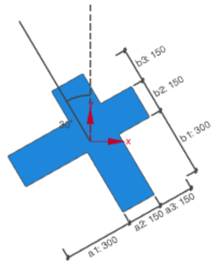
Punching shear check

In accordance with BS EN 1992-1-1:2004 + A1:2014 + UK NA

Column and slab geometry

Description	Value
Column dimension, a_1	300 mm
Column dimension, a_2	150 mm
Column dimension, a_3	150 mm
Column dimension, b_1	300 mm
Column dimension, b_2	150 mm
Column dimension, b_3	150 mm
Column rotation angle, β	30.0 °
Slab corner distance, e_x	300 mm
Slab corner distance, e_y	500 mm
Edge 1 angle, α_1	44.0 °
Edge 2 angle, α_2	44.0 °
Slab thickness, h	300 mm
Cover to top bars T1, c	30 mm
Slab effective depth for reinforcement in direction 1, d_1	260 mm
Slab effective depth for reinforcement in direction 2, d_2	240 mm
Slab effective depth (average), d	250 mm

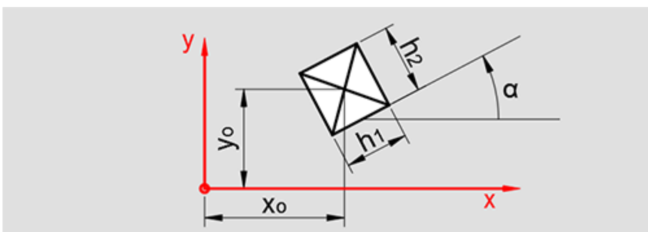
Column dimensions



Openings

No	x_o (mm)	y_o (mm)	h_1 (mm)	h_2 (mm)	α (°)
1	-200	1000	200	150	0.0
2	500	1000	100	100	45.0
3	500	-200	100	300	71.0

Opening conventions



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Steel: main slab reinforcement

Description	Value
Area of main reinforcement T1, As_1	1571 mm²
Diameter of bars T1, d_{T1}	20 mm
Area of main reinforcement T2, As_2	1571 mm²
Diameter of bars T2, d_{T2}	20 mm
Longitudinal reinforcement ratio (dir1), ρ_{l1}	0.006
Longitudinal reinforcement ratio (dir2), ρ_{l2}	0.007
Longitudinal reinforcement ratio (mean value), ρ_l	0.006

Steel: punching shear reinforcement

Description	Value
Characteristic yield strength of shear reinforcement, f_{ywk}	500.0 MPa
Partial factor for reinforcement, γ_s	1.150
Diameter of shear link, Φ_{link}	10 mm
Design yield strength of shear reinforcement, f_{ywd}	434.783 MPa
Effective design yield strength of shear reinforcement, $f_{ywd,eff}$	312.500 MPa
First radial spacing factor, k_{s0}	0.35
Radial spacing factor, k_{sr}	0.70

Concrete

Description	Value
Characteristic compressive cylinder strength of concrete after 28 days, f_{ck}	30.0 MPa
Partial factor for concrete, γ_c	1.500
Coefficient for long term effect, α_{cc}	1.000
Design value of concrete compressive strength, f_{cd}	20.000 MPa

Loading

Description	Value
Design vertical load, V_{Ed}	600.000 kN
Eccentricity factor (user defined), β	1.50

Control perimeter U_0, at column face

Control perimeter length (reduced by opening dead zones)	$U_0 = 1024$ mm
Shear stress at column face perimeter U_0 [BS EN 6.4.5(3)]	$v_{Ed,U0} = \frac{\beta \cdot V_{Ed} \cdot 10^3}{U_0 \cdot d} = \frac{1.50 \cdot 600.000 \cdot 10^3}{1024 \cdot 250} = 3.515$ MPa
Stress reduction factor [BS EN 6.2.2(6)]	$v = 0.6 \cdot \left(1 - \frac{f_{ck}}{250}\right) = 0.6 \cdot \left(1 - \frac{30.0}{250}\right) = 0.528$
Design value of max punching shear stress resistance for control perimeter [UK NA 6.4.5(3)]	$v_{Rd,max} = 0.5 \cdot v \cdot f_{cd} = 0.5 \cdot 0.528 \cdot 20.000 = 5.280$ MPa

Stress check [BS EN 6.4.3(2)].

$$\frac{v_{Ed,U0}}{v_{Rd,max}} = 0.666$$

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✓ The check has passed.

Control perimeter U_1, at 2d = 500 mm from column face

Control perimeter length (reduced by opening dead zones)	$U_1 = 3505$ mm
Shear stress at column face perimeter U_1 [BS EN 6.4.3(1)]	$v_{Ed,U1} = \frac{\beta \cdot V_{Ed} \cdot 10^3}{U_1 \cdot d} = \frac{1.50 \cdot 600.000 \cdot 10^3}{3505 \cdot 250} = 1.027$ MPa
Coefficient [BS EN 6.4.4(1)]	$C_{Rd,c} = \frac{0.18}{\gamma_c} = \frac{0.18}{1.500} = 0.120$
Coefficient [BS EN 6.4.4(1)]	$k = \min\left(1 + \sqrt{\frac{200}{d}}, 2\right) = \min\left(1 + \sqrt{\frac{200}{250}}, 2\right) = 1.894$
Minimum concrete shear stress resistance [BS EN 6.2.2(1)]	$v_{min} = 0.035 \cdot \sqrt{k^3} \cdot \sqrt{f_{ck}} = 0.035 \cdot \sqrt{1.894^3} \cdot \sqrt{30.0} = 0.500$ MPa
Design value of the punching shear resistance without punching shear reinforcement [BS EN 6.4.4(1)]	$v_{Rd,c} = \max\left(C_{Rd,c} \cdot k \cdot (100 \cdot \rho_l \cdot f_{ck})^{\frac{1}{3}}, v_{min}\right)$ $= \max\left(0.120 \cdot 1.894 \cdot (100 \cdot 0.006 \cdot 30.0)^{\frac{1}{3}}, 0.500\right) = 0.605$ MPa

Stress check at perimeter U_1 [UK NA 6.4.5(3)].

$$\frac{v_{Ed,U1}}{2 \cdot v_{Rd,c}} = 0.849$$

✓ The check has passed.

Punching shear reinforcement requirement check [BS EN 6.4.3(2)].

$$\frac{v_{Ed,U1}}{v_{Rd,c}} = 1.697$$

ℹ Punching shear reinforcement is required

Effective design yield strength of shear reinforcement [BS EN 6.4.5(1)]	$f_{ywd,eff} = \min(250 + 0.25 \cdot d, f_{ywd}) = \min(250 + 0.25 \cdot 250, 434.783) = 312.500$ MPa
Reinforcement required for perimeter U_1 [BS EN 6.4.5(1)]	$A_{swU1,Req} = \frac{(v_{Ed,U1} - 0.75 \cdot v_{Rd,c}) \cdot U_1 \cdot k_{sr} \cdot d}{1.5 \cdot f_{ywd,eff}}$ $= \frac{(1.027 - 0.75 \cdot 0.605) \cdot 3505 \cdot 0.70 \cdot 250}{1.5 \cdot 312.500} = 750$ mm²

Notes:

1. For provided reinforcement see results diagram, and reinforcement perimeter tables.

2. Calculations assume that the shear stud heads provide sufficient anchorage to develop the yield strength of the studs with ductile failure mode.

3. For columns situated closer than d from a slab edge or corner, special edge reinforcement should be provided in accordance with EC2 cl 9.3.1.4.

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Control perimeter U_{outer}, at 1207 mm from column face

Control perimeter length (reduced by opening dead zones)

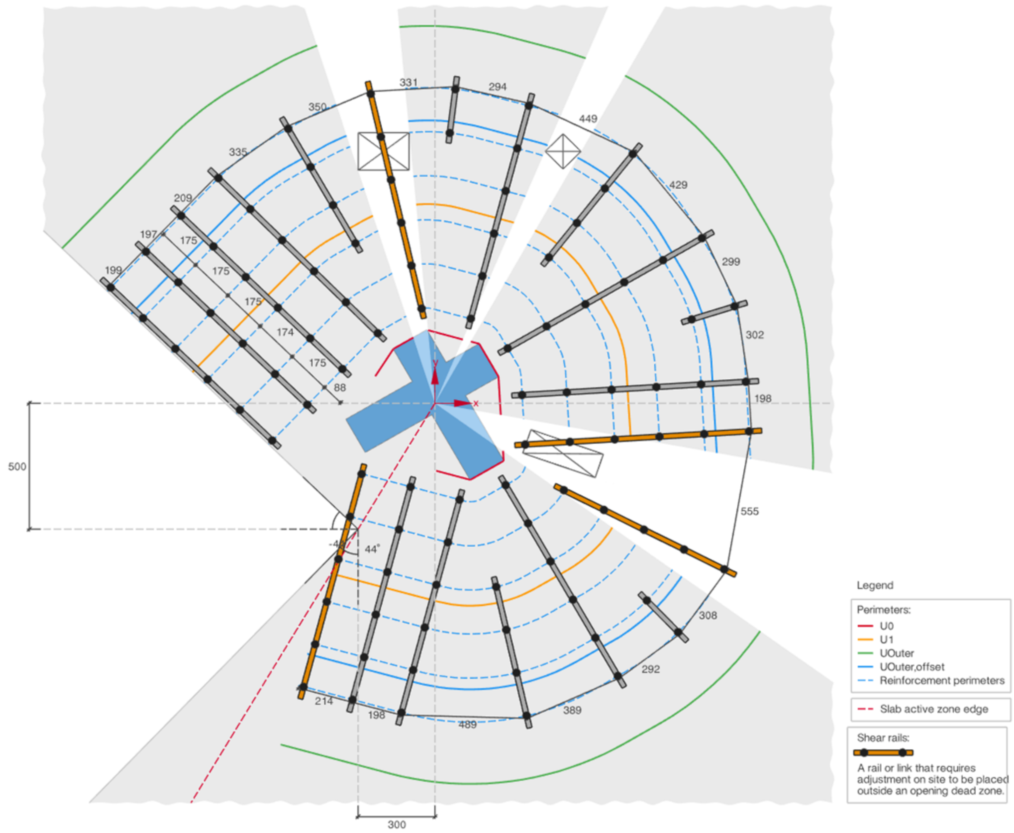
$U_{outer} = 5949$ mm

Shear stress at perimeter U_{outer} [BS EN 6.4.3(3)]

$$v_{Ed,Uouter} = \frac{\beta \cdot V_{Ed} \cdot 10^3}{U_{outer} \cdot d} = \frac{1.50 \cdot 600.000 \cdot 10^3}{5949 \cdot 250} = 0.605 \text{ MPa}$$

$$\frac{v_{Ed,Uouter}}{v_{Rd,c}} = 1.000$$

Punching shear reinforcement diagram



Notes:

1. Where rail studs are located close to opening/slab edges such rails to be adjusted manually to provide adequate cover to studs.

2. The outermost shear reinforcement perimeter should be positioned at least 832 mm from the nearest column face (based on the code distance kd = 375 mm, measured from the perimeter U_{outer}).

Summary results

Check	Value	Limit	Utilisation	Result
Stress check at perimeter U_0	3.515 MPa	5.280 MPa	0.666	✓ Pass
Stress check at perimeter U_1	1.027 MPa	1.210 MPa	0.849	✓ Pass

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Reinforcement perimeters

No	Column offset (mm)	$U_{reduced}$ (mm)	$As_{Req,U1}$ (mm²)	As_{Prov} (mm²)	Spacing s_t limit (mm)	Max s_t (mm)	$As_{stud,min}$ (mm²)	$As_{stud,Prov}$ (mm²)	Number of studs
1	88	2080	750	1021	375	198	20	79	13
2	262	2684	750	1100	375	335	34	79	14
3	438	3289	750	1335	375	369	38	79	17
4	612	3894	750	1335	500	455	47	79	17
5	788	4499	750	1571	500	472	48	79	20
6	963	5103	750	1571	500	494	51	79	20

Notes:

1. $As_{Req,U1}$ (mm²) is the total area of punching shear reinforcement required for the control perimeter U_1.

2. Maxs_t (mm) is the maximum spacing of punching shear reinforcement provided measured along the length of the relevant perimeter.

3. $As_{stud,min}$ (mm²) is the minimum area per stud or link as required by BS EN 1992-1-1 clause 9.4.3(2) eqn 9.11.

4. Maxs_t has been used in eqn 9.11 as spacing st, when calculating $As_{stud,min}$.

Punching shear rails schedule

Number of studs per rail	Quantity of rails
6	13
5	1
4	3
2	3

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