NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2018-19

CV4102 - ADVANCED STEEL DESIGN

November / December 2018 **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 partially overlapped K-joint is shown in Figure Q1. The overlapped brace is welded completely to the chord; while the overlapping brace is partially welded to the brace and the chord. All members are made of square hollow sections (SHS) in accordance to EN 10210, and the steel Grade is S355 as given in Table 3.1 of EN 1993-1-1: 2014. Use design recommendations given in Eurocode 3, EN 1993-1-8: 2010,

(a) Calculate the joint parameters γ and β, and the ranges of validity of the overlapped K-joint.

(6 marks)

(b) Calculate the percentage of overlapped λ_{ov}, and the eccentricity e of the K-joint.

(9 marks)

(c) Determine the design axial resistance $N_{1,Rd}$ of the joint using the appropriate design formulae given in Table 7.10 of Eurocode 3, EN 1993-1-8: 2010.

(10 marks)

Note: Question No. 1 continues on Page 2

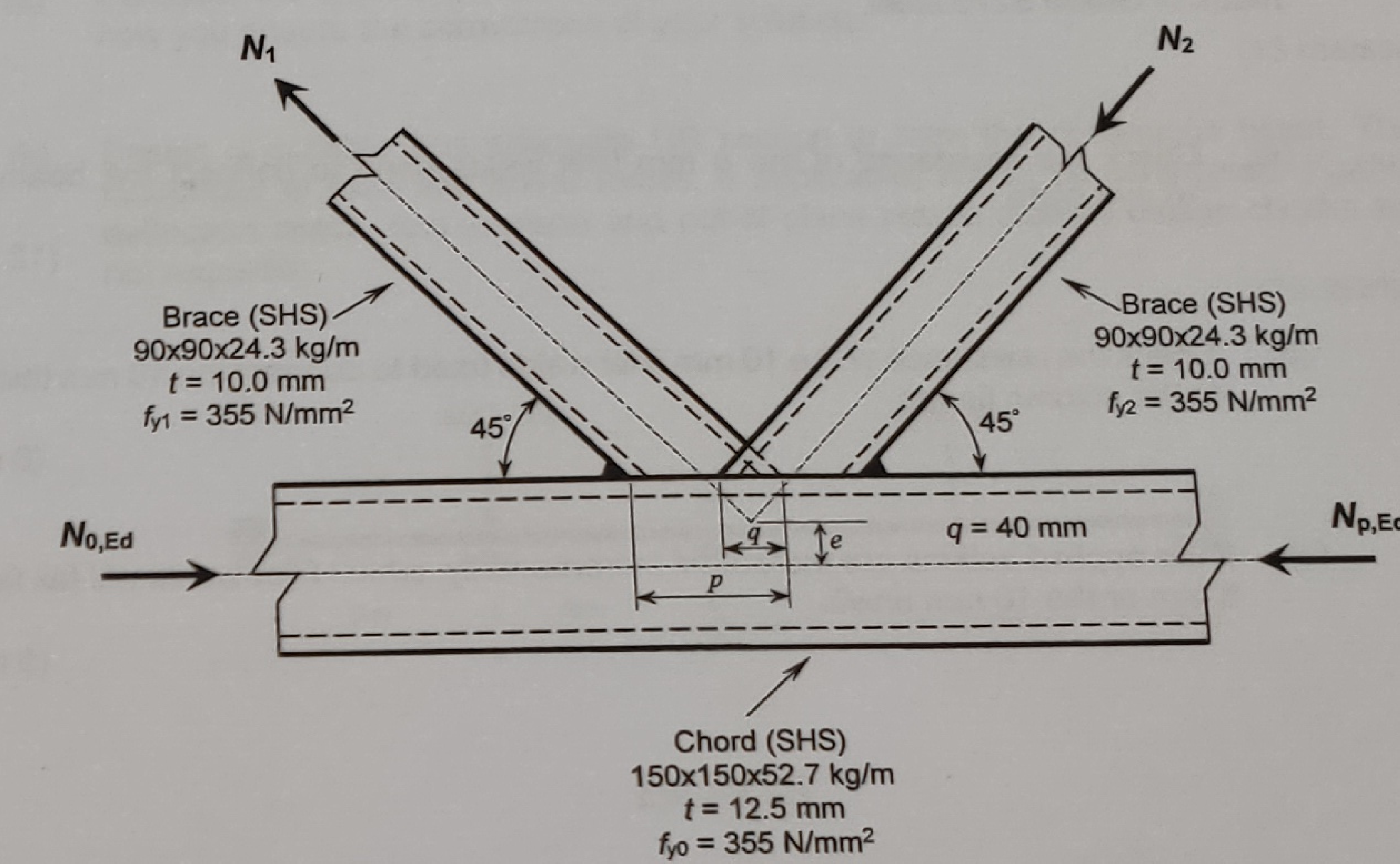
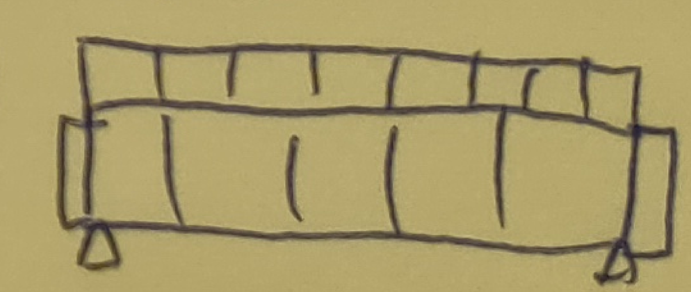


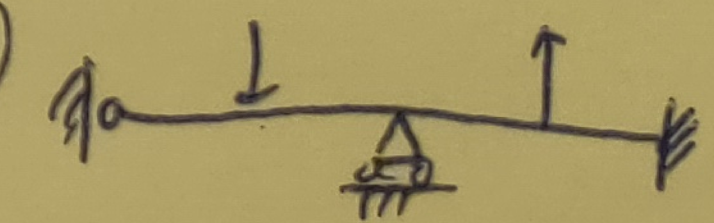
Figure Q1

(Note: drawings are not drawn to scale)

① overlapped k-joint (calc e)
② Perpendicular moment welded
③



④



2. Figure Q2 shows a rigid welded moment connection. It is subjected to design moment M_{Ed}=120 kNm and shear force V_{Ed}=300 kN. A 305x165x54 kg/m UB is welded to a 16 mm thick end-plate, and in turn, the end-plate is welded to the flange of 250x250x91.9 kg/m square hollow section (SHS) using 10 mm fillet welds around the plate. All the welds are made of Grade S275 steel.

(a) Check the resistance of the 8 mm fillet welds used to connect the beam to the 16 mm plate.

(12 marks)

(b) Check the resistance of the 10 mm fillet welds used to connect the 16 mm thick plate to the column flange.

(8 marks)

(c) If the applied actions are increased incrementally, which fillet welds will fail first, the 8 mm or the 10 mm one?

(5 marks)

Note: Question No. 2 continues on Page 4

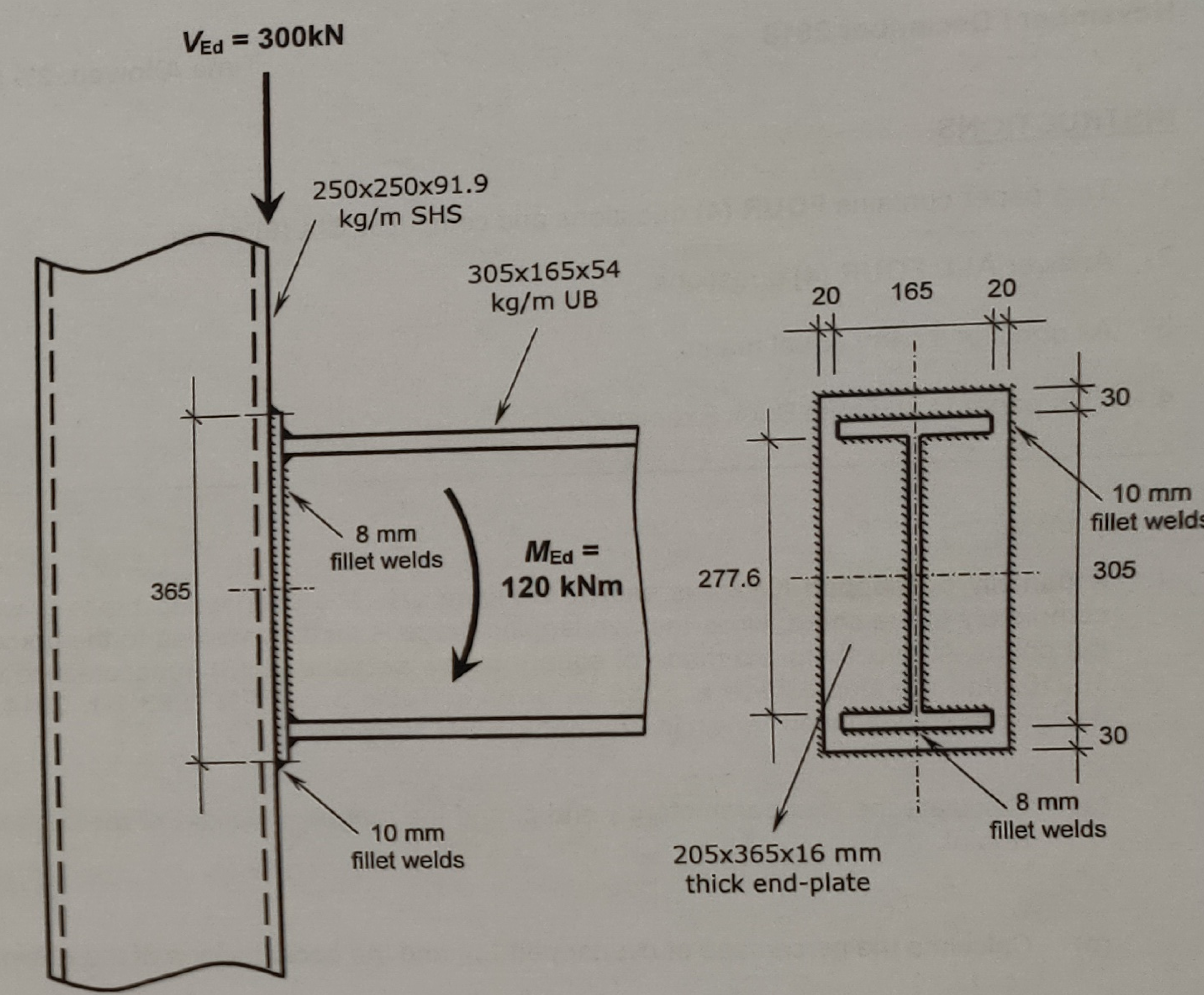


Figure Q2

(Note: drawings are not drawn to scale)

(All dimensions are in mm unless otherwise stated)

3. The 30 m 2-span continuous plate girder ABC 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 a factored design u.d.l of *w* kN/m throughout. Details of the stiffeners are given in Figure Q3(b). Assume all the end posts and stiffeners are rigid.

   (a) Compute the bending resistance of the plate girder.
   (b) Compute the shear resistance of the plate girder.
   (c) Compute the load bearing resistance of the stiffener at support B.
   (d) What is the allowable u.d.l *w* kN/m?
   (e) Explain the considerations needed to ensure minimum maintenance cost of the plate girder throughout its service life.

(25 marks)

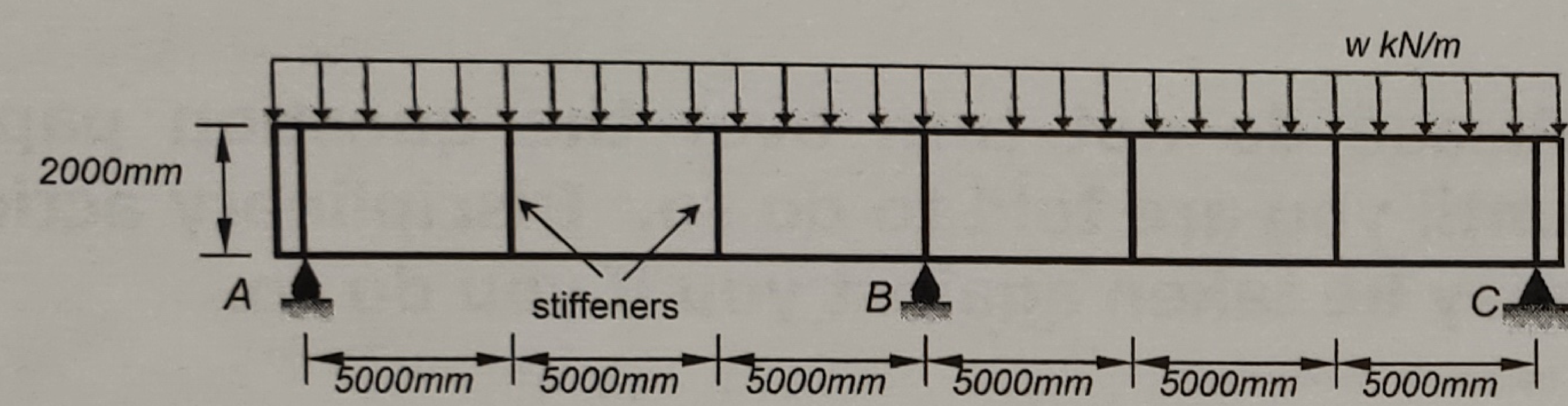
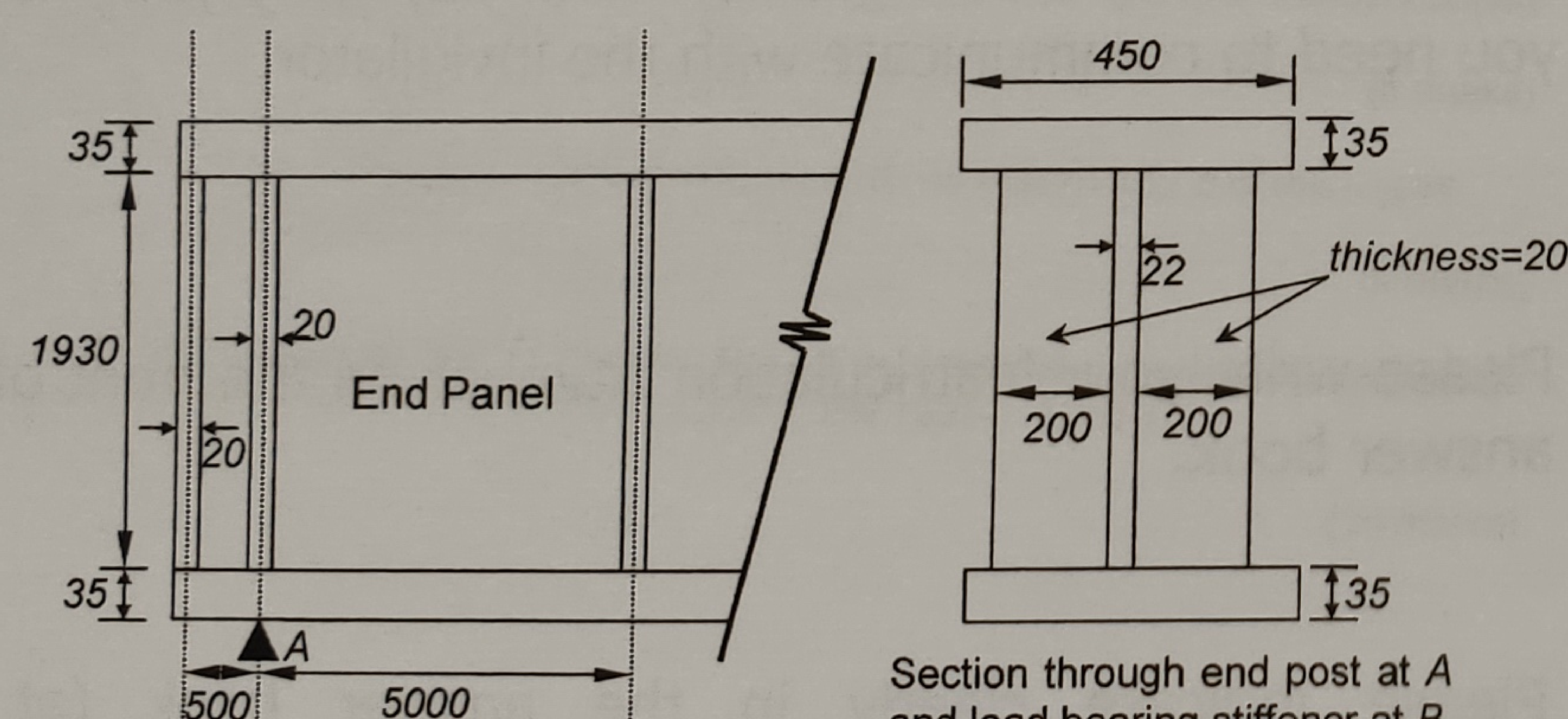


Figure Q3(a)
(Drawing not to scale)



Elevation view of end post at A

Section through end post at A and load bearing stiffener at B

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

Figure Q3(b)
(Drawing not to scale)

4. The continuous uniform beam ABCDE shown in Figure Q4 is pinned at A, roller-supported at C and fixed at E, and is subjected to factored design concentrated loads at B and D. It is fabricated using uniform S355 steel section throughout. Adequate restraints against stability are provided.

   (a) Calculate the required plastic moment of resistance for the continuous beam. Show how you ensure the correctness of your solution.

(13 marks)

   (b) Design a suitable and adequate UB section to form the continuous beam. 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)

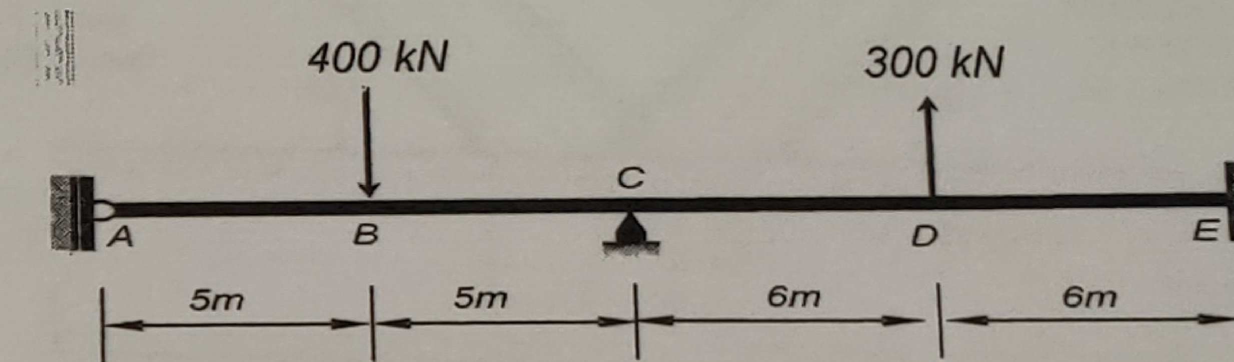
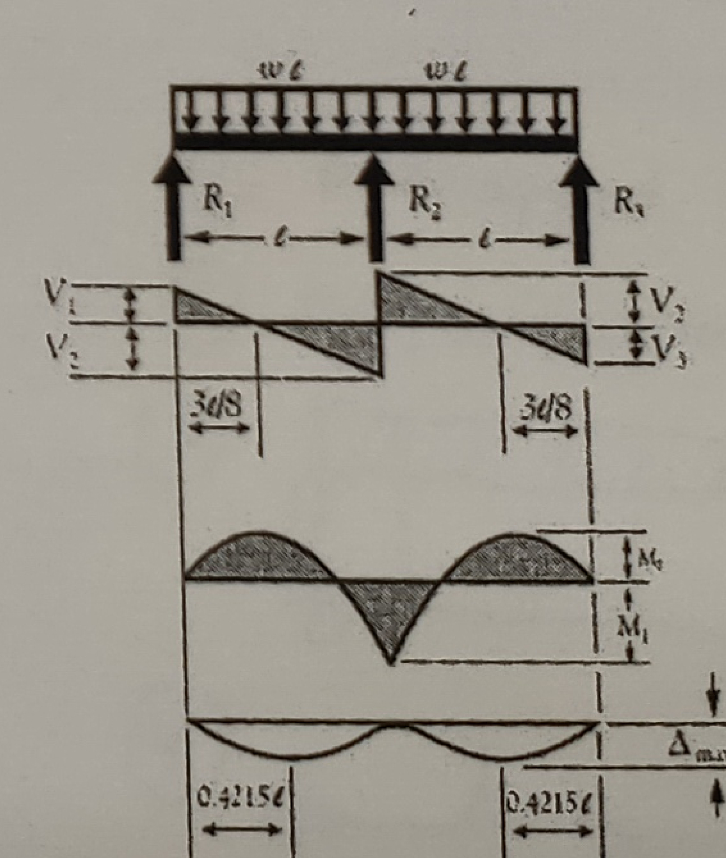


Figure Q4

Continuous Beam – Two Equal Spans – Uniformly Distributed Load



$R_1 = V_1 = R_3 = V_3 \ldots = \frac{3w\ell}{8}$

$R_2 \ldots = \frac{10w\ell}{8}$

$V_2 = V_{max} \ldots = \frac{5w\ell}{8}$

$M_1 \ldots = \frac{w\ell^2}{8}$

$M_2 \left(\text{at } \frac{3\ell}{8}\right) \ldots = \frac{9w\ell^2}{128}$

Δ_{max} (at $0.4215\,\ell$, approx. from R_1 and R_3) $\ldots = \frac{w\ell^4}{185EI}$

END OF PAPER

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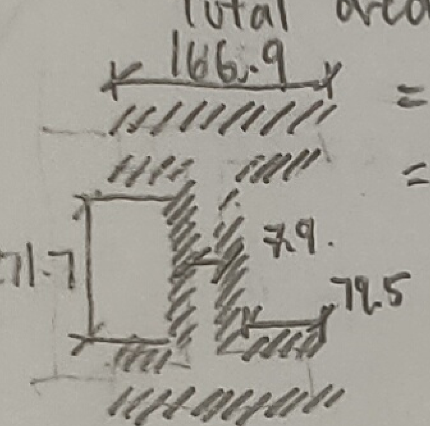
2) a) Thoart length of 8mm fillet weld

$= 8 \times \cos 45° = 5.66$ mm

Total area of 8mm fillet weld



$= (2\times166.9 + 2\times271.7 + 4\times79.5)\times5.66$

$= 6764.83\ mm^2$

$5.66/2 = 2.83$

Maximum vertical shear stress

$f_s = \frac{P}{\text{Area of weld}} = \frac{300}{6764.83}$

$= 44.35$ kPa ✓

Second moment of weld group

$I_{yy} = 2\left(\frac{5.66\times271.7^3}{12}\right) + 2\left[\frac{166.9\times5.66^3}{12} + (166.9\times5.66)\times\left(\frac{310.4+(2\times2.83)}{2}\right)^2\right]$

$+ 4\left[\frac{79.5\times5.66^3}{12} + (79.5\times5.66)\times\left(\frac{271.7+(2\times2.83)}{2}\right)^2\right]$

$= 18920564.78 + 47187641 + 34620353648$

$= 100728559.3\ mm^4$

$W_{el} = \frac{I_{yy}}{y} = \frac{100728559.3}{\frac{310.4}{2}+5.66} = 626187.74\ mm^3$ (~~[illegible]~~)

maximum bending stress

$f_b = \frac{P\times e}{W_{el}} = \frac{120}{626187.74} = 191.64$ kPa (~~[illegible]~~)

maximum stress

$f_r = \sqrt{f_s^2 + f_b^2} = $ ~~191.29~~ 196.7 kPa.

Design shear strength of weld

$f_{vw,d} = \frac{f_u/\sqrt{3}}{\beta_w\times\gamma_{M2}} = \frac{430/\sqrt{3}}{0.85\times1.25} = 233.66$ kPa > ~~191.29~~ 196.7 kPa

OK!

b) Thoart length of 10mm fillet weld

$= 10\times\cos 45° = 7.07$ mm ✓

Total area

$= (205\times2 + 365\times2)\times7.07$

$= 8059.8\ mm^2$ ✓

$f_s = \frac{300}{8059.8} = 37.22$ kPa

$I_{yy} = 2\left(\frac{7.07\times365^3}{12}\right) + 2\left(\frac{205\times7.07^3}{12} + \left(\frac{365+3.535\times2}{2}\right)^2(205\times7.07)\right)$

$= 57298962.29 + 100333244.5$

$=$ ~~161480994.9~~ mm^4 157632206.4 ✓

$W_{el} = \frac{I_{yy}}{y} = \frac{\text{~~161480994.9~~}}{\frac{365}{2}+7.07} = $ ~~851837.8~~ 831529.064 mm^3 ✓

$f_b = \frac{P\times e}{W_{el}} = \frac{120}{\text{~~851837.8~~}} = $ ~~140.87~~ 144.31 kPa ✓

$f_r = \sqrt{f_s^2 + f_b^2} = \sqrt{37.22^2 + \text{~~140.87~~}^2}$ (144.31) $=$ ~~145.71~~ ~~144.31~~ 149 kPa ✓

c) 8mm fillet weld will fail first as the fr of 8mm is 191.29 kPa which is larger than fr of 10mm of 145.71 kPa.

3) a) For Grade S275,

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

Flange

$\frac{c_f}{t_f} = \frac{225-22}{35} = 5.8 \leq 9\varepsilon = 8.316$

class 1

Web

$\frac{c_w}{t_w} = \frac{1930}{22} = 87.73 < 124\varepsilon = 114.576$

class 3

Bending resistance

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

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

$= (450 \times 35)(1930+35)(275)$

$= 8510.91$ kNm

$I_w = \frac{1930^3 \times 22}{12} = 1.318 \times 10^{10}$ mm^4

$W_{el,w} = I_w/z = \frac{1.318 \times 10^{10}}{1930/2} = 13657966.67$ mm^3

$W_{el,w} f_{yw} = 3755.94$ kNm

$M_{y,Rd} = 8510.91 + 3755.94 = 12266.85$ kNm.

b) $a/h_w = \frac{5000}{1930} = 2.59 > 1.0$

$k_\tau = 5.34 + 4\left(\frac{h_w}{a}\right)^2 = 5.936$

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

$\frac{1930}{22} = 87.73 \leq 31 \frac{(0.924)}{1}\sqrt{5.936} = 69.8$

web is NOT stocky

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

$\bar{\lambda}_w = \frac{h_w}{37.4 t_w \varepsilon \sqrt{k_\tau}} = \frac{1930}{37.4(22)(0.924)\sqrt{5.936}}$

$= 1.04 < 1.08$

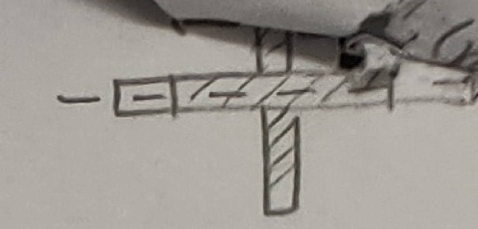
$\chi_w = 0.83/\bar{\lambda}_w = 0.797$

$V_{bw,Rd} = \frac{\chi_w f_{yw} h_w t_w}{\sqrt{3}\gamma_{M1}} = \frac{0.797 \times 275 \times 1930 \times 22}{\sqrt{3}(1.0)}$

$= 5372.92$ kN

* Assume no flange contribution

c) Load Bearing stiffener @ B.



$15\varepsilon t_w = 15(0.924)(22) = 304.92$ mm

$A_{st} = (304.92 + 20 + 304.92) \times 22 + 2(200 \times 20)$

$= 21856.48$ mm^2

$I_{st} = (200+22+200)^3 \times 20/12 + 2(304.92 \times 22^3/12)$

$= 125793544.7$ mm^4

$\lambda = 93.9\varepsilon = 86.764$

$i_{st} = \left(\frac{I_{st}}{A_{st}}\right)^{0.5} = 75.86$ mm

$\bar{\lambda} = \frac{(930)}{75.86}\frac{1}{86.764} = 0.293 > 0.2$ (0.75hw)

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

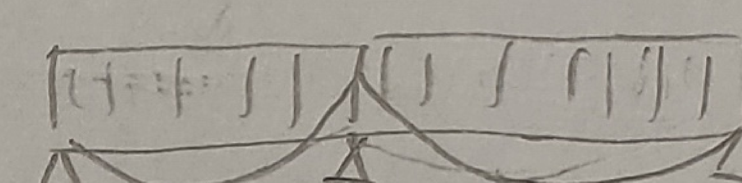
$= 0.566$

$\bar{\chi} = \frac{1}{\phi + \sqrt{\phi^2 + \bar{\lambda}^2}} = 0.952.$

$N_{b,Rd} = 0.952 \times A_{st} \times f_y$

$= 5725$ kN

d)



$V_2 = V_{max} = \frac{5wl}{8}$

$M_{max} = \frac{wl^2}{8}$

$\frac{wl^2}{8} < 12266.85$

$\frac{w(15)^2}{8} < 12266.85$

< 436.15 kN/m.

$\sigma_m = 0.5\left(\frac{\sigma}{b}\right)\left(\frac{1}{a} + \frac{w}{a}\right)$

$\downarrow$

$\Delta N_{s,ten} = \frac{\sigma_m^2 h_w}{\pi^2}$

$\frac{5wl}{8} < 5372.92$

$w < 573.11$ kN/m

load bearing

Deviation forces due to direct stress

$a = 5000 > b = 2000$ $\sigma_m = 0.265375$

$\sigma_{cr,c}/\sigma_{cr,p} \approx 0 \Rightarrow$ set 0.5

$M_{Ed} = \frac{225}{8} w$

To simplify calc, assume fy reach extreme fibre of web

$N_{Ed} = \frac{1930}{2} \times 22 \times \frac{275}{2} = 2653.75$

(22: web thickness)

$\Delta\sigma_{s,ten}$

$= ~~100.155~~$

Axial force

$= \frac{10wl}{8} + 100.155$

$+ \frac{5wl}{8} - 6232.831$

e) Accessibility → holes for servicing

corrosion protection

fatigue causing crack initiation.

$= \frac{15wl}{8} - 6132.68$

< 5725

$\frac{15wl}{8} < 11857$

$w <$ ~~421.61 kN~~

420.31

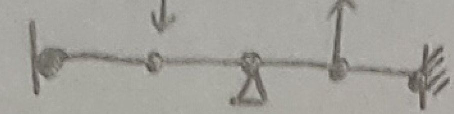
TFA

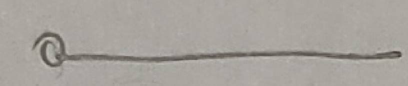
$\hookrightarrow V_{Ed} - \frac{1}{\bar{\lambda}_w}\frac{h_w f_{yw} t_w}{\sqrt{3}\gamma_{M1}}$

$= \frac{5wl}{8} - 6232.831$

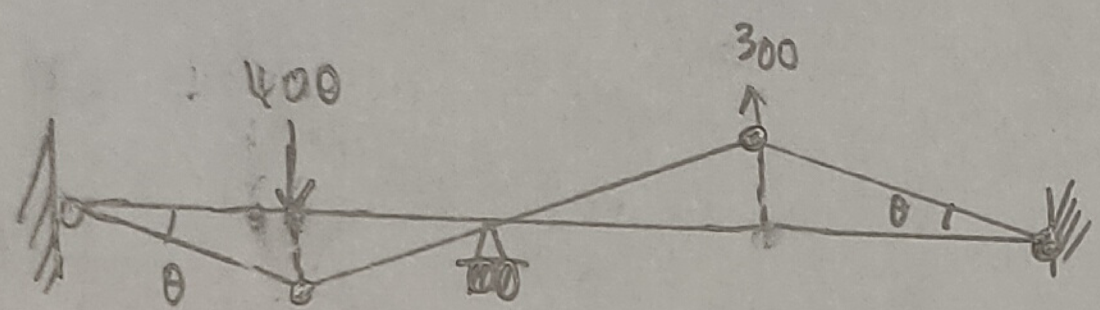
$n_s = (2+1+3) - 3 = 3$

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





Mechanism 1 (B-D-E)



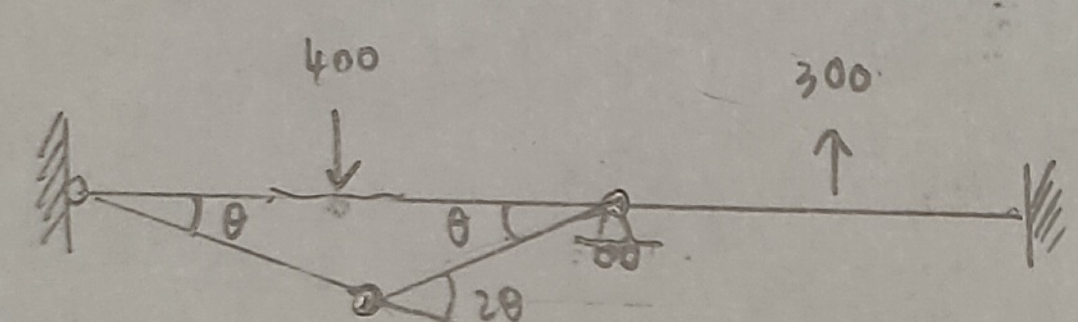
$\Sigma W_e = \Sigma W_i$

$400(5\theta) + 300(6\theta) = M_p(2\theta) + M_p(2\theta) + M_p(\theta)$

$3800 = 5M_p$

$M_p = 760$ KNm

Mechanism 2 (B-C)



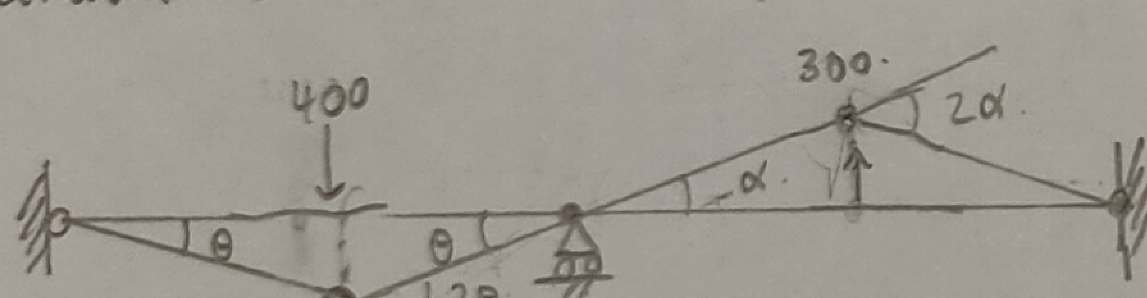
$\Sigma W_e = \Sigma W_i$

$400(5\theta) + 300(0) = M_p(\theta) + M_p(2\theta)$

$2000 = 3M_p$

$M_p = 666.67$ KNm

Mechanism 3 (B-C-D-E)



$5\theta = 6\alpha$

$\theta = 1.2\alpha$

$\Sigma W_e = \Sigma W_i$

$400(5\theta) + 300(6\alpha) = M_p(2\theta) + M_p(\theta) + M_p(\theta) + M_p(\theta)$ ~~$1.2M_p\alpha + 2.4M_p\alpha + 3M_p\alpha$~~ $6M_p\alpha$.

$2400\alpha + 1800\alpha =$

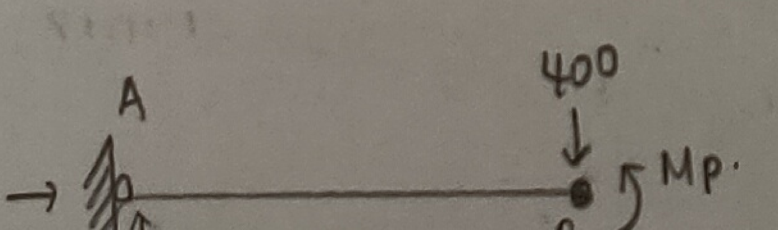
$4200 =$ ~~$6.6M_p$~~

$M_p =$ ~~636.36 KNm~~

700 KNm

Mechanism 1 has the highest Mp → correct mechanism

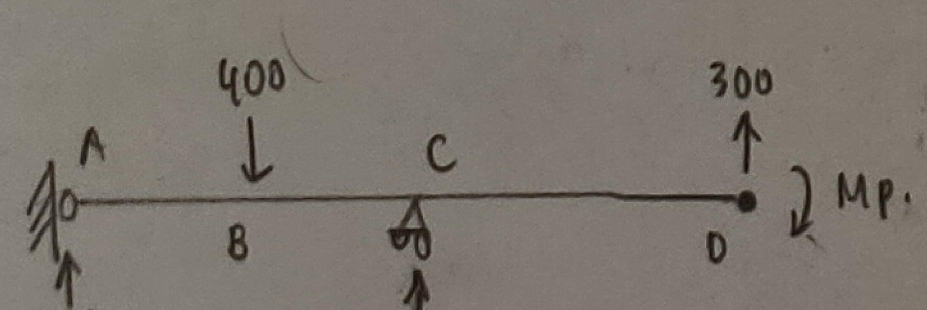
Equilibrium check



$\Sigma M_B = 0$

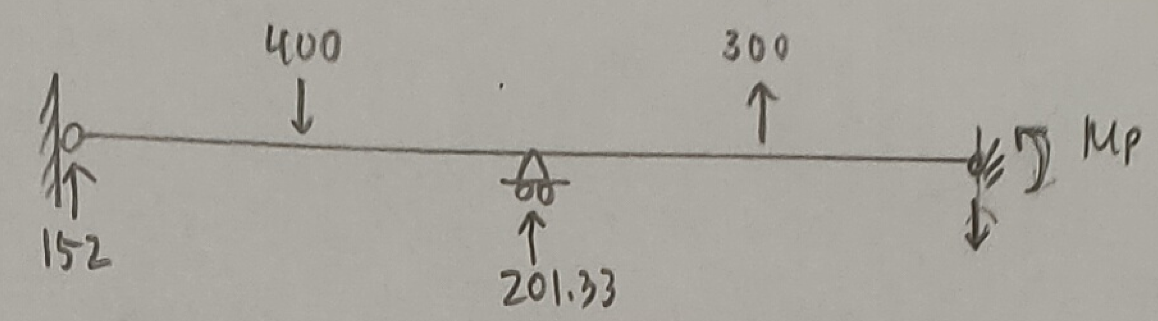
$A_y(5) = M_p$

$A_y = 152$ KN



$\Sigma M_D = 0$ $\quad 152(16) + M_p + C_y(6) = 400(11)$

$C_y = 201.33$ KN



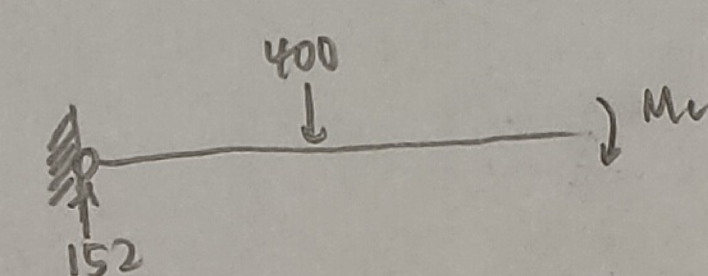
$\Sigma M_C = 0$ $\quad 152(10) + E_y(12) = M_p + 300(5) + 400(6)$

$E_y = 253.33$

Σ Vertical force $= 152 + 201.33 - 253.33 = 100 = 400 - 300$

Equilibrium is satisfied!

check moment at C



$\Sigma M_C = 0$

$152(10) + M_C = 400(5)$

$M_C = 480$ KNm < 760 KNm

∴ Mechanism 1 is the correct mechanism.

b) $W_{pl} \geq \frac{M_p}{f_y} = \frac{760 \times 10^3}{355} = 2140.85$ cm³

Try $533 \times 210 \times 92$, $W_{pl} = 2360$ cm³

$h_w = 476.5$ mm

$t_w = 10.1$ mm

$t_f = 15.6$ mm

$b_f = 209.3$ mm

$r = 12.7$ mm

$A = 11700$ mm²

$f_y = 355$ N/mm²

Section Classification

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

$\frac{b_f/2}{t_f} = 6.71 < 9\varepsilon = 7.326$

$\frac{h_w}{t_w} = \frac{476.5}{10.1} = 47.18 < 72\varepsilon = 58.61$

} class 1

Bending & shear

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

$= 11700 - 2(209.3)(15.6) + (10.1 + 2(12.7))(15.6)$

$> 476.5 \times 10.1$

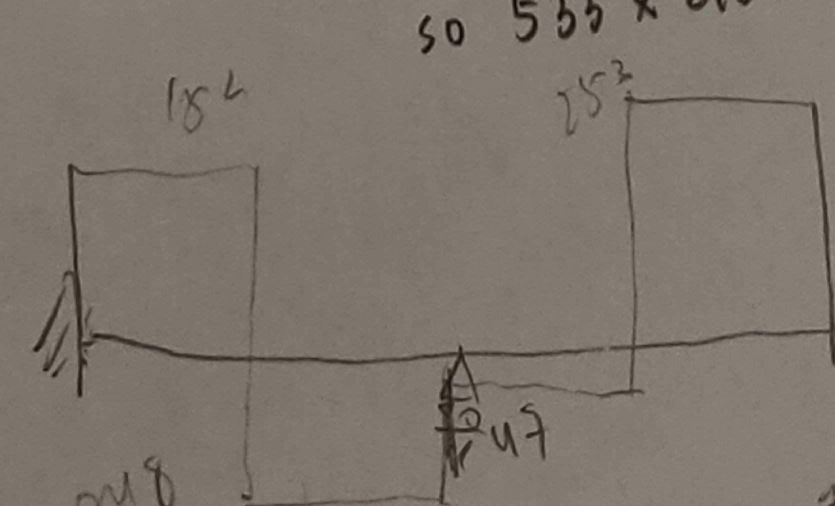
$= 5723.64 > 4812.65$

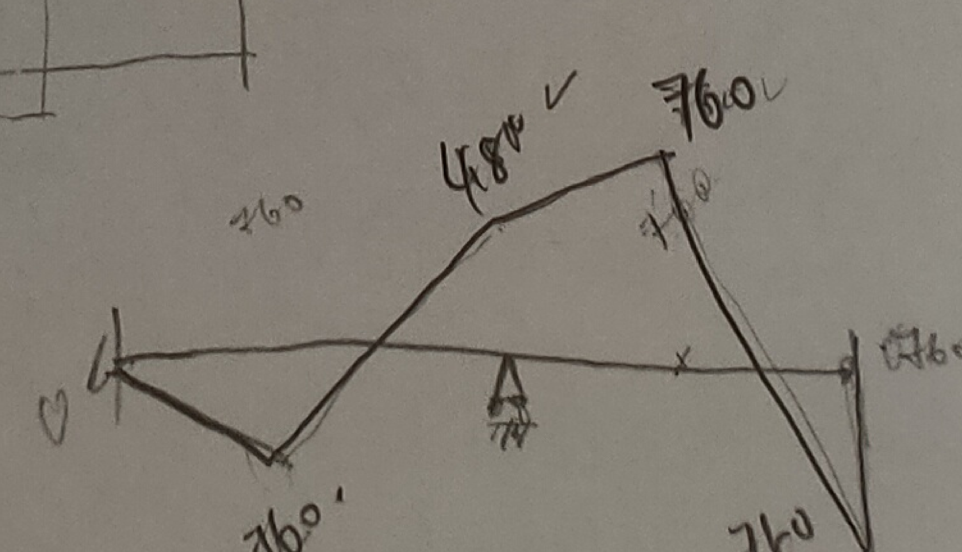
$V_{pl,Rd} = \frac{A_v f_y}{\sqrt{3}} = 1173.11$ KN $> V_{max}$

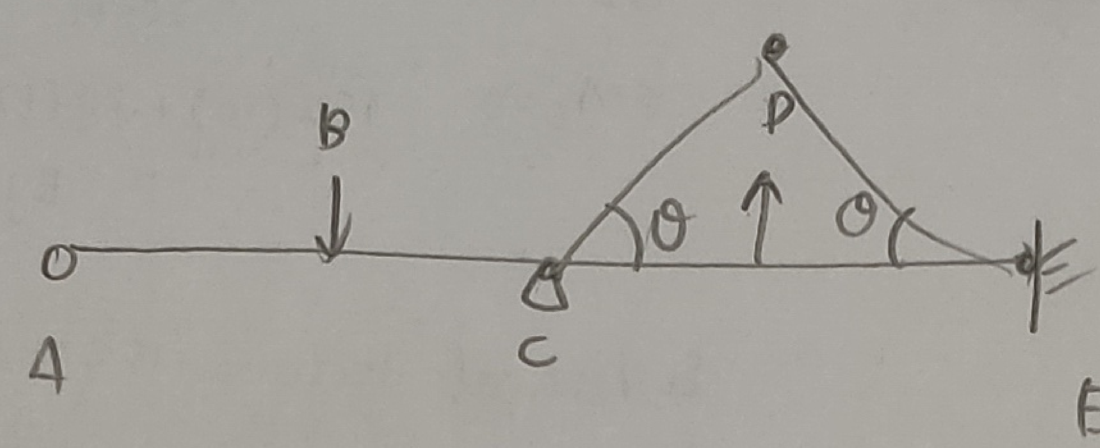
$M_{c,Rd} = f_y W_{pl} = 335(2360)(1000) = 790.6$ KNm

low shear ⇒ no moment reduction

so $533 \times 210 \times 92$ is satisfactory!







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

$$1800\theta = 4M_p\theta$$

$$M_p = 450 \text{ kNm}$$