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CIVIL ENGINEERING

STEEL STRUCTURES

Text Book: Theory with worked out Examples and Practice Questions

Design of Steel Structures
(Solutions for Text Book Practice Questions)

01. Materials and Specifications

19. Ans: 108 kN

Sol: A column of a building is subjected to the following:

Working loads:

Dead load = 48 kN

Live load = 24 kN

∴ Factored load = 48 × 1.5 + 24 × 1.5

= 108 kN

02. Riveted Connections

01. Ans: (a)

Sol: $\eta = \frac{p-d}{p} \times 100$

$p_{min} = 2.5\phi$

$d = \phi + 1.5$

$= \frac{2.5\phi - \phi}{2.5\phi} \times 100$

$= \frac{1.5\phi}{2.5\phi} \times 100$

$\eta = 60\%$

05. Ans: (b)

Sol: ISA 50 × 50 × 6

t = 5 mm

d = 16 mm

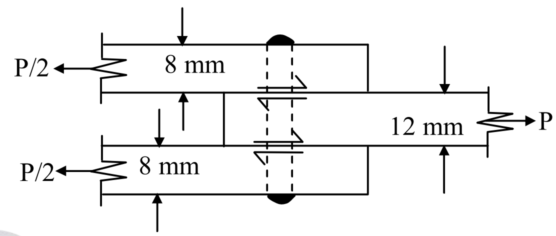
$\sigma_{bt} = 250$ MPa

$P_b = d \times t \times \sigma_{bt}$

= 16 × 5 × 250 = 20 kN

06. Ans: (b)

Sol:



Nominal dia of rivet (ϕ) = 16 mm

For field Rivets permissible shear stress in Rivet .

$\tau_{vf} = 90$ MPa

Bearing stress in Rivet $\sigma_{pf} = 270$ MPa

Rivet value

R_v = lesser of P_s & P_b

$\phi = 16$ mm ($\phi \le 25$ mm)

$d = \phi + 1.5 = 17.5$ mm

$P_s = 2 \times \frac{\pi}{4}(d)^2 \times \tau_{vf}$

$= 2 \times \left(\frac{\pi}{4}\right)(17.5)^2 \times 90$

$P_s = 43.29 \times 10^3$ N

= 43.29 kN

Bearing strength of one rivet

$P_b = d \times t \times \sigma_{pf}$

t = thickness of main thinner plate (or) sum of cover plates thickness, which ever is minimum in cause of a butt joint

$t_{mp} = 12$ mm

$t_{cp} + t_{cp} = 8 + 8 = 16$ mm

$P_b = 17.5 \times 12 \times 270$

$P_b = 56.7$ kN

R_v = lesser of P_s & P_b

$\therefore$ $R_v = 43.29$ kN

07. Ans: (d)

Sol: $P_s = 2 \times \frac{\pi}{4}(d)^2 \times \tau_{vf} = 80\,kN$

$P_s = \frac{\pi}{4} d^2 \times \tau_{vf} = 40\,kN$

$P_s = 40$ kN, $P_b = 60$ kN, $P_{tr} = 70$ kN

$n = \frac{P}{R_v} = \frac{P}{P_s} = \frac{200}{40} = 5$

09. Ans: (d)

Sol: Minimum pitch of rivets in compression zone

$\left.\begin{matrix} 12t\,mm \\ 200\,mm \end{matrix}\right\}$ whichever is minimum

t = 10 mm

$\left.\begin{matrix} 12t = 12 \times 10 = 120\ mm \\ 200\,mm \end{matrix}\right\}$ whichever is minimum

Pitch = 120 mm

Design of Simple bolted connection

04. Ans: (d)

Sol: $f_u = 400$ N/mm^2

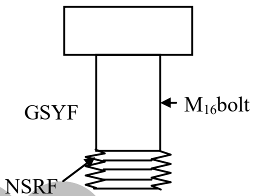
$f_y = 0.6\, f_u$

$= 0.6 \times 400$

$= 240$ N/mm^2

08. Ans: (d)

Sol:



For M_{16} bolt d = 16 mm

For Grade 4.6; $f_{ub} = 400$ MPa

$f_{yb} = 240$ MPa

Design tensile strength of bolt T_{db} = ?

T_{db} is based on Gross section

$$T_{db_1} = \frac{A_{sb} f_{yb}}{\gamma_{mo}}$$

$$T_{db_1} = \frac{\frac{\pi}{4} \times (16)^2 \times 240}{1.1}$$

$= 43.86 \times 10^3$ N = 43.86 kN

T is based on net section rupture

$$T_{db_2} = \frac{0.9 A_{nb} f_{ub}}{\gamma_{mb}}$$

$$= \frac{0.9(0.78 \times \frac{\pi}{4} \times (16)^2 \times 400)}{1.25}$$

$T_{db_2} = 45.166\,\text{kN}$

T_{db} is lesser of T_{db_1} & T_{db_2}

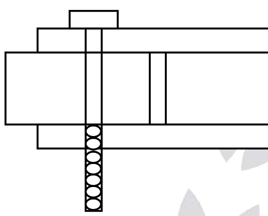
$\therefore\ T_{db} = 43.86$ kN

10. Ans: (d)

Sol: Cover plate = 12 mm, d = 16 mm,

$f_{ub} = 400$ MPa, $f_{yb} = 240$ MPa,

$\gamma_{mb} = 1.25$, $k_b = 0.50$



$$\therefore A_{sb} = \frac{\pi}{4}(16)^2 = 201.06\ \text{mm}^2$$

$$A_{nb} = 0.78 \times A_{sb} = 156.82\ \text{mm}^2$$

$$\therefore V_{dsb} = \frac{f_{ub}}{\sqrt{3}.\gamma_{mb}}(n_n A_{nb} + n_s A_{sb})$$

$$= \frac{400}{\sqrt{3}\times 1.25}[0\times 156.82 + 2\times 201.06]$$

$$= 74.29\ \text{kN}$$

$$V_{dpb} = \frac{2.5k_b.d.t.f_u}{\gamma_{mb}}$$

$$= \frac{2.5\times 0.50\times 16\times 16\times 410}{1.25} = 104.96\ \text{kN}$$

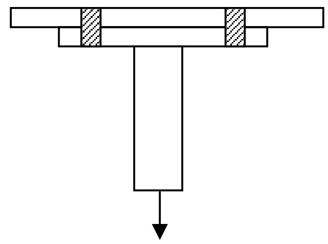
$\therefore\ V_{db} = 74.29$ kN

Assume force, P = 300 kN

$$\therefore\ n = \frac{P}{B_v} = \frac{300}{74.29} = 4\ \text{bolts}$$

12. Ans: (c)

Sol: Hanger connection looks like this one



In hanger connections bolts experience only tensile stress. Then we clearly taken, Strength of rivet is equal to the design strength of bolt in tension.

$\overline{P}_{db} = 45\,\text{kN}$ = Design bolt strength

$$\text{Number of bolts required} = \frac{180\text{kN}}{45\text{kN}} = 4\ \text{no's}$$

13. Ans: (b)

Sol: P = 240 kN; $V_{dsb} = 40$ kN; $V_{dpb} = 50$ kN;

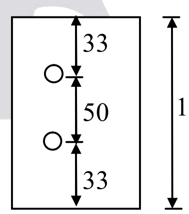
$T_{db} = 30$ kN; V_{db} = lesser of V_{dsb}, V_{dpb}

$$n = \frac{P}{V_{db}} = \frac{240}{40}$$

n = 6 no's

14. Ans: (b)

Sol:



d = 20 mm, $d_o = 20 + 2 = 22$ m,

B = 140 mm

$e = 1.5 \times d_o$ $= 1.5 \times 22$ $= 33$ mm

$p = 2.5 \times d$ $= 2.5 \times 20$ $= 50$ mm

$\therefore$ n = 2 bolts

15. Ans: (b)

Sol: P = 90 kN, t = 20 mm,

e = 29 mm, p = 40 mm ;

$t_1 + t_2 > 5d$

$2 + 20 < 5 \times 16$

$32 < 80$ mm

$$\therefore V_{dpb} = \frac{2.5.k_b.d.t.f_u}{\gamma_{mb}}$$

$$= \frac{2.5 \times 0.50 \times 16 \times 20 \times 410}{1.25}$$

= 77.14 kN

$$\therefore V_{dsb} = \frac{400}{\sqrt{3} \times 1.25}[1 \times 156.82 + 0]$$

= 28.97 kN

$$\therefore \text{No. of bolts, } n = \frac{90}{28.97} = 3.1 \simeq 4 \text{ bolts}$$

18. Ans: (c)

Sol: $T_{dp2} > T_{dp1}$

$T_{dn2} > T_{dn1}$

$A_{n2} > A_{n1}$

$$T_{dn} = \frac{0.9A_n.f_y}{\gamma_{m1}}$$

$$\left[(B - n'd_o) + \frac{Ps^2}{4g}\right]t > (B - n'd_o)t$$

$$\left[(B - 2d_o) + \frac{Ps^2}{4g}\right]t > (B - d_o)t$$

$$-2d + \frac{Ps^2}{4g} > -d$$

$$\frac{Ps^2}{4g} > d$$

$Ps^2 > 4gd$

19. Ans: (c)

Sol: B = 30 cm, t = 10 mm, d = 18 mm

n′ = 1

$\therefore A_n = (B - n' d_o)t$

$= (30 - 1 \times 2.0) \times 1$

$= 28.00 \text{ cm}^2$

20. Ans: 362.16

Sol: d = 20 mm, $d_o = 20 + 2 = 22$ mm

$f_{ub} = 410$ MPa, $f_u = 400$ MPa

$f_y = 240$ MPa, $k_b = 0.53$, B = 190 mm

t = 12 mm or 8 + 8 mm

$n_n = 2$, $n_s = 0$

$$\therefore A_{sb} = \frac{\pi}{4}d^2 = \frac{\pi}{4}(20)^2 = 314.15 \text{ mm}^2$$

$A_{nb} = 0.78\ A_{sb} = 245.04 \text{ mm}^2$

$$\therefore V_{dsb} = \frac{f_{ub}}{\sqrt{3}.\gamma_{mb}}[n_n.A_{nb} + n_s.A_{sb}]$$

$$= \frac{400}{\sqrt{3} \times 1.25}[2 \times 245.04 + 0]$$

= 90.54 kN

$$\therefore V_{dpb} = \frac{2.5 \times k_b \times d \times t \times f_u}{\gamma_{mb}}$$

$$= \frac{2.5 \times 0.53 \times 20 \times 12 \times 410}{1.25}$$

=104.34 kN

$\therefore A_g = B \times t$ $\qquad$ $A_n = (B - n'd_o)t$

$= 190 \times 12$ $\qquad$ $= (190 - 2 \times 22) \times 12$

$= 2280 \text{ mm}^2$ $\qquad$ $= 1224 \text{ mm}^2$

$\therefore T_{dg} = \frac{A_g.f_u}{\gamma_{mo}}$ $\qquad \therefore T_{dn} = \frac{0.9A_n f_u}{\gamma_{m1}}$

$= \frac{2280\times 240}{1.10}$ $\qquad = \frac{0.9\times 1224\times 410}{1.25}$

$= 497.45$ kN $\qquad = 517.79$ kN

$\therefore V_{dc} = 4\ V_{dsb}$ $\qquad V_{dc} = 4\ V_{dpb}$

$= 4 \times 90.54$ $\qquad = 4 \times 104.34$

$= 362.16$ kN $\qquad = 417.36$ kN

$V_{dc} = T_{dn} = 517.19$ kN

$\therefore V_{dc} = 362.16$ kN

21. Ans: (b)

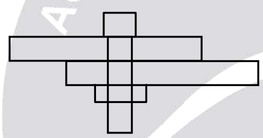
Sol: Design strength values

$V_{dpb} = 1,50,000$ N

$T_{dp} = 1,80,000$ N

$T_{sp} = 2,40,000$ N

$V_{dsb} = 1,60,000$ N



$$\eta = \frac{\text{design strength of bolted connection } (V_{dc})}{\text{design strength of solid plate} (T_{sp})}\times 100$$

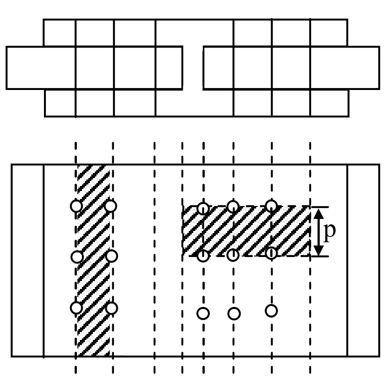
V_{dc} is lesser of $\begin{pmatrix} V_{dsp} & T_{db} \\ V_{dpb} & T_{dp} \end{pmatrix}$

$\eta = \frac{1,50,000}{2,40,000}\times 100 = 62.5\%$

$\eta = 62.5\%$

22. Ans: (d)

Sol:



$V_{dc} = n.V_{dsb}$

$= 3\left[\frac{f_{ub}}{\sqrt{3}\gamma_{mb}}(n_n A_{nb} + n_s A_{sb})\right]$

$= 3\left[\frac{f_{ub}}{\sqrt{3}.\gamma_{mb}}(2\times A_{nb} + 0)\right]$

$V_{dc} = 6\left[\frac{f_{ub}.A_{nb}}{\sqrt{3}.\gamma_{mb}}\right]$

$V_{dc} = n.V_{dpb}$

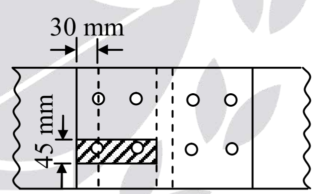
$= 1\left[\frac{f_{ub}}{\sqrt{3}.\gamma_{mb}}(\overset{0}{n_n}.A_{nb} + \overset{0}{n_s}.A_{sb})\right]$

$= \frac{}{\sqrt{3}.\gamma_{mb}}$

$\therefore V_{dc} = 6$ times

23. Ans: 60%

Sol:



$n = 2,\ n' = 1$

$d = 16$ mm, $d_o = 18$ mm

$f_y = 250$ MPa, $f_{ub} = 400$ MPa

$p = 45$ mm

$A_{sb} = \frac{\pi}{4}d^2 = \frac{\pi}{4}(16)^2 = 201.06\ mm^2$

$A_{nb} = 0.78A_{sb} = 0.78 \times 201.06$

$= 156.82\ mm^2$

$V_{dsb} = \frac{f_{ub}}{\sqrt{3}.\gamma_{mb}}[n_n.A_{nb} + n_s.A_{sb}]$

$= \frac{400}{\sqrt{3}\times 1.25}[2\times 156.82 + 0] = 57.94$ kN

$$\therefore V_{dpb} = \frac{2.5 \times k_b \times d \times t \times f_u}{\gamma_{mb}}$$

$$= \frac{2.5 \times 0.50 \times 16 \times 8 \times 410}{1.25} = 52.46 \text{ kN}$$

$\therefore A_g = p \times t$ $\quad A_n = (p - n'd_o)t$

$= 45 \times 8$ $\quad = (45 - 1 \times 18) \times 8$

$= 360 \text{ mm}^2$ $\quad = 216 \text{ mm}^2$

$$\therefore T_{dg} = \frac{A_g . f_y}{\gamma_{mo}} \qquad T_{dn} = \frac{0.9 . A_n . f_u}{\gamma_{m1}}$$

$$= \frac{360 \times 250}{1.10} \qquad = \frac{0.9 \times 216 \times 410}{1.25}$$

$= 81.81$ kN $\quad = 63.76$ kN

$\therefore V_{dc} = 4 \times V_{dpb} = 4 \times 52.46 = 290.84$ kN

$$T_{sp} = \frac{0.9 . A_g . f_u}{\gamma_{m1}} = \frac{0.9 \times 45 \times 8 \times 410}{1.25}$$

$= 106.27$ kN

$V_{dc} = 4 \times V_{dsb} = 4 \times 57.94 = 231.76$ kN

$\therefore T_{dp} = 63.76$ kN

$$\therefore \eta = \frac{V_{dc}}{T_{sp}} = \frac{63.76}{106.27} = 59.99\%$$

03. Welded Connections

12. Ans: (b)

Sol: Size = 5 mm, $L_w = 100$ mm, A = ?

$\therefore t_t = K \times S$ $\quad \therefore L_w = 100 - 2 \times 5$

$= 0.7 \times 5$ $\quad = 90$ mm

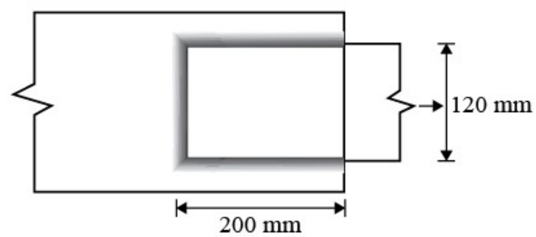
$= 0.35$

$\therefore$ Area $= t_t \times L_w \times 1 = 0.35 \times 90$

$= 315 \text{ mm}^2$

13. Ans: 413.586 kN

Sol:



$f_u = 400$ MPa, S = 6 mm

$\therefore t_t = K \times S$ $\quad L_w = 200 + 200 + 120$

$= 0.7 \times 6$ $\quad = 520$ mm

$= 0.42$ mm

$$\therefore P_{dw} = L_w . t_t \times \frac{f_u}{\sqrt{3} \times \gamma_{mw}}$$

$$= 520 \times 0.42 \times \frac{410}{\sqrt{3} \times 1.25} = 413.58 \text{ kN}$$

14. Ans: (a)

Sol: S = 5 mm, $f_y = 250 \text{ N/mm}^2$, $f_u = 410$ MPa

$t_t = K \times S$ $\quad L_w = 150 + 150 + 150$

$= 0.7 \times 5$ $\quad = 450$ mm

$= 3.5$ mm

$$\therefore P_{dw} = L_w \times t_t \times \frac{f_u}{\sqrt{3} . \gamma_{mw}}$$

$$= 450 \times 3.5 \times \frac{410}{\sqrt{3} \times 1.25} = 298.25 \text{ kN}$$

$$\therefore \text{Service load} = \frac{P_{dw}}{1.5} = \frac{298.25}{1.5} = 198.83 \text{ kN}$$

15. Ans: (b)

Sol: $S = 10$ mm; $f_y = 250$ MPa $= f_{yw}$; $f_u = 410$ MPa;

$\gamma_{mw} = 1.25$; $P = 270$ kN

$= f_{yw}$

$\therefore L_w = l_j + l_j = 2l_j$

$$P \le P_{dw} = L_w \times t_t \times \frac{f_u^1}{\sqrt{3}\gamma_{mw}}$$

$$\Rightarrow 270\times10^3 = (2\times \ell_j)\times(k\times S)\times\frac{f_u^1}{\sqrt{3}\gamma_{mw}}$$

$$\Rightarrow 270\times10^3 = (2\times \ell_j)\times(0.7\times10)\times\frac{410}{\sqrt{3}\times1.25}$$

$$l_j = 101.8 \text{ mm} \simeq 105 \text{ mm}$$

16. Ans: (b)

Sol: $L_j = 300\ t_t$

$$P_{dw} = L_w \times t_t \times \frac{f_u}{\sqrt{3}\times\gamma_{mw}}\times\beta_{\ell w}$$

$$\therefore \beta_{\ell w} = 1.2 - \frac{0.2L_j}{150t_t} = \frac{1.2 - 0.2\times300t_t}{150t_t} = 0.8$$

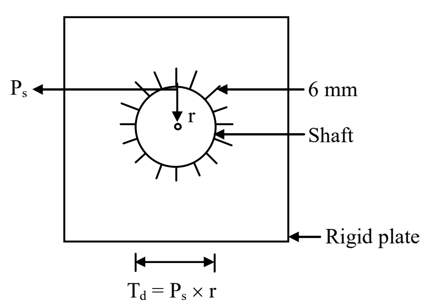
$\therefore$ Assume 100%

$P_{dw} = \beta_{lw} \times 100 = 0.8 \times 100 = 80\%$

Reduced by 20%

17. Ans: (b)

Sol:

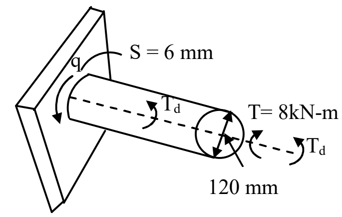


Size of weld (S) = 6 mm

Torque T = 8 kN-m

$= 8 \times 10^6$ N-mm

Maximum stress in weld q =?



Twisting moment capacity of weld

$$T_d = P_s \times r = P_s \times \frac{d}{2}$$

$$= L_w.t_t.q.\frac{d}{2}$$

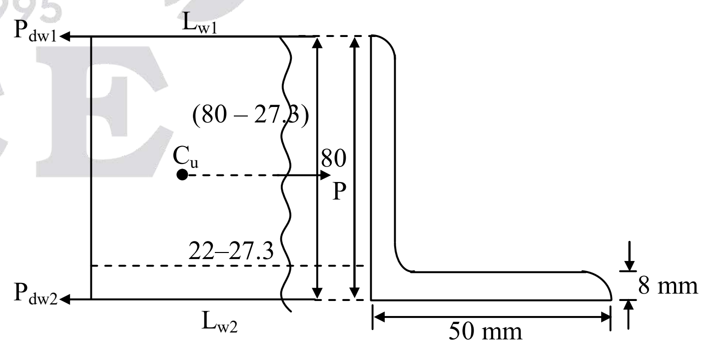
$$T = \pi d(ks)q.\frac{d}{2}$$

$$8\times10^6 = \pi\times120\times(0.7\times6)\times q\times\frac{120}{2}$$

$$q = 84.2 \text{ N/mm}^2 \simeq 85 \text{ MPa}$$

20. Ans: 403 mm

Sol:



S = 5 mm, ISA 80 × 50 × 8 mm

$A_g = 978$ mm^2, $C_{zz} = 27.3$ mm

$t_t = K \times S = 0.7 \times 5 = 3.5$ mm

$\therefore P \le T_{dg}$

$$P = \frac{A_g f_u}{\gamma_{mo}} = \frac{978\times250}{1.10} = 222 \text{ kN}$$

$$\therefore P_{dw} = L_w.t_t \times \frac{f_u}{\sqrt{3}\times\gamma_{mw}}$$

$$222\times10^3 = L_w \times 3.5\times\frac{410}{\sqrt{3}\times1.50}$$

L_w = 402.42 mm

24. Ans: (c)

Sol: L_w = 200 mm, t_e = 16 mm, f_y = 250 MPa

$$\therefore T_{dw} = \frac{L_w \times t_e \times f_y}{\gamma_{mw}}$$

$$= \frac{200\times16\times250}{1.25}$$

= 640 kN

04. Eccentric Connections

05. Ans: (d)

Sol: P = 10 kN, e = 100 mm,

d = 10 mm of 4 bolts

$$F_1 = \frac{P}{n} = \frac{10}{4} = 2.5 \text{ kN}$$

M = Pe = 10 × 100 = 1000 kNm

$$r = \sqrt{40^2+30^2} = 50 \text{ mm}$$

$$\therefore F_2 = \frac{Mr}{\Sigma x^2+\Sigma y^2} = \frac{1000\times50}{4\times40^2+30^2\times4} = 5 \text{ kN}$$

$$\therefore F_R = \sqrt{F_1^2+F_2^2+2F_1F_2\cos\theta}$$

$$= \sqrt{2.5^2+5^2+2\times2.5\times5\times\cos(4/5)}$$

= 7.49 kN

$$F_1x = \frac{P_x}{n} = 0,\ F_2y = \frac{P_y}{n} = \frac{10}{4} = 2.5 \text{ kN}$$

$$F_2x = \frac{1000\times30}{4\times40^2+4\times30^2} = 3 \text{ kN}$$

$$F_2y = \frac{1000\times40}{4\times40^2+4\times30^2} = 4 \text{ kN}$$

$$\therefore F_R = \sqrt{(F_1x+F_2x)^2+(F_1y+F_2y)^2}$$

$$= \sqrt{(0+3)^2+(2.5+4)^2} = 7.15 \text{ kN}$$

06. Ans: (c)

Sol: B = 150 mm, x = 80 mm, y = 60 mm

$$r = \sqrt{x^2+y^2} = \sqrt{80^2+60^2} = 100 \text{ mm}$$

$$\therefore F_1 = \frac{P}{n} = \frac{P}{4}$$

$$\therefore F_2 = \frac{Mr}{\Sigma x^2+\Sigma y^2} = \frac{P\times150\times100\times2}{4\times80^2+4\times60^2}$$

$$= \frac{15\times10^3\times P}{40\times10^3}$$

$$= \frac{3P}{4}$$

$$F_R = \sqrt{F_1^2+F_2^2+2F_1F_2\cos\theta} = \sqrt{F_2^2}$$

$$= \sqrt{\left(\frac{3P}{4}\right)^2}$$

$$F_R = \frac{3P}{4}$$

07. Ans: (b)

Sol: e = 150 mm

M = 150 × P – 150 × P = 0

$$F_1 = \frac{P}{n} = \frac{2P}{4} = \frac{P}{2}$$

$F_2 = 0$

$$\therefore F_R = \sqrt{F_1^2} = \frac{P}{2}$$

08. Ans: 156.20

Sol: An eccentric load may be replaced by set of one direct concentric load (p) and in plane moment (M)

$M = p.e$

$= (100)\,(600)$

$= 6\times10^4$ kN-mm

Force in each bolt due to direct concentric load (F_a)

$$F_a = \frac{p}{n} = \frac{100}{5} = 20\text{kN}$$

Force in critical bolt due to moment (F_m)

$$= \frac{p.e.r}{r^2}$$

$$= \frac{M.r}{\Sigma r^2} = \frac{6\times10^4\times75\sqrt{2}}{4\times\left(75\sqrt{2}\right)^2+0}$$

$$= \frac{6\times10^4\times75\sqrt{2}}{4\times75^2\times2}$$

$= 141.42$ kN

Maximum Resultant force in critical bolt 1 and 2 is

$$F_{Rmax} = \sqrt{F_m^2+F_a^2+2F_aF_m\cos\theta}$$

$$= \sqrt{(141.42)^2+(20)^2+2\times20\times(141.42)\times\left(\frac{1}{\sqrt{2}}\right)}$$

$= 156.20$ kN

09. Ans: 6 kN

Sol: Given load P = 10 kN

Eccentricity = 150 mm

Number of rivets =4

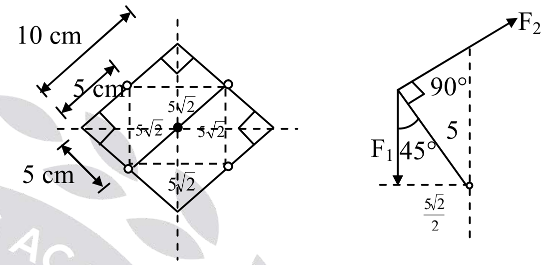
Force in rivet 1 due to direct loading = $\frac{P}{4}$

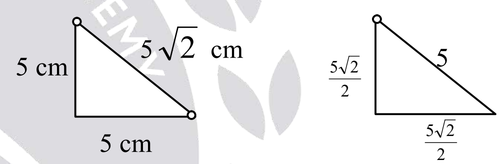
$F_1 = 2.5$ kN

Force in rivet 1 due to twisting moment

$$= \frac{M.r_e}{\Sigma r^2}$$

M = P[150] kN-mm





$$F_2 = \frac{[10]\times150\times50}{4\times[50]^2} = 7.5\text{ kN}$$

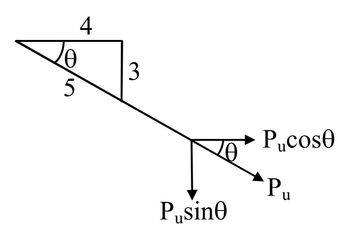
Resultant force $F_R = \sqrt{F_1^2+F_2^2+2F_1F_2\text{Cos}\theta}$

$\theta = 135°$

$F_R = 5.99$ kN

11. Ans: (d)

Sol:



$n = 6$, $P_u = 250$ kN, $\cos\theta = 4/5$, $\sin\theta = 3/5$

If all bolts are subjected to

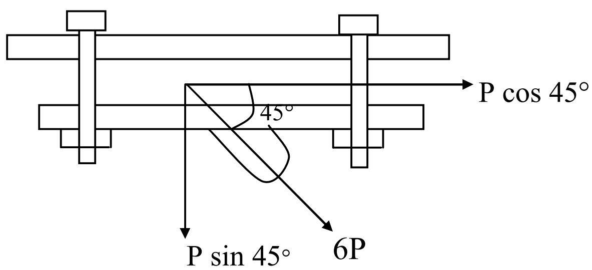
Tension

$$T_b = \frac{P}{n} = \frac{P_u \cos\theta}{6} = \frac{250 \times 4}{6 \times 5} = 33.33 \text{ kN}$$

$$V_b = \frac{P}{n} = \frac{P_u \sin\theta}{6} = \frac{250 \times 3}{6 \times 5} = 25 \text{ kN}$$

12. Ans: (d)

Sol:



Design shear strength of bolt V_{db} = 30 kN

Design tensile strength of bolt T_{db} = 40 kN

Factored shear force in any bolt due to vertical component of 6P

$$V_b = \frac{P \cos 45^\circ}{4} = \frac{P}{4\sqrt{2}}$$

Factored tensile force in any bolt due to vertical component of 6P

$$T_b = \frac{P \sin 45^\circ}{n} = \frac{P \sin 45^\circ}{4}$$

$$= \frac{P}{4\sqrt{2}}$$

$$\left(\frac{V_b}{V_{db}}\right)^2 + \left(\frac{T_b}{T_{db}}\right)^2 \le 1.0$$

$$\left(\frac{P}{4\sqrt{2}} \times \frac{1}{30}\right)^2 + \left[\frac{P}{4\sqrt{2}} \times \frac{1}{40}\right]^2 \le 1.0$$

$$\frac{P^2}{16 \times 2 \times 900} + \frac{P^2}{16 \times 2 \times 1600} = 1$$

P = 135.76 kN

The maximum design load applied can be on the joint is 135.76 kN

15. Ans: 147.98

Sol: f = 120 MPa, q = 50 MPa

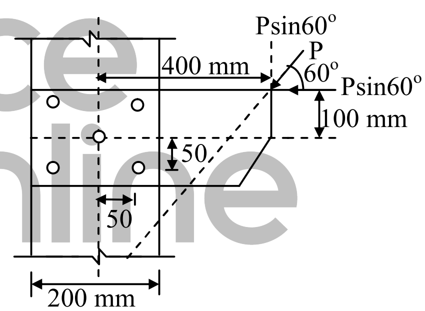
$$\therefore f_e = \sqrt{f^2 + 3q^2}$$

$$= \sqrt{120^2 + 3(50)^2}$$

= 147.98 MPa

17. Ans: 66

Sol:



$P_x = P \cos 60^\circ$, $P_y = P \sin 60^\circ$

B = 400 mm

$$\therefore F_1x = \frac{P_x}{n} = \frac{P\cos 60^\circ}{5}$$

$$= \frac{P}{10}$$

$$F_1y = \frac{P_y}{n} = \frac{P\sin 60^\circ}{5} = \frac{\sqrt{3}P}{10}$$

M = P sin 60° × 400 – P cos60° × 100

= 296.41 P

$\therefore \Sigma x^2 + \Sigma y^2 = 4 \times 50^2 + 4 \times 50^2$

= 20000 mm

$$\therefore F_2x = \frac{M_{xr}}{\Sigma x^2 + y^2} = \frac{296.41P \times 50}{20000} = 0.74P$$

$$F_R = \sqrt{(F_1x + F_2x)^2 + (F_1y + F_2y)^2}$$

$$= \sqrt{\left(\left(\frac{P}{10}\right) + 0.74P\right)^2 + \left(\frac{\sqrt{3}P}{2} + 0.74P\right)^2}$$

$$= \sqrt{70.56P^2 + 0.83P^2} = 1.24P$$

$\therefore$ As, $V_{db} = 82$ kN

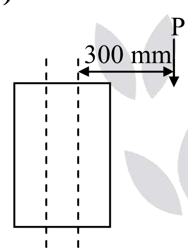
$1.24P = 82$

$$P = \frac{82}{1.24}$$

$P = 66.12$ kN

18. Ans: (b)

Sol:



$P = 60$ mm, $e = 300$ mm, $n' = ?$

$V_{db} = 40$ kN, $P = 150$ kN

$$\therefore n' = \sqrt{\frac{6M}{mPV_{db}}}$$

$$= \sqrt{\frac{6 \times 150 \times 300}{2 \times 60 \times 40}}$$

$n' = 7.5 \simeq 8$ bolts

05. Tension Members

02. Ans: 1015

Sol: $\therefore A_{nc} = (x - t/2 - d_0)t$

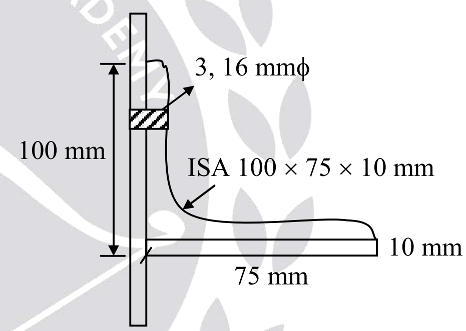
$$= \left(100 - \frac{10}{2} - 20\right) \times 10$$

$= 750$ mm^2

$A_{go} = (y - t/2)t$

$$= \left(75 - \frac{10}{2}\right) \times 10$$

$= 700$ mm^2



$d_0 = 16 + 2 + 2 = 20$ mm

$A_n = A_{nc} + A_{go}$

$= 750 + 700$

$= 1450$ mm^2

$\therefore A_{ne} = \alpha \times A_n$

$= 0.7 \times 1450$

$= 1015$ mm^2

03. Ans: (c)

Sol: For ISA 100 × 100 × 10 mm

$x = 100$ mm, $y = 100$ mm, $t = 10$ mm

$\therefore A_g = (x - t/2)t + (y - t/2)t$

$= (100 - 10/2) \times 10 + (100 - 10/2) \times 10$

$= 1900$ mm^2

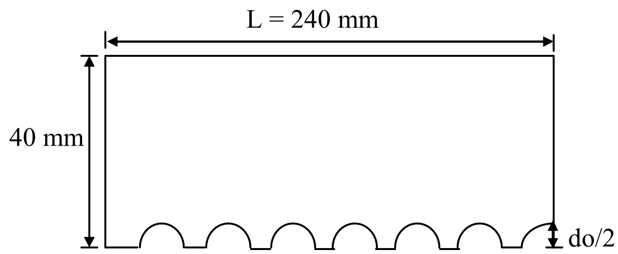
04. Ans: 846 mm² & 186 mm²

Sol: d_o = 18 mm, g = 60 mm, t = 10 mm,

ISA 100 × 75 × 6 mm

↓

(A = 1010 mm²)



$A_{vg} = L \times t$

$= 240 \times 6$

$= 1440 \text{ mm}^2$

$A_{vn} = (L - d_0)\, t$

$= (240 - 5 \times 18 - 18/2) \times 6$

$= 846 \text{ mm}^2$

$A_{tg} = b \times t$

$= 40 \times 6$

$= 240 \text{ mm}^2$

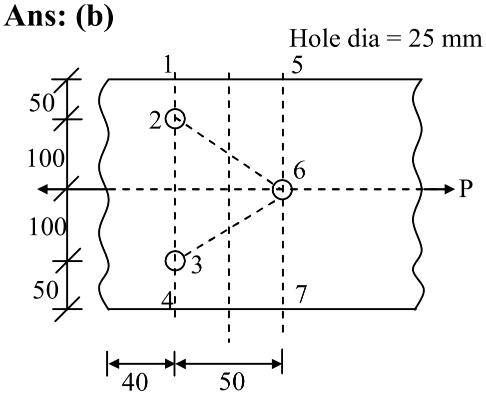
$A_{tn} = (b - d_0/2)t$

$= (40 - 18/2) \times 6$

$= 186 \text{ mm}^2$

05. Ans: (b)

Sol:



Possible failure sections are

- 1–2–3–4
- 1–2–6–7
- 1–2–6–3–4

A_n along section 1–2–3–4

$$A_n = [B - nd_o] \times t$$

$$= [300 - 2 \times 25] \times 10 = 2500 \text{ mm}^2$$

A_n along section 1–2–6–7

$$A_n = (B - nd_o)t + \frac{P_1^2 t}{4g_1}$$

$$= (300 - 2 \times 25) \times 10 + \frac{50^2 \times 10}{4 \times 100}$$

$$= 2562.5 \text{ mm}^2$$

A_n along section 1–2–6–3–4

$$A_n = (B - nd_o)t + \frac{P_1^2 t}{4g_1} + \frac{P_2^2 t}{4g_2}$$

$$= (300 - 3 \times 25) \times 10 + \frac{50^2 \times 10}{4 \times 100} + \frac{50^2 \times 10}{4 \times 100}$$

$\therefore A_n = 2375 \text{ mm}^2$

Hence Critical sectional area A_n= 2375 mm²

06. Ans: (b)

Sol: B = 300 mm, d_0 = 20 + 2 = 22 mm,

t = 6 mm

$A_{n)1\text{-}2\text{-}3\text{-}4} = (B - n'\, d_0)t$

$= (300 - 2 \times 22) \times 6$

$= 1536 \text{ mm}^2$

$$A_{n)1-2-5-6-7} = \left[(300 - 3 \times 22) + \frac{60^2}{4 \times 70}\right] \times 6$$

$= 1481.22 \text{ mm}^2$

$$A_{n)1-2-5-8-10-11} = \left[(300 - 4\times 22) + \frac{3\times 60^2}{4\times 70}\right]\times 6$$

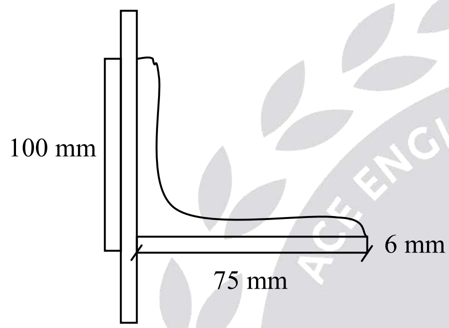
$= 1503.42\ mm^2$

$\therefore A_{n)min} = 1481.22\ mm^2$

10. Ans: 198.73 kN

Sol: ISA 100 × 75 × 6 mm; t = 10 mm,

f_y = 250 MPa, f_u = 410 MPa, L_C = 200 mm



$$\therefore T_{dg} = \frac{A_g.f_y}{\gamma m_0}$$

$$= \frac{1010\times 250}{1.10} = 229.54\ kN$$

$\therefore A_{nc} = (x - t/2 - d_0)\ t$

$= (100 - 6/2 - 18) \times 6 = 474\ mm^2$

$A_{go} = (y - t/2)\ t$

$= (75 - 6/2) \times 6 = 432\ mm^2$

$\therefore b_s = w + w_1 - t$

$= 75 + 60 - 6 = 129$ mm

$$\therefore \beta = 1.40 - 0.076\left[\frac{w}{t}\times\frac{f_y}{f_u}\times\frac{b_s}{L_c}\right]$$

$$= 1.40 - 0.076\left[\frac{75}{6}\times\frac{250}{410}\times\frac{129}{200}\right]$$

$= 10.0246$

$$\therefore Td_n = \frac{0.9A_{nc}f_u}{\gamma_{m1}} + \beta.\frac{A_{go}f_y}{\gamma_{mo}}$$

$$= \frac{0.9\times 474\times 410}{1.25} + \frac{1.02\times 432\times 250}{1.10}$$

$= 240.07$ kN

$$\therefore T_{db_1} = \frac{A_{vg}f_u}{\sqrt{3}.\gamma_{m0}} + \frac{0.9A_{tn}f_u}{\gamma_{m1}}$$

$$= \frac{1440\times 250}{\sqrt{3}\times 1.10} + \frac{0.9\times 186\times 410}{1.25}$$

$= 243.85$ kN

$$T_{db_2} = \frac{0.9A_{vn}f_u}{\sqrt{3}.\gamma_{m1}} + \frac{A_{tg}.f_u}{\gamma_{m0}}$$

$$= \frac{0.9\times 84.6\times 410}{\sqrt{3}\times 1.25} + \frac{240\times 250}{1.10}$$

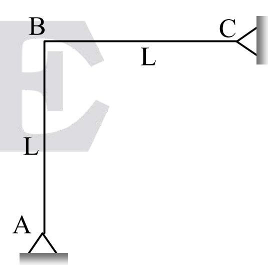
$= 198.73$ kN

$\therefore T_d = 198.73$ kN

06. Compression Members

03. Ans: (c)

Sol:

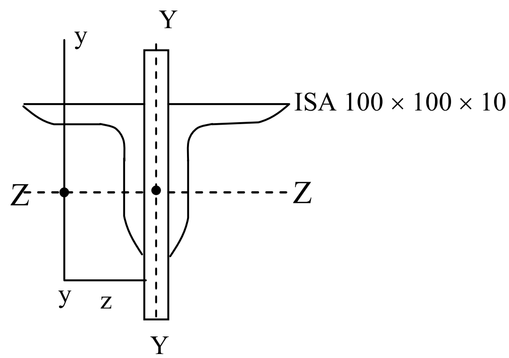


	M	θ	
Hinged	X	√	1L
Rigid	√	√	L
Fixed	√	X	0.8L

AB = 0.8L < L < L

05. Ans: (b)

Sol:



Symmetric w.r.t yy axis

$A = 1903\ mm^2$

$I_{zz} = I_{yy} = 177\times10^4\ mm^4$

$I_{yy} = 2\left(I_{yy} + Az^2\right)$

Gusset plates one at joint member only.

$I_{ZZ} = 2.I_{zz} = 2 \times 177 \times 10^4$

$= 354 \times 10^4\ mm^4$

$I_{min} = 2 \times I_{ZZ}$

$$r_{min} = \sqrt{\frac{I_{ZZ}}{A}}$$

$$= \sqrt{\frac{2\times177\times10^4}{2\times1903}} = \sqrt{\frac{354\times10^4}{3806}}$$

$= 30.49\ mm \simeq 30.5\ mm$

07. Ans: (d)

Sol: $L = 3m,\ r_{min} = 51.8\ mm$

$$\therefore\ \lambda_{max} = \frac{KL}{r_{min}} = \frac{1\times3000}{51.8}$$

$= 57.92$

08. Ans: (c)

Sol: $r_x = 40\ mm,\ r_y = 10\ mm,\ L_x = 1.2\ m,$

$L_y = 1m, \quad \lambda_{max} = 120$

$$\therefore\ \lambda_{max} = \frac{(KL)_{zz}}{r_{zz}} = \frac{1.2\times L_{zz}}{40}$$

$$120 = \frac{1.2\times L_{zz}}{40}$$

$L_{zz} = 4000\ mm = 4\ m$

$$\therefore\ \lambda_{max} = \frac{(KL)_{yy}}{r_{yy}}$$

$$120 = \frac{1\times L_{yy}}{10}$$

$L_{yy} = 1200\ mm = 1.2\ m$

$\therefore\ L_{max} = 4\ m$

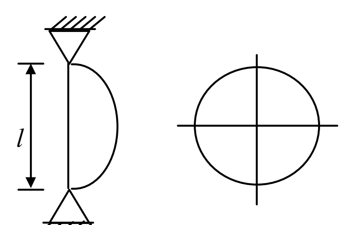
09. Ans: (c)

Sol: KL = effective length

K = effective length constant

$$\left(\frac{KL}{r}\right) = 200$$

$$\frac{\ell}{d} = ?$$



K = 1

Radius of gyration, $r_{min} = \sqrt{\frac{I}{A}}$

$$= \sqrt{\frac{\pi d^4}{64}\times\frac{4}{\pi d^2}}$$

$$= \sqrt{\frac{d^2}{16}} = \frac{d}{4}$$

$$\frac{KL}{r_{min}} = \frac{1.0\ell}{\frac{d}{4}} = 200 \qquad (\because k = 1)$$

$$\frac{\ell}{d} = \frac{200}{4} = 50$$

12. Ans: (d)

Sol: Square 300 mm × 300 mm, r_{min} = 10 mm, C = ?

λ_{max} built up column = 40

$\therefore 0.7 \times \lambda_{max} = 0.7 \times 40$

$$\left(\frac{C}{10}\right) = 28$$

C = 280 mm

16. Ans: (d)

Sol: $\theta = 45^o$

Service load = 1000 kN

Factored load = 1.5×1000 = 1500 kN

V = 2.5% of factored column load

$$V = \frac{2.5}{100} \times P$$

$$= \frac{2.5}{100} \times 1500 = 37.50 \text{ kN}$$

17. Ans: (d)

Sol: F = ?

$$\therefore F = \frac{V}{N \sin\theta} = \frac{37.5}{2 \times \sin 45^o}$$

$$= 26.51 \text{ kN}$$

21. Ans: (c)

Sol: P = 1000 kN, S = 500 mm, S_1 = 250 mm, V = ?

BM = ?

$\therefore$ V = 2.5% P

$$V = \frac{2.5}{100} \times 1000$$

V = 25 kN

$$\therefore F = \frac{VC}{NS} = \frac{25 \times 500}{2 \times 250}$$

$$= 25 \text{ kN}$$

$$\therefore BM = \frac{VC}{2N}$$

$$= \frac{25 \times 500}{2 \times 2}$$

= 3125 N.mm

22. Ans: (d)

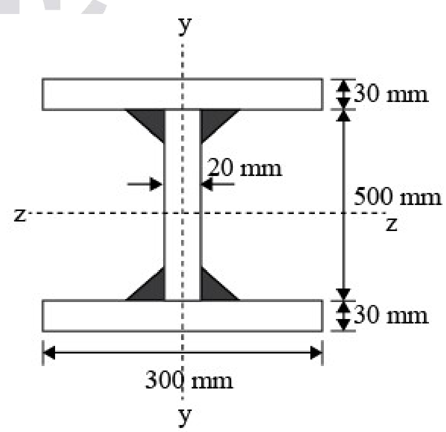
Sol: P = 1000 MPa, f_y = 250 MPa, b_f = 250 mm, t_f = 15 mm

λ = ?

$$\therefore \lambda = \sqrt{\frac{f_y}{f_{cc}}} = \sqrt{\frac{250}{1000}} = 0.50$$

23. Ans: 69.52 mm

Sol:



$A = 300 \times 30 + 20 \times 500 + 300 \times 30$

$= 28000 \text{ mm}^2$

$$\therefore I_{zz} = 2\left[\frac{300 \times 30^3}{12} + Ah_1^2\right] + \frac{20 \times 500^3}{12}$$

$$= 2\left[\frac{300 \times 30^3}{12} + 28000\left(\frac{500}{2} + \frac{30}{2}\right)^2\right] + \frac{20 \times 500^3}{12}$$

$= 4142.83 \times 10^6 \text{ mm}^4$

$$I_{yy} = 2\left[\frac{30 \times 300^3}{12}\right] + \frac{500 \times 20^3}{12}$$

$= 135.33 \times 10^6 \text{ mm}^4$

$\therefore I_{zz} > I_{yy}$

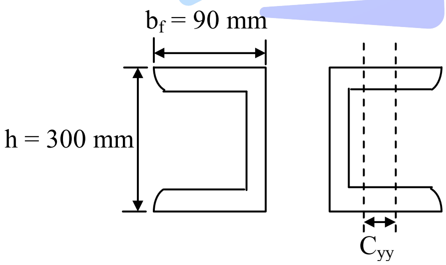
$\therefore$ Column will buckle about y-y axis

$\therefore I_{yy} = I_{min} = 135.33 \times 10^6 \text{ mm}^4$

$$\therefore \sigma_{min} = \sqrt{\frac{I_{min}}{A}} = \sqrt{\frac{135.33 \times 10^6}{28000}} = 69.52 \text{ mm}$$

24. Ans: (b)

Sol:



$r_{zz} = 118.1$ mm

$r_{yy} = 26.1$ mm

$C_{yy} = 23.6$ mm

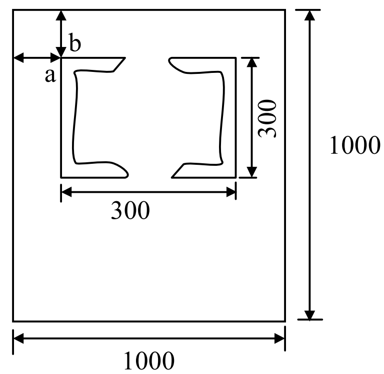
$$S = 2\sqrt{\sigma_{zz}^2 - \sigma_{yy}^2} - C_{yy}$$

$$= 2\sqrt{118.1^2 - 26.1^2} - 2 \times 23.6 = 183.15 \text{ mm}$$

07. Column Bases & Column Splices

04. Ans: (d)

Sol:



$A = 1 \text{ m}^2$, $B \times L = 300 \times 300$ mm,

$P = 2000$ kN, $t = ?$

$$\therefore \; w = \frac{P}{L \times B} = \frac{2000 \times 10^3}{1000 \times 1000} = 2 \text{ MPa}$$

$$\therefore \; t = \frac{1000 - 300}{2} = 350 \text{ mm} = b$$

$$\therefore \; t = \sqrt{\frac{2.5w}{f_y}\left[a^2 - 0.3\,b^2\right]\gamma_{mo}}$$

$$= \sqrt{\frac{2.5 \times 2}{250}\left[350^2 - 0.3350^2\right] \times 1.10}$$

$= 43.43$ mm

05. Ans: (c)

Sol: $f_{ab} = 410$ MPa, $d = 20$ mm, $f_{ck} = 20$ MPa

From IS : 456 – 2000

Bearing strength $= 0.45\, f_{ck}$

$= 0.45 \times 20$

$= 9 \text{ N/mm}^2$

06. Ans: (b)

Sol: $P_u = 2000$ kN, t = 16 mm,

$B \times L = 650 \text{ mm} \times 420 \text{ mm}$

$\therefore$ q ≤ bearing strength of concrete

$$\frac{P_u}{L \times B} \le 0.45\ f_{ck}$$

$$\frac{2000 \times 10^3}{650 \times 420} \le 0.45\ f_{ck}$$

$7.32 \le 0.45\ f_{ck}$

$f_{ck} \ge 16.26$ MPa

Minimum grade of concrete required is M20

07. Ans: (d)

Sol: $P_u = 2000$ kN, $f_{ck} = 20$ MPa

$\therefore$ Bearing strength $= 0.45\ f_{ck}$

$= 0.45 \times 20$

$W = 9\ \text{N/mm}^2$

$\therefore$ w ≤ 9 MPa

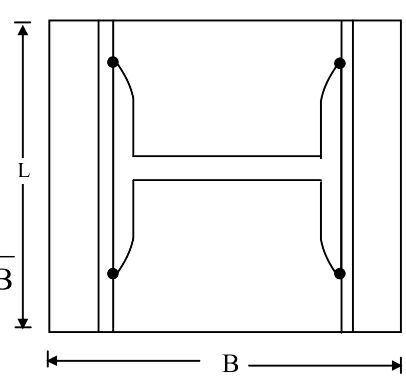
$$\frac{P_u}{L \times B} \le 9\ \text{MPa}$$

$$\frac{2000 \times 10^3}{L^2} = 9$$

L = 471.40 mm = 47.14 cm

08. Ans: (b)

Sol:



$$w = \frac{P}{L \times B}$$

$$t = C\sqrt{\frac{2.75\,w}{f_y}}$$

$$W = \frac{P}{L \times B}$$

$\therefore$ If area↑, the W↓ then t↓ but here area

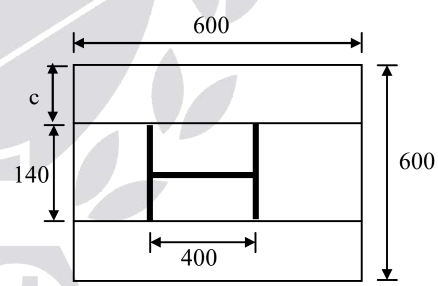
⇒ same

So $\sqrt{\dfrac{W}{f_y}}$ ⇒ constant for all options

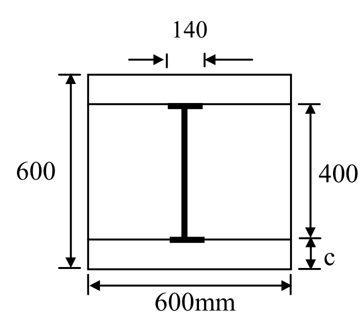
$\therefore$ t α c

Gusset plate to be provided along full width of base plate cantilever projection is available along length of base plate direction

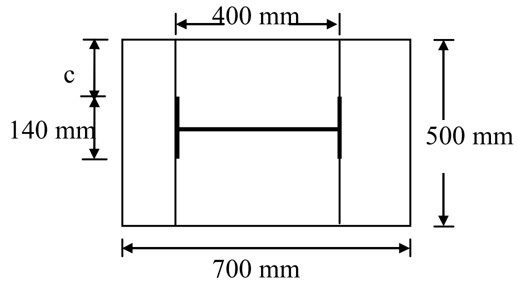
a) $c = \dfrac{600 - 140}{2} = 230\,\text{mm}$



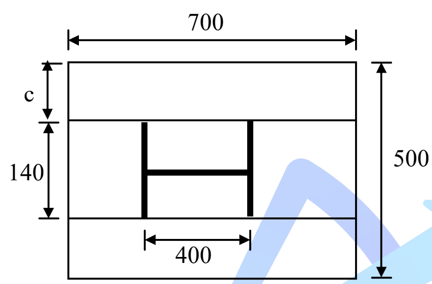
b) $c = \dfrac{600 - 400}{2}$ =100mm



c) $c = \dfrac{500 - 140}{2} = 180\,\text{mm}$



d) $c = \dfrac{700 - 400}{2} = 150\text{ mm}$



08. Beams

02. Ans: 669.201

Sol: ISMB 500 :h = 500 mm, f_{yw} = 250 MPa,

f_u = 410 MPa

γ_{m0} = 1.10, t_w = 10.2 mm,

t_f = 17.2 mm, v_d = ?

$\therefore A_V = h \times t_w$

$= 500 \times 10.2$

$= 5100\text{ mm}^2$

$$\therefore V_d = A_V \times \frac{f_{yw}}{\sqrt{3}.\gamma_{mo}}$$

$$= 5100 \times \frac{250}{\sqrt{3} \times 1.10}$$

= 669.20 kN

03. Ans: (d)

Sol: ISMB 125, h = 125 mm,

$Z_e = 71.8 \times 10^3\text{ mm}^3$, f_y = 250 MPa

$Z_p = 81.85 \times 10^3\text{ mm}^3$

For semi compact section

$$\therefore \beta_b = \frac{Z_e}{Z_p} = \frac{71.8 \times 10^3}{81.85 \times 10^3} = 0.8772$$

$$\therefore M_d = \frac{\beta_b.Z_p.f_y}{\gamma_{mo}}$$

$$= \frac{0.8722 \times 81.85 \times 10^3 \times 250}{1.10}$$

= 16.22 kN-m

09. Ans: (b)

Sol: $\beta_b = 1$, $Z_P = 3.94 \times 10^6\text{ mm}^3$, f_y = 250 MPa,

$M_{cr} = 16866 \times 10^6$ N-mm

$$\lambda_{LT} = \sqrt{\frac{\beta_b.Z_p.f_y}{M_{cr}}}$$

$$= \sqrt{\frac{1 \times 3.94 \times 10^6 \times 250}{16866 \times 10^6}} = 0.2416$$

10. Ans: (a)

Sol: $Z_e = 500\text{ cm}^3$, $Z_P = 650\text{ cm}^3$

Laterally unrestrained beam semi compact section

Design bending compressive stress

f_{bd} = 200 MPa

The flexural (or) bending strength

$M_d = \beta_b .Z_p. f_{bd}$

$$= \frac{Z_e}{Z_P}.Z_p.f_{bd}$$

$= 500 \times 10^3 \times 200 = 100 \times 10^6$ N-mm

M_d = 100 kN-m

13. Ans: (b)

Sol: $f = 140\text{ MPa},\ \delta_{max} \le \dfrac{L}{480}$

$$BM = \frac{WL}{4}$$

$$\text{But, } \delta_{max} = \frac{WL^3}{48EI}$$

$$= \frac{WL}{4} \times \frac{L^2}{12EI}$$

$$= M \times \frac{L^2}{12EI}$$

$$\text{As, } \frac{M}{I} = \frac{f}{y}$$

$$M = f \times \frac{I}{y}$$

$$\therefore \delta_{max} = f \times \frac{I}{y} \times \frac{L^2}{12EI}$$

$$\frac{L}{480} = \frac{f}{y} \times \frac{L^2}{12E}$$

$$\frac{1}{480} = \frac{f}{(h/2)} \times \frac{L}{12E}$$

$$\frac{1}{480} = \frac{fL}{6Eh}$$

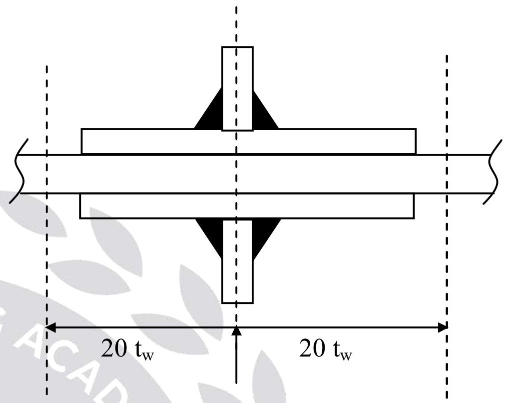
$$\frac{1}{480} = \frac{140 \times L}{6 \times 2 \times 10^5 \times h}$$

$$\therefore \frac{h}{L} = 0.056$$

09. Plate Girders

13. Ans: (b)

Sol:



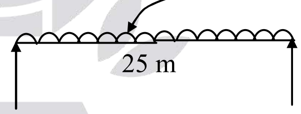
$\therefore A_e = 2 \times \text{area of flat} + (40\ t_w)\ t_w$

$= (2 \times 100 \times 5) + (40 \times 10) \times 10$

$= 5000\text{ mm}^2$

14. Ans: (a)

Sol:



$L = 25\text{ m},\ k = 200,\ f_y = 250\text{ MPa},\ t_w = ?$

$$\therefore BM = \frac{WL^2}{8}$$

$$= \frac{80 \times 25^2}{8} = 6250\text{ kN-m}$$

Self weight of welded plate girder

$$= \frac{w}{400} = \frac{w \times L}{400} = \frac{80 \times 25 \times 1.5}{400}$$

$$= 7.5\text{ kN/m}$$

$$\therefore \quad BM = \frac{wL^2}{8}$$

$$= \frac{(80+7.5)\times 25^2}{8}$$

= 6640.62 kN-m

$$\therefore \quad d = \left(\frac{MK}{f_y}\right)^{0.33}$$

$$= \left(\frac{6640.62\times 200}{250}\right)^{0.33}$$

= 17.12 mm

$$\therefore \quad k = \frac{d}{t_w}$$

$$200 = \frac{17.44}{t_w}$$

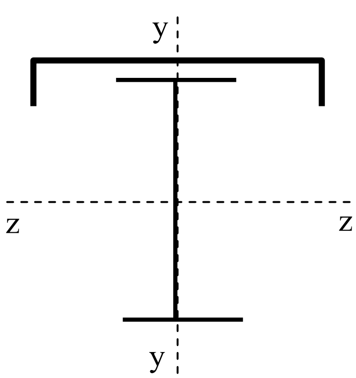
$t_w = 8.72$ mm

$t_w \approx 10$ mm

10. Gantry Girders

01. Ans: (a)

Sol:



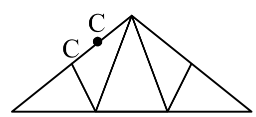
$I_{yy} = (I_{yy\ of\ ISWB} + I_{zz\ channel})$

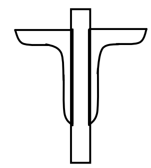
11. Roof Trusses

01. Ans: (d)

Sol: Rigidity due to weld connections

$\Rightarrow$ Rigidity will be there top chord member bottom chord member.

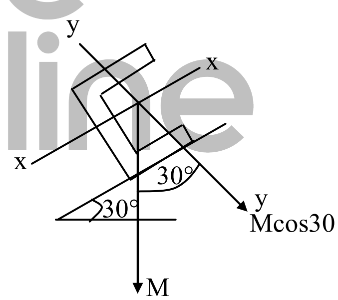




Purlins if placed of intermediate section then cause secondary stresses

02. Ans: (a)

Sol:



$$M_{xx} = M\cos\theta\,(\theta = 30^0) = \frac{\sqrt{3}}{2}M$$

$$M_{yy} = M\sin\theta = \frac{M}{2}$$