Punching shear B6

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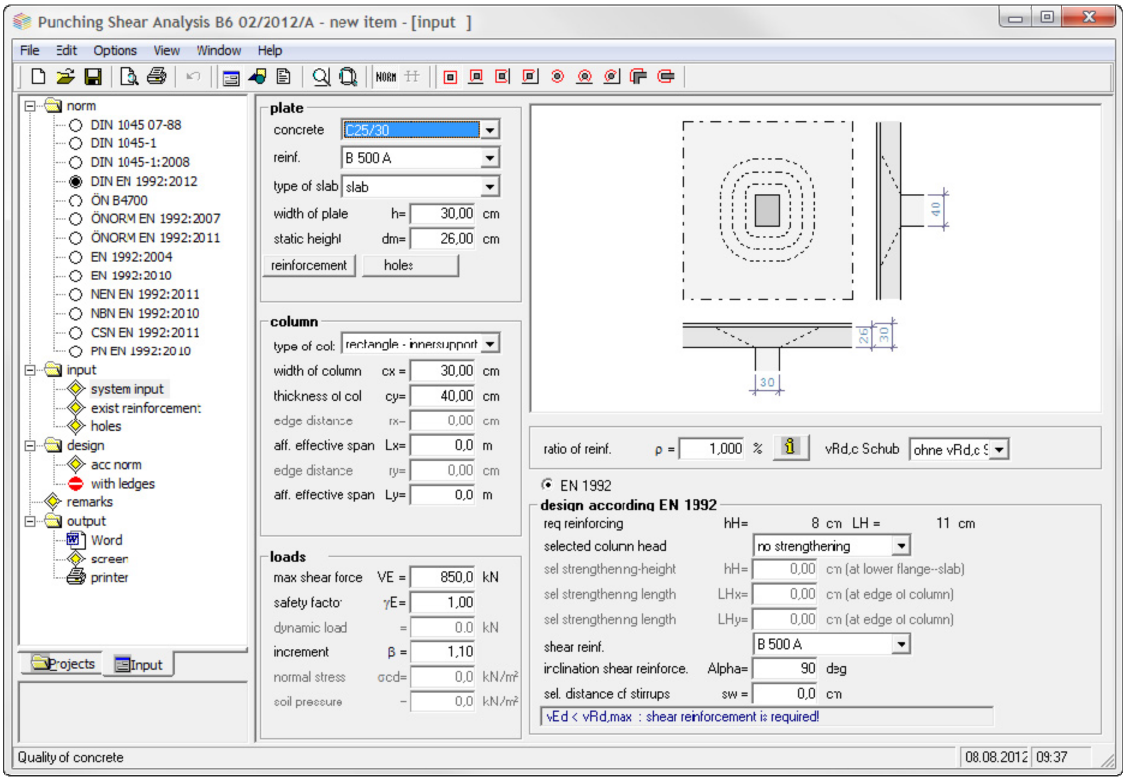


Punching shear B6

Note: *This document describes the **Eurocode-specific application**. Documents referring to former standards are available in our document archive at* *www.frilo.de >> Service >> Documentation >>Manuals>Archive.*

Contents

Further information and descriptions are available in the relevant documentations:

Basic operating instructions.pdf	General operating instructions for the user interface of Frilo applications
FCC	Frilo.Control.Center - the easy-to-use administration module for projects and items
FDD	Frilo.Document.Designer - document management based on PDF
Frilo.System.Next	Installation, configuration, network, database
Menu items.pdf	
Output and printing	
Import and export.pdf	

Application options

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

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 our without enlarged head.

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

- DIN EN 01/01/1992/NA: 2011 + DIN EN 1992-1-1/NA Ber 1:2012-06
- ÖNORM B 1992-1-1:2007
- ÖNORM B 1992-1-1:2011
- NEN EN 1992-1-1+C2/NB:2011
- NBN EN 1992-1-1 ANB:2010
- CSN EN 1992-1-1:NA:2011
- PN EN 1992-1-1/NA:2010

The original version of Eurocode EN 1992-1-1:2004 is available as an additional option.

The B6 application allows the calculation of punching shear problems on plates, foundation slabs, compact foundations and enlarged column heads.

The shear force design resistances are calculated in the decisive critical perimeters in accordance with the applicable NA for the areas around column 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.

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.

Approvals for shear rails based on the Eurocodes are not available yet (B6 version 92/2012).

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 /12/ and /16/.

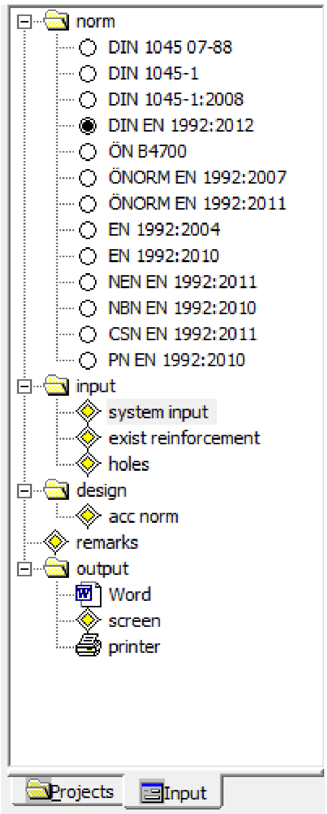
For the solution of an actually existing punching shear problem, it is important to map the structural problem correctly in the software and define an adequate decisive length of the circular cross section. If the load transfer is non-uniform, local peak loading should be compensated with the help of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

In the course of the ongoing software development, we plan implementing a calculation of the β-factors in accordance with Para. 6.4.3 (3).

Input

Standard selection

Select the desired standard from the list.



Input of the system

Slab

Material selection

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.

Type of slab

You can select among the slab types:

- Floor slab

- Foundation slab

- Compact foundation

For the foundation slab and the compact foundation, the area inside the critical perimeter a_{crit} is always 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

Slab thickness:

h [cm] >= 20 cm as per EN 1992 Para. 9.3.2 slab with punching shear reinforcement

Average effective height	d_m [cm]	= h - co - dsl
with foundation	d_m [cm]	= h - co - dsl

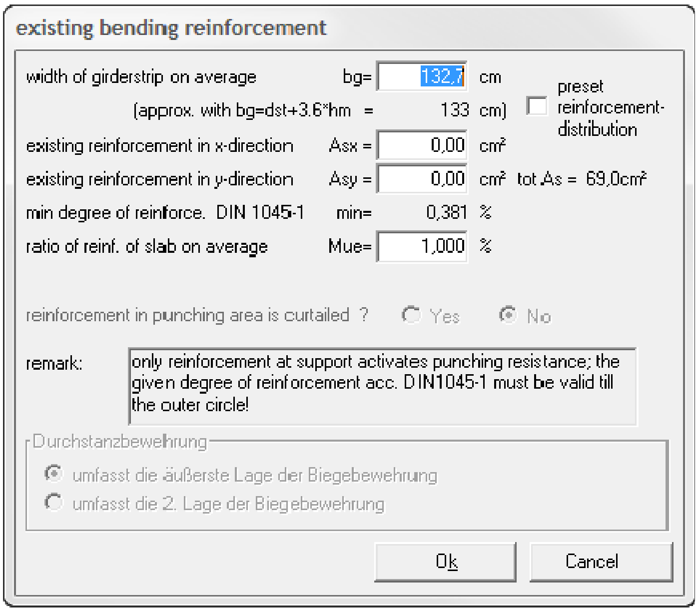
h	slab thickness
cu/co	upper/lower concrete cover
dsl	diameter of the longitudinal reinforcement

Additional buttons provide access to the input dialogs for the existing bending reinforcement and the block-outs.

Longitudinal reinforcement

The input dialog for bending reinforcement is accessible via the button [reinforcement].

Alternatively, the user can enter the reinforcement ratio mu (µ) or rho (ρ) manually in the corresponding input fields of the user interface.



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.

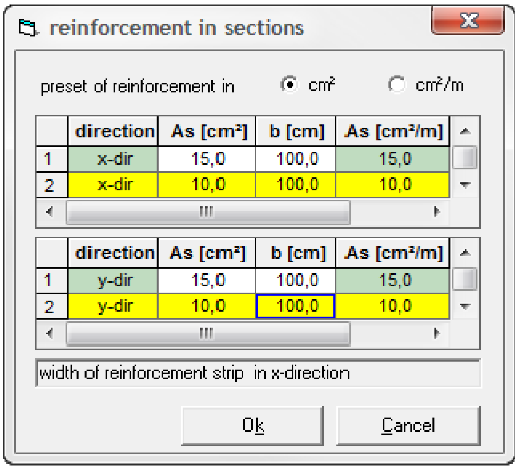
We recommend specifying a value of 100 cm for "bg". The required As is then indicated per linear meter. The pre-set reinforcement ratio must be guaranteed up to the outermost control perimeter. The required span is specified as "erf bg".

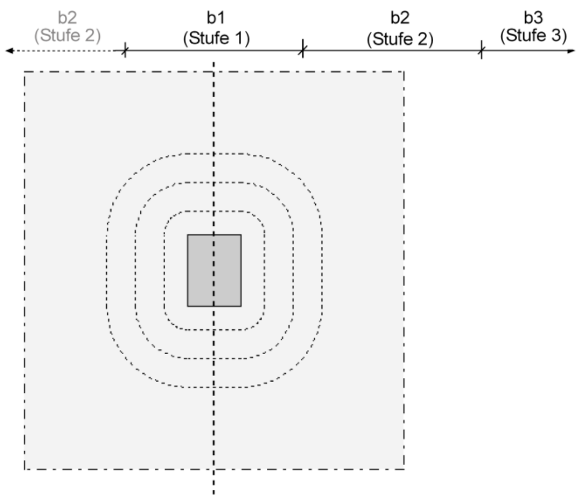
Presetting of the reinforcement distribution

Sectioned reinforcement can be defined in three different areas for the design.

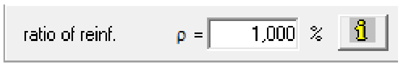
A_{s1} and b1 describe the central column area, A_{s2} and b2 the adjacent transition areas and A_{s3} the average reinforcement in the remaining slab area. You can optionally specify the reinforcement with the unit cm^2 or cm^2/m. b1/2/3 correspond to the different rows of the sections 1/2/3.

b1 (section 1) **b2 (section**





Bending reinforcement ratio



When entering the bending reinforcement ratio or calculating it from the pre-set As 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 (ρ in %) manually as a mean value. Otherwise, the software application calculates this value automatically by referencing the reinforcement cross section areas A_{sx} [cm^2] and A_{sy} [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 As values are specified per linear metre.
The required column strip width "erf bg" describes the statically required minimum width or diameter on an ideal interior column system based on the calculation results.

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.

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)).

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

$\max\rho \le 2.0\%$ according to the German NA /2/ the following applies in addition: $\max\rho \le 0{,}5\frac{f_{cd}}{f_{yd}}$

(NDP) 6.4.4 (1)

According to the Austrian NA /6/ the following applies in addition: $\max\rho \le 0{,}4\frac{f_{cd}}{f_{yd}}$

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

Since shear reinforcement can extend very far into the slab area in verifications, three different reinforcement areas can be pre-set in x and y direction. The reinforcement ratio is re-assessed in each current control perimeter. It is the mean value of the existing steel bars referenced to the perimeter area.

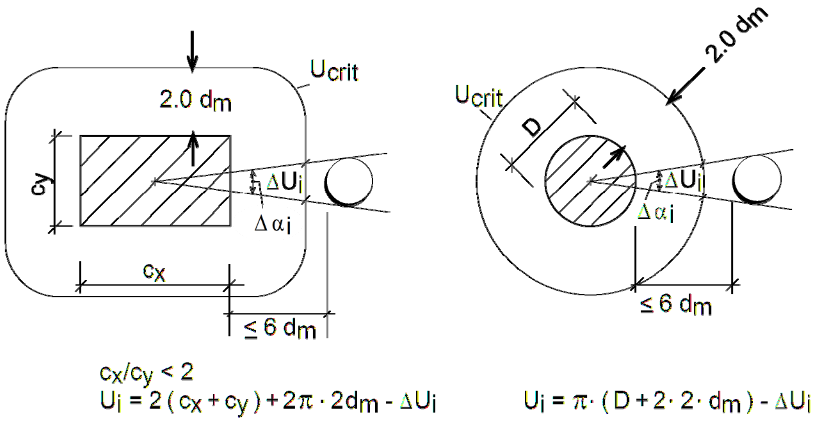
A_{s1} and b1 describe the central column area, A_{s2} and b2 the adjacent transition areas and A_{s3} the average reinforcement in the remaining slab area. You can optionally specify the reinforcement with the unit cm^2 or cm^2/m.

Block-outs

Block-outs can be taken into consideration with all kinds and types of columns.

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

The sum of the length deductions ΔU_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.

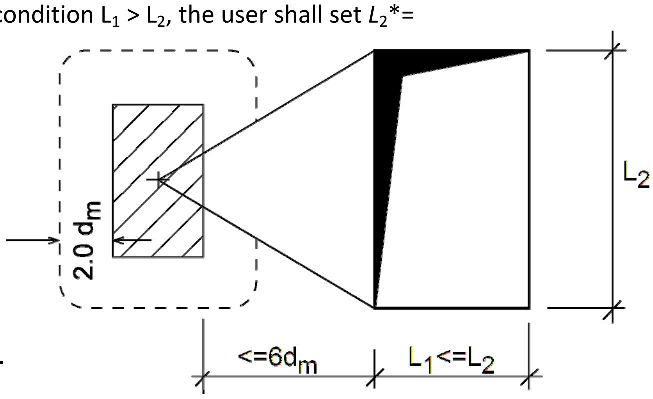


Ill.: *Inner perimeters (interior columns) for the perimeter deduction ΔU_i as per EN 1992-1-1*

The relation between the deduction length ΔU_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 block-out for a staircase, for instance, the edge column type should be used instead of the interior column type in combination with a block-out. The column type with the lower perimeter length should be used as an initial system. In the proximity of staircase block-outs, 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 block-out width.

- For the condition $L_1 > L_2$, the user shall set L_2^*=



$\sqrt{L_1 \cdot L_2}$

Ill.: Large block-outs

Direct pre-setting of individual block-outs

The pre-definition of rectangular or circular block-outs in the x-y system of coordinates allows the determination of the reduction values for the length deduction ΔU_i and the angle deduction $\Delta\alpha_i$ in the decisive perimeter areas.

The definition of individual block-outs 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 block-outs.

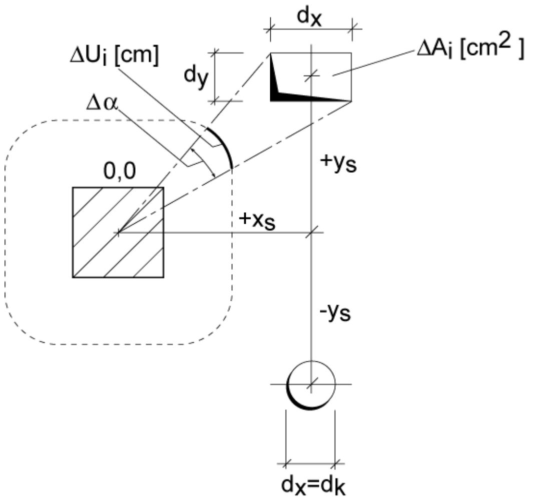
With larger block-outs, we recommend using the edge or corner column type instead. If the software application does not allow the definition of a large block-out, it can be approximated by defining several smaller ones. It is important for the verification that the perimeter deduction is mapped correctly.

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

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

The block-out should be outside of the centre of the column and enclosed in an opening angle below 45° if possible.

For block-outs that are not calculated by the software application striking numerical values are displayed ($\Delta A_i = 999$ $\Delta U_i = 999$ $\Delta\alpha_i = 360°$).



Ill.: Definition for the input of individual block-outs

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 block-out. In any case, the user should check the plausibility of the total results and the deduction lengths resulting for the block-outs in particular.

The deduction lengths of the block-outs are extrapolated or interpolated to the spacing of the perimeters in question.

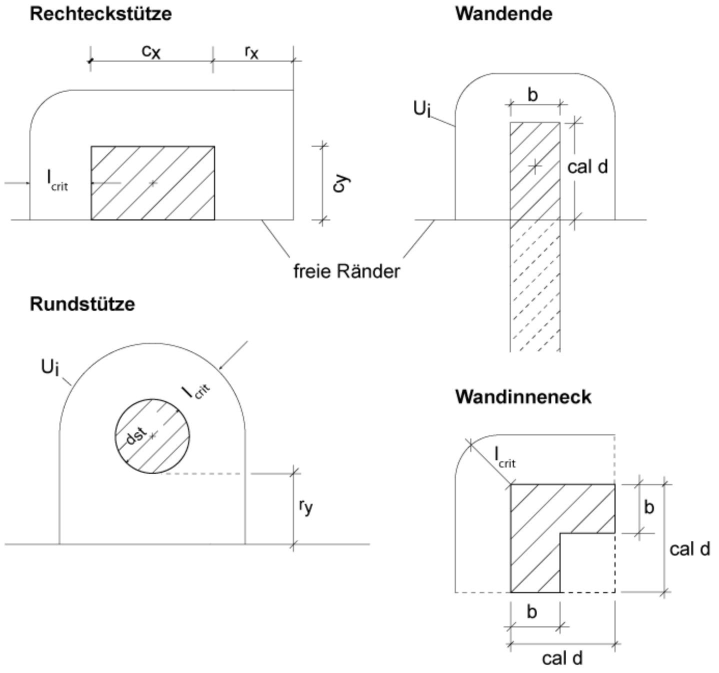
Distance to the edge

For edge columns, the user can pre-set the distance to the edge r_x [cm] or r_y [cm] 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 [cm] and r_y [cm] 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*

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 β 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. /12/ or /16/ is suitable for the estimation of this factor.

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/) and 15 % as per NA Netherlands /7/. 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 β value of 1.35 for wall ends and 1.2 for wall corners. Other β 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:

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

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

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

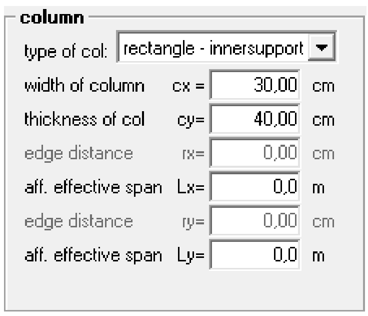
$b_1 = \min\{b; 2.8d\}$, $a_1=\min\{a; 2b; 5{,}6d-b_1\}$ NA Austria /6/ Para. 9.4.1

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.

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

Lx supporting width in y-direction pertaining to ry

D diameter of circular column

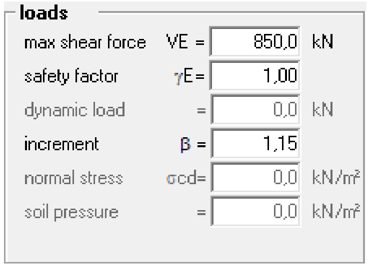
b pre-set wall thickness (wall end or interior wall corner)

d affected length defined for the load introduction area of the wall

Lx and Ly are used as length values for the graphical representation of an isolated foundation.

Loading

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.

In order to facilitate the switching over between standards for reasons of comparison, a safety factor **γE** 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 · γE. If a result was produced in accordance with the combination rules of EN 1992, the value γE should be set to 1.0.

Foundation - soil pressure

If a foundation slab or a compact foundation was selected instead of a floor slab, the column load and the soil pressure must be entered. In accordance with EN 1992 NA Germany, 100 % of the soil pressure inside the critical perimeter determined by iteration may be deducted.

Total load factor

The shear design force should be increased by a factor β 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:

β = 1.10 for general interior columns

β = 1.15 for interior columns as per NA Austria /6/ and Netherlands /7/

β = 1.40 for edge columns

β = 1.50 for corner columns

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

β = 1.35 for the wall end and

β = 1.20 for the interior wall corner

Other β values can be assessed in closer examinations.

The automatic assessment of the β value as per EN 1992-1-1-: 2010, Para. 6.4.3 (3) is not currently not implemented.

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

Soil pressure

For foundation slabs, the user can enter a soil pressure to be included in the decisive combination in addition to the column load. The shear force VEd is calculated in accordance with the standard-specific restrictions of actions.

Design

The design method is selectable via the main tree

- as per EN 1992-1-1:2010

- as per DIN EN 1992-1-1:2012

- as per ÖNORM EN 1992-1-1:2007

- as per ÖNORM EN 1992-1-1:2011

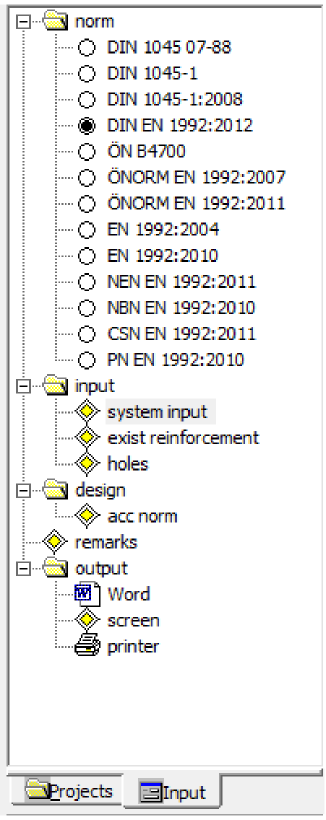
- as per NEN EN 1992-1-1:2011

- as per NBN EN 1992-1-1:2010

- as per CSN EN 1992-1-1:2011

- as per PN EN 1992-1-:2010

- as per EN 1992-1-1:2004



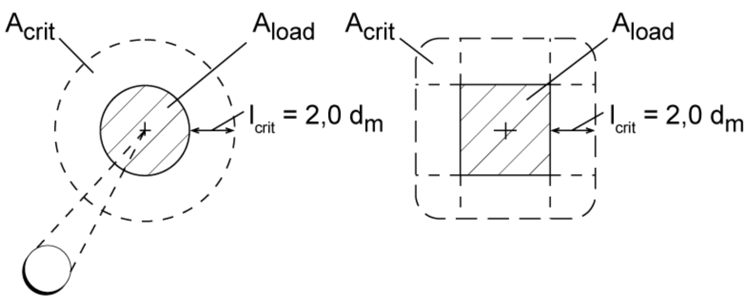
EN 1992:2010

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 floor 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.



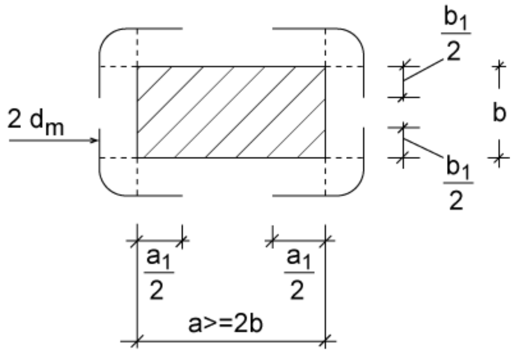
Ill.: Critical perimeter around load introduction areas as per EN 1992, 6.4.2

Conditions for punching shear as per EN 1992

The geometric dimensions of the load introduction area are only limited in the NA Germany /2/ and /3/ 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.

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

$u_0 \leq 12 \cdot d_m$	(circle)	as per NA Germany
$D \leq 3{,}5 \cdot d_m$	(circle)	as per NA Austria
$u_0 \leq 12 \cdot d_m$	(rectangle)	as per NA Germany
$u_0 \leq 11 \cdot d_m$	(rectangle)	as per NA Austria



Ill.: 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:

$b_1 \leq 3.0 \cdot d_m \leq$ exist.b = min(cx,cy) as per NA Germany

$b_1 \leq 2.8 \cdot d_m \leq$ exist.b = min(cx,cy) as per NA Austria

$a_1 \leq 6.0 \cdot d_m - b_1 \leq 2 \cdot$ exist.b $\leq$ exist.a = max(cx,cy) as per NA Germany

$a_1 \leq 5.6 \cdot d_m - b_1 \leq 2 \cdot$ exist.b $\leq$ exist.a = max(cx,cy) 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 floor slabs. This increases the limit for the installation of punching shear reinforcement. The total resistance $v_{Rdc,g}$ (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.

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

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

$v_{Rd,max}$ 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.

β	=	correction factor for non rotation-symmetrical load introduction
β	=	1.10 for interior columns (1.15 as per NA Austria and Netherlands)
β	=	1.40 for edge columns
β	=	1.50 for corner columns
β	=	1.35 for the wall end
β	=	1.20 for the interior wall corner

Other β values can be assessed in closer examinations.

V_{Ed}	=	existing shear force in the ultimate limit state
u	=	circumference of the considered perimeter minus the perimeter deduction due to the block-outs 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 block-outs.

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

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

Alternatively, the user can include the shear resistance as per Para. 6.2 for floor 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 / γc or as per NA
k_1	=	0.1 or as per NA

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

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

$$v_{min} = 0,035 \cdot k^{1,5} \cdot fck^{0,5} \qquad (6.3N)$$

According to NA Germany the following applies:

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

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

It is permissible to interpolate the intermediate values.

ρ_l = average longitudinal reinforcement ratio in the examined perimeter

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

Additionally applies:

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

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

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

σ_{cd} = design value of the axial concrete stress in [N/mm²] inside the examined perimeter:

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

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

with σ_{cd} (+ = pretension, - = tensile stress) sign definition as per EN 1992

a = distance from perimeter to face

In the current version of the B6 application (B6 02/2012), axial concrete stress cannot be considered in the punching shear analysis in accordance with the Eurocode.

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.

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.

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

Moment coefficients ηx , ηy :

	η_x	η_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

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:

$v_{Rd,c} \leq vR_{d,cs} \leq v_{Rd,max}$

The following equation applies to each reinforcement row:

$$v_{Rd,cs} = 0{,}75 \cdot v_{Rd,c} + 1{,}5 \cdot \frac{(d/s_r) \cdot A_{sw} \cdot f_{ywd,ef}}{u_1 \cdot d_m} \cdot \sin(\alpha)$$ 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 block-outs at a distance < $6{\cdot}d_m$.

s_r = effective width of one single reinforcement row; $s_r \leq 0{,}75 \cdot d_m$

$v_{Rd,max} = 0{,}4 \cdot \nu \cdot f_{cd}$

$v_{Rd,max} = 0{,}5 \cdot \nu \cdot f_{cd}$ as per NA Belgium and NA Austria to ÖNorm B 1992-1-1; 2007

with

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

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

Oblique bars as punching shear reinforcement

The bars must be installed with an inclination angle of 45 ° <= α <= 60° 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 · d = 1.5 · 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:

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

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

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

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

$f_{ywd,ef} = 250 + 0{,}25 \cdot d_m \leq f_{ywd}$	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
α	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.

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

$$\min A_{sw} = [0{,}08 \cdot \frac{\sqrt{f_{ck}}}{f_{yk}} / (1{,}5 \cdot \sin(\alpha) + \cos(\alpha))] \cdot (s_r \cdot u_i)$$

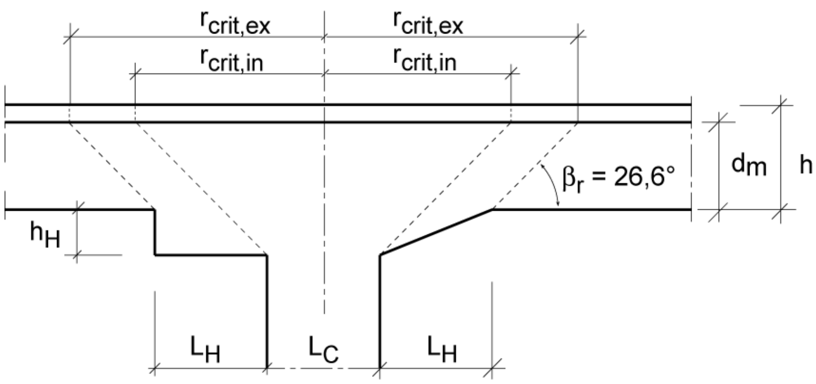
$$\min A_{sw} = [0{,}08 \cdot \frac{\sqrt{f_{ck}}}{f_{yk}} / (1{,}5 \cdot \sin(\alpha))] \cdot (s_r \cdot u_i)$$ for Germany in accordance with /14/

For foundation slabs and compact foundations, the foundation self-weight is automatically taken into account. 1.35 is assumed as safety factor.

The shear force to be taken into account in the calculation of foundation slabs and compact foundations can be reduced by the portion ΔV_{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). 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 ΔV_{Ed}.

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

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



Ill.: 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 As-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 floor 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 99999 is proposed for LH.

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·d_m; at least two reinforcement rows are proposed. The reinforcement perimeters extend from U_1 at a spacing >= 0.3·d_m from the outer edge of the column to a nationally defined distance to the outer control perimeter U_a, which is determined with the help of the expression $v_{Ed,a} \approx v_{Rd,a}$. For reinforcement perimeters, the condition $s_w \leq 0.75 \cdot d_m$ 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 $s_w = 0.75 \cdot d_m$ 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

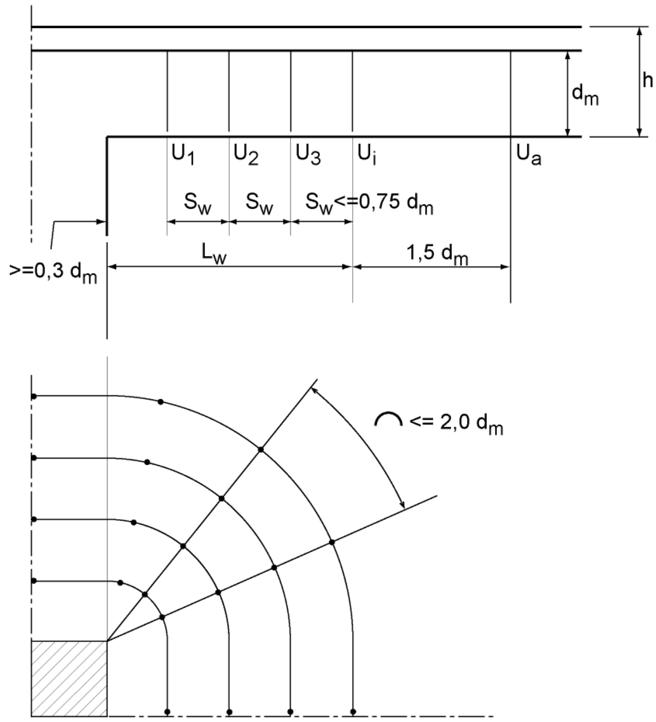
Distance:

U_1:	to the outer edge of the column 0.5·d_m
U_2 to U_i:	s_w
U:	from U_i 1.5·d_m (only verification)

Maximum radial reinforcement spacing:	s_w	≤ 0.75·d_m
maximum tangential reinforcement spacing		≤ 1.5·d_m in the critical perimeter
maximum tangential reinforcement spacing		≤ 2.0d_m in the outer perimeter

Ill.:

Punching shear reinforcement with vertical stirrups EN 1992 9.4.3
Tangential spacing inside the critical parameter:
<=1.5 · d_m,
and outside: <=2.0 · d_m

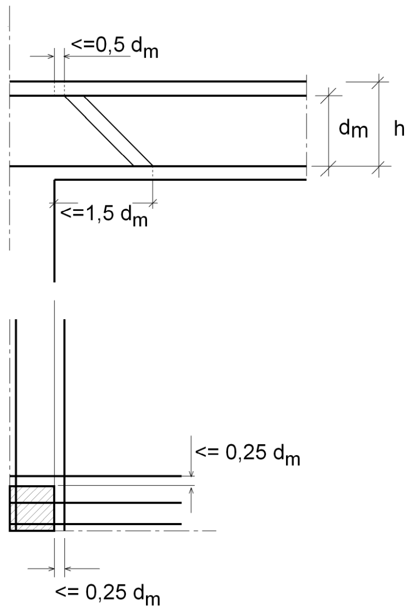


Oblique bars

Inclination: 45° ≤ α ≤ 60° angle to the slab plane

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

Maximum reinforcement projection: ≤ $0.25 \cdot d_m$



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

Output

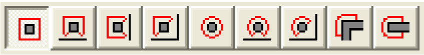
Output of the system data, results and graphical representations on the screen or the printer.

The Output item in the main tree allows you to start the output on a printer or the screen.

Word	output to MS-Word, if this software is installed on the computer
Screen	displays the values in a text window on the screen
Print	starts the output on the printer

File >> Page view displays a print preview as a PDF

The buttons



display different types of graphics.

The function of the different buttons is indicated per tool tip (point with the cursor to the button)

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/ NEN EN 1992-1-1+C2 / NB:2011

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/9/ CSN EN 1992-1-1 NA ed. A Prosinec 2011

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/12/ Draft for Booklet 600, Erläuterungen zu Eurocode 2, DAfStb

/13/ 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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/15/ Beispiele zur Bemessung nach Eurocode 2, volume 1: Hochbau, 2011 Verlag: Wilhelm Ernst und Sohn

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/17/ Goris A., Hegger J.: "Durchstanzen" in "Stahlbetonbau aktuell 2012", Bauwerk Verlag , S. D. 80 et seq.