NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2017-2018

CV4102 - ADVANCED STEEL DESIGN

November / December 2017 **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. A single-span plane lattice girder is shown in Figure Q1. The girder is made of square hollow sections (SHS) according to EN 10210, and the steel Grade is S355 according to Table 3.1 of EN 1993-1-1: 2014. Using design recommendations given in Eurocode 3, EN 1993-1-8: 2010,

   (a) Determine the joint parameters γ and β, and the ranges of validity of the Y-joint shown in Figure Q1. (6 marks)

   (b) If the maximum design compressive stress $\sigma_{0,Ed}=0.85f_{y0}$ in the chord and the brace of the Y-joint is subjected to axial tension, calculate the joint strength $N_{1,Rd}$ and state the failure mechanism. (12 marks)

   (c) Check the adequacy of the 10 mm fillet welds used to join the brace and the chord. (7 marks)

Note: Question No. 1 continues on Page 2

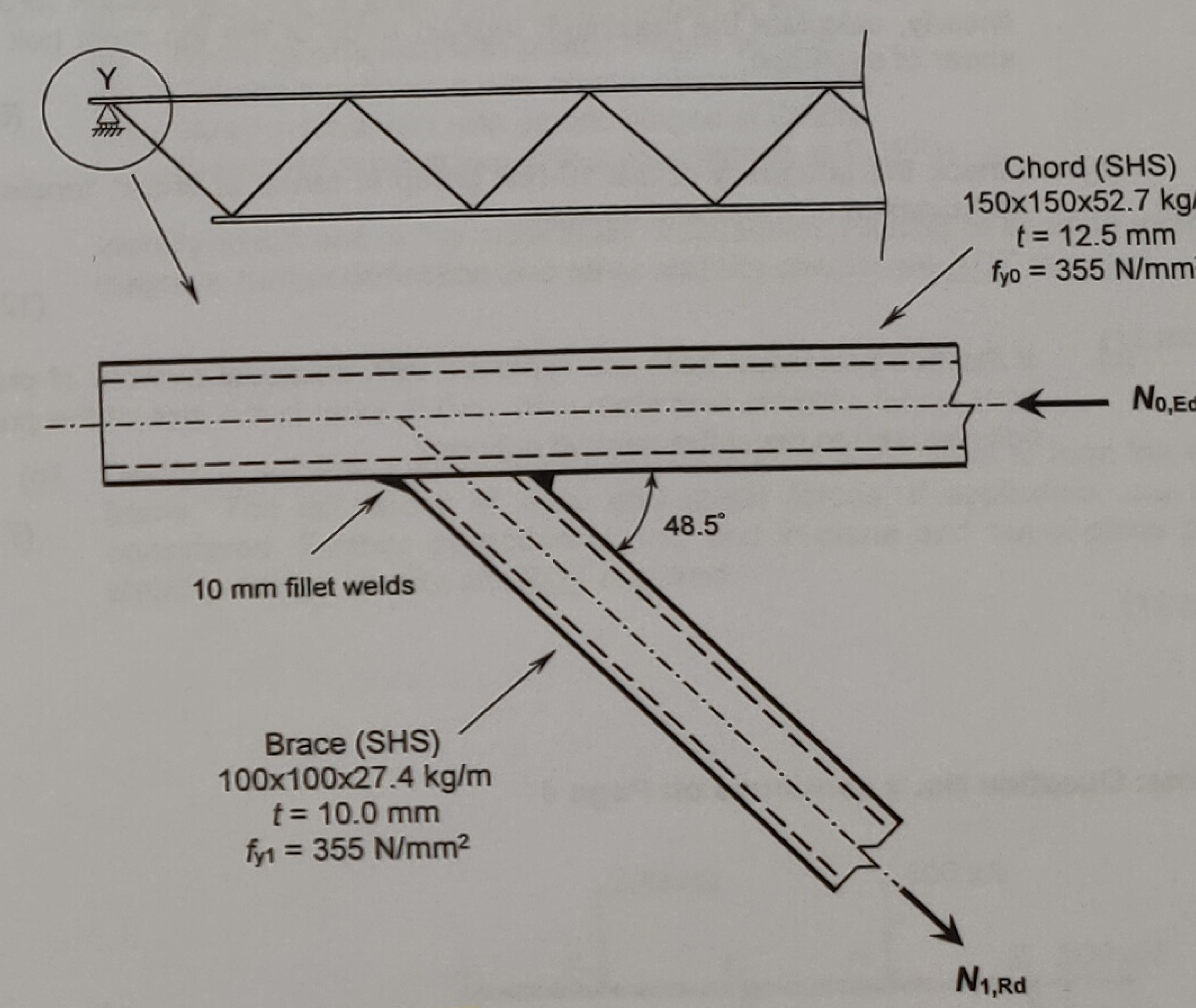
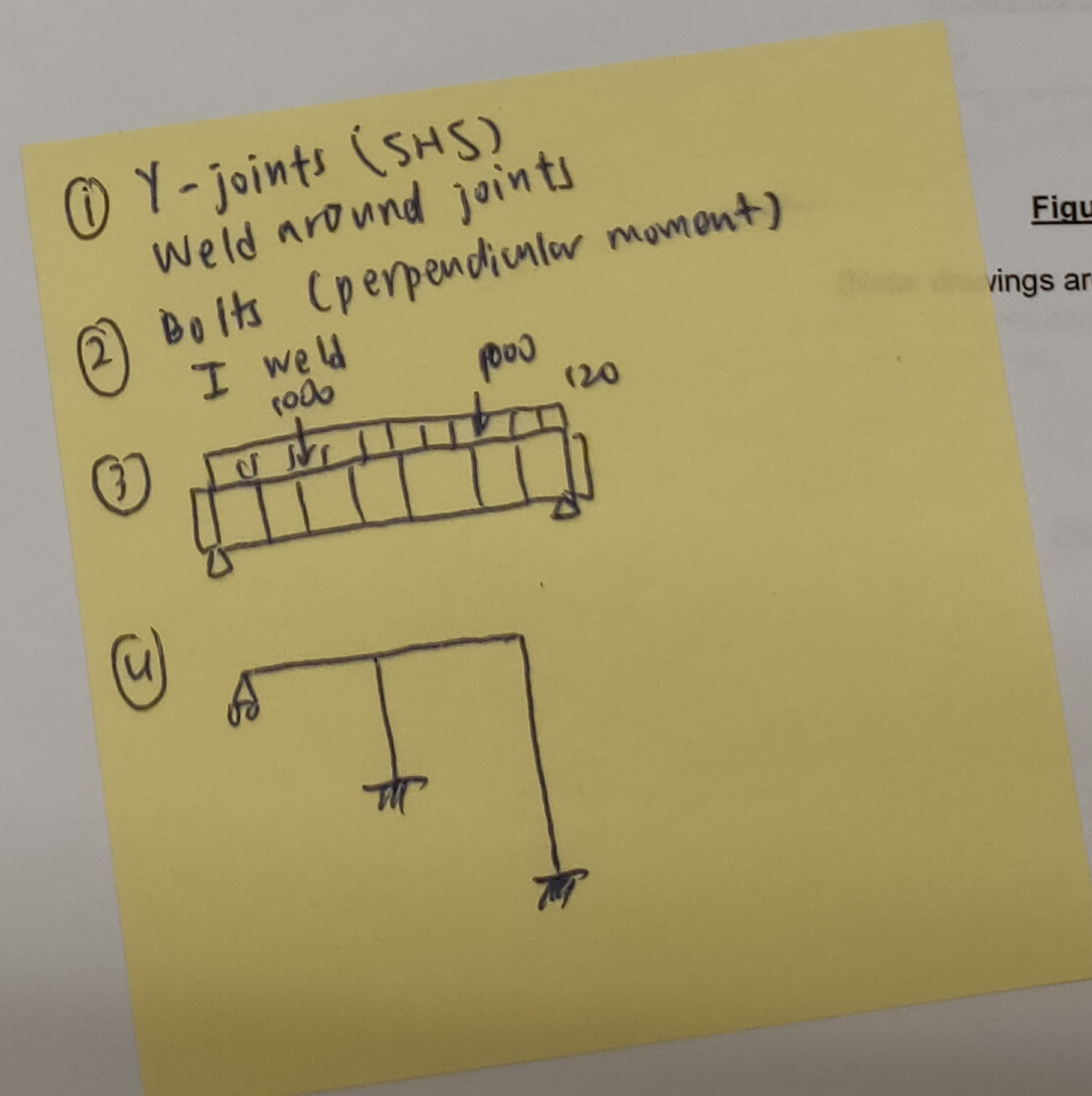


Figure Q1

(Note: drawings are not drawn to scale)



2. Figure Q2 shows the knee joint of a uniform rectangular portal frame. It is subjected to design moment M_{Ed}=520 kNm and shear force V_{Ed}=350 kN. A 610x305x149 kg/m UB is welded to an 18 mm thick end-plate, and in turn, the end-plate is bolted to the flange of 356x406x235 kg/m UC using 10 number of M24 class 8.8 non-preloaded bolts in Grade S275 steel.

(a) Assuming the centre of rotation is at point A and the tension force varies linearly, calculate the maximum tension force of the top most bolt and the shear of each bolt.

(6 marks)

(b) Check the adequecy of the 10-bolt group in terms of shear, tension and a combination of shear and tension.

(12 marks)

(c) If the non-preloaded bolts are replaced with an equal number of preloaded bolts under ultimate limit state with μ=0.5, what is the size of the preloaded bolt required to resist the applied actions?

(7 marks)

Note: Question No. 2 continues on Page 4

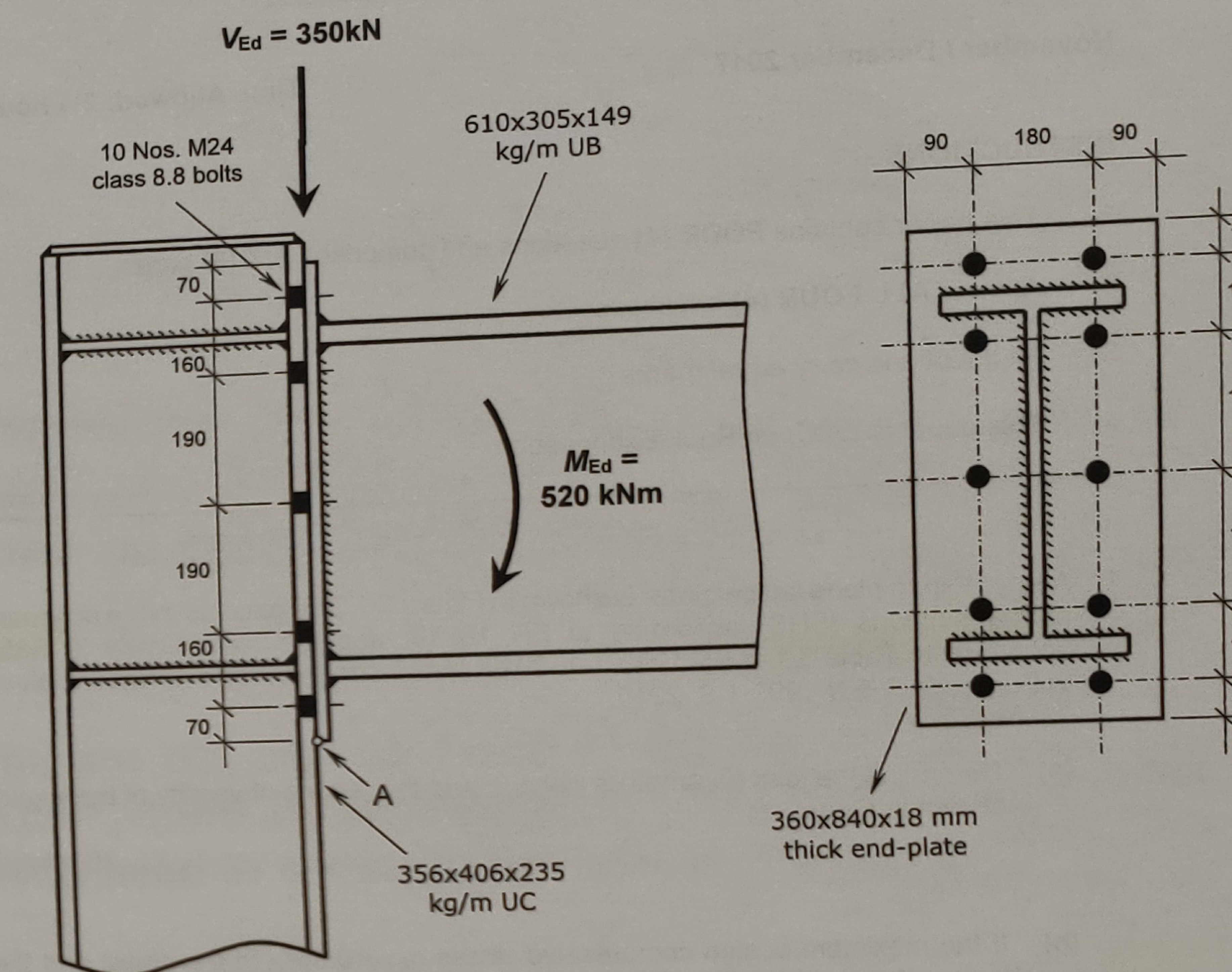


Figure Q2

(Note: drawings are not drawn to scale)

(All dimensions are in mm unless otherwise stated)

3. The 24 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 D, and effectively restrained in the lateral direction along the entire plate girder. It is supporting two (2) factored design concentrated load of 1000 kN each at load bearing stiffeners B and C, plus a factored design u.d.l of 120 kN/m throughout. Details of the stiffeners are given in Figure Q3(b). Assume that all the end posts and stiffeners are rigid.

   (i) Classify the flange and web of the girder.
   (ii) Check the adequacy of the girder in terms of its bending resistance.
   (iii) Check the adequacy of the girder in terms of its shear resistance.
   (iv) Check the adequacy of the rigid end posts.
   (v) Explain the purposes of the stiffeners, and the requirements they need to satisfy.

(25 marks)

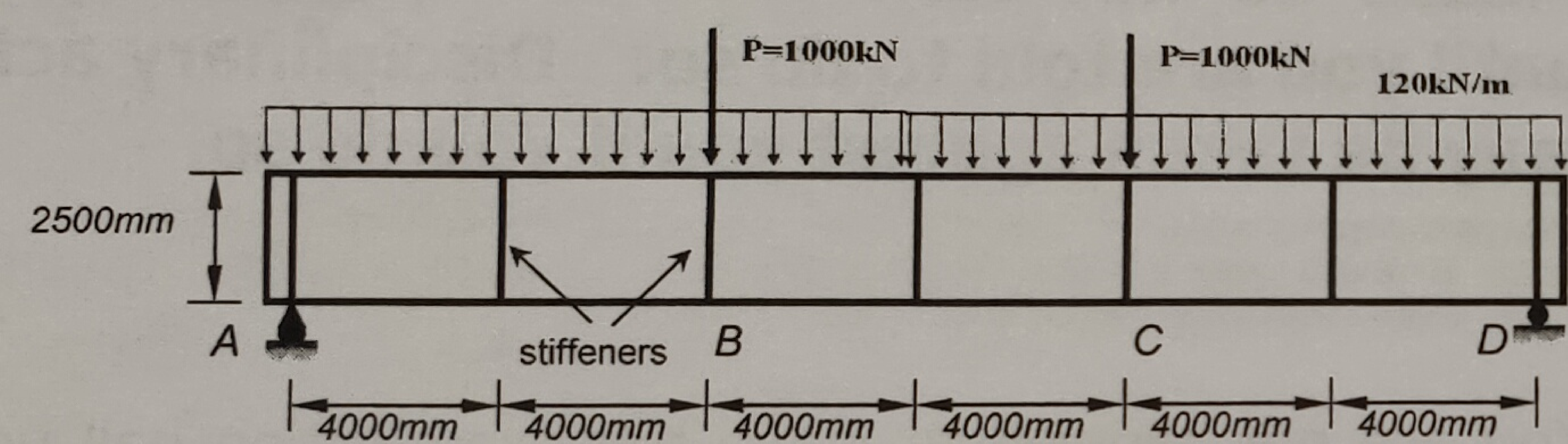
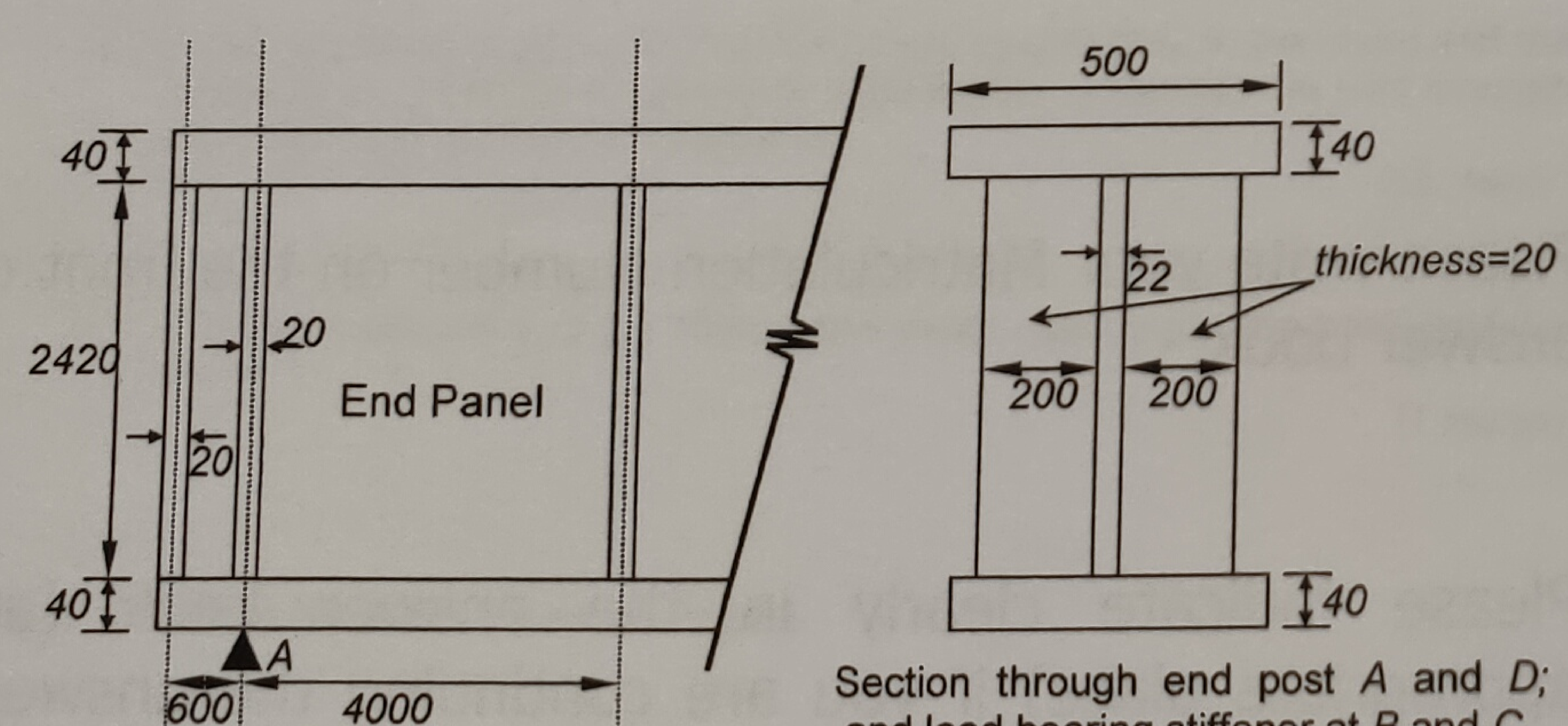


Figure Q3(a)



Elevation view of end post at A

Section through end post A and D; and load bearing stiffener at B and C

Note:
(i) Elevation details for end post at D is identical as end post at A.
(ii) All dimensions are in mm.

Figure Q3(b)

4. The frame *ABCDEFGH* shown in Figure Q4 is supported by a roller at *A*, fixed at *F* and *H*, and is subjected to four (4) factored design concentrated loads at B, D, E and G. The plastic moment resistances for all members of the frame are M_p. Adequate restraints against in-plane and out-of-plane stability are provided.

   (a) Compute the required plastic moment of resistance M_p for the frame corresponding to the following mechanisms:
      (i) Beam mechanism with plastic hinges at BC
      (ii) Beam mechanism with plastic hinges at CDE
      (iii) Column mechanism with plastic hinges at EGH
      (iv) Sway mechanism with plastic hinges at CFEH
      (v) Combined mechanism with plastic hinges at CDEFH

      Identify which one is the most likely mechanism. Plotting of bending moment diagram, further deflection and other stability checks are **NOT** required.

(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)

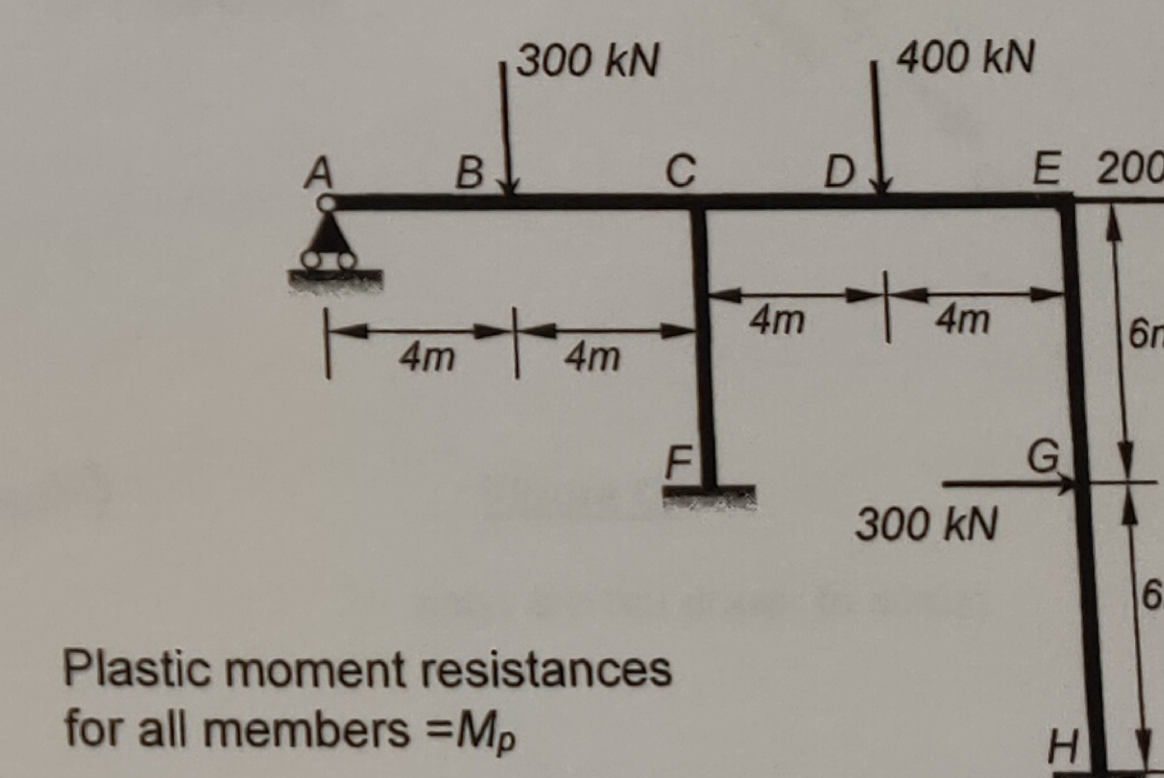


Figure Q4

END OF PAPER

CV4102 PYP 2017/18

1) a) $\gamma = \frac{b_0}{2t_0} = \frac{150}{2(12.5)} = 6$ ✓

$\beta = \frac{b_1}{b_0} = \frac{100}{150} = 0.67$ ✓

Ranges of validity,

$\frac{b_1}{b_0} = \frac{100}{150} = 0.67 \geq 0.25$

Brace in tension

$\frac{h_1}{t_1} = \frac{b_1}{t_1} = \frac{100}{10} = 10 \leq 35 < 38\varepsilon = 30.932$ (class 2)

$0.5 \leq \frac{h_0}{b_0} = \frac{h_1}{b_1} = 1 \leq 2.0$

$\frac{b_0}{t_0} = \frac{h_0}{t_0} = \frac{150}{12.5} = 12 \leq 35$ ✓

For SHS,

$\frac{b_1}{b_0} = \frac{100}{150} = 0.67 \leq 0.85$

$\frac{b_0}{t_0} = \frac{150}{12.5} = 12 \geq 10$

∴ Table 7.10 can be used.

b) $\beta = 0.67 \leq 0.85$

Chord face failure

$N_{1,Rd} = \frac{k_n f_{y0} t_0^2}{(1-\beta)\sin\theta_1}\left(\frac{2\beta}{\sin\theta_1} + 4\sqrt{1-\beta}\right)/\gamma_{M5}$

Given $\sigma_{0,Ed} = 0.85 f_{y0}$

$n = \frac{\sigma_{0,Ed}}{f_{y0}} = 0.85$

$n > 0$ (compression)

$k_n = 1.3 - \frac{0.4n}{\beta} \leq 1.0$

$= 1.3 - \frac{0.4(0.85)}{0.67} \leq 1.0$

$= 0.793$

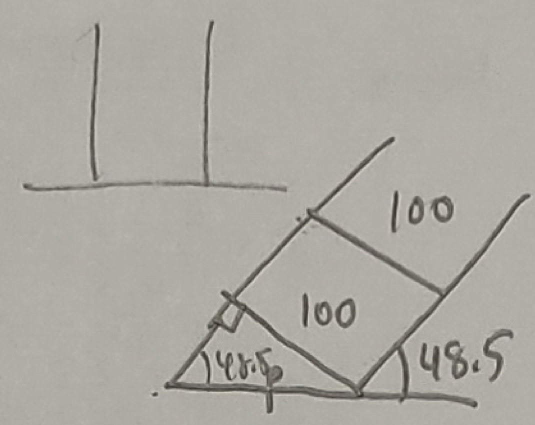
$N_{1,Rd} = \frac{0.793(355)(12.5)^2}{(1-0.67)\sin 48.5}\left(\frac{2(0.67)}{\sin 48.5} + 4\sqrt{1-0.67}\right)/1.0$

$= 727.37$ kN ✓

$A_1 f_{y1} = \frac{\pi}{4}\{100^2 - 80^2\}(355)$

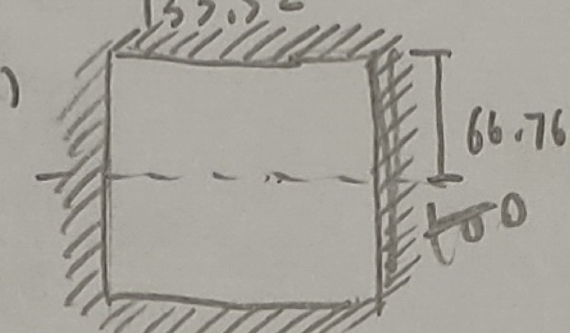
$= 1003.74$ kN

∴ Failure mechanism is chord face failure.



$\sin 48.5 = \frac{100}{P}$

$P = 133.52$ mm



c) Throat length of 10mm fillet welds

$= 10 \times \cos 45° = 7.07$ mm

Total area of 10mm fillet welds,

$= (133.52 \times 4) \times 7.07$

$= 3775.92$ mm²

$I_{yy} = 2\left(\frac{133.52^3 \times 7.07}{12}\right) + 2\left[\frac{133.52 \times 7.07^3}{12} + (133.52)(7.07)\left(\frac{133.52}{2}\right)^2\right]$

$= 2804833.814 + 8422365.62$

$= 11227199.43$ mm⁴

$W_{el} = \frac{I_{yy}}{y} = \frac{11227199.43}{\frac{133.52}{2} + 7.07}$

$= 152068.3$ mm³

Shear force

$f_s = N_{1,Rd} \cos 48.5$

$f_s = 481.97$ kN

$f_s = \frac{481.97}{3775.92}$

$= 127.64$ kN

$< f_{yw}$

~~tension~~

~~$f_t = N_{1,Rd} \sin 48.5$~~

~~$f_t = 544.77$ kN~~

~~$f_R = \sqrt{f_t^2 + f_s^2}$~~

~~$= 727.37$~~

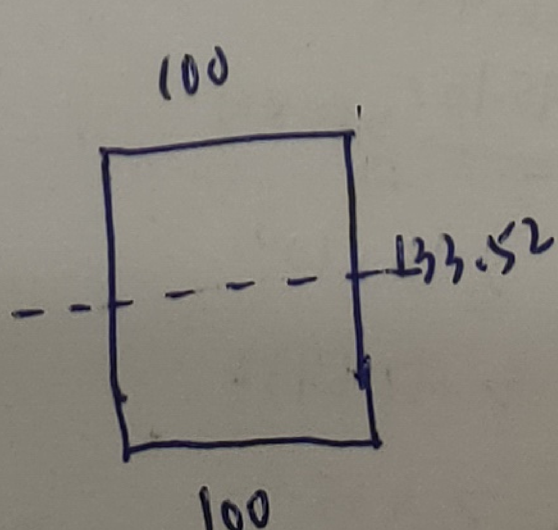
$f_s = \frac{481.97}{3301.97}$

$= 145.96$ kN

$< f_{vw,d}$

$f_{yw,} = \frac{f_u/\sqrt{3}}{\beta_w \times \gamma_{M2}} = \frac{490/\sqrt{3}}{0.9 \times 1.25}$

$= 251.47 > 127.64$



throat length

$= 10 \times \cos 45° = 7.07$ mm

total area

$= (133.52 \times 2 + 100 \times 2)\, 7.07$

$= (467.04)\, 7.07$

$= 3301.97$ mm²

$I_{yy} = 2\left[\frac{100 \times 7.07^3}{12} + 100(7.07)\left(\frac{133.52 + 2(3.535)}{2}\right)^2\right] + 2\left(\frac{133.52^3 \times 7.07}{12}\right)$

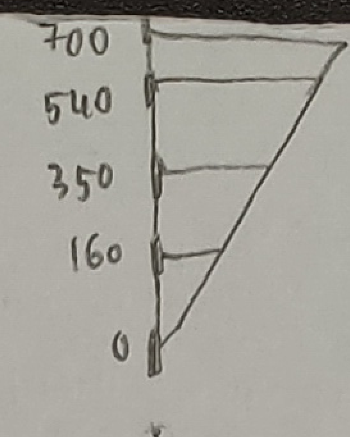
$= 6993011.141 + 2804833.814$

$= 9797844.955$ mm⁴

$W_{el} = \frac{I_{yy}}{y} = \frac{9797844.955}{\frac{133.52}{2} + 7.07} = 132708.18$ mm³

2) a) $F_{max} = \frac{P e y_{max}}{n \sum y^2}$

$= \frac{520 \times 10^6 \times 700}{2(160^2 + 350^2 + 540^2 + 700^2)}$



$F_{t,Ed} = 195.76$ KN

F = 350 KN

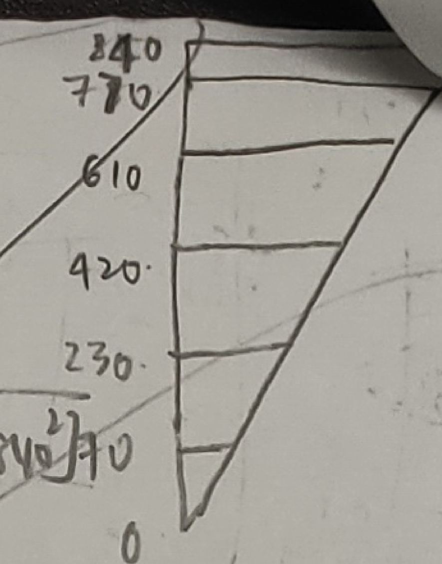
$F_{v,Ed} = \frac{350}{10} = 35$ KN/bolt ✓

$F_{max} = \frac{P e y_{max}}{n \sum y^2}$

$= \frac{520 \times 10^6 \times 840}{2[70^2 + 230^2 + 420^2 + 610^2 + 770^2 + 840^2]}$ ~~70~~

$= 114657.71$

$= 114.66$ KN



$F_{v,Ed} = \frac{350}{10} = 35$ KN/bolt.

b) $F_{v,Rd} = \frac{\alpha_v f_{ub} A}{\gamma_{M2}}$ M24, class 8.8 non-preloaded

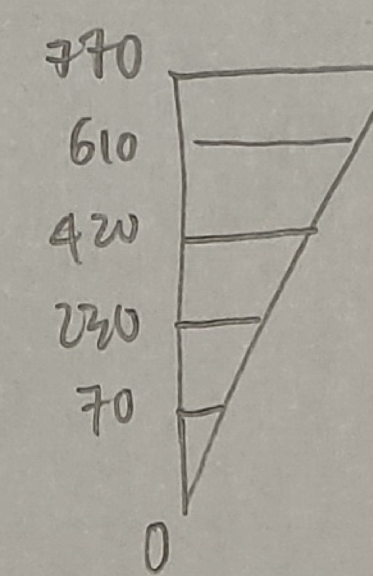
$= \frac{0.6(800)(353)}{1.25}$

$= 135.55$ KN > 135 KN ok! ✓

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

$= \frac{0.9(800)(353)}{1.25}$ (114.66)

$= 203.328$ KN > 195.76 KN ok! ✓



$F_{max} = \frac{P e y_{max}}{n \sum y^2}$

$= \frac{520 \times 770}{2(70^2 + 230^2 + 420^2 + 610^2 + 770^2)}$

$= 166.945$ KN

$\frac{35}{135.55} + \frac{166.945}{1.4(203.328)} = 0.848 \leq 1.0$

combined shear & torsion

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

$\frac{35}{135.55} + \frac{195.76}{1.4(203.328)} = 0.946 \leq 1.0$ ok! ✓

Combi

↳ $\frac{35}{135.55} + \frac{114.66}{1.4(203.328)} = 0.661 < 1.0$ ✓ ok!

c) 10 preloaded bolts ⇒ $\mu = 0.5$

slip resistance

$F_{s,Rd} = \frac{k_s n \mu}{\gamma_{M3}} F_{p,C}$

~~$F_{t,Rd} = \frac{k_2 f_{ub} A_s}{\gamma_{M2}} = \frac{0.9(800)A_s}{1.25}$~~ ~~= 576 A_s~~

$F_{p,C} = 0.7 f_{ub} A_s$

$= 0.7(800)A_s$

$= 560 A_s$

slip at uls

$F_{s,Rd} = \frac{k_s n \mu (F_{p,C} - 0.8 F_{t,Ed})}{\gamma_{M3}} > 35 \times 10^3$ 166.945

$\frac{(1)(1)(0.5)(560A_s - 0.8 \times 195.76)}{1.25} > 35 \times 10^3$

$224 A_s - 62.643 > 35 \times 10^3$

$224 A_s > 97.6432$

$A_s > 435.9$

$280 A_s - $ ~~137.556~~ 66.778 > 43.15 ⇒ use 30mm diameter //

110.828 561 mm²

$280 A_s >$ ~~[illegible]~~

$A_s > 394.74$

⇒ 30mm diameter //

$F_{s,Rd} = \frac{k_s n \mu}{\gamma_{M3}} F_{p,C}$

$= \frac{(1)(1)(0.5)(560 A_s)}{1.25}$

↑ uls

$= 224 A_s > 35 \times 10^3$

$A_s > 156.25$ mm²

∴ use 16mm bolts. (157mm²)

$F_{s,Rd} = \frac{k_s n \mu (F_{p,C} - 0.8 F_{t,Ed})}{\gamma_{M3}}$

$= \frac{(1)(1)(0.5)(560A_s - 0.8 \times 114.66)}{1.25}$

$= 224 A_s - 36.69 > 35 \times 10^3$

$= A_s > 320$ mm²

∴ use 24 mm bolt (353 mm²)

Flange ... classification
For grade S275
$\varepsilon = \sqrt{235/f_y} =$

Classification

For Grade S275,

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

Flange

$\frac{c_f}{t_f} = \frac{250-22}{40} = 5.97 < 9\varepsilon = 8.316$ (~~$\frac{500-22}{2}$~~)

∴ Class 1

Web

$\frac{c_w}{t_w} = \frac{2420}{22} = 110 < 124\varepsilon = 114.576$

∴ Class 3

ii) Bending

⇒ method 1

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

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

$= (500 \times 40)(2420 + 40)(275)$

$= 13530 \text{ kNm}$

$I_w = \frac{2420^3 \times 22}{12} = 2.598 \times 10^{10} \text{ mm}^4$

$W_{el,w} = \frac{I_w}{z} = \frac{2.598 \times 10^{10}}{2420/2} = 21473466.67 \text{ mm}^3$

$W_{el,w} f_{yw} = 5905.203 \text{ kNm}$

$M_{y,Rd} = 13530 + 5905.203 = 19435.203 \text{ kNm}$ ~~< 32320 kNm~~ > 16640.

Not ok!

iii) Shear resistance.

$a/h_w = 4000/2420 = 1.65 > 1.0$

$k_\tau = 5.34 + 4\left(\frac{2420}{4000}\right)^2 = 6.804$

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

$\frac{2420}{22} = 110 \leq 31 \frac{0.924}{1} \sqrt{6.804} = 74.72$

web is <u>NOT</u> stocky.

$\bar{\lambda}_w = \frac{h_w}{37.4 t_w \varepsilon \sqrt{k_\tau}} = \frac{2420}{37.4(22)(0.924)\sqrt{6.804}} = 1.22 > 1.08$

$\chi_w = 1.37/(0.7 + \bar{\lambda}_w) = 0.713$

$V_{bw,R} = \frac{\chi_w f_{yw} h_w t_w}{\sqrt{3}\,\gamma_{M1}} = \frac{0.714(275)(2420)(22)}{\sqrt{3}(1.00)}$

$= 6035.43 \text{ kN} > 2440 \text{ kN}$

OK!

$V_{bf,Rd}$.

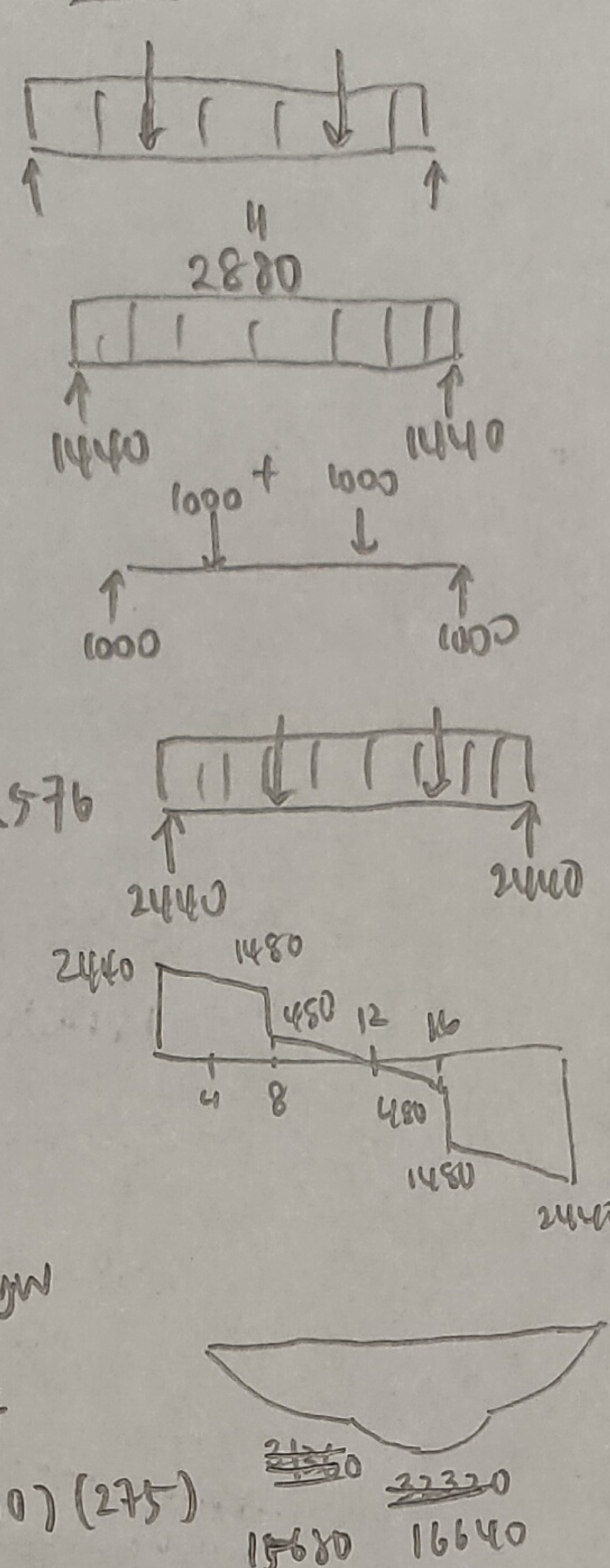
$c = 4000\left(0.25 + \frac{1.6(500)(40)^2(275)}{(22)(2420)^2(275)}\right)$

$= 1039.74$

$V_{bf,Rd} = \frac{500(40)^2(275)}{1039.74}(1-0)$ (M_Ed at support = 0)

$= 211.591 \text{ kN}$

Loadings



iv) Rigid End Post

Same as 2015/16

$N_{b,Rd} = 7830.23 \text{ kN}$

$\bar{\lambda}_w = 1.22$

$N_{sten} = 2440 - \frac{1}{1.22^2} \times \frac{2420 \times 275 \times 22}{1000\sqrt{3}}$

$= -3239.24$

∴ TFA not mobilised

$N_{Ed} = 2440 \text{ kN} < 7830.23$ ok!

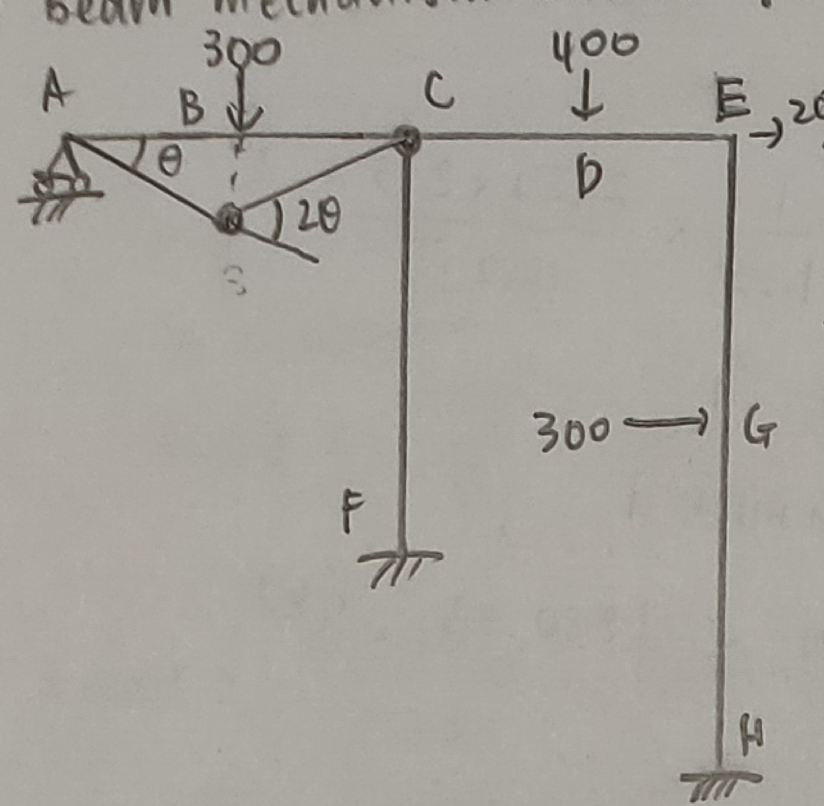
v) The purpose of having stiffeners is to prevent buckling of web due to bending and shear. This is because plate girders normally has very thin webs and hence are more susceptible to buckling. Stiffeners are also used to prevent local failure under patch loads.

☆ Generally, stiffeners need to be at least class 2. There are 2 general performance requirements for all transverse stiffeners. that is requirement A and requirement B. Requirement A is to verify using second order elastic analysis that at ULS, σ_{max}, ultimate stress (elastic) of stiffeners are $< f_y/\gamma_{M1}$. Also the ultimate lateral deflection w, shld be lesser than b, panel height divide by 300. For requirement B, it is to verify that the stiffeners will not fail by torsional buckling.

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

$n_{ph} = n_s + 1 = 4 + 1 = 5$

i) Beam mechanism with hinges at BC



$\Sigma W_E = \Sigma W_i$

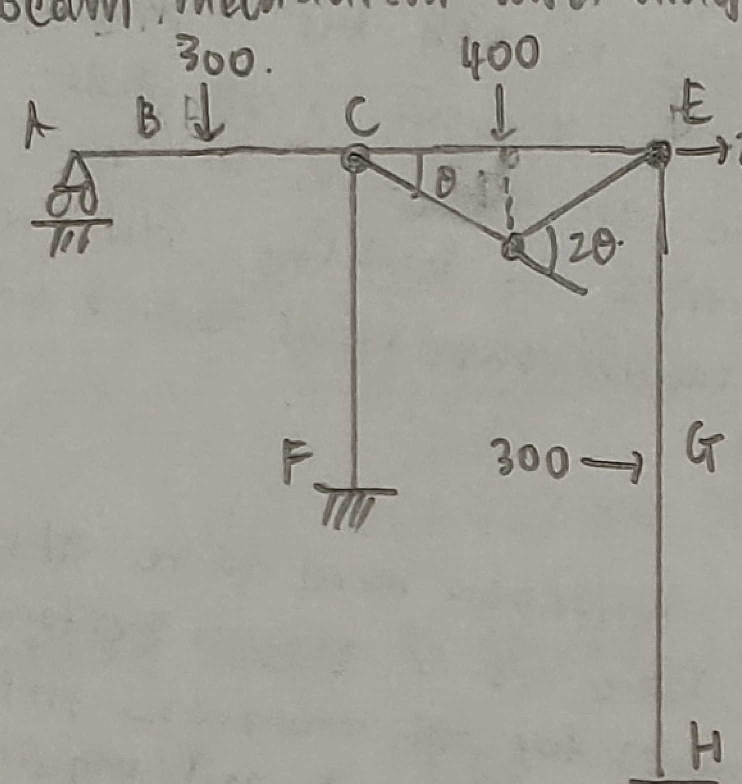
$300(4\theta) + 400(0) + 300(0)$

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

$1200 = 3M_p$

$M_p = 400$ kNm

ii) Beam mechanism with hinges at CDE



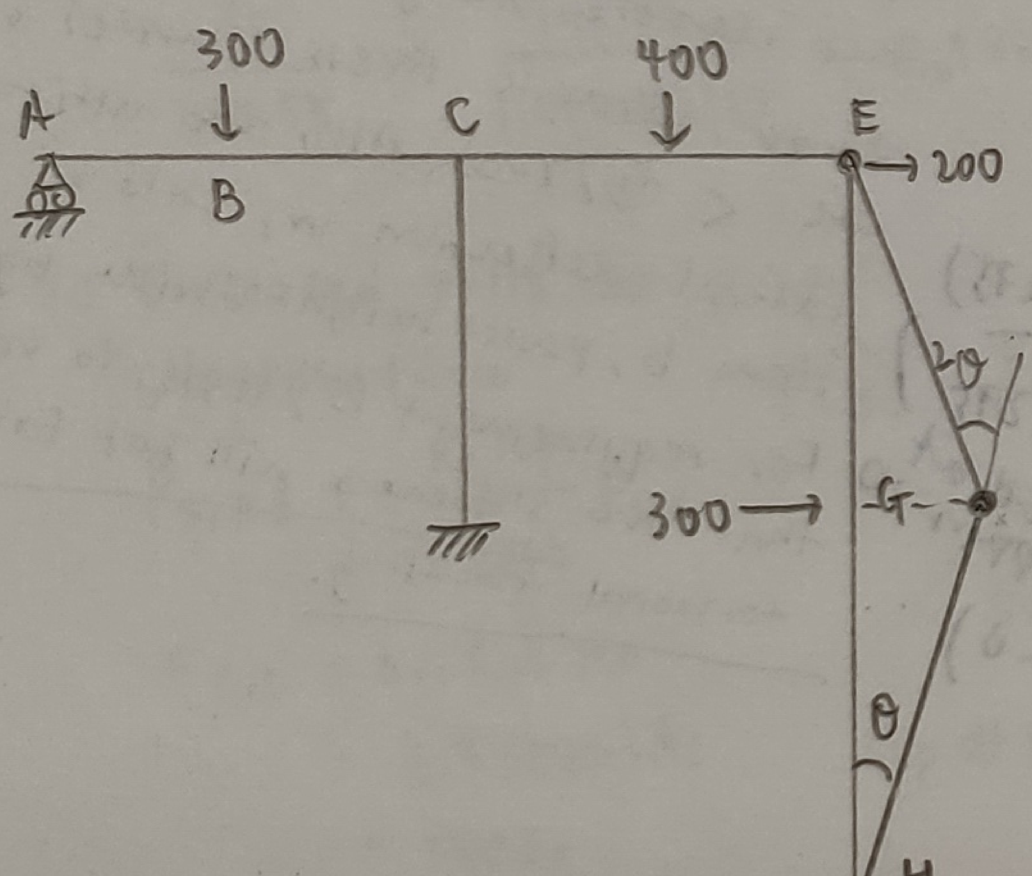
$\Sigma W_E = \Sigma W_i$

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

$1600 = 4M_p$

$M_p = 400$ kNm

iii) Column mechanism with plastic hinges at EGH



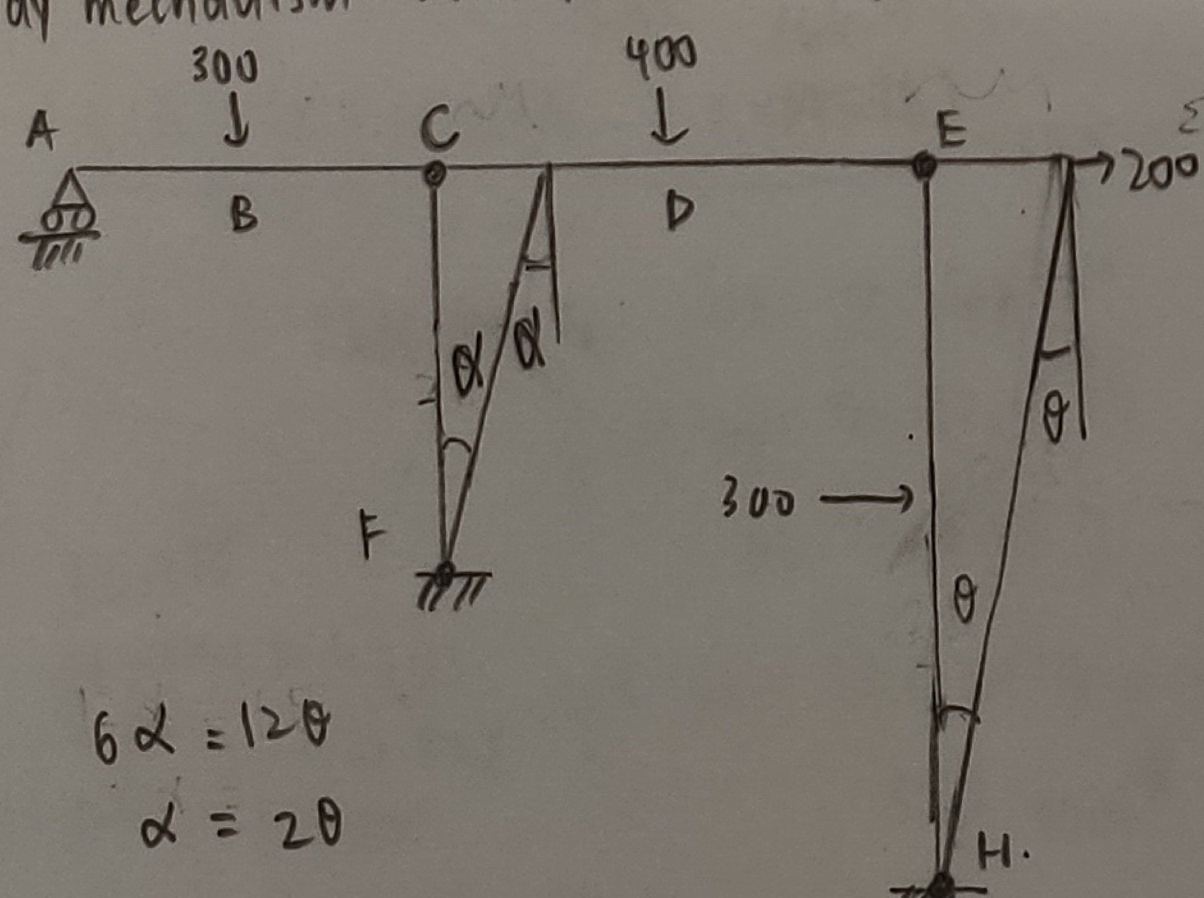
$\Sigma W_E = \Sigma W_i$

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

$1800 = 4M_p$

$M_p = 450$ kNm

iv) Sway mechanism with plastic hinges at CFEH



$\Sigma W_E = \Sigma W_i$

$200(12\theta) + 300(6\theta)$

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

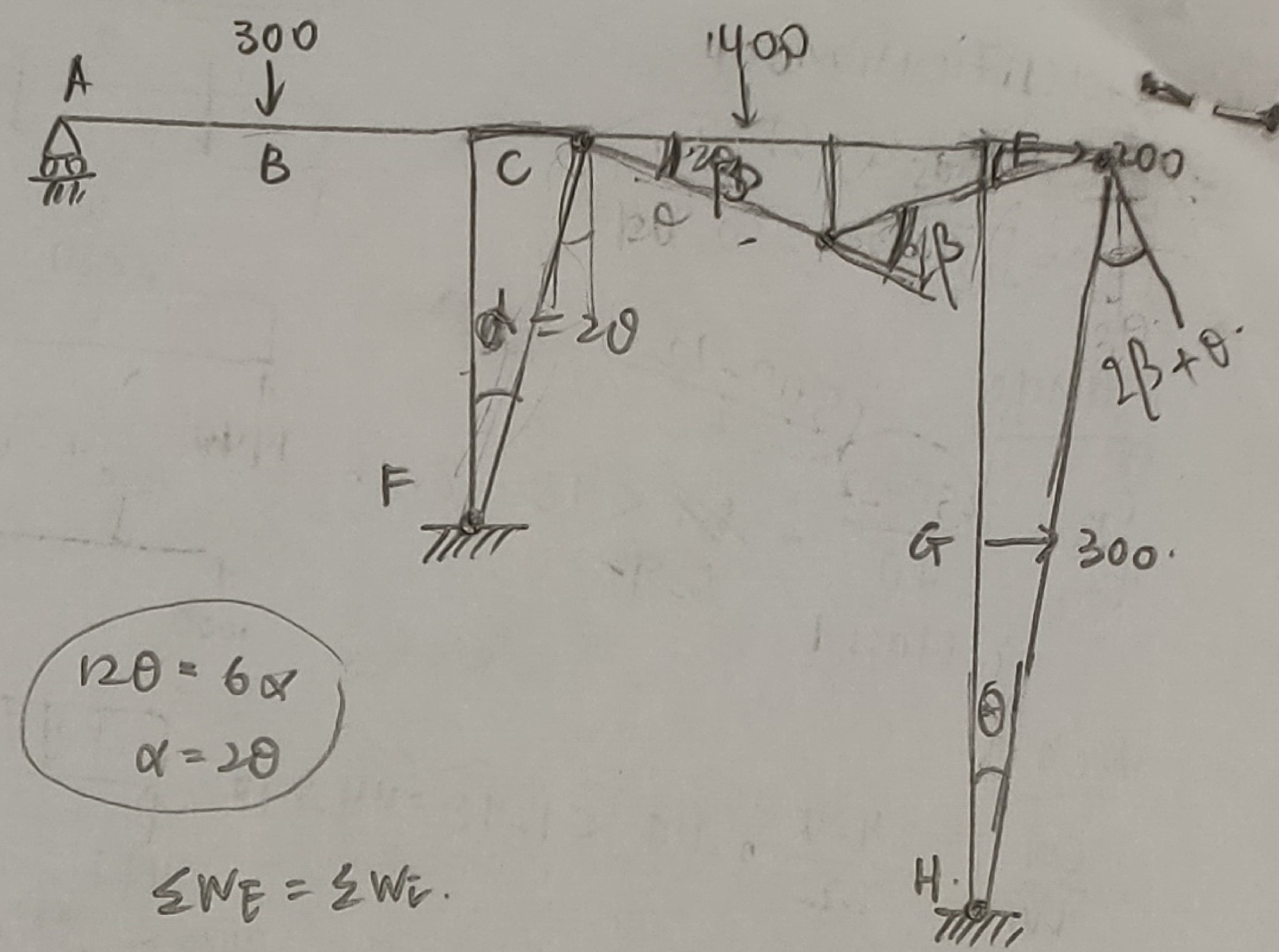
$4200 = 6M_p$

$M_p = 700$ kNm

$6\alpha = 12\theta$

$\alpha = 2\theta$

v) Combined mechanism with plastic hinges at CDEFH.



$12\theta = 6\alpha$

$\alpha = 2\theta$

$\Sigma W_E = \Sigma W_i$

$200(12\theta) + 300(6\theta) + 400(4 \times 2\theta)$

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

$7400 = 12M_p$

$M_p = 616.67$ kNm.

Hence, mechanism 4 is most likely the correct mechanism with $M_p = 700$ kNm

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

b) $W_{pl} \geq \frac{M_p}{f_y} = \frac{700}{355} = 1972\ cm^3$

Choose $457 \times 191 \times 98$ ($W_{pl} = 2230\ cm^3$)

$h_w = 407.6$ mm

$t_w = 11.4$ mm

$b_f = 192.8$ mm

$t_f = 19.6$ mm

$r = 10.2$

$c_f/t_f = 4.11 < 9\varepsilon$
$c_w/t_w = 35.8 < 72\varepsilon$ } class 1

$A = 12500$

$A_v = A - 2b_f t_f + (t_w + 2r) t_f > h_w t_w$

$= 12500 - 2(192.8)(19.6) + (11.4 + 2(10.2))(19.6)$

$> (407.6)(11.4)$

$= 5565.52 > 4646.64$

$V_{pl,Rd} = \frac{A_v f_y}{\sqrt{3}} = \frac{5565.52(355)}{\sqrt{3}}$

$= 1140.71$ kN

$M_{c,Rd} = f_y W_{pl} = 791.7$ kNm

≥ 700 ✓✓