Chapter 3

Strength of RC Section in Shear, Torsion and Bond

CHAPTER HIGHLIGHTS

- *Introduction*
- *Shear*
- *Torsion*
- *Bond*
- *Splicing of tension reinforcement*

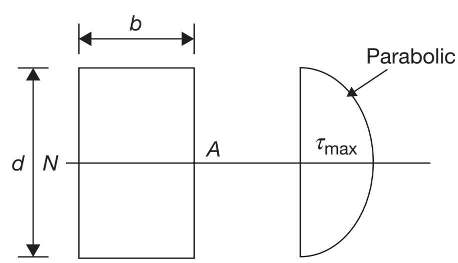
Introduction

Beam is subjected to shear due to bending. Hence, the RC section should be strong enough to resist the limit state of collapse in shear also. An important assumption made in design of RC sections is, there is a perfect bond between steel and concrete. It is possible only when bond stress is within the limit. In some cases, beam may be subjected to torsion. Hence, the beam should have sufficient strength to resist torsion. The present chapter outlines the strength of RC sections in shear, torsion and bond to ensure safety against shear due to external loads and to have perfect bond between steel and concrete and also in torsion.

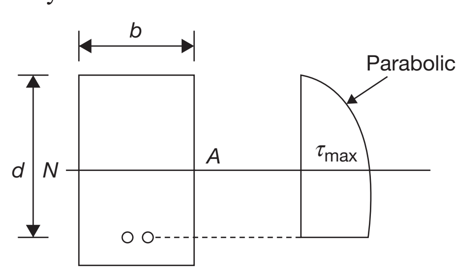
Shear

Shear Stress in Beam

1. **Homogenous beams:** The variation of shear stress across the homogenous beam of rectangular section is parabolic, i.e., it is zero at top and bottom, and maximum at the neutral axis. The variation of shear stress for homogenous beam of rectangular cross-section is shown in figure.



2. **Reinforced concrete beams:** In case of reinforced concrete beams, shear stress parabolically varies from zero at top compression face to maximum at neutral axis. It is constant from neutral axis to the center of gravity of steel.



Procedure for Design of Shear

1. **Nominal shear stress (τ_v):** In case of beams of uniform depth, $\tau_v = \frac{V_u}{bd}$

   Where,
   V_u = Factored shear force
   d = Effective depth
   b = Width of member

   In case of beams of varying depth:

   Nominal shear stress, $\tau_v = \frac{V_u \pm \left(\frac{M_u}{d}\right)\tan\beta}{bd}$

   Where,
   M_u = Factored bending moment at section
   β = Angle between top and bottom edges of beam
   Use –ve sign when BM increases with increase in effective depth and +ve sign when BM decrease with increase in effective depth.

2. **Design shear strength of concrete (τ_c):** τ_c is based on grade of concrete and percentage of tension steel given in table 19 of IS:456–2000.

Design shear strength of concrete τ_c, N/mm^2 (Table 19 in IS:456–2000)

$100\frac{A_{st}}{bd}$	M15	M20	M25
≤0.15	0.28	0.28	0.29
0.25	0.35	0.36	0.36
0.50	0.46	0.48	0.49
0.75	0.54	0.56	0.57
1.00	0.60	0.62	0.64

3. **Maximum shear stress in concrete (τ_{cmax}):** To avoid compression failure of the section in shear, the nominal shear stress (τ_c) should not exceed the maximum shear stress in concrete (τ_{cmax}) values given in Table 20 of IS:456–2000.

Maximum shear stress τ_{cmax}, N/mm^2 (Table 20 of IS:456–2000)

Concrete Grade	M15	M20	M25	M30	M35	M40 (onwards)
τ_{cmax}	2.5	2.8	3.1	3.5	3.7	4.0

4. **Design of shear reinforcement:** The shear reinforcement is provided to resist the diagonal tensile stresses caused by shear force. The shear reinforcement can be provided in any of the following forms when t_v exceeds t_c, but not greater than τ_{cmax}.
   (a) Vertical stirrups
   (b) Bent up bars along with stirrups
   (c) Inclined stirrups

Vertical Stirrups

Shear to be resisted by shear reinforcement is given by

$$V_{us} = V_u - \tau_c bd$$

$$V_{us} = \frac{0.87 f_y A_{sv} \cdot d}{s_v} \qquad s_y = \frac{0.87 f_y A_{sv} \cdot d}{V_{us}}$$

Bent up Bars

Bent up bars alone are not effective in resisting shear failure. The shear resistance of bent up bars shall not exceed 50% of total shear to be resisted by shear reinforcement.

If all the bars are bent up at the same cross-section at an angle 'α', the shear resistance of bent up bars is given by:

$$V_{usb} = 0.87 f_y A_{sb} \sin\alpha$$

$$V_{usb} \le \frac{V_{us}}{2}$$

V_{usb} : Shear resistance of bent up bars
A_{sb} : Total area of bent up bars
α : Angle between the bent up bars and the axis of the member (>45°)

Inclined Stirrups

If the bent up bars or inclined stirrups are provided at a spacing of s_v, the shear resistance: $V_{us} = \frac{0.87 f_y A_{sv}(\sin\alpha + \cos\alpha)d}{s_v}$

Asv = Total cross-sectional area of stirrup legs or bent up bars with a distance of S_V.

Maximum Spacing of Shear Reinforcement

- Spacing of vertical stirrups should not exceed 0.75d or 300 mm whichever is less.
- For inclined stirrups at 45°, the maximum spacing is d or 300 mm whichever is less.

Minimum Shear Reinforcement

If $t_v < t_c$: minimum shear reinforcement is provided.

$$\frac{A_{sv}}{b \cdot s_v} = \frac{0.4}{0.87 f_y}$$

SOLVED EXAMPLE

Example 1

The width and effective depth of a reinforced concrete beam is 250 mm and 440 mm, respectively. The beam is provided with 4 numbers of 20 mm for bars in the tension zone. The beam is subjected to a shear force of 150 kN (factored). Check the requirement of shear reinforcement and provide if required. Grade of concrete is M20 and that of steel is Fe415. The shear strength of concrete for different percentages of tensile steel is given below. 8 mm diameter vertical stirrups are available.

[$v_{us} = 0.87 f_y A_{sv} d/s_v$ and $(A_{sv}/s_v) \geq 0.4b/f_y$ with the terms having usual meaning] **[GATE, 1999]**

% of Steel	Shear Strength of Concrete (τ_c) in N/mm^2
1.0	0.62
1.25	0.67
1.50	0.72

Solution

Given,

$b = 250$ mm; $d = 440$ mm;

$$A_{st} = 4 \times \frac{\pi}{4} \times 20^2; \; V_u = 150 \text{ kN}$$

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

Step 1: Nominal (average) shear stress due to loads, $\tau_v = \frac{V_u}{bd} = \frac{150 \times 10^3}{250 \times 440}$.

$$\boxed{\tau_v = 1.36 M_{pa}}$$

Step 2: Design shear strength of concrete (τ_c).

τ_c is based on percentage tension steel and f_{ck}

$$P_t = \frac{100 A_{st}}{bd} = \frac{100 \times 4 \times \frac{\pi}{4} \times 20^2}{250 \times 440}$$

$P_t = 1.14\%$ and $f_{ck} = 20$ N/mm^2

From the given table:

P_t	τ_c (N/mm^2)
1.0	0.62
1.14	?
1.25	0.67

$$(\tau_c - 0.62) = \frac{75.8 \times 10^7}{46,400 \times 56}(1.14 - 1.0)$$

τ_c(at $P_t = 1.14\%$)

$$= 0.62 + \left[\frac{0.67 - 0.62}{1.25 - 1.0}\right](1.14 - 1.0)$$

$\tau_c = 0.648$ N/mm^2

$\tau_v > \tau_c$; so, shear reinforcement is required

Step 3: Design of shear reinforcement.

Given, 8 mm diameter vertical stirrups shear reinforcement is required for:

$V_{us} = Vu - \tau_c bd$

$= 150 \times 10^3 - (0.648)(250 \times 440)$

$V_{us} = 78.720$ kN

Provide two-legged 8 mm diameter vertical stirrups.

$$A_{sy} = 2 \times \frac{\pi}{4} \times 8^2 = 100.5 \text{ mm}^2$$

Spacing of stirrups: Least of the following:

1. $$V_{us} = \frac{0.87 f_y A_{sv} d}{s_v}$$

$$S_y = \frac{0.87 \times 415 \times 100.5 \times 440}{78.720 \times 10^2} = 202.8 \text{ mm}$$

For vertical stirrups:

2. Maximum spacing, $sv = 0.75 \times 440 = 330$ mm
3. $S_v = 300$ mm

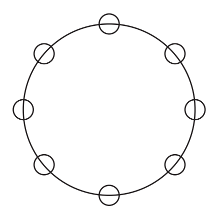
∴ Use minimum spacing as 200 mm centre to centre.

Torsion

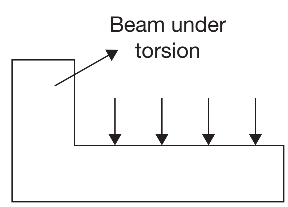
- The moment causing twisting of cross- section is called 'twisting moment' or 'torsion'.

Examples:

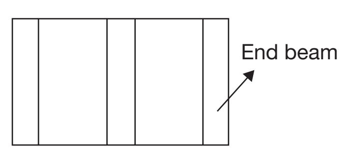
1. Ring beam of a circular water tank.
2. A beam with cantilever slab.
3. End beam or L-beam of a frame.



Plan of circular beam resting on columns



Beam with cantilever slab



End beam/L-beam of a frame

Indian Standard Recommendations on Design for Torsion

- IS method is based on skew bending theory proposed by Hsu.
- According to this method, there is no separate calculation for torsion reinforcement instead longitudinal reinforcement is a function of actual bending moment and torsion. Similarly, shear reinforcement is a function of actual shear and torsion.

Design Procedure

1. **Equivalent shear (V_e):** It is given by:

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

2. **Equivalent nominal shear stress (τ_{ve}):**

$$\tau_{ve} = \frac{V_e}{bd}$$

Where, $b = b_w$

For flanged sections:

(a) $\tau_{ve} \le \tau_{cmax} \Rightarrow$ safe

(b) If $\tau_{ve} > \tau_{cmax} \Rightarrow$ section should be redesigned.

(c) if $\tau_{ve} \le \tau_c \Rightarrow$ minimum shear reinforcement shall be provided in the form of stirrups.

$$\frac{A_{sv}}{b \cdot s_v} = \frac{0.4}{0.87\,fy}$$

(D) If τ_{ve} exceeds τ_c, both longitudinal and transverse reinforcement shall be provided as shown in the following steps.

3. **Reinforcement:**

(a) **Longitudinal Reinforcement:** These are provided in flexural tension face to resist an equivalent bending moment (M_{e1}) given by:

$$M_{e1} = M_u + M_T \qquad M_T = \frac{T_u\left[1+\frac{D}{b}\right]}{1.7}$$

Where

M_u = Factored bending moment

M_T = BM contributed by factored torsion moment (Tn)

Tu = Factored twisting moment

D = Overall depth of beam

b = Width of beam

If $M_T > M_u$, the longitudinal reinforcement shall be provided in the flexural compression face to resist equivalent moment (M_{e2}) given by:

$$M_{e2} = M_T - M_u$$

(b) **Transverse reinforcement:** Area of cross-section (Asv) of two-legged closed hoops enclosing the corner longitudinal bars is given by:

$$A_{sy} = \frac{T_u \cdot s_v}{b_1 d_1 (0.87\,fy)} + \frac{V_u \cdot s_v}{2.5 d_1 (0.87\,fy)}$$

A_{SV} shall not be less than $\frac{(\tau_{ve} - \tau_c)\, b \cdot s_v}{0.87\,fy}$.

The spacing of stirrups shall not exceed (least of):

(i) x_1

(ii) $\frac{x_1 + y_1}{4}$

(iii) 300 mm

b_1 = Centre to center distance between corner bars in direction of width.

d_1 = Centre-to-centre distance between corner bars in the direction of depth.

x_1 = Short dimension of stirrup

y_1 = Long dimension of stirrup

(c) **Side face reinforcement:** It is provided,

(i) when $D > 450$ mm and subjected to torsion

(ii) when $D > 750$ mm and not subjected to torsion.

Total area of such reinforcement shall not be less than 0.1 percent of web area and distributed equally on two faces at a spacing not exceeding 300 mm or web thickness, or whichever is less.

Direction for solved examples 2 and 3:

At the limit state of collapse, an RC beam is subjected to flexural moment 200 kN-m, shear force 20 kN and torque 9 kN-m. The beam is 300 mm wide and has a gross depth of 425 mm, with an effective cover of 25 mm. The equivalent nominal shear stress (τ_{ve}) as calculated by using the design code turns out to the lesser than the design shear strength (τ_c) of the concrete. **[GATE, 2004]**

Example 2

The equivalent shear force (V_e) is

(A) 20 kN (B) 54 kN

(C) 56 kN (D) 68 kN

Solution

Equivalent shear force (V_e)

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

$$= 20 + \frac{1.6 \times 9}{0.3}$$

$$V_e = 68 \text{ kN}$$

Hence, the correct answer is option (D).

Example 3

The equivalent flexural moment (Me_1) for designing the longitudinal tension steel is

(A) 187 kN/m (B) 200 kN/m
(C) 209 kN/m (D) 213 kN/m

Solution

Since $\tau_{ve} < \tau_c$; longitudinal tensile reinforcement is based on M_u only, ignoring the effect of torsion directly.

$\therefore Me_1 = M_u = 200$ kN/m

Hence, the correct answer is option (B).

Bond

- Bond between steel and concrete should be perfect at service loads and they have to act together without any slip.
- The main function of bond is to transfer stress from steel to the surrounding concrete and vice-versa based on strain compatibility.

Bond Stress

- Bond stress is the shear stress developed between the contact surface of steel and concrete to keep them together.
- It resists any force that tries to pull out the rods from concrete.

Bond developed is due to combined effect of:

(a) Adhesion between concrete and steel: It is provided by concrete during its setting.
(b) Friction: It is developed due to shrinkage of concrete.
(c) Deformed bars: The values of design bond stress prescribed by IS:456–2000 are given in the following table:

Design bond stress in plain bars in tension (Clause 26.2.1.1 in IS: 456–2000)

Grade of concrete	M20	M25	M30	M35	M40 and above
Design Bond stress τ_{bd}, N/mm^2	1.2	1.4	1.5	1.7	1.9

NOTES

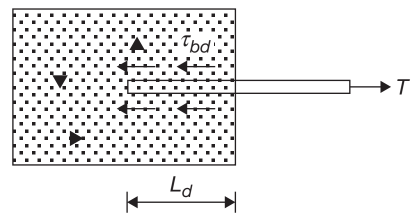
1. For deformed bars, these values may be increased by 60%.
2. For bars in compression, the above values may be increase by 25%.

Types of Bond

1. **Anchorage bond:** It develops in the anchorage zones, i.e., at the ends of bar (or) before the bar is terminated.
2. **Flexural bond:** Also known as local bond. It develops along the length of beam in order to let steel and concrete act together.

Development Length (L_d)

The minimum length of the bar required to transfer the force in the bar to the surrounding concrete through bond is called 'development length'.



Pull out test

The development length can be determined by pull out test.

Ultimate bond force = pull out force

$$(\pi_{bd})(\pi\phi\, L_d) = (0.87\, f_y)\left(\pi\frac{\phi^2}{4}\right)$$

$$L_d = \frac{0.87\, f_y\, \varphi}{4\tau_{bd}}$$

Where

τ_{bd} : Anchorage bond stress
ϕ : Diameter of reinforcing bar

Equivalent Development Lengths of Hooks and Bends

- The anchorage provided to longitudinal reinforcement in the form of hooks or bends is known as equivalent development length.
- The anchorage value of a standard bend shall be taken as 4 times the diameter of the bar for each 45° bend subjected to a maximum of 16 times the diameter.

Anchorage values of hooks and bends

Type of hook/bend	45°	90°	135°	180°
Anchorage value	4ϕ	8ϕ	12ϕ	16ϕ

Check for Development Length

$$L_d \le \frac{M_1}{V} + L_o$$

Where

M_1 = Moment of resistance of section corresponding to area of steel continued into the support.

V = Shear force at the support due to the design loads.

L_o = Extended length of bar beyond point of zero bending = 12ϕ, or the effective depth of beam whichever is more.

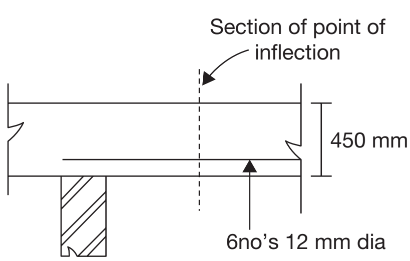
- The value of $\frac{M_1}{V}$ in the above expression may be increased by 30% when the ends of the reinforcement are confined by a compressive reaction.

Splicing of Tension Reinforcement

- Splices are provided when the length of the bar available is less than the required.
- Splicing should be done as far as possible away from the sections of maximum stresses and should be staggered.
- In flexural members, splicing is not allowed at sections where bending moment is more than 50% of moment of resistance.
- For larger diameter bars (ϕ >36 mm), the bars should be welded.
- Lap length for bars in flexural tension should be L_d or 30 ϕ whichever is greater, and for direct tension should be $2L_d$ or 30ϕ whichever is greater and in bending compression should be L_d or 24ϕ, or whichever is greater.

Example 4

A continuous beam of 250 mm × 450 mm carries 6 number of 12 mm diameter longitudinal bars as shown in the figure. The factored shear force at the point of inflection is 200 kN. Check if the beam is safe in bond. Assume M15 mix with σ_{ck} = 15 N/mm^2 and mild steel with σ_y = 250 N/mm^2. A clear cover of 25 mm can be assumed. The design bond stress for mild steel bars in M15 concrete is specified to be 1.0 N/mm^2. **[GATE, 2000]**



Solution

Check for bond:

$$L_d \le \frac{M_1}{V} + L_o$$

$$L_d = \text{Development length} = \frac{\phi\sigma_s}{4\tau_{bd}}$$

$$= \frac{(12)(0.87\times 250)}{4\times 1.0}$$

$$L_d = 652.5 \text{ mm}$$

M_1: Moment of resistance at the section of Inflexion point

Calculation of x_u:

$$C = T$$

$$0.36 f_{ck}\, b\, xu = 0.87 f_y\, Ast$$

$$x_u = \frac{0.87\times 250\times 6\times \frac{\pi}{4}\times 12^2}{0.36\times 15\times 250}$$

$$x_u = 109.32 \text{ mm}$$

$$x_{umax} = 0.53d$$

where $d = D - \text{clear cover} - \frac{\phi}{2}$

$$= 450 - 25 - \frac{12}{2} = 419 \text{ mm}$$

$\therefore x_{umax} = 0.53\,(419)$

$x_{umax} = 222.07$ mm

$\therefore x_u < x_{umax} \Rightarrow$ Under reinforced section

$M_1 = M_u = 0.87 f_y A_{st}(d - 0.42\, x_u)$

$$= 0.87\times 250\times 6\times \frac{\pi}{4}\times 12^2(419 - 0.42(109.32))$$

$M_1 = 55.06$ kN/m

$V : V_u = 200$ kN

$L_o = 12\phi$ or d whichever is less

= 12(12) or 419

$L_o = 144$ mm

$$\therefore \frac{M_1}{V} + L_o = \frac{55.06}{200} + 0.144$$

= 0.4193 m = 419.3 mm

$$L_d > \frac{M_1}{V} + L_o$$

Hence, the beam is not safe in bond.

Exercises

1. The appropriate expression in assessing development length is
   (A) $L_d = \frac{\phi\sigma_s}{4\tau_{bd}}$ (B) $L_d = \frac{\phi\sigma_s}{\tau_{bd}}$
   (C) $L_d = \frac{\sigma_s}{4\tau_{bd}}$ (D) $L_d = \frac{\phi\sigma_s}{8\tau_{bd}}$
2. A beam is designed for uniformly distributed loads causing compression in the supporting column. Where is the critical section for shear?
   (A) A distance $d/2$ from the face of support
   (B) A distance 'd' from the face of support
   (C) At center of support
   (D) At the face of support
3. Minimum shear reinforcement in beams is provided in the form of stirrups
   (A) to resist extra shear force due to live load.
   (B) to resist the effect of shrinkage of concrete.
   (C) to resist principle tension.
   (D) to resist shear cracks at the bottom of the beam.
4. Shear span is defined as the zone where
   (A) BM is zero.
   (B) SF is zero.
   (C) SF is constant.
   (D) BM is constant.
5. A reinforced concrete beam of 10 m effective span and 1 m effective depth is simply supported. If the total udl on the beam is 10 MN/m, the design shear force for the beam is
   (A) 50 MN (B) 47.5 MN
   (C) 32.5 MN (D) 40 MN
6. If ϕ = nominal diameter of reinforcing bar, f_s = compressive stress in the bar and f_{bd} = design bond stress of concrete, the anchorage length, L_a of straight bar in compression is equal to
   (A) $L_a = \frac{\phi f_s}{f_{bd}}$ (B) $L_a = \frac{\phi f_s}{2 f_{bd}}$
   (C) $L_a = \frac{\phi f_s}{\pi f_{bd}}$ (D) $L_a = \frac{\phi f_s}{4 f_{bd}}$
7. If the nominal shear stress (τ_v) at a section does not exceed the permissible shear stress (τ_c)
   (A) minimum shear reinforcement is still provided.
   (B) shear reinforcement is provided to resist the nominal shear stress.
   (C) no shear reinforcement is provided.
   (D) shear reinforcement is provided for the difference of the two.
8. In limit state design, permissible bond stress in the case of deformed bars is more than that in plain bars by
   (A) 60% (B) 50%
   (C) 40% (D) 25%
9. Shear span is defined as the zone where
   (A) bending moment is zero.
   (B) shear force is zero.
   (C) shear force is constant.
   (D) bending moment is constant.
10. The maximum permissible shear stress τ_c, max given in **BIS:456–1978** is based on
    (A) diagonal tension failure.
    (B) diagonal compression failure.
    (C) flexural tension failure.
    (D) flexural compression failure.
11. In a reinforced concrete member, the best way to ensure adequate bond is
    (A) to provide minimum number of large diameter bars.
    (B) to provide large number of smaller diameter bars.
    (C) to increase the cover for reinforcement.
    (D) to provide additional stirrups.
12. What is the anchorage value of a standard hook of a reinforcement bar of diameter D?
    (A) $4D$ (B) $8D$
    (C) $12D$ (D) $16D$
13. In design for shear in Reinforced concrete structures, which of the following is considered explicitly.
    (A) Dowel action
    (B) Aggregate interlocking
    (C) Concrete in compression zone
    (D) All of these
14. A hook of Fe415 Grade is provided in compression in M20 grade concrete with $\tau_{bd} = 1.2\text{Mpa}$, Then the development length L_d = _______ ϕ.
    (A) 44.17 (B) 37.6
    (C) 21.61 (D) Not allowed (hook)
15. Match the following with reference to RCC.

List I		List II	
a.	Torsional analysis	**1.**	Truss analogy
b.	Shear stress analysis	**2.**	Skew bending theory
c.	Limit state method	**3.**	Semi probabilistic approach
d.	Working stress method	**4.**	Deterministic

Codes:

	a	b	c	d
(A)	1	2	3	4
(B)	2	1	3	4
(C)	2	1	4	3
(D)	1	2	4	3

16. A reinforced concrete beam of rectangular cross-section of breadth 300 mm and effective depth 500 mm is subjected to maximum factored shear force of 400 kN. The grades of concrete and steel are M25 and Fe415 respectively. Based on the area of main steel provided grade of concrete the design shear stress τ_c as

per IS:456–2000 is 0.64 N/mm^2. If 2 – 16ϕ bars are used as bent up bars α = 50°) Design shear reinforcement spacing of (8 mm ϕ) 2 legged vertical stirrups ($\tau_{c\,max}$ = 3.1 N/mm^2)
(A) 90 mm (B) 110 mm
(C) 130 mm (D) 280 mm

17. A rectangular beam of 500 mm × 700 mm with effective cover of 40 mm is subjected to a factored values of shear force 12 kN, bending moment 150 kN-m and a torsional moment 15 kN-m. Find the design bending moment for the design in kN-m. Use share resistance of the cross section τ_c = 1.3 MPa.
(A) 100 (B) 114
(C) 150 (D) 171

18. Shear span is defined as the zone where
(A) BM is zero.
(B) SF is zero.
(C) BM is constant.
(D) SF is constant.

19. A mild steel bar of 20 mm diameter is embedded in M20 concrete with τ_{bd} as 1.2 Mpa, as per IS:456–2000. Given that bar is under compression. Then, find development length of the bar if it is provided with 90° bend?
(A) 906 mm (B) 725 mm
(C) 746 mm (D) 565 mm

20. A rectangle RC beam of 300 mm width and 500 mm depth is subjected to maximum factored shear force of 250 kN. The grades of concrete, main steel and stirrup steel are M20, Fe415 and Fe250 respectively. The design shear strength τ_c, as per IS:456 is given as 0.48 N/mm^2. Determine the spacing (in mm) of 2-legged 6 mm vertical stirrups to be provided.
(A) 34.55 mm (B) 102.5 mm
(C) 250 mm (D) 300 mm

21. Match the List I with List II

	List I		List II
P.	Flexure	**1.**	Minimum depth of section
Q.	Shear	**2.**	Longitudinal steel reinforcement
R.	Bond	**3.**	Stirrups
S.	Deflection	**4.**	Anchorage in support

(A) P – 2, Q – 3, R – 4, S – 1
(B) P – 2, Q – 4, R – 3, S – 1
(C) P – 1, Q – 3, R – 4, S – 2
(D) P – 3, Q – 2, R – 1, S – 2

22. Identify the losses considered for the pre-tensioned beams, from the following.
I. Anchorage loss
II. Shrinkage
III. Creep
IV. Relaxation
V. Friction
VI. Elastic shortening
(A) II, III, IV, V only (B) I, II, III, IV, VI only
(C) II, III, IV, VI only (D) I, II, III, V only

23. If the stirrup spacing is equal to 0.75 times the effective depth of an RC beam, then the shear capacity of stirrup steel is equal to
(A) 1.25($fy \cdot A_{sv}$) (B) 1.35($fy \cdot A_{sv}$)
(C) 1.45($fy \cdot A_{sv}$) (D) 1.15($fy \cdot A_{sv}$)
Where fy is yield strength and A_{sv} is cross-sectional area of the stirrup steel.

24. The development length of a deformed reinforcement bar can be expressed as $\left(\frac{1}{K}\right)\left(\frac{\phi\sigma_s}{\tau_{bd}}\right)$. From the IS: 456–2000 the value of K can be calculated as ______.
(A) 4 (B) 1.6
(C) 6.4 (D) 8

Previous Years' Questions

Direction for questions 1 and 2:
A reinforced concrete beam of rectangular cross-section of breadth 230 mm and effective depth 400 mm is subjected to a maximum factored shear force of 120 kN. The grades of concrete, main steel and stirrup steel are M20, Fe415 and Fe250 respectively. For the area of main steel provided, the design shear strength τ_c as per IS:456–2000 is 0.48 N/mm^2. The beam is designed for collapse limit state. **[GATE, 2008]**

1. The spacing (mm) of a 2 – legged 8 mm stirrups to be provided is:
(A) 40 (B) 115
(C) 250 (D) 400

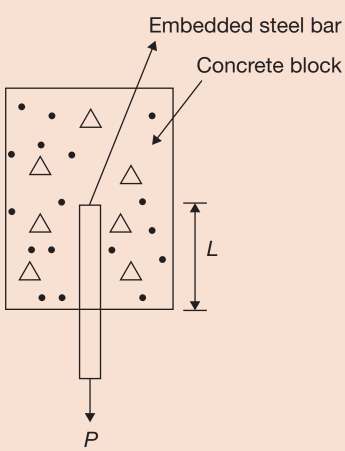
2. In addition, the beam is subjected to a torque whose factored value is 10.90 kN-m. The stirrups have to be provided to carry a shear (kN) equal to
(A) 50.42 (B) 130.36
(C) 151.67 (D) 200.23

3. In the design of a reinforced concrete beam the requirement for bond is not getting satisfied. The economical option to satisfy the requirement for bond is by **[GATE, 2008]**
(A) bundling of bars.
(B) providing smaller diameter bars more in number.
(C) providing larger diameter bars less in number.
(D) providing same diameter bars more in number.

4. Consider two RCC beams, P and Q, each having the section 400 mm × 750 mm (effective depth, d = 750 mm) made with concrete having a $\tau_{c\max}$ = 2.1 N/mm^2. For the reinforcement and the grade of concrete used, it may be assumed that the τ_c = 0.75 N/mm^2. The design shear in beam P is 400 kN and in beam Q is 750 kN. Considering the provisions of IS:456–2000, which of the following statements is TRUE? **[GATE, 2011]**

(A) Shear reinforcement should be designed for 175 kN for beam P and the section for beam Q should be revised.
(B) Nominal shear reinforcement is required for beam 'P' and the shear reinforcement should be designed for 120 kN for beam Q.
(C) Shear reinforcement should be designed for 175 kN for beam 'P' and the shear reinforcement should be designed for 525 kN for beam Q.
(D) The sections for both beams P and Q to be revised.

5. Consider a bar of diameter 'b' embedded in a large concrete block as shown in the adjoining figure, with a pull out force P being applied. Let σ_b and σ_{st}, be the bond strength (between the bar and concrete) and the tensile strength of the bar, respectively. If the block is held in position and it is assumed that the material of the block does not fail, which of the following option represents the maximum value of P? **[GATE, 2011]**



(A) Maximum of $\left(\frac{\pi}{4}D^2\sigma_b\right)$ and $(\pi DL\sigma_{st})$

(B) Maximum of $\left(\frac{\pi}{4}D^2\sigma_{st}\right)$ and $(\pi DL\sigma_b)$

(C) Minimum of $\left(\frac{\pi}{4}D^2\sigma_{st}\right)$ and $(\pi DL\sigma_b)$

(D) Minimum of $\left(\frac{\pi}{4}D^2\sigma_b\right)$ and $(\pi DL\sigma_{st})$

6. As per IS:456–2000 for M20 grade concrete and plain bars in tension the design bond stress τ_{bd} = 1.2 Mpa. Further, IS:456–2000 permits this design bond stress value to be increased by 60% for HYSD bars. The stress in the HYSD reinforcing steel bars in tension, σ_s = 360 Mpa. Find the required development length, L_d, for HYSD bars in terms of the bar diameter, ϕ ________. **[GATE, 2013]**

7. The development length of a deformed reinforcement bar can be expressed as $(1/k)\ (\phi\ \sigma_s/\tau_{bd})$. From the IS:456–2000, the value of k can be calculated as _______. **[GATE, 2015]**

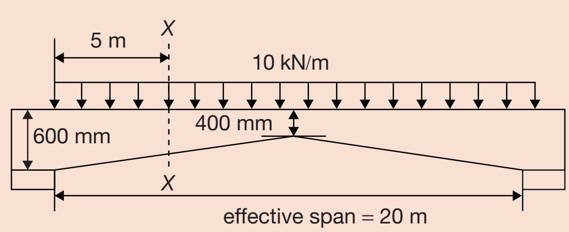
8. In shear design of an RC beam, other than the allowable shear strength of concrete (τ_c), there is also an additional check suggested in IS:456–2000 with respect to the maximum permissible shear stress ($\tau_{c\max}$). The check for $\tau_{c\max}$ is required to take care of **[GATE, 2016]**

(A) additional shear resistance from reinforcing steel
(B) additional shear stress that comes from accidental loading
(C) possibility of failure of concrete by diagonal tension
(D) possibility of crushing of concrete by diagonal compression

9. As per IS:456–2000 for the design of reinforced concrete beam, the maximum allowable shear stress ($\tau_{c\max}$) depends on the **[GATE, 2016]**

(A) grade of concrete and grade of steel.
(B) grade of concrete only.
(C) grade of steel only.
(D) grade of concrete and percentage of reinforcement.

10. A haunched (varying depth) reinforced concrete beam is simply supported at both ends, as shown in the figure. The beam is subjected to a uniformly distributed factored load of intensity 10 kN/m. The design shear force (expressed in kN) at the section X-X of the beam is ______. **[GATE, 2016]**



Answer Keys

Exercises

1. A	**2.** B	**3.** B	**4.** C	**5.** D	**6.** D	**7.** A	**8.** A	**9.** C	**10.** B
11. B	**12.** D	**13.** A	**14.** D	**15.** B	**16.** A	**17.** C	**18.** D	**19.** D	**20.** A
21. A	**22.** C	**23.** D	**24.** C						

Previous Years' Questions

1. B	**2.** C	**3.** B	**4.** A	**5.** C	**6.** 46.87	**7.** 6.4	**8.** D	**9.** B	**10.** 65