NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2016-2017

CV4102 - ADVANCED STEEL DESIGN

November/December 2016 **Time Allowed: 2½ hours**

INSTRUCTIONS

1. This paper contains **FOUR (4)** questions and comprises **SIX (6)** pages.
2. Answer **ALL FOUR (4)** questions.
3. All questions carry equal marks.
4. This paper is an Open Book Examination.

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1. Figure Q1 shows a T-joint fabricated using circular hollow section (CHS) members, together with the loading conditions, detailed specifications and dimensions of the members. Use design recommendations given in Eurocode 3, EN-1993, Part 1-8: 2013,

   (a) Determine the joint parameters γ and β, and the ranges of validity. If the brace is subjected only to axial compression N_{Ed} of 360 kN, calculate the joint strength, the compressive stress in the chord $\sigma_{0,Ed}=0.6f_{y0}$, and state the critical failure mechanism.
   not $\sigma_{p,Ed}$
   (12 Marks)

   (b) Recalculate the joint strength if an additional in-plane bending moment $M_{ip,Ed}$ of 60 kNm is applied to the brace, and also check the interaction equation given in the codes.
   (10 Marks)

   (c) What is the effect of increasing the compression stress in the chord from $0.6f_{y0}$ up to its maximum value of f_{y0} on the joint strength?
   (3 Marks)

Note: Question No. 1 continues on page 2.

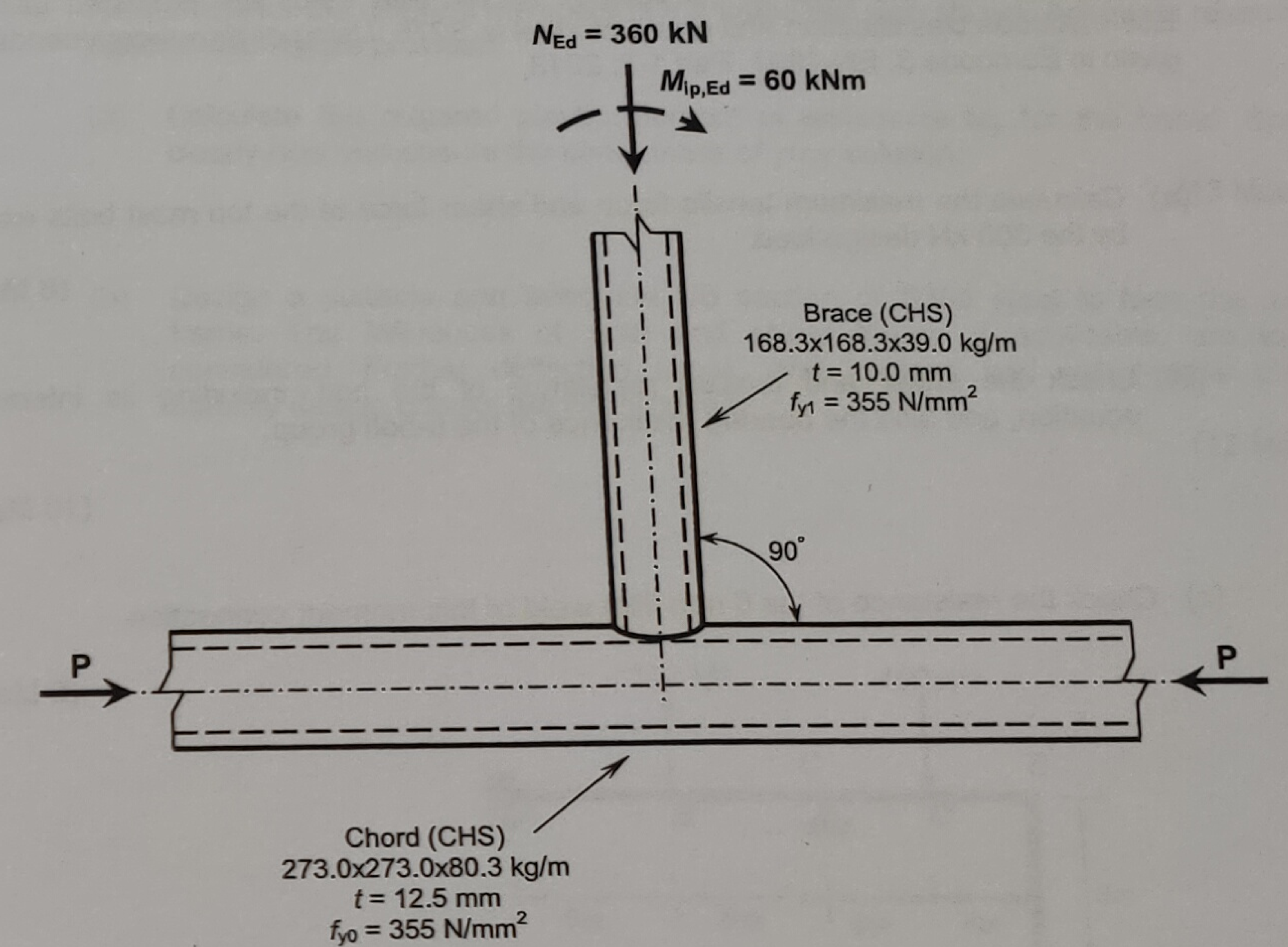
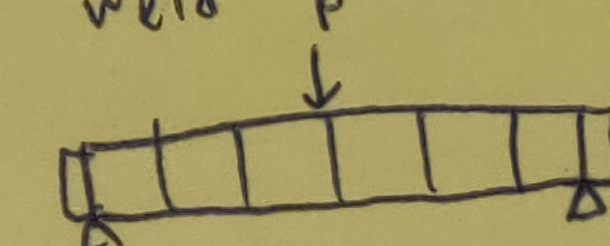
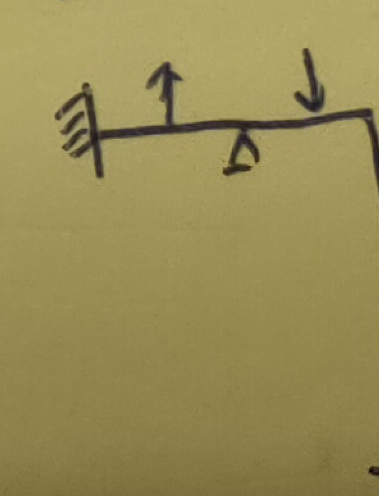


Figure Q1

(Note: drawings are not drawn to scale)

① T joint with Mip,Ed CHS
② C-shape perpendicular moment weld
③


④


2. A moment connection shown in Figure Q2 is used to connect 260x75x28 kg/m C-section to 254x254x107 kg/m UC. The C-section is welded to the end-plate using 6 mm fillet weld and in turn it is bolted to the flange of the column using six numbers of Class 8.8 ϕ16 mm non-preloaded bolts. A design load of 300 kN is applied at a distance of 120 mm from the edge of the column. All the fillet welds are produced using an E35 electrode classification and grade of steel is S275. Using design recommendations given in Eurocode 3, EN-1993, Part 1-8: 2013,

(a) Calculate the maximum tensile force and shear force of the top most bolts exerted by the 300 kN design load. (6 Marks)

(b) Check the shear and tension resistance of the bolt, including its interaction equation, and also the bearing resistance of the 6-bolt group. (10 Marks)

(c) Check the resistance of the 6 mm fillet weld of this moment connection. (9 Marks)

Note: Question No. 2 continues on page 4.

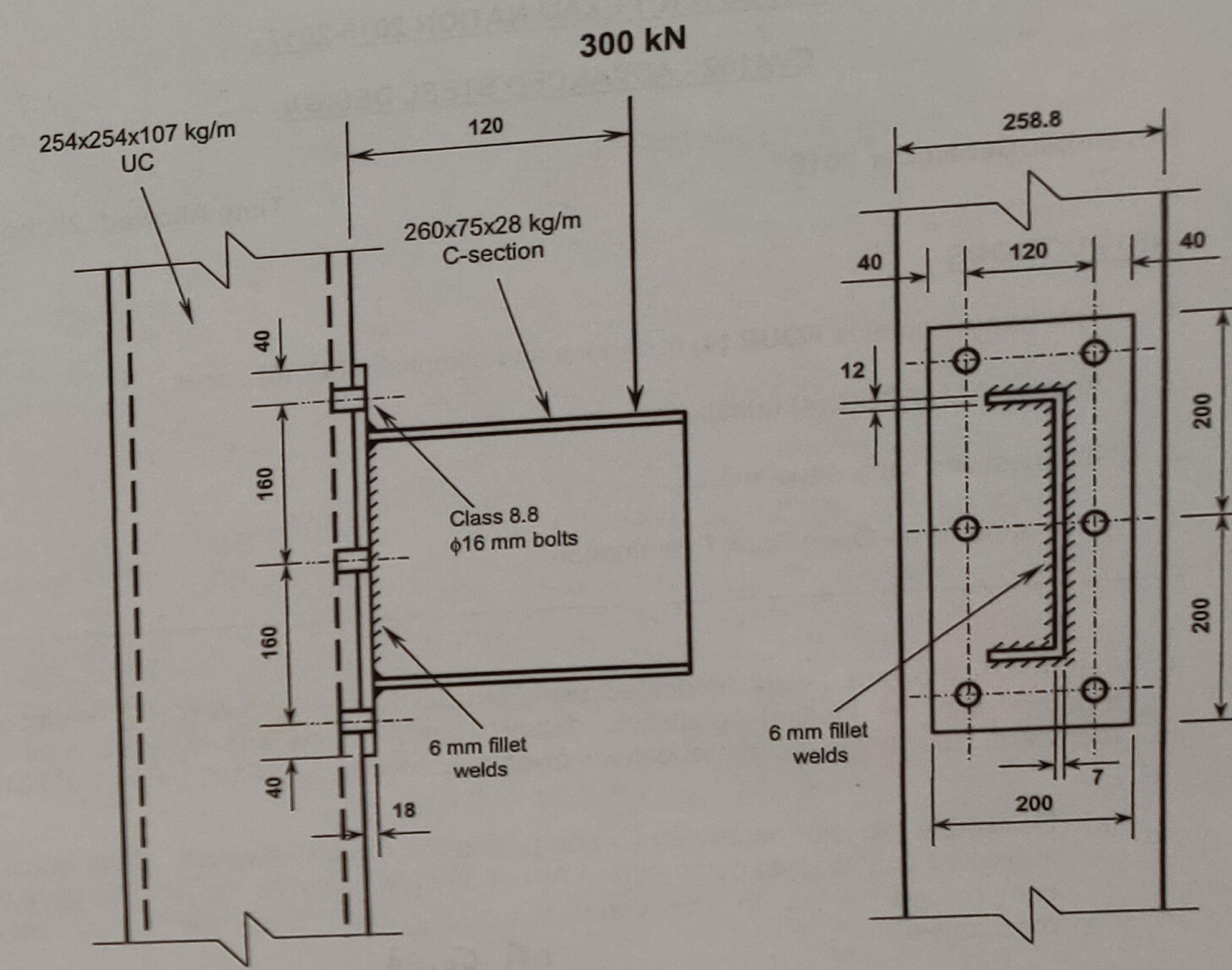


Figure Q2

(Note: drawings are not drawn to scale)

(All dimensions are in mm unless otherwise stated)

3. The 30 m span simply-supported plate girder shown in Figure Q3(a) is fabricated from Grade S275 steel plates throughout. It is simply supported at end posts A and C, and effectively restrained in the lateral direction along the entire plate girder. It is supporting one (1) factored design concentrated load P kN at load bearing stiffener B located at mid-span. Details of the load bearing stiffener are given in Figure Q3(b). Assume that all the end posts, intermediate stiffeners and load bearing stiffener are rigid.

(i) Classify the flange and web of the girder.
(ii) Compute the bending resistance of the girder.
(iii) Compute the shear resistance of the girder.
(iv) Compute the load bearing resistance of the stiffener at B.
(v) What is the allowable load P?

(25 Marks)

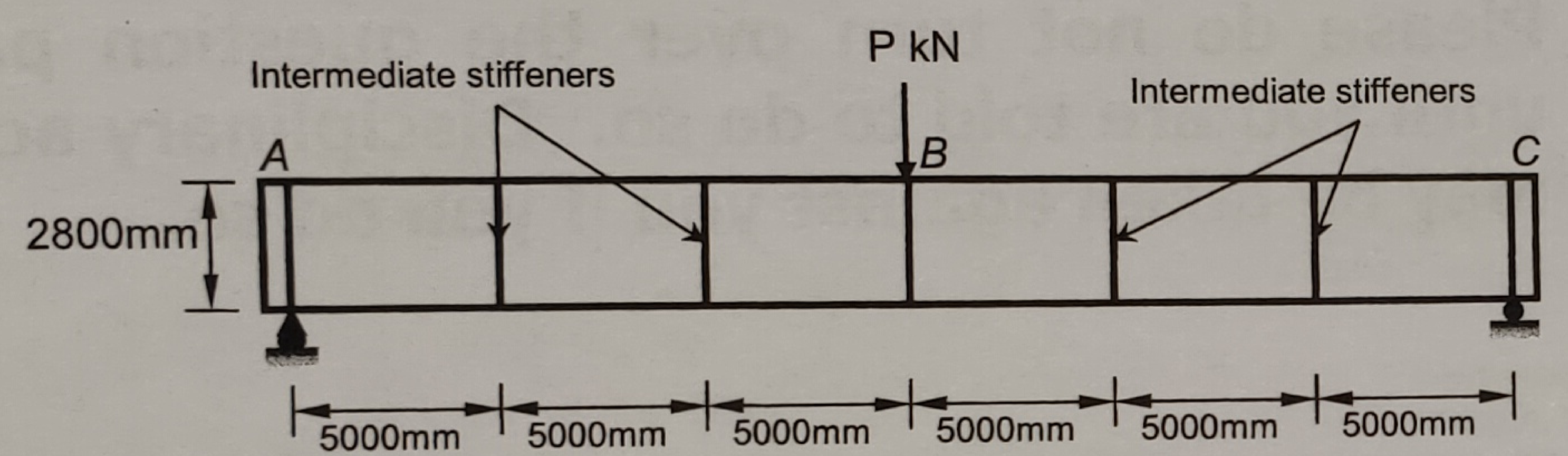
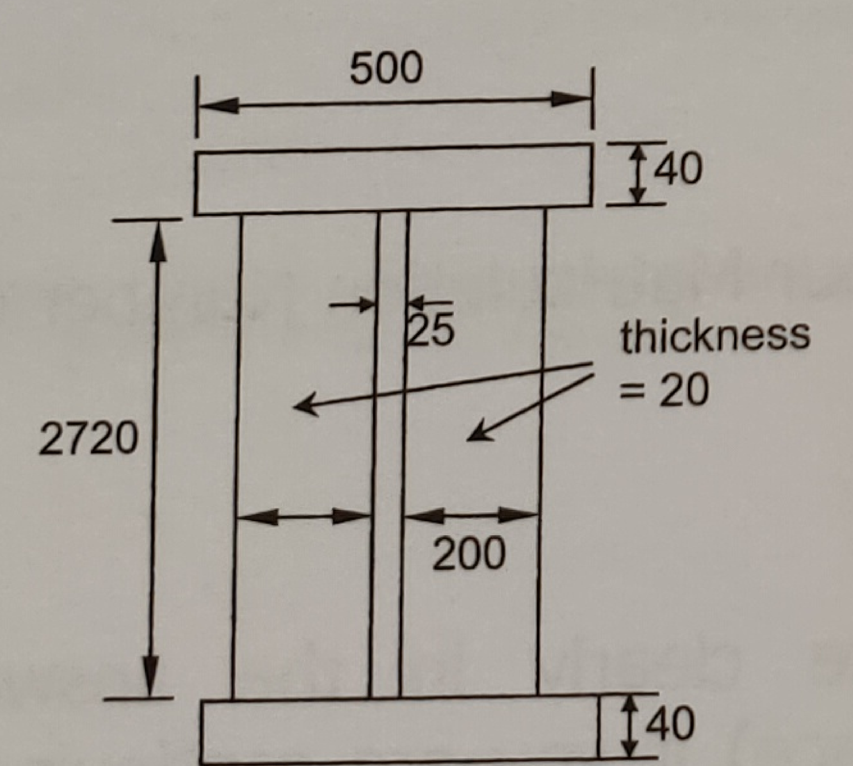


Figure Q3(a)



Section through load bearing stiffener at B.

Note: All dimensions in mm.

Figure Q3(b)

4. The frame shown in Figure Q4 is fixed at A, simply supported at C and pinned at G, and is subjected to three (3) factored design concentrated loads. The plastic moment resistances for the different members of the frame are also shown. Adequate restraints against stability are provided.

(a) Calculate the required plastic moment of resistance M_p for the frame. Show clearly how you ensure the correctness of your solution.

(13 Marks)

(b) Design a suitable and adequate UB section of S355 steel to form the entire frame. The influences of axial and shear forces, if applicable, are to be considered. Further deflection check, and in-plane and out-of-plane plastic stability design checks are not required.

(12 Marks)

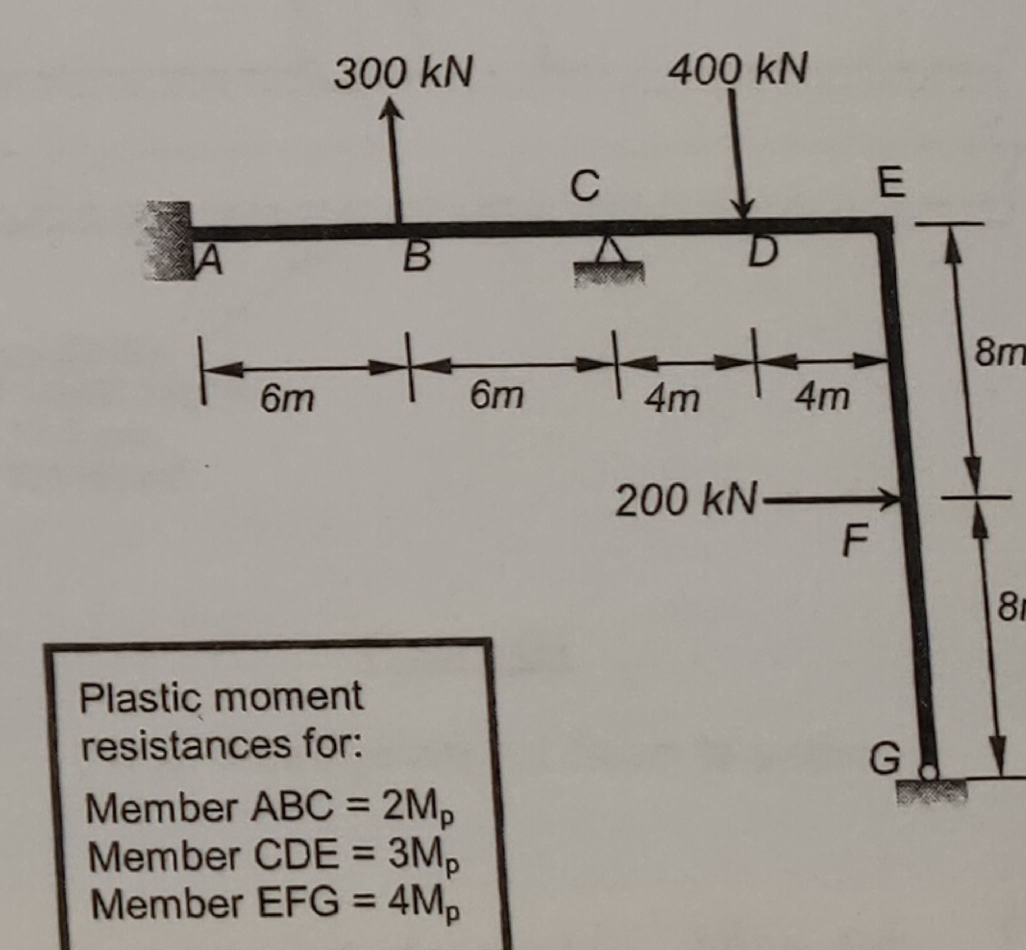


Figure Q4

END OF PAPER

CV4402 PYP 2016/17

1) a) $\gamma = \frac{d_0}{2t_0} = \frac{273}{2(12.5)} = 10.92$ ✓

$\beta = \frac{d_1}{d_0} = \frac{168.3}{273} = 0.616$ ✓

Ranges of validity

$0.2 \leq \frac{d_1}{d_0} = \frac{168.3}{273} = 0.616 \leq 1.0$ ✓

chord in compression

$10 \leq \frac{d_0}{t_0} = \frac{273}{12.5} = 21.84 \leq 50 < 46.3$ (class 2) ✓

Braces in compression

$10 \leq \frac{d_1}{t_1} = \frac{168.3}{10} = 16.83 \leq 50 < 46.3$ (class 2) ✓

$N_{1,Rd} = \frac{\gamma^{0.2} k_p f_{y0} t_0^2}{\sin\theta_1}(2.8 + 14.2\beta^2)/\gamma_{M5}$

~~$N_{p,Ed} = N_{0,Ed} - \Sigma N_{i,Ed}\cos 90°$~~ * CHS use $\sigma_{p,Ed}$!

$N_{p,Ed} = N_{0,Ed}$ ✓

$\sigma_{0,Ed} = \sigma_{p,Ed} = 0.6 f_{y0}$

$n_p = \frac{\sigma_{p,Ed}}{f_{y0}} = 0.6$

For $n_p > 0$ (compression)

$k_p = 1 - 0.3 n_p(1+n_p) \leq 1.0$

$= 1 - 0.3(0.6)(1+0.6) \leq 1.0$

$= 0.712 \leq 1.0$ ✓

$N_{1,Rd} = \frac{10.92^{0.2}(0.712)(355)(12.5)^2}{\sin 90°}[2.8 + 14.2(0.616)^2]/1.0$

$= 521.633$ kN (chord face failure). ✓

$d_1 = 168.3 \leq d_0 - 2t_0 = 273 - 2(12.5) = 248$ ✓

need to check for punching shear failure.

$N_{1,Rd} = \frac{f_{y0}}{\sqrt{3}} t_0 \pi d_1 \frac{1+\sin\theta_1}{2\sin^2\theta_1}$

$= \frac{355}{\sqrt{3}}(12.5)\pi(168.3)\frac{1+\sin 90°}{2\sin^2 90°}$

$= 1354.6$ kN ✓

$A_1 f_{y1} = \frac{\pi}{4}\{168.3^2 - 148.3^2\}(355)$

$= 1765.47$ kN

∴ critical failure mechanism ⇒ chord face failure ✓

??

b) Chord face failure

$M_{ip,1,Rd} = 4.85 \frac{f_{y0} t_0^2 d_1}{\sin\theta_1}\sqrt{\gamma}\,\beta k_p/\gamma_{M5}$

$n_p = 0.6 > 0$ (compression)

$k_p = 1 - 0.3 n_p(1+n_p)$

$= 1 - 0.3(0.6)(1+0.6)$

$= 0.712$

$M_{ip,1,Rd} = 4.85 \frac{355(12.5)^2(168.3)}{\sin 90°}\sqrt{10.92}(0.616)(0.712)/1.0$

$= 65.62$ kNm > 60 kNm

Punching shear failure:

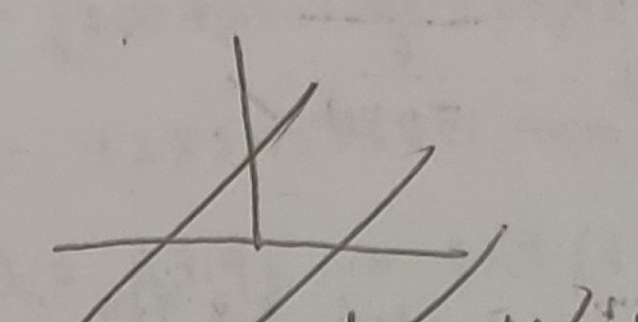
$M_{ip,1,Rd} = \frac{f_{y0} t_0 d_1^2}{\sqrt{3}} \frac{1+3\sin\theta_1}{4\sin^2\theta}/\gamma_{M5}$

$= \frac{355(12.5)(168.3)^2}{\sqrt{3}} \frac{1+3\sin 90°}{4\sin^2 90°}/1.00 = 72.57$ kNm > 60 kNm

$\frac{N_{1,Ed}}{N_{1,Rd}} + \left[\frac{M_{ip,1,Ed}}{M_{ip,1,Rd}}\right]^2 \leq 1.0$

$\frac{360}{521.633} + \frac{60}{65.62} = 1.604 \geq 1.0$

NOT ok!



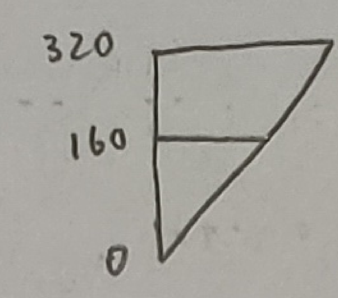
~~$\sigma_{p,Ed} = \frac{N_{p,Ed}}{A_0} + \frac{M_{0,Ed}}{W_{el,0}}$~~

c) When increase $\sigma_{0,Ed}$ to f_{y0}, $n_p = 1$,

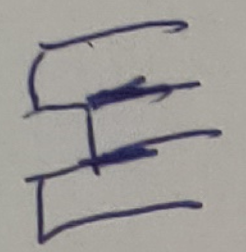
$k_p = 0.4$

This lowers the resistance of the brace against chord face failure.

2) a) $F_{t,Ed} = \frac{Pey_1}{2\sum y_i^2}$



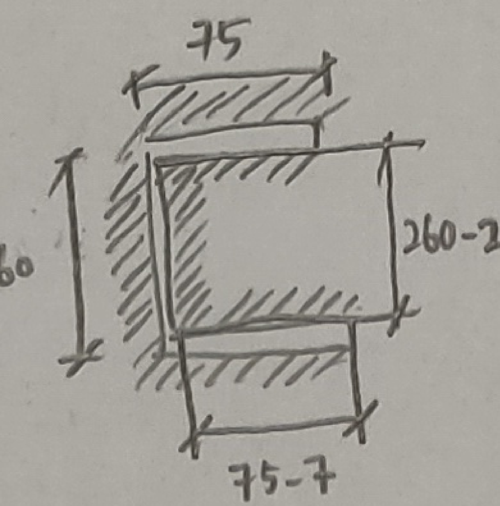
$= \frac{300(120)(320)}{2\times(160^2+320^2)}$



$= 45\ kN$ ✓

$F_{v,Rd} = \frac{P}{\text{No. of bolts}} = \frac{300}{6}$

$= 50\ kN$ ✓



c) Throat length of 6mm fillet weld

$\Rightarrow a = 6\times\cos 45^\circ = 4.24\ mm$ ✓

Total area of 6mm fillet weld

$= [2\times 75 + 260 + (260-24) + 2\times(75-7)]\times 4.24$

$= 3315.68\ mm^2$ ✓

$f_s = \frac{P}{\text{Area of weld}} = \frac{300}{3315.68}$

$= 90.5\ kPa$ ✓

b) From bolt table, Non-preloaded 8.8, $\phi 16$

$F_{t,Rd} = 90.4\ kN > 45\ kN$ ok!

$F_{v,Rd} = 60.3\ kN > 50\ kN$ ok!

I_{yy} (75-7, 260-24, $\frac{260}{2}-12$)

$= 2\left(\frac{75\times 4.24^3}{12} + 75\times 4.24\times\left(\frac{260}{2}\right)^2\right) + \frac{4.24\times 260^3}{12}$

$+ \frac{236^3(4.24)}{12} + 2\left(\frac{68\times 4.24^3}{12} + 68\times 42.4\times 118^2\right)$

~~= 1018... mm⁴~~

$= 10749352.81 + 6210186.667 + 4644303.787$

$+ 8029999.244$

$= 29633842.51\ mm^4$ ✓

$F_{v,Rd} = \frac{\alpha_v f_{ub} A}{\gamma_{m2}}$

$F_{t,Rd} = \frac{k_2 f_{ub} A_s}{\gamma_{M2}}$

$= \frac{0.9(800)(157)}{1.25}$

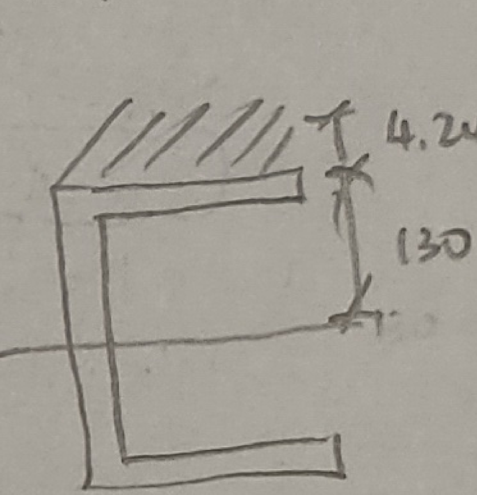
$= 90.4\ kN > 45\ kN$ ✓

class 8.8 → $\alpha_v = 0.6$, $f_{ub} = 800$

$\phi 16$ → $A_s = 157$

$F_{v,Rd} = \frac{0.6(800)(157)}{1.25}$

$= 60.3\ kN > 50\ kN$ ✓



$W_{el,y} = \frac{I_{yy}}{y}$

$= \frac{29633842.51}{130+4.24}$

$= 220752.7\ mm^3$ ✓

Combined shear & tension

$\frac{F_{v,Ed}}{F_{v,Rd}} + \frac{F_{t,Ed}}{1.4F_{t,Rd}} \le 1.0$

$\frac{50}{60.3} + \frac{45}{1.4(90.4)} = 1.185 > 1.0$ NOT ok!

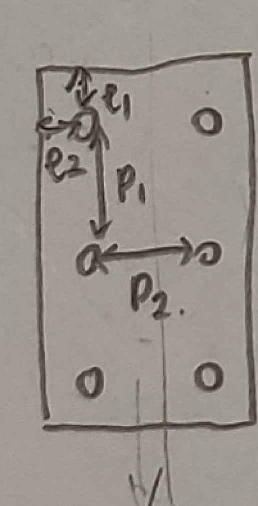
$f_b = \frac{P\times e}{Z_{xx}} = \frac{M}{W_{el}} = \frac{300(120)}{220752.7}$

$= 163.08\ kPa$ ✓

Bearing resistance check

$F_{b,Rd} = \frac{k_1\alpha_b f_u d t}{\gamma_{M2}}$

$\alpha_b = \min\left(\alpha_d, \frac{f_{ub}}{f_u}, 1.0\right)$



$f_r = \sqrt{f_s^2 + f_b^2} = \sqrt{90.5^2 + 163.08^2}$

$= 186.51\ kPa$ ✓

In direction of load transfer,

end $\Rightarrow \alpha_d = \frac{e_1}{3d_0} = \frac{40}{3(18)} = 0.74$ $\boxed{\alpha_b = 0.74}$ ✓

* $d_0 = 16+2$

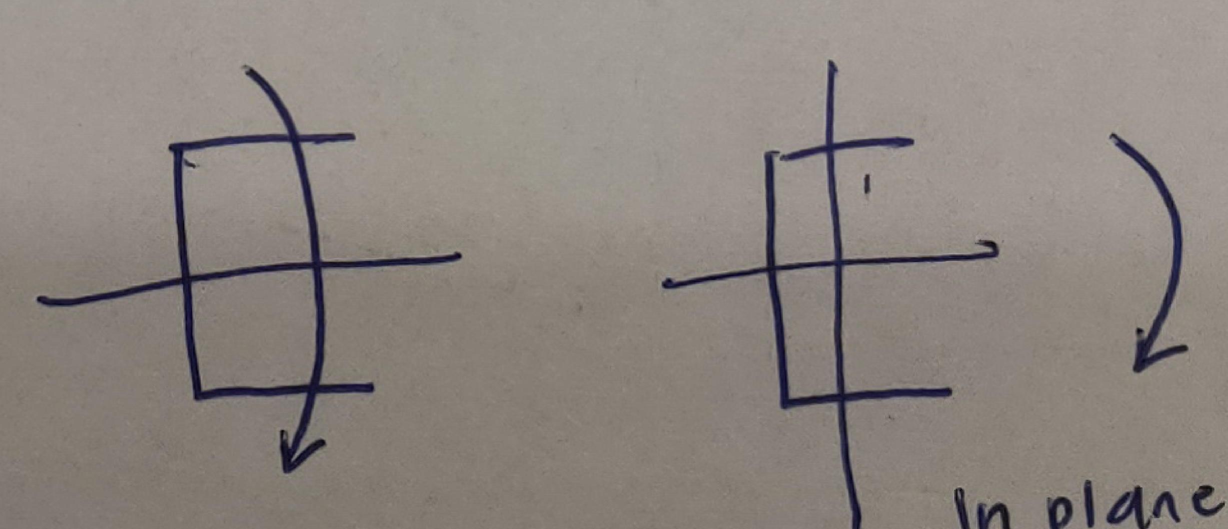
inner $\Rightarrow \alpha_d = \frac{P_1}{3d_0} - \frac{1}{4} = \frac{(200-40)}{3(18)} - \frac{1}{4} = 2.71$ $\boxed{\alpha_b = 1.0}$ ✓

Weld Resistance

$f_{vw,d} = \frac{f_u/\sqrt{3}}{\beta_w\times\gamma_{M2}} = \frac{430/\sqrt{3}}{0.85\times 1.25}$ (5275)

$= 233.657 > 186.51$ ok!

$\frac{f_{ub}}{f_u} = \frac{800}{430} = 1.86$



Perpendicular to load transfer,

end $\Rightarrow k_1 = \min\left(2.8\frac{e_2}{d_0} - 1.7, 2.5\right)$

$= \min\left(2.8\left(\frac{40}{18}\right) - 1.7, 2.5\right)$

$= \min(4.52, 2.5)$

$= 2.5$ ✓

Bearing resistance

$= 2(183.28) + 4(247.68)$

$= 1357.28\ kN$

inner $\Rightarrow k_1 = \min\left(1.4\frac{P_2}{d_0} - 1.7, 2.5\right)$

$= \min\left(1.4\left(\frac{120}{18}\right) - 1.7, 2.5\right)$

$= \min(7.63, 2.5)$ ✓

$= 2.5$

thickness of plate?

For end bolts, $F_{b,Rd} = \frac{(2.5)(0.74)(430)(16)(18)}{1.25}$

$= 183.28\ kN$

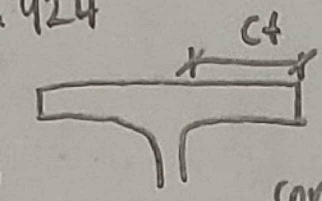
For inner bolts, $F_{b,Rd} = \frac{(2.5)(1)(430)(16)(18)}{1.25}$

$= 247.68\ kN$

* support reactions
⇒ P/2

i) For Grade S275 steel

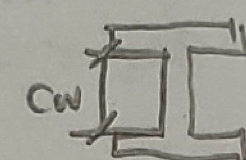
$\varepsilon = \sqrt{235/275} = 0.924$



Flange $\frac{c_f}{t_f} = \frac{(500-25)/2}{40} = \frac{250 - 25}{40} = 5.625 \leq 9\varepsilon = 8.316$ compression

∴ Flange is class 1

Web



$\frac{c_w}{t_w} = \frac{2720}{25} = 108.8 \leq 124\varepsilon = 114.576$ bending

∴ Web is class 3

ii) Bending resistance ($t \leq 40$, $f_y = 275\,N/mm^2$)

Flange Class 1, web class 3

⇒ method 1

$M_{y,Rd} = W_{pl,f} f_{yf} + W_{el,w} f_{yw}$

Resistance From Flange ⇒ $W_{pl,f} f_{yf} = A_f (h_w + t_f) f_{yf}$

$= (500 \times 40)(2720 + 40)(275)/10^{-6}$

$= 15180$ kNm

$I_w = \left(\frac{2720^3 \times 25}{12}\right) = 4.192 \times 10^{10}\ mm^4$

$W_{el,w} = I_w / z = \frac{4.192 \times 10^{10}}{2720/2} = 30826666.67\ mm^3$

$W_{el,w} f_{yw} = 8477.33$ kNm ✓

$M_{y,Rd} = 15180 + 8477.33 = 23657.33$ kNm ✓

→ Flange induced buckling

iii) For stiffened web,

$\frac{h_w}{t_w} \leq 31 \frac{\varepsilon}{\eta} \sqrt{k_\tau}$

$a = 5000$

$a/h_w = 5000/2720 = 1.84 \geq 1$

$k_\tau = 5.34 + 4\left(\frac{h_w}{a}\right)^2 = 6.524$

$\frac{h_w}{t_w} = \frac{2720}{25} = 108.8 \leq 31 \frac{0.924}{1}\sqrt{6.524} = 73.16$ ✓

∴ Web is NOT stocky ✓

$V_{b,Rd} = V_{bw,Rd} + V_{bf,Rd} \leq \frac{\eta f_{yw} h_w t_w}{\sqrt{3}\,\gamma_{M1}}$

Web

→ $V_{bw,Rd} = \frac{\chi_w f_{yw} h_w t_w}{\sqrt{3}\,\gamma_{M1}}$

TFA

$= V_{Ed} - \frac{1}{\bar{\lambda}_w^2} \frac{h_w f_{yw} t_w}{\sqrt{3}\,\gamma_{M1}}$

$= P - \frac{1}{1.233^2} \frac{2720(275)(25)}{\sqrt{3}}$

$= P - 7101.577$

For transverse & intermediate transverse stiffener

$\bar{\lambda}_w = \frac{h_w}{37.4 t_w \varepsilon \sqrt{k_\tau}} = \frac{2720}{37.4(25)(0.924)\sqrt{6.524}}$

$= 1.233 \geq 1.08$ ✓

For rigid end post,

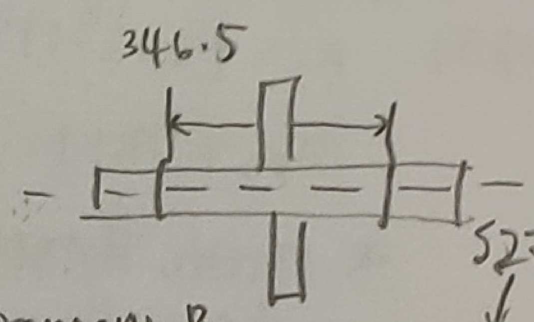
$\chi_w = 1.37/(0.7 + 1.233) = 0.71$ ✓

$V_{bw,Rd} = \frac{0.71(275)(2720)(25)}{\sqrt{3}(1.00)} = 7665.5$ kN ✓

* Assume no contribution from flange (resist bending moment)

$\eta_3 = \frac{V_{Ed}}{V_{R,Rd}} < 0.5$ ← no V_{Ed} how to check?

iv) Load bearing stiffener @ B.



$15\varepsilon t_w = 15(0.924)(25) = 346.5$ ✓

$A_{st} = (346.5 + 20 + 346.5)\,25 + 2(200 \times 20)$

$= 25825\ mm^2$ ✓

* requirement B ⇒ $b/t = 200/20 = 10 < 12\varepsilon$

$I_{st} = (200 + 25 + 200)^3 \times 20/12 + 2(346.5 \times 25^3/12)$

$= 128845052.1\ mm^4$ ✓

$\lambda = 93.9\varepsilon = 93.9(0.924) = 86.764$

$i_{st} = \left(\frac{I_{st}}{A_{st}}\right)^{0.5} = 70.63$ mm ✓

$\bar{\lambda} = \frac{L_{cr}}{i}\frac{1}{\lambda} = \frac{2720}{70.63}\frac{1}{86.764}$?

$= 0.444 > 0.2$ ✓

curve c, $\alpha = 0.49$

$\Phi = 0.5[1 + \alpha(\bar{\lambda} - 0.2) + \bar{\lambda}^2]$

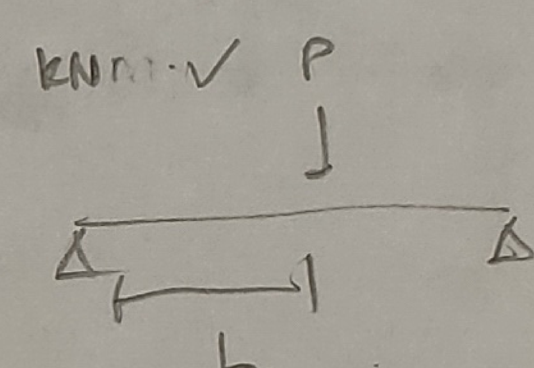
$= 0.658$ ✓

$\chi = \frac{1}{\Phi + \sqrt{\Phi^2 - \bar{\lambda}^2}} = 0.874$ ✓

$N_{b,Rd} = 0.874 \times 25825 \times 275$ (A_{st}, f_y)

$= 6205.54$ kN ✓

v). Support reaction



⇒ $\frac{P}{2}$

$V_{max} = P/2$

$M_{max} = \frac{PL}{4} = \frac{P(30)}{4} = 7.5P$

~~$M_{y,Rd} > 7.5P$~~

$P < 3154.31$ kN ← governing

~~$V_{bw,Rd} > P/2$~~

$P < 15331$ kN

⇒ load bearing stiffener

$a = 5000 >> b = 2800$

$\frac{\sigma_{cr,c}}{\sigma_{cr,p}} = 0.5$

assume f_y reach extreme fibre.

$N_{Ed} = \left(\frac{2720}{2}\right)(25)\left(\frac{275}{2}\right)$

$= 4675$ kN.

$\sigma_m = 0.5\left(\frac{4675}{2800}\right)\left(\frac{1}{5000} + \frac{1}{5000}\right)$

$= 0.334$.

$\Delta N_{s,ten} = \frac{0.334(2720)^2}{\pi^2}$

$= 250.317$ kN.

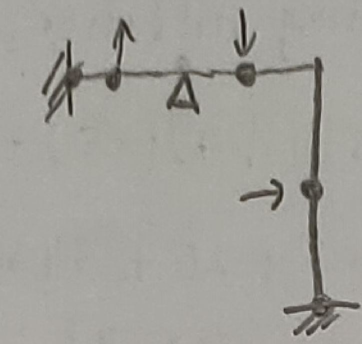
Force $= P + P - 7101.577 + 250.317 < 6205.54$

$2P < 13056.8$

$P < 6528.4$.

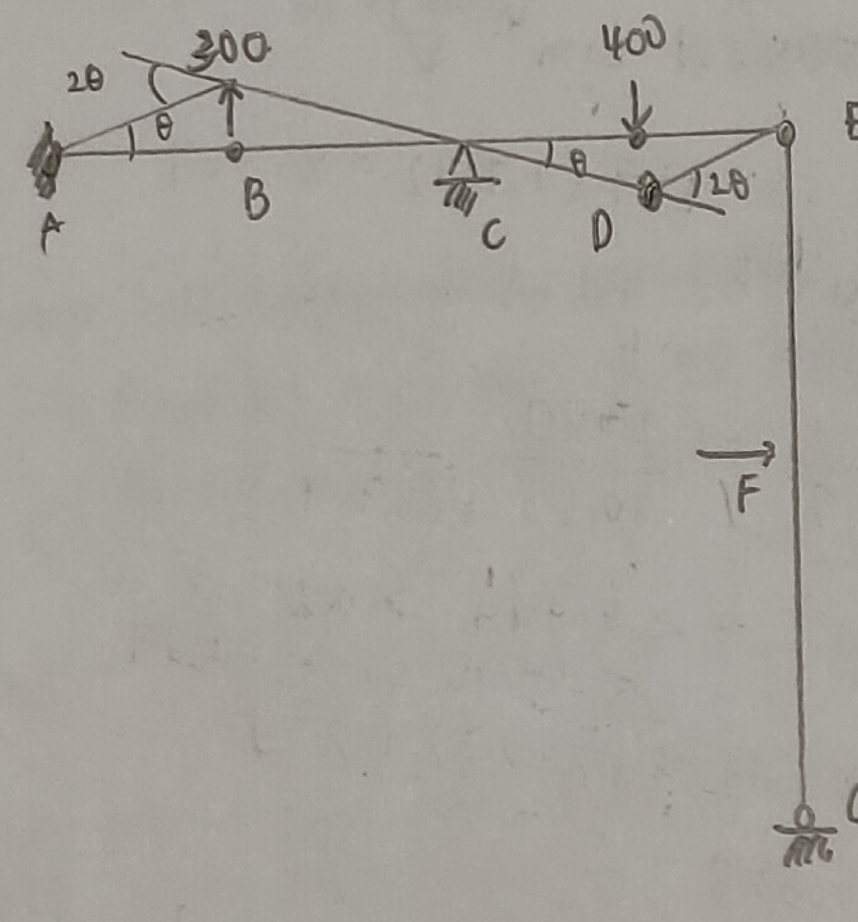
4) a) $n_s = (3+2+1) - 3 = 3$

$n_{ph} = n_s + 1 = 3 + 1 = 4$



* Plastic hinges form at:
  - → supports
  - → pts of conc. loads
  - → pts of max. moments
  - → pts of cross section change (diff Mp)

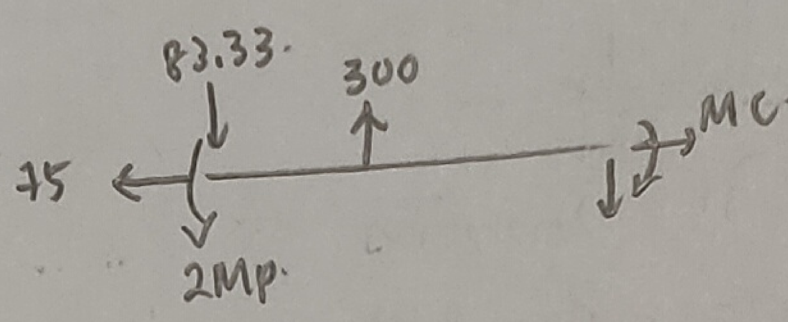
Mechanism 1 (A-B-D-E)



$300(6\theta) + 400(4\theta)$
$= 2Mp(\theta) + 2Mp(2\theta) + 3Mp(\theta) + 3Mp(2\theta)$

$Mp = 226.67$ KNm

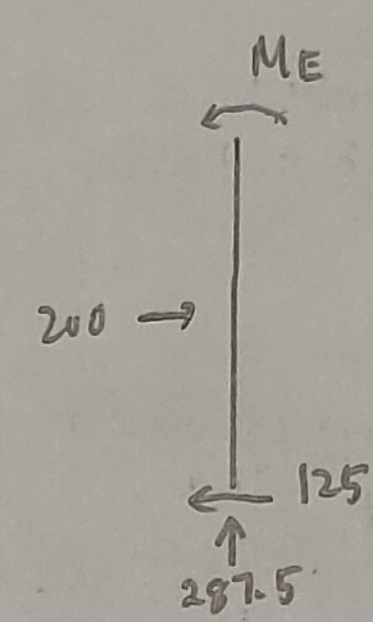
Check Mc and ME



$\Sigma M_C = 0$

$2Mp + 83.33(12) = 300(6) + M_C$

$M_C = -300$ KN $< 2Mp = 500$



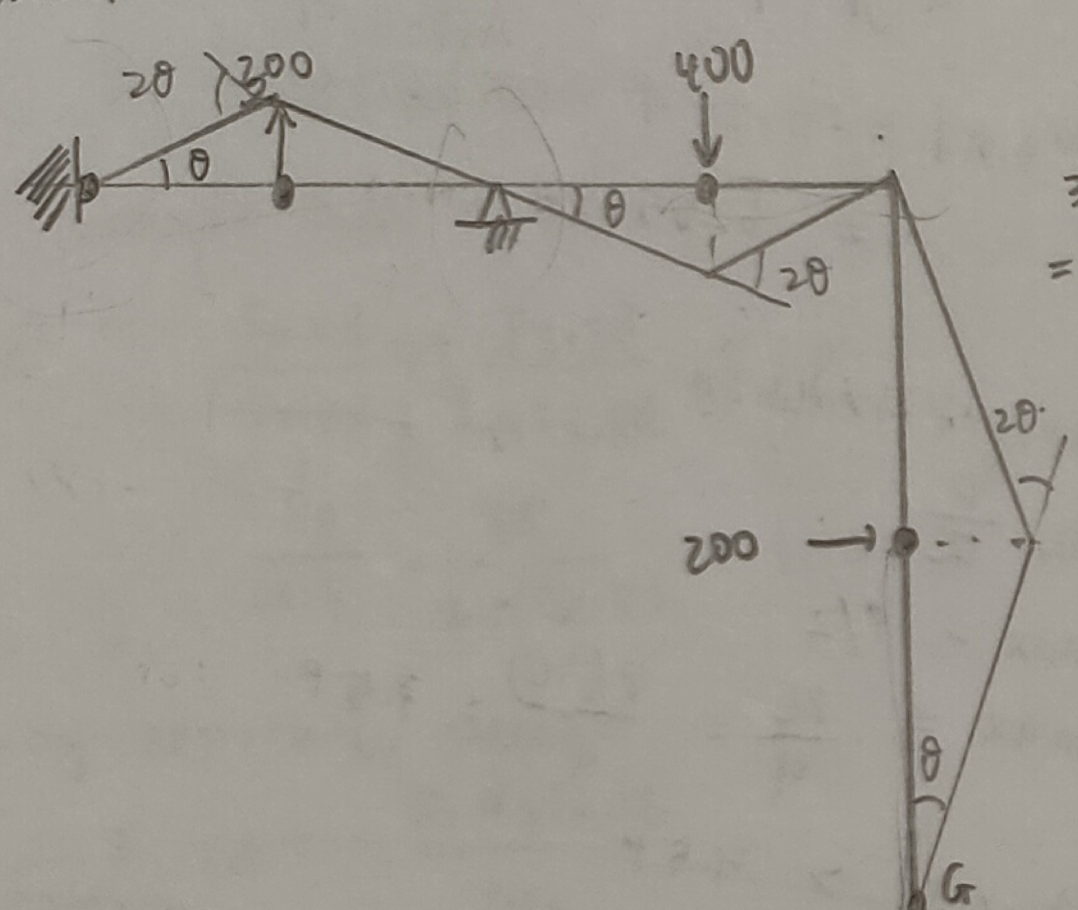
$\Sigma M_E = 0$

$125(16) = 200(8) + M_E$

$M_E = 200$ KN $< 3Mp = 750$

plasticity satisfied.

Mechanism 2 (A-B-D-F)



$300(6\theta) + 400(4\theta) + 200(8\theta)$
$= 2Mp(\theta) + 2Mp(2\theta) + 3Mp(2\theta) + 4Mp(2\theta)$

$5000 = 20Mp$

$Mp = 250$ KNm

(Hypothesis: correct mechanism)

b) $W_{pl} \geq \frac{4Mp}{f_y} = \frac{1000}{355} \times 10^3$
$= 2816.9 \text{ cm}^3$

Choose 610 x 229 x 101

$W_{pl} = 2880 \text{ cm}^3$

Grade S355

$h_w = 602.6$ mm
$t_w = 10.5$ mm
$t_f = 14.8$ mm
$b_f = 227.6$ mm
$r = 12.7$ mm
$A = 129 \text{ cm}^2$

$\varepsilon = \sqrt{235/355}$
$= 0.814$

Section classification

Flange

$\frac{c_f}{t_f} = 6.48 \leq 9\varepsilon = 7.32$

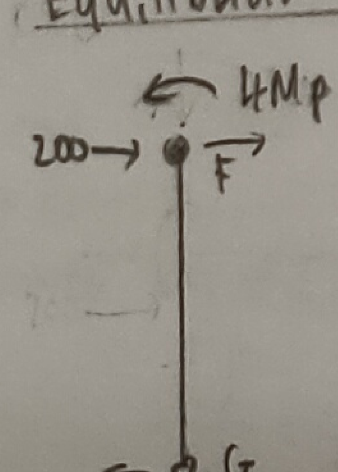
class 1

Web

$\frac{c_w}{t_w} = 52.2 \leq 72\varepsilon = 58.61$

class 1

Equilibrium check



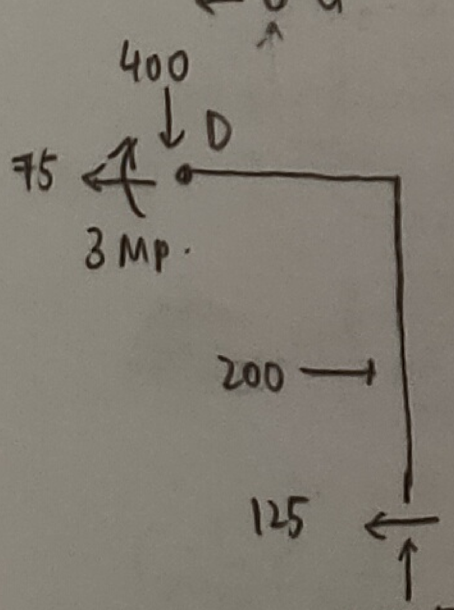
$\Sigma F_y = 0 \quad G_y = 0$

$\Sigma M_F = 0$

$G_x(8) = 4Mp$

$G_x = 0.5Mp$

$= 125$ KN



$\Sigma F_x = 0 \quad D_x = 75$

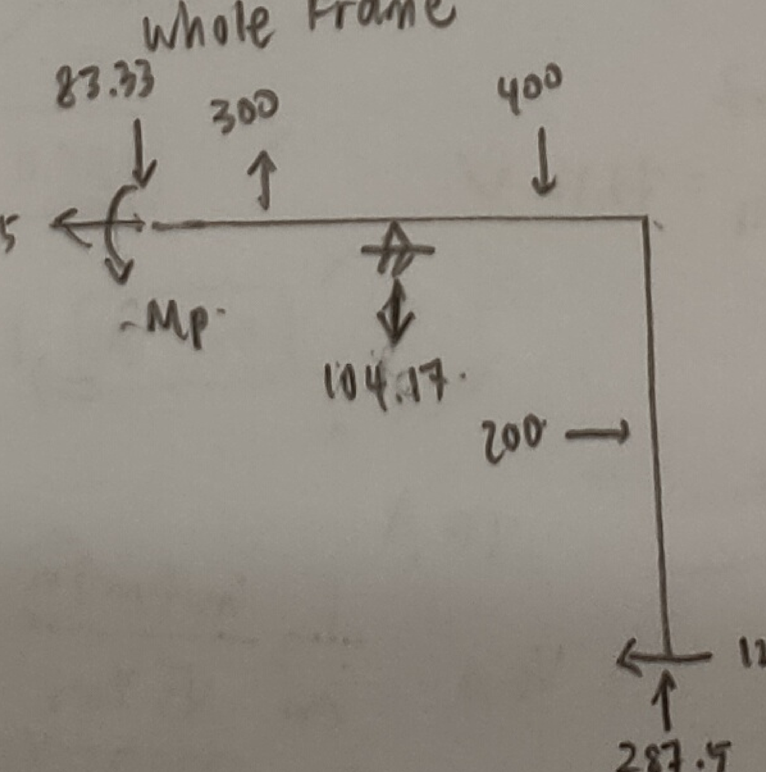
$\Sigma M_D = 0$

$200(8) + G_y(4) = 3Mp + 125(16)$

$G_y = 287.5$ KN

∴ Equilibrium satisfied.

Whole Frame



$\Sigma M_A = 0$

$300(6) + 200(8) + 287.5(20) + R_C(12) + 2Mp$
$= 400(16) + 125(16)$

$R_C = 104.17$ KN

$\Sigma F_y = 0 \quad A_y = 300 + 287.5 - 400 - 104.17$
$= 83.33$ kN

Shear capacity

$A_v = A - 2b_f t_f + (t_w + 2r)t_f > h_w t_w$
$= 12900 - 2(227.6)(14.8) + (10.5 + 12.7)(14.8)$
$> 602.6(10.5)$
$= 6694.36 > 6327.3$

$V_{pl,Rd} = \frac{A_v f_y}{\sqrt{3}} = \frac{6694.36(355)}{\sqrt{3}}$
$= 1372.07$ KN
$> V_{max}$ (287.5)

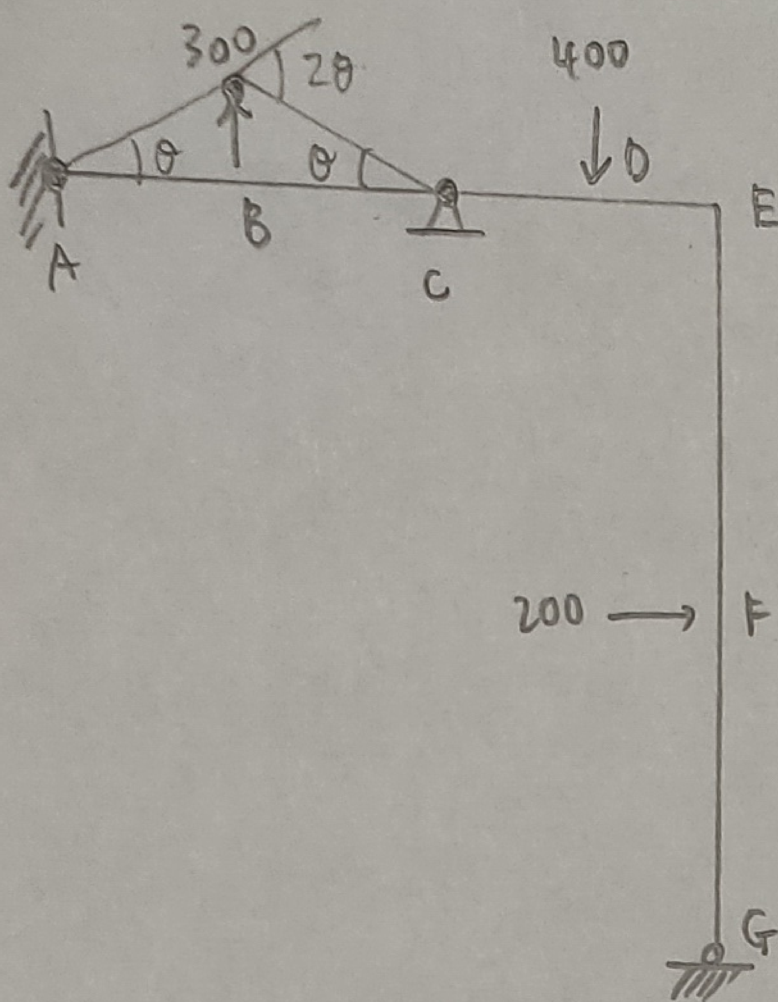
ok!

shear is low → no reduction in moment capacity.

∴ 610 x 229 x UB101 is satisfactory

$M_{c,Rd} = f_y W_{pl} = 355 \times 2880 \times 1000$
$= 1022.4$ KNm

Mechanism 1 (PH at A, B, C only) - Beam



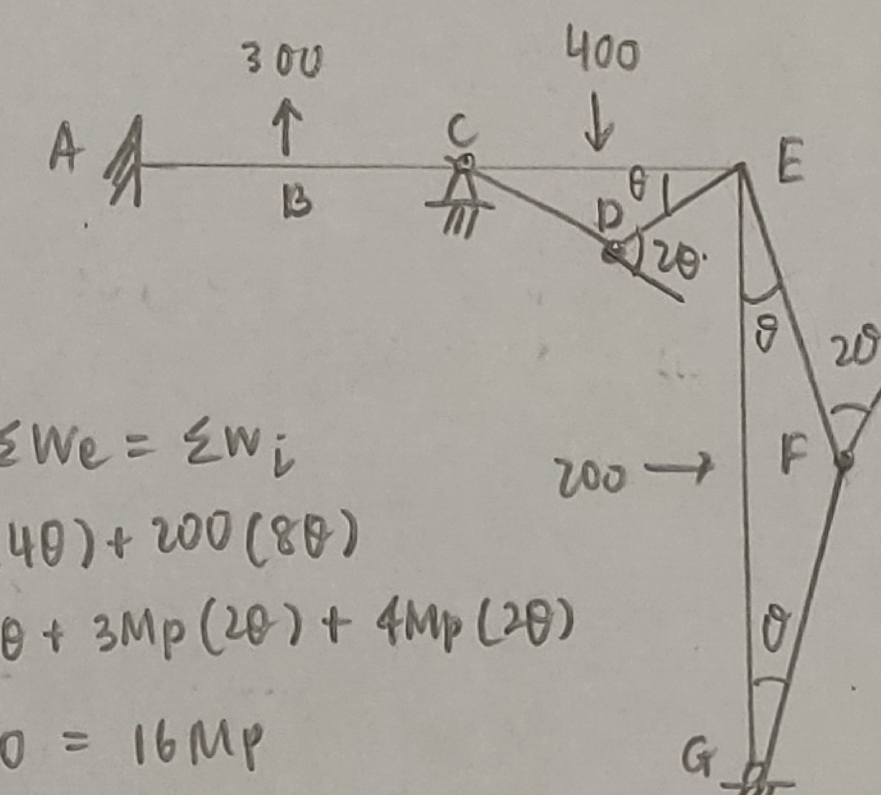
$$\Sigma W_e = \Sigma W_i$$

$$300(6\theta) = 2M_p(\theta) + 2M_p(2\theta) + 2M_p\theta$$

$$1800 = 8M_p$$

$$M_p = 225 \text{ kN m}$$

Mechanism 5 (PH at C, D, F) - Combined column



$$\Sigma W_e = \Sigma W_i$$

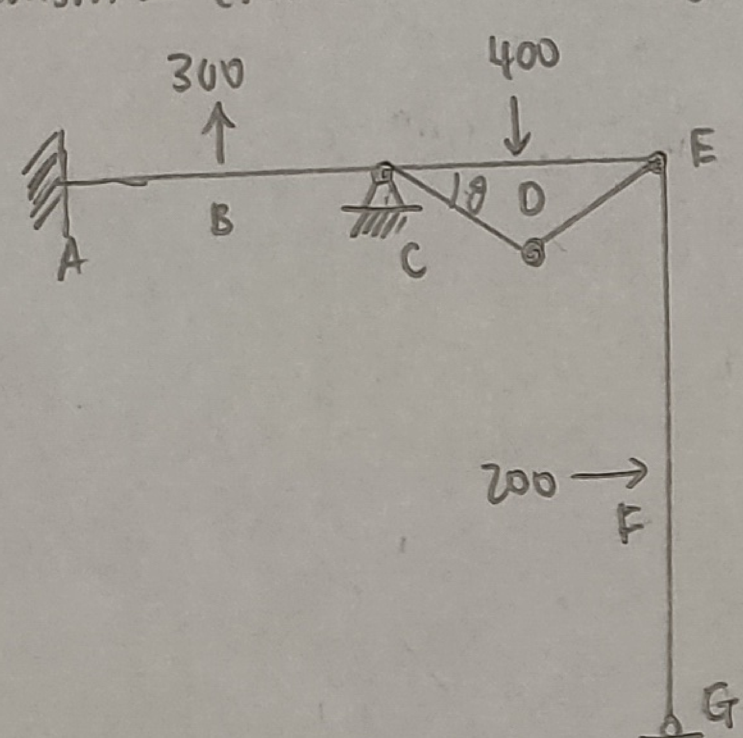
$$400(4\theta) + 200(8\theta)$$

$$= 2M_p\theta + 3M_p(2\theta) + 4M_p(2\theta)$$

$$3200 = 16M_p$$

$$M_p = 200 \text{ kNm}$$

Mechanism 2 (PH at C, D, E only) - Beam



$$\Sigma W_e = \Sigma W_i$$

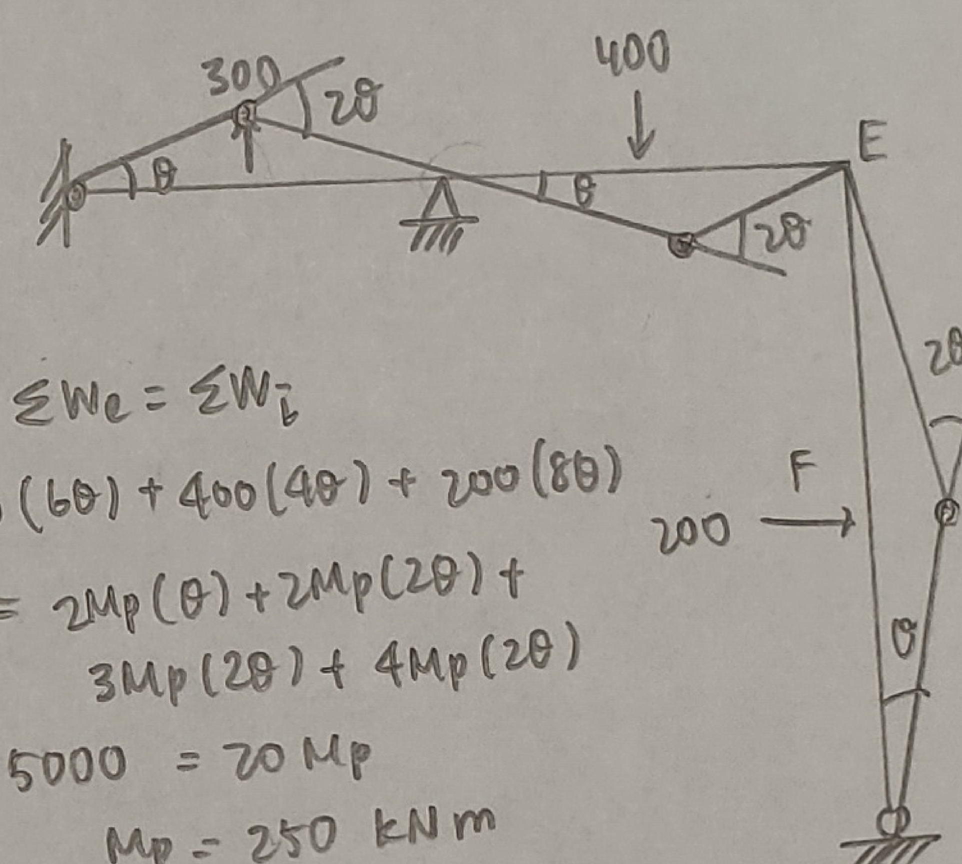
$$400(4\theta) = 2M_p(\theta) + 3M_p(2\theta) + 3M_p\theta$$

$$1600 = 11M_p$$

$$M_p = 145.45 \text{ kNm}$$

Mechanism 6 (PH at A, B, D, F only)

Combined Beam



$$\Sigma W_e = \Sigma W_i$$

$$300(6\theta) + 400(4\theta) + 200(8\theta)$$

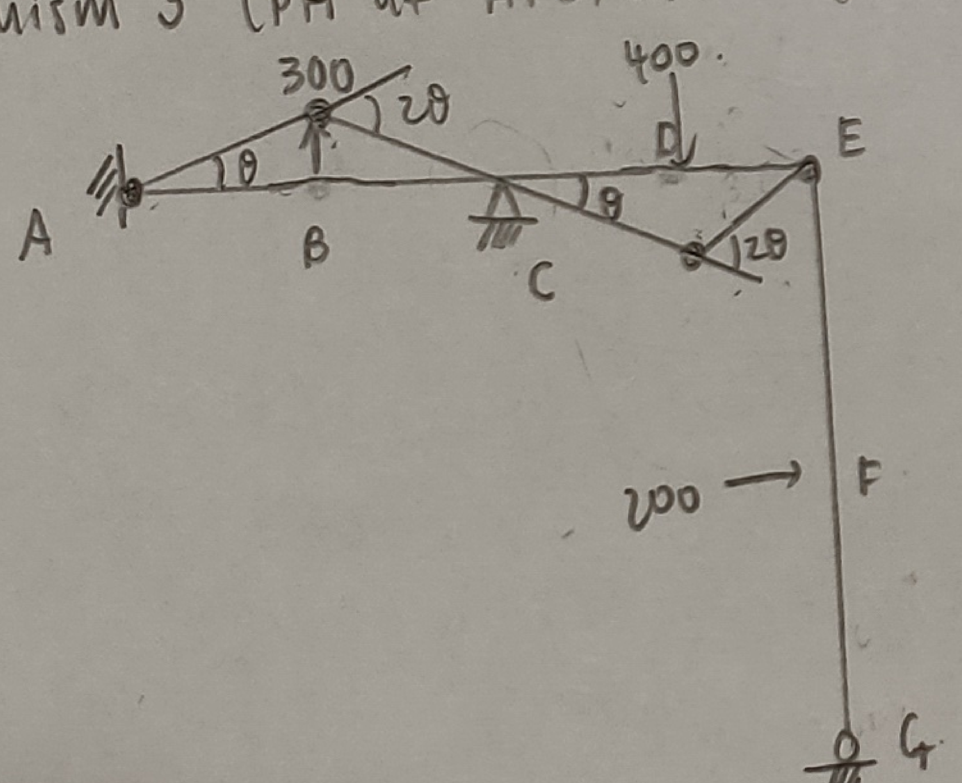
$$= 2M_p(\theta) + 2M_p(2\theta) + 3M_p(2\theta) + 4M_p(2\theta)$$

$$5000 = 20M_p$$

$$M_p = \underline{250} \text{ kNm}$$

Hence, mechanism 6 is the most likely the correct mechanism

Mechanism 3 (PH at A, B, D, E only) - combined beam



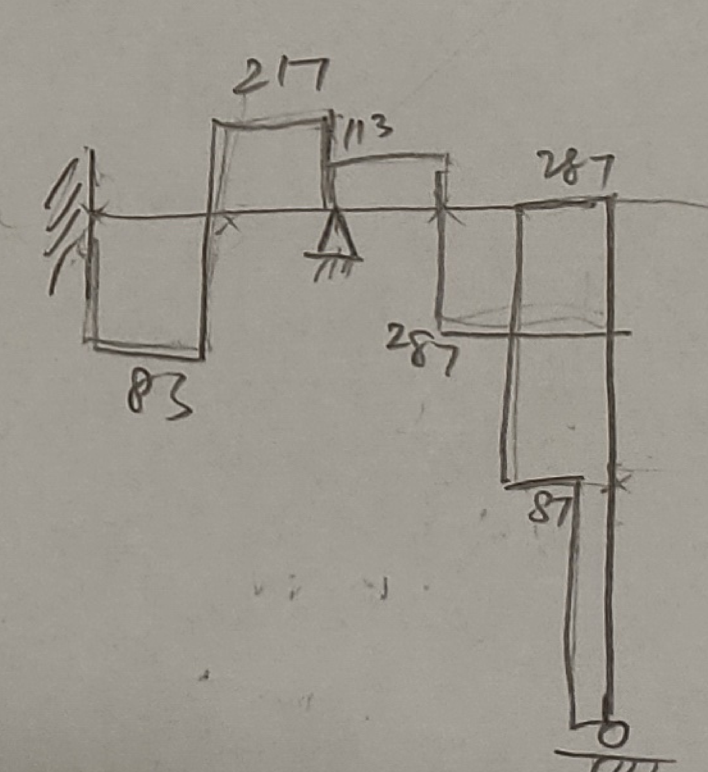
$$\Sigma W_e = \Sigma W_i$$

$$300(6\theta) + 400(4\theta) =$$

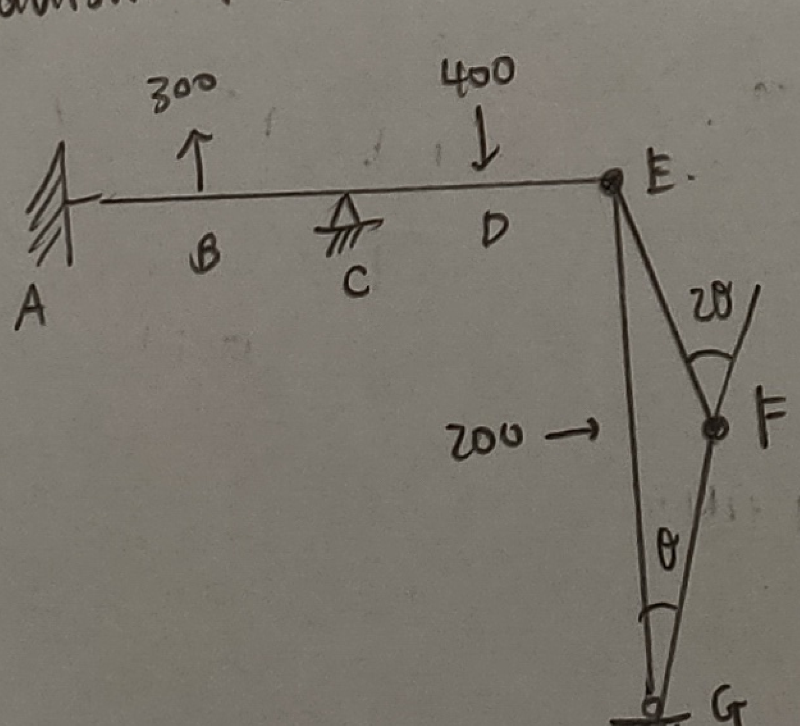
$$2M_p\theta + 2M_p(2\theta) + 3M_p(2\theta) + 3M_p(\theta)$$

$$3400 = 15M_p$$

$$M_p = 226.67 \text{ kNm}$$



Mechanism 4 (PH at E, F only) - column

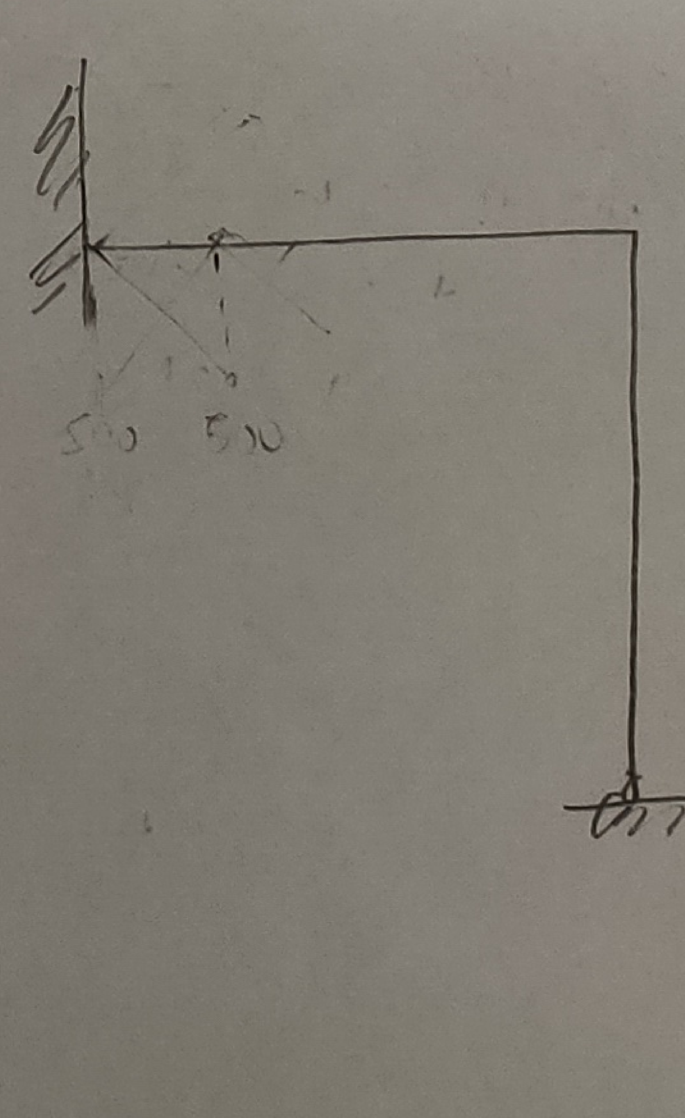


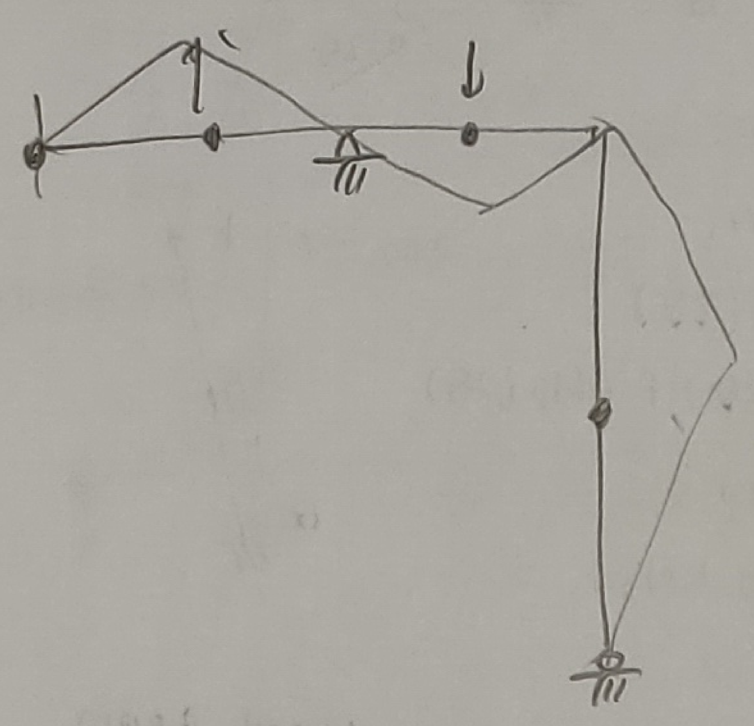
$$\Sigma W_e = \Sigma W_i$$

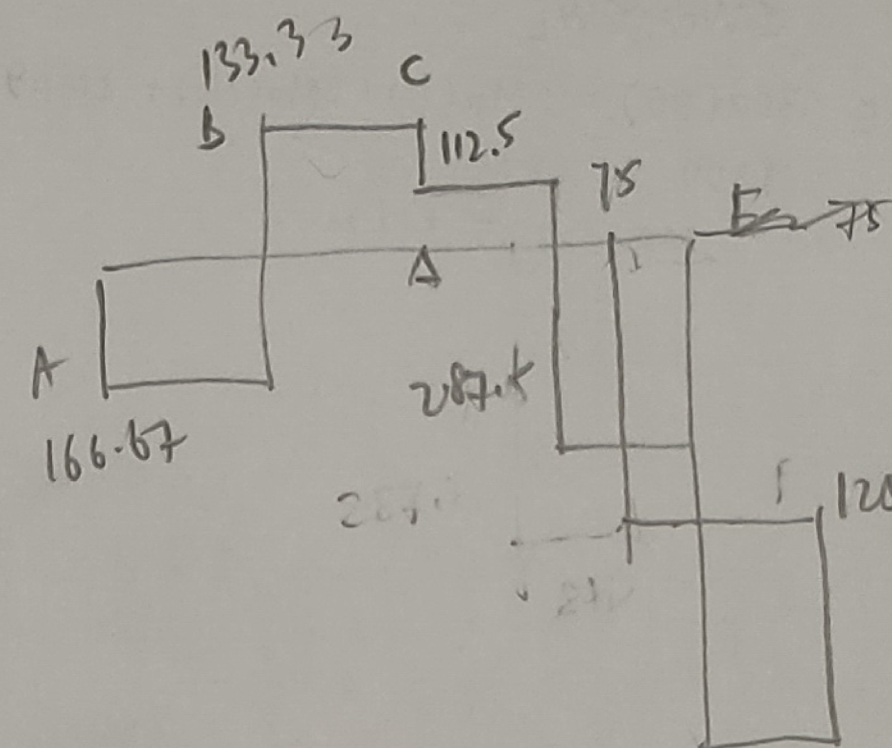
$$200(8\theta) = 3M_p\theta + 4M_p(2\theta)$$

$$1600 = 11M_p$$

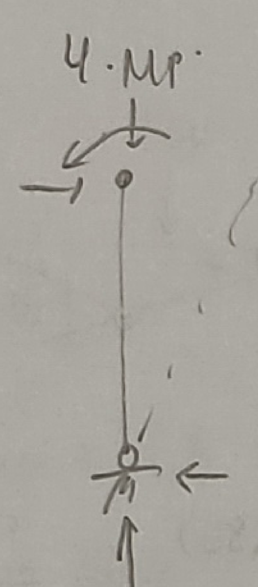
$$M_p = 145.45 \text{ kNm}$$







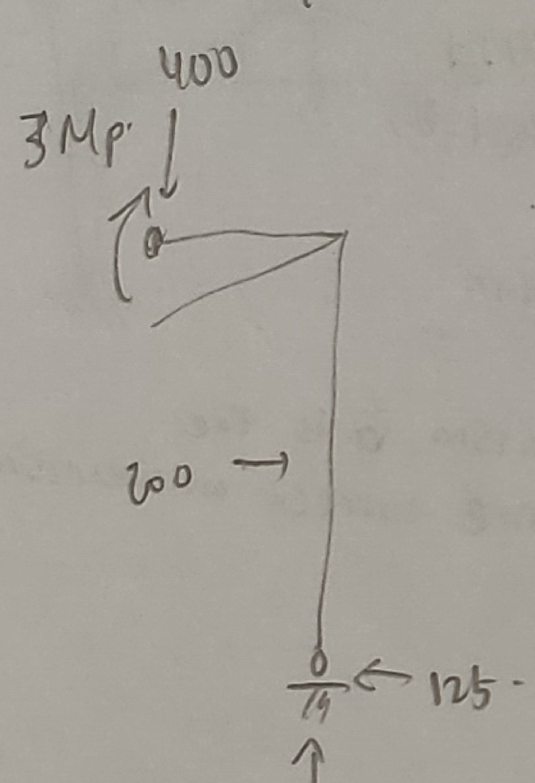
$M_p = 250$



$\Sigma M_F = 0$

$G_x(8) = 4M_p$

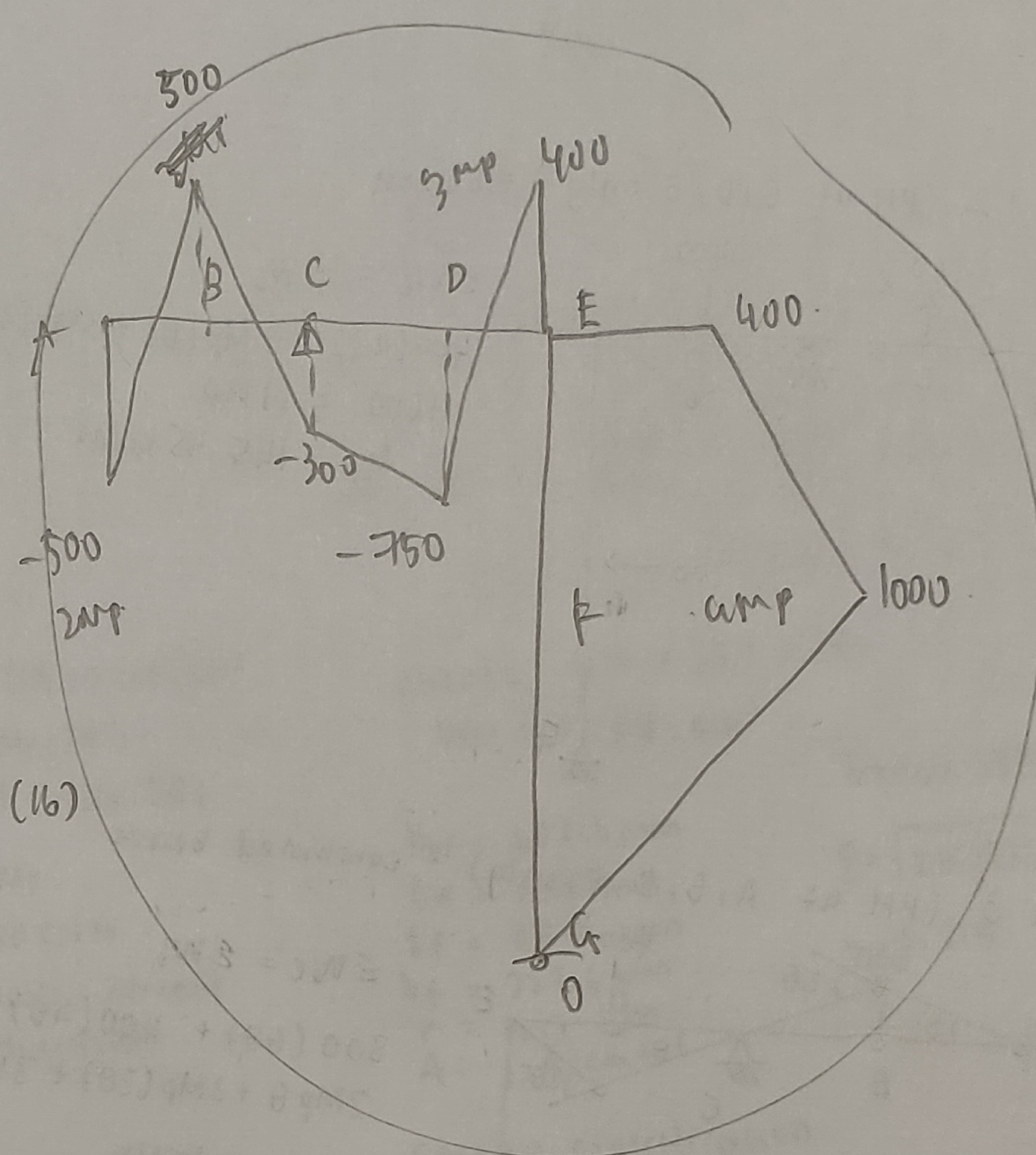
$G_x = 125\ kN$

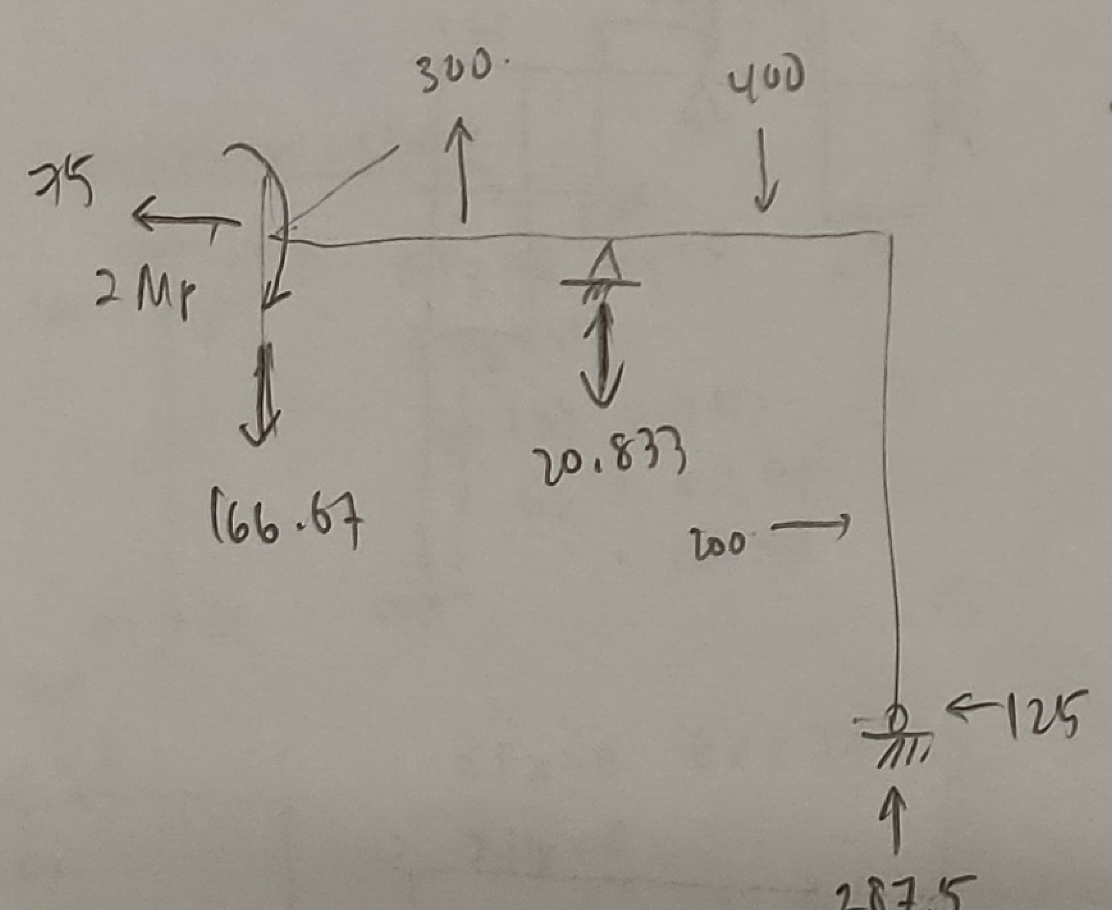


$\Sigma M_D = 0$

$G_y(4) + 200(8) = 3M_p + 125(16)$

$G_y = 287.5\ kN$





$\Sigma M_C = 0 \quad A_y(12) + 300(6) + 400(4) + 2M_p + 125(16) = 287.5(8) + 200(8)$

$5900 + 12A_y = 3900$

$A_y = 166.67$

$\Sigma M_G = 0 \quad 300(14) + 2M_p + 200(8) + A_x(16) = 166.67(20) + 20.833(8) + 400(4)$

$A_x = 75 \quad (\leftarrow)$

$\Sigma M_A = 0 \quad 300(6) + 287.5(20) + 200(8) = 125(16) + 400(16) + R_C(12) + 2M_p$

$R_C = 20.833\ MPa$