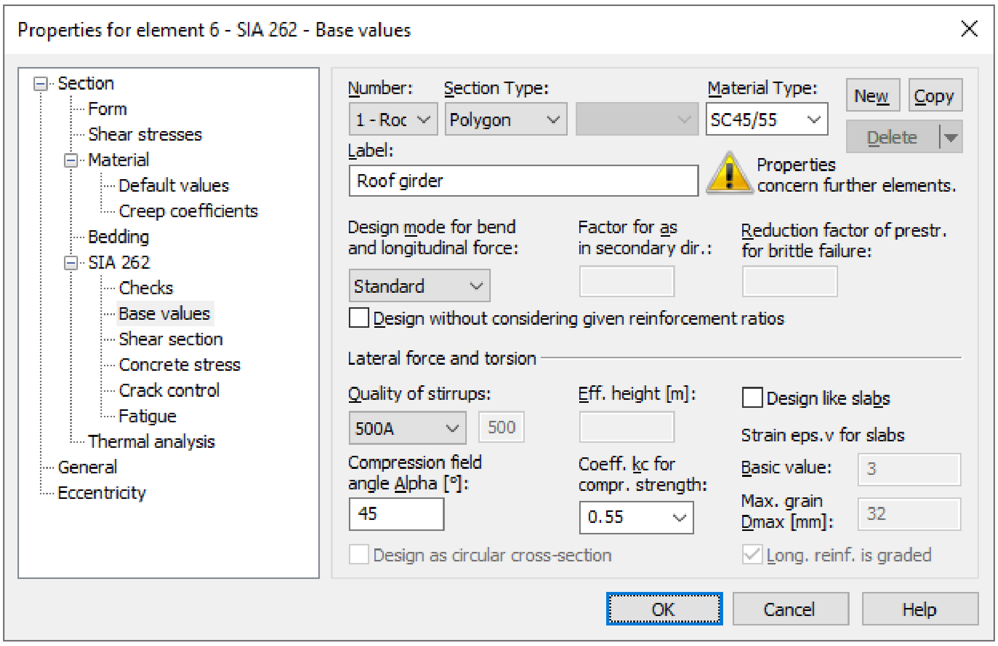
- *not prestressed*
- *subsequent bond*
- *without bond*
- *external*
- *mixed construction*

Requirement

The requirement for crack formation determines the actions and steel stress limits for crack width limitation according to SIA 262, Table 17 and Figure 31.

Base Values

Unless otherwise specified, the base values apply for all checks in the ultimate, fatigue and serviceability limit states.



Design mode

- *Standard*: Standard design mode for bending with normal force throughout the load range. Reinforcement will be calculated in the tensile section to the greatest degree possible.
- *Symmetrical*: Design for symmetrical reinforcement. As opposed to the standard mode, all of the reinforcement layers will be increased if a reinforcement increase is necessary.
- *Compression member*: For compression members, a symmetrical design is carried out with allowance for the minimum reinforcement according to SIA 262, Chapter 5.5.4.

Factor for as in secondary direction

According to SIA 262, Chapter 5.5.3.2, secondary longitudinal reinforcement of slabs should not be less than 20% of the principal reinforcement. The examination is carried out on the program side with the results of the bending design separately for the upper and lower side of the cross-section. The direction with the largest amount of reinforcement per cross-sectional side defines each principal reinforcement direction. The assignment of the factorized reinforcement in secondary direction then takes place via corresponding reinforcement layers.

Reduction factor of prestr. for brittle failure

In the program, the regulations of EN 1992-2, Chapter 6.2 (110) are decisive for the arrangement of robustness reinforcement. Thus for the determination of the tensile zone the statically determined effect of prestressing is not taken into account. Because this cannot be determined for area elements, the prestress can alternatively be reduced by a reduction factor. The specification of an appropriate value is subject to the discretion of the user.

Design without considering given reinforcement ratios

If selected, the reinforcement increase required in the design is performed without taking into account the reinforcement ratios specified by the basic reinforcement.

Quality of stirrups

Steel quality for stirrup and longitudinal reinforcement from lateral force in MN/m².

Effective height

Effective static height for the shear design of area elements [m].

Design like slabs

Beams or design objects are treated like slabs.

Strain eps.v for slabs

- *Basic value*: Strain ε_v according to Section 4.3.3.2.2 for calculation of the absorbable lateral force without lateral force reinforcement [‰].
- *Max. grain Dmax*: Maximum grain of the concrete for the calculation of k_g according to Equation (37).
- *Longitudinal reinforcement is graded*: Switch for the increase of ε_v according to Section 4.3.3.2.3.

Compression field angle Alpha [°]

Angle of the concrete compressive field according to Section 4.3.3.3.2.

Coefficient kc for compress. strength

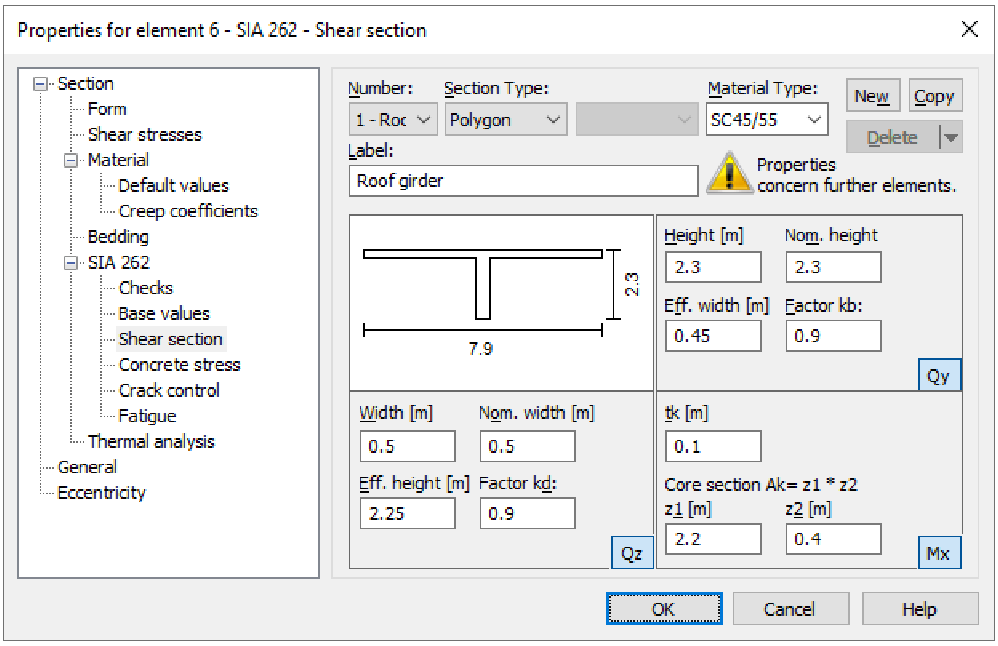
Coefficient for the concrete compressive strength according to Section 4.2.1.7.

Design as circular cross-section

For circular and annular cross-sections, the lateral force design according to Bender et al. (2010) can be selected as an alternative for the resulting shear force $Q_r = \sqrt{(Q_y{}^2 + Q_z{}^2)}$. The corresponding inputs are made on the *Shear Section* dialog page.

Shear Section

For polygon and composite sections, additional section dimensions are required for the lateral force and torsion design according to SIA 262. These dimensions are explained in the following. In case of sections with internal prestressing or with a shape that differs from a rectangle, the dimensions suggested by the program should be reviewed.



Width

Section width for calculating the lateral force load-bearing capacity for Q_z [m].

Height

Section height for calculating the lateral force load-bearing capacity for Q_y [m].

Effective height

Effective static height for calculating the lateral force load-bearing capacity for Q_z [m].

Effective width

Effective static width for calculating the lateral force load-bearing capacity for Q_y [m].

Nom. width, nom. height

The nominal width or height of internally prestressed components as per SIA 262, Section 4.3.3.3.5, for including the duct diameter in the calculation of the design value of the lateral load-bearing capacity $V_{Rd,c}$.

Factor kb, Factor kd

Factor for calculating the inner lever arm z from the effective width b_n or effective height d in the lateral load-bearing capacity check for Q_y or Q_z.

tk

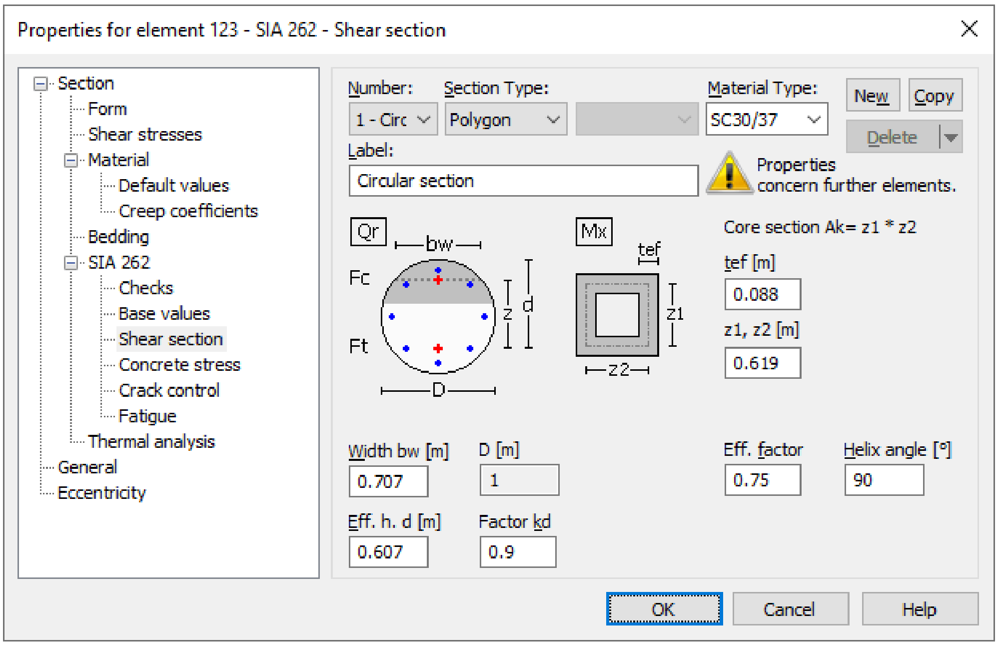
The effective wall thickness of the torsion section [m].

Core section Ak= z1 * z2

Dimensions of the core section for calculating the torsion reinforcement [m].

Circular and annular cross-section

If the circular design according to Bender et al. (2010) was selected for the resulting lateral force Q_r on the *Base values* dialog page, the equivalent cross sections for the shear design must be defined in the following dialog.



Width bw

Effective section width for calculation of the lateral force bearing capacity for $Q_r = \sqrt{(Q_y{}^2 + Q_z{}^2)}$. According to the recommendation of the German Committee for Standardization in Civil Engineering (NABau), the smaller value of the section width at the center of gravity of the steel tensile forces and the concrete compressive forces should be selected for the effective width b_w. For circular cross-sections, the program suggests the dimension of the square inscribed in the circle ($R \cdot \sqrt{2}$) for b_w, and twice the wall thickness for annular cross-sections.

Effective height d

Statically effective height for calculation of the lateral force bearing capacity for Q_r. The program suggests $d = h - d_1$, where the height is set to $h = R \cdot \sqrt{2}$ and d_1 indicates the edge distance of the outer reinforcement layer.

Factor kd

Factor for calculating the inner lever arm z from the effective height d in the verification for Q_r.

Efficacy factor

According to Bender et al. (2010), p. 422, the efficacy factor α_k is stress-dependent ($0.715 \le \alpha_k \le 0.785$) and can be assumed with the mean value $\alpha_k = 0.75$.

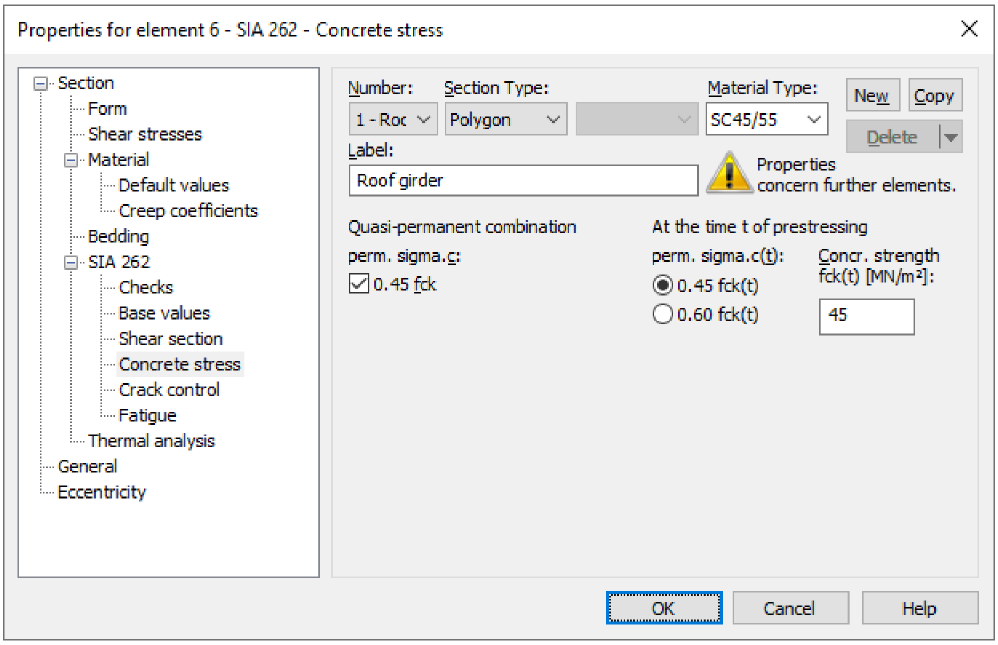
Helix inclination

Angle between shear force reinforcement and component axis. When entering an inclination of 90°, annular single stirrups are assumed.

z1, z2, tef

The dimensions z_1, z_2 of the square core cross-section and the effective wall thickness t_{ef} of the torsion box are defined according to SIA 262, Figure 19. The design for torsion is carried out according to the standard for vertical stirrups.

Concrete Stress



perm. sigma.c

In accordance with SIA 262, Section 3.1.2.6.3, the effect of the load level on the creep is to be taken into account for concrete stresses $\sigma_c > 0.45\, f_{ck}$. The compliance of this stress limit is verified for the quasi-continuous combination referring to EN 1992-1-1, Section 7.2 (3).

perm. sigma.c(t)

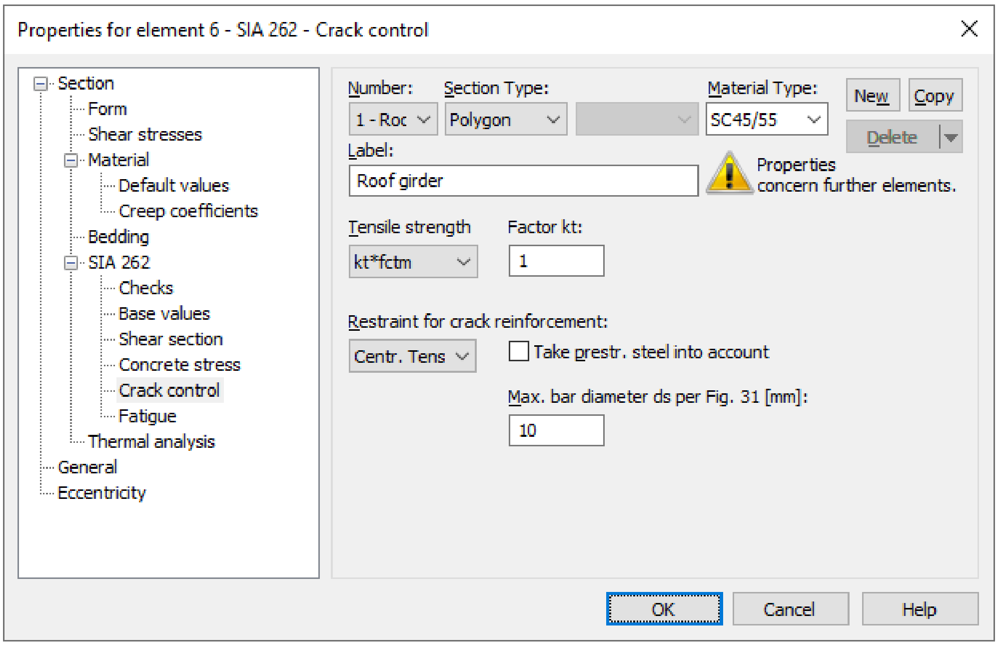
Permissible concrete stress σ_c(t) at time t when prestressing is introduced according to SIA 262, Section 4.1.5.2.4, Equation (23). If the compressive stress exceeds the value $0.45 \cdot f_{ck(t)}$, the nonlinearity of the creep should be taken into account according to Section 3.1.2.6.3. The program assumes that prestressing is introduced in design situation G1+P.

fck(t)

Concrete strength at time t when prestressing is introduced as per Section 4.1.5.2.4 [MN/m²].

Crack Control

These specifications apply to the check against brittle failure, the calculation of the crack reinforcement and the crack width limitation.



Tensile strength fctd

The concrete tensile strength f_{ctd} can be calculated either with SIA 262, Equation (98), or with Equation (100).

Factor kt

Reduction factor k_t for taking into account the dimension of the tension chord t according to Equation (99).

Restraint for crack reinforcement

Selection of the tensile zone according to Section 4.4.2.3.6 for distribution of the crack reinforcement in case of restraint.

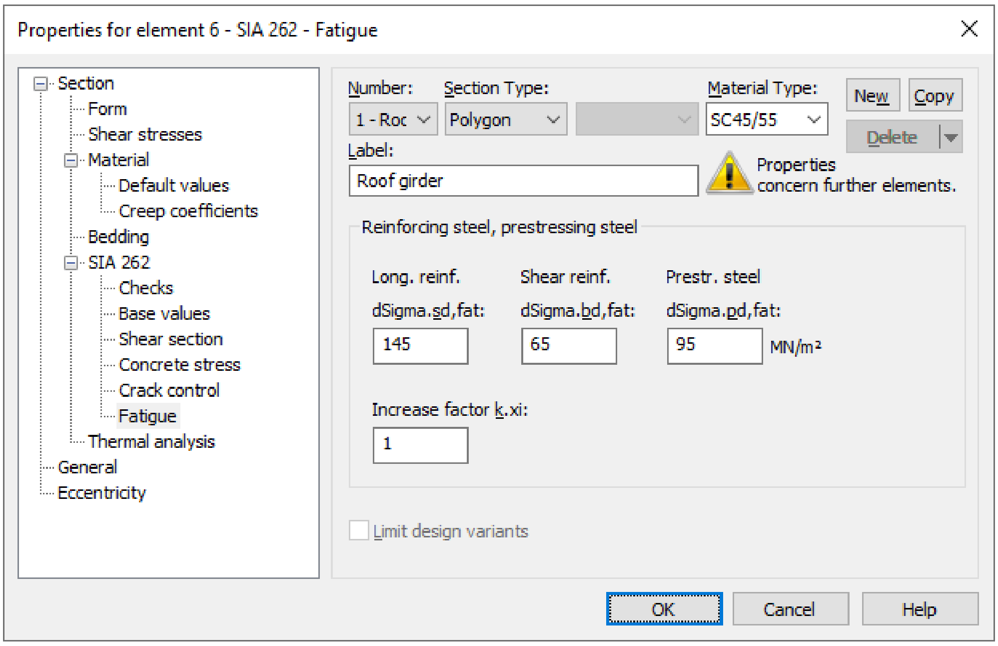
Take prestr. steel into account

Bonded prestressing steel within the tensile zone is taken into account according to Section 4.4.2.3.10.

Max. bar diameter ds per Fig. 31 [mm]

Largest existing bar diameter of the reinforcing steel for determination of the stress limits according to Figure 31.

Fatigue



dSigma.sd,fat, dSigma.bd,fat, dSigma.pd,fat

Design values of the fatigue strength of the longitudinal reinforcement, the shear reinforcement and the prestressing steel according to SIA 262, Table 13. For calculation of the coefficient $k_\varnothing$ according to Equation (85) for shear reinforcement, the mandrel diameter is taken to be $d_i = 4\ \varnothing_s$.

Increase factor k.xi

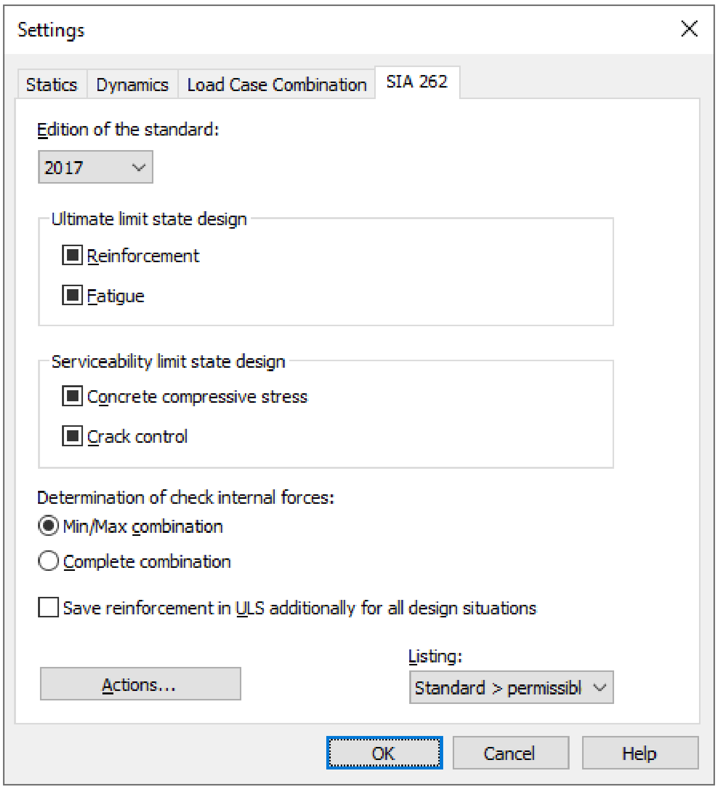
Increase factor k_ξ for the reinforcing steel stress of the longitudinal reinforcement. This factor is used to take into account the varying bonding behavior of concrete and prestressing steel as per Section 4.3.8.1.4.

Limit design variants

For area elements, the variants for determining the stress range can be limited to the corresponding sets of design internal forces. For more information see chapter '*Check Against Fatigue > Special Characteristic of Shell Structures*'.

Analysis Settings

The *SIA 262* dialog page can be opened using the *Settings* function of the *Analysis* menu.



Edition of the standard

The edition you select will be used for all subsequent calculations.

Check selection

When selecting checks, the following cases are to be distinguished:

 or  The check is performed according to the settings in the section dialog (see *Section inputs*).

 or  The check is performed for all sections of the structure.

 or  The check is performed for no sections of the structure.

Corresponding section settings are bundled as follows:

Reinforcement	Bend and longitudinal force Lateral force Torsion Robustness
Crack control	Brittle failure Crack reinforcement from restraint Crack width limitation

An overview of the checks can be accessed using the *Design Settings* function in the *SIA 262 Design* folder of the database.

Determination of the check internal forces

- *Min/Max combination*
  The minimum and maximum values are determined for each component of the internal forces in compliance with the combination rule. Together with the associated values, these form the check internal forces.
- *Complete combination*
  To determine the check internal forces, all possibilities of interaction of actions resulting from the combination rule are taken into account. The calculation effort increases exponentially with the number of inclusive load cases.

The differences between the two methods are explained in more detail in the section *Check internal forces*.

Save reinforcement in ULS additionally for all design situations

In addition to the maximum required ultimate limit state reinforcement, the reinforcement is saved separately for each design situation in the ultimate limit state.

Actions...

Open the dialog for describing actions.

Listing

- *No*: No log is generated by the checking program.
- *Standard*: Log with tabular output of results.
- *Detailed*: Additional output of the decisive combination internal forces at the check locations.
- *Standard > permissible*: Standard log limited to check locations where the permissible limit values are exceeded.
- *Detailed > permissible*: Detailed log limited to check locations where the permissible limit values are exceeded.

Single Design

The single design function allows you to analyze individual section polygons separately from the whole system using predefined internal forces. The calculation is carried out from the opened input table via the *Single Design* item in the *Analysis* menu or the *Print Preview* function. The entry table can be found in the *SIA 262 Design* folder of the database.

Section

Number of the section to be designed.

Concrete

Concrete class SC12/15, ... SC50/60 or LSC12/13, ... LSC50/55

Apparent density

Apparent density of the lightweight concrete [kg/m³].

Combination

Design situation according to SIA 261, Section 4.4.3.4 or 4.4.3.5.

- *0*: Permanent and temporary design situation.
- *1*: Accidental design situation.

Nsd, Mysd, Mzsd

Internal forces that are designed.

Mode

- *Standard*: Standard design mode for bending with normal force throughout the load range. Reinforcement will be calculated in the tensile section to the greatest degree possible.
- *Symmetrical*: Design for symmetrical reinforcement. As opposed to the standard mode, all of the reinforcement layers will be increased if a reinforcement increase is necessary. The predefined relationships between the reinforcement layers will not be affected.
- *Compression member*: For compression members, a symmetrical design is carried out with allowance for the minimum reinforcement according to SIA 262, Section 5.5.4.
- *Strains*: Determine strain state for existing reinforcing steel layers.
- *Strains SLS*: Determine strain state in the serviceability limit state for existing reinforcing steel layers. In the compression zone, a linear strain-stress curve of the concrete with the gradient $\tan \alpha = E_{cm}$ is used.
- *Strains SLS2*: Determine strain state in the serviceability limit state for existing reinforcing steel layers. A nonlinear strain-stress curve of the concrete with a strength of f_{cm} is used. Note that a horizontal progression is assumed for strains exceeding ε_{c1}.
- *Load bearing capacity*: Determination of the load bearing capacity. All internal forces are increased up to the ultimate limit state, taking into account the existing reinforcing steel layers.
- *Maximum bending moment My*: Determination of the maximum bearable bending moment M_y. The moment M_y is increased up to the ultimate limit state, taking into account the other internal forces and the existing reinforcing steel layers.
- *Inactive*: Design disabled.

Punching Shear Check

When you select a check node, the key data for the checks is displayed in a dialog field. This dialog is divided into three pages.

1a. Input data, column

The column forms *Rectangle* and *Round*, with the viewpoints *Intern*, *Edge parallel to x*, *Edge parallel to y* and *Corner* are available. When you enter a new column, the program will suggest the dimensions of existing columns. The edge distances a_x and a_y are used to calculate the perimeters u_i of the check sections for columns near to an edge or a corner.

1b. Input data, slab

This section presents the material properties, the existing bending reinforcement (a_{sx}, a_{sy}) as well as other coefficients for the calculation of the punching shear resistances:

D_{max}	maximum grain of the concrete [mm]
d_x, d_y	static height for the x and y direction to determine the average static height d [m]
d_v	effective static height for the absorption of the shear force [m]
β	inclination of the reinforcement according to Figure 26 [°]
d_{int}	static height for the determination of the reinforcement for protection against total collapse [m]
s_{int}	sum of bar spacings of reinforcement for protection against total collapse [m]
l_x, l_y	spans according to Figure 24 [m]

1c. Input data, action

The action V_d and M_d can either be taken as a support reaction from a previous design according to SIA 262, or entered directly. Possible average soil pressures σ_0 decrease the design value of the lateral force.

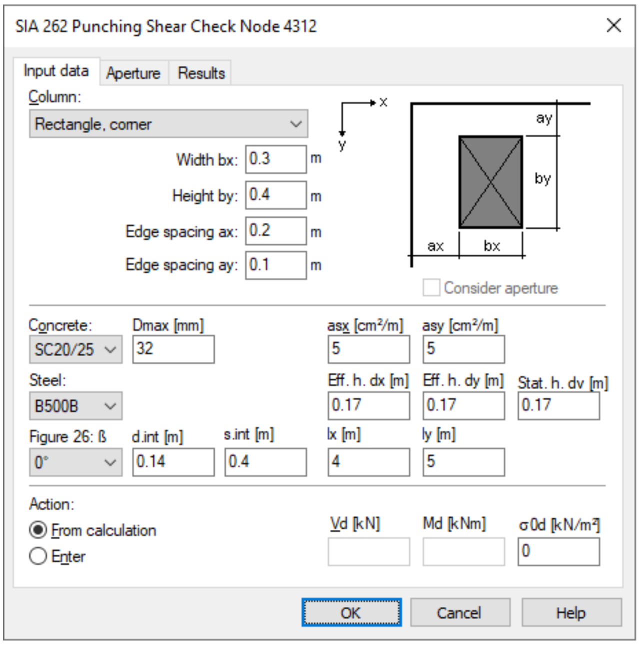
2. Aperture

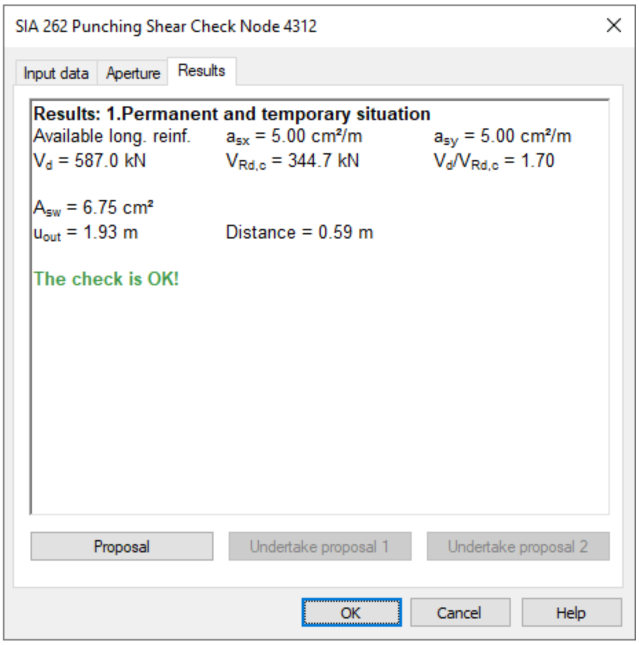
This dialog page is used to define the geometry and location of an opening.

3. Results

This dialog page shows the calculated punching shear resistances, the necessary punching shear reinforcement (if applicable) and the minimum bending reinforcement.

Example



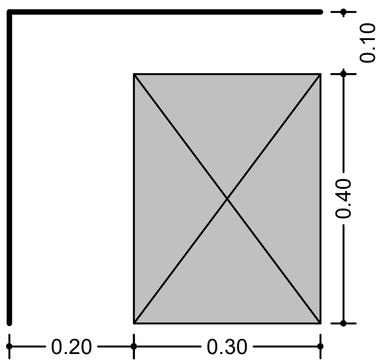


Punching shear check node 146

The check is performed according to SIA 262:2017.

1. Measurements, situation and material

Rectangular column with width b_x = 0.30 m and height b_y = 0.40 m
Situation: Corner column; Edge spacing a_x = 0.20 m; Edge spacing a_y = 0.10 m



Static height d_v = 0.170 m
Critical perimeter u = 1.13 m (distance = 0.09 m); A_{crit} = 0.34 m²

Available long. reinf. a_{sx} / a_{sy} = 5.00 / 5.00 cm²/m
Eff. height of the slab d_x / d_y = 0.170 / 0.170 m; d = (d_x + d_y)/2 = 0.170 m
Spans l_x / l_y = 4.00 / 5.00 m
Truss angle α = 90.0°

Concrete: SC20/25; D_{max} = 32 mm
$\tau_{cd} = 0.3 \cdot \eta_t \cdot \sqrt{f_{ck}} / \gamma_c = 0.3 \cdot 1.0 \cdot \sqrt{20.00} / 1.50 = 0.89$ N/mm²
$f_{bd} = 1.4 \cdot f_{ctm} / \gamma_c = 2.05$ N/mm²

Reinforcement: B500B
E_s = 205000 N/mm²; $f_{sd} = f_{sk} / \gamma_s = 500.00 / 1.15 = 434.78$ N/mm²

Collapse protection as per Figure 26
β = 0°; d_{int} = 0.140 m; s_{int} = 0.40 m

2. Action: 1.Permanent and temporary situation

V_d = 587.00 kN; M_d = 0.00 kNm

3. Punching resistance without punching reinforcement

Coefficient k_e as per Chapter 4.3.6.2.4
$e_u = 0$; $k_e = 1$

Distance r_s as per Chapter 4.3.6.4.4
$r_{s,x} = 0.22 \cdot l_x = 0.88$ m; $r_{s,y} = 0.22 \cdot l_y = 1.10$ m
$b_s = \min(1.5 \cdot \sqrt{(r_{s,x} \cdot r_{s,y})}; l_{min}) = 1.48$ m

Bending resistance and comparison moment as per Chapter 4.3.6.4.7
$m_{Rd,x}$ = 36.79 kNm; $m_{Rd,y}$ = 36.79 kNm
$m_{sd,x} = m_{sd,y} = \max(V_d \cdot (1/8 + |e_u| / 2b_s); V_d / 2) = 293.50$ kNm

Slab rotation ψ as per Chapter 4.3.6.4.1 at approximation level 2
$\psi_x = 1.5 \cdot r_{s,x} / d \cdot f_{sd} / E_s \cdot (m_{sd,x} / m_{Rd,x})^{3/2} = 0.37$
$\psi_y = 1.5 \cdot r_{s,y} / d \cdot f_{sd} / E_s \cdot (m_{sd,y} / m_{Rd,y})^{3/2} = 0.46$
$\psi = \max(\psi_x; \psi_y) = 0.46$

Coefficient k_r as per Chapter 4.3.6.3.2
$k_g = 48 / (16 + D_{max}) = 1.00$
$k_r = \min(1 / (0.45 + 0.18 \cdot \psi \cdot d \cdot k_g); 2) = 2.00$

Punching resistance as per Chapter 4.3.6.3.1
$V_{Rd,c} = k_r \cdot \tau_{cd} \cdot d_v \cdot k_e \cdot u = 344.71$ kN

$V_d / V_{Rd,c} = 587.00 / 344.71 = 1.70 > 1$ $\Rightarrow$ Punching reinforcement is required!

4. Punching reinforcement perpendicular to the slab plane

Design lateral force as per Chapter 4.3.6.5.2
$V_{d,s} = \max(V_d - V_{Rd,c}; V_d / 2) = 293.50$ kN

Punching reinforcement as per Chapter 4.3.6.5.4
$V_{Rd,s} = A_{sw} \cdot k_e \cdot \sigma_{sd} \cdot \sin 90°$
$\varnothing_{sw} = 14$ mm as per Table 20
$\sigma_{sd} = \min(E_s \cdot \psi / 6 \cdot (1 + f_{bd} / f_{sd} \cdot d / \varnothing_{sw}); f_{sd}) = 434.78$ N/mm²

$A_{sw} = V_{d,s} / k_e / \sigma_{sd} = 6.75$ cm²

Reinforcement arrangement as per Chapter 5.5.3.8, Figure 39 and Table 20
- The punching reinforcement should consist of two or more rows
- The first row should have a minimal distance of 0.06 m and max. 0.11 m from the edge of the supported area
- The radial distance of the reinforcing rows must not exceed 0.11 m
- The outmost row should have a distance of 0.51 m from the edge of the supported area
- In the second row, the tangential distance of the reinforcing elements must not exceed 0.26 m

Check of the concrete compressive strut at the supported area as per Chapter 4.3.6.5.7
$V_{Rd,c} = \min(2 \cdot k_r; 3.5) \cdot \tau_{cd} \cdot d_v \cdot k_e \cdot u = 603.24$ kN

$V_d / V_{Rd,c} = 587.00 / 603.24 = 0.97 \le 1$ $\Rightarrow$ Check is OK!

Punching shear check outside of the reinforced zone as per Chapter 4.3.6.5.9 and Figure 25
Check perimeter $u_{out} = 1.93$ m; Distance = 0.59 m
The static height is assumed to be $d_v = 0.17$ m
$V_{Rd,c,out} = k_r \cdot \tau_{cd} \cdot d_v \cdot k_e \cdot u_{out} = 587.85$ kN

$V_d / V_{Rd,c,out} = 587.00 / 587.85 = 1.00 \le 1$ $\Rightarrow$ Check is OK!

5. Collaps protection

Check section as per Figure 26: $u_{int} = s_{int} + \pi / 2 \cdot d_{int} = 0.62$ m

$k_\beta = 0.37$ as per Table 12 for ductility class B
Residual resistance at check section as per Chapter 4.3.6.7.2
$V_{Rd,res} = A_s \cdot f_{sd} \cdot k_\beta \le 1.7 \cdot \tau_{cd} \cdot d_{int} \cdot u_{int}$

$A_s = \min(V_d; 1.7 \cdot \tau_{cd} \cdot d_{int} \cdot u_{int}) / (f_{sd} \cdot k_\beta) = 8.20$ cm²

Prestressed Structures

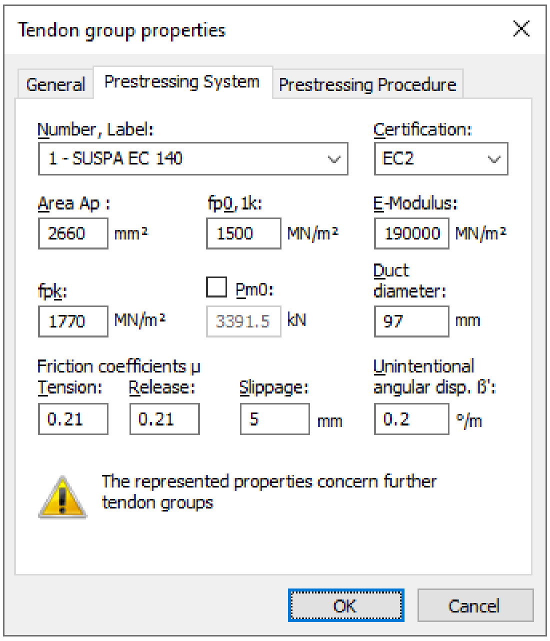
Internal Prestressing

For internal prestressing, the tendon groups as well as the prestressing system and procedures are entered using the *Prestressing* function of the *Structure* menu. To include them in the FEM calculation, you then need to define a load case of the *Prestressing* load type.

Prestressing with bond and prestressing without bond are differentiated in the section inputs and the specifications for the *Creep and shrinkage* load case. For prestressed components with subsequent bond the tendons can be set ungrouted for the respective design situation in the action dialog.

Prestressing System

The prestressing system combines typical properties that are then assigned to the tendon groups using a number.



Number, Label

Number and name of the prestressing system. The option <Database> enables to load or to store properties by use of the file *Igraph.dat*.

Certification

- DIN 1045-1
- DIN 4227
- EC2
- OENORM
- SIA 262

By selection of the certification, the prestressing force P_{m0} is determined according to the standard.

Area Ap

Section area A_p of a tendon [mm²].

ßs, ß02

Yield strength or $\beta_{0.2}$ limit of the prestressing steel according to DIN 4227 [MN/m²].

fp0,1k

Characteristic value of the 0.1% strain limit of the prestressing steel per DIN 1045-1, OENORM, SIA 262 and EC2 [MN/m²].

E-Modulus

E-modulus of the prestressing steel [MN/m²].

ßz

Tensile strength of the prestressing steel according to DIN 4227 [MN/m²].

fpk

Characteristic value of the tensile strength of the prestressing steel per DIN 1045-1, OENORM, SIA 262 and EC2 [MN/m²].

Pm0

The permissible prestressing force of a tendon [kN] that corresponds to the selected certification is displayed where the minimum of the two possible values is decisive. After releasing the input field, a different prestressing force can be defined.

Certification as per DIN 1045-1:
$P_{m0} = A_p \cdot 0.85 f_{p0,1k}$ or $A_p \cdot 0.75 f_{pk}$ according to DIN 1045-1, Eq. (49).

Certification as per DIN 4227:
$P_{m0} = A_p \cdot 0.75 \beta_s$ or $A_p \cdot 0.55 \beta_z$ according to DIN 4227-1, Tab. 9, Row 65.

Certification as per EC2:
$P_{m0} = A_p \cdot 0.85 f_{p0,1k}$ or $A_p \cdot 0.75 f_{pk}$ according to EN 1992-1-1, Eq. (5.43).

Certification as per OENORM:
$P_{m0} = A_p \cdot 0.80 f_{p0,1k}$ or $A_p \cdot 0.70 f_{pk}$ according to OENORM B 4750, Eq. (4) and (5), and OENORM B 1992-1-1, Chapter 8.9.6.

Certification as per SIA 262:
$P_{m0} = A_p \cdot 0.7 f_{pk}$ according to SIA 262, Eq. (22), Chapter 4.1.5.2.2.

Duct diameter

Is used for the decompression check according to the European standard and for beam tendons to calculate the net section values [mm].

Friction coefficients

Friction coefficients μ for prestressing and release.

Slippage

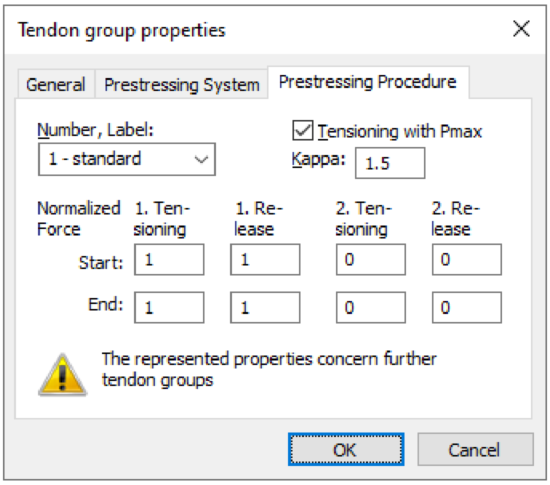
Slippage at the prestressing anchor [mm].

Unintentional deviation angle ß'

Unintentional deviation angle of a tendon [°/m].

Prestressing Procedure

The prestressing procedure differentiates between the start and end of the tendon group. The size of the maximum prestressing force is determined by factors regarding the permissible prestressing. In general, this is P_{m0} (see *Prestressing system*). Using the factor specified for the release, the maximum prestressing force remaining in the tendon group is defined with respect to P_{m0}. The prestressing force that remains at the prestressing anchor is calculated from this by the program. The resulting prestressing involves immediate losses due to friction and slippage, but not due to the elastic deformations of the concrete and the short-term relaxation. Each prestressing anchor can be prestressed and released twice. The prestressing procedures are numbered.



Number, Label

Number and name of the prestressing procedure.

Tensioning with Pmax

Selecting this check box causes the factors for tensioning correspond to the maximum force P_{max} for tendons certified according to DIN 1045-1 or EC2 (see the following example).

Kappa

If tensioning with P_{max} is selected, the permissible maximum force is calculated using the allowance value κ to ensure there is an overstressing reserve.

1. Tensioning

Factor relating to P_{m0} or P_{max} for the prestressing force at the tie at the 1st instance of tensioning.

1. Release

Factor relating to P_{m0} for the maximum remaining prestressing force at the 1st release. '0': no release!

2. Tensioning

Factor relating to P_{m0} or P_{max} for the prestressing force at the tie for the 2nd tensioning. '0': no 2nd tensioning!

2. Release

Factor relating to P_{m0} for the maximum remaining prestressing force at the 2nd release. '0': no 2nd release!

The prestressing force curve is determined in the following sequence:

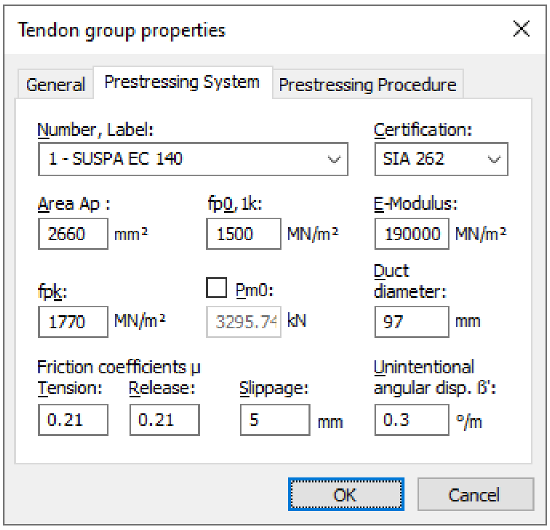
- Tensioning and release at the start,
- Tensioning and release at the end,
- Slippage at the start,
- Slippage at the end.

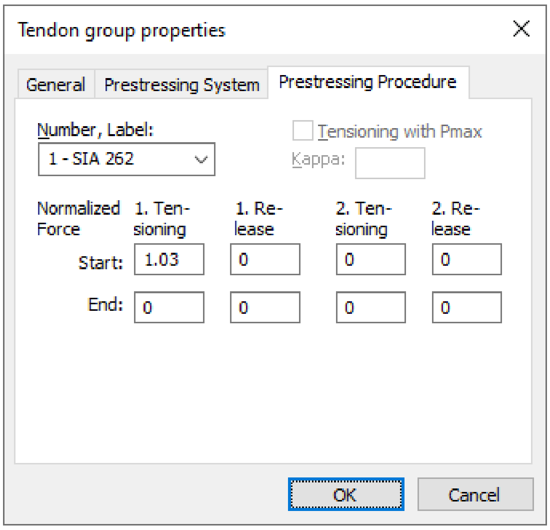
The differences between tensioning with P_{m0} and P_{max} are described in the following examples.

The user is responsible for checking the permissibility of the maximum force during the stressing process.

Examples for Prestressing Procedures According to SIA 262

The mode of action of the factors *Tensioning* and *Release* can be clarified using the example of an St 1570 / 1770 single tendon with prestressing anchor at the tendon start certified according to SIA 262.





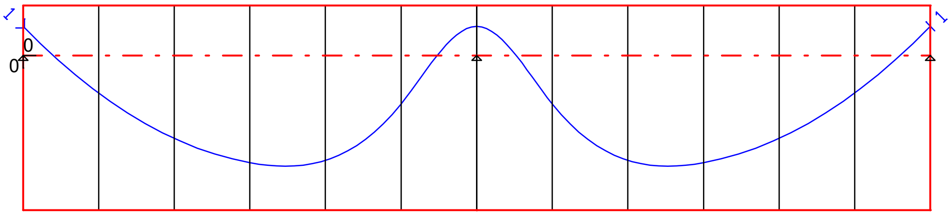
The permissible prestressing forces ar defined by:

$P_{max} = A_p \cdot 0.75 f_{pk} = 3531.2$ kN

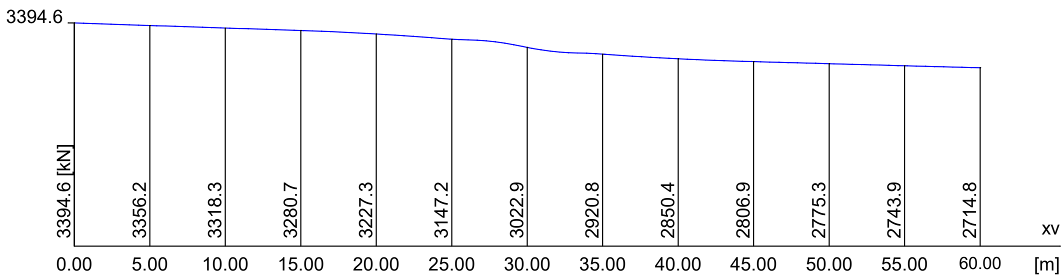
$P_{m0} = A_p \cdot 0.70 f_{pk} = 3295.7$ kN

The first prestressing force curve of the following illustration results after overstressing with 3% using a factor of 1.03 relating to P_{m0}, i.e. the maximum prestressing force is 3394.6 kN < P_{max}.

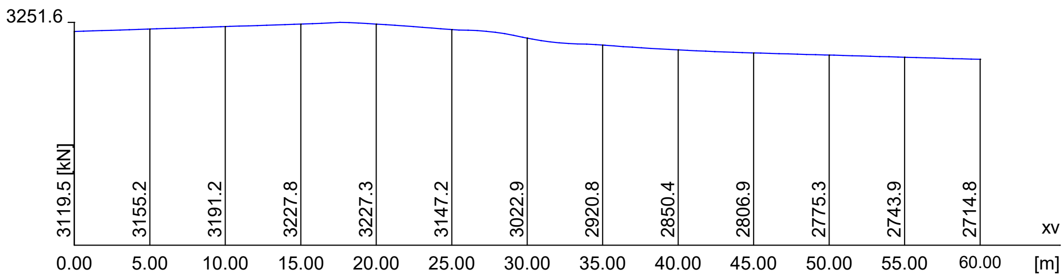
The second prestressing force curve results after setting down the press, i.e. the maximum prestressing force that remains in the tendon after it is fixed into place is 3251.6 kN < P_{m0}.



Single tendon, 10 times superelevated



Prestressing force curve after the 1st tensioning with a factor of 1.03



Prestressing force curve after anchor slip of 5 mm (setting down the press)

A release of the tendon was not taken into account here to illustrate the effects described above. Slippage would result in an additional variation of the prestressing force curve. A second prestressing and release procedure would have similar effects. The same holds true for prestressing and release at the tendon end.

External Prestressing, Mixed Construction

External prestressing can be taken into account by entering the external forces directly in the program. For mixed construction, the additional tendons with bond must be entered as described above.

Creep and Shrinkage

Similar to prestressing, creep and shrinkage are taken into account by specifying a corresponding load case (*Creep and shrinkage* load type) in the FEM calculation. Besides the creep-generating permanent load case, you also need to specify whether the internal forces relocation between concrete and prestressing steel is to be taken into account. This option is only useful in the case of tendons with bond.
The decisive creep and shrinkage coefficients for calculating the *Creep and shrinkage* load case are entered in the section dialog.

The program determines concrete creep and shrinkage based on a time-dependent stress-strain law developed by Trost.

$$\sigma_b(t) = \frac{E_b}{1+\rho \cdot \varphi}\left(\varepsilon_b(t) - \varphi \cdot \varepsilon_{b,0} - \varepsilon_{b,S}\right)$$

In this case:

$\sigma_b(t)$	Concrete stress from creep and shrinkage at time t.
E_b	E-modulus of the concrete.
ρ	Relaxation coefficient according to Trost for time t (normally ρ = 0.80).
φ	Creep coefficient for time t.
$\varepsilon_b(t)$	Concrete strain from creep and shrinkage at time t.
$\varepsilon_{b,0}$	Concrete strain from creep-generating continuous load.
$\varepsilon_{b,s}$	Concrete strain from shrinkage.

Under consideration of these relationships, a time-dependent global stiffness matrix and the associated load vectors are constructed which, in turn, yield the internal forces and deformations of the concrete. The resulting stress changes in the prestressing steel are also determined provided they are selected in the load case. Any influence from the relaxation of the prestressing steel will be ignored in this case. According to Zilch/Rogge (2002, p. 256), this influence can be calculated separately (see following section) and combined with the changes from creep and shrinkage for all time-dependent prestressing losses:

$$\Delta\sigma_{p,csr} = \Delta\sigma_{pr} + E_p \cdot \Delta\varepsilon_{cpt}$$

with

$\Delta\sigma_{pr}$	Prestressing loss from relaxation of the prestressing steel.
$\Delta\varepsilon_{cpt}$	Concrete strain change from creep and shrinkage.
E_p	E-modulus of the prestressing steel.

Relaxation of Prestressing Steel

According to SIA 262, Section 3.3.2.7.1, the design values of the stress loss from relaxation of the prestressing steel for a duration of 1000 h can be taken from Figure 8. Long time values of the stress loss can be determined by multiplying these values with the factor 3.

You can define the stress losses in the CSR actions of the *SIA 262 Actions* dialog.

Check Internal Forces

The calculation of load cases results in a set of internal forces for each load case at the check location (e.g. Nx, My). The check internal forces are then determined from the results of the load cases with the combination rules relevant for the ultimate limit state, fatigue and serviceability limit state. One of the following methods can be selected in the analysis settings:

- *Min/Max combination*
  The results of a load case are added to the set of internal forces with the minimum or maximum of an internal force, if this increases the amount of the extreme value. Result sets from traffic actions in which the control variable is less than the threshold 10^{-3} are not combined. The min/max combination delivers a constant number of sets regardless of the number of load cases and thus represents a particularly economical solution for the checks.
- *Complete combination*
  To determine the evidence internal forces, all possibilities of interaction of actions resulting from the combination rule are taken into account. The number of records increases exponentially with the number of inclusive load cases and can therefore result in high time and memory requirements for the checks.

For beams, design objects and axisymmetric elements, the resulting sets of internal forces are used directly in the checks. For area elements, *design internal forces* are derived from this, as will be described in more detail in the following section.

The internal forces relevant for the checks are documented in the detailed check listing. Regardless of the selection made, the results of the min/max combination are saved for the graphical representation. The load cases involved in the combination can be displayed using the *Combination information* context function.

The differences between the two combination methods mentioned before can be seen from the following example of a uniaxially stressed beam. The load cases 2, 3 and 4 shown can act simultaneously (inclusive). All safety and combination factors are assumed to be 1 for the example.

Action	Nx	My	Load case
G - permanent	-15	40	1
Q - variable	0	20	2
	5	10	3
	0	-10	4

Internal forces of the load cases

Extreme value	Nx	My	Combination
min Nx	-15	40	L1
max Nx	-10	50	L1+L3
min My	-15	30	L1+L4
max My	-10	70	L1+L2+L3

Results of min/max combination

Set	Nx	My	Combination
1	-15	40	L1
2	-15	60	L1+L2
3	-10	50	L1+L3
4	-15	30	L1+L4
5	-10	70	L1+L2+L3
6	-15	50	L1+L2+L4
7	-10	40	L1+L3+L4
8	-10	60	L1+L2+L3+L4

Results of complete combination

Design internal forces for area elements

With area elements, the design internal forces correspond to the plasticity approach from Wolfensberger and Thürlimann. This approach takes into account how much the reinforcement deviates from the crack direction. Due to the current lack of precise data regarding the combined load of reinforced concrete shell structures from bending and normal force, the design internal forces for bending and normal force are calculated independently according to the static limit theorem of the plasticity theory and then used together as the basis for the design in the two reinforcement directions. This approach should always lead to results that are on the safe side.

Depending on the type of area element and reinforcement configuration, the variants of design internal forces listed below are taken into account for the checks.

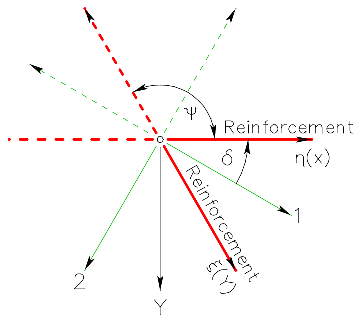
Orthogonal area reinforcement

Slabs	$m_x \pm \lvert m_{xy}\rvert$
	$m_y \pm \lvert m_{xy}\rvert$
Plain stress	$n_x \pm \lvert n_{xy}\rvert$
elements	$n_y \pm \lvert n_{xy}\rvert$
Shells	$m_x \pm \lvert m_{xy}\rvert$ and $n_x \pm \lvert n_{xy}\rvert$
	$m_y \pm \lvert m_{xy}\rvert$ and $n_y \pm \lvert n_{xy}\rvert$

Oblique area reinforcement

The bending design of slabs with oblique reinforcement assemblies is carried out according to Kuyt or Rüsch. Here the design moments are calculated with the help of the principal moments m_1, m_2 according to the equations given in Book 166 DAfStB.

For load case combinations, the calculation is based on the extreme values of m_1, m_2. For combined loads (bending and longitudinal force), both the design moments and the normal design forces are independently derived from n_1, n_2. The normal design forces are then used together as the basis for the design. This should also result in an upper limit for the load.



Coordinate systems

Extreme values (principal bending moments):

$$m_{1,2} = \frac{1}{2}\cdot(m_x + m_y) \pm \frac{1}{2}\sqrt{(m_x - m_y)^2 + 4m_{xy}^2}$$

with $m_1 \geq m_2$

The angle δ assigned to m_1 is:

$$\tan\delta = \frac{2\cdot m_{xy}}{(m_x - m_y) + \sqrt{(m_x - m_y)^2 + 4\cdot m_{xy}^2}}$$

Design moments:

$$m_\eta = \frac{1}{\sin^2\psi}\left[m_1\sin^2(\delta+\psi) + m_2\cos^2(\delta+\psi) \pm \left|\, m_1\sin\delta\,\sin(\delta+\psi) + m_2\cos\delta\,\cos(\delta+\psi)\right|\,\right]$$

$$m_\xi = \frac{1}{\sin^2\psi}\left[m_1\sin^2\delta + m_2\cos^2\delta \pm \left|\, m_1\sin\delta\,\sin(\delta+\psi) + m_2\cos\delta\,\cos(\delta+\psi)\right|\,\right]$$

The formulas apply accordingly for the normal design forces.

Checks in the Ultimate Limit States

The following checks are available:

- Bending and bending with normal force (SIA 262, Chapter 4.3.2)
- Lateral force (Chapter 4.3.3)
- Torsion and combined load (Chapter 4.3.5)
- Punching shear (Chapter 4.3.6).
- Fatigue (Chapter 4.3.8)

The following combinations in accordance with SIA 260, Chapter 4.4.3, are taken into account in the ultimate limit states:

- Permanent and temporary design situations

  $$E_d = E\{\gamma_G \cdot G_k, \gamma_P \cdot P_k, \gamma_{Q,1} \cdot Q_{k,1}, \psi_{0,i} \cdot Q_{k,i}\} \qquad (16)$$

- Accidental design situations

  $$E_d = E\{G_k, P_k, A_d, \psi_{2,i} \cdot Q_{k,i}\} \qquad (17)$$

- Design situations resulting from earthquakes (A_E) according to SIA 261, Section 16.1.4.

  $$E_d = E\{G_k, P_k, A_E, \psi_{2,i} \cdot Q_{k,i}\}$$

- Fatigue combination according to SIA 262, Chapter 4.3.8, combined with EN 1992-1-1, Chapter 6.8.3, Equation (6.68).

  $$E_d = E\{\{G_k, P_k, \psi_{1,1} \cdot Q_{k,1}, \psi_{2,i} \cdot Q_{k,i}\}; Q_{fat}\} \qquad (6.68)$$

  In this equation $Q_{k,1}$ and $Q_{k,i}$ are non-cyclic, non-permanent actions, whereas Q_{fat} defines the action of the relevant fatigue load.

For each combination you can define different design situations for the construction stages and final states. When conducting the check, the extreme value deriving from all combinations and situations is decisive.

Stress-Strain-Curves

The following characteristics are used for section design:

- Concrete: parabola-rectangle diagram according to SIA 262, Figure 12 and Equation (28). The coefficient η_t in Equations (2) and (3) which considers the effect of load duration on concrete strength, is assumed to be $\eta_t = 1$ according to Section 4.2.1.3.
- Reinforcing steel: stress-strain curve according to Figure 16, with rising upper branch and $k_s = 1.05$.
- Prestressing steel: stress-strain curve according to Figure 17, with horizontal upper branch according to Section 4.2.3.5.

The check against fatigue is carried out in the cracked state with a linear stress-strain curve according to Section 4.3.8.1.3.

Design for Bending and Bending With Normal Force

The design for bending and bending with normal force is carried out using a detailed section analysis according to SIA 262, Section 4.3.2.3, where the coefficient for the concrete compressive strength k_c = 1.0 is assumed. As a simplification, calculations are performed with k_s = 1.05 and ε_{ud} = 0.020 for all reinforcing steel types. The design includes slab, plain stress and shell elements with perpendicular or inclined reinforcement as well as beams. For each internal force combination, the necessary reinforcement due to the equilibrium conditions of the reinforced concrete section is determined iteratively. The final result is derived from the extreme value of all calculated reinforcements.

You can control the result of the design by specifying the reinforcement geometry and choosing one of three design modes.

Mode Standard

This is the standard design mode for bending with longitudinal force throughout the entire load area. Reinforcement will be calculated in the tensile section to the greatest degree possible. Given ratios between certain reinforcement layers in the tension or compression zone are maintained as far as possible, unless this is deselected in the design specifications. For reasons of economy, if the steel strain ε_{sd} part of the steel strength f_{sd} is exceeded, compressive reinforcement is determined. The required transverse reinforcement of slab as per Section 5.5.3.2 is considered during design according to user specification. However, the provision for horizontal reinforcement of walls as per Section 5.5.4.11 is not taken into account.

Mode Symmetrical

In contrast to the standard design, the reinforcement will be applied at all predefined locations in all strain areas, if necessary. The specified ratios between the reinforcement layers will not be affected unless this is deselected in the design specifications.

Mode Compression member

The design is performed symmetrically. Additionally, the minimum reinforcement of 0.6% required according to Section 5.5.4.2 of the standard is determined. This calculation is based on the entire area of the concrete section. For beams and design objects with tendons with bond the prestressing steel area is taken into account.

Design for Lateral Force

The design for lateral force includes the determination of lateral force reinforcement and the check of the resistance of the concrete compressive field according to SIA 262, Chapter 4.3.3. The following special conditions apply:

- The angle of the diagonal tensile reinforcement is assumed to be 90°.
- The minimum reinforcement according to Section 5.5.2.2 of the standard is included in the calculated stirrup reinforcement.
- For beams and design objects, the shear design is performed separately for the Q_y and Q_z lateral forces.
- Slab and shell elements are designed for the lateral force $q_r = \sqrt{(q_x^2 + q_y^2)}$.
- There is **no** limitation on the check locations according to Section 4.3.3.2.1 or 4.3.3.4.1 as well as **no** reduction of the action from loads near supports according to Section 4.3.3.2.7.
- For beams and design objects, the decisive values of the equivalent rectangle are determined by the user independently of the normal section geometry. The coefficients for calculating the inner lever arm z based on the effective width and effective height according to Section 4.3.3.4.2 must also be specified.
- For area elements, the calculation is normally performed with the lever arm $z = 0.9\, d$.
- The coefficient k_c for the concrete compressive strength defined by the user is taken into account.

Formulas used from the standard:

4.3.3.2 **Components without Lateral Force Reinforcement**

4.3.3.2.1 Lateral force resistance of slabs without lateral force reinforcement

$$v_{Rd} = k_d\, \tau_{cd}\, d_v \qquad (35)$$

$$k_d = \frac{1}{1 + \varepsilon_v\, d\, k_g} \qquad (36)$$

$$k_g = \frac{48}{16 + D_{max}} \qquad (37)$$

D_{max} Maximum grain in the concrete. $D_{max} = 0$ for lightweight concrete.

τ_{cd} Design value of the shear stress limit.

$$\tau_{cd} = \frac{0.3\,\eta_t \sqrt{f_{ck}}}{\gamma_c} \qquad (3)$$

d Static height, average static height given several reinforcement layers [mm].

d_v Effective static height for absorbing the lateral force $d_v = d$ is assumed.

η_t Coefficient to take into account the effect of the load duration on the concrete strength. In accordance with Section 4.2.1.3, $\eta_t = 1$ is assumed.

4.3.3.2.2 If the bending reinforcement remains in the elastic state:

$$\varepsilon_v = \frac{f_{sd}}{E_s}\,\frac{m_d}{m_{Rd}} \qquad (38)$$

If plastic deformation of the bending reinforcement cannot be ruled out:

$$\varepsilon_v = 1.5\,\frac{f_{sd}}{E_s} \qquad (39)$$

m_d Design value of the bending moment.

m_{Rd} Design value of the bending resistance.

4.3.3.2.3 The strain ε_v is to be increased by 50% if the longitudinal reinforcement in the check area is staged.

4.3.3.2.4 The strain ε_v is to be increased with $1/(\sin^4 \vartheta + \cos^4 \vartheta)$, where ϑ is the Angle between the principal reinforcement and principal direction of the lateral force ($\arctan q_y / q_x$).

4.3.3.3 Components with Lateral Force Reinforcement (Standard design)

4.3.3.4.3 Resistance of a vertical lateral force reinforcement

$$V_{Rd,s} = A_{sw}/s \cdot z \cdot f_{sd} \cot \alpha \qquad (43)$$

4.3.3.3.2 The compression field angle can freely be chosen between the following limits:

$$\alpha_{min} \le \alpha \le 45° \qquad (40)$$

The minimum compression field angle α_{min} is:

- α_{min} = 30° in the normal case,
- α_{min} = 25° if a significant longitudinal compressive force acts on the web,
- α_{min} = 40° if a longitudinal tensile force acts on the web or plastic deformations of the chord in the observed part of the girder are expected.

4.3.3.4.6 Resistance of the concrete compressive field

$$V_{Rd,c} = b_w \cdot z \cdot k_c \cdot f_{cd} \cdot \sin \alpha \cdot \cos \alpha \qquad (45)$$

k_c Coefficient for determination of the concrete strength according to Section 4.2.1.7.

4.3.3.4.12 Longitudinal tensile force as a result of lateral force

$$F_{tVd} = V_d\,(\cot \alpha - \cot \beta) \qquad (50)$$

β Angle of the stirrup reinforcement (here 90°).

$F_t = 0.5 \cdot |V_d| \cot \alpha$ (additional tensile force in the longitudinal reinforcement)

5.5.2.2 Minimum stirrup reinforcement of girders

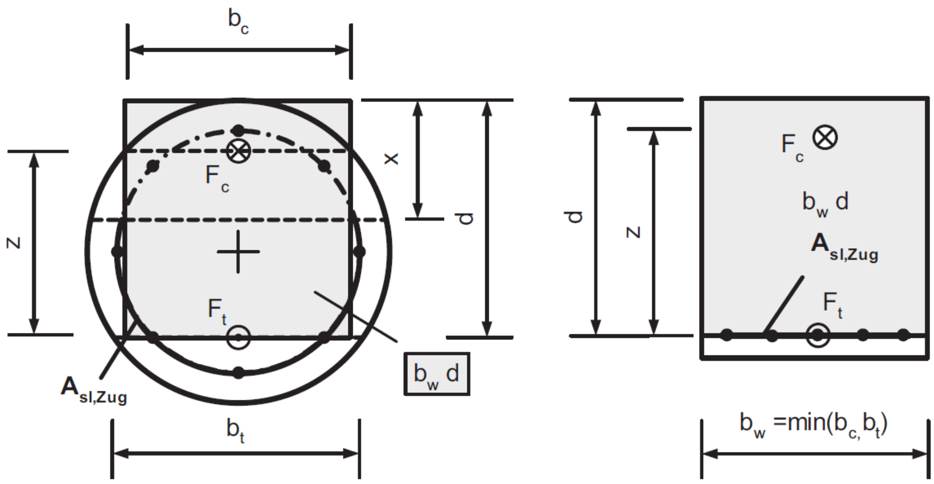
$$\rho_w = \frac{A_{sw}}{s\,b_w} \ge 0{,}001\sqrt{\frac{f_{ck}}{30}}\,\frac{500}{f_{sk}} \qquad (110)$$

5.5.3.4 The reinforcement content of slabs also has to satisfy the condition of Equation (110), if shear reinforcement is necessary.

Lateral force design for circular and annular cross-sections according to Bender et al.

For circular and annular cross sections with annular single stirrups or helixes, the lateral force design is optionally carried out according to Bender et al. (2010) for the resulting shear force $Q_r = \sqrt{(Q_y{}^2 + Q_z{}^2)}$.

In its interpretation of 1 June 2012 of Chapter 10.3 of DIN 1045-1:2008, the German Committee for Structural Engineering (NABau) recommends using the smaller value of the section width at the center of gravity of the steel tensile forces and the concrete compressive forces for the effective width b_w (see following figure). The values for the width b_w, the effective height d and the inner lever arm z are defined in the cross-section dialog.



Definition of the effective width bw as per NABau (2012) [Fig. from: Bender et al. (2006), p. 87]

For structural members without shear reinforcement, the resistance $V_{Rd,ct}$ is given according to Bender et al. (2006), Equ. (1), in accordance with DIN 1045-1:2008, Equ. (70). Therefore, the program uses the above equations (35) of SIA 262 with the selected value for b_w.

For structural members with shear reinforcement, the design is carried out according to Bender et al. (2010):

$$V_{Rd,sy} = \alpha_k \cdot A_{sw} / s_w \cdot f_{yd} \cdot z \cdot \cot\Theta \cdot \sin\alpha \quad (10)$$

$$V_{Rd,max} = \alpha_k \cdot b_w \cdot z \cdot \alpha_c \cdot f_{cd} \cdot \cot\Theta / [(\cot\Theta \cdot \cot\alpha)^2 + 1] \quad (11)$$

where

α_k	is an efficacy factor, which is stress-dependent ($0.715 \le \alpha_k \le 0.785$) according to Bender et al. (2010), p. 422, and can be assumed with the mean value $\alpha_k = 0.75$.
A_{sw}	is the section area of the lateral force reinforcement per length s_w.
s_w	is the distance of the lateral force reinforcement as measured along the component axis.
b_w	is the effective cross-section width.
z	is the inner lever arm.
Θ	is the inclination of the concrete compressive struts.
α	is the angle between the lateral force reinforcement and the component axis (helix inclination).
f_{yd}	is the design value for the yield strength of the lateral force reinforcement.
f_{cd}	is the design value of the concrete compressive strength.
α_c	is a coefficient to account for the stress state in the compression chord.

The additional tensile force in the longitudinal reinforcement due to lateral force Q_r is determined according to equation (50) of the standard. In case of simultaneous loading by lateral force and torsion, the torsion design is carried out according to the standard for vertical stirrups assuming a square torsion box.

The design results are stored separately from the standard design results.

Design for Torsion and Combined Loads

The design for torsion is carried out according to SIA 262, Chapter 4.3.5. The stirrup reinforcement, the longitudinal reinforcement and the resistance of the concrete compressive field are determined. According to the standard, for simultaneously acting lateral force and torsional load, the combined utilization of the concrete compressive field

$$\frac{V_d}{V_{Rd,c}} + \frac{T_d}{T_{Rd,c}}$$

is checked. The ideal hollow section on which this design is based is defined by the user independently of the normal section geometry.

Formulas used from the standard:

4.3.5 Torsion and combined load

4.3.5.2 Equivalent plain stress element forces

$$V_{d,i} = \frac{T_d}{2A_k} z_i \quad (54)$$

$V_{d,i}$ Design value of the lateral force in the plain stress element i .

T_d Design value of the torsional moment.

A_k Section area according to Figure 19.

z_i Lever arm of the longitudinal force in the plain stress element i .

4.3.5.3 Effective plain stress element thickness of solid sections

$$t_k \le d_k / 8 \quad (55)$$

d_k Maximum diameter that can be placed inside area A_k .

Punching Shear

The check of the load-bearing safety with respect to punching shear is carried out according to SIA 262, Chapter 4.3.6. The necessary punching reinforcement and longitudinal reinforcement to protect against collapse are determined.

The following special conditions apply:

- The factor k_e is determined according to Section 4.3.6.2.4.
- The average static height d results from the input parameters d_x and d_y with $d = (d_x + d_y) / 2$. The static height d_v for absorption of lateral force according to Section 4.3.6.2.1 is to be specified by the user.
- The action can be entered directly or taken from the analyzed design situation at the ultimate limit state. In this case, V_d is set to the maximum support force R_z for each corresponding action combination. The moment for consideration of the load eccentricity M_d results from the support moments M_x and M_y with $M_d = \sqrt{(M_x^2 + M_y^2)}$. It is therefore important that the support is oriented correctly. The least favorable combination is logged.
- In accordance with Section 4.3.6.2.6 soil pressures within the check perimeter can be used to reduce the design value of the lateral force V_d. This is taken into account if the value σ_0 is entered in the punching shear dialog.

The punching shear check is fulfilled when:

$V_d \le V_{Rd}$.

The following formulas are used:

4.3.6.2.4 Reduction factor for the circumference of the check perimeter

$$k_e = \frac{1}{1 + \frac{e_u}{b}} \quad (56)$$

e_u Load eccentricity of the column with:

$e_u = | M_d / V_d |$

M_d Moment for calculation of the load eccentricity.

b Diameter of a circle with the same area as the area of the column.

4.3.6.3.1 Punching resistance without punching reinforcement

$V_{Rd,c} = k_r \, \tau_{cd} \, d_v \, u$ (57)

with

τ_{cd} Design Value of the Shear Stress Limit

$$\tau_{cd} = \frac{0.3 \eta_t \sqrt{f_{ck}}}{\gamma_c} \quad (3)$$

d_v Static height.

u Circumference of the perimeter under consideration according to Figure 21 and 22.

η_t Coefficient to take into account the effect of the load duration on the concrete strength. In accordance with Section 4.2.1.3, $\eta_t = 1$ is assumed.

4.3.6.3.2
$$k_r = \frac{1}{0.45 + 0.18 \psi \, d \, k_g} \le 2 \quad (58)$$

with

4.3.6.4.1
$$\psi = 1.5 \frac{r_s}{d} \frac{f_{sd}}{E_s} \left(\frac{m_{sd}}{m_{Rd}} \right)^{3/2} \quad (59)$$

r_s Radial distance between column axis and moment zero point according to Section 4.3.6.4.4: r_s = Maximum (0.22 l_x; 0.22 l_y)

d Effective static height.

f_{sd} Design value for the yield criterion of reinforcing steel.

E_s Elasticity modulus of the reinforcing steel.

m_{sd} Average moment in the support band, determined for approximation level 2 according to Section 4.3.6.4.7 with Equations (61) to (64).

m_{Rd} Average value of the bending resistance in the support band.

k_g Coefficient for consideration of the maximum grain diameter according to Section 4.3.3.2.1.

4.3.6.5.4 Punching resistance with punching reinforcement

$V_{Rd,s} = \sum A_{sw} \, k_e \, \sigma_{sd} \sin\beta$ (67)

with

A_{sw} Area of the punching reinforcement.

σ_{sd} Design value of the stress in the punching reinforcement

$$\sigma_{sd} = \frac{E_s \psi}{6} \left(1 + \frac{f_{bd}}{f_{sd}} \frac{d}{\varnothing_{sw}} \right) \le f_{sd} \quad (68)$$

with

f_{bd} Design value of the bond stress

$$f_{bd} = \frac{1.4 \, f_{ctm}}{\gamma_c} \quad (103)$$

$\varnothing_{sw}$ Diameter of the punching reinforcement elements. The limit value of Table 20 is used in the program.

4.3.6.5.2 The design of punching reinforcement is carried out using the following lateral force

$V_{d,s} = V_d - V_{Rd,c}$ (65)

$V_{d,s} \ge V_d / 2$ (66)

4.3.6.5.7 Crack resistance of the concrete compressive diagonals

$V_{Rd,c} = 2 \, k_r \, \tau_{cd} \, d_v \, u \le 3.5 \, \tau_{cd} \, d_v \, u$ (67)

4.3.6.5.9 An additional check at the perimeter u_{out} is performed to determine the size of the area with punching reinforcement.

$V_d \leq V_{Rd,c,out}$

$V_{Rd,c,out} = k_r \tau_{cd} d_v u_{out}$

For the static height d_v, the value entered in accordance with Section 4.3.6.2.1 is used for the sake of simplicity.

4.3.6.7 Protection against collapse

Determination of the required longitudinal reinforcement on the side of the slab under bending compression.

$$V_{Rd,res} = \sum (A_s f_{sd} k_\beta) \leq 1.7\ \tau_{cd}\ d_{int}\ u_{int} \quad (70)$$

$$u_{int} = \sum (s_{int} + \pi/2\ d_{int}) \quad (71)$$

with

d_{int} Distance between bending reinforcement and reinforcement against collapse according to Figure 26.

s_{int} Distance between the outer reinforcing bars according to Figure 26.

k_β Coefficient according to Table 12.

Check Against Fatigue

Fatigue of Longitudinal Reinforcement, Shear Reinforcement and Prestressing Steel

The fatigue check is carried out according to SIA 262, Chapter 4.3.8. The steel stresses are calculated for longitudinal reinforcement from bending and longitudinal force as well as for prestressing steel in beams and design objects under the assumption of a cracked concrete section. For shear and longitudinal reinforcement from lateral force and torsion, the stresses are calculated according to Section 4.3.8.1.7 based on a truss model with the strut angle $tan\ \alpha_{fat} = \sqrt{tan\ \alpha} \leq 1$.

Where α is the angle between the concrete compression struts and the beam axis used in the corresponding ultimate limit state design. The prestressing steel stresses in area elements are determined at the uncracked concrete section. Tendons without bond and external tendons are not checked.

The check is carried out for the long-time strength according to Section 4.3.8.2.3, Equation (86):

$$\Delta\sigma_{sd}(Q_{fat}) \leq \Delta\sigma_{sd,D} \quad (86)$$

with

$$\Delta\sigma_{sd,D} \cong 0.8 \cdot \Delta\sigma_{sd,fat} \quad (86)$$

$\Delta\sigma_{sd}(Q_{fat})$ Stress range of fatigue action Q_{fat}.

$\Delta\sigma_{sd,fat}$ Design value of the fatigue strength according to Table 13.

In case of bonded presstressed tendons the stresses in the reinforcing steel are increased by the factor k_ξ according to Equation (81) to take into account the varying bond behavior of reinforcing and prestressing steel.

The values for $\Delta\sigma_{sd,fat}$ and k_ξ are specified by the user in the Section dialog.

Calculation method

The maximum from the robustness, crack and bending reinforcement is taken as the existing bending reinforcement. If as a result the load from the fatigue action in state II cannot be absorbed, the design will be repeated using the existing reinforcement and the check internal forces.

The maximum stress range per steel layer that results from the strain state in state II or the truss model is determined separately for each check situation. Multiplying the coefficient k_ξ yields the stress range $\Delta\sigma_{sd}$. If for longitudinal and shear reinforcement this range exceeds the permitted stress range according to Equation (86), the necessary reinforcement will be iteratively increased until the check succeeds for all situations. In the *Symmetrical* and *Compression member* design modes the longitudinal reinforcement is applied at all predefined locations. This will not affect the predefined relationships between the individual reinforcement layers.

The decisive reinforcement used for the check, which may have been increased, is recorded in the check log and saved for graphical representation.

Fatigue of Concrete Under Compressive Stress

The fatigue check for concrete that is subject to compressive stress is performed for bending and longitudinal force at the cracked section. This check takes into account the final longitudinal reinforcement and may include an increase applied during the fatigue check for reinforcing steel. The struts of components subject to lateral force stress are not analyzed.

The check according to Section 4.3.8.3.1 is proved, if Equation (91) is fulfilled:

$$|\sigma_{cd}|_{max} \leq 0.5\, k_c f_{cd} + 0.45\, |\sigma_{cd}|_{min} \leq 0.9\, k_c f_{cd} \tag{91}$$

with

$|\sigma_{cd}|_{max}$, $|\sigma_{cd}|_{min}$ Design values of the maximum and minimum concrete compressive stress for the fatigue action Q_{fat}. In the case of tensile stresses, $|\sigma_{cd}|_{min}$ is assumed to be zero.

k_c The reduction coefficient for the concrete compressive strength is assumed to be k_c = 1.0 according to Section 4.2.1.7.

Special Characteristic of Shell Structures

In shell structures the strain state at the cracked concrete section under general stress cannot be determined unambiguously. The design is therefore carried out separately for the reinforcement directions x and y with the design internal forces from Wolfensberger/Thürlimann or Rüsch as described above. The reinforcement calculated in this manner yields a reliable load-bearing capacity.

When calculating the stress range for reinforcing steel and concrete, this method can lead to unrealistic results in the case of torsional or shear stresses as shown in the following example:

Assume two identical sets of slab internal forces:

Set	mx [kNm/m]	my [kNm/m]	mxy [kNm/m]
1	300	200	100
2	300	200	100

According to Wolfensberger/Thürlimann, this results in design variants for the x direction:

Set	Variant	m [kNm/m]
1	1	mx + |mxy| = 400
	2	mx – |mxy| = 200
2	1	mx + |mxy| = 400
	2	mx – |mxy| = 200

The torsional moments generate a variation of the design moments and thus a calculatory stress range. This may lead to a necessary reinforcement increase in the fatigue check due to apparent overstressing. For normal design forces, this applies correspondingly to the shear forces.

Selecting ***Limit design variants*** in the Section dialog allows you to avoid the described effect. In this case only the corresponding variants are compared when determining the stress range, i.e. only the first and second variants of both sets in this example. Assuming constant stress, the stress range is thus correctly determined to be zero.

This alternative, however, does not ensure that all conceivable stress fluctuations are analyzed. You should therefore be particularly careful when assessing the results. For this purpose the detailed log indicates the main variants and design internal forces used for the check.

When determining the design internal forces according to Rüsch for inclined reinforcement, the described relationships apply accordingly.

Checks in the Serviceability Limit States

The following checks are performed:

- Limiting the concrete compressive stresses (SIA 262, Section 3.1.2.6.3 and 4.1.5.2.4).
- Minimum reinforcement against brittle failure (robustness reinforcement) (Chapter 4.4.2).
- Crack reinforcement in case of restraint (Chapter 4.4.2).
- Crack width limitation (Chapter 4.4.2).

In accordance with SIA 260, Section 4.4.4.4, the following combinations are taken into account in the serviceability limit states:

- Rare situations

$$E_d = E\{ G_k, P_k, \psi_{0,i} \cdot Q_{k,i} \} \tag{20}$$

- Frequent situations

$$E_d = E\{ G_k, P_k, \psi_{1,1} \cdot Q_{k,1}, \psi_{2,i} \cdot Q_{k,i} \} \tag{21}$$

- Quasi-continuous situations

$$E_d = E\{ G_k, P_k, \psi_{2,i} \cdot Q_{k,i} \} \tag{22}$$

Limiting the Concrete Compressive Stresses

The concrete compressive stress check is carried out in state I. For area elements the concrete stresses are calculated at the gross section. For beams and design objects, the bending stress is calculated

- without internal tendons at the gross section,
- with internal tendons without bond at the net section,
- with internal tendons with bond for situations before being grouted at the net section or otherwise at the ideal section.

In accordance with SIA 262, Section 3.1.2.6.3, the influence of the load level on the creep behavior is to be taken into account for concrete stresses $\sigma_c > 0.45\ f_{ck}$. If selected in the section dialog, this stress limit is verified for the quasi-continuous combination based on EN 1992-1-1, Section 7.2 (3).

In prestressed concrete components the concrete compressive stresses during and after the prestressing process may not exceed the value $0.6\, f_{ck}(t)$ at any location of the structure out of the anchoring area according to SIA 262, Section 4.1.5.2.4. If the concrete compressive stress also exceeds the value $0.45\, f_{ck}(t)$, the nonlinearity of the creep must be taken into account. $f_{ck}(t)$ indicates the characteristic value of the concrete compressive strength at time t when the prestressing is introduced.

The program assumes the time of introducing the prestressing to coincide with situation G1+P. If a quasi-continuous situation G1+P is defined, the concrete stress is checked against the limit value $0.45\, f_{ck}(t)$ or $0.6\, f_{ck}(t)$ for this situation depending on the user's specification. The value for $f_{ck}(t)$ is also defined in the dialog.

Minimum Reinforcement Against Brittle Failure

According to SIA 262, Chapter 4.4.2, brittle failure of concrete in the tensile zone must be prevented by installation of a minimum reinforcement. The minimum reinforcement (Robustness reinforcement) is calculated for the crack moment using the design values of the tensile strength f_{ctd} and the steel strength f_{sd}:

$$A_s = M_{cr} / (f_{sd} \cdot z)$$

with

M_{cr}	Crack moment by which a tensile stress of f_{ctd} occurs without prestressing effect at the section edge.
z	Lever arm of internal forces.

The crack moment results in $M_{cr} = W_c \cdot f_{ctd}$, the lever arm z of the internal forces is assumed to be $0.9 \cdot d$ for the sake of simplicity. In accordance with Section 4.4.2.3.6 the minimum reinforcement is to be placed in the tensile zone of the components. Referring to EN 1992-2, Section 6.1 (110), the rare action combination is used to determine the tensile zone.

In this process the statically undetermined prestressing effect should be taken into account rather than the statically determined prestressing effect. The program determines all stresses at the gross section. The statically determined prestressing effect can only be subtracted for beams and design objects. For area elements the prestress is alternatively reduced by a user-defined reduction factor.

The calculated reinforcement is evenly distributed to the reinforcement layers in the tensile zone. In the design mode *symmetrical* reinforcement is also applied to the remaining layers. This will not affect the predefined relationships between the individual reinforcement layers. For sections with mode *compression member* the robustness reinforcement is not checked because minimum reinforcement is already determined during the design for bending with longitudinal force.

Crack Reinforcement in Case of Restraint

The installation of a minimum reinforcement can be used to limit the crack width in case of imposed or obstructed deformations according to SIA 262, Section 4.4.2.3.7. In accordance with Section 4.4.2.3.6 the minimum reinforcement is to be placed in the tensile zone of the components. The tensile zone is defined by the user in the section dialog by selection of a restraint action (tension at the top/bottom, central tension).

The minimum reinforcement is calculated with the following equation:

$$A_s = k_s \cdot f_{ctd} \cdot A_{ct} / \sigma_{s,adm}$$

with

k_s Coefficient for consideration of stress distribution prior to crack formation:

$k_s = 1.0$ for centrical restraint

$k_s = 0.4$ for bending restraint of rectangular sections, deduced from SIA D 0182, Eq. (10.7)

$k_s = 0.9 \cdot F_{cr} / A_{ct} / f_{ctd} \geq 0.5$ in all other cases according to EN 1992-1-1, Eq. (7.3)

with the tensile force F_{cr} in the tension chord in state I directly before crack formation with the edge stress f_{ctd}. The tensile force is calculated by integrating the tensile stresses over the area A_{ct}.

f_{ctd} Design value of the concrete tensile strength. Depending on the selection in the section dialog one of the following equations is used:

$$f_{ctd} = k_t \cdot f_{ctm} \quad (98)$$

$$f_{ctd} = k_t \cdot f_{ctk0.95} \quad (100)$$

with

$$k_t = \frac{1}{1 + 0.5t} \quad (99)$$

t Smallest dimension of the observed tension chord [m]. For slabs and rectangular sections under bending load, $t = h/3$ applies.
The coefficient k_t can be defined in the section dialog. The suggested value is $k_t = 1.0$.

A_{ct} Area of the concrete tensile zone at initial crack formation in state I.

$\sigma_{s,adm}$ Reinforcing steel strength according to SIA 262:2017, Equation (100a), depending on the selected requirement (Table 17) and the bar diameter of the longitudinal reinforcement.

$$\sigma_{s,adm} = \sqrt{\frac{9 \cdot E_s \cdot f_{ctm} \cdot w_{nom}}{\varnothing_s}} \quad (100a)$$

w_{nom} Nominal crack width in the center of gravity of the reinforcement.

$\varnothing_s$ Diameter of a reinforcing bar.

If selected by the user, bonded prestressing steel within the tensile zone can optionally be taken into account for A_s according to Section 4.4.2.3.10.

Crack Width Limitation

Limitation of crack width is performed by comparing the existing reinforcing steel stresses with the permitted steel stresses according to SIA 262:2017, Table 17 and Equation (100a). The reinforcing steel stresses are calculated in state II for the maximum of robustness, crack and bending reinforcement including a possible increase resulting from the fatigue check. Depending on the selected requirement, the reinforcing steel stresses may not exceed the following values:

Requirement	Action combination	
	frequent	quasi-continuous
normal	-	$\sigma_s \leq f_{sd}$
raised	$\sigma_s \leq f_{sd}$ - 80 N/mm²	$\sigma_s \leq \sigma_{s,adm}$ for w_{nom} = 0.5 mm
high	$\sigma_s \leq f_{sd}$ - 80 N/mm²	$\sigma_s \leq \sigma_{s,adm}$ for w_{nom} = 0.2 mm

If the check cannot be proved with the existing reinforcement, the crack reinforcement will be increased.

Limiting Deformations

According to SIA 262, Chapter 4.4.3, the deformations of a component or structure may not impair its proper functioning or appearance. Considering that, the deformation should not exceed the limits specified in SIA 260.

The InfoCAD program system allows you to perform a realistic check as part of a nonlinear system analysis for beam and shell structures that takes geometric and physical nonlinearities into account. The resistance of the tendons with bond is currently not included in the calculation.

Editing is performed in the following steps:

- Define the check situation with the *Load group function* in the Load dialog through grouping the decisive individual load cases. The variable loads must first be weighted with the combination coefficients of the combination specified in SIA 260.
- Select the check load cases in the *Nonlinear Analysis / Serviceability* dialog of the analysis settings for the FEM or framework analysis.
- Set the reinforcement determined in the ultimate limit state in the *Start reinforcement* selection field (maximum from bending, robustness, crack check and fatigue).
- Perform the FEM or framework analysis to determine the deformations in state II.
- Check the system deformations displayed graphically or in tabular form.

For a detailed description of the nonlinear system analysis, refer to the relevant chapter of the manual.

Results

The extremal values for internal forces, support reactions, deformations, soil pressures and stresses are saved for all check situations. The resulting bending, minimum- and crack reinforcement, the decisive maximum value and the stirrup and torsion reinforcement are provided for the graphical representation as well.

The log shows the design internal forces and necessary reinforcements, checked stresses or crack widths at each result location. If the permissible limit values are exceeded, they are reported as warnings and indicated at the check location. The detailed log also lists the decisive combination internal forces of all design situations.

Stresses for beams and design objects

σ_x	Longitudinal stress in the concrete compressive stress check [MN/m²].
σ_s, $\Delta\sigma_s$	Stresses and stress ranges for reinforcing steel [MN/m²].
σ_p, $\Delta\sigma_p$	Stresses and stress ranges for prestressing steel [MN/m²].
σ_{cd}, $\Delta\sigma_{cd}$	Stresses and stress ranges in the fatigue check for concrete under longitudinal compression [MN/m²].
$\Delta\sigma_{sb,y}$, $\Delta\sigma_{sb,z}$	Stress ranges for shear reinforcement from Q_y and Q_z [MN/m²].
$\Delta\sigma_{sb,T}$, $\Delta\sigma_{sl,T}$	Stress ranges for shear reinforcement from torsion and for longitudinal torsion reinforcement [MN/m²].
σ / σ_{perm}	Stress utilization.
$\Delta\sigma / \Delta\sigma_{perm}$	Stress range utilization.

Stresses for area elements

σ_x, σ_y	Longitudinal stress in x or y direction [MN/m²].
σ_{sx}, $\Delta\sigma_{sx}$	Stresses and stress ranges for reinforcing steel in the x direction [MN/m²].
σ_{sy}, $\Delta\sigma_{sy}$	Stresses and stress ranges for reinforcing steel in the y direction [MN/m²].
σ_p, $\Delta\sigma_p$	Stresses and stress ranges for prestressing steel [MN/m²].
$\sigma_{cd,x}$, $\Delta\sigma_{cd,x}$,	Stresses and stress ranges in the concrete fatigue check under longitudinal compression in the x-
$\sigma_{cd,y}$, $\Delta\sigma_{cd,y}$	and y-direction [MN/m²].
$\Delta\sigma_{s,b}$	Stress ranges for shear reinforcement [MN/m²].
σ / σ_{perm}	Stress utilization.
$\Delta\sigma / \Delta\sigma_{perm}$	Stress range utilization.

Bending Reinforcement

A_s	Bending reinforcement [cm²] for beams.
a_{sx}, a_{sy}	Bending reinforcement [cm²/m] for area elements in the x and y direction.
$a_{s\varphi}$	Meridian reinforcement [cm²/m] for axisymmetric shell elements.
$a_{s\upsilon}$	Ring reinforcement [cm²/m] for axisymmetric shell elements.

Reinforcement from lateral force

a_{sb}	Stirrup reinforcement [cm²/m²] of area and axisymmetric shell elements.
$A_{sb.y}$	Stirrup reinforcement of beams from Q_y [cm²/m].
$A_{sb.z}$	Stirrup reinforcement of beams from Q_z [cm²/m].
a_{sq}	Longitudinal reinforcement from the lateral force design of area elements [cm²/m].
$A_{sl.y}$	Longitudinal reinforcement of beams from Q_y [cm²].
$A_{sl.z}$	Longitudinal reinforcement of beams from Q_z [cm²].

Torsion reinforcement

A_{sb}	Stirrup reinforcement of beams from torsion [cm²/m].
$A_{sl,T}$	Longitudinal reinforcement of beams from torsion [cm²].

Design values

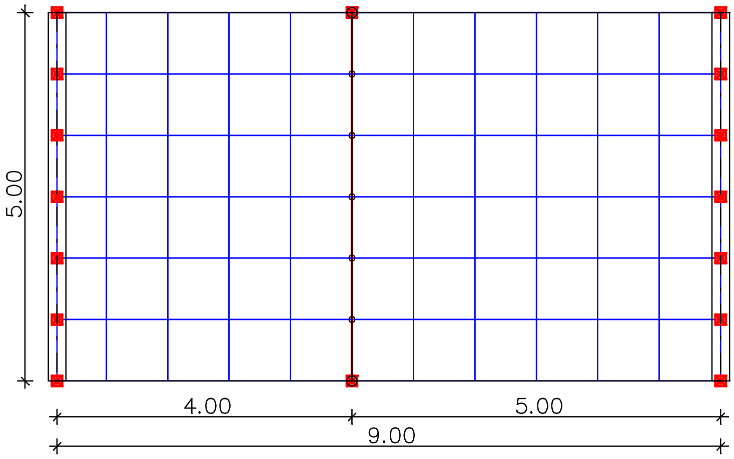
V_{yRdc}	Resistance of the concrete compressive field with respect to Q_y [kN].
V_{zRdc}	Resistance of the concrete compressive field with respect to Q_z [kN].
$Q/V_{Rdc}+M_x/T_{Rdc}$	Utilization of the concrete compressive field as a result of combined load from lateral force and torsion.
T_{Rdc}	Resistance of the concrete compressive field with respect to M_x [kNm].

Examples

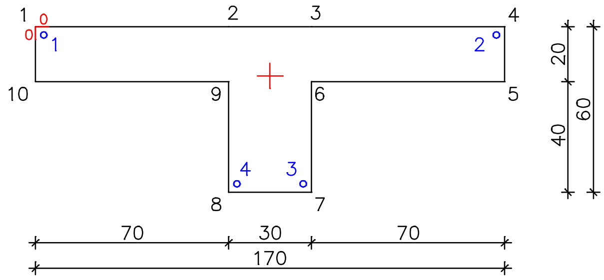
Slab With Downstand Beam

In this example a rectangular slab (d = 20 cm, *SC25/30*) with a downstand beam is analyzed. This joint-supported slab will be subjected to a traffic load of 10 kN/m².

The necessary design specifications and the stirrup reinforcements calculated for the slab and the downstand beam are shown.



The following image shows the dimensions of the downstand beam. The axis distance of the reinforcing steel from the section edge is 3 cm. The dead load of the downstand beam is reduced by the share attributed to the slab.



SIA 262 actions

Standard design group

G - Dead load

```
Gamma.sup / gamma.inf = 1.35 / 0.8

Load cases
----------
1    Dead load
```

QN - Imposed load, traffic load

```
Gamma.sup / gamma.inf = 1.5 / 0

Combination coefficients for: Buildings
Working load - category A - floor spaces
Psi.0 / Psi.1 / Psi.2 = 0.7 / 0.5 / 0.3

Load cases 1. Variant, inclusive
--------------------------------
2    Traffic span 1
3    Traffic span 2
```

1. Permanent and temporary situation

```
Final state
G  - Dead load
QN - Imposed load, traffic load
```

1. Rare (characteristic) situation

```
Final state
G  - Dead load
QN - Imposed load, traffic load
```

1. Frequent situation

```
Final state
G  - Dead load
QN - Imposed load, traffic load
```

1. Quasi-continuous situation

```
Final state
G  - Dead load
QN - Imposed load, traffic load
```

Design overview

Se.	Prestress of component	Requi- rement	Reinforc. M R B Q T	Fatig. S P C	Crack width	Comp.- stress
1	Not prestressed	raised	x + x x .	. . .	x	.
2	Not prestressed	raised	x + x x .	. . .	x	.

```
(M) Nominal reinforcement against brittle failure (robustness reinforcement).
(R) Crack reinforcement from restraint (x), required reinf. due to load (+).
(B) Flexural reinforcement at ultimate limit state.
(Q) (Nominal)lateral force reinforcement at ultimate limit state.
(T) Torsional reinforcement at ultimate limit state.
(S) Reinforcing steel at fatigue check.
(P) Prestressing steel at fatigue check.
(C) Concrete at fatigue check.
```

Settings for flexural and shear reinforcement

```
M,N      Design mode for bend and longitudinal force:
         (ST) Standard, (SY) Symmetrical, (CM) Compression member.
Red.     Reduction factor of prestress for determining the tensile zone for
         distribution of reinf. against brittle failure for area elements.
Fac. as  Factor for bending reinf. of slabs in secondary dir. per 5.5.3.2.
eta.t    Coefficient for concrete strength as per 4.2.1.3.
fsk      Quality of stirrups [MN/m²].
Alpha    Compression field angle [°].
kc       Reduction factor for concrete strength as per 4.2.1.7.
Slab     Beams are designed like slabs.
eps.v    Base value of strain as per 4.3.3.2.2 [o/oo].
Dmax     Max. grain of concrete as per Eq. (37) [mm].
Long.    Longitudinal reinforecent is graded as per 4.3.3.2.3.
```

Se.	Concrete	Des. for M,N	Red. pre- str.	Fac. as	eta.t	fsk [MN/m²]	Alpha [°]	kc	Des. like slabs	Base value eps.v	Dmax [mm]	Long. reinf. graded
1	SC25/30	ST	.	0.20	1.00	500	45.00	0.55	.	3.00	32	.
2	SC25/30	ST	.	.	1.00	500	45.00	0.55	.	.		.

Shear sections

```
bw.nom   Nominal width of the prestressed section according to 4.3.3.3.5.
h.nom    Nominal height of the prestressed section according to 4.3.3.3.5.
kb, kd   Factor to calculate the inner lever arm z from the eff. width bn resp.
         from the eff. height d according to 4.3.3.4.2.
z1, z2   Dimensions of the ideal hollow section for torsion as per 4.3.5.1.
tk       Thickness of the ideal hollow section.
```

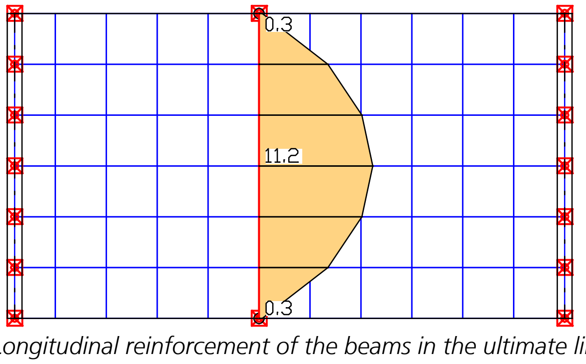
Se.	Width [m] bw	bw.nom	Eff. width bn [m]	kb	Height[m] h	h.nom	Eff.height d [m]	kd	Torsion section [m] z1	z2	tk
1	1.000	.	.	.	0.200	.	0.170	0.90	.	.	.
2	0.300	.	0.270	0.90	0.600	.	0.570	0.90	0.540	0.240	0.060

Settings for crack control

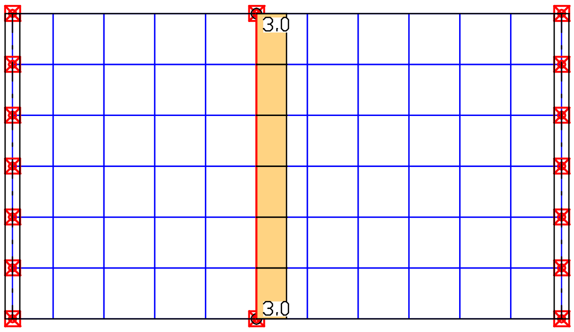
```
ds       Max. given bar diameter of the reinforcing steel as per Fig. 31
fctd     Design value of concrete tensile strength.
kt       Reduction factor for concrete tensile strength.
```

Se.	Type of restraint	ds [mm]	kt	fctd	Regard pre- str. steel
1	.	10	1.00	kt*fctm	.
2	.	10	1.00	kt*fctm	.

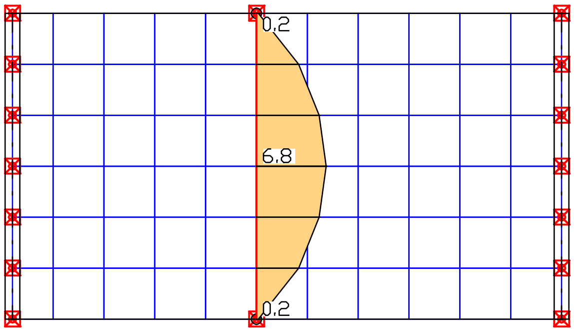
The calculated reinforcements are shown in the illustrations below.



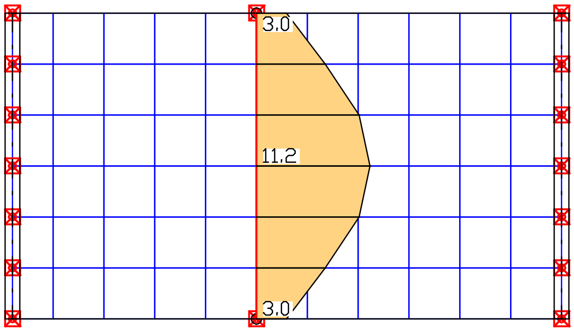
Longitudinal reinforcement of the beams in the ultimate limit state [cm²]



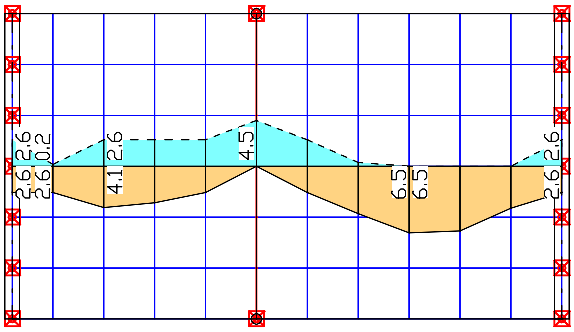
Longitudinal reinforcement of the beams to ensure robustness [cm²]



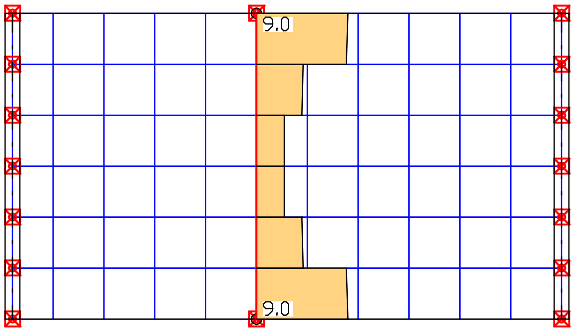
Longitudinal reinforcement of the beams to limit the crack width [cm²]



Maximum longitudinal reinforcement of the beams [cm²]



Maximum slab reinforcement in the intersection direction based on the robustness, crack width and design checks in the ultimate limit state [cm²/m]



Lateral force reinforcement of the beams [cm²/m]

An excerpt of the detailed log for the midspan of the downstand beam is provided below.

Design of longitudinal reinforcement

```
The calculated requ. reinforcement includes the specified basic reinforcement.

(M) Nominal reinf. against brittle failure acc. to Chapter 4.4.2 (Charact. C.).
    fctd    Design value of concrete tensile strength as per Chapter 4.4.1 [MN/m²]
    zs,t/b  Lever arm of inner strengths top/bottom with zs=0,9*d [m]
    S.s,adm Admissible steel stress as per Fig. 31 [MN/m²]
    max Sc  Maximum concrete edge stress from Charact. C. [MN/m²]
(R) Required reinforcement as per 4.4.2 for crack width limitation
    Increase of reinforcement due to crack width check is marked by "!".
    ds      Maximal given steel diameter [mm]
(B) Design of reinforement at ultimate limit state
    In case of dominant bending, compression reinforcement is marked with "*".
    fck     Concrete strength for design of reinforcement [MN/m²]
```

Beam 70

Location 1

```
Beam 70, x = 0.00 m (Beam length 0.83 m)
Cross-section 2: Polygon - SC25/30
Steel 2; Design mode: Standard
(M) fctd=2.6; zs,o/u=0.513/0.513; Sigma.s,adm=435
(R) fctd=2.6; ds=10
(B) fck=25
```

Section properties	A [m²]	ys [m]	zs [m]	Iy [m4]	Iz [m4]	Iyz[m4]
gross :	0.460	0.850	0.178	0.0107	0.0828	0.0000

1. Characteristic (rare) combination (CC.1): G+QN, Final state

Concrete internal forces

	Nx[kN]	My[kNm]	Mz[kNm]
Nx- :	0.00	69.95	0.00
Nx+ :	0.00	69.95	0.00
My- :	0.00	69.95	0.00
My+ :	0.00	196.53	0.00
Mz- :	0.00	69.95	0.00
Mz+ :	0.00	69.95	0.00

1. Frequent combination (TC.1): G+QN, Final state

Concrete internal forces

	Nx[kN]	My[kNm]	Mz[kNm]
Nx- :	0.00	69.95	0.00
Nx+ :	0.00	69.95	0.00
My- :	0.00	69.95	0.00
My+ :	0.00	133.24	0.00
Mz- :	0.00	69.95	0.00
Mz+ :	0.00	69.95	0.00

1. Quasi-continuous combination (QC.1): G+QN, Final state

Concrete internal forces

	Nx[kN]	My[kNm]	Mz[kNm]
Nx- :	0.00	69.95	0.00
Nx+ :	0.00	69.95	0.00
My- :	0.00	69.95	0.00
My+ :	0.00	107.92	0.00
Mz- :	0.00	69.95	0.00
Mz+ :	0.00	69.95	0.00

1. Permanent and temporary comb. (PC.1): G+QN, Final state

Concrete internal forces

	Nx[kN]	My[kNm]	Mz[kNm]
Nx- :	0.00	55.96	0.00
Nx+ :	0.00	55.96	0.00
My- :	0.00	55.96	0.00
My+ :	0.00	284.31	0.00
Mz- :	0.00	55.96	0.00
Mz+ :	0.00	55.96	0.00

Design of longitudinal reinforcement

Reinforcement Lay.	Type	Nx [kN]	My [kNm]	Mz [kNm]	max Sc [MN/m²]	Ap' [cm²]	req.As [cm²]	Situation
1	M	0.00	69.95	0.00	.	.	0.00	CC.1,Nx-
	R	0.00	0.00	0.00	0.00	.	0.00	-,-
	B	0.00	55.96	0.00	.	.	0.00	PC.1,Nx-
2	M	0.00	69.95	0.00	.	.	0.00	CC.1,Nx-
	R	0.00	0.00	0.00	0.00	.	0.00	-,-
	B	0.00	55.96	0.00	.	.	0.00	PC.1,Nx-
3	M	0.00	196.53	0.00	7.73	.	1.48	CC.1,My+
	R	0.00	133.24	0.00	.	.	3.41!	TC.1,My+
	B	0.00	284.31	0.00	.	.	5.58	PC.1,My+
4	M	0.00	196.53	0.00	7.73	.	1.48	CC.1,My+
	R	0.00	133.24	0.00	.	.	3.41!	TC.1,My+
	B	0.00	284.31	0.00	.	.	5.58	PC.1,My+

Design of shear reinforcement

```
The percentage of nominal reinforcement acc. to 5.5.2.2 is considered.

bw        Effective width for calculation of shear stresses from Qz [m]
bn        Statically effective width for shear design using Qy [m]
kb        Factor to calculate the inner lever arm from bn
h         Effective height for calculation of shear stresses from Qy and Mx [m]
d         Statically effective height for shear design using Qz [m]
kd        Factor to calculate the inner lever arm from d
fsk       Strength of stirrup reinforcement [MN/m²]
kc        Reduction coefficient to determine the concrete strength
Qy, Qz    Lateral forces for design in y- and z-direction [kN]
VRd       Lateral force resistance without lateral reinforcement [kN]
VRdc      Lateral force resistance of the compression field [kN]
z         Inner lever arm z=kb*bn resp. z=kd*d
Alpha     Compression filed angle [°]
Asb.y,z   Req. stirrup reinforcement from aus Qy, Qz [cm²/m]
Asl.y,z   Req. longitudinal reinforcement from Qy, Qz [cm²]
```

Beam 70

Location 1

```
Beam 70, x = 0.00 m (Beam length 0.83 m)
Cross-section 2: Polygon - SC25/30
bw/bn/kb=0.3/0.27/0.9; h/d/kd=0.6/0.57/0.9
fsk=500; kc=0.55
```

1. Permanent and temporary comb. (PC.1): G+QN, Final state

```
Concrete internal forces
         Nx[kN]   My[kNm]   Mz[kNm]   Mx[kNm]    Qy[kN]    Qz[kN]
Nx-  :     0.00     55.96      0.00      0.00      0.00     -5.41
Nx+  :     0.00     55.96      0.00      0.00      0.00     -5.41
My-  :     0.00     55.96      0.00      0.00      0.00     -5.41
My+  :     0.00    284.31      0.00      0.00      0.00    -30.79
Mz-  :     0.00     55.96      0.00      0.00      0.00     -5.41
Mz+  :     0.00     55.96      0.00      0.00      0.00     -5.41
Mx-  :     0.00     55.96      0.00      0.00      0.00     -5.41
Mx+  :     0.00     94.43      0.00      0.00      0.00     -9.13
Qy-  :     0.00     55.96      0.00      0.00      0.00     -5.41
Qy+  :     0.00     55.96      0.00      0.00      0.00     -5.41
Qz-  :     0.00    284.31      0.00      0.00      0.00    -30.79
Qz+  :     0.00     55.96      0.00      0.00      0.00     -5.41
```

Check of the shear reinforcement and the compressive struts

```
Qy            :    0.00 kN    Alpha     :  45.00 °
Qy/VyRdc      :    0.00       z         :   0.24 m
Situation     : -,-           req.Asb.y :   0.00 cm²/m
                              req.Asl.y :   0.00 cm²

Qz            :  -30.79 kN    Alpha     :  45.00 °
Qz/VzRdc      :    0.04       z         :   0.51 m
Situation     : PC.1,Qz-      req.Asb.z :   2.74 cm²/m
                              req.Asl.z :   0.35 cm²
```

Check of crack widths

```
The check is led by limiting the steel stress.
The final long. reinforcement as the maximum from robustness, crack and bending
reinf. incl. a possible increase resulting from the fatigue check is decisive.

(TC) Frequent, (QC) Quasi-continuous combination

ds       Maximal given steel diameter [mm]
Sigma.c  Maximal concrete edge stress in state I [MN/m²]
Sigma.s  Reinf. steel stress in state II [MN/m²]
per.     Permissible steel stress as per Table 17 and Fig. 31 [MN/m²]
```

Beam 70

Location 1

```
Beam 70, x = 0.00 m (Beam length 0.83 m)
Cross-section 2: Polygon - SC25/30
Requirement: raised; ds=10; fctm=2.6

Section properties    A [m²]   ys [m]   zs [m]   Iy [m4]   Iz [m4]   Iyz[m4]
          gross  :     0.460    0.850    0.178    0.0107    0.0828    0.0000
```

1. Frequent combination (TC.1): G+QN, Final state

```
Concrete internal forces
         Nx[kN]   My[kNm]   Mz[kNm]
Nx-  :     0.00     69.95      0.00
Nx+  :     0.00     69.95      0.00
My-  :     0.00     69.95      0.00
My+  :     0.00    133.24      0.00
Mz-  :     0.00     69.95      0.00
Mz+  :     0.00     69.95      0.00
```

1. Quasi-continuous combination (QC.1): G+QN, Final state

```
Concrete internal forces
          Nx[kN]   My[kNm]    Mz[kNm]
Nx-  :      0.00     69.95       0.00
Nx+  :      0.00     69.95       0.00
My-  :      0.00     69.95       0.00
My+  :      0.00    107.92       0.00
Mz-  :      0.00     69.95       0.00
Mz+  :      0.00     69.95       0.00
```

Check of crack width for reinf. layer 3 (bottom) - Frequent combination

```
Nx  [kN]  :      0.00     Sigma.c [MN/m²]:   5.24
My  [kNm] :    133.24     As      [cm²]  :   5.58
Mz  [kNm] :      0.00     Sigma.s [MN/m²]: 218.56   per. 355.00
Situation : TC.1,My+
```

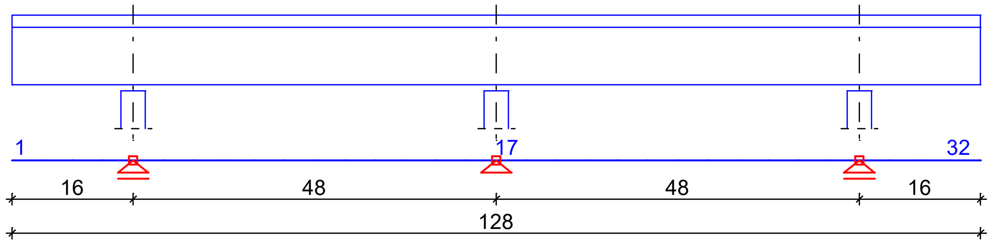
Check of crack width for reinf. layer 3 (bottom) - Quasi-continuous combination (w.nom = 0.5 mm)

```
Nx  [kN]  :      0.00     Sigma.c [MN/m²]:   4.25
My  [kNm] :    107.92     As      [cm²]  :   5.58
Mz  [kNm] :      0.00     Sigma.s [MN/m²]: 176.93   per. 435.00
Situation : QC.1,My+
```

Prestressed Roof Construction

This example involves the wide-spanned roof construction of an entrance hall that is represented as a continuous girder over two spans with a double-sided cantilever. A T-beam is selected as the section. The figure below shows the system in longitudinal and lateral section view.

Limited prestressing with subsequent bond is applied to the roof construction in the longitudinal direction. Prestressing in the lateral direction is not applied for reasons of economy. Increased requirements apply for cracking.

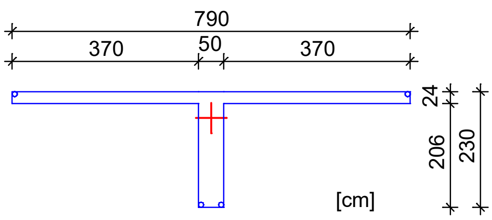


Static system and dimensions [m]

Material

Concrete	*SC45/55*
Reinforcing steel	*BSt 500*, axis distance from edge 5 cm

Section

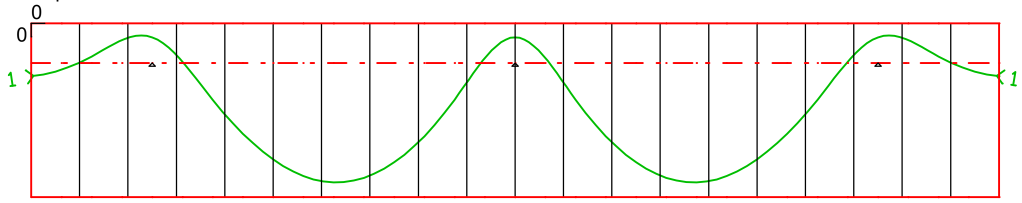


Prestressing steel and prestressing system

Prestressing steel quality	St 1520/1770
Certification of the prestressing system	SIA 262
Number of tendons in the bundle	4
Section surface A_p	1800 mm²
E-modulus of the prestressing steel	195000 MN/m²
0.1% strain limit (yield strength) of the prestressing steel $f_{p0.1k}$	1520 MN/m²
Tensile strength of the prestressing steel f_{pk}	1770 MN/m²
Permissible prestressing force of a tendon P_{m0}	2230.2 kN
Prestressing loss from relaxation of prestressed steel	4.5 %
Friction coefficients when prestressing and releasing μ	0.2
Unintentional deviation angle of a tendon β'	0.3 °/m
Slippage at prestressing anchor	6 mm
Duct diameter d_h	82 mm

The tendon guide is shown in the next figure. 4 bundled tendons are arranged such that they stretch across the entire girder length and are prestressed at both girder ends. The prestressing system, prestressing procedure and prestressing curve for a tendon group are also shown.

Tendon groups in beam series view 1, [-16.00/0.00/0.00] - [112.00/0.00/0.00] / [-16.00/0.00/1.00]
Superelevation = 10



Tendon group ordinates zv [cm] at the base points

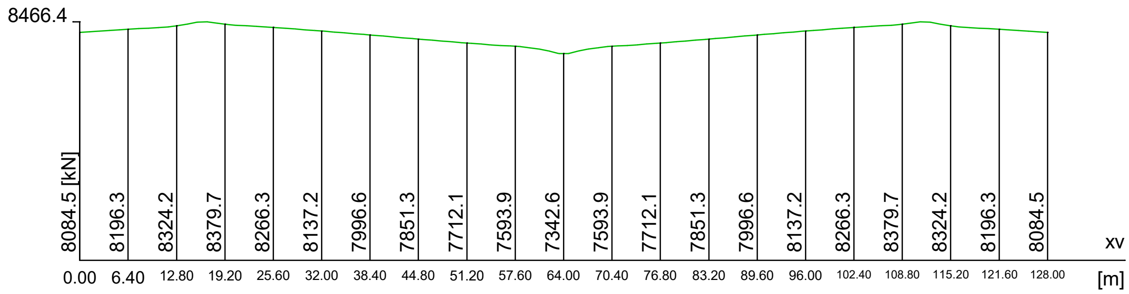
xv	0.00	6.40	12.80	19.20	25.60	32.00	38.40	44.80	51.20	57.60	64.00	70.40	76.80	83.20	89.60	96.00	102.40	108.80	115.20	121.60	128.00
1	70.0	52.0	19.2	42.0	120.2	180.1	208.8	201.5	157.4	78.3	18.5	78.3	157.4	201.5	208.8	180.1	120.2	42.0	19.2	52.0	70.0

Force function of tendon group 1 (4 tendon(s), l = 128.41 m)

Prestressing system 1 - Example. Certification according to SIA 262.
Pm0 = 2230.2 kN, Ap = 1800.0 mm², μa = 0.20, Angle ß' = 0.30 °/m
E-Modulus= 195000 MN/m², Ah = 5281.0 mm², μn = 0.20, Slippage = 6.00 mm

Prestressing procedure 1 - Example

		Start	End
Pre. anchor	:	Start	End
Normal. force	:	1.000	1.000
Pre. force	[kN]:	2230.2	2230.2
Extension	[mm]:	674.9	70.8



Tendon guide and prestressing curve in the longitudinal section (4 tendons).

Loads

Load case 1 Dead load

Load case 2 Additional dead load: q=11.06 kN/m

Load case 3 Snow load: q=7.90 kN/m

Load case 10 Prestressing

Load case 15 Creep-generating permanent load: Dead load, additional dead load and prestressing

Load case 20 Creep and shrinkage
Coefficients: $\varphi_{t\infty} = 2.55$; $\rho = 0.8$; $\varepsilon_{t\infty} = -24.8 \cdot 10^{-5}$
Creep-generating permanent load case: 15
The redistribution of internal forces between concrete and prestressing steel are taken into account.

SIA 262 actions

Standard design group

G - Dead load

Gamma.sup / gamma.inf = 1.35 / 0.8

Load cases

1 Dead load

G - Additional dead load

Gamma.sup / gamma.inf = 1.35 / 0.8

Load cases

2 Additional dead load

QS - Snow and ice load

Gamma.sup / gamma.inf = 1.5 / 0

Combination coefficients for: Buildings
Snow loads
Psi.0 / Psi.1 / Psi.2 = 1 / 1 / 1

Load cases 1. Variant, inclusive

3 Snow load

P - Prestressing

Gamma.sup / gamma.inf = 1 / 1

Load cases internal prestressing

10 Prestressing

CSR1 - Creep, shrinkage, relaxation

Prestressing loss from relaxation of prestressed steel: 4.5 %.

Load cases

20	Creep, shrinkage

1. Permanent and temporary situation

Construction stage - Ungrouted

G	Dead load
P	Prestressing

2. Permanent and temporary situation - t0

Final state

G	Dead load
G	Additional dead load
P	Prestressing
QS	Snow and ice load

3. Permanent and temporary situation - too

Final state

G	Dead load
G	Additional dead load
P	Prestressing
CSR1	Creep, shrinkage, relaxation
QS	Snow and ice load

1. Rare (characteristic) situation

Construction stage - Ungrouted

G	Dead load
P	Prestressing

2. Rare (characteristic) situation - t0

Final state

G	Dead load
G	Additional dead load
P	Prestressing
QS	Snow and ice load

3. Rare (characteristic) situation - too

Final state

G	Dead load
G	Additional dead load
P	Prestressing
CSR1	Creep, shrinkage, relaxation
QS	Snow and ice load

1. Frequent situation

Construction stage

G	Dead load
P	Prestressing

2. Frequent situation - t0

Final state

G	Dead load
G	Additional dead load
P	Prestressing
QS	Snow and ice load

3. Frequent situation - too

Final state

G	Dead load
G	Additional dead load
P	Prestressing
CSR1	Creep, shrinkage, relaxation
QS	Snow and ice load

1. Quasi-continuous situation

Construction stage

G	Dead load
P	Prestressing

2. Quasi-continuous situation - t0

Final state

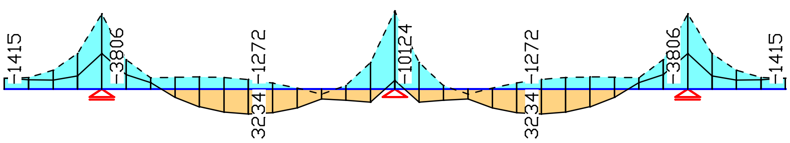
G	Dead load
G	Additional dead load
P	Prestressing
QS	Snow and ice load

3. Quasi-continuous situation - too

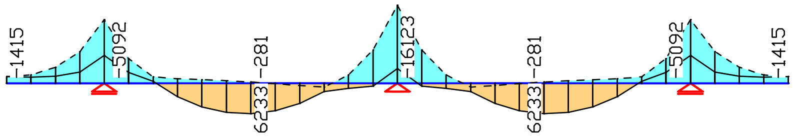
Final state

G	Dead load
G	Additional dead load
P	Prestressing
CSR1	Creep, shrinkage, relaxation
QS	Snow and ice load

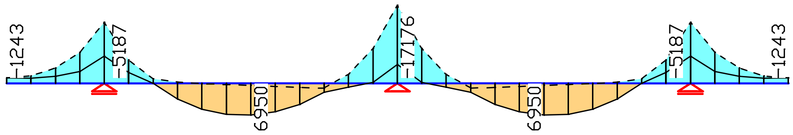
In this example all possible combinations of load cases are generated and designed. This method is selected in the calculation settings and can be very slow when applied for a large number of load cases.
Below you will find an example of the curve of bending moment M_y for design situations in the ultimate limit states.



Bending moment M_y of the 1. permanent and temporary situation [kNm]



Bending moment M_y of the 2. permanent and temporary situation [kNm]



Bending moment M_y of the 3. permanent and temporary situation [kNm]

Design according to SIA 262 (2017)

Design overview

Se.	Prestress of component	Requi- rement	Reinforc. M R B Q T	Fatig. S P C	Crack width	Comp.- stress
1	Subsequent bond	raised	x + x x .	. . .	x	x

(M) Nominal reinforcement against brittle failure (robustness reinforcement).
(R) Crack reinforcement from restraint (x), required reinf. due to load (+).
(B) Flexural reinforcement at ultimate limit state.
(Q) (Nominal-)lateral force reinforcement at ultimate limit state.
(T) Torsional reinforcement at ultimate limit state.
(S) Reinforcing steel at fatigue check.
(P) Prestressing steel at fatigue check.
(C) Concrete at fatigue check.

Settings for flexural and shear reinforcement

M,N	Design mode for bend and longitudinal force: (ST) Standard, (SY) Symmetrical, (CM) Compression member.
Red.	Reduction factor of prestress for determining the tensile zone for distribution of reinf. against brittle failure for area elements.
Fac. as	Factor for bending reinf. of slabs in secondary dir. per 5.5.3.2.
eta.t	Coefficient for concrete strength as per 4.2.1.3.
fsk	Quality of stirrups [MN/m²].
Alpha	Compression field angle [°].
kc	Reduction factor for concrete strength as per 4.2.1.7.
Slab	Beams are designed like slabs.
eps.v	Base value of strain as per 4.3.3.2.2 [o/oo].
Dmax	Max. grain of concrete as per Eq. (37) [mm].
Long.	Longitudinal reinforecent is graded as per 4.3.3.2.3.

Se.	Concrete	Des. for M,N	Red. pre- str.	Fac. as	eta.t	fsk [MN/m²]	Alpha [°]	kc	Des. like slabs	Base value eps.v	Dmax [mm]	Long. reinf. graded
1	SC45/55	ST	.	.	1.00	500	45.00	0.55	.	.		.

Shear sections

bw.nom	Nominal width of the prestressed section according to 4.3.3.3.5.
h.nom	Nominal height of the prestressed section according to 4.3.3.3.5.
kb, kd	Factor to calculate the inner lever arm z from the eff. width bn resp. from the eff. height d according to 4.3.3.4.2.
z1, z2	Dimensions of the ideal hollow section for torsion as per 4.3.5.1.
tk	Thickness of the ideal hollow section.

Se.	Width [m] bw	bw.nom	Eff. width bn [m]	kb	Height[m] h	h.nom	Eff.height d [m]	kd	Torsion section [m] z1	z2	tk
1	0.500	0.500	0.450	0.90	2.300	2.300	2.250	0.90	2.200	0.400	0.100

Settings for crack control

ds	Max. given bar diameter of the reinforcing steel as per Fig. 31
fctd	Design value of concrete tensile strength.
kt	Reduction factor for concrete tensile strength.

Se.	Type of restraint	ds [mm]	kt	fctd	Regard pre- str. steel
1	.	10	1.00	kt*fctm	.

Settings for the check of concrete compressive stresses

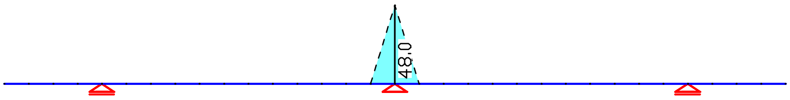
Sigma.c	Concrete compressive stress in the serviceability limit state.
(QC)	Quasi-continuous combination.
fck(t)	Compressive strength of concrete at the time t of prestressing.
Sigma.c(t)	Concrete compressive stress at the time t of prestressing.

Se.	per.sigma.c (QC)	fck(t) [MN/m²]	per.sigma.c(t)
1	0.45 fck	45.00	0.45 fck(t)

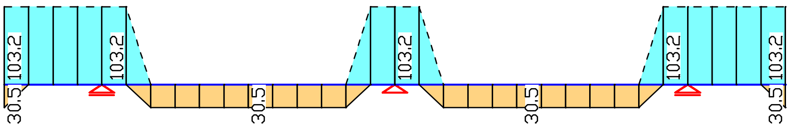
Stress calculation for beams

```
While calculating the reinforcement for robustness, the gross section
is used.

At crack width limitation, the bending stress is calculated using the
gross section.

At the check of decompression and compressive stress of concrete, calculation
of bending stress is carried out
- without internal tendons: at gross section,
- with internal tendons without bond: at net section,
- with internal tendons with bond before grouting:
  at net section, otherwise at ideally section.
```

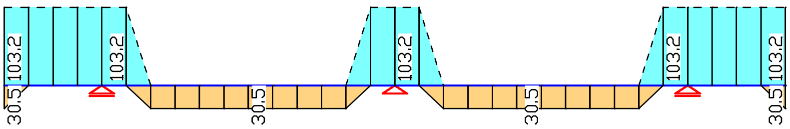
The following illustrations show the curve of the required bending and shear reinforcement.



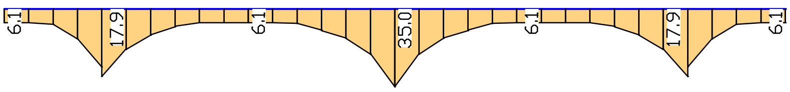
Longitudinal reinforcement A_s from the design in the ultimate limit states [cm²]
(upper reinforcement with dashed lines).



Minimum reinforcement A_s for ensuring robustness (ductility) [cm²]
(upper reinforcement with dashed lines).



Enclosing reinforcement A_s from the checks [cm²]
(upper reinforcement with dashed lines).



(Minimum) lateral force reinforcement $A_{sb,z}$ in the ultimate limit states [cm²/m].

The following pages contain excerpts from the detailed check log for beam 16 at location 2 (middle column).

Design of longitudinal reinforcement

```
The calculated requ. reinforcement includes the specified basic reinforcement.

(M) Nominal reinf. against brittle failure acc. to Chapter 4.4.2 (Charact. C.).
    fctd     Design value of concrete tensile strength as per Chapter 4.4.1 [MN/m²]
    zs,t/b   Lever arm of inner strengths top/bottom with zs=0,9*d [m]
    S.s,adm  Admissible steel stress as per Fig. 31 [MN/m²]
    max Sc   Maximum concrete edge stress from Charact. C. [MN/m²]
             without the statically determined part of prestressing
(R) Required reinforcement as per 4.4.2 for crack width limitation
    Increase of reinforcement due to crack width check is marked by "!".
    ds       Maximal given steel diameter [mm]
(B) Design of reinforement at ultimate limit state
    In case of dominant bending, compression reinforcement is marked with "*".
    fck      Concrete strength for design of reinforcement [MN/m²]
    N0, M0   Statically determined forces of tendons with bond [kN, kNm]
    fp0.1k   Charact. value of the 0.1% strain limit of the prestr. steel [MN/m²]
    fpk      Charact. value of the tensile strength of the prestr. steel [MN/m²]
```

Location 2

```
Beam 16, x = 4.00 m (Beam length 4.00 m)
Cross-section 1: Polygon - SC45/55, 1 tendon group with bond
Steel 1; Design mode: Standard
(M) fctd=3.8; zs,o/u=2.025/2.025; Sigma.s,adm=435
(R) fctd=3.8; ds=10
(B) fck=45

Section properties    A [m²]   ys [m]   zs [m]   Iy [m4]   Iz [m4]   Iyz[m4]
          gross  :     2.926    3.950    0.525    1.2560    9.8822    0.0000
          net    :     2.905    3.950    0.527    1.2535    9.8822    0.0000
          ideally:     2.958    3.950    0.521    1.2597    9.8822    0.0000
```


Tendon groups with bond

```
 No. E-Modul  fp0.1k   fpk       y       z     Ap   Duct    Prestress   Inclin.
     [MN/m²] [MN/m²] [MN/m²]    [m]     [m]  [mm²]  d [mm]        [kN]       [°]
   1  195000   1520    1770   3.950   0.185   7200     82     7342.65     0.00
```

1. Characteristic (rare) combination (CC.1): G.1+P, Construction stage ungrouted

```
Relevant concrete internal forces from 1 sets of internal forces
Set      Nx[kN]   My[kNm]   Mz[kNm]
1    : -7342.59  -4388.77      0.00

Load case combinations for the relevant sets of internal forces
Set    Combination
1    : L1+L10
```

2. Characteristic (rare) combination (CC.2): G.1+G.2+P+QS, Final state grouted

```
No set of internal forces in this situation was relevant.
```

3. Characteristic (rare) combination (CC.3): G.1+G.2+P+CSR1+QS, Final state grouted

```
Loss of prestress by CSR in tendon groups
 No.  CSR[%]   No.  CSR[%]   No.  CSR[%]   No.  CSR[%]   No.  CSR[%]
   1    9.64          -.-           -.-           -.-           -.-

Stat. determ. part (P+CSR): Nx0=-6635.00 kN; My0=2255.90; Mz0=0.00 kNm

Relevant values from 2 sets of internal forces
         Concrete section             Bond section
Set      Nx[kN]   My[kNm]   Mz[kNm]    Nx[kN]   My[kNm]   Mz[kNm]
2    : -6520.60  -9688.93      0.00    114.41 -11944.83      0.00

Load case combinations for the relevant sets of internal forces
Set    Combination
2    : L1+L2+0.96*L10+L20+L3
```

1. Frequent combination (TC.1): G.1+P, Construction stage grouted

```
No set of internal forces in this situation was relevant.
```

2. Frequent combination (TC.2): G.1+G.2+P+QS, Final state grouted

```
Relevant concrete internal forces from 2 sets of internal forces
Set      Nx[kN]   My[kNm]   Mz[kNm]
1    : -7342.59  -6866.21      0.00

Load case combinations for the relevant sets of internal forces
Set    Combination
1    : L1+L2+L10
```

3. Frequent combination (TC.3): G.1+G.2+P+CSR1+QS, Final state grouted

```
No set of internal forces in this situation was relevant.
```

1. Quasi-continuous combination (QC.1): G.1+P, Construction stage grouted

```
No set of internal forces in this situation was relevant.
```

2. Quasi-continuous combination (QC.2): G.1+G.2+P+QS, Final state grouted

```
No set of internal forces in this situation was relevant.
```

3. Quasi-continuous combination (QC.3): G.1+G.2+P+CSR1+QS, Final state grouted

```
No set of internal forces in this situation was relevant.
```

1. Permanent and temporary comb. (PC.1): G.1+P, Construction stage ungrouted

```
Relevant concrete internal forces from 2 sets of internal forces
Set      Nx[kN]   My[kNm]   Mz[kNm]
2    : -7342.59  -1111.65      0.00

Load case combinations for the relevant sets of internal forces
Set    Combination
2    : 0.80*L1+L10
```

2. Permanent and temporary comb. (PC.2): G.1+G.2+P+QS, Final state grouted

```
No set of internal forces in this situation was relevant.
```

3. Permanent and temporary comb. (PC.3): G.1+G.2+P+CSR1+QS, Final state grouted

```
Loss of prestress by CSR in tendon groups
 No.  CSR[%]   No.  CSR[%]   No.  CSR[%]   No.  CSR[%]   No.  CSR[%]
   1    9.64          -.-           -.-           -.-           -.-

Stat. determ. part (P+CSR): Nx0=-6635.00 kN; My0=2255.90; Mz0=0.00 kNm

Relevant values from 8 sets of internal forces
         Concrete section             Bond section
Set      Nx[kN]   My[kNm]   Mz[kNm]    Nx[kN]   My[kNm]   Mz[kNm]
2    : -6520.60 -17175.80      0.00    114.41 -19431.70      0.00

Load case combinations for the relevant sets of internal forces
Set    Combination
2    : 1.35*L1+1.35*L2+0.96*L10+L20+1.50*L3
```

Design of longitudinal reinforcement

```
Reinforcement Nx        My        Mz   max Sc    Ap'   req.As  Situation
Lay. Type    [kN]     [kNm]     [kNm] [MN/m²]  [cm²]   [cm²]
  1   M    114.41 -11944.83      0.00   5.03      .     51.62  CC.3,2
      R  -7342.59  -6866.21      0.00    .        .      0.00  TC.2,1
      B  -6520.60 -17175.80      0.00    .        .     24.01  PC.3,2
  2   M    114.41 -11944.83      0.00   5.03      .     51.62  CC.3,2
      R  -7342.59  -6866.21      0.00    .        .      0.00  TC.2,1
      B  -6520.60 -17175.80      0.00    .        .     24.01  PC.3,2
  3   M      0.06  -6885.27      0.00    .        .      0.00  CC.1,1
      R      0.00      0.00      0.00   0.00      .      0.00  -,-
      B  -7342.59  -1111.65      0.00    .        .      0.00  PC.1,2
  4   M      0.06  -6885.27      0.00    .        .      0.00  CC.1,1
      R      0.00      0.00      0.00   0.00      .      0.00  -,-
      B  -7342.59  -1111.65      0.00    .        .      0.00  PC.1,2
```

Design of shear reinforcement

```
The percentage of nominal reinforcement acc. to 5.5.2.2 is considered.

bw        Effective width for calculation of shear stresses from Qz [m]
bw.nom    Nominal value of the width when deducting the duct diameter [m]
bn        Statically effective width for shear design using Qy [m]
kb        Factor to calculate the inner lever arm from bn
h         Effective height for calculation of shear stresses from Qy and Mx [m]
h.nom     Nominal value of the height when deducting the duct diameter [m]
d         Statically effective height for shear design using Qz [m]
kd        Factor to calculate the inner lever arm from d
fsk       Strength of stirrup reinforcement [MN/m²]
kc        Reduction coefficient to determine the concrete strength
Qy, Qz    Lateral forces for design in y- and z-direction [kN]
VRdc      Lateral force resistance of the compression field [kN]
z         Inner lever arm z=kb*bn resp. z=kd*d
Alpha     Compression field angle [°]
Asb.y,z   Req. stirrup reinforcement from aus Qy, Qz [cm²/m]
Asl.y,z   Req. longitudinal reinforcement from Qy, Qz [cm²]
```

Location 2

```
Beam 16, x = 4.00 m (Beam length 4.00 m)
Cross-section 1: Polygon - SC45/55, 1 tendon group with bond
bw/bw.nom/bn/kb=0.5/0.5/0.45/0.9;  h/h.nom/d/kd=2.3/2.3/2.25/0.9
fsk=500; kc=0.55
```

1. Permanent and temporary comb. (PC.1): G.1+P, Construction stage ungrouted

```
No set of internal forces in this situation was relevant.
```

2. Permanent and temporary comb. (PC.2): G.1+G.2+P+QS, Final state grouted

```
No set of internal forces in this situation was relevant.
```

3. Permanent and temporary comb. (PC.3): G.1+G.2+P+CSR1+QS, Final state grouted

```
Relevant concrete internal forces from 8 sets of internal forces
Set      Nx[kN]   My[kNm]   Mz[kNm]   Mx[kNm]    Qy[kN]    Qz[kN]
2    : -6520.60 -17175.80      0.00      0.00      0.00  -3078.27

Load case combinations for the relevant sets of internal forces
Set    Combination
2    : 1.35*L1+1.35*L2+0.96*L10+L20+1.50*L3
```

Check of the shear reinforcement and the compressive struts

```
Qy            :    0.00 kN    Alpha     :  45.00 °
Qy/VyRdc      :    0.00       z         :   0.41 m
Situation     : -,-           req.Asb.y :   0.00 cm²/m
                              req.Asl.y :   0.00 cm²

Qz            :-3078.27 kN    Alpha     :  45.00 °
Qz/VzRdc      :    0.42       z         :   2.02 m
Situation     : PC.3,2        req.Asb.z :  34.96 cm²/m
                              req.Asl.z :  35.40 cm²
```

Check of crack widths

```
The check is led by limiting the steel stress.
The final long. reinforcement as the maximum from robustness, crack and bending
reinf. incl. a possible increase resulting from the fatigue check is decisive.

(TC) Frequent, (QC) Quasi-continuous combination

ds       Maximal given steel diameter [mm]
fctm     Mean value of the concrete tensile strength [MN/m²]
Sigma.c  Maximal concrete edge stress in state I [MN/m²]
Sigma.s  Reinf. steel stress in state II [MN/m²]
per.     Permissible steel stress as per Table 17 and Fig. 31 [MN/m²]
```

Location 2

```
Beam 16, x = 4.00 m (Beam length 4.00 m)
Cross-section 1: Polygon - SC45/55, 1 tendon group with bond
Requirement: raised; ds=10; fctm=3.8

Section properties    A [m²]   ys [m]   zs [m]   Iy [m4]   Iz [m4]   Iyz[m4]
          gross  :     2.926    3.950    0.525    1.2560    9.8822    0.0000
          net    :     2.905    3.950    0.527    1.2535    9.8822    0.0000
          ideally:     2.958    3.950    0.521    1.2597    9.8822    0.0000
```


Tendon groups with bond

```
 No.  E-Modul  fp0,1k    fpk      y        z     Ap   Duct    Prestress   Inclin.
      [MN/m²] [MN/m²] [MN/m²]    [m]      [m]  [mm²]  d [mm]        [kN]      [°]
   1   195000   1520    1770   3.950   0.185   7200      82     7342.65     0.00
```

1. Frequent combination (TC.1): G.1+P, Construction stage grouted

```
No set of internal forces in this situation was relevant.
```

2. Frequent combination (TC.2): G.1+G.2+P+QS, Final state grouted

```
No set of internal forces in this situation was relevant.
```

3. Frequent combination (TC.3): G.1+G.2+P+CSR1+QS, Final state grouted

```
Loss of prestress by CSR in tendon groups
 No.  CSR[%]   No.  CSR[%]   No.  CSR[%]   No.  CSR[%]   No.  CSR[%]
   1    9.64          -.-          -.-          -.-          -.-

Stat. determ. part (P+CSR)  : Nx0=-6635.00 kN; My0=2255.90; Mz0=0.00 kNm

Relevant values from 2 sets of internal forces
         Concrete section             Bond section
Set      Nx[kN]   My[kNm]   Mz[kNm]    Nx[kN]   My[kNm]   Mz[kNm]
2    : -6520.60  -9688.93      0.00    114.41 -11944.83      0.00

Load case combinations for the relevant sets of internal forces
Set    Combination
2    : L1+L2+0.96*L10+L20+L3
```

1. Quasi-continuous combination (QC.1): G.1+P, Construction stage grouted

```
No set of internal forces in this situation was relevant.
```

2. Quasi-continuous combination (QC.2): G.1+G.2+P+QS, Final state grouted

```
No set of internal forces in this situation was relevant.
```

3. Quasi-continuous combination (QC.3): G.1+G.2+P+CSR1+QS, Final state grouted

```
Loss of prestress by CSR in tendon groups
 No.  CSR[%]   No.  CSR[%]   No.  CSR[%]   No.  CSR[%]   No.  CSR[%]
   1    9.64          -.-          -.-          -.-          -.-

Stat. determ. part (P+CSR)  : Nx0=-6635.00 kN; My0=2255.90; Mz0=0.00 kNm

Relevant values from 2 sets of internal forces
         Concrete section             Bond section
Set      Nx[kN]   My[kNm]   Mz[kNm]    Nx[kN]   My[kNm]   Mz[kNm]
2    : -6520.60  -9688.93      0.00    114.41 -11944.83      0.00

Load case combinations for the relevant sets of internal forces
Set    Combination
2    : L1+L2+0.96*L10+L20+L3
```

Check of crack width for reinf. layer 2 (top) - Frequent combination

```
Nx  [kN]  : -6520.60     Sigma.c [MN/m²]:   1.82
My  [kNm] : -9688.93     As      [cm²]  :  51.62
Mz  [kNm] :     0.00     Sigma.s [MN/m²]:  63.71   per. 355.00
Situation : TC.3,2
```

Check of crack width for reinf. layer 2 (top) - Quasi-continuous combination (w.nom = 0.5 mm)

```
Nx  [kN]  : -6520.60     Sigma.c [MN/m²]:   1.82
My  [kNm] : -9688.93     As      [cm²]  :  51.62
Mz  [kNm] :     0.00     Sigma.s [MN/m²]:  63.71   per. 435.00
Situation : QC.3,2
```

Check of concrete compressive stress

```
For the check, a non-cracked concrete section is assumed.

fck          Characteristic compressive concrete strength [MN/m²]
fck(t)       Average compressive strength of concrete at time t of the beginning
             of prestressing (Situation G1+P) as per 4.1.5.2.4 [MN/m²]
Sigma.x,min  Total maximal longitudinal compressive stress [MN/m²]
Sigma.x,per  = 0.60*fck for Q.-cont. C. (QC) as per 4.1.5.2.4
             = 0.45*fck for Q.-cont. C. (QC) as per 3.1.2.6.3
top, bottom  Position of the edge point: above, below of centre
```

Location 2

```
Beam 16, x = 4.00 m (Beam length 4.00 m)
Cross-section 1: Polygon - SC45/55, 1 tendon group with bond
0.45*fck=20.25; 0.45*fck(t)=20.25

Section properties    A [m²]   ys [m]   zs [m]   Iy [m4]   Iz [m4]   Iyz[m4]
          gross  :     2.926    3.950    0.525    1.2560    9.8822    0.0000
          net    :     2.905    3.950    0.527    1.2535    9.8822    0.0000
          ideally:     2.958    3.950    0.521    1.2597    9.8822    0.0000
```

1. Quasi-continuous combination (QC.1): G.1+P, Construction stage grouted

```
Relevant concrete internal forces from 1 sets of internal forces
Set      Nx[kN]   My[kNm]   Mz[kNm]
1    : -7342.59  -4388.77      0.00

Load case combinations for the relevant sets of internal forces
Set    Combination
1    : L1+L10
```

2. Quasi-continuous combination (QC.2): G.1+G.2+P+QS, Final state grouted

No set of internal forces in this situation was relevant.

3. Quasi-continuous combination (QC.3): G.1+G.2+P+CSR1+QS, Final state grouted

Relevant concrete internal forces from 2 sets of internal forces

Set	Nx[kN]	My[kNm]	Mz[kNm]
2 :	-6520.60	-9688.93	0.00

Load case combinations for the relevant sets of internal forces

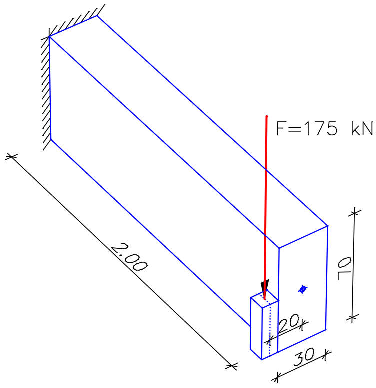
Set	Combination
2 :	L1+L2+0.96*L10+L20+L3

Check of compressive stress in concrete for the Quasi-continuous combination

Side	Se.-Pnt.	Sigma.x,min [MN/m²]	Sigma.x,per [MN/m²]	Period	Situation
top	1	-0.67	-20.25	Constr.	QC.1,1
bottom	7	-15.89	-20.25	Final	QC.3,2

Torsional Beam

The depicted cantilever is subjected to an eccentrically acting load F = 175 kN. The required shear, torsion longitudinal and stirrup reinforcements are listed in the following log.



System drawing

SIA 262 actions

Standard design group

G - Dead load

Gamma.sup / gamma.inf = 1.35 / 0.8

Load cases
----
1 Load

1. Permanent and temporary situation

Final state

G - Dead load

Settings for flexural and shear reinforcement

```
M,N      Design mode for bend and longitudinal force:
         (ST) Standard, (SY) Symmetrical, (CM) Compression member.
Red.     Reduction factor of prestress for determining the tensile zone for
         distribution of reinf. against brittle failure for area elements.
Fac. as  Factor for bending reinf. of slabs in secondary dir. per 5.5.3.2.
eta.t    Coefficient for concrete strength as per 4.2.1.3.
fsk      Quality of stirrups [MN/m²].
Alpha    Compression field angle [°].
kc       Reduction factor for concrete strength as per 4.2.1.7.
Slab     Beams are designed like slabs.
eps.v    Base value of strain as per 4.3.3.2.2 [o/oo].
Dmax     Max. grain of concrete as per Eq. (37) [mm].
Long.    Longitudinal reinforecent is graded as per 4.3.3.2.3.
```

Se.	Concrete	Des. for M,N	Red. pre-str.	Fac. as	eta.t	fsk [MN/m²]	Alpha [°]	kc	Des. like slabs	Base value eps.v	Dmax [mm]	Long. reinf. graded
1	SC35/45		.	.	.	500	45.00	0.55	.	.		.

Shear sections

```
bw.nom   Nominal width of the prestressed section according to 4.3.3.3.5.
h.nom    Nominal height of the prestressed section according to 4.3.3.3.5.
kb, kd   Factor to calculate the inner lever arm z from the eff. width bn resp.
         from the eff. height d according to 4.3.3.4.2.
z1, z2   Dimensions of the ideal hollow section for torsion as per 4.3.5.1.
tk       Thickness of the ideal hollow section.
```

Se.	Width [m] bw	bw.nom	Eff. width bn [m]	kb	Height[m] h	h.nom	Eff.height d [m]	kd	Torsion section [m] z1	z2	tk
1	0.300	.	0.245	0.90	0.700	.	0.645	0.90	0.595	0.195	0.105

Design of shear reinforcement

```
The percentage of nominal reinforcement acc. to 5.5.2.2 is considered.

bw        Effective width for calculation of shear stresses from Qz and Mx [m]
bn        Statically effective width for shear design using Qy [m]
kb        Factor to calculate the inner lever arm from bn
h         Effective height for calculation of shear stresses from Qy and Mx [m]
d         Statically effective height for shear design using Qz [m]
kd        Factor to calculate the inner lever arm from d
z1, z2    Height and width of the core section Ak for torsion [m]
tk        Wall thickness of the torsion section [m]
fsk       Strength of stirrup reinforcement [MN/m²]
kc        Reduction coefficient to determine the concrete strength
Qy, Qz    Lateral forces for design in y- and z-direction [kN]
VRd       Lateral force resistance without lateral reinforcement [kN]
VRdc      Lateral force resistance of the compression field [kN]
z         Inner lever arm z=kb*bn resp. z=kd*d
Alpha     Compression filed angle [°]
Asb.y,z   Req. stirrup reinforcement from aus Qy, Qz [cm²/m]
Asl.y,z   Req. longitudinal reinforcement from Qy, Qz [cm²]
Mx        Torsional moment for design [kNm]
TRdc      Torsional resistance of the compression field [kNm]
Asb.T     Req. stirrup reinforcement from torsion [cm²/m]
Asl.T     Req. longitudinal reinforcement from torsion [cm²]
```

Beam 1

Location 1

```
Beam 1, x = 0.00 m (Beam length 2.00 m)
Cross-section 1: Polygon - SC35/45
bw/bn/kb=0.3/0.245/0.9; h/d/kd=0.7/0.645/0.9
fsk=500; kc=0.55
Torsion section z1/z2=0.595/0.195; tk=0.105
```

1. Permanent and temporary comb. (PC.1): G, Final state

```
Concrete internal forces
         Nx[kN]   My[kNm]   Mz[kNm]   Mx[kNm]    Qy[kN]    Qz[kN]
Nx-  :     0.00   -280.00      0.00     28.00      0.00    140.00
Nx+  :     0.00   -280.00      0.00     28.00      0.00    140.00
My-  :     0.00   -472.50      0.00     47.25      0.00    236.25
My+  :     0.00   -280.00      0.00     28.00      0.00    140.00
Mz-  :     0.00   -280.00      0.00     28.00      0.00    140.00
Mz+  :     0.00   -280.00      0.00     28.00      0.00    140.00
Mx-  :     0.00   -280.00      0.00     28.00      0.00    140.00
Mx+  :     0.00   -472.50      0.00     47.25      0.00    236.25
Qy-  :     0.00   -280.00      0.00     28.00      0.00    140.00
Qy+  :     0.00   -280.00      0.00     28.00      0.00    140.00
Qz-  :     0.00   -280.00      0.00     28.00      0.00    140.00
Qz+  :     0.00   -472.50      0.00     47.25      0.00    236.25
```

Check of the shear reinforcement and the compressive struts

```
Qy             :    0.00 kN    Alpha     :  45.00 °
Qy/VyRdc       :    0.00       z         :   0.22 m
Situation      : -,-           req.Asb.y :   0.00 cm²/m
                               req.Asl.y :   0.00 cm²

Qz             :  236.25 kN    Alpha     :  45.00 °
Qz/VzRdc       :    0.22       z         :   0.58 m
Situation      : PC.1,Qz+      req.Asb.z :   9.36 cm²/m
                               req.Asl.z :   2.72 cm²

Mx             :   47.25 kNm   Alpha     :  45.00 °
Q/VRdc+Mx/TRdc:    0.54        req.Asb.T :   4.68 cm²/m
Situation      : PC.1,Qz+      req.Asl.T :   7.40 cm²
```

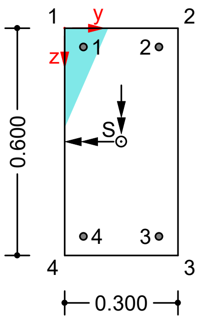
Single Design

A single rectangular section is designed for bending and normal force.

Pos. 1 - Reinforced concrete design per SIA 262

Section 1

Sc. = 1 : 20
Pressure



Action	N = 10.00 kN; My = 67.50; Mz = 27.00 kNm
Resistance	N = 10.00 kN; My = 67.50; Mz = 27.00 kNm
Force system	ys / zs = 0.150 / 0.300 m
Strength	SC20/25; gamma.c = 1.50; gamma.s = 1.15
Design mode	Standard
Reinforcement	3.63 cm²; 0.20 %; Concrete area = 1800.00 cm²

Concrete section

Point	y [m]	z [m]	eps[‰]	sigma[MPa]
1	0.000	0.000	-3.00	-13.33
	0.115	0.000	0.00	0.00
2	0.300	0.000	4.80	0.00
3	0.300	0.600	11.64	0.00
4	0.000	0.600	3.84	0.00
	0.000	0.263	0.00	0.00

Inner Forces	y [m]	z [m]	F [kN]
Compr.	0.034	0.078	-150.45
Tension	0.210	0.512	160.45
Lev. arm	0.175	0.435	

Reinforcement

Point	y [m]	z [m]	d1 [m]	Es, ßs	[MPa]	Zv0 [kN]	eps[‰]	sigma[MPa]	As [cm²]
1	0.050	0.050	0.050	205000	500	0.0	-1.13	-231.68	0.00
2	0.250	0.050	0.050	205000	500	0.0	4.07	437.15	0.28
3	0.250	0.550	0.050	205000	500	0.0	9.77	444.08	2.61
4	0.050	0.550	0.050	205000	500	0.0	4.57	437.76	0.74

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