



Project no		Date	09/10/2019
Name		Prepared by	
Item		Checked by	
Notes		Revision	
File	Untitled.cads	Page	1 of 5

Computer and Design Services Ltd, Arrowsmith Court, 10 Station Approach, Broadstone, Dorset, BH18 8AX, Tel: +44 (0)1202 603031, Email: support@cad.s.co.uk

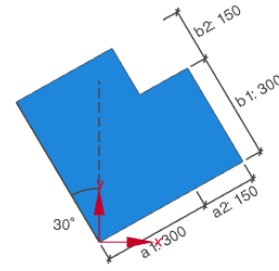
Punching shear check

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, b_1	300 mm
Column dimension, b_2	150 mm
Column rotation angle, β	30.0 °
Slab corner distance, e_x	500 mm
Slab corner distance, e_y	500 mm
Edge 1 angle, α_1	0.0 °
Edge 2 angle, α_2	30.0 °
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

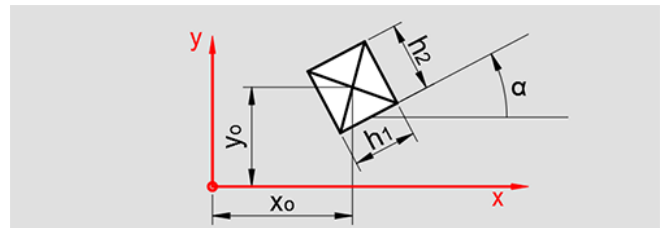
Column dimensions



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

Opening conventions





Project no		Date	09/10/2019
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Notes		Revision	
File	Untitled.cads	Page	2 of 5

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Steel: main slab reinforcement

Description	Value
Area of main reinforcement T1, A_{S1}	1571 mm ²
Diameter of bars T1, d_{T1}	20 mm
Area of main reinforcement T2, A_{S2}	1571 mm ²
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, $f_{yw,k}$	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}	500.000 kN
Eccentricity factor (user defined), β	1.50

Control perimeter U_0 , at column face

Control perimeter length (reduced by opening dead zones)

$$U_0 = 742 \text{ mm}$$

Shear stress at column face perimeter U_0 [BS EN 6.4.5(3)]

$$v_{Ed,U0} = \frac{\beta \cdot V_{Ed} \cdot 10^3}{U_0 \cdot d} = \frac{1.50 \cdot 500.000 \cdot 10^3}{742 \cdot 250} = 4.043 \text{ MPa}$$

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)]

$$v_{Rd,max} = 0.5 \cdot v \cdot f_{cd} = 0.5 \cdot 0.528 \cdot 20.000 = 5.280 \text{ MPa}$$

Stress check [BS EN 6.4.3(2)].

$$\frac{v_{Ed,U0}}{v_{Rd,max}} = 0.766$$



Project no		Date	09/10/2019
Name		Prepared by	
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Notes		Revision	
File	Untitled.cads	Page	3 of 5

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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)

$$U_1 = 2922 \text{ mm}$$

Shear stress at column face perimeter U_1 [BS EN 6.4.3(1)]

$$v_{Ed,U1} = \frac{\beta \cdot V_{Ed} \cdot 10^3}{U_1 \cdot d} = \frac{1.50 \cdot 500.000 \cdot 10^3}{2922 \cdot 250} = 1.027 \text{ MPa}$$

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)]

$$v_{min} = 0.035 \cdot \sqrt{k^3} \cdot \sqrt{f_{ck}} = 0.035 \cdot \sqrt{1.894^3} \cdot \sqrt{30.0} = 0.500 \text{ MPa}$$

Design value of the punching shear resistance without punching shear reinforcement [BS EN 6.4.4(1)]

$$v_{Rd,c} = \max\left(C_{Rd,c} \cdot k \cdot (100 \cdot \rho_l \cdot f_{ck})^{\frac{1}{3}}, v_{min}\right)$$

$$= \max\left(0.120 \cdot 1.894 \cdot (100 \cdot 0.006 \cdot 30.0)^{\frac{1}{3}}, 0.500\right) = 0.605 \text{ MPa}$$

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

$$\frac{v_{Ed,U1}}{2 \cdot v_{Rd,c}} = 0.848$$

✓ The check has passed.

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

$$\frac{v_{Ed,U1}}{v_{Rd,c}} = 1.696$$

i Punching shear reinforcement is required

Effective design yield strength of shear reinforcement [BS EN 6.4.5(1)]

$$f_{ywd,eff} = \min(250 + 0.25 \cdot d, f_{ywd}) = \min(250 + 0.25 \cdot 250, 434.783) = 312.500 \text{ MPa}$$

Reinforcement required for perimeter U_1 [BS EN 6.4.5(1)]

$$A_{swU1,Req} = \frac{(v_{Ed,U1} - 0.75 \cdot v_{Rd,c}) \cdot U_1 \cdot k_{sr} \cdot d}{1.5 \cdot f_{ywd,eff}}$$

$$= \frac{(1.027 - 0.75 \cdot 0.605) \cdot 2922 \cdot 0.70 \cdot 250}{1.5 \cdot 312.500} = 625 \text{ mm}^2$$

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.

Control perimeter U_{outer} , at 1742 mm from column face

Control perimeter length (reduced by opening dead zones)

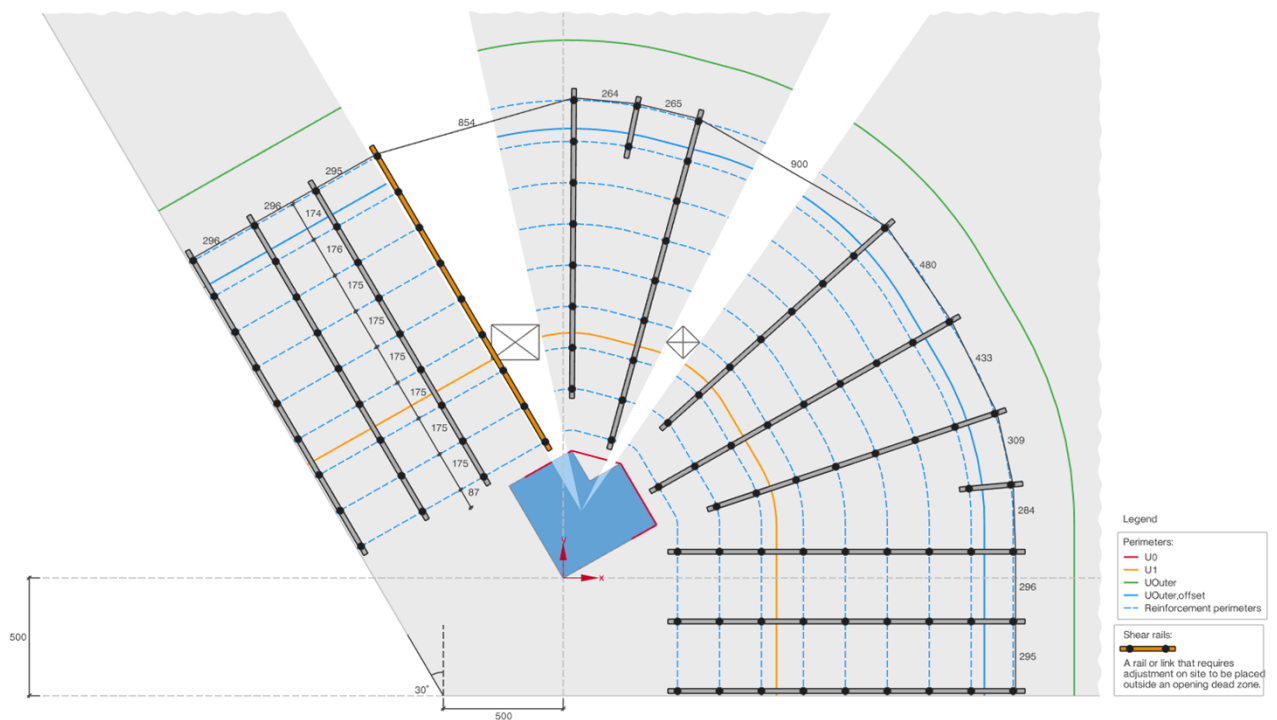
$$U_{outer} = 4957 \text{ mm}$$

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

$$V_{Ed,U_{outer}} = \frac{\beta \cdot V_{Ed} \cdot 10^3}{U_{outer} \cdot d} = \frac{1.50 \cdot 500.000 \cdot 10^3}{4957 \cdot 250} = 0.605 \text{ MPa}$$

$$\frac{V_{Ed,U_{outer}}}{V_{Rd,c}} = 1.000$$

Punching shear reinforcement diagram



Notes:

- Where rail studs are located close to opening/slab edges such rails to be adjusted manually to provide adequate cover to studs.
- The outermost shear reinforcement perimeter should be positioned at least 1367 mm from the nearest column face (based on the code distance $kd = 375 \text{ mm}$, measured from the perimeter U_{outer}).

Summary results

Check	Value	Limit	Utilisation	Result
Stress check at perimeter U_0	4.043 MPa	5.280 MPa	0.766	✓ Pass
Stress check at perimeter U_1	1.027 MPa	1.210 MPa	0.848	✓ Pass



Project no		Date	09/10/2019
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Notes		Revision	
File	Untitled.cads	Page	5 of 5

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Reinforcement perimeters

No	Column offset (mm)	U_{reduced} (mm)	$A_{S_{\text{Req},U1}}$ (mm ²)	$A_{S_{\text{Prov}}}$ (mm ²)	Spacing s_t limit (mm)	Max s_t (mm)	$A_{S_{\text{stud,min}}}$ (mm ²)	$A_{S_{\text{stud,Prov}}}$ (mm ²)	Number of studs
1	88	2246	625	707	375	295	30	79	9
2	262	2533	625	942	375	295	30	79	12
3	438	2820	625	942	375	316	32	79	12
4	612	3107	625	942	500	416	43	79	12
5	788	3393	625	942	500	495	51	79	12
6	963	3680	625	942	500	423	43	79	12
7	1137	3967	625	942	500	480	49	79	12
8	1312	4253	625	1100	500	484	49	79	14
9	1487	4540	625	1100	500	481	49	79	14

Notes:

- $A_{S_{\text{Req},U1}}$ (mm²) is the total area of punching shear reinforcement required for the control perimeter U_1 .
- Max_{s_t} (mm) is the maximum spacing of punching shear reinforcement provided measured along the length of the relevant perimeter.
- $A_{S_{\text{stud,min}}}$ (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.
- Max_{s_t} has been used in eqn 9.11 as spacing s_t , when calculating $A_{S_{\text{stud,min}}}$.

Punching shear rails schedule

Number of studs per rail	Quantity of rails
9	9
8	3
2	2