

# Flight of Stairs B7+

## Contents

Application options	2
Basic parameters	4
Structural system	5
Loading	7
Design	7
Calculation	8
Superposition of the internal forces	8
Design	8
Bending design	8
Shear design	9
Crack width verification	9
Calculation of the deflection	9
Design of the half joints	10
Output	13

## 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](http://www.frilo.com) ▶ Support ▶ Articles/Information ▶ Basic operating instructions.

## Application options

B7+ provides for the structural calculation and design of single-flight stairs with or without half-landing.

The geometry of the flight of stairs inclusive landings and corbels is precisely considered. The supporting conditions are freely selectable. Therefore, you can simulate the support of a stairway close to reality, no matter whether it is made of prefabricated components or of cast-in-place concrete.

In addition, if available, the support corbels can be dimensioned.

The software offers an interactive graphical user interface that allows you to edit the input values in the graphical representation.

### Design

- DIN EN 1992 1-1: 2012/2013/2015
- ÖNORM EN 1992 1-1: 2011/2018
- BS EN 1992 1-1: 2015
- PN EN 1992-1-1: 2010
- NTC EN 1992 1-1: 2018
- EN 1992-1-1: 2014

### Support/landings

Three types of supports are available for the flight of stairs:

- Articulated support with corbel
- Pinned support without corbel
- Restraint in landing

The structural system is modelled in such a way that the members coincide with the lines of gravity of the corresponding stairway parts (landing on bottom/top, flight of stairs without consideration of the steps).

### Loads

You can define the permanent load  $g$  and the live load  $q$  on the flight of stairs and the landing independently of each other.

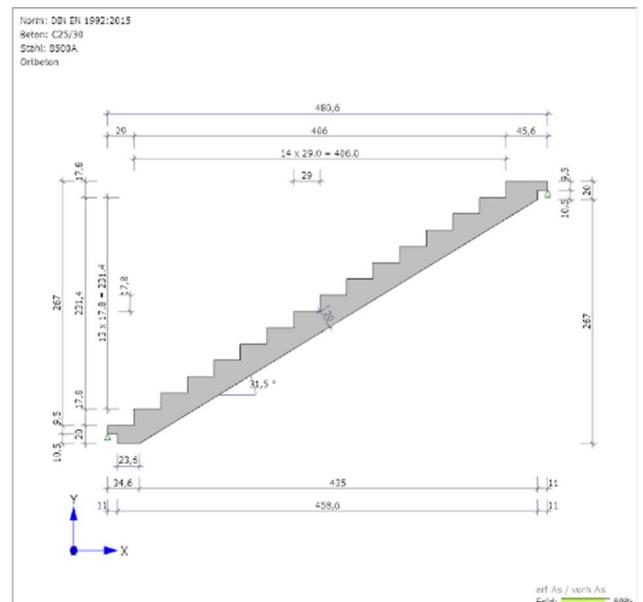
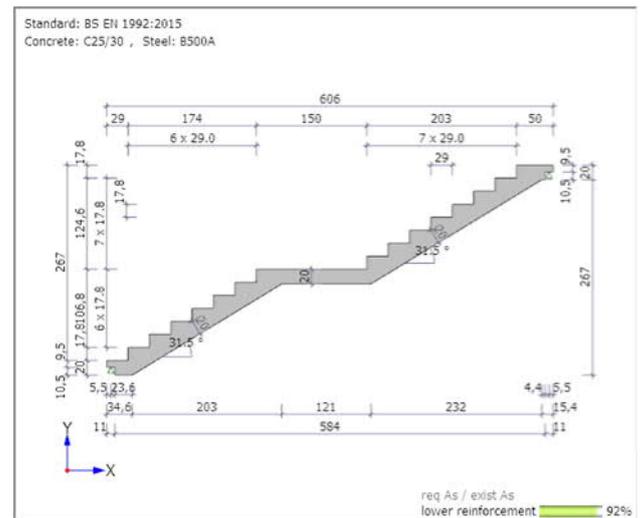
The live load can be assigned to an action group (important for the  $\psi$ -values).

### Output & results

The output includes the system graph, the complete system values, the structural system, the loads and optionally, the durability requirements and the design of the flight of stairs (bending design, shear design, crack width verification and deflection calculation). The result of the bending design proposes a bending reinforcement (number of bars, diameter and spacing). The user can edit and customize the proposed reinforcement.

The crack width verification is based on the quasi-permanent load combination, optionally with or without consideration of creep.

You can determine the maximum deflection for state I and select whether the characteristic, frequent or quasi-permanent combination of actions should be used and whether creep should be considered or not.



If the flight of stairs is restrained on one or both sides or if a compressive reinforcement is required, a reinforcement proposal for the (upper) longitudinal reinforcement is submitted for the corresponding components and the crack width verification is performed in addition to the bending design and the shear design.

The support reactions are put out with their characteristic and design values separately for the permanent and live load portions and the portion of the total support reactions.

The result values indicate the forces per linear meter of width.

In addition, you can put out the internal forces of the design load combination and the required  $A_s$ -values in the form of a table.

If a design of the corbels has been carried out, an output of the design results can be selected.

## Basic parameters

### Concrete material

Select the desired standard, the concrete (normal, lightweight) and the steel grade.

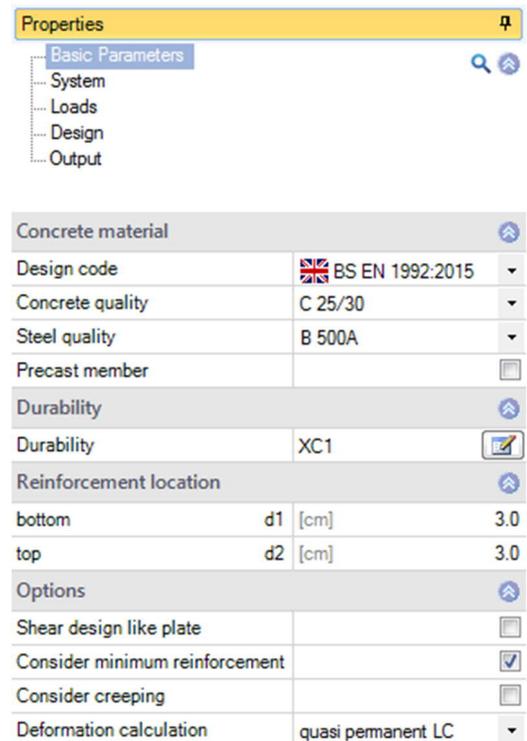
**Prefab. comp.** check this option to design a prefabricated component. Depending on the selected design standard, you can reduce the material safety factors for concrete and steel.

### Durability

Activating the button  displays the [Durability dialog](#).

If the durability requirements concerning the concrete class and/or the reinforcement spacing (d1 and d2) are higher than the adjusted values, a message is displayed after closing the durability dialog informing the user and asking him/her whether the values should be adjusted to the requirements. If the user confirms the prompt with "Yes", the concrete class and/or the reinforcement bar spacing is adjusted automatically.

The reinforcement bar diameters determined automatically in the calculation or defined by the user are displayed as default values in the durability dialog. Therefore, we recommend accessing the durability dialog after completion of the data entry to determine the durability requirements with the decisive reinforcement bar diameters.



Properties		
Basic Parameters		
System		
Loads		
Design		
Output		
Concrete material		
Design code		BS EN 1992:2015
Concrete quality		C 25/30
Steel quality		B 500A
Precast member		<input type="checkbox"/>
Durability		
Durability		XC1 
Reinforcement location		
bottom	d1 [cm]	3.0
top	d2 [cm]	3.0
Options		
Shear design like plate		<input type="checkbox"/>
Consider minimum reinforcement		<input checked="" type="checkbox"/>
Consider creep		<input type="checkbox"/>
Deformation calculation		quasi permanent LC

### Reinforcement layers

For the distance of the centres of gravity of the longitudinal reinforcement to the top and the bottom edges, the values d1 and d2 are set to 3 cm by default.

d1 = lower reinforcement layer, d2 = upper reinforcement layer.

### Options

- |                                |   |
|--------------------------------|---|
| Shear design for a slab        | check this option when the shear design should always be performed as for a slab (e.g. design of a strip of one metre width). In this case, a minimum shear reinforcement as per (NDP) 9.2.2 (5), eq. (9.5aDE) is not considered.   |
| Consider minimum reinforcement | check this option to consider the minimum longitudinal reinforcement that is required to ensure the ductile component behaviour as per para. 9.2.1.1 (1).   |
| Consider creep                 | check this option to consider creep in a deformation calculation and in the crack width verification (or in the calculation of the limit diameter). In this case, the effective modulus of elasticity is calculated with $E_{c,eff} = E_{cm} / (1 + \Phi)$ , see equation (7.20). Click on the editing button  to access the 'Creep and shrinkage' dialog. |
| Deformation calculation        | optional selection of the combination of actions (characteristic, frequent or quasi-permanent) that should be used in the calculation of the deformation.   |

# Structural system

## Geometry

You can see the dimensions in the graphical representation of the system.

*Tip:* A short description of the input value is displayed as a tool tip or in the information area at the bottom of the screen.

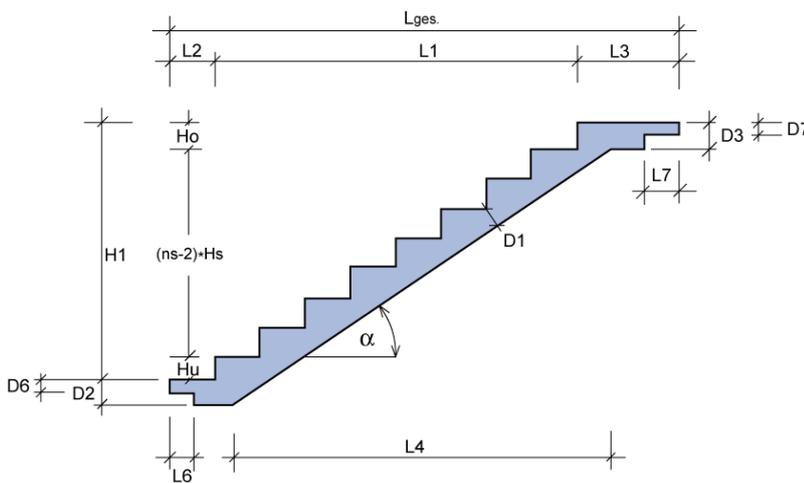


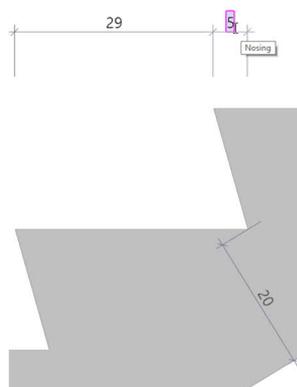
Fig.: Dimensions of the structural system

Type of system: with/without half-landing, specification of the thickness D8 and the length L9 of the half-landing.

Flight width / covering width / live load with: B1/B2/B3:

The values B1 and B2 allow you to distinguish between the width of the flight of stairs and of the tread covering. The covering width only influences the way the permanent load *g* is considered. The value B3 allows you to define the width of a live load separately.

The undercut value *u* (nosing) specifies the horizontal distance between the front edge of a tread and the rear edge of the tread below.



Properties		
Basic parameter		
System		
Geometry		
System type		with intermediate platform
Length lower stairway	L8	without intermediate platform
Length of stairway	L10	with intermediate platform
		[cm] 205.0
Number of steps, lower	nsu	7
Number of steps, upper	nso	8
Height of stairway	Hs	[cm] 17.8
Step tread	Ls	[cm] 29.0
Nosing	u	[cm] 0.0
Height of step bottom	Hu	[cm] 17.8
Height of step top	Ho	[cm] 17.8
width of flight	B1	[cm] 120.0
Width of cover	B2	[cm] 120.0
Live load width	B3	[cm] 120.0
Thickness of stairs	D1	[cm] 20.0
Thickness of lower landing	D2	[cm] 21.0
Thickness of upper landing	D3	[cm] 21.0
supports/landings		
Thickness intermediate platform	D8	[cm] 20.0
Length intermediate platform	L9	[cm] 150.0
Lower landing		hinged with console
Length lower landing	L2	[cm] 29.0
Length lower console	L6	[cm] 13.0
Thickness lower console	D6	[cm] 10.0
Distance lower support	L14	[cm] 7.0
Upper landing		hinged with console
Length upper landing	L3	[cm] 50.0
Length upper console	L7	[cm] 13.0
Thickness upper console	D7	[cm] 10.0
Distance upper support	L15	[cm] 7.0
Details of supports		
bottom vertical	Cv	rigid <input checked="" type="checkbox"/>
bottom horizontal	Ch	rigid <input checked="" type="checkbox"/>
bottom torsion	Cphi	[kNm/rad] 0.0 <input type="checkbox"/>
top vertical	Cv	rigid <input checked="" type="checkbox"/>
top horizontal	Ch	[kN/m] 0.00 <input type="checkbox"/>
top rotation	Cphi	[kNm/rad] 0.0 <input type="checkbox"/>
Remarks		
... about the system		

The software checks whether the safety and step-height rules are complied with. In case of non-compliance, the verification button turns yellow. It also turns yellow when the crack-width verification fails or in the event of a geometric conflict at the lower or upper landing.

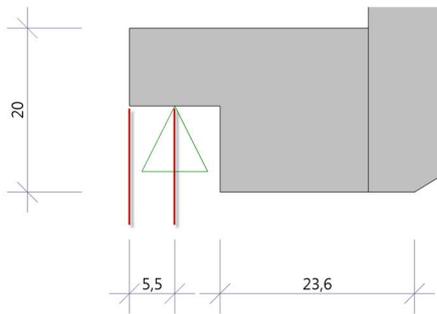
## Support/landings

Three types of supports are available for the flight of stairs:

- Pinned support with corbel
- Pinned support without corbel
- Restraint in landing

You can specify the support conditions manually. This allows you to consider spring stiffnesses.

The distance of the upper/lower support corresponds to the horizontal distance of the support from the upper or lower corbel end if corbel support was defined.



## Support details

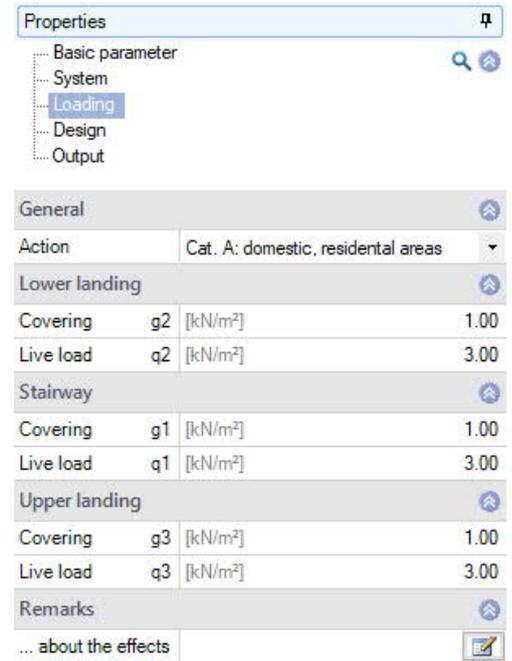
You can enter the spring stiffness of the support. Make sure that the value complies with the selected dimensional unit. For a rigid support, tick the check box. '0.0' corresponds to a free support.

## Remarks

Enter your own [comments](#), which will also be displayed in the output.

## Loading

The loads acting on the flight of stairs, the landings and the corbel are divided into a permanent load  $g$  (covering) and a live load  $q$ . Always enter characteristic loads. The permanent load  $g$  merely describes the self-weight of the covering. The self-weight of the stairs is automatically considered by the software.



Properties			
Basic parameter			
System			
Loading			
Design			
Output			
General			
Action	Cat. A: domestic, residential areas		
Lower landing			
Covering	g2	[kN/m <sup>2</sup> ]	1.00
Live load	q2	[kN/m <sup>2</sup> ]	3.00
Stairway			
Covering	g1	[kN/m <sup>2</sup> ]	1.00
Live load	q1	[kN/m <sup>2</sup> ]	3.00
Upper landing			
Covering	g3	[kN/m <sup>2</sup> ]	1.00
Live load	q3	[kN/m <sup>2</sup> ]	3.00
Remarks			
... about the effects			

## Design

The required reinforcement (req. As) and the existing reinforcement (exist. As) are displayed.

Optionally, you can set the same existing lower reinforcement for all components that require a lower reinforcement or enter a separate value for each component.

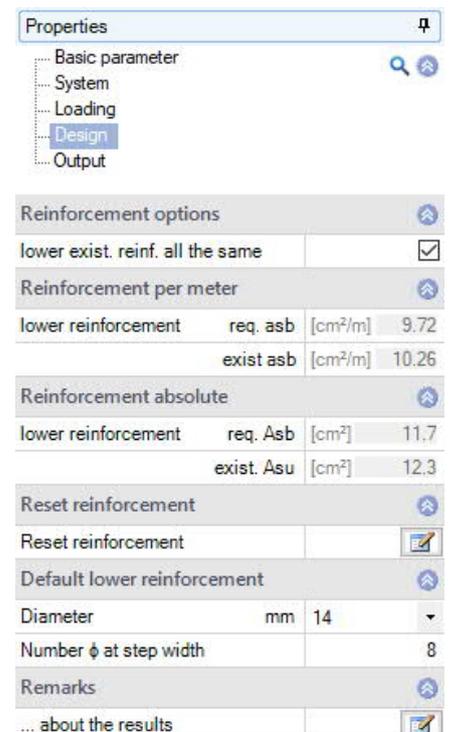
Diameter                      diameter of the reinforcement of the flight of stairs

Number  $\phi$  at step width      number of selected diameters for the entire width of the flight of stairs

For stairways restrained on one or both sides, the required reinforcement and the existing reinforcement as well as the number and the diameter of the upper reinforcement of the corresponding landings and, if applicable, of the flight of stairs are displayed in addition.

*Note:*                      *The existing relative reinforcement exist. As (cm<sup>2</sup>/m) is determined under the condition that the axes of the two outermost lateral reinforcement bars have a distance of 5.0 cm to the lateral surfaces of the stairs. The remaining reinforcement bars are distributed evenly between the two outer bars. The spacing of the geometric axes between two reinforcement bars is determined as follows:*

$$\text{Distance} = (\text{stairway width} - 2 * 5 \text{ cm}) / (\text{number of reinforcement bars} - 1)$$



Properties			
Basic parameter			
System			
Loading			
Design			
Output			
Reinforcement options			
lower exist. reinf. all the same	<input checked="" type="checkbox"/>		
Reinforcement per meter			
lower reinforcement	req. asb	[cm <sup>2</sup> /m]	9.72
	exist asb	[cm <sup>2</sup> /m]	10.26
Reinforcement absolute			
lower reinforcement	req. Asb	[cm <sup>2</sup> ]	11.7
	exist. Asu	[cm <sup>2</sup> ]	12.3
Reset reinforcement			
Reset reinforcement			
Default lower reinforcement			
Diameter	mm	14	
Number $\phi$ at step width	8		
Remarks			
... about the results			

Remarks: You can use the [editor](#) to enter your own text/images, which will then appear in the output document with the results.

## Calculation

### Superposition of the internal forces

The superposition of the internal forces for EN standards is based on EN 1990-1-1 including the relevant National Annex.

#### For the design

$Q_d = 1.35 * G_k + 1.5 * Q_k$  as per eq. (6.10) for NA Germany (NA-D), for NA Austria (NA-A)

$Q_{d1} = 1.35 * G_k + 1.5 * \psi_0 * Q_k$  or

$Q_{d2} = \chi * 1.35 * G_k + 1.5 * Q_k$  as per eq. (6.10a) or eq. (6.10b) for NA Great Britain (NA-GB), NA Poland (NA-PN) or the original Eurocode

The higher value of  $Q_{d1}$  and  $Q_{d2}$  is decisive.

$\psi_0$  in accordance with the action group and the respective NA

$\chi$  in accordance with the respective NA

#### For the crack-width verification (quasi-permanent combination of actions)

$Q_d = G_k + \psi_2 * Q_k$  as per eq.(6.16b)

$\psi_2$  in accordance with the action group and the respective NA

## Design

### Bending design

The internal forces are determined, and the bending design is performed on a grid of sections with a spacing of approx. 15 cm for each stairway component (lower/upper landing, flight of stairs). The max. As-values and the associated internal forces are put out.

Moreover, you can put out the internal design forces and the As-values at the points of the section grid in the form of a table.

The bending design is performed in accordance with the kd-method. The minimum reinforcement for bending specified in para. 9.2.1.1 can optionally be taken into consideration. For stairways restrained on one or both sides, the limitation of the pressure zone height  $x_d/d$  as per DIN EN 1992-1-1 Para. 5.4 (NA.5) is considered to ensure sufficient ductility.

If the starting step height  $H_u$  is greater than the rise  $H_s$  a constriction of the structural height occurs in the area of the starting step. Therefore, the structural height of the flight of stairs is reduced in the area of the constriction. If it falls below 10 cm because of the reduction, the design is aborted, and the verification button turns red. This will also happen if no reasonable bending design can be performed because of an insufficient structural height.

The verification button will also turn red, when the supports were defined incorrectly (mobile systems).

The B7+ application generates a reinforcement proposal (number of reinforcement bars, diameter and bar spacing) based on the required reinforcement. You can edit the proposed values as required. In this connection, you can select whether the reinforcement proposal shall be identical for all components (flight of stairs, upper/lower landing, half-landing, if applicable) or different for each component.

## Shear design

The shear design is performed at the front end and rear end of the landings and the flight of stairs. To facilitate comprehension and ensure traceability, intermediate values are also put out. The software indicates when the minimum shear reinforcement becomes decisive. Optionally, you can perform the shear design as for a slab.

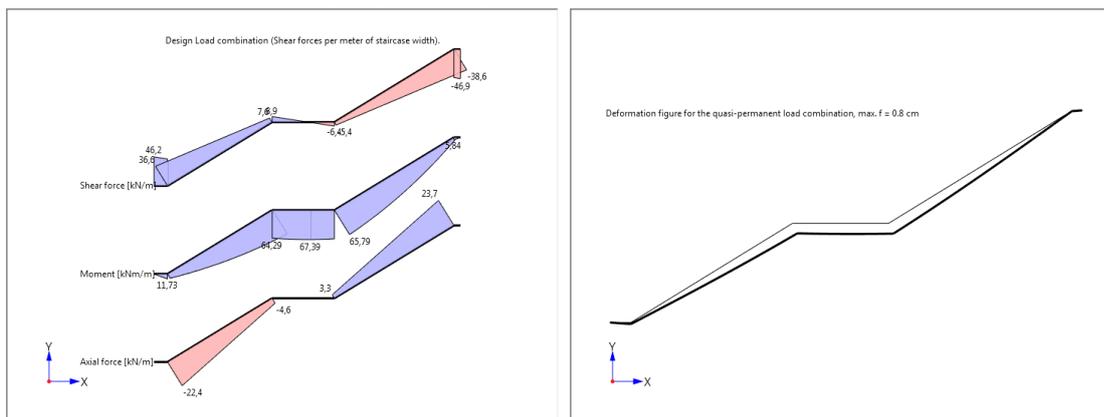
## Crack width verification

The crack width verification is performed for the span area and, if applicable, at the points of restraint. The limit diameter and the calculated crack width are put out and compared to the diameter of the existing reinforcement and the permissible crack width.

## Calculation of the deflection

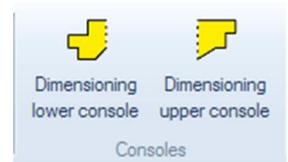
The calculation of the maximum deflection is performed for state I (uncracked cross-section) with the selected combination of actions, either characteristic, frequent or quasi-permanent. You can consider creep by reducing the modulus of elasticity. The parameters that have an influence on creep can be edited in detail.

The internal forces of the individual load combinations, the As-values of the design load combination and the deflection shape can be displayed graphically.

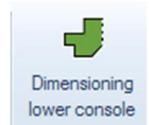


## Design of the half joints

If reinforced concrete half joints exist, it is possible to design the half joints as per DIN EN, ÖNORM EN an PN EN standards in connection with normal concrete. For lightweight concrete, the console icons are set to inactive. Icons for the lower and upper half joints are displayed in the upper screen area. If their colour is yellow, the corresponding half joint has not yet been designed. After clicking on one of these icons, a menu opens in which the corresponding half joint is displayed and further values can be entered for the design.



After leaving the menu (with OK), the icon colour changes to green (if the design was successful) or to red (if a design error has occurred). In the case of a design error, the verification traffic light also turns red.



If input values for the flight of stairs are changed after the half joint design so that other support reactions can result, the half joint icons are reset to yellow (half joint not yet designed). It is therefore advisable to carry out the half joint design only after the flight of stairs has been completely defined.

Dimensioning lower console
✕

System		
Width of the strip bearing	bstl [cm]	5.0
Thickness of the strip bearing	hstl [cm]	0.5
Depth of the strip bearing	b [cm]	120.0
Console force	FEd [kN/m]	46.02
Horizontal force component	20% of the console force	
Horizontal force	HEd [kN/m]	9.20
Show frame model	<input checked="" type="checkbox"/>	
Concrete cover console		
top	cv.top [cm]	2.0
bottom	cv.bot [cm]	2.0
left	cv.le [cm]	2.0
Console reinforcement		
required	as [cm²/m]	2.04
selected	Ø 8 / 10	
available	as [cm²/m]	5.03
Concrete cover suspension reinforcement		
bottom	cv.bot [cm]	2.6
left	cv.le [cm]	2.0
Gambrel stick		
required	as [cm²/m]	1.13
selected	Ø 8 / 10	
available	as [cm²/m]	5.03
Cross bars		
Diameter	10	

ac / hc = 0.60	Bearing pressure	7 %
VRd,c = 37.6 kN	as console	41 %
FEd / VRd,c = 1.22	as hangings	22 %
Strut inclination (bar 1-2) = 30.1°	Struts 1-2	12 %
Factor ac / hc = 0.6 > 0.5 and VEd / VRd,c > 1.0 a second link is required.	Anchoring console end	76 %

OK Cancel

### Basis of calculation for the half-joint design

#### Calculation in accordance with EN 1992-1-1

The calculation is based on a strut-and-tie model for perpendicular suspension reinforcement.  
The design is performed with the rebar diameters specified by the user.

#### Geometry and reinforcement

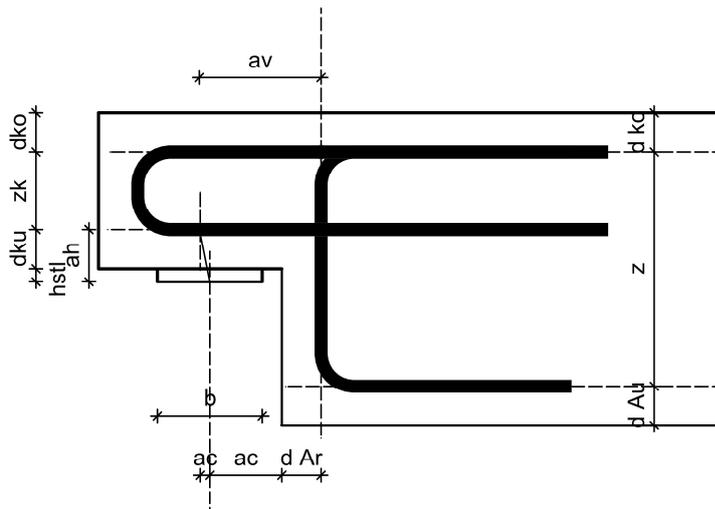
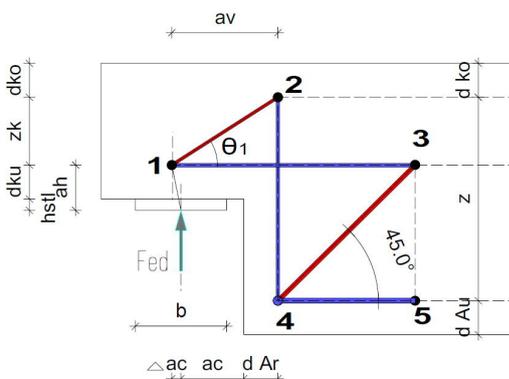


Figure 1

#### Strut-and-tie models for perpendicular suspension reinforcement

First, the model is determined from the geometry and the reinforcement layer in accordance with Figure 1. Various models are used for the calculation of the vertical force and the horizontal load (see Figure 2). The member forces of the two models are then added up for the design.

#### Model for the vertical force



#### Model for the horizontal force

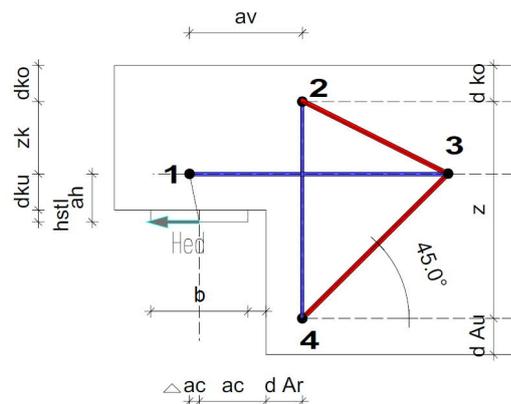


Figure 2

The exact compression strut position with the dimensions for nodes 1 and 2 results from the strut-and-tie model.

A precondition is that the permissible tension

$\sigma_{Rdmax} = k_2 \cdot v' \cdot f_{cd}$  in node 2 is adhered to, with  $k_2$  and  $v'$  in accordance with the applicable National Annex (NA).

- for Germany:  $k_2 = 0.75$   $v' = 1.1 - f_{ck} / 500 \leq 1.0$

- for Austria:  $k_2 = 0.9$   $v' = 1.0 - f_{ck} / 250$

By specifying unfavourable half joint dimensions, the inclination of the compression strut could fall below  $30^\circ$ . In this case, the software aborts the calculation because a design based on such a strut-and-tie model is not permitted.

If the geometry of the half joint results in an invalid model, it must be adapted in the system data of the flight of stairs. The result of the half joint is discarded and the design must be launched again.

**Tensile force in the vertical suspension reinforcement:**

$$F_{td(2-4)} = F_{ed} + H_{ed} \cdot \frac{z_k}{z}$$

Compression strut inclination:

$$\Phi_1 = \text{atn}\left(\frac{z_k}{a_v}\right)$$

Compression strut force:

$$F_{cd(1-2)} = -F_{ed} / \sin(\Phi_1)$$

**Horizontal force due to the compression strut geometry that is to be anchored:**

$$F_{td(1-3)} = F_{ed} \cdot (a_v / z_k) + H_{ed}$$

**Verification node 1 (bearing stress):**

The verification of the compressive stress underneath the load plate is based on EN 1992-1-1:

With the following conditions underneath the load plate:

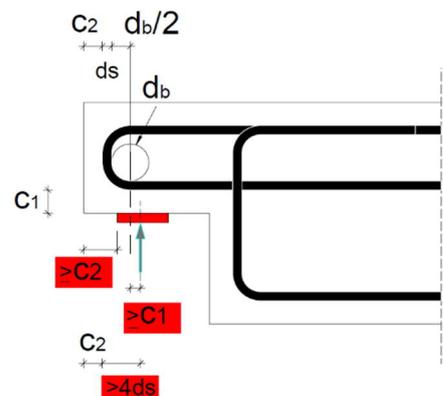
$$\sigma_{ld} = \frac{F_{ed}}{l_p \cdot b_p} \leq \sigma_{rd} = k_2 \cdot v' \cdot f_{cd} \quad \text{With } k_2 \text{ and } v' \text{ in accordance with the applicable National Annex (NA)}$$

- for Germany:  $k_2 = 0.75$   $v' = 1.1 - f_{ck} / 500 \leq 1.0$

- for Austria:  $k_2 = 0.9$   $v' = 1.0 - f_{ck} / 250$

**Additional verification**

In addition to checking the bending roll diameter, the required edge distances are also checked as shown in Figure 3.



# Output

Output of the system data, results and graphical representations on the screen or the printer. You can find further information in the document [Output and Printing](#)

The user can customize the output scope by ticking the desired options in the output profile.

- Brief or comprehensive output
- System graph with dimensioning
- Geometrical data
- Durability requirements
- Shear force analysis
- Results of the crack-width verification
- Deflection
- Table of internal forces
- Dimensioning console

**Properties** 🔍

- ..... Basic parameter 🔍
- ..... System
- ..... Loading
- ..... Design
- ..... **Output**

---

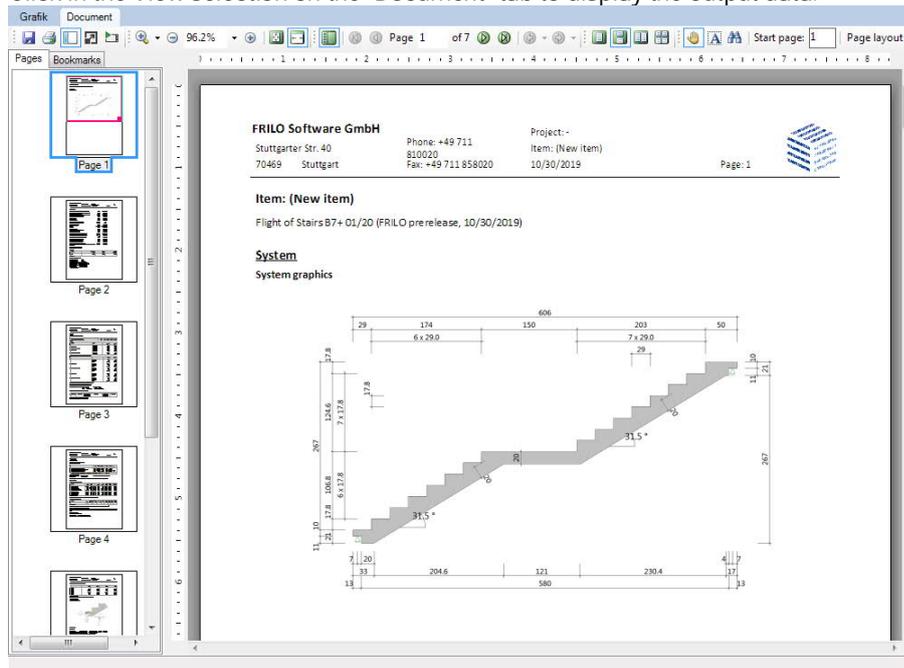
**General settings** ⚙️

Brief output	<input type="checkbox"/>
--------------	--------------------------

**Output layout** ⚙️

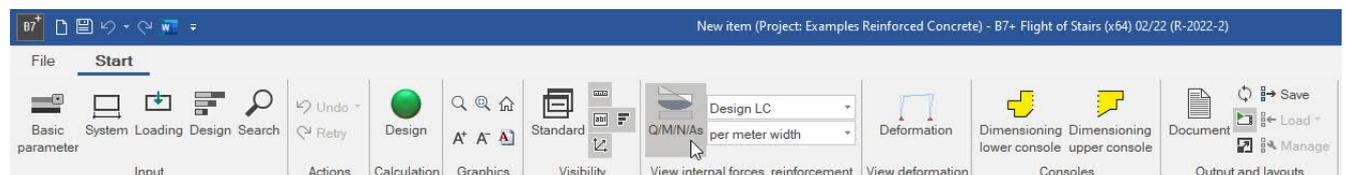
Output system graphics	<input checked="" type="checkbox"/>
Output load graph	<input type="checkbox"/>
Output geometry	<input checked="" type="checkbox"/>
Output requirements durability	<input checked="" type="checkbox"/>
Always output shear force check	<input checked="" type="checkbox"/>
Output crack widths	<input checked="" type="checkbox"/>
Output deflection	<input checked="" type="checkbox"/>
Output internal forces table	<input type="checkbox"/>

Click in the View selection on the "Document" tab to display the output data.



## Result graphs

In the "Views" area in the top ribbon you can display and also save graphics on internal forces, reinforcement, deformation (context menu ▶ View ▶ Save graphic).



### Output of the support reactions

The output support reactions refer to the global x-/z-system of coordinates (x-axis: positive to the right, z-axis: positive to the top).

Vertical support reactions are positive when they act from the bottom to the top. Horizontal support reactions are positive when they act in the positive direction (to the right) of the x-axis.

Torques on the support are positive when they cause tension at the bottom side.

### Save stair cross-section as a DXF file

You can save the stair cross-section as a DXF graphic via File ▶ Export ▶ DXF.