# 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 $l_y > l_x$)

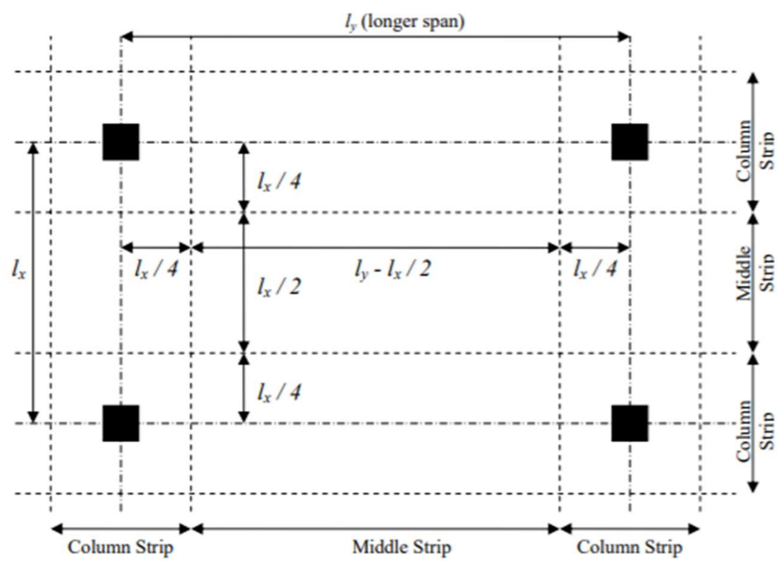


*Figure 1 Column and middle strip*

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

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

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

*( Flexure analysis 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 = $f_{yk}$ / $\gamma_s$

where :

$f_{yk}$ is characteristic yield strength of steel

$\gamma_s$ is material safety factor

*Spacing* (s)

$$s = b * \frac{a_s}{\mathrm{A_s}} \leq 2 * D$$

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

$f_{yk}$ is characteristic yield strength of steel

$b_t$ is breadth of the tension zone

d is effective depth of the concrete

*Maximum reinforcement requirement*

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

where:

$A_c$ is area of concrete

*Number of reinforcement bars*

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

where :

$a_s$ is an area of a single reinforcement bar

*Check minimum spacing between bars*

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

**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] |

*Figure 2 EuroCode 2 concise table*

## 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

$d_x$ 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, $f_{ck} / \gamma_c$

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

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) ($v_{Rd,c}$)*

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

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

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

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

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 $\rho_x$, $\rho_y$ 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*

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

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

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

$f_{ywd}$ 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

$s_t$ is the spacing of the links in the tangential direction

$f_{ck}$ 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 7**
**Recommended standard values for β**

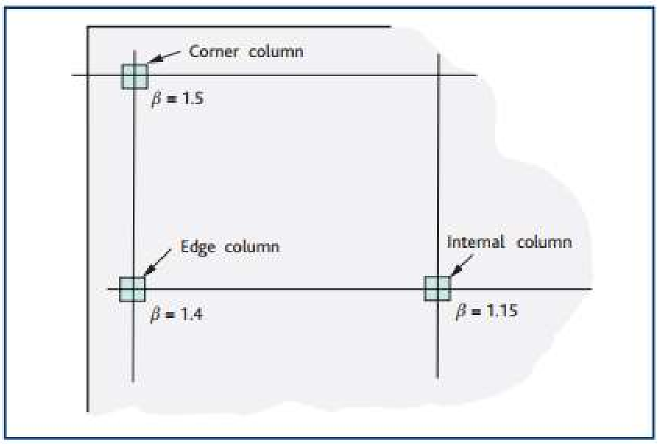


*Table 3. Values for $v_{Rd,max}$*

| $f_{ck}$ | $V_{Rd,max}$ |
|---|---|
| 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 |