

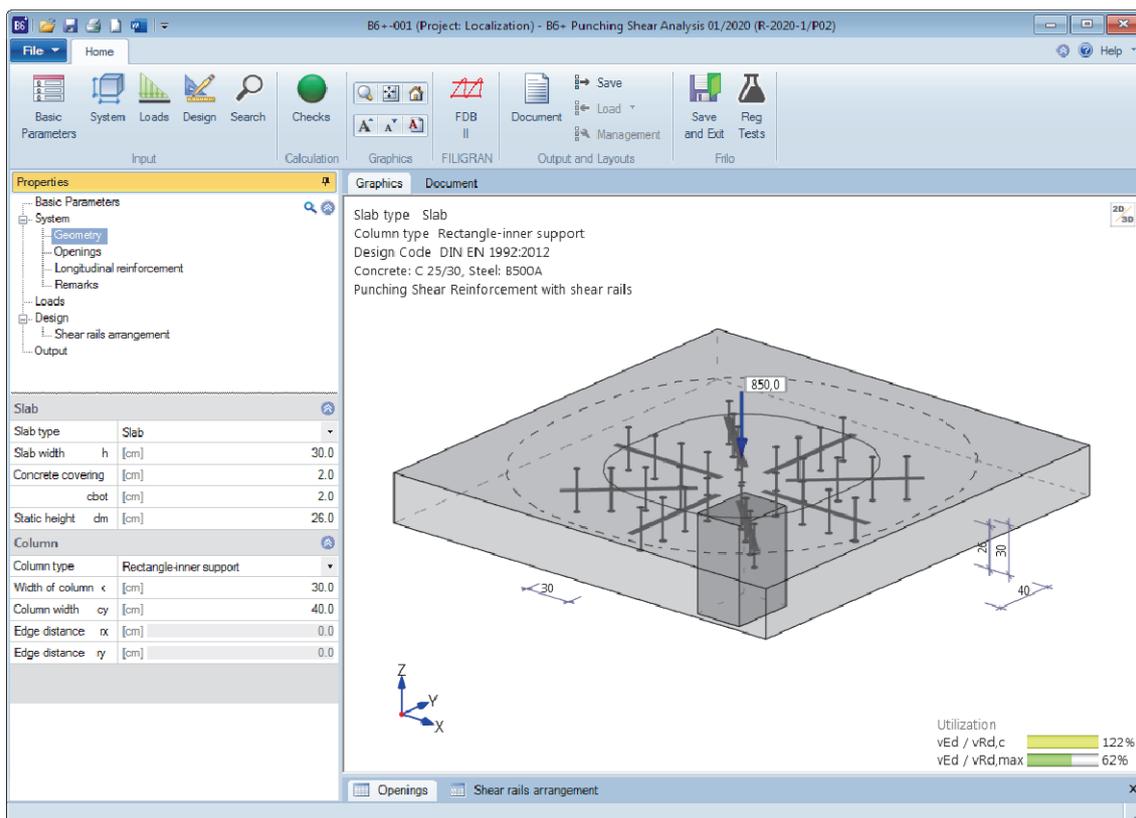
# Punching Shear Analysis B6+

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# Punching Shear Analysis B6+

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## 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

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

- Slabs
- Foundation slabs
- Isolated footings
- enlarged column heads.

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 EN 1992-1-1:2004/AC:2010 Para. 6.4 for columns with or without enlarged head.

The following National Annexes (NA) are available for this calculation:

- DIN EN 1992-1-1/NA: 2011 + DIN EN 1992-1-1/NA Ber. 1:2012-06
- DIN EN 1992-1-1:2013-04
- DIN EN 1992-1-1:2015-12
- ÖNORM B 1992-1-1:2007
- ÖNORM B 1992-1-1:2011
- BS EN 1992-1-1:2009
- BS EN 1992-1-1:2015
- EN 1992:2004/2010/2014

Still available:

- DIN 1045:1988, DIN 1045-1:2001/2008

### Shear connector rails

B6+ allows the design of shear connector rails as per ETA approval for DIN EN 1992:2012, DIN EN 1992:2013, DIN EN 1992:2015, ÖNORM EN 1992:2011, BS EN 1992:2009 and BS EN 1992:2015. Shear connector rails of different manufacturers (Schöck, Halfen, Jordahl) are available for selection.

### Filigran punching shear analysis FDB II

Data transfer from B6+ to the Filigran punching program Profi.exe allows the design of punching reinforcement made of lattice girders.

The shear force design resistances are calculated in the decisive critical perimeters in accordance with the applicable NA 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. In this case, the user must change the system parameters or select a suitable design alternative (e.g. shear rails).

If punching shear reinforcement should be dispensed with, the resistance values in the perimeters could be increased with the help of an enlarged column head.

## Basis of calculation

The calculations performed in the punching shear application are based on the standard EN 1992-1-1:2004/AC:2010, Para. 6.4 and 9.4.3 and the above-mentioned National Annexes.

The following European Technical Approvals for shear rails will be considered:

- Halfen HDB, certification: ETA-12/0454 from 18.12.2017
- Schöck BOLE, certification: ETA-13/0076 from 12.03.2018
- Jordahl JDA, certification: ETA-13/0136 from 20.03.2018

inclusively

- EAD 160003 -00-0301 from May 2018 and
- TR 060 from November 2017

For any problems in connection with punching shear, such as the load-bearing behaviour in the limit state, or concerning different construction and design solutions, please refer to the corresponding expert literature such as /9/ and /13/.

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 [Loading](#)).

## Input

The input of values and control parameters has to be done in the menu on the left side of the window – the so called FDC area (Frilo.Data.Control). You can check the results immediately in the 3D graphic on the right side. See "[Basic operating instructions-PLUS](#)".

### Basic Parameters

Select the desired [standard](#) from the list.

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

The available material options depend on the selected standard.

### System

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

### Geometry

#### Slab

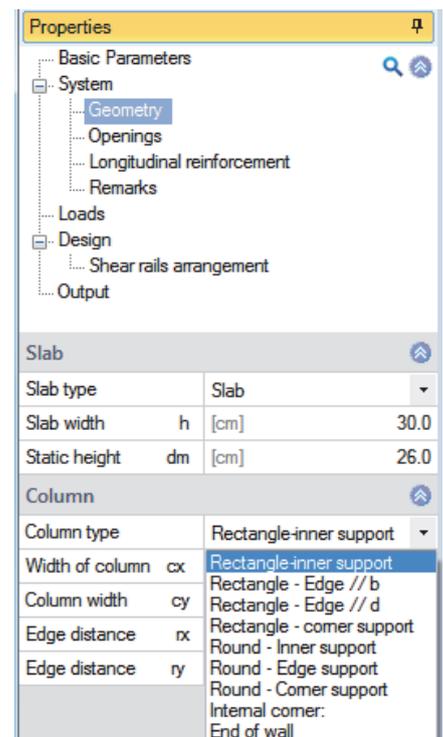
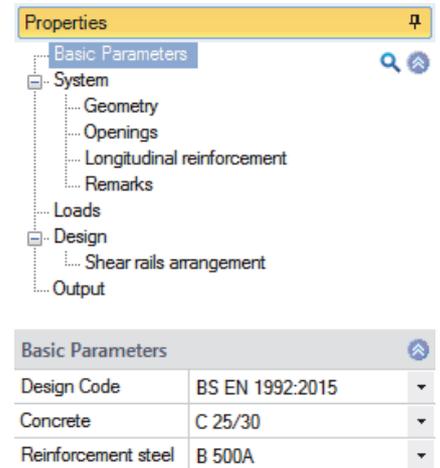
You can select among the slab types:

- Slab
- Foundation slab
- Compact foundation (isolated foundation)

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  $a_{crit} = 1.0 \cdot d_m$ . A verification with a critical perimeter of  $a_{crit} = 1.0 \cdot d_m$  is possible with consideration of the border conditions for foundation slabs and compact foundations (without head enlargement in each case) in combination with the codes DIN EN 1992-1-1:2012, DIN 1992-1-1:2013, DIN EN 1992-1-1:2015 and ÖNORM B 1992-1-1:2007 or ÖNORM B 1992-1-1:2011.

#### 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 h >= 18 cm when using shear rails	
dm	effective height Average effective height with foundation co/cu dsl	$d_m = h - c_o - d_{sl}$ $d_m = h - c_u - d_{sl}$ 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.

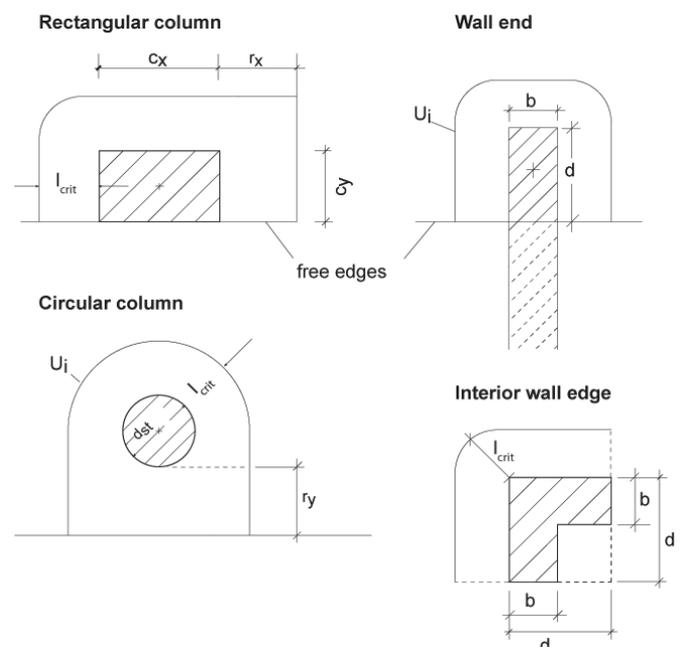
**Distance to the edge**

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.

The geometric dimensions of the equivalent column for the wall end and the interior wall corner are checked in accordance with /2/ figure NA 6.12.1 or /6/ figure 3 when the user enters the corresponding values.

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 by EN 1992*

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. /9/ or /13/ 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 [Loading](#)).

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 10 % (as per NA Austria /6/ 15 %). The values vary in the individual National Annexes. 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.

The National Annexes for Germany /2/ and Austria /6/ prescribe a  $\beta$  value of 1.35 for wall ends and 1.2 for wall corners. Other  $\beta$  values can be assessed in a closer examination.

#### 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. The software application checks the length limitation of "cal d" to  $1.5 \cdot d_m$  as specified by the NA for Germany /2/ or to  $1.4 \cdot d_m$  as specified for wall corners by the NA for Austria /6/. 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.

The load introduction area which is either defined by the user or assessed automatically on the basis of restrictions is evaluated in accordance with EN 1992 and the perimeter is limited in accordance with the following expression:

$$U_{load} \leq 12 \cdot d_m, \quad b/d \leq 2.0 \quad \text{as well}$$

$$b_1 = \min\{b; 3d\}, \quad a_1 = \min\{a; 2b; 6d - b_1\} \quad \text{NA Germany /2/ (NCI) to 6.4.1 (2) P}$$

$$U_{load} \leq 11 \cdot d_m, \quad b/d \leq 2.0 \quad \text{as well}$$

$$b_1 = \min\{b; 2.8d\}, \quad a_1 = \min\{a; 2b; 5.6d - b_1\} \quad \text{NA Austria /6/ Para. 9.4.1}$$

In the other National Annexes, there is no comparable specification.

The verification of the load introduction area is performed in the same way for enlarged column heads.

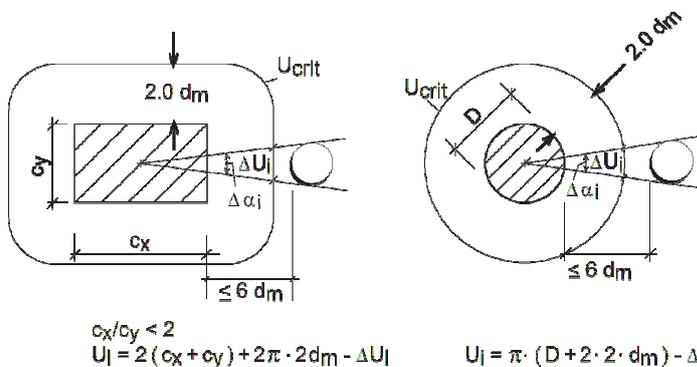
### Holes (Openings)

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

Input of several holes: Register „openings“

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  $1.5 \cdot d_m$  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. Correspondingly, the sum of the angles  $\Delta \alpha_i$  [degrees] is defined as the sum of the opening angles of the cut-out tangents. This value is not relevant to the verification but necessary for the corrective calculation.

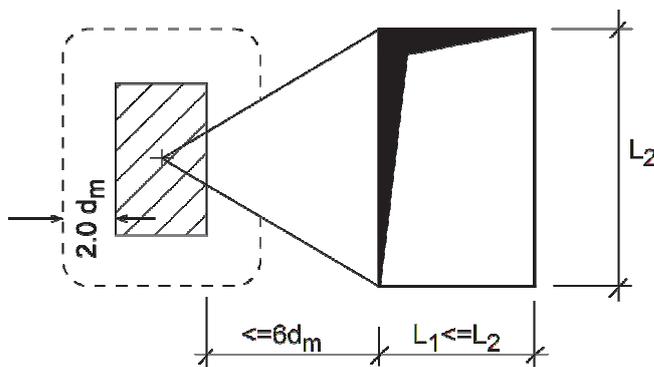


Ill.: Inner perimeters (interior columns) for the perimeter deduction  $\Delta U_i$  as per EN 1992-1-1

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 in / 2 / or ill. H6-32 S. 93 in / 9 /. For items of older versions without this function (< 02/2015) a conversion can be made, if necessary.

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



Ill.: Large holes

Properties			
Basic Parameters			
System			
Geometry			
Openings			
Longitudinal Reinforcement			
Remarks			
Loads			
Design			
Position of shear rails			
Output			
Sub areas			
Openings 1/1			
Distance of axis	xs	[cm]	-100.0
Distance of axis	ys	[cm]	0.0
Length (diam.)	dx(dk)	[cm]	20.0
Width	dy	[cm]	20.0
delta Ai	δ Ai	[cm <sup>2</sup> ]	0.0
delta ui	δ ui	[cm]	14.9
delta Alpha	δ α	[grad]	12.7
Sum / for further calculations			
Summe delta ui berechnet	Σ δ ui	[cm]	14.9
Summe delta ui vorgeben			
for further calculation (at 2*d <sub>m</sub> )	Σ δ ui	[cm]	14.9

### 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  $\Delta U_i$  and the angle deduction  $\Delta \alpha_i$  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. If the geometry is edited, the values are not adjusted automatically. If the circumference of the load introduction area  $u_{load}$  of a column is larger than the permissible value specified by illustration 6.12.1 (NA Germany) or illustration 3 (NA Austria), the deduction values, being on the safe side, are fully assigned to the decomposed perimeters for the punching shear resistance verification independently of the location of the holes.

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.

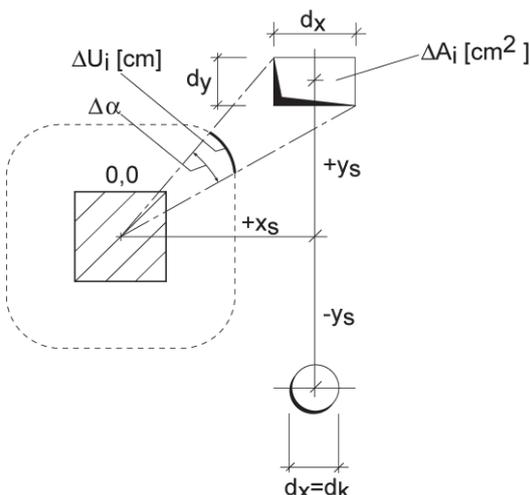
The software application offers an algorithm that checks polygonal intersections and calculates the results for the individual holes. In a subsequent calculation, overlaps of the totals of the lengths and angles are roughly taken into consideration.

An individual hole is defined by the coordinates of its centre of gravity  $x_s, y_s$  and its outer dimensions. For a circular hole, the y-dimension must be set to "0" (circle with  $d_k = d_x, d_y = 0$ ).

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 ratio
Width girder-strip averaged g		Reinforcement ratio
Exist. reinforcement x-dir. Asx		Reinforcement layer distributed reinforcement
Exist. reinforcement y-dir. Asy		[cm <sup>2</sup> ] 0.0
Min reforc. ratio	min	[%] 0.370
Reinforcement ratio slab average		[%] 1.000
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] 26.4
Reinforcement ratio Rho	[%]	0.609
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  $b1$  describe the central column area,  $A_{s2}$  and  $b2$  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.

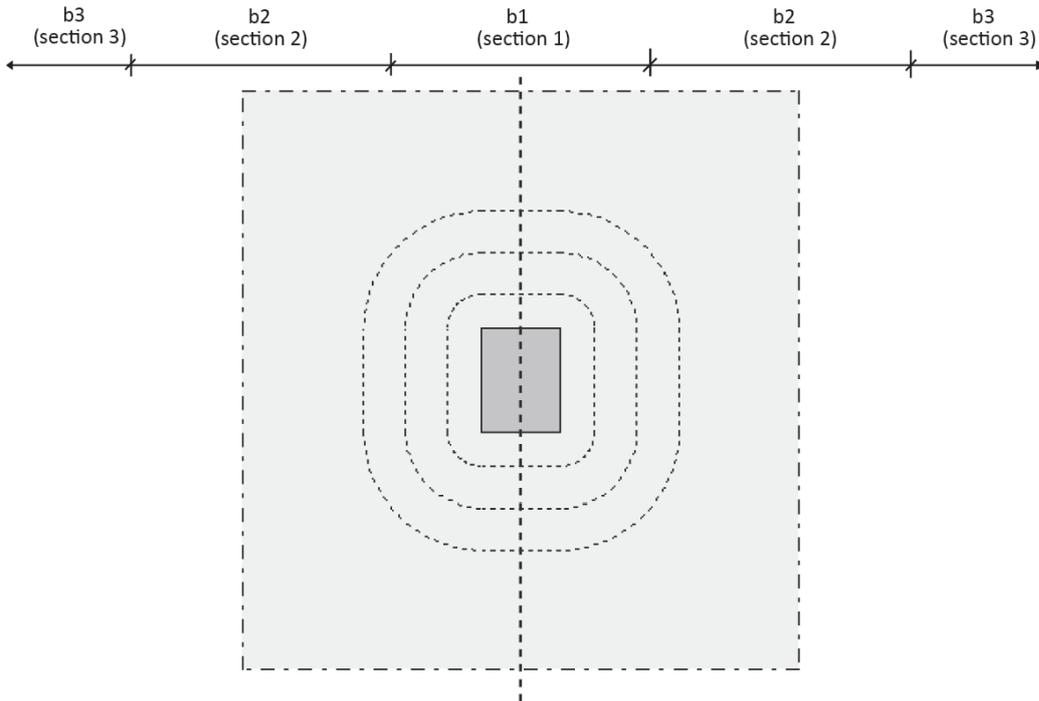
As/m, As: You can optionally specify the reinforcement with the unit  $cm^2$  or  $cm^2/m$ .

$b1/2/3$  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 (le/ri of middle)	Asy2	[ $cm^2$ ]	0.0
Width x-direction	bx2	[cm]	100.0
y-Direction (le/ri 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. If a verification is required in the inner perimeter of an enlarged head, the software application recalculates the reinforcement ratio on the basis of the current cross sectional properties in the perimeter. 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  $A_{sx}$  [ $\text{cm}^2$ ] and  $A_{sy}$  [ $\text{cm}^2$ ] 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.

The German /2/ and Austrian NA /6/ require that the minimum reinforcement ratio for punching shear is respected. The minimum reinforcement ratio is displayed for the countries mentioned above.

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.

The user should note that in Germany only the supporting reinforcement of the slab that is loaded by tension may contribute to the punching shear resistance.

The minimum reinforcement ratio is determined via the design of an equivalent minimum column moment in accordance with the NA Germany (Para. 6.4.5(5)).

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

$$\text{max } \rho = 0,5 \cdot \frac{f_{cd}}{f_{yd}} \leq 2,0\% \quad \text{according to the German NA /2/ the following applies in addition:}$$

$$\text{max } \rho \leq 0,5 \frac{f_{cd}}{f_{yd}} \quad (\text{NDP } 6.4.4 (1))$$

$$\text{According to the Austrian NA /6/ the following applies in addition: } \text{max } \rho \leq 0,4 \frac{f_{cd}}{f_{yd}} \quad \text{Para. 9.4.8}$$

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

Collapse reinforcement should be installed in the lower layer of a column connection in accordance with the NAs for Germany and Austria. The German NA (Para. 9-4.1(3)) prescribes the following calculation:

$$A_s = V_{Ed} / 1.4 / f_{yk} \text{ with } \gamma_F = 1.0.$$

## Loads

### Column load 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.

Loads		
Max shear force	VE	[kN] 850.0
Safety factor	$\gamma_E$	1.00
Increment	$\beta$	1.100
Pre-stress	$\sigma_{cd}$	[N/mm <sup>2</sup> ] 00
Soil pressure		[kN/m <sup>2</sup> ] 0.00
Total load factor		
Calculate beta		<input checked="" type="checkbox"/>
Moment	MEx,col	[kNm] 0.00
Moment	MEy,col	[kNm] 0.00
$\beta$ Slab		1.100

### 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 VEd is the product of VE  $\cdot \gamma_E$ . 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<sub>Ex,col</sub> and M<sub>Ey,col</sub>.

### Total load factor

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 EN 1992-1-1:

$\beta = 1.10$  for general interior columns

$\beta = 1.15$  for interior columns as per NA Austria /6/

$\beta = 1.40$  for edge columns

$\beta = 1.50$  for corner columns

According to NA Germany /2/, the following applies in addition:

$\beta = 1.35$  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.

### Pretension

The consideration of an axial concrete stress (pretension, compression)  $\sigma_{cd}$  is possible for slabs (without column head reinforcement) in combination with DIN EN 1992-1-1:2012. The pretension value to be entered is limited in the range of  $0.0 \leq \sigma_{cd} \leq 2.0$  N/mm<sup>2</sup>, because reference /9/ only allows a consideration of pretension up to 2.0 N/mm<sup>2</sup> in the calculation. Compressive stress should have a positive sign (attention: other sign definition as with DIN 1045-1).

### 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.

### 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	ME <sub>x,col</sub>	[kNm]	0.00
moment	ME <sub>y,col</sub>	[kNm]	0.00
$\beta$ Slab			1.100

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

The variable and indexes have the following meaning:

$M_{E_{x,col}}$  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.

$M_{E_{y,col}}$  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 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 /9/.

With greater load introduction areas and a critical perimeter that is subdivided by these areas,  $u_1$ ,  $W_{1,x}$  and  $W_{1,y}$  refer to the global perimeter (i.e. not subdivided) for reasons of simplification.

For a moment around one axis only, equation 6.39 is used instead of eq. NA 6.39.1.

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

*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 in accordance with reference /21/.

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

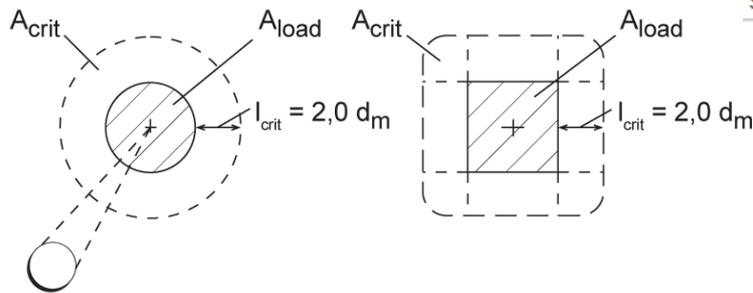
## Design

### Punching shear analysis as per EN 1992:2010 - without column head enlargement

#### Designations and definitions as per EN 1992

The verifications for EN 1992 were developed on the basis of EN 1992-1-1:2010 and its National Annexes (NA).

The verification for column head enlargements is optionally available. The verification for rail reinforcement is disabled because of a lack of approvals based on EN2. 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  $l_{crit} = 2.0 \cdot d_m$  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

Design 			
Punching Shear Reinforcement		acc.to code	
Reinforcement ratio	Rho	[%]	1.000
vRd,c shear		without vRd,c shear	
Design according to code 			
Required reinforcing ca.	hH	[cm]	7.3
	LH	[cm]	11.0
Column head		none	
Selected reinforcing height	hH	none	
Selected reinforcing length	LHx	stepped	
		inclined	
Selected reinforcing length	LHy	[cm]	0.0
Shear reinforcement		B500A	
Inclination shear reinforce.	Alpha	[Grad]	90
Selected distance of links	sr	[cm]	0.0

### Conditions for punching shear as per EN 1992

The geometric dimensions of the load introduction area are only limited in the NA Germany /2/, /3/ and /7/ and Austria /6/. Therefore, the load introduction areas are checked and limited in accordance with NA Germany 6.1.21 and NA Austria figure 3, if these NAs are selected.

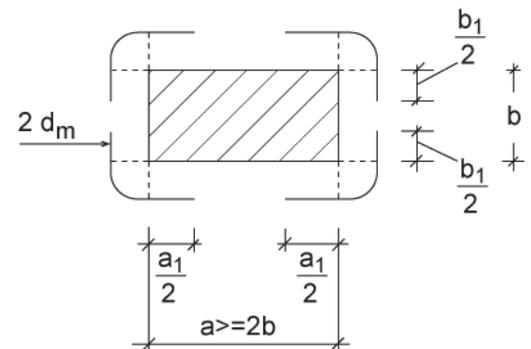
$$\frac{c_x}{c_y} \leq 2 \quad \text{bzw.} \quad \geq 0,5$$

$$u_0 \leq 12 \cdot d_m \quad (\text{circle}) \quad \text{as per NA Germany}$$

$$D \leq 3,5 \cdot d_m \quad (\text{circle}) \quad \text{as per NA Austria}$$

$$u_0 \leq 12 \cdot d_m \quad (\text{rectangle}) \quad \text{as per NA Germany}$$

$$u_0 \leq 11 \cdot d_m \quad (\text{rectangle}) \quad \text{as per NA Austria}$$



III.: Load introduction area with decomposed perimeter as per EN 1992 figure 6.12.1 NA Germany or figure 3 NA Austria.

The perimeters of adjacent load introduction area must not overlap. If this condition is not satisfied, the perimeter must be decomposed.

The following applies for all decomposed cross sections:

$$b_1 \leq 3,0 \cdot d_m \leq \text{exist.} b = \min(c_x, c_y) \quad \text{as per NA Germany}$$

$$b_1 \leq 2,8 \cdot d_m \leq \text{exist.} b = \min(c_x, c_y) \quad \text{as per NA Austria}$$

$$a_1 \leq 6,0 \cdot d_m - b_1 \leq 2 \cdot \text{exist.} b \leq \text{exist.} a = \max(c_x, c_y) \quad \text{as per NA Germany}$$

$$a_1 \leq 5,6 \cdot d_m - b_1 \leq 2 \cdot \text{exist.} b \leq \text{exist.} a = \max(c_x, c_y) \quad \text{as per NA Austria}$$

If the permissible load introduction proportions are exceeded, the decomposed perimeter (reduced perimeter length) is used in the calculation in accordance with /2/ or /6/.

Alternatively, the user can additionally include the shear resistance  $v_{Rd,c}$  as per Para. 6.2 (shear) for the areas between the perimeter sections for slabs. This increases the limit for the installation of punching shear reinforcement. The total resistance  $v_{Rd,c,g}$  (see output) refers to the length of the critical perimeter.

If punching shear reinforcement is required nonetheless, the portion of the shear resistance  $v_{Rd,c}$  as per Para. 6.2 (shear) is **not** included in the calculation. In this case, the punching shear reinforcement should be arranged in the areas of the perimeter sections (corner areas). In the areas between the sections, minimum shear reinforcement should be placed as prescribed by DIN 1045-1.

The user shall only consider the shear resistance as per Para. 6.2 in the areas between the perimeter sections if the distribution of the shear force along the perimeter corresponds roughly to that of the resistance  $v_{Rd,c}$ . Otherwise, the system should be modelled with the help of the wall end or the interior wall corner.

### Verification in the limit state

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

$v_{Rd,max}$  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.

In accordance with the NA Germany /2/ (NDP 6.4.5 (3)), the maximum load-bearing capacity is verified in the critical perimeter  $u_1$ .

- $\beta$  = correction factor for non rotation-symmetrical load introduction  
 $V_{Ed}$  = existing shear force in the ultimate limit state  
 $u$  = circumference of the considered perimeter minus the perimeter deduction due to the holes at a distance  $< 6 \cdot d_m$ . In general,  $u = u_0$ , as per NA Germany  $u = u_1$

In combination with edge or corner columns, the critical perimeter may reach up to the orthogonal intersection with the edge, as long as this perimeter is smaller than the solid section or the perimeter reduced by holes.

#### 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

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

Alternatively, the user can include the shear resistance as per Para. 6.2 for slabs if the proportions of the load introduction are exceeded.

For foundations, the following condition applies:

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

with

$$C_{Rd,c} = 0.18 / \gamma_c \text{ or as per NA}$$

$$k_1 = 0.1 \text{ or as per NA}$$

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

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

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

According to NA Germany the following applies:

$$v_{min} = \frac{0,0525}{\gamma_c} \cdot k^{1,5} \cdot f_{ck}^{0,5} \text{ for } d \leq 600 \text{ mm}$$

$$v_{min} = \frac{0,0375}{\gamma_c} \cdot k^{1,5} \cdot f_{ck}^{0,5} \text{ for } d \geq 800 \text{ mm}$$

It is permissible to interpolate the intermediate values.

$\rho_l$  = average longitudinal reinforcement ratio in the examined perimeter  
 $\rho_l = \sqrt{\rho_{lx} \cdot \rho_{ly}} \leq 0,02$

Additionally applies:

$$\rho_l \leq 0,5 \cdot \frac{f_{cd}}{f_{yd}} \text{ as per NA Germany /2/ or}$$

$$\rho_l \leq 0,4 \cdot \frac{f_{cd}}{f_{yd}} \text{ as per NA Austria /6/}$$

$\rho_{lx}, \rho_{ly}$  = 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, - = tensile stress) sign definition as per EN 1992

a = distance from perimeter to face

In combination with DIN EN 1992-1-1:2012, DIN EN 1992:2013 respectively DIN EN 1992:2015, axial concrete stress (pretension) can be considered for slabs (without column head reinforcement) . The value to be entered for the pretension is limited to the range of  $0.0 \leq \sigma_{cd} \leq 2.0$  N/mm<sup>2</sup>, because reference /9/ only allows a consideration of pretension up to 2.0 N/mm<sup>2</sup> in the calculation. Compressive stress should have a positive sign (attention: other sign definition as with DIN 1045-1).

As specified in the NA Germany /2/  $C_{Rd,c} = 0.15 / \gamma_c$  should be used for compact foundations. The draft /4/ recommends  $C_{Rd,c} = 0.15 / \gamma_c$  for foundation slabs too. To provide for sufficient safety, the B6 application uses  $C_{Rd,c} = 0.15 / \gamma_c$  also for foundation slabs.

In DIN EN 1992:2013 the above mentioned value  $C_{Rd,c} = 0,15 / \gamma_c$  for foundation slabs incorporated.

### Minimum reinforcement

To ensure sufficient shear force bearing capacity, slabs shall be designed in the column area for minimum moments as per Para 6.4.5 (5) of NA Germany or Para. 9.4 NA Austria.

$$m_{Ed,x} = \eta_x \cdot V_{Ed} \quad \text{and} \quad m_{Ed,y} = \eta_y \cdot V_{Ed}$$

Moment coefficients  $\eta_x, \eta_y$  :

	$\eta_x$	$\eta_y$
Interior column	0.125	0.125
Edge column, edge x	0.25	0.125
Edge column, edge y	0.125	0.25
Corner column	0.5	0.5
wall end (in x-direction)	0.125	0.25
wall corner	0,125	0.125

In the verification of the minimum reinforcement of foundation slabs and compact foundations, the shear force to be included is only reduced by the soil pressure inside the column cross section (minus the foundation self-weight).

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

Punching shear reinforcement is required, if the following applies:

$$V_{Rd,c} \leq V_{Rd,cs} \leq V_{Rd,max}$$

The following equation applies to each reinforcement row:

$$V_{Rd,cs} = 0,75 \cdot V_{Rd,c} + 1,5 \cdot \frac{(d/s_r) \cdot A_{sw} \cdot f_{ywd,ef}}{u_1 \cdot d_m} \cdot \sin(\alpha) \text{ as per EN 1992 (6.52)}$$

When using stirrups, at least two reinforcement rows should be installed. In accordance with the NA Germany, always two reinforcement rows should be defined in the software application if punching shear reinforcement is required.

- $V_{Ed}$  = 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
- $u$  = 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;  $s_r \leq 0,75 \cdot d_m$

$$V_{Rd,max} = 0,4 \cdot v \cdot f_{cd}$$

$$V_{Rd,max} = 0,5 \cdot v \cdot f_{cd} \quad \text{as per NA Austria to ÖNorm B 1992-1-1; 2007}$$

with

$$v = 0,6 \cdot (1 - f_{ck}/250)$$

$$V_{Rd,max} = 1,4 \cdot V_{Rd,c,u1} \quad \text{as per NA Germany}$$

**Oblique bars as punching shear reinforcement**

The bars must be installed with an inclination angle of  $45^\circ \leq \alpha \leq 60^\circ$  to the slab plane. If oblique bars are used exclusively, they must be installed in the area of  $1.5 \cdot d_m$  around the column as specified by the NA Germany, figure 9.10 punching shear reinforcement. The design equation (6.52) applies here too.

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:

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

If a pretension  $\sigma_{cd}$  was defined, the more favourable effect of pretensioning (compression) is taken into account for the concrete load-bearing portion  $V_{Rd,c}$  in eq. 6.52 with  $0.5 \cdot k_1 \cdot \sigma_{cd}$  in accordance with reference /9/ for the determination of the punching shear reinforcement.

For compact foundations and foundation slabs as per NA Germany (NCI to 6.45 (1) applies:

$$\text{req. } A_{sw,1+2} = \frac{\beta \cdot V_{Ed,red}}{f_{ywd,ef}} \quad \text{Total of the first two reinforcement rows for stirrups}$$

$$\text{req. } A_{sw,1+2} = \frac{\beta \cdot V_{Ed,red}}{1.3 \cdot f_{ywd} \cdot \sin(\alpha)} \quad \text{Total of the first two reinforcement rows for bent reinforcement}$$

$$f_{ywd,ef} = 250 + 0,25 \cdot d_m \leq f_{ywd} \quad \text{Effective design value for the yield strength of the punching shear reinforcement}$$

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

$$\alpha \quad \text{angle of punching shear reinforcement to slab plane}$$

According to the NA Germany, the required punching shear reinforcement of the first row is to be multiplied by the factor 2.5 and that of the second row by 1.4. This does not apply to foundation slabs and compact foundations. With column head enlargements, these factors apply to the first two rows inside **and** outside of the enlargement. According to the NA Austria of 2011, the factor 1.6 applies to the first two rows inside and outside.

$$\begin{aligned} \text{min } A_{sw} &= \text{required minimum reinforcement as per Para. 9.4.3 (9.11) (per reinforcement row)} \\ \text{min } A_{sw} &= [0,08 \cdot \frac{\sqrt{f_{ck}}}{f_{yk}} / (1,5 \cdot \sin(\alpha) + \cos(\alpha))] \cdot (s_r \cdot u_i) \\ \text{min } A_{sw} &= [0,08 \cdot \frac{\sqrt{f_{ck}}}{f_{yk}} / (1,5 \cdot \sin(\alpha))] \cdot (s_r \cdot u_i) \quad \text{for Germany in accordance with /11/} \end{aligned}$$

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.

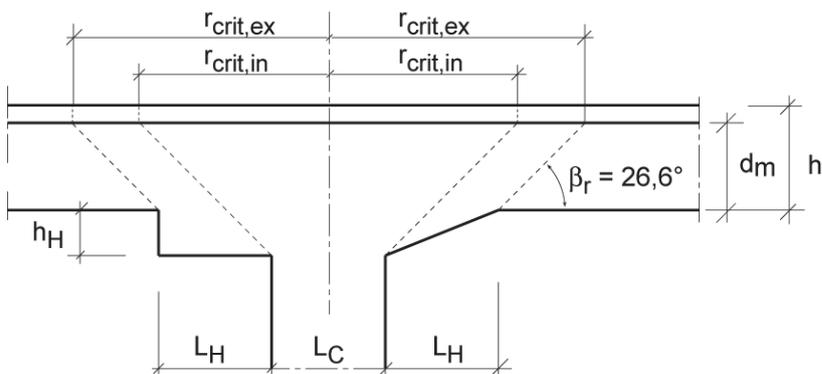
For the calculation of the punching shear reinforcement from the third row on, the area inside the corresponding reinforcement ring is taken into account, except in combination with NA Austria. NA Austria /6/ stipulates that always the area inside the critical perimeter must be used for the calculation of  $\Delta V_{Ed}$ .

If you select  $a_{crit} = d_m$  in combination with DIN EN 1992-1-1:2012, DIN EN 1992-1-1:2013 respectively DIN EN 1992-1-1:2015, only 50 % of the defined soil pressure are taken into account in the punching shear analysis in accordance with reference /9/. When calculating the punching shear reinforcement (of reinforced concrete), only 50 % of the soil pressure are taken into account for the first two reinforcement rows, if  $a_{crit}$  was set to  $d_m$  in combination with the NA for Germany. If the critical perimeter is determined by iteration, it is permissible to take 100 % of the soil pressure into account in the punching shear analysis and the calculation of the punching shear reinforcement in accordance with the NA for Germany.

### Punching shear analysis as per EN 1992 - with column head enlargement

Note: For isolated foundations head reinforcements are no longer permitted.

#### Designations as per EN 1992 6.2.4 (8)-(11)



III.: Punching shear as per EN 1992 figure 6.17 or 6.18 with column head enlargement

$h_H$  height of column head

$L_H$  length of column head (distance of column head edge to column edge)

$L_C$  diameter of side length of the column

An enlargement is considered as being circular when equal head lengths are specified for a circular column, otherwise a rectangular enlargement (outline) is assumed.

The term  $r_{crit}$  instead of  $r_{cont}$  is used for the distance of the critical perimeter in the above illustration.

For  $l_H < 2h_H$  (compact column head), the punching shear resistance must be verified outside of the column head enlargement. For  $l_H < 2h_H$  (slender column head), the punching shear resistance must be verified inside and outside of the column head enlargement.

As specified by the NA Germany /2/, the verification limit  $l_H < 2h_H$  is to be replaced by  $l_H < 1.5h_H$ . For column head enlargements with  $1.5h_H < l_H < 2.0h_H$ , an additional verification is required at a distance of  $1.5(d + h_H)$ .

#### Punching shear analysis for the column head enlargement

The punching shear analysis of the column head enlargement is similar to the verification of the unreinforced slab. As static height in accordance with Para. 6.4.2(10), the static height  $d_H$  at the face of the column head enlargement is taken into account.

The reinforcement ratio of the longitudinal reinforcement is matched to the static height in a corrective calculation:

$$\rho_l = \rho_l \cdot \frac{d_m}{d_H} \quad \text{with} \quad d_H = d_m + h_H$$

The area of the column cross section is considered to be the load introduction area  $A_{load}$ . The specifications concerning the spacing of the perimeters in the output refer to the outer column edge. If required by the selected NA, the length of the critical perimeter is checked against the permissible value.

### **Punching shear analysis outside of the column head enlargement**

The punching shear analysis of the column head enlargement is similar to the verification of the unreinforced slab.

The cross section of the head enlargement is considered as the load introduction area. The specifications concerning the spacing of the perimeters in the output refer to the outer edge of the head enlargement. If required by the selected NA, the length of the critical perimeter is checked against the permissible value.

We like to point out at this occasion that the punching shear resistance is not always increased in comparison to the shear resistance in connection with slender head enlargements (see also Interpretation of DIN 1045-1, current number 268 by the German Building and Civil Engineering Standards Committee NABau).

### **Further comments on the column head enlargement**

If punching shear reinforcement is required inside and outside of the column head enlargement, the  $A_s$ -values of the first two reinforcement rows inside and outside of the head enlargement must be multiplied with the alignment factors 2.5 or 1.4 specified by the NA Germany /2/ or 1.6 specified by the NA Austria /6/.

A pre-design of the column head enlargement is available for slabs. The dimensions are selected in such a manner that no punching shear analysis is required inside the head enlargement and no punching shear reinforcement is required for the slab outside of the column head enlargement.

The proposed head dimensions are calculated by iteration. The user can still reduce the iteratively determined head dimensions, if required.

If the punching shear resistance cannot be verified despite the head enlargement, a value of "1" is proposed for LH. The verification-light on ribbon bar shows red.

If a head enlargement is required, the value 1 is displayed for hH and LH.

For foundation slabs and compact foundations, no pre-design of the head enlargement is performed because the double iteration for the determination of the critical perimeter and the calculation of the head dimensions would take a relatively long time. This would slow down the input process considerably because the double iteration is performed each time a new value is entered.

### Punching shear reinforcement as per EN 1992

The required cross-sectional area  $A_{sw}$  is calculated on the basis of the concrete quality and the inclination angle of the punching shear reinforcement. The punching shear reinforcement should be installed with a closer spacing within the spacing range of  $1.50 \cdot d_m$ ; 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 nationally defined distance 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.

The layout of the punching shear reinforcement is determined by the stipulations of EN 1992 Para. 9.4.3.

Bar diameter  $d_s \leq 0.05 \cdot d_m$ , oblique bars  $d_s \leq 0.08 \cdot d_m$

If only a single reinforcement row is statically required when using stirrups, always a second row with a minimum reinforcement of  $s_r = 0.75 \cdot d_m$  should be arranged for. If oblique bars are installed, the software application requires two reinforcement rows as specified by the NA Germany. The control perimeter lies on the intersection point of the slab axis and the oblique bar.

### Vertical stirrup reinforcement

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  $\leq 2.0 d_m$  in the outer perimeter

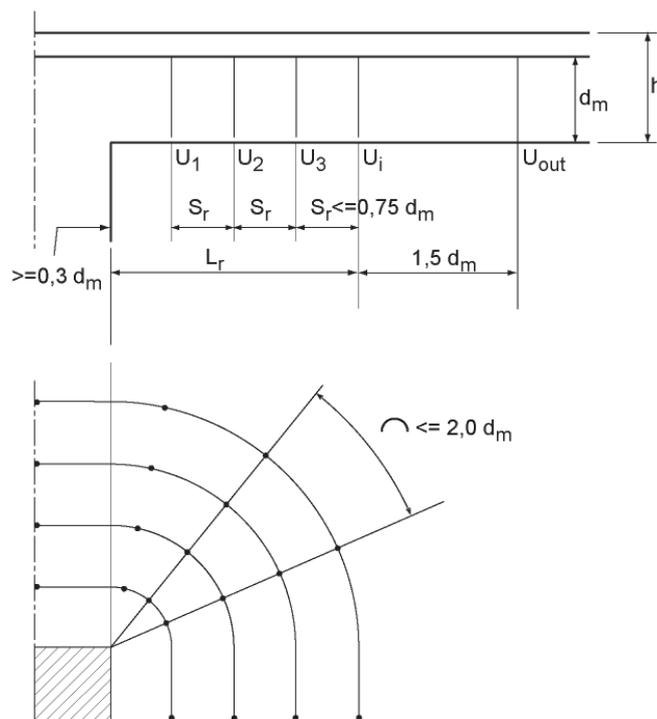
III.:

*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:  $\leq 2.0 \cdot d_m$*

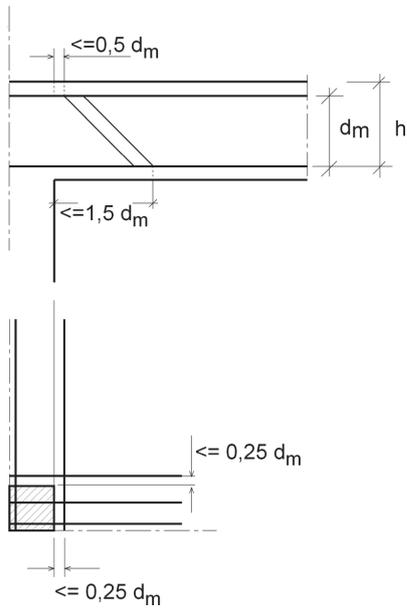


**Oblique bars**

Inclination:  $45^\circ \leq \alpha \leq 60^\circ$  angle to the slab plane

Spacing:  $\leq 0.5 \cdot d_m$  to  $\leq 1.5 \cdot d_m$

Maximum reinforcement projection:  $\leq 0.25 \cdot d_m$



*Ill.: Punching shear reinforcement with oblique bars as per NA Germany*

### Punching shear analysis with shear connector rails

B6+ allows the design of shear connector rails as per ETA approval for DIN EN 1992:2012, DIN EN 1992:2013, DIN EN 1992:2015, ÖNORM EN 1992:2011 and BS EN 1992:2009 and BS EN 1992:2015 (see reference /18/ to /20/).

Shear connector rails of different manufacturers (Schöck, Halfen, Jordahl) are available for selection.

In accordance with reference /15/ to /17/, the concrete strength class for the punching shear analysis with shear connector rails must not be lower than C20/25 and not higher than C 50/60. In B6+, only the permissible concrete strength classes are available.

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).

In the case of edge or corner supports with large edge projections of the ceiling or of the foundation plate, it is possible to choose between 2 types of the shear connection rail arrangement (edge-parallel or segment-shaped).

Editing is possible on the "position of stud rails" 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:

- Total number of required shear anchors for the C-area
- Number of shear anchors on a rail (separately for the C- and D-areas)
- 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.

If there are any holes, you should check, whether the actual tangential distance of the edge connector rails to the sector borders has a reasonable magnitude (the sector borders are tangent to the hole and run through the centre of the column).

The design of the shear connector rails is only available for unreinforced slabs (no head reinforcement).

Design			
punching shear reinforcement		with stud rails	▼
Stud rails		Schöck BOLE	▼
reinforcem ratio	Rho	[%]	1.000
design Schöck BOLE			
chosen stud rail		14 mm, 8*( 2C+ 1D)	▼
Reset strips			...
number of rails/column	nL		8
number of studs/rail	nD		3
concr. cover:	co	[cm]	2.0
	cu	[cm]	2.0
accept proposal in output			<input checked="" type="checkbox"/>



position of stud rails			
position of stud rails	4/8		
distance	x	[cm]	15.0
distance	y	[cm]	20.0
angle	Phi	[grad]	146.0

If the permissible border conditions for the load introduction area are not complied with ( $u_0 / d_m > 12$ , and/or.  $c_{max} / c_{min} > 2$ ), you should divide the column cross section into two wall ends or four wall corners to design it, because the shear rail connectors are only effective in the area of the critical perimeter. If the limits of the afore-mentioned border conditions are only slightly exceeded, you can relocate individual connector rails.

*Note: For foundation slabs with shear connector rails, a  $C_{Rdc}$ -value of 0.10 ( $= 0.15 / \gamma_c$ ) is used in the verification of the critical perimeter analogously to foundation slabs with punching shear reinforcement.*

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

In the design of the shear connector rails preferably the standard elements are taken into account

For more detailed information on the verifications, see reference [/18/](#).

### **Punching shear analysis with lattice girders (interface to FILIGRAN software)**

If you have installed the FILIGRAN design program ProFi 4.0, you can start it with the FILIGRAN icon. B6 + transfers the data to the program with which the FILIGRAN® punching reinforcement FDB II can be dimensioned. See also [www.filigran.de](http://www.filigran.de)



## 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	automatically	

Graphics Document
95.9%
Page 2 of 2
Start page: 1 Page layout

Pages Bookmarks

Page 1

Page 2

**Friolo Software**

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Position: B6-001  
12/2/2019

Seite: 2

**Results**

Analysis for Schöck BOLE:

Given shear force  $V_e = 850.0$  kN  
Increase  $\beta = 1.100$

crit. contour perimeter  $u_1 = 466.7$  cm (on  $a_{crit} = 52.0$  cm)  
Design shear force  $V_{Ed} = 0.771$  N/mm<sup>2</sup>  
Prefactor  $C_{Red,c} = 0.120$   
Scale factor  $k = 1.877 < 2.0$   
Design resistance  $VR_{d,c} = 0.634$  N/mm<sup>2</sup>  
 $V_{min} = 0.450$  N/mm<sup>2</sup>  
max. design resistance  $VR_{d,max} = 1.242$  N/mm<sup>2</sup> ( $= 1.96 * VR_{d,c}$ )  
exist reinforc. ratio  $exist p = 0.890$  % (at  $a = 78.0$  cm)

Result:  $VR_{d,c} < V_{Ed} \leq VR_{d,max}$  Punching shear reinforcement required

Punching reinforcement with Schöck-BOLE acc. to ETA-13/0076 (March 2018)

outer control perimeter : req  $u_{out} = 686.6$  cm exist  $u_{out} = 802.9$  cm req  $L_s = 48.0$  cm exist  $L_s = 66.5$  cm

Increase  $\beta_{red} = \beta = 1.100$  (user defined)  
Design shear force  $V_{Ed} = 0.448$  N/mm<sup>2</sup>  
Design resistance  $VR_{d,c} = 0.523$  N/mm<sup>2</sup>  
 $V_{min} = 0.450$  N/mm<sup>2</sup>

max perm. distance at  $d_m = 44.0$  cm  $\geq$  exist.distance at  $d_m = 38.3$  cm  
at  $L_s = 91.0$  cm  $\geq$  at  $L_s = 67.6$  cm  
on stud rail = 20.0 cm  $\geq$  on stud rail = 19.0 cm

Note:  $L_s$  is the distance from the column edge to the outermost one stud.

Studs : B500A,  $\phi = 14$  mm,  $F_{t,d} = 63.1$  kN,  $F_{s,d} = 58.4$  kN, Height = 26.0 cm  
Studs req. : 15 piece area C + 8\*2 pcs Zone D  
Studs sel. : 8 Rails \*(2C + 2D) bolt = 32 pcs-tot  
Covering above/ below Studs :  $c_{bot} = 2.0$  cm,  $c_{top} = 2.0$  cm

Selected type of rails per column :  
8\*Schöck BOLE 14 - 260 - 4 / 760 - 20(95/190/190/95)

Ultimate reinforcement bellow  $A_{su} \geq 12.1$  cm<sup>2</sup> ( $A_s = V_{Ed}/f_{yk}$ ,  $\gamma_F = 1.0$ )

Shear rails arrangement

Nr	$x_a$ cm	$y_a$ cm	$x_e$ cm	$y_e$ cm	Phi deg
1	15.0	0.0	81.5	0.0	0.0
2	15.0	20.0	63.8	65.2	42.8
3	0.0	20.0	0.0	86.5	90.0
4	-15.0	20.0	-63.8	65.2	137.2
5	-15.0	0.0	-81.5	0.0	180.0

## Reference literature

- /1/ EN 1992-1-1:2004 / AC:2010
- /2/ DIN EN 1992-1-1 / NA:2011-01
- /3/ DIN EN 1992-1-1 / NA Ber 1:2012-06
- /4/ E DIN EN 1992-1-1 / NA / A1:2012-05
- /5/ ÖNORM B 1992-1-1:2007-02-01
- /6/ ÖNORM B 1992-1-1:2011-12-01
- /7/ DIN EN 1992-1-1 / NA:2013-04
- /08/ EN 1992-1-1:2004
- /09/ Draft for Booklet 600, Erläuterungen zu Eurocode 2, DAfStb
- /10/ Ricker M., Siburg C., Hegger J.: "Durchstanzen von Fundamenten nach NA(D) zu Eurocode 2" in: Bauingenieur, 06/2012 pages 267 to 276
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- /13/ Goris A., Hegger J.: "Hintergründe und Nachweise zum Durchstanzen nach Eurocode 2-NAD" in "Stahlbetonbau aktuell 2011", Bauwerk Verlag, S. E.3 et seq.
- /14/ Goris A., Hegger J.: "Durchstanzen" in "Stahlbetonbau aktuell 2012", Bauwerk Verlag, S. D. 80 et seq.
- /15/ Halfen HDB Dübelleiste, Europäische Technische Zulassung ETA-12/0454 vom 18.12.2017
- /16/ Durchstanzbewehrung Schöck Bole, Europäische Technische Zulassung ETA-13/0076 vom 12.03.2018
- /17/ Jordahl Durchstanzbewehrung JDA, Europäische Technische Zulassung ETA-13/0136 vom 20.03.2018
- /18/ DIN EN 1992-1-1 / NA:2015-12