2.2.3.2. Limits of reinforcement ratio

1- Balanced condition (ρb)

Ideal condition as when the stress in the steel reaches f_y and stress in concrete reaches max strength at the same time which called balance condition

$[\sum F_x = 0]\ C = T\ ;$

$0.85{f'}_c\beta_1 cb = A_s f_y = \rho_b f_y bd$

$$\rho_b = \frac{0.85{f'}_c}{f_y}\beta_1\left(\frac{\varepsilon_{cu}}{\varepsilon_{cu}+\varepsilon_y}\right)$$

$Substitute\,\varepsilon_{cu} = 0.003,\quad \varepsilon_y = \dfrac{f_y}{2.0\times 10^5}$

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

$\rho = \rho_b:\ balance,\qquad \rho > \rho_b: overRC,\qquad \rho < \rho_b: underRC$

2- Maximum reinforcement ratio (ρmax)

To make sure that the actual reinforcement ratio $\rho \le \rho b$ then the codes limit the reinforcement ratio by maximum ratio of reinforcement

$$\rho_{max} = 0.85\beta_1\frac{f_c'}{f_y}\frac{\epsilon_{cu}}{\epsilon_{cu}+0.004}$$

If the ρ >ρmax it leads to sudden failure and the section is called over reinforced section.

3- Minimum reinforcement ratio (ρmin)

To make sure that the cracks will not appear on the building you must take the reinforcement ratio not less than the minimum value that is:

$$Minimum steel ratio:\ \rho_{min} = \max\left(\frac{1.4}{f_y},\frac{\sqrt{f_c'}}{4f_y}\right)(concrete first crack)$$

$$4-\ \rho_t = 0.85\beta_1\frac{f_c'}{f_y}\frac{\epsilon_{cu}}{\epsilon_{cu}+0.005}$$

2.2.3.3. Reduction Factor (φ)

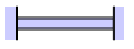
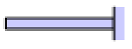
$\varphi = 0.9 \qquad\qquad\qquad if\ \rho \le \rho_t$

$\varphi = 0.483 + 83.3\,\epsilon_t > 0.65 \qquad if\ \rho > \rho_t$

$$where\quad \rho_t = 0.85\beta_1\frac{f_c'}{f_y}\frac{\epsilon_{cu}}{\epsilon_{cu}+0.005}\quad ,\ \epsilon_t = \epsilon_{cu} * \frac{d_t - c}{c}\ ,and\ d_t \approx d$$

2.2.3.4. Design Procedure for Section with Tension Reinforcement only

First step: Select *d* from the recommended *h*

				
oneway slab	L/20	L/24	L/28	L/10
BEAM	L/16	L/18.5	L/21	L/8

where d = h – cover – stirrup diameter -0.5 main reinforcement diameter Then
Second step: Find b where (d / b ≈1.5 to 2)

Third step: Find *Wu*

Wu = 1.2 D.L + 1.6 L.L

Fourth step: Find Mu as followed:

Case	Positive moment
At end span with discontinuous unrestrained end	WuL2/11
At end span with discontinuous integral with support end	WuL2/14
At interior span	WuL2/16
Case	Negative moment
At exterior face of first interior support for two spans	WuL2/9
At exterior face of first interior support for more than two spans	WuL2/10
At other faces of interior support	WuL2/11

Fifth step: Assume $\varphi = 0.9$ to be check later

Sixth step: Compute tension reinforcement ratio

compute ρ from:$M_u = \varphi \rho b d^2 f_y \left(1 - 0.59\rho \frac{f_y}{f'_c}\right)$

And then check $\rho_{max} \leq \rho \leq \rho_{min}$

$$\rho_{min} = \max\left(\frac{1.4}{f_y}, \frac{\sqrt{f_c'}}{4f_y}\right)$$

$$\rho_{max} = 0.85\beta_1 \frac{f_c'}{f_y} \frac{\epsilon_{cu}}{\epsilon_{cu} + 0.004}$$

$$\beta_1 = \begin{cases} 0.85 & if\ (f'_c \leq 28\ MPa) \\ 0.85 - 0.05\left(\frac{f'_c - 28}{7}\right) & if\ (28 < f'_c \leq 56) \\ 0.65 & if\ (f'_c > 56\ MPa) \end{cases}$$

Seventh step: Check φ

$if\ \rho \leq \rho_t \qquad then\ \varphi = 0.9$

$if\ \ \rho > \rho_t$ $\qquad then\ \varphi = 0.483 + 83.3\,\epsilon_t > 0.65$

$and\ redesign\ from\ step\ five$

$$where\ \ \rho_t = 0.85\beta_1 \frac{f_c{}'}{f_y} \frac{\epsilon_{cu}}{\epsilon_{cu} + 0.005} \quad , \ \epsilon_t = \epsilon_{cu} * \frac{d_t - c}{c} \ , and\ d_t \approx d$$

Eighth Step: select steel reinforcement

$$A_s = \rho bd$$

Ninth step: check strength of section

$$M_u \le \varphi \rho b d^2 f_y \left(1 - 0.59\rho \frac{f_y}{f'_c}\right)$$