SRI VIDYA COLLEGE OF ENGINEERING & TECHNOLOGY

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CE6505 DESIGN OF REINFORCED CONCRETE ELEMENTS

UNIT – III

LIMIT STATE DESIGN FOR BOND, ANCHORAGE SHEAR & TORSION

QUESTIONS & ANSWERS

PART – A

1. What are the types of shear failure in reinforced concrete beams?

1. Shear – tension (or) Diagonal tension
2. Flexure – shear
3. Shear compression
4. Shear – bond

2. How do you prevent minimum shear reinforcements?

- Brittle shear failure cracks which can occur without shear reinforcements
- Sudden failure due to bursting of concrete of concrete cover and bond to the tension reinforcements
- The shear reinforcements help to hold the main reinforcement while concreting forming an effective cage
- Formation of cracks due to the thermal and shrinkage stresses are minimized.
- Shear reinforcement act as effective ties for the compression steel and make them effective.

3. How do you develop bond mechanisms between concrete?

- Chemical adhesion is the grip developed due to the gum like property of the gum like property of the hydration products of cement in concrete.
- Frictional resistance developed due to the relative movements between concrete and steel bars depending upon the surface characteristics on f the bars and the grip developed due to shrinkage of concrete.

- Shearing resistance or dilatancy due to mechanical interlock developed as a consequence of surface protrusion as ribs in deformed bars.

4. Define bond stress.

The tangential or shear stress developed along the contact surface of the reinforcing bar and the surrounding concrete if generally termed as bond stress and is expressed in terms of the tangential force per unit nominal surface of the reinforcing bar.

5. List out the various types of reinforcement.

1. Lapping of bars
2. Stirrups at splice locations
3. Staggered splicing
4. Mechanical connections
5. Butt welding of bars
6. Lap welding of bars.

6.Write the formula for developing length.

Development length $L_d = \varphi\sigma_s/4\tau_{bd}$

Where L_d Development length

Φ is the diameter of the bar

σ_s is the stress in the bar

τ_{bd} is the design bond stress

7. What are the criteria recommended by IS 456-2000 for anchorage value of bend?

(a) The radius of the bend be not less than twice the diameter of the round bar

(b) The length of the straight part of the bar beyond the end of the curve be at least four times the diameter of the round bar.

(c) Whatever be the angle through which the bar is bend, the assumed anchorage value should not taken as more than equivalent to a length of bar equal to sixteen times the diameter of the round bar.

8. What is the necessity of bending reinforcement?

Bars are bent under different circumstances

- They may be bent to form hooks so as to develop proper anchorage
- Bars have to be bent so as to form loops as in the case of stirrups as shear reinforcement
- Bars may be also be bent to resist diagonal tension. They may also bend up to form necessary reinforcement for hogging bending moments.

9. What are the points to be considered in anchoring shear reinforcement?

(a) Inclined bars: The development length shall be as for bars in tension. This length shall be measured as under.

(i) In tension zone, from the end of the sloping or inclined portion of the bar

(ii) In compression zone, from the mid depth of the beam.

(b) Stirrups: For stirrups and ties, the complete development lengths and anchorage shall be deemed to have provided when the bar is bent through and angle of at least 90^o

10. What are the criteria recommended by IS 450-2000 for cover to reinforcement?

1.At each end of a reinforcing bar – not less not 25mm nor less than twice the diameter of such bar.

2. For longitudinal reinforcement in a column- not less than 40mm nor less the diameter of such bar

3.For longitudinal reinforcement in a beams- not less than 25mm nor less the diameter of such bar

4. For tensile, compressive, shear and other reinforcement in a slab and other reinforcement in a slab- not less than 15mm nor less the diameter of reinforcement

11. Give the property of good a bond between concrete reinforcement.

1. Sufficient cover for reinforcement
2. Richness of concrete
3. using twisted bars, welding the stirrup bars with the main bars
4. Roughness of steel

12. What is meant by end anchorage?

Mild steel bars embedded in concrete are sometimes hooked so as to have proper anchorage with concrete. If bars are provided with hooks, the necessary grip or bond length can be reduced. The anchorage value of the hook alone is considered as 16d where d is the diameter of the bar

13. Write short note on splices in tensile reinforcement.

Splices at point of maximum tensile stress shall be avoided wherever possible, splices where used shall be welded, lapped or otherwise fully developed. In any case the splice shall transfer the entire computed stress from bar to bar.

Lapped splices in tension shall not be used for bars of sizes larger than 36mm diameter and such splices shall preferably be welded.

14. Define shear strength.

The resistance to sliding offered by the material of beam is called shear strength.

15. What are the important factors affecting the shear resistance of a Reinforced concrete member without shear reinforcement?

The important factors affecting the shear resistance of a reinforced concrete member without shear reinforcement are

- Characteristic strength of concrete
- Percentage of longitudinal steel
- Shear span to depth ratio
- Axial compressive / Tensile force
- Effect of cross section
- Effect of two way action

16. What are the types of reinforcement used to resist shear?

The types of reinforcement used to resist shear are

a. Vertical Stirrups

b. Inclined Stirrups

c. Bent up bars along with stirrups

17. Define Torsion.

Equal and opposite moments applied at both ends of structural element (Member) or its part about its longitudinal axis is called Torsion. Also termed as torsional moment or twist or torque.

18.What is compatibility torsion? Give an example

Compatibility torsion is the torsion induced in the member due to compatibility of rotations at the joint of interconnected members.

Examples:

Spandrel beam rigidly connected to cross beam, inter connected bridge girder and grids in horizontal plane.

19.Explain Equilibrium Torsion.

Torsional moment developed in one or more elements of a structure to maintainequilibrium is called as equilibrium torsion. It is also known as determinate torsion or Primary Torsion.

20. Define bond. (Or) What is bond?

Bond is defined as grip between concrete and steel.

(Or)

The force that prevents the relative movement between concrete and steel is known as bond.

(Or)

Bond in reinforced concrete beams is the adhesive force developed between concrete and steel bars embedded in concrete, which resists any force that tends to push or pull the bars.

21. List out the different types of bond.

The different types of bond are

Flexure bond

Anchorage bond

22. Define flexure bond

In flexure member on account of shear of a variation in bending moment, which inturn causes a variation in axial tension along the length of bar.

23. What is meant by Anchorage bond?

Over the length of anchorage provided for a bar or near the end (or cutoff point) of a reinforcing bar.

24.Reinforced concrete slabs are generally safe and do not require shear reinforcement. Why?

The thickness of slab (controlled by limiting deflection criteria) is usually adequate in terms of shear capacity.

(Or)

Normally the thickness of slab is so chosen that the shear can be resisted by concrete itself and the slab does not need extra shear reinforcements

UNIT 3

LIMIT STATE DESIGN FOR BOND, ANCHORAGE SHEAR & TORSION

PROBLEM 1:

A beam of rectangular section of 350 mm width and 550 mm effective depth is reinforced with 6 numbers of 20 mm diameter bars out which three bars have been bent up at 45°. Determine shear resistance of the bent-up bars and the additional shear reinforcement required if it is subjected to an ultimate shear force of 300 kN. M20 concrete and Fe-415 steel are used. **(Anna Univ. Nov/Dec. 2007)**

Solution

(i) Given Data

$b = 350$ mm, $d = 550$ mm

$$A_{st} = 3 \times \frac{\pi \times 20^2}{4} = 942 \text{ mm}^2 \; ; \; f_{ck} = 20 \text{ N/mm}^2 = f_y = 415 \text{ N/mm}^2$$

3 bars of 20 mm dia bent-up at 45°

(ii) Percentage of Tension Reinforcement

$$p_t = \left(\frac{100\, A_{st}}{b\, d} \right) = \frac{100 \times 942}{350 \times 550} = 0.49$$

From Table 5.2, for $p_t = 0.49$ and $f_{ck} = 20$ N/mm^2

we have $\tau_c = 0.475$ N/mm^2

(iii) Shear Resisted by Concrete

$$V_{uc} = \tau_c\, b\, d = (0.475 \times 350 \times 550) \times 10^{-3}$$

$$= 91.44 \text{ kN}$$

(iv) Shear Resistance by Bent-bars

$$V_{us} = A_{st}\, (0.87\, f_y) \sin \alpha$$

$$= (942\, (0.87 \times 415) \times \sin 45°) \times 10^{-3}$$

$$= 240.46 \text{ kN}$$

Shear resistance offered by bent–bars $= 240.46$ kN *(v) Total Shear Resistance at the Support*

$$V_{ST} = V_{uc} + V_{sv}$$
$$= 91.44 + 240.66$$
$$= 331.9 \text{ kN}$$

Ultimate shear force at the support = 300 kN.

Hence no additional shear reinforcement is needed.

PROBLEM : 2

A RC beam 250 mm wide and 450 mm deep is reinforced with 3 numbers of 20 mm diameter bars on tension side with an effective cover of 50 mm. If the shear reinforcement of two-legged 8 mm diameter stirrups at a spacing of 160 mm centre to centre is provided at a section, determine the shear strength of the section. Assume M20 concrete and Fe-415 steel have been used. If one of the tension bars is bent up at the section at 45°, what is the design strength of the section in shear. Adopt limit state design method.

(Anna Univ. Nov/Dec. 2010)

Solution

(i) Given Data

$$A_{st} = 3 \times \frac{\pi \times 20^2}{4} = 942 \text{ mm}^2 \text{ ; } A_{sv} = 2 \times 50 = 100 \text{ mm}^2$$

$$f_{ck} = 20 \text{ N/mm}^2 \text{ ; } f_y = 415 \text{ N/mm}^2\text{; } b = 250 \text{ mm}$$

Assuming 50 mm cover Effective depth, $d = 400$ mm

(a) No Bent-bars

(ii) Percentage Tension Reinforcement

$$p_t = \left(\frac{100\, A_{st}}{b\, d} \right) = \frac{100 \times 942}{250 \times 400} = 0.942$$

From Table 5.2, for $p_t = 0.942$ and $f_{ck} = 20$ N/mm^2

τ_c is interpolated as $\tau_c = 0.606$ N/mm^2

(iii) Shear Resisted by Concrete

$$V_{uc} = (\tau_c\, b\, d) = 0.606 \times 250 \times 400 \times 10^{-3}$$

$$= 60.6 \text{ kN}$$

(iv) Shear Resisted by Vertical Stirrups

$$V_{us} = \frac{100\,(0.87 f_y)\, 400}{160} = \frac{900 \times 0.87 \times 415 \times 400}{160 \times 100}$$

$$= 90.26 \text{ kN}$$

(iii) Total Shear Strength at the Support

$$V_u = (V_{uc} + V_{us})$$

$$= 60.6 + 90.26$$

$$= 150.86 \text{ kN}$$

Shear strength of section = 150.86 kN

(b) One Bent-bar

(i) Percentage Tension Reinforcement

$$P_t = \frac{100\, A_{st}}{b\, d} = \frac{100 \times 2 \times 314}{250 \times 400} = 0.628$$

From Table 5.2, for $p_t = 0.628$ and $f_{ck} = 20$ N/mm^2, τ_c is obtained by interpolation as $\tau_c = 0.521$ N/mm^2

(ii) Shear Resisted by Concrete

$$V_{uc} = \tau_c\, b\, d = (0.521 \times 250 \times 400) \times 10^{-3}$$

$$= 52.1 \text{ kN}$$

(iii) Shear Resisted by Vertical Stirrups

$$V_{us_1} = \frac{A_{st} \times 0.87 \times f_y\, d}{s_v} = \frac{100 \times 0.87 \times 415 \times 400}{160}$$

$$= 90.26 \text{ kN}$$

(iv) Shear Resisted by Bent Bars

$$V_{us_2} = A_{st}\,(0.87 f_y)\sin\alpha$$

$$= 314\,(0.87 \times 415) \times \sin 45° \times 10^{-3}$$

$$= 80.15 \text{ kN}$$

(v) Total Shear Resistance at the Support

$$V_u = V_{uc} + V_{us_1} + V_{us_2}$$

$$= (52.1 + 90.26 + 80.15)$$

$$= 222.51 \text{ kN}$$

Shear strength of section $= 222.51$ kN

PROBLEM 3

A simply supported beam with clear span 600 mm, $b = 400$ mm, $d = 500$ mm carries a limit state load of 175 kN/m (including self weight, dead load and live load). It is reinforced with 4 bars of 28 mm diameter tension steel ($A_{st} = 2464$ mm^2) which continue right into the support. Take $f_{ck} = 20$ N/mm^2 and $f_y = 250$ N/mm^2. Design shear reinforcement

(Anna Univ. April/May 2011)

Solution

(i) Given Data

$$b = 400 \text{ mm};\ d = 560 \text{ mm}$$

Assume d as effective depth

$$A_{st} = 4 \times \frac{\pi \times 28^2}{4} = 2464 \text{ mm}^2, f_{ck} = 20 \text{ N/mm}^2 \text{ and } f_y = 415 \text{ N/mm}^2$$

(ii) Percentage Tension Reinforcement

$$p_t = \frac{100\,A_{st}}{b\,d} = \frac{100 \times 2464}{400 \times 560} = 1.10$$

From Table 5.2, for $p_t = 1.232$ and $f_{ck} = 20$ N/mm^2, τ_c is interpolated as

$$\tau_c = 0.640 \text{ N/mm}^2$$

(iii) Shear Resisted by Concrete

$$V_{uc} = \tau_c\, b\, d = (0.640 \times 400 \times 560) \times 10^{-3}$$

$$= 143.36 \text{ kN}$$

(iv) Shear Reinforcement Required

$$\text{Shear force at support} = V = \frac{W}{2} = V = \frac{175 \times 6000}{2 \times 1000} = 525 \text{ kN}$$

$$V_u = V_{uc} + V_{us}$$

$$525 = 143.36 + V_{us}$$

$$V_{us} = 525 - 143.36 = 381.64 \text{ kN}$$

Provide 8 mm dia two-legged stirrups

$$\therefore \quad 381.64 = \frac{A_{st} \times 0.87 f_y \times d}{s_v}$$

$$= \frac{100 \times 0.87 \times 415 \times 560}{s_v \times 10^3}$$

$$\therefore \quad s_v = \frac{100 \times 0.87 \times 415 \times 560}{381.64 \times 10^3} = 52.98 \text{ mm}$$

8 mm diameter two-legged stirrups may be provided at a spacing of 50 mm.

PROBLEM 4

A reinforced beam 350 mm wide and 550 mm effective depth is reinforced with 4 numbers of 25 mm bars as main tension steel. Two of its four main bars are symmetrically bent at the ends of the beam at 45°. Find the stirrups required for resistance against shear failure at the ends, if the factored shear force at the critical section is 250 kN. Assume M25 grade of concrete and Fe-415 steel bars. **(Anna Univ. May/June 2012)**

Solution

(i) Given Data

$$b = 350 \text{ mm}; \; d = 550 \text{ mm}, \; f_{ck} = 25 \text{ N/mm}^2$$

$$f_y = 415 \text{ N/mm}^2; \; A_{st} = \frac{2 \times \pi \times 25^2}{4} = 981.25 \text{ mm}^2$$

(ii) Percentage Tension Reinforcement

$$p_t = \frac{100 \times A_{st}}{b\,d} = \frac{100 \times 981.25}{350 \times 550} = 0.51$$

From Table 5.2, $p_1 = 0.51$ and $f_{ck} = 25$ N/mm^2 τ_c is interpolated as $\tau_c = 0.493$ N/mm^2

(iii) Shear Resisted by Concrete

$$V_{uc} = (\tau_c\, b\, d) = (0.493 \times 350 \times 550) \times 10^{-3}$$

$$= 94.9 \text{ kN}$$

(iv) Shear Resisted by Bent-bars

$$V_{us_2} = A_{st} \times 0.87 f_y \times \sin\alpha$$

$$= (981.25 \times 0.87 \times 415 \times \sin 45°) \times 10^{-3}$$

$$= 200.48 \text{ kN}$$

(v) Shear Resistance at the Support

$V_u = V_{uc} + V_{us} = 94.9 + 200.48 = 295.38$ kN, $V_u > 250$ kN. Hence no stirrups are needed.

PROBLEM 5

Design the reinforcements required for a rectangular beam section with the following data:
Size of the beam section = 300 mm × 600 mm
Factored shear force = 95 kN
Factored torsion = 45 kN.m
Factored bending moment = 115 kN.m
Materials = M20 concrete and Fe-415 steel. Adopt Limit state design method.

(Anna Univ. Nov/Dec. 2010)

Solution

(i) Given Data

Factored shear force, $V_u = 95$ kN

Factored torsion, $T_u = 45$ kN.m

Factored bending moment, $M_u = 15$ kN.m

$b = 300$ mm; $d = 600 - 50$ (assumed); $= 550$ mm

$f_{ck} = 20$ N/mm^2 ; $f_y = 415$ N/mm^2

(ii) Bending Moment

Bending moment developed due to torsion $\Big\}$ $M_t = T_u \left(\dfrac{1 + D/b}{1.7} \right)$

$$M_t = 45 \left(\frac{1 + \frac{600}{300}}{1.7} \right) = 79.41 \text{ kN.m}$$

Equivalent Bending moment | $M_{e_1} = M_u + M_t$

$$M_e = 15 + 79.41 = 94.41 \text{ kN.m}$$

(iii) Reinforcement Required

We know,

$$M_e = 0.87 f_y A_{st} d\left[1-\left(\frac{A_{st} f_y}{b d f_{ck}}\right)\right]$$

$$94.41\times10^6 = 0.87\times415\times A_{st}\times550\left[1-\left(\frac{A_{st}\,415}{300\times550\times20}\right)\right]$$

$$94.41\times10^6 = 0.199\times10^6 A_{st}\,[1-1.26\times10^{-4} A_{st}.$$

$$94.41\times10^6 = 0.199\times10^6 A_{st} - 0.25\times10^2 A_{st}^2$$

$$A_{st}^2 - 0.796\times10^4 + 377.64\times10^4 = 0$$

$$A_{st} = \frac{+0.796\times10^4 \pm\sqrt{(-0.796\times10^4)^2 - 4\times1\times377.64\times10^4}}{2}$$

$$= \frac{0.796\times10^4 \pm 696^2\times10^4}{2} = \frac{0.100\times10^4}{2}$$

$$= 0.05\times10^4$$

$$= 500 \text{ mm}^2$$

Assuming, b_1 = 200 mm and $d_1 = 250$ m and a spacing $s_v = 100$ mm the area of stirrups can be calculated from

$$A_{sv} = \left[\frac{T_u s_v}{b_1 d_1 (0.87 f_y)} + \frac{V_u s_v}{2.5 d_1 (0.87 f_y)}\right]$$

$$= \left[\frac{45\times1000^2\times100}{200\times250\,(0.87\times415)} + \frac{95\times1000\times100}{2.5\times250\times0.87\times415}\right]$$

$$= 291.37 \text{ mm}^2$$

Adopt 2-legged 8 mm diameter stirrups

$$\text{No. of stirrups} = \frac{291.37}{2\times\pi\times\frac{8^2}{4} = 2.9} \approx 3$$

Three two-legged stirrups of 8 mm diameter are provided.

PROBLEM 6

A R.C.C section 200 mm × 400 mm is subjected to the following: Factored Torsional mom of 25 kN.m and a transverse shear of 60 kN. Assume M25 grade concrete and Fe-415 ba determine the reinforcement required according to IS 456 code provisions, using the followi data: Over all depth: 400 mm, Effective depth = 350 mm, b_1 = 150 mm and d_1 = 300 mm.

(Anna Univ. April/May 200

Solution

(i) Given Data

Beam size: 200 mm × 400 mm ; $f_{ck} = 20$ N/mm^2

Factored Torsional moment = 25 kN.m ; $f_y = 415$ N/mm^2

Factored Transverse shear = 60 kN

$D = 400$ mm; $d = 350$ mm; $b_1 = 150$ mm; $d_1 = 300$ mm

(ii) Bending Moment

Bending moment developed due to torsion, $M_t = T_u \left(\dfrac{1 + \dfrac{D}{b}}{1.7} \right)$

$$M_t = 25 \frac{\left(1 + \frac{400}{200}\right)}{1.7} = 44.1 \text{ kN.m}$$

Equivalent bending moment, $M_e = M_u + M_t$

Assuming a factored bending moment equal to that of torsional moment

$$M_e = 44.1 + 44.1 = 88.2 \text{kN.m}$$

(iii) Reinforcement Required

$$M_e = 0.87 f_y A_{st} d \left[1 - \left(\frac{A_{st} f_y}{b\, d\, f_{ck}} \right) \right]$$

$$88.2 \times 10^6 = 0.87 \times 415 \times A_{st} \times 350 \left[1 - \frac{A_{st}\, 415}{200 \times 350 \times 25} \right]$$

$$88.25 \times 10^6 = 126367.5\, A_{st} - 29.97\, A_{st}^2$$

$$A_{st}^2 - 4216.5\, A_t + 2942942.9 = 0$$

$$A_{st} = \frac{+4216.5 \pm \sqrt{(-4216.5)^2 - 4 \times 1 \times 2942942.9}}{2}$$

$$= \frac{4216.5 \pm 2450.9^2}{2} = 882.8 \text{ mm}^2$$

Provide 3 bars of 20 mm diameter

Assuming a spacing of 100 mm, area of stirrups can be found.

$$A_{sv} = \left[\frac{T_u s_v}{b_1 d_1 (0.87 f_y)} + \frac{V_u s_v}{2.5 d_1 (0.87 f_y)} \right]$$

$$= \left[\frac{44.1 \times 100 \times 10^6}{150 \times 300 \times 0.87 \times 415} + \frac{60 \times 100 \times 10^3}{2.5 \times 300 \times 0.87 \times 415} \right]$$

$$= 271.43 + 22.56 = 293.99 \text{ mm}^2$$

Number of two legged stirrups of 8 mm dia.

$$= \frac{293.99}{2 \times 50} \approx 2 \text{ Nos}$$

7. Describe the procedure for design of shear reinforcement. (APRL MAY 11)

- The nominal shear stress value is determined using the formula

  =shear force / (bxd) in KN/mm².

- The design shear strength of concrete is determined by using the tables in IS456-2000, page no 73, table no 19.

- Compare the nominal shear strength and design shear strength, the nominal shear stress value is less then design shear strength the minimum shear reinforcement is provided in the form of vertical stirrups, in the case IS456-2000-26.5.1.6 is referred.

- The nominal shear stress value is exceeds the design shear strength, shear reinforcement shall be provided in any of the following forms.

  a) Vertical stirrups

  b) Bent up bars along with stirrups,
  c) Inclined stirrups.

- Where bent up bars are provided their contribution towards shear resistance shall not be more than half that of the total shear reinforcement.

- Shear reinforcement shall be provided to carry a shear equal to the strength of shear reinforcement.