LECTURE # 2

1. NOMINAL CAPACITY OF CONCENTRICALLY LOADED COLUMN AT ULTIMATE STAGE:

At ultimate stage, $f_{st} = f_y$ and $f_c = f_c'$

Therefore,

P_n = (Concrete Area x Maximum Concrete Stress) + (Steel Area x Maximum Steel stress)

$P_n = 0.85 f_c' A_c + f_y A_{st}$

$P_n = 0.85 f_c' (A_g - A_{st}) + f_y A_{st}$

$P_n = 0.85 f_c' A_g + (f_y - 0.85 f_c') A_{st}$

Now, for a tied column,

$P_u = \phi P_n = (0.65 \text{ x } 0.8) [0.85 f_c' A_g + (f_y - 0.85 f_c') A_{st}]$

and for a spirally reinforced column,

$P_u = \phi P_n = (0.75 \text{ x } 0.85) [0.85 f_c' A_g + (f_y - 0.85 f_c') A_{st}]$

2. MAXIMUM AND MINIMUM STEEL RATIOS:

Steel ratio = $\rho = \dfrac{A_{st}}{b.h}$

ρ_{min} = 0.01 or 1%

ρ_{max} = 0.08 or 8%

A reasonable reinforcement ratio is between 1% to 3%. It is not advisable to use higher reinforcement ratios then 3 – 4% to avoid congestion of steel reinforcement.

Note: A minimum of 4 longitudinal bars should be used in case of tied columns whereas a minimum of 6 longitudinal bars should be used in case of spiral columns.

3. CLEAR COVER REQUIREMENTS:

According to **ACI 318-08, 7.7.1**;

1. Clear cover = 3 inch (if soil is in contact)
2. Clear cover = 1.5 inch (if soil is not in contact)

4. DESIGN OF TIES:

Lateral ties do not depend upon the applied loading and is usually independent of the loads. When dealing with design of lateral ties we have to decide three things;

1. Diameter of the tie bar.
2. Shape of the ties
3. Longitudinal spacing of the ties.

1. Diameter of tie bar:

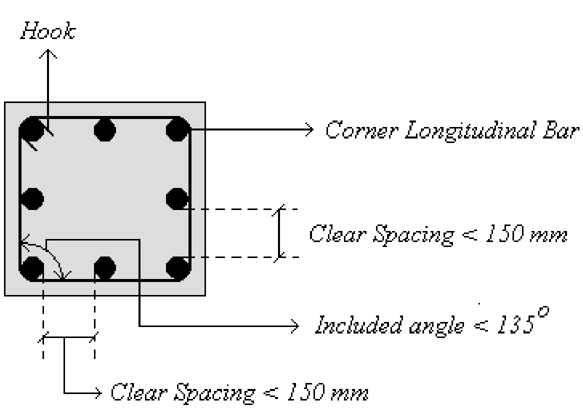
We use the following diameters of the tie bar;

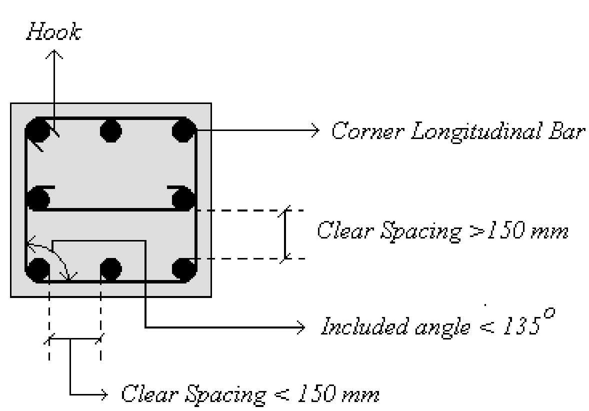
- # 3 diameter tie bar for longitudinal steel having diameter $\leq$ 1.25 inch (32mm)
- # 4 diameter tie bar for longitudinal steel having diameter > 1.25 inch (32mm)

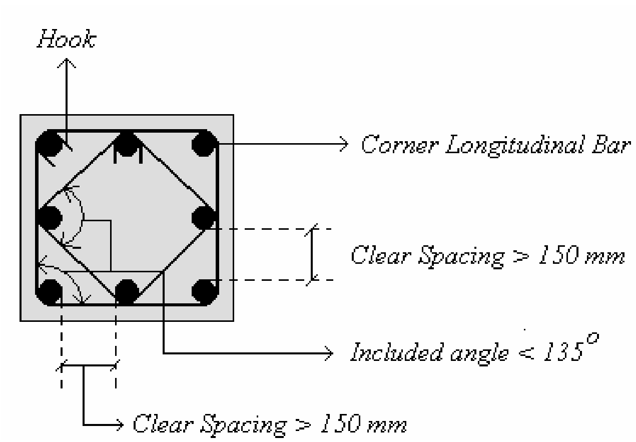
2. Shape of the ties:

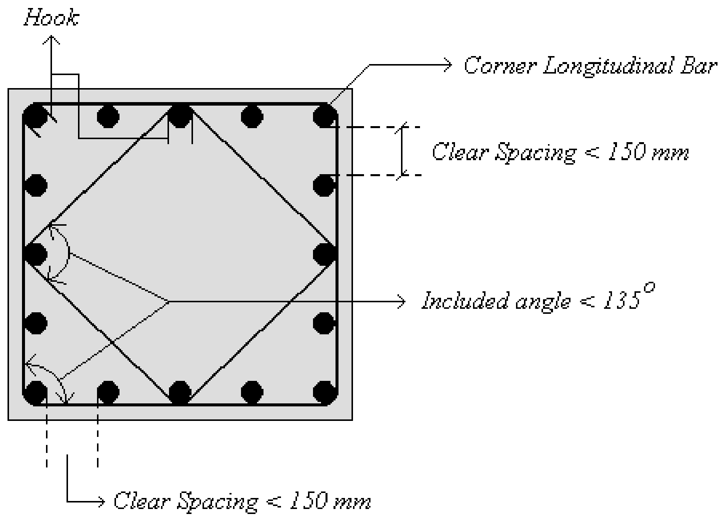
Ties should be placed in such a way so that every corner longitudinal bar, every alternate bar and bars having clear spacing greater than 6 inch (150 mm), should be enclosed by a tie having an included angle not greater than $135°$.

The lateral ties should have a $135°$ hook at the ends having same length. The ties should not have bent except at the longitudinal bars.









3. Longitudinal spacing of the ties:

Spacing = minimum of;

a. 16 x (Diameter of the smallest longitudinal bar).

b. 48 x (Diameter of the Tie).

c. Least column dimension.

d. 12 inch (300 mm).

5. SPIRAL REINFORCEMENT:

It is also called helical lateral reinforcement and is very useful in increasing the ductility of the member in earthquake sensitive regions.

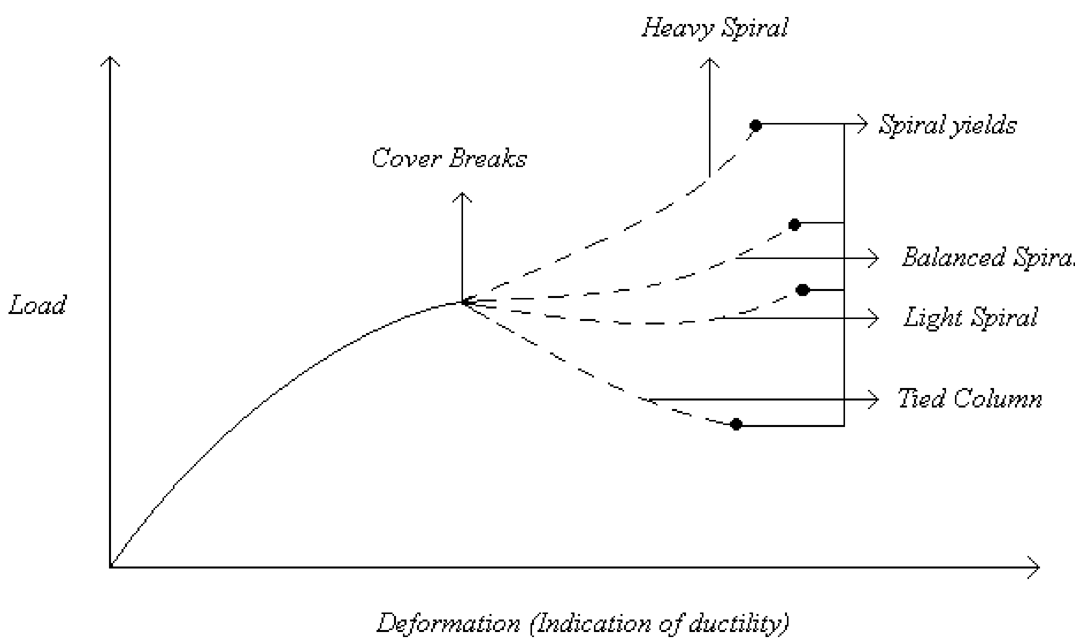
Spiral reinforcement is usually provided in circular columns and the concrete which is present inside the spiral is called core concrete and the cover is called shell or concrete cover.

Normally when the unusual lateral earthquake forces strike the structure, the concrete outside the core concrete totally spalls and the cover breaks. There is no effect of confinement on the core concrete before falling of the cover or shell but after falling of the concrete cover, when more load acts on the column, the confinement of the core concrete becomes larger and larger. So the core concrete strength becomes larger and larger but when the spiral yields, the core concrete strength becomes lesser and failure takes place at very large deformations.

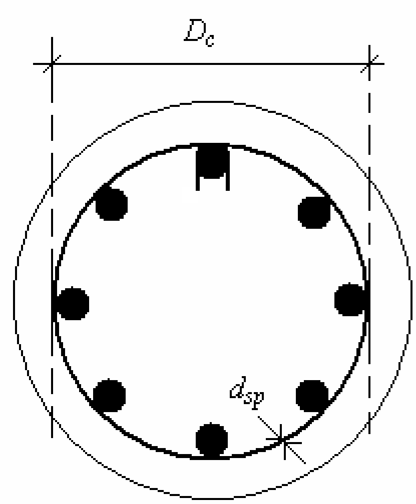
Note: Tied column ductility is very much less at ultimate condition as compared to spiral columns.

Three types of spirals are;

1. Balanced Spiral.
2. Heavy Spiral.
3. Light Spiral.



Terminologies:



f_c* = Confined core concrete strength.

f_2 = Lateral confinement stress applied by spiral on core concrete.

f_2' = Maximum value of f_2 when spiral starts yielding.

f_2 = Unconfined compressive strength of concrete.

d_{sp} = Diameter of spiral reinforcement.

A_{sp} = Area of one spiral bar.

ρ_{sp} = Spiral reinforcement ratio.

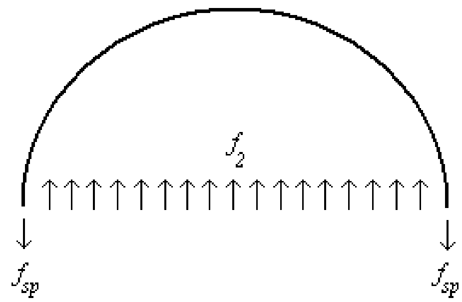
D_c = Diameter of core concrete.

L_{sp} = Length of one turn of spiral = πD_c

f_{sp} = Stress in steel spiral.

S = Pitch of the spiral.

Spiral Formulae:



$f_c^* = 4 f_2' + 0.85 f_c'$ ……………………… (1)

considering equilibrium of forces,

$2 A_{sp} f_{sp} = f_2 D_c S$

$$f_2 = \frac{2.A_{sp}.f_{sp}}{D_c.S}$$ …………………………… (2)

$$\rho_{sp} = \frac{\text{ume of spiralsteel}}{\text{ne of core concrete}} = \frac{\left(\pi/4\right) d_{sp}^2 \; \pi D_c}{\left(\pi/4\right) D_c^2 \; S}$$

$$\rho_{sp} = \frac{4 A_{sp}}{D_c S}$$ ……………………………….. (3)

$$\frac{\rho_{sp}}{4} = \frac{A_{sp}}{D_c S}$$ ……………………………… (4)

Using equation (4) in (2),

$$f_2 = \frac{\rho_{sp} f_{sp}}{2}$$ ……………………………… (5)

taking, $f_{sp} = f_y$

$$f_2 = \frac{\rho_{sp} f_y}{2}$$ ……………………………… (6)

Using equation (6) in (1),

$f_c^* = 2 \rho_{sp} f_y + 0.85 f_c'$

Now,

Additional strength = $2 \rho_{sp} f_y$

Reduction in strength due to falling of cover = $0.85 f_c' (A_g - A_c)$

Strength added due to confinement = $2 \rho_{sp} f_y A_c$

For balanced spiral,

$$0.85 f_c'(A_g - A_c) = 2\,\rho_{sp}\, f_y A_c$$

$$\rho_{sp} = 0.425\,\frac{f_c'}{f_y}\left(\frac{A_g}{A_c} - 1\right)$$

According to **ACI 318-08, 10.9.3**,

$$\rho_{sp(min)} = 0.45\,\frac{f_c'}{f_y}\left(\frac{A_g}{A_c} - 1\right) \quad for\ f_y \le 700\ MPa \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Note:- 1 Kip/sq-in = 6.895 MPa

Now from equation (3),

$$\rho_{sp} = \frac{4A_{sp}}{D_c\,S} = \frac{4\left(\pi/4\right)d_{sp}^{\ 2}}{D_c\,S} = \frac{\pi\,d_{sp}^{\ 2}}{D_c\,S} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Equating equation (7) and (8),

$$0.45\,\frac{f_c'}{f_y}\left(\frac{A_g}{A_c} - 1\right) = \frac{\pi\,d_{sp}^{\ 2}}{D_c\,S}$$

So,

$$S_{max} = \frac{\pi\,d_{sp}^{\ 2} f_y}{0.45\,D_c\,f_c'\left(\frac{A_g}{A_c} - 1\right)}$$

6. <u>DESIGN OF SPIRAL REINFORCEMENT:</u>

1. Diameter of the spiral bar = 3/8" inch or less
2. Minimum pitch, S_{min} = larger of;
    a. 1.5 x (Maximum aggregate size)
    b. 1inch (25mm)
3. Clear pitch must not be larger than 3 inch (Thumb rule).
4. $S_{max} = \dfrac{\pi\,d_{sp}^{\ 2} f_y}{0.45\,D_c\,f_c'\left(\frac{A_g}{A_c} - 1\right)}$.