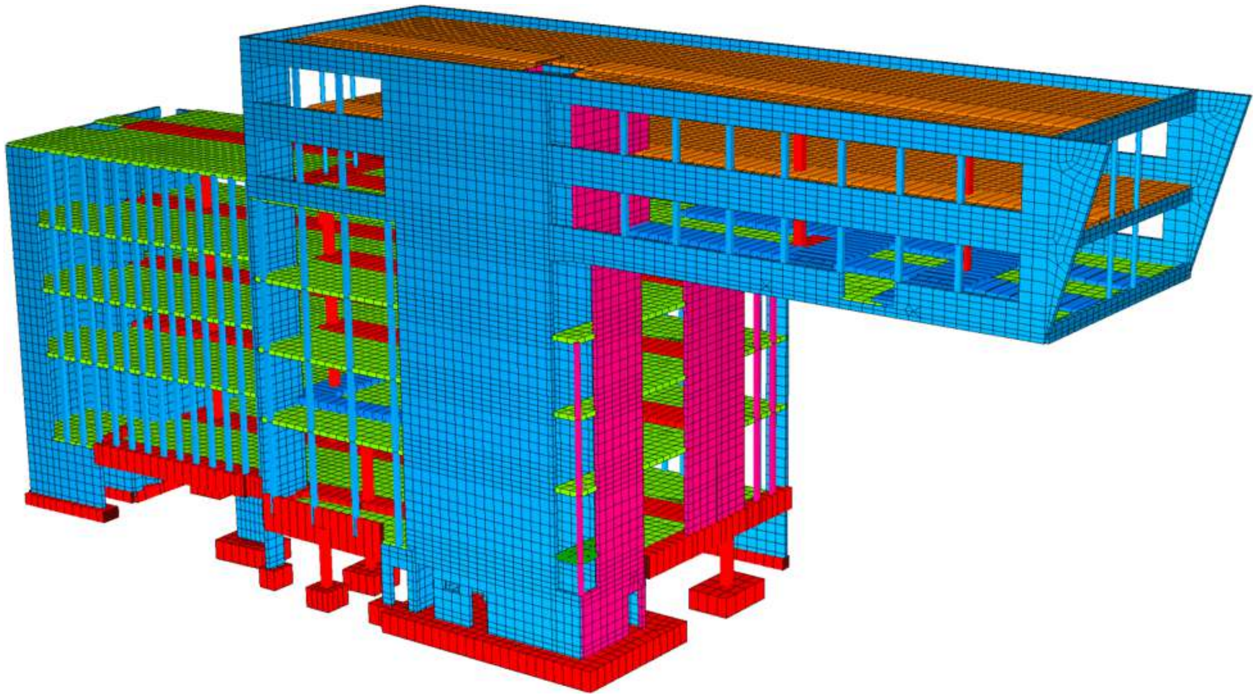
Reinforced and Prestressed

Concrete Design

according to DIN 1045-1



InfoGraph

Software für die Tragwerksplanung

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Contents

Basics

The reinforced concrete and prestressed concrete design according to DIN 1045-1 can be used for all engineering structures that need not be checked according to the guidelines of the DIN Technical Report 102. In the calculation settings you can select which version of the standard will be used:

- DIN 1045-1:2001-07 with revision A2:2005-06
- DIN 1045-1:2008-08

Permitted structure models include 2D and 3D beam and area 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 DIN 1055-100. 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 *C12/15* to *C100/115* and *LC12/13* to *LC60/66*. For strength classes *C55/67* and *LC55/60* or higher Guideline 5.3.3 (9) of the standard applies.

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

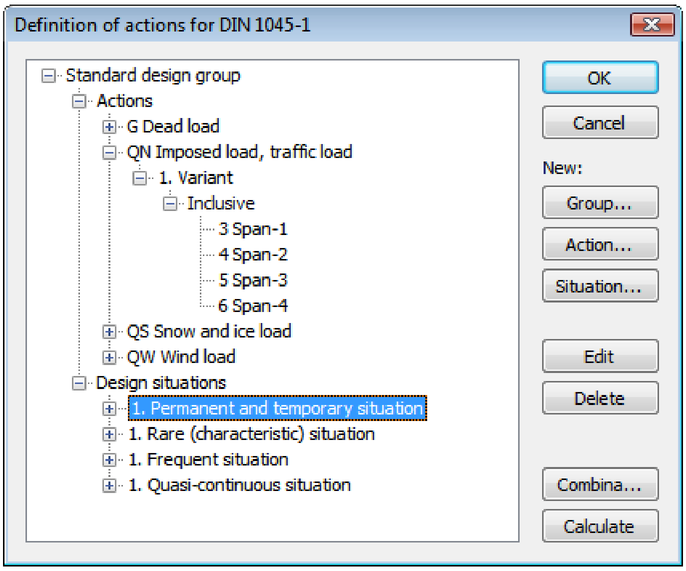
In the *DIN 1045-1 Design* folder of the database you can also perform a single design for user-defined polygon sections or composite sections.

Input

Definition of Actions and Design Situations

The load design values are calculated based on the internal forces of individual load cases and load case combinations. To do so, the existing load cases and load case combinations must be assigned to actions. These actions are then used to establish 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)
  These actions already contain the partial safety factors and combination coefficients. They are combined exclusively.
- Cyclic fatigue actions (Qfat)

Group...

Open the dialog for entering a new design group. Optionally, particular actions and design situations can be defined for specific components (sections).

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 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 deflection theory analysis or nonlinear analysis.

Calculate

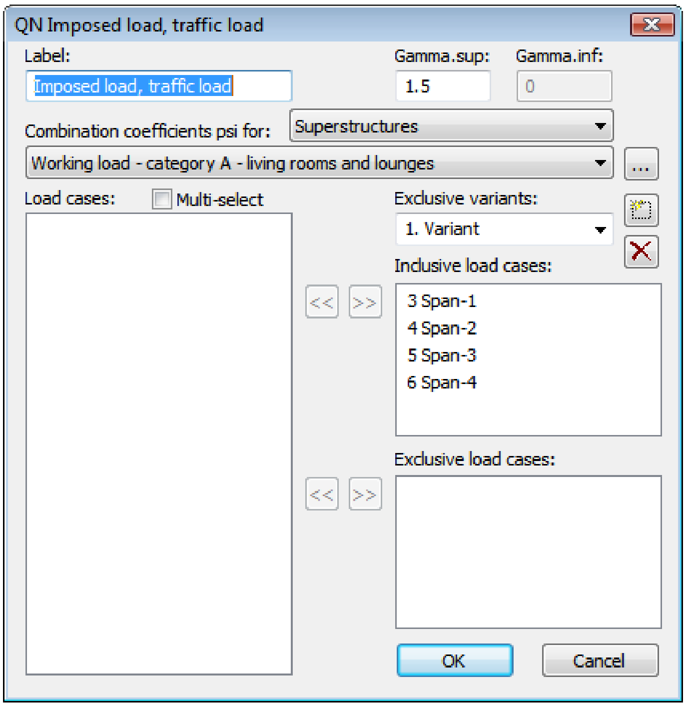
Calculate the defined design situations. Once calculated, the extremal results (internal forces, support reactions) can be accessed for all situations in the database. This allows you to evaluate the results without having to open the checking module. Each time you open the checking module, all results 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 DIN 1045-1 chapters.

Situation	Ultimate limit state	Chapter	Serviceability limit state	Chapter
Permanent and temp. Accidental Earthquake	Longitudinal reinf. Lateral reinf. Torsional reinf.	10.2 10.3 10.4		
Characteristic (rare)	Robustness (following DIN TR 102, 4.3.1.3)	5.3.2	Concrete compr. stress Reinforcing steel stress Prestressing steel stress Decompression Class A Crack reinforcement Crack width Class B	11.1.2 11.1.3 11.1.4 11.2.1 11.2.2 11.2.4
Frequent	Fatigue, simplified	10.8.4	Decompression Class B Crack width Class C, D	11.2.1 11.2.4
Quasi-continuous			Concrete compr. stress Prestressing steel stress Decompression Class C Crack width Class E, F Deformations	11.1.2 11.1.4 11.2.1 11.2.4 11.3
Fatigue	Fatigue reinf. steel Fatigue prestr. steel Fatigue concrete	10.8.3 10.8.3 10.8.3		

Definition of an Action

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



QN Imposed load, traffic load

Label: Imposed load, traffic load

Gamma.sup: 1.5

Gamma.inf: 0

Combination coefficients psi for: Superstructures

Working load - category A - living rooms and lounges

Load cases: ☐ Multi-select

Exclusive variants: 1. Variant

Inclusive load cases:

3 Span-1
4 Span-2
5 Span-3
6 Span-4

Exclusive load cases:

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 change the selected combination coefficients ψ_0, ψ_1 and ψ_2.

Load cases

List of possible load cases or load case combinations. You can choose an item from the list by selecting it and clicking the corresponding button or by using 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 with the ▤ or ✕ buttons.

Inclusive load cases

Selected load cases and combinations that can act simultaneously.

Exclusive load cases

Selected load cases and combinations that exclude each other.

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 CS load cases, you can allow for the effect of creep and shrinkage 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

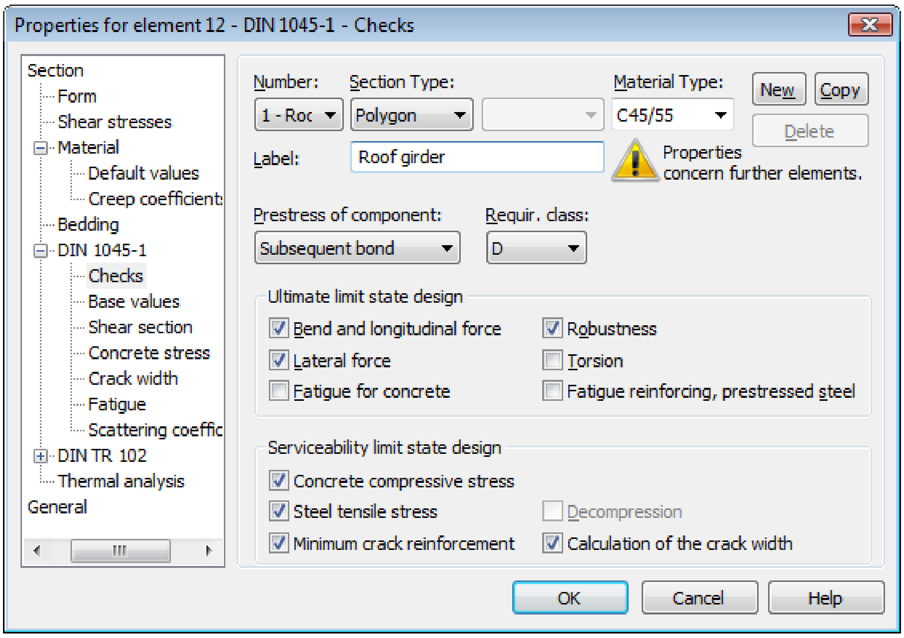
The partial safety factors of the construction materials are preset with the values specified by DIN 1045-1, Table 1, and can be modified if necessary. In design situations resulting from earthquakes, the factors of the permanent and temporary design situation apply as specified in DIN 4149:2005-04, Chapter 8.1.3 (3). In version 6.12 or higher, the partial safety factors for actions are determined by the definition of actions in accordance with Table 2 of the standard. These factors appear in the Partial Safety Factors dialog for compatibility reasons only and therefore cannot be modified.

Section Input

The section inputs contain all of the specific settings made for checks in the ultimate limit and serviceability states. An overview of the design specifications can be accessed in the *DIN 1045-1* section of the database.

Checks

The following dialog is used to define which ultimate limit state and serviceability checks are available for the section. Any check that is selected in this dialog will only be carried out if it is also selected in the analysis settings.



Number: 1 - Roc

Section Type: Polygon

Material Type: C45/55

Label: Roof girder

Properties concern further elements.

Prestress of component: Subsequent bond

Requir. class: D

Ultimate limit state design

☑ Bend and longitudinal force
☑ Robustness
☑ Lateral force
☐ Torsion
☐ Fatigue for concrete
☐ Fatigue reinforcing, prestressed steel

Serviceability limit state design

☑ Concrete compressive stress
☑ Steel tensile stress
☐ Decompression
☑ Minimum crack reinforcement
☑ Calculation of the crack width

Prestress of component

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

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

Reqirement class

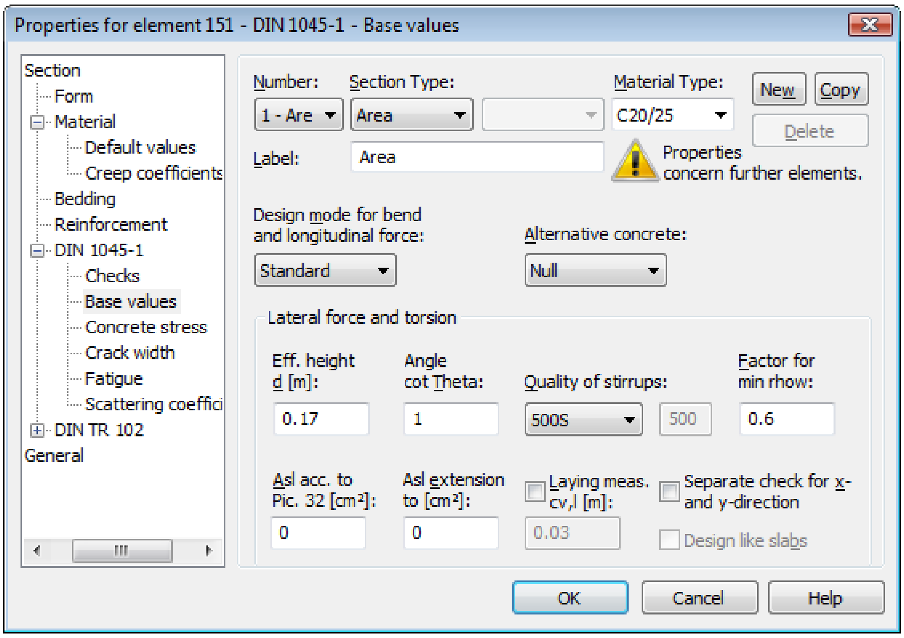
The check conditions for the decompression and crack width check are defined in DIN 1045-1, Chapter 11.2.1, Table 18, based on the requirement classes A through F. The minimum requirement class is derived from Table 19 depending on the exposure class of the structure and the prestress type of the component.

Robustness

This check determines the minimum reinforcement for ensuring ductile component behavior according to DIN 1045-1, Chapter 5.3.2 (also referred to as robustness reinforcement in Book 525).

Base Values

The base values apply for all checks in the ultimate limit and serviceability states.



Number: 1 - Are
Section Type: Area
Material Type: C20/25
Label: Area
Properties concern further elements.

Design mode for bend and longitudinal force: Standard
Alternative concrete: Null

Lateral force and torsion

Eff. height d [m]: 0.17
Angle cot Theta: 1
Quality of stirrups: 500S 500
Factor for min rhow: 0.6
Asl acc. to Pic. 32 [cm²]: 0
Asl extension to [cm²]: 0
☐ Laying meas. cv,l [m]: 0.03
☐ Separate check for x- and y-direction
☐ Design like slabs

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. 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 DIN 1045-1, Chapter 13.5.2.

Alternative concrete

Entering this value is only necessary if the general material type *Beton* is used.

Effective height

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

Truss angle cot Theta

Strut angle according to DIN 1045-1, Chapter 10.3.4 (3). The program will suggest a value of 1 (45° strut angle). You can choose to ignore the suggestion and pick any value between 0.58 and 3 (normal concrete) or 2 (lightweight concrete). Entering a higher number will normally result in a lower necessary lateral force reinforcement A_{sw}, a lower absorbable lateral force $V_{Rd,max}$ and a larger displacement a_1 according to Eq. (147).

In the calculation, the value for $\cot \Theta$ is limited to the range permitted in accordance with DIN 1045-1, Eq. (73) (method with load-dependent strut angle). The actual effective concrete strut angle is logged for each check location.

Bending reinforcement Asl according to picture 32

The bending reinforcement to be added according to DIN 1045-1, Chapter 10.3.3, Figure 32 [cm²].

Automatic extension of Asl to

You can optionally specify a maximum value for area elements and the program will automatically increase the above input value until that maximum value is reached in order to avoid stirrup reinforcement [cm²].

Quality of stirrups

- *420S*: Reinforcing rods according to DIN 488, Part 1.
- *500S*: Reinforcing rods according to DIN 488 Part 1 and DIN 1045-1 Tab. 11.
- *500M*: Reinforcing meshes according to DIN 488 Part 1 and DIN 1045-1 Tab. 11.
- *General*: User-definable steel quality [MN/m²].

Factor for min rhow

The minimum reinforcement level $\min \rho_w$ complies with DIN 1045-1, Chapter 13.2.3 (5), and is defined using a factor related to the standard values ρ according to Tab. 29. The program will suggest a factor of 1 for beams and design objects and a factor of 0.6 for area elements as per 13.3.3 (2). The factor can be any number between 0 and 1.6, which is the nominal value for structured sections with prestressed tension chord.

Design like slabs

Beams or design objects are treated like slabs, which means that a minimum lateral force reinforcement will not be determined as per 13.3.3 (2) if no lateral force reinforcement is required for computation.

Laying measure cv,l

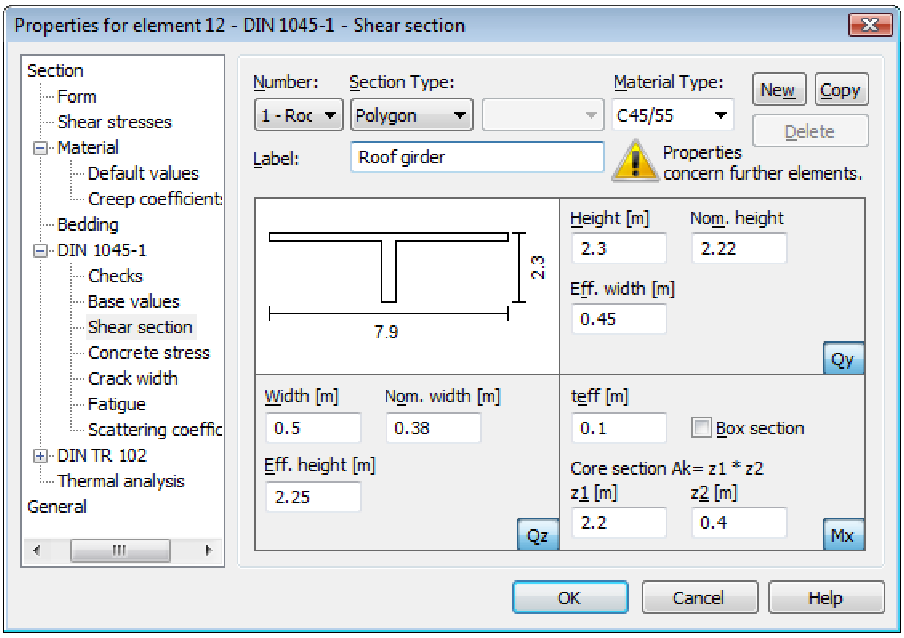
In DIN 1045-1:2008-08, Chapter 10.3.4(2), and NABau No. 24, the internal lever arm z is limited to the maximum value derived from $z = d - c_{v,l} - 30$ mm and $z = d - 2c_{v,l}$. Note that $c_{v,l}$ is the laying measure of the longitudinal reinforcement in the concrete compressive zone. For $c_{v,l}$ the program will suggest the shortest axis distance of the longitudinal reinforcement from the section edge d_1.

Separate check for x and y direction

For two-axes stressed slabs, the lateral force check can be performed separately in the x and y stress directions as described in DIN 1045-1:2008-08, Chapter 10.3.1(5), and NABau No. 76. The user is responsible for properly aligning the reinforcement directions.

Shear Section

For polygon sections, additional section dimensions are required for the lateral force and torsion design according to DIN 1045-1. These dimensions are explained in the following.



Number: 1 - Roc
Section Type: Polygon
Material Type: C45/55
Label: Roof girder
Properties concern further elements.
Height [m]: 2.3
Nom. height: 2.22
Eff. width [m]: 0.45
Width [m]: 0.5
Nom. width [m]: 0.38
Eff. height [m]: 2.25
teff [m]: 0.1
☐ Box section
Core section Ak= z1 * z2
z1 [m]: 2.2
z2 [m]: 0.4

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].

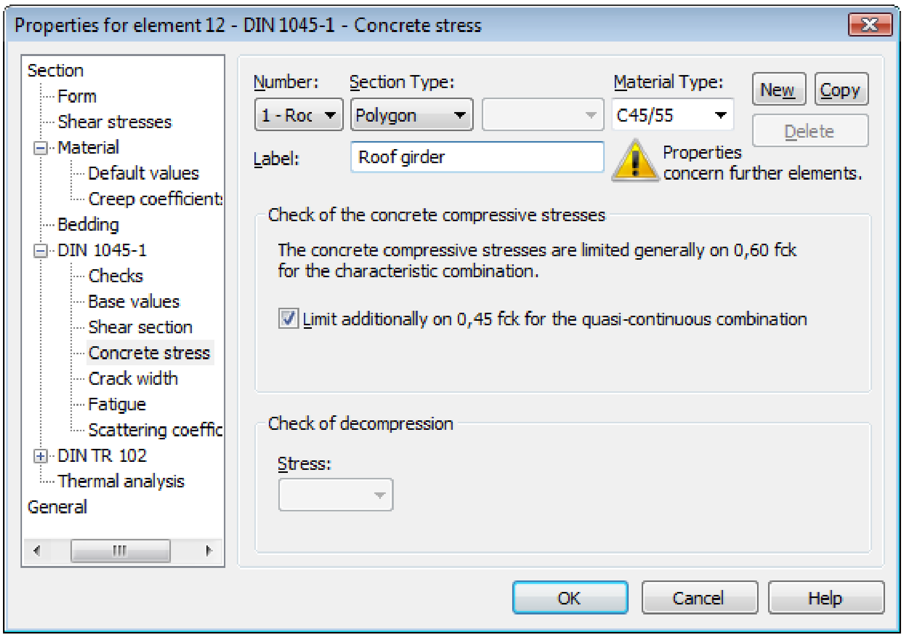
Nom. width, nom. height
The nominal width or height of internally prestressed components as per DIN 1045-1, Chapter 10.3.4 (8) for including the duct diameter in the calculation of the design value of the lateral load-bearing capacity $V_{Rd,max}$.

Core section Ak= z1 * z2
Dimensions of the core section for calculating the torsion reinforcement [m].

teff
The effective wall thickness of the torsion section according to DIN 1045-1, Figure 36 [m].

Box section
Data for determining torsion section utilization according to DIN 1045-1, Eq. (94) or (95).

Concrete Stress



Properties for element 12 - DIN 1045-1 - Concrete stress

Number: 1 - Roc

Section Type: Polygon

Material Type: C45/55

Label: Roof girder

Properties concern further elements.

Check of the concrete compressive stresses

The concrete compressive stresses are limited generally on 0,60 fck for the characteristic combination.

☑ Limit additionally on 0,45 fck for the quasi-continuous combination

Check of decompression

Stress:

Concrete compressive stress

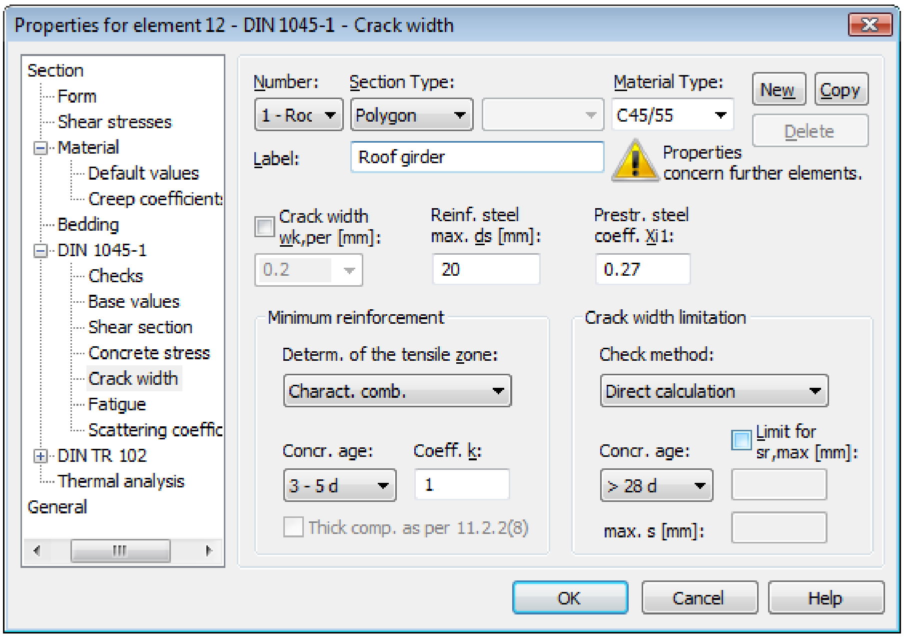
The concrete compressive stress σ_c must be limited to $0.60\,f_{ck}$ under the rare (characteristic) combination in the construction stages and final states according to DIN 1045-1, Chapter 11.1.2 (1). This condition is normally checked by the program. If serviceability is significantly influenced by creep, the limit $0.45\,f_{ck}$ should be maintained under the quasi-continuous combination according to 11.1.2 (2).

Decompression

Decisive stress for the decompression check for area elements (σ_1, σ_x, σ_y).

Crack Width

These specifications apply to the minimum crack reinforcement calculation and the crack width check.



Properties for element 12 - DIN 1045-1 - Crack width

Number: 1 - Roc

Section Type: Polygon

Material Type: C45/55

Label: Roof girder

Properties concern further elements.

☐ Crack width wk,per [mm]: 0.2

Reinf. steel max. ds [mm]: 20

Prestr. steel coeff. Xi1: 0.27

Minimum reinforcement

Determ. of the tensile zone: Charact. comb.

Concr. age: 3 - 5 d

Coeff. k: 1

☐ Thick comp. as per 11.2.2(8)

Crack width limitation

Check method: Direct calculation

Concr. age: > 28 d

☐ Limit for sr,max [mm]:

max. s [mm]:

wk

Calculated value of the crack width according to DIN 1045-1, Chapter 11.2.1, Table 18 [mm]. The program will suggest a tabular value based on the selected requirement class and the prestressing of the component. This value can be modified after the input field is enabled.

ds

Largest existing bar diameter of the reinforcing steel reinforcement according to 11.2.2 (6), Eq. (131) [mm].

Xi1

The bond coefficient ξ_1 according to DIN 1045-1, Eq. (130) defines the extend to which prestressing steel as per 11.2.2 (7) can be taken into account for the minimum crack reinforcement. It is also used in the calculation of the effective reinforcement level according to Eq. (133) and thus the direct calculation of the crack width. Data input is blocked for area elements since prestressing steel is normally not taken into account here.

Specifying the concrete tensile zone

You can specify the tensile zone where the minimum crack reinforcement described in Chapter 11.2.2 will be placed by selecting either an action combination (AC) or a restraint (bending, centrical tension).

Thick component

Based on Chapter 11.2.2(8) of edition 2008 the minimum reinforcement for the crack width limitation in the case of thicker components under centrical restraint can be determined to Equation (130a). Therewith a reduction compared to the calculation with Equation (127) can be achieved.

k

Coefficient used to take into account nonlinearly distributed concrete tensile stress in the section according to 11.2.2 (5).

Concrete age

The age of the concrete is used to determine the effective concrete tensile strength $f_{\mathrm{ct,eff}}$ as per 11.2.2 (5). This is done separately for the minimum reinforcement calculation and the crack width calculation.

Checking method

The crack width check can be performed either through direct calculation of the standard as described in Chapter 11.2.4 or by simply limiting the bar distances according to the information provided in Table 21. According to *Zilch* and *Rogge* (2002, p. 277), the simplified method only yields definitive results for single-layer tensile reinforcement with $d_1 = 4$ cm. The user is responsible for the evaluation of these requirements.

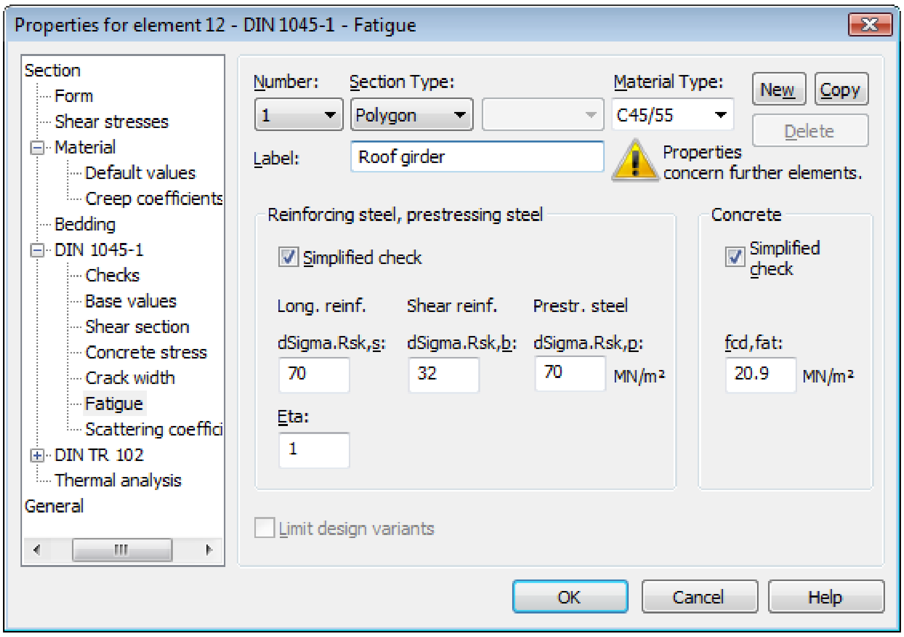
sr,max

When calculating the crack width, by default the crack distance is determined using Equation (137) of the standard. Alternatively, you can preset an upper limit for $s_{\mathrm{r,max}}$ [mm] so that, for example, the special conditions of Equation (138) or Paragraph (8) of Chapter 11.2.4 are taken into account.

max s

Largest existing bar distance of the reinforcing steel reinforcement for the simplified crack width check [mm].

Fatigue



Number: 1
Section Type: Polygon
Material Type: C45/55
Label: Roof girder
Properties concern further elements.

Reinforcing steel, prestressing steel

☑ Simplified check

Long. reinf.	Shear reinf.	Prestr. steel	
dSigma.Rsk,s:	dSigma.Rsk,b:	dSigma.Rsk,p:	
70	32	70	MN/m²

Eta: 1

Concrete

☑ Simplified check

fcd,fat: 20.9 MN/m²

☐ Limit design variants

dSigma.Rsk,s, **dSigma.Rsk,b**

The permissible characteristic stress range $\Delta\sigma_{Rsk}$ (N^*) of the longitudinal reinforcement and shear reinforcement at N^* load cycles according to the Wöhler curves specified in Chapter 10.8.3 [MN/m²]. The value found in Table 16, Row 1 (beam sections) resp. Row 2 (area sections, edition 2008-08), is suggested in the dialog. For the shear reinforcement, the mandrel diameter is taken to be $d_{br} = 4\ d_s$.

dSigma.Rsk,p

The permissible characteristic stress range $\Delta\sigma_{Rsk}$ (N^*) of the prestressing steel at N^* load cycles according to the Wöhler curves specified in Chapter 10.8.3 [MN/m²]. The value found in Table 17, Row 4, is suggested in the dialog.

Augmentor Eta

Increase factor η 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 Chapter 10.8.2 (3), Eq. (118).

fcd,fat

Concrete compressive strength before onset of cyclic load according to DIN 1045-1, Chapter 10.8.4, Eq. (124) [MN/m²]. In general, the following applies:

$$f_{cd,fat} = \beta_{cc}(t_0) \cdot f_{cd} \cdot \left(1 - \frac{f_{ck}}{250}\right) \qquad (124)$$

with

$\beta_{cc}(t_0) = e^{0.2\,(1-\sqrt{28/t_0}\,)}$, t_0 = time of the initial stressing of the concrete.

$f_{cd,fat}$ for $t_0 = 28$ and $f_{cd} = 0.85 \cdot f_{ck} / \gamma_{c,fat}$ is suggested in the dialog.

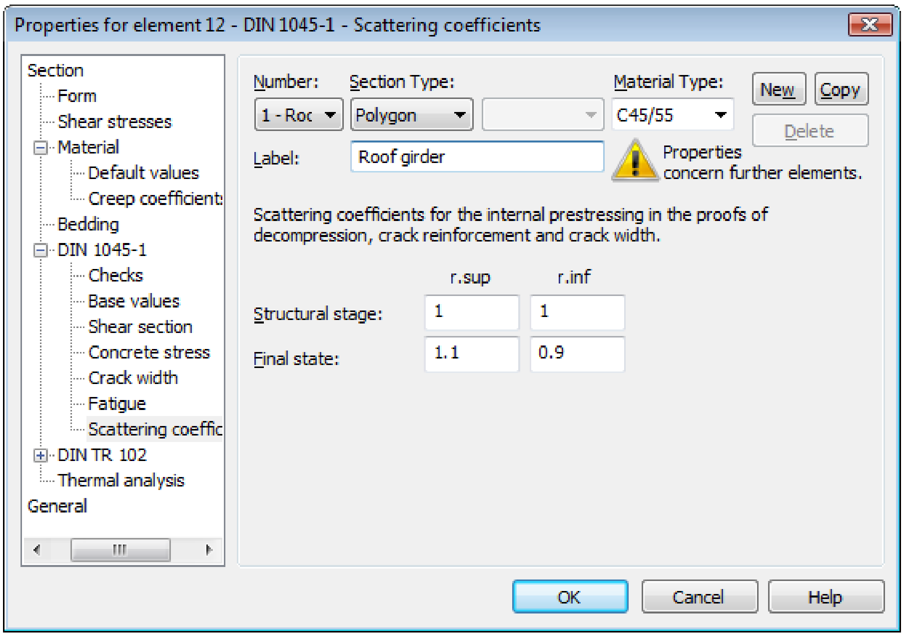
Simplified check

The simplified check according to Chapter 10.8.4 bases on the frequent action combination including the traffic loads used for the serviceability checks. The method for concrete is defined in Chapter 10.8.4(4), the permissible stress ranges for steel are suggested according to Chapter 10.8.4(2) in the dialog. For shear reinforcement this value is reduced analogous to Table 16.

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 "Fatigue Checks / Special Characteristic for Shell Structures".

Scattering Coefficients


Properties for element 12 - DIN 1045-1 - Scattering coefficients

Number: 1 - Roc

Section Type: Polygon

Material Type: C45/55

Label: Roof girder

Properties concern further elements.

Scattering coefficients for the internal prestressing in the proofs of decompression, crack reinforcement and crack width.

	r.sup	r.inf
Structural stage:	1	1
Final state:	1.1	0.9

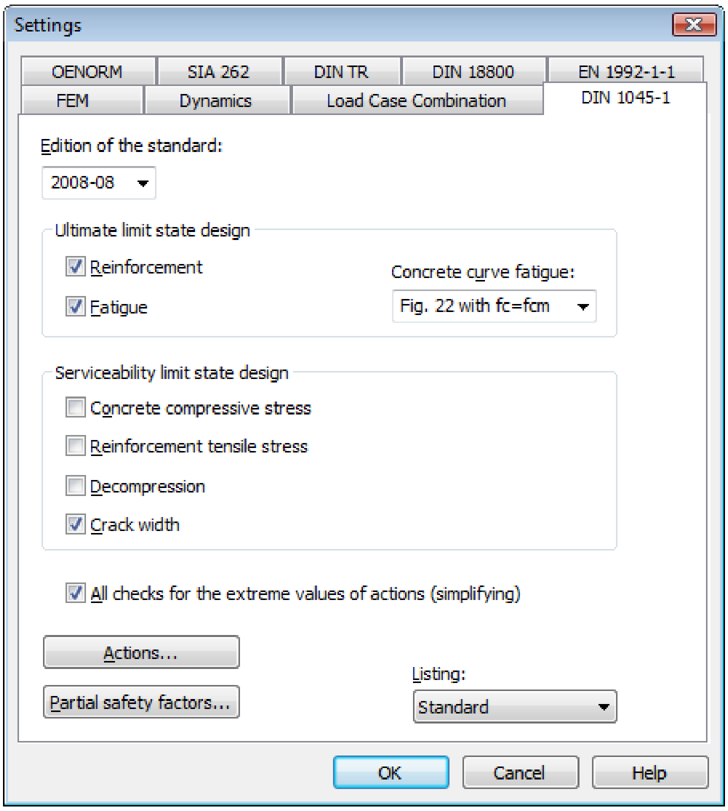
The coefficients used to take into account the scattering of prestressing force are defined in DIN 1045-1 depending on the prestressing type. In the dialog, values are suggested according to Chapter 8.7.4 (2) for subsequent bond. Lower scattering levels can be specified in the construction stage as shown in Book 525. The defined scattering coefficients are taken into account for the effects from internal prestressing in the following checks:

- Decompression check.
- Minimum reinforcement for crack width limitation.
- Crack width check.

Regarding the effects from external prestressing, the scattering coefficients correspond to $r_{\text{sup}} = r_{\text{inf}} = 1$ on the basis of DIN Technical Report 102, Chapter 2.5.4.2 (4).

Analysis Settings

The *DIN 1045-1* dialog page can be opened using the *Settings* function of the Analysis menu.



Edition of the standard: 2008-08

Ultimate limit state design
☑ Reinforcement
☑ Fatigue
Concrete curve fatigue: Fig. 22 with fc=fcm

Serviceability limit state design
☐ Concrete compressive stress
☐ Reinforcement tensile stress
☐ Decompression
☑ Crack width

☑ All checks for the extreme values of actions (simplifying)

Listing: Standard

Edition of the standard

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

Check selection

The checks that are normally carried out for the entire structure are defined in this dialog. A selected check will only be carried out for those elements for which that check has also been activated in the section description (see section inputs).

Concrete curve fatigue

For the fatigue checks, the curve to determine the concrete compressive stresses can be selected.

All checks for the extreme values of actions (simplifying)

When you make a selection, the minimum and maximum values are generated for each internal force component. They will then be used together with their associated values to execute the design. Alternatively, all possible combinations of load cases can be generated and designed as well. This option can, however, greatly slow down calculation if there is a large number of load cases.

Actions...

Open the dialog for describing actions.

Partial safety factors...

Open the dialog for modifying partial safety factors.

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 sections independently of the global system using predefined internal forces. The following data needs to be entered in the *Single Design* table, which is located in the *DIN 1045-1 Design* folder of the database.

Section

Number of the section to be designed. Both polygon and composite sections can be designed.

Concrete

Concrete class *C12/15*, ... *C100/115* or *LC12/13*, ... *LC60/66*

Apparent density

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

Combination

Design situation according to DIN 1045-1, Table 2:

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

Nsd, Mysd, Mzsd

Internal forces being designed. The internal forces refer to the centroid in polygon sections or the section zero point in composite sections.

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 DIN 1045-1, Chapter 13.5.2.
- *Strains*: Determine strain state for existing reinforcing steel layers.
- *Strain state SLS*: Determine strain state in the serviceability limit state for existing reinforcing steel layers. A linear strain-stress curve of the concrete is used in the compression zone to determine the strain state.
- *Strain state SLS2*: Determine strain state in the serviceability limit state for existing reinforcing steel layers. A nonlinear strain-stress curve of the concrete is used as shown in Figure 22. Note that a horizontal progression is assumed for strains exceeding ε_{c1}.
- *Inactive*: Design disabled.

The calculation can be carried out while the input table is open using the *Single Design* or Page Preview menu item.

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.

1b. Input data, slab

This section shows the material properties, the existing reinforcement as well as additional coefficients for calculating punching shear resistances.

1c. Input data, action

The action V_{Ed} can either be added from a previous calculation (design according to DIN 1045-1) or defined directly. All medium soil pressures σ_0 lower the design value of the lateral force by $0.5 \cdot \sigma_0 \cdot A_{crit}$. The medium longitudinal forces N_{Ed} are used to calculate the normal concrete stress.

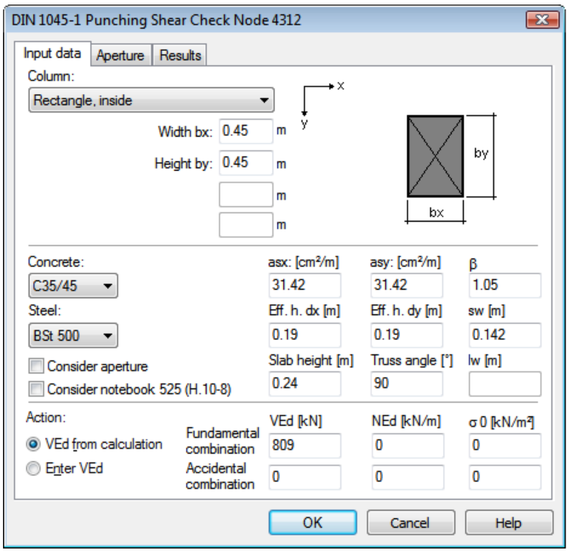
2. Opening

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. You can call up an improved bending reinforcement by clicking the *Proposal* button.

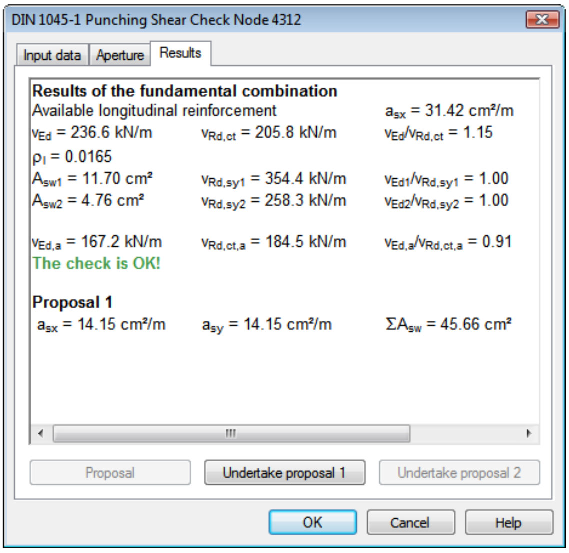
Example



Column: Rectangle, inside
Width bx: 0.45 m
Height by: 0.45 m
Concrete: C35/45
Steel: BSt 500
asx: [cm²/m] 31.42
asy: [cm²/m] 31.42
β 1.05
Eff. h. dx [m] 0.19
Eff. h. dy [m] 0.19
sw [m] 0.142
☐ Consider aperture
☐ Consider notebook 525 (H.10-8)
Slab height [m] 0.24
Truss angle [°] 90
lw [m]

Action:
● VEd from calculation
○ Enter VEd

	VEd [kN]	NEd [kN/m]	σ 0 [kN/m²]
Fundamental combination	809	0	0
Accidental combination	0	0	0



Results of the fundamental combination

Available longitudinal reinforcement a_{sx} = 31.42 cm²/m

v_{Ed} = 236.6 kN/m $v_{Rd,ct}$ = 205.8 kN/m $v_{Ed}/v_{Rd,ct}$ = 1.15

ρ_l = 0.0165

A_{sw1} = 11.70 cm² $v_{Rd,sy1}$ = 354.4 kN/m $v_{Ed1}/v_{Rd,sy1}$ = 1.00

A_{sw2} = 4.76 cm² $v_{Rd,sy2}$ = 258.3 kN/m $v_{Ed2}/v_{Rd,sy2}$ = 1.00

$v_{Ed,a}$ = 167.2 kN/m $v_{Rd,ct,a}$ = 184.5 kN/m $v_{Ed,a}/v_{Rd,ct,a}$ = 0.91

The check is OK!

Proposal 1

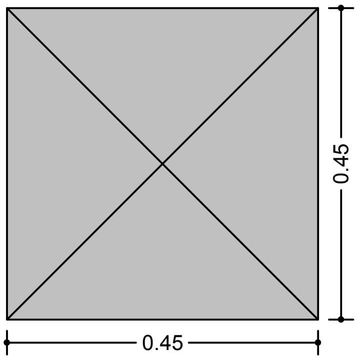
a_{sx} = 14.15 cm²/m a_{sy} = 14.15 cm²/m ΣA_{sw} = 45.66 cm²

Punching shear check node 4312

The check is performed according to DIN 1045-1:2008-08.

1. Measurements, situation and material

Rectangular column with width b_x = 0.45 m and height b_y = 0.45 m
Situation: Inside; β = 1.05



Critical perimeter u = 3.59 m (distance = 0.29 m); A_{crit} = 0.97 m²

Slab height h = 0.240 m
Effective height of the slab d_x = 0.190 m; d_y = 0.190 m
Available longitudinal reinforcement a_{sx} = 31.42 cm²/m; a_{sy} = 31.42 cm²/m
Truss angle α = 90.0°

Concrete: C35/45 f_{ck} = 35.00 N/mm² α = 0.85
γ_c = 1.50 $f_{cd} = \alpha \cdot f_{ck} / \gamma_c$ = 19.83 N/mm²

Reinforce.: BSt 500 f_{ck} = 500.00 N/mm² γ_c = 1.15
$f_{yd} = f_{yk} / \gamma_s$ = 434.78 N/mm²

2. Action from fundamental combination

V_{Ed} = 809.00 kN N_{Ed} = 0.00 kN/m σ_0 = 0.00 kN/m²
$v_{Ed} = \beta \cdot V_{Ed} / u$ = 236.57 kN/m

3. Punching resistance without punching reinforcement

$$v_{Rd,ct} = \left((0{,}21/\gamma_c) \cdot \eta_1 \cdot \kappa \cdot (100 \cdot \rho_l \cdot f_{ck})^{1/3} - 0{,}12\sigma_{cd}\right) \cdot d$$

with η_1 = 1.00 κ = 2.00
ρ_l = 0.0165 f_{ck} = 35.00 N/mm²
σ_{cd} = 0.00 N/mm² d = 0.19 m

$v_{Rd,ct}$ = 205.79 kN/m

$v_{Ed} / v_{Rd,ct}$ = 1.15 > 1 Punching reinforcement is required!

4. Punching reinforcement (normal)

$$A_{sw,1} = \frac{(v_{Ed} - v_{Rd,c}) \cdot u_1}{\kappa_s \cdot f_{yd}} \qquad A_{sw,i} = \frac{(v_{Ed} - v_{Rd,c}) \cdot u_i \cdot s_w}{\kappa_s \cdot f_{yd} \cdot d}$$

$A_{sw,min} = \min\rho_w \cdot s_w \cdot u_i$

with $v_{Rd,c}$ = 205.79 kN/m f_{yd} = 434.78 N/mm²
κ_s = 0.70 s_w = 0.142 m
$\min\rho_w$ = 0.102 % d = 0.19 m

Row 1: Distance = 0.10 m; u_1 = 2.40 m; $v_{Ed,1}$ = 354.39 kN/m;
$A_{sw,1}$ = **11.70 cm²** > $A_{sw,1,min}$ = 3.47 cm²
Row 2: Distance = 0.24 m; u_2 = 3.29 m; $v_{Ed,2}$ = 258.26 kN/m;
$A_{sw,2}$ = 4.24 cm² < $A_{sw,2,min}$ = **4.76 cm²**

External perimeter: Distance = 0.52 m; u_a = 5.08 m; $v_{Ed,a}$ = 167.22 kN/m;
κ_a = 0.897; $v_{Rd,ct,a}$ = 184.52 kN/m
$v_{Ed,a} \leq v_{Rd,ct,a}$ The check is OK!

5. Minimum momenta and corresponding longitudinal reinforcement according to section 10.5.6

$m_{Ed,x} = \eta_x \cdot V_{Ed} = 0.125 \cdot 809.00 = 101.13$ kNm/m
corresponding longitudinal reinforcement $a_{sx,min}$=12.93 cm²/m ≤ a_{sx}=31.42 cm²/m
$m_{Ed,y} = \eta_y \cdot V_{Ed} = 0.125 \cdot 809.00 = 101.13$ kNm/m
corresponding longitudinal reinforcement $a_{sy,min}$=12.93 cm²/m ≤ a_{sy}=31.42 cm²/m

Prestressed Structures

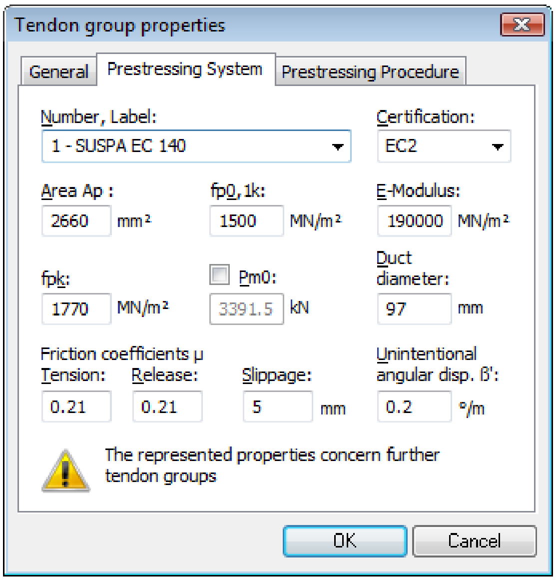
Internal Prestressing

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

Prestressing with bond and prestressing without bond are differentiated in the section inputs and the specifications for the *Creep and shrinkage* load case.

Prestressing System

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



Number, Label: 1 - SUSPA EC 140
Certification: EC2
Area Ap : 2660 mm²
fp0,1k: 1500 MN/m²
E-Modulus: 190000 MN/m²
fpk: 1770 MN/m²
☐ Pm0: 3391.5 kN
Duct diameter: 97 mm
Friction coefficients μ Tension: 0.21 Release: 0.21
Slippage: 5 mm
Unintentional angular disp. ß': 0.2 °/m

The represented properties concern further tendon groups

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

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 $ß_{0.2}$ 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 according to DIN 1045-1, OENORM 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 according to DIN 1045-1, OENORM 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:
$P_{m0} = A_p \cdot 0.75 ß_s$ or $A_p \cdot 0.55 ß_z$ according to DIN 4227, 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)

Duct diameter

Is only used for beam tendons to calculate the net and ideal section values [mm].

Friction coefficients

Friction coefficients μ for prestressing and release.

Slippage

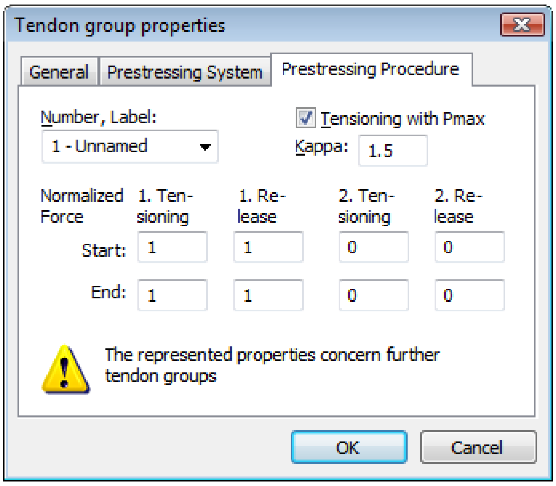
Slippage at the prestressed tie bolt [mm].

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 tie bolt is calculated from this by the program. Each tie bolt can be prestressed and released twice. The prestressing procedures are numbered.



Number, Label: 1 - Unnamed

☑ Tensioning with Pmax

Kappa: 1.5

Normalized Force	1. Tensioning	1. Release	2. Tensioning	2. Release
Start:	1	1	0	0
End:	1	1	0	0

The represented properties concern further tendon groups

Number, Label

Number and name of the prestressing procedure.

Tensioning with Pmax

Selecting this check box causes the factors for tensioning correspond to the maximim force P_{max} for tendons certified according to DIN 1045-1 or EC2.

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. The distance x used corresponds to the full tendon length for one-sided prestressing; otherwise, it corresponds to half the tendon length (see the following example).

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.

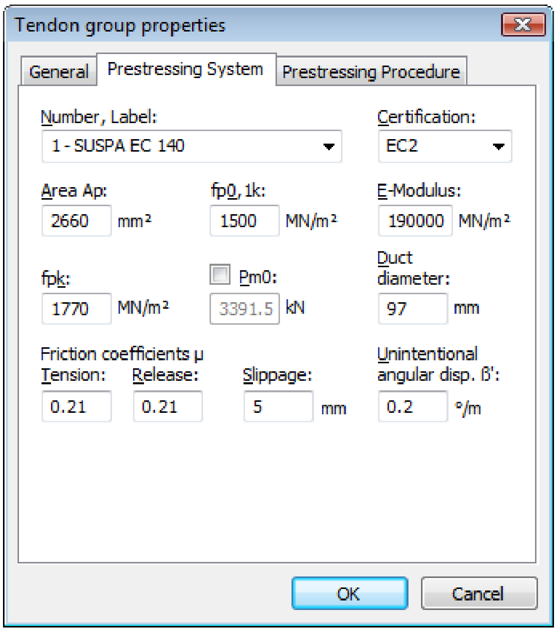
The differences between tensioning with P_{m0} and P_{max} are described in the following examples.

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

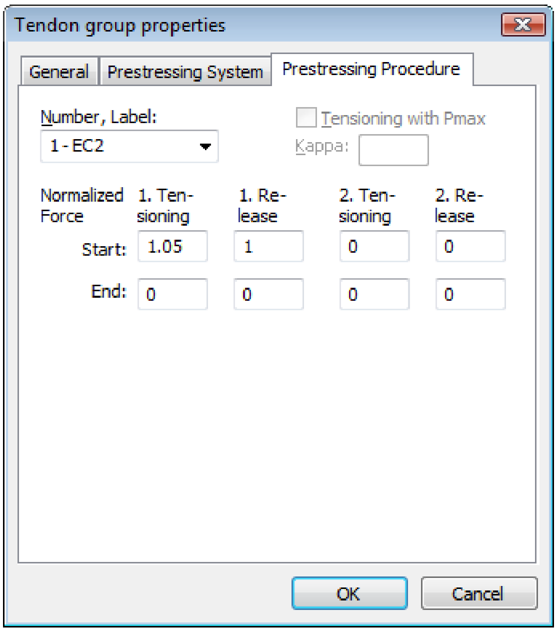
Examples for Prestressing Procedures

Tensioning with P_{m0}

The mode of action of the factors *Tensioning* and *Release* can be clarified using the example of an St 1570 / 1770 single tendon with bolt at the tendon start certified according to EC2.



Number, Label: 1 - SUSPA EC 140
Certification: EC2
Area Ap: 2660 mm²
fp0,1k: 1500 MN/m²
E-Modulus: 190000 MN/m²
fpk: 1770 MN/m²
☐ Pm0: 3391.5 kN
Duct diameter: 97 mm
Friction coefficients µ
Tension: 0.21
Release: 0.21
Slippage: 5 mm
Unintentional angular disp. ß': 0.2 °/m



Number, Label: 1 - EC2
☐ Tensioning with Pmax
Kappa:

Normalized Force	1. Tensioning	1. Release	2. Tensioning	2. Release
Start:	1.05	1	0	0
End:	0	0	0	0

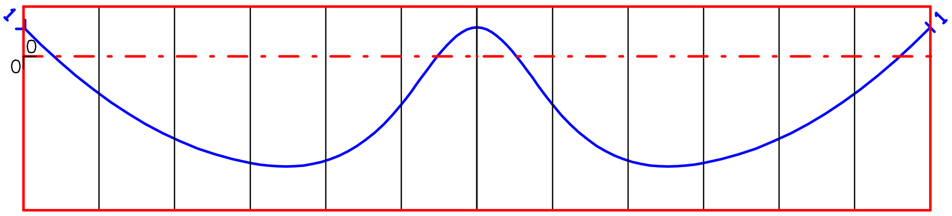
The permissible prestressing forces ar defined by:

$$P_{max} = min(A_p \cdot 0.80\, f_{pk}\ ,\ A_p \cdot 0.90\, f_{p0.1k}\ ) = 3591.0 \text{ kN}$$

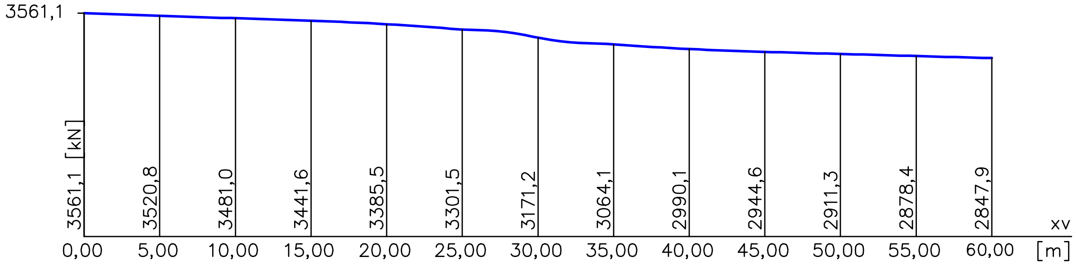
$$P_{m0} = min(A_p \cdot 0.75\, f_{pk}\ ,\ A_p \cdot 0.85\, f_{p0.1k}\ ) = 3391.5 \text{ kN}$$

The first prestressing force curve of the following illustration results after overstressing with 5% using a factor of 1.05 relating to P_{m0}, i.e., the maximum prestressing force is 3561.1 kN < P_{max}.

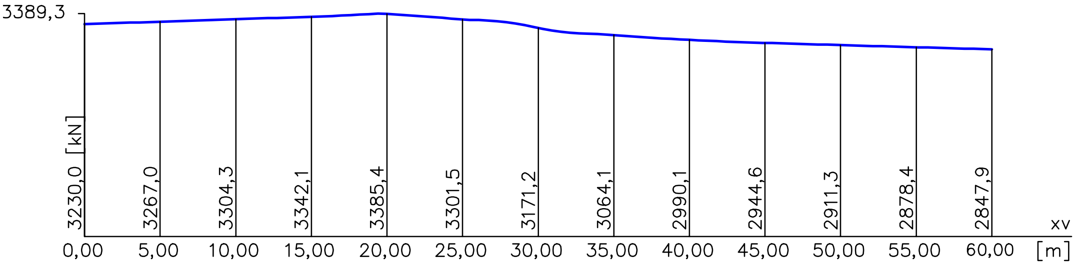
The second prestressing force curve results after tensioning and release with the factors 1.05 and 1.0, i.e., the maximum prestressing force that remains in the tendon after it is fixed into place is 3389.3 kN < P_{m0}.



Single tendon, 10 times superelevated



Prestressing force curve after the 1st tensioning with a factor of 1.05



Prestressing force curve after the 1st release with a factor of 1.0

Potential slippage 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.

Tensioning with P_{max}

According to DIN 1045-1, DIN Technical Report 102 and DIN EN 1992-1-1, for tendons with certification as per DIN 1045-1 and EC2 the maximum force applied to the tendon during the stressing process may not exceed the smaller value from the following:

$P_{max} = A_p \cdot 0.80 f_{pk} e^{-\mu\gamma(\kappa-1)}$ or $A_p \cdot 0.90 f_{p0.1k} e^{-\mu\gamma(\kappa-1)}$

with:

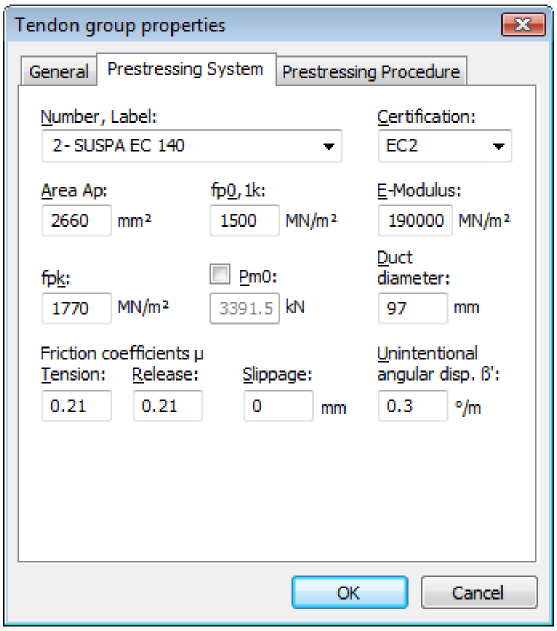
μ	Friction coefficient according to the general certification from the building authorities.
γ	$\Phi + k \cdot x$ Φ = sum of planned deviation angle over the length x, k = unintentional deviation angle per unit of length (ß' in the dialog), x = the distance between the prestressed anchor and the fixed anchor in the case of one-sided prestressing or the influence length of the respective anchor in the case of two-sided prestressing.
κ	Allowance value for ensuring an overstressing reserve with $1.5 \leq \kappa \leq 2$ for tendons with supplemental bond and $\kappa = 1$ for all other cases.

The program uses the specified allowance value k to determine the maximum permissible value P_{max}. The influence length x is assumed to be the tendon length for one-sided prestressing or simply half of the tendon length for two-sided prestressing.

In this setting the overstressing factor refers to P_{max}, which means the value 1.0 is used to select the maximum force permitted by the standard.

The release factor continues to refer to P_{m0}. Setting the value to 1.0 also assures that the force remaining in the tendon after it fixed into place is within the permissible range.

Using an St 1570 / 1770 single tendon prestressed on both sides with certification as per EC2, the prestressing force curve is illustrated for a value of κ = 1.5. Slippage is ignored for the sake of simplicity.



Number, Label: 2 - SUSPA EC 140

Certification: EC2

Area Ap: 2660 mm²

fp0,1k: 1500 MN/m²

E-Modulus: 190000 MN/m²

fpk: 1770 MN/m²

☐ Pm0: 3391.5 kN

Duct diameter: 97 mm

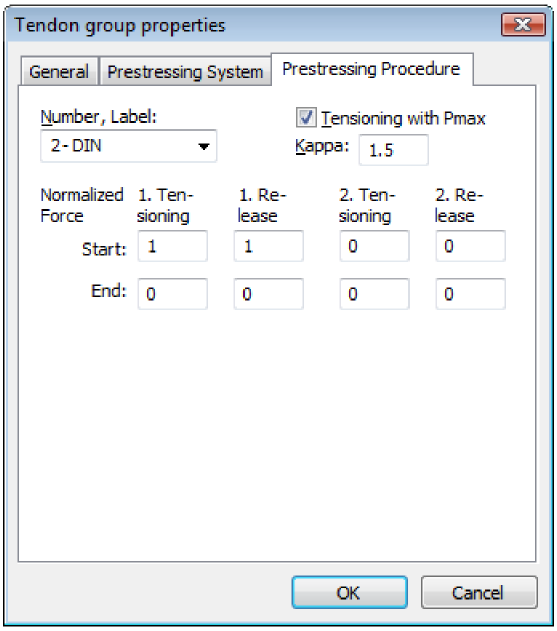
Friction coefficients μ

Tension: 0.21

Release: 0.21

Slippage: 0 mm

Unintentional angular disp. ß': 0.3 °/m



Number, Label: 2 - DIN

☑ Tensioning with Pmax

Kappa: 1.5

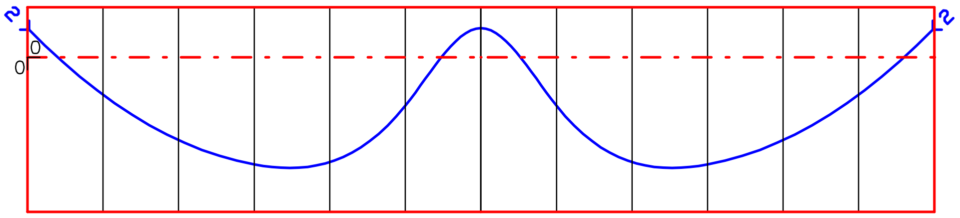
Normalized Force	1. Tensioning	1. Release	2. Tensioning	2. Release
Start:	1	1	0	0
End:	0	0	0	0

The program will determine the permissible prestressing forces as follows:

$$P_{max} = e^{-\mu\gamma(\kappa-1)} \cdot min(A_p \cdot 0.80\, f_{pk} , A_p \cdot 0.90\, f_{p0.1k}) = 0.9457 \cdot 3591 = 3395.9 \text{ kN}$$

$$P_{m0} = min(A_p \cdot 0.75\, f_{pk} , A_p \cdot 0.85\, f_{p0.1k}) = 3391.5 \text{ kN}$$

The maximum force P_{max} is automatically maintained with a tensioning factor of 1.0. As shown in the following force curve, 3391.2 kN remain in the tendon after it is fixed into place. Thus the limit P_{m0} is also observed.

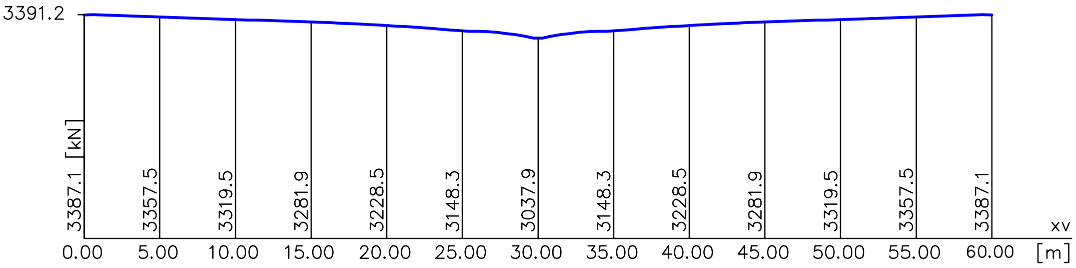


Single tendon, 10 times superelevated

```
Force function of tendon group 2 (1 tendon(s), l = 60.16 m)

Prestressing system 2 - SUSPA EC 140. Certification according to EC2.
Pm0      = 3391.5 kN,     Ap = 2660.0 mm², µa = 0.21, Angle  β' =  0.30 °/m
E-Modul  = 190000 MN/m², Ah = 7389.8 mm², µn = 0.21, Slippage  =  0.00 mm

Pre. procedure  2: <: 1.000 :> 1.000 |  1.000:> 1.000<:  (DIN)
Pre. forces   [kN]:   3395.9   3387.1 |  3395.9  3387.1
Extension     [mm]:    362.2     -0.0 |    26.0    -0.0
Tensioning with Pmax (DIN Report, DIN 1045-1, DIN EN 1992-1-1). Kappa = 1.5.
```



Prestressing force curve after tensioning and release

If the force calculated during prestressing is less than the value during release, then the program will make sure that the smaller value is not exceeded after the component is fixed into place.

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.

Scattering of Prestressing

For checks in the ultimate limit state, the following applies for the design value of the prestressing force according to DIN 1045-1, Chapter 8.7.5 (1):

$$P_d = \gamma_P \cdot P_{m,t}$$

with:

$P_{m,t}$	Mean value of prestressing force at time t including prestressing losses from friction, slippage, creep, shrinkage and relaxation.
γ_P	Partial safety factor of prestressing force, $\gamma_P = 1$ as specified in Chapter 8.7.5 (1).

In the serviceability limit state, two characteristic values for the prestressing force are defined in Chapter 8.7.4 (1):

$P_{k,sup} = r_{sup} \cdot P_{m,t}$	Upper characteristic value acc. to DIN 1045-1, Eq. (52)
$P_{k,inf} = r_{inf} \cdot P_{m,t}$	Lower characteristic value acc. to DIN 1045-1, Eq. (53)

The scattering coefficients for internal prestressing are defined separately for construction stages and final states. They are used in the following checks:

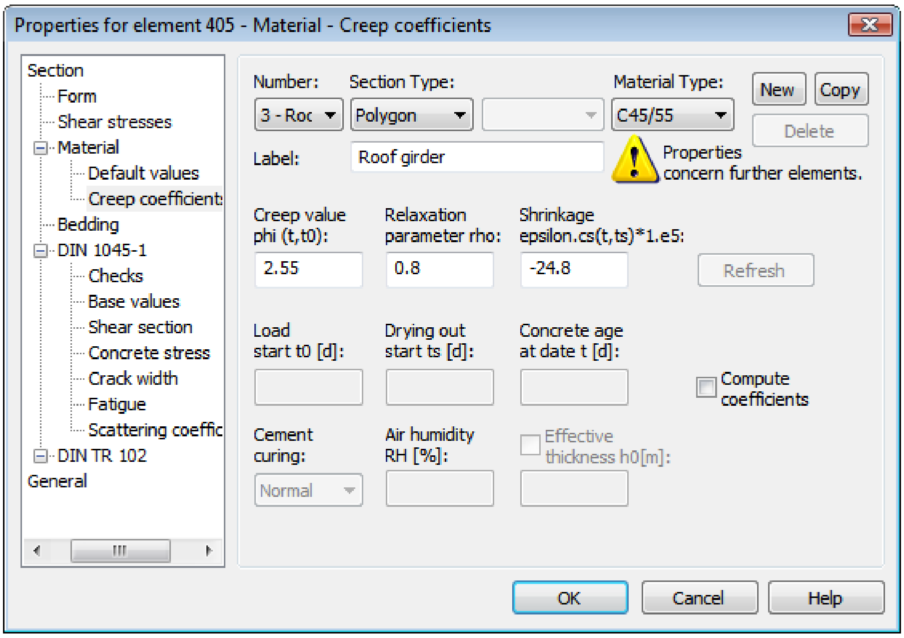
- Minimum reinforcement for crack width limitation
- Crack width check
- Decompression check

Regarding the effects from external prestressing, the scattering coefficients are set to $r_{sup} = r_{inf} = 1$ on the basis of DIN Technical Report 102, Chapter 2.5.4.2 (4).

Creep and Shrinkage

Similar to prestressing, creep and shrinkage are taken into account by specifying a corresponding load case (*Ks* 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 *Ks* load case are entered in the Section dialog. Alternatively, you can also use this dialog to calculate the coefficients according to Book 525, Section 9.1.4.



Properties for element 405 - Material - Creep coefficients

Number: 3 - Roc
Section Type: Polygon
Material Type: C45/55
Label: Roof girder
Properties concern further elements.
Creep value phi (t,t0): 2.55
Relaxation parameter rho: 0.8
Shrinkage epsilon.cs(t,ts)*1.e5: -24.8
Load start t0 [d]:
Drying out start ts [d]:
Concrete age at date t [d]:
☐ Compute coefficients
Cement curing: Normal
Air humidity RH [%]:
☐ Effective thickness h0[m]:

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 $\rho = 0.80$).
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 DIN 1045-1, Chapter 8.7.3, the stress change $\Delta\sigma_{pr}$ in the tendons at position x caused by relaxation must be taken into account in addition to the stress loss from concrete creep and shrinkage. This change may taken from the building inspection certification and for the ratio of initial stress to characteristic tensile stress (σ_{p0}/f_{pk}) with an initial stress of

$$\sigma_{p0} = \sigma_{pg0} - 0.3\ \Delta\sigma_{p,csr} \qquad (51)$$

This includes:

$\Delta\sigma_{p,csr}$ Stress change in the tendons due to creep, shrinkage and relaxation at position x at time t,

σ_{pg0} Initial stress in the tendons from prestressing and permanent actions.

Since the entire stress loss cannot be known in advance, the input value $\Delta\sigma_{p,csr}$ for Eq. (51) must be estimated and then iteratively corrected if necessary (cf. König et al. 2003, p. 38). Alternatively, you can set $\sigma_{p0} = \sigma_{pg0}$ and for conventional buildings $\sigma_{p0} = 0.95 \cdot \sigma_{pg0}$ according to DIN 1045-1 for the sake of simplicity and to be on the safe side. The following table shows an example of stress loss due to relaxation.

Characteristic values of the stress losses $\Delta\sigma_{pr}$ in % of the initial tension σ_{p0} for prestressing steel strand St 1570 / 1770 with very low relaxation

σ_{p0}/f_{pk}	Time interval after prestressing in hours						
	1	10	200	1000	5000	$5 \cdot 10^5$	10^6
0.45							
0.50							
0.55						1.0	1.2
0.60					1.2	2.5	2.8
0.65				1.3	2.0	4.5	5.0
0.70			1.0	2.0	3.0	6.5	7.0
0.75		1.2	2.5	3.0	4.5	9.0	10.0
0.80	1.0	2.0	4.0	5.0	6.5	13.0	14.0

For tendons with DIN 4227 certification, the example of $t = \infty$ with a permissible utilization of 0.55 according to DIN 4227, Tab. 9, Row 65, results in a stress loss of around 1%, which generally can be ignored.

Tendons with new certification may be utilized by up to 0.65 according to DIN 1045-1, Chapter 11.1.4. This results in significantly higher stress losses that must be accounted for.

You can define the stress losses in the CSR actions of the *DIN 1045-1 Actions* dialog.

Checks in the Ultimate Limit States

The following checks are available:

- Bending with or without longitudinal force or longitudinal force only (Chapter 10.2 of the standard).
- Ensuring ductile component behavior (Chapter 5.3.2).
- Lateral force (Chapter 10.3).
- Torsion and combined stressing (Chapter 10.4).
- Punching shear (Chapter 10.5).
- Fatigue check (Chapter 10.8).

Design Combinations

The following combinations in accordance with DIN 1055-100, Chapter 9.4, are taken into account in the ultimate limit states:

- Combination for permanent and temporary design situations

$$E\left\{\sum_{j\geq 1}\gamma_{G,j}\cdot G_{k,j}\oplus\gamma_P\cdot P_k\oplus\gamma_{Q,1}\cdot Q_{k,1}\oplus\sum_{i>1}\gamma_{Q,i}\cdot\psi_{0,i}\cdot Q_{k,i}\right\} \tag{14}$$

- Combination for accidental design situations

$$E\left\{\sum_{j\geq 1}\gamma_{GA,j}\cdot G_{k,j}\oplus\gamma_{PA}\cdot P_k\oplus A_d\oplus\psi_{1,1}\cdot Q_{k,1}\oplus\sum_{i>1}\psi_{2,i}\cdot Q_{k,i}\right\} \tag{15}$$

- Combination for design situations resulting from earthquakes (A_E)

$$E\left\{\sum_{j\geq 1}G_{k,j}\oplus P_k\oplus\gamma_1\cdot A_{Ed}\oplus\sum_{i\geq 1}\psi_{2,i}\cdot Q_{k,i}\right\} \tag{16}$$

For the check against fatigue two alternative action combinations can be used:

- Frequent combination for simplified checks according to DIN 1055-100, Chapter 10.4, Equation (23) in conjunction with DIN 1045-1, Chapter 10.8.4.

$$E\left\{\sum_{j\geq 1}G_{k,j}\oplus P_k\oplus\psi_{1,1}\cdot Q_{k,1}\oplus\sum_{i>1}\psi_{2,i}\cdot Q_{k,i}\right\} \tag{23}$$

- Fatigue combination according to DIN EN 1992-1-1, Chapter 6.8.3, Equation (6.69) for checks with damage equivalent stress ranges based on DIN 1045-1, Chapter 10.8.3

$$E\left\{\left(\sum_{j\geq 1}G_{k,j}\oplus P_k\oplus\psi_{1,1}\cdot Q_{k,1}\oplus\sum_{i>1}\psi_{2,i}\cdot Q_{k,i}\right)\oplus Q_{fat}\right\} \tag{6.69}$$

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 applies.

Stress-Strain-Curves

The following characteristics are used for section design:

- Concrete: parabola-rectangle diagram according to DIN 1045-1, Figure 23.
- Reinforcing steel: stress-strain curve according to DIN 1045-1, Figure 27.
- Prestressing steel: stress-strain curve according to DIN 1045-1, Figure 28, with upper horizontal branch according to Chapter 9.3.3 (2) of the standard.

For the fatigue checks, the user defines one of the following curves to determine the concrete compressive stresses:

- Stress-strain curve according to DIN 1045-1, Figure 22, with $f_c = f_{cm}$.
- Parabola-rectangle diagram according to DIN 1045-1, Figure 23.
- Linear curve with the gradient $\arctan E_{cm}$.

Design Internal Forces

The design internal forces are derived from the action combinations, with separate results for the variants defined in the construction stages and final states.

For 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. This approach should always yield an upper limit for the load-bearing capacity.

For 3D stressed beams and design objects, the shear design is performed separately for the Q_y and Q_z lateral forces. The simultaneous effect of shear and torsion stress is taken into account in accordance with DIN 1045-1, Chapter 10.4.

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

Beam reinforcement

Design for m, n

$min\ N_x$, $corresp.\ M_y$, $corresp.\ M_z$
$max\ N_x$, $corresp.\ M_y$, $corresp.\ M_z$
$min\ M_y$, $corresp.\ M_z$, $corresp.\ N_x$
$max\ M_y$, $corresp.\ M_z$, $corresp.\ N_x$
$min\ M_z$, $corresp.\ N_x$, $corresp.\ M_y$
$max\ M_z$, $corresp.\ N_x$, $corresp.\ M_y$

Shear and torsion design

$min\ Q_y$
$max\ Q_y$
$min\ Q_z$
$max\ Q_z$
$min\ M_x$
$max\ M_x$

$min\ Q_y$, $corresp.\ M_x$
$max\ Q_y$, $corresp.\ M_x$
$min\ Q_z$, $corresp.\ M_x$
$max\ Q_z$, $corresp.\ M_x$
$min\ M_x$, $corresp.\ Q_y$
$max\ M_x$, $corresp.\ Q_y$
$min\ M_x$, $corresp.\ Q_z$
$max\ M_x$, $corresp.\ Q_z$

Orthogonal area reinforcement

Slabs
$min\ m_x - |corresp.\ m_{xy}|$; $max\ m_x + |corresp.\ m_{xy}|$
$min\ m_y - |corresp.\ m_{xy}|$; $max\ m_y + |corresp.\ m_{xy}|$
$corresp.\ m_x \pm |min\ m_{xy}|$; $corresp.\ m_x \pm |max\ m_{xy}|$
$corresp.\ m_y \pm |min\ m_{xy}|$; $corresp.\ m_y \pm |max\ m_{xy}|$

Plain stress elements

$\mathit{min}\ n_x - |\mathit{corresp.}\ n_{xy}|;\quad \mathit{max}\ n_x + |\mathit{corresp.}\ n_{xy}|$
$\mathit{min}\ n_y - |\mathit{corresp.}\ n_{xy}|;\quad \mathit{max}\ n_y + |\mathit{corresp.}\ n_{xy}|$
$\mathit{corresp.}\ n_x \pm |\mathit{min}\ n_{xy}|;\quad \mathit{corresp.}\ n_x \pm |\mathit{max}\ n_{xy}|$
$\mathit{corresp.}\ n_y \pm |\mathit{min}\ n_{xy}|;\quad \mathit{corresp.}\ n_y \pm |\mathit{max}\ n_{xy}|$

Shells

$\mathit{min}\ m_x - |\mathit{corresp.}\ m_{xy}|,\quad \mathit{corresp.}\ n_x \pm |\mathit{corresp.}\ n_{xy}|$
$\mathit{max}\ m_x + |\mathit{corresp.}\ m_{xy}|,\quad \mathit{corresp.}\ n_x \pm |\mathit{corresp.}\ n_{xy}|$
$\mathit{min}\ m_y - |\mathit{corresp.}\ m_{xy}|,\quad \mathit{corresp.}\ n_y \pm |\mathit{corresp.}\ n_{xy}|$
$\mathit{max}\ m_y + |\mathit{corresp.}\ m_{xy}|,\quad \mathit{corresp.}\ n_y \pm |\mathit{corresp.}\ n_{xy}|$
$\mathit{corresp.}\ m_x \pm |\mathit{min}\ m_{xy}|,\quad \mathit{corresp.}\ n_x \pm |\mathit{corresp.}\ n_{xy}|$
$\mathit{corresp.}\ m_x \pm |\mathit{max}\ m_{xy}|,\quad \mathit{corresp.}\ n_x \pm |\mathit{corresp.}\ n_{xy}|$
$\mathit{corresp.}\ m_y \pm |\mathit{min}\ m_{xy}|,\quad \mathit{corresp.}\ n_y \pm |\mathit{corresp.}\ n_{xy}|$
$\mathit{corresp.}\ m_y \pm |\mathit{max}\ m_{xy}|,\quad \mathit{corresp.}\ n_y \pm |\mathit{corresp.}\ n_{xy}|$
$\mathit{min}\ n_x - |\mathit{corresp.}\ n_{xy}|,\quad \mathit{corresp.}\ m_x \pm |\mathit{corresp.}\ m_{xy}|$
$\mathit{max}\ n_x + |\mathit{corresp.}\ n_{xy}|,\quad \mathit{corresp.}\ m_x \pm |\mathit{corresp.}\ m_{xy}|$
$\mathit{min}\ n_y - |\mathit{corresp.}\ n_{xy}|,\quad \mathit{corresp.}\ m_y \pm |\mathit{corresp.}\ m_{xy}|$
$\mathit{max}\ n_y + |\mathit{corresp.}\ n_{xy}|,\quad \mathit{corresp.}\ m_y \pm |\mathit{corresp.}\ m_{xy}|$
$\mathit{corresp.}\ n_x \pm |\mathit{min}\ n_{xy}|,\quad \mathit{corresp.}\ m_x \pm |\mathit{corresp.}\ m_{xy}|$
$\mathit{corresp.}\ n_x \pm |\mathit{max}\ n_{xy}|,\quad \mathit{corresp.}\ m_x \pm |\mathit{corresp.}\ m_{xy}|$
$\mathit{corresp.}\ n_y \pm |\mathit{min}\ n_{xy}|,\quad \mathit{corresp.}\ m_y \pm |\mathit{corresp.}\ m_{xy}|$
$\mathit{corresp.}\ n_y \pm |\mathit{max}\ n_{xy}|,\quad \mathit{corresp.}\ m_y \pm |\mathit{corresp.}\ m_{xy}|$

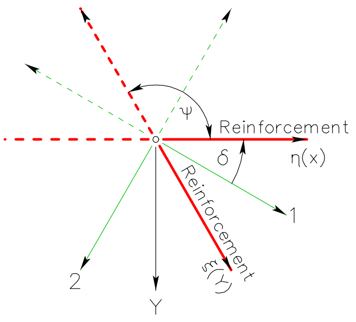
Axisymmetric shells

$\mathit{min}\ N_\varphi,\ \mathit{corresp.}\ M_\varphi;\quad \mathit{max}\ N_\varphi,\ \mathit{corresp.}\ M_\varphi$
$\mathit{min}\ M_\varphi,\ \mathit{corresp.}\ N_\varphi;\quad \mathit{max}\ M_\varphi,\ \mathit{corresp.}\ N_\varphi$
$\mathit{min}\ N_\upsilon,\ \mathit{corresp.}\ M_\upsilon;\quad \mathit{max}\ N_\upsilon,\ \mathit{corresp.}\ M_\upsilon$
$\mathit{min}\ M_\upsilon,\ \mathit{corresp.}\ N_\upsilon;\quad \mathit{max}\ M_\upsilon,\ \mathit{corresp.}\ N_\upsilon$

Oblique area reinforcement

The bending design of slabs with oblique reinforcement assemblies is carried out based on Kuyt/Rüsch. The design moments are calculated with the help of principal moments m_1, m_2 based on the equations outlined in Book 166 of the DAfStB (German Committee of Reinforced Concrete).

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:

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

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

The formulas apply accordingly for the normal design forces.

Shear design for slabs and shells

The shear design of slabs or shells is carried out for the maximum resulting lateral force of a design point. Consequently, the size of the stirrup reinforcement is independent of the internal force direction and has the dimension [cm²/m²]. The following design variants are derived:

$$\sqrt{min\ q_x^2 + corresp.\ q_y^2}\ , \qquad \sqrt{max\ q_x^2 + corresp.\ q_y^2}$$

$$\sqrt{min\ q_y^2 + corresp.\ q_x^2}\ , \qquad \sqrt{max\ q_y^2 + corresp.\ q_x^2}$$

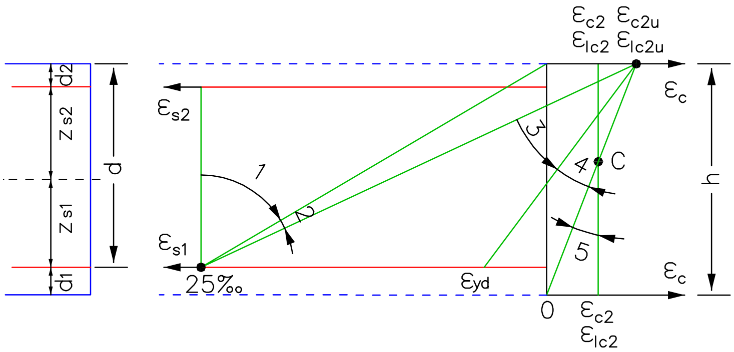
For two-axes stressed slabs, the lateral force check can be performed separately in the x and y stress directions as described in Chapter 10.3.1(5). Consequently, the design is carried out for the following variants:

$min\ q_x,\qquad max\ q_x$

$min\ q_y,\qquad max\ q_y$

Design for Bending with or without Longitudinal Force or Longitudinal Force only

The design for longitudinal force and bending moment is performed according to Chapter 10.2 of the standard.The reinforcement required for each internal force combination at the reinforced concrete section is determined iteratively based on the formulation of equilibrium conditions as well as the limit strain curve depicted in the illustration below. The final result is derived from the extreme value of all calculated reinforcements.



Strain areas for the design

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. Due to reasons of economy and to limit the compression zone height according to DIN 1045-1, Chapter 8.2(3), the compression reinforcement in strain area 3 will be determined in such a way that the following applies for steel strain ε_{s1}:

$$\varepsilon_{s1} \geq \max\left(\varepsilon_{yd},\ \frac{\varepsilon_{c2u}}{x/d} - \varepsilon_{c2u}\right) \quad [‰]$$

with:

ε_{yd}	The steel strain associated with the design value for strength f_{yd}.
x/d	Referenced compressive zone height. ≤ 0.45 for concrete qualities up to C50/60. ≤ 0.35 for concrete qualities C55/67 or higher and lightweight concrete.

The procedure in strain areas 4 and 5 is the same as with symmetrical design.

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 relationships between the reinforcement layers will not be affected.

Mode Compression member

The design is performed symmetrically. In addition, the minimum reinforcement required by DIN 1045-1, Chapter 13.5.2, is calculated:

$$A_{s,min} = 0.15\,|\,N_{Ed}\,|\,/\,f_{yd} \qquad (155)$$

with:

N_{Ed}	Design value of the longitudinal force to be absorbed.
f_{yd}	Design value of the reinforcing steel strength at the yield strength.

Inclusion of tendons with bond

For area elements, the strain reserves of the tendons with bond are not used when designing the longitudinal reinforcement.

When designing beams and design objects, the internal forces of the concrete section is reduced by the statically determined portions which result from prestressing minus the losses from creep, shrinkage and prestressing steel relaxation (CSR). Situations prior to the grouting of the tendons are excluded. So only the restraint portions from "P+CSR" and the external loads are contained in the remaining internal forces for the composite section. If necessary, the reinforcing steel positioned by the user will be increased until the composite internal forces can be absorbed.

The position of the tendon groups in the section, the prestressing losses from CSR, the statically determined portions and the internal forces of the concrete section and the composite section are written to the detailed log.

Minimum Reinforcement for Ensuring Ductile Component Behavior

According to DIN 1045-1, Chapter 5.3.2, component failures that occur without warning during initial crack formation must be prevented (ductility criterion). This requirement is fulfilled for reinforced concrete and prestressed concrete components as long as a minimum reinforcement is included as described in Chapter 13.1.1. This minimum reinforcement, which is also referred to as the *Robustness reinforcement* in Book 525 and Technical Report 102, must be calculated for the crack moment (given prestressing without taking into account the prestressing force) using the average tensile strength of concrete f_{ctm} and steel stress $\sigma_s = f_{yk}$:

$A_s = M_{cr} / (f_{yk} \cdot z_s)$

with

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

The reinforcement must be distributed throughout the tensile zone based on the constructive guidelines set forth in Chapter 13.1.1 (3). DIN 1045-1 provides no information on the action combination that is used to determine the tensile zone. The corresponding rule specified in DIN Technical Report 102, Chapter 4.3.1.3, is therefore used in the program. Based on that rule, the minimum reinforcement should be placed in areas where tensile stresses in the concrete occur under the infrequent action combination. According to Technical Report 102, Chapter 4.3.1.3 (107), the statically undetermined prestressing effect should be taken into account in this combination rather than the statically determined prestressing effect. Since the infrequent combination is not defined in DIN 1045-1, to be on the safe side it is replaced by the rare (characteristic) combination for the check. It is the responsibility of the user to observe the remaining constructive guidelines of Chapter 13.1.1 (3).

The program determines all stresses at the gross section. The statically determined prestressing effect can only be subtracted for beams and design objects. The crack moment results in $M_{cr} = W_c \cdot f_{ctm}$, the lever arm z_s of the internal forces is assumed to be $0.9 \cdot d$ for the sake of simplicity. 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.

The option to take tendons into account as per DIN 1045-1, Chapter 13.1.1 (2), remains unused.

Minimum Surface Reinforcement for Prestressed Members

A minimum surface reinforcement must always be specified for prestressed components in accordance with DIN 1045-1, Chapter 13.1.2, regardless of the guidelines on robustness or crack reinforcement. The reinforcement determined according to Table 29 and 30 can be entered into the program by specifying a base reinforcement in the reinforcing steel description.

Design for Lateral Force

Lateral force design involves determining the diagonal tensile reinforcement and includes a concrete strut check as defined by DIN 1045-1, Chapter 10.3. The following special conditions apply:

- The angle of the diagonal tensile reinforcement is assumed to be 90°.
- In the calculation, the value for $\cot \Theta$ is limited to the range permitted in accordance with DIN 1045-1, Eq. (73) (method with load-dependent strut angle). The actual effective concrete strut angle is logged for each check location. Edition 2008-08, Chapter 10.3.4(3): For perpendicular stirrups or longitudinal tensile load, $\cot \Theta$ should not exceed the limit value of 1.0. This is guaranteed by the program provided the user does not specify a smaller value.
- The minimum reinforcement is maintained in the calculated stirrup reinforcement as described in Chapter 13.2.3 of the standard while the reinforcement level ρ specified in Table 29 is weighted with a user-defined factor. For areas, the minimum reinforcement will only be determined if a lateral force reinforcement is required for computation (cf. Building and Civil Engineering Standards Committee (NABau) No. 131).
- Slab and shell elements are designed for lateral force $q_r = \sqrt{(q_x^2 + q_y^2)}$. Depending on which has a negative effect, either the principal compressive force or principal tensile force is used for the associated longitudinal force. If selected, the check will be carried out separately for the reinforcement directions x and y in accordance with Chapter 10.3.1(5). If lateral force reinforcement is necessary, it must be added from both directions.
- There is no reduction of the action from loads near supports, as specified in Chapter 10.3.2, Section (1) or (2) of the standard.
- For beams and design objects, the decisive values of the equivalent rectangle are determined by the user independently of the normal section geometry.
- As described in Chapter 10.3.4 (2), the internal lever arm is assumed as $z = 0.9\,d$ and is limited to the maximum value derived from $z = d - c_{v,l} - 30$ mm and $z = d - 2c_{v,l}$ (cf. NABau No. 24). Note that $c_{v,l}$ is the laying measure of the longitudinal reinforcement in the concrete compressive zone. If $c_{v,l}$ is not specified, the program will use the shortest axis distance of the longitudinal reinforcement from the section edge d1 in its place.
- According to Chapter 10.3.4 (2), the value z (inner lever arm) is assumed to be $z = 0.9\,d$. To avoid additional user input, the value is limited with $z = d - 2 \cdot d_1$ instead of $z = d - 2 \cdot c_{nom}$. In the above, d_1 is the smallest axis distance of the longitudinal reinforcement from the edge of the section.
- For beam sections with internal prestressing, the design value of lateral load-bearing capacity $V_{Rd,max}$ according to Chapter 10.3.4 (8) is determined using the nominal value $b_{w,nom}$ of the section width.
- Edition 2008-08: The lateral load-bearing capacity $V_{Rd,max}$ is only checked for lateral forces $V_{Ed} > V_{Rd,ct}$ as explained in Chapter 10.3.1(4) .
- The necessity of a lateral force reinforcement is analyzed according to Chapter 10.3.3 of the standard. As in the previous case, **no** reduction of the action from loads near supports occurs.

The formulas of DIN 1045-1 that are used are listed below.

Components without computationally necessary lateral force reinforcement

$$V_{Rd,ct} = \left[0.10\kappa \cdot \eta_1 \cdot (100\rho_1 \cdot f_{ck})^{1/3} - 0.12 \cdot \sigma_{cd}\right] \cdot b_w \cdot d \qquad (70{:}2001\text{-}07)$$

$$V_{Rd,ct} = \left[\frac{0.15}{\gamma_c} \cdot \kappa \cdot \eta_1 \cdot (100\rho_1 \cdot f_{ck})^{1/3} - 0.12 \cdot \sigma_{cd}\right] \cdot b_w \cdot d \qquad (70{:}2008\text{-}08)$$

with

$V_{Rd,ct}$ Design value of the absorbable lateral force in a component without lateral force reinforcement. Edition 2008-08: In this case you may use a minimum value for the lateral load-bearing capacity $V_{Rd,ct,min}$ based on Equation (70a):

$$V_{Rd,ct,min} = [\eta_1 \cdot v_{min} - 0{,}12\,\sigma_{cd}] \cdot b_w \cdot d \qquad (70a)$$

with at least

$$v_{min} = \frac{\kappa_1}{\gamma_c} \cdot \sqrt{\kappa^3 \cdot f_{ck}}$$

κ	a scale factor with $\kappa = 1 + \sqrt{\frac{200}{d}} \le 2.0$ (71)
γ_c	the partial safety factor for reinforced concrete as per 5.3.3(6), Table 2.
η_1	= 1.0 for normal concrete; for lightweight concrete Table 10 applies.
ρ_l	the longitudinal reinforcement level with $\rho_l = \frac{A_{sl}}{b_w \cdot d} \le 0.02$
A_{sl}	the area of the tensile reinforcement that extends beyond the section being viewed by at least measure d and is effectively fixed at that position (see Figure 32). For prestressing with immediate bond, the entire prestressing steel area can be taken into account for A_{sl}.
b_w	the smallest section width in the tensile zone of the section in mm.
d	the effective static height of the bending reinforcement in the viewed section in mm.
f_{ck}	the characteristic value of the concrete compressive strength in N/mm².
σ_{cd}	the design value of the concrete longitudinal stress at the level of the section's centroid with $\sigma_{cd} = N_{Ed} / A_c$ in N/mm².
N_{Ed}	the design value of the longitudinal force in the section as a result of external actions or prestressing ($N_{Ed} < 0$ as longitudinal compressive force).
κ_1	$= 0.0525$ for $d \le 600$ mm $= 0.0375$ for $d \ge 800$ mm For 600 mm $< d <$ 800 mm, κ_1 can be interpolated linearly.

Components with computationally necessary lateral force reinforcement

$$V_{Rd,sy} = \frac{A_{sw}}{s_w} \cdot f_{yd} \cdot z \cdot \cot\Theta \qquad (75)$$

$V_{Rd,sy}$	design value of the absorbable lateral force that is limited by the load-bearing capacity of the lateral force reinforcement.
A_{sw}	the section area of the lateral force reinforcement.
s_w	the distance of the reinforcement perpendicular to the component axis measured in the direction of the component axis.
z	$= 0.9 \cdot d < d - 2\,c_{nom}$ (c_{nom} = minimum size of concrete cover).
$\cot\Theta$	strut angle of the truss with

$$0.58 \le \cot\Theta \le \frac{1.2 - 1.4\,\sigma_{cd} / f_{cd}}{1 - V_{Rd,c} / V_{Ed}} \quad \begin{array}{l} \le 3.0 \text{ for normal concrete} \\ \le 2.0 \text{ for lightweight concrete} \end{array} \qquad (73)$$

Edition 2008: $\cot\Theta < 1$ should only be used as an exception. In the case of longitudinal tensile stress this lower limit applies basically (ref. also Book 525, Corr. 1:2005-05). The program takes the limit into account as long as the user does not enter a smaller value.

$$V_{\text{Rd,c}} = \beta_{\text{ct}} \cdot 0.10 \cdot \eta_1 \cdot f_{\text{ck}}^{1/3}(1+1.2\frac{\sigma_{\text{cd}}}{f_{\text{cd}}}) \cdot b_{\text{w}} \cdot z \qquad (74{:}2001\text{-}07)$$

$$V_{\text{Rd,c}} = c_{\text{j}} \cdot 0.48 \cdot \eta_1 \cdot f_{\text{ck}}^{1/3}(1+1.2\frac{\sigma_{\text{cd}}}{f_{\text{cd}}}) \cdot b_{\text{w}} \cdot z \qquad (74{:}2008\text{-}08)$$

β_{ct} $= 2.4$

c_{j} $= 0.50$

η_1 $= 1.0$ for normal concrete; for lightweight concrete Table 10 applies.

σ_{cd} the design value of the concrete longitudinal stress at the level of the section's centroid with
$\sigma_{\text{cd}} = N_{\text{Ed}} / A_{\text{c}}$ in N/mm²

N_{Ed} the design value of the longitudinal force in the section as a result of external actions or prestressing ($N_{\text{Ed}} < 0$ as longitudinal compressive force).

V_{Ed} the design value of the acting lateral force.

$$V_{\text{Rd,max}} = \frac{b_{\text{w}} \cdot z \cdot \alpha_{\text{c}} \cdot f_{\text{cd}}}{\cot\Theta + \tan\Theta} \qquad (76)$$

$V_{\text{Rd,max}}$ design value of the absorbable lateral force that is limited by the strut strength.

α_{c} the reduction factor for the strut strength.
$\alpha_{\text{c}} = 0.75 \cdot \eta_1$ with $\eta_1 = 1.0$ for normal concrete; for lightweight concrete Table 10 applies.

Lateral force reinforcement

$$\rho_{\text{w}} = \frac{A_{\text{sw}}}{s_{\text{w}} \cdot b_{\text{w}} \cdot \sin\alpha} \qquad (151)$$

ρ_{w} the reinforcement level of the lateral force reinforcement.

α the angle between the lateral force reinforcement and the beam axis.

$min\ \rho_{\text{w}}$ minimum value of ρ_{w} according to 13.2.3(5)
In general: $\rho_{\text{w}} = 1.0\ \rho$
areas: $\rho_{\text{w}} = 0.6\ \rho$
Structured sections with prestressed tension chord: $\rho_{\text{w}} = 1.6\ \rho$

ρ Value according to Table 29 of the standard.

Design for Torsion and Combined Loads

The design for torsion is carried out according to Chapter 10.4 of the standard. This design involves determining the diagonal tensile reinforcement and the longitudinal reinforcement and includes a concrete strut check under maximum torsion stress based on formula (91) or (92) and a concrete strut check under simultaneously acting lateral force based on formula (93) of the standard.

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

Formulas used from the standard:

$$T_{\text{Ed}} \le \frac{V_{\text{Ed}} \cdot b_{\text{w}}}{4.5} \qquad (87)$$

$$V_{\mathrm{Ed}}\left[1+\frac{4.5\,T_{\mathrm{Ed}}}{V_{\mathrm{Ed}}\cdot b_{\mathrm{w}}}\right]\le V_{\mathrm{Rd,ct}} \tag{88}$$

$$V_{\mathrm{Ed,T}}=\frac{T_{\mathrm{Ed}}\cdot z}{2A_{\mathrm{k}}} \tag{89}$$

$V_{\mathrm{Ed,T}}$	the shear force in a wall of the check section as a result of a torsion moment.
A_{k}	the area enclosed by the center lines of the walls.
z	the height of the wall, which is defined by the distance of the intersection points of the wall center line to the center lines of the adjacent walls.

$$V_{\mathrm{Ed,T+V}}=V_{\mathrm{Ed,T}}+\frac{V_{\mathrm{Ed}}\cdot t_{\mathrm{eff}}}{b_{\mathrm{w}}} \tag{90}$$

V_{Ed}	the design value of the acting lateral force according to 10.3.2.
t_{eff}	the effective thickness of a wall; t_{eff} is twice the distance from the center line to the exterior but not greater than the thickness of the existing wall (see Figure 36).

$$T_{\mathrm{Rd,sy}}=\frac{A_{\mathrm{sw}}}{s_{\mathrm{w}}}\cdot f_{\mathrm{yd}}\cdot 2A_{\mathrm{k}}\cdot\cot\Theta \tag{91}$$

$$T_{\mathrm{Rd,sy}}=\frac{A_{\mathrm{sl}}}{u_{\mathrm{k}}}\cdot f_{\mathrm{yd}}\cdot 2A_{\mathrm{k}}\cdot\tan\Theta \tag{92}$$

$T_{\mathrm{Rd,sy}}$	the design value of the absorbable torsion moment of the section.
A_{sw}	the section area of the torsion reinforcement perpendicular to the component axis.
s_{w}	the distance of the torsion reinforcement measured in the direction of the component axis.
A_{sl}	the section area of the torsion longitudinal reinforcement.
u_{k}	the perimeter of area A_{k}.
Θ	strut angle of the truss.

$$T_{\mathrm{Rd,max}}=\frac{\alpha_{\mathrm{c,red}}\cdot f_{\mathrm{cd}}\cdot 2A_{\mathrm{k}}\cdot t_{\mathrm{eff}}}{\cot\Theta+\tan\Theta} \tag{93}$$

$T_{\mathrm{Rd,max}}$	design value of the maximum absorbable torsion moment of the section.
$\alpha_{\mathrm{c,red}}$	$= 0.7\alpha_{\mathrm{c}}$ in general (with α_{c} according to 10.3.4(6)).
$\alpha_{\mathrm{c,red}}$	$= \alpha_{\mathrm{c}}$ for box sections with reinforcement at the inner and outer sides of the walls.

$$\left[\frac{T_{\mathrm{Ed}}}{T_{\mathrm{Rd,max}}}\right]^2+\left[\frac{V_{\mathrm{Ed}}}{V_{\mathrm{Rd,max}}}\right]^2\le 1 \text{ for compact sections} \tag{94}$$

$$\frac{T_{\mathrm{Ed}}}{T_{\mathrm{Rd,max}}}+\frac{V_{\mathrm{Ed}}}{V_{\mathrm{Rd,max}}}\le 1 \qquad \text{for box sections} \tag{95}$$

$V_{\mathrm{Rd,max}}$	design value of the absorbable lateral force according to DIN 1045-1, Eq. (76).

Punching Shear

The load-bearing safety check against punching shear is carried out according to Chapter 10.5 of the standard. This check is used to determine the necessary punching reinforcement. The following special conditions apply:

- The average static height d is determined based on the input parameters d_x and d_y at d = (d_x+d_y) /2. They are selected as shown in Figure 37, 42, 43 or 45.
- The action can be entered directly or taken from the analyzed design situation at the ultimate limit state. In this case, V_{Ed} is set to the maximum support force R_z for each corresponding action combination.

The check is considered fulfilled if:

1. For slabs without punching reinforcement

$$v_{Ed} \le v_{Rd,ct}. \tag{101}$$

2. For slabs with punching reinforcement

$$v_{Ed} \le v_{Rd,max}, \tag{102}$$

$$v_{Ed} \le v_{Rd,sy}, \tag{103}$$

$$v_{Ed} \le v_{Rd,ct,a}. \tag{104}$$

3. The minimum longitudinal reinforcement is maintained.

with

$$v_{Ed} = \frac{ß \cdot V_{Ed}}{u} \tag{100}$$

v_{Ed}	Lateral force to be absorbed in the check section under consideration for each unit of length.
V_{Ed}	Design value of the entire lateral force to be absorbed.
$ß$	Coefficient for taking into account the non-rotationally symmetric distribution of lateral force in the perimeter of the edge and corner columns and for internal columns in irregular systems. For edge and corner columns in conventional buildings, this value may be reduced when performing the ultimate limit state check outside the punching reinforcement ($v_{Ed} \le v_{Rd,ct,a}$) according to Book 525, Eq. (H.10-8). $ß_{red} = \frac{ß}{1+0.1 \cdot l_w / d} \ge 1.1 \qquad$ (H.10-8)
l_w	Width of the area with punching reinforcement outside of the load discharge area (see Figure 45).
d	Average effective height in mm. d = (d_x+d_y) /2
d_x, d_y	Effective height of the slab in the x or y direction in the perimeter under consideration.
u	Circumference of the perimeter under consideration according to Figure 45.
$v_{Rd,ct}$	Design value of the lateral force bearing capacity along the critical perimeter of a slab without punching reinforcement.
$v_{Rd,ct,a}$	Design value of the lateral force bearing capacity along the external perimeter outside the punching reinforced area. This design value describes the transfer of the punching resistance without lateral force reinforcement $v_{Rd,ct}$ to the lateral force resistance according to 10.3.3 in relation to the width l_w of the punching reinforced area (see Figure 45).
$v_{Rd,sy}$	Design value of the lateral force bearing capacity with punching reinforcement along the internal check sections.

$v_{\text{Rd,max}}$ Maximum lateral force bearing capacity for slabs with punching reinforcement in the critical perimeter.

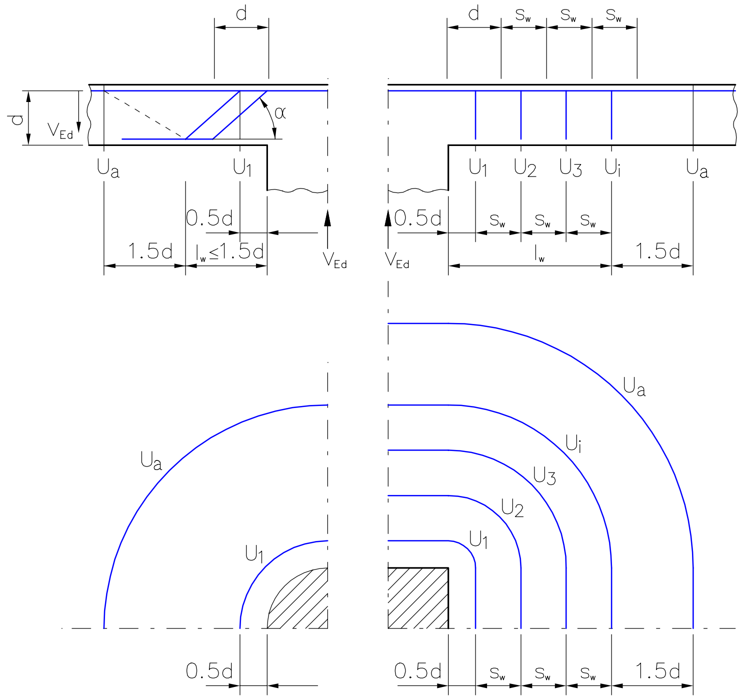


Figure 45 – Check sections of the punching reinforcement

The load discharge areas and check sections as per DIN 1045-1, Chapter 10.5.2, Section (1) to (9), are taken into consideration. The user-specified opening dimensions are used to calculate the check sections.

Punching resistance without punching reinforcement is calculated as

$$v_{\text{Rd,ct}} = \left[0.14\ \eta_1 \kappa \cdot (100 \cdot \rho_1 \cdot f_{\text{ck}})^{1/3} - 0.12\ \sigma_{\text{cd}} \right] \cdot d \qquad (105{:}2001\text{-}07)$$

$$v_{\text{Rd,ct}} = \left[(0{,}21 / \gamma_c) \cdot \eta_1 \cdot \kappa \cdot (100 \cdot \rho_1 \cdot f_{\text{ck}})^{1/3} - 0{,}12 \cdot \sigma_{\text{cd}} \right] \cdot d \qquad (105{:}2008\text{-}08)$$

with

$$\kappa = 1 + \sqrt{\frac{200}{d}} \le 2.0 \qquad (106)$$

η_1 = 1.0 for normal concrete; for lightweight concrete Table 10 applies.

ρ_1 The longitudinal reinforcement level with

$$\rho_1 = \sqrt{\rho_{\text{lx}} \cdot \rho_{\text{ly}}} \begin{cases} \le 0.40\ f_{\text{cd}} / f_{\text{yd}} \\ \le 0.02 \end{cases}$$ (Edition 2001-07)

$$\rho_1 = \sqrt{\rho_{\text{lx}} \cdot \rho_{\text{ly}}} \begin{cases} \le 0.50\ f_{\text{cd}} / f_{\text{yd}} \\ \le 0.02 \end{cases}$$ (Edition 2008-08)

ρ_{lx}, ρ_{ly} The reinforcement level based on the tensile reinforcement in the x or y direction which is located inside the perimeter under consideration and fixed in place outside the perimeter under consideration. For corner and edge columns, see 10.5.2 (9).

σ_{cd} The design value of the normal concrete stress within the perimeter under consideration with
$\sigma_{\text{cd}} = N_{\text{Ed}}$ / *slab thickness*

N_{Ed} The design value of the average longitudinal force
($N_{\text{Ed}} < 0$ as longitudinal compressive force).

Punching resistances with punching reinforcement are calculated as

1) $v_{\mathrm{Rd,max}} = 1.5\ v_{\mathrm{Rd,ct}}$ (107)

2a) For the first reinforcement series with a distance of $0.5\ d$ from the column edge, the following applies:

$$v_{\mathrm{Rd,sy}} = v_{\mathrm{Rd,c}} + \frac{\kappa_{\mathrm{s}} \cdot A_{\mathrm{sw}} \cdot f_{\mathrm{yd}}}{u} \qquad (108)$$

2b) For the other reinforcement series with a distance of $s_{\mathrm{w}} \leq 0.75\ d$ from each other, the following applies:

$$v_{\mathrm{Rd,sy}} = v_{\mathrm{Rd,c}} + \frac{\kappa_{\mathrm{s}} \cdot A_{\mathrm{sw}} \cdot f_{\mathrm{yd}} \cdot d}{u \cdot s_{\mathrm{w}}} \qquad (109)$$

The individual parts of which are

$v_{\mathrm{Rd,c}}$ Concrete bearing portion; $v_{\mathrm{Rd,c}} = v_{\mathrm{Rd,ct}}$ from equation (105) can be assumed.

κ_{s} The coefficient for taking into account how the component height influences the efficiency of the reinforcement with

$$\kappa_{\mathrm{s}} = 0.7 + 0.3 \frac{d-400}{400} \begin{cases} \geq 0.7 \\ \leq 1.0 \end{cases} \text{ with } d \text{ in mm} \qquad (110)$$

3) For diagonal bars ($45° \leq \alpha° \leq 60°$) as punching reinforcement, the following applies:

$$v_{\mathrm{Rd,sy}} = v_{\mathrm{Rd,c}} + \frac{1.3 A_{\mathrm{s}} \cdot \sin\alpha \cdot f_{\mathrm{yd}}}{u} \qquad (111)$$

4) For the external perimeter with a distance of $1.5\ d$ from the last reinforcement series, the following applies:

$v_{\mathrm{Rd,ct,a}} = \kappa_{\mathrm{a}} \cdot v_{\mathrm{Rd,ct}}$ (112)

with

κ_{a} The coefficient for taking into account the transition to the slab area with the load-bearing capacity as per 10.3.3 with

$$\kappa_{\mathrm{a}} = 1 - \frac{0.29\ l_{\mathrm{w}}}{3.5\ d} \geq 0.71 \qquad (113)$$

5) For the minimum required punching reinforcement of the internal check sections, the following applies:

$$\rho_{\mathrm{w}} = \frac{A_{\mathrm{sw}}}{s_{\mathrm{w}} \cdot u} \geq \min\ \rho_{w} \qquad (114)$$

or

$$\rho_{\mathrm{w}} = \frac{A_{\mathrm{s}} \cdot \sin\alpha}{d \cdot u} \geq \min\ \rho_{\mathrm{w}}$$ with $\min\ \rho_{\mathrm{w}}$ according to 13.2.3 (5) of the standard.

In accordance with 13.3.3 (7) of the standard, the following also applies:

If only one reinforcement series is computationally necessary with respect to stirrups as the punching reinforcement, a second series with the minimum reinforcement according to equation (114) must always be provided. In this case use $s_{\mathrm{w}} = 0.75\ d$. The minimum longitudinal reinforcement is found based on the design of the minimum moments:

$m_{\mathrm{Ed,x}} = \eta_{\mathrm{x}} \cdot V_{\mathrm{Ed}}$ and $m_{\mathrm{Ed,y}} = \eta_{\mathrm{y}} \cdot V_{\mathrm{Ed}}$ (115)

with

$\eta_{\mathrm{x}}, \eta_{\mathrm{y}}$ The moment coefficient as per Table 14 for the x or y direction.

Check against Fatigue

The user can select two alternative methods for design:

- Simplified check for the frequent action combination according to DIN 1045-1, Chapter 10.8.4, taking the relevant traffic loads at SLS into account.
- Check with damage equivalent stress ranges for the fatigue combination according to DIN 1045-1, Chapter 10.8.3, considering the specific fatigue load Q_{fat}.

The curve to determine the concrete compressive stresses in state II is selected in the settings dialog.

Fatigue of longitudinal reinforcement, shear reinforcement and prestressing steel

The fatigue check is carried out according to Chapter 10.8 of the standard. 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 10.8.2 (4) based on a truss model with the strut angle $\tan \Theta_{fat} = \sqrt{\tan \Theta}$ acc. to 10.8.2 (5). The prestressing steel stresses in area elements are determined at the uncracked concrete section. Tendons without bond and external tendons are not checked.

Simplified check

According to Chapter 10.8.4(2), adequate fatigue resistance may be assumed if the stress range under the frequent action combination does not exceed 70 MN/m² for unwelded reinforcing bars. The condition described in Chapter 10.8.4(3) for couplings in prestressed components is not examined by the program.

Check with damage equivalent stress ranges

The check is considered completed if the following applies for reinforcing steel and prestressing steel:

$$\gamma_{F,fat} \cdot \gamma_{Ed,fat} \cdot \Delta\sigma_{s,equ} \leq \Delta\sigma_{Rsk}(N^*) / \gamma_{s,fat} \qquad (119)$$

with

$\gamma_{F,fat} = \gamma_{Ed,fat}$	= 1 as specified in Chapter 5.3.3 (2).
$\gamma_{s,fat}$	= 1.15 for reinforcing steel and prestressing steel with new certification. = 1.25 for reinforcing steel with DIN 4227-1 certification in accordance with ARS 11/03 (13).
$\Delta\sigma_{Rsk}(N^*)$	Permitted characteristic stress range at N^* load cycles based on the Wöhler curves specified in Tab.17 for prestressing steel or Tab.16 for reinforcing steel.
$\Delta\sigma_{s,equ}$	Damage equivalent stress range with $\Delta\sigma_{s,equ} = \max \Delta\sigma_s$ according to 10.8.3 (5).
$\max \Delta\sigma_s$	Calculated maximum stress range for longitudinal reinforcement from bending and longitudinal force including increase factor η as specified in Chapter 10.8.2 (3) to account for the varying bond behavior of reinforcing and prestressing steel.

The values for $\Delta\sigma_{Rsk}(N^*)$ and η 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 combination 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 η yields the damage equivalent stress range $\Delta\sigma_{s,equ}$. If this range exceeds the permitted stress range according to Eq. (119), the necessary reinforcement will be iteratively increased until the check succeeds for all situations. In the *Symmetrical* and *Compression member* design modes the reinforcement is applied at all predefined locations. This will not affect the predefined relationships between the individual reinforcement layers.

The main 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 strut angles of components subject to lateral force stress are not analyzed.

Simplified check

The check according to Chapter 10.8.4(4) is considered successfully if Eq. (123) is fulfilled.

$$\frac{\max|\sigma_{\mathrm{cd}}|}{f_{\mathrm{cd,fat}}} \leq 0.5 + 0.45 \cdot \frac{\min|\sigma_{\mathrm{cd}}|}{f_{\mathrm{cd,fat}}} \begin{array}{l} \leq 0.9 \text{ for concrete up to } C50/60 \text{ or } LC50/55 \\ \leq 0.8 \text{ for concrete of at least } C55/67 \text{ or } LC55/60 \end{array} \qquad (123)$$

with

$\max|\sigma_{\mathrm{cd}}|$, $\min|\sigma_{\mathrm{cd}}|$	Design values of the maximum and minimum concrete compressive stress. In the case of tensile stresses, $\min|\sigma_{\mathrm{cd}}|$ is assumed to be zero.
$f_{\mathrm{cd,fat}}$	Design value of the concrete compressive strength before cyclic load is applied. You can specify this value in the Section dialog.

Check with damage equivalent concrete compressive stress

The check according to Chapter 10.8.3(6) is proved, if Eq. (120) is fulfilled:

$$E_{cd,\max,equ} + 0{,}43\sqrt{1 - R_{equ}} \leq 1 \qquad (120)$$

with

R_{equ} = min | $\sigma_{\mathrm{cd,equ}}$ | / max | $\sigma_{\mathrm{cd,equ}}$ | (121)

$E_{\mathrm{cd,max,equ}}$ = max | $\sigma_{\mathrm{cd,equ}}$ | / $f_{\mathrm{cd,fat}}$ (122)

In that max | $\sigma_{\mathrm{cd,equ}}$ | and min | $\sigma_{\mathrm{cd,equ}}$ | are the upper and lower compressive stress of the damage equivalent stress range for N = 10^6 cycles.

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:

- Limit of concrete compressive stresses (Chapter 11.1.2 of the standard).
- Limit of reinforcing steel stresses (Chapter 11.1.3).
- Limit of prestressing steel stresses (Chapter 11.1.4).
- Decompression check (Chapter 11.2.1).
- Minimum reinforcement for crack width limitation (Chapter 11.2.2).
- Crack width check (Chapter 11.2.3 and 11.2.4).
- Limiting deformations (Chapter 11.3).

Design Combinations

In accordance with DIN 1055-100, Chapter 10.4, the following combinations are taken into account in the serviceability limit states:

- Combination for rare (characteristic) situations

$$E\left\{\sum_{j\geq 1} G_{\mathrm{k,j}} \oplus P_{\mathrm{k}} \oplus Q_{\mathrm{k,1}} \oplus \sum_{i>1} \psi_{0,\mathrm{i}} \cdot Q_{\mathrm{k,i}}\right\} \tag{22}$$

- Combination for frequent situations

$$E\left\{\sum_{j\geq 1} G_{\mathrm{k,j}} \oplus P_{\mathrm{k}} \oplus \psi_{1,1} \cdot Q_{\mathrm{k,1}} \oplus \sum_{i>1} \psi_{2,\mathrm{i}} \cdot Q_{\mathrm{k,i}}\right\} \tag{23}$$

- Combination for quasi-continuous situations

$$E\left\{\sum_{j\geq 1} G_{\mathrm{k,j}} \oplus P_{\mathrm{k}} \oplus \sum_{i\geq 1} \psi_{2,\mathrm{i}} \cdot Q_{\mathrm{k,i}}\right\} \tag{24}$$

For each combination you can define different design situations for the construction stages and final states. If necessary, the combination required by the check will automatically be determined from the section specifications. Each check is carried out for all the situations of a combination.

Stress Determination

For uncracked concrete sections, the program assumes that concrete and steel under tensile and compressive stress behave elastically. With respect to cracked concrete sections, the concrete compressive stresses are determined by the strain-stress curve shown in Figure 22. Note that a horizontal course is assumed for strains exceeding ε_{c1} (cf. Reg. No. 098 in the Knowledge Base of the Building and Civil Engineering Standards Committee (NABau)).

Area elements

For area elements the concrete stresses are calculated at the gross section. The steel stress check is carried out for reinforcing steel by determining the strain state at the cracked concrete section and for the prestressing steel at the uncracked concrete section.

Beams and design objects

The action combination stresses that can be determined without checks are always calculated at the gross section.

Conversely, in the checks the stresses are determined as follows and are graphically displayed or logged:

- When checking the crack reinforcement and crack width, the concrete stress is calculated at the gross section.
- When checking the decompression and concrete compressive stresses, the concrete 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.
- The reinforcing and prestressing steel stresses are checked by determining the strain state at the cracked concrete section.

Limiting the Concrete Compressive Stresses

The concrete compressive stress check is carried out according to DIN 1045-1, Chapter 11.1.2. Based on DIN Technical Report 102, Chapter 4.4.1.1 (5), the cracked state is assumed if the tensile stress calculated in the uncracked state under the rare action combination exceeds the value f_{ctm}.

The calculation in the cracked state is performed by determining the strain state with the final longitudinal reinforcement (maximum from robustness, crack and bending reinforcement including a possible increase from the fatigue check). For beams and design objects, the tendons with bond are taken into account on the resistance side provided that they are grouted in the check situation. For area elements the compressive stress for both reinforcement directions is determined separately and the extreme value is checked since the general strain state cannot be determined unambiguously.

In the construction stages and final states, the concrete compressive stress σ_c as defined in Chapter 11.1.2 (1) is to be limited to $0.60 f_{\text{ck}}$ under the rare combination. If serviceability is significantly impacted by the effect of creep, the limit $0.45 f_{\text{ck}}$ should be maintained under the quasi-continuous combination according to 11.1.2 (2). Both options are considered based on the user's specifications.

Limiting the Reinforcing and Prestressing Steel Stresses

Reinforcing steel

For reinforcing steel, the limitation of steel stress under the rare combination to $0.80 f_{\text{yk}}$ is checked in accordance with 11.1.3. In this check the reinforcement corresponds to the maximum value from the robustness, crack and bending reinforcement, including a possible increase as a result of the fatigue check. The determination of the strain state is performed at the cracked concrete section. If beam tendons with bond are grouted in the check situation, they will be taken into account on the resistance side.

Prestressing steel

For tendons with bond, the limitation of steel stress is checked at the cracked concrete section for beams and design objects and at the uncracked concrete section for area elements. In such cases the following limits apply:

Tendons with DIN 1045-1 and EC2 certification

- $0.65 f_{\text{pk}}$ as per Chapter 11.1.4 (1) under the quasi-continuous combination
- $0.90 f_{\text{p0.1k}}$ or $0.80 f_{\text{pk}}$ as per Chapter 11.1.4 (2) under the rare combination

Tendons with DIN 4227 certification

- $0.75\beta_s$ or $0{,}55\beta_z$ according to DIN 4227, Tab. 9, Row 65, under the quasi-continuous combination and rare combination

For situations prior to grouting and for tendons without bond, the stress σ_{pm0} is checked in accordance with DIN 1045-1, Eq. (49) or DIN 4227, Tab. 9, Row 65. External tendons are not checked.

Check of Decompression

This check is carried out for prestressed components of requirement classes A-C with the combinations specified in Table 18 of the standard. For area sections, the principal tensile stress σ_1 or one of the longitudinal stresses σ_x or σ_y are checked based on the user's selection. The latter can be used to limit the check to the direction of the prestressing if the internal force systems are appropriately aligned (cf. Reg. No. 069 of the Knowledge Base of the Building and Civil Engineering Standards Committee (NABau) on DIN Technical Report 102). In all other cases, the rules for stress analysis listed above apply. The permissible stress limits are defined in DIN 1045-1, Chapter 11.2.1 (9) as follows:

Construction stage

In the construction stage, the section "at the edge of the precompressed tensile zone as a result of prestressing" (i.e., at the section edge facing the tendon) must be subjected to compressive stresses. The program determines the above edge as follows:

- Beams and design objects: If the edge point next to the tendon is above the centroid, the stress on the upper side of the section will be checked. If not, the lower side of the section will be checked.
- Area elements: The check will be carried out for the upper or lower section edge if the tendon next to the check point is located above or below the centroid level of the element in question. Tendons outside of the element are taken into account at a distance of up to five times the section height.

If the tendon guide is ambiguous, the check will be carried out for both sides.

Final state

In the final state the section must be completely subjected to compressive stresses.

Minimum Reinforcement for Crack Width Limitation

The minimum reinforcement for crack width limitation is defined in DIN 1045-1, Chapter 11.2.2. According to 11.2.2(5), minimum reinforcement is to be applied in areas where tensile forces are expected. Areas under tension can be defined in the section dialog by choosing either an action combination or a restraint (bending, centrical tension). Reinforcing steel layers that are not under tension are also provided with reinforcement in the *symmetrical* and *compression member* design modes. This will not affect the predefined relationships between the individual reinforcement layers.

For profiled sections, each subsection (web or flange) should be checked individually in accordance with Section (4). This cannot be done if any polygonal section geometries are taken into consideration. For this reason, the program always determines the minimum reinforcement based on the entire section. For full rectangular sections, Equation (128) is used. In all other cases, Equation (128a) applies.

Determining the minimum reinforcement

The minimum reinforcement A_s is determined using Equation (127) of the standard:

$$A_s = k_c \cdot k \cdot f_{ct,eff} \cdot A_{ct} / \sigma_s \qquad (127)$$

In this formula:

k_c is the coefficient for consideration of stress distribution prior to crack formation.

For rectangular sections and webs of T-beams and box girders:

$$k_c = 0.4\,(1 + \sigma_c / (k_1 \cdot f_{ct,eff})) \le 1 \qquad (128)$$

For tension flanges of T-beams and box girders:

$$k_c = 0.9 \cdot F_{cr} / A_{ct} / f_{ct,eff} \ge 0.5 \qquad (128a)$$

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

σ_c is the concrete stress at the level of the centroidal axis of the section or subsection, which, in an uncracked state, is subject to the action combination on the entire section that leads to the initial crack formation. ($\sigma_c < 0$ for compressive stress).

k_1 $= 1.5\ h/h'$ for compressive normal force

$= 2/3$ for tensile normal force

h is the height of the section or subsection.

h' $= \min(h;\ 1\ \text{m})$.

k is the coefficient for taking into account nonlinearly distributed tensile stresses entered by the user.

A_{ct} is the area of the concrete tensile zone at initial crack formation in condition I. Here the program scales the bending moments caused by the action combination until the maximum edge stress in condition I reaches the value $f_{ct,eff}$.

$f_{ct,eff}$ Effective concrete tensile strength depending on the age of the concrete according to 11.2.2 (5):

$f_{ct,eff} = 0.5 f_{ctm}$ at an age of 3-5 days,

$f_{ct,eff} = f_{ctm}$ at an age of 6-28 days,

$f_{ct,eff} = f_{ctm}$, but no less than 3 MN/m², if older than 28 days.

σ_s is the maximum permitted stress in the reinforcing steel reinforcement in relation to the limiting diameter of the reinforcing steel.

The largest available bar diameter d_s is specified in the section dialog. Equation (129) provides a modified limiting diameter d_s^* to be used as an input value for Table 20:

$$d_s = d_s^* \cdot k_c \cdot k \cdot h_t\ /\ (4(h-d)) \cdot f_{ct,eff}\ / f_{ct0} \ \ge\ d_s^* \cdot f_{ct,eff}\ / f_{ct0} \qquad (129)$$

Where

d_s^* is the effective area of the reinforcement according to Table 20.

h is the component height.

d is the effective height.

h_t is the height of the tensile zone in the section or subsection before initial crack formation.

f_{ct0} is the tensile strength of the concrete, derived from the values in Table 20 ($f_{ct0} = 3.0$ MN/m²).

According to *Zilch/Rogge* (2002, p. 277), the expression $k_c \cdot k \cdot h_t$ / $(4(h\text{-}d))$ is generalized to $0{,}6 \cdot k_c \cdot k \cdot A_{ct}$ / $A_{c,eff}$ with the effective tensile zone $A_{c,eff}$ as shown in Figure 53. Using the modified limiting diameter d_s* and the allowed crack width w_k, the permissible reinforcing steel stress σ_s for equation (127) can be determined from Table 20 or from Book 525 (2003, p. 196), Equation (21).

If the crack width check is to be carried out at the same time, the program will determine whether the specified crack width according to Chapter 11.2.4 is maintained by inserting the calculated minimum reinforcement. If necessary, the minimum reinforcement can be increased iteratively until the check limit is reached. The increased reinforcement is indicated by an exclamation mark "!" in the log.

Guideline 11.2.1(13) for the reinforcing mesh joint areas is not considered by the program.

Edition 2008: Based on Chapter 11.2.2(8), the minimum reinforcement for the crack width limitation in the case of thicker components under centrical restraint can be determined to Equation (130a), but the value may not fall below the value in Equation (130b). It is not necessary to insert more reinforcing steel as results from Equation (127). The rules specified before will be used, if the option is selected by the user, whereas the possibility of lower reinforcement for slowly hardening concrete according to Section (9) will not be used.

Special characteristic of prestressed concrete structures

According to Chapter 11.2.2(7), for a 300 mm square section around a tendon with immediate or subsequent bond, the minimum reinforcement required for this region may be reduced by
$\xi_1 \cdot A_p$.

Where

A_p	is the section area of the prestressing steel in the tendon.
ξ_1	is the ratio of the prestressing and reinforcing steel bond strengths.

For beams and design objects, the tendons with bond can be added using the ξ_1 value specified in the section dialog as long as they are grouted in the check situation. Note that prestressed steel cannot be taken into account for area elements.

According to Section (3) of Chapter 11.2.2, the minimum reinforcement for prestressed components with bond is not necessary in areas in which compressive concrete stresses larger than 1 MN/m² occur at the section edge under the rare (characteristic) action combination and the characteristic prestress values. This condition is automatically checked by the program.

Determination of the effective tensile zone $A_{c,eff}$

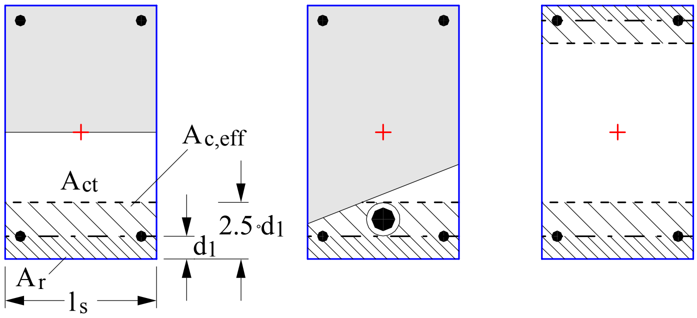
According to DIN 1045-1, Figure 53, the effective tensile zone $A_{c,eff}$ defines the area of a rectangular, uniaxially stressed concrete section in which the model assumptions specified in Book 466 are applicable (cf. Book 525, Figure 53). Although the program can apply this model to any section and stress situation, the user has the responsibility and discretion to do so.

When determining $A_{c,eff}$, the program performs the following steps:

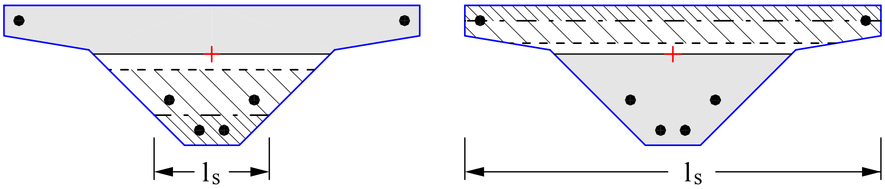
- Determine tensile zone A_{ct} in condition I: when calculating the minimum reinforcement, use the stress that led to the initial crack; when calculating the crack width, use the check combination based on the requirement class.
- Define the centroid line of the reinforcement as a regression line through the reinforcing steel layers in the tensile zone. In 2D frameworks and for area elements, a horizontal line through the centroid of the reinforcement layers under tension is assumed.

- Determine the truncated residual area A_r to the edge and the sum of section lengths l_s. The average overlap is then assumed as $d_1 = A_r / l_s$, yet not less than the smallest edge distance of the reinforcing steel layers in the tensile zone.
- Shift the centroid line in parallel by 1.5 · d_1. For area elements, $2.5 \cdot d_1 \leq$ (h-x) / 2 is maintained (x = compression zone height).
- The resulting polygon is intersected with the tensile zone and then defines the effective tensile zone $A_{c,eff}$.
- If all the reinforcing steel layers of the section are under tension, then two zones will be determined; one for the layers above the centroid and the other for layers below the centroid. The area of each zone is limited to $A_c / 2$.

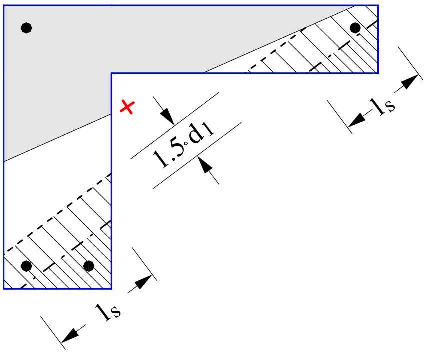
The following illustrations show the effective tensile zones determined by the program in typical situations. The last case (edge beam) deviates from the model assumptions in Book 466 to such a degree that it is questionable as to whether it should be used.



Effective tensile zones at the rectangular section under uniaxial bending, normal force with double bending and centrical tension



Effective tensile zones at the bridge section under uniaxial bending



Effective tensile zone at an edge beam under uniaxial bending

Calculation of the Crack Width

The crack width check is performed by means of direct calculation as per DIN 1045-1, Chapter 11.2.4, with the action combination that is based on the requirement class specified in Tab. 18. Enter the limit diameter and the age of the concrete in the Section dialog to determine the effective tensile strength.

Depending on concrete edge stress σ_c in state I, the following crack states must be differentiated (cf. Book 525, p. 191):

$\sigma_c \leq f_{ct,eff}$	Stage of single crack formation
$\sigma_c > f_{ct,eff}$	Stage of completed crack formation

with

$f_{ct,eff}$ Effective concrete tensile strength depending on the age of the concrete according to 11.2.2 (5): Edition 2008-08: In this case a minimum concrete tensile strength is not included.

By limiting the maximum crack distance and the difference among the strains, the formulas in Section 11.2.4 of the standard as specified in Book 525, p. 104, can be used for the both the single crack formation and the completed crack formation stages. This is why the program checks the crack width for all cases where $\sigma_c > 0$.

The program performs the check according to the following steps:

- Determine strain state II under the check combination defined by the requirement class with the stress-strain curve shown in Figure 22. For beams and design objects, all tendons in a bond are considered on the resistance side.
- Define effective tensile zone $A_{c,eff}$ (see above), determine reinforcing steel and prestressing steel layers within $A_{c,eff}$.
- Calculate reinforcement level:

  $$eff\,\rho = (A_s + \xi_1^2 \cdot A_p) / A_{c,eff} \quad (133)$$

  $$\rho_{tot} = (A_s + A_p) / A_{c,eff} \quad (134)$$

  ξ_1 = bond coefficient according to user specification

- Determine individually for each reinforcing steel layer:

  Difference of the average strain for concrete and reinforcing steel

  $$\varepsilon_{sm} - \varepsilon_{cm} = [\sigma_s - 0.4 \cdot f_{ct,eff} / eff\,\rho\ (1 + \alpha_E \cdot eff\,\rho)] / E_s \geq 0.6\ \sigma_s / E_s \quad (136)$$

  with

  $\alpha_E = E_s / E_{cm}$

  $$\sigma_s = \sigma_2 + 0.4 f_{ct,eff}\ (1/eff\,\rho - 1/\rho_{tot}) \quad (132)$$

  σ_2 = reinforcing steel stress from strain state II

  $f_{ct,eff}$ = effective concrete tensile strength at specified age of concrete

  Maximum crack spacing

  $$s_{r,max} = d_s / (3.6\ eff\,\rho) \leq \sigma_s \cdot d_s / (3.6 f_{ct,eff}) \quad (137)$$

  If an upper limit for the crack distance based on Equation (137) was specified in the section dialog, then the special conditions of Equation (138) and Paragraph (8) of Chapter 11.2.4 can be taken into account.

Calculated crack width

$$w_k = s_{r,max} \cdot (\varepsilon_{sm} - \varepsilon_{cm}) \quad (135)$$

The layer with the largest calculated crack width is shown in the log.

- For sections under tension, the check is performed separately for each of the two effective tensile zones. The maximum value is shown in the log.

If the minimum reinforcement check for limiting the crack width is not selected, the program will automatically determine a crack reinforcement that is required to maintain the crack width. For that purpose a design is carried out using the decisive check combination for calculating the crack width. The resulting calculated reinforcement is indicated by an exclamation mark "!" in the check log.

The crack width is checked for the final longitudinal reinforcement (maximum from the robustness, crack and bending reinforcement including a possible increase resulting from the fatigue check).

Crack Width Check by Limitation of the Bar Distances

As an alternative to direct calculation of the crack width according to Chapter 11.2.4, the simplified check as specified in 11.2.3(2) for limiting the bar distances as specified in Table 21 can be selected in the section dialog.

The program performs the check according to the following steps:

- Determine the strain state II under the check combination specified by the requirement class with the stress-strain curve shown in Figure 22. For beams and design objects, all tendons with bond are considered on the resistance side.
- Calculate the reinforcing steel stress σ_s for every reinforcement layer using Equation (132).
- Compare the value given in the dialog ($\max. s$) with the table value ($\text{perm. } s$), which results from the calculated steel stress σ_s and the permissible crack width w_k. The position with the largest ($\max. s$ / $\text{perm. } s$) quotient is indicated in the protocol.

If the minimum reinforcement check for limiting the crack width is not selected, the program will automatically determine a crack reinforcement that is required to maintain the permissible bar distances. For that purpose a design calculation is carried out using the action combination relevant for the check. The resulting calculated reinforcement is indicated by an exclamation mark "!" in the check log.

The bar distance check is then carried out for the final longitudinal reinforcement (maximum from the robustness, crack and bending reinforcement including a possible increase resulting from the fatigue check).

Note:

According to DIN 1045-1, Chapter 11.2.3(2), the simplified check can only be applied in the case of crack formation resulting from mainly direct actions (loads). Further, according to *Zilch* and *Rogge* (2002, p. 277) this method only provides safe results with a single layer of tensile reinforcement with d_1= 4 cm. The user is responsible for the evaluation of these requirements.

Limiting Deformations

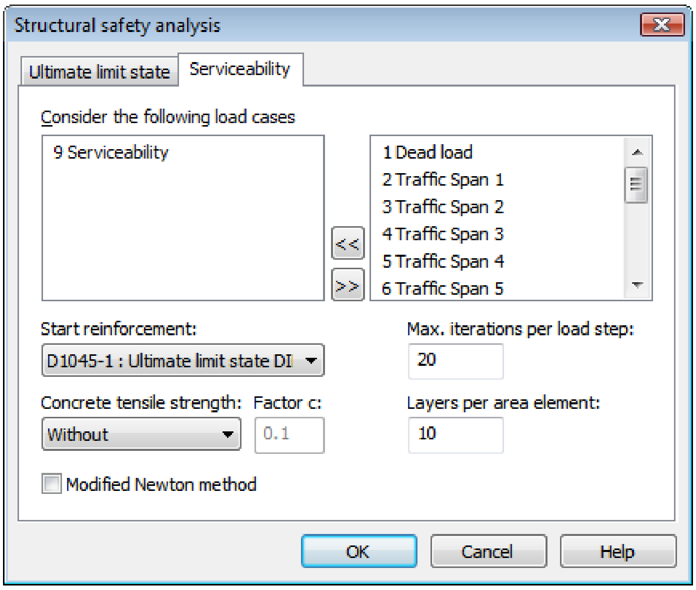
According to DIN 1045-1, Chapter 11.3.1, the deformations of a component or structure may not impair its proper functioning or appearance. Consequently, a beam, slab or cantilever under the quasi-continuous action combination should not sag more than 1/250th of the span as specified in Section (8). To avoid damaging adjacent components, the deformation should be limited to 1/500th of the span.

The standard does not include a method for direct calculation of deformations. Book 525, Section 11.3.2, only makes references to various bibliographic sources.

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 ψ_2 for the quasi-continuous combination.
- 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.



Consider the following load cases

9 Serviceability

1 Dead load
2 Traffic Span 1
3 Traffic Span 2
4 Traffic Span 3
5 Traffic Span 4
6 Traffic Span 5

Start reinforcement: D1045-1 : Ultimate limit state DI

Max. iterations per load step: 20

Concrete tensile strength: Without

Factor c: 0.1

Layers per area element: 10

☐ Modified Newton method

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

Results

The extremal design values for internal forces, support reactions, deformations, soil pressures and stresses are saved for all check situations.

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. If a compression reinforcement results for primarily bending, this is marked with a "*".

The detailed log also lists the decisive combination internal forces of all design situations for each result location.

Internal forces

N_x, Q_y, Q_z	Extremal normal and lateral forces [kN] for beams and design objects.
M_x, M_y, M_z	Extremal torsional and bending moments [kNm] for beams and design objects.
n_x, n_y, n_{xy}	Extremal normal and shear forces [kN/m] for area elements.
q_x, q_y	Extremal lateral forces [kN/m] for area elements.
q_r	Maximum resultant lateral force [kN/m] for area elements.
m_x, m_y, m_{xy}	Extremal bending and torsional moments [kNm/m] for area elements.
N_φ, N_υ, Q_φ	Extremal normal and lateral forces [kN/m] for axisymmetric shell elements.
M_φ, M_υ	Extremal bending moments [kNm/m] for axisymmetric shell elements.

Support reactions

R_x, R_y, R_z	Extremal support forces [kN].
M_x, M_y, M_z	Extremal support moments [kNm].
R_r, R_z	Extremal support forces [kN/m] for axisymmetric shell elements.
M_φ	Extremal support moment [kNm/m] for axisymmetric shell elements.

Stresses for beams and design objects

σ_x	Longitudinal stresses in the decompression and concrete compressive stress checks [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].

Stresses for area elements

σ_x, σ_y, σ_1	Longitudinal stress in x or y direction or principal tensile stresses in the decompression check (depending on user specification) [MN/m²].
σ_2	Principal compressive stresses [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.
$\sigma_{cd,y}$, $\Delta\sigma_{cd,y}$	under longitudinal compression in the x and y direction [MN/m²].
$\Delta\sigma_{s,b}$	Stress ranges for shear reinforcement [MN/m²].

The maximum bending, robustness and crack reinforcement resulting from the combinations in the ultimate limit state, the resulting maximum value and the stirrup and torsion reinforcement are saved using the data set extension *D1045-1*.

Bending reinforcement, Robustness reinforcement, Crack reinforcement

A_s	Bending reinforcement [cm²] for beams and design objects.
a_{sx}, a_{sy}	Bending reinforcement [cm²/m] for area elements in 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 from q_r.
a_{sbx} , a_{sby}	Stirrup reinforcement [cm²/m²] of area elements from q_x and q_y.
$A_{sb.y}$, $A_{sb.z}$	Stirrup reinforcement [cm²/m] of beams and design objects from Q_y and Q_z.
A_{sl} for $a_{sb}=0$	Longitudinal reinforcement [cm²] of area elements.

Torsion reinforcement

$A_{sb.T}$	Torsional stirrup reinforcement [cm²/m] of beams and design objects from M_x.
$A_{sl.T}$	Torsional longitudinal reinforcement [cm²] of beams and design objects from M_x .

Design values

$v_{Rd,ct}$	Absorbable design lateral force without shear reinforcement.
$v_{Rd,max}$	Absorbable design lateral force of concrete struts for area elements.
$V_{Rd,max}$	Absorbable design lateral force of concrete struts for beams and design objects.
$T_{Rd,max}$	Design value of the maximum absorbable torsion moment.
$Q/V_{Rd}+M_x/T_{Rd}$	For compact sections: $(Q/V_{Rd,max})^2 + (M_x/T_{Rd,max})^2$ For box sections: $Q/V_{Rd,max} + M_x/T_{Rd,max}$

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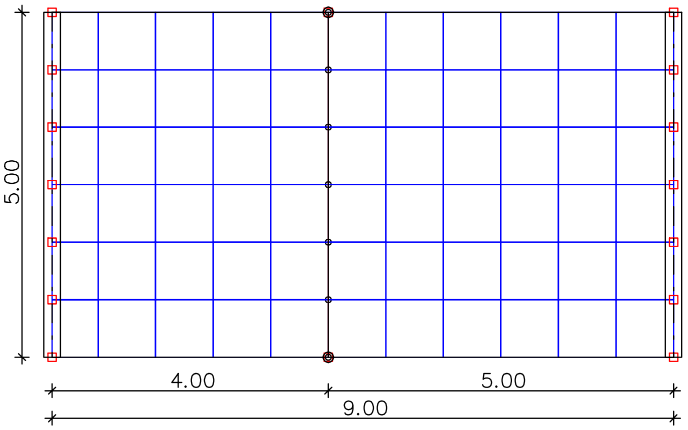
Examples

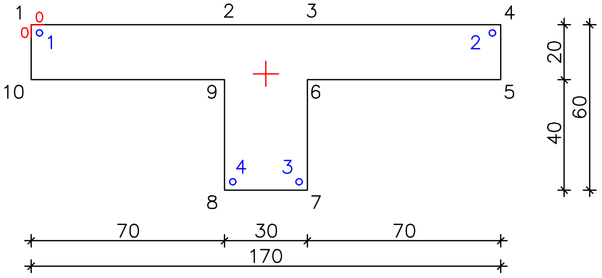
Slab with Downstand Beam

In this example a rectangular slab (d = 20 cm, C30/37, BSt 500 S, requirement class E) with a downstand beam will be analyzed. This slab supported with joints will be subjected to its dead load and a traffic load of 10 kN/m².

The checks will be carried out for all possible combinations of load cases. This method is selected in the calculation settings and can take a very long time to complete if there is a large number of load cases.



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 portion attributed to the slab.



Design specifications and reinforcing steel description of the slab (section 1):

- Edge distance of the reinforcing steel for the x and y direction of the upper (1st) and lower (2nd) layer: 0.03 m
- Bending design mode: *Standard*
- Steel quality: *500S*
- Effective height: 0.17 m
- Strut angle $cot\ \Theta$: 3.0. The default value is limited to the range specified in DIN 1045-1, Eq. (73) when the design is carried out.
- Bending tensile reinforcement A_{sl} for the lateral force design: 1.88 cm²

Design specifications of the torsion-flexible downstand beam (section 2):

- Bending design mode: *Standard*
- Steel quality of the stirrups: *500S*
- Shear section:
  Width: 0.30 m
  Effective height: 0.57 m
- Strut angle $cot\ \Theta$: 3.0. The default value is limited to the range specified in DIN 1045-1, Eq. (73) when the design is carried out.
- Bending tensile reinforcement A_{sl} for the lateral force design: 2.90 cm²

Definition of actions for DIN 1045-1

Standard design group

G - Dead load

Gamma.sup / gamma.inf = 1.35 / 1

Load cases	
1	Dead load

QN - Imposed load, traffic load

Gamma.sup / gamma.inf = 1.5 / 0

Combination coefficients for: Superstructures
Working load - category A - living rooms and lounges
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. Quasi-continuous situation

Final state

G	Dead load
QN	Imposed load, traffic load

Design overview DIN 1045-1 (2008-08)

```
Se. Class, Prestress      Reinforc.  Fatig.  Crack- De-    Stress checks
      of component       M R B Q T  S P C   width  comp. Comp.  S P
  1 E  Not prestressed   x x x x .  . . .     x      .     x    x .
  2 E  Not prestressed   x x x x .  . . .     x      .     x    x .

(M) Nominal reinforcement to guarantee robustness (ductility).
(R) Nominal reinforcement for crack width limitation.
(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 stress and fatigue check.
(P) Prestressing steel at stress and fatigue check.
(C) Concrete at fatigue check.
```

Settings for flexural and lateral reinforcement

```
fyk     Quality of stirrups [MN/m²].
Theta   Angle of concrete truss. Program-sided, the given value of cot Theta
        is limited to the range of values acc. to equ. (73).
        (Method of variable truss angle).
Slabs   Beams are designed like slabs.
Asl     Given reinforcement according to picture 32, increase to maximum.
rhow    Minimum reinf. min rhow = Factor * rho with rho according to table 29.
x,y     Separate lateral force design for reinforcement directions x and y.
```

```
cvl     Laying measure of the long. reinforcement to limt the lever arm z.

Se. Concrete Den-     Design        fyk  Truss  Dsn.  Asl [cm²]    Fac.  Dsn. L.m.
             sity     for         Stirr. cot    like   Pic. 32     for   for   cvl
             [kg/m³]  M and N    [MN/m²] Theta  Sl.   given    max rhow  x,y   [m]
  1 C30/37        .   Standard      500   3.00   .     0.00   0.00 0.60   .   0.03
  2 C30/37        .   Standard      500   3.00   .     0.00     .  1.00   .   0.03
```

Shear sections

```
bw.nom  Nominal width of the prestressed section acc. to 10.3.4 (8).
h.nom   Nominal height of the prestressed section acc. to 10.3.4 (8).
z1, z2  Height and width of the core section for torsion.
teff    Thickness of the torsion box.
B.      Box section.

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

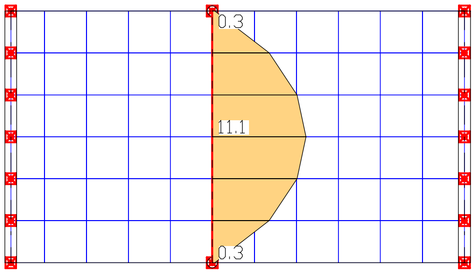
Settings for the check of crack widths

```
ds        Maximal given bar diameter of the reinforcing steel.
max.s     Maximal given bar spacing of the reinforcing steel.
Xi1       Bond coefficient of prestressing steel for beam sections.
k         Coefficient for consideration of non-linear distributed tensile stress.
sr,max    Upper limit for the crack spacing from equ. (137).
Method    Direct calculation of the crack width as per chapt. 11.2.4 or
          check by limiting the bar spacing according to table 21.
TM        Thick member according to chapt 11.2.2(8) to determine As,min.

 Se. wk,per ds max.s   Coeff.   sr,max  Concr. age   Method for  Tensile zone  TM
       [mm] [mm] [mm]  Xi1    k   [mm]  As,min   wk  crack w.    for As,min
   1  0.30   12    .    .   1.00     .  3- 5d  > 28d Calcul.     Rare Comb.     .
   2  0.30   12    .    .   1.00     .  3- 5d  > 28d Calcul.     Rare Comb.     .
```

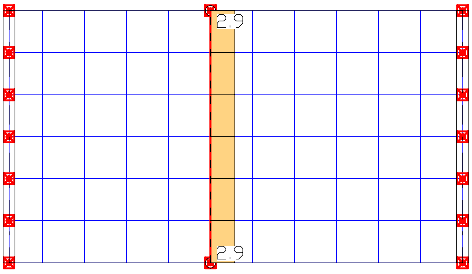
Settings for the check of concrete stresses

```
(CC) Characteristic combination (QC) Quasi-continuous combination

Se.     per.sigma.c    per.sigma.c   Dekompression
            (CC)           (QC)          Stress
  1        0.60 fck         .               .
  2        0.60 fck         .               .
```

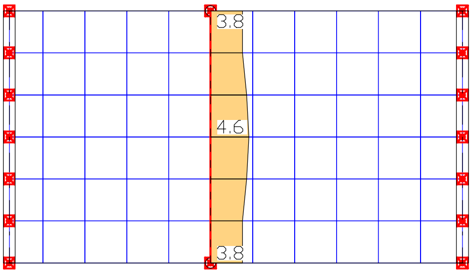
The calculated reinforcements are shown in the illustrations below.



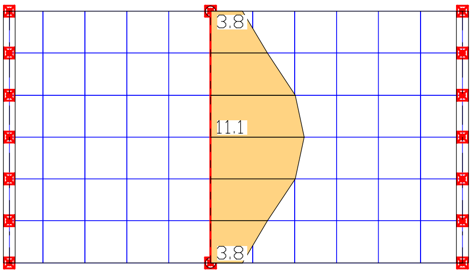
Longitudinal reinforcement of the beams in the ultimate limit state [cm²]



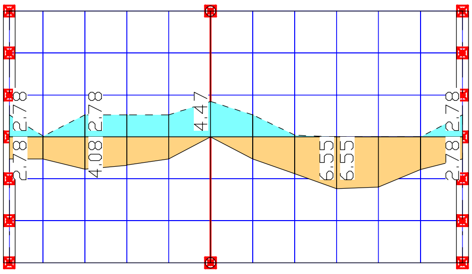
Longitudinal reinforcement of the beams to ensure robustness (ductility) [cm²]



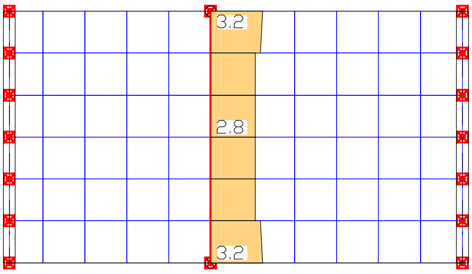
Longitudinal reinforcement of the beams to limit the crack width [cm²]



Maximum longitudinal reinforcement of the beams [cm²]



Slab reinforcement in the intersection direction based on the robustness (ductility), crack width and design checks in the ultimate limit state [cm²/m]



Stirrup reinforcement of the beams [cm²/m]

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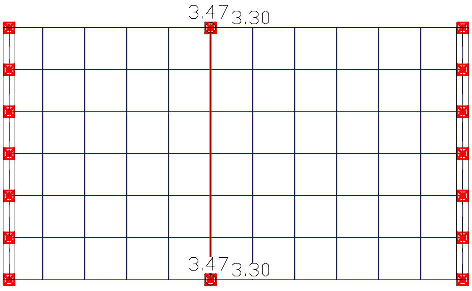


Averaged stirrup reinforcement of the slab at the nodes [cm²/m²]

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

Design of longitudinal reinforcement

```
(M) Nominal reinforcement to guarantee robustness (Charact. C.).
    fctm     Average centric concrete tensile strength [MN/m²]
    h        Section height [m]
    zs,t/b   Lever arm of inner strengths top/bottom
    fyk,t/b  Strength of longitudinal reinforcement top/bottom [MN/m²]
    max Sx   Maximal edge stress from Charact. C.
(R) Nominal or required reinforcement for crack width limitation.
    Increase of reinforcement due to crack width check is marked by "!".
    wk,per   Permissible crack width [mm].
    ds       Maximal given steel diameter [mm].
    k        Coefficient for consideration of non-linear distributed tensile stress.
    fct,eff  Concrete strength at date of cracking [MN/m²].
    kc       Coefficient to consider stress distribution in tensile zone.
    Ap'      Part of prestr. steel area Xi1*Ap which was used to reduce req.As.
    Xi1      Bond coefficient for prestressing steel.
    max Sx   Maximal edge stress from action combination.
(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, Loc. 1

```
Section 2, Polygon - C30/37
Steel 2; Design mode: Standard
(M) fctm=2.9; zs,t/b=0.513/0.513; fyk,t/b=500/500
(R) wk,per=0.3; ds=12; k=1; fct,eff=1.45; Xi1=0
(B) fck=30

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

```
Relevant concrete internal forces from 4 set of internal forces
Set      Nx[kN]   My[kNm]   Mz[kNm]
2    :     0.00    196.53      0.00

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

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

```
Relevant concrete internal forces from 4 set of internal forces
Set      Nx[kN]   My[kNm]   Mz[kNm]
2    :     0.00    107.92      0.00

Load case combinations for the relevant sets of internal forces
Set    Combination
2    : L1+0.30*L2+0.30*L3
```

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

```
Relevant concrete internal forces from 8 set of internal forces
Set      Nx[kN]   My[kNm]   Mz[kNm]
1    :     0.00     94.43      0.00
2    :     0.00    284.31      0.00

Load case combinations for the relevant sets of internal forces
Set    Combination
1    : 1.35*L1
2    : 1.35*L1+1.50*L2+1.50*L3
```

Design of longitudinal reinforcement

```
Reinforcement Nx        My        Mz   max Sx   kc      Ap'   req.As  Situation
Lay. Type    [kN]      [kNm]     [kNm] [MN/m²]         [cm²]   [cm²]
  1   M      0.00      69.95      0.00     .     .       .      0.00  CC.1,1
      R      0.00      69.95      0.00     .     .       .      0.00  CC.1,1
      B      0.00      69.95      0.00     .     .       .      0.00  PC.1,5
  2   M      0.00      69.95      0.00     .     .       .      0.00  CC.1,1
      R      0.00      69.95      0.00     .     .       .      0.00  CC.1,1
      B      0.00      69.95      0.00     .     .       .      0.00  PC.1,5
  3   M      0.00     196.53      0.00  7.73     .       .      1.44  CC.1,2
      R      0.00     107.92      0.00     .     .       .      2.28! QC.1,2
      B      0.00     284.31      0.00     .     .       .      5.57  PC.1,2
  4   M      0.00     196.53      0.00  7.73     .       .      1.44  CC.1,2
      R      0.00     107.92      0.00     .     .       .      2.28! QC.1,2
      B      0.00     284.31      0.00     .     .       .      5.57  PC.1,2
```

Shear reinforcement from ultimate limit state design

```
The percentage of nominal reinforcement acc. to 13.2.3 (5) 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 width for shear design using Qz [m]
kd        Factor to calculate the inner lever arm from d
Angle     Angle cot Theta between the compressive strut and the beam axis
Asl       Chargeable longitudinal reinf. acc. to Pic. 32 [cm²]
min rhow  Minimal percentage of lateral reinforcement acc. to 13.2.3 (5)
Qy, Qz    Lateral forces for design in y- and z-direction [kN]
VRdct     Resisting lateral force without shear reinforcement [kN]
VRdmax    Resisting lateral force of the concrete struts [kN]
z         Inner lever arm z=kb*bn resp. z=kd*d [m], z<=max(d-2cvl,d-cvl-30mm)
cvl       Laying measure of the long. reinforcement to limit the lever arm z [m]
req.Asb.y, Asb.z Req. stirrup reinforcement from Qy resp. Qz [cm²/m]
req.Asl   Req. longitudinal reinf. acc. to Pic. 32 [cm²] for req.Asb
```

Beam 70, Loc. 1

```
Section 2, Polygon - C30/37
bw/bn/kb=0.3/0.27/0.9; h/d/kd=0.6/0.57/0.9
cvl=0.03; fyk=500; Asl giv./max=0/0; min rhow=1*rho
```

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

```
Relevant concrete internal forces from 8 set of internal forces
Set      Nx[kN]   My[kNm]   Mz[kNm]   Mx[kNm]    Qy[kN]    Qz[kN]
2    :     0.00    284.31      0.00      0.00      0.00    -30.79

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

Design of shear reinforcement

```
Qy            :    0.00 kN    Angle      :   3.00
Qy/VRdct      :    0.00       z          :   0.21 m
Qy/VRdmax     :    0.00       req.Asb.y  :   0.00 cm²/m
Situation     : -,-           req.Asl    :   0.00 cm²
```

```
Qz            :  -30.79 kN    Angle     :   3.00
Qz/VRdct      :    0.47       z         :   0.51 m
Qz/VRdmax     :    0.05       req.Asb.z :   2.79 cm²/m
Situation     : PC.1,2        req.Asl   :   0.00 cm²
```

Check of crack widths

```
The check calculates the crack width directly.
(CC) Charact. (rare), (TC) Frequent, (QC) Quasi-continuous combination

wk,per   Permissible crack width [mm]
ds       Maximal given steel diameter [mm]
fct,eff  Concrete strength at date of cracking [MN/m²]
Sigma.x  Maximal edge stress in state I [MN/m²]
wk       Calculated value of crack width [mm]
sr,max   Calculated resp. given value of maximal crack spacing [mm]
Ac,eff   Effective region of reinf. [m²] acc. to Pic. 53
As,eff   Reinforcing steel within Ac,eff [cm²]
Ap,eff   Prestressing steel with bond within Ac,eff [cm²]
Sigma.s  Reinf. steel stress in state II [MN/m²]
```

Beam 70, Loc. 1

```
Section 2, Polygon - C30/37
wk,per=0.3; ds=12; fct,eff=2.9

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

```
Relevant concrete internal forces from 4 set of internal forces
Set      Nx[kN]   My[kNm]   Mz[kNm]
2    :     0.00    107.92      0.00

Load case combinations for the relevant sets of internal forces
Set    Combination
2    : L1+0.30*L2+0.30*L3
```

Check of crack width for reinf. layer 4 (bottom)

```
Nx        :     0.00 kN      As,eff  :  11.15  cm²
My        :   107.92 kNm     Ap,eff  :    .    cm²
Mz        :     0.00 kNm     Ac,eff  :   0.023 m²
Sigma.x   :     4.25 MN/m²   Sigma.s : 176.55  MN/m²
Situation : QC.1,2           sr,max  :  67.37  mm
                             wk      :   0.05  per. 0.30 mm
```

Check of concrete compressive stress

```
For the check, a cracked concrete section (II) is assumed if the tensile stress
from the char. comb. exceeds the value of fctm. Otherwise, a non-cracked section
(I) is used. If the strain is not treatable on cracked section, (I*) is marked.
(CC)  Characteristic (rare) combination, (QC) Quasi-continuous combination

fck          Characteristic compressive concrete strength [MN/m²]
min Sigma.x  Total maximal longitudinal compressive stress [MN/m²]
top, bottom  Position of the edge point: above, below of centre
```

Beam 70, Loc. 1

```
Section 2, Polygon - C30/37
0.6*fck=18

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

```
Relevant concrete internal forces from 4 set of internal forces
Set      Nx[kN]   My[kNm]   Mz[kNm]
1    :     0.00     69.95      0.00
2    :     0.00    196.53      0.00

Load case combinations for the relevant sets of internal forces
Set    Combination
1    : L1
2    : L1+L2+L3
```

Check of compressive stress in concrete for the Characteristic (rare) combination

```
Side   Se.-  min Sigma.x  per. Sigma.x  Period   Situation
       Pnt.      [MN/m²]       [MN/m²]
top       4  (II)  -6.37        -18.00  Final    CC.1,2
bottom    7  (II)   0.00        -18.00  Final    CC.1,1
```

Check of steel stress

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

Type B  Bending reinf., layer number, Charact. C. (CC)
fck     Concrete strength to determine the strain state [MN/m²]
```

Beam 70, Loc. 1

```
Section 2, Polygon - C30/37
fck=30; Steel 2

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

```
Relevant concrete internal forces from 4 set of internal forces
Set      Nx[kN]   My[kNm]   Mz[kNm]
1    :     0.00     69.95      0.00
2    :     0.00    196.53      0.00

Load case combinations for the relevant sets of internal forces
Set    Combination
1    : L1
2    : L1+L2+L3
```

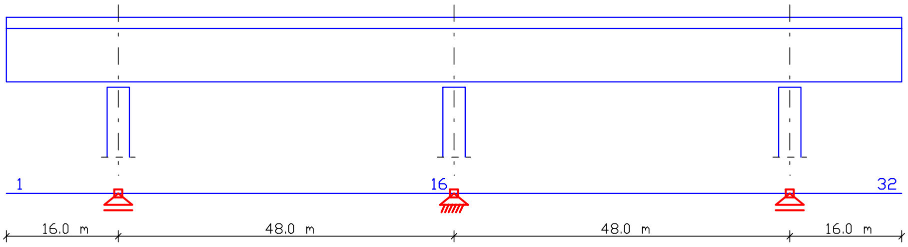
Check of steel stress

```
Steel         Nx        My        Mz       As  Sigma.s     per.  Situation
Type No.     [kN]     [kNm]     [kNm]    [cm²]  [MN/m²]   [MN/m²]
 B    1      0.00     69.95      0.00     0.00       .      400.00 CC.1,1
 B    2      0.00     69.95      0.00     0.00       .      400.00 CC.1,1
 B    3      0.00    196.53      0.00     5.57   321.62     400.00 CC.1,2
 B    4      0.00    196.53      0.00     5.57   321.62     400.00 CC.1,2
```

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. The construction is designed to meet requirement class D. According to Table 18 of the DIN, a decompression check is not necessary for this class.

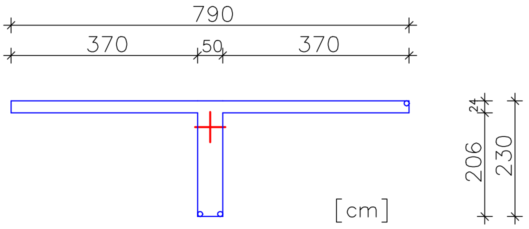


Static system and dimensions (longitudinal and lateral section)

Material

Concrete	*C45/55*
Reinforcing steel	*BSt 500*, axis distance from edge 5 cm

Section



Prestressing steel and prestressing system

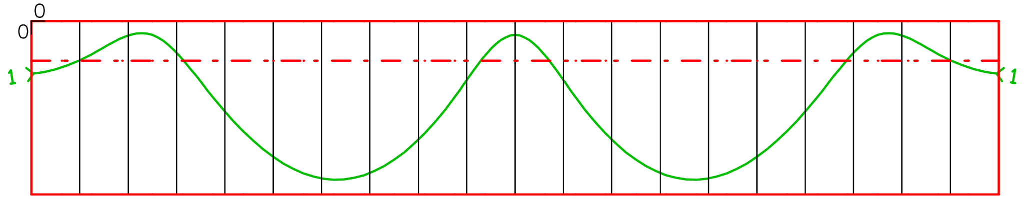
Prestressing steel quality	St 1500/1770
Certification of the prestressing system	DIN 1045-1, Cona 1206
Number of tendons in the bundle	4
Section surface A_p	1800 mm²
E-modulus of the prestressing steel	195000 MN/m²
0.1% strain limit (yield strength) of the prestressing steel $f_{p0.1k}$	1500 MN/m²
Tensile strength of the prestressing steel f_{pk}	1770 MN/m²
Permissible prestressing force of a tendon P_{m0}	2295 kN
Friction coefficients when prestressing and releasing μ	0.2
Unintentional deviation angle of a tendon β'	0.3 °/m
Slippage at prestressed tie bolt	6 mm
Duct diameter d_h	82 mm
Allowance value for ensuring an overstressing reserve κ	1.5

Scattering coefficients of the internal prestressing as per DIN 1045-1, Eq. 52/53

Construction stage according to Book 525 (r_{sup} / r_{inf})	1.0 / 1.0
Final state (r_{sup} / r_{inf})	1.1 / 0.9

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.

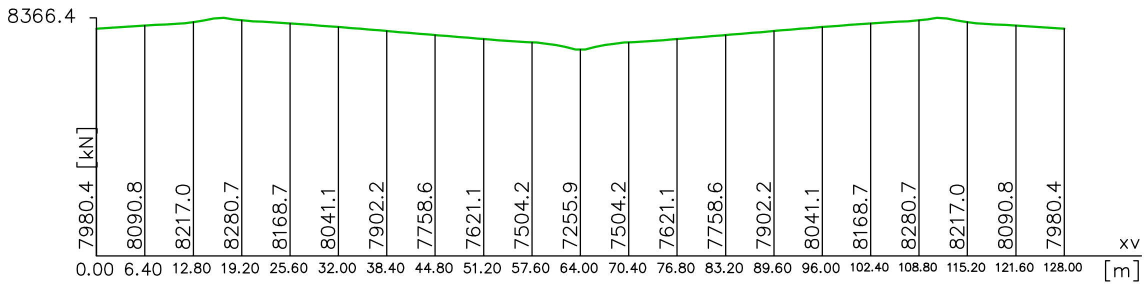
```
Tendon groups in beam series , [-16.00,0.00,0.00] - [112.00,0.00,0.00] / [-16.00,0.00,1.00]
Superelevation = 10
```



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

```
Pre. procedure  1:  <:  1.000  |   1.000:>  (Unnamed)
Pre. forces    [kN]:   2203.9  |   2203.9
Extension      [mm]:    667.0  |     70.0
Tensioning with Pmax (DIN Report, DIN 1045-1, DIN EN 1992-1-1). Kappa = 1.5.
```



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

Loads

Load case 1	Dead load (G1).
Load case 2	Additional loads q=11.06 kN/m (G2).
Load case 3	Traffic load (snow load) q=7.90 kN/m (Q).
Load case 10	Prestressing (P).
Load case 15	Creep-generating permanent load: G1+P+G2
Load case 20	Creep and shrinkage (CSR). Coefficients: $\varphi_{t\infty}$ = 2.55; ρ = 0.8; $\varepsilon_{t\infty}$ = -24.8 · 10^{-5} Creep-generating permanent load case: 15 The redistribution of internal forces between concrete and prestressing steel are taken into account.

Definition of actions for DIN 1045-1

Standard design group

G - Dead load

Gamma.sup / gamma.inf = 1.35 / 1

Load cases	
1	Dead load

G - Additional dead load

Gamma.sup / gamma.inf = 1.35 / 1

Load cases	
2	Additional dead 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

QS - Snow and ice load

Gamma.sup / gamma.inf = 1.5 / 0

Combination coefficients for: Superstructures
Snow and ice load - places to NN + 1000 m
Psi.0 / Psi.1 / Psi.2 = 0.5 / 0.2 / 0

Load cases 1. Variant, inclusive

3 Snow load

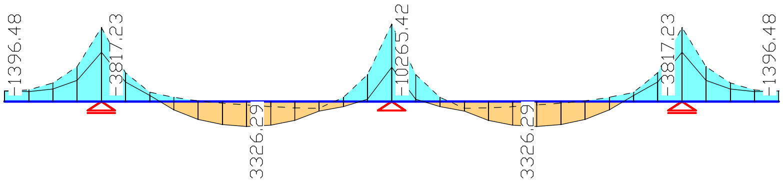
In this example all possible combinations of load cases are generated and designed. This method is selected in the calculation settings and can be very slow when applied for a large number of load cases.

Below you will find an example of the curve of bending moment M_y for design situations in the ultimate limit states.

1. Permanent and temporary situation - Structural cond.

Construction stage - Un grouted

G Dead load
P Prestressing

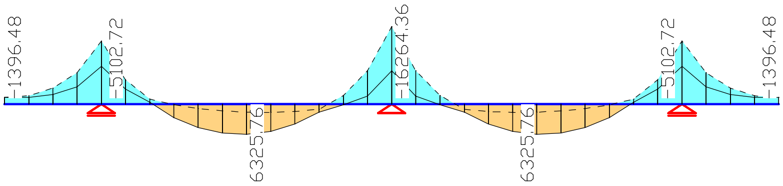


Bending moment M_y [kNm]

2. Permanent and temporary situation - t0

Final state

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

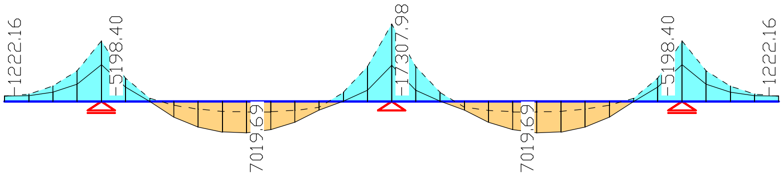


Bending moment M_y [kNm]

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



Bending moment M_y [kNm]

Design overview DIN 1045-1 (2008-08)

```
Se. Class, Prestress     Reinforc.  Fatig.  Crack- De-    Stress checks
      of component       M R B Q T  S P C   width  comp.  Comp.   S P
  1 D  supplem. bond     x x x x .  . . .     x      .      x     x x

(M) Nominal reinforcement to guarantee robustness (ductility).
(R) Nominal reinforcement for crack width limitation.
(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 stress and fatigue check.
(P) Prestressing steel at stress and fatigue check.
(C) Concrete at fatigue check.
```

Dispersion of prestressing

```
The dispersion of prestressing is considered at the following checks:
- Check of decompression
- Nominal reinforcement for crack width limitation
- Check of crack width
All other checks are made using the mean value Pm,t of prestressing.

Se.  Prestressing of   Const.period   Final state
        component      r.sup  r.inf   r.sup  r.inf
  1  supplem. bond      1.00   1.00    1.10   0.90
```

Settings for flexural and lateral reinforcement

```
fyk     Quality of stirrups [MN/m²].
Theta   Angle of concrete truss. Program-sided, the given value of cot Theta
        is limited to the range of values acc. to equ. (73).
        (Method of variable truss angle).
Slabs   Beams are designed like slabs.
Asl     Given reinforcement according to picture 32, increase to maximum.
rhow    Minimum reinf. min rhow = Factor * rho with rho according to table 29.
x,y     Separate lateral force design for reinforcement directions x and y.
cvl     Laying measure of the long. reinforcement to limt the lever arm z.

Se. Concrete Den-     Design        fyk   Truss  Dsn.  Asl [cm²]    Fac.  Dsn. L.m.
             sity     for          Stirr. cot    like   Pic. 32     for   for   cvl
             [kg/m³] M and N      [MN/m²] Theta  Sl.   given   max  rhow  x,y   [m]
  1 C45/55        .   Standard      500   3.00    .     0.00    .   1.60   .   0.05
```

Shear sections

```
bw.nom  Nominal width of the prestressed section acc. to 10.3.4 (8).
h.nom   Nominal height of the prestressed section acc. to 10.3.4 (8).
z1, z2  Height and width of the core section for torsion.
teff    Thickness of the torsion box.
B.      Box section.

Se.   Width [m]    Eff. width    Height [m]  Eff.height    Torsion section [m]
      bw    bw.nom  bn [m]        h      h.nom   d [m]        z1     z2     teff B.
  1  0.500  0.380   0.450      2.300  2.220   2.250       2.200  0.400  0.100 .
```

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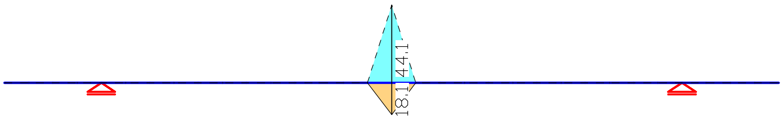
Settings for the check of crack widths

```
ds        Maximal given bar diameter of the reinforcing steel.
max.s     Maximal given bar spacing of the reinforcing steel.
Xi1       Bond coefficient of prestressing steel for beam sections.
k         Coefficient for consideration of non-linear distributed tensile stress.
sr,max    Upper limit for the crack spacing from equ. (137).
Method    Direct calculation of the crack width as per chapt. 11.2.4 or
          check by limiting the bar spacing according to table 21.
TM        Thick member according to chapt 11.2.2(8) to determine As,min.

 Se. wk,per ds max.s   Coeff.  sr,max  Concr. age   Method for   Tensile zone  TM
      [mm] [mm] [mm]  Xi1    k   [mm]  As,min    wk  crack w.     for As,min
   1  0.20   20    .  0.27 1.00     .  3- 5d  3- 5d  Calcul.      Rare Comb.     .
```

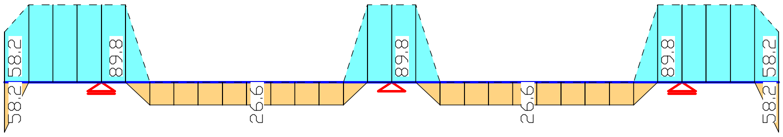
Settings for the check of concrete stresses

```
(CC) Characteristic combination (QC) Quasi-continuous combination

Se.    per.sigma.c   per.sigma.c   Dekompression
          (CC)          (QC)           Stress
  1       0.60 fck      0.45 fck      Sigma.x
```

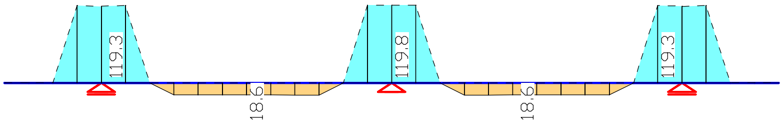
The following illustration shows the curve of the required bending and shear reinforcement.



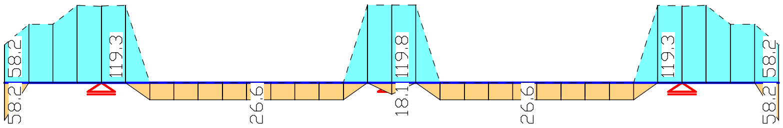
Longitudinal reinforcement A_s from a design in the ultimate limit states [cm²]
(upper reinforcement with dashed lines).



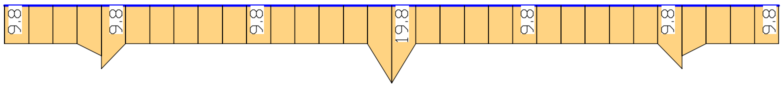
Minimum reinforcement A_s for ensuring robustness (ductility) [cm²]
(upper reinforcement with dashed lines).



Reinforcement A_s for limiting the crack width [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

```
(M) Nominal reinforcement to guarantee robustness (Charact. C.).
    fctm    Average centric concrete tensile strength [MN/m²]
    h       Section height [m]
    zs,t/b  Lever arm of inner strengths top/bottom
    fyk,t/b Strength of longitudinal reinforcement top/bottom [MN/m²]
    max Sx  Maximal edge stress from Charact. C.
            without the statically determined part of prestressing
(R) Nominal or required reinforcement for crack width limitation.
    Increase of reinforcement due to crack width check is marked by "!".
    wk,per  Permissible crack width [mm].
    ds      Maximal given steel diameter [mm].
    k       Coefficient for consideration of non-linear distributed tensile stress.
    fct,eff Concrete strength at date of cracking [MN/m²].
    kc      Coefficient to consider stress distribution in tensile zone.
    Ap'     Part of prestr. steel area Xi1*Ap which was used to reduce req.As.
    Xi1     Bond coefficient for prestressing steel.
    max Sx  Maximal edge stress from action combination.
(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]


Section 1, Polygon - C45/55, 1 Tendon groups with supplemental bond
Steel 1; Design mode: Standard
(M) fctm=3.8; zs,t/b=2.025/2.025; fyk,t/b=500/500
(R) wk,per=0.2; ds=20; k=1; fct,eff=1.9; Xi1=0.27
    r.sup/inf(Constr.)=1/1; r.sup/inf(Final)=1.1/0.9
(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    1.2536    9.8822    0.0000
          ideally:     2.962    3.950    0.521    1.2601    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    1500    1770    3.950    0.185   7200      82     7255.93      0.00
```

1. Characteristic (rare) combination (CC.1): G.1+P, Construction period n. grouted

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

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[%]  No.  CSR[%]
  1    9.63         -.-          -.-          -.-          -.-          -.-

Stat. determ. part (P+CSR): Nx0=-6557.10 kN; My0=2229.41; 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    : -6430.65  -9821.11      0.00    126.44 -12050.52      0.00

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

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

```
Relevant concrete internal forces from 4 set of internal forces
Set       Nx[kN]   My[kNm]   Mz[kNm]
2    : -5787.59 -10902.26      0.00 r.inf
```

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

1. Permanent and temporary comb. (PC.1): G.1+P, Construction period n. grouted

```
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

```
Loss of prestress by CSR in tendon groups
No.  CSR[%]  No.  CSR[%]  No.  CSR[%]  No.  CSR[%]  No.  CSR[%]  No.  CSR[%]
  1    9.63         -.-          -.-          -.-          -.-          -.-

Stat. determ. part (P+CSR): Nx0=-6557.10 kN; My0=2229.41; 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    : -6430.65 -17307.98      0.00    126.44 -19537.39      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 Sx  kc      Ap'   req.As  Situation
Lay. Type    [kN]     [kNm]     [kNm] [MN/m²]        [cm²]   [cm²]
  1   M    126.44 -12050.52      0.00   5.08   .       .     44.91  CC.3,2
      R  -5787.59 -10902.26      0.00   2.58  0.50     .     59.91  CC.3,2
      B  -6430.65 -17307.98      0.00    .     .       .     22.06  PC.3,2
  2   M    126.44 -12050.52      0.00   5.08   .       .     44.91  CC.3,2
      R  -5787.59 -10902.26      0.00   2.58  0.50     .     59.91  CC.3,2
      B  -6430.65 -17307.98      0.00    .     .       .     22.06  PC.3,2
  3   M      0.06  -6997.47      0.00    .     .       .      0.00  CC.1,1
      R  -7255.87  -4530.46      0.00    .     .       .      0.00  CC.1,1
      B  -6430.65 -17307.98      0.00    .     .       .      9.03* PC.3,2
  4   M      0.06  -6997.47      0.00    .     .       .      0.00  CC.1,1
      R  -7255.87  -4530.46      0.00    .     .       .      0.00  CC.1,1
      B  -6430.65 -17307.98      0.00    .     .       .      9.03* PC.3,2
```

Shear reinforcement from ultimate limit state design

```
The percentage of nominal reinforcement acc. to 13.2.3 (5) is considered.

bw        Effective width for calculation of shear stresses from Qz and Mx [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 width for shear design using Qz [m]
kd        Factor to calculate the inner lever arm from d
Angle     Angle cot Theta between the compressive strut and the beam axis
Asl       Chargeable longitudinal reinf. acc. to Pic. 32 [cm²]
min rhow  Minimal percentage of lateral reinforcement acc. to 13.2.3 (5)
Qy, Qz    Lateral forces for design in y- and z-direction [kN]
VRdct     Resisting lateral force without shear reinforcement [kN]
VRdmax    Resisting lateral force of the concrete struts [kN]
z         Inner lever arm z=kb*bn resp. z=kd*d [m], z<=max(d-2cvl,d-cvl-30mm)
cvl       Laying measure of the long. reinforcement to limit the lever arm z [m]
req.Asb.y, Asb.z Req. stirrup reinforcement from Qy resp. Qz [cm²/m]
req.Asl   Req. longitudinal reinf. acc. to Pic. 32 [cm²] for req.Asb
```

```
Section 1, Polygon - C45/55, 1 Tendon groups with supplemental bond
bw/bw.nom/bn/kb=0.5/0.38/0.45/0.9; h/h.nom/d/kd=2.3/2.22/2.25/0.9
cvl=0.05; fyk=500; Asl giv./max=0/0; min rhow=1.6*rho
```

1. Permanent and temporary comb. (PC.1): G.1+P, Construction period n. grouted

```
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 set of internal forces
Set      Nx[kN]   My[kNm]   Mz[kNm]   Mx[kNm]    Qy[kN]    Qz[kN]
2    : -6430.65 -17307.98      0.00      0.00      0.00  -3080.21

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 shear reinforcement

```
Qy             :    0.00 kN    Angle      :   3.00
Qy/VRdct       :    0.00       z          :   0.37 m
Qy/VRdmax      :    0.00       req.Asb.y  :   0.00 cm²/m
Situation      : -,-           req.Asl    :   0.00 cm²

Qz             :-3080.21 kN    Angle      :   1.76
Qz/VRdct       :    5.35       z          :   2.02 m
Qz/VRdmax      :    0.49       req.Asb.z  :  19.83 cm²/m
Situation      : PC.3,2        req.Asl    :   0.00 cm²
```

Check of crack widths

```
The check calculates the crack width directly.
(CC) Charact. (rare), (TC) Frequent, (QC) Quasi-continuous combination

wk,per   Permissible crack width [mm]
ds       Maximal given steel diameter [mm]
fct,eff  Concrete strength at date of cracking [MN/m²]
Sigma.x  Maximal edge stress in state I [MN/m²]
wk       Calculated value of crack width [mm]
sr,max   Calculated resp. given value of maximal crack spacing [mm]
Ac,eff   Effective region of reinf. [m²] acc. to Pic. 53
As,eff   Reinforcing steel within Ac,eff [cm²]
Ap,eff   Prestressing steel with bond within Ac,eff [cm²]
Sigma.s  Reinf. steel stress in state II acc. to equ. (132) [MN/m²]

Section 1, Polygon - C45/55, 1 Tendon groups with supplemental bond
wk,per=0.2; ds=20; fct,eff=1.9; Xi1=0.27
r.sup/inf(Constr.)=1/1; r.sup/inf(Final)=1.1/0.9

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    1.2536    9.8822    0.0000
          ideally:     2.962    3.950    0.521    1.2601    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   1500    1770    3.950    0.185   7200      82     7255.93      0.00
```

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

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

2. Frequent combination (TC.2): 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[%]  No.  CSR[%]
  1    9.63          -.-          -.-          -.-          -.-          -.-
```

```
Stat.determ.part (P+CSR)*r.inf: Nx0=-5901.39 kN; My0=2006.47; Mz0=0.00 kNm

Relevant values from 4 sets of internal forces
         Concrete section              Bond section
Set      Nx[kN]   My[kNm]   Mz[kNm]     Nx[kN]   My[kNm]   Mz[kNm]
2    : -5787.59  -9486.58      0.00    113.80 -11493.06      0.00 r.inf

Load case combinations for the relevant sets of internal forces
Set    Combination
2    : L1+L2+0.96*L10+L20+0.20*L3
```

Check of crack width for reinf. layer 1 (top)

```
Nx        : -5787.59 kN      As,eff  : 119.83  cm²
My        : -9486.58 kNm     Ap,eff  :   0.00  cm²
Mz        :     0.00 kNm     Ac,eff  :   0.987 m²
Sigma.x   :     1.99 MN/m²   Sigma.s :  63.13  MN/m²
Situation : TC.2,2           sr,max  : 184.60  mm
                             wk      :   0.03  per. 0.20 mm
```

Check of concrete compressive stress

```
For the check, a cracked concrete section (II) is assumed if the tensile stress
from the char. comb. exceeds the value of fctm. Otherwise, a non-cracked section
(I) is used. If the strain is not treatable on cracked section, (I*) is marked.
(CC)  Characteristic (rare) combination, (QC) Quasi-continuous combination

fck          Characteristic compressive concrete strength [MN/m²]
min Sigma.x  Total maximal longitudinal compressive stress [MN/m²]
top, bottom  Position of the edge point: above, below of centre


Section 1, Polygon - C45/55, 1 Tendon groups with supplemental bond
0.45*fck=20.25; 0.6*fck=27

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    1.2536    9.8822    0.0000
          ideally:     2.962    3.950    0.521    1.2601    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   1500    1770    3.950    0.185   7200      82     7255.93      0.00
```

1. Characteristic (rare) combination (CC.1): G.1+P, Construction period n. grouted

```
Relevant concrete internal forces from 1 set of internal forces
Set      Nx[kN]   My[kNm]   Mz[kNm]
1    : -7255.87  -4530.46      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[%]  No.  CSR[%]
  1    9.63          -.-          -.-          -.-          -.-          -.-

Stat. determ. part (P+CSR): Nx0=-6557.10 kN; My0=2229.41; 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    : -6430.65  -9821.11      0.00    126.44 -12050.52      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+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[%]  No.  CSR[%]
  1   9.63         -.-         -.-         -.-         -.-         -.-

Stat. determ. part (P+CSR): Nx0=-6557.10 kN; My0=2229.41; Mz0=0.00 kNm

Relevant values from 1 sets of internal forces
         Concrete section              Bond section
Set      Nx[kN]   My[kNm]   Mz[kNm]    Nx[kN]   My[kNm]   Mz[kNm]
1    : -6430.65  -8051.51      0.00    126.44 -10280.92      0.00

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

Check of compressive stress in concrete for the Characteristic (rare) combination

```
Side   Se.-  min Sigma.x  per. Sigma.x  Period   Situation
       Pnt.      [MN/m²]       [MN/m²]
top       1  (I)   -0.59        -27.00  Constr.  CC.1,1
bottom    7  (I)  -16.04        -27.00  Final    CC.3,2
```

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

```
Side   Se.-  min Sigma.x  per. Sigma.x  Period   Situation
       Pnt.      [MN/m²]       [MN/m²]
top       1  (I)    1.16        -20.25  Final    QC.1,1
bottom    7  (I)  -13.54        -20.25  Final    QC.1,1
```

Check of steel stress

```
For the check, a cracked concrete section is assumed.
For tendon groups without bond and/or for situations before grouting,
the prestressing steel stress is checked acc. to Eq. (49).

Type B  Bending reinf., layer number, Charact. C. (CC)
Type P  Prestressing steel, Tendon number, Q.-cont. C. (QC)
        and Charact. C. (CC)
N0, M0  Statically determined forces of tendons with bond [kN, kNm]
fck     Concrete strength to determine the strain state [MN/m²]

Section 1, Polygon - C45/55, 1 Tendon groups with supplemental bond
fck=45; Steel 1

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    1.2536    9.8822    0.0000
          ideally:     2.962    3.950    0.521    1.2601    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   1500    1770    3.950    0.185   7200      82     7255.93     0.00
```

1. Characteristic (rare) combination (CC.1): G.1+P, Construction period n. grouted

```
Relevant concrete internal forces from 1 set of internal forces
Set      Nx[kN]   My[kNm]   Mz[kNm]
1    : -7255.87  -4530.46      0.00

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

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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[%]  No.  CSR[%]
  1    9.63         -.-          -.-          -.-          -.-          -.-

Stat. determ. part (P+CSR): Nx0=-6557.10 kN; My0=2229.41; 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    : -6430.65  -9821.11      0.00    126.44 -12050.52      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+G.2+P+CSR1+QS, Final state grouted

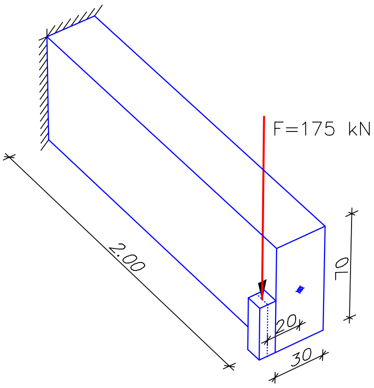
```
Loss of prestress by CSR in tendon groups
No.  CSR[%]  No.  CSR[%]  No.  CSR[%]  No.  CSR[%]  No.  CSR[%]  No.  CSR[%]
  1    9.63         -.-          -.-          -.-          -.-          -.-

Stat. determ. part (P+CSR): Nx0=-6557.10 kN; My0=2229.41; Mz0=0.00 kNm

Relevant values from 1 sets of internal forces
         Concrete section              Bond section
Set       Nx[kN]   My[kNm]   Mz[kNm]    Nx[kN]   My[kNm]   Mz[kNm]
1    : -6430.65  -8051.51      0.00    126.44 -10280.92      0.00

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

Check of steel stress

```
Steel         Nx         My         Mz       As  Sigma.s     per.  Situation
Type No.     [kN]      [kNm]      [kNm]   [cm²]  [MN/m²]   [MN/m²]
 B    1  -6430.65  -9821.11       0.00    59.91    54.05    400.00 CC.3,2
 B    2  -6430.65  -9821.11       0.00    59.91    54.05    400.00 CC.3,2
 B    3  -7255.87  -4530.46       0.00     9.03   -48.90    400.00 CC.1,1
 B    4  -7255.87  -4530.46       0.00     9.03   -48.90    400.00 CC.1,1
 P    1  -6430.65  -8051.51       0.00    72.00   923.60   1150.50 QC.1,1
 P    1         .         .          .    72.00  1007.77   1275.00 CC.1,--
```

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

Design according to DIN 1045-1 (2008-08)

Settings for flexural and lateral reinforcement

```
fyk      Quality of stirrups [MN/m²].
Theta    Angle of concrete truss. Program-sided, the given value of cot Theta
         is limited to the range of values acc. to equ. (73).
         (Method of variable truss angle).
Slabs    Beams are designed like slabs.
Asl      Given reinforcement according to picture 32, increase to maximum.
rhow     Minimum reinf. min rhow = Factor * rho with rho according to table 29.
x,y      Separate lateral force design for reinforcement directions x and y.
cvl      Laying measure of the long. reinforcement to limt the lever arm z.

Se. Concrete Den-     Design       fyk   Truss  Dsn.  Asl [cm²]    Fac.  Dsn. L.m.
             sity     for        Stirr.  cot    like   Pic. 32     for   for   cvl
             [kg/m³]  M and N   [MN/m²] Theta   Sl.  given    max  rhow  x,y   [m]
  1 C35/45       .                 500   1.00    .    1.00     .   1.00   .   0.05
```

Shear sections

```
bw.nom   Nominal width of the prestressed section acc. to 10.3.4 (8).
h.nom    Nominal height of the prestressed section acc. to 10.3.4 (8).
z1, z2   Height and width of the core section for torsion.
teff     Thickness of the torsion box.
B.       Box section.

Se.   Width [m]   Eff. width    Height [m]  Eff.height    Torsion section [m]
       bw    bw.nom   bn [m]       h      h.nom   d [m]        z1      z2      teff B.
  1  0.300    .        0.245     0.700    .       0.645      0.590   0.190   0.110 .
```

Shear reinforcement from ultimate limit state design

```
The percentage of nominal reinforcement acc. to 13.2.3 (5) 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 width 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]
teff       Wall thickness of the torsion section [m]
Angle      Angle cot Theta between the compressive strut and the beam axis
Asl        Chargeable longitudinal reinf. acc. to Pic. 32 [cm²]
min rhow   Minimal percentage of lateral reinforcement acc. to 13.2.3 (5)
Qy, Qz     Lateral forces for design in y- and z-direction [kN]
VRdct      Resisting lateral force without shear reinforcement [kN]
```

```
VRdmax    Resisting lateral force of the concrete struts [kN]
z         Inner lever arm z=kb*bn resp. z=kd*d [m], z<=max(d-2cvl,d-cvl-30mm)
cvl       Laying measure of the long. reinforcement to limit the lever arm z [m]
req.Asb.y, Asb.z Req. stirrup reinforcement from Qy resp. Qz [cm²/m]
req.Asl   Req. longitudinal reinf. acc. to Pic. 32 [cm²] for req.Asb
Mx        Torsional moment for design [kNm]
Q/VRd+    Block section: (Q/VRdmax)²+(Mx/TRdmax)²
Mx/TRd    Box section:  Q/VRdmax+Mx/TRdmax
TRdmax    Resisting torsional moment of the concrete struts [kNm]
req.Asb.T Req. stirrup reinforcement from torsion [cm²/m]
req.Asl.T Req. longitudinal reinforcement from torsion [cm²]
```

Beam 1, Loc. 1

```
Section 1, Polygon - C35/45
bw/bn/kb=0.3/0.245/0.9; h/d/kd=0.7/0.645/0.9
cvl=0.055; fyk=500; Asl giv./max=1/0; min rhow=1*rho
Block section z1/z2=0.59/0.19; teff=0.11
```

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

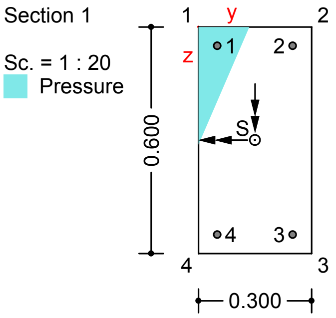
Design of shear reinforcement

```
Qy             :    0.00 kN    Angle     :   1.00
Qy/VRdct       :    0.00       z         :   0.16 m
Qy/VRdmax      :    0.00       req.Asb.y :   0.00 cm²/m
Situation      : -,-           req.Asl   :   1.00 cm²

Qz             :  236.25 kN    Angle     :   1.00
Qz/VRdct       :    3.24       z         :   0.56 m
Qz/VRdmax      :    0.19       req.Asb.z :   9.70 cm²/m
Situation      : PC.1,Qz+      req.Asl   :   1.00 cm²

Mx             :   47.25 kNm   Angle     :   1.00
Qz/VRd+Mx/TRd :    0.17       req.Asb.T :    4.85 cm²/m
Angle          :    1.00       req.Asl.T :    7.56 cm²
Situation      : PC.1,Qz+      Situation : PC.1,Qz+
```

Single Design Reinforced Concrete

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

Pos. 1 - Reinforced concrete design per DIN 1045-1



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	C20/25; gamma.c = 1.50; gamma.s = 1.15
Design mode	Standard
Reinforcement	3.87 cm²; 0.21 %; Concrete area = 1800.00 cm²

Concrete section

Point	y [m]	z [m]	eps[‰]	sigma[MPa]
1	0.000	0.000	-3.50	-11.33
	0.135	0.000	0.00	0.00
2	0.300	0.000	4.29	0.00
3	0.300	0.600	11.04	0.00
4	0.000	0.600	3.24	0.00
	0.000	0.312	0.00	0.00

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	200000	500	0.0	-1.64	-327.84	0.00
2	0.250	0.050	0.050	200000	500	0.0	3.56	436.10	0.41
3	0.250	0.550	0.050	200000	500	0.0	9.17	441.45	2.55
4	0.050	0.550	0.050	200000	500	0.0	3.98	436.50	0.91

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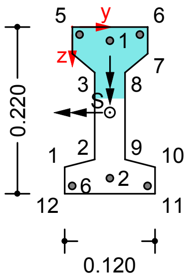
Single Design Prestressed Concrete

In the following example a failure safety check is performed on a prestressed concrete section.

Pos. 1 - Reinforced concrete design per DIN 1045-1

Section 1

Sc. = 1 : 10
🟦 Pressure



Action	N = 0.00 kN; My = 40.00; Mz = 0.00 kNm
Resistance	N = -0.00 kN; My = 40.00; Mz = 0.00 kNm
Force system	ys / zs = 0.050 / 0.113 m
Strength	C45/55; gamma.c = 1.50; gamma.s = 1.15
Design mode	Standard
Reinforcement	4.90 cm²; 3.30 %; Concrete area = 148.50 cm²

Concrete section

Point	y [m]	z [m]	eps[‰]	sigma[MPa]
1	-0.010	0.185	3.35	0.00
2	0.030	0.175	2.98	0.00
	0.030	0.095	0.00	0.00
3	0.030	0.060	-1.28	-22.17
4	0.000	0.035	-2.20	-25.50
5	0.000	0.000	-3.50	-25.50
6	0.100	0.000	-3.50	-25.50
7	0.100	0.035	-2.20	-25.50
8	0.070	0.060	-1.28	-22.17
	0.070	0.094	0.00	0.00
9	0.070	0.175	2.98	0.00
10	0.110	0.185	3.35	0.00
11	0.110	0.220	4.65	0.00
12	-0.010	0.220	4.65	0.00

Reinforcement

Point	y [m]	z [m]	d1 [m]	Es, ßs	[MPa]	Zv0 [kN]	eps[‰]	sigma[MPa]	As [cm²]
1	0.050	0.018	0.018	205000	1420	12.0	-2.83	-280.83	0.40
2	0.050	0.200	0.020	205000	1420	117.6	3.91	1234.78	1.20
3	0.010	0.010	0.010	200000	500	0.0	-3.13	-435.69	0.78
4	0.090	0.010	0.010	200000	500	0.0	-3.13	-435.69	0.78
5	0.100	0.210	0.010	200000	500	0.0	4.28	436.79	0.87
6	0.000	0.210	0.010	200000	500	0.0	4.28	436.79	0.87

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