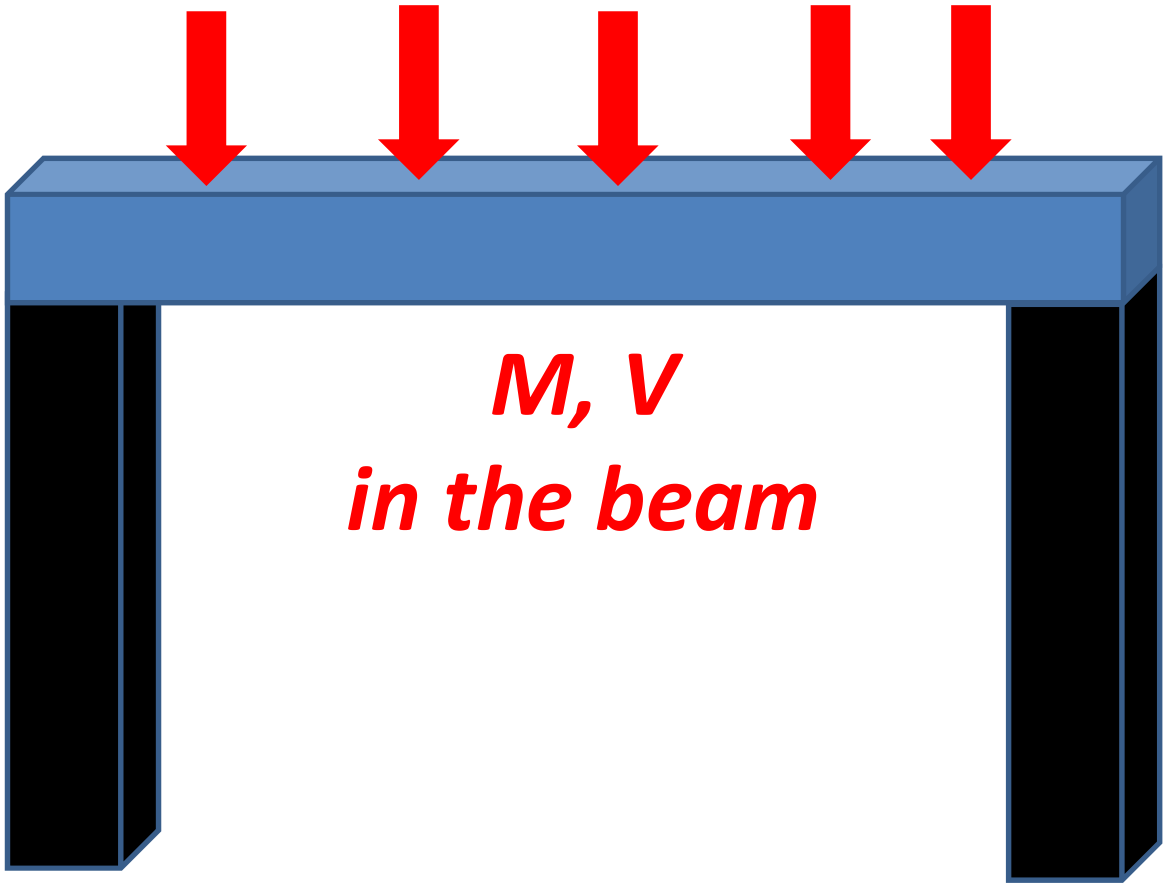
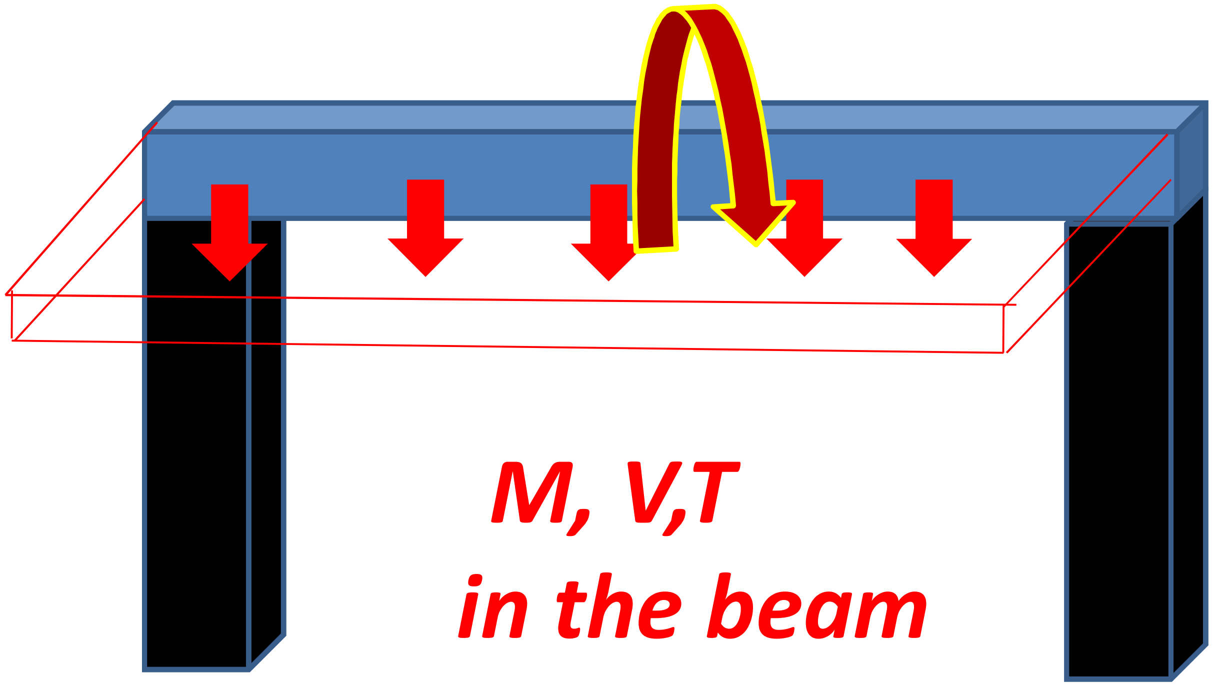
Limit State of Collapse – TORSION

CL 41

Loads acting normal to the plane of bending will cause bending moment and shear force.



Loads away from the plane of bending will induce torsional moment along with bending moment and shear.



Torsional moments are of two types:

(i) Primary or equilibrium torsion, and

(ii) Secondary or compatibility torsion.

Primary torsion is required for the basic static equilibrium of most of the statically determinate structures. Accordingly, this torsional moment must be considered in the design

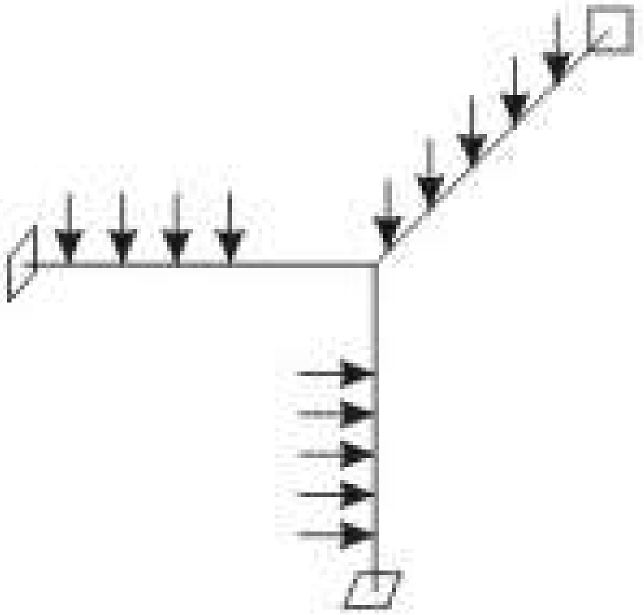
Secondary torsion is required to satisfy the compatibility condition between members. No specific design for torsion is necessary.

Clause 41 of IS 456 stipulates that,

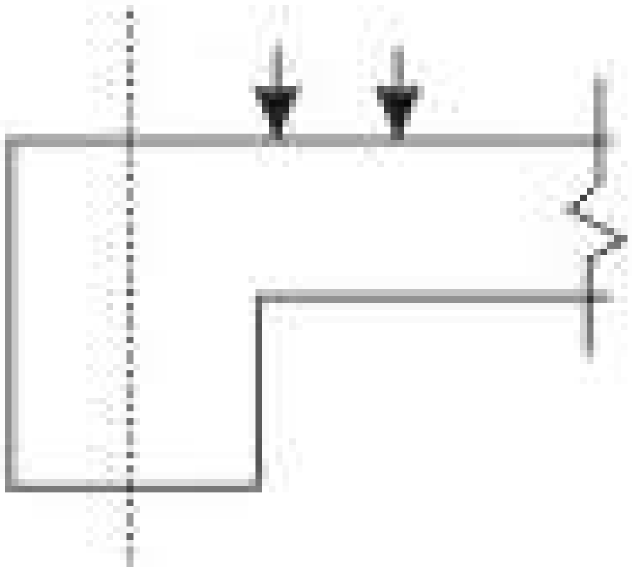
"In structures, where torsion is required to maintain equilibrium, members shall be designed for torsion in accordance with 41.2, 41.3 and 41.4”

However, for such indeterminate structures where torsion can be eliminated by releasing redundant restraints, no specific design for torsion is necessary, provided torsional stiffness is neglected in the calculation of internal forces.

Adequate control of any torsional cracking is provided by the shear reinforcement as per CL. 40".

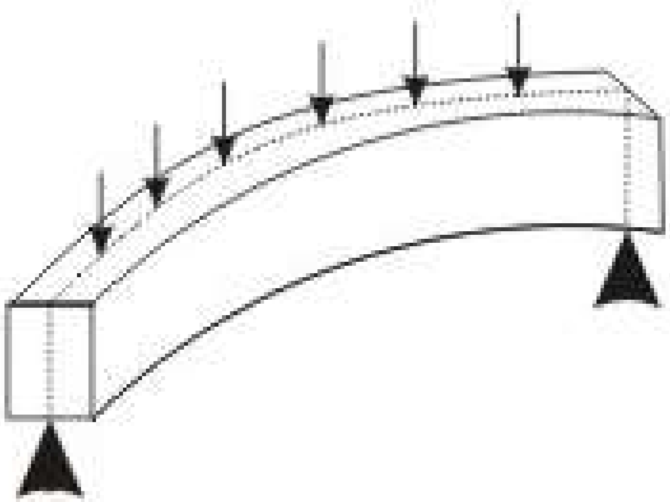


Space frames - Secondary Torsion

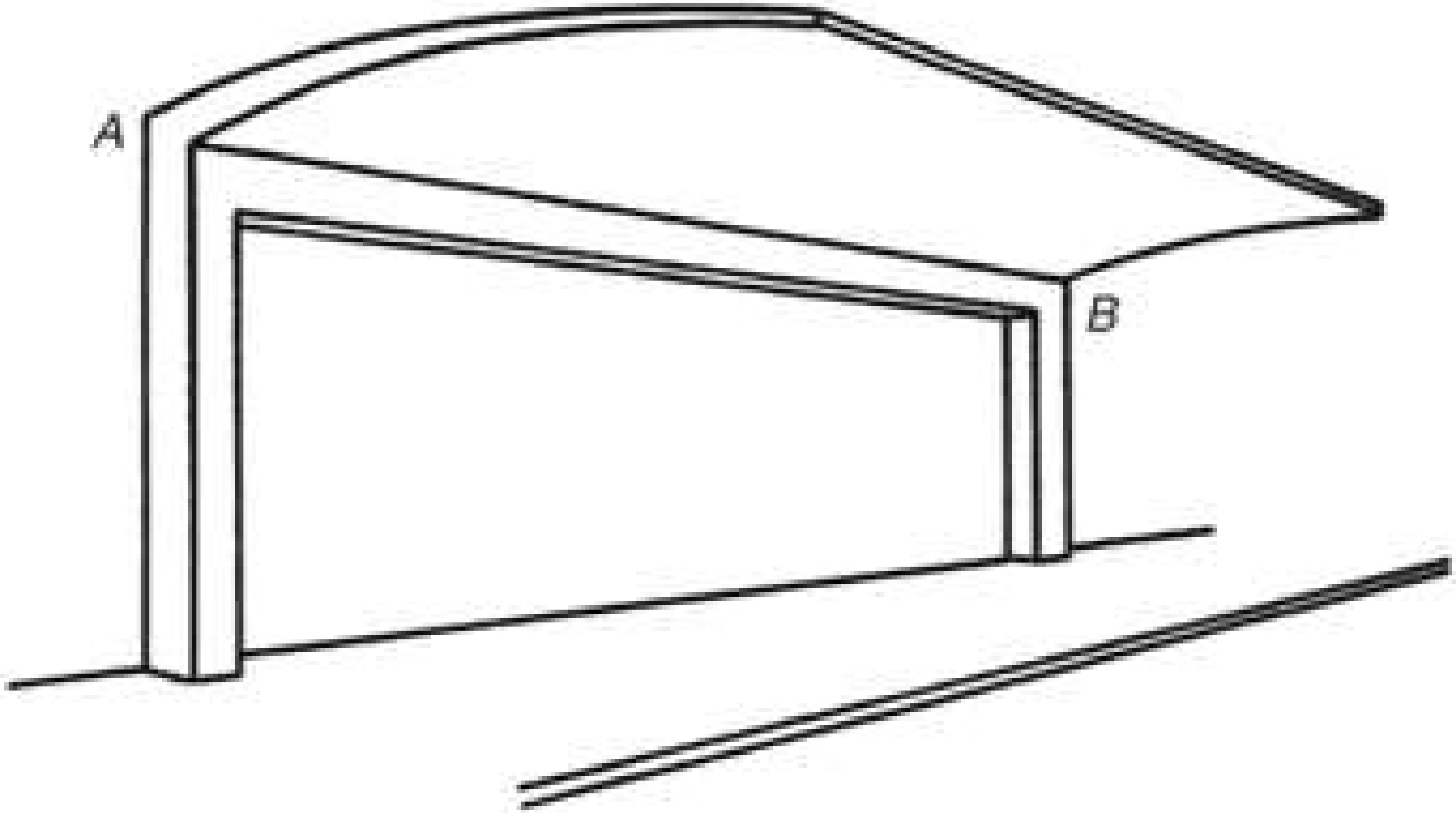


L-beams supporting cantilever sunshades and canopies – Primary Torsion

Edge Beams – Secondary Torsion

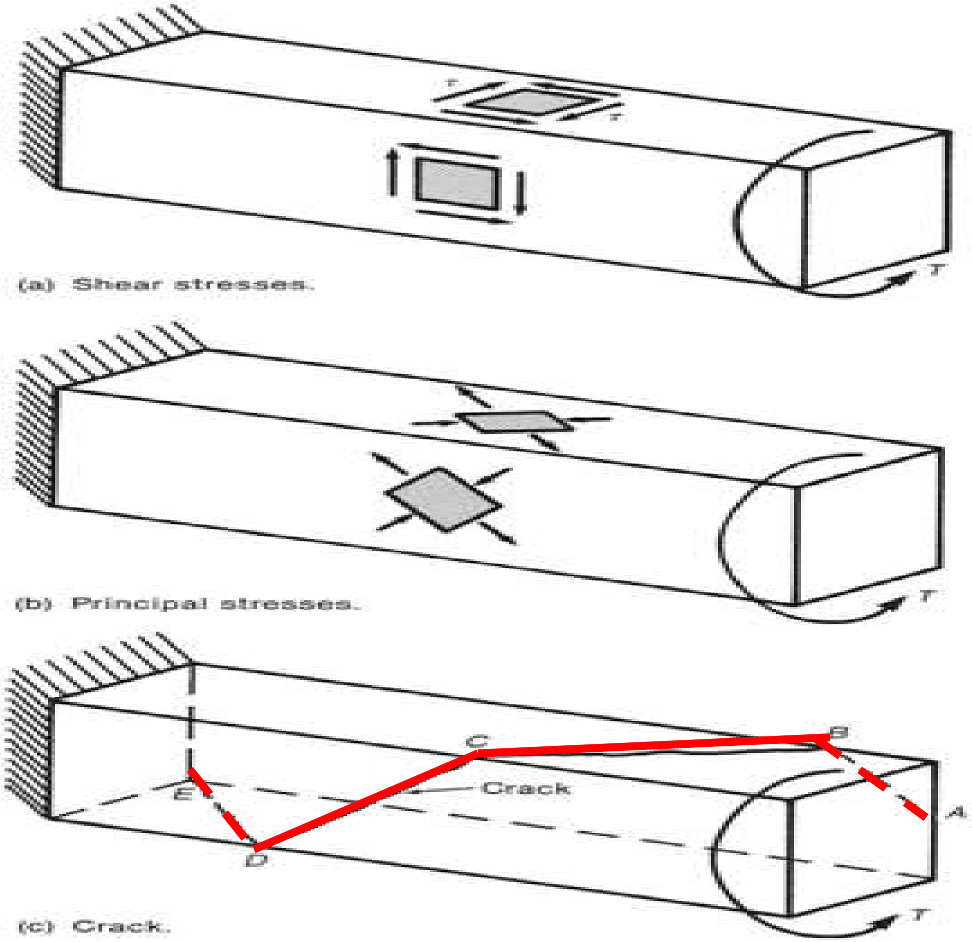


Beams curved in plan – Primary Torsion



Primary Torsion

Behaviour in Torsion



Torsional Cracks:

Crack pattern is of helical shape

They can be present on all the four faces

<u>Crack Profile: A-B-C-D-E</u>

ED – Bottom face

DC – Front face

CB – Top face

BA – Back face

Equivalent Shear and Moment as per IS 456

- takes into account the combined effects of bending moment, shear force and torsional moment by two empirical relations for

- Equivalent shear, Ve: *CL 41.3.1*

- Equivalent bending moment, Me1: *CL 41.4.2*

41.3.1 ***Equivalent Shear***

Equivalent shear, V_e, shall be calculated from the formula:

$$V_e = V_u + 1.6\frac{T_u}{b}$$

where

V_e = equivalent shear,

V_u = shear,

T_u = torsional moment, and

b = breadth of beam.

The equivalent nominal shear stress, τ_{ve} in this case shall be calculated as given in **40.1**, except for substituting V_u by V_e. The values of τ_{ve} shall not exceed the values of $\tau_{c\,max}$ given in Table 20.

41.4.2 *Longitudinal Reinforcement*

The longitudinal reinforcement shall be designed to resist an equivalent bending moment, M_{el}, given by

$$M_{el} = M_u + M_t$$

where

M_u = bending moment at the cross-section, and

$$M_t = T_u \left(\frac{1 + D/b}{1.7} \right)$$

Example1

A reinforced concrete rectangular beam b = 300 mm, d = 600 mm and D = 650 mm is subjected to factored shear force V_u = 70 kN in one section. Assuming the percentage of tensile reinforcement as 0.5 in that section, determine the factored torsional moment that the section can resist if

(a)no additional reinforcement for torsion is provided,
(b) maximum steel for torsion is provided in that section,
Assume M 30 concrete.

Case (a)

When no additional reinforcement for torsion is provided

For M 30 concrete with 0.5 per cent tensile reinforcement, from

Table 19, $\tau_c = 0.5\ N/mm^2$

Equivalent Nominal shear Stress, $\tau_{ve} = \tau_c = 0.5\ N/mm^2$.

Equivalent Shear, $V_e = \tau_{ve}\ b\ d$

$= 0.5 \times 300 \times 600 / 1000 = 90\ kN$

$Ve = Vu + (1.6\ Tu/b)$ CL 41.3.1

$90 = 70 + (1.6\ Tu/0.3)$

$Tu = 3.75\ kNm$

Case (b)

maximum steel for torsion is provided in that section

For M 30 concrete ,from Table 20 $\tau_{c,max}$= 3.5 N/mm^2

Equivalent Nominal shear Stress, τ_{ve} = 3.5 N/mm^2.

Equivalent Shear, $V_e = \tau_{ve}\ b\ d$

$= 3.5 \times 300 \times 600 / 1000 = 630$ kN

$V_e = V_u + (1.6\ T_u/b)$ CL 41.3.1

$630 = 70 + (1.6\ T_u/0.3)$

$T_u = 105$ kNm

Reinforcement for Combined Effects of Bending, Shear and Torsion

Provided in the form of

(A) Transverse reinforcement only

OR

(B) Longitudinal and Transverse - Both

Case (A)

Transverse Reinforcement Only

CL 41.3.2

41.3.2 If the equivalent nominal shear stress, τ_{ve} does not exceed τ_c given in Table 19, minimum shear reinforcement shall be provided as per **26.5.1.6**.

Case (B)

Longitudinal and Transverse Reinforcement - Both

CL 41.3.3

41.3.3 If τ_{ve} exceeds τ_c given in Table 19, both longitudinal and transverse reinforcement shall be provided in accordance with **41.4**.

B1 .Longitudinal Reinforcement on Flexural Tension Face

CL 41.4.2

41.4.2 ***Longitudinal Reinforcement***

The longitudinal reinforcement shall be designed to resist an equivalent bending moment, M_{e1}, given by

$$M_{e1} = M_u + M_t$$

where

M_u = bending moment at the cross-section, and

$$M_t = T_u \left(\frac{1 + D/b}{1.7} \right)$$

where

T_u is the torsional moment, D is the overall depth of the beam and b is the breadth of the beam.

B2. Longitudinal Reinforcement on Flexural Compression Face

CL 41.4.2.1

41.4.2.1 If the numerical value of M_t as defined in **41.4.2** exceeds the numerical value of the moment M_u, longitudinal reinforcement shall be provided on the flexural compression face, such that the beam can also withstand an equivalent M_{e2} given by $M_{e2} = M_t - M_u$, the moment M_{e2} being taken as acting in the opposite sense to the moment M_u.

B3 . Transverse Reinforcement

CL 41.4.3

41.4.3 ***Transverse Reinforcement***

Two legged closed hoops enclosing the corner longitudinal bars shall have an area of cross-section A_{sv}, given by

$$A_{sv} = \frac{T_u s_v}{b_1 d_1 (0.87 f_y)} + \frac{V_u s_v}{2.5 d_1 (0.87 f_y)},$$

but the total transverse reinforcement shall not be less than

$$\frac{(\tau_{ve} - \tau_c) b . s_v}{0.87 f_y}$$

Distribution of Torsion Reinforcement

pg.48-CL 26.5.1.7

26.5.1.7 *Distribution of torsion reinforcement*

When a member is designed for torsion (*see* **41** or **B-6**) torsion reinforcement shall be provided as below:

a) The transverse reinforcement for torsion shall be rectangular closed stirrups placed perpendicular to the axis of the member. The spacing of the stirrups shall not exceed the least of x_1, $\frac{x_1 + y_1}{4}$ and 300 mm, where x_1 and y_1 are respectively the short and long dimensions of the stirrup.

b) Longitudinal reinforcement shall be placed as close as is practicable to the corners of the cross-section and in all cases, there shall be at least one longitudinal bar in each corner of the ties. When the cross-sectional dimension of the member exceeds 450 mm, additional longitudinal bars shall be provided to satisfy the requirements of minimum reinforcement and spacing given in 26.5.1.3.

Side face reinforcement cl. 26.5.1.3 and 26.5.1.7b

CL 26.5.1.3

Beams exceeding the depth of 750 mm and subjected to bending moment and shear shall have side face reinforcement.

The total area of side face reinforcement shall be at least 0.1 per cent of the web area and shall be distributed equally on two faces at a spacing not exceeding 300 mm or web thickness, whichever is less.

CL 26.5.1.7b

However, if the beams are having torsional moment also, the side face reinforcement shall be provided for the overall depth exceeding 450 mm.

Example2

A reinforced concrete rectangular beam *b = 300 mm, d = 600 mm and D = 650 mm is subjected to factored shear force* V_u *= 70 kN, Mu = 215 kNm, Tu = 100 kNm*
Assume M 30 concrete, Fe415 steel
design the reinforcement.

Step 1: Equivalent Shear *Cl 41.3.1*

$V_e = V_u + 1.6\ (T_u/b)$

$V_e = 70 + 1.6\ (100/0.30\ ) = 603\ kN$

$\tau_{ve} = 603\ x1000/(300x600) = 3.35\ N/mm^2$

For M 30 concrete ,from Table 20 $\tau_{c,max} = 3.5\ N/mm^2$

$\tau_{ve} < \tau_{c,max}$. *Hence Depth provided is OK*

Step 2: Equivalent Moment **CL 41.4.2**

$M_{e1} = M_u + M_t = M_u + (T_u/1.7)\ \{1 + (D/b)\}$

$M_{e1} = 215 + (100 / 1.7)\ \{ 1 + (650/300)\}$

$\quad = 215 + 186.3$

$M_{e1} = 401.3$ kNm

As per CL 41.4.2.1;

since Mt =186.3 < Mu=215; No compression reinforcement is required. Only longitudinal tension reinforcement is provided.

Step 3: Tension Reinforcement

$X_{u,max}/d = 0.48$

As per G.1.1 (c)

$M_{u,lim} = 0.36 x 0.48(1- 0.42 x 0.48) x 300 x 600^2 x 30 / 10^6$

$= 447$ kNm > Me1

Hence the beam is under reinforced.

As per CL G 1.1 (b) determine Ast

$401.3x10^6$ = 0.87x415xAstx600(1- (Ast x415/ (300x600x30)

= 216630 Ast – 16.65 Ast^2

16.65 Ast^2 - 216630 Ast + $401.3x10^6 = 0$

Ast = 2237 mm^2 provide 5-#25 (2454 mm^2) OK

Step 4: **Side face reinforcement**

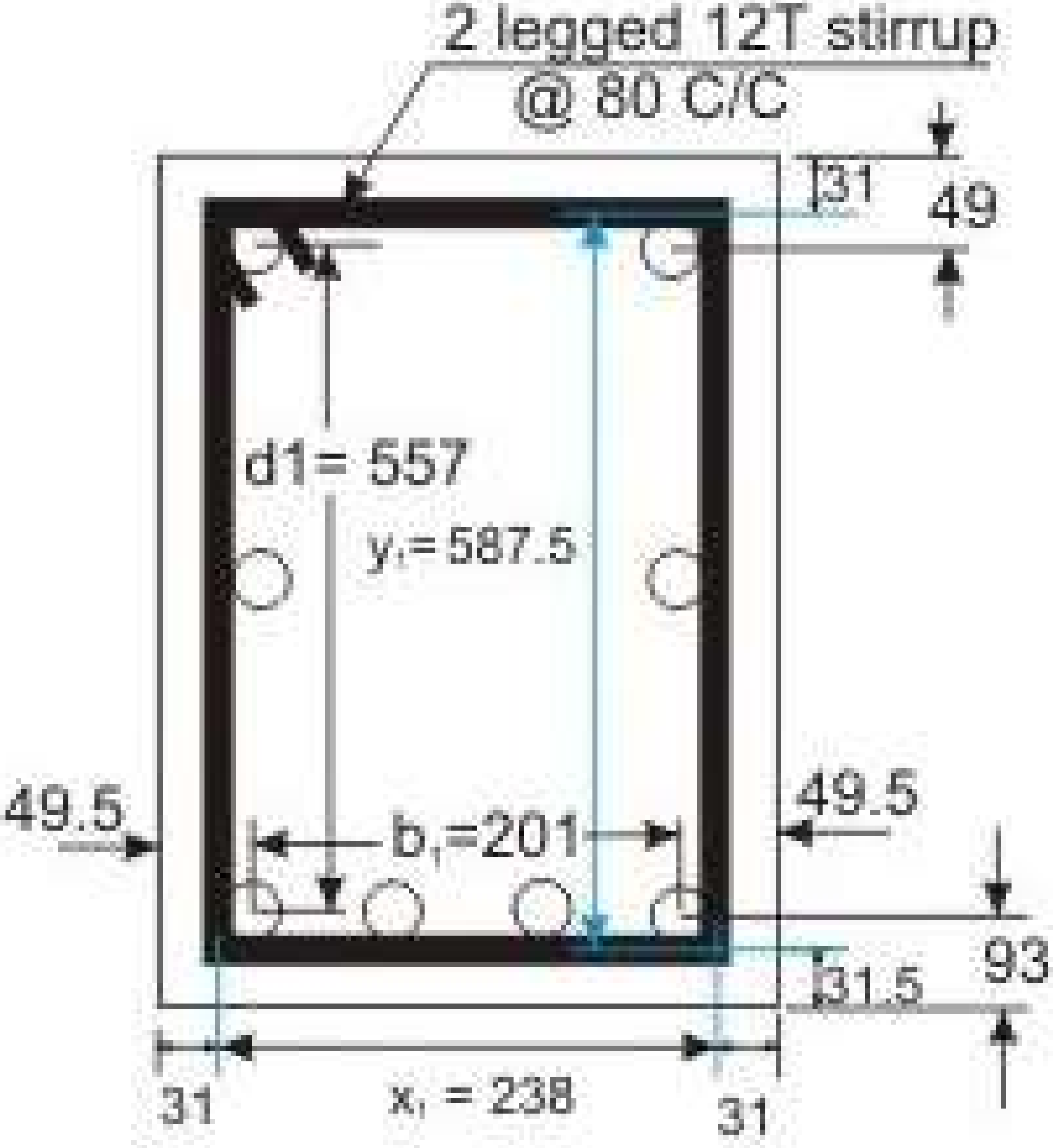
Since the depth of the beam exceeds 450 mm, provide side face reinforcement

Provide Two bars near the mid-depth of the beam, one on each side

Web area = 300x(650)

Area required = 0.1 x 300x650= 195 mm^2

Adopt 2 - #12, Area provided = 226.08 mm^2 > 195 mm^2 OK



2 legged 12T stirrup
@ 80 C/C
31
49
d1= 557
y1= 587.5
49.5
49.5
b1=201
93
31.5
31
x1 = 238
31

Step 5: Transverse Reinforcement CL 41.4.3

Assuming 2 legged 12 mm dia stirrup

$d_1 = (600 - 25 - 12 - 12.5) = 550.5\ mm$

$b_1 = (300 - 2x(25 + 12 + 12.5)) = 201\ mm.$

$0.87\ fy\ Asv / S_V = (Tu/b1\ d1) + (Vu/2.5d1)$

$= 100x10^6 / (201x\ 550.5) + 70\ x\ 10^3/(2.5x550.5)$

$0.87\ fy\ Asv / S_V = 954.61$ N/mm

But

0.87 fy Asv/Sv >= (τve-τc) b

To get $\tau_{c,}$ find 100 Ast/ bd = 100 x 2454 / (300 x600)

= 1.36

Table 19, τ_c = 0.735 N/mm^2

087 fyAsv/Sv > = (3.35 – 0.735)300 = 784.5 N/mm

Adopt 087 fyAsv/Sv = 954.61 N/mm

Adopt 0.87 fyAsv/Sv = 954.61 N/mm

Asv = 2 x(π x12 ^{2}/4) = 226 mm^2

Sv = 0.87 x415 x 226 / 954.61 = 85.47mm

Step 5: Check for *Sv* *CL 26.5.1.7*

X1 = (300 – 2(25+6)) = 238 mm

Y1 = 650 - 2(25+6) = 588 mm

Sv,max = Min (X1, (X1+Y1)/4 , 300) = 206mm

> Sv OK

Adopt 2L - #12 @ 80 mm c/c