CHAPTER 3

DESIGN AND DETAILING OF BEAM COLUMN JOINT SPECIMENS

3.1 General

This chapter gives a detailed outlook of the dimensions, the load calculations, the design specifications and the detailing of beam-column specimens as per code IS 456:2000 and code IS 13920:1993.The details of the preparation of the control and retrofitted reinforced concrete beam-column joint specimens are also given in this chapter.

3.2 Design and Detailing of Beam-Column Joint Specimens as per Code IS 456:2000 for M 20 Concrete

The test specimen consists of a column portion of cross-section 200 mm x 200 mm and a cantilever beam portion having the same cross-section. The height of the column is 1.5 m and the length of the cantilever portion is 0.6 m. The grade of concrete is M 20 and the grade of steel is Fe 415 for main reinforcement & Fe 250 for transverse reinforcement.

3.2.1 Tension Reinforcement in Beam

According to code IS 456:2000, Cl 26.5.1.1 (a), the minimum tension reinforcement should not be less than the following

$$A_s = 0.85bd/f_y \quad , \text{ where}$$

A_s = minimum area of tension reinforcement

b = breadth of beam

d = effective depth

f_y = Characteristic strength of reinforcement in N/mm^2

i.e. A_s = 0.85 x 200 x 170/ 415

Therefore the Minimum area of tension reinforcement required is 69.63 mm^2.

The maximum area of tension reinforcement according to code IS 456: 2000, Cl 26.5.1.1(b) is given as 0.04bD.

i.e. 0.04 x 200 x 200 = 1600mm^2

Two numbers of 16 mm diameter bars has been adopted as tension reinforcement. The area of tension reinforcement provided is 402.18 mm^2 which is within the above limits.

3.2.2 Compression Reinforcement in Beam

According to code IS 456:2000, Cl 26.5.1.2, the maximum area of compression reinforcement is less than 0.04bD.

$$\text{i.e. } 0.04 \times 200 \times 200 = 1600 \text{mm}^2.$$

Two numbers of 12mm diameter bars has been adopted as compression reinforcement for the static load test. Two numbers of 16 mm diameter bars has been provided in compression side also for the load reversal test. The area of reinforcement provided are 226.19 mm^2 and 402.12 mm^2 which is less than the maximum limit prescribed in the code.

3.2.3 Shear Reinforcement in Beam

According to code IS 456:2000, Cl 26.5.1.6, the minimum shear reinforcement in the form of stirrups shall be provided such that

$$(A_{sv} / b \, S_{v)} = 0.4 / \, 0.87 \, f_y$$

where A_{sv} = total cross-sectional area of stirrup legs effective in shear

S_v = stirrup spacing along the length of the member

b = breadth of the beam

f_y = characteristic strength of the stirrup reinforcement in N/mm^2

$$A_{sv} = 0.4 \times 200 \times 120 / 0.87 \times 415$$

$$= 26.58 \text{ mm}^2.$$

Using 2-legged 6mm diameter bar as stirrup, the cross-sectional area of stirrup is worked out to be 56.54 mm^2.

3.2.3.1 Spacing of Shear Reinforcement

According to IS 456:2000, cl 26.5.1.5, the maximum spacing of shear reinforcement measured along the axis of the member shall not exceed 0.75 d for vertical stirrups where d is the effective depth of the section under consideration. In no case shall the spacing exceed 300 mm.

$$\text{i.e. } 0.75d = 127.5 \text{ mm}$$

Therefore, 6mm Ø stirrups had been adopted at a spacing of 120mm centre to centre.

3.2.3.2 Check for Bending

$A_{st} = 402.18$ mm^2 ; $A_{sc} = 226.23$ mm^2

$T_u = 0.87 \, f_y \, A_{st} = 0.84 \times 415 \times 402.18 = 145207$ N

$C_u = 0.36\ f_{ck}\ x_u\ b + f_{sc}\ A_{sc} - 0.446\ f_{ck}\ A_{sc}$

$\quad = 0.36\ x\ 20\ x\ 200\ x\ x_u + 226.23\ f_{sc} - 0.446\ x\ 20\ x\ 226.23$

$\quad = 1440\ x_u + 226.23f_{sc} - 2018$

Let assume $x_u = 50$; $3/7\ x_u = 21 > 20$ which is d' [ref: fig.7, IS 456:2000]

$\quad \varepsilon_{cu} = 0.0035(x_u\text{-}d')/x_u = 0.0021$: $f_{sc} = 330$ N/mm^2 [ref. Table A , SP 16 ,page.6]

$\quad Cu = 1440\ x\ 50 + 226.23\ x\ 330 - 2018 = 144637$ N

$\quad C_u \approx T_u$

$\quad Mu = C_{cu}\ (d\text{-}0.416\ x_u) + C_{su}\ (d\text{-}d')$

$\quad\quad = 72000\ (170\text{-}0.416\ x\ 50) + 72638\ (170\text{-}20)$

$\quad\quad = 21.6\ x\ 10^6\ \text{N-mm}$

But $M_u =$ Bending moment (i.e) $M_u = Wl$

$\quad\quad$ where W= Load on the beam

$\quad\quad\quad$ l = Distance of the load

$\quad\quad 21.6\ x\ 10^6 = W\ x\ 600$

$\quad\quad\quad W = 35.5$ kN

According to IS 456:2000, cl 40.1, the nominal shear stress in beams of uniform depth can be calculated as

$$\tau_v = V_u/\ bd$$

$\quad$ where $\tau_v =$ Nominal shear stress

$\quad\quad V_u =$ shear force due to design loads

$\quad\quad\quad b =$ breadth of the member, which for flanged section shall be taken as

$\quad\quad\quad\quad$ the breadth of the web, bw

$\quad\quad d =$ effective depth.

$$\tau_v = 35500/\ (200\ x\ 170)$$

$$\tau_v = 1.044\ \text{N/mm}^2$$

100Ast/bd = 100 x 402.18/200 x 170 = 1.18%

The design shear strength of concrete τ_c had been obtained from Table 19 of IS 456 : 2000 as 0.65 N/mm^2.

From Table 20, of IS 456:2000, the maximum shear stress, τ_{cmax} for M$_{20}$ grade of concrete had been obtained as 2.8

According to IS 456:2000, cl 40.2.3, the nominal shear stress in beams τ_v, should not exceed τ_{cmax} given in Table 20 of code IS 456:2000.

$$\tau_{cmax} > \tau_v > \tau_c$$

Tthe shear reinforcement is to be provided according to IS 456:2000, cl 40.3

According to IS 456:2000, cl 40.4, shear reinforcement shall be provided to carry a shear equal to $(V_u - \tau_c bd)$ The strength of shear reinforcement V_{us} shall be calculated as

$$V_{us} = 0.87 \times f_y \times A_{sv} \times d / s_v$$

Where A_{sv} = total cross-sectional area of stirrup legs or bent-up bars within a distance s_v.

s_v = spacing of the stirrups or bent-up bars along the length of the member.

τ_c = design shear strength of the concrete.

b = breadth of the member.

f_y = characteristic strength of the stirrup or bent-up reinforcement which shall not be taken greater than 415 N/mm^2,

d = effective depth.

Therefore, $V_{us} = (V_u - \tau_c bd)$

$$= (35500 - 0.65 \times 200 \times 170)$$

$$= 13400 \text{ N}$$

But, $V_{us} = 0.87 \times f_y \times A_{sv} \times d / s_v$

i.e. $s_v = 0.87 \times f_y \times A_{sv} \times d / V_{us}$

$$= 0.87 \times 250 \times 56.54 \times 170 / 13400 \quad s_v = 156 \text{ mm}$$

But the adopted stirrup spacing in the beam is 120mm which is less than the above requirement for shear. So, the beam is safe against shear.

3.2.3.3 Anchorage Length

According to IS 456:2000, cl 26.2, the calculated tension or compression in any bar at any section shall be developed on each side of the section by an appropriate development length or end anchorage or by a combination.

The development length L_d is given in cl 26.2.1 of code IS 456:2000 as,

$$L_d = (\emptyset \sigma_s / 4 \tau_{bd})$$

Where $\emptyset$ = nominal diameter of the bar,

σ_s = stress in bar at the section considered at design load

τ_{bd} = design bond stress given in cl 26.2.1.1 of IS 456:2000.

According to IS 456: 2000, the design bond stress in limit state method for plain bars in tension for M 20 grade concrete is given as 1.2 N/mm^2. Also it is given that for the deformed bars the value of design bond stress is to be increased by 60 percent and for the bars in compression, the values of bond stress for bars in tension shall be increased by 25 percent.

Fe 415 bars of 16 mm $\emptyset$ have been used as the tension reinforcement and 12mm $\emptyset$ have been used as compression reinforcement for static test.

Therefore the anchorage length for the tension rod in the beam can be obtained as,

$$L_d = (16 \times 0.87 \times 415) / (4 \times 1.2 \times 1.6) = 753 \text{ mm}.$$

The anchorage length for the compression rod in the beam can be obtained as,

$$L_d = (12 \times 0.87 \times 415) / (4 \times 1.2 \times 1.25 \times 1.6) = 451mm.$$

Fe 415 bars of 16 mm diameter bars have been used as the tension and compression reinforcement for load reversal.

Therefore the anchorage length for rods in the beam can be obtained as,

$$L_d = (16 \times 0.87 \times 415) / (4 \times 1.2 \times 1.25) = 753 \text{ mm}.$$

3.2.4 Longitudinal Reinforcement in Column

According to code IS 456:2000, cl 26.5.3.1 (a), the cross-sectional area of longitudinal reinforcement, shall be not less than 0.8 percent and not more than 6 percent of the gross cross- sectional area of the column.

As given in cl 26.5.3.1(c) & (d), the minimum number of longitudinal bars provided in a column shall be four in rectangular columns and the bars shall not be less than 12 mm in diameter.

Four numbers of 12 mm diameter rods has been provided as longitudinal reinforcement. Cross section area of reinforcement = $452.39mm^2$

Percentage of steel is 1.13 %, which is greater than 0.8 % and less than 6 %.

3.2.5 Lateral Ties in Column

The diameter of the polygonal links or lateral ties shall be not less than one-fourth of the diameter of the largest longitudinal bar, and in no case less than 6 mm.
6 mm diameter bar was adopted for the lateral ties which are greater than one fourth diameter of the longitudinal bar of 12mm diameter bar.

3.2.5.1 Spacing of Lateral Ties

According to IS 456:2000, cl 26.5.3.2(c), the spacing of transverse reinforcement shall be not more than the least of the following distances:

    i)   The least lateral dimension of the compression members

        i.e. 200 mm

    ii) Sixteen times the smallest diameter of the longitudinal reinforcement bar to

      be tied;

      i.e. 16 x 12 = 192 mm.

    iii) 300 mm.

The least of the above three dimensions is 192 mm. Therefore the spacing should be less than or equal to 192 mm. The spacing for the lateral ties in the column has been fixed as 180 mm

center to center. Fig.3.1 shows the reinforcement details for the beam-column joint specimen detailed as per code IS 456: 2000 subjected to static load. Fig.3.2 shows the reinforcement detail for M20 concrete beam-column joint specimen detailed as per code IS 456: 2000 subjected to load reversal.
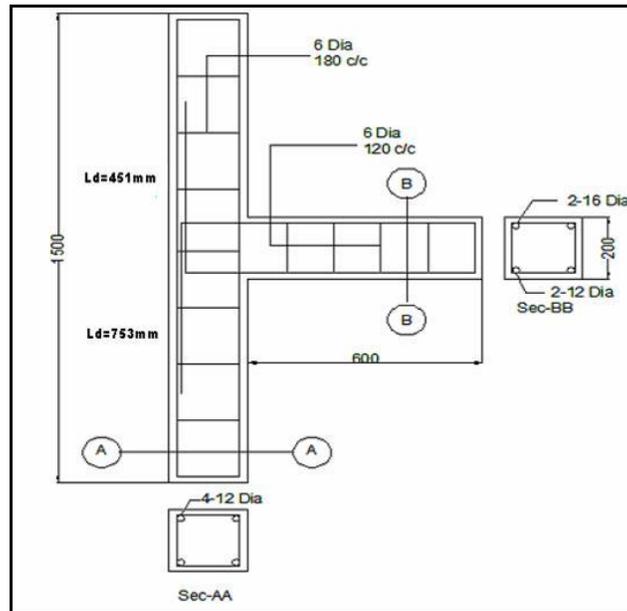

Fig.3.1 Reinforcement Details for M20 Concrete Specimen
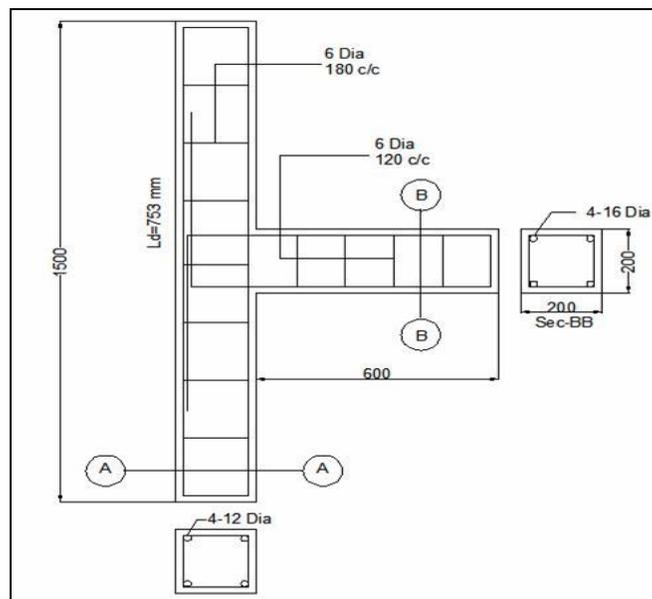as per Code IS 456: 2000 Subjected to Static Load

Fig.3.2 Reinforcement Details for M20 Concrete Specimen
as per Code IS 456: 2000 Subjected to Load Reversal

3.3 Design and Detailing of Beam-Column Joint Specimens as per Code IS 456:2000 for M 25 Concrete

The test specimen consists of a column portion of cross-section 200 mm x 200 mm and a cantilever beam portion having the same cross-section. The height of the column is 1.5 m and the length of the cantilever portion is 0.6 m. The grade of concrete is M 25 and the grade of steel is Fe 415 for main reinforcement & Fe 250 for transverse reinforcement.

3.3.1 Tension Reinforcement in Beam

According to code IS 456:2000, Cl 26.5.1.1 (a), the minimum tension reinforcement should not be less than the following

$$A_s = 0.85bd/f_y \quad \text{, where}$$

A_s = minimum area of tension reinforcement

b = breadth of beam

d = effective depth

f_y = Characteristic strength of reinforcement in N/mm^2

i.e. A_s = 0.85 x 200 x 170/ 415

Therefore the Minimum area of tension reinforcement required is 69.63 mm^2.

The maximum area of tension reinforcement according to code IS 456: 2000, Cl 26.5.1.1(b) is given as 0.04bD.

i.e. 0.04 x 200 x 200 = 1600mm^2

Two numbers of 16 mm diameter bars has been adopted as tension reinforcement. The area of tension reinforcement provided is 402.18 mm^2 which is within the above limits.

3.3.2 Compression Reinforcement in Beam

According to code IS 456:2000, Cl 26.5.1.2, The maximum area of compression reinforcement is less than 0.04bD.

i.e. 0.04 x 200 x 200 = 1600mm^2.

Two numbers of 12mm diameter bars has been adopted as compression reinforcement for the static load test. Two numbers of 16 mm diameter bars has been provided in compression side also for the load reversal test. The area of reinforcement provided are 226.19 mm^2 and 402.12 mm^2 which is less than the maximum limit prescribed in the code.

3.3.3 Shear Reinforcement in Beam

According to code IS 456:2000, Cl 26.5.1.6, the minimum shear reinforcement in the form of stirrups shall be provided such that:

$$(A_{sv} / b\, S_v) = 0.4/\,0.87\, f_y$$

where A_{sv} = total cross-sectional area of stirrup legs effective in shear

S_v = stirrup spacing along the length of the member

b = breadth of the beam

f_y = characteristic strength of the stirrup reinforcement in N/mm^2

$$A_{sv} = 0.4 \text{ x } 200 \text{ x } 120 / 0.87 \text{ x } 415$$

$$= 26.58 \text{ mm}^2.$$

Using 2-legged 6mm diameter bar as stirrup, the cross-sectional area of stirrup is worked out to be 56.54 mm^2.

3.3.3.1 Spacing of Shear Reinforcement

According to IS 456:2000, cl 26.5.1.5, the maximum spacing of shear reinforcement measured along the axis of the member shall not exceed 0.75 d for vertical stirrups where d is the effective depth of the section under consideration. In no case shall the spacing exceed 300 mm.

$$\text{i.e. } 0.75d = 127.5 \text{ mm}$$

Therefore, 6mm Ø stirrups had been adopted at a spacing of 120mm centre to centre.

3.3.3.2 Check for Bending

$$A_{st} = 402.18 \text{ mm}^2 \quad ; \quad A_{sc} = 226.23 \text{ mm}^2$$

$$T_u = 0.87\, f_y\, A_{st} = 0.87 \text{ x } 415 \text{ x } 402.18 = 145207 \text{ N}$$

$$C_u = 0.36\, f_{ck}\, x_u\, b + f_{sc}\, A_{sc} - 0.446\, f_{ck}\, A_{sc}$$

$$= 0.36 \text{ x } 25 \text{ x } 200 \text{ x } x_u + 226.23\, f_{sc} - 0.446 \text{ x } 25 \text{ x } 226.23$$

$$= 1800\, x_u + 226.23 f_{sc} - 2523$$

Let assume $x_u = 48$; $3/7\, x_u = 20.6 > 20$ which is d' [ref: fig.7, IS 456:2000]

$\varepsilon_{cu} = 0.0035(x_u\text{-d'})/x_u = 0.00204$: $f_{sc} = 320$ N/mm^2 [ref. Table A , SP 16 ,page.6]

$C_u = 1800 \text{ x } 48 + 226.23 \text{ x } 320 - 2523 = 156197 \text{ N}$

$C_u \approx T_u$

$M_u = C_{cu} (d-0.416\ x_u) + C_{su} (d-d')$

$\quad = 86400\ (170-0.416\ x\ 48) + 69797\ (170-20)$

$\quad = 23.432\ x\ 10^6\ \text{N-mm}$

But M_u = Bending moment (i.e.) $M_u = Wl$

where W = Load on the beam

$\quad\quad$ l = Distance of the load

$23.432\ x\ 10^6 = W\ x\ 600$

$\quad\quad W = 39\ kN$

According to IS 456:2000, cl 40.1, the nominal shear stress in beams of uniform depth can be calculated as

$$\tau v = V_u /\ bd$$

where τ_v = Nominal shear stress

$\quad\quad V_u$ = shear force due to design loads

$\quad\quad$ b = breadth of the member, which for flanged section shall be taken as

$\quad\quad\quad$ the breadth of the web, bw

$\quad\quad$ d = effective depth.

$$\tau v = 39200 /\ (200\ x\ 170)$$

$$\tau v = 1.153\ \text{N/mm}^2$$

$$100Ast/bd = 100\ x\ 402.18/200\ x\ 170 = 1.18\%$$

The design shear strength of concrete τ_c had been obtained from Table 19 of IS 456 : 2000 as 0.65 N/mm^2.

From Table 20, of IS 456:2000, the maximum shear stress, τ_{cmax} for M$_{25}$ grade of concrete had been obtained as 3.1 .According to IS 456:2000, cl 40.2.3, the nominal shear stress in beams τ_v, should not exceed τ_{cmax} given in Table 20 of code IS 456:2000.

$$\tau_{cmax} > \tau_v > \tau_c$$

The shear reinforcement is to be provided according to IS 456:2000, cl 40.3

According to IS 456:2000, cl 40.4, shear reinforcement shall be provided to carry a shear equal to $(V_u - \tau_c\, bd)$ The strength of shear reinforcement V_{us} shall be calculated as

$$V_{us} = 0.87 \text{ x } f_y \text{ x } A_{sv} \text{ x } d \,/\, s_v$$

Where A_{sv} = total cross-sectional area of stirrup legs or bent-up bars within a distance s_v.

s_v = spacing of the stirrups or bent-up bars along the length of the member.

τ_c = design shear strength of the concrete.

b = breadth of the member.

f_y = characteristic strength of the stirrup or bent-up reinforcement which shall

not be taken greater than 415 N/mm^2,

d = effective depth.

Therefore, $V_{us} = (V_u - \tau_c\, bd)$

$$= (39200 - 0.65 \text{ x } 200 \text{ x } 170\,)$$

$$= 17100 \text{ N}$$

But, $V_{us} = 0.87 \text{ x } f_y \text{ x } A_{sv} \text{ x } d \,/\, s_v$

i.e. $s_v = 0.87 \text{ x } f_y \text{ x } A_{sv} \text{ x } d \,/\, V_{us}$

$$= 0.87 \text{ x } 250 \text{ x } 56.54 \text{ x } 170 \,/\, 17100 \quad s_v = 123 \text{ mm}$$

But the adopted stirrup spacing in the beam is 120mm which is less than the above requirement for shear. So, the beam is safe against shear.

3.3.3.3 Anchorage Length

According to IS 456:2000, cl 26.2, the calculated tension or compression in any bar at any section shall be developed on each side of the section by an appropriate development length or end anchorage or by a combination.

The development length L_d is given in cl 26.2.1 of code IS 456:2000 as,

$$L_d = (\emptyset\sigma_s/4\tau_{bd})$$

Where $\emptyset$ = nominal diameter of the bar,

σ_s = stress in bar at the section considered at design load

τ_{bd} = design bond stress given in cl 26.2.1.1 of IS 456:2000.

According to IS 456: 2000, the design bond stress in limit state method for plain bars in tension for M 25 grade concrete is given as 1.4 N/mm^2. Also it is given that for the deformed bars the value of design bond stress is to be increased by 60 percent and for the bars in compression, the values of bond stress for bars in tension shall be increased by 25 percent.

Fe 415 bars of 16 mm $\emptyset$ have been used as the tension reinforcement and 12mm $\emptyset$ have been used as compression reinforcement for static test.

Therefore the anchorage length for the tension rod in the beam can be obtained as,

$$L_d = (16 \times 0.87 \times 415) / (4 \times 1.4 \times 1.6) = 645 \text{ mm.}$$

The anchorage length for the compression rod in the beam can be obtained as,

$$L_d = (12 \times 0.87 \times 415) / (4 \times 1.4 \times 1.25 \times 1.6) = 387 \text{ mm.}$$

Fe 415 bars of 16 mm diameter bars have been used as the tension and compression reinforcement for load reversal.

Therefore the anchorage length for rods in the beam can be obtained as,

$$L_d = (16 \times 0.87 \times 415) / (4 \times 1.2 \times 1.25) = 645 \text{ mm.}$$

3.3.4 Longitudinal Reinforcement in Column

According to code IS 456:2000, cl 26.5.3.1 (a), the cross-sectional area of longitudinal reinforcement shall be not less than 0.8 percent and not more than 6 percent of the gross cross sectional area of the column.

As given in cl 26.5.3.1(c) & (d), the minimum number of longitudinal bars provided in a column shall be four in rectangular columns and the bars shall not be less than 12 mm in diameter.

Four number12 mm diameter bar has been provided as longitudinal reinforcement.

Cross section area of reinforcement = 452.39 mm^2

Percentage of steel is 1.13 %, which is greater than 0.8 % and less than 6 %.

3.3.5 Lateral Ties in Column

The diameter of the polygonal links or lateral ties shall be not less than one- fourth of the diameter of the largest longitudinal bar, and in no case less than 6 mm. 6 mm diameter bar was adopted for the lateral ties which are greater than one fourth diameter of the longitudinal bar of 12mm diameter bar.

3.3.5.1 Spacing of Lateral Ties

According to IS 456:2000, cl 26.5.3.2(c), the spacing of transverse reinforcement shall be not more than the least of the following distances:

i)   The least lateral dimension of the compression members i.e. 200 mm

ii) Sixteen times the smallest diameter of the longitudinal reinforcement bar to
      be tied; i.e. 16 x 12 = 192 mm.

iii) 300 mm.

The least of the above three dimentions is 192 mm. Therefore the spacing should be less than or equal to 192 mm. The spacing for the lateral ties in the column has been fixed as 180mm center to center. Fig.3.3 shows the reinforcement details for M25 concrete beam-column joint specimen detailed as per code IS 456: 2000 subjected to static load. Fig.3.4 shows the reinforcement details for M25 concrete beam-column joint specimen detailed as per code IS 456 : 2000 subjected to load reversal.
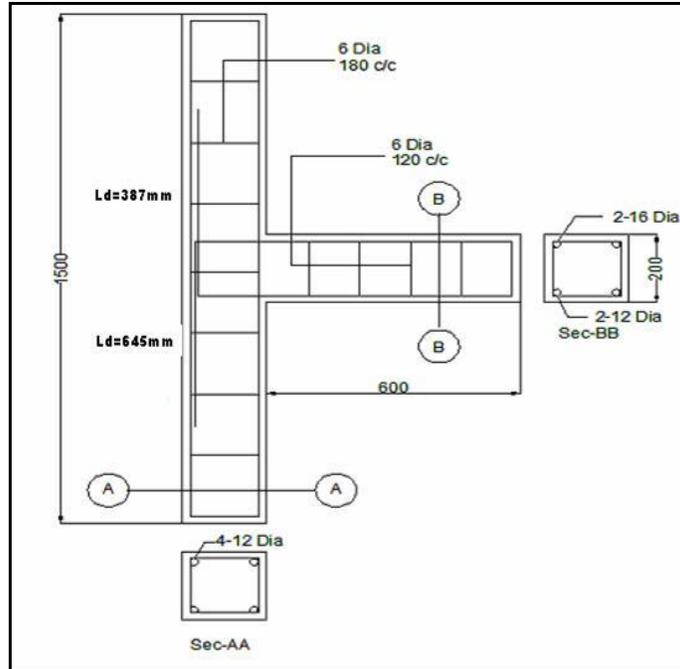
Fig.3.3 Reinforcement Details for M25 Concrete Specimen
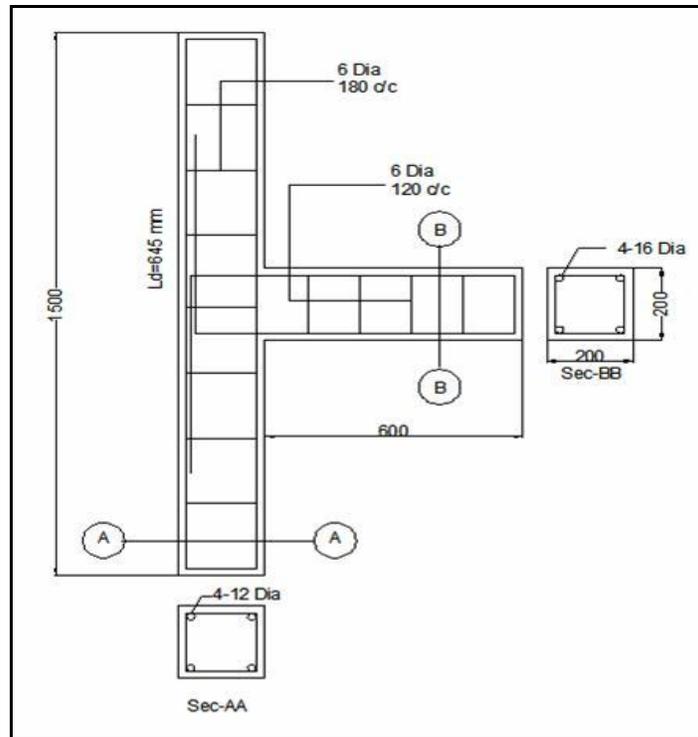as per IS 456: 2000 Subjected to Static Load

Fig.3.4 Reinforcement Details for M25 Concrete Specimen
as per IS 456: 2000 Subjected to Load Reversal

3.4 Design and Detailing of Beam-Column Joint Specimens as per Code IS 456:2000 for M 30 Concrete

The test specimen consists of a column portion of cross-section 200 mm x 200 mm and a cantilever beam portion having the same cross-section. The height of the column is 1.5 m and the length of the cantilever portion is 0.6 m. The grade of concrete is M 30 and the grade of steel is Fe 415 for main reinforcement & Fe 250 for transverse reinforcement.

3.4.1 Tension Reinforcement in Beam

According to code IS 456:2000, Cl 26.5.1.1 (a), the minimum tension reinforcement should not be less than the following

$$A_s = 0.85bd/f_y \quad , \text{ where}$$

A_s = minimum area of tension reinforcement

b = breadth of beam

d = effective depth

f_y = Characteristic strength of reinforcement in N/mm^2

i.e. $A_s = 0.85$ x 200 x 170/ 415

Therefore the Minimum area of tension reinforcement required is 69.63 mm^2.

The maximum area of tension reinforcement according to code IS 456: 2000, Cl 26.5.1.1(b) is given as 0.04bD.

i.e. 0.04 x 200 x 200 = 1600mm^2

Two numbers of 16 mm diameter bars has been adopted as tension reinforcement. The area of tension reinforcement provided is 402.18 mm^2 which is within the above limits.

3.4.2 Compression Reinforcement in Beam

According to code IS 456:2000, Cl 26.5.1.2, The maximum area of compression reinforcement is less than 0.04bD.

i.e. 0.04 x 200 x 200 = 1600mm^2.

Two numbers of 12mm diameter bars has been adopted as compression reinforcement for the static load test. Two numbers of 16 mm diameter bars has been provided in compression side also for the load reversal test. The area of reinforcement provided are 226.19 mm^2 and 402.12 mm^2 which is less than the maximum limit prescribed in the code.

3.4.3 Shear Reinforcement in Beam

According to code IS 456:2000, Cl 26.5.1.6, the minimum shear reinforcement in the form of stirrups shall be provided such that:

$$(A_{sv}/b\,S_v) = 0.4/\,0.87\,f_y$$

where A_{sv} = total cross-sectional area of stirrup legs effective in shear

S_v = stirrup spacing along the length of the member

b = breadth of the beam

f_y = characteristic strength of the stirrup reinforcement in N/mm^2

$$A_{sv} = 0.4 \times 200 \times 120 / 0.87 \times 415$$

$$= 26.58 \text{ mm}^2.$$

Using 2-legged 6mm diameter bar as stirrup, the cross-sectional area of stirrup is worked out to be 56.54 mm^2.

3.4.3.1 Spacing of Shear Reinforcement

According to IS 456:2000, cl 26.5.1.5, the maximum spacing of shear reinforcement measured along the axis of the member shall not exceed 0.75 d for vertical stirrups where d is the effective depth of the section under consideration. In no case shall the spacing exceed 300 mm.

$$\text{i.e. } 0.75d = 127.5 \text{ mm}$$

Therefore, 6mm Ø stirrups had been adopted at a spacing of 120mm centre to centre.

3.4.3.2 Check for Bending

$A_{st} = 402.18$ mm^2 ; $A_{sc} = 226.23$ mm^2

$T_u = 0.87\,f_y\,A_{st} = 0.84 \times 415 \times 402.18 = 145207$ N

$C_u = 0.36\,f_{ck}\,x_u\,b + f_{sc}\,A_{sc} - 0.446\,f_{ck}\,A_{sc}$

$\quad = 0.36 \times 30 \times 200 \times x_u + 226.23\,f_{sc} - 0.446 \times 30 \times 226.23$

$\quad = 2160\,x_u + 226.23f_{sc} - 3027$

Let assume $x_u = 47$; $3/7\,x_u = 20.14 > 20$ which is d' [ref: fig.7, IS 456:2000]

$\varepsilon_{cu} = 0.0035(x_u\text{-}d')/x_u = 0.002$: $f_{sc} = 310$ N/mm^2 [ref. Table A , SP 16 ,page.6]

Cu = 2160 x 47 + 226.23 x 310 – 3027 = 168624 N

$C_u \approx T_u$

$M_u = C_{cu} (d-0.416 \, x_u) + C_{su} (d-d')$

    = 101520 (170-0.416 x 47) + 67104 (170-20)

    = 25.4 x 10^6 N-mm

    But M_u = Bending moment (i.e). $M_u = Wl$

    where W= Load on the beam

        l = Distance of the load

    25.4 x 10^6 = W x 600

      W = 42.2 kN

According to IS 456:2000, cl 40.1, the nominal shear stress in beams of uniform depth can be calculated as

$$\tau_v = V_u / \, bd$$

where τ_v = Nominal shear stress

    V_u = shear force due to design loads

    b = breadth of the member, which for flanged section shall be taken as

      the breadth of the web, bw

    d = effective depth.

$$\tau_v = 42200 / \, (200 \text{ x } 170)$$

$$\tau_v = 1.24 \text{ N/mm}^2$$

100Ast/bd = 100 x 402.18/200 x 170 = 1.18%

The design shear strength of concrete τ_c had been obtained from Table 19 of   IS 456 : 2000 as 0.65 N/mm^2.

From Table 20 of IS 456:2000, the maximum shear stress, τ_{cmax} for M$_{30}$ grade of concrete had been obtained as 3.5.

According to IS 456:2000, cl 40.2.3, the nominal shear stress in beams τ_v, should not exceed τ_{cmax} given in Table 20 of code IS 456:2000.

$$\tau_{cmax} > \tau_v > \tau_c$$

Tthe shear reinforcement is to be provided according to IS 456:2000, cl 40.3.

According to IS 456:2000, cl 40.4, shear reinforcement shall be provided to carry a shear equal to (V_u - τ_c bd) The strength of shear reinforcement V_{us} shall be calculated as

$$V_{us} = 0.87 \times f_y \times A_{sv} \times d / s_v$$

Where

A_{sv} = total cross-sectional area of stirrup legs or bent-up bars within a distance s_v.

s_v = spacing of the stirrups or bent-up bars along the length of the member.

τ_c = design shear strength of the concrete.

b = breadth of the member,

f_y = characteristic strength of the stirrup or bent-up reinforcement which shall not be taken greater than 415 N/mm^2,

d = effective depth.

Therefore, V_{us} = (V_u - τ_c bd)

$$= (42200 - 0.65 \times 200 \times 170)$$

$$= 20100 \text{ N}$$

But, $V_{us} = 0.87 \times f_y \times A_{sv} \times d / s_v$

i.e. $s_v = 0.87 \times f_y \times A_{sv} \times d / V_{us}$

$= 0.87$ x 250 x 56.54 x $170 / 20100$ $s_v = 121$ mm

But the adopted stirrup spacing in the beam is 120 mm which is less than the above requirement for shear. So, the beam is safe against shear.

3.4.3.3 Anchorage Length

According to IS 456:2000, cl 26.2, the calculated tension or compression in any bar at any section shall be developed on each side of the section by an appropriate development length or end anchorage or by a combination.

The development length L_d is given in cl 26.2.1 of code IS 456:2000 as,

$$L_d = (\emptyset\sigma_s/4\tau_{bd})$$

Where $\emptyset$ = nominal diameter of the bar,

σ_s= stress in bar at the section considered at design load

τ_{bd} = design bond stress given in cl 26.2.1.1 of IS 456:2000.

According to IS 456: 2000, the design bond stress in limit state method for plain bars in tension for M 30 grade concrete is given as 1.5 N/mm^2. Also it is given that for the deformed bars the value of design bond stress is to be increased by 60 percent and for the bars in compression, the values of bond stress for bars in tension shall be increased by 25 percent.

Fe 415 bars of 16 mm $\emptyset$ have been used as the tension reinforcement and 12mm $\emptyset$ have been used as compression reinforcement for static test.

Therefore the anchorage length for the tension rod in the beam can be obtained as,

$L_d = (16$ x 0.87 x $415) / (4$ x 1.5 x $1.6) = 602$ mm.

The anchorage length for the compression rod in the beam can be obtained as,

$L_d = (12$ x 0.87 x $415) / (4$ x 1.5 x 1.25 x $1.6) = 361$mm.

Fe 415 bars of 16 mm diameter bars have been used as the tension and compression reinforcement for load reversal.

Therefore the anchorage length for rods in the beam can be obtained as,

$L_d = (16$ x 0.87 x $415) / (4$ x 1.2 x $1.25) = 602$ mm.

3.4.4 Longitudinal Reinforcement in Column

According to code IS 456:2000, cl 26.5.3.1 (a), the cross-sectional area of longitudinal reinforcement shall be not less than 0.8 percent and not more than 6 percent of the gross cross-sectional area of the column.

As given in cl 26.5.3.1(c) & (d), the minimum number of longitudinal bars provided in a column shall be four in rectangular columns and the bars shall not be less than 12 mm in diameter.

Four numbers of 12 mm diameter bar has been provided for the tension reinforcement. Cross section area of reinforcement = 452.39 mm^2

Percentage of steel is 1.13 %, which is greater than 0.8 % and less than 6 %.

3.4.5 Lateral Ties in Column

The diameter of the polygonal links or lateral ties shall be not less than one-fourth of the diameter of the largest longitudinal bar, and in no case less than 6 mm. 6 mm diameter bar was adopted for the lateral ties which are greater than one fourth diameter of the longitudinal bar of 12mm diameter bar.

3.4.5.1 Spacing of Lateral Ties

According to IS 456:2000, cl 26.5.3.2(c), the spacing of transverse reinforcement shall be not more than the least of the following distances:

i) The least lateral dimension of the compression members
   i.e. 200 mm

ii) Sixteen times the smallest diameter of the longitudinal reinforcement bar to be tied;
   i.e. 16 x 12 = 192 mm.

iii) 300 mm.

The least of the above three dimensions is 192 mm. Therefore the spacing should be less than or equal to 192 mm. The spacing for the lateral ties in the column has been fixed as 180mm center to center. Fig.3.5 shows the reinforcement details for M30 concretebeam-column joint specimen detailed as per code IS 456: 2000 subjected to static load. Fig.3.6 shows the reinforcement details for M30 Concrete beam-column joint specimen detailed as per code IS 456: 2000 subjected to load reversal.
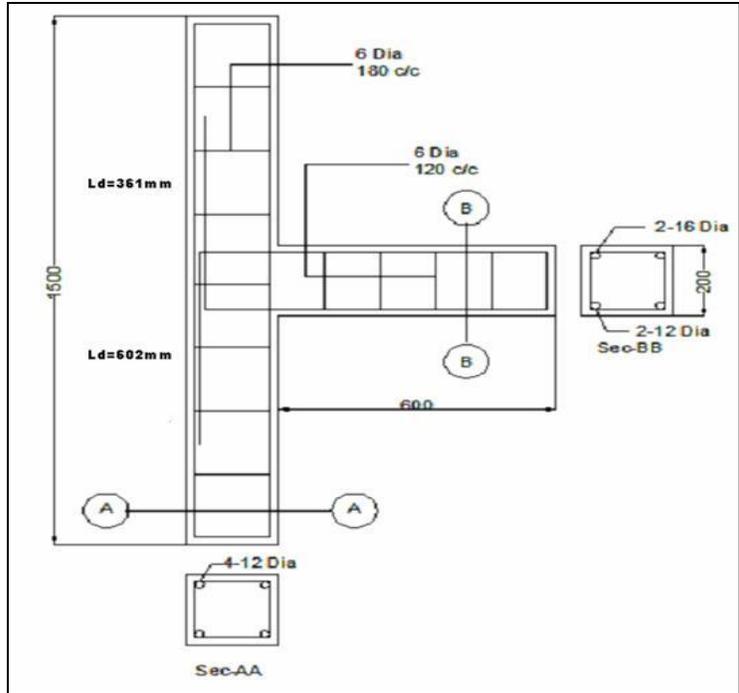
Fig.3.5 Reinforcement Details for M30 Concrete Specimen
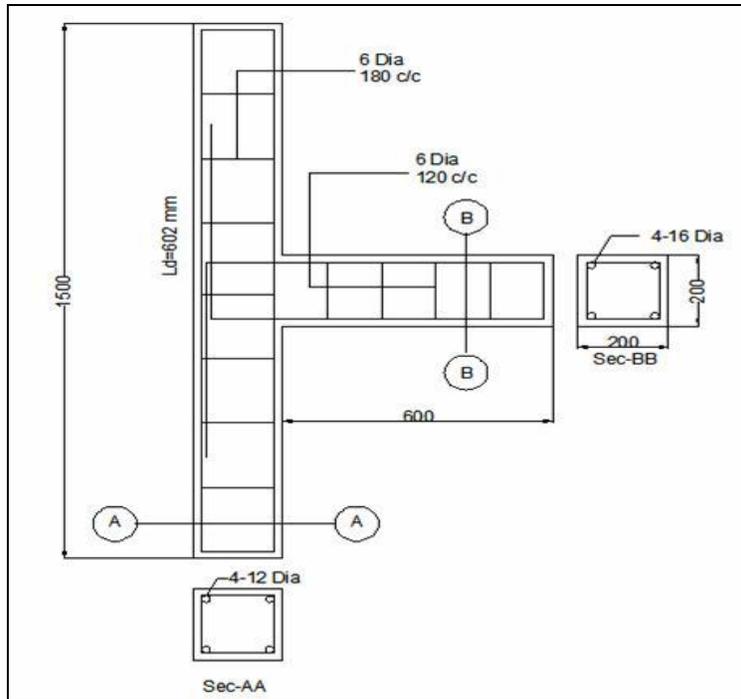as per IS 456: 2000 Subjected to Static Load

Fig.3.6 Reinforcement Details for M30 Concrete Specimen
as per IS 456: 2000 Subjected to Load Reversal

3.5 Design and Detailing of Beam -Column Joint Specimens as per Code IS 13920 :1993

3.5.1 Design of Beam

According to clause 6.1 of code IS 13920:1993 the following requirements have to be satisfied for a flexural member.

As per clause 6.1.2, the member shall preferably have a width to depth ratio of more than 0.3. Here the cross section of beam is 200 mm x 200 mm. The width to depth ratio is 1 which is more than 0.3.

As per clause 6.1.3, the width of the member shall not be less than 200 mm. Here, the width of the member is equal to 200 mm.

3.5.1.1 Web Reinforcement

According to cl 6.3.1 of code IS 456:2000 web reinforcement shall consist of vertical hoops which vertical closed stirrups are having a 135° hook with a 10 diameter extension (but not < 75 mm) at each end that is embedded in the confined core as shown below. Also the minimum diameter of the bar forming a hoop shall be 6 mm as shown in Fig 3.7.
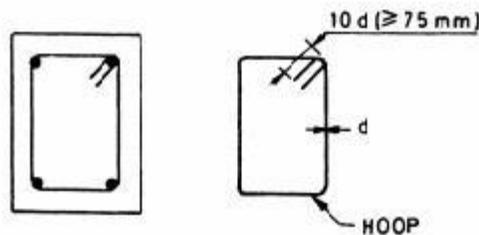

Fig 3.7 Stirrups in Beam as per Code IS 13920:1993

For the present study, the diameter of the stirrup used for the beam portion is 6mm and the 135° hook provided is of 80 mm extension into the core which is greater than 75mm. The details of the stirrup are shown in Fig 3.8.
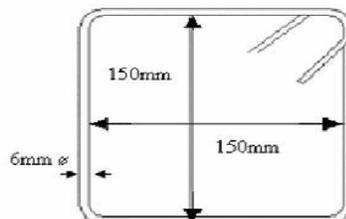

Fig 3.8 Hoop Rod as per Code IS 13920:1993

3.5.1.2 Spacing of Hoops

According to cl 6.3.5 of code IS 13920:1993, for a length of 2d at either end of a beam the spacing of hoops shall not exceed d/4 and 8 times the diameter of the smallest longitudinal bar. The first hoop shall be at a distance not exceeding 50 mm from the joint face. For the rest of the beam portion the stirrups are to be provided at a spacing not greater than d/2, where d is the effective depth of the member. The details are shown in Fig 3.9.
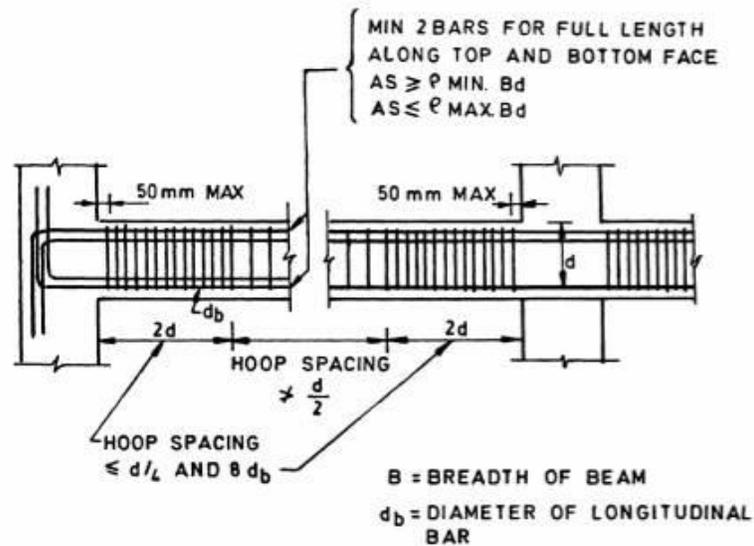

Fig 3.9 Beam Reinforcement as per Code IS 13920:1993

The distance 2d in the beam portion of the beam column joint is 340mm. The spacing d/4 is 42.5 mm and 8ø is 120 mm. So the least of the above values were considered and the spacing of the stirrups was fixed as 40mm center to center.The rest of the beam portion the spacing of stirrups was adopted as 80mm which is less than half of the least lateral dimension. Also the first stirrup was placed at a distance of 50mm from the joint face.

3.5.1.3 Anchorage Length

According to IS 13920:1993, clause 6.2.5, in an external joint, both the top and the bottom bars of the beam shall be provided with anchorage length, beyond the inner face of the column, equal to the development length in tension plus 10 times the bar diameter minus the allowance for 90 degree bend. In an internal joint, both face bars of the beam shall be taken continuously through the column.
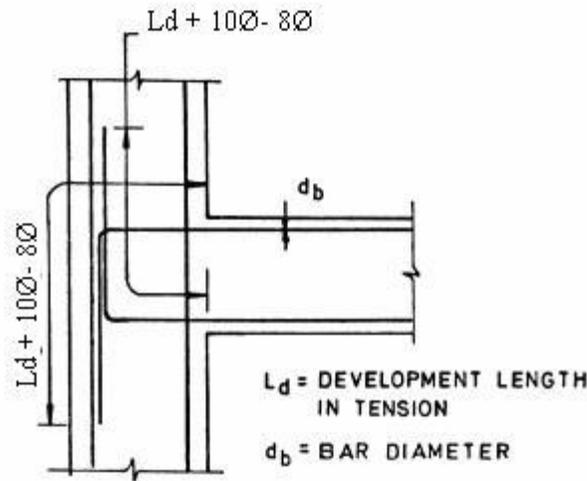
Fig 3.10 Anchorage of Beam Bars in an External Joint

According to code IS 456:2000, cl. 26.2.2.1(b), the anchorage value of a 90° bend is 8 times of the diameter of the bar. Substituting the anchorage value of the 90° bend, the expression for the anchorage length is given by $L_d + 10\emptyset - 8\emptyset$. The beam reinforcement is to be anchored into the column as shown in Fig 3.10.

Where L_d = Development length in tension for the as per IS 456:2000 given as

$$L_d = (\emptyset\sigma_s/4\tau_{bd})$$

$\emptyset$ = nominal diameter of the bar.

σ_s = stress in bar at the section considered at design load.

τ_{bd} = design bond stress given in cl 2.6.2.1.1 of IS 456:2000.

16 mm $\emptyset$ Fe 415 bars were used as longitudinal reinforcement for the beam.

The anchorage length for the beam reinforcements for the M 20 concrete specimens can be obtained as,

$$L_d = ((16 \times 0.87 \times 415)/(4 \times 1.2 \times 1.6)) + 2 \times 12$$

$$= 785 \text{ mm}.$$

The anchorage length for the beam reinforcements for the M 25 concrete specimens can be obtained as,

$$L_d = ((16 \times 0.87 \times 415)/ (4 \times 1.4 \times 1.6)) + 2 \times 12$$

$$= 677 \text{ mm.}$$

The anchorage length for the beam reinforcements for the M 30 concrete specimens can be obtained as,

$$L_d = ((16 \times 0.87 \times 415)/ (4 \times 1.6 \times 1.6)) + 2 \times 12$$

$$= 634 \text{ mm.}$$

3.5.2 Design of Column

According to cl 7.1.2 of code IS 13920:1993 , the minimum dimension of the member shall not be less than 200 mm. Hence the cross-section of the column portion is kept as 200 x 200 mm. As per cl 7.1.3, the ratio of the shortest cross sectional dimension to the perpendicular dimension shall preferably not be less than 0.4. The ratio of the shortest cross sectional dimension to the perpendicular dimension is 1 which is greater than 0.4 in the designed beam.

3.5.2.1 Transverse Reinforcement

IS 13920:1993, cl. 7.3.1 states that rectangular hoops may be used as transverse reinforcement for rectangular columns. A rectangular hoop is a closed stirrup having a 135° hook with a 10 diameter extension but not less than 75 mm at each end that is embedded in the confined core.

Clause 7.3.3 of code IS 13920:1993 states that the spacing of hoops shall not exceed half the least lateral dimension of the column, except where special confining reinforcement is provided.

The least lateral dimension of the column is 200 mm and half of the least lateral dimension is 100 mm. Hence a transverse reinforcement of 6 mm hoops at a spacing of 100 mm center to center has been adopted.

3.5.2.2 Special Confining Reinforcement

Clause 7.4.1 of code IS 13920:1993 emphasizes on the special confining reinforcement that is to be provided in the column portion. It reveals that the special

confining reinforcement is to be provided over a length l_o from each joint face, towards mid span, and on either side of any section, where flexural yielding may occur under the effect of earthquake forces. The length l_o shall not be less than

(a) larger lateral dimension of the member at the section where yielding occurs,

(b) 1/6 of clear span of the member

(c) 450 mm.

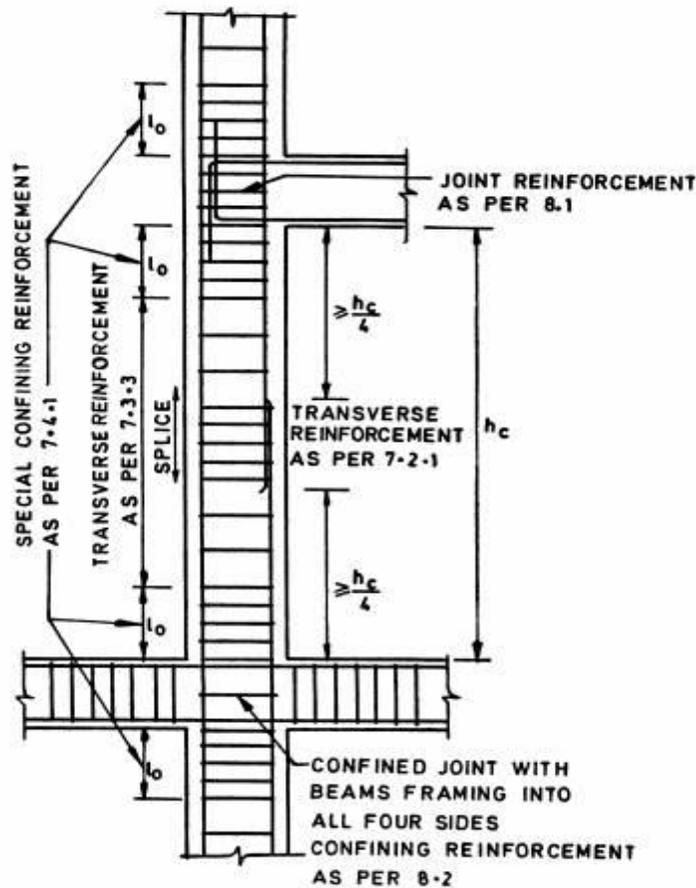The special confining reinforcement is shown in the Fig 3.11

Fig 3.11 Column and Joint Detailing as per Code IS 13920:1993

Clause7.4.6 of code IS 13920:1993 gives that the spacing of hoops used as special confining reinforcement shall not exceed ¼ of minimum member dimension but need not be less than 75 mm nor more than 100 mm.

Clause 7.4.8 of code IS 13920:1993 gives the cross section area of the bar to be used as special confining reinforcement in the column. The states that the area of cross section, A_{sh}, of the bar forming rectangular hoop, to be used as special confining reinforcement shall not be less than the following expression.

$$A_{sh} = 0.18 \ S \ h \ (f_{ck}/f_y) \ ((A_g/A_k)-1) \quad \text{where}$$

A_{sh} = area of the bar cross section.

S = spacing of hoops.

h = longer dimension of the rectangular confining hoop measured to its

     outer face. It shall not exceed 300 mm.

f_{ck} = characteristic compressive strength of concrete cube

f_y = yield stress of steel

A_g = gross area of the column cross section

A_k = area of confined concrete core in the rectangular hoop measured to

     its outside dimensions.

From the above expression , the diameter of the bar that to be used as the special confining reinforcement was fixed as 8 mm with a length of 1100 mm and is shown in Fig. 3.12. The spacing of hoops or lateral ties in the special confining zone was fixed as 50mm which is not greater than ¼ of minimum dimension of the column.
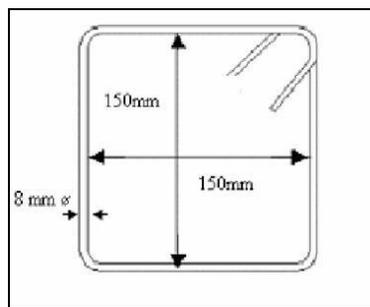

Fig 3.12 Hoops used for Special Confinement

From the three criterions given in clause 7.4.1 of code IS 13920:1993, for deciding the length of the special confining zone, the maximum value of 450 mm from the face joint

face was adopted. That is the special confining reinforcement was provided at a distance of 450mm from the face of joint on both sides of the joint in the column portion.

3.5.2.3 Joints of Frames

Clause 8.1 of code IS 13920:1993 states that the special confining reinforcement as required at the column shall be provided through the joint as well, unless the joint is confined such that it has beams framing into all vertical faces of it and where each beam width is at least 3/4 of the column width, may be provided with half the special confining reinforcement required at the end of the column and the spacing of hoops shall not exceed 150 mm as specified in clause 8.2 of code IS 13920:1993. Since the column is not confined as specified in the code provision of clause 8.2 as given above, the special confining reinforcement was extended into the column portion also. Fig. 3.13 shows the reinforcement detailing for the M20 concrete beam-column joint specimens as per code IS 13920:1993. Fig. 3.14 shows the reinforcement detailing for the M 25 concrete beam-column joint specimens as per code IS 13920:1993. Fig. 3.15 shows the reinforcement detailing for the M 30 concrete beam-column joint specimens as per code IS 13920:1993
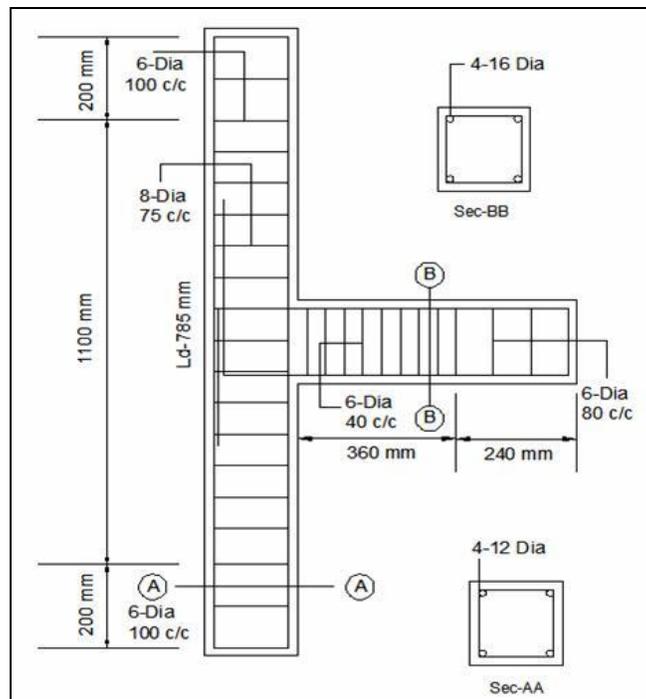

Fig. 3.13 Reinforcement Detailing for M 20 Concrete Beam-Column Joint Specimens as per Code IS 13920:1993
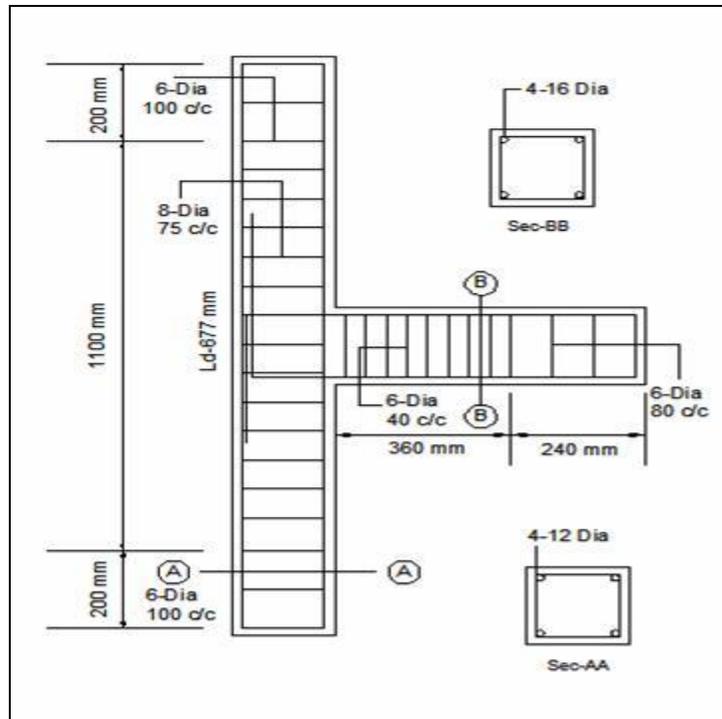
Fig. 3.14 Reinforcement Detailing for the M 25 Concrete Beam-Column Joint
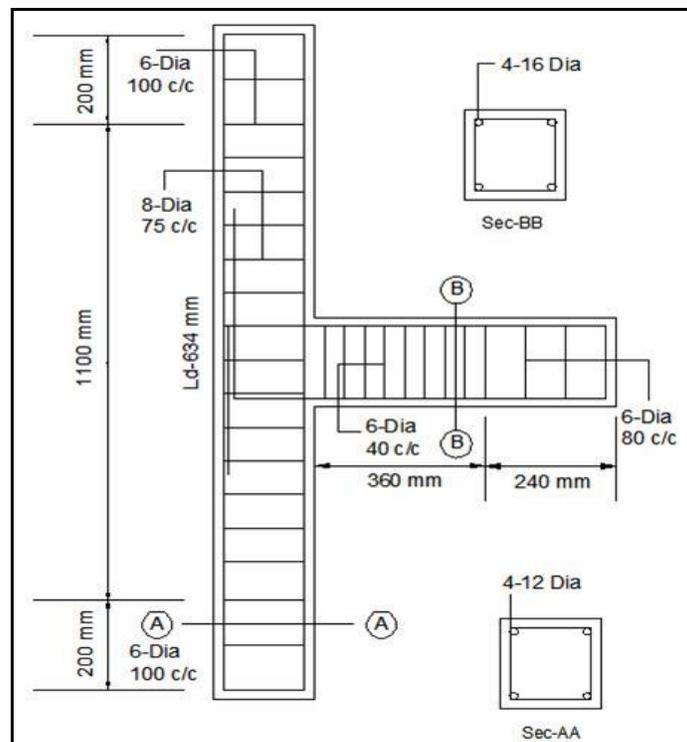Specimens as per Code IS 13920:1993

Fig. 3.15 Reinforcement Detailing for the M 30 Concrete Beam-Column Joint
Specimens as per Code IS 13920:1993

44

3.6 Preparation of the Beam-Column Joint Specimens

The reinforced concrete beam-column joint specimens were cast using fabricated steel moulds. Reinforcement was prepared and placed inside the mould.

3.6.1 Mix Design

Concrete mix design is a procedure by mean of which the proportions of cement, water, course aggregate, fine aggregate and admixtures if any are determined. Indian standard method of mix design has been adopted for obtaining the mix proportions of M 20, M25 and M30 concrete.

The design steps for M 20 concrete are given below.

Specific Gravity of C.A	=2.85
Specific Gravity of FA	=2.714
Specific Gravity of cement	=3.15
Sand Zone	=Zone 3
Size of Aggregate	=20 mm
Grade of Concrete	=M20
S.D for different degree of control	=Very Good

Step.1 Target Strength for Mix Design

$$F_{ck}^- = f_{ck} + 1.65s$$

The value of standard deviation has been selected from Table1 of code IS 10262:1982,page 5

$$=20 + 1.65 \times 3.6$$
$$=25.94 \text{N/mm}^2$$

Step.2   Selection of Water Cement Ratio

For the target strength of 25.94 N/mm^2 , the value of water-cement ratio has been found from the graph given in page 7 of IS 10262:1982

$$\text{W/C} = 0.506$$

Step.3 Selection of Water and Cement Content

The water and sand content have been found from Table 4 found on page 9 of IS 10262:1982,

Water Content   =186 kg

Sand Content   =35%

Step. 4 Adjustment of Value in Water Content and Sand %

The water content and the sand content are adjusted as shown below.

Change in Condition	Water content	% Sand in Total Aggregate
Sand conforming Zone	0	-1.5
Increase or decrease in the value of compacting factor	3	0
Each 0.05 increase or decrease in free w/c ratio	0	-1.88
	3	-3.38

Total sand content $= 35 - 3.38$

                                   $= 31.62\ \%$

Total water content $= 186 + 186 \times 3/100$

                                   $= 191.58\ kg$

Step. 5 Determination of Cement Content

Cement $= 191.58 / 0.506$

                                   $= 378.70\ kg$

Step. 6 Determination of Coarse and Fine Aggregate

The quantities of course aggregate and fine aggregate are found using the formula given in page11 of code IS 10262:1982,

           $0.98 = (191.58 + 378.70 / 3.15 + (1/0.3162) \times (f_a/2.714)) \times (1/1000)$

Therefore, f_a $= 573.38\ kg$

And

           $0.98 = (191.58 + 435.4 / 3.15 + (1/0.68) \times (f_c/2.714)) \times (1/1000)$

Therefore f_c $= 1302.25\ kg$

The quantities have been found for 1 bag of cement and the mix proportion for M 20 concrete is given in Table 3 .1

Table 3.1 Mix Proportions for M 20 Concrete

Cement	Fine Aggregate	Course Aggregate	Water
50	75.70	171.94	25.29
1	1.51	3.44	0.51

Similarly the mix proportions for M 25 and M 30 concrete were found and the mix proportions are given in Table 3.2

Table.3.2 Mix Proportions for M 20 , M 25 & M 30 Concrete

Grade of Concrete	Mix Proportions
M 20	1:1.51:3.44:0.51
M 25	1:1.25:2.885:0.42
M 30	1:1.028:2.6:0.39

Concrete was mixed in a tilting type mixer machine. Care was taken to see that concrete was properly placed and compacted. The sides of the mould were removed 24 hours after casting and the test specimens were cured in water for 28 days. In case of retrofitted specimens, the faces were ground mechanically to remove any laitance. All the voids were filled with putty. Then a two component primer system was applied on the concrete surface and allowed to cure for 24 hours. A two component epoxy coating was then applied on the primer coated surface and one layer of sheet was immediately wrapped over the surface of the reinforced concrete beam-column joint. A hand roller was then applied gently over the wrap so that good adhesion was achieved between the concrete surface and the wrapping sheets and allowed to cure for seven days. Another coat of the two component epoxy was applied over the fiber sheet. Then the second wrap was applied following the same procedure and allowed to cure for a further period of seven days. Both the wrapped layers were orthogonal to each other. The details of the retrofitting sheets made of glass fiber reinforced polymer (GFRP), carbon fiber reinforced polymer (CFRP), aramid fiber reinforced polymer (AFRP) and sisal fiber sheets are given in Table 3.3.

Table.3.3 Details of the Retrofitting sheets

Product Name	Fiber Type	Fiber Strength (Mpa)	FiberStiffness (Gpa)	ArealWeight (g/m2)	Fabric Thickness(mm)
SK-G600	GFRP	2300	76	600	0.230
SK-N300	CFRP	4900	230	300	0.166
SK-A415	AFRP	2880	100	415	0.288
SISAL	SISAL	1800	75	950	0.450

Fig. 3.16, Fig. 3.17, Fig. 3.18 , Fig. 3.19 and Fig. 3.20 shows the fabrication of reinforcement , placing of reinforcement in the mould , casting, curing and typical view of beam-column joint specimen. Fig. 3.21, Fig. 3.22, Fig. 3.23, and Fig. 3.24 shows the typical

views of retrofitted beam-column joint specimens wrapped with GFRP, CFRP, AFRP, and SISAL sheets respectively.

Fig.3.16 Typical View of Fabrication of Reinforcement

Fig.3.17 Typical View of Placing of Reinforcement in the Mould

Fig.3.18 Typical View of Casting of Beam-Column Joint Specimen

Fig.3.19 Typical View of Curing of Specimen

Fig. 3.20 Typical View of Beam-Column Joint Specimen

Fig.3.21 Typical View of Beam-Column Joint Specimen Retrofitted with GFRP Sheet

Fig.3.22 Typical View of Beam-Column Joint Specimen Retrofitted with CFRP Sheet

Fig.3.23 Typical View of Beam-Column Joint Specimen Retrofitted with AFRP Sheet

Fig.3.24 Typical View of Beam-Column Joint Specimen Retrofitted with
Sisal Fiber Sheet