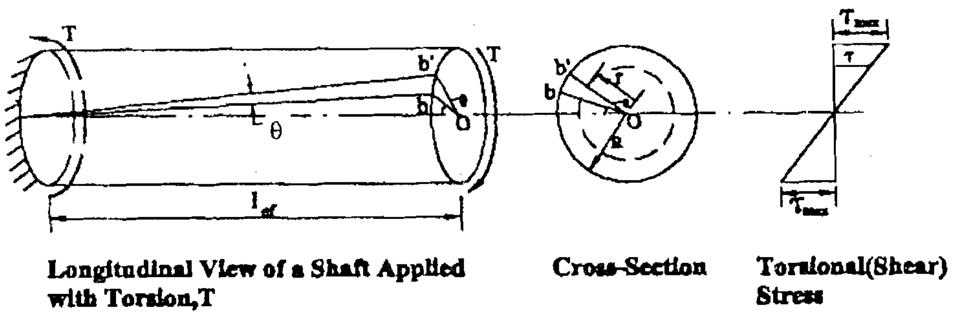
UNIT 4 TORSION

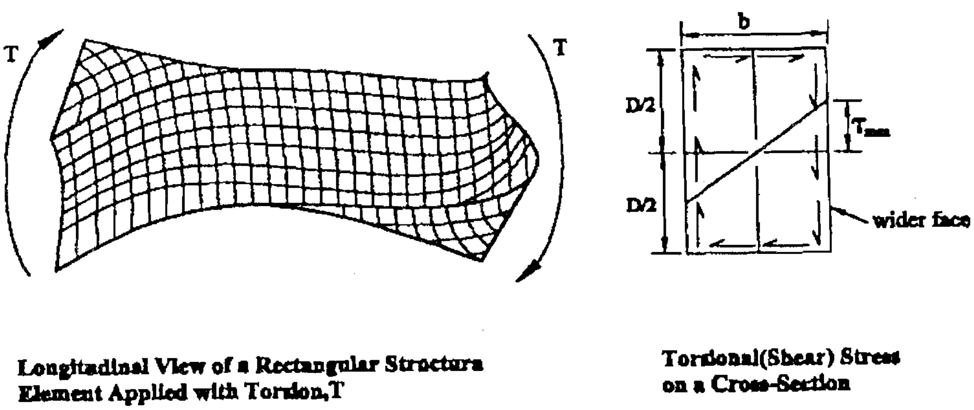
Structure

4.1 INTRODUCTION

Equal and opposite moments applied at both ends of an structural element (member) or its part about its longitudinal axis is called **torsional moment** or twist or torque or torsion (Figure 4.1).



(a)



(b)

Figure 4.1 : A Shaft and a Rectangular Structural Element under Torsion, T

From Strength of Materials Principles, for a *circular* shaft, $\frac{T}{J} = \frac{\tau}{r} = \frac{G\theta}{\ell}$

where, T= Applied Torsion on the shaft (Figure 4.1(a)),

J= Polar Moment of Intertia of the cross section,

τ = Torsional (Shear) stress at radius r from the centre,

G = Modulus of Rigidity,

θ = Angle of Twist, and

ℓ = Length of the shaft.

Torsional Rigidity is defined as torsion per unit deformations (angle of twist)

Mathematically,

$$\text{Torsional Rigidity} = \frac{T}{\theta} = \frac{GJ}{\ell}$$

But R. C. structural members are mostly of rectangular, tee or ell sections. Evaluation of torsional rigidity, shear stress etc. required for design purposes are based on experimental results rather than on Theory of Elasticity which is cumbersome and yet not fully in agreement with the experimental results.

Accordingly, **Torsional Rigidity** of a rectangular R. C. Section may be taken as GC

where G = 0.4 E, and

$$C = \frac{1}{2} \times \text{St. Venant's Torsional Constant (K) calculated for } \textit{plain concrete} \text{ section.}$$

Again $K = kbD^3$ where k is a function of $\frac{D}{b}$. The values of k for varying $\frac{D}{b}$ ratio are given in Table 4.1.

Table 4.1: Values of k for Different Ratio $\frac{D}{b}$

$\frac{D}{b}$	k	$\frac{D}{b}$	k
1.0	0.14	2.5	0.25
1.2	0.17	3.0	0.26
1.5	0.20	4.0	0.28
2.0	0.23	5.0	0.29

The maximum shear stress $\tau_{t,max}$ for rectangular section (4.1b) occures on *wider* face and may be evaluated by the equation $\tau_{t,max} = \frac{T}{k'b^2d}$ where k' is **'Shape Factor'** varying with $\frac{D}{b}$ ratio given in Table 4.2.

Table 4.2 : Values of k' w.r.t. $\frac{D}{b}$ for Rectangular Cross Sections

$\frac{D}{b}$	1	1.5	2	2.5	3	4	5	6	10	∞
k'	0.208	0.231	0.246	0.256	0.267	0.282	0.292	0.299	0.307	0.313

$\tau_{t,max}$ along with its complementary shear stress produces diagonal tension of the same intensity (Figure 3.2(e)). Adequate tensile reinforcements to resist diagonal tension produced by torsion may be provided. Experiments have shown that strength of a R. C. member under torsion *only* or in combination with shear and bending moment is dependent on (i) *strenght of concrete, and* (ii) *amount of longitudinal as well as transverse reinforcements.*

If *only* torque is applied on a R. C. member, the 'Torque- Deformation (angle of twist)' curve is as shown in Figure 4.2.

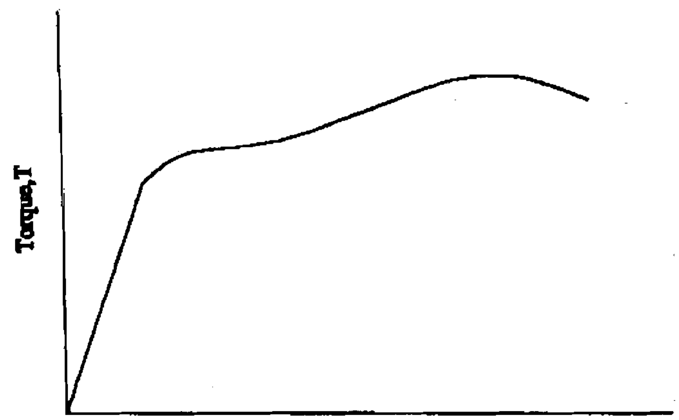


Figure 4.2 : T-θ Curve for R. C. Beams

This curve indicates that in the initial stage (i.e. until *cracks* form along the length of the member), the T- θ curve is linear, and, thereafter, resistance for torsion is dependent upon amount of longitudinal as well as transverse reinforcements.

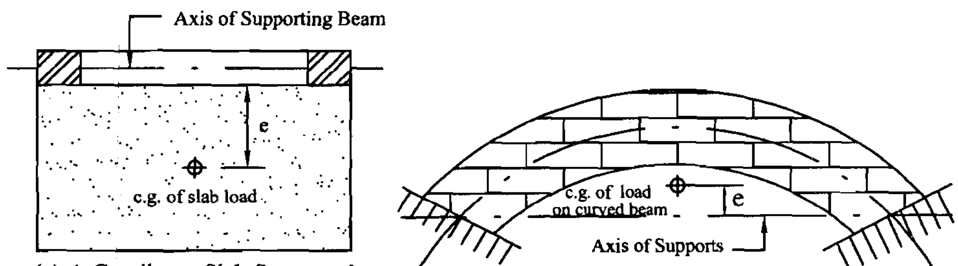
In practical cases, since in a structural element, torsion is accompanied by shear and bending moment, and since increase in transverse as well as longitudinal reinforcements increase torsion resisting capacity of a beam, **reinforcements for torsion are not designed separately. The torsional resistance of a member may be enhanced by increasing strength of concrete and the amount of longitudinal as well as transverse reinforcements over and above those required for bending and shear respectively.**

Torsion in a flexural member can develop only when the transverse loading on it is not lying in the vertical plane passing through its axis or through its *shear centre*. A few examples of members under torsion are shown in Figure 4.3.

Torsional moment applied on any element of a structure may be termed either as

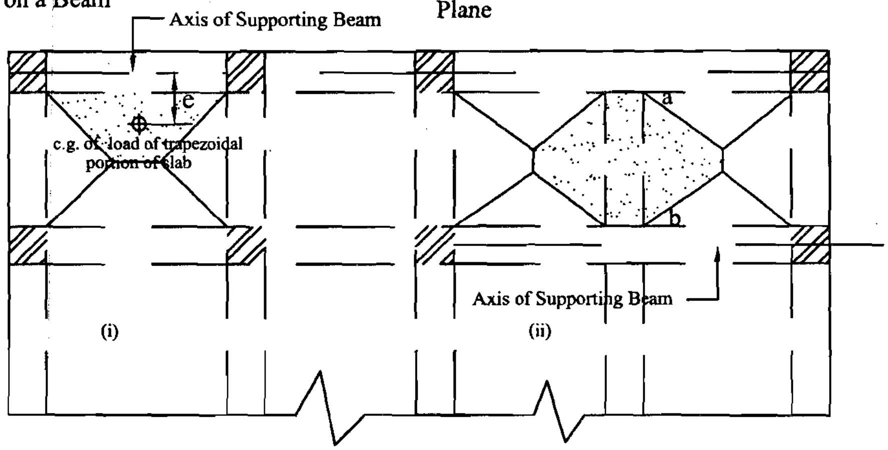
i) **Primary Torsion** (equilibrium or determinate torsion), or

ii) **Secondary Torsion** (indeterminate or compatibility torsion).

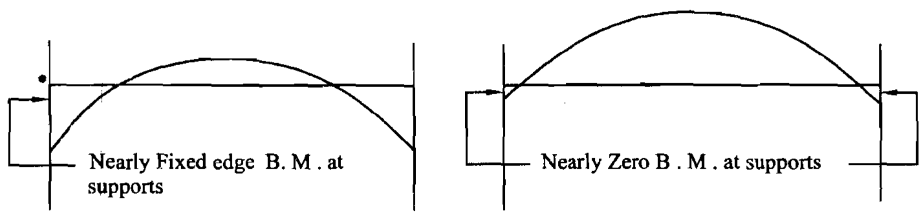


(a) A Cantilever Slab Supported on a Beam

(b) Wall Load on a Curved Beam in Horizontal Plane



(c) (i) A trapezoidal portion of Slab supported on outer Beam of a floor system(L.H.S.),and
(ii) A Secondary Beam supported on Main Beams of a floor system(R.H.S.)



(d) (i) B. M. D. of an element when its supports are torsionally stiff.

(d) (ii) B. M. D. of an element when its supports are torsionally *not* stiff.

Figure 4.3 : Showing Torsional Moment due to Eccentric Loading on Supporting Element

i) Equilibrium Torsion : It is a torsional moment developed in one or more elements of a structure to maintain equilibrium. For example, beam AB and columns at A and B of Figure 4.3(a) and curved beam of AB of Figure 4.3(b) will collapse if adequate provisions for resisting torque and thereby to maintain equilibrium are *not* made.

ii) **Compatibility Torsion :** This type of torque develops to maintain compatibility between members of a structure (Figure 4.3(c)). If edge beams are torsionally stiff as well as supporting columns can provide necessary resisting torque, then the slab moment of Figure 4.3(c) (i) and beam moment of Figure 4.3(c) (ii) will be similar to those of fixed edge moment shown in Figure 4.3(d) (i). But if the edge beams has little torsional stiffness and supporting columns do not provide necessary resisting torque, then slab moment in Figure 4.3(c) (i) and beam **ab** of Figure 4 .3(c) (ii) will approximate to those for a *hinged edge* Figure 4.3(d) (ii). Therefore, the code permits that in case of compatibility torsion, where torsional resistance or stiffness of members have not been taken into account in the analysis of the structure, provision for torsional resistance in the members will *not be necessary*. Only nominal shear reinforcement will be adequate for controlling torsional cracks. Members under compatibility torsion will be designed to resist torsion *only* when their torsional resistance or stiffness are taken into account in the analysis.

Objectives

After going through this unit students will be able to understand the following :

i) Basics of applied torsion and its resistance by a R. C. member,

ii) Design principles for torsion, and

iii) Provisions made for design of members to resist torsion.

SAQ 1

i) Define torsion.

ii) Explain the formula for evaluating torsional rigidity for a R.C. member of rectangular cross section.

iii) Write formula for the maximum shear stress in a rectangular R.C. section and indicate the face on which it occurs.

iv) How torsional resistance of a R. C. members may be enhanced. Why design for torsinal resistance is done in combination with those for bending and shear.

v) Explain determinate and indeterminate torsion.

4.2 BASIS OF DESIGN PROVISIONS FOR TORSION

4.2.1 Explanations of Codal Provisions for Design

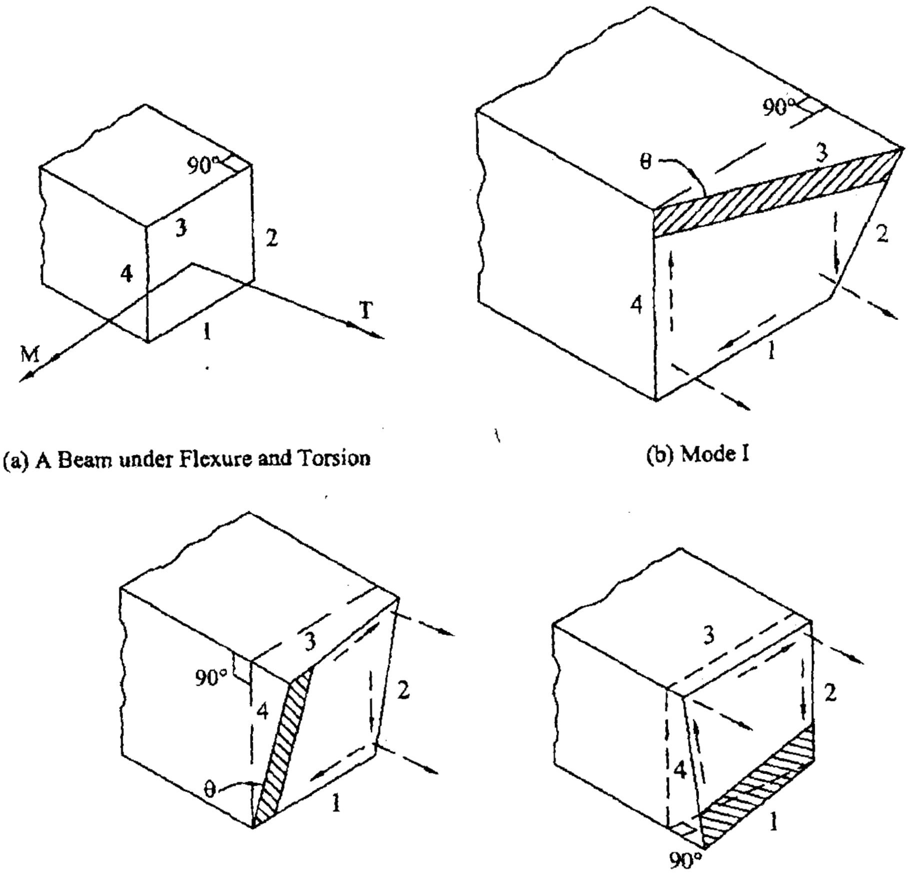
The codal provisions for design of rectangular beams are based on 'Skew Bending Theory'. According to this, a beam under combined flexural and torsion may fail in either of the three modes : (i) Mode I, (ii) Mode II, and (iii) Mode III

Mode I : When bending is predominant, compression zone becomes skewed due to torsion, but remains on the same side where it were if bending were only applied (Figure 4.4(b)). This is the most common type of failure for flexural members.

Mode II : If torsion is predominant and the section is narrow, compression face due to bending is skewed to the side faces (Figure 4.4(c)). In this case, beam fails just as it would have failed if lateral bending were applied.

Mode III : If the bending effect is much less than that of torsion and/or the section is too narrow; then under the influence of torsion, the compression face will move to the opposite face to that in pure bending (Figure 4.4(d)) as if opposite moment had been applied. The shear accompanying bending moment in a flexural member further reduces the strength of a beam applied with torsion. The above observations on collapse of a structural member under the combined effect of bending, shear and torsion are based on experimental results.

Therefore, torsional resistance of a member is not treated separately from those for bending and shear described in Unit 3 & 4.



(a) A Beam under Flexure and Torsion

(b) Mode I

(c) Mode II

(d) Mode III

Figure 4.4 : Showing Different Modes under Combined Flexure & Torsion

4.2.2 Reinforcements for Torsion

Effect of torsion is combined with shear and an increased value of shear called **Equivalent (Fictitious) Shear** is calculated as $V_e = V_u + 1.6\frac{T_u}{b}$ ...(4.1)

The shear reinforcement for V_e is provided in a similar manner to that for shear V_u in Unit 4. If $V_e \leq Vc$, only nominal shear reinforcement is provided as desbribed in section 3... If $V_e > \tau_{c,max}$ bd, the section shall be redesigned; but if

$V_c < V_e < \tau_{c,max}$ bd, shear reinforcement shall be provided as desbribed below :

Only **two-legged closed stirrups** enclosing the corner longitudinal bars are to be provided to resist *equivalent* shear force having a cross-sectional area of

$$A_{sv} = \{\frac{T_u s_v}{b_1 d_1 (0.87 f_y)} + \frac{V_u s_v}{2.5 d_1 (0.87 f_y)}\} \quad \ldots(4.2)$$

which in no case shall be less than $\frac{(\tau_{ve}-\tau_c)bs_v{}^*}{0.87f_y}$ ...(4.3)

where b_1 = c/c distance between corner bars along the width (Figure 4.5),

d_1 = c/c distance bewteen corner bars along the depth, and

$\tau_{ve} = \frac{V_e}{bd}$ (Equivalent Shear Stress).

Similarly, effect of torsion is combined with bending and an **equivalent (fictitious) bending moment** is derived for providing equivalent flexural longitudinal reinforcement as follows :

Equivalent Bending Moment,

$$M_{e1}=M_u+M_t \qquad \text{...(4.4)}$$

where $M_t = T_u\left(\frac{1+D/b}{1.7}\right)$ ...(4.5)

T_u = Torsional Moment.

If $M_t > M_u$, longitudinal reinforcement shall be provided on flexural compression face for an equivalent moment $M_{e2} = M_t - M_u$ ...(4.6)

4.2.3 Additional Rules for Design

a) Sections located at a distance less than d from the face of a support shall be designed for the same torsion as computed at a distance d from it.

b) The design rules laid down above shall be applicable for rectangular beams only. For L-beams and T-beams (i.e. flanged beams) the code mentions that b_w may be taken for b in the design, though it is very much on conservative side.

4.2.4 Distribution of Reinforcements

The longitudinal as well as transverse reinforcements are a bit different from those provided for bending and shear on the following counts :

1) Longitudinal reinforcement shall be at least one in each corner and each corner bar shall be placed as near to the corner as possible.

2) When total depth, D, of a beam exceeds 450, reinforcement shall *also* be provided on two side faces. The cross sectional area of such reinforcement shall be 0.1% of the web area and shall be distributed equally on both side faces at a spacing not exceeding 300 mm or web thickness whichever is less.

3) Transverse reinforcements shall *only* be two-legged closed stirrups placed perpendicular to the axis of the members. The spacing shall not exceed $x_1, \frac{x_1+y_1}{4}$ and 300 mm, where x_1 and y_1 are respectively the short and long dimensions of the stirrups (Figure 4.5).

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* Multiplying the marked(*) expression both in nominator as well as in denominator by d it becomes

$\frac{(V_e-V_c)s_v}{0.87f_y d} = \frac{V_{us}s_v}{0.87f_y d}$ which is the same as Eq. (3.6).

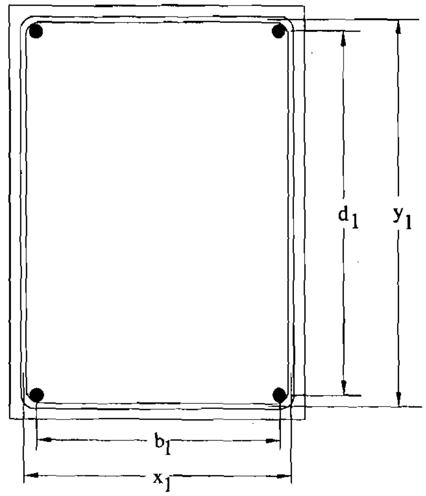

Figure 4.5 : Details of Transverse Reinforcement

SAQ 2

i) Explain 'Skew Bending Theory' as the basis of design for torsion.

ii) Define and explain 'Equivalent Bending Moment' and 'Equivalent Shear Force'.

iii) In what ways the bending and shear reinforcements distribution differ from those for combined bending, shear and torsion reinforcements.

4.3 EXAMPLES

Two types of design problems may arise depending upon values of M_t w.r.t M_u

TYPE I : Design of a beam in which only longitudinal *tensile* reinforcements are required, and

TYPE II : Design of a beam in which reinforcement on compression face is also provided for $(M_t - M_u)$

Design of a Beam in which $M_t < M_u$

Example 4.1

Design a reinforced concrete beam of rectangular cross-section for the following data :

b = 300; d = 800; D = 850; f_{ck} = 15; f_y = 250; M_u = 200 kNm; V_u = 100 kN and

T_u = 50 kNm.

Solution

Equivalent Shear

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

$$= 100 + 1.6 \times \frac{50}{0.3} = 366.67\text{kN}$$

$$\tau_{ve} = \frac{366.67 \times 10^3}{300 \times 800} = 1.53\,\text{N/mm}^2$$

For M15 concrete, $\tau_{c,max} = 2.5$ MPa (Table 3.2)

Since tensile reinforcement is not known at the outset; therefore, for the minimum % of tensile steel, i.e. for

$$100\frac{A_{st}}{bd} = 100 \times \frac{0.85}{f_y} = 100 \times \frac{0.85}{250} = 0.34\%$$

$$\tau_c = 0.35 + \frac{(0.46 - 0.35)}{(0.5 - 0.25)} \times (0.34 - 0.25) = 0.39\text{MPa} < \tau_{ue} \quad \text{(Table 3.1)}$$

Hence, both longitudinal and transverse reinforcement shall be provided.

Equivalent Bending Moment

$$M_{el} = M_u + M_t = 200 + T_u \cdot \frac{(1 + D/b)}{1.7} \quad \ldots(4.4)$$

$$= 200 + 50 \times \frac{(1 + 850/300)}{1.7} = 200 + 112.75 = 312.75\text{kNm}$$

Since $M_u > M_t$, *no* longitudinal reinforcement will be required on compression flange.

Longitudinal Reinforcement

$$M_{el} = 0.87 f_y A_{st} d(1 - \frac{A_{st} f_y}{bdf_{ck}}) \quad \ldots(2.5(b))$$

or, $312.75 \times 10^6 = 0.87 \times 250 \times A_{st} \times 800(1 - \frac{A_{st} \times 250}{300 \times 800 \times 15})$

or, $12.08 A_{st}^{\,2} - 174000 A_{st} + 312.75 \times 10^6 = 0$

or, $A_{st} = 2105.06\text{mm}^2$

Provided 4 ϕ 28

$$100 \times \frac{A_{st}}{bd}\% = 100 \times \frac{4 \times \frac{\pi}{4} \times 28^2}{300 \times 800}\% = 1.03\% > 0.34\% \ (A_{st,min})$$

Now revised τ_c is given as

$$\tau_c = 0.6 + \frac{(0.64-0.6)}{(1.25-1.0)} \times (1.03-1.0) = 0.605\text{MPa} \qquad \text{(Table 3.1)}$$

Transverse Reinforcement

$$A_{s\upsilon} = \frac{T_u s_\upsilon}{b_1 d_1 (0.87f_y)} + \frac{V_u s_\upsilon}{2.5d_1(0.87f_y)} \qquad \ldots (4.2)$$

Providing side and top cover of 30mm and 2 ϕ 10 bars at the top

$$b_1 = 300 - 30 - 30 - \frac{28}{2} - \frac{28}{2} = 212\text{mm}$$

$$d_1 = 800 - 30 - \frac{10}{2} = 765\text{mm}$$

Assuming ϕ 8 two-legged stirrups

$$A_{s\upsilon} = 2 \times \frac{\pi}{4} \times 8^2 = 100.53 \text{ mm}^2$$

Substituting these values in the above equation

$$100.53 = \frac{50 \times 10^6 s_\upsilon}{212 \times 765 \times (0.87 \times 250)} + \frac{100 \times 1000 s_\upsilon}{2.5 \times 765 \times (0.87 \times 250)}$$

Minimum shear reinforcement

$$A_{s\upsilon} = \frac{(\tau_{\upsilon e} - \tau_c) b s_\upsilon}{0.87f_y} \qquad \ldots (4.3)$$

$$\text{or, } 100.53 = \frac{(1.53 - 0.605) \times 300 \times s_\upsilon}{0.87 \times 250}$$

$$\text{or, } s_\upsilon = 78.79\text{mm} > 60.64 \text{ mm}$$

i) $s_{\upsilon,max} = x_1 = (300 - 30 - 30 + \frac{8}{2} + \frac{8}{2}) = 248$

ii) $s_{\upsilon,max} = \frac{x_1 + y_1}{4}$

where $y_1 = 800 - 30 + \frac{8}{2} + \frac{8}{2} + \frac{28}{2} = 792$ mm

Substituting y_1 in the above equation

$$s_{\upsilon,max} = \frac{248 + 792}{4} = 251$$

iii) $s_{\upsilon,max} = 300$

iv) $s_{\upsilon,max} = 0.75d = 0.75 \times 800 = 600$

As side reinforcement

$= 0.1 \times$ web area (section 4.2.4)

$= 0.1 \times 300 \times 850$

$= 250 \text{ mm}^2$

Provided 2 ϕ 10 on each face.

The arrangement of reinforcements is shown in Figure 4.6 below.

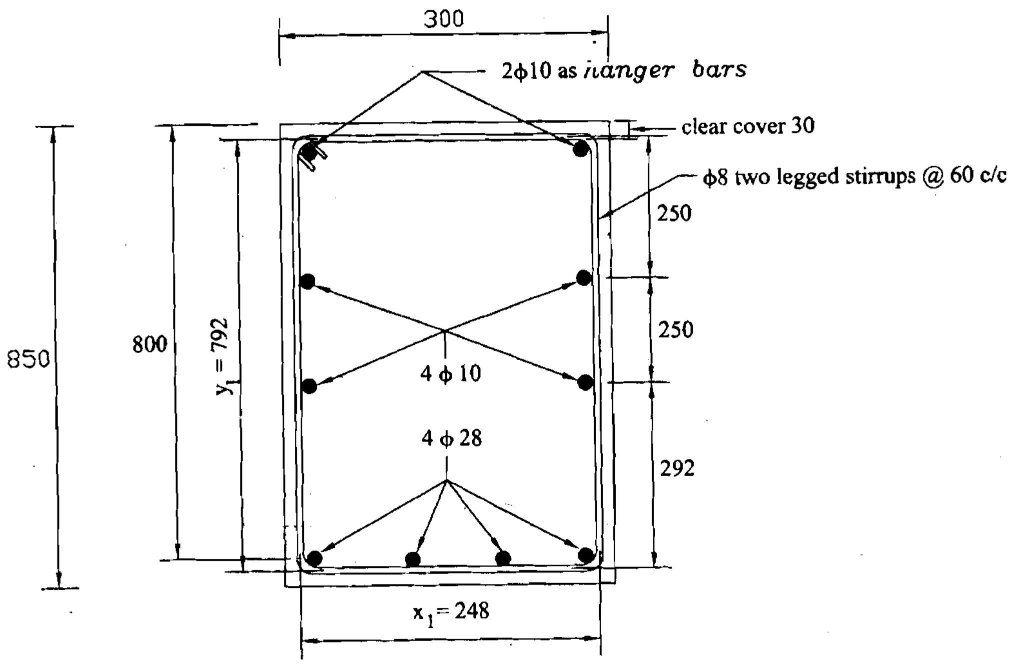

Figure 4.6 : Details of Reinforcement for Combined M_u, V_u, and T_u having $M_t < M_u$

Design of a Beam in which $M_t > M_u$

Example 4.2

Design a rectangular R.C. beam for the following data :

$b = 300$; $d = 800$; $D = 850$; $M_u = 200$ kNm; $V_u = 100$ kN; $T_u = 95$ kNm; $f_{ck} = 20$ MPa; and $f_y = 415$ MPa.

Solution

Equivalent Shear

$$V_e = V_u + 1.6 \frac{T_u}{b} \qquad \ldots (4.1)$$

$$= 100 + 1.6 \times \frac{95}{0.3} = 606 \text{ kN}$$

$$\therefore \quad \tau_{ve} = \frac{606.67 \times 10^3}{300 \times 800} = 2.53 \text{ MPa}$$

For M20 concrete, $\tau_{c\,\max} = 2.8 > \tau_{ve}$

Since tensile reinforcement is not known at the outset; therefore, for minimum % of tensile reinforcement

i.e., for $100\,\frac{A_{st}}{bd}\,\% = 100 \times \frac{0.85}{415}\,\% = 0.205\%$

$$\tau_c = 0.33 + \frac{(0.205 - 0.2)}{(0.25 - 0.2)} \times (0.36 - 0.33) = 0.333 < \tau_{ve} \ (2.53 \text{ MPa}) \quad (\text{T } 3.1)$$

Hence, both longitudinal as well as transverse reinforcement shall be provided.

Equivalent Bending Moment

$$M_{e1} = M_u + M_t = M_u + T_u \left(\frac{1 + D/b}{1.7}\right) \qquad \ldots (4.4)$$

$$= 200 + 95\,\frac{(1 + 850/300)}{1.7} = (200 + 214.22) \text{ kNm}$$

$$= 414.22 \text{ kNm}$$

Here, $M_t > M_{e1}$; therefore, longitudinal reinforcement on compression face will *also* be provided for a bending moment of $(M_t - M_u)$

$$M_{e2} = M_t - M_u = 214.22 - 200 = 14.22 \text{ kNm} \qquad \ldots (4.6)$$

$$M_{u,\,\mathrm{lim}} = 0.36\,\frac{X_{u,\,\max}}{d}\left(1 - 0.42\,\frac{X_{u,\,\max}}{d}\right) bd^2 f_{ck}$$

Here for Fe 415 $\frac{X_{u,\,\max}}{d} = 0.48$ ... (2.6(a))

$$\therefore \quad M_{u,\,\mathrm{lim}} = 0.36 \times 0.48\ (1 - 0.42 \times 0.48) \times 300 \times 800^2 \times 20$$

$$= 529.92 \text{ kNm} > M_{e1} \ (414.22 \text{ kNm})$$

Hence, the beam will be under reinforced.

Longitudinal Reinforcement on Tension Side

$$M_{e1} = 0.87 f_y A_{st}\left(1 - \frac{A_{st} f_y}{bd f_{ck}}\right) \qquad \ldots (2.5(b))$$

or, $414.22 \times 10^6 = 0.87 \times 415 \times A_{st} \times 800 \left(1 - \frac{A_{st} f_y \times 415}{300 \times 800 \times 20}\right)$

or, $24.97 A_{st}^2 - 288840 A_{st} + 414.22 \times 10^6 = 0$

or, $A_{st} = 1677.29 \text{ mm}^2$

Provided $5\phi22$ (= 1900 mm^2)

Longitudinal Reinforcement on Compression Face

$$M_{e2} = 0.87 f_y A_{st} (d - d')$$

or, $14.22 \times 10^6 = 0.87 \times 415 A_{st} (800 - 25)$

or, $A_{st} = 50.82 \text{ mm}^2$

Provided $2\phi10$ (= 157 mm^2)

Transervse Reinforcement

$$A_{st} = \frac{T_u s_v}{b_1 d_1 (0.87 f_y)} + \frac{V_u s_v}{2.5 d_1 (0.87 f_y)} \qquad \ldots (4.2)$$

Providing $\phi8$ two legged stirrups

$$A_{sv} = 2 \times \frac{\pi}{4} \times 8^2 = 100.53 \text{ mm}^2$$

Again taking clear cover on top and on sides = 25 mm

$$b_1 = 300 - 25 - 25 - \frac{22}{2} = 228 \text{ mm}$$

$$d_1 = 800 - 25 - \frac{10}{2} = 770 \text{ mm}$$

Substituting these values in the above Eq.

$$100.53 = \frac{95 \times 10^6}{228 \times 770 (0.87 \times 415)} + \frac{100 \times 10^3 s_v}{2.5 \times 770 (0.87 \times 415)}$$

or, $s_v = 61.2$

As $P_t \% = \frac{5 \times \frac{\pi}{4} \times 22^2}{300 \times 800} \times 100\% = 0.79\%$

$\tau_c = 0.56 + \frac{(0.62 - 0.56)}{(1 - 0.75)} \times (0.79 - 0.75) = 0.57 \text{ MPa}$ (T 3.1)

$$\text{Now, } A_{sv} = \frac{(\tau_{ve} - \tau_c)\, b s_v}{0.87 f_y} \qquad \ldots(4.3)$$

$$\text{or, } 100.53 = \frac{(2.53 - 0.57) \times 300 s_v}{0.87 \times 415}$$

$$\text{or, } s_v = 61.73 \qquad > 61.2$$

$$\text{Again} \quad x_1 = 300 - 25 - 25 + \frac{8}{2} + \frac{8}{2} = 258$$

$$y_1 = 800 - 25 + \frac{8}{2} + \frac{22}{2} + \frac{8}{2} = 794$$

Spacing of transverse reinforcement shall be the least of the following :

i) 61.2

ii) $x_1 = 258$

iii) $\dfrac{x_1 + y_1}{4} = \dfrac{258 + 794}{4} = 263$

iv) $0.75d = 0.75 \times 800 = 600$

Therefore, provided ϕ 8 two legged stirrups @ 60 c/c.

Since, the depth of the beam is greater than 450, side face reinforcement area

$$A_s = \frac{0.1}{100} \times bD = \frac{0.1}{100} \times 300 \times 850 = 255\text{mm}^2$$

Hence provided 2 ϕ 10 on each side face.

The arrangement of reinforcement is shown in Figure 4.7 below.

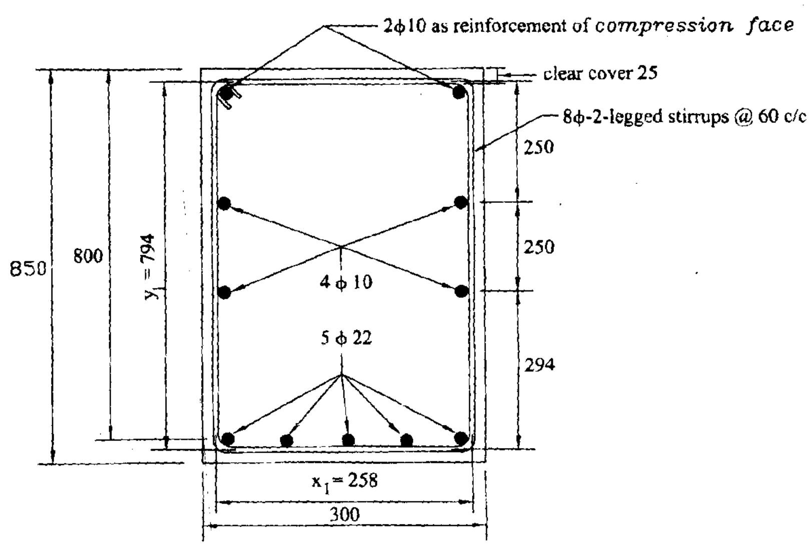

Figure 4.7 : Details of Reinforcements for Combined M_u, V_u, and T_u having $M_t > M_u$

SAQ 3

i) Design cross section of a R.C. rectangular beam for the following data :

$b = 300$; $D = 750$; $f_y = 415$ MPa; $f_{ck} = 20$ MPa; $M_u = 90$ kNm; $V_u = 90$kN and

$T_u = 35$ kNm

Provide 50 mm *effective* cover to tensile reinforcement and 25 mm *clear* cover on sides and top longitudinal reinforcements.

ii) Design a reinforcement concrete rectangular cross section for the following data :

$b = 300$; $D= 750$; $M_u= 90$ kNm; $V_u = 90$kN; $T_u = 60$kNm; $f_y= 415$ MPa and

$f_{ck} = 20$ MPa

Provide 50 mm *effective* cover to tensile reinforcement and 25 mm *clear* cover on sides and top longitudinal reinforcements.

4.4 SUMMARY

Torsion causes twisting rotation of a structural element. Determination of internal stresses, strains, torque resisting capacity etc. for design purposes are based on experimental results as theoretical analysis for the same is cumbersome and not in agreement with actual behaviour.

Applied torsion can either be *Primary Torsion* or *Secondary Torsion.*

If a member is designed *not* to resist any torsion and if it collapses under the applied torque, such member is said to be under primary torsion. In other words, the element becomes unstable under the influence of torque if adequate provisions for resisting torsion by the element and its supporting elements are not made. But where a member under the application of torque adjusts itself in such a way that the torque vanishes or becomes negligible due to *compatible deformations* in itself as well as other connected elements and *yet* keep the element and the structure of which it is a part in equilibrium; then such torsion is called secondary torsion.

Torsional resistance can be enhanced by increasing longitudinal as well as transverse reinforcements. Therefore, design for torsion is accomplished by providing

i) longitudinal reinforcements for *Equivalent Bending Moment* which is a function of actual bending moment and torsion, and

ii) transverse reinforcement for *Equivalent Shear* which is a function of actual shear and torsion.

4.5 ANSWERS TO SAQs

SAQ 1

i) Refer 4.1

ii) Refer 4.1

iii) Refer 4.1

iv) Refer 4.1

v) Refer 4.1

SAQ 2

i) Refer 4.2.1

ii) Refer 4.2.2

iii) Refer 4.2.3

SAQ 3

i)

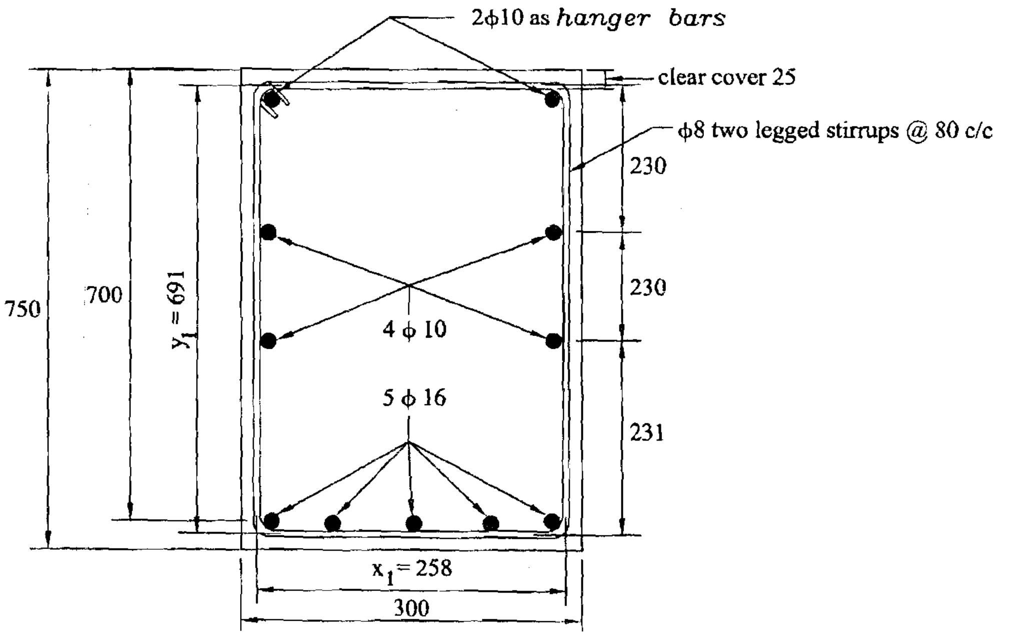

Figure 4.8 : Details of Reinforcement for Combined M_u, V_u, and T_u having $M_t < M_u$

ii)

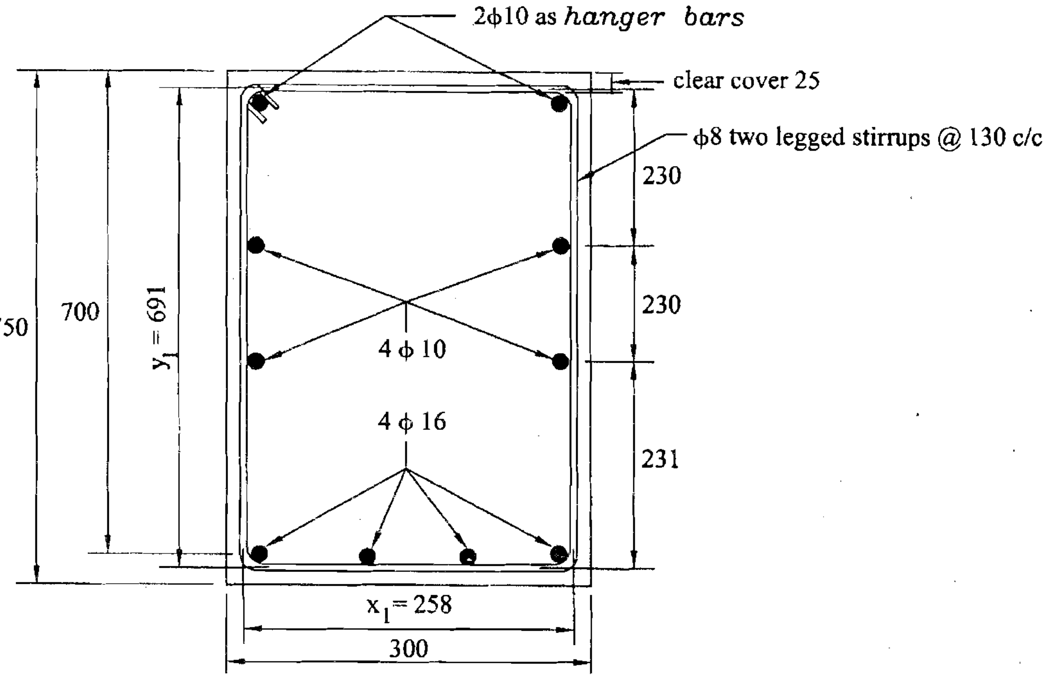

Figure 4.9 : Details of Reinforcement for Combined M_u, V_u, and T_u having $M_t > M_u$