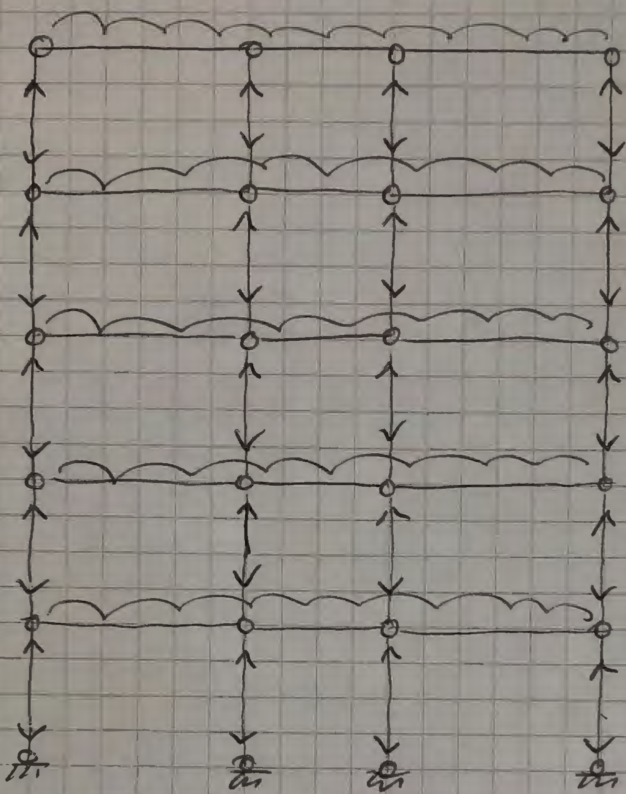
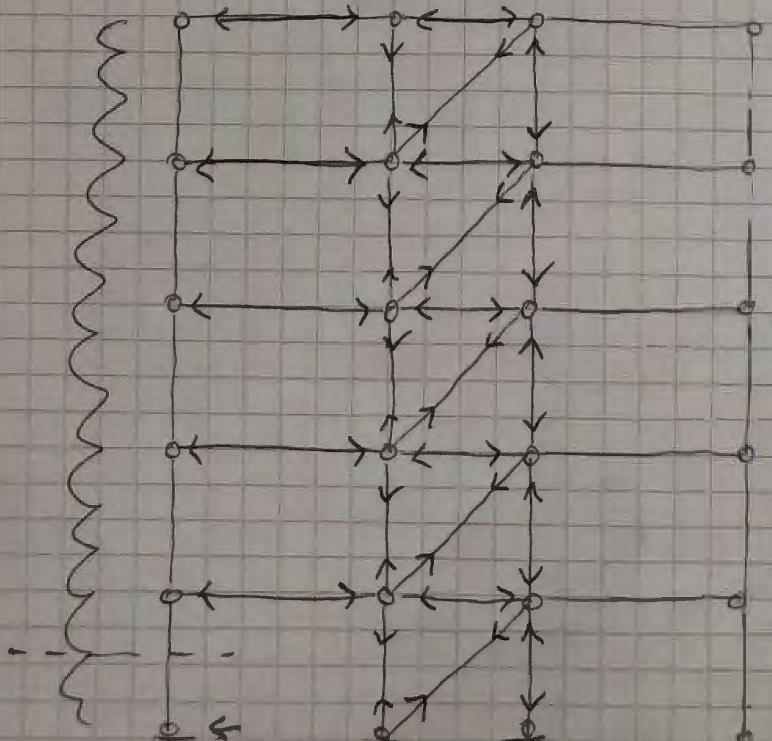
i)

a)



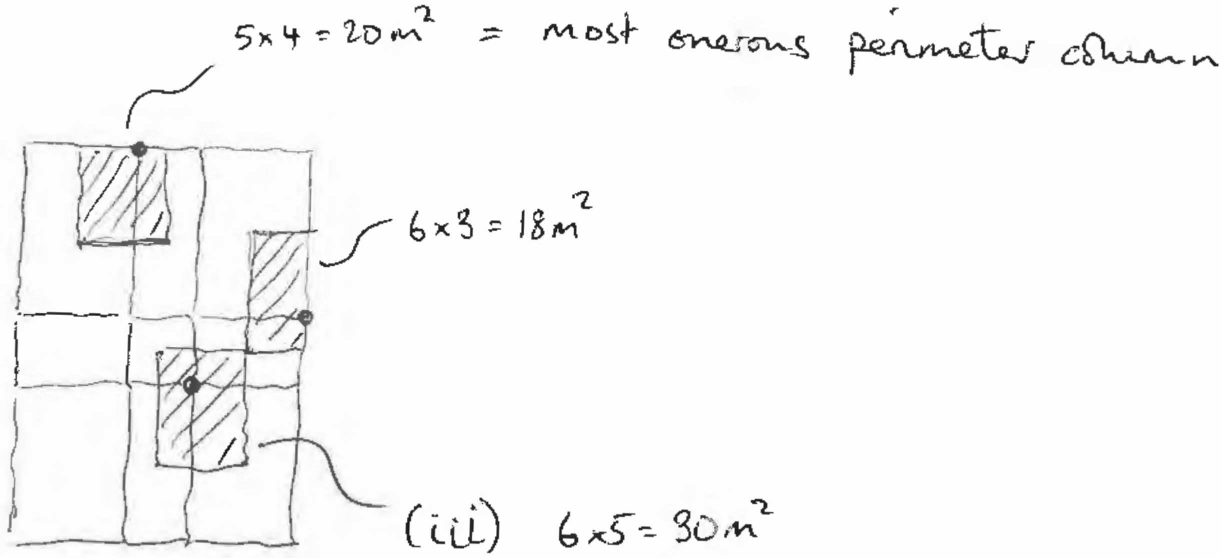
Slab spans one-way to secondary beams, secondary beams span to primaries, primary beams span to columns, which carry loads axially to foundation



Lateral loads ~~are~~ spanned between slab edges ~~to~~ by facade (assumption). Forces transferred by diaphragm action to braced core. Braced core acts as truss cantilever.

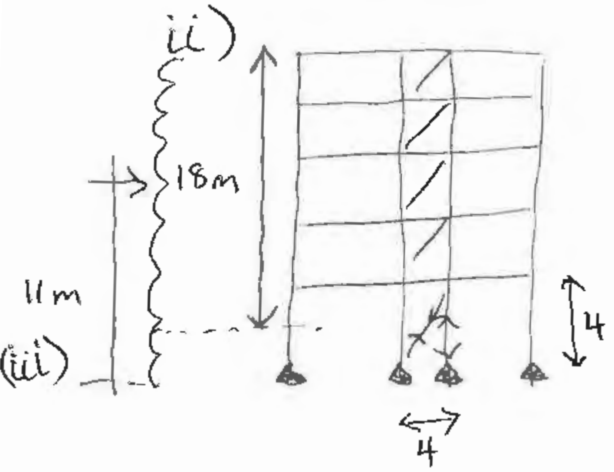
b)

i)



@ ground floor : $20 \times 5 \times (1.35g + 1.5q) = \underline{\underline{135g + 150q}}$

ii)



@ ground floor bracing:

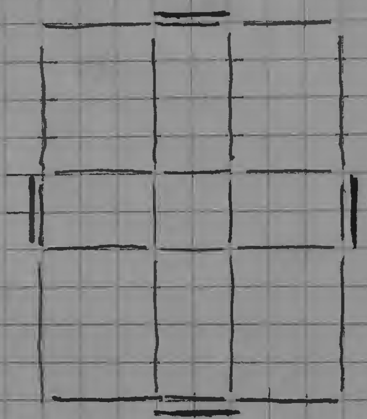
$$18 \times \frac{20}{2} \times 0.75p \times \sqrt{2} = \underline{\underline{191p}}$$

iii) @ ground floor : $30 \times 5 \times (1.35g + 1.5q)$

$+ 18 \times \frac{20}{2} \times 0.75p \times 11 \times 1/4$

$= \underline{\underline{202.5g + 225q + 371.25p}}$

c)



~ more bracing outwards
- i.e. from core to perimeter

d) Providing fixity (moment resistance) to the joints would allow the structure ~~as~~ to act as a sway frame. Alternatively a reinforced concrete core could be considered.

Question 1

Approximately two-thirds (11/18) of candidates attempted this question and did so with reasonable success.

a) Qualitative description of load paths – mostly done well.

b) i) Load in perimeter column – mostly done well, but with small errors in calculating tributary areas

ii) Force in bracing – mostly done poorly, with candidates not recognizing that the bracing at ground floor resists the lateral load for the whole building, not just for that level.

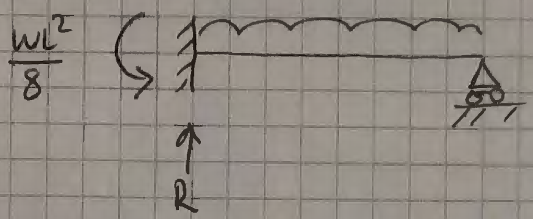
iii) Load in column of braced core – gravity loads often assessed correctly but contribution of lateral loads (due to truss action of braced core) often not correctly considered.

c) Bracing redesign – many were able to make sensible proposals

d) Alternative means of resisting lateral loads – many were able to make sensible proposals.

2)

a) By databook:



$RL = \frac{WL^2}{8} + \frac{WL^2}{2}$

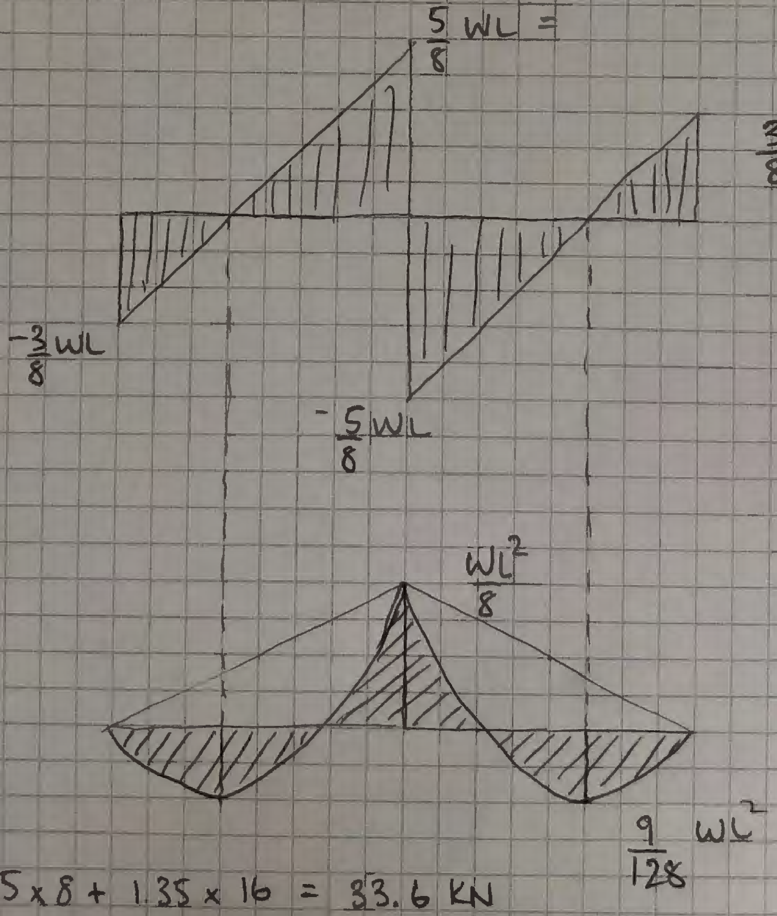
$R = \frac{5}{8} WL$

$V_B = 2R = \frac{5}{4} WL$, $V_A = V_C = \frac{3}{8} WL$

$M_B = \frac{WL^2}{8}$

$M_A = M_C = 0$

Shear



$W_{ED} = 1.5 \times 8 + 1.35 \times 16 = 33.6 \text{ kN}$

$V_{ED} = \frac{5}{8} \times 33.6 \times 8 = 168.0 \text{ kN}$

$M_{ED} = \frac{33.6 \times 8^2}{8} = 268.8 \text{ kNm}$

b) ≈ end span of continuous beam

$$\frac{8000}{18} = 445 \text{ mm} = d$$

c) $f_{cd} = \frac{50}{1.5} = 33.3$ MPa

$f_{yd} = \frac{500}{1.15} = 434$ MPa

$M_u = 0.225 \times 33.3 \times 300 \times 445^2 = 445$ kNm $> M_{ED}$ ✓

so singly reinforced.

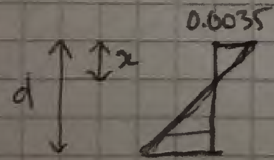
$$A_s = \frac{M_{ED}}{z f_{yd}} \approx \frac{268.8 \times 10^6}{0.8 \times 445 \times 434} = 1740 \text{ mm}^2$$

$A_{s,prov} = \underline{\underline{4H25}} = \underline{\underline{1963}}$ mm^2

check $7 \times 25 + 2 \times 35 = 245 < 300$ mm so single layer fits

Check that $A_{s,prov}$ remains underreinforced

$$x = \frac{d A_s f_{yd}}{0.6 b d f_{cd}} = 142.1 \text{ mm}$$



$$\frac{(d-x)\varepsilon_c}{x} = \frac{445 - 142.1}{142.1} \times 0.0035 = 0.007$$

so steel has yielded ✓

d)

$k = 1 + \sqrt{200/445} = 1.67$

$A_L = \dfrac{1963}{300 \times 445} = 0.015$

$V_{RD,c} = \left[\dfrac{0.18}{1.5} \times 1.67 \times (100 \times 0.015 \times 40)^{1/3} \right] 300 \times 445 = 104.7$ KN

~~or~~

$= (0.035 \times 1.67^{3/2} \times 40^{1/2})\, 300 \times 445 = 63.8$ KN

$V_{RD,c} = 104.7$ KN $< V_{ED}$ so design reinforcement

check capacity at $21.8°$

$f_{c,max} = 0.6\left(1 - \dfrac{40}{250}\right) 33.3 = 16.8$ N/mm^2

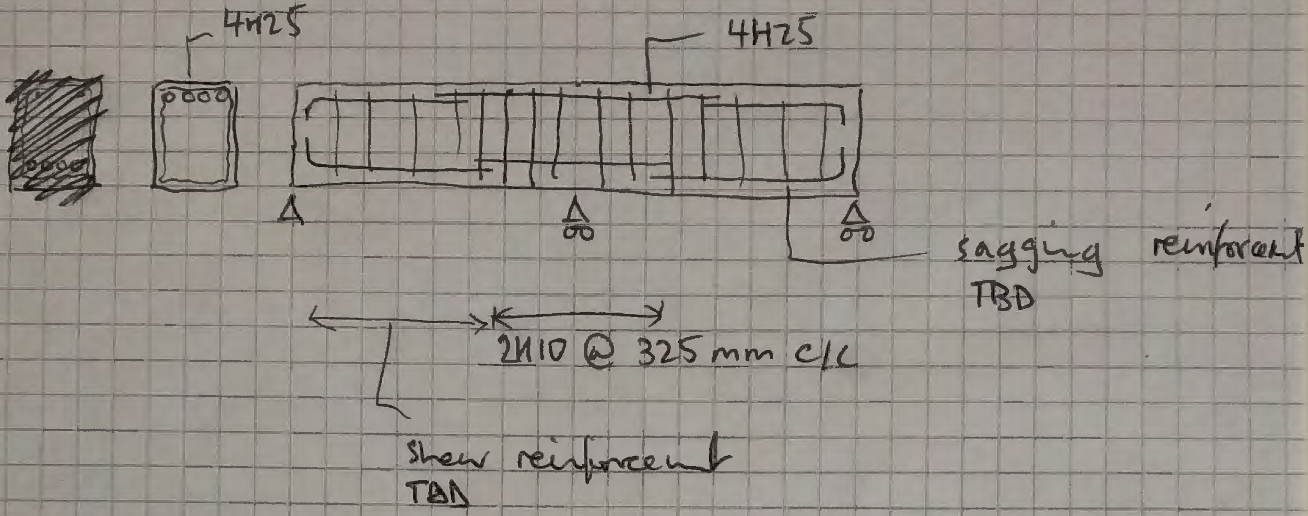
$$V_{RD,max} = 16.8 \times \frac{300 \times 0.9 \times 445}{\frac{\cos 21.8}{\sin 21.8} + \tan 21.8} = 695 \text{ KN}$$

So $V_{RD,max}$ @ $21.8° \gg V_{ED}$

Assume 2 legs H10 link $\Rightarrow$ $A_{sw} = 157$ mm^2

$$S_w = \frac{157 \times 434 \times 0.9 \times 445 \times \left(\frac{\cos 21.8}{\sin 21.8}\right)}{168 \times 10^3} = 406 \text{ mm}$$

$0.75d = 333$ mm so design 10 mm links @ 325 c/c e)



f) Only uniform loading has been considered. Under one-span pattern loading, sagging in the fully loaded span will increase - requiring greater sagging reinforcement.

Question 2

All candidates attempted this question and did so with reasonable success.

a) Shear and moment – many candidates could straightforwardly calculate and plot these for this statically indeterminate beam, either using compatibility or symmetry or databook cases - but a surprising number could not.

b) Initial sizing – most candidates correctly used the span/depth tables for initial sizing but a significant minority seemingly just guesstimated. Inappropriate values of depth then sometimes led to more difficult design subsequently for bending and/or shear.

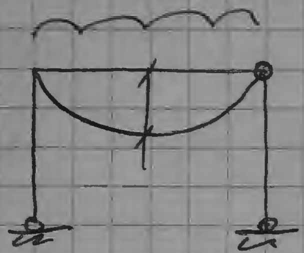
c) Flexure – Generally quite well done. Candidates who applied miscalculated values from a) were not penalized.

d) Shear – Generally quite well done. Candidates who applied miscalculated values from a) were not penalized.

e) Sketches were generally rather scruffy, but along the right lines.

f) Usually well done, where answered.

3)



$$\frac{wL^2}{8} = M$$

From databook, for class I :

$k_{mod,inst} = 1.1$

$k_{mod,med} = 0.8$

$k_{mod,perm} = 0.6$

$W_{ED,perm} = [0.5 \times 4.5 + 0.5] \times 1.35 = 3.71 \text{ kN/m}$

$W_{ED,med} = [0.5 \times 4.5 + 0.5] \times 1.35 + [1.2 \times 4.5] \times 1.5 = 11.81 \text{ kN/m}$

$W_{ED,inst} = [0.5 \times 4.5 + 0.5] \times 1.35 + [1.5 \times 4.5] \times 1.5 = 13.84 \text{ kN/m}$

check critical duration :

$$\frac{3.71}{0.6} = 6.18$$

$$\frac{11.81}{0.8} = 14.76$$

so medium load duration governs (snow)

$$\frac{13.84}{1.1} = 12.58$$

$$M_{ED} = \frac{11.81 \times 9^2}{8} = 119.58 \text{ kNm}$$

$f_{m,d} = k_{mod} \times k_h \times k_{crit} \times k_{LS} \times f_{m,k} / \gamma_m$

$= 0.8 \times 1 \times 1 \times 1 \times 24 / 1.3 = 14.77 \text{ N/mm}^2$

$$d \geq \sqrt{\frac{6 M_{ED}}{b f_{m,d}}} = \sqrt{\frac{6 \times 119.58 \times 10^6}{200 \times 14.77}} = \underline{\underline{493\ mm}}$$

b) $f_{gd,s} = \frac{k_{mod} \times k_A \times f_{gk}}{\gamma_{MA}} + \frac{f_{rk}}{\gamma_{mV}} = \frac{0.74 \times 1 \times 45}{1.8} + \frac{90}{1.2} = 93.5\ MPa$

$$f_{gd,m} = \frac{0.43 \times 1 \times 45}{1.8} + \frac{90}{1.2} = 85.8\ MPa$$

$$f_{gd,L} = \frac{0.29 \times 1 \times 45}{1.8} + \frac{90}{1.2} = 82.3\ MPa$$

$$M_{ED,S} = \frac{1.5 \times 1.5 \times 1.8^2}{8} = 0.91\ kNm$$

$$M_{ED,m} = \frac{1.5 \times 1.2 \times 1.8^2}{8} = 0.73\ kNm$$

$$M_{ED,L} = \frac{1.35 \times 0.5 \times 1.8^2}{8} = 0.27\ kNm$$

2 cases for equivalent monolithic thickness
(from databook)

$\omega = 0.2$ for short term / instantaneous

$$h_{eq,s} = \sqrt{\frac{2 \times 8^3}{8}} = 11.31\ mm$$

$\omega = 0$ for all other cases

$$h_{eq,d} = \sqrt{\frac{0.8 \times 2 \times 8^3 + 0.2 \times 16^3}{8 + 2 \times 0.2 \times \frac{8}{2}}} = 13.06\ mm$$

$$\sigma_s = \frac{M_{ED,S}}{\frac{b\,h_{eq}^2}{6}} = \frac{\cancel{0.40}\ 0.91 \times 10^6}{\frac{1000 \times 13.06^2}{6}} = 32.01 \text{ N/mm}^2$$

$$\sigma_m = \frac{M_{ED,M}}{\frac{b\,h_{eq}^2}{6}} = \frac{0.73 \times 10^6}{\frac{1000 \times 11.31^2}{6}} = 34.24 \text{ N/mm}^2$$

$$\sigma_L = \frac{M_{ED,L}}{\frac{b\,h_{eq}^2}{6}} = \frac{0.27 \times 10^6}{\frac{1000 \times 11.31^2}{6}} = 12.66 \text{ N/mm}^2$$

Load duration interaction check:

$$\frac{\sigma_s}{f_{gd,s}} + \frac{\sigma_m}{f_{gd,m}} + \frac{\sigma_L}{f_{gd,L}} \leq 1$$

$$\frac{32.01}{93.5} + \frac{34.24}{85.8} + \frac{12.66}{82.3} = \underline{\underline{0.90}}$$

Question 3

Approximately two-thirds (12/18) of candidates attempted this question and did so with reasonable success.

a) Timber beam design – generally done fairly well – although the critical load duration case was not always correctly identified.

b) Glass plate verification – generally done ok – although a number of candidates failed to use the necessary interaction equation to properly account for the stress history.

4. (a)

Class 3 limit web :

$$124\varepsilon = 124(0.81) = 100.4 = c/t \rightarrow t = 9.84 \rightarrow t_w = 10 \text{ mm}$$

$(c = 988)$

Class 1 limit flange :

$$9\varepsilon = 7.29 \qquad c = \frac{550 - 10 - 12}{2} = 264 \rightarrow t = 36.2 \rightarrow t_f = 37 \text{ mm}$$

(b)

$$I_z = 2\frac{b^3 t_f}{12} = 1.02(10^9) \text{ mm}^4$$

$$I_T = \frac{1}{3}t_w^3 h + \frac{2}{3}t_f^3 b = 1.89(10^7) \text{ mm}^4$$

$$I_w = I_z \frac{(h+t_f)^2}{4} = 2.75(10^{14}) \text{ mm}^6$$

$$\left.\begin{aligned} L_{cr} &= 4000 \text{ mm} \\ C_1 &= 1.0 \end{aligned}\right\} \text{ central portion is critical}$$

$$M_{cr} = 67\,090 \text{ kNm}$$

$$I_y = \frac{t_w h^3}{12} + 2bt_f\left(\frac{h}{2} + \frac{t_f}{2}\right)^2 = 1.18(10^{10}) \text{ mm}^4$$

$$W_{el} = I_y / \left(\frac{h}{2} + t_f\right) = 2.19(10^7) \text{ mm}^3$$

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_{el} \cdot f_y}{M_{cr}}} = 0.341 \qquad \frac{h}{b} < 2 \rightarrow \text{curve } c \qquad \alpha = 0.49$$

$$\phi = 0.59 \rightarrow \chi = 0.928$$

$$M_u = \chi \cdot W_{el} \cdot f_y = 7226 \text{ kNm}$$

$$M_{Ed} = (1400)(4) = 5600 \text{ kNm} \quad \underline{\text{Ok}}$$

(c) $V_{pl} = t_w \cdot h \, f_y/\sqrt{3} = 2050 \text{ kN}$

$h/t_w > 72 \qquad K = 5.34 \rightarrow \tau = k \dfrac{\pi^2 E}{12(1-\nu^2)} \left(\dfrac{t}{b}\right)^2 = 89.8 \text{ MPa} \quad (b = 1037)$

$\lambda = 0.76 \sqrt{\dfrac{f_y}{\tau_{cr}}} = 1.51$

$\chi = \dfrac{1.37}{0.7 + \lambda} = 0.62$

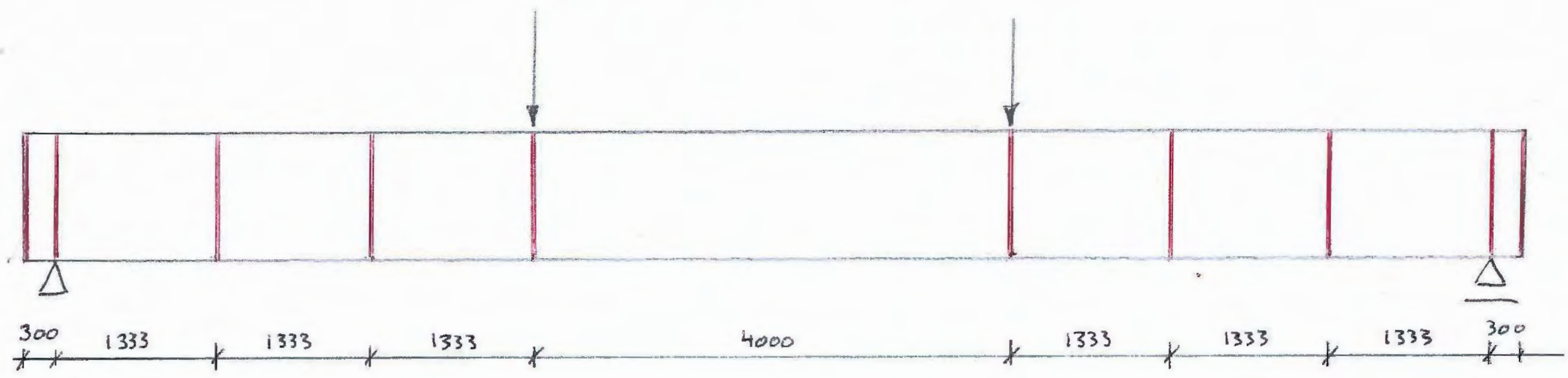
$\chi \cdot V_{pl} = 1270 \text{ kN} < 1400 \text{ kN} \rightarrow$ stiffeners needed

Try to divide the shear span in 3 panels :

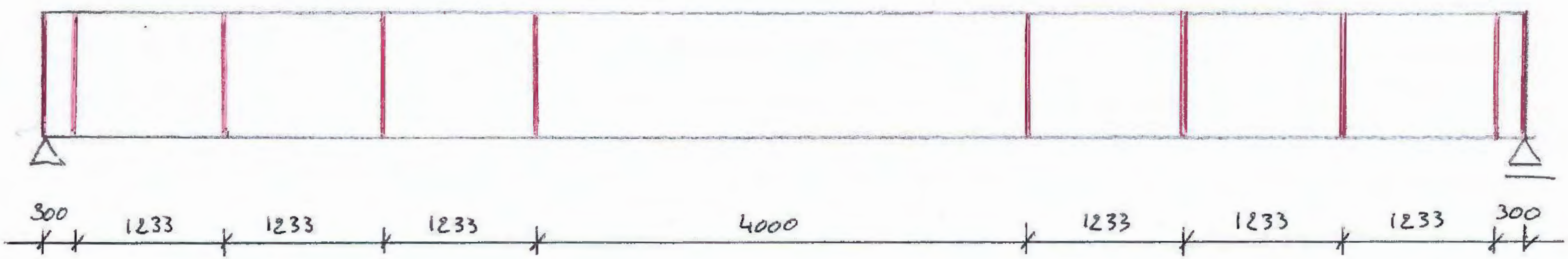
$a = 4/3 = 1.33 \text{ m} \rightarrow a/h = 1.33 \rightarrow K = 5.34 + \dfrac{4}{1.33^2} = 7.59$

$\tau_{cr} = 127.6 \text{ MPa} \rightarrow \lambda = 1.27 \rightarrow \chi = 0.70$

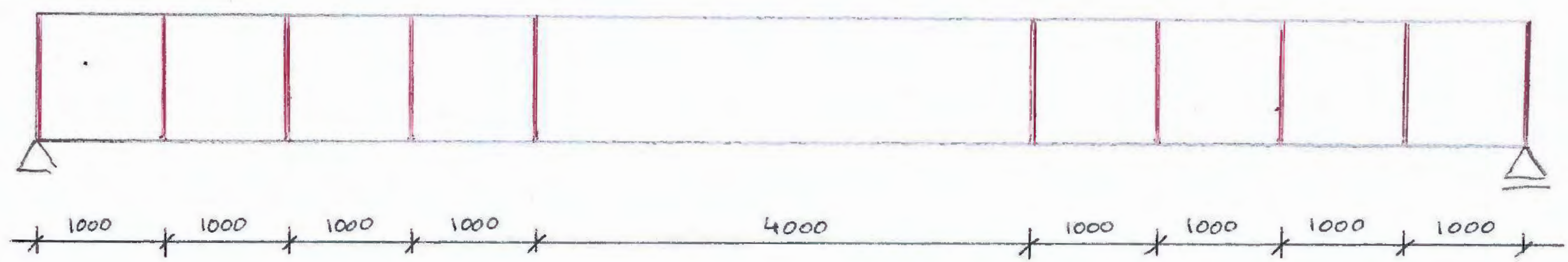
$\chi \cdot V_p = 1427 \text{ kN}$ Ok



or:



or: (no endpost)



Question 4

Approximately two thirds (13/18) of candidates attempted this question and did slightly less well than for the other questions. For many candidates this was their last question and poor time management may have played a part.

a) Section classification – mostly done well but a number of candidates incorrectly characterized the web as being in pure compression.

b) Lateral torsional buckling – many candidates made a decent attempt but accumulated errors as they went. In general, it did not feel as if candidates were as practiced in the procedure for designing a steel beam as one might expect given the fairly standard nature of the question.

c) Shear stiffening – most candidates seemed to be low on time by this point and rushing. A number set out the steps they would use if they had time – which did gain them some marks.