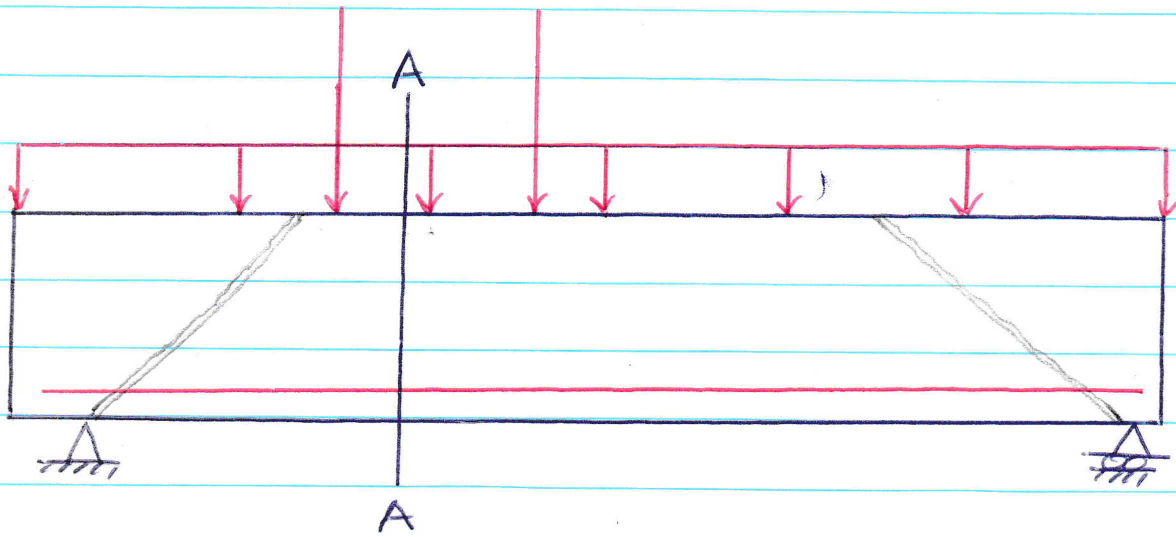
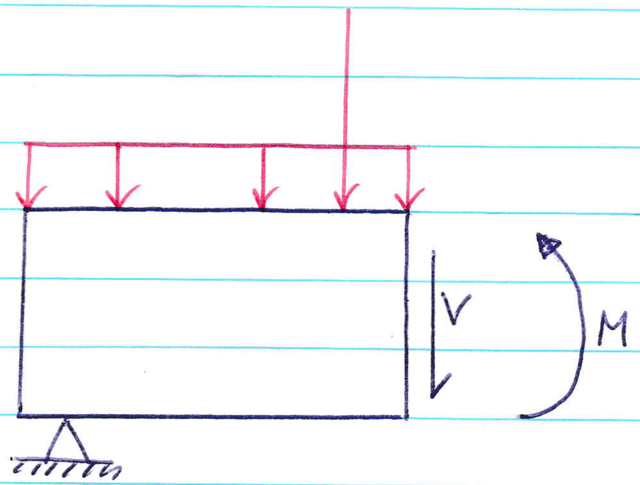
Dr. Jamal Zalatimo

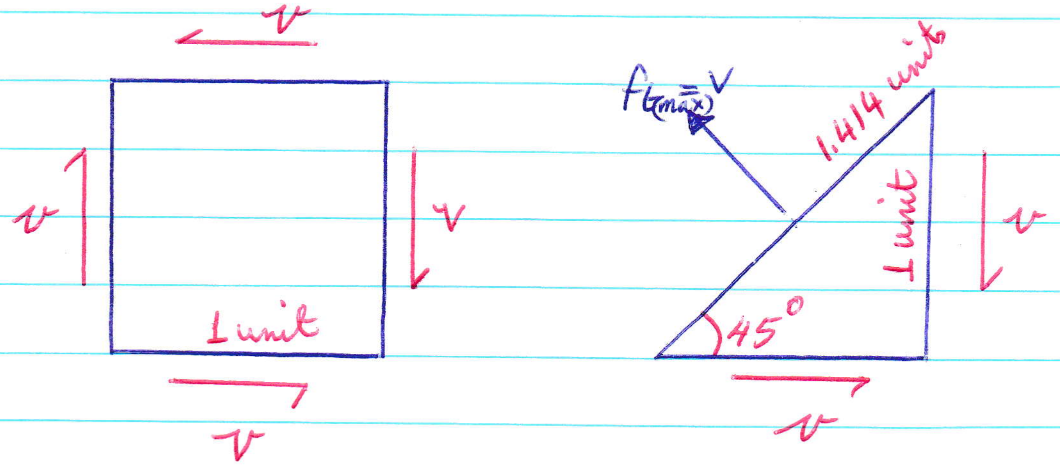
Shear Strength and Shear Reinforcement





For vertical force equilibrium, the summation of the vertical shear stresses on the face of the section must be equal to the internal Shear force V acting on the face (V is a result of the external applied loads).

Below the neutral axis there is nearly a state of pure shear since concrete cannot support tensile stresses without cracking at a relatively low stress.



for equilibrium :

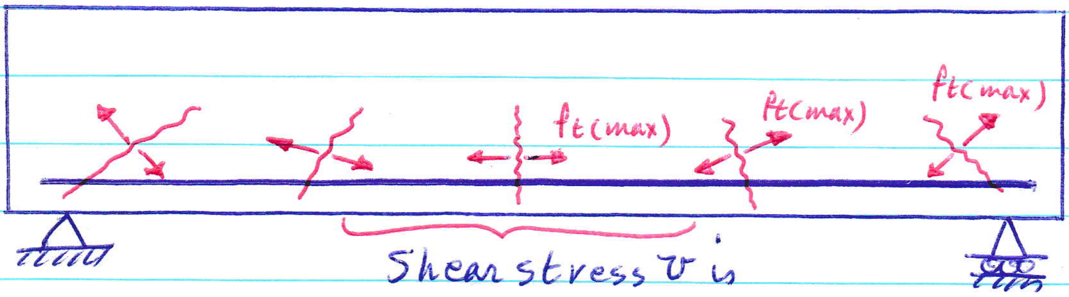
$$2\,(v)(1)(\cos 45) = (f_t)(1.414)$$

$$\therefore f_t = v$$

∴ The resulting tensile stress is equal to the shear stress v.

This diagonal tension constitutes the main cause of <u>inclined cracking</u> in the tension zone.

Directions of Potential Cracks in a Simply Supported Beam:



$f_t(max) \approx$ longitudinal tensile stress f_t, and its direction is nearly horizontal

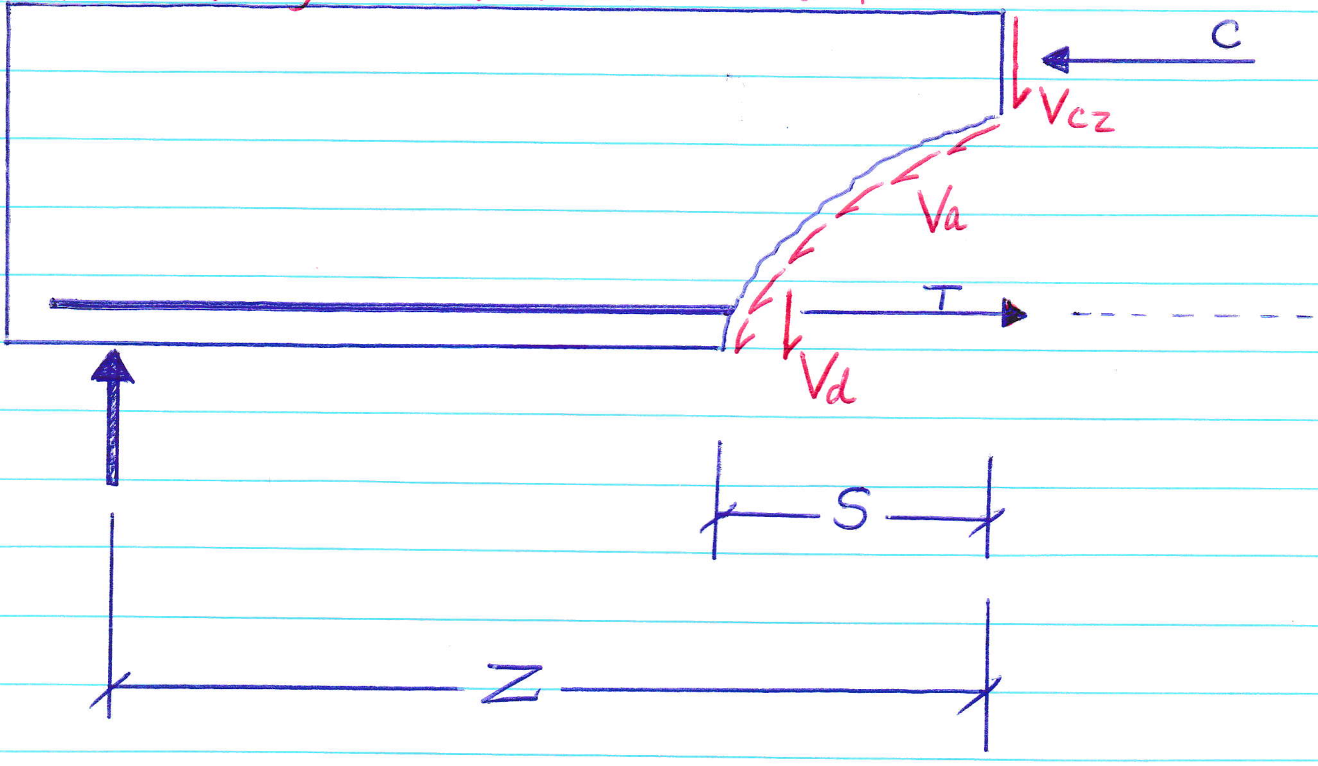
longitudinal tensile stress f_t is small

$f_t(max) \approx$ shear stress v, and its direction is nearly at 45°

Transfer of Shear

Transfer of shear in reinforced concrete members occurs by a combination of the following mechanisms:

Note: The ability of a beam to carry additional load after an inclined crack has formed depends on the ability of the beam to redistribute the shear force across the inclined crack and the rest of the x-section as follows:



1) Shear resistance of the uncracked concrete, Vcz.

2) Aggregate interlock (interface shear) force Va – which is similar to a frictional force.

3) Dowel action, Vd – the resistance of the longitudinal reinforcement to a transverse force.

4) Arch action (deep beams).

5) Shear reinforcement resistance, Vs.

∴ Shear tends to cause inclined cracks.

When no shear reinforcement is used, Failure Possibilities:

1) No inclined cracks form: The nominal flexural strength determines the capacity of the beam.

2) Inclined crack forms: a "diagonal tension failure" and the shear strength of the beam is assumed to be reached, i.e., shear strength determines the capacity of the beam.

Shear Strength of Beams Without Shear Reinforcement:

The strength at which an inclined crack (usually a flexure - shear crack) forms is taken to be the shear strength of a beam without shear reinforcement.

$$V_c = \frac{1}{6}\sqrt{f'_c}\, b_w d = 0.17\sqrt{f'_c}\, b_w d$$

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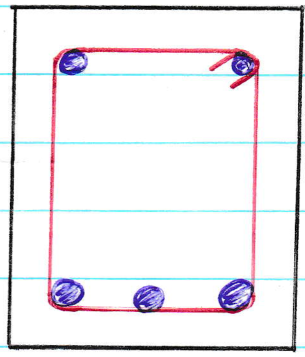
with f'_c in MPa, b_w, d in mm, and $\sqrt{f'_c} \leq 8.3$ MPa ACI

for members subject to shear and flexure only.

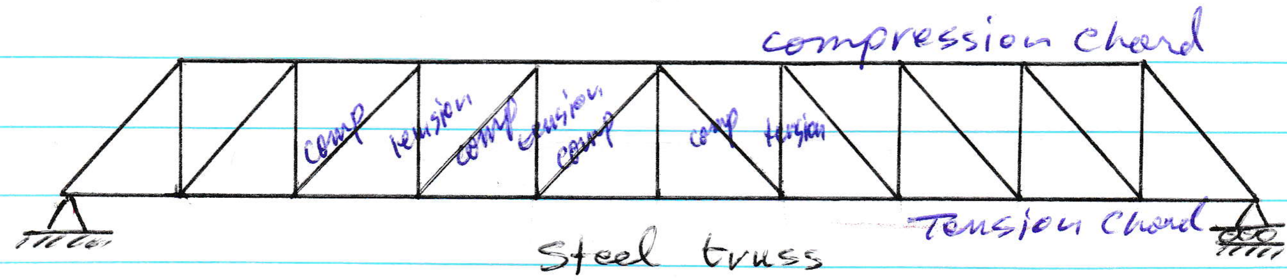
Function of Shear Reinforcement

1) Vertical stirrups

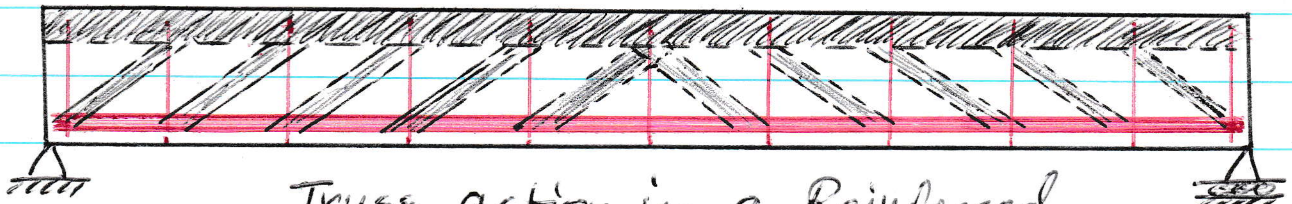
2) Bent bars (longitudinal reinforcement).



the truss model:



Steel truss



Truss action in a Reinforced Concrete Beam

* Compressive forces carried by concrete.
* Steel reinforcement carries the tensile forces.

Shear reinforcement functions:

1) Carry part of the shear load once an inclined crack has formed (V_s).

2) Restrict the growth of the inclined

crack and thus help maintain aggregate interlock (interface shear transfer) (V_a).

3) Tie the longitudinal bars in place and thereby increase their strength (V_d) in dowel action.

* If the amount of shear reinforcement is too little, it will yield immediately at the formation of an inclined crack and the beam fails.

* If the amount is too much, there will be a shear-compression failure without the yielding of the shear reinforcement.
(a flexure-shear crack: an inclined crack originating at the top of and becoming an extension to a previously existing flexural crack. After the flexure-shear crack develops, it extends further into the compression zone as the load increases, eventually crushing failure in the concrete near the compression face may take place, this is a "Shear-compression" failure).

* The optimum amount is when shear reinforcement and the compression zone both continue to carry increasing shear after the formation of the inclined crack until the shear reinforcement yields (ductile failure).

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$$Av_{min} = 0.062\sqrt{f'_c}\,\frac{b_w s}{f_y} \geq 0.35\,\frac{b_w s}{f_y}$$

$\Longrightarrow$

strength:

$$S_{max} = \frac{(A_v)(f_y)}{0.062\sqrt{f'_c}\,b_w}$$

$$\leq \frac{(A_v)(f_y)}{0.35\,b_w}$$

geometry:

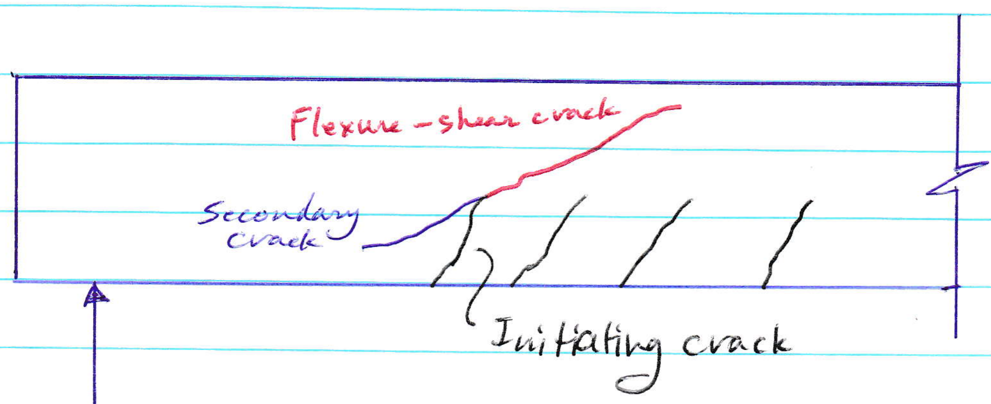
$$\leq \frac{d}{2} \qquad \frac{d}{4}$$

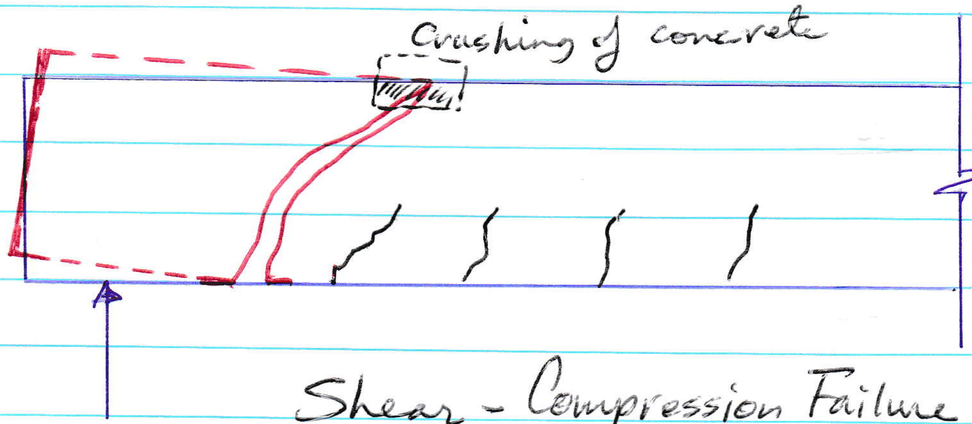
$$\leq 60\ cm \qquad 30\ cm$$

Smallest

$$\Longrightarrow V_{s\,min} = \frac{A_v f_y d}{s}$$

for the selected Av, then s.





Shear-Compression Failure

Shear Strength of Beams with Shear Reinforcement:

$V_n = V_c + V_s$ ACI

$V_s = (A_v f_y d)/s$ ACI

(Min. Reinforcement) (min) A_v = ACI

$A_{v_{min}} = 0.062\sqrt{f_c'}\,\dfrac{b_w s}{f_y} \geq 0.35\, b_w s / f_y$ (MPa)

s = spacing of shear reinforcement, A_v in mm^2

b_w, s in mm

f_y in MPa

ACI Code Provisions for Shear Strength

$$\phi V_n \geq V_u \qquad \phi = 0.75 \text{ ACI}$$

$$V_n = V_c + V_s$$

$$V_c = \frac{\sqrt{f'_c}\, b_w\, d}{6}$$

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$V_c = 0.17\lambda\sqrt{f'_c}\, b_w d$

$$V_s = \frac{A_v f_y d}{s}$$

Design Categories:

I. $V_u \leq (0.5)(\phi V_c)$

in this category, no shear reinforcement is required ← ACI

II. $0.5\phi V_c < V_u \leq \phi V_c$

minimum shear reinforcement is required except for:

a) slabs and footings.
b) floor joist construction.
c) beams with total depth ≤ 25 cm, $2\frac{1}{2} t_f$, $\frac{1}{2} b_w$, (t_f = flange thickness) whichever

III. $\phi V_c < V_u \leq \phi V_c + \phi V_{s\,min}$

Minimum shear reinforcement is required.

No exceptions.

IV. $\phi V_c + \phi V_{s\,min} < V_u < 3\phi V_c$

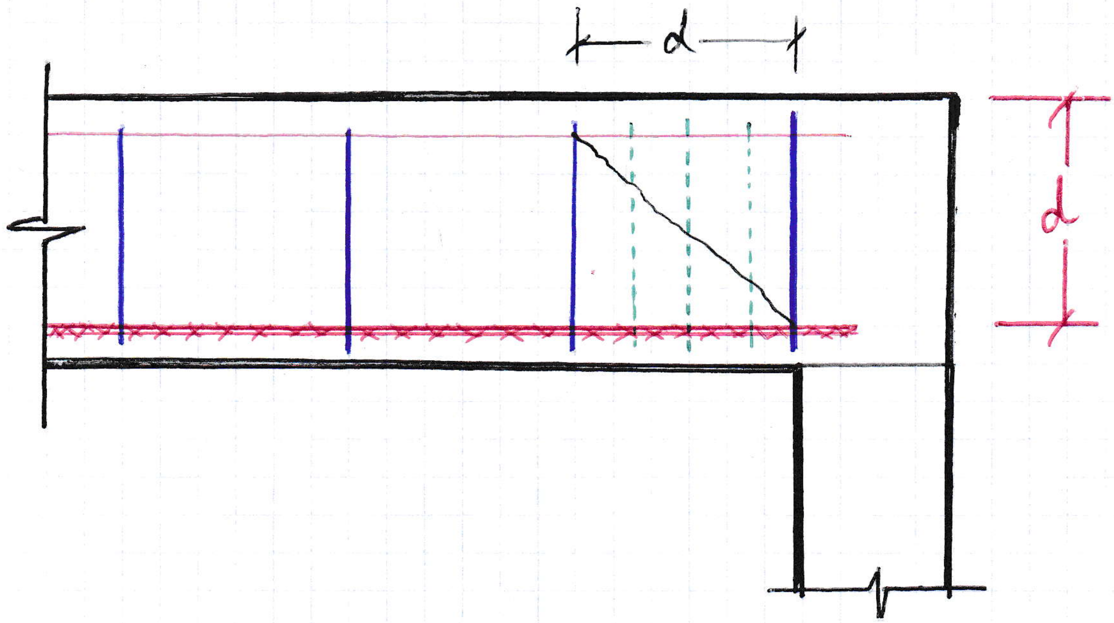
$$\phi V_{s\,req} = V_u - \phi V_c$$

$$S_{req} = \frac{\phi A_v f_y d}{\phi V_{s\,req}}$$

Always compare to the S_{max} limits

V. $3\phi V_c < V_u \leq 5\phi V_c$

Same as category IV,
except that the S_{max}
limits for geometry
are now: $d/4$, 30cm



Critical Section for Nominal Shear Strength Calculation:

Sections located less than a distance d from face of support may be designed for the same shear V_u as that computed at a distance d, i.e., shear reinforcement must be provided between the face of support and the distance d therefrom, using the same requirements as the critical section.

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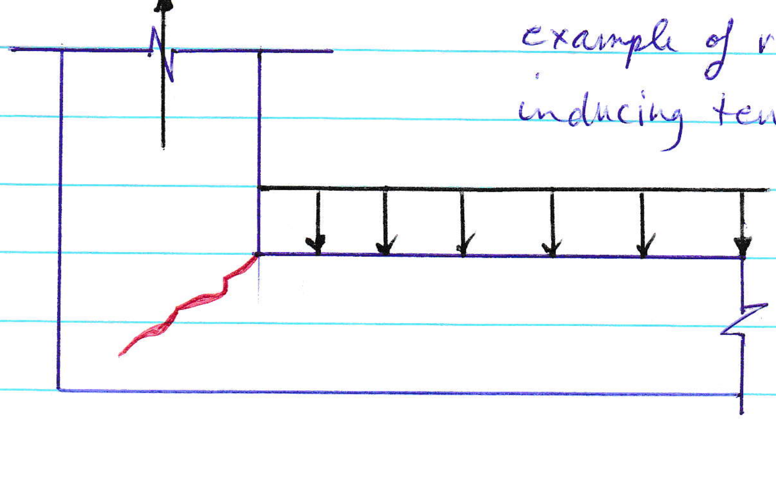
The critical section must be taken at the face of support when:

1. The support is a beam (does not introduce compression into the end region)
2. When a concentrated load occurs between the face of support and the distance d therefrom.
3. When a potential inclined crack may occur at the face of support or extend into it.



example of reaction inducing tension.