

# Punching Shear Analysis B6+ RFA-Tech

## Contents

About FRILO-Software	2
Installation, configuration and basic operating instructions	2
Application options	3
Basis of calculation	4
Input	5
Basic Parameters	5
System	5
Geometry	5
Holes (Openings)	8
Bending reinforcement	10
Loads	13
Design	16
Punching shear analysis as per BS EN 1992:2015	16
Punching shear reinforcement as per EN 1992	20
Punching shear analysis with RFA-Tech shear connector rails	21
Reduction of the circular section with extended support surfaces	22
Output	23
Reference literature	24

## 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) in the Campus-download-section.

## About FRILO-Software

With more than 40 years of experience and about 100 static software solutions FRILO is one of the leading providers of innovative calculation programs for structural analysis and structural design.

FRILO software solutions are characterized by their ease of use, fast results and continuous adaptation to current standards. In doing so, FRILO follows the practical requirements of the engineer's everyday life and, in addition, provides highly qualified customer service.

In 1999, FRILO joined the Nemetschek Group as an independent brand. The FRILO headquarter is located in Stuttgart.

website: <https://www.frilo.eu/>

## Installation, configuration and basic operating instructions

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) in the Campus-download-section.

For installation, configuration or the FRILO Control Center (starting programs, data administration, folders, projects, items) please have a look into our basic documents for the general operation of FRILO Software: .

[Frilo.Software](#) FSO: Installation, Configuration, Control-Center

[Control Center](#) Data administration, Folder, Projects, Items

## Application options

This software application allows you to verify the resistance to punching shear of slabs with point-type supports for:

- Slabs
- Foundation slabs
- Isolated footings

Unlike shear with beams and plates, the shear resistance behaviour under punching shear load is characterized by a three-dimensional stress state, which is caused by rotation-symmetric loading.

The software application performs the following separate calculations:

- Punching shear analysis as per BS EN 1992-1-1:2015 Para. 6.4 for shear rails from RFA-Tech.

The shear force design resistances are calculated in the decisive critical perimeters for the floorarea threatened by punching shear. The problem types interior columns, edge columns and corner columns, wall end and interior wall corner are distinguished. The verification reveals either that the load-bearing capacity of the reinforced concrete is sufficiently high or that punching shear reinforcement must be installed. If the verification limits are exceeded, the verification result is marked as not permissible.

## Basis of calculation

The calculations performed in the punching shear application are based on the standard BS EN 1992-1-1: 2015, Para. 6.4 and 9.4.3.

Technical approvals for shear rails:

- RFA-Tech Sheartech (Technical Solutions) and
- CARES Technical Approval Report TA7 5028

For the solution of an actually existing punching shear problem, it is important to map the structural problem correctly in the software and define an adequate decisive length of the circular cross section. If the load transfer is non-uniform, local peak loading should be compensated with the help of a lump-sum factor  $\beta$  for  $V_{Ed}$ . The selection of this total load factor  $\beta$  is at the user's discretion. The standard recommends values for standard cases.

The B6+ application provides for the calculation of  $\beta$  in accordance with the method of plastic shear stress distribution (see chapter [Loads](#)).

# Input

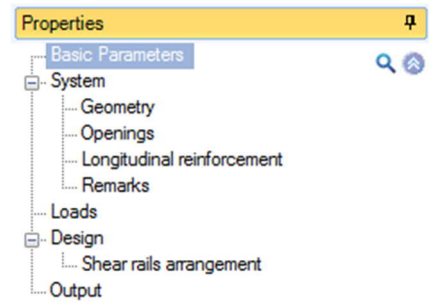
The most important values and parameters are entered using the [wizard](#). The resulting system can then be adapted via the interactive input options in the 3D graphics.

See "[Basic operating instructions-PLUS](#)".

## Basic Parameters

Standard: BS EN 1992:2015

The concrete and reinforcement selection lists allow the user to select the concrete strength and the reinforcement steel quality.



Basic Parameters	
Design Code	BS EN 1992:2015
Concrete	C 25/30
Reinforcement steel	B 500A

## System

Remarks: You can enter additional Text, which shows up in the output.

## Geometry

### Slab

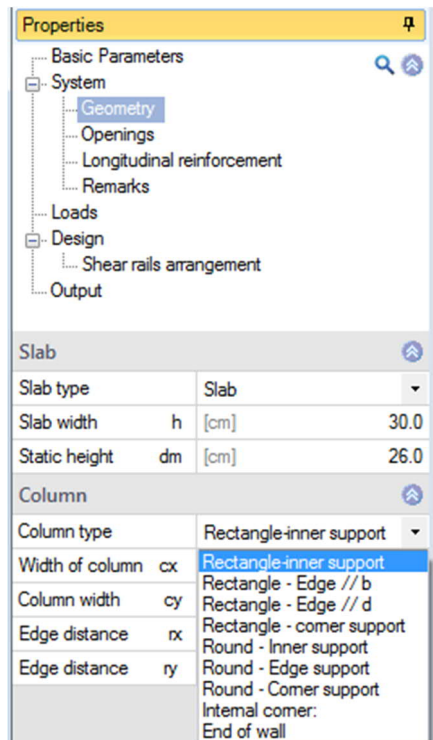
You can select among the slab types:

- Slabs
- Foundation slabs
- Isolated footings

For the foundation slab and the compact foundation, the area inside the critical perimeter  $a_{crit}$  is per default determined by iteration. This method produces more favourable results for the user than the approximation  $a_{crit} = 1.0 \cdot d_m$ .

### Slab thickness and statically effective height

h	Slab thickness h >= 20 cm as per EN 1992 Para. 9.3.2 slab with punching shear reinforcement		
dm	effective height Average effective height with foundation co/cu dsl reinforcement	$d_m = h - co - d_{sl}$ $d_m = h - cu - d_{sl}$	upper/lower concrete cover diameter of the longitudinal reinforcement



## Column

The following column types are available for selection:

- Rectangular - interior column
- Rectangular - edge // b
- Rectangular - edge // d
- Rectangular - corner column
- Circular - interior column
- Circular - edge column
- Circular - corner column
- Interior wall edge
- Wall end

## Dimensions

Depending on the selected shape/type of column, the associated input fields are enabled.

- cx column dimensions in x-direction (horizontal)  
 cy column dimensions in y-direction (vertical)  
 rx distance to the edge in x-direction of edge and corner columns  
 Lx supporting width in x-direction pertaining to rx  
 ry distance to the edge in y-direction of edge and corner columns  
 Ly supporting width in y-direction pertaining to ry

### circular column:

- c diameter of circular column

### Wall end or Interior wall edge:

- b pre-set wall thickness (wall end or interior wall corner)  
 d affected length defined for the load introduction area of the wall

When selecting the compact foundation, Lx and Ly are the dimensions of the foundation in the x- and y-directions.

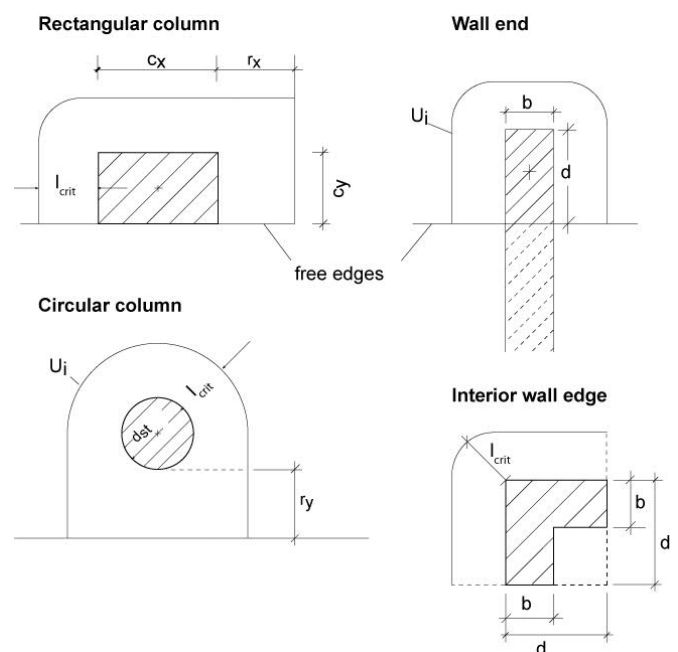
## Distance to the edge

For edge columns, the user can pre-set the distance to the edge  $r_x$  or  $r_y$  depending on the location of the free edge.  $r_x$  and  $r_y$  refer to the distance in x- and y-direction of the column edge to the slab or foundation edge. With (rectangular) edge columns, the direction of the edge must be defined.

For corner columns, the distance to the edges  $r_x$  and  $r_y$  can be pre-set.

If the load situation cannot be mapped in a satisfactory manner with the definitions described above, the corner column or edge column type can be used instead.

*Ill.: Critical perimeters for edge column, corner column, wall end and interior wall corner at a distance of  $l_{crit} = 2.0 \cdot d_m$  stipulated according to EN 1992-1-1*



If for edge or corner columns, the length of the perimeters shown above exceeds that of a circumferential perimeter (of an inner column), the circumferential perimeter is used in the calculation as per para. 6.4.2 (4).

Non rotation-symmetrical shear force loading applies because of the column geometry or the column dimensions, for instance, or because a moment is transferred to the column or because the loads in the total frame system are not transferred uniformly. The total load factor  $\beta$  is intended to map the maximum loading. The approach based on an eccentricity as described in EN 1992-1-1, Para. 6.4.3 (3) or in the expert literature, e. g. /2/ or /4/ is suitable for the estimation of this factor.

The calculation of the total load factor  $\beta$  in accordance with the method of plastic shear stress distribution can be done with B6+ (see the paragraph [Loads](#)).

If a rectangular column grid is defined with braced systems for edge columns mainly under perpendicular loading, the shear force action may be increased by 40 % for reasons of simplification, if the widths of the columns do not vary by more than 25 %. For corner columns, 50 % are recommended, for interior columns 15 %. Total load factors are entered by the user and should be evaluated in regard to the geometric and static conditions. If the prerequisites are not satisfied, the load introduction area must be verified sectorwise under particular conditions.

#### Wall end - interior wall corner

In addition to the wall width  $b$ , the user can specify the affected length "cal d" in order to improve the mapping of the loading situation. If the available wall surface does not comply with the static requirements, the structural system of the edge or corner column should be used.

The shear force to be included in the calculation should be the wall load acting on the defined area portion. In finite-elements calculations, often restraint moments with high compression loading at the outermost discretization point are defined at singularity points. Normally, these values are peaks, which are reduced by constructive measures or relocation of the stiffness proportions due to cracks.

### Holes (Openings)

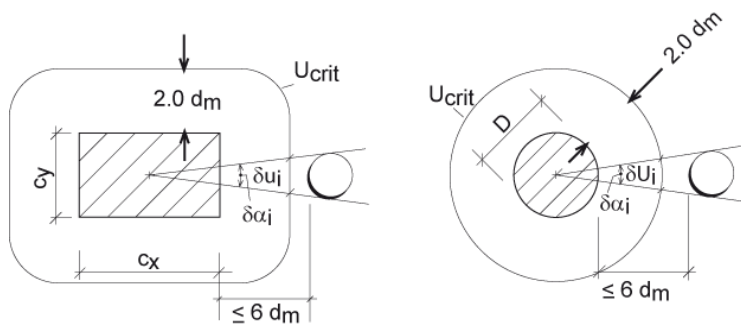
Holes can be taken into consideration with all kinds and types of columns.

Input of several holes: Register „openings“.

See ["Data entry via tables"](#) (Basic operating instructions) - alternatively the table entry can also be called up via the "Openings" tab below the graphic.

In accordance with EN 1992, holes with a distance to the column edge smaller than  $6 \cdot d_m$  are considered as decisive.

The sum of the length deductions  $\delta u_i$  [cm] describes the section of the inner perimeter at a distance of  $2.0 \cdot d_m$  that is limited by the intersecting tangents of the cut-outs running from the column's centre of gravity to the cut-out perimeters. Internally, a corrective calculation for the current perimeter is performed.



$$c_x/c_y < 2$$

$$u_i = 2 \cdot (c_x + c_y) + 2\pi \cdot 2d_m - \delta u_i$$

$$u_i = \pi \cdot (D + 2 \cdot 2 \cdot d_m) - \delta u_i$$

Sub areas			
Openings 1/1			
Distance of center	xs	[cm]	-100.0
Distance of center	ys	[cm]	0.0
Hole type			Rectangle
Length (diam.)	dx(dk)		Rectangle
Width	dy	[cm]	20.0
delta Ai	$\delta A_i$	[cm <sup>2</sup> ]	0.0
delta ui	$\delta u_i$	[cm]	14.8
delta Alpha	$\delta \alpha$	[grad]	12.7
Sum / for further calculations			
Sum delta ui calculated	$\Sigma \delta u_i$	[cm]	14.8

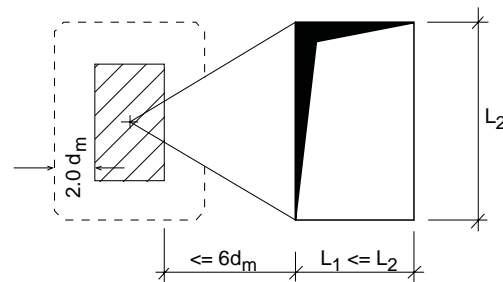
III.: Inner perimeters (interior columns) for the perimeter deduction  $\delta u_i$  as per EN 1992-1-1

The relation between the deduction length  $\delta u_i$  and the total perimeter length of the column type in question must be within the permissible range. If an interior column is close to a large hole for a staircase, for instance, the edge column type should be used instead of the interior column type in combination with a hole. The column type with the lower perimeter length should be used as an initial system. In the proximity of staircase holes, concentrated loading caused by stair loads for instance or loads from the building bracing may apply. Such loading could reduce the punching shear resistance.

With long chases, the opening dimensions should be re-assessed with the help of an ideal hole width  $L_2^*$ . This is done according to ill. 6.14 or ill. H6-32 S. 93 in /2/.

- For the condition  $L_1 > L_2$ ,  $L_2^* = \sqrt{L_1 \cdot L_2}$

III.: Large holes





### Direct pre-setting of individual holes

The pre-definition of rectangular or circular holes in the x-y system of coordinates allows the determination of the reduction values for the length deduction  $\Delta U_i$  in the decisive perimeter areas.

The definition of individual holes is only an aid to facilitate the determination of the summary deduction values and the geometrical presentation of the punching shear problem. The software application uses only the confirmed summary values.

With larger holes, we recommend using the edge or corner column type instead. If the software application does not allow the definition of a large hole, it can be approximated by defining several smaller ones. It is important for the verification that the perimeter deduction is mapped correctly.

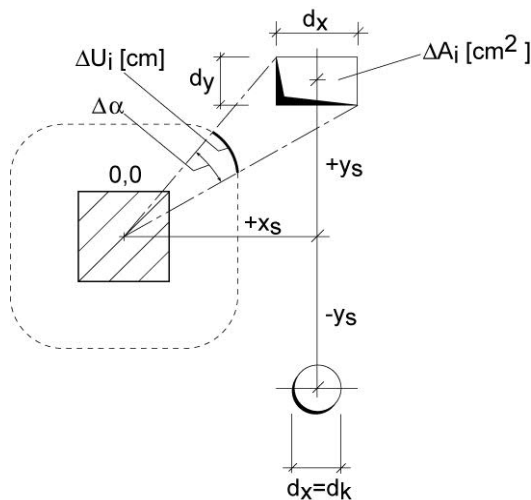
The software application offers an algorithm that checks polygonal intersections and calculates the results for the individual holes. In a subsequent calculation, overlaps of the totals of the lengths are taken into consideration.

An individual hole is defined by the coordinates of its centre of gravity  $x_s, y_s$  and its outer dimensions.

When defining holes, make sure that  $x_s$  and  $y_s$  are not equal to zero at the same time and that  $d_x$  is greater than zero. The default settings for holes are  $x_s = -100$  cm,  $y_s = 0$  cm,  $d_x = d_y = 20$  cm.

The hole should be outside of the centre of the column and enclosed in an opening angle below  $45^\circ$  if possible.

For holes that are not calculated by the software application striking numerical values are displayed ( $\Delta A_i = 999$   $\Delta U_i = 999$   $\Delta \alpha_i = 360^\circ$ ).



III.: Definition for the input of individual holes

The user can finish the input by specifying non-permissible values such as  $x_s = 0$  and  $y_s = 0$  for the centre of gravity of the hole. In any case, the user should check the plausibility of the total results and the deduction lengths resulting for the holes in particular.

The deduction lengths of the holes are extrapolated or interpolated to the spacing of the perimeters in question.

## Bending reinforcement

### Input via the reinforcement ratio

To be able to determine the reinforcement ratio, a column strip width "bg" must be defined, because it describes the closer area where punching shear applies in both supporting directions. All displayed As values refer to the default "bg" of an ideal interior column system. Where edge columns and corner columns are concerned, only the As portions in the existing slab area should be laid in.

The columns strip width "bg" indicates the width that is considered in the calculation of the reinforcement ratio.

We recommend specifying a value of 100 cm for "bg". The required As is then indicated per linear meter. The pre-set reinforcement ratio must be guaranteed up to the outermost control perimeter. The required span is specified as "erf bg".

The output of "erf bg" is performed separately for the x- and y-direction. Edge spacing of the columns from the ceiling edge will be considered for edge- or corner columns.

See also [bending reinforcement ratio](#)

Longitudinal reinforcement		
Reinforcement input	by	Reinforcement i
Width girder-strip averaged	bg	Reinforcement ratio
Exist. reinforcement x-dir.	Asx	Reinforcement layer distributed reinforcement
Exist. reinforcement y-dir.	Asy	[cm <sup>2</sup> ]
Reinforcement ratio slab averaged	Rho	0.621
Anzeigesteuerung		
Show reinforcement area		<input type="checkbox"/>

### Show reinforcement area

If the option "Show reinforcement area" is selected, the distances bgli, bgre, bgob and bgun are shown in the graphic. These are the distances from the respective column edge to the left, right, up and down. These specify up to which distance from the respective column edge the longitudinal reinforcement assumed in the calculation is to be arranged (req. bgx = bgli + cx + bgre, req. bgy = bgun + cy + bgob).

### Input via reinforcement layers

With the input via reinforcement layers, the longitudinal reinforcement (reinforcement on the tension side of the plate) can be defined in layers by the diameter and the center distance of the reinforcing bars. Alternatively, you can also enter the number of reinforcement bars per meter.

For ceiling slabs this means the reinforcement is at the top of the slab, for floor slabs and individual foundations the reinforcement is at the bottom side. It is assumed that the reinforcement extends laterally arbitrarily far.

The 1st layer is closest to the associated surface and the reinforcement runs in the x direction. Directly below the 2nd layer runs in the y-direction. Optionally, a 3rd reinforcement layer (reinforcement in x-direction) and a 4th layer (reinforcement in y-direction) can be defined. The rebars of all layers lie directly (crosswise) on each other. The diameter and the center distance (or the number per meter) can be defined independently for each layer.

Longitudinal reinforcement		
Reinforcement input	by	Reinforcement layer
Reinforcement layer		
Number of layer		2
Input bars	by	Diameter and center distance
Static height	dm	[cm] 25.9
Reinforcement ratio	Rho	0.621
Layer 1 in X-direction (outermost layer)		
Diameter [mm]		16
Spacing		[cm] 12.5
Layer 2 in Y-direction		
Diameter [mm]		16
Spacing		[cm] 12.5
Anzeigesteuerung		
Show reinforcement area		<input type="checkbox"/>

From these values and the concrete cover above or below, the center of gravity for the reinforcement in the x- or y-direction is determined. From the mean value, the static height dm results. Furthermore, the reinforcement ratio Rho (and Rhox and Rhoxy) is determined.

### Presetting of the reinforcement distribution

Sectioned reinforcement can be defined in three different areas (for each direction) for the design.

$A_{s1}$  and  $b_1$  describe the central column area,  $A_{s2}$  and  $b_2$  the adjacent transition areas and  $A_{s3}$  the average reinforcement in the remaining slab area.

The reinforcement areas are always assumed (also in the case of edge and corner columns) as symmetrical to the column axes. The same applies to wall ends and internal corners.

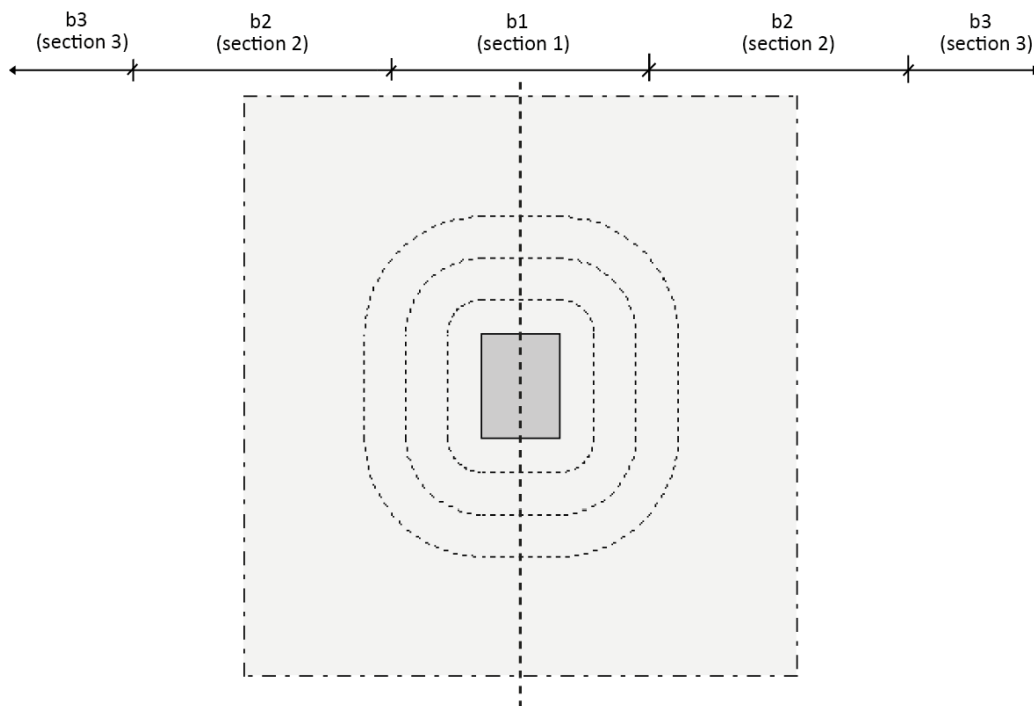
As/m, As: You can optionally specify the reinforcement with the unit  $cm^2$  or  $cm^2/m$ .

$b_1/2/3$  correspond to the different rows of the sections 1/2/3 (in the [output](#)).

reinforcement default  $A_{sx}, A_{sy}$  stepped :

Step 1:	$A_{sx} = 26.00 \text{ cm}^2$	$b_y = 100.0 \text{ cm}$	$a_{sx} = 26.00 \text{ cm}^2/m$
Step 2:	$A_{sx} = 20.00 \text{ cm}^2$	$b_y = 100.0 \text{ cm}$	$a_{sx} = 20.00 \text{ cm}^2/m$
Step 3:			$a_{sx} = 15.00 \text{ cm}^2/m$
Step 1:	$A_{sy} = 26.00 \text{ cm}^2$	$b_x = 100.0 \text{ cm}$	$a_{sy} = 26.00 \text{ cm}^2/m$
Step 2:	$A_{sy} = 20.00 \text{ cm}^2$	$b_x = 100.0 \text{ cm}$	$a_{sy} = 20.00 \text{ cm}^2/m$
Step 3:			$a_{sy} = 15.00 \text{ cm}^2/m$

Longitudinal reinforcement			
Reinforcement input	by	distributed reinforcement	
Input as	As / m		
in x-direction			
x-Direction (middle)	Asx1	$[cm^2]$	0.0
Width in y-direction (middle)	by1	$[cm]$	100.0
x-Direction (middle)	asx1	$[cm^2/m]$	0.00
x-Direction (up/be of middle)	Asx2	$[cm^2]$	0.0
Width y-direction	by2	$[cm]$	100.0
x-Direction (up/be of middle)	asx2	$[cm^2/m]$	0.00
x-Direction (outside)	asx3	$[cm^2/m]$	0.00
in y-direction			
y-Direction (middle)	Asy1	$[cm^2]$	0.0
Width x-direction (middle)	bx1	$[cm]$	100.0
y-Direction (middle)	asy1	$[cm^2/m]$	0.00
y-Direction (e./n. of middle)	Asy2	$[cm^2]$	0.0
Width x-direction	bx2	$[cm]$	100.0
y-Direction (e./n. of middle)	asy2	$[cm^2/m]$	0.00
y-Direction (outside)	asy3	$[cm^2/m]$	0.00
Anzeigesteuerung			
Show reinforcement area			<input type="checkbox"/>



### Show reinforcement area

If the option "Show reinforcement area" is selected, the reinforcement areas Level 1 and Level 2 are measured in the graph for the x and y direction.

### Bending reinforcement ratio

When entering the bending reinforcement ratio or calculating it from the pre-set  $A_s$  values, the user should note that the reinforcement ratio is to be referenced to the normal unreinforced slab. The reinforcement ratio entered by the user may exceed the permissible value. During the calculation, it is reduced to the value permitted for this calculation.

The user can enter the bending reinforcement ratio  $\rho$  ( $\rho$  in %) manually as a mean value. Otherwise, the software application calculates this value automatically by referencing the reinforcement cross section areas  $A_{sx}$  [cm<sup>2</sup>] and  $A_{sy}$  [cm<sup>2</sup>] to an ideal column strip width.

The column strip width pre-set for the calculation "cal bg" determines the reference concrete area. It is freely selectable. If bg is set to 100 cm, the  $A_s$  values are specified per linear metre.

The output of the required laying widths for longitudinal reinforcement is performed separately for x- and y-direction. Edge spacing will be considered for edge- and corner columns.

For a given reinforcement, the reinforcement ratio in each round section currently to be tested is newly determined as the mean value of the existing reinforcement, relative to the area within the round section.

$$\text{vorh } \rho = 100 \cdot \frac{\sqrt{A_{sx} \cdot A_{sy}}}{2 \cdot b_g \cdot (d_m \text{ or } d_r)}$$

If the existing reinforcement ratio exceeds the permissible maximum value, the calculated reinforcement ratio is reduced.

## Loads

### Max shear force VE

VE is the shear force resultant in the perimeter around the column. In most cases, it is set in accordance with the column load. If a uniform area loading applies (with foundation slabs and compact foundations), the load could be reduced by the area load portion inside the perimeter. If strongly asymmetrical loading applies (e. g. at the wall end or with columns under bending load) either the shear force bearing capacity should be increased or the verification should be performed sectorwise in partial areas of the column. As column type, edge or corner column should be selected in this case.

The shear force resultant is shown in the 3D-view.

### safety factor $\gamma_E$

In order to facilitate the switching over between standards for reasons of comparison, a safety factor  $\gamma_E$  is available. It is considered as a mean value to map the influence of the partial safety factors and combination coefficients. The design value  $V_{Ed}$  is the product of  $V_E \cdot \gamma_E$ . If a result was produced in accordance with the combination rules of EN 1992, the value  $\gamma_E$  should be set to 1.0. The safety factor  $\gamma_E$  also applies to the soil pressure and for the moments  $M_{Ex,col}$  and  $M_{Ey,col}$ .

### Increment $\beta$

The shear design force should be increased by a factor  $\beta$  because of the loading applies not rotation-symmetrically. The factor is used to verify the punching shear force resistance for peak stresses.

Current recommendations as per BS EN 1992-1-1:2015

$\beta = 1.15$  for general interior columns

$\beta = 1.40$  for edge columns

$\beta = 1.50$  for corner columns

Following DIN EN 1992-1-1:2015 Figure 6.21DE, the following beta values are suggested for wall ends and corners:

$\beta = 1.35$  for the wall end and

$\beta = 1.20$  for the interior wall corner

Other  $\beta$  values can be assessed in closer examinations.

If there are no cut-outs, the total load factor  $\beta$  can be calculated in accordance with the method of plastic shear stress distribution.

The total load factor is also considered in the calculation of the punching shear reinforcement.

### Soil pressure

For foundation slabs or compact foundations, the user can enter a soil pressure to be included in the decisive combination in addition to the column load. If the specified soil pressure is  $> 0$  kN/m<sup>2</sup>, the foundation self-weight multiplied by 1.35 is deducted from the soil pressure in the punching shear analysis.

Loads			
Max shear force	VE	[kN]	850.0
Safety factor	$\gamma_E$		1.00
Increment	$\beta$		1.150
Soil pressure		[kN/m <sup>2</sup> ]	0.00
Total load factor			
Calculate beta			<input checked="" type="checkbox"/>
Moment	$M_{Ex,col}$	[kNm]	0.00
Moment	$M_{Ey,col}$	[kNm]	0.00
$\beta$ Slab			1.100

### Calculation of the total load factor $\beta$

The calculation of the total load factor  $\beta$  in accordance with the method of plastic shear stress distribution is optionally available if no holes have been defined.

Total load factor			
Calculate beta X			<input checked="" type="checkbox"/>
moment	MEx,col	[kNm]	0.00
moment	MEy,col	[kNm]	0.00
$\beta$ Slab			1.100

For the calculation of  $\beta$ , the moments  $M_{Ex,col}$  and  $M_{Ey,col}$  can be defined by the user. If  $M_{Ex/y,col} \neq 0$ : moments are represented graphically.

The variable and indexes have the following meaning:

$M_{Ex,col}$  moment around the x-axis referring to the column centre.  
It is positive, if the moment vector points in the positive direction of the axis.

$M_{Ey,col}$  moment around the y-axis referring to the column centre.  
It is positive, if the moment vector points in the positive direction of the y axis.

These moments are internally converted to refer to the centre of gravity of the critical perimeter.

The calculation of  $\beta$  is based on the equation 1992-1-1 / NA.6.39.1 in the National Annex for Germany.

$$\beta = 1.0 + \sqrt{\left(k_x \frac{M_{Ed,x}}{V_{Ed}} \frac{u_1}{W_{1,x}}\right)^2 + \left(k_y \frac{M_{Ed,y}}{V_{Ed}} \frac{u_1}{W_{1,y}}\right)^2} \geq 1.10 \quad \text{Eq. NA 6.39.1}$$

with

$k_x, k_y$  shape coefficients as per table 6.1

$M_{Ed,x/y}$  moment around the x- or y-axis referring to the centre of gravity of the perimeter (calculated internally by the software)

$V_{Ed}$  corresponds to VE, see [max. shear force](#). For foundations and slabs  $V_{Ed,red}$  instead of  $V_{Ed}$  should be used in the calculation based on eq. 6.51 or eq. NA.6.51.1 (is automatically done by the software)

$u_1$  length of the critical perimeter

$W_{1,x/y}$  plastic section modulus of the critical perimeter referring to the x- or y-axis

The formulas for  $W_{1,x}$  and  $W_{1,y}$  as well as the centre of gravity of the perimeter are taken from reference /2/.

For a moment around one axis only, equation NA 6.39 is used.

$$\beta = 1.0 + k \cdot \frac{M_{Ed}}{V_{Ed}} \frac{u_1}{W_1} \geq 1.10 \quad \text{Eq. 6.39}$$

*Note: the initial parameters are the same as with eq. NA 6.39.1.*

For interior columns with a circular cross section, a simplified version of eq. 6.39 is applied:

$$\beta = 1.0 + 0.6\pi \frac{e}{D + 2l_u} \geq 1.10 \quad \text{analogous to eq. 6.42}$$

with

$e$  resulting load eccentricity referring to the column centre

$D$  diameter of the column

$l_u$  distance of the critical perimeter  $u_1$  to the border of the load introduction area

For better illustration, both the critical perimeter with its centre of gravity and the load application point (application point of the column load displaced by the moments) are shown in the graphic window. If the load application point coincides with the centre of gravity of the critical perimeter, the distribution of the plastic

shear forces along the critical perimeter would theoretically be uniform, i.e.  $\beta = 1.0$ . According to the NCI to 6.4.3 (3)  $\beta < 1.10$  is not permitted. Therefore,  $\beta = 1.10$  is put out. The larger the distance of the load application to the centre of gravity of the perimeter, the greater becomes  $\beta$ .

For slabs and foundations,  $\beta$  is constantly recalculated in the iteration for the determination of the critical perimeter.

You can put out intermediate results for a better control of  $\beta$ .

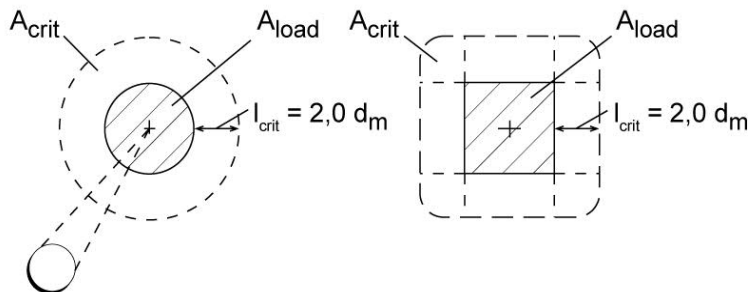
## Design

### Punching shear analysis as per BS EN 1992:2015

#### Designations and definitions as per EN 1992

The verifications for EN 1992 were developed on the basis of BS EN 1992-1-1:2015.

Dynamic loading cannot be handled currently. Slabs must have a solid cross section in the area of the load introduction. The critical perimeter for slabs is placed at a distance of  $A_{crit} = 2.0 \cdot d_m$  from the column edge. With foundation slabs and compact foundations, the distance of the critical perimeter is determined by the greatest ratio of loading to resistance.



III.: Critical perimeter around load introduction areas as per EN 1992, 6.4.2

#### Verification in the limit state

$$v_{Ed,u_0} = \frac{\beta \cdot V_{Ed}}{u_0 \cdot d_m} \leq v_{Rd,max} \quad [N/mm^2] \quad (6.38), (6.53)$$

$v_{Rd,max}$  must not be exceeded. The decisive section for the verification of the concrete compressive strain should have the perimeter  $u_0$  at the column face.

- $\beta$  = correction factor for non rotation-symmetrical load introduction
- $V_{Ed}$  = existing shear force in the ultimate limit state
- $u_0$  = circumference of the perimeter minus the perimeter deduction due to the holes at a distance  $< 6 \cdot d_m$ .

#### Design criteria as per EN 1992 without punching shear reinforcement.


Without punching shear reinforcement, the following condition must be satisfied in the control perimeter

$V_{Ed} \leq v_{Rd,c}$ , with

$$v_{Rd,c} = [C_{Rd,c} \cdot k \cdot (100 \cdot \rho_l \cdot f_{ck})^{1/3} - k_1 \cdot \sigma_{cd}] \geq (v_{min} + k_1 \cdot \sigma_{cd}) \quad (6.47)$$

For foundations, the following condition applies:

$$v_{Rd,c} = [C_{Rd,c} \cdot k \cdot (100 \cdot \rho_l \cdot f_{ck})^{1/3} \cdot 2d_m/a] \geq (v_{min} \cdot 2 \cdot d_m/a) \quad (6.50)$$

Design			
Punching Shear Reinforcement	with shear rails		
Stud rails	RFA-Tech		
Design with shear rails			
Concrete covering:	co	[cm]	2.5
cbot	cbot	[cm]	2.5
sel. rail	10 mm, 14* ( 4 An )		
Reset rails			
Number of rails/column	nL	14	
Number of studs/rail	nD	4	



with

$$C_{rd,c} = 0.18 / \gamma_c$$

$$k_1 = 0.1$$

$$d_m \text{ [mm]} = \text{average effective height} = \frac{d_{m,x} + d_{m,y}}{2}$$

$$k = 1 + \sqrt{\frac{200}{d_m}} \leq 2,0$$

$$v_{min} = 0,035 \cdot k^{1,5} \cdot f_{ck}^{0,5} \quad (6.3N)$$

$\rho_l$  = average longitudinal reinforcement ratio in the examined perimeter

$$\rho_l = \sqrt{\rho_{lx} \cdot \rho_{ly}} \leq 0,02$$

$\rho_{lx}, \rho_{ly}$  = reinforcement ratio in x- or y-direction inside the examined perimeter.

$\sigma_{cd}$  = design value of the axial concrete stress in [N/mm<sup>2</sup>] inside the examined perimeter:

$$\sigma_{cd} = \frac{\sigma_{cd,x} + \sigma_{cd,y}}{2}$$

$$\sigma_{cd,x} = \frac{N_{Ed,x}}{A_{c,x}} \quad \text{and} \quad \sigma_{cd,y} = \frac{N_{Ed,y}}{A_{c,y}}$$

with  $\sigma_{cd}$  (+ = pretension) sign definition as per EN 1992

a = distance from perimeter to face

Pretension cannot be taken into account when calculating RFA-Tech shear rails.

It is also checked that the following condition is met:

$$V_{Ed,u1} \leq 2 \cdot V_{Rd,c}$$

with

$$V_{Ed,u1} = \frac{\beta \cdot V_{Ed}}{u_1 \cdot d_m}$$

$u_1$  = Length of the critical perimeter

### Design criteria as per EN 1992 with punching shear reinforcement

Punching shear reinforcement is required, if the following applies:

$$V_{Rd,c} \leq V_{Ed,u1} \leq 2 \cdot V_{Rd,c} \quad \text{and} \quad V_{Ed,u0} \leq V_{Rd,max}$$

The total load-bearing capacity of concrete and steel  $V_{Rd,cs}$  is determined (for vertical punching shear reinforcement) as follows:

$$V_{Rd,cs} = 0,75 \cdot V_{Rd,c} + 1,5 \cdot \frac{A_{sw} \cdot f_{ywd,ef}}{s_r \cdot u_1} \quad \text{according to EN 1992 (6.52)}$$

- $V_{Ed}$  = design value of the mean shear force applying in the considered perimeter.
- $V_{Ed}$  = design value of the mean shear force permitted in the considered perimeter.
- $V_{Rd,c}$  = supporting portion of the concrete in the critical perimeter.
- $A_{sw}$  = cross-sectional area of the existing reinforcement per row
- $U_1$  = circumference of the critical perimeter minus the perimeter deduction due to the holes at a distance  $< 6 \cdot d_m$ .
- $s_r$  = effective width of one single reinforcement row;  $s_r \leq 0,75 \cdot d_m$
- $V_{Rd,max} = 0,5 \cdot v \cdot f_{cd}$  as per NA+A2:2014 to BS EN 1992-1-1

with

$$v = 0,6 \cdot (1 - f_{ck}/250) \quad \text{BS EN 1992-1-1 6.6N}$$

The following applies to the outer perimeter:

The outer perimeter is placed at a distance  $k \cdot d = 1,5 \cdot d_m$  to the outer reinforcement row.

$$V_{Ed} \leq V_{Rd,c}$$

- $V_{Ed}$  = design value of the shear force applying inside the outer perimeter.
- $V_{Rd,c}$  = design value of the shear force resistance as per equation 6.2a or 6.2b inside the outer perimeter.

### Reinforcement cross section required by EN 1992

In general, it applies:

$$\text{req. } A_{sw} = \frac{(V_{Ed,cs} - 0.75 \cdot V_{Rd,c}) \cdot u_1 \cdot d}{1.5 \cdot (d/s_r) \cdot f_{ywd,ef} \cdot \sin(\alpha)} \quad \text{equation 6.52 rearranged to obtain } A_{sw}$$

$f_{ywd,ef} = 250 + 0.25 \cdot d_m \leq f_{ywd}$  Effective design value for the yield strength of the punching shear reinforcement

$f_{ywd}$  Design value for the yield strength of the punching shear reinforcement

$\alpha$  angle of punching shear reinforcement to slab plane

$\min A_{sw}$  required minimum reinforcement as per Para. 9.4.3 (9.11) (per reinforcement row)

$$\min A_{sw} = \left[ 0.08 \cdot \frac{\sqrt{f_{ck}}}{f_{yk}} / (1.5 \cdot \sin(\alpha) + \cos(\alpha)) \right] \cdot (s_r \cdot u_i)$$

The shear force to be taken into account in the calculation of foundation slabs and compact foundations can be reduced by the portion  $\Delta V_{Ed}$  in accordance with equation 6.48. In the calculation of the punching shear reinforcement, the application automatically includes the soil pressure inside the critical perimeter (minus the foundation self-weight multiplied with 1.35). If no soil pressure is entered, no foundation self-weight is subtracted.

For the calculation of the punching shear reinforcement from the third row on, the area inside the corresponding reinforcement ring is taken into account.

## Punching shear reinforcement as per EN 1992

For the arrangement of the punching shear reinforcement, the regulations from EN 1992-1-1, para. 9.4.3 apply. The punching shear reinforcement should be installed with a closer spacing within the spacing range of  $1.5 \cdot d_m$ ; at least two reinforcement rows are proposed. The reinforcement perimeters extend from  $U_1$  at a spacing  $\geq 0.3 \cdot d_m$  from the outer edge of the column to a distance of  $1.5 \cdot d_m$  to the outer control perimeter  $U_{out}$ , which is determined with the help of the expression  $v_{Ed,a} \approx v_{Rd,a}$ . For reinforcement perimeters, the condition  $s_r \leq 0.75 \cdot d_m$  must be satisfied.

If only one row of reinforcement is required, a second row with  $s_r = 0.75 \cdot d_m$  is always arranged in accordance with EN 1992-1-1, 9.4.3(1).

### Arrangement in B6+ RFA-Tech

Distance:

$U_1$ : to the outer edge of the column  $0.5 \cdot d_m$

$U_2$  to  $U_i$ :  $s_r$

$U$ : from  $U_i$   $1.5 \cdot d_m$  (only verification)

Maximum radial reinforcement spacing:  $s_r \leq 0.75 \cdot d_m$

maximum tangential reinforcement spacing  $\leq 1.5 \cdot d_m$  in the critical perimeter

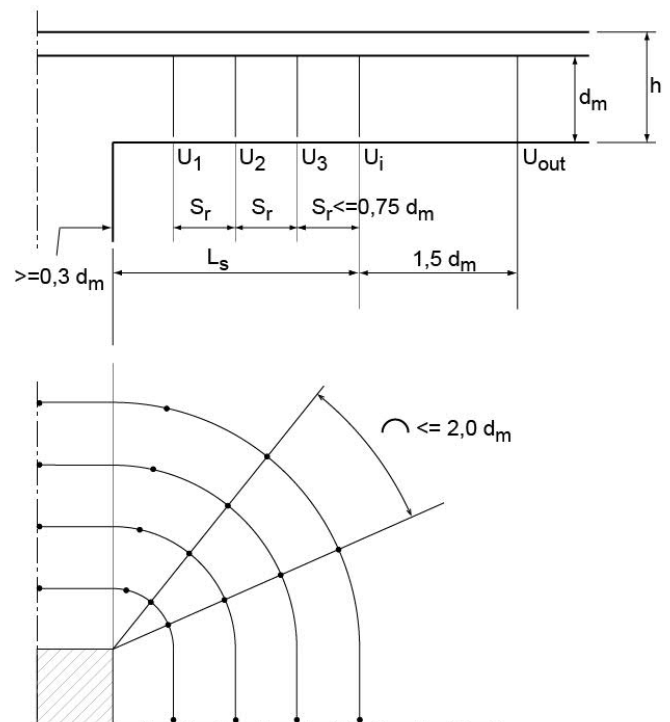
maximum tangential reinforcement spacing  $\leq 2.0 \cdot d_m$  in the outer perimeter

III.:

*Punching shear reinforcement with vertical stirrups  
EN 1992 9.4.3 Tangential spacing inside the critical  
parameter:*

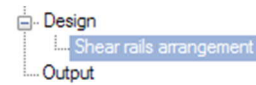
$\leq 1.5 \cdot d_m$ ,

and outside:  $\leq 2.0 \cdot d_m$

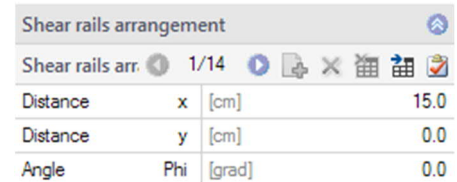


## Punching shear analysis with RFA-Tech shear connector rails

B6+ allows the design of shear connector rails as per CARES approval for RFA-Tech shear connector rails according to BS EN 1992:2015.



The user shall define the arrangement of the shear connector rails if possible. Holes in the slab are taken into account. You can edit the anchor diameter, the number of shear connector rails per column (nL), the number of anchors per rail (nD) as well as the arrangement of the shear connector rails (front end and angle to the x-axis, in case of circular columns only the angle to the x-axis). Moreover, you can specify the concrete cover on top and on bottom (co and cu).



Shear rails arrangement			
Shear rails arr. 1/14			
Distance	x	[cm]	15.0
Distance	y	[cm]	0.0
Angle	Phi	[grad]	0.0

Editing is possible on the "shear rails arrangement" tab (3-d GUI) or, alternatively, via the buttons of the [table toolbar](#).

The following parameters relevant for the verification are calculated and put out:

- Number of shear anchors on a rail
- Actual loading on the anchor
- Actual load-bearing capacity of the anchor
- anchor length (height)
- Number of rails
- Actual rail length
- Permitted tangential maximum spacing of the rails
- Actual tangential spacing of the rails

Moreover, the correct rail designation is put out.

Optionally, you can put out the arrangement of the connector rails (coordinates of the rail front end, coordinates of the outermost anchor and angle between the rail and the x-axis for each rail) in a table.

The generation of a DXF file, in particular for the acquisition of the dowel bar assembly in the formwork plan is possible.

### Reduction of the circular section with extended support surfaces

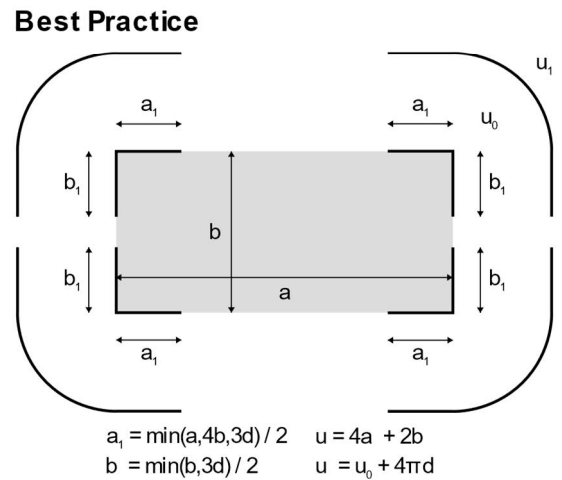
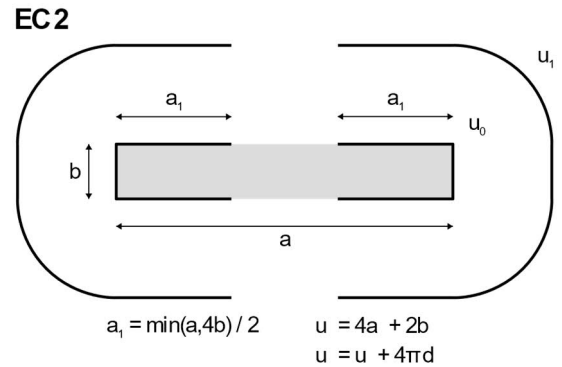
According to investigations /6/, a 3-dimensional stress state occurs at the column corners in the case of rectangular support areas, which is the reason for the increased load-bearing capacity during punching. This effect decreases with increasing distance from the corners and this is particularly evident for large and long columns.

However, neither the Eurocode nor the British Standard reflect the load concentration at column corners in their verifications. Only the distinction between columns and walls by the aspect ratio 1:4 in BS EN 1992-1-1, 9.5.1 can be used as an approach to account for the effect.

B6+ RFA-Tech offers two variants to include the effect in the calculation. A reduction of the load introduction round section for extended columns according to EC2 or according to "Best Practice" method can be selected.

Fig.: Reduction of the critical round cut with extended support areas

Alternatively, for a wall-type column or a column with a large load application area, it is recommended to design the column divided into wall ends or corners.



# Output

## Output profile

Tick the options to define the range of the output.  
Furthermore you can define the font size and the scale.

## Output as PDF document

The "Document" tab displays the output document in PDF format and can be printed.

See also [Output and Printing](#)

**Properties** 🔍

- Basic Parameters
- System
  - Geometry
  - Openings
  - Longitudinal reinforcement
  - Remarks
- Loads
- Design
  - Shear rails arrangement
- Output

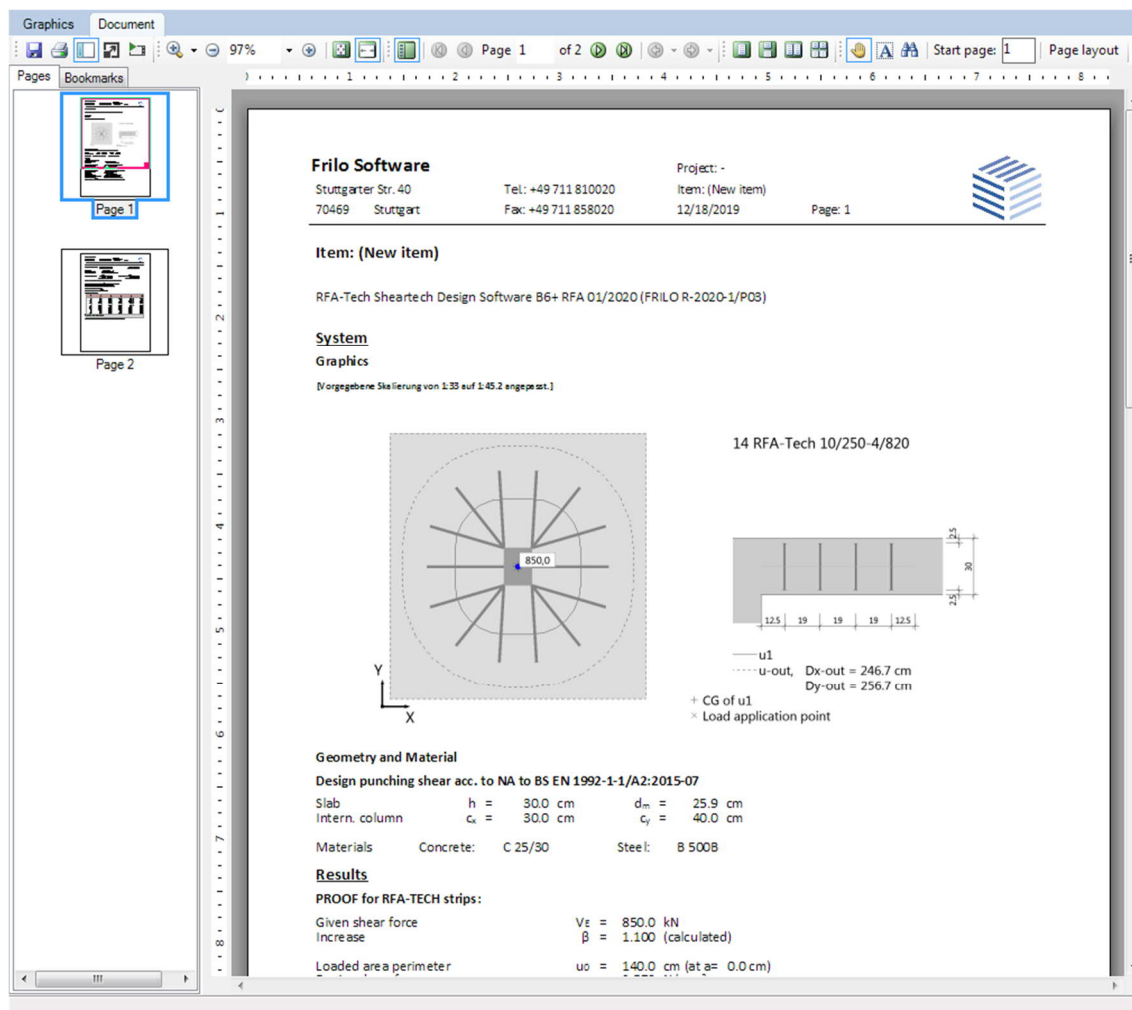
**Output Layout** ⬆

Output openings	<input type="checkbox"/>
Dimension of the openings	<input type="checkbox"/>
Output shear rails arrangement	<input checked="" type="checkbox"/>
Output intermediate values of beta calculation	<input type="checkbox"/>

**Graphics** ⬆

Font size	Output	0.35 cm	▼
Scale		1:33	▼



## Reference literature

- /1/ EN 1992-1-1:2004 / AC:2010
- /2/ Draft for Booklet 600, Erläuterungen zu Eurocode 2, DAfStb
- /3/ Ricker M., Siburg C., Hegger J.: "Durchstanzen von Fundamenten nach NA(D) zu Eurocode 2" in: Bauingenieur, 06/2012 pages 267 to 276
- /4/ Goris A., Hegger J.: "Hintergründe und Nachweise zum Durchstanzen nach Eurocode 2-NAD" in "Stahlbetonbau aktuell 2011", Bauwerk Verlag, S. E.3 et seq.
- /5/ DIN EN 1992-1-1 / NA:2015-12
- /6/ Einpaul, J., Bujnak, J., Fernandez Ruiz, M. and Muttoni, A.: "Study on Influence of Column Size and Slab Slenderness on Punching Strength" in: "ACI Structural Journal", V. 113, 2016, S. 135-146
- /7/ BS EN 1992-1-1 / NA+A2: 2014