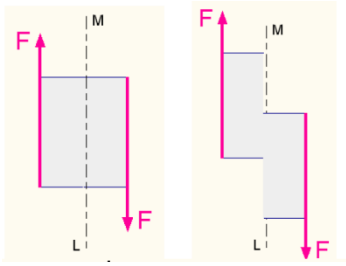
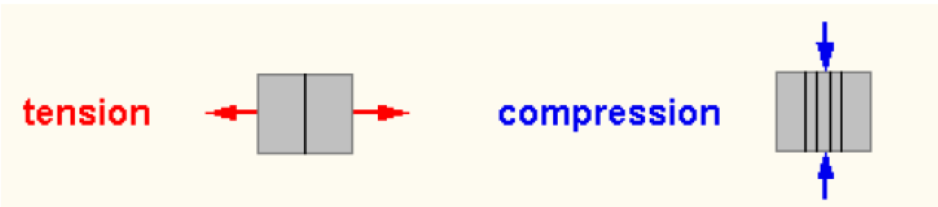
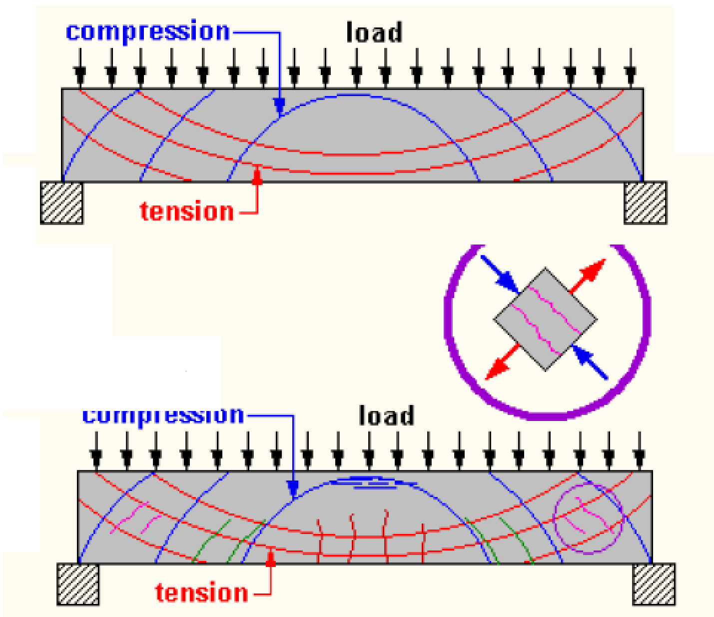
Design of Shear reinforcement in singly reinforced beam

***Shear force:** In case of beam, Shear force at any section is nothing but only the algebraic sum of all vertical forces of one side (either left or right side) from that section.*







According to revised I.S. code

1. **Nominal shear stress (τ_v):** it must be taken by beam safely.

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

   Where, s= shear force due to design load. ($s = \frac{wl}{2}$)

   b= breadth of the section

   d = effective depth of the section.

2. **Permissible nominal shear stress(τ_c):** allowable shear stress which can be safely taken by beam. Its value can be determined by I.S. code 456 (page no 84, Table no 23).

   (value of τ_c are in N/mm^2, for intermediate % of steel use interpolation method)

% STEEL = $\frac{A_{st}}{bd} \times 100$	M 15	M 20	M 25
≤ 0.15	0.18	0.18	0.19
0.25	0.22	0.22	0.23
0.50	0.29	0.30	0.31
0.75	0.34	0.35	0.36
1.00	0.37	0.39	0.40
1.25	0.40	0.42	0.44
1.50	0.42	0.45	0.46

3. **Maximum Nominal shear stress ($\tau_{c\,max}$):** It is the maximum shear stress taken by any grade of concrete. It should never used by concrete for good sake. Its value can be found by using I.S. code 456 (page no 85, Table no 24).

Concrete Grade	M 15	M 20	M 25	M 30
$\tau_{c\,max}$ (N/mm^2)	1.6	1.8	1.9	2.2

4. **Minimum reinforcement in beam:**

$$\frac{A_{sv}}{bs_v} \geq \frac{0.4}{\sigma_y}$$

Where,

$A_{sv} = total\ c/s\ area\ of\ stirrup\ legs\ effective\ in\ shear, (n \times \frac{\pi Ø^2}{4})$

$s_v = spacing\ of\ stirrups\ along\ the\ length\ of\ the\ member\ centre\ to\ centre,$

$b = breadth\ of\ the\ beam,$

$\sigma_y = characteristics\ strength\ of\ the\ stirrup\ reinforcementt\ in\ N/mm^2$

Case arises with τ_v, τ_c & $\tau_{c\,max}$:

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

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

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

CASE 1: $\tau_v < \tau_c < \tau_{c\,max}$

Since in this case value of nominal shear stress (τ_v) is less than the allowable shear stress (τ_c). *so beam is safe in shear and there is no need of shear reinforcements.*
But according to I.S. 456, Minimum Shear Reinforcement should be provided.

$$\frac{A_{sv}}{bs_v} \geq \frac{0.4}{\sigma_y}$$

CASE 2: $\tau_c < \tau_v < \tau_{c\,max}$

Since in this case value of nominal shear stress (τ_v) is greater than the allowable shear stress(τ_c). *so beam is not safe in shear and there is need of shear reinforcements.*

There are two types of sub-cases arise:

Sub-case 1: No bar has been cranked.

$$s_v \leq \frac{A_{sv} \times \sigma_{sv} \times d}{V_s}$$

Where,

$s_v = Spacing\ of\ stirrups\ along\ the\ length\ of\ beam\ centre\ to\ centre.$

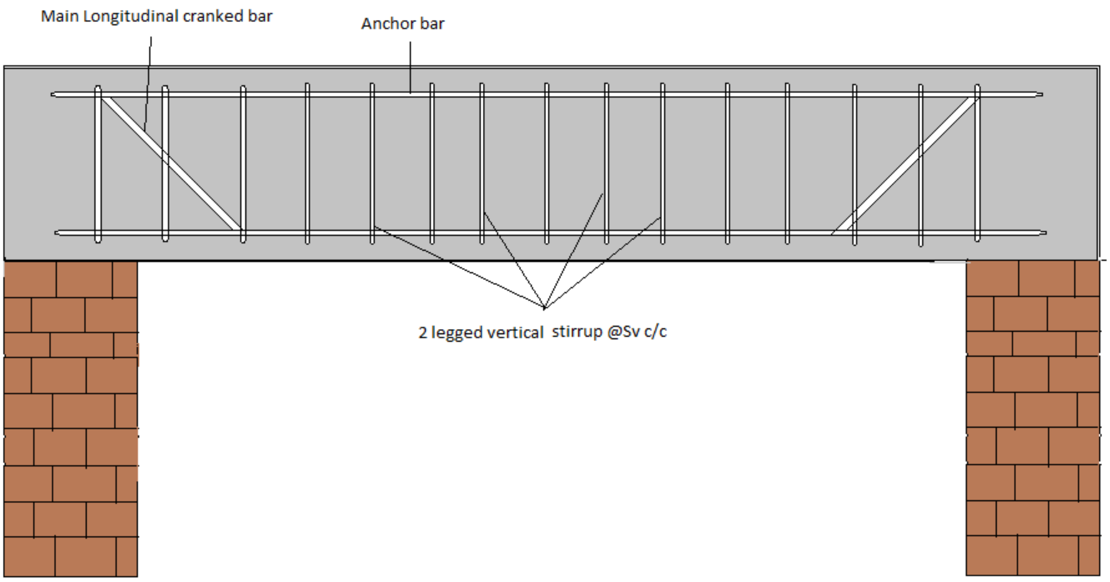
$V_s = (\tau_v - \tau_c)\, b\, d$

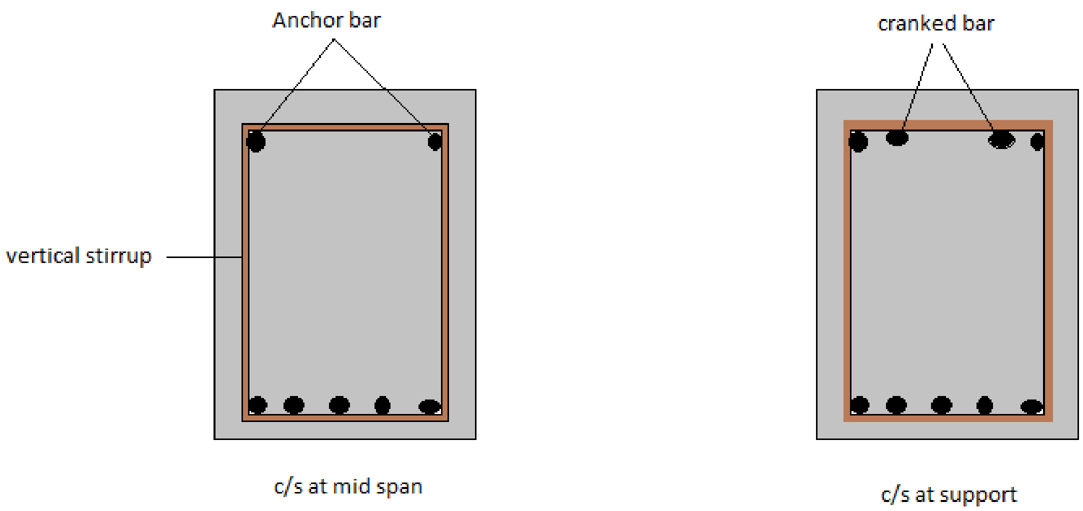
$d = effective\ depth\ of\ the\ beam$

$\sigma_{sv} = permissible\ stress\ in\ stirrup = \sigma_{st}$

$A_{sv} = total\ c/s\ area\ of\ stirrup\ legs\ effective\ in\ shear, (n \times \frac{\pi Ø^2}{4})$

Sub-case 2: Some alternate longitudinal bars have been cranked.





For cranked bar section:

$$s_v \leq \frac{A_{sv} \times \sigma_{sv} \times d}{V_i}$$

$$V_i = V_s - No.of\ bars\ cranked \times \sigma_{sv} \times \frac{\pi Ø^2}{4} \times sin\alpha$$

$$\Rightarrow V_i = V_s - f$$

f should be less than $\frac{V_s}{2}$

If $f > \frac{V_s}{2}$, take it equal to $\frac{V_s}{2}$.

<u>CASE 3:</u> $\tau_c < \tau_{c\,max} < \tau_v$

This type of case is result of wrong design. We have to redesign the beam by changing b and d or changing in concrete & steel grade if possible.

5. Minimum Spacing of stirrups centre to centre :

The spacing of stirrups shall not exceed the following:

I. *300 mm*
II. *0.75 d*
III. $s_v \leq \frac{0.87\,\sigma_{ck}}{0.4}\,\frac{A_{sv}}{b}$

Example 1: An R.C. beam of span 5 m is 250 mm wide and 500 mm deep to the centre of tensile reinforcement, which consist of 4 bars of 22 mm diameter. The beam carries a load of 30 KN/m inclusive of its weight. Design the shear reinforcement by stirrups. Use M_{20} concrete and Fe_{415} steel.

Sol^n: Given data:

$l = 5\,m$

$b = 250\,mm$

$d = 500\,mm$

$A_{st} = n \times \frac{\pi}{4}\,\text{Ø}^2 = 4 \times \frac{\pi}{4}\,22^2 = 1520\,mm^2$

$w = 30\,KN/m$

Max^m shear force in SSB, $s = \frac{wl}{2} = \frac{30\times5}{2} = 75\,KN$

Nominal Shear Stress, $\tau_v = \frac{s}{bd} = \frac{75\times10^3}{250\times500} = 0.60\,N/mm^2$

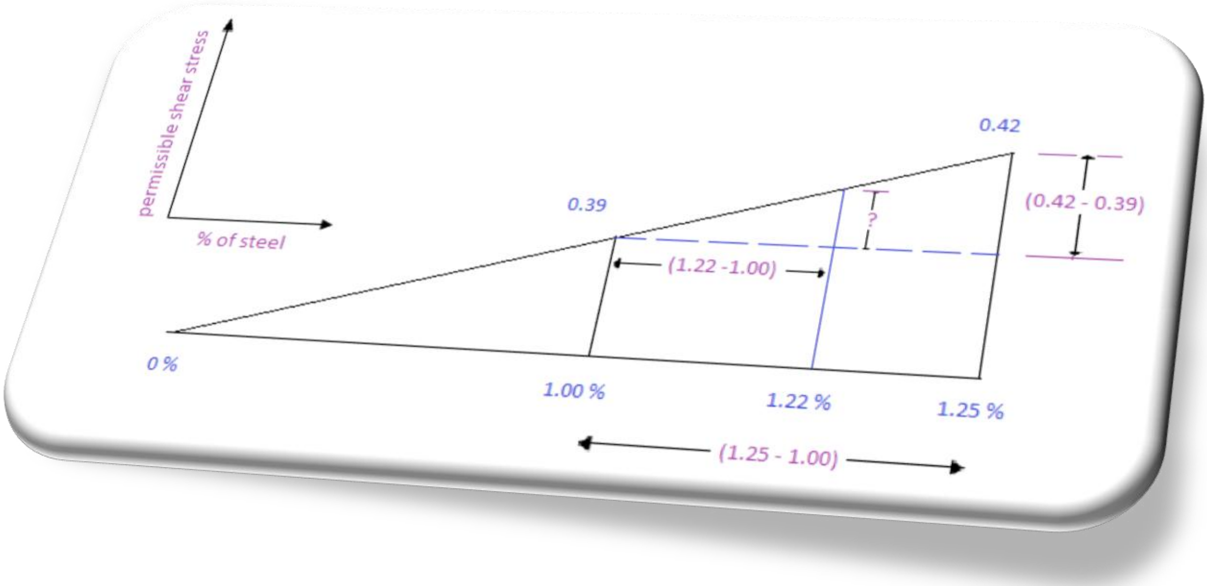
Percentage of steel provided$= \frac{A_{st}}{bd} \times 100 = \frac{1520}{250\times500} \times 100 = 1.22\%$

From I.S. 456, (page no 84, Table no 23).

For M_{20} grade of concrete and 1.22% steel,

Since for 1.22% steel value of permissible stress (τ_c) is not given so we will find out by using Interpolation formula.

% of steel	Permissible shear stress (τ_c)
1.00	0.39
1.25	0.42



By using interpolation formula:

$$\tau_c = 0.39 + \frac{(1.22-1.00)}{(1.25-1.00)} \times (0.42 - 0.39) = 0.416\ N/mm^2$$

Now from I.S. code 456 (page no 85, Table no 24),

$\tau_{c\,max} = 1.8\ N/mm^2$, for M_{20} concrete

Now comparing values, it is clear that;

$\tau_c < \tau_v < \tau_{c\,max}$, Hence need to provide shear reinforced.

Let us provide 2 legged 8 mm Ø stirrups.

$\therefore A_{sv} = 2 \times \frac{\pi}{4} \times 8^2 = 100\ mm^2$

Since there is no any bar cranked so spacing of stirrups c/c;

$$s_v \le \frac{A_{sv} \times \sigma_{sv} \times d}{V_s} = \frac{100 \times 230 \times 500}{(0.60 - 0.416) \times 250 \times 500} = 500\ mm$$

Spacing of stirrups shall not exceed the following:

I. *300 mm*
II. *0.75 d = 0.75 x 500 = 375 mm*
III. $s_v \le \frac{0.87\ \sigma_{ck}}{0.4} \frac{A_{sv}}{b} = 361\ mm$

So , provide 2 legged stirrups @ 300 mm c/c.

Example 2: An R.C. beam of span 6.50 m is 300 mm wide and 750 mm deep to the centre of tensile reinforcement which consist of 6 bars of 20 mm diameters. The beam carries a load of 45 KN/m including its weight. Design the shear reinforcement if 50 % of the tensile reinforcement is curtailed near the support. Use M_{20} concrete and Fe_{415} steel.

Sol^n: Given data:

l = 6.50 m

b = 300 mm

d = 750 mm

$A_{st} = 6 \times \frac{\pi}{4} \times 20^2 = 1884.955\ mm^2$

W = 45 KN/m

50 % tensile reinforcement is curtailed.

So area of steel at supports, A'_{st}= 50 % of A_{st} = 942 mm^2

$$\text{Max}^m \text{ shear force in SSB, } s = \frac{wl}{2} = \frac{45\times 6.50}{2} = 146.25\ KN$$

$$\text{Nominal Shear Stress, } \boldsymbol{\tau_v} = \frac{s}{bd} = \frac{146.25\times 10^3}{300\times 750} = 0.65\ N/mm^2$$

$$\text{Percentage of steel at support} = \frac{A'_{st}}{bd} \times 100 = \frac{942}{300\times 750} \times 100 = 0.42\%$$

From I.S. 456, (page no 84, Table no 23).

For M_{20} grade of concrete and 0.42 % steel,

Since for 0.42% steel value of permissible stress (τ_c) is not given so we will find out by using Interpolation formula.

% of steel	Permissible shear stress ($\boldsymbol{\tau_c}$)
0.25	0.22
0.50	0.30

By using interpolation formula:

$$\boldsymbol{\tau_c} = 0.22 + \frac{(0.42-0.25)}{(0.50-0.25)} \times (0.30 - 0.22) = 0.27\ N/mm^2$$

Now from I.S. code 456 (page no 85, Table no 24),

$$\boldsymbol{\tau_{c\,max}} = 1.8\ N/mm^2 \text{ , for } M_{20} \text{ concrete}$$

Now comparing values, it is clear that;

$$\tau_c < \tau_v < \tau_{c\,max} \text{ , Hence need to provide shear reinforced.}$$

Let us provide 2 legged 8 mm Ø stirrups.

$\therefore A_{sv} = 2 \times \frac{\pi}{4} \times 8^2 = 100\ mm^2$

Spacing of stirrups c/c;

$$\boldsymbol{s_v} \leq \frac{\boldsymbol{A_{sv}} \times \boldsymbol{\sigma_{sv}} \times \boldsymbol{d}}{\boldsymbol{V_s}} = \frac{100 \times 230 \times 750}{(0.65 - 0.27) \times 300 \times 750} = 201.75\ mm$$

Spacing of stirrups shall not exceed the following:

I. *300 mm*
II. *0.75 d = 0.75 x 750 = 562.5 mm*
III. $s_v \leq \frac{0.87\ \sigma_{ck}}{0.4} \frac{A_{sv}}{b} = 300.875\ mm$

So , provide 2 legged stirrups @ 300 mm c/c.