NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2015-2016

CV4102 - ADVANCED STEEL DESIGN

November/December 2015 **Time Allowed: 2½ hours**

INSTRUCTIONS

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

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1. Figure Q1 shows a K-joint fabricated using (SHS) square hollow section 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: 2005,

   (a) Check if the joint parameters satisfy the ranges of validity. Hence, calculate the joint strength if the compressive stress in the chord $\sigma_{0,Ed}=0.6f_{y0}$, and state the critical failure mechanism.

   (12 Marks)

   (b) Recalculate the joint strength if the compressive stress in the chord is increased to 90% of the design strength, i.e. $\sigma_{0,Ed}=0.9f_{y0}$, and discuss the effect of increasing and decreasing its magnitude and direction.

   (8 Marks)

   (c) What is the limit of g when the K-joint can be considered as two separate Y-joints?

   (5 Marks)

Note: Question 1 continues on Page 2

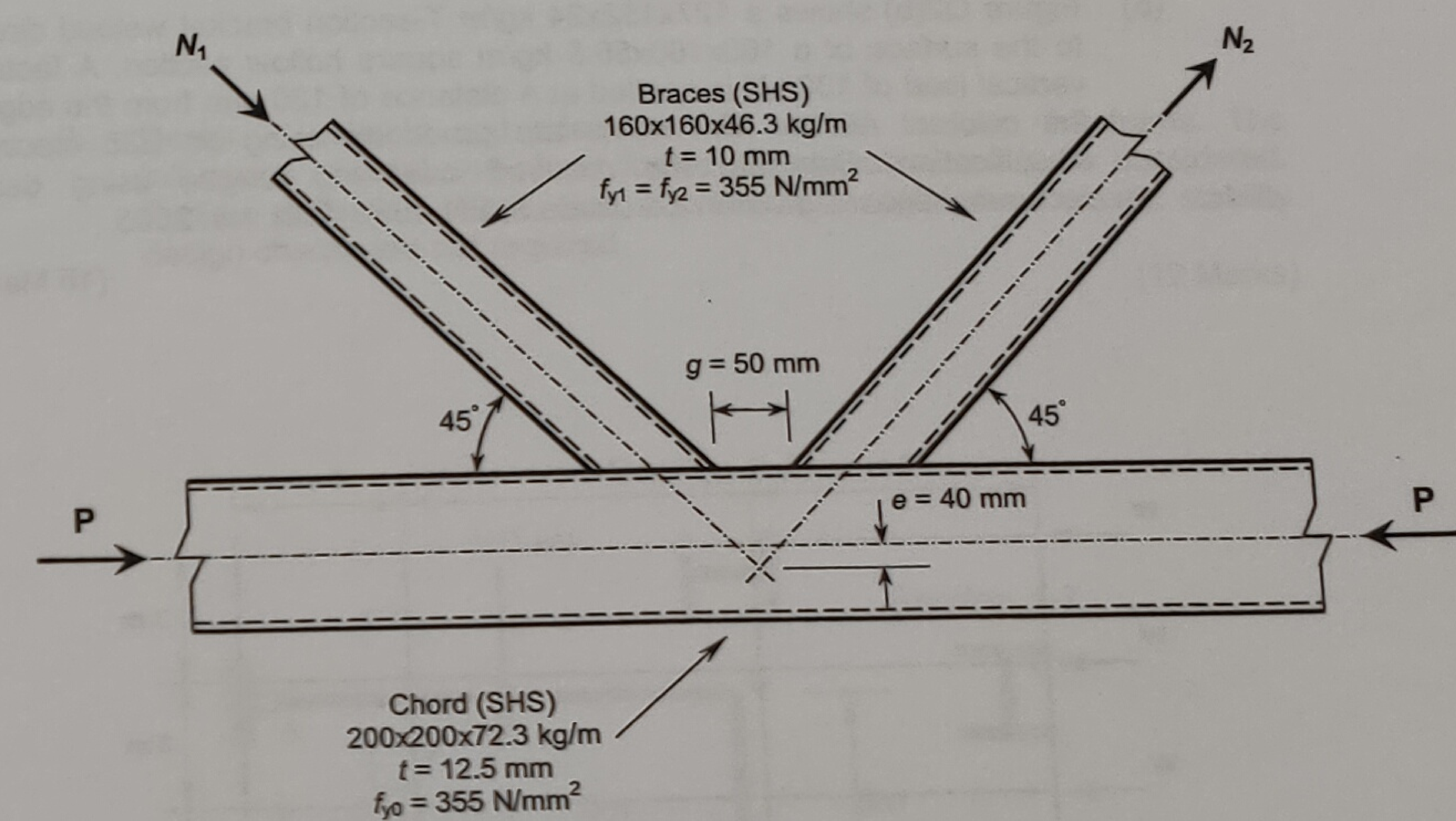
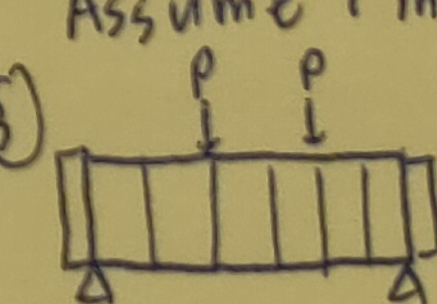
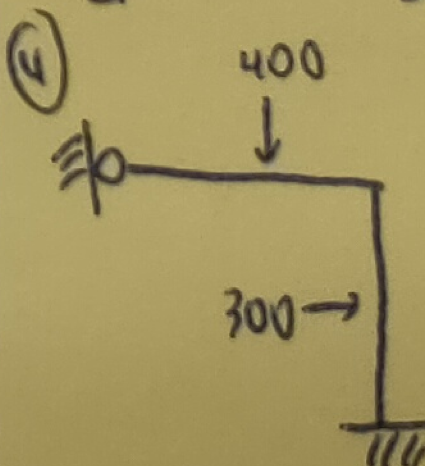


Figure Q1

(Note: drawings are not drawn to scale)

① K-gap SHS
② Portal Frame
Assume 1 mm weld thoart
③


④


2. (a) A seven-storey rigid frame shown in Figure Q2(a) is subjected to factored horizontal wind load, *w* equal to 3 kN. The columns are fixed at the base. Using the portal frame method, calculate the axial force, shear force and bending moment of column marked A.

(10 Marks)

(b) Figure Q2(b) shows a 127x152x24 kg/m T-section bracket welded directly to the surface of a 160x160x56.5 kg/m square hollow section. A factored vertical load of 130 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. Calculate the required weld leg length, using design recommendations given in Eurocode 3, EN-1993, Part 1-8: 2005.

(15 Marks)

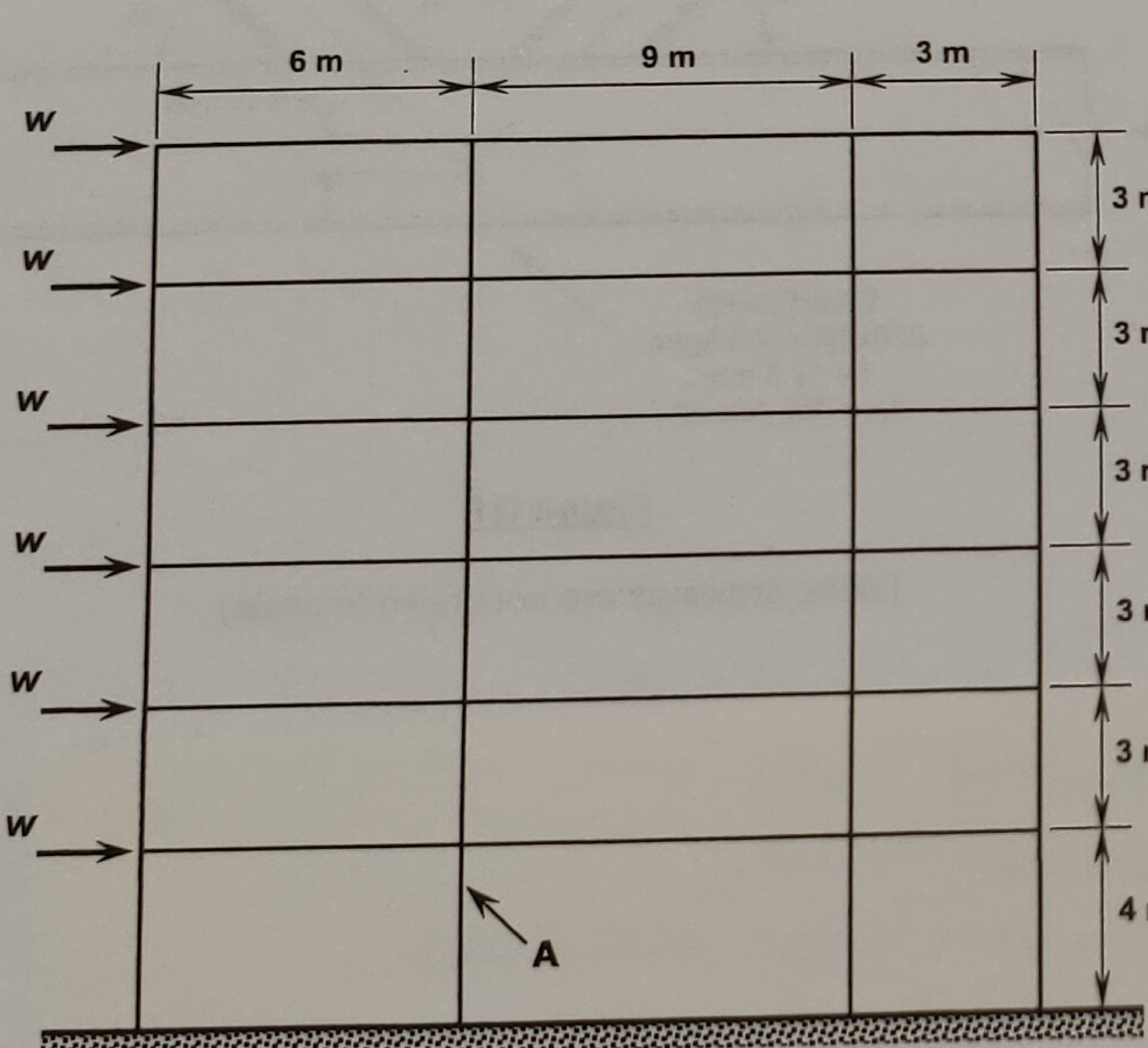


Figure Q2(a)

(Note: drawings are not drawn to scale)

Note: Question 2 continues on Page 4

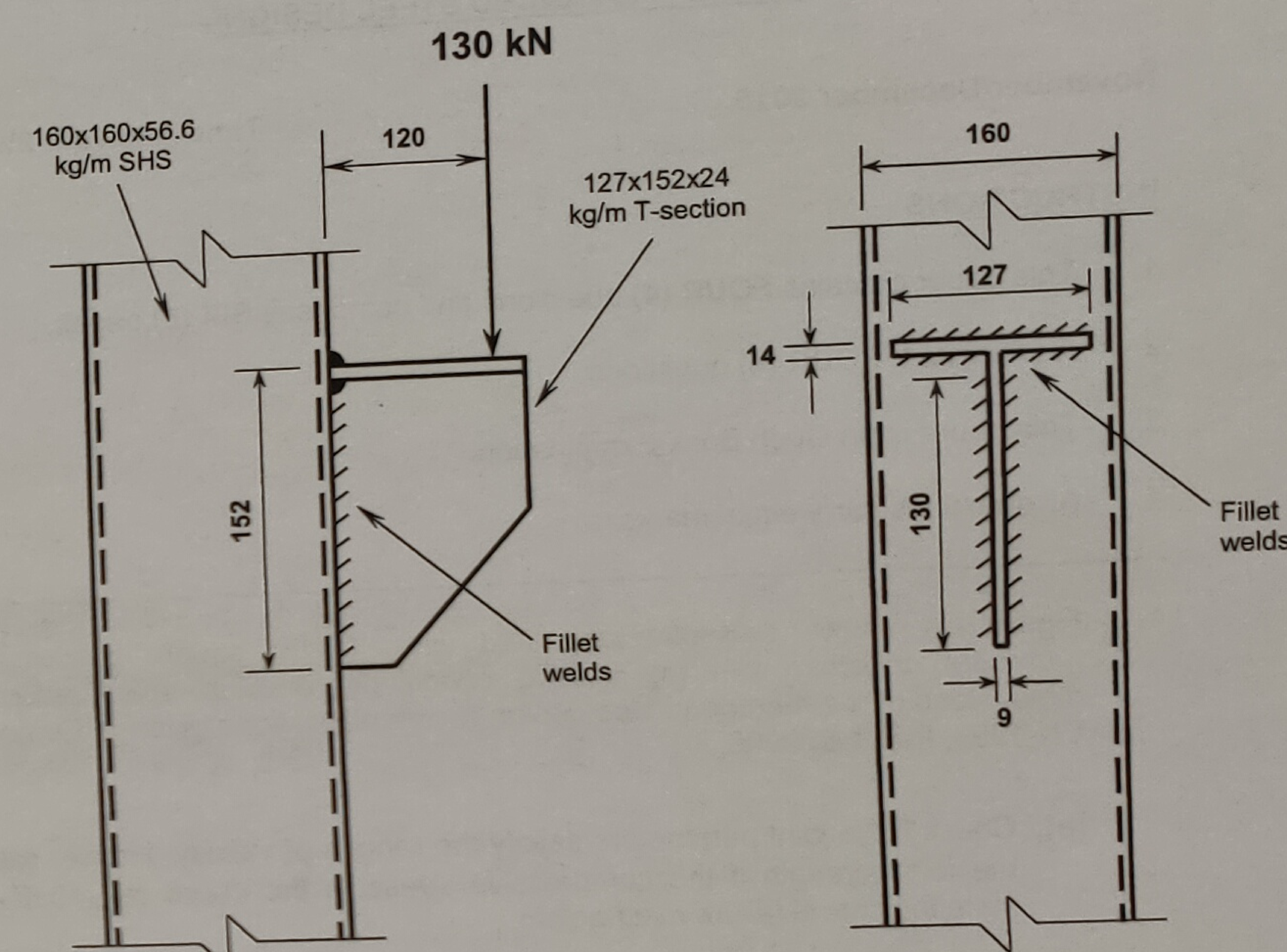


Figure Q2(b)

(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. The girder is simply supported at the rigid end posts *A* and *D*, and effectively restrained in the lateral direction along the entire girder. It is supporting two (2) factored design concentrated loads, each *P* kN acting at the intermediate stiffeners *B* and *C*. Details of the rigid end posts at *A* and *D* and the stiffeners at *B* and *C* are shown in Figure Q3(b).

   (i) Classify the flanges and the web of the plate girder.
   (ii) Compute the bending resistance of the plate girder.
   (iii) Compute the shear resistance of the plate girder.
   (iv) Compute the load bearing resistance of the rigid end posts at *A* and *D*.
   (v) Compute the load bearing resistance of the stiffeners at *B* and *C*.
   (vi) What is the allowable load *P*?

(25 Marks)

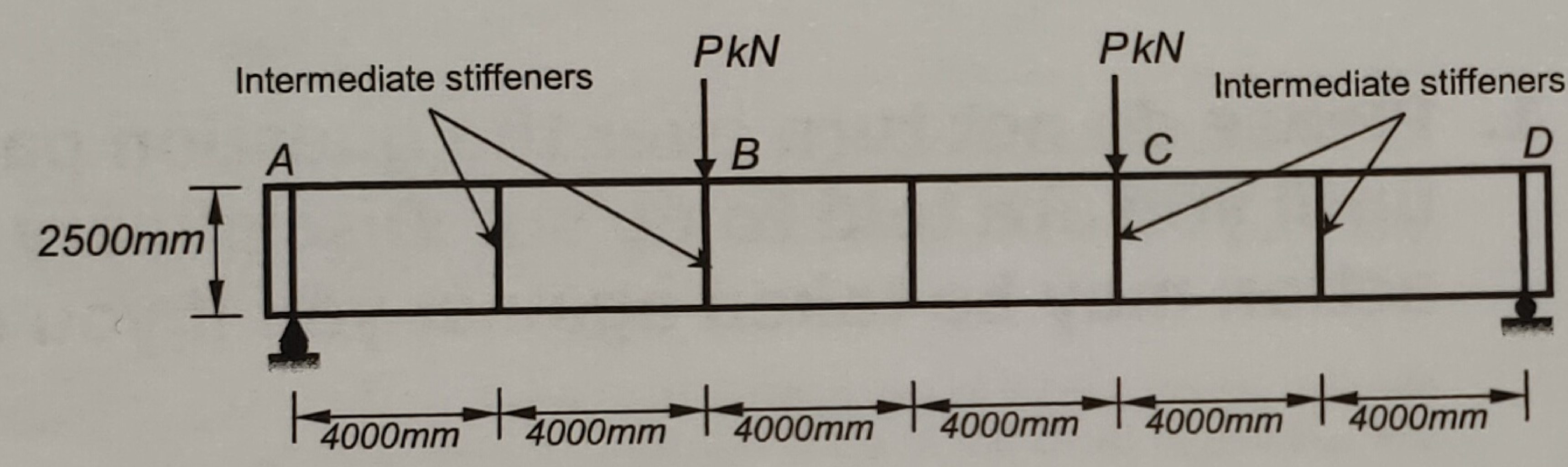
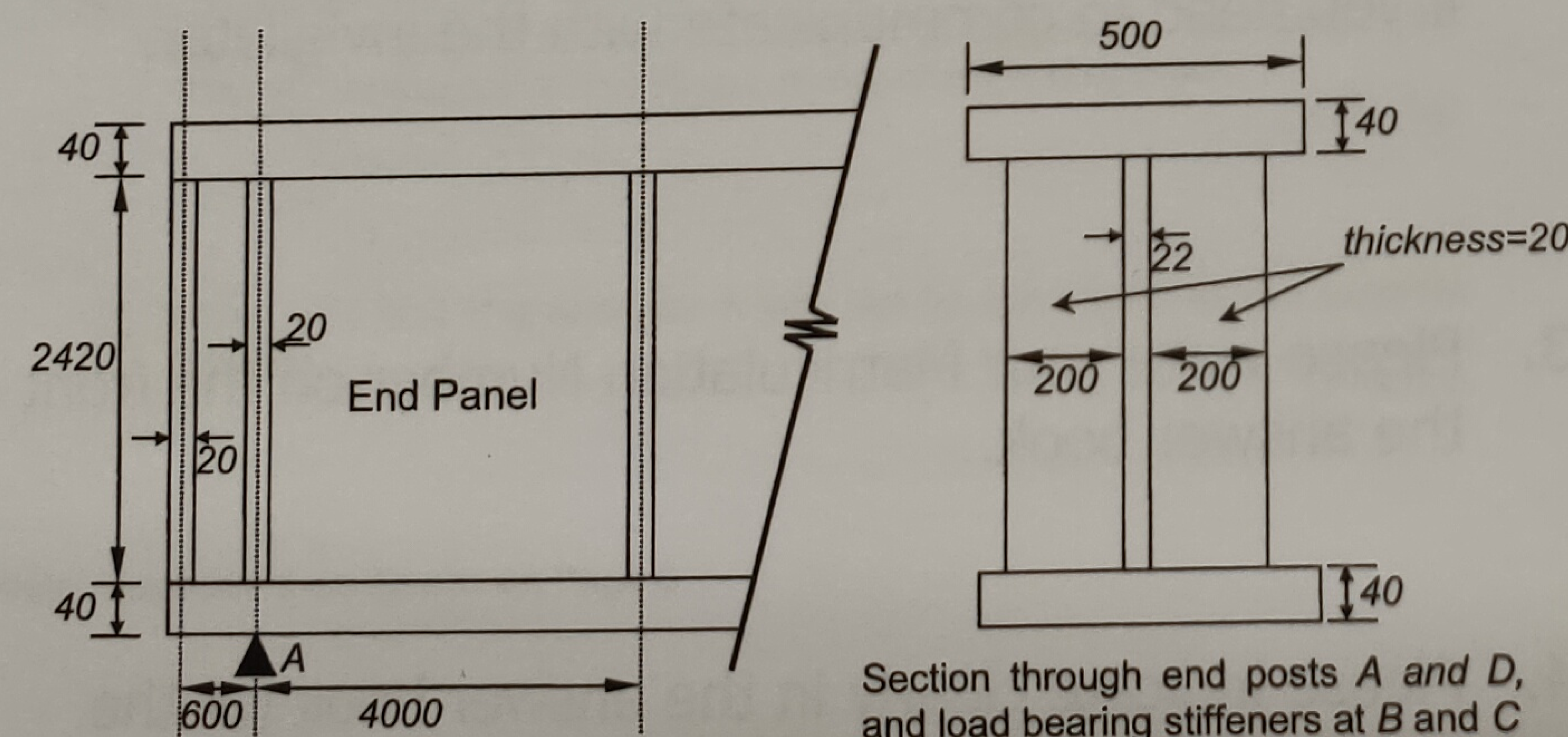


Figure Q3(a)



Elevation view of end post at *A*

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

Figure Q3(b)

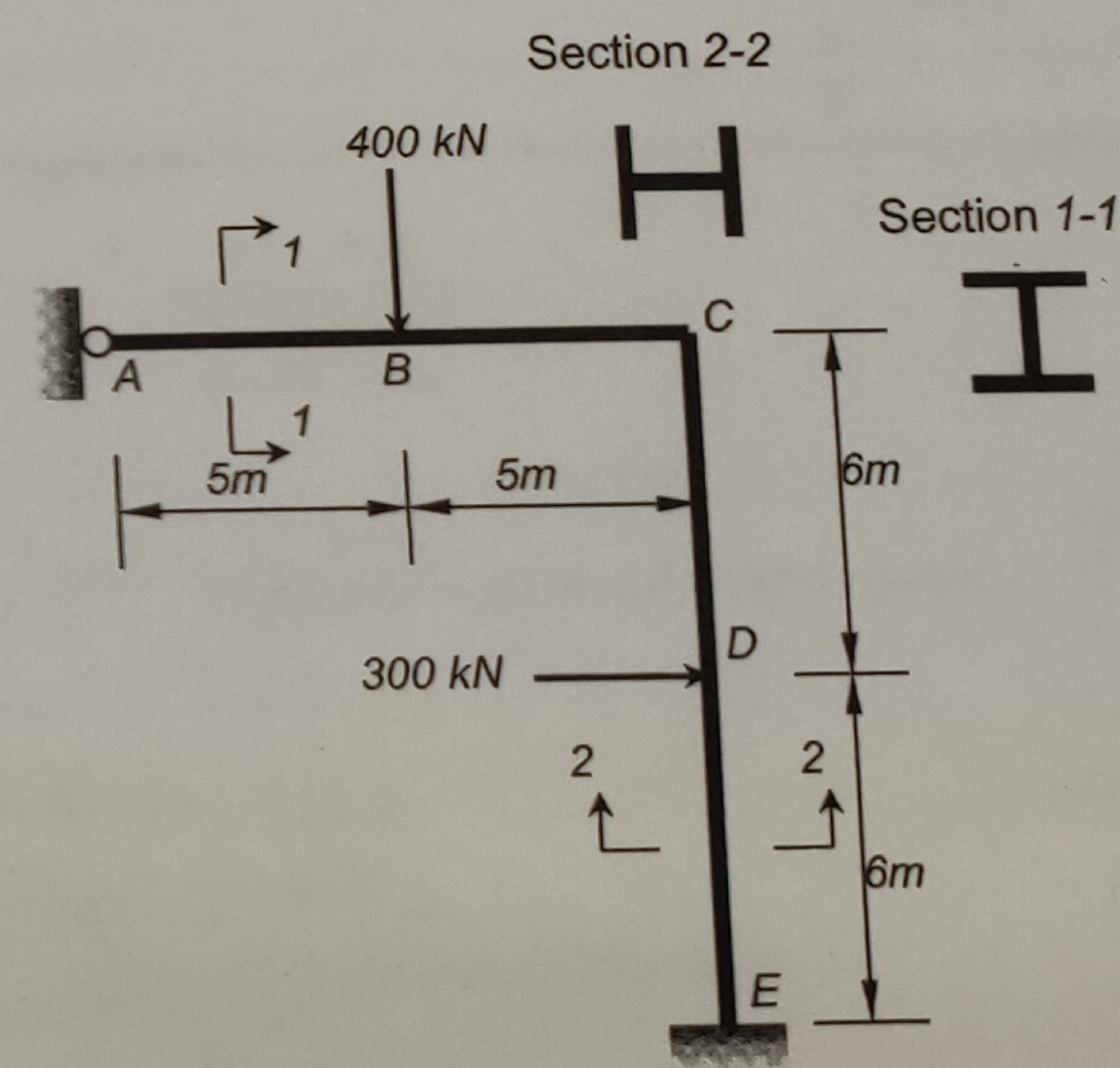
4. The frame shown in Figure Q4 is pinned at *A* and fixed at *E*, and is subjected to factored design concentrated loads at *B* and *D*. It is fabricated using uniform S355 steel section throughout. Adequate restraints against stability are provided.

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

(13 Marks)

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



CV4102 2015/16 PYP

1) a) $\gamma = \frac{b_0}{2t_0} = \frac{200}{2(12.5)} = 8$

$\beta = \frac{b_1+b_2}{2b_0} = \frac{160+160}{2(200)} = 0.8$

Ranges of validity,

$\frac{b_1}{b_0} = \frac{b_2}{b_0} = \frac{160}{200} = 0.8 \geq 0.35$

$\geq 0.1 + 0.01\frac{b_0}{t_0}$

$= 0.1 + 0.01\left(\frac{200}{12.5}\right)$

$= 0.26$

Brace in compression (N_1)

$\frac{h_1}{t_1} = \frac{b_1}{t_1} = \frac{160}{10} = 16 \leq 35 \leq 38\varepsilon = 30.932$ (class 2, ok)

Brace in tension

$\frac{b_2}{t_2} = \frac{h_2}{t_2} = \frac{160}{10} = 16 \leq 35$

$0.5 \leq \frac{h_0}{b_0} = \frac{h_1}{b_1} = \frac{h_2}{b_2} = 1.0 \leq 2.0$

$\frac{b_0}{t_0} = \frac{h_0}{t_0} = \frac{200}{12.5} = 16 \leq 35 \leq 38\varepsilon$ (class 2, ok)

$g = 50$ mm

$\frac{g}{b_0} = \frac{50}{200} = 0.25$

$0.5(1-\beta) = 0.5(1-0.8) = 0.1$

$1.5(1-\beta) = 1.5(1-0.8) = 0.3$

$0.1 < \frac{g}{b_0} = 0.25 < 0.3$

$t_1 + t_2 = 10 + 10 = 20$ mm

$g = 50$ mm $\geq t_1 + t_2$ //

For SHS,

$0.6 \leq \frac{b_1+b_2}{2b_1} = \frac{160+160}{2(160)} = 1.0 \leq 1.3$

$\frac{b_0}{t_0} = \frac{200}{12.5} = 16 \geq 15$

∴ Table 7.10 can be used.

$\beta \leq 1.0$

$N_{1,Rd} = \frac{8.9\gamma^{0.5} k_n f_{y0} t_0^2}{\sin\theta_1}\left(\frac{b_1+b_2}{2b_0}\right)/\gamma_{M5}$

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

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

$k_n = 1.3 - \frac{0.4(0.6)}{0.8} \leq 1.0$

$= 1.0$

$N_{1,Rd} = \frac{8.9(8)^{0.5}(1)(355)(10)^2}{\sin 45°}\left(\frac{160+160}{2(200)}\right)/1.0$

$= 1579.75$ kN

Since $\theta_1 = \theta_2 = 45°$

$N_{2,Rd} = 1579.75$ kN

$\frac{e}{h_0} = \frac{40}{200} = 0.2$

Since

$-0.55 \leq \frac{e}{h_0} \leq 0.25$

the moment resulting from eccentricity can be neglected in the design of connection

$A_2 f_{y2} = A_1 f_{y1} = \frac{\pi}{4}\{160^2 - 140^2\}(355)$

$= 1672.9$ kN

⇒ chord face failure

b) $\sigma_{0,Ed} = 0.9 f_{y0}$

$n = \frac{\sigma_{0,Ed}}{f_{y0}} = 0.9 > 0$ (compression)

$k_n = 1.3 - \frac{0.4(0.9)}{0.8} \leq 1.0$

$= 0.85$

$N_{1,Rd} = \frac{8.9\gamma^{0.5} k_n f_{y0} t_0^2}{\sin\theta_1}\left(\frac{b_1+b_2}{2b_0}\right)/\gamma_{M5}$

$= \frac{8.9(8)^{0.5}(0.85)(355)(12.5)^2}{\sin 45°}\left(\frac{160+160}{2(200)}\right)/1.00$

$= 1342.79$ kN

since $\theta_1 = \theta_2 = 45°$

$N_{2,Rd} = 1342.79$ kN

By increasing the magnitude of the compressive strength, n value, where $n = \frac{\sigma_{0,Ed}}{f_{y0}}$ will increase and this causes the k_n value to further decrease. ~~A decrease~~ As $N_{1,Rd} \propto k_n$, a decrease in k_n results in a decrease in $N_{1,Rd}$, the resistance of the brace towards chord face failure.

If the direction is change to negative, means the chord is under tension, k_n will be equal to 1.0 and $N_{1,Rd}$ value will be 1579.75 kN.

c) For SHS, the joint can be treated as two separated T or Y joints if $g/b_0 > 1.5(1-\beta)$

in this case,

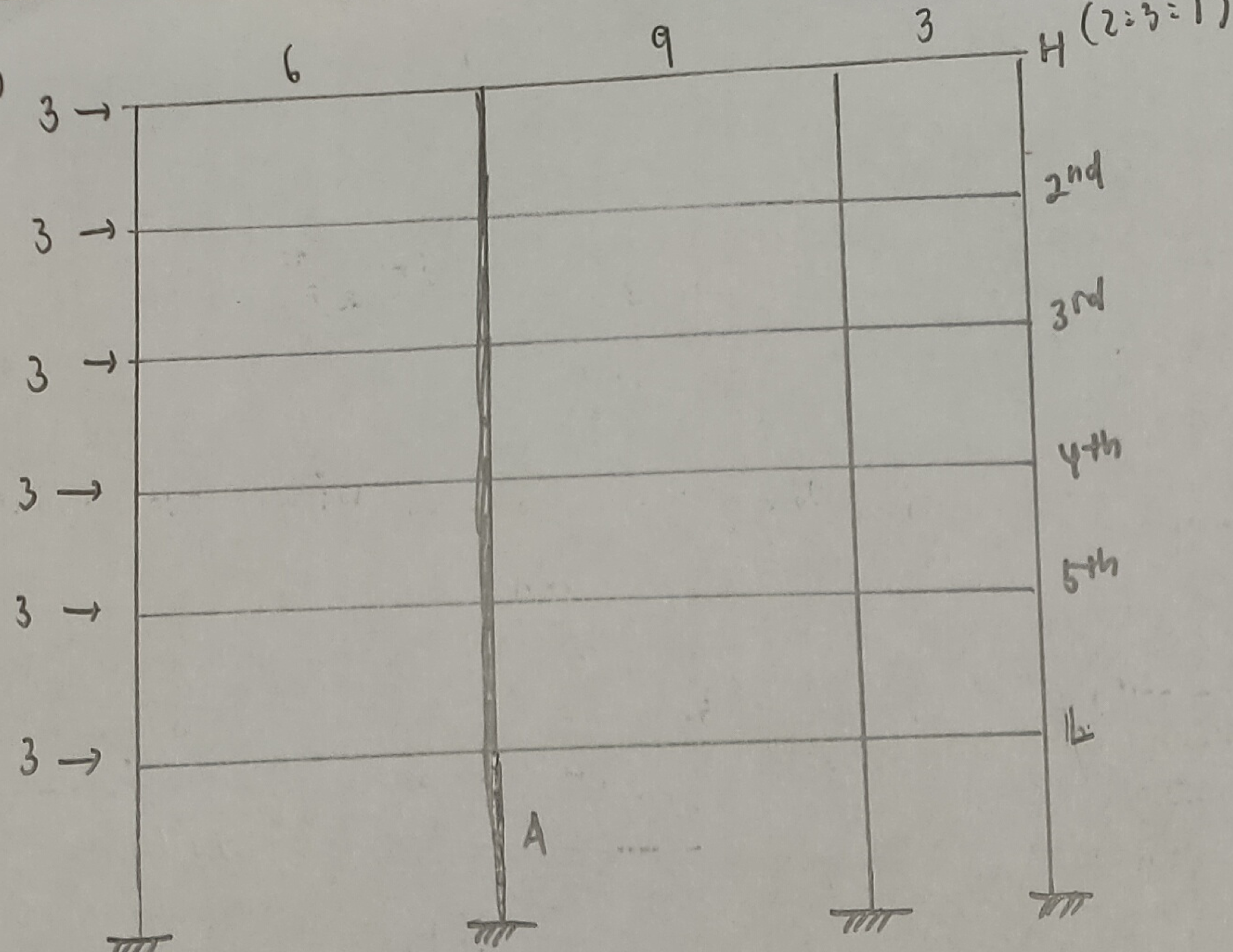
$\frac{g}{b_0} > 1.5(1-\beta)$

$\frac{g}{200} > 1.5(1-0.8)$

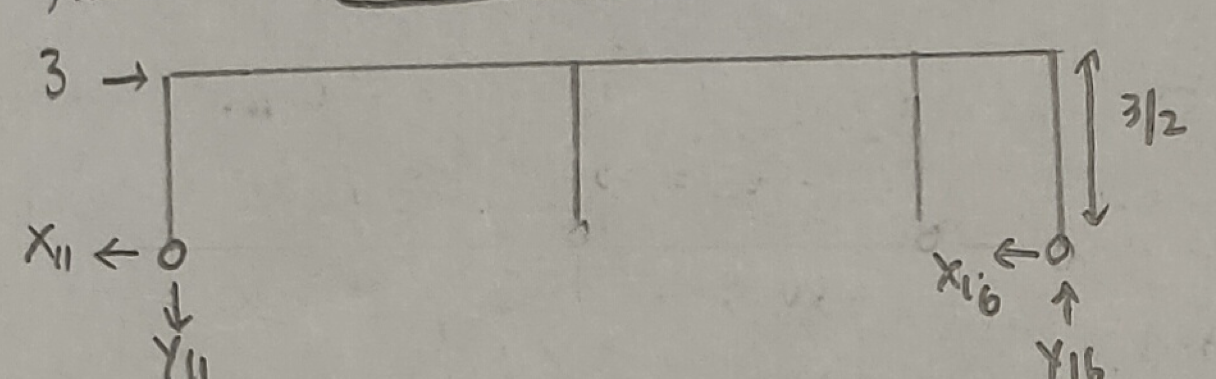
$g > 0.3(200)$

$g > 60$ m //

2) a)



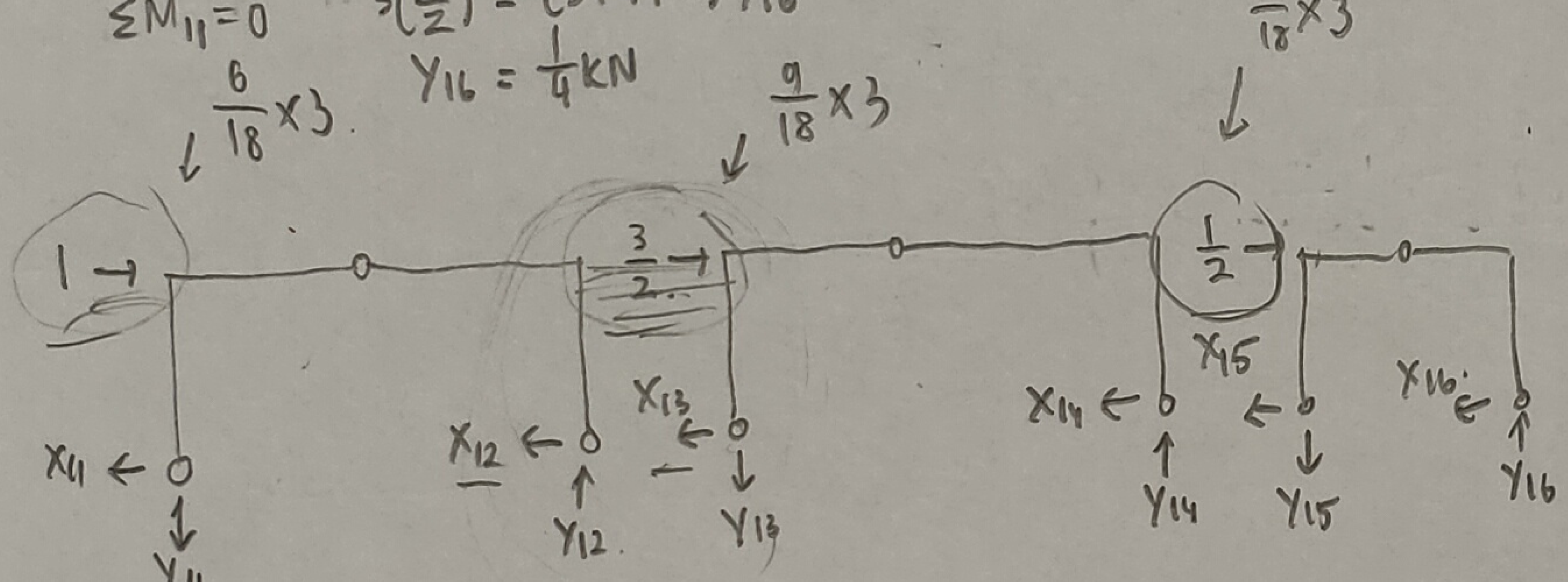
Start with highest storey



$Y_{11} = Y_{16}$

$\Sigma M_{11} = 0$ $\quad 3(\frac{3}{2}) = (3+9+6)\,Y_{16}$

$Y_{16} = \frac{1}{4}$ kN



* $Y_{11} = Y_{12} = Y_{13} = Y_{14} = Y_{15} = Y_{16}$

Using symmetry,

$X_{11} = X_{12} = \frac{1}{2}$ kN

$X_{13} = X_{14} = \frac{3/2}{2} = \frac{3}{4}$ kN

$X_{15} = X_{16} = \frac{1/2}{2} = \frac{1}{4}$ kN

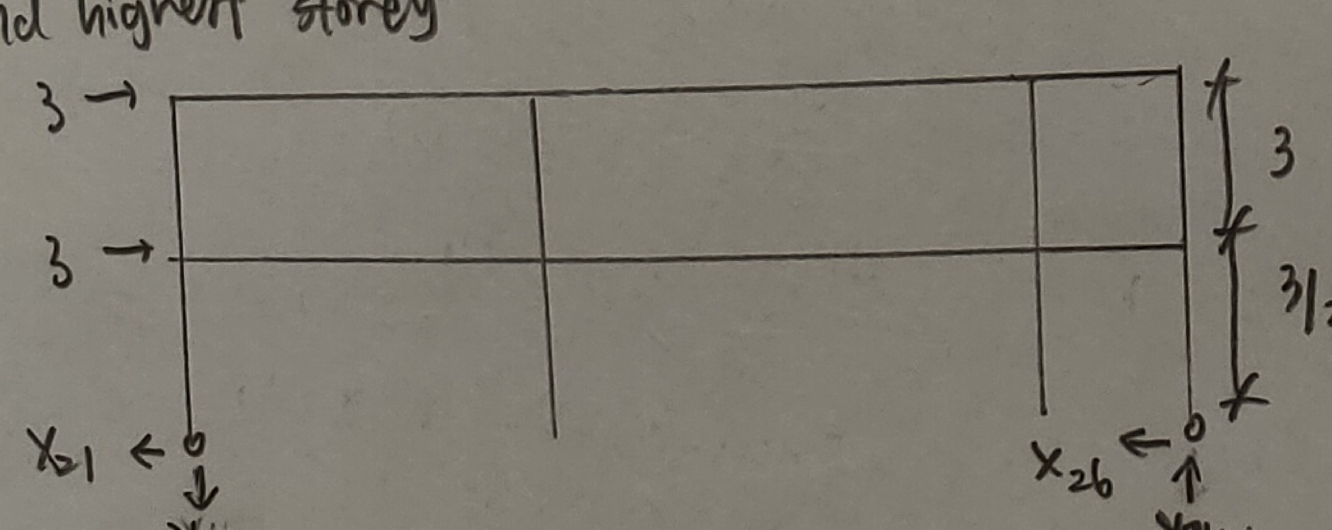
$X_{23} = X_{24} = (\frac{3}{2} + \frac{3}{2})/2$

$= 3/2$

$X_{21} = X_{22} = (1+1)/2$

$= 1$

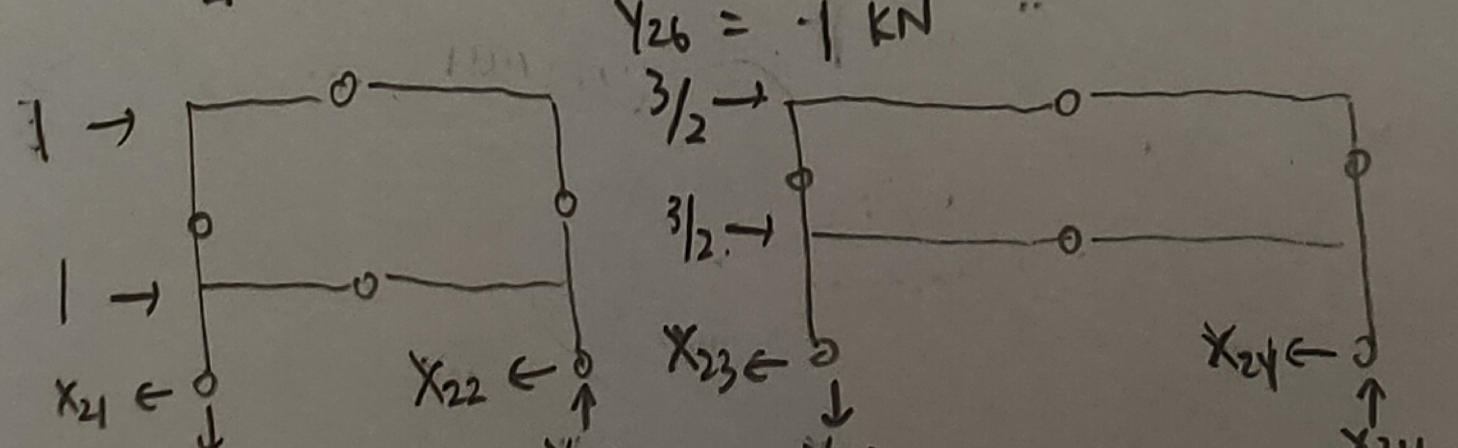
2nd highest storey



$Y_{21} = Y_{26}$

$\Sigma M_{21} = 0$ $\quad 3(3+\frac{3}{2}) + 3(3/2) = Y_{26}(3+6+9)$

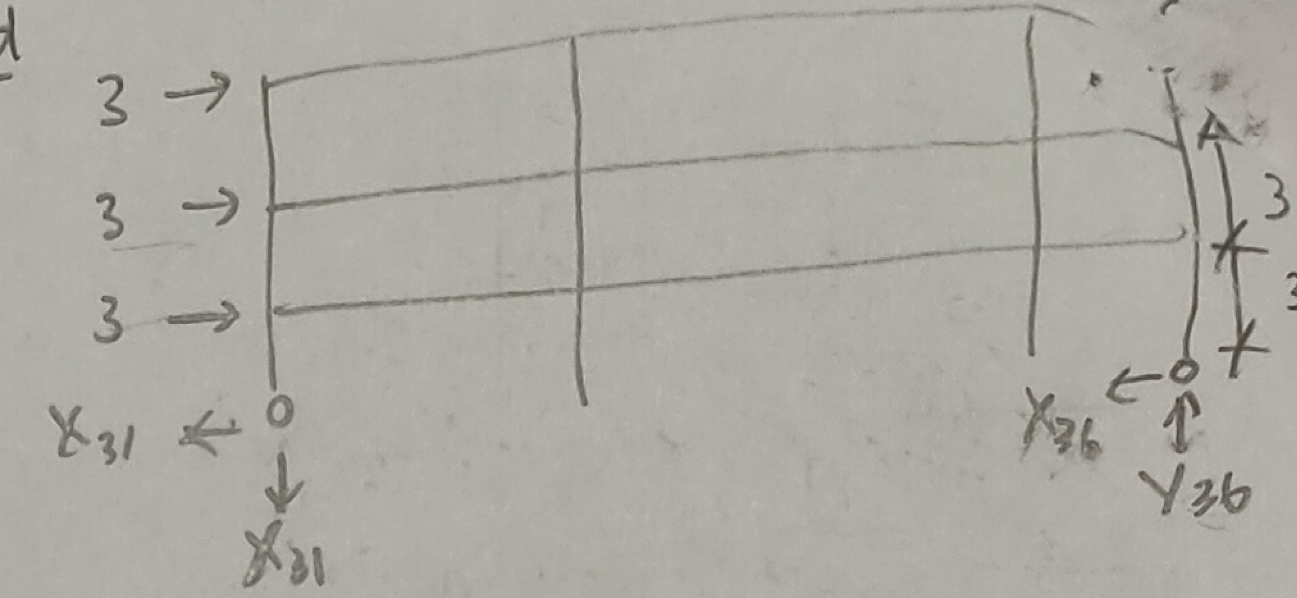
$Y_{26} = 1$ kN



$X_{21} = X_{22} = \frac{1}{2}(1+1) = 1$ kN

$X_{23} = X_{24} = \frac{1}{2}(\frac{3}{2} + \frac{3}{2}) = \frac{3}{2}$ kN

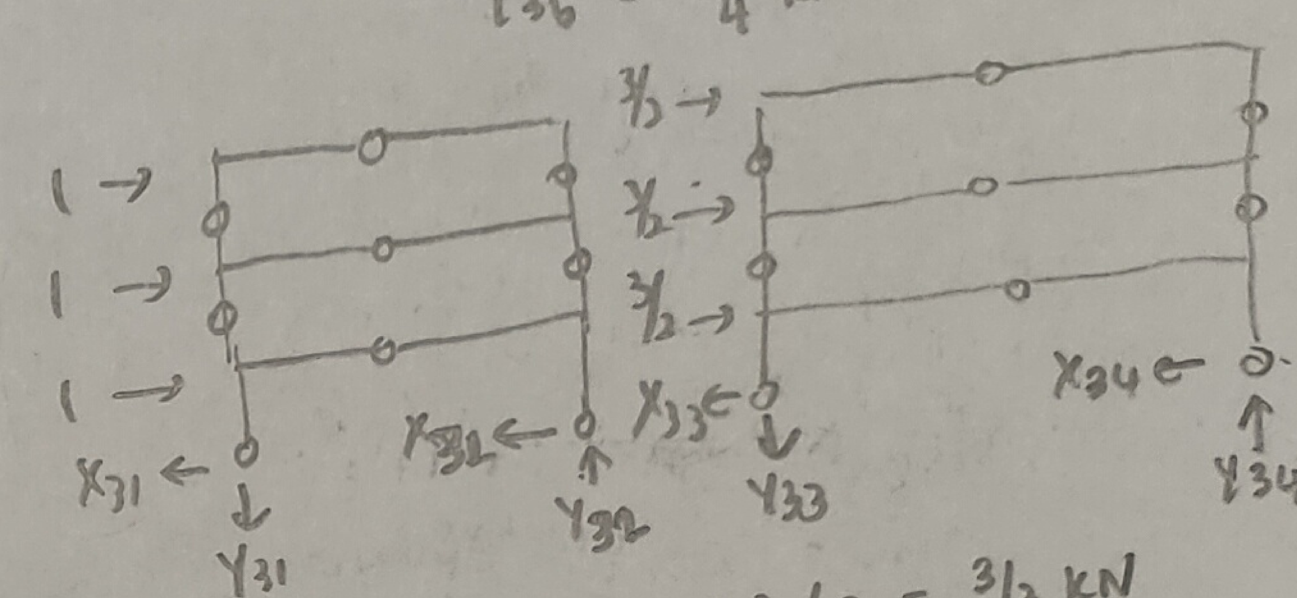
3rd



$Y_{31} = Y_{36}$.

$\Sigma M_{31} = 0$ $\quad 3(3+3+3/2) + 3(3+3/2)$
$+ 3(3/2) = (3+6+9)\,Y_{36}$

$Y_{36} = \frac{9}{4}$ kN



$X_{31} = X_{32} = (1+1+1)/2 = 3/2$ kN

$X_{33} = X_{34} = (3/2 + 3/2 + 3/2)/2 = \frac{9}{4}$ kN

By induction.

4th storey $\Rightarrow$ $Y_{46} = Y_{41} = \dfrac{3(3+3+3+3/2) + 3(3+3+3/2) + 3(3+3/2) + 3(3/2)}{3+6+9}$

$= 4$ kN.

5th storey $\Rightarrow$ $Y_{56} = Y_{51} = \dfrac{3(3+3+3+3+3/2) + 3(3+3+3+3/2) + 3(3+3+3/2) + 3(3+3/2) + 3(3/2)}{3+6+9}$

$= 6.25$ kN

$X_{41} = X_{42} = (1+1+1+1)/2 = 2$ kN

$X_{43} = X_{44} = (3/2 + 3/2 + 3/2 + 3/2)/2 = 3$ kN

$X_{51} = X_{52} = (1\times 5)/2 = 5/2$ kN

$X_{53} = X_{54} = (3/2 \times 5)/2 = \frac{15}{4}$ kN

Lowest storey.

$Y_{61} = Y_{66}$

$\Sigma M_{66} = 0$ $\quad 3(3+3+3+3+3+2) + 3(3+3+3+3+2)$
$+ 3(3+3+3+2) + 3(3+3+2) + 3(3+2) + 3(2)$
$= Y_{66}(3+6+9)$

$Y_{66} = \frac{23}{3}$ kN.

$X_{61} = X_{62} = (1\times 6)/2 = 3$ kN.

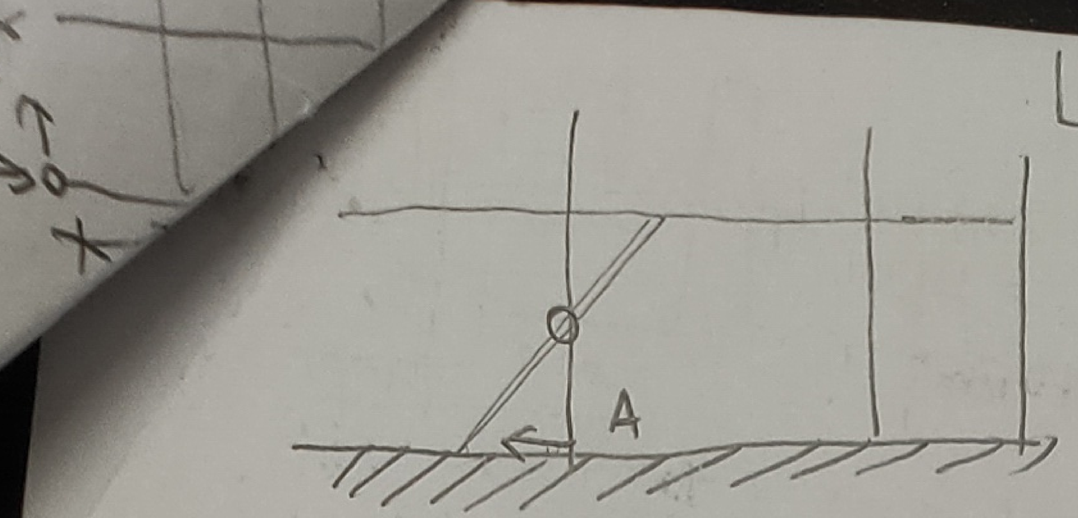
$X_{63} = X_{64} = (3/2 \times 6)/2 = \frac{9}{2}$ kN

Column A

	Shear	Axial
H	$X_{12} + X_{13} = 5/4$	0
2	$X_{22} + X_{23} = 5/2$	0
3	$X_{32} + X_{33} = 15/4$	0
4	$X_{42} + X_{43} = 5$	0
5	$X_{52} + X_{53} = 25/4$	0
L	$X_{62} + X_{63} = 15/2$	0

inner column

15/16



Bending moment, $P = (X_{62} + X_{63})\,2$

$= 15/2 \times 2$

$= 15$ kN/m.

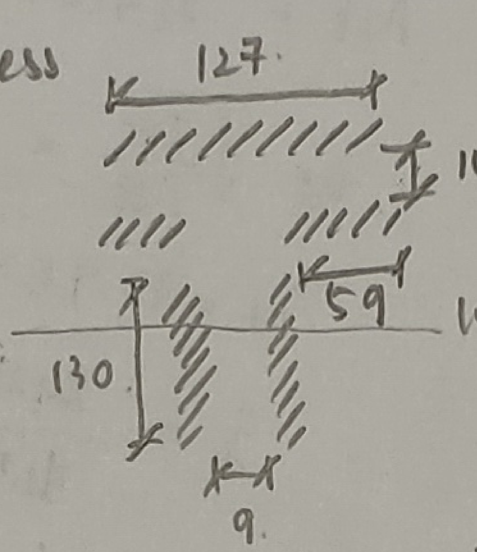
$h = 155.4$.
$b =$

b) Assume 1mm weld throat thickness

Total area of weld

$= 127 + (130 \times 2) + (59 \times 2)$

$= 505 \text{ mm}^2$



Find centroid, (wrt bottom)

$127(1)(155.4 + 0.5) + 2(130)(1)\left(\frac{130}{2}\right) + 2(59)(1)(130 + 0.5) = 505\, Y_{cen}$

$52098.3 = 505\, Y_{cen}$

$Y_{cen} = 103.165$ mm.

$I_{yy} = \left[\frac{127(1)^3}{12} + 127(1)(155.4 - 103.165)^2\right] + 2\left[\frac{130^3(1)}{12} + 130(1)\left(103.65 - \frac{130}{2}\right)^2\right]$

$+ 2\left[\frac{59(1)^3}{12} + 59(1)(130 - 103.165)^2\right]$

$= 346529.5 + 754560.5 + 84983.7$

$= 1186073.67 \text{ mm}^3$

$W_{el} = \frac{I_{yy}}{y} = \frac{1186073.67}{\frac{155.4}{2} + 1}$ → 15070.82.

Vertical load = 130 kN.

$e = 120$ mm

$M = Pe = 15.6$ kNm

$f_b = \frac{Pe}{W_{el}} = 1635.11 \text{ N/mm}^2$.

$f_s = \frac{P}{\text{Area of weld}} = \frac{130}{505} = 257.43 \text{ N/mm}^2$.

$f_r = \sqrt{f_s^2 + f_b^2} = 1066.64 \text{ N/mm}^2$

$f_{vw,d} = \frac{f_u/\sqrt{3}}{\beta_w \gamma_{M2}} = \frac{430/\sqrt{3}}{0.85(1.25)} = 233.7 \text{ N/mm}^2$

f_R calc based on $a = 1$.

Actual stress $= f_R / a$

$1066.64 / a = 233.7$

$a = 4.56$

Assuming equal leg fillet weld

Weld leg length

$s = 4.56/0.707 = 6.455$ mm

provide at least 7mm fillet weld

$I_{yy} =$

$\left[\frac{127(1)^3}{12} + 127(47.97)^2\right]$

$+ \left[\frac{127(1)^3}{12} + 127(32.97)^2\right]$

$+ 2\left[\frac{130^3 \times 1}{12} + 130(39.53)^2\right]$

$= 292252.94$

$+ 138062.24$

$+ 772448.1$

$= 1202763.281$ mm

$W_{el} = \frac{I_{yy}}{y} = \frac{1202763.281}{152 - 104.53 + 1}$

$= 24814.6 \text{ mm}^3$.

$f_b = \frac{Pe}{W_{el}}$

$= \frac{130 \times 120}{24814.6}$

$= 628.66 \text{ N/mm}^2$

$f_s = \frac{P}{\text{Area}}$

$= \frac{130 \times 10^3}{514}$

$= 252.92 \text{ N/mm}^2$

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

$= 677.63$

$677.63 / a = 233.7$

$a = 2.9$

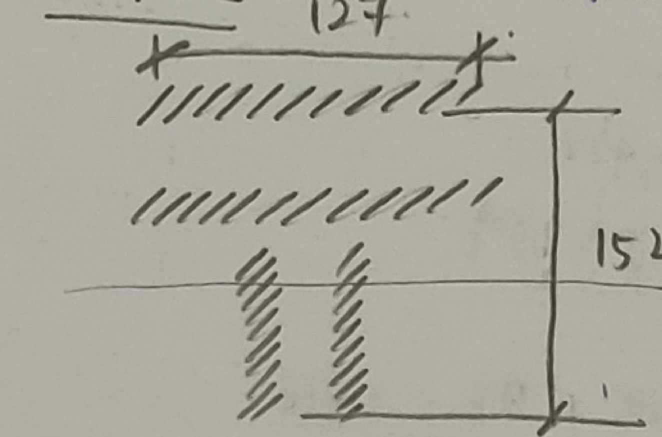
$s = 2.9 / \cos 45°$

$= 4.1$ mm

at least 5mm weld.

Simplify

Assume 1mm ~~fillet~~ throat ~~weld thickness~~



Total area

$= 127 + 127 + 130 + 130$

$= 514 \text{ mm}^2$ ✓

$152 - 14.5 = 137.5$

$127(1)(152 + 0.5) + 127(1)(130 + 0.5) + 2(130)(1)\left(\frac{130}{2}\right)$

$= 514(y_{cen})$

$Y_{cen} = \frac{52841\ (53730)}{514} = 102.8$ mm. → 104.53.

$I_{yy} = \left[\frac{127(1)^3}{12} + 127(1)(0.5 + 49.2)^2\right]$ (152 − 102.8)

$+ \left[\frac{127(1)^3}{12} + 127(1)(0.5 + 27.2)^2\right]$ (130 − 102.8)

$+ 2\left[\frac{130^3(1)}{12} + 130(1)(102.8 - 65)^2\right]$ (130/2)

$= 313712 + 97456.41$

$+ 737665.07$

$= 1148833.5 \text{ mm}^4$.

$W_{el} = \frac{I_{yy}}{y} = \frac{1148833.5}{152 + 1 - ~~102.8~~}$ 11.53

$= 22885.13 \text{ mm}^3$.

Vertical load = 130 kN

$e = 120$ mm

$Pe = M = 15.6$ kNm

$f_b = \frac{Pe}{W_{el}} = 681.67 \text{ N/mm}^2$

$f_s = \frac{P}{\text{Area}} = \frac{130 \times 10^3}{514} = 253 \text{ N/mm}^2$

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

$= 727.1 \text{ N/mm}^2$.

$f_{vw,d} = 233.7 \text{ N/mm}^2$.

f_r based on $a = 1$

$f_R / a = 727.1 / a = 233.7$

$a = 3.12$.

Assuming equal leg fillet weld

$s = 3.12 / \cos 45°$

$= 4.41$

provide 5mm fillet weld

3) i) Classification

For Grade S275,

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

Flange

$\left(\frac{500-22}{2}\right) = 239$

$\frac{c_f}{t_f} = \frac{250-22}{40} = \cancel{5.7} \leq 9\varepsilon = 8.316$

5.975

Class 1

Web

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

Class 3

ii) Bending resistance

⇒ Method 1

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

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

$= (500 \times 40)(2420 + 40)(275)/10^6$

$= 13530$ KNm

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

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

$W_{el,w} f_{yw} = 5905.2$ KNm

$M_{y,Rd} = 13530 + 5905.2 = 19435.2$ KNm

→ Flange induced buckling $\frac{h_w}{t_w} \leq K \frac{E}{f_{yf}} \sqrt{\frac{A_w}{A_{fc}}}$

iii) Shear resistance

$a/h_w = 4000/2420 = 1.65 \geq 1$

$K_\tau = 5.34 + 4\left(\frac{h_w}{a}\right)^2 = 6.804$

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

$\frac{2420}{22} = 110 \leq 31 \frac{(0.924)}{1} \sqrt{6.804} = 78.72$

web is ~~NOT~~ stocky

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

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

$= 1.22 > 1.08$

$\chi_w = 1.37/(0.7 + \bar{\lambda}_w) = 0.714$

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

$= \cancel{6035.43\ kN}$

* Assume no contribution from flange

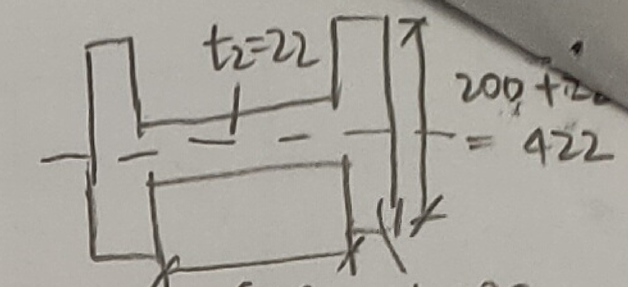
$V_{bf,Rd} = \frac{(500)(40)^2(275)}{(1039.74)(1.00)}\left(1 - 0\right)$ ← $M_{Ed} = 0$ at support

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

$= 1039.74$

$= 211.591$ kN

iv) Rigid End Post



$e = 600 + \cancel{11 t_f r} = 622\ mm > 0.1 h_w$
$= 242$

$A_e = A_u = 422 \times 20 = 8440\ mm^2$

$\frac{4 h_w t_w^2}{e} = 7532.34\ mm^2$

Hence, minimum size requirement ok!

$I_{st} = 2\left(\frac{422^3 \times 20}{12}\right) + \frac{600 \times 22^3}{12} = 251037226.7\ mm^4$

$A_{st} = 2(422 \times 20) + 600 \times 22 = 30080\ mm^2$

$i_{st} = \sqrt{\frac{I_{st}}{A_{st}}} = 91.35$ mm.

$\lambda_1 = 93.9\varepsilon = 86.764$

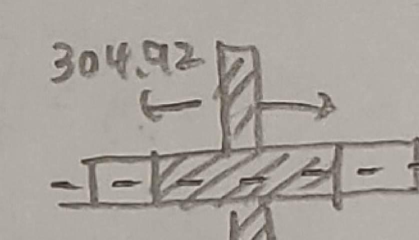
$\bar{\lambda} = \frac{2420}{91.35} \frac{1}{86.764} = 0.305 > 0.2$

$\phi = 0.5[1 + \alpha(\bar{\lambda} - 0.2) + \bar{\lambda}^2] = 0.572$

$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} = 0.947$

$N_{b,Rd} = 0.947 \times A_{st} \times f_y = 7830.23$ kN

v) Load Bearing stiffener



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

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

$= 21856.48\ mm^2$

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

$= 125793544.7\ mm^4$

$i_{st} = \sqrt{\frac{I_{st}}{A_{st}}} = 75.865$ mm.

$\lambda_1 = 93.9\varepsilon = 86.764$

$\bar{\lambda} = \frac{2420}{75.865} \times \frac{1}{86.764} = 0.368 > 0.2$

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

$= 0.609$

$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} = 0.914$

$N_{b,Rd} = 0.914 \times 21856.48 \times 275$

$= 5494.336$ KN

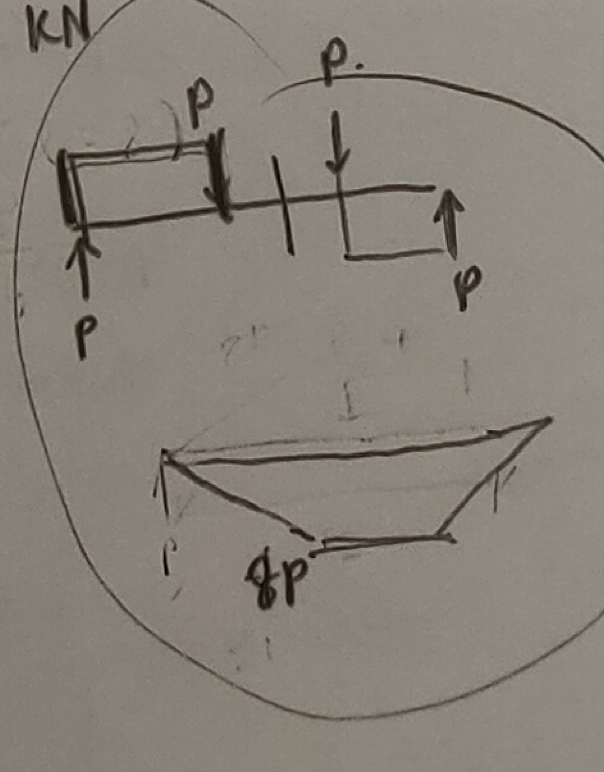
vi) $V_{max} = P$

$M_{max} = 8P$

$8P < 19435.2$

$P < 2429.4$ kNm

$P < 6035.43$ kNm



For end post.

$\bar{\lambda}_w = 1.22$

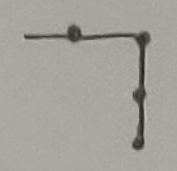
$N_{st,ten} = P - \frac{1}{1.22^2} \frac{2420 \times 275 \times 22}{1000\sqrt{3}}$

$= P - 5679.24$

$N_{Ed} = 2P - 5679.24 < 7830.23$

$P < 6754.735$

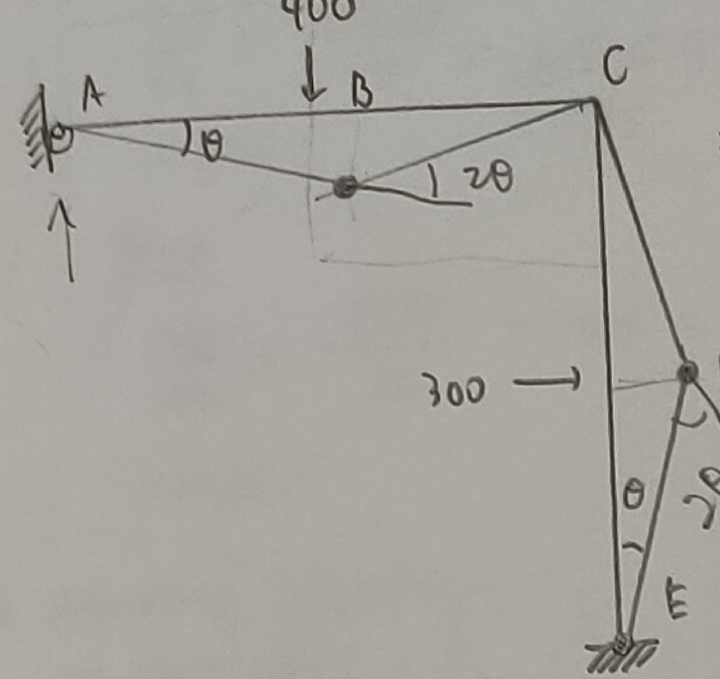
4) a) $n_s = (2+3)-3 = 2$
$n_{ph} = 2+1 = 3$



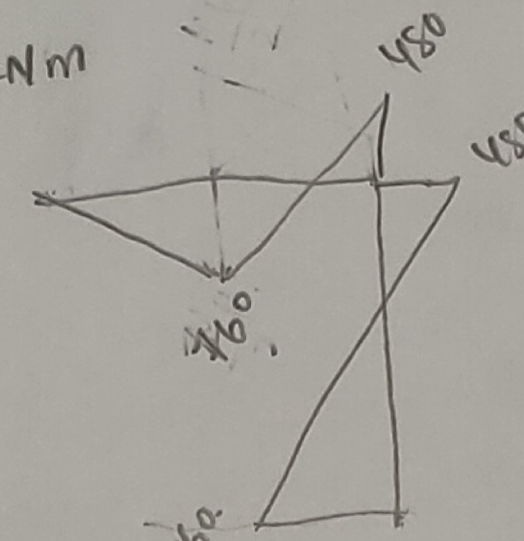
$n_{ph} = n_s + 1$
$= 2+1 = 3$ (mechanism satisfied)

* Uniform steel ⇒ Mp same throughout

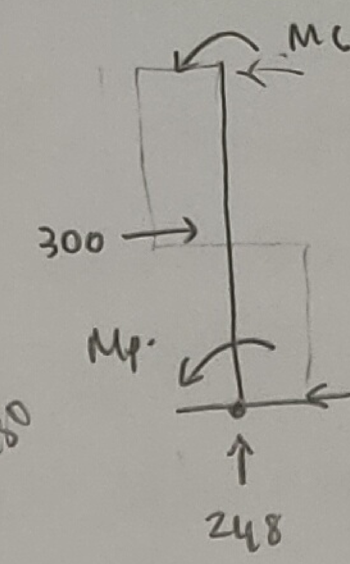
Mechanism 1 (B-D-E). combined



$\Sigma W_e = \Sigma W_i$
$400(5\theta) + 300(6\theta)$
$= M_p(2\theta) + M_p(2\theta) + M_p(\theta)$
$3800 = 5M_p$
$M_p = \underline{760}$ KNm



check moments @ C

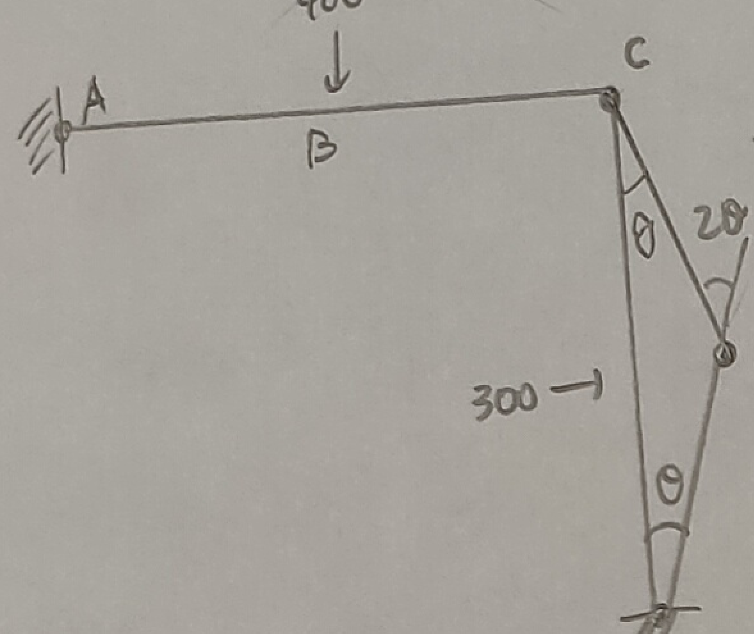


$\Sigma M_C = 0$
$253.33(12) = M_p + M_C + 300(6)$
$M_C = 480$ kN $< M_p$
∴ plasticity satisfied

∴ Mechanism 1 is the correct mechanism!

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

Mechanism 2 (C-D-E) column



$\Sigma W_e = \Sigma W_i$
$300(6\theta) = M_p(\theta) + M_p(2\theta) + M_p(\theta)$
$1800 = 4M_p$
$M_p = 450$ KN/m

Choose 457×191×98 $W_{pl} = 2230\ cm^3$

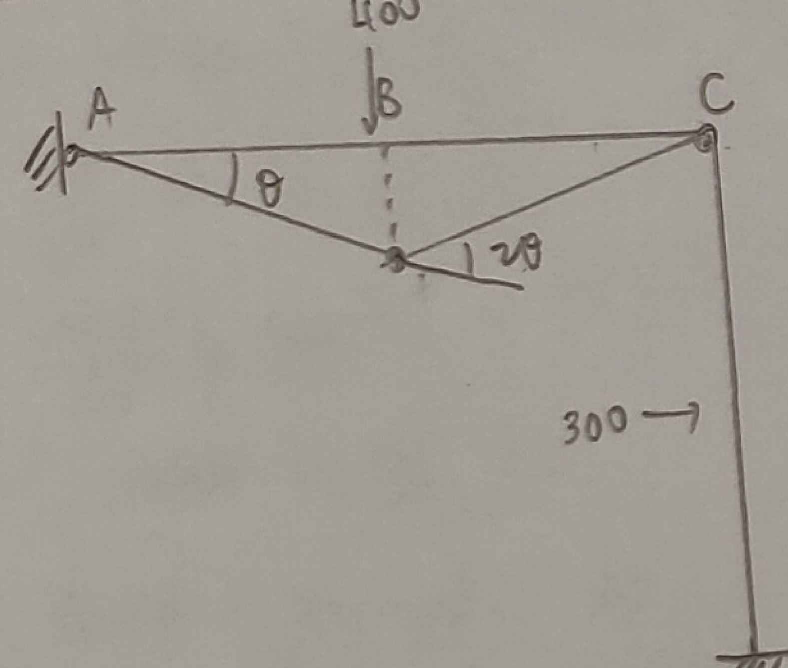
$A = 12500\ mm^2$
$h_w = 407.6$ mm
$t_w = 11.4$ mm
$b_f = 192.8$ mm
$t_f = 19.6$ mm
$r = 10.2$ mm
$c_f/t_f = 4.1 > 9\varepsilon$
$c_w/t_w = 35.8 > 72\varepsilon$ } class 1

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

$A_v = A - 2b_f t_f + (t_w + 2r) t_f > h_w t_w$
$= 12500 - 2(192.8)(19.6) + [11.4 + 2(10.2)](19.6)$
$> 407.6(11.4)$
$= 5565.52 > 4646.64$

$(0.5 V_{pl,Rd}) > 253.33$ low shear

Mechanism 3 (B-C). Beam.



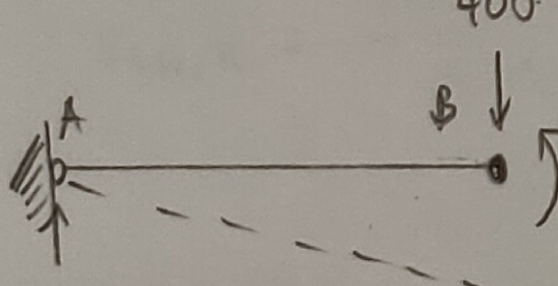
$\Sigma W_e = \Sigma W_i$
$400(5\theta) = M_p(2\theta) + M_p(\theta)$
$2000 = 3M_p$
$M_p = 666.67$ KNm.

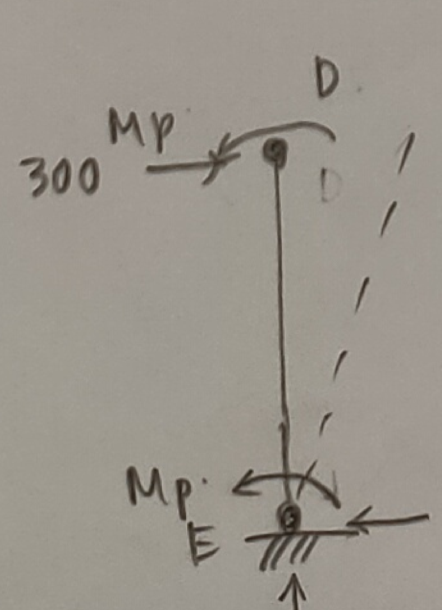
$V_{pl,Rd} = \frac{A_v f_y}{\sqrt{3}}$
$= 1140.71$ kN > 253.33

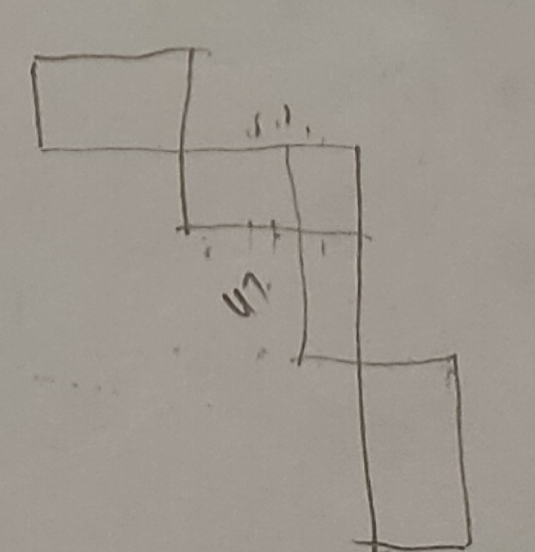
$M_{c,Rd} = f_y W_{pl} = 791.65$ kN
> 700

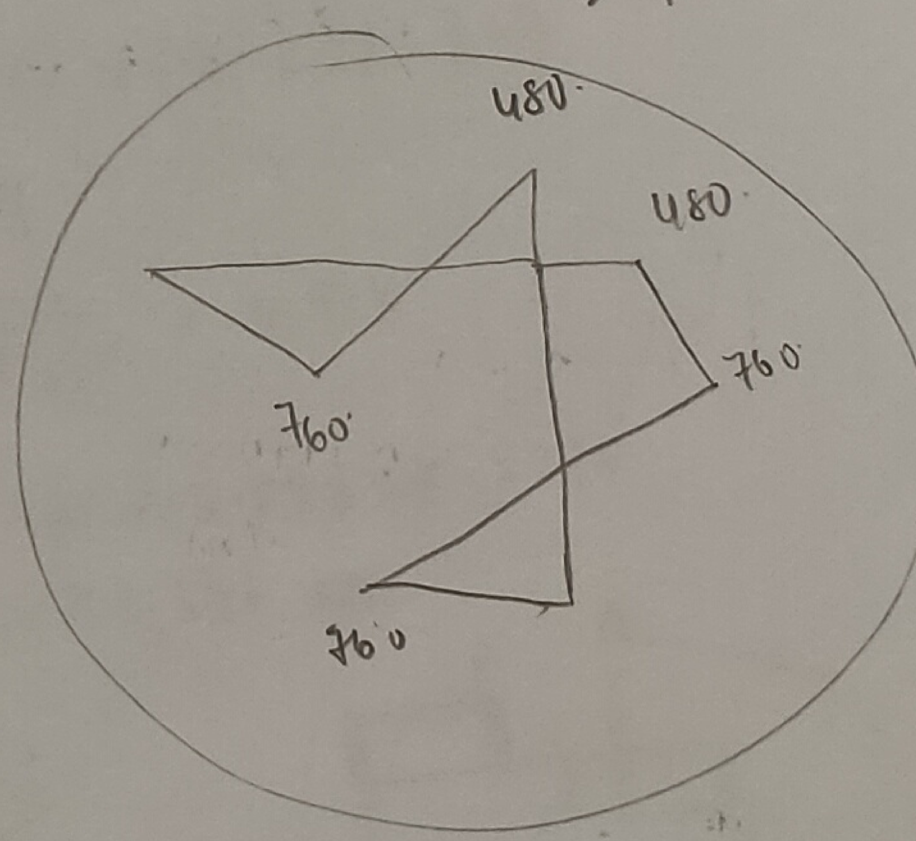
∴ Mechanism 1 is the most likely correct mechanism with $M_p = 760$ KNm

Equilibrium check

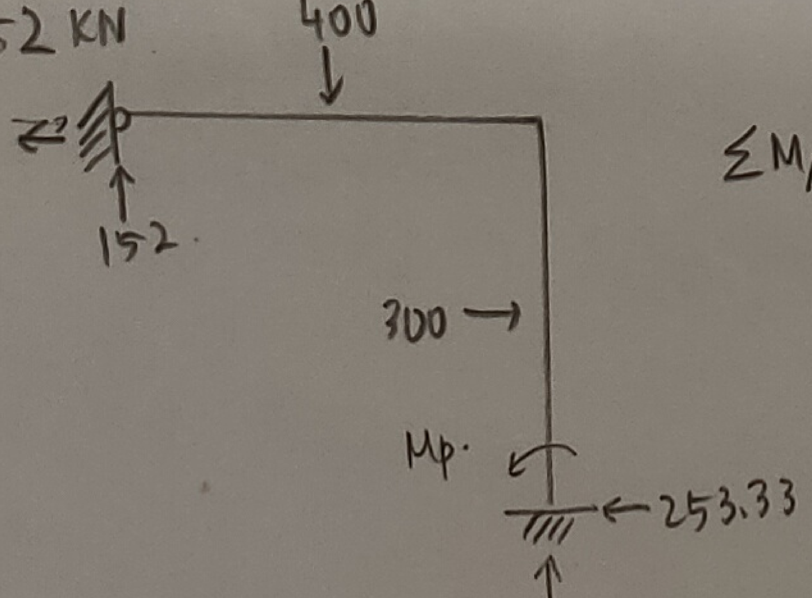








$\Sigma M_B = 0$
$A_y(5) = M_p$
$A_y = 152$ KN



$\Sigma M_D = 0 \quad M_p + M_p = E_x(6)$
$E_x = 253.33$ kN

$\Sigma M_A = 0 \quad 400(5) + 253.33(12)$
$= 300(6) + E_y(10) + M_p$
$E_y = 248$ KN

$\Sigma M_E = 0 \quad 152(10) + 300(6) = M_p + 400(5) + A_x(12)$
$A_x = 46.67$ kN
$\Sigma F_y = 152 + 248 - 400 = 0$ "
$\Sigma F_x = 253.33 + 46.67 - 300 = 0$ "

Equilibrium is satisfied!