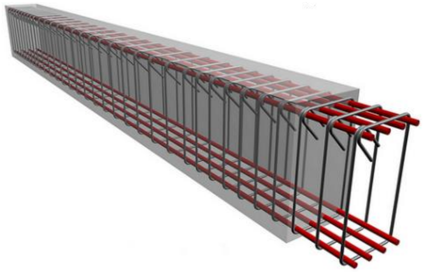
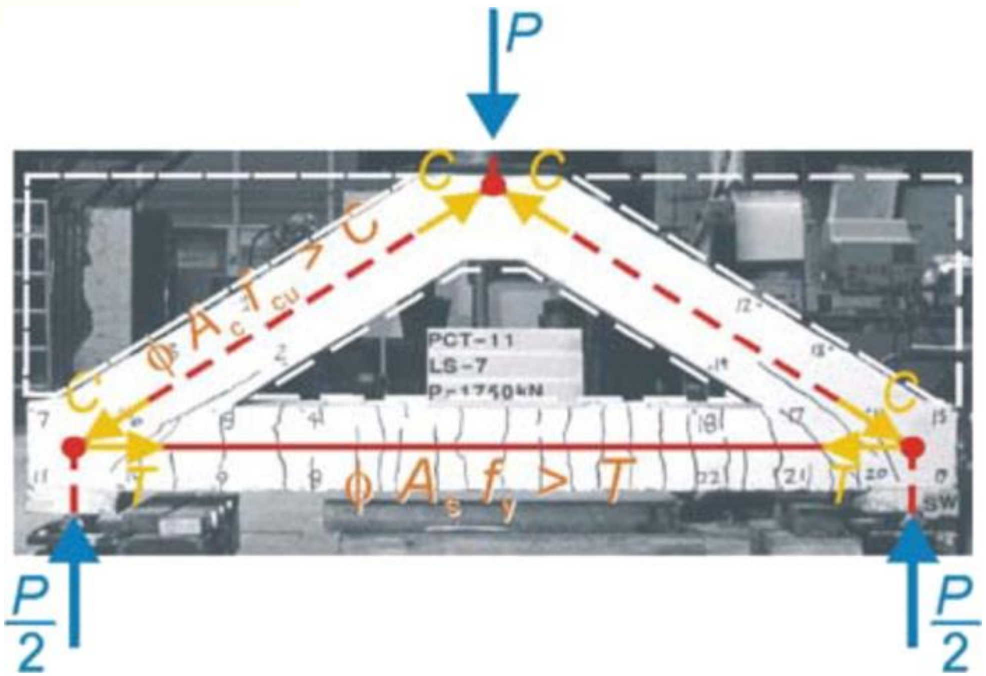
5



Advanced RC Structures

PART 3

Strut-and-Tie Model



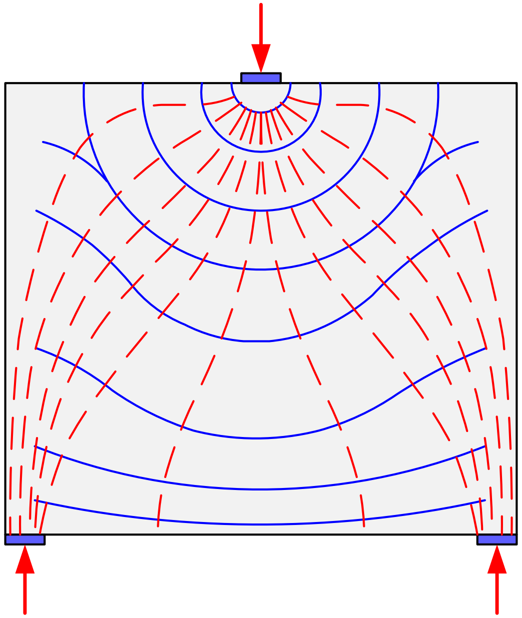
Deep Beam

Mongkol JIRAVACHARADET

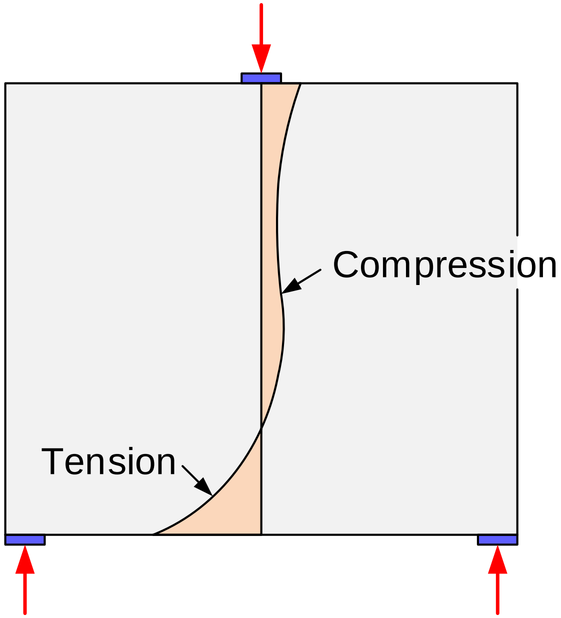
SURANAREE UNIVERSITY OF TECHNOLOGY
INSTITUTE OF ENGINEERING
SCHOOL OF CIVIL ENGINEERING

Deep Beam

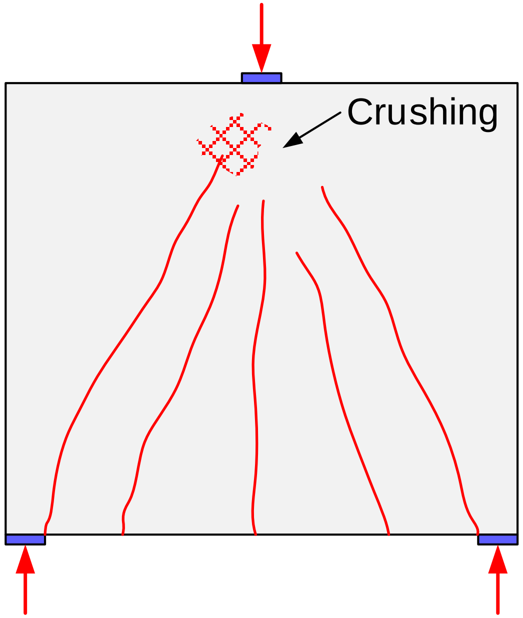
Deep beam with one point load on top



Stress trajectories

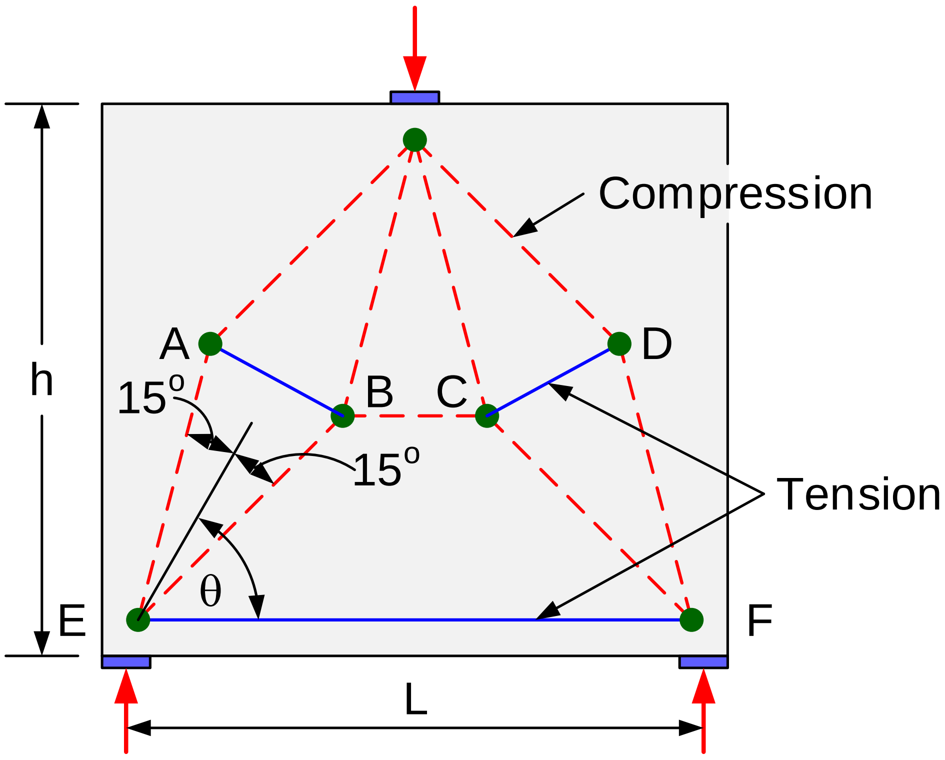


Stress distribution
@ mid-span section

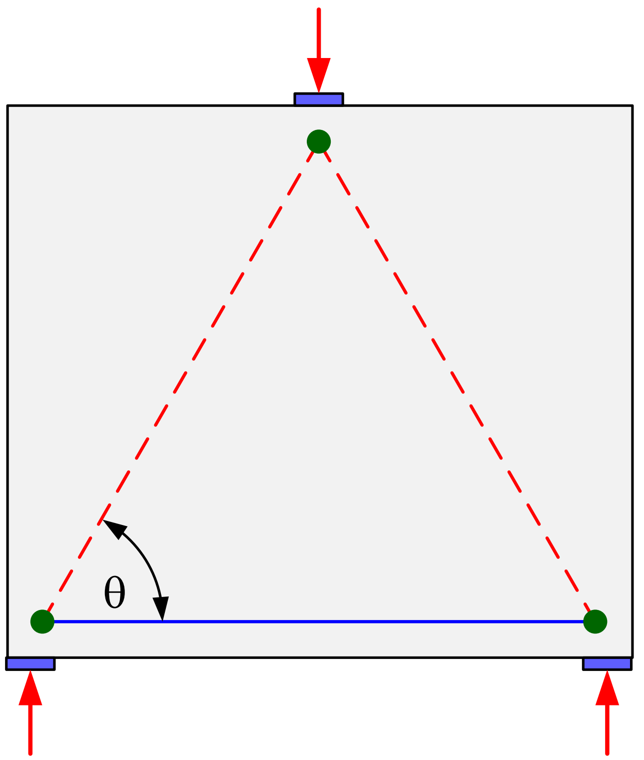


Crack pattern

Deep Beam

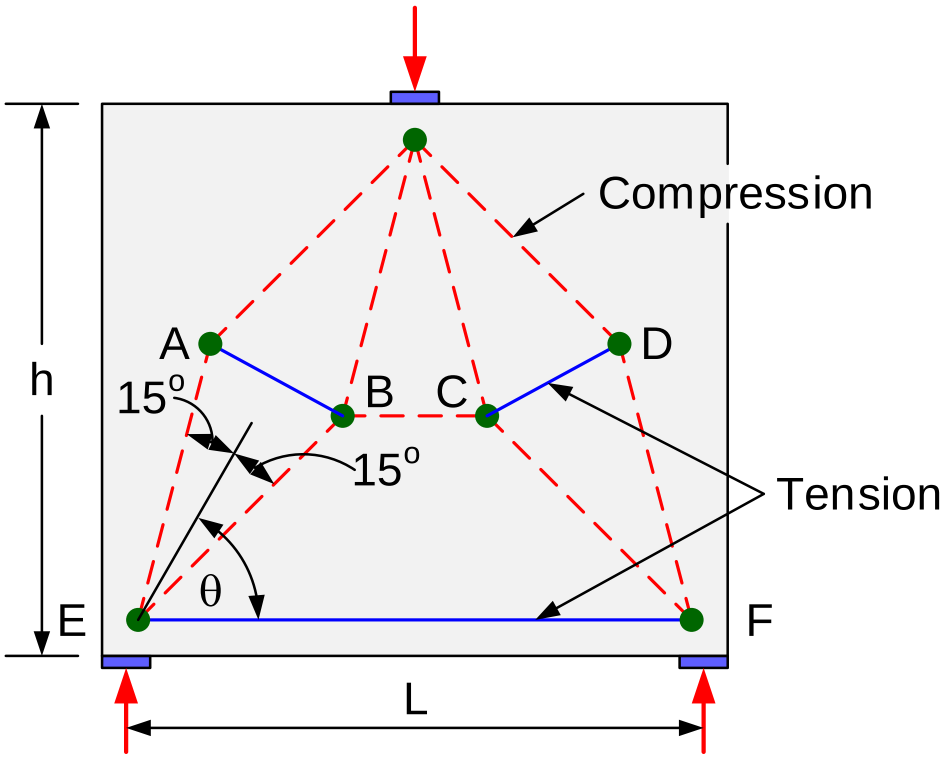


Truss Model

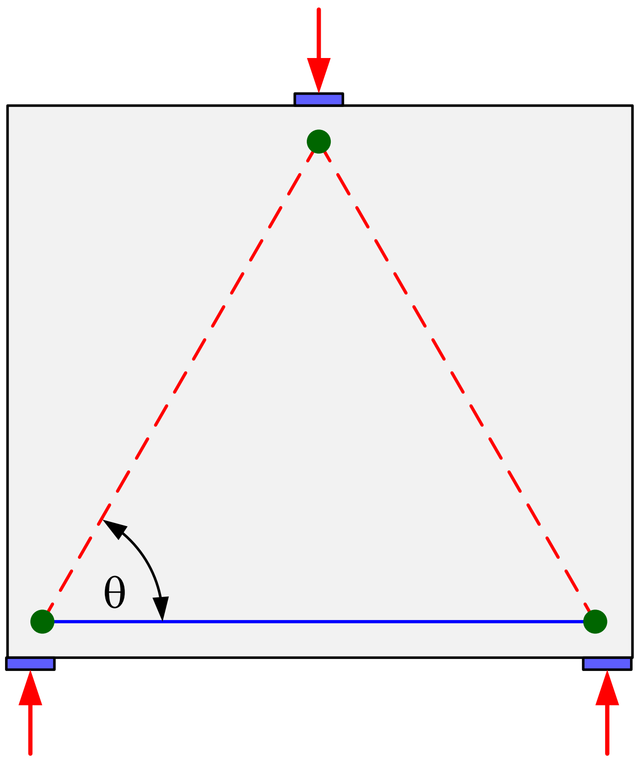


Simple Truss Model

Deep Beam

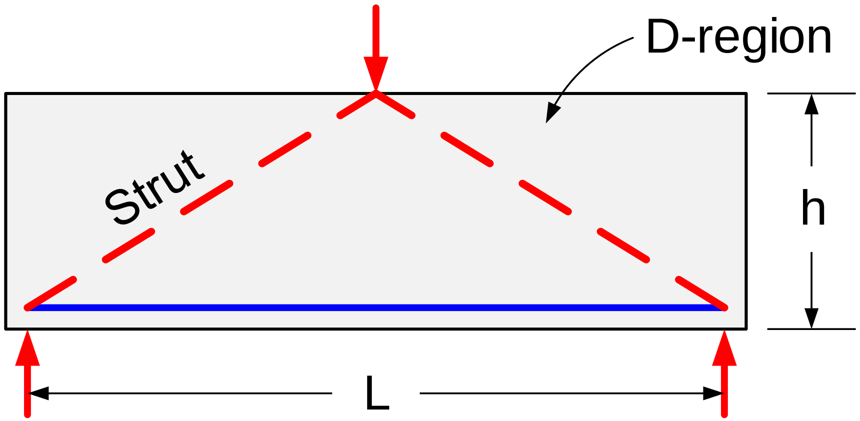


Truss Model



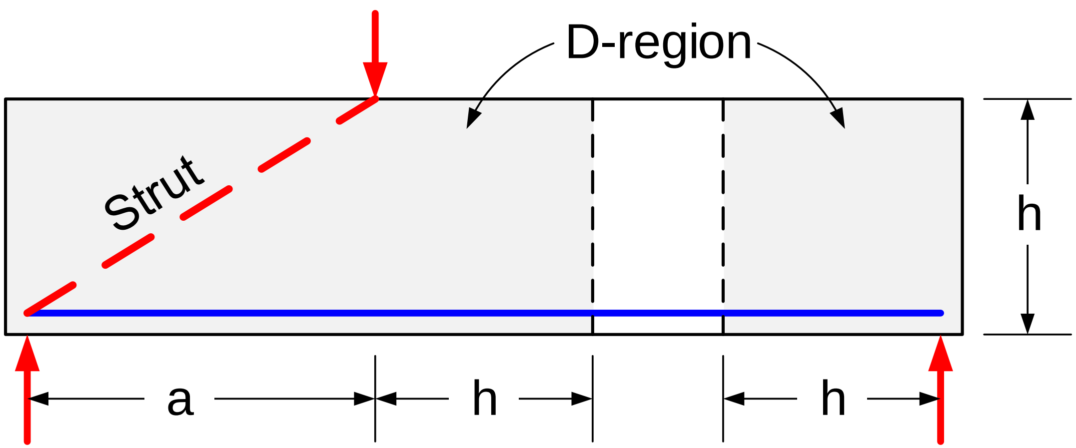
Simple Truss Model

Deep Beam



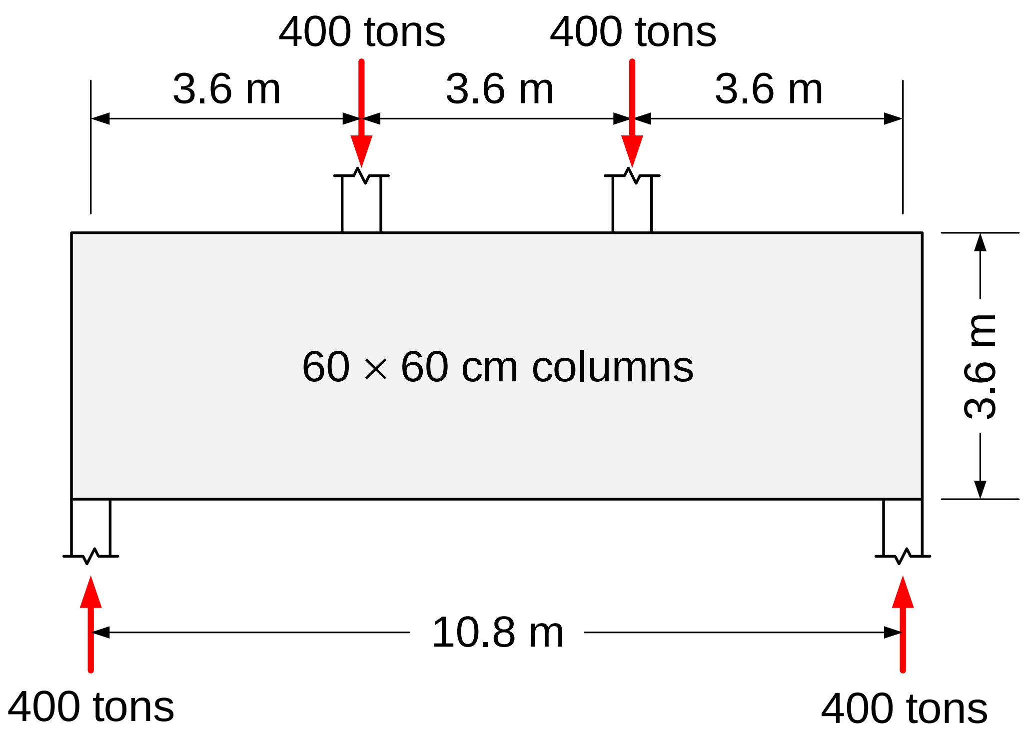
Deep beam with L ≤ 4h

Beams with clear spans less than or equal to 4 times the total member depth or with concentrated loads placed within twice the member depth of a support are classified as deep beams



Deep beam with L > 4h

EX1 : Deep Beam A transfer girder is to carry two 60 cm. square columns, each with factored loads of 400 tons located at the third points of its 10.8 m span. The beam has a thickness of 0.6 m and a total height of 3.6 m Design the beam for the given loads, ignoring the self-weight, using f'_c = 280 ksc and f_y = 4,000 ksc.



วิธีทำ (1) Span-to-depth ratio:

$$L/h = 10.8/3.6 = 3 < 4$$

∴ Can be considered as deep beam

$$\text{Assume } d = 0.9h = 3.24 \text{ m}$$

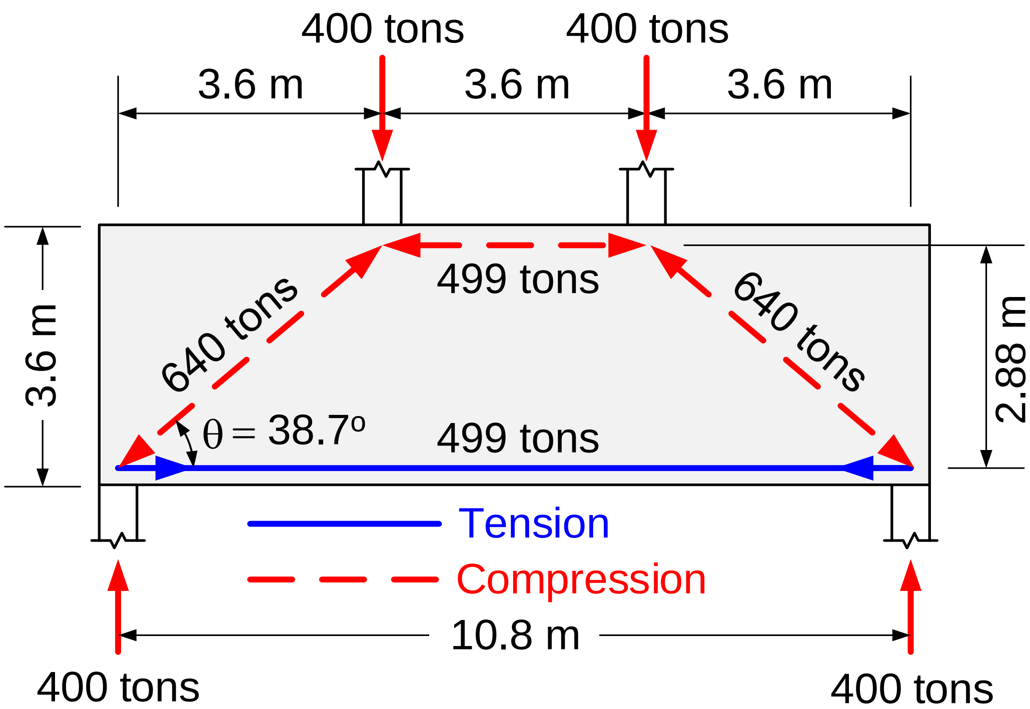
(2) Max shear capacity:

$$V_n = 2.65\sqrt{280} \times 60 \times 324 / 10^3$$

$$= 862 \text{ tons}$$

$$V_u/\phi = 400/0.75 = 533 < V_n$$ **OK**

(3) Truss Model:



Assume distance between top strut & ties:

$$0.8\,h = 0.8(3.6) = 2.88\text{ m}$$

$$\theta = \tan^{-1}(2.88/3.6) = 38.7^\circ$$

Diagonal strut compression:

$$F_{uc} = 400/\sin 38.7^\circ = 640\text{ tons}$$

Top strut & tie tension:

$$F_{ut} = 400/\tan 38.7^\circ = 499\text{ tons}$$

(4) Size of Struts & Nodal zones:

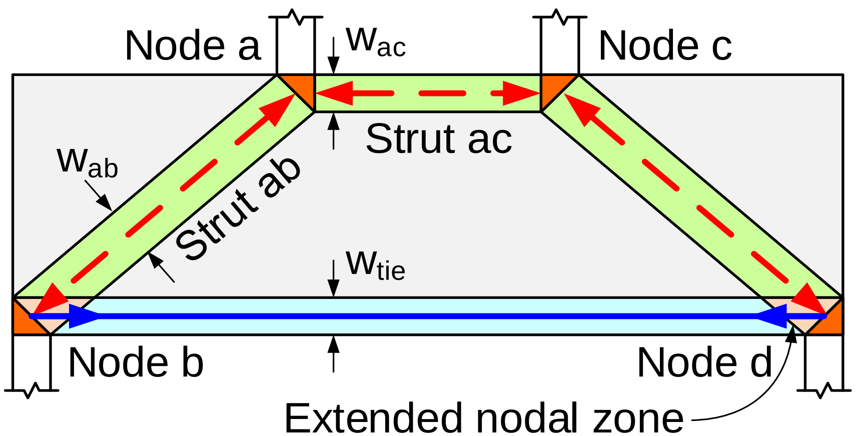
@ Node a & c, nodal stress under column

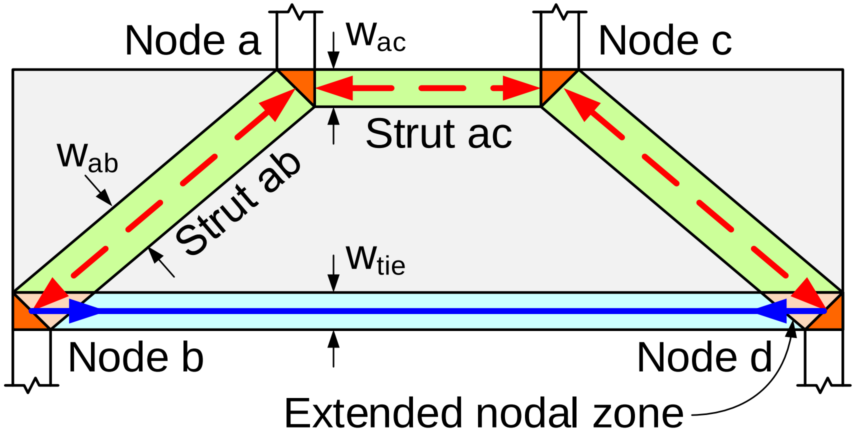
$$f_{un} = 400\times 10^3/(60\times 60) = 111\text{ ksc}$$

For node C-C-C, $\beta_n = 1.0$

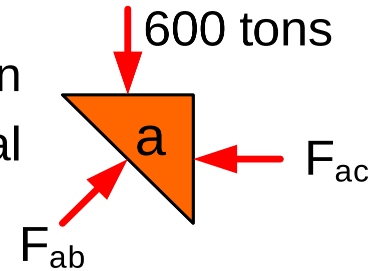
$$\phi f_{ce} = \phi 0.85\beta_n f'_c = 0.75\times 0.85\times 1.0\times 280$$

$$= 179\text{ ksc} > f_{un}$$ **OK**

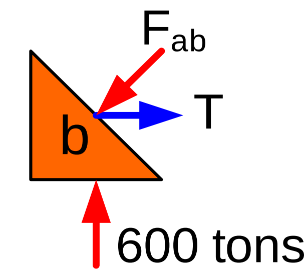




For hydrostatic compression nodel, areas are proportional to compressive forces.



$$w_{ac} = F_{ac}/(b_s \times f_{un}) = 499\times10^3/(60\times111) = 75 \text{ cm}$$



$$w_{ab} = F_{ab}/(b_s \times f_{un}) = 640\times10^3/(60\times111) = 96 \text{ cm}$$

$$w_{tie} = T/(b_s \times f_{un}) = 499\times10^3/(60\times111) = 75 \text{ cm}$$

Center-to-center distance between top strut & tie = 3.6 – 0.75 = 2.85 m ≈ 2.88 m **OK?**

(5) Strength of Struts: $\phi F_{ns} = \phi 0.85 \beta_s f'_c w_i b_s$

Assume uniform section for top strut and bottle-shaped for diagonal struts.

Strut ac ($\beta_s = 1.0$): $\phi F_{ns} = 0.75\times0.85\times1.0\times280\times75\times60/1{,}000$

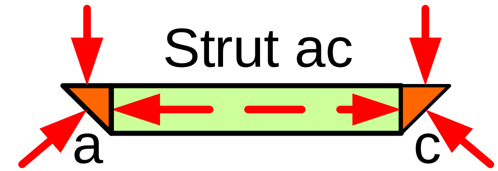
$= 803 \text{ tons} > 499 \text{ tons}$ **OK**

Strut ab ($\beta_s = 0.75$): $\phi F_{ns} = 0.75\times0.85\times0.75\times280\times96\times60/1{,}000$

$= 771 \text{ tons} > 640 \text{ tons}$ **OK**

(6) Strength of Nodal Zones: $\phi F_{nn} = \phi 0.85 \beta_n f'_c w_i b_s$

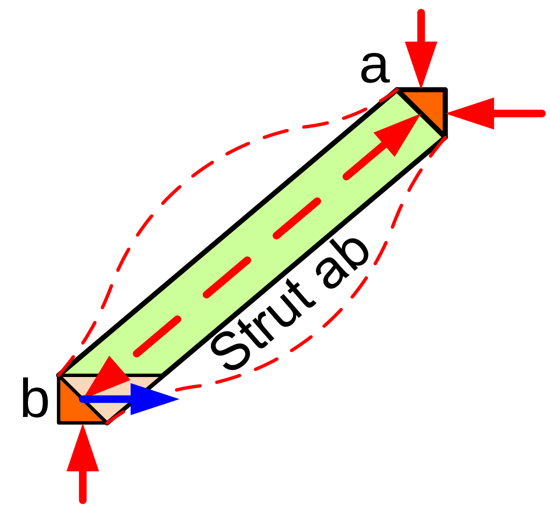
At ends of strut ac, node a & c (C-C-C) $\beta_n = 1.0$,



$$\phi F_{nn} = 0.75 \times 0.85 \times 1.0 \times 280 \times 75 \times 60 / 1{,}000$$

$$= 803 \text{ tons} > 499 \text{ tons} \quad \textbf{OK}$$

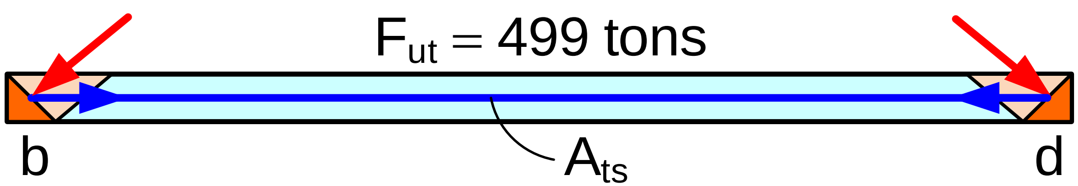
At ends of strut ab, node a (C-C-C) $\beta_n = 1.0$, node b (C-C-T) $\beta_n = 0.8$, **control**



$$\phi F_{nn} = 0.75 \times 0.85 \times 0.8 \times 280 \times 96 \times 60 / 1{,}000$$

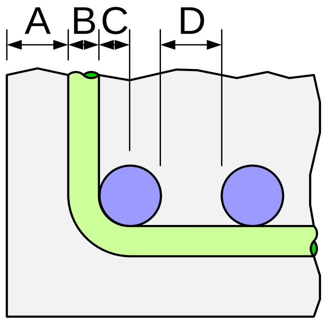
$$= 823 \text{ tons} > 640 \text{ tons} \quad \textbf{OK}$$

(7) Design of Ties and Anchorage:



Steel area of tie: $A_{ts} = F_{ut} / \phi f_y = 499/(0.75 \times 4.0) = 166 \text{ cm}^2$

USE 17-DB36 ($A_{ts} = 173 \text{ cm}^2$)

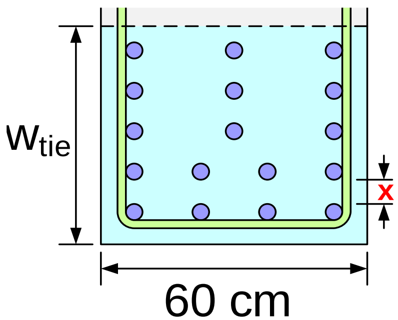


Steel detailing for DB36:

A = 4 cm, B = 1.2 cm, C = 1.8 cm and D = 3.6 cm

Max. number of DB36 in one layer:

7-DB36: b = 7(3.6) + 2(4+1.2) + 6(3.6) = 57.2 cm < 60 cm **OK**



USE 5 layers of steel 4+4+3+3+3 = 17-DB36 (trial&error)

Tie Width: $w_{tie} = 5(3.6) + 4(\mathbf{11.6}) + 2(4+1.2)$

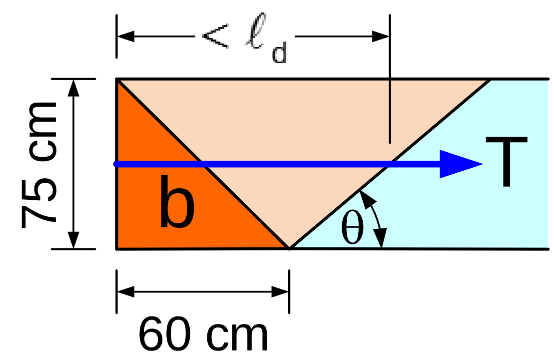
$= 74.8 \text{ cm} \approx 75 \text{ cm}$ **OK**

Anchorage length of DB36: $\ell_d = \dfrac{0.19 f_y}{\sqrt{f'_c}} d_b$

$= 45.4 d_b = 163.5 \text{ cm}$

Nodal + Extended zones: $= 60 + 0.5 \times 75 \cot 38^o$

$= 108 \text{ cm} < \ell_d$



∴ Need 90º hook or mechanical anchor

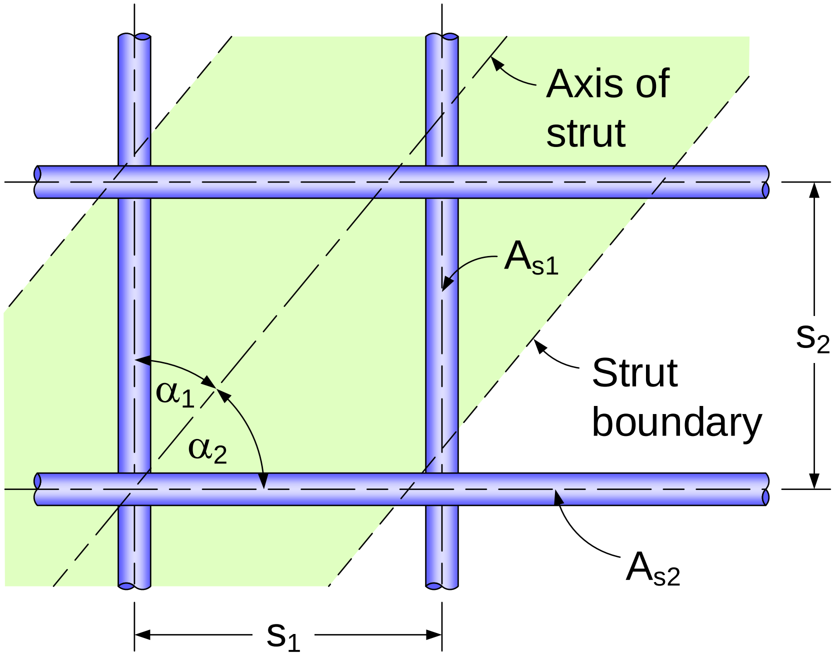
(8) Shear Reinforcements: using DB12: $A_v = A_h =$ 2.26 cm^2 and $s_1 = s_2$

$$\frac{A_v}{s_1} = \frac{A_v}{s_2} = 0.0025\,b_w = 0.0025(60) = 0.15\ \text{cm}^2/\text{cm}$$

$$s_1 = s_2 = 2.26/0.15 = 15.1\ \text{cm}$$

USE DB12 @ 0.15 m # E.F.

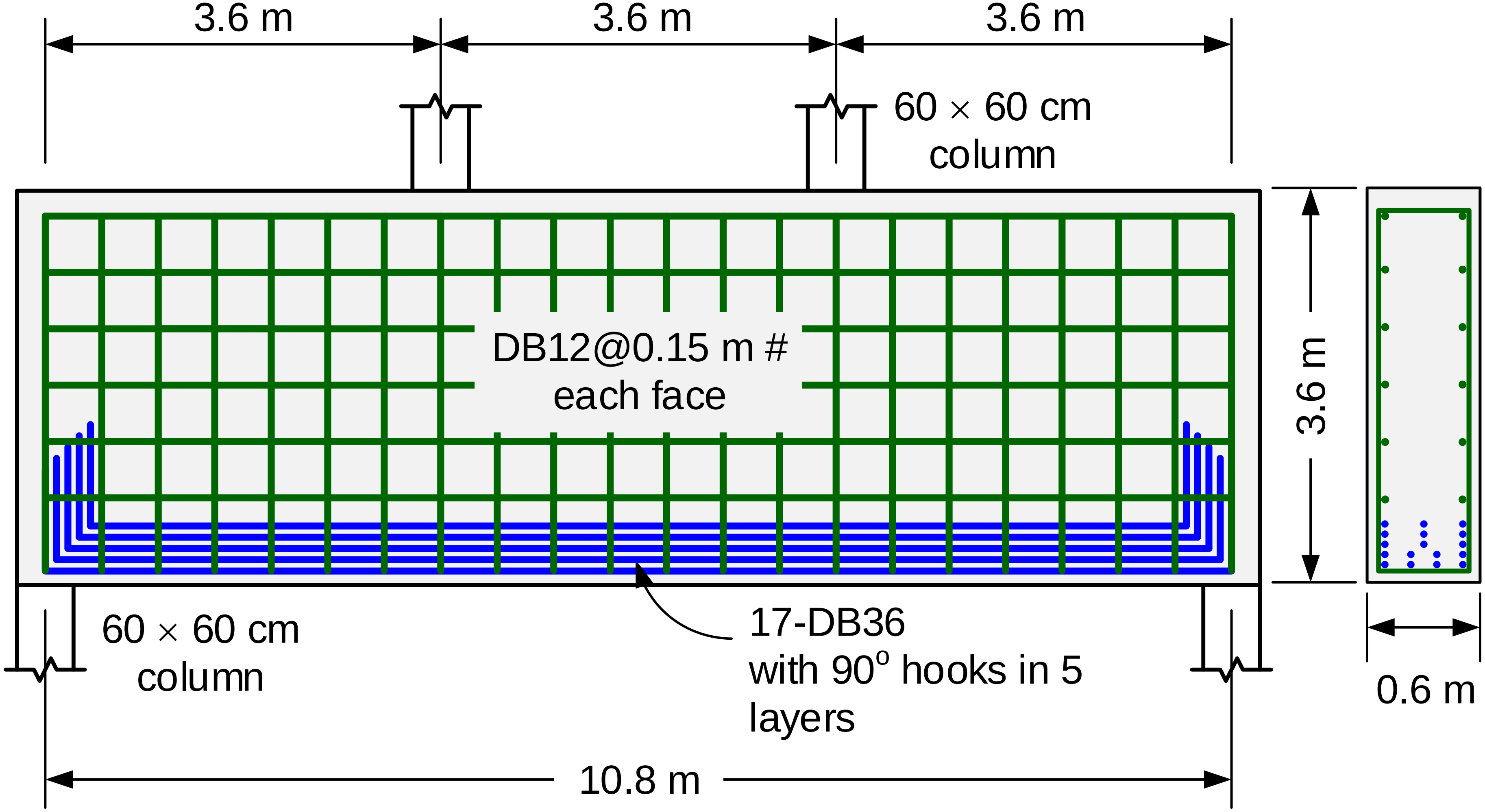
Check splitting of bottle shape strut: $\Sigma \frac{A_{si}}{b\,s_i} \sin\alpha_i \geq 0.003$



$$\frac{2.26\sin 38^\circ + 2.26\sin 52^\circ}{60 \times 15}$$

$$= 0.0035 > 0.003 \quad \textbf{OK}$$

(9) Reinforcement details:



End of Lecture