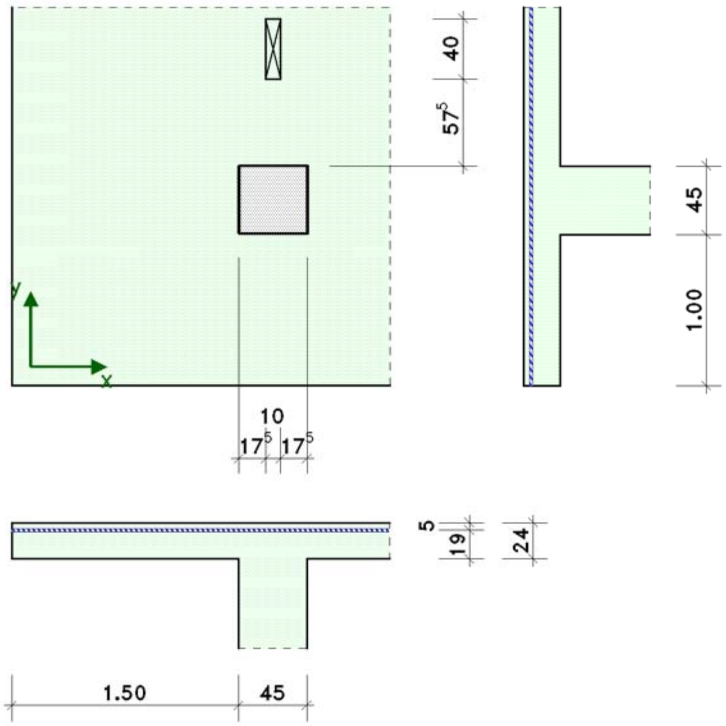
POS. 50: CORNER COLUMN BELOW FLOOR SLAB WITH OPENING

Punching shear calculation of column below floor slab

Acc. to DIN EN 1992-1-1 (EC 2, 1.11) with National Annex Germany
(4H-STANZ version: 8/2012-1a)

scale 1:50



anchored tension reinforcement
$a_{s,zug,x}$ = 31.42 cm²/m
$a_{s,zug,y}$ = 31.42 cm²/m

concrete strength class **C35/45**
steel class **BSt 500 S(A)**

1. Load

design values of punching shear load in centroid of load distribution

LK	notation	design situat.	V_{Ed} kN	$M_{Ed,x}$ kNm	$M_{Ed,y}$ kNm
1	full load	permanent	400.00	100.00	50.00
2	accidental load	accident.	650.00	300.00	150.00

V_{Ed} - shear force $M_{Ed,x}/M_{Ed,y}$ - moments

2. Material safety factors

design situat.	γ_c	γ_s
permanent	1.50	1.15
accident.	1.30	1.00

3. Action within the basic control perimeter

$v_{Ed,crit} = \beta \cdot V_{Ed}/(u_1 \cdot d)$
$\beta = 1 + \text{sqrt}((k_x \cdot M_{Ed,x}/V_{Ed} \cdot u_1/W_{1,x})^2 + (k_y \cdot M_{Ed,y}/V_{Ed} \cdot u_1/W_{1,y})^2) \geq 1.10$
$W_1 = \int |e|\, dl$ mit dl:differential of perimeter
e :distance of dl to axis of M_{Ed}

coefficient for the calculation of shear stresses from moment action
(acc. to [1], table 6.1)
$c_1 = c_2 = 0.45 \Rightarrow k_x = k_y = 0.6$

distance and length of the basic control perimeter
$a_1 = 2 \cdot d = 38$ cm $\Rightarrow u_1 = 4$ m

moment of resistance alongside the basic control perimeter
- at moment action about the x-axis $W_{1,x}$ = 2.14 m²
- at moment action about the y-axis $W_{1,y}$ = 2.66 m²

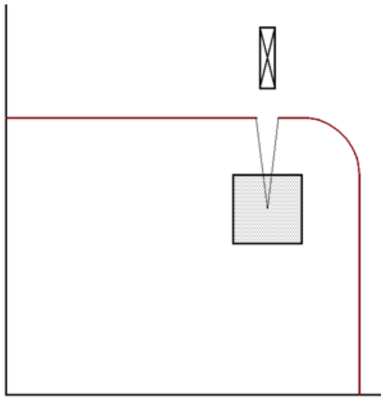
distance between control perimeter and centre of column

Δx = -0.08 m
Δy = 0.17 m

LK	V_{Ed}	$M_{Ed,x,Sp}$	$M_{Ed,y,Sp}$	β	$v_{Ed,crit}$
-	kN	kNm	kNm	-	N/mm²
1	400.00	33.23	81.89	1.21	**0.635**
2	650.00	191.50	201.81	1.43	**1.226**

W_1 - moment of resistance alongside the basic control perimeter $M_{Ed,x,Sp}/M_{Ed,y,Sp}$ - moments concerning centre of control perimeter
β - load increase factor from eccentric load $v_{Ed,crit}$ - decisive shear stress within the basic control perimeter

4. Punching shear resistance within the basic control perimeter



$v_{Rd,c} = C_{Rd,c} \cdot k \cdot (100 \cdot \rho_{l,zug} \cdot f_{ck})^{1/3} \geq v_{min}$ [N/mm²]
$C_{Rd,c} = 0.18/\gamma_c$
$k = 1 + \text{sqrt}(200/d) \leq 2.0$ with d [mm]
$\rho_{l,zug,max} = \min(0.02,\ 0.5 \cdot f_{cd}/f_{yd})$
$\rho_{l,zug} = \text{sqrt}(\rho_{lx,zug} \cdot \rho_{ly,zug}) \leq \rho_{l,zug,max}$
$v_{min} = 0.0525/\gamma_c \cdot k^{3/2} \cdot f_{ck}^{1/2}$ for $d \leq 600$ mm

scale factor
$k = 1 + \text{sqrt}(200/190) = 2.03 > 2 \Rightarrow k = 2$

longitudinal reinf. ratio of the anchored tension reinf.
mean of the tension reinforcement to the distance 3d from the column
$\rho_{lx,zug} = 31.42/19 \cdot 10^{-2} = 0.01654$
$\rho_{ly,zug} = 31.42/19 \cdot 10^{-2} = 0.01654$
$\rho_{l,zug} = \text{sqrt}(0.01654 \cdot 0.01654) = 0.01654$

4.1. Permanent and transient design situation (LK 1)

$C_{Rd,c} = 0.18/1.5 = 0.12$
$\rho_{l,zug,max} = \min(0.02,\ 0.5 \cdot 19.83/434.78) = 0.02 > 0.0165$
$v_{min} = 0.0525/1.5 \cdot 2^{3/2} \cdot 35^{0.5} = 0.586$ N/mm²
$v_{Rd,c} = 0.12 \cdot 2 \cdot (100 \cdot 0.01654 \cdot 35)^{1/3} = 0.928$ N/mm² > 0.586 N/mm²

0.635 N/mm² < 0.928 N/mm² ⇒ no additional reinforcement required

4.2. Accidental design situation (LK 2)

$C_{Rd,c} = 0.18/1.3 = 0.14$
$\rho_{l,zug,max} = \min(0.02,\ 0.5 \cdot 22.88/500) = 0.02 > 0.0165$
$v_{min} = 0.0525/1.3 \cdot 2^{3/2} \cdot 35^{0.5} = 0.676$ N/mm²
$v_{Rd,c} = 0.14 \cdot 2 \cdot (100 \cdot 0.01654 \cdot 35)^{1/3} = 1.071$ N/mm² > 0.676 N/mm²

1.226 N/mm² > 1.071 N/mm² ⇒ shear reinforcement required

maximal load-bearing resistance
$v_{Rd,max} = 1.4 \cdot v_{Rd,c}$

$v_{Rd,max} = 1.4 \cdot 1.071 = 1.5$ N/mm²

1.226 N/mm² < 1.5 N/mm² ⇒ $v_{Ed,crit}$ enabled to resist with shear reinforcement

basic value of the minimum shear reinforcement
$A_{sw,crit} = (v_{Ed} - 0.75 \cdot v_{Rd,c}) \cdot s_r \cdot u_1/(1.5 \cdot f_{ywd,ef})$
$f_{ywd,ef} = 250 + 0.25 \cdot d \leq f_{ywd}$

$f_{ywd,ef} = 250 + 0.25 \cdot 190 = 297.5$ N/mm²
$f_{ywd} = 500/1 = 500$ N/mm² > 297.5 N/mm²
$s_r = 0.75 \cdot 19 = 14.3$ cm
$A_{sw,crit} = (1.226 - 0.75 \cdot 1.071) \cdot 14.3 \cdot 4/(1.5 \cdot 297.5) \cdot 100 = 5.39$ cm²

5. Design calculation for decisive load spectrum 2

5.1. Stirrup reinforcement rows

$A_{sw,min} = \kappa_{sw} \cdot A_{sw,crit}$
$A_{sw,min} = 0.08/1.5 \cdot f_{ck}^{0.5}/f_{yk} \cdot s_r \cdot u$

bar diameter
max $Ø_{sw} \leq 0.05 \cdot 190 \approx 10$ mm ⇒ **selected Ø 10**
information on erection of 10er stirrups: both reinforcement layers have to be covered

Nr	κ_{sw}	$A_{sw,min}$	s_r	l_w	u	$A_{sw,min}$	min n	selected	$\bar{s}_t$	$A_{sw,exis}$
	-	cm²	cm	cm	m	cm²	-	leg	cm	cm²
1	2.50	13.48	9.5	9.5	2.40	1.44	9	**18 Ø 10**	13.3	14.14
2	1.40	7.55	14.3	23.8	3.29	2.96	12	**12 Ø 10**	27.4	9.42
3	1.00	5.39	14.3	38.0	4.00	3.59	15	**16 Ø 10**	25.0	12.57
4	1.00	5.39	14.3	52.3	4.22	3.80	12	**12 Ø 10**	35.2	9.42
5	1.00	5.39	14.3	66.5	4.44	4.00	12	**12 Ø 10**	37.0	9.42

Nr	κ_{sw} -	$A_{sw,min}$ cm²	s_r cm	l_w cm	u m	$A_{sw,min}$ cm²	min n -	selected leg	$\bar{s}_t$ cm	$A_{sw,exis}$ cm²
6	1.00	5.39	14.3	80.8	4.67	4.20	13	14 Ø 10	33.3	11.00
7	1.00	5.39	14.3	95.0	4.89	4.40	13	14 Ø 10	34.9	11.00
8	1.00	5.39	14.3	109.3	5.12	4.60	14	14 Ø 10	36.5	11.00

permitted spacing of link legs:
$s_t \leq 28.5$ cm in 1., 2. and 3. row
$s_t \leq 38.0$ cm in der 4., 5., 6., 7. and 8. Reihe

information on the positional tolerance:
acc. to [3] radial deflection up to ±0.2d (here ±3.8cm) concerning theoretical section allowed.
for this it is important that the first row always lies between 0.3d and 0.5d.

κ_{sw} - adjustment factor acc. to [2], NCI to 6.4.5 (1) s_r - distance to preceding row in radial direction l_w - distance to column edge
u - length of effective control perimeter $A_{sw,min}$ - minimum shear reinforcement of total row
$\bar{s}_t$ - mean spacing of link legs in section

5.2. Verification of outer control perimeter

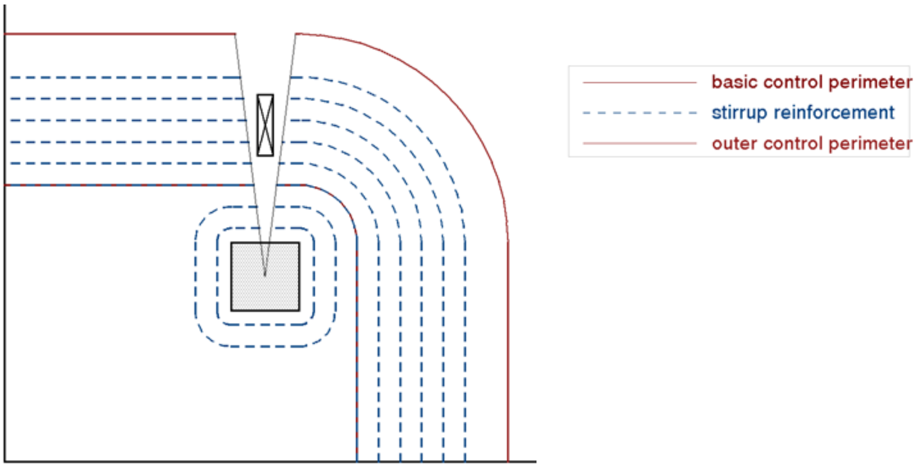
shear resistance at a distance of 1.5d from the last reinforcement row
$v_{Rd,c} = C_{Rd,c} \cdot k \cdot (100 \cdot \rho_{l,zug} \cdot f_{ck})^{1/3} \geq v_{min}$ [N/mm²]
$C_{Rd,c} = 0.15/\gamma_c$

perimeter of outer control perimeter
$l_{w,out} = 109.2 + 1.5 \cdot 19 = 137.7$ cm $\Rightarrow u_{out} = 5.56$ m

decisive shear stress
$v_{Ed,out} = 1.226 \cdot 4/5.56 = 0.881$ N/mm²

shear resistance
$C_{Rd,c} = 0.15/1.3 = 0.12$
$v_{Rd,c} = 0.12 \cdot 2 \cdot (100 \cdot 0.01654 \cdot 35)^{1/3} = 0.893$ N/mm² > 0.676 N/mm²

0.881 N/mm² < 0.893 N/mm² ⇒ Verification done



6. Minimum longitudinal reinforcement to ensure shear resistance

acc. to [1] table tab. NA.6.1.1

tension face	direction	η	$m_{Ed,min}$ kNm/m	$a_{so,min}$ cm²/m	$a_{su,min}$ cm²/m	distribution width m
top	x	0.125	81.25	8.63	----	2.02
	y	0.125	81.25	8.63	----	2.02

η - moment coefficient $m_{Ed,min} = \eta \cdot V_{Ed}$ - minimum design moment

[1] DIN EN 1992-1-1: Eurocode 2: Bemessung und Konstruktion von Stahlbeton- und Spannbetontragwerken, Teil 1-1, Januar 2011
[2] DIN EN 1992-1-1/NA: Nationaler Anhang - National festgelegte Paramter - Eurocode 2, Teil 1-1, Januar 2011
[3] DAfStb Heft 525: Erläuterungen zu DIN 1045-1, 2. überarb. Aufl., Beuth, 2010