GATE – CIVIL ENGINEERING

REINFORCED CEMENT CONCRETE (RCC)

Prof.B.Jayarami Reddy
Professor and Head
Department of Civil Engineering
Y.S.R. Engineering College of
Yogi Vemana University,
Proddatur, Y.S.R.(Dt.), A.P-516360.
E.mail : bjrcivilgate@gmail.com

Design for Shear & Torsion

Prof. B. Jayarami Reddy

What is shear Reinforcement

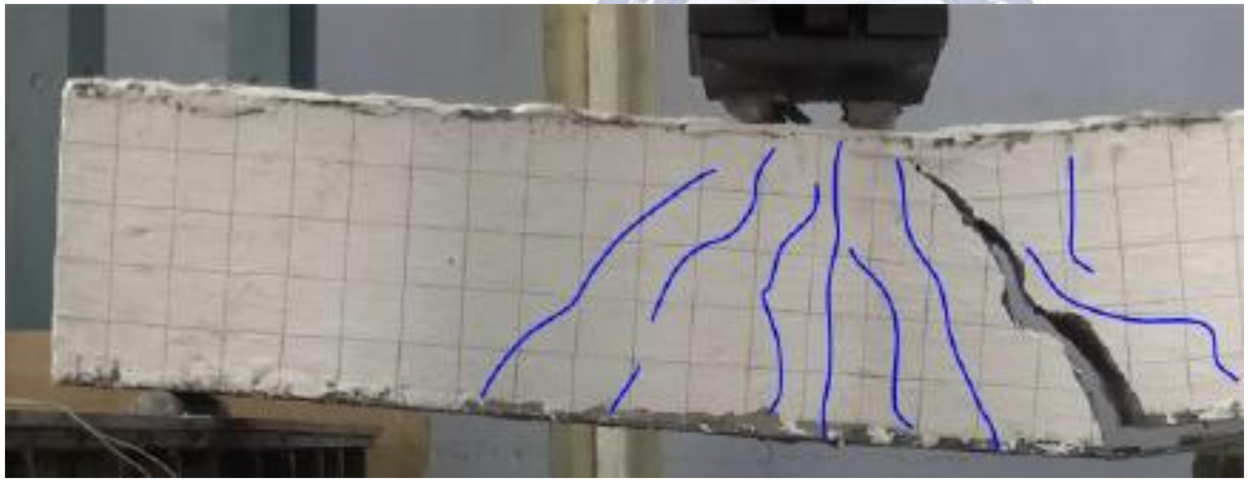
Shear reinforcement, is to provide the resistance against shear forces to which a beam is subjected to and is usually in the form of stirrups which also serve the purpose of holding the main tensile and compression reinforcement in place.

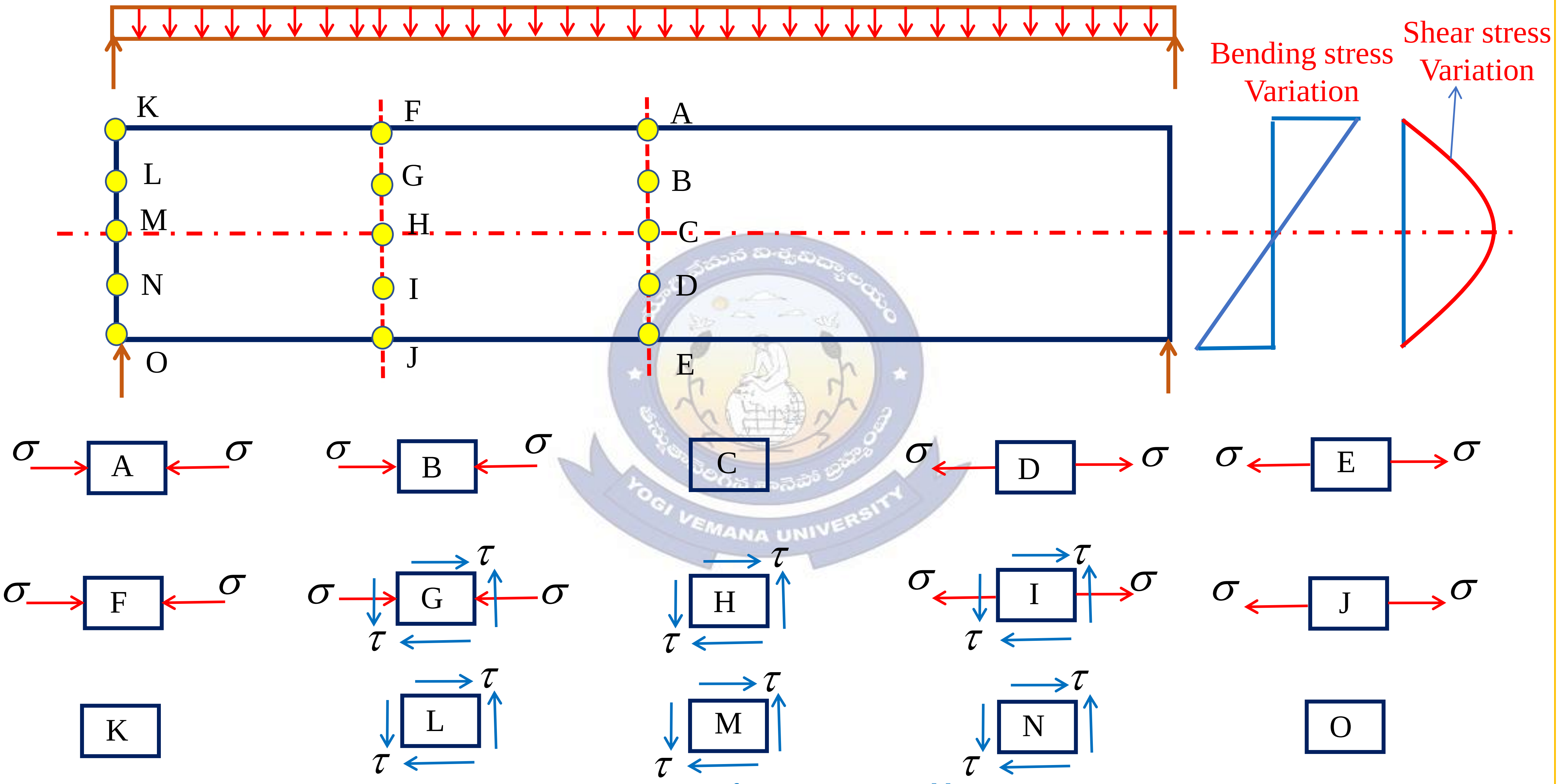
Shear Reinforcement

Prof. B. Jayarami Reddy

Why Shear Reinforcement is required:

- Whenever the value of actual shear stress exceeds the permissible shear stress of the concrete used, the shear reinforcement must be provided.
- The purpose of shear reinforcement is to prevent failure in shear, and to increase beam ductility and subsequently the likelihood of sudden failure will be reduced.





Prof. B. Jayarami Reddy

Principal stress are given by

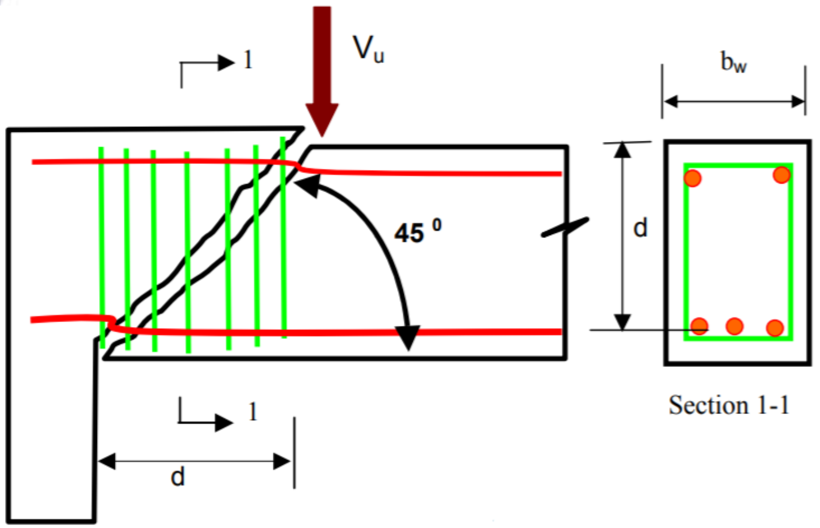
$$\sigma_{1,2} = \frac{\sigma_x + \sigma_y}{2} \pm \frac{1}{2}\sqrt{\left(\sigma_x - \sigma_y\right)^2 + 4\tau^2}$$

$$\sigma_1 = \sigma, \quad \sigma_2 = 0 \quad \tau = \tau$$

$$\sigma_{1,2} = \frac{\sigma}{2} \pm \frac{1}{2}\sqrt{\sigma^2 + 4\tau^2}$$

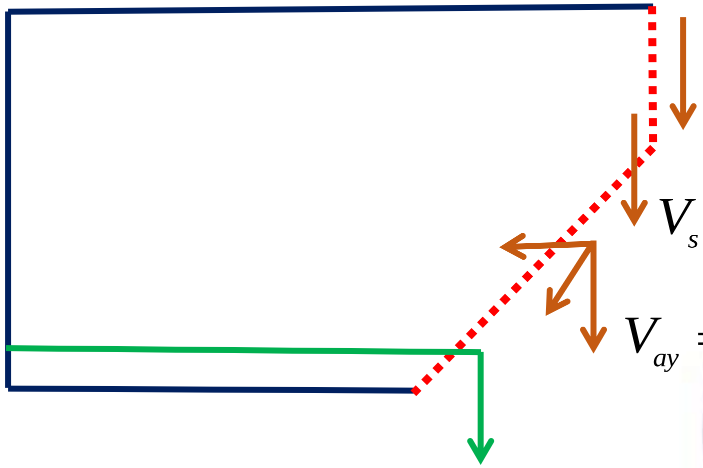
Shear Strength of concrete

- The shear strength (V) of reinforced concrete (RC) beams consists of two parts: Shear resistance of concrete (Vc) and Shear resistance of the transverse reinforcement (Vs).
- One of the main objectives of the design of reinforced concrete beams is safety. Sudden failure due to shear low strength is not desirable mode of failure.
- The reinforced concrete beams are designed primarily for flexural strength and shear strength.
- Beams are structural members used to carry loads primarily by internal moments and shears.



Prof. B. Jayarami Reddy

Shear Resistance of Concrete:



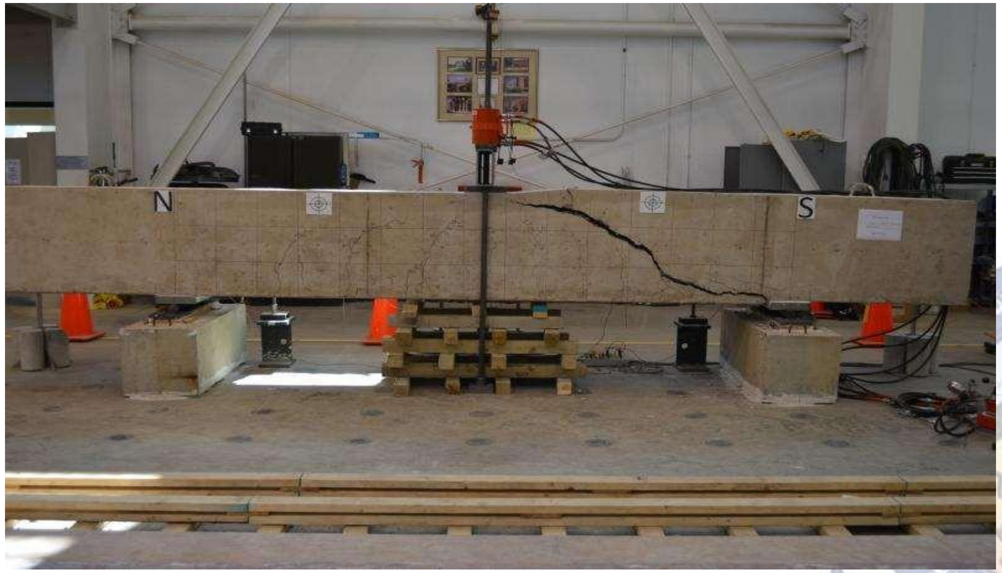
V_{cz} = shear resistance by uncracked portion of concrete

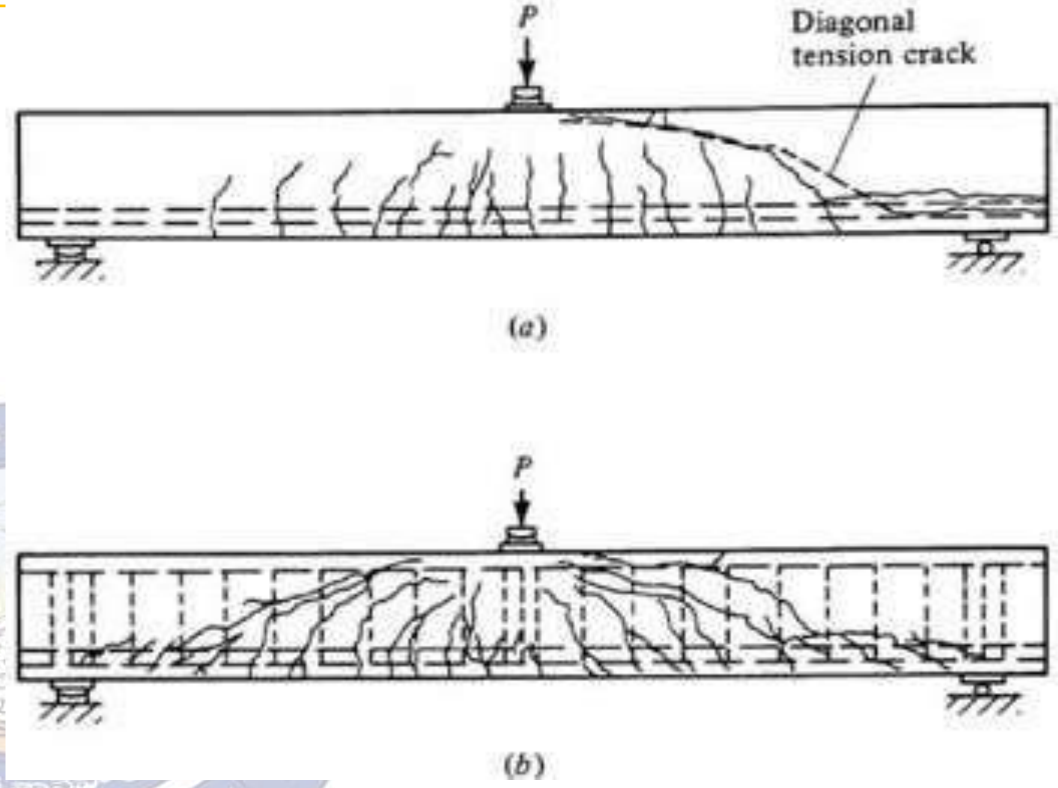
V_s = shear resisted by shear reinforcement

V_{ay} = vertical component of aggregate interlock force

V_d = Dowel force in tension reinforcement

Modes of Cracking in RCC beam



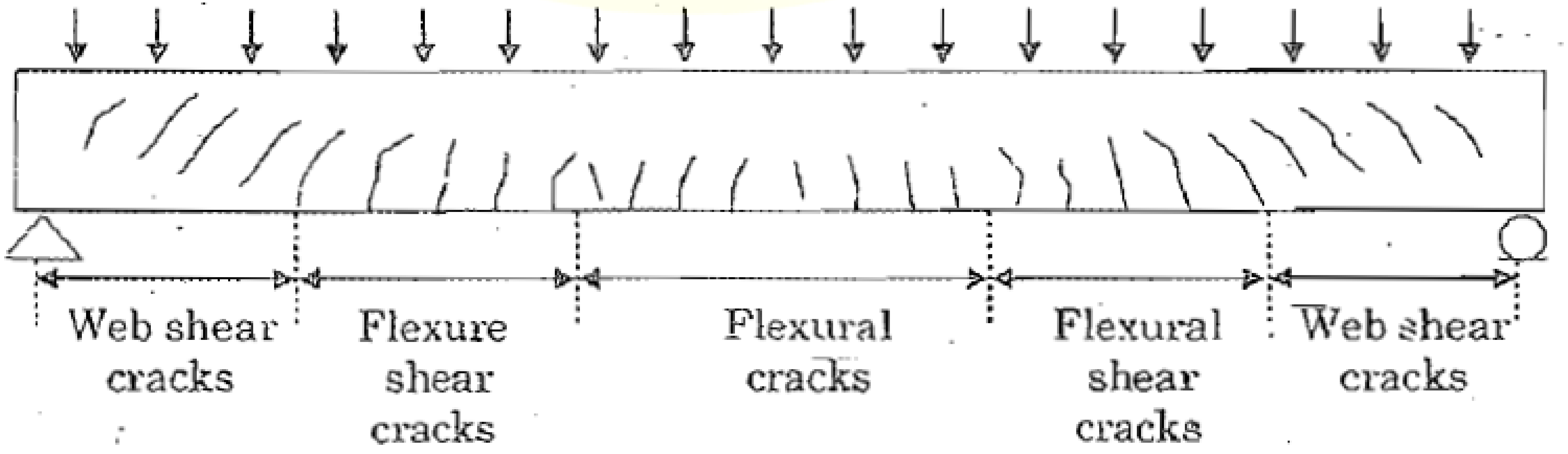


Two types of inclined cracking occur in concrete beams

- Web Shear Cracking
- Flexure – Shear Cracking

Prof. B. Jayarami Reddy

- Web Shear cracking starts from near NA location when the PTS due to shear exceed the tensile strength of concrete. Usually occur in I beams (thin webs)
- Flexure – Shear cracking is an extension of vertical flexural cracking and develops due to combined shear and flexural tensile stresses exceed the tensile strength of concrete.

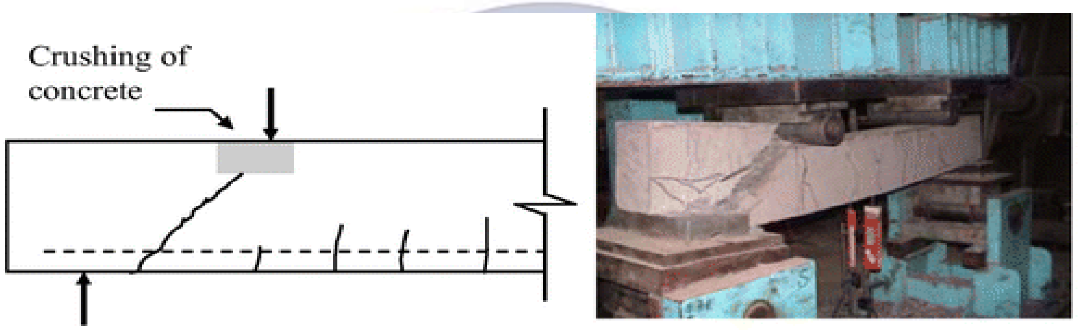


Prof. B. Jayarami Reddy

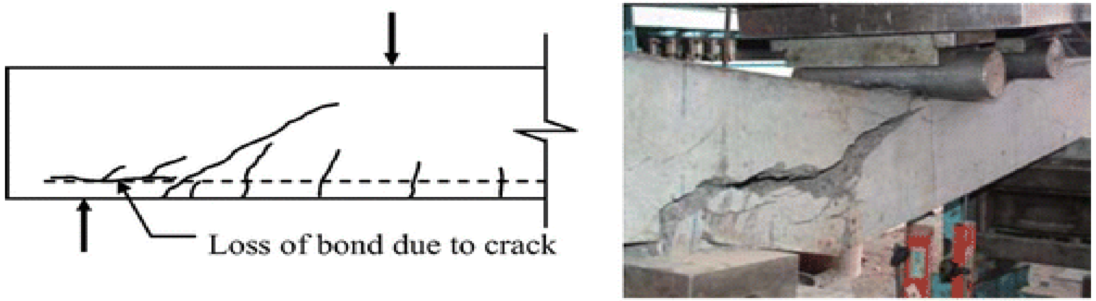
a. Crushing of the reduced concrete section above the tip of the crack under combined shear and compression, termed shear-compression failure

b. Secondary cracking along the tension reinforcement, termed shear -tension failure.

Such failures usually occur before the failure due to moment resisting capacity of beam is exhausted



(a) Shear-compression failure

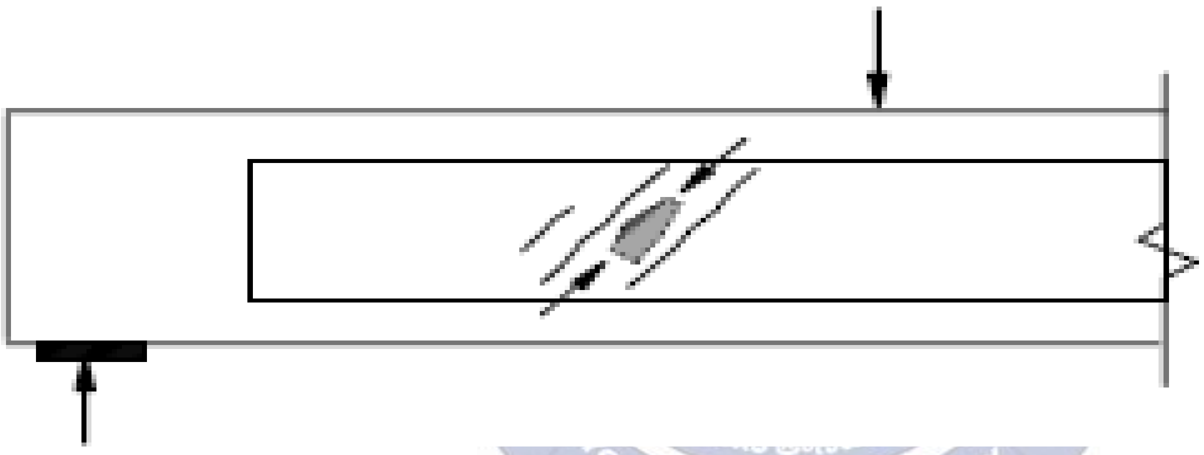


(b) Shear-tension failure

Prof. B. Jayarami Reddy

Web–Crushing Failure

I–beams with web reinforcement may fail by the crushing of concrete in the web portion between the inclined cracks under diagonal compression forces

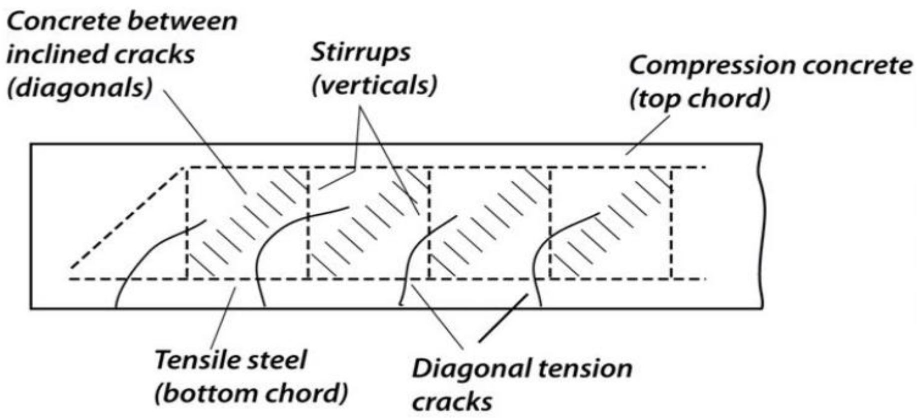


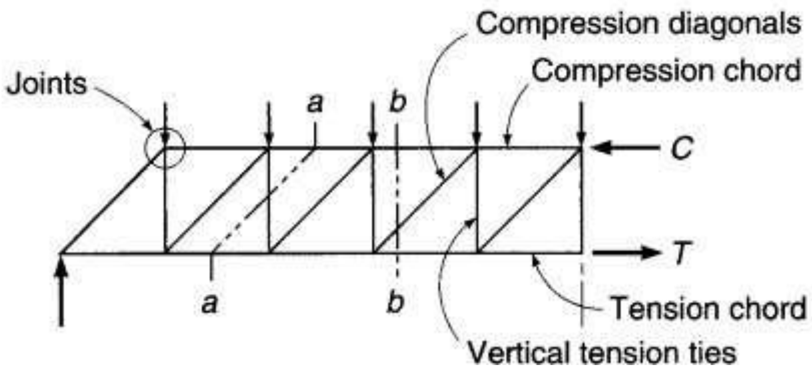
Prof. B. Jayarami Reddy

- Since shear failure is frequently sudden with little or no advanced warning, the design for shear must ensure that the shear strength for every member in the structure exceeds the flexural strength.
- The shear failure mechanism varies depending upon the cross-sectional dimensions, the geometry, the types of loading, and the properties of the member.
- Diagonal cracks are the main mode of shear failure in reinforced concrete beams located near the supports and caused by excess applied shear forces.
- Beams fail immediately upon formation of critical cracks in the high-shear region near the beam supports.
- Normally, the inclined shear cracks start at the middle height of the beam near support at approximately 450 and extend toward the compression zone.
- In reinforced concrete building construction, stirrups are most commonly used as shear reinforcement, for their simplicity in fabrication and installation. Stirrups are spaced closely at the high shear region.
- Bent up bars are also used along with stirrups in the past to carry some of the applied shear forces.

Truss Analogy

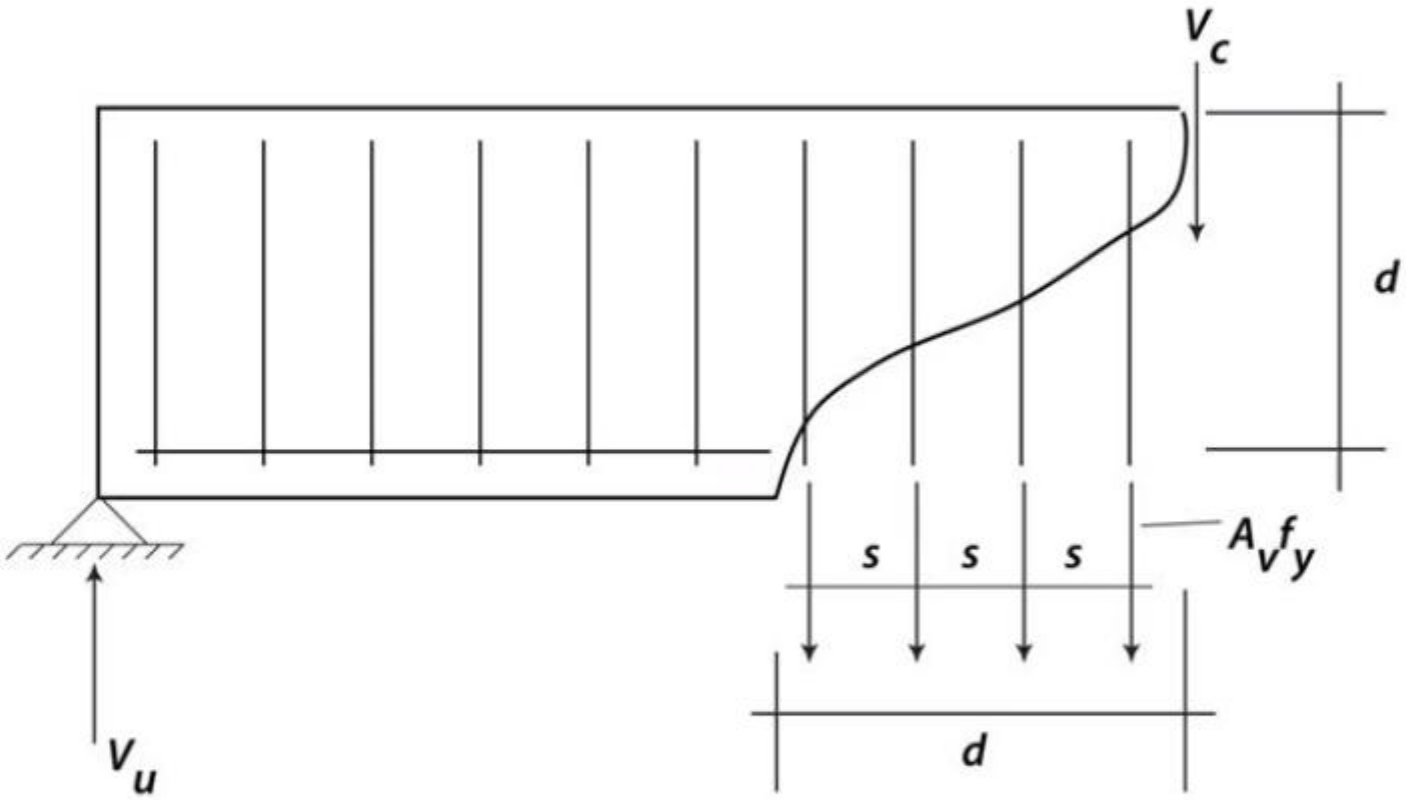
- The Provision of shear reinforcement (i.e. in the form of vertical stirrups, inclined stirrups or bent-up bars) is based on truss analogy.
- In a steel truss under gravity loading, upper and lower chords (i.e. principal rafter and main tie) are in tension and compression respectively.
- The diagonal members/ web members (slings and struts) are alternatively in tension and compression.
- The analogy is that tensile forces in tie members are resisted by shear reinforcement and compression forces in diagonal struts are resisted by concrete.
- The interlinking action between steel and concrete to resist tensile and compressive forces in RCC members is on the principle of truss analogy.





Prof. B. Jayarami Reddy

Design for Shear



Prof. B. Jayarami Reddy

Nominal Shear Stress

The nominal shear stress in beams of uniform depth shall be obtained by the following equation:

$$\tau_v = \frac{V_u}{bd}$$

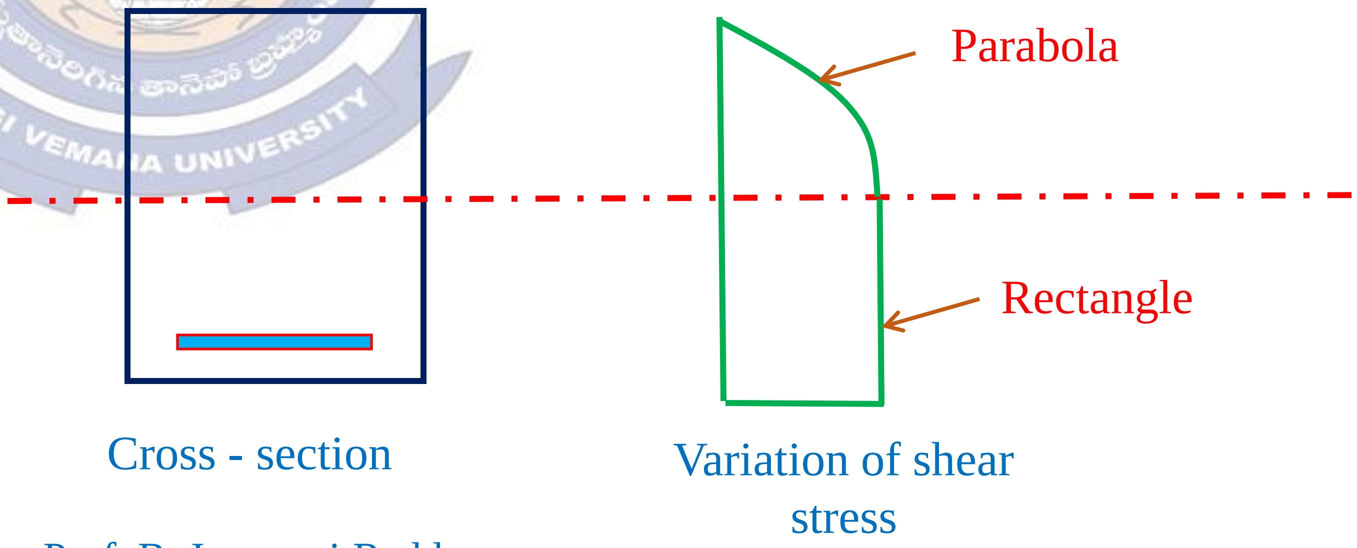
Where,

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, b_w; and

d=effective depth

- For a rectangular concrete beam the shear stress varies parabolically upto neutral axis and after remains constant.

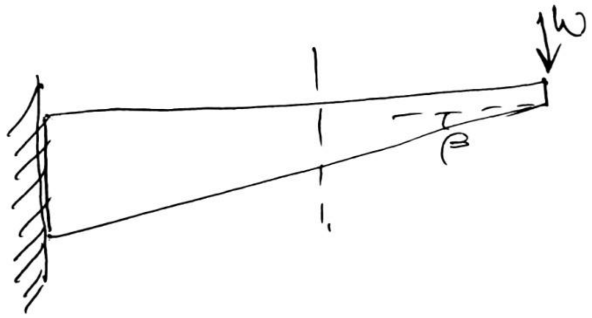


Prof. B. Jayarami Reddy

Beams of Varying Depth

In the case of beams of varying depth the equation shall be modified as:

$$\tau_v = \frac{V_u \pm \frac{M_u}{d}\tan\beta}{bd}$$



← BM increases

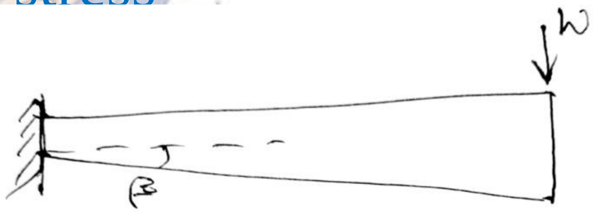
← Depth increases

Where

τ_v, V_u, d and b are the same as in Nominal Shear stress

M_u=bending moment at the section, and

β=angle between the top and the bottom edges



← BM increases

→ Depth increases

The negative sign in the formula applies when the bending moment M_u increases numerically in the same direction as the effective depth d increases, and the positive sign when the moment decreases numerically in this direction.

Design Shear Strength of Concrete

The design shear strength of concrete in beams without shear reinforcement is given in Table 19.

For solid slabs, the design shear strength for concrete shall be $\tau_c.k$, where k has the values given below:

Overall Depth of Slab, mm	300 or more	275	250	225	200	175	150 or less
k	1.00	1.05	1.10	1.15	1.20	1.25	1.30

Shear Strength of Members under Axial Compression

For members subjected to axial compression P_u, the design shear strength of concrete, given in Table 19, shall be multiplied by the following factor:

$$\delta = 1 + \frac{3P_u}{A_g f_{ck}} \text{ but not exceeding } 1.5$$

Where

P_u = axial compressive force in Newtons,

A_g = gross area of the concrete section in mm^2

f_{ck} = characteristic compressive strength of concrete

Prof. B. Jayarami Reddy

If $\tau_v < 0.5\tau_c \Rightarrow$ No shear reinforcement

If $0.5\tau_c < \tau_v < \tau_c \Rightarrow$ Minimum shear reinforcement

If $\tau_c < \tau_v < \tau_{c,\max} \Rightarrow$ Design shear reinforcement

If $\tau_v > \tau_{c,\max} \Rightarrow$ Redesign the section

Factors Affecting Shear strength of concrete:

Shear strength of concrete depends on

- Grade of concrete.
- Percentage of tension steel.
- Size and spacing of Stirrups.
- Cranked bars.

(100 A_s/b d)	Grade of concrete				
	M 20	M 25	M 30	M 35	M40 and above
≤ 0.15	0.28	0.29	0.29	0.29	0.30
0.25	0.36	0.36	0.37	0.37	0.38
0.50	0.48	0.49	0.50	0.50	0.51
0.75	0.56	0.57	0.59	0.59	0.60
1.00	0.62	0.64	0.66	0.67	0.68
1.25	0.67	0.70	0.71	0.73	0.74
1.50	0.72	0.74	0.76	0.78	0.79
1.75	0.75	0.78	0.80	0.82	0.84
2.00	0.79	0.82	0.84	0.86	0.88
2.25	0.81	0.85	0.88	0.90	0.92
2.50	0.82	0.88	0.91	0.93	0.95
2.75	0.82	0.90	0.94	0.96	0.98
≥ 3.00	0.82	0.92	0.96	0.99	1.01

Grade of concrete	M 20	M 25	M 30	M 35	M 40 and above
T_{cmax}, N/mm^2	2.8	3.1	3.5	3.7	4.0

Prof. B. Jayarami Reddy

Design of Shear Reinforcement

When τ_v exceeds τ_c , shear reinforcement shall be provided in any of the following forms:

a. Vertical stirrups,

b. Bent-up bars along with stirrups, and

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 strength of concrete, $V_c = \tau_c.bd$

Shear reinforcement shall be provided to carry a shear, $V_{us} = V_u - V_c$

The strength of shear reinforcement V_{us} shall be calculated as below:

a. For vertical stirrups:

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

Prof. B. Jayarami Reddy

b. For inclined stirrups or a series of bars bent-up at different cross-sections:

$$V_{us} = \frac{0.87 f_y A_{sv} d}{s_v}(\sin\alpha + \cos\alpha)$$

c. For single bar or single group of parallel bars, all bent-up at the same cross-section:

$$V_{us} = 0.87 f_y A_{sv} d \sin\alpha$$

Where

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

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

τ_v=nominal shear stress

τ_c=design shear strength of the concrete

b=breadth of the member or the breadth of the web b_w

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

α = angle between the inclined stirrup or bent- up bar and the axis of the member, not less than 45°, and d = effective depth

Prof. B. Jayarami Reddy

Maximum spacing of shear reinforcement

The maximum spacing of shear reinforcement measured along the axis of the member shall not exceed *0.75d* for vertical stirrups

d for inclined stirrups at 45^0

where *d* is the effective depth of the section under consideration.

In no case shall the spacing exceed 300 mm.

Minimum shear reinforcement

Minimum shear reinforcement in the form of stirrups shall be provided such that:

$$\frac{A_{sv}}{bs_v} \geq \frac{0.4}{0.87\, f_y}$$

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 or breadth of the web of flanged beam, and

f_y=characteristic strength of the stirrup reinforcement in N/mm^2 which shall not be taken greater than 415 N/mm^2 .

Prof. B. Jayarami Reddy

Shear and Torsion
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, $\tau_{ve} = \frac{V_e}{bd}$

The values of τ_{ve} shall not exceed the values of $\tau_{c,\max}$

Prof. B. Jayarami Reddy

If $\tau_{ve} < \tau_c$, minimum shear reinforcement shall be provided.

If $\tau_{ve} > \tau_c$, both longitudinal and transverse reinforcement shall be provided.

Reinforcement in Members Subjected to Torsion

Reinforcement for torsion, when required, shall consist of longitudinal and transverse reinforcement.

Prof. B. Jayarami Reddy

Longitudinal Reinforcement

The longitudinal reinforcement shall be designed to resist an equivalent bending moment

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

M_u = bending moment at the cross- section, and

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

T_u : Torsional moment,

D: Overall depth of the beam   b: Breadth of the beam

If $M_t > M_u$, 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 .

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

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

Where

T_u = torsional moment,

V_u = shear force,

s_v = spacing of the stirrup reinforcement,

b_1 = centre-to-centre distance between corner bars in the direction of the width,

d_1 = centre-to-centre distance between corner bars.

b = breadth of the member,

f_y = characteristic strength of the stirrup reinforcement,

τ_{ve} = equivalent shear stress as specified in 41.3.1, and

τ_c = shear strength of the concrete as per Table 19.

Distribution of torsion reinforcement

When a member is designed for torsion, 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 comers 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.

Design for Shear & Torsion

Numerical Questions

Prof. B. Jayarami Reddy

01. A reinforced concrete rectangular beam of size 300mm×500mm effective is reinforced with 1500mm^2 on tension face and 500mm^2 on compression face. The characteristic strength of concrete and steel are 25MPa and 500MPa respectively. The shear strength of concrete with the percentage of steel reinforcement is shown below

P%	τ_c, N/mm2
0.75	0.57
1.00	0.65
1.25	0.70

It is subjected to a shear force of 200kN at working loads.

a. The shear resisted by concrete is ………

$$p = \frac{100A_{st}}{bd} = \frac{100\times1500}{300\times500} = 1\%$$

$$\text{For } p = 1\%, \tau_c = 0.65\text{N/mm}^2$$

$$V_c = \tau_c.bd = 0.65\times300\times500 = 97.5\text{kN}$$

Prof. B. Jayarami Reddy

b. The shear to be resisted by stirrups is ………

$$V_u = 1.5V = 1.5 \times 200 = 300\text{kN}$$

V_{us} : shear to be resisted by stirrups

$$= V_u - V_c = 300 - 97.5 = 202.5\text{kN}$$

c. Spacing of 8 mm diameter 2 legged vertical stirrups is …………

τ_v : Nominal shear stress

$$= \frac{V_u}{bd} = \frac{300 \times 10^3}{300 \times 500} = 2\text{N/mm}^2$$

For M25 grade concrete $\tau_{c,\,max}$=3.1N/mm^2

$\tau_c < \tau_v < \tau_{c,\max} \Rightarrow$ provide design shear reinforcement

$$V_{us} = \frac{0.87 f_y . A_{sv} . d}{s_v} \Rightarrow 202.5 \times 10^3 = \frac{0.87 \times 500 \times 2 \times 50 \times 500}{s_v} \Rightarrow s_v = 107.4\text{mm}$$

Prof. B. Jayarami Reddy

02. A reinforced concrete rectangular beam of size 300mm×500mm effective is reinforced with 1500mm² on tension face and 500mm² on compression face. The characteristic strength of concrete and steel are 25MPa and 500MPa respectively. The shear strength of concrete with the percentage of steel reinforcement is shown below

P%	**τ_c, N/mm2**
0.75	0.57
1.00	0.65
1.25	0.70

It is subjected to a shear force of 50kN at working loads.

a. spacing of 8mm diameter 2 legged stirrups is………

$$\tau_v = \frac{V_u}{bd} = \frac{1.5\times 50\times 10^3}{300\times 500} = 0.5\text{N/mm}^2$$

$0.5\tau_c < \tau_v < \tau_c \Rightarrow$ provide minimum shear reinforcement

$$\frac{A_{sv}}{b.s_v} \geq \frac{0.4}{0.87 f_y} \Rightarrow \frac{2\times 50}{300\times s_v} \geq \frac{0.4}{0.87\times 500} \Rightarrow s_v \leq 362.5\text{mm}$$

Prof. B. Jayarami Reddy

03. A reinforced concrete rectangular beam of size 300mm×500mm effective is reinforced with 1500mm^2 on tension face and 500mm^2 on compression face. The characteristic strength of concrete and steel are 25MPa and 500MPa respectively. The shear strength of concrete with the percentage of steel reinforcement is shown below

P%	τ_c, N/mm2
0.75	0.57
1.00	0.65
1.25	0.70

It is subjected to a ultimate shear force of 500kN, spacing of 8mm diameter 2 legged stirrups is………

$$\tau_v = \frac{V_u}{bd} = \frac{500 \times 10^3}{300 \times 500} = 3.33\text{N/mm}^2$$

$$\tau_{c,\max} = 3.1\text{N/mm}^2$$

$$\tau_v > \tau_{c,\max} \Rightarrow \text{Redesign the section}$$

Prof. B. Jayarami Reddy

Design for Shear & Torsion

Previous GATE Questions

Prof. B. Jayarami Reddy

01. An RCC beam of rectangular cross section has factored shear of 200 kN at its critical section. Its width *b* is 250 mm and effective depth *d* is 350 mm. Assume design shear strength τ_c of concrete as 0.62 N/mm^2 and maximum allowable shear stress $\tau_{c,max}$ in concrete as 2.8 N/mm^2. If two legged 10 mm diameter vertical stirrups of Fe250 grade steel are used, then the required spacing (in cm, up to one decimal place) as per limit state method will be CE1 2018

Ans. 8.2

Size of RCC beam, b = 250 mm, d = 350 mm.

Factored shear force, V_u= 200 kN

Design shear strength of concrete, τ_c = 0.62 N/mm^2

Maximum allowable shear stress, $\tau_{c,max}$ = 2.8 N /mm^2

Shear reinforcement: 10mm ϕ 2 legged vertical stirrups of grade Fe 250

Spacing of vertical stirrups, S_v = ?

Nominal shear stress, $\tau_v = \frac{V_u}{bd} = \frac{200\times10^3}{250\times350}$ = 2.286N/mm^2.

Prof. B. Jayarami Reddy

$$\tau_c < \tau_v < \tau_{c,\max}$$

The beam is acceptable with design shear reinforcement.

Shear strength of concrete, $V_c = \tau_c.b.d = 0.62 \times 250 \times 350 = 54.25$ kN

Shear to be resisted by vertical stirrups, $V_{us} = V_u - V_c = 200 - 54.25 = 145.75$ kN

Spacing of vertical stirrups is given by

$$V_{us} = \frac{0.87\, f_{y\,ASV}.d}{S_v} \Rightarrow 145.75 \times 10^3 = \frac{0.87 \times 250 \times 2 \times 78.5 \times 350}{S_v}$$

S_v=82mm=8.2cm

Prof. B. Jayarami Reddy

02. As per IS 456:2000 for the design of reinforced concrete beam, the maximum allowable shear stress ($\tau_{c,max}$) depends on the CE2 2016

a. grade of concrete and grade of soil

b. grade of concrete only

c. grade of steel only

d. grade of concrete and percentage of reinforcement.

Ans. b

As per IS:456-2000 for the design of reinforced concrete beam, the maximum allowable shear stress $\tau_{c,max}$ depends on the grade of concrete.

Grade of concrete	N/mm^2
M20	2.5
M25	2.8
M30	3.1

Prof. B. Jayarami Reddy

03. 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 CE1 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

Ans. d

As per IS:456-2000,

The maximum permissible shear stress ($\tau_{c,max}$) check is required to take care of possibility of crushing of concrete by diagonal compression.

If $\tau_v > \tau_{c,max}$, diagonal compression failure occurs in concrete.

04. A rectangular beam of width (b) 230 mm and effective depth (d) 450 mm is reinforced with four bars of 12 mm diameter. The grade of concrete is M 20 and grade of steel is Fe 500. Given that for M 20 grade of concrete the ultimate shear strength, τ_{uc}=0.36N/mm^2 for steel percentage, p=0.25, and τ_{uc}=0.48N/mm^2 for steel percentage, p= 0.5. For a factored shear force of 45 kN, the diameter (in mm) of Fe 500 steel two legged stirrups to be used at spacing of 325 mm, should be CE1 2014

a. 8 b. 10 c. 12 d. 16

Ans. a

Width of beam, b=230mm

Effective depth, d=450mm

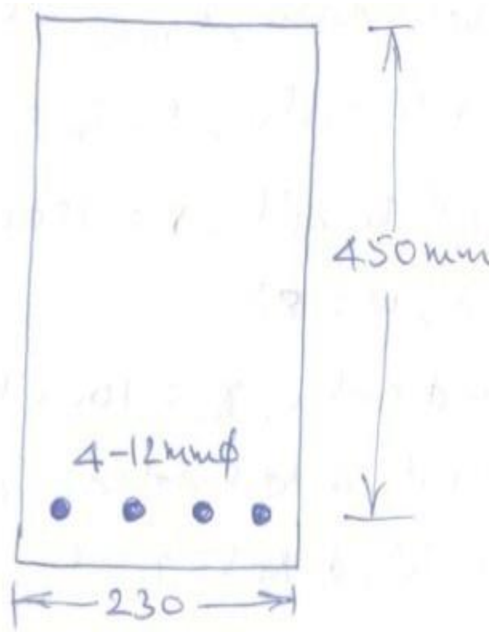
Steel reinforcement = 4 bars of 12 mm ϕ

f_{ck}=20N/mm^2, f_y=500N/mm^2

Shear strength of concrete τ_c = 0.36N/mm^2 for p=0.25%

τ_c= 0.48N/mm^2 for p= 0.5%

Factored shear force, V_u=45kN



Prof. B. Jayarami Reddy

Diameter of stirrups = 8mm

Spacing of 2 legged stirrups, S_v=325mm

Nominal shear stress, $\tau_v = \frac{V_u}{bd} = \frac{45\times10^3}{230\times450} = 0.44\ \text{N/mm}^2$

Percentage of tensile steel reinforcement, $p = \frac{100A_{st}}{bd} = \frac{100\times4\times113}{230\times450} = 0.433\%$

Shear strength of concrete, $\tau_c = 0.36 + \frac{0.48-0.36}{0.50-0.25}(0.433-0.25) = 0.45\ \text{N/mm}^2$

Since $\tau_v < \tau_c$, minimum shear reinforcement is to be provided.

Minimum area of shear reinforcement is given by $\frac{A_{sv}}{b.S_v} \geq \frac{0.4}{0.87\ f_y}$

$$A_{sv} \geq \frac{0.4\times230\times325}{2\times0.87\times500} = 34.35\,\text{mm}^2 \Rightarrow \frac{\pi\phi^2}{4} \geq 34.35 \Rightarrow \phi \geq 6.61\text{mm}$$

05. Consider two RCC beams, P and Q, each having the section 400 mmx750 mm (effective depth, *d*= 750 mm) made with concrete having a $\tau_{c,max}$=2.1 N/mm^2. For the reinforcement provided 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? 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 need to be revised.

Prof. B. Jayarami Reddy

Ans. a

For beams P and Q

Width of beam, b= 400 mm   Effective depth of beam, d= 750 mm

Permissible maximum shear stress, $\tau_{c,max}$ = 2.1N/mm^2

Shear strength of concrete, τ_c= 0.75 N/mm^2

For beam P, design shear = 400 kN

τ_v : Nominal shear stress $= \frac{V}{bd} = \frac{400 \times 10^3}{400 \times 750}$ = 1.33 N/mm^2 $< \tau_{c,\max}$

V_c: Shear strength of concrete = $\tau_c .bd$ = 0.75 × 400 × 700 = 225kN

V_s: Shear to be resisted by steel reinforcement =V-V_c= 400 – 225 = 175 kN

Therefore, the beam P should be designed for shear reinforcement for 175 kN

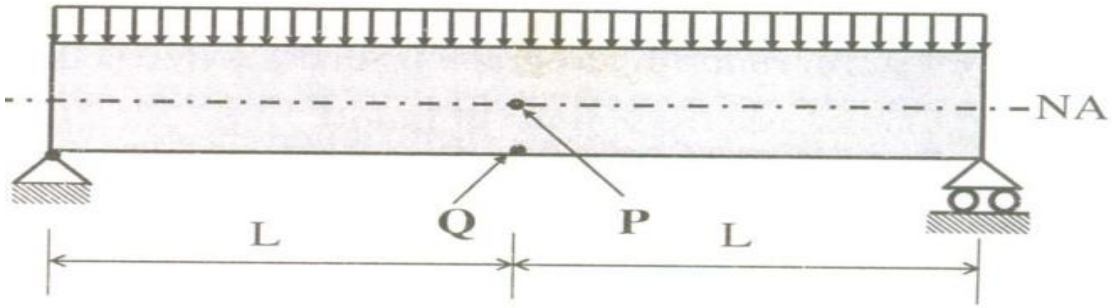
For beam Q, design shear = 750 kN

τ_v :Nominal shear stress $= \frac{V}{bd} = \frac{750 \times 10^3}{400 \times 750}$ = 2.5 N/mm^2 $> \tau_{c,\max}$

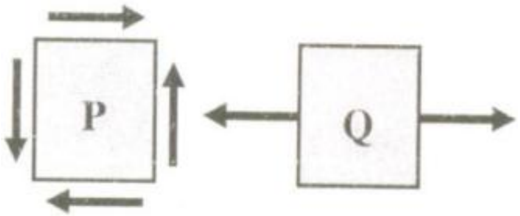
Therefore, the section of the beam Q should be revised.

06. Consider a simply supported beam with a uniformly distributed load having a neutral axis (NA) as shown. For points P (on the neutral axis) and Q (at the bottom of the beam) the state of stress is best represented by which of the following pairs?

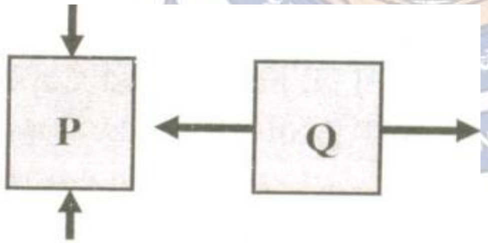
2011



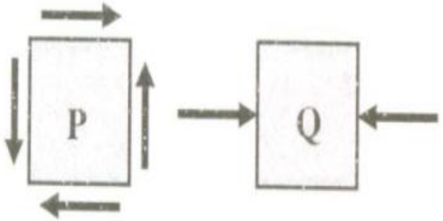
a.



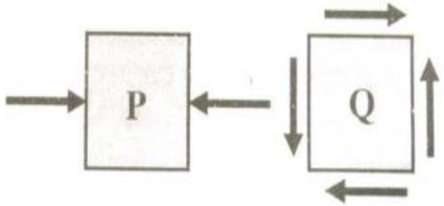
b.



c.



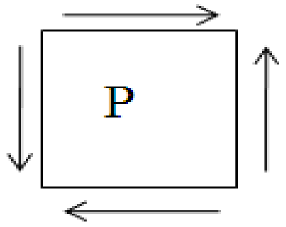
d.



Prof. B. Jayarami Reddy

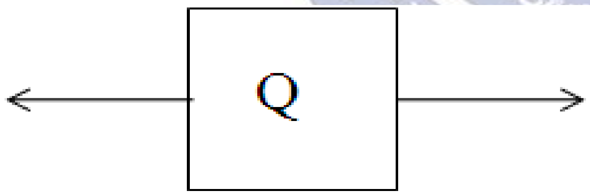
Ans. a Most appropriate answer only

Point P at midspan at NA:



At neutral axis, the bending stress is equal to zero in direction. At neutral axis, the point is subjected to shear stress.

Point Q at bottom of midspan:



The bending stress is maximum and is tensile in nature. The shear stress at the extreme fibre is equal to zero.

Common Data for Questions 07 and 08:

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 grade of concrete, main steel and stirrup steel are M20, F415 and Fe 250 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. 2008

07. The spacing (mm) of 2-legged 8 mm stirrups to be provided is

a. 40 **b.** 115 c. 250 d. 400

Ans. b

Width of rectangular beam, b= 230 m

Effective depth, d= 400 mm

Factored shear force, V_u= 120 kN

Design shear strength, τ_c = 0.48 N/mm^2

Shear resistance of concrete, $V_c = \tau_c.bd$ = 0.48x230x400 = 44.16 kN

Shear to be resisted by stirrups, $V_{us}=V_u-V_c$ = 120 – 44.16 = 75.84 kN

Spacing of 8 mm dia. 2 legged stirrups is given by $s_v = \dfrac{0.87\ f_y\ A_{sv} d}{V_{us}}$

$$= \frac{0.87 \times 250 \times 2 \times 50 \times 400}{75.84 \times 10^3}$$

$$= 114.7 mm \simeq 115 mm$$

Prof. B. Jayarami Reddy

08. In addition, the beam is subjected to a torque whose factored value is 10.90 kNm. The stirrups have to be provided to carry a shear (kN) equal to 2008

a. 50.42 b. 130.56 **c.** 151.67 d. 200.23

Ans. c

Factored torque, T_u= 10.9 kNm

Equivalent shear force, $V_e = V + 1.6\frac{T}{b} = 120 + 1.6 \times \frac{10.9}{0.23} = 195.83\,\text{KN}$

Shear to be resisted by stirrups, $V_{us}=V_u-V_c$ = 195.83 – 44.16 = 151.67 kN

Prof. B. Jayarami Reddy

09. Assuming concrete below the neutral axis to be cracked, the shear stress across the depth of a singly-reinforced rectangular beam section, 2006

a. increases parabolically to the neutral axis and then drops suddenly to zero value.

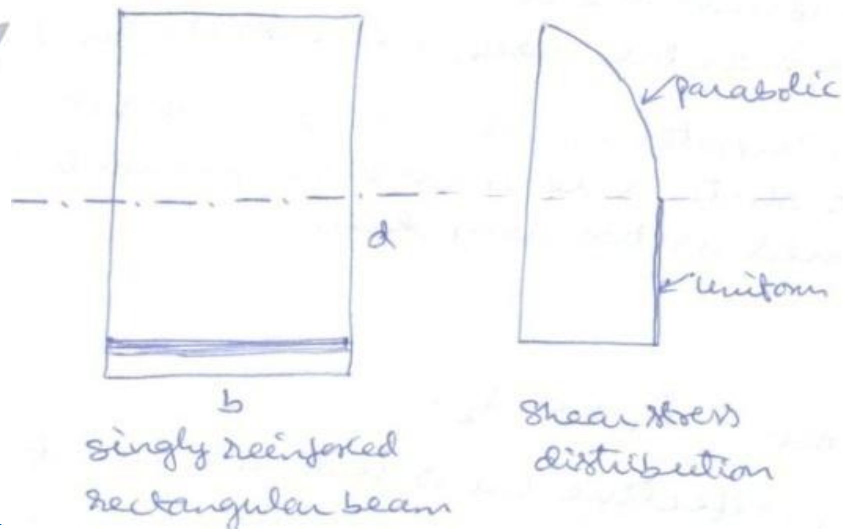
b. increases parabolically to the neutral axis and then remains constant over the remaining depth

c. increases linearly to the neutral axis and then remains constant up to the tension steel

d. increases parabolically to the neutral axis and then remains constant up to the tension steel.

Ans. d

Shear stress across the depth of a singly reinforced rectangular beam section increases parabolically to the neutral axis and then remains constant up to the tension steel.



Prof. B. Jayarami Reddy

Data for Q.10-11 given below. Solve the problems and choose the correct answers.

At the limit state of collapse, an R.C. 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 be lesser than the design shear strength (τ_c) of the concrete. 2004

10. The equivalent shear force (V_c) is

a. 20 kN b. 54 kN c. 56 kN **d.** 68 kN

Ans. d

Factored moment, M_u= 200 kNm Factored shear force, V_u= 20 kN

Factored torque, T_u= 9 kNm Width of beam, b= 300 mm

Overall depth of beam, D= 425 mm

Effective cover = 25 mm

Equivalent shear force, $V_e = V + 1.6\frac{T}{b} = 20 + 1.6 \times \frac{9}{0.3}$ = 20 + 48 = 68 kN

Prof. B. Jayarami Reddy

11. The equivalent flexural moment (M_{eq}) for designing the longitudinal tension steel is

a. 187 kN-m b. 200 kN-m c. 209 kN-m **d.** 213 kN-m

Ans. d

Equivalent flexural moment, $M_{eq} = M + \frac{T}{1.7}\left(1 + \frac{D}{B}\right)$

$$M_{eq} = 200 + \frac{9}{1.7}\left(1 + \frac{425}{300}\right) = 200 + 12.8 = 212.8 \text{kNm} \simeq 213 kNm$$

Prof. B. Jayarami Reddy

12. The state of two dimensional stress acting on a concrete lamina consists of a direct tensile stress, σ_x=1.5N/mm^2,and shear stress τ =1.20 N/mm^2, which cause cracking of concrete. Then the tensile strength of the concrete in N/mm^2 is

a. 1.5 b. 2.08 **c.** 2.17 d. 2.29 2003

Ans. c

Direct tensile stress, σ_x = 1.5 N/mm^2

Shear stress, τ = 1.20 N/mm^2

The major and minor principle stresses are given by

$$\sigma_{1,3} = \frac{\sigma_x + \sigma_y}{2} \pm \frac{1}{2}\sqrt{(\sigma_x - \sigma_y)^2 + 4\tau^2}$$

$$= \frac{1.5}{2} \pm \frac{1}{2}\sqrt{(1.5)^2 + 4(1.2)^2}$$

$$= 0.75 \pm \frac{1}{2}\sqrt{2.25 + 5.76} \quad = 0.75 \pm 1.42$$

$$\sigma_1 = 0.75 + 1.42 = 2.17\ \text{N/mm}^2$$

Prof. B. Jayarami Reddy

01. A rectangular beam is of size 230 mm × 350 mm (effective depth). The factored shear force acting at a section is 80 kN. If the permissible shear stress in concrete is 0.25 MPa, the design shear force is nearly

a. 100 kN b. 80 kN **c.** 60 kN d. 20 kN

1 Ans. c

b = 230 mm, d = 350 mm

$V_u = 80\text{kN} \qquad \tau_c = 0.25\text{MPa} \qquad V_u = ?$

$$\tau_c = \frac{V_u}{bd} \Rightarrow 0.25 = \frac{V_u}{230 \times 350} \Rightarrow V_u = 80\text{kN}$$

Shear strength of concrete, $V_c = \tau_c.b.d = 0.25 \times 230 \times 350 = 20.125\text{kN}$

Shear to be resisted by steel reinforcement, $V_{us} = V_u - V_c$

$$V_{us} = 80 - 20.125 = 59.875\text{kN} \simeq 60\text{kN}$$

Prof. B. Jayarami Reddy

02. As per IS 456-2000, the maximum permissible shear stress, $\tau_{c,\max}$, is based on

a. Diagonal tension failure **b.** Diagonal compression failure

c. Flexural tension failure d. Flexural compression failure

Ans. b

03. In a reinforced concrete section, shear stress distribution is diagrammatically

a. Wholly Parabolic

b. Wholly Rectangular

c. Parabolic above NA and Rectangular below NA

d. Rectangular above NA and Parabolic below NA

Ans. c

04. Consider two RCC beams, P and Q, each of width 400 mm and effective depth 750 mm, made with concrete having $\tau_{c,\max}$ =2.0 MPa. For the reinforcement provided and the grade of concrete used, it may be assumed that $\tau_{c,\max}$ =0.75 MPa. If the design shear for the beams P and Q is 400 kN and 750 kN, respectively, which of the following statements is true considering the provisions of IS 456-2000?

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 as 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 section for beam Q should be designed for 525 kN for beam Q.

d. The section for both beams, P and Q, need to be revised

Ans. a

Ans. A

b = 400 mm   d = 750 mm

$\tau_{c,\max} = 2.0\text{MPa} \quad \tau_c = 0.75\text{MPa}$

For Beam P; $V_u = 80\text{kN}$

$$\tau_c = \frac{V_u}{bd} = \frac{400\times10^3}{400\times750} \Rightarrow V_u = 1.333\text{N/mm}^2$$

$\tau_c < \tau_v < \tau_{c,\max} \Rightarrow$ Design shear reinforcement

$V_c = \tau_c.b.d = 0.75\times400\times750 = 225\text{kN}$

$V_{us} = V_u - V_c = 400 - 225 = 175\text{kN}$

For Beam Q, $V_u = 750\text{kN}$

$$\tau_v = \frac{V_u}{bd} = \frac{750\times10^3}{400\times750} = 2.5\text{N/mm}^2$$

$\tau_v > \tau_{c,\max} \Rightarrow$ Redesign the section

05. If a 2-legged 8 mm diameter HYSD bar is used as shear reinforcement for a beam of with 230 mm and effective depth 300 mm, what is the nearest magnitude of the spacing of minimum shear reinforcement.

a. 420 mm **b.** 390 mm c. 350 mm d. 320 mm

Ans. b

$$b = 230\text{mm}$$

$$d = 300\text{mm}$$

$$A_{sv} : 8\,\text{mm-}2\,\text{legged stirrups}$$

$$f_y = 415\text{N/mm}^2$$

Minimum shear reinforcement is given by

$$\frac{A_{sv}}{b.s_v} \geq \frac{0.4}{0.87 f_y}$$

$$\frac{2 \times 50}{230 \times s_v} \geq \frac{0.4}{0.87 \times 415} \Rightarrow s_v = 392\text{mm}$$

Prof. B. Jayarami Reddy

06. 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 $(f_y A_{sv})$ **b.**1.16 $(f_y A_{sv})$ c. 1.00$(f_y A_{sv})$ d.0.80 $(f_y A_{sv})$

Where f_y is yield strength and A_{sv} is cross-sectional area of the stirrup steel.

Ans. b

$$s_v = 0.75d$$

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

$$= \frac{0.87 f_y . A_{sv} . d}{0.75d} = 1.16 f_y . A_{sv}$$

Prof. B. Jayarami Reddy

07. Assuming the concrete below the neutral axis to be cracked, the shear stress across the depth of a singly reinforced rectangular beam section

a. increases parabolically to the neutral axis and then drops abruptly to zero value.

b. increases parabolically to the neutral axis and then remains constant over the remaining depth.

c. increases linearly to the neutral axis and then remains constant up to the tension steel.

d. increases parabolically to the neutral axis and then remains constant up to the tension steel.

Ans. d

08. In a reinforced concrete section, the shape of the nominal shear stress diagram is

a. parabolic over the full depth

b. parabolic above the neutral axis and rectangular below the neutral axis.

c. rectangular over the full depth

d. rectangular above the neutral axis and parabolic below the neutral axis.

Ans. c

09. If a two-way slab is found to be unsafe in shear, then the preferred remedy is

a. to provide shear stirrups
b. to increase the flexural reinforcement by 15%
c. to increase the thickness of the slab adequately
d. to increase the distribution reinforcement in edge strips.

Ans.c

Prof. B. Jayarami Reddy

10. Shear resistance of concrete in a reinforced concrete beam is dependent on

a. Tension reinforcement in the beam
b. Compression reinforcement in the beam
c. Shear reinforcement in the beam
d. None of the reinforcements in the beam.

Ans. a

11. What is the adoptable maximum spacing between vertical stirrups in an RCC beam of rectangular cross-section having an effective depth of 300 mm?

a. 300 mm b. 275 mm c. 250mm **d.** 225 mm

Ans. d

$$\text{Maximum spaciing for vertical stirrups, } s_v = 0.75d$$

$$= 0.75 \times 300 = 225\text{mm}$$

Prof. B. Jayarami Reddy

12. How can shear strength be ensured in a beam?

a. By providing binding wire on main bars

b. By providing HYSD bars instead of mild steel bars

c. By providing rounded aggregate

d. By providing stirrups

Ans. d

13. An R.C. structural member rectangular in cross section of width b and depth D is subjected to a combined action of bending moment M and torsional moment T. The longitudinal reinforcement sha1l be designed for moment M_e given by

a. $M_e = M + \frac{T\left(1+D/b\right)}{1.7}$ b. $M_e = M + \frac{T\left(1-D/b\right)}{1.7}$ c. $M_e = \frac{T\left(1+D/b\right)}{1.7}$ d. $M_e = \frac{T\left(1-b/D\right)}{1.7}$

Ans. a

14. Shear strength of concrete in a reinforced concrete beam is a function of which of the following:

1. Compressive strength of concrete
2. Percentage of shear reinforcement
3. Percentage of longitudinal reinforcement in tension in the section
4. Percentage total longitudinal reinforcement in the section

Select the correct answer using the code given below

a. l, 2 and 4 b. l, 2 and 3 **c**. only 1 and 3 d. only 1 and 4

Ans. c

Prof. B. Jayarami Reddy

15. Assertion (A): Minimum shear reinforcement in all shallow beams is provided when shear stress exceeds $0.5\tau_c$ (where τ_c is design shear stress).

Reason (R): Minimum shear reinforcement prevents formation of inclined cracks and avoids abrupt failures and introduces ductility in shear.

a. Both A and R are individually true and R is the correct explanation of A

b. Both A and R are individually true but R is not the correct explanation of A

c. A is true but R is false

d. A is false but R is true

Ans. a

16. Assertion (A): In certain special situations, omitting the shear effect deformations can lead to significant errors.

Reason (R): In general, when the bending moments vary along the length of the beams, the shearing stress, resultants will be present and will influence deformation.

a. Both A and R are individually true and R is the correct explanation of A

b. Both A and R are individually true but R is not the correct explanation of A

c. A is true but R is false

d. A is false but R is true

17. Assertion (A): A rectangular element is subjected to pure shear. This will result in cracks along one diagonal and crushing along the other diagonal.

Reason (R): Pure shear on a rectangular element results in tension along one diagonal and compression along the other diagonal.

a. Both A and R are individually true and R is the correct explanation of A

b. Both A and R are individually true but R is not the correct explanation of A

c. A is true but R is false

d. A is false but R is true

18. Assertion (A): Minimum shear reinforcement as stirrups must be provided in beams, even if the shear stress τ_v is less than the shear strength of concrete τ_c.

Reason (R): The bending of beams creates a tendency in the particles to slide upon each other within the beam. This tendency is called shear.

a. Both A and R are individually true and R is the correct explanation of A

b. Both A and R are individually true but R is not the correct explanation of A

c. A is true but R is false

d. A is false but R is true.

Ans. b

19. Minimum shear reinforcement is provided to

a. resist shear force at the support

b. resist shear on account of accidental torsion

c. arrest the longitudinal cracks on side faces due to shrinkage and temperature variation

d. resist shear in concrete developing on account of non-homogeneity of concrete

Ans.c

20. The critical section for computing design shear force in an R.C. beam where the supports exert a compressive reaction is at

a. the centre of support

b. the face of support

c. a distance of half of effective depth from the face of support

d. a distance of effective depth from the face of support

Ans. d

21. Diagonal tension reinforcement is provided in a beam as

a. longitudinal bars

b. bent up bars

c. helical reinforcement

d. 90^0 bend at the bends of main bars

Ans. b

Prof. B. Jayarami Reddy

22. 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 principal tension
d. to resist shear cracks at the bottom of beam

Ans. c

23. A reinforced concrete beam of 10 m effective span and 1m effective depth is supported on 500 mm × 500 mm columns. If the total uniformly distributed load on the beam is 10 MN/m, the design shear force for the beam is

a. 50 MN　　b. 47.5 MN　　**c.** 37.5 MN　　d. 43 MN

Ans. c

Prof. B. Jayarami Reddy

24. The codal provisions recommend minimum shear reinforcement in the form of stirrups in the beams :

1. to cater for any torsion in the beam section
2. to improve ductility of the cross-section
3. to improve dowel action of longitudinal tension bars

Select the correct answer using the codes given below :

a. 1,2 & 3 **b.** 2 & 3 c. Only 1 d. Only 2

Ans. b

25. For a reinforced concrete beam section the shape of the shear stress diagram is

a. parabolic over the whole section with maximum value at the neutral axis
b. parabolic above the neutral axis and rectangular below the neutral axis
c. linearly varying as the distance from the neutral axis
d. dependent on the magnitude of shear reinforcement provided

Ans.b

26. The chances of diagonal tension cracks in R.C.C. member reduce when

a. axial compression and shear force act simultaneously
b. axial tension and shear force act simultaneously
c. only shear force act
d. flexural and shear force act simultaneously

Ans. a

Prof. B. Jayarami Reddy

27. The maximum permissible shear stress $\tau_{c,\max}$ given in BIS 456 is based on

a. diagonal tension failure **b**. diagonal compression failure
c. flexural tension failure d. flexural compression failure

Ans.b

Prof. B. Jayarami Reddy

28. While checking shear resistance of reinforced concrete beams for limit state of collapse as per IS: 456, which one of the following nominal shear stress recommendations is to be adhered to ? (V_u is shear force at vertical cross-section, '*b*' and '*d*' are overall breadth and effective depth of beam respectively)

a. $0.5V_u/bd$ b. $2V_u/5bd$ c. $V_u/0.5bd$ **d.** V_u/bd

Ans. d

Prof. B. Jayarami Reddy

29. Assertion (A): Shear capacity of a concrete beam increases with the increase in tension reinforcement.

Reason (R): Increase in tension reinforcement increases aggregate interlocking force.

a. Both A and R are true and R is the correct explanation of A

b. Both A and R are true but R is NOT the correct explanation of A

c. A is true but R is false

d. A is false but R is true

Ans. a

30. Which one of the following statements is correct?

a. Web shear cracks start due to high diagonal tension in case of beams with their webs and high prestressing force.

b. Shear design for a prestressed concrete beam is based on elastic theory.

c. In the zone where bending moment is dominant and shear is insignificant, cracks occur at 20° to 30°.

d. After diagonal cracking, the mechanism of shear transfer in a prestressed concrete member is very much different from that in reinforced concrete members.

Ans. b

31. 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

Ans. c

32. 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

Ans. a

33. Torsion resisting capacity of a given RC section

a. decreases with decrease in stirrup spacing

b. decreases with increase in longitudinal bars

c. does not depend upon stirrup and longitudinal steel

d. increases with the increase in stirrup and longitudinal steel

Ans. d

Prof. B. Jayarami Reddy