Reinforced concrete beam design

Flexure design

Design load

$$Design\ load\ =\ Live\ load\ *\ SF,qk\ +\ Dead\ load\ *\ SF,gk$$

where :

$SF_{,qk}$ and $SF_{,gk}$ are safety factors for live load and dead load respectively

Design moment

$$M_{ED} = \frac{ql^2}{8}$$

where :

q is design load

l is length of the beam

Determine K and K'

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

where :

M_{ED} is design moment

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

b is width of the beam section

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', under reinforced (**Singly reinforced concrete design**) -No compression steel needed.

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

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

Minimum reinforcement requirements

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

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

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

If $K \geq K'$, over reinforced (**Doubly reinforced concrete design**) -compression steel needed.

Compression reinforcement (A_{s2})

$$A_{s2} = \frac{M_{Ed} - M'}{f_{sc}(d - d_2)}$$

Tension reinforcement (A_{s1})

$$A_{s1} = \frac{M'}{f_{yd} z} + A_{s2} \frac{f_{sc}}{f_{yd}}$$

where :

M_{ED} is design moment

$M' = k' b d^2 f_{ck}$

d is effective depth, $d = h - cover - \emptyset_{tie} - \emptyset/2$

$f_{sc} = 700\ (x_u - d_2)/\ x_u \leq f_{yd}$

where :

d_2 effective depth to compression reinforcement, d_2= cover + Ø_{tie} + Ø/2

$x_u = (\delta - 0.4)d$

where

δ is redistribution ratio

Shear design

Design shear load

$$V_{ED} = ql/2$$

where :

q is design load

l is length of the beam

Design shear stress

$$v_{ED} = V_{ED}\ /(b_w z)$$

where :

V_{ED} is design shear load at d distance from the face of the column

z is lever arm = $\frac{d}{2}(1 + \sqrt{1 - 3.53K}\,) \leq 0.95d$

b_w is breadth of the beam section

Concrete strut capacity v_{Rd} (refer Table 1)

If $v_{ED} < v_{Rd,\max \cot\theta=2.5}$, proceed to calculating area of shear reinforcement. ($\cot\theta = 2.5$).

If $v_{ED} < v_{Rd,\max \cot\theta=1.0}$;

Determine θ from

$$\theta = 0.5\ \sin^{-1}[\frac{v_{ED}}{0.20 f_{ck}(1 - \frac{f_{ck}}{250})}]$$

where :

v_{ED} is design shear stress

f_{ck} is characteristic compressive strength of the concrete

If $v_{ED} > v_{Rd,\max \cot\theta=1.0}$, redesign section.

Area of shear reinforcement

$$\frac{A_{SW}}{s} = \frac{v_{ED} b_w}{f_{ywd} \cot\theta}$$

where :

v_{ED} is design shear stress

b_w is breadth of the beam section

f_{ywd} is deign yield strength of shear reinforcement

s is spacing

Check maximum spacing for vertical shear reinforcement

$$s_{l,max} = 0.75\ d$$

where :

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

Table 1. Minimum and maximum concrete strut capacity in terms of stress(MPa)

f_{ck}	$v_{Rd,max}\cot\ \cot\theta = 2.5$	$v_{Rd,max}\cot\ \cot\theta = 1.0$
20	2.54	3.68
25	3.10	4.50
28	3.43	4.97
30	3.64	5.28
32	3.84	5.58
35	4.15	6.02
40	4.63	6.72
45	5.08	7.38
50	5.51	8.00