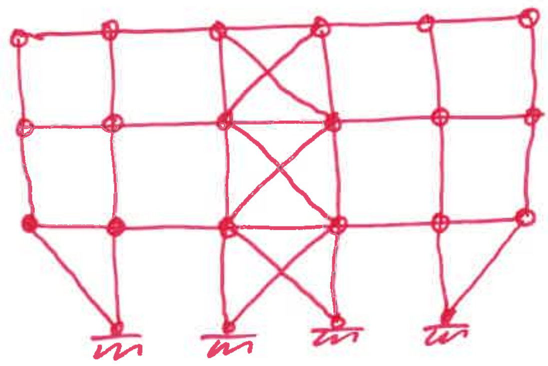
3D3 Crib 2026 RMF3

1 a)



Many possible solutions. Key considerations:

- resisting lateral loads through bracing/core/swayframing
- resisting gravity loads ~~through~~ on end-bays through bracing or Vierendeel action, or by adding columns!

Note the need to support cantilevering corners.

Typical gravity load path: RC deck → secondary beams → primary beams → columns → foundations

Typical lateral load path: wind on facade → deck edge → diaphragm action of deck → braced core.

b) Disproportionate collapse is an extent of failure that is disproportionate to the initiating event. Your colleague may be concerned about the cantilevering end bays / corner bays. If the corner ground floor column were lost then collapse extent could be disproportionate. Mitigations include: tying for robustness, designing as key element, checking element removal - or simply adding column (i.e. removing cantilever).

c) i) May check worst case load duration, or may use an interaction formula to consider the effect of load history. Both approaches may be reasonable.

Considering worst case load duration:

$$M_{Ed,m} = \frac{w_m L^2}{8} = \frac{(0.5\times1.5 + 0.5\times1.35)\times4.5^2}{8} = 3.61 \text{ kNm}$$

$$M_{Ed,L} = \frac{w_L L^2}{8} = \frac{(0.5\times1.35)\times4.5^2}{8} = 1.71 \text{ kNm}$$

$$f_{gd,m} = \frac{0.43\times1\times45}{1.8} + \frac{90}{1.2} = 85.8 \text{ MPa}$$

$$f_{gd,L} = \frac{0.29\times1\times45}{1.8} + \frac{90}{1.2} = 82.3 \text{ MPa}$$

$$d = \sqrt{\frac{6M_{E,d}}{b\,f_{g,d}}}$$

hence:

$$d_{,m} = \sqrt{\frac{6\times3.61\times10^6}{1000\times85.8}} = 15.9 \text{ mm}$$

$$d_{,L} = \sqrt{\frac{6\times1.71\times10^6}{1000\times82.3}} = 11.17 \text{ mm}$$

So medium term load governs.

c) ii)

$$\frac{d}{2} = \sqrt{\frac{6\frac{M}{2}}{b\sigma}} \Rightarrow d = 2\times\sqrt{\frac{6\times\frac{3.61\times10^6}{2}}{1000\times 85.8}} = \underline{\underline{22.46\,mm}}$$

i.e. $2\times12\,mm$ thick

iii) The interlayer holds the glass together after fracture, possibly allowing catenary action or other alternative load paths to be engaged. Connections will need to be designed to sustain forces generated by altered geometry. May also mention energy dissipation and avoidance of flying fragments.

Q2

a) simply supported

Beam i.e. highly stressed

So $L/d = 14$ $\Rightarrow$ $9000/14 = 643\text{ mm}$

say $d = 650\text{ mm}$

$V_{Ed} = 172\text{ kN}$

min breadth for shear is:

$\frac{172\,000}{2 \times 650} = 133\text{ mm}$

So 200 mm breadth for fire governs.

but 200 is narrow for reinforcement, so prudent to choose 300 mm wide.

b)

$M_{Ed} = 387\text{ kNm}$

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

$f_{cd} = \frac{40}{1.5} = 26.7\text{ MPa}$

$d = 650\text{ mm}$

$b = 300\text{ mm}$

$A_s \approx \frac{387 \times 10^6}{0.8 \times 650 \times 434} = 1725\text{ mm}^2$

Say $4H25 = 1963\text{ mm}^2$

check width: $7 \times 25 + 2 \times 65 - 2 \times 12.5$

$= 280\text{ mm}$ ✓

check x: $\frac{d A_s f_{yd}}{0.6 f_{cd} b d} = 177\text{ mm} \ll \frac{d}{2}$

✓

2) c)

check $V_{Rd,c}$

$$k = 1 + \sqrt{200/d} = 1.56$$

$$A_L = \frac{A_s}{bd} = 0.01$$

$$V_{Rd,c} = \left[\frac{0.18}{1.5} \times 1.56 \left(100 \times 0.01 \times 32\right)^{1/3} \right] 300 \times 645 = 115 \text{ kN}$$

or $\left(0.035 \times 1.56^{(3/2)} \times 32^{(1/2)}\right) 300 \times 645 = 44 \text{ kN}$

so $V_{Rd,c} = 115 \text{ kN} < 172 \text{ kN} = V_{Ed}$

so shear reinforcement required.

Try $\theta = 21.8°$

$$V_{Rd,max} = 0.6\left(1 - \frac{32}{250}\right) 26.7 \times \frac{300 \times 0.9 \times 645}{\cot\theta + \tan\theta} = 839 \text{ kN} \gg V_{Ed}$$ ✓

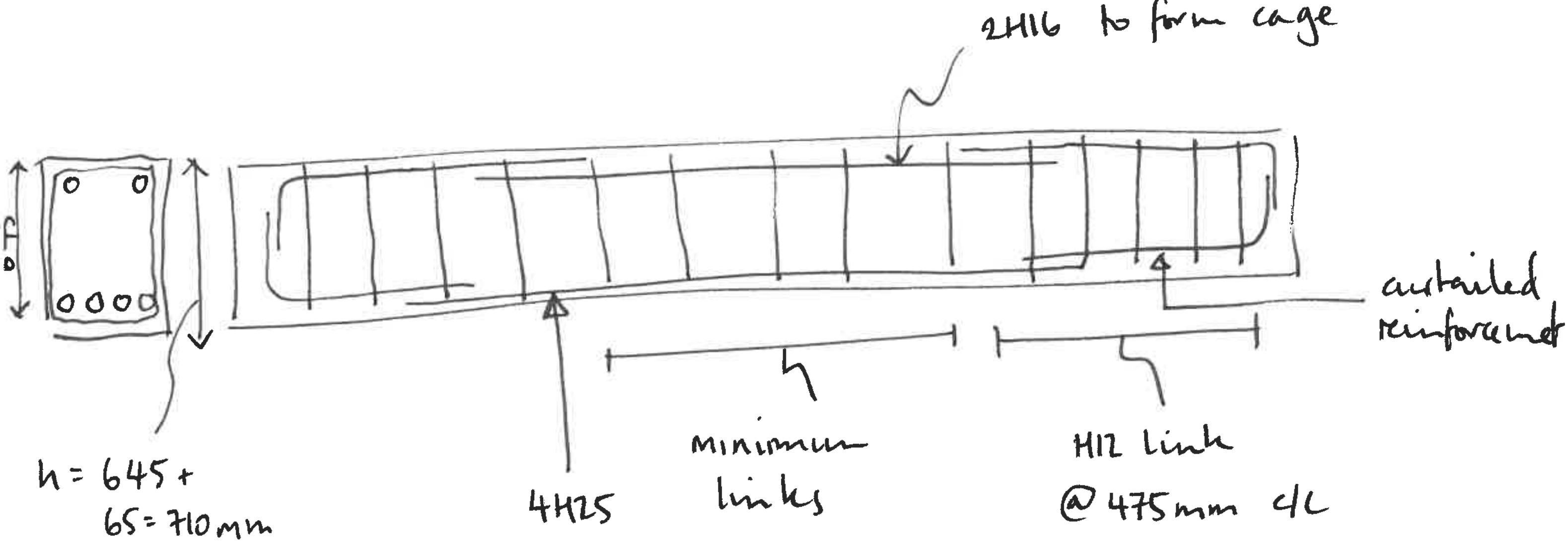
If A_{sw} = 2 × 10 mm legs = 157 mm²

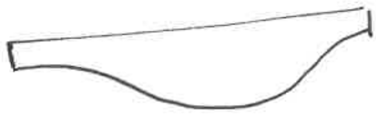
$$S_w = \frac{157 \times 434 \times 0.9 \times 645 \times \cot\theta}{172 \times 10^3} = 574 \text{ mm}$$

max spacing $0.75 \times 645 \nless 475$ mm so choose $\cancel{S_w = 475}$

2 H10 @ 475 mm c/c

e)



f) · consider variable section beam 

- consider effect of changing concrete mix
- consider cement replacements
- consider reducing spans - i.e. adding columns
- consider lighter flooring options e.g. CLT
- consider other structural materials - e.g. steel, glulam

3)

a) deflection limit = span/360 = 6000/360 = 16.7 mm = δ_{max}

$$\delta = \frac{5 w L^4}{384 EI} \qquad I = \frac{bd^3}{12}$$

$$\therefore \quad d = \sqrt[3]{\frac{60 w L^4}{384 E \delta_{max} b}} = \sqrt[3]{\frac{60 \times 9 \times 6000^4}{384 \times 11\,000 \times 150 \times 16.7}} = 404.4 \text{ mm}$$

$$= \underline{\underline{405 \text{ mm}}}$$

checking also long term...

$$d = \sqrt[3]{\frac{60 \times 5.5 \times 6000^4}{384 \times 11000 \times 150 \times \frac{16.7}{1.6}}} = 401.4 \text{ mm}$$

so medium term deflection governs.

b) i) check governing case

$$W_{med} / k_{mod,med} = \cancel{\frac{4\times1.35}{0.67}} \quad \frac{4\times1.35 + 5\times1.5}{0.8}$$

$$= 16.125$$

$$W_{perm} / k_{mod,perm} = \frac{4\times1.35}{0.6} = 9$$

so medium term loading governs

$$\sigma = \frac{M}{Z} \qquad Z = \frac{bd^2}{6} \qquad M_{Ed} = \frac{(4\times1.35 + 5\times1.5)\times 6^2}{8} = 58 \text{ kNm}$$

$$f_{m,d} = 0.8\times1\times1\times1\times1\times24 / 1.3 = 14.77 \text{ MPa}$$

$$\sigma_{Ed} = \frac{6\times58\times10^6}{150\times405^2} = 14.14 \text{ MPa}$$

$$f_{m,d} = 14.77 > 14.14 = \sigma_{E,d}$$

✓ adequate

ii)

$$V_{Ed} = \frac{(4 \times 1.35 + 5 \times 1.5) \times 6}{2} = 38.7 \text{ KN}$$

$$f_{v,d} = \frac{2.5 \times 0.8 \times 0.67}{1.3} = 1.03 \text{ MPa}$$

$$\tau_{Ed} = \frac{38.7 \times 10^3 \times 1.5}{150 \times 405} = 0.95 \text{ MPa}$$

$f_{v,d} > \tau_{Ed}$ ✓ so adequate

3b (iii)

$V_{Ed} = 38.7$ kN

Wall is 150 mm thick. Beam is 150 mm wide.

$$\sigma_b = \frac{38.7 \times 10^3}{150 \times 150} = 1.72 \text{ MPa}$$

$$f_{c,90,d} = \frac{0.8 \times 5.3}{1.3} = 3.26 \text{ MPa}$$ (for medium term loading)

$f_{c,90,d} > \sigma_b$ so ok ✓

3 b (iv)

Bearing.

One-sided loading from beam, so triangular load distribution assumed:

$$\sigma_{max} = 2 \times \frac{38.7 \times 10^3}{150 \times 150} = 3.44 \text{ MPa}$$

$$f_d = \frac{2}{3} = 0.67 \text{ MPa}$$

$\sigma_{max} > f_d$ so not adequate in bearing

Buckling

To avoid excessive conservatism, assume load spread 45°.

Area at 0.6 H $= 150 \times (2 \times 0.4 \times 3000 + 150) = 382\,500 \text{ mm}^2$

$$h/t = \frac{3000}{150} = 20$$

$e = t/6 = 0.17t$ So, reading from graph $\beta \approx 0.55$

$$f_{d,buckling} = 0.55 \times \frac{2}{3} = 0.37 \text{ MPa}$$

$$\sigma_{buckling} = 0.10 \text{ MPa}$$

so $f_{d,buckling} > \sigma_{buckling}$ ✓

So adequate in buckling if bearing failure avoided!

3D3 - 2025 - Steel

$A = (1700)(18) + 2(600)(40) = 78\,600 \ mm^2$

$I_{zz} = 2(40)(600)^3/12 = 1.44(10^9) \ mm^4$

$I_{yy} = (18)(1700)^3/12 + 2(40)(600)\left(\frac{1700}{2} + \frac{40}{2}\right)^2 = 4.37(10^{10}) \ mm^4$

$I_T = 2.89(10^7) \ mm^4$ (given)

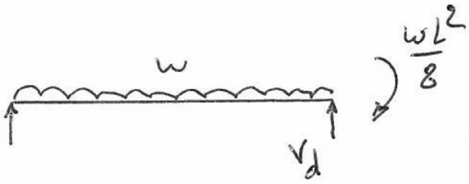
$I_w = 1.09(10^{15}) \ mm^6$ (given)

$S.W. = A(78.5 \ kN/m^3) = 6.17 \ kN/m$

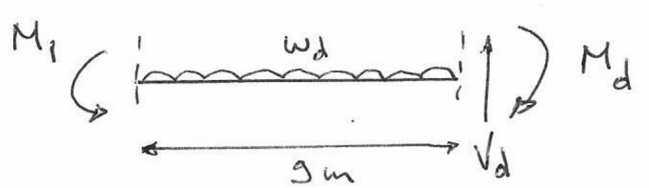
$w_d = 1.35(15 + 6.17) + 1.5(12.5) = 47.3 \ kN/m$

$M_d = w_d \frac{(45)^2}{8} = 11\,980 \ kNm$

$V_d = \left(\frac{wL^2}{2} + \frac{wL^2}{8}\right)/L = \frac{5}{8} wL = 1331 \ kN$



(i) $M_{cr,0} = \frac{\pi^2 E I_{zz}}{L_{cr}^2} \sqrt{\frac{I_w}{I_{zz}} + \frac{L_{cr}^2 G I_T}{\pi^2 E I_{zz}}} = 31\,782 \ kNm$ $(L_{cr} = 9 \ m)$



$M_1 = M_d - V_d \cdot 9 + w_d \frac{9^2}{2}$

$= 2154 \ kNm$

Data sheets: $\psi = \frac{M_1}{M_d} = 0.18 \rightarrow C_1 \approx 1.65$

$\rightarrow M_{cr} = C_1 M_{cr,0} = 52\,500 \ kNm$

Class?

web: $c/t = \frac{1700}{18} < 100 \rightarrow$ Class 3

flange: $c/t = \frac{(600-18)/2}{40} = 7.27 < 10\varepsilon \rightarrow$ Class 2

$\Big\}$ 3

$W_{el} = \frac{I_{yy}}{1700/2 + 40} = 4.91(10^7) \ mm^3$

$M_c = (355) W_{el} = 17\,431 \ kNm$

$$\lambda_{LT} = \sqrt{\frac{M_c}{M_{cr}}} = 0.576 \qquad \text{curve d}: \alpha = 0.76$$

$$\phi = \frac{1}{2}\left(1 + (\lambda_{LT} - 0.2)\alpha + \lambda_{LT}^2\right) = 0.809$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \lambda_{LT}^2}} = 0.726$$

$$M_{b,Rd} = \chi M_c = 12660 \text{ kNm} \quad \underline{\text{Ok}}$$

(ii) $$V_{pl} = \left(\frac{355}{\sqrt{3}}\right)(18)(1700) = 6272 \text{ kN} \qquad \frac{h_w}{t_w} = \frac{1700}{18} > 72\varepsilon$$

$$K = 5.34 + \frac{4}{(9000/1700)^2} = 5.48$$

$$\tau_{cr} = K \frac{\pi^2 E}{12(1-\nu^2)} \left(\frac{18}{1700}\right)^2 = 111 \text{ MPa}$$

$$\lambda_w = 0.76\sqrt{\frac{355}{111}} = 1.36$$

$$\chi_w = \frac{1.37}{0.7 + 1.36} = 0.665$$

$$V_{b,Rd} = \chi \cdot V_{pl} = 4174 \text{ kN} \quad \underline{\text{Ok}}$$

(iii) a, c : bearing stiffeners : avoid bearing failure (web crippling / crushing) under concentrated reaction force.

b : • creates a 'rigid post' = 'anchor field' allowing full mobilisation of tension field action.

- can also be used as a jacking stiffener to replace bearings.