Design of Singly Reinforced Concrete Rectangular Section for Flexure

1- Calculate the maximum factored bending moment M_u experienced by the section.

2- Calculate β_1 (ACI 10.2.7.3):

$$\beta_1 = \begin{cases} 0.85 & f_c' \le 28\,\text{MPa} \\ 0.85 - \dfrac{0.05}{7}\left(f_c' - 28\right) & 28 < f_c' < 55\,\text{MPa} \\ 0.65 & f_c' \ge 55 \end{cases}$$

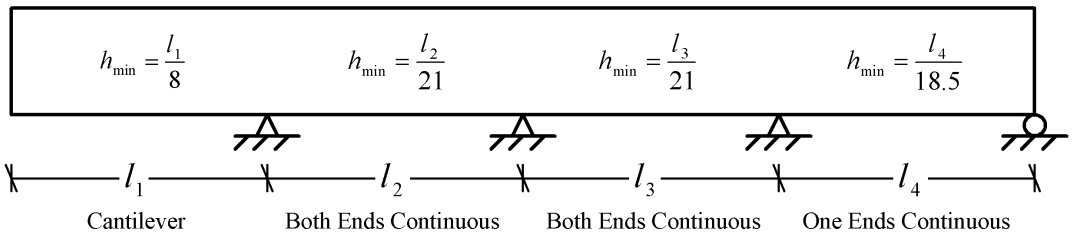
3- Assume an initial reinforcement ratio. To ensure ductile behavior, try 40% - 60% ρ_b, where

$$\rho_b = 0.85\beta_1 \frac{f_c'}{f_y}\left(\frac{600}{600 + f_y}\right)$$

4- Establish height of cross section (*h*), use table 9.5(a) from ACI. (Table 1)

Table 1: Minimum Thickness of Non-Prestressed Beams Unless Deflections are Calculated

Minimum thickness (*h*)			
Simply Supported	One end continuous	Both ends continuous	Cantilever
f_y = 420 MPa			
$\frac{l}{16}$	$\frac{l}{18.5}$	$\frac{l}{21}$	$\frac{l}{8}$
All values of f_y			
$\left(0.40 + \frac{f_y}{700}\right)\frac{l}{16}$	$\left(0.40 + \frac{f_y}{700}\right)\frac{l}{18.5}$	$\left(0.40 + \frac{f_y}{700}\right)\frac{l}{21}$	$\left(0.40 + \frac{f_y}{700}\right)\frac{l}{8}$

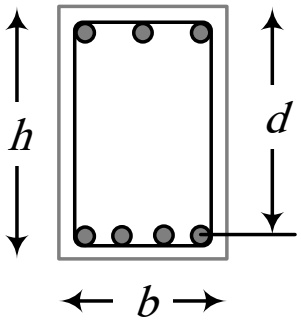


Note: for span 2 (l_2) to be considered as "Both ends continuous", (l_1) should be greater than $\left(\frac{l_2}{3}\right)$ otherwise, it will be considered as "One end continuous".

5- For simpler construction on site, round *h* (up) to the nearest (50 mm)

6- Once h is established, d can be **estimated** from $d = h - 65(\text{mm})$

Note: Unless a greater concrete cover is required by ACI 7.7.6 or ACI 7.7.8, specified cover for reinforcement shall not be less than the cover specified by Table 2



7- For $M_u = \phi R_n b d^2$ Calculate the strength factor R_n

$$R_n = \rho f_y \left(1 - 0.59\rho \frac{f_y}{f_c'}\right)$$

M_u: Factored bending moment developed in the beam section due to external "factored" loads.

Table 2: Concrete protection for reinforcement for Cast-in-place concrete (Non-Prestressed)

Exposure Situation	Concrete Cover (mm)
Concrete cast against and permanently exposed to earth	75
Concrete exposed to earth or weather:	
No. 19 through No. 57 bars ……...	50
No. 16 bar, MW200 or MD200 wire, and smaller ……	40
Concrete not exposed to weather or in contact with ground:	
Slabs, walls, joists:	
No. 43 and No. 57 bars ……..	40
No. 36 bar and smaller ……..	20
Beams, columns:	
Primary reinforcement, ties, stirrups, spirals …….	40
Shells, folded plate members:	
No. 19 bar and larger …….	20
No. 16 bar, MW200 or MD200 wire, and smaller ……	13

8- b needed can be calculated from $b = \dfrac{M_u}{\phi R_n d^2}$

9- For simpler construction on site, round b (up or down) to the nearest (50 mm)

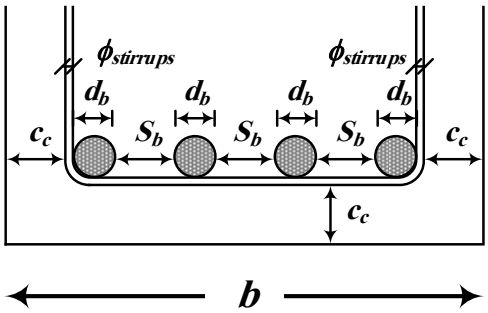
10- Calculate A_s from $A_s = \rho b d$

11- Check A_s minimum

$$A_{s\,\min} = 0.25\frac{\sqrt{f_c'}}{f_y} b_w d \geq \frac{1.4}{f_y} b_w d \quad \text{(ACI 10.5.1)}$$

12- Check if steel yielded or not

$$\varepsilon_s = \varepsilon_c \left(\frac{0.85\beta_1}{\rho} \frac{f_c^{'}}{f_y} - 1 \right) > 0.005$$



13- Select reinforcement

14- Check bar spacing (S_b)

$$S_b = \frac{b - 2\phi_{\text{stirrups}} - 2c_c - \sum d_b}{N_{d_b} - 1} > d_b > 25\,\text{mm}$$

15- Check S_{max}:

$$S_{\max} = 380\left(\frac{280}{f_s}\right) - 2.5c_c < 300\left(\frac{280}{f_s}\right), \text{ assume } f_s = \frac{2}{3} f_y \text{ (ACI 10.6.4)}$$

where f_s is the calculated stress in reinforcement closest to the tension face at service load.

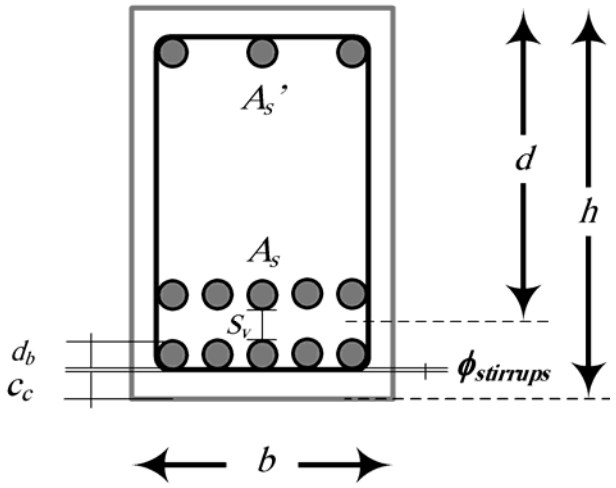
S_{max} can be written as

$$S_{\max} = 380\left(\frac{420}{f_y}\right) - 2.5c_c < 300\left(\frac{420}{f_y}\right) \text{ (ACI 10.6.4)}$$

16- If one layer is not enough, distribute reinforcement in two layers

17- In case of two layers of reinforcement, calculate the new effective depth of the section:

$$d = h - \left(c_c + \phi_{\text{stirrups}} + d_b + \frac{S_v}{2} \right)$$



Where, S_v is the vertical spacing between reinforcing bars in subsequent layers.

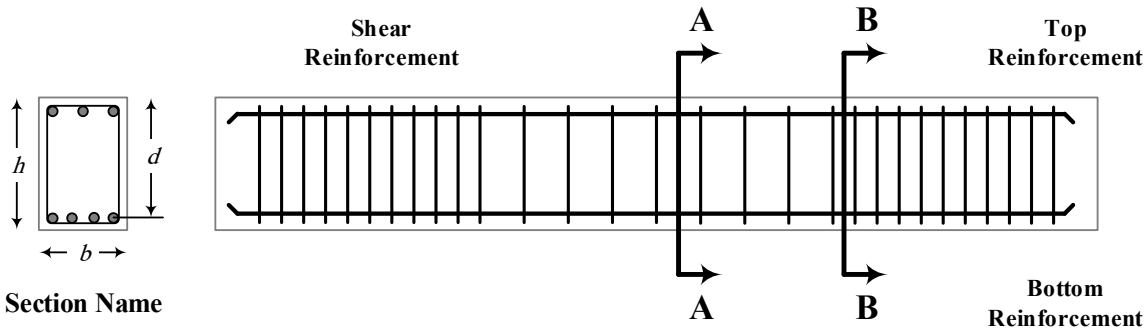
Note: the new effective depth is located at the geometric centroid of the new layering layout.

18- Check the capacity of the new section with new modified values of ρ and d

$$\phi M_n = \phi \rho f_y b d^2 \left(1 - 0.59\rho \frac{f_y}{f_c^{'}} \right) \geq M_u$$

19- For sections where, theoretically, no reinforcement is needed, use $A_{s\,min}$. It is a good practice to use the same bar size of major reinforcement for minor reinforcement.

20- Draw the reinforcement details.


Shear
Reinforcement
A
B
Top
Reinforcement
h
d
b
Section Name
A
B
Bottom
Reinforcement