Verification of Reinforced Concrete Cross-Sections B2+

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Further relevant information and descriptions can be found in the documentation:
[Analysis on the reinforced concrete cross-section]

[Durability - creep and shrinkage]

Basic Documentation – Overview

In addition to the individual program manuals, you will find basic explanations on the operation of the programs on our homepage www.frilo.com in the Campus-download-section.

Application options

Reinforced concrete cross-sections can be dimensioned with the FRILO B2+ program. Table 1 provides an overview of the available cross-section types and the associated possible scope of processing:

Action effect	Cross-section	Verifications					
		Bending + axial force	Shear force + torsion	Shear joint *1)	effective stiffness ULS/SLS	Stress steel/concrete	Crack width
Uniaxial	Rectangle	✓	✓	✓	✓	✓	✓
	T-beams	✓	✓	✓	✓	✓	✓
	Layers	✓	✓	✓	✓	✓	✓
Uni- or biaxial	Rectangle	✓	✓*2)	-	✓	✓	-
	Rectangular hollow box	✓	-	-	✓	✓	-
	Circle	✓	✓*3)	-	✓	✓	✓
	Annulus	✓	-	-	✓	✓	-

*1) Optionally, a cast-in-place concrete addition can be entered for uniaxially loaded cross-sections

*2) only for DIN EN 1992-1-1

*3) only uniaxial shear force

Table. 1: Action effect types, cross-section types and verifications available in B2+

Standards

The design is possible according to

- Original Eurocode and according to
- national annexes of Germany, Austria, Great Britain and Poland.

The standards available in B2+ and the associated abbreviations used in this document are listed below:

	Abbreviation	Standard
Original Eurocode	EN	EN 1992-1-1:2004 /A1:2014 and EN 1992-1-2:2004 /AC:2008
Germany	NA-D	DIN EN 1992-1-1/NA/A1:2015-12 DIN EN 1992-1-1/NA:2013-04 DIN 1992-1-1/NA:2011-01 with DIN 1992-1-1/NA Ber 1:2012-06
Austria	NA-A	ÖNORM B 1992-1-1:2018-01 ÖNORM B 1992-1-1:2011-12
Great Britain	NA-GB	NA+A2:2014 to BS EN 1992-1-1:2004+A1:2014 (2015-07)
Poland	NA-PL	PN EN 1992-1-1:2008/NA:2010

If parameters in the national annexes deviate from the original Eurocode, this is indicated in this document with the following abbreviation:

NDP – parameter definable in the National Annex

Otherwise, the statements of the original Eurocode apply in the same way to all national annexes.

Calculation bases

Explanations of the calculation bases and verifications can be found in the document "Analysis on the reinforced concrete cross-section".

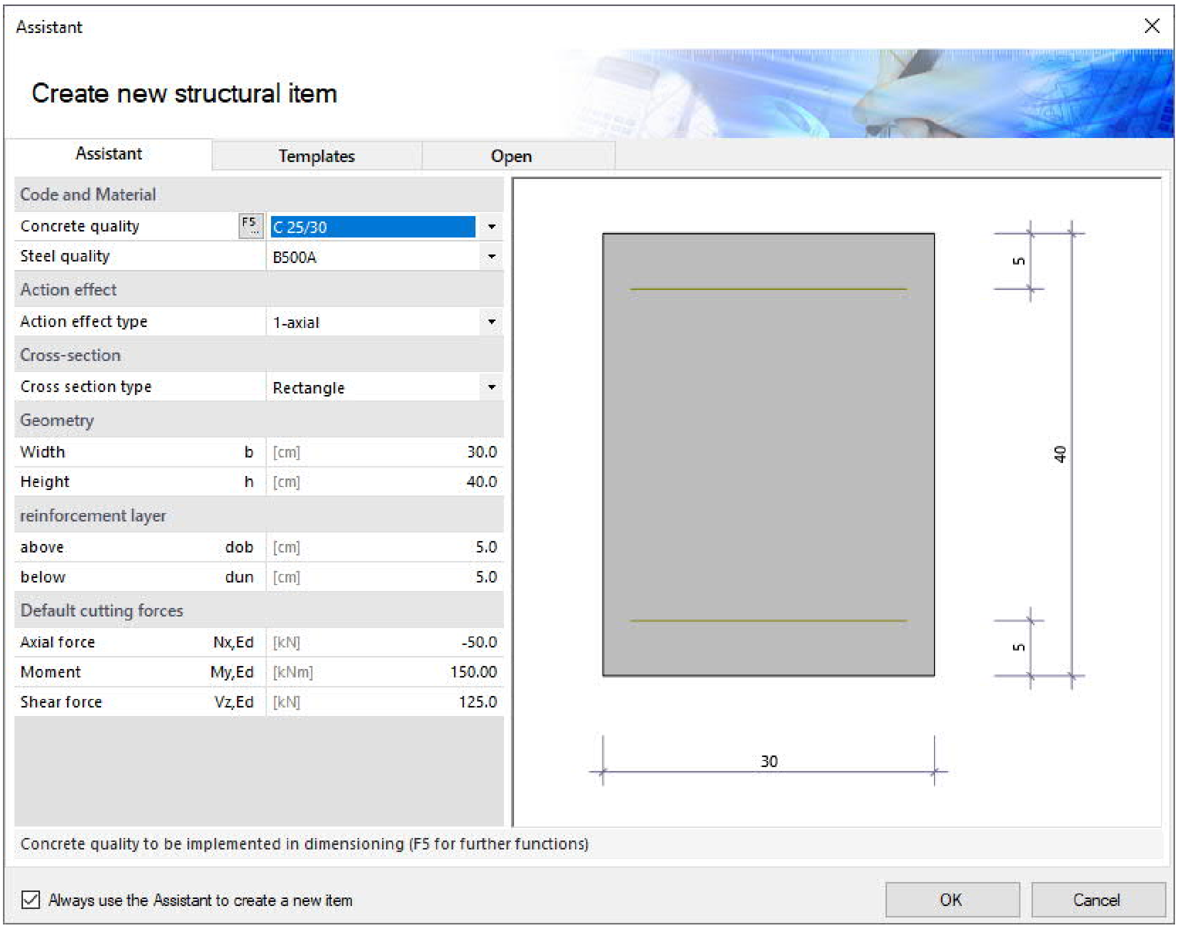
Input – general operating instructions

Wizard/Assistant

When the program starts, the Wizard/Assistant window appears automatically.

The most important key data of the system can be entered here quickly, which can then be edited in the input area and/or in the interactive graphic interface.

Self-defined items can also be imported here as templates. Saving as a template is done via ▸ File ▸ Save as ▸ Select the option "Use as template".



The entries in the program can then be easily supplemented and processed further.

See also basic operating instructions-plus

Graphic input

The values and control parameters are usually entered in the menu on the left-hand side of the screen window. The interactive input option in the graphic on the right side of the window is recommended for quick changes to a cross-section that has already been defined.

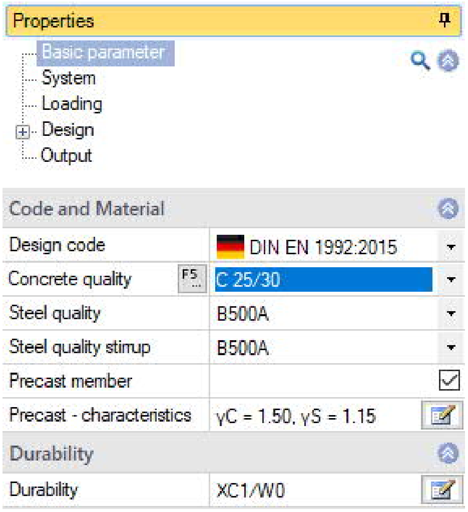
See also “Interactive-Graphic – Input options” in basic operating instructions-plus.

Remarks

You can enter your own comments in the individual input sections - see also “Remarks editor” in basic operating instructions-plus.

Basic parameters

Design standard and material



First select the desired design standard.

Depending on the selected standard, the corresponding material grades for the concrete (cross-section and optional cast-in-place concrete addition) and reinforcing steel (longitudinal and stirrup reinforcement) are listed for selection.

Alternatively, you can define the concrete material values yourself (see Concrete – user-defined below).

Concrete quality

C12/15 ... C90/105	standard concrete according to EN, Tab. 3.1
C100/115	for NA-D and NA-GB normal concrete according to EN, Tab. 3.1 + NDP
LC12/13 ... LC80/88	lightweight concrete according to EN, Tab. 11.3.

Note: *For high-strength concrete (> C50/60), it may be useful to activate the "Design with net Ac" option.*

The selected class of concrete should meet the requirements of durability. If a lower concrete class is selected, a program message appears.

Concrete – user-defined

A dialog is called up via the F5 key or the "F5" button in the "Concrete quality" input field.

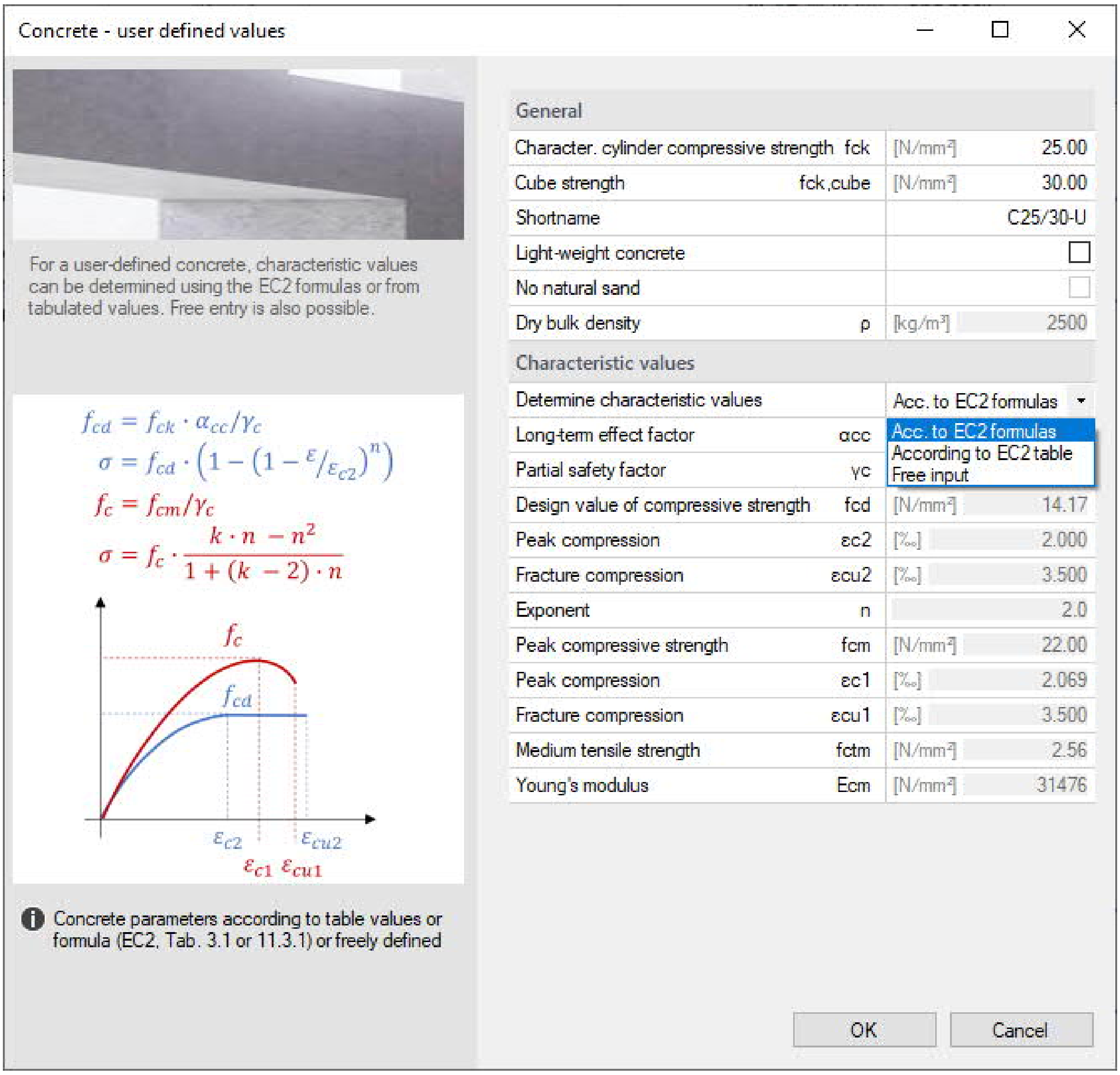
There are three variants available for determining the concrete parameters:

According to EC2 formulas	normal and lightweight concrete with any f_{ck}-value The concrete parameters are determined according to the formulas in EN, Table 3.1 + NDP or EN, Table 11.3.1 + NDP
According to EC2 table 3.1	standardized normal and lightweight concrete The concrete parameters are taken from EN, Table 3.1 + NDP or EN, Table 11.3.1 + NDP.

For an explanation of the partial safety factor γ_c and the factor for the long-term effect $\boldsymbol{\alpha}_{cc}$, see the chapter "Design bases" in the document "Analysis on the reinforced concrete cross-section".

Free input all concrete parameters are freely definable

In order to control the lightweight concrete parameters, it is necessary to enter the raw density and, if necessary, the information "No natural sand" (control εlc1 according to EN, Tab. 11.3.1).



Tip: Information about the individual parameters can be displayed as tooltips.

Steel quality

according to EN, 3.2 and EN, Appendix C as well as national regulations

EN: B220(A), B420(A), B500(A), B500(B), B500(C), B550(A), B550(B), B600(A)

NA-D: B500A and B500B according to DIN 488 (2009) also BSt 420 S(A)

NA-A: B500A, B550A, B600A, B550B

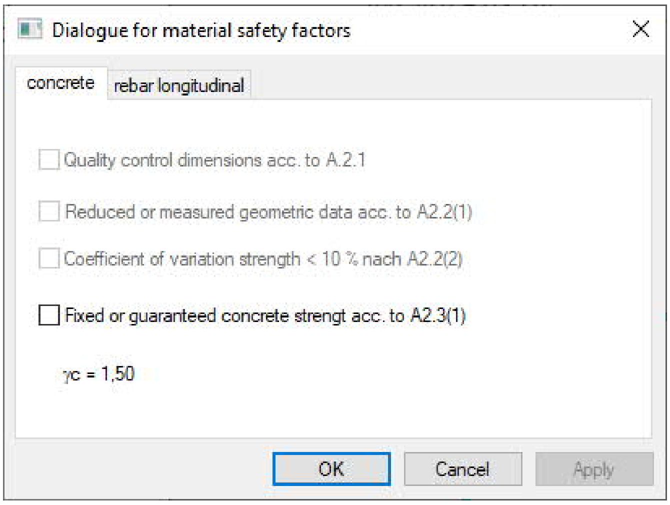
NA-GB: B500A, B500B, B500C, grade 460 TH, grade 460 YH, grade 485 WH, grade 485 WN

NA-PL: B500(A), B500(B), B500(SP)

Ductility class: A (normal), B (high), C (very high)

Precast unit - Partial safety factors for concrete and reinforcing steel

For precast units that are subject to special quality control, reduced partial safety factors can be taken into account in accordance with EN, Appendix A. After activating the "Precast member" option, the dialog for selecting precast part-specific partial safety factors can be opened.



Durability

Durability, creep and shrinkage

The button opens a dialog in which the requirements for the durability and the creep and shrinkage behavior of the component can be defined.

→ See document Durability, creep rate and shrinkage

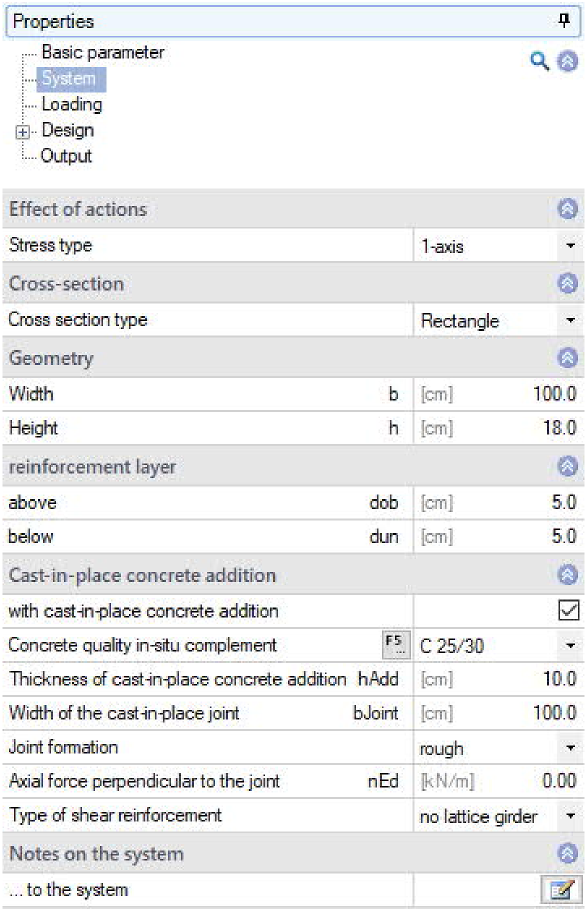
System

Effect of actions

Choice between uni- and biaxial action effect.

- 1-axial: rectangle, T-beam, layer cross-section
- 2-axial: rectangle/hollow box, circle/annulus

See also application options, Table 1.



Cross-section

Cross-section type selection – see also "Geometry".

1-axial

rectangle

T-beam

layers cross-section

2-axial

circle or annulus

rectangle or rectangle with recess

Geometry

Depending on the selected cross-section type, the appropriate parameters (width, height ...) are displayed for input.

Rectangle 1-axial / T-beam

b width (≥ 10 cm)

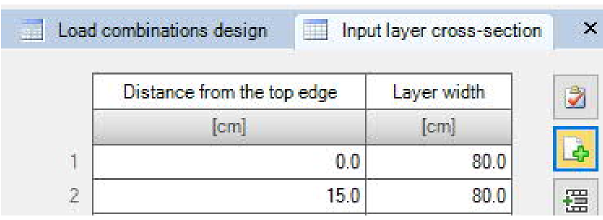
h height (≥ 10 cm)

Layers cross-section

Any simply symmetrical cross-sections can be entered. Each layer has a distance from the top edge of the member and a width. The distance of the first layer from the upper edge of the member is assigned the value "0".

The layers are entered in tabular form via the "Input layer cross-section" tab below the graphic:

Use the icon to create a new entry (a new table row) for each shift. See also table input in the operating basics.



Tip: Edit the dimensions directly in the interactive graphic.

Circle / annulus

da outer diameter (≥ 10 cm)

di inner diameter (≤ da – 12 cm, full circle: di = 0)

Rectangle 2-axial

b width (≥ 10 cm)

h height (≥ 10 cm)

bi width of the recess (≤ b – 10 cm, full cross-section: bi = 0)

hi height of the recess (≤ h – 10 cm, full cross-section: hi = 0)

Reinforcement layer

Rectangle 1-axial / T-beam / layered cross-section

dob Distance of the center of gravity of the upper reinforcement from the upper edge of the cross-section (in the case of a cast-in-place concrete addition: upper edge of the cast-in-place concrete addition).

dun Distance of the center of gravity of the lower reinforcement from the lower cross-section edge.

Circular cross-section

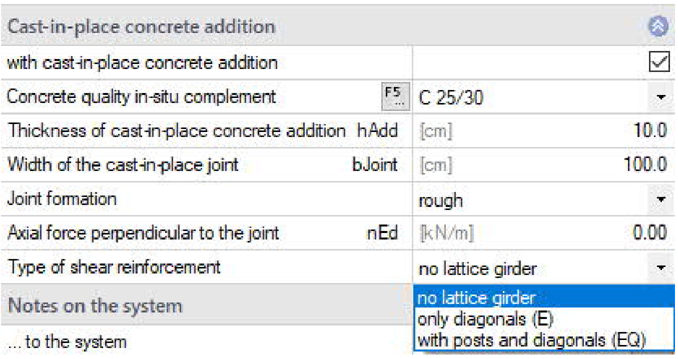
d1 Distance of the center of gravity of the reinforcement from the outer edge

Rectangular cross-section, 2-axial

b1 Distance of the center of gravity of the upper or lower reinforcement from the upper or lower edge of the cross-section.

d1 Distance of the center of gravity of the reinforcement on the right or left side from the right or left edge of the cross-section

Cast-in-place concrete addition



Cast-in-place concrete additions can be entered for the uniaxial cross-section types rectangular, T-beam and layered. After activating the option "with cast-in-place concrete addition" you can define the properties of the cast-in-place concrete addition.

Concrete quality Selection of the concrete quality for normal and lightweight concrete of the cast-in-place concrete addition for semi-precast units. In another dialog, user-defined characteristic values can be determined using the formulas of EC2 or from tabulated values by pressing the F5 key. Free entry is also possible. A name can be assigned and the material can be saved.

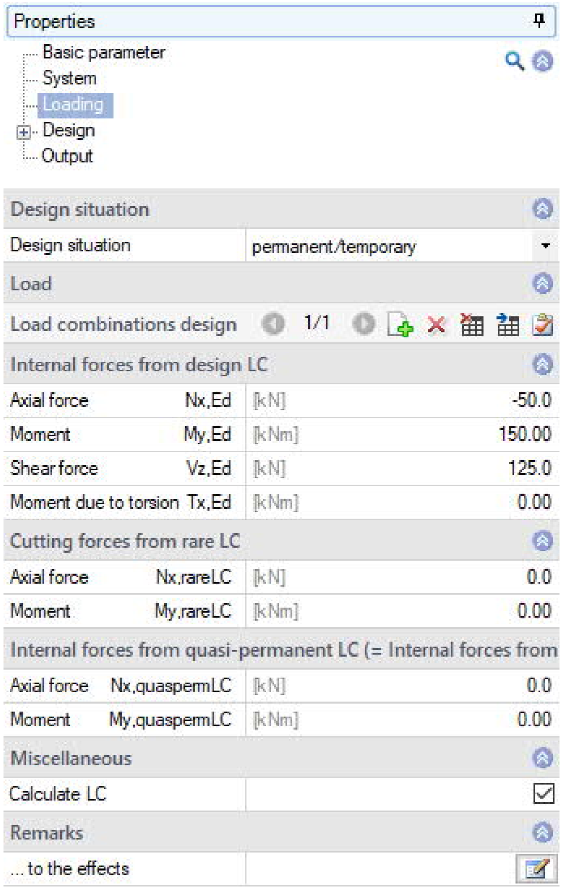
hAdd thickness (height) of the in-situ concrete layer

rectangular cross section:	3cm ≤ h_{Add} ≤ h - 5 cm
T-beam cross-section:	h_{Add} ≤ do or if do = 0, then h_{Add} ≤ h - du
layer cross-section:	h_{Add} ≤ thickness of the 1st layer

bJoint	Width of the cast-in-place joint. By default, the width of the cross-section at the level of the joint is set as the joint width. A smaller joint width can be defined manually (e.g. if the width is reduced by a prefabricated formwork).
Joint formation	Surface categories according to EN, 6.2.5 (2). See NA for additional rules.
	Very smooth — Concreted against steel, plastic or smooth wooden formwork.
	Smooth — Surface stripped or manufactured in the sliding or extruder process or untreated.
	Rough — Grain structure ≥ 3 mm exposed (generated by raking with a tine spacing of approx. 40 mm, exposing the aggregates or other methods that bring about an equivalent behavior).
	Interlocked — Design of the interlock according to EN, Figure 6.9.
nEd	Lower design value of the axial force perpendicular to the joint per unit length, negative pressure. In the case of an beam (t-beam cross-section with slab below) and n_{Ed} = 0, it is assumed to be on the safe side that the joint is vertically under tension and therefore the adhesive bond component of the joint load-bearing capacity must not be taken into account (v_{Rdi0} = 0 kN/m²).
Type of shear reinforcement	Lattice girders in element slabs as joint reinforcement for NA-D. When designing according to NA-D, lattice girders can be selected as joint reinforcement for slabs (the rectangular cross-section must be b/h ≥ 5 or the "Shear design like slab" option is activated). The design is based on the information provided by several general building authority approvals for lattice girders (see /67/ to /72/). Explanations of the verification can be found in the chapter "Shear design for element slabs with lattice girders" of the document "Analysis on reinforced concrete cross-sections".

Loading

Design situation



Selection of the design situation:

- permanent/temporary
- extraordinary
- earthquake

Through the selection, the partial material safety factors are assigned according to the selected design situation (see chapter "Design bases" in the document "Analysis on reinforced concrete cross-sections").

Loading (input for the design)

Depending on the type of action effect selected, the internal force components for uniaxial or biaxial action effect are activated. Each cutting force combination can be individually activated or deactivated ("Calculate LC" option).

Input of the internal forces via the "Load combinations design / Ultimate Limit State Verification" tab (below the graphic) or alternatively directly in the left menu tree - see Table input in the operating basics.

Use the icon  to create a new entry (a new table row) for each shift.

Internal forces from design LC

The following design loads are used in the bending, shear force, shear joint and torsion design.

Nx,Ed	Design of axial force (compressive force negative)
My,Ed	Design moment about y-axis
Mz,Ed	Design moment about z-axis
Vy,Ed	Design shear force in the y-direction
Vz,Ed	Design shear force in the z-direction
Tx,Ed	Design of the torsional moment

Internal forces from rare LC

The following design loads are used for the stress analysis in the serviceability limit state.

Nx,rareLC	Axial force from rare load combination (negative compressive force)
My,rareLC	Moment about the y-axis from rare load combination
Mz,rareLC	Moment about the z-axis from rare load combination

Internal forces from quasi-permanent LC (= internal forces from crack-LC)

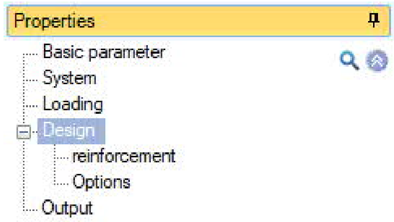
The following design loads are used for the stress analysis in the serviceability limit state and for the crack width analysis.

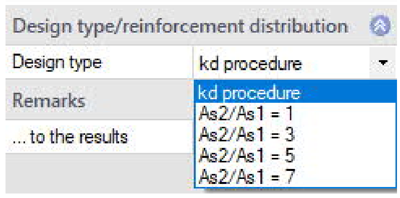
Nx,quaspermLC	Axial force from quasi-permanent load combination (negative compressive force)
My,quaspermLC	Moment about the y-axis from quasi-permanent load combination
Mz,quaspermLC	Moment about the z-axis from quasi-permanent load combination

Design

Design type / reinforcement distribution

For uniaxially stressed cross-sections





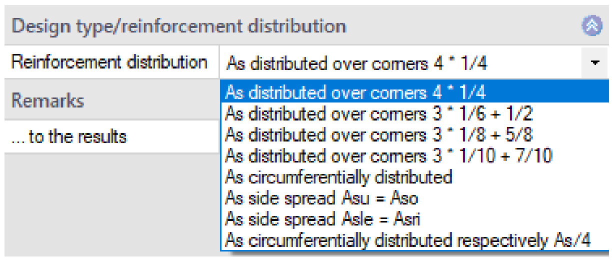
kd-procedure — See also design using the kd-method in the document "Analysis on reinforced concrete cross-sections".

Reinforcement distribution

As2 / As1 = 1 / 3 / 5 / 7 — The higher reinforcement content is arranged on the member side that is subject to greater tensile stress.

See also Design for a given reinforcement ratio in the document "Analysis on the reinforced concrete cross-section".

For biaxially stressed rectangular cross-sections



As corner distributed — The total reinforcement content is arranged in the corners of the cross-section according to the selected ratio (see selection list on the right). The arrangement is made individually for each load combination. This means that the position of the maximum reinforcement strand can differ between the load combinations.

As circumferentially distributed — Uniform reinforcement content over the circumference u (u at a distance of b1/d1 from the member surface).

As side distributed Asu = Aso — Uniform reinforcement content over the length l (l at a distance of d1 from the top/bottom of the member with l = b – 2 b1).

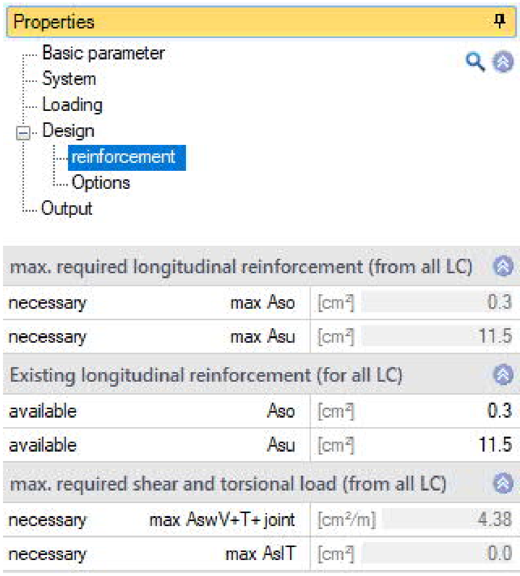
As side distributed Asle = Asri — Uniform reinforcement content over the length l (l at a distance of b1 from the member side with l = h – 2 d1).

As circumferentially distributed in each case As/4 — Uniform total reinforcement content per member side.

For biaxially stressed circular cross-sections

As circumferentially distributed — Uniform reinforcement content over the circumference u (u at a distance of d1 from the member surface).

Reinforcement



Maximum required longitudinal reinforcement

Display of the maximum values of the required total longitudinal reinforcement of all calculated internal force combinations from the Design LC (moment and axial force action effect).

Available longitudinal reinforcement

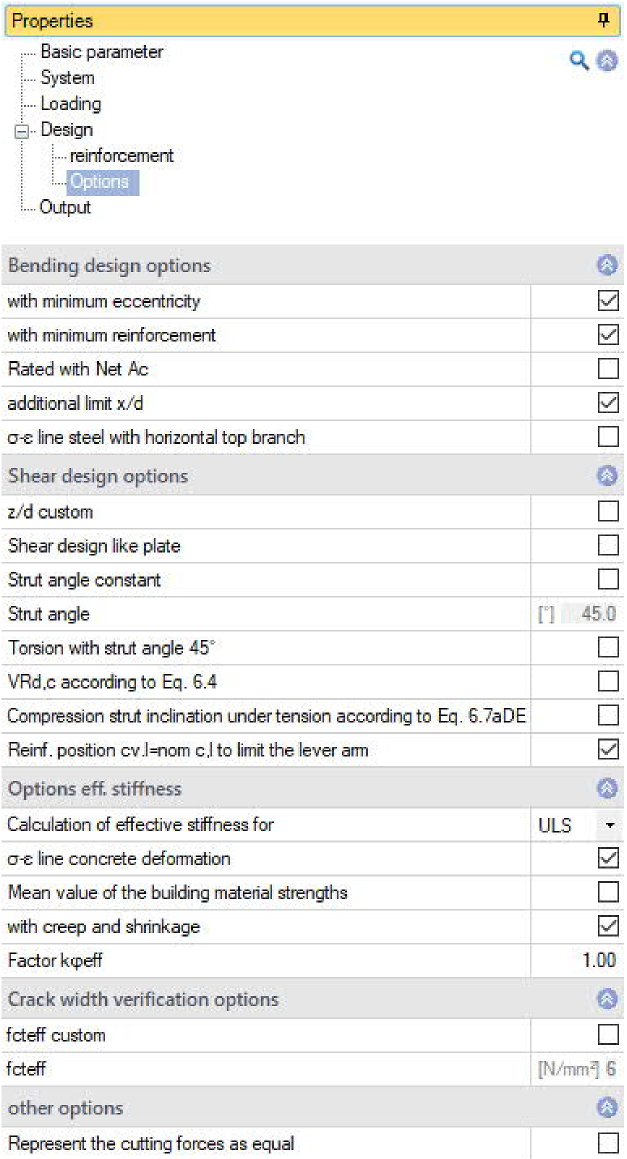
By default, the existing longitudinal reinforcement is set according to the maximum required longitudinal reinforcement. If the existing reinforcement is defined by the user, there is no longer an automatic adjustment.

Maximum required shear and torsional reinforcement

Display of the maximum values of the required shear reinforcement of all calculated internal force combinations from the design LC (shear and torsional action effect).
The longitudinal reinforcement max AslT must be considered in addition to the longitudinal reinforcement from the bending/axial force action effect (display under "Maximum required longitudinal reinforcement") in the cross-section.

Options

When an option is marked (tick) the following applies:



Bending design options

With minimum eccentricity A minimum eccentricity according to EN, Section 6.1 (4) is considered.

With minimum reinforcement Considers the minimum reinforcement for

- Bending components according to EN, Section 9.2.1.1 or NA-D, Section 9.2.1.1 (*option for uniaxially stressed cross-sections*),
- Compression members (supports) according to EN, Section 9.5.2(2) or NA-D, Section 9.5.2(2) or NA-A, Section 12.5.3 and
- Compression members (walls) according to EN, Section 9.6.2 (1) or NA-D, Section 9.6.2(1).

For explanations, see the chapter "Minimum reinforcement for components subjected to bending loads" / "Minimum reinforcement for compression members" in the document "Analysis on reinforced concrete cross-sections".

Design with net Ac Only considers the compression zone area of the concrete. The pressure zone area displaced by the steel is not considered.

Note: When using high-strength concrete (> C50/60) and a high degree of reinforcement in the compression zone, it may make sense to set the "Design with net Ac" option (/66/ p.67).

additional limitation x/d Assuming that the reinforcement is loaded in the ULS up to the yield point and the elongation at break of the concrete is reached at the same time, the height of the compression zone is limited

x ($x/d = \varepsilon_{cu} / (\varepsilon_{cu} - \varepsilon_{yd})$). In order to ensure sufficient ductility, the pressure zone height must also be limited for linear-elastic calculations of continuous beams. The additional limitation according to EN 1992-1-1, Section 5.6.3.(2) can be selected here.

Compliance with the criterion is achieved by a correspondingly modified steel limit strain, from which pressure reinforcement is determined.

σ-ε line steel with horiz. upper branch For the stress-strain curve of the rebar, neglect the slope of the top branch. For example, comparable results can be achieved with design tables.

Shear design options

z/d user-defined

The relative lever arm z/d can be specified for the shear design. Otherwise, the lever arm calculated in the bending design is used. If no bending design has been carried out, $z = 0.9 \cdot d$
or additionally for NA-D z < max (d – 2 nomc, d – 3 nomc).

Shear design like plate

The shear design is independent of the cross-sectional dimensions as with a plate. Accordingly, the minimum shear reinforcement for plates according to EN, Section 9.3.2 or NA-D, Section 9.3.2 is considered.

For explanations, see the chapter "Shear design" in the document "Analysis on reinforced concrete cross-sections".

Strut angle constant

For the shear and torsion design, a constant strut inclination can be specified regardless of the loading condition.

The option is used, for example, for sections that are not decisive for the verification of the shear force resistance but are to be calculated with the angle of inclination applicable to the decisive section.

Note: The limitations of the strut angle that apply to the respective standards (see chapter "Shear design" in the document "Analysis on reinforced concrete cross-sections") are not checked with the user-defined strut inclination!

Torsion with strut angle 45°

Determines the torsional reinforcement in a simplified manner with a strut angle of 45° and adds this to the shear reinforcement due to $V_{z,Ed}$, , according to NA-D, 6.3.2 (2).

VRd,c according to Eq. 6.4

In the case of single-span, statically determined prestressed concrete components without shear reinforcement, the shear force resistance, $V_{Rd,c}$ may be determined in the uncracked state on the basis of the concrete tensile strength f_{ctd} if the flexural tensile stress is less than f_{ctd}. If the option is activated, $V_{Rd,c}$ according to EN, Eq. 6.4 determined.

Compression strut inclination under tension according to Eq. 6.7aDE *Option for NA-D.*

Also determines the strut inclination according to DIN EN 1992-1-1 NA Eq. 6.7aDE. Compared to a calculation with the simplified approach of $\cot \theta = 1.0$ this usually results in more favorable design results.

Reinforcement layer cv.l = cnom,l to limit the lever arm *Option for NA-D.*

According to NA-D to 6.2.3 (1) the lever arm shall be limited to $z < \max (d - 2 c_{v,l}; d - 30 \text{ mm} - c_{v,l})$. When the option is activated, the corresponding concrete cover $c_{nom,l}$ is used for the placement dimension of the compression reinforcement $c_{v,l}$. This can be set in the durability dialog (see chapter "Basic parameters"). Otherwise, $c_{v,l}$ is determined using the centroid of the compression reinforcement (d_{ob} or d_{un}) and the diameter of the longitudinal reinforcement.

for concrete > C50 fck without reduction *Option for NA-GB.*

If the concrete shear strength is verified by a test, for concretes > C50/60 according to NA-GB f_{ck} can also be considered without reduction.

increased fcd according to PD 6687:2006 *Option for NA-GB.*

According to PD 6687:2006, an increased f_{cd} determined with $\alpha_{cc} = 1.0$ may be considered for the verification of the shear force load bearing capacity.

Span reinforcement complete to support *Option for NA-A.*

Span reinforcement is carried out completely up to the support, which means that a flatter strut angle can be used according to NA-A, Section 6.2.3 (2).

Compression strut angle for **σ**sd < fyk *Option for NA-A.*

Limitation of the strut angle according to NA-A, Section 6.2.3 (2) for $\sigma_{sd} < f_{yk}$.

Effective stiffness options

with effective stiffness in ULS/SLS	The effective stiffness is determined using the internal forces in the ULS or using the internal forces from the quasi-permanent load combination in the SLS.
σ-**ε** line concrete deformation	If the option is activated, the effective stiffness is calculated with the stress-strain curve for the deformation calculation of the concrete according to EN, Figure 3.2 and 5.8.6 (3) with $f_c = f_{cd}$ and $k = E_{cm} / \gamma_{cE} \cdot \varepsilon_{c1} / f_c$ (E_{cm}, ε_{c1} and ε_{c1u} according to Tab .3.1 or 11.3.1, γ_{cE} is NDP). Otherwise, the calculation is based on the parabola-rectangle diagram according to EN, Figure 3.3 and parameters according to EN, Table 3.1 or 11.3.1.
Mean value of the building material strengths	For the "Concrete deformation stress-strain curve" option, the determination of the effective stiffness can be calculated using the mean value of the building material strengths.
with creep and shrinkage	If the option is activated, creep and shrinkage are considered when determining the effective stiffness. Otherwise, the effects of creep and shrinkage are not considered. For explanations, see the chapter "Determination of the effective stiffness" in the document "Analysis on reinforced concrete cross-sections".
factor k**φ**eff	For the "with creep and shrinkage" option, the factor $k\varphi_{eff}$ can be selected between 0.0 and 1.0. The $k\varphi_{eff}$ value is included as a factor of φ_{eff} in the calculation of the effective stiffness.

Crack width verification options

(Options for uniaxially loaded cross-sections)

fcteff user-defined	The concrete tensile strength can be modified. The mean value of the concrete tensile strength f_{ctm} is defined as the standard value (strength after 28 days).
Effective plate width top / bottom	*Option for T-beams* The width of the effective zone of the tension reinforcement in the slabs of T-beams can be defined. An example for the calculation of the effective plate width can be found in /13/ p.145: $b_{eff,II} = 0.5 * b_{eff,,I} + 2 * c_I$ with $c_I = c_{nom,I}$ and $b_{eff,,I}$ = bo or bu

Other options

Represent the internal forces as equal	The internal forces are always displayed in the same size. Otherwise, the size displayed is determined in relation to the maximum value from all load combinations (LC lines).

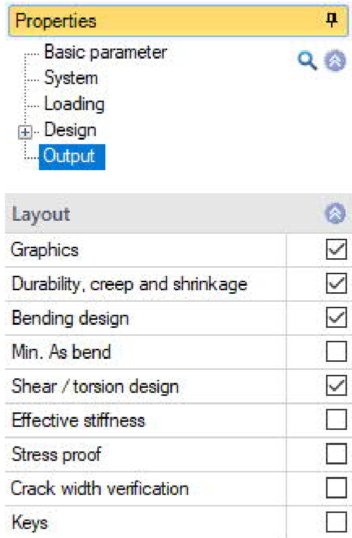
Output / results

You call up the output document by clicking on the Document tab (above the graphic).

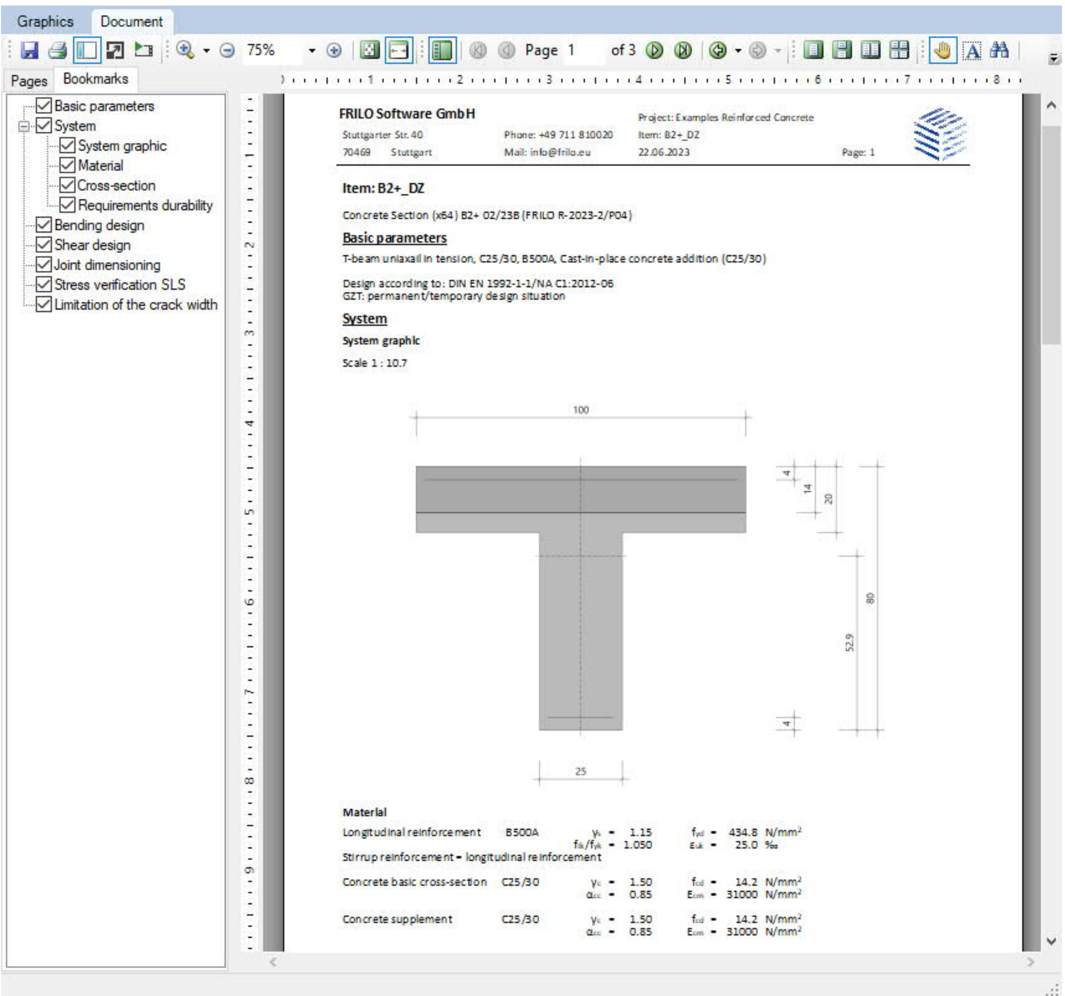
Output profile

Here you specify the scope of the output. To do this, select the desired output options:

- Graphics
- Durability, creep and shrinkage
- Bend design
- Minimum bending reinforcement Min. As
- Shear design / Torsion design
- Effective stiffness
- Stress verification
- Crack width verification
- Legends (additional explanations for individual values)



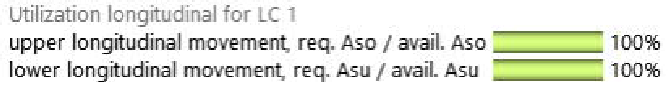
See also Document Output and Printing.

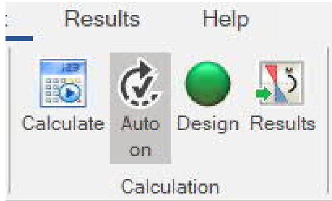


Tip: *in the "Bookmarks" tab you can individually select and deselect individual chapters in the document.*

Results

The utilization is shown in the graphic.





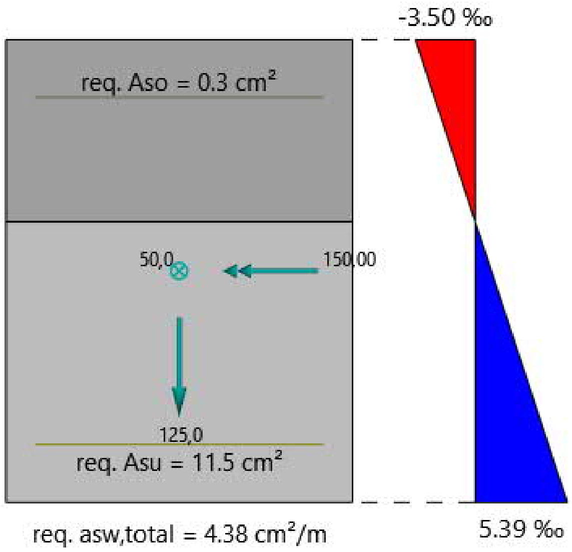
If verifications or geometric requirements are not met, the verification traffic light is colored red and a corresponding message is given. The non-compliance with requirements / verifications are marked accordingly in the printout.

In the "Results" tab, the cross-section, the reinforcement and the strain status of the set check and the selected load combination are displayed graphically.

The following graphics can be displayed:

- Design values (ULS)
- Effective stiffness (ULS)
- Concrete stress from rare load combination (SLS)
- Reinforcing steel stress from rare load combination (SLS)
- Concrete stress from quasi-permanent load combination (SLS)
- Values of the crack width analysis (SLS)

Furthermore, the load combination for the design can be selected.



Import/export

Import and export functions can be accessed via the "File" tab at the top of the screen. The following file formats are available in B2+:

Import: FRILO XML

Export: FRILO XML, Word, PDF

Literature

See the document "Analysis of reinforced concrete cross-sections", chapter Literature.