Flat slab design

Flexure design

Column strip and middle strip

$$column\ strip = \min(0.5\, l_x, 0.5 l_y)$$

$$middle\ strip_x = l_x - column\ strip$$

$$middle\ strip_y = l_y - column\ strip$$

Effective span

$$span_{,eff} = l_y - 2(\text{column size}/2) + (\text{Slab thickness}/2)$$

where :

l_y is a span length in y direction. (It is assumed $l_y > l_x$)

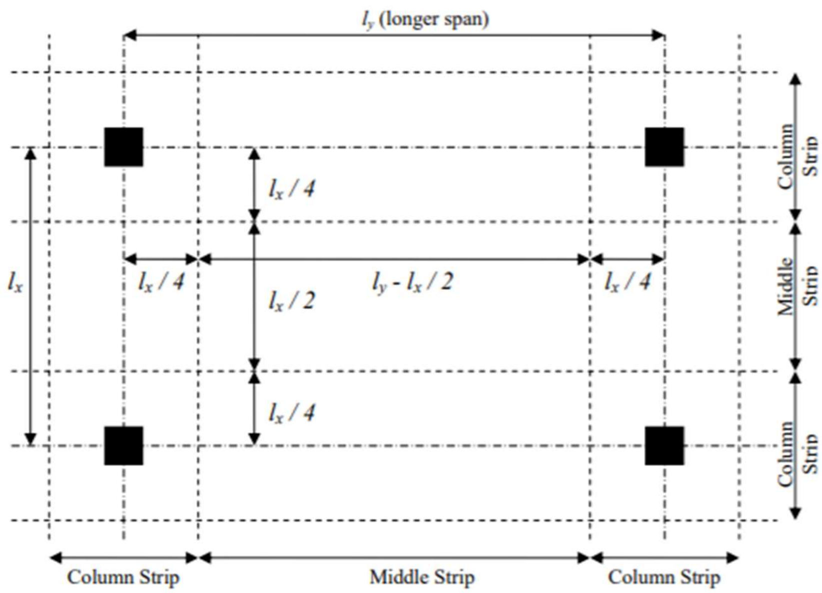


Figure 1 Column and middle strip

Design load

$$Design\ load = Live\ load * SF, q_k + Dead\ load * SF, g_k$$

where :

SF,q_k and SF,g_k are safety factors for live load and dead load respectively

Moment

Sagging moment (In panel)- Positive moments

$$M_{ED,S} = [\, SF_{,gk} * g_k * 0.09 + SF_{,qk} * q_k * 0.100]\, l_x * span_{,eff}{}^2$$

where :

g_k and q_k are dead load and live load respectively.

$Span_{,eff}$ is effective span

The coefficient 0.09 is 'Moment g_k' from the EC concise table

(50% of the sagging moment is taken in to the column and middle strips)

Column strip : $M_{ED,+v} \;=\; 0.5 \; * \; M_{ED,S} \; / \; column\ strip$

Middle strip : $M_{ED,+ve} \;=\; 0.5 \; * \; M_{ED,S} \; / \; column\ strip$

Hogging moment (Along support)- Negative moments

$$M_{ED,H} \;=\; Design\ load \; * \; 0.106 \; * \; l_x \; * span_{,eff}{}^2$$

where :

The coefficient 0.106 is 'Moment q_k' from the EC concise table.

(70% taken in column strip and 30% in middle strip)

Column strip : $M_{ED,-v} \;=\; 0.70 \; * \; M_{ED,H} \; / \; column\ strip$

Middle strip : $M_{ED,-ve} \;=\; 0.30 \; * \; M_{ED,H} \; / \; column\ strip$

(Flexure design for $M_{ED,+ve}$ and $M_{ED,-ve}$ at the column and middle strip)

Determine K and K'

$$K = \frac{M_{ED}}{bd^2 f_{ck}}$$

where :

M_{ED} is design moment per length

d is effective depth, d= h - cover - $Ø_{tie}$ - Ø/2

b is width of the section (b = 1 m)

f_{ck} is characteristic compressive strength of the concrete

$$K' = \; 0.6\,\delta \; - \; 0.18\delta^2 \; - \; 0.21$$

(δ=1.0 means no redistribution and δ = 0.8 means 20% moment redistribution).

If K ≤ K', no compression steel needed. If K ≥ K', compression reinforcement required – not recommended for typical slabs.

Lever arm (z)

$$z = \frac{d}{2}\left(1 + \sqrt{1 - 3.53K}\,\right) \le 0.95d$$

where :

d is effective depth of the concrete

Area of tensile reinforcement (A_s)

$$A_s = \frac{M_{ED}}{f_{yd} z}$$

where :

M_{ED} is design moment per length

z is lever arm

f_{yd} is deign yield strength of steel = f_{yk} / γ_s

where :

f_{yk} is characteristic yield strength of steel

γ_s is material safety factor

Number of reinforcement bars

$$n = \frac{A_s}{a_s}$$

where :

A_s is area of tensile reinforcement

a_s is an area of a single reinforcement bar

Spacing (s)

$$s = \frac{b}{(\frac{A_s}{a_s} - 1)} \leq s_{limit}$$

where :

a_s is area of a single reinforcement bar

A_s is area of tensile reinforcement per length

D is the slab thickness

b is width of the section, (b = 1 m)

Minimum reinforcement requirements

$$A_{s,min} \geq \frac{0.26\ _{ctm} b_t d}{f_{yk}} \geq 0.0013 b_t d\ , \text{ where } f_{ck} \geq 25$$

where :

f_{ctm} is tensile strength of the concrete

$f_{ctm} = 0.3f_{ck}^{2/3}$ for concrete class $\leq$ C50/C60

f_{yk} is characteristic yield strength of steel

b_t is breadth of the tension zone

d is effective depth of the concrete

Maximum reinforcement requirement

$$A_{s,max} \leq 0.04A_c$$

where:

A_c is area of concrete

Check minimum spacing between bars

$$Spacing > \emptyset_{bar} > 20 > A_{gg} + 5 \ (mm)$$

Figure 2 EuroCode 2 concise table

Coefficients for use with beams (and one-way spanning slabs) to Eurocode 2

Coefficient	Location				
	Outer support	Near middle of end span	At 1st interior support	At middle of interior spans	At interior supports
Moment g_k and q_k	25% span[a]	—	0.094	—	0.075
Moment g_k	—	0.090	—	0.066	—
Moment q_k	—	0.100	—	0.086	—
Shear	0.45	—	0.63:0.55	—	0.50:0.50[b]

Punching shear design

Factor β (refer to figure 7 or Expressions (6.38) to (6.46)of the Eurocode)

Corner column : β is 1.5

Edge column : β is 1.4

Internal column : β is 1.15

Design shear stress (at face of column)

$$v_{ED,max} = \frac{\beta V_{ED}}{u_1 d}$$

where :

V_{ED} applied load in the slab

u_1 is control perimeter around the loaded area (check Figure 5)

d_x and d_y are the effective depths in orthogonal direction,

$d = (d_x + d_y) / 2$

Determine $v_{Rd,max}$ (refer to table 3:concise table for respective concrete grade)

$$v_{RD,max} = 0.5 v f_{cd}$$

where :

f_{cd} is design compressive strength, f_{ck} / γ_c

$v = 0.6 \, (1 - f_{ck}/250) \, \alpha_{cc}$

where :

f_{ck} is characteristic compressive strength of the concrete

$\alpha_{cc} = 1.0$

If $v_{ED,max} \leq v_{Rd,max}$, proceed to the next step - otherwise redesign the section. (Increase the compressive strength of the slab)

Concrete punching shear capacity (without shear reinforcement) ($v_{Rd,c}$)

$$v_{RD,c} = C_{Rd,c} \, k(100\rho f_{ck})^{\frac{1}{3}} \, b_w d \ \geq V_{min}$$

$$V_{min} = 0.035 \, k^{1.5} f_{ck}^{0.5}$$

$$\rho_x = \frac{A_{s,1}}{l * d_1} \ \rho_y = \frac{A_{s,2}}{b * d_2}$$

$$\rho = \left(\rho_x * \rho_y\right)^{\frac{1}{2}} \leq 0.02$$

where :

$C_{RD,c}$ is coefficient derived from test (0.18/ 1.5) ;

b_w is width of the section, (b = 1 m)

d is effective depth, $d = (d_1 + d_2)/2$

k is size factor, $k = 1 + \sqrt{200/d} \leq 2.0$

d is effective depth, $d = (d_x + d_y) / 2$

ρ is steel ratio and ρ_x, ρ_y are steel ratio along x and y direction

f_{ck} is characteristic compressive strength in MPa;

If $v_{ED,max} \leq v_{Rd,c}$, punching shear reinforcement not required.

If $v_{ED,max} \geq v_{Rd,c}$, determine the punching shear reinforcement per perimeter.

Punching shear reinforcement

$$A_{sw} = \left(v_{ED} - 0.75v_{RD,c}\right)s_r u_1/(1.5f_{ywd,ef})$$

where :

v_{ED} is design shear stress

$v_{Rd,c}$ is concrete shear capacity

s_r is radial spacing of shear reinforcement

u_1 is control perimeter around the loaded area (check Figure 5)

$f_{ywd,ef} = 250 + 0.25\,d \ \leq \ f_{ywd}$

f_{ywd} is design yield strength of shear reinforcement

Minimum punching shear reinforcement

$$A_{sw,min} \ \geq (0.053 s_r s_t \sqrt{f_{ck}}\,)/f_{yk}$$

where :

s_r is the spacing of the links in the radial direction $s_{r,max} = 0.75d$

s_t is the spacing of the links in the tangential direction $s_{t,max} = 1.5d$

f_{ck} is characteristic compressive strength in MPa

f_{yk} is characteristic yield strength of steel

Length of the outer perimeter where shear reinforcement not required

$$u_{out,ef} = \ \beta v_{ED}/(v_{RD,c} * d)$$

where :

β is punching shear factor for column position (1.15, 1.4, 1.5)

v_{ED} is design shear stress

$v_{Rd,c}$ is concrete shear capacity

d is effective depth, $d = \ (d_x + \ d_y\,)\ /\ 2$

Figure 3 Recommended standard values for betta

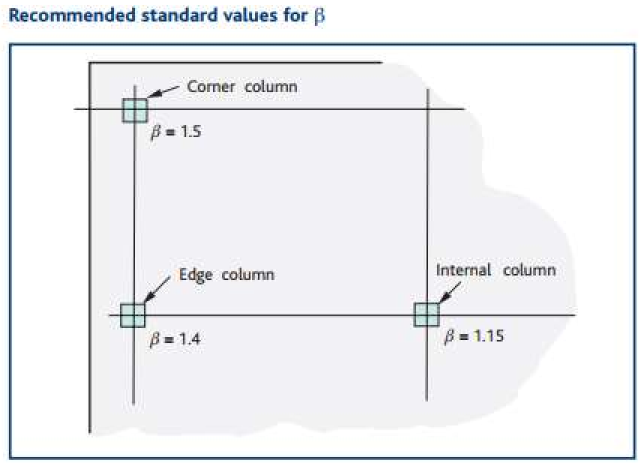
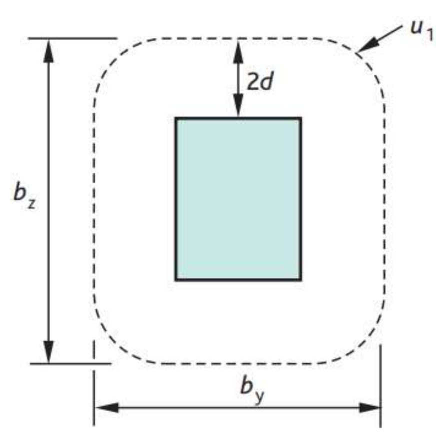


Table 3. Values for $v_{Rd,max}$

f_{ck}	$V_{Rd,max}$
20	3.31
25	4.05
28	4.48
30	4.75
32	5.02
35	5.42
40	6.05
45	6.64
50	7.20

Figure 4 Control perimeter around the loaded area u1



Reference

Moss, R. and Brooker, O. ,2006. *How to design concrete structures using Eurocode 2*. Camberley: Concrete Centre, pp.51-57.

Picture reference

Web page

Flat slab section
https://civiltoday.com/structural-engineering/54-flat-slab-design-and-detailing-pdf

Description

Narayanan, R. and Goodchild, C. (2006). *Concise Eurocode*. 2nd ed. Crowthorne: British Cement Association.