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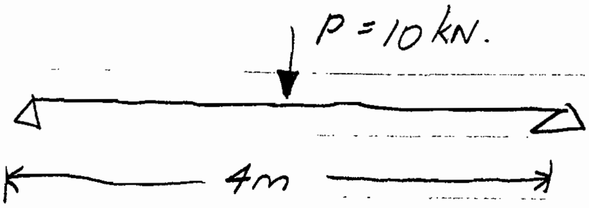
Q1 (a)



Load effect

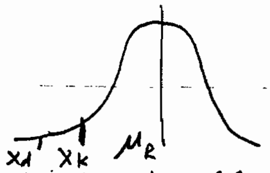
$\mu_S = M = \frac{PL}{4} = \frac{10\times 4}{4} = 10 \text{ kNm}$ $\quad CoV = \frac{\sigma_S}{\mu_S} = 0.2$

$\gamma_f = 1.4$ $\quad \sigma_S = 0.2\times\mu_S = 0.2\times 10 = 2 \text{ kNm}$

Strength

$\mu_R = 40 \text{ kNm}$ $\quad CoV = \frac{\sigma_R}{\mu_R} = 0.18$ $\quad \sigma_R = 0.18\times 40 = 7.2 \text{ kNm}$

$\gamma_m = 1.5$



(i) Characteristic load effect, F_k (95% level)

$$F_k = \mu_S + 1.645\times\sigma_S = 10 + 1.645\times 2 = 13.29 \text{ kNm}$$

Design load effect, F_d

$$F_d = \gamma_f \times F_k = 1.4\times 13.29 = 18.6 \text{ kNm}$$

(ii) Characteristic strength (resistance), X_k (5% level)

$$X_k = \mu_R - 1.645\times\sigma_R = 40 - 1.645\times 7.2 = 28.2 \text{ kNm}$$

Design strength.

$$X_d = \frac{X_k}{\gamma_m} = \frac{28.2}{1.5} = 18.8 \text{ kNm}$$

(iii) $\underset{(18.8)}{X_d} > \underset{(18.6)}{F_d} \Rightarrow$ Design OK from codes of practice.

1(b) $\beta = \dfrac{\mu_R - \mu_S}{\sqrt{\sigma_R^2 + \sigma_S^2}} = \dfrac{40-10}{\sqrt{7.2^2+2^2}} = \dfrac{30}{\sqrt{55.8}} = \dfrac{30}{7.5} = \underline{4.015}$

From tables for $\beta = 4.01$ $\Phi(\beta) = 0.9^4 6964$

4.02 $= 0.9^4 7090$.

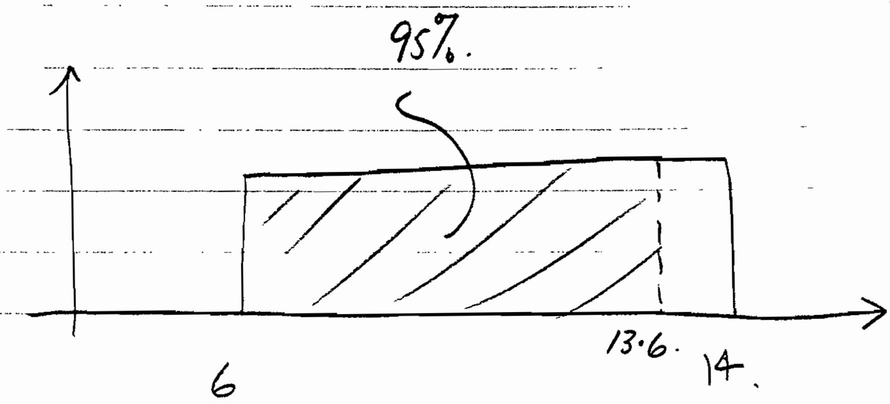
$\beta = 4.015$ $= 0.9^4 7027$

$P_f = \Phi(-\beta) = 1 - \Phi(\beta) = 1 - 0.9^4 7027 = \underline{29.7 \times 10^{-6}}$

$\underline{P_f \simeq 3 \times 10^{-5}}$

(c)

Load S



P uniform 6-14 kN $\qquad M = \frac{PL}{4} = P \times \frac{4}{4} = P$ kNm.

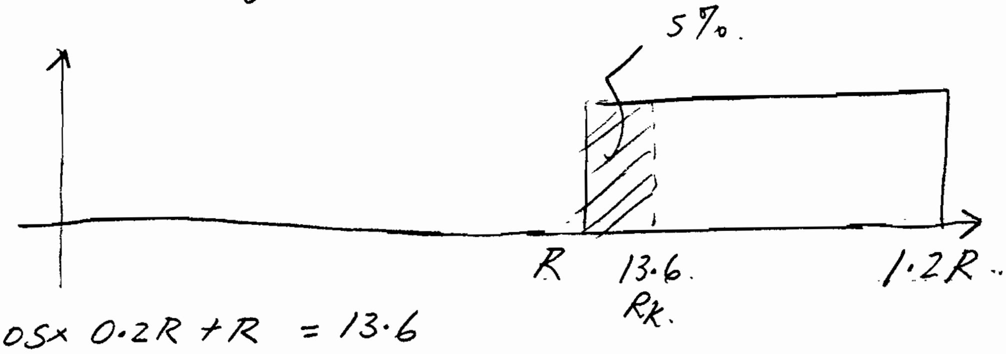
M " 6-14 kN.

Characteristic load (95% value)

$$S_k = 0.95(14-6) + 6 = 13.6 \text{ kNm}$$

(d)

Resistance (Strength) R given $\quad R_k = S_k = 13.6$ kNm



$R_k = 0.05 \times 0.2R + R = 13.6$

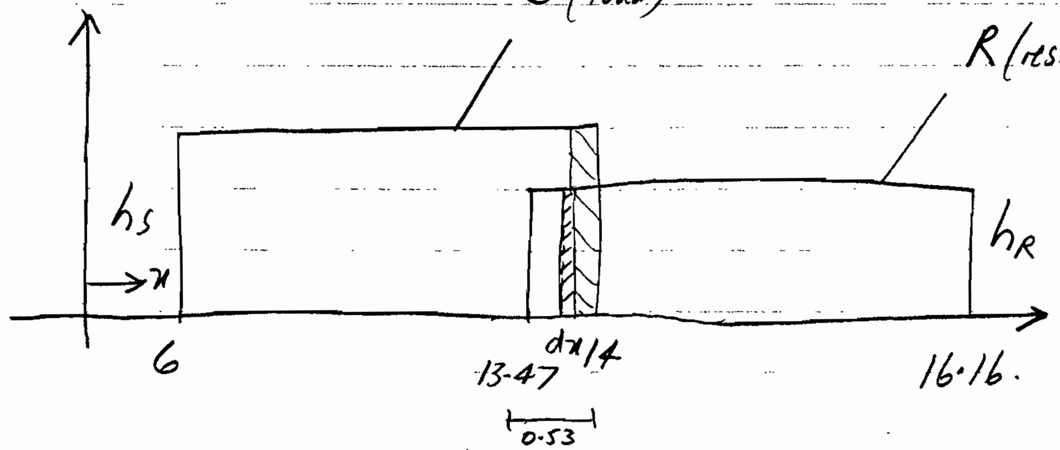
$\therefore \quad 1.01R = 13.6$

Lower limit $\quad R = \frac{13.6}{1.01} = 13.47$ kNm

Upper limit $\quad 1.2R = 1.2 \times 13.47 = 16.16$ kNm

Prob. fail

$$P_f = \Sigma\, \text{Prob}(R \text{ in range } dx) \times \text{Prob}(S > R_{dx})$$



Height of R pdf. Area $= h_R \times (16.16 - 13.47) = 1.0$

$$h_R = \frac{1}{2.69} = 0.3717.$$

Height of S pdf Area $= h_S \times (14-6) = 1.0$

$$h_S = \frac{1}{8} = 0.125.$$

Prob resistance in range x to $x+dx$. is area under pdf of R

$$= h_R . dx = 0.3717\, dx.$$

Prob load is greater than x is area above x under pdf of S.

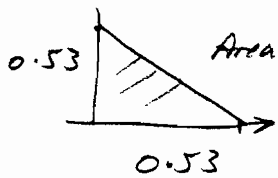
$$= (14-x) h_S = 0.125(14-x).$$

$$\therefore P_f = \int_{13.47}^{14} (14-x)\, 0.125 \times 0.3717\, dx.$$

$$= 0.125 \times 0.3717 \int_0^{0.53} (0.53 - x)\, dx.$$

$$= 0.125 \times 0.3717 \times \frac{0.53^2}{2}$$

Area under graph.
At $x = 14$ $I = 0$
At $x = 13.74$ $I =$



Area $= \frac{1}{2} \times 0.53^2$

$\underline{P_f = 6.53 \times 10^{-3}}$

(e) Green concrete

- primary difference is reduced cement content by using higher % of pfa &/or microsilica.
- Also improved grading of aggregates reduces amount of cement paste required hence the need for cement.

Q2. (a) AAR
Chemical Attack
Abrasion
Freezing + thawing

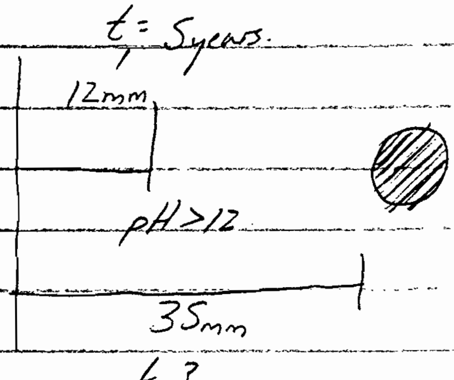
(b) See notes of Structural Failure Case Studies.
Long-term deterioration
- Ynys-y-gwas - Tendon corrosion / road salts
- rupture lead to deck collapse
- needed protection of tendons + waterproofing of joints.
- Stepney Swimming pool - HAC / conversion
- prevent conversion - no/use HAC
- FDR drive - road salts / spalling
- dropped on car + killed passenger
- waterproofing of deck / sealant / CP.

(c) Earthquakes } Main two forms of natural hazard leading to
Flood (scour) } collapse
- Details - ductility - stirrups/confinement
- continuity - continuous members / limited joints
- redundancy - multiple load paths
- continuity - tie members together to avoid pulling apart

(d) Water/Cement ratio - low.
Cover - protects reo from corrosion
Curing - reduces permeability + hence ↓ rate of initiation of corrosion
Cement Content - reduces permeability, ↓ pore/capillary size, ↑ alkalinity.
Compaction - reduces voids, air gaps hence ↓ permeability + hence corrosion

(e)

$t_0 = 1960$ Cover 35mm



Carbonation rate $\propto \sqrt{t}$.

$$12\text{mm} \propto \sqrt{5}$$
$$35\text{mm} \propto \sqrt{t_2}$$
$$\sqrt{\frac{t_2}{5}} = \frac{35}{12} \qquad t_2 = \left(\frac{35}{12}\right)^2 \cdot 5 = 42.5 \text{ years to initiation when pH} > 12.$$

Assume C_0 = constant. D is constant.

Chlorides $x_1 = 10$mm $C_1 = 0.2\%$ $t_1 = 2$ years
$x_2 = 10$mm $C_2 = 0.6\%$ $t_2 = 8$ years
$x_3 = 35$mm $C_3 = 0.4\%$ $t_3 = ?$ years.

$$C = C_0\left(1 - \text{erf}\left(\frac{x}{2\sqrt{Dt}}\right)\right) = C_0(1 - \text{erf}(z))$$

$$C_1 = C_0\left(1 - \text{erf}\,\frac{10}{2\sqrt{D \cdot 2}}\right) = 0.002$$

$$C_2 = C_0\left(1 - \text{erf}\,\frac{10}{2\sqrt{D \cdot 8}}\right) = 0.006$$

$$\frac{0.006}{0.002} = \frac{1 - \text{erf}(z_2)}{1 - \text{erf}(z_1)} = 3 \qquad (1) \qquad Cl^- < 0.4\%$$

$$z_1 = \frac{10}{2\sqrt{D \cdot 2}} \qquad z_2 = \frac{10}{2\sqrt{D8}} \qquad \frac{z_2}{z_1} = \frac{\sqrt{2}}{\sqrt{8}} = \frac{1}{2} \Rightarrow z_1 = 2z_2 \quad (2)$$

From tables in (1) & (2): Guess $z_1 = 1$ $z_2 = 0.5$
$\text{erf}(z_1) = 0.84$ $\text{erf}(z_2) = 0.52$. $\frac{1-\text{erf}\,z_2}{1-\text{erf}\,z_1} = 3$. OK

$\therefore z_1 = 1$

Question number Sheet number

$$C_1 = C_0\left(1 - \mathrm{erf}\frac{10}{2\sqrt{D2}}\right) = 0.002$$

$$C_4 = C_0\left(1 - \mathrm{erf}\frac{x_4}{2\sqrt{Dt_4}}\right) = 0.004.$$

$$\frac{4}{2} = \frac{1-\mathrm{erf}(z_4)}{1-\mathrm{erf}(z_1)}$$ where $z_1 = 1$, $\mathrm{erf}\, z_1 = 0.84$.

$$1-\mathrm{erf}(z_4) = 2(1-0.84) = 0.32$$

$$\mathrm{erf}(z_4) = 0.68.$$

From tables for $\mathrm{erf}(z_4) = 0.68$ $z_4 = 0.7$.

$$\therefore z_4 = \frac{x_4}{2\sqrt{D2}} = 0.7$$ where $t_4 = t_1 = 2$ years.

$$z_1 = \frac{10}{2\sqrt{D2}} = 1.0$$

$$x_4 = 0.7 \times 10 = 7\text{mm}$$ (where $C_4 = 0.4\%$ at $t = 2$ years)

Have $C_4 = 0.4\%$ at $x_4 = 7$mm after 2 years.

Want time until $C_3 = 0.4\%$ at $x_3 = 35$ mm.

Diffusion distance $\propto \sqrt{t}$.

$$x_4 \propto \sqrt{t_4}$$

$$x_3 \propto \sqrt{t_3}$$

$$\frac{7}{35} = \frac{\sqrt{2}}{\sqrt{t_3}} \Rightarrow t_3 = \left(\frac{35}{7}\right)^2 \times 2 = \underline{50\text{ years}}.$$

c.f. 42.5 years for carbonation

$\Rightarrow$ Corrosion starts due to carbonation at $T = 42.5$ years.

Question number

Sheet number

(ii) Factors affecting propagation of Corrosion?

Quality of surface concrete in cover region + availability of CO_2 + Cl.

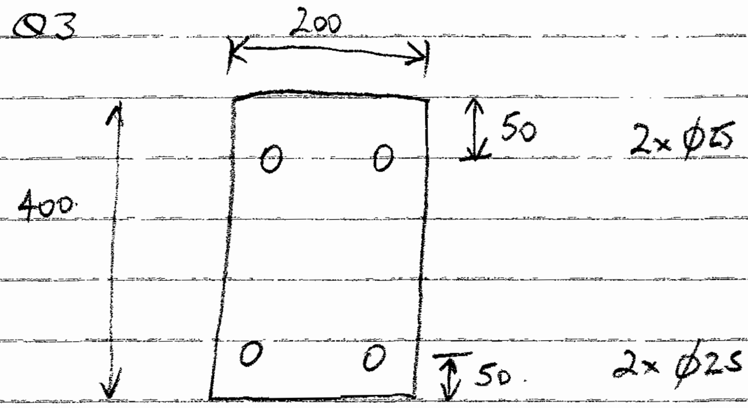
Carbonation. - concentration of CO_2

- quality of concrete / impermeability

Chlorides - Surface chloride concentration & initially concentration

- quality of concrete
- value of D (in practice non-linear)

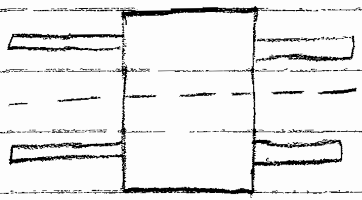
Q3



$E_{steel} = 200\,GPa.$

$E_{conc} = 25\,GPa.$

$$m = \frac{E_s}{E_c} = \frac{200}{25} = 8.$$



Allow for area of concrete taken up by bars ⇒ ×(m−1)

$A_{st} = 2 \times \frac{\pi \times 25^2}{4} = 982\,mm^2$ $(m-1)A_{st}$ $7 \times 982 = 6874..$

(a)

$$I_{uncracked} = \frac{bd^3}{12} + 2 \times A_{bar\,(c)} \times shift^2$$

$$= \frac{200 \times 400^3}{12} + 2 \times 6874 \times 150^2 \quad (\text{Ignore } I_{bar\,(c)} \text{ about own axis})$$

$$= 1.067 \times 10^9 + 309 \times 10^6$$

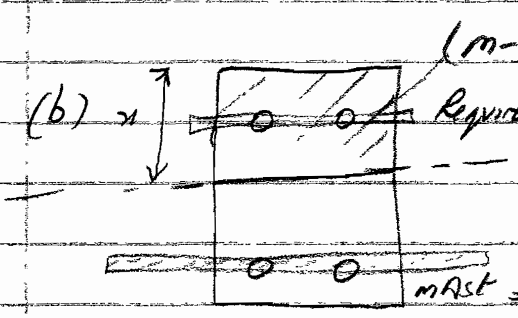
$$I_{unc} = 1.376 \times 10^9\,mm^4$$

Modulus of rupture $\sigma_t = 4$ MPa.

$$\sigma = \frac{My}{I} \Rightarrow M = \frac{\sigma I}{y} = \frac{4 \times 1.376 \times 10^9}{200} = \frac{27.52 \times 10^6 \times 10^3 \times 1}{1 \times 10^{-3}}$$

$$M_{cr} = 27.5\,kNm$$

(b)



Require $I_{cracked}$.

$mA_{st} = 8 \times 982 = 7856\,mm^2$

Find NA. $200x \cdot \frac{x}{2} + 6874 \times (x - 50) = 7856(350 - x)$

$$100x^2 + 6874x - 6874 \times 50 = 7856 \times 350 - 7856x$$

$$100x^2 + 14.73 \times 10^3 x - 3.093 \times 10^6 = 0.$$

$$x^2 + 147.3x - 30.933 \times 10^3 = 0.$$

$$x = \frac{-147.3 \pm \sqrt{147.3^2 + 4\times 1 \cdot 30.933\times 10^3}}{2}$$

$$x = \frac{-147.3 \pm 381.35}{2} = \underline{117.0\ mm}$$

NB $\frac{bd^3}{12} + bd\left(\frac{d}{2}\right)^2 = \frac{bd^3}{12} + \frac{bd^3}{4} = \frac{bd^3 + 3bd^3}{12} = \frac{bd^3}{3}$

$x = 117\ mm$

$$\therefore I_{cracked} = \underbrace{\frac{200\times 117^3}{12} + 200\times 117\times\left(\frac{117}{2}\right)^2}_{\frac{bd^3}{3}} + 6874\times(\underbrace{117-50}_{67})^2 + 7856\times(\underbrace{350-117}_{233})^2$$

$$= 106.77\times 10^6 + 30.86\times 10^6 + 426.49\times 10^6$$

$I_{cracked} = \underline{564.1\times 10^6\ mm^4}$

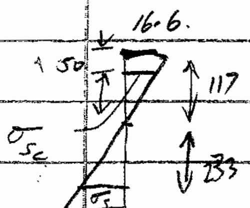
$M = 80\ kNm$ Find salient stresses in steel & concrete.

$\sigma = \frac{My}{I}$ Concrete in compression $\sigma_{conc} = \frac{80\times 10^3 \times 117\times 10^{-3}}{564.1\times 10^6\times 10^{-12}}$

$= 16.6\times 10^6\ N/m^2$ (16.6 MPa)

Steel in compression $\sigma_{s_{comp}} = \frac{(117-50)}{117}\times 16.6\times 8 = \underline{76\ MPa}$

Steel in tension (concrete I to steel by dividing by m).



$$\sigma_{steel\ tension} = \frac{My}{I} = \frac{80\times 10^3\times(350-117.0)\times 10^{-3}}{\frac{564.1\times 10^{-6}}{8}} = 264\times 10^6$$

$\underline{\sigma_{steel} = 264\ MPa}$

OR $\sigma = \frac{233}{117}\times 16.6\times 8 = \underline{264.5\ MPa}$

Crack width. $w_k = \beta\ S_{rm}\ \varepsilon_{sm}$ from data sheet

$\beta = 1.7$ $S_{rm} = 50mm + 0.25\ k_1 k_2 \frac{\phi}{\rho_r}$ $k_1 = 0.8$ for high bond. $k_2 = 0.5$ for bending.

$\phi = 25mm$ $\rho_r = \frac{A_{st}}{A_{c_{eff}}} = \frac{982}{25\times 10^3} = 39.28\times 10^{-3}$ $A_{c_{eff}} = 2.5(h-d)b = 2.5(400-350)\times 200 = 25\times 10^3$

$A_{st} = 982\ mm^2$

ε_{sm} = mean overall steel strain (assuming cracked elastic theory).

$\sigma_{\substack{steel \\ tension}} = 264$ MPa. $\quad E_{steel} = \cancel{210}^{\,200}$ GPa $\quad$ (~~from databook~~ given)

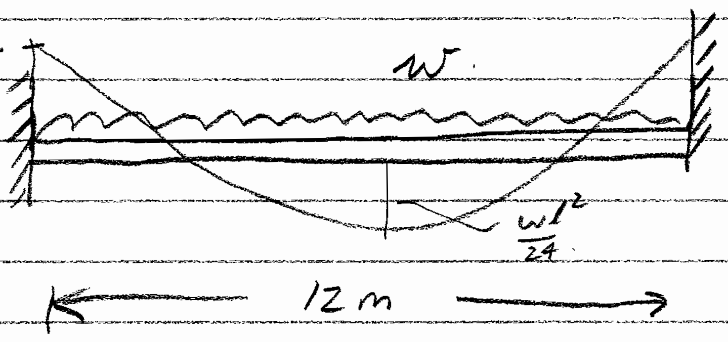
$\sigma = \varepsilon E$

$\therefore \varepsilon_{sm} = \dfrac{\sigma}{E} = \dfrac{264}{200 \times 10^3} = 0.00132 \quad (1.32 \times 10^{-3})$

$\Rightarrow \; S_{rm} = 50 + 0.25 \times 0.8 \times 0.5 \times \dfrac{25}{39.28 \times 10^{-3}} = 113.6$ mm. average crack spacing

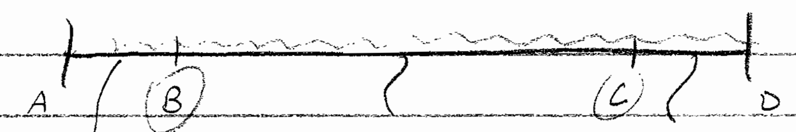
$w_k = 1.7 \times 113.6 \times 1.32 \times 10^{-3} = \underline{0.255 \text{ mm}}$. $\underline{< 0.3\text{mm limit}}$

Q3 (c)



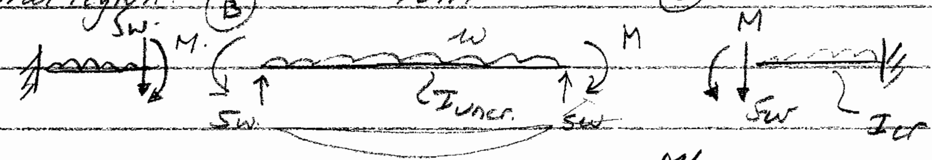
$M_{max} = \frac{wl^2}{12}$ at support. $M_{crack} = 28.4$ kNm from (a)

$\therefore \quad w = \frac{12 M_{cr}}{l^2} = \frac{\cancel{12} \times 27.5}{\cancel{12} \times 12} = \underline{2.29 \text{ kN/m}}$.



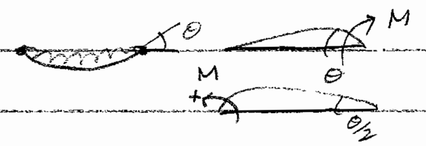
Varying stiffness along beam once cracked.

FBD. Central region.

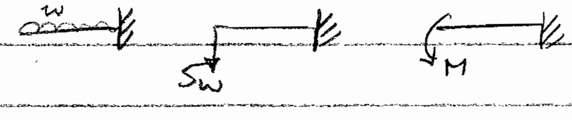


Must have same slope at C & B.

Beam BC $\quad \theta_{C_{Left}} = \frac{wl_1^3}{24EI_{un}} - \underbrace{\frac{Ml_1}{3EI_{un.}} - \frac{Ml_1}{6EI_{un.}}}_{\frac{Ml}{2EI_{un}}}$



$\theta_{C_{Right}} = \frac{wl_2^3}{6EI_{cr}} + \frac{5w.\,l_2^2}{2EI_{cr}} + \frac{M.\,l_2}{EI_{cr.}}$



$\therefore \quad \frac{1000w}{24EI_{un}} - \frac{5M}{EI_{UN}} = \frac{w}{6EI_{cr}} + \frac{5w}{2EI_{cr}} + \frac{M}{EI_{cr}}$

Q3 (c) cont.

CORRECTED 30/3/07.

$$w\left[\frac{1000}{24 I_{UN}} - \frac{1}{6 I_{CR}} - \frac{5}{2 I_{CR}}\right] = \frac{M}{I_{CR}} + \frac{5M}{I_{UN}}$$

Multiply through by I_{CR}

$$w\left[41.7\frac{I_{CR}}{I_{UN}} - 0.167 - 2.5\right] = M\left[1 + 5\frac{I_{CR}}{I_{UN}}\right]$$

$$\frac{I_{CR}}{I_{UN}} = \frac{564.1 \times 10^6}{1.376 \times 10^9} = 0.41$$

$$\therefore M = w\frac{[17.1 - 0.167 - 2.5]}{[1 + 2.05]} = \frac{14.43w}{3.05} = 4.73w$$

<u>Midspan moment</u>

$$M_{midspan} = \frac{wl^2}{8} - M = \frac{w \times 100}{8} - 4.73w = (12.5 - 4.73)w$$
$$= 7.77w$$

<u>Support moment</u>

$$M_{support} = 5w \times 1 + w \times 1 \times 0.5 + M$$
$$= 5w + 0.5w + 4.73w = 10.23w$$

$$\therefore \frac{M_{support}}{M_{midspan}} = \frac{10.23w}{7.77w} = 1.32$$

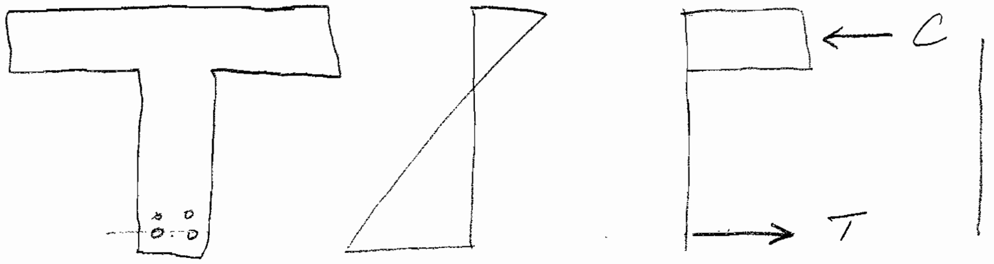
c.f. $\frac{M_{support}}{M_{midspan}} = 2.0$ when uncracked.

i.e. $\frac{2 - 1.32}{2} = 0.34$ 34% redistribution

This is a quite high level of redistribution of moment from the supports to midspan. It relies on the section at the supports having sufficient ductility to accommodate the rotation at the supports i.e. adequate rotation capacity.

CORRECTED 30/3/07

Q4/ $f_{cd} = 25\,MPa$ $f_{yd} = 400\,MPa$ (Long) $f_{yd} = 240\,MPa$ (stirrups)



$l = 600-70-50 = 4$… mm

(a) Neglect web + assume NA at level of soffit of slab. Assume all steel yields

$$T = A_{st} f_{yd} = \cancel{4} \times \frac{\pi 32^2}{\cancel{4}} \times 400 = 1.287 \times 10^6\,N$$

$$= 1287\,kN.$$

$$\text{Moment} = T.l = 1287 \times 10^3 \times 0.48 \times 10^{-3} \quad \underline{617.7\,kNm} \; (618\,kNm)$$

(b) $\tau_{Rd} = 0.5\,MPa$

$$V_{Rd1} = b_w d \left\{ \tau_{Rd}\, k\,(1.2 + 40\rho_l) + \cancel{0.15 \frac{N}{A_c}} \right\} \quad 0.$$

$$= 0.15 \times 0.53 \left\{ 0.5 \times 10^6 \times (1.6 - 0.53)(1.2 + 40 \times 0.0405) \right\} = 119.9 \times 10^3\,N$$

$$= \underline{120\,kN}$$

$$\rho_l = \frac{A_s}{bd} = \frac{\cancel{4} \times \frac{\pi 32^2}{\cancel{4}}}{150 \times 530} = \frac{3217}{79500} = 0.0405$$ using width of web only.

(4%) ' High % steel.

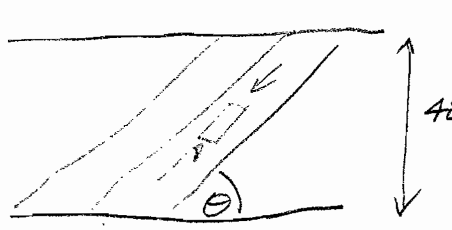
Stirrups

$$V_{Rd3} = A_{sw} f_{ywd} \frac{0.9d}{s} = 2 \times \frac{\pi 10^2}{4} \times 240 \times 0.9 \times \frac{530}{100} = 179.8 \times 10^3\,N$$

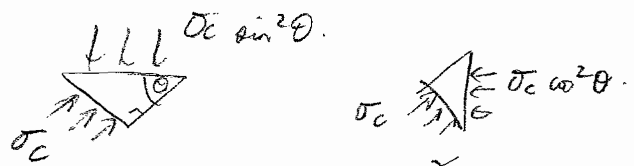
$$= \underline{180\,kN}$$

$$V_{Rd} = V_{Rd1} + V_{Rd3} = 120 + 180 = \underline{300\,kN}.$$

(c)



$f_{c\,eff} = 0.5 \times 25 = 12.5\,MPa.$



$$\rho = \frac{A_{sw}}{bs} = \frac{2 \times \pi . 10^2}{4} \cdot \frac{1}{150 \times 100}$$

$$= 10.47 \times 10^{-3}$$

$$\rho \sigma_s = \sigma_c \sin^2\theta$$

$$10.47 \times 10^{-3} \times 240 = 12.5 \sin^2\theta.$$

$$\sin^2\theta = 0.201 \quad \underline{\theta = 26.64^\circ}$$

Q4 (c) cont.

$$\tau = \sigma_c \sin\theta \cos\theta$$
$$= 12.5 \sin 26.6 \cos 26.6 = \underline{5 \text{ MPa}}$$

$$V = \tau \times bd = 5 \times 150 \times 480 = 360 \times 10^3 N = \underbrace{360 kN}_{\text{c.f. } 300 kN}$$

(d) ↓ in Ast of anchored bars by 3/4. (20% higher)
<u>Code formula</u> $k = 1.0$ c.f. 1.07 earlier since >50% steel curtailed.

$$\therefore V_{Rd,1} = \frac{120}{1.07} = 112.2 \text{ kN}$$

$$\therefore V_{Rd} = 112.2 + 180 = 292.2 \text{ kN}$$ 7.8 kN less.
$\left(\frac{7.8}{300} \times \frac{100}{1} = 2.6\%\right)$.

<u>Truss analogy</u> Only $\frac{1}{4}$ long. steel anchored. $\sigma_c \cos^2\theta$

Force in long bars $F_s = \frac{M}{z} + \frac{V}{2}\cot\theta$
At support $M = 0$
Assume bar yielded but only 1 bar
$$F_s = \frac{\pi 32^2}{4} \times 400 = 321.7 \times 10^3 \; (321.7 \text{ kN})$$

Vertical equilibrium ① $\sigma_c' \sin^2\theta' = \rho\sigma_s = \frac{A_w}{b_w s} f_{yd} = \frac{2 \times \frac{\pi 10^2}{4} \times 240}{150 \times 100}$ (157 mm²)
$$= 2.51 \text{ MPa}$$

Horizontal equilibrium $(\sigma_c' \cos^2\theta') \times b_w z = 2F_s$

② $\sigma_c' \cos^2\theta' = \frac{\frac{\pi}{4} 32^2 \times 400 \times 2}{150 \times 480} = \frac{643.4 \times 10^3}{150 \times 480} = \underline{8.936 \text{ MPa}}$

① ÷ ② $\tan^2\theta = \frac{2.51}{8.936} = 0.281$ $\tan\theta = 0.530$

$\underline{\theta' = 27.93^\circ}$ $\therefore \sigma_c' = \frac{2.51}{\sin^2(27.93)} = \underline{11.44 \text{ MPa}}$
This is less than $\sigma_c = 12.5$ MPa so OK.

Q4 (cont.)

Shear force.

$$\tau = \frac{V}{b_w z} = \sigma_c' \sin\theta' \cos\theta'$$

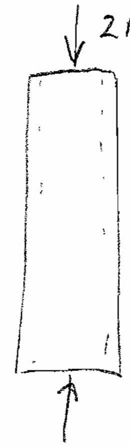
$$\therefore V = 11.44 \times \sin 27.93 \cos 27.93 \times 150 \times 480$$
$$= 340.9 \times 10^3$$

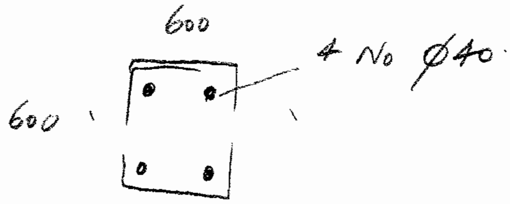
341 kN   c.f. 360 kN before for truss analogy.

$$\therefore \% \text{ diff} = \frac{360-341}{360} \times \frac{100}{1} = 5.3\%$$

$\therefore$ larger reduction in truss analogy – this is more realistic allowance for reduced anchorage.

Q5/

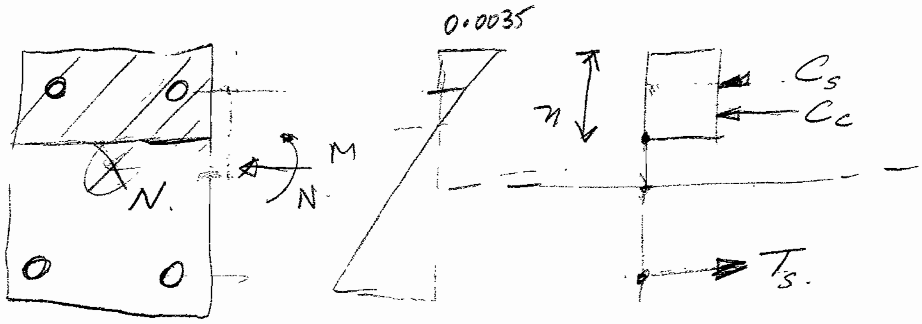




$\frac{f_{cu}}{\gamma_m} = 30$ MPa $\qquad \frac{f_y}{\gamma_m} = 400$ MPa.

Steel all yielded at failure.

$\varepsilon_{cu} = 0.0035$
$\varepsilon_y = 0.002$.



(a)

Axial load $N = 2$ MN. taken by concrete compression zone.

$$N = 2\times10^3 \text{ kN} = 0.6 f_{cd} \times 600 \times x.$$

$$x = \frac{2\times10^6}{0.6\times30\times600} = \underline{185.2 \text{ mm}}$$

Assume bars are yielded. $T = \underbrace{\frac{\pi 40^2}{4}}_{A_{st}} \times \underbrace{400}_{f_{yd}} \times \underbrace{2}_{no.} = 1.005\times10^6$ N

$$= \underline{1005 \text{ kN}}$$

<u>Moment about ℄.</u>

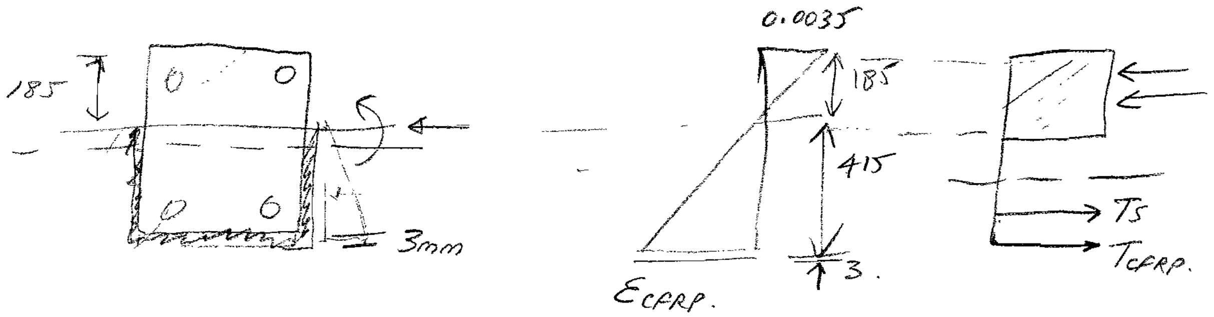
$$M_u = 2000 \times \left(300 - \frac{185}{2}\right) + 1005 \times (600 - 60 - 60)$$
$$= \underline{897.4 \text{ kNm}}.$$

<u>Check steel yielded</u> $\quad \frac{0.0035}{185} = \frac{\varepsilon_{s\,comp}}{(185-60)} \quad \varepsilon_{s\,comp} = \frac{125}{185} \times 0.0035 = 0.0024$
> 0.002 <u>OK</u>

$\varepsilon_{s\,tension}$ must have yielded since dist. to tension ft > than dist to comp steel
So assumption that steel has yielded is correct.

5 (b) Column confined by CFRP — $E_{CFRP} = 120\,GPa$

Only long fibres in tension act. $f_{CFRP} = 1400\,MPa$.



$$\varepsilon_{\substack{max \\ CFRP}} = \frac{418}{185} \times 0.0035 = 7.908 \times 10^{-3}.$$

$$\sigma = E\varepsilon$$

Strain at failure $\varepsilon_{CFRP} = \frac{\sigma}{E} = \frac{1400}{120\times10^3} = \underline{11.67\times10^{-3}}$

Since $\varepsilon_{\substack{CFRP \\ failure}} > \varepsilon_{\substack{CFRP \\ max}} \Rightarrow$ CFRP has not ruptured/failed when concrete compression limit reached.

Consider average stress across 3mm CFRP sheet (get stress at centre of sheet).

av. σ in CFRP. $\sigma_{CFRP} = E.\varepsilon_{av} = \underbrace{120\times10^3}_{E} \times \overbrace{\left(\frac{416.5}{185}\times0.0035\right)}^{\varepsilon}$

$$= \underline{945.6\ MPa}$$

∴ Force from CFRP $T_{CFRP} = \sigma.A = 945.6\times3\times600$ END STRIP

$+ \frac{945.6}{2}\times3\times415\times2$ SIDE STRIPS.

$= 1.702\times10^6 + 1.177\times10^6 = 2.879\times10^6$ N

Added Moment from CFRP about ℄.

$M_{extra} = 1.702\times10^3\times0.3015$

$+ 1.177\times10^3\times\left(0.3 - \frac{0.415}{3}\right)$

$= 513.2 + 190.28$

$= 703.4\ \underline{kNm}$ additional moment.

5(c) (i) Long fibres in compression - yes - no buckling strength.
Trans. fibres - conservative - will get confinement of concrete beam

(ii) Interaction diagram - generate this by redoing calculation again & again using different values of distance to neutral axis to get Interaction diagram.